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SOUTH AMERICA

South of the Amazon River

A Climatological Study

by

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AUGUST 1992

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13. Abstract: A climatological study of South America south of the Amazon River. The study area includes Brazil south of the Amazon, Peru south of 5 degrees south and south of the Maranon River, and the countries of Argentina, Bolivia, Chile, Paraguay and Uruguay. It also includes the Falkland (Malvinas) Islands. After describing general geography, the report discusses the major meteorological features of South America. Next, the geography and major climatic controls of each of four major subregions (West Central, Tropical, Subtropical, and Southern South America) are discussed. Finally, each of the four subregions is broken into "zones of climatic commonality." "Seasons," which vary in each of these zones, are defined and discussed in considerable detail.

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PREFACE

This study was prepared by the USAF Environmental Technical Applications Center's Environmental Applications Branch, Readiness Support Section (USAFETAC/ECR) as USAFETAC project 80829, in response to a support assistance request (SAR) from the 5th Weather Wing, Langley AFB, VA, under the provisions of Air Weather Service Regulation 105-18. Like its predecessors (climatological studies of the Persian Gulf, the Caribbean Basin, and Southwest Asia-Northeast Africa), this work is complemented by studies of refractivity and transmittance climatology.

The project would not have been possible without the dedicated support of the many people and agencies we have listed below in the sincere hope we've not omitted anyone.

First, our deepest gratitude and appreciation to Mr Walter S. Burgmann, Mr Wayne E. McCullom, Mr David P. Pigors, Mrs Kay E. Marshall, Mrs Susan A. Tarbell, Mrs Elizabeth M. Mefford, and Mrs Susan L. Keller of the Air Weather Service Technical Library (AWSTL).

Thanks also to Mr Henry (Mac) Fountain, Mr Vann Gibbs, Mr Dudley (Lee) Foster, Mr William R. Bobb, and other members of Operating Location A (OL-A), USAFETAC, Asheville, NC, for providing data, data summaries, and technical support.

Thanks to Mr Kenneth R. Walters Sr, Maj Kathleen M. Traxler, Capt Kevin P. Martin and TSgt Ronald L. Coleman of USAFETAC for their assistance.

Thanks also to those many United States and South American meteorologists whose discussions with various brach members over the past 10 years have shed considerable light on South American meteorology. This study would have been much poorer without their contributions.

Finally, all the authors owe sincere gratitude to the Publications Services team of the AWSTL, Mr George M. Horn and Sgt Corinne M. Kawa. Without their patience and cooperation, this project could not have been completed.

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INTRODUCTION

AREA OF INTEREST. This study describes the climatology and meteorology of South America south of the Amazon and Maranon Rivers. As shown in Figure 1-1, the study area is divided into four major geographical regions:

- *Tropical South America* covers most of Brazil and the eastern portions of Peru and Bolivia south of the Amazon-Maranon River system. It resumes where The Caribbean Basin study (USAFETAC/TN-89/003) left off.

- *West Central South America* extends from 5° S to 28° S. It includes the Pacific coastline and most of the Andes Mountains of Peru, Bolivia, northern Chile, and northern Argentina.

- *Subtropical South America* includes the extreme southern portions of Brazil and Bolivia, as well as all of Uruguay, Paraguay, and northern Argentina.

- *Southern South America* includes most of Chile and Argentina, along with the Falkland/Malvinas Islands.

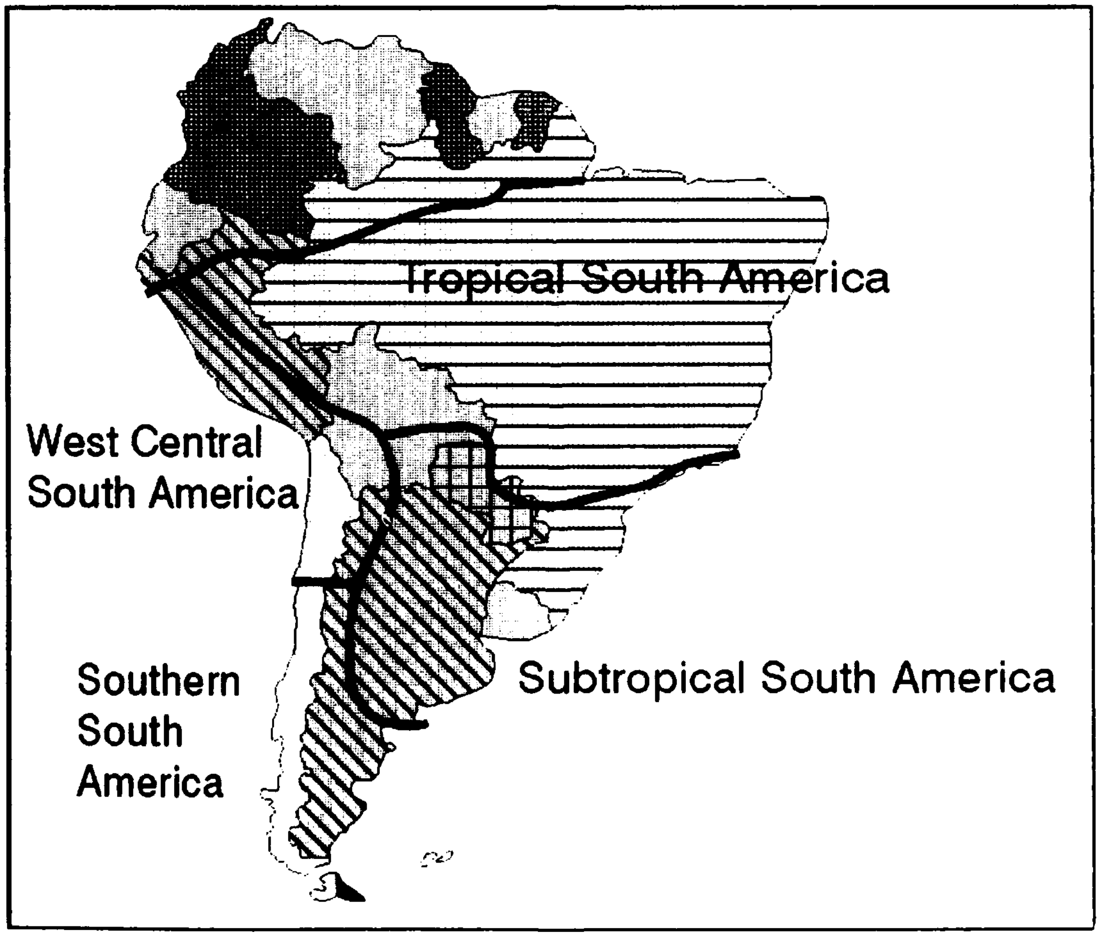


Figure 1-1. South America and Its Four Major Regions.

STUDY CONTENT. Chapter 2 is a general discussion of the major meteorological features that affect South America. These features include semipermanent climatic controls, synoptic disturbances, and mesoscale and local features. Individual treatments of each region in subsequent chapters do not repeat descriptions of these features; instead, they discuss specific effects of these features that are unique to that region. Therefore, meteorologists using this study should read and consider the general discussion in Chapter 2 before trying to understand or apply individual climatic discussions in Chapters 3 through 6. This is particularly important because the study was designed with two purposes in mind: first, as a master reference for South America, and second, as a modular reference to each individual climatic zone.

Chapters 3 through 6 amplify the general discussions in Chapter 2 by describing the geography, climate, and meteorology of the subregions shown in Figure 1-1. These chapters provide even more detailed discussions of the various "climatic zones of commonality" selected on the basis of their reasonably homogeneous climatology and meteorology. Note: In the Andes mountains and in northeast Brazil, weather and climate are not necessarily internally homogeneous and are distinctly different from that of the areas immediately adjacent. Discussions of "seasons" in each of the climatic zones are organized in this order:

General Weather
Sky Cover
Visibility
Winds
Precipitation
Thunderstorms
Temperature
Flight hazards
Ground hazards

CLIMATOLOGICAL REGIMES. This study covers weather phenomena varying from the tropical systems over the Amazon to the frontal systems over the "roaring forties" and "furious fifties" of southern Chile and Argentina. South America extends so far from north to south that it crosses three weather regimes (*tropical, subtropical,* and *mid-latitude*) and is affected by still a fourth--*sub-Antarctic.* The Andes mountains are a formidable barrier to wind flow; they influence the weather of the entire continent.

Each of the climatic zones is discussed by season. The traditional four seasons of the mid-latitudes are found in some of the zones, but others, especially in the tropics, have "wet" and "dry" seasons. These terms are relative; they refer simply to a *change* in the amount of precipitation received. This means that the "wet" season of a desert zone may have less precipitation than the "dry" season over the Amazon jungle. Note that since we are below the Equator, cyclonic circulations are clockwise, and anticyclones are counterclockwise.

CONVENTIONS. The spellings of place names and geographical features are those used by the United States Defense Mapping Agency's Aerospace Center (DMAAC). Distances are in nautical miles, except for visibilities, which are in statute miles. Elevations are in feet with a meter or kilometer value immediately following. Temperatures are in degrees Fahrenheit with a Celsius conversion (°C) following. Wind speeds are in knots. Precipitation amounts are in inches, with a millimeter (mm) conversion following. Most synoptic charts are given in Greenwich Mean Time (GMT or Z). When synoptic charts are not provided, only local standard time (L) is used. Cloud bases and ceilings are above ground level (AGL); tops are above mean sea level (MSL). Note, however, that since cloud bases are generalized over large areas, readers must consider terrain in all discussions of cloud bases in and around the mountains. For example, the AGL cloud bases in Chapter 3's discussions of the Andes Mountains are generally representative of *valley* reporting stations; readers should assume that stations at higher elevations might be obscured by those reported cloud layers. To help alleviate confusion in discussions of mountain weather, some cloud bases are given as MSL, rather than AGL.

DATA SOURCES. Most of the information used in preparing this study came from two sources, both within the United States Air Force Environmental Technical Applications Center (USAFETAC). Studies, books, atlases, and so on were supplied by the Air Weather Service Technical Library (AWSTL), the only dedicated atmospheric sciences library in the Department of Defense and the largest such library in the United States.

Climatological data came direct from the Air Force's Climatic Database at Asheville, NC, or through Operating Location A, USAFETAC--the division of USAFETAC responsible for maintaining and managing the database.

RELATED REFERENCES. This study, while more than ordinarily comprehensive, is certainly not the only source of meteorological and climatological information for the military meteorologist concerned with South America. USAFETAC/TN-89/003, *The Caribbean Basin*, should be consulted for coverage of South America north of the Amazon River. USAFETAC/DS-90/032, *Station Climatic Summaries--Latin America*, provides summarized meteorological observational data for several major airports in the study area. Staff weather officers and forecasters are urged to contact the AWSTL for more data on the study area.

Chapter 2

MAJOR METEOROLOGICAL FEATURES OF SOUTH AMERICA

The "major meteorological features" of South America south of the Amazon are listed below and are described in this chapter. These features affect the weather and climate of South America the year-round or in certain seasons. The same features are discussed more specifically in subsequent chapters as they relate to individual regions and zones.

SEA SURFACE CONDITIONS

Surface Currents. Figure 2-1 shows the location and direction of ocean currents near South America. These currents play a major role in the weather of the continent. Warm waters help to enhance cyclogenesis and thunderstorm development, while cold water is a stabilizing influence that generally produces more of a stratiform cloud along the coasts.

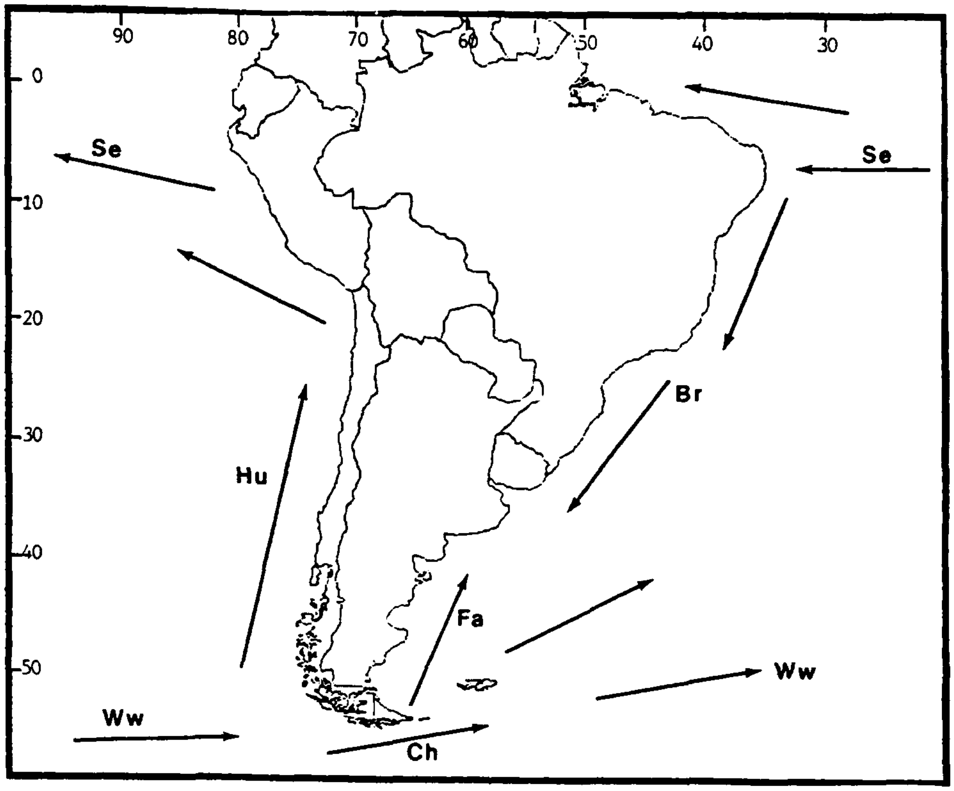


Figure 2-1. Ocean Currents Near South America. The arrows show the normal direction of the ocean currents. The text below gives average speeds for individual currents. Abbreviations are: Br - Brazil Current, Ch - Cape Horn Current, Fa - Falkland Current, Hu - Humboldt (or Peru) Current, Se - South Equatorial Currents, Ww - West Wind Drift (or Antarctic Circumpolar Current).

The West Wind Drift (or Antarctic Circumpolar Current) feeds the three cold currents that affect South America. It flows uninterrupted from west to east around the entire globe between Antarctica and the Southern Hemisphere land masses. Average speeds vary from 0.1 to 0.5 knots.

The cold Humboldt Current (or Peru Current) flows northward along the coast of Chile before turning westward along the Peruvian coast. Since the flow is away from the Peru coast, there is an upwelling of colder, subsurface water. Average speeds are 0.2 knots.

The cold Cape Horn Current, actually just a part of the West Wind Drift, flows through Drake Passage with average speeds from 0.2 to 0.5 knots. The cold Falkland Current flows north from the Cape Horn Current along the coast of Argentina, normally to the Rio de la Plata at 35° S. Average speed is 0.2 knots.

The Brazil Current is the only warm current. Its source, the South Atlantic Equatorial Current, has undergone substantial warming while crossing the tropical Atlantic. The Brazil Current flows down the Brazilian coast until meeting the Falkland Current. Average speeds vary from 0.2 to 0.5 knots.

Sea Surface Temperatures (SSTs). Figures 2-2a-d show mean SSTs for the waters bordering South America. Temperatures in the tropical waters off the coast of Brazil vary only 1-2° F throughout the year because of the year-round presence of the Brazil Current. The changing seasons have a greater effect on cold-current temperatures. The largest change is evident in the Falkland Current off the coast of Argentina. The average temperature just south of the Rio de la Plata is 15° F (8° C) lower in winter than in summer. The Falkland Current produces a strong temperature gradient and a northward bulge in the isotherms the year-round. The Humboldt Current also remains cold year-round. Seasonal changes are not as strong; the average temperature change is only about 8° F (4° C).

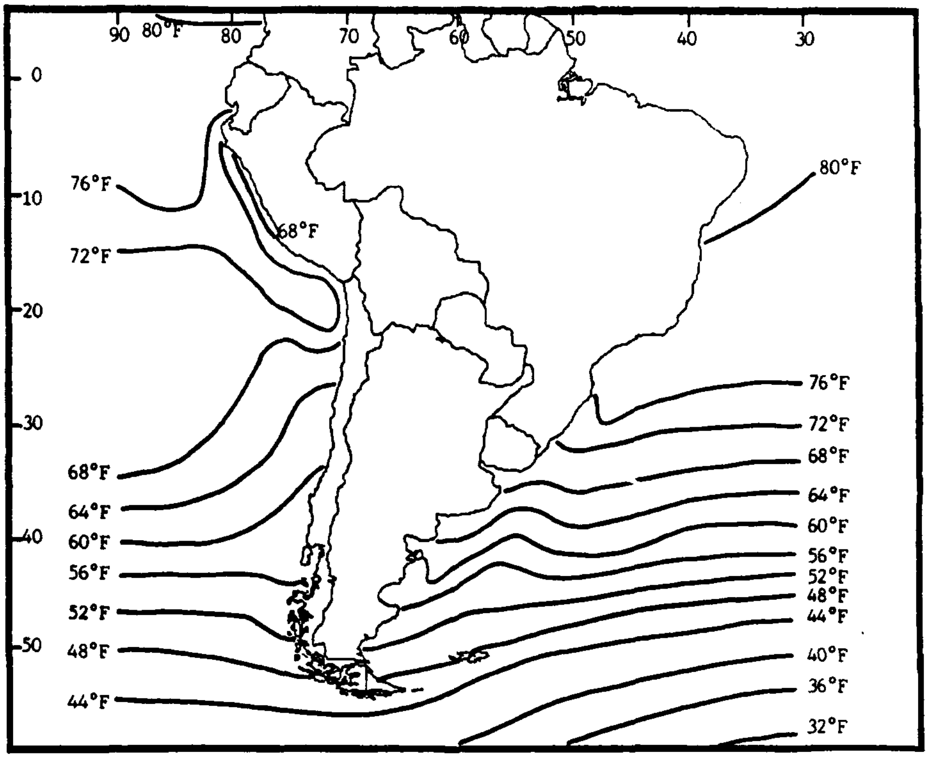


Figure 2-2a. Mean January Sea-Surface Temperatures.

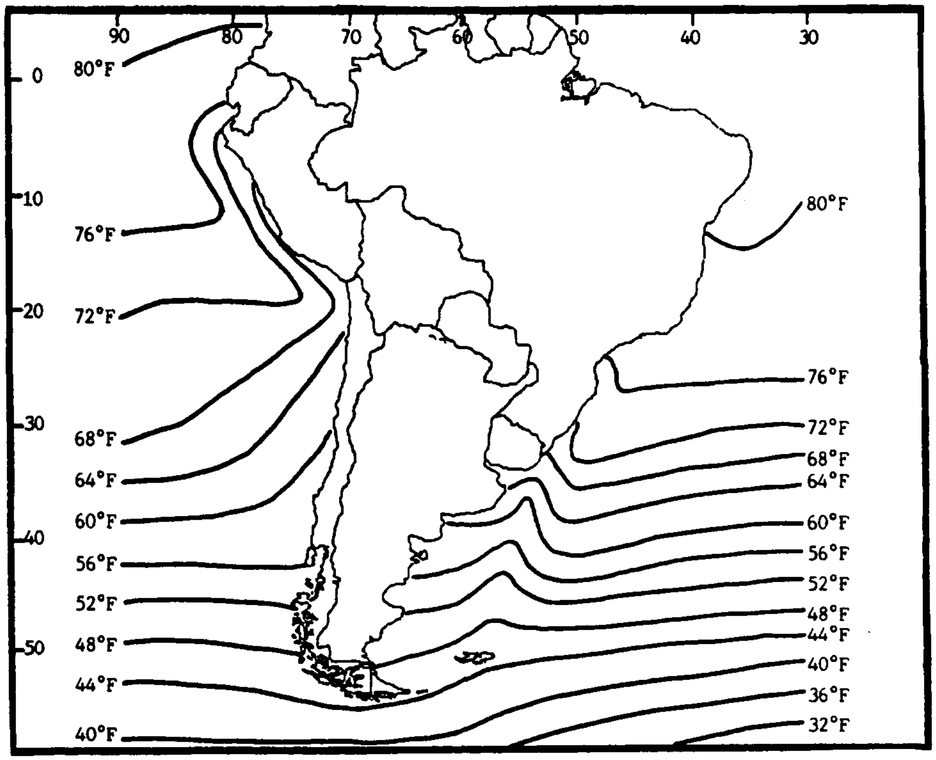


Figure 2-2b. Mean April Sea-Surface Temperatures.

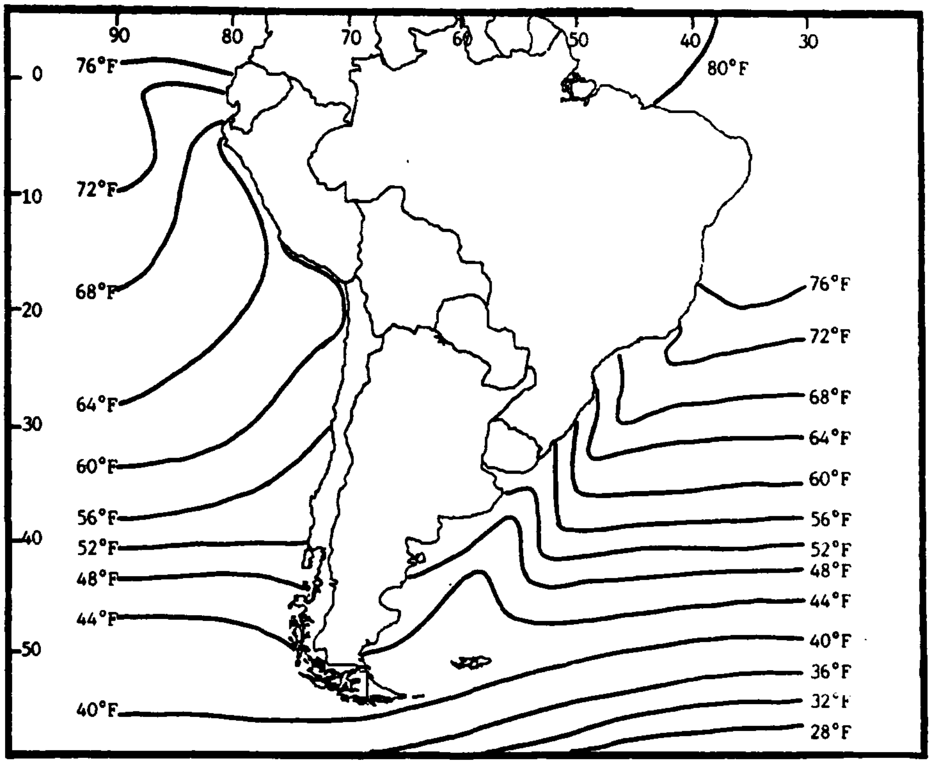


Figure 2-2c. Mean July Sea-Surface Temperatures.

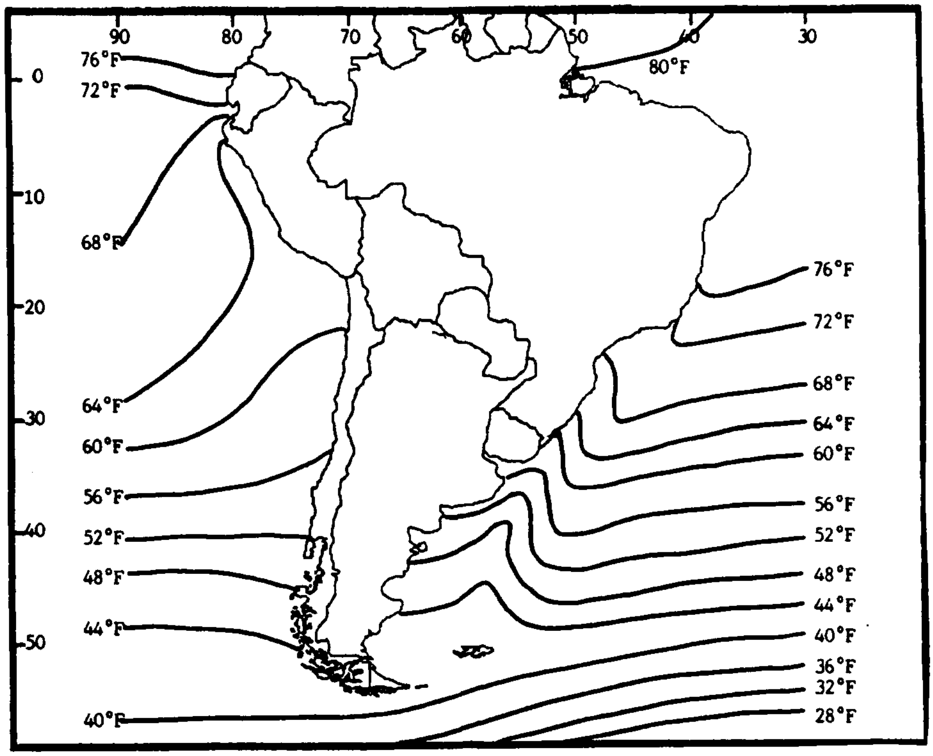


Figure 2-2d. Mean October Sea-Surface Temperatures.

Sea Ice. Figure 2-3 shows the average northern limits of pack ice at the end of summer (March) and the end of winter (September). March and September mark the minimum and maximum average extents of the ice pack. The northern limit of drifting icebergs is also shown in Figure 2-3.

The presence of sea ice is a hazard to shipping as well as an influence on the development of extratropical cyclones. Cyclogenesis is favored on the sea side of the sea-ice margin but discouraged over the sea ice since the air is stabler and drier than over the open ocean (see Extratropical Cyclone Activity).

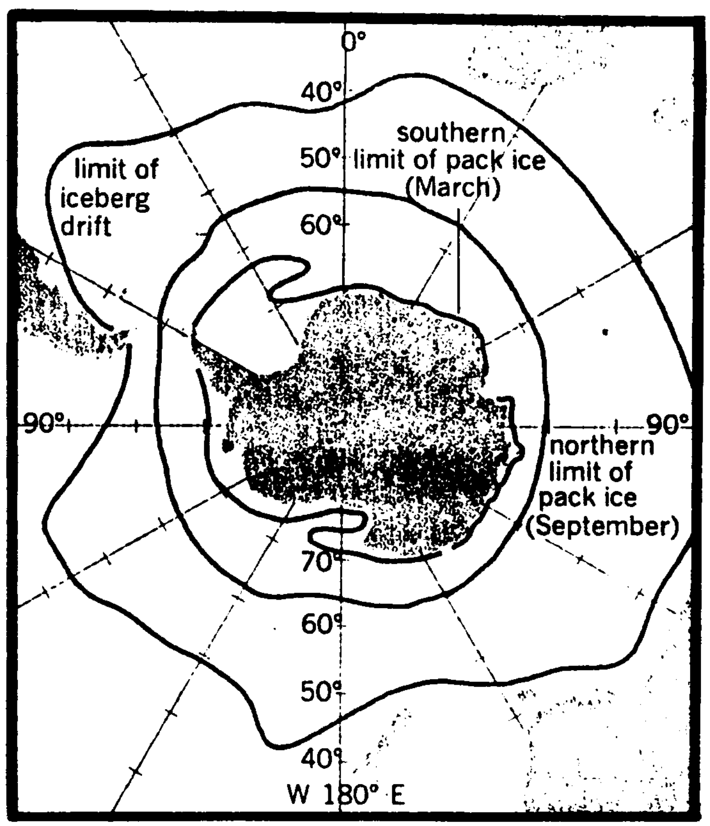


Figure 2-3. Ice Limits in the Southern Hemisphere.

SOUTH PACIFIC HIGH. This semipermanent high-pressure cell is well-defined over the eastern South Pacific because the Andes Mountains block its eastward movement. Mean central pressures range from 1021 mb in April to 1026 mb in October. The divergent outflow has a major influence on the coastal regions of Peru and Chile. Between 10 and 30° S, surface flow is predominantly southerly or southwesterly. Between 30 and 45° S, surface outflow is turned poleward in the winter and equatorward in the summer. South of 45° S, the Andes no longer significantly deflect low-level flow, and winds vary from northwesterly to southwesterly. Significant weakening of the South Pacific High in the winter allows frontal activity northward to 25-30° S between April and October. Figures 2-4a-d show mean sea-level pressures for January, April, July, and October. Flow from the South Pacific High over the cold Humboldt Current produces advection fog along the coast. The High slopes toward the Equator with height and produces a subsidence layer/inversion that penetrates to the western Andean foothills.

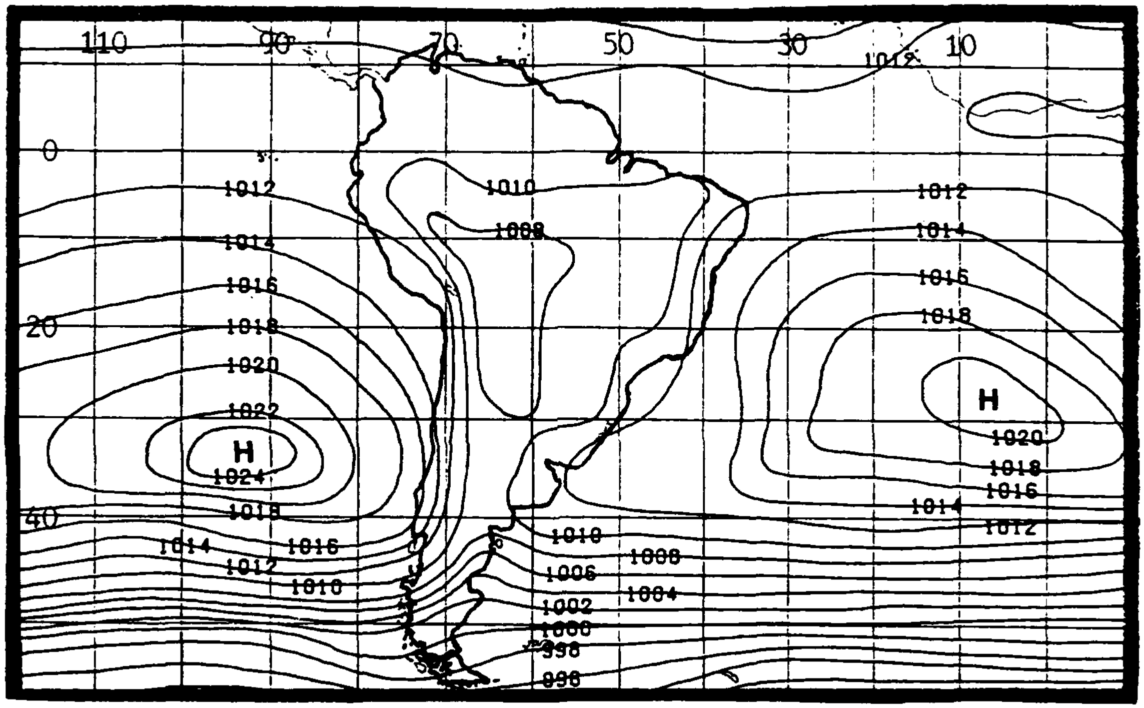


Figure 2-4a. Mean Sea-Level Pressure for January.

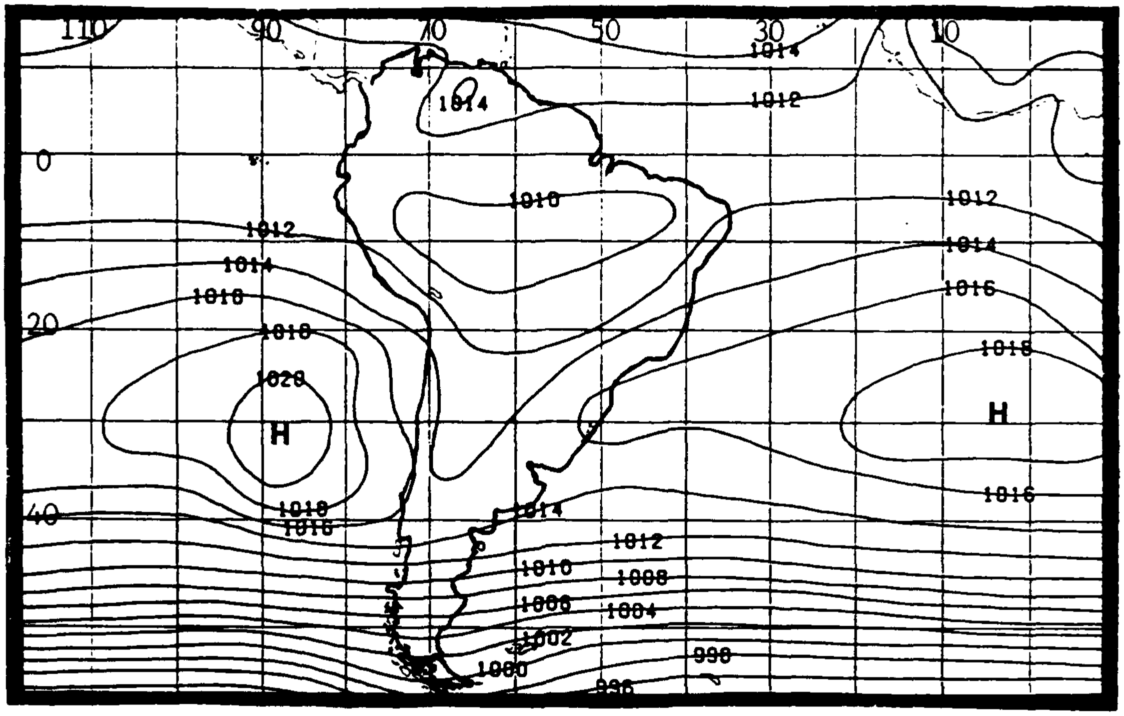


Figure 2-4b. Mean Sea-Level Pressure for April.

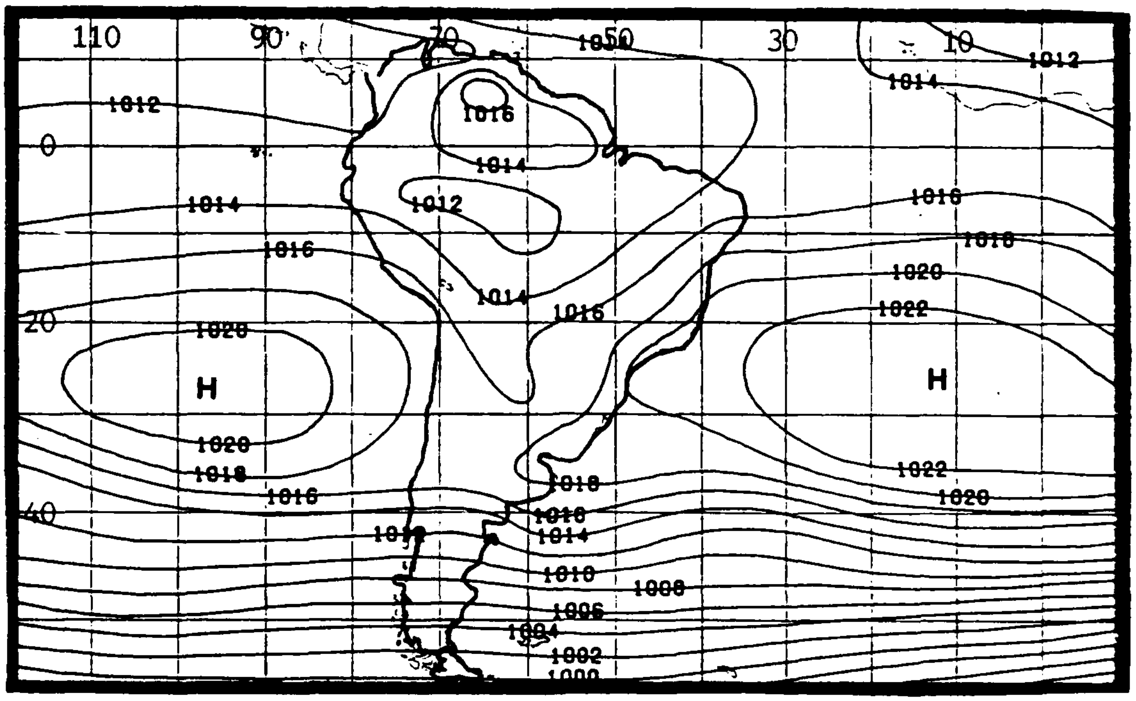


Figure 2-4c. Mean Sea-Level Pressure for July.

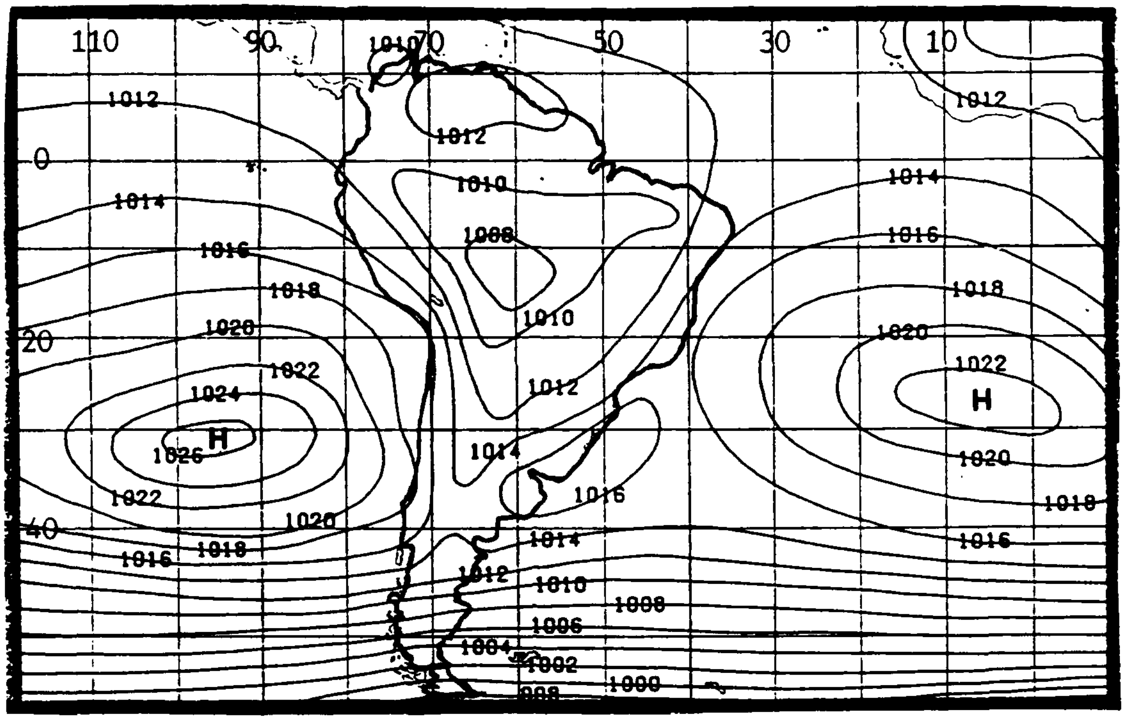


Figure 2-4d. Mean Sea-Level Pressure for October.

SOUTH ATLANTIC (ST HELENA) HIGH. Figures 2-4a-d also show the South Atlantic High's mean positions and sea-level pressures for January, April, July, and October. Mean pressure ranges from 1018 mb in March to 1025 mb in September. The cell migrates northwestward from 32° S, 8° W in summer to 26° S, 12° W in winter. Its counterclockwise circulation (we're in the Southern Hemisphere, remember?) produces a southeasterly outflow that dominates the Southern Atlantic basin from the equator to 20° S. Outflow becomes northwesterly by 35° S. Surface wind speeds average 12-14 knots to the high's north and west. Wind speeds progressively increase south of the high, reaching a mean of 25 knots along mid-latitude storm tracks. In winter, the South Atlantic High ridges over the Amazon basin, occasionally separating and forming a second center in Brazil, perhaps in response to extratropical disturbances. When separating, low-level convergence occurs between the two centers, potential for cloudiness and precipitation along the Brazilian coast between 10 and 25° S is increased. Intensified ridging east of the Falkland/Malvinas Islands is not uncommon between April and October. On rare occasions, the South Atlantic High may ridge into the Weddell Sea from 55 to 60° S. The South Atlantic High slopes westward and equatorward with height, becoming part of the Subtropical Ridge in the upper troposphere.

THE NEAR EQUATORIAL TROUGH (NET). The NET, also called the "Intertropical Convergence Zone" (ITCZ) or the "Meteorological Equator," results from the convergence of the northern and Southern Hemisphere trade winds. "Trade-Wind Trough" and "Monsoon Trough" are common terms that pertain to specific forms of the NET. Trade-wind troughs occur with confluence between northeasterly flow in the Northern Hemisphere and southeasterly flow in the Southern Hemisphere from the subtropical highs. Most associated cloudiness occurs along the axis of confluence. Monsoon troughs are characterized by a directional shear zone that has westerlies on the equatorward side and easterlies on the poleward side. Most associated cloudiness occurs equatorward of the NET.

The NET forms where the trade winds from the North Atlantic High meet trade winds from the South Pacific and South Atlantic Highs. During most of the year, the Pacific segment (a Monsoon Trough from April through November and a Trade-Wind Trough from December through March) is separated from the continental segment by the Andes Mountains. A Trade-Wind Trough develops over South America, but terrain makes it difficult to locate. The continental segment moves north and south more readily than the oceanic segments during transition seasons because the land mass heats and cools faster than the oceans. Southward continental surges from the Northern Hemisphere often cause the continental segment to separate from the Atlantic Trade-Wind Trough by early summer. These surges, with vertical structures similar to mid-latitude warm fronts, are most important to this area from October through February. They can be preceded by high- and mid-level cloudiness and followed by extensive low cloudiness and precipitation. Thunderstorms are common.

The entire NET is affected by short-term, north-south oscillations that occur most often in January and February and in July through September. These oscillations are caused by synoptic and mesoscale low-pressure disturbances intersecting with, or passing near, the NET. Such disturbances include Extratropical Cyclones, Low-Latitude Upper-Tropospheric Cyclonic Vortices, Trade-Wind Surges, Sea-Breeze Fronts, and the Tropical Convergence Zone, all of which are discussed in subsequent sections. Surface low-pressure areas normally draw the NET toward them. Cold fronts initially pull it toward them before driving it away with the cold surge behind.

Most convection occurs where the NET interacts with synoptic and mesoscale disturbances, old thunderstorm and squall line outflow boundaries, and topography. Cirrus "blow-off" from convective clusters often merges to give a solid appearance in satellite imagery. Diurnally, the NET is more active over land during afternoons and evenings, and more active over water during nights and mornings.

Seasonal NET Positions:

Summer (December-January). The NET's Pacific segment reaches its Southernmost position between 2 and 5° N. Extreme southerly positions to 5° S can occur during El Niño years (see Southern Oscillation). The continental segment is now separated from, and moving independently of, both oceanic segments, extending east-northeast from the eastern Andean slopes near 10° S to about 5° S, 50° W. The Atlantic segment's mean position is between 2 and 6° N. Since this segment remains in the Northern Hemisphere or near the equator, the study area is not affected by hurricanes. Figure 2-5a shows monthly summer positions of the Near Equatorial Trough.

Fall (March-May). The Pacific segment moves northward in response to the return of strong cross-equatorial flow from the northward-moving South Pacific High. The continental segment also moves north, assisted by increasing Southern Hemisphere polar outbreaks. The Trade-Wind Trough over the Atlantic, however, reaches its Southernmost position in early fall since the ocean does not begin cooling before April. Near the coast, its mean position is between 2° N and 3° S before moving northward in May to a mean position between 2 and 4° N. The continental and Atlantic portions of the NET normally remain connected after April. NET location is very important to northeast Brazil. Extreme southerly positions have caused abnormally wet conditions, while positions north of average have produced droughts. Extreme southerly positions often occur when the NET moves toward approaching Southern Hemisphere cold fronts. Frontal invasions not only act to attract the NET, but can also weaken the South Atlantic High's southeasterly trade winds. Warming of equatorial South Atlantic water also produces trough positions farther south than normal. More northerly positions are produced by an unusually strong South Atlantic High and/or unusually warm North Atlantic waters. The period of anomalous "anchoring" of the trough and subsequent droughts in the northeast varies from 2 to 10 years, but averages 4. Brazilian (and some American) meteorologists believe that trade-wind surges along the north side of the trough recurve as cross-equatorial flow. According to this theory, they become northwesterlies, and eventually drive the NET southward into eastern Brazil during March and April. Figure 2-5b shows mean fall NET positions.

Winter (June-August). The NET normally remains outside the study area in winter. The Pacific portion parallels the Pacific coast of Central America. Strong equatorial southwesterlies in the eastern Pacific can, in extreme cases, drive the NET north to about 15° N. The continental portion can be difficult to locate due to the rugged terrain in northern South America. The South Atlantic portion extends from the South American coast to 30° W--the mean position is near 10° N. Figure 2-5c shows mean NET winter positions.

Spring (September-November). The South Pacific High moves southwestward, causing the eastern Pacific NET to begin moving southward. Over South America, a combination of weaker flow from the South Atlantic, repeated Northern Hemisphere polar surges, and the southward movement of the Sun drives the NET southward into the interior of South America. The Atlantic portion moves southward in response to the solar cycle and associated southward movement of the North and South Atlantic Highs. Figure 2-5d shows mean NET spring positions.

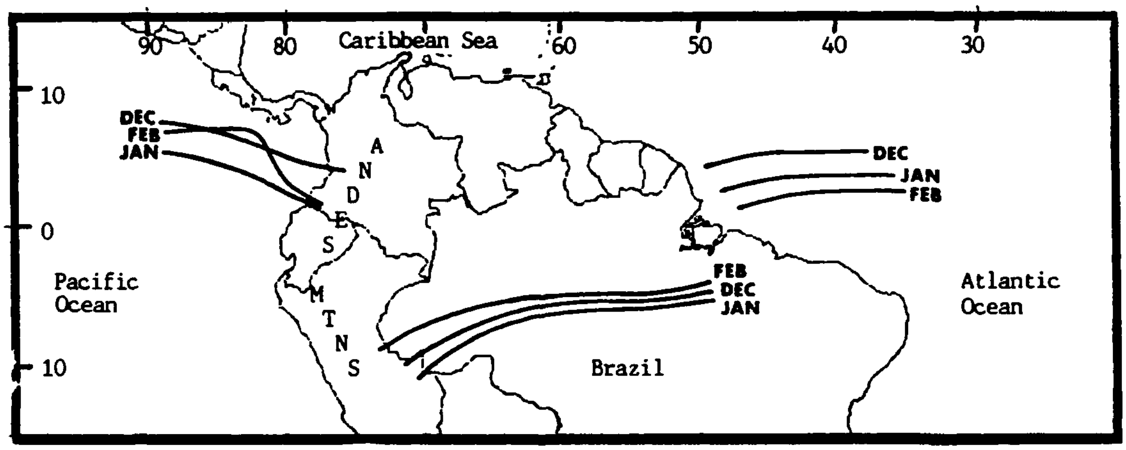


Figure 2-5a. Mean NET Positions for December, January, and February.

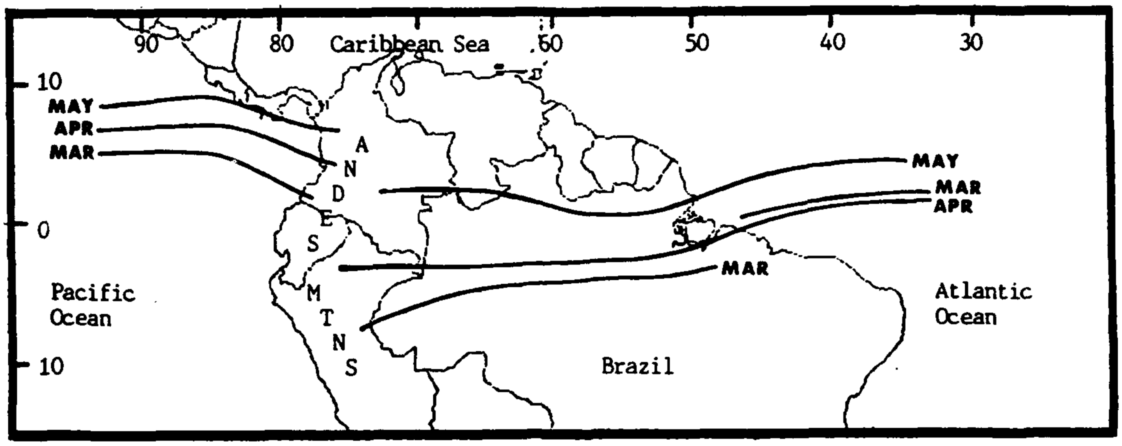


Figure 2-5b. Mean NET Positions for March, April, and May.

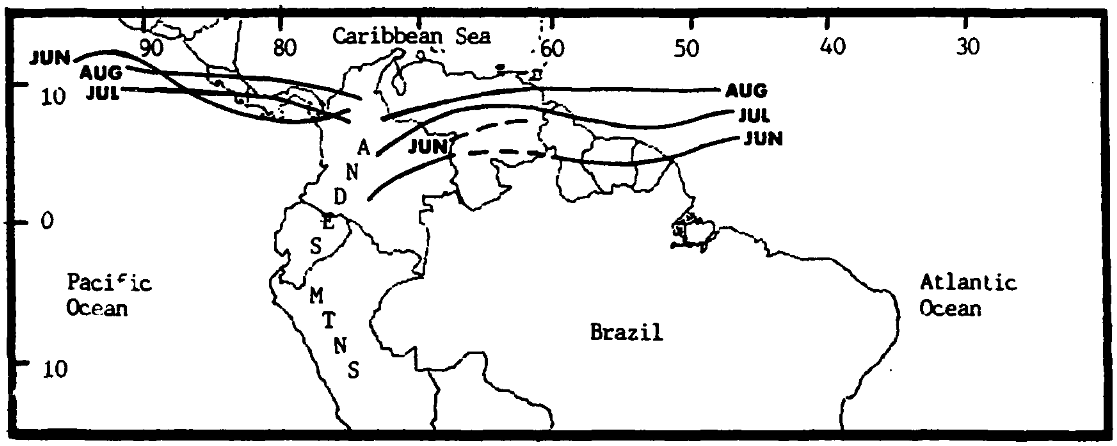


Figure 2-5c. Mean NET Positions for June, July, and August. Dashed lines show two possible mean June positions. Mountainous terrain in northern South America breaks up the NET and makes the mean position variable.

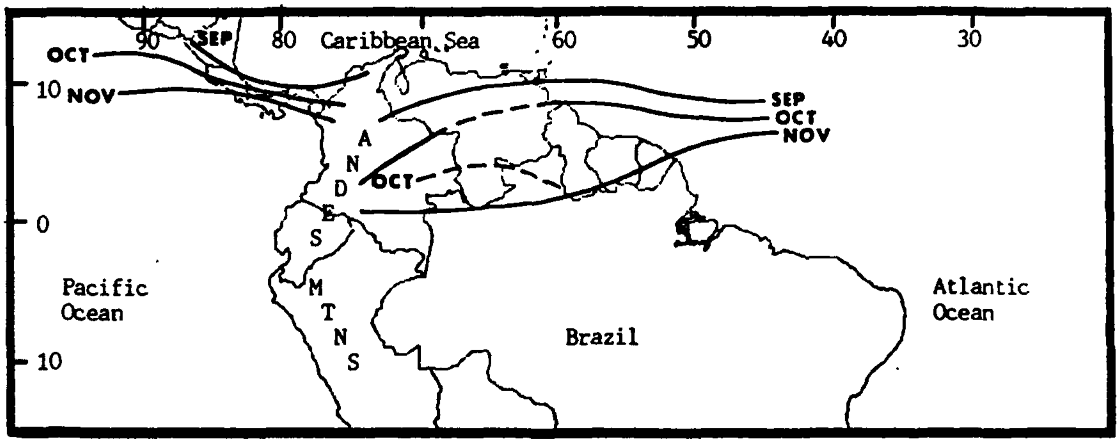


Figure 2-5d. Mean NET Positions for September, October, and November. Dashed lines show two possible mean October positions. Mountainous terrain in northern South America breaks up the NET and makes the mean position variable.

The NET is the primary source of convection. Figures 2-6a-d show NET positions and the "zone of significant convection." "Significant" convection is the result of an average of at least two organized convective systems at least 200 km in size occurring during the month. These systems are cloud clusters (individual cells embedded in a common cirrostratus canopy) responsible for most of the rainfall received. Satellite cloud composites were in good agreement with zones of significant convection. The number of occurrences increases toward the center of each area. Monthly and yearly variability is greatest on the edges.

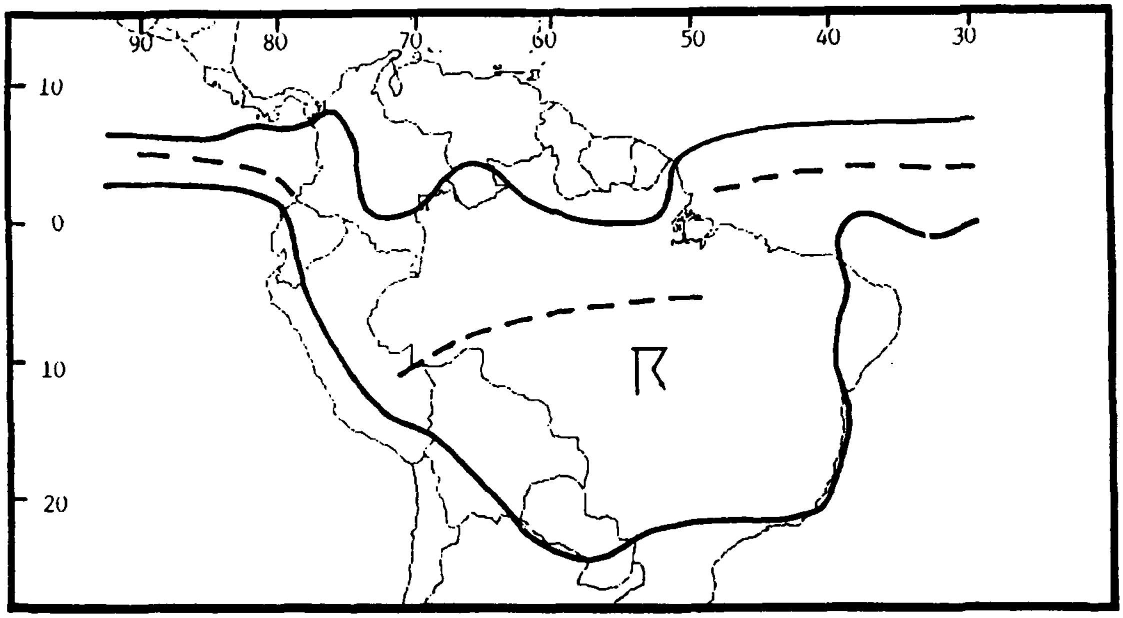


Figure 2-6a. Mean January Position of the NET and Associated Convection. Dashed lines show NET position; solid lines are boundaries of convection. Convection has reached its Southernmost location.

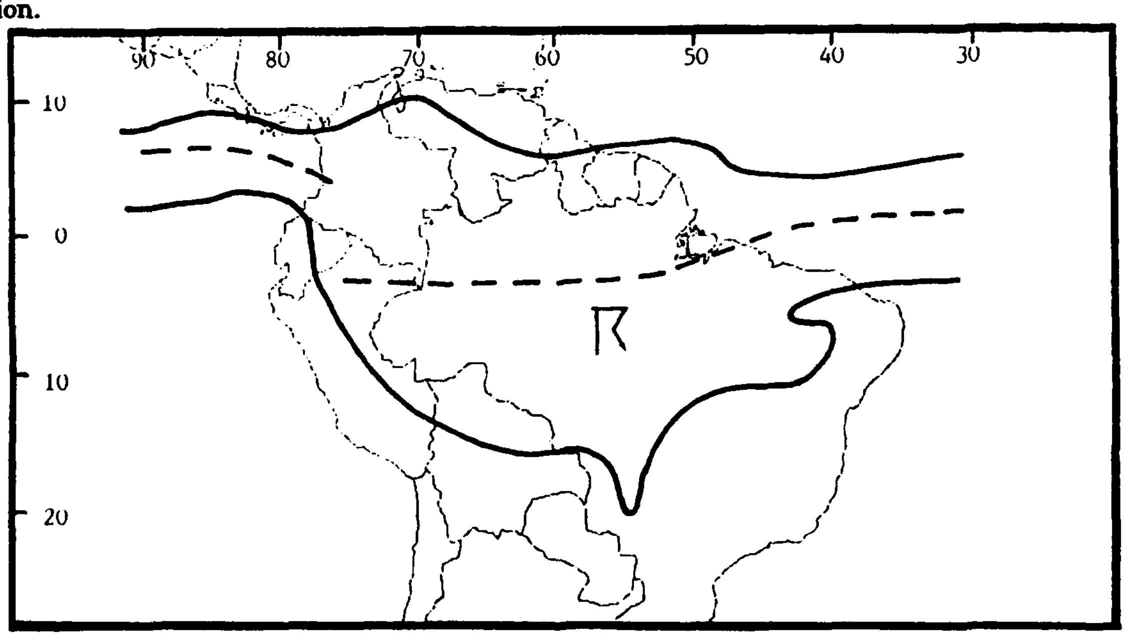


Figure 2-6b. Mean April Position of the NET and Associated Convection. Dashed lines show NET position; solid lines are boundaries of convection. Development of convection is shifting northward.

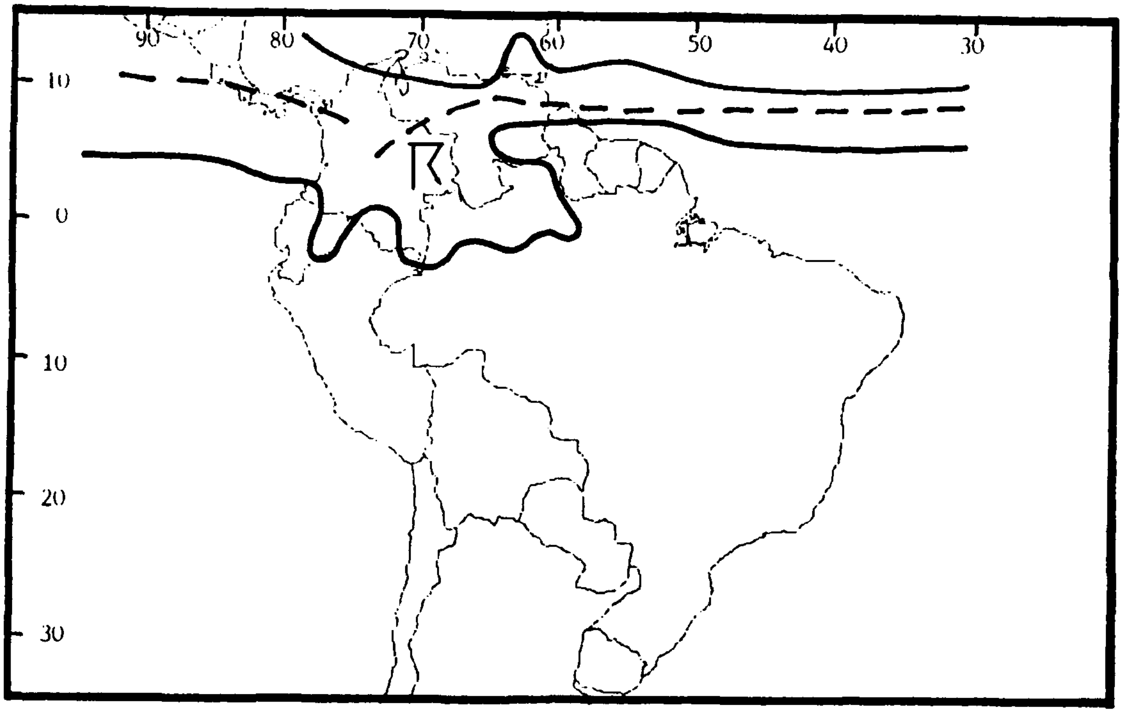


Figure 2-6c. Mean July Position of the NET and Associated Convection. Dashed lines show NET position; solid lines are boundaries of convection. Convection is north of the entire region.

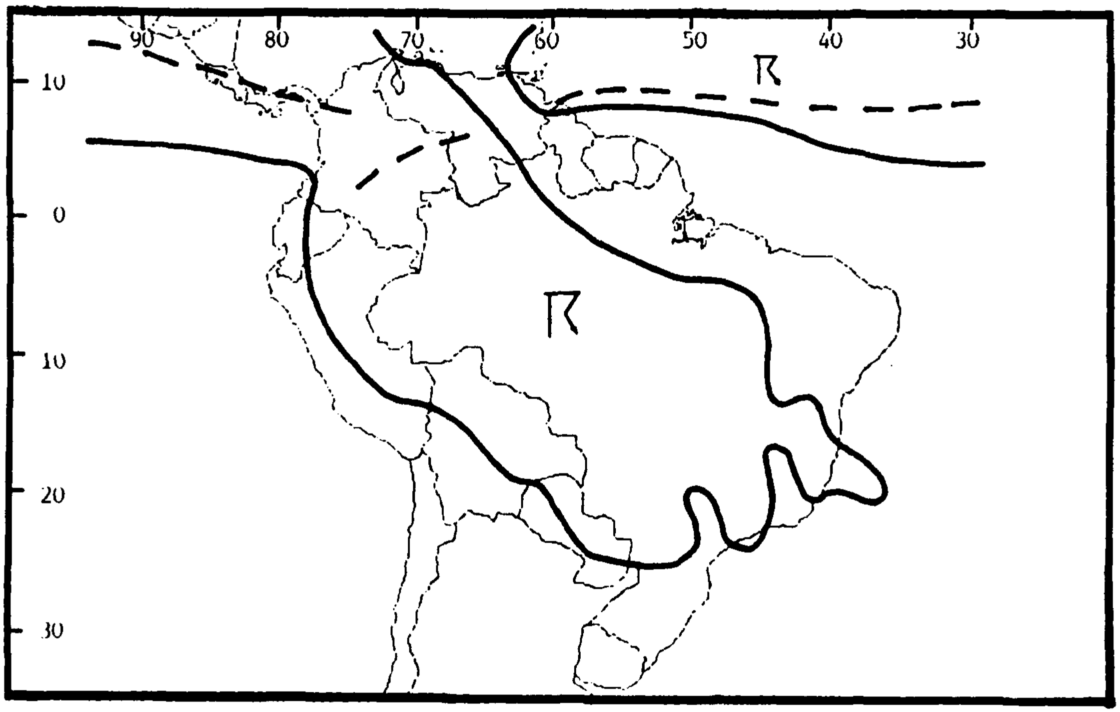


Figure 2-6d. Mean October Position of the NET and Associated Convection. Dashed lines show NET position; solid lines are boundaries of convection. Development of convection is shifting southward. The convection across southeast Brazil is initiated by Southern Hemisphere frontal boundaries moving into the area.

SEMIPERMANENT CLIMATIC CONTROLS

THE AMAZONIAN LOW is a semipermanent feature of the Amazon Basin that enhances convection. Figures 2-7a and b show mean positions of the Amazonian Low and its relationship to the NET, as well as mean low-level flow during January and July. The primary cause of the Amazonian Low appears to be latent heat of condensation. A possible contributor is low-level easterly and northeasterly flow that is channeled north along the eastern Andean slopes to create cyclonic circulation.

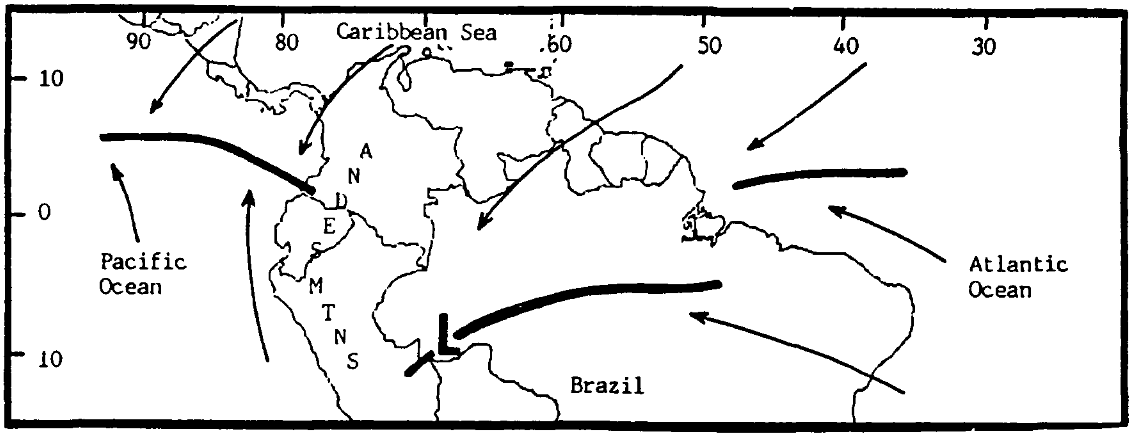


Figure 2-7a. Mean Amazonian Low and NET Positions (bold lines) for January. The low is at its Southernmost position; surface pressures average 1008 mb.

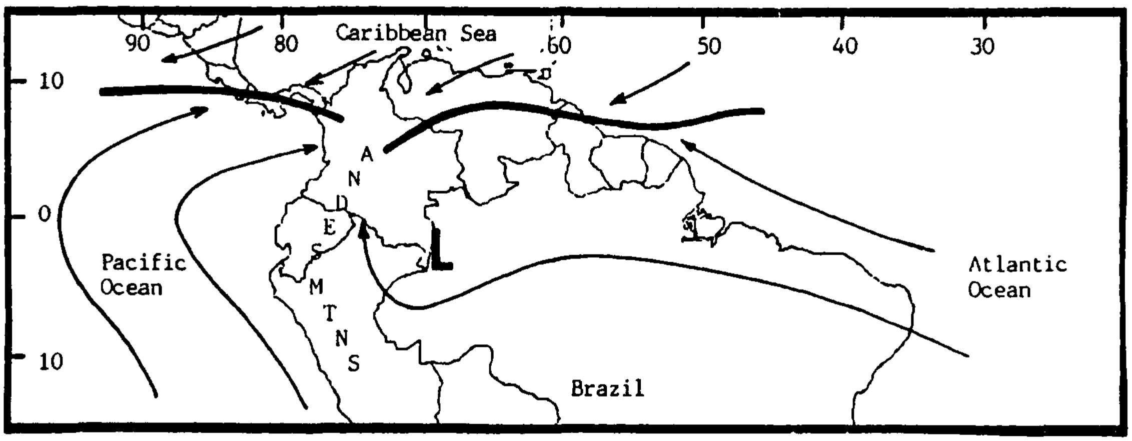


Figure 2-7b. Mean Amazonian Low and NET Positions (bold lines) for July. Surface pressures range from 1011 to 1015 mb.

THE NORTHWEST ARGENTINE DEPRESSION (NAD) is a semipermanent low-pressure area formed by topography and intensive surface heating. The Andes Mountains block zonal wind flow at low levels and allow advection of hot air from the northwest. Low-level flow is channelled between the Andes lee side and the foothills to the east, further enhancing the hot air advection. The NAD's center is generally found east of the Andes at about 27° S, 66° W over relatively high and dry terrain. Figure 2-8 shows the mean summer position. The NAD is intense and persistent in summer with central pressures as low as 980 mb. It normally extends up to 850-700 mb. During winter, the NAD behaves like a lee-side trough. Its circulation enhances the easterly flow of warm, moist, and unstable air from the South Atlantic onto the continent as far west as the Andes.

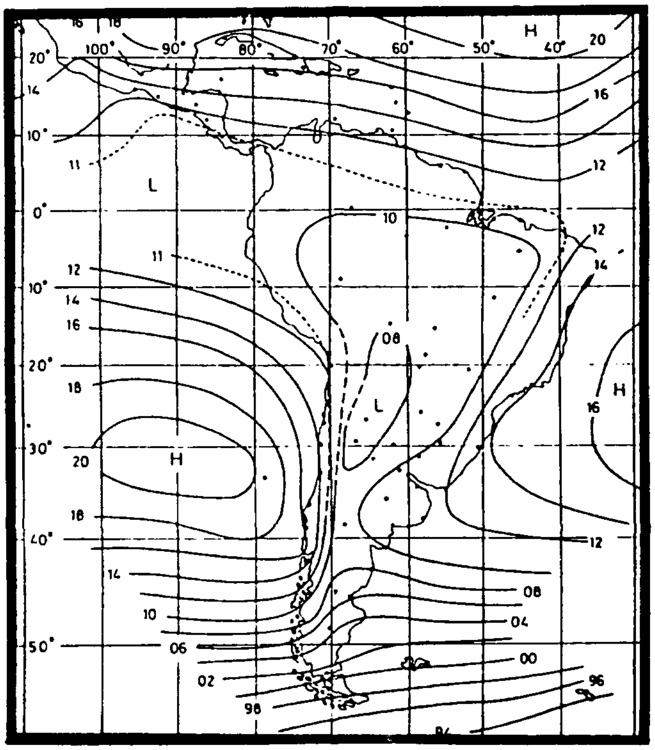


Figure 2-8. Atmospheric Pressure at Sea Level Shows NAD During Southern Hemisphere Summer (from Schwerdtfeger, 1976).

The Zonda (a warm, dry, downslope wind similar to a foehn or chinook) may contribute to NAD intensification. The Zonda usually develops between May and November in western Argentina (centered on Mendoza at 33° S, 69° W) with a warm, dry air mass. It is preceded by an approaching trough or cyclone from the west that creates orographic lift on the western slopes of the Andes. Air flows over and down the eastern slopes with local terrain funneling it into valleys. Temperatures can rise quickly due to adiabatic warming. Maximum speeds are found between 800 and 850 mb. Surface wind speeds frequently exceed 30 knots; 110-knot winds have occurred in the high mountain ranges to the west of Mendoza.

MID- AND UPPER-LEVEL FLOW PATTERNS. Figures 2-9 through 2-12 show South American streamline flow for January, April, July, and October at 850 mb, 700 mb, 500 mb, 300 mb , and 200 mb. The 850-mb, 700-mb, and 500-mb levels are derived from the Surface Analysis Data Set Network (SADS). The 300-mb and 200-mb levels are from Sadler (1975).

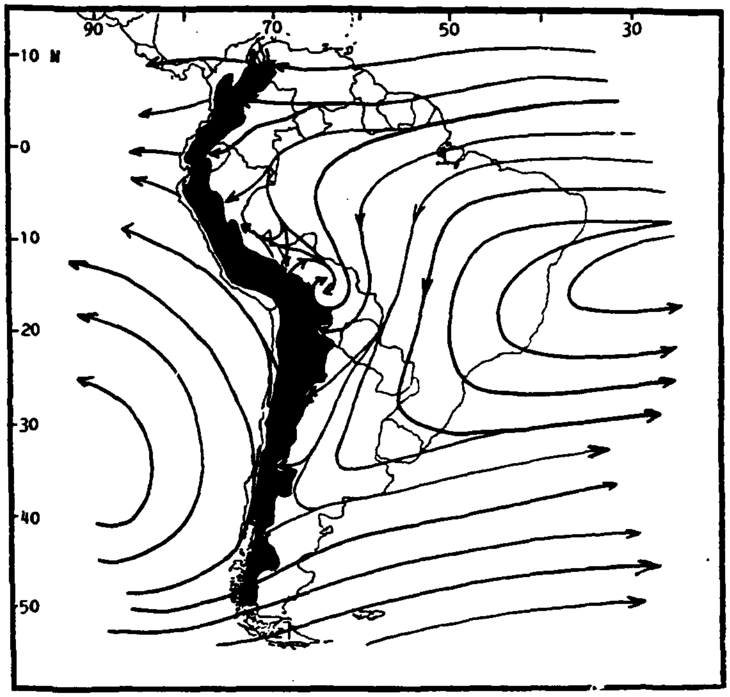


Figure 2-9a. Mean January Upper-Air Flow Patterns, 850 mb. Shaded area shows terrain in the Andes above 5,000 feet (1,525 meters).

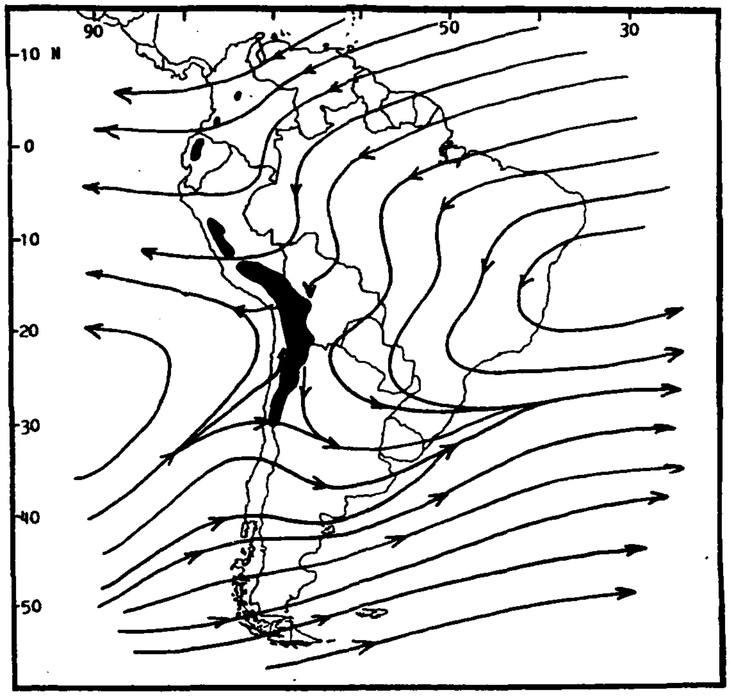


Figure 2-9b. Mean January Upper-Air Flow Patterns, 700 mb. Shaded area shows terrain over 10,000 feet (3,050 meters).

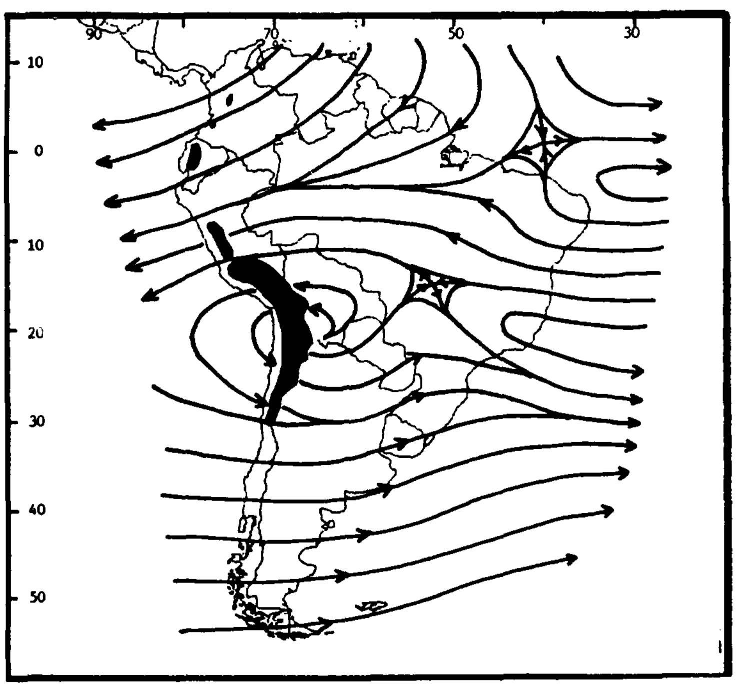


Figure 2-9c. Mean January Upper-Air Flow Patterns, 500 mb. Shaded area shows terrain over 18,000 feet (5,490 meters).

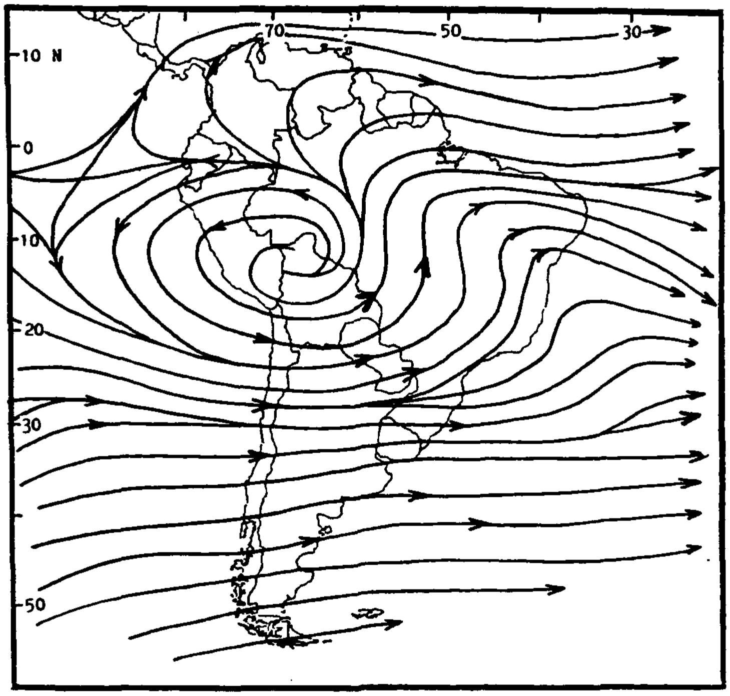


Figure 2-9d. Mean January Upper-Air Flow Patterns, 300 mb.

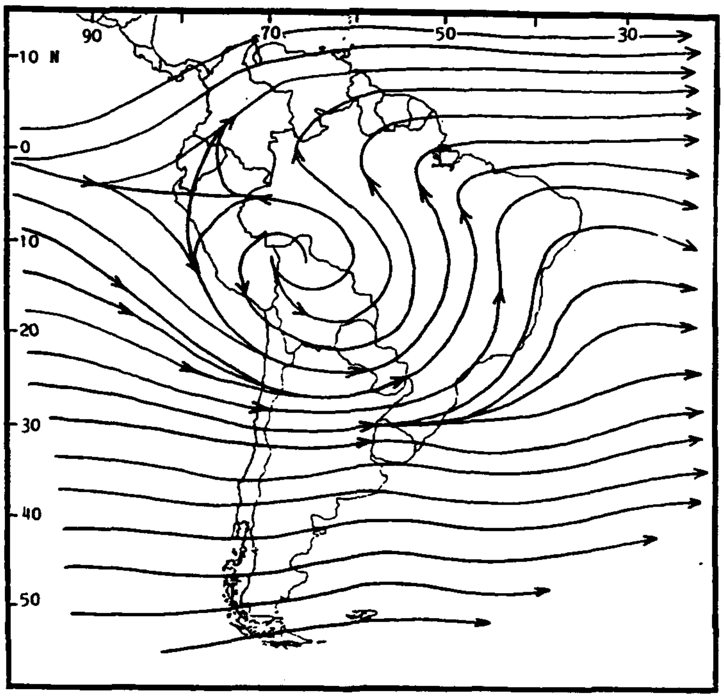


Figure 2-9e. Mean January Upper-Air Flow Patterns, 200 mb.

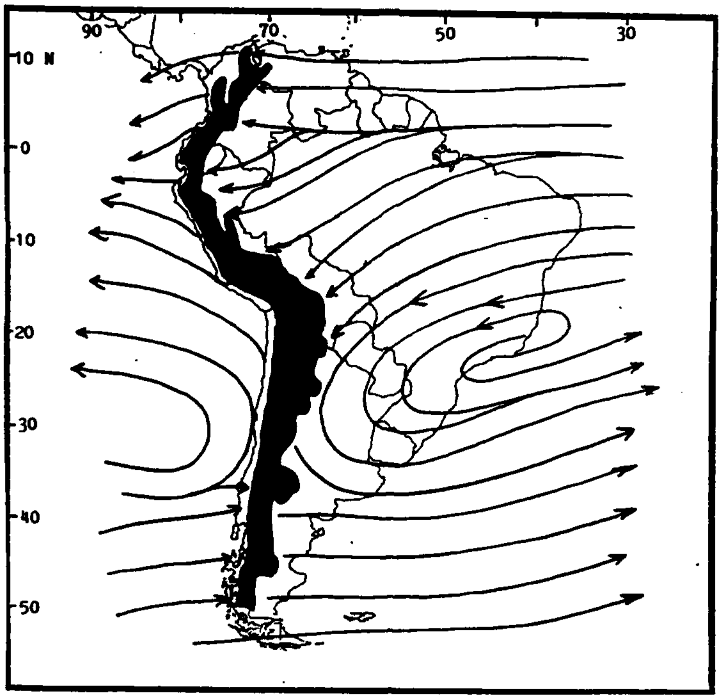


Figure 2-10a. Mean April Upper-Air Flow Patterns, 850 mb. Shaded area shows terrain in the Andes above 5,000 feet (1,525 meters).

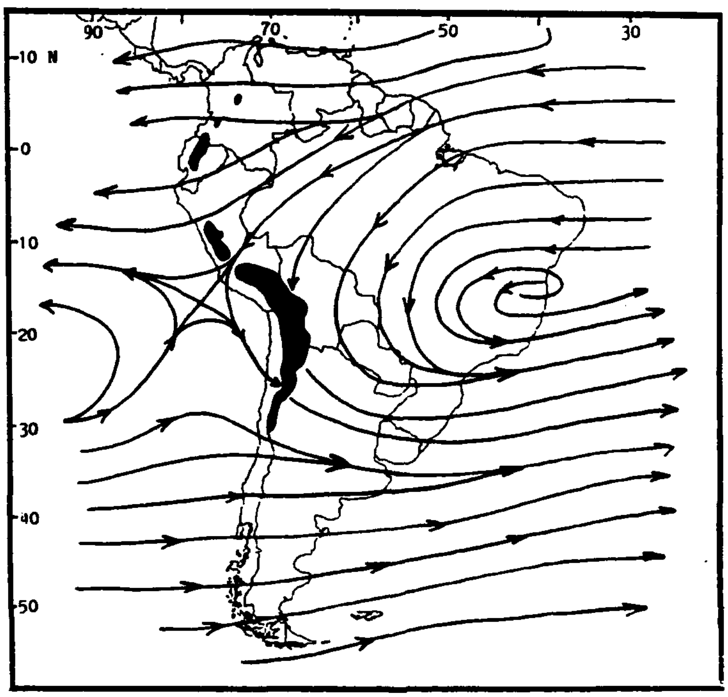


Figure 2-10b. Mean April Upper-Air Flow Patterns, 700 mb. Shaded area shows terrain over 10,000 feet (3,050 meters).

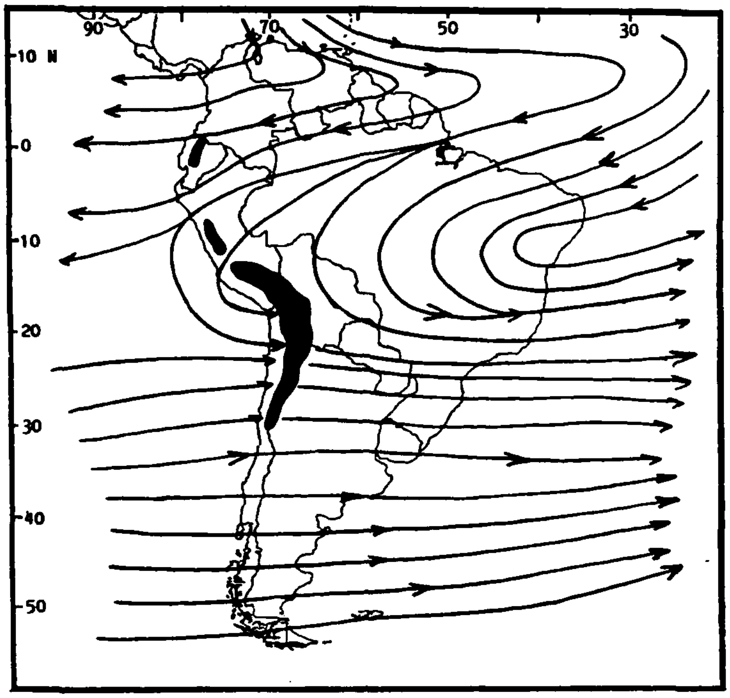


Figure 2-10c. Mean April Upper-Air Flow Patterns, 500 mb. Shaded area shows terrain over 18,000 feet (5,490 meters).

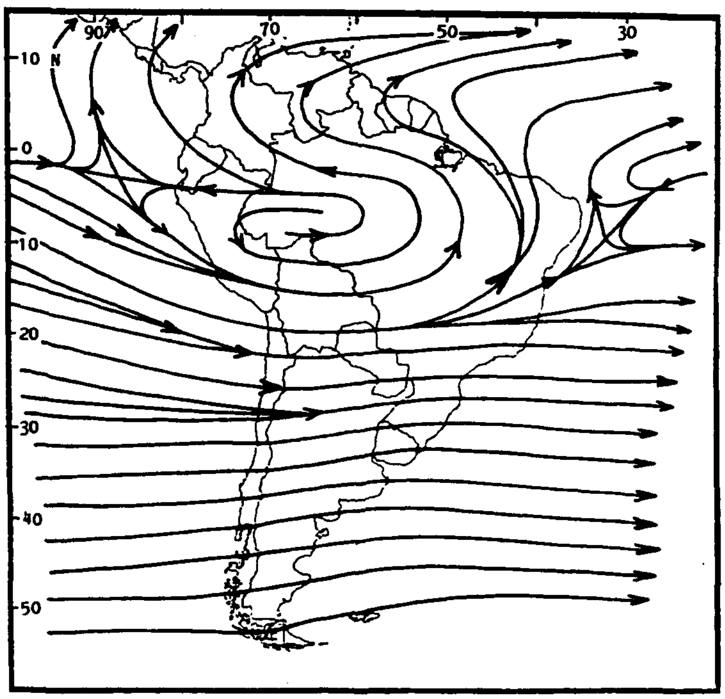


Figure 2-10d. Mean April Upper-Air Flow Patterns, 300 mb.

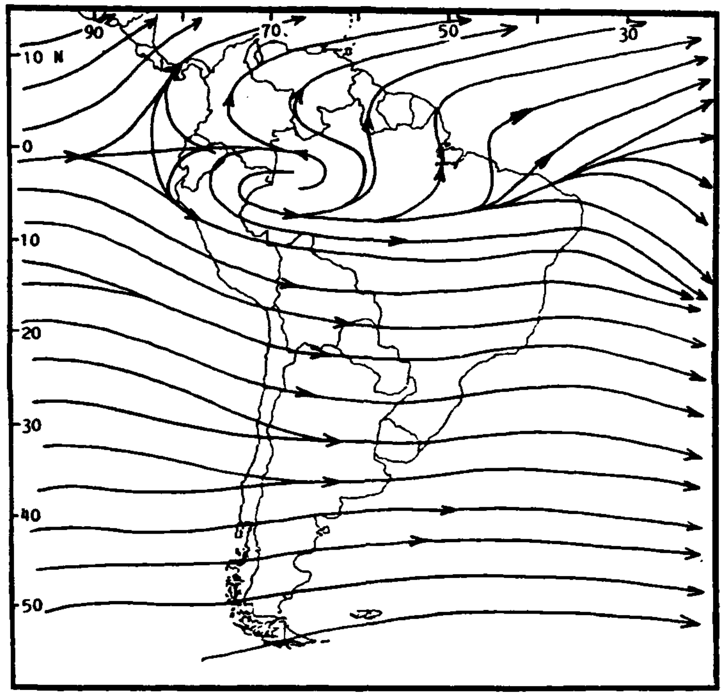


Figure 2-10e. Mean April Upper-Air Flow Patterns, 200 mb.

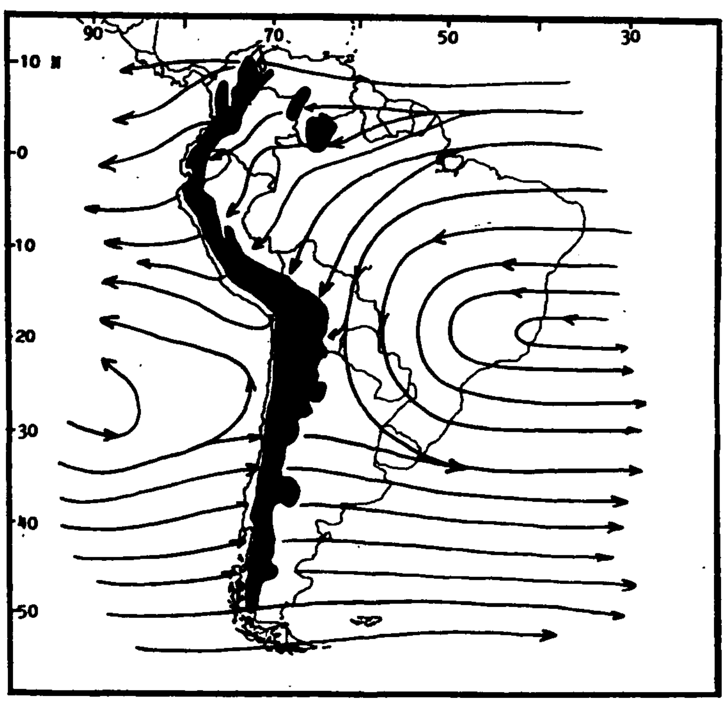


Figure 2-11a. Mean July Upper-Air Flow Patterns, 850 mb. Shaded area shows terrain in the Andes above 5,000 feet (1,525 meters).

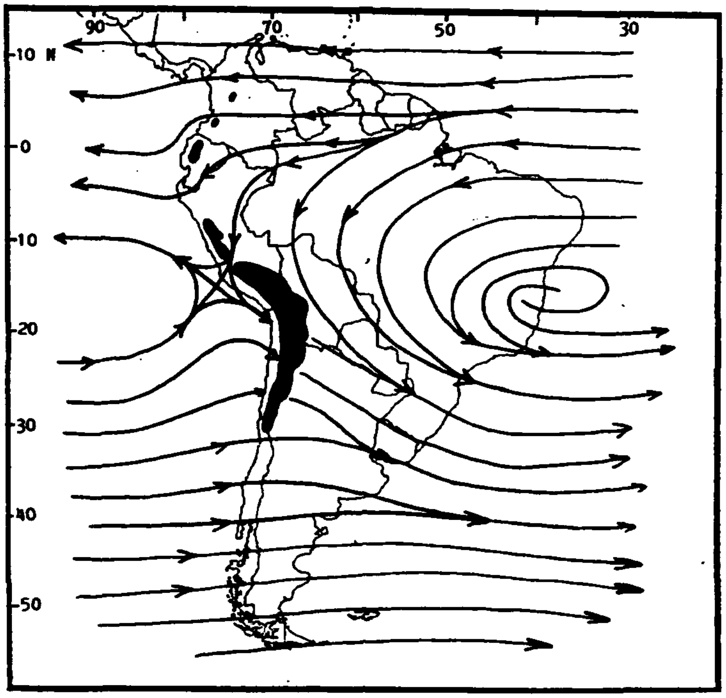


Figure 2-11b. Mean July Upper-Air Flow Patterns, 700 mb. Shaded area shows terrain over 10,000 feet (3,050 meters).

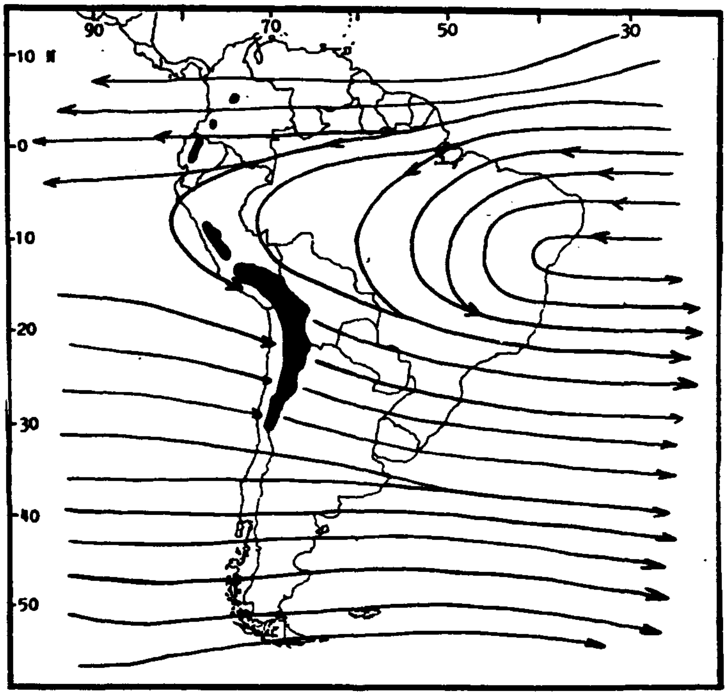


Figure 2-11c. Mean July Upper-Air Flow Patterns, 500 mb. Shaded area shows terrain over 18,000 feet (5,490 meters).

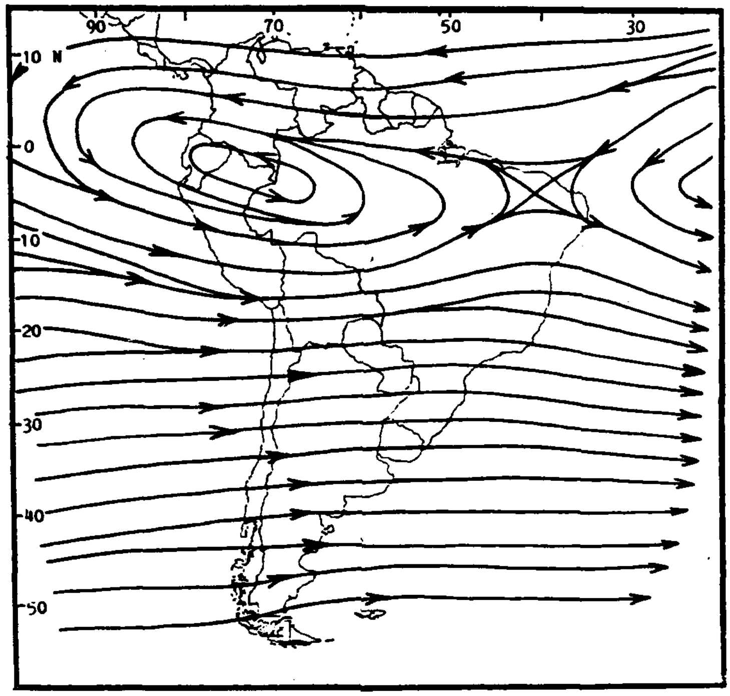


Figure 2-11d. Mean July Upper-Air Flow Patterns, 300 mb.

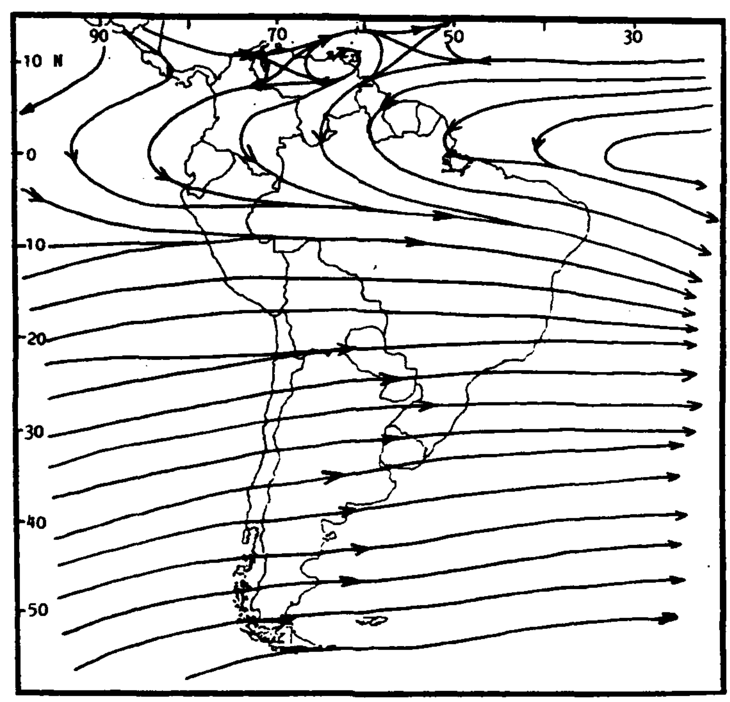


Figure 2-11e. Mean July Upper-Air Flow Patterns, 200 mb.

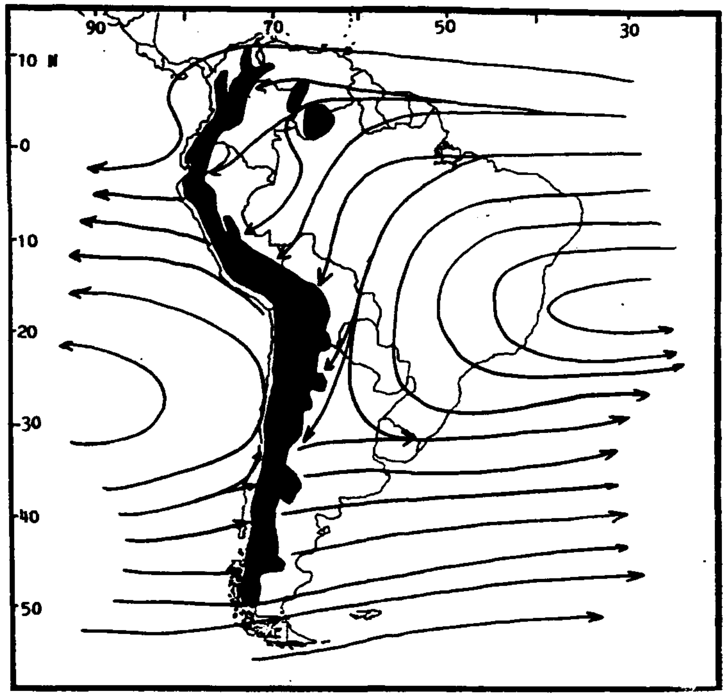


Figure 2-12a. Mean October Upper-Air Flow Patterns, 850 mb. Shaded area shows terrain in the Andes above 5,000 feet (1,525 meters).

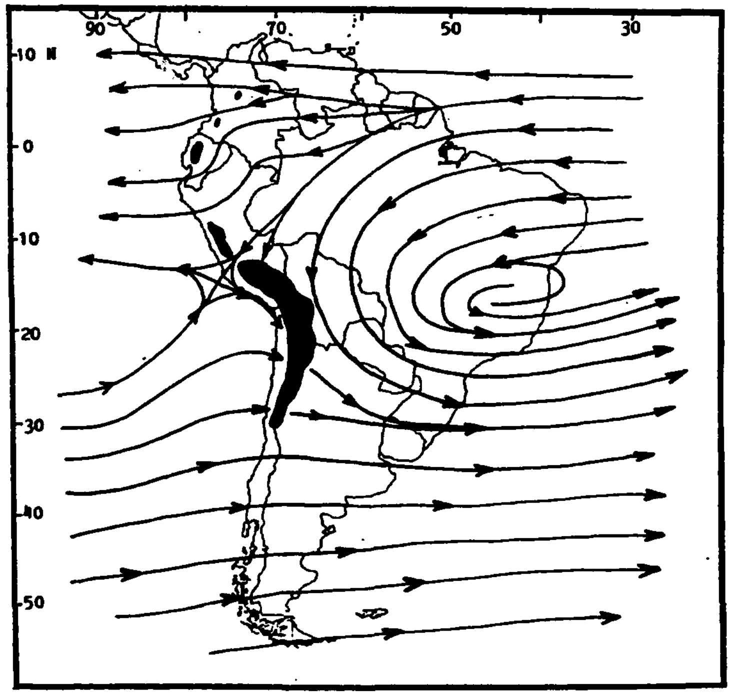


Figure 2-12b. Mean October Upper-Air Flow Patterns, 700 mb. Shaded area shows terrain over 10,000 feet (3,050 meters).

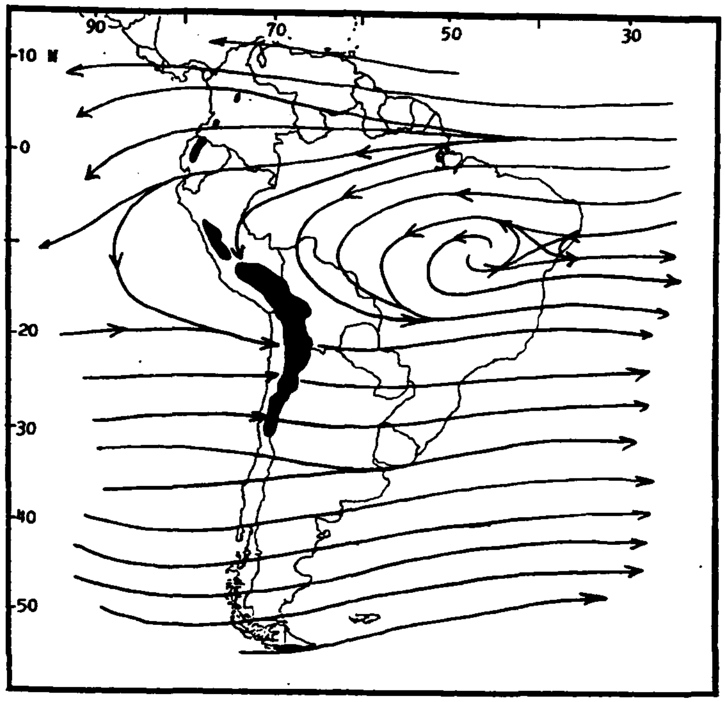


Figure 2-12c. Mean October Upper-Air Flow Patterns, 500 mb. Shaded area shows terrain over 18,000 feet (5,490 meters).

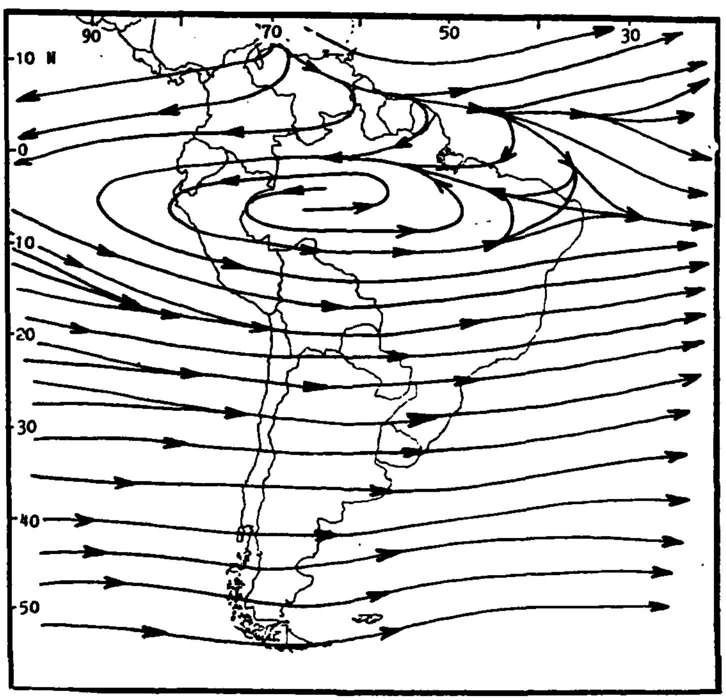


Figure 2-12d. Mean October Upper-Air Flow Patterns, 300 mb.

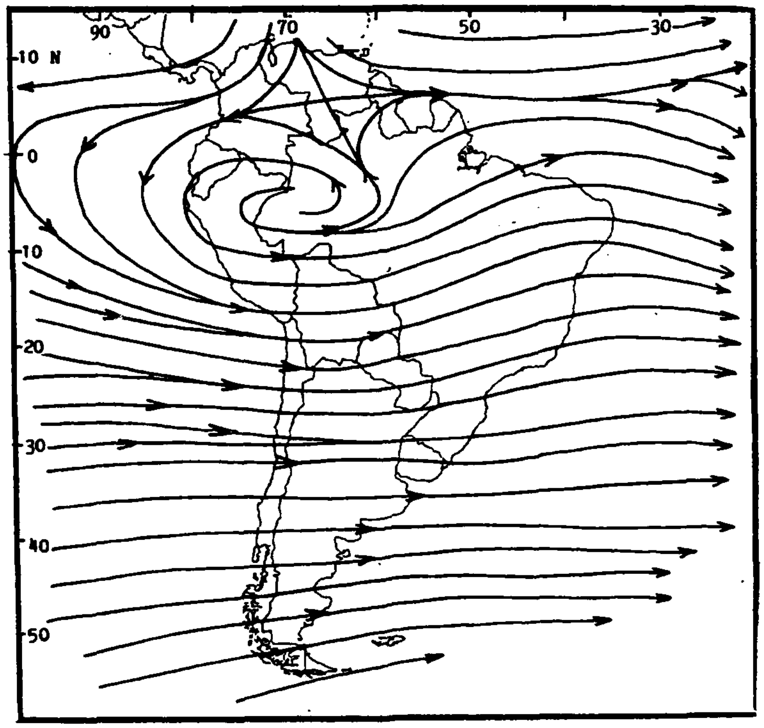


Figure 2-12e. Mean October Upper-Air Flow Patterns, 200 mb.

SOUTHERN HEMISPHERE JET STREAMS.

Polar Jet Stream (PJ). There is about a 10-degree latitude change in the mean position of the PJ from summer to winter. It is generally found frum 48 to 52° S during January and near 40° S in July (see Figures 2-13a and b). Winter 300-mb jet core wind speeds normally range from 90 to 130 knots, with peak speeds up to 170 knots. Mean trough and ridge positions are controlled by thermal rather than orographic influences. In late winter and early spring, a strong blocking ridge can develop near 50-60° S east of the continent, forcing the jet around it to the south. Blocking ridges rarely develop west of Chile.

Subtropical Jet Stream (STJ). The main flow of these upper-level westerlies passes over the Andes near 200 mb from 35 to 40° S--see Figures 2-13a and b. Speeds average 100 knots, but can reach 180 knots in winter. A branch of the STJ flows over the Bolivian Andes around 23° S, providing outflow for the development of thunderstorms (see the Bolivian High).

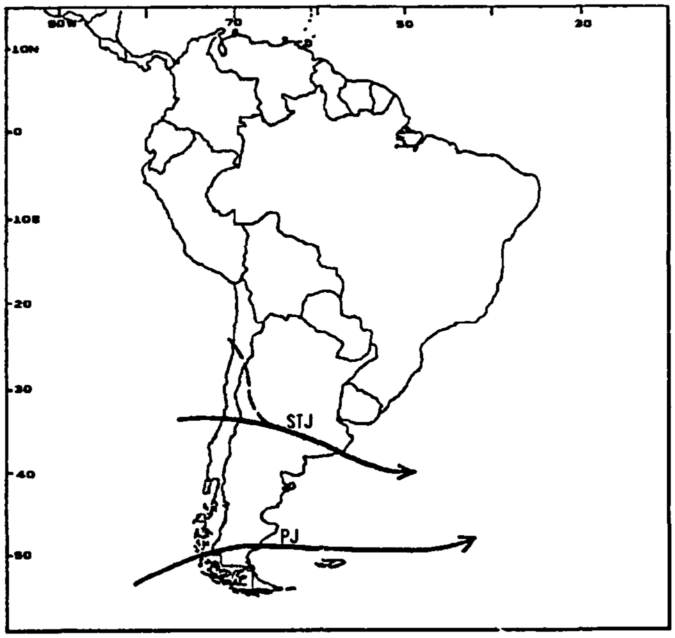


Figure 2-13a. Mean Summer (January) Positions of the Polar and Subtropical Jets Over South America.

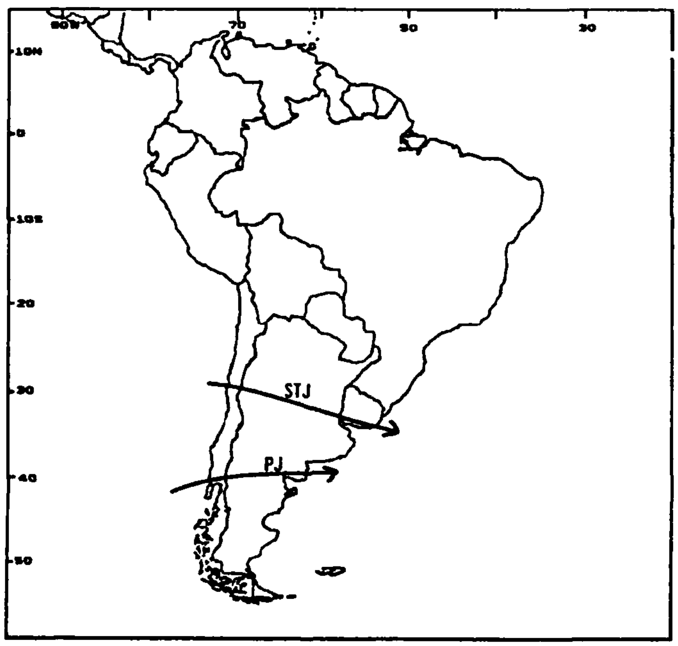


Figure 2-13b. Mean Winter (July) Positions of the Polar and Subtropical Jets Over South America.

Low-Level Jets are present on both sides of the Andes. In northern and central Chile, the Andes block westerly flow and create a low-level jet known as a "barrier wind" below the peaks on the windward (Pacific) side. This jet is generally centered between 10,000 and 13,000 feet (3,000 and 3,900 meters). Winds have been recorded at 30 knots, but reporting stations are scarce. Barrier winds in North America's Rocky Mountains have been measured at 60 knots. Figure 2-14 shows the vertical profile of a barrier wind across central Chile at night. It parallels the mountain range from the north-northwest. The resulting wind shear can create moderate to severe turbulence. Winds aloft must be southwesterly to westerly (perpendicular to the Andes) in order to to create a barrier wind; this can happen with a warm ridge to the west. The air is stable and resists being forced up over the Andes, creating a region of higher pressure below the peaks. The barrier wind is the outflow from this area of high pressure. It disappears when the warm ridge aloft is displaced to the east. The barrier wind is not believed to occur in other regions of South America as the winds aloft are not favorable or the mountains are too low.

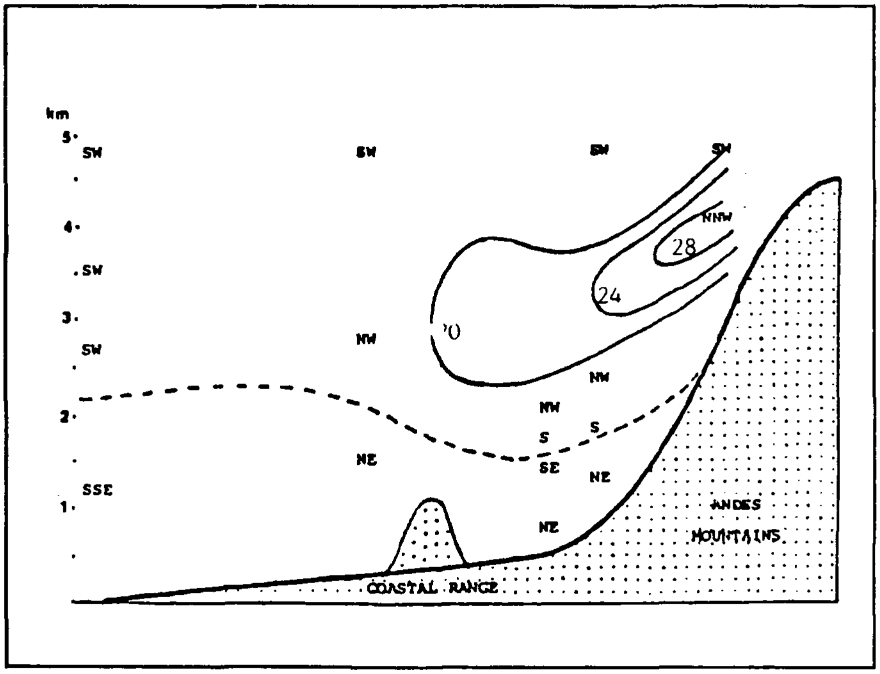


Figure 2-14. Barrier Wind. This horizontal cross section (from west to east) shows wind direction and speed (knots) of a barrier wind over central Chile.

Terrain along the coast of Peru can produce a low-level jet near the surface. Where Peru's coast turns to the northwest, low-level southerly flow converges against the Andes. Subsidence aloft prevents this air from rising, leading to funneling. Winds are southerly or southeasterly at speeds of 40 knots or more; speeds are highest in the early afternoon near the surface.

East of the Andes, a nocturnal low-level jet forms near 10° S, 65° W, but it can be found as far south as 30° S. It is created through a combination of topography and the South Atlantic High. Adiabatically warm dry air drains from the Andes out over the adjacent plain. Flow about the South Atlantic High penetrates as far as 65° W where it converges with the air from the Andes. At night, this convergence is intensified by a radiation inversion. A frontal or subsidence inversion may also be located over the area, producing a northwesterly low-level jet along the eastern slopes of the Andes at about 1,500 feet AGL that reaches speeds of 50 knots. This low-level jet is an important factor in producing nocturnal convection.

BOLIVIAN HIGH (Upper-Level). The Bolivian High is generated through a combination of heating over the Andes Mountains/Bolivian Altiplano and the latent heat of condensation released by intense convection over the western Amazon basin. It forms in December and remains a major feature through March. It normally loses its support in early April as the NET moves back to the north. Streamlines identify the 200-mb center at roughly 13° S, 68° W (see Figure 2-15a). Note that the high slopes to the north from the surface of the Altiplano. Winds are generally light (5-10 knots at 200 mb) in the center, picking up to around 30 knots on the periphery. Wind speeds are higher to the south of the high due to the presence of the Subtropical Jet. The Bolivian High and the STJ provide good venting for thunderstorm development.

The Bolivian High is a thermal anticyclone with a warm core. The intense heating of the Altiplano by solar radiation is greatest before noon when cloudiness is least. The Bolivian High is the sole source for upper-level easterlies south of the Amazon in northern Bolivia, western Brazil, and eastern Peru. There is some evidence that the high gets larger and expands into the eastern Pacific in El Niño years (see Southern Oscillation).

SUBTROPICAL RIDGE (Upper-Level). This feature is the division between upper-level westerly and easterly flow. The Subtropical Ridge provides upper-level outflow for convection, especially in the western Amazon Basin. It moves north-south with the sun and the NET and merges with the Bolivian High during the summer (see Figure 2-15a). Other positions during the year are shown in Figures 2-15b, c, and d. Downward from 200 mb, the Subtropical Ridge slopes toward the south, away from the equator.

WESTERN SOUTH ATLANTIC TROUGH. This is an upper-level trough extending from the central South Atlantic into northern Brazil (see Figure 2-15a). From November to March it splits the Subtropical Ridge into two parts--one over South America, the other over Africa. Flow between the trough and the Bolivian High contributes to precipitation in the tropics by bringing surface and upper-level disturbances into the area. The trough itself acts as an area of upper-level cyclogenesis in the tropics (see Low-Latitude Upper-Level Cyclonic Vortices). Upper-level cyclones typically weaken the trough, disrupting normal flow patterns.

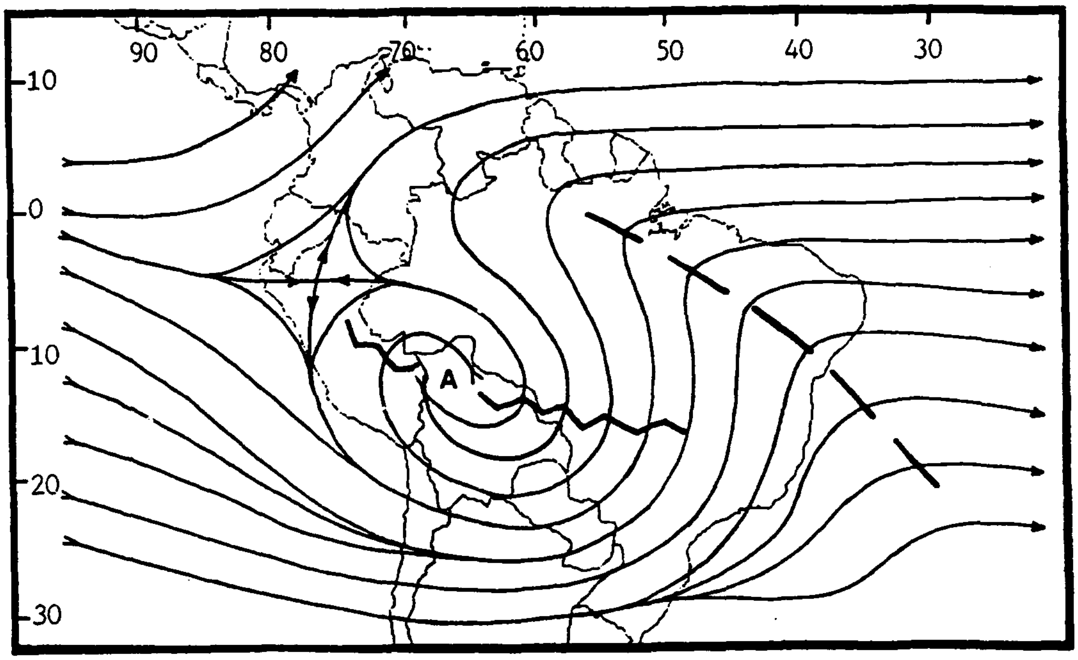


Figure 2-15a. Bolivian High, Subtropical Ridge, and Western South Atlantic Trough at 200 mb in January. The Bolivian High is marked as an anticyclone (A) in this streamline analysis. The Western South Atlantic Trough (dashed line) is also referred to as the Tropical Upper-Tropospheric Trough (TUTT).

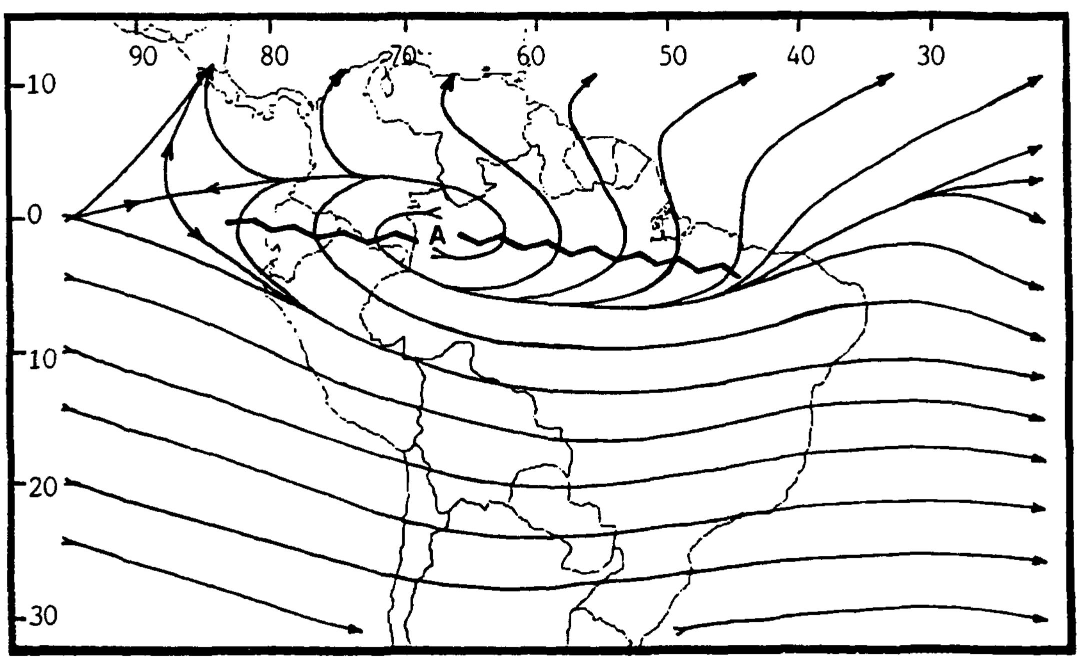


Figure 2-15b. Subtropical Ridge at 200 mb in April.

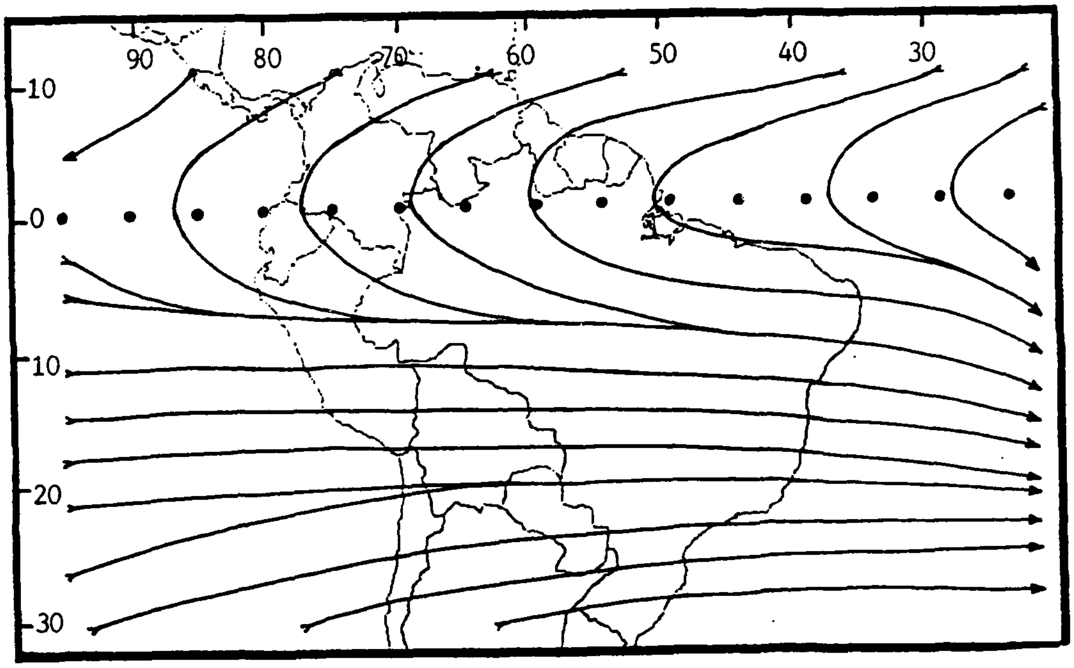


Figure 2-15c. Subtropical Ridge at 200 mb in July. Large dots are used to mark the ridge axis, a buffer zone over the Equator.

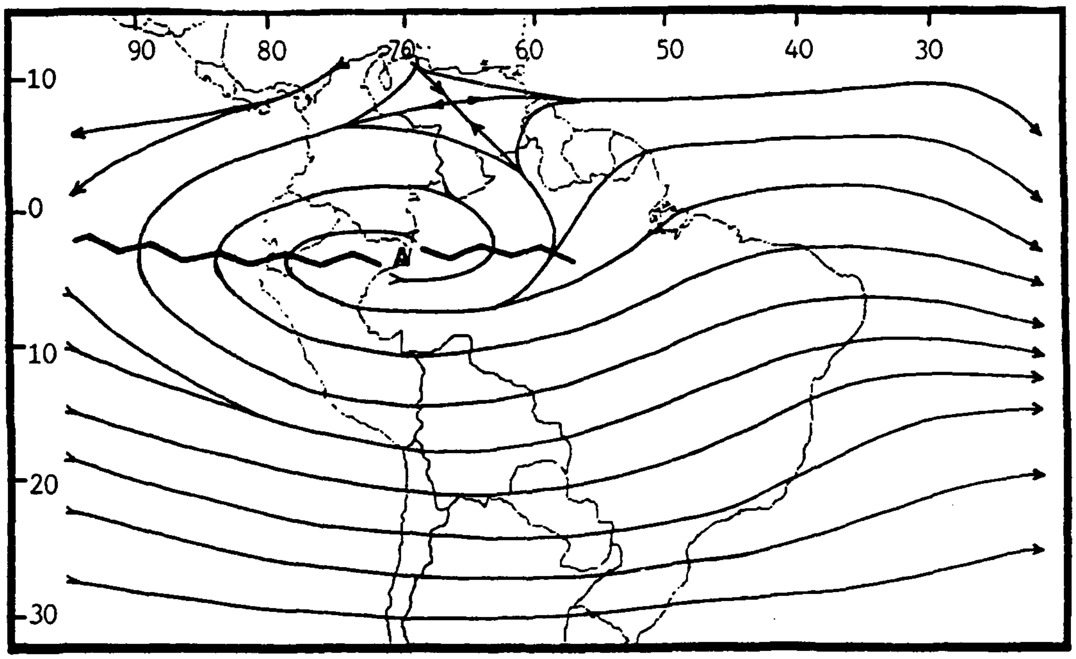


Figure 2-15d. Subtropical Ridge at 200 mb in October.

TRADE-WIND INVERSION. Subsidence from the South Atlantic High forms this mid-level inversion that suppresses South American tropical cloudiness and precipitation except where convergence lines and upslope flow are strong enough to penetrate it. It is strongest in winter, dominating northern and eastern Bolivia and nearly all of Brazil. In spring, the South Atlantic High moves southeast and the inversion weakens and recedes eastward. In summer, the inversion appears to affect only northeast Brazil.

Radiosonde data is too scarce for an accurate assessment of the inversion's mean height, thickness, strength, and area of coverage, but available information indicates that mean base height during winter ranges from 5,000 feet (1,520 meters) MSL in eastern Brazil to 10,000-12,000 feet (3,050-3,660 meters) MSL in western Brazil and Bolivia. During summer, mean base heights are 5,000 feet (1,524 meters) MSL on Brazil's east coast, rising and dissipating west of 45° W and south of 20° S.

THE TROPICAL CONVERGENCE ZONE (TCZ), also referred to as a "Tropical Convergence Trough" by some American meteorologists, normally forms between 10 and 25° S, and from 45 to 55° W. The convergence generally occurs between 700 and 500 mb, where northerly flow over Brazil meets the mid-latitude westerlies. The TCZ develops during Southern Hemisphere spring and summer. It oscillates from east to west and seldom dissipates. The northern edge of the convergence zone occasionally interacts with the NET during February and March. Cloudiness and precipitation associated with the TCZ are extensive. Cloud types are altostratus, nimbostratus, cirrostratus, and embedded cumulonimbus. Associated activity can be enhanced by migratory disturbances.

SOUTHERN OSCILLATION (El Niño, La Niña). The term "Southern Oscillation" originally referred to a sequence in which higher and lower pressure alternated between the tropical waters of the Indian and Pacific Oceans. The Southern Oscillation now, however, is known to be a complex, global atmospheric/oceanic phenomenon. This discussion is limited to the synoptic features and conditions that affect South America. The Southern Oscillation, as it affects South America, is made up of two phases: a warm "El Niño" and a cold "La Niña," with short transitions between the two. The time to complete one cycle is irregular, varying between 2 and 10 years and averaging 3. The transition between El Niño and La Niña normally takes a few months, the time needed for a change to occur in the wind field and the ocean currents of the eastern Pacific. The changes in the wind field for El Niño and La Niña are examined using the Walker Circulation, a series of cells depicting the global east-west air-flow pattern in the tropics. The rest of this section covers the synoptic situations associated with the La Niña and El Niño, the effects the El Niño phase has on South American regional weather, and a listing of some techniques used to forecast their onset.

The La Niña phase of the Southern Oscillation sees high surface pressure over the tropical eastern Pacific and low surface pressure over Indonesia. The top section of Figure 2-16 shows the Walker Circulation for the La Niña with ascending air forming convection over Indonesia, upper-level westerlies across the Pacific, descending air in the eastern Pacific, and low-level easterly trade winds. These low-level easterly trade winds are strong and persistent enough to push the warm surface waters westward via the South Equatorial Current across the Pacific, actually raising the sea level near Indonesia by 16 inches (40 cm). Water flowing away from the Peruvian coast is replaced by an upwelling of cold, subsurface waters. Descending air in the eastern Pacific, combined with the cold sea-surface temperatures, lead to stable conditions along the coast of Peru that cause the NET to remain in the Northern Hemisphere during summer.

The El Niño phase of the Southern Oscillation (often referred to as an ENSO event) sees high surface pressure over Indonesia and low surface pressure over the eastern Pacific. The bottom of Figure 2-16 shows the Walker Circulation to consist of descending air over Indonesia, low-level westerlies across the Pacific, ascending air forming convection in the eastern Pacific, and a return flow of upper-level easterlies. This reversal in the flow pattern creates changes in the weather affecting South America.

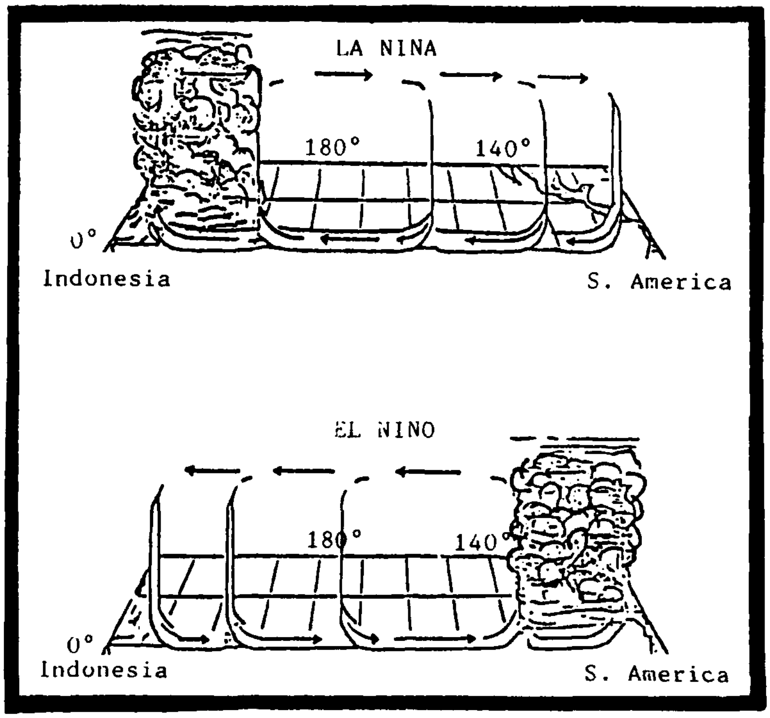


Figure 2-16. Walker Circulations During La Niña (top) and A Strong El Niño (bottom).

The shift to low-level westerly winds modifies the ocean currents. Figure 2-17 shows the direction of movement of the ocean currents during an El Niño phase. The South Equatorial Current is significantly weakened and warm water is brought in by the counter current. A deep, warm ocean layer builds in the eastern Pacific. Figure 2-18 shows sea-surface temperatures in November 1982 during a strong ENSO event (ENSO events are categorized as being "strong," "moderate," "weak," or "very weak"). Figure 2-19 shows the mean sea-surface temperatures in November for comparison. The low-level westerlies normally don't reach all the way to the Peruvian coast. Southeasterly winds from the South Pacific High still flow northwestward along the coast, but don't extend very far offshore. These meteorological and oceanic changes move the NET into the Southern Hemisphere at around 5° S.

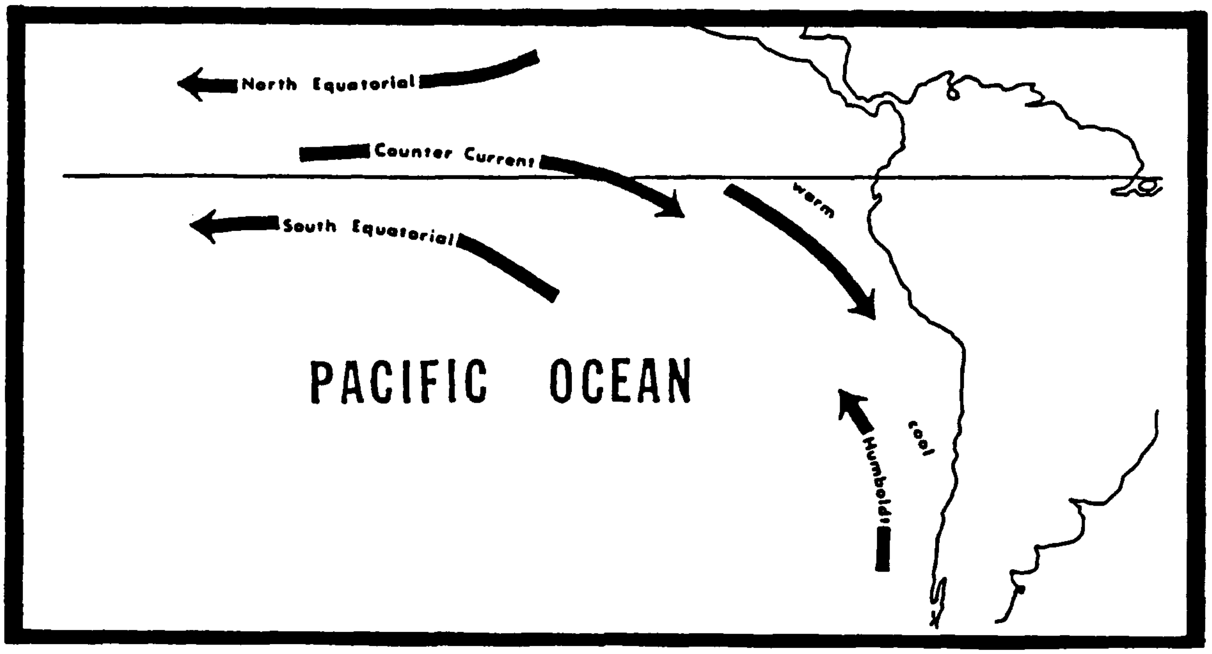


Figure 2-17. Eastern Pacific Currents During A Strong El Niño.

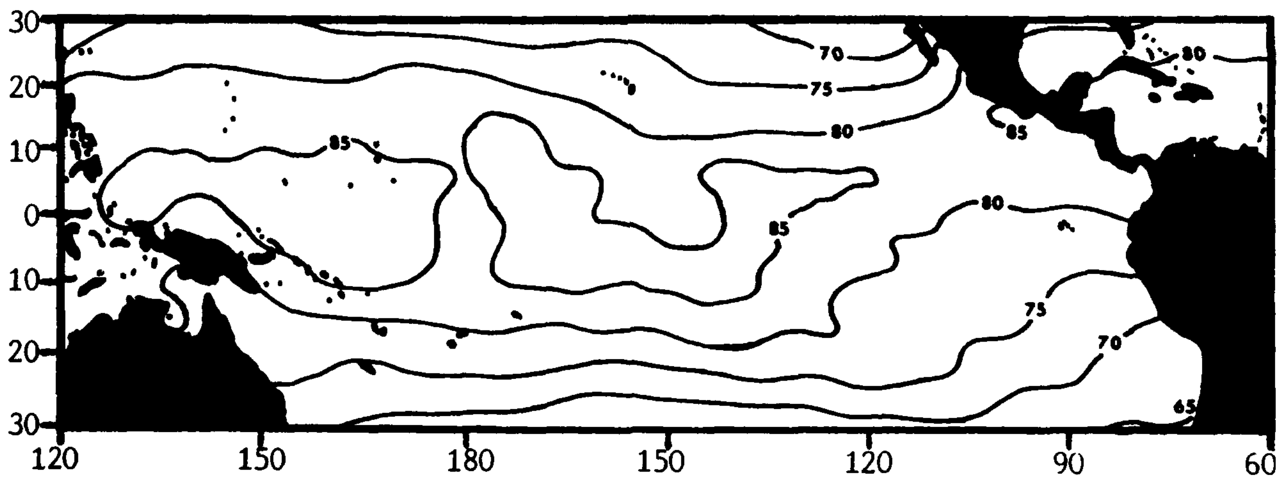


Figure 2-18. Sea-Surface Temperatures (° F) for November 1982 El Niño. Temperatures across the eastern and central Pacific average 5° F higher than normal.

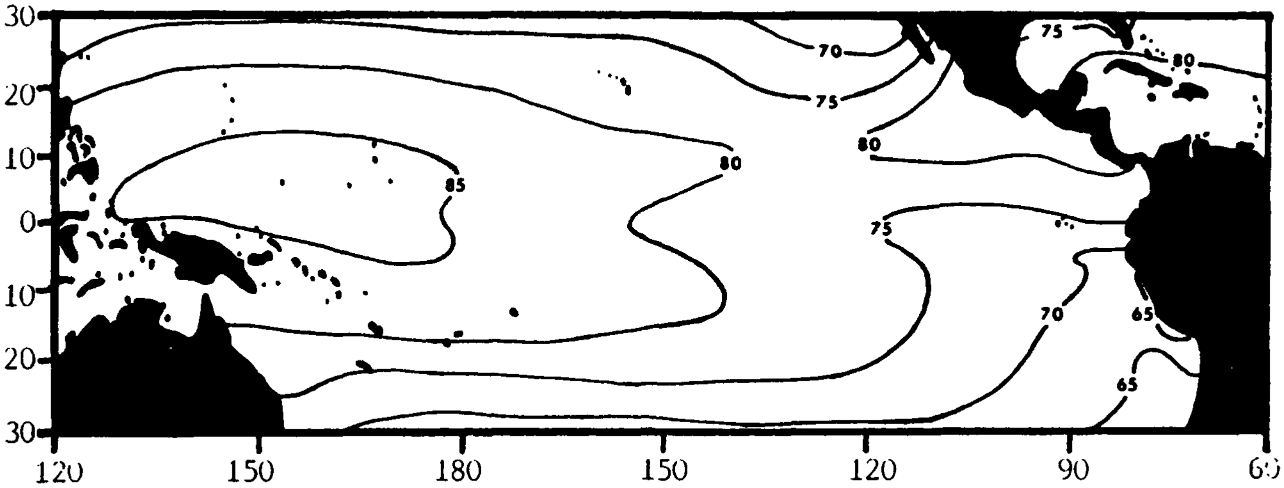


Figure 2-19. Mean Sea Surface Temperatures (° F) for November.

At 200 mb, anticyclones form at about 15° N, 140° W and 15° S, 140° W, enhancing the easterly winds and the outflow for the NET. The upper-level Bolivian High (which see) is believed to move from its normal position out over the Pacific, providing outflow for the NET. In addition, the subtropical jet over the Southern mid-latitudes intensifies.

The El Niño phase has an average length of 18 months. It begins in December or January in the eastern Pacific (hence the term El Niño, "The Child"). The modified wind field normally changes the ocean currents by March or April. Some weather effects are felt during the winter (June-August), primarily in the mid-latitudes. El Niño reaches peak intensity during the following summer (December-February) when the NET is most likely to move into the Southern Hemisphere.

Weather changes during an El Niño can cause torrential rains and floods in northern Peru, abnormal rainfall in the desert regions of southern Peru and northern Chile, droughts over sections of northeast Brazil, less snow than normal in the central Andes from 5 to 20° S, more snow than normal in the Andes from 20 to 45° S, and more rainfall than normal over southern Brazil, northern Argentina, and Uruguay. These El Niño effects will now be examined in more detail.

The movement of the NET into the Southern Hemisphere in the summer brings a great deal of rain to the desert regions of northern Peru. In March 1925, for example, Trujillo (8° S, 70° W) got 15.5 inches (394 mm), compared to the 0.7 inches (18 mm) it had received during the previous 5 years. The heavy rainfall normally doesn't reach as far south as Lima (12° S, 78° W), but increased precipitation and flash flooding is still a problem because of the mountains and lack of vegetation.

The central Andes between 5 and 20° S, along with sections of northeast Brazil, actually see a decrease in precipitation. Thunderstorm activity over the coast of Peru apparently causes or enhances descending air over these regions, as shown in Figure 2-20. For northeast Brazil, however, other factors such as sea-surface temperature anomalies in the Atlantic are equally important. It's estimated that only 10% of droughts are due to the El Niño phase.

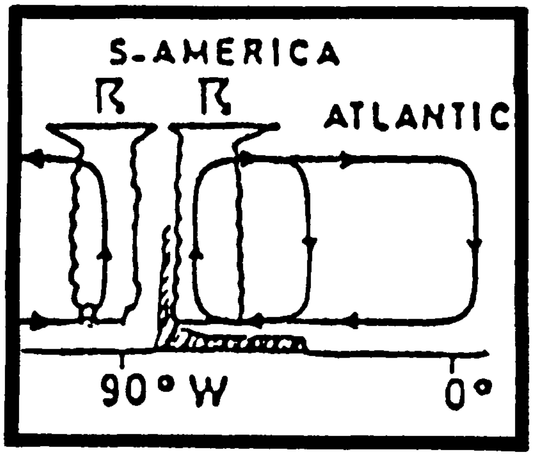


Figure 2-20. Walker Circulation Over South America and the Atlantic During El Niño.

Synoptic changes, particularly the strengthening of the subtropical jet, also cause cyclonic activity to increase by as much as 25% in the winter across South America between 20 and 45° S. This increases rainfall (and snow) within these latitudes.

Several techniques have been developed to attempt to forecast the onset, duration, and intensity of ENSO events, and computer models now have some skill at predicting onset. The process is still not completely understood, however, and each ENSO event seems unique in some way. For example, some events have been preceded by:

- Low readings of the Southern Oscillation Index (SOI), which measures the standardized difference of the sea-level pressure anomalies at Tahiti minus Darwin.

- The eastward movement of warm waters.

- A weakened pressure gradient over the central Pacific, with easterly surface winds becoming lighter or even westerly.

- An eastward-moving minimum of the outgoing longwave radiation index (due to convection).

A detailed examination of these and other techniques (as well as the Southern Oscillation itself) is beyond the scope of this study. The reader is encouraged to review the references listed in the bibliography for more information as needed--Philander (1990) is highly recommended.

EXTRATROPICAL CYCLONE ACTIVITY. In this section, we cover four major topics; the first is a discussion of satellite-based extratropical cyclone models. Since most Southern Hemisphere low-pressure systems occur over water, satellite meteorology has greatly improved analysis and forecasting here. Next, we show the primary storm tracks during the summer and winter, and then the controls that affect cyclogenesis, along with some examples of cyclogenesis in the region. Finally, we discuss and provide examples of synoptic patterns for each of the four seasons.

Satellite Models. Figures 2-21a-c show Southern Hemisphere flow patterns for a vortex-deformation cloud zone, the baroclinic-leaf cloud, and the mature comma-cloud system, respectively. Southern Hemisphere lows rotate clockwise with warm, moist air coming from the north or northeast.

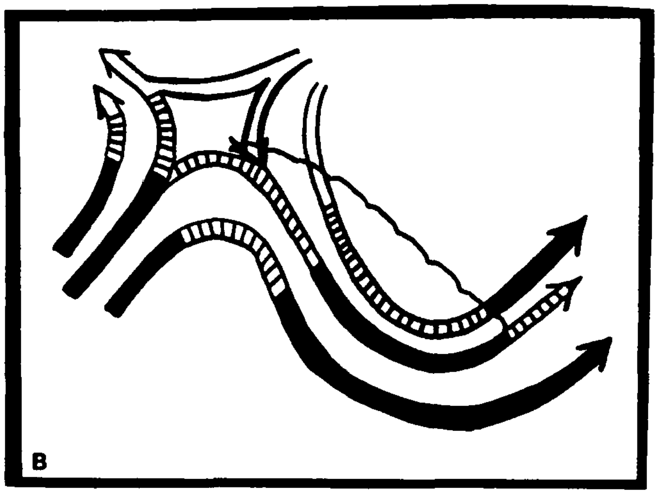


Figure 2-21b. Flow Pattern for the Baroclinic-Leaf Cloud Zone. Airflow trajectories show low-level (white arrow segments), mid-level (hatched arrow segments), and upper-level flow (dark arrow segments). The shaded region represents cloud.

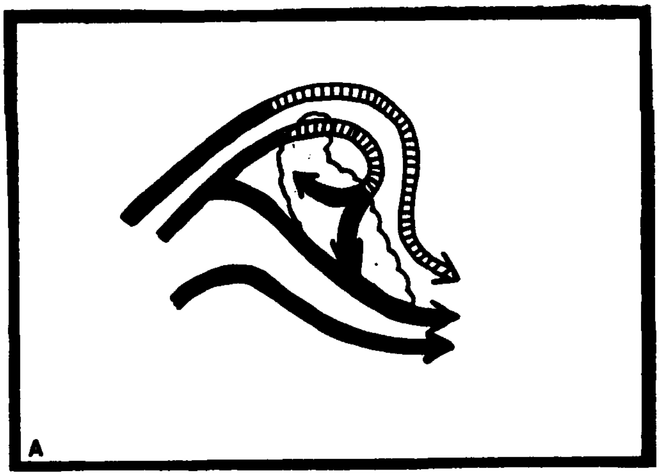


Figure 2-21a Flow Pattern for the Vortex-Deformation Cloud Zone. Airflow trajectories show mid-level (hatched arrow segments) and upper-level flow (dark arrow segments). The shaded region represents cloud.

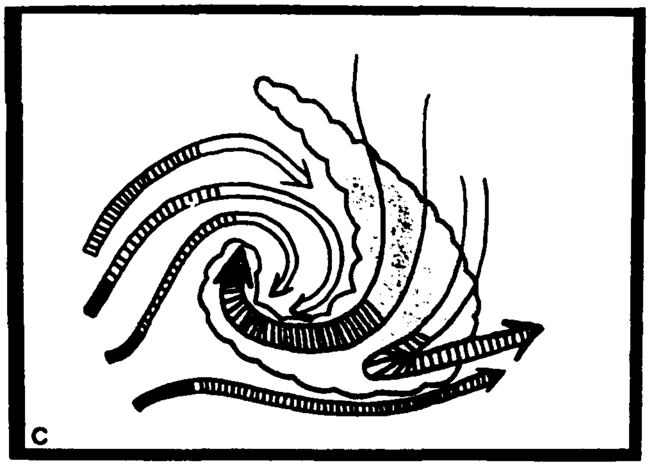


Figure 2-21c. Flow Pattern for the Mature Comma-Cloud Zone. Airflow trajectories show low-level (white arrow segments), mid-level (hatched arrow segments), and upper-level flow (dark arrow segments). The shaded region represents cloud.

SYNOPTIC DISTURBANCES

In the eastern South Pacific, connected vortices (or "cyclone families") commonly develop 200-400 NM west of the southern Chilean coast (45-55° S). These cyclone families can develop directly through cyclogenesis, or pre-existing vortices may combine as a result of deep mid- or upper-level troughs. Deeper troughs often slow down when approaching a strong ridge. Successive troughs may combine with their surface fronts joining together and intensifying (see Figure 2-22).

Cyclone families may also develop through the "instant" occlusion process, as shown in Figure 2-23. This occurs when a comma cloud or vorticity maximum advances on a frontal wave. The comma cloud merges with the wave; the resulting satellite signature looks like an occluded system.

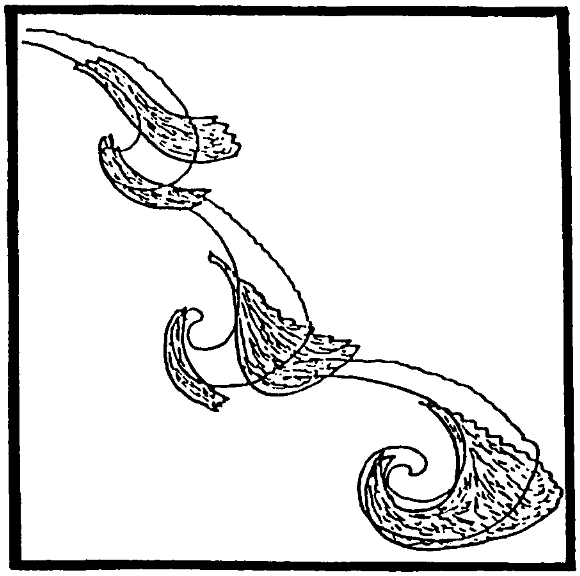


Figure 2-22. Cyclone "Families"; A Common Development Sequence in the Eastern South Pacific (from Bell, 1986). The tail of the downstream vortex aligns and merges with the head of the upstream comma cloud system (white area). On occasion, this continuous cloud pattern is visible, but middle and high clouds normally overlay the region.

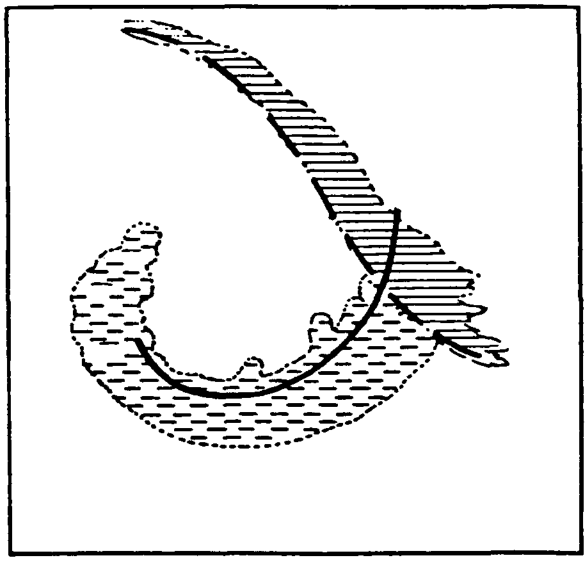


Figure 2-23. The "Instant" Occlusion. The solid line represents the comma cloud or vorticity maximum; broken hatching, the associated cloud. The dashed line represents the well-defined edge of the polar cloud band; clouds are shown by the solid hatching.

Storm Tracks. Extratropical cyclone activity can affect South America throughout the year. Figure 2-24 shows the primary storm tracks for systems affecting South America. The Andes Cordillera is a major barrier to systems approaching South America. Pacific air masses rarely extend eastward across the Andes north of 45° S. Drake Passage provides the primary pathway for Pacific lows and Pacific air mass penetration into South America and the South Atlantic Ocean. Lows developing along the eastern South American coast generally move southeast into the South Atlantic.

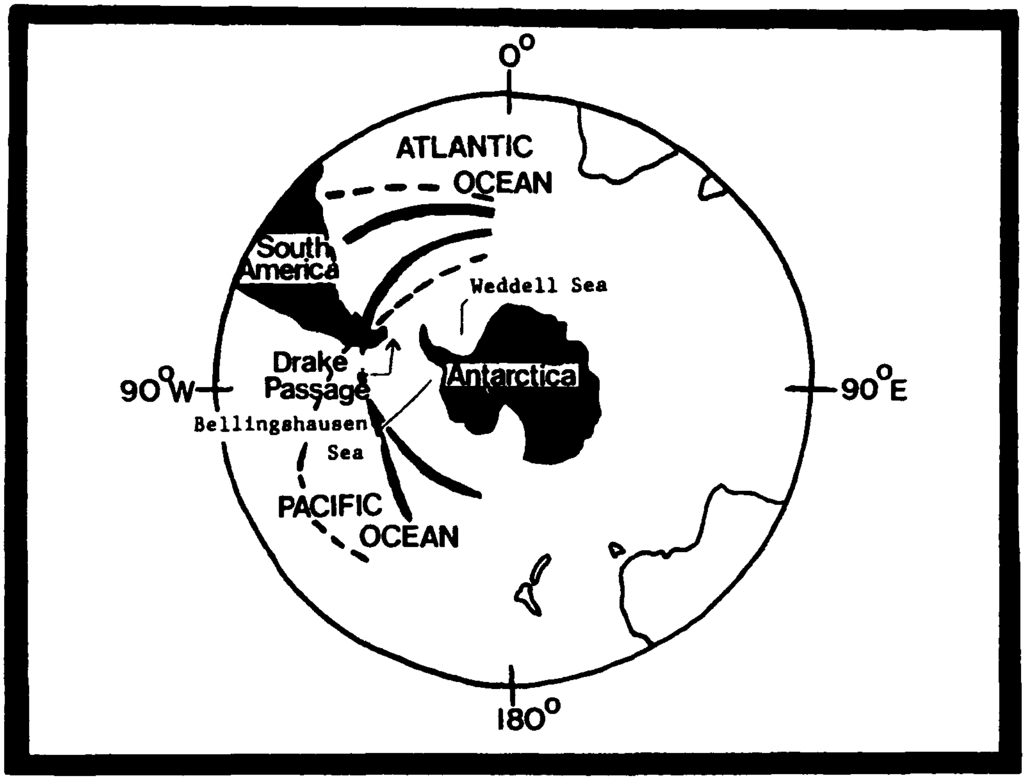


Figure 2-24. Storm Tracks. The solid line represents summer (December-February) storm tracks; the dashed line, winter (June-August).

Cyclogenesis. The most important semipermanent climatic features to cyclogenesis are the South Pacific High, the South Atlantic High, and the Circumpolar Trough. High pressure ridging, or "blocking", can also occur. The El Niño-Southern Oscillation (ENSO) is not a semipermanent climatic feature, but its occurrence causes abnormal conditions. These features are all discussed, in turn. Examples of cyclogenesis/frontogenesis are also provided.

The South Pacific High produces zonal flow south of 45° S. The cell is extremely well-defined during the summer. The extensive high-pressure ridge at the surface dominates the eastern South Pacific and normally does not permit systems to penetrate north of 45° S.

During the winter, the cell weakens enough to regularly allow cold fronts and accompanying precipitation north of 45° S into central and Southern Chile. Failure of the South Pacific High to weaken produces abnormally dry winters across Southern Chile and Argentina. Figure 2-25a and b show the mean sea-level pressures for winters that are abnormally dry or wet.

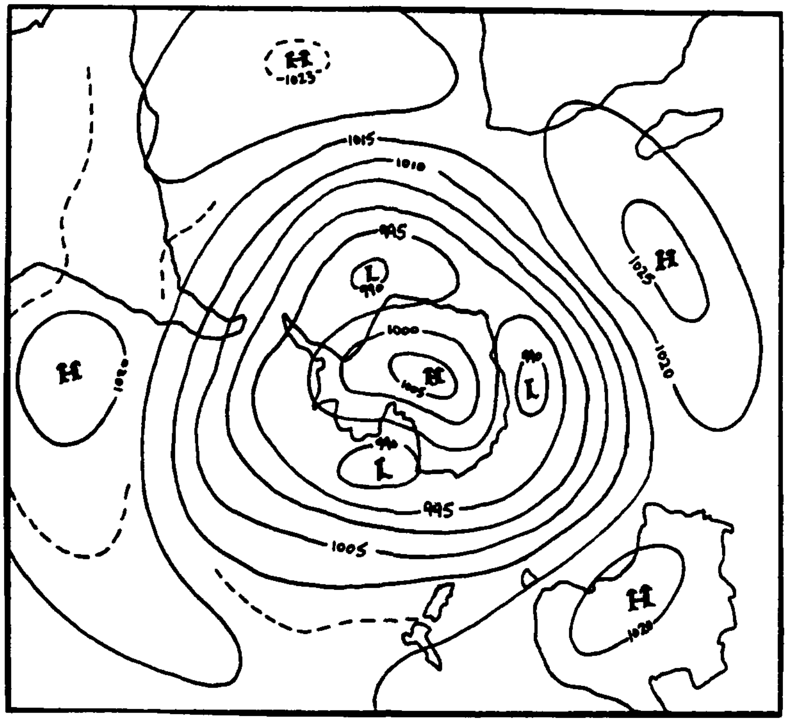


Figure 2-25a. Mean Seasonal Sea-Level Pressure for the Dry Winter (June-August) of 1952 in South-Central Chile. High-pressure ridging extends southward off the Chile coast, cutting off any development or movement.

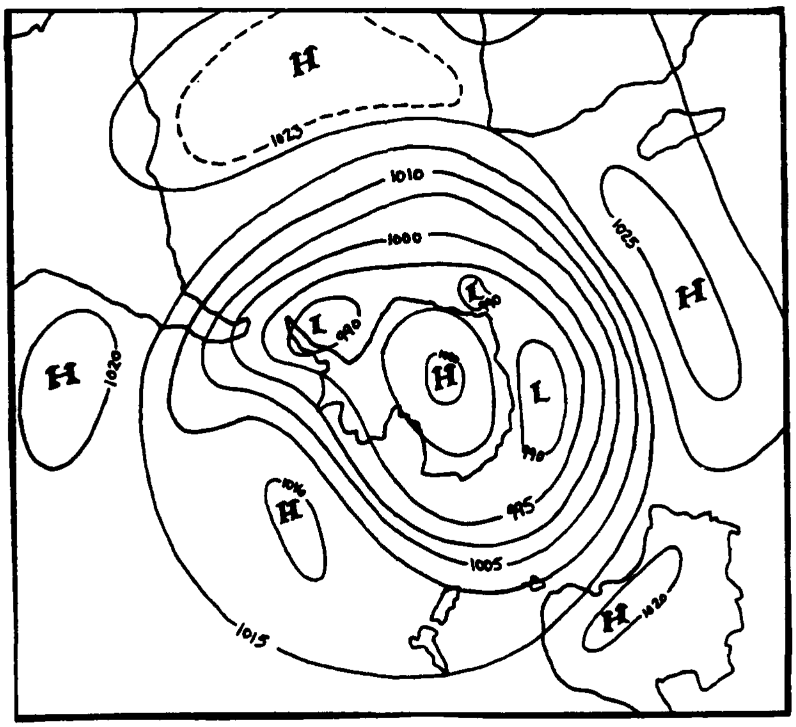


Figure 2-25b. Mean Seasonal Sea-Level Pressure for the Wet Winter (June-August) of 1953 in South-Central Chile. Note the trough extending from the Weddell Sea across Southern Chile. Low-pressure systems are able to reach central Chile.

The South Atlantic High is an important factor in cyclogenesis off the southeastern coast of South America throughout the year. Its position and strength also determine the track for migratory low-pressure cells moving eastward through the Drake Passage. South Atlantic High outflow often provides additional moist northeasterly surface flow into developing cyclones over northern Argentina and the Rio de la Plata. Subsequent movement by lows is southeastward along the South Atlantic High's Southern flank. Figures 2-26a-d show a typical air-mass convergence pattern for extratropical cyclone development over northern Argentina and the Rio de la Plata. Figures 2-27a-c are satellite imagery showing the development of a low over the Rio de la Plata and subsequent movement out into the Atlantic.

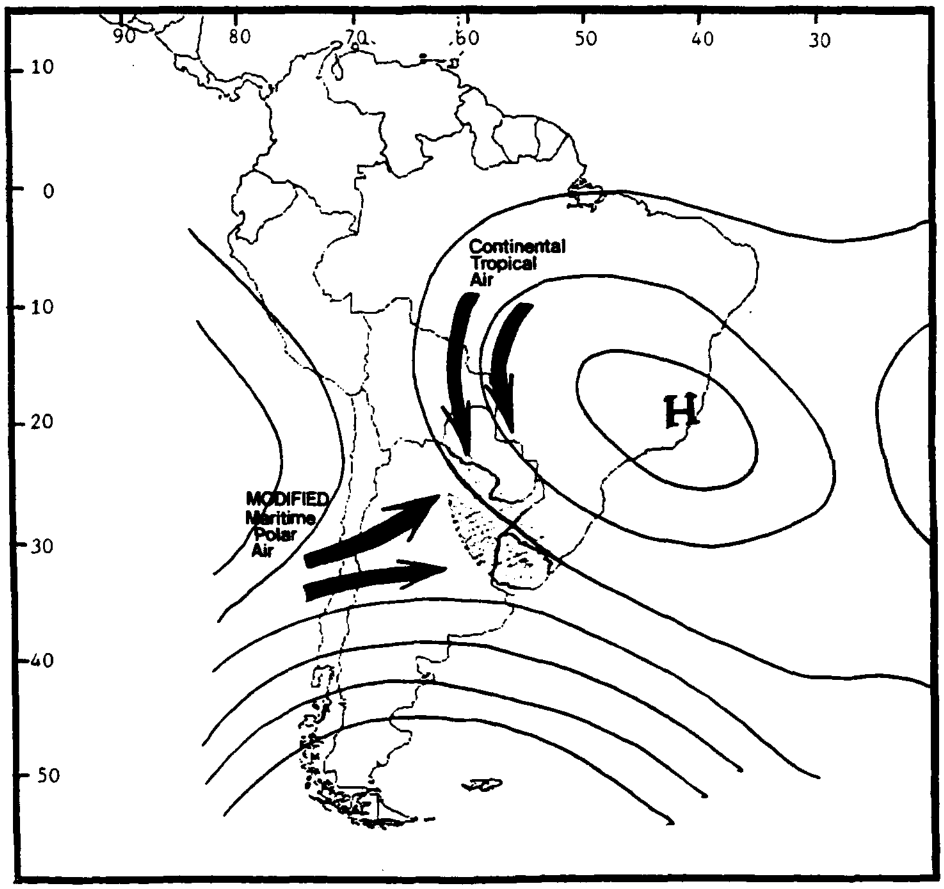


Figure 2-26a. Typical Summer Cyclogenesis/Frontogenesis Surface Pressure Pattern Along the Southeast Coast of South America. The South Atlantic High brings continental tropical air southward into northern Argentina.

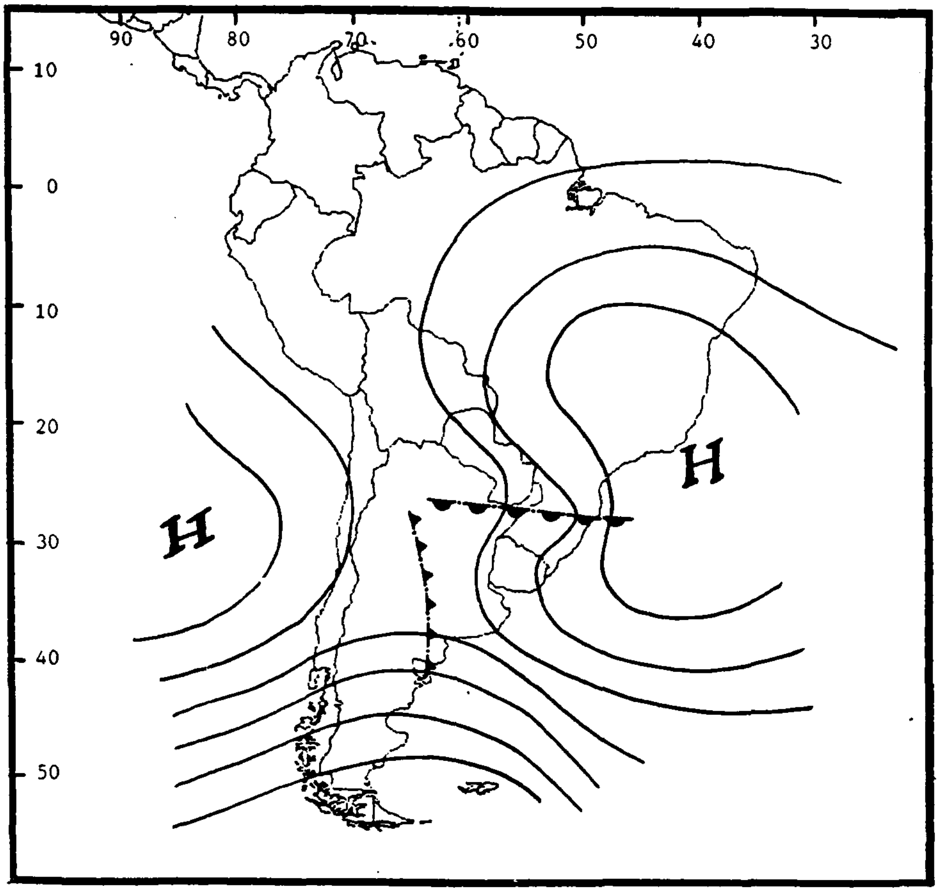


Figure 2-26b. Frontogenesis Produced by Troughing Between the Semipermanent High-Pressure Cells of the South Pacific and South Atlantic.

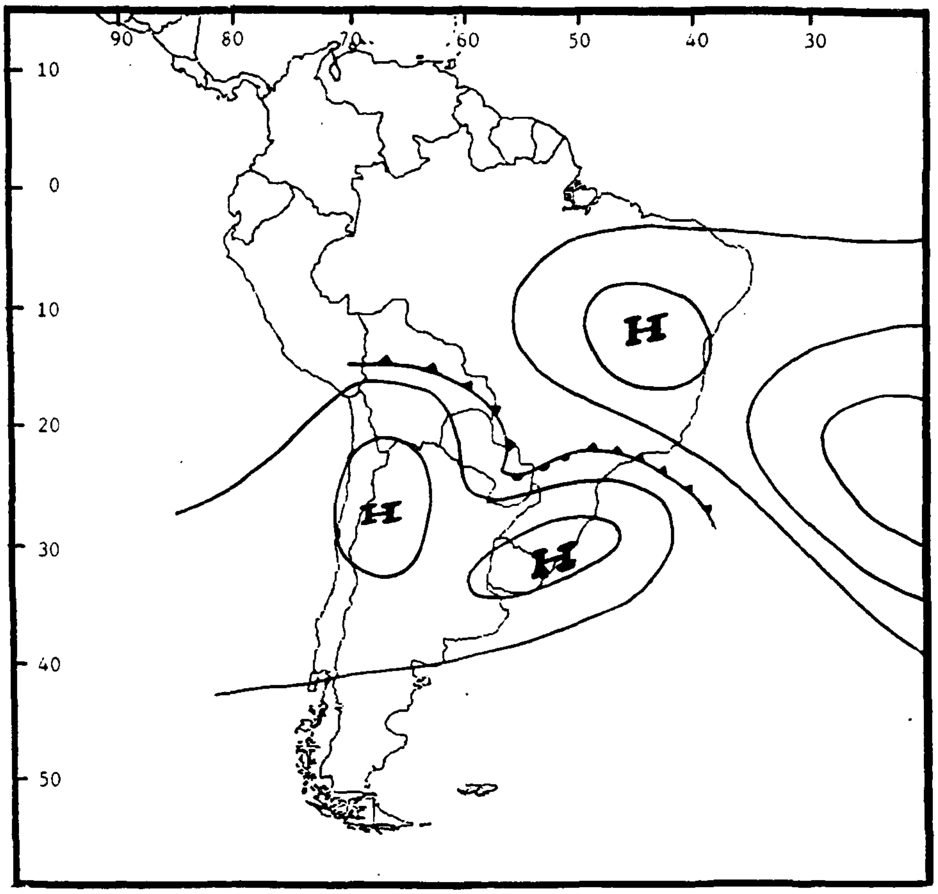


Figure 2-26c. A Wave Develops on the Boundary Between Air Masses.

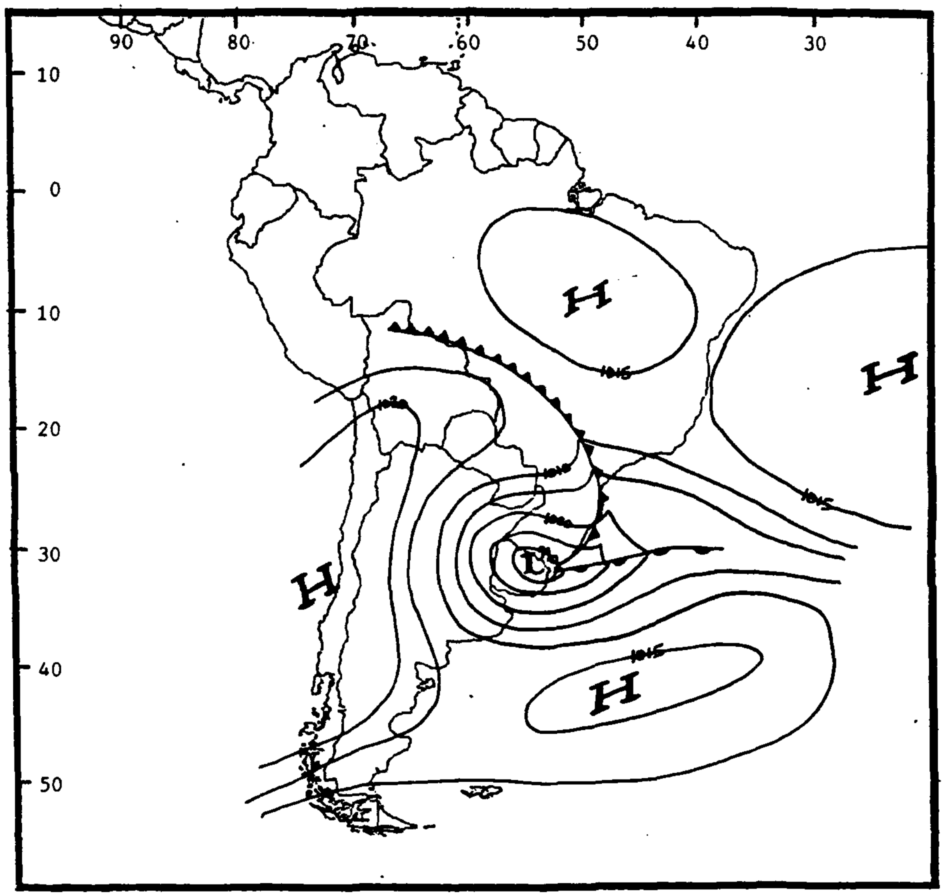


Figure 2-26d. Mature Extratropical Cyclone Moving Southeastward into the South Atlantic. The surface "cold" front is often a discontinuity in moisture rather than temperature during summer.

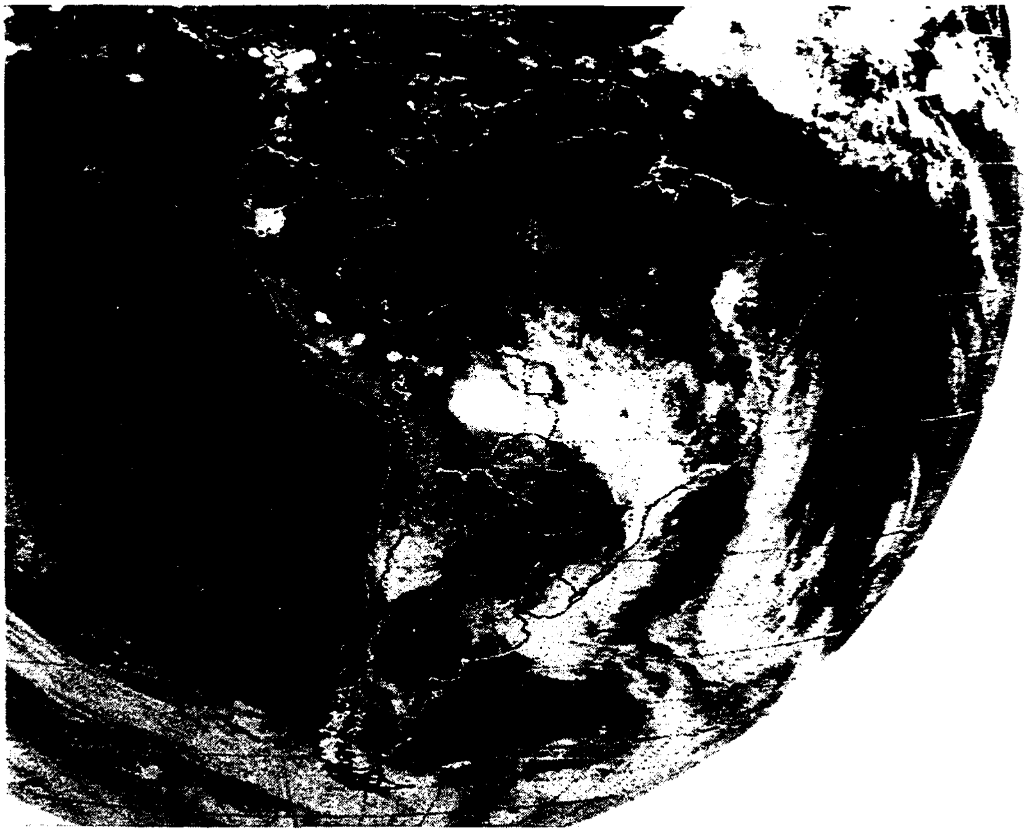


Figure 2-27a. Cyclogenesis Over Rio de la Plata, 13 November 1983 (0700Z IR). The low can be seen developing just south of Uruguay with a cold front extending just north of Paraguay into Southern Bolivia. Stratus is present in the cold air along the mountains; convection is produced north of the front. (Photo courtesy of NOAA/NESDIS).

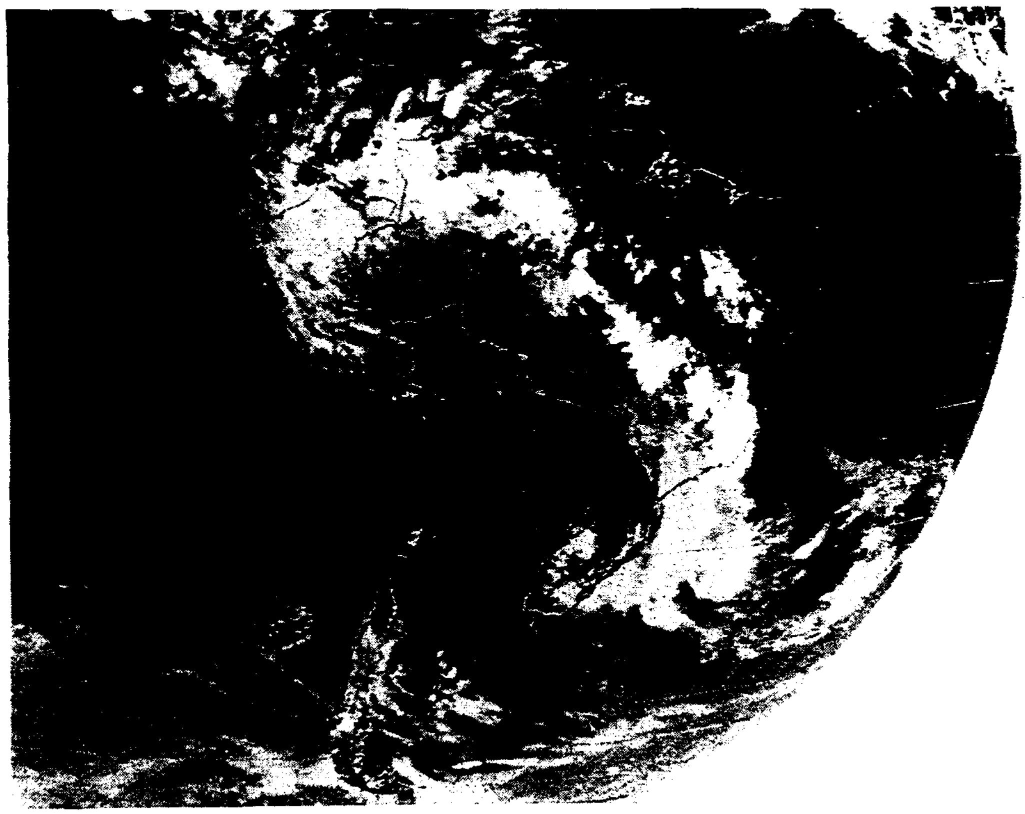


Figure 2-27b. Cyclogenesis Over Rio de la Plata, 15 November 1983 (1900Z IR). The low is on the Uruguay/Brazil border with the cold front moving east and north into Brazil. Convection has developed out in front of it, particularly since it is in the afternoon. (Photo courtesy of NOAA/NESDIS).

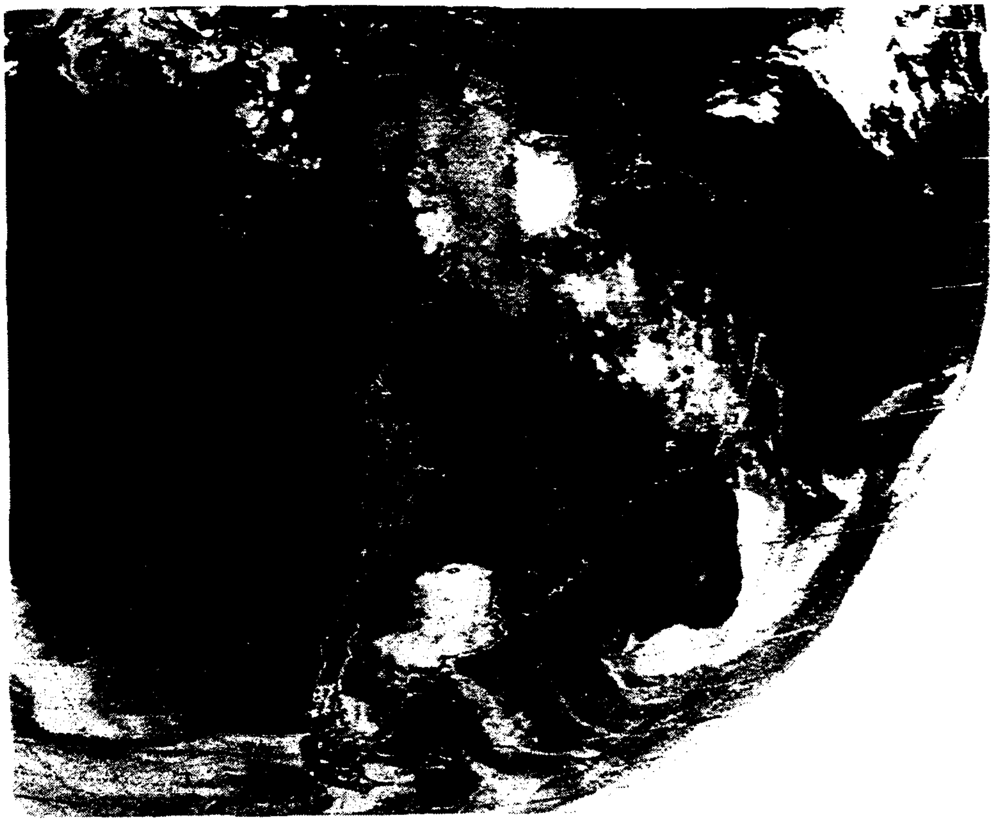


Figure 2-27c. Cyclogenesis Over Rio de la Plata, 17 November 1983 (0700Z IR). The low has moved southeast into the South Atlantic. The cold front is very evident, producing cloudiness into northern Brazil. The clouds are mainly stratiform in this late night image; convection often develops with the daytime heating. (Photo courtesy of NOAA/NESDIS).

Antarctic topography and land/sea temperature differences produce three favorable areas for semipermanent low surface pressures around the landmass. These areas show little variation from season to season; hence, the name "Circumpolar Trough." This trough has a significant effect on extratropical cyclone activity. It produces persistent zonal mid- and upper-level flow patterns over the polar regions. Figures 2-28a & b show the mean sea-level pressure patterns in January and July. Subtle variations in the Circumpolar Trough's mean position are produced by sea ice distributions.

Local drainage winds off Antarctica occasionally produce intense vortices in the Weddell Sea and Bellingshausen Sea between May and September. These "Polar Lows" produce low-level, spiral cloud patterns. Their movement remains close to the sea/ice interface. Occasionally they pass through Drake Passage. Polar Lows are generally small but intense; they produce strong winds, heavy precipitation, and low clouds.

A strong temperature gradient between Antarctic air and the surrounding oceanic air is present all year. It drives the westerly circulation from 850 to 500 mb over Antarctica and the surrounding oceans. Maximum westerly flow varies seasonally between 42° 30' S and 50° S.

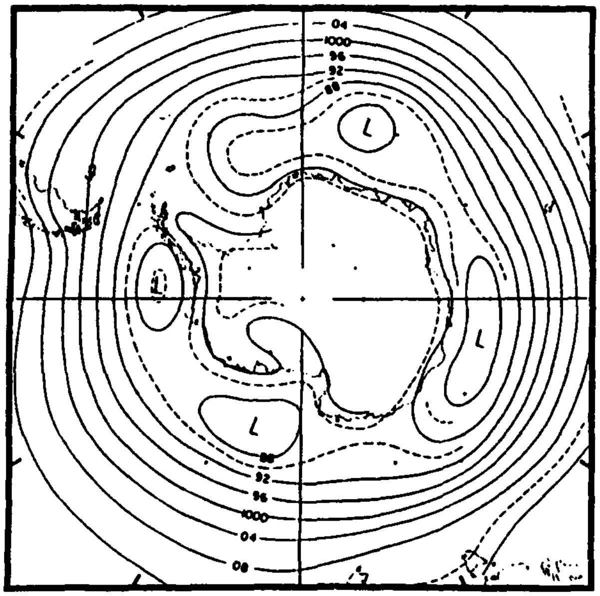


Figure 2-28a. Semipermanent Low Surface Pressure Areas Defining the Circumpolar Trough for January (from Schwerdtfeger, 1970). Pressure in millibars.

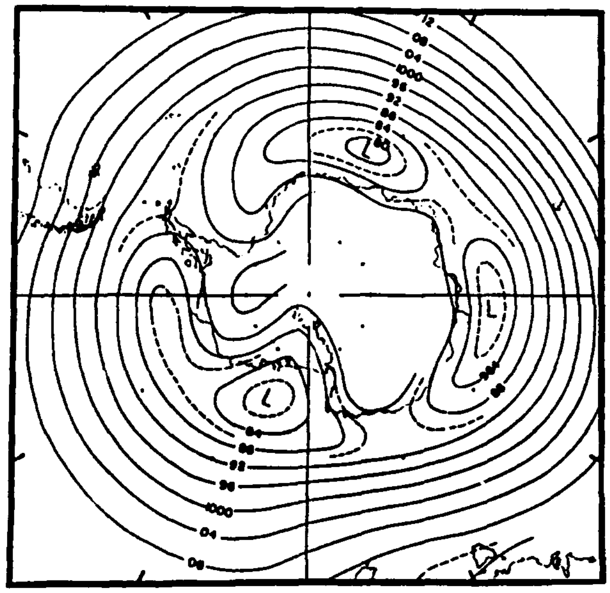


Figure 2-28b. Semipermanent Low Surface Pressure Areas Defining the Circumpolar Trough for July (from Schwerdtfeger, 1970). Pressure in millibars.

The frequency of extratropical cyclones across South America can be extremely variable from year to year. The cause and effect relationship for the severe drought and excessive rainfall that periodically affects South America is not fully understood. Blocking high-pressure cells and the ENSO, however, are recognized as two of the causes.

Blocking high-pressure cells over mid-latitude oceans may cause longwave troughs to temporarily alter cyclogenesis and resultant storm tracks during any season. Southern Hemisphere meteorologists have identified individual and interactive blocking patterns developing over the South Pacific, South Atlantic, and South Indian Oceans.

The ENSO has been identified as a cause for large-scale variations in circulation patterns (see Southern Oscillation discussion for details). The South Pacific surface ridge weakens enough in the summer to allow extratropical activity to penetrate farther northward than normal. This was the case in January 1953 across much of Chile south of 33° S, when Santiago (33° 27' S), received 0.25 inch (6.4 mm), six times its normal (0.04 inches/1.1 mm) January precipitation.

Summer Seasonal Analysis (December-February). The Southern Hemisphere summer synoptic weather pattern is dominated at the surface by daily oscillations of the South Pacific and South Atlantic Highs. A typical midsummer weather pattern for South America features a strong surface ridge between the two. December has the lowest frequency of cyclogenesis. Extratropical cyclones are steered eastward from Drake Passage into the Weddell Sea. The 8-13 January 1963 period in Figures 2-29a-h shows how 500-mb flow can temporarily disturb typical summer surface conditions. The surface charts and 500-mb analysis have been adapted from the South African Weather Bureau Analysis. Surface pressure is in millibars, and 500-mb height contours are in tens of geopotential meters (GPM).

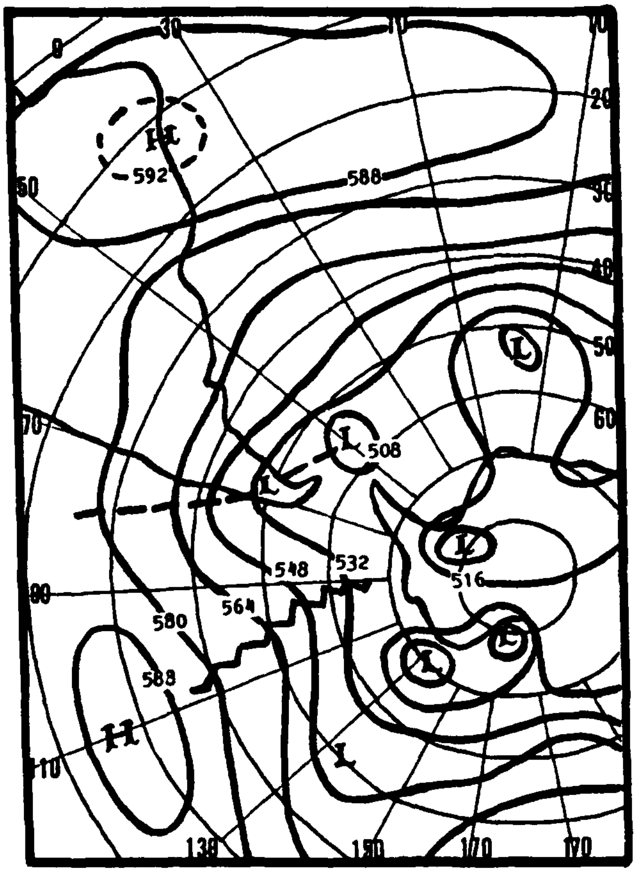


Figure 2-29a. 500-mb Chart, 8 January 1963 (1200Z). A 500-mb low (508 GPM) is positioned at 55° S, 50° W. Its trough axis extends to the northwest to 27° S, 80° W. 500-mb troughs often reach to 30° S when strong ridging--as is the case here--develops over the Bellingshausen Sea.

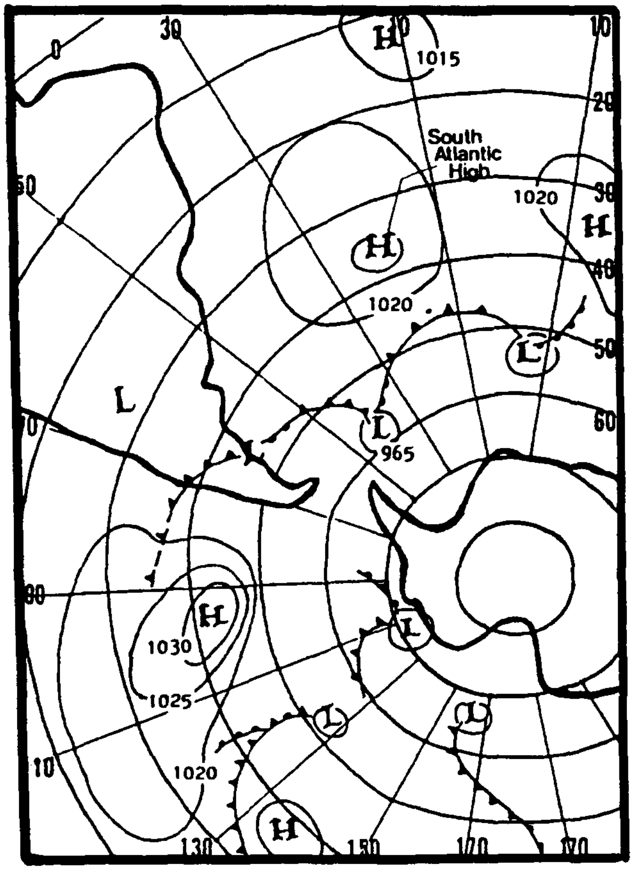


Figure 2-29b. Surface Chart, 8 January 1963 (1200Z). The circumpolar trough around Antarctica is well-defined. A deep surface low (965 mb) near 57° S, 42° W and the South Atlantic High outflow (northeasterlies) form a weak warm front over water just off the Argentine coast at 45° S, 61° W. Over land, the frontal boundary becomes a weak frontal wave produced by South Pacific High outflow (southwesterlies). The Northwest Argentine Depression is shown at 27° S, 66° W.

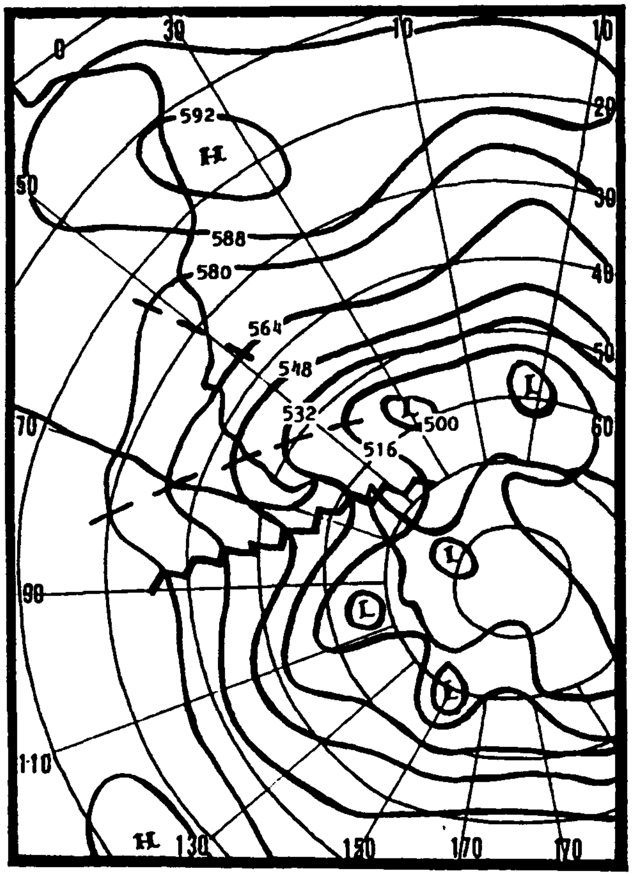


Figure 2-29c. 500-mb Chart, 9 January 1963 (1200Z). The 500-mb ridge has migrated eastward into Drake Passage and the Weddell Sea and is assisting in frontal wave development over Argentina. The 500-mb low (500 GPM) and trough axis have moved east across Argentina and intensified. Normally, the zonal westerly flow around Antarctica at 500 mb produces a ESE-to-WNW tilt to 500-mb troughs between December and late March.

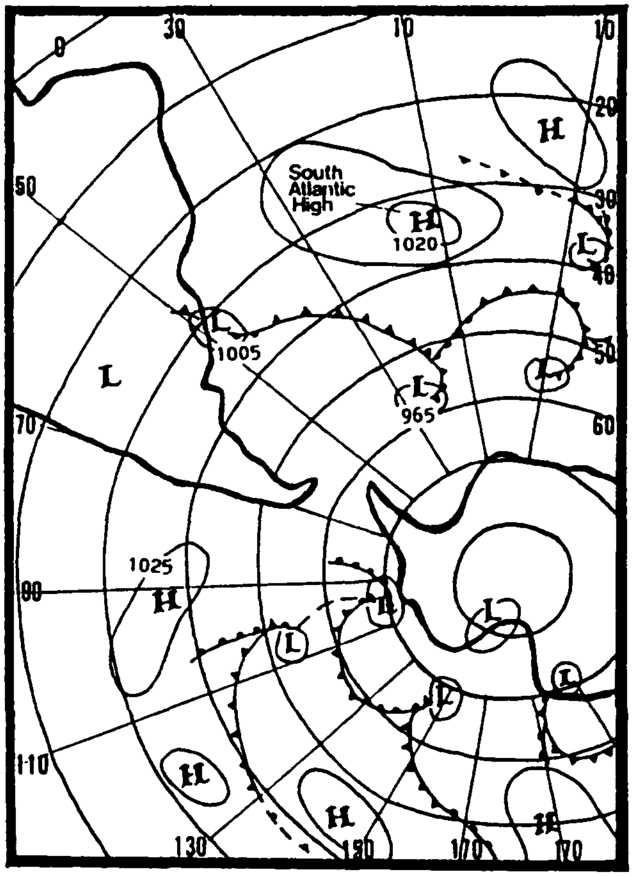


Figure 2-29d. Surface Chart, 9 January 1963 (1200Z). The surface low (965 mb) identified in Figure 2-29b has moved eastward to 58° S, 28° W. The South Atlantic High shifts eastward in advance of the cold front from 23° W (see Figure 2-29b) to 14° W. A weak low (1005 mb) has developed at 31° S, 50° W over the Rio de la Plata. Moderate southwesterly to westerly outflow from the South Pacific High and the 500-mb shortwave trough are enhancing its development.

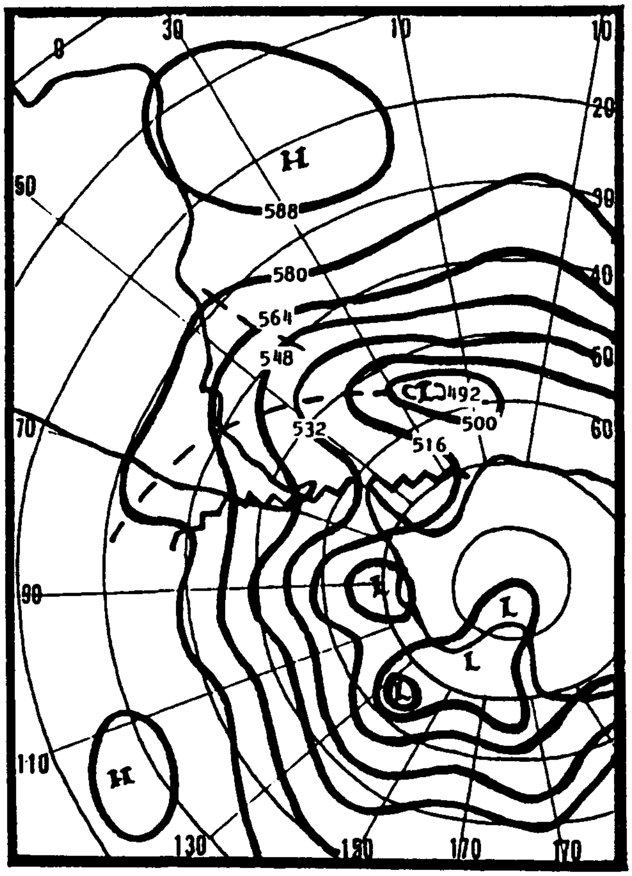


Figure 2-29e. 500-mb Chart, 10 January 1963 (1200Z). The 500-mb ridge has moved slowly eastward with intensification of the 500-mb low at 55° S, 25° W.

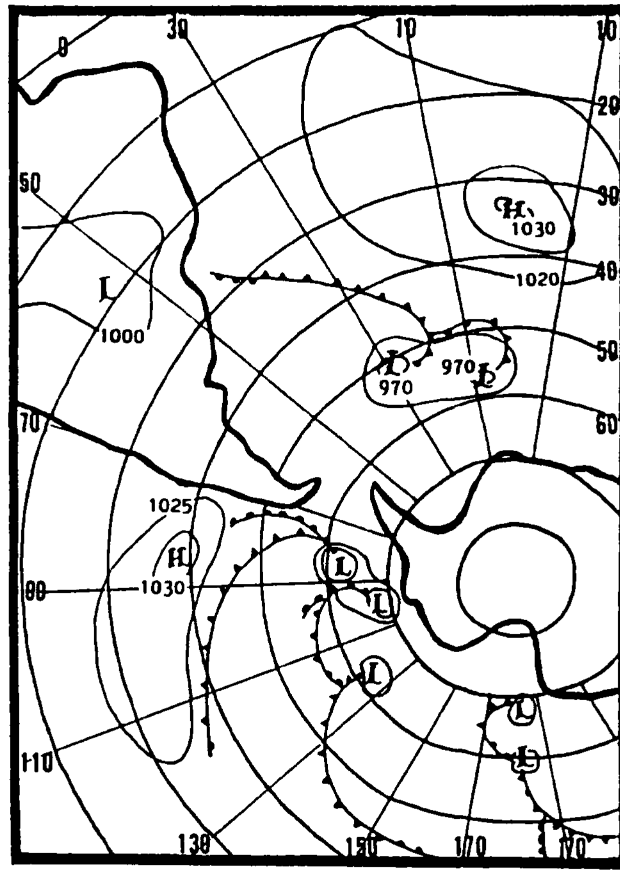


Figure 2-29f. Surface Chart, 10 January 1963 (1200Z). The South Pacific High strengthens significantly and extends eastward into Argentina. A new surface low has developed at 51° S, 30° W, equatorward of the 500-mb level low at 55° S, 25° W. The low that was over the Rio de la Plata on 9 January becomes ill-defined as support at 500 mb weakens significantly and the South Atlantic High continues southeastward.

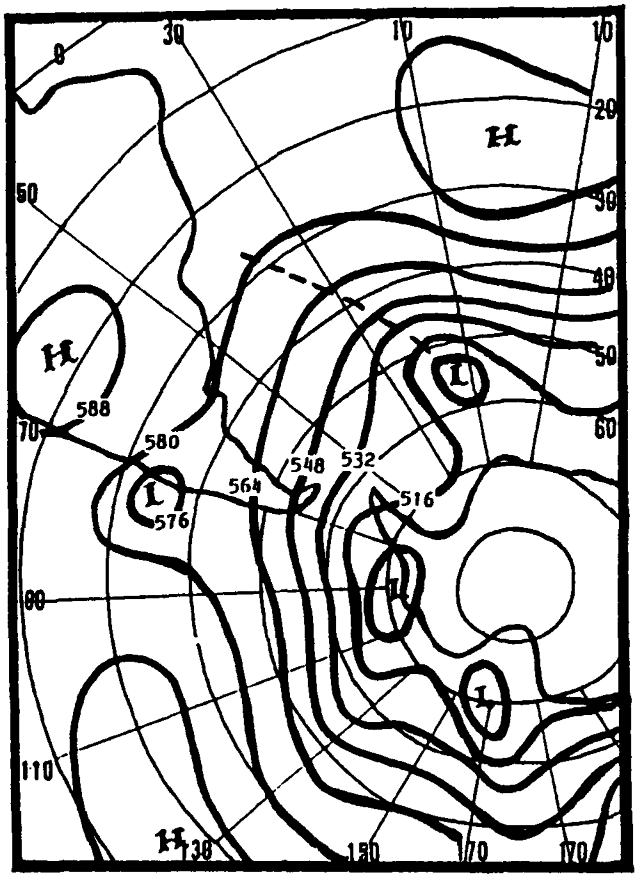


Figure 2-29g. 500-mb Chart, 11 January 1963 (1200Z). Zonal flow--the normal 500-mb pattern--rapidly moves the 500-mb low and trough across the South Atlantic. As a result, a weak closed low (572 GPM) develops to the west of the Andes at 35° S, 75° W. In summer, these fill quickly.

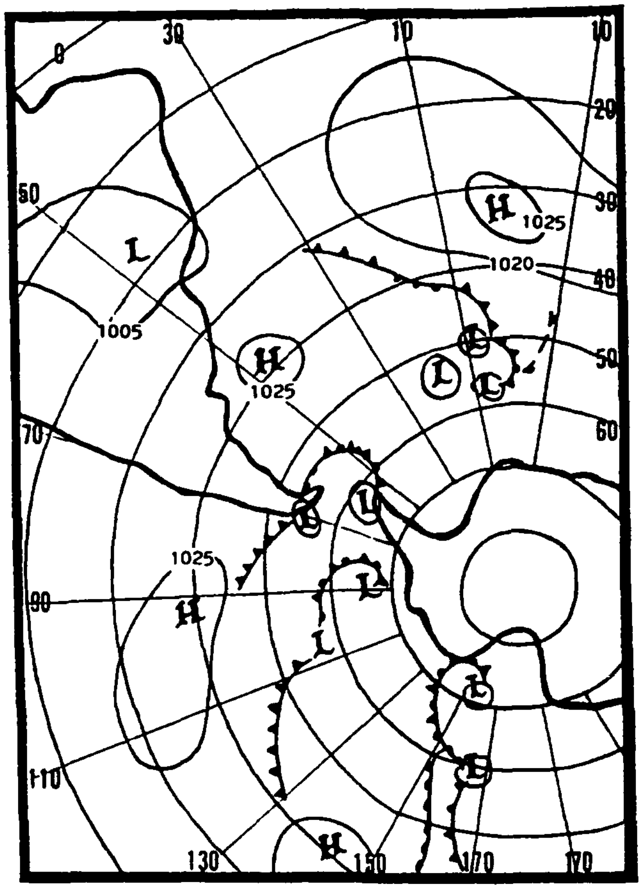


Figure 2-29h. Surface Chart, 11 January 1963 (1200Z). With zonal flow established at 500 mb, the typical surface high-pressure pattern dominates South America between 30 and 45° S.

Fall Seasonal Analysis (March-May). Pacific-generated extratropical cyclone activity increases in frequency and intensity in April and May as the South Pacific High weakens in strength and persistence. Colder air spreads out over Antarctica, intensifying the Circumpolar and 500-mb troughs that prefer to deepen over the Bellingshausen Sea and Drake Passage with weakened ridging over the southeastern Pacific. Most fall transition weather south of 35° S occurs with deep 500-mb troughs or lows off the South American coasts between 35 and 45° S. Figures 2-30a-f show a typical late fall synoptic pattern.

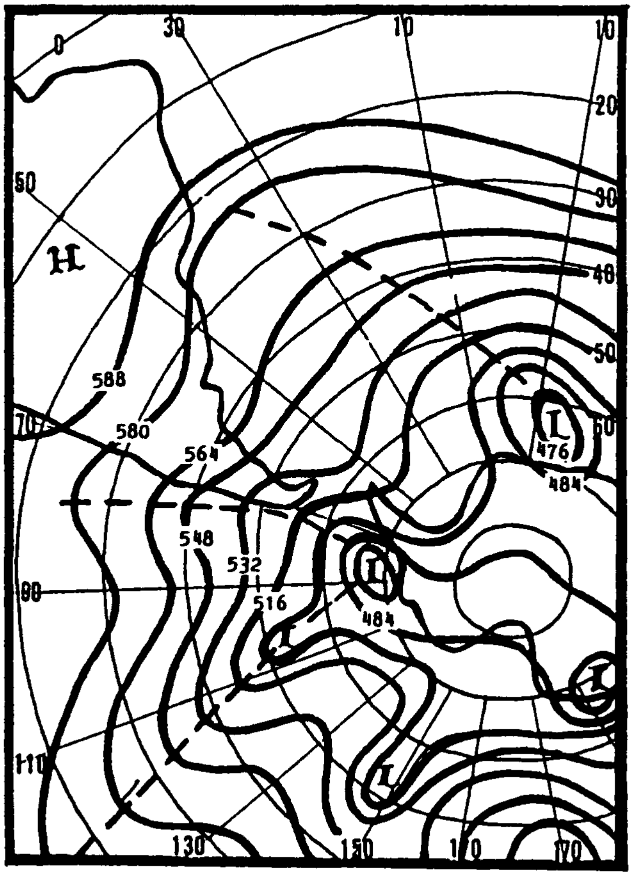


Figure 2-30a. 500-mb Chart, 21 May 1963 (1200Z). Three longwave 500-mb troughs dominate flow over the southeast Pacific and South Atlantic.

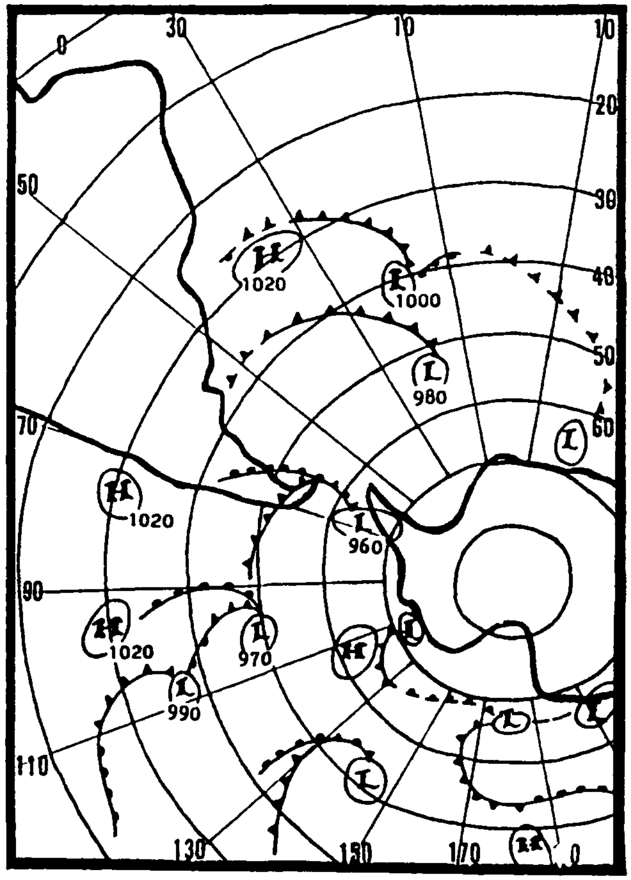


Figure 2-30b. Surface Chart, 21 May 1963 (1200Z). When intense cyclogenesis develops in the Bellingshausen Sea during the fall, southwesterly or westerly flow through Drake Passage often exceeds 25 knots at the surface.

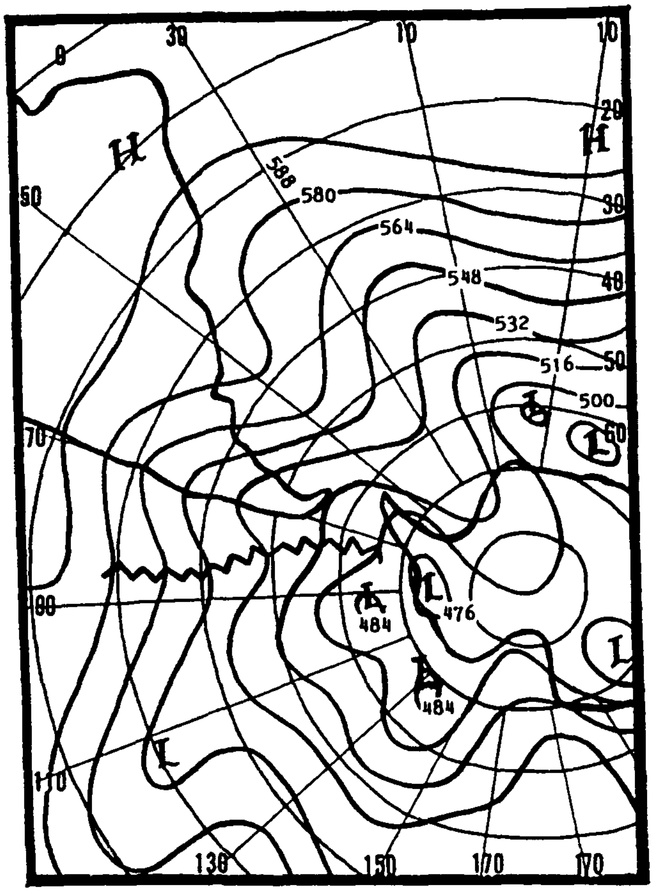


Figure 2-30c. 500-mb Chart, 22 May 1963 (1200Z). A closed low begins to form at 32° S, 113° W.

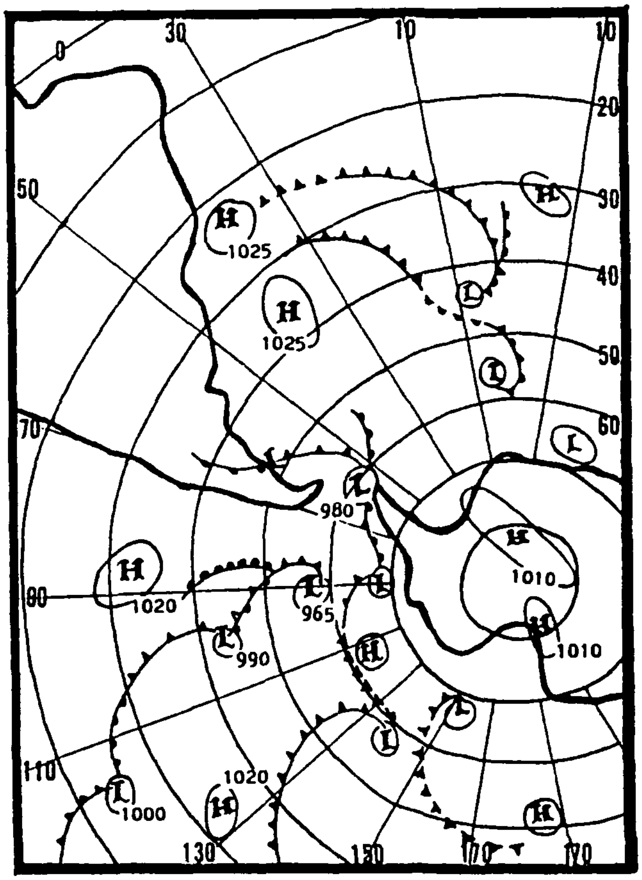


Figure 2-30d. Surface Chart, 22 May 1963 (1200Z). A "cyclone family" stretches from 58° S, 90° W to 27° S, 117° W.

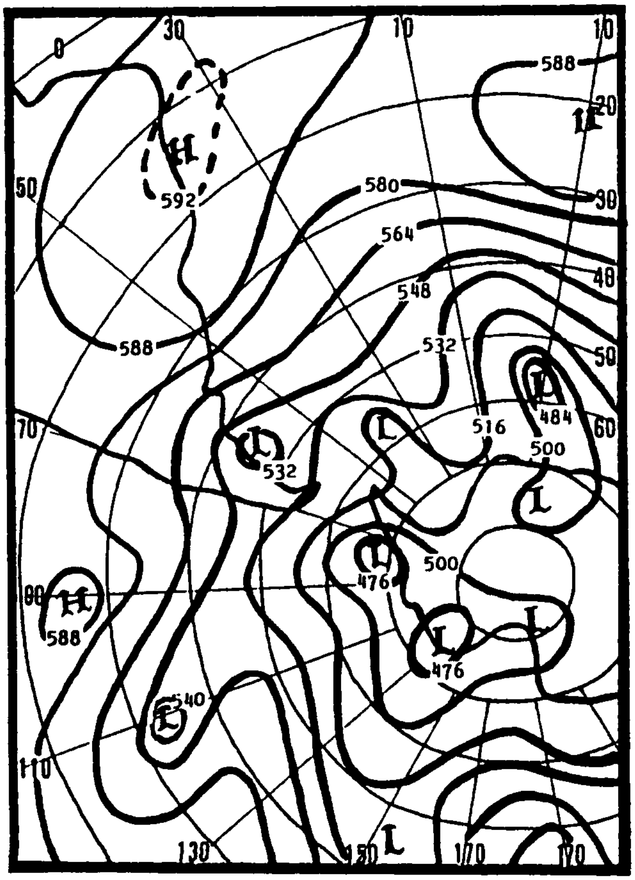


Figure 2-30e. 500-mb Chart, 23 May 1963 (1200Z). A forerunner to surface cyclogenesis over Argentina and the Rio de la Plata often includes a 500-mb low such as at 44° S, 59° W.

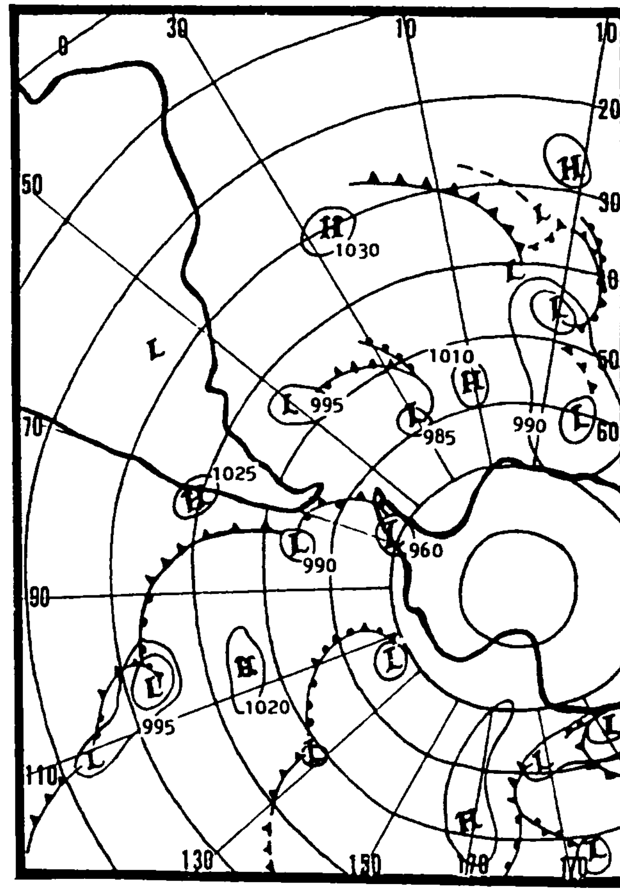


Figure 2-30f. Surface Chart, 23 May 1963 (1200Z). The 500-mb low intensifies the frontal wave into a low at 45° S, 50° W.

SYNOPTIC DISTURBANCES

Winter Seasonal Analysis (June-August). Winter has the highest frequency of cyclogenesis. The high-pressure ridges over both oceans are weaker from mid-June to early September, allowing variations in 500-mb longwave trough and ridge patterns around Antarctica to dominate. Migratory 500-mb troughs often produce cold fronts that bring subfreezing temperatures, freezing rain, and snow to stations south of 45° S. Between 35 and 45° S, strong winds, moderate-to-heavy rainfall, and isolated thundershowers are common. Temperatures rarely drop below 34° F (1° C). North of 35° S, heavy rainfall may occur, but temperatures rarely fall below 50° F (10° C). The amount of precipitation received on the lee side of the Andean range is dramatically reduced.

Strong 500-mb ridges are not uncommon in winter. They may form over either ocean, or simultaneously over both oceans. Strong ridging over land, however, is not common. Strong Pacific ridges may cause "surges" of cold air to penetrate northward into central Argentina. In two to six cases every winter, cold air "surges" reach the Amazon River, but two conditions are necessary: strong 500-mb ridge tilting from southeast to northwest, and a deepening trough. This implies an intense wind speed maxima along the downstream edge that allows very cold polar or Antarctic air to move northwestward into the base of the trough. The frontal wave/surface low development along the 500-mb trough axis is the catalyst for cold air penetration northward into the tropics. Figure 2-31 shows the most common positions for surface low-pressure centers and their cold fronts.

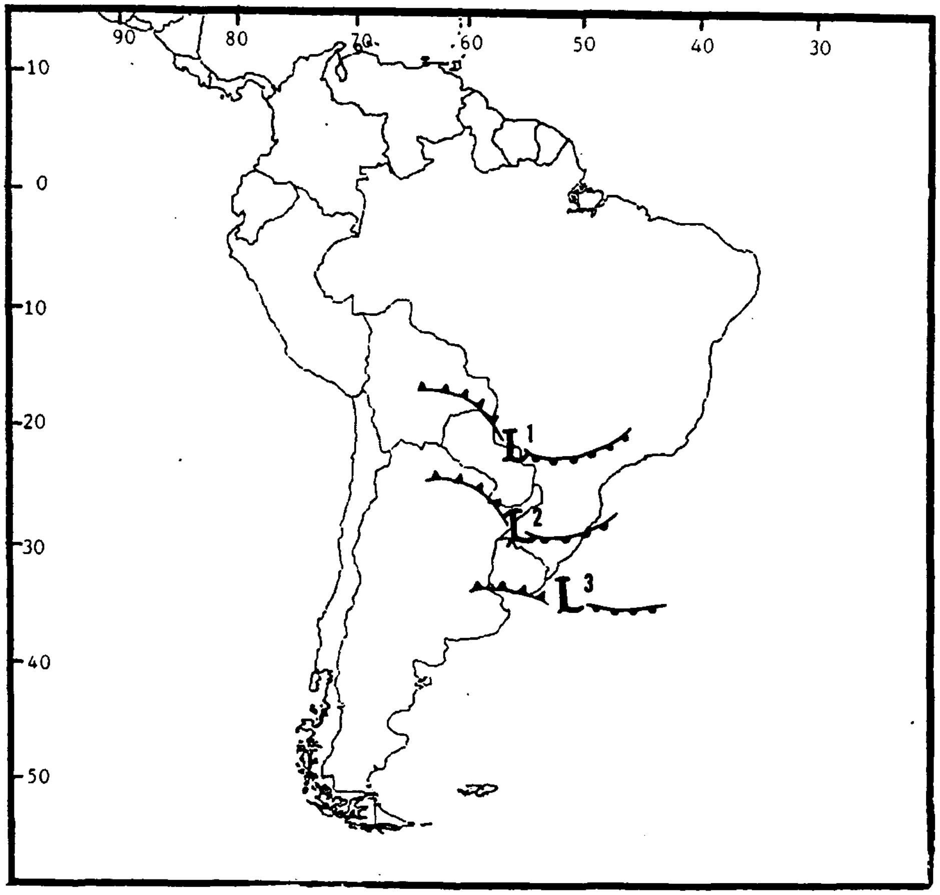


Figure 2-31. Common Surface Low and Cold Front Positions. Low 1 shows where maximum cold air penetration can be expected.

In Figures 2-32a and 2-32c, a strong 500-mb ridge (axis drawn) migrates eastward through Drake Passage. A trough extending over South America induces an intense cut-off low near 43° S, 50° W, which assists in cyclogenesis over the Rio de la Plata. When a cut-off low forms off the Chilean coast, shortwaves may propagate slowly eastward across the Andes into central Argentina to 30° S, but the cut-off low may not migrate eastward over the Andes. Figures 2-32b and d show the surface charts coinciding with 500-mb flow. Figures 2-33a-f show a winter synoptic situation in which strong ridging at 500 mb persists over the continent, impeding the normal storm track.

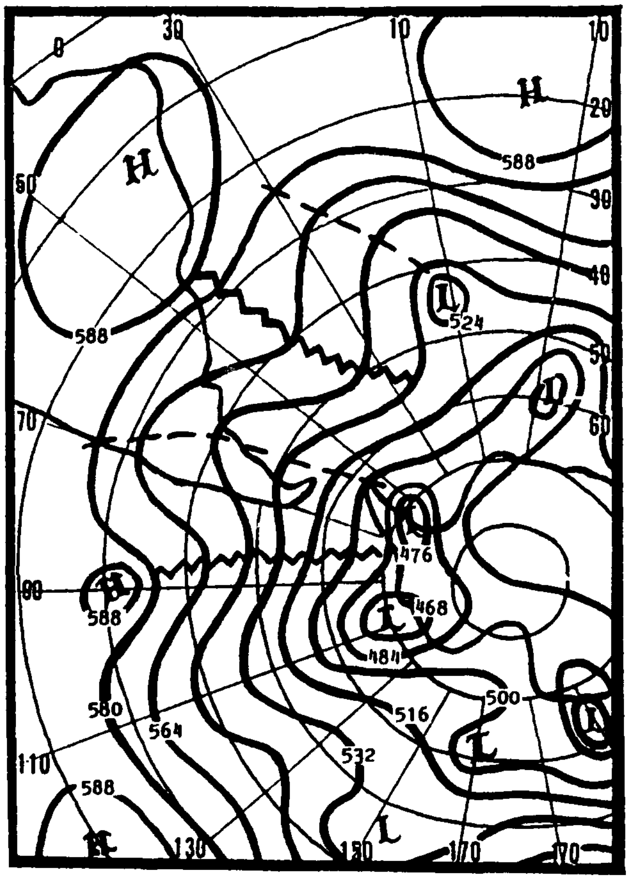


Figure 2-32a. 500-mb Chart, 3 August 1963 (1200Z). In winter, deep 500-mb troughs produced by strong ridging over either ocean are common. The 500-mb trough pattern usually digs over South America when 500-mb ridging is tilted.

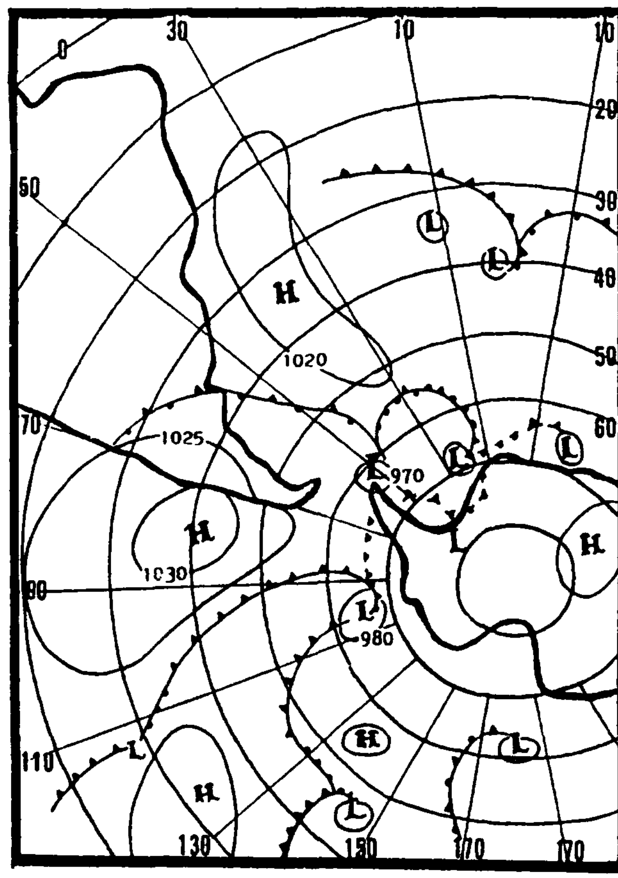


Figure 2-32b. Surface Chart, 3 August 1963 (1200Z). The migratory high spills into western and Southern Argentina.

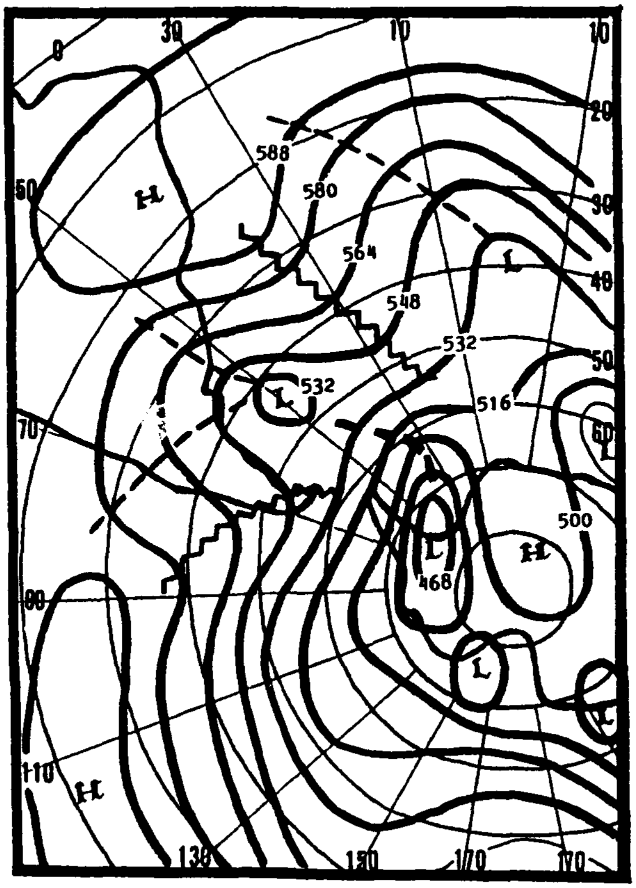


Figure 2-32c. 500-mb Chart, 4 August 1963 (1200Z). A closed low has developed at 43° S, 50° W. Two troughs extend equatorward from the center.

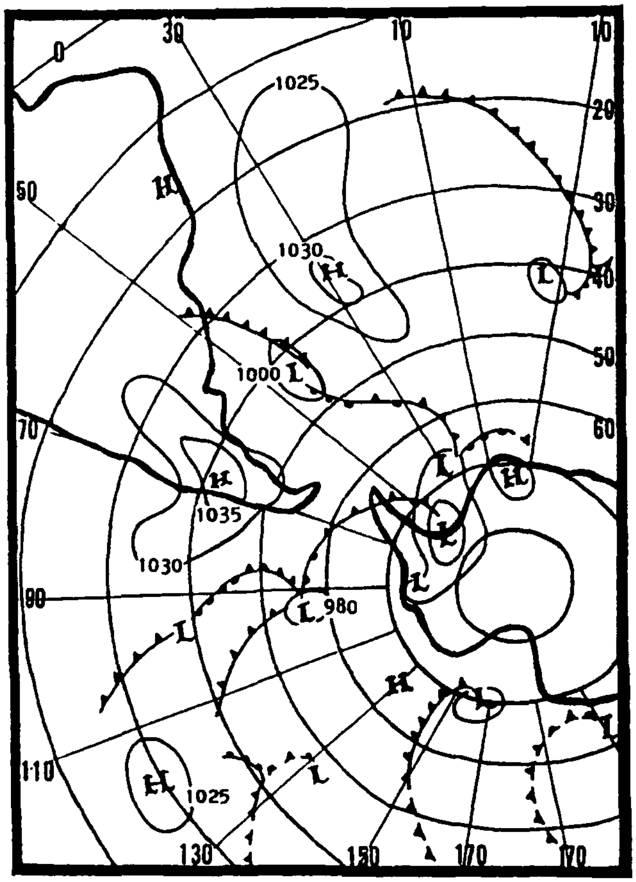


Figure 2-32d. Surface Chart, 4 August 1963 (1200Z). The strong 500-mb ridge and associated surface high fill behind the trough. Very cold surface highs can produce sub-freezing temperatures to 25° S on rare occasions, while extremely cold 500-mb lows may produce significant snowfall over west-central Argentina to 40° S. A 1,000-mb low has developed at the surface at 43° S, 45° W.

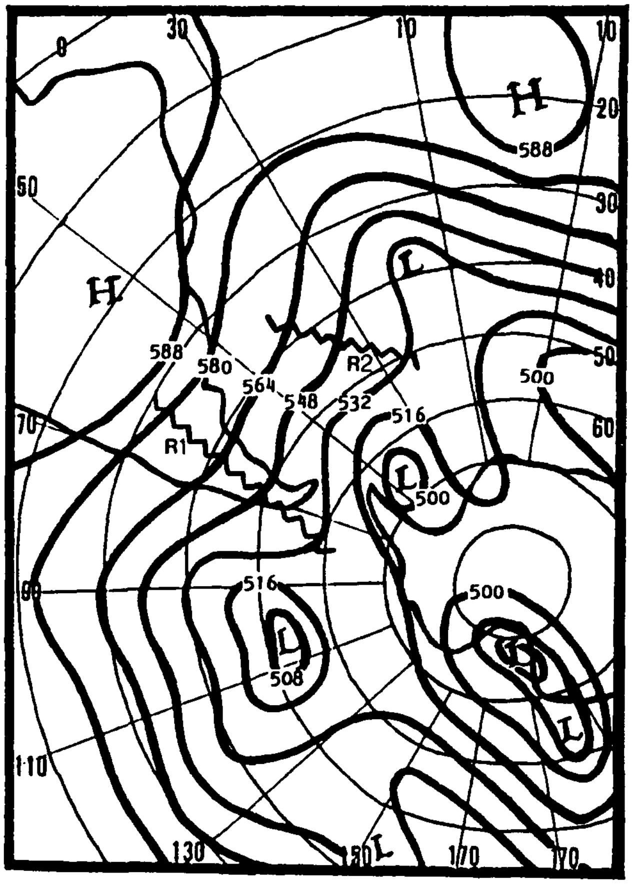


Figure 2-33a. 500-mb Chart, 27 August 1963 (1200Z). The 500-mb ridge (R1) extends from 30 to 60° S (Bellingshausen Sea). Another ridge (R2) is present in the South Atlantic.

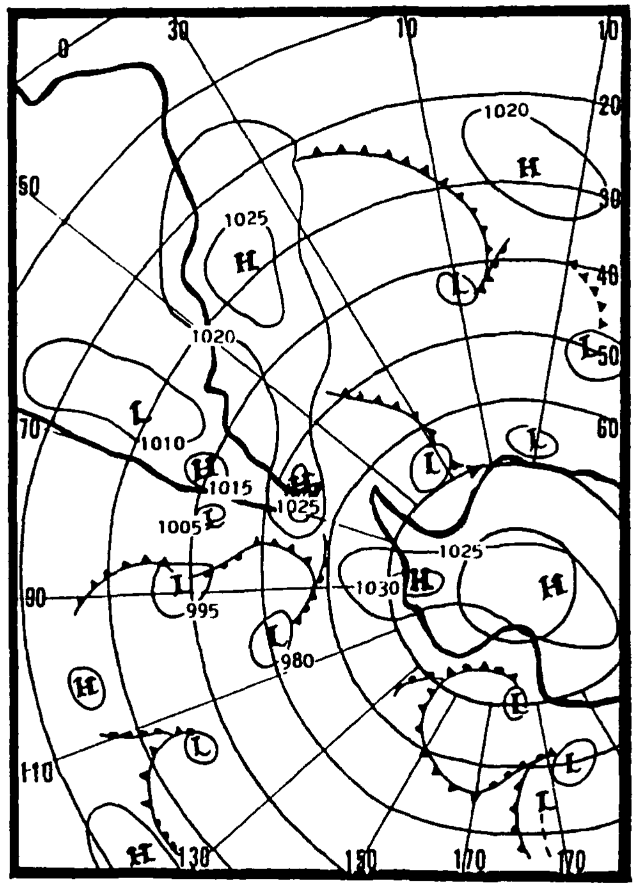


Figure 2-33b. Surface Chart, 27 August 1963 (1200Z). Surface high pressure dominates South America from 35° S to the Bellingshausen Sea. This synoptic pattern impedes the storm track through Drake Passage.

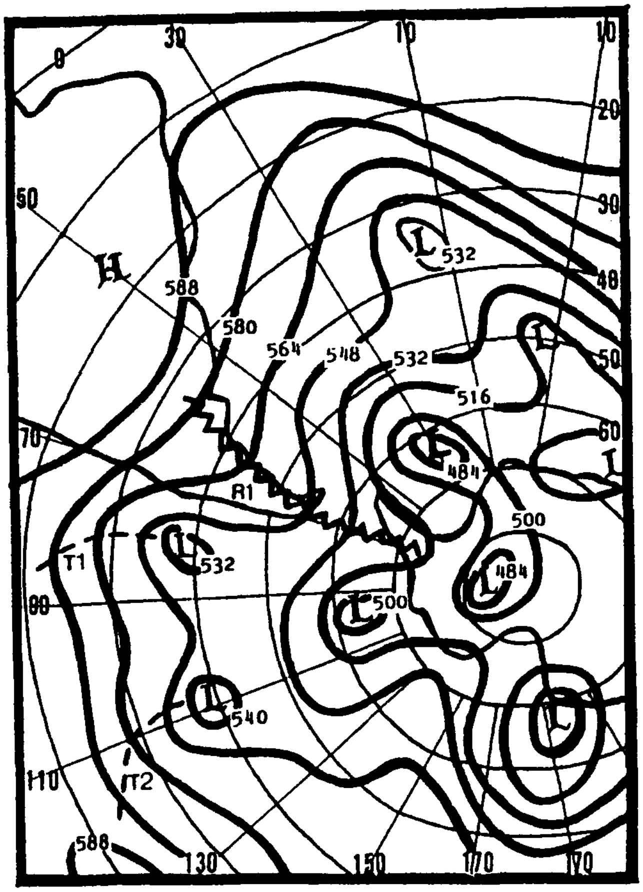


Figure 2-33c. 500-mb Chart, 28 August 1963 (1200Z). The 500-mb ridge (R1) now extends into the Weddell Sea. Two slow-moving 500-mb troughs (T1 and T2) dominate the southeastern Pacific.

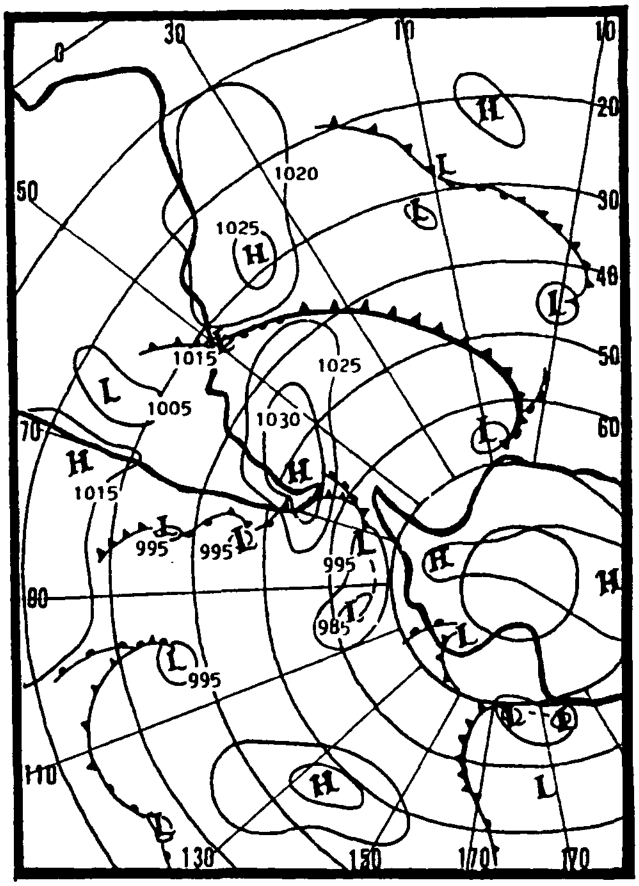


Figure 2-33d. Surface Chart, 28 August 1963 (1200Z). Several surface lows form in the southeastern Pacific along the 500-mb trough axes.

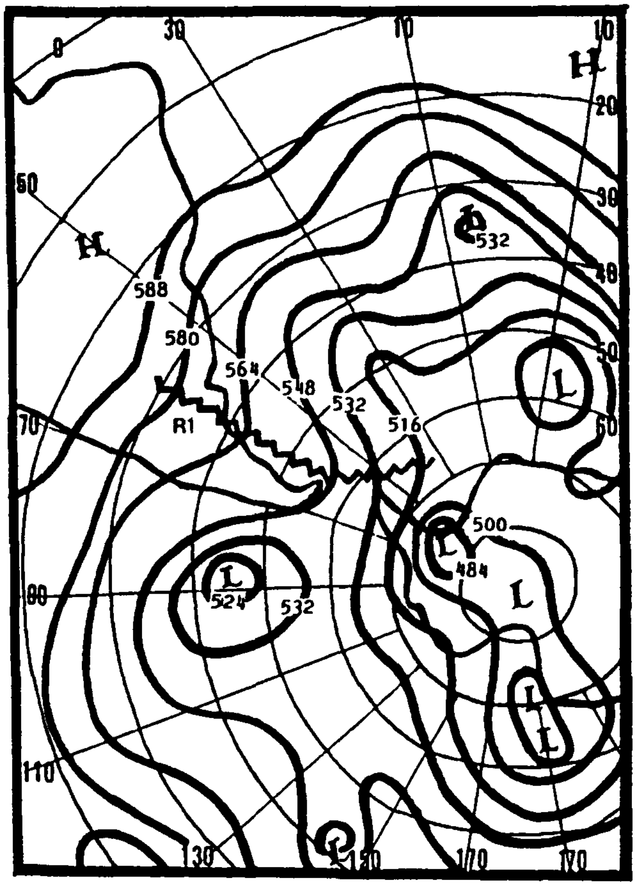


Figure 2-33e. 500-mb Chart, 29 August 1963 (1200Z). The 500-mb ridge (R1) continues to strengthen over Drake Passage. As a result, a 500-mb low at 45° S, 87° W (524 GPM) organizes over the southeastern Pacific. Compare this to the 548-GPM contours for 28 August in Figure 2-33c.

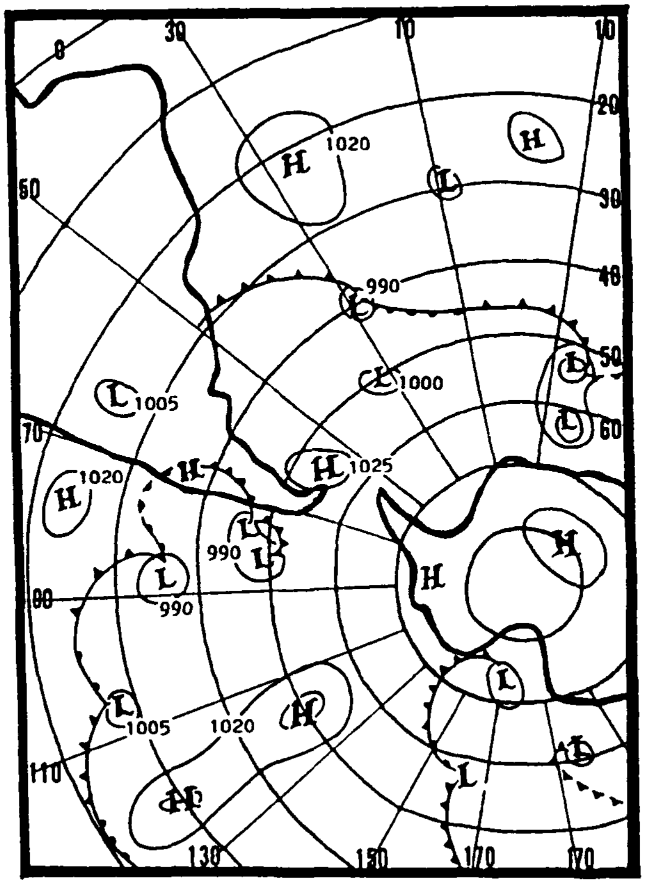


Figure 2-33f. Surface Chart, 29 August 1963 (1200Z). A series of surface lows track into Chile as intense ridging at 500 mb causes a dramatic shift in cyclonic activity away from Drake Passage.

Spring Seasonal Analysis (September-November). The significant spring weather feature is the mid-November reappearance of persistent 500-mb ridging over both oceans. Cyclogenesis occurs frequently over the Rio de la Plata and northeastern Argentina, with 500-mb troughing over the southwest Atlantic. Although 500-mb troughs occur often in the spring, their strength and frequency diminish greatly when subtropical high pressure reestablishes. Surges of cold air continue to occur frequently in September and early October. Their affect on weather across the Amazon Basin is even more significant than in the winter and is discussed in the respective zones. Figures 2-34a-f illustrate an early spring weather pattern. This situation is only 12 days later than the one in Figures 2-33a-e, but it provides an excellent example of the major changes that take place in spring. An extensive longwave trough/ridge pattern is around Antarctica. Cut-off lows form over the continent as the South Atlantic and South Pacific Highs begin to migrate poleward. This example also shows how the 500-mb cut-off low aids in cyclogenesis over the Rio de la Plata.

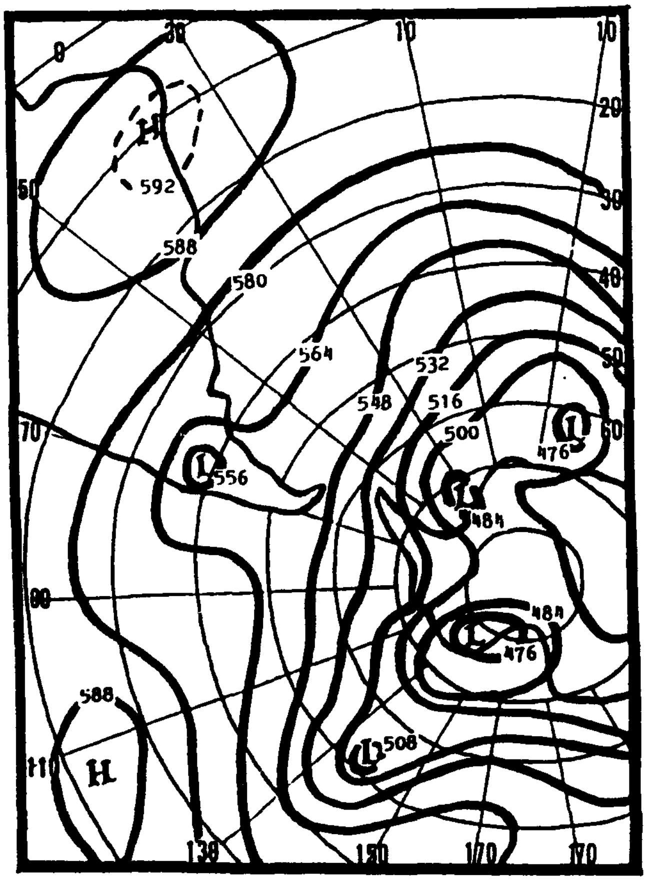


Figure 2-34a. 500-mb Chart, 9 September 1963 (1200Z). Subtropical high pressure at 500 mb is evident over the Pacific and Atlantic Oceans. A low (556 GPM) is located over central Argentina. In this case, a weak wind maximum downstream of the 500-mb ridge is provided by the closed low.

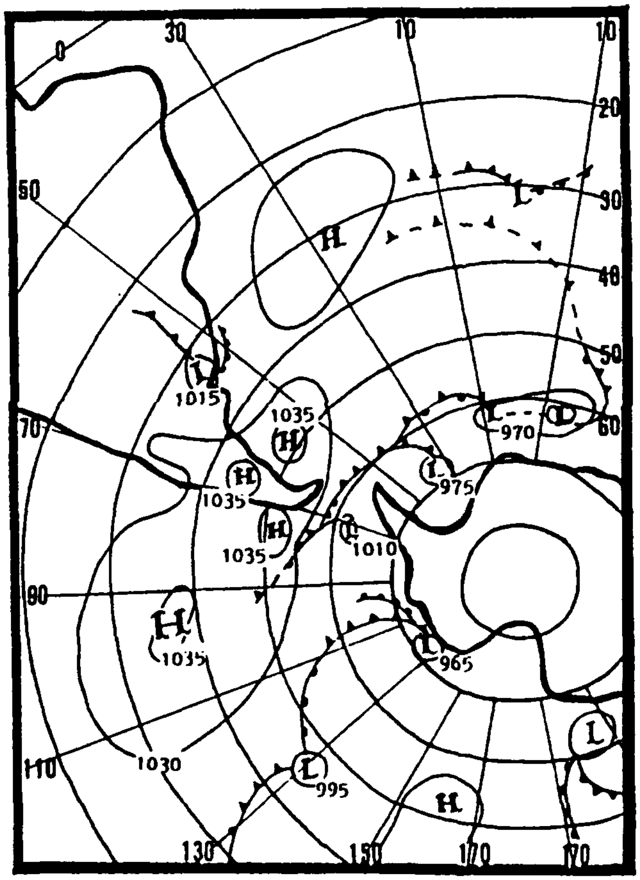


Figure 2-34b. Surface Chart, 9 September 1963 (1200Z). The surface low forms near 34° S, 55° W, and the cold high-pressure cell fills in behind the cold front.

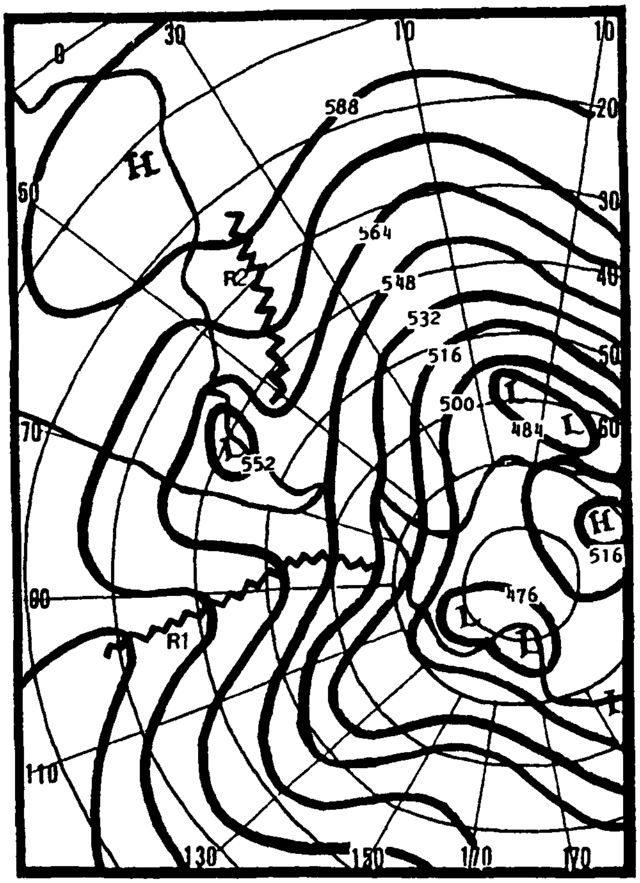


Figure 2-34c. 500-mb Chart, 10 September 1963 (1200Z). The 500-mb cut-off low deepens (552 GPM) within a broad trough over the continent. The strengthening ridge (R1) intensifies the downstream wind maxima into the closed low. Significant ridging (R2) is also occurring over the southwestern Atlantic.

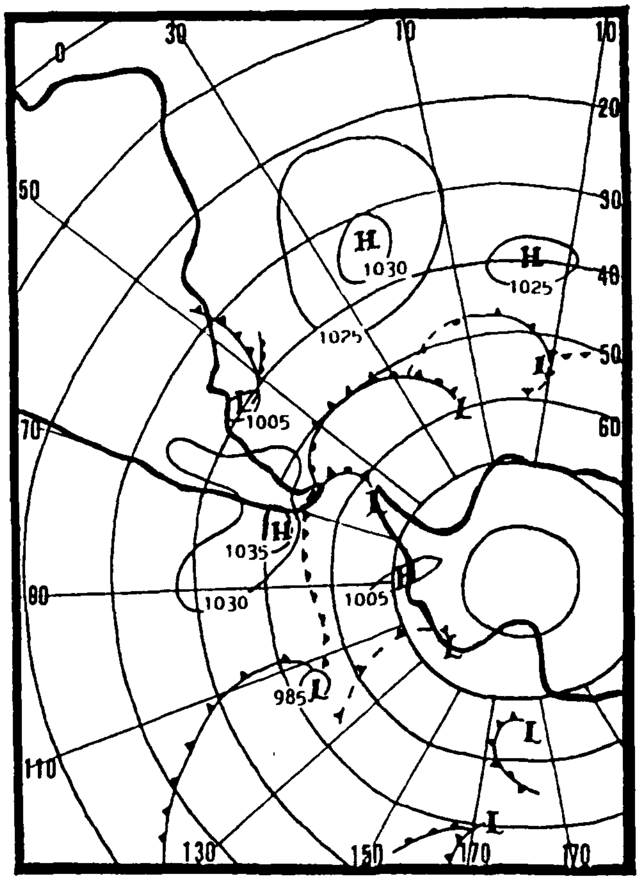


Figure 2-34d. Surface Chart, 10 September 1963 (1200Z). The surface low at 40° S, 55° W is moving due south. This funnels cold air northward along the eastern Andes.

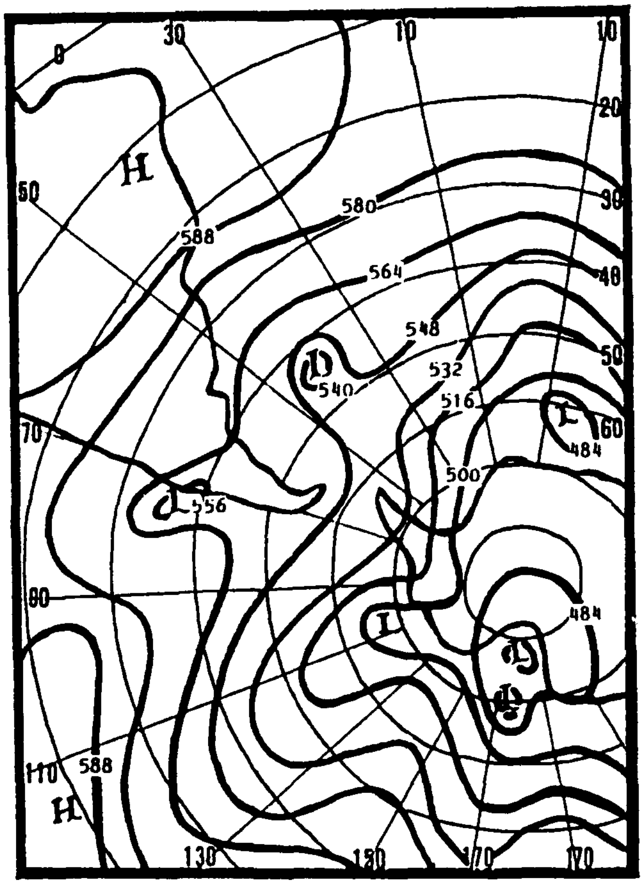


Figure 2-34e. 500-mb Chart, 11 September 1963 (1200Z). The closed low moves eastward, while another low (556 GPM) forms in the trough west of the Andes.

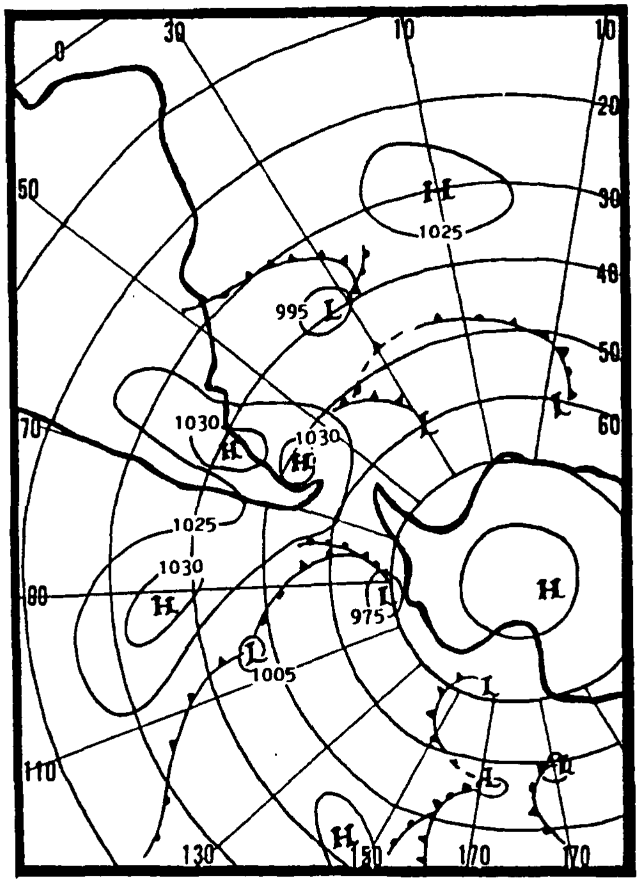


***Figure 2-34f. Surface Chart, 11 September 1963* (1200Z).** The surface low that moved due south in Figure 2-34d has turned eastward with the closed 500-mb low and intensified. A high-pressure cell lies over Argentina.

Figures 2-35a-d illustrate a mid-November weather pattern. The most important features in this sequence are the widespread subtropical high-pressure areas over South America at 500 mb, and the less extensive 500-mb trough patterns around Antarctica.

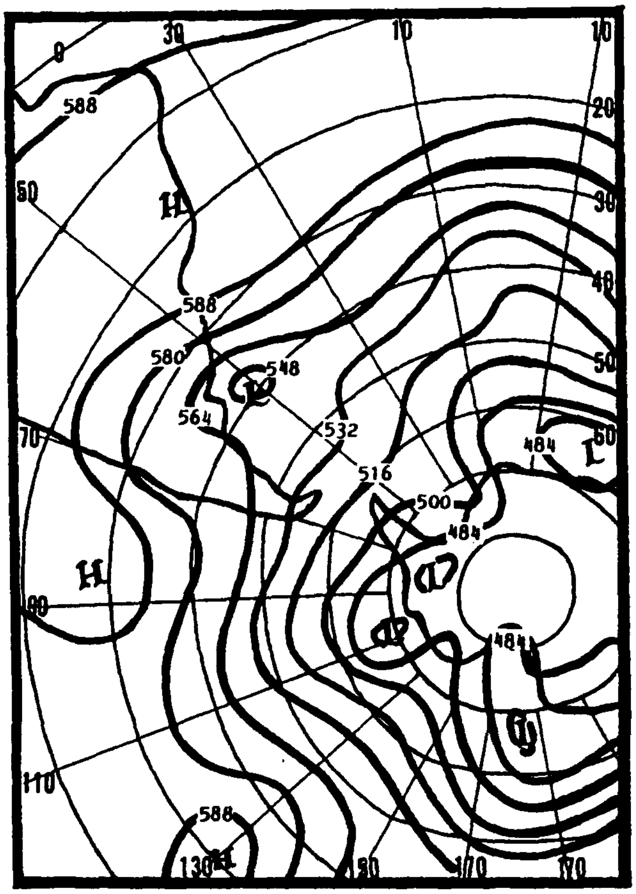


Figure 2-35a. 500-mb Chart, 20 November 1963 (1200Z).

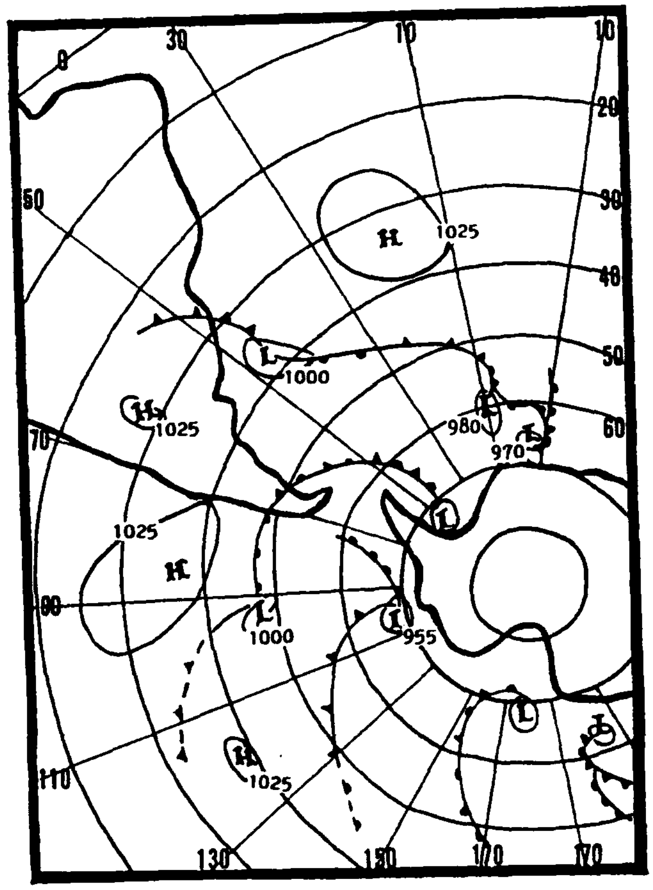


Figure 2-35b. Surface Chart, 20 November 1963 (1200Z).

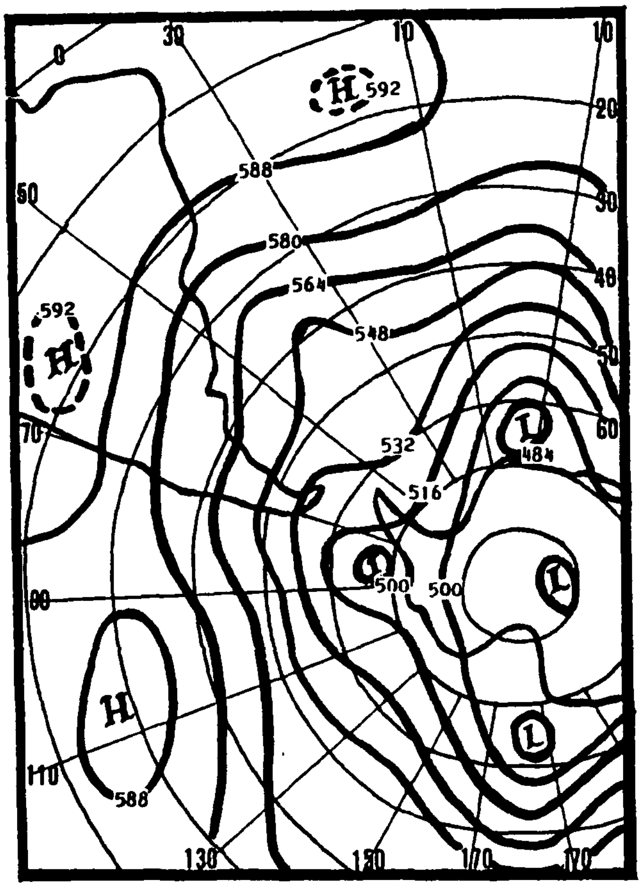


Figure 2-35c. 500-mb Chart, 21 November 1963 (1200Z).

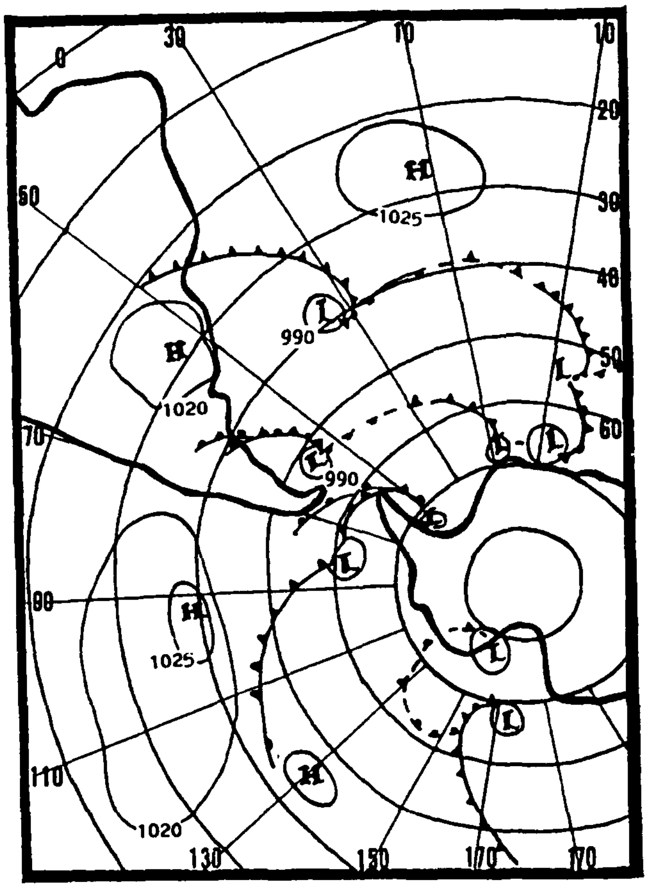


Figure 2-35d. Surface Chart, 21 November 1963 (1200Z).

THE ARGENTINE CONTINENTAL HIGH is a mean wintertime surface feature that occurs with the periodic influx of cold air into the South American interior. It is generally centered at 34° S, 64° W, with an average pressure of 1018 mb. The continental high re-routes and lessens the flow from the South Atlantic High. This cold core and baroclinic high establishes itself after frontal passage; the interval between polar surges determines its duration. Figure 2-36 shows its wintertime mean position. During winter, subsidence from the South Pacific High ridges over the continent and sometimes develops a temporary, shallow high-pressure center, with or without the Argentine High.

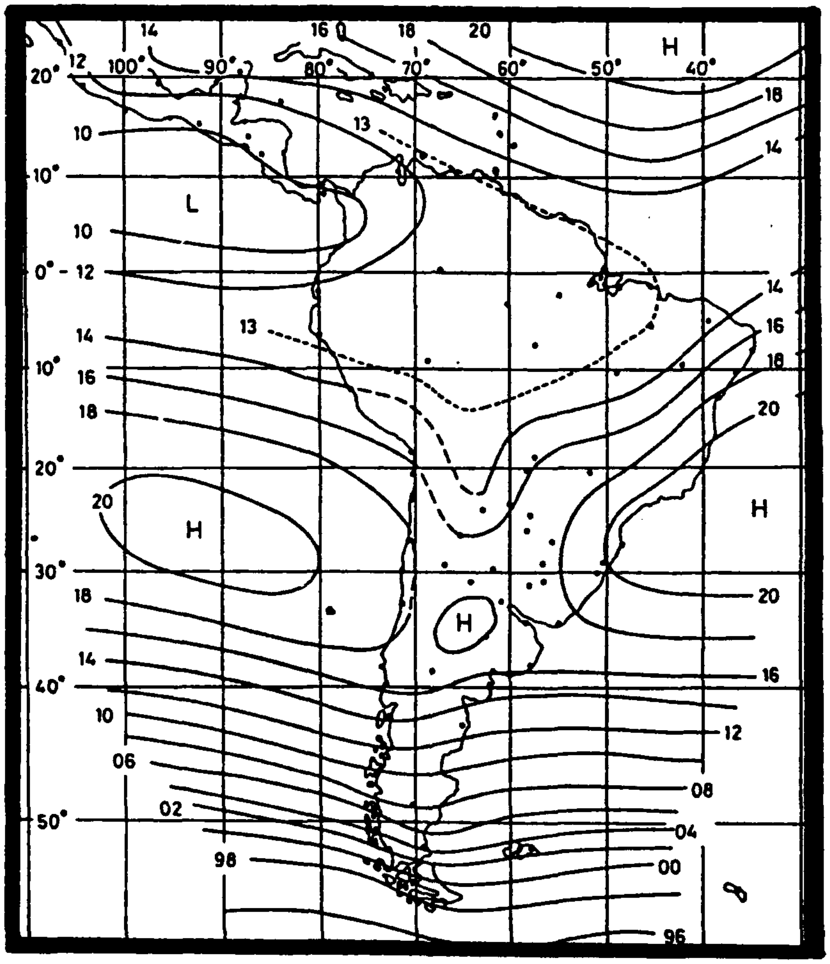


Figure 2-36. Atmospheric Pressure at Sea Level Shows the Argentine Continental High During Southern Hemisphere Winter (from Schwerdtfeger, 1976).

SYNOPTIC DISTURBANCES

LEE SIDE TROUGHS/WAVES. Lee-side Troughs are elongated low-pressure areas that form on the lee sides of mountain ranges when wind flow is nearly perpendicular to the ridge. Trough formation is normally caused by adiabatic warming of sinking air on the lee side of a mountain. Two prominent areas of lee-side troughing in South America are in the Brazilian Highlands and the Southern Andes south of 25° S. During spring, strong prefrontal northwest winds form a lee-side trough along the coast where the Brazilian Highlands drop abruptly to the sea. Adiabatic warming produces temperatures as high as 104° F (40° C). Troughs on the lee side of the Southern Andes are due more to orographic than thermal causes.

Migratory lows moving along the lee slopes of mountains or through Drake Passage may also form lee-side troughing. Such lows may eventually become linked to lee-side waves.

Although lee-side waves first resemble lee-side troughs, they are dynamic disturbances that often precede cold fronts. They form between 10 and 30° S and average 600 to 900 NM (965 to 1450 km) in length. They develop when winds exceed 80 knots across the Andes between 25 and 30° S. A lee-side wave creates instability as it moves to the east from its source region near the Andes. It produces various levels of stratus-type clouds with light-to-moderate rain; stronger waves can produce thunderstorms.

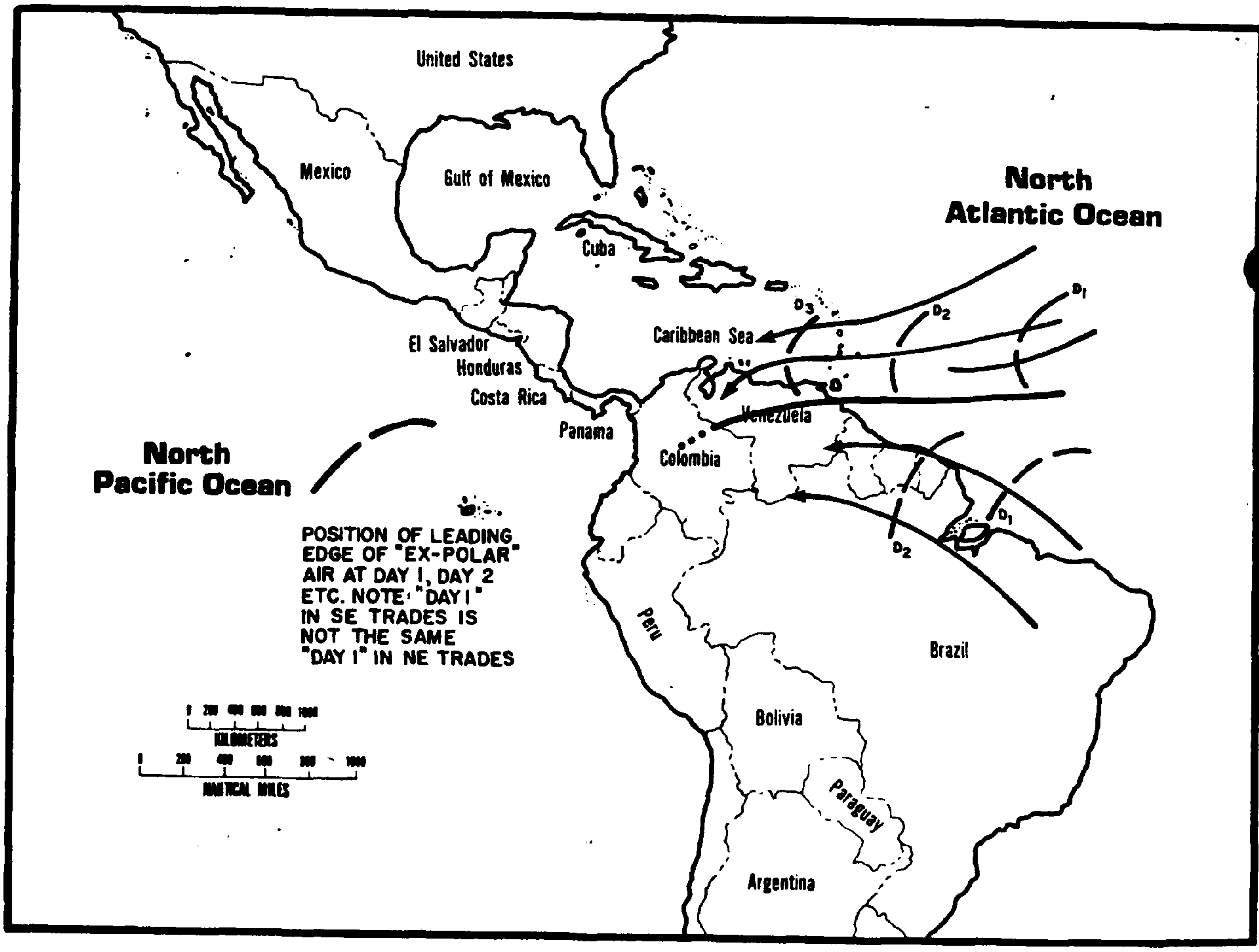


Figure 2-37. Trade-Wind Surges in Northeast and Southeast Atlantic Trades.

TRADE-WIND SURGES are a form of instability line creating organized convection in the tropics. Most originate in the mid-latitudes with a migratory high-pressure cell driving a cold front equatorward. Mountain ranges, such as the Andes along the Pacific and the Brazilian Highlands along the Atlantic, channel flow northward. The cold front transitions into a shear line as it penetrates deeper into the tropics and the high loses its polar air mass characteristics. As they reach the prevailing trade-wind flow, they are steered into South America where they dissipate or recurve poleward.

Various studies support North Atlantic surge periodicities of 5 to 7 days. Little is known about surges moving westward in the South Atlantic. Some Brazilian and British research supports trade-wind surges entering northern Brazil during fall and winter. Figure 2-37 is an example of the process in the Atlantic. Although studies of the South Pacific High west of South America are few, a similar process is believed responsible for pulses in the eastern Pacific equatorial westerlies. Figure 2-38 illustrates the progression of surges in the Pacific.

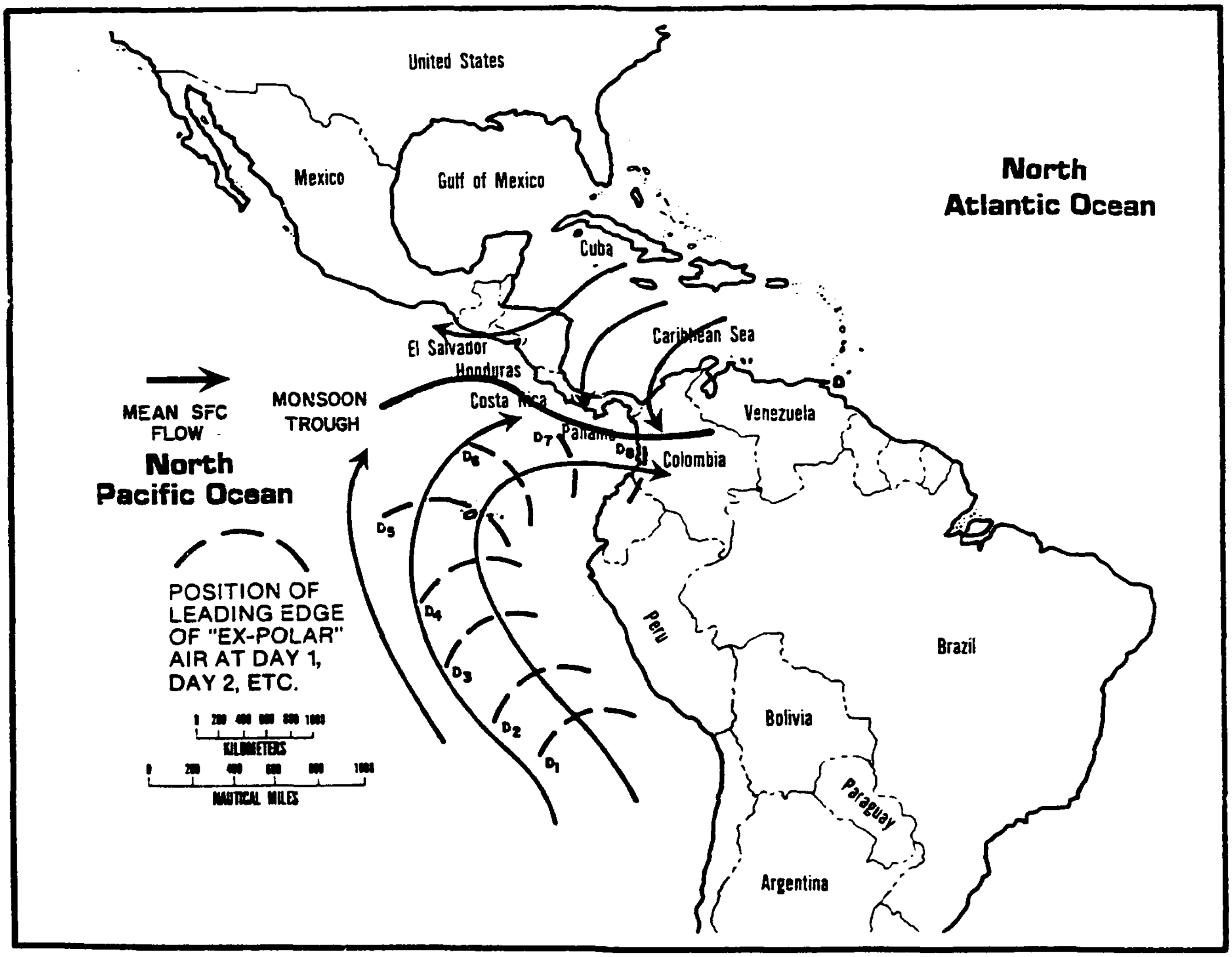


Figure 2-38. Trade-Wind Surge Entering the Equatorial Westerlies from the Southeast Pacific Trades.

TROPICAL SQUALL LINES affecting South America develop most often with trade-wind surges and sea-breeze fronts moving westward on r near the equator. They differ from mi latitude squall lines in severity and precipitation. These systems do not produce severe weather such as tornadoes or extreme winds. Hail doesn't reach the surface because freezing levels in squall-line cells average 16,000 to 17,000 feet (4,800 to 5,100 meters). Studies also indicate that nearly half of the precipitation occurs in the layered middle and high clouds trailing the line. The 1987 Amazon Boundary Layer Experiment (ABLE) indicated that similarly organized features produce 40 to 70% of their rainfall from convective activity and 30 to 60% from trailing cloud layers. Virga is also common from these cloud layers.

Figure 2-39 is a vertical cross section of an Amazonian squall line. The upstream boundary-layer air is the primary source of inflow for the system's updrafts. Inflow from the mid-troposphere strengthens downdrafts and appears to contribute to sinking motion in the wake of the system. Low-level outflow from downdrafts reach depths of 660 to 1,330 feet (200 to 400 meters). This shallow, stable layer spreads out below the broad mesoscale subsidence produced by the precipitation trailing the system. It appears as if the large area of trailing subsidence helps sustain the low-level outflow layer. Outflow spreading ahead of the squall line converges with upstream boundary layer winds to generate new cells and subsequent propagation of the squall-line system. Evaporative cooling from the precipitation beneath trailing cloud layers also appears to contribute to lifting out ahead of the system.

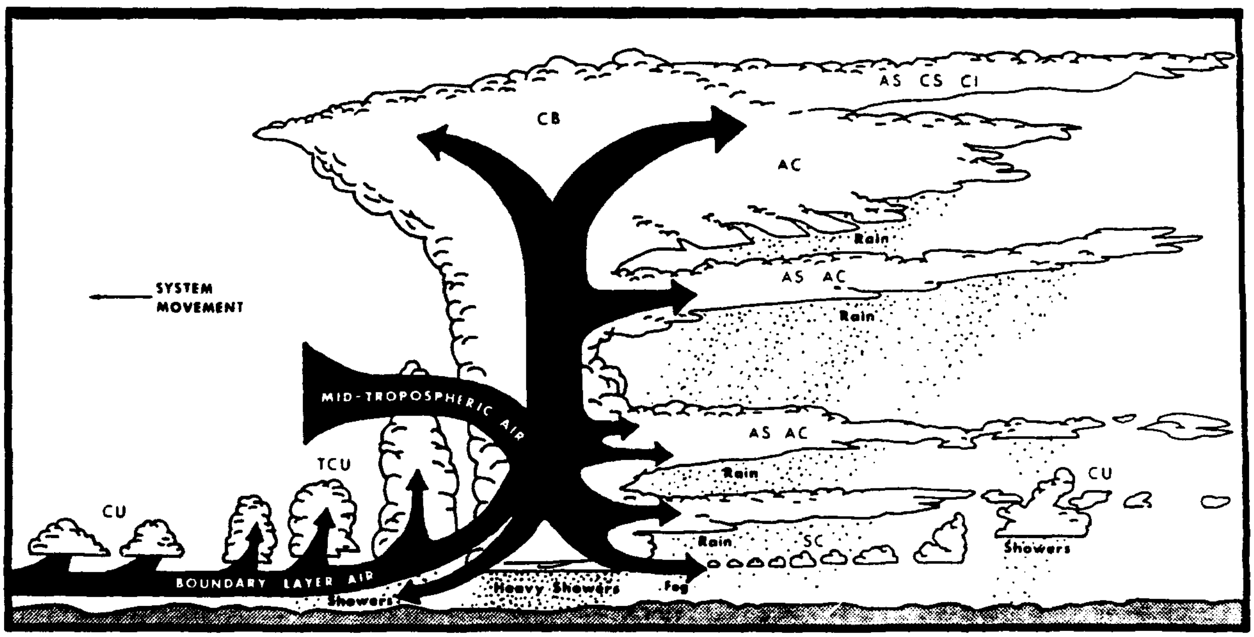


Figure 2-39. Vertical Cross Section of a Tropical Squall Line.

Visibilities, which can be near zero in the core of the precipitation, average 2 to 4 miles in trailing rainfall. Convective activity has tops averaging 50,000 feet (15 km), but with bases as low as 500 feet (150 meters). Satellite imagery shows that upper-level cloudiness associated with tropical squall lines average 755 miles long by 92 miles wide. Squall-line speeds average 30 knots. In winter, some lines have been tracked for 1,100 miles. There is a direct correlation between an exceptionally well-defined NET (suggesting strong trades) and squall lines traveling great distances. They seem to occur most often in winter, but this may be because squall lines occurring in other seasons are masked or disrupted by other convective activity.

LOW-LATITUDE UPPER-TROPOSPHERIC CYCLONIC VORTICES. About 10 to 15 of these cold-core systems affect South America every year. Most occur from December through March, but they can develop as early as September and as late as April. Formation is normally in the Western South Atlantic Trough between 10 and 25° S, and between 25 and 45° W. Most of these systems move west or west-northwest, entering South America between 5 and 15° S. They travel an average of 220 to 300 miles a day and normally dissipate in 3 to 5 days. Systems developing south of 15° S often become absorbed into strong troughs in the mid-latitude westerlies, but some can move to lower latitudes where easterly flow takes them into South America.

This upper-level cyclone normally develops (or an existing one intensifies) 12 to 24 hours after a strong cold front penetrates deep into South America. Figure 2-40 shows the development sequence. Developing convection ahead of the cold front increases latent heat release and strengthens the Bolivian High. An upper-level ridge develops southeast from the Bolivian High, primarily from advection of warm air ahead of the cold front. This creates an upper-level wave pattern that ultimately leads to a cut-off low.

Upper-level cyclones normally have convergence into their centers producing downward motion and clear skies. Divergence normally occurs along the periphery of the cyclone with rising motions causing cloudy skies and precipitation, as shown in Figure 2-41. Over land, however, convective activity is often present near the centers in the afternoon when enough instability is produced by a combination of daytime surface heating and the upper-level low's cold core. The strongest convection normally occurs along the western periphery ahead of westward-moving cyclones. After formation, these cyclones weaken the Bolivian High and the Western South Atlantic Trough and disrupt the typical upper-level southerly flow over the continent, inhibiting subsequent northward penetration of mid-latitude systems.

Figure 2-42 is a GOES IR image of an upper-level cyclone over northeast Brazil.

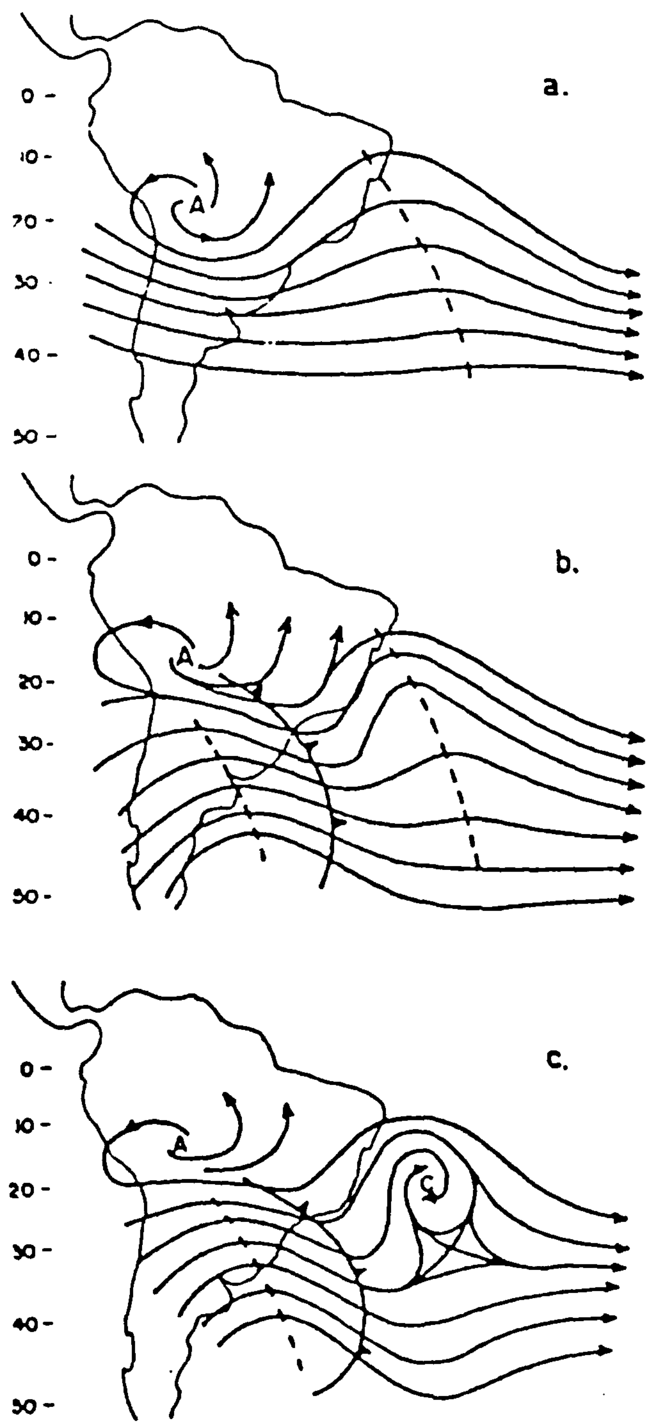


Figure 2-40. Sequence for the Formation of a 200-mb Cyclone in the South Atlantic (from Kousky, 1983). a: Typical 200-mb pattern during summer, b: Initial changes at 200 mb during strong cold frontal penetration, c: Developed 200-mb cyclone.

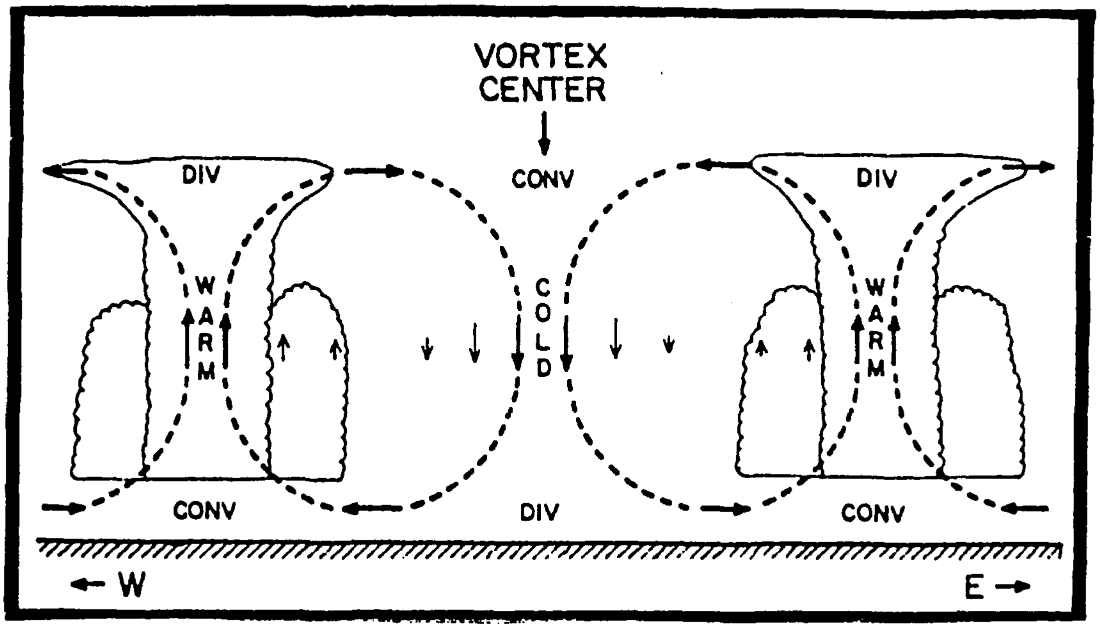


Figure 2-41. Vertical Cross Section Through an Upper-Tropospheric Cyclonic System (from Kousky, 1983). Converging air in the center sinks to result in clear skies.

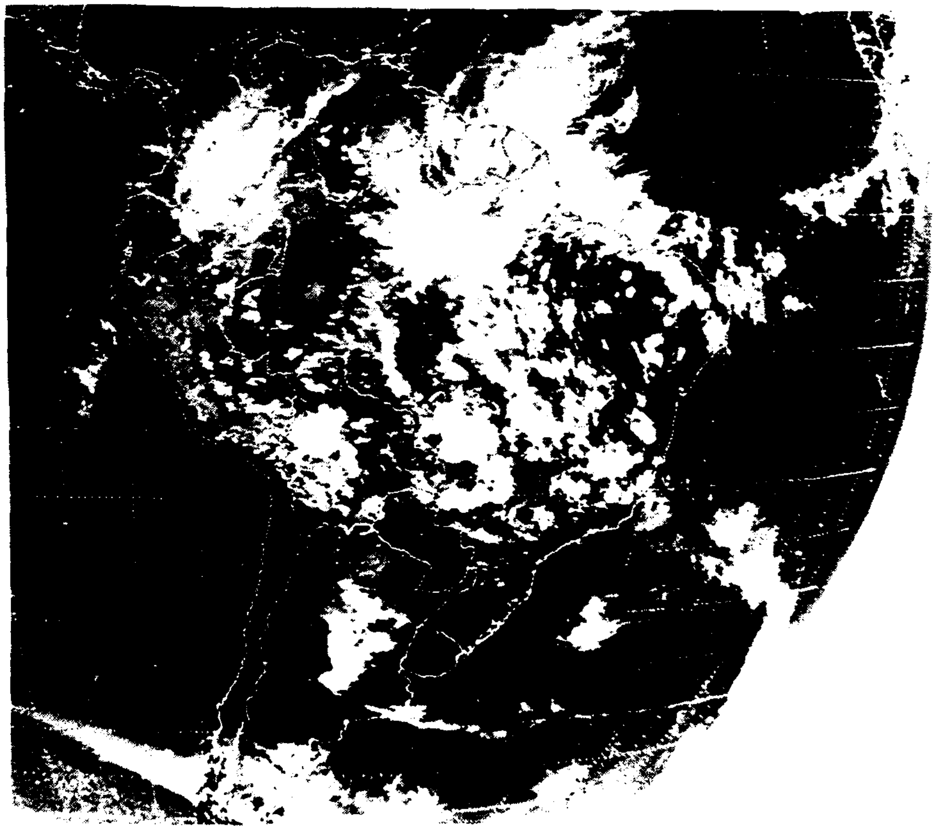


Figure 2-42. Satellite Imagery of Upper-Tropospheric Cyclone over Northeast Brazil, 20 March 1982 (1800Z IR). The cyclone is over the clear area at 8° S, 43° W. The convection is cyclonically curved around it. Convection is enhanced where an old frontal boundary extends from the South Atlantic into central Brazil. (Photo courtesy of NOAA/NESDIS).

EASTERLY WAVES. Whether or not easterly waves affect the study area is controversial. Some Brazilian meteorologists claim that easterly waves affect Brazil during Southern Hemisphere fall, but a few contend that they also occur in winter. A British study done in the equatorial South Atlantic at Ascension Island identified the possibility of easterly waves occurring once or twice a decade. Most studies, however, claim that easterly waves enter South America north of the Equator; this suggests that few of those occurring in the South Atlantic ever reach the coast. Supporting this is recent information indicating that certain other disturbances affecting the study area are often mistaken for easterly waves. For more information, see Low-Latitude Upper Tropospheric Cyclonic Vortices, Land-Sea Breezes, and Trade-Wind Surges.

MESOSCALE CONVECTIVE SYSTEMS (MCSs). These massive convective cloud clusters develop between mid-Spring (October) and late-Fall (May) over the Bolivian Plateau, Argentina's Gran Chaco, and Paraguay. They form less frequently in the central and eastern Amazon Basin, and very rarely south of 35° S. MCSs here are up to 60% larger than their Northern Hemisphere counterparts; their average cloud shield at the time of maximum extent can be 500,000 square km, compared to 300,000 square km in North America.

Initial convection often develops about 1900L, but highly-organized MCSs do not usually occur until 2100L. They normally attain maximum size by 0000L and dissipate by 0900L. Strongest convection occurs in the north and west quadrants of the system.

Other important differences between North and South American MCSs include these:

- North American systems form between 30 and 50° N. South American MCSs rarely develop south of 35° S. Figure 2-43 shows MCS formation between April 1981 and May 1983. Note the high concentrations of activity over Bolivia, Paraguay, and northeastern Argentina.

- South American storm tracks change from west to east in late spring to equatorward in mid-summer, then back to west to east in fall. North American MCS tracks do not vary by season. Figure 2-44a-c shows storm tracks for November, December-February, and March-April.

Figures 2-45a-f are satellite imagery of an MCS developing over Argentina. All photos courtesy of NOAA/NESDIS.

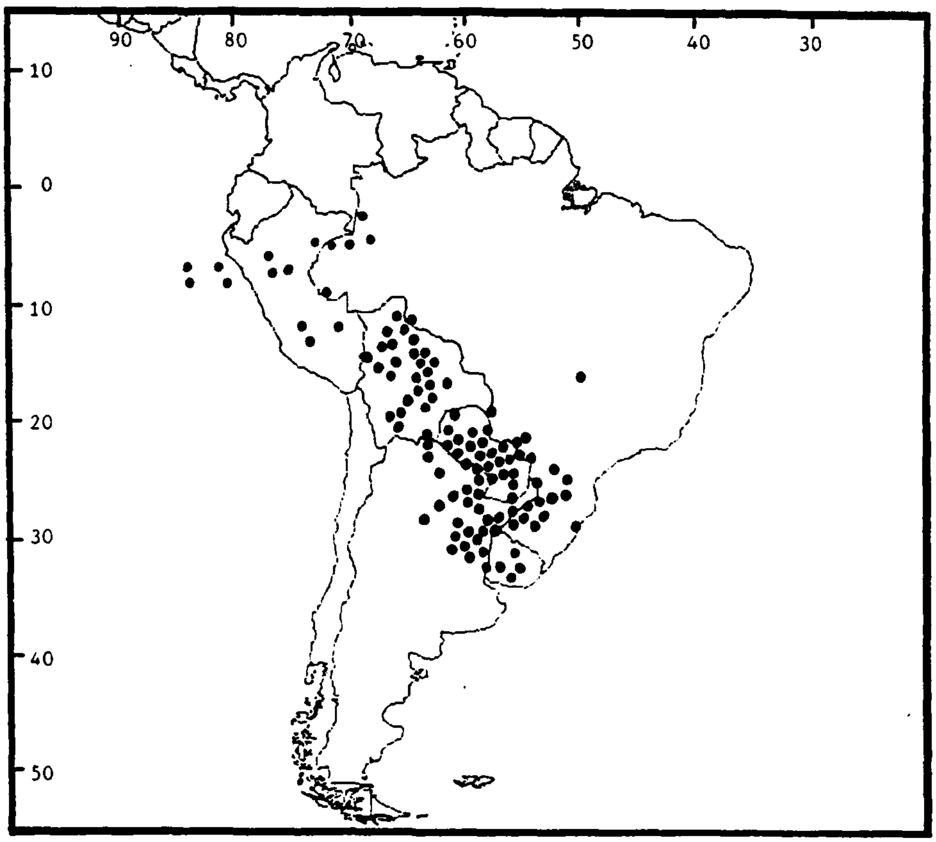


Figure 2-43. Location of MCSs Across South America Between April 1981 and May 1983 (from Velasco and Fritsch, 1986). Each dot represents the origin of one MCS.

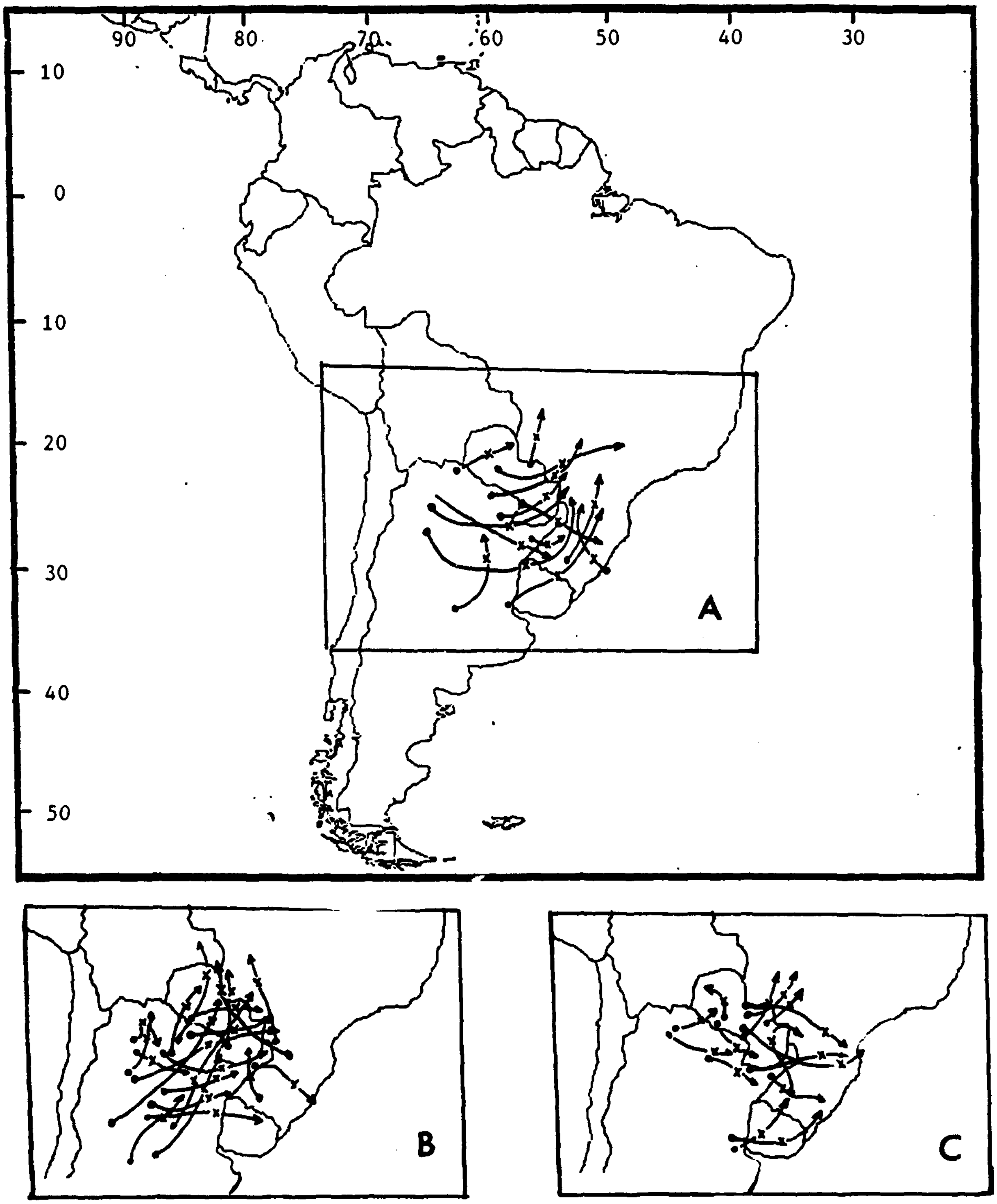


Figure 2-44. MCS Tracks Over South America. A - Tracks for two spring seasons (November); B - Tracks for two summer seasons (December-February); C - Tracks for two fall seasons (March-April). Dots show points of formation, while the "X" shows position of maximum areal extent. Arrows depict system movement.

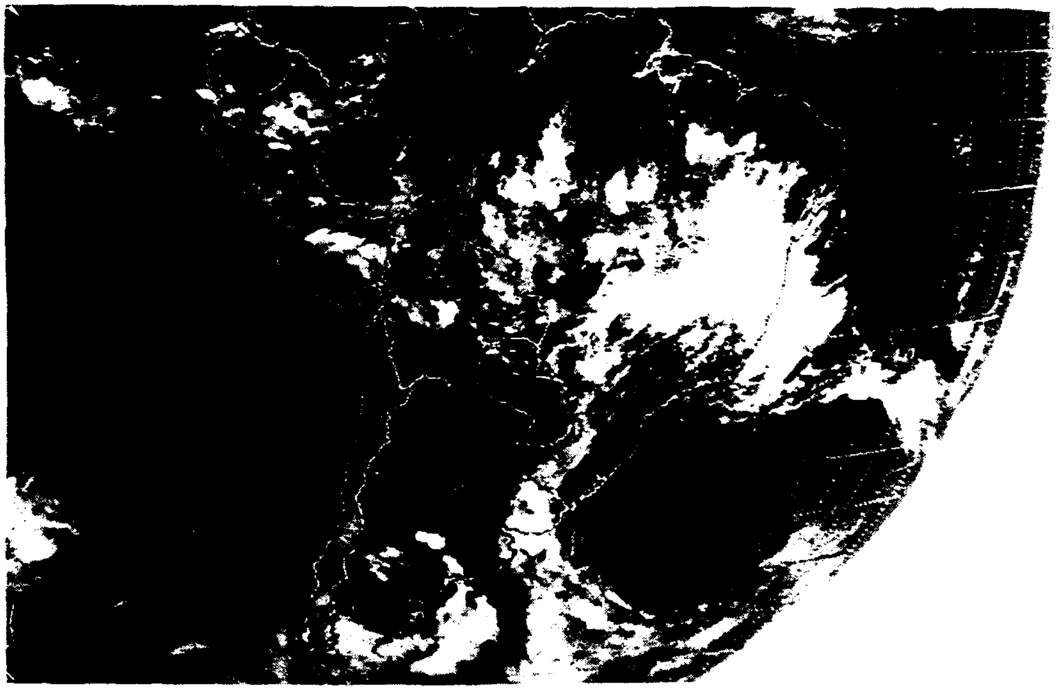


Figure 2-45a. MCS Sequence, 25 January 1983 (0600Z IR). Initial convection is in central Argentina.

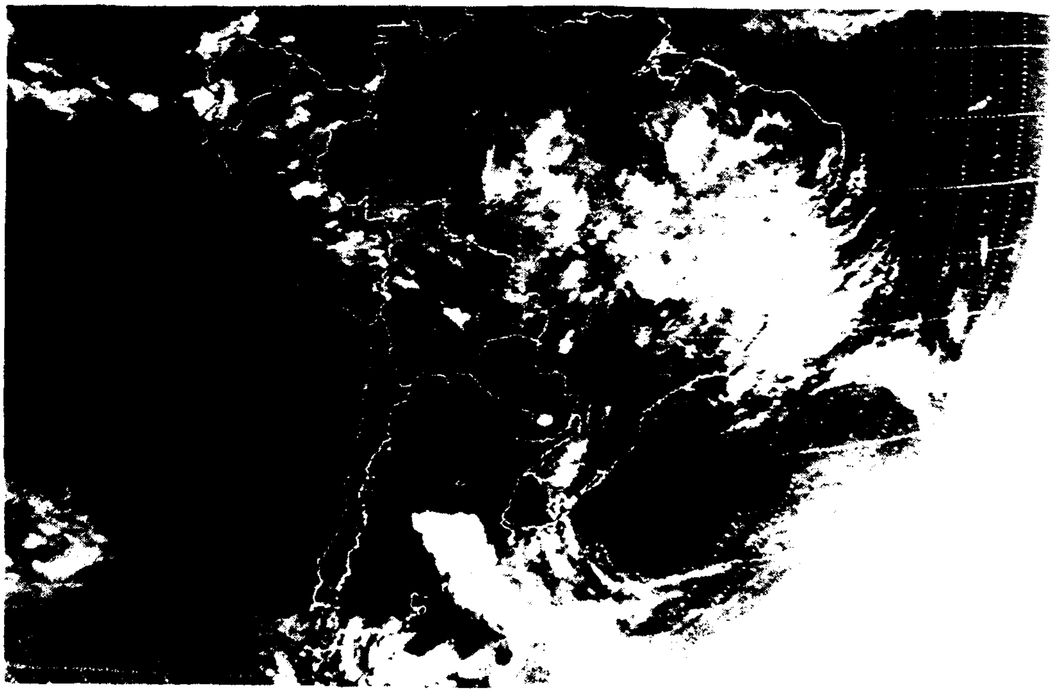


Figure 2-45b. MCS Sequence, 25 January 1983 (1200Z IR).

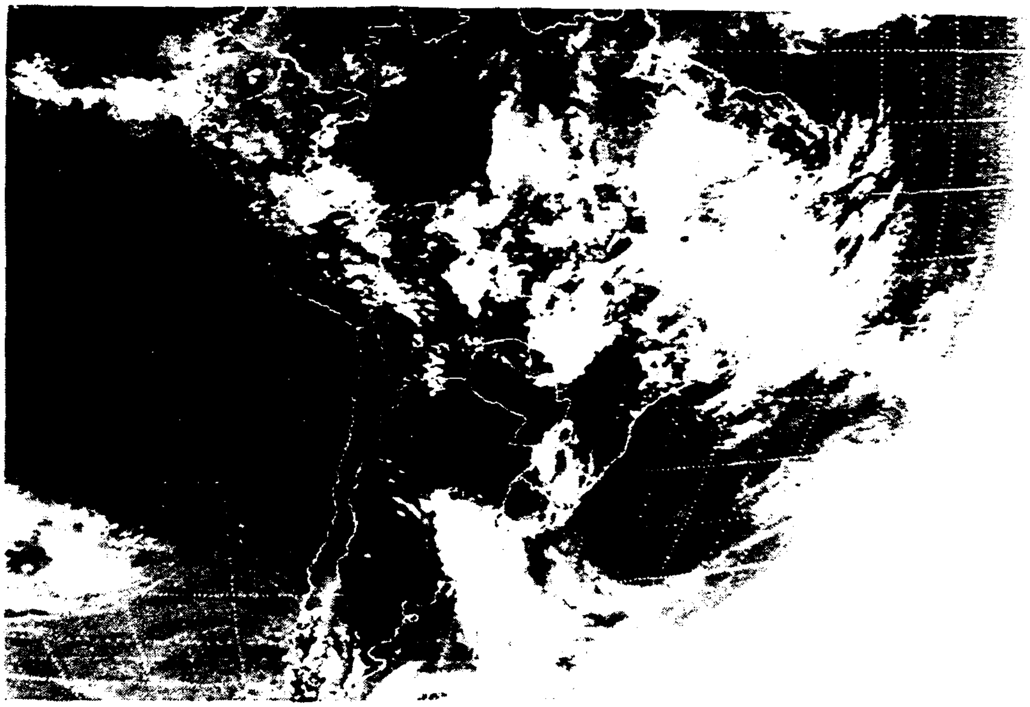


Figure 2-45c. MCS Sequence, 25 January 1983 (1759Z IR).

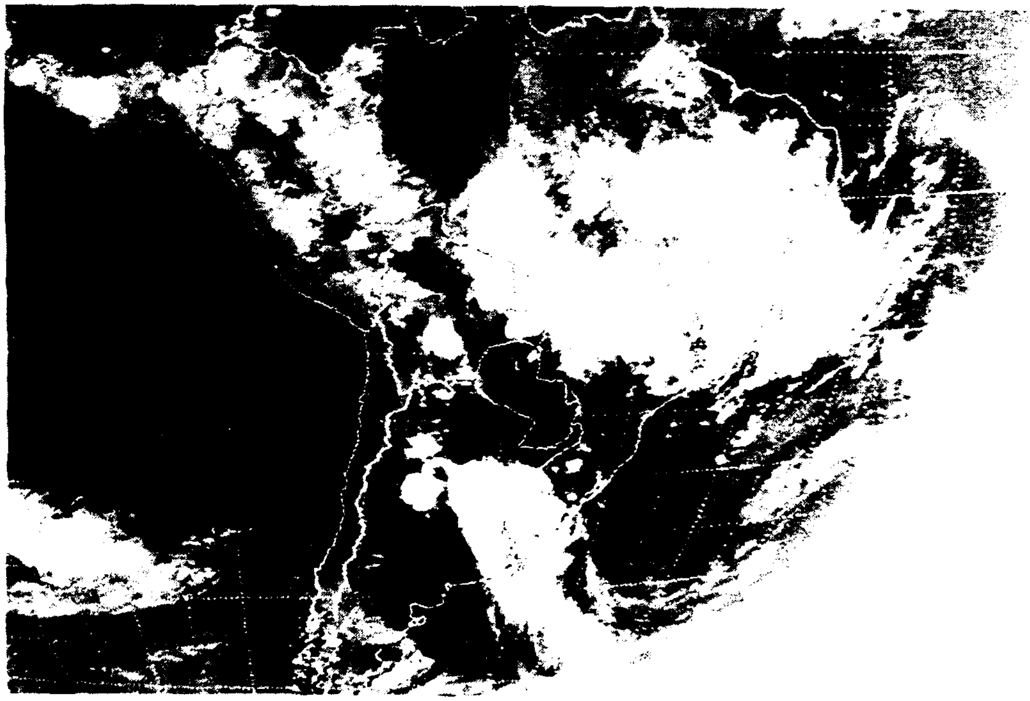


Figure 2-45d. MCS Sequence, 26 January 1983 (0000Z IR). Additional convection is developing west of the main complex which is moving northeast.

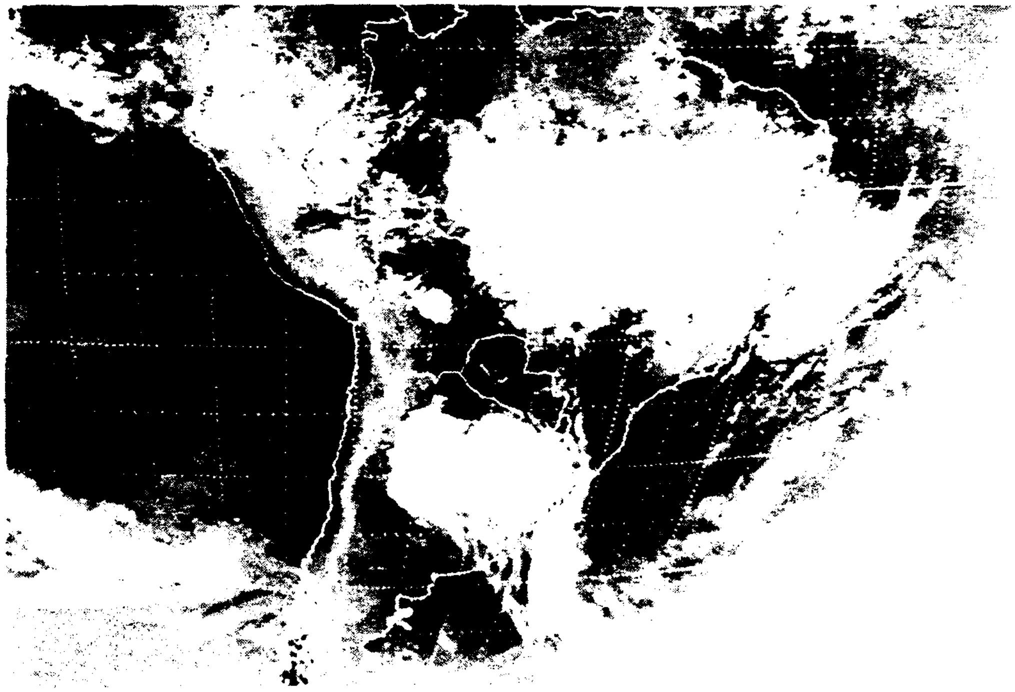


Figure 2-45e. MCS Sequence, 26 January 1983 (0600Z IR). Convection now extends over much of northern Argentina and Uruguay.

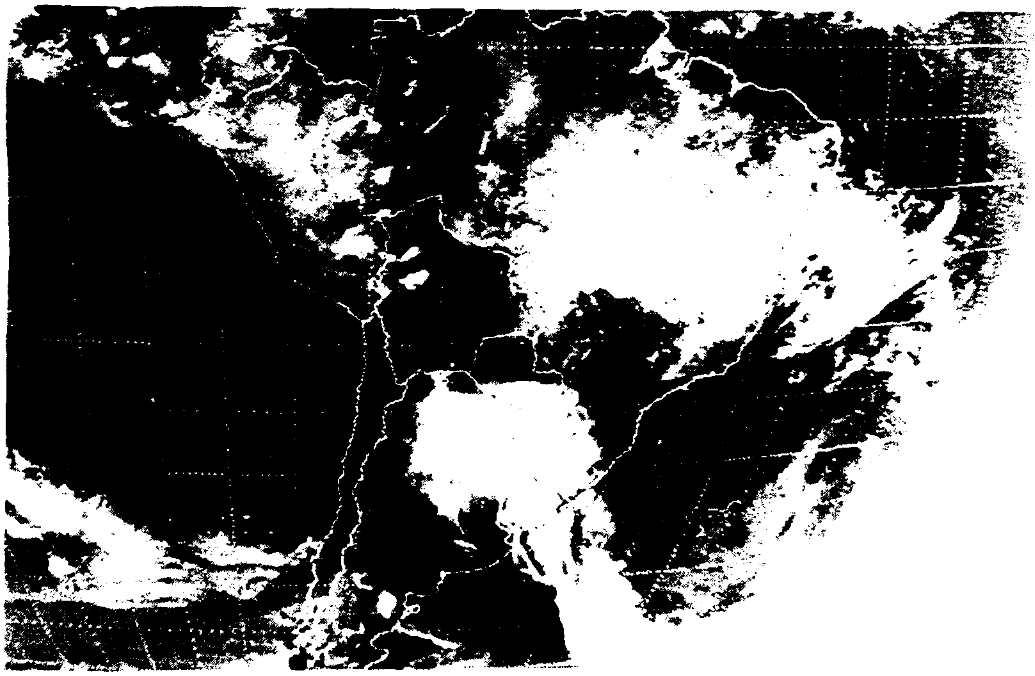


Figure 2-45f. MCS Sequence, 26 January 1983 (1200Z IR).

LAND/SEA BREEZE. Differential heating along coasts produces this diurnal phenomenon. Sea-breeze depth (the marine boundary layer) ranges from 3,000 to 5,000 feet (900-1,500 meters) AGL. Maximum sea-breeze penetration with weak or nonexistent synoptic flow is 27 NM along mid-latitude coastlines and 35 NM in the tropics. Sea-breeze wind speeds range from 8 to 12 knots, but may exceed 20 knots along the Peruvian coast with calm synoptic flow. Several types of land/sea breezes are found in South America.

"Common" land/sea breezes affect the entire South American coastline, but coastal topography, prevailing synoptic flow, and coastline configuration produce local variations in speed and prevailing direction. Figure 2-46 illustrates the "common" land/sea breeze circulation under calm synoptic conditions, with uniform coastal configurations, and no topographic influences. Onshore (A) and offshore (B) flow intensifies in proportion to the daily heat exchange between land and water. "Common" land/sea breezes always reverse at dawn and dusk. The "common" land/sea breeze dominates the western South American coastline. Strong land breeze circulations are accelerated by mountain/valley breezes along the Andes Cordillera.

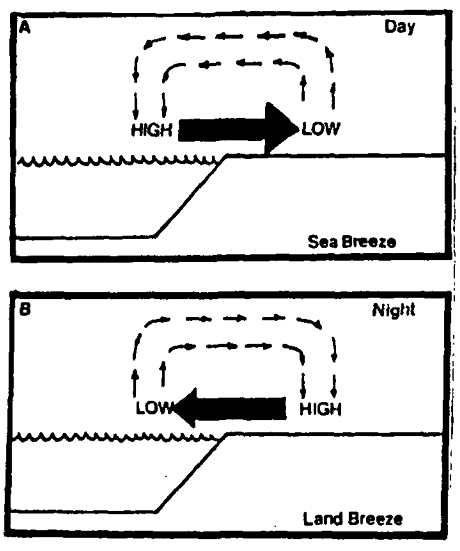


Figure 2-46. The "Common" Daytime Sea Breeze (A) and Nighttime Land Breeze (B). Thick arrows represent pressure gradient and direction of flow.

"Frontal" land/sea breezes are the product of the "front" between land and sea air masses. The transition for wind reversal is delayed by 1-4 hours as gradient flow prevents the sea-breeze boundary layer or "front" from moving ashore. Figure 2-47a-f show a typical "frontal" land/sea breeze sequence. These "frontal" land/sea breezes are usually found along mid-latitude Atlantic shorelines. Thick arrows show gradient flow, while thin arrows show wind direction within the marine boundary layer.

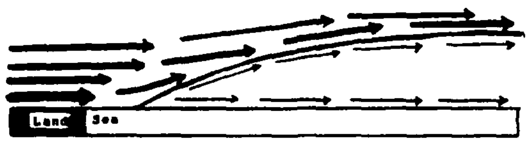


Figure 2-47a. Gradient Flow With Offshore Wind Component Sloping Gently Over Dense, Cooler Marine Boundary Layer Air Mass. Shearing action along the "front", or land/sea air mass interface, compacts the marine boundary layer. Gradient flow strength determines the magnitude of compacting.

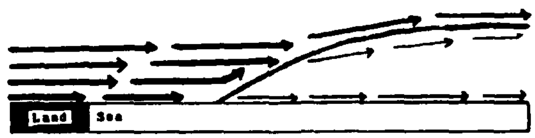


Figure 2-47b. Increased Compacting of the Marine Boundary Layer Tightens Pressure Gradient Along Land/Sea Interface. If the gradient is weak, land surfaces heat rapidly. As a result, the surface pressure gradient and winds resemble those in Figure 2-47a.

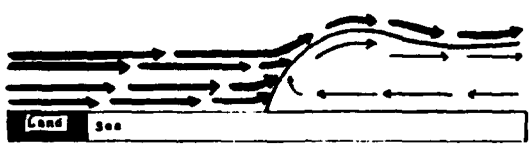


Figure 2-47c. Maximum Compacting of the Marine Boundary Layer. At this instant, surface winds inside the marine boundary layer show onshore direction. The marine layer surface flow may take several hours to reach the coast. Momentum accelerates wind speed with time.

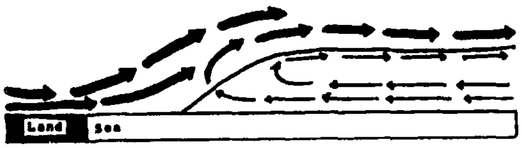


Figure 2-47d. "Frontal" Sea Breeze Accelerates Towards Shore. Initial "frontal" sea breezes may sustain 15-knot winds for 15-45 minutes.

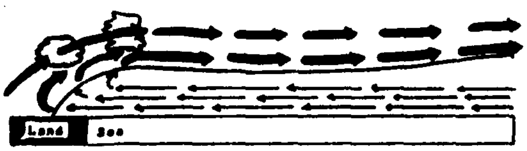


Figure 2-47e. Sea Breeze "Front" Reaches the Coast. The cloud cover (fair weather cumulus) develops where the "front" converges over land with offshore gradient flow.

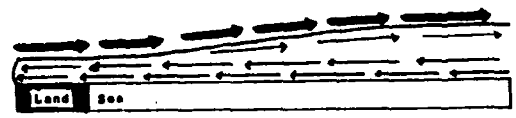


Figure 2-47f. Land/Sea Breeze Mechanism in Full Swing. Offshore flow aloft, onshore flow at surface.

Figure 2-48 shows the land/sea circulation with onshore gradient winds and coastal topography. Onshore gradient flow accelerates orographic uplift by day and produces localized convergence over open water with land breeze during the early morning hours. This land/sea breeze convection pattern is found along the Brazilian Highlands and western Andean foothills of Peru and northern Chile above 1,000 meters (3,280 feet) MSL. Onshore gradient flow at the mouth of the Amazon assists development of sea-breeze cumulus in the absence of coastal topography.

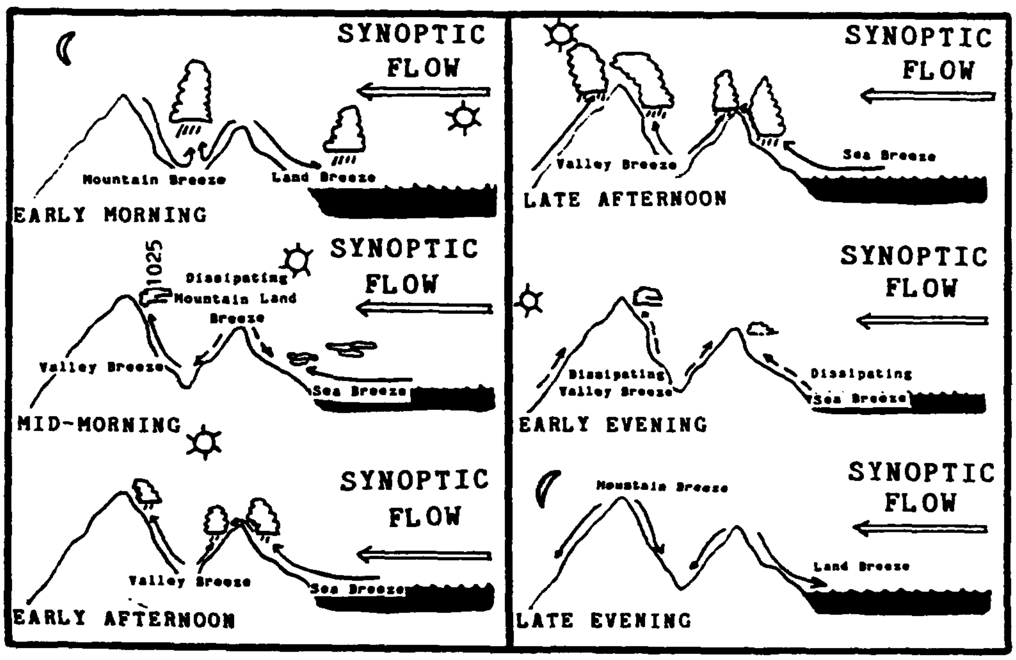


Figure 2-48. Land/Sea Breeze With Onshore Gradient Flow.

Several localized variations of a land/sea breeze circulation are caused by differential heating over large lakes, bays, and the Amazon River basin. This circulation occurs in the absence of strong synoptic flow and has a vertical depth ranging from 650 to 1,650 feet (200-500 meters) AGL. Figure 2-49 shows a land/lake circulation and cloud pattern. In late afternoons (top illustration), a cloud-free lake is surrounded by a ring of convection some 10 to 20 NM inland from shore. The arrows show the direction of flow. By early morning, the flow reverses and localized convergence occurs over open water. Southern Peru's Lake Titicaca is an example of a very complex land/lake circulation. At 12,500 feet (3,790 meters) MSL, upper-air troughs and the rugged terrain can rapidly transform the circulation into moderate to severe turbulence.

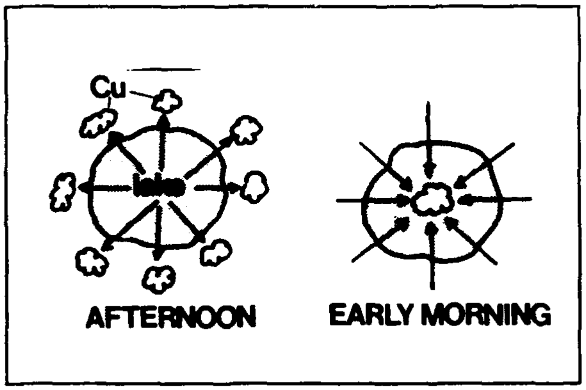


Figure 2-49. Typical Land/Lake Breeze With Cloud-Cover Pattern.

Over large bays or inlets, the sea breeze funnels into an enclosed water basin with the characteristics of a sea-breeze "front," as shown by Figures 2-47a-f; however, the flow within the basin, rather than an offshore gradient flow, produces the convergence. Figure 2-50 illustrates flow patterns (arrows) and cloud cover distributions. Terrain often deforms the convergence line over open water with cloud cover anchored along the shoreline on either side of the basin. Cloud cover reverses direction between early morning and afternoon. Local drainage winds determine the final shape and position of the convergence line.

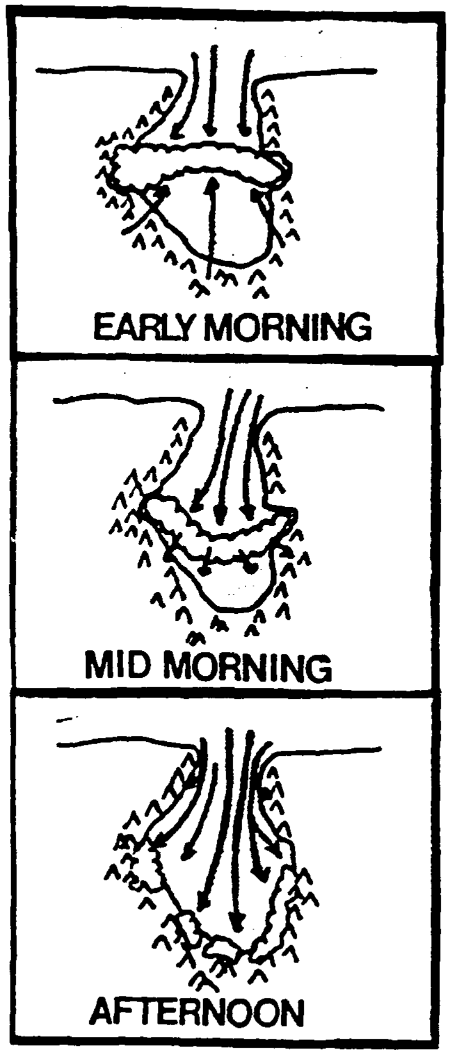


Figure 2-50. Complex Land/Lake Circulation and Resultant Cloud Cover Pattern.

LAND/RIVER CIRCULATION. The Amazon River Basin produces a localized land/river circulation. The river and its main tributaries provide mesoscale differential heating between land and water. Cooler jungle air flows over the wide river basin, producing nocturnal convergence and scattered cumulus, often embedded within a thick cover of jungle stratus or mist. Cloud bases develop below 1,000 feet (300 meters) AGL; cloud tops rarely exceed 1,500 feet (450 meters) MSL. The cumulus and heavy mist usually dissipate by 1000L. Figure 2-51 is a "look down" view of cloud cover distribution over the Amazon with weak synoptic flow.

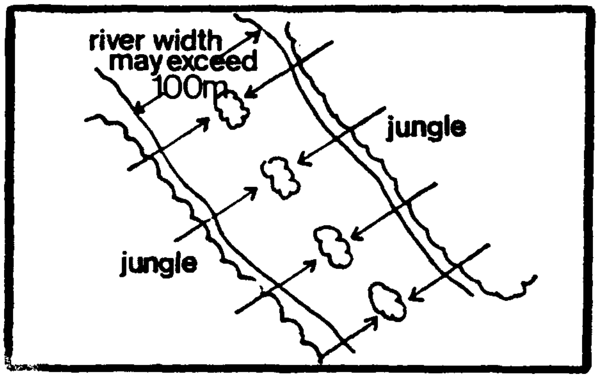


Figure 2-51. Cloud Cover Pattern (Top View) Over the Amazon River Basin. This pattern occurs when the synoptic flow is weak.

Rivers perpendicular to significant low-level flow and more than 8 NM wide (as certain portions of the Amazon River basin are) develop the circulation pattern shown in Figure 2-52. The figure shows mesoscale circulation patterns and surface temperatures for affected locations during the day (top) and at night (bottom). Jungle or forest heats and cools much more quickly than rivers; large rivers can be as much as 5° F (3° C) cooler than jungle or forest during the day and 15° F (9° C) warmer at night. During the day, approaching air sinks along the upwind shore and over the cooler river. After accelerating across the smoother river surface, it rises, slows and converges over the warmer, rougher opposite shore. At night, warmer river temperatures cause approaching air to rise over the upwind shore and the river. The air sinks over the cooler, downwind shore.

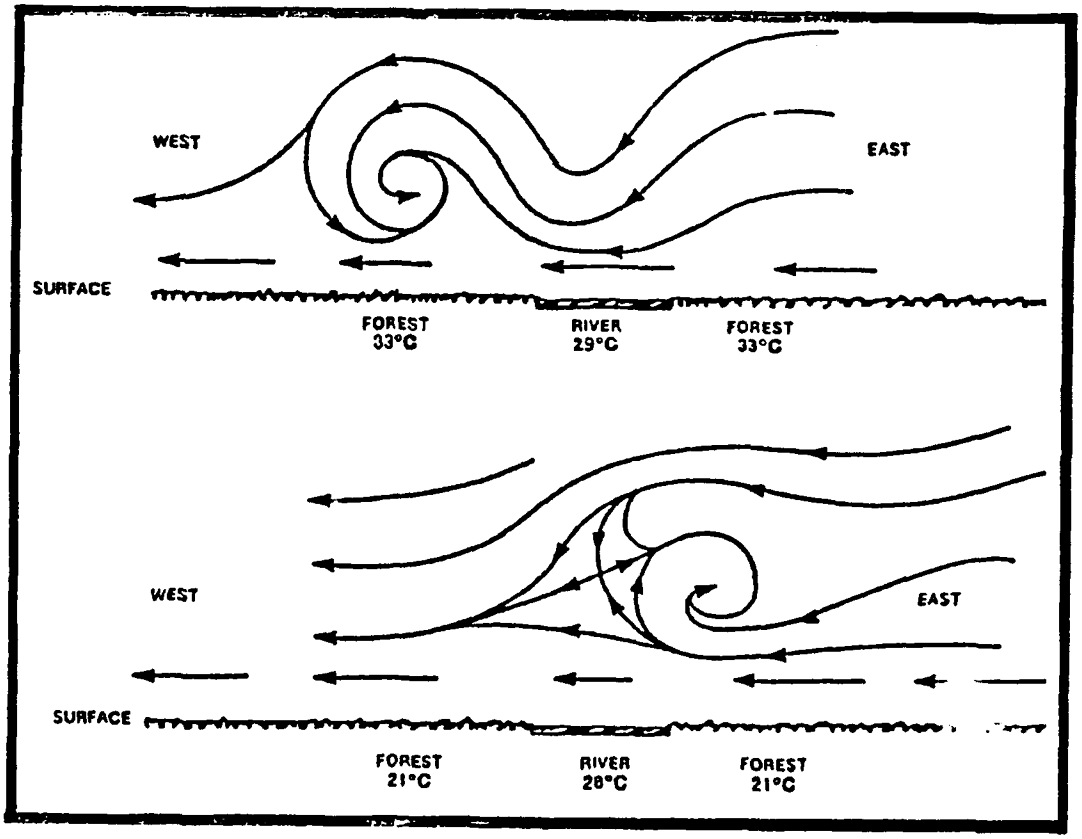


Figure 2-52. Mesoscale Circulation Over and Near Large Rivers of the Central Amazon During the Day (top) and at Night (bottom) (from Greco, 1989). Synoptic flow is easterly.

MOUNTAIN/VALLEY WINDS depend on mountain orientation and terrain complexity. Windward slopes see an enhancement of valley (upslope) breezes and drastic weakening or elimination of mountain (downslope) breezes. These breezes result in the formation of mountain cumulus, heavier precipitation along ridges, and increased chances of ground fog in valleys. Lee-side slopes experience adiabatic warming and reduced cloudiness.

There are many variations on the simple mountain-valley breeze. Deep mountain canyons often see much higher temperatures due to adiabatic warming. Wide mountain valleys experience afternoon convection spaced across the valley. The strongest effects of the classic mountain-valley breeze are normally found in the dry season when prevailing winds are lighter and cloud cover less.

Drainage, or "fall," winds occur during the clear nights of winter in the high Andes. Air that has undergone radiational cooling on the slopes of these mountains pour down across adjacent valleys. This rush of air is generally shallow, with wind speeds of over 60 knots measured at the surface. Strong downslope winds normally cease 2 or 3 hours after sunrise.

Mountain/Valley winds develop under fair skies with light and variable synoptic flow. The two types of terrain-induced winds are valley winds and slope winds, as shown in Figure 2-53. Valley winds tend to be stronger than slope winds and can override their influence.

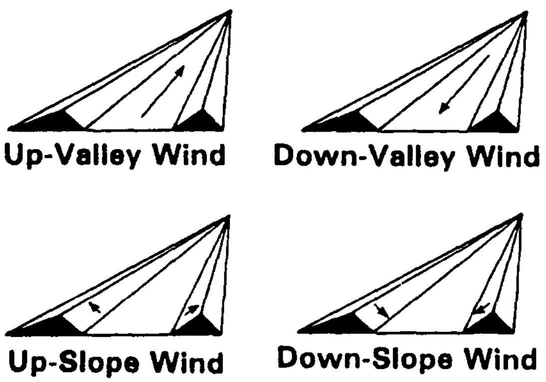


Figure 2-53. Valley and Slope Winds (from Whiteman, 1990).

Valley winds are produced in response to a pressure gradient between a mountain valley and a plain or slope outside the valley. Air in the valley heats and cools faster than air over the plain. Daytime, up-valley winds are strongest, averaging 10 to 15 knots between 650 and 1,300 feet (200 and 400 meters) AGL. Nighttime down-valley winds average only 3 to 7 knots at the same level. Peak winds are found at the valley exit. Deep valleys develop more nocturnal cloud cover than shallow valleys because nocturnal airflow convergence is stronger. The mesoscale mountain/valley circulation has a maximum vertical extent of 6,560 feet (2,000 meters) AGL, depending on valley depth and width, the strength of prevailing winds in the mid-troposphere (stronger winds producing a shallower circulation), and the breadth of microscale slope winds. Return flow aloft is much weaker and broader since it isn't confined to a narrow valley.

Slope winds develop along the surface boundary layer (0-500 feet/0-150 meters AGL) of mountains and large hills. Mean daytime upslope wind speeds are 6 to 8 knots at elevations no higher than 130 feet (40 meters) AGL; mean nighttime downslope speeds are 4 to 6 knots. Steeper slopes can produce higher speeds. Downslope winds are strongest during the season with the greatest cooling, while upslope winds are strongest during the season of greatest heating. Upslope winds are strongest on the slope facing the sun. Winds from a larger mountain can disrupt the winds of a smaller mountain. In some locations, cold air can be dammed up on a plateau or in a narrow valley. When enough air accumulates, it can spill over in an "air avalanche" of strong winds.

Figures 2-54a-h (from Barry, 1981) show the life cycle of a typical mountain/valley wind circulation. Both valley and slope winds are shown in relation to two ridges (BK and BB) oriented NNW-SSE. The dark arrows show the flow near the ground; the light arrows show the vertical movement and the flow above the surface flow.

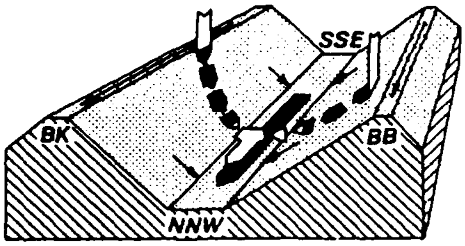


Figure 2-54a. Midnight to Sunrise on the East Slope. Downslope winds feed the mountain circulation.

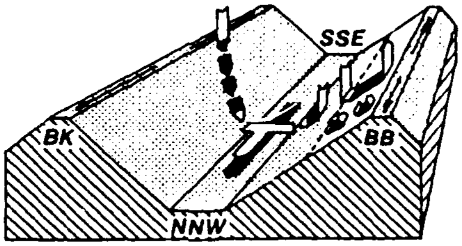


Figure 2-54b. Sunrise on the Upper East Slope. Sunshine almost immediately generates upslope wind, but the downslope mountain wind and the down-valley wind persists elsewhere.

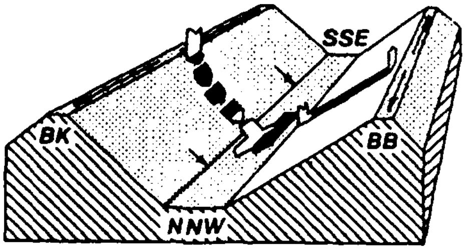


Figure 2-54c. Whole East Slope in Sunlight. Widespread surface heating continues to generate upslope wind on sunlight side; down-valley wind has weakened.

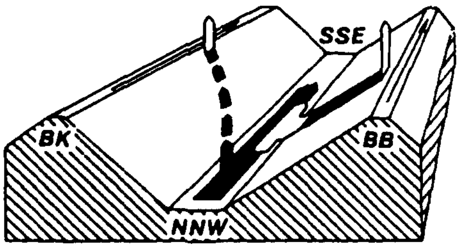


Figure 2-54d. Whole Valley in Sunlight. Sunshine covers the entire valley floor; upslope flow and up-valley flow support each other.

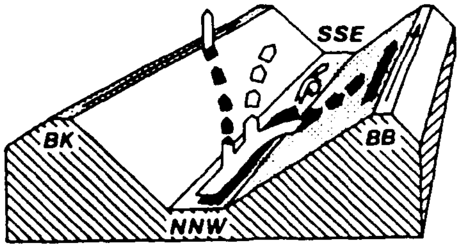


Figure 2-54e. West Slope Receiving More Solar Radiation Than East Slope. East-facing slopes begin to cool, weakening upslope flow.

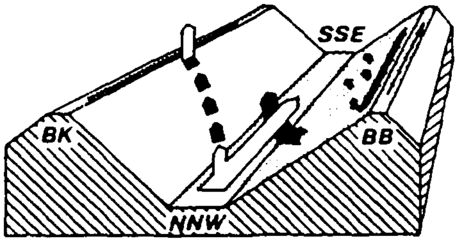


Figure 2-54f. Solar Radiation Only Tangential to East Slope. Downslope flow begins on east slope with colder air undercutting the up-valley wind.

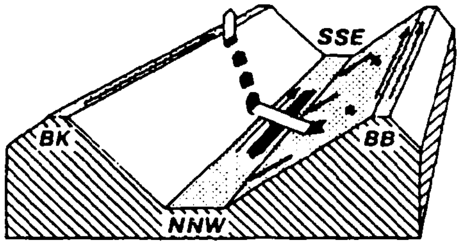


Figure 2-54g. Sunset on East Slope and Valley Floor. Down-valley winds develop; downslope winds from east slope extend cross-valley to feed upslope winds on the west slope.

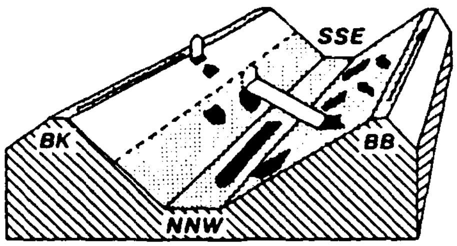


Figure 2-54h. After Sunset on the Lower West Slope. Down-valley and downslope winds everywhere except tops of sunlight peaks.

Mountain inversions develop when cold air builds up along wide valley floors where nighttime downslope wind convergence is weak. Cold air descends from slopes above the valley at 8 to 12 knots but loses momentum when it spreads out over the valley floor. By the time the downslope flow from both slopes converge, wind speeds average only 2 to 4 knots. The cold air replaces warm, moist valley air at the surface and produces a thin smoke and fog layer near the base of the inversion. First light initiates upslope winds by warming the cold air trapped on the valley floor. Warming of the entire boundary layer begins near the 500-foot (150 meter) level AGL.

MOUNTAIN WAVES. Mountain-wave turbulence is the irregular vertical fluctuation of air flow on the lee side of mountains. Criteria for mountain wave formation includes: sustained wind speeds between 15 and 25 knots, winds increasing with height, and wind flow within 30 degrees of perpendicular to the ridge, with little variation. Waves develop when air at lower levels is forced up over the windward side of a ridge. Waves are stronger to the lee of ridges than to the lee of isolated peaks, extending higher and propagating a greater distance downwind. The wavelength amplitude is dependent on the wind speed and temperature lapse rate above the ridge. Light winds follow the contour of the ridge with little displacement above; stronger winds displace air above a stable inversion layer. Downstream, the wave propagates for an average distance of 50 times the ridge height. The strong winds that frequently blow over the central and Southern Andes are normally very turbulent and often form mountain waves. These waves are most frequent in the winter and can be identified by the presence of a cap cloud, rotor clouds, or lenticular clouds when not obscured. Figure 2-55 shows the typical pattern.

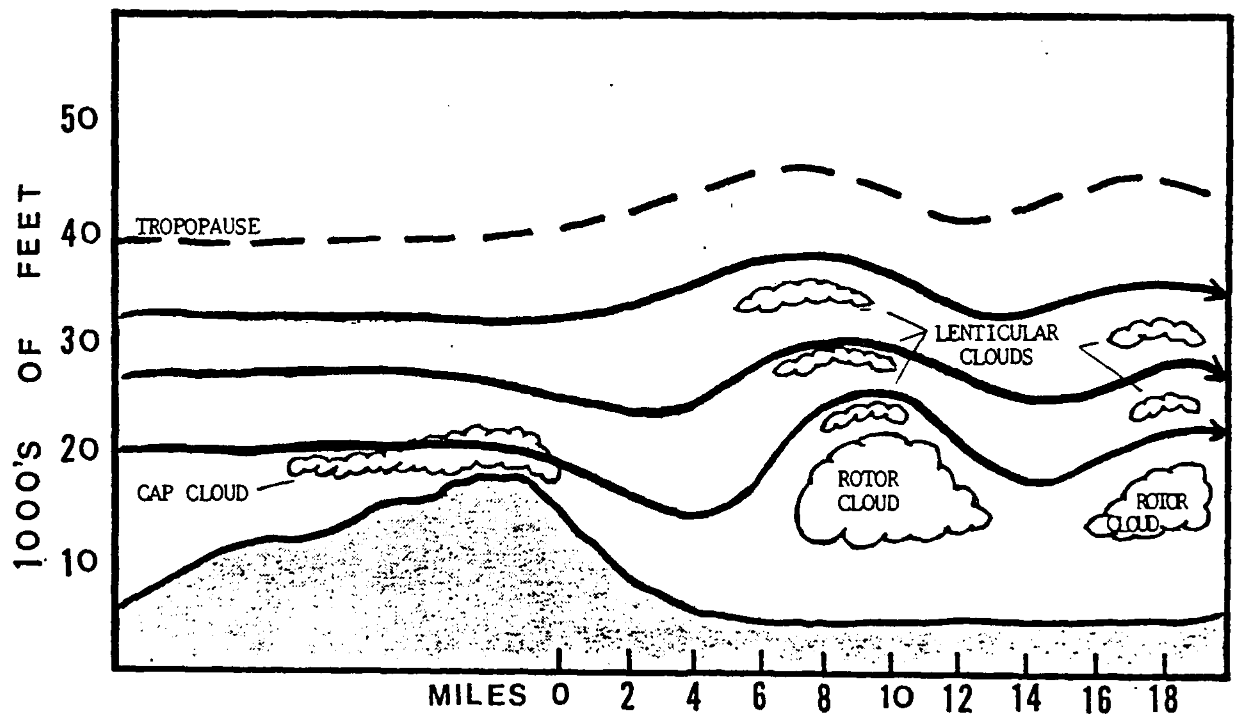


Figure 2-55. Typical Mountain-Wave Pattern and Associated Clouds.

WET-BULB GLOBE TEMPERATURE (WBGT) HEAT STRESS INDEX provides values that can be used to calculate the effects of heat stress on individuals. WBGT is computed by using the formula:

$$WBGT = 0.7\ WB + 0.2\ BG + 0.1\ DB,$$

where: WB = wet-bulb temperature
BG = Vernon black-globe temperature
DB = dry-bulb temperature

A complete description of the WBGT heat stress index and the apparatus used to derive it is given in Appendix A of TB MED 507, *Prevention, Treatment and Control of Heat Injury,* July, 1980, published by the Army, Navy and Air Force. The physical activity guidelines shown in Figure 2-56 are based on those used by the three services. Note that the wear of body armor adds 10° F (6° C) to the WBGT, and activities should be adjusted accordingly.

Figures 2-57a-d give the average maximum WBGTs for January, April, July, and October. For more information, see USAFETAC/TN--90/005, *Wet-Bulb Globe Temperature, A Global Climatology.*

WBGT (°F)	WATER REQUIREMENT	WORK/REST INTERVAL	ACTIVITY RESTRICTIONS
90-up	2 quarts/hour	20/40	Suspend all strenuous exercise.
88-90	1.5-2 quarts/hour	30/30	No heavy exercise for troops with less than 12 weeks hot weather training.
85-88	1-1.5 quarts/hour	45/15	No heavy exercise for unacclimated troops, no classes in sun, continue moderate training 3rd week.
82-85	.5-1 quart/hour	50/10	Use discretion in planning heavy exercise for unacclimated personnel.
75-82	.5 quart/hour	50/10	Caution: Extremely intense exertion may cause heat injury.

Figure 2-56. WBGT Index and Hot Weather Doctrine (from TB MED 507). Work/Rest and water consumption guidance from DA Cir 40-82-3 and GTA 8-5-45.

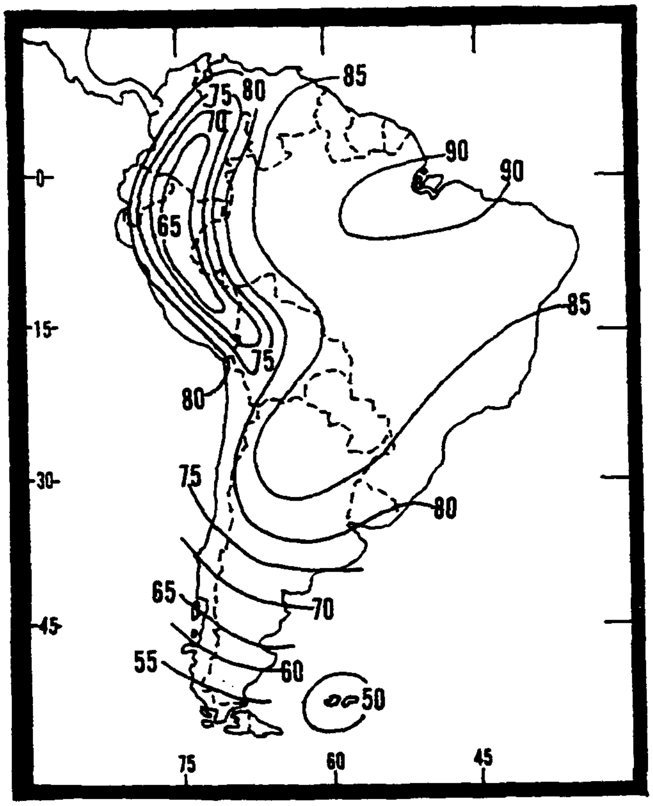
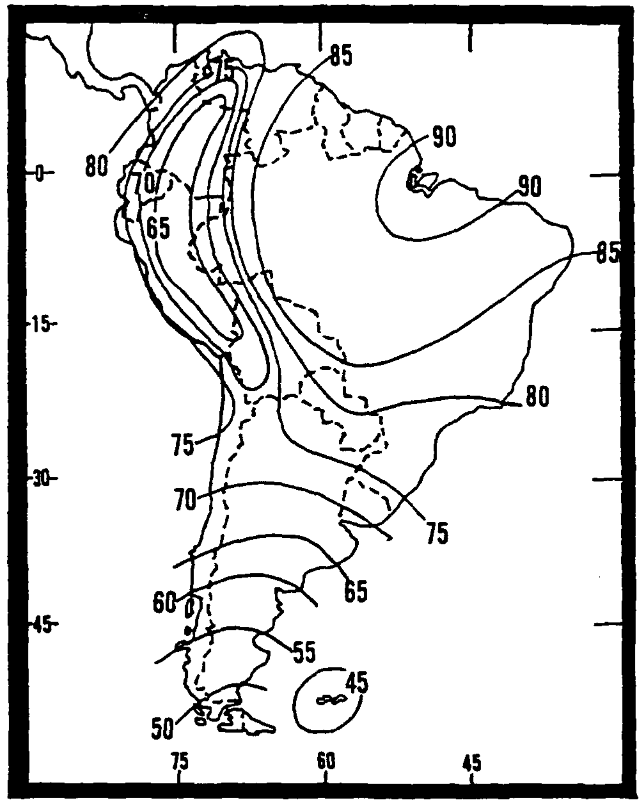


Figure 2-57a. Average Maximum WBGT Index (January). High summer humidities and air temperatures produce extensive areas of WBGTs with values above 85° F (30° C) in the Amazon Basin, south-central Brazil, Paraguay, and northern Argentina.



Figures 2-57b. Average Maximum WBGT Index (April). WBGTs above 85° F (30° C) are confined to the Amazon basin, northearn Brazil, and extreme northeastern Bolivia.

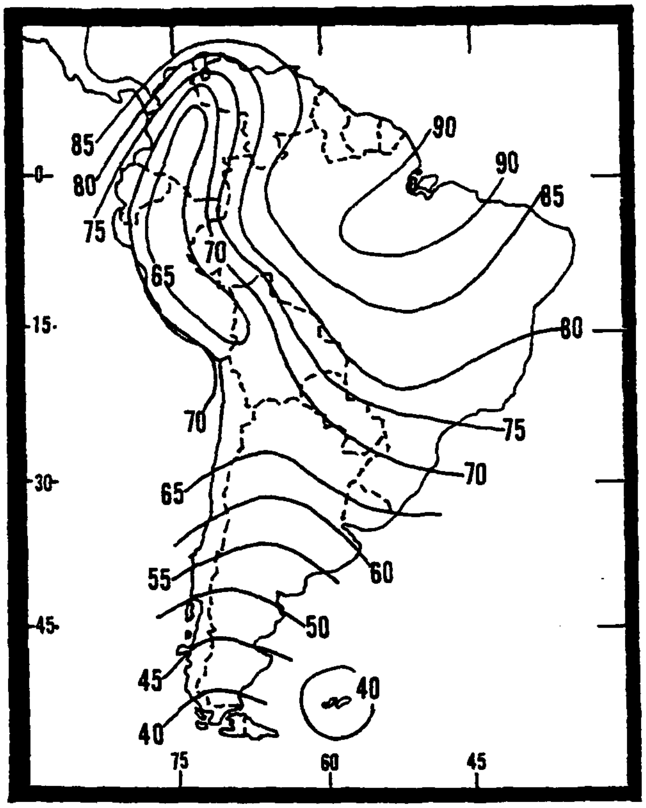


Figure 2-57c. Average Maximum WBGT Index (July). WBGTs above 85° F (30° C) are concentrated in the Amazon Basin.

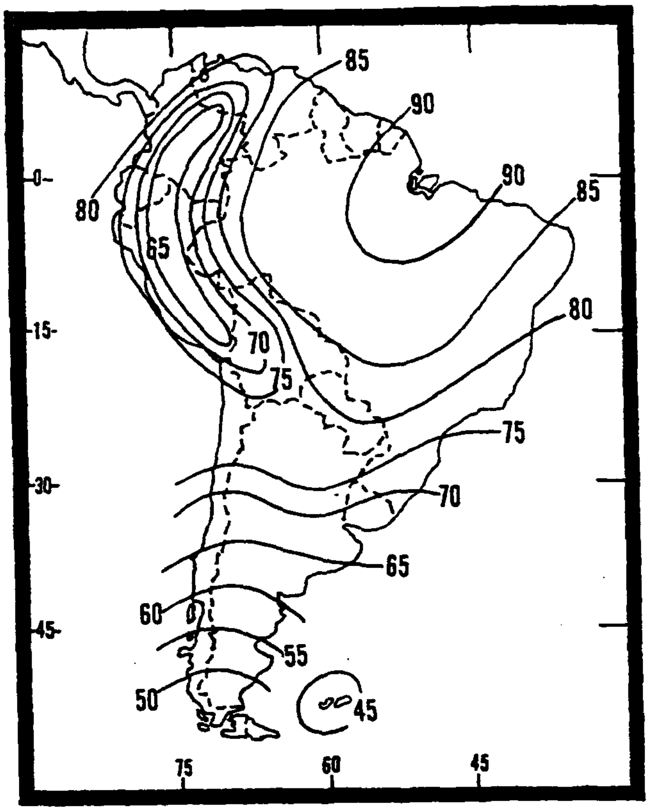


Figure 2-57d. Average Maximum WBGT Index (October). WGBT distributions are very similar to April distributions.

Chapter 3

WEST-CENTRAL SOUTH AMERICA

This chapter describes the situation and relief, major climatic controls, geography, and general weather of west-central South America between 5 and 28° S. The study area includes Peru's Pacific coast and its highlands, Bolivia's highlands, the coastal and highland regions of Chile to 28° S, and a small portion of the highlands of northwestern Argentina. The study area is divided into two zones (the Pacific Arid Zone and the Central Andes) that have been selected on the basis of topographic and climatic similiarities. These zones are shown in Figure 3-1 and discussed in turn.

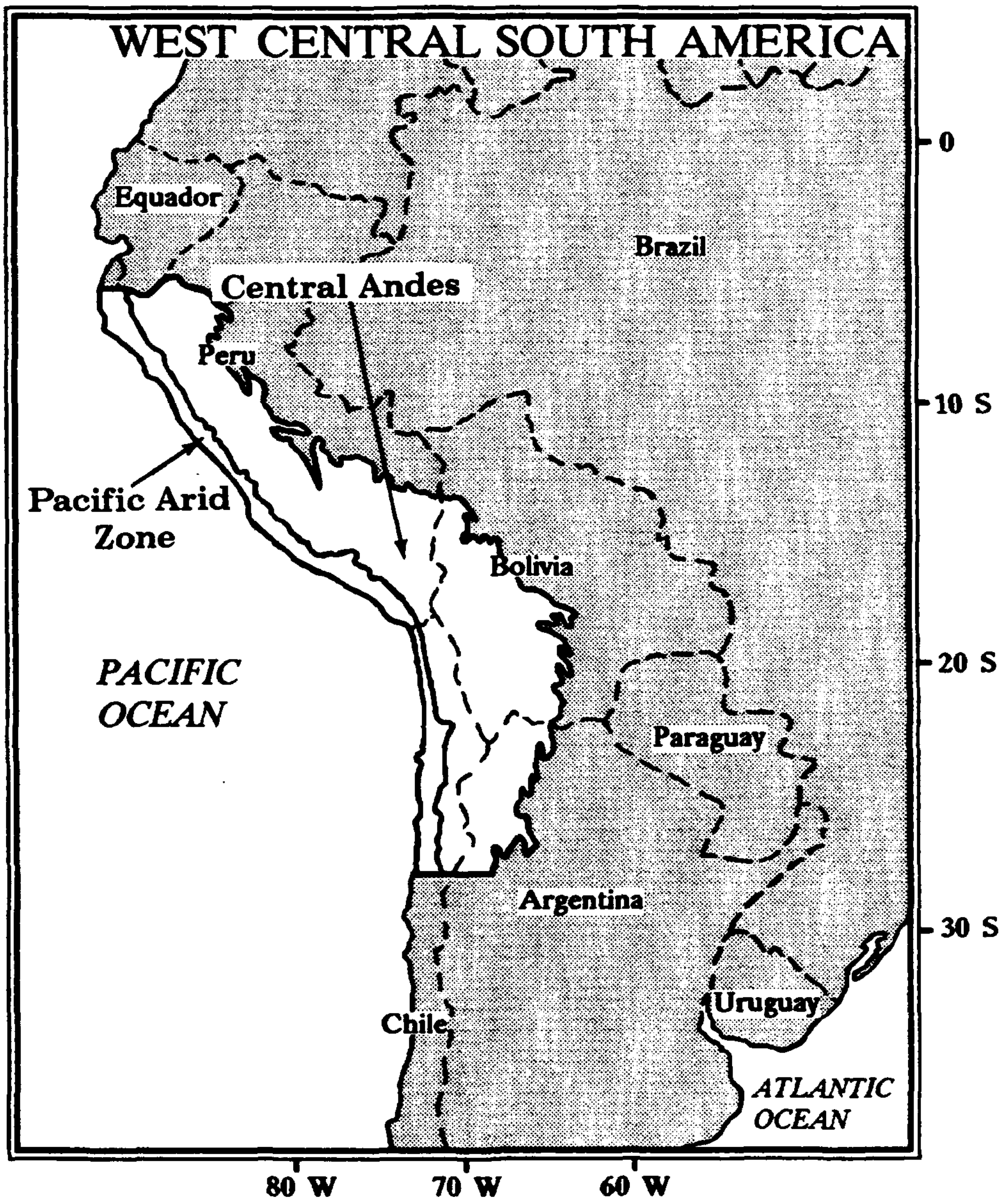


Figure 3-1. West-Central South America. The region is divided into its two zones of climatic and topographic commonality: the Pacific Arid Zone and the Central Andes.

WEST-CENTRAL SOUTH AMERICA

SITUATION AND RELIEF. West-Central South America, as defined in this study and shown in Figure 3-1, contains a rugged mountain region, an extremely arid coastal plain, and a high plateau called the "Altiplano."

The rugged Andes Mountains form a natural barrier to the general atmospheric flow. Stretching north to south for more than 1,600 NM from the Peru-Ecuador border to 28° S, they affect every meteorological variable. The Andes chain has numerous peaks above 10,000 feet (3,050 meters) MSL.

The widest point (700 NM) is at 20° S where a large and high plateau is completely surrounded by even higher terrain. This plateau (the "Altiplano") contains several glacier-fed lakes, large dry lake beds, and numerous salt flats. At 5 and 28° S, the mountains narrow to 200 NM and 250 NM, respectively.

The coastal deserts of Peru and Chile lie between the western slopes of the Andes (the Cordillera Occidental) and the Pacific Ocean. The arid landscape contains gently sloping plains and elongated terraces that gradually descend to the sea. Other stretches of coastline are extremely narrow, with coastal ranges separated by narrow valleys.

MAJOR CLIMATIC CONTROLS. West-central South America's climate is affected by tropical and mid-latitude airstreams. The transition zone from tropical to mid-latitude systems is between 20 and 28° S, where upper-level flow patterns converge routinely throughout the year.

Air Masses. Two dominant air masses (the Pacific and the Atlantic) influence west-central South America, but the Andes Mountains prevent a regular exchange between them below 8,000 feet (2,440 meters) MSL except, in rare cases, from 5 to 8° S. Above 8,000 feet (2,440 meters) MSL, a large upper-level anticyclone brings Atlantic moisture to the high mountains between November and April.

The Pacific Air Mass is cool, moist, and stable. It lies below 5,000 feet (1,525 meters) MSL. It originates from the South Pacific High, a semipermanent high-pressure cell that also drives the Humboldt Current, which is the primary cause of intense upwelling and low sea-surface temperatures along the Pacific coast of South America. The cool waters regulate a strong low-level inversion along the Peru and Chile coastlines. The largest land/sea temperature gradients in the inversion layer occur between April and October.

The Atlantic Air Mass is moist and unstable from November to April when northeasterly tradewinds bring Amazon basin moisture to the eastern Andes. It becomes stable from May to October when the South Atlantic High spreads subsidence across the Amazon basin.

Upper-level Anticyclone. This feature, commonly called the "Bolivian High," is responsible for lifting and spreading moist, unstable low-level Amazon air over the Central Andes. The circulation serves as an outflow mechanism for sustaining heavy convection north of its ridge axis, which rarely penetrates south of 20° S. South of the ridge axis, the Bolivian High produces subsidence in the upper levels.

3.1 THE PACIFIC ARID ZONE

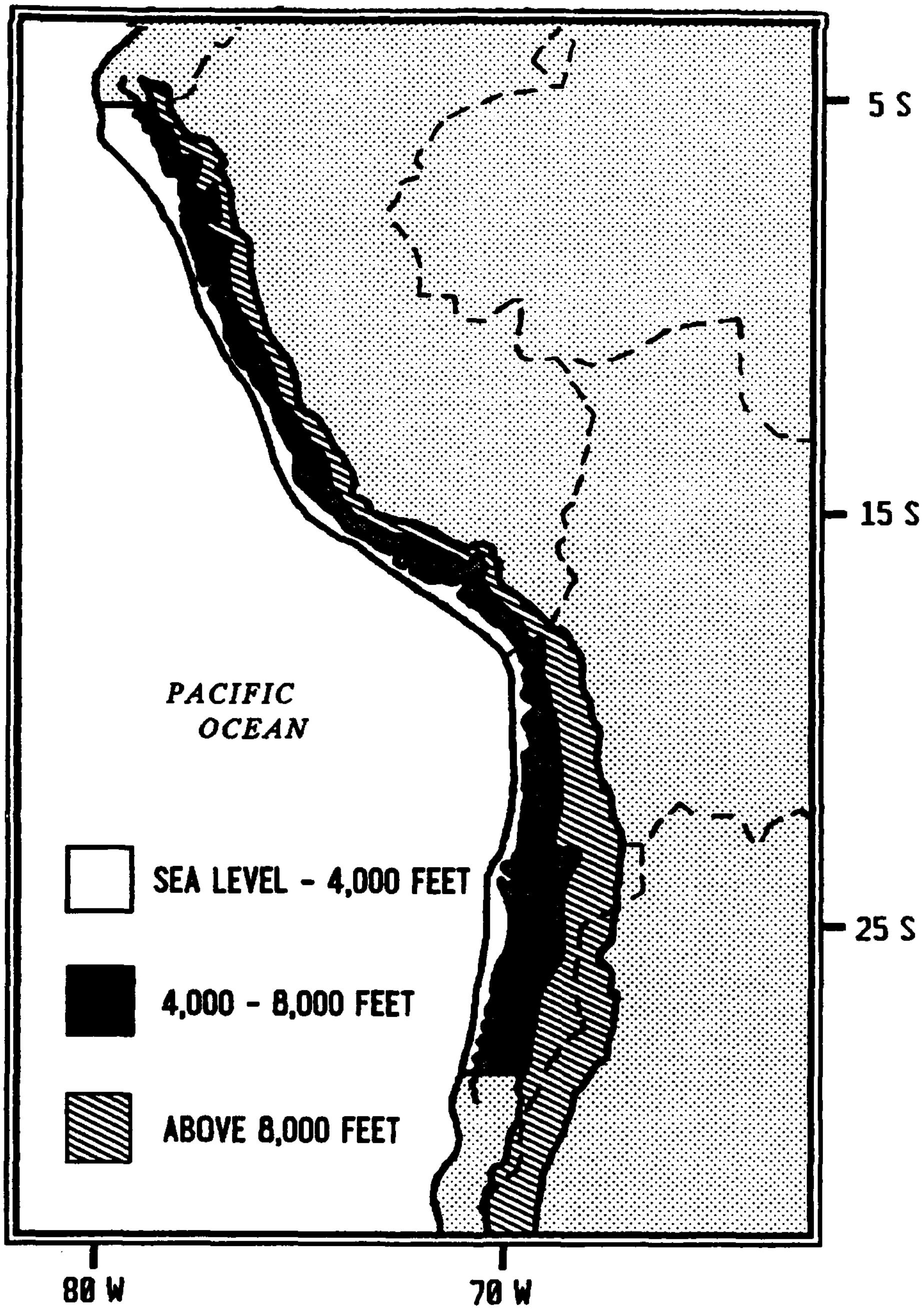
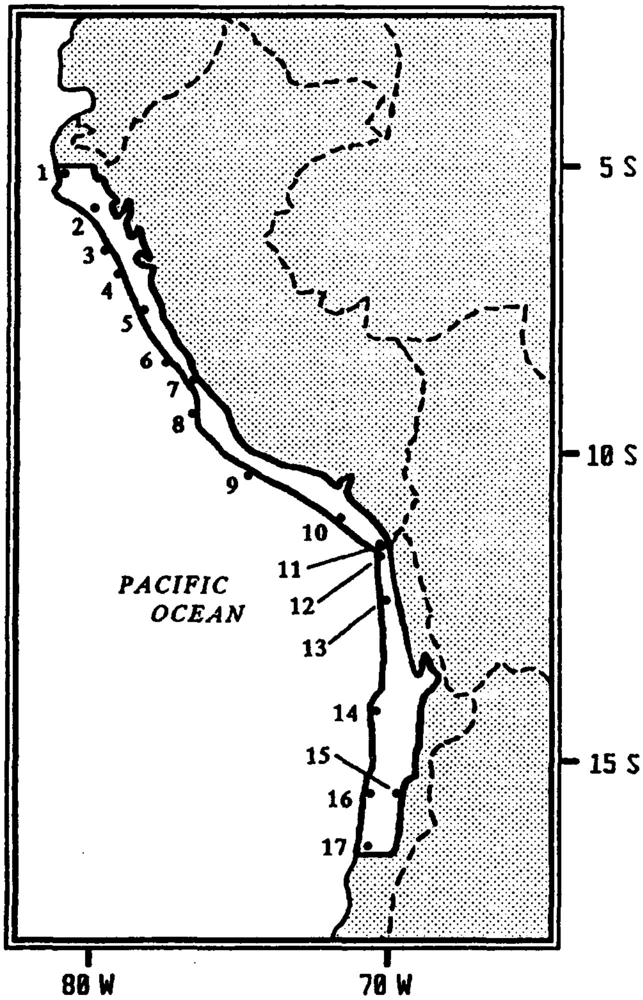


Figure 3-2. The Pacific Arid Zone. This zone includes the coastal plains of Peru and Chile, along with the western slopes of the Andes (Cordillera Occidental) below 8,000 feet (2,440 meters) MSL from 5 to 28° S. Only one season (year-round) is discussed because several important climatic controls produce extreme aridity all year long. Figure 3-3 shows the station data network used in this study.



1. PIURA	5 12'S	80 37'W
2. CHICLAYO	6 47'S	79 50'W
3. TRUJILLO	8 05'S	79 07'W
4. CHIMBOTE	9 10'S	78 31'W
5. PARAMONGA	10 40'S	77 49'W
6. LOMAS de LACHAY	11 21'S	77 23'W
7. LIMA	12 01'S	77 07'W
8. PISCO	13 45'S	76 13'W
9. SAN JUAN	15 23'S	75 10'W
10. MOLLENDO	17 02'S	72 01'W
11. TACNA	18 04'S	70 16'W
12. ARICA	18 21'S	70 21'W
13. IQUIQUE	20 13'S	70 09'W
14. ANTOFAGASTA	23 26'S	70 28'W
15. PORTRERILLOS	26 30'S	69 27'W
16. CHANARAL	26 19'S	70 37'W
17. COPIAPO	27 18'S	70 25'W

Figure 3-3. Climatic Station Network, Pacific Arid Zone.

The Cordillera Occidental (shown in Figure 3-4) is the primary mountain range bordering the Pacific Arid Zone on the east. Its steep ridges parallel the entire Peruvian coast; they often rise to 8,000 feet (2,440 meters) MSL within 25 NM of the Pacific Ocean. Many stretches of coastline have less than 100 feet (30 meters) of beach. Steep foothills may reach 1,620 feet (500 meters) MSL. The Desierto de Sechura, a coastal desert plain in northwestern Peru between 5 and 7° S, is an exception to this terrain pattern. In Chile, the mountains' average width is 85 NM, but broad terraces rise from the coastline to heights of 1,000 feet (305 meters) MSL. A series of terraces spaced about 15 NM apart extend to the Cordillera Occidental. They extend 80 NM inland at the widest point. Shifting sand dunes are common. Figures 3-5, 3-6 and 3-7 show several common coastal plain landscapes in the Pacific Arid Zone.

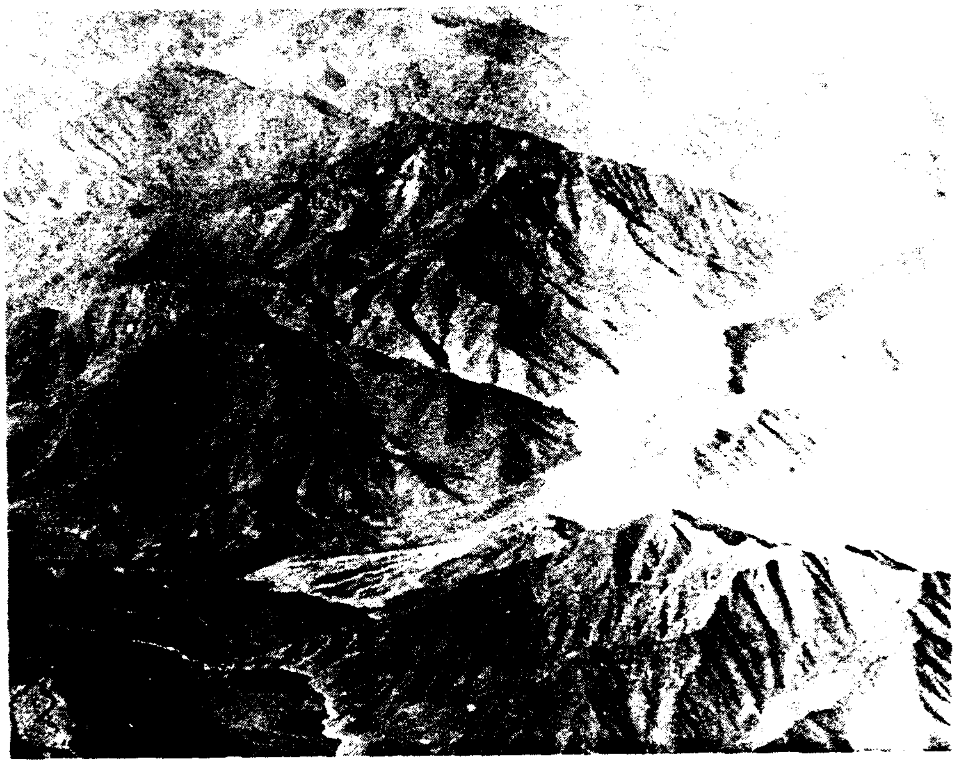


Figure 3-4. Cordillera Occidental Foothills Near 12° S (from American Geographical Society, 1930). These dry western foothills are commonly cut by narrow river valleys. Valley floors are usually at 1,000 to 2,000 feet (305-610 meters, MSL and 1-3 NM wide. This figure shows the Rimac River east of Lima, Peru. Its heavily-irrigated floodplain (shown on the left) intersects with an alluvial fan, a common feature in the Pacific Arid Zone. These fans form when heavy rains in the Cordillera Occidental produce strong runoff.

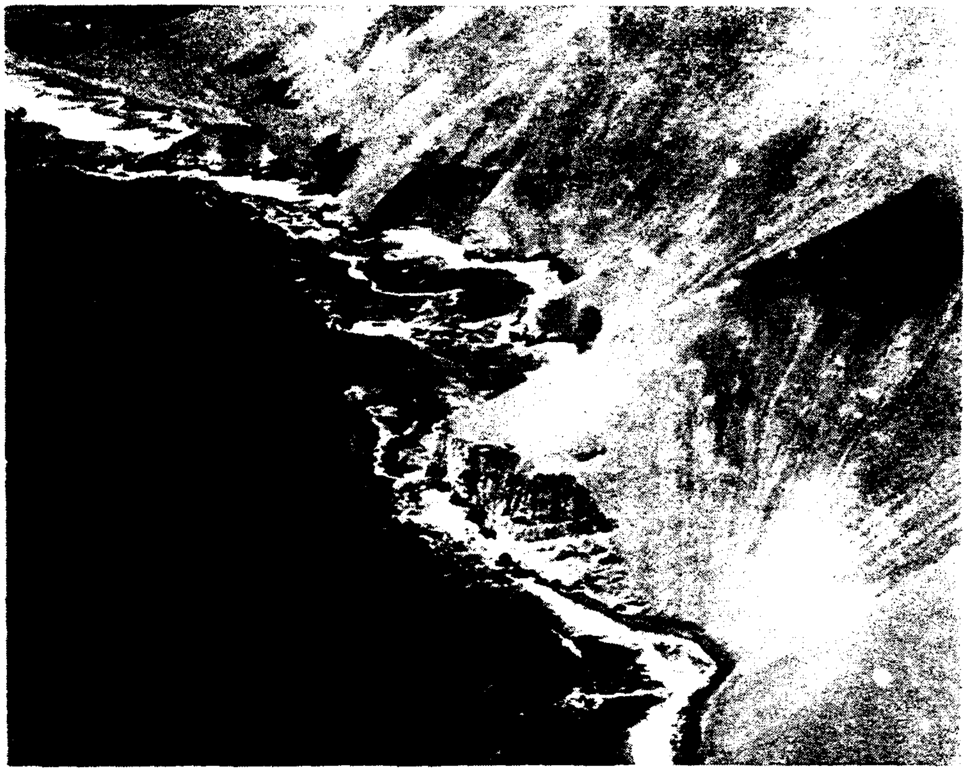


Figure 3-5. Coastal Hills Bordering the Pacific Ocean Near Ancon Bay (11° S) (from American Geographical Society, 1930).

Figure 3-6. Dry Coastal Plains Near Pisco Bay, Peru, at 14° S (from American Geographical Society, 1930). In the background, barren coastal hills are in contrast to the level, sand-covered plain.

Figure 3-7. Typical Coastal Terrain South of 22° S (from American Geographical Society, 1930).

The mountains are the major topographic barrier to weather systems and airflow below 700 mb. The highest peak (22,572 feet/6,882 meters MSL) is Ojos del Salado (27° 06' S, 68° 30' W). Mountain passes average 10,500 feet (3,200 meters) MSL between 20 and 28° S.

The Atacama Desert, also called the "Great North" or "Norte Grande," is the dominant terrain feature in Chile between the coast and the Andes. This arid desert plain extends eastward from the first coastal terrace to the Cordillera Occidental from Chile's northern border to 27° S.

Chile's river valleys extend from the Cordillera Occidental to the Pacific Ocean. They are dry most of the year. The intermittent rainfall rarely fills these valleys for more than 2 weeks. The only permanent river in Northern Chile is the Loa. In Peru, numerous meltwater rivers and streams reach the coast. Major rivers from north to south include the Chicama, the Rimac, the San Juan, and the Ocona.

VEGETATION. The arid environment supports little vegetation. The landscape is often completely barren, but stunted shrubs and grass clumps can be found on mountain slopes and in upland valleys where ice and snow-capped peaks produce runoff, as well as in isolated areas affected by rare rainfalls during El Niño events. Isolated grasslands (or "lomas") grow in narrow bands along the Cordillera Occidental where coastal stratus produces fine mist or drizzle. I igated agriculture is found near rivers.

PACIFIC ARID ZONE CLIMATIC PECULIARITIES

Severe aridity across the Pacific Arid Zone is sustained by the cold Humboldt Current, which regulates air temperatures below 2,000 feet (610 meters) MSL. The marine boundary layer rarely penetrates to more than 20 NM inland. The South Pacific High intensifies offshore upwelling, setting up a strong temperature inversion over the coastal waters and coastline. A subsidence inversion develops over the coastal plain as dry air overrides the cool, moist boundary layer. The subsidence layer may extend to 60 NM offshore and reach heights of 6,000 feet (1,830 meters) MSL. The inversion traps stratus, fog, and light drizzle or fine mist (known locally as "garua") beneath it. The inversion's temperature gradient and thickness fluctuates from month to month. Its penetration inland may also fluctuate diurnally even if a sea breeze is not present.

"Cool Season." Although the Pacific Arid zone is dry the year-round, there is a distinct "cool" season when low sea-surface temperatures and strong subsidence inversions are present from June to October. Clouds and precipitation reach inland stations only where the marine boundary layer penetrates to the Cordillera Occidental along very narrow coastal plains with deep river valleys.

Temperature/Dew-Point Profiles. Figures 3-8a-d and 3-9a-d show mean temperature/dew point profiles at two Pacific Arid Zone coastal stations. These figures show a subsidence inversion ranging in thickness from 2,000 to 3,000 feet (610-915 meters) MSL along the coastline. The two locations shown (Lima and Antafagosto) are the only upper-air stations in the Pacific Arid Zone. The seasonal change in inversion layer strength and thickness at Lima may be generalized for coastal locations between 5 and 14° S where the Cordillera Occidental is 20 to 40 NM wide. South of 14° S, the temperature profile may also include the narrow coastal plains where the Cordillera Occidental is frequently less than 5 NM from the coastline.

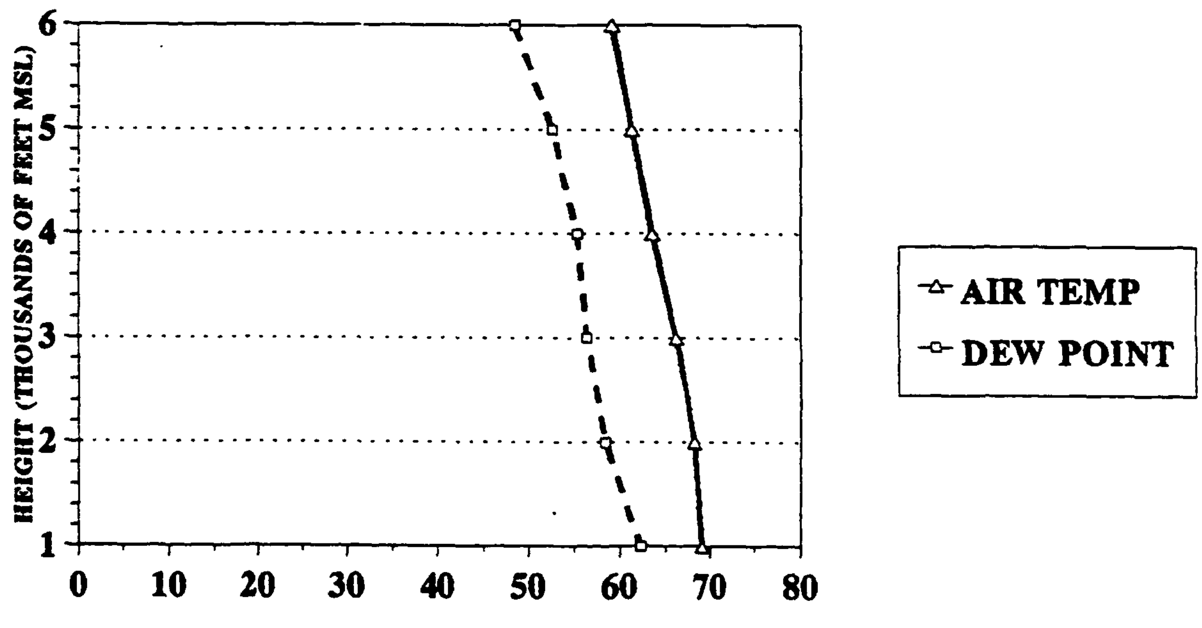


Figure 3-8a. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--January, Lima, Peru. The inversion layer at Lima is not always present. For example, it is weak or non-existent in January when sea-surface temperatures are highest.

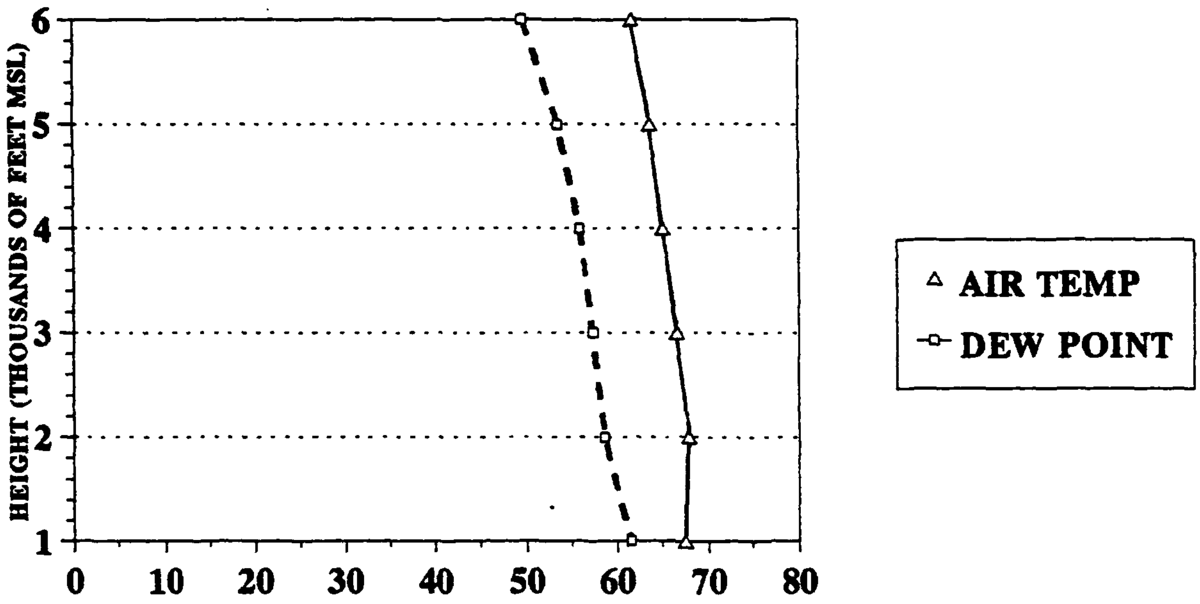


Figure 3-8b. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--April, Lima, Peru. By April, a weak inversion begins to form below 2,000 feet (610 meters) MSL as intense upwelling lowers sea-surface temperatures. The mean air temperature at 1,000 feet (305 meters) MSL drops 2° F (1° C) between January and April; the 2,000-6,000-foot layer warms by 1.5° F (1° C).

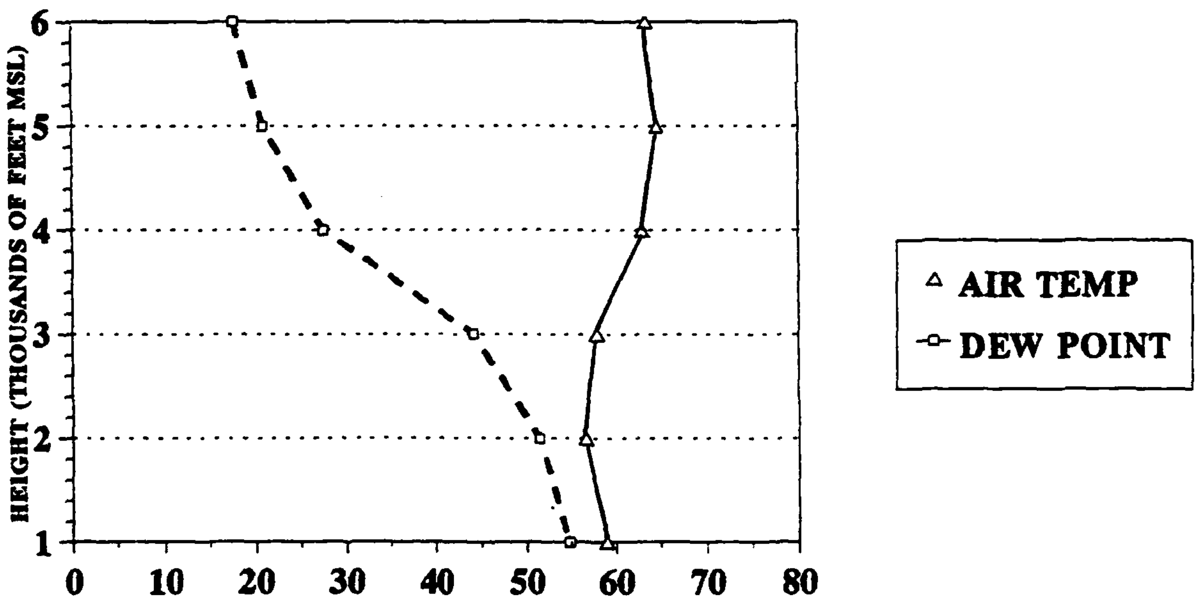


Figure 3-8c. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--July, Lima, Peru. By July, the inversion layer between 3,000 and 5,000 feet (915-1,525 meters) MSL is well-defined. Mean air temperature is 9-11° F (3-4° C) lower than in April, indicating that intense upwelling is rapidly modifying the marine boundary layer. Between 4,000 and 6,000 feet (1,220-1,830 meters) MSL, the mean air temperature rises another 2° F (1° C), or 3.5° F (2° C) between January and July.

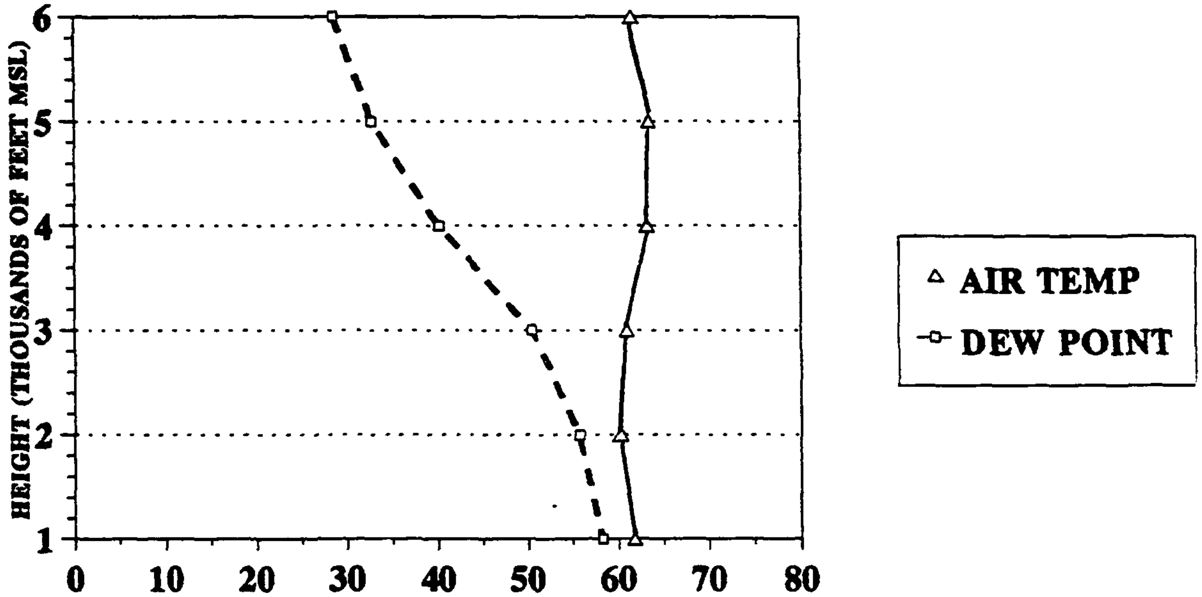


Figure 3-8d. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--November, Lima, Peru. The subsidence layer remains between 2,000 and 5,000 feet (610-1,525 meters) MSL, but mean air temperature from 1,000 to 3,000 feet (305-915 meters) MSL drops by another 3° F (2° C).

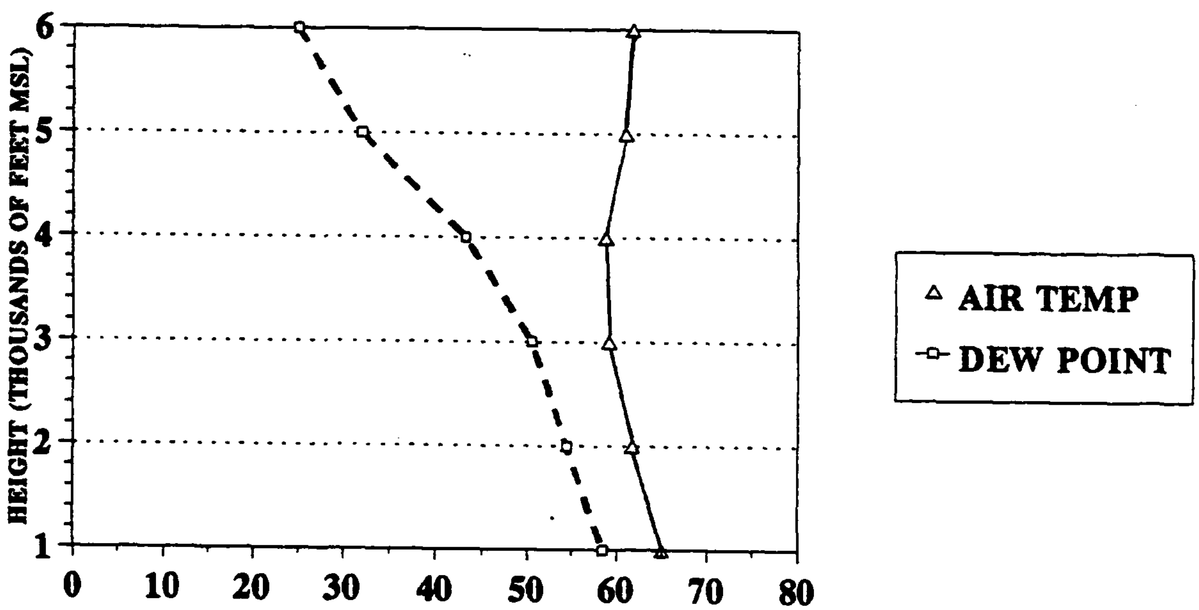


Figure 3-9a. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Fet (305-1,830 meters) MSL--January, Antofagasta, Chile. At Antofagasta, the inversion persists throughout the year. In January, the mean inversion layer is between 3,000 and 6,000 feet (915-1,830 meters) MSL.

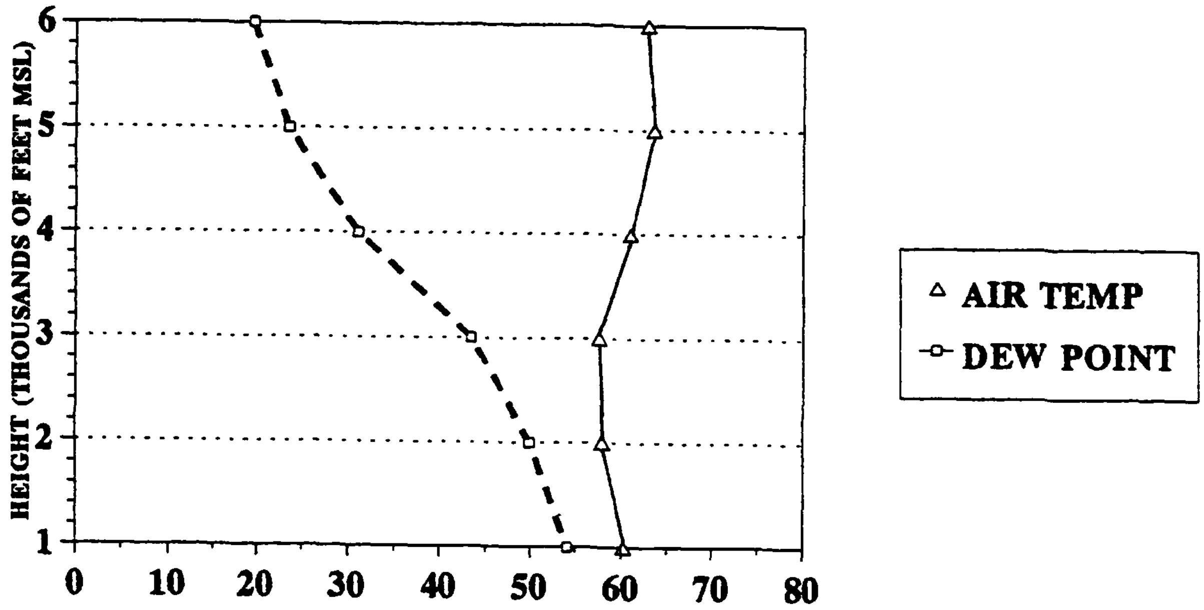


Figure 3-9b. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--April, Antofagasta, Chile. In April, the mean inversion layer is between 2,000 and 5,000 feet (610-1,525 meters) MSL.

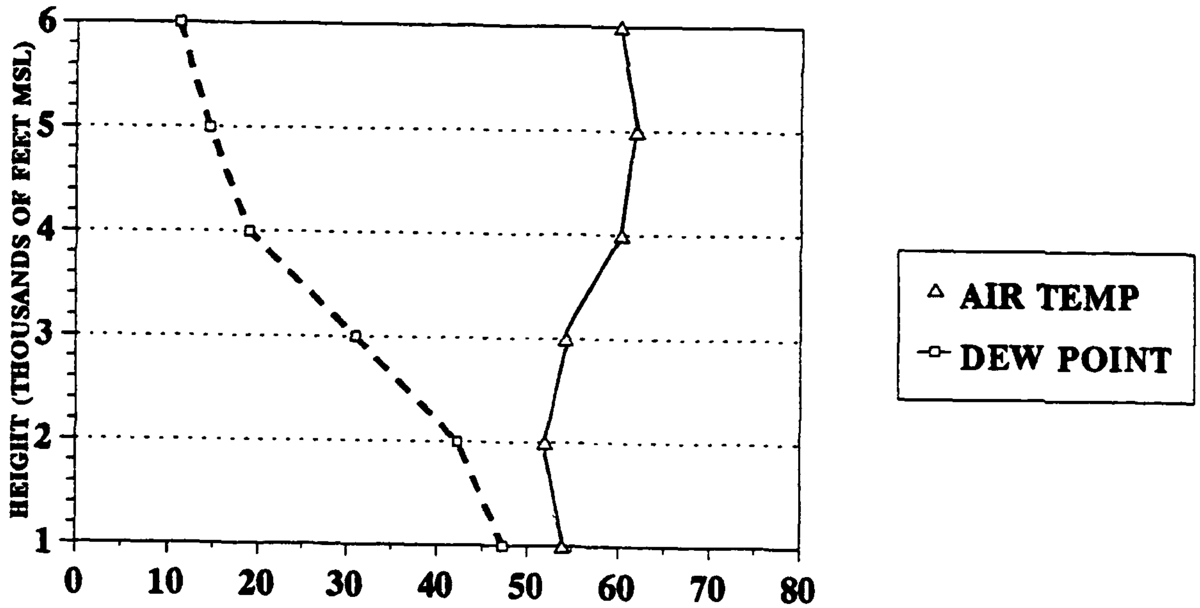


Figure 3-9c. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL--July, Antofagasta, Chile. In July, the mean inversion layer is the same as in April.

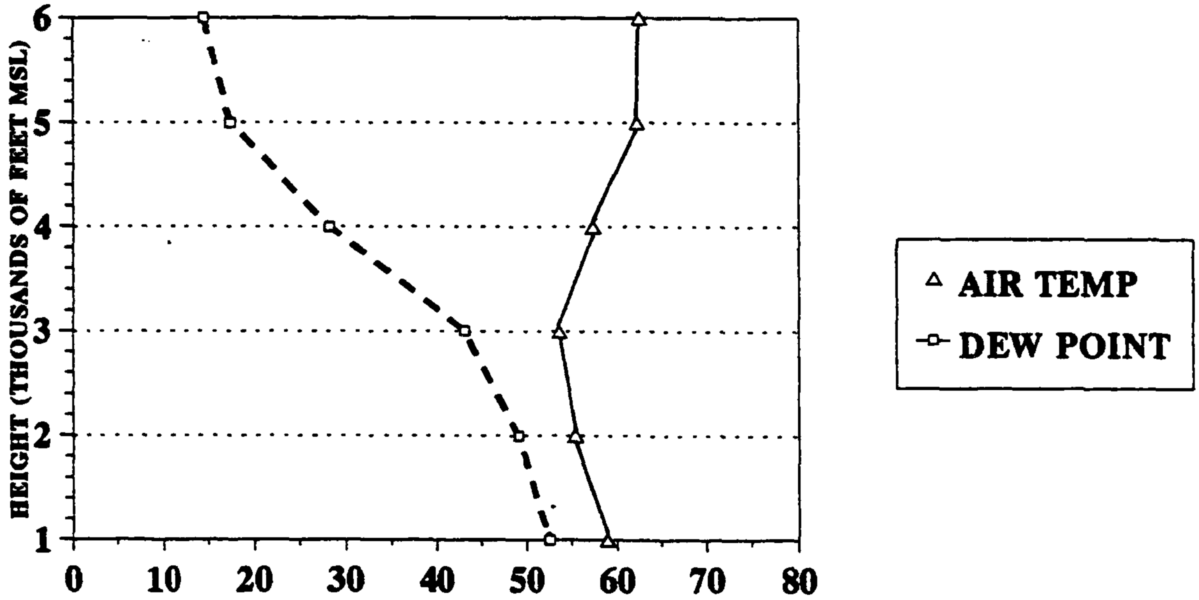


Figure 3-9d. Mean Vertical Temperature and Dewpoint Profile (° F) Between 1,000 and 6,000 Feet (305-1,830 meters) MSL, Antofagasta--November, Chile. By November, the inversion again between 3,000 and 6,000 feet (915-1,830 meters) MSL. Mean thickness is probably less than 1,000 feet (305 meters) within 20 NM of the coast. Over the eastern Atacama Desert, the terrain rises above the thin inversion layer and is only occasionally affected by the moist marine layer beneath the inversion. Fog is common when moist maritime air reaches the Atacama Desert.

Terrain Configuration. Figures 3-10a-b show a vertical cross-section of the typical terrain configuration in Peru and Chile. The average height, thickness, temperature, and distance from the coastline are shown.

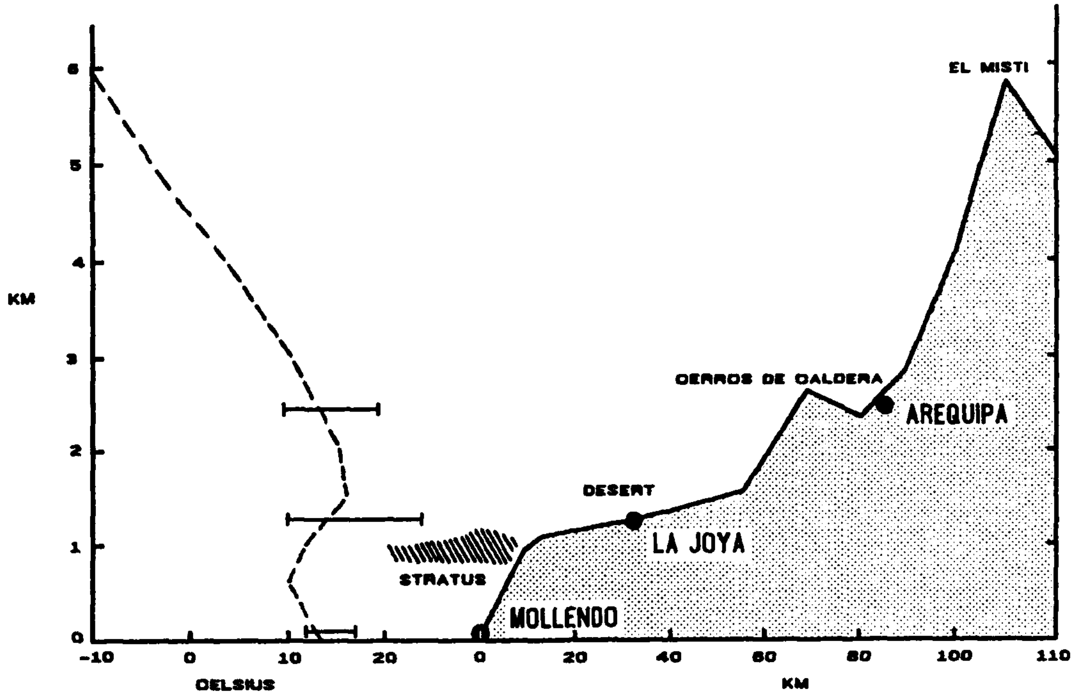


Figure 3-10a. Generalized Coastal Terrain Configuration for Peru Between 8° S and 18° S (from Lettau and Lettau, 1973). The horizontal bars show temperature ranges at various altitudes.

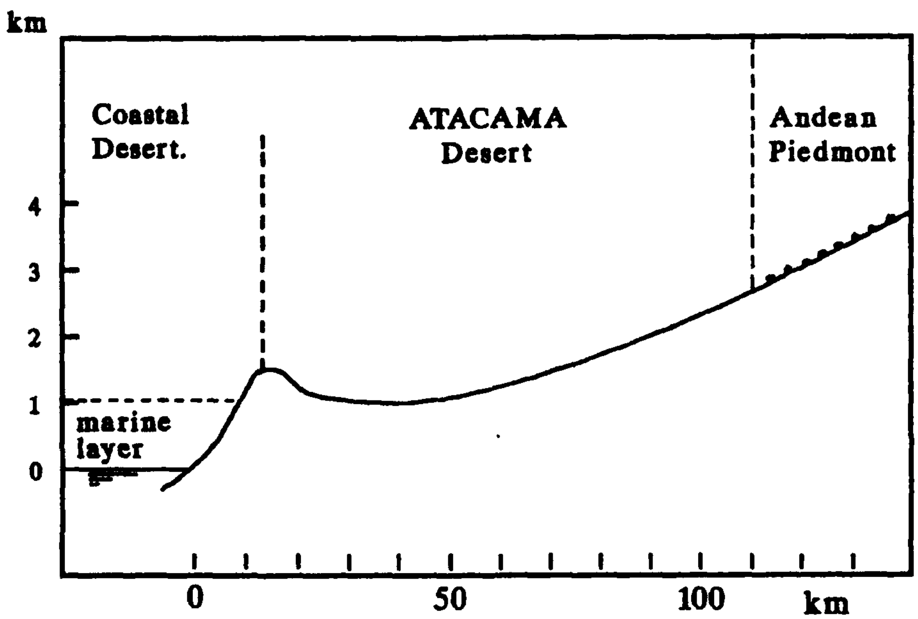


Figure 3-10b. Generalized Coastal Terrain Configuration for Chile Between 18° S and 28° S (from Lettau and Lettau, 1973).

Local Winds. Local terrain and land/sea temperature differences produce narrow bands of high winds or low-level jets just inland. A southerly low-level jet is usually found below 2,000 feet (610 meters) MSL; it parallels the coastline between 10 and 20° S. Wind speeds may reach 70 knots between 1,000 and 2,000 feet (305-610 meters) AGL for 3 to 9 hours during the day, enhancing the sea breeze. These strong local winds significantly alter the vertical temperature and moisture profiles over short distances.

Convective Development. Diurnal thunderstorm activity along the western Andes of Peru between December and March produces most of the convective cloud cover found in the Pacific Arid zone. The mechanisms for diurnal convective cumulus development along the western Cordillera Occidental are much different than the synoptics or dynamics normally expected with shear-line or frontal convective activity. These differences include: (1) the diurnal distributions of cloud bases and tops, (2) the source(s) of moisture and instability, (3) the Bolivian High, and (4) the extent and duration of individual cells. The diurnal heating mechanism on upland valley floors begins at about 1000L and ends abruptly by 1800. If extensive cumulus with tops at or above 10,000 feet (3,050 meters) MSL develops by 1200L along the Cordillera Occidental, it's likely that tops to 20,000 feet (6,100 meters) MSL will develop by 1400L.

Most moisture comes from the Amazon Basin, but occasionally moist air from the Pacific Ocean is driven inland by a strong sea breeze whenever a strong inversion layer is not present. The sea breeze usually reaches the Cordillera Occidental between 14 and 18° S where the coastline is very narrow and cut by steeply-sloped valleys.

The Bolivian High is responsible for sustaining diurnal convection and mid-level moisture in the western Andes. Persistent easterly outflow carries heavy convection westward from the eastern Andes above 5,000 feet (1,525 meters) MSL. The cells propagate westward into the western Andes and interior valleys above 10,000 feet (3,050 meters) MSL by 2000L. Thunderstorm tops may exceed 50,000 feet (15,240 meters) MSL. Between 5 and 8° S, convection may be refueled along the western Andes above 8,000 feet (2,440 meters) MSL by sea or valley breezes.

The Bolivian High also helps sustain convection beyond the normal diurnal heating cycle. Isolated thunderstorms may continue through 2000L if Amazon moisture continues to filter into upland valleys. Localized upper-level divergence immediately north of the Bolivian High ridge axis is usually present across southeastern Peru during these rare events.

Between 7 and 18° S, there is seldom more than cirrus blow-off or scattered altocumulus with bases between 15,000 and 18,000 feet (4,575-5,490 meters) MSL and tops to 22,000 feet (6,710 meters) MSL. Although individual thunderstorm cells may reach 50,000 feet (15,240 meters) MSL, few storm cells ever reach the coastline farther south.

El Niño Effects. Abnormally heavy convection is possible during an El Niño event because of the anomalous warm ocean currents off the Pacific Arid Zone coast. North of 18° S, heavy convection can develop between March and May. With these rare events, sea-breeze moisture funnels inland to the western Andes. Extensive lines of cumulus may have 5,000-foot (1,525-meter) MSL bases, but tops rarely exceed 40,000 feet (12,190 meters) MSL. South of 18° S between April and October, the El Niño apparently increases the strength and frequency of mid-latitude upper-level troughs and frontal-type cloud cover in the south Cordillera Occidental.

GENERAL WEATHER. Stratus, fog, mist, and scattered stratocumulus dominate the coastline and offshore waters, but the coastal desert plain only 5 to 15 NM inland is clear and dry. The clouds usually lie beneath the inversion. Dry easterlies and southerlies over the coastal desert plains override the moist marine layer at the surface near the coast. Coastline configuration and terrain produce significant variations in the penetration of the sea breeze.

Heavy rainfall during El Niño events is rare, but it can occur when abnormal increases in sea-surface temperatures eliminate the temperature inversion for several months at a time. Storm tracks may move north of 30° S, producing heavy convection along the Cordillera Occidental south of 20° S. Heaviest rains fall above 10,000 feet (3,050 meters) MSL; floodwaters descend onto the coastal plains with devastating results. North of 14° S, abnormally heavy convection may be caused by a southward shift in the Near Equatorial Trough; Figure 3-11 shows such a rare rainfall event. Low-level instability allows the sea breeze to initiate diurnal convection in the Cordillera Occidental. Several coastal ports have been relocated after floodwaters washed out large sections of beach. In 1925, Trujillo, Peru, got 16 inches (406 mm) of rain.

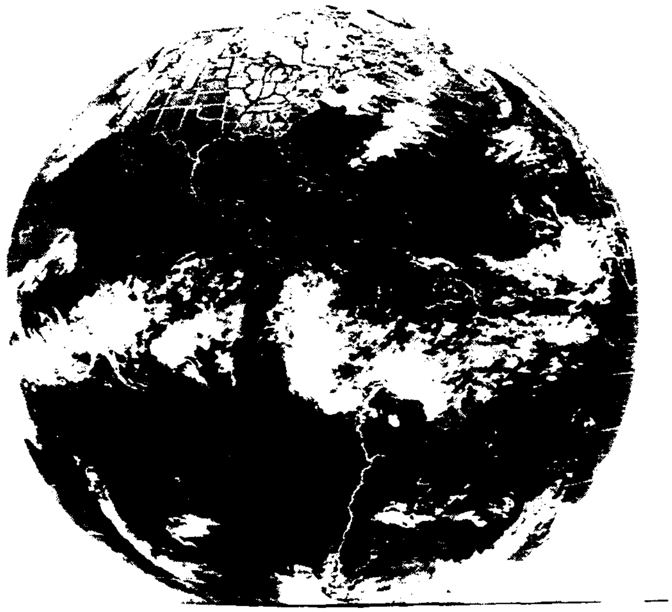


Figure 3-11. Abnormally Heavy Convection in Peru With a Southward-Displaced Near Equatorial Trough (10 March 1983, 0630Z). Note the well-developed cloud band stretching across the equatorial Pacific and Amazon river basin.

On rare occasions, heavy convection along the eastern Andes between December and April may produce a short-lived rainshower between 10 and 18° S. This rainfall may be caused by an El Niño event, or it may be from strong mid-level moisture advection westward.

SKY COVER. The coastline and coastal waters are dominated by early morning stratus and scattered stratocumulus. Stratus decks may persist all day along the coast, particularly between December and March from 7 to 18° S. Stratus bases are 500 feet (150 meters) MSL; tops vary from 2,500 to 4,000 feet (760-1,220 meters) MSL.

From Chiclayo south to Antofagasta, broken-to-overcast skies with stratus bases at or below 1,000 feet (305 meters) MSL are common. Stratus may form before 0700L every day and move inland by 0800L. North of 18° S, patchy stratocumulus with bases between 3,000 and

4,000 feet (915-1,220 meters) MSL and tops to 4,500 feet (1,372 meters) MSL may move 10 to 15 NM inland by 1100L before dissipating in the dry, subsiding air aloft.

Most stratocumulus development between May and October is found near isolated coastal ranges and hillsides due to orographic lifting. Stratocumulus may develop into scattered cumulus by 1400L along Peru's Cordillera Occidental or coastal ranges above 6,000 feet (1,830 meters). Tops rarely exceed 8,000 feet (2,440 meters) MSL.

Low stratus decks, scattered stratocumulus, and cumulus along the Cordillera Occidental develop in a diurnal cycle between November and April north of 18° S. Low stratus decks develop offshore and along the coastline between 2200 and 0700L. The low stratus can be fog or heavy mist (garua) at the surface. The stratus may move onshore by 0800 or 0900L, but it lifts into broken or scattered stratocumulus within 5 NM of the coastline. The stratocumulus usually dissipates by 1100L due to intense heating on the desert plain. Warm, stable easterlies above the inversion layer (3,000 to 8,000 feet/915-2,440 meters MSL) assist with its dissipation. There is little or no significant cumulus development above 8,000 feet (2,440 meters) MSL.

Sea fog (actually the stratus deck over open water) may roll into Lima, Peru, as late as 1600 or 1700L. On some occasions, the stratus remains offshore during the day when dry surface easterlies reach the coast, normally between 10 and 14° S.

The stratus decks observed south of 18° S are often 1,000 to 2,000 feet (305-610 meters) thick. Cloud bases immediately offshore may be 500 eet (150 meters) MSL. The stratus deck slopes upward over land; cloud bases only 10 NM inland average 1,500 feet (460 meters) AGL. The top of the inversion layer fluctuates between 4,000 and 6,000 feet (1,220-1,830 meters), but clouds rarely form above 3,000 feet (915 meters) MSL.

South of 20° S, long periods of stratus and fog are most common between May and October. Cloud decks are rarely more than 3,000 feet (915 meters) thick over open water, and 1,000 feet (305 meters) thick over land.

Between 20 and 25° S, stratus forms nearly every morning along the coast, but little stratocumulus or cumulus develops inland. Although the inversion is well-developed along the coastline throughout the year, it rarely extends more than 35 NM inland. In fact, the Atacama Desert is always above the inversion layer, and the rare stratocumulus or stratus is only observed between 2300 and 0900L.

From May to October, a rare mid- or upper-level disturbance can temporarily disrupt the inversion along the coast for 3 to 12 hours south of 18° S. Broken multilayered skies have 4,000-foot (1,220-meter) MSL bases. Cloud tops rarely reach 20,000 feet (6.1 km) MSL along the coast. Thin radiation fog over the coastal desert between 2300 and 0700L can develop with calm, clear conditions after these disturbances migrate into the Andes.

Mid-latitude troughs and shear lines can produce extensive lines of cumulus south of 20° S along the western Andes above 8,000 feet/2,440 meters MSL year-round. Cloud bases average 9,000 feet (2,745 meters) MSL along the trough axis, and ridge crests above 10,000 feet (3,050 meters) MSL may be totally obscured by clouds. Scattered cumulus may first appear over the Pacific near 7,000 or 8,000 feet (2,135-2,440 meters) MSL. Cumulus tops average 20,000 feet (6,100 meters) MSL between May and October, and 30,000 feet (9,145 meters) MSL from November to April.

As shown in Figures 3-12a-b, low ceilings are common at 0700L along the coastline where the inversion is present. Stratus and stratocumulus usually develop below the inversion near the Humboldt Current's coldest waters. Therefore, many coastal stations north of 24° S have high occurrences of low ceilings between May and September (Figure 3-12b). Frequency distributions of cumulus with ceilings below 3,000 feet (915 meters) AGL at 1300L vary with coastal topography.

PIURA

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	na	na	na	na	na	na
07 L	76	67	42	37	33	32
13 L	2	5	4	10	7	6
19 L	4	3	5	22	19	20

CHICLAYO

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	28	15	11	5	8	9
07 L	38	28	19	9	12	11
13 L	15	10	7	3	2	2
19 L	37	17	11	8	8	8

LIMA

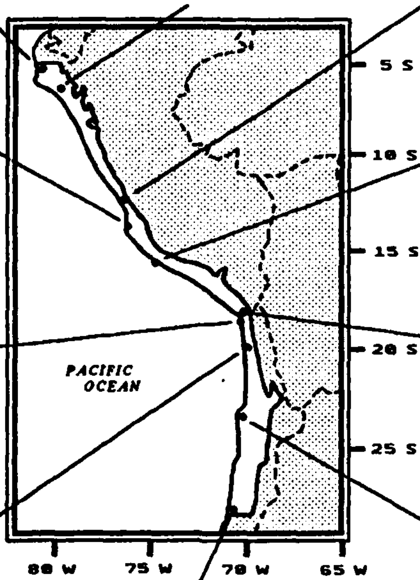
	OCT	NOV	DEC	JAN	FEB	MAR
01 L	91	72	49	28	18	17
07 L	95	87	74	48	44	44
13 L	79	65	29	13	6	7
19 L	65	45	24	12	9	8

PISCO

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	42	29	26	25	14	11
07 L	66	56	46	33	23	19
13 L	27	21	20	13	10	8
19 L	22	19	15	13	17	9

SAN JUAN

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	47	51	42	36	13	16
07 L	60	50	45	23	11	11
13 L	18	17	15	9	2	2
19 L	38	40	40	24	12	12



ARICA

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	87	69	63	25	4	30
07 L	88	67	48	23	8	22
13 L	11	3	3	3	1	2
19 L	54	26	10	7	1	2

TACNA

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	na	na	na	na	na	na
07 L	88	74	55	30	18	29
13 L	4	2	3	1	2	1
19 L	60	46	29	13	8	14

IQUIQUE

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	na	na	na	na	na	na
07 L	69	46	21	9	4	12
13 L	27	14	7	1	1	1
19 L	76	49	21	5	5	9

ANTOFAGASTA

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	93	74	48	26	24	14
07 L	74	61	37	18	15	28
13 L	14	13	4	1	4	2
19 L	70	50	36	23	19	22

COPIAPO

	OCT	NOV	DEC	JAN	FEB	MAR
01 L	na	na	na	na	na	na
07 L	79	66	64	65	63	70
13 L	5	4	1	3	2	1
19 L	2	1	1	3	1	0

HIGH SUN
CEILINGS BELOW 3,000 FEET
(PERCENT)

na - DATA NOT AVAILABLE

	OCT	NOV	DEC	JAN	FEB	MAR
01 L						
07 L						
13 L						
19 L						

Figure 3-12a. Percent Frequencies of Ceilings Below 3,000 Feet (915 meters)--High-Sun Period.

PIURA

	APR	MAY	JUN	JUL	AUG	SEP
01 L	na	na	na	na	na	na
07 L	22	30	64	81	84	85
13 L	2	3	12	17	8	3
19 L	12	4	5	6	3	2

CHICLAYO

	APR	MAY	JUN	JUL	AUG	SEP
01 L	15	8	21	30	35	37
07 L	10	15	37	52	61	57
13 L	#	5	25	40	35	19
19 L	8	12	20	32	39	43

LIMA

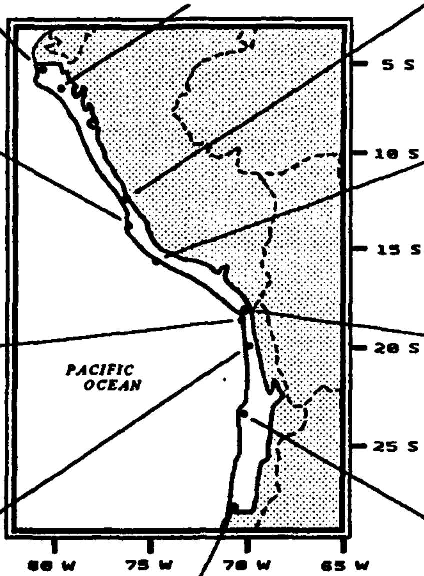
	APR	MAY	JUN	JUL	AUG	SEP
01 L	26	53	81	91	95	98
07 L	52	65	92	99	98	100
13 L	13	43	78	88	92	93
19 L	15	27	69	81	86	88

PISCO

	APR	MAY	JUN	JUL	AUG	SEP
01 L	9	32	43	52	60	45
07 L	23	46	70	79	81	73
13 L	14	27	43	54	49	34
19 L	9	21	35	35	35	28

SAN JUAN

	APR	MAY	JUN	JUL	AUG	SEP
01 L	9	23	48	58	58	62
07 L	8	30	60	78	78	73
13 L	2	9	29	39	42	35
19 L	7	10	30	48	49	46



ARICA

	APR	MAY	JUN	JUL	AUG	SEP
01 L	30	52	71	89	94	96
07 L	35	61	84	90	91	94
13 L	6	21	31	42	43	32
19 L	7	23	39	51	57	60

TACNA

	APR	MAY	JUN	JUL	AUG	SEP
01 L	na	na	na	na	na	na
07 L	45	72	88	94	89	91
13 L	2	7	9	8	11	14
19 L	22	48	60	63	67	71

IQUIQUE

	APR	MAY	JUN	JUL	AUG	SEP
01 L	na	na	na	na	na	na
07 L	27	52	67	69	76	79
13 L	13	27	34	47	50	42
19 L	24	42	75	87	84	83

ANTOFAGASTA

	APR	MAY	JUN	JUL	AUG	SEP
01 L	28	54	74	81	73	84
07 L	45	59	60	67	72	78
13 L	14	6	14	16	16	14
19 L	29	41	57	68	60	64

COPIAPO

	APR	MAY	JUN	JUL	AUG	SEP
01 L	na	na	na	na	na	na
07 L	58	60	40	42	44	66
13 L	7	5	5	4	4	4
19 L	1	2	4	3	5	2

LOW SUN
CEILINGS BELOW 3,000 FEET
(PERCENT)
- LESS THAN 0.5 PERCENT

na - DATA NOT AVAILABLE

	APR	MAY	JUN	JUL	AUG	SEP
01 L						
07 L						
13 L						
19 L						

Figure 3-12b. Percent Frequencies of Ceilings Below 3,000 Feet (915 meters)--Low-Sun Period.

VISIBILITY is below 3 miles (Figures 3-13a-b) most frequently with thick stratus or fog at or below 1,000 feet (305 meters) AGL (Figures 3-14a-b) along the coast. Haze and smoke add to the incidence of low visibility around heavily industrialized areas such as Lima, Trujillo, and Antofagasta when the air is stagnant. At Lima and Trujillo, visibilities below 3 miles are most frequent around 0700L between December and May.

Blowing dust rarely lowers visibility to 3 miles except along isolated strips of coastal desert plain. Between 15 and 19° S, the "Paracas" (see "Winds") often lowers visibility to less than 2 miles for 6 to 10 hours every day between June and October. These strong winds are caused by a combination of the sea breeze and low-level jet along the coastline. A rare shear-line disturbance or a convective downburst wind may also raise dust; visibilities may be below 2 miles for several hours.

Blowing dust can lower local visibilities significantly in the Atacama Desert between 1000 and 1700L. Extremely fine-grained, loose surface soils require only a 10-knot wind to become suspended. Visibilities below 2 miles can be expected over localized areas during any month. Along the coastline and isolated coastal ranges, salt and dust haze are common between November and April, but visibility is rarely below 4 miles.

#	#	1	1	2	0
#	0	#	1	#	1
#	0	#	na	#	#
#	#	#	2	1	#

PIURA

0	#	#	1	1	#
#	#	1	4	2	2
#	0	#	1	#	#
#	0	#	1	#	#

CHICLAYO

#	#	1	1	3	2
1	2	3	3	8	6
0	#	#	#	1	0
#	#	0	#	1	#

LIMA

#	#	0	1	1	#
1	2	6	10	9	4
#	#	#	#	#	0
#	0	#	1	#	1

TRUJILLO

1	0	0	#	0	1
1	#	#	1	1	#
0	#	#	#	1	0
#	#	0	#	1	#

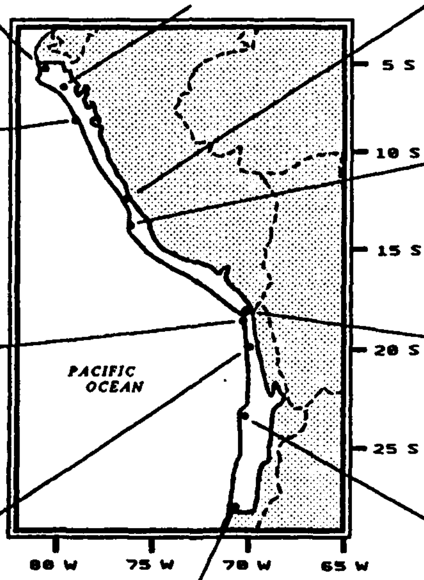
PISCO

0	0	0	0	0	0
#	0	1	0	1	0
0	#	#	0	0	0
2	#	1	0	0	0

ARICA

2	#	0	0	1	0
1	1	#	#	#	0
#	0	0	#	0	#
1	#	#	1	1	#

TACNA



na	na	na	na	na	na
0	0	#	0	0	0
0	0	#	0	0	0
0	1	0	0	0	0

IQUIQUE

0	1	0	0	0	0
0	#	#	#	#	1
0	0	0	0	0	0
0	0	0	0	0	0

ANTOFAGASTA

na	na	na	na	na	na
16	7	3	3	4	15
1	0	0	0	0	1
na	na	na	na	na	na

COPIAPO

HIGH SUN
VISIBILITY BELOW 3 MILES
(PERCENT)

\# - LESS THAN 0.5 PERCENT

na - DATA NOT AVAILABLE

	OCT	NOV	DEC	JAN	FEB	MAR
01 L						
07 L						
13 L						
19 L						

Figure 3-13a. Percent Frequencies of Visibility Below 3 Miles--High-Sun Period.

#	0	#	0	#	#
#	#	#	#	#	#
#	#	#	0	0	0
#	#	#	#	0	#

PIURA

#	#	0	0	#	0
3	2	2	1	1	#
#	#	#	#	1	#
#	#	#	#	#	#

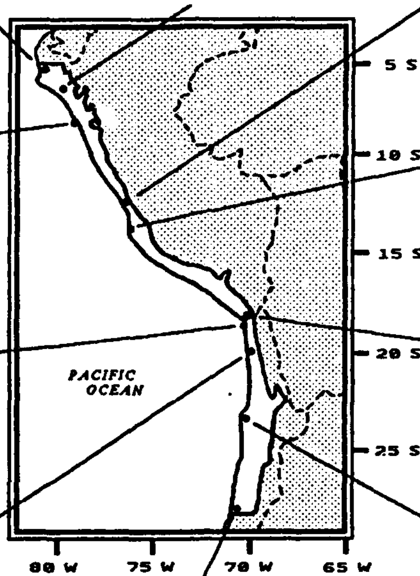
CHICLAYO

5	2	1	#	#	#
18	14	7	3	3	1
#	#	1	#	#	#
1	#	1	#	#	#

LIMA

#	1	#	0	#	#
5	3	1	#	2	#
#	#	#	0	#	0
1	#	1	#	#	#

TRUJILLO



#	0	#	#	0	0
2	4	2	1	1	1
#	1	1	1	1	1
0	#	#	1	1	0

PISCO

0	3	2	1	0	2
#	1	#	1	1	1
1	0	1	1	#	0
0	1	2	3	1	1

ARICA

#	#	3	7	5	6
#	1	5	10	8	5
0	#	#	1	2	#
#	0	3	3	4	2

TACNA

na	na	na	na	na	na
1	0	#	0	0	0
0	0	0	0	#	0
0	1	1	0	0	1

IQUIQUE

2	4	1	1	0	1
1	1	1	2	1	1
1	0	0	0	0	0
1	1	1	#	0	0

ANTOFAGASTA

na	na	na	na	na	na
15	19	11	22	7	8
0	1	0	1	0	1
na	na	na	na	na	na

COPIAPO

LOW SUN
VISIBILITY BELOW 3 MILES
(PERCENT)
- LESS THAN 0.5 PERCENT

na - DATA NOT AVAILABLE

	APR	MAY	JUN	JUL	AUG	SEP
01 L						
07 L						
13 L						
19 L						

Figure 3-13b. Percent Frequencies of Visibility Below 3 Miles--Low-Sun Period.

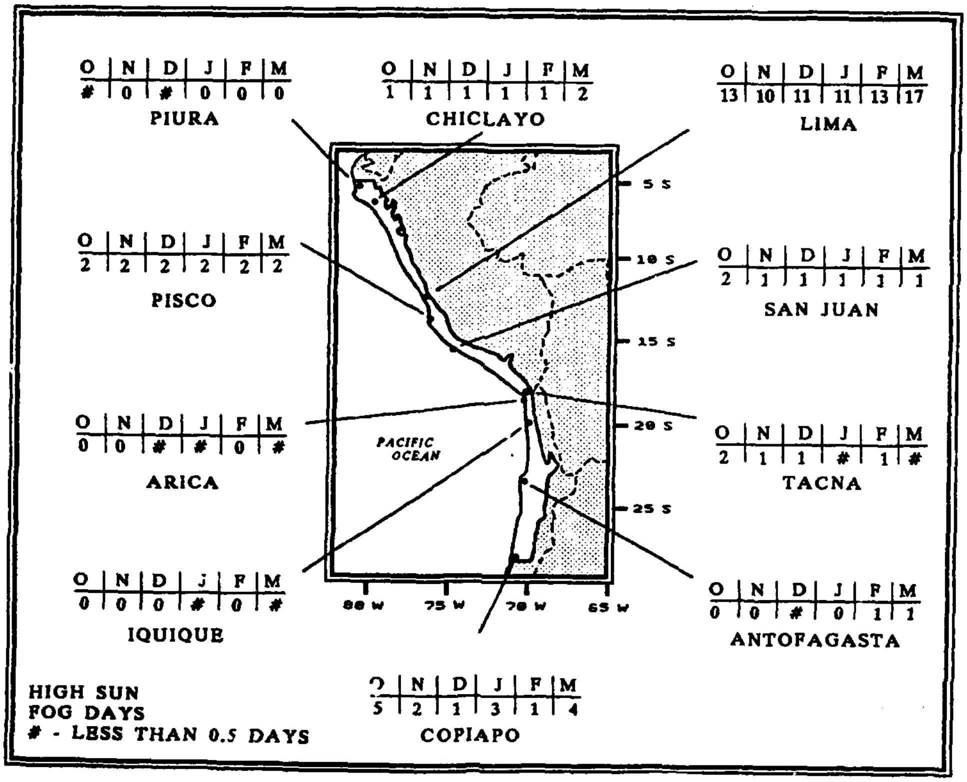


Figure 3-14a. Mean Fog Days--High-Sun Period.

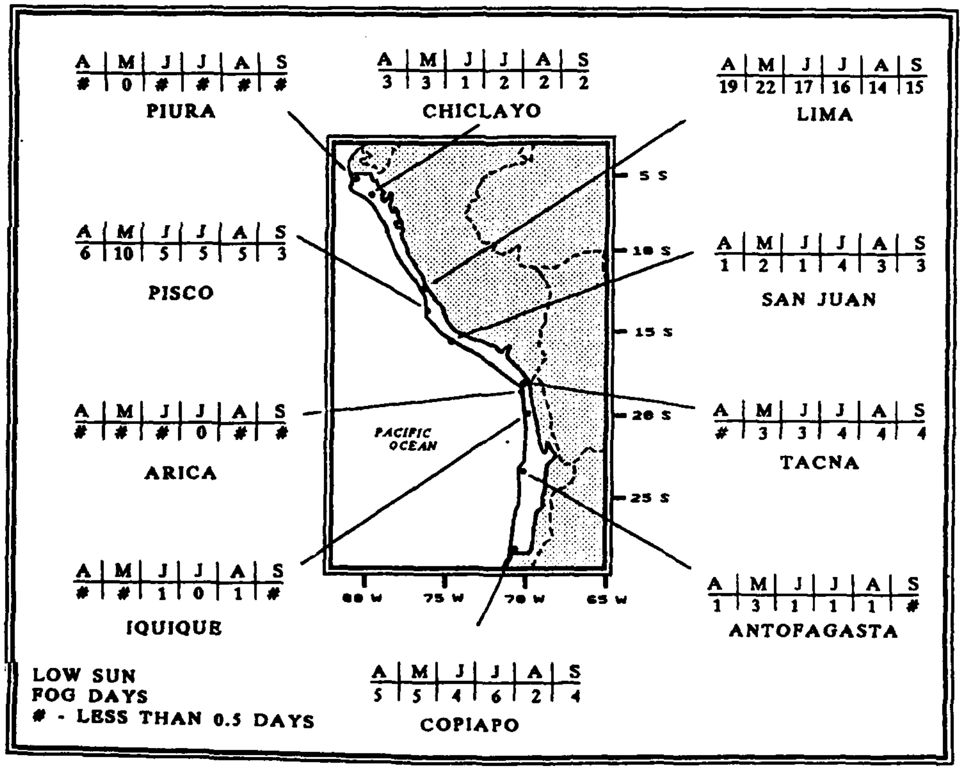


Figure 3-14b. Mean Fog Days--Low-Sun Period.

WINDS. The South Pacific High circulation and the Cordillera Occidental produce consistent southerly flow (from 150 to 230°) on all coasts, all year. Wind speeds are 7-13 knots. Local terrain and sea breezes provide slight diurnal variations. Weak easterly katabatic winds may develop between 2300 and 0700L along the coastal deserts.

In the inversion layer from the surface to 2,000 feet (610 meters), the South Pacific High generates southerly flow all year. The South Pacific High's northernmost position in July (see Figure 2-4c) coincides with the lowest sea-surface temperatures along the Pacific Arid Zone coast. The marine inversion layer that forms over cold water has a southerly wind component and a strong low-level jet. Wind speeds may exceed 40 knots between 1000 and 1800L near the steepest temperature gradients below 2,000 feet (610 meters) MSL. South of 20° S, southerly flow may extend to 4,000 feet (1,220 meters) MSL between May and October with diurnal variations in inversion strength. Surface wind speeds between Pisco and Tacna may exceed 20 knots during daylight hours. Locals call this wind the "Paracas." Particularly strong occurrences do not permit outdoor activity of any kind.

When a subsidence inversion intensifies over the Pacific Arid Zone, low-level flow in the inversion layer may increase to 15-20 knots between 1200 and 1700L. The strongest subsidence inversions occur between May and October when offshore water temperatures are lowest. If a strong inversion persists for more than 7 days, a tight pressure gradient develops over land. These tight gradients often occur between 8 and 16° S where the coastline is less than 15 NM wide; southerly winds may exceed 60 knots between 1000 and 1800L. Local water currents in shallow bays along the entire Peruvian coast may create a fluctuating sea-surface temperature gradient between 2000 and 0800L that can result in localized wind shifts and variable wind speeds in these areas.

In some cases, the sea breeze may penetrate inland along the western Cordillera Occidental through narrow coastal canyons underneath the inversion base. On windward slopes above 5,000 feet (1,525 meters) MSL, airflow may rise through the inversion layer and combine with dry, subsiding air above it. Strong sea breezes may combine with a well-developed valley breeze where higher terrain is extremely close to the coastline. This is most likely to occur between November and March from 1400 to 1800L north of 20° S. This pattern develops along mountain slopes between 2,000 and 7,000 feet (610-2,135 meters) MSL. Winds can reach 25 knots by 1600L, but rarely. Lettau and Lettau (1973) found that the sea breeze rarely penetrates more than 5 NM inland between 16 and 18° S because of the low-level jet.

The Andes Mountains prevent moist low-level easterlies originating in the Amazon Basin from reaching the Pacific Arid Zone south of 20° S. North of 20° S, low-level easterlies may reach the zone as warm and stable katabatic winds between 5,000 and 10,000 feet (1,525-3,050 meters) MSL. This mid-level easterly flow remains above the inversion base (3,000 to 8,000 feet/915-2,440 meters MSL). A high-pressure ridge from the South Atlantic High extends across central Peru between November and April. Flow becomes northerly along the western Andes between 5 and 10° S; northwesterlies are common between 10 and 13° S. The ridge axis oscillates from 4° S in July to near 12° S in January. The northwesterlies migrate with the ridge. The tropical northwesterlies merge with mid-latitude westerlies to form a broad convergent flow pattern between 15 and 28° S.

On rare occasions, heavy convection along the eastern Andes results in temporary easterly or northeasterly flow along the western slopes of the Cordillera Occidental. This flow may descend onto the coastal desert plain between 5 and 8° S, but it usually appears only with mesoscale or synoptic scale outflow boundaries between 1500 and 1900L. Wind speeds may reach 30 knots between 3,000 and 8,000 feet (915-2,440 meters) MSL, but rarely exceed 10 knots along the coast.

Figures 3-15a-b show mean monthly surface wind speed across the Pacific Arid Zone. Mean surface wind speeds range from 3 knots at Pisco to 11.8 knots at Chimbote. A strong sea-breeze circulation may develop by 1100L and continue through 1800L at most coastal stations. Wind speeds may exceed 20 knots between 1400 and 1800L. Winds are usually light and variable at night.

STATION	MEAN WIND SPEED					
	OCT	NOV	DEC	JAN	FEB	MAR
ANTOFAGASTA	9	9	9	9	8	8
ARICA	7	7	7	8	8	7
CHARANAL	9	10	11	10	10	9
CHICLAYO	11	11	10	10	8	8
CHIMBOTE	12	12	11	11	11	11
COPIAPO	9	10	10	10	10	9
LIMA	7	8	8	9	8	7
PISCO	4	4	5	5	5	5
TRUJILLO	10	10	10	10	9	9

Figure 3-15a. Mean Surface Wind Speeds (kts)--High-Sun Period.

STATION	MEAN WIND SPEED					
	APR	MAY	JUN	JUL	AUG	SEP
ANTOFAGASTA	7	7	8	8	8	9
ARICA	6	6	6	6	6	7
CHARANAL	8	7	7	7	8	9
CHICLAYO	10	11	10	9	10	11
CHIMBOTE	11	10	9	8	9	11
COPIAPO	8	6	6	6	7	8
LIMA	6	6	5	6	7	7
PISCO	4	3	3	3	4	4
TRUJILLO	10	9	9	9	9	10

Figure 3-15b. Mean Surface Wind Speeds (kts)--Low-Sun Period.

Figures 3-16a-d show surface wind roses for several stations in the Pacific Arid Zone. Numbers within the circle represent percentage frequencies of calm conditions. Terrain at these coastal stations determines the prevailing wind direction, even though the South Pacific High remains the dominant influence.

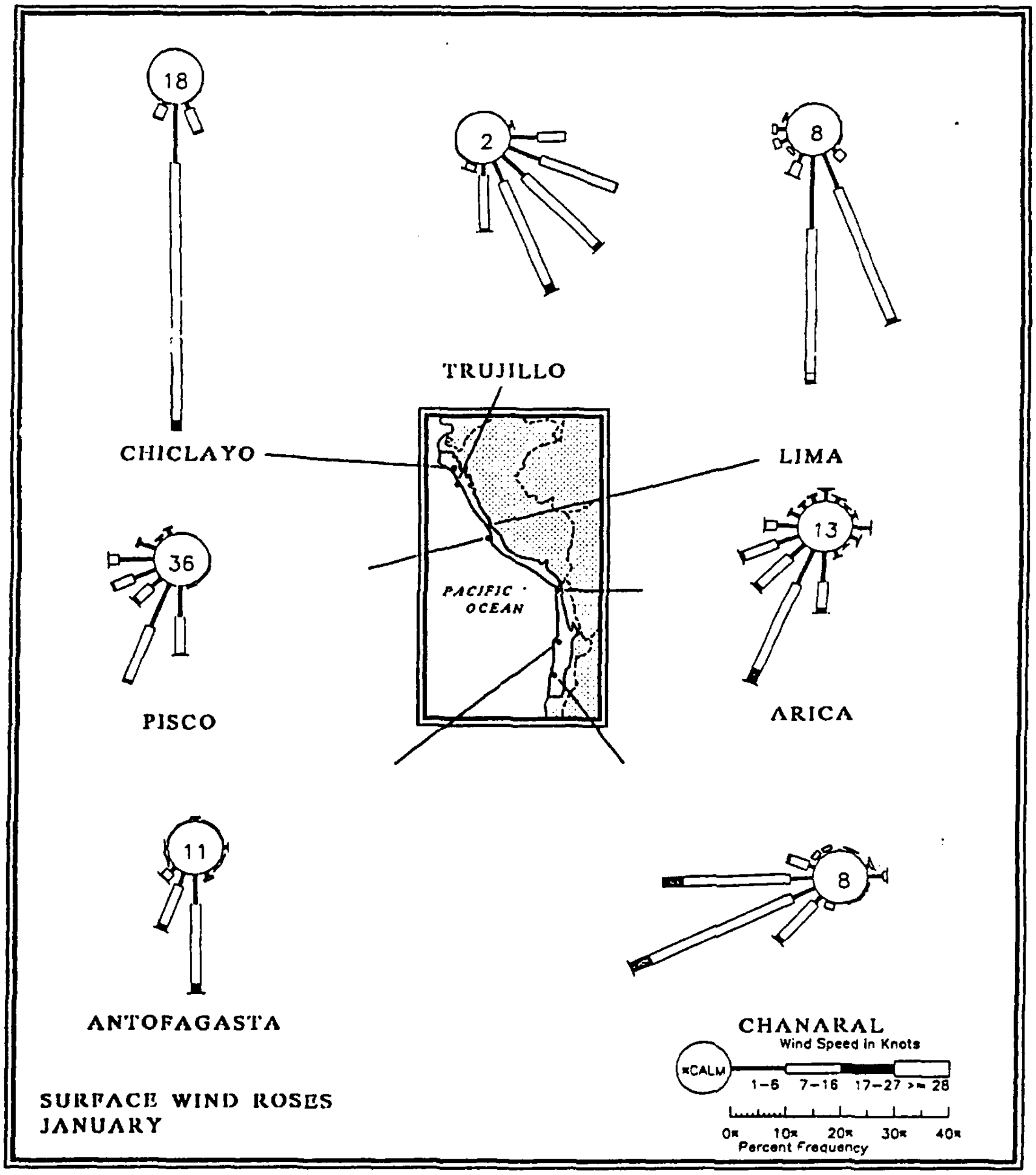


Figure 3-16a. Surface Wind Roses--January.

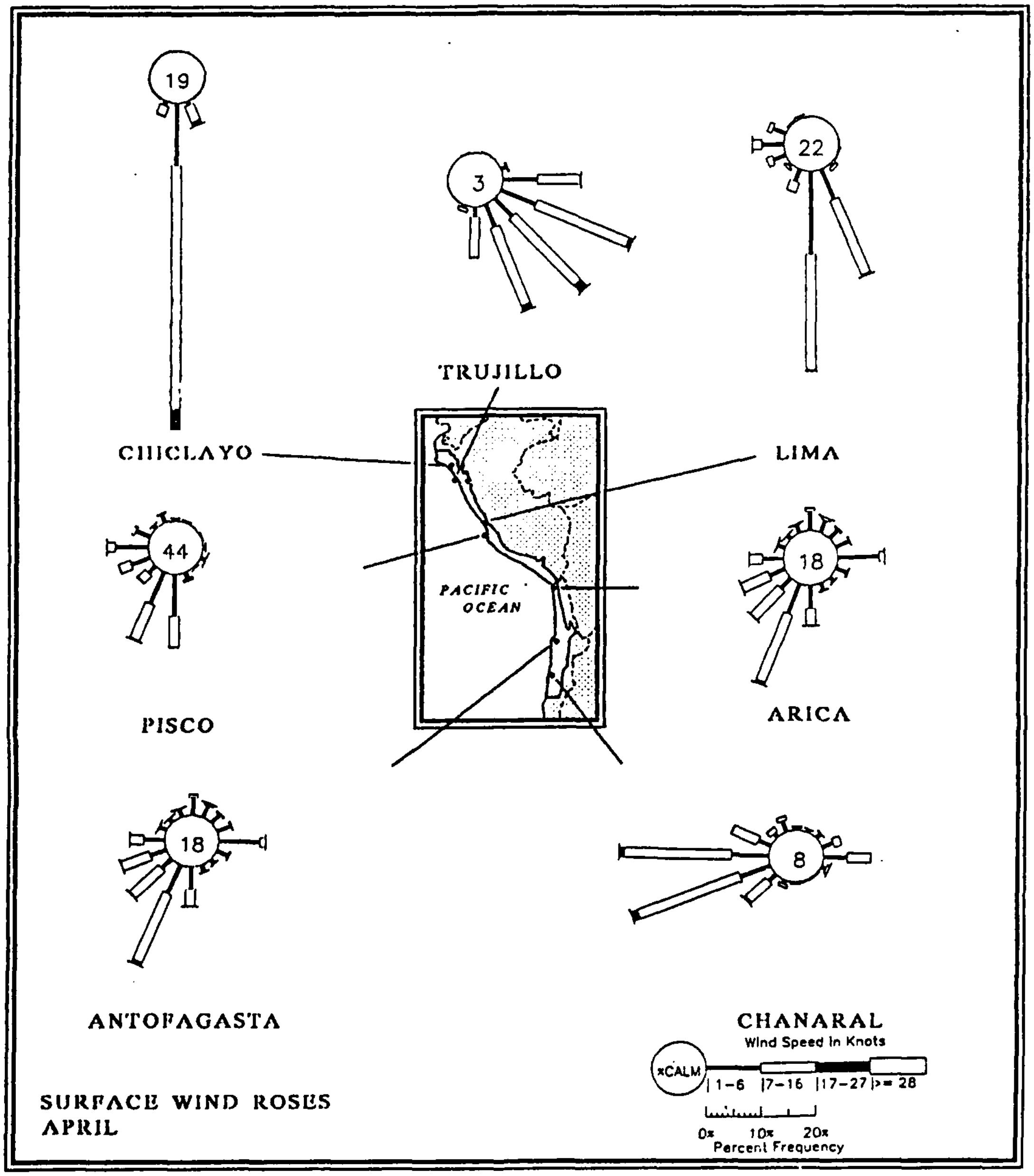


Figure 3-16b. Surface Wind Roses--April.

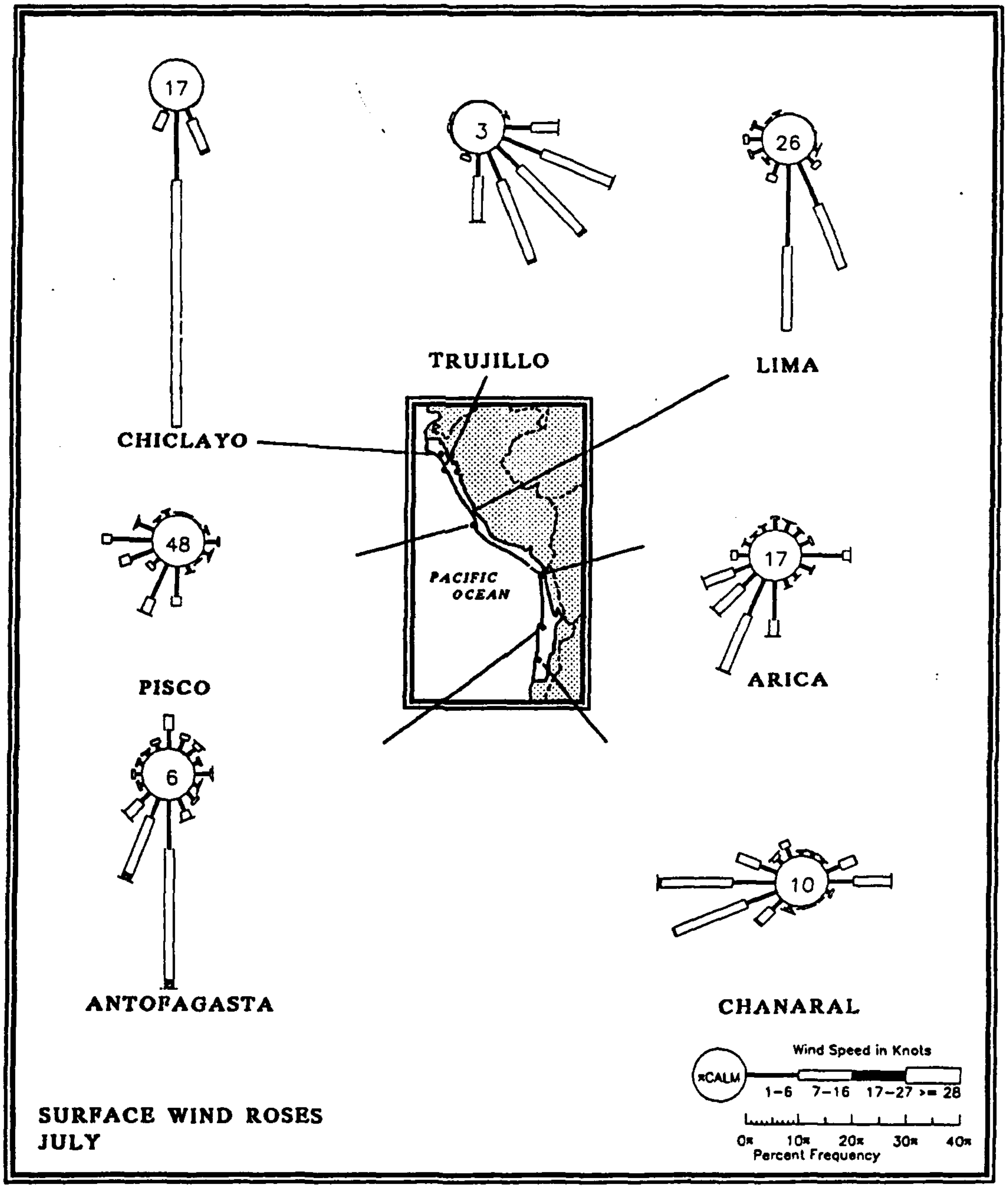


Figure 3-16c. Surface Wind Roses--July.

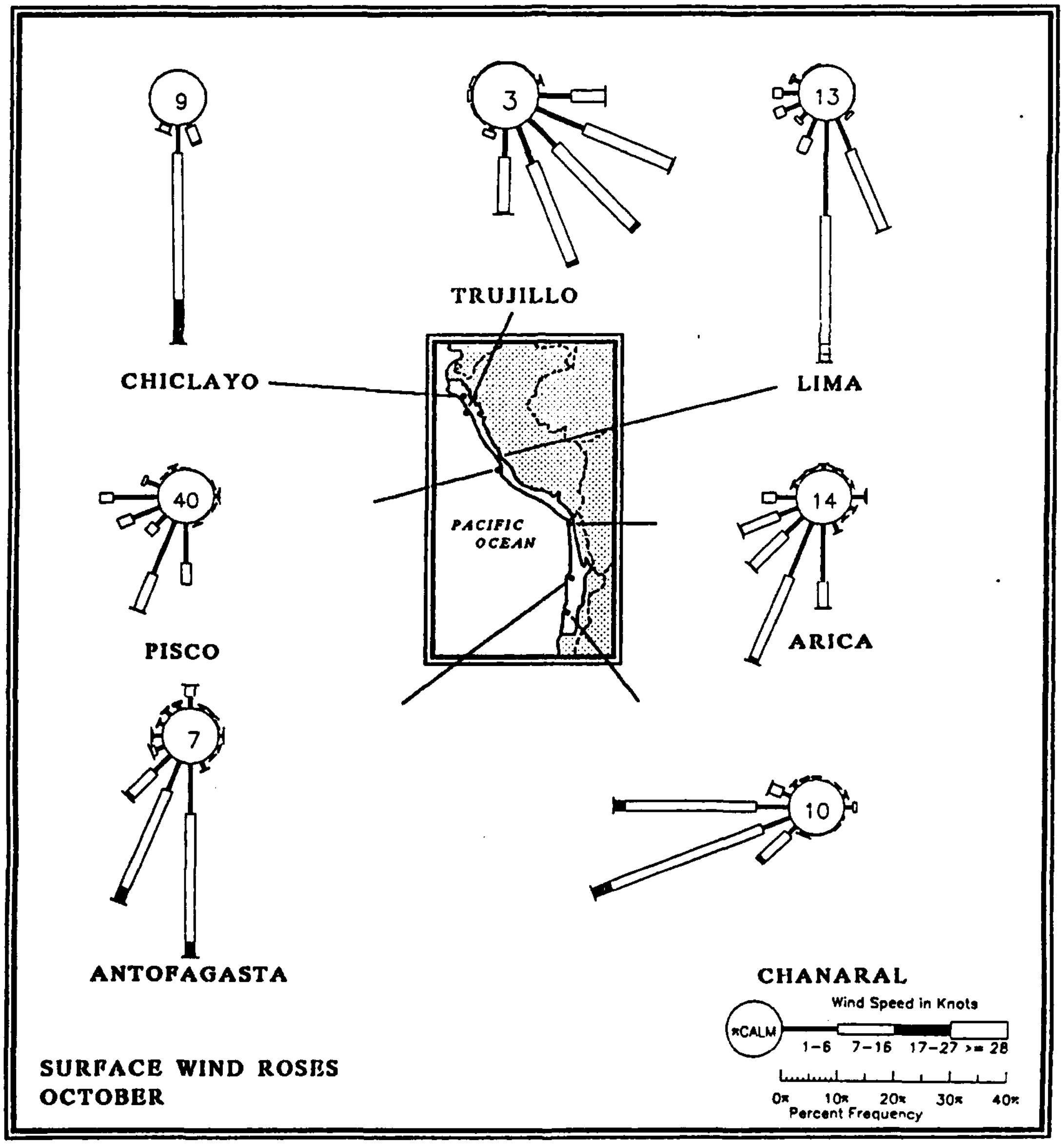


Figure 3-16d. Surface Wind Roses--October.

In Chile, the Cordillera Occidental is also parallel to the coastline, but 75 to 125 NM inland. As a result, the sea breeze and South Pacific High outflow deflect surface winds to southerly and southwesterly at 5-15 knots up to 15 NM inland. Over the Atacama Desert, where surface winds are influenced by topography, southerlies and southwesterlies can exceed 15 knots, but they are more variable along the coast. At night, drainage winds are light easterly or calm.

In rare cases, nocturnal mountain drainage winds from the east or northeast can reach 50 knots on the desert plain. They originate in upland valleys above 9,000 feet (5,475 meters) MSL and descend to the coast. Average wind speed along the coast is only 10 knots.

Mean mid-level (5,000 to 15,000 feet/1,525-4,575 meters) MSL wind direction is variable. Equatorial and mid-latitude flow converges between 16 and 28° S depending on the time of the year.

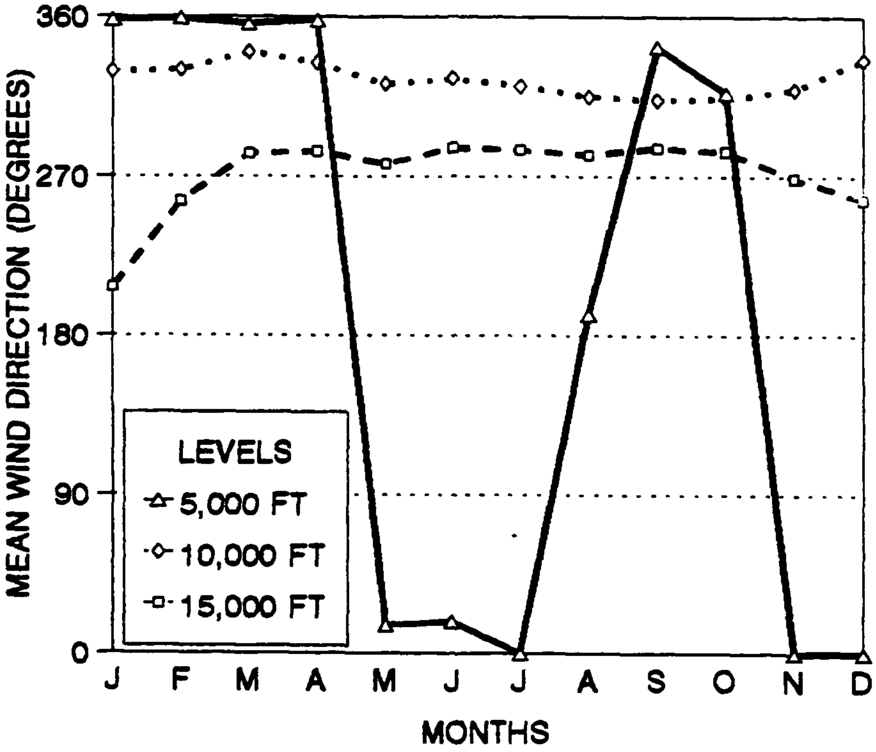


Figure 3-17a. Mean Monthly Mid-Level Wind Directions for Antofagasta, Chile. Upper-air data from Antofagasta is reresentative of stations south of 20° S. Northerlies dominate at 5,000 feet (1,525-meters) all year. Mean wind speeds range from 8 to 10 knots. At 10,000 feet (3,050 meters) MSL, northwesterlies prevail year-round. Mean wind speeds range from 8 knots (December to February) to 13 knots (June to September). At 15,000 feet (4,575 meters) MSL, westerlies prevail all year, except in January and February, when southwesterlies take over. Mean wind speeds range from 9 knots (January and February) to 21 knots (August).

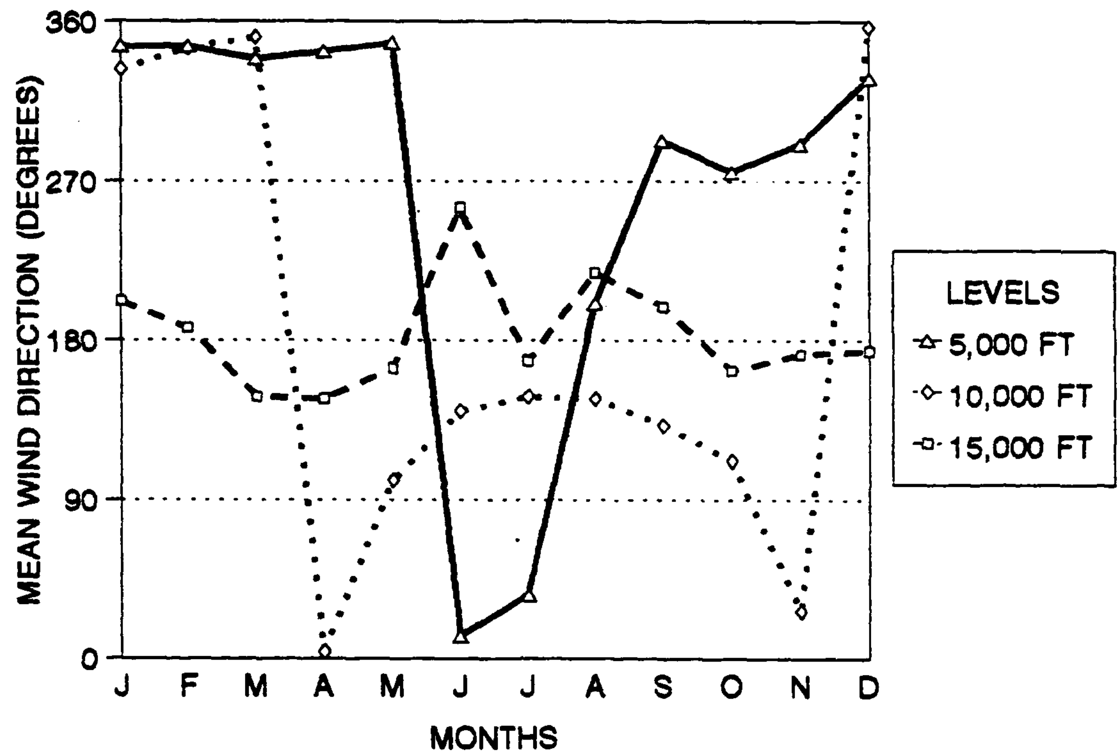


Figure 3-17b. Mean Monthly Mid-Level Wind Directions for Lima, Peru. Lima is representative of stations north of 20° S. Mean 5,000-foot (1,525-meter) MSL wind direction is northerly or northeasterly from January to July, but northwesterly from September to December. Mean speed is 5-8 knots. At 10,000 feet (3,050 meters) MSL, winds are east to southeast at 6 knots from May to October, but northerly from November to April. Speeds are 6-9 knots. At 15,000 feet (4,575 meters) MSL, mean direction shifts from southeasterly to west-southwesterly at 6 knots all year.

Above 20,000 feet (6,100 meters) MSL, the Pacific Arid Zone is dominated by the Bolivian High, which is centered at 12° S, 70' W in January; at 9° S, 68' W in April; and at 5° S, 68' W in October. In July, the high usually disappears as the Subtropical Ridge extends across South America near the Equator.

At Antofagasta, Chile, upper-level flow is westerly all year. Highest mean speeds are between 39,000 and 41,000 feet (11.9-12.5 km) MSL, ranging from 35 knots in January and February to a maximum of 74 knots in September, the result of the Subtropical Jet that occasionally reaches 22° S between late June and early September.

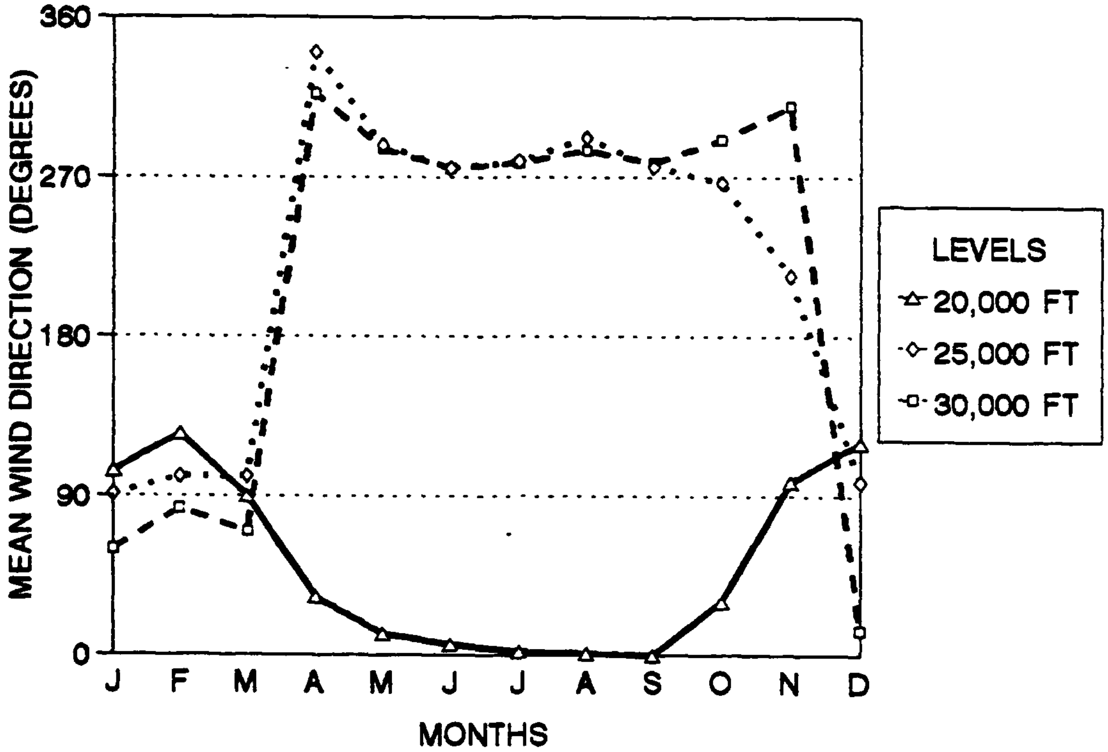


Figure 3-18. Mean Monthly Upper-Level Wind Directions, Lima, Peru.

Upper-level winds at Lima are easterly at 8-17 knots between October and April, but westerlies or northerlies dominate between May and September. At 30,000 feet (9,135 meters) MSL, westerlies at 21 knots prevail from May to early December. Highest mean speeds are found between 40,000 and 44,000 feet (12.2-13.4 km) MSL all year, ranging from 22 knots in March to 37 knots in June. Mean upper-level flow for Lima is shown in Figure 3-18.

PRECIPITATION. Mean annual precipitation does not exceed 9.8 inches (250 mm). Above average rainfall is a possibility only with an El Niño event. The extreme year-round aridity is caused by a combination of strong subsidence below 5,000 feet (1,525 meters) MSL, convergence aloft, an extremely hot and dry coastal desert plain, and cold ocean currents. Although rainfall is extremely rare, heavy rain is possible. Any rain south of 20° S between April and September is usually caused by upper-air troughs. Even drier conditions between November and April are the result of the Andes' rain shadow effect and the inversion along the coast. The Cordillera Occidental prevents Amazon basin moisture and orographic convection from reaching the Atacama Desert.

The persistent stratus or fog is confined to the coast. It rarely produces measurable rainfall. Thick mist ("garúa"), fog, and low stratus may provide the only "precipitation" in any given year; it usually "falls" between 2300 and 0900L. Accumulation seldom exceeds 0.05 inches (1 mm) except along the Cordillera Occidental, usually between 2,000 and 4,000 feet (610 to 1,220 meters) MSL from 9 to 18° S. Measurable precipitation is often less than 0.1 inches (2.5 mm) a month. True rainfall (i.e., droplets) is extremely rare. Maximum annual precipitation at many stations below 5,000 feet (1,525 meters) MSL is less than 4 inches (102 mm); *mean* annual precipitation is less than 1 inch (25 mm). North of 20° S, most rainfall occurs between December and March when the Bolivian High sustains convection in the Cordillera Occidental, and when a strong sea breeze produces orographic lift during El Niño events. South of 20° S, rainfall between May and November is usually caused by cyclonic activity or mid-latitude troughs.

Only three synoptic situations can temporarily produce "true" rainfall in the form of light rain showers or isolated thundershowers. All three are related to an El Niño event. Large-scale changes in the atmospheric circulation and Pacific Ocean currents allow the Near Equatorial Trough (NET), cyclonic activity, and/or diurnal heating to produce rainfall in the Pacific Arid Zone.

The NET may surge southward to 5° S between December and February if southerlies weaken and sea-surface temperatures rise along the Peruvian coast. This destabilizes the lower layers, temporarily disrupting the inversion layer between 5 and 8° S. Light rain showers usually develop from cirrus blow-off produced by isolated convective clusters within the NET. On very rare occasions, individual convective cells reach the coastal plains, fueled at low levels by convergence of the sea breeze and easterlies from the Amazon Basin; as a result, maximum monthly rainfall at Chiclayo and Piura is abnormally large in February, March, and April.

Between 9 and 16° S, the weak inversion permits sea-breeze penetration into upland valleys. The moisture converges with pre-existing convection along the eastern Andes or easterly outflow from the Bolivian High.

Shear lines or upper-air troughs are rare, and usually associated with El Niño events, but a weak South Pacific High allows rare trough penetration to 20 or 22° S. Troughs also temporarily disrupt the inversion layer; heavy rainfall is common with such disturbances along the western Andes above 10,000 feet (3,050 meters) MSL.

Between 16 and 20° S, troughs may help the sea breeze penetrate to the western slopes of the Cordillera Occidental. Otherwise, the sea breeze is rarely a cause for orographic showers in this transition zone. Weak divergence can be found in the northwest quadrant of the Bolivian High over southern and southeastern Peru. Figures 3-19a (high-sun period) and 3-19b (low-sun period) show precipitation data for the Pacific Arid Zone.

#	#	0.1	0.4	0.3	1.1
0.1	0.1	0.8	1.8	10.2	6.1
0.1	0.1	0.7	0.9	2.6	5.1

PIURA

0.1	0.1	#	0.3	0.3	0.5
0.4	0.5	0.1	1.1	2.0	2.6
0.2	0.2	0.1	0.8	2.0	0.9

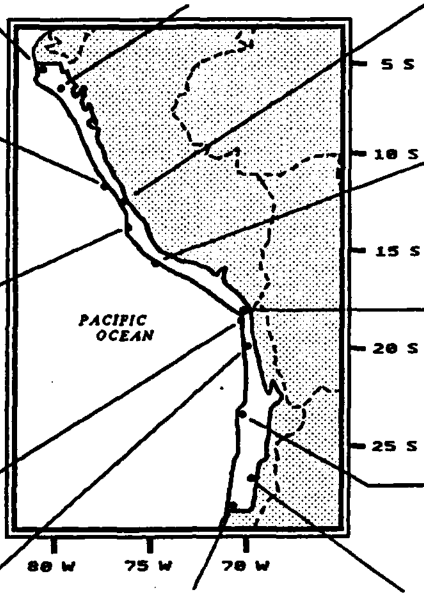
CHICLAYO

0.1	#	#	#	#	#
0.3	0.2	0.1	0.2	0.1	0.1
0.1	#	0.1	0.1	#	#

LIMA

1.0	0.6	0.3	0.3	0.1	0.1
1.9	1.4	1.2	1.3	0.6	0.4
0.3	0.1	0.3	0.2	0.5	0.1

LOMAS de LACHAY



0.1	0.1	#	#	#	#
0.3	0.3	#	#	0.1	0.3
0.2	0.3	#	#	0.1	0.3

SAN JUAN

#	#	#	#	#	0.1
#	0.1	#	#	0.2	1.1
#	0.1	#	#	0.2	1.1

PISCO

0.3	0.2	0.1	0.2	#	0.1
0.7	1.0	0.4	0.7	0.1	0.4
0.2	0.4	0.2	0.7	0.1	0.4

TACNA

#	0.0	0.0	#	#	0.0
#	0.0	0.0	#	#	0.0
#	0.0	0.0	#	#	0.0

ARICA

#	#	#	0.0	0.0	0.0
0.4	0.1	#	0.0	0.0	0.0
0.4	0.1	#	0.0	0.0	0.0

ANTOFAGASTA

#	0.0	0.0	#	#	0.0
#	0.0	0.0	0.1	#	0.0
#	0.0	0.0	0.1	#	0.0

IQUIQUE

#	#	0.0	0.0	#	#
0.8	0.4	0.0	0.0	#	0.4
0.7	0.4	0.0	0.0	#	0.4

COPIAPO

0.1	#	0.0	#	0.1	0.1
1.1	0.1	0.0	0.5	1.3	1.4
0.9	0.1	0.0	0.2	1.3	1.0

PORTRERILLOS

HIGH SUN
TABULAR PRECIPITATION DATA
(INCHES)
- LESS THAN 0.05 INCHES

	OCT	NOV	DEC	JAN	FEB	MAR
MEAN MONTHLY						
MAXIMUM MONTHLY						
MAXIMUM 24-HOUR						

Figure 3-19a. Tabular Precipitation Data--High-Sun Period.

0.1	#	0.0	#	0.2	#
3.1	0.2	0.1	0.1	1.3	0.1
2.4	0.1	#	0.1	1.3	0.1

PIURA

0.2	#	#	#	#	0.1
0.8	#	#	#	#	0.4
0.8	#	#	#	#	0.4

CHICLAYO

#	0.1	0.2	0.2	0.2	0.2
0.1	0.4	0.5	0.5	0.6	0.5
0.1	0.1	0.1	0.1	0.1	0.1

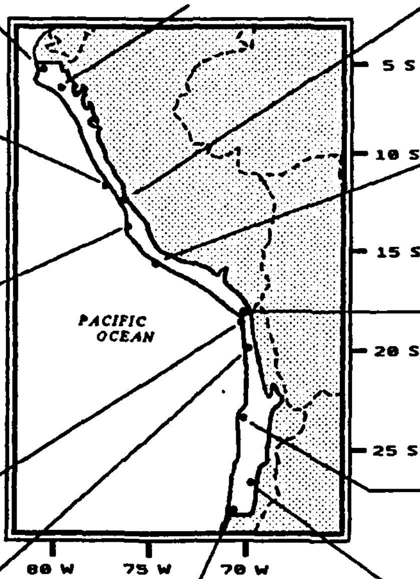
LIMA

0.1	0.7	1.5	1.8	1.8	1.4
0.5	2.3	2.2	3.5	2.4	1.9
0.2	0.5	0.5	0.5	0.3	0.3

LOMAS de LACHAY

0.1	#	#	#	0.1	0.1
0.8	#	0.1	0.1	0.3	0.3
0.4	#	0.1	0.1	0.3	0.3

SAN JUAN



#	#	0.2	0.1	#	#
0.2	0.2	0.4	0.4	0.1	#
0.2	0.2	0.4	0.4	0.1	#

PISCO

0.1	0.2	0.2	0.2	0.4	0.5
0.6	1.2	0.7	0.8	1.5	1.4
0.2	0.3	0.2	0.2	0.4	0.4

TACNA

0.0	0.0	#	#	#	#
0.0	0.0	0.1	0.2	0.2	0.5
0.0	0.0	#	0.2	0.2	0.5

ARICA

#	#	0.1	#	#	#
0.3	#	1.5	0.7	0.1	0.2
0.3	#	1.5	0.7	0.1	0.2

ANTOFAGASTA

0.0	#	#	#	#	#
0.0	0.0	0.1	0.2	0.2	0.5
0.0	0.0	#	0.2	0.2	0.5

IQUIQUE

#	0.2	0.3	0.1	0.1	#
0.8	1.2	2.0	1.0	1.3	0.5
0.8	1.2	1.3	0.9	1.3	0.5

COPIAPO

0.1	0.3	0.5	0.3	0.2	0.1
1.6	1.9	6.1	2.3	2.9	1.0
1.5	1.9	4.3	1.3	2.2	0.9

PORTRERILLOS

LOW SUN
TABULAR PRECIPITATION DATA
(INCHES)
- LESS THAN 0.05 INCHES

	APR	MAY	JUN	JUL	AUG	SEP
MEAN MONTHLY						
MAXIMUM MONTHLY						
MAXIMUM 24-HOUR						

Figure 3-19b. Tabular Precipitation Data--Low-Sun Period.

THUNDERSTORMS are rare. Diurnal thunderstorms can form on the Cordillera Occidental between December and March, but showers rarely reach the coastal desert plain or the coastline south of 8° S. The western slopes of the Cordillera Occidental between 3,000 and 8,000 feet (915-2,440 meters) MSL may get light showers from a towering cumulus, but amounts rarely exceed 0.25 inches (6 mm). In extreme northern Chile (18-22° S), occasional thunderstorms form on the slopes of the Cordillera Occidental above 15,000 feet (4,575 meters) MSL.

Between June and August, an active shear line may enter the Pacific Arid Zone from the south. If it is accompanied by a low- or mid-level trough, it may temporarily break down the inversion layer along the coast for 24 to 36 hours. If it moves onshore with a well-developed sea breeze from 1200 to 1600L, scattered cumulonimbus may form until 1800 or 1900L along the highest ridge crests and at or below 1,000 feet (305 meters) AGL in upland valleys. Tops can reach 35,000 feet (10,670 meters) MSL. Figures 3-20a-b show mean monthly thunderstorm days.

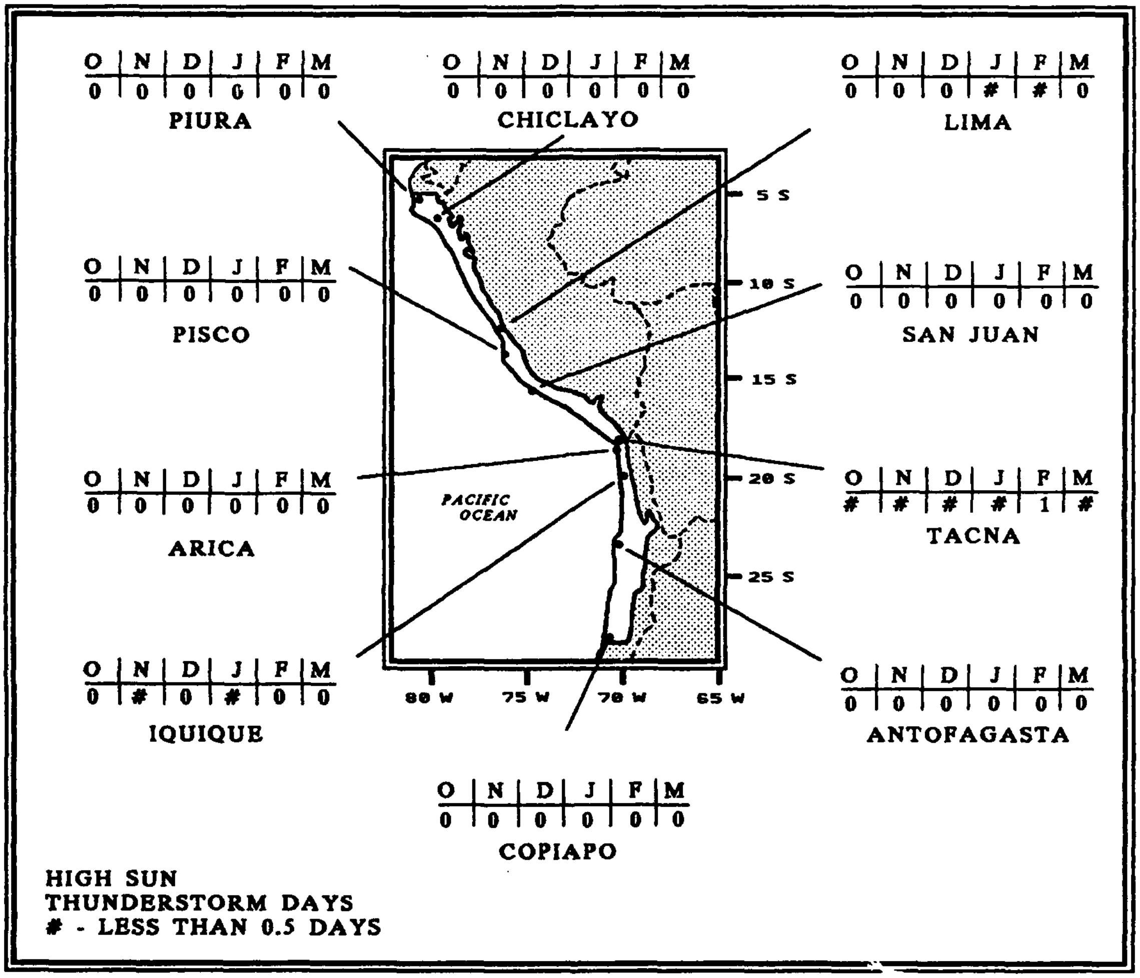


Figure 3-20a. Mean Thunderstorm Days--High-Sun Period.

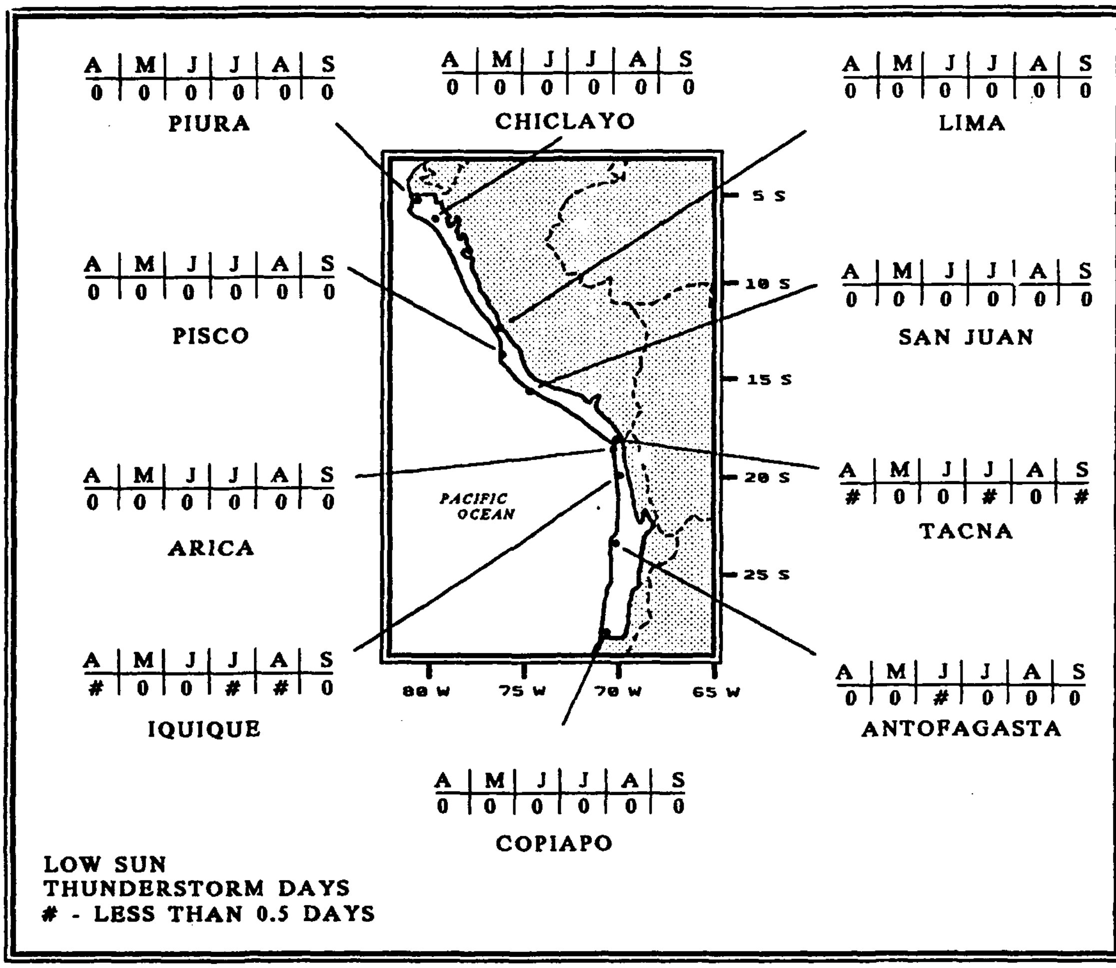


Figure 3-20b. Mean Thunderstorm Days--Low-Sun Period.

TEMPERATURE. Mean daily highs range from 60° F (16° C) to 86° F (30° C) in Peru. In Chile, highs range from 62° F (17° C) to 85° F (29° C). Mean daily highs are lowest between 14 and 24° S in July, August, and September. At many stations in Chile above 2,000 feet (610 meters) MSL, mean daily highs never exceed 68° F (20° C). The highest mean daily highs (80-86° F/27-30° C) are in February or March, mostly recorded at stations along the coastline north of 14° S or south of 24° S.

Mean daily lows range from 47° F (8° C) to 68° F (20° C) in Peru and from from 40° F (4° C) to 61° F (16° C) in Chile. Mean daily lows are lowest from July to September; the highest are along the coastline in February or March.

Record highs rarely exceed 93° F (34° C). Record lows rarely reach 32° F (0° C) below 5,000 feet (1,525 meters) MSL. Most record highs are in February, but highs in January, March, April, or May are occasionally between 88° F (31° C) and 93° F (34° C). Figures 3-21a-b show monthly temperature data.

93	93	98	102	101	103
86	86	89	93	93	95
61	62	65	69	71	71
50	50	53	57	61	61

PIURA

84	90	90	93	93	93
76	77	81	84	86	86
60	61	63	66	68	68
50	50	54	54	54	52

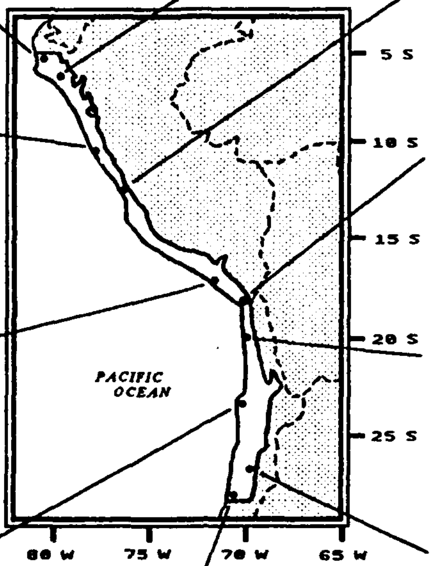
CHICLAYO

77	80	87	89	92	91
71	74	78	82	84	83
58	60	62	66	67	66
52	51	56	58	59	61

LIMA

76	77	83	85	87	84
70	73	76	79	80	80
58	59	63	67	67	66
53	51	57	54	63	61

PARAMONGA



86	84	89	96	95	90
73	76	79	83	83	81
53	55	57	61	62	59
39	39	40	48	50	43

TACNA

78	80	84	90	90	89
70	74	77	79	80	78
59	62	64	66	67	66
53	56	58	61	61	59

MOLLENDO

82	87	86	87	87	88
69	71	75	77	78	77
61	62	65	66	66	66
50	52	53	55	54	48

IQUIQUE

81	81	85	86	87	84
65	67	71	74	74	72
57	59	62	64	63	62
44	48	49	50	47	45

ANTOFAGASTA

73	78	78	78	77	73
62	64	65	65	66	65
44	47	49	49	49	48
23	23	39	38	36	34

PORTRERILLOS

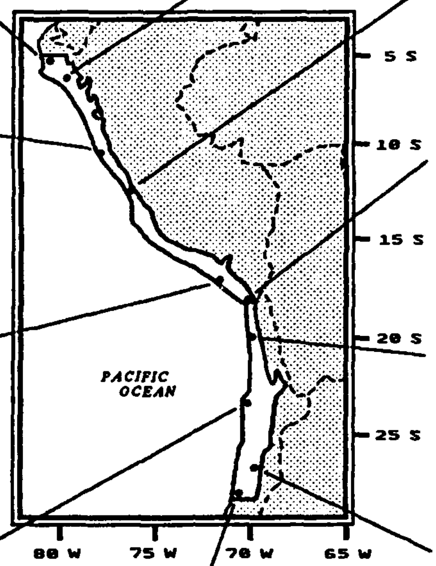
88	88	91	92	96	93
79	80	84	85	85	82
50	53	55	58	58	54
45	48	48	52	55	50

COPIAPO

HIGH SUN
TEMPERATURES (F)

	OCT	NOV	DEC	JAN	FEB	MAR
EXTREME MAX						
AVERAGE MAX						
AVERAGE MIN						
EXTREME MIN						

Figure 3-21a. Tabular Temperature Data (° F)--High-Sun Period.



PIURA

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	101	99	95	97	93	99
AVERAGE MAX	93	89	85	83	83	85
AVERAGE MIN	68	65	62	61	61	61
EXTREME MIN	54	50	50	48	53	54

CHICLAYO

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	91	88	90	91	86	84
AVERAGE MAX	83	80	77	75	75	75
AVERAGE MIN	65	63	61	60	59	59
EXTREME MIN	50	52	50	54	50	54

LIMA

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	93	83	82	75	81	78
AVERAGE MAX	80	74	68	67	66	68
AVERAGE MIN	63	60	58	57	56	57
EXTREME MIN	56	52	51	50	51	51

PARAMONGA

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	86	85	83	74	75	73
AVERAGE MAX	77	74	70	69	68	69
AVERAGE MIN	64	62	61	59	59	58
EXTREME MIN	59	57	54	52	54	54

TACNA

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	87	83	81	84	86	82
AVERAGE MAX	78	73	68	67	68	70
AVERAGE MIN	55	51	49	47	48	50
EXTREME MIN	38	39	32	32	37	37

MOLLENDO

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	84	82	78	74	77	76
AVERAGE MAX	76	72	69	67	66	67
AVERAGE MIN	63	61	58	57	57	57
EXTREME MIN	57	55	50	50	51	52

IQUIQUE

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	83	82	73	72	74	77
AVERAGE MAX	73	69	65	64	64	66
AVERAGE MIN	63	60	59	57	57	59
EXTREME MIN	43	39	39	39	41	43

ANTOFAGASTA

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	81	76	75	75	76	80
AVERAGE MAX	69	66	63	62	62	63
AVERAGE MIN	59	57	54	53	54	55
EXTREME MIN	39	42	35	38	37	41

PORTRERILLOS

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	77	78	72	71	75	74
AVERAGE MAX	64	60	56	57	58	60
AVERAGE MIN	47	43	39	40	40	42
EXTREME MIN	32	23	15	9	10	19

COPIAPO

	APR	MAY	JUN	JUL	AUG	SEP
EXTREME MAX	85	84	80	86	85	88
AVERAGE MAX	77	71	69	69	72	76
AVERAGE MIN	49	45	41	41	44	46
EXTREME MIN	44	37	36	33	34	36

LOW SUN
TEMPERATURES (F)

Figure 3-21b. Tabular Temperature Data (° F)--Low-Sun Period.

Relative humidity (RH) below the inversion is high. At 0700L, RH is above 75% all year along the entire coastline. In Peru, RH often exceeds 85% at 0700L, but above 6,000 feet (1,830 meters) MSL, it rarely exceeds 55%. RH is lowest (55-75%) between 1300 and 1500L. RH at 1300L is highest between April and September, lowest between December and February. Above 6,000 feet (1,830 meters) MSL, 1300L RH is 15-30%. After 1700L, RH is consistently above 70% below 6,000 feet (1,830 meters) MSL. Along the coast, RH may average 80% throughout the evening (1800-0500L) north of 20° S. Above 6,000 feet (1,830 meters) MSL, RH averages less than 40% all year, except for December, January, and February. Figures 3-22a-d depict mean (isolines) and maximum (bar graphs with highest temperature fixed above) wet-bulb globe temperatures (WBGTs) along the Pacific Arid zone.

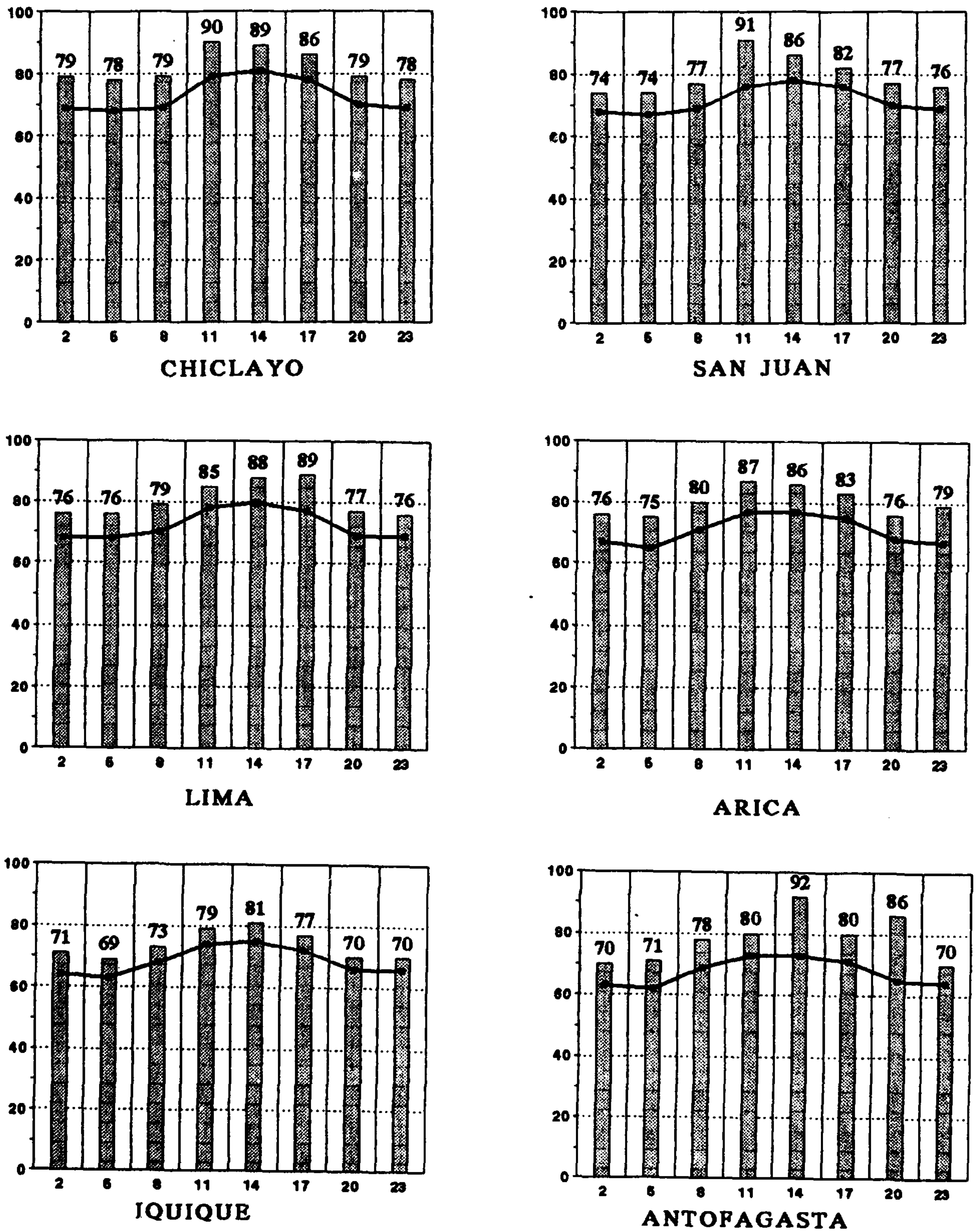


Figure 3-22a. January Wet-Bulb Globe Temperatures (° F). Mean and maximum WBGTs peak between 1100 and 1400L. Lima is the only exception; maximum WBGT (89° F/32° C) is at 1700L.

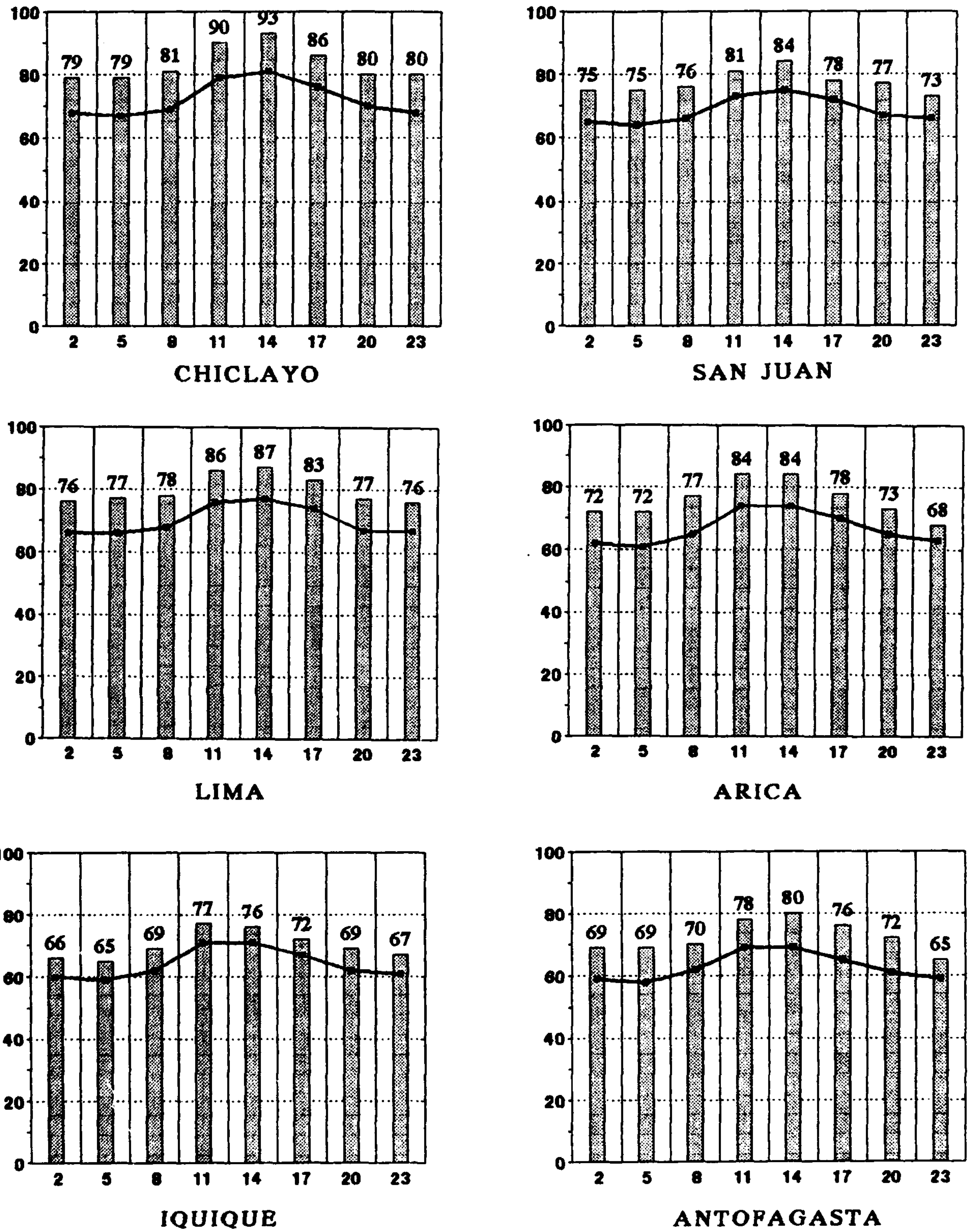


Figure 3-22b. April Wet-Bulb Globe Temperatures (° F). In all cases, mean and maximum WBGTs are between 1100 and 1400L.

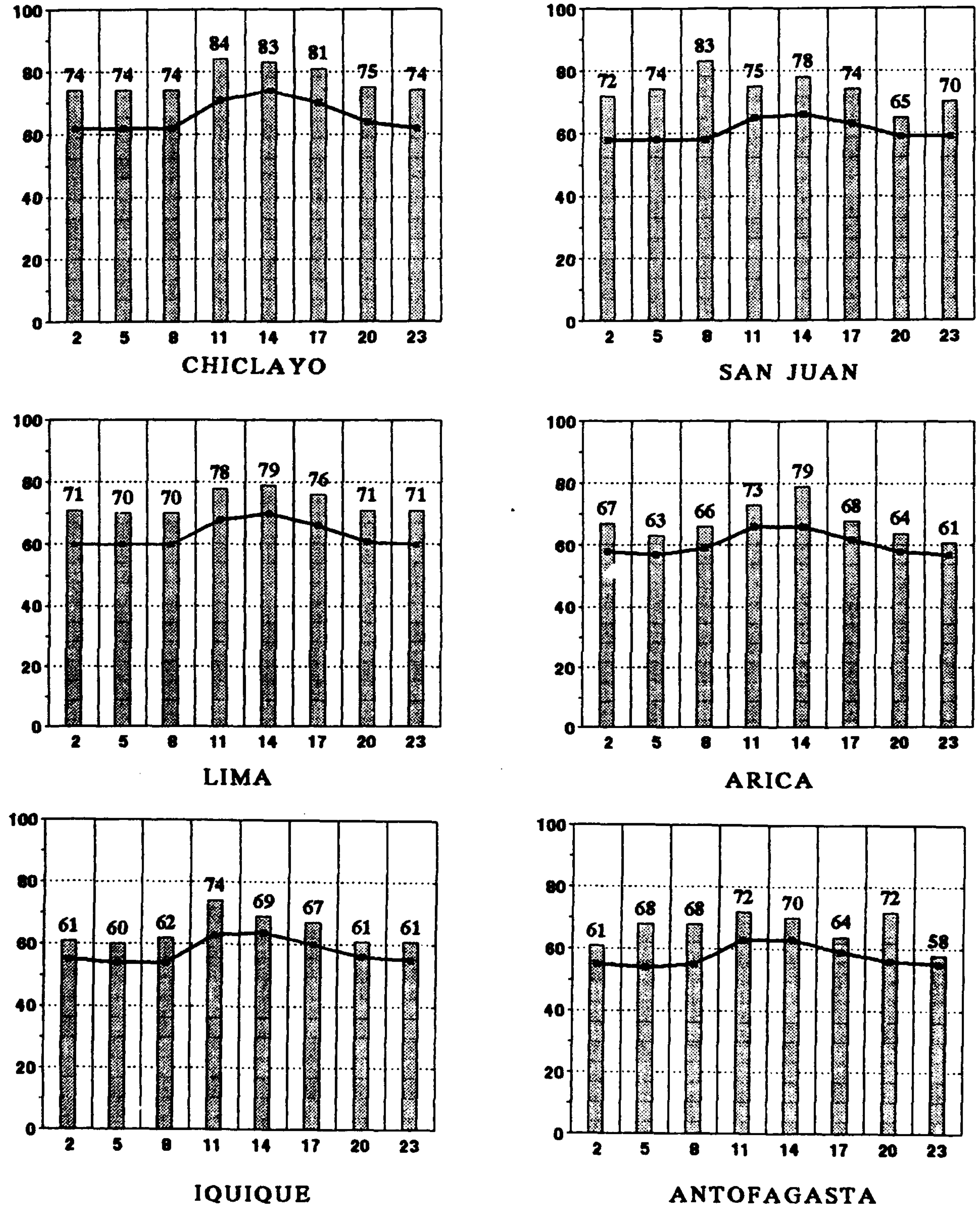


Figure 3-22c. July Wet-Bulb Globe Temperatures (° F). Highest mean and maximum WBGTs are at Chiclayo (6° 47' S), the northernmost station used.

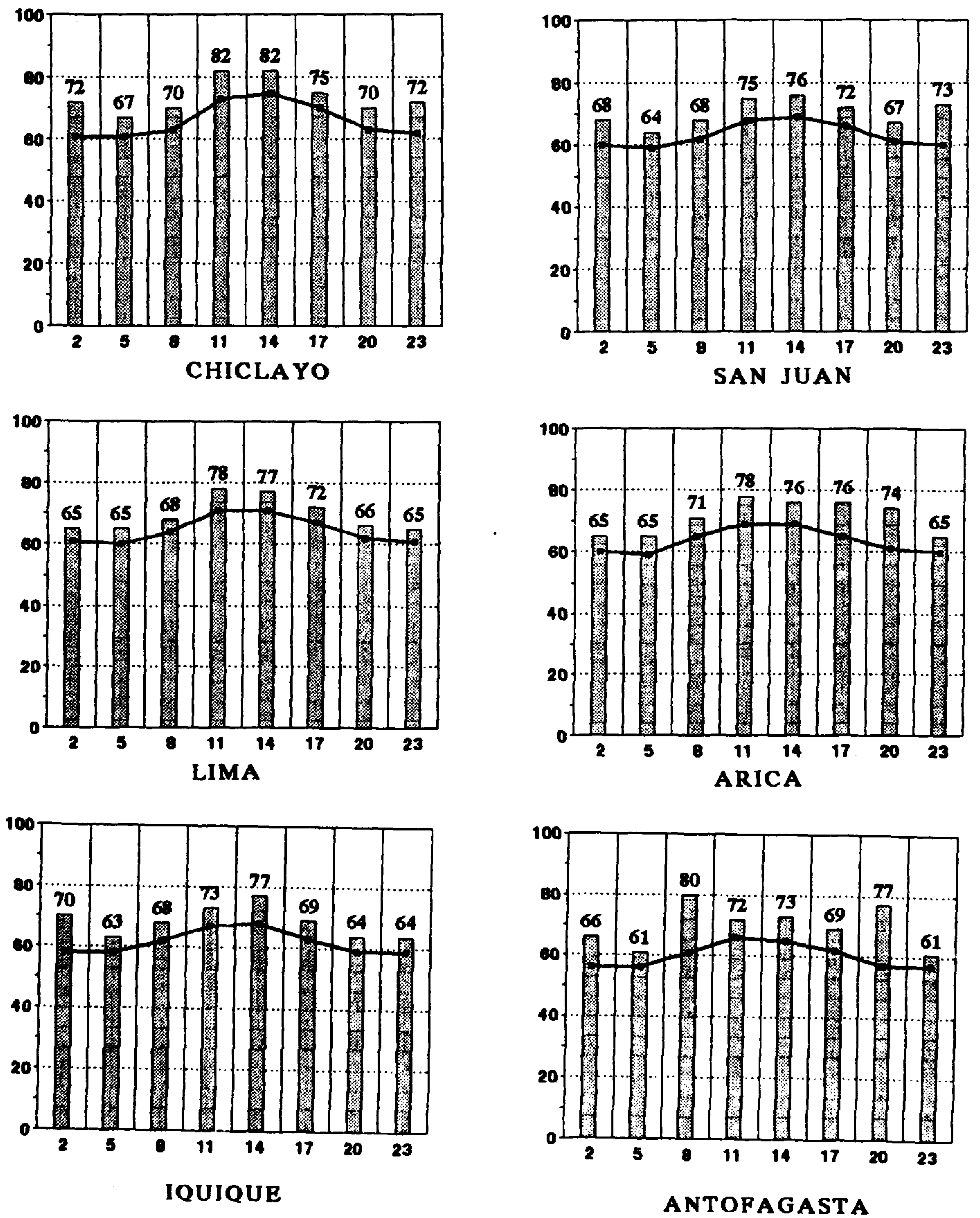


Figure 3-22d. October Wet-Bulb Globe Temperatures (° F). Antofagasta is the only station at which maximum WBGTs do not occur between 1100 and 1400L.

FLIGHT HAZARDS. The usual thunderstorm hazards apply. Light or occasionally moderate turbulence below 8,000 feet (2,440 meters) MSL may occur with strong inversions along the coast. Low stratus can be expected along immediate coastlines between 2300 and 0900L. Peak low-cloud months are June through September. Ground fog occasionally drops visibility below 3 miles. When the Paracas wind reaches maximum intensity between 1100 and 1400L, visibility drops to 1 mile in blowing dust and sand.

GROUND HAZARDS. Flash flooding on the coastal plain may occur after the rare synoptic disturbance. Rainfall in the Cordillera Occidental may suddenly cascade through river valleys onto the coastal desert plains, producing large alluvial fan deposits of sand and silt that can cover 3- to 5-mile sections of beach and wash away everything in their path.

3.2 CENTRAL ANDES

The Central Andes zone (as shown in Figure 3-23) is characterized by rugged mountains with numerous ranges separated by deep narrow valleys, complex fault zones, and broad elevated plateaus. It includes central Peru, western Bolivia, eastern Chile and extreme northwestern Argentina between 5 and 28° S. After describing this area's geography, this chapter discusses "typical weather conditions" by season for the two subzones within the Central Andes: The "Altiplano" and the "Tropical Ranges." These two subzones are discussed separately because of certain differences in climate that result from elevation and orientation with respect to seasonal airflow. For example, the Altiplano has a short 2- to 3-month wet season, whereas the Tropical Ranges have a 6- to 7-month wet season. Figure 3-24 shows the reporting stations selected to represent each subzone.

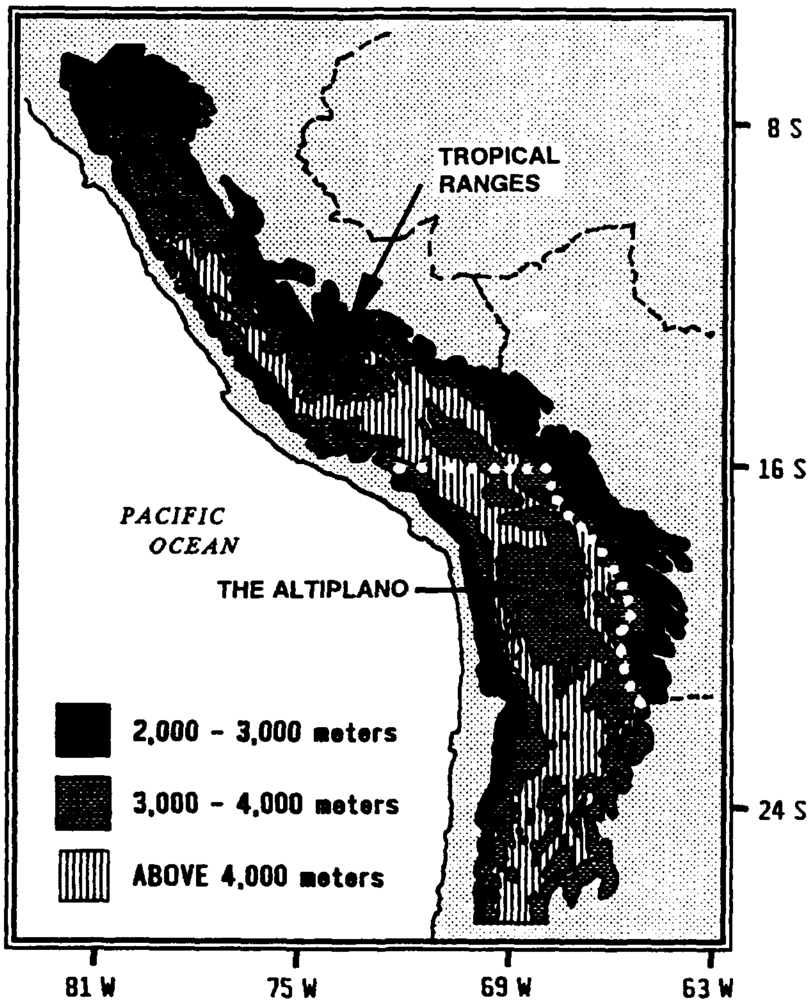
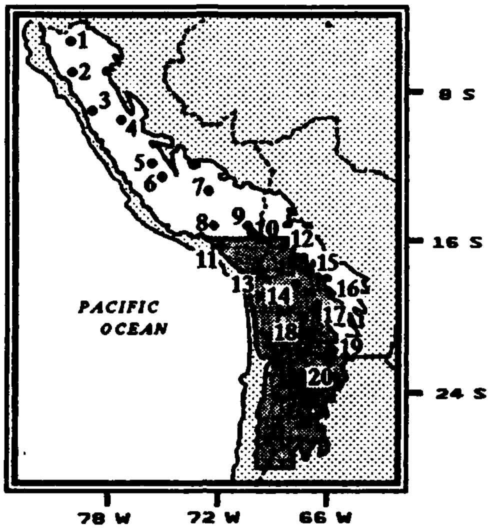


Figure 3-23. The Central Andes. The "Tropical Ranges" are in the north; the "Altiplano," in the south. The Tropical Ranges begin at 5° S. The western boundary follows the 8,000-foot (2,440-meter) MSL contour south to 16° S. The eastern boundary follows the 6,562-foot (2,000-meter) MSL contour south from 5° S to the Argentina border. Here, the boundary heads west to the 9,843-foot (3,000-meter) MSL contour, then north to 16° S. The Altiplano extends from 16 to 28° S. The 8,000-foot (2,440-meter) MSL contour is its western boundary; the 9,843-foot (3,000-meter) MSL contour from the Bolivia-Argentina border to 16° S is the eastern boundary.



1.	CHACHAPOYAS	6°13'S 77°50'W		11.	AREQUIPA	16°19'S 71°33'W
2.	CAJAMARCA	7°08'S 78°31'W		12.	LA PAZ	16°30'S 68°10'W
3.	HUARAZ	9°21'S 77°36'W		13.	CHARANA	17°36'S 69°28'W
4.	HUANUCO	9°54'S 76°14'W		14.	ORURO	17°59'S 67°09'W
5.	HUANCAYO	12°04'S 75°14'W		15.	COCHABAMBA	17°24'S 66°09'W
6.	AYACUCHO	13°08'S 74°13'W		16.	SUCRE	19°02'S 65°17'W
7.	CUZCO	13°13'S 71°59'W		17.	POTOSI	19°35'S 65°45'W
8.	CAILLOMA	15°12'S 71°46'W		18.	UYUNI	20°28'S 66°50'W
9.	JULIACA	15°29'S 70°09'W		19.	TARIJA	21°31'S 64°45'W
10.	PUNO	15°50'S 70°01'W		20.	LA QUIACA	21°52'S 65°23'W

Figure 3-24. Climatic Station Network, Central Andes. The Altiplano is the shaded area. Climatic data used in this study represents average conditions for major airfields in the region; because of terrain, it may or may not accurately represent surface weather conditions nearby.

CENTRAL ANDES GEOGRAPHY

The Andes ranges ("Cordillera") are oriented parallel to the Pacific coastline. This discussion covers the four major ranges of the Andes (referred to here as the "Tropical Ranges") and the Altiplano, a high plateau between the Cordillera Real and Cordillera Occidental. It is often difficult to determine exactly where one range begins and another ends. Elevations in this part of South America are not well known--large sections have yet to be mapped. Different sources often give different elevations for the same peaks in remote areas.

The Tropical Ranges.

Cordillera Occidental. This is the primary mountain range of the Central Andes. It lies in western Peru where it forms the border of Chile with Bolivia and Argentina. Mt Huscaran (9° 12' S, 77° 36' W) is the highest peak at 22,205 feet (6,768 meters) MSL. Several other peaks are over 20,000 feet (6,098 meters) MSL, but most average 15,000 feet (4,573 meters) MSL. In Chile, the mountains are rugged, with steep slopes. The narrow rivers draining westward onto the Atacama Desert are perennial above 12,000 feet (3,660 meters) MSL. The mountains along the coast of Peru form a series of rolling hills cut by winding river valleys that change to an extensive chain of cinder-cone volcanic peaks within 50 NM of the coast. Numerous rivers descend onto the coastal desert plain.

Cordillera Central. The rugged central mountains are in north-central Peru between 5 and 11° S. In Bolivia, the range reforms along the southeastern edge of the Altiplano. In Chile, it runs north of Lake Poopo. The topography from 5 to 9° S is a combination of glacial and volcanic formations; rugged, snow-capped ranges average 15,000 to 20,000 feet (4,575 and 6,100 meters) MSL. The Maranon River Valley separates the Cordillera Central from the Cordillera Occidental to the west. The river and its deep valley extends northward from 10° S before turning northeastward (at 5° S) toward the Amazon Basin. The river valley is sometimes less than 0.5 NM wide between 8 and 10° S.

Cordillera Oriental. The eastern mountains extend from north-central Peru to the Gran Chaco of Bolivia between 8 and 22° S. Its east-facing slopes support thick tropical rain forests between 7,000 and 10,000 feet (2,135-3,050 meters) MSL and alpine vegetation above 10,000 feet (3,050 meters). The highest peaks are between 13 and 17° S. The highest of these is Mount Salcantay, at 20,574 feet (6,271 meters) MSL (13° 12' S, 72° 49' W). The Apurimac and Huallaga River Valleys separate the Cordillera Oriental from the Cordillera Central north of 14° S.

Cordillera Real. This high range lies between 15 and 17° S. There are several peaks over 20,000 feet (6,100 meters) MSL. The highest is believed to be Nevado Ancohuma (15° 54' S, 68° 30' W) at 21,489 feet (6,550 meters). Some references, however, list it as being over 23,000 feet (7,012 meters). The Real range is located near Lake Titicaca's eastern end, where it frequently produces strong drainage winds over the lake. Most peaks above 16,000 feet (4,880 meters) MSL are snow-capped except during extreme drought.

The Altiplano.

The "High Plateau" is nestled between the Cordillera Real and Cordillera Occidental. It averages 80 NM in width. Elevation varies from 12,000 to 12,500 feet (3,660 to 3,810 meters) MSL. Higher terrain completely surrounds the plateau, which has an internal drainage basin. The salt evaporation lake beds and surrounding salt flats south of 17° S resemble the Great Basin of Nevada and Utah. Lake Titicaca (16° S, 69° W) is the highest freshwater lake in the world at 12,000 feet (3,660 meters) MSL. It has an average depth of 922 feet (281 meters) and covers 3,200 square miles. Drainage from Lake Titicaca reaches Lake Poopo (19° S, 67° W) via the Desaguadero River. Lake Poopo averages 15 feet (5 meters) in depth and covers 977 square miles.

VEGETATION. A wide variety of vegetation is found in the Central Andes. The type is controlled by rainfall and temperature. The general discussion below covers a typical vertical distribution; however, slopes and floors of interior valleys may have significant differences over short distances.

The tropical rain forest usually reaches 4,500 feet (1,375 meters) MSL, but "cloud forests" with dense vegetation may reach 7,000 or 8,000 feet (2,135-2,440 meters) MSL along the Cordilleras Oriental and Central. The cloud forest is a high-altitude version of the tropical rain forest, modified by heavy cloud cover and lower temperatures. The windward sides of ranges may have isolated cloud forests in remote canyons up to 10,000 feet (3,050 meters) MSL. They are intermixed with thick evergreen forests on adjacent hillsides. Evergreen forests contain shrubs and small trees that thin out above 10,000 feet (3,050 meters) MSL.

Sub-xerophytic (arid climate) vegetation, the opposite of cloud forest vegetation, develops along slopes where rain shadow effects are pronounced. Various species of shrubs and cacti dominate the landscape. Evergreen scrub vegetation (shrubs and small trees) is found in localized areas of abundant moisture. Above 12,000 feet (3,660 meters) MSL, the climate supports grasslands, or "punas". Coarse grasses, herbs, and mosses extend up to the permanent snow line, which averages 17,000 feet/5,180 meters but varies with slope orientation and seasonal precipitation distributions.

On the Cordillera Occidental in Peru, tall grasses and scrub dominate the slopes north of 8° S above 10,000 feet (3,050 meters) MSL, while short grasses and alpine vegetation are common south of 13° S. Both types of vegetation are found between 8 and 13° S. Below 10,000 feet (3,050 meters) MSL, short grasses and barren landscapes dominate the western Cordillera. In Chile, the tree line begins near 13,000 feet (3,965 meters) MSL and ends at the permanent snowline near 17,000 feet (5,180 meters) MSL. In between, isolated meadows and desert flora are intermixed.

There is a tropical rain forest between 5 and 7° S along the Maranon River Valley and other river valley slopes opening to the Amazon basin. There is also a tropical rain forest in the foothills of the Cordillera Oriental, which has a cloud forest on its eastern slopes. The evergreen and "cloud" forests also penetrate into the eastern slopes of the Cordillera Real. The climate west and south of the Cordillera Real becomes considerably drier; thin forests and thornbrush dominate. The northeast Altiplano is moist; coarse bunch grass, scattered scrub, and marshlands are common.

CENTRAL ANDES CLIMATIC PECULIARITIES

There are many microclimates in the Central Andes because of the extensive network of long and narrow valleys that slope upward into the remote mountain ranges. Numerous river valleys above 8,000 feet (2,440 meters) MSL are dominated by low-level Amazon moisture and unstable air. The amount of unstable low-level flow into these valleys varies from month to month. Deep moisture penetrates into the interior mountain ranges only when low-level airflow funnels into river valleys; convection is fueled by moisture lifted into the middle and upper levels and redistributed. The magnitude and duration of the moist flow varies from season to season.

Figures 3-25a-d show the interaction between low- and upper-level wind patterns by season. The onset and duration of the wet season are determined by the persistence of these wind patterns.

The upper-level flow pattern in Figure 3-25a shows a large anticyclone over the western Amazon basin. North of the ridge axis, easterly flow assists the easterly to northeasterly flow at low levels, advecting unstable air westward to the highest elevations. Sustained heavy convection rarely penetrates southward of the ridge axis.

By late December, the moist flow pattern fuels an intense diurnal heating cycle in individual valleys, leading to widespread showery-type precipitation. Moisture and heavy convection often originate below the 10,000-foot (3,050-meter) level as the Bolivian High lifts moisture into the upper levels. If upslope valley winds can lift the moisture along the adjacent ridge crests, isolated convection may occur over the high plateau and valleys where low-level Amazon airflow is not present. South of 16° S, low-level airflow into the Altiplano has less moisture because its source is modified by the Northwest Argentine Depression (NAD). Orographic showers and thundershowers over the southeastern Altiplano and the eastern slopes of the southern Cordillera Oriental often develop during a 3-month period when unstable low-level flow is southeasterly. The upper-level flow is too dry to sustain heavy convection.

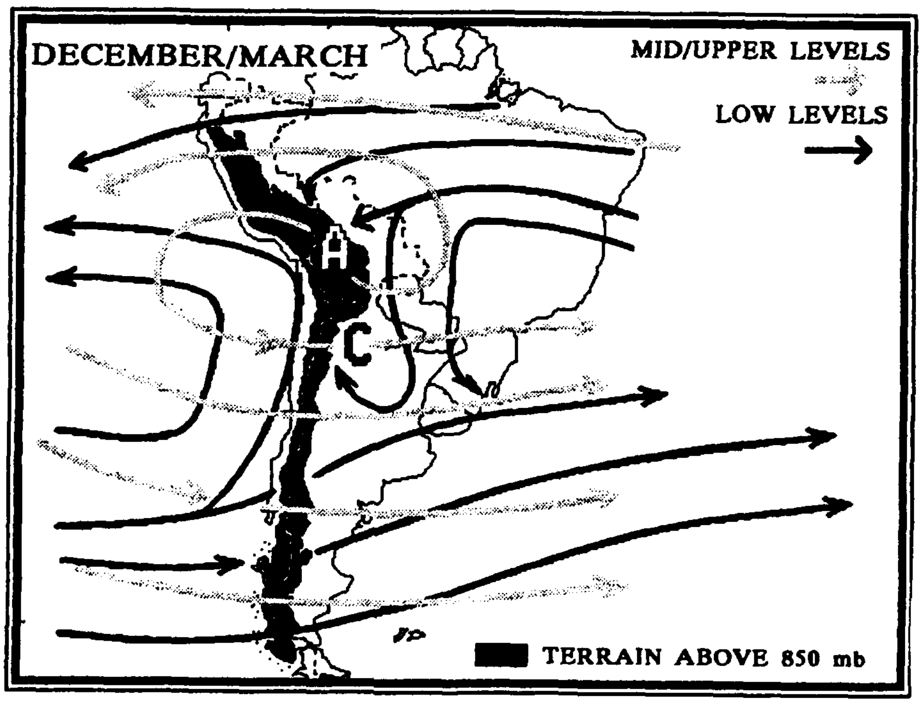


Figure 3-25a. Airflow Over the Andes Cordillera During Southern Hemisphere Summer. "A" marks the Bolivian High; the "C" is the NAD.

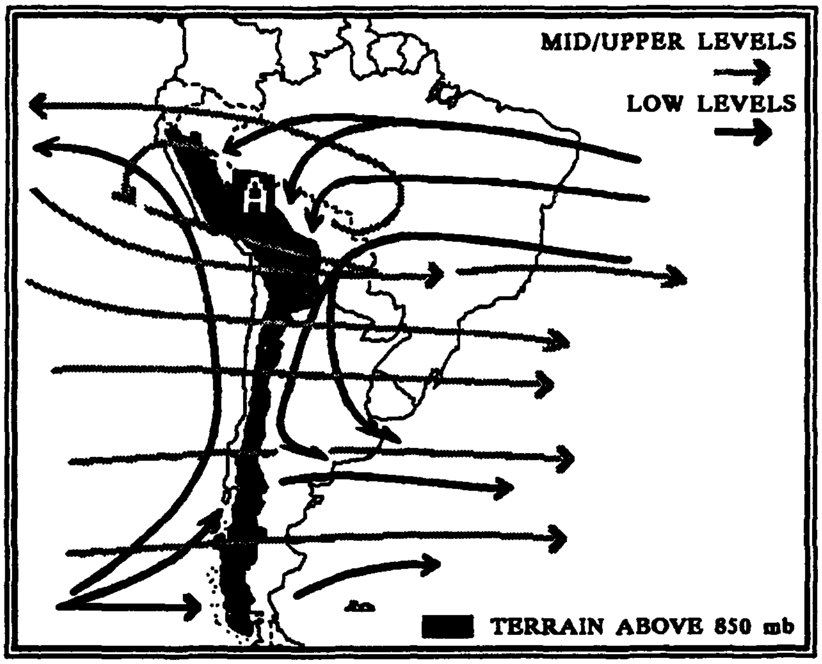


Figure 3-25b. Airflow Over the Andes Cordillera During Southern Hemisphere Fall. "A" marks the Bolivian High, which remains the dominant April upper-air feature, sustaining heavy convection in areas affected by low-level unstable air. Dry northwesterlies on the southern edge of the Bolivian High appear south of 16° S and converge with mid-latitude westerlies over the Altiplano. Low-level moisture is absent; the NAD is replaced by dry, stable airflow from the South Atlantic High.

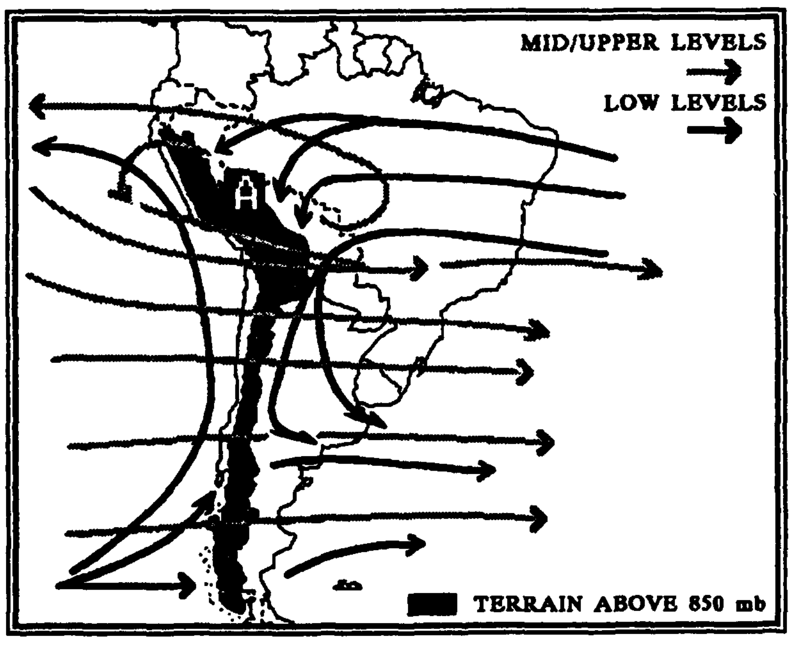


Figure 3-25c. Airflow Over the Andes Cordillera During Southern Hemisphere Winter. "SR" identifies the Subtropical Ridge. From May to September, mid-latitude westerlies dominate South America in the middle and upper levels south of 16° S. Moisture advection from the Amazon basin into the middle and upper levels rarely occurs south of 10° S. The Bolivian High has been replaced by the Subtropical Ridge. In the lower levels, the Amazon air mass affects only the near-equatorial regions (7° N to 7° S).

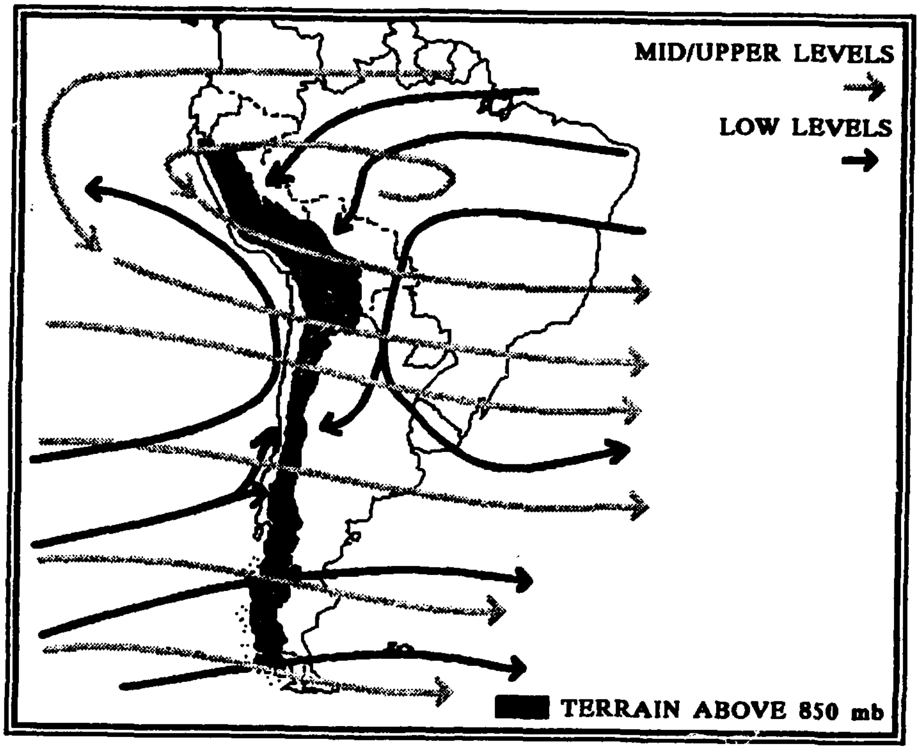


Figure 3-25d. Airflow Over the Andes Cordillera During Southern Hemisphere Spring. Low-level moisture is extremely shallow. Most convection is confined to the eastern Andes' slopes adjacent to the Amazon lowlands between 5 and 10° S.

GENERAL WEATHER. The Bolivian High, moist low-level easterlies, and strong surface heating combine to fuel diurnal convection in the Tropical Ranges throughout the wet season. Towering cumulus and cumulonimbus dominate. Thunderstorms form along ridge crests and move downwind within the Bolivian High outflow. The Bolivian High ridges west-northwestward across northern Bolivia and central Peru, providing outflow for sustained heavy convection, which builds rapidly north of the ridge with intense surface heating and valley breezes initiating orographic lift along mountain slopes. The ridge usually migrates southward to between 12 and 16° S by late January.

Over the Altiplano, the diurnal convection cycle is well-established by early January, but it dissipates by mid-March with the weakening of the Bolivian High. Convection is fueled by moisture advected into the middle and upper levels. Low-level flow enters the Altiplano from the southeast. Orographic lift produces abundant rainfall between 20 and 28° S. The air mass is rarely modified until it gets to 30 or 40 NM west of the easternmost mountain ranges. Daytime heating produces strong upslope flow through a network of short, deep river valleys. Convergence occurs along the highest ridge crests.

Dry-air entrainment from the westerlies often produces severe thunderstorms with 3/4-inch (19-mm) hail, and strong winds. Localized upper-level speed divergence is caused by the Bolivian High and Pacific mid-latitude westerlies. Figure 3-26 shows extensive areas of wet-season cloud cover usually present between 1200 and 1800L.

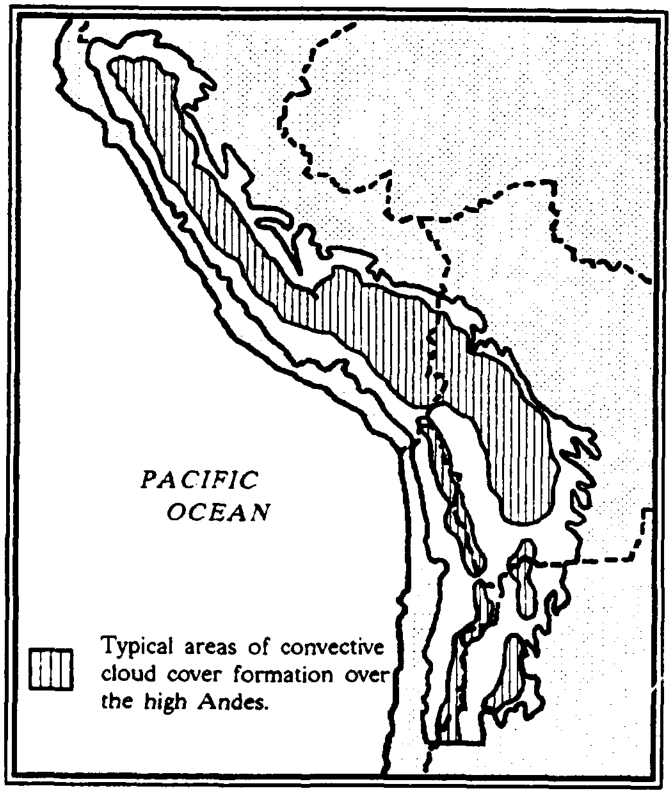


Figure 3-26. Typical Convective Cloud Pattern Across the Central Andes During the Wet Season.

GENERAL SKY COVER. Abundant low- and mid-level moisture originates with the easterlies from the Amazon basin. The Cordillera Oriental, closest to the moisture source, is the cloudiest. The Maranon, Huallaga, Apurimac, and several other major river valleys are natural pathways for funneling low-level moisture around the Cordillera Oriental to the Cordilleras Real, Central, and to a lesser extent, the Occidental. The persistent easterlies help produce a daily cycle of mid-afternoon convection. Diurnal cumulus development begins at 1000 or 1100L and ends by 1900L. The Eastern ranges and adjacent valley floors closest to the moist low-level flow may be totally cloud-covered from 1000 to 1800L; successive ridges and valleys to the west and south often have less extensive cloud cover. Cloudiness is usually greatest along the Cordillera Oriental between 8 and 16° S and least along the Cordillera Occidental below 10,000 feet (3,050 meters) MSL between 8 and 28° S. Towering cumulus and cumulonimbus are dominant between 1400 and 2200L. Figure 3-27 shows percent occurrence frequencies of ceilings below 3,000 feet (915 meters).

27	28	37	41	33
15	14	17	18	18
12	11	10	12	13
16	17	16	14	19

HUANUCO

2	2	6	10	5
0	2	4	5	4
#	#	1	3	1
3	2	3	6	3

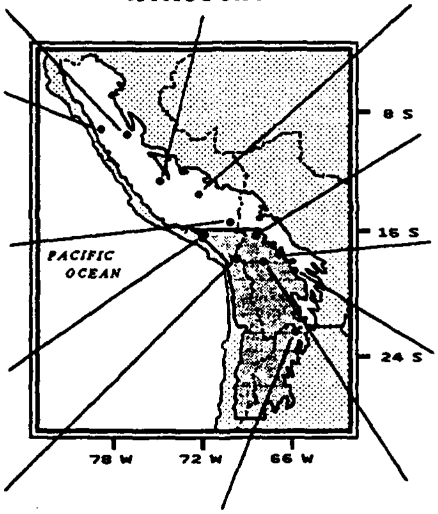
AYACUCHO

#	#	3	2	1
#	1	2	#	#
#	#	#	#	#
1	1	1	2	1

CUZCO

6	15	15	26	21
1	3	3	5	4
15	18	17	25	24
15	20	20	33	33

HUARAZ



19	29	40	35	38
16	26	43	36	32
19	30	47	43	38
11	16	30	24	18

LA PAZ

21	35	51	45	42
23	37	45	44	44
25	30	38	31	30
30	39	44	39	36

JULIACA

2	4	3	2	4
1	1	2	1	2
#	#	#	#	#
#	#	#	1	1

COCHABAMBA

#	#	10	12	8
0	#	9	16	9
2	11	30	47	38
2	11	29	38	35

AREQUIPA

27	31	38	40	41
18	24	26	30	26
16	20	23	20	15
18	24	22	20	18

SUCRE

13	24	35	38	29
14	27	42	39	38
33	43	53	52	56
na	na	na	na	na

CHARANA

27	28	49	48	47
23	38	62	54	44
52	59	51	50	42
36	47	56	44	39

LA QUIACA

8	20	29	29	20
8	25	33	31	26
26	41	45	47	41
24	31	39	40	31

ORURO

WET SEASON
CEILINGS BELOW 3,000 FEET
(PERCENT)
- LESS THAN 0.5 PERCENT
na - DATA NOT AVAILABLE

	NOV	DEC	JAN	FEB	MAR
08 L					
11 L					
17 L					
20 L					

Figure 3-27. Wet-Season Frequencies of Ceilings Below 3,000 Feet (915 meters).

Tropical Ranges Sky Cover North of 16° S.

Cordillera Oriental/Central. Skies are broken-to-overcast with cumulus, towering cumulus, and cumulonimbus. Bases are 6,000-10,000 feet (1,830-3,050 meters) MSL between 1200 and 1800L. Tops rarely exceed 15,000 feet (4,570 meters) MSL before 1200L, but may exceed 25,000 feet (7,620 meters) as early as 1400L. The cloud forests along the Cordillera Oriental's eastern slopes are regularly covered by thick cumulonimbus at or above 6,000 feet (1,830 meters) MSL by 1000L. River valleys may be cloudless while cumulus cells on the slopes produce rain showers.

River valleys along the Cordillera Oriental open to warm, moist low-level Amazon flow have scattered cumulus above the valley floor by 1100L. Bases average 4,000 feet (1,220 meters) AGL. Tops rarely exceed 11,000 feet (3,350 meters) MSL. Adjacent ridge crests may be totally obscured in cloud by 1200L, with tops exceeding 30,000 feet (9,145 meters) MSL by 1600L.

Valley floors in the Cordillera Central are covered by less cumulus than in the Cordillera Oriental. Airflow along valley floors moves southward and upward; towering cumulus and cumulonimbus bases move south or southeast along the north-south oriented ridge crests, but cloud towers move slowly westward with upper-level easterlies. Since most valleys slope upward from north to south--especially the Maranon River Valley--cloud cover concentrates at the southern ends. Scattered cumulus with bases averaging 12,000 feet (3,660 meters) MSL and tops to 20,000 feet (6,100 meters) MSL are common along the ridge crests of many valleys north of 10°S. Between 10 and 16° S, broken-to-overcast conditions are common. Cumulus bases are 14,000 feet (4,270 meters) MSL, with tops to 25,000 feet (7,620 meters) MSL.

Between 8 and 14° S, cloud cover spills over into the Cordillera Central's river valleys. The "spillover" cloud cover rarely expands vertically because development is limited by descending motion along leeside slopes. Altocumulus, stratocumulus, and fractocumulus are common. Bases average 3,000 feet (915 meters) AGL. Clouds are rarely more than 1,000 feet (305 meters) thick. Embedded cumulonimbus and towering cumulus along the ridge crest may be obscured from the valley floor.

Residual moisture from late afternoon convection may reform into isolated cloud "clusters" after 2000L in the Cordillera Central. Most clusters form in areas of upper-level divergence associated with the Bolivian High. Favored regions for development are between 5 and 8° S (at 77° W), and between 12 and 16° S (at 73° W) where mountain winds and easterly synoptic flow converge at the surface. Bases average 12,000 feet (3,660 meters) MSL with tops to 40,000 feet (12,190 meters). Occasionally, tops reach 50,000 feet (15,240 meters).

Early morning stratocumulus usually forms along mountain slopes and above valley floors after a night of rainfall. Bases average 4,000 feet (1,220 meters) AGL, but are occasionally between 2,000 and 3,000 feet (610-915 meters) AGL along shaded slopes between 0600 and 1000L.

Cordillera Occidental. Scattered cumulus clouds form along mountain peaks above 12,000 feet (3,660 meters) MSL. Tops rarely exceed 17,000 feet (5,180 meters). Isolated cumulonimbus and towering cumulus are only common after 1800L when late afternoon convection along the Cordillera Central regenerates into large cloud clusters north of 9° S.

Thin, patchy radiation fog and shallow stratocumulus may form along valley floors between 5 and 11° S by 2200L. Ceilings may be as low as 500 feet (150 meters) AGL. The fog usually burns off by 1000L, but along steep shaded slopes, thin fog may persist until 1200L or become thin stratocumulus with bases at or above 2,000 feet (610 meters) AGL. Stratocumulus without fog usually dissipates by 1000L unless a thunderstorm developed overnight. Stratocumulus may reform after 1900L in the wake of heavy late afternoon convection. In fair weather, cirrus and altocumulus dominate; clouds are scattered around peaks between 15,000 and 25,000 feet (4,570-7,620 meters) MSL.

Tropical Ranges Sky Cover South of 16° S.
Cordillera Oriental/Central/Real. Broken cumulus forms on the eastern slopes of Cordillera Oriental and Cordillera Real. Ceilings average 15,000 feet (4,570 meters) MSL with tops to 25,000 feet (7,620 meters) MSL. Between late January and late March, tops to 45,000 feet are not uncommon after 1600L along the Cordillera Real between 16 and 17° S, the Cordillera Central from 17 to 21° S, and the Cordillera Oriental from 16 to 23° S.

On rare occasions, thin stratocumulus with bases at or above 10,000 feet (3,050 meters) MSL forms in the wake of nocturnal thunderstorms. It is rarely more than 1,000 feet (305 meters) thick. Along the western Cordillera Central between 17 and 22° S, the stratocumulus fsorm along the main ridge lines above 13,000 feet (3,960 meters) MSL.

Cordillera Occidental. There is rare cumulus development in localized areas of upper-level divergence along the Bolivian High's ridge axis between 16 and 20° S. Persistent upper-level westerlies and orographic lift occasionally produce scattered cumulus along main ridge lines above 13,000 feet (3,960 meters) MSL. Towering cumulus may develop in upland valleys by 1700L, but tops rarely exceed 35,000 feet (10,670 meters) MSL. Early morning stratus and stratocumulus between 8,000 and 12,000 feet (2,440-3,660 meters) MSL are possible from 0100 to 0900L. Light winds in river valleys opening to the coastal desert plain are most susceptible to thin, patchy low cloud. Bases near 9,000 feet (2,745 meters) MSL are common.

Altiplano Sky Cover.
Radiation fog forms in low-lying areas between 2200 and 0800L. Stratocumulus may develop between 0700 and 1000L. Bases average 3,000 feet (915 meters) AGL, but tops rarely exceed 10,000 feet (3,050 meters) AGL. By 1200L, it is replaced by scattered cumulus with bases at or above 14,000 feet (4,270 meters) MSL and tops to 20,000 feet (6,100 meters) MSL. Isolated towering cumulus forms along isolated ranges; In January and February, tops reach 30,000 feet (9,145 meters) MSL by 1400 or 1500L. There is heavy convection along the southeastern Altiplano between 1400 and 2000L; cells may have 10,000-foot (3,050-meter) bases and tops exceeding 50,000 feet (15,240 meters) MSL.

VISIBILITY. Early morning radiation fog, heavy afternoon rainfall, and blowing dust are the main obstructions to vision. Radiation fog occurs most often between 2300 and 0800L along the western slopes of the Cordillera Occidental and connecting valleys; light winds and clear skies may lower visibilities below 3 miles for short periods between 0400 and 0700L. Visibility between 4 and 6 miles is common with thin fog along the shorelines of large lakes in the Altiplano. Thick fog with visibility below 1 mile is possible in low-lying areas. Figure 3-28a shows mean wet season fog days for the Central Andes.

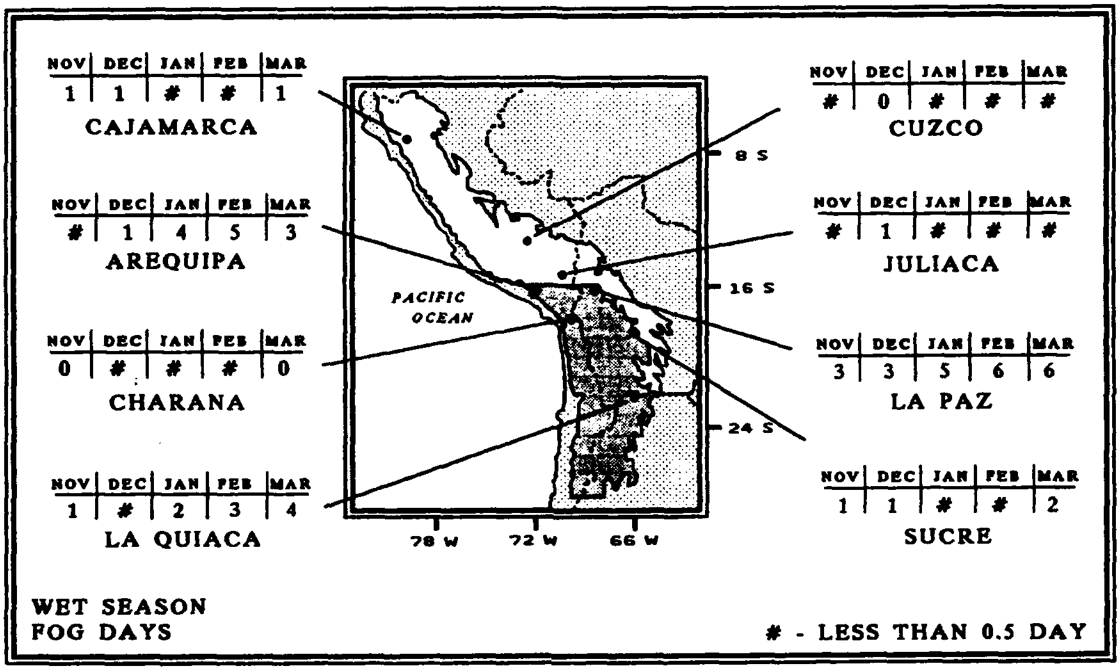


Figure 3-28a. Mean Number of Wet-Season Fog Days.

Between 1200 and 1800L, heavy rainfall frequently lowers visibility below 3 miles for several minutes to an hour along most ridge crests. Visibility may drop to zero with heavy rain, hail, and strong winds. The station data for the Central Andes (Figure 3-28b) shows percent occurrence frequencies of visibilities below 3 miles; the data may be misleading, however, because most reporting stations are on valley floors and much of the heavy rainfall and low visibilities occur in uninhabited forests along mountain slopes.

On the Altiplano, dry conditions allow downburst winds to stir up dust. Visibility may drop below 1 mile for 10 to 30 minutes. Heavy rain may produce zero visibility for several minutes on isolated peaks.

CHACHAPOYAS

	NOV	DEC	JAN	FEB	MAR
07 L	2	2	3	2	2
10 L	#	#	#	#	0
13 L	#	#	#	#	#
16 L	#	#	#	#	0

HUANUCO

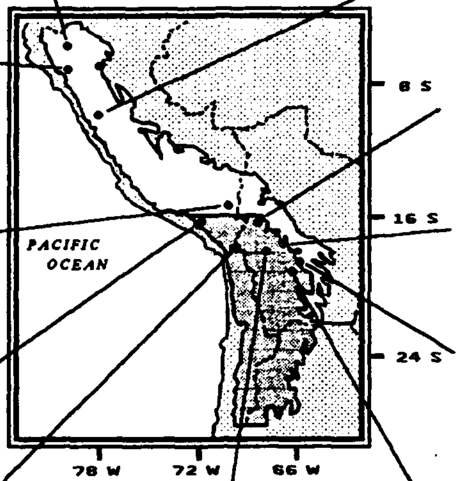
	NOV	DEC	JAN	FEB	MAR
07 L	#	1	#	2	1
10 L	0	#	#	#	#
13 L	#	0	#	#	#
16 L	#	#	#	#	#

CAJAMARCA

	NOV	DEC	JAN	FEB	MAR
07 L	#	#	#	#	#
10 L	0	0	#	#	#
13 L	0	0	0	#	0
16 L	#	0	#	0	0

LA PAZ

	NOV	DEC	JAN	FEB	MAR
07 L	1	1	2	1	2
10 L	#	0	#	#	#
13 L	#	0	#	#	#
16 L	#	#	#	#	#



JULIACA

	NOV	DEC	JAN	FEB	MAR
07 L	#	#	#	#	#
10 L	0	0	#	#	0
13 L	#	#	#	#	#
16 L	0	0	#	#	#

COCHABAMBA

	NOV	DEC	JAN	FEB	MAR
07 L	1	2	3	2	2
10 L	#	#	1	1	1
13 L	#	#	1	1	1
16 L	#	1	1	1	#

AREQUIPA

	NOV	DEC	JAN	FEB	MAR
07 L	0	1	9	18	4
10 L	0	#	2	5	#
13 L	#	#	4	4	1
16 L	0	2	9	17	7

SUCRE

	NOV	DEC	JAN	FEB	MAR
07 L	3	3	5	8	5
10 L	1	0	3	2	2
13 L	1	#	1	1	1
16 L	#	1	3	1	#

CHARANA

	NOV	DEC	JAN	FEB	MAR
07 L	2	#	2	2	1
10 L	#	#	1	1	#
13 L	#	1	2	1	1
16 L	2	3	4	3	4

ORURO

	NOV	DEC	JAN	FEB	MAR
07 L	1	5	6	1	2
10 L	#	1	1	#	2
13 L	#	1	#	#	3
16 L	2	4	2	2	1

POTOSI

	NOV	DEC	JAN	FEB	MAR
07 L	#	1	2	1	2
10 L	0	#	#	0	1
13 L	0	#	2	#	0
16 L	1	#	1	0	0

WET SEASON
VISIBILITY BELOW 3 MILES
(PERCENT)
- LESS THAN 0.5 PERCENT

	NOV	DEC	JAN	FEB	MAR
07 L					
10 L					
13 L					
16 L					

Figure 3-28b. Wet-Season Percent Frequencies of Visibility Below 3 Miles.

GENERAL WINDS. A two-tiered wind profile distributes moisture to the Central Andes between 5 and 20° S. Low-level winds have two components: a Pacific airstream with westerlies, and an Atlantic (or Amazon) airstream with easterlies. The Pacific flow is stable and dry; it affects only the Cordillera Occidental. The Atlantic flow is unstable and moist; it affects the Cordillera Central and Cordillera Oriental.

South of 20° S, the low-level flow entering the Cordillera Oriental and Altiplano is generated by the Northwest Argentine Depression (NAD). In the middle and upper levels, mid-latitude westerly and southwesterly winds converge with northwesterlies over the southern Altiplano and Cordillera Occidental.

Terrain is important in determining prevailing surface winds at nearly every station. Stations in the Cordillera Occidental are the only locations where a nocturnal mountain breeze ispronounced. January wind roses for the Central Andes are shown in Figure 3-29. Figure 3-30 shows mean surface wind speeds for all hours at several stations in the Central Andes.

Winds in the Tropical Ranges.

Cordillera Oriental. Winds are easterly to northerly from 5 to 20° S. Extensive river valley networks modify low-level flow between 5,000 and 15,000 feet (1,525-4,570 meters) MSL. Low-level flow selectively penetrates the higher elevations, flowing upstream along valley floors. In the Apurimac, Maranon, and other extensive north-south river valleys, northerlies move upslope along valley floors.

Below 1,000 feet (305 meters) AGL, wind speeds after 1400L may exceed 15 knots. Along steeply-sloped terrain above 8,000 feet (2,440 meters) MSL, speeds may reach 20 knots as air rises toward the ridge crest. Along the crests, easterlies converge with the upslope flow. Light and variable winds are common at night along valley floors.

Cordillera Central. The Bolivian High produces moderate easterly flow north of 12° S above 15,000 feet (4,570 meters) MSL. Speeds range between 10 and 20 knots. South of 12° S, winds turn to the northwest from 8 to 15 knots. Above 15,000 feet (4,570 meters) MSL, flow is not affected by terrain. The Bolivian High's ridge axis is oriented WNW to ESE across central Peru between 12 and 16° S. Easterlies north of the ridge recurve over the Pacific, becoming northerly, then northwesterly between 75 and 80° W. Northwesterlies may not develop until 85 or 90° W if the ridge intensifies across central Peru.

The Maranon River Valley is the only place below 10,000 feet (3,050 meters) MSL where local influences may override Bolivian High outflow. Here, wind speeds average only 5 to 8 knots between 5 and 7° S, but 10 to 15 knots between 7 and 10° S. Light easterly or southerly mountain breezes range from 2 to 5 knots. Calm conditions at night are common north of 7° S. High terrain surrounding the Maranon Valley between 8 and 10° S is snow-capped from December to March. Local mountain breezes can produce 10-knot winds. Thunderstorm activity may produce sudden wind shifts with gusts exceeding 40 knots, day or night.

Cordillera Occidental. Light easterlies prevail from 5 to 9° S. Dry, subsiding northwesterlies dominate between 9 and 16° S--speeds range from 8 to 20 knots. Below 10,000 feet (3,050 meters) MSL, weak Pacific southerlies or westerlies occasionally penetrate the western foothills north of 16° S through a series of short, connected river valleys. Northwesterlies change to mid-latitude westerlies and southwesterlies between 18 and 24° S--speeds average 9 knots. South of 20° S, westerlies and southwesterlies dominate--speeds average 15 knots, but reach 25 knots. Mountain winds are weak.

Winds on the Altiplano.

Winds are variable between 16 and 20° S. If the Bolivian High dominates the flow pattern, speeds are only 5 to 10 knots above 15,000 feet (4,570 meters) MSL and direction is determined by terrain. Westerlies prevail south of 20° S. Speeds are highest (15 to 25 knots) between 1300 and 1500L. On rare occasions, upper-air troughs or isolated thunderstorms produce 40- to 50-knot gusts. Most drainage winds on the plateau are light and variable.

Winds on the Altiplano, Cont'd.
Between 20 and 25° S, synoptic flow changes from northerly to westerly or southeasterly in the extreme southeastern sections of the Altiplano. Southeasterlies along the eastern slopes of the Cordillera Oriental penetrate the plateau. Above 8,000 feet (2,440 meters) MSL, westerlies dominate all mountain ranges south of 25° S; local mountain-valley breezes or weak troughs resulting in the only exceptions.

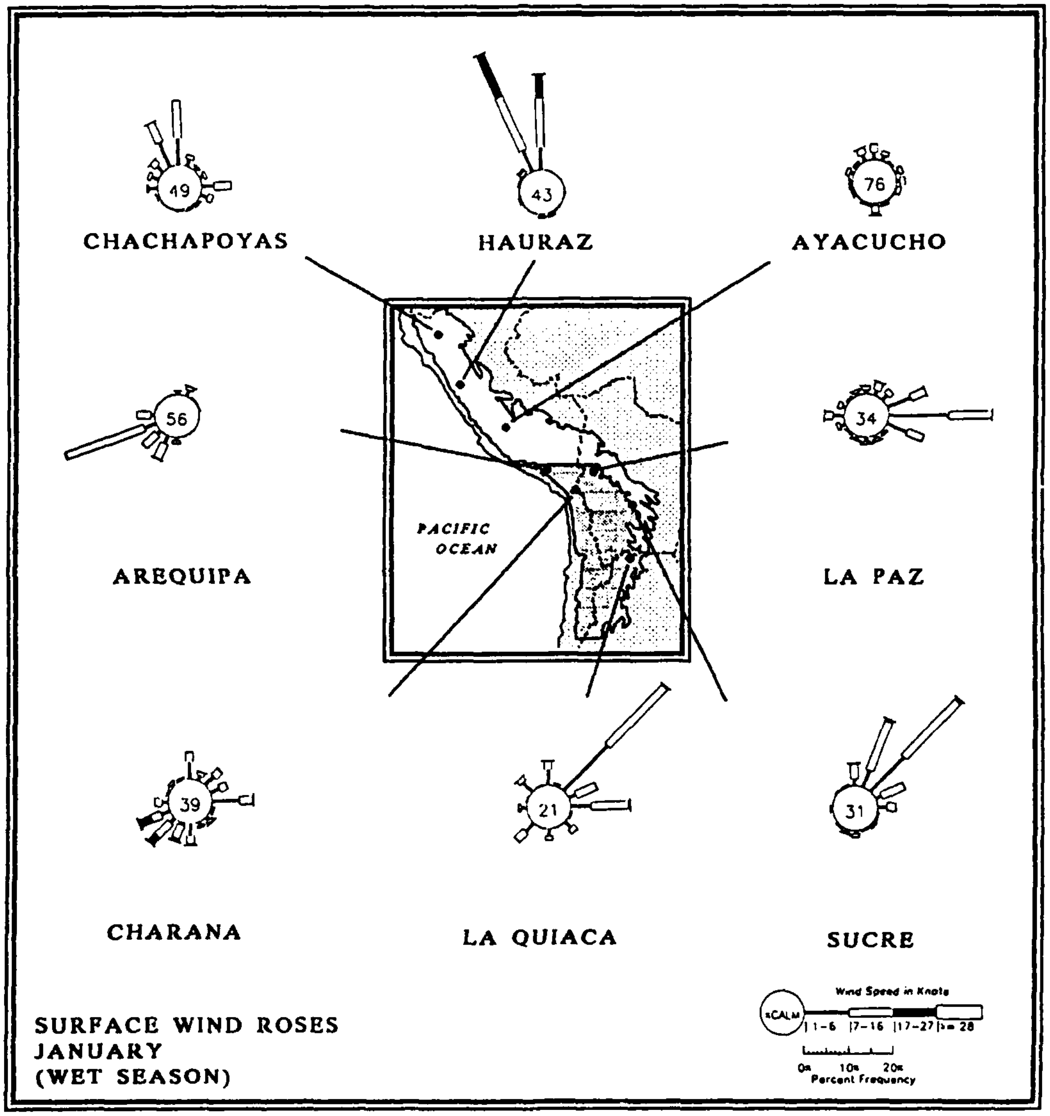


Figure 3-29. January Surface Wind Roses, Central Andes.

STATION	MEAN WIND SPEED				
	NOV	DEC	JAN	FEB	MAR
AREQUIPA	5	4	4	4	4
CAJAMARCA	3	3	4	3	3
CALAMA	16	17	16	15	15
LA PAZ	5	5	5	5	5
LA QUIACA	8	7	7	6	6
ORURO	8	8	7	7	7

Figure 3-30. Mean Surface Wind Speeds (kts).

Figure 3-31 shows mean upper-air wind directions at La Paz, Bolivia. From November to March, winds are northeast to southeast to 30,000 feet (9,145 meters) MSL; maximum speeds range from 28 knots (November) to 20 knots (January and March) and are found between 41,000 and 46,000 feet (12,500-14,025 meters) MSL. At 25° S (Salta, Argentina), mean wind direction is westerly at all levels above 15,000 feet between November and March. Maximum speeds are The highest speeds occur in November (60 knots at 41,000 feet/12,500 meters MSL); the lowest, in February (35 knots).

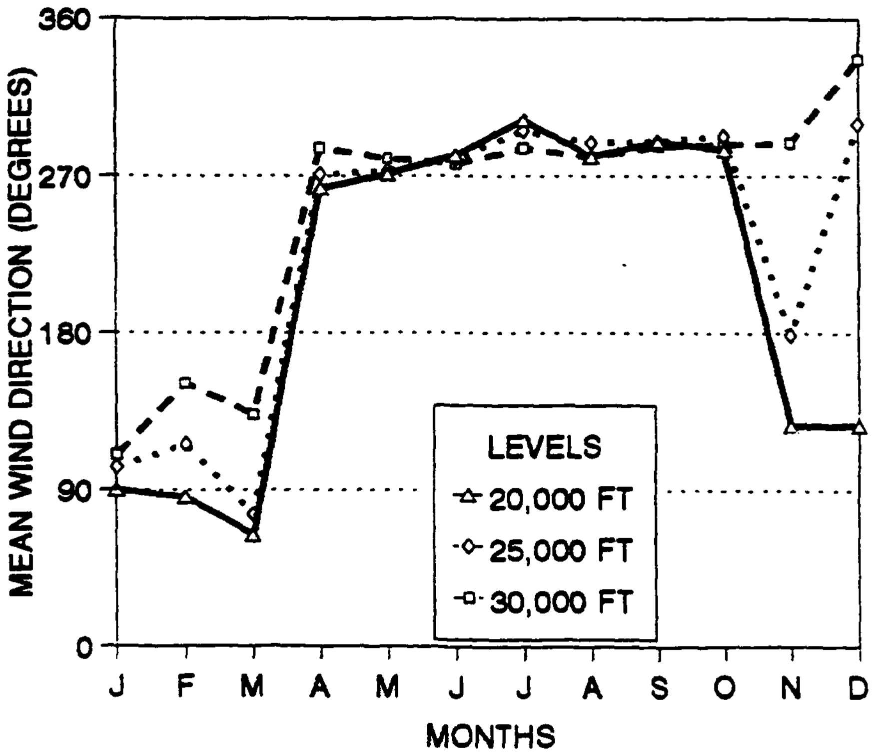


Figure 3-31. Mean Monthly Wind Direction at Various Levels, La Paz, Bolivia.

CENTRAL ANDES PRECIPTATION. Figure 3-32 shows average January precipitation for the Central Andes. The central Cordillera Oriental (10-14° S, 71°-72 W) and Cordillera Central (8-10° S, 75-77° W) are the wettest. Highest precipitation amounts are found immediately east of the Urubamba, Apurimac, and Huallaga river valleys. Low-level easterlies recurve in these valleys to northerly or northwesterly as they move upward into the southern ends of the valleys. Convergence between these winds and easterlies above the Cordillera Oriental and Central ridge crests produce heavy rainfall from 1100 to 1700L nearly every day. Heavy rains fall on east-facing slopes; rainfall can exceed 2 inches (51 mm) an hour. Individual cells move westerly until 69° W, then southerly to southeasterly along the upwind side of the Bolivian High ridge axis. West-facing slopes of the Cordillera Real and south-facing slopes of the Cordillera Central have 1 or 2 showers a day. Moisture from Lake Titicaca may produce a short-lived, late afternoon thunderstorm; rates of 1 inch an hour are common.

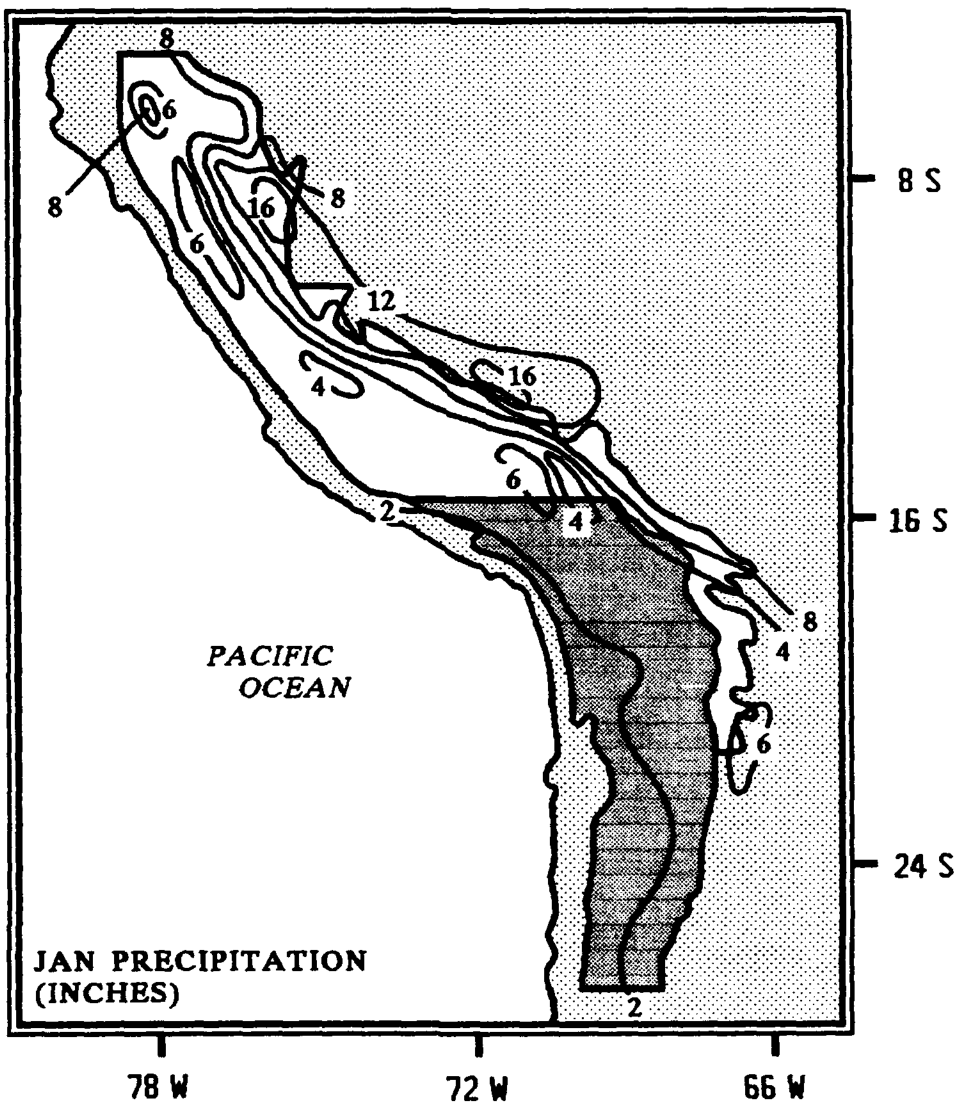


Figure 3-32. Mean January Precipitation, Central Andes.

Tropical Ranges Precipitation.
Cordillera Oriental. Widespread showers or isolated thunderstorms are common by 1400L along the Cordillera Oriental's eastern slopes. Small hail is possible above 12,000 feet (3,660 meters) MSL. Spillover onto western slopes is usually limited to heights within 2,000 feet (610 meters) of the ridge crests. Scattered light-to-moderate rainshowers are common between 1200 and 1600L. The successive ranges to the west are dominated by isolated rain showers from cirrus blow-off. It is not uncommon for heavy convection to develop at the southern end of extensive river valleys after 1600L. Strong valley winds often converge with easterly synoptic flow along ridge crests.

Cordillera Central. A complex ridge and valley network of high peaks and long, deep NNW-SSE valleys produces extremely variable rainfall distributions. Mountain slopes have several short-lived periods of moderate-to-heavy showers and occasional thundershowers every day. Rain usually falls 4,000-5,000 feet (1,220-1,525 meters) above the valley floor along adjacent slopes. Brief, scattered light or moderate rainshowers may reach valley floors, but heavy rain is rare unless cumulonimbus develops into large cloud clusters in the upper (southern) ends of the range.

Snowfall is limited to peaks above 17,000 feet (5,180 meters) MSL. Short periods of wet snow mixed with hail and rain may fall with heavy convection in the Cordillera Central between 8 and 11° S.

Cordillera Occidental. Rainfall below 15,000 (4,570 meters) MSL is rare between 8 and 16° S, but isolated light showers occur along major ridge crests and isolated peaks. Showers rarely last more than 15 minutes. A well-developed El Niño event can produce heavy rainfall if Pacific low-level moisture moves inland along the western Occidental; widespread showers and thundershowers may develop between 1200 and 1800L, and heavy rainfall can exceed 2 inches (51 mm) an hour.

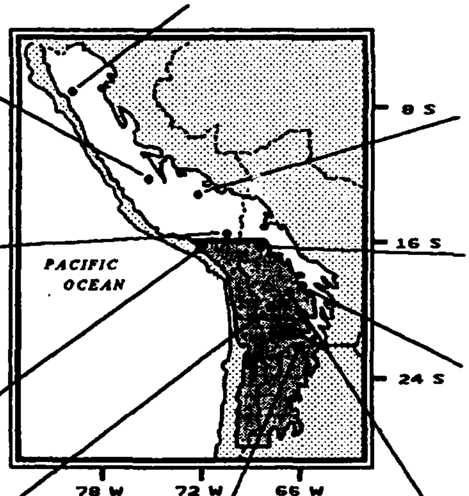
The section of the Occidental between 16 and 24° S is in the rain shadow of the Cordilleras Oriental and Central. Late afternoon rainfall is rare below 17,000 feet (5,180 meters) MSL except near isolated peaks. Light snow may fall above 20,000 feet (6,100 meters) MSL. Light drizzle occurs once or twice a wet season when a cirrus canopy drifts westward over this area. Nocturnal rainfall is possible because mountain breezes are pronounced. River valleys in the Cordillera Occidental do not have strong easterlies to override the mountain breeze--as a result, areas of convergence occasionally develop short-lived showers. Rainfall totals rarely exceed 0.1 inch (2.5 mm).

Strong upper-air troughs may produce late afternoon showers and thundershowers south of 24° S. Narrow convergence lines regularly develop above 20,000 feet (6,100 meters) MSL. Rainfall totals may exceed 0.5 inches (13 mm). Heavy convection can, in rare cases, spill eastward into southwestern Bolivia between 69 and 67° W, but only if westerly upper-level flow is moist and there is moist, unstable southerly flow behind the trough axis.

Altiplano Precipitation. The wet season on the plateau (December through February) is shorter than in the mountains to the north because it is sheltered on all sides. Also, the Bolivian High, which must be present to sustain diurnal convection, is only over the plateau for this short period. Low-level moisture must enter the high plateau through narrow river valleys, and the air mass is often modified before it gets there. The rest of the time, dry westerlies from the Pacific and mid-latitudes prevail. Maximum monthly rainfall occurs in February when Bolivian High outflow is strongest.

Most Altiplano precipitation falls as scattered diurnal thundershowers between 1200 and 1900L. Heaviest rainfall is concentrated along isolated mountain peaks, but thundershowers and thunderstorms (occasionally severe) may propagate onto the plateau from the Cordillera Real or the Cordillera Oriental. With upper-air troughs, widely-scattered areas of steady rainfall may be present on 3 or 4 days of each wet season.

Mean monthly precipitation for stations on the Altiplano (the shaded area in Figure 3-33) ranges between 0.3 and 4.4 inches (8-112 mm), but in remote locations near isolated peaks, mean precipitation may be significantly higher or lower, depending on winds.



Station		NOV	DEC	JAN	FEB	MAR
CAJAMARCA	MEAN MONTHLY	2.4	3.2	3.6	4.1	4.9
	MAXIMUM MONTHLY	4.3	5.3	7.7	7.1	6.8
	MAXIMUM 24-HOUR	1.9	2.0	1.4	1.4	1.2
HUANCAYO	MEAN MONTHLY	2.7	3.5	5.6	4.4	4.5
	MAXIMUM MONTHLY	5.9	6.2	7.8	7.3	9.1
	MAXIMUM 24-HOUR	1.5	1.3	1.3	1.2	1.6
CUZCO	MEAN MONTHLY	3.4	5.5	6.1	5.7	4.3
	MAXIMUM MONTHLY	9.8	9.8	8.9	7.2	5.9
	MAXIMUM 24-HOUR	2.4	1.9	2.6	1.6	1.4
PUNO	MEAN MONTHLY	2.0	2.2	4.8	4.4	3.0
	MAXIMUM MONTHLY	10.7	3.8	8.5	9.4	4.1
	MAXIMUM 24-HOUR	0.4	1.1	1.3	0.7	0.9
LA PAZ	MEAN MONTHLY	1.9	3.7	4.6	4.0	2.7
	MAXIMUM MONTHLY	5.4	6.4	9.7	7.0	6.7
	MAXIMUM 24-HOUR	1.6	1.4	1.0	2.0	1.1
AREQUIPA	MEAN MONTHLY	#	0.3	1.5	1.8	0.7
	MAXIMUM MONTHLY	0.3	0.4	8.2	5.7	0.9
	MAXIMUM 24-HOUR	0.2	0.2	2.3	2.0	0.6
SUCRE	MEAN MONTHLY	2.6	4.3	7.3	4.9	3.7
	MAXIMUM MONTHLY	3.6	5.0	5.6	11.5	16.0
	MAXIMUM 24-HOUR	0.7	1.4	1.4	1.8	2.0
UYUNI	MEAN MONTHLY	0.2	0.8	1.7	1.6	0.5
	MAXIMUM MONTHLY	1.7	4.4	7.9	4.4	4.0
	MAXIMUM 24-HOUR	na	na	na	na	na
LA QUIACA	MEAN MONTHLY	1.1	2.5	3.6	2.9	1.8
	MAXIMUM MONTHLY	3.7	5.7	9.0	6.7	4.8
	MAXIMUM 24-HOUR	1.2	1.3	1.7	1.2	1.1
POTOSI	MEAN MONTHLY	1.2	2.1	4.8	3.7	2.7
	MAXIMUM MONTHLY	1.6	1.3	3.8	6.3	10.0
	MAXIMUM 24-HOUR	na	na	na	na	na

WET SEASON
TABULAR PRECIPITATION DATA
(INCHES)
- LESS THAN 0.5 INCHES
na - DATA NOT AVAILABLE

Figure 3-33. Mean Wet-Season Precipitation (inches), Central Andes. The Altiplano (shaded area) has a shorter rainy season than in the surrounding mountains. As a result, November and March are often considered as "transition" seasons.

THUNDERSTORMS usually develop from mid- to late afternoon (1500 to 1800L) along most major ridge crests of the Cordillera Central between 8 and 11° S, in the Cordillera Real near Lake Titicaca, and in the southern Cordillera Oriental above 15,000 feet (4,570 meters) MSL. Strong valley breezes usually converge with moist, easterlies aloft. Cloud movement is usually southward or southwestward toward the Bolivian High ridge axis. Most thunderstorm cells are short-lived because the valley breeze usually dissipates by 1800L.

Nocturnal thunderstorms with frequent lightning and heavy rain may develop after 2000L along ridges on the southern ends of major river valleys. Outflow boundaries from dissipating convective cells and mountain breezes may converge along ridge crests above 16,000 feet (4,880 meters) MSL. These nocturnal storms are concentrated along the Cordillera Central from 5 to 10° S and in the Cordillera Real near Lake Titicaca. Moderate-to-heavy rainfall rarely exceeds 1 inch (25 mm) an hour. Cloud tops rarely exceed 40,000 feet (12,190 meters) MSL.

Rapidly-developing severe thunderstorms with large hail and strong winds are rare except in the Cordillera Real and southern Cordillera Oriental. A strong upper-air trough may cause widespread severe thunderstorm activity along the Cordillera Occidental and southern Altiplano south of 22° S. Thunderstorm days are shown in Figure 3-34.

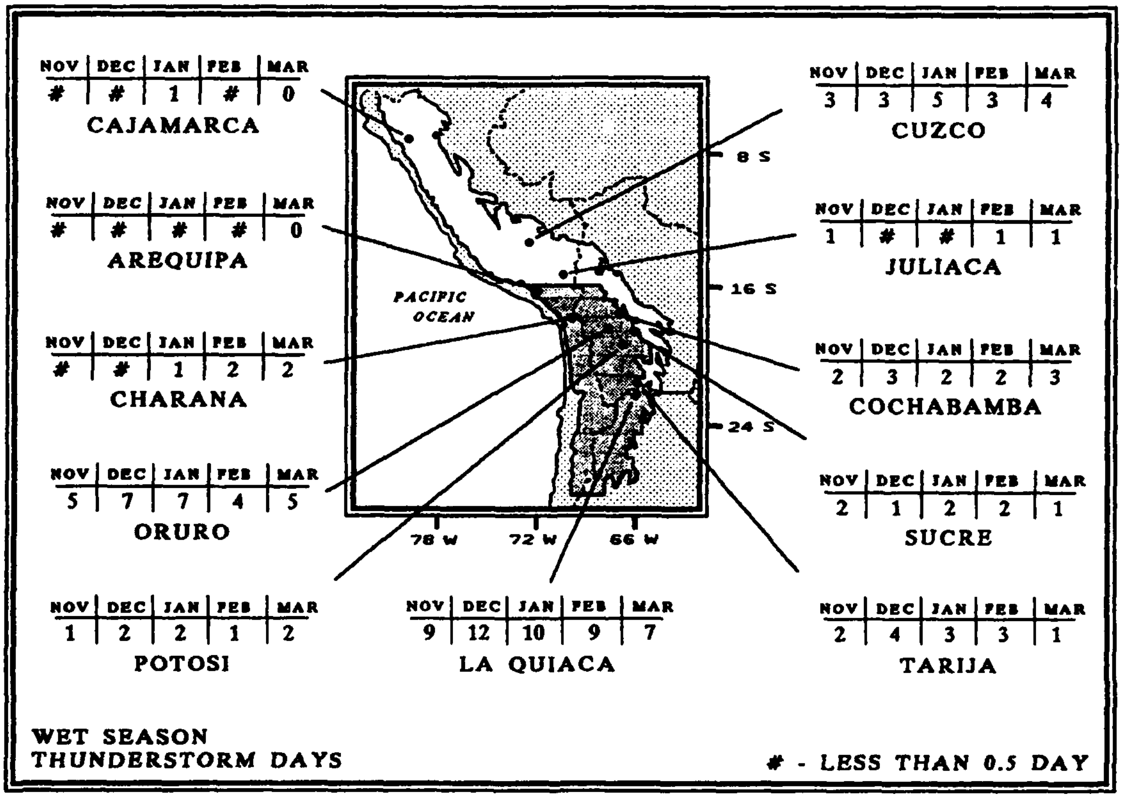


Figure 3-34. Mean Thunderstorm Days, Central Andes.

TEMPERATURE.

The Tropical Ranges. The unshaded area in Figure 3-35 shows temperature data for stations in the Tropical Ranges. On the eastern slopes of the Cordillera Oriental and the western slopes of the Cordillera Occidental below 10,000 feet (3,050 meters) MSL, mean daily highs range from 70 to 80° F (21-27° C). Mean daily lows range from 43 to 65° F (6-18° C). Highs may reach 90° F (32° C) before 1200L when daytime skies are cloud-free. Lows reach 23° F (-5° C) when strong polar fronts reach northern Chile and Argentina with clear and calm conditions.

Mean daily highs over the Cordillera Central and Cordillera Real range from 57 to 75° F (14-24° C). Diurnal temperature ranges are large. Mean daily lows range from 24 to 49° F (-4 to 9° C). Record lows reach 5° F (15° C). No wet-bulb globe temperature (WBGT) data is available for the Central Andes, but WBGTs must often exceed 80° F (27° C) along the extreme eastern slopes of the Cordillera Oriental between 6,500 and 10,000 feet (2,000-3,050 meters) MSL.

The Altiplano. The shaded area in Figure 3-35 shows temperature data for Altiplano stations. The average elevation on the Altiplano is 12,000 feet (3,660 meters) MSL; diurnal temperature ranges are large and daily highs extremely variable. Temperatures may rise or fall 15° F (6-7° C) within minutes after cloud cover dissipates or develops.

Mean daily highs on the Altiplano range from 56 to 72° F (13-22° C); lows range from 24 to 42° F (-04 to 06° C). The record low is -07° F (-22° C), but temperatures probably reach -15° F (-26° C) in remote canyons and glacier fields. The mean freezing level averages 16,000 feet (4,880 meters) MSL between November and March. Record highs range from 74 to 90° F (23-32° C). Highest temperatures usually occur south of 22° S when the Bolivian High temporarily shifts southward over the Altiplano.

81	81	79	79	79
72	72	71	70	70
44	45	47	47	47
28	21	23	23	27

CAJAMARCA

76	77	74	75	74
69	67	64	64	64
42	44	44	44	43
30	33	34	33	33

HUANCAYO

80	80	82	79	76
69	68	66	65	65
43	44	44	44	44
30	36	32	36	34

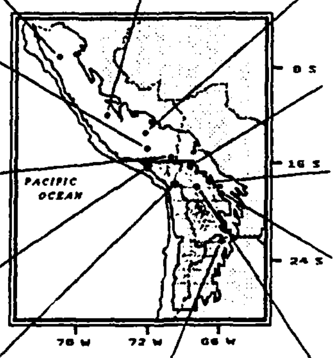
CUZCO

82	78	72	73	71
63	61	58	57	57
24	27	29	30	29
10	5	10	18	5

CAILLOMA

86	76	82	76	79
67	65	63	63	64
42	42	43	43	42
24	23	32	32	30

LA PAZ



75	75	72	73	73
66	65	62	62	62
36	37	38	38	38
25	28	28	26	28

PUNO

90	92	96	87	87
80	77	75	75	77
51	53	53	53	51
41	34	45	38	36

COCHABAMBA

82	82	79	84	79
72	72	71	70	71
43	45	46	46	45
27	30	32	30	32

AREQUIPA

79	78	80	75	82
68	66	62	62	64
48	49	48	48	48
40	41	40	41	38

SUCRE

81	77	78	77	74
67	64	62	62	64
24	27	32	32	29
7	10	16	19	11

CHARANA

86	86	87	90	87
73	72	69	70	70
38	41	42	42	40
22	27	26	30	23

LA QUIACA

79	79	77	74	74
65	64	61	62	62
47	48	47	47	46
19	21	25	28	18

ORURO

WET SEASON TEMPERATURES (F)

	NOV	DEC	JAN	FEB	MAR
EXTREME MAXIMUM					
AVERAGE MAXIMUM					
AVERAGE MINIMUM					
EXTREME MINIMUM					

Figure 3-35. Wet-Season Tabular Temperature Data (° F).

FLIGHT HAZARDS. The usual thunderstorm hazards are present along the highest ridge crests of the mountains. Moderate turbulence for light aircraft between 1200 and 1700L is possible in the Maranon, Huallaga, Apurimac, and other large valleys that separate the Cordillera Oriental and Central. Turbulence is caused by wind shear from two sources: intense daytime upslope winds and mesoscale outflow boundaries from heavy convection. Between 1000 and 0100L, 3/4-inch (19-mm) hail and downburst winds to 60 knots are possible.

GROUND HAZARDS. Heavy rains frequently wash out unpaved mountain roads. Bridges above deep river valleys are occasionally destroyed by landslides. Flash flooding in deep river valleys may occur with little or no warning. Early morning fog is possible between 0300 and 0900L along valley floors after nights of heavy rainfall. Over the Altiplano, clear nights often produce favorable conditions for radiation fog that usually burns off by 1000L.

GENERAL WEATHER. The moist low-level northeasterly and easterly flow recedes northward by late April, and a dry air mass begins to appear along the Cordillera Oriental south of 16° S. The South Atlantic High moves northwestward over the east Brazil coast, building a surface high-pressure ridge westward into the Amazon. The Bolivian High weakens and migrates northward to 8° S; there is no longer an outflow mechanism for sustaining heavy convection south of 16° S. South of 16° S, diurnal convective activity is driven locally by upslope valley flow and deep upper-air troughs. Mid-afternoon convection rarely develops below the highest ridge crests. North of 16° S, most diurnal convection occurs along the eastern Cordillera Oriental and Cordillera Central, which are closest to the low-level moisture source.

SKY COVER. Cumulus, jet-stream cirrus, and early morning stratus and stratocumulus are the primary cloud types. Localized convection dominates the Cordillera Oriental north of 16° S. By 1000L, cumulus develops along mountain slopes at 6,000 to 8,000 feet (1,830-2,440 meters) MSL. By 1400L, tops may exceed 20,000 feet (6,100 meters) MSL as thunderstorm cloud canopies move westward toward the Cordillera Central. North of 8° S, strong valley breezes may produce convergence lines along the highest ridge crests through 1800L in the Cordillera Central, but valley floors may be cloud-free. On rare occasions, thunderstorm cells exceed 40,000 feet (12,190 meters) MSL and move into the Cordillera Occidental. Convection may build through 2100L in the Cordillera Occidental. Thunderstorm bases average 10,000 feet (3,050 meters) MSL.

Slow-moving upper-air troughs produce cirrus at or above 35,000 feet (10,670 meters) MSL. Along the western Cordillera Occidental and the Altiplano south of 20° S, scattered altocumulus and towering cumulus may develop near the trough axis. Bases are 16,000 feet (4,880 meters) MSL and tops 22,000 feet (6,710 meters) MSL. Along the highest ridge crests, isolated thunderstorm cells can develop within small areas of upper-level divergence associated with the Subtropical Jet. Bases average 16,000 feet (4,880 meters) MSL with tops to 45,000 feet (13,720 meters) MSL. After the trough breaks down or passes over the Altiplano, temporary southeasterly flow may initiate heavy convection along the extreme southern sections of the Cordillera Oriental. Isolated thunderstorm cells reach 50,000 feet (15,240 meters) MSL and bases average 10,000 feet (3,050 meters) MSL.

During calm conditions, radiation fog, stratus, or stratocumulus forms over the Altiplano and interior mountain valleys between 2200 and 0700L. Patchy ground fog may develop into shallow stratus with bases near 3,000 feet (915 meters) AGL by 0800L. The stratus dissipates or lifts into shallow stratocumulus by 1000L. Stratocumulus forms at 4,000 to 5,000 feet (1,220-1,525 meters) AGL, but is rarely more than 1,000 feet (305 meters) thick. By 1200L, the stratocumulus dissipates or reforms into scattered cumulus along high terrain. Bases average 5,000 feet (1,525 meters) AGL. Tops rarely exceed 10,000 feet (3,050 meters) MSL. Ceilings below 3,000 feet (915 meters) AGL are shown in Figure 3-36.

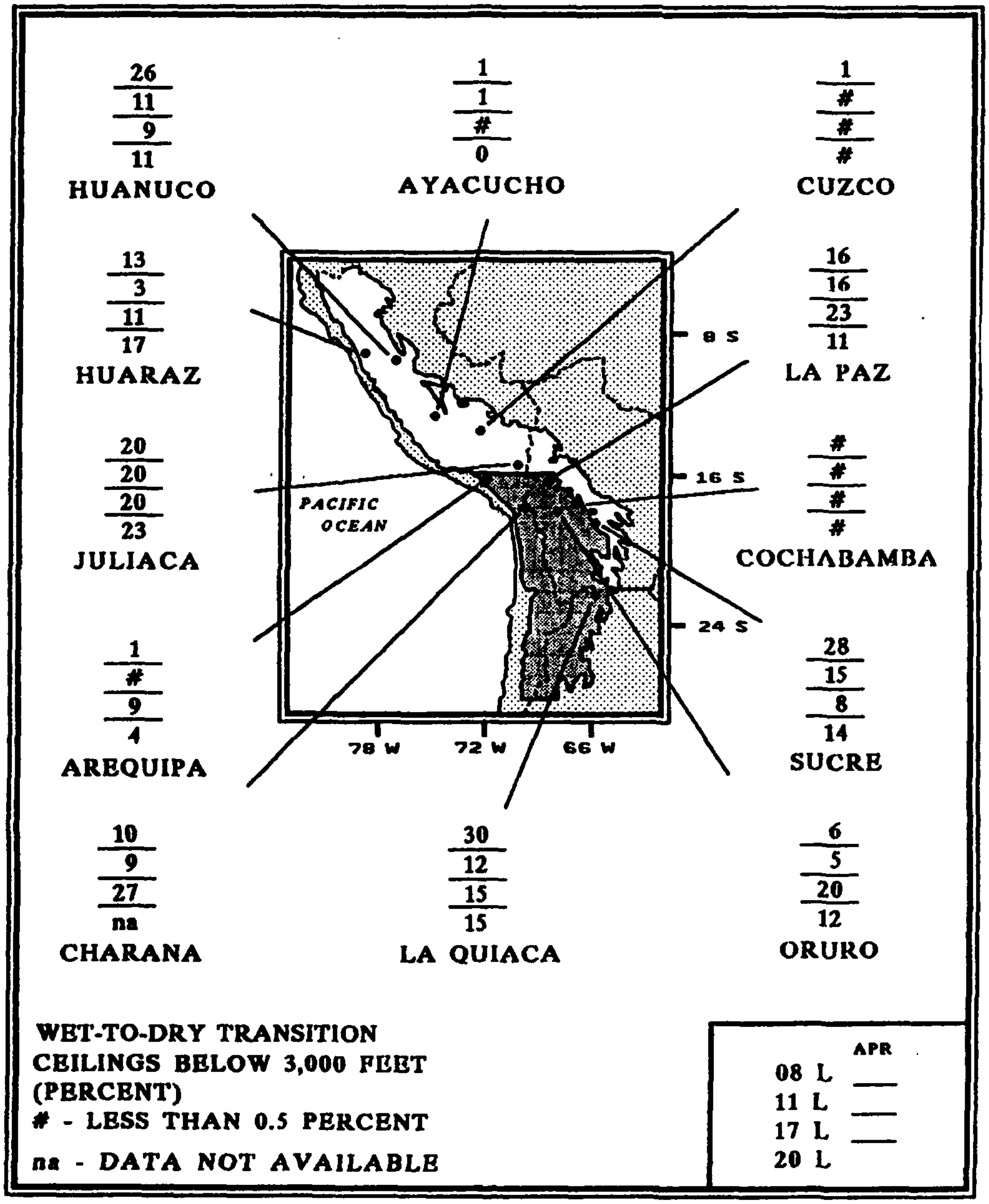


Figure 3-36. April Percent Frequencies of Ceilings Below 3,000 Feet (915 meters).

VISIBILITY. Early morning ground fog and heavy convective showers/thundershowers are the main obstructions to vision. Patchy fog frequently occurs in isolated river valleys between 2200 and 0700L. The main fog formation areas are: the western Cordillera Occidental, eastern Cordillera Oriental, and the numerous river valleys separating the western Cordillera Oriental and Central ranges. Visibility rarely drops below 3 miles between 2200 and 0100L except after heavy rainfall. Thick fog with visibility below 1 mile rarely occurs for more than 6 hours. Fog that forms between 0800 and 1400 rarely persists for more than 12 hours. Isolated fog is possible between 2300 and 0800L with calm conditions around Lake Titicaca and Lake Poopo because of the local moisture. Figure 3-37 shows April days with fog.

STATION	APRIL
AREQUIPA	1
CAJAMARCA	#
CHARANA	#
CUZCO	#
JULIACA	1
LA PAZ	4
LA QUIACA	4
SUCRE	2

- LESS THAN 0.5 DAY

Figure 3-37. Mean April Fog Days.

Much of the Altiplano is dry, flat desert terrain; strong winds may occasionally produce blowing dust or sand; visibility rarely drops below 1 mile. During extended periods of clear skies and no rainfall, dust haze may accumulate in stagnant air above the Altiplano. Industrial areas intensify the haze layer; visibility can drop to 3 or 4 miles for 5 to 9 days.

Heavy downpours may drop visibility to zero for up to an hour. Visibilities are below 3 miles for up to 3 hours after a heavy rainfall. The worst visibilities are found in remote canyons and valleys ascending major ridge crests. Figure 3-38 shows frequencies of visibilities below 3 miles for selected stations. The data may not accurately represent nearby locations where terrain and airflow favors fog formation or heavy convective activity.

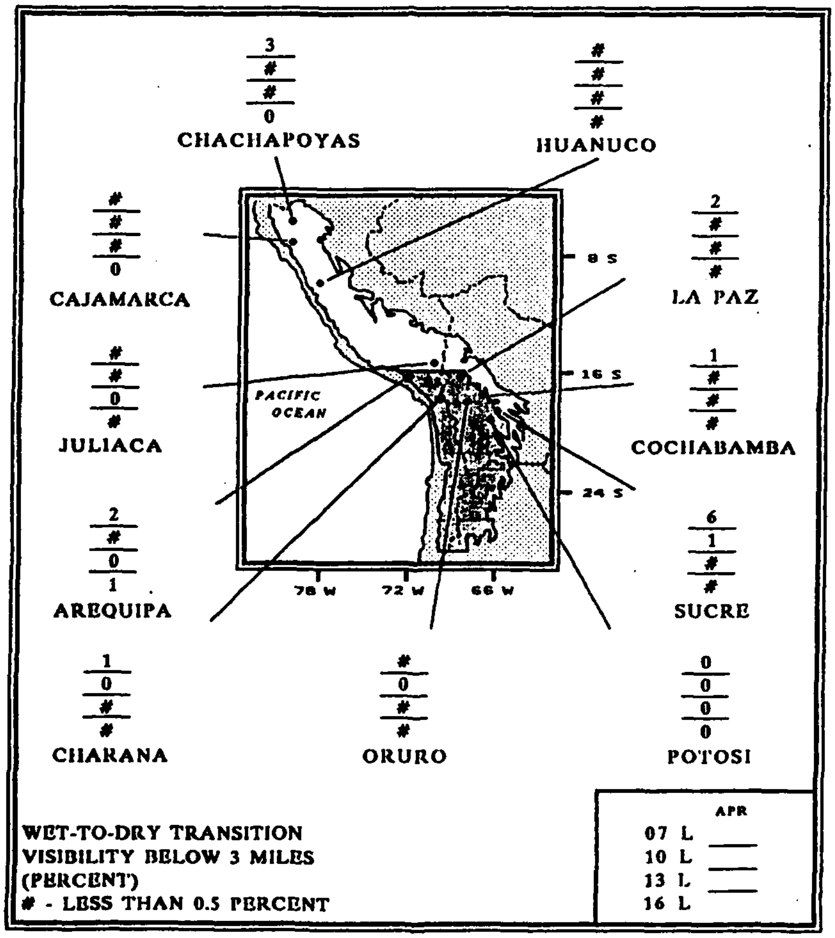


Figure 3-38. Percent Frequencies of Visibility Below 3 Miles.

WINDS. Synoptic-scale flow above 15,000 feet (4,570 meters) MSL is still controlled north of 12° S by the Bolivian High. Easterlies average 6 knots across the Cordillera Oriental and Cordillera Central. Northerlies are common in river valleys. In the mountains, the valley breeze increases wind speeds between 1000 and 1800L. The mountain breeze sometimes reaches 10 knots between 1900 and 0800L. Speeds may exceed 20 knots near snow-capped peaks and glacier fields.

The Cordillera Occidental is dominated by westerlies south of 10° S. Northwesterlies from the Bolivian High range from 5 to 15 knots and affect locations between 10 and 18° S above 15,000 feet (4,570 meters) MSL. South of 18° S, west to southwest winds at 8 to 15 knots are produced by the mid-latitude westerlies. The convergent flow over the Altiplano produces strong westerlies at the surface. In Figure 3-39, Calama, Chile, is shown as having much stronger mean April wind speeds than other stations in the Central Andes.

STATION	MEAN WIND SPEED APRIL
AREQUIPA	4
CAJAMARCA	3
CALAMA	15
LA PAZ	4
LA QUIACA	6
ORURO	5

Figure 3-39. Mean Surface Wind Speeds (kts).

Figure 3-40 gives wind roses for several stations in the Central Andes. The figure illustrates surface flow and local terrain effects, but also shows a well-defined quasi-stationary Bolivian High ridge axis dividing easterlies from westerlies. Note the predominance of northerlies and easterlies in the Tropical Ranges, while westerlies are more prevalent on the Altiplano and in the southern Cordillera Occidental.

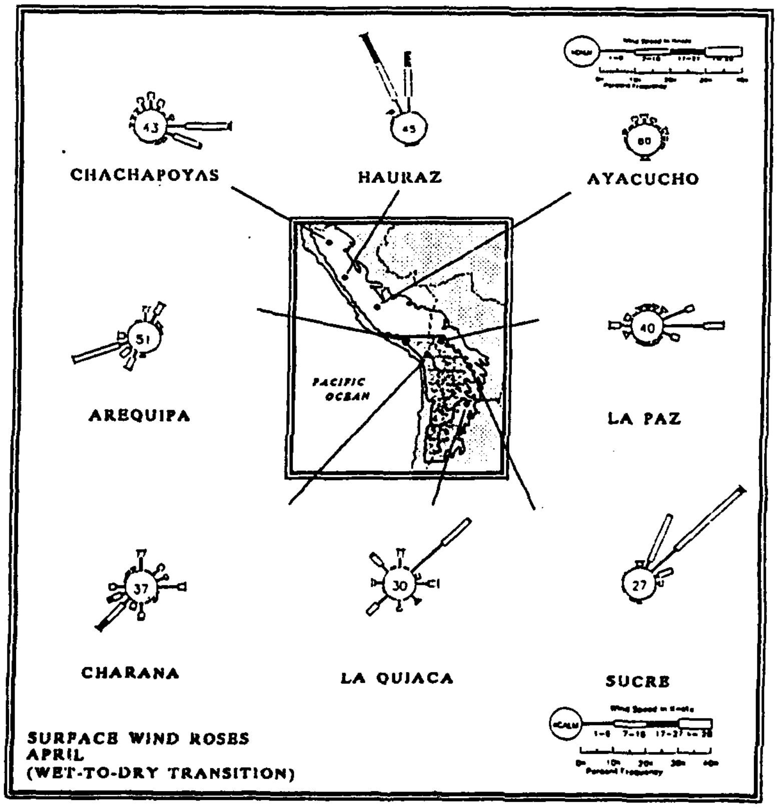


Figure 3-40. Surface Wind Roses–April.

In late April, mid- and upper-level polar troughs begin to increase in frequency across the southern Central Andes. Strongest winds along the trough axis may be associated with the Subtropical Jet. Mean April wind speed at 41,000 feet (12,495 meters) MSL at 25° S is 62 knots; near 16° S, the mean wind speed is only 37 knots. A branch of the Subtropical Jet is usually present south of 16° S during April. Upper-air troughs often stall or dissipate across the Altiplano. Shifting winds aloft and variable speeds often accompany these decaying troughs. Wind shear and mountain wave turbulence can be widespread for up to 72 hours after the trough breaks down.

PRECIPITATION. Mean April rainfall (Figure 3-41) rarely exceeds 2 inches (51 mm) except along the Cordilleras Oriental and northern Cordillera Central (5 to 9° S). Moderate-to-heavy rain rarely lasts for more than 30 minutes and usually occurs between 1400 and 1800L; maximum 24-hour totals rarely exceed 2 inches (51 mm). Small hail is possible along mountain slopes above 16,000 feet (4,880 meters) MSL. The permanent snow line is between 15,500 and 17,500 feet (4,725-5,335 meters) MSL, but it varies locally. Most snowfalls are less than 6 inches (154 mm). Figure 3-42 shows station precipitation data for the Central Andes.

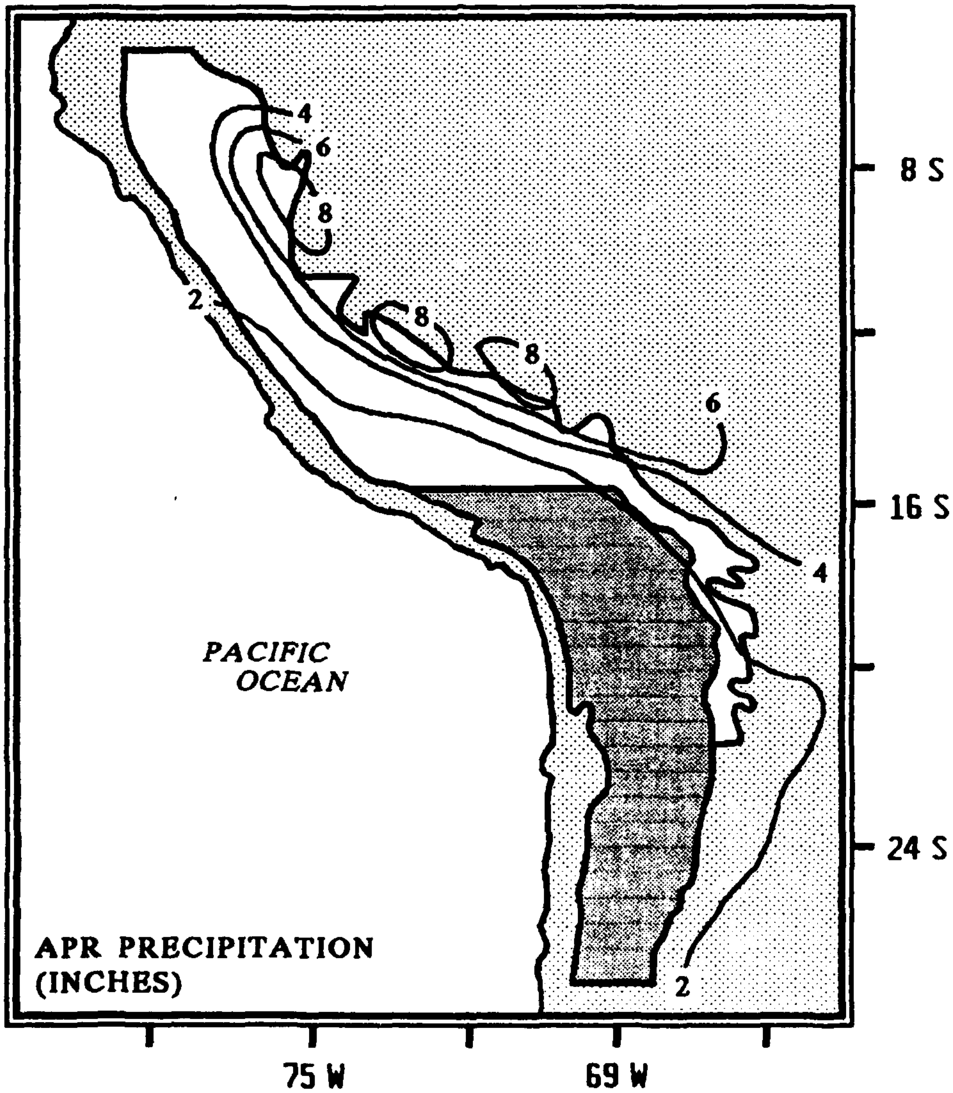


Figure 3-41. Mean April Precipitation (mm).

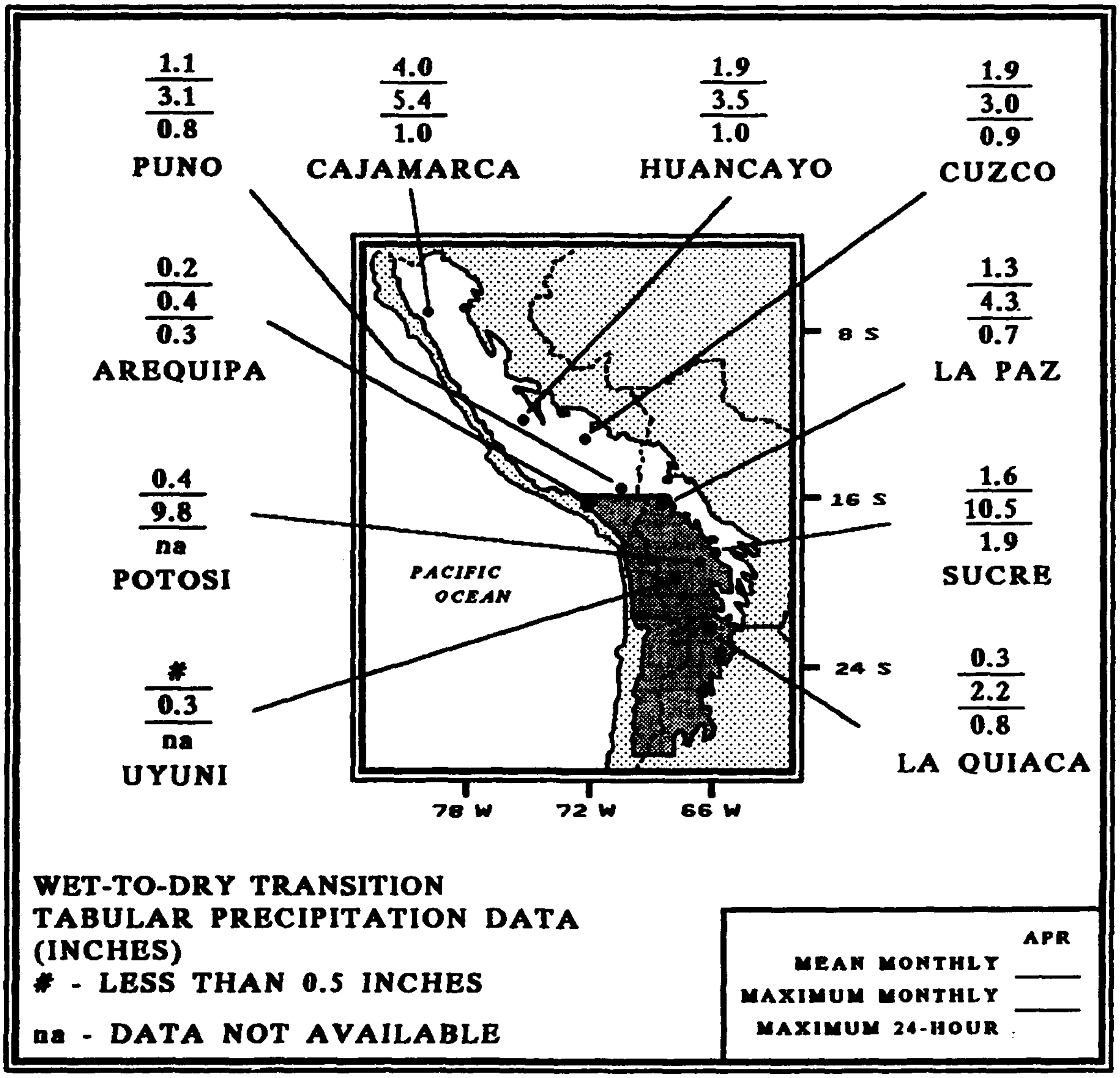


Figure 3-42. April Mean, Maximum, and 24-Hour Precipitation.

THUNDERSTORMS are concentrated along terrain above 15,000 feet (4,570 meters) MSL between 1400 and 1800L. Favored areas for development include the Cordillera Real, the Cordillera Central between 5 and 8° S, and the Cordillera Occidental between 22 and 28° S. In the Cordillera Oriental, thunderstorms are concentrated from 5 to 10° S and from 22 to 26° S. Cloud bases usually average 5,000 feet (1,525 meters) AGL with tops to 45,000 feet (13,720 meters) MSL.

Nocturnal thunderstorms are common in the Cordillera Central and Cordillera Oriental between 5 and 8° S. Most originate as Mesoscale Convective Systems in the western Amazon lowlands during the afternoon hours. Subsequent heavy convection regenerates between 1800 and 2200L along high terrain as mountain/valley breezes converge with moist easterlies. Occasionally, tops reach 50,000 feet (15,240 meters) MSL. Lightning is common, but hail is rare below 15,000 feet (4,570 meters) MSL. Figure 3-43 shows April thunderstorm days for several stations in the Central Andes.

STATION	APRIL
AREQUIPA	0
CAJAMARCA	#
CHARANA	#
COCHABAMBA	1
CUZCO	3
JULIACA	1

STATION	APRIL
LA QUIACA	2
ORURO	2
POTOSI	1
SUCRE	1
TARIJA	#

- LESS THAN 0.5 DAY

Figure 3-43. Mean April Thunderstorm Days.

TEMPERATURE. North of 16° S, mean daily highs for April range from 65 to 78° F (18-26° C); mean daily lows, from 40 to 61° F (4-16° C). The mean freezing level at 10° S is 17,500 feet (5,340 meters) MSL. South of 16° S, daily highs range from 56 to 63° F (13-17° C); daily lows from 26 to 35° F (-03 to 2° C). The mean freezing level is 16,000 feet (4,880 meters) MSL. Record highs range from 71 to 88° F (22-31° C), while record lows range from 50° F (10° C) at Apolo to 5° F (-15° C) at Cailloma. Figure 3-44 gives mean daily maximum/minimum temperature data for April in the Central Andes.

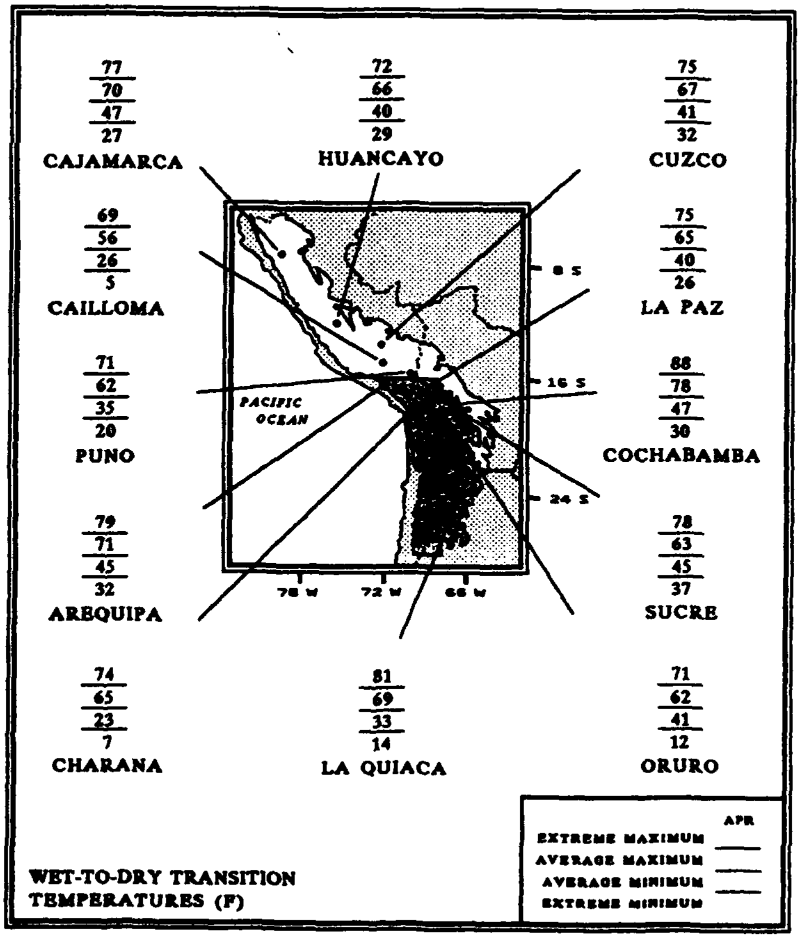


Figure 3-44. Mean April Tabular Temperature Data (°F)

FLIGHT HAZARDS. The usual thunderstorm hazards are present along the Cordilleras Central, Real, and Oriental above 10,000 feet (3,050 meters) MSL. Large hail (3/4-inch/19 mm) is possible. Wind gusts to 70 knots can be expected along outflow boundaries, especially along the southern Cordillera Oriental. South of 18° S, mountain wave turbulence over the southern Cordillera Occidental and Altiplano is possible ahead of and behind slow-moving upper-air polar troughs from 20,000 to 45,000 feet (6,100-13,720 meters) MSL. Severe turbulence is rare. Mountain/valley breezes in the Maranon, Apurimac, and Huallaga river valleys may produce strong wind shear between 1,000 and 4,000 feet (305-1,220 meters) AGL.

GROUND HAZARDS. Heavy rainfall can cause flash flooding and restrict visibility in the Cordillera Oriental. Mountain roads may be impassible for weeks due to landslides. Thick fog is rare, but it occasionally drops visibility below 1 mile.

GENERAL WEATHER. Cool, dry air at the middle and upper levels is associated with extensive high-pressure ridges over South America between the Equator and 20° S. Subsidence caps extensive diurnal convection. Low-level moisture from the Amazon Basin may generate convection that is limited to ridge and valley networks east of a line from 5° S, 79' W to 20° S, 67' W. The Altiplano is located within the rain shadow of the Cordillera Occidental and southern Cordillera Oriental. South of 20° S, intense upper-air troughs provide nearly all dry-season precipitation.

SKY COVER. Widespread cloud cover is rare. As shown in Figure 3-45, the highest percent frequency occurrences of stratus/stratocumulus ceilings below 3,000 feet (915 meters) AGL are at locations along the Cordillera Oriental's eastern slopes. An upper-air ridge produces dry, subsiding air. Convection is limited to the highest ridge crests across the northern Cordilleras Central and Oriental. Nighttime and early morning low-cloud development is common in the sheltered valleys of the Cordillera Oriental north of 14° S, Cordillera Central, Cordillera Occidental, and the Altiplano. Thin stratus and scattered shallow stratocumulus develop from strong radiative cooling between 0400 and 1100L. Isolated fair-weather cumulus is usually present between 1200 and 1900L. Cumulus bases average 4,000 feet (1,525 meters) AGL; tops rarely exceed 15,000 feet (4,570 meters) MSL, but in rare cases with upper-level troughs, tops reach 30,000 feet (9,145 meters) MSL along the southern Cordillera Occidental.

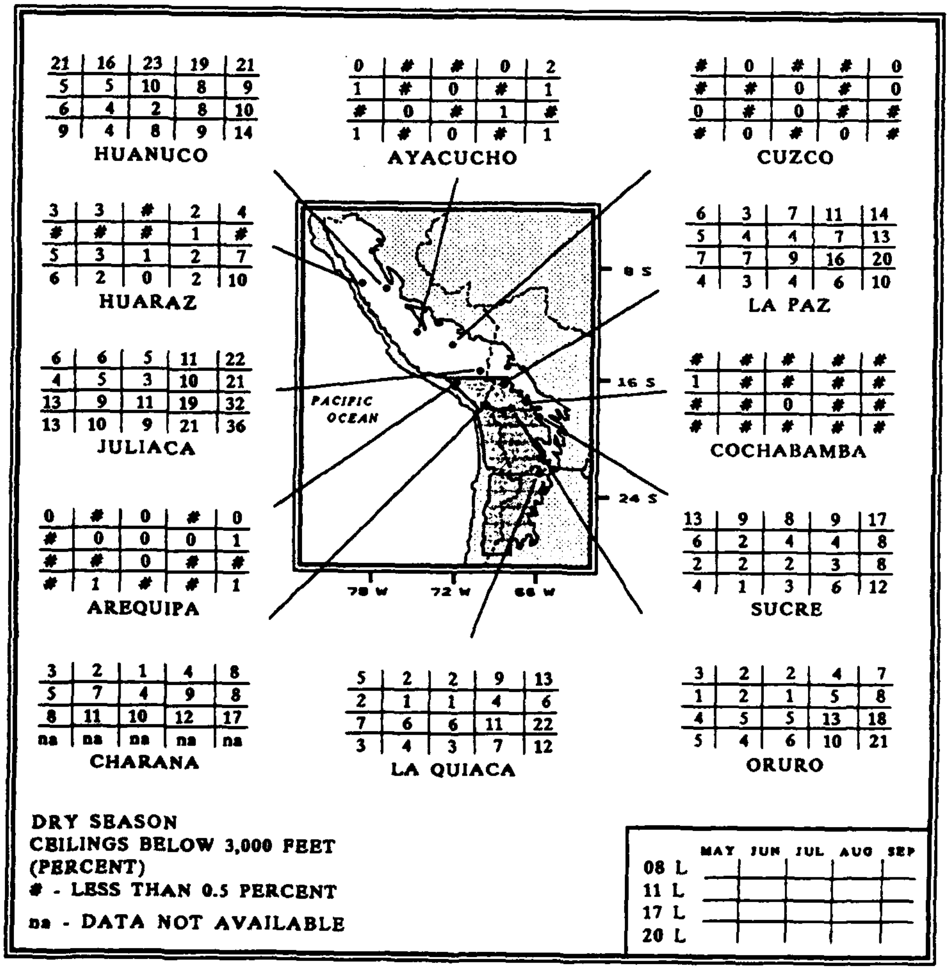


Figure 3-45. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters).

Stratus clouds usually form during the mountain/valley breeze transition between 0500 and 0800L. Local convergence zones move slowly downslope after sunrise. The eastern Cordillera Oriental and its major river valleys may have 1,000- to 3,000-foot (305- to 915-meter) bases in the cloud forests until 1000 or 1100L. Stratus tops rarely exceed 8,000 feet (2,440 meters) MSL. In the northern Maranon Valley, stratus is usually thin; ceilings below 3,000 feet (915 meters) AGL are rare. Exceptions occur when heavy rain has fallen during the night.

Between 1000 and 1100L, shallow stratocumulus begins to form along slopes where stratus is more than 500 feet (150 meters) thick. Strong heating along valley floors lifts stratocumulus to 4,000 feet (1,220 meters) AGL. Tops rarely exceed 12,000 feet (3,660 meters) MSL. Figure 3-45 shows frequencies of ceilings below 3,000 feet (915 meters) AGL.

After 1100L, stratocumulus may dissipate or generate into shallow, fair-weather cumulus that usually develops between 12,000 and 16,000 feet (3,660-4,880 meters) MSL and dissipates by sunset. Tops rarely exceed 20,000 feet (6,100 meters) MSL except when an upper-level trough provides added instability aloft. Tops may reach 30,000 feet (9,145 meters) MSL.

Favorable areas for fog formation include sheltered upland valleys and large water bodies. Fog is usually thin and rarely forms a ceiling. Many Altiplano stations report patchy, thin fog until 0800L. Fog may be thick below 500 feet (150 meters) AGL if rainfall occurs after 2000L.

VISIBILITY is good between May and early August. Strong upper-level troughs may produce isolated heavy thundershowers or scattered snowshowers along major ridge crests above 17,000 feet (5,180 meters) MSL, reducing visibility below 1 mile for up to 12 hours. Upper-level troughs occasionally produce blowing dust in the western Cordillera Occidental south of 20° S, lowering visibility to 1 mile for up to 6 hours.

By late August, visibilities below 3 miles are caused by fog and heavy rainfall/blowing snow at higher elevations. Fog usually reduces visibility to 2 or 3 miles near Lake Titicaca and Lake Poopo. In the upland valleys of the Cordillera Occidental, thin patchy ground fog usually forms between 0300 and 0800L, but visibilities remain between 4 and 6 miles. Blowing snow may occur above 14,000 feet (4,270 meters) MSL. Figure 3-46 shows visibility data for the Central Andes. Station data may not be representative of all remote areas. Figure 3-47 shows fog days for selected stations in the Central Andes.

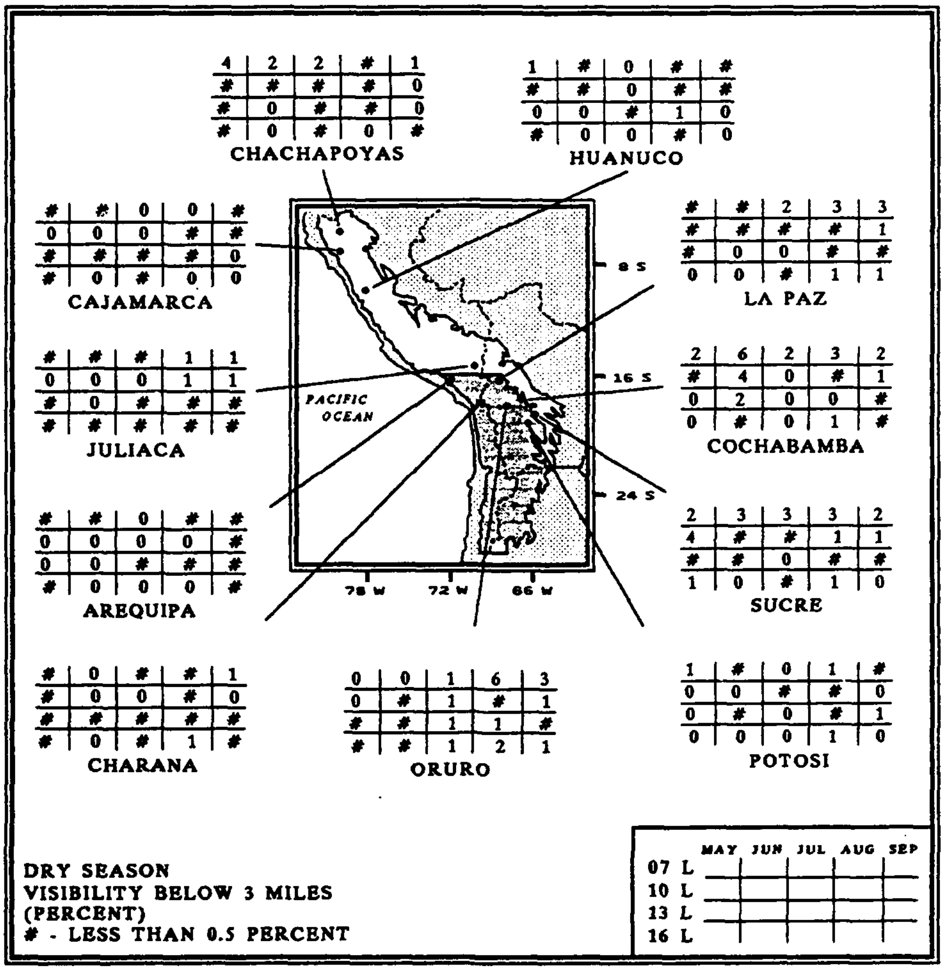


Figure 3-46. Dry-Season Percent Frequencies of Visibility Below 3 Miles.

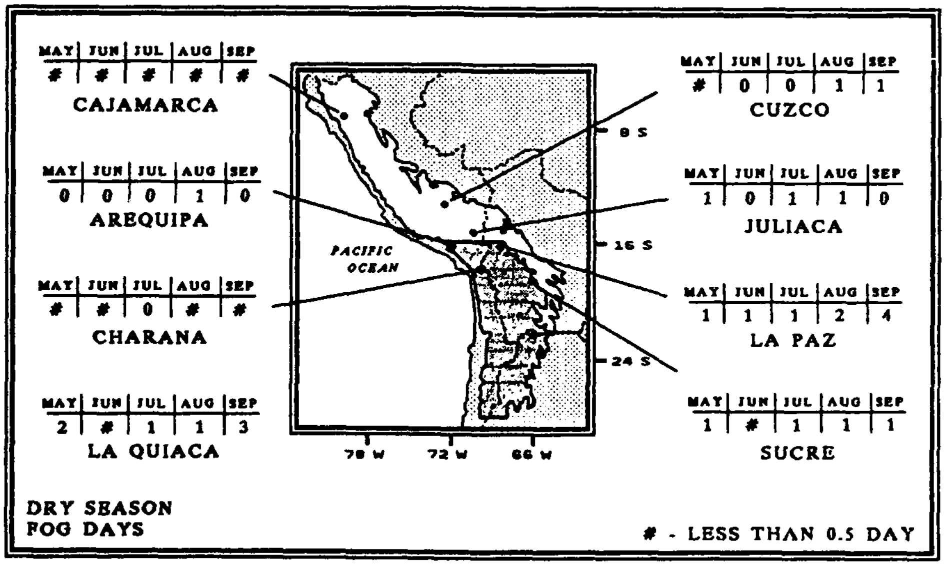


Figure 3-47. Mean Fog Days--Dry Season, Central Andes.

WINDS. Below 5,000 feet (1,525 meters) MSL, light northeasterly trade winds affect the Cordillera Oriental north of 16° S and the Cordillera Central. Numerous river valleys channel flow into the interior ranges. Prevailing surface flow is usually northerly by day and light and variable at night. A small section of the Cordillera Oriental (16 to 18° S) has a prevailing easterly to southeasterly flow below 5,000 feet (1,525 meters) MSL. The river valleys of the western Cordillera Occidental are dominated by low-level westerlies and southwesterlies.

Figure 3-48 shows mean surface wind speeds for stations in the Central Andes. The highest surface wind speed recorded for the region is 76 knots at Calama, Chile, in September. At many other stations, surface wind speeds commonly exceed 40 knots, the result of strong drainage winds from high terrain. Local prevailing wind speed and direction may be affected by cold air accumulation over large glacier fields on the Central Andes. Cold-air drainage, triggered by upper-level troughs, may suddenly filter into valleys and other low-lying areas, Extended fair weather periods can cause cold air to pile up in large low-lying basins.

Figure 3-49 shows July surface wind roses for the Central Andes. Note the frequency of strong winds at many stations south of 16° S. The converging mid- and upper-level westerlies produce the strong surface winds.

STATION	MEAN WIND SPEED				
	MAY	JUN	JUL	AUG	SEP
AREQUIPA	6	7	7	7	6
CAJAMARCA	3	4	7	7	5
CALAMA	15	15	15	15	16
LA PAZ	4	5	5	5	5
LA QUIACA	5	5	6	6	8
ORURO	4	5	5	7	7

Figure 3-48. Mean Surface Dry-Season Wind Speeds (kts).

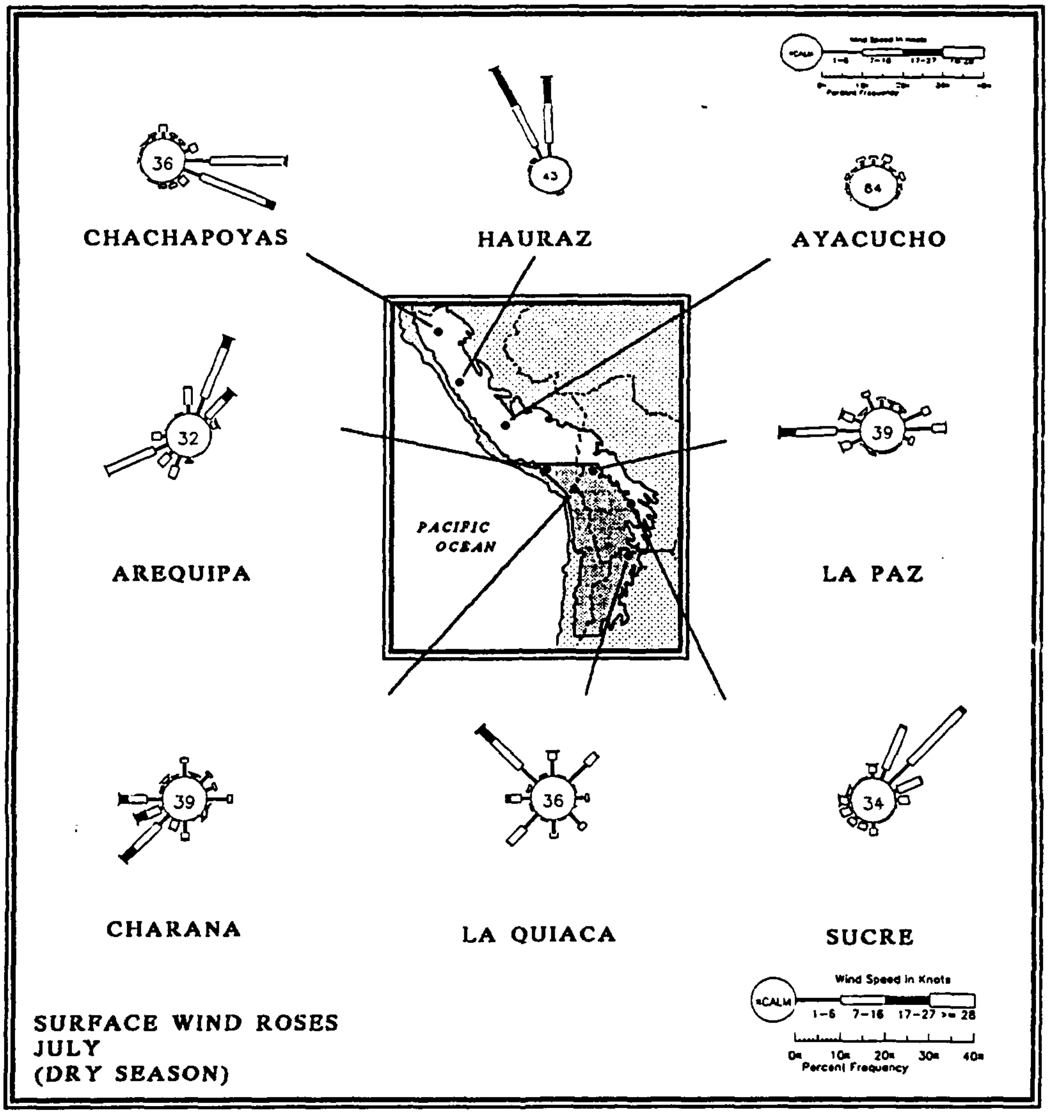


Figure 3-49. July Wind Roses, Central Andes.

At the middle and upper levels, the Central Andes are affected by two different air streams. By early May, the Bolivian High is replaced by an extensive anticyclone couplet centered near the Equator (see July 300- and 200-mb flow). North of 16° S, the couplet produces a 9- to 15-knot northwesterly wind from the equatorial Pacific Ocean to the northern Altiplano. South of 16° S, this northwesterly flow converges with the mid-latitude westerlies. From 16 to 28° S, the flow changes from northwesterly to southwesterly.

Mean maximum 30,000-foot (9,145-meter) wind speeds at La Paz (16° S) range from 41 knots in September to 55 knots in May. Throughout the dry season, the maximum wind-speed core is found near 41,000 feet (12,495 meters) MSL. At Salta Argentina (25° S), maximum wind speeds range from 66 to 72 knots between 41,000 and 43,000 feet (12,495-13,005 meters) MSL throughout the dry season. A 100- to 150-knot jet is possible with deep troughs.

PRECIPITATION. Isolated diurnal convective showers and weak thunderstorms produce most precipitation in the Tropical Ranges. The dry Altiplano and the highest ridge crests of the Cordillera Occidental south of 23° S are affected by scattered light rain along upper-air troughs. If a branch of the Subtropical Jet accompanies the upper-air trough, isolated areas of thunderstorms are possible northeast of the trough axis in the zone of highest wind speeds. Isolated showers may fall on the highest mountain peaks during fair weather.

Mean July rainfall (Figure 3-50) shows representative dry-season rainfall distributions. Much of the eastern Cordillera Central and northern Cordillera Oriental have at least 2 inches (51 mm) every month. The driest months are July and August when strong ridging caps orographic lifting. The high-pressure ridges over the Amazon basin and Central Andes are quasi-stationary. As a result, rainfall west of these ranges is light, while isolated thundershowers are confined to elevations above 16,000 feet (4,880 meters) MSL.

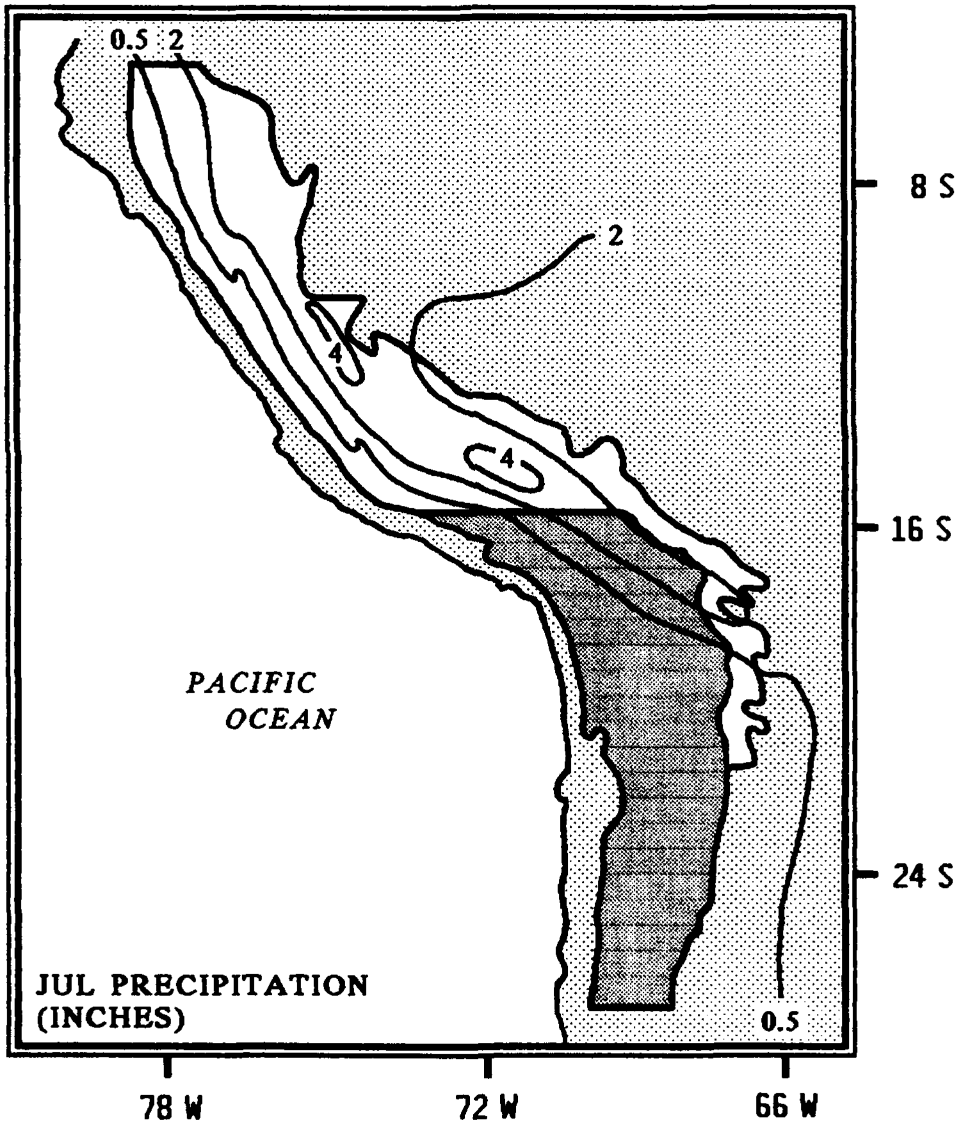
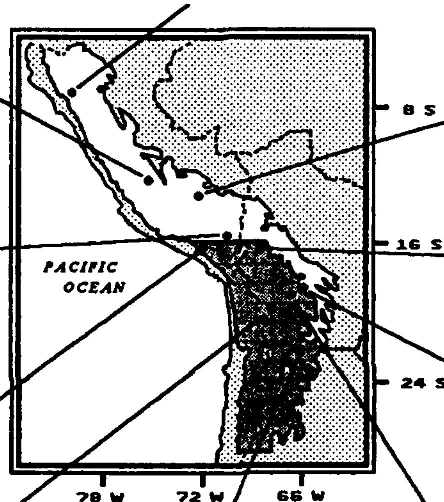


Figure 3-50. Mean July Precipitation (mm), Central Andes.

Snow is common; amounts vary from a light dusting to blizzard conditions along high peaks. Frozen precipitation is found as far north as 16° S, but snowfall rarely exceeds 3 inches (76 mm) on the Altiplano. Snow usually melts within 3 hours after a trough passage except along the Cordillera Occidental's highest mountain peaks. Figure 3-51 shows mean monthly, maximum 24-hour/monthly rainfall for the dry season.



Station		MAY	JUN	JUL	AUG	SEP
CAJAMARCA	MEAN MONTHLY	1.6	0.6	0.2	0.3	1.3
	MAXIMUM MONTHLY	2.9	2.0	1.1	0.8	3.4
	MAXIMUM 24-HOUR	2.0	0.8	1.4	1.3	1.1
HUANCAYO	MEAN MONTHLY	1.0	0.4	0.2	0.6	2.3
	MAXIMUM MONTHLY	3.1	0.6	0.6	1.2	3.2
	MAXIMUM 24-HOUR	1.4	0.5	0.3	0.6	0.9
CUZCO	MEAN MONTHLY	0.6	0.1	0.3	0.4	1.0
	MAXIMUM MONTHLY	1.3	0.5	1.5	1.2	1.8
	MAXIMUM 24-HOUR	0.4	0.4	1.3	1.0	0.9
PUNO	MEAN MONTHLY	0.4	0.1	0.2	0.3	0.9
	MAXIMUM MONTHLY	0.8	0.6	0.5	1.2	2.0
	MAXIMUM 24-HOUR	0.3	0.3	0.2	0.2	0.6
LA PAZ	MEAN MONTHLY	0.5	0.3	0.3	0.5	1.1
	MAXIMUM MONTHLY	1.6	2.4	1.9	2.4	2.5
	MAXIMUM 24-HOUR	0.6	0.2	0.4	0.1	1.1
AREQUIPA	MEAN MONTHLY	#	#	#	#	#
	MAXIMUM MONTHLY	0.4	#	#	0.5	0.4
	MAXIMUM 24-HOUR	0.4	#	#	0.5	0.2
SUCRE	MEAN MONTHLY	0.2	0.1	0.2	0.3	1.0
	MAXIMUM MONTHLY	9.8	4.3	1.6	1.0	1.8
	MAXIMUM 24-HOUR	1.9	2.2	0.2	0.3	0.6
UYUNI	MEAN MONTHLY	0.0	#	0.0	#	#
	MAXIMUM MONTHLY	0.2	1.2	0.2	2.7	0.9
	MAXIMUM 24-HOUR	na	na	na	na	na
LA QUIACA	MEAN MONTHLY	#	#	#	#	0.1
	MAXIMUM MONTHLY	0.5	1.1	1.2	0.6	0.6
	MAXIMUM 24-HOUR	0.1	0.1	1.2	0.2	0.3
POTOSI	MEAN MONTHLY	0.2	0.2	0.2	0.0	0.3
	MAXIMUM MONTHLY	5.0	2.7	1.1	2.1	2.4
	MAXIMUM 24-HOUR	na	na	na	na	na

DRY SEASON
TABULAR PRECIPITATION DATA
(INCHES)
- LESS THAN 0.5 INCHES
na - DATA NOT AVAILABLE

Figure 3-51. Dry-Season Mean Precipitation (inches).

THUNDERSTORMS develop with strong upslope valley flow by 1400L. Bases range from 4,000 to 6,000 feet (1,220-1,830 meters) AGL with tops to 40,000 feet (12,190 meters) MSL. South of 22° S, upper-air troughs produce widespread thunderstorms over isolated peaks above 17,000 feet (5,180 meters) MSL. Individual cells may reach 45,000 feet (13,720 meters) MSL. Figure 3-52 shows the mean number of thunderstorm days across the Central Andes.

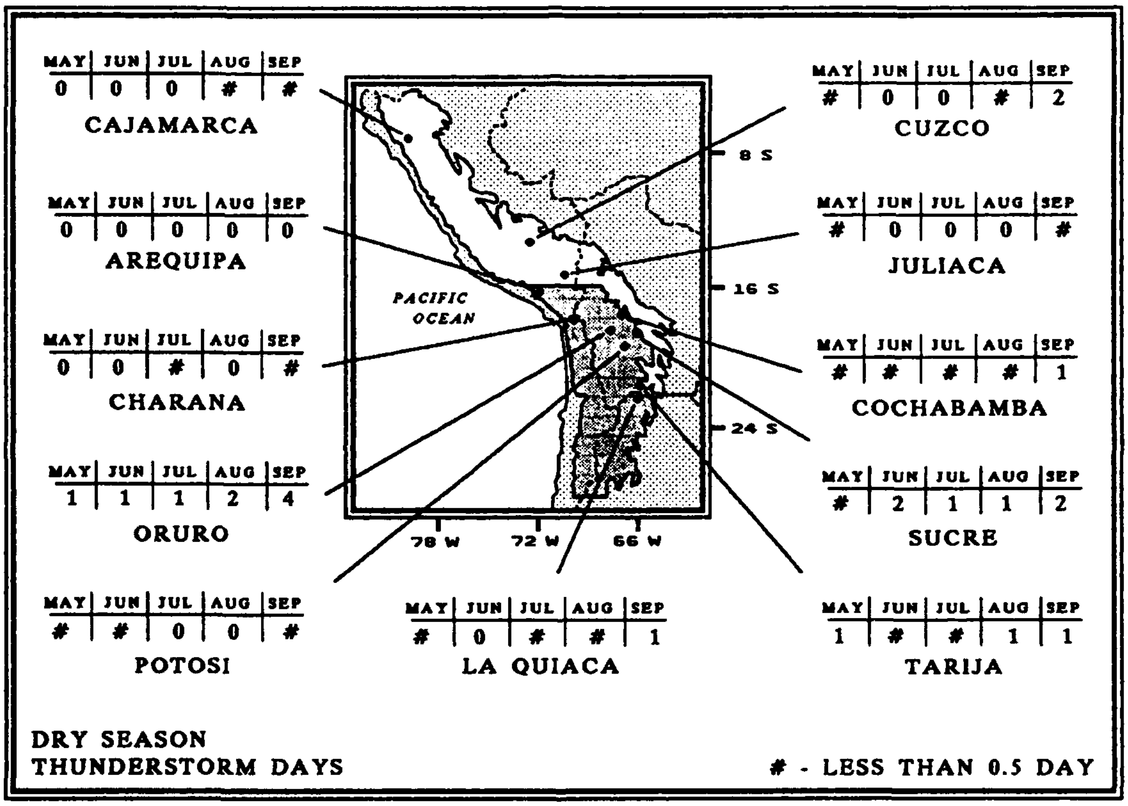


Figure 3-52. Mean Dry-Season Thunderstorm Days.

TEMPERATURE. Daily highs in the Tropical Ranges vary with location and elevation. Highs in the eastern Cordillera Oriental range from 65 to 78° F (18-26° C) and lows range from 32 to 45° F (0-7° C). Record highs rarely exceed 80° F (27° C).

In the other Central Andes mountain ranges, highs average 65° F (18° C); lows, 33° F (1° C). Sheltered valleys above 15,000 feet (4,570 meters) MSL, glacier fields, and snow-capped mountain peaks may have lows between 0 and 10° F (-18 and -12° C). The mean freezing level ranges from 15,000 feet (4,570 meters) MSL in July to 16,000 feet (4,880 meters) MSL in May and September. No wet-bulb globe temperature (WBGT) data is available for the Central Andes, but WBGTs can approach 90° F (32° C) north of 8° S between 1100 and 1900L. Figure 3-53 shows mean monthly temperature data for the Central Andes.

79	79	79	79	80
71	71	71	71	72
41	40	39	41	43
30	21	18	28	30

CAJAMARCA

71	71	71	72	75
66	65	66	67	67
36	35	32	36	42
22	20	14	22	31

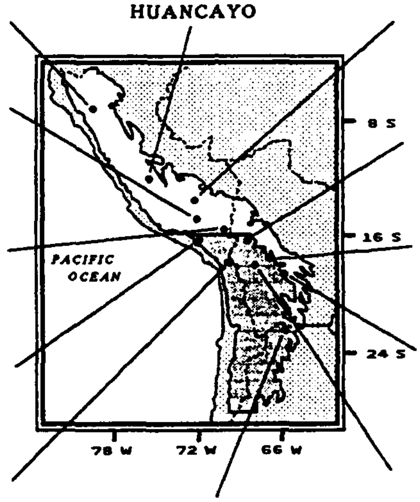
HUANCAYO

76	76	77	77	80
66	66	64	68	68
38	34	33	36	40
27	25	23	25	28

CUZCO

70	73	66	70	72
55	53	52	55	58
19	14	14	15	19
2	4	10	5	5

CAILLOMA



75	75	73	75	80
64	62	62	63	64
37	34	33	35	38
12	12	14	11	18

LA PAZ

69	70	70	73	75
61	60	60	62	63
31	29	29	30	32
21	18	11	17	20

PUNO

84	86	85	86	89
76	74	74	77	78
38	38	34	38	43
23	20	23	22	26

COCHABAMBA

79	79	77	79	79
71	70	70	71	72
42	40	40	41	42
27	23	25	21	28

AREQUIPA

72	72	74	78	77
62	61	61	65	67
40	38	37	40	44
29	27	25	30	29

SUCRE

72	70	72	68	71
62	59	59	61	62
18	11	10	12	16
-2	-9	-8	-9	-2

CHARANA

82	75	78	78	82
64	60	60	64	66
23	17	17	21	27
8	0	0	1	9

LA QUIACA

66	64	66	68	72
58	55	55	57	60
33	27	27	32	38
-3	-3	-4	-1	5

ORURO

DRY SEASON TEMPERATURES (F)

	MAY	JUN	JUL	AUG	SEP
EXTREME MAXIMUM					
AVERAGE MAXIMUM					
AVERAGE MINIMUM					
EXTREME MINIMUM					

Figure 3-53. Dry-Season Tabular Temperature Data (° F).

FLIGHT HAZARDS. The usual thunderstorm hazards apply. Mountain wave turbulence is possible with strong troughs between 20,000 and 45,000 feet (6,100-13,720 meters) MSL. Strong wind shear associated with the Subtropical Jet is usually found between 18 and 28° S along the eastern slopes of the Cordillera Occidental, southern Cordillera Oriental, and southern rim of the Altiplano above 30,000 feet (9,145 meters) MSL. Strong low-level winds are common between 16 and 20° S along the western Cordillera Occidental below 15,000 feet (4,570 meters) MSL. Diurnal wind circulations in the Maranon, Huallaga, Apurimac, and other river valleys may produce strong wind shear from 1,000 to 4,000 feet (305-1,220 meters) AGL between 5 and 11° S.

GROUND HAZARDS. Heavy rainfall along major ridge crests occasionally produces flash flooding in deep river valleys. Mountain roads may be closed by landslides. Fog is occasionally thick near the large lakes in the Altiplano.

GENERAL WEATHER. Although diurnal convection redevelops along the windward Cordillera Oriental, the moist easterlies that carry Amazon moisture rarely penetrate the interior Central Andes between 8 and 28° S. Valley winds produce some localized convection in the Cordilleras Real, Central, and extreme northern Occidental. High-pressure ridging dominates the Central Andes in the middle and upper levels. Two to four times every October, an upper-level trough replaces the well-developed ridge system and produces nearly all the rainfall south of 16° S. Subtropical Jet support is necessary for widespread rain showers and thundershowers.

SKY COVER. Shallow ground fog, stratus, and shallow stratocumulus prevail between 2200 and 1000L in mountain valleys, over high terrain, and on the Altiplano. Radiation cooling is strong in October across the Central Andes. Patchy, thin radiation fog may form on any morning. By 0900L, fog lifts to 4,000 feet (1,220 meters) AGL and becomes thin stratus or stratocumulus. This shallow cloud cover prevails along the windward slopes of the Cordillera Oriental and upland valleys of the Cordillera Central. Thin cloud cover also affects the Cordillera Occidental between 5 and 16° S. By 1000L, most stratus and stratocumulus dissipates or reforms into shallow diurnal cumulus with bases near 5,000 feet (1,525 meters) AGL. Cumulus thickness rarely exceeds 1,000 feet (305 meters) until 1100 or 1200L.

Between 1100 and 2000L, scattered cumulus forms throughout the Central Andes. At several locations where a local moisture source, terrain, and prevailing surface circulation combine to produce low-level convergence, there are high frequencies of cumulus with bases between 2,000 and 3,000 feet (610-915 meters) AGL. Orographic cumulus forms in terrain above 14,000 feet (4,270 meters) MSL. Fair-weather cumulus tops rarely exceed 20,000 feet (6,100 meters) MSL, but by 1600L, intense surface heating may produce tops near 35,000 feet (10,670 meters) MSL.

In the Cordillera Oriental, which is affected by moist easterlies from the Amazon Basin, clouds with bases at or above 7,000 feet (2,135 meters) MSL form along windward slopes between 5 and 18° S. Tops rarely exceed 30,000 feet (9,145 meters) MSL before 1400L, but higher bases and tops may develop westward from the first ranges of the Oriental through 1700L. In rare cases, isolated towering cumulus or thunderstorm cells develop; bases average 15,000 feet (4,570 meters) MSL, and tops can exceed 40,000 feet (12,190 meters) MSL. Figure 3-54 shows frequencies of ceilings below 3,000 feet (915 meters) AGL for stations in the Central Andes.

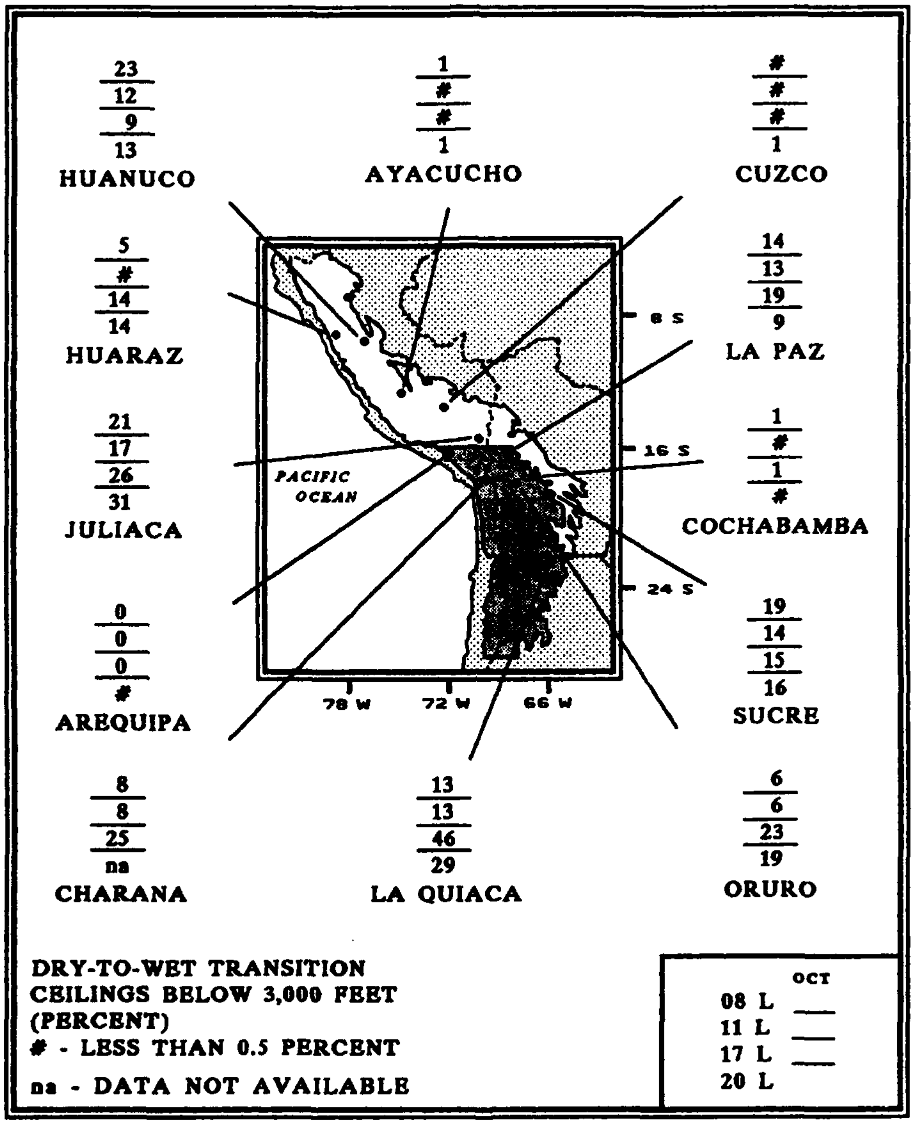


Figure 3-54. October Percent Frequencies of Ceilings Below 3,000 Feet (915 meters).

VISIBILITY. Ground fog, isolated heavy rainfall, and blowing dust are the main visibility restrictions. Cold mid-tropospheric air and the dry conditions on the Altiplano promote strong radiation cooling that results in fog if there is enough moisture in the boundary layer. Visibility is below 3 miles (Figure 3-55) most often with fog between 2200 and 0900L along the Altiplano and the Lake Titicaca-Lake Poopo drainage basin. Upland valleys of the Cordillera Occidental and Central north of 10° S also have thin ground fog. Fog days are shown in Figure 3-56.

Heavy rainfall may produce visibilities below 1 mile for up to 30 minutes along the Cordillera Oriental, usually on ridge crests and remote mountain peaks above 13,000 feet (3,960 meters) MSL. In rare cases, upper-air troughs produce blowing and drifting snow in the Cordillera Occidental south of 24° S at elevations above 17,000 feet (5,180 meters) MSL. Visibilities may be below 3 miles for up to 6 hours.

With upper-air troughs, blowing dust and sand is possible across the Altiplano. Wind speeds may exceed 60 knots and reduce visibility to zero for several minutes to several hours. If winds are light for 2 to 3 consecutive days, dust haze in the boundary layer may reduce visibility to 3 to 4 miles in industrial areas between 1900 and 1000L.

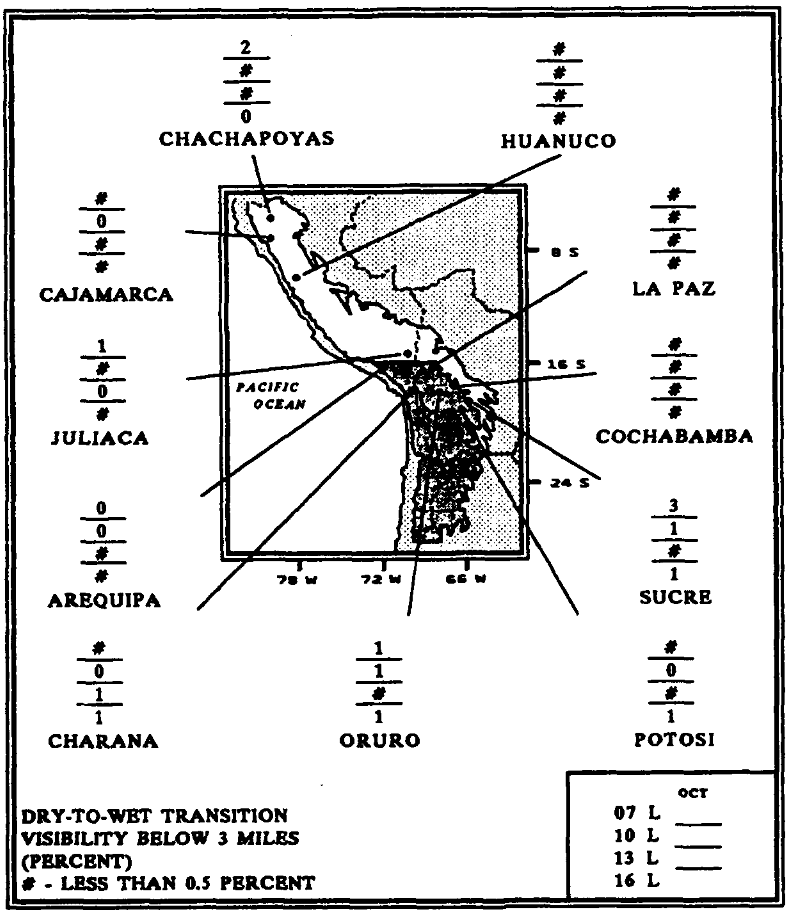


Figure 3-55. October Percent Frequencies of Visibility Below 3 Miles.

STATION	OCTOBER
AREQUIPA	0
CAJAMARCA	1
CHARANA	#
CUZCO	#
JULIACA	#
LA PAZ	3
LA QUIACA	2
SUCRE	1

Figure 3-56. Mean October Fog Days.

WINDS. October surface winds along the Cordillera Oriental north of 20° S are northeasterly at 4-8 knots. Valley breezes between 1000 and 1800L deflect and accelerate surface flow to northerly; wind speeds range from 6 to 10 knots. Northeasterlies may penetrate to the Cordillera Occidental north of 7° S, becoming northerlies or northwesterlies in the steep valleys between 7 and 12° S that separate the Cordilleras Central and Occidental. Between 12 and 18° S, the mid-level flow produces north to northwest surface winds. The Cordillera Occidental prevents Pacific low-level flow from penetrating inland beyond its western slopes. South of 18° S, mid-latitude westerlies dominate the width of the Central Andes. Speeds average 15 knots between 8,000 and 12,000 feet (2,440-3,660 meters) MSL along the Cordillera Occidental. Local mountain-valley circulations may produce slight variations to the prevailing westerly flow. Between 2000 and 0300L, the mountain breeze may accelerate to 20 knots over the western Altiplano.

STATION	MEAN WIND SPEED OCTOBER
AREQUIPA	5
CAJAMARCA	4
CALAMA	17
LA PAZ	5
LA QUIACA	8
ORURO	7

Figure 3-57. Mean October Mean Surface Wind Speeds (kts).

Figure 3-57 shows mean October surface wind speeds for stations in the Central Andes. Maximum sustained wind speeds may exceed 50 knots along thunderstorm outflow boundaries in the Cordillera Oriental and Central. In the Cordillera Occidental south of 22° S, surface winds have reached 70 knots with intense troughs. Figure 3-58 gives surface wind rose data for the Central Andes.

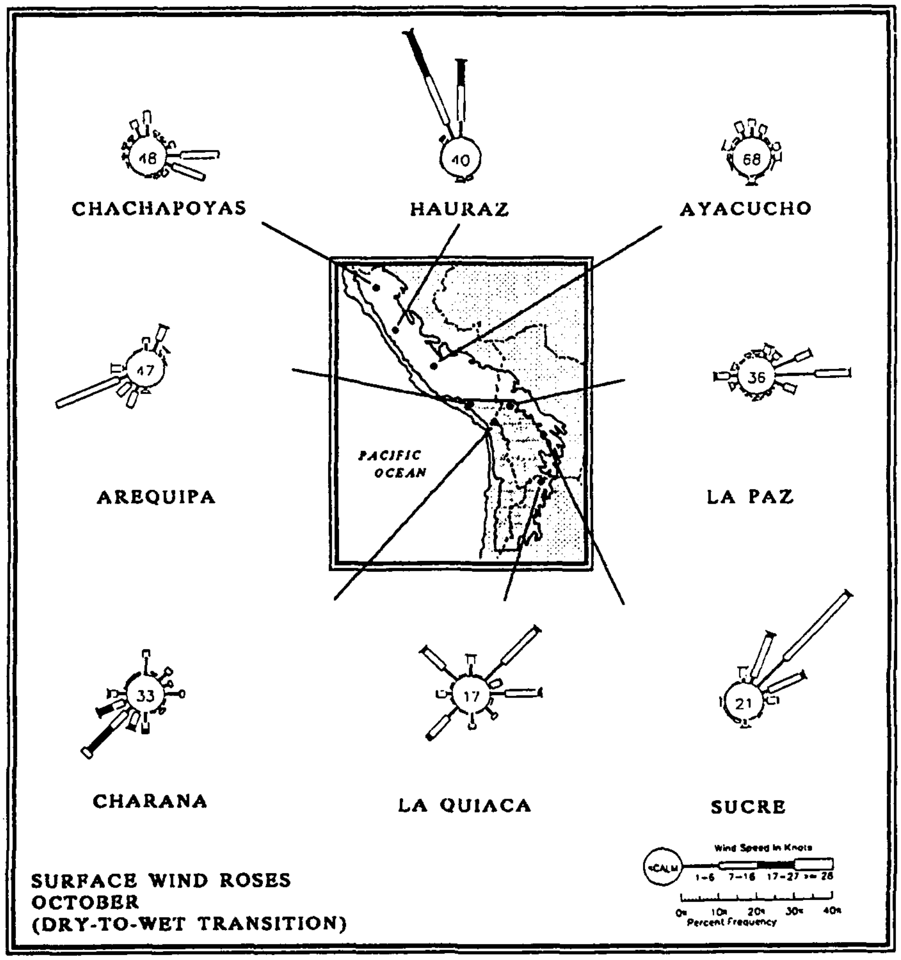


Figure 3-58. October Surface Wind Roses.

Mid- and upper-level winds are controlled by an anticyclonic circulation, the precursor of the Bolivian High. Near 18,000 feet (5,490 meters) MSL, the high-pressure ridge extends east-to-west across the Central Andes at 12° S. Northeasterlies and northerlies average 9 to 15 knots. The south side of the ridge is dominated by westerlies. South of 20° S, flow converges with mid-latitude westerlies. At 300 and 200 mb, an anticyclonic circulation is centered at 7° S, 70° W. The ridge extends westward over the equatorial eastern Pacific Ocean. Easterlies average 12 knots north of 7° S, but recurve on the south side of the ridge to become northerlies between 7 and 9° S over the Pacific Ocean and Peru's northern coastline; speeds average 10 knots. Between 9 and 16° S, flow is northwesterly at 22 knots; between 16 and 28° S, westerly at 28-64 knots. Mean maximum wind are found near 41,000 feet (12,495 meters) MSL; at 25° S, mean maximum winds are 64 knots, but only 28 knots at 16° S.

PRECIPITATION. October rainfall (Figure 3-59) is concentrated along the eastern (windward) Cordillera Oriental where moist easterly low-level flow is lifted orographically. Mountain/valley circulations provide low-level convergence in the Cordillera Central and northern (5-9° S) Cordillera Occidental from 1200 to 1800L; short-lived rain showers or weak thundershowers are common in these areas. Airflow is dry in the Altiplano and Cordillera Occidental between 10 and 28° S. Isolated diurnal convection is limited to mountain ranges abo·-: 16,000 feet (4,880 meters) MSL.

Most rainfall south of 16° S is the result of upper-air troughs that produce scattered rain showers along the trough axis. There is rarely more than 0.25 inches (5 mm) except in those rare cases when the Subtropical Jet flows along the base of the trough and generates thunderstorms. Snow falls above 18,000 feet (5,490 meters) MSL. Figure 3-60 shows mean and maximum monthly and 24-hour October rainfall statistics for the Central Andes. Few stations report more than 1 inch (25 mm) of rainfall in October.

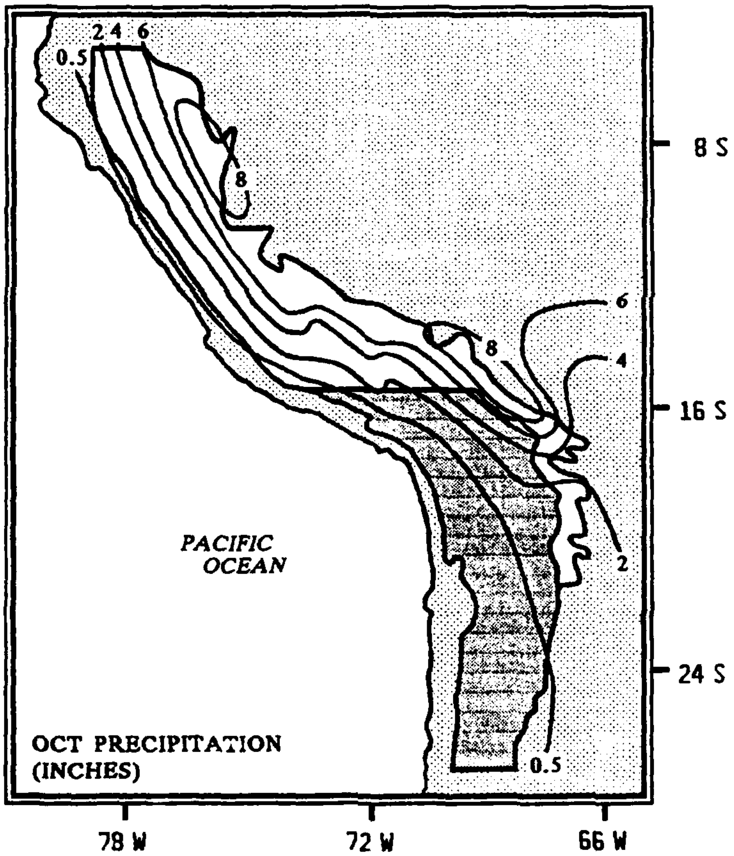


Figure 3-59. Mean October Precipitation.

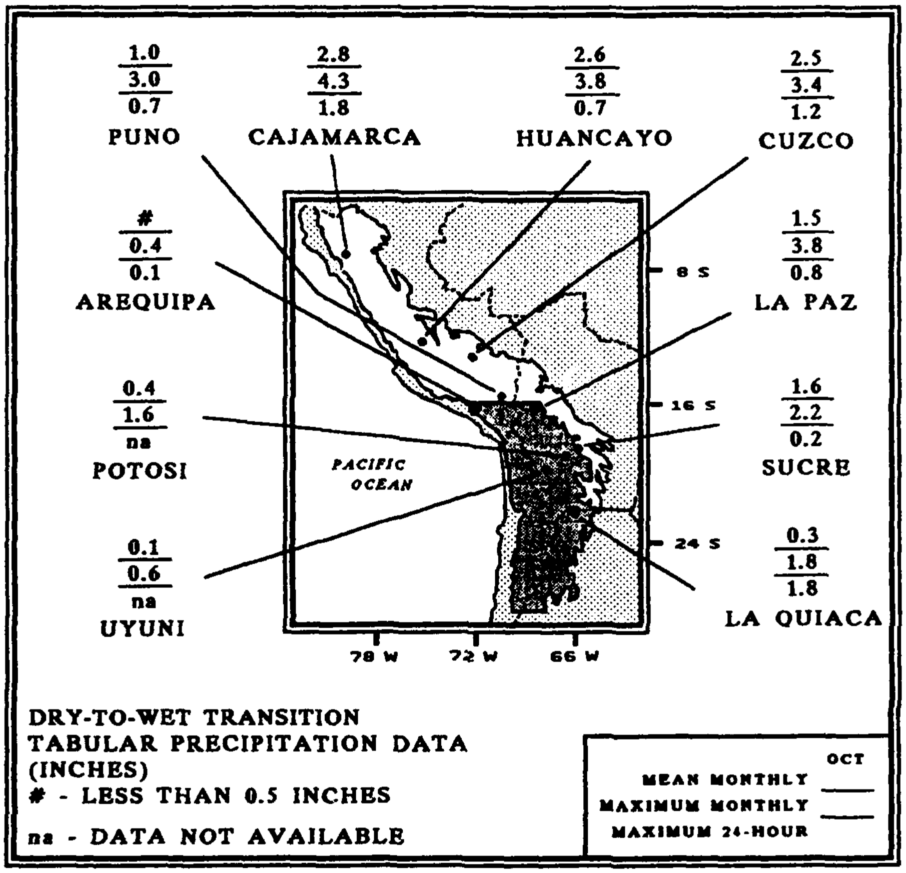


Figure 3-60. Mean October Tabular Precipitation Data.

THUNDERSTORMS associated with upper-air troughs frequently occur between 1200 and 1800L in the southern portions of the Cordillera Real, Central, and Oriental. Small hail, lightning, and strong downburst winds may occur above 16,000 feet (4,880 meters) MSL in the western Cordillera Occidental south of 22° S. Thunderstorm days for October are shown in Figure 3-61.

Weak mid-level westerlies with Pacific origins occasionally meet easterlies from the Amazon Basin over the lower elevations of the Cordillera Central; the result is a rare thunderstorm between 4 and 8° S and west of 76°. Cloud bases average 10,000 feet (3,050 meters) MSL with tops to 50,000 feet (15,240 meters) MSL.

STATION	OCTOBER
AREQUIPA	0
CAJAMARCA	#
CHARANA	#
COCHABAMBA	2
CUZCO	3
JULIACA	#

STATION	OCTOBER
LA QUIACA	#
ORURO	3
POTOSI	1
SUCRE	1
TARIJA	2

- LESS THAN 0.5 DAY

Figure 3-61. Mean October Thunderstorm Days.

TEMPERATURE. Mean daily highs in the Cordillera Oriental are 73-80° F (23-27° C). The eastern slopes of the Cordillera Oriental below 10,000 feet (3,050 meters) are the warmest in the range because of the tropical air mass. Over the Altiplano and all the major mountain ranges, mean daily highs range from 63 to 72° F (17-22 C). Record highs in October rarely exceed 85° F (29° C), but Cochabamba has recorded 92° F (33° C). Highs are usually reached between 1100 and 1300L before diurnal convection decreases sunshine.

Mean daily lows are determined by terrain, elevation, and the prevailing air mass. Stations near high mountain peaks and in sheltered valley stations are usually affected by nocturnal drainage winds. The tropical air mass from the Amazon Basin penetrates to the Cordillera Oriental, while the cool Pacific air mass only affects the Cordillera Occidental. The Cordillera Central is equally affected by both air masses, but the air is extremely dry.

Temperatures on the Altiplano are controlled by mid-tropospheric air temperatures. Mean daily lows decrease west of the mountain ranges Lows range from 61° F (16° C) along the eastern Cordillera Oriental to 20° F (-7° C) at Charana, Chile, along the western Cordillera Occidental. The lowest temperatures are found on the glaciers and snowpack. The record low for all stations in Figure 3-62 is 0° F (-18° C). It is likely that deep upper-air troughs produce temperatures in the -5° F (-21° C) to -15° F (-26° C) range at elevations above 15,000 feet (4,570 meters) MSL. The mean freezing level in October is 15,500 feet (4,720 meters) MSL.

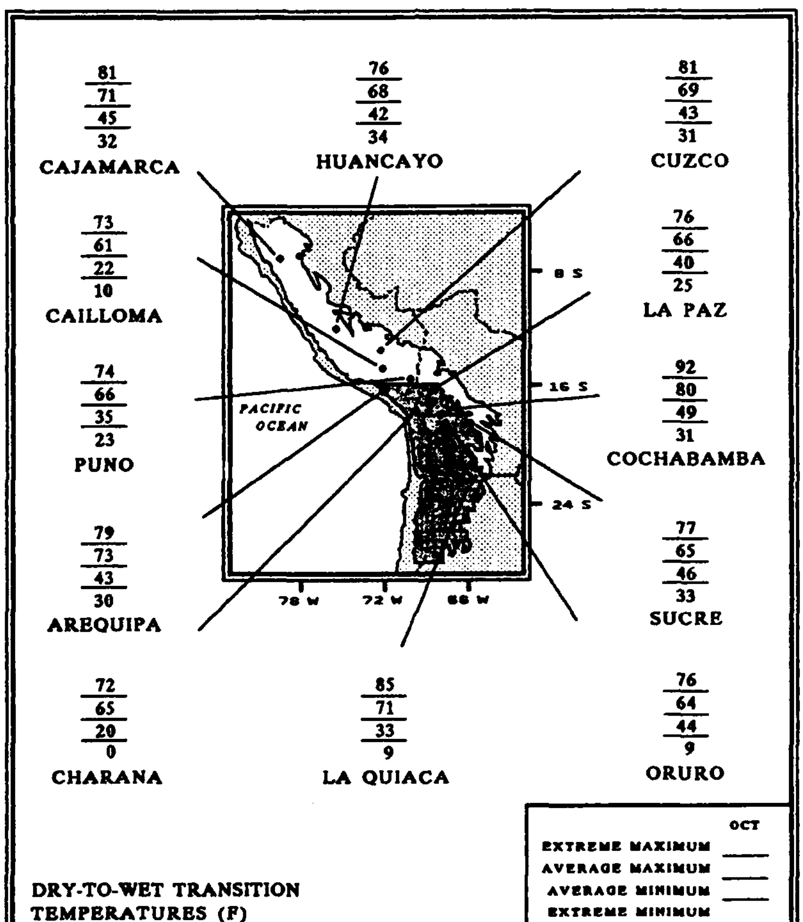


Figure 3-62. Mean October Tabular Temperature Data (°F).

FLIGHT HAZARDS. The usual thunderstorm hazards apply in the Cordillera Oriental, Central and Real. Thunderstorms are most frequent between 1200 and 1800L; on rare occasions, activity may extend beyond 2200L. Wind shear along the Cordillera Oriental is from convergence along ridge crests caused by upslope valley winds and easterly synoptic flow. Occasional moderate turbulence for small aircraft is possible between 1000 and 1800L. Upper-air troughs and strong upper winds may produce mountain wave turbulence (marked by rotor and lenticular clouds) over the Cordillera Occidental south of 18° S, and over the Altiplano.

GROUND HAZARDS. Blowing dust is common with upper-level troughs across the Altiplano. Visibilities may be below 1 mile for up to an hour; zero visibilities are possible in isolated areas. Radiation fog can be thick on sheltered upland valley floors between 5 and 10° S. Visibilities are below 3 miles between 2200 and 0800L on clear, calm nights. thick fog can develop several hours after sunset following a heavy late-afternoon rainfall. Heavy rains may produce flash flooding downstream from high terrain without warning. Water levels may increase by 5 to 15 feet (1.5-4.6 meters) in remote canyons. Landslides from flooding and earthquakes can occur.

Chapter 4

TROPICAL SOUTH AMERICA

This chapter describes the situation and relief, major climatic controls, geography, and general weather of "Tropical South America," an area that includes sections of Brazil, Peru, and Bolivia. The region is further subdivided into six zones of climatic and topographic commonality. These zones (the Western Amazon Basin, Central Amazon Basin, Eastern Amazon Basin, Brazilian East Coast, Northeast Brazil, and Brazilian Plateau) are shown in Figure 4-1 and discussed in turn.

TROPICAL SOUTH AMERICA

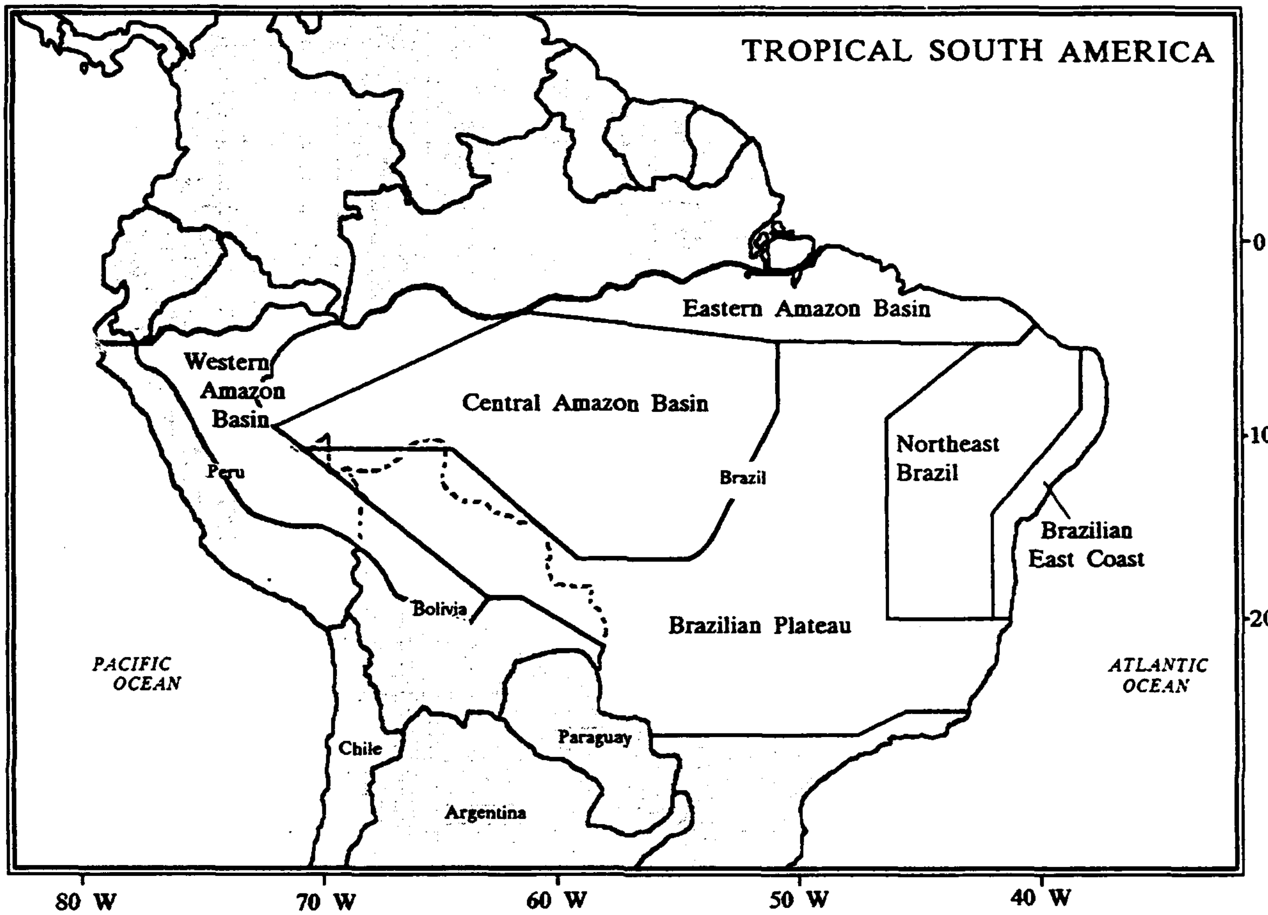


Figure 4-1. Tropical South America. The region is shown divided into its six zones of climatic and topographic commonality: the Western, Central, and Eastern Amazon basins, the Brazilian East Coast, Northeast Brazil, and the Brazilian Plateau.

SITUATION AND RELIEF. Tropical South America comprises most of Brazil, the eastern lowlands of Peru, and the northeastern lowlands of Bolivia. At 5° S, the region is 3,000 miles wide from west to east. At 48° W, it is 1,520 miles from north to south.

Much of the region lies below 1,970 feet/600 meters. It is either rain forest (the Amazon Basin), plateau grassland (the Brazilian Plateau), or river valley (Parana, Paraguay, and Sao Francisco Rivers). Mountain ranges in and around the zone have a significant affect on climate. The Andes shelter the area from Pacific moisture, and the highlands in eastern and southeastern Brazil, where a few peaks reach 8,860 feet (2,700 meters), block moist flow from the South Atlantic. The north coast of Brazil, including the Amazon Delta, offers the only opening for significant moisture advection. At least 50% of the Amazon Basin's moisture, however, is provided by evapotranspiration (evaporation and transpiration) from tropical rain forests. The Amazon Basin itself is a major moisture source for much of South America east of the Andes.

MAJOR CLIMATIC CONTROLS. The five most important features that affect climate in Tropical South America are the South Atlantic High, the Near Equatorial Trough (NET), the Tropical Convergence Zone (TCZ), Extratropical Fronts, and the Amazon forests themselves.

The South Atlantic High is the primary cause of dry weather. Its widespread subsidence stabilizes the atmosphere while drying it adiabatically; tropical moisture is confined to a shallow layer. The high creates a subsidence inversion at about 15,000 feet (4,570 meters) MSL, while the associated easterly trades produce a second, lower inversion. The South Atlantic High dominates the Brazilian East Coast and Northeast Brazil year-round. It begins ridging westward in fall, becoming the dominant climatic control across most of the region in winter. A surface trough often forms along the east coast in winter, breaking the high into two centers. The high recedes rapidly in spring.

The Near Equatorial Trough (NET), the result of the converging North and South Atlantic trades, is a major control from December through March. Its continental and oceanic segments are often separated from one another in summer and early fall as the continental segment moves southward more quickly than the oceanic segment. Terrain often causes the NET's continental segment to be ill-defined. Although NET activity is mostly cumuliform, stratiform cloudiness (including nimbostratus) occasionally occurs over the continent. Most activity occurs equatorward of the NET. The primary exception occurs with north/south surges in the NET, when activity increases up to 600 NM ahead of the trough and 300 NM behind it. Activity also increases when other disturbances approach the NET, often causing it to oscillate.

The Tropical Convergence Zone (TCZ), a major control from October through March, should not be confused with the NET. The TCZ is the result of low- and mid-level convergence between northeasterly flow around the South Atlantic Ridge and westerly mid-latitude flow. Associated weather shows that the TCZ is usually oriented north-south from 10 to 25° S and positioned between 45 and 55° W. It oscillates east/west when other disturbances are near. This is especially true with fronts, which can cause the TCZ to surge eastward almost to the coast. Cumuliform clouds are prevalent, but all cloud types are possible.

Extratropical Cold Fronts in the Southern Hemisphere are the major weather-producers from May through November, but they affect the tropics year-round. Northward-moving shear lines or trade-wind surges originate as cold fronts over the South Atlantic. Cold fronts entering the region sometimes become stationary; they occasionally recede toward the southeast as warm fronts. Extratropical fronts cause oscillations in the NET during summer and fall and in the TCZ from spring through fall. Extratropical fronts also produce other disturbances, such as Trade-Wind Surges, Low-Latitude Upper-Level Cyclones, and Coastal Convergence Zones. The first two are explained in Chapter 2; the last, in 4.4, "Climatic Peculiarities."

Summer fronts (December through February) only reach as far north as the region's southern fringes. Cumuliform clouds are prevalent, but all types can occur.

Fall fronts (March through May) affect most or all of the region west of 55° W, but terrain destroys most fronts between 55° W and the coast. All cloud types can occur along fall fronts. Cold fronts are often followed by stratus, and occasionally by stratocumulus.

Winter fronts (June through August) affect the entire region west of 55° W, but high terrain again destroys most between 55° W and the coast. Stratiform clouds are prevalent along winter fronts, but all types are possible. Winter cold fronts are followed by widespread stratus, which is sometimes followed by stratocumulus.

Spring fronts (September through November) are oriented northwest to southeast and have comparatively deep air masses. This allows them to pass over higher terrain and, in extreme cases, cross the entire region. The average springtime frontal penetration is a line from roughly 3° S, 70° W to about 20° S, 40° W. Cumuliform clouds are prevalent, but all types are possible. Many spring cold fronts are followed by stratus; occasionally, by stratocumulus.

Amazon Rain Forests have a major, if indirect, effect on the region's climate in that they supply vast quantities of moisture to the region through evapotranspiration, a process that produces at least half the Amazon Basin's moisture. It is also a major moisture source for areas downstream. Besides supplying precipitable water, evapotranspiration provides moisture for morning stratus and fog in the forests.

Amazon deforestation is also likely to have a significant effect on the climate. The clearing of forests, for example, is likely to reduce the area's stratus and fog. Evidence suggests that clearing efforts may have already contributed to a decrease in this century's precipitation. Temperatures may also be affected. One very real effect is the dense and widespread late winter/early spring haze that results from burning. A rise in the Amazon Basin's annual river flood crests has also been attributed to forest clearing; more water drains into the rivers because there is less vegetation to absorb it. Data collected from Iquitos, Peru, shows that the Amazon River's annual flood crest depth rose from an average of 82 feet (25 meters) in the 1960's to about 89 feet (27 meters) in the 1970's. The Amazon's depth, which never reached 85 feet (26 meters) in the 60's, was never below 85 feet (26 meters) in the 70's. More recent data is unavailable.

4.1 WESTERN AMAZON BASIN

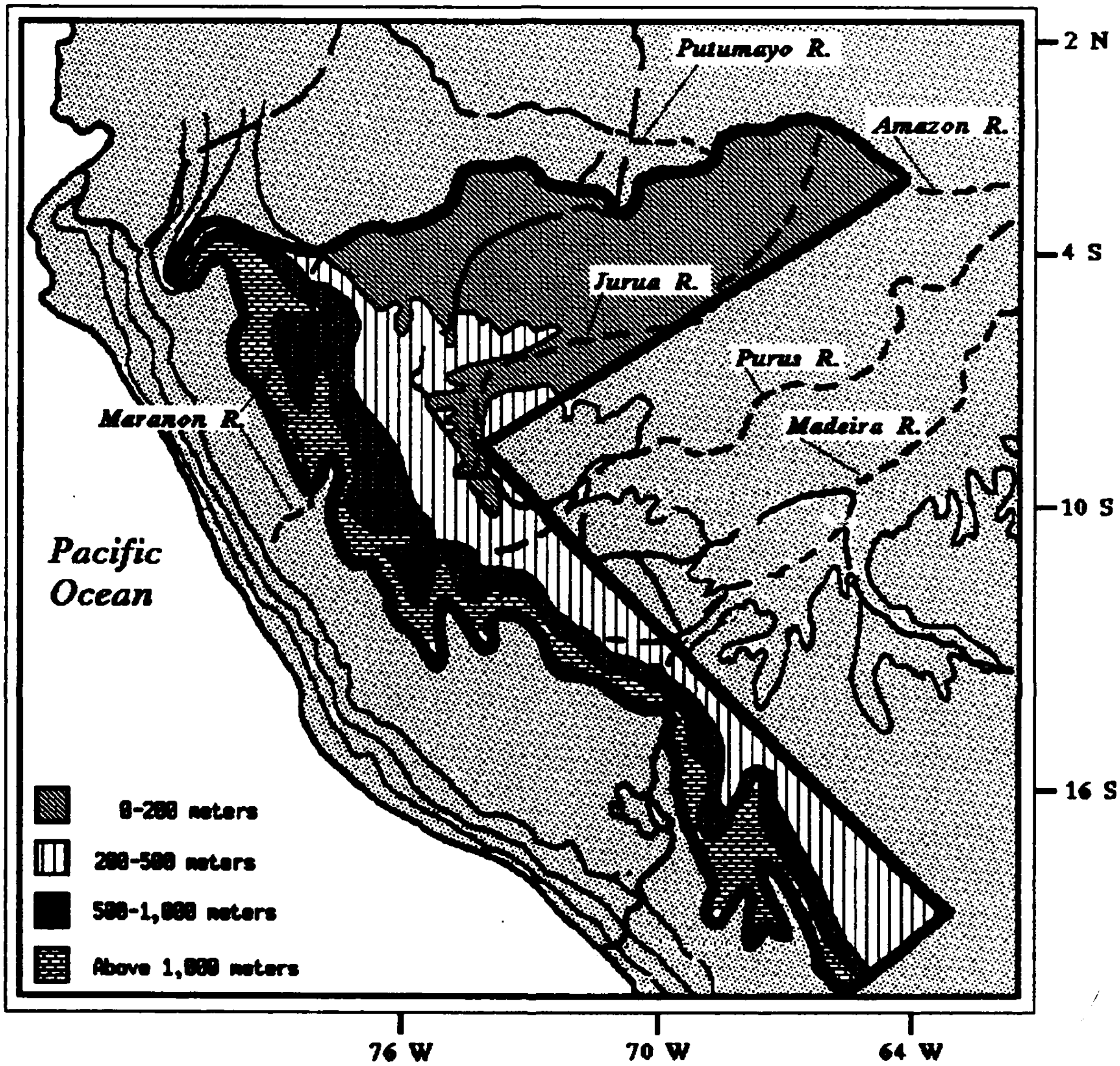
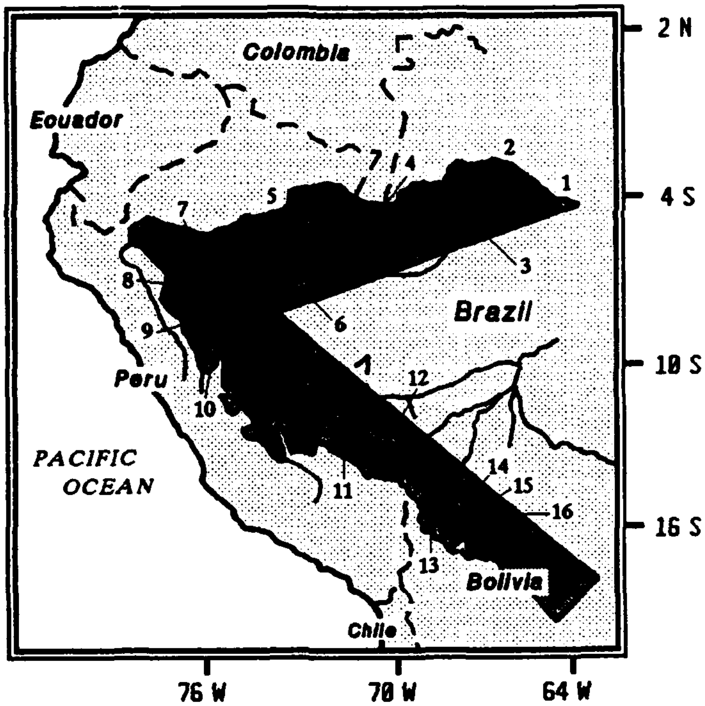


Figure 4-2. Western Amazon Basin.



	ELEVATION (FEET)		ELEVATION (FEET)
1. COARI	148	9. PUCALLPA	478
2. FONTE BOA	176	10. TINGO MARIA	2133
3. CARAUARI	212	11. QUINCE MIL	2034
4. BENJAMIN CONSTANT	209	12. PUERTO MALDONADO	853
5. IQUITOS	404	13. APOLO	4539
6. CRUZEIRO DO SUL	545	14. RURRENABAQUE	648
7. YURIMAGUAS	590	15. SAN BORJA	622
8. JUANJUI	1152	16. SAN IGNACIO DO MOXO	706

Figure 4-3. Climatic Station Network, Western Amazon Basin.

WESTERN AMAZON BASIN GEOGRAPHY

As shown in Figures 4-2 and 4-3, The Western Amazon Basin covers most of the eastern lowlands of Peru, the central Bolivian foothills and lowlands, and a portion of western Brazil south of the Amazon River. This zone is distinguished from the Central Amazon Basin by the higher amounts of precipitation that fall as elevations rise toward the west. At least 2 inches of rain falls here during every month of the year.

BOUNDARIES. The region is bounded as follows:

On the north: by the Amazon and Maranon Rivers beginning in the west about where the Maranon meets the 5,000-foot (1,525-meter) contour of the Andean foothills and ending in the east at 4° S, 64° W.

On the east: by a line starting along the Amazon River at 64° W and extending southwest to 8° S, 73° W. From there the boundary drops south to 10° S, then turns southeast to 17° S, 63°30' W. From this point it continues south to about the 5,000-foot (1,525-meter) contour at 18° S, 64° W.

On the west: roughly by the 5,000-foot (1,525-meter) contour along the eastern Andean foothills from about 18° S northwestward to the Maranon River.

No southern boundary is given; the east and west boundaries meet at the southernmost point.

TERRAIN. The terrain drops from the 5,000-foot (1,525-meter) contour of the Andean foothills in the west to less than 1,640 feet (500 meters) 100 miles to the east, where it becomes rich alluvial plain covered by tropical rain forest. Elevations drop below 655 feet (200 meters) along the major rivers, especially the Ucayali and the approach to the Maranon 100 miles or more from the south. Along the Amazon, elevations slip to less than 330 feet (100 meters).

RIVERS AND LAKES. Most rivers originate in the Andes Mountains or their foothills and flow northeastward to join major rivers that eventually empty into the Amazon. Six large rivers (including the Granoe, the Yapacani, and the Ichilo) originate in the area around and west of Santa Cruz, Bolivia. They converge along 65° W between 15 and 16° S to form the Mamore River before crossing into the Brazilian Plateau zone. The Beni River begins in the Yungas Range northeast of Lake Titicaca and enters the zone at 14°30' S, 67°30' W, flowing NNE across it. Thirty miles east of the Beni is Lake Rogagua at 13°55' S, 66°50' W. The lake is 25 miles long from north to south and 12 miles wide. Several smaller lakes dot the area between Lake Rogagua and the Andean foothills.

In Peru, the Madre de Dios River starts in the Andes of eastern Peru, and follows the base of the foothills eastward into the Central Amazon Basin. The Ucayali River starts where the Tambo and Urubamba Rivers meet at 10°50' S, 73°55' W; it flows north, parallel to the eastern Peru border, to meet the Maranon River 52 miles SSW of Iquitos. The Maranon originates far to the south along the western range of the Andes, flows north over 530 miles, and finally enters the zone at 4° 40' S, 77°20' W. The Maranon continues another 150 miles east before joining the Amazon at 4°25' S, 73°35' W. The Amazon then runs eastward across Brazil.

In Brazil, the Yavari River forms the Brazil-Peru border from 7° S to 4°05' S, where it joins the Amazon. The Jurua River begins in Peru at 10° S, 73° W and runs north to Cruzeiro do Sul, then turns northeast to empty into the Amazon at 2°45' S, 65°50' W. The Jurua is about 1,000 miles long.

VEGETATION. East Andean slopes are covered by dense mountain rain forests below 5,905 feet (1,800 meters). These gradually become tropical rain forests in the foothills and western lowlands. See 4.2 and 4.3 (the Central and Eastern Amazon Basin) for a more detailed explanation of tropical rain forest.

WESTERN AMAZON BASIN CLIMATIC PECULIARITIES

The Western Amazon Basin is distinguished from other tropical zones by its extremes of precipitation, humidity, and temperature. Mean annual rainfall exceeds 120 inches (3,000 mm) at many locations, and may exceed 340 inches (8,600 mm) in the Andean foothills--see Figure 4-4. Morning relative humidity (RH) is generally in excess of 90%; afternoon RH often remains above 70% during the wet season. Late in the dry season, temperatures above 100° F (37° C) are common if afternoon skies remain scattered. This combination of heavy rainfall, high humidity, and high temperatures poses a significant hazard for people and equipment.

Moist Atlantic air flows westward across the continent with the trade winds. This air is cooler than the underlying surface. Along the way, evapotranspiration from the tropical rain forest adds additional moisture. The large amounts of moisture, combined with tropical heating, results in frequent conditional instability. The air crosses 3,000 miles of jungle relatively unimpeded before encountering the sharply rising Andes Mountains where orographic lift causes significant rainfall and cloudiness along the eastern slopes.

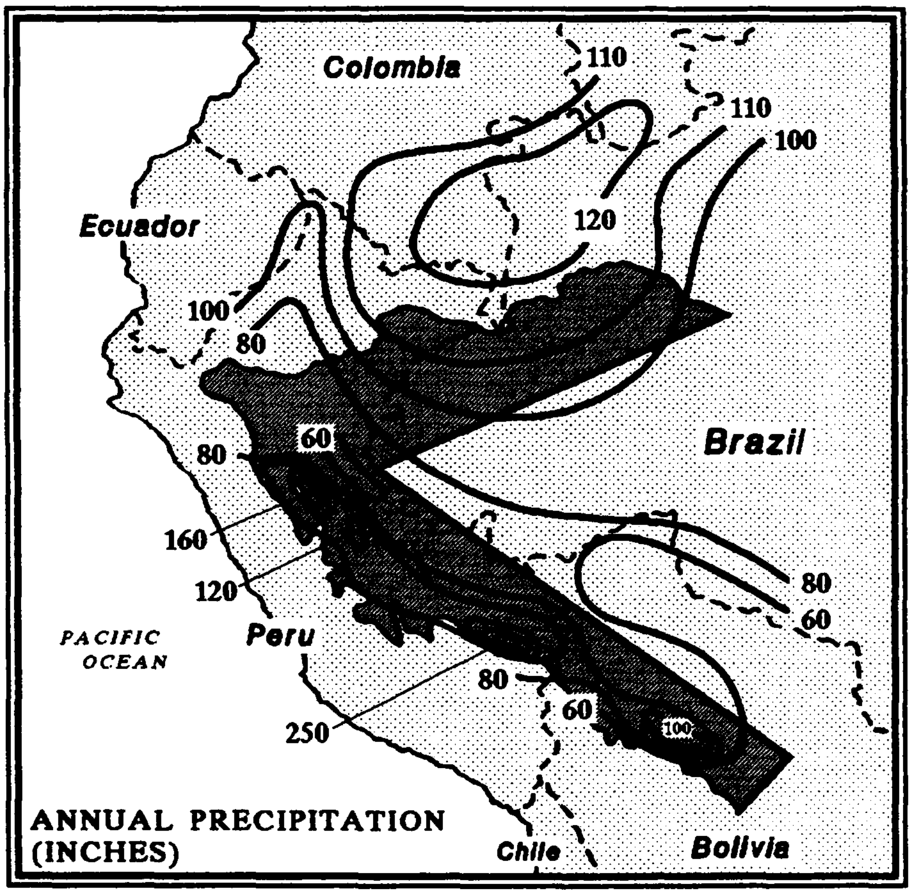


Figure 4-4. Mean Annual Precipitation, Western Amazon Basin.

While the *ranges* of the climatic elements are similar throughout the zone, the *causes* of the climate are not. For example, three distinct precipitation regimes are evident in Figure 4-4. The first covers the northern and eastern portions of the zone. Precipitation here is most closely linked with the climates of Colombia and Venezuela and reflects the broad influence of the Near Equatorial Trough (NET). The second regime covers the extreme west-central part of the zone. The large amounts of rain in this area result from the orographic lifting of warm, moist air encountering the Andes Mountains. The third precipitation regime is in the south, in the jungles east of La Paz. While rain here is enhanced from orographic lift, much of it results from cyclonic activity. This area is, by and large, the northernmost limit of storms originating in southern South America. This pattern of these three distinct precipitation regimes will become more evident throughout the seasonal discussions that follow.

Rainfall and cloudiness in this zone are produced by general low-level convergence, orographic lifting of moist air, and mountain/valley breeze convergence. Simple mechanical deflection by the Andes often causes two or more air streams to collide. This helps explain why certain valleys (e.g., The Inambari River valley) get heavier rainfall than others.

Just as there are spatial differences in the causes of precipitation, there are temporal differences as well. In the north, east, and south, most rain falls during the afternoon because of afternoon heating that leads to increased instability. In the west along the mountains, most precipitation falls at night. Estimates indicate that up to two-thirds of rain showers are nocturnal, resulting from nighttime low-level convergence along the Andean wall and from thunderstorms blown westward from Brazil.

There is very little information available on the effects of the El Niño-Southern Oscillation (ENSO) on the Western Amazon Basin, but preliminary studies indicate that very little change occurs during ENSO events. During ENSO years, thunderstorm frequency tends to diminish due to capping at the upper levels. However, increased subsidence over the interior of the continent enhances the westerly flow of surface air into the zone. Orographic lift leads to increased shower activity; as a result, precipitation amounts vary little between ENSO and non-ENSO years.

The Western Amazon Basin has only two seasons: wet and dry. Transition seasons are too short to be of any consequence. As it is described here, the wet season runs from October to April; the dry season, from May to September. It must be noted, however, that the wet season may be significantly longer in some areas, particularly in the west, and that in some years there might not *be* a true dry season. Generally speaking, however, clouds and precipitation follow the Sun, increasing in Southern Hemisphere summer and decreasing in winter. The climate is closely tied to the shifting trade winds, the formation and decay of the trade-wind inversion, and the presence of thermal lows.

GENERAL WEATHER. The wet season can begin as early as September when a series of pulses forming on the NET penetrate the northern portions of the zone. The North Atlantic High again becomes a dominant influence as the northeasterly trade winds draw moist air off the Atlantic and carry it westward. Local evapotranspiration from the rain forests provides additional moisture. The formation of deep thermal lows, such as the Amazon Low and the Northwest Argentine Depression (NAD), enhance the trades. The conditionally unstable air is easily triggered by low-level convergence and heating, resulting in widespread cloudiness, rainshowers, and thunderstorms. Except in the extreme south, frontal activity is nonexistent.

Weather follows a predictable diurnal cycle. Stratus hanging over the jungle dissipates quickly after sunrise, followed by general clearing. Clouds begin to increase by noon; afternoon skies are broken to overcast. Continuous light rainshowers and isolated thunderstorms blanket the lowlands. By early evening, skies again begin to clear. Thunderstorms are a daily occurrence over the mountains. Low clouds and rain may linger along the Andes' eastern slopes until midnight. Morning calms are typical--thick fog forms after 0300L. By afternoon, winds are generally light and tend to follow the local terrain. Temperatures are above 100° F (38° C) frequently, especially early and late in the season.

SKY COVER. The wet season is the cloudiest time of year. Afternoon cloud cover averages 80%. Warm, moist air enters the zone from the north and east with the trade winds and is deflected southward by the Andes, aided by flow into the NAD. Along the way, the air filters into the numerous river vallevs leading down from the Andes.

There are a number of mechanisms for lifting the conditionally unstable air and forming clouds. In the north and east, the NET provides the additional instability. The effects of the NET may reach as much as 300 NM south of its main axis. To the west, orographic lifting enhances cloud development. Valley winds aid cloud formation during the day, and low-level convergence between mountain and valley breezes also produce diurnal clouds. Convergence associated with a strong nocturnal jet running southeastward along the Andes also enhances cloudiness. The lower slopes of the eastern Andes are shrouded in persistent stratus and stratocumulus with bases at 2,000 feet (610 meters) MSL and tops to 5,000 feet (1,525 meters) MSL. In this zone is the "cloud forest," an almost impenetrable area of dense, stunted growth and twisted vines.

Cloudiness in the south is caused by orographic lift and by cyclonic activity originating in southern South America. These systems weaken rapidly once they get north of Santa Cruz, Bolivia. Also, the high Caupolican range of the Andes, oriented north and south, may induce the formation of a regular mesoscale low-pressure cell in conjunction with the Amazon Low.

Wet-season cloudiness follows a diurnal pattern. Near dawn, skies above rivers are generally clear, but a thin layer of jungle stratus forms over forested areas. It usually burns off within 2 hours after sunrise. By 0900L, scattered stratus and stratocumulus form, with bases at 1,500 feet (460 meters) MSL and tops to 6,000 feet (1,830 meters) MSL. The south generally has less stratus than the north. Altostratus--the remnants of the previous day's thunderstorm activity--is usually present, with 14,000-foot (4,270-meter) MSL bases and 18,000-foot (5,490-meter) MSL tops.

Clouds increase throughout the morning; by early afternoon, they are broken to overcast. Cumulus is now dominant with bases at 2,500 feet (760 meters) MSL and tops to 8,000 feet (2,440 meters) MSL. Towering cumulus (TCU) develops over the mountains and, to a lesser extent, over the lowlands. TCU builds rapidly to 35,000 feet (10.7 km) MSL from 1,000-foot (305 meter) MSL bases. By late afternoon, middle clouds are at a minimum, and isolated cumulonimbus with 1,000-foot (305-meter) MSL bases and 50,000-foot (15.2-km) tops have formed. Over the Brazilian lowlands, thunderstorms dissipate rapidly or drift westward toward Peru.

By 1900L, skies over the eastern lowlands begin to clear. Scattered stratocumulus with 2,500-foot (762-meter) MSL bases and 6,000-foot (1,830-meter) MSL tops predominate. Thick altostratus and altocumulus with bases at 14,000 feet (4,270 meters) MSL and tops to 22,000 feet (6.7 km) may temporarily form a ceiling. Cirrus and cirrostratus also tend to be thick, with 25,000-foot (7.6-km) MSL bases and tops to 37,000 feet (11.3 km). Along the mountains to the west, low ceilings may persist until well after midnight. Rain showers and thunderstorms are common.

Figure 4-5 shows January's mean cloud cover--it is generally lowest in the east (particularly the southeast) and highest in the west.

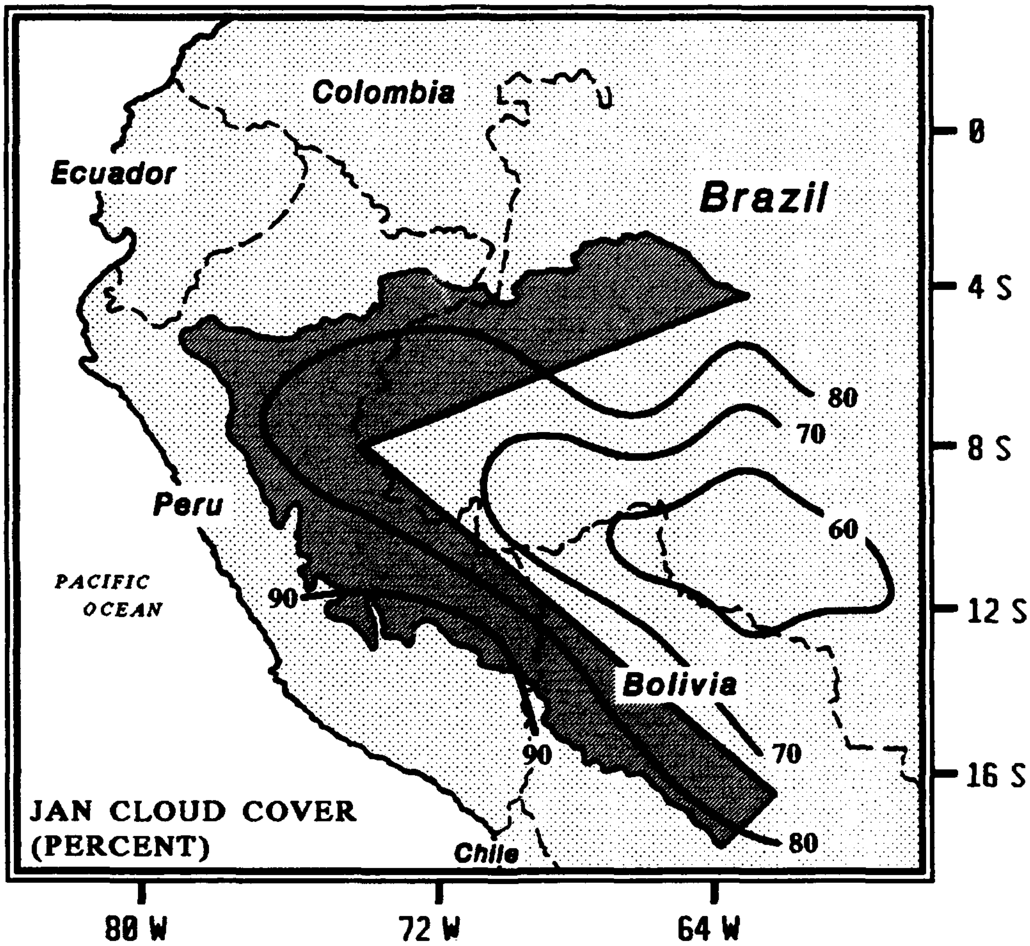


Figure 4-5. Mean January Cloud Cover, Western Amazon Basin.

As shown in Figure 4-6, there is a high frequency of ceilings below 3,000 feet (915 meters) AGL. Low ceilings are most common near dawn when jungle stratus, stratus, and stratocumulus combine. Ceilings normally break or lift rapidly after sunrise except in the northwest, where 1,000-foot ceilings may persist until noon. Afternoon ceilings generally form at 2,000 feet (610 meters) AGL and are widespread across Brazil and Peru. The zone averages only 1-4 clear days a month.

YURIMAGUAS

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	34	39	36	34	41	45	50
13 L	38	45	45	44	38	42	44
19 L	12	12	9	9	9	19	14

IQUITOS

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	32	39	36	40	42	40	46
13 L	48	50	46	44	40	41	47
19 L	28	29	27	25	27	27	32

CARAUARI

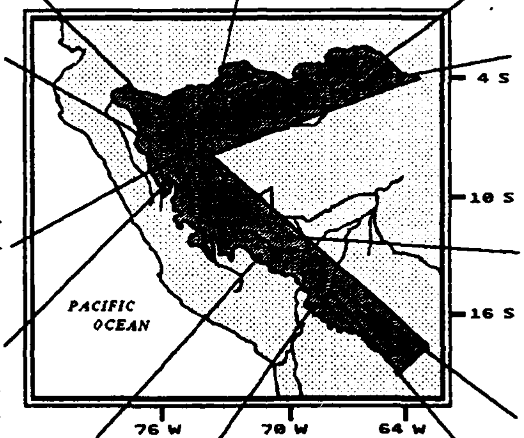
	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	71	74	75	72	77	75	78
13 L	64	70	77	75	71	65	69
19 L	3	5	6	7	9	3	13

JUANJUI

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	48	53	49	51	51	67	71
13 L	13	17	15	17	20	18	13
19 L	22	21	20	18	27	25	22

COARI

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	58	67	70	68	77	81	67
13 L	59	61	57	67	66	70	62
19 L	12	14	28	2	10	11	13



PUCALLPA

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	32	37	40	44	40	48	43
13 L	31	35	37	43	42	50	43
19 L	31	36	23	24	30	28	36

PUERTO MALDONADO

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	36	38	52	40	51	50	51
13 L	44	50	51	49	61	52	38
19 L	23	28	30	25	33	30	24

TINGO MARIA

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	58	66	69	72	73	71	62
13 L	21	24	26	35	37	32	23
19 L	33	30	22	25	26	29	28

SAN IGNACIO DO MOXO

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	21	30	37	46	48	37	20
13 L	28	40	48	63	61	49	37
19 L	17	8	13	14	14	17	18

QUINCE MIL

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	43	41	49	55	56	56	43
13 L	51	47	51	58	58	55	41
19 L	36	44	51	48	51	53	52

APOLO

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	27	37	42	48	58	53	52
13 L	15	18	20	24	20	23	16
19 L	na	na	na	na	na	na	na

RURRENABAQUE

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L	41	60	66	74	72	67	53
13 L	37	45	51	58	60	61	44
19 L	na	na	na	na	na	na	na

WET SEASON
CEILINGS BELOW 3,000 FEET
(PERCENT)
na - DATA NOT AVAILABLE

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L							
13 L							
19 L							

Figure 4-6. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Western Amazon Basin.

VISIBILITY. Low visibilities are primarily caused by fog and precipitation. Early morning winds are calm. The best precursor of fog is rainfall the previous day; under these conditions, ground fog forms after 0300L. By dawn, visibilities below 6 miles are common. Fog tends to be thickest in the northwest and on the flat plains away from the mountains. There are high frequencies of low visibility in the lower Huallaga Valley and at stations in northwestern Brazil (see Figure 4-7). These areas are extremely flat and lack the influence of nocturnal drainage winds. The frequency of visibilities below 0.5 mile (800 meters) is greater than 20% throughout Peru's Loreto district, particularly at places like Yurimaguas and Juanjui. In Brazil, nights tend to remain clear later, allowing fog to become thicker. Low visibility is rarely a problem under jungle canopies due to weak radiational cooling. Fog over eastern Peru dissipates by 1000L; visibilities are generally good the rest of the day. In western Brazil, visibilities below 3 miles continue well into the afternoon.

The predominantly showery precipitation does not restrict visibilities to less than 6 miles, but with fog, visibility drops below 2 miles for hours at a time. Strong convective storms reduce visibility to 1/8 mile (125 meters) for up to 1/2 hour. Visibility in the south is generally better than in the north.

20	25	18	26	30	32	36
2	2	3	3	3	3	2
1	2	1	1	3	1	1

YURIMAGUAS

8	7	8	7	8	11	12
#	#	#	#	#	1	1
1	1	1	1	#	1	1

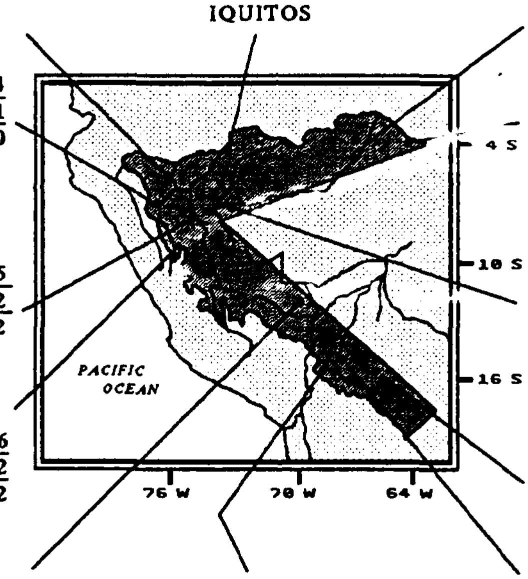
IQUITOS

63	59	63	58	61	60	58
29	36	46	37	36	32	19
74	75	77	76	74	81	73

CARAUARI

32	31	30	32	33	47	44
2	1	1	1	1	1	1
#	0	1	1	2	1	0

JUANJUI



21	20	21	29	27	32	27
6	7	16	6	8	8	9
44	42	37	34	38	47	49

COARI

10	9	8	7	9	10	15
2	2	2	1	2	4	2
#	1	1	2	1	1	2

PUCALLPA

68	75	78	78	70	69	69
23	30	37	26	28	26	25
22	35	41	34	34	34	38

CRUZEIRO DO SUL

15	17	15	19	20	22	16
1	2	1	3	3	4	2
1	2	2	2	2	3	2

TINGO MARIA

8	7	5	9	9	9	3
3	2	5	6	6	5	2
#	#	#	2	2	#	#

SAN IGNACIO DO MOXO

4	3	10	10	16	20	25
na	na	na	na	na	na	na
na	na	na	na	na	na	na

PUERTO MALDONADO

9	10	8	14	12	14	11
3	4	5	4	4	4	3
4	5	1	5	6	3	4

APOLO

6	8	11	15	17	14	8
1	5	3	4	9	6	3
#	#	#	0	0	0	#

RURRENABAQUE

WET SEASON
VISIBILITY BELOW 3 MILES
(PERCENT)
- LESS THAN 0.5 PERCENT
na - DATA NOT AVAILABLE

	OCT	NOV	DEC	JAN	FEB	MAR	APR
07 L							
13 L							
19 L							

Figure 4-7. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Western Amazon Basin.

WINDS. The trade winds are extremely light by the time they reach the Western Amazon Basin; this is reflected in surface wind speeds (Figure 4-8). Terrain effects become important in the absence of strong gradients. The high frequency of calm winds in this zone is remarkable. In eastern Peru, winds are calm more than 80% of the time at most stations. Higher frequencies over the plains east of the mountains affect the frequency of low-visibility. Calm winds also inhibit the vertical transport of heat; most clouds are stratus or shallow cumuus, and rainfall is mostly showery.

Winds are calm most mornings; afternoon winds increase to 3-5 knots and follow local terrain. In the south, afternoon winds are stronger, at 8-10 knots. Adjacent to the Andes, there is a well-established mountain/valley circulation. Daytime valley breezes blow upslope at 6-8 knots; nighttime drainage winds average 2-3 knots. Thunderstorm gusts are generally less than 25 knots, but 70 knots have been recorded. Little more than a wind shift is noted during frontal passages.

STATION	MEAN WIND SPEED						
	OCT	NOV	DEC	JAN	FEB	MAR	APR
APOLO	8	8	8	8	7	6	7
IQUITOS	2	2	2	2	2	2	2
JUANJUI	3	2	3	3	2	2	3
PUCALLPA	3	3	3	3	3	3	2
PUERTO MALDONADO	3	3	3	3	3	3	3
QUINCE MIL	2	1	1	2	2	2	2
RURRENABAQUE	3	3	2	2	2	2	2
SAN IGNACIO DO MOXO	6	6	6	6	5	4	4
TINGO MARIA	2	1	1	1	1	1	1
YURIMAGUAS	1	2	2	2	2	1	1

Figure 4-8. Mean Wet-Season Wind Speeds, Western Amazon Basin.

Surface wind roses (Figures 4-9 through 4-11) show the changes that take place during the wet season. At San Borja, Bolivia, winds are mostly from the northwest at the beginning of the season (October), indicating the deflection of the northeasterly trades by the Andes. There is also an occasional southeasterly component that shows the declining influence of the South Atlantic High. By January, the winds are almost constantly north or northwesterly, with a barely discernible southeasterly component. The moist trade winds have penetrated southward to their maximum extent. By the end of the wet season (April), note the stronger southeasterly component. The South Atlantic High is strengthening, and the dry season is not far off. Readily apparent also is the high frequency of calm winds, particularly in the north. Mountain/valley circulations at Tingo Maria (north-south) and Quince Mil (east-west) are obvious. Finally, note that wind speeds are consistently stronger in the south than the north.

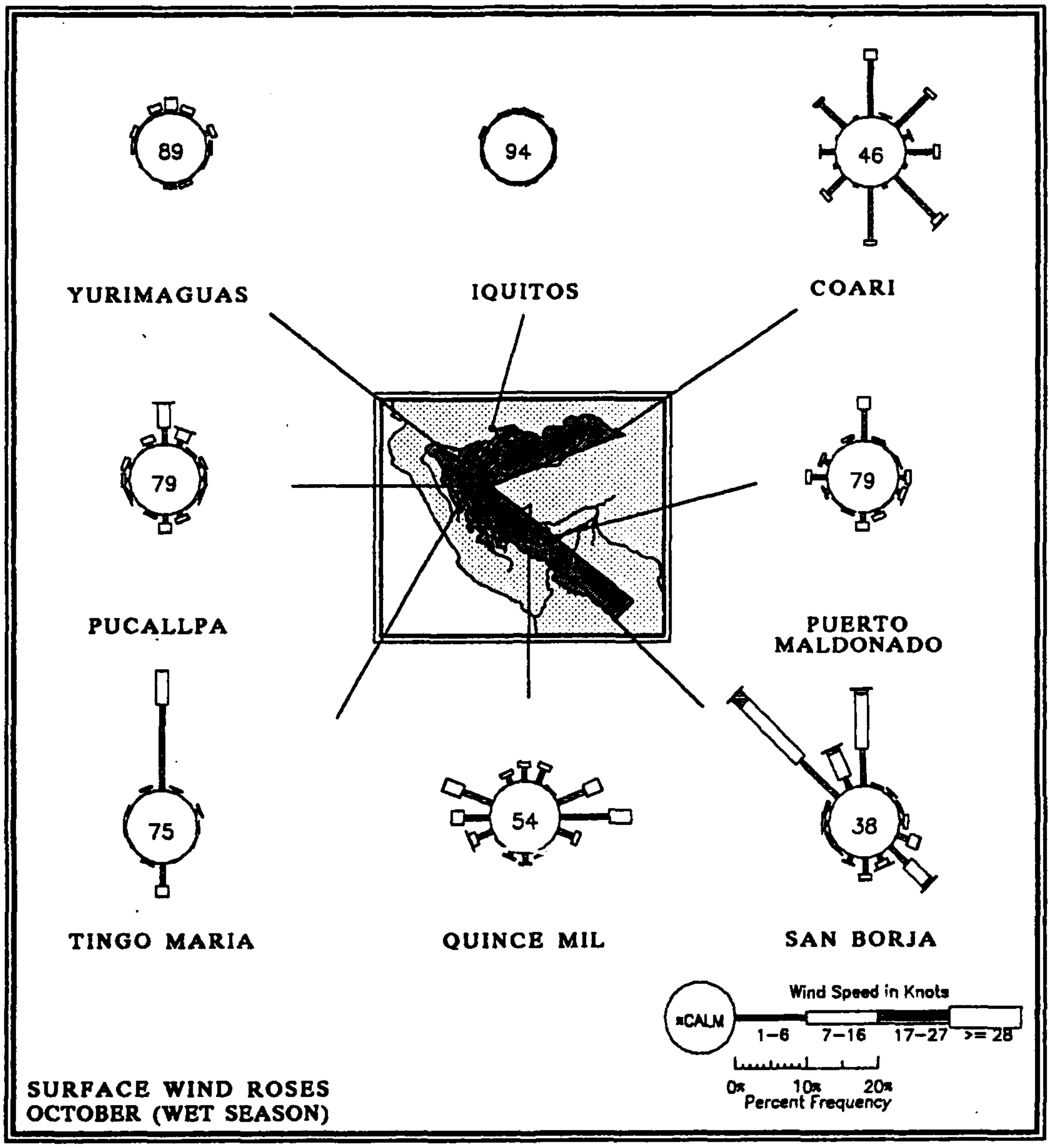


Figure 4-9. October Surface Wind Roses, Western Amazon Basin.

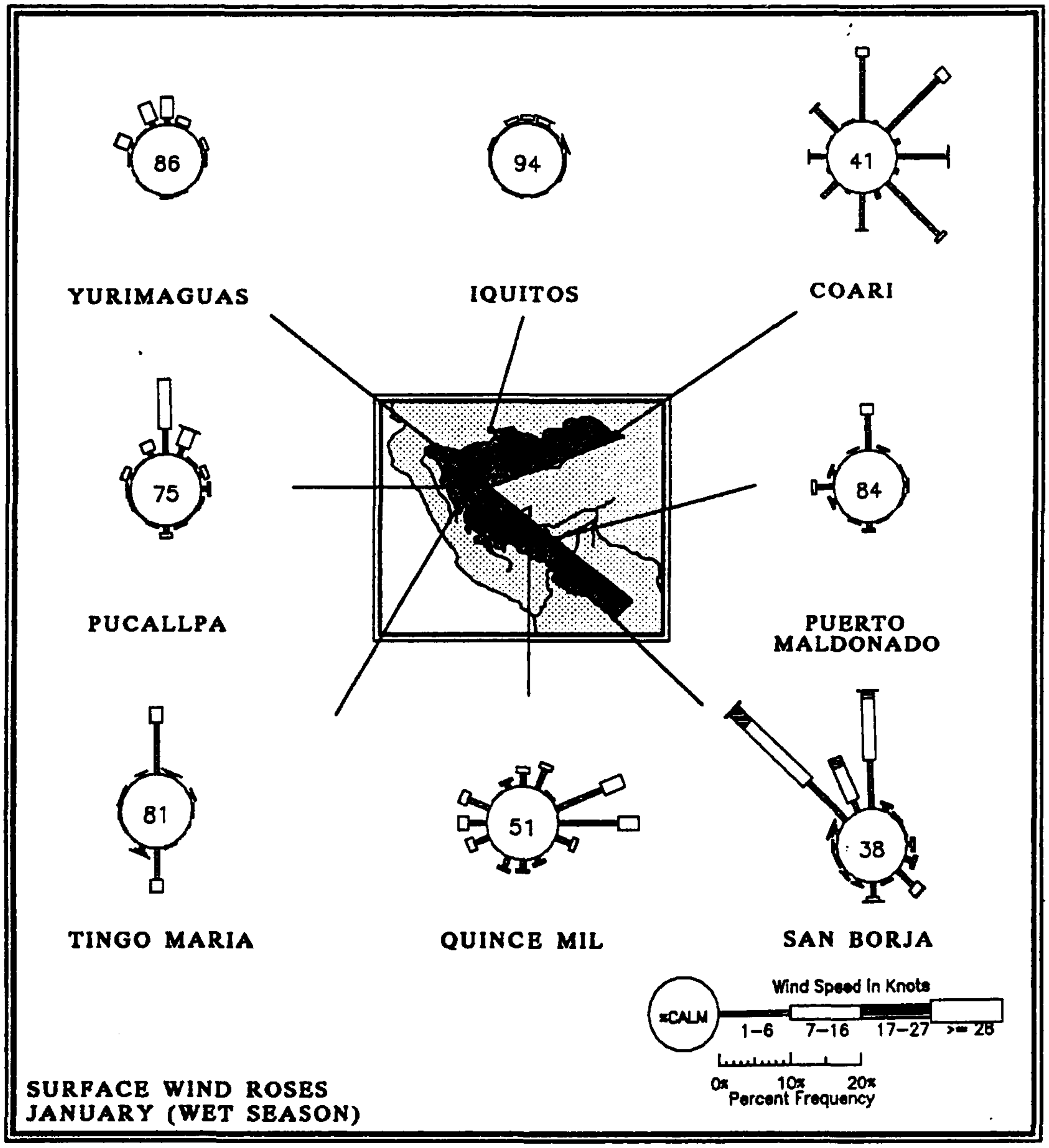


Figure 4-10. January Surface Wind Roses, Western Amazon Basin.

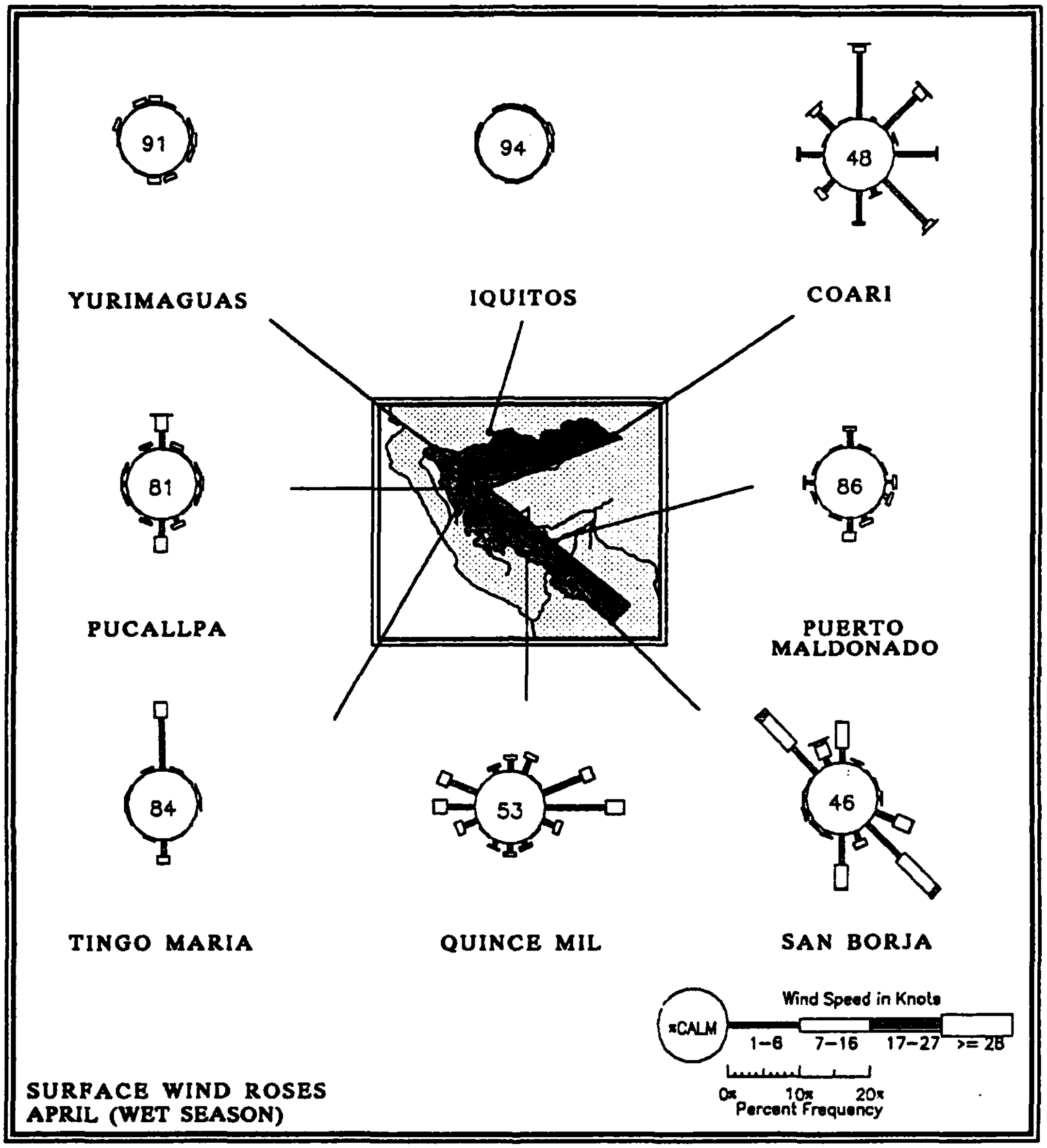


Figure 4-11. April Surface Wind Roses, Western Amazon Basin.

Mean upper-level wind directions are illustrated in Figures 4-12 and 4-13. During the wet season, the unstable airmass reaches 13,000 feet (4,000 meters) MSL. Inside this layer, winds are primarily northwesterly or northeasterly at 12 knots. Winds above are consistently easterly, seldom reaching more than 20 knots. Note (in Figure 4-12) that the boundary layer winds for Iquitos are northeasterly, becoming northwesterly further south at Pucallpa (Figure 4-13). This change is due to the deflection of the winds by the Andes. The differences disappear at and above the 20,000-foot (6.1-km) MSL level. A strong nocturnal jet forms near 10° S, 65° W at about 1,500 feet (460 meters) AGL; speeds reach 50 knots (see Chapter 2). Strong convergence along its leading edge is conducive to nocturnal rain showers.

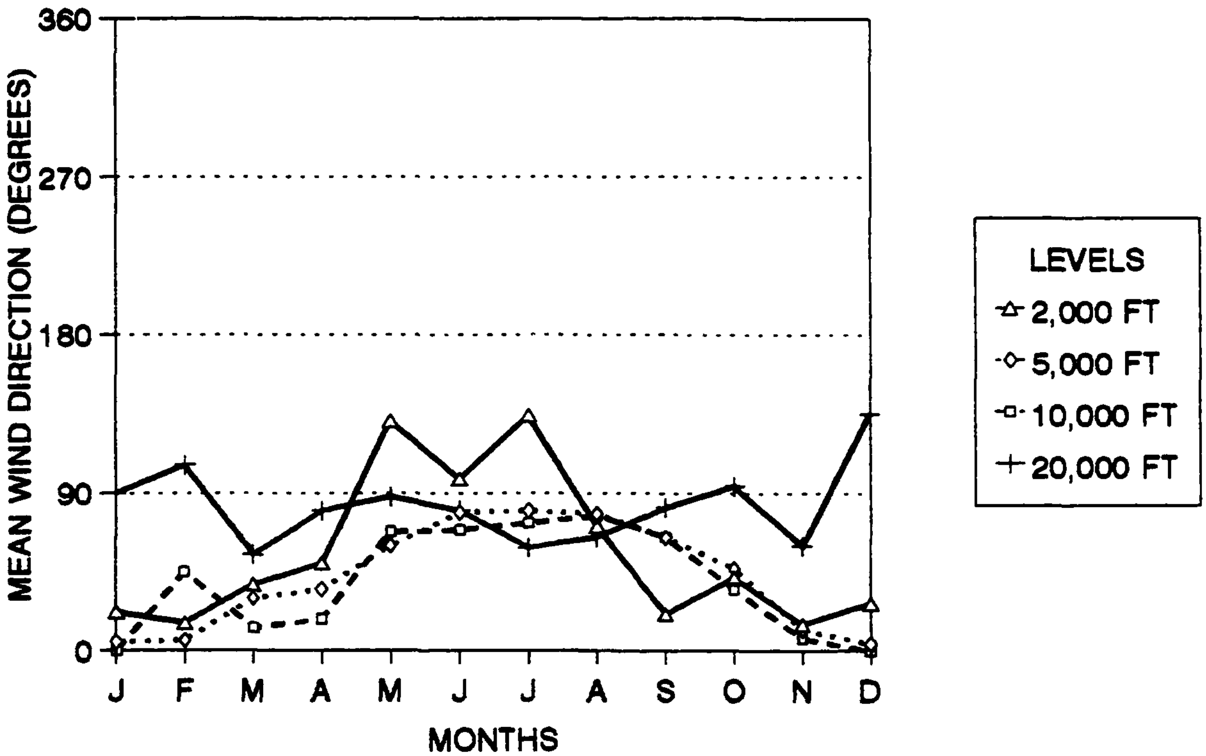


Figure 4-12. Mean Monthly Wind Directions at Various Levels at Iquitos, Western Amazon Basin.

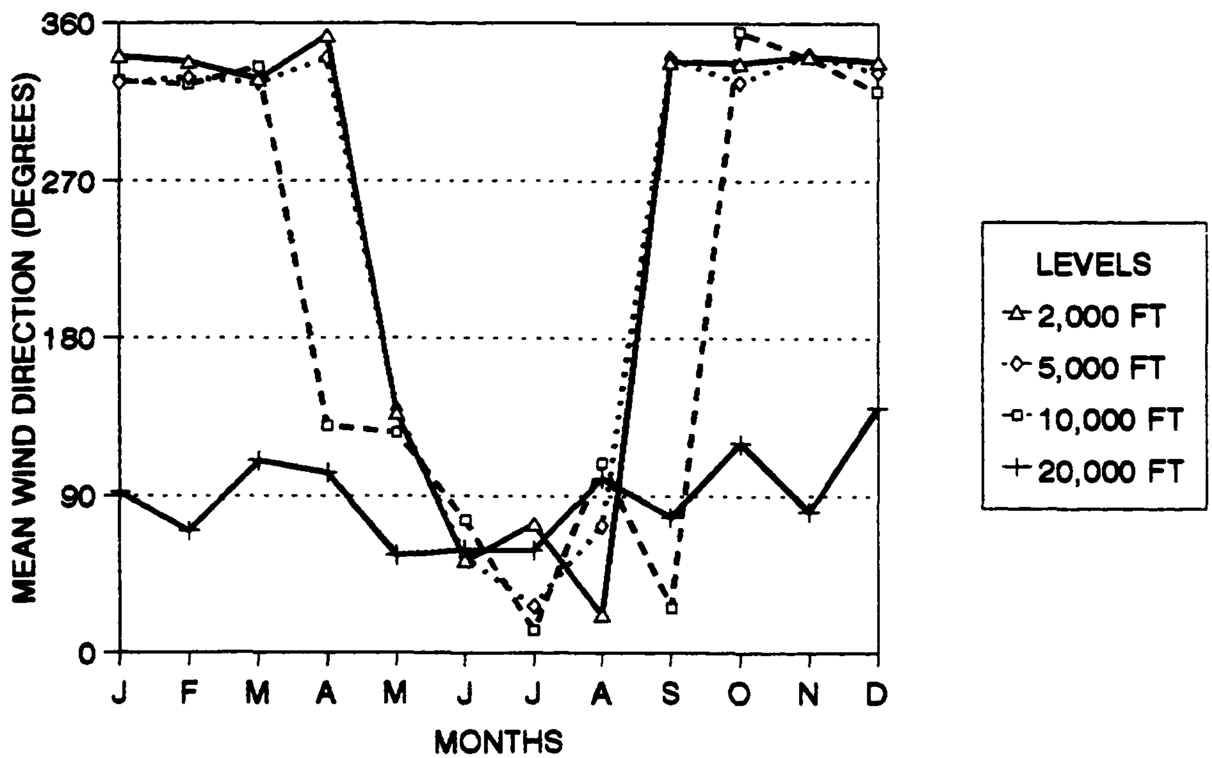


Figure 4-13. Mean Monthly Wind Directions at Various Levels at Pucallpa, Western Amazon Basin.

PRECIPITATION. The same mechanisms that cause widespread cloud cover are also responsible for triggering precipitation. In the north and east, the NET provides the additional instability needed to produce rain. It makes two passes over the zone during this season, first heading south in late November or early December, then north in March. A double precipitation maximum is evident at some locations in the north and east.

In the zone's west-central part, numerous low-level convergence mechanisms produce showers. Low-level convergence of conditionally unstable air east of the Andes, not tropical disturbances, cause the heaviest precipitation in this zone. Orographic lift begins on the eastern approaches to the Andes, becoming stronger closer to the mountains. Convergence with the mountain/valley circulation and simple mechanical deflection create opposing airstreams and showers. At night, strong convergence along the leading edge of the nocturnal jet enhances shower activity.

In the south, high terrain and orographic lift result in widespread showers. The south is also prone to cyclonic activity. Storms originating in southern South America often travel only as far north as Santa Cruz, Bolivia, before weakening to a simple wind shift line. But energetic storms can reach the southern Western Amazon Basin with some residual strength. They can produce violent thunderstorms, hail, and tornados. Other cyclonic activity may be generated locally. Cool air draining off the Caupolican (a high, north-south feature of the Andes) may induce the formation of a mesoscale low-pressure center. Within Bolivia's Beni district, this low may provide enough instability to trigger increased showers.

Instability lines and trade-wind surges also produce precipitation. Instability lines are thought to form off the Brazilian coast in areas of sea-breeze convergence, or from the deep cross-equatorial penetration of Northern Hemisphere systems. They last for 48 hours, moving westward on the trade winds and covering about 10° of longitude a day. Instability lines intensify with daytime heating and are generally inactive at night. Trade-wind surges (see Chapter 2) are rare during the wet season, but they can enhance convergence along the eastern Andes.

Rain falls on 2 out of 3 days a month at the height of the wet season, most as continual light showers. Thunderstorms cause sudden, heavy downpours. Rainfall amounts are greatest along eastern Andean slopes between 1,500 and 5,000 feet (460 and 1,525 meters) or just below the cloud forest. On leeward mountain slopes, seasonal rainfall may be up to 75% less than on windward slopes due to the strong rain shadow effect that results in almost semiarid conditions in deep canyons of some river valleys.

As mentioned in "Climatic Peculiarities," there are three distinct precipitation regimes in this zone. Figures 4-14 through 4-16 show these three regimes and how they change through the season.

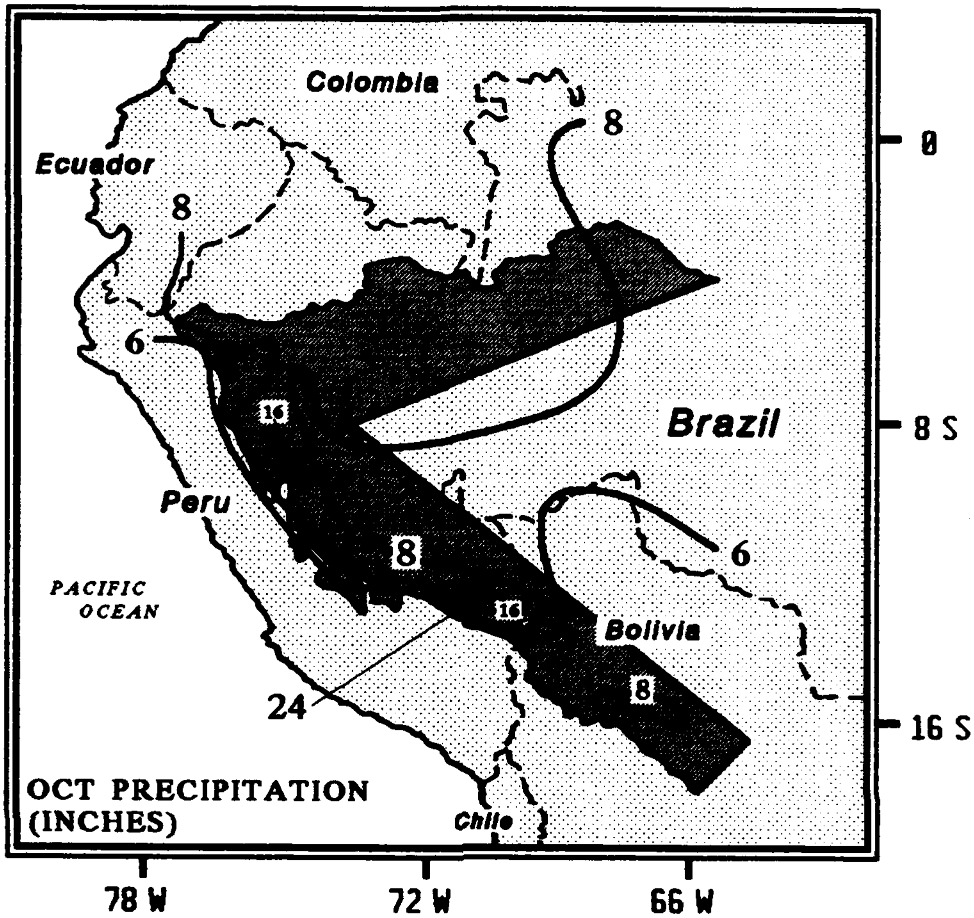


Figure 4-14. Mean October Precipitation, Western Amazon Basin. At the start of the wet season, precipitation amounts begin to increase. Perturbations forming on the NET find their way southward into the zone's northeast. Increased solar insolation leads to greater afternoon convective activity, particularly over the Brazilian lowlands. Most important, a stronger North Atlantic High reestablishes the moist northeasterly trade wind flow into western South America.

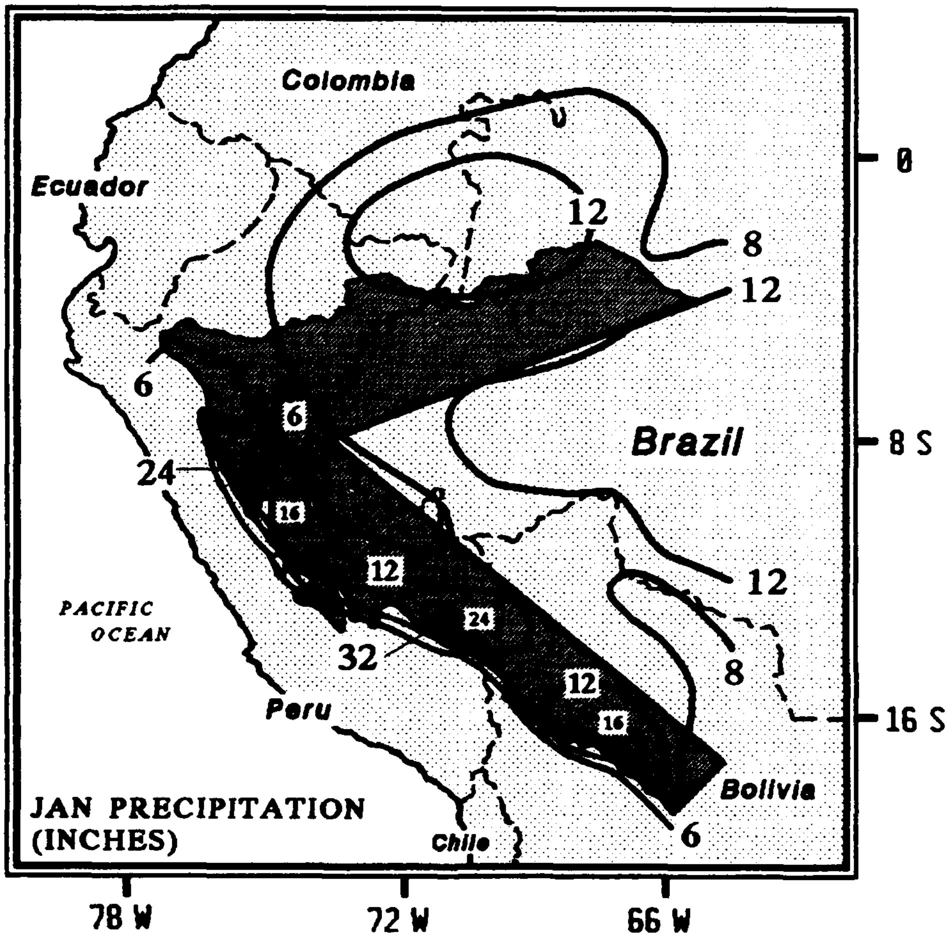


Figure 4-15. Mean January Precipitation, Western Amazon Basin. At the height of the wet season, the NET's influence is clearly apparent in the north and east, as indicated by the 12-inch isohyet. Along the eastern Andes, low-level convergence causes the highest monthly rainfall totals of the year; precipitation gradients are also very high. High monthly rainfall totals also occur in the south due to a combination of orographic lift, afternoon convection, and cyclonic activity.

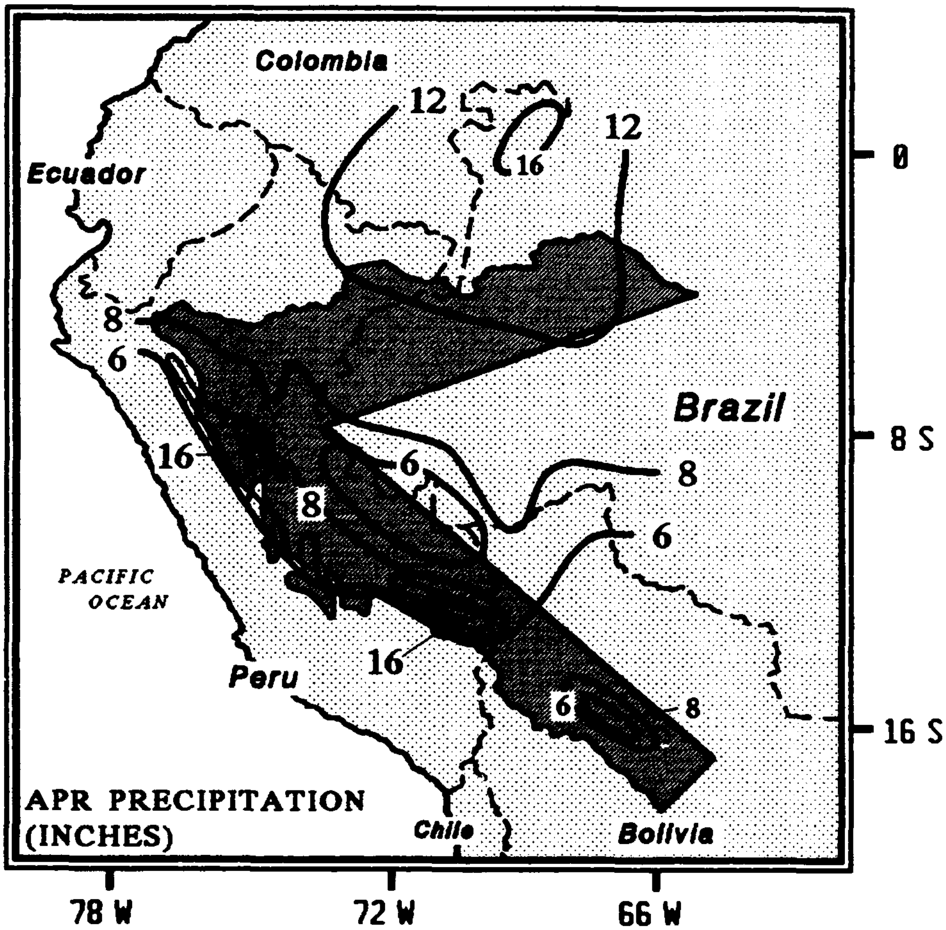


Figure 4-16. Mean April Precipitation, Western Amazon Basin. By season's end, the NET is retreating northward, as indicated by the 16-inch isohyet and the 50% reduction in monthly rainfall totals in the west and south. The northeasterly trades are substantially weaker as a trade-wind inversion begins to form over northeastern Bolivia.

WESTERN AMAZON BASIN

Wet Season

October-April

Figure 4-17 shows tabular precipitation data for the Western Amazon Basin. Notable are the significantly higher extreme values near the mountains. Quince Mil, where mean January rainfall exceeds 51 inches (1,300 mm), lies at the western end of the east-west oriented Inambari River valley. The moist trades here are immediately lifted by the high Andes not more than 2 miles from the town. Precipitation extremes and days with precipitation are lowest in the south. The highest precipitation values tend to occur in the middle of the season.

11.3	10.5	13.7	11.2	10.1	12.5	13.8
4.8	3.0	3.7	2.6	4.7	3.9	6.3
13	15	15	15	13	17	17
4	4	3	4	4	3	3

YURIMAGUAS

16.1	24.4	17.3	14.2	28.3	42.1	21.8
4.1	7.9	5.9	6.3	5.7	7.9	5.3
15	14	15	17	15	19	19
1	1	1	#	#	#	#

IQUITOS

na	na	na	na	na	na	na
6.2	4.6	7.9	3.4	5.1	6.0	3.9
16	16	17	17	14	16	15
na	na	na	na	na	na	na

BENJAMIN CONSTANT

9.6	7.6	12.0	10.6	6.4	6.5	10.4
3.6	3.9	4.7	3.7	2.5	2.2	6.7
12	12	9	9	9	12	15
#	#	#	0	#	0	#

JUANJUI

na	na	na	na	na	na	na
2.6	3.0	3.2	5.1	3.6	2.6	4.1
na	na	na	na	na	na	na
na	na	na	na	na	na	na

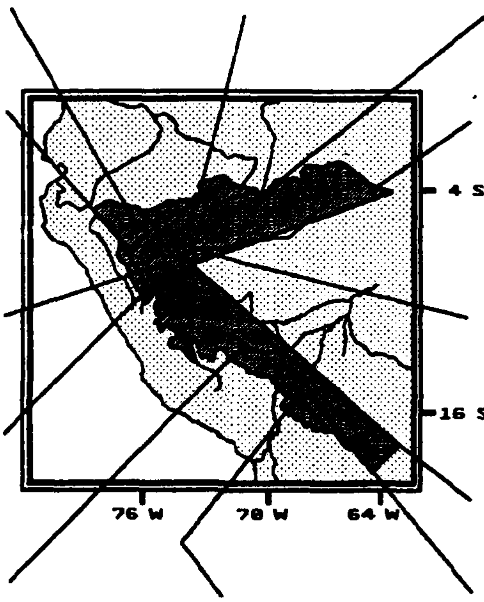
COARI

9.2	10.6	20.7	7.9	12.8	[illegible]	[illegible]
3.7	3.8	6.3	2.5	4.8	5.1	4.0
10	12	12	10	12	[illegible]	14
1	#	#	1	1	1	#

PUCALLPA

na	na	na	na	na	na	na
4.3	4.7	4.0	4.6	4.0	6.4	4.3
na	na	na	na	na	na	na
na	na	na	na	na	na	na

CRUZEIRO DO SUL



17.9	16.6	21.7	31.3	23.0	24.3	22.8
3.2	3.3	7.4	3.9	4.1	4.3	6.3
19	20	21	24	22	22	20
1	2	2	2	1	1	1

TINGO MARIA

7.9	10.5	19.3	14.6	19.2	19.4	15.6
2.8	2.7	6.1	3.2	4.2	7.1	2.2
11	11	17	18	17	20	9
1	#	#	1	#	#	#

PUERTO MALDONADO

44.6	36.5	72.5	74.0	53.8	55.5	38.8
10.4	11.5	16.9	18.9	15.7	14.6	12.2
12	15	20	20	19	20	17
1	1	1	1	1	1	1

QUINCE MIL

10.8	10.5	11.5	14.4	10.5	10.0	6.4
na	na	na	na	na	na	na
9	9	9	9	6	8	10
10	11	9	5	5	5	5

APOLO

11.0	12.4	11.8	19.5	11.7	14.7	9.0
6.4	4.7	3.2	4.5	3.1	4.2	3.2
9	10	11	11	10	14	13
2	3	3	3	2	2	1

RURRENABAQUE

WET SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	OCT	NOV	DEC	JAN	FEB	MAR	APR
MAXIMUM MONTHLY							
MAXIMUM 24-HOUR							
PRECIPITATION DAYS							
THUNDERSTORM DAYS							

Figure 4-17. Wet-Season Tabular Precipitation Data, Western Amazon Basin.

THUNDERSTORMS. In the absence of a significant trade-wind inversion, free convection takes place on most afternoons. Divergence at the upper levels is provided by the Bolivian High, which acts as an exhaust mechanism for thunderstorm activity. The thunderstorm values given in Figure 4-17 grossly underestimate thunderstorm activity over the eastern Andes, where thunderstorms form almost daily. Thunderstorms also develop over the Central Amazon Basin during early afternoon and build westward toward Peru. In the east, most thunderstorm activity is over by 1900L. Nighttime thunderstorms are common in the west. Frontal thunderstorms are rare in the wet season, but they can be severe. Tornados have been reported in eastern Bolivia and southeastern Peru.

Thunderstorms occur more often at the beginning and end of the season when fewer clouds allow for greater surface heating. They are rarely embedded. Thunderstorm bases are as low as 800 feet (245 meters) AGL, and tops can reach 50,000 feet (15 km) MSL. Thunderstorms are accompanied by extremely heavy rainfall, lightning, and moderate-to-heavy mixed icing. Hail has also been reported. Wind gusts are normally less than 25 knots, but extremes of 70 knots have occurred. Mesoscale Convective Systems (MCSs) are rare over this portion of the Basin. When they do occur, they form over northwestern Brazil and generally grow to affect the northern half of the zone, building westward to the Andes. An MCS generally lasts between 18 and 36 hours.

TEMPERATURE. Despite the fact that this zone covers 18 degrees of latitude and 25 degrees of longitude, temperatures are very uniform. Typical of tropical areas, daily temperature ranges are greater than the annual ranges. Seasonal temperatures are high throughout the zone--see Figure 4-18. Mean daily highs range from the high 80's (° F) to the low 90's. Mean daily lows are generally in the high 60's to the low 70's.

Temperatures are lower in the south. Extreme lows of 50° F (10° C) were recorded at Tingo Maria and Apolo. Pucallpa recorded the season's extreme high of 102° F (39° C). Temperatures are higher in the lowlands than on mountain slopes; although elevation plays a role, this is mainly due to the greater amounts of cloud cover over the mountains. The average height of the freezing level is 15,500 feet (4,725 meters) MSL; the average tropopause height is 55,000 feet (16.8 km) MSL.

97	97	97	99	97	100	93
90	89	90	90	90	89	88
71	71	71	71	71	71	70
63	59	64	57	61	61	55

YURIMAGUAS

99	99	97	97	100	97	97
89	89	89	89	88	88	88
70	72	72	72	72	72	72
63	62	60	61	59	62	63

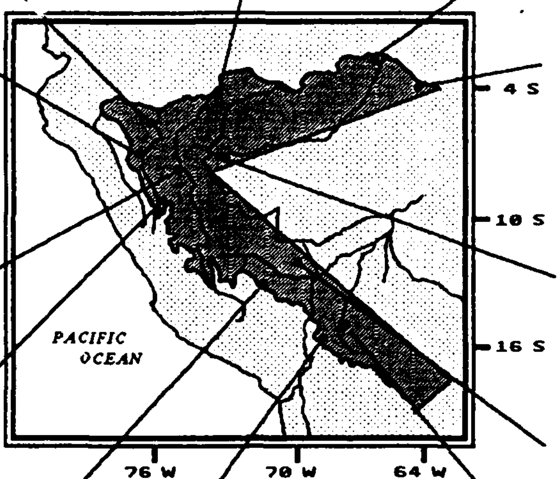
IQUITOS

95	96	96	91	94	94	92
88	88	87	86	86	86	86
69	69	69	69	69	68	69
59	58	54	57	55	54	54

FONTE BOA

100	99	100	100	99	99	97
90	91	92	91	90	89	88
69	70	70	70	69	69	69
57	59	57	61	63	63	54

JUANJUI



97	94	96	94	95	94	94
88	88	87	86	86	86	86
72	72	72	71	71	71	70
63	63	63	64	64	64	64

COARI

102	102	100	102	100	100	99
92	91	92	93	91	90	89
70	71	71	71	71	71	70
59	59	55	59	64	61	61

PUCALLPA

97	96	95	95	95	95	94
87	87	86	86	86	86	85
69	69	70	71	71	71	71
61	61	59	62	64	62	59

CRUZEIRO DO SUL

99	99	97	97	99	95	97
88	88	88	86	86	86	88
64	66	66	66	66	66	66
50	50	50	55	55	55	55

TINGO MARIA

101	101	95	100	97	100	97
90	90	88	88	88	88	88
68	69	69	69	69	68	68
50	57	57	57	57	55	37

PUERTO MALDONADO

95	93	91	90	90	90	90
84	85	83	83	83	83	83
65	66	67	67	67	66	66
57	55	59	61	59	59	57

QUINCE MIL

86	84	84	83	84	83	82
79	78	77	77	76	76	76
65	66	66	66	65	66	65
54	54	56	55	55	54	50

APOLO

101	100	98	99	99	97	94
91	88	90	89	90	89	87
68	69	71	71	71	70	68
56	59	59	64	61	59	56

RURRENABAQUE

WET SEASON
TEMPERATURES (F)

	OCT	NOV	DEC	JAN	FEB	MAR	APR
EXTREME MAXIMUM							
AVERAGE MAXIMUM							
AVERAGE MINIMUM							
EXTREME MINIMUM							

Figure 4-18. Wet-Season Tabular Temperature Data, Western Amazon Basin.

Relative humidity (RH) is extremely high, averaging 80% on most mornings and falling to 60 to 70% by the afternoon. On the Brazilian and Peruvian lowlands, morning RH often reaches 90% or more. Within the cloud forest halfway up the mountainside, RHs consistently exceed 90%. The combination of high humidity and high temperature result in the highest wet-bulb globe temperatures in South America (see Figures 4-19 through 4-24). Afternoon WBGTs reach 90° F (32° C); an extreme WBGT of 100° F (38° C) occurred at Iquitos.

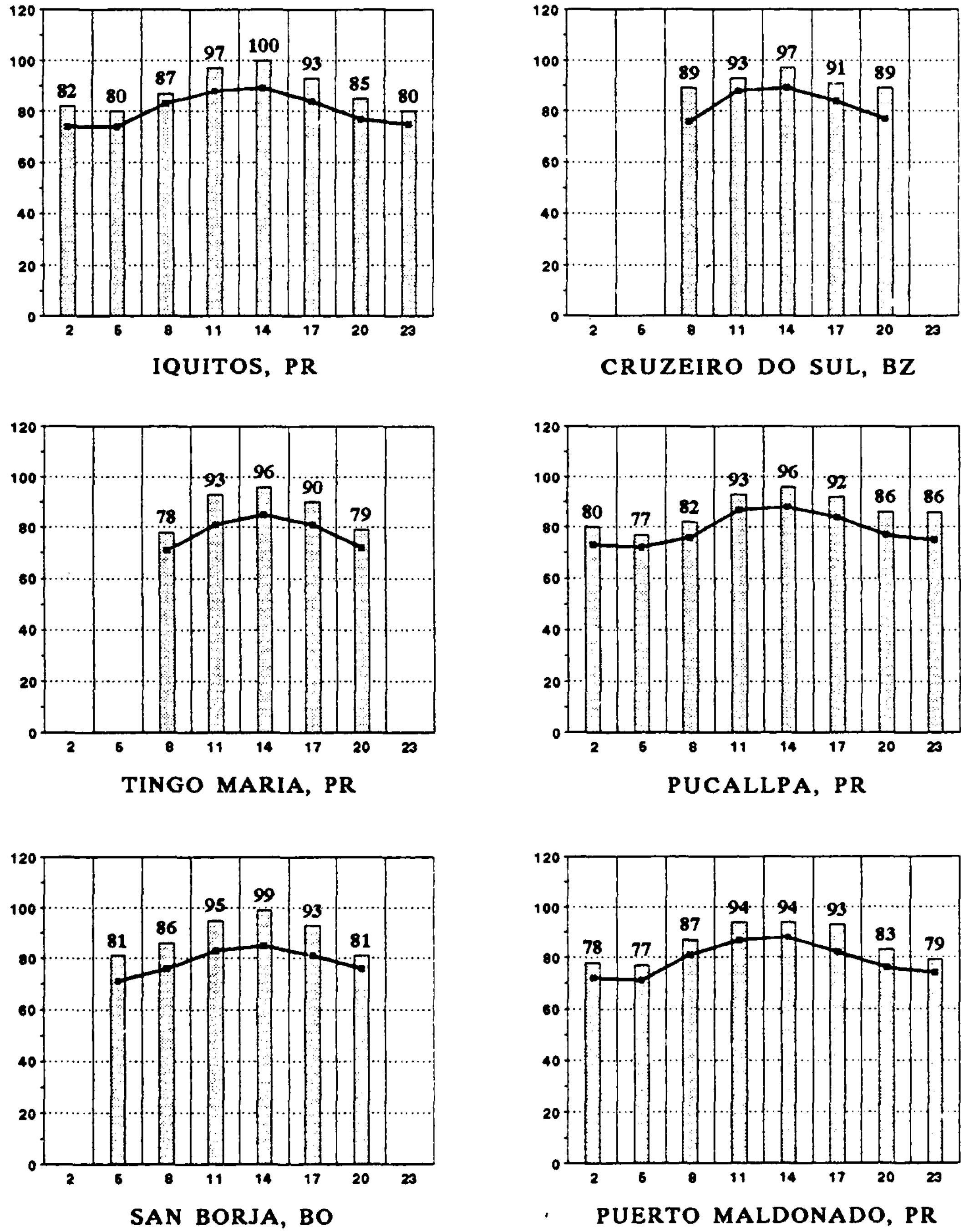


Figure 4-19. Mean Wet-Season Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F), Western Amazon Basin.

FLIGHT HAZARDS. The major flight hazards are turbulence and icing. Light to moderate turbulence can be expected when crossing narrow canyons and some river valleys. Pilots have commented on the particularly strong winds and turbulence near San Ramon Canyon. Light to moderate turbulence has also been reported at 13,000 feet (3,965 meters) MSL between Trujillo and Juanjui. At night, moderate turbulence is associated with a strong nocturnal low-level jet. Above 20,000 feet (6.1 km) MSL, light to moderate turbulence has been reported east of Cajamarca, Peru. In Bolivia, some mountain-wave turbulence may be encountered east of La Paz in the westerlies crossing the Andes. Standing waves have also been reported east of the Andes between Sunchubamba and Cajamarca. Moderate turbulence is found near thunderstorms, along with moderate to heavy mixed icing and hail.

GROUND HAZARDS. Heavy wet-season rainfall leads to serious flooding and landslides. Rivers fill quickly, and it is not unusual for two rivers to join, forming one large stream. In the south, the clay hardpan traps water at the surface where it stands for weeks at a time. Near the mountains, the rivers rush down at great speed, only slowing on the very flat plains. Extremely high temperatures and humidity affect human endurance and promote disease. High humidity leads to maintenance concerns; corrosion, rot, mildew, and mold cause deterioration of unprotected equipment. Tornadoes have been sighted in Bolivia and southeastern Peru.

GENERAL WEATHER. Beginning in May, the influence of the northeasterly trade winds is significantly reduced. The atmosphere is generally more stable than during the wet season. A strong trade-wind inversion forms in northern and eastern Bolivia and caps significant convection. The South Atlantic High and the southeasterly trades now become dominant, particularly in the south. The trades arrive at the zone relatively dry after losing South Atlantic moisture crossing the Brazilian highlands. Elsewhere, the NET has retreated northward, exerting very little influence on the zone.

There is more frontal activity in the dry season, with three to five frontal passages from May through August. Cold fronts push northward from southern South America; by the time they reach the zone, they may continue northward from inertia or with a push from a strong high-pressure cell building behind the front. These fronts are shallow (normally not more than 1,500 feet/500 meters deep), and not very active. They continue to weaken as they move northward. Widespread stratus accompanies them, with generally clear skies behind. During the day, very light showers fall with frontal passage. Drizzle is more common at night. The significance of these fronts is that temperatures drop well below normal; flying weather behind them is the best of the year. High frequencies of blocking over both oceans reduces the number of fronts reaching the Amazon.

Dry-season weather is similar to that of the wet season--the main difference is its *intensity*. Dry season cloudiness has a diurnal pattern that is not as pronounced as that of the wet season. Rain falls regularly, but in smaller amounts and with less intensity. Humidity is high, but not oppressive. Dry-season temperature extremes are greater than in the wet season.

SKY COVER. The dry season is the least cloudy time of the year, as shown in Figure 4-20. Afternoon cloud cover averages between 4 and 6/10ths. Although there are many similarities in cloud cover between the two seasons, including the basic diurnal cycle, there are notable differences. Chief among these is the decrease in afternoon dry-season cloudiness, especially at the middle and high levels. A greater number of clear days is also characteristic of the dry season. These important differences largely result from diminished solar insolation during the Southern Hemisphere winter and the shift in the zone's dominant influence from the North Atlantic High to the South Atlantic High, which is ridging well onto the continent by May, and shifting the trade winds from northeast to southeast. The southeasterly trades lose most of their moisture crossing the Brazilian highlands and arrive in the Western Amazon Basin with much less moisture and with more stable air. A strong trade-wind inversion forms between 10,000 and 12,000 feet (3,050 and 3,660 meters) MSL over western Brazil and eastern Bolivia, where it caps most convection.

Low-level convergence along the Andes remains the most important mechanism for producing clouds. The NET retreats northward and is not as active even when near the zone. Other tropical disturbances are also much less active. Afternoon convection is less predictable, becoming strong in some places and on some days, but weaker at other places and times.

The diurnal cycle of cloudiness is similar to that of the wet-season, but less pronounced. Thin layers of jungle stratus hang over forested areas at dawn. Most low stratus dissipates within 2 hours after sunrise, and the least cloudy time of day is between 1000 and 1300L. Stratiform clouds with bases at 2,000 feet (610 meters) MSL and tops to 6,000 feet (1,830 meters) MSL are more common on dry season mornings due to greater atmospheric stability. Scattered altostratus with bases at 12,000 feet (3,660 meters) MSL and tops to 15,000 feet (4,575 meters) MSL are also present, but there is less cirrus because of diminished thunderstorm activity.

Clouds increase after 1300L, becoming more cumuliform in response to daytime heating. The cumulus has 2,500-foot (760-meter) MSL bases and 8,000-foot (2,440-meter) MSL tops. Towering cumulus is prevalent on the mountains and, to a lesser extent, on the lowlands; tops range upwards of 35,000 feet (10.7 km) MSL from 2,000-foot (610-meter) MSL bases. Isolated cumulonimbus have bases as low as 1,000 feet (305 meters) MSL and tops to 40,000 feet (12.2 km) MSL. Thunderstorms and cloudiness in general diminish by 1900L in the east and south. Low-cloud ceilings can linger along the Andes until after midnight.

During frontal passages, stratus and stratocumulus closely attend the front, with clearing behind. The stratus fans out to cover the entire zone as the front crosses into Peru. The front is usually followed by 2-3 days of clearing skies. The day after frontal passage is usually marked by a scattered layer of altocumulus between 12,000 and 16,000 feet (3,660 and 4,880 meters) MSL.

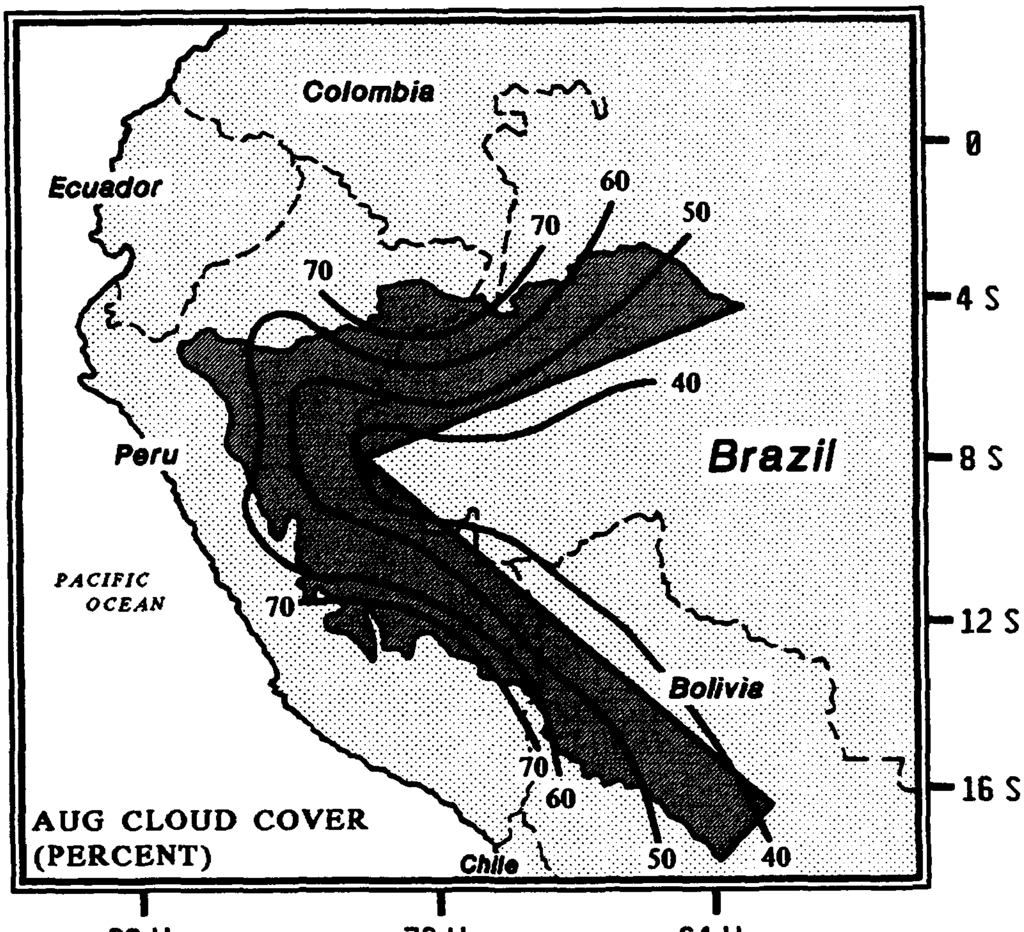


Figure 4-20. Mean July Cloud Cover, Western Amazon Basin.

Morning frequencies of ceilings below 3,000 feet (915 meters) AGL are nearly identical to those of the wet season. Jungle stratus and "normal" stratus combine to form low ceilings at dawn. These ceilings usually dissipate or lift within a few hours after sunrise. Afternoon low-ceiling frequencies are slightly lower during this season due to the drier conditions. The zone has between 2 and 5 clear days a month.

YURIMAGUAS

	MAY	JUN	JUL	AUG	SEP
07 L	41	38	31	28	29
13 L	39	35	33	27	31
19 L	15	9	11	10	13

IQUITOS

	MAY	JUN	JUL	AUG	SEP
07 L	42	47	38	35	30
13 L	49	53	46	42	43
19 L	30	31	27	21	26

CARAUARI

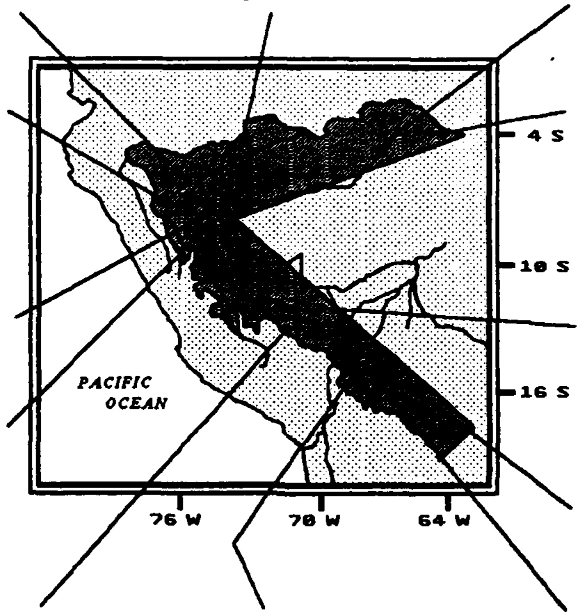
	MAY	JUN	JUL	AUG	SEP
07 L	74	61	57	61	66
13 L	74	66	67	66	64
19 L	4	na	na	5	4

JUANJUI

	MAY	JUN	JUL	AUG	SEP
07 L	73	71	61	53	49
13 L	12	9	8	11	14
19 L	18	15	10	13	17

COARI

	MAY	JUN	JUL	AUG	SEP
07 L	66	52	43	33	44
13 L	64	52	37	47	51
19 L	6	5	2	6	9



PUCALLPA

	MAY	JUN	JUL	AUG	SEP
07 L	39	38	31	22	26
13 L	40	44	38	30	32
19 L	25	17	17	15	25

PUERTO MALDONADO

	MAY	JUN	JUL	AUG	SEP
07 L	41	50	50	30	30
13 L	37	36	27	20	26
19 L	18	20	22	8	15

TINGO MARIA

	MAY	JUN	JUL	AUG	SEP
07 L	65	66	52	47	45
13 L	18	15	16	15	17
19 L	23	14	14	15	22

SAN IGNACIO DO MOXO

	MAY	JUN	JUL	AUG	SEP
07 L	26	27	17	16	18
13 L	37	40	20	17	28
19 L	24	17	14	17	15

QUINCE MIL

	MAY	JUN	JUL	AUG	SEP
07 L	50	65	52	41	33
13 L	42	49	48	37	30
19 L	51	56	50	37	31

APOLO

	MAY	JUN	JUL	AUG	SEP
07 L	45	43	42	30	30
13 L	6	8	8	7	11
19 L	na	na	na	na	na

RURRENABAQUE

	MAY	JUN	JUL	AUG	SEP
07 L	57	61	53	34	35
13 L	46	52	41	26	26
19 L	na	na	na	na	na

DRY SEASON
CEILINGS BELOW 3,000 FEET
(PERCENT)
na - DATA NOT AVAILABLE

	MAY	JUN	JUL	AUG	SEP
07 L					
13 L					
19 L					

Figure 4-21. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Western Amazon Basin.

VISIBILITY. Visibilities are worse in the dry season, particularly in the morning, when abundant moisture and calm winds are extremely conducive to fog formation. Fog, precipitation, and smoke are the primary restrictions. The longer nights are generally less cloudy and therefore allow for more radiational cooling. The best precursor of morning fog is rain on the previous day.

Fog occurs most mornings; visibilities below 3 miles are widespread (see Figure 4-22). Visibility in the north is much worse than in the south. In the lower Huallaga River Valley, visibilities are below 1/2 mile about 1 day in 3, and the frequency of visibility below 3 miles is near 60% at some locations. In Peru, fog dissipates around 1000L, resulting in excellent afternoon visibilities, even better than those of the wet season. In northwestern Brazil, nights are generally clearer and cooler with low visibilities on 2 days in 3. Low visibilities persist well into afternoon in the stagnant Brazilian jungles.

The dry season's light rain showers generally don't cause visibilities to fall much below 6 miles, but heavy downpours can reduce visibility below 1/4 mile for up to 30 minutes. A combination of fog and precipitation reduces visibilities below 2 miles for several hours. Smoke and haze become a problem late in the dry season due to widespread burning; visibilities below 3 miles can last all day in Bolivia.

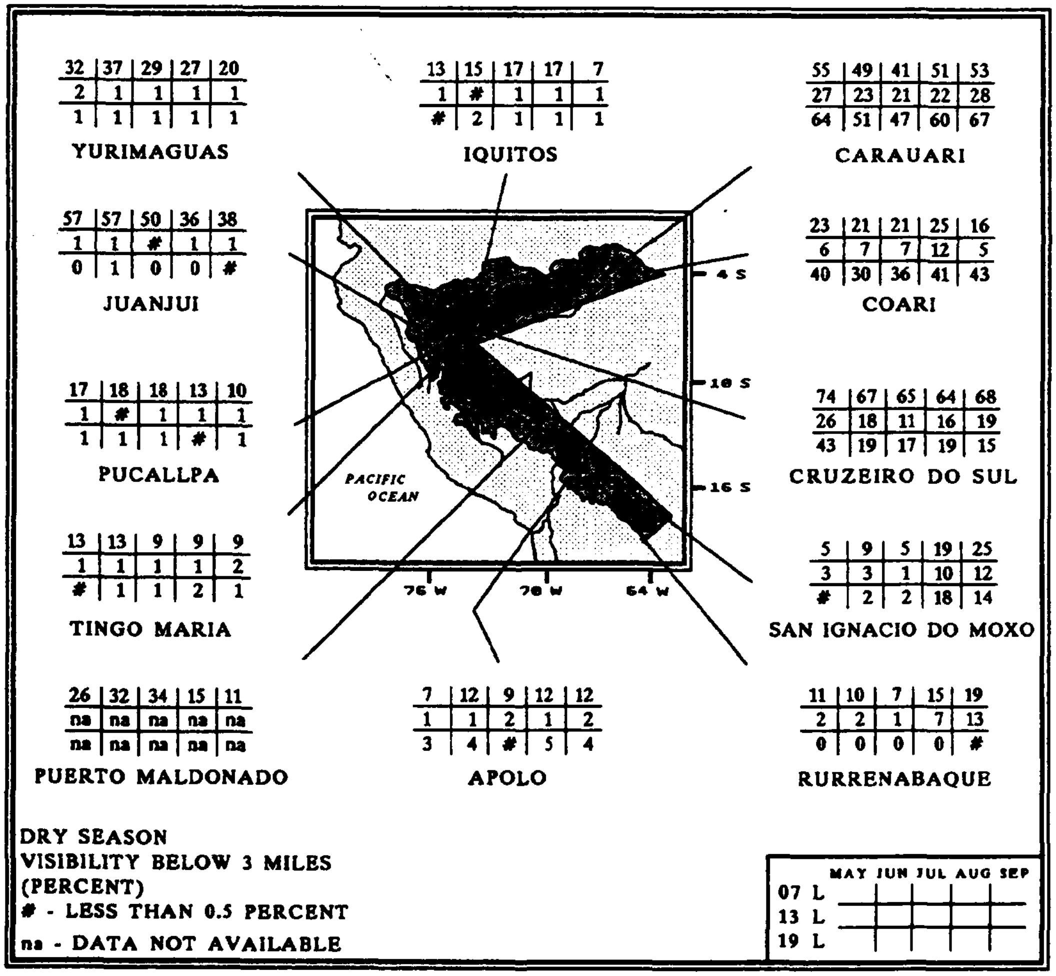


Figure 4-22. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Western Amazon Basin.

WINDS. Dry-season surface winds are similar to those of the wet season. The trade winds continue to be very light; local terrain exerts a greater influence. July surface wind roses (Figure 4-23) are representative of the entire dry season. Note the high frequency of calm conditions which, in the lower Huallaga River Valley, aid early morning fog formation. Mountain/valley circulations are prominent, as illustrated by the Tingo Maria and Quince Mil wind roses.

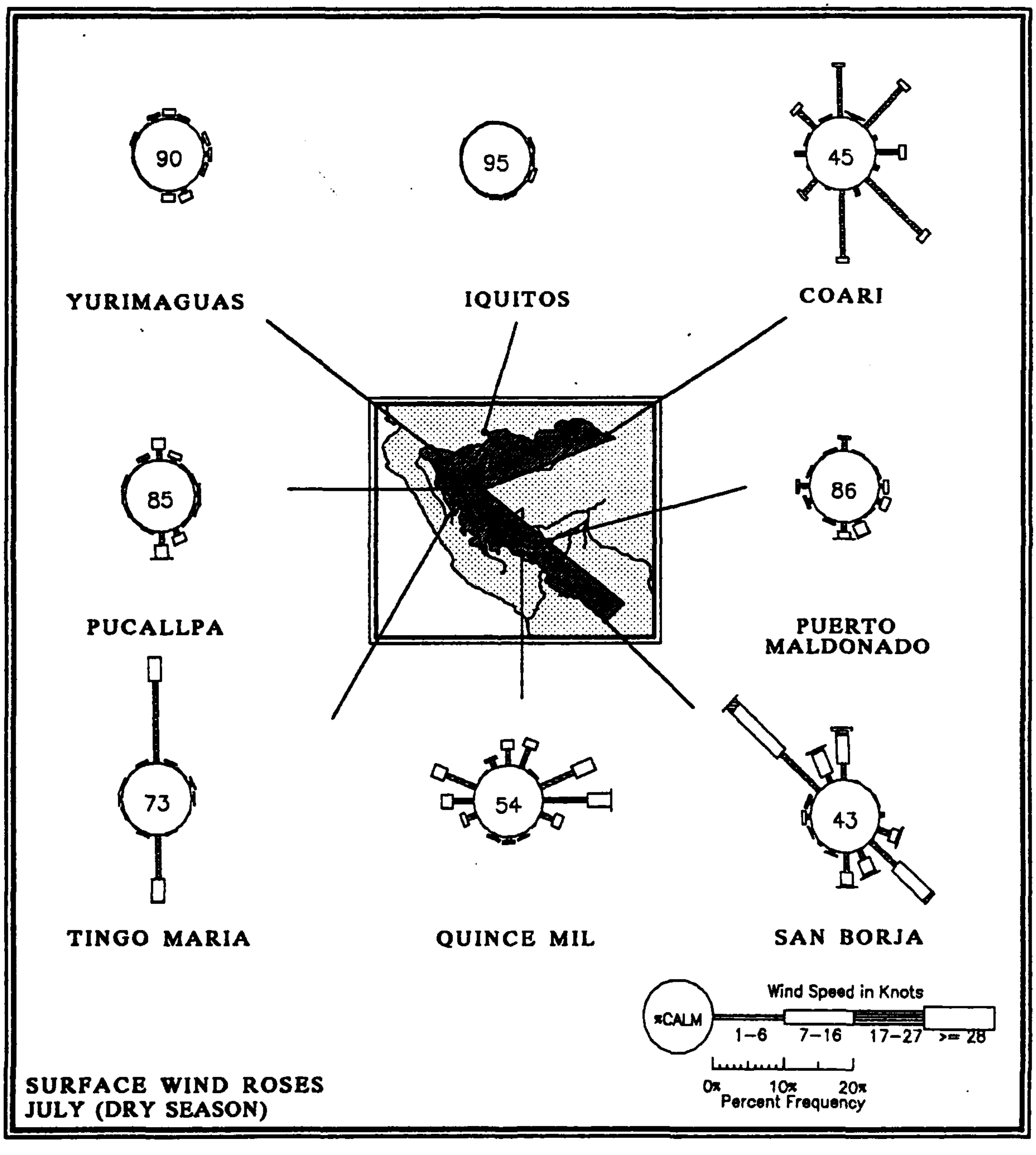


Figure 4-23. July Surface Wind Roses, Western Amazon Basin.

Winds are calm most mornings, increasing to 3-5 knots in the afternoon as they follow local terrain. In the south, afternoon winds are stronger at 8-10 knots (Figure 4-24). A mountain/valley circulation is well established; daytime valley breezes blow up mountain slopes at 6-8 knots and nighttime drainage winds average 2-3 knots. Thunderstorm gusts are generally less than 25 knots, but speeds approaching 70 knots have been recorded. Little more than a wind shift is noted during frontal passages.

STATION	MEAN WIND SPEED				
	MAY	JUN	JUL	AUG	SEP
APOLO	7	8	9	9	9
IQUITOS	2	2	2	2	2
JUANJUI	2	3	3	3	2
PUCALLPA	2	2	2	3	3
PUERTO MALDONADO	2	2	2	3	3
QUINCE MIL	1	1	1	2	2
RURRENABAQUE	2	2	2	3	3
SAN IGNACIO DO MOXO	4	5	7	6	6
TINGO MARIA	1	1	1	2	2
YURIMAGUAS	1	1	1	1	2

Figure 4-24. Mean Dry-Season Wind Speeds, Western Amazon Basin.

During the dry season, the airmass is unstable to 1,500 feet (460 meters) AGL. Winds below 1,500 feet are southeasterly and seldom exceed 12 knots (see Figures 4-12 and 4-13); easterlies prevail above. Speeds average 25 knots at 20,000 feet (6.1 km) MSL. A strong nocturnal northwesterly jet that reaches speeds of 50 knots forms near 10° S, 65° W at about 1,500 feet (460 meters) AGL--see Chapter 2. Strong convergence along its leading edge is conducive to nocturnal rain showers.

PRECIPITATION. Precipitation amounts are smaller because the South Atlantic High is dominant and the air is significantly drier and more stable. Fewer tropical disturbances affect the zone. Much of the precipitation that does fall comes at the beginning and end of the season during the brief seasonal transitions.

Figures 4-25 and 4-26 show mean June and August precipitation. Note the absence of the strong precipitation gradients near the Andes that were so evident during the wet season.

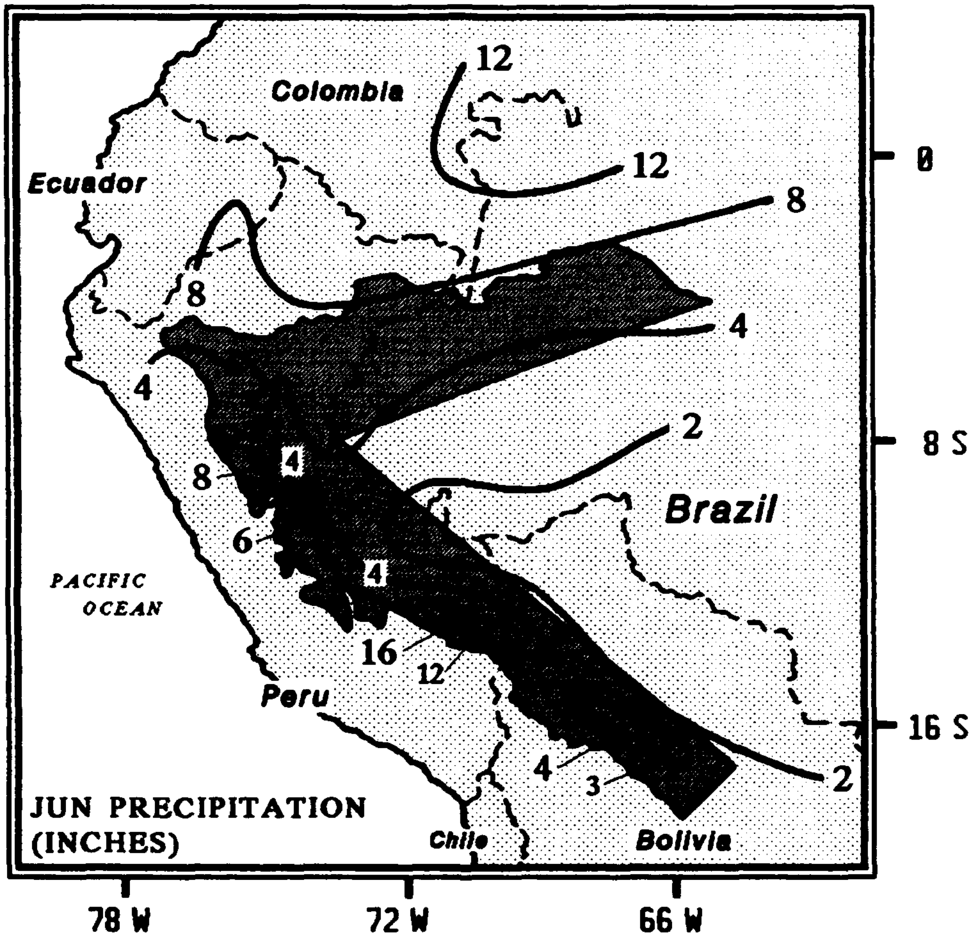


Figure 4-25. Mean June Precipitation, Western Amazon Basin. In June, precipitation associated with the NET has retreated far northward into Colombia and Venezuela.

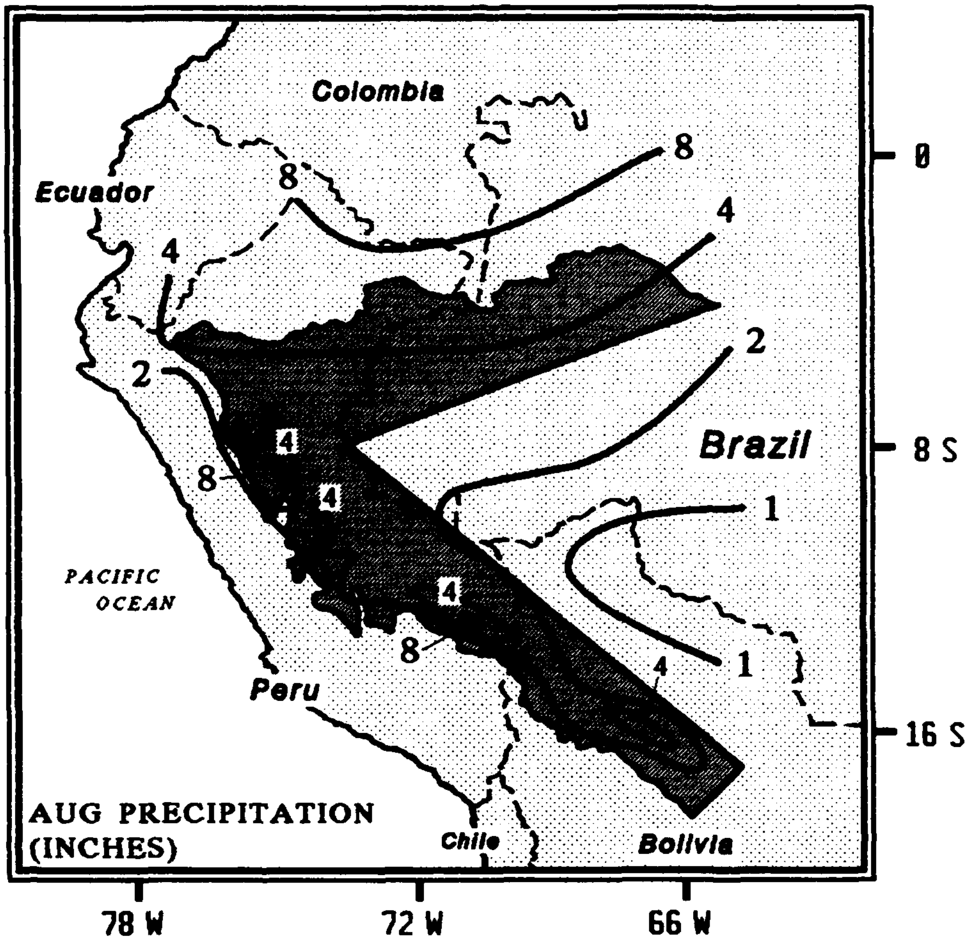


Figure 4-26. Mean August Precipitation, Western Amazon Basin. The June trend is even stronger during August. Low-level convergence continues to be the primary cause of rainfall along the mountains. Rain showers in the west are primarily nocturnal and are enhanced by a low-level jet running down the Andes' eastern slopes. Precipitation continues to be showery, but thunderstorms occasionally produce heavy showers. Cyclonic activity is responsible for most of the rainfall in the south. Fronts are accompanied by very light showers during the day and drizzle during the night.

Figure 4-27 shows that precipitation extremes are 50% or less those of the wet season. The highest values occur at the beginning and end of the season when the atmosphere is less stable. The largest amounts fall on the Andes' eastern slopes between 1,500 and 5,000 feet (460 and 1,525 meters) AGL in/near the cloud forest.

The highest values in the lowlands are at Quince Mil and San Ramon; the lowest are in the south. Days with precipitation have dropped from the wet season's 2 days out of 3 to only 1 day out of 3. The frequency is even lower in the south.

YURIMAGUAS

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	9.5	4.3	5.6	4.8	5.8
MAXIMUM 24-HOUR	2.7	2.0	3.5	1.9	2.4
PRECIPITATION DAYS	15	9	6	7	11
THUNDERSTORM DAYS	1	1	1	1	3

IQUITOS

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	24.4	33.0	13.6	25.8	13.5
MAXIMUM 24-HOUR	7.6	7.8	3.5	9.7	4.5
PRECIPITATION DAYS	18	13	14	12	12
THUNDERSTORM DAYS	#	#	#	#	1

BENJAMIN CONSTANT

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	na	na	na	na	na
MAXIMUM 24-HOUR	10.6	6.0	5.8	6.5	6.5
PRECIPITATION DAYS	15	12	12	12	12
THUNDERSTORM DAYS	na	na	na	na	na

JUANJUI

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	5.5	3.0	2.8	4.4	5.4
MAXIMUM 24-HOUR	3.1	1.3	1.7	2.2	2.4
PRECIPITATION DAYS	12	6	6	7	11
THUNDERSTORM DAYS	0	#	0	#	#

COARI

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	na	na	na	na	na
MAXIMUM 24-HOUR	3.0	2.5	2.2	1.7	2.7
PRECIPITATION DAYS	na	na	na	na	na
THUNDERSTORM DAYS	na	na	na	na	na

PUCALLPA

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	5.6	4.7	3.4	6.8	5.4
MAXIMUM 24-HOUR	3.4	3.9	2.4	2.8	3.2
PRECIPITATION DAYS	10	6	5	5	8
THUNDERSTORM DAYS	#	0	0	#	1

CRUZEIRO DO SUL

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	na	na	na	na	na
MAXIMUM 24-HOUR	3.3	3.1	2.3	2.7	3.1
PRECIPITATION DAYS	na	na	na	na	na
THUNDERSTORM DAYS	na	na	na	na	na

TINGO MARIA

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	16.5	9.9	9.4	10.9	12.1
MAXIMUM 24-HOUR	4.3	2.0	1.8	2.4	2.8
PRECIPITATION DAYS	16	14	13	13	13
THUNDERSTORM DAYS	1	#	#	1	1

PUERTO MALDONADO

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	16.5	7.4	3.9	5.2	13.5
MAXIMUM 24-HOUR	3.8	2.0	2.8	2.8	7.1
PRECIPITATION DAYS	8	4	3	4	9
THUNDERSTORM DAYS	0	#	#	0	#

QUINCE MIL

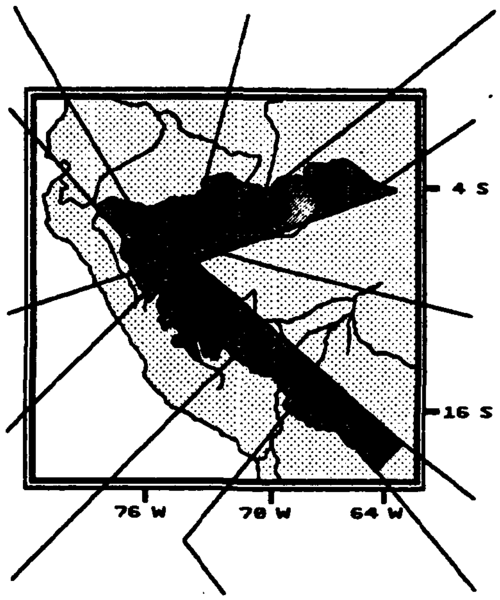
	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	18.7	27.4	37.5	18.4	28.4
MAXIMUM 24-HOUR	5.9	11.0	9.8	10.1	13.0
PRECIPITATION DAYS	11	12	11	10	11
THUNDERSTORM DAYS	1	0	#	1	#

APOLO

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	4.3	2.6	2.2	2.6	5.4
MAXIMUM 24-HOUR	na	na	na	na	na
PRECIPITATION DAYS	7	3	2	2	3
THUNDERSTORM DAYS	2	1	2	4	9

RURRENABAQUE

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY	8.1	13.1	6.5	7.8	7.2
MAXIMUM 24-HOUR	3.0	3.4	5.0	2.9	3.1
PRECIPITATION DAYS	12	7	6	6	6
THUNDERSTORM DAYS	1	2	1	1	2



DRY SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY					
MAXIMUM 24-HOUR					
PRECIPITATION DAYS					
THUNDERSTORM DAYS					

Figure 4-27. Dry-Season Tabular Precipitation Data, Western Amazon Basin.

THUNDERSTORMS. Thunderstorms become rarer during the dry season. The Bolivian High is gone, eliminating the upper-level outflow mechanism for convection. Available moisture is reduced due to the shift in the trade winds. A strong trade-wind inversion forms in the south between 10,000 and 12,000 feet (3,050 and 3,660 meters) MSL, effectively capping most convection. Elsewhere, isolated thunderstorms form during early afternoon hours in Brazil and drift westward toward Peru.

Most thunderstorm activity in the east is over by 1900L. Thunderstorms continue to form over the mountains, especially in the northwest, but with less frequency. Fewer afternoon instability showers occur in August than in any other month. Fronts are generally weak, and the air being replaced is generally so stable that frontal thunderstorms are also weak. Toward the end of the dry season, however, a strong cold push from the south can produce violent thunderstorms and even tornados. Thunderstorms have 1,000-foot (305-meter) MSL bases and tops to 40,000 feet (12.2 km) MSL. They produce lightning, heavy downpours, moderate-to-heavy mixed icing, and even hail in the south. Although extreme speeds have approached 70 knots, winds are generally less than 25 knots and tend to dissipate rapidly within the jungle.

MCSs form occasionally in western Brazil during May and June. They generally last 18 to 36 hours, but can become stationary and last longer over the extreme Western Amazon Basin.

TEMPERATURE. In the tropics, daily extremes are greater than annual extremes; differences between wet- and dry-season temperatures are small. Mean daily highs are again in the high 80's (° F) or low 90's (see Figure 4-28). Mean daily lows are in the high 60's to the low 70's, but somewhat lower in the south and at higher elevations along the Andes. The extreme high for the season is 104° F (40° C) at Pucallpa. This is higher than the wet-season high because there is less cloud cover. The extreme low is 36° F (2° C) at Puerto Maldonado. The mean freezing level is 13,500 feet (4.1 km) MSL, and the mean tropopause height is 55,000 feet (16.8 km) MSL.

Cold-air outbreaks reach the zone an average of three to five times between May to August. The Brazilians call them "friagems." Shallow cold fronts move up from the south; once past the Caupolican, the cold air fans out over the entire zone. Some of these outbreaks have been tracked all the way to the Caribbean Sea. During a friagem, temperatures can fall as much as 10 to 25° F (6 to 14° C) from their average values. Deviations from the mean are greater in the south. Friagems normally last 3 to 5 days, but in extreme cases may persist for up to 2 weeks.

YURIMAGUAS

93	95	97	99	99
87	87	87	90	91
70	68	67	68	70
52	54	54	55	61

IQUITOS

97	100	100	100	100
88	88	86	89	89
70	70	68	70	70
59	59	54	51	59

FONTE BOA

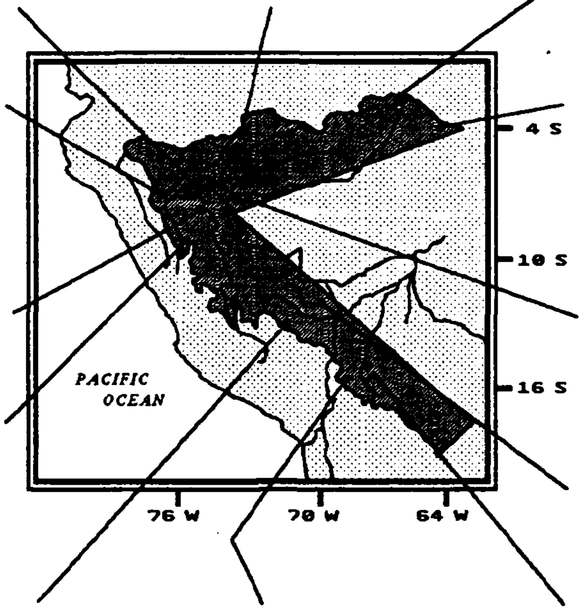
93	91	91	94	95
85	85	85	87	88
68	68	68	69	69
57	54	50	59	58

JUANJUI

95	95	102	100	102
87	87	88	91	92
68	67	65	65	68
59	54	54	55	54

COARI

94	94	94	96	97
86	86	87	88	89
71	70	70	71	72
63	58	59	61	59



PUCALLPA

97	100	100	102	104
89	89	89	92	93
69	67	66	67	69
54	55	50	46	50

CRUZEIRO DO SUL

93	93	93	97	98
85	85	85	87	87
69	67	65	65	67
51	51	50	50	53

TINGO MARIA

95	95	94	97	97
88	88	88	88	88
66	64	64	64	64
50	52	50	48	53

PUERTO MALDONADO

99	103	101	101	101
88	85	86	90	92
66	62	60	64	66
39	36	43	48	48

QUINCE MIL

91	88	88	91	93
80	78	77	82	84
64	63	62	63	64
54	48	48	50	55

APOLO

84	82	81	83	88
75	74	74	76	78
64	61	61	62	63
49	45	45	46	50

RURRENABAQUE

93	95	93	95	101
83	85	85	83	89
63	63	62	60	64
48	46	48	50	55

DRY SEASON TEMPERATURES (F)

	MAY	JUN	JUL	AUG	SEP
EXTREME MAXIMUM					
AVERAGE MAXIMUM					
AVERAGE MINIMUM					
EXTREME MINIMUM					

Figure 4-28. Dry-Season Tabular Temperature Data, Western Amazon Basin.

Relative humidity is much lower during the dry season. In the north, morning RH averages 80%; in the afternoon, only 60%. Values are lower in the south, but higher in the cloud forest. Wet-bulb globe temperatures remain high (Figures 4-34 through 4-39). This is particularly true in the northwest.

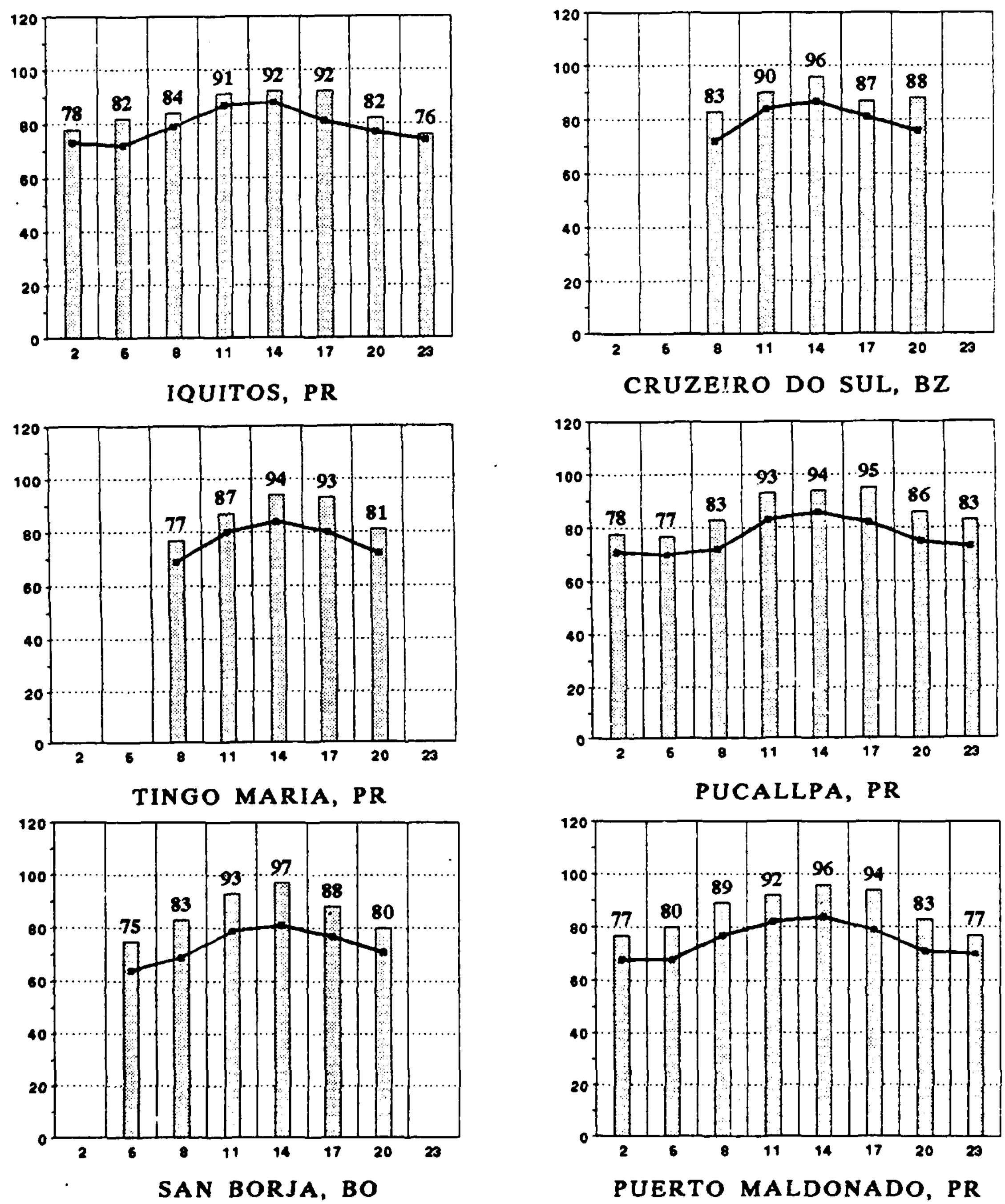


Figure 4-29. Mean and Maximum Dry-Season Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F), Western Amazon Basin.

FLIGHT HAZARDS. The major flight hazards are turbulence and icing. Light-to-moderate turbulence can be expected crossing narrow canyons and some river valleys. Pilots have commented on the particularly strong winds and turbulence near San Ramon Canyon. Light-to-moderate turbulence has also been reported at 13,000 feet (3,965 meters) MSL between Trujillo and Juanjui. At night, moderate turbulence is associated with a strong nocturnal low-level jet. Above 20,000 feet (6.1 km) MSL, light-to-moderate turbulence has been reported east of Cajamarca, Peru. In Bolivia, some mountain-wave turbulence may be encountered east of La Paz in the westerlies crossing the Andes; standing waves have also been reported east of the Andes between Sunchubamba and Cajamarca. Moderate turbulence occurs near thunderstorms. Moderate-to-heavy mixed icing and hail may be encountered in thunderstorms.

GROUND HAZARDS. Ground hazards are less severe during the dry season, but sudden heavy rainfalls can still lead to serious flooding and landslides. Rivers rush down at great speed near the mountains, but slow on the flat plains. Morning visibilities are extremely poor, particularly in the northwest. During a friagem, low temperatures may affect the unacclimated. At other times, extremely high temperatures and humidity affect human endurance and promote disease. High humidity also leads to corrosion, rot, mildew, and mold in unprotected equipment. Tornadoes have been sighted in Bolivia and southeastern Peru.

4.2 CENTRAL AMAZON BASIN

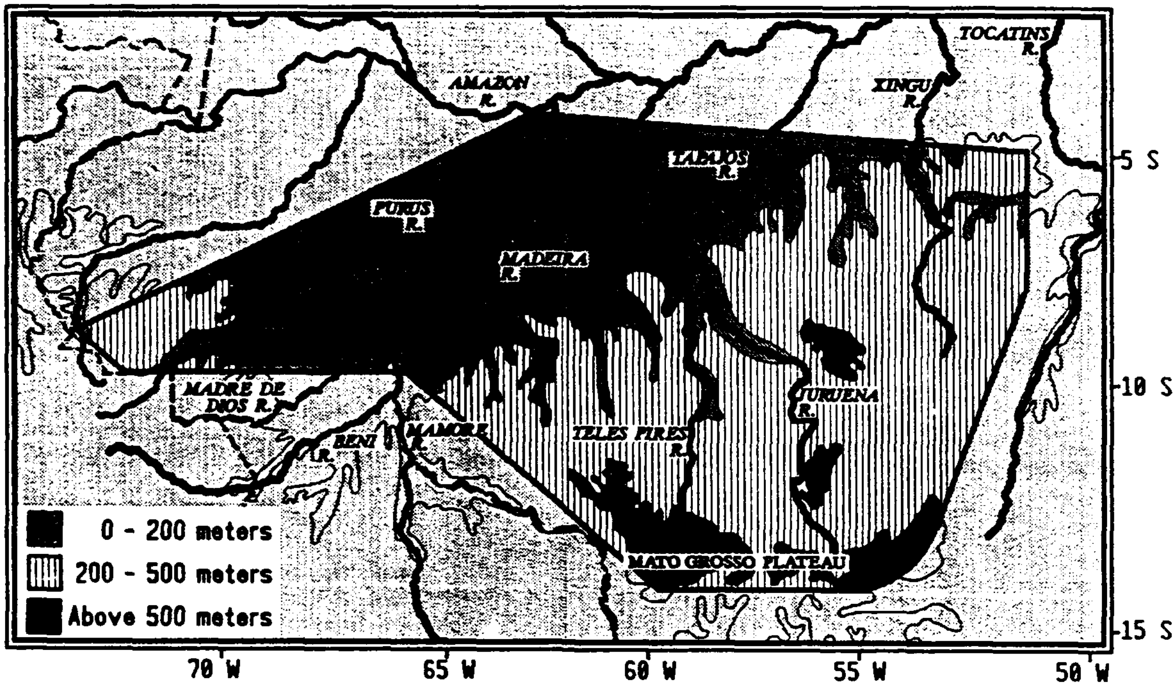
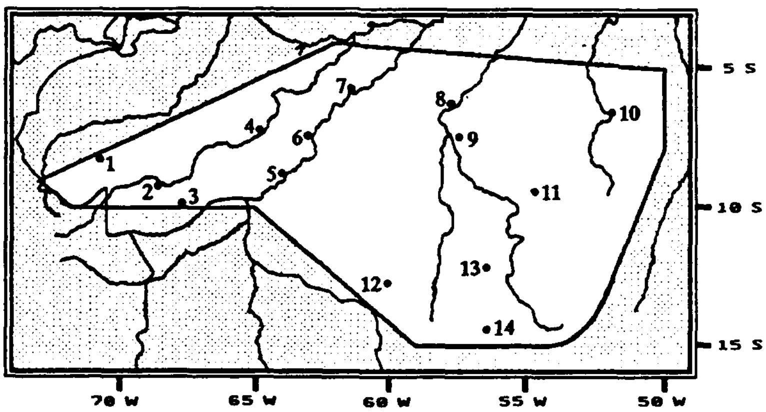


Figure 4-30. Central Amazon Basin.



	ELEVATION (FEET)		ELEVATION (FEET)
1. TARAUACA	623	8. JACAREACANGA	321
2. SENA MADUREIRA	443	9. MISSAO DO CURURU	325
3. RIO BRANCO	446	10. SAO FELIX DO XINGU	492
4. LABREA	254	11. CACHIMBO	1420
5. PORTO VELHO	249	12. VILHENA	2140
6. HUMAITA	164	13. VERA	1200
7. MANICORE	72	14. DIAMANTINO	900

Figure 4-31. Climatic Station Network, Central Amazon Basin.

CENTRAL AMAZON BASIN GEOGRAPHY

The Amazon River basin is the world's largest. It drains 40% of South America and can be described as an immense canyon opening into the Atlantic with a marshy delta over 150 miles wide. The basin contains 39% of the world's tropical rain forest and covers 40% of Brazil's land mass. Ninety percent of the basin is covered by forest, mostly evergreen. This section describes the central portion of the basin south of the Amazon River.

BOUNDARIES. The zone is bounded:

On the north: by a line from 9° S, 73° W northeast to the Amazon River at 62° W. The boundary then turns slightly ESE along a line to 5° S, 50° W.

On the east: by a line from 5° S, 50° W south to 8° S, which then curves SSW to 15° S, 54° W.

On the south: by a line from 15° S, 54° W to 15° S, 59° W and then extending northwest to 10° S, 65° W. From there the boundary follows 10° S to 72° W.

No western boundary is given; the north and south boundaries meet at their westernmost points.

TERRAIN. The Central Amazon Basin is almost totally free of hills. From the foothills of the Serra dos Parecis in the south, with elevations generally less than 1,640 feet (500 meters), the terrain slopes north to less than 330 feet (100 meters) along and as far as 200 miles south of the Amazon River. The slope from west to east is more gentle; it goes from about 500 feet (150 meters) in the west to less than 100 feet (30 meters) in the east. The southern plateau is cut by numerous rivers and streams that descend to the Amazon. Major rivers join the Amazon River about every 250 miles along its southern banks.

RIVERS. Over 20 major rivers flow directly or indirectly into the Amazon from the south side. Altogether, it has over 1,000 tributaries that swell the water mass and make the Amazon the largest volume of water carried in the world. From source to mouth, the Amazon is over 4,000 miles long with seven tributaries of more than 1,000 miles. The five largest tributaries are spaced an average of 250 miles apart along the Amazon's southern bank. From west to east, they are the Purus, Madeira, Tapajos, Xingu, and Tocantins Rivers.

The Purus begins in Peru and runs northeast for over 1,050 miles to join the Amazon just north of the study zone.

The Madeira begins in southern Peru as the Madre de Dios before crossing northern Bolivia and joining the Beni and Mamore Rivers. It becomes the Madeira at its junction with the Mamore along the Bolivia-Brazil border. It follows the border north to Abuna, Brazil, before turning northeast to parallel the Purus River and emptying into the Amazon 170 NM east of the Purus River in the Eastern Amazon Basin. From source to mouth the Madeira is almost 2,100 miles long.

The Tapajos begins as the Teles Pires in the northern sierra of the Mato Grosso Plateau. The Teles Pires flows north for more than 600 miles, joining the Juruena River at about 7° S, 58° W, where it becomes the Tapajos and flows northeast to meet the Amazon at about 54° 45' W in the Eastern Amazon Basin. Its total length is over 1,100 miles.

The Xingu starts in the transition zone between savanna and tropical rain forest at 13° S, 52° W and runs north for just over 1,000 miles to enter the widening Amazon, 200 miles from its mouth, in the Eastern Amazon Basin.

The Tocantins originates 150 miles southwest of Brasilia and flows north through the Brazilian Plateau for over 900 miles before entering the Central Amazon Basin at 6° S, 47° W. It curves west from there to meet the Araguaia River at 5° S, 48° W. It exits the zone at 4° 40 S, 49° W as it turns north to join the Para River before widening northeastward into the Atlantic. The Tocantins River is over 1,300 miles long from its source to it's junction with the Para.

VEGETATION. Almost all of the Central Amazon Basin is covered with tropical rain forest. Most of the trees are evergreen, but the variety is so enormous that there may be more than 110 different species in an area of half a square mile. A small part of the zone's southern plateau is savanna grasslands. The tropical rain forest varies from place to place in a number of ways. The rain forest is classified as to "type" and "level," as shown below.

Forest Types.

On solid ground: Above the level that floods even in the wettest years.

Varzea: Lower-lying areas that flood temporarily, but become solid during the dry season.

Igapo: Lowest-lying areas that remain permanently flooded in all seasons.

Forest Levels.

1st Level. The topmost tier, or "emergent layer," consists of a few trees reaching heights of 130 feet (40 meters) or more.

2nd Level. The ceiling level, or "canopy" tier, consists of forest giants exceeding 65 feet (20 meters) in height. Evapotranspiration from the top of the rain forest is a major source of water vapor into the atmosphere. The contribution to the water vapor content of weather systems is as great as many large water bodies. As a result, transient air masses retain virtually the same amount of low-level moisture over the western Amazon Basin as they had leaving the tropical Atlantic Ocean. These high moisture contents will not be present once large forest areas are cleared.

3rd Level. This level, the "middle" tier, consists of a dense growth of shorter trees between 16 and 65 feet (5 and 20 meters) in height. Some trees may be covered with epiphytic plants, such as orchids, ferns, succulents, etc. Epiphytes are plants that use other plants for mechanical support, but not for food.

4th Level. The "shrub" tier consists of scattered bushes and herbs not exceeding 16 feet (5 meters) in height. This level varies depending on the amount of sunlight reaching it. It can be thick where taller levels thin out, and sparse where taller levels are exceptionally dense.

5th Level. The "ground" level is a mosaic of small shade-tolerant herbs, ferns, and tree seedlings. This level is normally bare when taller levels are exceptionally dense. Sunlight here at noon averages only 1% of that found above the rain forest.

CENTRAL AMAZON BASIN CLIMATIC PECULIARITIES

The Central Amazon Basin is distinguished by abundant low-level moisture, unstable summers, and very stable winters. At least half the zone's low-level moisture is from evapotranspiration. The other primary moisture source is the Atlantic Ocean. The extent of the South Atlantic High establishes the zone's western and northern boundaries. The eastern and southern boundaries are formed by higher terrain that prevents most low-level moisture from escaping. The southwestern boundary is formed by the combined effects of higher terrain and drier air associated with a mean frontal boundary and adiabatic processes near the Andes.

Most large rivers have a localized climate where cloudiness, precipitation, and fog occur less frequently than in surrounding areas. It is not unusual for broad rivers to be nearly cloud-free while dense forests are overcast. Rainfall and cloudiness also vary from one river shore to the other, depending on the time of day and synoptic flow (see "Land-River Circulation" in Chapter 2). Differences in vegetation and surface albedo also cause localized climatic variations, notably in diurnal temperature differences. Variations are largest in central locations and a small area near the Bolivian border.

A study of the northeastern fringes of the zone suggests that the normal diurnal precipitation cycles is affected by subsidence produced in the wake of thunderstorm activity. The subsidence resulting from widespread precipitation under thunderstorm anvils stabilizes the atmosphere temprarily and inhibits thunderstorm develpment. Nocturnal thunderstorms may damp typical daytime convective activity. This effect does not occur in the dry season, when stable conditions inhibit thunderstorm development at any time other than the afternoon; nocturnal thunderstorms are rare.

Two nocturnal, low-level jet streams enhance convection. One flows from east to west just south of the Equator between 50 and 60° W; the other, from northwest to southeast over the Central Amazon Basin's southwest border. Both usually occur at night above a radiation inversion. The east-west jet's seasonal characteristics are explained in seasonal discussions that follow; the other is discussed in Chapter 2 and in the "wet season" section of this chapter.

Other very important climatic factors include daytime heating and upper-air diffluence. Evidence suggests that weak lee-side troughs also occasionally form near the zone's eastern border when strong, low-level easterly flow crosses northeast Brazil's higher terrain.

There is evidence that points to decreases in precipitation amounts during this century. Causes are still subject to speculation, but the continued clearing of Amazon forests is a primary suspect. The precipitation decrease may not be very obvious in the short term because amounts vary so much; known annual precipitation extremes range from about half the mean to 50% higher than the mean. Seasonal and monthly ranges are similarly variable. With deforestation, water levels are actually expected to rise initially as there is less vegetation to absorb moisture. Sky cover and visibilities are affected significantly by the burning. Deforestation may cause temperatures to rise, with more diurnal variation.

GENERAL WEATHER. Although tropical disturbances predominate in the wet season, mid-latitude features occasionally affect the zone. Tropical disturbances include the Near Equatorial Trough (NET), the Amazonian Low, the Tropical Convergence Zone (TCZ), and various tropical waves (Tropical Squall Lines, Easterly Waves, etc.). The NET oscillates north-south, the TCZ oscillates east-west, and tropical waves move westward. The NET's southerly surges cause poor weather up to 600 NM to its south. Oscillating tropical disturbances are caused by mid-latitude disturbances passing nearby; these include occasional upper-level lows, upper-level troughs/short waves, very rare cold fronts/shear lines, and other troughs (such as leeside waves). The upper-level lows originate in the tropics, but are caused by mid-latitude circulations (see Chapter 2). They approach from the east, whereas other mid-latitude features normally approach from between the south and west. Upper-level diffluence and surface heating by the high February sun also contribute to the wet season's poor weather.

SKY COVER. Mean coverage, as represented by January in Figure 4-32, is high. Skies are normally overcast in the morning and broken afternoons and evenings. Skies are rarely clear at night. Cloud cover is sparse over wide rivers, while dense forests see widespread stratus in the morning and heavy cumulus in the afternoon (see "Climatic Peculiarities" for details).

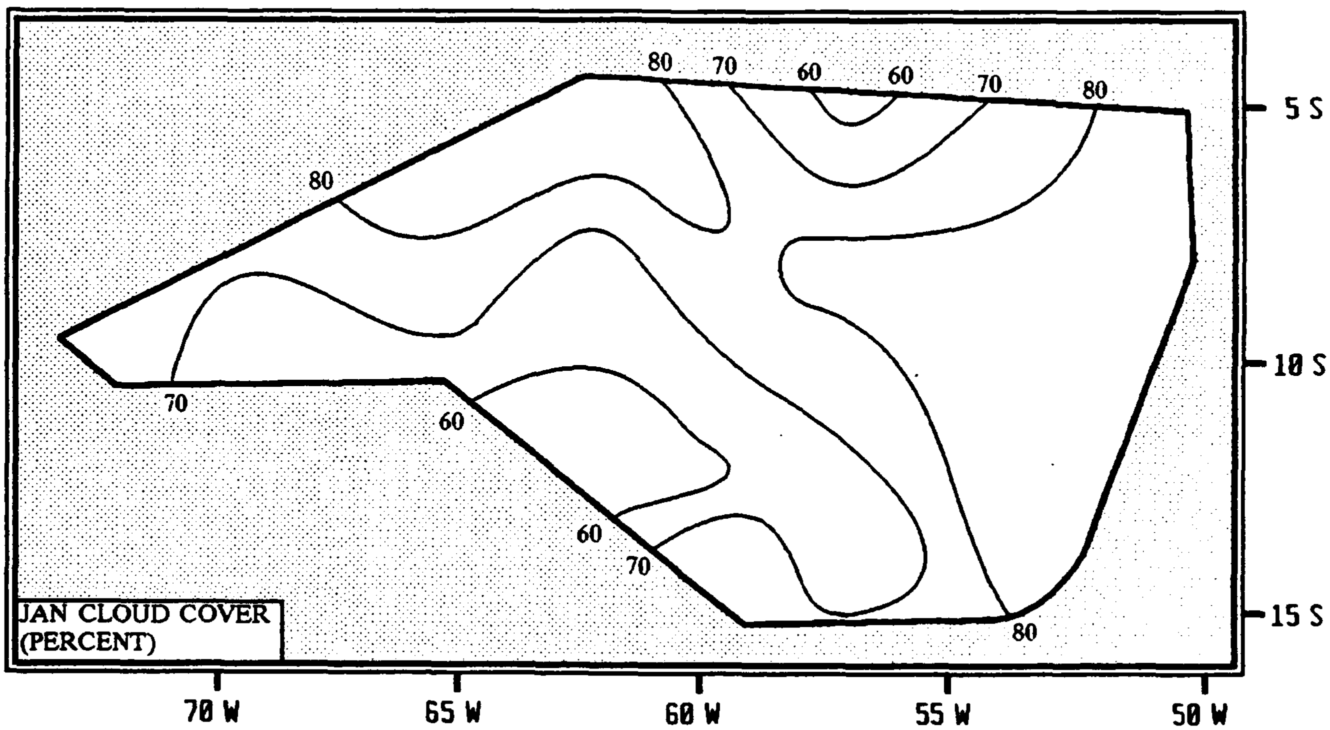


Figure 4-32. Mean January Cloud Cover, Central Amazon Basin.

Disturbances produce all cloud types. Stratus and stratocumulus are the most common at night and in the morning along disturbances, while towering cumulus and cumulonimbus are most common in the afternoons. Low clouds may hide middle and high clouds; it isn't unusual for cumuliform clouds to be embedded in nimbostratus when disturbances are strong. This is characteristic of easterly surges of the TCZ. When the TCZ recedes, cloudiness separates into layers of stratus and cumulus. During undisturbed periods, the predominant early morning cloud type is stratus; stratocumulus, altocumulus, cumulus, and towering cumulus are common at other times. Isolated cumulonimbus forms with afternoon heating.

Morning low-cloud bases range from 1,000 feet (305 meters) MSL in the northwest to about 3,000 feet (915 meters) MSL in the south and southeast. In the afternoon, low-cloud bases range from 2,500 feet (760 meters) MSL in the northwest to about 4,000 feet (1,220 meters) MSL over the high terrain in the south. There is little data on cloud tops, but what is available suggests most are below 25,000 feet (7.6 km) MSL.

Ceilings below 1,000 feet (305 meters) AGL occur most often in the morning in densely-forested areas. Morning frequencies range from 1% or less in the southeast to 56% in the west. Most high frequencies in the west are due to jungle stratus, which occurs in forest canopies where moderate to heavy rainfall has fallen on the previous afternoon or evening. This stratus is normally less than 1,000 feet (305 meters) thick; it dissipates soon after sunrise. "Jungle stratus" occasionally occurs immediately after heavy rainfall. This, along with low cloud bases during heavy precipitation, account for the exceptionally low afternoon ceilings. Afternoon frequencies of ceilings below 1,000 feet (305 meters) AGL are less than 3% everywhere except in the extreme west and northwest, where they reach 35%.

Most high areas in the south and southeast have ceilings below 3,000 feet (915 meters) AGL most often in the afternoon (Figure 4-33), in the lower elevations, they normally occur in the morning, due to orographic effects. Afternoon frequencies of ceilings below 3,000 feet (915 meters) AGL range from 7% at Diamantino to 63% at Cachimbo. Morning frequencies range from about 30% at Porto Velho to 82% in the densely forested Tarauaca area.

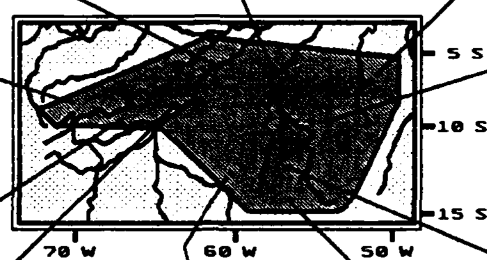
In the evening, the atmosphere becomes increasingly stable, producing lower, more stratiform clouds. This accounts for an afternoon to evening rise in low-ceiling frequencies at some stations, such as Diamantino.

MANICORE					
52	58	73	66	62	62
41	38	42	47	48	43
na	na	na	na	na	na

JACAREACANGA					
44	45	54	60	67	60
38	45	53	64	55	46
12	21	20	23	17	10

SAO FELIX DO XINGU					
53	50	44	51	47	48
30	32	32	27	20	25
19	19	22	26	26	16

TARAUACA					
78	80	82	82	82	80
53	54	56	58	51	51
na	na	na	na	na	na



CACHIMBO					
23	29	38	37	41	38
49	50	63	70	67	72
12	18	16	17	17	19

RIO BRANCO					
30	40	40	42	41	31
20	26	26	29	19	25
na	na	na	na	na	na

VERA					
30	39	43	47	36	28
23	30	37	32	26	24
26	28	29	34	25	15

PORTO VELHO					
20	25	30	29	24	20
17	16	20	20	20	19
na	na	na	na	na	na

VILHENA					
25	36	38	33	23	22
49	59	62	63	57	56
na	na	na	na	na	na

DIAMANTINO					
22	33	31	32	19	22
4	9	7	6	6	7
26	28	25	25	17	17

WET SEASON
CEILINGS BELOW 3,000 FEET
(PERCENT)

na - DATA NOT AVAILABLE

	NOV	DEC	JAN	FEB	MAR	APR
09 L						
15 L						
21 L						

Figure 4-33. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Amazon Basin.

VISIBILITY. Fog in the north and precipitation in the south cause most visibility restrictions. Most fog occurs around sunrise within forests where it rained on the previous afternoon or evening. Such fog normally originates within forest canopies as "jungle stratus." It is normally less than 1,000 feet (305 meters) deep and it dissipates by noon. Fog sometimes forms immediately after heavy rainfall. Upslope flow is occasionally strong enough to enhance fog formation on slopes in the southeast.

The densely forested west, northwest, and north experience low visibilities most often. Low visibilities occur least often on ridges and plateaus in the southeast, such as at Cachimbo. Vilhena, although higher than Cachimbo, is the most representative of lower elevations in the southeast because it lies in a small basin. Morning frequencies of visibilities below 3 miles at Cachimbo and Vilhena average about 6% and 11%, respectively (see Figure 4-34).

The highest morning frequencies of visibilities below 3 miles occur in the northwest, where they exceed 45% at Labrea in November. Afternoon frequencies at most stations have seasonal averages between 2 and 8%. Evening frequencies below 3 miles are more variable, averaging from 2% in the east to about 13% in the west. Morning frequencies below 1 mile range from 1% at Cachimbo in January to 29% at Sao Felix Do Xingu. Afternoon and evening frequencies of visibilities below 1 mile are less than 7% everywhere.

LABREA

	NOV	DEC	JAN	FEB	MAR	APR
09 L	46	39	41	35	32	33
15 L	3	5	4	7	4	6
21 L	17	9	17	19	12	8

JACAREACANGA

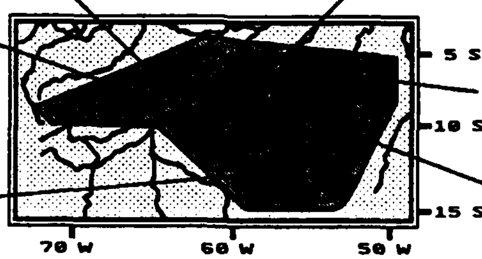
	NOV	DEC	JAN	FEB	MAR	APR
09 L	8	8	10	9	8	12
15 L	2	3	2	2	1	2
21 L	1	1	3	2	2	1

PORTO VELHO

	NOV	DEC	JAN	FEB	MAR	APR
09 L	7	13	16	11	15	15
15 L	0	2	15	5	6	9
21 L	0	0	4	3	7	0

SAO FELIX DO XINGU

	NOV	DEC	JAN	FEB	MAR	APR
09 L	32	31	28	31	25	25
15 L	5	8	9	6	6	4
21 L	7	9	5	5	5	4



VILHENA

	NOV	DEC	JAN	FEB	MAR	APR
09 L	8	10	11	13	13	11
15 L	2	4	6	4	3	2
21 L	na	na	na	na	na	na

CACHIMBO

	NOV	DEC	JAN	FEB	MAR	APR
09 L	4	5	4	7	6	7
15 L	3	1	2	3	3	2
21 L	3	1	1	2	1	1

WET SEASON
VISIBILITY BELOW 3 MILES
(PERCENT)
- LESS THAN 0.5 PERCENT
na - DATA NOT AVAILABLE

	NOV	DEC	JAN	FEB	MAR	APR
09 L						
15 L						
21 L						

Figure 4-34. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Central Amazon Basin.

WINDS. Synoptic flow is slowed by surface friction, resulting in low wind speeds (see Figure 4-35). Lowest speeds are over dense forests, which offer the most wind resistance. Mean speeds for all hours range from only 1 knot in the north and west to just 2 knots in most of the east and south. Nights are calm, with occasional slope winds along inclines in the east and south. Daytime speeds are normally less than 5 knots. Predominant wind directions are easterly in the north and east, northerly in the south and west. Uneven surface heating, caused by differences in vegetation and cloud cover, can cause winds to vary during the day. Strong winds are rare, especially in densely forested areas where they are dissipated at treetop level. Thunderstorms are the primary cause of high winds; speeds up to 50 knots have been recorded.

STATION	MEAN WIND SPEED					
	NOV	DEC	JAN	FEB	MAR	APR
CACHIMBO	2	2	2	2	3	3
DIAMANTINO	2	2	2	2	2	2
JACAREACANGA	2	1	1	1	1	1
LABREA	1	1	1	1	1	1
MANICORE	1	1	1	1	1	2
MISSAO DO CURURU	1	1	1	1	1	1
PORTO VELHO	2	2	2	2	2	2
RIO BRANCO	1	1	1	1	1	1
SAO FELIX DO XINGU	2	2	2	2	2	2
SENA MADUREIRA	1	1	1	1	1	1
TARAUACA	1	1	1	1	1	1
VERA	2	2	1	1	1	1
VILHENA	2	2	2	2	2	2

Figure 4-35. Mean Wet-Season Wind Speeds, Central Amazon Basin.

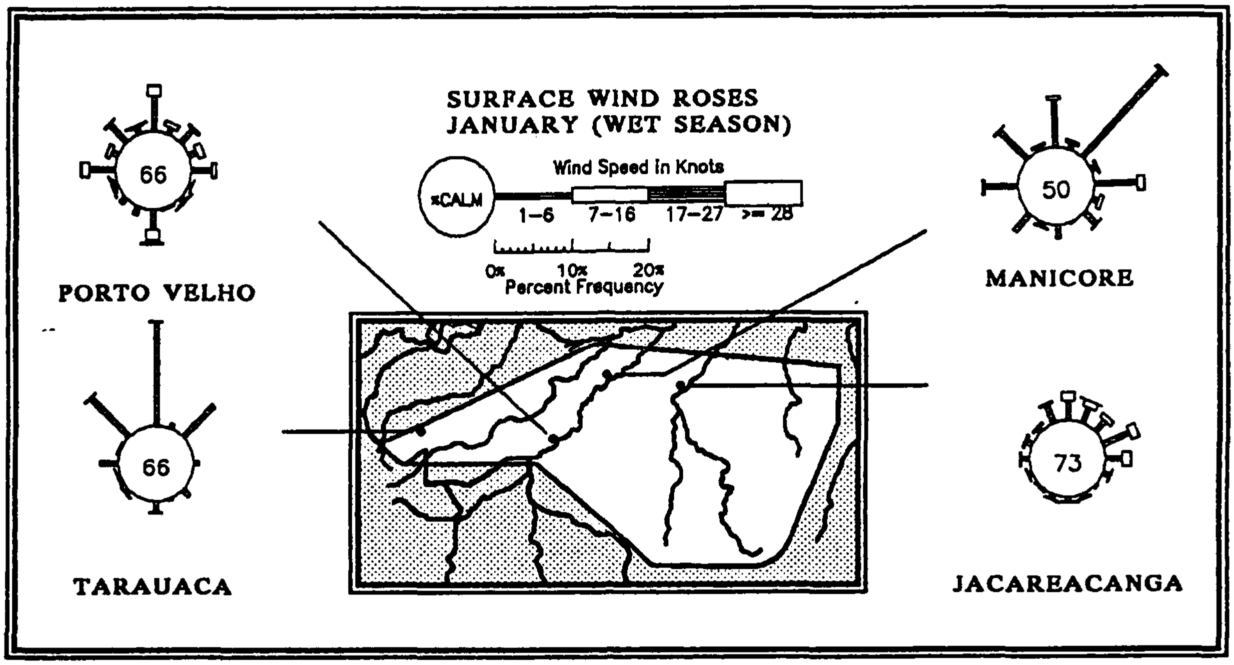


Figure 4-36. January Surface Wind Roses, Central Amazon Basin. There is no reliable wind data for the rest of zone's reporting stations.

Mean winds at 5,000 feet (1,525 meters) MSL range from northeasterly at 15 knots in the north to northerly at 10 knots in the south and west. However, a nocturnal, northwesterly low-level jet known to occur in the west can produce winds up to 50 knots at about 1,500 feet (455 meters) MSL. Another low-level wind maximum occurs along the eastern part of the zone's northern border. Its east-to-west core is around 1,500 feet (455 meters) MSL; speeds are known to exceed 30 knots.

Upper-air wind directions are shown in Figures 4-37 through 4-40. They veer with height, becoming east-southeasterly by 20,000 feet (6.1 km) MSL. Mean speeds are less than 25 knots through at least 30,000 feet (9.1 km) MSL. Diffluent flow occurs above this height in the zone's central and western sections. Flow ranges from easterly in the south to southeasterly along the zone's northern border.

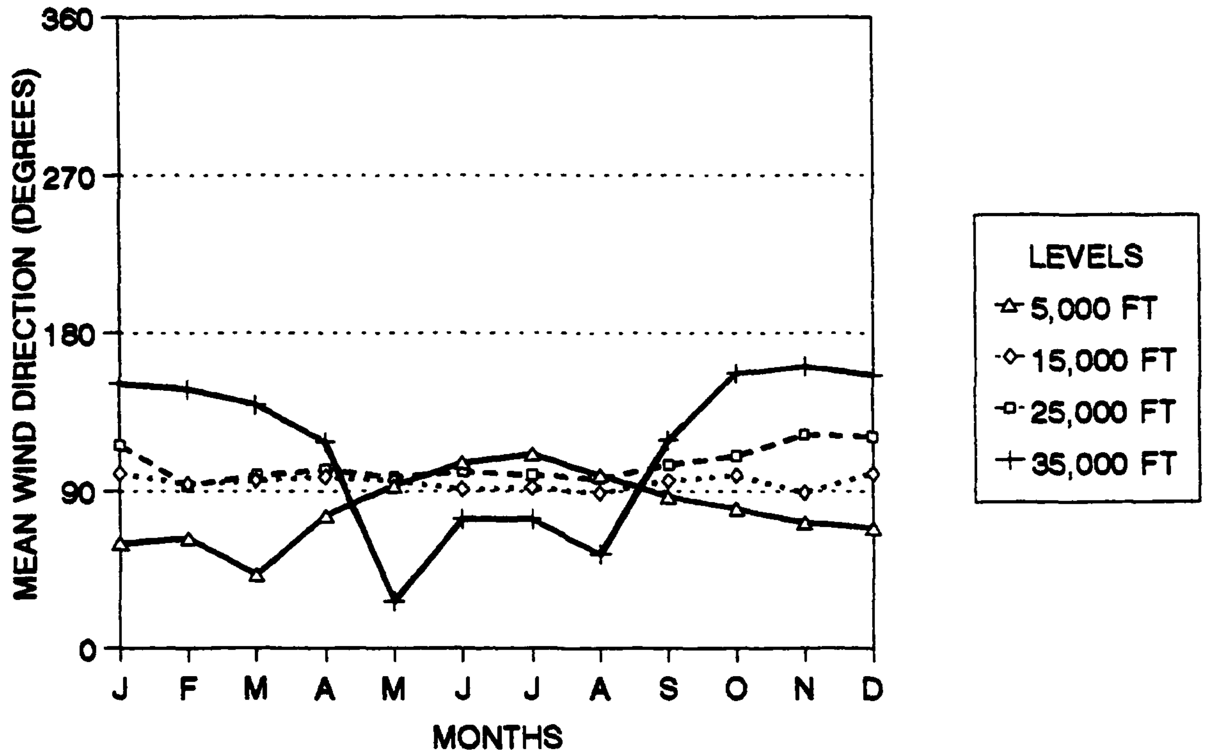


Figure 4-37. Mean Monthly Wind Directions for Various Levels at Manaus, (Eastern Amazon Basin).

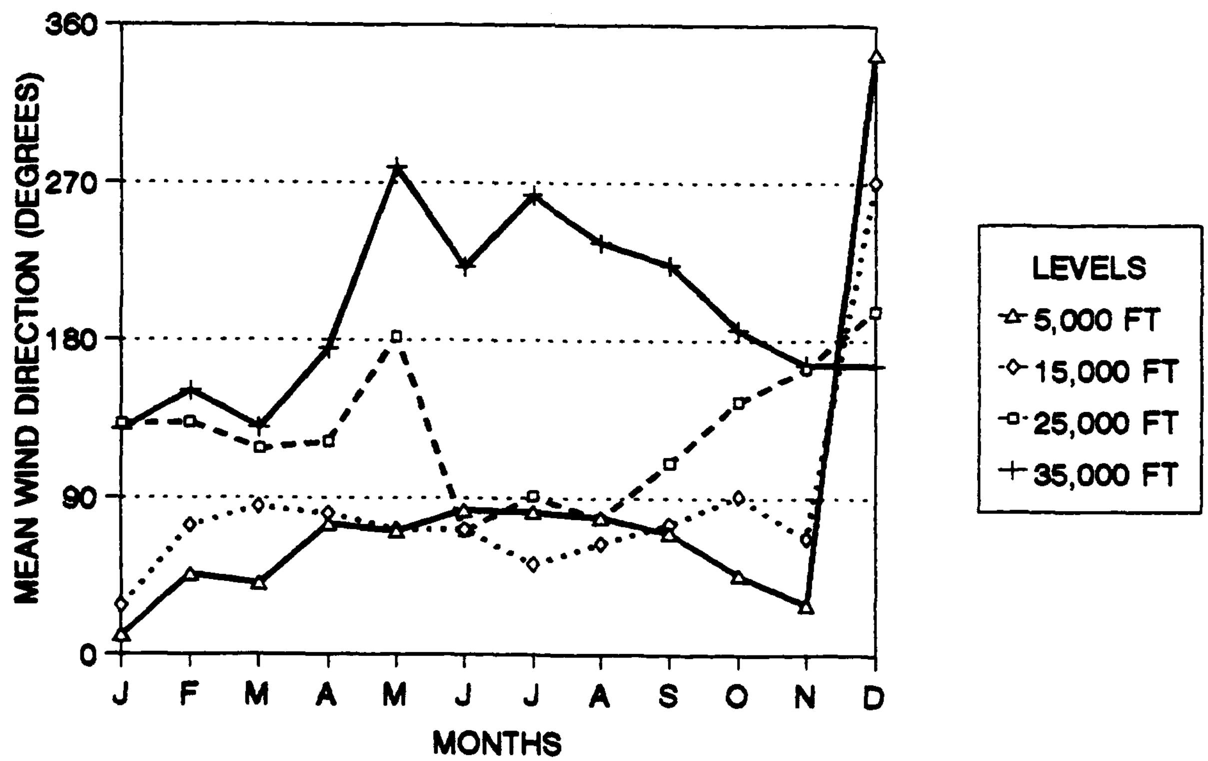


Figure 4-38. Mean Monthly Wind Directions for Various Levels at Cachimbo, Central Amazon Basin.

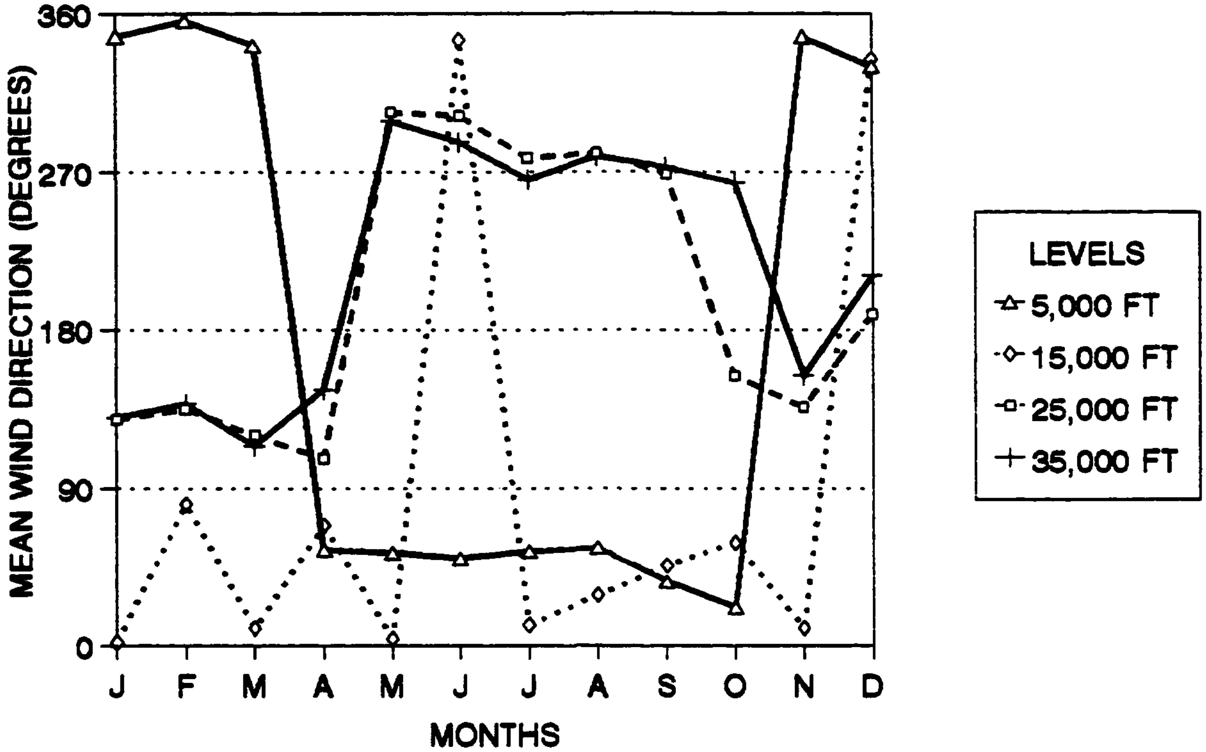


Figure 4-39. Mean Monthly Wind Directions for Various Levels at Vilhena, Central Amazon Basin.

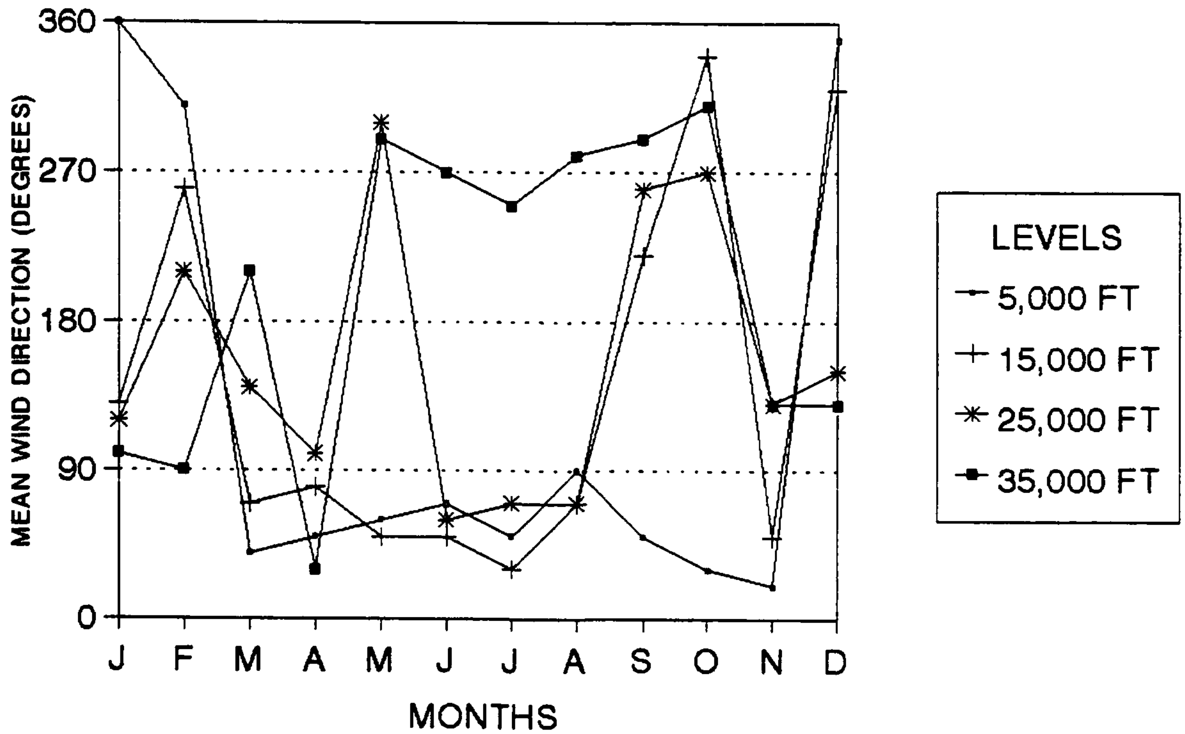


Figure 4-40. Mean Monthly Wind Directions for Various Levels at Porto Velho, Central Amazon Basin.

PRECIPITATION. Most precipitation falls as moderate to heavy afternoon rain showers along disturbances. The TCZ can produce steady rain from nimbostratus, as well as showery precipitation from cumulus. Upper-level diffluence and convergence associated with the low-level jets in the north and west contribute to wet-season rainfall. Differential heating between cloudy and clear areas can cause convective development along cloud mass fringes. This may also be caused by differences in vegetation and albedo. Convective heating alone is often enough to cause moderate afternoon rainshowers and isolated thunderstorms.

Rainfall amounts tend to be similar along different disturbances, regardless of their strength or type. As a result, disturbance *frequencies* are more important than their characteristics. Most precipitation occurs near the NET. Missao, the station most affected by the NET, averages 24 rainfall days a month (see Figure 4-41). Southern stations have the fewest rainfall days, averaging about 10. Figure 4-42 shows mean January precipitation amounts above 12 inches (305 mm) across most of the zone and over 16 inches (406 mm) near its center. Maximum monthly amounts have exceeded 32 inches (813 mm) at Porto Velho in March. Although there is little data for verification, even higher amounts have probably occurred near Missao. Maximum 24-hour amounts have reached 8 inches (203 mm) at Humaita in March.

na	na	na	na	na	na
5.7	4.5	5.3	4.3	7.9	4.9
na	na	na	na	na	na
na	na	na	na	na	na

HUMAITA

na	na	na	na	na	na
2.6	3.9	3.0	2.5	2.4	2.2
na	na	na	na	na	na
na	na	na	na	na	na

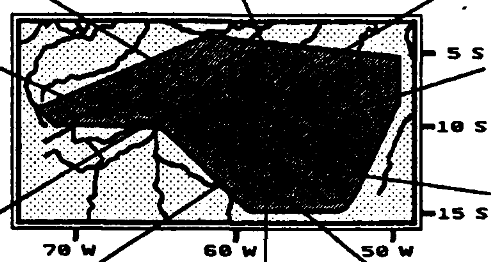
JACAREACANGA

na	na	na	na	na	na
4.5	5.3	4.5	4.7	6.1	4.0
22	24	26	24	25	23
14	10	7	6	7	7

MISSAO DO CURURU

na	na	na	na	na	na
2.7	2.8	3.8	3.5	2.8	4.4
12	16	18	16	17	15
7	6	7	6	7	5

SENA MADUREIRA



na	na	na	na	na	na
2.3	3.1	2.4	4.1	3.7	1.7
na	na	na	na	na	na
15	12	9	9	11	6

CACHIMBO

19.6	24.5	28.6	25.0	32.7	12.1
3.1	3.4	4.1	3.9	3.3	3.9
12	18	19	19	20	17
8	10	7	6	6	3

PORTO VELHO

na	na	na	na	na	na
na	na	na	na	na	na
na	na	na	na	na	na
5	4	4	3	4	2

VERA

na	na	na	na	na	na
na	na	na	na	na	na
na	na	na	na	na	na
6	6	4	4	5	4

VILHENA

na	na	na	na	na	na
na	na	na	na	na	na
7	10	10	12	13	3
10	6	2	3	5	4

UTIARITI

na	na	na	na	na	na
na	na	na	na	na	na
na	na	na	na	na	na
9	10	7	6	8	5

DIAMANTINO

WET SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	NOV	DEC	JAN	FEB	MAR	APR
MAXIMUM MONTHLY						
MAXIMUM 24-HOUR						
PRECIPITATION DAYS						
THUNDERSTORM DAYS						

Figure 4-41. Wet-Season Tabular Precipitation Data, Central Amazon Basin.

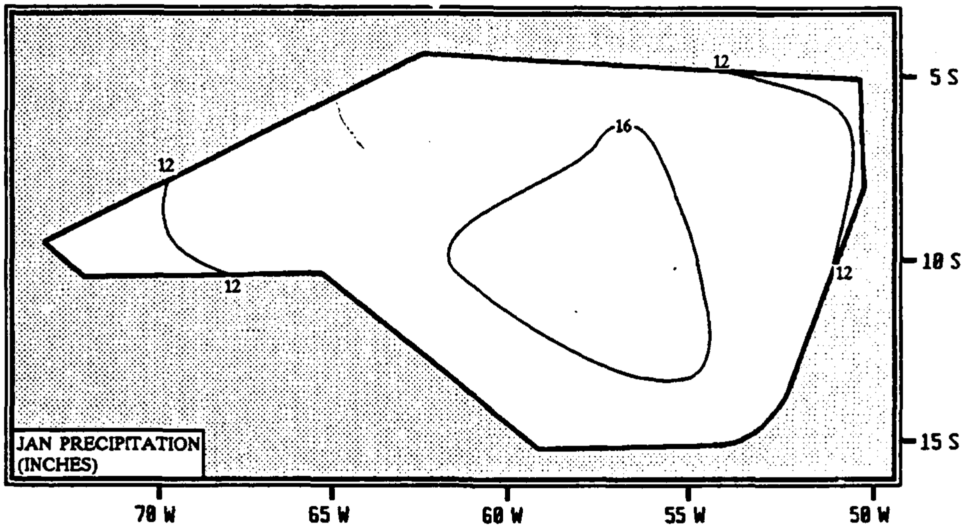


Figure 4-42. Mean January Precipitation, Central Amazon Basin.

THUNDERSTORMS. Thunderstorms are common, occurring as semiorganized activity along disturbances and as brief, unorganized, afternoon convection. They would be more common if convective heating were not inhibited by widespread cloud cover. Bases are below 3,000 feet (915 meters) MSL and often below 1,000 feet (305 meters) MSL. Most tops are between 40,000 and 50,000 feet (12.2 and 15.2 km) MSL. Heavy rainfall is likely; hail melts before reaching the ground. Tornado activity, cannot be verified, but the possibility should not be ruled out. Disturbance-associated thunderstorms can produce gusts to 50 knots but, such winds are usually weakened or dissipated within dense forest canopies. Some photographic evidence of tropical rain forest "blowdowns" indicates that downbursts do occur. Mean monthly thunderstorm days, decreasing through the season, are lowest in the south and highest near the zone's center. Mean thunderstorm days decrease at Vera from 5 in November to 2 in April and at Cachimbo from 15 in November to 6 in April (see Figure 4-41).

Thunderstorm-associated mid-level cloudiness often causes light to moderate rainfall that can become widespread and cause as much precipitation as the thunderstorm cores. These clouds, unlike those in the mid-latitudes, sometimes trail *behind* the thunderstorm cells (see Tropical Squall Lines, Chapter 2).

TEMPERATURE. Temperatures are moderated by the basin's moisture-laden tropical forests. Diurnal variations appear to depend mostly on albedo and type or amount of vegetation. This may explain why diurnal temperature variations are greatest near the zone's center and in the vicinity of Sena Madureira; the effects of elevation and the variation in moisture amounts are small. In wooded areas, most radiation heating and cooling occurs in forest canopies, whereas clearings heat and cool at ground level. During the season's rare clear periods, temperatures in canopies average a couple degrees warmer than the underlying surface at night and roughly 10° F (6° C) warmer in the afternoon. Temperature characteristics will probably change if deforestation continues.

At most locations, mean lows are between 70 and 75° F (21 and 24° C) and mean highs are between 80 and 90° F (27 and 32° C) (see Figure 4-43). Mean temperatures change little through the season, but extremes vary. Extreme highs occur at most stations in November; extreme lows usually occur in April. Extreme highs range from 96° F (35° C) at Cachimbo and Vilhena to 104° F (40° C) at Rio Branco and Humaita. Extreme lows range from 54° F (12° C) at Vilhena to 68° F (20° C) at Manicore and Sao Felix Do Xingu.

MANICORE

99	99	96	96	97	98
87	86	85	85	86	86
77	76	76	76	76	77
68	68	70	70	68	68

JACAREACANGA

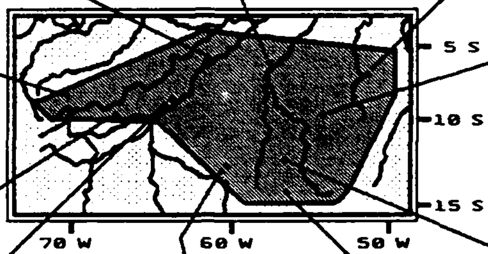
100	96	94	96	96	97
90	87	87	86	86	87
73	72	72	72	73	72
68	68	68	67	66	67

SAO FELIX DO XINGU

95	96	94	96	97	95
85	83	82	82	83	84
76	75	75	75	75	75
70	68	69	70	68	70

TARAUACA

96	100	99	100	97	101
82	82	81	81	82	83
75	75	74	74	74	74
64	66	67	67	66	62



CACHIMBO

95	94	96	94	94	93
82	81	81	81	82	83
73	73	72	72	73	73
64	62	65	65	64	65

RIO BRANCO

104	97	98	100	100	100
84	82	82	83	83	83
75	75	74	74	74	74
64	66	67	67	66	62

VERA

95	96	98	99	99	95
83	82	81	82	84	84
74	74	73	74	74	74
66	66	66	66	66	64

PORTO VELHO

100	97	98	97	96	97
87	85	85	85	86	86
76	76	76	76	76	76
64	66	68	69	66	62

VILHENA

96	96	94	94	94	93
80	79	79	79	80	81
72	72	72	72	72	72
64	65	65	65	61	54

DIAMANTINO

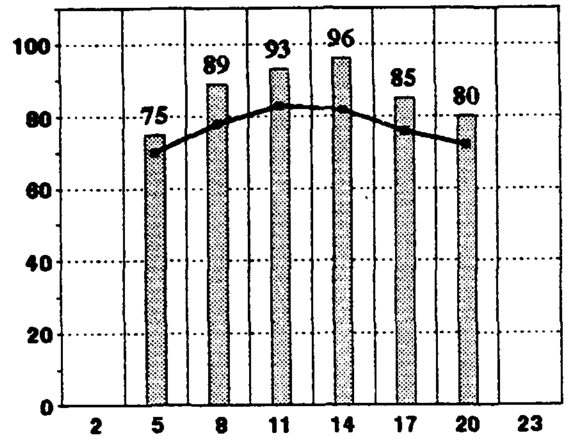
102	98	98	98	96	97
85	85	85	85	85	85
76	76	76	76	76	75
60	68	69	69	66	62

WET SEASON TEMPERATURES (F)

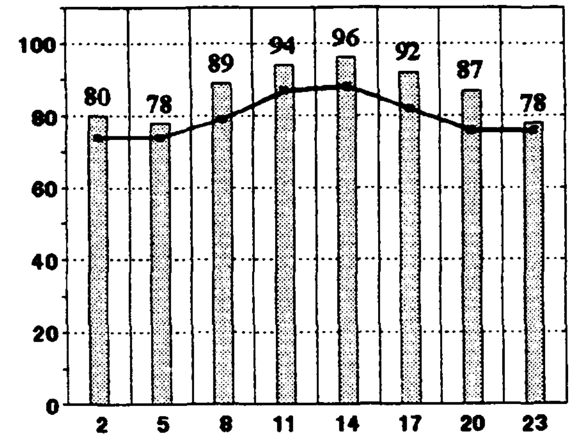
	NOV	DEC	JAN	FEB	MAR	APR
EXTREME MAXIMUM						
AVERAGE MAXIMUM						
AVERAGE MINIMUM						
EXTREME MINIMUM						

Figure 4-43. Wet-Season Tabular Temperature Data, Central Amazon Basin.

Relative humidities are high. Monthly mean minimums range from 60% in the extreme southeast to more than 70% within dense northwestern forests. At most places, mean maximums are above 95%. Humidities vary slightly from month to month, but they are slightly higher midway through the season. Figure 4-44 shows two stations with wet-bulb globe temperature data (° F) at specific hours in January.



CACHIMBO



PORTO VELHO

Figure 4-44. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (°F) for January, Central Amazon Basin. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Most flight hazards are thunderstorm-related. Turbulence can be severe from the surface through 30,000 feet (9.1 km) MSL. Most icing occurs in cumuliform clouds; icing bases range from 15,000 feet (4,570 meters) in the north to 18,000 feet (5,490 meters) in the south; tops are about 35,000 feet (10.7 km) MSL throughout the zone. Bases are higher in the south because the sun angle is greater. Icing is likely to be severe in cumulonimbus and moderate in cumulus.

Speed shear occurs along the zone's southwest edge and along the Amazon River where low-level jets occasionally form. Shear is greatest at night immediately above radiation inversions between 990 and 2,300 feet (300 and 700 meters) MSL. The jet along the Amazon reaches 30 knots, while the one in the southwest can reach 50 knots. These same areas can also experience light to occasionally moderate mechanical turbulence during the day.

GROUND HAZARDS. Ground hazards are rainfall-related. Heavy precipitation not only reduces visibilities well below 1 mile; it also causes annual floods. Slow run-off causes water levels in the zone's west and north to vary by as much as 45 feet (14 meters) annually. Water levels begin rising in October and peak in May. Most places become swamp-like, preventing travel on flooded roads. The higher terrain in the south does not flood as seriously due to better drainage.

GENERAL WEATHER. As the South Atlantic ridge moves in, it brings subsidence; skies clear rapidly. There is still plenty of moisture, however, to feed the few tropical disturbances. These include the Amazon Low in the northwest, tropical waves (tropical squall lines, easterly waves, trade-wind surges, etc.) moving westward, and the retreating Near Equatorial Trough (NET). Although the NET is to the north, the zone is affected by activity up to 300 NM south of the trough's axis. Mid-latitude disturbances include cold fronts, shear lines, and disturbances aloft; they cause activity that moves northeasterly or easterly. Cold fronts and shear lines enter the southwest part of the zone about once a week, but they rarely penetrate into the northeast.

SKY COVER. Cloud cover decreases from south to north, following the Sun. Figure 4-45 shows that coverage in May ranges from 30% in the south to 70% in the north. Most mornings are overcast with stratus, but clear nights and mornings become more common. Afternoon cumuliform cloudiness decreases from mostly broken in May to scattered-to-broken in June. Evenings are similar, with cloudiness decreasing from mostly broken in May to scattered in June. Cloud cover over broad rivers is minimal, while dense forests see morning stratus and widespread afternoon cumuliform clouds (see "Climatic Peculiarities").

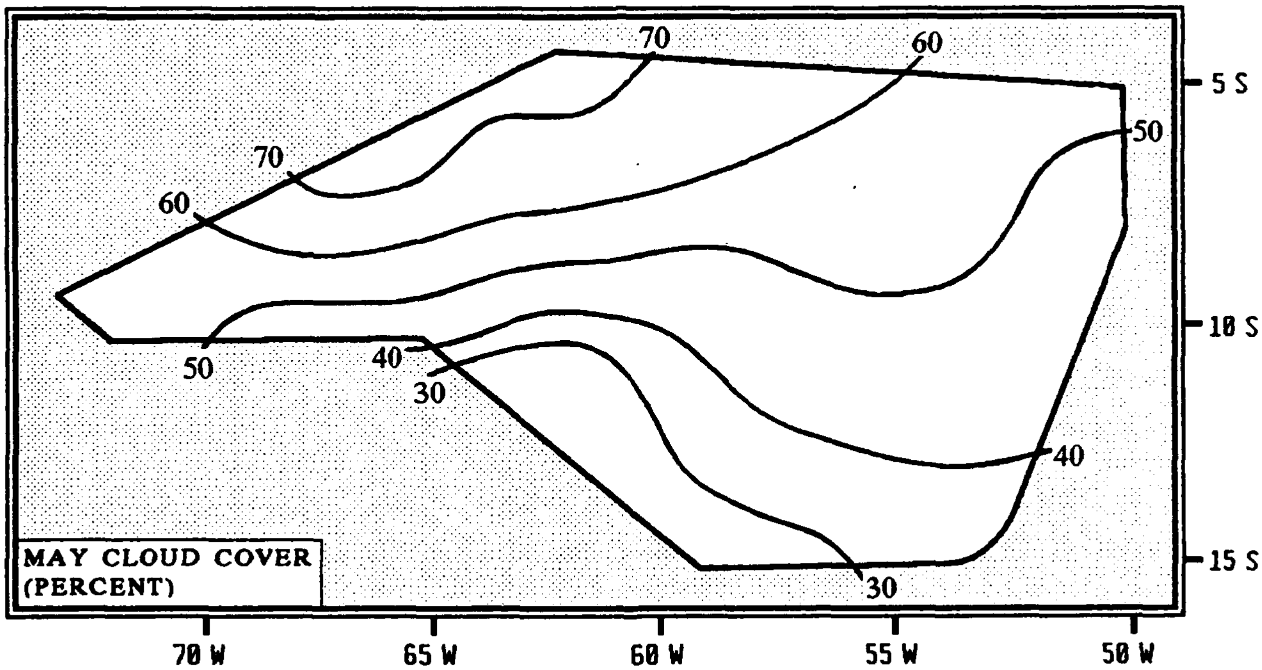


Figure 4-45. Mean May Cloud Cover, Central Amazon Basin.

Disturbances can bring many different cloud types. Stratus and stratocumulus are predominant along disturbances at night, while cumulus and towering cumulus prevail in the afternoon. Occasional strong disturbances have cumuliform clouds embedded in nimbostratus. Low-cloud bases are similar to those of the wet season. In the morning, bases range from 1,000 feet (305 meters) MSL in the northwest to 3,000 feet (915 meters) MSL in the southeast. Afternoon bases range from 2,500 feet (760 meters) MSL in the west, northwest, and north to 4,000 feet (1,220 meters) MSL in the south. Most cumulus tops are below 15,000 feet (4,570 meters) MSL.

Frequencies of low ceilings vary, but they are most frequent during the morning in the northwest's dense forests. Morning frequencies of ceilings below 1,000 feet (305 meters) AGL range from less than 1% in the southeast to 58% in the west, at Tarauaca. "Jungle stratus" is the main cause of ceilings below 1,000 feet (305 meters) AGL; it occurs most often in the morning in forested areas where rain has fallen on the previous afternoon or evening. It occasionally forms immediately after heavy rainfall. Stratus also forms at night and in the morning behind cold fronts and shear lines. Morning stratus, regardless of its cause, is typically less than 1,000 feet (305 meters) thick. It dissipates shortly after sunrise. Repeated shear-line passages can cause stratus to persist. Low clouds that form during and immediately after heavy precipitation account for afternoon ceilings below 1,000 feet (305 meters) AGL. Afternoon low-ceiling frequencies are below 3% everywhere except in the extreme west and northwest, where they reach 35%.

Frequencies of morning ceilings below 3,000 feet (915 meters) AGL range from 12% at Porto Velho to 79% at Tarauaca. Afternoon frequencies range from 5% at Diamantino to 57% at Cachimbo. Clouds spread out horizontally and become lower as the atmosphere stabilizes in the evening. This is why places like Diamantino see an increase in low-ceiling frequencies from afternoon to evening.

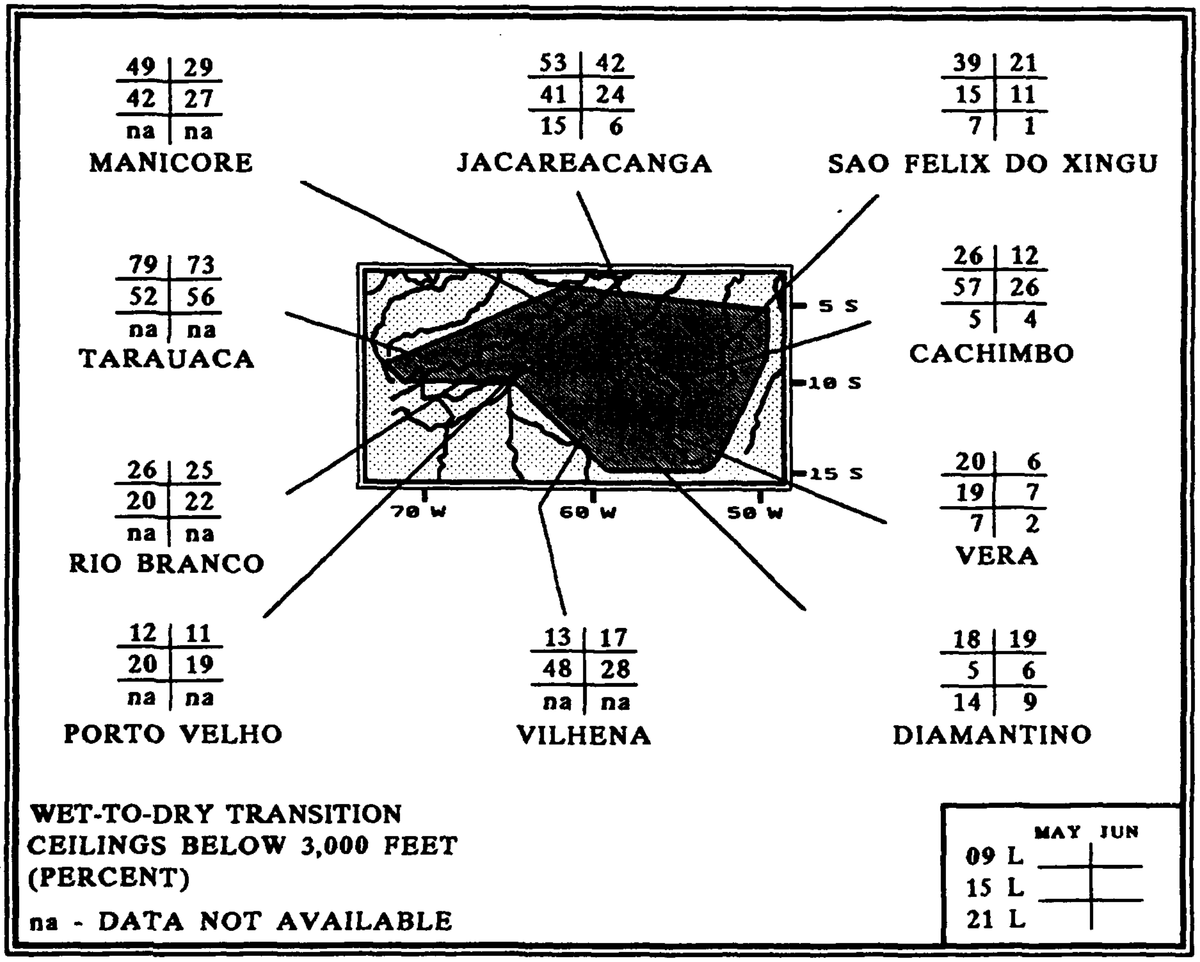


Figure 4-46. Wet-to-Dry Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Amazon Basin.

VISIBILITY. Fog causes most low visibilities. It occurs most often around sunrise in forested areas that received heavy rainfall on the previous afternoon or evening. This fog normally originates within forest canopies as "jungle stratus." Fog also forms in the morning following cold front passages. In the southeast, fog can be enhanced by strong upslope flow. Morning fog, regardless of the cause, is normally less than 1,000 feet (305 meters) thick. It dissipates by noon. Occasionally daytime fog occurs immediately after a heavy rainfall. Precipitation causes most afternoon visibility restrictions. Haze occasionally reduces visibilities below 3 miles when plant particles accumulate and become suspended during stable periods.

Most low visibilities occur in the west, northwest, and north. They are least common in the southeast, especially on ridges and plateaus. Cachimbo is the best example of a southeastern site on a ridge. Vilhena, although at a higher elevation, lies in a small basin and is consequently most representative of low-lying areas in the southeast. Morning frequencies of visibilities below 3 miles at Cachimbo and Vilhena average about 5 and 12%, respectively (see Figure 4-47). Morning visibilities are below 3 miles most frequently at Labrea, where frequencies exceed 40% in June. Afternoon and evening frequencies exceed 10% at Labrea, but they are less than 5% at most places. Morning frequencies of visibilities below 1 mile range from 4% at Cachimbo in June to nearly 25% at Sao Felix Do Xingu in May. Afternoon and evening frequencies below 1 mile are less than 5% everywhere.

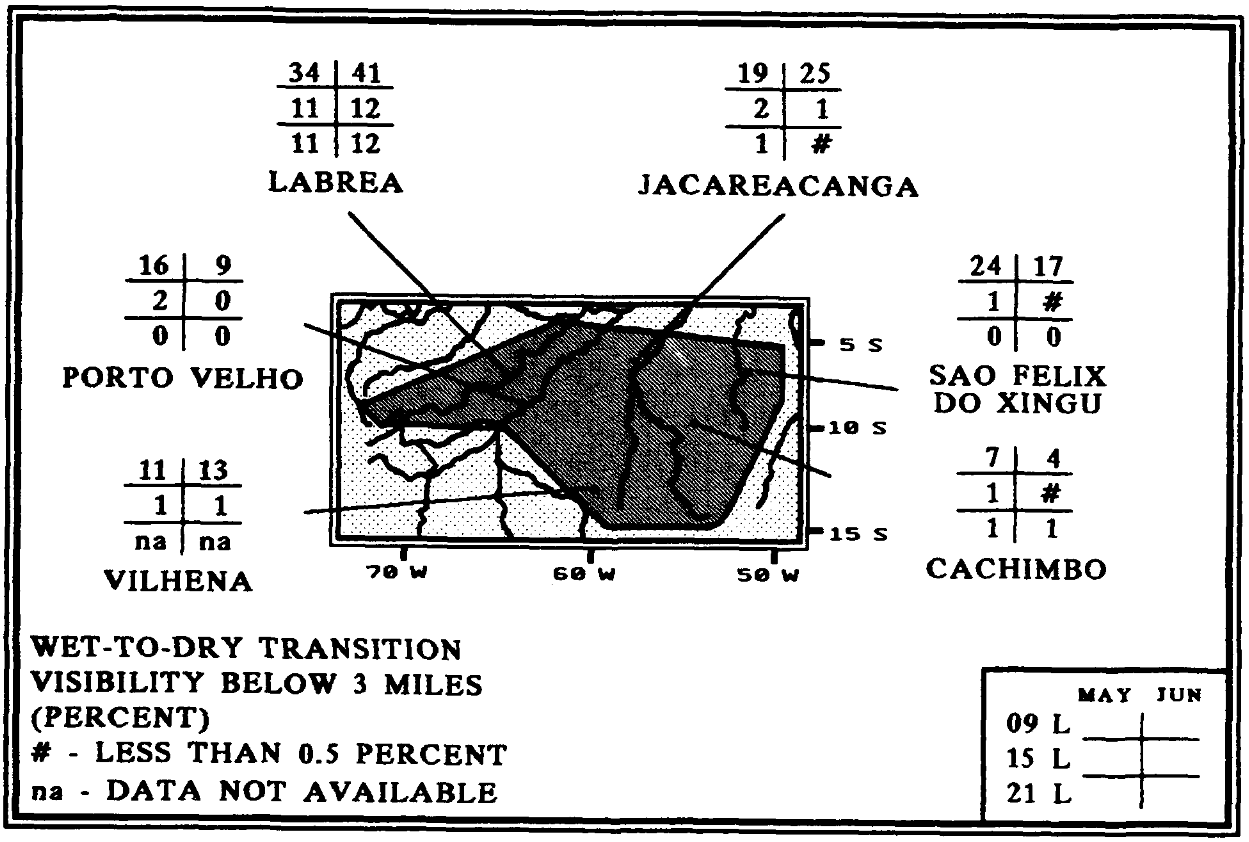


Figure 4-47. Wet-to-Dry Transition Percent Frequencies of Visibility Below 3 Miles, Central Amazon Basin.

WIND. Surface friction reduces synoptic flow--surface winds are light nearly everywhere. Mean speeds for all hours, shown in Figure 4-58, range from 1 knot in the densely forested west to 3 knots in the less heavily wooded southeast. Winds are calm at night, with weak slope winds possible along inclines in the southeast. Daytime speeds range from calm to 5 knots. Wind directions are normally easterly, but varying vegetation, cloud cover, and surface moisture cause uneven heating and variable wind direction.

Strong winds are rare, especially in dense forests where winds are weakened or dissipated within tree canopies. Most strong winds are caused by thunderstorms, with gusts near 50 knots possible in less densely wooded areas.

STATION	MEAN WIND SPEED	
	MAY	JUN
CACHIMBO	3	3
DIAMANTINO	2	2
JACAREACANGA	1	2
LABREA	1	1
MANICORE	2	2
MISSAO DO CURURU	1	2
PORTO VELHO	2	2
RIO BRANCO	1	1
SAO FELIX DO XINGU	2	2
SENA MADUREIRA	1	1
TARAUACA	1	1
VERA	2	2
VILHENA	2	2

Figure 4-48. Mean Wet-to-Dry Transition Wind Speeds, Central Amazon Basin.

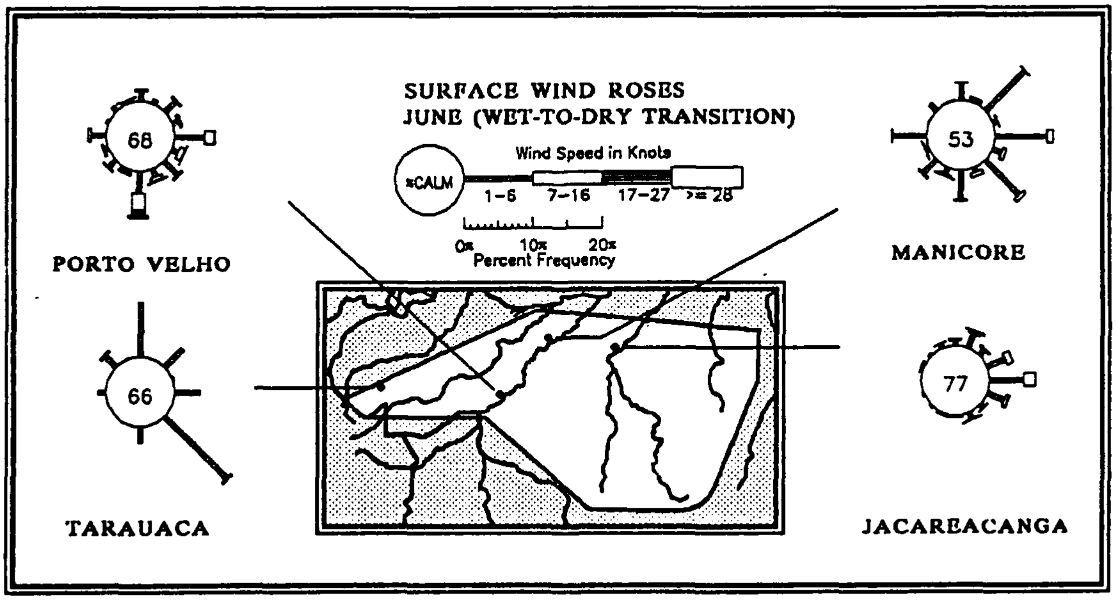


Figure 4-49. June Surface Wind Roses, Central Amazon Basin. There is no reliable wind data for other stations in the Central Amazon Basin.

Mean winds at 5,000 feet (1,525 meters) MSL range from easterly at 15 knots in the north to northeasterly at 10 knots in the south. A low-level wind maximum occasionally occurs near the eastern half of the zone's northern border. Associated easterly winds can reach 30 knots at about 1,500 feet (455 meters) MSL. By 20,000 feet (6.1 km) MSL, a distinct ridge is oriented east-west across the zone's center. Resulting directions range from easterly on the zone's northern border to westerly along the southern border. The ridge becomes displaced farther north with increasing heights, resulting in westerly flow throughout the zone by 40,000 feet (12.2 km) MSL. Upper-air wind directions are shown in Figures 4-37 through 4-40. Mean upper-air speeds are less than 30 knots through 40,000 feet (12.2 km) MSL.

PRECIPITATION. Rainfall amounts decrease progressively as the stable trades and the South Atlantic High grow gradually stronger. The effects can be seen by comparing Figure 4-50 (May amounts) to Figure 4-42 (January amounts). May amounts range from less than 3 inches (76 mm) in the south to over 6 inches (152 mm) in the north. June amounts (not shown) are much lower.

Most precipitation falls as afternoon rainshowers along disturbances, but there is also rainfall from thunderstorms and associated middle cloudiness. Precipitation amounts don't vary much from one disturbance to another; frequencies of disturbances are more important than their type or strength. Satellite pictures clearly show disturbances as enhanced shower and thunderstorm activity. Low-level convergence associated with a low-level wind maximum in the north results in the fact that precipitation is most frequent in the north.

Figure 4-51 shows how rapidly rainfall decreases; in June, there is less than half as much as in May. Mean rainfall days range from only 1 in the south in June to nearly 10 in the north in May. Maximum monthly rainfall amounts, also shown in Figure 4-51, have exceeded 10 inches (254 mm) at Porto Velho in May. More rainfall is possible in the data-sparse north where mean monthly rainfall amounts are highest. The maximum recorded 24-hour amount is 4 inches (102 mm) at Missao in May.

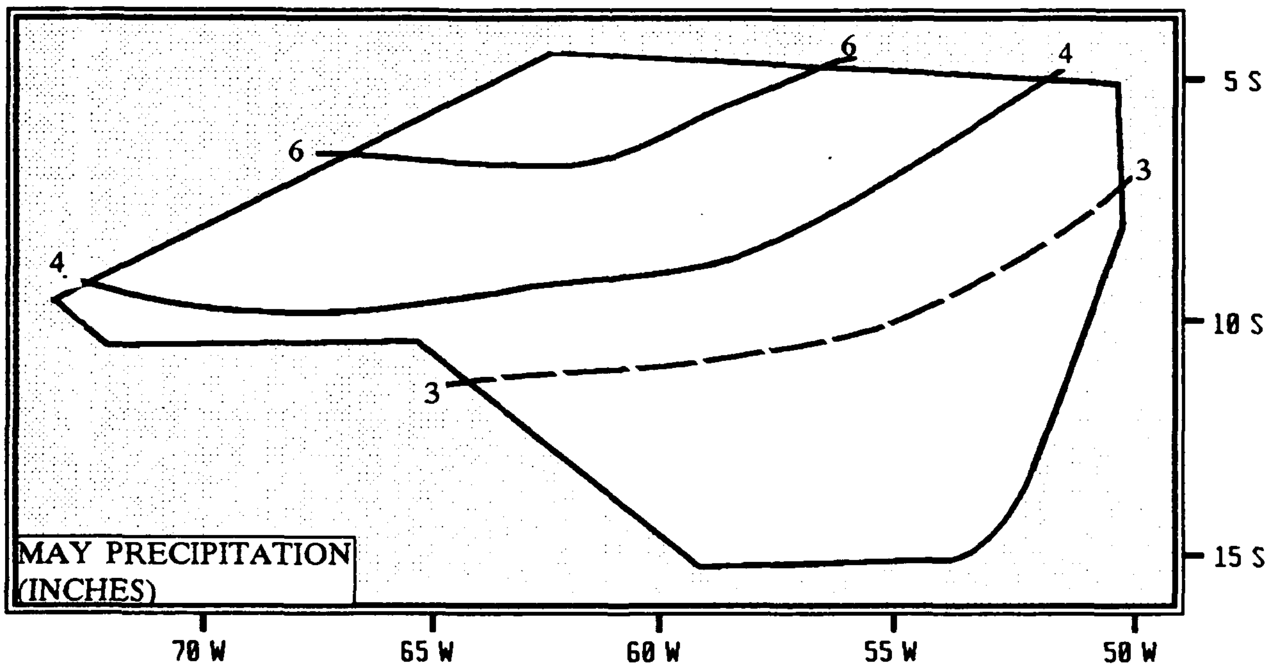
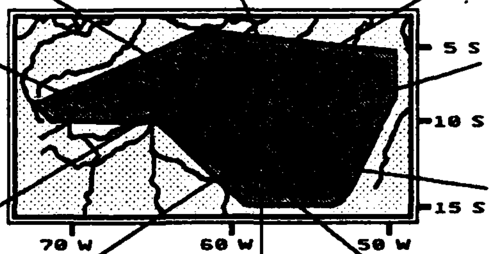


Figure 4-50. Mean May Precipitation, Central Amazon Basin.



Station	Maximum Monthly MAY	Maximum Monthly JUN	Maximum 24-Hour MAY	Maximum 24-Hour JUN	Precipitation Days MAY	Precipitation Days JUN	Thunderstorm Days MAY	Thunderstorm Days JUN
HUMAITA	na	na	3.2	2.8	na	na	na	na
JACAREACANGA	na	na	3.2	1.7	na	na	na	na
MISSAO DO CURURU	na	na	4.1	1.5	14	4	5	4
SENA MADUREIRA	na	na	3.4	2.4	8	7	4	3
CACHIMBO	na	na	1.3	1.9	na	na	6	1
PORTO VELHO	10.2	4.2	2.8	0.2	12	6	4	4
VERA	na	na	na	na	na	na	1	0
VILHENA	na	na	na	na	na	na	2	1
UTIARITI	na	na	na	na	1	1	1	1
DIAMANTINO	na	na	na	na	na	na	2	#

WET-TO-DRY TRANSITION
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

Figure 4-51. Wet-to-Dry Transition Tabular Precipitation Data, Central Amazon Basin.

THUNDERSTORMS. Thunderstorms become less common. Most occur as organized activity along disturbances, but they occasionally result from brief, isolated afternoon convection. Thunderstorm bases are below 3,000 feet (915 meters) and sometimes below 1,000 feet (305 meters). Most tops are below 45,000 feet (13.7 km) MSL. Moderate to heavy rain is likely; hail melts before reaching the ground. Although there isn't enough data to verify tornado activity, it shouldn't be ruled out. Thunderstorms along disturbances can cause 50-knot gusts, but these winds are weakened or dissipated by dense forest canopies. Downbursts, as evidenced by forest "blowdowns," are known to occur.

Mean monthly thunderstorm days are lowest in the south and highest in the north. Thunderstorm days are fewest at Vera, averaging less than 1 a month, and greatest at Missao, averaging at least 4 a month.

Thunderstorm-associated mid-level clouds often cause light to moderate precipitation. They occasionally become widespread and produce as much precipitation as the thunderstorm cores. These clouds, unlike those in the mid-latitudes, trail *behind* thunderstorm cores (see "Tropical Squall Lines," Chapter 2). Outflow can be channeled through terrain gaps in the southeast, occasionally producing thunderstorms elsewhere.

TEMPERATURES are moderated by the Amazon Basin's moisture-laden tropical forests, but lower. Polar outbreaks that bring abnormally cool, dry air are the exceptions. Radiation cooling following strong outbreaks results in record low temperatures (called "friagems"), which occur up to five times from May through August. Friagems normally last from 3 to 5 days, but some persist for a couple of weeks. They have their greatest and most persistent effects in the south and west where cold air masses enter the zone. Sena Madureira, Vilhena, and Diamantino have recorded the season's lowest temperatures, which were as low as 45° F (7° C). Friagems don't occur in the northeast, as shown by the extreme lows of 65° F (18° C) at Manicore and Sao Felix Do Xingu.

Mean minimum and maximum temperatures show the moderating effects of Amazon moisture (see Figure 4-52). Mean lows range from 66° F (19° C) at Sena Madureira to 75° F (24° C) at Manicore. Mean highs range from 81° F (27° C) at Vilhena to 91° F (33° C) at Missao Do Cururu. These values suggest that diurnal temperature variations depend mostly on changes in the albedo caused by the type and amount of vegetation. This could explain why the greatest variations occur near Sena Madureira and the zone's center where the effects of elevations and moisture amounts appear to be small. With clear skies, nighttime forest canopy temperatures are a couple of degrees warmer than the underlying surface. In the afternoon, the canopies are about 10° F (6° C) warmer. Radiation heating and cooling occurs within forest canopies, not at ground level. Temperature characteristics are likely to change if deforestation continues.

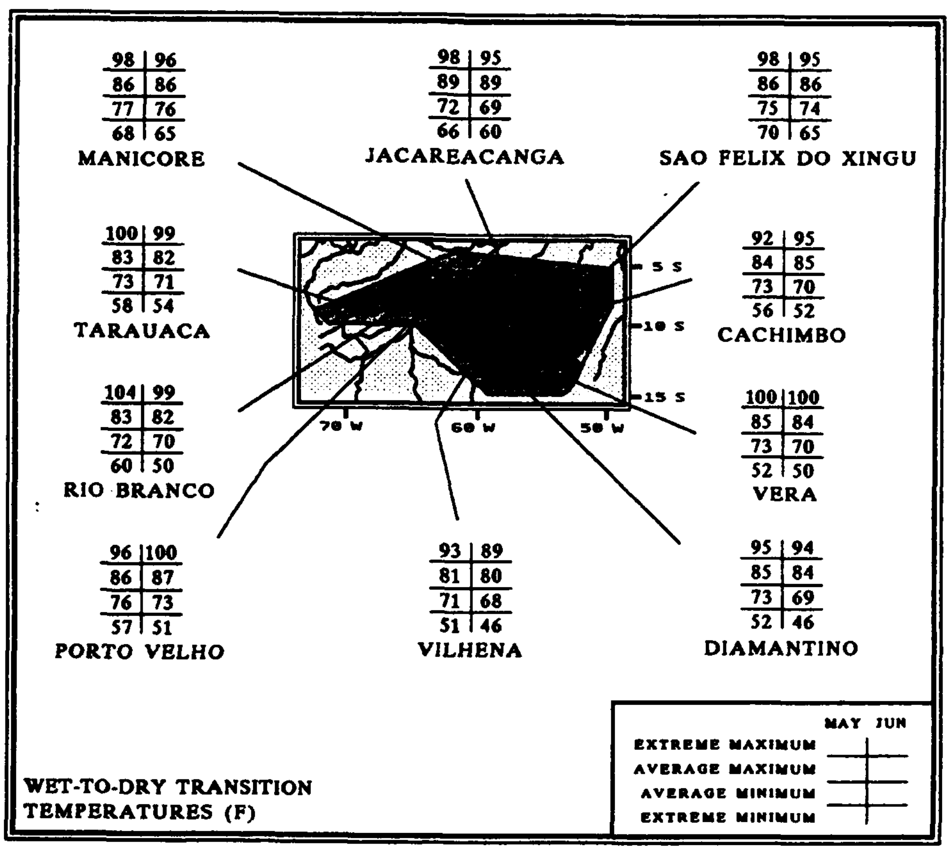


Figure 4-52. Wet-to-Dry Transition Tabular Temperature Data, Central Amazon Basin.

Relative humidities decrease, but more slowly in areas of poor drainage where wet-season flood water persists. Mean minimum RH ranges from 45% in the extreme southeast to more than 70% in the extreme northwest. Mean maximums range from 91% in the southeast to nearly 100% in the west and north. Figure 4-53 shows two stations with wet-bulb globe temperature data (° F) at specific hours in May.

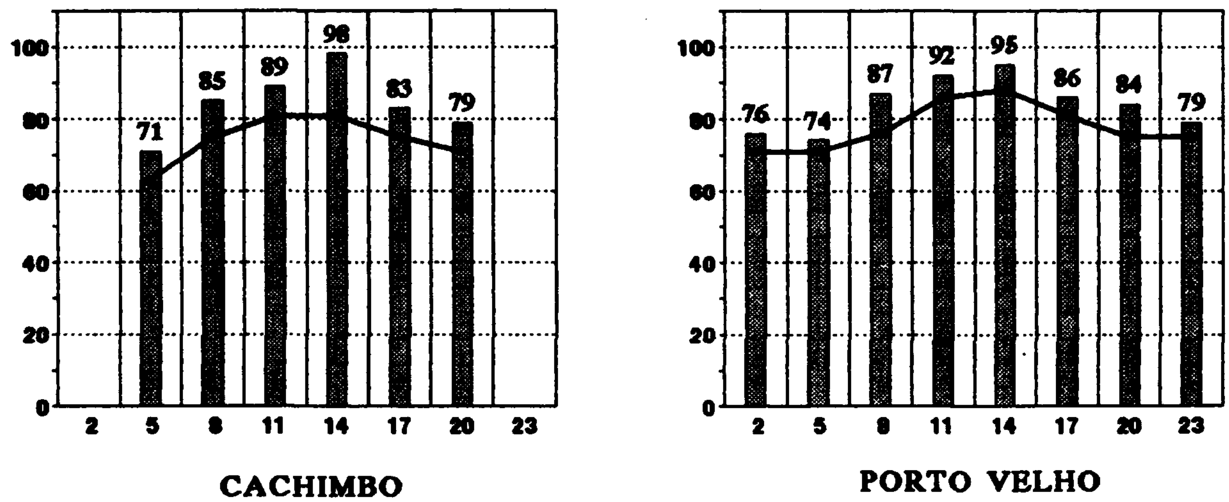


Figure 4-53. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (°F) for May, Central Amazon Basin. Mean WBGT is shown by the line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms can cause severe turbulence from the surface through at least 30,000 feet (9.1 km) MSL. Icing is likely to be severe in cumulonimbus and at least moderate in cumulus. Icing bases are above 15,000 feet (4,570 meters) and tops are about 30,000 feet (9.1 km) MSL. Haze occasionally reduces in-flight visibilities below 3 miles, obscuring cumuliform cells. The haze is mostly made up of suspended plant particles that accumulate during prolonged stable periods.

Speed shear occurs along the Amazon River where a low-level wind maximum occasionally forms. Shear is greatest at night immediately above radiation inversions between 990 and 2,300 feet (300 and 700 meters) MSL. Core speeds reach 30 knots, with speeds above and below decreasing rapidly.

GROUND HAZARDS. Slow run-off in the west and north allows wet-season water levels to persist. Water levels begin rising in October and peak in May, varying by as much as 45 feet (14 meters) year-round. Most areas remain swamp-like, preventing travel on flooded roads. Flooding is not a serious problem in the south where the drainage is better.

GENERAL WEATHER. Strong subsidence beneath the South Atlantic Ridge creates stability and dries the air adiabatically, but there is still enough surface moisture for fog and low clouds. Tropical Squall Lines are the only tropical disturbances, but some instability associated with the Amazonian Low can also contribute to activity in the extreme northwest. Mid-latitude disturbances include cold fronts, shear lines, and disturbances aloft. Any activity associated with these features moves toward the northeast and east. Fronts and shear lines enter the zone's southwest an average of once a week, but most don't penetrate into the extreme northeast. They are preceded and accompanied by cumuliform activity and followed by more stratiform conditions. Disturbances aloft may cause an increase in cloudiness at and above their height.

Historical data from the past 20 to 30 years suggests that the effects of haze from controlled burning has spread westward from east of 60° W to about 63° W, as well as near much of Bolivia's northern border.

SKY COVER. Smoke and haze from burning vegetation becomes a major contributor to sky cover by season's end. Figure 4-54 shows that mean daily sky cover for July ranges from 20% in central and eastern areas to 50% in the densely-forested northwest. Skies are most often clear or overcast in the morning; afternoons are scattered to broken, becoming scattered in the evening. Broad rivers are usually cloud-free, while cloudiness elsewhere often consists of morning stratus and afternoon cumulus (see "Climatic Peculiarities.")

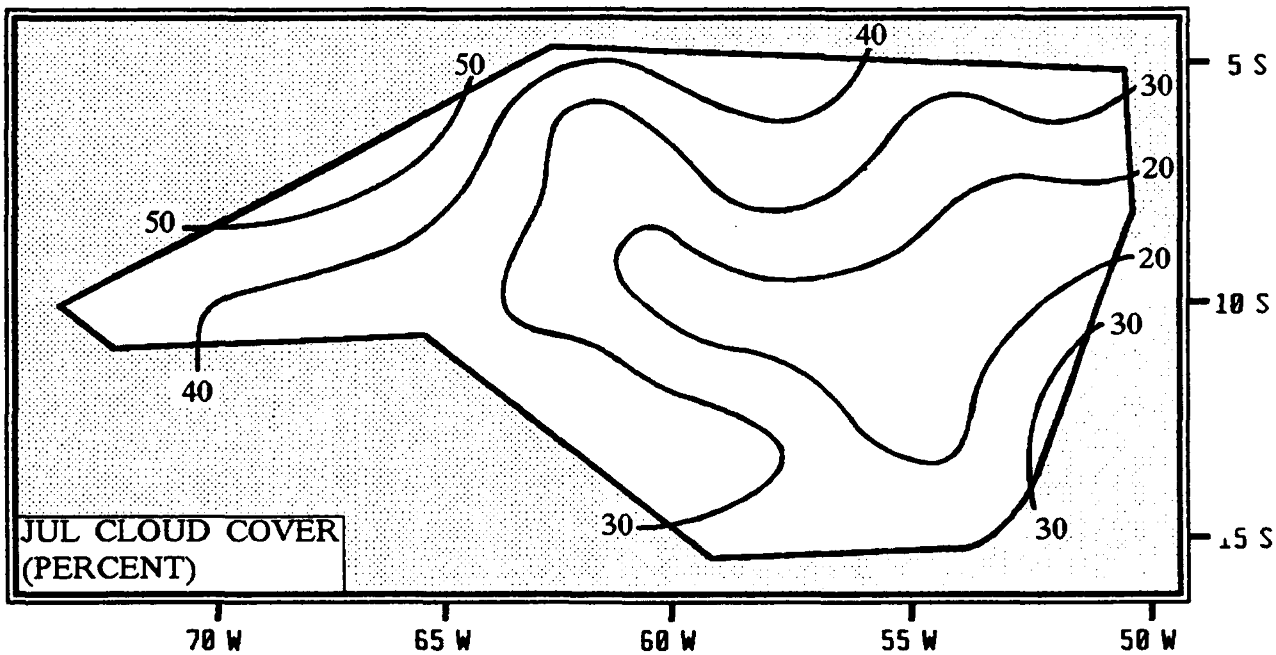


Figure 4-54. Mean July Cloud Cover, Central Amazon Basin.

The predominant cloud types, regardless of whether or not disturbances are occurring, are stratus, stratocumulus, and cumulus. Stratus is common within the air masses that follow cold fronts or shear lines. It often occurs for great distances behind the front, reinforced by subsequent shear lines. It can persist throughout the day, but is most important in the morning when it can produce drizzle. Stratocumulus can occur anytime, but it's most common in the evening. Cumulus is the main afternoon cloud type. Strong disturbances can produce many different cloud types, including rare nimbostratus.

Low-cloud bases are similar to those in the other seasons. In the morning, they range from 1,000 feet (305 meters) in the northwest to 3,000 feet (915 meters) in the southeast. Afternoon bases range from 2,500 feet (760 meters) MSL in the northwest to 4,500 feet (1,370 meters) in the southeast. Most tops are below 10,000 feet (3,050 meters).

Ceilings are below 1,000 feet (305 meters) AGL most often in densely forested areas during the morning. Morning frequencies range from less than 1% in the southeast to about 51% in the west at Tarauaca. Stratus behind cold fronts/shear lines and "jungle stratus" are the primary causes. Jungle stratus occurs most often in forest canopies where moderate to heavy precipitation has fallen on the previous afternoon or evening. Although jungle stratus usually dissipates shortly after sunrise, frontal/shear line stratus can persist through the day; bases normally rise above 1,000 feet (305 meters) AGL. Afternoon frequencies of ceilings below 1,000 feet (305 meters) AGL range from less than 1% in all but the extreme west and northwest, where they are more than 5% and as high as 30%. Occasional heavy showers contribute to afternoon occurrences. Ceilings below 3,000 feet (915 meters) AGL in the morning range from 5% at Vera to 63% at Tarauaca; during afternoons, from less than 5% in the southeast to 43% at Labrea. Diurnal variations depend on moisture availability. Clouds that don't dissipate spread out horizontally and become lower as the atmosphere stabilizes in the evening. As a result, low-ceiling frequencies increase from afternoons to evenings at a few places, such as Diamantino.

The increased effects of smoke and haze from burning vegetation can be seen in Figure 4-55; compare July and August at Sao Felix Do Xingu. Smoke and haze layers cause morning ceiling frequencies below 3,000 feet (915 meters) AGL to increase from 15 to 52%; frequencies of ceilings below 1,000 feet (305 meters) AGL go from 10 to 41%. Low-ceiling frequencies depend on where and when burning takes place.

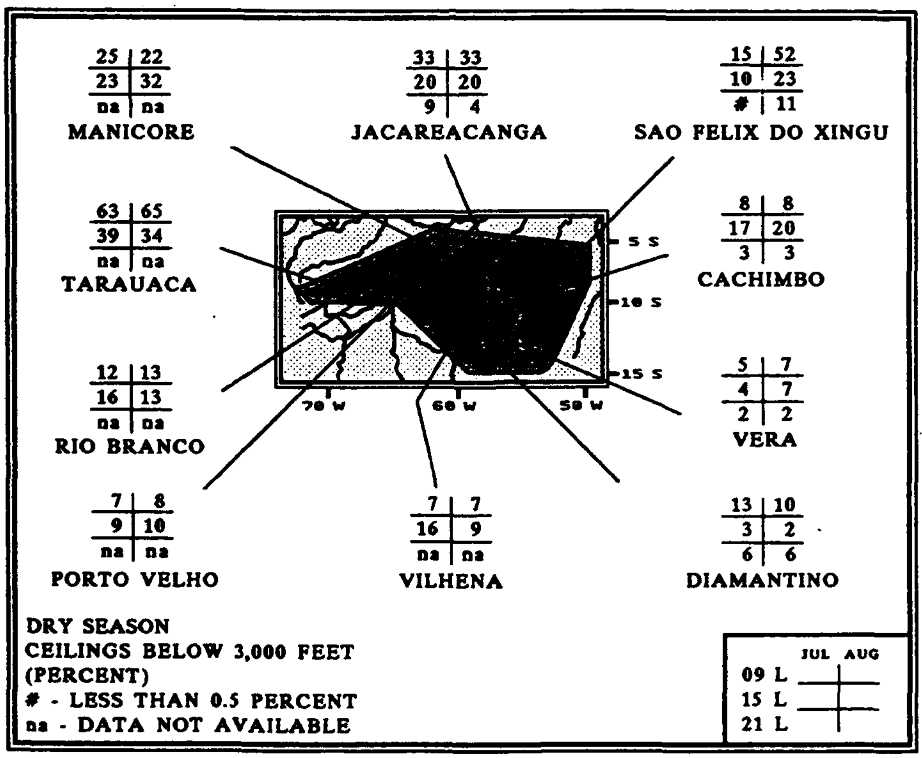


Figure 4-55. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Amazon Basin.

VISIBILITY. Stability makes fog the primary cause of low visibility. Peaking in the dry season, fog occurs most often with radiation cooling of moist surfaces and on mornings immediately following cold frontal passages. Forested areas where rain fell on the previous afternoon or evening are the best places for radiation fog to form. Fog may originate within forest canopies as "jungle stratus." Morning fog, regardless of the cause, is normally less than 1,000 feet (305 meters) thick and dissipates by noon. During the daytime, fog can form immediately after the season's rare heavy rainfalls. Precipitation, however, is a more important cause of low afternoon visibilities. Fog formation is enhanced on slopes in the southeast when upslope flow is strong enough. Haze, discussed in more detail below, also contributes to low visibilities.

Frequencies of visibilities below 3 miles are lowest in the dry season, even though most fog occurs at this time of year. Visibilities are restricted most often in the northwest and least often in the southeast. Figure 4-56 shows that morning frequencies of visibilities below 3 miles range from 3% in July at Cachimbo to 42% at Sao Felix Do Xingu in August. Much of the haze observed in the zone's eastern half during the period of record used for Figure 4-56 originated as smoke from burning tropical vegetation. Consequently, the values are representative of locations that are influenced by man. Future visibility climatology will depend on where, when, and how much burning takes place. As of Spring 1992, burns were underway everywhere south of 5° S and east of 63° W, as well as near the Bolivian border. The entire zone is occasionally below 3 miles in haze that results from suspended plant particles. Afternoon and evening, visibilities are below 3 miles less than 10% of the time everywhere.

Visibilities are generally below 1 mile less than 5% of the time except in August where smoke and haze from burning accumulates. In these places, visibilities are below 1 mile 40% of the time in the mornings and nearly 10% of the time in August afternoons and evenings.

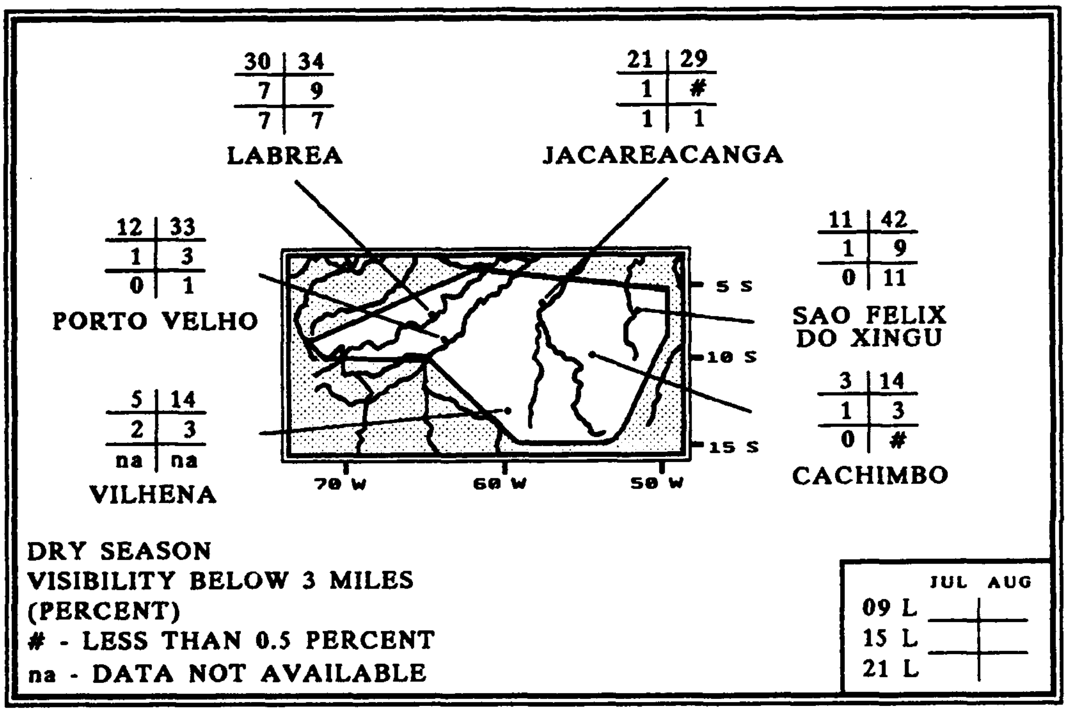


Figure 4-56. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Central Amazon Basin.

WINDS. Winds are strongest during the dry season, but still light everywhere because of surface friction. The prevailing direction is easterly. Speeds are least over forests. As shown in Figure 4-67, mean wind speeds for all hours range from 1 knot in densely-forested western areas to 4 knots in the less-densely forested southeast. Nights are calm, but weak slope winds are possible along inclines in the southeast. Average daytime speeds range from calm to 7 knots. Uneven heating of terrain caused by differences in vegetation, cloud cover, and surface moisture cause local variations. Thunderstorms are the primary cause of high winds, with gusts near 50 knots possible.

STATION	MEAN WIND SPEED	
	JUL	AUG
CACHIMBO	3	4
DIAMANTINO	3	2
JACAREACANGA	2	2
LABREA	1	1
MANICORE	2	2
MISSAO DO CURURU	2	2
PORTO VELHO	2	2
RIO BRANCO	1	1
SAO FELIX DO XINGU	2	2
SENA MADUREIRA	1	1
TARAUACA	1	1
VERA	2	2
VILHENA	2	2

Figure 4-57. Mean Dry-Season Wind Speeds, Central Amazon Basin.

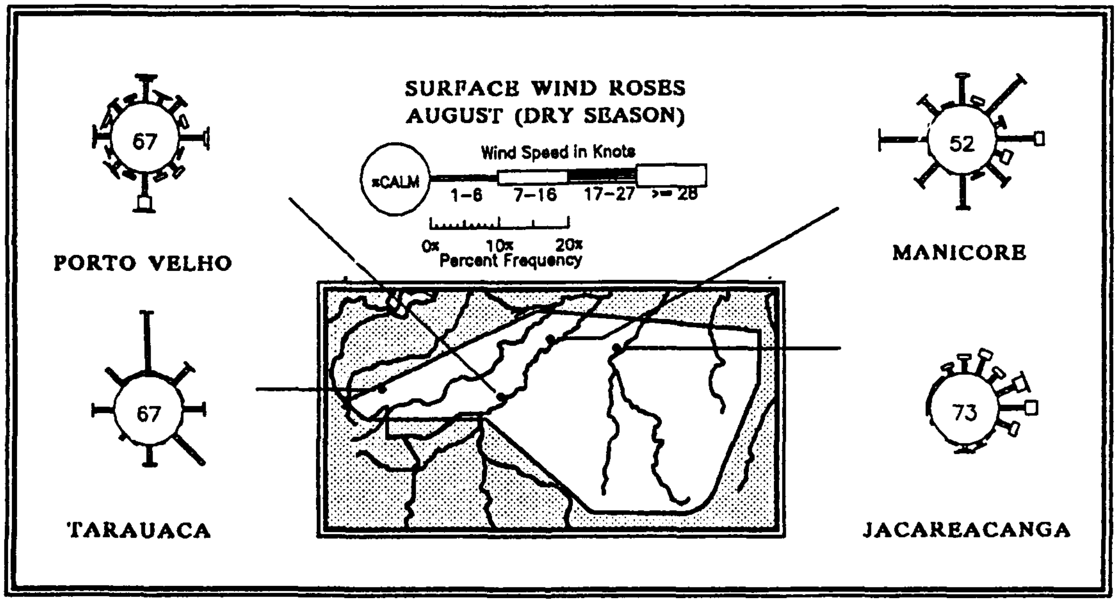


Figure 4-58. August Surface Wind Roses, Central Amazon Basin. There is no reliable data for other stations.

Mean winds immediately above the surface friction layer range from easterly at 15 knots in the north and east to northeasterly at 10 knots in the south and west, they producing diffluent flow. A low-level wind maximum occasionally occurs near the eastern half of the zone's northern border; winds near 1,500 feet (455 meters) MSL can reach 30 knots from the east. Upper-air wind directions, shown in Figures 4-37 through 4-40, are much like those of the previous season. A distinct ridge is oriented east-west across the zone's center at 20,000 feet (6.1 km) MSL, resulting in directions that range from easterly on the northern border to westerly along the southern border. The ridge is displaced northward with increasing height, resulting in westerly flow across the zone by 40,000 feet (12.2 km) MSL. Mean upper-air wind speeds do not exceed 30 knots below 40,000 feet (12.2 km) MSL.

PRECIPITATION. Dry air aloft, along with stability associated with the trade winds and the South Atlantic High, inhibit rainfall. Diffluent low-level flow also contributes to stability. Most precipitation falls from thunderstorms or as scattered rainshowers when the combined effects of disturbances and convective heating overcome stability. Disturbances are clearly defined by enhanced cloud development on satellite pictures. Cold fronts may be followed by drizzle, particularly on the first night after frontal passage. Light rainfall and virga may occur beneath thunderstorm-associated middle cloudiness.

Mean days with rainfall range from more than 3 in the west and north to 1 or less in the south. Mean monthly dry-season rainfall (represented by July in Figure 4-59) is 1 inch or less (25 mm) everywhere except in the northwest, where it reaches 2 inches (51 mm). Higher amounts correlate with denser forests. Maximum monthly amounts can reach 5 inches (127 mm), but it is common for some places to get no rainfall at all during the entire season.

As shown in Figure 4-60, maximum 24-hour amounts can reach 2.5 inches (64 mm) in the west, northwest, and north; this is due in part to weakening stability with increasing distance inland. Instability associated with the Amazonian Low may also contribute to higher amounts in the northwest. Low-level convergence associated with an occasional low-level wind maximum in the north also contributes to rainfall in that area.

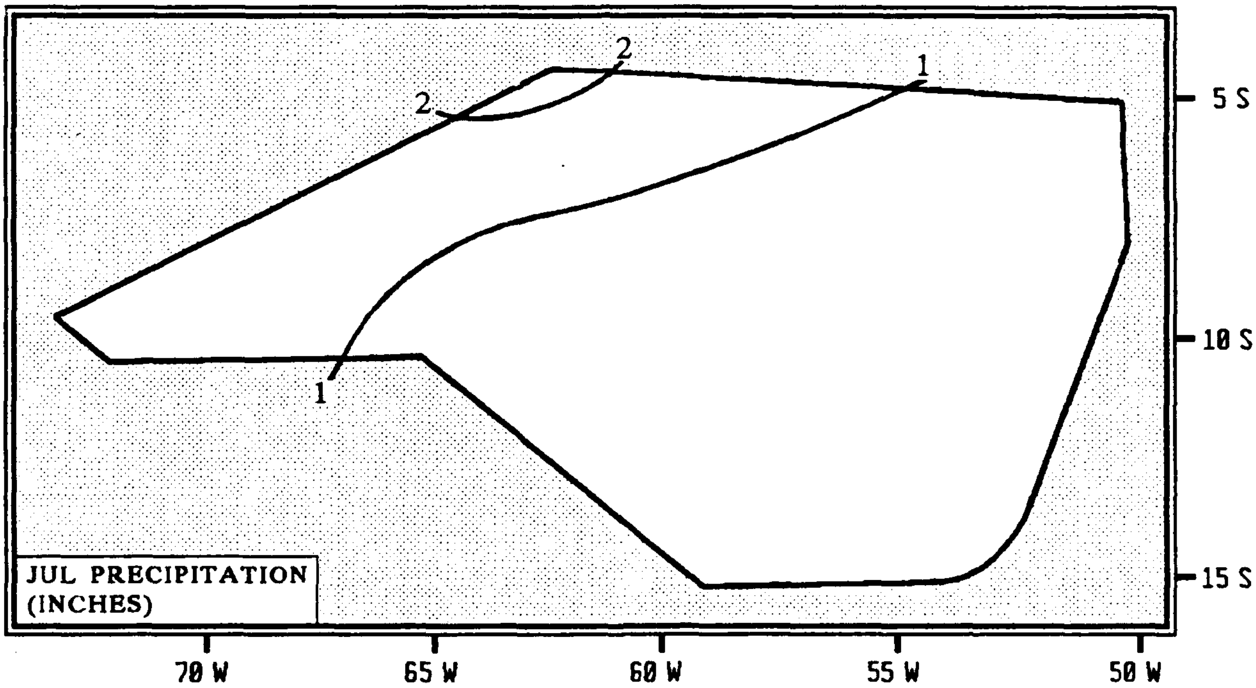
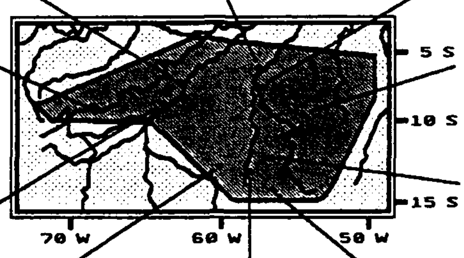


Figure 4-59. Mean July Precipitation, Central Amazon Basin.



Station	Maximum monthly JUL	Maximum monthly AUG	Maximum 24-hour JUL	Maximum 24-hour AUG	Precipitation days JUL	Precipitation days AUG	Thunderstorm days JUL	Thunderstorm days AUG
HUMAITA	na	na	2.1	2.3	na	na	na	na
JACAREACANGA	na	na	1.4	0.9	na	na	na	na
MISSAO DO CURURU	na	na	1.5	2.6	2	6	3	7
SENA MADUREIRA	na	na	2.1	2.5	5	5	2	4
CACHIMBO	na	na	0.2	0.2	na	na	1	3
PORTO VELHO	2.6	4.9	0.8	1.9	3	4	2	6
VERA	na	na	na	na	na	na	#	1
VILHENA	na	na	na	na	na	na	1	2
UTIARITI	na	na	na	na	#	#	#	1
DIAMANTINO	na	na	na	na	na	na	1	2

DRY SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

JUL AUG
MAXIMUM MONTHLY
MAXIMUM 24-HOUR
PRECIPITATION DAYS
THUNDERSTORM DAYS

Figure 4-60. Dry-Season Tabular Precipitation Data, Central Amazon Basin.

THUNDERSTORMS. Even though stability prevails in the dry season, thunderstorm frequencies are similar to those of the transition as less cloud cover allows for greater convective heating. Thunderstorms occur most often as isolated afternoon cells when disturbances pass through. They are least common in the south (averaging 1 day a month) and most common in the north (up to 5 days a month).

There are more days with thunderstorms than days with precipitation at many locations.

Precipitation from thunderstorm-associated middle and high clouds is not as common as in other seasons. Tornado activity is rare to nonexistent. Freezing levels are above 15,000 feet (4,570 meters) MSL. There is no hail.

Thunderstorm gusts occasionally exceed 40 knots, but they are damped in the dense forest canopies. Most thunderstorm bases are between 2,000 and 4,000 feet (610 and 1220 meters) MSL. Most tops are below 40,000 feet (10.6 km) MSL.

TEMPERATURE. Widespread subsidence beneath the South Atlantic High results in moisture and cloud cover minimums during the dry season. Surface characteristics have a greater effect on local and diurnal temperature variations. Figure 4-61 shows mean annual lows ranging from 67° F (20° C) at Jacareacanga to 75° F (24° C) at Manicore. Mean highs range from 83° F (28° C) at Vilhena to 92° F (33° C) at Jacareacanga. Diurnal differences are due to type and amount of vegetation and surface albedo. The greatest diurnal variations occur in the center of the zone. Elevation and relative humidity effects are small compared to those from deforestation.

Clear skies allow temperatures in tropical forest canopies to average a couple of degrees higher than the underlying surface at night, and 10° F (6° C) warmer during afternoons. Radiation heating and cooling occurs within forest canopies and at ground-level clearings. Seasonal highs range from 97° F (36° C) at Labrea to 102° F (39° C) at Vera. Record lows result from radiation cooling within strong polar outbreaks, called "friagems," which affect the zone up to 5 times from May through August. Friagems usually last between 3 and 5 days, but they have been known to cause abnormally low temperatures for a couple of weeks. They have their greatest and most persistent effects toward the south and west where they enter the zone; Sena Vilhena recorded the season's lowest recorded temperature at 41° F (5° C). The effects are less pronounced towards the northeast, as shown by an extreme low of 62° F (17° C) at Sao Felix Do Xingu.

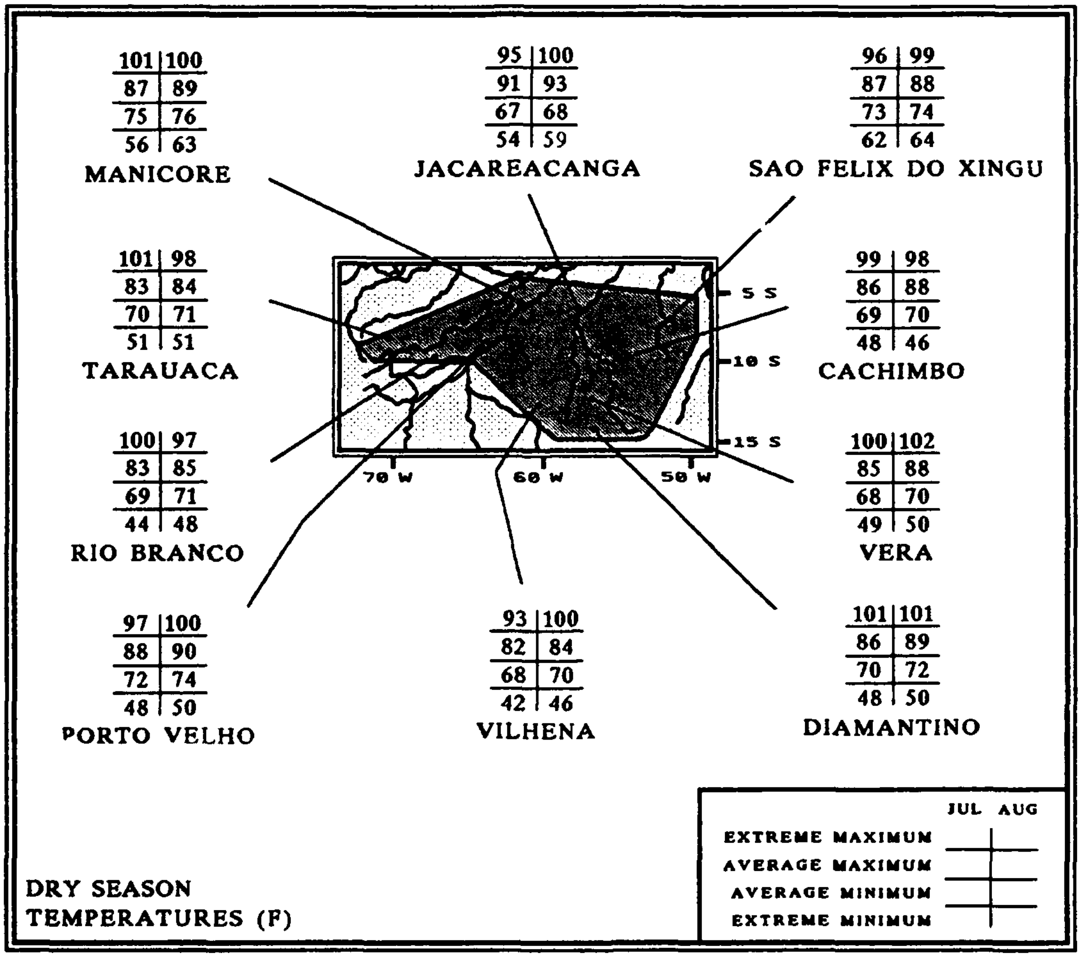


Figure 4-61. Dry-Season Tabular Temperature Data, Central Amazon Basin.

Relative humidities are lowest in the dry season. They vary a great deal from the southeast to the northwest, correlating with types and amounts of vegetation, precipitation, and cloud cover. Mean minimums range from 35% in the extreme southeast to 70% in the extreme northwest. Mean maximums range from 80% in the southeast to more than 95% in the west and north. Figure 4-62 shows two stations with wet-bulb globe temperature data (° F) at specific hours in July.

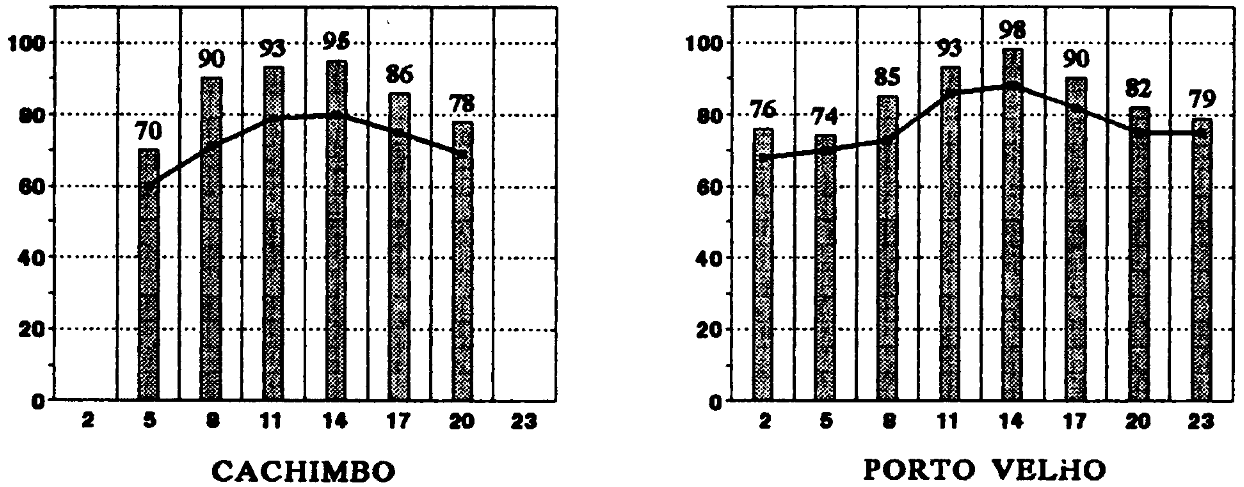


Figure 4-62. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Central Amazon Basin. Mean WBGT is shown as a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. This is the least hazardous season for flying. The most significant threat is the occasional cumuliform cell, a few of which may produce moderate to severe turbulence and icing. Turbulence is possible through 20,000 feet (6.1 km) MSL. Icing layer bases are above 15,000 feet (4,570 meters) MSL; tops, 30,000 feet (9.1 km) MSL. The few cells would be easily navigable were it not for the increasing haze. The plant particle haze of the previous season now becomes overshadowed by haze and smoke from burning. The haze, heaviest in the zone's eastern half late in the season, occurs from the surface through 20,000 feet (6.1 km) MSL. It can be particularly dense between 7,000 and 16,000 feet (2,130 and 4,880 meters) MSL. Haze density depends more on stability than on the amount of burning. Exceptionally stable conditions can result in haze that lowers inflight visibilities below 1 mile and obscures cumuliform cells.

Speed shear occasionally occurs along the zone's northern fringes because of an east-to-west low-level wind maximum that can reach 30 knots immediately above a radiation inversion between 990 and 2,300 feet (300 and 700 meters) MSL. Wind speeds above and below the jet decrease rapidly, producing shear and light mechanical turbulence.

GROUND HAZARDS. Flood waters recede. Their lowest level, which is as much as 40 to 45 feet (12 to 14 meters) below their highest annual level, is reached during the dry-to-wet transition. Although travel is easier, wet soil can still be a problem.

GENERAL WEATHER. Weather deteriorates rapidly, often from day to day. Mid-latitude disturbances become more frequent. Cold fronts and shear lines pass through the entire zone once every 5 days, more often than at any other time of year. Surface and upper-air troughs are also present, but they normally cause less organized activity. All mid-latitude disturbances are active. Between them, broad areas of fair weather prevail. System movement is toward the northeast or east. The TCZ is normally the only tropical disturbance active at this time of year. It oscillates east-west. Since one of the two high-sun periods occurs in October, convective heating is a factor.

SKY COVER. Cloud cover begins to increase in the central section and expands outward as the transition progresses. The most rapid expansion is toward the northwest. Transition sky-cover distributions are represented by October in Figure 4-63. They show mean daily coverage ranging from 40% in the southwest to 60% in the northwestern and central eastern sections. Overcast mornings become increasingly common. Afternoon skies transition from scattered-to-broken to predominantly broken-to-overcast. Evening sky cover changes rapidly from scattered to broken and overcast. There is less clouding over broad than the surrounding areas (see "Climatic Peculiarities").

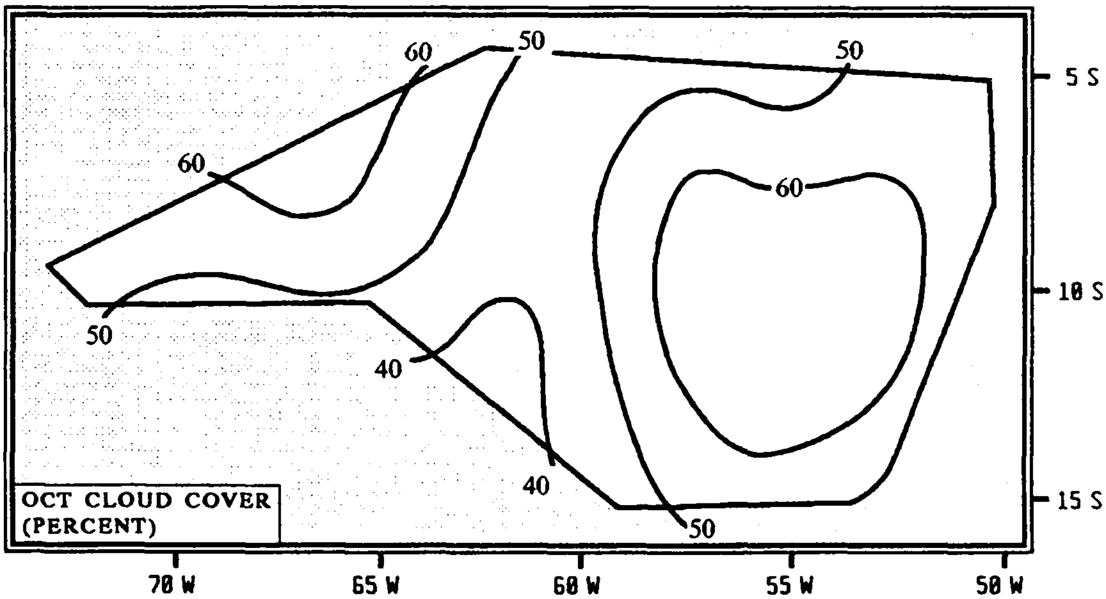


Figure 4-63. Mean October Cloud Cover, Central Amazon Basin.

Prevailing cloud types during settled periods are morning stratus and afternoon stratocumulus and cumulus. Disturbances usually bring cumuliform clouds ranging from stratocumulus to isolated cumulonimbus in the morning and widespread cumulus, towering cumulus, and cumulonimbus in the afternoon. Stratus can form the morning after cold front of shear line passage. On rare occasions, this stratus can persist through the entire day. Nimbostratus with embedded towering cumulus and cumulonimbus can occur with strong disturbances. Mean low-cloud bases are similar to those of the dry season. Mornings, they range from 1,000 feet (305 meters) in the northwest to 3,000 feet (915 meters) in the southeast. Afternoon bases range from 2,500 feet (760 meters) in the northwest to 4,000 feet (1,220 meters) in the southeast. Tops increase rapidly from below 15,000 feet (4,570 meters) MSL to below 25,000 feet (7.6 km).

Transition ceiling frequencies below 3,000 and 1,000 feet (305 and 915 meters) AGL are less variable diurnally, probably due to greater day-to-day variability associated with disturbances. Cold fronts and shear lines are effective at suppressing diurnal variations.

As usual, most low ceilings develop in the zone's most densely forested areas. Morning frequencies of ceilings below 1,000 feet (305 meters) AGL range from less than 1% in the southeast to 52% at the very cloudy Tarauaca in the west. Such ceilings are either a result of "jungle stratus" or post-frontal stratus. Jungle stratus forms most often within forest canopies on mornings after rain fell during the previous afternoon or evening. This stratus is typically less than 1,000 feet (305 meters) thick and dissipates shortly after sunrise.

Post-frontal stratus may be thicker and persist throughout the day. Afternoon ceilings below 1,000 feet (305 meters) AGL are caused by post-frontal stratus (low bases with heavy showers) and jungle stratus that occasionally occurs immediately after heavy showers. Frequencies below 1,000 feet (305 meters) AGL are below 3% everywhere except in the extreme west and northwest, where 30% is possible. Frequencies of morning ceilings below 3,000 feet (915 meters) AGL range from about 7% at Vilhena in the south to as high as 65% at Tarauaca in the west. Afternoon frequencies range from 7% at Diamantino to nearly 50% at Labrea. Low-ceiling frequencies increase from afternoons to evenings at some places such as Diamantino, where increasing stability causes clouds to spread out horizontally and become lower.

The effects of smoke and haze caused by cropland burning are most notable at Sao Felix Do Xingu, where low-ceiling frequencies are much higher than they would be otherwise. This is shown in Figure 4-64. Smoke and haze cause frequencies of ceilings below 3,000 feet (915 meters) AGL to increase from 15% in July to 52% in August; frequencies of ceilings below 1,000 feet (305 meters) AGL increase from 10 to 41%.

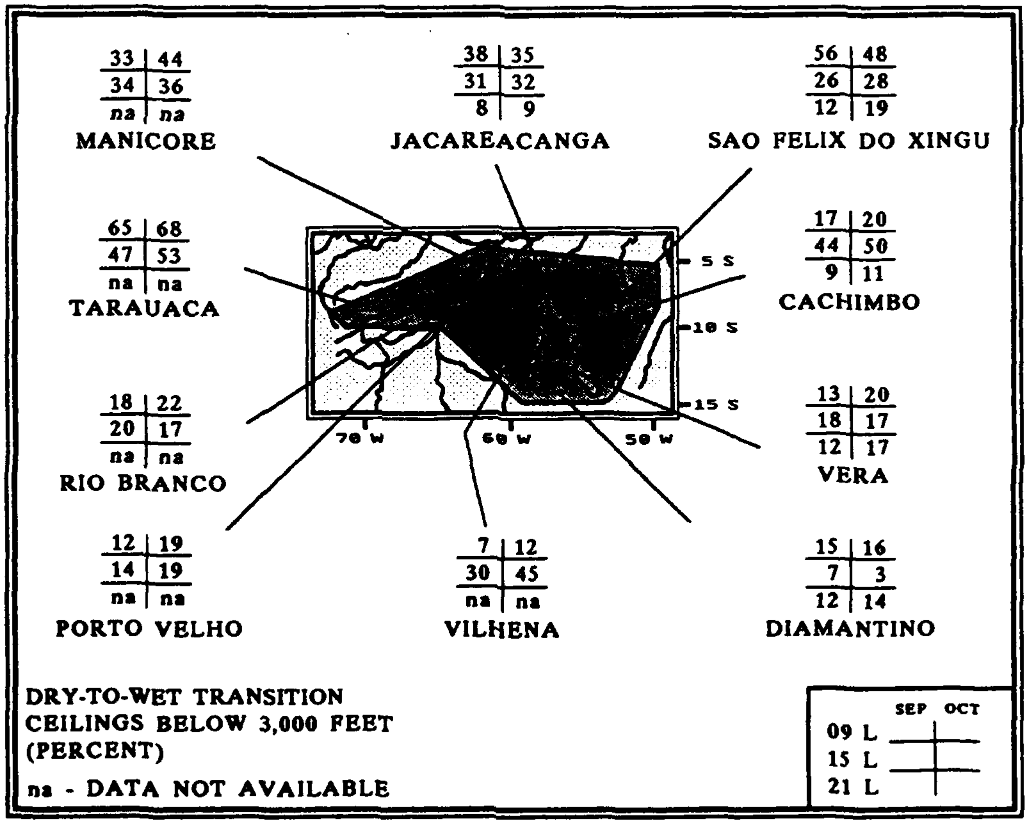


Figure 4-64. Dry-to-Wet Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Amazon Basin.

VISIBILITY. Fog continues to be the most important cause of lowered visibilities, especially in forested areas in the morning. Fog is thickest where significant rainfall has occurred. Fog may form immediately after heavy rainfall, but more often forms where it rained on the previous afternoon or evening. This "jungle stratus" most often originates in forest canopies. Occasionally, fog forms on the first morning following a cold front passage. Upslope flow on inclines in the southeast is occasionally strong enough to enhance fog formation there. Regardless of the cause, morning fog is normally less than 1,000 feet (305 meters) thick. It dissipates by noon.

Precipitation and haze also reduce visibility. Precipitation is most common in the extreme northwest, while haze obstructs visibilities most in the southeast. Much of the haze observed in the zone's eastern half during the period of record used for Figure 4-65 originated as smoke from cropland burning. Future visibility climatology will depend on where, when, and how much burning takes place. Haze produced by suspended plant particles occasionally reduces visibilities to below 3 miles.

Low visibilities occur more often than in the dry season. They are most common in the northwest and least common in the southeast. Morning frequencies of visibilities below 3 miles (Figure 4-65) range from 4% in October at Vilhena (after most haze has cleared out) to 44% at Labrea in September. Afternoons, visibilities below 3 miles range from below 3% in the east to 9% in the west. Evening averages range from less than 7% in the east to about 13% in the west.

Morning frequencies of visibilities below 1 mile range from as low as 3% at Cachimbo and Vilhena in October (after most haze has cleared out) to as high as 37% at Sao Felix Do Xingu (before the haze clears). Afternoon frequencies of visibilities below 1 mile are less than 4% everywhere; evenings, less than 7% everywhere.

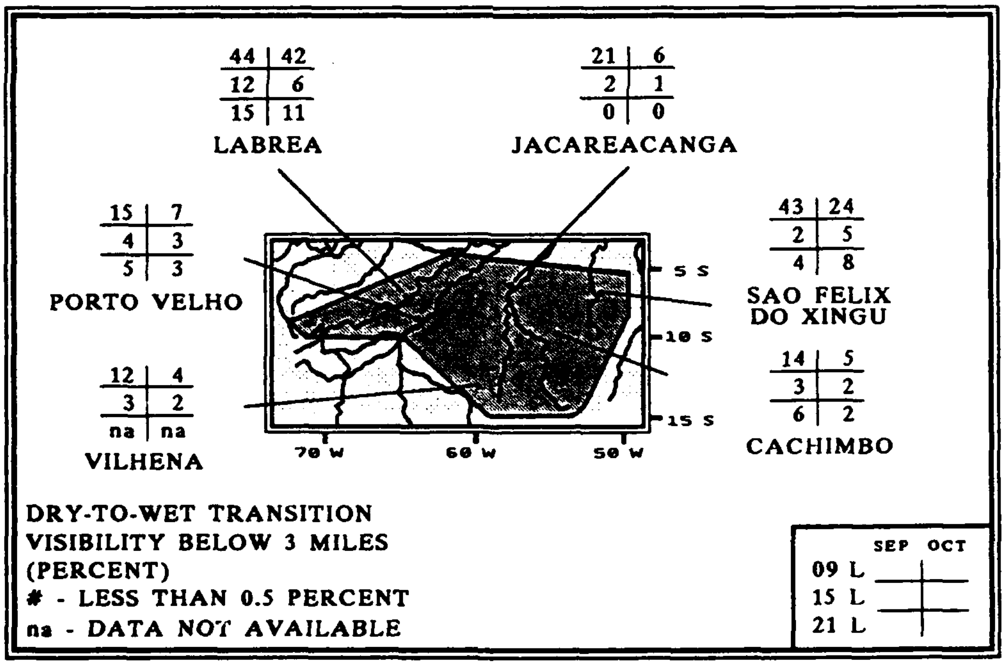


Figure 4-65. Dry-to-Wet Transition Percent Frequencies of Visibility Below 3 Miles, Central Amazon Basin.

WINDS. Synoptic flow is reduced by surface friction, resulting in low wind speeds everywhere. Forests are especially effective in damping winds; the lowest speeds are in wooded areas. Mean speeds for all hours (shown in Figure 4-66) range from as low as 1 knot in densely forested western areas to as high as 3 knots in the less wooded southeast. Winds are calm at night, but weak slope winds occasionally occur along inclines in the southeast. Daytime speeds range from calm to 5 knots; directions are most often easterly. Uneven heating caused by vegetation, cloud cover, or surface moisture cause localized variations. Strong winds are rare, especially in dense forests where winds are weakened or dissipated within the tree canopies. Thunderstorms are the primary cause of high winds; gusts around 45 knots are possible.

STATION	MEAN WIND SPEED SEP	OCT
CACHIMBO	3	3
DIAMANTINO	2	2
JACAREACANGA	2	2
LABREA	1	1
MANICORE	2	2
MISSAO DO CURURU	1	1
PORTO VELHO	2	2
RIO BRANCO	1	1
SAO FELIX DO XINGU	2	2
SENA MADUREIRA	1	1
TARAUACA	1	1
VERA	2	2
VILHENA	2	2

Figure 4-66. Mean Dry-to-Wet Transition Wind Speeds, Central Amazon Basin.

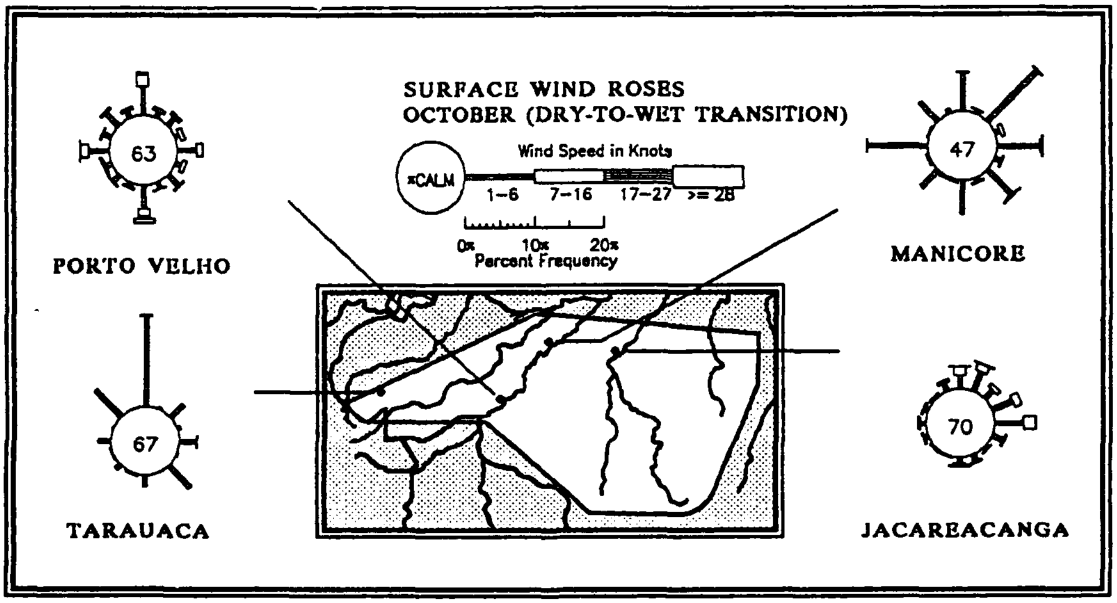


Figure 4-67. October Surface Wind Roses, Central Amazon Basin. No reliable data exists for other stations.

Mean winds immediately above the friction layer are east-northeasterly across the entire zone. Speeds range from 10 knots in the south to 15 knots in the north and east. On occasion, a low-level easterly wind maximum that can reach 30 knots occurs at 1,500 feet (455 meters) MSL along the eastern half of the zone's northern border. Upper-air wind directions are shown in Figures 4-37 through 4-40. Flow is little changed from the rest of the year. A distinct ridge is oriented east-west across the zone's midsection at 20,000 feet (6.1 km) MSL. Resulting wind directions range from easterly on the northern border to westerly along the southern border. The ridge becomes displaced farther north with increasing heights. Unlike the wet-to-dry transition and the dry season, diffluent flow out of the ridge is common above 20,000 feet (6.1 km) MSL. Mean upper-air speeds are less than 30 knots through 40,000 feet (12.2 km) MSL.

PRECIPITATION. Rainfall increases considerably as South Atlantic High and trade-wind stability rapidly weaken and disturbance frequencies increase. Frequent upper-air diffluent flow also contributes to decreasing stability. On satellite pictures, disturbances are clearly defined by enhanced, and often organized, shower and thunderstorm activity. Rainfall amounts are more dependent on disturbance frequencies than on their type or strength; amounts do not vary much from one disturbance to another. Low-level convergence associated with an occasional low-level wind maximum in the north increases rainfall there. Convective heating is a major contributor to thunderstorm development. Differential heating between areas of varied cloud cover, vegetation, and surface moisture cause localized convergence and subsequent cumuliform development.

Rain begins to fall over the central section where gently-sloping terrain faces northwest, implying that northwesterly upslope flow plays a role in precipitation development. This flow is most often seen ahead of cold fronts and shear lines. As the season progresses, the original rainfall area expands outward, especially northwestward, from its origins.

Most rain falls from thunderstorms and as showers, either as organized activity along disturbances or as sporadic afternoon convection. Rainfall from thunderstorms associated with middle cloudiness is also significant. Unlike the rest of the year, most precipitation occurs around noon. Mean rainfall amounts for September range from 3 to more than 4 inches (76 to 102 mm). Mean October amounts (Figure 4-68), as well as other rainfall statistics, are twice those for September. Maximum monthly amounts of over 22 inches (559 mm) occurred at Porto Velho in October. Higher amounts are likely to have occurred, especially toward the east. Maximum 24-hour amounts for the season have exceeded 3.5 inches at most locations in October. Mean precipitation days range from 5 along the eastern and southern fringes in September to more than 15 in central sections (see Figure 4-69) during October.

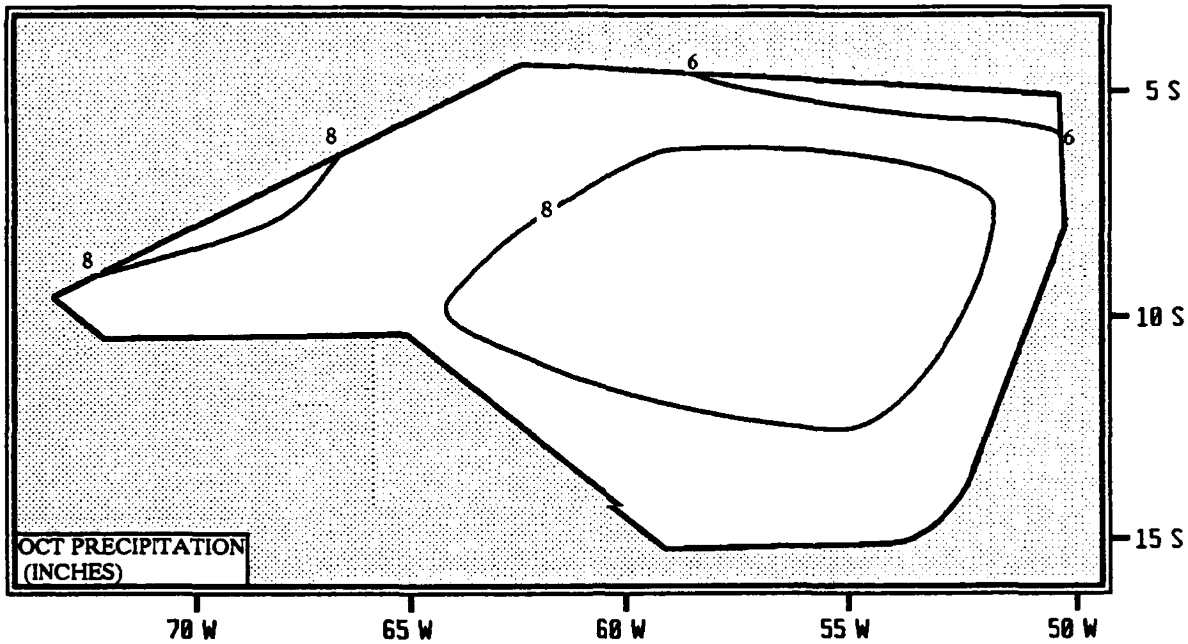


Figure 4-68. Mean October Precipitation, Central Amazon Basin.

na	na
4.0	3.8
na	na
na	na

HUMAITA

na	na
1.4	2.4
na	na
na	na

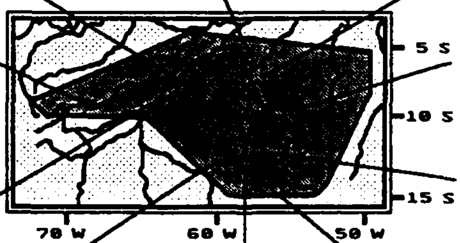
JACAREACANGA

na	na
2.8	3.9
15	19
13	14

MISSAO DO CURURU

na	na
3.6	2.5
8	11
7	8

SENA MADUREIRA



na	na
2.4	2.6
na	na
11	16

CACHIMBO

7.4	22.8
1.4	3.7
11	12
10	8

PORTO VELHO

na	na
na	na
na	na
3	6

VERA

na	na
na	na
na	na
4	7

VILHENA

na	na
na	na
4	7
7	8

UTIARITI

na	na
na	na
na	na
6	10

DIAMANTINO

DRY-TO-WET TRANSITION
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	SEP	OCT
MAXIMUM MONTHLY		
MAXIMUM 24-HOUR		
PRECIPITATION DAYS		
THUNDERSTORM DAYS		

Figure 4-69. Dry-to-Wet Transition Tabular Precipitation Data, Central Amazon Basin.

THUNDERSTORMS. Instability resulting from increased insolation, decreasing cloud cover, and the year's strongest mid-latitude disturbances result in the most thunderstorms of the year. Most occur in the central section, where mean thunderstorm days range from 10 to 15. They can occur as organized activity along disturbances or as very brief, unorganized, afternoon convection. They bring moderate to heavy rain. There is not enough data to verify tornado activity, but the possibility can't be ruled out. Hail melts before reaching the surface; mean freezing levels are above 15,000 feet (4,570 meters) MSL. Thunderstorms can produce gusts to 50 knots, but they are weakened or dissipated in dense forest canopies. Downbursts have been observed. Thunderstorm bases are often below 3,000 feet (915 meters) MSL and, on rare occasions, below 1,000 feet (305 meters) MSL. Most tops are below 50,000 feet (15.2 km) MSL. Middle and high clouds associated with thunderstorms can become widespread and produce as much precipitation as the thunderstorm cores (see "Tropical Squall Lines," Chapter 2).

TEMPERATURE. Day-to-day temperature and moisture variations are greatest during the transition, primarily due to the strength and frequency of cold fronts entering the zone. "Friagems" do not occur now as the sun, directly overhead in October, keeps surface temperatures up. Polar outbreaks are still responsible for record low temperatures which, as shown in Figure 4-70, range from 50 F (10° C) at Vilhena to 67° F (19° C) at Manicore and Jacareacanga. Extreme highs range from 96° F (35° C) at Tarauaca, where dense forests moderate daytime temperatures, to 104° F (40° C) at Porto Velho. Mean lows range from 70 to 75° F (21 to 24° C) at most locations. Mean highs are more variable, ranging from 82° F (28° C) at Tarauaca and Vilhena to 93° F (34° C) at Jacareacanga.

These values suggest that diurnal variations are controlled mostly by type and amount of vegetation; they do not correlate well with variations in elevation and relative humidity. Consequently, clearing of vegetation can have a significant effect on temperature characteristics.

Clear skies allow temperatures in tropical forest canopies to average a couple of degrees warmer than the underlying surface at night; they are about 10° F (6° C) warmer during afternoons. This is characteristic of radiation heating and cooling within forest canopies, rather than at ground level in clearings.

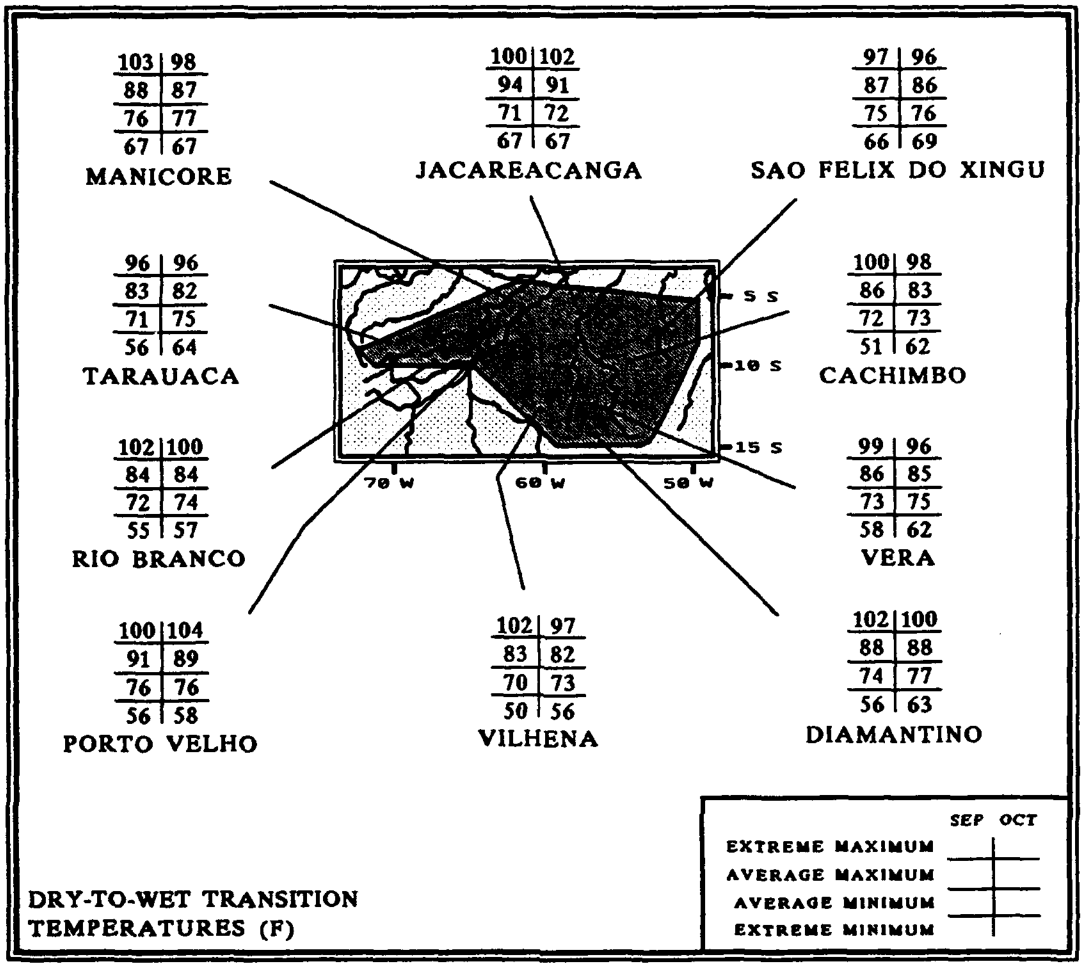
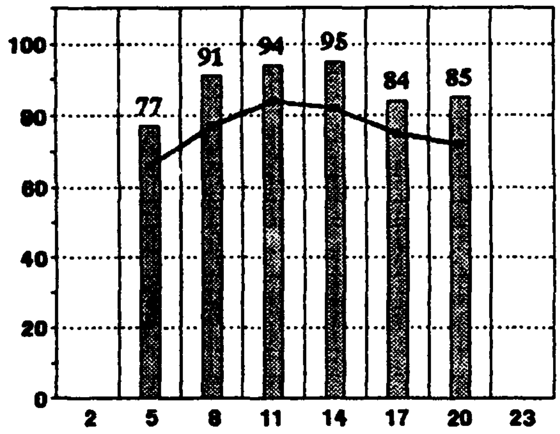
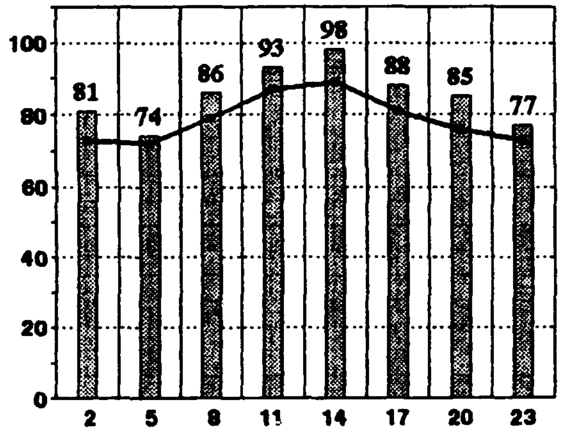


Figure 4-70. Dry-to-Wet Transition Tabular Temperature Data, Central Amazon Basin.

Relative humidities change little. Mean minimums range from as low as 45% in the extreme southeast to more than 70% in the extreme northwestern forests. Mean maximums range from as low as 85% in the southeast to more than 95% toward the west and north. Figure 4-71 shows two stations with wet-bulb globe temperature data (° F) at specific hours in October.



CACHIMBO



PORTO VELHO

Figure 4-71. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Central Amazon Basin. Mean WBGT is shown as a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms become more common. They produce moderate to severe turbulence and icing. Severe turbulence is possible through 30,000 feet (9.1 km) MSL. Icing is generally between 16,000 and 30,000 feet (4.6 and 9.1 km) MSL. Cells are difficult to navigate because they may be embedded in other clouds or form solid lines during disturbed periods. They can also be hidden in haze during stable periods. This haze, especially early in the season, is primarily caused by cropland burning, mostly in the zone's eastern half. Haze occurs from the surface through 20,000 feet (6.1 km) MSL, but can become dense between 7,000 and 16,000 feet (2,130 and 4,880 meters) MSL. Density depends more on stability than on the amount of burning. Exceptionally stable conditions can result in inflight visibilities below 1 mile.

Speed shear occasionally occurs along the zone's northern fringes where an east-to-west low-level wind maximum is found. It can reach 30 knots immediately above a radiation inversion between 990 and 2,300 feet (300 and 700 meters) MSL. Speeds above and below the "jet" rapidly decrease, producing shear and light mechanical turbulence.

GROUND HAZARDS. Heavy rains begin, but water levels are lowest of the year. Travel is still difficult when heavy showers cause temporary flooding.

4.3 EASTERN AMAZON BASIN

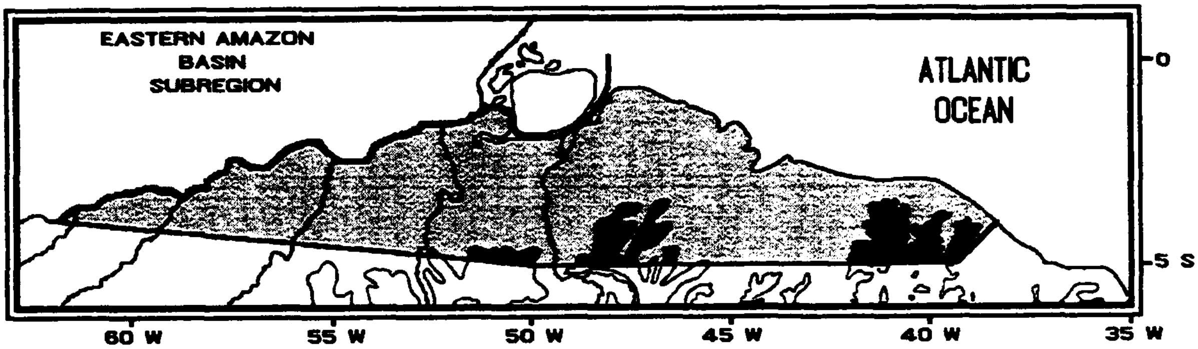
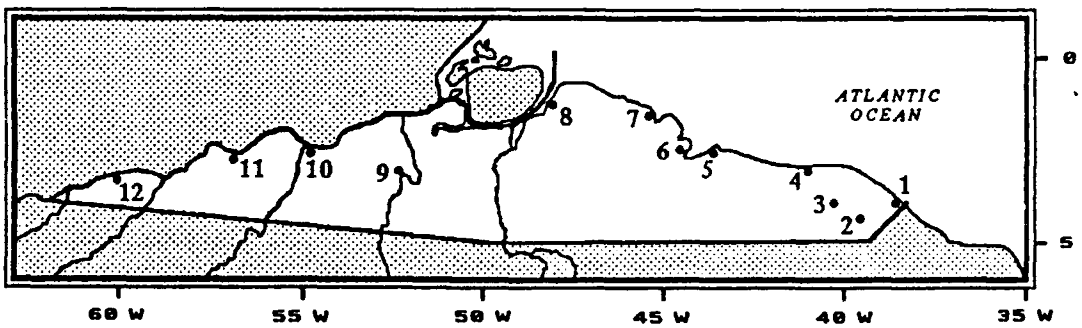


Figure 4-72. Eastern Amazon Basin. Note contours at 200 (open) and 500 meters (darkened) (655 and 1,640 feet).



1.	FORTALEZA	3°47'S	38°32'W	7.	TURI-ASSU	1°38'S	45°20'W
2.	GUARAMIRANGA	4°15'S	39°01'W	8.	BELEM	1°23'S	48°29'W
3.	SOBRAL	3°42'S	40°21'W	9.	ALTAMIRA	3°12'S	52°12'W
4.	PARNAIBA	2°55'S	41°45'W	10.	SANTAREM	2°25'S	54°42'W
5.	SAO LUIZ	2°31'S	44°15'W	11.	PARINTINS	2°38'S	56°44'W
6.	SAO BENTO	2°41'S	44°51'W	12.	MANAUS	3°02'S	60°03'W

Figure 4-73. Climatic Station Network, Eastern Amazon Basin.

EASTERN AMAZON BASIN GEOGRAPHY

The Amazon River basin is the world's largest. It drains 40% of South America and can be described as an immense canyon opening into the Atlantic with a marshy delta over 150 miles wide. The basin contains 39% of the world's tropical rain forest and covers 40% of Brazil's land mass. Ninety percent of the basin is covered by forest, mostly evergreen. This section describes the eastern portion of the basin south of the Amazon River.

BOUNDARIES. As shown in Figures 4-72, the zone is bounded:

On the north: by the Amazon River from 61° 30' W eastward to the Para River, then the Para River to Brazil's northeast coast.

On the east: by the Atlantic Ocean from the Para River to 4° S then southwestward to 5° S, 39° W.

On the south: by a line from 39° W along the 5th parallel to 50° W then west-northwest to the Amazon River at 62° W.

No western boundary is given; the north and south boundaries meet at their westernmost points.

TERRAIN. Most of the terrain south of the Amazon is lowland river plain, with coastal plain along the Atlantic. Elevations are below 655 feet (200 meters), except in the south between river valleys where they exceed 985 feet (300 meters). Serra da Ibrapas extends from northeastern Brazil northward along 41° W to within 45 miles of the coast at elevations above 1,640 feet (500 meters). Its northern slope quickly drops below 330 feet (100 meters) 40 miles from the coast. River valley and coastal elevations below 330 feet (100 meters) cover 60% of the zone and extend deeply into the plateaus to the south of the Amazon.

RIVERS. Over 20 major rivers flow directly or indirectly into the Amazon from the south side. Altogether, it has more than 1,000 tributaries that swell the water mass and make the Amazon the largest volume of water carried in the world. From source to mouth, the Amazon is over 4,000 miles long with seven tributaries of more than 1,000 miles.

The four largest tributaries in the Eastern Amazon Basin are spaced an average of 250 miles apart along the Amazon River's southern bank. From west to east, they are the Madeira, Tapajos, Xingu, and Tocantins Rivers.

The Madeira begins in southern Peru as the Madre de Dios before crossing northern Bolivia and joining the Beni and Mamore Rivers. It becomes the Madeira at its junction with the Mamore along the Bolivia-Brazil border. The Madeira follows the border north to Abuna, Brazil, before turning northeast to parallel the Purus River and emptying into the Amazon in the Eastern Amazon Basin. From source to mouth, the Madeira River is almost 2,100 miles long.

The Tapajos begins as the Teles Pires in the northern serra of the Mato Grosso Plateau. The Teles Pires flows north for more than 600 miles, joining the Juruena River at about 7° S, 58° W, where it becomes the Tapajos and flows northeast to meet the Amazon at about 54° W in the Eastern Amazon Basin. Its total length is over 1,100 miles.

The Xingu starts in the transition zone between savanna and tropical rain forest at 13° S, 52° W and runs north for just over 1,000 miles to enter the Amazon 200 miles from the Atlantic.

The Tocantins originates 150 miles southwest of Brasilia and flows north for over 900 miles before entering the Central Amazon Basin. It then curves westward to meet the Araguaia River. It enters the Eastern Amazon Basin at 4° 40° S, 49° W as it turns north to join the Para River before widening northeastward into the Atlantic. The Tocantins River is over 1,300 miles long from its source to the Para River.

The Grajau, Mearim, and Itapicuru start in the Brazilian Plateau's northern highlands and flow northward through the central portion of the Eastern Amazon Basin. They converge to enter the Atlantic on either side of the island containing the city of Sao Luis.

The Jaguaribe is at the zone's eastern end. It originates 75 miles northwest of Iguatu and flows for 300 miles east, then northeast, to the coast about 70 miles southeast of Fortaleza.

VEGETATION. The northeast coast features sandy beaches with occasional clusters of mangroves and marshlands near the ends of major river deltas. East of 43° W, the coast quickly gives way to savanna, except for the river valleys, which mainly have palm trees. Some small areas of barren, rocky terrain can be found in the east. The area west of 43° W is more than 95% tropical rain forest, which can be classified by "type" and "level," as shown below.

Forest Types.

On solid ground: Above the level that floods even in the wettest years.

Varzea: Lower-lying areas that flood temporarily but become solid during the dry season.

Igapo: Lowest-lying areas that remain permanently flooded in all seasons.

Forest Levels.

1st Level. The topmost tier, or "emergent layer," consists of a few trees reaching heights of 130 feet (40 meters) or more.

2nd Level. The ceiling level, or "canopy" tier, consists of forest giants exceeding 65 feet (20 meters) in height. Evapotranspiration from the top of the rain forest is a major source of water vapor into the atmosphere. The contribution to the water vapor content of weather systems is as great as many large water bodies. These high moisture contents will not be present once large forest areas are cleared.

3rd Level. This level, the "middle" tier, consists of a dense growth of shorter trees between 16 and 65 feet (5 and 20 meters) in height. Some trees may be covered with epiphytic plants, such as orchids, ferns, succulents, etc. Epiphytes are plants that use other plants for mechanical support, but not for food.

4th Level. The "shrub" tier consists of scattered bushes and herbs not exceeding 16 feet (5 meters) in height. This level varies depending on the amount of sunlight reaching it. It can be thick where taller levels thin out, and sparse where taller levels are exceptionally dense.

5th Level. The "ground" level is a mosaic of small shade-tolerant herbs, ferns, and tree seedlings. This level is normally bare when taller levels are exceptionally dense. Sunlight here at noon averages only 1% of that found above the rain forest.

EASTERN AMAZON BASIN CLIMATIC PECULIARITIES

The seasonal presence (or absence) of the Near Equatorial Trough (NET) and the ever-present land/sea breeze are the primary factors that distinguish the Eastern Amazon Basin from the other zones. The abundant moisture in this meteorologically complex area is controlled by a variety of mesoscale and synoptic features. Maritime air is found at least 160 NM (296 km) inland. Amazon rain forests, through evapotranspiration, provide as much moisture as the Atlantic Ocean.

Land/sea breeze circulations affect the entire zone (Figure 4-4). Like the NET, they interact with other disturbances. There is a direct correlation between land/sea breeze circulations and high frequencies of low ceilings and precipitation, including thunderstorms. These correlations are shown in Figures 4-75a through c, which give areas of annual maximum low ceilings and precipitation frequencies.

Some interseasonal variations occur, depending on trade-wind directions and strengths. *Directions* determine when and where land/sea breezes occur, while *strengths* determine seaward and landward penetrations. Directional effects are most pronounced along the coast where the results depend on whether flow has an onshore or offshore component. Coast with onshore flow get most low cloudiness and precipitation with night and morning land breezes; sections with offshore flow get most low cloudiness and precipitation from the afternoon and evening sea breezes.

Strong trades enhance the sea breeze. In most cases, sea breezes weaken at night before reaching the zone's western end. However, on the following day, uneven heating between remaining cloudiness and adjacent clear air can cause convective development along cloud mass fringes. Such convection often propagates westward through the rest of the zone.

Deforestation is on a relatively small scale in this zone, and mostly concentrated along the southern border. Evidence shows that the burning has a significant effect on ceilings and visibilities. Although still subject to speculation, deforestation may cause precipitation amounts to decrease, river water levels to rise (as less *moisture* is absorbed by vegetation). Temperature may rise, with more diurnal variation.

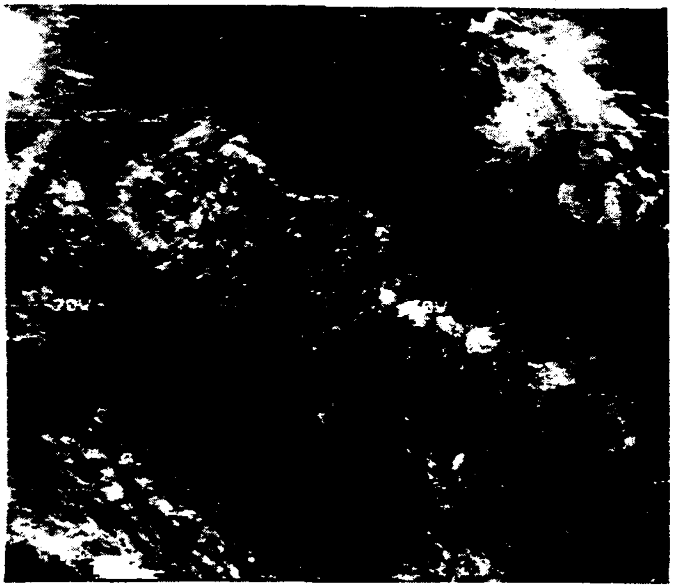


Figure 4-74. Sea Breeze Activity Near the Coast, 1700Z 15 September 1979.

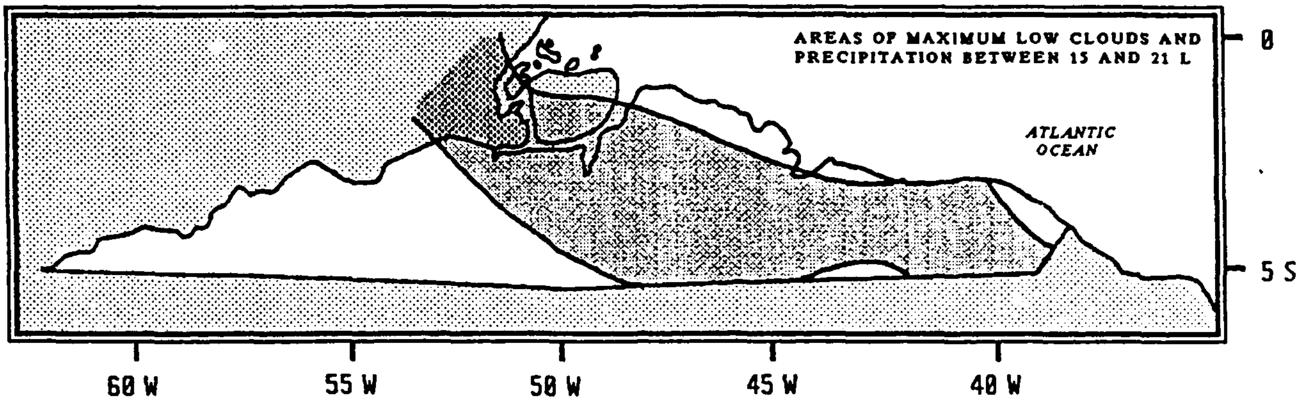


Figure 4-75a. Annual Area of Maximum Low Ceiling and Precipitation Frequencies, 1500-2100L. Note that the maximum area correlates with the mean sea breeze front position for this period.

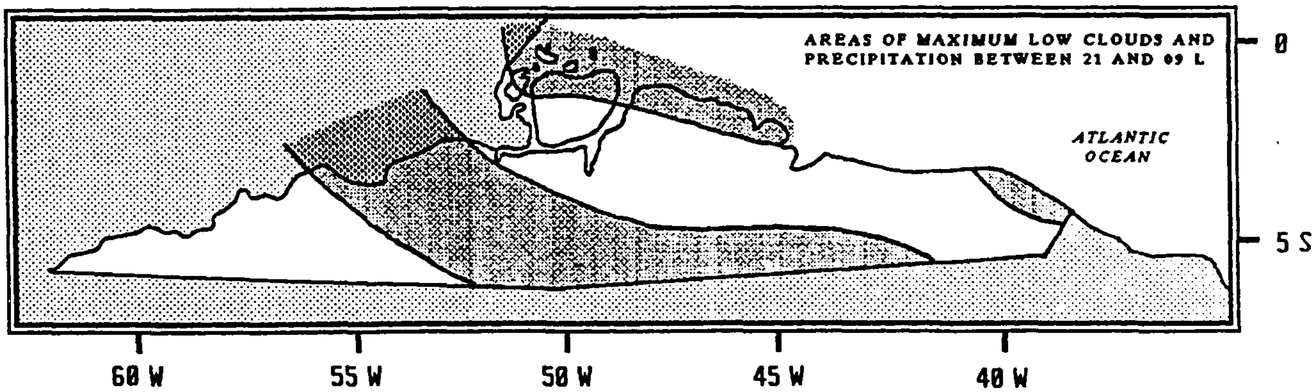


Figure 4-75b. Annual Area of Maximum Low Ceiling and Precipitation Frequencies, 2100-0900L. The maximum area in the previous figure has shifted farther west, correlating with those sea breezes continuing to penetrate inland. The maximum areas along the coast correlate with convergence between a weak land-breeze circulation and trade-wind flow.

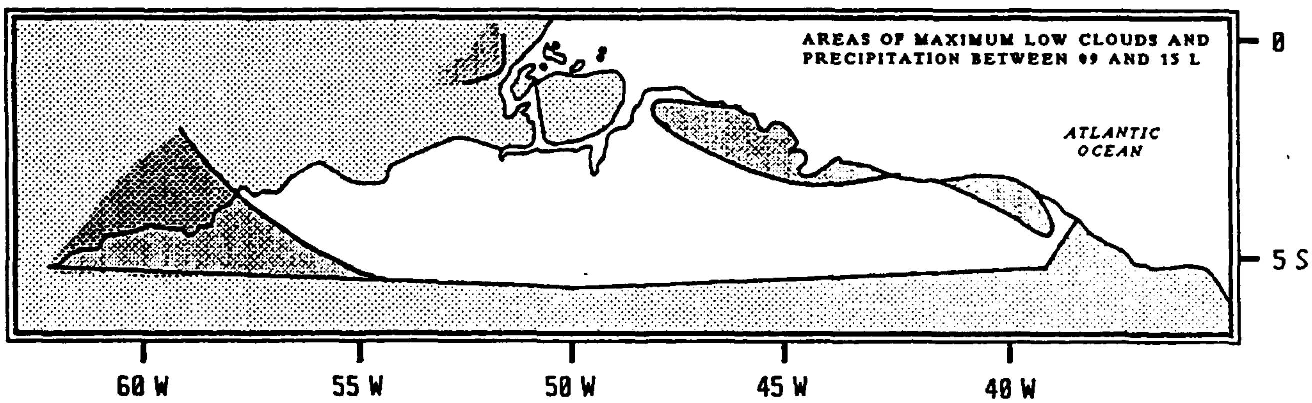


Figure 4-75c. Annual Area of Maximum Low Ceiling and Precipitation Frequencies, 0900-1500L. The inland area has continued to shift westward. The areas shown along the coast result from sea breezes developing after land breezes dissipate. This new sea-breeze activity intensifies, becoming the maximum area shown in Figure 4-74a.

Most large rivers have localized climates with less cloudiness, precipitation, and fog than areas. However, near the Amazon River between 52 and 56° W, topography enhances nighttime cloudiness and precipitation. Cloudiness is occasionally enhanced by convergence associated with a low-level jet stream that sets up at night when a radiational inversion reduces surface drag. The jet's seasonal characteristics are explained in each season's "Flight Hazards."

Studies done near Manaus suggest that diurnal precipitation cycles (which, as explained above, are mostly controlled by sea breezes) are affected by subsidence produced in the wake of thunderstorm activity. Subsidence resulting from widespead precipitation falling from thunderstorm anvils temporarily stablizes the atmosphere. This can enhance or disrupt the normal diurnal cycle; disruptions can last for several days. This phenomenon does not normally occur in the dry season, when stable conditions inhibit all but afternoon thunderstorm development.

GENERAL WEATHER. Most wet-season activity occurs where the NET interacts with some other disturbance, such as land/sea breeze circulations, tropical squall lines, low-latitude upper-tropospheric cyclones, trade-wind surges, and rare easterly waves. Although mid-latitude features rarely enter the zone, they occasionally get near enough to enhance activity along the NET. In the east, conditions vary from year to year, depending on whether the NET's Atlantic section stays to the north or drops south. Early in the season, upper-level flow diverges in the west and converges in the east. There is upper-level divergence across the zone by season's end.

SKY COVER. In Figure 4-76, mean daily cloud cover ranges from 60% in the east to 80% in the central and western portions. Cumulus and cumulonimbus are the predominant cloud types along disturbances. They can also occur as afternoon convection inland. Stratocumulus is common at night and in the morning along disturbances and the coast. Nimbostratus occasionally occurs with surges of the NET early in the season.

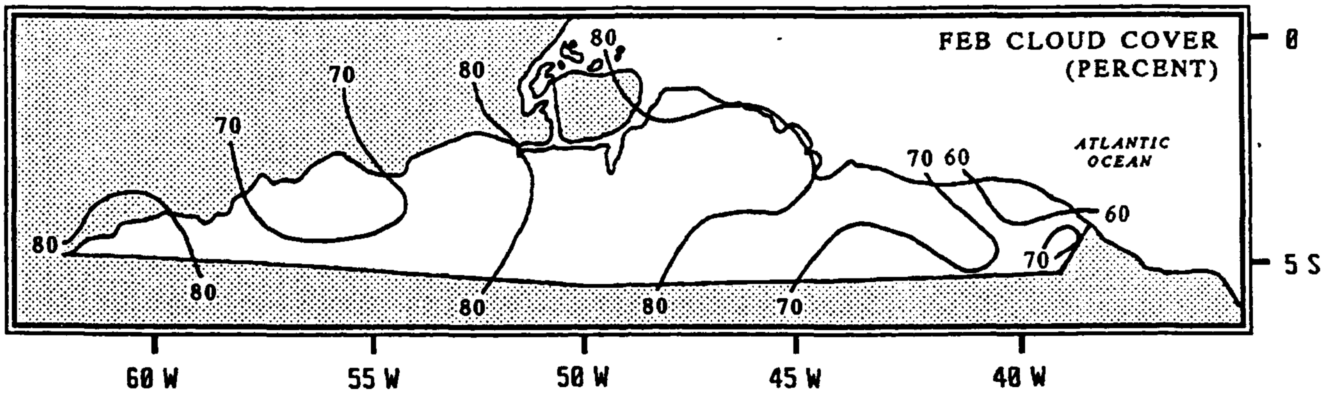


Figure 4-76. Mean February Cloud Cover, Eastern Amazon Basin.

Throughout the zone, low cloudiness (as represented by low-ceiling frequencies shown in Figure 4-77) correlates well with precipitation associated with land/sea breeze circulations. Most low-cloud bases are between 1,000 and 2,000 feet (305 and 610 meters) in the morning and between 2,000 and 3,000 feet (610 and 915 meters) MSL in the afternoon; terrain above these heights can be obscured. Showers and thunderstorms often produce broken to overcast cloudiness below 1,000 feet (305 meters) MSL. Tops of clouds vary considerably during unsettled periods, but most are below 12,000 feet (3,660 meters) MSL during settled periods. The higher terrain in the east produces cloud tops 2,000 to 7,000 feet (610 to 2,130 meters) above surrounding tops. Morning "jungle stratus" often produces ceilings at forest canopy elevations in the morning. This stratus originates in forested areas where moderate to heavy rainfall has occurred on the previous afternoon or evening. It is less than 1,000 feet (305 meters) thick and dissipates shortly after sunrise.

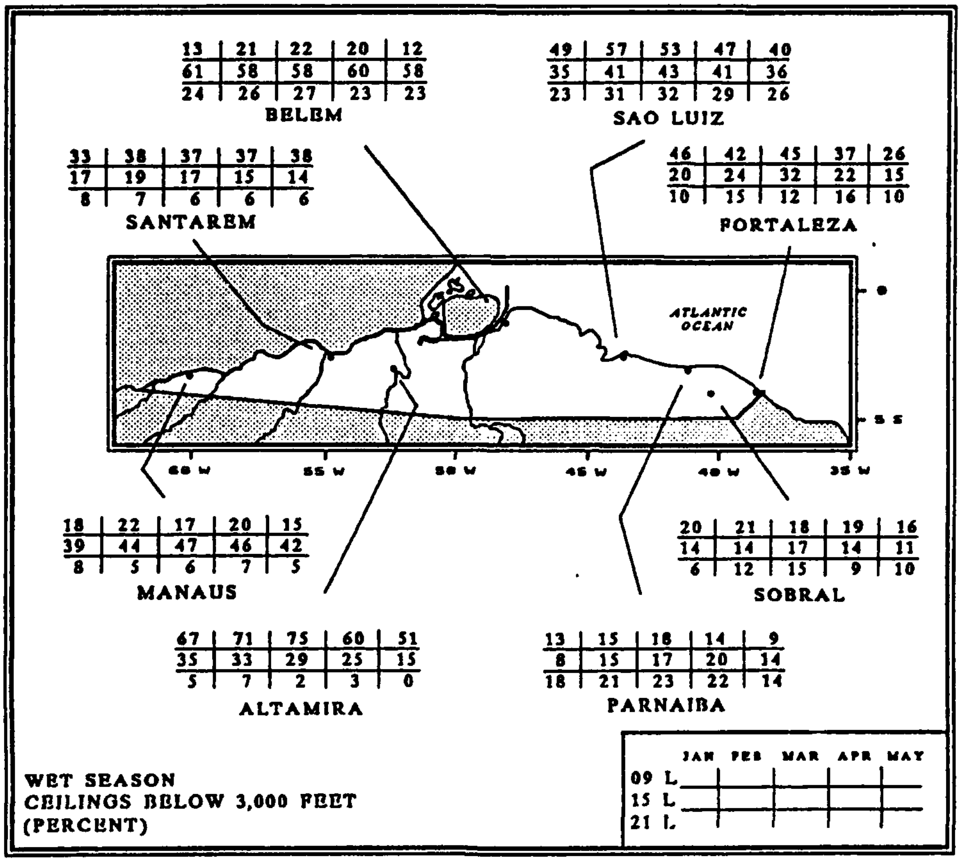


Figure 4-77. Percent Frequencies of Ceilings Below 3,000 feet (915 meters), Eastern Amazon Basin.

VISIBILITY. Visibilities are generally good, but can go below a mile in precipitation. Fog is the next largest cause of low visibilities, lowering them routinely below a mile in western and central forests. Haze may occasionally reduce visibilities below 7 miles during the day.

Figure 4-78 shows that percent frequencies of visibilities below 3 miles range from less than 1% during afternoons and evenings in the east to more than 20% well inland. Western frequencies, however, are not representative of densely forested areas because reporting stations are along major rivers where fog is not as common. Fog occurs most often near sunrise within forested areas that have received significant precipitation on the previous afternoon or evening. Such fog originates most often within forest canopies as "jungle stratus," which usually dissipates shortly after sunrise. Upslope flow enhances fog formation on inclines.

Sea salt causes most haze near the Atlantic coast. Inland, suspended plant particles (pollen, spores, etc.) become the main cause.

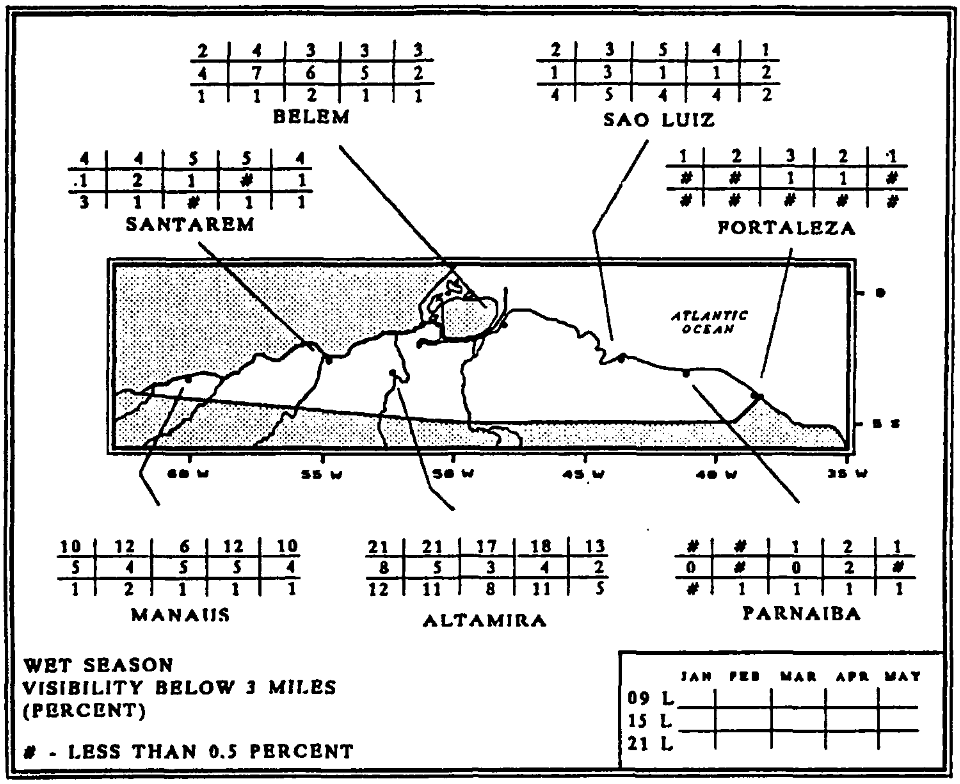


Figure 4-78. Percent Frequencies of Visibility Below 3 Miles, Eastern Amazon Basin.

WINDS. Flow is controlled by the trade winds and land/sea breezes. As shown in Figure 4-79, mean speeds across the zone range from 7 knots in the east to 3 knots in the west. Mean directions inland range from east-northeasterly in the west to east-southeasterly in the east. Sea breezes cause northeasterly winds to prevail along much of the Atlantic coast. Affected coastal locations include Belem, Turi-Assu, Sao Luiz, Sao Bento, and Parnaiba. Sea breezes, supported by trade-wind flow, cause the zone's highest daily wind speeds at coastal locations. Afternoon speeds at coastal stations range from 10 to 15 knots (with gusts to 20 knots), while afternoon speeds at western inland stations only average around 5 knots.

	MEAN WIND SPEED				
STATION	JAN	FEB	MAR	APR	MAY
FORTALEZA	7	6	5	5	6
SOBRAL	7	6	5	4	4
PARNAIBA	7	6	5	5	5
SAO LUIZ	5	4	4	3	3
BELEM	6	6	6	5	6
ALTAMIRA	3	3	3	2	3
SANTAREM	7	6	6	6	5
PARINTINS	3	4	3	3	3
MANAUS	3	3	4	3	3

Figure 4-79. Mean Wet-Season Wind Speeds, Eastern Amazon Basin.

Strong winds are rare, especially in dense forests where winds are weakened or dissipated at treetop level. Thunderstorms are the primary cause of high winds--gusts over 40 knots are possible. Weak land breezes and calm winds are prevalent at most coastal locations between 2100 and 0500L. At most inland stations, calm winds begin a few hours earlier and end a few hours later. Manaus is an example of a location well inland where calm winds prevail at least 50% of the time during all hours. Calm conditions can be expected to prevail in most forested areas. Slope winds can occur at night along inclines. Stations at elevations near or above the mean height of nighttime radiation inversions seldom experience calms; the best example is Guaramiranga, at 2,500 feet/760 meters MSL.

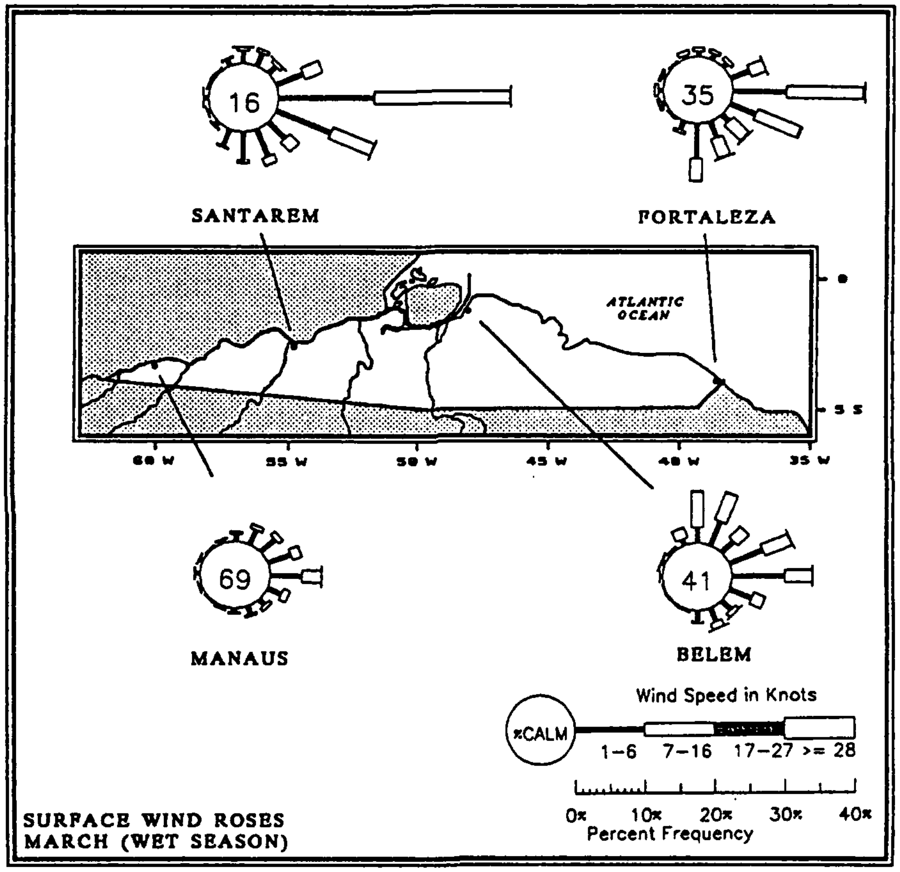


Figure 4-80. March Surface Wind Roses, Eastern Amazon Basin.

Mean upper-air speeds are less than 20 knots at all levels. Directions are shown in Figures 4-81 through 4-84. Easterlies prevail through 20,000 feet (6.1 km) MSL early in the season and through 35,000 feet (10.7 km) MSL late. Above 35,000 feet, directions range from westerly in the east to southerly in the west.

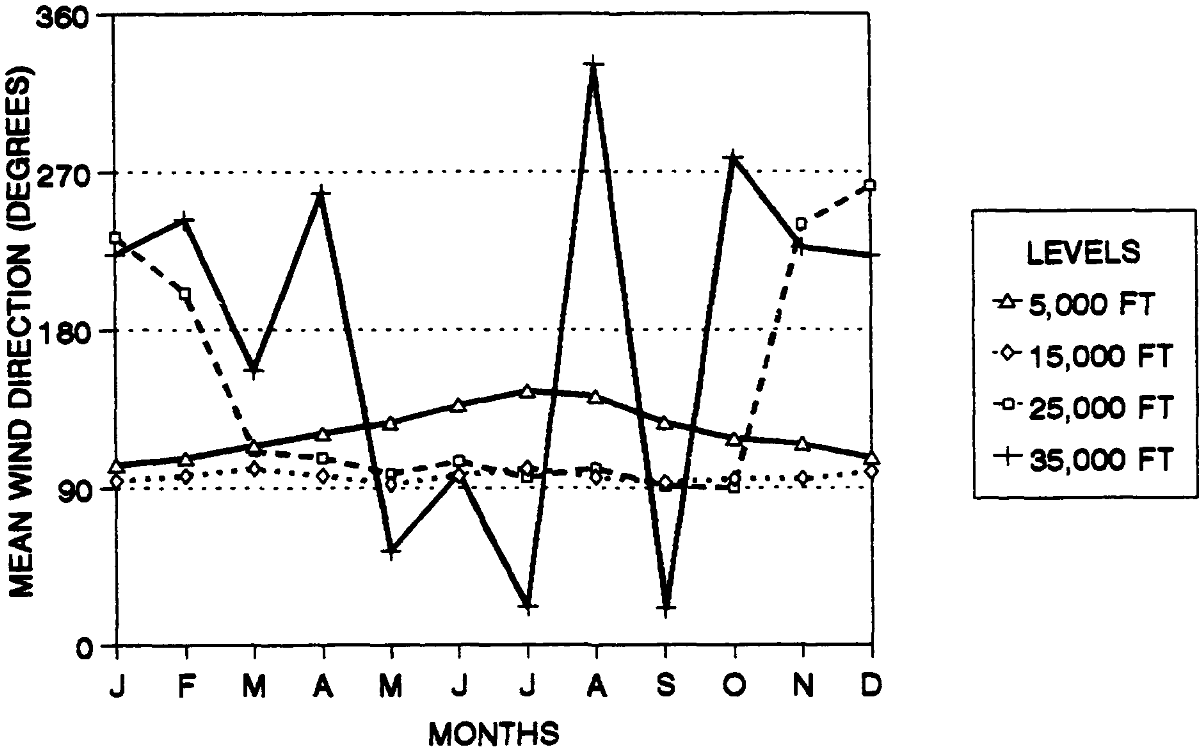


Figure 4-81. Mean Annual Wind Directions for Various Levels at Fortaleza, Eastern Amazon Basin.

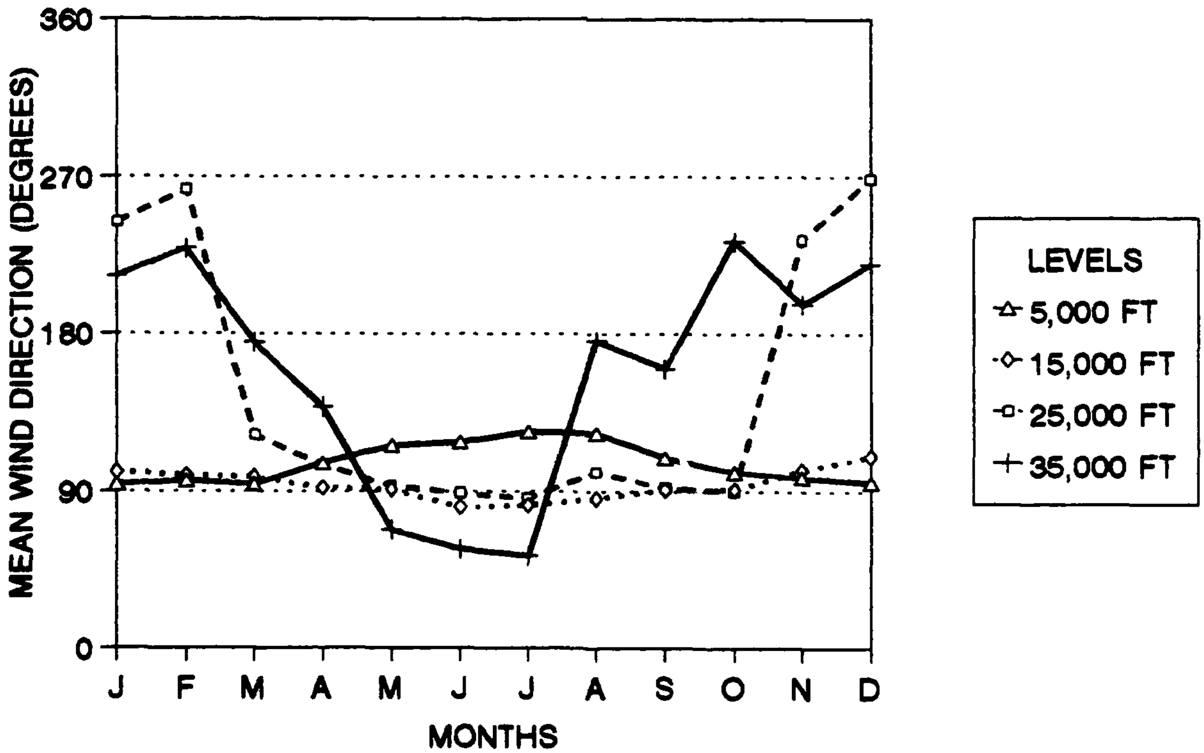


Figure 4-82. Mean Annual Wind Directions for Various Levels at Sao Luiz, Eastern Amazon Basin.

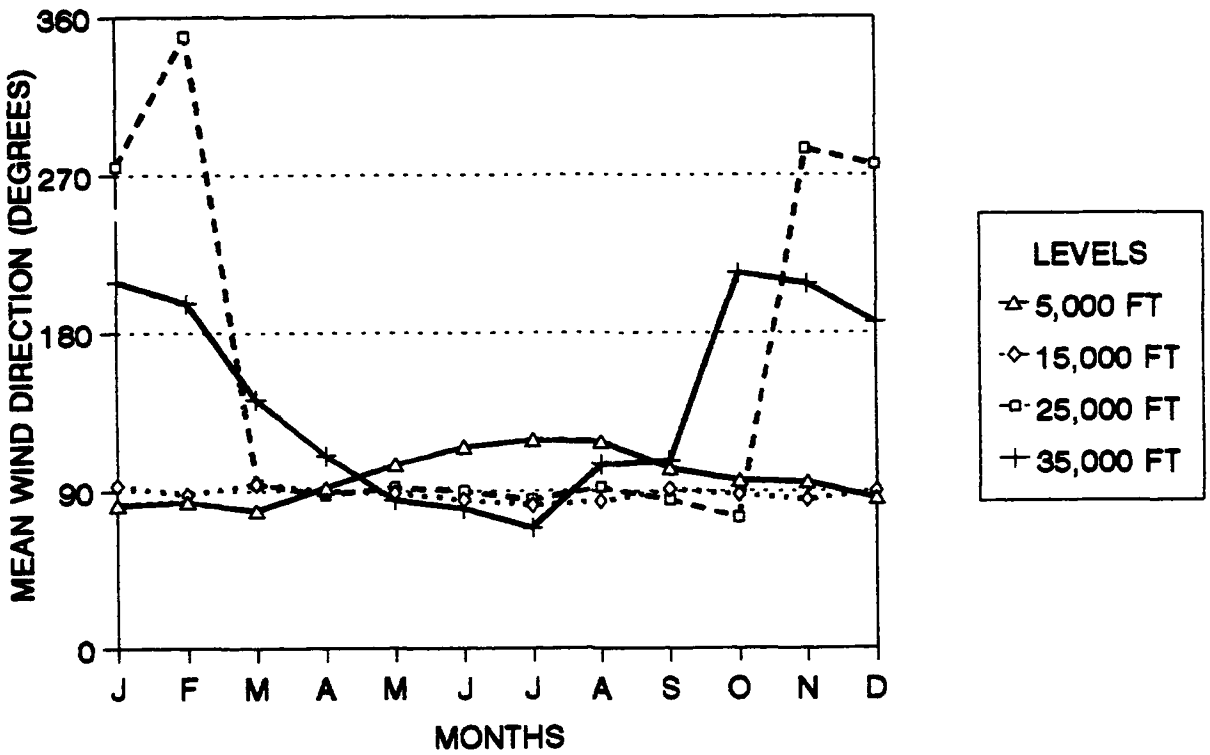


Figure 4-83. Mean Annual Wind Directions for Various Levels at Belem, Eastern Amazon Basin.

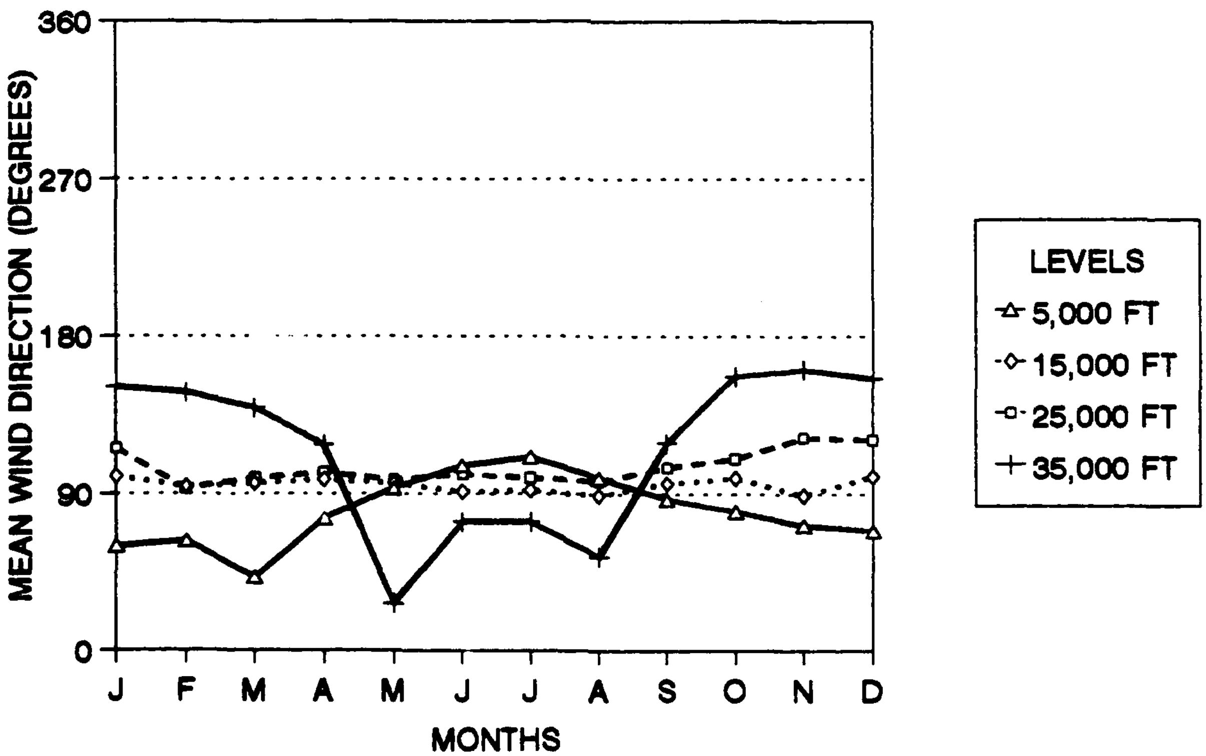


Figure 4-84. Mean Annual Wind Directions for Various Levels at Manaus, Eastern Amazon Basin.

PRECIPITATION. Most rain falls as showers, but the variety and nature of disturbances cause complex precipitation distributions. As shown in Figure 4-85, the mean number of days a month with precipitation varies from east to west; the number ranges from 7 to 19 at Fortaleza in the east, from 25 to 28 at Belem, and from 19 to 21 at Manaus in the far west. Guaramiranga, near 2,500 feet (760 meters) MSL, is an example of stations that see more precipitation days than their neighbors because of terrain and, to some extent, sea breezes.

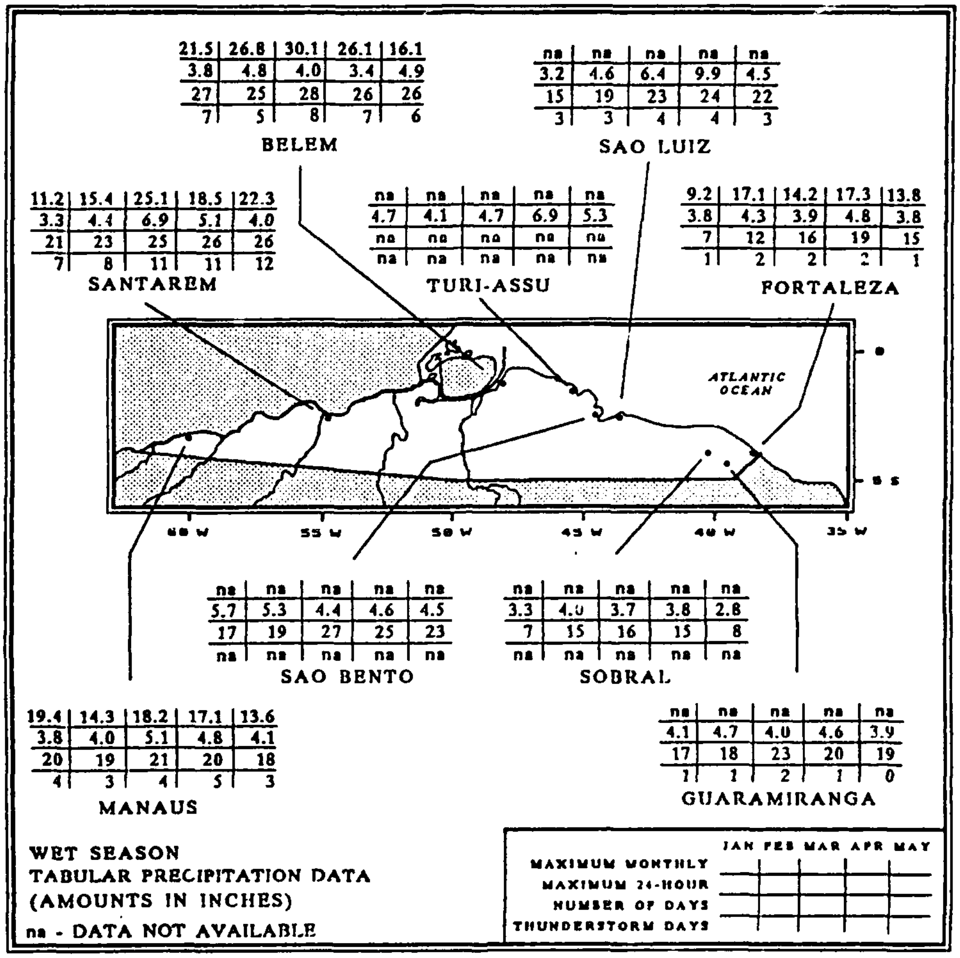


Figure 4-85. Wet-Season Tabular Precipitation Data, Eastern Amazon Basin.

Figure 4-85 shows maximum monthly amounts as high as 30 inches (762 mm) at Belem and maximum 24-hour amounts nearing 10 inches (254 mm) at Sao Luiz. Mean monthly amounts range from 2-8 inches (51-203 mm) east to 12-18 inches (305-457 mm) central to 8-11 inches (203-279 mm) west. Figures 4-86 through 4-88, gives average amounts for 3 wet-season months.

The maximum band shown paralleling the coast results from afternoon showers and thunderstorms associated with sea-breeze fronts. A decrease appears farther inland where most sea-breeze precipitation weakens at night. See "General Weather" for a detailed explanation of correlations between land/sea breezes and diurnal precipitation frequencies.

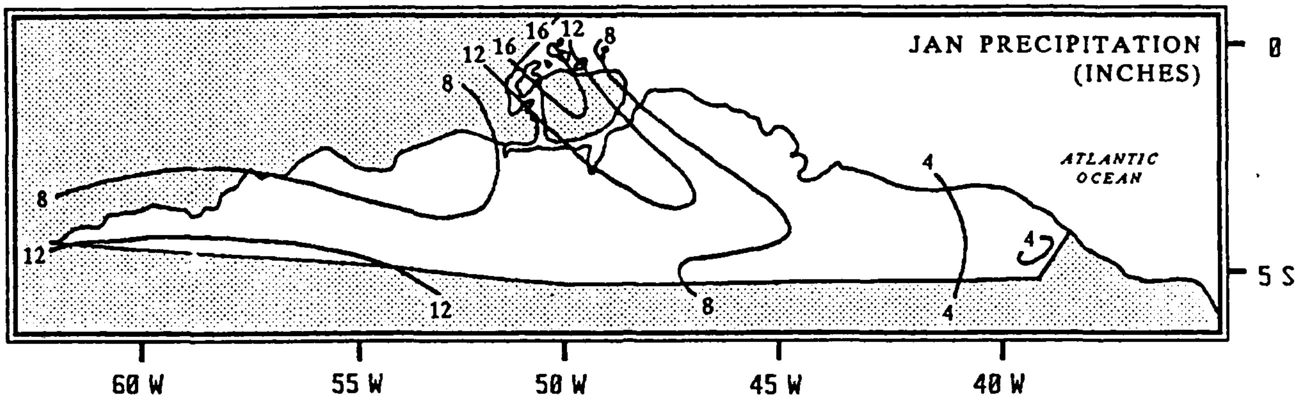


Figure 4-86. Average Precipitation for January, Eastern Amazon Basin.

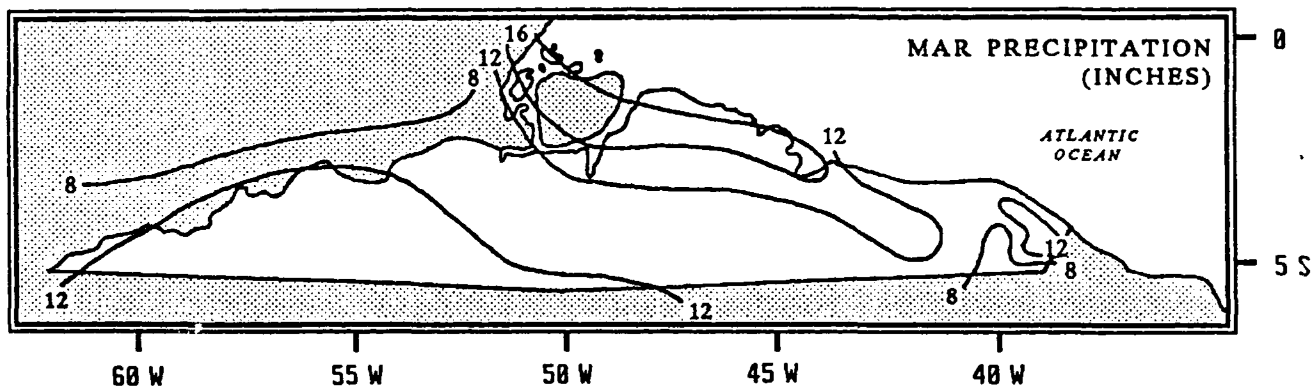


Figure 4-87. Average Precipitation for March, Eastern Amazon Basin. Note the increase from January across the zone, especially in the east.

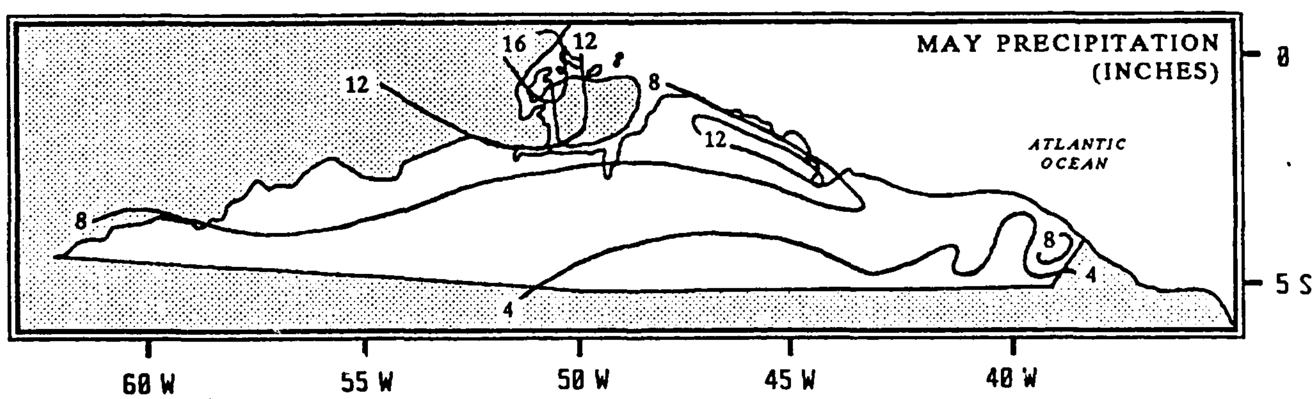


Figure 4-88. Average Precipitation for May, Eastern Amazon Basin. Note the decrease from March, especially along most of the Eastern Amazon Basin's southern boundary.

THUNDERSTORMS. Thunderstorms are common as organized activity along disturbances and from very brief, unorganized afternoon convection. Higher thunderstorm frequencies appear to correlate with land/sea breeze circulations. Near the Amazon River, the mean number of days a month with thunderstorms ranges from 4 at Manaus, to 10 near Santarem, to about 6 at Belem. Although the Santarem area has more thunderstorm days, the stronger and longer-lasting activity occurs near Manaus and Belem. Thunderstorms occur least often southeast of a line extending from 5° S, 50° W to the coast at 42° W, where the mean number of days a month for most locations is less than 4.

Thunderstorm bases are often below 1,000 feet (305 meters) MSL and tops are usually between 40,000 and 50,000 feet (12.2 and 15.2 km) MSL. Heavy downpours are common. Tornados are rare to nonexistent, and hail does not occur. Gusts occasionally exceed 40 knots, but they are often completely dissipated in the dense forest canopies in the zone's central and western sections. Thunderstorm-associated mid- and high-level clouds often become widespread and can produce as much precipitation as the thunderstorm cores. These clouds, unlike those in the mid-latitudes, often appear to trail *behind* thunderstorm cells because the cells propagate faster than mid- and upper-level flow. Such apparent cell movement results from westerly to southwesterly propagation, either along some low-level disturbance or toward the strongest portion of low-level thunderstorm outflow. Propagation in other directions is normally caused by lowland areas that channel thunderstorm outflow.

TEMPERATURE. Temperatures are moderated diurnally and seasonally by moisture-laden tropical forests and oceanic air. This can be seen in Figure 4-89, where most stations have average lows near 75° F (24° C) and highs between 85 and 90° F (29 and 32° C). The exceptions are Guaramiranga and Sobral. Guaramiranga, at a higher elevation, has the zone's lowest recorded temperature at 57° F (14° C). Sobral, with the zone's highest recorded temperature (103° F/39° C), is inland and less heavily wooded.

Radiation heating and cooling occurs in forest canopies in the zone's central and western sections, but takes place at the ground in the east. During clear skies, temperatures in canopies average a few degrees warmer than the underlying surface at night and about 10° F (6° C) warmer in the afternoon.

WET SEASON TEMPERATURES (F)

	JAN	FEB	MAR	APR	MAY
EXTREME MAX					
AVERAGE MAX					
AVERAGE MIN					
EXTREME MIN					

BELEM

94	93	94	93	93
87	86	86	86	88
74	74	74	74	75
65	65	68	70	69

SAO LUIZ

95	94	92	94	95
87	86	86	87	88
75	74	74	74	74
68	68	69	68	68

SANTAREM

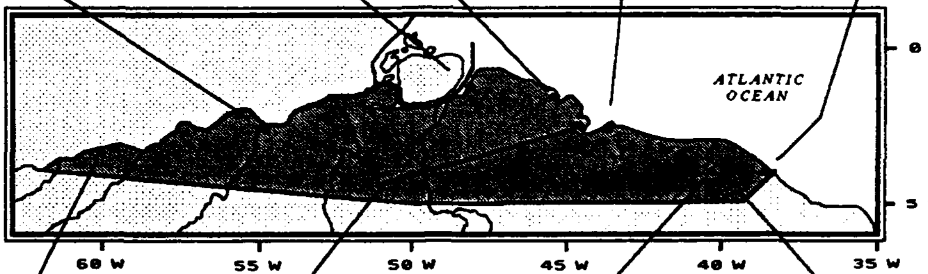
95	93	91	91	93
87	86	86	86	87
76	75	76	76	76
68	68	68	70	68

TURI-ASSU

96	96	95	95	94
89	87	86	87	87
72	71	71	71	73
60	59	61	61	67

FORTALEZA

96	95	94	95	95
88	87	87	87	87
77	76	75	75	75
69	67	64	65	68



SAO BENTO

96	96	98	93	92
89	88	88	88	88
73	73	74	74	74
67	66	68	69	69

SOBRAL

103	102	100	100	98
95	91	90	90	91
75	74	74	74	73
69	69	69	68	66

MANAUS

99	100	97	95	95
88	88	89	89	89
74	74	74	74	74
68	68	66	68	68

GUARAMIRANGA

89	88	89	88	86
81	79	77	76	75
65	65	65	65	64
60	60	57	59	58

Figure 4-89. Wet-Season Tabular Temperature Data, Eastern Amazon Basin.

Central and western forests maintain the zone's highest relative humidities. Mean minimums exceed 80% in the forests, and range from 65 to 75% along the Amazon River. In the east, mean minimums are 70-80% along the Atlantic coast and 60-70% inland. Mean maximum relative humidities range from 85 to 95% in the zone's central and western sections and along the Atlantic coast. They are lowest in eastern inland locations, where they range from 75 to 85%. Figure 4-90 shows five stations with wet-bulb globe temperature data (° F) at specific hours in February.

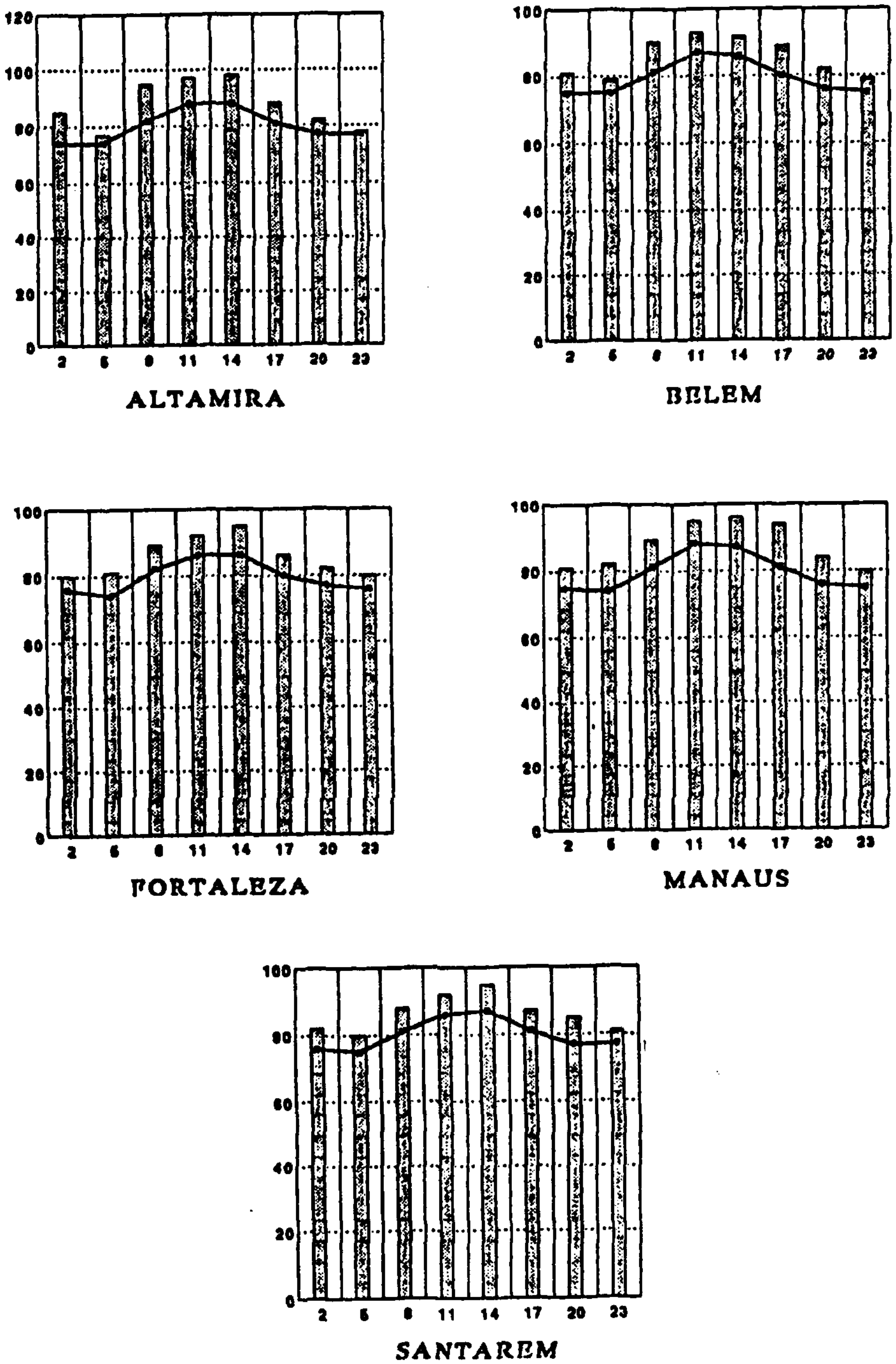


Figure 4-90. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (°F) for February, Eastern Amazon Basin. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. With thunderstorms, severe turbulence is likely from the surface through at least 20,000 feet (6.1 km) MSL. Severe mixed icing is common between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL. At least moderate turbulence and icing can be expected at similar heights within cumulus clouds. Afternoon thermal turbulence is common over the more rocky, barren areas in the east. It can be moderate through 5,000 feet (1,525 meters) AGL and light through 10,000 feet (3,050 meters) AGL. Directional shear occurs along sea breeze fronts. Speed shear may take place near tops of radiation inversions and occasionally along the Amazon where a low-level jet stream can form at night immediately above radiation inversions. Speeds in this small jet, typically centered between 990 and 2,300 feet (300 and 700 meters) MSL, may reach 30 knots.

GROUND HAZARDS. Heavy precipitation reduces visibilities well below a mile and causes annual flooding. Heavy Amazon basin rainfall, along with sluggish run-off, causes annual water levels to vary by 40 to 45 feet (12 to 14 meters). Water levels begin rising in December and peak in May. Much of the area becomes swampy, hindering travel. Flash flooding is possible in the east.

GENERAL WEATHER. Eastern Amazon Basin weather becomes less complex as the trade-wind inversion moves in and the Near Equatorial Trough (NET) moves north. As the trade-wind inversion becomes stronger, droughts become more possible in the east. However, plenty of moisture remains available for disturbances that include land/sea breeze circulations, tropical squall lines, and trade-wind surges. Most disturbances produce westerly propagating clouds and precipitation. Easterly cloud movement normally only occurs with the occasional shear line that approaches from the southwest. These, along with trade-wind surges that occasionally move northwestward along the coast, are the remains of old Southern Hemisphere cold fronts.

SKY COVER. Cloud cover is uniform in central and western sections, but terrain causes local variations in the east. Figure 4-91 shows mean daily coverages as high as 60% in central and western parts and as low as 30% in the east. Mean daily values do not show the diurnal changes that occur across the zone. For example, the 30% region in the east experiences most of its cloud cover in the mornings and is often nearly cloud-free in the afternoon. Diurnal variations are also reflected in the low-ceiling frequencies shown in Figure 4-92. High frequencies of low ceilings correlate with cloudiness and precipitation associated with land/sea breeze circulations.

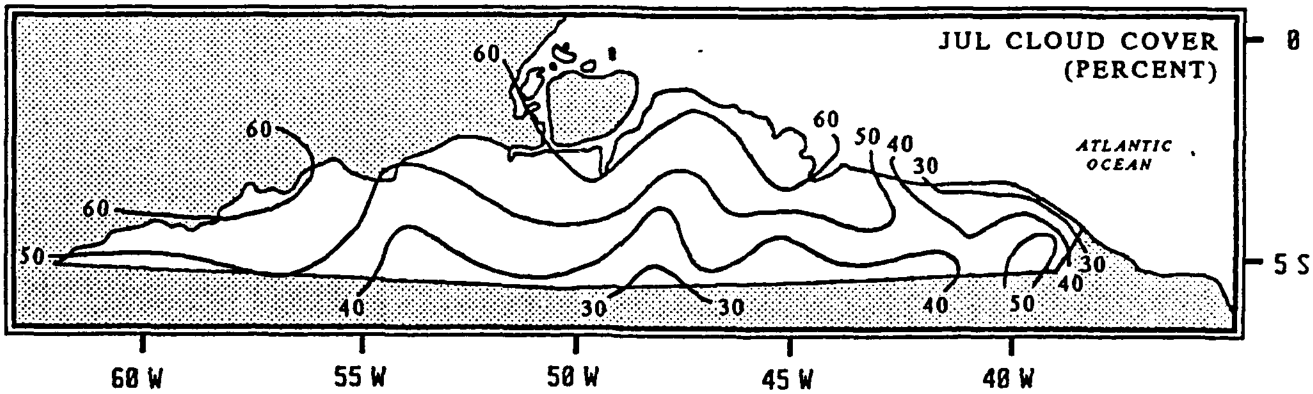


Figure 4-91. Mean July Cloud Cover, Eastern Amazon Basin. These isopleths, shown at 10% intervals, take all cloud types into account.

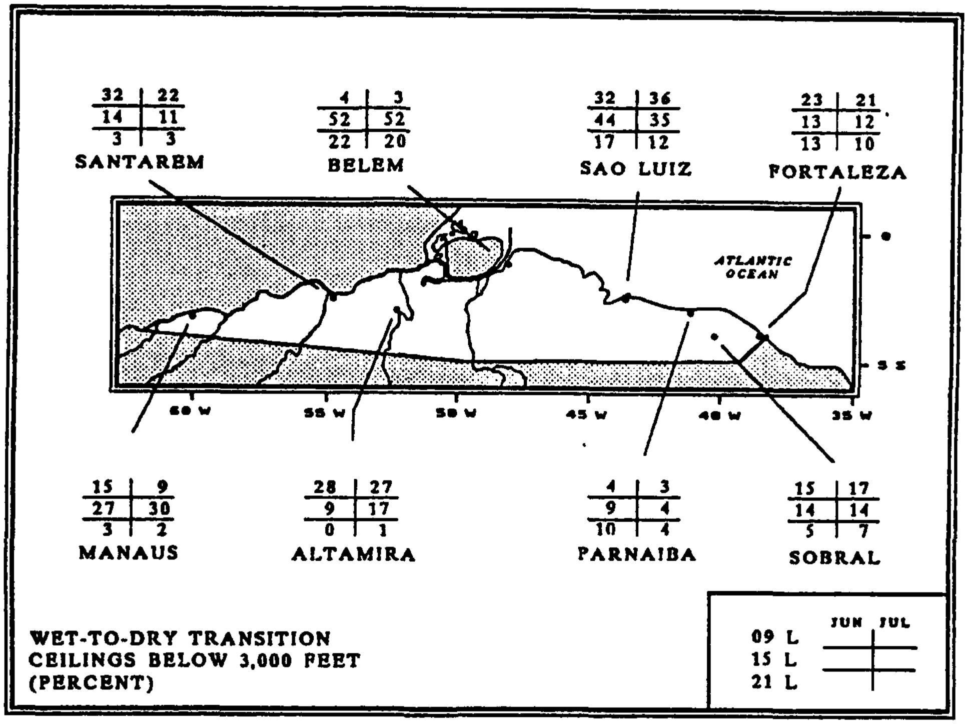


Figure 4-92. Percent Frequencies of Ceilings Below 3,000 feet (915 meters), Eastern Amazon Basin.

Throughout the zone, mean low-cloud bases range from between 1,000 and 2,000 feet (305 and 610 meters) MSL in the morning to between 2,500 and 4,000 feet (760 and 1,220 meters) MSL in the afternoon--terrain above these heights can be obscured. Showers and thunderstorms can produce broken to overcast bases below 1,000 feet (305 meters) MSL. Similar bases occur with morning "jungle stratus" that can form in forested areas where significant precipitation has occurred on the previous afternoon or evening. This stratus is less than 1,000 feet (305 meters) thick and dissipates shortly after sunrise. Low stratus is also prevalent behind the occasional fronts or shear lines that move in from over the continent. Cumuliform clouds form along most disturbances, as afternoon convection inland, and during nights and mornings along the coast. Stratocumulus prevails nights and mornings along most disturbances and on the coast. Cloud tops vary during unsettled periods, but most are below 12,000 feet (3,660 meters) MSL during settled periods. The higher terrain in the east normally produces cloud tops that are 2,000 to 7,000 feet (610 to 2,130 meters) above surrounding tops.

VISIBILITY. Visibilities are generally good. Precipitation has the greatest effect--visibilities below a mile are possible. Fog is the second most important cause, with visibilities below a mile common in the forested west and central sections. Haze occasionally reduces visibilities below 7 miles during the day.

Figure 4-93 shows that percent frequencies of visibilities below 3 miles range from less than 1% in afternoons and evenings in the east to more than 10% well inland. However, western frequencies are not representative of forested areas because most reporting stations are along major rivers where fog is less common. Fog occurs most often near sunrise within forested areas that received significant precipitation on the previous afternoon or evening. Such fog typically originates within forest canopies as "jungle stratus" usually dissipates shortly after sunrise. Upslope fog can occur along inclines. Most haze in the west is caused by plant particles, but sea salt is the most important cause in the east.

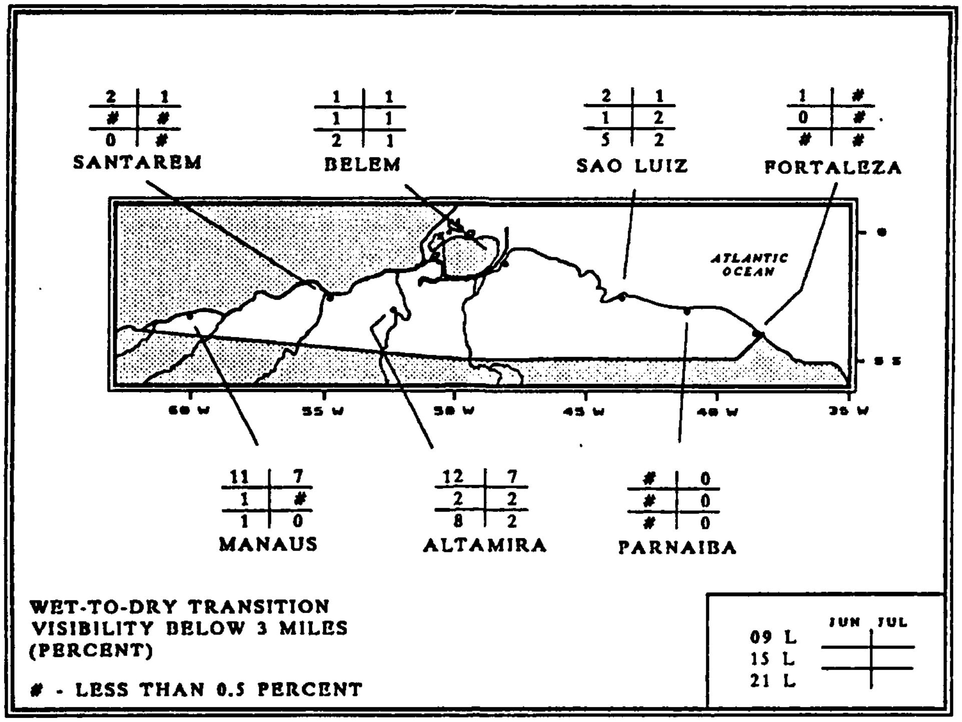


Figure 4-93. Percent Frequencies of Visibility Below 3 Miles, Eastern Amazon Basin.

WINDS. Winds are primarily controlled by the trade winds and by land/sea breeze circulations. As a result, mean inland surface directions are east-southeasterly, while northeasterly winds prevail along much of the coast. The zone's highest daily wind speeds occur at coastal locations where sea breezes are supported bytrade-wind flow. Afternoon speeds average about 15 knots with gusts to 20, while afternoon speeds at western stations average around 5 knots. As shown in Figure 4-105, mean speeds across the zone range from 8 knots in the east to only 2 knots in the west.

	MEAN WIND SPEED	
STATION	JUN	JUL
FORTALEZA	7	8
SOBRAL	5	5
PARNAIBA	6	7
SAO LUIZ	4	4
BELEM	6	6
ALTAMIRA	3	3
SANTAREM	5	6
PARINTINS	2	3
MANAUS	3	3

Figure 4-94. Mean Wet-to-Dry Transition Wind Speeds, Eastern Amazon Basin.

Strong winds are uncommon, especially in dense forests where winds are weakened or dissipated at treetop level. Thunderstorms are the primary cause of high winds--gusts over 40 knots are possible. Weak land breezes and calm winds are prevalent at coastal locations between 2200 and 0400L. At inland stations, calm winds start a few hours earlier and end a few hours later. As in the wet season, Manaus is an example of a location well inland where calm winds prevail at least 50% of the time during all hours. Slope winds can occur at night. Stations at elevations near or above the mean height of nighttime radiation inversions have fewer calm winds--an example is Guaramiranga, at 2,500 feet (760 meters) MSL.

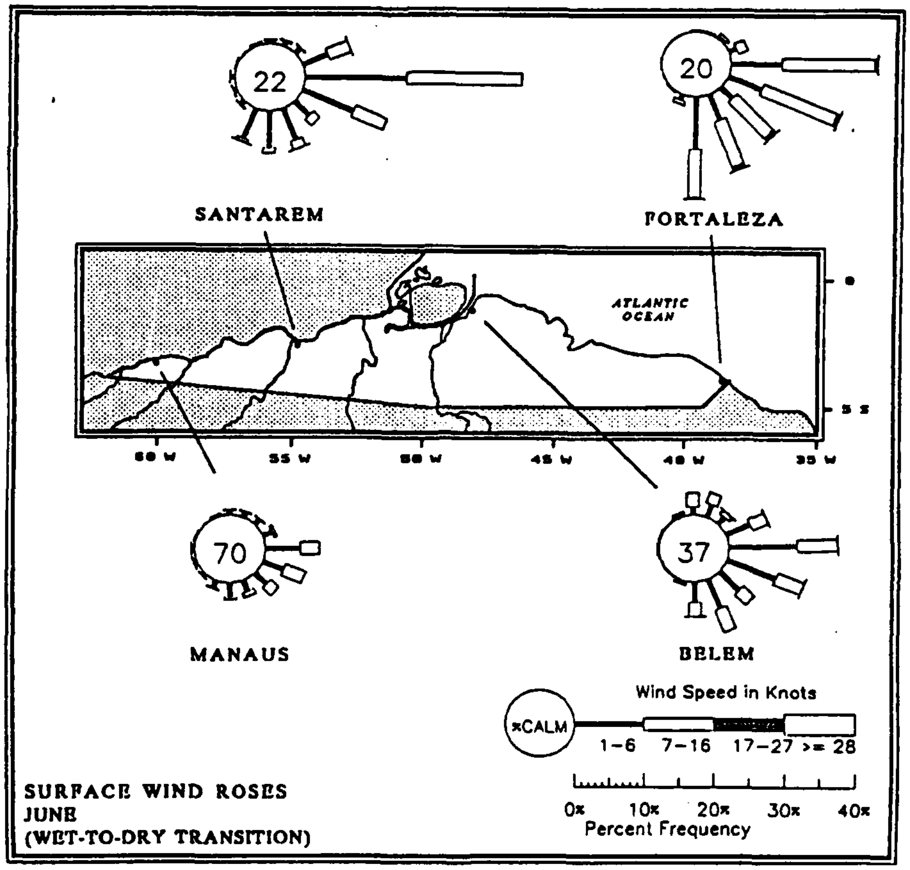


Figure 4-95. June Surface Wind Roses, Eastern Amazon Basin.

Mean upper wind speeds are less than 25 knots at all levels. Upper-air directions, shown in Figures 4-81 through 4-84 (see "Wet Season"), are east-southeasterly below 10,000 feet (3,050 meters) MSL, easterly through about 37,000 feet (11.3 km) MSL, and westerly above.

PRECIPITATION. Increasing stability begins to inhibit cumuliform development. Unorganized convection begins occurring less frequently. Most rain falls as showers when disturbances overcome the trade-wind inversion.

As shown in Figure 4-96, the mean number of days a month with rainfall varies from 2 to 3 at Sobral in the east, from 16 to 22 at Belem in the central sections and from 8 to 12 at Manaus in the far west. Sobral is sheltered by mountains and consequently has fewer precipitation days than surrounding locations. Guaramiranga, near 2,500 feet (760 meters) MSL, is an example of a station that has more precipitation days than its neighbors because of terrain and sea breezes. Maximum 24-hour amounts (Figure 4-96) are as high as 5 inches (127 mm).

Rainfall amounts and frequencies decrease as the transition passes. The maximum band shown near the coast in Figure 4-97 results from afternoon showers associated with sea-breeze fronts. Amounts decrease farther inland where sea-breeze showers weaken at night. Figure 4-97 shows that mean monthly rainfall amounts are lowest in the east (less than 1 inch)--droughts are possible here. Mean monthly amounts across the rest of the zone range from 6 inches (152 mm) central to 3 inches (76 mm) west.

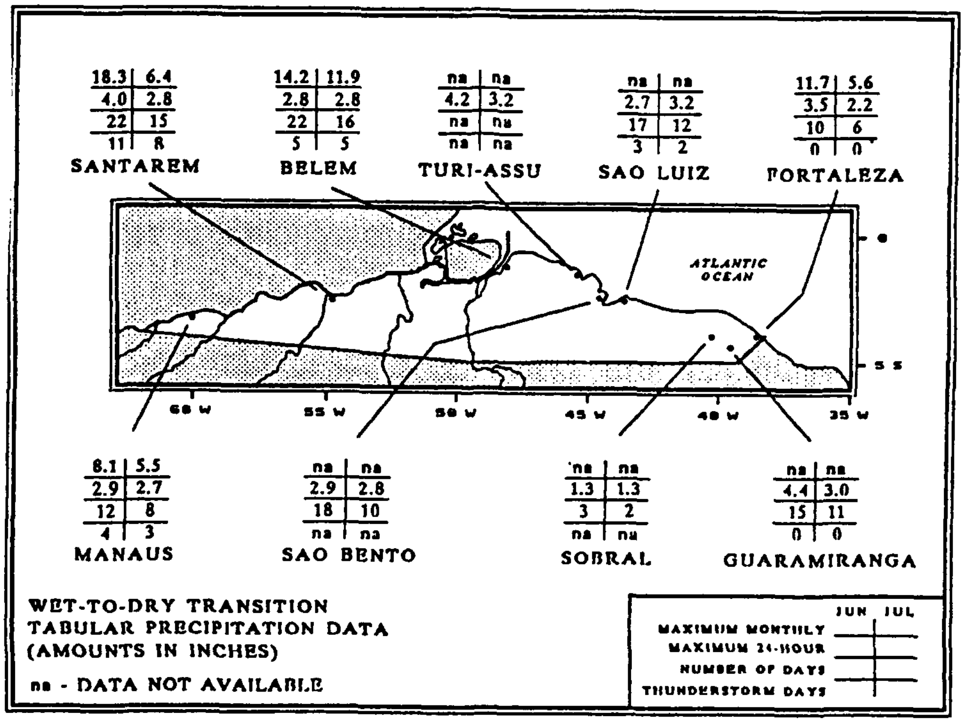


Figure 4-96. Wet-to-Dry Transition Tabular Precipitation Data, Eastern Amazon Basin.

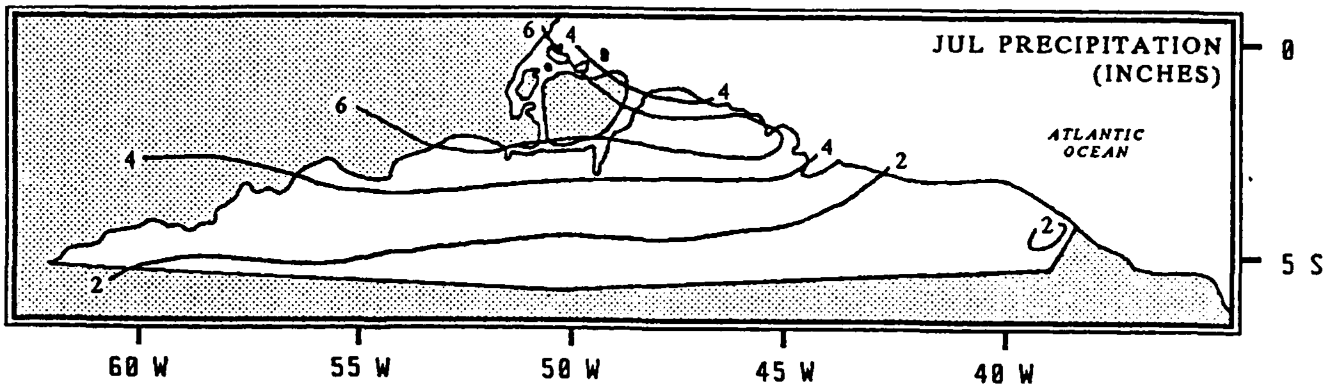


Figure 4-97. Average Precipitation for July, Eastern Amazon Basin.

THUNDERSTORMS often occur as organized activity along disturbances and occasionally from very brief, unorganized afternoon convection. During the transition, most thunderstorms occur near the Amazon River where the mean number of days a month with thunderstorms ranges from 4 at Manaus, to 9 near Santarem, to about 5 at Belem. Although the Santarem area has more thunderstorm days, the stronger activity occurs near Manaus and Belem. As in the wet season, thunderstorms are not as common southeast of a line extending from 5° S, 50° W, to the coast at about 42° W. Most of this area has less than 3 mean thunderstorm days a month.

Thunderstorm bases are often below 1,000 feet (305 meters) AGL; tops are usually between 40,000 and 50,000 feet (12.2 and 15.2 km) MSL. Heavy downpours are common. Tornados are rare to nonexistent, and high freezing levels prevent hail from reaching the ground. Gusts occasionally exceed 40 knots, but they are often completely dissipated in the dense forest canopies of the zone's central and western sections. Thunderstorm-associated middle and high clouds often become widespread and can produce as much precipitation as the thunderstorm cores. Unlike the mid-latitudes, these clouds often appear to trail *behind* thunderstorm cells as the cells propagate faster toward mid- and high-level flow. This apparent thunderstorm movement is mostly due to propagation along a low-level disturbance or toward low-level thunderstorm outflow. In this season, propagation is toward the west, but lowland areas can channel thunderstorm outflow, resulting in propagation in other directions.

TEMPERATURE. Temperatures are moderated diurnally and seasonally by moisture-laden air; this can be seen in Figure 4-98. Most stations have average low temperatures between 70 and 75° F (21 and 24° C). Average highs are between 85 and 90° F (29 and 32° C). The primary exceptions are Guaramiranga and Sobral. Guaramiranga, at a higher (cooler) elevation, has the zone's lowest recorded temperature at 56° F (13° C). Sobral, an inland, less densely wooded site, has the zone's highest recorded temperature at 100° F (38° C). Radiation heating and cooling occurs in forest canopies in the zone's central and western sections, but at ground level in the east. Clear skies over forested areas are accompanied by canopy temperatures averaging a few degrees higher than the underlying surface at night and roughly 10° F (6° C) higher in the afternoon.

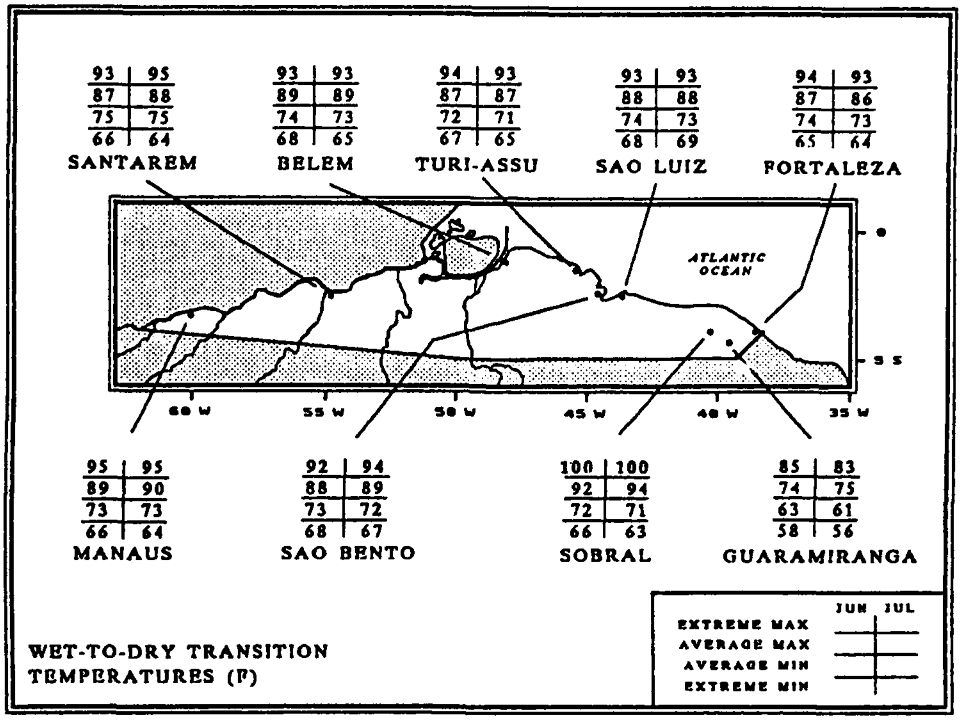


Figure 4-98. Wet-to-Dry Transition Tabular Temperature Data, Eastern Amazon Basin.

Central and western forests have the zone's highest relative humidities. Mean minimums exceed 75% within forests and range from 60 to 70% along the Amazon River. Mean minimums range from 65 to 75% along the Atlantic coast and from 50 to 60% at eastern inland locations. Mean maximum RH ranges from 85 to 95% in the zone's entire central and west sections and along the Atlantic coast. Mean maximum relative humidities are lowest at eastern inland locations, where they range from 70 to 80%. Figure 4-99 shows five stations with wet-bulb globe temperature data (° F) at specific hours in July.

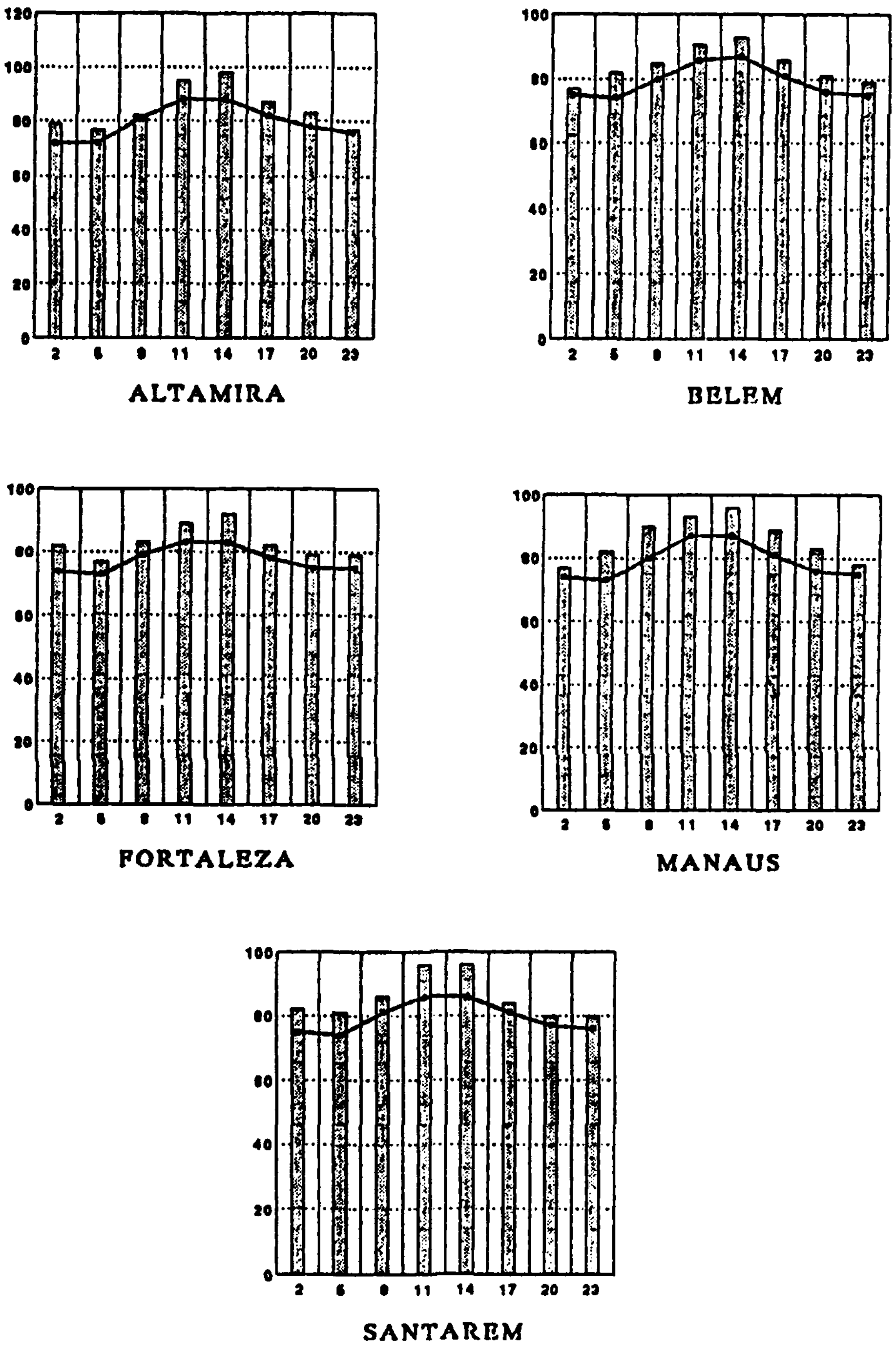


Figure 4-99. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Eastern Amazon Basin. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms can cause severe turbulence from the surface through at least 20,000 feet (6.1 km) MSL, along with severe mixed icing between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL. At least moderate icing and turbulence can be expected at such heights in cumulus clouds. Thermal turbulence can occur afternoons over rocky, barren areas in the east. It can be moderate through 5,000 feet (1,525 meters) AGL and light through 10,000 feet (3,050 meters) AGL. Terrain-induced afternoon turbulence is also possible. It is typically light, but can be moderate between 52 and 56° W. Directional shear can occur along sea-breeze fronts. Speed shear may occur near tops of radiational inversions and along the Amazon River where a low-level jet-stream often develops at night immediately above radiational inversions. Speeds in this jet can reach 30 to 40 knots, usually centered between 990 and 2,300 feet (300 and 700 meters) MSL.

GROUND HAZARDS. Heavy precipitation reduces visibilities well below a mile and maintains the high water levels established during the wet season. Water levels average 40 to 45 feet above minimum levels that occur in October and November. Much of the area is swampy, hindering travel. Flash flooding is possible with thunderstorms in the east.

GENERAL WEATHER. Upper-level convergence and the trade-wind inversion cause the predominantly stable dry season. Droughts are possible in the east. Plenty of moisture, either off the ocean or from the Amazon forests, still remains available for any disturbances that can overcome the stability. Disturbances include shear lines from old Southern Hemisphere fronts, land/sea breeze circulations, tropical squall lines, low-latitude upper-level cyclones, and trade-wind surges. Most of these features produce westerly propagating clouds and precipitation. Cold fronts and shear lines from the southwest are the exception, They cause easterly moving cloudiness. Shear lines are also found to enter the zone near Fortaleza, moving northwestward along the coast as trade-wind surges.

SKY COVER. As represented by Figure 4-100, mean daily coverage ranges from 30 to 70%. However, these values do not show the important localized and diurnal changes that occur across the zone. For example, the 30% area in the east experiences most of its cloud cover in the morning and is often nearly cloud free in afternoon. Diurnally, high frequencies of low ceilings (shown in Figure 4-101) correlate with cloudiness and precipitation associated with land/sea breeze circulations.

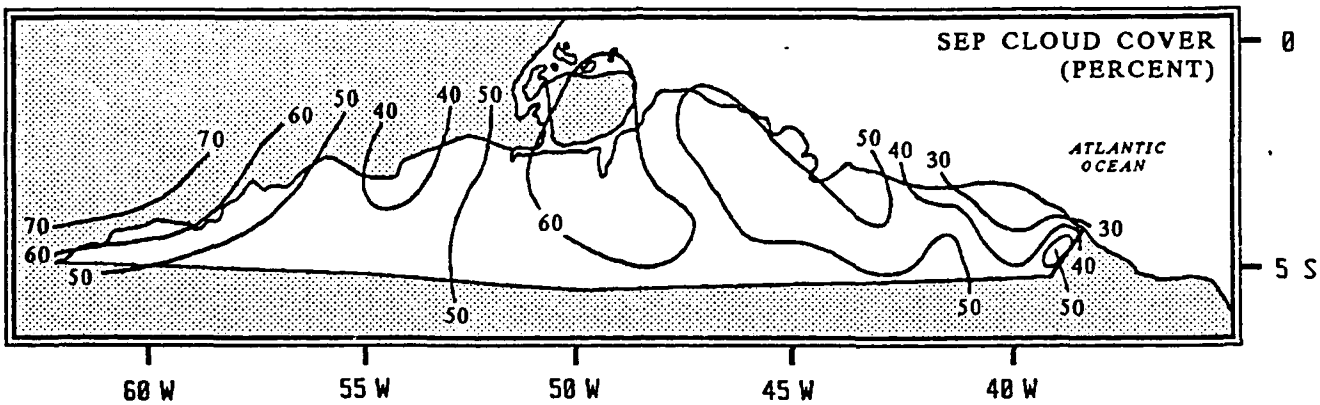


Figure 4-100. Mean September Cloud Cover, Eastern Amazon Basin. These isopleths, at 10% intervals, take all cloud types into account.

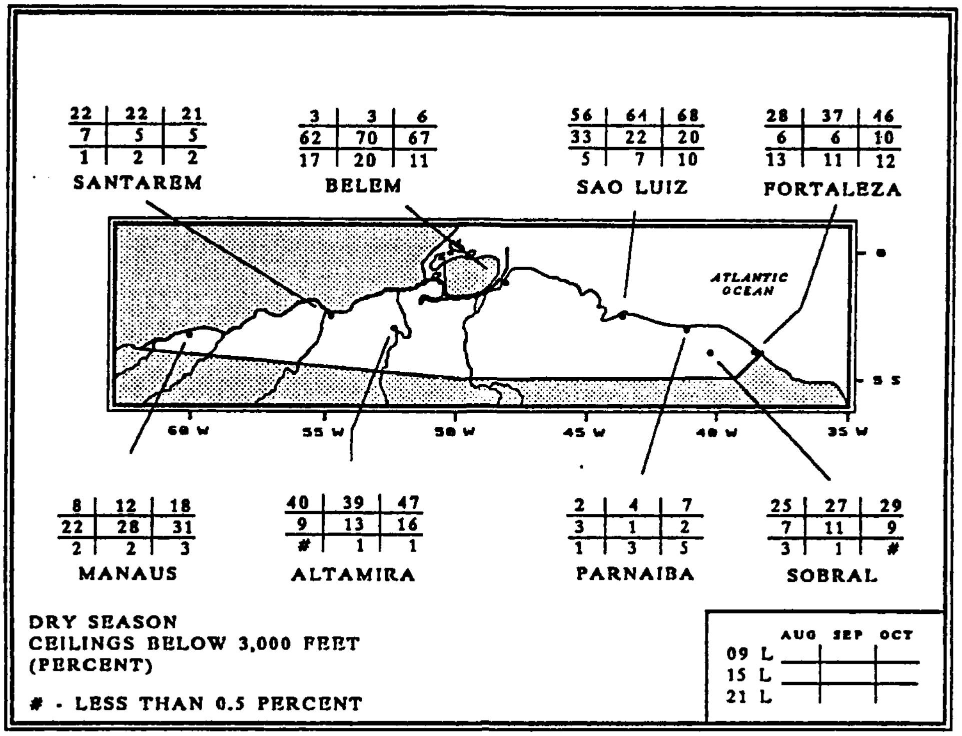


Figure 4-101. Percent Frequencies of Ceilings Below 3,000 feet (915 meters), Eastern Amazon Basin.

Throughout the zone, mean morning cloud bases range from 1,500 to 2,500 feet (455 to 760 meters); afternoons, from 2,500 to 4,000 feet (760 to 1,220 meters). Terrain above these heights can be obscured. Showers and thunderstorms can produce broken to overcast bases below 1,000 feet (305 meters) MSL. Similar bases are possible with morning "jungle stratus." Although occurring less frequently than in other seasons, jungle stratus is still possible in forested areas where significant rain has fallen on the previous afternoon or evening. Jungle stratus is usually less than 1,000 feet (305 meters) thick. It dissipates shortly after sunrise. Stratiform cloudiness may accompany the infrequent synoptic disturbance, but cumulus, stratocumulus, and cumulonimbus accompany most disturbances. The exception occurs early in the season, when fronts and shear lines approaching from over the continent are followed by stratus, stratocumulus, and middle clouds. Settled periods bring afternoon cumulus, especially over higher terrain. Mornings, scattered to broken stratocumulus and cumulus are common along the coast during settled periods. Most cloud tops are at or below 10,000 feet (3,050 meters) MSL, but can be higher during afternoons with disturbances.

VISIBILITY Dry-season visibilities are good. Precipitation in the zone's eastern and central sections can lower visibilities below a mile; fog and haze can reduce visibilities below a mile. Precipitation, fog, and haze all contribute about equally in the west, where visibilities below a mile are also possible.

Figure 4-102 shows percent frequencies of visibilities below 3 miles ranging from less than 1% afternoons and evenings in the east to more than 10% well inland. Western frequencies are not representative of forested areas since reporting stations are along major rivers; fog occurs more often in the forests where there are no stations. Fog frequently occurs around sunrise in forested areas that have received significant precipitation on the previous afternoon or evening. It typically originates within forest canopies as "jungle stratus" dissipates shortly after sunrise. The causes of haze also need to be considered when viewing Figure 4-102. It is important to know that much of the haze observed during the period of record used for that figure originated as smoke from burning tropical vegetation near the zone's southern and southwestern border. Future visibility climatology will depend on where, when, and how much burning will occur. Smoke and sea salt contribute to haze in the west, but plant particles are the primary cause of haze there. Sea salt is the most important cause of haze in the east.

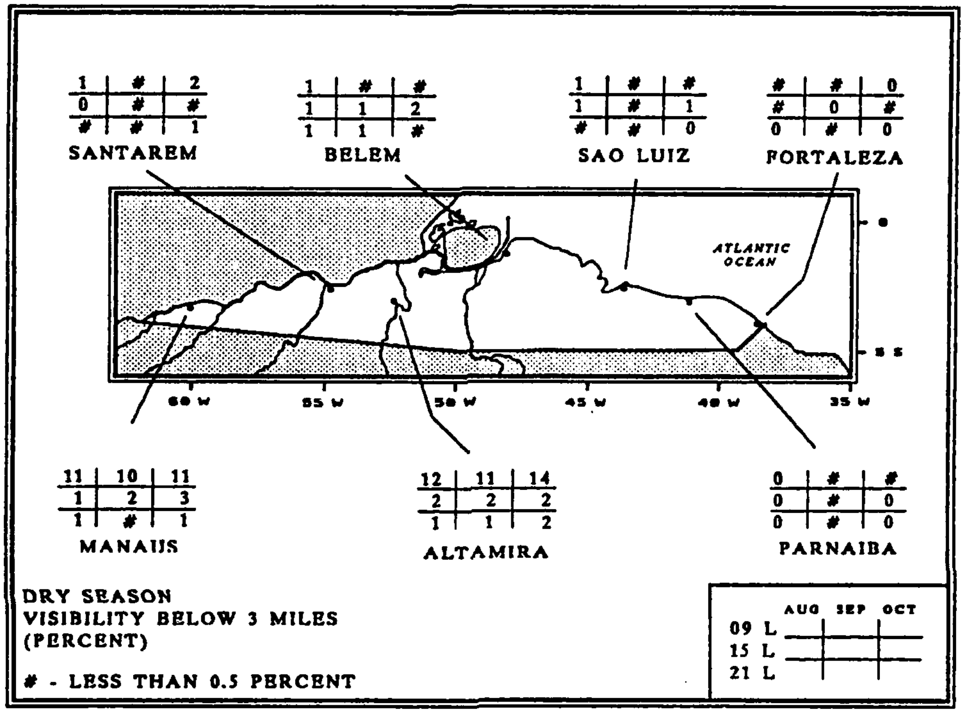


Figure 4-102. Percent Frequencies of Visibility Below 3 Miles, Eastern Amazon Basin.

WINDS. Winds are controlled by the trade winds and land/sea breeze circulations. Mean inland surface winds are east-southeasterly, but they are northeasterly along parts of the Atlantic coast. The zone's highest daily wind speeds are at coastal locations where sea breezes are supported by trade wind flow. Afternoon speeds at such locations range from 15 to 20 knots with gusts to 25 knots. Examples are Belem, Turi-Assu, Sao Luiz, Sao Bento, and Parnaiba. Afternoon speeds at western sites average 5 knots or less. As shown in Figure 4-103, mean speeds for all hours range from 11 knots in the east to 3 knots in the west.

STATION	MEAN WIND SPEED AUG	SEP	OCT
FORTALEZA	9	10	10
SOBRAL	6	8	8
PARNAIBA	9	11	11
SAO LUIZ	6	7	7
BELEM	7	7	8
ALTAMIRA	3	3	3
SANTAREM	6	7	7
PARINTINS	3	3	3
MANAUS	3	3	3

Figure 4-103. Mean Dry-Season Wind Speeds, Eastern Amazon Basin.

Strong winds are uncommon, especially in dense forests where winds are weakened or dissipated at tree top level. Thunderstorms are the primary cause of high winds, with gusts over 40 knots possible. At night, winds along the Atlantic coast often weaken while maintaining an onshore component, but weak land breezes or calm winds may occur. Calm winds are prevalent at most inland sites in the evening and at night. Manaus is an example of a location well inland where calm winds prevail at least 50% of the time during all hours. Slope winds may affect portions of the zone at night. Stations at elevations near or above the mean height of nighttime radiation inversions experience calm winds less frequently--an example is Guaramiranga, at 2,500 feet (760 meters) MSL.

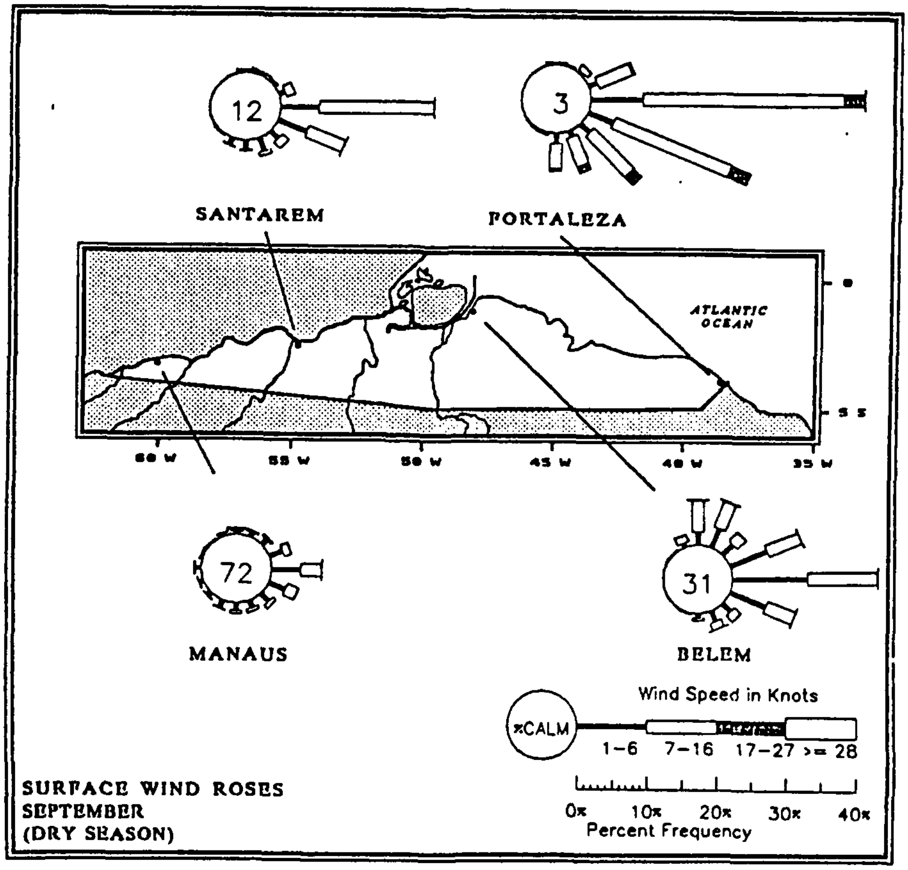


Figure 4-104. September Surface Wind Roses, Eastern Amazon Basin.

Upper winds are less than 20 knots at all levels; see Figures 4-81 through 4-89 in "Wet Season." East-southeasterly winds prevail through 10,000 feet (3,050 meters) MSL. Above 10,000 feet (3,050 meters) MSL, winds are easterly winds through 35,000 feet (10.7 km) MSL early in the season and through 20,000 feet (6.1 km) MSL late in the season. Above, winds are west-southwestery.

PRECIPITATION. As in the other seasons, most dry-season precipitation falls as showers. Stable conditions inhibit significant cumuliform development except when disturbances overcome the trade-wind inversion. Periods of rainfall produce less precipitation than in other seasons, as indicated by maximum 24-hour amounts around 4 inches (102 mm). Mean monthly precipitation amounts are lowest in the east (less than 1 inch); droughts occur in some years. Mean monthly rainfall for the rest of the zone ranges from 3-5 inches (76-127 mm) central to 1-5 inches (25-127 mm) west.

Peak rainfall periods range from early in the season in the west to late in the season in the east. As shown in Figure 4-106, the mean number of days a month with precipitation range from 1 or less at Sobral (in the east), to 15-18 at Belem, to 6-11 at Manaus in the west. Note that Sobral is sheltered by mountains. Guaramiranga, near 2,500 feet (760 meters) MSL, is an example of a station that has a greater frequency of precipitation days than its neighbors because of terrain and sea breezes. Figure 4-105, showing average amounts for September, reflects land/sea breeze circulation effects. The maximum area shown near the mouth of the Amazon results from afternoon showers associated with sea-breeze fronts. A decrease appears farther inland where most sea-breeze showers weaken at night. See "General Weather" for details on the diurnal relationships of precipitation and land/sea breeze circulations.

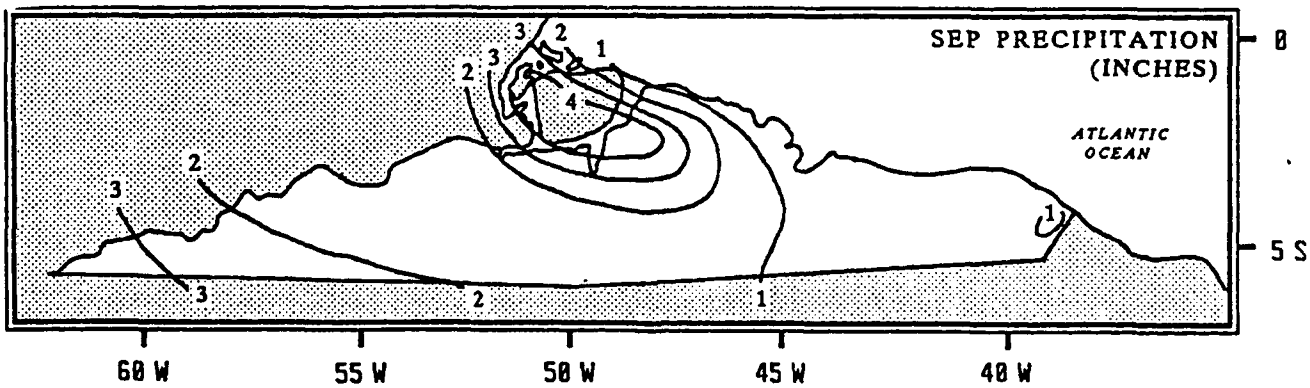


Figure 4-105. Average Precipitation for September, Eastern Amazon Basin. Isopleths are at one-inch intervals.

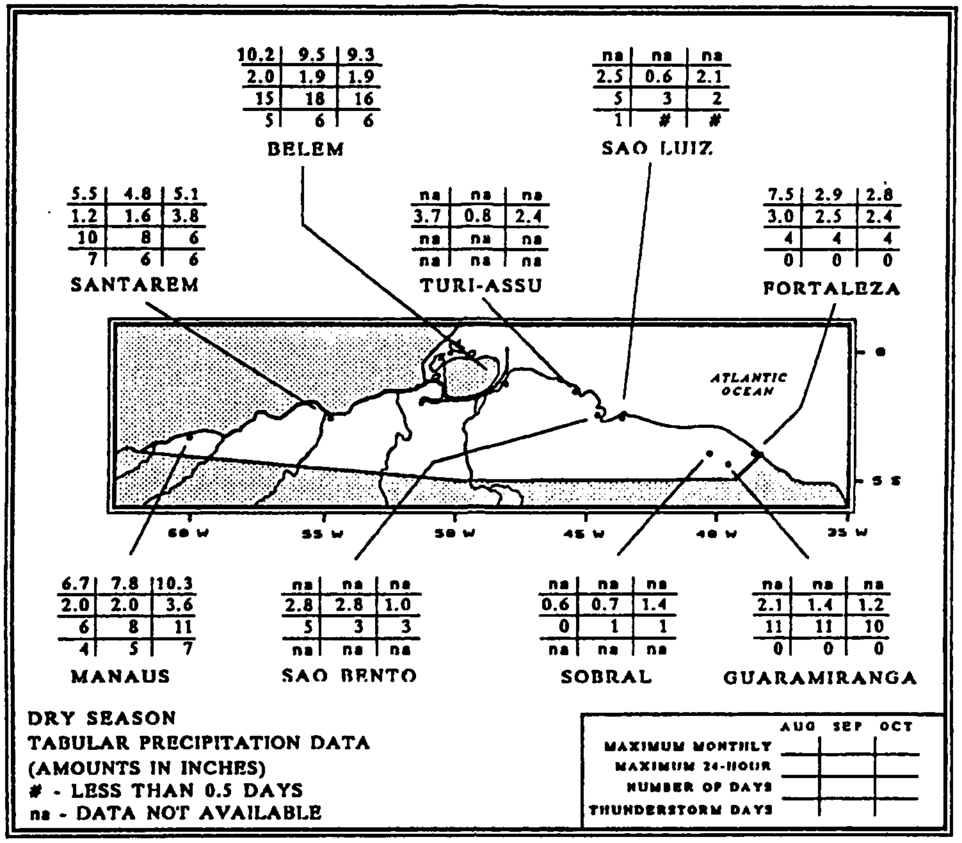


Figure 4-106. Dry-Season Tabular Precipitation Data, Eastern Amazon Basin.

THUNDERSTORMS. Most thunderstorms occur as organized activity along disturbances during afternoons and evenings. Convective thunderstorms normally only occur along large masses of low cloudiness when uneven heating between cloudy and clear areas causes convective lift along cloud mass fringes. Thunderstorms are brief, usually lasting less than an hour.

Thunderstorm frequencies correlate well with land/sea breeze circulations that cause most cells near the Amazon River's mouth. Thunderstorms occur here on an average of 5-6 days a month. The stronger and longer-lived activity normally occurs in the vicinities of Manaus and Belem; the area southeast of a line from 5° S, 50° W to the coast at about 42° W sees fewer disturbances. This, combined with a stronger trade-wind inversion, results in less than 2 thunderstorm days a month at most locations.

Although thunderstorm frequencies vary, characteristics do not. Bases below 1,000 feet (305 meters) MSL are possible and tops are often above 40,000 feet (12.2 km) MSL. Moderate to heavy rainfall is common. Tornados are rare to nonexistent, and hail does not occur. Gusts occasionally exceed 40 knots, but are often completely dissipated in the dense forest canopies of the zone's central and western sections. Thunderstorm-associated middle and high clouds can become widespread and produce as much precipitation as cell cores. These clouds, unlike those in the mid-latitudes, often appear to trail behind thunderstorm cells as cells propagate faster than (or toward) mid- and high-level flow. This apparent movement of thunderstorms is mostly due to propagation either along some low-level disturbance or toward low-level thunderstorm outflow. During the dry season, such propagation is normally toward the west. Lowland areas can channel thunderstorm outflow and affect propagation.

TEMPERATURES. Temperatures are moderated diurnally and seasonally by moisture-laden air. The dry season's comparatively sunny skies result in the highest temperatures of the year at most locations. Figure 4-118 shows that most stations have average high temperatures around 90° F (32° C) and that extreme highs range from 95° F (35° C) to about 100° F (38° C). Guaramiranga and Sobral are exceptions. Guaramiranga, at a higher elevation, is the coolest station in the zone, with mean lows from 61 to 63° F (16 to 17° C) and extreme lows from 57 to 60° F (14 to 15° C).

Highest temperatures are at Sobral, an inland, less wooded location. Average monthly highs at Sobral reach 98° F (37° C), and the extreme high is 103° F (39° C).

Radiation heating and cooling occurs in the zone's central and western forest canopies; in the the east, it occurs at ground level. With clear skies, temperatures in forest canopies average a few degrees warmer than the underlying surface at night and about 10° (6° C) warmer in the afternoon.

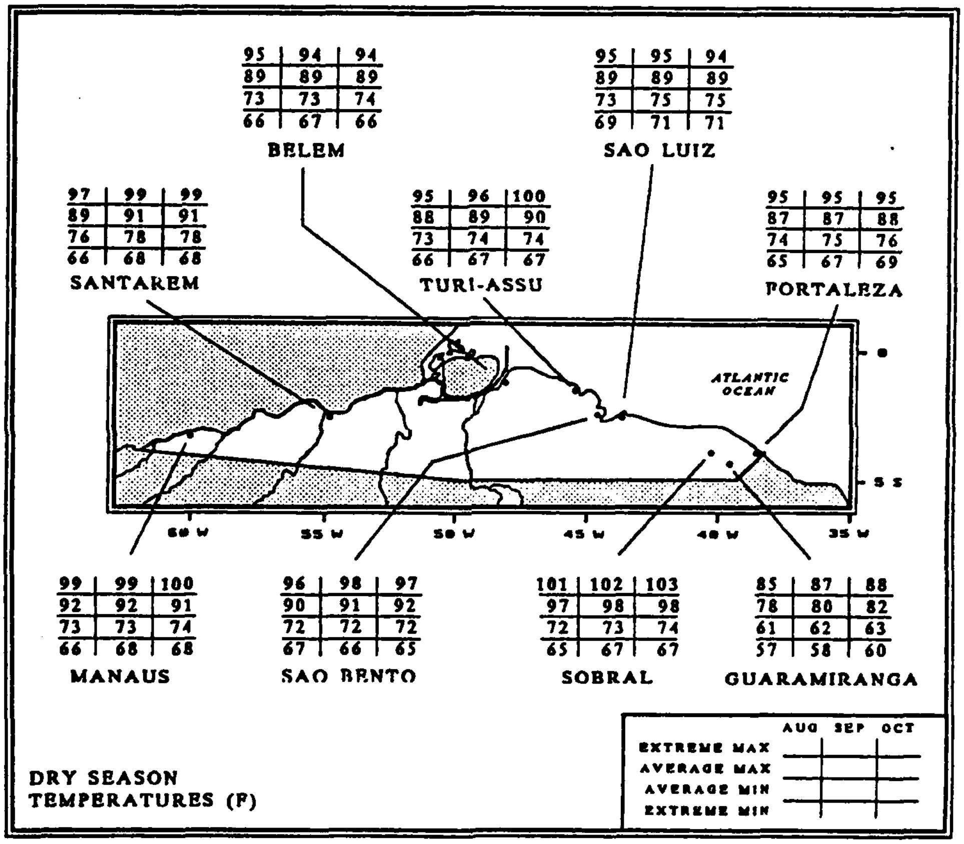


Figure 4-107. Dry-Season Tabular Temperature Data, Eastern Amazon Basin.

Central and western forests maintain high relative humidities in the dry season. Mean minimums exceed 70% in the forests, but range from 55 to 65% along the Amazon River. Throughout the rest of the zone, mean minimums range from 60 to 70% along the Atlantic coast and from 40 to 50% in eastern inland locations.

Mean maximum relative humidities are highest near the Amazon's mouth, where they range from 90 to 95%. Mean maximums for inland central and western areas, as well as for most of the Atlantic coast, range from 80 to 90%. Relative humidities are lowest in eastern inland locations, where maximums range from 60 to 70%.

Figure 4-119 shows five stations with wet-bulb globe temperature data (° F) at specific hours in September.

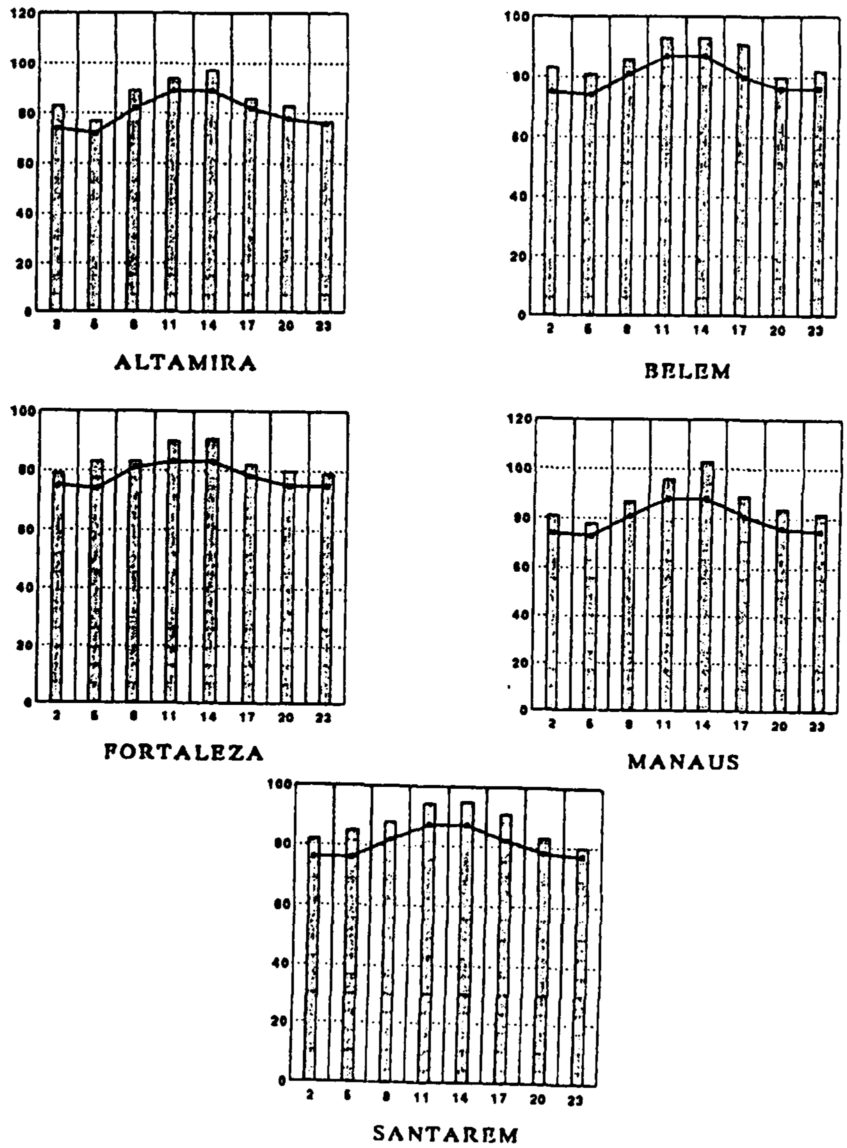


Figure 4-108. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for September, Eastern Amazon Basin. Mean WBGT is shown as a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Severe thunderstorm turbulence is likely from the surface through at least 20,000 feet (6.1 km) MSL. Severe mixed icing occurs between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL. Expect at least moderate icing and turbulence at similar heights in cumulus clouds. In the east, afternoon thermal turbulence is common. It can be moderate through 5,000 feet (1,525 meters) AGL and light through 10,000 feet (3,050 meters) AGL in rocky, barren areas. Terrain-induced afternoon turbulence is also possible; it is typically light, but can reach moderate intensity between 52 and 56° W. Directional shear occurs along sea-breeze fronts. Speed shear occurs above radiation inversions at night. A low-level jet-stream along the Amazon River at night can cause strong speed shear immediately above radiation inversions. This jet reaches 30- to 40-knots between 990 and 2,300 feet (300 and 700 meters) MSL.

Late in the season, cropland burning causes haze from the surface through 20,000 feet (6.1 km) MSL. It can be particularly dense between 7,000 and 16,000 feet (2,130 and 4,880 meters) MSL. Density depends more on stability than on the amount of burning. Exceptionally stable conditions can produce haze that lowers visibility to less than a mile. The haze is hazardous when it obscures afternoon convective clouds.

GROUND HAZARDS. Heavy precipitation can reduce visibilities below a mile. Flood waters and swamps begin to recede by September. The waters reach their lowest levels of the year in October and November.

GENERAL WEATHER. The Near Equatorial Trough (NET) returns, the trade-wind inversion weakens, and high-level convergence decreases. Since the east is last to be affected, drought is still possible there. Most activity occurs where the NET interacts with some other disturbance, such as land/sea breezes, tropical squall lines, low-latitude upper-level cyclones, and trade-wind surges. All these features usually produce westerly propagating clouds and precipitation. Shear lines that occasionally approach from the southwest result in northeasterly to easterly propagation. These shear lines, along with trade-wind surges that move up along the coast, are remnants of old Southern Hemisphere cold fronts.

SKY COVER. Cloud cover increases across the entire zone. As shown in Figure 4-109, mean daily coverage ranges from 50% in the east to 80% in the west. These values do not show diurnal variations; high frequencies of low ceilings (see Figure 4-110) correlate with cloudiness and precipitation associated with land/sea breeze circulations.

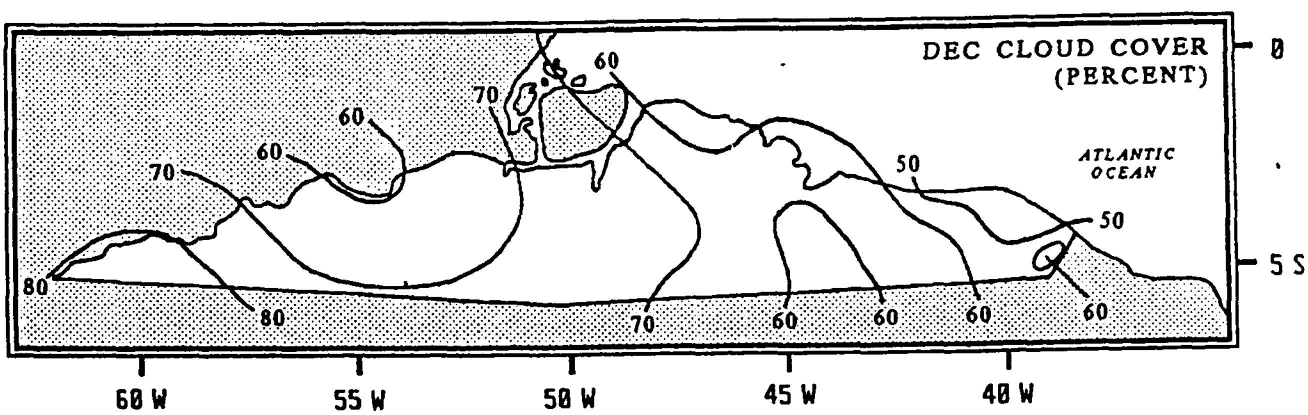


Figure 4-109. Mean December Cloud Cover, Eastern Amazon Basin.

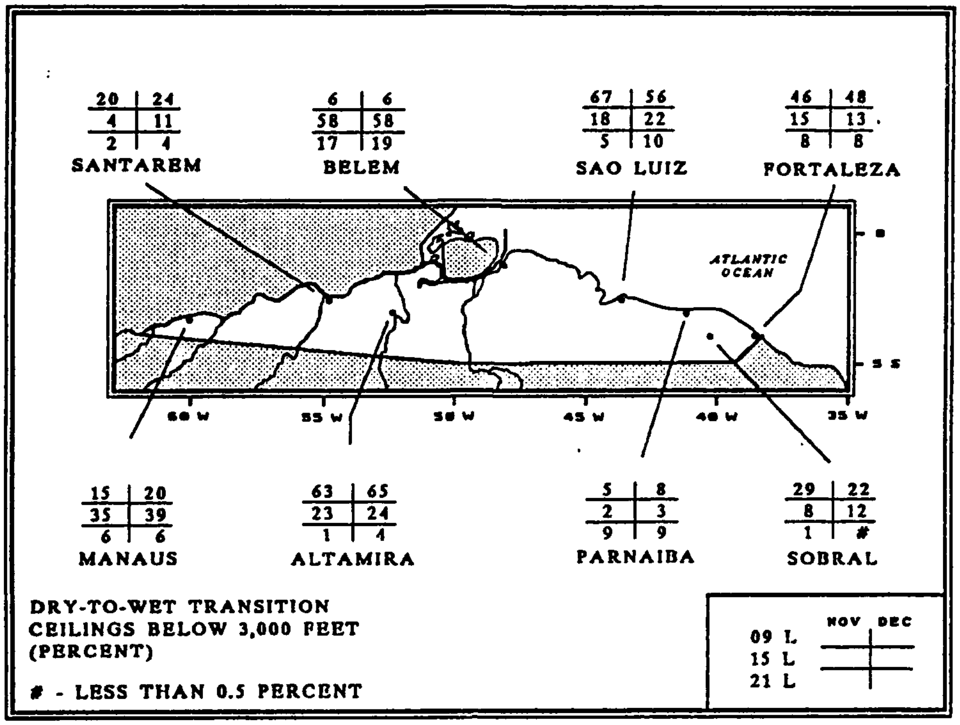


Figure 4-110. Percent Frequencies of Ceilings Below 3,000 feet (915 meters), Eastern Amazon Basin.

Throughout the zone, morning mean low-cloud bases range from 1,500 to 2,500 feet (455 to 760 meters) MSL; afternoons, from 2,500 to 3,500 feet (760 to 1,065 meters) MSL. Terrain above can be obscured. Showers and thunderstorms can produce broken to overcast bases below 1,000 feet (305 meters). "Jungle stratus" forms in forested areas where significant precipitation fell on the previous afternoon or evening; it is less than 1,000 feet (305 meters) thick and dissipates shortly after sunrise. Nimbostratus occasionally occurs, but only with surges of the NET. Shear lines are often followed by stratus, stratocumulus, and middle clouds; otherwise cumulus and cumulonimbus are the predominant cloud types along disturbances. Cumuliform clouds can also form from afternoon convection inland, and during nights and mornings along the coast. Settled periods frequently bring scattered to broken stratocumulus and cumulus along the coast during nights and mornings. Cloud tops vary during unsettled periods, but during settled periods, most are below 12,000 feet (3,660 meters) MSL. The higher terrain in the east produces cloud tops that are 2,000 to 7,000 feet (610 to 2,130 meters) above other clouds.

VISIBILITY. Transition visibilities are good. Although fog and haze are factors, precipitation causes most low visibilities in eastern and central sections; visibilities below a mile are possible. Precipitation, fog, and haze contribute about equally in the west, where visibilities below a mile are also possible.

Figure 4-111 shows that frequencies of visibilities below 3 miles range from less than 1% during afternoons and evenings in the east to around 20% well inland. Western frequencies are not representative of forested areas since most reporting stations are along major rivers. Fog often forms in deep forests where data is unavailable; it frequently forms around sunrise where significant precipitation fell on the previous afternoon or evening. Such fog typically originates within forest canopies as "jungle stratus" that usually dissipates shortly after sunrise.

Haze has its greatest effect of the year on visibility. Much of the haze observed during the period of record used for Figure 4-111 originated as smoke from burning tropical vegetation near the zone's southern and southwestern border. Future effects on visibility depend on where, when, and how much burning occurs. Smoke and plant particles are the primary cause of haze in the west, with an assist from sea salt, the primary cause of haze in the east.

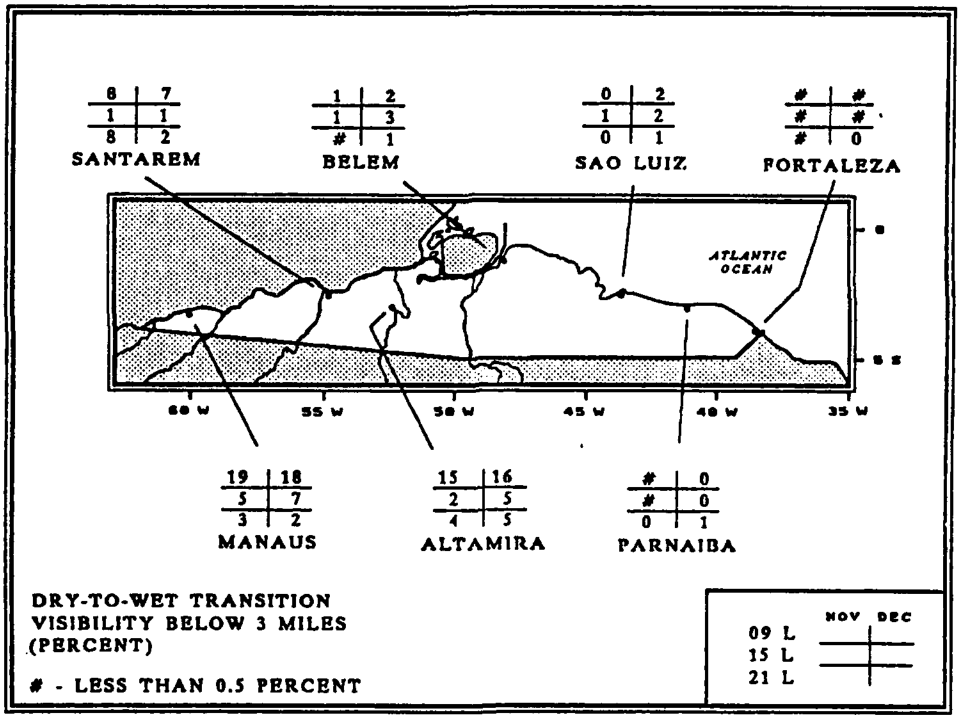


Figure 4-111. Percent Frequencies of Visibility Below 3 Miles, Eastern Amazon Basin.

WINDS. Winds are primarily controlled by the trade winds and land/sea breeze circulations. As a result, mean inland surface directions range from east-southeasterly in the east to east-northeasterly in the west.

STATION	MEAN WIND SPEED NOV	DEC
FORTALEZA	10	9
SOBRAL	8	8
PARNAIBA	11	10
SAO LUIZ	7	6
BELEM	8	7
ALTAMIRA	3	3
SANTAREM	8	7
PARINTINS	3	3
MANAUS	3	3

Figure 4-112. Mean Dry-to-Wet Transition Wind Speeds, Eastern Amazon Basin.

Northeasterlies prevail along much of the Atlantic coast. The zone's highest daily wind speeds occur at coastal locations (such as Belem, Turi-Assu, Sao Luiz, Sao Bento, and Parnaiba) where sea breezes are supported by the trades. Afternoon speeds at such locations range from 10 to 15 knots with gusts to 20 knots, while afternoon speeds at western stations average 5 knots or less. As shown in Figure 4-112, mean speeds across the zone range from 11 knots in the east to 3 knots in the west.

Strong winds are rare. This is especially true in dense forests where winds are weakened or dissipated at treetop level. Thunderstorms are the primary cause of high winds; gusts over 40 knots are possible. At night, winds along the Atlantic coast often weaken while maintaining an onshore component, but weak land breezes or calm winds can occur. Calm prevails at most inland sites during evening and nighttime hours. Manaus is a location well inland where calm winds prevail at least 50% of the time at all hours. Slope winds may affect parts of the zone at night. Stations at elevations near or above the mean height of radiation inversions are calm less frequently; an example is Guaramiranga, at 2,500 feet (760 meters) MSL.

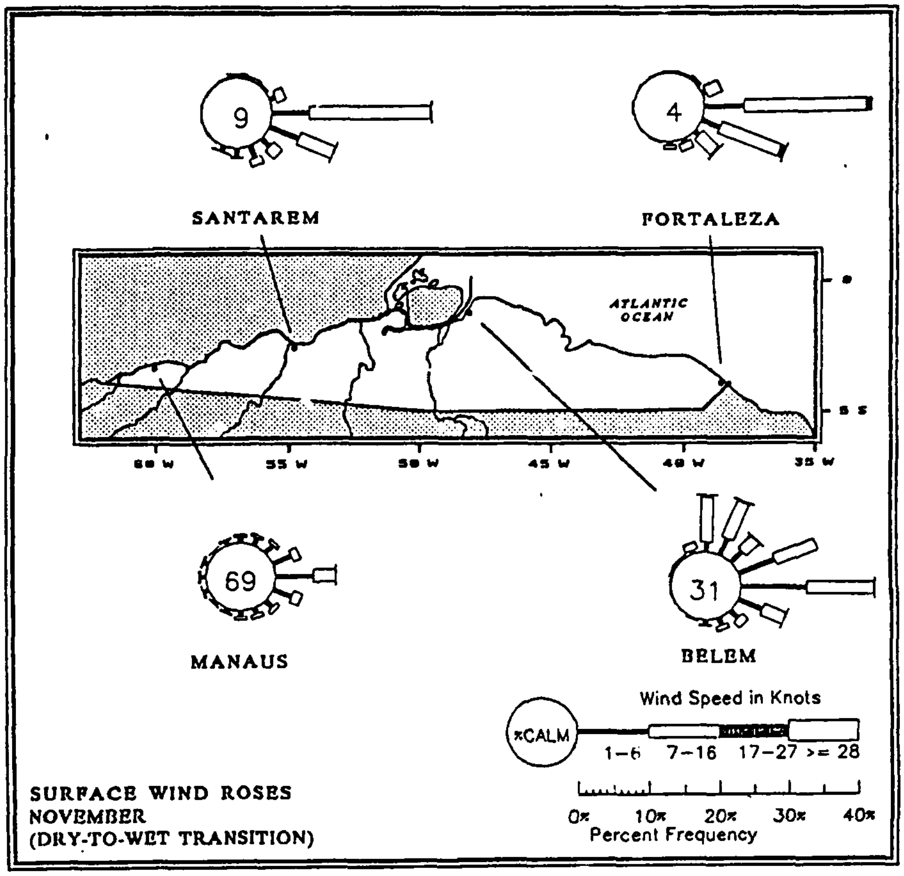


Figure 4-113. November Surface Wind Roses, Eastern Amazon Basin.

Mean upper-air winds are less than 30 knots at all levels. Easterlies prevail through 20,000 feet (6.1 km) MSL; above, winds vary from west-southwesterly in the east to southerly in the west.

PRECIPITATION. As in the other seasons, showers are the most common form of precipitation, most as organized activity along disturbances. However, sporadic convection begins occurring more often in the zone's central and western sections as the trade-wind inversion weakens.

The mean number of days a month with precipitation range from 1 at Sobral in the east, to 13-16 at Belem, to near 12 at Manaus in the west (see Figure 4-114). Sobral is sheltered by mountains and consequently has fewer precipitation days than surrounding locations. At Guaramiranga, near 2,500 feet/760 meters, there are more precipitation days than nearby locations because of terrain and sea breezes.

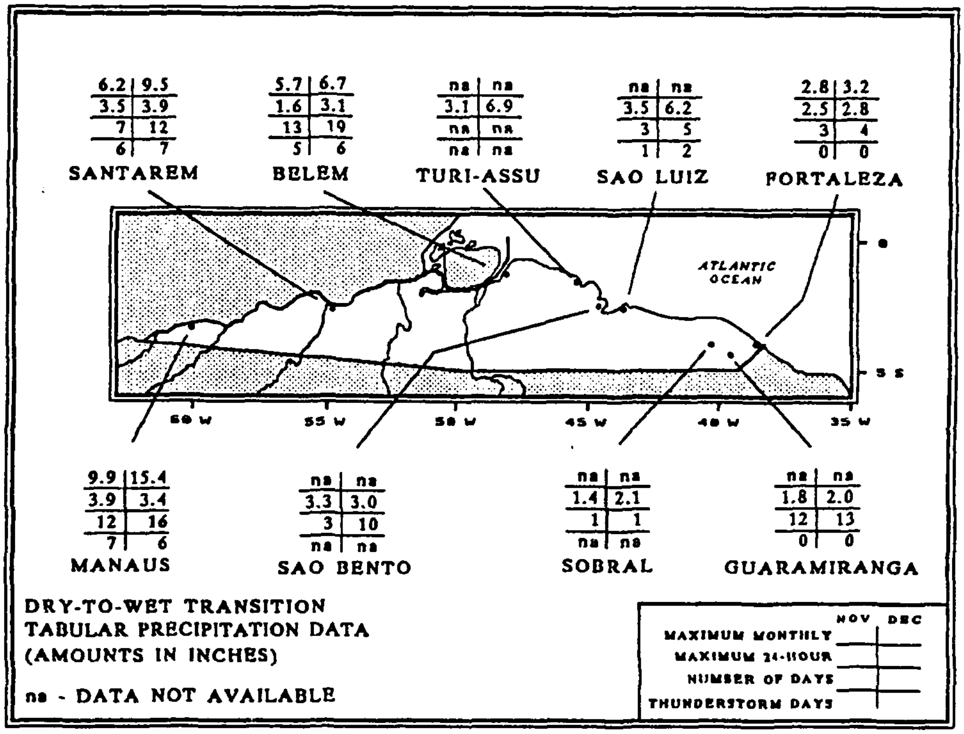


Figure 4-114. Dry-to-Wet Transition Tabular Precipitation Data, Eastern Amazon Basin.

Rainfall becomes heavier, as indicated by maximum 24-hour amounts near 7 inches (178 mm). The zone's mean monthly rainfall amounts are lowest in the east (less than 1 inch) where droughts are possible. Mean monthly amounts in the central section range from 3 to 4 inches (76-102 mm) and in the west from 5 to 6 inches (127-152 meters). Figure 4-115, showing average amounts for November, reflects land/sea breeze circulation effects. The band of higher amounts near the coast is caused by afternoon showers associated with sea-breeze fronts. Amounts decrease farther inland where sea-breeze activity weakens at night.

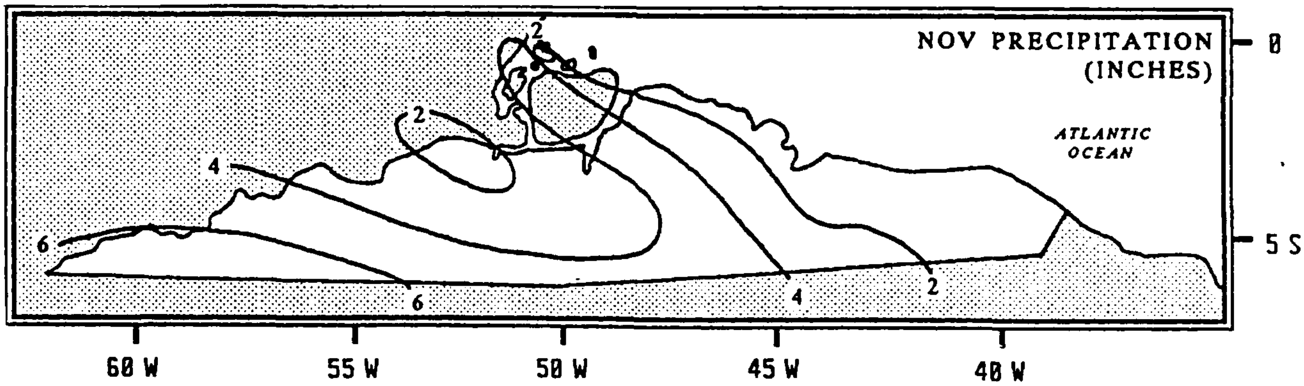


Figure 4-115. Average Precipitation for November, Eastern Amazon Basin.

THUNDERSTORMS. Thunderstorms can occur as organized activity along disturbances on from very brief unorganized afternoon convection. Most occur in the zone's central and western sections where the mean number of thunderstorm days ranges from 4 to 8 a month. The eastern section has fewer thunderstorm days since the trade-wind inversion remains strong there. Mean thunderstorm days in the east are less than 1 a month.

Bases of thunderstorms can be less than 1,000 feet (305 meters) MSL. Tops are usually between 40,000 and 50,000 feet (12.2 and 15.2 km) MSL. Heavy downpours are common. Tornado activity is rare to nonexistent, and hail does not occur. Gusts occasionally exceed 40 knots, but they usually dissipate as they penetrate the dense central and western forest canopies. Thunderstorm-associated middle and high clouds can become widespread and produce as much precipitation as thunderstorm cores. Unlike in the mid-latitudes, these clouds often appear to trail behind thunderstorm cells, the result of the cells propagating faster than (or toward) mid- and high-level flow. Such apparent thunderstorm movement is mostly due to propagation either along some low-level disturbance or toward low-level thunderstorm outflow. Propagation is typically southwesterly during the dry-to-wet transition. Channeling of thunderstorm outflow in lowland areas can cause propagation in other directions.

TEMPERATURE. Temperatures are moderated diurnally and seasonally by moisture-laden tropical forests and exposure to oceanic air. This can be seen in Figure 4-116, where most stations have average lows near 75° F (24° C) and average highs near 90° F (32° C). The primary exceptions are Guaramiranga and Sobral. Guaramiranga, at a higher elevation, has the zone's lowest recorded temperature at 61° F (16° C). Sobral, with the zone's highest recorded temperature at 102 F (39° C), is an inland, less wooded, station.

Radiation heating and cooling occurs in forest canopies in the zone's central and western sections, but occurs at ground level in the east. Under clear skies, temperatures in canopies average a few degrees warmer than the underlying surface at night and roughly 10° F (6° C) warmer during afternoons.

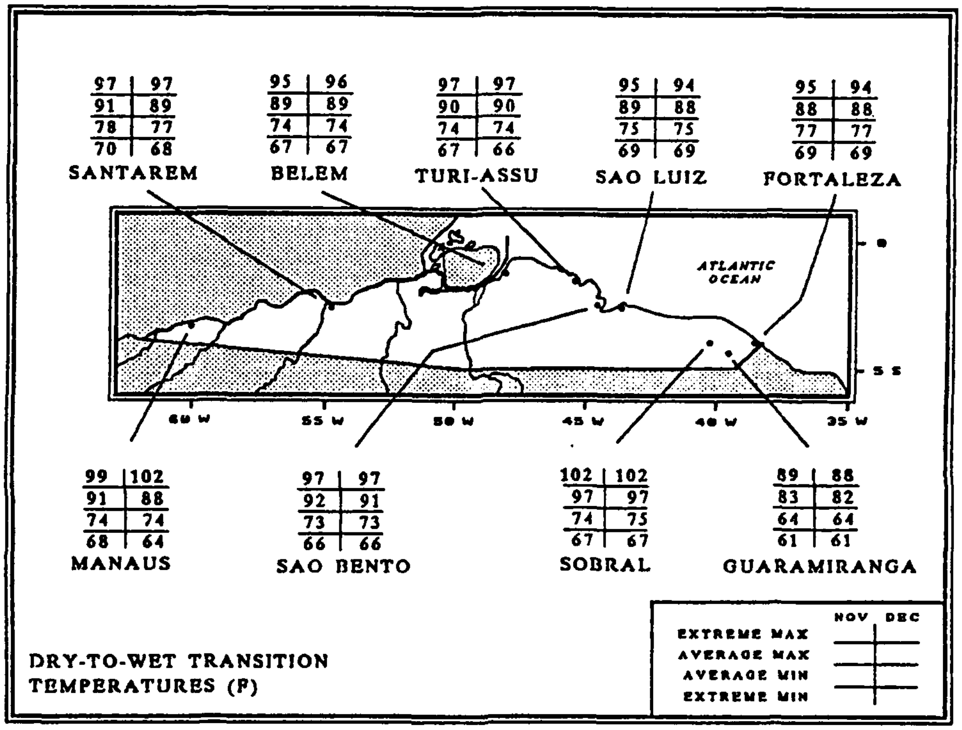


Figure 4-116. Dry-to-Wet Transition Tabular Temperature Data, Eastern Amazon Basin.

Central and western forests have the zone's highest relative humidities. Mean minimums exceed 70% within the forests while ranging from 60 to 70% along the Amazon River. In the east, mean minimums range from 60 to 70% along the Atlantic coast and from 40 to 50% at inland locations.

Mean maximum relative humidities for the entire central and western portions, and in the maritime air along the Atlantic coast, range from 80 to 90%. They are lowest in eastern inland locations, where mean maximums range from 60 to 70%. Figure 4-117 shows five stations with wet-bulb globe temperature data (° F) at specific hours in December.

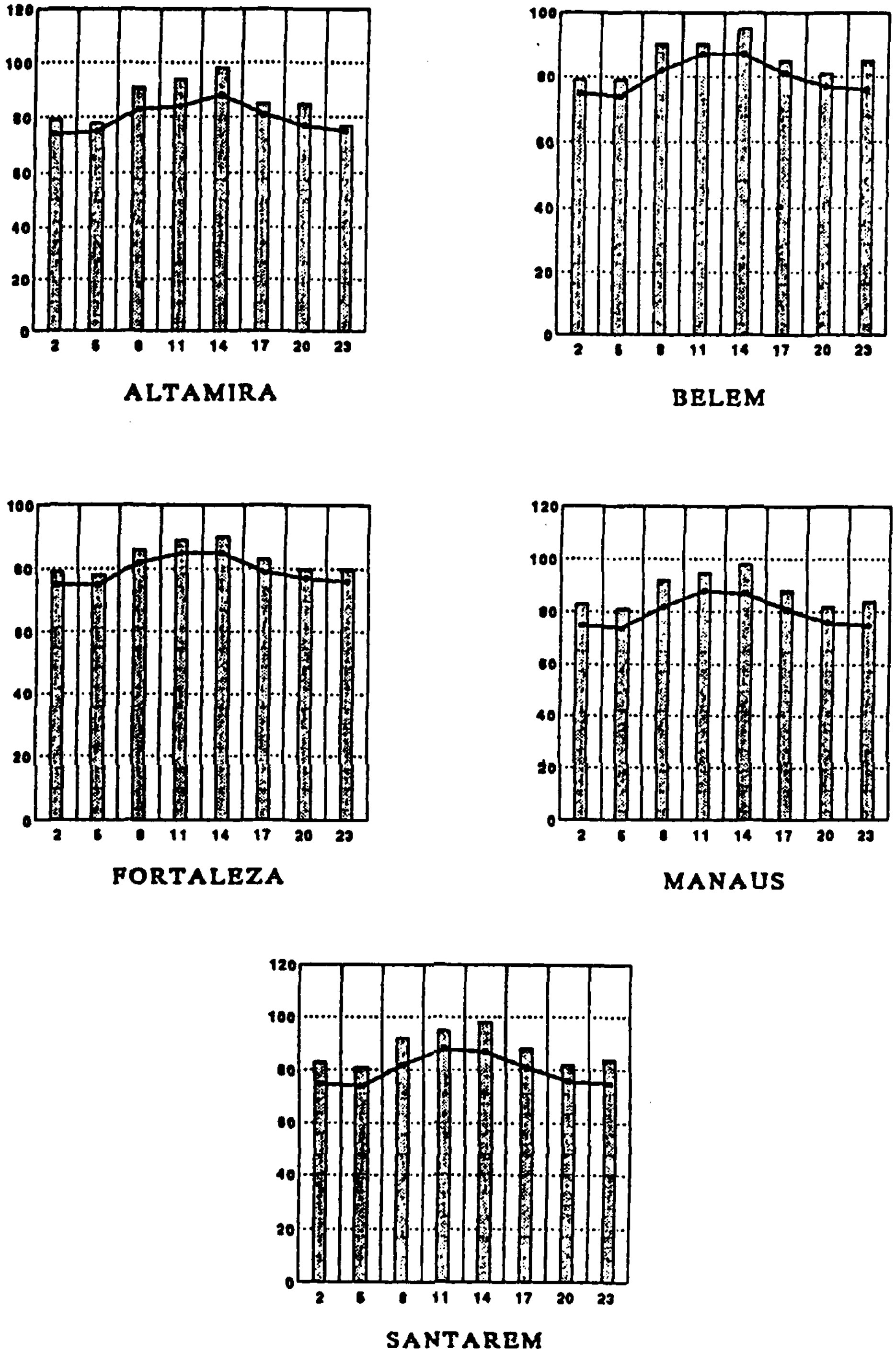


Figure 4-117. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for December, Eastern Amazon Basin. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Severe thunderstorm turbulence is likely from the surface through at least 20,000 feet (6.1 km) MSL. Severe mixed icing occurs between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL. Expect at least moderate icing and turbulence at similar heights in cumulus clouds. In the east, afternoon thermal turbulence is common. It can be moderate through 5,000 feet (1,525 meters) AGL and light through 10,000 feet (3,050 meters) AGL in rocky, barren areas. Terrain-induced afternoon turbulence is also possible; it is typically light, but it can reach moderate intensity between 52 and 56° W. Directional shear occurs along sea-breeze fronts. Speed shear occurs above radiation inversions at night. A low-level jet-stream along the Amazon River at night can cause strong speed shear immediately above radiation inversions. This jet reaches 30- to 40-knots between 990 and 2,300 feet (300 and 700 meters) MSL. Late in the season, cropland burning causes haze from the surface through 20,000 feet (6.1 km) MSL. It can be particularly dense between 7,000 and 16,000 feet (2,130 and 4,880 meters) MSL. Density depends more on stability than on the amount of burning. Exceptionally stable conditions can produce haze that lowers visibility to less than a mile. The haze is hazardous when it obscures afternoon convective clouds.

GROUND HAZARDS. Heavy precipitation can reduce visibilities below a mile. Water levels, at their lowest in October and November, begin rising in December. Heavy rains and sluggish run-off cause annual water levels to vary by 40-45 feet. Much of the area becomes swampy and travel is difficult. Flash floods are possible in the east.

4.4 BRAZILIAN EAST COAST

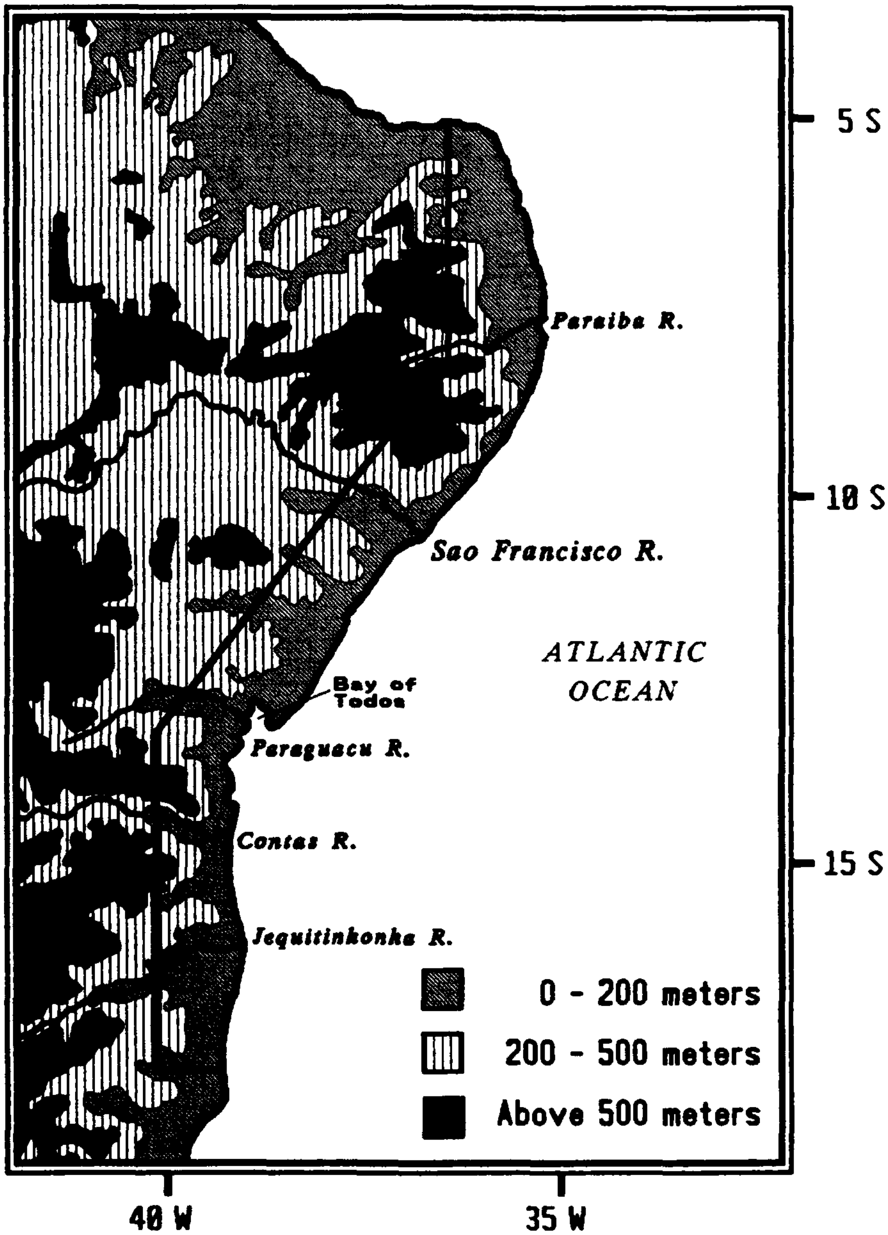
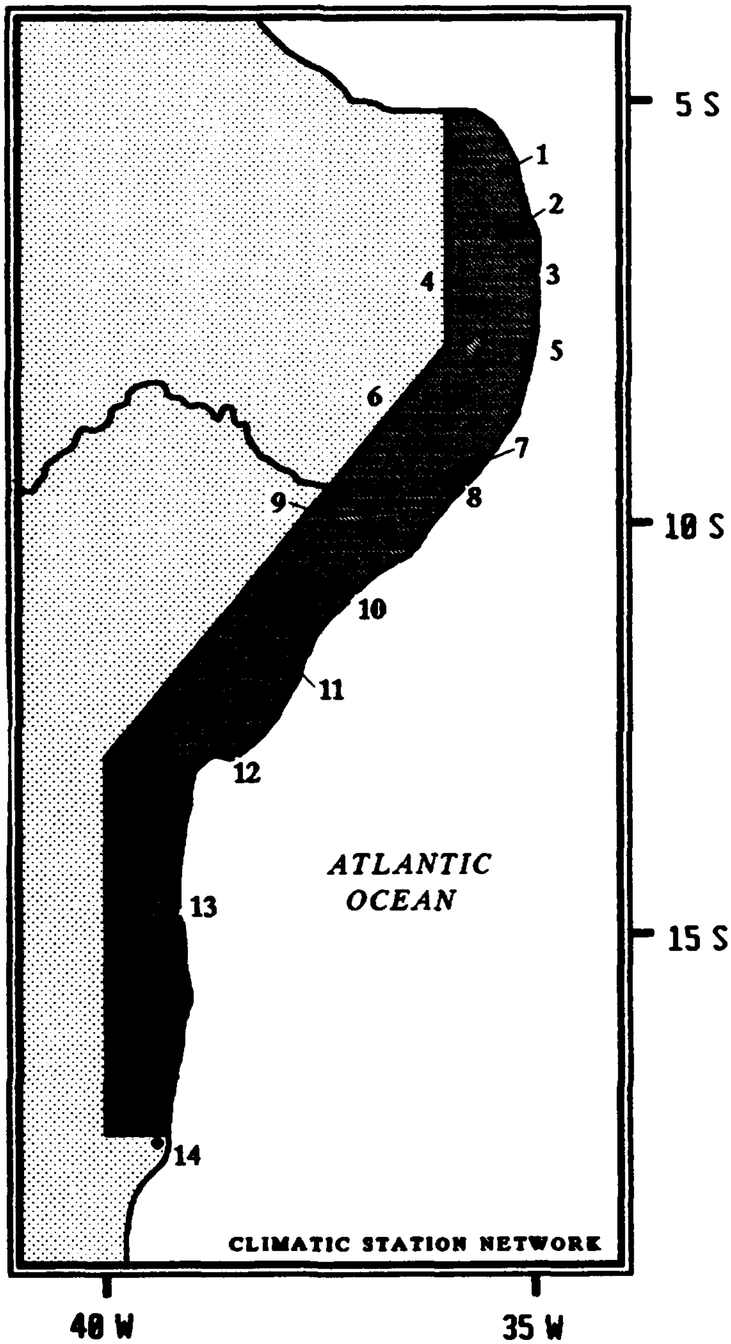


Figure 4-118. Brazilian East Coast. This zone follows the coastal plain of Brazil from 5 to 19° S. It is 60 to 70 miles wide and includes the first range of the Brazilian Highlands fronting the narrow coastal plain.



	ELEVATION (FEET)
1. NATAL	171
2. GUARABIRA	331
3. JOAO PESSOA	23
4. CAMPINA GRANDE	1,837
5. RECIFE	62
6. GARANHUNS	2,696
7. CAMPO DOS PALMARES	377
8. MACEIO	292
9. PROPRIA	62
10. ARACAJU	30
11. ITABAIANINHA	682
12. SALVADOR	20
13. ILHEUS	16
14. CARAVELAS	13

Figure 4-119. Climatic Station Network, Brazilian East Coast.

BRAZILIAN EAST COAST GEOGRAPHY

TERRAIN. The coastal plain consists of a series of sandbars and lagoons with many miles of white, sandy beaches and numerous sand dunes. The coastline is fairly smooth. It has only one natural harbor of any size: the Bay of Todos (or Santos) near the city of Salvador. The mountain range facing the coast south of Salvador is called the "Great Escarpment" and is the eastern edge (or serra) of the Brazilian Highlands. Several serras face the east coast, a few exceeding 3,300 feet (1,006 meters) south of Salvador and west and north of Recife. They often drop sharply to the coast. In other places, there are a series of short steps more conducive to vegetation.

RIVERS. Four rivers are fairly evenly spaced from north to south. Each cuts deeply through the highlands from west to east. The largest and most well-known is the Sao Francisco River. The Paraguacu River empties into the Bay of Todos west of Salvador.

VEGETATION. The coast is mostly sand. Vegetation is of the dune type, with occasional groves of mangrove trees. Almost nothing but palm trees grow at 1,970 feet (600 meters). Tropical rain forest covers the higher slopes, but changes quickly to palm trees again on the lee side of the crest. The transition is more gradual atop a plateau.

BRAZILIAN EAST COAST CLIMATIC PECULIARITIES

THE SOUTH ATLANTIC HIGH, a persistent trade-wind inversion, and extratropical disturbances are the major meteorological controls. The South Atlantic High and associated trades cause year-round inversions, one based at 5,000 to 6,000 feet (1,525 to 1,830 meters) MSL and (often) another based at about 15,000 feet (4,570 meters) MSL. As a result, disturbances are weakened and often appear to be unorganized. They affect a relatively shallow layer of the atmosphere.

EXTRATROPICAL SYSTEMS occur in the fall and winter seasons. These are the most important disturbances; they include cold fronts and associated leeside troughs, shear lines, upper-level cyclones, and coastal convergence zones (also called "frontal-induced troughs").

Cold fronts. Most cold fronts lose air mass discontinuity before moving north to 15° S. Shear lines often result. Westerly flow across the mountains north of cold fronts often causes leeside troughing along the coast. Persistent westerly flow can create temporary upwelling, enhancing coastal stratus.

Frontal-induced troughs are different from leeside troughs. They are important in this zone, but have minimal effects elsewhere. They occur most often, and are most intense, during the wet season. Transitions have a weaker, less defined version, and they don't occur at all during the dry season. Frontal troughs only develop when frontolysis occurs toward the south; trough location depends on where frontolysis occurs. The trough normally forms oriented north-south between about 400 and 800 miles north of the frontolysis; this is usually along the coast between 5 and 10° S, but can occur along any part of the coast. Frontal-induced troughs follow a 4- to 7-day cycle, beginning with the destruction of the trade-wind inversion, a veering of the surface winds to southerly, and up to 24 hours of rain showers. The showery period is followed by up to 24 hours of settled weather. Cirrostratus and altostratus then approach from the east and surface winds back to easterly. For the next 1 or 2 days, lines of heavy showers and occasional thunderstorms move westward into the zone. The weather improves as the convergence zone rapidly weakens.

ANOMALOUS SEA SURFACE TEMPERATURES (SSTs) in the western South Atlantic may cause abnormal weather across eastern Brazil. Unusually high SSTs along the coast can promote cumuliform cloud development; lower SSTs may cause stratiform clouds and fog.

A NOTE ON DATA SCARCITY. Data is sparse in the mountains and interior lowlands and may not be representative of all areas. For example, precipitation data is available for only one inland station. The highest maximum 24-hour rainfall amount available for precipitation figures is 10.5 inches (267 mm) at Ilheus in April; however, 24-hour amounts are known to have reached 16 inches (406 mm) in the zone's central mountains during January.

GENERAL WEATHER. Precipitation amounts are low because frontal troughs are rare and weak high-level convergence adds stability. Cold fronts and shear lines are at their strongest early in the dry season, but their northward penetration is inhibited by the South Atlantic High. They often cause a brief November-December rainy period south of 11° S as the South Atlantic High recedes from the continent (see Figure 4-129b). The dry season is very distinct north of 11° S. The greatest precipitation occurs where disturbances intersect; stability increases and weather improves throughout the surrounding area. Leeside troughs, occasional upper-level cyclones, and local effects are other dry season features.

SKY COVER. Figures 4-120a-c show that mean dry-season cloudiness exceeds 50% across most of the zone, mostly due to low clouds. Low-cloud amounts vary locally and diurnally. They are most common in the north. Middle and high clouds also occur.

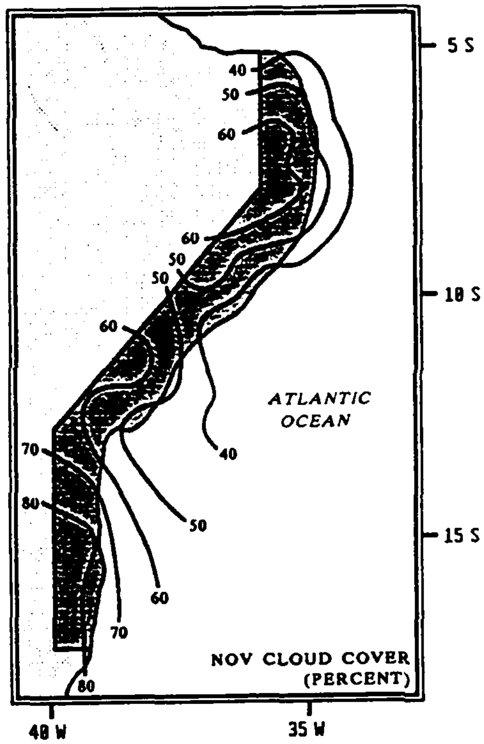


Figure 4-120b. Mean November Cloud Cover, Brazilian East Coast.

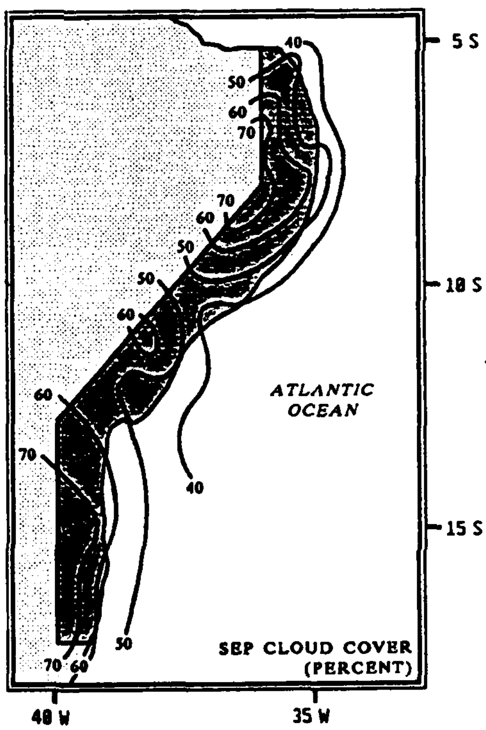


Figure 4-120a. Mean September Cloud Cover, Brazilian East Coast.

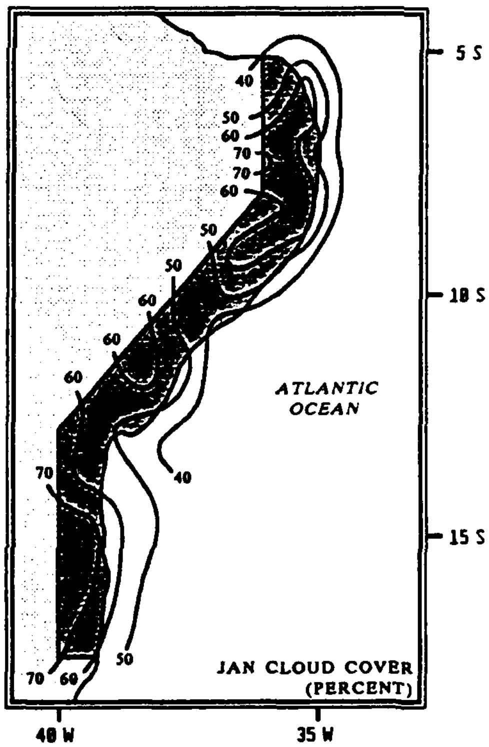


Figure 4-120c. Mean January Cloud Cover, Brazilian East Coast.

Disturbances produce broken clouds with bases between 1,000 and 2,000 feet (305 and 610 meters) MSL. Most tops are below 15,000 feet (4,570 meters) MSL in the north and 20,000 feet (6.1 km) MSL in the south. Clouds can be stratiform or cumuliform, depending on the strength of the system, but cumulonimbus and nimbostratus are rare. Disturbances are easiest to locate over land at night when associated cloudiness is shallow and organized.

Local effects influence cloud formation during undisturbed periods. Low clouds are most common on east-facing slopes due to orographic lift. During the afternoon, sea breezes and convective heating cause cumulus and towering cumulus inland. Land breezes, possibly enhanced by slope winds, can converge with trade-wind flow and cause scattered to broken stratocumulus near the coast at night. The stratocumulus begins moving inland after local nocturnal breezes dissipate. Differential friction between land and water causes convergence and low clouds near the coast. Fair weather periods see scattered to broken stratocumulus and cumulus, with bases at 4,000 to 6,000 feet (1,220 to 1,830 meters) MSL. Most tops are between 8,000 and 13,000 feet (2,440 and 3,960 meters) MSL.

In most of the zone, low ceilings are most common in the morning and least common in the evening; however, areas that experience localized convergence exclusively during daytime hours, are likely to have high frequencies of low ceilings during the day. Low ceilings are most common in the mountains. This is shown by the Figure 4-121 data for Campina Grande, the only mountain station with ceiling data available.

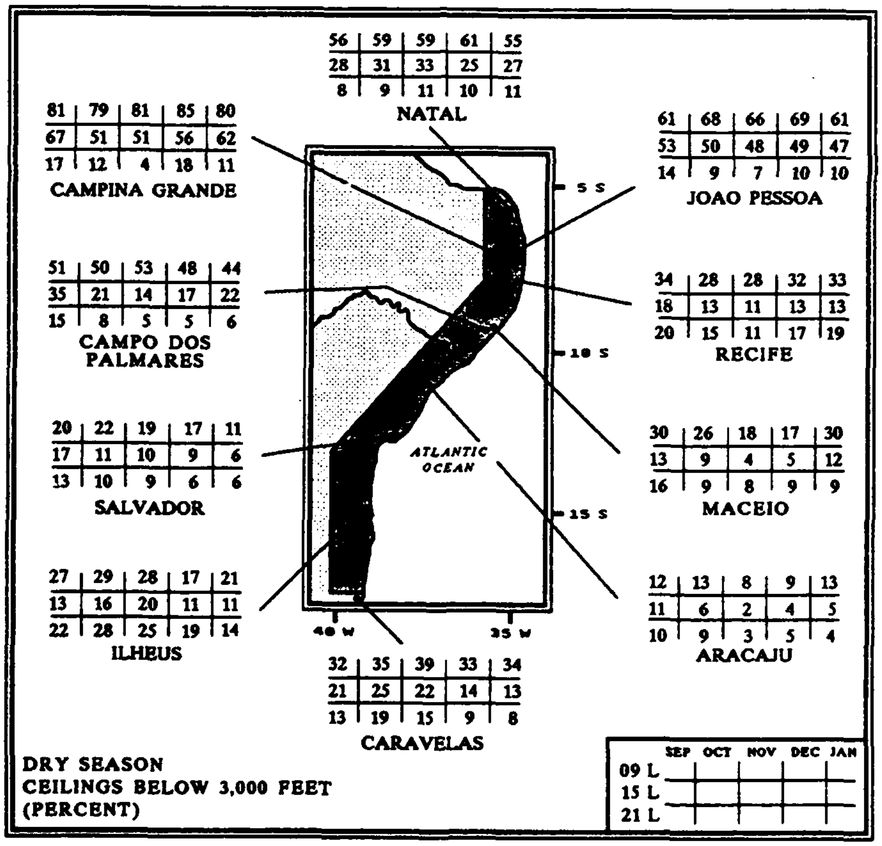


Figure 4-121. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian East Coast. Low-ceiling frequencies are higher and more diurnally variable in the north.

VISIBILITY. Dry-season visibilities are generally good. Salt haze, most common during afternoons, doesn't cause poor visibilities so much as it prevents exceptionally good ones; precipitation and fog are the primary causes of low visibilities. Precipitation reduces visibilities below 6 miles less than 5% of the time throughout the zone. Fog, varies locally and diurnally, accounting for higher frequencies of low visibilities in the mountains and during morning.

Becasue of the zone's frequent clouidiness, fog generally doesn't result in exceptionally low visibilities. Local nocturnal wind systems, such as downslope winds and land breezes, also help dry the air. Mountain fog is caused by radiation cooling, upslope flow, and saturation of the air by precipitation. Depending on terrain, fog can reduce visibilities below 6 miles up to 10 days a month, but less than 5 days a month on the coast. Warm ocean currents are unfavorable for sea fog formation.

Figure 4-121 shows that low dry-season visibilities are rare. Visibilities below 3 miles normally last for less than an hour and rarely for more than 2 hours. They occur less than 3% of the time on the coast regardless of the time of day. Visibilities in the mountains vary diurnally; frequencies below 3 miles are as high as 10% mornings and less than 3% at other times. Visibilities less than 1 mile are very rare, occurring less than 1% of the time everywhere.

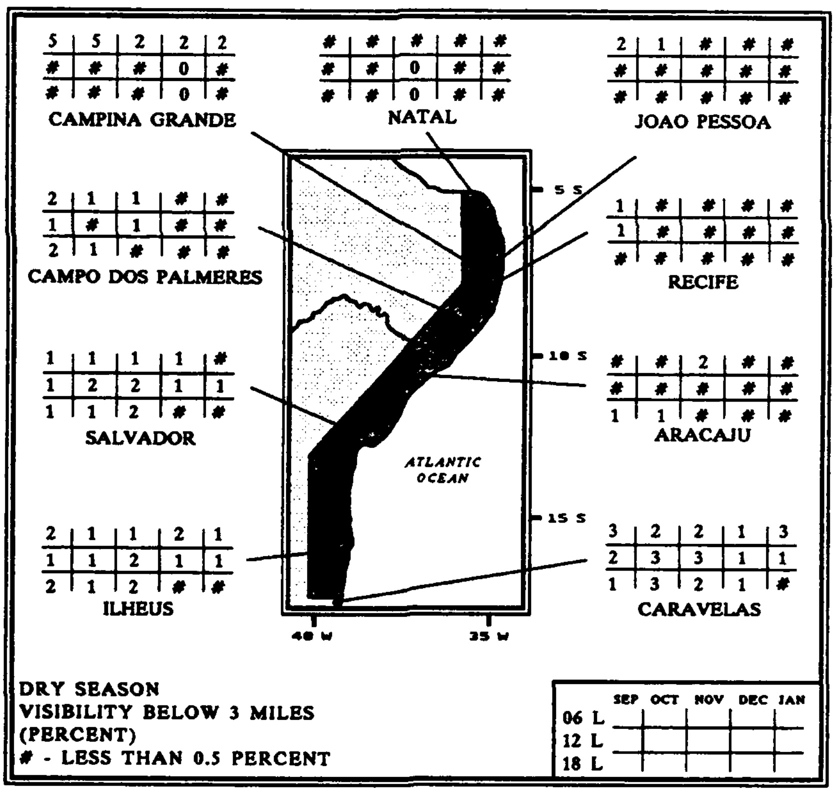


Figure 4-122. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Brazilian East Coast.

WINDS. The trade-winds dominate, with variations caused by land/sea breeze circulations, mountainous terrain, and cold fronts/shear lines. Weak land breezes occasionally occur around sunrise. Sea breezes strengthen afternoon trade-wind flow. Mountain/valley circulations can enhance or dampen land/sea breezes and trade winds. Mountainous terrain can block or channel flow. Most cold fronts/shear lines are preceded by light and variable winds, but westerlies are not uncommon. Cold fronts/shear lines are followed by weak southerlies.

The highest wind speeds occur over the Atlantic where surface friction and radiation inversions are insignificant; mean speeds can exceed 10 knots. Salvador's peninsular location makes its winds similar to those over the ocean (see Figure 4-123). High mean speeds also occur in the north where the trades are stronger; they range from 6 to 8 knots as opposed to 4 to 7 knots in the southern two-thirds of the zone. Maximum speeds in the north exceed 35 knots and are caused by exceptionally strong trades. Afternoon winds in the north are usually southeasterly at about 15 knots, gusting to 20 knots; in the south, they are north to east-northeasterly and slightly weaker. Between 2100 and 0800L, winds range from calm to variable at 5 knots. In the south, strong trades, rare thunderstorms, and gradient flow associated with rare cold fronts can cause brief 30-knot gusts. On occasion, winds ahead of cold fronts flow down eastern mountain slopes, causing adiabatic warming and leeside troughing.

STATION	MEAN WIND SPEED				
	SEP	OCT	NOV	DEC	JAN
ARACAJU	6	7	7	6	6
CAMPINA GRANDE	7	8	8	8	8
CAMPO DOS PALMARES	4	4	5	5	5
ILHEUS	5	5	5	5	4
JOAO PESSOA	6	6	6	6	6
MACEIO	4	4	5	5	5
NATAL	8	7	7	7	6
RECIFE	7	6	7	7	6
SALVADOR	9	9	9	8	8

Figure 4-123. Mean Dry-Season Wind Speeds, Brazilian East Coast.

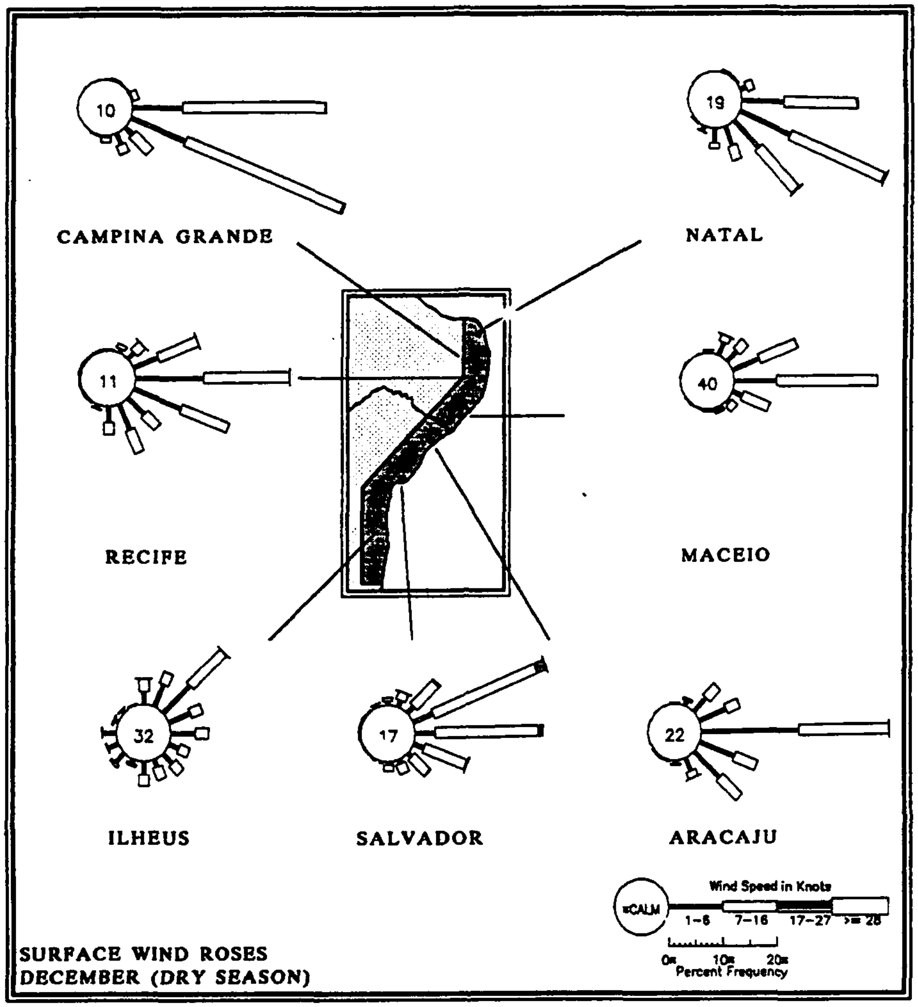


Figure 4-124. December Surface Wind Roses, Brazilian East Coast.

Figures 4-125 through 4-128 show upper-air wind directions. East-southeasterlies prevail below 20,000 feet (6.1 km) MSL in the north; they are east-northeasterly below 15,000 feet (4,570 meters) MSL in the south. Above these heights, winds become westerly and, with increasing height, gradually back to southerly. Mean upper-air speeds are less than 20 knots below 30,000 feet (9.1 km) MSL and 20 to 35 knots above.

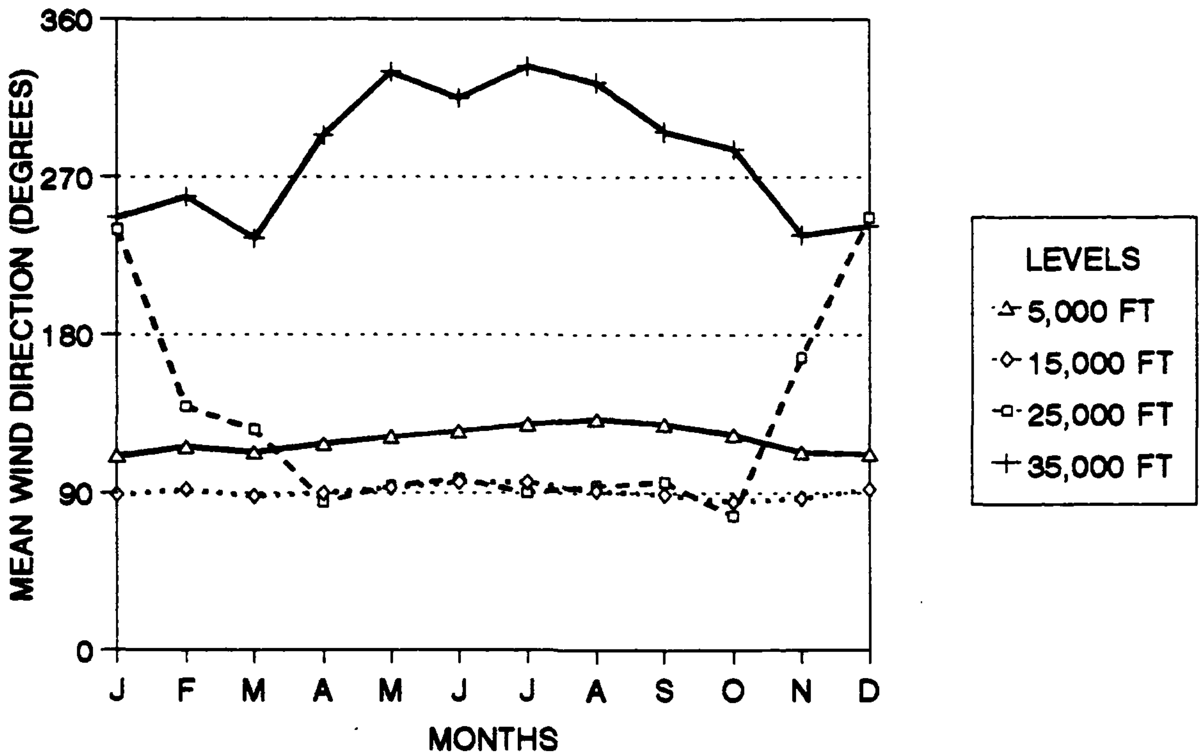


Figure 4-125. Mean Monthly Wind Directions for Various Levels at Natal.

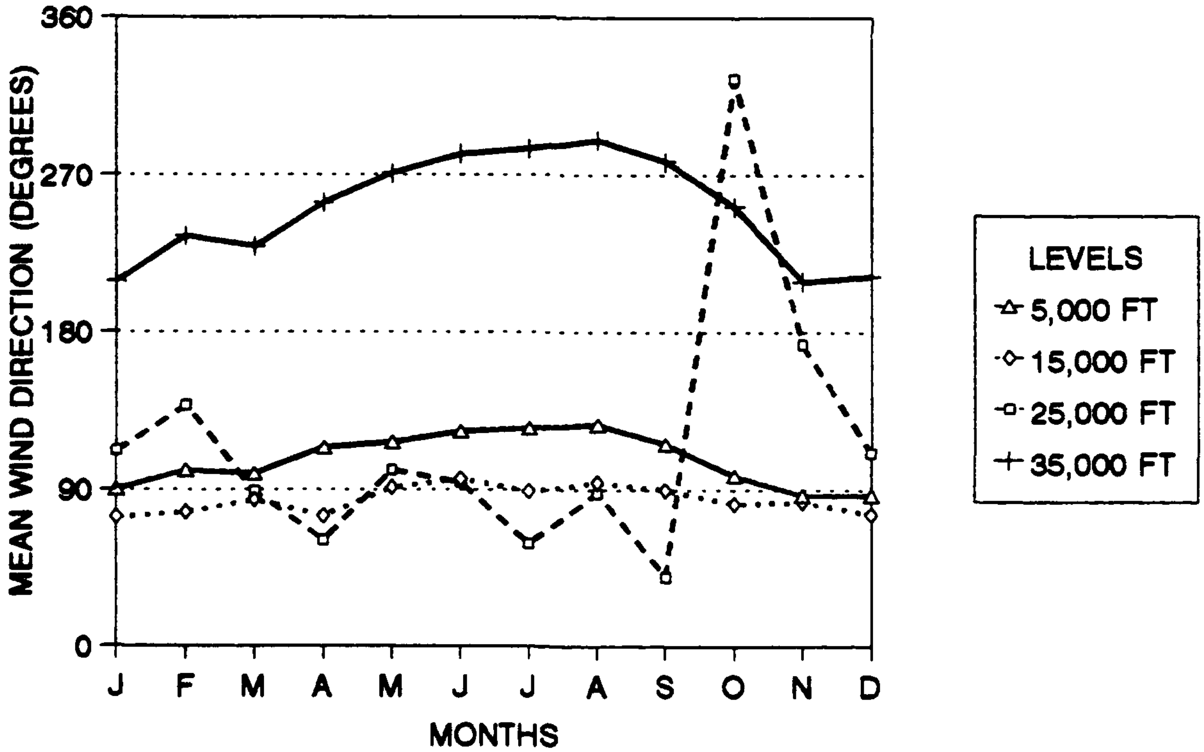


Figure 4-126. Mean Monthly Wind Directions for Various Levels at Recife.

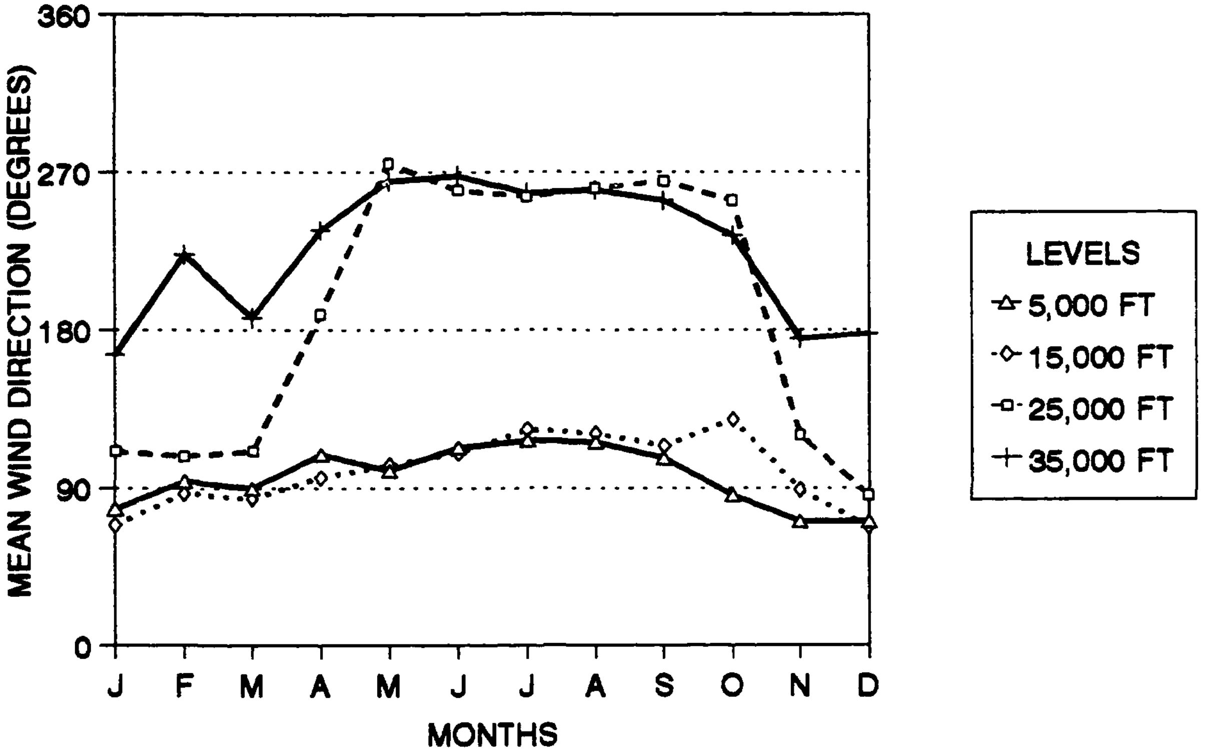


Figure 4-127. Mean Monthly Wind Directions for Various Levels at Salvador.

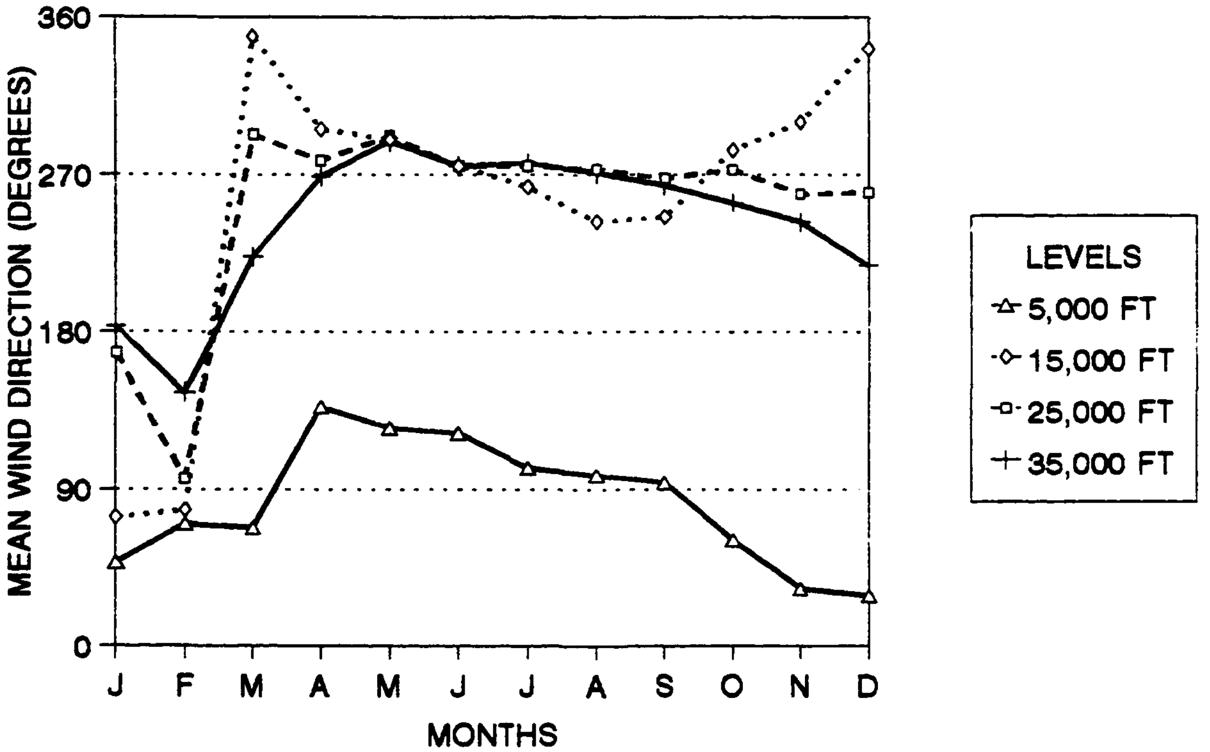


Figure 4-128. Mean Monthly Wind Directions for Various Levels at Caravelas.

PRECIPITATION. Cold fronts and shear lines are the primary cause of rainfall in the southern half; a November and December rainfall peak appears in Figures 4-129a-c.

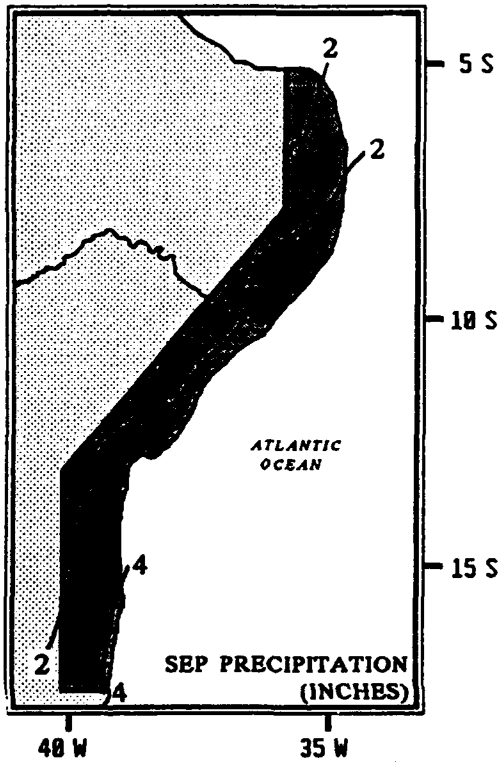


Figure 4-129a. Mean September Precipitation, Brazilian East Coast.

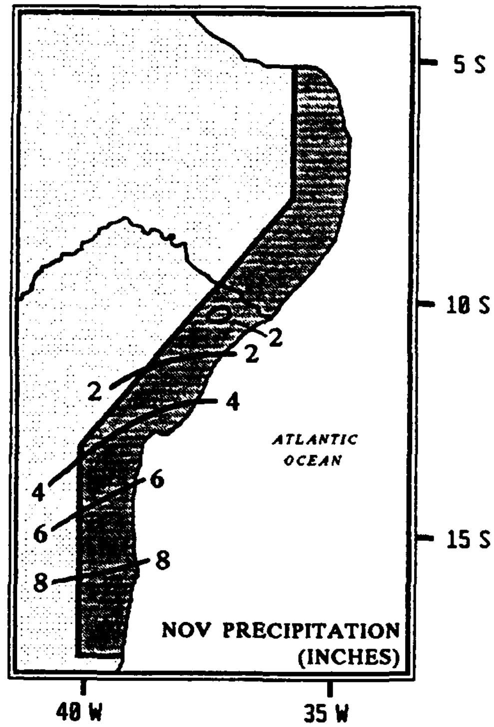


Figure 4-129b. Mean November Precipitation, Brazilian East Coast.

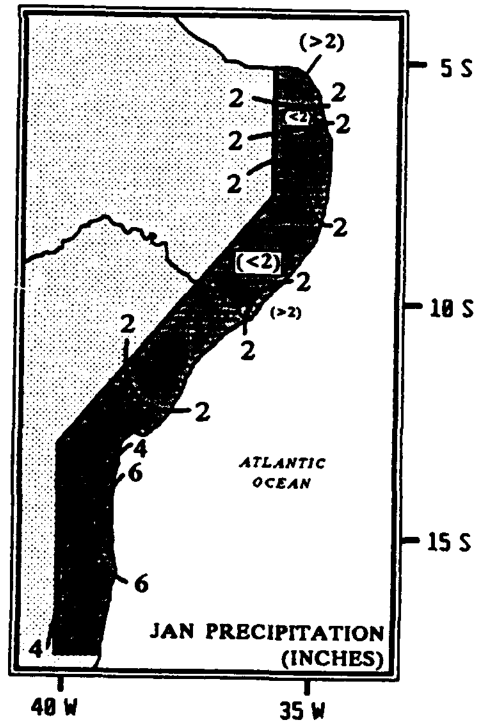


Figure 4-129c. Mean January Precipitation, Brazilian East Coast.

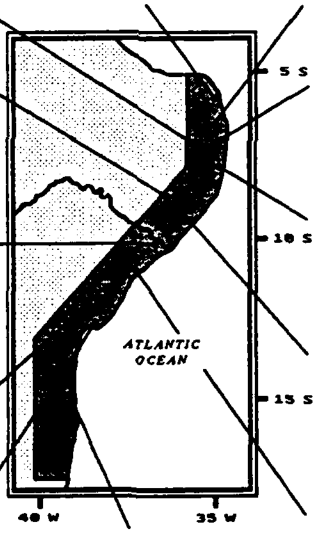
Most precipitation falls as light to moderate showers, but drizzle occasionally falls along windward coastal slopes. Heavy rainfall only occurs where disturbances intersect or are enhanced by local effects. This is most common in the south where rainfall amounts range from 3 inches (76 mm) in September, to 8 inches (203 mm) in November, to 5 inches (127 mm) in January. Central and northern sections average less than 3 inches (76 mm) for all months.

Land breezes, possibly enhanced by slope winds, converge with synoptic flow to cause morning coastal showers. Radiation cooling of cloud tops over the ocean can also create enough instability for morning showers near the coast.

Upslope flow occurs on southern slopes with and after passage of cold fronts/shear lines, as well as on eastern slopes during normal easterly flow. Convective heating and sea breezes contribute to inland convergence and precipitation during the afternoon. Two or more days of intermittent light precipitation occurs with most disturbances.

Maximum 24-hour rainfall amounts are known to have reached 16 inches (406 mm) in the zone's central mountains during January. Precipitation days are highest along the southern coast, ranging from 9 to 17. The northern and southern inland areas average a few days less (Figure 4-130).

Station		SEP	OCT	NOV	DEC	JAN
CAMPINA GRANDE	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	1.2	1.8	1.0	0.9	1.8
	Precipitation days	na	na	na	na	na
	Thunderstorm days	na	na	na	na	na
NATAL	Maximum monthly	7.9	3.3	4.4	3.0	4.5
	Maximum 24-hour	2.9	1.3	1.6	1.2	1.8
	Precipitation days	8	5	6	7	10
	Thunderstorm days	0	0	0	0	0
GUARABIRA	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	1.0	1.1	1.0	1.2	2.9
	Precipitation days	6	2	2	4	6
	Thunderstorm days	na	na	na	na	na
GARANHUNS	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	4.6	6.0	4.1	5.9	3.8
	Precipitation days	12	7	4	7	8
	Thunderstorm days	0	1	1	1	2
JOAO PESSOA	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	2.4	0.9	1.7	2.0	2.4
	Precipitation days	16	8	8	11	15
	Thunderstorm days	na	na	na	na	na
PROPRIA	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	1.5	1.7	3.4	2.2	2.4
	Precipitation days	4	5	3	2	7
	Thunderstorm days	4	4	3	13	11
RECIFE	Maximum monthly	10.2	5.0	3.6	6.0	5.6
	Maximum 24-hour	2.1	2.8	2.7	6.0	4.3
	Precipitation days	13	9	8	8	11
	Thunderstorm days	0	#	#	1	#
ITABAIANINHA	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	2.0	3.4	4.0	2.4	2.4
	Precipitation days	na	na	na	na	na
	Thunderstorm days	na	na	na	na	na
MACEIO	Maximum monthly	6.2	11.2	8.8	6.0	7.1
	Maximum 24-hour	2.3	2.9	2.1	6.0	3.8
	Precipitation days	10	6	6	6	10
	Thunderstorm days	#	0	#	#	#
SALVADOR	Maximum monthly	10.2	9.5	13.8	11.7	8.5
	Maximum 24-hour	2.7	3.2	4.5	5.1	3.2
	Precipitation days	16	14	15	14	14
	Thunderstorm days	0	1	2	3	3
ILHEUS	Maximum monthly	na	na	na	na	na
	Maximum 24-hour	2.6	5.0	7.0	3.9	3.9
	Precipitation days	13	12	13	13	11
	Thunderstorm days	0	1	2	2	2
ARACAJU	Maximum monthly	6.4	4.1	5.0	4.4	3.9
	Maximum 24-hour	3.6	3.8	1.9	3.7	1.7
	Precipitation days	14	9	6	6	8
	Thunderstorm days	0	0	#	1	1



DRY SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	SEP	OCT	NOV	DEC	JAN
MAXIMUM MONTHLY					
MAXIMUM 24-HOUR					
PRECIPITATION DAYS					
THUNDERSTORM DAYS					

Figure 4-130. Dry-Season Tabular Precipitation Data, Brazilian East Coast. Campina Grande and Garanhuns are mountain stations. Guarabira, Propria, and Itabaianinha are lowland interior stations; the rest are coastal.

THUNDERSTORMS only form when disturbances destroy the trade wind inversion that suppresses vertical development. They are not severe, but gusts can reach 30 knots. Most tops are less than 30,000 feet (9.1 km) MSL. Disturbances break down an inversion most effectively when accompanied by cold-air advection aloft. Land/sea breezes, mountain/valley breezes, orographic lift, and convective heating enhance thunderstorm development. Most thunderstorms occur during the day in interior central and southern sections. Thunderstorm days can exceed 10 a month inland, but a few sheltered slopes and valleys average only 1 day a month. On central and southern coasts, mean monthly thunderstorm days range from 0 to 3; in the north near the coast, where the trade-wind inversion is infrequently destroyed, they range from 0 to 5.

TEMPERATURE. Temperatures are moderated by the South Atlantic Ocean. Diurnal variations become greater with increasing distance from the coast. Extreme lows in the south occur with cold fronts. Extreme highs leeward of mountains occur where westerly flow causes adiabatic warming. Leeside effects also cause unusually low relative humidities.

Mean lows along the coast are in the low 70's (21-23° C). The lower elevations inland are similar, but the mountains can be up to 10° F (18° C) cooler. Mean highs along the coast range from as low as 80° F (27° C) in the south to as high as 88° F (31° C) in the north. Mean maximums in the mountains are similar to those on the coast, but low elevations inland are about 5° F (9° C) warmer. Extreme lows range from 50° F (10° C) in the south and in the mountains to 66° F (19° C) on the central coast. Extreme highs range from 91° F (33° C) on the central coast to 104° F (40° C) in central and southern lowland areas.

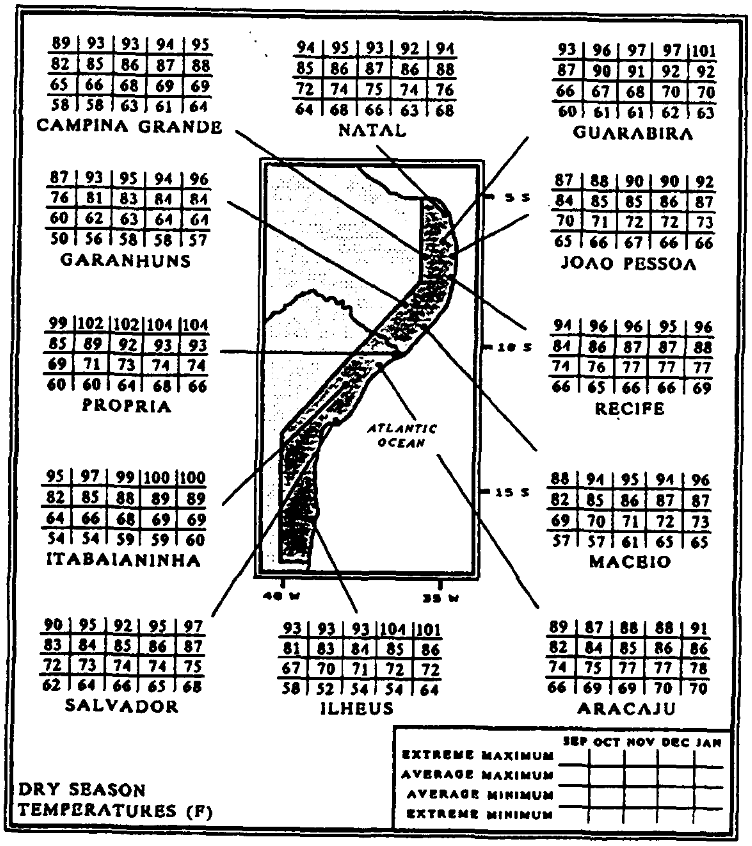


Figure 4-131. Dry-Season Tabular Temperature Data, Brazilian East Coast.

Relative humidities reflect maritime and terrain effects. Along the coast, mean RHs range from minimums of 65-75% to maximums of 80-90%. RH is more variable inland, with minimums as low as 50% and maximums as high as 90%. Figure 4-132 shows five stations with wet-bulb globe temperature data (° F) at specific hours in November.

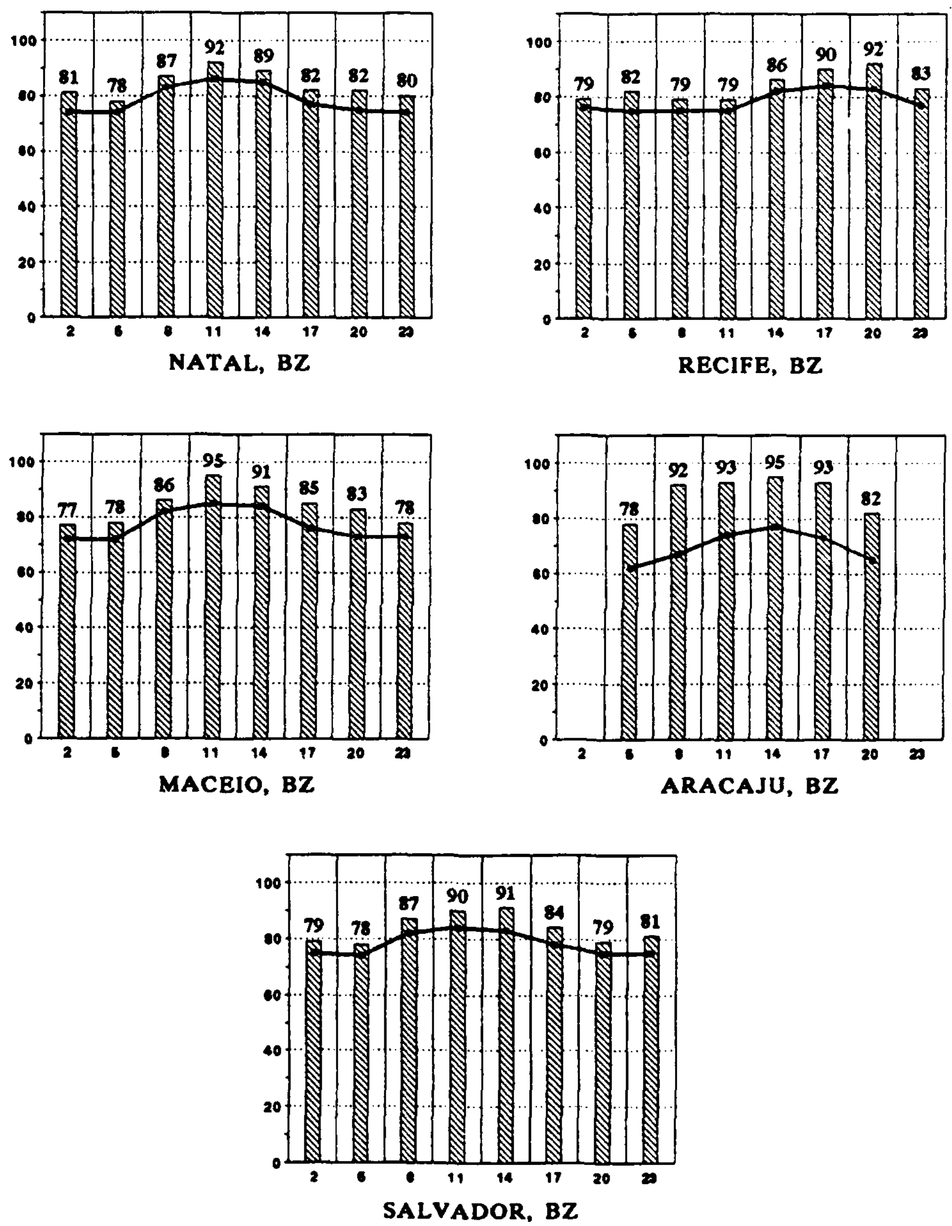


Figure 4-132. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for November, Brazilian East Coast. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. The typical thunderstorm hazards are present. Light to moderate mechanical turbulence occurs over the mountains during strong easterly flow; it affects the southern coast and mountains with strong westerly flow. Wind shear can occur near tops of radiation inversions, especially in the north. Surface winds drop below 5 knots at night, but winds above 1,000 feet (305 meters) AGL average near 20 knots. Clouds between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL are most favorable for icing, but icing can be found 2,000-3,000 feet (610-915 meters) lower with upper-tropospheric cyclones. Freezing levels average 15,000 ft (4,575 meters) MSL except with upper-tropospheric cyclones.

GROUND HAZARDS. Flash floods are the only dry-season ground hazard, but they are rare, occurring only with rapid mountain run-off after heavy or frequent moderate precipitation. Most flash floods occur on slopes and in low-lying areas near 9 and 10° S.

GENERAL WEATHER. Disturbances include extratropical fronts, shear lines, leeside troughs, frontal induced troughs, upper-level cyclones, and rare easterly waves. Recent research indicates that one (possibly two) easterly waves a season may reach the zone north of 10° S. Weak high-level divergence contributes to instability. The most active weather occurs when and where disturbances intersect; weather surrounding the intersection often improves.

SKY COVER. Cloudy skies are common across most of the zone. As shown in Figure 4-133, mean March cloudiness exceeds 50% nearly everywhere. Middle and high clouds are common, but most coverage is low cloudiness, which is most common and diurnally variable in the north.

Most disturbances cause zone-wide broken cloud cover with bases between 500 and 1,500 feet (150 and 455 meters) MSL. Most tops are below 20,000 feet (6.1 km) MSL in the north and less than 25,000 feet (7.6 km) MSL in the south. Cloud types can be stratiform or cumuliform, depending mostly on system strength. Easterly waves normally cause considerable heavy cumulus over the coastal ranges and inland for about 100 miles. Nimbostratus is rare. Disturbances are easiest to locate over land at night when clouds are shallow and more organized.

Local effects on sky cover include orographic lift, local wind systems, convective heating, and differential friction. Cloudiness is most widespread on east-facing slopes where upslope flow occurs most often. Afternoon sea breezes and convective heating contribute to inland convergence and the formation of cumulus and towering cumulus. Land breezes, sometimes enhanced by slope winds, can converge with trade-wind flow and cause scattered to broken cumulus and stratocumulus along the coast at night; clouds begin moving inland after land breezes end. Differential low-level wind friction between the land and water causes convergence that contributes to low cloudiness near the coast. Fair-weather periods normally see scattered to broken stratocumulus and cumulus with bases at 4,000 to 6,000 feet (1,220 to 1,830 meters) MSL. Most tops are between 8,000 and 13,000 feet (2,440 and 3,960 meters) MSL. Disturbance-associated heavy cumulus tops reach 25,000 to 30,000 feet (7.6 to 9.2 km) MSL.

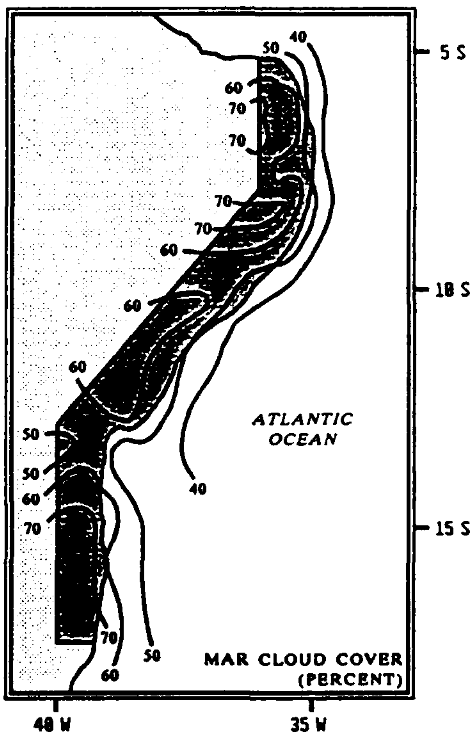


Figure 4-133. Mean March Cloud Cover, Brazilian East Coast.

Low ceilings are most frequent in the morning and least frequent in the evening. Those areas that have localized convergence exclusively during daytime hours are likely to have higher frequencies of low ceilings during the day. Low ceilings are most common in the mountains, as shown in Figure 4-134 by Campina Grande (the only mountain station with ceiling data available). Upslope flow contributes to higher frequencies of low ceilings.

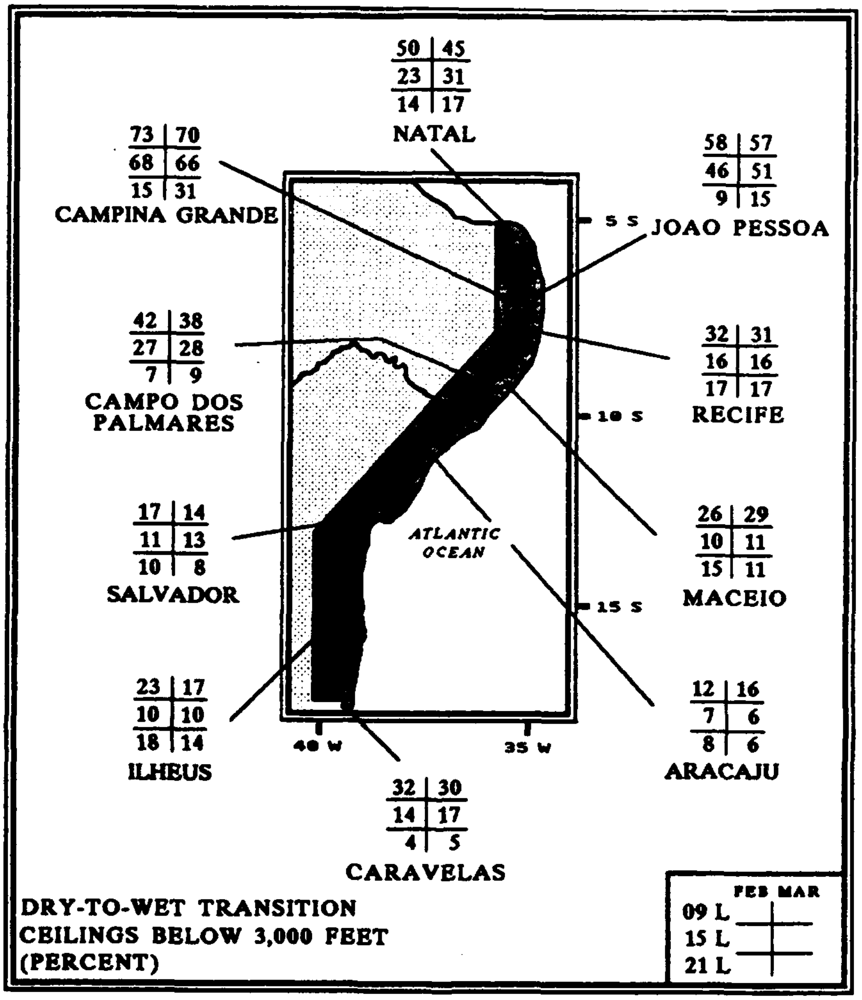


Figure 4-134. Dry-to-Wet Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian East Coast. Low-ceiling frequencies are higher and more diurnally variable in the north.

VISIBILITY. Salt haze, precipitation, and fog affect visibilities most often, but precipitation and fog are the main causes of significant reductions. Salt haze is most common during afternoons; although it doesn't cause low visibilities, it does prevent exceptionally good ones. Precipitation effects are relatively uniform, reducing visibilities below 6 miles less than 5% of the time everywhere. Fog, on the other hand, varies locally and diurnally and accounts for higher frequencies of low visibilities in the mountains and in the morning.

Fog lowers visibilities below 6 miles up to 15 days a month; on the coast, less than 10 days. Coastal fog is caused by radiation cooling and precipitation that saturates the air. Warm ocean currents are unfavorable for sea fog formation. Fog generally doesn't cause exceptionally low visibilities for two reasons: (1) the large frequency and amount of sky cover, and (2) local nighttime wind systems, such as downslope winds and land breezes, that help dry the air. Mountain fog is caused by radiational cooling, upslope winds, and saturation of the air by precipitation.

Figure 4-135 shows that coastal stations' visibility is below 3 miles less than 3% of the time. Visibilities are more diurnally variable in the mountains; frequencies below 3 miles range from 10% in the morning to less than 3% at other times. Visibilities less than 1 mile are very rare, occurring less than 1% of the time everywhere. Extremely low visibilities normally last for less than an hour, and rarely for more than 2.

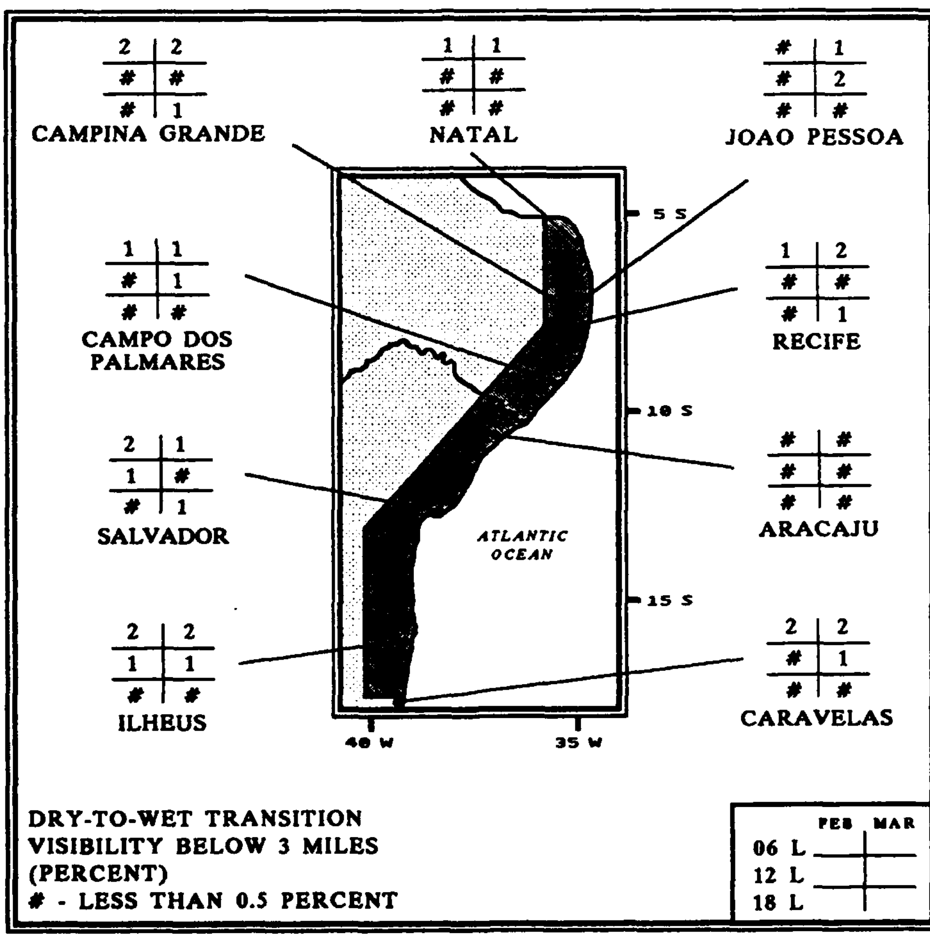


Figure 4-135. Dry-to-Wet Transition Percent Frequencies of Visibility Below 3 Miles, Brazilian East Coast.

WINDS. The trade winds dominate, but land/sea circulations and extratropical systems often cause variations. Land breezes occasionally occur at night, while sea breezes strengthen daytime trades. Mountainous terrain may block or channel inland flow. Mountain/valley circulations can enhance or dampen land/sea breezes and synoptic flow. Most cold fronts/shear lines are preceded by light and variable winds, but a few produce westerlies. Cold fronts/shear lines are followed by southerly winds.

The highest mean speeds occur over the ocean where surface friction and radiation inversions are insignificant; mean speeds are greater than 10 knots. Salvador's peninsular location results in winds similar to those over the ocean (see Figure 4-136). Higher speeds (5-7 knots) also occur in the north where the trades are strongest; speeds are 3-5 knots elsewhere. Afternoon winds are southeasterly throughout the zone; speeds average 15 knots in the north and between 10 and 15 knots elsewhere. Winds are calm to 5 knots between 2100 and 0800L.

The north's highest speeds reach 35 knots, caused by exceptionally strong trades. Thunderstorms can cause brief 35-knot gusts. Rare 30-knot gusts occur with gradient flow immediately ahead of and behind cold fronts in the south. Winds preceding cold fronts can flow down eastern mountain slopes and cause adiabatic warming and leeside troughing. Offshore winds can cause temporary upwelling, enhancing stratus formation.

STATION	MEAN WIND SPEED	
	FEB	MAR
ARACAJU	6	5
CAMPINA GRANDE	7	6
CAMPO DOS PALMARES	4	3
ILHEUS	4	4
JOAO PESSOA	5	5
MACEIO	4	3
NATAL	6	5
RECIFE	6	5
SALVADOR	8	6

Figure 4-136. Mean Dry-to-Wet Transition Wind Speeds, Brazilian East Coast.

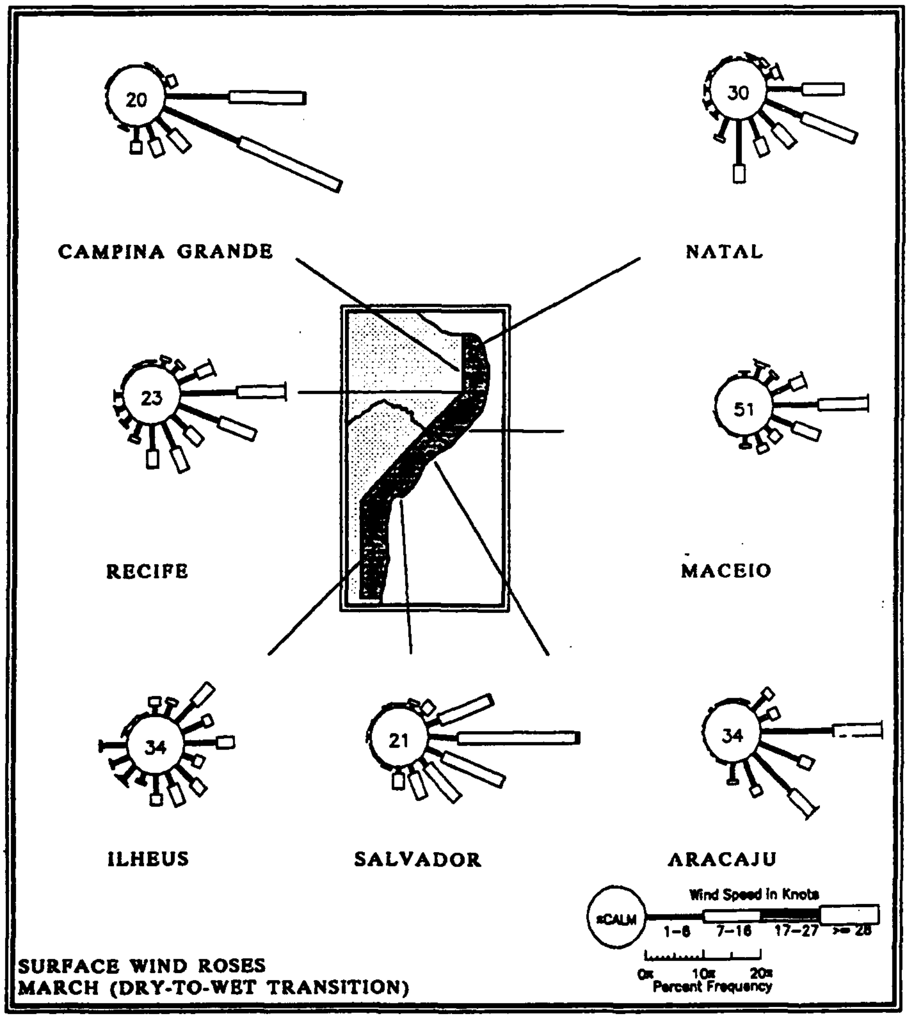


Figure 4-137. March Surface Wind Roses, Brazilian East Coast.

Mean upper-air speeds are less than 20 knots below 30,000 feet (9.1 km) MSL and 20 to 35 knots above. Figures 4-125 through 4-128 (see "Dry Season") show upper-air wind directions, which are east-southeasterly below 25,000 feet (7.6 km) MSL, and west-southwesterly above.

PRECIPITATION. The large number and variety of disturbances result in increasing rainfall amounts. Most disturbances cause more than 2 days of intermittent light to moderate showers. Drizzle can occur with upslope flow. Most heavy rain falls where disturbances intersect, but the weather surrounding this intersection often improves.

Local effects are also important. Land breezes, possibly enhanced by slope winds, can converge with synoptic flow to cause morning coastal showers. Radiation cooling of cloud tops over the Atlantic can create enough instability for isolated morning showers near the coast. Differential friction between land and water causes convergence, enhancing precipitation near the coast. Upslope effects occur on southern slopes with and after passage of cold fronts/shear lines and on eastern slopes during normal easterly flow. Sea breezes and convective heating can contribute to inland convergence and afternoon rainfall. Figure 4-138 clearly shows the effects of local wind systems and friction. Mean precipitation amounts reach 8 inches (203 mm) in the north and south where synoptic flow is perpendicular to the coast. Local wind systems and friction are less important in the zone's central section where synoptic flow has less of an onshore component; average rainfall amounts are as low as 2 inches (51 mm).

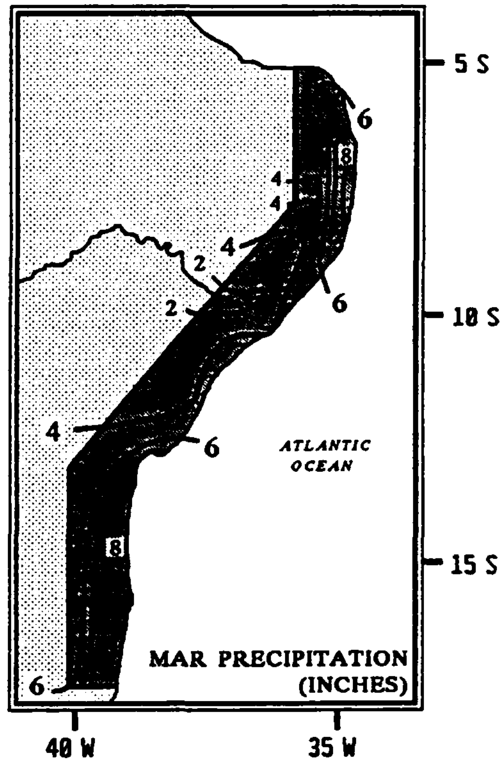


Figure 4-138. Mean March Precipitation, Brazilian East Coast.

As shown in Figure 4-139, maximum monthly rainfall amounts can reach 20 inches (508 mm); maximum 24-hour amounts exceed 5 inches (127 mm), but studies suggest that 24-hour rainfall can exceed 10 inches (254 mm).

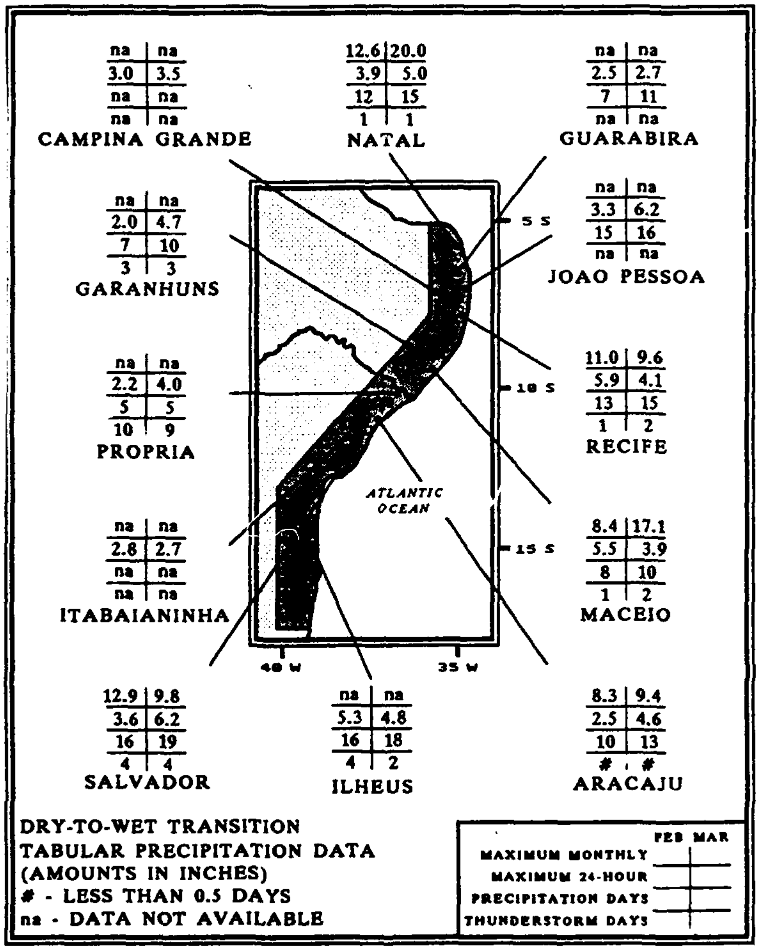


Figure 4-139. Dry-to-Wet Transition Tabular Precipitation Data, Brazilian East Coast. Campina Grande and Garanhuns are mountain stations. Guarabira, Propria, and Itabaianinha are lowland interior stations. The remaining stations are coastal.

THUNDERSTORMS. The trade-wind inversion suppresses vertical development; thunderstorms only develop when disturbances destroy the inversion. Disturbances break down an inversion most effectively when they're accompanied by cold air advection aloft. Land/sea breezes, mountain/valley breezes, orographic lift, and convective heating enhance thunderstorm development. Most thunderstorms occur during the day in the zone's interior central and southern sections. Thunderstorm days average up to 10 a month, but only 1 a month on a few sheltered slopes and in a few valleys. The central and southern coast average 1-4 thunderstorm days a month. In the north near the coasts, the average is 1 a month; near the coast, 5. Most thunderstorm tops are less than 35,000 feet (10.7 km) MSL. Thunderstorms are not severe, but gusts can reach 35 knots.

TEMPERATURES. Temperatures are moderated by the South Atlantic Ocean. Diurnal variations increase with increasing distance inland. Extreme temperatures vary by terrain. Extreme lows in higher elevations and in the south occur with cold fronts. Extreme highs at lower elevations occur where westerly flow causes adiabatic warming leeward of mountains. Leeside effects are also the cause of unusually low relative humidities. Mean lows are in the 70's°F (21° C) along the coast. The lower inland areas are similar, but it can be up to 10° F (18° C) cooler in the mountains. Mean highs range from around 85° F (29° C) to 88° F (31° C). Mean highs in the mountains are similar to those on the coast, but low inland areas are up to 5° F (9° C) higher. Extreme lows range from 52° F (11° C) in the south to 70° F (21° C) on the central coast. Extreme highs range from 92° F (33° C) on the central coast to 104° F (40° C) in central inland areas.

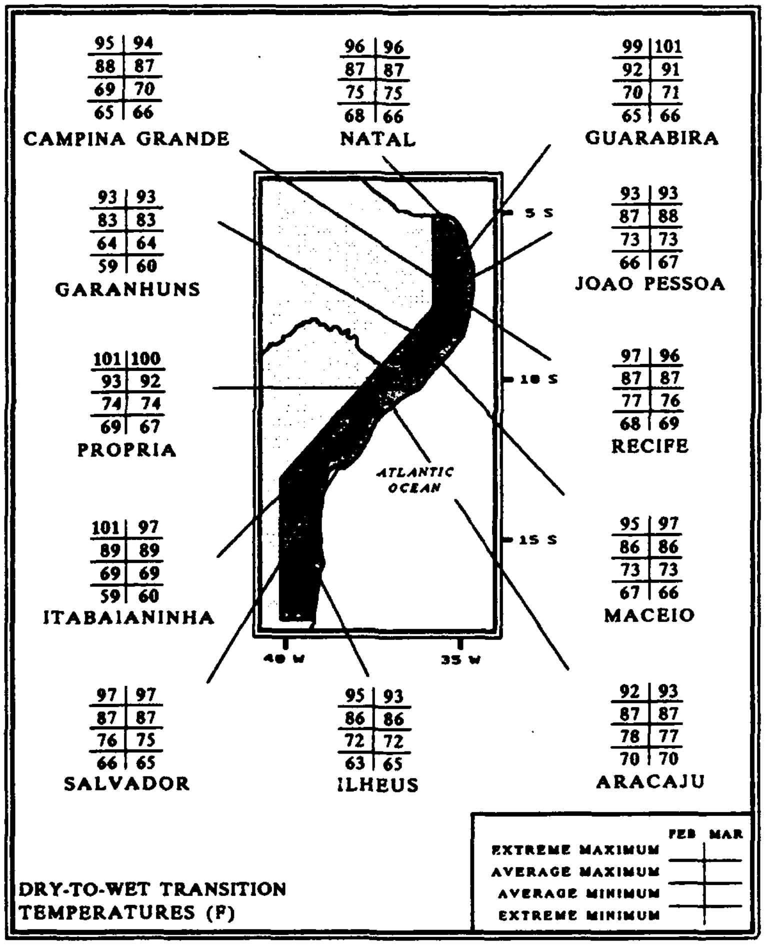


Figure 4-140. Dry-to-Wet Transition Tabular Temperature Data, Brazilian East Coast.

Relative humidities reflect maritime and terrain effects. Mean coastal RHs range from minimums between 65% and 80% to maximums between 80% and 95%. RH is more variable inland, with minimums as low as 55% and maximums as high as 90%. Figure 4-141 shows five stations with wet-bulb globe temperature data (° F) at specific hours in March.

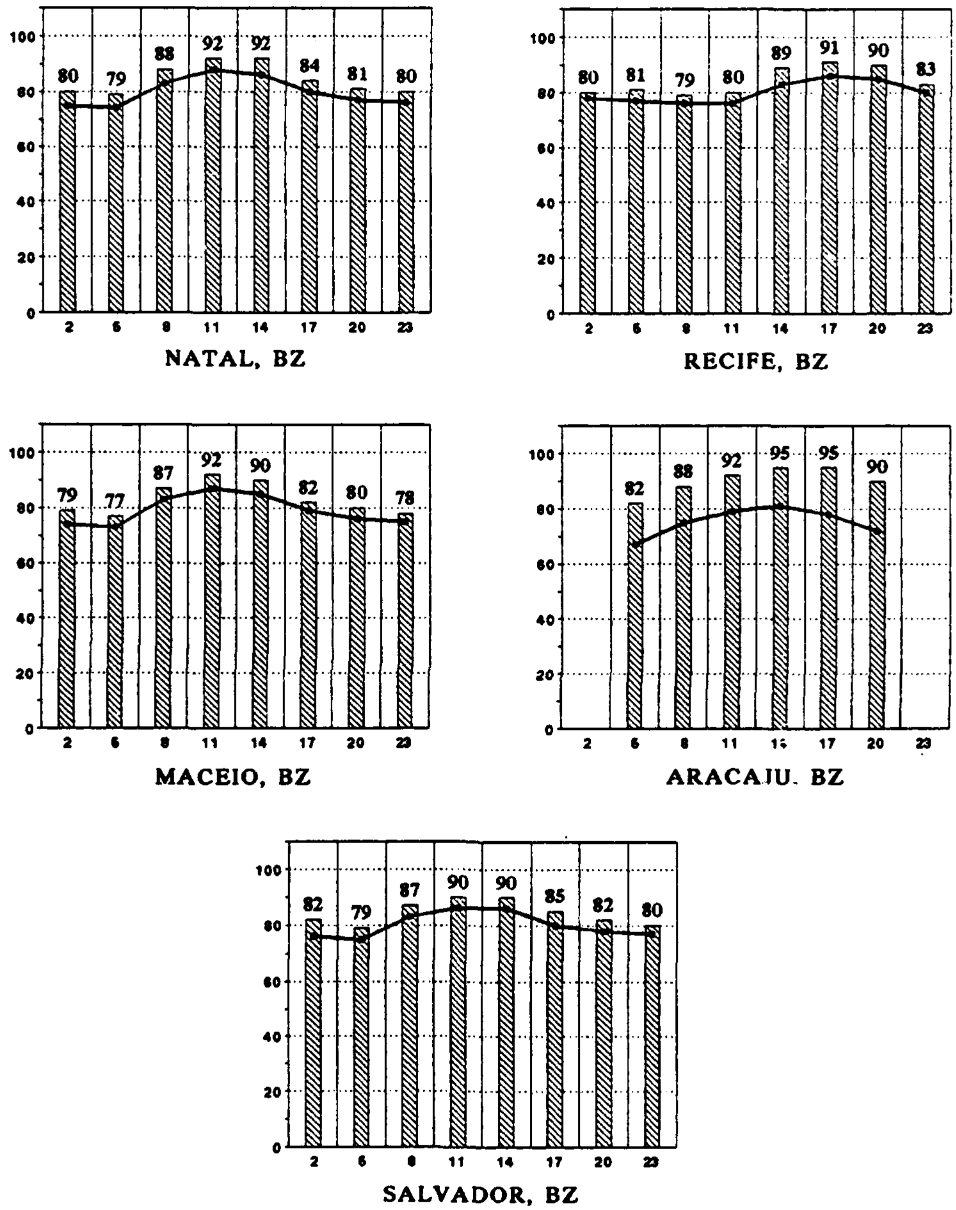


Figure 4-141. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for March, Brazilian East Coast. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Light to moderate mechanical turbulence affects the mountains during strong easterly flow; it can affect the south with strong westerly flow. Wind shear occasionally occurs along sea-breeze fronts and near tops of radiation inversions; shear caused by radiation inversions occurs most often in the north. Surface winds drop below 5 knots at night; above 1,000 feet (305 meters) AGL, they average 20 knots. Icing is most often found in clouds between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL, but those heights can drop a couple of thousand feet with upper-tropospheric cyclones. Towering cumulus and cumulonimbus are normally the only clouds that reach these heights. Freezing levels average 15,000 ft (4,575 meters) MSL, but are lower in the cores of upper-tropospheric cyclones.

GROUND HAZARDS. Flash floods occur with rapid mountain run-off of heavy or frequent moderate precipitation. Most flash floods occur on slopes and in low-lying areas in the vicinity of 9 and 10° S.

GENERAL WEATHER. Extratropical disturbances cause most poor wet season weather. Frontally induced troughs are most important, but rare easterly waves and a weak coastal convergence zone also contribute. The convergence zone forms when land breezes meet the trade winds. It is most important from June through August, but can occur year-round. The area's worst weather occurs where disturbances intersect; weather surrouning the inter section improves.

SKY COVER. Figure 4-142 shows that mean May cloud cover exceeds 70% across most of the zone. Middle and high clouds are common in all places at all hours; low clouds vary locally and diurnally. Low clouds are most widespread in the north.

Disturbances give most of the zone broken to overcast clouds with bases between 300 and 1,000 feet (90 and 305 meters) MSL. Most tops are below 20,000 feet (6.1 km) MSL in the north and less than 25,000 feet (7.6 km) MSL in the south. Cloud types can be stratiform or cumuliform, depending mostly on the strength of the disturbance; cumulonimbus is the only uncommon cloud type. Disturbances are easiest to locate over land at night when associated cloudiness is more shallow and organized.

Cloud formation is influenced by local effects that include orographic lift, local wind systems, convective heating, and differential friction. The most widespread cloudiness takes place on eastward-facing slopes where orographic lift occurs most often. Sea breezes and convective heating contribute to inland convergence and the formation of afternoon cumulus. Land breezes, possibly enhanced by slope winds, converge with trade-wind flow and cause stratocumulus and cumulus ceilings along the coast at night; these clouds begin moving inland after nocturnal breezes dissipate. Differential wind friction between land and water causes convergence that can enhance low cloudiness near the coast. Scattered to broken stratocumulus and cumulus with bases at 4,000 to 6,000 feet (1,220 to 1,830 meters) MSL are prevalent during fair-weather periods. Most tops are between 8,000 and 13,000 feet (2,440 and 3,960 meters) MSL.

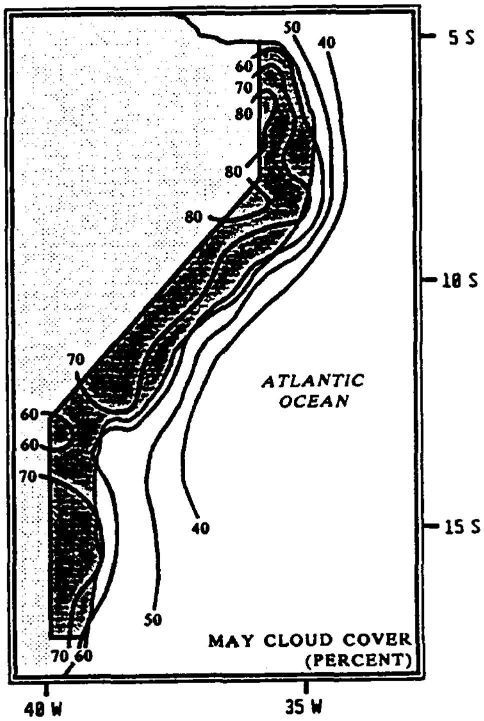


Figure 4-142. Mean May Cloud Cover, Brazilian East Coast.

Low-ceiling frequencies vary less diurnally in the wet season than during the rest of the year, the result of frequent disturbances that overshadow local effects; this is especially true in the south (see Figure 4-143). The north has low ceilings most often. The mountains have especially high frequencies of low ceilings; compare Campina Grande (the only mountain station with ceiling data available) with other stations in Figure 4-143. No data is available from stations that see localized convergence exclusively during daytime hours. Such areas are likely to have abnormally high frequencies of low ceilings during the day.

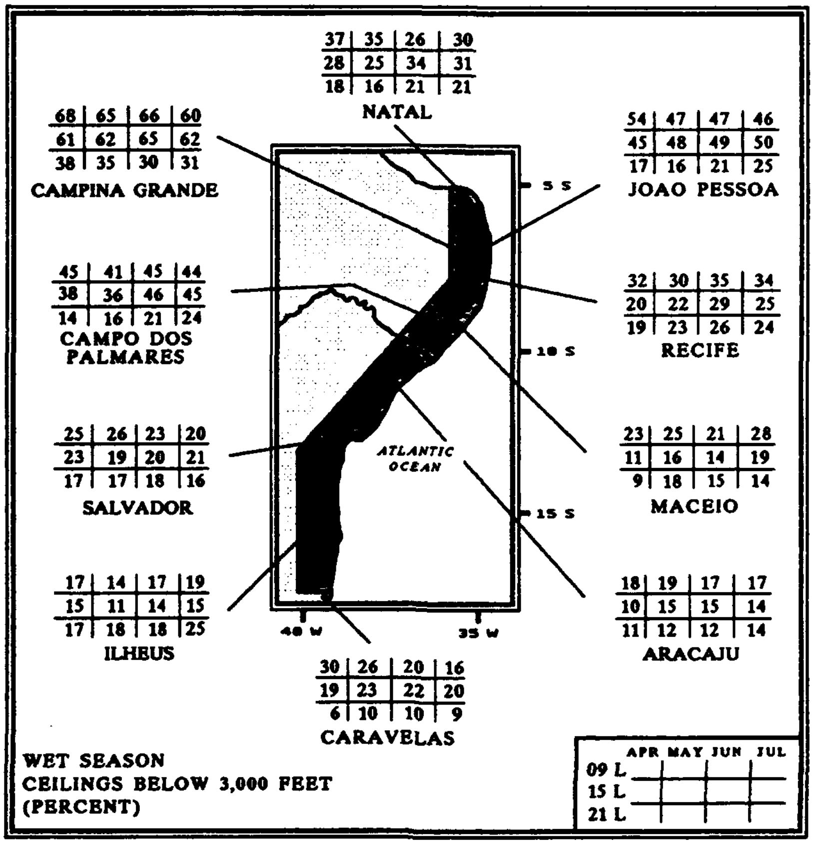


Figure 4-143. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian East Coast.

VISIBILITY. Precipitation and fog are the main causes of visibility reductions. Salt haze, most common during afternoons, does not cause low visibilities, but it does prevent exceptionally good ones. Precipitation reduces visibilities uniformly below 6 miles no more than 10% of the time everywhere. Fog, on the other hand, varies locally and diurnally, accounting for higher frequencies of low visibilities in the mountains and during mornings.

Fog normally doesn't result in exceptionally low visibilities because of frequent cloudiness and the local nocturnal wind systems, such as downslope winds and land breezes, that help dry the air. Fog in the mountains is caused by radiation cooling, upslope flow, and saturation of the air by precipitation. Depending on terrain, fog can reduce visibilities below 6 miles up to 15 days a month, but along the coast, visibilities are below 6 miles in fog no more than 10 days a month due to radiation cooling and saturation of the air by precipitation. Warm ocean currents are unfavorable for sea fog formation.

On the coast, morning visibilities are below 3 miles less than 10% of the time, but less than 5% at other times (see Figure 4-144). Frequencies of visibilities below 3 miles in the mountains range from 15% mornings to less than 5% at other times. Visibilities less than 1 mile are very rare, occurring less than 1% of the time everywhere. Periods of low visibility normally last less than 2 hours and rarely persist for more than 3 hours.

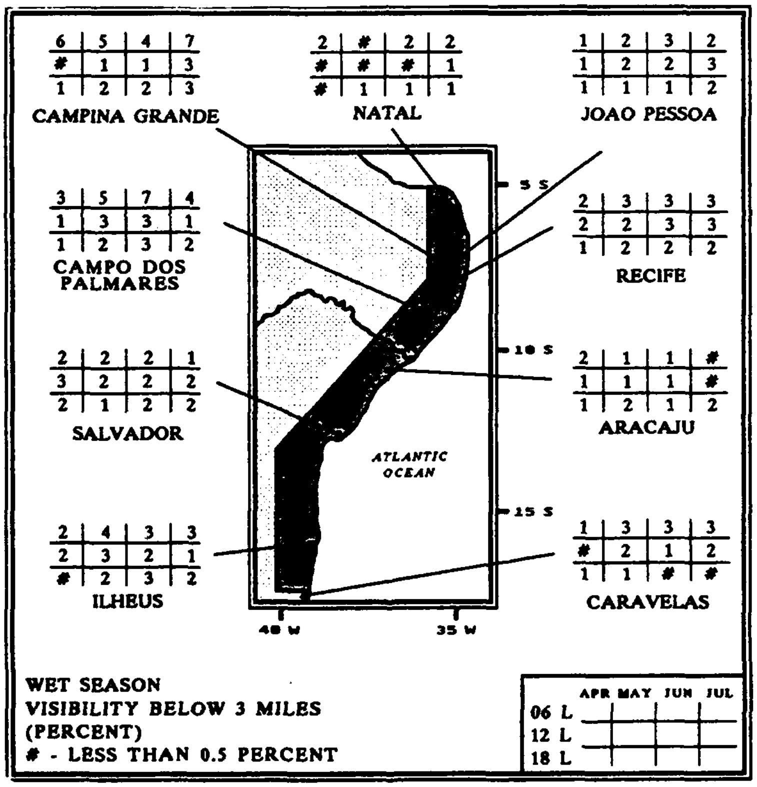


Figure 4-144. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Brazilian East Coast.

WINDS. The trade winds dominate. Variations are caused by land/sea breeze circulations, high pressure over Brazil, and extratropical features. Weak land breezes are common at night, while sea breezes strengthen the trades during the day. Mountainous terrain in the west can block or channel flow. Mountain/valley circulations can enhance or dampen land/sea breezes and synoptic flow. Nocturnal wind directions often have an offshore component. Southerly winds occur when high-pressure centers form over eastern Brazil (see "South Atlantic High," Chapter 2). Most cold fronts/shear lines are preceded by light and variable winds and followed by southerlies.

The highest mean wind speeds are over the Atlantic where surface friction and radiation inversions are insignificant; mean speeds can exceed 10 knots. Similar winds occur at Salvador because of its peninsular location (see Figure 4-145). Mean speeds are also high (5-7 knots) in the north where the trades are stronger; most mean speeds are 3-5 knots in the southern two-thirds of the zone. Afternoon winds are southeasterly everywhere, reaching 10-15 knots in the north and around 10 knots elsewhere. Winds range from calm to 5 knots between 2100 and 0800L. Maximum wind speeds in the north reach 35 knots; they are caused by exceptionally strong trades and are otherwise associated with good weather. In the south, thunderstorms and gradient flow ahead of and behind cold fronts can cause brief 35-knot gusts. Winds preceding some cold fronts flow down eastern mountain slopes and cause adiabatic warming and leeside troughing.

STATION	MEAN WIND SPEED			
	APR	MAY	JUN	JUL
ARACAJU	4	3	4	5
CAMPINA GRANDE	5	5	5	6
CAMPO DOS PALMARES	3	3	3	3
ILHEUS	5	5	5	5
JOAO PESSOA	5	5	5	6
MACEIO	3	3	3	3
NATAL	5	6	7	7
RECIFE	5	5	5	6
SALVADOR	8	7	8	8

Figure 4-145. Mean Wet-Season Wind Speeds, Brazilian East Coast.

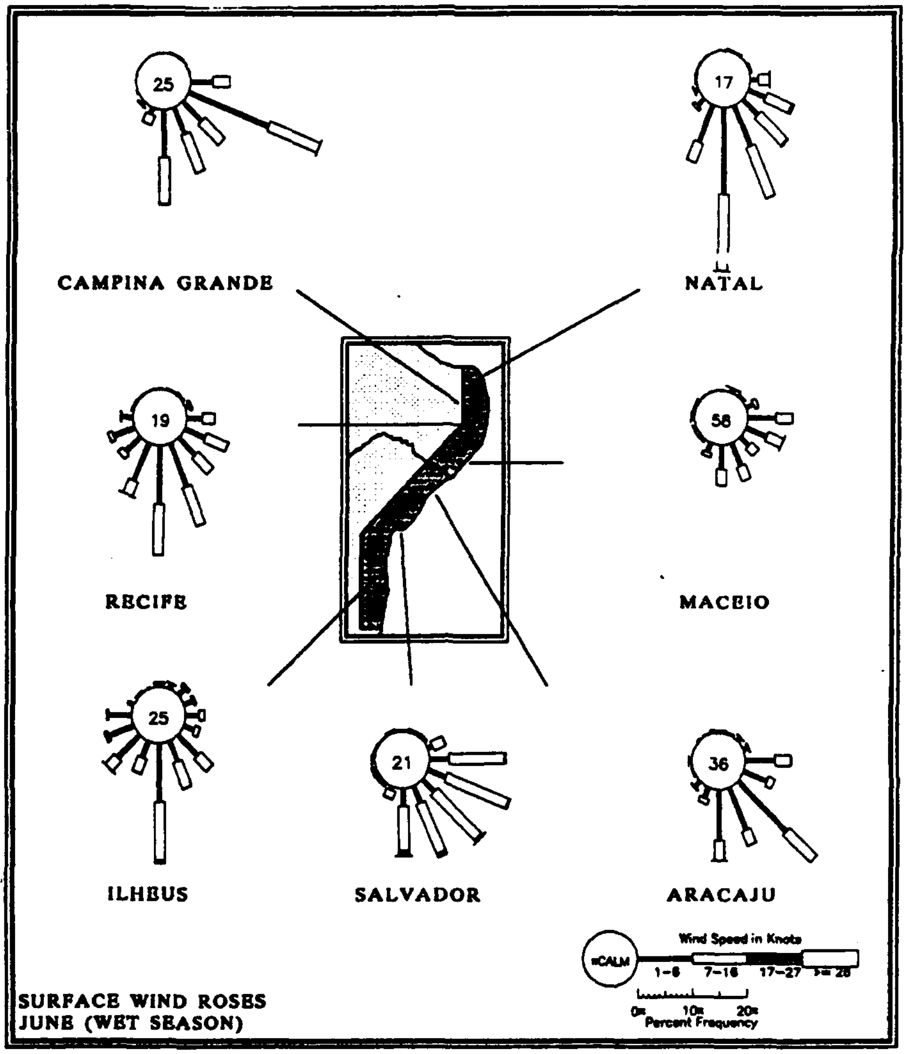


Figure 4-146. June Surface Wind Roses, Brazilian East Coast.

Figures 4-125 through 4-128 (see "Dry Season") show upper-air wind directions. Prevailing directions are east-southeasterly below 30,000 feet (9.1 km) MSL in the north and below 15,000 feet (4,570 meters) MSL in the south. Directions are westerly above. Mean upper-air speeds are less than 25 knots below 25,000 feet (7.6 km) MSL and 25-50 knots above.

PRECIPITATION. Cold fronts/shear lines and frontally induced troughs are the primary causes of wet-season rainfall. On rare occasions, easterly waves reach the zone north of 11° S. Most disturbances cause more than 2 days of intermittent rainfall. Precipitation is liquid and usually light to moderate. Heavy rainfall can occur where mesoscale disturbances intersect or where they are enhanced by local effects. In the area surrounding the intersection of such disturbances, there is increasing stability and improving weather.

Local effects are also an important cause of precipitation. Land breezes, possibly enhanced by slope winds, are sometimes strong enough to cause convergence with synoptic flow; this results in morning showers along the coast. Radiation cooling of cloud tops over the ocean can create enough instability to cause morning showers near the coast. Differential wind friction between land and water causes convergence that can enhance precipitation near the coast. These three factors cause the coast to receive most of the zone's rain (see Figures 4-147 and 4-148). Inland, orographic lift contributes to rainfall on southern slopes with and after cold front/shear line passages, as well as on eastern slopes during normal easterly flow. Sea breezes can also contribute to inland convergence and precipitation during afternoons.

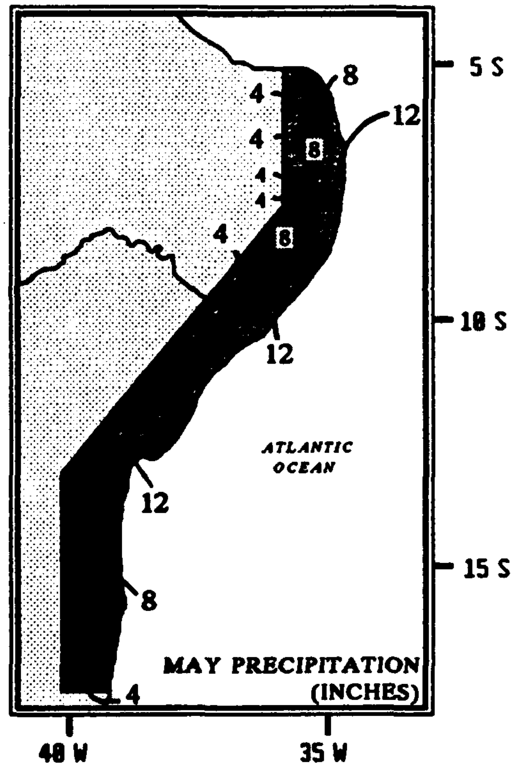


Figure 4-147. Mean May Precipitation, Brazilian East Coast.

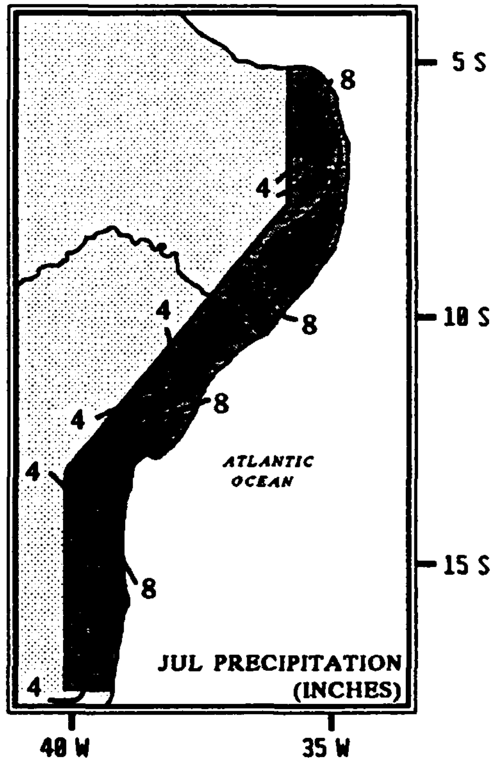


Figure 4-148. Mean July Precipitation, Brazilian East Coast.

The coast averages about 25 precipitation days a month, while inland areas average 7 (see Figure 4-149). The zone's maximum monthly rainfall amounts can exceed 23 inches (584 mm) and maximum 24-hour amounts can exceed 10 inches (254 mm). However, studies suggest that 24-hour amounts in excess of 15 inches (381 mm) are possible.

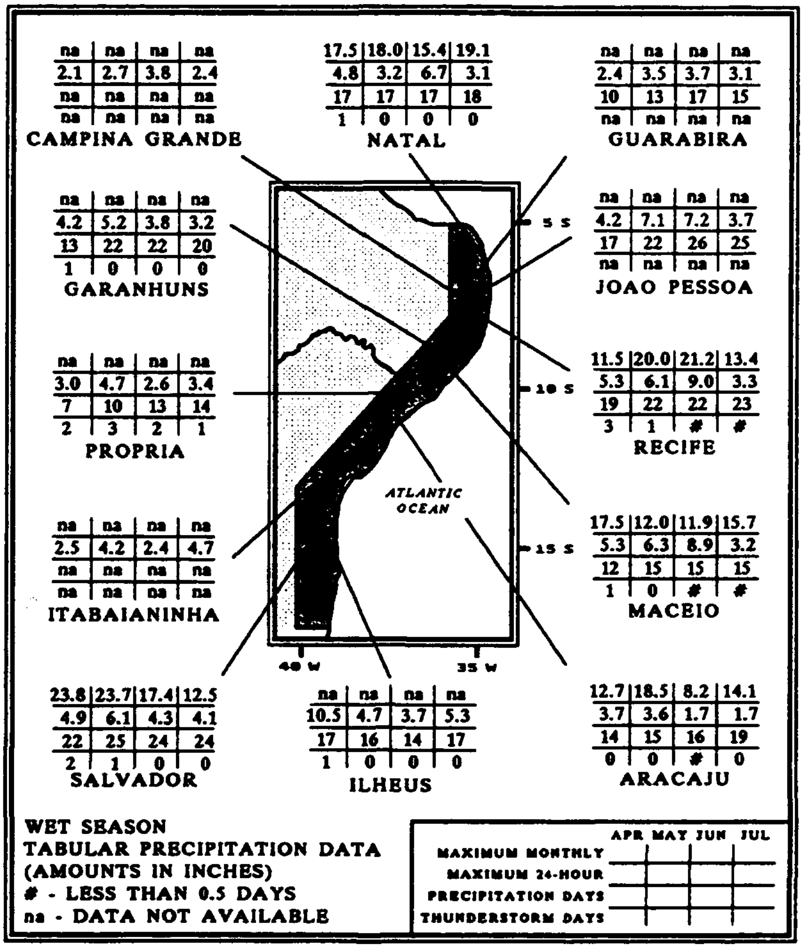


Figure 4-149. Wet-Season Tabular Precipitation Data, Brazilian East Coast. Campina Grande and Garanhuns are mountain stations. Guarabira, Propria, and Itabaianinha are lowland interior stations. The remaining stations are coastal.

THUNDERSTORMS. The trade-wind inversion restricts vertical development; thunderstorms only develop when disturbances destroy the inversion. They are not severe. Disturbances can break down an inversion most effectively if accompanied by cold air advection aloft. Land/sea breezes, mountain/valley breezes, and orographic lift can enhance thunderstorm development. Most thunderstorms occur inland where thunderstorm days vary little through the season and range from 1 to 5 a month. Monthly thunderstorm days along the coast decrease as the season progresses; they range from 1 to 3 in April, but some sections of the coast never see thunderstorms during the rest of the season. Thunderstorm tops, normally less than 30,000 feet (9.1 km) MSL, can reach 45,000 ft (13.7 km) MSL. Gusts can reach 40 knots.

TEMPERATURES. Temperatures are moderated by the South Atlantic. Diurnal variations increase inland. Extreme lows at higher elevations and in the south occur with cold fronts. Extreme highs at lower elevations occur where westerly flow causes adiabatic warming leeward of mountains. Leeside effects are also the cause of unusually low relative humidities. Along the coast, mean lows range from 65° F (18° C) in the south to around 75° F (24° C) in the north. Inland low elevations average a few degrees less and the mountains can be up to 10° F (18° C) cooler. Mean highs along the coast range from around 80° F (27° C) in the south to as high as 87° F (30° C) in the north. Mean highs at low elevations inland are similar to the coast, but the mountains are about 5° F (9° C) cooler. Extreme lows range from 45° F (7° C) in the south to 66° F (19° C) on the central coast. Extreme highs range from 91° F (33° C) on the central coast to 100° F (38° C) in central inland areas.

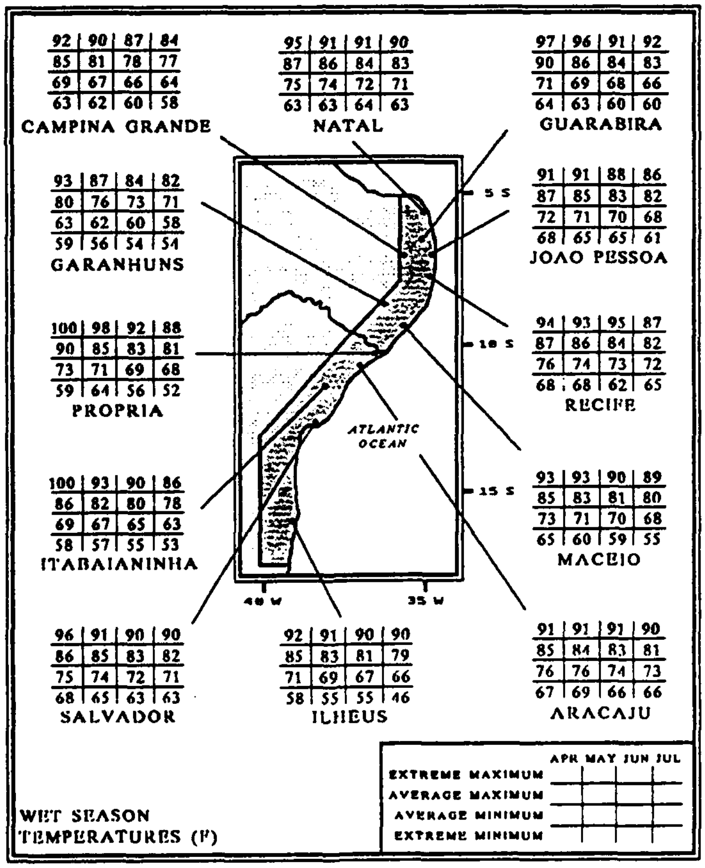


Figure 4-150. Wet-Season Tabular Temperature Data, Brazilian East Coast.

Relative humidities reflect maritime and terrain effects. Along the coast, mean RH ranges from minimums between 65% and 80% to maximums above 85%. RH is more variable inland, with minimums as low as 60% and maximums as high as 95%. Figure 4-151 shows five stations with wet-bulb globe temperature data (° F) at specific hours in June.

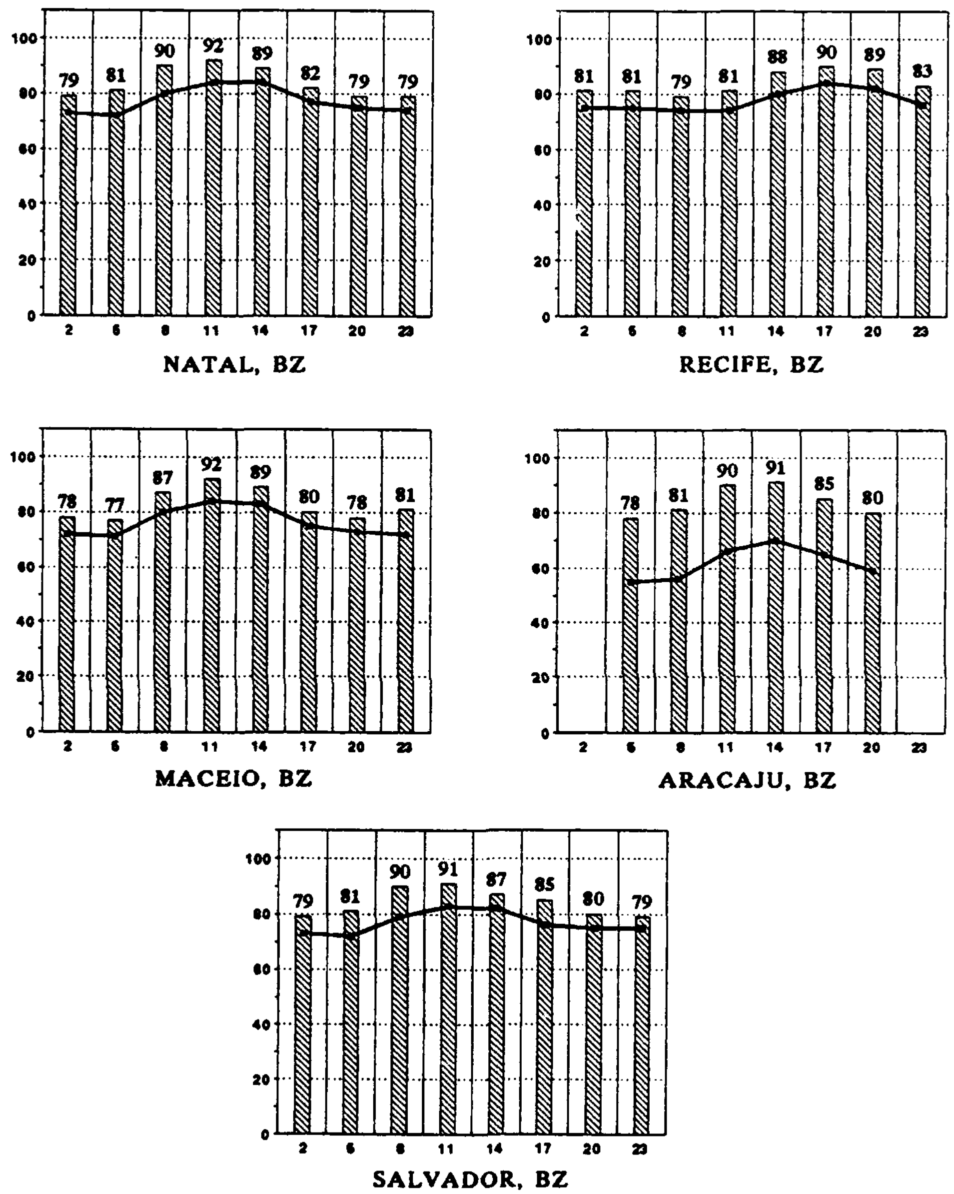


Figure 4-151. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for June, Brazilian East Coast. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Light to moderate mechanical turbulence is found over rough terrain in the mountains with strong easterly flow; it is also found across the entire south with strong westerly flow. Wind shear can occur near tops of radiation inversions, especially in the north, where surface winds are below 5 knots at night and winds above 1,000 feet (305 meters) AGL are about 20 knots. Clouds between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL are most favorable for icing. Most icing is in towering cumulus and cumulonimbus; most other clouds don't reach high enough above the freezing level to produce more than light icing. Freezing levels average 15,000 ft (4,575 meters) MSL.

GROUND HAZARDS. Flash floods result from rapid mountain run-off of heavy or frequent moderate precipitation. Most occur on slopes and low-lying areas in the vicinity of 9 and 10° S.

GENERAL WEATHER. Extratropical fronts/shear lines and associated disturbances occur less often. The only other disturbance results from convergence between land breezes and trade-wind flow. The worst weather occurs where disturbances intersect, but weather improves in the area surrounding the intersection.

SKY COVER. August cloud cover exceeds 60% across most of the zone (see Figure 4-152). Middle and high clouds are common in all places at all hours, but low cloudiness varies more locally and diurnally. Low clouds are most common and diurnally variable in the north.

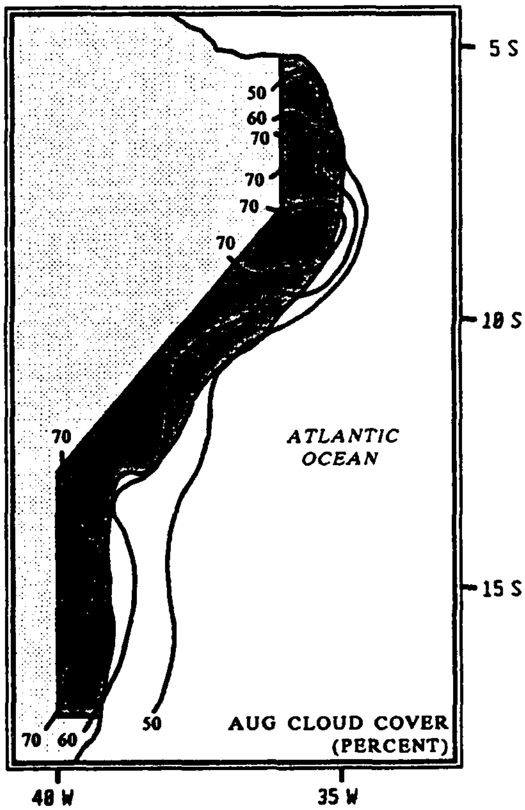


Figure 4-152. Mean August Cloud Cover, Brazilian East Coast.

Most disturbances produce broken low clouds with bases between 500 and 1,500 feet (150 and 455 meters) MSL. Most tops are below 15,000 feet (4,570 meters) MSL in the north and less than 20,000 feet (6,100 meters) MSL in the south. Cloud types can be stratiform or cumuliform, depending primarily on disturbance strengths. Cumulonimbus and nimbostratus are the only uncommon cloud types. Disturbances are easiest to locate over land at night when associated cloudiness is more shallow and organized.

Local effects that include orographic lift, local wind systems, convective heating, and differential friction influence cloud formation during undisturbed periods. The most widespread cloud cover occurs with orographic lift along eastern slopes. Sea breezes and convective heating can contribute to inland convergence and the formation of stratocumulus and cumulus during afternoons. Land breezes, possibly enhanced by slope winds, converge with trade-wind flow and cause scattered to broken stratocumulus and cumulus along the coast at night. These clouds begin moving inland after nocturnal breezes dissipate. Differential wind friction between land and water causes convergence, leading to low cloudiness near the coast. Scattered to broken stratocumulus and cumulus with bases at 4,000 to 6,000 feet (1,220 to 1830 meters) MSL are prevalent during fair weather periods. Most tops are between 8,000 and 13,000 feet (2,440 and 3,960 meters) MSL.

The highest frequencies of low ceilings are in the morning; the lowest, during evenings. However, no data is available in areas that see localized convergence exclusively during daytime hours; such areas are likely to have abnormally high frequencies of low ceilings during the day. Most low ceilings occur in the mountains, as represented by Campina Grande (the only mountain station with ceiling data available) in Figure 4-153.

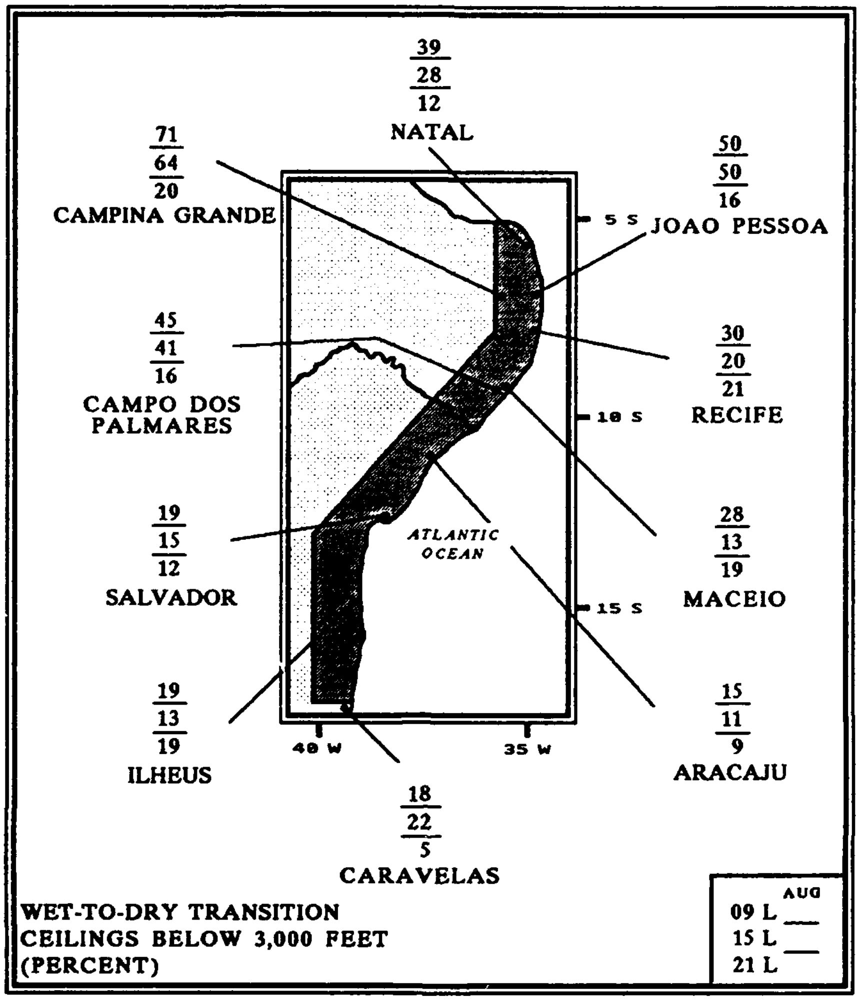


Figure 4-153. Wet-to-Dry Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian East Coast. Low ceilings occur more often and are more diurnally variable in the north.

VISIBILITY. Precipitation and fog are the primary causes of low visibilities. Salt haze, most common during afternoons, does not cause low visibilities, but it does prevent exceptionally good ones. Precipitation effects are generally uniform, reducing visibilities below 6 miles no more than 5% of the time everywhere. Fog is more diurnally variable and accounts for higher frequencies of low visibilities in the mountains and during mornings.

Fog rarely causes exceptionally low visibilities anywhere in the zone, due to the frequent cloud cover and the local nighttime wind systems, (such as downslope winds and land breezes), that help dry the air. Fog in the mountains is caused by radiation cooling, upslope flow, and saturation of the air by precipitation. Depending on terrain, fog can reduce visibilities below 6 miles up to 15 days a month. Along the coast, visibilities are below 6 miles less than 10 days a month from radiation cooling. and occasional saturation of the air by precipitation. Warm ocean currents are unfavorable for sea fog formation.

Visibilities below 3 miles usually last less than an hour and rarely persist for more than 2 hours. Coastal station visibilities are below 3 miles less than 5% of the time in the morning to less than 3% at other times (see Figure 4-154). Visibilities are below 3 miles in the mountains from as much as 10% of the time in the mornings to less than 3% at other times. Visibilities less than 1 mile are very rare, occurring less than 1% of the time anywhere.

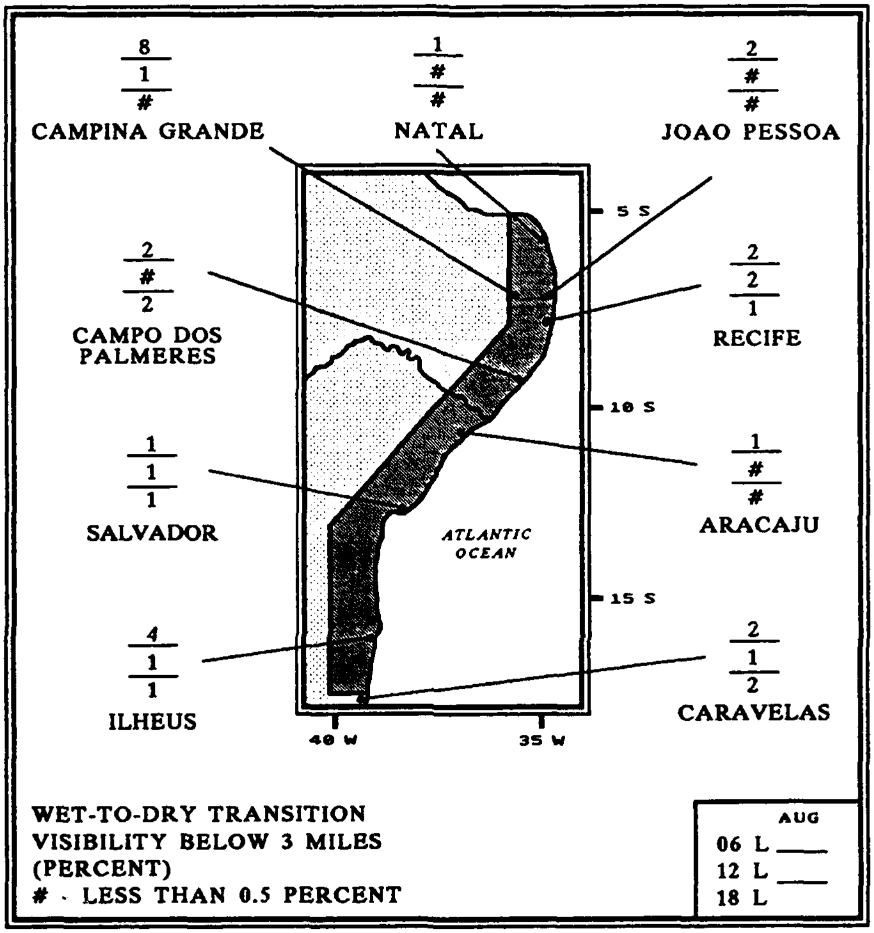


Figure 4-154. Wet-to-Dry Transition Percent Frequencies of Visibility Below 3 Miles, Brazilian East Coast.

WINDS. The trade winds dominate. Land/sea breeze circulations and mid-latitude fronts/shear lines cause variations. Weak land breezes often occur near sunrise, and sea breezes strengthen the trades during the day. Mountainous terrain blocks or channels flow in the west. Mountain/valley circulations enhance or dampen land/sea breezes and synoptic flow. Southerly winds develop behind passing cold fronts/shear lines.

The strongest mean winds occur over the Atlantic where surface friction and radiation inversions are insignificant; mean speeds over open water exceed 10 knots. Winds are similar at Salvador because of its peninsular location. Mean speeds are also high (6-7 knots) in the north where the trades are stronger; mean speeds elsewhere range from 3 to 5 knots (see Figure 4-155). Afternoon winds are southeasterly throughout the zone; speeds are near 15 knots in the north and between 10 and 15 knots elsewhere. Winds are calm to 5 knots between 2100 and 0800L. Maximum wind speeds in the north reach 35 knots, usually with exceptionally strong trades and associated with otherwise good weather. Gradient flow immediately ahead of and behind cold fronts can cause 30-knot gusts in the south. Winds preceding some cold fronts flow down eastern mountain slopes and cause adiabatic warming and, sometimes, leeside troughs. On rare occasions, thunderstorms produce brief 30-knot gusts.

STATION	AUG
ARACAJU	5
CAMPINA GRANDE	7
CAMPO DOS PALMARES	3
ILHEUS	5
JOAO PESSOA	6
MACEIO	3
NATAL	7
RECIFE	7
SALVADOR	8

Figure 4-155. Mean Wet-to-Dry Transition Wind Speeds, Brazilian East Coast.

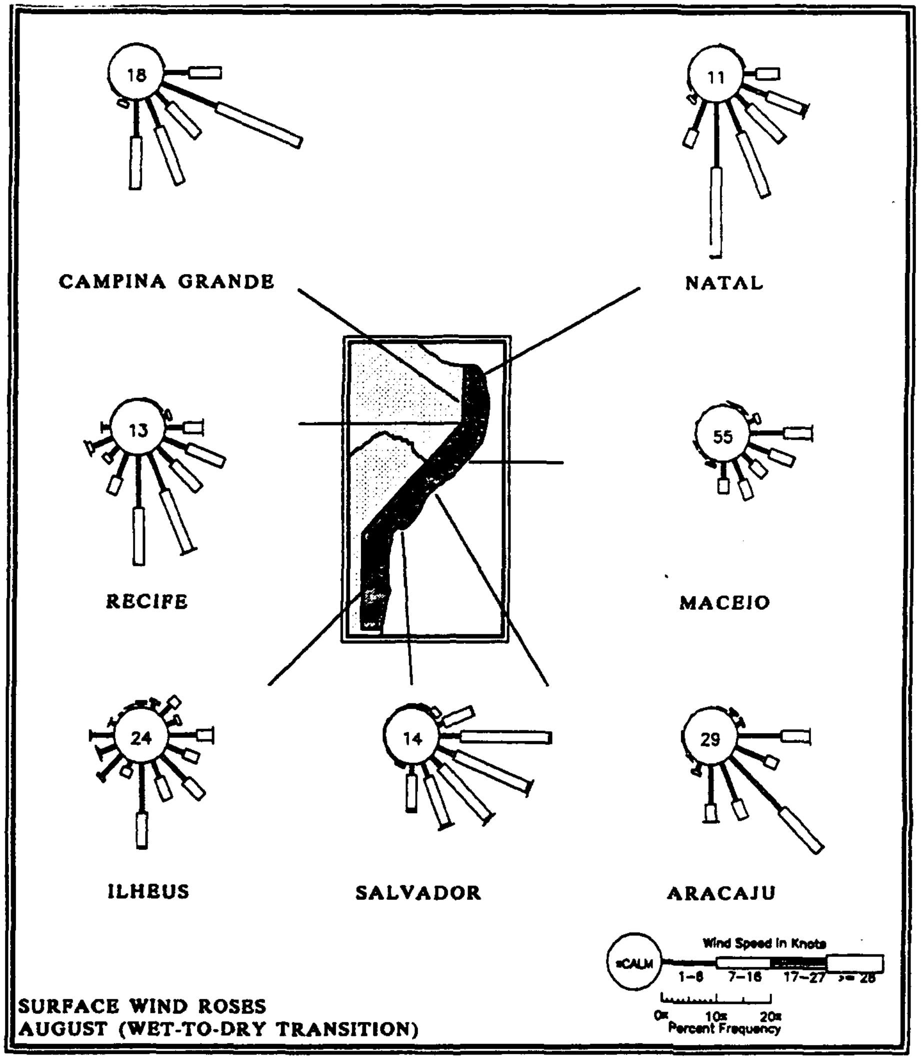


Figure 4-156. August Surface Wind Roses, Brazilian East Coast.

Figures 4-125 through 4-128 (see "Dry Season") show upper-air wind directions. East-southeasterlies prevail below 30,000 feet (9.1 km) MSL in the north and below 15,000 feet (4,570 meters) MSL in the south; flow above is westerly. Mean speeds are less than 25 knots below 25,000 feet (7.6 km) MSL and 25 to 50 knots above.

PRECIPITATION. Cold fronts/shear lines and associated surface troughs are still the primary causes of rainfall, but they occur less often. They usually cause more than 2 days of intermittent light to moderate precipitation. The heaviest rainfall occurs where disturbances intersect.

Numerous local effects are responsible for precipitation. Land breezes, possibly enhanced by slope winds, are occasionally strong enough to cause convergence with synoptic flow and produce morning coastal showers. Radiation cooling of cloud tops over the ocean can cause enough instability for morning showers near the coast. Differential friction between land and water causes convergence that can contribute to precipitation near the coast. These three local effects explain why the coast gets most of the zone's rain (see Figure 4-157). Farther inland, upslope precipitation can fall on southern slopes with and after passage of cold fronts/shear lines moving north, as well as on eastern slopes during normal easterly flow. Sea breezes and convective heating can contribute to inland convergence and precipitation during afternoons.

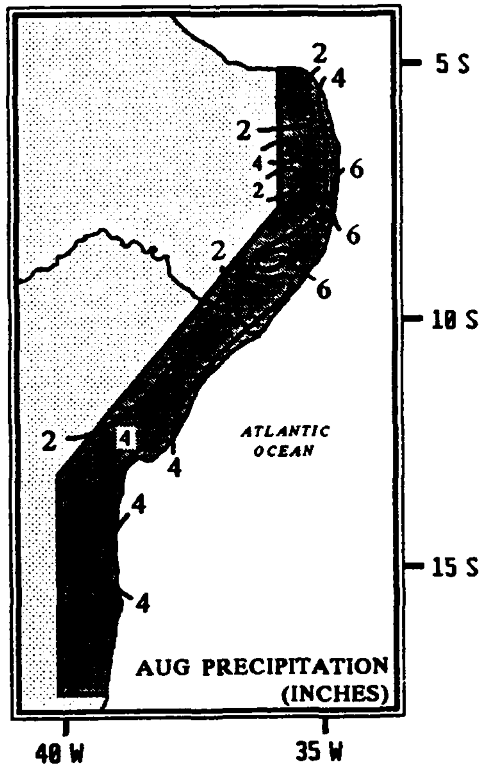


Figure 4-157. Mean August Precipitation, Brazilian East Coast.

Local effects result in a higher number of precipitation days on the coast (23) than inland (10)--see Figure 4-158. Maximum monthly rainfall amounts can exceed 17 inches. Maximum 24-hour amounts exceed 4 inches, but studies indicate that much greater 24-hour amounts are possible.

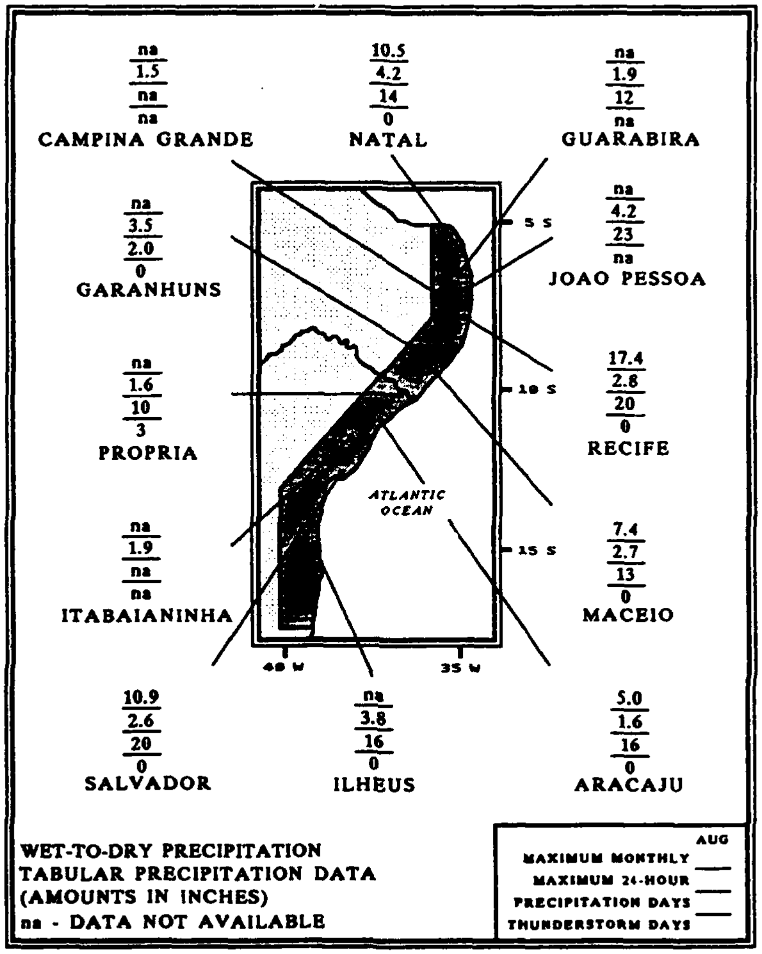


Figure 4-158. Wet-to-Dry Transition Tabular Precipitation Data, Brazilian East Coast. Campina Grande and Garanhuns are mountain stations. Guarabira, Propria, and Itabaianinha are lowland interior stations. The other stations are coastal.

THUNDERSTORMS. The trade-wind inversion restricts vertical development. Thunderstorms only develop when migratory disturbances destroy the inversion. None are severe. Disturbances can break down an inversion most effectively if accompanied by cold air advection. Land/sea breezes, mountain/valley breezes, and orographic lift can enhance thunderstorm development.

Most of the coast never sees thunderstorms in August; inland locations average less than 5 days with thunderstorms. Tops are less than 35,000 feet (10.7 km) MSL. Gusts can reach 30 knots.

TEMPERATURE. Temperatures are moderated by the South Atlantic. Terrain and occasional cold fronts determine local variations. Adiabatic warming with westerly flow can cause unusually high temperatures and low relative humidities. Cold fronts are responsible for extreme low temperatures in the south.

Mean lows along the coast range from 65° F (18° C) in the south to around 70° F (21° C) in the north. Inland low areas are a few degrees cooler. The mountains are up to 15° F (27° C) cooler. Mean highs along the coast range from 78° F (25° C) in the south to 84° F (29° C) in the north. Mean highs at low inland areas are similar to those on the coast, while the mountains can be up to 10° F (18° C) cooler. Extreme lows range from 48° F (9° C) in the south to 64° F (18° C) in the north. Extreme highs range from 83° F (28° C) in the mountains to 92° F (38° C) on the north coast.

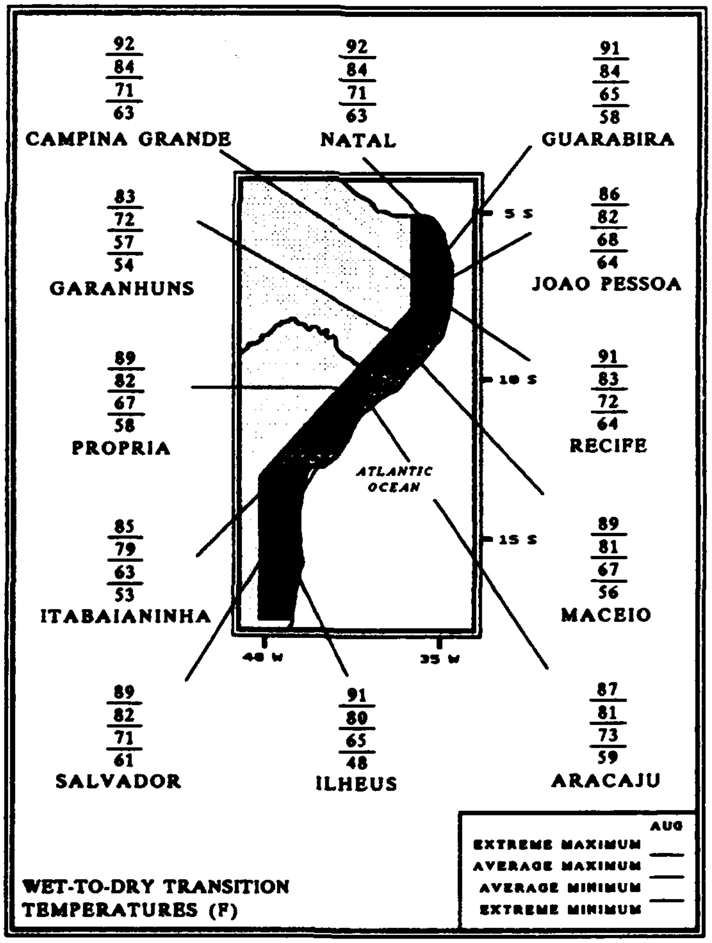


Figure 4-159. Wet-to-Dry Transition Tabular Temperature Data, Brazilian East Coast.

Residual wet-season moisture and the South Atlantic's maritime influence cause high relative humidities, which range from minimums between 65% and 80% to maximums between 80% and 95%. Figure 4-160 shows five stations with wet-bulb globe temperature data (° F) at specific hours in August.

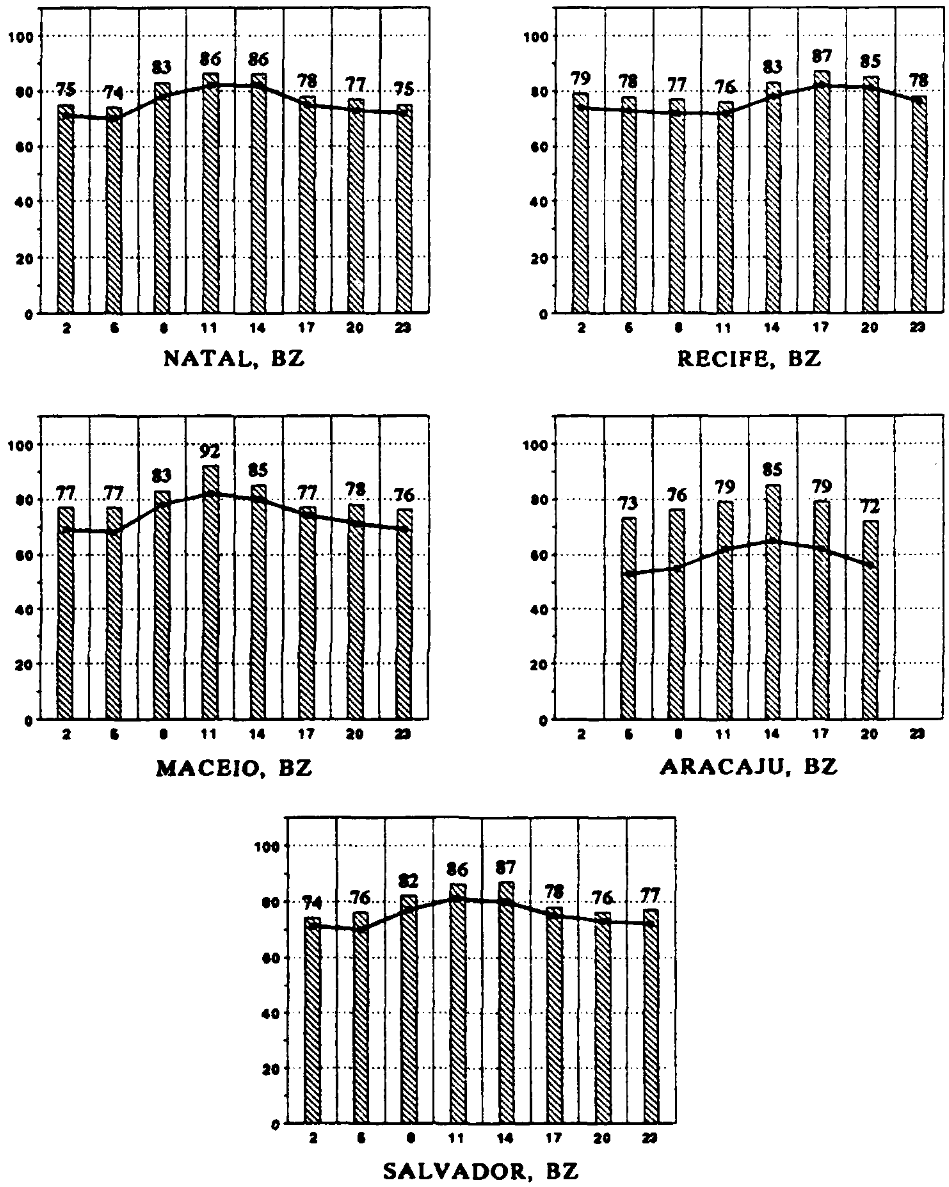


Figure 4-160. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for August, Brazilian East Coast. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Light to moderate mechanical turbulence is found over rough terrain. It affects the mountains during strong easterly flow and can affect the entire south during strong westerly flow. Wind shear can occur near tops of radiation inversions, especially in the north where surface winds drop below 5 knots at night while winds above 1,000 feet (305 meters) AGL average near 20 knots. Significant icing is rare since towering cumulus and cumulonimbus, also rare, are normally the only clouds that reach the freezing level, which averages 15,000 feet/4,570 meters MSL).

GROUND HAZARDS. Flash floods, although rare, still occur with rapid mountain run-off of heavy or frequent moderate precipitation. Most occur on slopes and low-lying areas in the vicinity of 9 and 10° S.

4.5 NORTHEAST BRAZIL

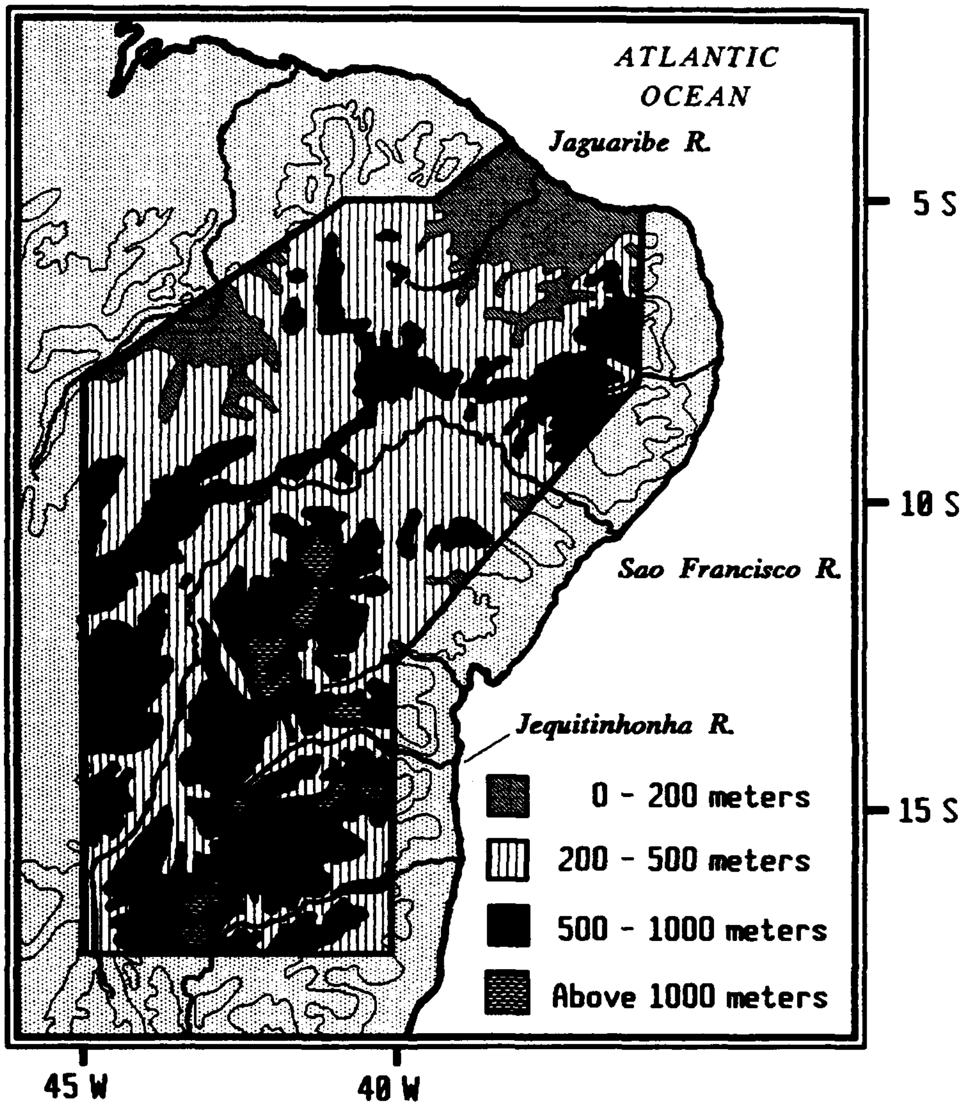


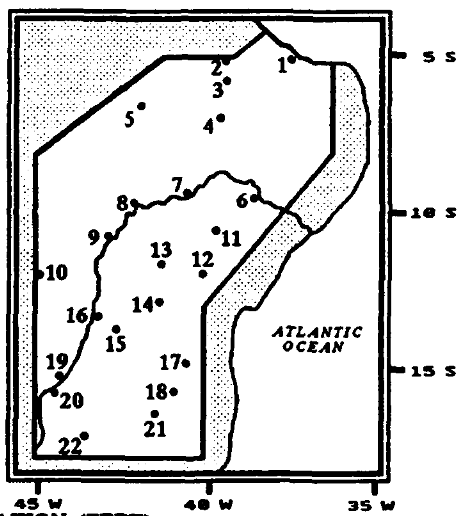
Figure 4-161. Northeast Brazil. This zone is known for its mountain peaks, dry climate, and thorny scrub vegetation. Set in the rain shadow of the east coast highlands, Northeast Brazil's eastern mountain peaks further deplete weather systems of their moisture. The zone's western range cuts off moisture from the tropical rain forest to the west. The Sao Francisco River runs through the zone's middle valley and is the main supplier of water to this dry area, which is subject to severe droughts.

NORTHEAST BRAZIL GEOGRAPHY

TERRAIN. The Sao Francisco River Basin runs through the northern half of the zone between two mountain ranges that run SSW to NNE. The southern ranges are the most rugged. The highest peaks are in the eastern range; the highest of these is 5,918 feet (1,804 meters) at 16° 05' S, 42° 01' W. The northern ranges are lower; the hills yield to narrow coastal plains that average 20 miles wide made up of sandy beaches and lagoons.

RIVERS. The Sao Francisco begins in the Brazilian Plateau zone near Brasilia. It enters eastern Brazil in the zone's southwest corner and flows north for 1,000 miles before turning east for 350 miles to the Atlantic coast and emptying into the ocean at 10° 50' S. Near the northern boundary, the Jaguaribe River originates 75 miles northwest of Iguatu and flows for 300 miles to the northeast coast through the Eastern Amazon Basin zone. Rio Jequitinhonha is a major river in the south, draining through the zone to the Atlantic.

VEGETATION. Most vegetation is small thorny scrub. Much of the landscape is open with little or no grass. Some savanna and palm trees line the banks of major rivers. The coast contains dune vegetation with occasional clusters of mangrove trees.



		ELEVATION (FEET)			ELEVATION (FEET)
1.	MOSSORO	75	12.	IPIRA	982
2.	QUIXERAMOBIM	653	13.	MORRO DE CHAPEU	3543
3.	IGUATU	505	14.	LENCOIS	1402
4.	BARBALHA	1342	15.	CAETITE	2953
5.	FLORIANO	453	16.	BOM JESUS	1411
6.	PAULO ALFONSO	832	17.	VITORIO da CONQUIST	2970
7.	PETROLINA	1233	18.	PEDRA AZUL	1906
8.	REMANSO	1348	19.	JANUARIA	1440
9.	BARRA	1339	20.	SAO FRANCISCO	1493
10.	BARREIRAS	2493	21.	ARACUAI	866
11.	MONTE SANTO	1624	22.	MONTES CLAROS	2120

Figure 4-162. Climatic Station Network, Northeast Brazil.

NORTHEAST BRAZIL CLIMATIC PECULIARITIES

The zone known as Northeast Brazil, although basically semiarid, is known for its climatic variability and persistent "wet" and "dry" periods. But because the location and timing of these so-called "wet and dry seasons" vary so much from place to place, Northeast Brazil is discussed in terms of the four seasons common to the mid-latitudes. Extremely dry periods result in major droughts, known locally as "Seca." Droughts are a major concern in Northeast Brazil and are very difficult to forecast. They are responsible for many deaths through dehydration and starvation.

Conditions here rarely change rapidly; an extremely dry season often indicates that the seasons to follow will also be unusually dry. The same rule applies to "wet" seasons. Unusually dry or wet periods may persist for as long as 2 to 3 years. Precipitation variability is discussed in each season's "General Weather" section.

Distinguishing this zone from the others are the combined effects of infrequent disturbances, the South Atlantic High, and the trade-wind inversion. Although a large variety of disturbances is possible, there are often long periods when disturbances are very rare.

The low mountains bordering much of the zone deplete most approaching low-level moisture. The highest mountains are in the southern half. Disturbances provide the primary source of mid-level moisture, but moisture must be two to three times the average to bring rainfall to Northeast Brazil. The easterly trades are the primary low-level moisture source all year. Amazon Basin moisture also enters the zone with the approach of summer disturbances. Low elevations in the north provide the easiest route for incoming moisture, but northerly flow is rare. In most cases, moisture entering from the north is due to the occasional sea breeze or associated with flow from the Near Equatorial Trough (NET). Sea breezes moving southwest from the Eastern Amazon Basin can enhance tropical disturbance development along the northwestern fringes of the zone. The sea breezes interact with the terrain, the NET, and easterly disturbances to cause showers and thunderstorms that rarely become widespread or organized before moving westward into the Brazilian Plateau.

South Atlantic High subsidence and tradewinds cause two distinct inversions. The bases of the first average 15,000 feet (4,570 meters) MSL; bases of the second vary by time and place from 5,000 to 8,000 feet (1,525 to 2,440 meters) MSL. A col or neutral area (explained in each seasonal "Winds" section) frequently overlies the zone and affects stability.

Disturbance frequencies depend on large-scale circulation patterns that include Northern Hemisphere features, South Atlantic High strength, the El Niño-Southern Oscillation (ENSO), and Atlantic sea surface temperatures. All these have nominal effects on trade wind location and strength, which act, in turn, as indicators for disturbances and rainfall potential.

Weak trades allow disturbances to enter the zone; strong ones keep them out. Strong ENSO occurrences almost totally supress "wet" seasons. When the South Atlantic High remains abnormally far north, trade-wind strength is maintained and Southern Hemisphere temperate zone disturbances are kept out of the zone. Mid-latitude disturbances can affect the south when the trades are displaced north; conversely, when the trades are displaced south, NET-associated rainfall can affect the north. Droughts in the north and south may not, therefore, occur at the same time.

GENERAL WEATHER. The variability of summer weather is shown in Figure 4-163, which gives monthly frequencies of precipitation amounts below 1 inch and greater than 8 inches at 15 stations across the zone. Montes Claros in the south and Quixeramobim in the north are two examples. In January at Montes Claros, monthly amounts are less than 1 inch 15% of the time and more than 8 inches 35% of the time; In December at Quixeramobim, monthly amounts are less than 1 inch 75% of the time, and more than 8 inches rarely.

Major causes of unsettled summer weather are upper-level cyclones, occasional cold fronts/shear lines in the south, the NET in the northwest, and the Tropical Convergence Zone (TCZ) everywhere except the northeast (all these features are explained in Chapter 2). Low-, mid- and upper-level troughs occasionally affect the area. The trade-wind inversion may suppress the effects of disturbances, especially in the east.

STATION	DEC		JAN		FEB	
	<1	>8	<1	>8	<1	>8
ARACUI	#	40	10	25	25	10
BARRA	5	25	15	10	10	10
BARREIRAS	0	35	5	25	#	20
BOM JESUS	5	35	15	20	15	15
FLORIANO	5	20	5	15	5	20
IGUATU	60	#	15	10	5	25
IPIRA	30	10	35	5	35	5
JUANRIA	0	50	10	25	15	10
MONTE SANTO	30	5	40	5	45	#
MONTES CARLOS	#	55	15	35	10	25
MORRO DO CHAPEU	20	10	20	5	35	5
PETROLINA	25	#	30	#	30	5
QUIXERAMOBIM	75	#	40	5	15	10
REMANSO	10	10	20	15	20	5
VITORIO da CONQUIST	10	15	20	5	30	5

- LESS THAN 0.5 PERCENT

Figure 4-163. Percent Probabilities of Monthly Precipitation Totals Less Than 1 Inch and Greater Than 8 Inches, Northeast Brazil. Values have been rounded to the nearest 5%.

SKY COVER. Low clouds account for most of Northeast Brazil's sky cover. Coverage and bases are unusually dependent on the synoptic situation; changes in synoptic flow interact with terrain and cause low-level moisture to vary by time and place. Coverage is greatest and base heights lowest along the zone's fringes that face synoptic flow. Rough terrain dries low-level air orographically with increasing distance downstream, resulting in decreased cloud cover and higher bases. Local variations are caused by upslope flow, convective heating, and local wind systems such as mountain/valley and sea breezes. Cumulus is characteristic of the west, stratocumulus of the east. Mean summer coverage, as represented by January in Figure 4-164, is about 40% in drier central areas and in the northeast where relatively flat terrain produces little lift. Mean coverage reaches 70% along the zone's high border terrain where lift and moisture are greater.

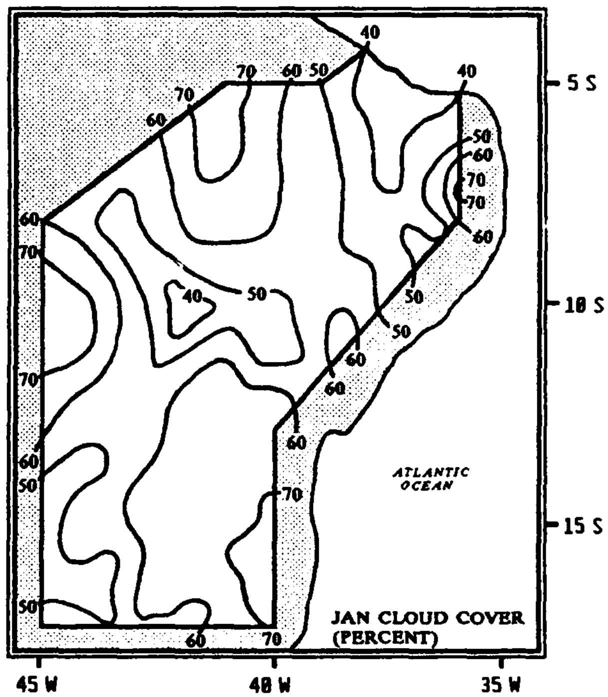


Figure 4-164. Mean January Cloud Cover, Northeast Brazil.

Cloud-base variability is reflected in the low-ceiling frequencies shown in Figure 4-165. Low ceilings form more often at higher elevations; the greatest frequencies are in high central and eastern areas at night where stratocumulus forms from the combined effects of moisture, stability, and radiation cooling. The best examples are Caetite and Vitorio Da Conquist, where frequencies of ceilings below 3,000 feet in February are 71% and 64%, respectively. Orographic lift can cause even higher frequencies on windward slopes. Diurnal variations are least evident in the west where disturbances cause most of the cloudiness. Since disturbances increase moisture and cause greater vertical mixing, cumulus forms. Low ceilings form least often at exceptionally dry low-lying areas, such as sheltered sections of the Sao Francisco River Valley. At Paulo Alfonso (in the east) and Bom Jesus (toward the southwest), mean frequencies of ceilings below 3,000 feet (915 meters) AGL are less than 20% at all hours.

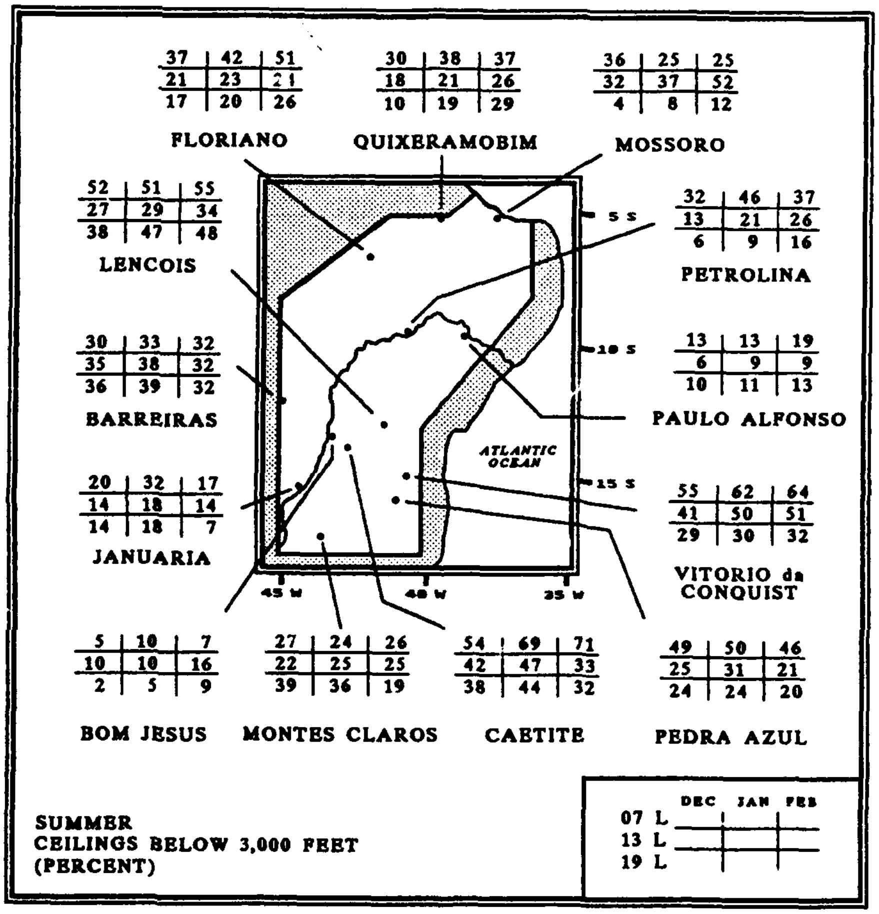


Figure 4-165. Summer Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Northeast Brazil.

During settled periods, stratocumulus is common everywhere, at all hours. Cumulus is common everywhere during the day and in the west at night. Afternoon towering cumulus forms in the west. Bases vary with moisture availability, but most are above 2,500 feet (760 meters) MSL in the morning and above 3,500 feet (1,065 meters) in the afternoon. Altocumulus is common everywhere at night, with nighttime and morning stratus sometimes following rainy days. Tops of most low and middle clouds do not extend above 15,000 feet (4,570 meters) MSL. Cirriform clouds from thunderstorms west of Northeast Brazil often move into the southern portions of the zone during afternoons and evenings.

Disturbances produce higher than normal cloud tops, along with a larger variety of low, middle, and high clouds. Disturbances can cause layered stratiform clouds and all types of cumulus. Cumulonimbus can form, but nimbostratus is rare. The zone's most extensive cloudiness occurs when the TCZ surges eastward toward northeast Brazil. Most clouds ahead of the surges are cumulus, towering cumulus, and cumulonimbus; they may be accompanied by altostratus and cirrostratus in the south.

VISIBILITY. Frequencies of low visibilities also vary depending on moisture availability; precipitation and fog are the two primary causes. As shown in Figure 4-166, visibilities below 3 miles are most frequent at Lencois and Vitorio Da Conquest, in the southeastern part of the zone where frequencies range from 10% in the evening to nearly 20% in the morning. In the Sao Francisco River valley and much of the zone's north, frequencies range from below 3% in the evening to around 5% in the morning. Throughout the zone, visibilities are below 1 mile about a third as often as they are below 3 miles.

In the northwest and southeast, precipitation causes most low visibilities; in the southwest, fog is the primary cause. In the rest of the zone, there is no single cause. Fog can result from upslope flow, radiation cooling, and saturation of the air by precipitation. Radiation fog occurs most often on clear mornings following rainy periods. Salt haze forms along the zone's eastern fringes and lowers visibilities in isolated areas.

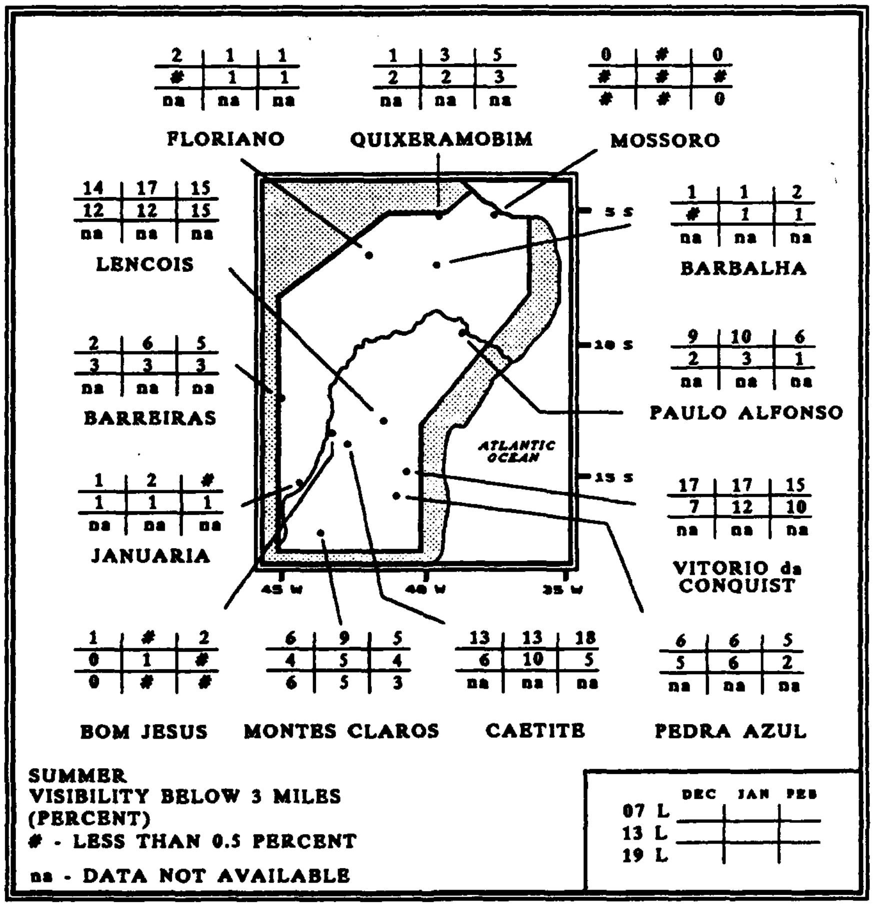


Figure 4-166. Summer Percent Frequencies of Visibility Below 3 Miles, Northeast Brazil.

WINDS. Winds are dominated by the easterly trades. Rugged terrain in the east blocks or channels the trades. As surface friction reduces trade-wind speeds, locations farther from the Atlantic are influenced more by mountain/valley circulations (see Chapter 2). As a result, winds at western stations are lighter and more variable. Changes in normal trade-wind flow are usually associated with surface troughs from the west. These are usually reflections of the TCZ, but can occasionally be lee-side waves (see "Lee-side Troughs" in Chapter 2). Winds often become northerly east of these troughs, while winds on the west side become variable or westerly. Cold fronts and shear lines that occasionally enter the zone are preceded by variable or westerly winds and followed by variable or southerly winds. Surface wind roses are shown in Figure 4-168.

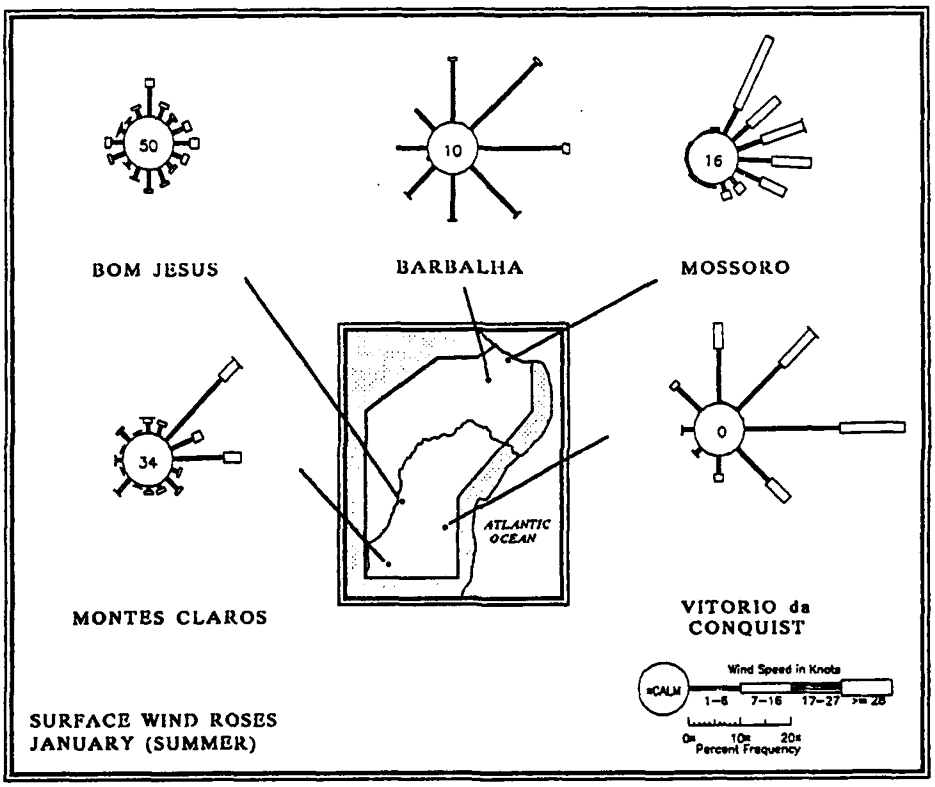


Figure 4-167. January Surface Wind Roses, Northeast Brazil.

Even in the most sheltered locations, the trades overcome terrain effects enough to give daytime wind directions an easterly component. Mean afternoon directions range from northerly at Bom Jesus (sheltered from the trades) to northeasterly at Mossoro (affected by sea breeze circulations) to southeasterly at Lencois (where the trades are channeled northwestward). Winds are more variable at night, especially toward the west where the weakened trades allow stronger radiation inversions and allow local wind systems to have greater effects.

Mean afternoon speeds range from less than 3 knots in the west and at sheltered locations to more than 7 knots in the east and at places exposed to the trades. Speeds at night average 3 knots or less throughout the zone. Maximum wind speeds occur in the south where the zone's most rugged terrain channels synoptic winds and thunderstorm gusts; speeds here can exceed 40 knots. Maximum speeds in the north, caused by

STATION	MEAN WIND SPEED DEC	JAN	FEB
ARACUI	2	2	2
BARBALHA	3	3	7
BARRA	3	3	3
BARREIRAS	3	3	3
BOM JESUS	3	3	3
CAETITE	6	6	6
FLORIANO	3	2	2
IGUATU	4	3	3
IRECE	5	4	5
JANUARIA	4	4	4
LENCOIS	2	3	3
MONTE SANTO	3	3	3
MOSSORO	6	5	4
PAULO ALFONSO	5	5	5
PEDRA AZUL	3	2	3
PETROLINA	4	3	3
QUIXERAMOBIM	8	7	5
REMANSO	3	2	3
SAO FRANCISCO	4	5	5
VITORIO da CONQUIST	5	5	5

Figure 4-168. Mean Summer Wind Speeds, Northeast Brazil.

Winds aloft are shown in Figures 4-169 through 4-171. Mean winds above the friction layer (5,000 feet/1,525 meters MSL) are 15 knots. Directions range from easterly in the north to east-northeasterly in the south. Winds weaken by 12,000 feet (3,660 meters) MSL, especially in the south where detailed analysis shows a col, or neutral point, beginning to appear. By 20,000 feet (6.1 km) MSL, the weak col area is found at about 13° S, 42° W. Winds north of the col are westerly at about 15 knots, and easterly at 10 knots to its south. Converging and diverging air flow associated with the col complicate stability. The col disappears by 30,000 feet (9.1 km) MSL. By 35,000 feet (10.7 km) MSL, winds become southwesterly at 30 knots over the entire zone.

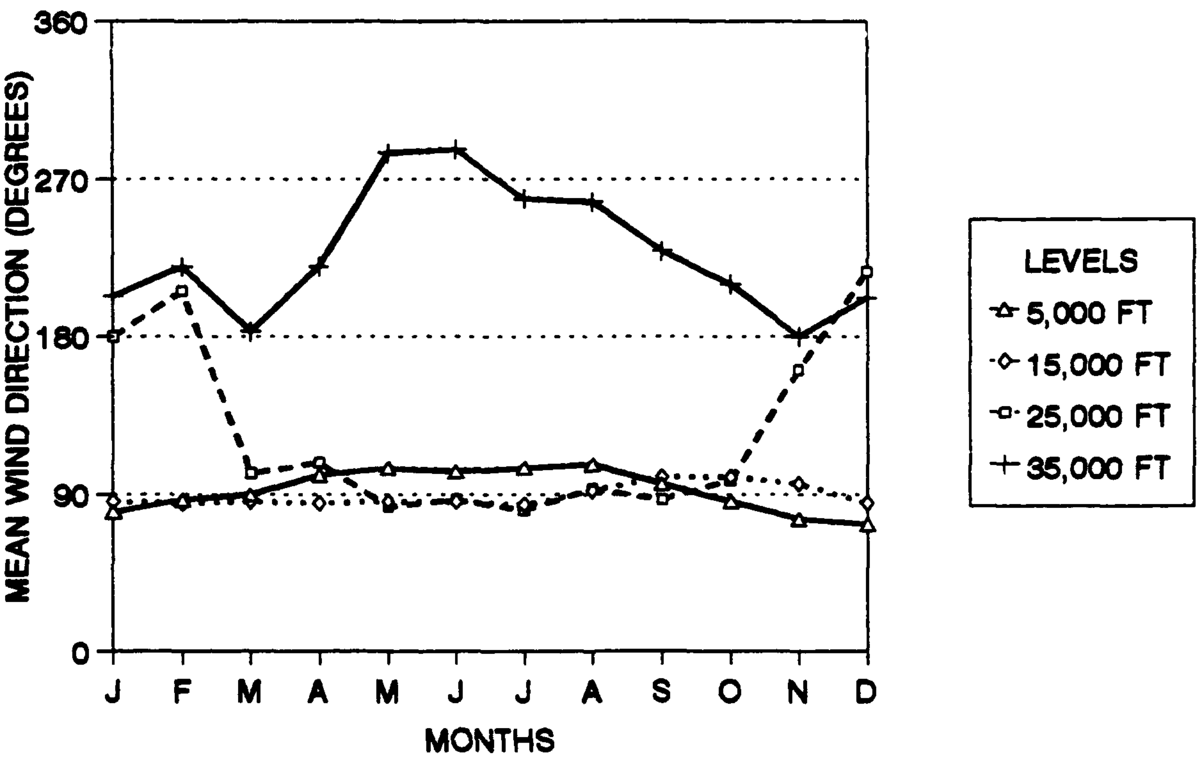


Figure 4-169. Mean Monthly Wind Directions for Various Levels at Floriano.

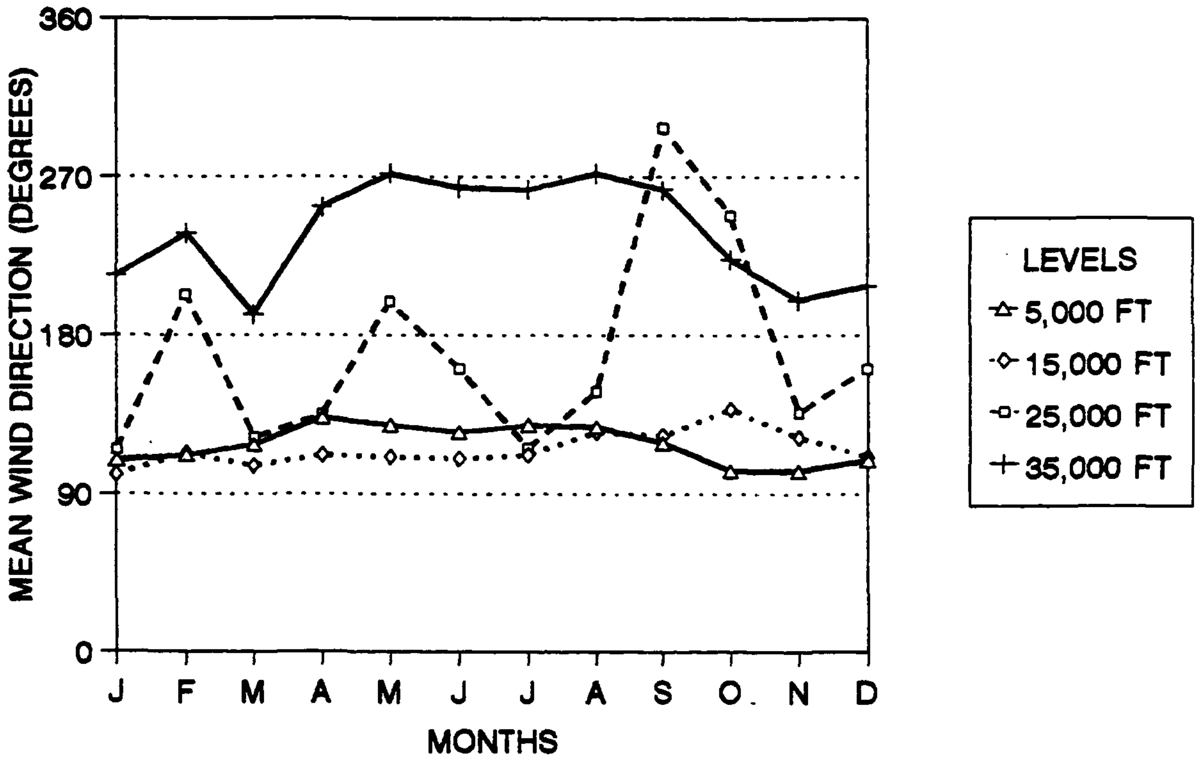


Figure 4-170. Mean Monthly Wind Directions for Various Levels at Petrolina.

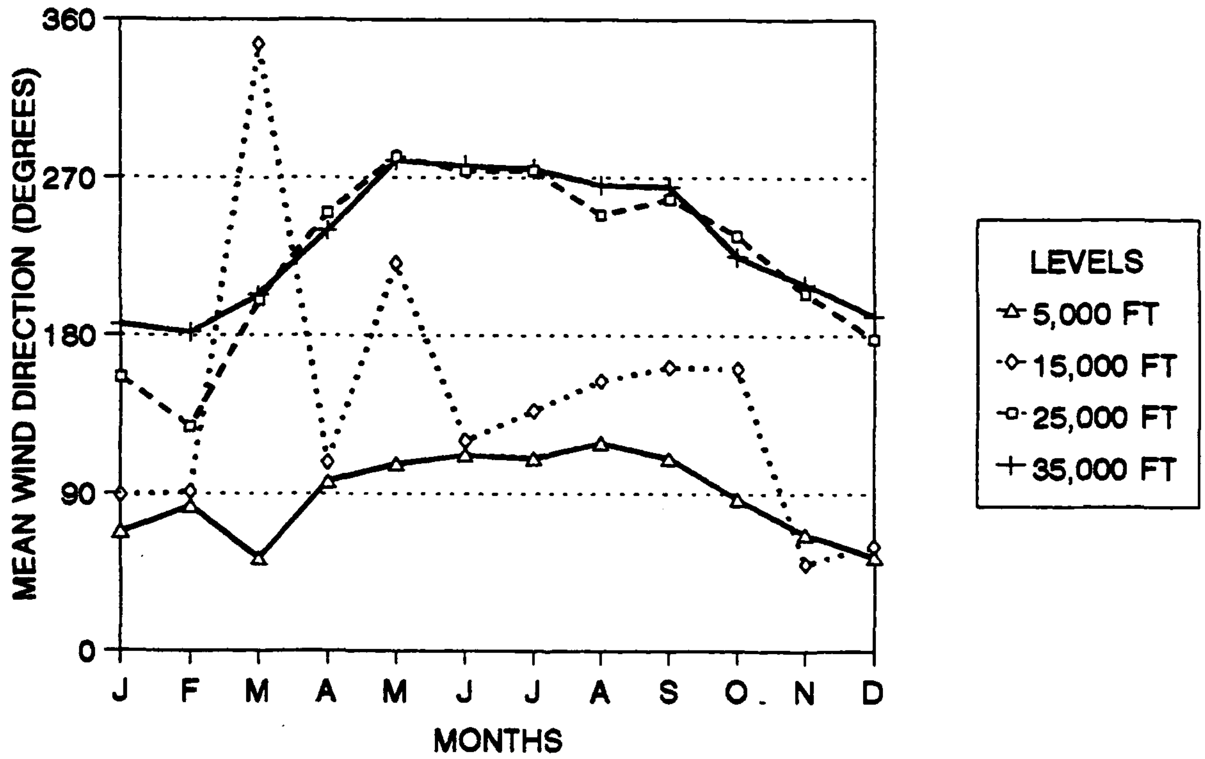


Figure 4-171. Mean Monthly Wind Directions for Various Levels at Bom Jesus.

PRECIPITATION. Summers are relatively wet, but precipitation is limited because of limited moisture and the trade-wind inversion. Monthly rainfall ranges from less than 2 inches north and east to 8 inches in the extreme west (see Figure 4-172). Most low-level moisture accompanying easterly trade-wind flow is confined to the north and east by terrain and is often capped by the trade-wind inversion. This, along with the scarcity of disturbances, make rainfall in the north and east lighter and less frequent than in the south and west, where the trade-wind inversion is weaker and where disturbances can cause low-level moisture to enter the zone from other directions. Mid- and upper-level convergent and divergent flow associated with the col mentioned in "Winds" are also important to stability and precipitation. Mountain/valley circulations enhance precipitation and cause more frequent afternoon and evening rainfall in the higher elevations, as well as more frequent nighttime rainfall in valleys. Upslope flow also enhances precipitation.

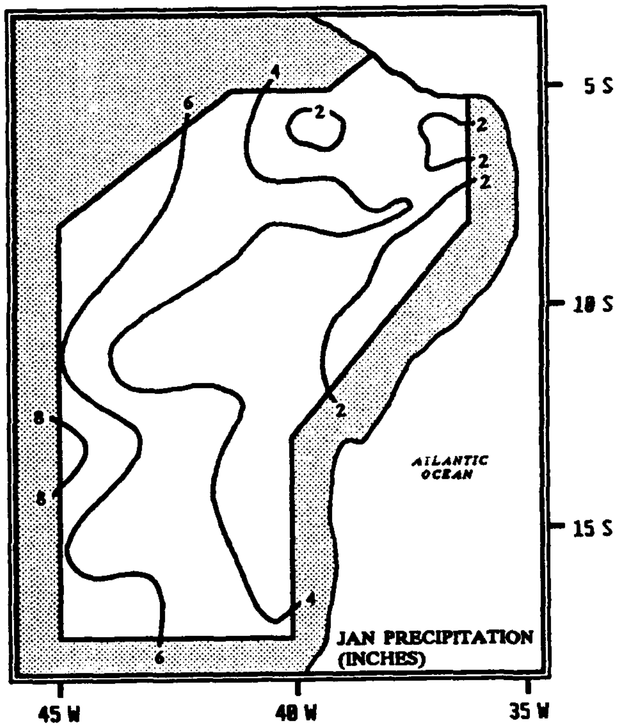


Figure 4-172. Mean January Precipitation, Northeast Brazil.

All available precipitation summary data is shown in Figure 4-173. Maximum 24-hour rainfall amounts range from less than 3 inches in exceptionally dry areas to more than 6 inches in the southwest. Days with precipitation range from less than 8 in the east to more than 12 in the west. Although most rainfall is light to moderate, amounts can be heavy with the instability associated with the TCZ and the NET. Most precipitation from disturbances is showery, but it can also be steady west of the TCZ. Regardless of the cause, rainy periods normally last for less than 5 hours on any given day at any one location. Most places have a few consecutive rainy days, followed by a few consecutive dry ones.

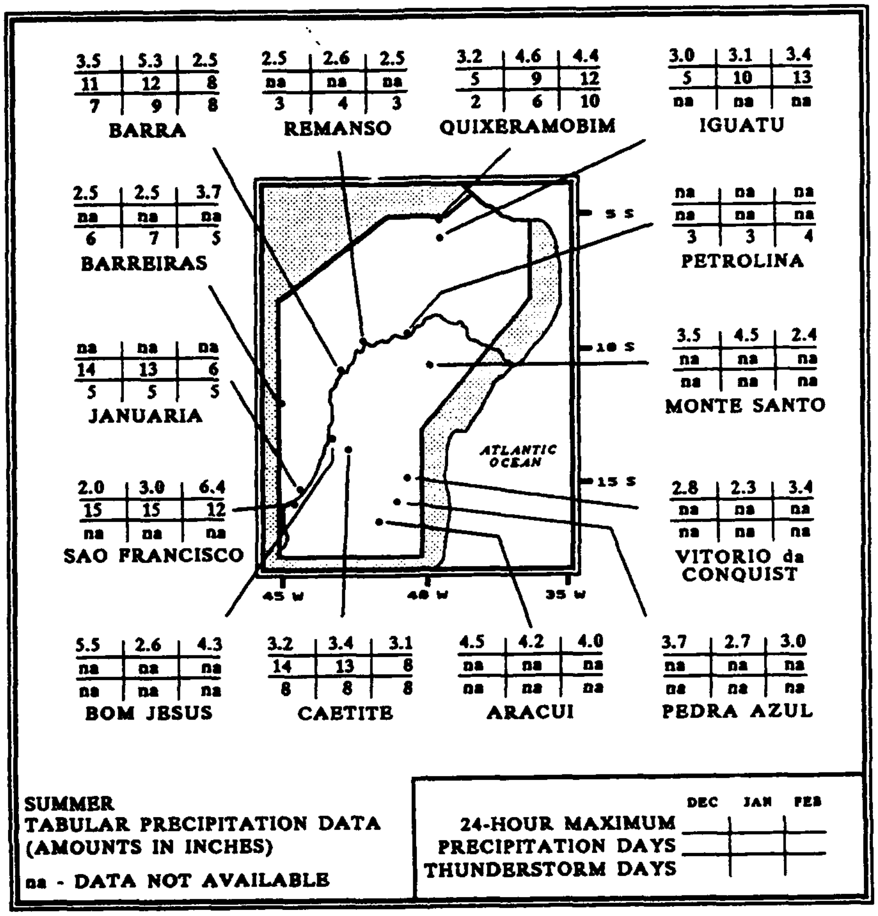


Figure 4-173. Summer Tabular Precipitation Data, Northeast Brazil.

THUNDERSTORMS. Vertical development is inhibited by dry air and stability associated with the trade-wind inversion. Although low-level moisture accumulates along the edge of the zone facing synoptic flow, it can't be forced aloft unless a disturbance destroys the trade-wind inversion. Even then, thunderstorms may not form unless the second inversion at 15,000 feet (4,570 meters) MSL is also destroyed. Disturbances can also increase the chance for thunderstorms by bringing in mid-level moisture. Because disturbances are most frequent in the west where the inversions are weaker, mean thunderstorm days there range from 5 to 9 days a month, as opposed to 3 to 5 days a month elsewhere.

Thunderstorm development is often enhanced by local wind systems; most thunderstorms form over peaks during afternoons and evenings and over valleys at night. Orographic lift also causes cell development. Thunderstorm movement is often unpredictable, and depends on the combined effects of steering flow, disturbance movement, and terrain.

Thunderstorm bases range from 1,000 feet to 3,000 feet (305 meters to 915 meters) MSL. Tops range from 30,000 feet (9.1 km) MSL in the east to as high as 45,000 feet (13.7 km) MSL in the west. Tornado activity is rare, and hail only occurs at high elevations. Thunderstorm gusts range from more than 40 knots in the south (especially where channeled by terrain) to around 30 knots in the north.

TEMPERATURE. Temperatures at higher elevations in the east are moderated diurnally by South Atlantic moisture. Amazon basin air does the same in the west. As a result, the greatest diurnal variations occur in the Sao Francisco River valley and other low-lying dry locations. Mean low temperatures (shown in Figure 4-174) do not correlate significantly with elevation because greater moisture and cloudiness in higher elevations inhibit radiation cooling. Mean lows range from 64° F (18° C) at Caetite to 78° F (25° C) at Paulo Alfonso. Mean highs are lowest at high elevations and highest in drier, low-lying areas. They range from 78° F (25° C) at Vitorio Da Conquist to 95° F (35° C) at Remanso and Iguatu. Extreme temperatures range from 50° F (10° C) at Remanso to 103° F (39° C) at numerous locations, including Remanso. Adiabatic warming leeward of slopes increases temperatures and lowers relative humidities.

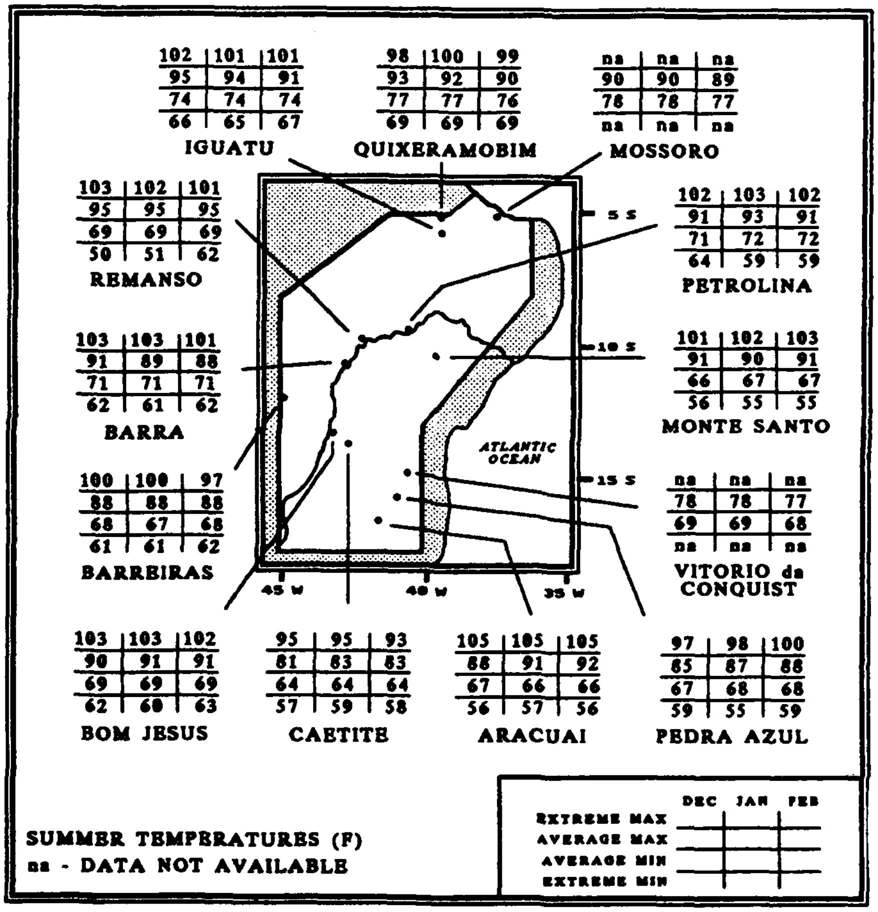


Figure 4-174. Summer Tabular Temperature Data, Northeast Brazil.

Relative humidities reflect terrain effects and are generally lowest in low-lying areas such as the Sao Francisco River Valley and other isolated valleys. The highest RHs occur where Amazon moisture enters the zone, such as at Barreiras, where RH ranges from as low as 65% during December afternoons to 87% on January mornings. Figure 4-175 shows three stations with wet-bulb globe temperature data (° F) at specific hours in January.

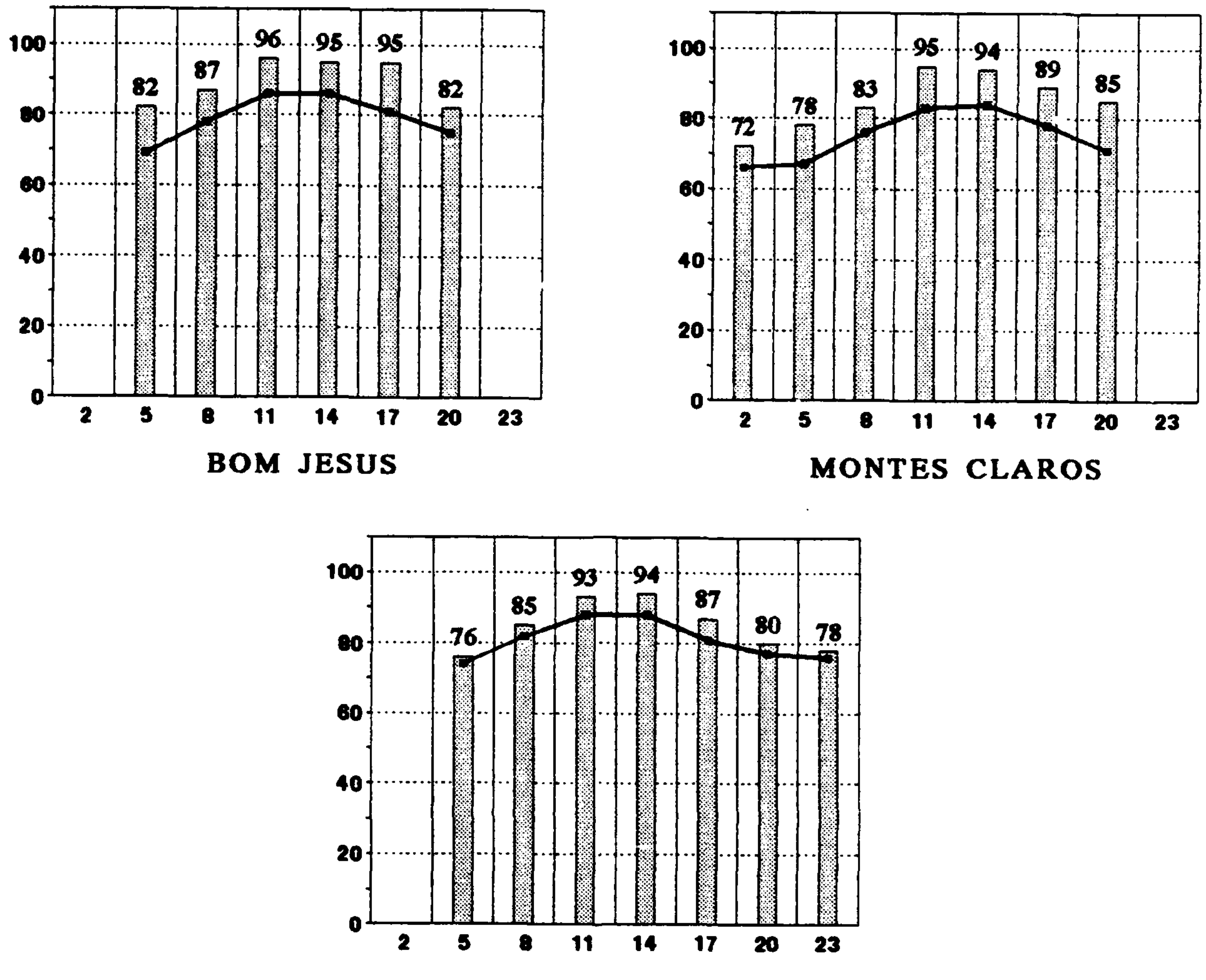


Figure 4-175. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Northeast Brazil. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Summer flight hazards not associated with thunderstorms include turbulence, icing between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL, and terrain that may be obscured by clouds and fog. Light-to-moderate mechanical turbulence and shear can occur over rough terrain, and there can be light to moderate thermal turbulence in dry, cloudless areas. Clouds and fog can obscure higher terrain, except in the north.

GROUND HAZARDS. Flash floods occur with rapid mountain run-off of heavy or frequent moderate precipitation.

GENERAL WEATHER. Large-scale patterns are persistent; that is, wet months usually follow wet months and dry months usually follow dry months. The variability of weather here can be inferred from the frequencies of rainfall amounts shown in Figure 4-176. For example, Bom Jesus rainfall is less than 1 inch 25% of the time in March, but in May it is less than 1 inch 90% of the time. In March, Bom Jesus rainfall is over 8 inches 20% of the time, but in May, there were 8 inches in only a few years of the record.

Unsettled fall weather is caused by upper-level cyclones, occasional cold fronts/shear lines in the south and west, the NET in the north, and occasional TCZ effects everywhere but in the northeast. Easterly waves and mid-latitude low, middle, and upper troughs also affect the zone, but disturbances are suppressed as the trade-wind inversion and South Atlantic High become stronger. Occasionally, Brazilian East Coast weather extends westward through gaps in the mountains.

STATION	MAR		APR		MAY	
	<1	>8	<1	>8	<1	>8
ARACUI	20	10	30	#	90	0
BARRA	15	20	30	5	75	#
BARREIRAS	10	20	15	5	80	#
BOM JESUS	25	20	45	5	90	#
FLORIANO	5	35	5	5	65	#
IGUATU	#	50	#	30	20	5
IPIRA	30	5	25	5	15	#
JUANRIA	25	10	50	5	80	#
MONTE SANTO	30	5	25	5	15	#
MONTES CARLOS	20	25	45	5	85	#
MORRO DO CHAPEU	25	10	20	10	35	0
PETROLINA	25	10	50	5	90	0
QUIXERAMOBIM	#	35	#	30	5	10
REMANSO	10	15	55	5	85	#
VITORIO da CONQUIST	25	5	40	#	75	0

- LESS THAN 0.5 PERCENT

Figure 4-176. Percent Probabilities of Monthly Precipitation Totals Less Than 1 Inch and Greater Than 8 Inches, Northeast Brazil. Values have been rounded to the nearest 5%.

SKY COVER. As in summer, most sky cover is low cloud. Coverage is greatest and bases lowest along the zone's fringes facing the synoptic flow. Clouds decrease and bases rise with increasing distance downstream as rough terrain dries low-level air orographically. Local variations result from upslope flow, convective heating, and local wind systems. Mean fall coverage, as represented by April in Figure 4-177, ranges from less than 40% in low, dry areas to more than 60% in the highest elevations and along high border terrain.

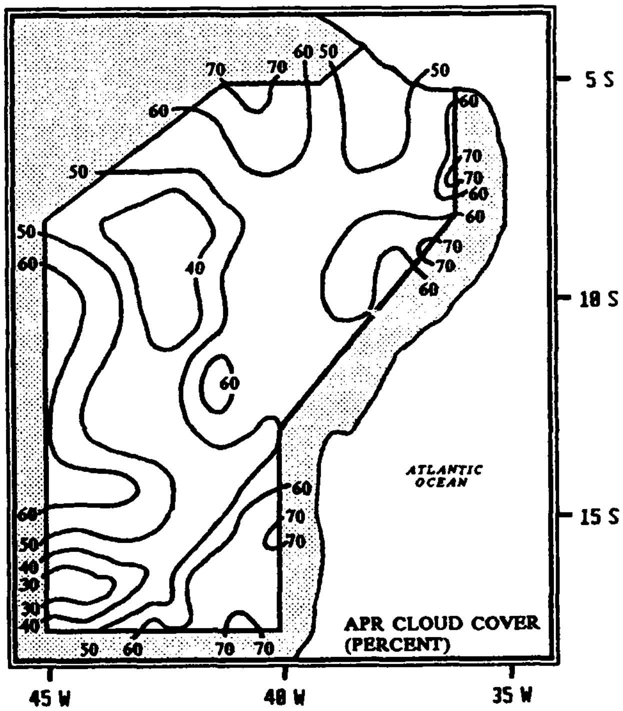


Figure 4-177. Mean April Cloud Cover, Northeast Brazil.

Because the oceanic NET is farthest south in March and April, cloudiness and frequency of low-cloud ceilings increase in the north (see Figure 4-178). Low ceilings in the east result from moisture brought in by the persistent easterly trades. Low ceilings are most common at high elevations at night; examples are Caetite and Vitorio Da Conquist, where April frequencies of ceilings below 3,000 feet (915 meters) AGL are 75% and 63%, respectively. Orographic lift causes even higher frequencies of low ceilings on windward slopes. Low ceilings in the west, especially at night and in the morning, are less common than in summer. Western daytime low-ceiling frequencies, however, are higher because of heating and increased low-level stability, stratocumulus replaces summer cumulus. Low ceilings are least frequent in dry, low-lying areas; for example, Januaria's frequencies below 3,000 feet (915 meters) AGL are below 20% during all hours.

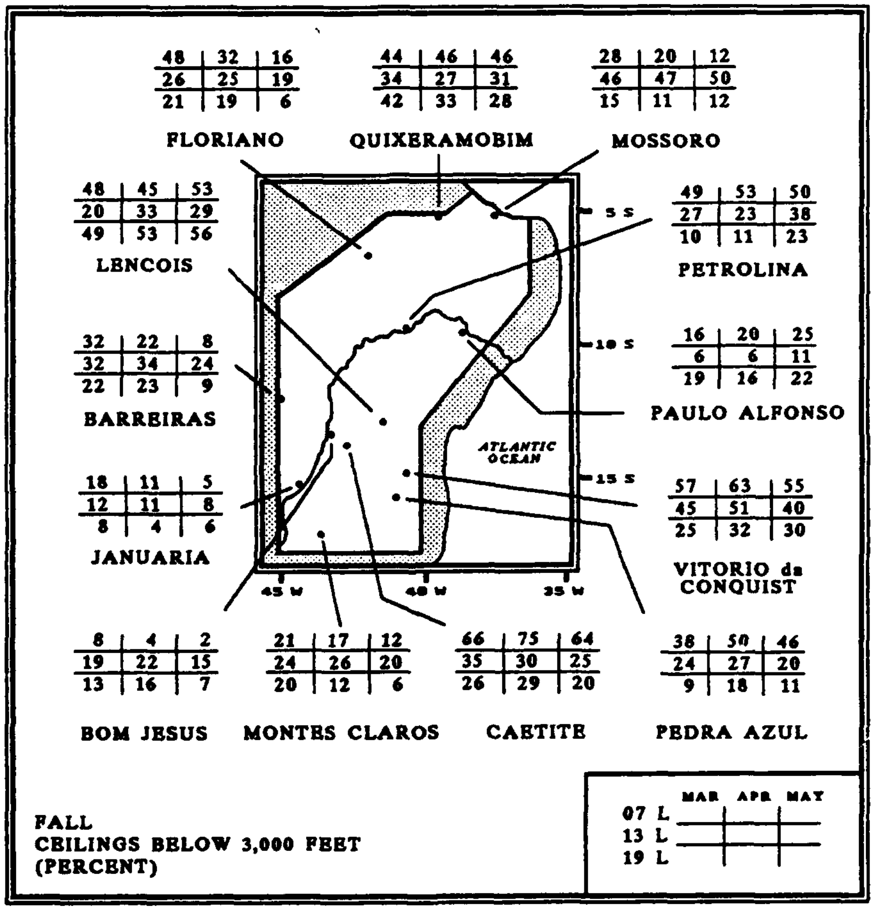


Figure 4-178. Fall Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Northeast Brazil.

Stratocumulus is prevalent everywhere during all hours. Cumulus is common during the day. Stratus normally occurs only at night where there is enough low-level moisture. Altocumulus can occur in most locations at night. During settled periods, cloud tops generally do not extend above 15,000 feet (4,570 meters) MSL. Disturbances result in higher tops and bring a variety of low, middle, and high cloud types. They often result in layered stratiform clouds. Cumulonimbus can occur in most places, but nimbostratus is rare. Most bases are above 2,500 feet (760 meters) MSL in the morning and above 3,500 feet (1,065 meters) in the afternoon.

NORTHEAST BRAZIL

VISIBILITY. In fall as in summer, low-visibiity frequencies depend on moisture availability. Low visibilities are least frequent at higher elevations where cloud cover limits radiation cooling and for formation. As shown in Figure 4-179, the greatest frequencies of low visibilities are in the southeast. Frequencies below 3 miles are highest at Vitorio Da Conquist, where they range from 15% or less in afternoons and evenings to as high as 22% in the morning; frequencies at most other stations are much lower. In the extreme south, west, and almost the entire zone north of 5° S, visibilities are below 3 miles less than 8% of the time during all hours. Visibilities are below 1 mile about half as often as they are below 3 miles.

In about half the zone, there is no single cause of low visibility, but in the north and on the eastern fringes, precipitation (and to a lesser degree, salt haze) is the main cause. In the southeast, fog forms with upslope flow, radiation cooling, and saturation of the air by precipitation. Radiation fog is common on clear mornings following rainy spells.

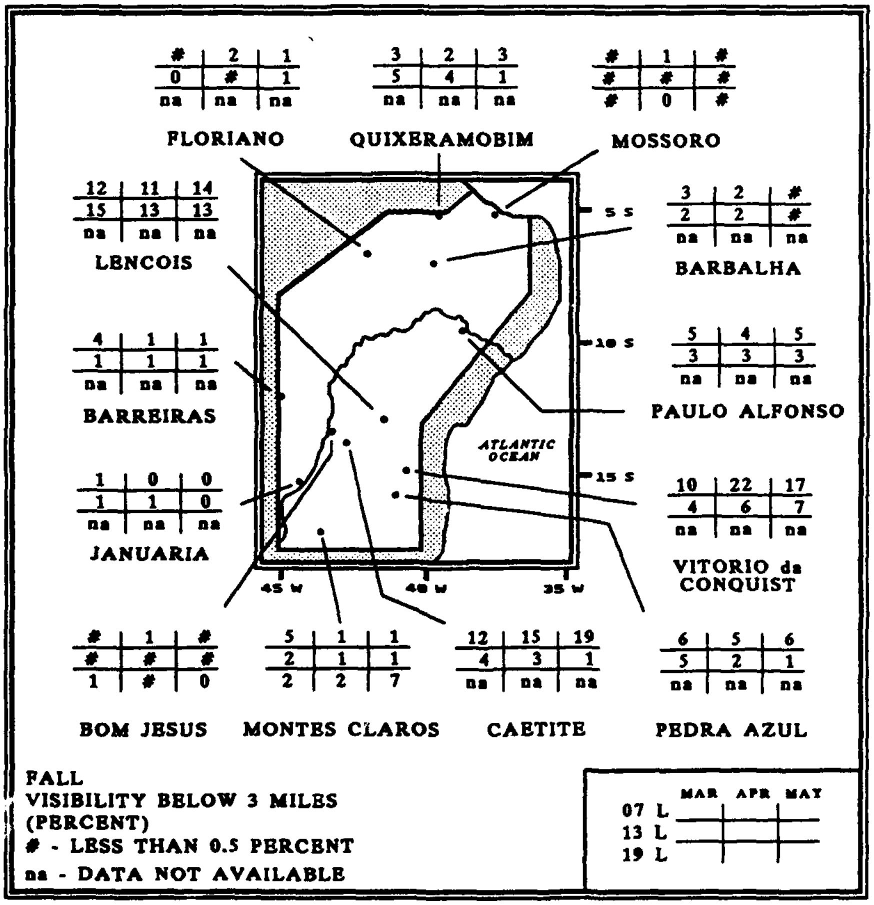


Figure 4-179. Fall Percent Frequencies of Visibility Below 3 Miles, Northeast Brazil.

WINDS. Fall wind patterns are similar to summer's. Although the trades are still in control, they normally weaken in the north where local wind systems become more important. Mountain/valley breezes (see Chapter 2) control flow in the west where terrain blocks or channels synoptic flow. With infrequent disturbances, easterlies prevail. But cold fronts/shear lines occcasionally change low-level synoptic flow. They are preceded by variable or westerly winds and followed by variable or southerly winds.

Mean winds for all hours at various locations are shown in Figure 4-180; wind roses are in Figure 4-181. Mean afternoon winds have an easterly component even though the trades are often weak. Mean afternoon directions range from northeasterly at Mossoro (which is affected by sea breeze circulations) to southerly at Bom Jesus (sheltered from the trades) and Lencois (where trades are channeled northward). Mean afternoon speeds range from less than 3 knots in the west and at sheltered locations to more than 6 knots at places exposed to trade-wind flow. Winds are more variable at night, especially in the west where radiation inversions form. Nighttime speeds average less than 3 knots throughout the zone. Maximum wind speeds in the south exceed 40 knots where rugged terrain channels synoptic winds and thunderstorm outflow. Winds in the north rarely exceed 30 knots.

STATION	MEAN WIND SPEED		
	MAR	APR	MAY
ARACUI	2	2	2
BARBALHA	3	3	3
BARRA	3	3	3
BARREIRAS	3	3	3
BOM JESUS	3	3	3
CAETITE	6	7	7
FLORIANO	2	3	4
IGUATU	2	2	3
IRECE	5	5	6
JANUARIA	4	4	4

STATION	MEAN WIND SPEED		
	MAR	APR	MAY
LENCOIS	3	3	2
MONTE SANTO	3	3	3
MOSSORO	4	3	3
PAULO ALFONSO	5	4	4
PEDRA AZUL	3	2	2
PETROLINA	3	4	5
QUIXERAMOBIM	4	4	4
REMANSO	2	2	3
SAO FRANCISCO	5	4	5
VITORIO da CONQUIST	5	5	4

Figure 4-180. Mean Fall Wind Speeds, Northeast Brazil.

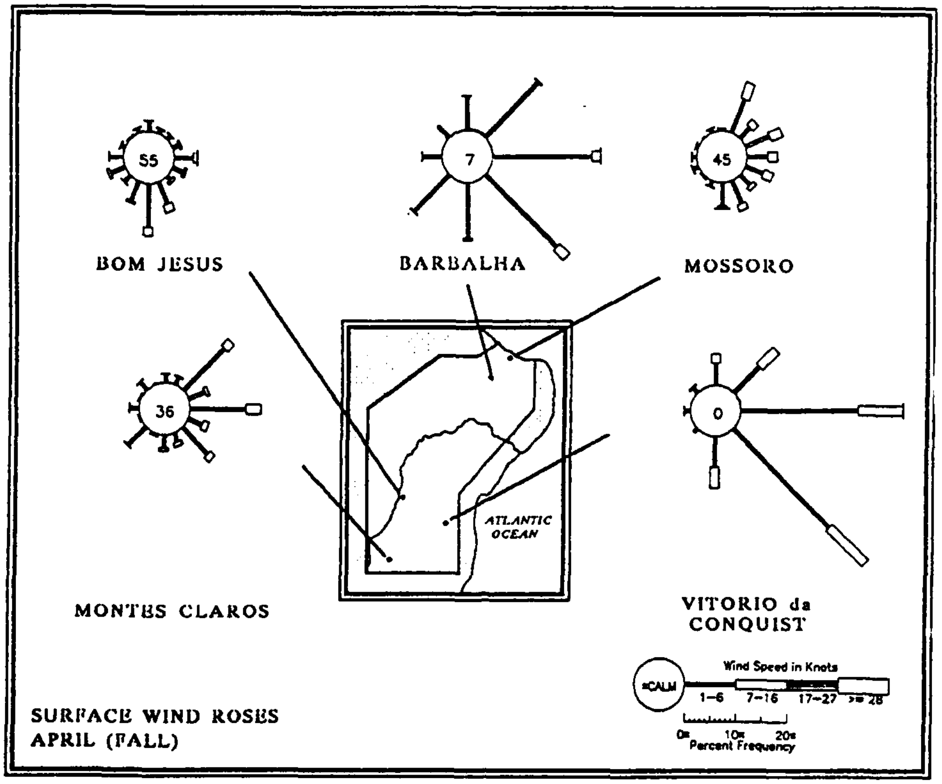


Figure 4-181. April Surface Wind Roses, Northeast Brazil.

Winds aloft are shown in Figures 4-169 through 4-171. Mean winds above the friction layer (about 5,000 feet/1,525 meters MSL) are less than 15 knots from the east. Wind speeds change little through 12,000 feet (3,660 meters) MSL. The col (or neutral area) present in summer has moved northeastward; by 20,000 feet (6.1 km) MSL, the col's mean fall position is about 12° S, 40° W. Southwesterly winds over the southwest corner diverge, flowing north and east from there. Winds are easterly north of the col, converging with southerly winds near the zone's central western border. Average wind speeds at 20,000 feet (6.1 km) MSL are only about 15 knots. The col has disappeared by 30,000 feet (9.1 km) MSL. By 35,000 feet (10.7 km) MSL, mean winds are southwesterly at 30 knots.

NORTHEAST BRAZIL

PRECIPITATION. Fall rainfall in the north is generally greater than summer's because of the proximity of the NET's Atlantic segment. Figure 4-182 shows that mean April rainfall reaches 8 inches in the north but only about 2 inches in drier, sheltered areas farther south. In central and southern regions, rainfall amounts and frequencies decrease through the season as the South Atlantic High builds over the area. As stability increases, fewer mid-latitude disturbances are able to enter the zone; the heaviest summer precipitation, however, has fallen as the result of fronts entering the zone's southwest corner. Sao Francisco has recorded more than 8 inches of rainfall in 24 hours during March (see Figure 4-183). Upper-air circulations produce vertical motions associated with convergent and divergent flow around the mid- and upper-level col. On a smaller scale, mountain/valley breezes account for higher rainfall frequencies over peaks during afternoons and evenings, and higher frequencies over valleys at night. Upslope winds also enhance rainfall.

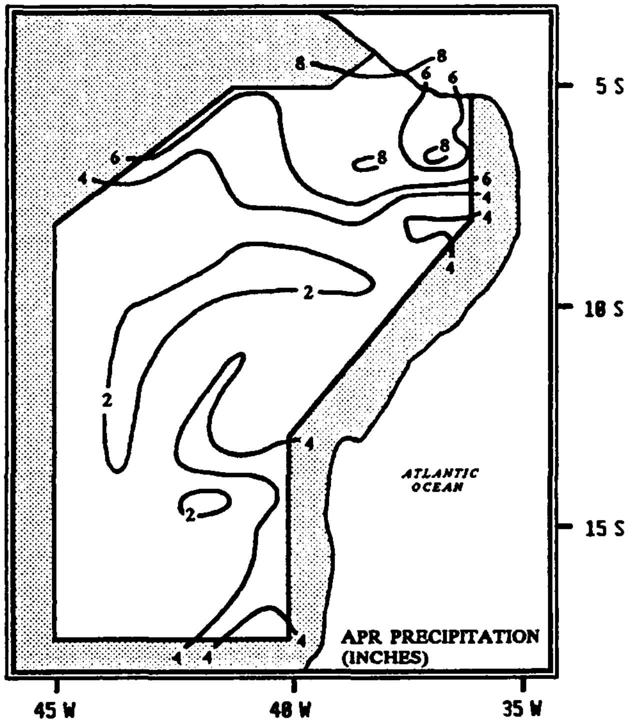


Figure 4-182. Mean April Precipitation, Northeast Brazil.

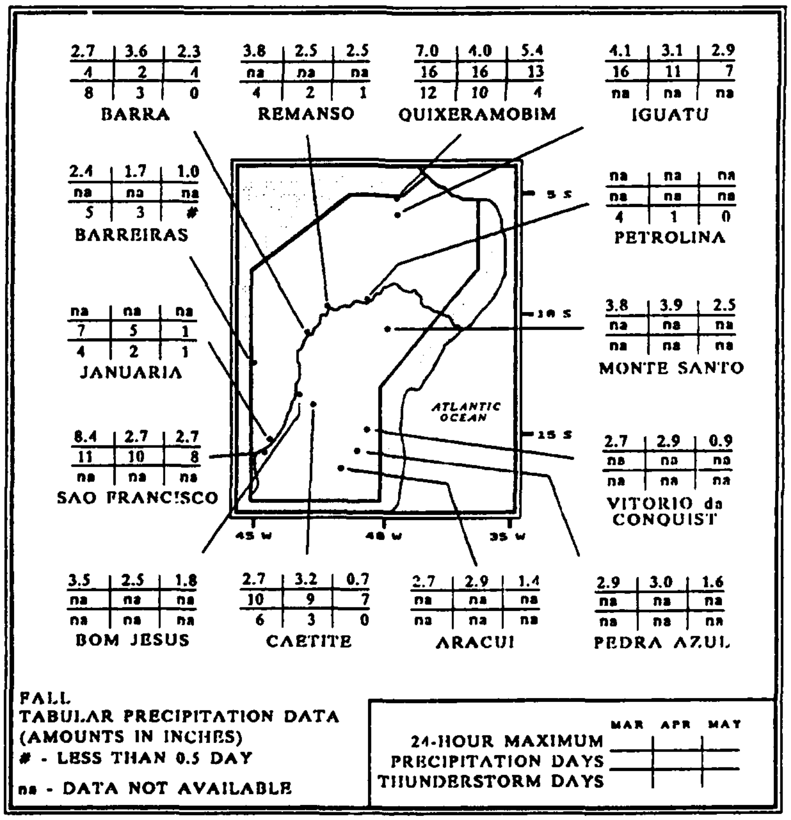


Figure 4-183. Fall Tabular Precipitation Data, Northeast Brazil.

Data for the tables in Figure 4-183 was sparse, but 24-hour rainfall amounts generally range from less than 2.5 inches in the west to more than 8 inches in the southwest. Mean rainfall days range from less than 5 in the west to 15 in the north and east. Most rainfall is light to moderate, but it can be heavier from instability associated with the NET, especially when mid-latitude fronts enter the southwest. Precipitation is steady as often as it is showery. Periods of rain normally last no more than 5 hours, but some places see this 5-hour period repeated daily for a few consecutive days before a dry spell sets in. Dry spells can last for many days, especially in sheltered locations.

THUNDERSTORMS. Thunderstorm development is inhibited by the combined effects of orographically dried low-level air, dry air above the trade-wind inversion, and the inversion's stability. Low-level moisture is more dependent on trade-wind flow in fall than in the summer. Most thunderstorms form on the zone's northern and eastern fringes. Vertical cloud development is sometimes capped by the second inversion, which is common at 15,000 feet (4,570 meters) MSL. In the north, thunderstorms are triggered by instability associated with the NET.

Thunderstorm days in the extreme north average 10 a month, but in the rest of the zone, the mean is only 1 to 3 a month in April and May. The heaviest precipitation occurs with those few cells in the southwest.

Close analysis shows that thunderstorm occurrences often correlate with local wind systems. The combined effects of mountain/valley breezes and necessary disturbances cause most thunderstorms to form over peaks during the day and evening, and over valleys at night. Orographic lift also enhances cell development. Fall thunderstorm movement is nearly as unpredictable as summer's. Movement depends on the combined effects of steering flow, disturbance movement, and terrain.

Thunderstorm bases range from 1,000 to 3,000 feet (305 to 915 meters) MSL, depending on moisture availability. Tops range from 30,000 feet (9.1 km) MSL in the east to 45,000 feet (13.7 km) MSL in the west. Tornados are rare to nonexistent, hail occurs only over high terrain. Thunderstorm gusts range from around 40 knots in the south when channeled by terrain to as high as 30 knots in the north.

TEMPERATURE. Fall temperatures are similar to summer's. Temperatures at high elevations in the east are moderated by South Atlantic moisture; in the west, by moisture from the Amazon Basin. Occasional cold fronts cause the zone's greatest temperature variations to occur in the south and in low-lying dry areas, such as the Sao Francisco River Valley. Mean low temperatures, shown in Figure 4-184, do not correlate well with synoptic influences. Greater moisture amounts and associated cloudiness in higher elevations prevent significant radiation cooling. Mean lows range from 60° F (15° C) at places affected by cold fronts in the south to 77° F (25° C) at Floriano in the zone's northwest corner. Mean maximums are lowest at high elevations and generally highest in the zone's drier, low-lying areas. They range from 78° F (25° C) at Vitorio Da Conquist to 95° F (35° C) at Remanso. Extreme temperatures follow similar rules, ranging from 41° F (10° C) at Aracuai to 101° F (39° C) at several locations. Adiabatic warming leeward of slopes enhances high temperatures and low relative humidities.

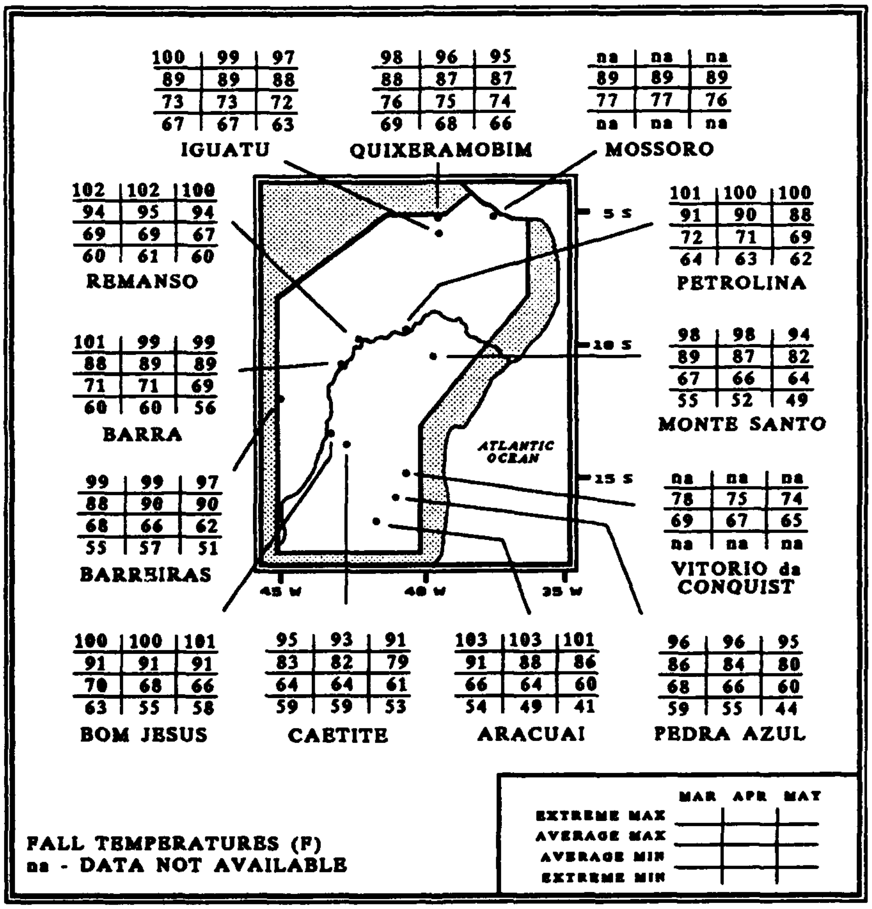


Figure 4-184. Fall Tabular Temperature Data, Northeast Brazil.

Relative humidities reflect terrain effects. They are generally lowest in low-lying areas such as the Sao Francisco river valley. Averages at Bom Jesus range from as low as 48% on May afternoons to 74% on March mornings. The highest relative humidities occur in the northeast where the NET and sea breezes provide additional moisture. Average Mossoro relative humidities range from 71% on May afternoons to 87% on March mornings. Figure 4-185 shows three stations with wet-bulb globe temperature data (° F) at specific hours in April.

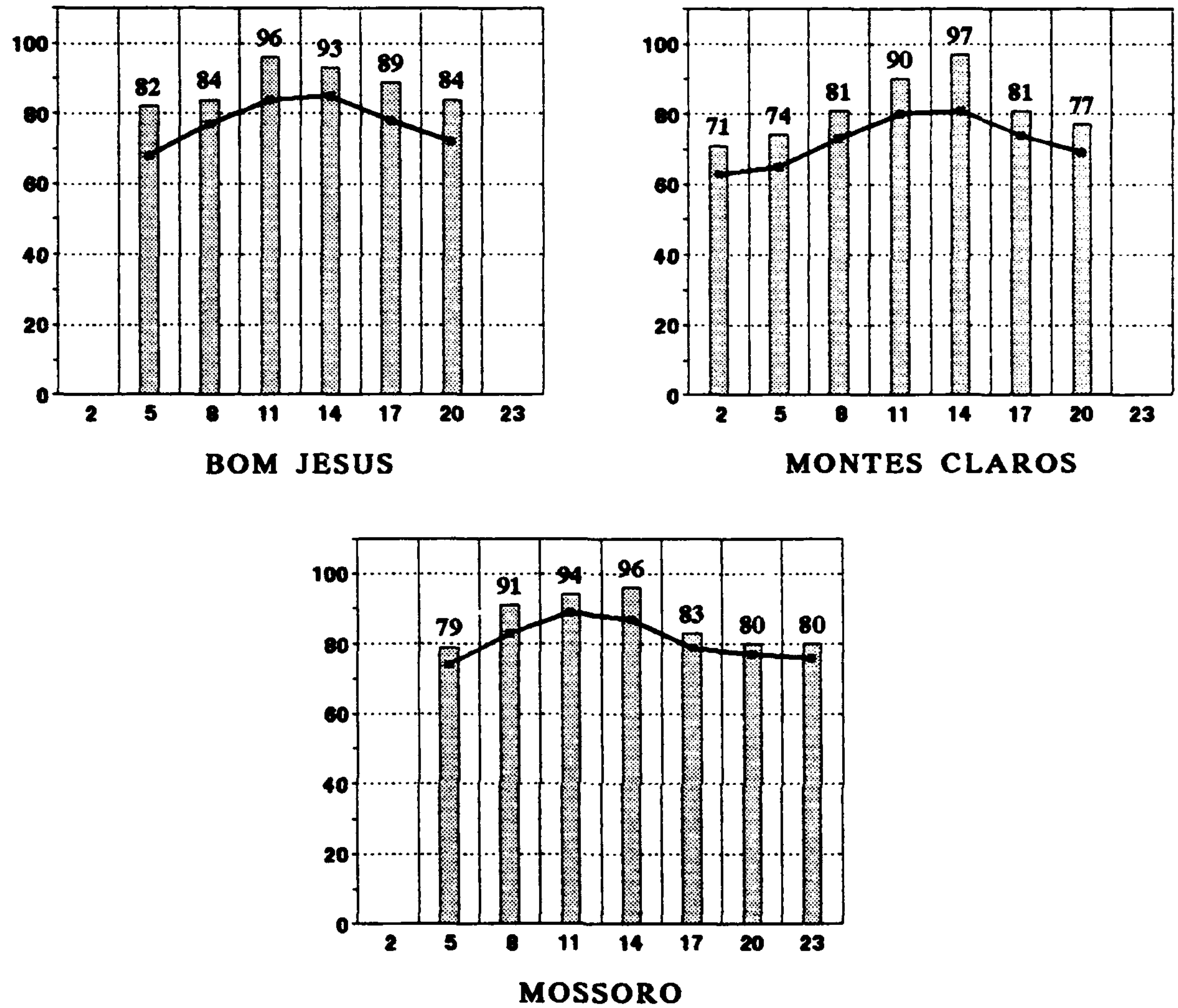


Figure 4-185. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Northeast Brazil. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Fall flight hazards not associated with thunderstorms include turbulence, icing between 15,000 and 30,000 feet (4.6 and 9.1 km) MSL, and terrain that may be obscured by clouds or fog. Light to moderate mechanical turbulence and shear can occur as winds cross rough terrain. Light to moderate thermal turbulence can occur over dry, cloudless areas. Clouds and fog can obscure higher terrain, especially in the east where Atlantic moisture enters the zone.

GROUND HAZARDS. Flash floods occur with rapid mountain run-off of heavy or frequent moderate precipitation.

GENERAL WEATHER. Winter weather normally varies less from year to year than in the other seasons. Variability is represented best by frequencies of precipitation amounts--see Figure 4-186. Barra and Remanso are good examples; August precipitation amounts at these locations are less than 1 inch about 95% of the time and over 8 inches about 5% of the time, showing that monthly amounts between 1 and 8 inches are rare. As mentioned earlier, large-scale conditions change slowly from month to month, causing abnormally wet months to be followed by more abnormally wet months.

A typical winter disturbance is greatly weakened by the trade-wind inversion and the South Atlantic High, but cold fronts and shear lines are still capable of penetrating the zone's southern half. Their effects are limited, however, by a lack of moisture. Winter stability allows for little cloud development along upper-air troughs. Most poor weather occurs along the zone's eastern fringes as weather from the Brazilian East Coast occasionally extends into Northeast Brazil.

STATION	JUN		JUL		AUG	
	<1	>8	<1	>8	<1	>8
ARACUI	95	0	95	0	100	0
BARRA	100	0	95	#	95	#
BARREIRAS	95	#	100	0	95	#
BOM JESUS	100	0	100	0	100	0
FLORIANO	90	#	100	0	100	0
IGUATU	60	#	85	0	90	0
IPIRA	15	5	10	5	20	0
JUANRIA	100	0	100	0	95	#
MONTE SANTO	30	#	5	0	35	0
MONTES CARLOS	95	#	90	#	100	0
MORRO DO CHAPEU	40	0	20	0	55	0
PETROLINA	100	0	95	#	100	0
QUIXERAMOBIM	40	#	60	#	90	0
REMANSO	100	0	95	0	95	5
VITORIO da CONQUIST	60	0	70	0	80	0

- LESS THAN 0.5 PERCENT

Figure 4-186. Percent Probabilities of Monthly Precipitation Totals Less Than 1 Inch and Greater Than 8 Inches, Northeast Brazil. Values have been rounded to the nearest 5%.

SKY COVER. The rarity of disturbances and scarce moisture account for sparse cloudiness in the west, but there is a great deal more in the east (see July cloud cover in Figure 4-187). Coverage ranges from as little as 20% at lower elevations in the west to 70% or more at higher elevations in the east and southeast. The higher frequencies in the east correlate with low-level moisture advected by the prevailing easterly trades and with middle and high clouds associated with Brazilian East Coast disturbances. Low-level easterly flow is dried orographically by rugged terrain, resulting in decreasing cloud cover and rising bases as one goes west. Local variations are caused by upslope flow, convective heating, and local wind systems. Mountain/valley breeze effects can be seen in Figure 4-188; Because of sea breezes, Mossoro has its highest low-ceiling frequencies in the afternoon; other stations have theirs in the morning.

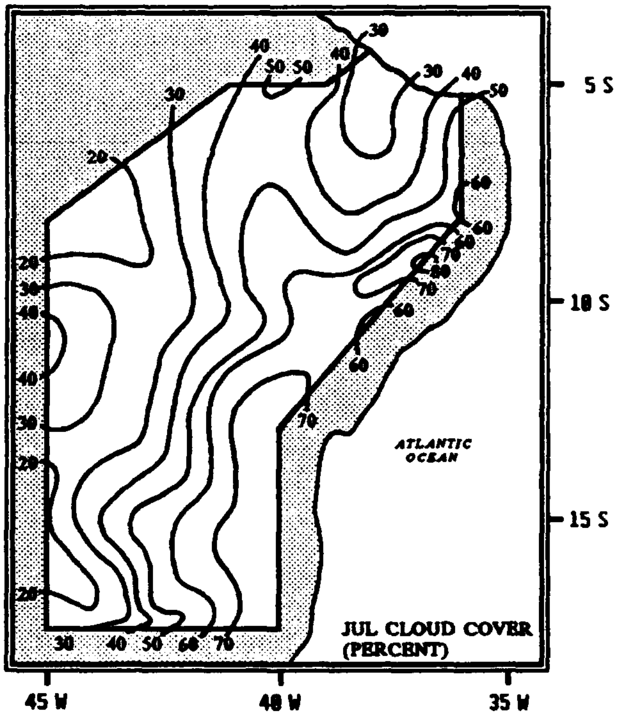


Figure 4-187. Mean July Cloud Cover, Northeast Brazil.

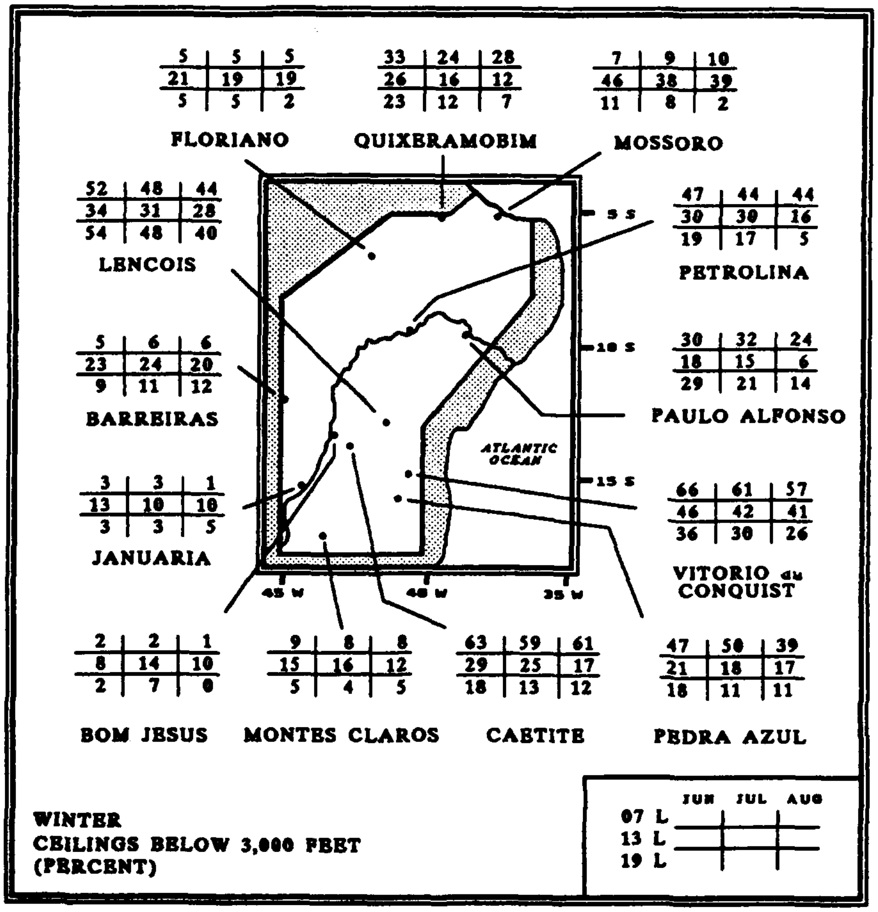


Figure 4-188. Winter Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Northeast Brazil.

Low ceilings are most common in the high central and eastern areas where there is more moisture. Radiation cooling makes low ceilings more common at night and in the morning. Ceiling frequencies below 3,000 feet (915 meters) AGL are greatest in June at Caetite (63%) and Vitorio Da Conquist (66%). Orographic lift causes even higher frequencies on windward slopes. Low surface moisture in the west results in exceptionally low morning frequencies. High daytime frequencies are possible. The trade-wind inversion caps cumulus development, producing broken stratocumulus. Low ceilings are least common at Januaria, where frequencies below 3,000 feet (915 meters) AGL range from 1% on August mornings to 13% on June afternoons.

Although the result of winter's exceptional stability is predominantly stratocumulus, the west gets occasional daytime cumulus and high clouds, while the east often sees layered middle and high clouds. Morning stratus is also common in the east. Cloud-base heights depend on moisture availability. Most winter bases are above 3,000 feet (915 meters) MSL in the east and above 4,000 feet (1,220 meters) MSL in the west. Most tops are below 10,000 feet (3,050 meters) MSL, but they can be higher with the occasional disturbance. Atmospheric stablility and controlled burning of cropland result in obscured skies from smoke and haze.

VISIBILITIES. Since most low visibilities are caused by precipitation and fog, they are most common in places that have the greatest moisture, such as in the higher elevations in the east. Frequencies of visibilities below 3 miles are greatest at Vitorio Da Conquist, where they range from less than 15% afternoons and evenings to as high as 23% in the morning. Except in the east, frequencies of visibilities below 3 miles are low, ranging from less than 3% afternoons and evenings to less than 5% in the morning. Throughout the zone, visibilities are below 1 mile about half as often as they are below 3 miles.

In at least three-fourths of the zone, there is no single cause of low visibility. Precipitation is the most common cause in the east; fog in the south. Most fog results from upslope flow and radiation cooling. The east is also affected by haze caused by sea salt. Haze and smoke caused by cropland burning can affect the entire zone, depending on where and when the burns take place. Burning near the zone's center has caused haze and smoke to reduce visibilities below 3 miles as much as 15% of all hours and below 1 mile as much as 10% of all hours.

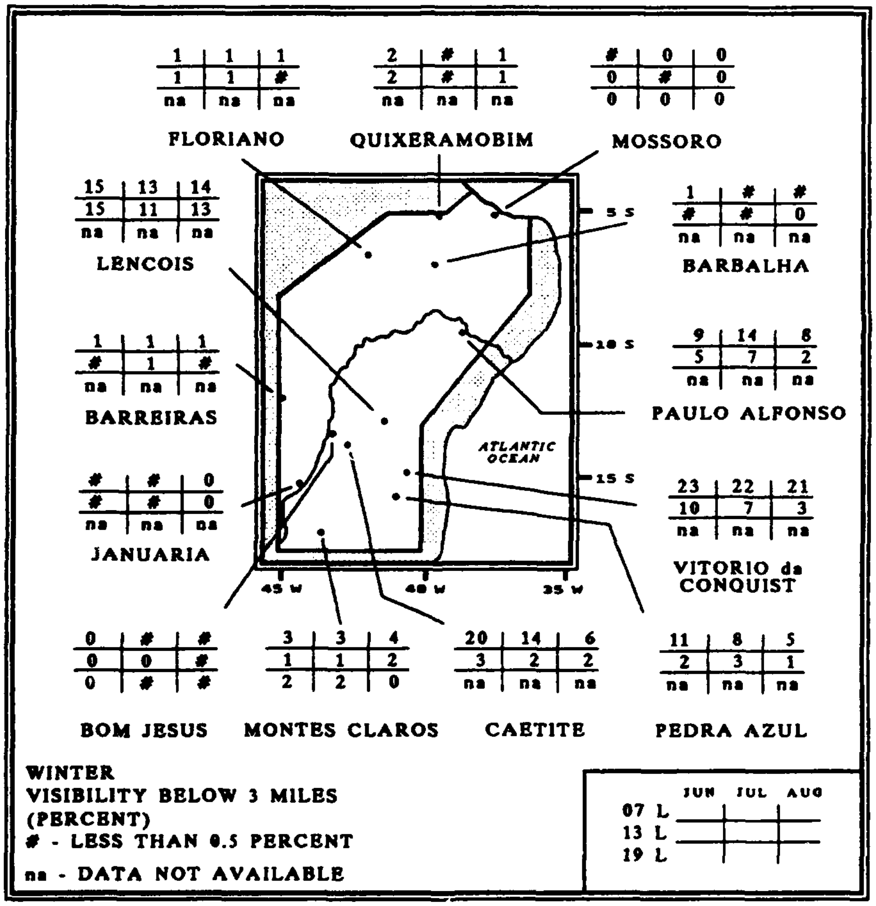


Figure 4-189. Winter Percent Frequencies of Visibility Below 3 Miles, Northeast Brazil.

WINDS. Easterly trade-wind speeds increase through winter. They peak in the north by the end of the season, reducing the frequencies and effects of local wind systems there. As in the other seasons, mountain/valley breezes (see Chapter 2) affect the west, where surface friction reduces trade-wind speeds. Blocking and channeling of synoptic winds are common. Occasional shear lines from the south change the synoptic flow from its easterly norm. Shear lines are preceded by variable or westerly winds and followed by variable or southerly winds.

Area wind roses (Figure 4-190) show the easterly trade-wind influence, and Figure 4-191 shows how trade-wind speeds have increased from fall. Local wind systems combine with the trades to cause localized variations in speeds and directions, especially at night, when radiation inversions isolate the trades from the surface in some areas. The trades are still strong enough to produce easterly nighttime winds (averaging 3 knots or less) at most places.

Because of the trades, mean afternoon directions range from northeasterly at Mossoro, which is affected by sea-breeze circulations, to south-southeasterly at Lencois, where flow is channeled northward by local terrain. Even areas sheltered by mountainous terrain have mean afternoon winds from an easterly direction. Average daytime wind speeds range from as low as 2 knots in sheltered areas to as high as 10 knots at places exposed to the trades. Maximum wind speeds are in the south where the channeling of synoptic winds is most pronounced; speeds here can exceed 40 knots, while speeds in the north rarely exceed 30 knots.

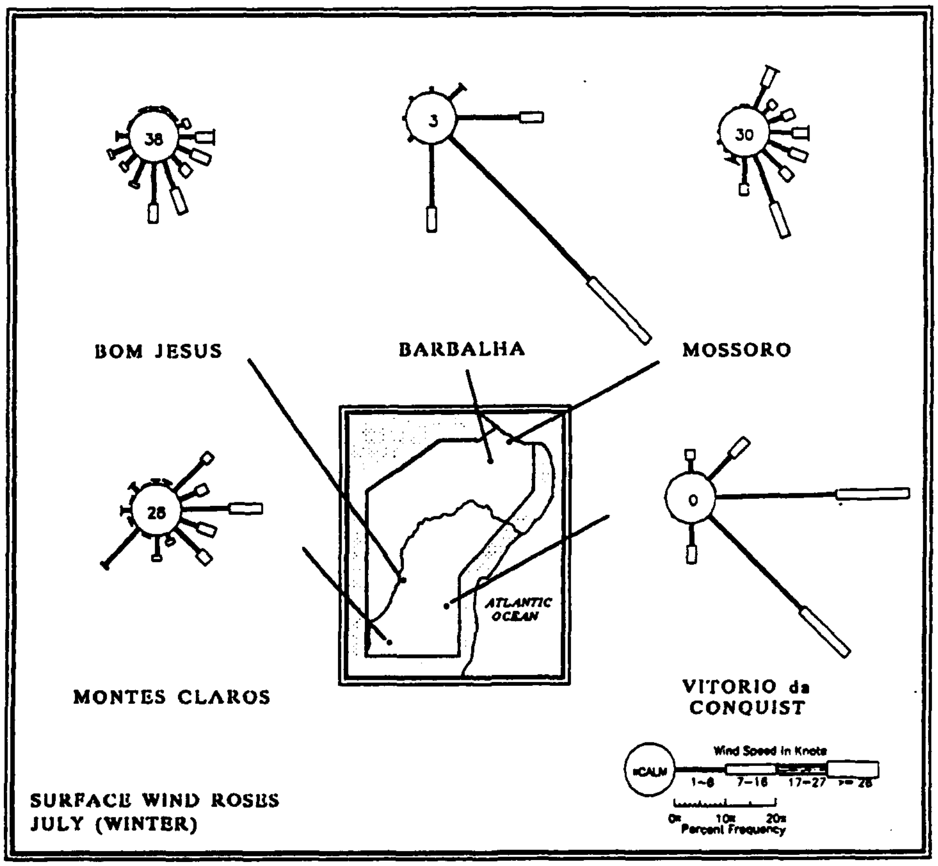


Figure 4-190. July Surface Wind Roses, Northeast Brazil.

STATION	JUN	JUL	AUG
ARACUI	2	3	3
BARBALHA	4	4	5
BARRA	3	4	4
BARREIRAS	3	4	4
BOM JESUS	3	4	4
CAETITE	7	7	8
FLORIANO	5	5	5
IGUATU	4	5	5
IRECE	7	8	8
JANUARIA	4	4	5
LENCOIS	2	3	3
MONTE SANTO	3	4	4
MOSSORO	4	4	5
PAULO ALFONSO	5	5	6
PEDRA AZUL	2	3	3
PETROLINA	5	6	5
QUIXERAMOBIM	5	5	7
REMANSO	3	3	3
SAO FRANCISCO	5	5	5
VITORIO da CONQUIST	5	5	5

Figure 4-191. Mean Winter Wind Speeds, Northeast Brazil.

Winds aloft are shown in Figures 4-169 through 4-171. Immediately above the friction layer (roughly 5,000 feet/1,525 meters MSL), mean winds are southeasterly with speeds ranging from 15 knots in the south to 20 knots in the north. With increasing height, directions become more variable and speeds decrease. By 20,000 feet (6.1 km) MSL, the weak col noted in previous seasons is centered at about 11° S, 38° W. The resulting winds are similar to fall's, as southwesterly winds over the southwest diverge and flow north and east. North of the col, easterly winds converge with southerlies over the zone's center. Speeds at 20,000 feet (6.1 km) MSL average about 15 knots. The col disappears by 30,000 feet (9.1 km) MSL. By 40,000 feet (12.2 km) MSL, winds become westerly at 30 knots.

PRECIPITATION. Rainfall decreases considerably in the winter, thanks to a strong trade-wind inversion and a dominant South Atlantic ridge. The resulting stability confines moisture to the lowest layers. Some winter precipitation is associated with the same disturbances that affect the Brazilian East Coast, but the direct effects of these disturbances are sporadic and confined to northeast Brazil's eastern fringes. Disturbances raise the depth of the moist layer into the middle levels and advect it into northeast Brazil, where it results in rainfall from orographic lift, the occasional disturbance, and upper-level diffluent flow associated with the col. East-west rainfall comparisons are shown in Figure 4-192. Winter mountain/valley breezes have the least effect on precipitation, but can still enhance rainfall slightly over valleys at night and over peaks during afternoons and evenings.

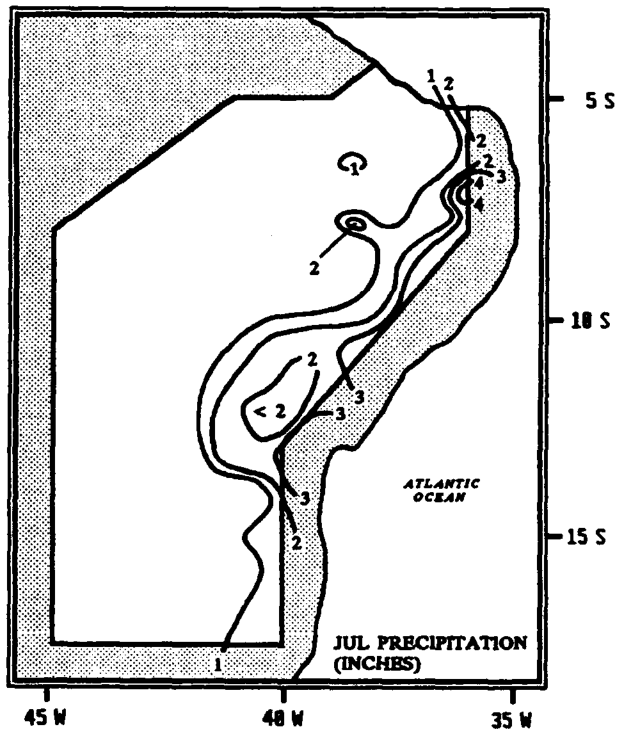


Figure 4-192. Mean July Precipitation, Northeast Brazil.

Rainfall data is scarce. Maximum 24-hour amounts shown range from 0.2 inches in the Sao Francisco valley's northwest section to 3.1 inches in the north. Mean rainfall days are extremely variable, ranging from less than 1 a month in the northwest to about 20 at eastern locations exposed to moister easterly flow. Mean monthly precipitation amounts in the east are low. Rainfall intensities are normally light. As shown in Figure 4-193, about three-fourths of the zone averages less than 1 inch of rainfall a month. Although showers do occur, most winter rainfall is intermittent or continuous, from stratiform clouds.

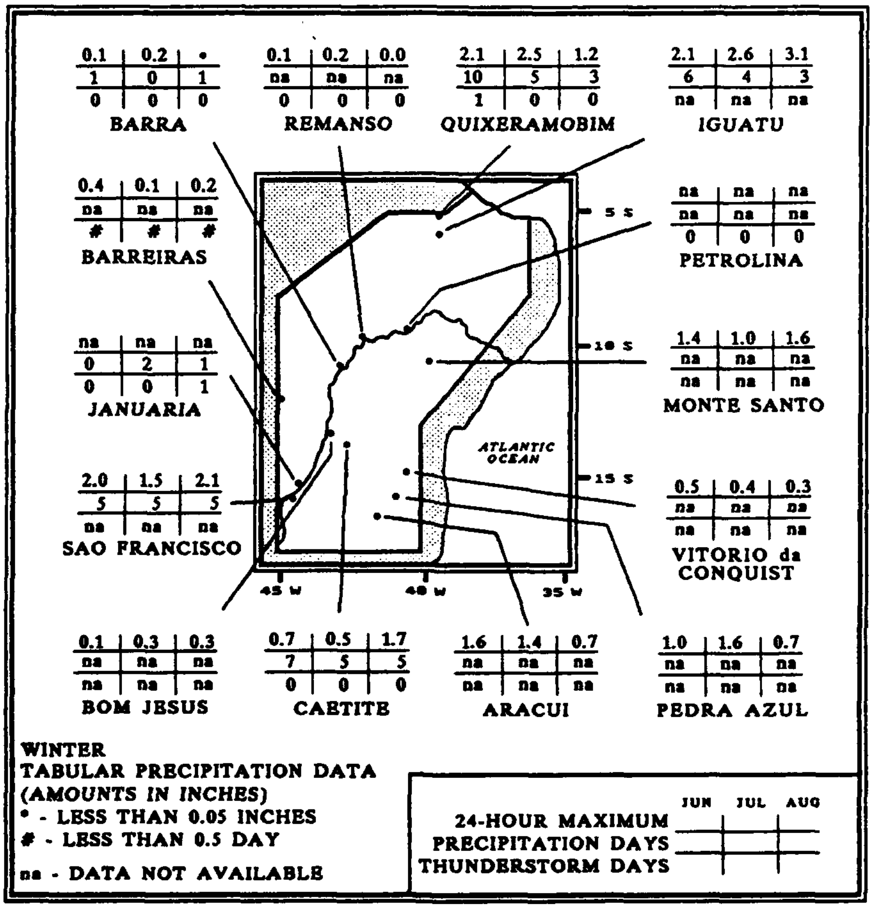


Figure 4-193. Winter Tabular Precipitation Data, Northeast Brazil.

THUNDERSTORMS. Thunderstorms are least frequent in winter. Development is inhibited by the combined effects of low-level air that has been orographically dried, dry air above the trade-wind inversion, and stability that is the result of the South Atlantic High and a strong trade-wind inversion. Low-level moisture in the northeast is sufficient for thunderstorm development if disturbances add mid-level moisture and destroy both the trade-wind inversion and the second inversion common at 15,000 feet (4,570 meters) MSL. Orographic lift and convective heating can contribute to afternoon development over higher elevations when disturbances are nearby. Thunderstorm days range from means of only 2 a month in the east to less than 1 a month elsewhere. Because of locally variable low-level moisture, thunderstorm bases range from 1,000 to 3,000 feet (305 to 915 meters) MSL. Tops are normally less than 30,000 feet (9.1 km) MSL across the zone. Tornados do not occur and hail is only possible over high terrain. Thunderstorm gusts rarely exceed 30 knots.

TEMPERATURE. South Atlantic moisture reduces winter temperature variations in the north and east, especially at higher elevations. Dry conditions in the zone's western fringes and in river valleys produce the greatest diurnal variations. Day to day variations are greatest in the south where cold fronts enter the zone. Mean low temperatures, shown in Figure 4-194, do not correlate with differing elevations as increased moisture and cloudiness in higher elevations prevent significant radiation cooling. Mean lows range from 54° F (12° C) at Sao Francisco to 77° F (25° C) at Floriano. Average highs are lowest at high elevations and generally highest in the zone's drier low-lying areas. In the north, highs are higher than in fall because of reduced cloud cover. Average highs range from 73° F (23° C) at Vitorio Da Conquist to 94° F (35° C) at Remanso and Barra. Extremes follow similar rules. They range from a low of 37° F (3° C) at Aracuai to a high of 101° F (38° C) at numerous dry locations. Adiabatic warming on leeward slopes can enhance high temperatures and low relative humidities.

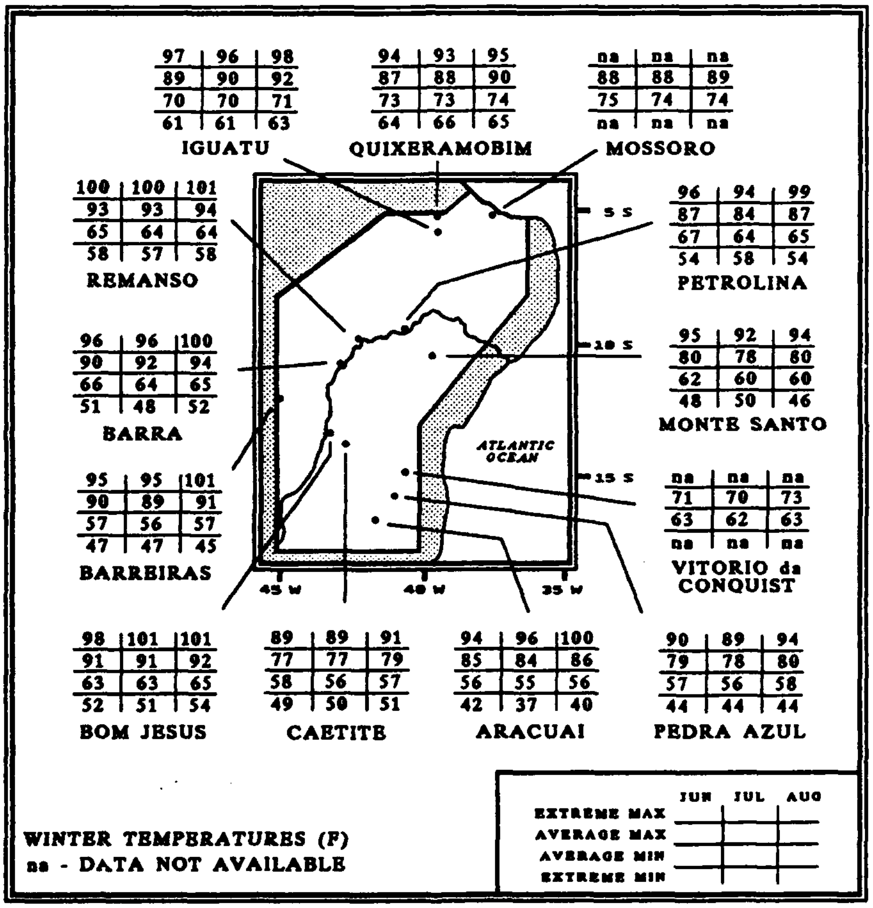


Figure 4-194. Winter Tabular Temperature Data, Northeast Brazil.

Terrain controls relative humidity. Orographic drying of Atlantic air results in low relative humidities across all but the zone's eastern fringes. The highest winter RHs are at Lencois and Vitorio Da Conquist. Average values at Lencois range from 67% on August afternoons to 87% on June mornings, and at Vitorio Da Conquist from 66% during August afternoons to 88% on June mornings. Figure 4-195 shows three stations with wet-bulb globe temperature data (° F) at specific hours in July.

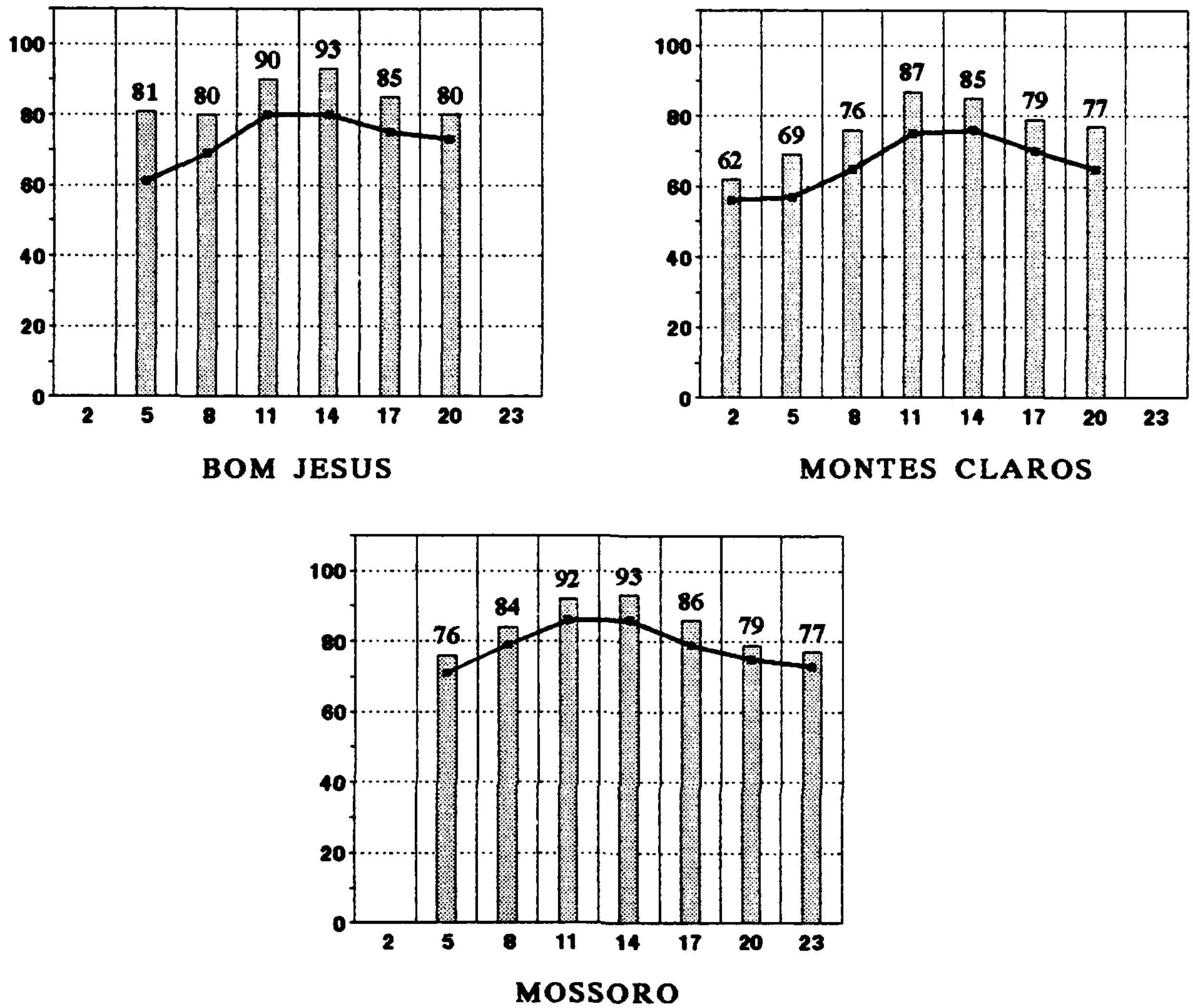


Figure 4-195. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Northeast Brazil. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Winter flight hazards not associated with thunderstorms include turbulence, icing between 15,000 and 30,000 feet (4.6 and 9.2 km) MSL, and terrain obscured by clouds and fog. Light to moderate mechanical turbulence and shear often occur over rough terrain. Light to moderate thermal turbulence can occur in dry, cloudless areas.

Clouds and fog obscure terrain in the eastern fringes. Haze can obscure terrain where and when cropland is being burned. Haze reduces visibilities to less than 1 mile through 15,000 feet (4,570 meters) MSL, resulting in the obscuration of occasional cumulus buildups, as well as terrain. Haze normally dissipates when disturbances enter the area.

GROUND HAZARDS. Flash floods in the zone's eastern fringes occur with rapid mountain run-off of either heavy or frequent moderate precipitation.

GENERAL WEATHER. Springtime weather is variable, as shown by frequencies of different precipitation amounts in Figure 4-196. November amounts at Morro Do Chapeu are less than 1 inch 20% of the time and more than 8 inches 15% of the time. In Petrolina and Remanso, September amounts are normally less than 1 inch 95% of the time; only in very rare years do they reach 8 inches. These values are especially important because large-scale patterns change slowly, often resulting in wet months followed by wet months and dry months followed by dry months.

Most unsettled springtime weather is the result of cold fronts and shear lines. Although most don't pass north of 15° S, they sometimes reach 5° S. Other disturbances include Tropical Convergence Zones (TCZ), upper-level cyclones, and troughs/short waves in the low-, mid-, and upper-levels. The effects of disturbances increase as the trade-wind inversion and South Atlantic High weaken through the spring.

SKY COVER. Low clouds are most common, but distribution, depends on how moisture is controlled by changes in synoptic flow and terrain. Coverage and base height are dependent on synoptic flow. The greatest coverages and lowest heights are on the fringes of the zone facing the synoptic flow. Orographic drying of low-level air causes decreasing coverage and rising base heights with increasing distance downstream. Upslope flow, convective heating, and mountain/valley breezes cause local variations. The resulting mean coverage, represented by October in Figure 4-197, ranges from as low as 20% in the northeast to more than 70% southeast and west. Coverage is low in the north where springtime disturbances and sea-breeze cloudiness are rare. Higher coverage in the southeast and west is mostly at higher elevations and results from more moisture from an increasing number of disturbances. The same disturbances pass through the southwest, but normally with less moisture. The generally dry Sao Francisco river valley has less cloud cover and a lower frequency of low ceilings.

STATION	SEP		OCT		NOV	
	<1	>8	<1	>8	<1	>8
ARACUI	75	#	25	5	#	30
BARRA	90	#	50	#	5	15
BARREIRAS	75	#	20	#	#	35
BOM JESUS	80	0	45	#	5	20
FLORIANO	95	0	35	#	5	10
IGUATU	90	0	80	#	80	#
IPIRA	60	#	50	#	20	10
JUANRIA	75	#	35	5	#	30
MONTE SANTO	80	0	80	#	35	5
MONTES CARLOS	70	#	35	5	#	40
MORRO DO CHAPEU	70	0	65	#	#	15
PETROLINA	95	#	85	#	35	#
QUIXERAMOBIM	100	0	95	#	95	0
REMANSO	95	#	75	#	15	5
VITORIO da CONQUIST	80	0	40	#	10	20

- LESS THAN 0.5 PERCENT

Figure 4-196. Percent Probabilities of Monthly Precipitation Totals Less Than 1 Inch and Greater Than 8 Inches, Northeast Brazil. Values have been rounded to the nearest 5%.

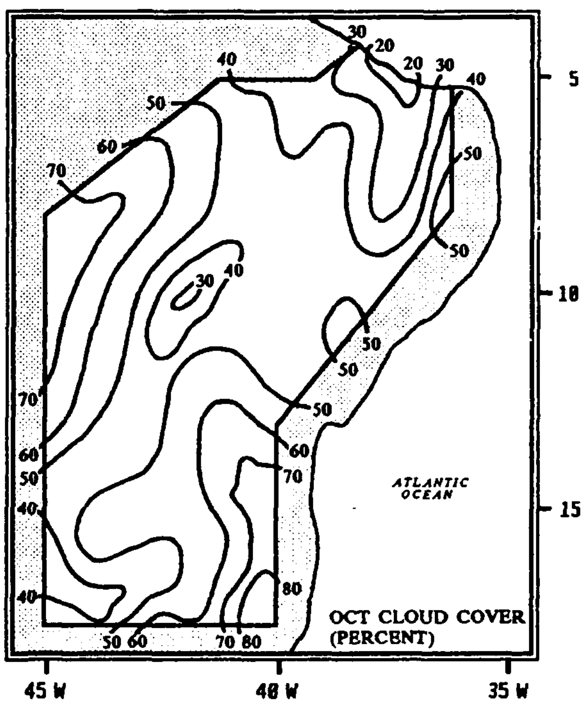


Figure 4-197. Mean October Cloud Cover, Northeast Brazil.

Changes in low-ceiling frequencies from winter reflect disturbance frequencies, which generally decrease in the northeast and rise elsewhere. The highest frequencies below 3,000 feet (915 meters) AGL occur at high elevations at night from radiation cooling. As in the other seasons, the two best examples are Caetite, with frequencies as high as 60% in October, and Vitorio Da Conquist, where frequencies reach 61% in November (see Figure 4-198). Orographic lift causes even higher frequencies on windward slopes. The zone's central western edge is unique in that low-ceiling frequencies are highest during afternoons and evenings due to predominantly stable conditions even though disturbance frequencies are increasing. Stability that caps convective cloud development results in broken stratocumulus. Low ceilings are least common in the Sao Francisco river valley's driest sections. The best examples are Paulo Alfonso and Bom Jesus, both with frequencies of ceilings below 3,000 feet (915 meters) AGL that rarely exceed 11%.

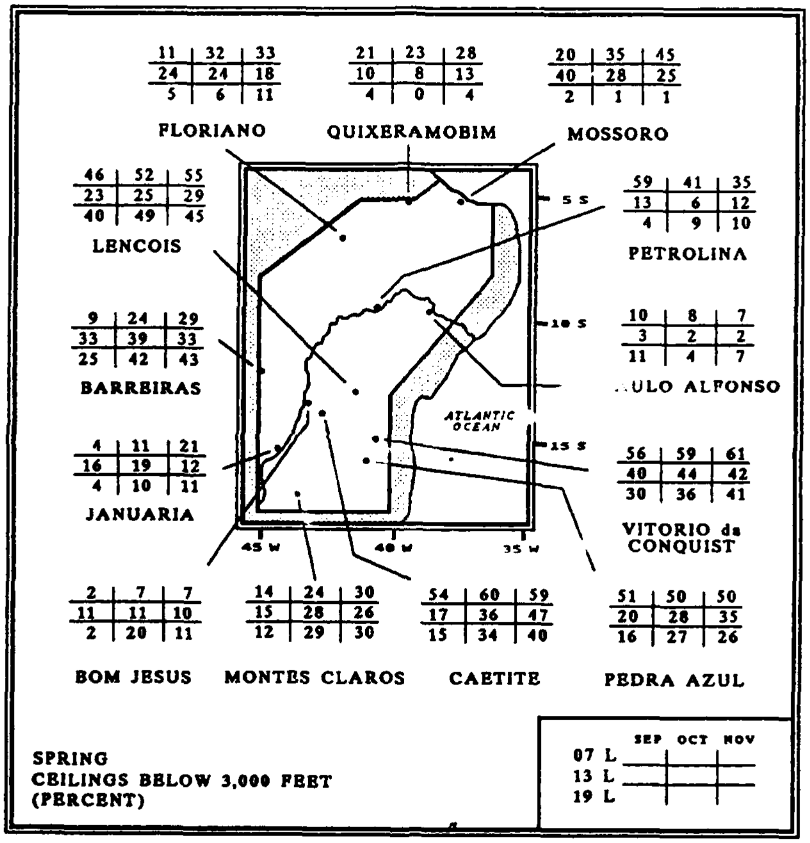


Figure 4-198. Spring Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Northeast Brazil.

Stratocumulus is the most common cloud type. During settled periods, cumulus is common during the day and is occasionally found at night in the south. Morning stratus occurs anywhere there is sufficient moisture and is most common late in the season following rains. Nighttime altocumulus can occur at most places. Towering cumulus is occasionally found in the south during undisturbed periods; tops range from 10,000 feet (3,050 meters) MSL in the north to 15,000 feet (4,570 meters) MSL in the south. Disturbances increase cumuliform cloud development and can bring low, middle, and high stratiform layers. They also cause cumulonimbus, especially in the south. Nimbostratus is rare everywhere.

Late spring surges of TCZs resemble summer surges. They are preceded by cumulus and towering cumulus, with occasional cumulonimbus, altostratus, and cirrostratus toward the south. All cloud types are possible along and west of TCZs. Stable periods allow sky conditions to be affected by smoke and haze, primarily from controlled cropland burning.

VISIBILITY. Precipitation and fog are the primary causes of restrictions; places with the most moisture have the highest frequencies of low visibilities. Visibilities below 3 miles are most common at Vitorio Da Conquest, where frequencies range from less than 10% in the afternoon and evening to as high as 17% in the morning. Frequencies of visibilities below 3 miles are low at lower elevations in the east and south, where they range from less than 3% in the evening to as high as 7% in the morning. Frequencies everywhere are below 1 mile about half as often as they are below 3 miles.

Roughly three-fourths of the zone has no one single cause of low visiblity, except in the southeast, where precipitation is the major factor. Isolated central locations may have fog or haze. Fog results from upslope flow, radiation cooling, and saturation of the air by precipitation. Haze is from sea salt in the east, but haze and smoke from burning cropland affect the entire zone. Specific areas affected depend on where and when the burns take place, but our data shows that most burning is in late winter and early spring. The zone's center has been affected most; visibilities below 3 miles occurring about 25% of all hours and below 1 mile about 20% of all hours.

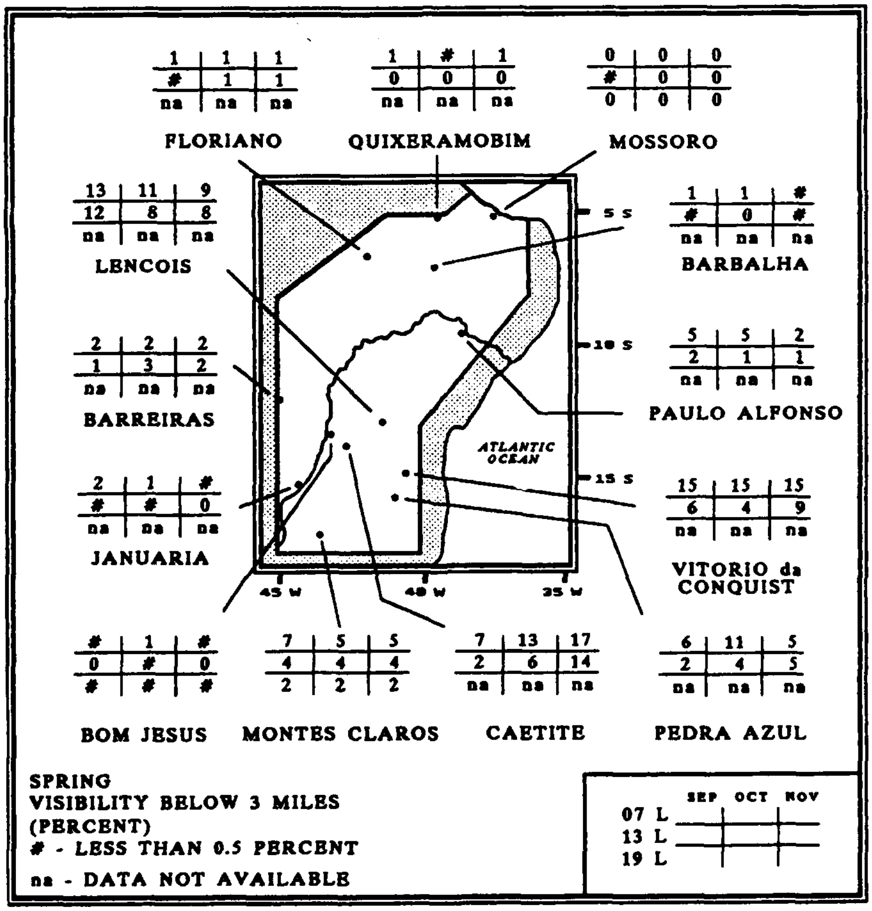


Figure 4-199. Spring Percent Frequencies of Visibility Below 3 Miles, Northeast Brazil.

WINDS. Trades weaken in the spring; local wind systems become more common by the end of the season. Mountain/valley breezes have their greatest effect in the west where surface friction slows trade-wind flow the most. Particularly rugged terrain not only causes greater surface friction, but also channels or blocks synoptic flow. Unlike the rest of the year, springtime synoptic flow is frequently affected by cold fronts or frontal shear lines, occasionally accompanied by lee-side waves or easterly surges of the TCZ. Winds east of lee-side waves and the TCZ are often northerly, while to their west (north of cold fronts and shear lines), winds are often westerly. Winds are southerly south of cold fronts and shear lines.

Figures 4-200 shows that winds are primarily controlled by the easterly trades. Mean speeds shown in Figure 4-201 are as high as they are in summer, showing that the effects of cold fronts/shear lines are still present and that the trades are often still strong. During afternoons, mean wind directions range from northeasterly at Mossoro (where the trades are affected by sea breeze circulations) to south-southeasterly at Lencois (where terrain channels flow northward) to southwesterly at Bom Jesus (which is sheltered from the trades). Mean afternoon speeds range from as low as 2 knots where synoptic flow is disrupted to 10 knots at exposed locations. There are local variations in wind speed and direction; local wind systems have their greatest effect at night when radiation inversions are strong. At Barreiras, nighttime slope winds often cause southwesterly flow. In areas where the trades remain strong, nighttime winds are easterly. Mean nighttime speeds are less than 4 knots. Peak gusts are associated with the channeling of strong trades and thunderstorm gusts; they range from more than 25 knots in the north to around 40 knots in the south.

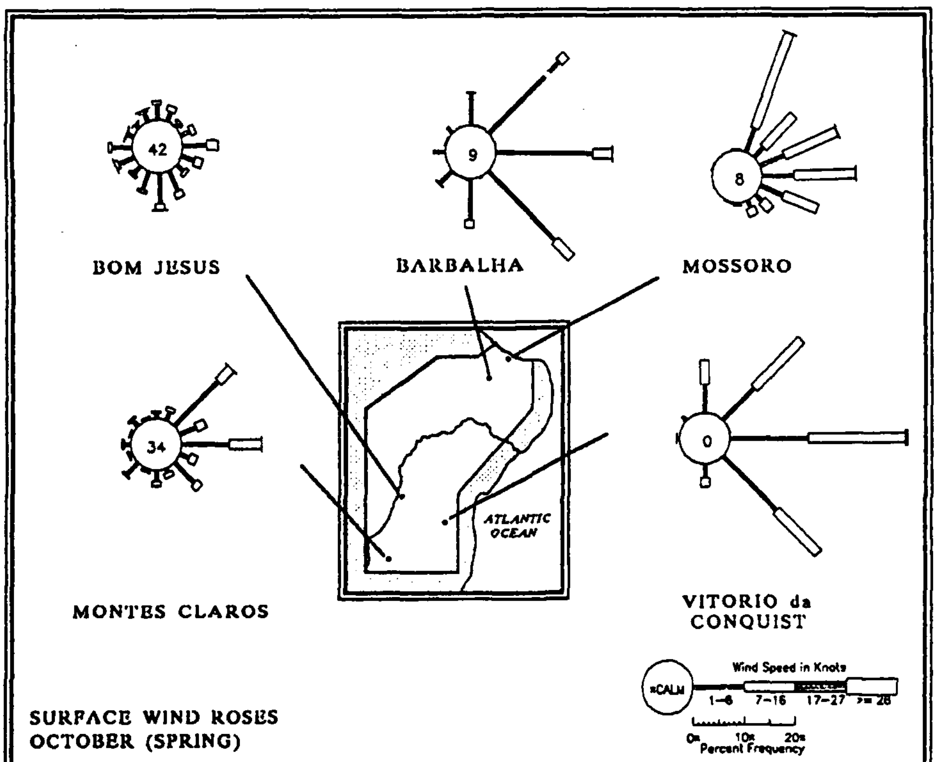


Figure 4-200. October Surface Wind Roses, Northeast Brazil.

STATION	SEP	OCT	NOV
ARACUI	3	3	2
BARBALHA	5	4	3
BARRA	5	5	4
BARREIRAS	4	4	3
BOM JESUS	4	4	3
CAETITE	9	8	7
FLORIANO	5	4	3
IGUATU	4	4	4
IRECE	8	6	6
JANUARIA	6	5	4
LENCOIS	3	3	3
MONTE SANTO	5	4	3
MOSSORO	5	6	6
PAULO ALFONSO	6	6	6
PEDRA AZUL	4	3	3
PETROLINA	5	4	4
QUIXERAMOBIM	8	9	9
REMANSO	3	3	3
SAO FRANCISCO	5	5	5
VITORIO da CONQUIST	5	6	5

Figure 4-201. Mean Spring Wind Speeds, Northeast Brazil.

Winds aloft are shown in Figures 4-169 through 4-171. Above the friction layer (roughly 5,000 feet/1,525 meters MSL), mean winds are easterly at 15-20 knots. The col appearing in the other three seasons is much stronger in spring; as a result, it shows up clearly in macroscale upper-level flow patterns (see Chapter 2) at 11° S, 39° W. The col causes winds in the south to diverge northward and eastward. Flow north of the col is easterly, converging with southerly winds in central western sections of northeast Brazil. Wind speeds at 20,000 feet (6.1 km) MSL average 15 knots. The col disappears by 30,000 feet (9.1 km) MSL. By 40,000 feet (12.2 km) MSL, winds are from the south-southwest at 30 knots.

PRECIPITATION. Rapid weakening of the trades and the South Atlantic ridge allow mid-latitude disturbances to penetrate the zone more freely and increase rainfall. Cold fronts, shear lines, and Tropical Convergence Zones are primary precipitation causes. As a result, most rainfall occurs in the south and west (see Figure 4-202). Small amounts occur where the trade-wind inversion and South Atlantic ridge are strongest. A lack of moisture also inhibits precipitation, especially near the zone's center. Precipitation in the north and east originates from moisture brought in by easterly flow. Elsewhere, precipitation originates from moisture associated with mid-latitude disturbances. Although the Amazon Basin provides moisture, springtime rainfall amounts are small. Mid- and upper-level convergent and divergent flow, associated with a col, also affects stability and precipitation. Mountain/valley breezes enhance rainfall, accounting for more afternoon and evening rain over peaks, and more nocturnal rain over valleys. Upslope flow also enhances rainfall.

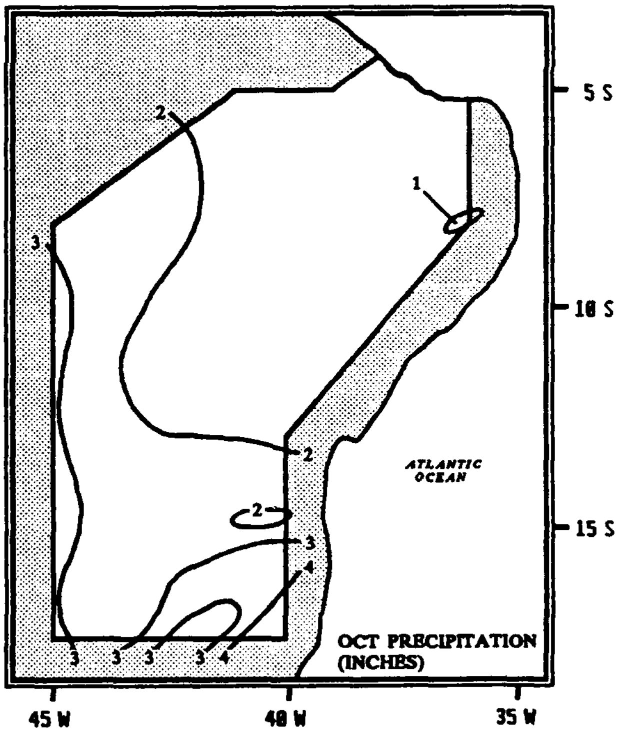


Figure 4-202. Mean October Precipitation, Northeast Brazil.

Rainfall data is scarce. Mean days with rainfall range from 2 in the north to 10 in the southeast and south. Maximum 24-hour amounts range from 1 inch in the north to 5 inches in the south. Mean monthly amounts range from 1 inch in the northeast to 4 inches in the southeast.

Intensities are normally light to moderate, but heavier amounts are possible with mid-latitude disturbances. Showers are prevalent toward the southwest, while intermittent or continuous rain from stratiform clouds prevails in the northeast.

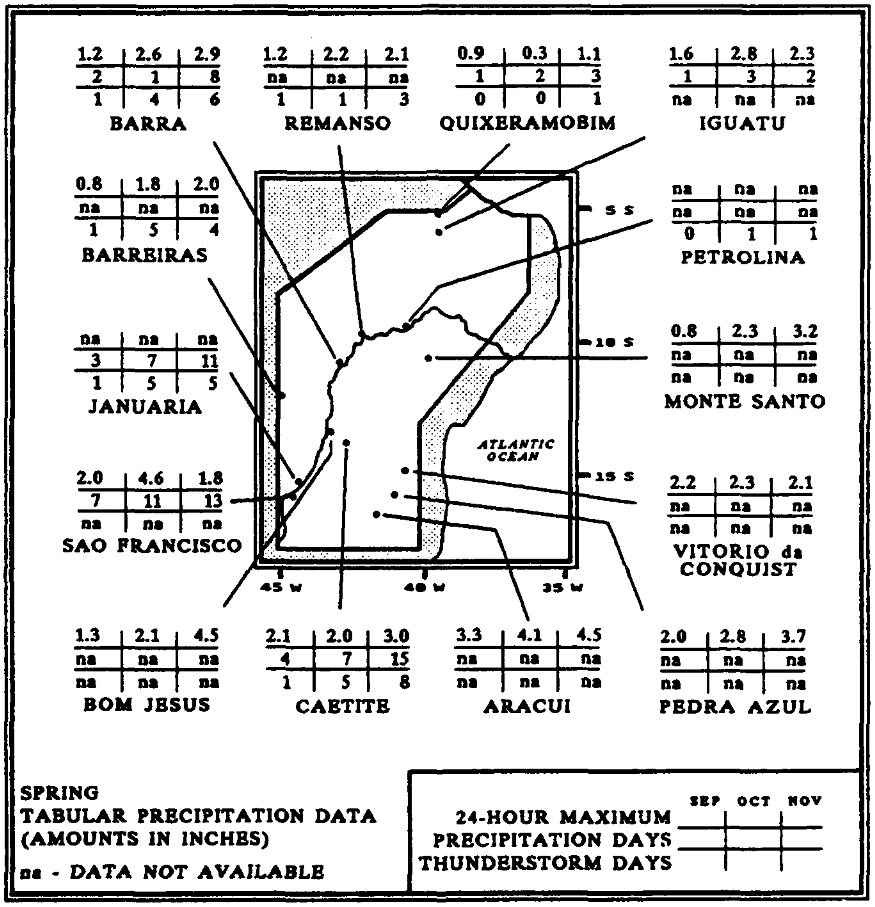


Figure 4-203. Spring Tabular Precipitation Data, Northeast Brazil.

THUNDERSTORMS. Thunderstorm frequency increases in the spring as the South Atlantic High recedes and the trade-wind inversion weakens to allow more disturbances. As during the rest of the year, however, cell development is inhibited by stability and lack of moisture. Although easterly flow is prevalent, disturbances can bring moisture from any direction. Most is lost in upstream rugged terrain, but the rest is available for synoptic disturbances. Cold fronts and shear lines are the most common cause of cell development. As a result, thunderstorm frequencies are highest in the south where thunderstorm days average 5 a month, compared to less than 1 a month in the north. Disturbances must be strong enough to destroy both the trade-wind inversion and the second inversion common at 15,000 feet (4,570 meters) MSL. They must also allow an influx of mid-level moisture. Close analysis shows that thunderstorm occurrences correlate with local wind systems. The combined affects of disturbances and local wind systems cause most thunderstorms to occur over peaks during afternoons and over valleys at night. Thunderstorm movement is often unpredictable because it depends on the combined affects of steering flow, disturbance movement, and terrain.

Bases of thunderstorms vary from 1,000 to 3,000 feet (305 to 915 meters) MSL, depending on moisture availability. Tops range from 30,000 feet (9,145 meters) MSL in the north and east to 45,000 feet (13,720 meters) MSL in the south and west. Tornados are rare and hail is only possible over higher terrain. Thunderstorm gusts can reach 40 knots in the south and 25 knots in the north.

TEMPERATURE. South Atlantic moisture moderates temperatures in the east, especially at higher elevations. Similar conditions begin occurring in the west as Amazon Basin moisture becomes more of a factor. The increased number of disturbances toward the south can cause moisture amounts and temperatures to vary daily. Dry air in river valleys allows the greatest diurnal temperature variations. Mean low temperatures shown in Figure 4-204 do not correlate with elevations; in the higher elevations, high moisture content and clouds trap heat, causing little radiational cooling. Mean lows range from 59° F (15° C) at Sao Francisco to 79° F (26° C) at Floriano. Afternoon temperatures are lowest at high elevations and generally highest in the drier, low-lying areas. Compared to other seasons, low cloud cover amounts in the north allow mean highs to peak in spring. Mean highs range from 77° F (25° C) at Vitorio Da Conquest to 97° F (36° C) at Remanso. Extremes follow similar rules, ranging from 43° F (6° C) at Aracuai to 105° F (40° C) at Bom Jesus. Adiabatic warming leeward of slopes can increase temperatures and lower relative humidities.

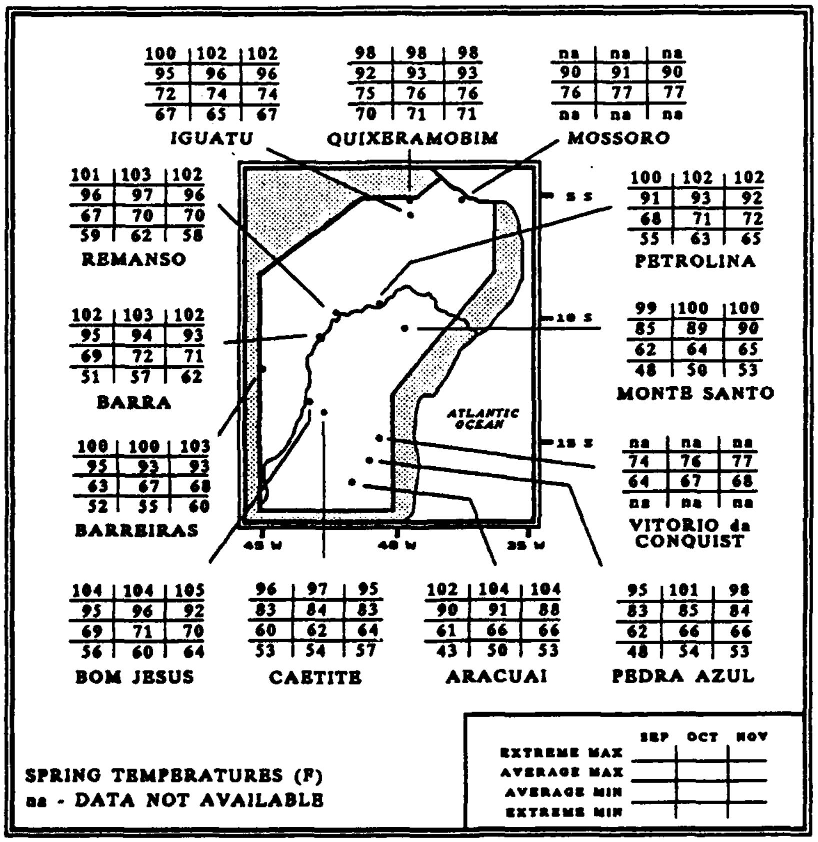


Figure 4-204. Spring Tabular Temperature Data, Northeast Brazil.

Relative humidities reflect the effects of frontal, Atlantic, and Amazon Basin moisture. Most moisture comes from the Atlantic, causing the highest RHs at high elevations in the southeast. Frontal and Amazon moisture raise RH from the south through the northwest. RHs are lowest in some northern locations because of a lack of precipitation. In spring, the lowest RHs are at Barbalha, where they range from mean minimums of 42% during afternoons to mean maximums of 60% on November mornings. The highest RHs in the zone are at Lencois and Vitorio Da Conquest, where they range from 63% on September and October afternoons to 82% on November mornings. Figure 4-205 shows three stations with wet-bulb globe temperature data (° F) at specific hours in October.

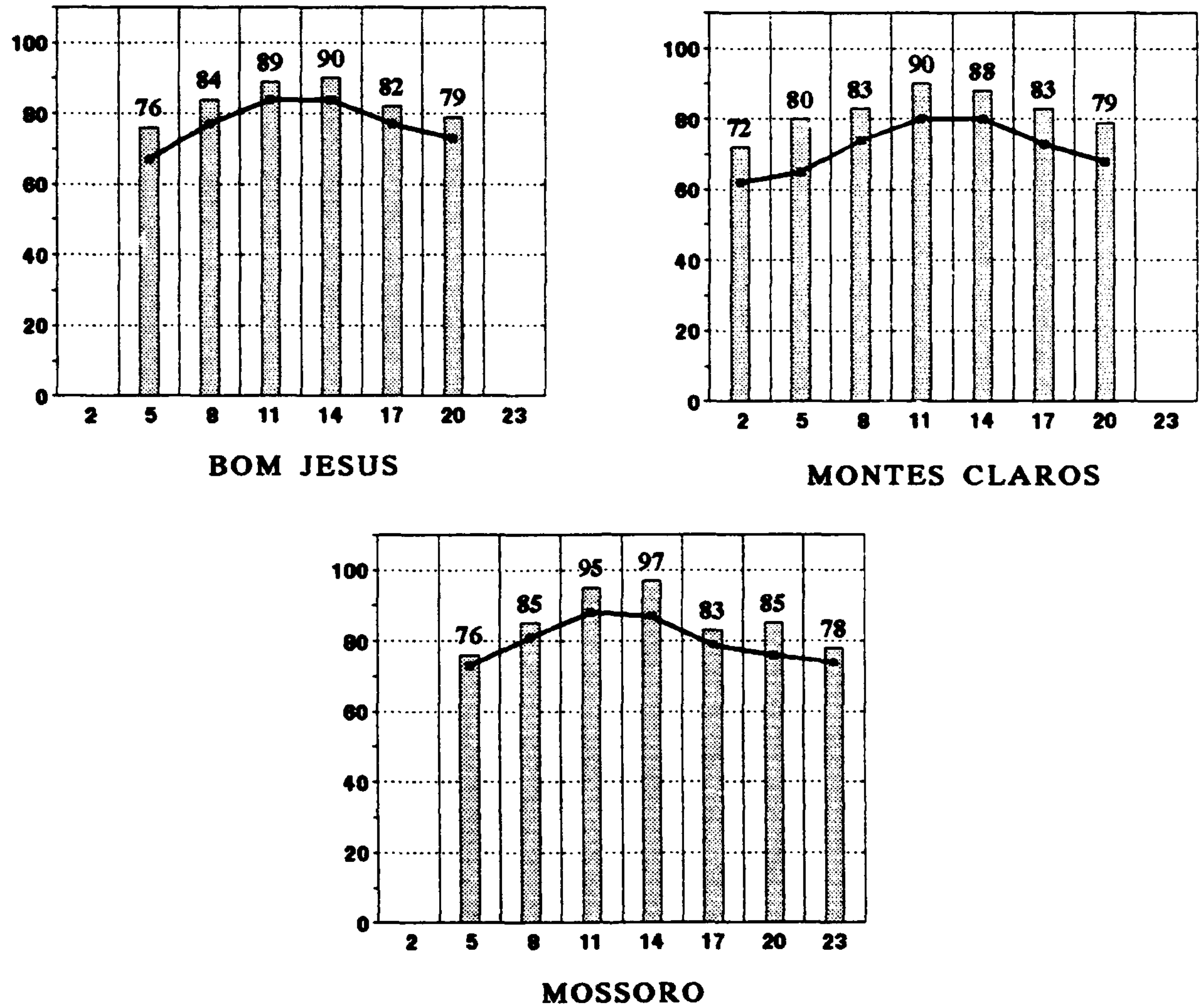


Figure 4-205. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Northeast Brazil. Mean WBGT is shown as a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Typical thunderstorm hazards apply. Flight hazards not associated with thunderstorms include turbulence, icing between 15,000 and 30,000 feet (4.6 and 9.1 km) AGL, and obscured terrain. Light to moderate mechanical turbulence and shear often occurs where winds cross rough terrain. Light to moderate thermal turbulence can occur in dry, cloudless areas. Precipitation, clouds, fog, and haze may obscure higher terrain. Areas affected depend on the moisture influx associated with the synoptic situation at that time. As a result, the terrain near the zone's eastern, southern, and western borders are obscured most often. Haze can occur anywhere, depending on where and when cropland is burned. Haze can reduce visibilities below 1 mile through 15,000 feet (4,570 meters) MSL, resulting in obscuration of convective cells, as well as terrain. Haze normally dissipates when disturbances enter the area.

GROUND HAZARDS. Flash floods are a hazard everywhere except in the extreme north. They occur with rapid mountain run-off of heavy or frequent moderate precipitation.

4.6 BRAZILIAN PLATEAU

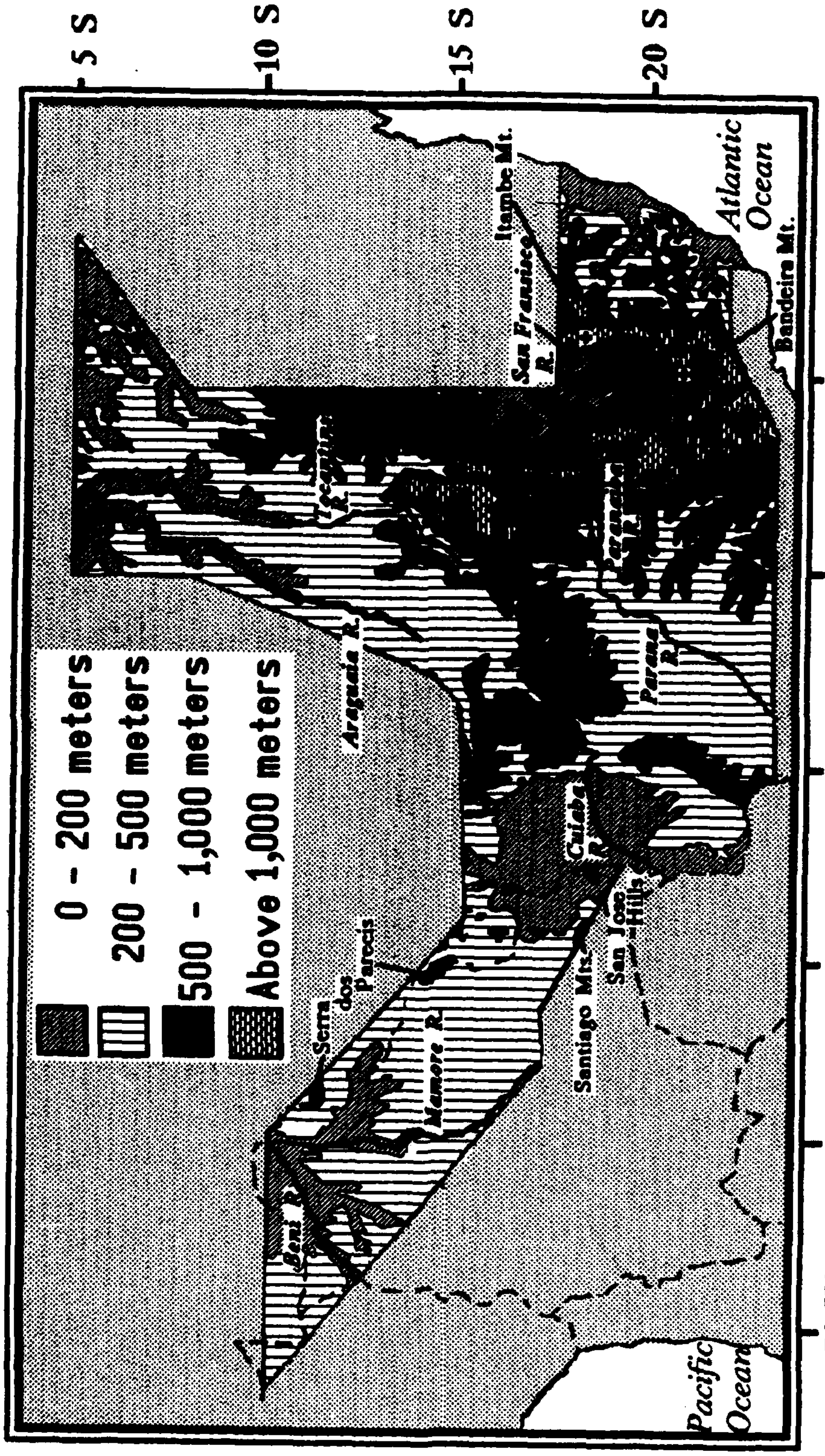
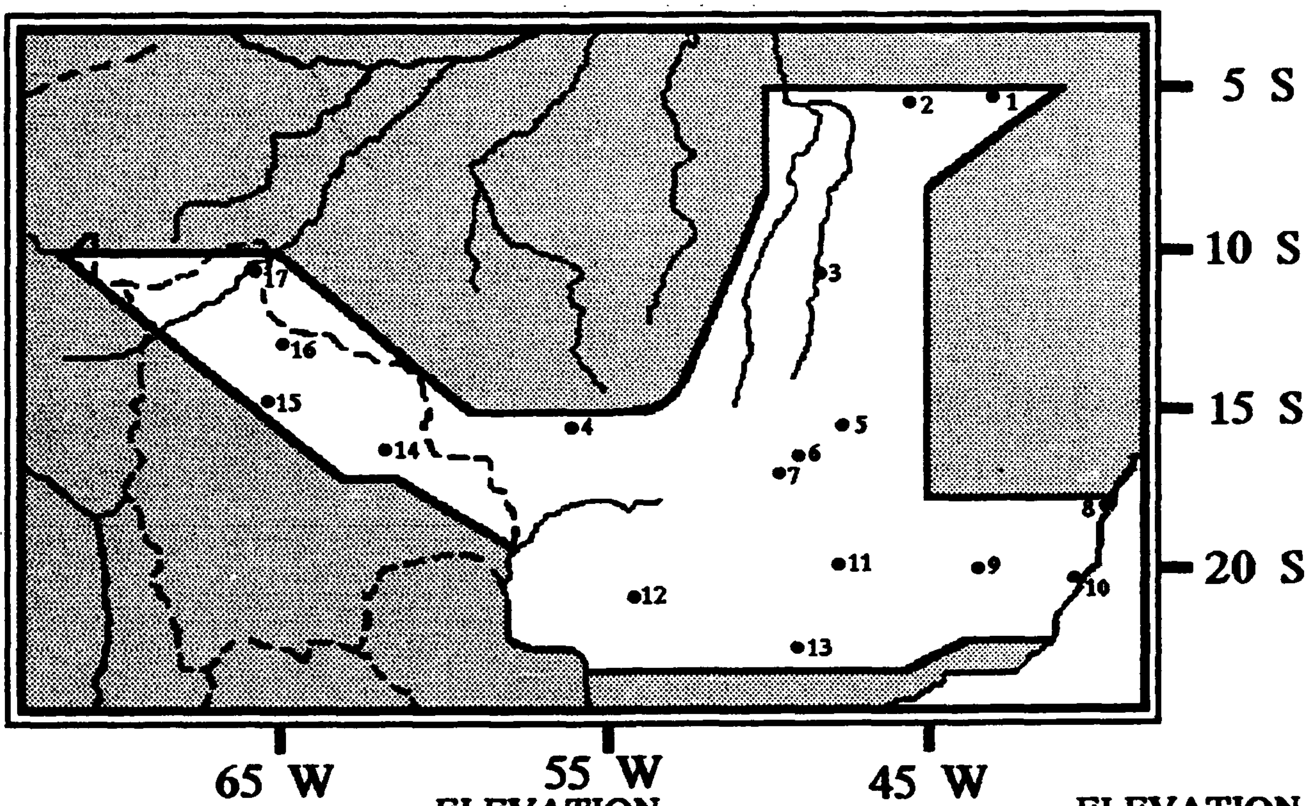


Figure 4-206. The Brazilian Plateau.



		ELEVATION (FEET)			ELEVATION (FEET)
1.	TERESINA	227	10.	VITORIO	13
2.	BARRA DO CORDA	572	11.	UBERABA	2451
3.	PORTO NACIONAL	952	12.	CAMPO GRANDE	1828
4.	CUIABA	598	13.	BAURU	1938
5.	BRASILIA	3481	14.	CONCEPCION	1631
6.	ANAPOLIS AFB	3720	15.	TRINIDAD	516
7.	GOIANIA	2451	16.	SAN JOAQUIN	459
8.	CARAVELAS	13	17.	RIBERALTA	443
9.	BELO HORIZONTE	2576			

Figure 4-207. Climatic Station Network, Brazilian Plateau.

BRAZILIAN PLATEAU GEOGRAPHY

The Brazilian Plateau comprises part of the lowlands of northeastern Bolivia, the central plateau of Brazil, and some of the eastern highlands. Savanna vegetation is present across the Plateau.

BOUNDARIES. This is the largest and most complex tropical zone in South America. It is bounded:

On the north: By a snake-like boundary marking the southern end of the tropical rain forest. The western end is at 10° S, 72° W, then goes eastward to 65° W and turns to 15° S, 59° W. It then curves east to 15° S, 54° W and arcs NNE to 8° S, 50° W. The boundary turns north to 5° S, then extends eastward along the 5th parallel to 41° W.

On the east: By the approximate transition from savanna to scrub vegetation. The northern end begins at 5° S, 41° W, goes southwest to 8° S, 45° W, turns south, and follows the 45th meridian to 17° 30' S. It then extends east along 17° 30' S to the Atlantic coast. From there the boundary is the coast southward to 22° S.

On the south: By the approximate course of the Paraiba do Sul River from the coast westward to the 23rd parallel at 46° W. It follows the 23rd parallel west to the Paraguay border, then follows the Paraguay border westward to the Paraguay River at 58° W.

On the west: by the Paraguay-Brazil border from 22° S, 58° W north to the Bolivia border. It follows the Bolivia border north to 19° S and then turns WNW, roughly along the Santiago Mountains and San Jose Hills, before turning westward to 17° S, 63° W. From there, it turns northwest to 10° S, 72° W.

TERRAIN is generally flat, mostly lowland plains or plateau with some short mountain ranges, isolated small table mountains, and dome-shaped rises. Elevations are below 700 feet (213 meters) along the Paraguay River valley. The Brazil Highlands in the southeast rise above 3,000 feet (915 meters) between Rio de Janeiro, on the coast; and Brasilia, about 360 NM inland. Serra Bandiera, Brazil's highest peak at 9,462 feet (2,885 meters), is about 100 NM west of the coastal city of Vitorio. Other peaks are the Point of Itambe (18° 20' S, 43° 15' W) at 6,670 feet (2,033 meters), and a peak 15 miles northwest of Brasilia at 4,820 feet (1,470 meters).

The highlands in the southeastern portion of the zone gradually descend in the west to the Parana River valley, which is surrounded on the west, north, and east through southeast by ridges with elevations above 1,000 feet (305 meters). North of Brasilia, the plateau slopes from elevations above 1,640 feet (500 meters) in the east to below 655 feet (200 meters) in the Araguaia River valley in the west.

The western portion of the zone is in Bolivia; it is mostly marshland below 1,640 feet (500 meters) descending southeastward into the Paraguay River valley, which is less than 655 feet (200 meters). The Serra dos Parecis forms part of the zone's northern boundary just northeast of the Bolivia-Brazil border. Some elevations exceed 2,100 feet (640 meters). These highlands shield the lowlands of eastern Bolivia from the heavier rainfalls of the Central Amazon Basin.

RIVERS. More than 30 major rivers (along with numerous small rivers and streams) drain the Brazilian Plateau. Many of the major rivers begin in the highlands of the southeast and flow west or south to join the Parana, which is over 1,700 miles long. The Parana originates as the Corumba River northwest of Brasilia and ends at Buenos Aires. One of its larger tributaries is the Rio Grande, which originates in the highlands northwest of Rio de Janeiro and flows northwest for 550 miles before entering the Parana.

The Brasilia area is known for the many rivers that emanate from its highlands. The Sao Francisco River begins east of Brasilia and flows southeast before turning northeast into Northeast Brazil. Two tributaries, one northeast and one west of Brasilia, flow north from the highlands and join at 12° 30' S, 48° 30' W to form the Tocantins river, which continues north into the Eastern Amazon Basin. The Araguaia River begins in the hills northwest of the Parana River valley. It runs NNE for 1,000 miles, paralleling the Tocantins about 90 miles to its east before joining it in the Eastern Amazon Basin. Four large rivers flow from the northern portion of the zone through the Eastern Amazon Basin to the coast. The Parnaiba is the largest of these, originating in the eastern plateau and running 750 miles northeastward to the Atlantic.

In Bolivia, a number of rivers originate in the higher elevations of the Santa Cruz area and flow NNW to the Brazil border where they join the Guapore River. Among these is the Mamore River, which runs from east of the city of Santa Cruz northward through the El Beni region of Bolivia to the Brazil border it is joined by the Guapore River. The Mamore continues into the Central Amazon Basin to become the Madiera River.

The Paraguay River starts in the eastern end of the Serra dos Parecis 260 miles east of Bolivia. It flows southward through the marshlands east of Bolivia, eventually forming the northeast Paraguay border before crossing Paraguay's mid-section. It stretches more than 900 miles before joining the Parana river in Argentina. The Paraguay's valley is only a few hundred feet above sea level. It floods annually and turns the vast alluvial plains of southern Bolivia and Brazil into an immense swamp during the rainy season.

VEGETATION. The predominant vegetation is savanna grassland, with some riverine forests, palm trees, and tropical scrub forest. Over most of the highlands and in the Parana River valley, eastern slopes grow tropical rain forests which give way to semideciduous forest on the western slopes. Tropical semideciduous forest lines the Tocantins and Araguaia River valleys. In Bolivia, savanna grasslands and woodlands change to tropical rain forest along the river valleys and in the lee of the Serra dos Parecis.

BRAZILIAN PLATEAU CLIMATIC PECULIARITIES

In this study, the Brazilian Plateau is often discussed as four subzones: (1) The "northern finger," (2) the "coastal (or eastern) finger," (3) the "western finger," and (4) the "central section." The northern finger comprises the area north of 15° S and east of 53° W. The coastal finger is the area east of about 45° W. The western finger is the part west of about 60° W. The central section includes everything south of 15° S and between 45 and 60° W. The low-lying area between 55 and 60° W can often be discussed separately from the central section--this is made clear wherever applicable. Other occasional variations are identified wherever they apply.

Wet-season length, as determined by the South Atlantic High (and, on occasion, by strong ENSO events) makes this zone distinctly different from the others in Tropical South America. The combined effects of terrain and frequent extratropical disturbances are major influences. The Andes Mountains and the higher terrain in northeast and southeast Brazil limit the amount of moisture that enters the Brazilian Plateau.

Cold fronts/shear lines are the most important extratropical disturbances. Tops of the air masses average 6,000 feet (1,830 meters) MSL; they are slightly lower in winter and slightly higher in spring. The southeast's high terrain causes many fronts to stall or dissipate, while the lower terrain in the west allows cold fronts to penetrate deeper into the tropics. Most spring cold air masses, however, are deep enough to pass over the high terrain. Fronts are oriented northwest to southeast. The fog and stratus behind many fronts are enhanced along the coast by cold upwelling created by a day or more of offshore flow as the fronts approach.

Coastal weather. Most poor coastal weather results from stratus. Weak land/sea breezes can occur from March through August, but their strengths are limited by lack of heating over coastal swampland.

Tropical wave. A unique tropical wave forms near Teresina and moves westward, normally during the wet season and both transitions. It appears to be caused by convergence between sea breezes and other disturbances, or possibly by orographic effects of the high terrain.

Strong ENSO events (with heavy convection over Ecuador and Peru) cause a dramatic intensification and lengthening of the wet season in the southern central section. Frontal systems become quasi-stationary, with extensive overrunning and sustained moderate to heavy rains. Rivers flood early in the season, and remain out of their banks for most of the summer and into early fall. Multilayered frontal clouds, embedded thunderstorms, poor low-level visibilities, and all the usual flight and ground hazards associated with such situations are present.

Research into this phenomenon by both south and north american meteorologics continues; the 1991-92 ENSO produced a similar sequence. The following is one synoptic explanation from preliminary research done by South American meteorologists using data from the 1982-83 ENSO.

After establishment of heavy and abnormally sustained southward convection on the Pacific coast of South America, the upper-level Bolivian high shifts northwestward. A flat upper-level trough becomes quasi-stationary along 60° W south of 20° S. The South Atlantic High intensifies, but maintains a more equatorward position than normal. This blocks the normal northward penetration of frontal systems in Central Brazil. The subtropical jet becomes quasi-stationary from west-northwest to east-southeast along a Paraguay-southern Brazil-northern Uruguay line. Cyclogenesis apparently occurs along stationary frontal systems in southern Paraguay; waves then track southeastward across extreme southern Brazil and northern Uruguay into the South Atlantic.

GENERAL WEATHER. Except for coastal areas, the Amazon Basin is the primary moisture source for the Brazilian Plateau. Most Atlantic moisture is lost in the high terrain to the east and south. January and February are the season's most active months for disturbances. Coastal weather variations are greatest in November and December due to the variability in northward penetration of cold fronts/shear lines. Increased convective activity follows the Sun as the Near Equatorial Trough (NET) moves south, then back north, during the season.

A number of disturbances affect the zone. The northern finger is affected by the NET, tropical waves, occasional surface and upper-air troughs, the Tropical Convergence Zone (TCZ), and Low-Latitude Upper-Tropospheric Cyclones. The coastal finger is affected most by cold fronts/shear lines moving north along the coast, especially from November through January. Disturbances affecting the zone's western finger include the NET, the Amazon Low, cold fronts/shear lines, mesoscale convective systems, and a variety of surface and upper-air troughs associated with mid-latitude flow. A low-level jet (described in "Flight Hazards"), can enhance convective activity in the west. The rest of the zone is affected by the TCZ, Low-Latitude Upper-Tropospheric Cyclones, cold fronts/shear lines, and various mid-latitude associated surface and upper-air troughs. Two disturbances that intersect enhance activity; as an example, the TCZ and NET often oscillate and become enhanced as extratropical disturbances approach, especially fronts. ENSO-associated quasi-stationary frontal systems affect the southern part of the central area.

Cold fronts occurring through January in the central section and coastal finger can become stationary at about 20° S for up to 4 days before moving southeast as warm fronts. The few that do drive northward rarely penetrate north of 15° S. Cold fronts can cause severe weather, especially west of 55° W. Cold fronts east of 55° W only reach the zone's southern border during February and March.

SKY COVER. Cloudy skies are common due to the frequent disturbances and certain local effects. Disturbances usually result in broken to overcast skies. High terrain facing synoptic flow enhances low cloudiness, but much of the moisture is lost with increasing distance from the highlands. Clouds are most persistent over high terrain in the south and on slopes facing the coast. Mountain/valley breezes increase cloudiness over peaks during afternoons and over valleys at night. Terrain causes the zone's most variable cloud cover east of 50° W. As shown in Figure 4-208, cloud cover ranges from 50% over the coast and river valleys in the northeast to as much as 80% over high terrain and places where Amazon Basin moisture enters.

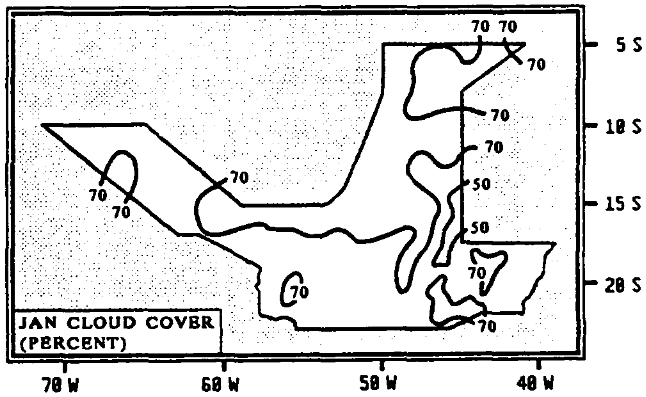


Figure 4-208. Mean January Cloud Cover, Brazilian Plateau.

Stratus is common with and after rains, especially in the morning. It can occur along stationary or slow-moving disturbances, but occasionally forms ahead of southeasterly-moving warm fronts or on windward slopes after cold frontal passage. Coastal stratus usually only forms behind cold fronts/shear lines about 2 to 3 days a month on the immediate coast. The patchy stratus dissipates by mid-morning in the absence of a disturbance. Low-cloud bases range from 1,000 to 3,000 feet (305 to 915 meters) MSL during mornings throughout the zone; they are 1,000 to 2,000 feet (305 to 610 meters) thick. Afternoon cloud bases range from 2,000 to 4,000 feet (610 to 1,220 meters) MSL, except over mountainous areas where they are about 5,000 feet (1,525 meters) MSL. Disturbances sometimes bring nimbostratus, especially in the zone's central section and coastal finger.

All types of afternoon cumulus can occur inland, with or without disturbances. Clouds along the coast are normally limited to patchy stratocumulus during fair weather. Nighttime sky cover is usually scattered, but scattered to broken in the daytime. Middle and high clouds are common, especially with disturbances. Most middle clouds have bases between 10,000 and 12,000 feet (3,050 and 3,660 meters) MSL; tops averaging 15,000 feet (4,570 meters) MSL. Disturbances produce multilayers--sometimes merging--with bases from 3,000 to 5,000 feet (915 to 1,525 meters) MSL and tops to 20,000 feet (6.1 km) MSL. Cumulonimbus is common, especially inland in daytime with disturbances. It can be embedded within other clouds everywhere except on the coast. Tops associated with disturbances can reach 50,000 feet (15.2 km) MSL. Most tops not associated with disturbances range from 15,000 to 20,000 feet (4.6 to 6.1 km) MSL; the lowest are in the zone's extreme north and east, and highest along the Central Amazon Basin's border.

Western ceilings below 3,000 feet (915 meters) are most frequent during afternoons; Frequencies range from 55 to 85%, with the highest at Concepcion--see Figure 4-209. The highest frequecy of low ceilings on the immediate coast and in the northern finger north of 15° S are in the morning.

Morning ceilings are below 1,000 feet (305 meters) AGL from less than 10% to nearly 45% of the time. They occur less than 10% of the time throughout the west during afternoons and evenings and during all hours on the coast and in the north. Low clouds along coastal slopes are more persistent than on the immediate coast.

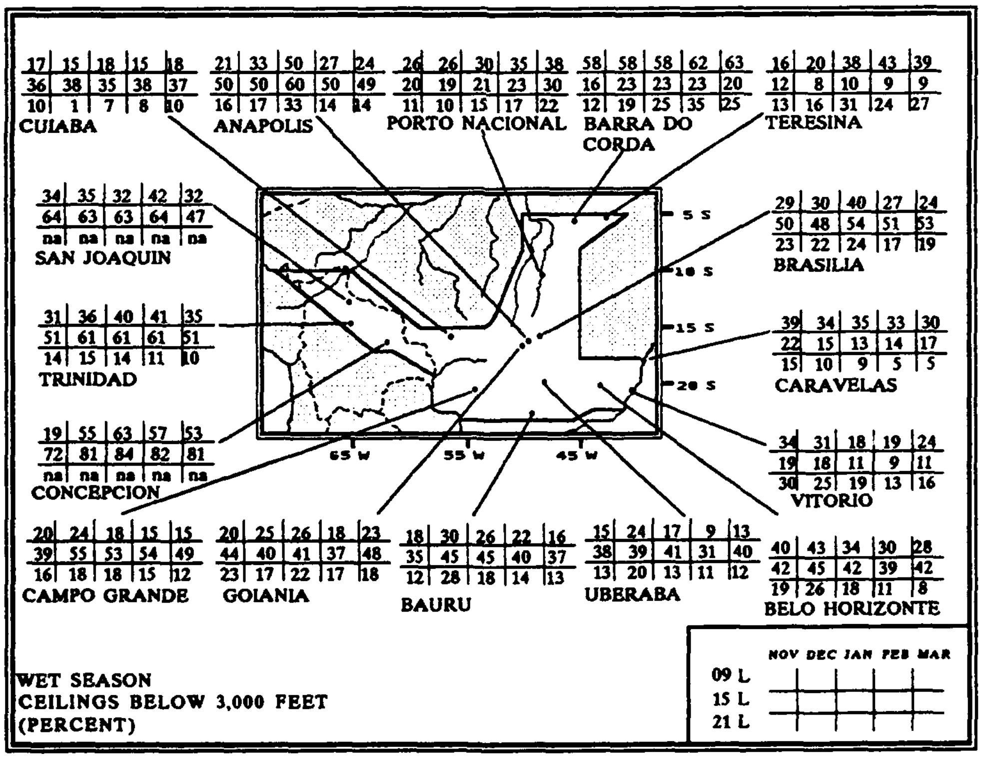


Figure 4-209. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian Plateau.

VISIBILITY. Visibilities are good across most of the zone, as shown in Figure 4-210. Fog and precipitation are the main causes for low visibilities during the wet season, but haze is an occasional factor. Most fog occurs in the morning, while precipitation is more frequent in the afternoon and evening. The only exception is the coastal finger, where rain can fall at any time. Fog becomes stratus over the Atlantic shoreline. Fog also occurs along some stationary and warm fronts, as well as in the morning following rainy days. Radiation fog occasionally forms in low-lying areas, but usually dissipates by 1000L. Most fog is less than 1,500 feet (455 meters) thick.

The worst reported visibilities are at Conceicao Araguaia, Porto Nacional, and Anapolis, all of which are exposed to Amazon Basin moisture. Conceicao Araguaia and Porto Nacional are most affected by the NET. Visibilities are between 1 and 3 miles most often at Conceicao Araguaia. At most stations, visibilities are below 1 mile less than 3% of all hours throughout the wet season. Porto Nacional and Concepcion are worst; they are below 1 mile between 5 and 10% of the time in March.

Figure 4-210 is not representative of visibilities along slopes exposed to moist flow. The worst case occurs when a cool air mass too shallow to pass over elevated terrain becomes lodged against a mountain range, resulting in a day or two of fog and drizzle along slopes. This occurs once or twice a month.

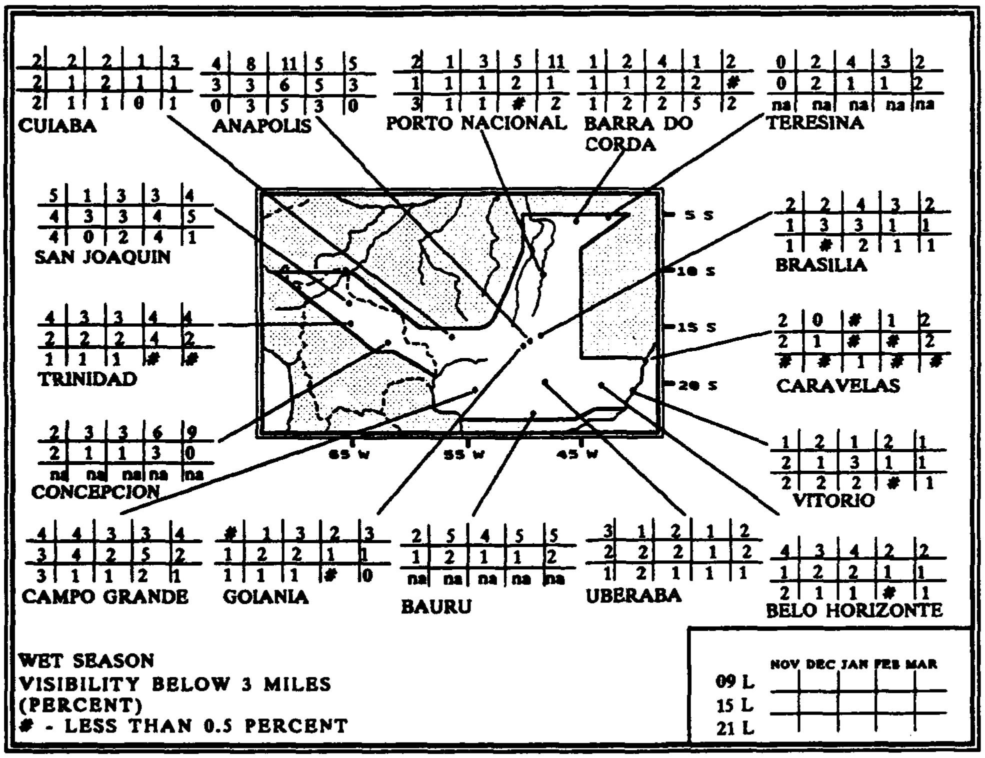


Figure 4-210. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Brazilian Plateau.

WINDS. Flow between the Northern Argentine Depression (NAD) and South Atlantic High result in the prevailing directions (shown in Figure 4-211) that range from northwesterly in the west to northeasterly along the coast. Cold fronts are normally preceded by northwesterlies and followed by southerlies. Gusts can exceed 30 knots, but usually last no more than 5 hours. Thunderstorms produce gusts over 40 knots. Terrain enhances speeds by channelling. Mountain/valley breezes can occur during settled periods in most areas.

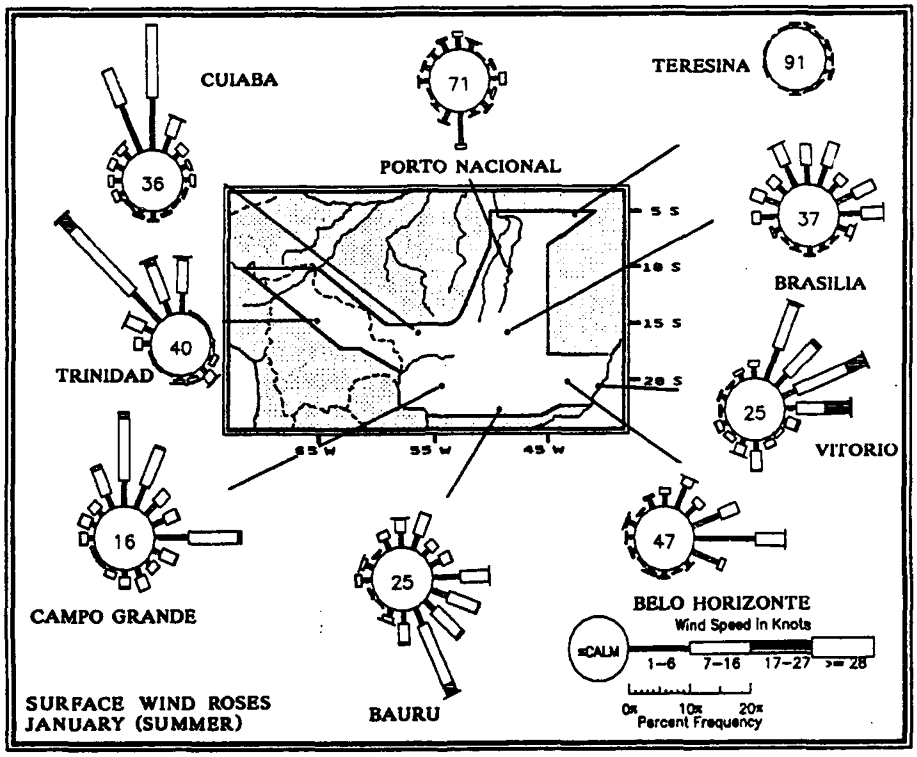


Figure 4-211. January Surface Wind Roses, Brazilian Plateau.

Average wind speeds, as shown in Figure 4-212, range from around 2 knots in the zone's northern finger, to 2-6 knots in the western finger and central section. Coastal speeds are 4-7 knots. Winds are usually calm at night except for mountain/valley breezes. Mean afternoon speeds are 3-5 knots in the zone's central section, 4-6 knots in the western finger, 2-3 knots in the northern finger, and 5-8 knots along the coast.

STATION	MEAN WIND SPEED NOV	DEC	JAN	FEB	MAR
ANAPOLIS	3	3	4	4	3
BARRA DO CORDA	2	1	1	1	1
BAURU	7	6	6	6	6
BELO HORIZONTE	3	2	2	2	2
BRASILIA	4	4	4	4	3
CAMPO GRANDE	6	6	6	6	6
CARAVELAS	5	5	5	4	4
CONCEPCION	6	6	5	5	4
CUIABA	3	3	3	3	3
GOIANIA	3	3	3	3	3
PORTO NACIONAL	1	1	1	1	1
RIBERALTA	2	2	2	2	2
TERESINA	1	1	1	1	1
TRINIDAD	5	5	5	5	5
UBERABA	5	5	5	5	5
VITORIO	7	7	7	7	6

Figure 4-212. Mean Wet-Season Wind Speeds, Brazilian Plateau.

Mean winds at 5,000 feet (1,525 meters) MSL range from northerly at 10 knots in the west to northeasterly at 15 knots in the east. A northwesterly low-level jet sometimes forms at about 10° S, 65° W. Its average height is about 1,500 feet (455 meters) MSL; 50-knot winds are possible at night. By 20,000 feet (6.1 km) MSL, winds north of 12° S are easterly at about 10 knots, becoming westerly at about 15 knots south of 15° S. By 35,000 feet (10.7 km) MSL, winds in the northern finger become southerly at about 20 knots. Southward to about 18° S, 35,000 foot (10.7 km) winds average about 20 knots from the east, becoming southwesterly at about 20 knots along the zone's extreme southern border. This flow reflects diffluence along a sharp ridge situated west to east across the zone's central section. The diffluence contributes to thunderstorm development. Winds aloft are shown in Figures 4-213 through 4-217.

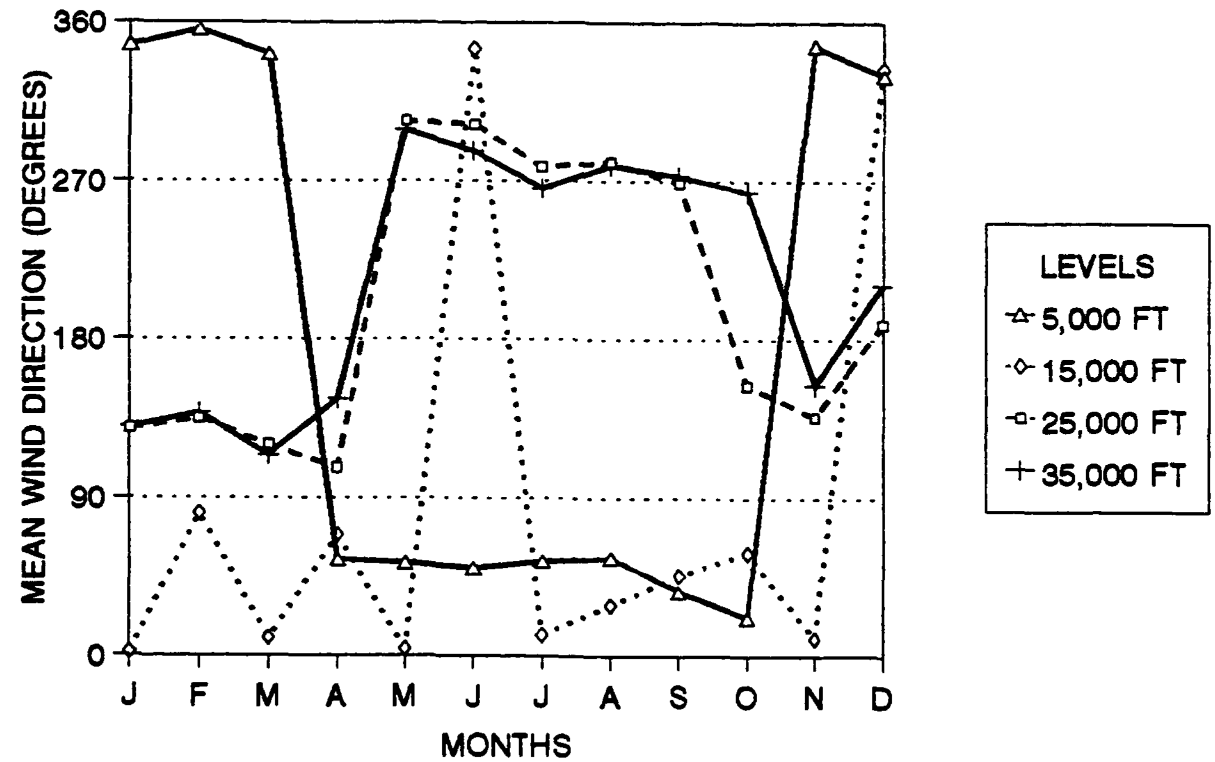


Figure 4-213. Mean Monthly Wind Directions for Various Levels at Vilhena.

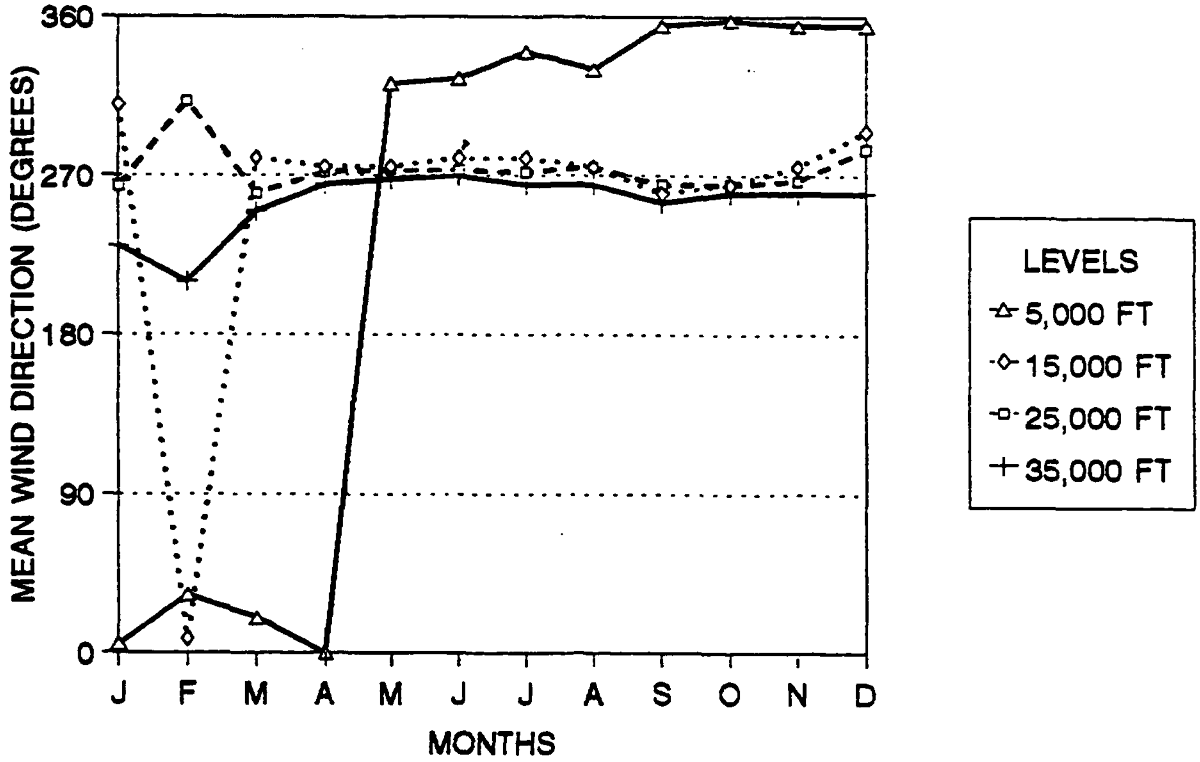


Figure 4-214. Mean Monthly Wind Directions for Various Levels at Rio De Janeiro.

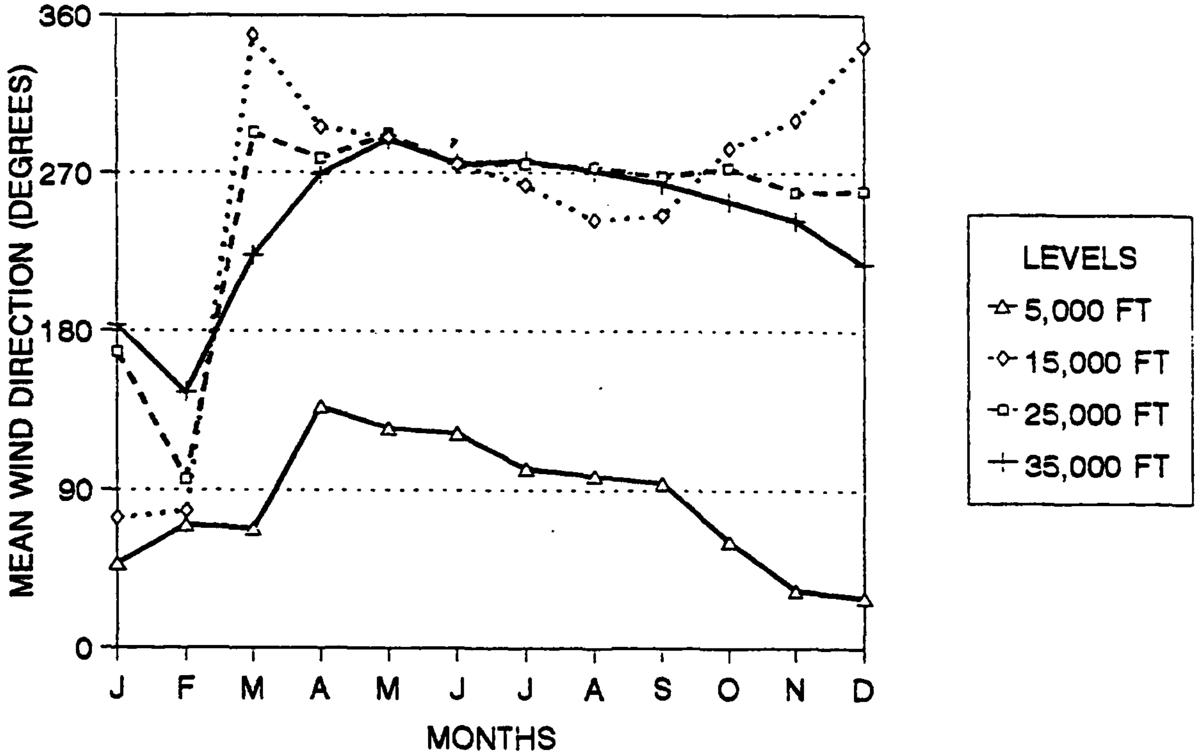


Figure 4-215. Mean Monthly Wind Directions for Various Levels at Caravelas.

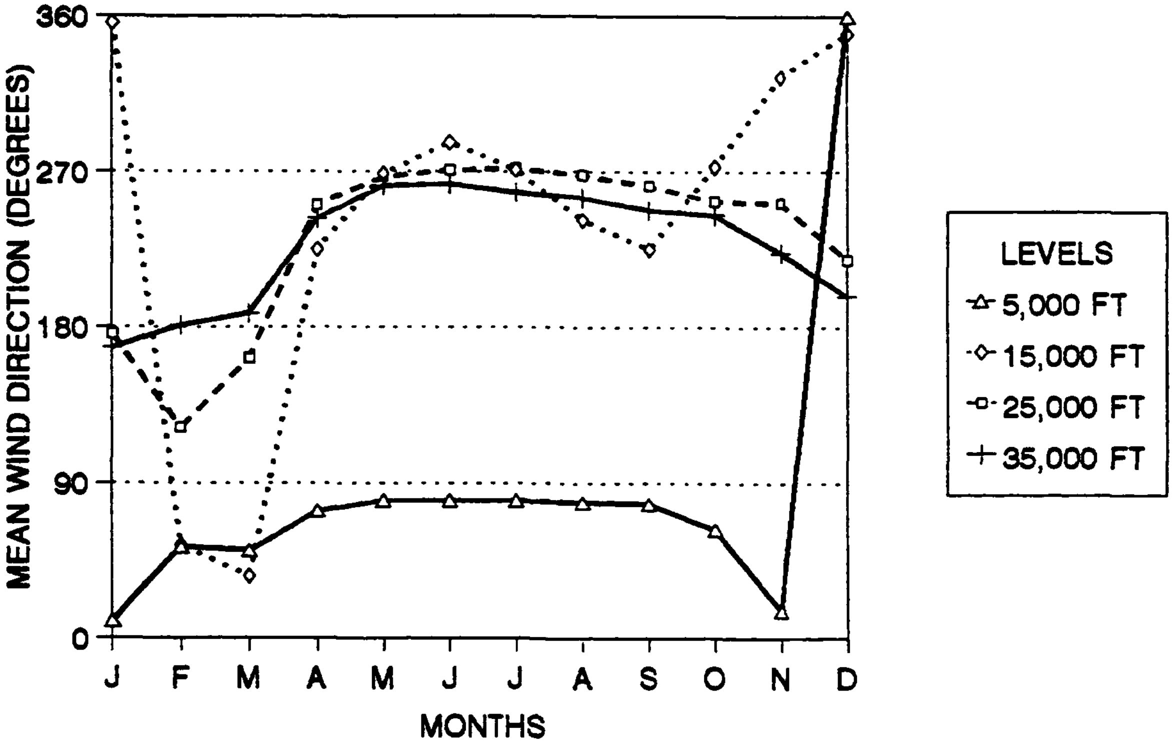


Figure 4-216. Mean Monthly Wind Directions for Various Levels at Brasilia.

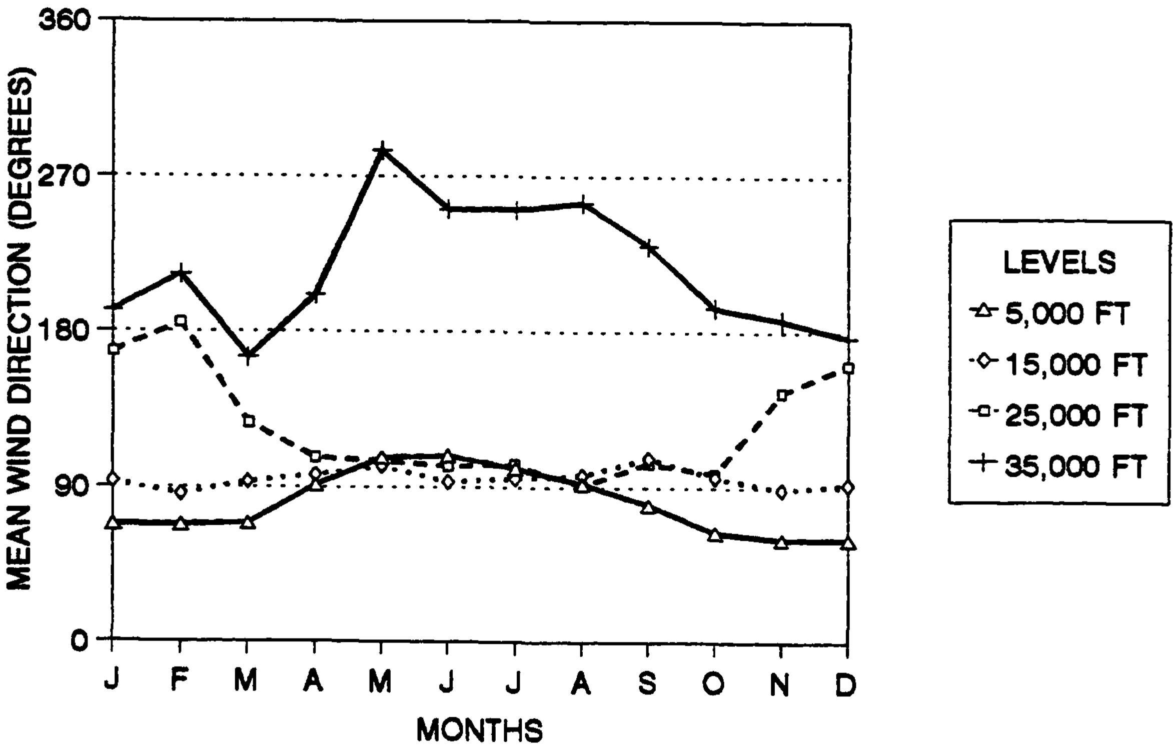


Figure 4-217. Mean Monthly Wind Directions for Various Levels at Carolina.

PRECIPITATION. Precipitation amounts, as shown in Figure 4-218, range from 4 to 6 inches (102 to 152 mm) along some eastern and southern borders and from 12 to 16 inches (305 to 406 mm) over some high areas exposed to Amazon Basin moisture. Monthly amounts can range from as low as half the norm to about twice the norm. Maximum 24-hour rainfall amounts, shown in Figure 4-219, range from 2.9 inches (74 mm) at Matto Grasso to 10.6 inches (269 mm) at Caravelas. Amounts can exceed 10 inches (254 mm) over southeastern mountains and cause flash floods. Heavy rainfall may be associated with strong ENSO events. Precipitation days increase through the season north of about 10° S and west of around 55° W.

Most precipitation falls as moderate to heavy showers from disturbances. Steady precipitation from stratiform clouds is also common. A day or two of drizzle can occur once or twice a month along coastal slopes when shallow air masses become lodged against coastal ranges, but the season's more common deep air masses can ride over elevated terrain and cause heavy showers. Afternoon heating causes or enhances precipitation over land. Solar heating of elevated terrain produces upslope winds, further enhancing convective development. Showers occasionally form offshore at night due to radiative cooling of cloud tops. Convective showers occasionally form along cloud mass fringes where differential heating occurs. Although land/sea breezes are weak, they contribute to increased precipitation near the coast by the end of the wet season. No snow or freezing precipitation occurs in the wet season.

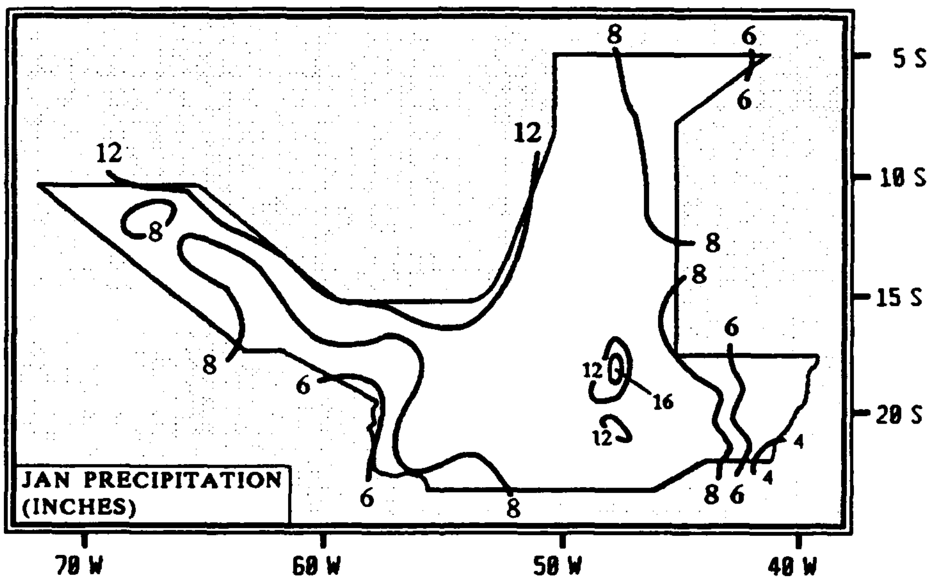


Figure 4-218. Mean January Precipitation, Brazilian Plateau.

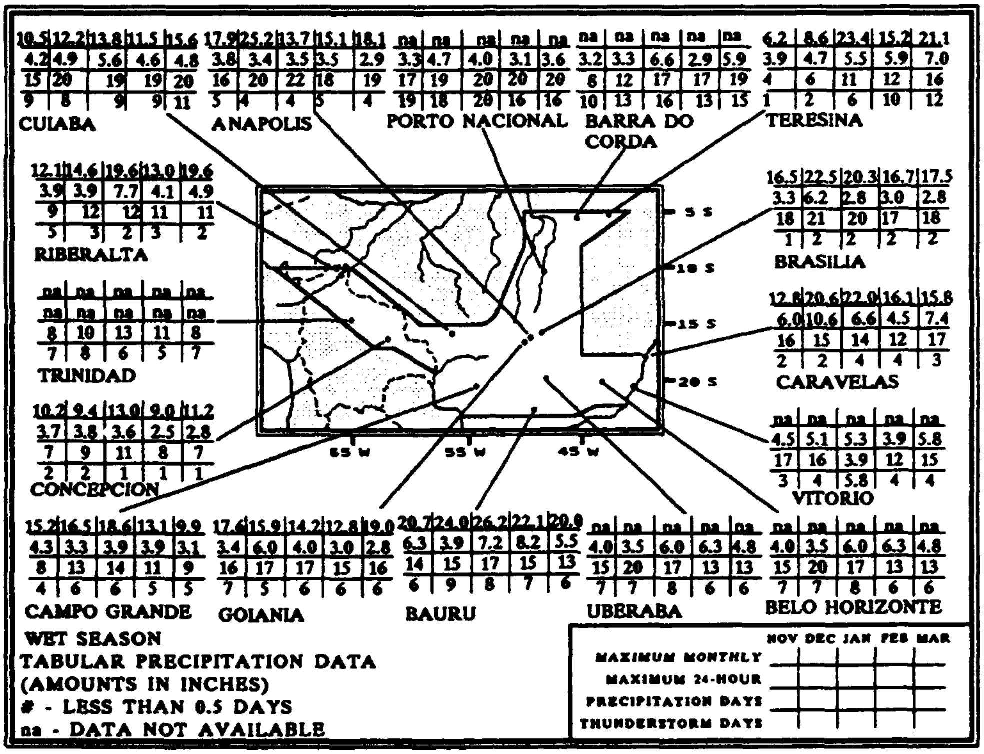


Figure 4-219. Wet-Season Tabular Precipitation Data, Brazilian Plateau.

THUNDERSTORMS. The wet-season normally begins with scattered to numerous thunderstorms, mainly during afternoons over elevated areas exposed to moist Amazon air. They become increasingly common as the season progresses, but begin decreasing everywhere in March, especially at low elevations. Most thunderstorms occur with disturbances and product severe weather. Air-mass thunderstorms are also common, but they are isolated, slow-moving, or stationary. They produce moderate to heavy rain, but rarely severe weather. Thunderstorms are least likely to occur along the coast; when they do, they are isolated and rarely embedded in other clouds. Thunderstorms along inland disturbances can become severe. Orographic lift and slope winds enhance development.

Monthly thunderstorm days, as shown in Figure 4-219, can reach 20 in the zone's northern finger, but are less than 10 in the coastal finger. They range from 4 to 21 in the zone's central section and from 2 to 8 in the western finger. Brazilian Plateau thunderstorms often produce intense lightning that can be seen from great distances. Associated middle clouds often produce moderate rainfall. Bases can be as low as 1,000 feet (305 meters) MSL; these, along with heavy rain, can obscure higher terrain. Tops can reach 50,000 feet (15.2 km) MSL.

Thunderstorms occurring along inland disturbances can form solid northwest to southeast lines. This is especially true along cold fronts/shear lines, where heavy rain, 50-knot gusts, and tornados can be found. There can be hail in higher elevations. Most severe storms occur in the central section and western finger. Thunderstorms along disturbances in the northern finger cause heavy downpours, but rarely tornado activity and never hail. Thunderstorms usually propagate either along a disturbance or in the direction of thunderstorm outflow; however, outflow is often channeled through valleys or other depressions and cause cell development in unexpected directions.

TEMPERATURE. Temperatures are controlled by fronts, surface albedo (vegetation), terrain, and moisture. They often rise slightly as cold fronts approach. Cold fronts produce the lowest temperatures, but most passages cause temperatures to fall less than 5° F (3° C). Westerly flow ahead of fronts results in the east coast's highest temperatures and lowest relative humidities by bringing in continental air and warming it adiabatically along coastal slopes. Onshore flow causes mild temperatures and high relative humidities along the coast. High moisture amounts provide widespread evaporative cooling that suppresses summer heat.

Record temperatures result from a combination of insolation, elevation, and adiabatic warming. The wet season's highest recorded temperature was 106° F (41° C) at Cuiaba and Campo Grande (see Figure 4-220). The record low is 38° F (3° C), set at Pocos De Caldas, the zone's highest station.

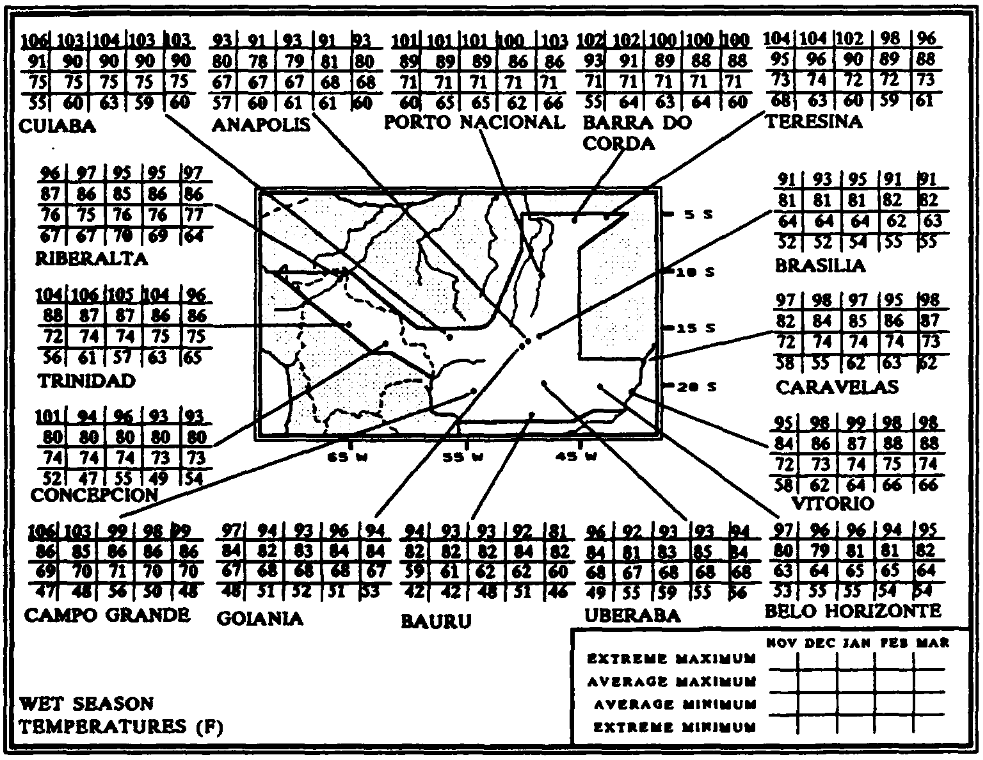


Figure 4-220. Wet-Season Tabular Temperature Data, Brazilian Plateau.

Relative humidities are highest in the western finger, averaging 73% afternoons and 93% mornings. Elsewhere, they range from afternoon lows of 60 to morning highs of 93%.

Figure 4-221 shows nine stations with wet-bulb globe temperature data (° F) at specific hours in January.

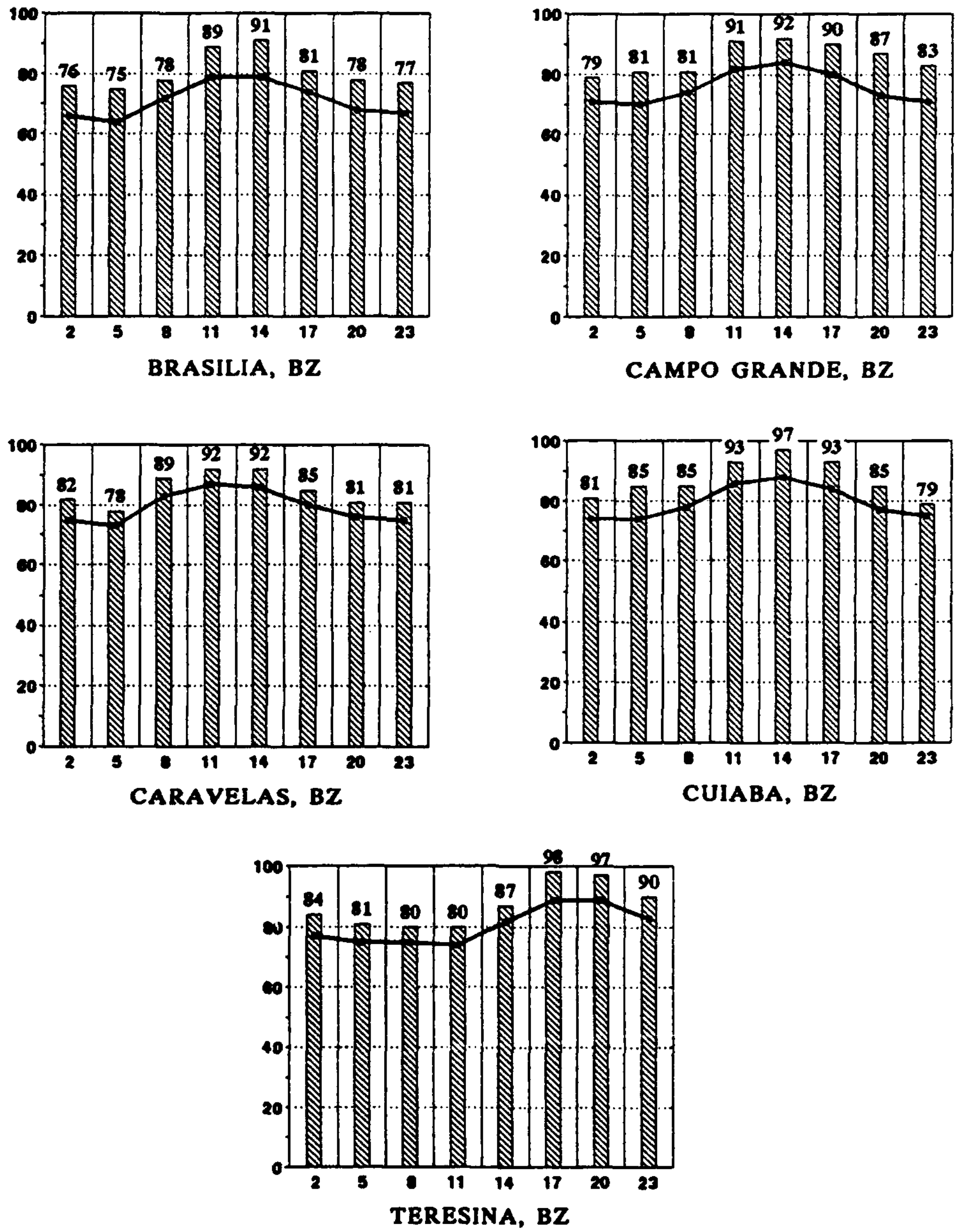


Figure 4-221. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Brazilian Plateau. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. The most important flight hazards are thunderstorm-related. Inland thunderstorms can form solid lines along disturbances. Hail, tornado activity, and severe low-level wind shear can accompany them. Severe turbulence from the surface through at least 20,000 feet (6.1 km) MSL is likely.

Thermal and mechanical turbulence occurs most often during daytime. Thermal turbulence occurs through 10,000 feet (3,050 meters) MSL and is usually light, but it can reach moderate intensity through 5,000 feet (1,525 meters) MSL, especially in the west. Most mechanical turbulence occurs over the southeastern mountains, becomining moderate to occasionally severe. Low-level wind shear occurs along the low-level jet that sometimes forms around 1,500 feet (455 meters) MSL near 10° S, 65° W. Radiation inversions isolate this jet from surface friction, allowing speeds to reach 50 knots as surface wind speeds decrease to produce severe wind shear.

Icing ranges from the freezing level (averaging 17,000 feet/ 5,180 meters MSL), to as high as 35,000 feet (10.7 km) MSL. Most icing occurs between the freezing level and about 25,000 feet (7.6 km) MSL; severe clear or mixed icing is possible in cumuliform clouds. Clouds and precipitation often obscure elevated terrain.

GROUND HAZARDS. Heavy showers can cause flash floods, especially in the mountainous areas, where bridges wash out. Rainy spells can make poorly drained areas accumulate water or become muddy. Such conditions can persist for several days after rain ends.

GENERAL WEATHER. Disturbance frequencies decrease as the Sun moves north and the stable South Atlantic High ridges west. Weather improves as the season progresses. The improvement is most rapid along the coast, where the South Atlantic High ridges first. Improvement is slowest in the west, which is farthest from the strengthening high. It is also slower in higher elevations because of orographic effects.

Cold fronts/shear lines, MCSs, and troughs associated with mid-latitude flow are important in the western finger. Troughs can affect the northern finger, but cold fronts/shear lines are very rare there. Most important in the north are the Tropical Convergence Zone and Low-Latitude Upper-Tropospheric Cyclones. The rest of the zone is affected by all disturbances characteristic of the transition.

Cold fronts/shear lines occur an average of once a week in the west, along the southern border, and along the coast. Most trailing air masses are shallow--the elevated terrain limits their northward penetration. Most fronts either stall along elevated terrain or dissipate while passing. Unusually deep air masses push north more easily; their associated weather is most persistent in the zone's mountainous southeast. Cold fronts/shear lines cause most poor coastal weather.

SKY COVER. Cloudiness decreases as the NET moves north. It decreases first at low elevations and last over high terrain. Disturbances normally produce broken to overcast skies, but cumulus is less frequent, with less development, than in the wet season. Mountain/valley breezes in the southeast cause increased cloudiness over peaks during afternoons and over valleys at night. Occasional sea breezes increase afternoon cloudiness near the coast. Figure 4-222 shows mean April sky cover. The highest values are toward the west where Amazon Basin moisture enters the zone. Rough terrain causes coverage to range from around 30% in river valleys to 70% over a few peaks.

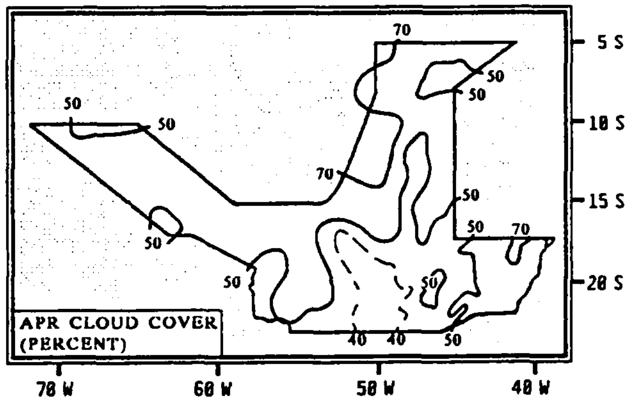


Figure 4-222. Mean April Cloud Cover, Brazilian Plateau.

Stratus becomes increasingly common. It forms in all locations with stationary or slow-moving disturbances and with warm-front overrunning in the south and along the coast. Most stratus occurs at night and in the morning following passages of cold fronts/shear lines. Cold frontal stratus enters the zone as low as 1,000 feet (305 meters) MSL, but rises as moisture is depleted over elevated terrain; tops usually range from 3,000 to 4,000 feet (915 to 1,220 meters). Without reinforcement by shear lines, stratus dissipates by mid-morning following frontal passage.

Broken stratocumulus is common along disturbances, especially at night. Scattered to broken stratocumulus is common along the coast, even during fair weather. Bases of low clouds vary across the zone. Morning bases west of 54° W normally range from 1,000 to 2,000 feet (305 to 610 meters) MSL, while north of about 15° S and on the coast they are 2,000 to 3,000 feet (610 to 915 meters) MSL. Low-level moisture is depleted over high terrain. The highest bases, therefore, occur in the mountains, where morning bases are between 4,000 and 5,000 feet (1,220 and 1,525 meters) MSL. Afternoon bases in mountainous areas range from 5,000 and 6,000 feet (1,525 and 1,830 meters) MSL.

Elsewhere, most afternoon bases range from 2,000 to 4,000 feet (305 to 1,220 meters) MSL. Most rainless cloud bases are 1,000 to 2,000 feet (305 to 610 meters) lower than normal, regardless of the location and time of day.

Cumulus normally forms during the day and with disturbances. Cumulonimbus that forms along disturbances inland is occasionally embedded in nimbostratus. Convective cloud tops reach 45,000 feet (13.7 km) MSL in disturbances. Most tops during settled periods are below 15,000 feet (4,570 meters) MSL in the coastal finger and in the extreme north, and below 20,000 feet (6.1 km) MSL along the border with the Central Amazon Basin. Disturbances also produce most of the middle and high clouds. Most middle cloud bases are between 10,000 and 12,000 feet (3,050 and 3,660 meters) MSL.

West of about 60° W, frequencies of ceilings below 3,000 feet (915 meters) AGL are higher in the afternoon (30-70%), than in the morning (Figure 2-223). In the zone's northern finger (north of about 15° S), most low ceilings are in the morning; afternoon bases are often a little higher than in the west. Low ceiling frequencies at higher elevations south of 15° S and between 43 and 60° W are highest in the afternoon (20-50%). East of 43° E, frequencies range from 10-30%, but coastal slopes exceed 30% in the morning.

Morning ceilings below 1,000 feet (305 meters) AGL are rare across most of the west, but their frequency can be as high as 30% at a few places; afternoon and evenings, less than 5%. Morning ceilings are below 1,000 feet less than 10% of the time across the north and are rare during afternoons and evenings. In the central section, they occur less than 15% of the time during all hours. The coastal slopes have morning ceilings below 1,000 feet (305 meters) AGL up to 20% of the time.

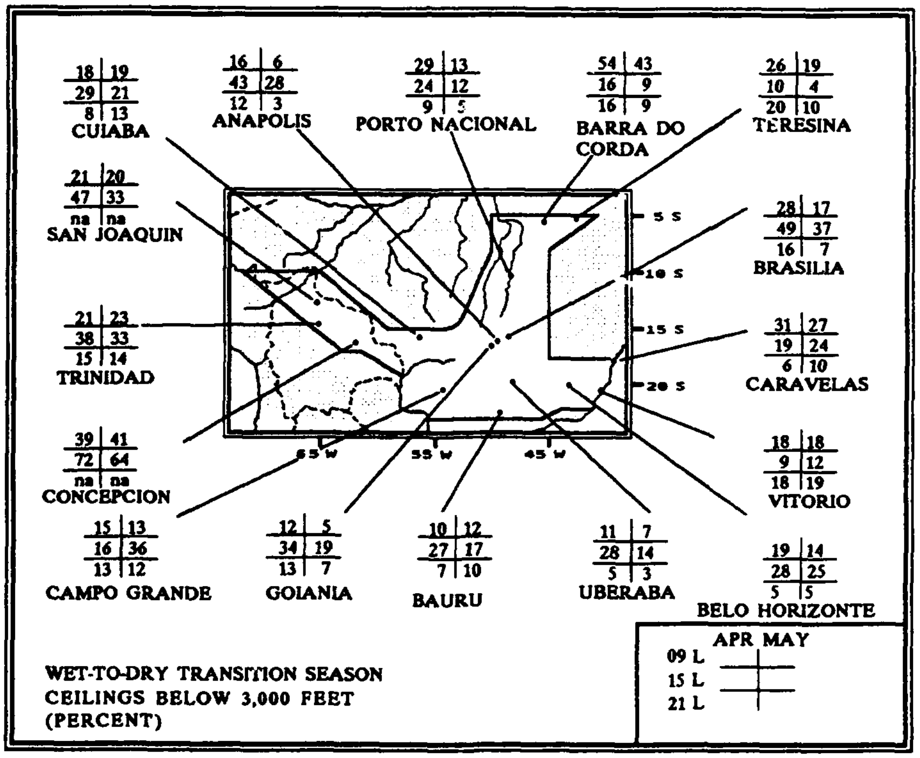


Figure 4-223. Wet-to-Dry Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian Plateau.

VISIBILITY. Visibilities are good across most of the zone, as shown in Figure 4-224. Concepcion and Conceicao Araguaia are the worst; at the latter, visibilities are below 3 miles more than at any other station. Most stations have visibilities below 1 mile less than 3% of the time during all hours, but at Concepcion, they occur more than 10% on May mornings.

Fog is the primary visibility restriction, occurring most often in the morning. Fog is most common on slopes exposed to moist flow and least common along the Atlantic shoreline, where it becomes stratus. Fog depths are normally less than 1,500 feet (455 meters). Cool air masses that are too shallow to pass over high terrain often cause a day or two of fog and drizzle along mountain slopes. Fog can form behind cold fronts, along stationary fronts, and beneath warm fronts. It can also form mornings following rainy days. Radiation fog occasionally forms in low areas, but dissipates by mid-morning.

Precipitation is the secondary visibility restriction; in the west, it reduces visibility most often in the afternoon, but at any time in other areas. Haze occasionally reduces visibilities below 3 miles; smoke has caused rare reductions below 3 miles in Bolivia.

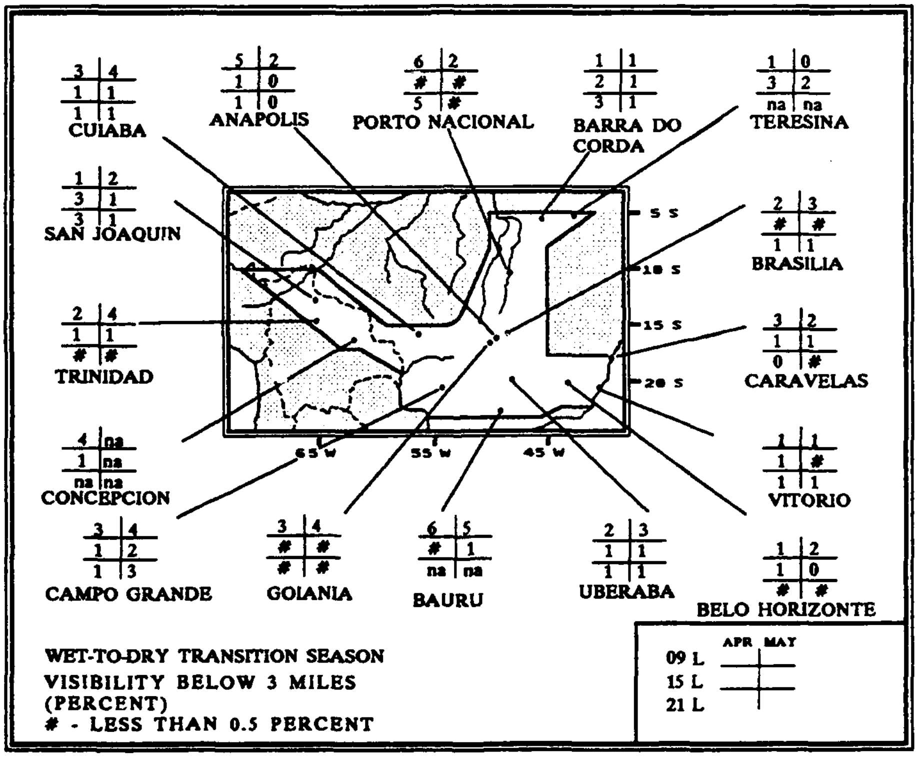


Figure 4-224. Wet-to-Dry Transition Percent Frequencies of Visibility Below 3 Miles, Brazilian Plateau.

WINDS. Winds are controlled by the weakening NAD and the strengthening South Atlantic ridge. Directions are variable, with easterlies slightly favored in some areas (see Figure 2-225). The Andes Mountains channel winds either northwestward or southeastward in the extreme west. Cold fronts/shear lines are preceded by westerly to northwesterly winds and followed by southerlies. Mountain/valley breezes become increasingly common. Land/sea breezes also occur more often, but they are weak because coastal swampland limits land/sea temperature differences.

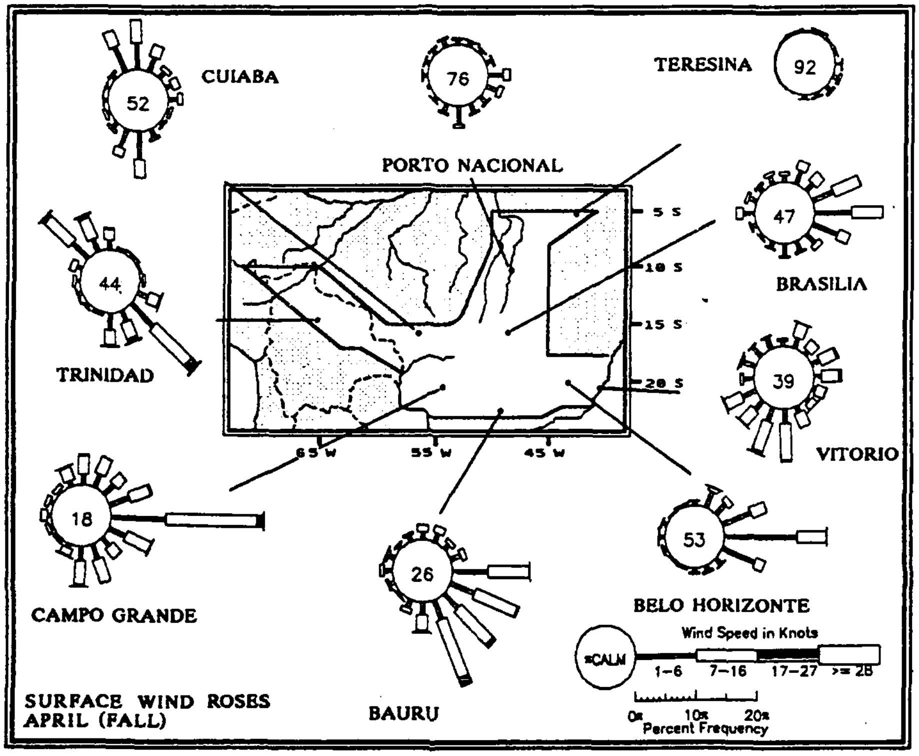


Figure 4-225. April Surface Wind Roses, Brazilian Plateau.

Wind speeds are less than 2 knots in the northern finger, 2-5 knots in the western finger, and 2-7 knots in the central section and eastern finger. Most variations are caused by terrain. Winds are calm at night where there are no local wind systems. Daytime speeds average 3 knots in the northern finger and 4-5 knots everywhere else except the immediate coast, where they are 5-7 knots. Strong winds are caused by thunderstorms and cold fronts. Thunderstorm gusts can exceed 40 knots, occasionally 50 knots. Gusts preceding and following cold fronts can be over 30 knots, especially in the western finger. Strong frontal winds usually last only a few hours. Frontal winds are weak and unimportant in the northern finger. Wind speeds are higher when channeled through valleys; speeds and directions change where flow is perpendicular to ranges.

STATION	MEAN WIND SPEED SEP	OCT
ANAPOLIS	3	3
BARRA DO CORDA	1	2
BAURU	6	6
BELO HORIZONTE	2	2
BRASILIA	3	3
CAMPO GRANDE	6	7
CARAVELAS	4	3
CONCEPCION	4	5
CUIABA	2	2
GOIANIA	3	3
PORTO NACIONAL	1	1
RIBERALTA	2	2
TERESINA	1	1
TRINIDAD	5	5
UBERABA	4	4
VITORIO	6	6

SPEED IN KNOTS

WET-TO-DRY TRANSITION SEASON

Figure 4-226. Mean Wet-to-Dry Transition Wind Speeds, Brazilian Plateau.

Mean winds at 5,000 feet (1,525 meters) MSL are northeasterly at 10 knots. By 20,000 feet (6.1 km), mean winds are easterly to northerly at 10-20 knots. Mean winds between 30,000 and 40,000 feet (9.1 and 12.2 km) MSL become northwesterly at 20 knots in the western finger and southerly at 20 knots in the northern finger; they are westerly at 30 to 40 knots elsewhere. Upper-level diffluence occurs in the northern finger, contributing to thunderstorm development there. Refer to Figures 4-213 through 4-217 in "Brazilian Plateau Wet Season."

PRECIPITATION. Following the Sun and the NET, precipitation amounts are highest in the north. Amounts range from less than 4 inches in the south to as high as 8 inches (203 mm) north of 12° S (Figure 4-227). Extreme monthly amounts range from as little as half the norm to about twice the norm. Most precipitation occurs with disturbances, but it occasionally occurs with afternoon heating over land. Shallow cold fronts can become lodged against high slopes and cause a day or two of drizzle; this is most common along coastal slopes. The season's infrequent deep air masses pass over high terrain and produce brief heavy showers. Weak land/sea breezes enhance precipitation near the coast. Air-mass showers arise through direct surface heating (and indirectly with differential heating) along the fringes of large cloud masses. Solar heating of elevated terrain causes upslope winds to enhance convection. Snow and freezing precipitation are very rare, occurring only at extreme southern locations at higher elevations.

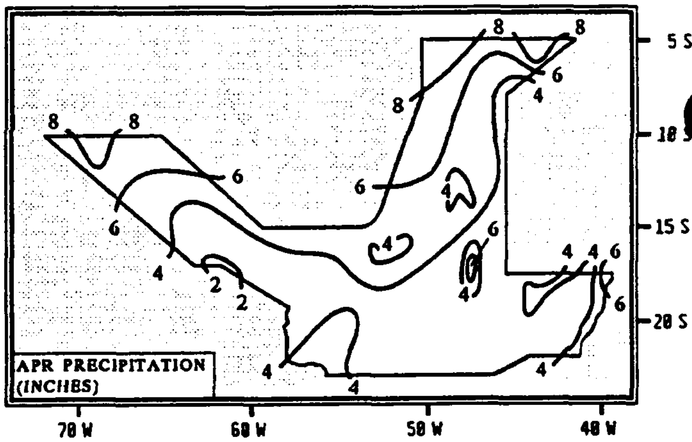


Figure 4-227. Mean April Precipitation, Brazilian Plateau.

Figure 4-228 shows the number of rain days decreasing across most of the zone. They range from 2 to 16, with the highest in the north and on the coast. Maximum 24-hour amounts range from 2.5 inches (64 mm) to 6.6 inches (168 mm) at Barra Do Corda. Amounts over 6 inches (152 mm) are also possible in some mountain areas. Rare flash floods can occur in the extreme north and in the southeastern mountains.

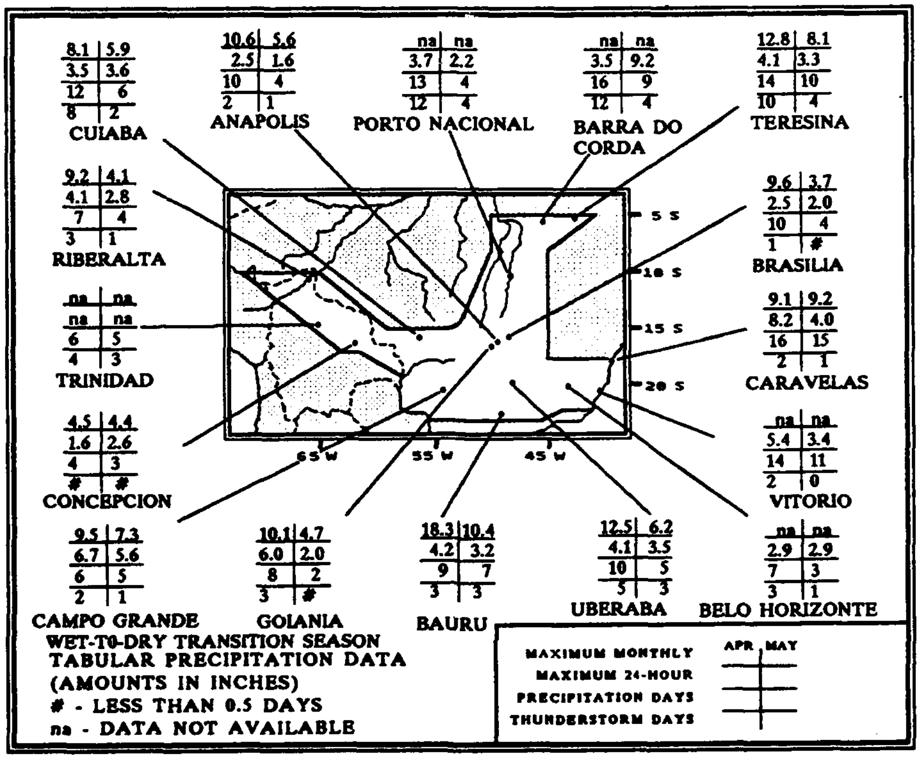


Figure 4-228. Wet-to-Dry Transition Tabular Precipitation Data, Brazilian Plateau.

THUNDERSTORMS. Most thunderstorms are disturbance-associated. They become less common as the season progresses. In the northern finger, thunderstorm days range from as high as 12 in April to as low as 2 in May (see Figure 4-228). Coastal locations have less than 5 a month, and some have none in May. The rest of the zone averages 2 to 8 days a month.

Thunderstorms with inland disturbances can cause moderate to heavy showers, gusts near 50 knots, rare tornado activity, and rare hail at higher elevations. These thunderstorms are occasionally embedded in other clouds. A few severe cells normally affect the zone's central section and western finger, but severe thunderstorms are rare in the north and near the coast. Associated middle and high clouds occasionally trail behind thunderstorm cores in the northern and western fingers, rather than preceding them the way mid-latitude cells do. This happens when cells propagate faster than (or toward) mid- and upper-level flow. Most propagate along disturbances or toward thunderstorm outflow, but because outflow can be channeled through valleys or other low areas, thunderstorms occasionally form in unexpected places. Orographic lift and slope winds enhance development in the south. Air-mass cells are rare and only occur inland. Thunderstorm bases range from 1,000 to 3,000 feet (305 to 915 meters) MSL; tops can reach 45,000 feet (13.7 km) MSL.

TEMPERATURE. Temperatures are controlled by cold fronts, surface albedo (vegetation), elevation, and moisture. Average highs range from 75-80° F (24-27° C) in the higher elevations to about 90° F (32° C) in the north. Average lows range from 50-55° F (10-13° C) at higher elevations to about 75° F (25° C) in the west. see Figure 4-229).

Cold fronts bring the season's lowest temperatures. Most cause temperatures to drop less than 5° F (3° C); however, exceptional cases called "friagems" occur west of 55° W, bringing clear skies and cold air. Friagems only occur with strong, southerly mid- and upper-level flow an average of five times a year from May through August; temperatures drop as much as 20° F (11° C). The abnormally cool air normally remains for less than 5 days, but has been known to persist for 2 weeks. The lowest temperature on record is 31° F (-1° C) was at Corumba, a station in the southwest part of the region.

Temperatures often rise slightly as cold fronts approach. Downslope westerly flow ahead of cold fronts cause the east coast's highest temperatures and lowest relative humidities. Onshore flow causes mild temperatures and high relative humidities near the coast. High temperatures depend mostly on high insolation, elevation, and adiabatic warming. The season's highest recorded temperature is 103° F (39° C) at Porto Nacional.

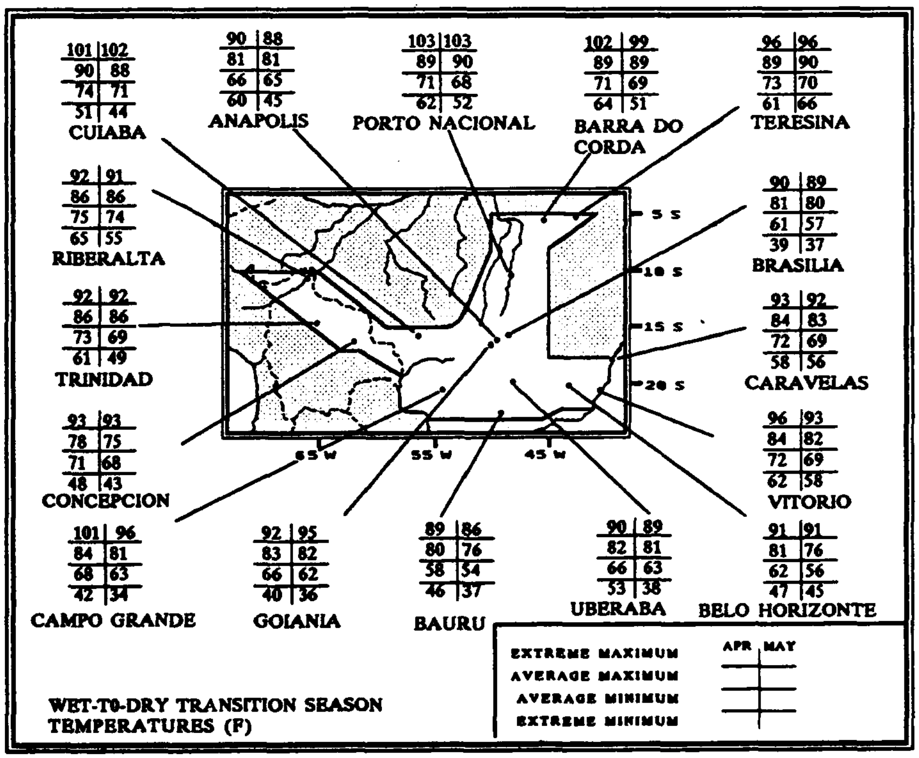


Figure 4-229. Wet-to-Dry Transition Tabular Temperature Data, Brazilian Plateau.

Lingering moisture keeps relative humidities similar to those of the wet season. They are highest in the western finger, ranging from 67 to 73% afternoons and from 88 to 95% mornings. In the extreme north and on the Atlantic coast, they range from 63 to 68% afternoons and from 91 to 95% mornings. Elsewhere, afternoon lows are 54 to 65% and morning highs are 76 to 94%. Figure 4-230 shows nine stations with wet-bulb globe temperature data (° F) at specific hours in

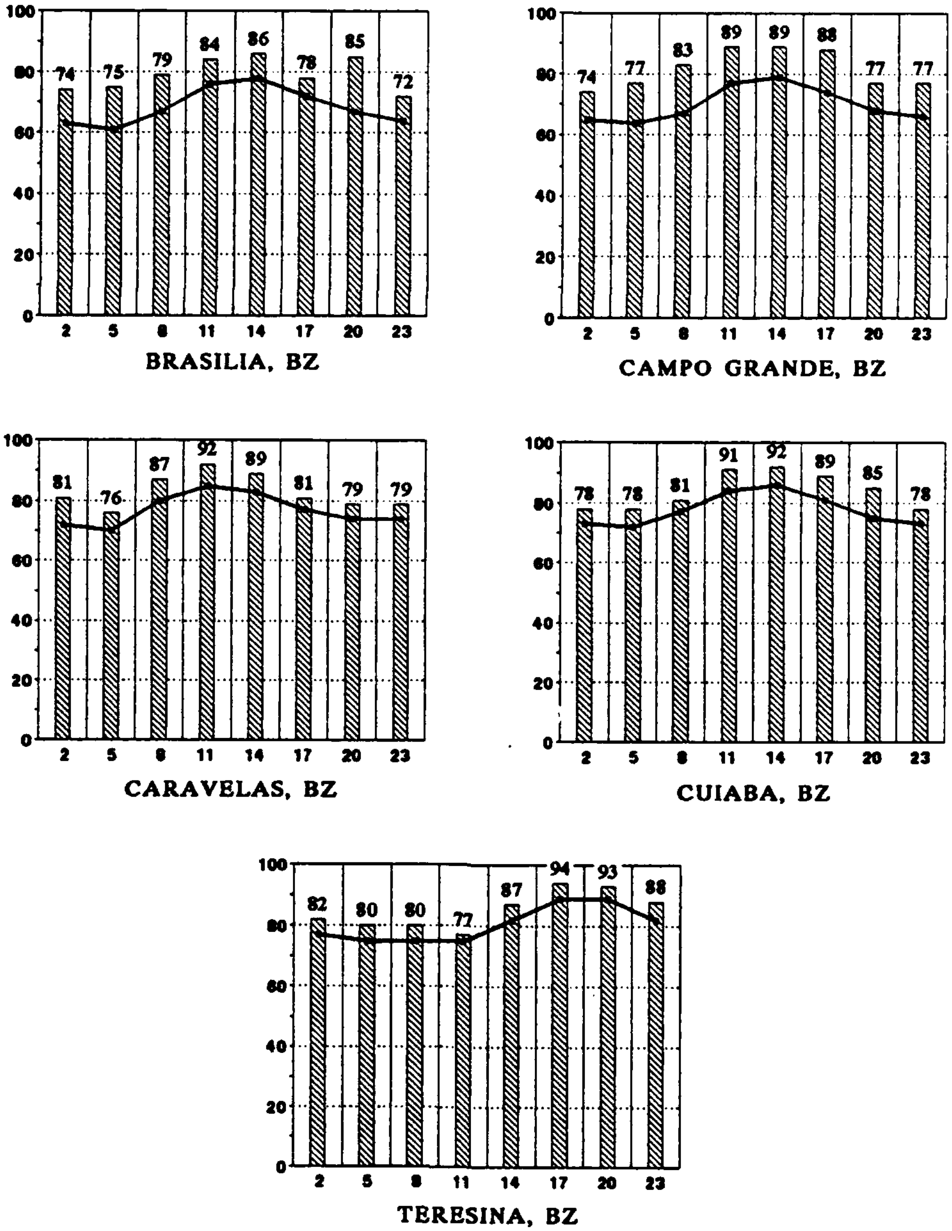


Figure 4-230. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Brazilian Plateau. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms rarely develop into solid lines or become severe, but they can cause severe turbulence from the surface through about 20,000 feet (6.1 km) MSL. Most turbulence occurs during the day, either with thunderstorms or as mechanical turbulence over rough terrain that reaches moderate (occasionally severe) intensities over southeastern mountains.

The average icing layer ranges from the freezing level at 15,000 to 16,000 feet (4,570 to 4,880 meters) MSL, to as high as 30,000 feet (9.1 km) MSL. Most icing is severe clear or mixed between the freezing level and about 20,000 feet (6.1 km) MSL within cumuliform clouds. Clouds and precipitation can obscure higher terrain.

GROUND HAZARDS. Rare flash floods are possible in the extreme north and southeastern mountains. Rain in the extreme north can cause poorly drained areas to accumulate standing water or become muddy. This can persist for several days after the rain ends.

GENERAL WEATHER. Stability and subsidence from the South Atlantic High, along with orographic drying of low-level air, produces generally good weather. The only "bad" weather occurs with exceptionally strong disturbances, which may include a few mid-latitude associated troughs that can affect the entire zone and cold fronts/shear lines that have an effect everywhere except in the northern finger.

Average frequencies of cold fronts/shear lines increase from one a week early in the season to one every 4 to 5 days by season's end. The air mass behind the front is normally too shallow to penetrate high terrain in the southeast. The occasional cold front that reaches this area normally takes about a day to pass through or undergo frontolysis. Cloudiness and scattered light precipitation can remain longer in the coastal finger.

SKY COVER. Strong South Atlantic High ridging suppresses cloud cover. The ridge deflects most disturbances, suppresses vertical motion, and reduces moisture through adiabatic drying. The few disturbances that enter the zone bring scattered to occasionally broken low clouds during afternoons and broken to occasionally overcast skies at night. Afternoon cloud types are mostly cumuliform, but stratiform at night. Upper-air disturbances only cause scattered to broken middle and high clouds. Sea breezes along the coast and solar heating of high terrain enhance afternoon cloudiness.

Sky cover is lowest n the south, west, and extreme north (Figure 4-231). The greatest coverage (70%) occurs when South Atlantic moisture accumulates along slopes near the coast. The northern finger between about 9 and 13° S has unusually high mean coverage; possible causes include smoke and haze from concentrated burning, radiation cooling that forms fog and stratus, daytime heating that produces stratocumulus, and low clouds forming from localized moisture tapped by extratropical disturbances. Local river valleys supply low-level moisture, especially the marshy Araguaia River valley.

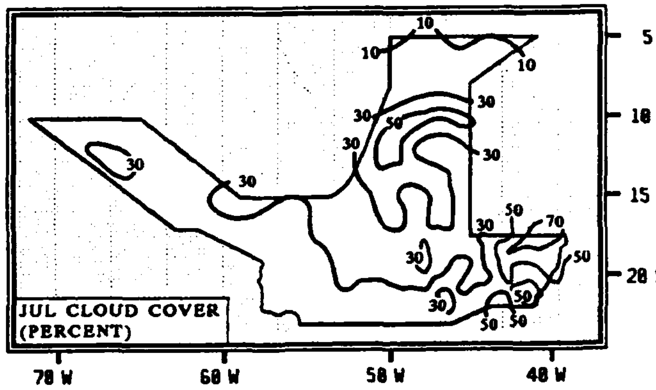


Figure 4-231. Mean July Cloud Cover, Brazilian Plateau.

Middle and high clouds dominate at the start of the dry season. Scattered to broken middle and high cloudiness is characteristic of upper-air disturbances. Mid-level bases average about 12,000 feet (3,660 meters) MSL; most tops are below 18,000 feet (5.9 km) MSL. Haze, smoke, and low clouds increase as the season progresses. Clear nights are common inland early in the season; later, there is widespread smoke and haze under radiation inversions at night. Stratus, mostly behind cold fronts/shear lines, enters the zone with bases at about 1,000 feet (305 meters) MSL; bases rise downstream as high terrain reduces moisture. Stratus dissipates in mid-morning following frontal passage. It is most persistent near the coast, obscuring slopes an average of 10 days a month. Cumulonimbus is very rare near the coast, while the infrequent nimbostratus occurs in the southeast. Fair weather brings scattered stratocumulus and cumulus inland during afternoons and near the coast at night.

Low-cloud bases west of about 53° W range from about 1,000 feet (305 meters) MSL in the mornings (due to moisture from local rivers and marshes) to as high as 3,000 feet (915 meters) MSL in the afternoon. Bases north of 13° S range from 1,500 feet (455 meters) MSL mornings to as high as 3,500 feet (1,065 meters) MSL afternoons. Drying on windward slopes makes bases highest over the southeastern mountains, where they are as low as 3,000 feet (915 meters) MSL mornings to as high as 6,000 feet (1,830 meters) MSL afternoons. Cloud bases along the coast show little diurnal variation, ranging from 2,000 to 3,000 feet (610 to 915 meters) MSL regardless of time of day. Most tops are below 12,000 feet (3,660 meters) MSL in the northern and coastal fingers, below 15,000 feet (4,570 meters) MSL east of 54° W, and less than 20,000 feet (6.1 km) MSL west of 54° W.

Afternoon ceilings are below 3,000 feet (915 meters) AGL 45% of the time at a few places in the western finger (Figure 2-232). Low ceilings in the northern finger occur no more than 25% of the time in the morning and decrease the rest of the day. Coastal ceilings are the least variable; they are below 3,000 feet (915 meters) AGL 5-25% of the time. Low-ceiling frequencies are variable across the rest of the zone, ranging from less than 15% at most places to more than 40% in the morning at isolated spots.

Frequencies of morning ceilings below 1,000 feet (305 meters) AGL reach 10% in the west, but they're rare at other times. They are very rare during all hours in the northern finger. Frequencies are less than 5% on the coast, increasing inland to more than 20% on some coastal slopes. They are less than 10% in the morning and rare at other times across the rest of the zone.

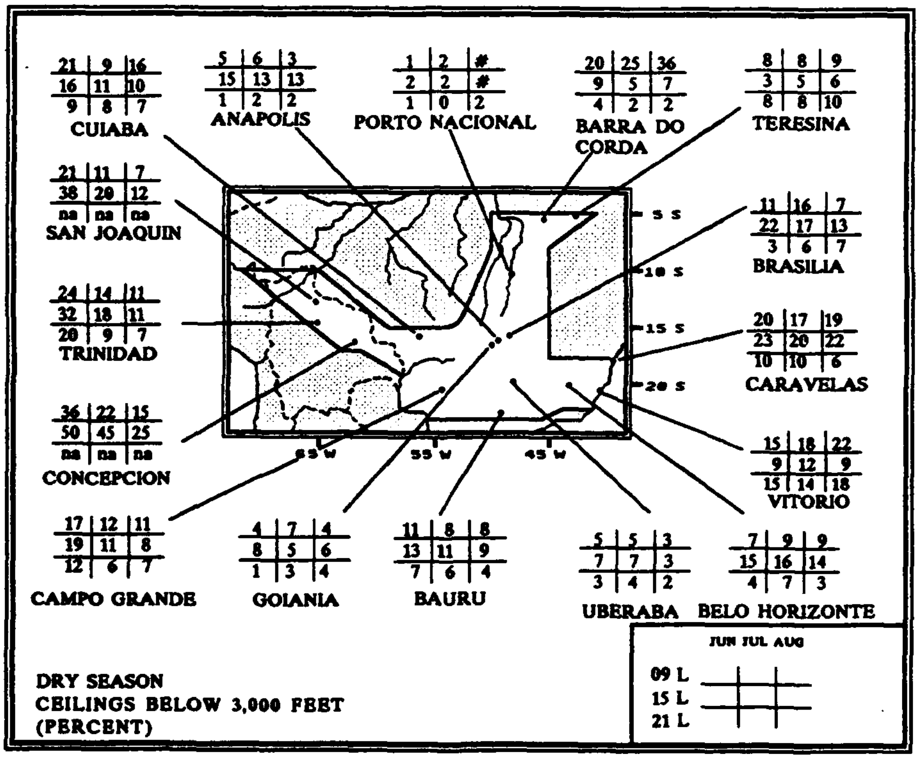


Figure 4-232. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian Plateau.

VISIBILITY. Visibilities are generally good during June and July, but smoke and haze cause worsening conditions in August. The stations affected most are Campo Grande, Trinidad, and Cuiaba; all have morning visibilities below 3 miles at least 10% of the time during August. In isolated northern areas, August visibilities are below 3 miles 35% of the time.

Morning visibilities are below 1 mile up to 10% of the time in June and July and up to 15% of the time in August. Isolated areas in the north are worst again; afternoon and evening frequencies below 1 mile are 5% or less at all stations. Although there is no data from coastal slopes where terrain is often obscured by stratus, visibilities there are worse than at the coastal stations shown in Figure 4-233.

Fog is the primary cause of low visibilities in June and July. Smoke and haze become more of a problem in August, when cropland burning can reduce visibility to 1/4 mile. On the coast, fog, precipitation, and salt haze reduce visibilities all season long. The effects of fog, smoke, and haze are greatest in the mornings.

Cool air masses too shallow to pass over high terrain become lodged against the mountains where they cause 1-2 days of fog and sometimes drizzle along slopes about 10 days a month. Fog along coastal slopes is seen as stratus on the immediate coast; fog normally doesn't form on immediate coasts. Radiation fog occasionally forms in low-lying areas and over the coastal plain south of Vitorio during cool periods. It is normally less than 1,000 feet (305 meters) deep and dissipates shortly after sunrise.

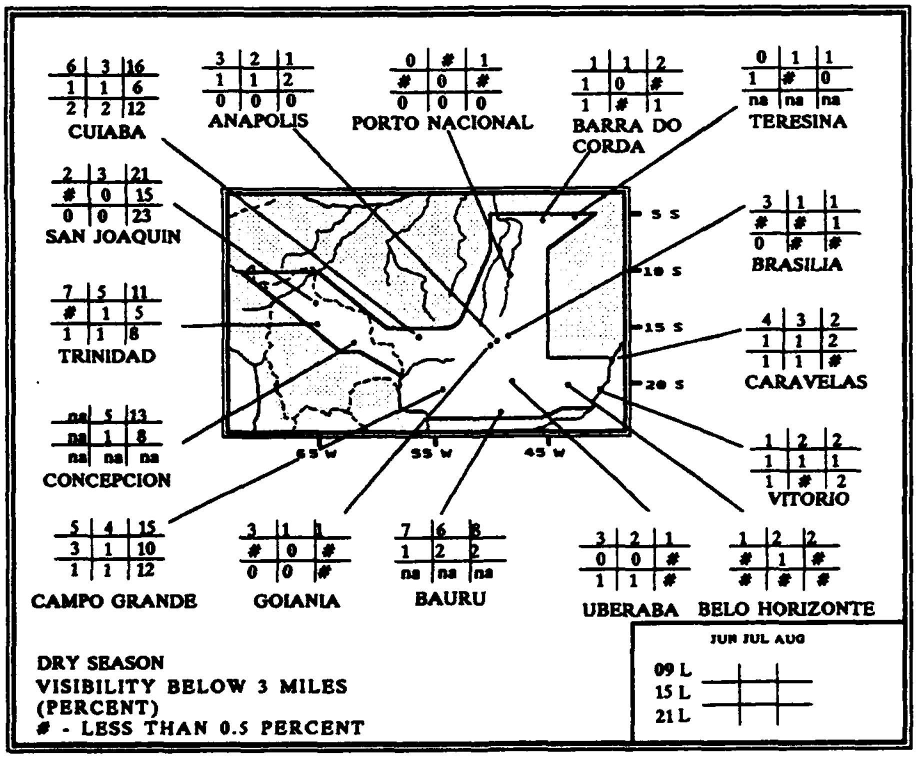


Figure 4-233. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Brazilian Plateau.

WINDS. Ridging from the South Atlantic High controls dry-season flow. Winds are easterly except in the extreme west where the Andes often channel winds toward the southeast (see Figure 4-234). Channeling increases wind speeds through passes. Speed and direction can change where low-level flow crosses perpendicular to ridges. Mountain/valley breezes are common. Land/sea breezes are weak because heating is limited over coastal swampland. Cold fronts are preceded by westerly to northwesterly winds and followed by southerlies.

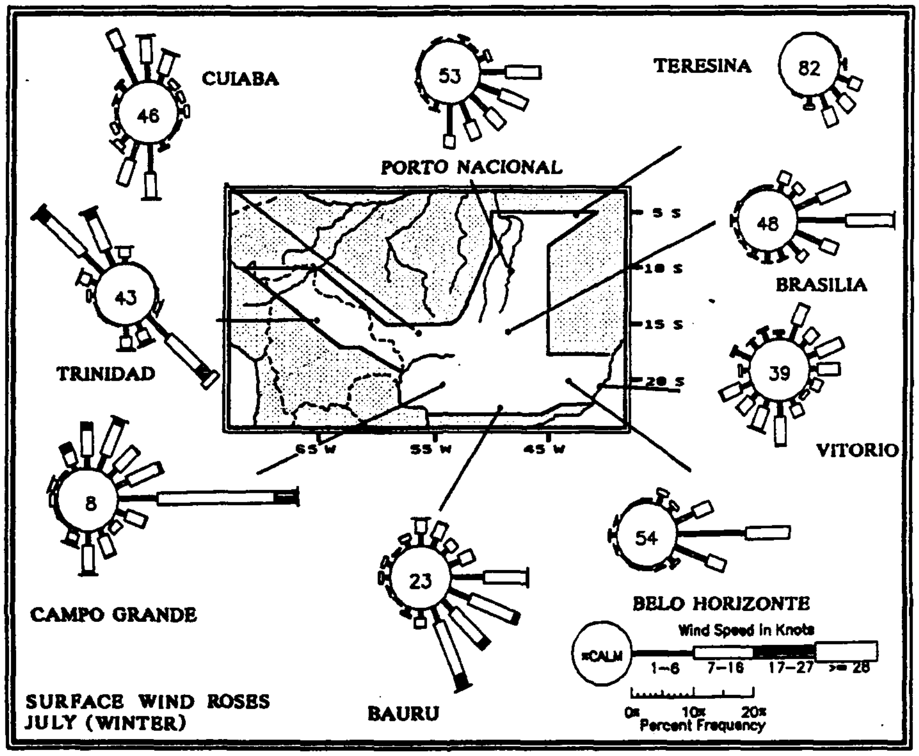


Figure 4-234. July Surface Wind Roses, Brazilian Plateau.

Wind speeds are lowest (about 2 knots) in the northern finger. Terrain affects speeds elsewhere, causing them to range from 2 to 8 knots (Figure 4-235). Winds are generally calm at night where local wind systems are weak. Afternoon winds are generally below 8 knots. The highest wind speeds in the western finger occur in the dry season; occasional cumuliform cells with high bases may be the reason. Speeds can reach 65 knots where terrain channeling takes place, but most strong winds are caused by cold fronts. Gusts can exceed 40 knots from either the northwest ahead of the front, or from the south to southwest behind them; they usually persist no more than a few hours. Strong, gusty winds also occur with the rare thunderstorm.

STATION	MEAN WIND SPEED		
	JUN	JUL	AUG
ANAPOLIS	3	3	3
BARRA DO CORDA	2	2	2
BAURU	6	7	7
BELO HORIZONTE	2	2	3
BRASILIA	3	3	4
CAMPO GRANDE	8	8	8
CARAVELAS	3	4	4
CONCEPCION	5	8	7
CUIABA	2	3	3
GOIANIA	3	3	3
PORTO NACIONAL	2	2	1
RIBERALTA	2	2	2
TERESINA	1	1	1
TRINIDAD	4	5	6
UBERABA	4	5	5
VITORIO	5	6	7

Figure 4-235. Mean Dry-Season Wind Speeds, Brazilian Plateau.

Winds aloft are shown in the "Brazilian Plateau Wet-Season," Figures 4-213 through 4-217. Mean winds above 5,000 feet (1,525 meters) MSL are easterly at 10 to 15 knots, becoming northeasterly at 15 knots over the zone's central section and northerly at around 10 knots over the western finger. Mean winds north of 10° S change little through 20,000 feet (6.1 km) MSL, where they are easterly at about 15 knots in the west and 25 knots in the central section and eastern finger. Easterly flow covers the entire zone by 35,000 feet (10.7 km) MSL; speeds range from 15 knots in the north to 50 knots along the southernmost border.

PRECIPITATION. Fronts/shear lines cause most dry-season precipitation. Amounts range from less than 1/2 inch (13 mm) toward the north to more than 1 inch (25 mm) along the coast and southern borders (Figure 4-236). The highest amounts are along the coast where Atlantic moisture is tapped by weak land/sea breezes and cold or stationary fronts. Extreme monthly amounts range from near zero in dry years to about twice the norm during abnormally wet years.

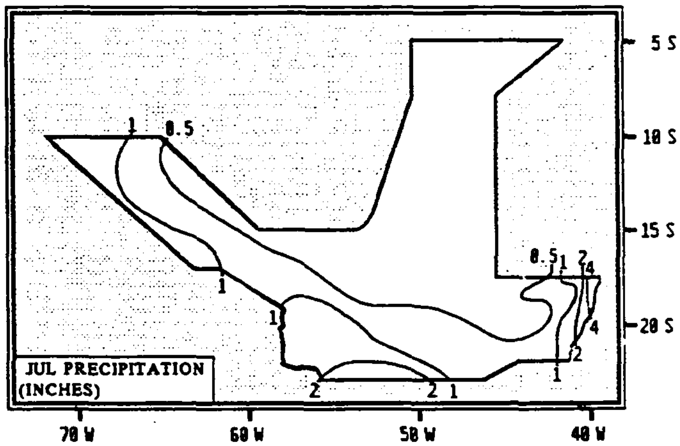


Figure 4-236. Mean July Precipitation, Brazilian Plateau.

Disturbances and local terrain often work together to cause precipitation. Shallow air masses behind cold fronts can become lodged against elevated terrain, producing up to 2 days of drizzle along slopes. This happens along coastal slopes between 5 and 10 days a month. It can occur on any slope where low-level moisture is sufficient. The season's infrequent deep air masses can cause brief moderate-to-heavy showers along cold fronts. Nights and mornings following cold-front passages often have drizzle. Precipitation intensities are normally light, but can be moderate to heavy. Virga occurs occasionally beneath clouds with high bases. Snow and freezing precipitation occur only at high elevations in the extreme south; there is little or no accumulation.

Precipitation days (Figure 4-237) differ at coastal and inland stations. The number of days with precipitation near the coast ranges from 8 to 15, while most inland stations have less than 5 rain days a month. Maximum 24-hour precipitation amounts range from 1.4 inches (36 mm) at Barra Do Corda and Brasilia to 6 inches (152 mm) at Bauru, in the extreme south. Heavy rains in the southern mountains can cause flash floods.

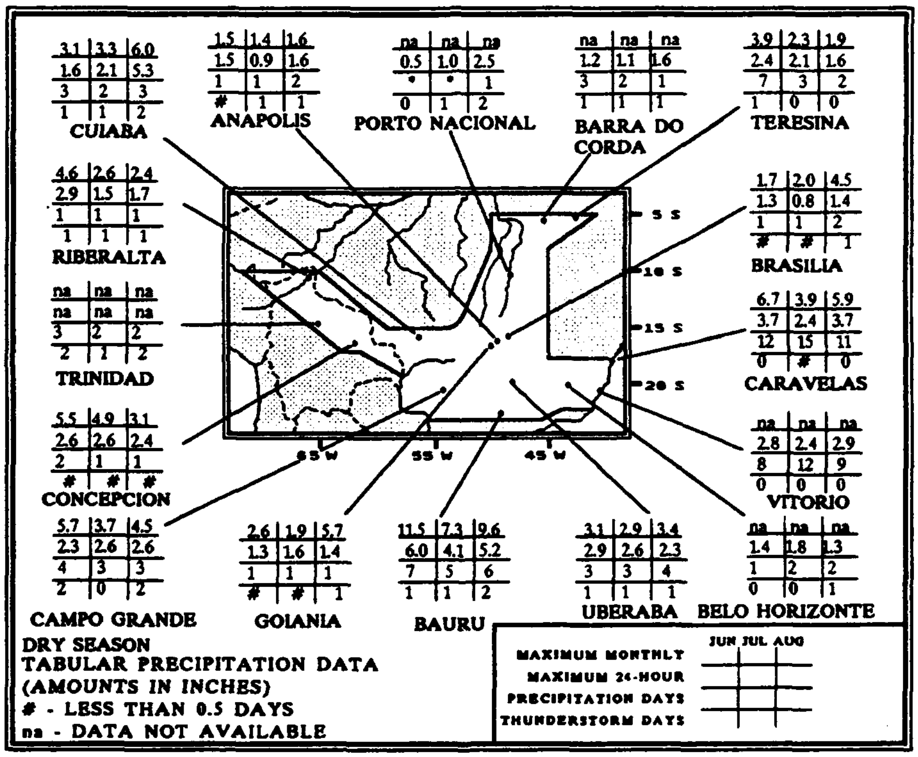


Figure 4-237. Dry-Season Tabular Precipitation Data, Brazilian Plateau.

THUNDERSTORMS. Dry-season thunderstorms are infrequent and very rarely severe. As shown in Figure 4-237, monthly thunderstorm days range from zero on the coast to only 2 in the western finger. The few thunderstorms that do occur form along strong disturbances and are short-lived. Development can be enhanced by orographic lift and slope winds. Most dry-season thunderstorms have bases ranging from 2,000 to 4,000 feet (610 to 1,220 meters) MSL and tops below 40,000 feet (12.2 km) MSL. The rare gust can reach 40 knots.

TEMPERATURE. Temperatures are mostly controlled by surface albedo (vegetation), elevation, and fronts. The heat of the dry season reflects the effects of light cloud cover, less surface moisture, and infrequent cold fronts; all these more than compensate for decreased insolation. Low surface moisture inhibits evaporative cooling--an important moderator during the two previous seasons. Average highs range from 75° F (24° C) at the highest elevations to about 95° F (37° C) in the north. Average lows range from 45-50° F (7-10° C) in the highest elevations to 70° F (21° C) in the west. See Figure 4-238.

Extreme highs are usually the result of adiabatic warming and warm northwest flow north of fronts. The highest recorded temperature is 113° F (45° C) at San Joaquin, a western station.. Temperatures usually rise slightly as cold fronts approach. Downslope westerly flow ahead of cold fronts results in the east coast's highest temperatures and lowest relative humidities. Onshore flow results in mild temperatures and high relative humidities near the coast.

Cold fronts cause the zone's lowest temperatures, but normally cause temperatures to drop less than 5° F (3° C). Extreme cases, called "friagems," occur west of about 55° W when a cold front penetrates exceptionally far north with strong southerly mid- and upper-level flow. Friagems occur an average of five times a year from May through August; temperatures drop as much as 20° F (11° C). Friagems normally last no more than 5 days, but they have been known to last 2 weeks. The lowest recorded temperature from a friagem is 31° F (-1° C) at Campo Grande. The zone's lowest temperature on record is 26° F (-3° C) at Pocos De Caldas (the zone's highest station, located in the southeast highlands).

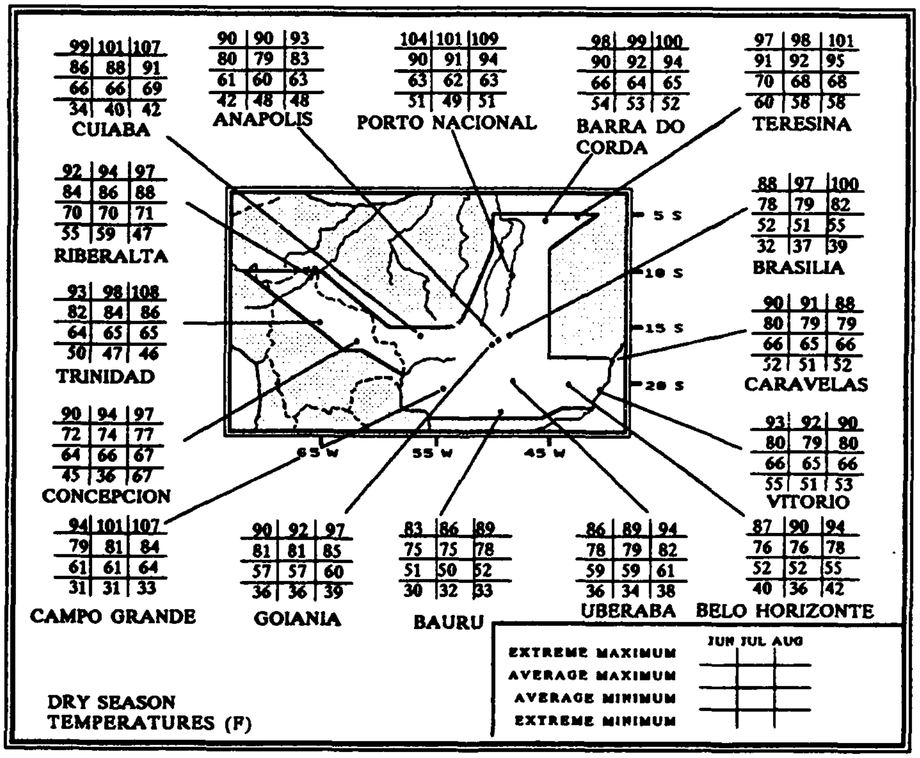


Figure 4-238. Dry-Season Tabular Temperature Data, Brazilian Plateau.

Relative humidities are much lower than in the two previous seasons. They are highest along the coast, where morning averages are around 93% and in the afternoon, 62 to 69%. RHs are also high in the zone's western finger, where they average 86 to 94% in the morning and from 56 to 67% in the afternoon. In the extreme north, RHs range from average morning highs of about 87% to afternoon lows of around 53%. RH across the rest of the zone ranges from morning highs of 65 to 87% to afternoon lows of 38 to 58% . Figure 4-239 shows nine stations with wet-bulb globe temperature data (° F) at specific hours in July.

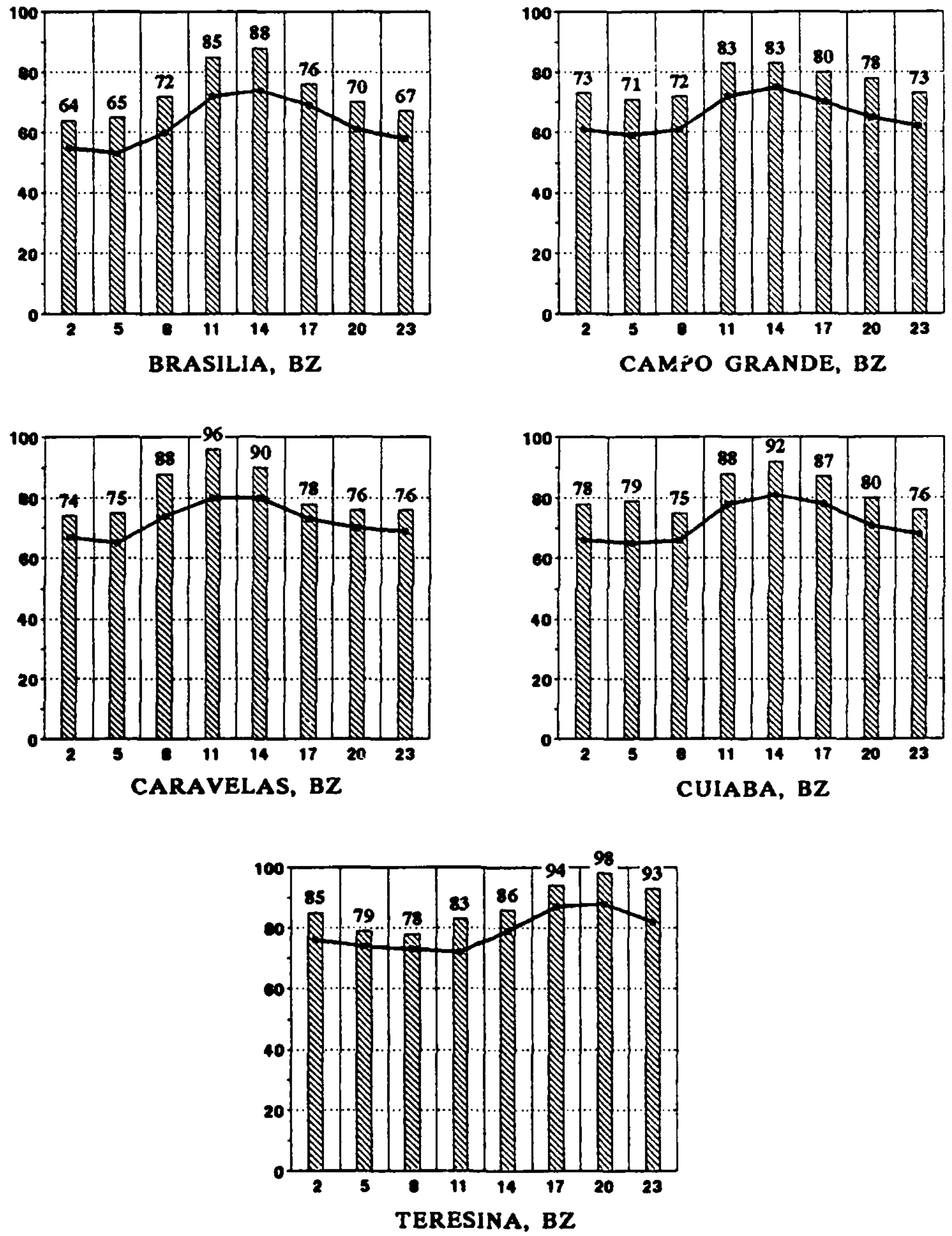


Figure 4-239. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Brazilian Plateau. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms are rare. They occasionally join with showers to form short lines, but these are normally navigable. Hail, tornado activity, and low-level wind shear are rare. Thunderstorms can cause moderate-to-severe turbulence from the surface through about 20,000 feet (6.1 km) MSL. Most zone turbulence is mechanical, and most occurs during afternoons over southeastern mountains, where it reaches moderate to occasional severe intensities.

Icing is least important in this season because of the reduced cloudiness. The freezing level ranges from 14,000 feet (4,270 meters) MSL in the southeast to 16,000 feet (4,880 meters) MSL in the north. Icing can be found as high as 30,000 feet (9.1 km) MSL, but normally only between the freezing level and about 20,000 feet (6.1 km) MSL. Severe clear and mixed icing is possible in the dry season's rare cumuliform clouds.

Clouds, late season haze, and occasional precipitation can obscure higher terrain. In the interior, haze often reduces in-flight visibilities below 1 mile in August, obscuring terrain and cumuliform cells. The haze becomes trapped beneath radiation inversions in the morning, often reducing visibilities below 1 mile from the surface through several hundred feet AGL. Pilot reports show that the worst effects of haze on visibility is found aloft. The haze is thickest between 5,000 and 15,000 feet (1,525 and 4,570 meters) MSL where reductions below 1/4 mile are possible. Maximum haze tops range from 15,000 feet (4,570 meters) MSL in the southeast to 25,000 feet (7.6 km) MSL in the west. Disturbances can remove the haze for 1 or 2 days.

GROUND HAZARDS. Very rare flash floods are possible in low areas of the zone's southeastern mountains.

GENERAL WEATHER. Transition weather is often violent. The receding South Atlantic High allows disturbances, especially cold fronts, to reach the zone with increasing frequency. The most rapid increase is over higher terrain. Cold fronts, shear lines, and other mid-latitude surface and upper-air troughs affect the entire zone. The Tropical Convergence Zone (TCZ) affects all but the zone's western finger. The NET is not yet near enough to affect the zone.

Cold fronts and shear lines cause weather conditions to vary dramatically from day to day, especially in the western finger. They enter and pass through the zone on the average of once every 4 to 5 days. Frontal/shear line frequencies usually begin decreasing by the end of the transition, but in some yearsthere is another increase at the beginning of the wet season. Severe thunderstorms are common with cold fronts, especially toward the west.

SKY COVER. The rising number of disturbances also increases cloudiness; first over higher terrain, especially along slopes exposed to moist, low-level flow. Cloud cover reaches 80% during October (Figure 4-240). It is highest where Amazon Basin moisture enters the northern finger and where Atlantic moisture enters the coastal finger. The least cloudy areas are over dry river valleys near 17° S, 45° W.

Disturbances usually produce broken to overcast skies, with clear to scattered skies separating them. Diurnal cloud cover variations are minimal. Haze from cropland burning greatly affects sky cover in September and persists as long as no disturbances are occurring. Disturbances remove the haze for 1 to 2 days early in the season; haze becomes less significant as disturbances become more common. The smoke and haze can be dense beneath radiation inversions and occasionally result in ceilings below 3,000 feet (915 meters) AGL. Disturbances normally produce cumuliform clouds. Stratocumulus is common along the coast, while most cumulus and cumulonimbus form inland during afternoons. Cumulonimbus can form into solid lines along cold fronts/shear lines except near the coast.

Most stratus forms on mornings following cold front passages, especially along coastal slopes. Frontal stratus is often followed by a narrow band of broken stratocumulus. Stratus occasionally occurs with warm and stationary fronts in the zone's central section and coastal finger. Stratus often occurs on mornings following moderate to heavy precipitation. It dissipates by mid-morning unless reinforced by new shear lines. Repeated shear lines can cause stratus to persist day and night. Nimbostratus, although rare, can also occur with disturbances.

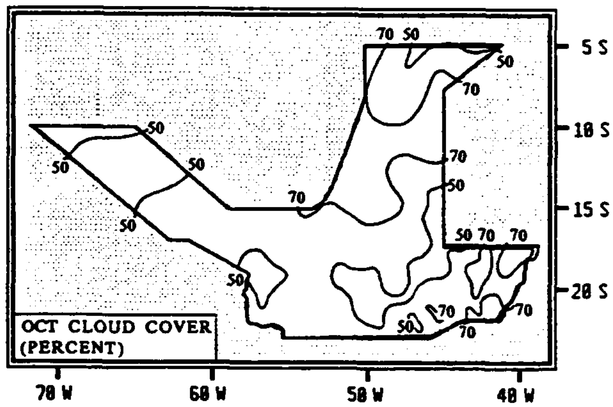


Figure 4-240. Mean October Cloud Cover, Brazilian Plateau.

Bases of low clouds are generally lowest in the west and highest over mountainous areas. Morning bases west of about 56° W are as low as 1,000 feet (305 meters) MSL, increasing to 2,000 to 3,000 feet (610 to 915 meters) MSL in the northern finger and along the immediate coast, and to 4,000 to 5,000 feet (1,220 to 1,525 meters) MSL over mountainous areas. The higher cloud bases are due to the depletion of low-level moisture on upstream slopes.

Afternoon bases range from 2,000 to 3,000 feet (610 to 915 meters) MSL across most of the zone, increasing to 4,000-6,000 feet (1,220-1,830 meters) MSL in mountainous areas. Clouds are usually 1,000 to 2,000 feet (305 to 610 meters) lower when precipitation is occurring. Most middle clouds have bases between 7,000 and 9,000 feet (2,135 and 2,745 meters) MSL. Maximum tops during settled periods range from about 10,000 feet (3,050 meters) MSL north of 15° S to nearly 20,000 feet (6.1 km) MSL along the southern border. Disturbances produce maximum tops from 30,000 feet (9.1 km) MSL in the north to 45,000 feet (13.7 km) MSL in the south. Layered middle and high clouds--often merging--are common along disturbances.

Ceilings below 3,000 feet (915 meters) AGL occur more frequently in the morning in most of the northern finger and east of 43° W, and in the afternoon elsewhere (Figure 4-241). In the north, morning frequencies can be as high as 65% at Barra Do Corda, but most places have frequencies below 20%. Most of the coastal finger east of 43° W has morning frequencies of 30 to 40%, the highest along coastal slopes. Frequencies are more variable in the rugged central section, where they are less than 35% in the morning, 10-50% in the afternoon, and less than 25% evenings. In the western finger, they peak in the afternoon at 30-60%.

Frequencies of ceilings below 1,000 feet (305 meters) AGL are less than 5% during all hours in the north. Near the coast, frequencies are less than 10% at most places, but may exceed 20% on coastal slopes. Frequencies are less than 10% mornings and less than 5% afternoons and evenings in the central section. In the western finger, they are less than 15% mornings and less than 5% afternoons and evenings.

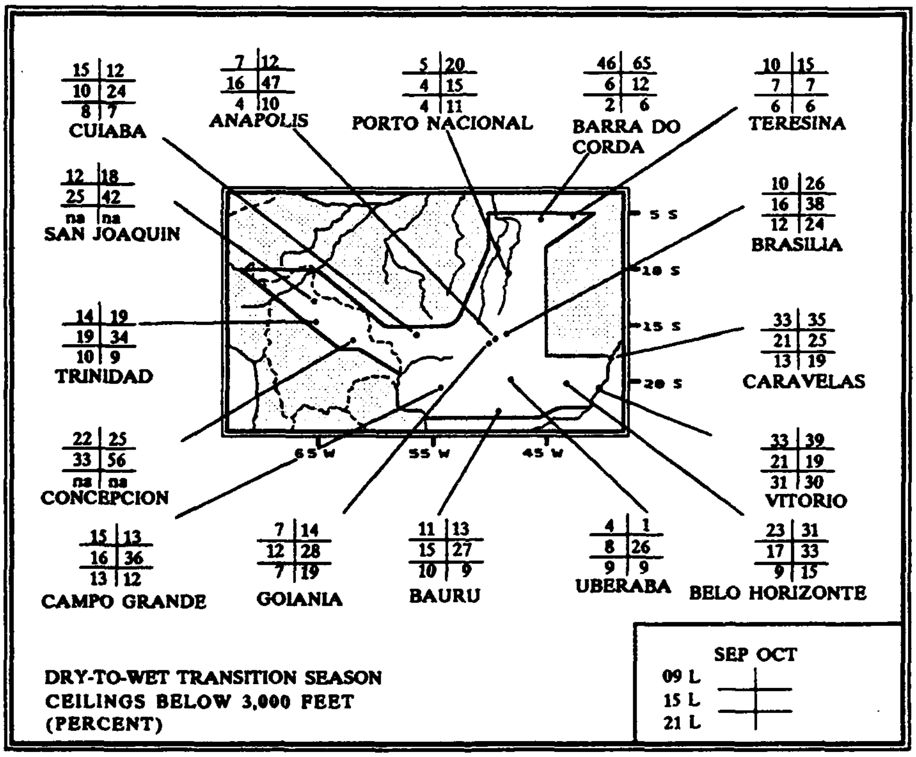


Figure 4-241. Dry-to-Wet Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Brazilian Plateau.

VISIBILITY. Smoke and haze are the primary causes of inland visibility restrictions in September. Cropland burning drops inland visibilities was as low as 1/4 mile beneath strong radiation inversions. Rising disturbance frequencies reduce the effects of smoke and haze in October, when fog and precipitation become primary visibility factors. Fog is more frequent in the morning; precipitation, in the afternoon. Most coastal haze is from sea salt, which only occasionally drops visibilities below 3 miles.

When cool, shallow airmasses become lodged against mountain ranges, the result is 1-2 days of fog (and sometimes drizzle) along slopes. Fog along the Atlantic shoreline becomes stratus. Radiation fog can form in low-lying areas, especially in the western finger. Although the coastline normally experiences little fog, radiation fog can occur over the coastal plains south of Vitorio on cool nights. It is normally less than 1,000 feet (305 meters) deep and dissipates shortly after sunrise.

Most low visibilities are in September. Smoke and haze are worst in the north and at Campo Grande, San Joaquin, and Cuiaba, where September morning visibilities are below 3 miles at least 10% of the time. Isolated areas in the west are worst; visibilities are below 3 miles nearly 45% of the time (Figure 4-242). Frequencies of morning visibilities below 1 mile are 15% in September and 10% in October, while afternoon and evening frequencies are 10% in September and less than 5% in October. Coastal slopes are often obscured by stratus and have much higher low-visibility frequencies than what is shown for the coastal stations.

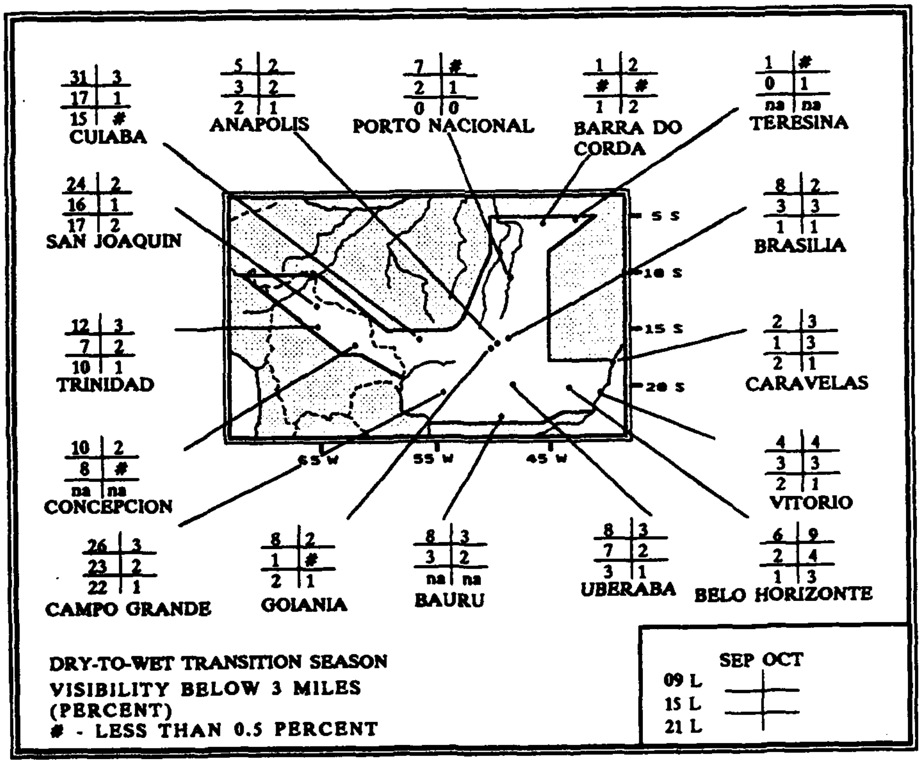


Figure 4-242. Dry-to-Wet Transition Percent Frequencies of Visibility Below 3 Miles, Brazilian Plateau.

WINDS. Low-level flow changes little from the dry season, even though the South Atlantic High is rapidly receding. Mean surface winds are easterly, except in the west where most winds are channeled toward the south by the Andes Mountains (Figure 4-243). Cold fronts/shear lines are preceded by westerly-to-northwesterly winds and followed by winds from the south or southwest. Winds channeled through passes strengthen; those crossing ridges perpendicular to the low level flow weaken. Mountain/valley breezes also occur.

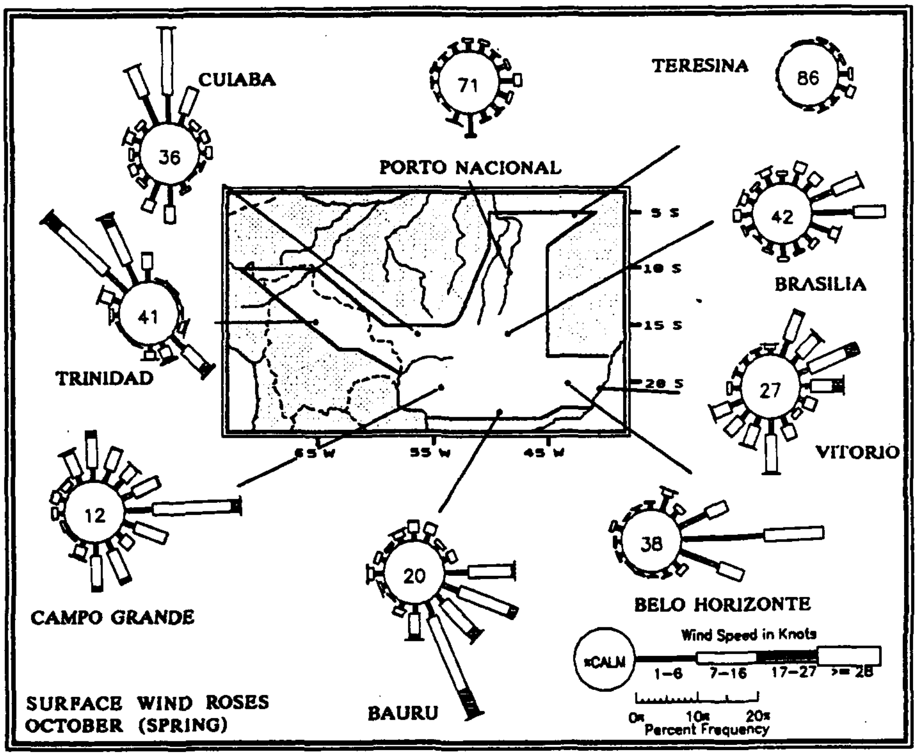


Figure 4-243. October Surface Wind Roses, Brazilian Plateau.

Wind speeds are lowest in the north, where they average 2 knots or less. Terrain greatly affects winds elsewhere; mean speeds (2-8 knots) peak in the afternoon (see Figure 4-244). Winds are calm at night where there are no local wind systems. The strongest winds are southerlies behind cold fronts and those with thunderstorms. Maximum recorded gusts range from 35 to 55 knots, usually where strong winds are channeled through passes.

STATION	MEAN WIND SPEED SEP	OCT
ANAPOLIS	3	3
BARRA DO CORDA	2	2
BAURU	7	7
BELO HORIZONTE	3	3
BRASILIA	4	4
CAMPO GRANDE	8	7
CARAVELAS	4	5
CONCEPCION	7	7
CUIABA	3	3
GOIANIA	3	3
PORTO NACIONAL	1	1
RIBERALTA	3	2
TERESINA	1	1
TRINIDAD	6	6
UBERABA	5	5
VITORIO	7	7

Figure 4-244. Mean Dry-to-Wet Transition Wind Speeds, Brazilian Plateau.

Winds aloft are shown in the "Brazilian Plateau Wet Season," Figures 4-213 through 2-217. Mean winds at 5,000 feet (1,525 meters) MSL are northeasterly at 10 knots across the entire zone. By 20,000 feet (6.1 km) MSL, winds north of 12° S are still northeasterly at 10 knots, but between 12 and 15° S, mean winds become northwesterly, and south of 15° S they turn easterly. Mean speeds at 20,000 feet (6.1 km) MSL range from 10 knots in the north to 20 knots in the south. Above 30,000 feet (9.1 km) MSL, mean winds north of 14° S are 15 knots and range from westerly in the western finger to southerly in the northern finger. Wind directions are westerly across the rest of the zone; speeds increase from 30 knots at 17° S to 50 knots along the zone's southernmost border.

PRECIPITATION. Precipitation increases rapidly as disturbances increase. The highest average amount is 6 inches in October (Figure 4-245), occurring where Amazon moisture enters the zone and in various areas toward the south. The lowest amounts are 4 inches or less over eastern Bolivia/southwestern Brazil and east of roughly 46° W. Extreme monthly amounts range from half the norm during dry years to about twice the norm during exceptionally wet years. Fronts are the most important disturbance. Shower intensities are normally moderate in the north and moderate to heavy elsewhere; flash floods are possible. Shallow air masses that can't pass over elevated terrain produce 1-2 days of drizzle along exposed slopes about 5 times a month. Precipitation can also be caused or enhanced by convective heating and upslope flow. Convective cells form from differential heating along cloud-mass fringes. Land/sea breezes can contribute to precipitation along the coast. The zone's rare snow and freezing precipitation only occurs in extreme southern mountains.

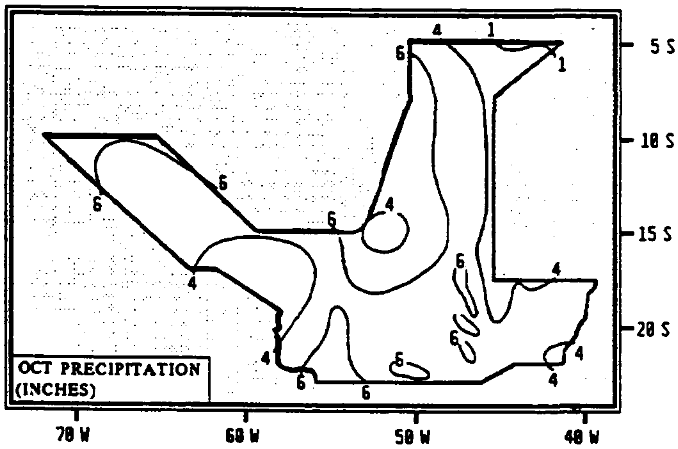
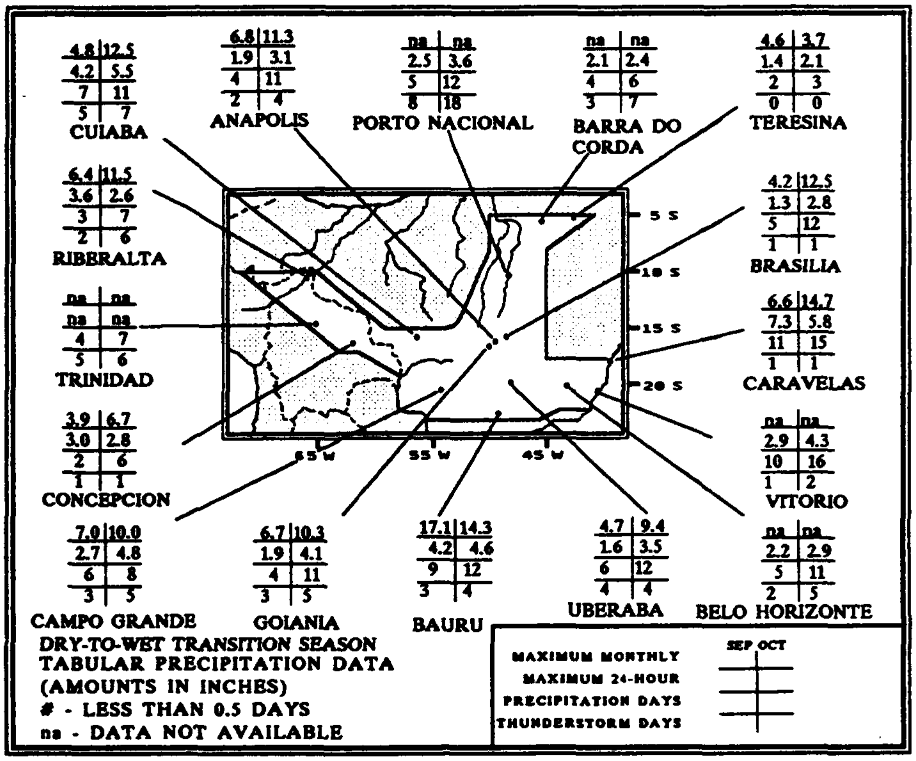


Figure 4-245. Mean October Precipitation, Brazilian Plateau.

Maximum 24-hour precipitation amounts, shown in Figure 4-246, range from 2.1 inches (53 mm) at Teresina in the extreme north to more than 10 inches (254 mm) in the zone's southern mountains. Precipitation days increase through the season, ranging from 3 to 8 in the western finger and extreme north to peaks of 9 to 16 along the coast.



Station	Element	Sep	Oct
Cuiaba	Maximum monthly	4.8	12.5
	Maximum 24-hour	4.2	5.5
	Precipitation days	7	11
	Thunderstorm days	5	7
Anapolis	Maximum monthly	6.8	11.3
	Maximum 24-hour	1.9	3.1
	Precipitation days	4	11
	Thunderstorm days	2	4
Porto Nacional	Maximum monthly	na	na
	Maximum 24-hour	2.5	3.6
	Precipitation days	5	12
	Thunderstorm days	8	18
Barra do Corda	Maximum monthly	na	na
	Maximum 24-hour	2.1	2.4
	Precipitation days	4	6
	Thunderstorm days	3	7
Teresina	Maximum monthly	4.6	3.7
	Maximum 24-hour	1.4	2.1
	Precipitation days	2	3
	Thunderstorm days	0	0
Riberalta	Maximum monthly	6.4	11.5
	Maximum 24-hour	3.6	2.6
	Precipitation days	3	7
	Thunderstorm days	2	6
Brasilia	Maximum monthly	4.2	12.5
	Maximum 24-hour	1.3	2.8
	Precipitation days	5	12
	Thunderstorm days	1	1
Trinidad	Maximum monthly	na	na
	Maximum 24-hour	na	na
	Precipitation days	4	7
	Thunderstorm days	5	6
Caravelas	Maximum monthly	6.6	14.7
	Maximum 24-hour	7.3	5.8
	Precipitation days	11	15
	Thunderstorm days	1	1
Concepcion	Maximum monthly	3.9	6.7
	Maximum 24-hour	3.0	2.8
	Precipitation days	2	6
	Thunderstorm days	1	1
Vitorio	Maximum monthly	na	na
	Maximum 24-hour	2.9	4.3
	Precipitation days	10	16
	Thunderstorm days	1	2
Campo Grande	Maximum monthly	7.0	10.0
	Maximum 24-hour	2.7	4.8
	Precipitation days	6	8
	Thunderstorm days	3	5
Goiania	Maximum monthly	6.7	10.3
	Maximum 24-hour	1.9	4.1
	Precipitation days	4	11
	Thunderstorm days	3	5
Bauru	Maximum monthly	17.1	14.3
	Maximum 24-hour	4.2	4.6
	Precipitation days	9	12
	Thunderstorm days	3	4
Uberaba	Maximum monthly	4.7	9.4
	Maximum 24-hour	1.6	3.5
	Precipitation days	6	12
	Thunderstorm days	4	4
Belo Horizonte	Maximum monthly	na	na
	Maximum 24-hour	2.2	2.9
	Precipitation days	5	11
	Thunderstorm days	2	5

Figure 4-246. Dry-to-Wet Transition Tabular Precipitation Data, Brazilian Plateau.

THUNDERSTORMS. Thunderstorms are most common initially over higher areas; the coast is the last part of the zone to see an increase in activity. Transition thunderstorms are similar to those of the wet season, but they are more organized and severe. Most occur along northwest-southeast oriented cold fronts/shear lines, often forming solid lines. They produce moderate to heavy showers and can cause 50-knot gusts, tornados, and rare hail at high elevations. Most severe cells occur in the zone's central section and western finger. Cells in the northern and coastal fingers can cause 40 knot gusts; very rarely, tornados or hail. Thunderstorm-associated middle and high clouds can produce light to moderate rainfall. Unlike those in the mid-latitudes, these clouds may trail behind the thunderstorm cores. Propagation is either along disturbances or toward thunderstorm outflow. Channeling of outflow through valleys or other depressions can cause cells to form in unexpected directions. Orographic lift, slope winds, and a high Sun angle contribute to thunderstorm development. The occasional air-mass cell is short-lived, slow-moving or stationary, and does not cause severe weather.

Thunderstorm bases range from 1,000 to 3,000 feet (305 to 915 meters) MSL; tops range from 30,000 feet (9.1 km) MSL along the zone's northernmost border to more than 45,000 feet (13.7 km) MSL in the central section and the western finger. Thunderstorms are most common at Porto Nacional, where they occur on 18 days in October (Figure 4-246). Similar frequencies occur over mountainous areas. The other stations have less than 10 thunderstorm days a month. The fewest are on the coast; there are only 2 thunderstorm days at Vitorio in October.

TEMPERATURES. Temperatures are controlled by changing air masses, surface albedo (vegetation), elevation, and moisture. Frequent cold fronts, preceded by warm, moist air and followed by rapid cooling and drying, cause significant daily variations. Mean highs and lows are given in Figure 4-247.

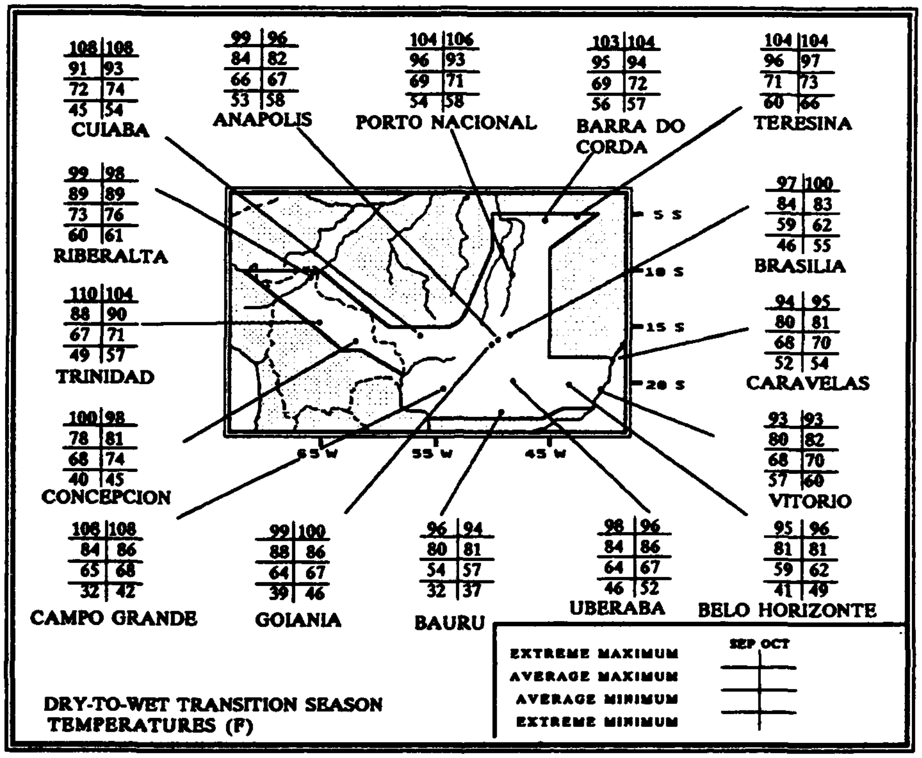


Figure 4-247. Dry-to-Wet Transition Tabular Temperature Data, Brazilian Plateau.

The zone's high temperatures depend mostly on insolation amounts, elevation, adiabatic warming, and warm-air flow north of fronts. The highest recorded temperature is 118° F (48° C), at San Joaquin. in the west. The relative lack of moisture is also important since it results in low evaporative cooling. Downslope westerly flow ahead of cold fronts causes the east coast's highest temperatures and lowest relative humidities. Onshore flow causes mild temperatures and high relative humidities near the coast.

Cold fronts produce the lowest temperatures under clear skies within air masses that move deep into the Amazon Basin. Most cause falls of less than 5° F (3° C), but in extreme cases, temperatures have dropped as much as 15° F (8° C). A few days of abnormally low temperatures follow. The lowest temperature on record is 27° F (-3° C) at Pocos De Caldas (the zone's highest station. located in the southeastern highlands.).

The coast has the zone's highest mean relative humidities; they range from afternoon lows of 65-71% to morning highs around 90%. Mean RHs are also high in the zone's western finger, where they range from afternoon lows of 55-68% to morning highs of 80-95%. Elsewhere, RHs range from afternoon lows of 47 to 54% to morning highs of 65 to 88%. Figure 4-248 shows nine stations with wet-bulb globe temperature data (° F) at specific hours in October.

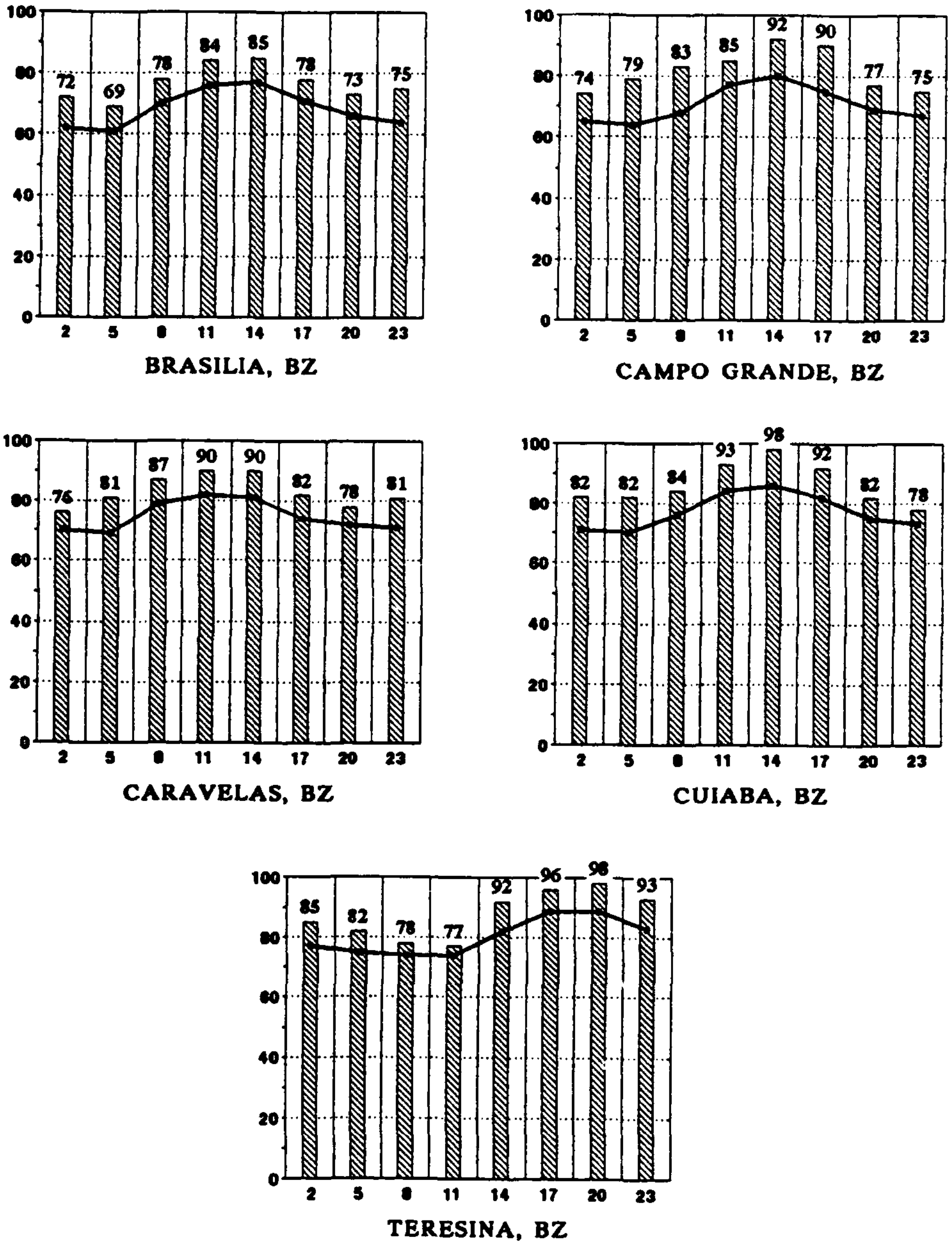


Figure 4-248. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Brazilian Plateau. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms become the most important hazard by season's end. They can be embedded in other clouds or form unnavigable lines along disturbances. Hail, tornado activity, and low-level wind shear are associated with them, especially in the zone's central section and western finger. Thunderstorms can cause moderate to severe turbulence from the surface through 20,000 feet (6.1 km) MSL. Most turbulence occurs during the day; it can be thermal or mechanical, or it can be associated with thunderstorms. Light thermal turbulence can occur through 10,000 feet (3,050 meters) MSL; it occasionally reaches moderate intensity through 5,000 feet (1,525 meters) MSL. Most mechanical turbulence occurs over southeastern mountains, reaching moderate to occasionally severe intensities.

Most icing ranges from the freezing level (normally at 15,000-16,000 feet/4,570-4,880 meters MSL), to 25,000 feet (7.6 km) MSL, but it can reach 30,000 feet (9.1 km). Severe clear and mixed icing are common in cumuliform clouds.

September haze often reduces flight visibilities below 1 mile, obscuring terrain and cumuliform cells. The coast is affected the least. Morning haze becomes trapped beneath radiation inversions, often reducing visibilities below 1 mile through several hundred feet AGL. Haze-associated visibilities are even lower aloft than on the ground. Haze aloft is thickest between 5,000 and 15,000 feet (1,525 and 4,570 meters) MSL, where reductions below 1/4 mile are possible. Maximum haze tops range from 15,000 feet (4,570 meters) MSL in the southeast to 25,000 feet (7.6 km) MSL in the west. Its importance depends more on disturbance frequencies than on the amount of burning taking place. Disturbances can remove the haze for 1 or 2 days; as they become more common in November, haze becomes less of a problem.

GROUND HAZARDS. Flash floods occur most often in the southeastern mountains. Rainy spells can make poorly drained areas accumulate water or become muddy for several days after rain ends.

Chapter 5

SUBTROPICAL SOUTH AMERICA

This chapter describes the situation and relief, major climatic controls, and general weather of Subtropical South America, which includes all of Paraguay and Uruguay and portions of Brazil, Bolivia, and Argentina. For this study, Subtropical South America is divided into two "zones of climatic and topographic commonality." These two zones are shown in Figure 5-1 and are discussed in turn.

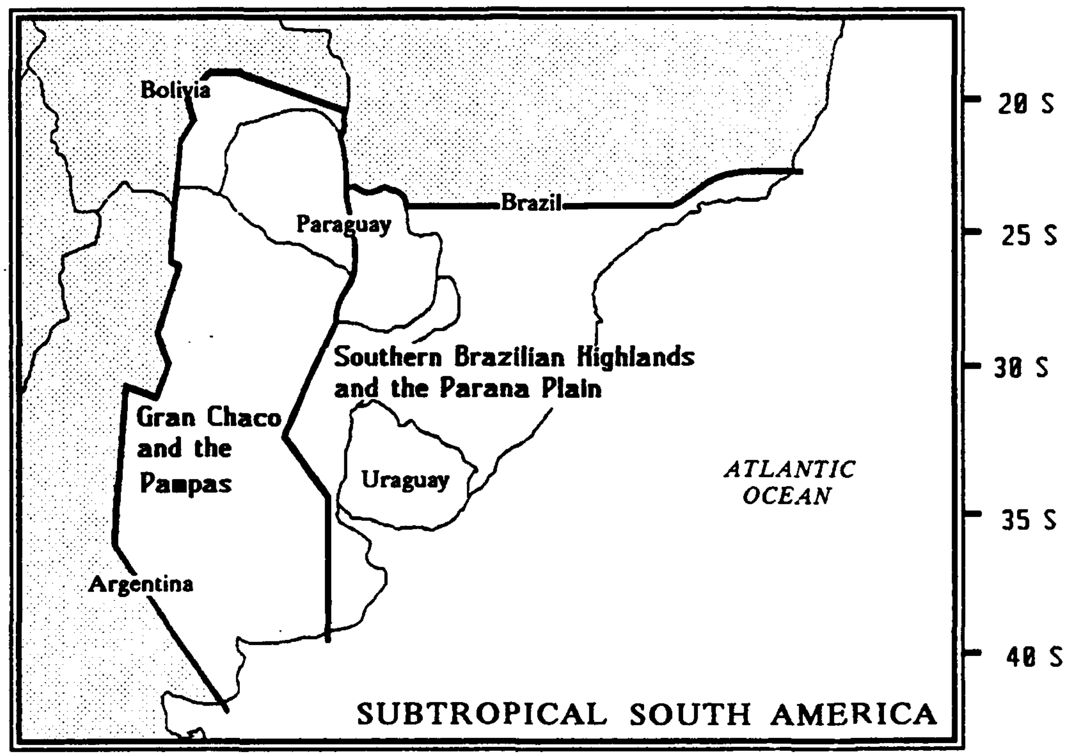


Figure 5-1. Subtropical South America. The region is further divided into two zones, as shown: The Gran Chaco/Pampas and the Southern Brazilian Highlands/Parana Plain.

SUBTROPICAL SOUTH AMERICA

SITUATION AND RELIEF. Subtropical South America, as shown in Figure 5-1, straddles the Tropic of Capricorn from the Central Highlands to the Patagonian Desert. Physical features include saltpans and sandbars, mountains and marshes, falls and lagoons, and an impressive estuary. The region contains the Gran Chaco, the Pampas, the Southern Brazilian Highlands, and the Parana Plain.

The Gran Chaco. This immense plain in interior south-central South America covers about 280,000 square miles. It is bounded on the west by the Andes mountains and on the east by the Paraguay and Parana rivers. The northern boundary extends to southeastern Bolivia while the southern boundary lies near Rio Salado in Argentina.

The Pampas. This feature, considered by some to be the richest farmland in the world, is bordered on the west by the Andes mountains, on the north by the Gran Chaco, on the east by the Parana River, and on the south by the Negro River. Situated in central Argentina, the Pampas covers approximately 294,000 square miles.

The Southern Brazilian Highlands. This area of hilly terrain with low mountains stretches across southern Brazil from the Atlantic Ocean to the eastern borders of Paraguay and Argentina. The Central Plains of Brazil delineates the northern boundary; the Uruguay border marks the southern border.

The Parana Plain is an area of transition from the Southern Brazilian Highlands in the east to the Paraguay and Parana river lowlands in the west. The plain slopes westward from the Highlands, with its low rolling hills and occasional ridges, to the wide plains and lowlands of the Chaco and Pampas. Beginning at the northern border of Paraguay, the Parana Plain extends southward through Buenos Aires to Necochea. The Upper Parana River valley dominates the northern sector, with an area of Argentina known as Mesopotamia (Greek for "middle river") in the middle.

Some other major physical features of this region are the Iguazu Falls on the Brazil Argentina border, Lagoa dos Patos near the southeast coast of Brazil, and Mirim Lake at the southern Brazil/Uruguay border. One of the world's greatest ports, Buenos Aires, is on the Rio de la Plata, an estuary that drains the Paraguay and Uruguay River systems.

MAJOR CLIMATIC CONTROLS.

The Northwest Argentine Depression (NAD) is a semipermanent low-pressure area created by topography and intense surface heating. The Andes Mountains block low-level flow and allow advection of hot, moist air from the northwest. Channeling between the Andes and the foothills to the east enhances advection. The NAD's center is generally found east of the Andes at about 29° S, 66° W, over high, dry terrain. The NAD's presence is intermittent and its depth variable. It weakens with height, but normally extends to 850-700 mb. It is intense and persistent during the summer; central pressure is as low as 980 mb. During winter, the NAD behaves like a leeside trough; its circulation enhances the easterly flow of warm, moist, and unstable air from the South Atlantic onto the continent as far west as the Andes.

The Zonda (a warm, dry downslope wind similar to a foehn or chinook) may contribute to NAD intensification. The Zonda usually develops between May and November in western Argentina (at 33° S, 69° W) with a warm, dry air mass. It is preceded by an approaching trough or cyclone from the west that creates orographic lift on the western slopes of the Andes. Air flows over and down the eastern slopes as local terrain funnels it into valleys. Maximum speeds occur between 800 and 850 mb. Surface wind speeds frequently exceed 30 knots, and 110-knot winds have occurred in the high mountain ranges to the west of Mendoza.

The Argentine Continental High is a mean wintertime surface feature that occurs with the periodic influx of cold air into the South American interior. It is cold-core and baroclinic, and is generally centered at 34° S, 64° W with an average pressure of 1018 mb. It establishes itself after a frontal passage; the interval between polar surges determines its duration. The Argentine High decreases and re-routes flow from the South Atlantic High. During winter, subsidence from the South Pacific High ridges over the continent and sometimes develops a temporary, shallow high-pressure center, with or without the Argentine High.

5.1 GRAN CHACO/PAMPAS

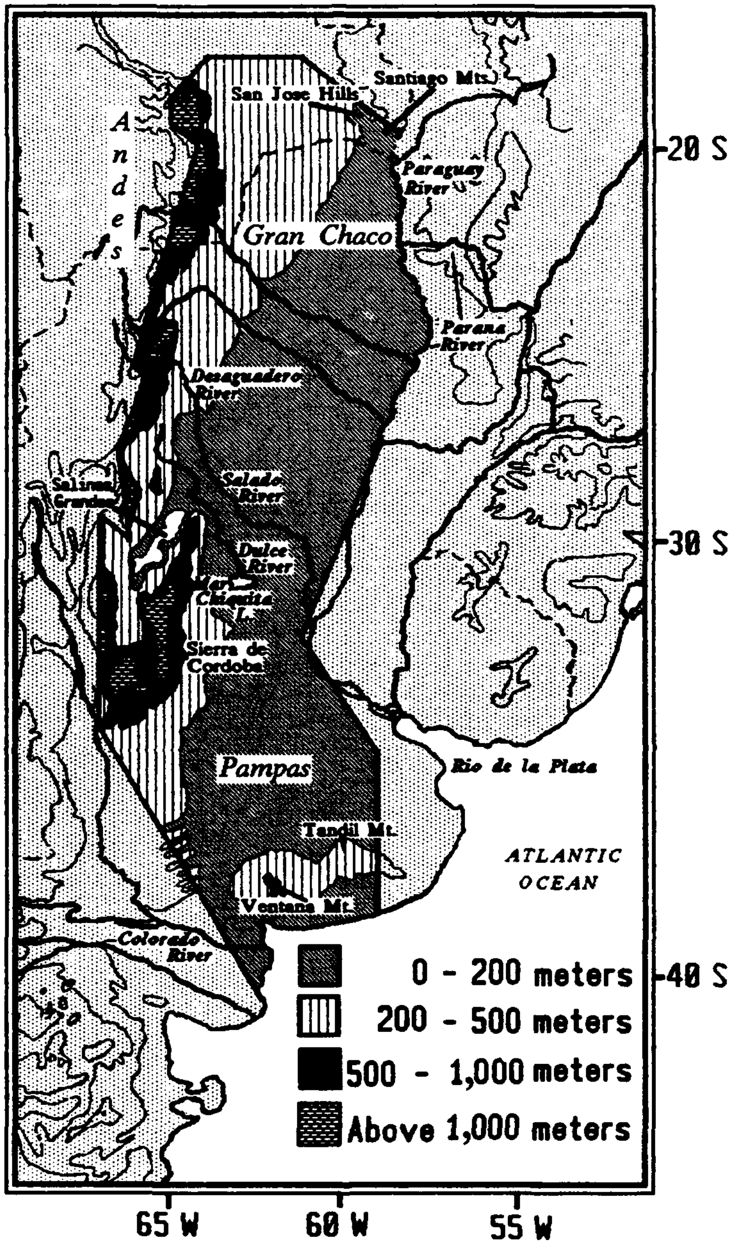
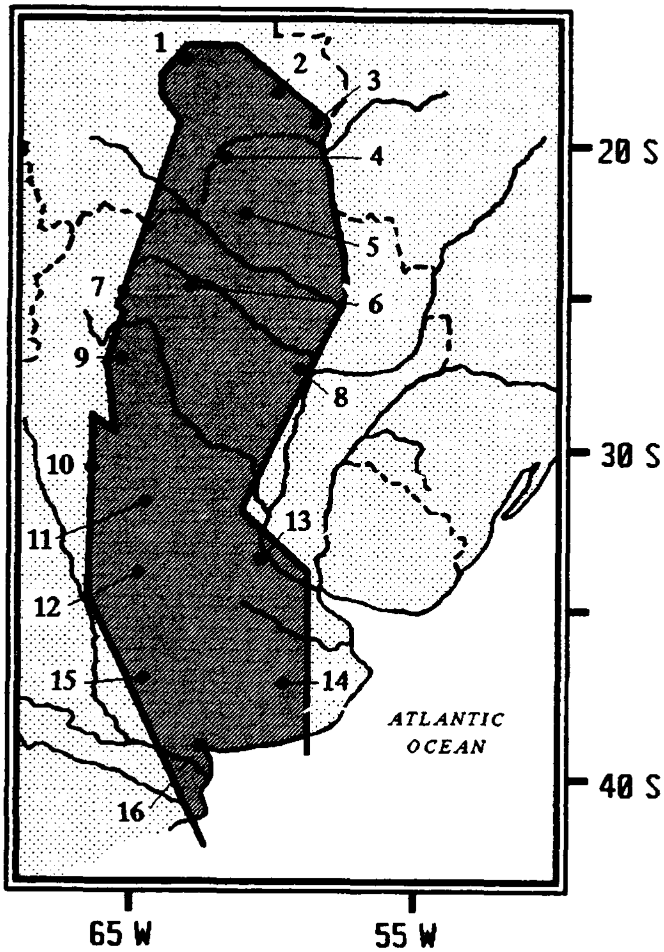


Figure 5-2. Gran Chaco/Pampas. As shown, this area covers most of southeastern Bolivia, western Paraguay, and much of northern Argentina. The Gran Chacos is in the north, the Pampas in the south. Most of the area lies below 500 meters.



	ELEVATION (FEET)
1. SANTA CRUZ	1,328
2. ROBORE	911
3. PUERTO SUAREZ	433
4. NUEVA ASUNCION	1,010
5. MARISCAL ESTIGARRIBIA	580
6. RIVADAVIA	658
7. SALTA	3,900
8. RESISTENCIA	167
9. TUCUMAN	1,444
10. LA RIOJA	1,376
11. CORDOBA	1,521
12. RIO CUARTO	1,351
13. ROSARIO	80
14. AZUL	423
15. SANTA ROSA	613
16. BAHIA BLANCA	266

Figure 5-3. Climatic Station Network, Gran Chaco/Pampas.

GRAN CHACO/PAMPAS GEOGRAPHY

BOUNDARIES. The zone is bounded:

On the north: by a line eastward from 17° S, 64° W, following the San Jose hills and Santiago mountains to the Bolivia-Brazil border at about 19° S, 58° W.

On the east: by the Bolivia-Brazil border south to Paraguay, continuing along the Paraguay-Brazil border to Puerto Sastre at 22° S, 58° W. The boundary then follows the Paraguay and Parana rivers from Puerto Sastre to just west of Buenos Aires at 35° S, 59° W. From 35° S, 59° W, it continues south along the 59th meridian to Necochea at 39° S, 59° W.

On the south: by the Atlantic coast to about 41° S, 62° W.

On the west: by a line from 41° S, 62° W, northwestward to 34° S, 67° W, then north to 30° S. From there, the border meanders north-northeastward along the Andes to about 26° S, 66° W. The border then stretches north-northeast to 20° S, 64° W before turning northwest along the Andes and arcing northeast to 17° S, 64° W.

TERRAIN. The zone is mainly level alluvial plains that stretch eastward from the base of the Andes. Most elevations range from less than 650 feet (200 meters) in the west to sea level in the east. The zone's highest peak (9,462 feet 2,886 meters) is in the Sierra De Cordoba, in the southwest. Small mountain ridges in the southeast include the Tandil (1,781 feet/543 meters) and Ventana (4,078 feet/1,244 meters) mountains. Soil types range from deep sandy, silty sediments in the north to sandy hills and fertile prairies in the south; there are marshy lowlands along rivers in the north and near the zone's eastern fringes.

WATERWAYS AND DRAINAGE. There are four major rivers. The Pilcomayo and Bermejo (Teuco) originate in the Andes and flow eastward to the Paraguay and Parana Rivers. The Colorado and Negro Rivers cross the zone's southern half from the Andes to the Atlantic. Other small streams and rivers begin along the Andes, such as the Dulce River, which drains into Mar Chiquita lagoon northeast of Cordoba. Northwest of the Sierra De Cordoba (between Tucuman and Cordoba) is the Salinas Grandes, a saltpan that includes sandbars and vast swamplands. This area floods rapidly every rainy season, but most of the water is lost to seepage and evaporation. Some major northern and eastern rivers also maintain marshland.

VEGETATION. Vegetation ranges from semiarid types in the west to tall savanna grasses and forests in the east. Thorny shrubs, low trees, cactus, thistles, and patchy tall grasses dominate the west. Agriculture has taken over much of the Argentine savannas in the east, while forestry is important in much of Paraguay. Patchy forests also grow near major Argentine rivers in the east. Marshes are found along major rivers in the north and east.

GENERAL WEATHER. Northerly flow from the the South Atlantic High to the Northwest Argentine Depression (NAD) brings very moist, unstable air from the Amazon Basin, the primary summer moisture source. Amazon moisture is greatest in the mid-levels since high terrain to the north tends to dry incoming low-level air. Low-level easterly flow from the Atlantic occasionally advect moisture into the zone's southern part. The Parana River also acts as a local moisture source.

Disturbances range from frontal systems upper-air troughs to squall lines and Mesoscale Convective Systems (MCSs). Frontogenesis occurs in central to western Argentina between 25 and 40° S about once every 4 days. The resulting cold fronts normally strengthen as they move northeastward; many may enter Paraguay but few go beyond the zone's northern border. As a result, cold fronts have their greatest effect in the eastern half of the zone between 20 and 35° S. Associated weather is usually confined to a narrow band either along the front or ahead of it as a squall line; there is little or no post-frontal weather. The term "cold front" is often misleading in summer since the invading air mass is sometimes modified by terrain to become as warm, and on rare occasions, warmer than the air mass it replaces.

True cold outbreaks often result in cold south or southwest winds over the pampas, known as "pamperos." Pampero weather is similar to strong late spring polar outbreaks in midwestern North America. They occur most often from October through December and result from a strong cold-air outbreak that crosses the southern Andes or southern Argentina and drives through the Pampas. Northwesterly surface winds preceding pamperos are often associated with foehns (locally called "zondas") and are consequently warm and dry. Since most moisture is in the mid-levels, Pampero-associated clouds often have high bases that range from 6,000 to 10,000 feet (1,830 to 3,050 meters) MSL; tops reach 40,000 feet (12.2 km) MSL.

Pamperos can take the form of severe squall lines when they meet warm, moist air from the north in the afternoon. Such lines have solid thunderstorm coverage along or ahead of the front. Cloud bases are much lower in these cases, especially toward the zone's north and east. Stormy conditions last for 2 to 3 hours, but then skies clear rapidly. Strong northwesterly to northerly winds signal the approach of the strongest pamperos. They are followed by strong southerly winds, rapidly falling temperatures, and occasional blowing dust. Frontal lows do not normally accompany pamperos.

Frontal lows occur along some cold fronts in December and, on rare occasion, in January and February. Cyclogenesis is most common south of the zone and just east of the zone south of 25° S. Strong lows can produce high winds and thunderstorms along the eastern fringes. Strong southeasterly flow southwest of lows can advect moist Atlantic air into the zone; low stratus, fog, and occasional light rain or drizzle results.

Upper-level troughs can cause widespread cloudiness and precipitation. Most produce thunderstorms and some are accompanied by clear-air turbulence. Strong troughs can produce squall-lines. Occasionally, deep troughs that stagnate west of the Andes produce repeated weak eastward-moving troughs .

Squall lines, like frontal waves, are common in summer, particularly in December. Most are pre-frontal, but some occur out ahead of strong upper-level troughs. Squall lines give the zone's eastern fringes some of the most severe thunderstorms in all of South America. Characteristics and intensities are similar to those of the United States midwest. Pre-frontal squall lines often form solid lines of thunderstorms; activity along the front itself is drastically reduced.

Mesoscale Convective Systems (MCSs) are common in summer. Like squall lines, their characteristics and intensities are similar to those of the United States midwest. They usually occur at night, associated with persistent localized convergence caused by smaller thunderstorm clusters. Once such convergence is established, thunderstorm clusters form repeatedly for several days; some of these grow into MCSs, most of which move northward. They often cause heavy showers and can produce severe thunderstorms, especially in the early stages of development. Flash flooding may result.

Foehns occurring along the Andes slopes are referred to locally as "zondas." Wind speeds can rival those of the lee slopes of the Rockies. Zondas have the most effect in the southwest during winter, but they can occur in any season. Winds range from westerly to northerly and are very warm and dry; temperatures can increase more than 50° F (28° C) and relative humidities can fall to less than 10%. Unlike foehns in some parts of the world, zondas can cause abnormally turbulent air and duststorms. The duststorms normally don't cause low visibilities for more than a few hours, but the dust can remain suspended for a few days, preventing "good" visibilities.

SKY COVER. Cloud cover is greatest in summer. Coverage is greater in the north than in the south, ranging from 80% at Robore to 50% at Bahia Blanca (see Figure 5-4). This distribution shows the effects of moisture advected into the zone from the Amazon Basin as well as upslope flow along the Andes. Cloud cover is most extensive during the afternoon when well-developed convective cells form; average bases range from around 6,000 feet (1,830 meters) MSL in the north to 10,000 feet (3,050 meters) MSL in the southwest; tops exceed 20,000 feet (6,100 meters) MSL. Air-mass thunderstorms and cells occurring along some fronts have similar bases, but the bases of cumulonimbus along many disturbances can be as low as 1,000 feet (305 meters) MSL, especially in the north and east; cumulonimbus tops often exceed 50,000 feet (15.2 km) MSL. Stratus and stratocumulus with bases around 2,000 feet (610 meters) MSL occur occasionally, most often along the coast and over the interior lowlands during mornings. They form after heavy rains or when a frontal low causes low-level flow south of the front to be off the Atlantic.

Cloud amounts and types associated with summer cold fronts depend on frontal strength. Most weak cold fronts are accompanied by scattered to broken cumulus and scattered cumulonimbus. These are immediately followed by a narrow band of stratocumulus and altocumulus, then clear skies. Strong fronts can be accompanied or preceded by one or more solid lines of cumulonimbus. They are followed by altostratus and cirrostratus, then rapid clearing. Early season frontal waves cause an increase in coverage of these cloud patterns and contribute to the stratus and stratocumulus discussed in the previous paragraph.

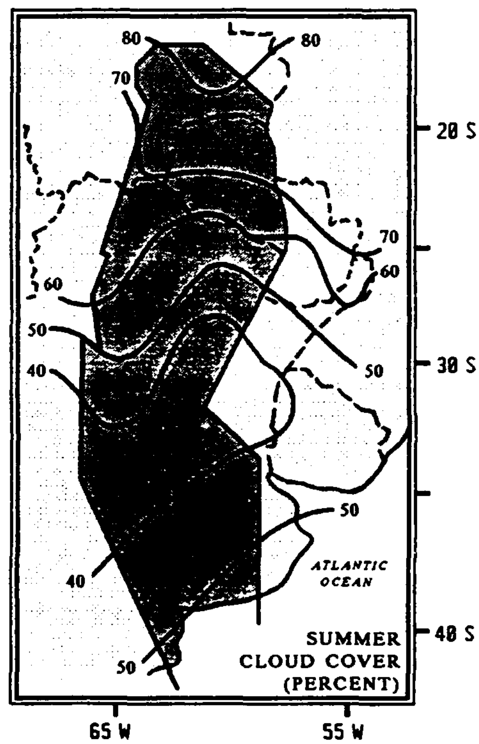


Figure 5-4. Mean Summer Cloud Cover, Gran Chaco/Pampas.

Frequencies of ceilings below 3,000 feet (915 meters) AGL are highest during late afternoon and early evening (see Figure 5-5). They range from 10% in the south to nearly 60% in the extreme north. Upslope flow produces slightly higher frequencies along the Andes foothills than in areas nearby. Ceilings below 3,000 feet (915 meters) AGL occur least often at night, with frequencies ranging from less than 5% in the south to more than 25% in the north.

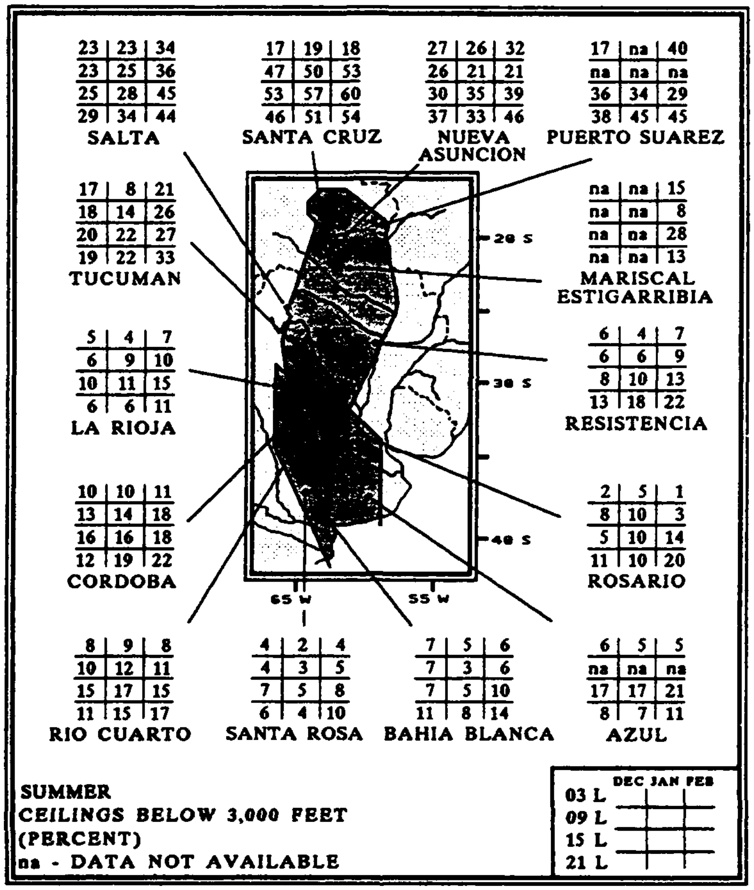


Figure 5-5. Summer Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Gran Chaco/Pampas.

VISIBILITY. Visibilities are good year-round, but best in summer. At most places, the frequency of visibilities below 3 miles is slightly higher in the morning (10%) than in the afternoon (5%)--see Figure 5-6.

Fog and precipitation are the primary visibility restrictions. Morning fog usually occurs in low areas after heavy rains or after frontal lows have brought in low-level moisture from the Atlantic. Radiation fog lifts or dissipates by noon. Extended periods of poor visibility are rare, occurring only with precipitation along slow-moving fronts. Afternoon convective showers occasionally lower visibility briefly. Thunderstorms can drop visibilities below 1 mile. Cold fronts and thunderstorms sometimes raise dust in the southwest, but visibilities are rarely reduced significantly or for very long.

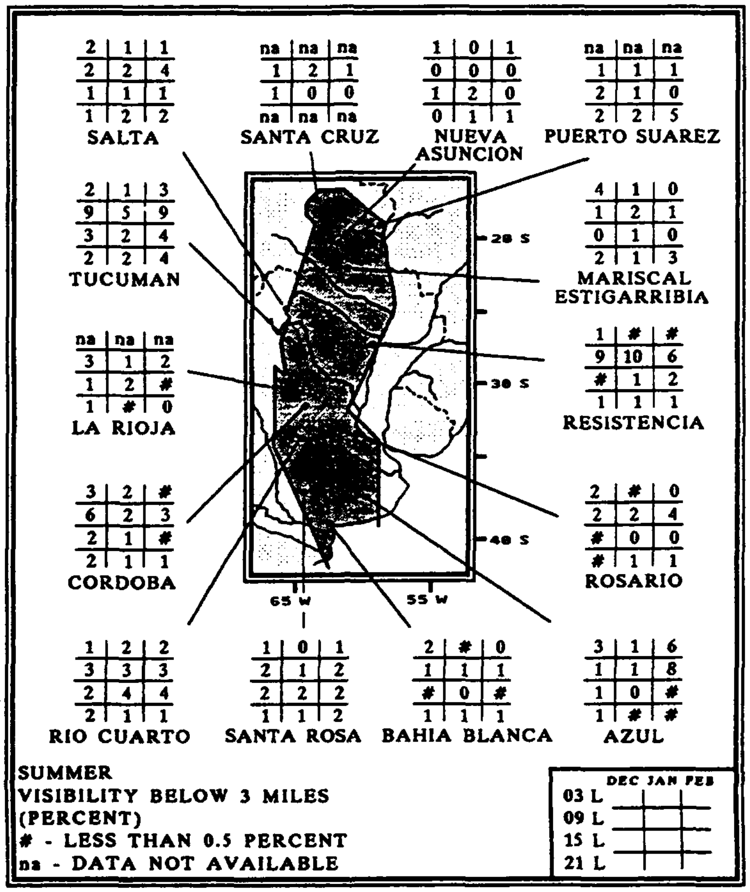


Figure 5-6. Summer Percent Frequencies of Visibility Below 3 Miles, Gran Chaco/Pampas.

WINDS. Surface winds are strongly influenced by the Northwest Argentine Depression (NAD). The southern displacement of the NAD during summer causes north-northwesterly to northerly winds in the zone's northwest; elsewhere, prevailing winds are northeasterly through easterly. Only near La Rioja, southwest of the NAD, are winds consistently from the south (see Figure 5-7). There are land and sea breezes on the coast. Bahia Blanca, for example, has a 10-knot land breeze at night that increases to nearly 15 knots by mid-morning; it is replaced by a 10 to 15 knot sea breeze in late afternoon and early evening. Morning coastal wind speeds range from less than 5 knots centrally to nearly 10 knots in the south and extreme north. Afternoon speeds are 5 to 10 knots centrally and 10 to 15 knots in the south and extreme north. Afternoon gusts are 15 to 20 knots at most locations, but they are 25 knots near Santa Cruz and Bahia Blanca. See Figure 5-8 for surface wind speeds.

Frontal systems are preceded by north to northwesterly winds and followed by south to southwesterly winds. Early season frontal waves can cause strong southeasterly post-frontal winds. Frontal systems and squall lines/thunderstorms can produce gusts over 50 knots; Argentine sources claim that gusts over 80 knots have occurred. A maximum surface wind speed of 62 knots from the northwest was recorded at Bahia Blanca during January.

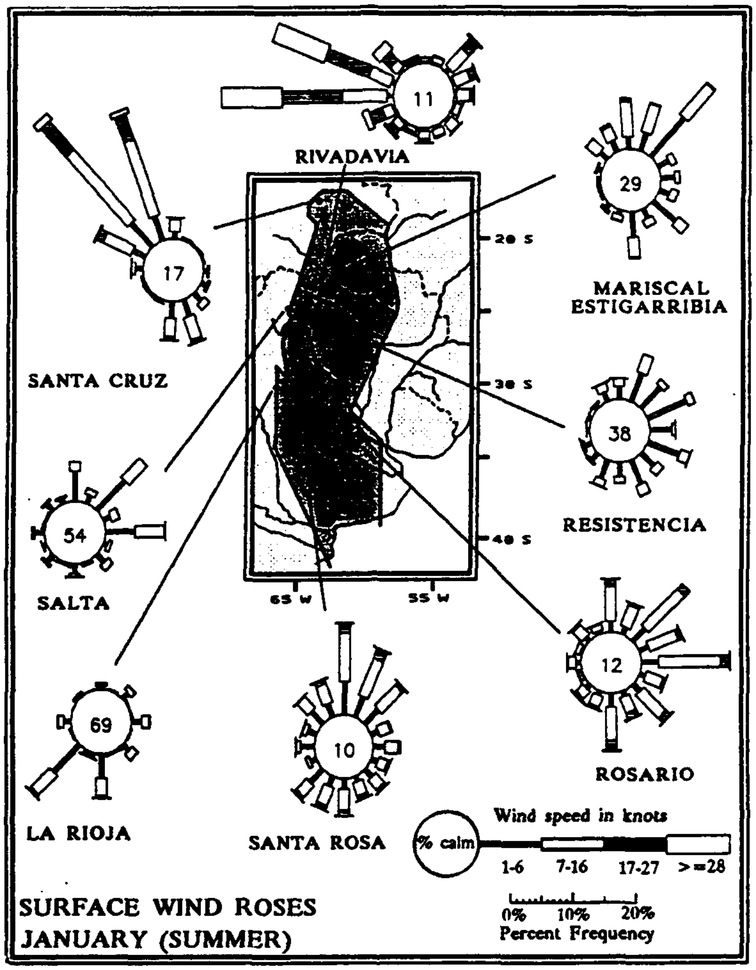


Figure 5-7. January Surface Wind Roses, Gran Chaco/Pampas.

STATION	MEAN WIND SPEED DEC	JAN	FEB	STATION	MEAN WIND SPEED DEC	JAN	FEB
AZUL	9	8	8	RIO CUARTO	10	9	9
BAHIA BLANCA	13	15	15	RIVADAVIA	5	4	5
CORDOBA	7	6	6	ROBORE	6	6	5
LA RIOJA	3	2	2	ROSARIO	10	10	9
MARISCAL ESTIGARRIBIA	4	5	4	SALTA	4	3	3
NUEVA ASUNCION	6	7	6	SANTA CRUZ	12	13	12
PUERTO SUAREZ	7	7	6	SANTA ROSA	8	8	8
RESISTENCIA	4	4	3	TUCUMAN	5	5	5

Figure 5-8. Mean Summer Wind Speeds, Gran Chaco/Pampas.

Winds aloft are weakest during summer. Equatorward of 35° S, winds are primarily from the north, averaging 10 knots through 10,000 feet (3,050 meters) MSL. Above 10,000 feet (3,050 meters) MSL, winds are westerly. Speeds increase with altitude, averaging 15 knots at 18,000 feet (5,490 meters) MSL and 35 knots at 30,000 feet (9.1 km) MSL. Poleward of 35° S, winds are westerly at all levels, averaging 15 knots through 10,000 feet (3,050 meters) MSL and 35 knots between 18,000 and 25,000 feet (5.5 and 7.6 km) MSL. Maximum upper-level wind speeds (50 knots) occur at 40,000 feet (12.2 km) MSL. Figures 5-9 and 5-10 give mean monthly wind directions for various levels at Cordoba and Resistencia, Argentina.

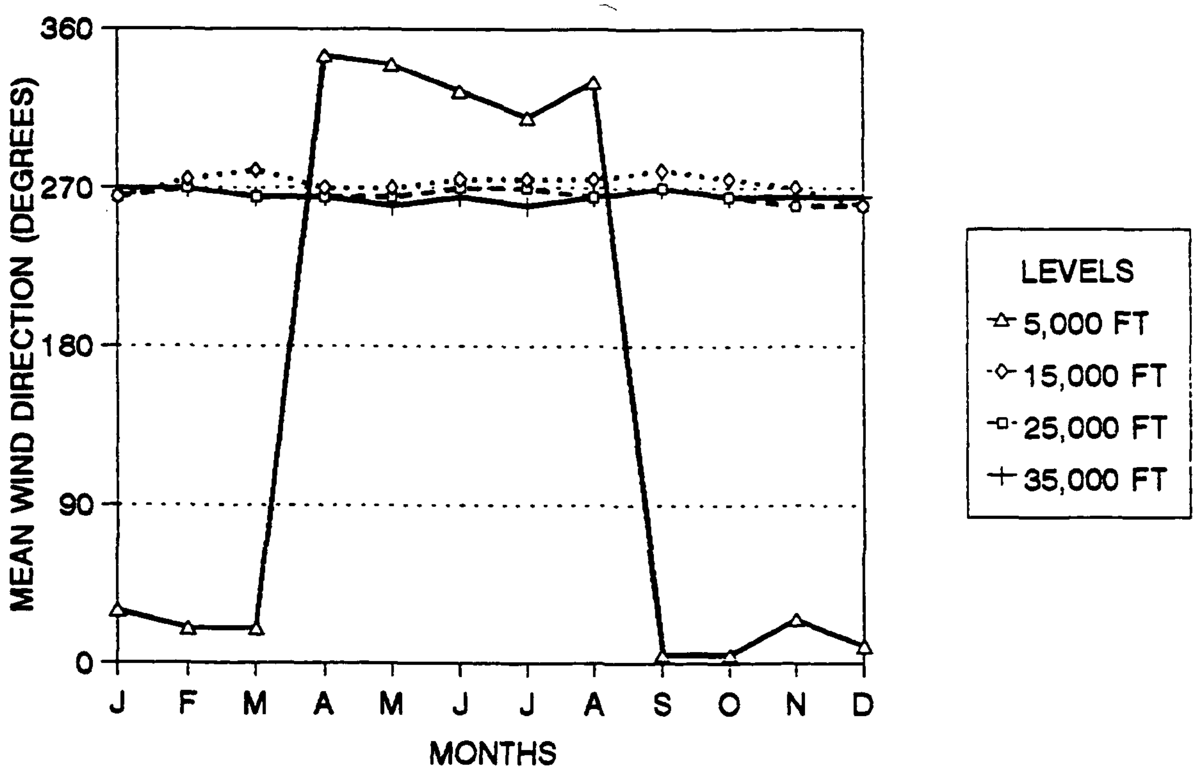


Figure 5-9. Mean Monthly Wind Directions for Various Levels at Cordoba.

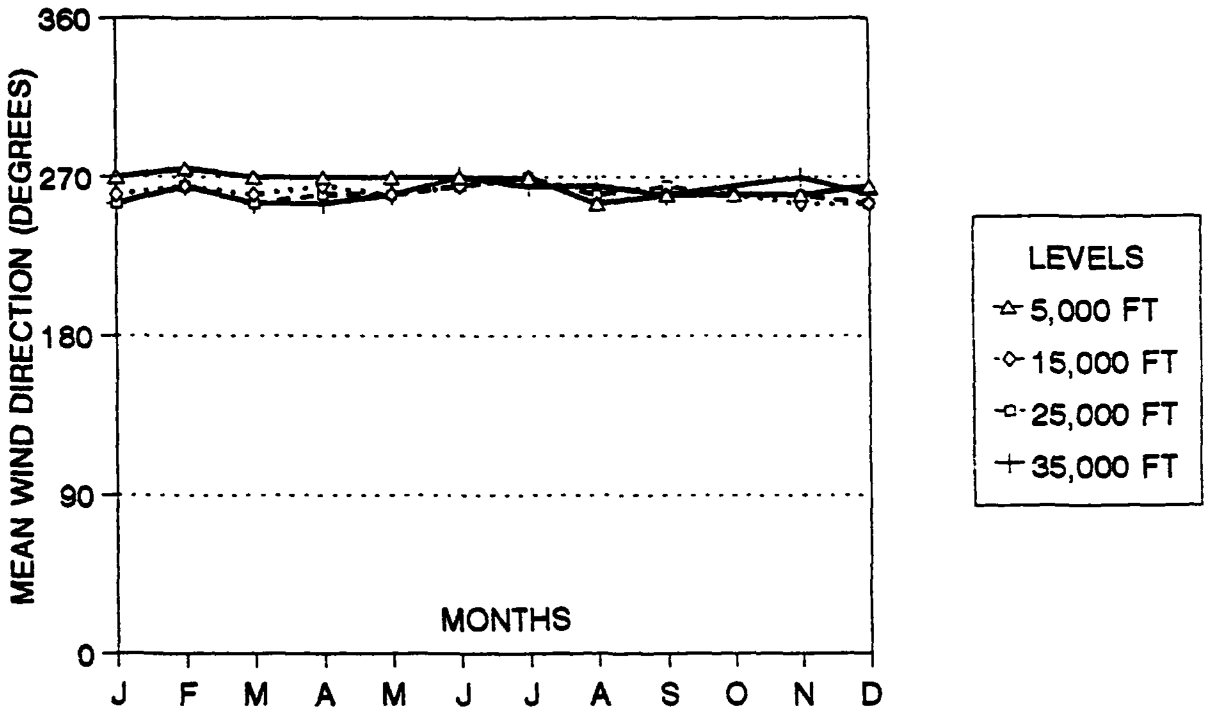


Figure 5-10. Mean Monthly Wind Directions for Various Levels at Resistencia.

PRECIPITATION. Most rain falls as moderate-to-heavy showers along cold fronts and squall lines, and orographically along the Andes. Heavy showers occasionally cause flash floods in narrow mountain valleys and along streams and rivers. Afternoon convective cells add to seasonal rainfall. Virga occasionally occurs with cumuliform cells, especially toward the southwest. Occasional light rain and drizzle are possible south and west of some frontal lows. Annual, seasonal, and monthly precipitation amounts are variable in the southeast. Across the zone, mean monthly amounts range from about 2 inches (50 mm) in the southwest to near 10 inches (255 mm) in the north (see Figure 5-11). Maximum 24-hour rainfalls are highest along the Andes foothills and toward the zone's eastern fringes where fronts are most active. In these areas, 24-hour amounts over 7 inches (175 mm) have been recorded. As shown in Figure 5-12, precipitation occurs on an average of 9 days a month; the highest frequencies occur with orographic lift along the Andes slopes.

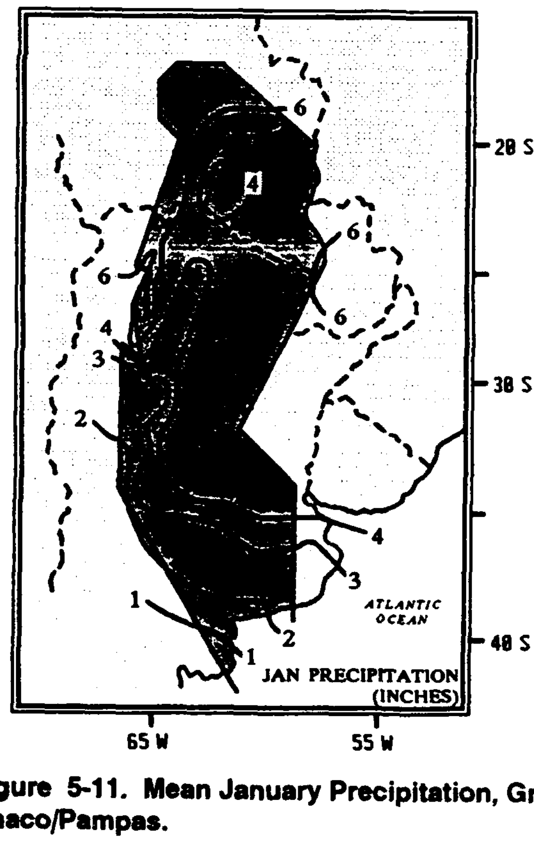


Figure 5-11. Mean January Precipitation, Gran Chaco/Pampas.

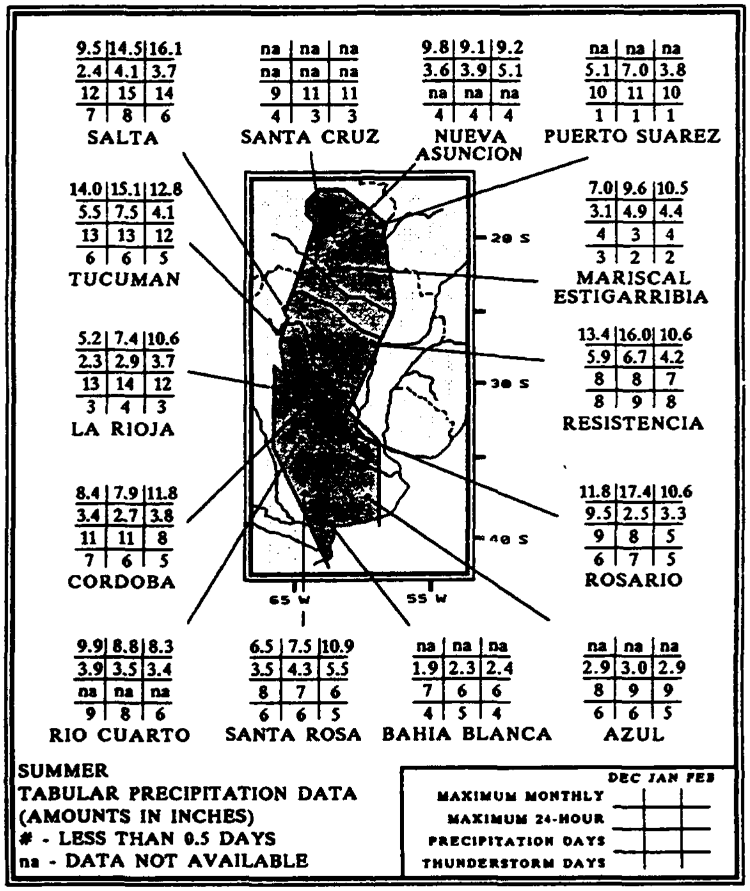


Figure 5-12. Summer Tabular Precipitation Data, Gran Chaco/Pampas.

THUNDERSTORMS. Isolated afternoon thunderstorms are common in the moist, unstable air flowing southward from the Amazon basin. Most thunderstorms occur in two places: (1) near the eastern fringes where frontal activity and MCSs are most common and (2) along the Andes' eastern slopes from La Quiaca to Rio Cuarto where orographic lift is greatest. Some places have about 10 thunderstorm days a month. The extreme north, where there are fewer frontal outbreaks, average 3 days a month. Thunderstorm coverage with disturbances ranges from isolated along weak systems to solid lines along or ahead of strong disturbances. Summer's occasional strong cold fronts are often preceded by squall lines. Summertime frontal thunderstorms can be violent, possibly producing heavy rain, hail, high winds, and tornados. Although hail occurs most often in the Andes foothills, severe thunderstorms are most common in the east.

Most thunderstorm tops are between 40,000 and 50,000 feet (12.2 and 15.2 km) MSL. Bases at 1,000 feet (305 meters) MSL are possible, but bases above 6,000 feet (1,830 meters) MSL are common near the Andes. Downbursts can occur beneath cells with high bases. These cells even occur along occasional cold fronts. On warm summer nights, a phenomenon known locally as "relampagos de calor" (heat lightning, or diffuse flashes of light from distant thunderstorms) is common. Intense, long-lasting, sheet lightning occurs in the north.

TEMPERATURE. The zone's most uncomfortable conditions are in the warm, moist tropical air from the Amazon basin (see the comfort indices for several stations in Figure 5-14). The highest mean annual temperatures occur in the extreme north where Amazon air is most persistent (see Figure 5-13). The zone's average highs range from less than 80° F (27° C) at higher elevations to 93° F (34° C) in Paraguay. Average lows range from 60° F (15° C) or less in higher elevations and in the south to about 80° F (27° C) in Paraguay. Adiabatically warmed air off the Andes result in the highest temperatures; 116° F (47° C) was recorded at La Rioja in December. Cold fronts result in summer's lowest temperatures, which can be as low 40° F (22° C) with pamperos. An extreme low of 33° F (1° C) was reported at Santa Rosa in December.

Relative humidities are lowest near the Andes and highest along the coast and in air from the Amazon Basin. Average morning RH is between 65 and 80% at most locations; afternoons average 55%. RHs are abnormally low with the occurrence of pamperos or zondas.

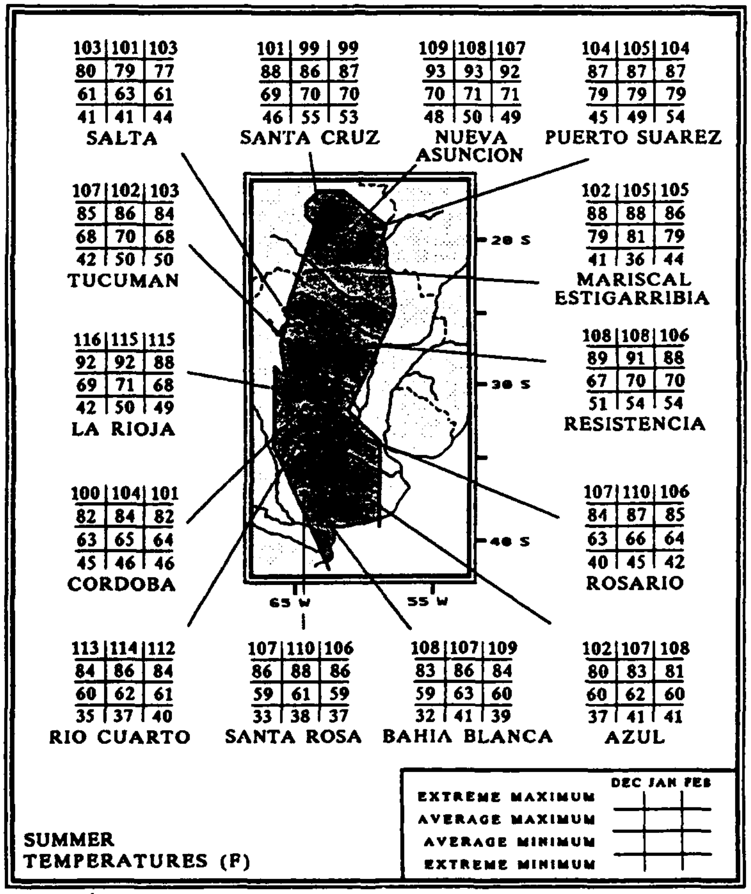


Figure 5-13. Summer Tabular Temperature Data, Gran Chaco/Pampas.

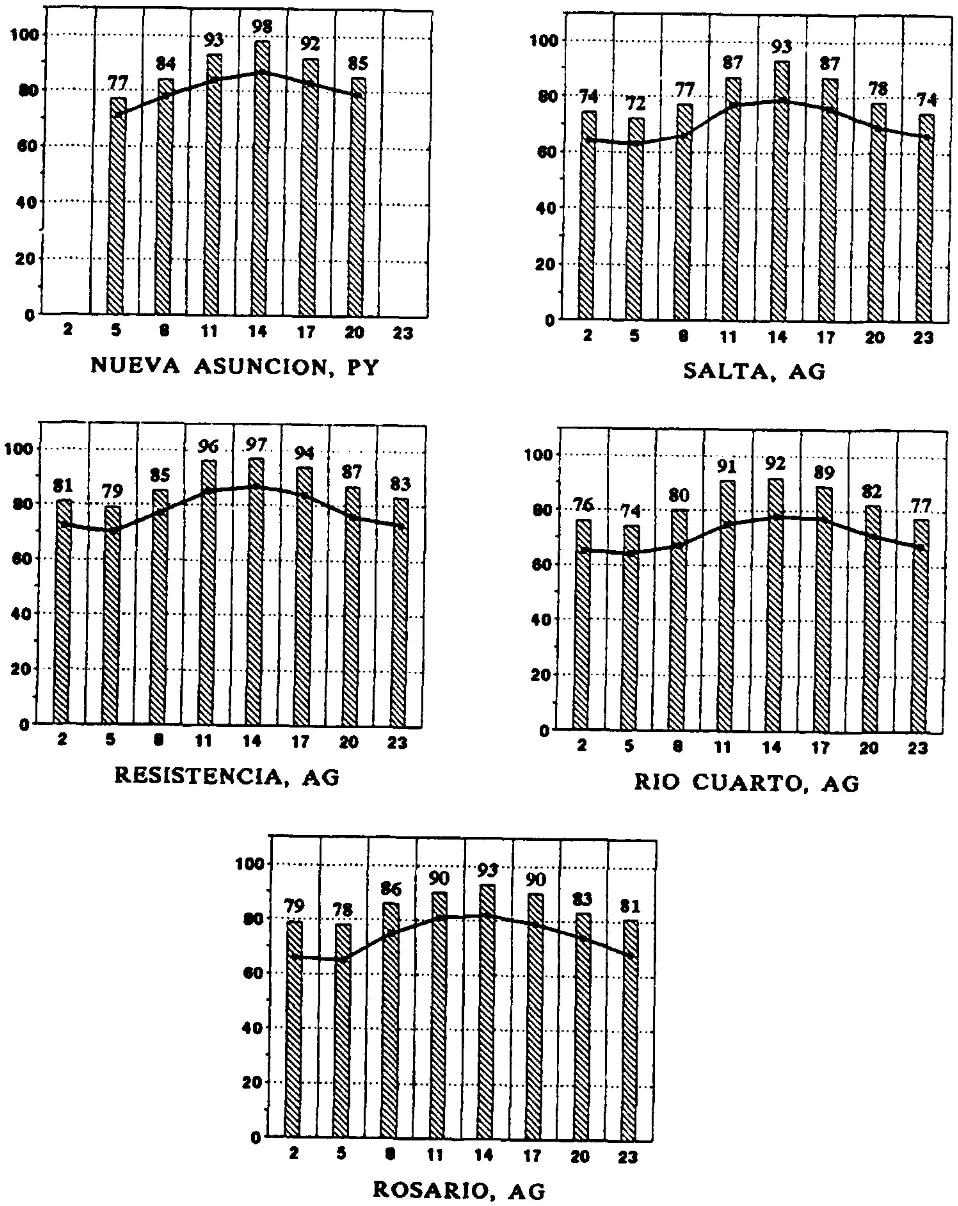


Figure 5-14. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Gran Chaco/Pampas. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Moderate to severe turbulence is common, caused by the Subtropical Jet, mountain waves, thunderstorm activity, intense surface heating, and occasionally, a strong cold front. The Subtropical Jet, found near 33° S at 40,000 feet (12.2 km) MSL, can produce turbulence, especially poleward and above the jet-stream core. Mountain-wave turbulence--possibly severe and often reaching up beyond the tropopause--is common along the Andes' eastern slopes, particularly in the mountains west of Tucuman. Although mountain-wave turbulence can usually be identified by cap, rotor, or lenticular clouds, the air is sometimes too dry for such clouds to form. Moderate to severe turbulence occurs with thunderstorms. Light to moderate low-level turbulence occurs from thermal convective caused by intense solar heating. Moderate turbulence through 10,000 feet (3,050 meters) AGL is rare but possible in the southwest with strong pampero outbreaks.

Moderate to severe mixed icing is primarily associated with intense cold fronts and thunderstorms. The mean height of the freezing level during summer ranges from 13,000 feet (3,960 meters) MSL in the south to 15,000 feet (4,570 meters) MSL in the north. Icing tops range from 25,000 feet (7.6 km) MSL in the south to 30,000 feet (9.1 km) MSL in the north.

GROUND HAZARDS. Moderate to heavy rainshowers occasionally cause flash floods. Considerable river flooding can occur with MCSs. Heavy rain can also cause the ground to remain wet and muddy through several dry, sunny, days; this occurs most often in the northern interior lowlands.

GENERAL WEATHER. Subsidence caused by South Atlantic High ridging over the Amazon Basin confines moisture to an increasingly shallow layer near the surface. Much of this moisture is blocked by the Planalto do Matto Grosso and the Brazilian Highlands, which prevent it from reaching the Gran Chaco/Pampas zone. Moisture is occasionally sufficient for severe weather during strong polar surges. Frontal lows become more common, often bringing in Atlantic moisture with post-frontal southeasterly flow; this is especially characteristic of winter (see "sudestadas" in this zone's "Winter" section). Southeasterly flow becomes increasingly common as the Argentine High develops by season's end.

Cold fronts are less frequent than in summer, averaging one every 6 or 7 days. They are still the most important cause of poor weather, even though many are weak. Pamperos (see this zone's "summer" section) occur only occasionally. Pre-frontal squall lines may occur, generally in early fall; they are common along the zone's eastern fringes between 25 and 35° S, but occur only occasionally elsewhere. Upper-level troughs are similar to those of summer, but poor weather is not as widespread; thunderstorms are less common and usually don't produce squall lines. Frontal lows affect the area occasionally, usually forming along the zone's eastern and southern fringes south of 25° S. They mostly affect the south, causing up to 12 hours of gusty winds, stratus, fog, rain, and drizzle. MCSs are still common, but most move from west to east in fall, often causing heavy showers. They can produce severe thunderstorms, especially during their early stages of development. An MCS at Buenos Aires in May of 1985 produced 11.8 inches (300 mm) of precipitation in 24 hours.

SKY COVER. Cloud cover depends on how much moisture enters the zone from Brazil and/or from the Atlantic. Clouds are most frequent along the Andes where upslope flow is most pronounced; this can be seen in the zone's mean cloudiness (Figure 5-15) and in its low-ceiling frequencies (Figure 5-16). Stratus and stratocumulus become less frequent, occurring primarily in southeasterly post-frontal flow off the Atlantic. Bases average 2,000 feet (610 meters) MSL, with tops to 5,000 feet (1,525 meters). Increased stability causes cumulus and cumulonimbus to occur less often, while altostratus and altocumulus occur more often. Even so, cumulus still causes cloud cover to be greatest during afternoons. Cumulus is scattered to broken, usually with bases near 6,000 feet (1,830 meters) MSL and tops to 20,000 feet (6.1 km) MSL. Middle clouds form most often during the morning and dissipate with daytime heating; bases range from 12,000 to 15,000 feet (3,660 to 4,570 meters) MSL, with an average thickness of 3,000 feet (915 meters). Cumulonimbus normally occurs with disturbances; depending on available moisture, bases can be as high as 6,000 feet (1,830 meters) MSL or as low as 1,000 feet (305 meters) MSL. Tops can exceed 50,000 feet (15.2 km) MSL.

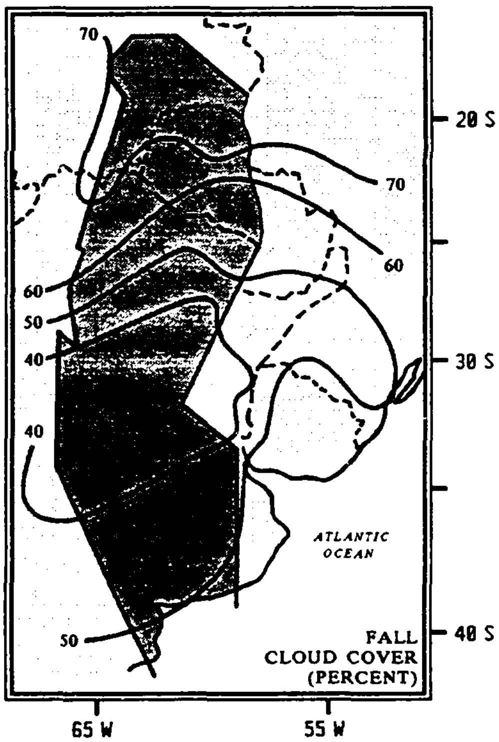


Figure 5-15. Mean Fall Cloud Cover, Gran Chaco/Pampas.

Low-ceiling frequencies decrease as daytime heating decreases, but they increase again toward the end of the season as frontal systems take on winter-like characteristics. Figure 5-16 shows that low ceilings occur most often during the afternoon and evening across much of the zone.

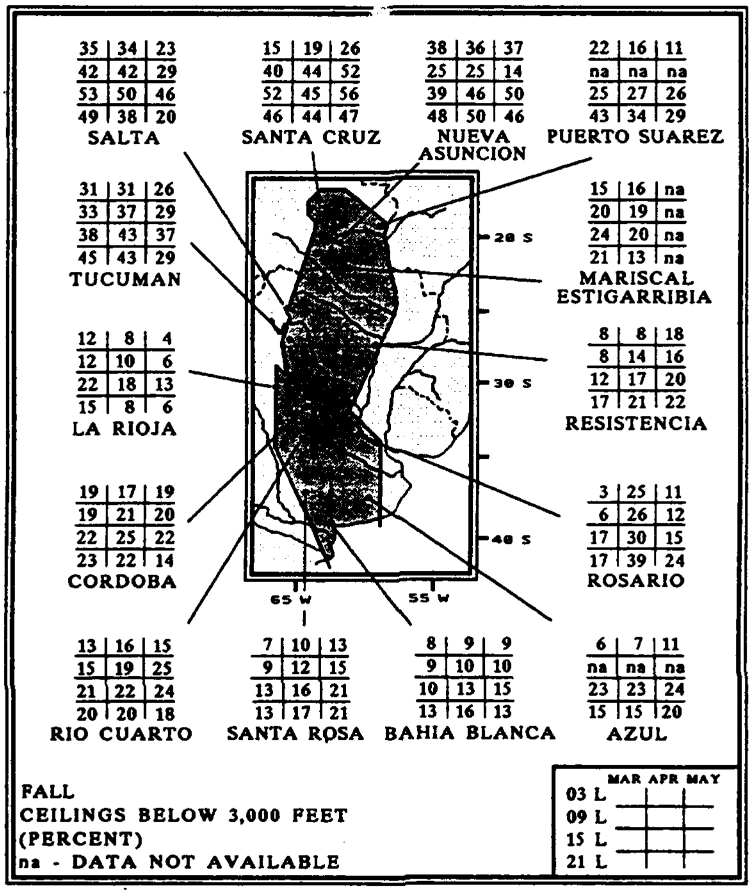


Figure 5-16. Fall Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Gran Chaco/Pampas.

VISIBILITY. Visibility restrictions, primarily fog and precipitation, increase through fall. Worst visibilities are with frontal systems, especially during post-frontal, onshore flow associated with the winter-like "sudestadas" (see this zone's "Winter" section), when the Atlantic provides the moisture needed to produce fog, rain, and drizzle. Onshore flow becomes more common as the Argentine High develops. From Santa Cruz to Mariscal Estigarribia, visibilities below 6 miles occur an average of only 2 days a month. From Rivadavia to Bahia Blanca, the number of days below 6 miles averages 12. The frequency of visibilities below 3 miles ranges from 3% or less in the morning to 8% or less in the afternoon (see Figure 5-17). Higher morning frequencies are due primarily to early-morning radiation fog that normally occurs post-frontally and dissipates by mid-day. It can, however, last for 12 hours or more with persistent southeasterly flow off the Atlantic.

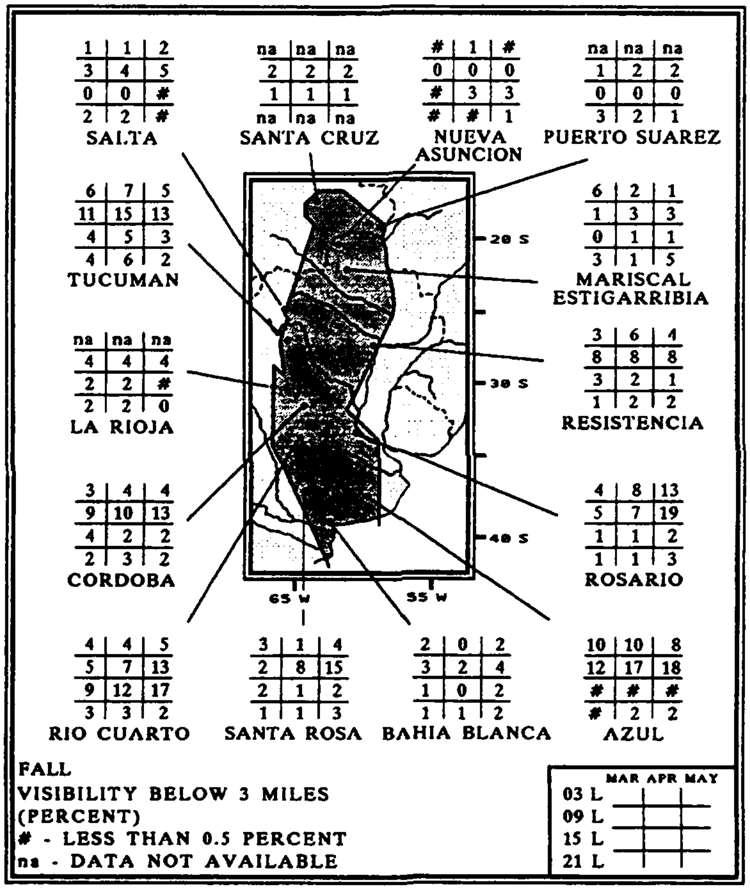


Figure 5-17. Fall Percent Frequencies of Visibility Below 3 Miles, Gran Chaco/Pampas.

WINDS. Mean wind directions continue to be influenced by the NAD, but some changes occur because it is weakening and moving north. Rivadavia, with mean surface wind directions shifting from north-northwest to south, shows the NAD's movement toward the northeast. More frequent frontal lows and the developing Argentine High cause southeasterly winds to become more common (see Figure 5-18). Land and sea breezes occasionally affect the coast; Bahia Blanca has a land breeze averaging near 10 knots at night and nearly 15 knots by late morning. An afternoon sea breeze causes coastal easterlies from 5 to 10 knots. Morning wind speeds throughout the zone range from less than 5 knots central to near 10 knots in the south and extreme north. Afternoon speeds are 5 to 10 knots central and near 15 knots afternoons in the south and extreme north. Afternoon gusts are generally less than 20 knots.

Most fronts are preceded by north to northwesterly winds and followed by southerlies. Occasionally, a cold front moving to the northeast is followed by a cold, squally, south or southwest wind called the "pampero" (See summer's "General Weather" section). Pampero winds can last 2 to 3 hours; they caused a recorded speed of 70 knots from the southwest at Bahia Blanca in April, but gusts over 80 knots have been known to occur. The sudestada frontal pattern occasionally causes strong post-frontal southeasterly winds in the south.

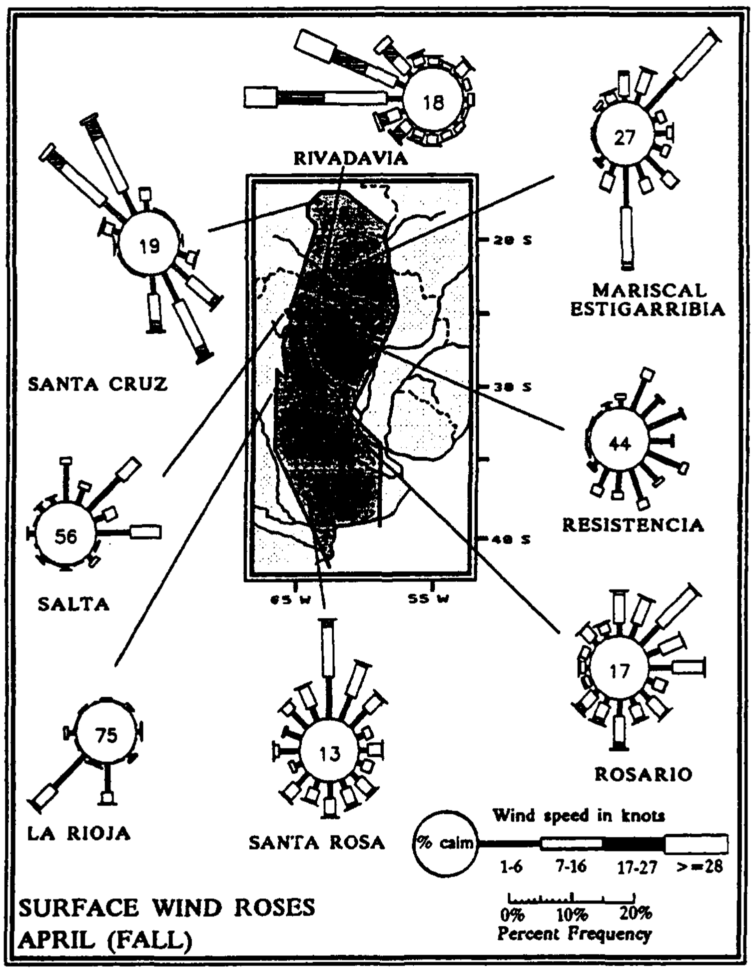


Figure 5-18. April Surface Wind Roses, Gran Chaco/Pampas.

STATION	MAR	APR	MAY
AZUL	7	6	6
BAHIA BLANCA	12	12	12
CORDOBA	6	6	6
LA RIOJA	2	2	1
MARISCAL ESTIGARRIBIA	4	3	3
NUEVA ASUNCION	6	7	8
PUERTO SUAREZ	6	5	5
RESISTENCIA	3	3	3
RIO CUARTO	9	8	8
RIVADAVIA	4	4	3
ROBORE	5	4	5
ROSARIO	9	8	9
SALTA	3	3	3
SANTA CRUZ	11	11	12
SANTA ROSA	8	7	6
TUCUMAN	4	4	3

Figure 5-19. Mean Fall Wind Speeds, Gran Chaco/Pampas.

Below 10,000 feet (3,050 meters) MSL, winds are northerly, ranging from 290 to 050 degrees; speeds average 14 knots. Winds are westerly above 10,000 feet (3,050 meters) MSL; speeds range from 15 knots at 10,000 feet (3,050 meters) MSL to 30 knots at 25,000 feet (7.7 km) MSL. Speeds increase to 45 knots at 30,000 feet (9.1 km) MSL and to 60 knots at 40,000 feet (12.2 km) MSL. Upper-level wind directions are shown in Figures 5-9 and 5-10.

PRECIPITATION. Most rainfall results from the instability provided by frontal and orographic lift. Showers are common; virga can fall from high bases. Post-frontal steady rain or drizzle can occur with fall's occasional sudestada frontal patterns, especially in the south at season's end. Snow can fall on rare occasions in the south, but with little or no accumulation. Monthly precipitation days are greatest in the Andes foothills, averaging near 15. Elsewhere, monthly precipitation days are less than 10. Mean monthly precipitation amounts decrease from 4 inches (100 mm) in March to less than 2 inches (50 mm) in May (see Figure 5-20). Monthly, seasonal, and annual amounts are more variable in the southeast than in the rest of the zone. Figure 5-21 gives tabular precipitation data.

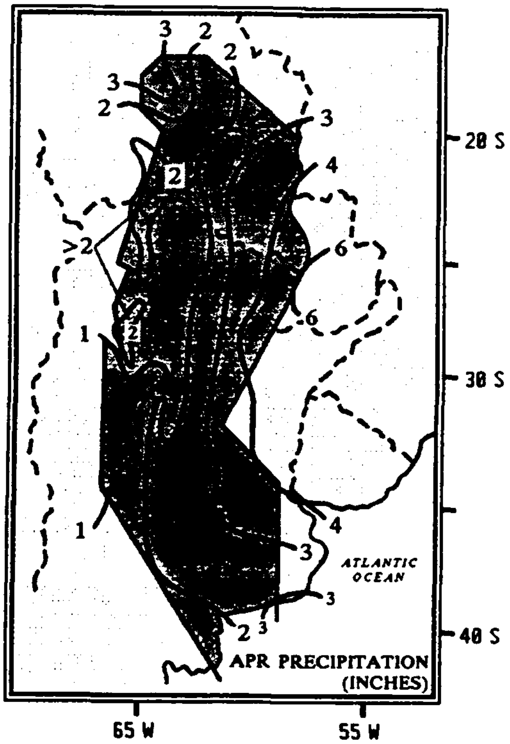
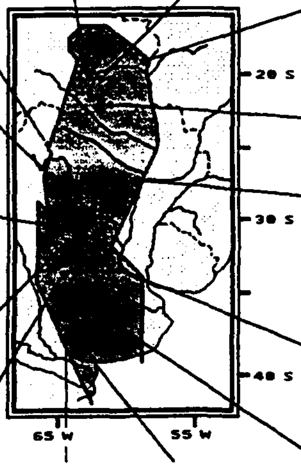


Figure 5-20. Mean April Precipitation, Gran Chaco/Pampas.

Station	Element	MAR	APR	MAY
SALTA	Maximum monthly	13.7	6.8	5.6
	Maximum 24-hour	3.1	3.1	2.1
	Precipitation days	12	8	3
	Thunderstorm days	4	1	#
SANTA CRUZ	Maximum monthly	na	na	na
	Maximum 24-hour	na	na	na
	Precipitation days	11	7	7
	Thunderstorm days	2	1	1
NUEVA ASUNCION	Maximum monthly	7.7	10.9	9.6
	Maximum 24-hour	3.1	2.8	2.1
	Precipitation days	na	na	na
	Thunderstorm days	3	3	1
PUERTO SUAREZ	Maximum monthly	na	na	na
	Maximum 24-hour	4.6	3.5	4.1
	Precipitation days	11	6	4
	Thunderstorm days	1	1	#
TUCUMAN	Maximum monthly	15.6	8.5	6.3
	Maximum 24-hour	8.1	2.6	3.0
	Precipitation days	12	11	8
	Thunderstorm days	1	1	0
MARISCAL ESTIGARRIBIA	Maximum monthly	7.9	11.2	7.2
	Maximum 24-hour	2.7	5.9	2.9
	Precipitation days	5	4	#
	Thunderstorm days	2	2	1
LA RIOJA	Maximum monthly	8.3	2.3	0.7
	Maximum 24-hour	3.1	1.6	0.6
	Precipitation days	8	2	#
	Thunderstorm days	1	#	#
RESISTENCIA	Maximum monthly	13.7	11.8	10.3
	Maximum 24-hour	7.1	3.5	3.5
	Precipitation days	9	9	7
	Thunderstorm days	7	6	5
CORDOBA	Maximum monthly	8.1	7.4	5.3
	Maximum 24-hour	3.5	3.9	3.7
	Precipitation days	9	7	4
	Thunderstorm days	3	2	1
ROSARIO	Maximum monthly	17.1	10.7	9.9
	Maximum 24-hour	9.1	7.0	5.9
	Precipitation days	9	8	4
	Thunderstorm days	5	4	2
RIO CUARTO	Maximum monthly	7.6	2.8	3.5
	Maximum 24-hour	3.7	2.6	2.3
	Precipitation days	na	na	na
	Thunderstorm days	5	2	1
SANTA ROSA	Maximum monthly	10.6	8.5	3.0
	Maximum 24-hour	4.3	1.7	3.0
	Precipitation days	6	4	3
	Thunderstorm days	5	3	1
BAHIA BLANCA	Maximum monthly	na	na	na
	Maximum 24-hour	2.1	2.5	1.2
	Precipitation days	5	4	5
	Thunderstorm days	1	2	1
AZUL	Maximum monthly	na	na	na
	Maximum 24-hour	5.2	2.3	4.3
	Precipitation days	8	6	6
	Thunderstorm days	5	2	2



FALL
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

MAR APR MAY: MAXIMUM MONTHLY / MAXIMUM 24-HOUR / PRECIPITATION DAYS / THUNDERSTORM DAYS

Figure 5-21. Fall Tabular Precipitation Data, Gran Chaco/Pampas.

THUNDERSTORMS. Thunderstorms decrease during fall. Mean monthly thunderstorm days range from about 1 a month along the southern Andes slopes and in the northeast to 6 a month along the zone's central-eastern fringes south of 25° S. Higher frequencies occur where fronts are most active. Thunderstorms are primarily frontal in the east and southeast, orographic along the Andes, and convective in the north. Frontal thunderstorms can form either along or ahead of the cold air; weak fronts result in isolated cells while strong fronts can cause solid thunderstorm lines that can form along or ahead of the front. Thunderstorm tops normally exceed 40,000 feet (12.2 km) MSL. Bases range from 2,000 to 8,000 feet (610 to 2,440 meters) MSL, depending on moisture. Strong cells can cause heavy showers, gusty winds, hail, and rare tornado activity. Evaporative cooling beneath high-based cells can cause downbursts.

TEMPERATURE. Summer to fall temperature changes are greatest in the south, reflecting increased cold air advection and decreased daylength. Average highs range from 89° F (32° C) in the north to 61° F (16° C) south, while average lows range from 79° F (26° C) to 42° F (6° C). Extreme highs are caused by adiabatic warming off the Andes; 109° F (43° C) was recorded at Azul in March (see Figure 5-22).

Extreme lows follow strong cold fronts; 19° F (-7° C) was recorded at Santa Rosa in May.

Falling temperatures cause rising relative humidities; average relative humidities range from 54% during afternoons to 84% during mornings. Abnormally low relative humidities occur with zondas. Figure 5-23 gives wet-bulb globe temperature data for several sites.

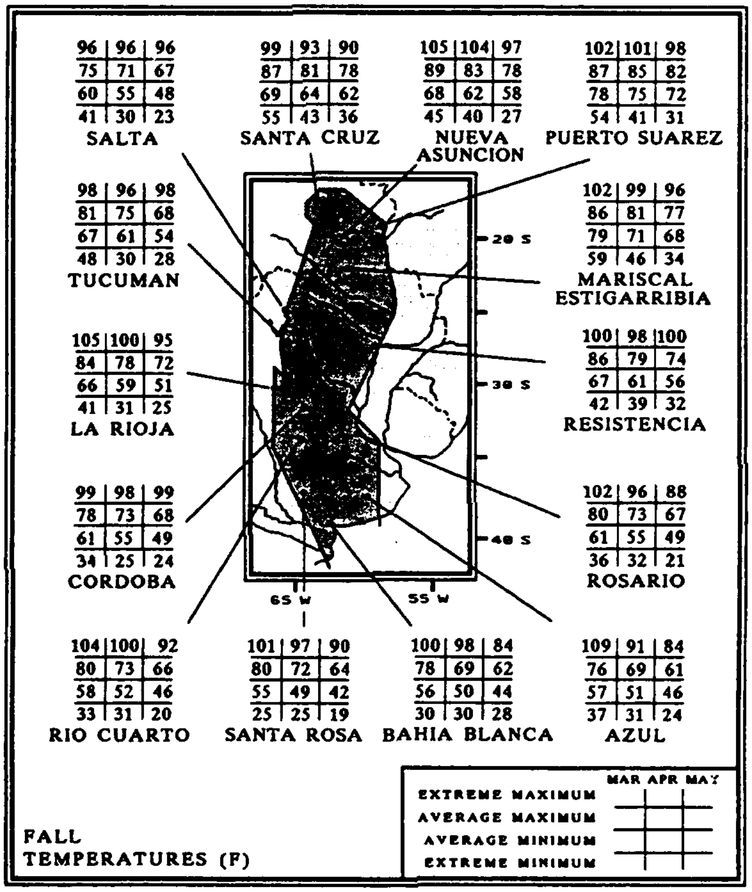


Figure 5-22. Fall Tabular Temperature Data, Gran Chaco/Pampas.

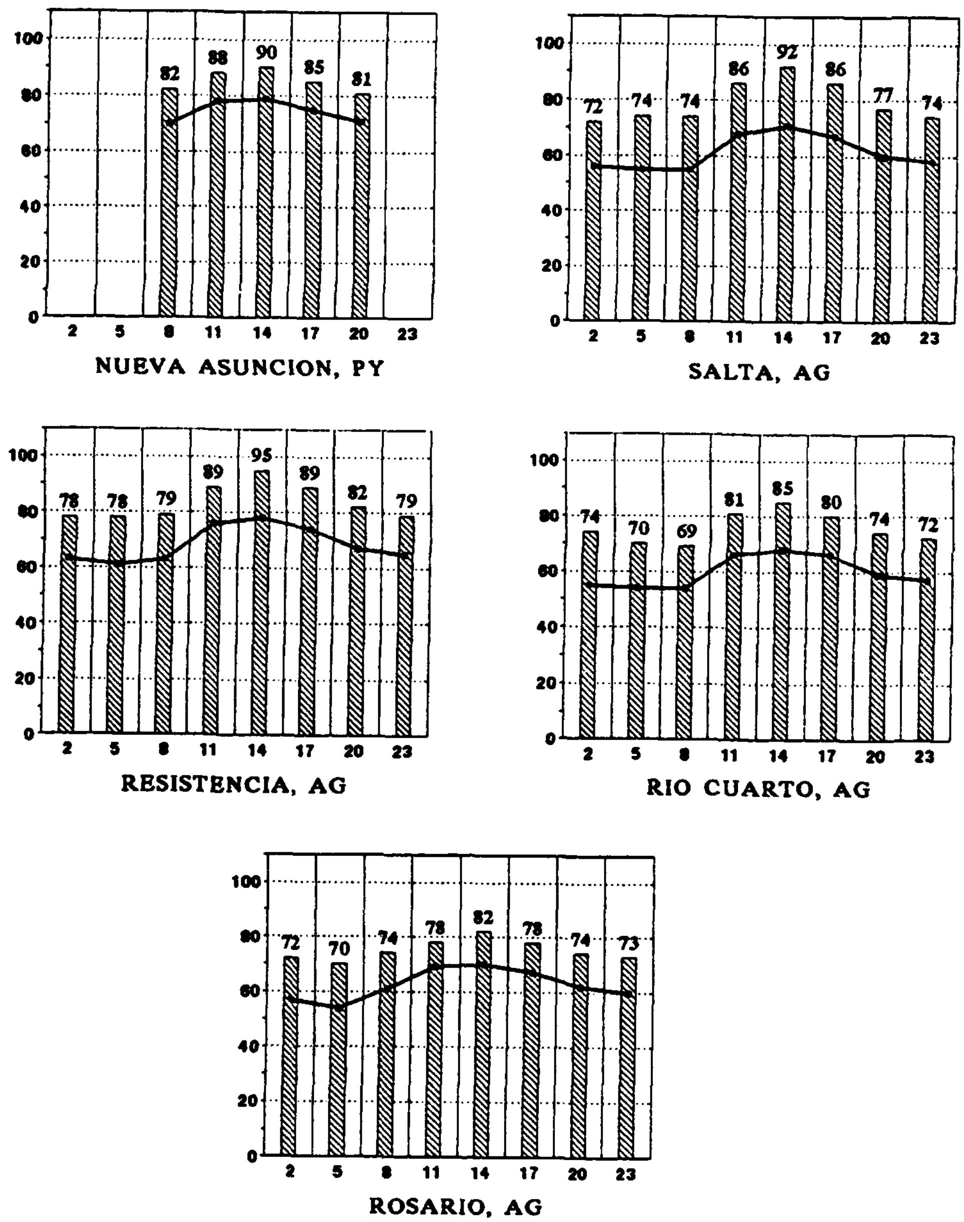


Figure 5-23. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Gran Chaco/Pampas. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Moderate to severe turbulence occurs with thunderstorms. Mountain wave turbulence is also moderate to severe along the Andes' eastern slopes, and often often reaches the tropopause; it can be identified by cap, rotor, or lenticular clouds, except when the air is too dry for clouds to form. Turbulence with the Subtropical Jet is strongest poleward and above the jet core; its mean position is 35° S at 40,000 feet (12.2 km) MSL. Turbulence also results from strong surface heating. Light aircraft will find light to moderate low-level turbulence below 5,000 feet (1,525 meters) AGL. Strong frontal outbreaks (pamperos) can cause light to moderate turbulence through 10,000 feet (3,050 meters) AGL.

Moderate to severe mixed icing is associated with intense cold fronts and thunderstorms. The mean height of the freezing level in the fall ranges from 11,000 feet (3,350 meters) MSL in the south to 15,000 feet (4,570 meters) MSL in the north. The top of the icing layer averages 25,000 feet (7.6 meters) MSL in the south and 30,000 feet (9.1 meters) MSL in the north.

GROUND HAZARDS. The wet season extends into fall; there are still some moderate to heavy rainshowers. Flash floods occur along streams and rivers and in narrow mountain valleys, especially in the north and east. Heavy rain from MCSs also occurs in the same areas. The ground tends to remain wet and muddy even after several dry, sunny days; crossing such terrain is difficult.

GENERAL WEATHER. The South Atlantic High becomes stronger as it extends westward well onto the continent. The resulting widespread subsidence confines Amazon basin moisture to a shallow layer near the surface. The Planalto do Matto Grosso prevents most of this moisture from entering the Gran Chaco/Pampas zone. Atlantic moisture from the east is blocked by the Brazilian Highlands. As a result, winters are dry. Most of the moisture that does affect the zone in winter enters from the southeast with onshore flow northeast of the Argentine High and southwest of frontal lows.

Sudestadas occur with frontal lows that cause shallow invasions of slow-moving cool air from the southeast. The invading air mass and the air mass it replaces are both stable. Southeasterly post-frontal flow brings in Atlantic moisture, producing widespread rain, drizzle, fog, and low cloud.

Weak cold fronts seldom bring in or confront significant moisture, but there is usually enough for light rain or drizzle. At times, multilayered convective clouds, isolated thunderstorms, and showers occur with strong cold fronts. Frontal passages occur every 4 to 5 days.

SKY COVER. Winter is the least cloudy season. Most clouds occur from late evening through early morning. Mean cloudiness ranges from 40% in the west to pockets of 60% in the extreme north and southeast (see Figure 5-24). Along the coast, greater mean cloudiness is the result of maritime influences and upslope flow. The pocket of higher cloud amounts over Paraguay is due to nocturnal stratus and stratocumulus from moisture provided by lowland marshes. Advection controls cloud distribution, but frontal cloudiness is also significant. Strong northward-moving cold fronts that encounter moist, maritime air off the Atlantic can cause extensive cloudiness. Widespread stratus can be advected northward through the zone when post-frontal flow is off the Atlantic (see "sudestadas," above). The season's rare pamperos (see summer's "General Weather") are characteristically dry; they are accompanied by scattered low, middle, and high clouds and followed by rapid clearing.

Scattered altocumulus and altostratus with bases averaging 12,000 feet (3,660 meters) and tops near 15,000 feet (4,570 meters) are the predominant cloud types. However, stratus and stratocumulus with bases averaging 2,000 feet (610 meters) MSL are common in the interior lowlands and along the coast. These clouds form during early morning and generally dissipate by early afternoon. Fair-weather cumulus with bases at 6,000 feet (1,830 meter) MSL form periodically during the afternoon; they generally lack much vertical extent. Cold fronts occasionally produce cumulus and cumulonimbus with bases below 3,000 feet (915 meters) MSL and tops to 40,000 feet (12.2 km).

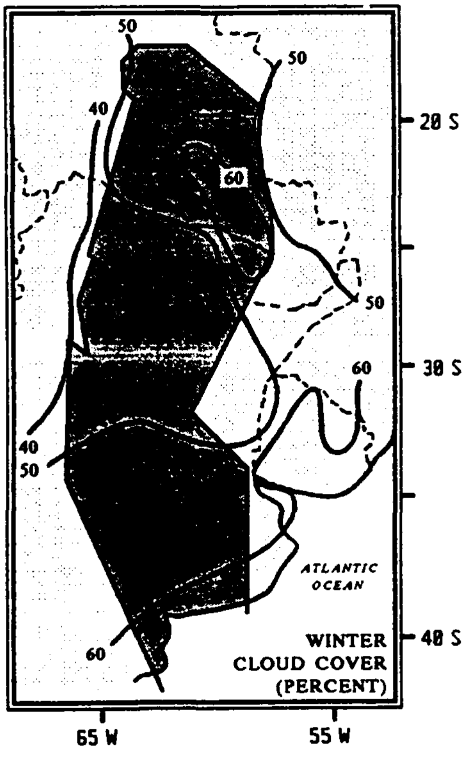


Figure 5-24. Mean Winter Cloud Cover, Gran Chaco/Pampas.

Low ceilings occur most often during winter. They are most common along the Parana River and toward the northern interior where lowland moisture is confined by higher elevations on three sides. As shown in Figure 5-25, the frequency of ceilings below 3,000 feet (915 meters) AGL decreases late in the season. Diurnal variations are slight, but frequencies are generally higher in mid-morning through late afternoon.

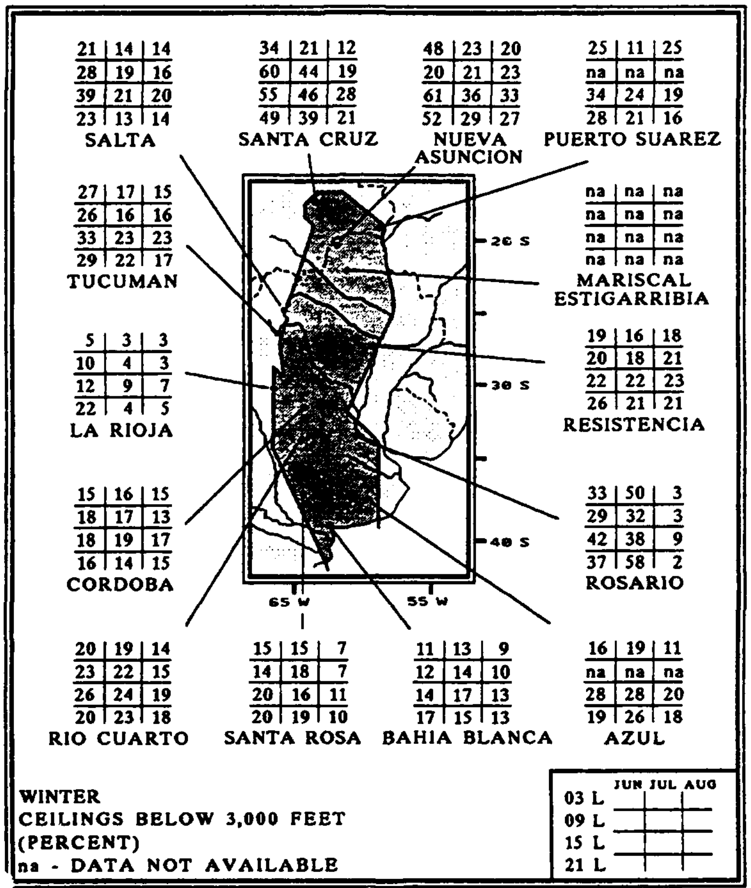


Figure 5-25. Winter Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Gran Chaco/Pampas.

VISIBILITY. Visibility is restricted most often in the winter, particularly in the interior lowlands and on the southeastern coast. The principal restrictions are fog and precipitation. Radiation fog can reduce visibilities greatly, most often post-frontally. It normally lifts or dissipates shortly after sunrise, but during late winter, it can persist into the afternoon. On rare occasions with persistent onshore flow, fog can last for 12 hours or more in the south. Although precipitation by itself seldom reduces visibility below 3 miles, precipitation and fog occurring together with sudestadas often do. Haze, dust, and smoke also restrict visibility at times, but with less severity and frequency. The mean number of days a month with visibilities below 6 miles ranges from 1 in the north to 23 in the south. The frequency of visibilities below 3 miles averages only 15% for the entire zone (see Figure 5-26). Pamperos, on rare occasions, cause blowing dust to reduce visibilities briefly in the southwest.

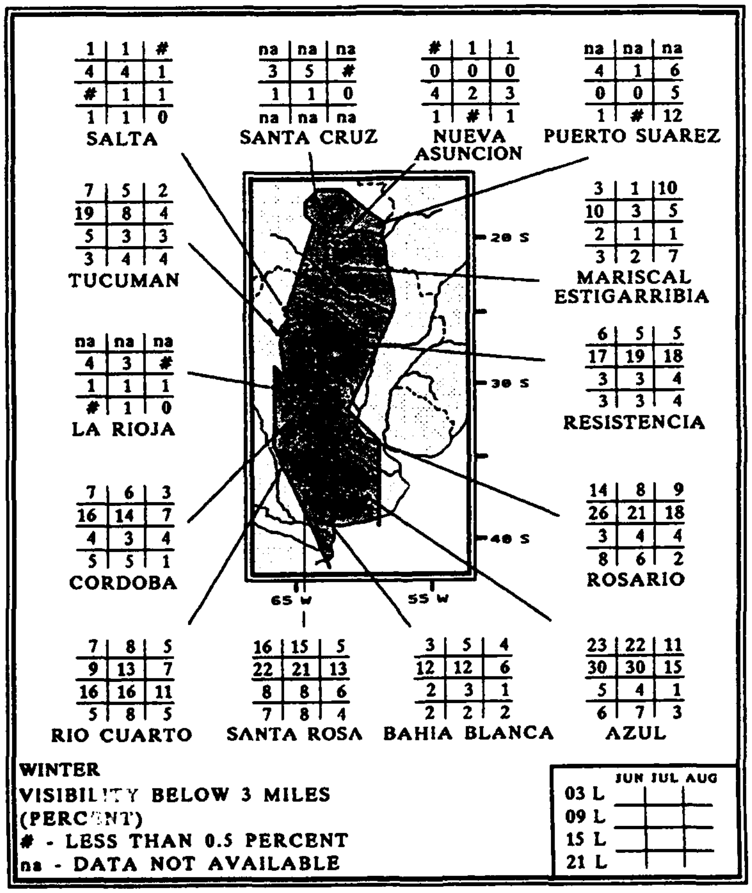


Figure 5-26. Winter Percent Frequencies of Visibility Below 3 Miles, Gran Chaco/Pampas.

WINDS. Mean surface wind directions are controlled by the NAD and the Argentine Continental High. The NAD's mean position is east-southeast of Rivadavia, where winds are southerly. North-northeast of the NAD, winds are generally north-northeasterly. Further variations occur around the Argentine High and with fronts. Figure 5-27 shows surface wind roses for several stations. Mean surface wind speeds for all hours are shown in Figure 5-28. Morning speeds range from less than 5 knots centrally to near 10 in the south and the extreme north. Afternoon speeds average around 10 knots centrally and from 10 to 15 knots in the south; afternoon gusts of 15 to 20 knots are common. Santa Cruz, in the foothills of the Andes where winds are channeled, is the zone's "windy city"--afternoon speeds here are 15 to 20 knots and gusts reach 25 knots. Fronts usually produce strong, gusty winds, especially on those rare occasions when a cold front moving northeast causes 2 to 3 hours of strong, cold, south-southwesterly winds (a pampero). The highest winter wind speed recorded was 60 knots from the south-southeast at Santa Cruz, in August.

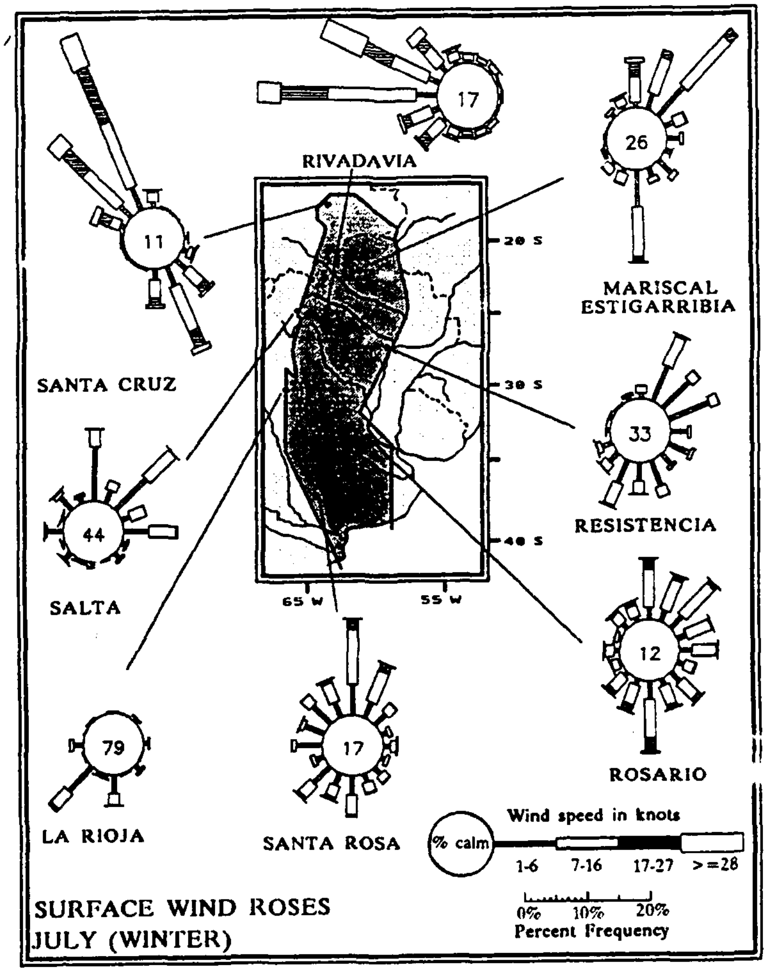


Figure 5-27. July Surface Wind Roses, Gran Chaco/Pampas.

STATION	MAR	APR	MAY
AZUL	6	7	8
BAHIA BLANCA	13	13	13
CORDOBA	5	6	7
LA RIOJA	1	2	2
MARISCAL ESTIGARRIBIA	5	5	5
NUEVA ASUNCION	7	10	10
PUERTO SUAREZ	5	6	5
RESISTENCIA	4	4	4
RIO CUARTO	7	9	9
RIVADAVIA	4	4	4
ROBORE	5	7	6
ROSARIO	9	10	10
SALTA	4	4	4
SANTA CRUZ	15	16	14
SANTA ROSA	5	7	8
TUCUMAN	3	4	5

Figure 5-28. Mean Winter Wind Speeds, Gran Chaco/Pampas.

Below 10,000 feet (3,050 meters) MSL, mean upper winds are primarily from the north (300-040 degrees); speeds average 13 knots. Above 10,000 feet (3,050 meters) MSL, winds are westerly from 260 to 290°. Equatorward of 30° S, speeds average 25 knots at 15,000 feet (4,570 meters) MSL, 50 knots at 30,000 feet (9.1 km) MSL, and 70 knots at 40,000 feet (12.2 km) MSL. Poleward of 30° S, winds average 30 knots at 15,000 (4,570 meters) MSL, 60 knots at 30,000 feet (9.1 km) MSL, and 65 knots near 40,000 feet (12.2 km) MSL. Maximum upper wind speeds are generally at 40,000 feet (12.2 km) MSL. Upper wind directions are shown in Figures 5-9 and 5-10.

PRECIPITATION. Winter is the dry season. Mean monthly precipitation amounts range from less than 0.5 inch (13 mm) in the west to more than 2 inches (50 mm) in the southeast and extreme northwest (see Figure 5-29). Most precipitation falls as showers along frontal boundaries and on the windward slopes of higher terrain. Steady light post-frontal precipitation is common. Snow falls on rare occasions south of 30° S, but with little or no accumulation. Enough moisture comes in from western Brazil to produce showers about 6 days a month in the zone's extreme northwest. In the south and west, precipitation frequencies and amounts decrease due to the rain shadow effect of the Andes; passing fronts and periodic orographic lift cause precipitation about 3 days a month. Atlantic moisture contributes to an average of 5 precipitation days a month near the coast. Figure 5-30 gives tabular precipitation data for selected stations.

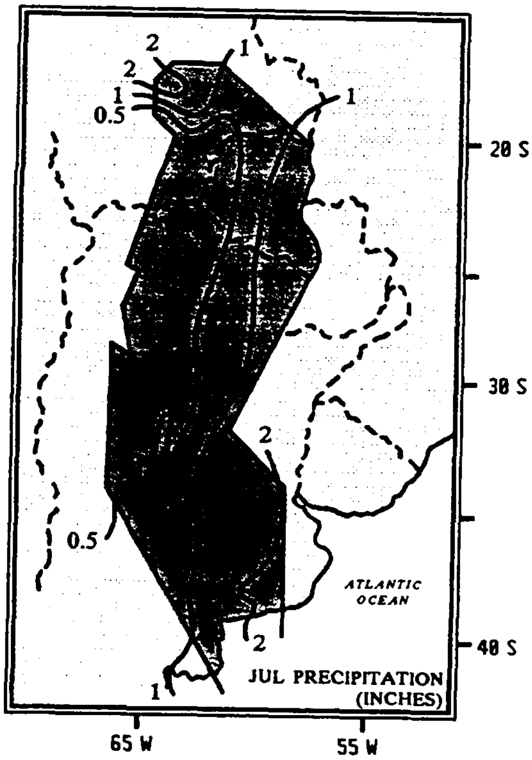


Figure 5-29. Mean July Precipitation, Gran Chaco/Pampas.

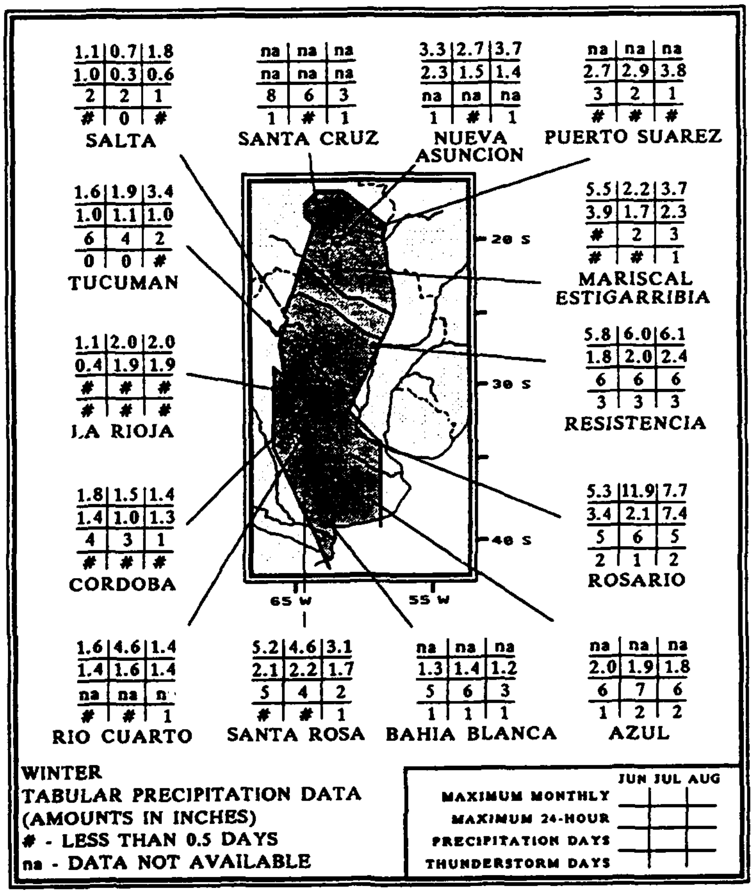


Figure 5-30. Winter Tabular Precipitation Data, Gran Chaco/Pampas.

THUNDERSTORMS. Thunderstorms occur on an average of 2 days a month, most toward the north and east, where higher temperatures result in less stability. Thunderstorms are primarily frontal, occurring as isolated cells along cold fronts. In extreme cases, solid lines can form along the front, producing heavy precipitation and frequent lightning. Cumulonimbus tops average 40,000 feet (12.2 km) MSL with bases below 1,000 feet (305 meters) MSL along the front.

TEMPERATURE. Winter temperatures are generally mild (see Figure 5-31). Mean daily highs range from 84° F (29° C) in the north to 54° F (12° C) in the south. Mean daily lows range from 69° F (21° C) to 33° F (1° C). Very low temperatures are rare because the continent is too narrow to produce very cold air masses. Furthermore, air masses are greatly warmed on their way northward. The coldest outbreaks are associated with the season's rare pamperos. The lowest temperature recorded is 9° F (-13° C), reported at Santa Rosa in July. In contrast, the zonda, a strong southwest wind blowing down the Andes' eastern slopes, can cause a sudden and significant increase in surface temperatures along those slopes; temperatures can rise more than 50° F (28° C). The extreme high temperature for winter is 110° F (43° C), recorded in August at Mariscal Estigarribia in the Andes' foothills.

In the absence of intruding polar air masses, the Argentine High results in flow off the Atlantic. This moisture combines with low temperatures to cause the year's highest relative humidities, which average 86% in the morning and 54% in the afternoon. Zondas can cause relative humidities to drop rapidly by as much as 70%. Figure 5-32 gives wet-bulb globe temperature data for selected sites in the zone.

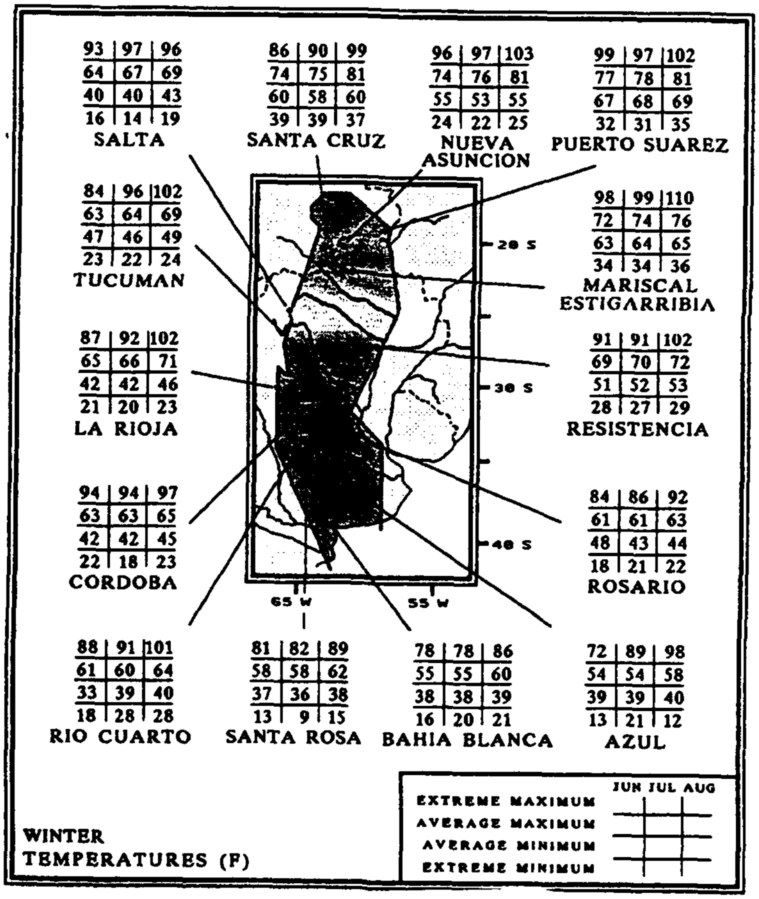


Figure 5-31. Winter Tabular Temperature Data, Gran Chaco/Pampas.

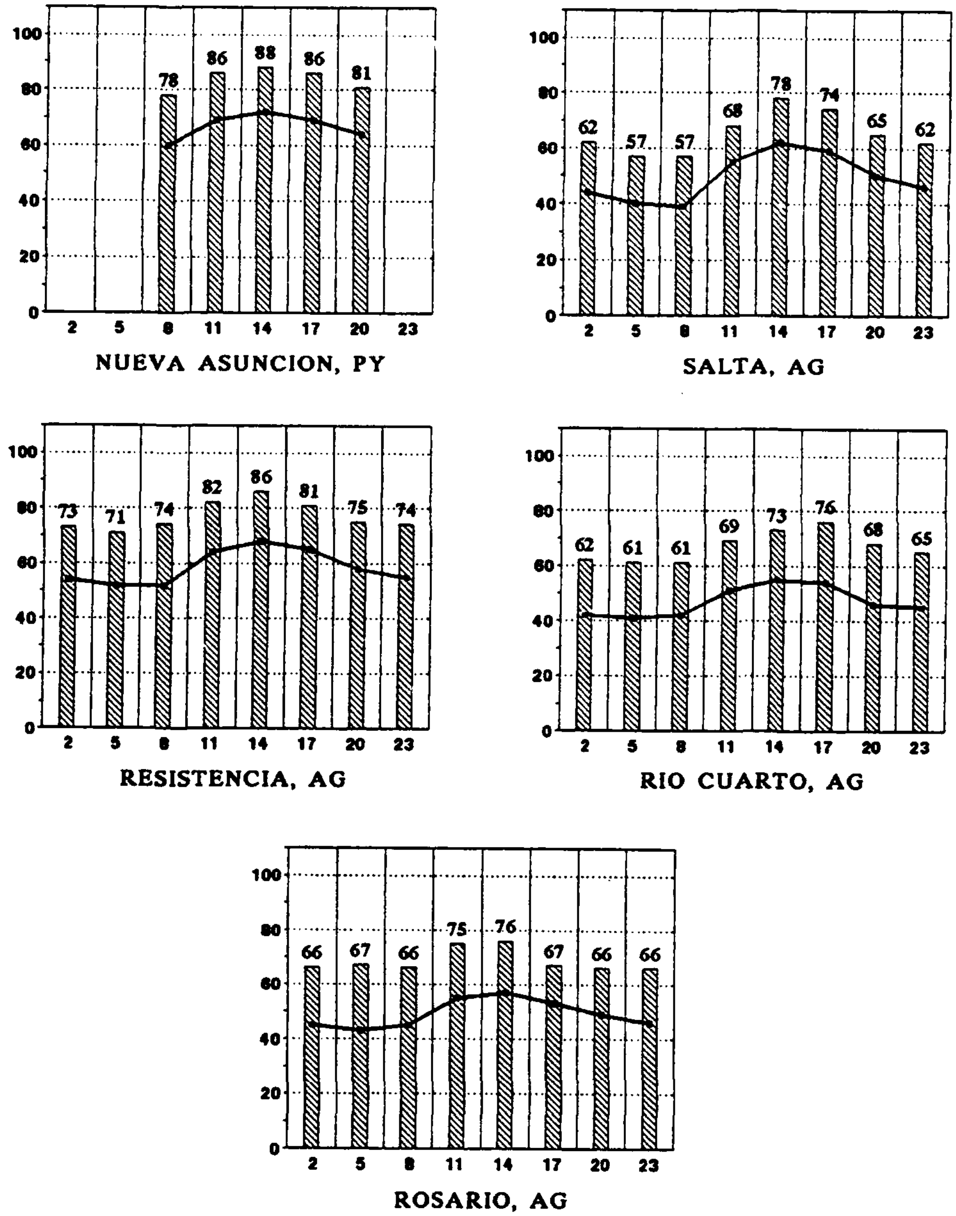


Figure 5-32. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Gran Chaco/Pampas. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Turbulence is the most significant flight hazard. Moderate to severe turbulence occurs with the occasional thunderstorm, which may be embedded in the extensive cloudiness accompanying some fronts. Mountain wave turbulence occurs along the Andes' eastern slopes, often extending through the tropopause. Although the presence of such turbulence may be identified by cap, rotor, or lenticular clouds, sometimes there is not enough moisture for these clouds to form. The Subtropical Jet is another cause of turbulence. Its mean position is near 33° S at 40,000 feet (12.2 km) MSL; turbulence is usually stronger poleward and above the jet stream core. Strong turbulence below 10,000 feet (3,050 meters) AGL is possible with winter's rare pamperos; brief 2- to 3-hour duststorms can occur in the southwest.

The mean height of the freezing level is 10,000 feet (3,050 meters) MSL; light rime icing is probable in clouds above. Moderate to severe mixed icing is primarily associated with intense cold fronts and thunderstorms.

GROUND HAZARDS. Haze and smoke from late-winter grass and brush fires occasionally restrict visibilities to less than 5/8 mile, especially in combination with rain or fog.

GENERAL WEATHER. Spring, the transition from cool to hot weather, is generally windy and stormy. The South Atlantic High moves eastward, allowing moisture from western Brazil--previously confined to a shallow layer near the surface--to enter the zone in greater amounts. The combined flow of the South Atlantic High and the developing NAD advects the moisture into the area. The South Atlantic is also a moisture source for frontal lows that cause southeasterly flow onto the zone's southern coast.

Stability decreases as temperatures and absolute humidity increase, resulting in more frequent rainshowers and thunderstorms along instability lines. Cold fronts pass every 4 to 5 days and can penetrate well north of the zone in spring. Frontal characteristics rapidly change from winter to summer as the season progresses; that is, widespread stratiform weather gives way to narrow bands of cumuliform clouds. The extensive stratiform weather associated with frontal lows changes similarly; coverage decreases and cumulus becomes increasingly common. Pamperos (see "Gran Chaco/Pampas Summer") are most common and severe in spring. Sudestadas (see "Gran Chacos/Pampas Winter") only occur occasionally in early spring. Cold frontogenesis occurs most often along the zone's western fringe between 25 and 40° S. The resulting fronts have their greatest effects toward the north and east where they are strongest. Squall lines are at their worst in spring; see summer's "General Weather" section for details. Upper-level troughs resemble those of summer.

SKY COVER. The spring distribution of mean cloudiness reflects the advection of warm, moist air from western Brazil and the rain-shadow effect of the Andes. Mean cloudiness ranges from 60% in the north to 40% over the Andes' foothills (see Figure 5-33). The higher cloud amounts over the northeast result from a combination of high moisture amounts and strong surface heating, as well as from orographic lift along the Brazilian Highlands.

The predominant cloud types are stratus and stratocumulus; bases average 2,000 feet (610 meters) MSL, with tops of 6,000 feet (1,830 meters). In the south, they are most common with post-frontal onshore flow, but they form most often in the north with early morning radiation cooling. Clouds usually dissipate or form fair-weather cumulus by midday, but continued onshore flow can cause them to persist in the south. Most fair-weather cumulus has bases between 6,000 and 10,000 feet (1,830 and 3,050 meters) MSL and lacks much vertical extent. Towering cumulus and cumulonimbus associated with frontal activity can have bases as low as 1,000 feet (305-meter) MSL, with tops to 40,000 feet (12.2 km). Lower amounts of moisture occasionally result in bases at or above 6,000 feet (1,830 meters) MSL.

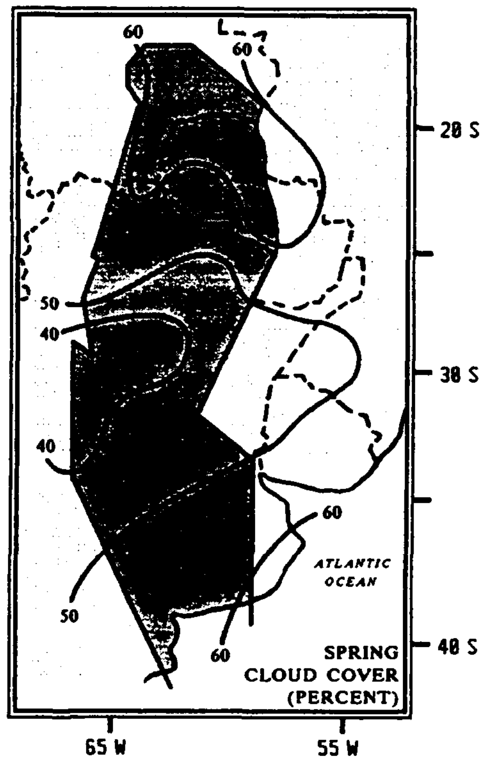


Figure 5-33. Mean Spring Cloud Cover, Gran Chaco/Pampas.

Low ceilings are not as common as in winter. Most ceilings below 3,000 feet (915 meters) AGL occur during the late afternoon and evening (see Figure 5-34). As in winter, the frequency of low ceilings is higher in the zone's northern interior equatorward of about 31° S.

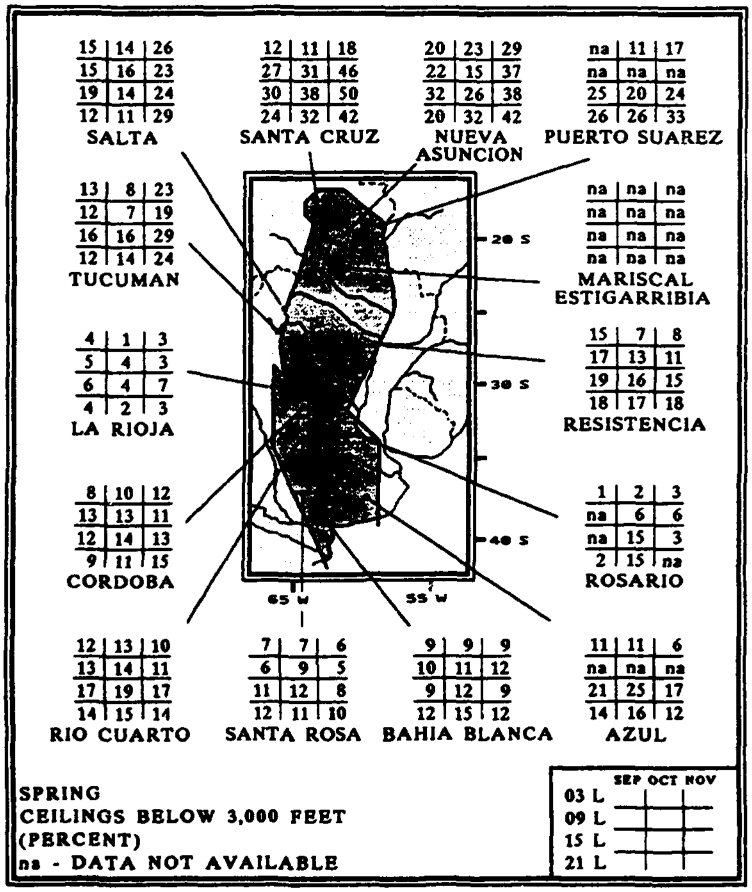


Figure 5-34. Spring Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Gran Chaco/Pampas.

VISIBILITY. Visibilities are lowest in late winter and early spring (August and September). Radiation fog is the major restriction, normally occurring after heavy rain or frontal passage. It forms overnight and usually dissipates by mid-morning. Precipitation also contributes to reduced visibilities; thunderstorms can cause reductions below 1 mile. Haze caused by burning can reduce visibilities early in the season. Dust associated with pamperos can reduce visibilities on rare occasions in the southwest.

From Santa Cruz to Salta, visibilities below 6 miles occur on an average of 1 to 2 days a month. Visibilities below 6 miles average 8 days a month south of Salta and east of 65° W. Frequencies of visibilities below 3 miles average near 4%, as shown in Figure 5-35.

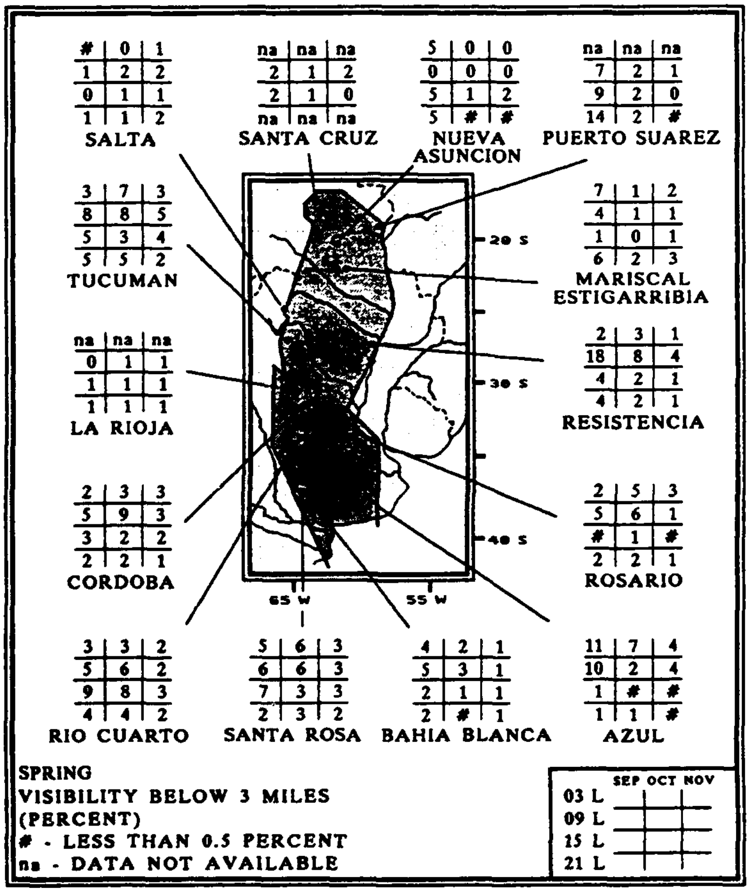


Figure 5-35. Spring Percent Frequencies of Visibility Below 3 Miles, Gran Chaco/Pampas.

WINDS. The Argentine Continental High weakens and the NAD intensifies as surface temperatures increase. North of the NAD, wind directions vary from north-northwest to east (see Santa Cruz and Mariscal Estigarribia in Figure 5-36). Mean wind directions at Rivadavia switch from south-southwest to north-northeast as the NAD moves southwestward. Mean wind directions east of the NAD generally range from the north-northwest to the north-northeast. Flow is disrupted by the Andes west of the NAD (see Figure 5-36). Land and sea breezes occasionally occur on the coast; Bahia Blanca has a 5- to 10-knot offshore wind at night that increases to around 15 knots by late morning, then changes to a 10-knot sea breeze during late afternoon and early evening.

Mean surface wind speeds at night are less than 5 knots centrally and range from 5 to 10 knots in the south and extreme north. Afternoon speeds are 5 to 10 knots centrally, 10 to 15 knots in the south, and 15 to 20 knots in the extreme north. Santa Cruz, located in the foothills of the Andes, is the windiest location; afternoon wind speeds range from 15 to 20 knots with gusts near 25 knots. The highest winds occur with strong fronts and thunderstorms. The highest recorded wind speed (60 knots from the northwest) was at Santa Cruz in September, but speeds greater than 80 knots are known to have occurred. Pamperos accompany many northeastward-moving cold fronts. Associated winds can exceed 30 knots and last 2 to 3 hours after frontal passage.

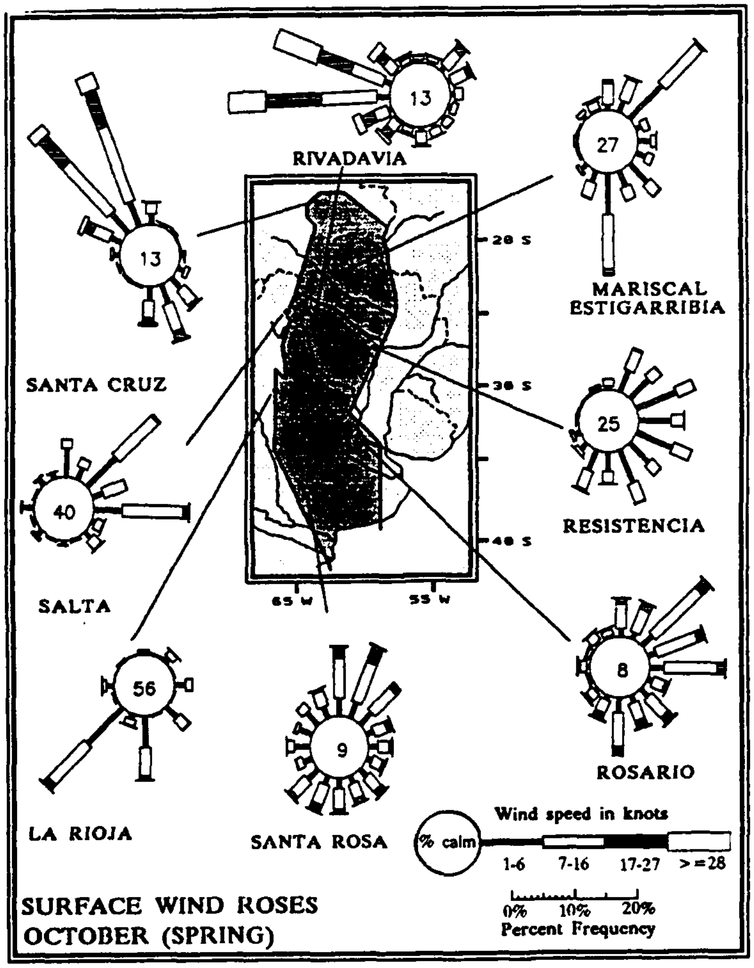


Figure 5-36. October Surface Wind Roses, Gran Chaco/Pampas.

STATION	SEP	OCT	NOV
AZUL	9	9	9
BAHIA BLANCA	13	13	14
CORDOBA	8	8	8
LA RIOJA	3	4	4
MARISCAL ESTIGARRIBIA	6	6	5
NUEVA ASUNCION	10	10	9
PUERTO SUAREZ	6	8	7
RESISTENCIA	5	5	5
RIO CUARTO	11	12	12
RIVADAVIA	5	5	5
ROBORE	6	7	7
ROSARIO	11	11	11
SALTA	5	5	5
SANTA CRUZ	14	13	13
SANTA ROSA	9	9	9
TUCUMAN	5	6	6

Figure 5-37. Mean Spring Wind Speeds, Gran Chaco/Pampas.

Upper-level wind directions are shown in Figures 5-9 and 5-10. Equatorward of 31° S, mean upper-level wind flow at 5,000 feet (1,525 meters) MSL is easterly at 11 knots; at 20,000 feet (6.1 km) MSL, westerly at 25 knots; and at 30,000 feet (9.1 km) MSL, westerly at 40 knots. Winds are westerly at all levels poleward of 31° S. The mean wind speed is 16 knots at 5,000 feet (1,525 meters) MSL, 33 knots at 20,000 feet (6.1 km) MSL, and 50 knots at 30,000 feet (9.1 km) MSL. Maximum upper-level winds occur near 40,000 feet (12.2 km) MSL, averaging 70 knots for the entire zone.

PRECIPITATION. As the NAD intensifies, more warm, moist, convectively unstable Amazon Basin air enters the zone, causing an increase in orographic showers along the Andes' eastern slopes. Moist Atlantic air also enters whenever there is onshore flow in the south. Much of the precipitation falls as moderate to heavy showers associated with fronts or orographic lift. Snow is possible in the south, but it's rare and doesn't accumulate. Virga occurs by season's end.

The mean number of days with precipitation range from 1 in September at La Rioja to 11 in November at Tucuman. Mean monthly precipitation increases from an average of 2 inches (50 mm) in September to greater than 3 inches (76 mm) in November (see Figure 5-38). Precipitation amounts in the southeast are more variable monthly, seasonally, and annually than in the north. Figure 5-39 provides tabular precipitation data for several stations in the zone.

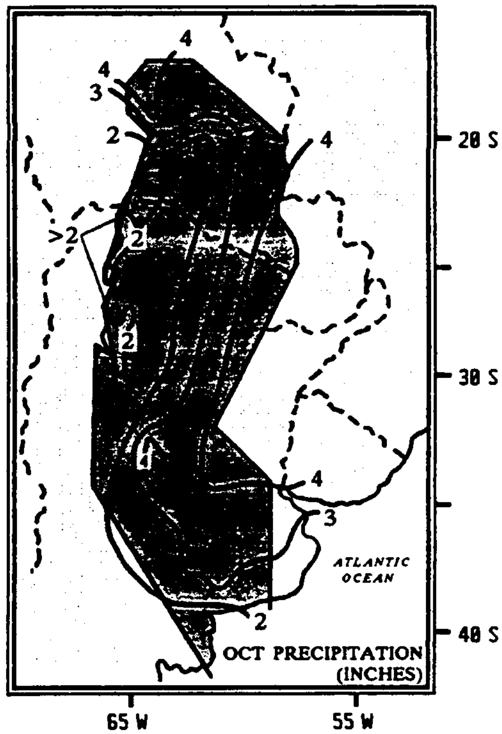


Figure 5-38. Mean October Precipitation, Gran Chaco/Pampas.

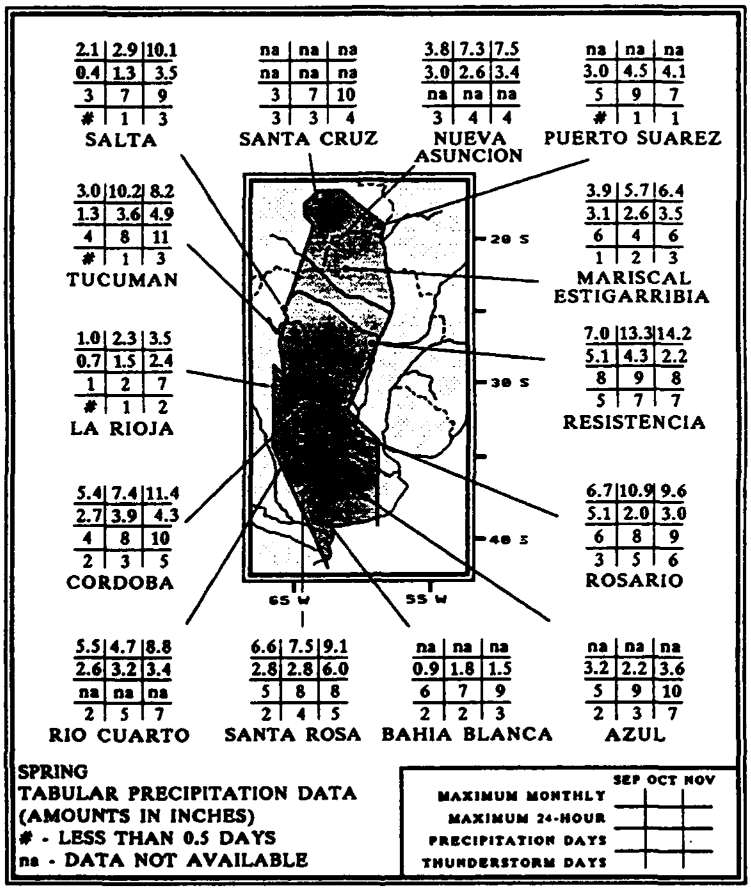


Figure 5-39. Spring Tabular Precipitation Data, Gran Chaco/Pampas.

THUNDERSTORMS. Thunderstorms, air-mass and frontal, occur on about 4 days a month, nearly double that of winter. Thunderstorm lines are common along and ahead of cold fronts. Severe thunderstorms develop when warm, moist, unstable air flowing southward from the Brazilian interior clashes with strong cold fronts. Spring thunderstorms are some of the most severe in all of South America. Squall lines produce the strongest; heavy showers, gusty winds, tornadoes, and hail are possible. Most hail occurs late in the season, in the northwest. Thunderstorm tops exceed 40,000 feet (12.2 km) MSL. Bases average 2,000 feet (610 meters) MSL, but are occasionally less than half that. Thunderstorms with high bases (at or above 6,000 feet/1,830 meters MSL) occasionally occur when the air is dry; evaporative cooling beneath these cells can cause downbursts.

TEMPERATURE. By late spring, mean daily highs are nearly as high as those of summer. They range from 90° F (32° C) at Neuva Ascuncion to 62° F (17° C) at Azul. Mean daily lows range from 80° F (27° C) to 42° F (6° C). Most extreme highs are due to zondas; extreme lows, to early-season pamperos. An extreme high of 115° F (46° C) was recorded at Rivadavia in November and an extreme low of 17° F (-8° C) was reported at Santa Rosa and Azul in September. Relative humidities average 70% during the morning and 47% in the afternoon.

SPRING TEMPERATURES (F)

Station		SEP	OCT	NOV
SALTA	EXTREME MAXIMUM	97	99	102
	AVERAGE MAXIMUM	75	78	79
	AVERAGE MINIMUM	47	54	58
	EXTREME MINIMUM	26	32	36
SANTA CRUZ	EXTREME MAXIMUM	100	98	105
	AVERAGE MAXIMUM	85	85	88
	AVERAGE MINIMUM	65	66	68
	EXTREME MINIMUM	44	37	48
NUEVA ASUNCION	EXTREME MAXIMUM	107	106	108
	AVERAGE MAXIMUM	85	88	90
	AVERAGE MINIMUM	60	64	67
	EXTREME MINIMUM	28	40	45
PUERTO SUAREZ	EXTREME MAXIMUM	107	107	103
	AVERAGE MAXIMUM	83	88	87
	AVERAGE MINIMUM	72	79	79
	EXTREME MINIMUM	42	49	49
TUCUMAN	EXTREME MAXIMUM	106	105	104
	AVERAGE MAXIMUM	75	83	82
	AVERAGE MINIMUM	54	62	65
	EXTREME MINIMUM	26	34	37
MARISCAL ESTIGARRIBIA	EXTREME MAXIMUM	106	104	104
	AVERAGE MAXIMUM	79	85	86
	AVERAGE MINIMUM	70	76	77
	EXTREME MINIMUM	46	52	46
LA RIOJA	EXTREME MAXIMUM	104	114	108
	AVERAGE MAXIMUM	77	86	89
	AVERAGE MINIMUM	52	61	66
	EXTREME MINIMUM	26	32	37
RESISTENCIA	EXTREME MAXIMUM	102	104	106
	AVERAGE MAXIMUM	76	82	84
	AVERAGE MINIMUM	55	60	64
	EXTREME MINIMUM	32	36	42
CORDOBA	EXTREME MAXIMUM	99	99	101
	AVERAGE MAXIMUM	70	76	79
	AVERAGE MINIMUM	49	55	59
	EXTREME MINIMUM	27	32	39
ROSARIO	EXTREME MAXIMUM	93	102	101
	AVERAGE MAXIMUM	68	74	80
	AVERAGE MINIMUM	47	54	58
	EXTREME MINIMUM	21	30	37
RIO CUARTO	EXTREME MAXIMUM	104	104	108
	AVERAGE MAXIMUM	69	75	80
	AVERAGE MINIMUM	46	52	56
	EXTREME MINIMUM	22	24	30
SANTA ROSA	EXTREME MAXIMUM	95	100	104
	AVERAGE MAXIMUM	67	74	80
	AVERAGE MINIMUM	42	48	54
	EXTREME MINIMUM	17	25	33
BAHIA BLANCA	EXTREME MAXIMUM	90	96	100
	AVERAGE MAXIMUM	65	70	76
	AVERAGE MINIMUM	43	49	53
	EXTREME MINIMUM	21	27	30
AZUL	EXTREME MAXIMUM	100	100	91
	AVERAGE MAXIMUM	62	67	73
	AVERAGE MINIMUM	44	51	54
	EXTREME MINIMUM	17	24	32

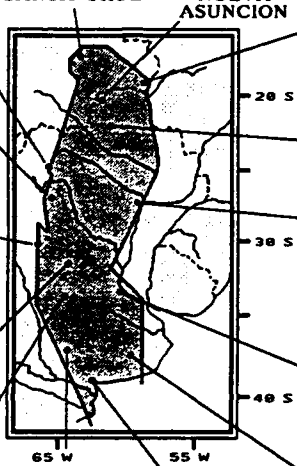


Figure 5-40. Spring Tabular Temperature Data, Gran Chaco/Pampas.

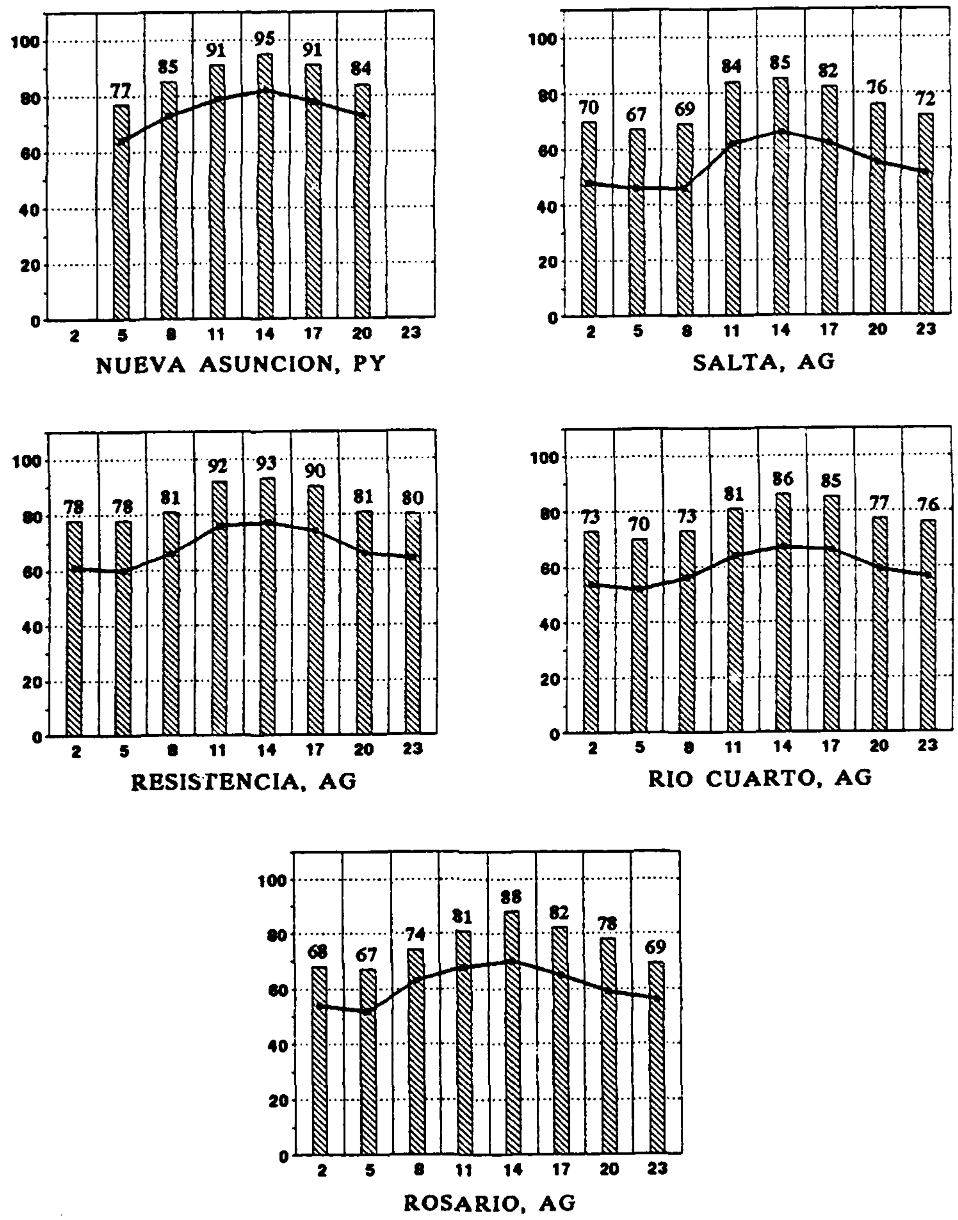


Figure 5-41. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Gran Chaco/Pampas. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. The frequency and intensity of thunderstorms increase, as well as the associated turbulence. Both air-mass and frontal thunderstorms occur; turbulence ranges from moderate to severe. Thunderstorms often develop solid lines and become unnavigable. Moderate to severe mountain wave turbulence occurs along the Andes' eastern slopes, often extending upward through the tropopause. Such turbulence may be identified by cap, rotor, or lenticular clouds, but dry air can prevent these clouds from forming. Light to moderate turbulence is also caused by the Subtropical Jet; its mean position during spring is 35° S at 40,000 feet (12.2 km) MSL. Turbulence associated with jet streams is usually stronger poleward and above the jet stream core. Strong surface heating causes light to moderate turbulence for light aircraft flying below 5,000 feet (1,525 meters) AGL. This turbulence occurs mostly during the afternoon over sparsely vegetated areas. Moderate turbulence can occur through 10,000 feet (3,050 meters) AGL with pamperos.

Moderate-to-severe mixed icing is primarily associated with intense cold fronts and thunderstorms. The mean height of the freezing level is 12,000 feet (3,660 meters) MSL during spring.

GROUND HAZARDS. Early season haze and smoke can restrict visibilities to less than 5/8 mile when occurring with rain or fog. Moderate to heavy rain showers occasionally cause flash floods, particularly along streams and rivers in the zone's northern lowlands and in narrow mountain valleys. The ground tends to remain wet and muddy even after several dry, sunny days; crossing such terrain can be difficult. Damaging hail is also a concern in the north. Brief, 2- to 3-hour duststorms occur on rare instances in the southwest with pamperos.

5.2 SOUTHERN BRAZILIAN HIGHLANDS/PARANA PLAIN

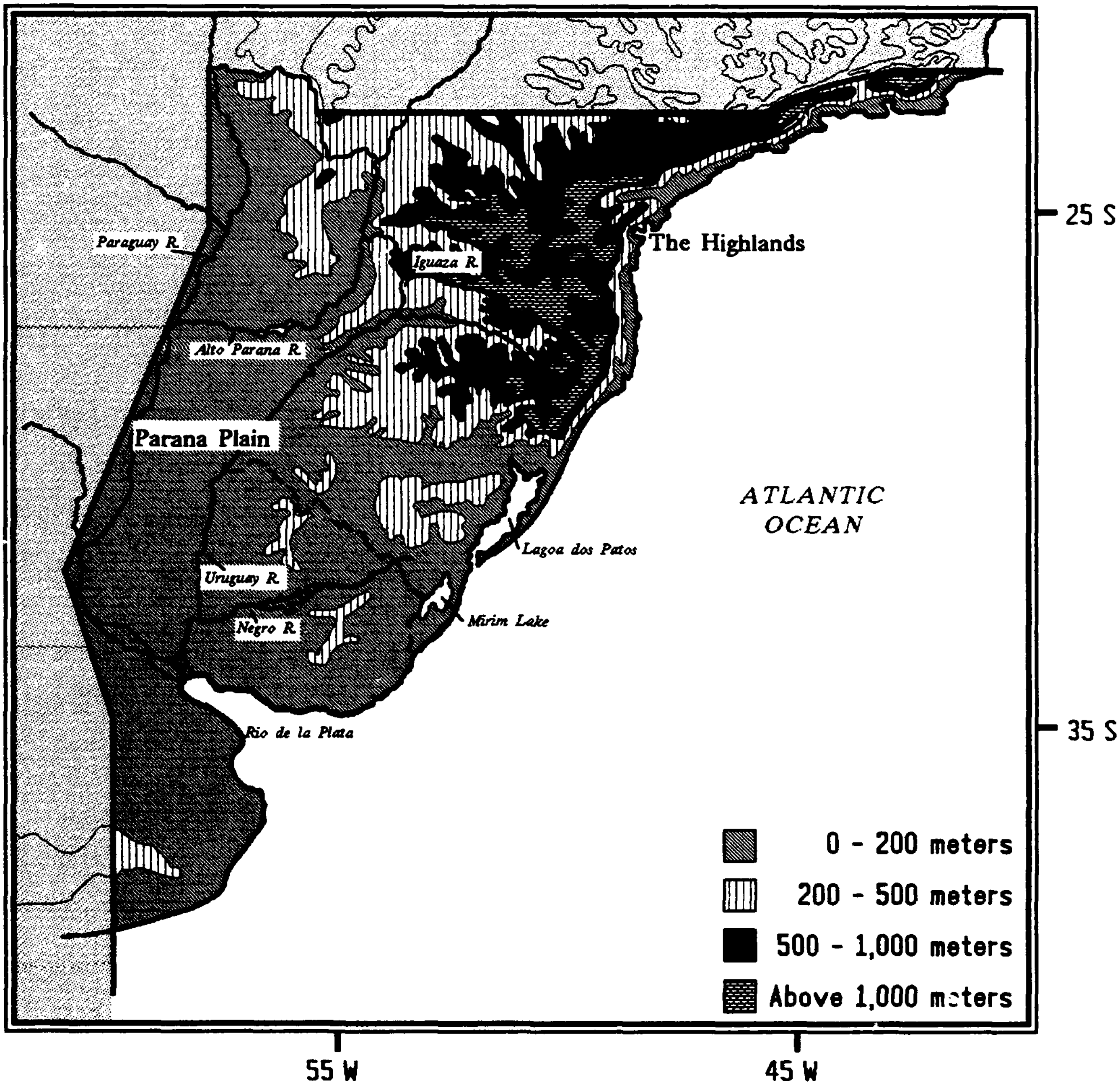
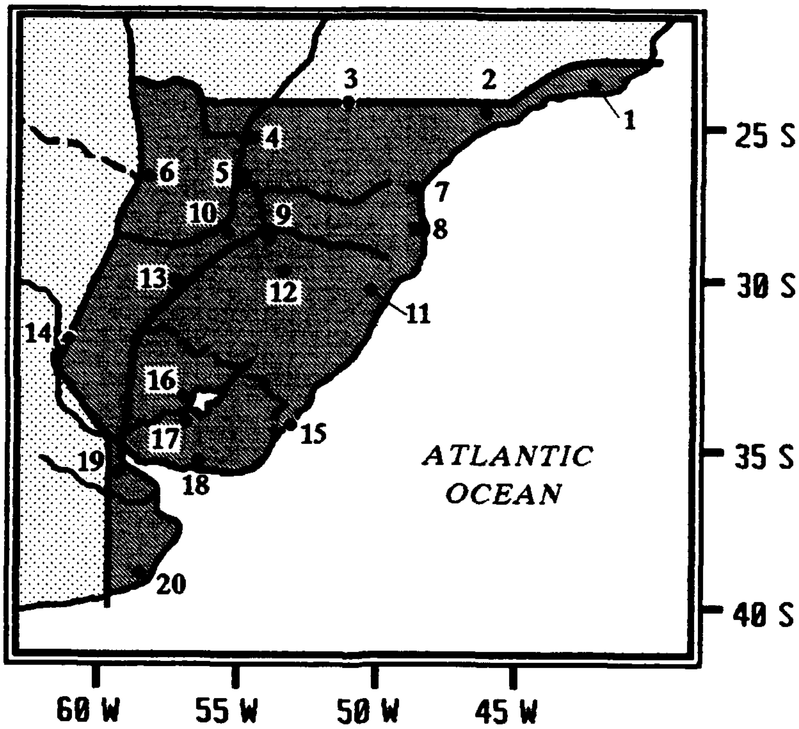


Figure 5-42. Southern Brazilian Highlands/Parana Plain. This zone covers northeastern Argentina, the eastern half of Paraguay, the southeastern corner of Brazil, and Uruguay.



	ELEVATION (FEET)		ELEVATION (FEET)
1. RIO de JANEIRO	89	11. PUERTO ALEGRE	79
2. SAO PAULO	2,608	12. SANTA MARIA	466
3. LONDRINA	1,867	13. PASO de los LIBRES	226
4, GUAIRA	722	14. PARANA	226
5. FOZ DO IGUACU	509	15. SANTA VICTORIA	23
6. ASUNCION	210	16. PASO de los TOROS	253
7. CURITIBA	3,114	17. DURAZNO	308
8. FLORIANOPOLIS	115	18. MONTEVIDEO	72
9. IRAI	709	19. BUENOS AIRES	66
10. POSADAS	446	20. MAR del PLATA	66

Figure 5-43. Climatic Station Network, Southern Brazilian Highlands/Parana Plain.

SOUTHERN BRAZILIAN HIGHLANDS/PARANA PLAIN GEOGRAPHY

TERRAIN. The zone is characterized by an elaborate pattern of hills, low mountains, and plateaus. Elevations range from 3,000 to 4,000 feet (915 to 1,220 meters), with a few peaks near 6,000 feet (1,830 meters) in the southeastern sector. The eastern extent of the Highlands descends abruptly to the sea, either over a series of steps or in one steep slope. There is no true coastal plain, but rather areas of sandbars or sand dunes, white sandy beaches, and lagoons. The largest of these is in the southeast corner of Brazil. The Parana Plain is characterized by occasional ridges, low plateaus, and rolling hills alternating with broad valleys; elevations do not exceed 2,000 feet (610 meters). Sand dunes and tidal lakes are along the coastline.

WATERWAYS AND DRAINAGE. Numerous small rivers and streams meander through this zone, especially in the southeastern half of Paraguay, part of the Parana Plain. Major rivers are the Iguaza, Alto Parana, Paraguay, Uruguay, and Negro.

The Iguaza begins in Brazil and later forms the northern boundary between Brazil and Argentina. It feeds the Iguaza Falls. The Iguaza Falls, located near 26° S, 54° W, are horseshoe-shaped, nearly 2 1/2 miles wide. The falls vary from 200 to 269 feet (60 and 82 meters) in height.

The Alto Parana, flowing southerly initially, converges at the Brazil and Paraguay border to intersect with the Iguaza River and the Iguaza Falls. It becomes the boundary between Paraguay and Argentina, turns west near 27° S, 56° W, and eventually flows into the Paraguay and Parana Rivers.

The Paraguay flows from north to south along the western border of the zone. The Uruguay flows from east to west in Brazil to the Argentina border. It turns south near 54° W to form the Brazil-Argentina border, then finally forms the Uruguay-Argentina border. The Negro River runs east-west; nearly all of it is in Uruguay.

The Alto Parana, Uruguay, and Rio Negro eventually reach the sea through the Rio de la Plata near Buenos Aires. Lagoa dos Patos and Mirim Lake are tidewater lagoons and lakes navigable by shallow vessels. Mirim Lake drains northeastward into Lagoa dos Patos. The waters of Lagoa dos Patos enter the sea through an opening in a sandbar near the port of Rio Grand do Sul.

VEGETATION. The zone contains mostly grassland, with a mixture of transitional palm forest near its center. A woodland area of pine forest covers the east-northeast. Mangrove trees and dune vegetation grow along the Atlantic shore. Vegetation is mainly cultivated fields, vineyards, scattered orchards, and grasslands. Tall, rich prairie grasses and trees are common in uncultivated areas. Broadleaf and evergreen forest, swamps, and marshes are also found, especially along rivers and streams.

SOUTHERN BRAZILIAN HIGHLANDS/PARANA PLAIN CLIMATIC PECULARITIES

Strong "ENSO" (El Niño-Southern Oscillation) events cause a dramatic intensification and lengthening of the wet season. Effects are most pronounced between 25° and 35° S. Frontal systems become quasi-stationary, with extensive overrunning and sustained moderate to heavy rains. Rivers flood early in the season, and remain out of their banks for most of the summer and into early fall. Multilayered frontal clouds, embedded thunderstorms, poor low-level visibilities, and all the usual flight and ground hazards associated with such situations are present. Note that a strong ENSO event, with heavy convection over Ecuador and Peru, is the necessary precursor.

Following is one synoptic explanation from preliminary research done by South American meteorologists using data from the 1982-1983 ENSO.

After establishment of abnormally southward-sustained convection on the Pacific South American coast, the upper-level Bolivian high shifts northwestward. A flat upper-level trough becomes quasistationary along 60° W south of 20° S. The South Atlantic High intensifies, but maintains a more equatorward position than normal, blocking the normal northward frontal system penetration into central Brazil. The Subtropical Jet becomes quasistationary from west-northwest to east-southeast along a Paraguay-southern Brazil-northern Uruguay line. Cyclogenesis apparently occurs along stationary frontal systems in southern Paraguay; waves then track southeastward across extreme southern Brazil and northern Uruguay into the South Atlantic.

More research by both South and North American meteorologists is ongoing. The 199
1992 ENSO may produce a similar sequence

GENERAL WEATHER. Summer is the wet season as the South Atlantic High moves southeast and reduces subsidence. Conditionally unstable air from the Amazon basin and wind flow off the Atlantic Ocean exert a greater influence, producing high temperatures, high humidities, showers, and thunderstorms. Instability is triggered by afternoon heating, frontal passages, upper-air troughs, and orographic lift. Thunderstorms can produce large hail, gusty winds, lightning and tornados, especially when associated with MCSs and squall lines. Hot, humid conditions are generally more intense on the Parana Plain.

Two types of frontal systems are common: the pampero and the sudestada. Pamperos, occurring most often from October through December, result from a strong fast-moving cold-air outbreak that crosses the southern Andes or southern Argentina and drives rapidly northeastward. They are initially dry and not overly active; however, by the time they reach the zone during warmer months, pamperos collide with moist tropical air and produce severe thunderstorm activity. They can cause squall lines and produce some of the worst thunderstorms in all of South America. The few pamperos that occur in cool months generally remain dry and are much less active. Strong northwesterly winds signal the approach of the strongest pamperos; they are followed by strong southerly winds, falling temperatures, and rapid clearing. Pampero effects are most pronounced toward the zone's southwest and west.

A sudestada occurs when a slow-moving, weak front precedes a shallow moist air mass wedged beneath a warm stable one. They are most important when a strong frontal low develops and causes strong post-frontal southeasterly flow. Sudestadas result in several days of low stratiform clouds, fog, drizzle, and rain spread out over a large area; this is most common in the zone's south and west. Such conditions are more pronounced and more persistent over slopes and coastal areas east of the highlands where the air mass butts up against the highlands and stagnates. High elevations, on the other hand, are least affected since the top of the invading air mass is often lower than the terrain. Sudestadas occur most often in winter, but those occurring in spring penetrate the farthest north. Strong winds occur along and inland 100 miles from the Atlantic coast and over the Rio de La Plata immediately behind rapidly intensifying cyclones moving southeastward from the coast. Extreme wind gusts at the Rio de la Plata mouth have exceeded 95 knots.

SKY COVER. The frequent interaction of moist air from the Amazon and Atlantic and the relatively dry continental air from Argentina results in active, cloudy weather. Sky cover averages slightly over 70% in the north to just under 50% in the south (see Figure 5-44). Maximum cloudiness occurs during early afternoon, with peak heating. Afternoon cumuliform clouds have 4,000-foot (1,220-meter) AGL bases and tops reaching 15,000 to 20,000 feet (4,575 to 6,100 meters). Stratiform clouds form along portions of the coast and inland near rivers, streams, and other low-lying areas; bases average 2,000 feet (610 meters) AGL; tops, 6,000 feet (1,830 meters). Clouds usually dissipate by mid-morning or early afternoon.

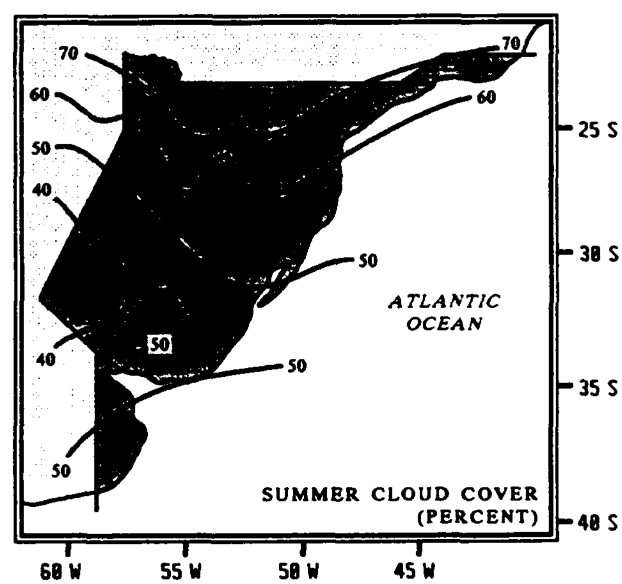


Figure 5-44. Mean Summer Cloud Cover, Southern Brazilian Highlands & Parana Plain.

Ceilings as low as 500 feet (150 meters) AGL can develop along the coast with light onshore flow. Nimbostratus bases may start out at the same height as other low-level clouds, but eventually lower to 500 feet (150 meters) AGL. Altocumulus and altostratus bases average 12,000 feet (3,660 meters) AGL. Cumulonimbus tops reach 50,000 feet (15.2 km); bases are often below 1,000 feet (305 meters) AGL.

The frequency of ceilings below 3,000 feet (915 meters) AGL averages 31% for the entire zone. Curitiba, on the highlands' eastern slopes, has the highest frequency due to orographically lifted maritime air (see Figure 5-45).

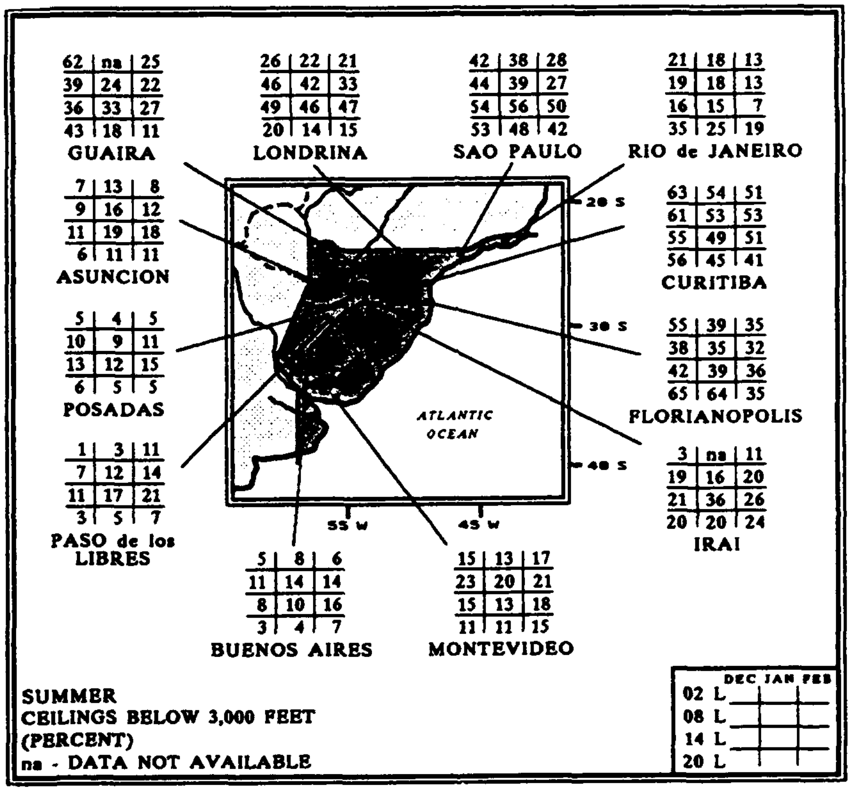


Figure 5-45. Summer Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Brazilian Highlands & Parana Plain.

VISIBILITY. The primary visibility restriction is precipitation from heavy convective and frontal rainshowers. Fog also restricts visibility, primarily at sunrise; it usually dissipates by 0900L. Haze and smoke from pollution restrict visibilities in cities and industrial areas. Figure 5-46 shows tabular visibility data at various places.

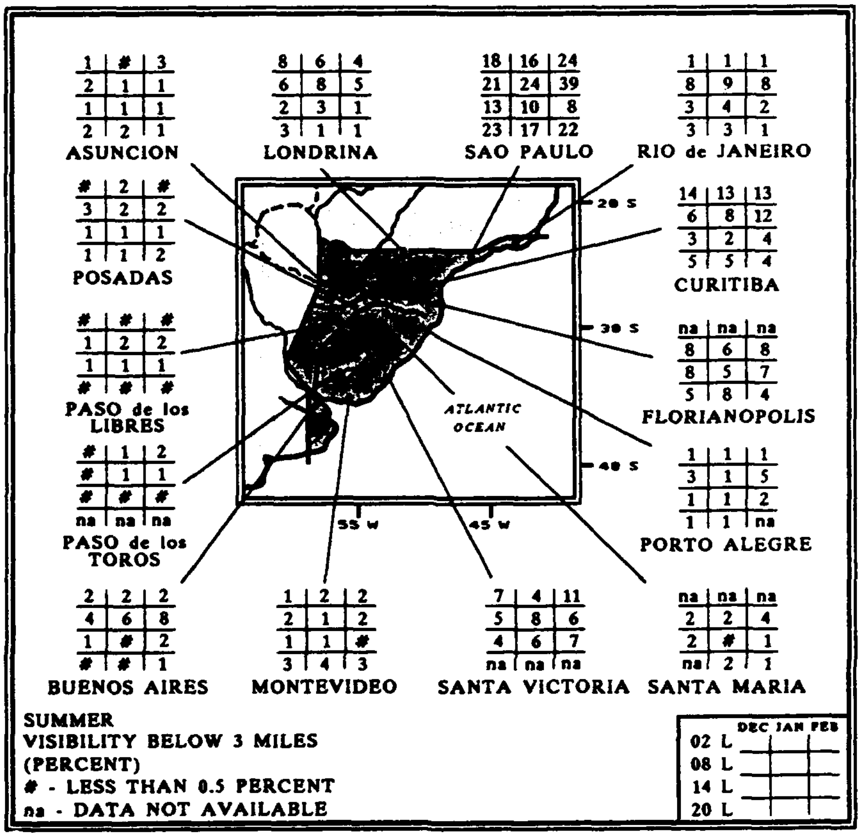


Figure 5-46. Summer Percent Frequencies of Visibility Below 3 Miles, Southern Brazilian Highlands & Parana Plain.

WINDS. The combined circulation of the Northwest Argentine Depression (NAD) and the South Atlantic High results in predominantly northerly flow (see Figure 5-47). Surface winds west of the highlands are generally northeasterly, but winds along the highlands' western slopes are mostly variable. In the highlands, daytime winds vary from west-northwest to east-northeast due to differential heating and cooling of slopes and valleys; nighttime drainage winds reverse the direction. Winds are primarily easterly along the coast from Rio de Janeiro to Florianapolis. Along the rest of the coast, winds are northerly to southeasterly. A weak land/sea breeze forms in the absence of strong synoptic flow.

Wind speeds generally range between 4 and 13 knots (Figure 5-48). The strongest winds are normally in the afternoon near Mar del Plata. Strong surface winds often accompany frontal passages. Generally, the stronger the frontal wind, the shorter its duration; strong pamperos last 2 to 3 hours, while weaker ones may last 1 or 2 days. The highest wind speed recorded during summer was 63 knots at Rio de Janeiro in January.

An unusually severe wind occurs at Santos, on the east side of a small island reached by sea through a narrow channel about 5 miles long. When winds blow off the mainland, temperatures approach 100° F (38° C). The contrast with the cooler air over the ocean results in a great rush of cool air funneled through the channel. Winds have been known to nearly reach hurricane velocity here. Sometimes this phenomenon occurs twice in a single day.

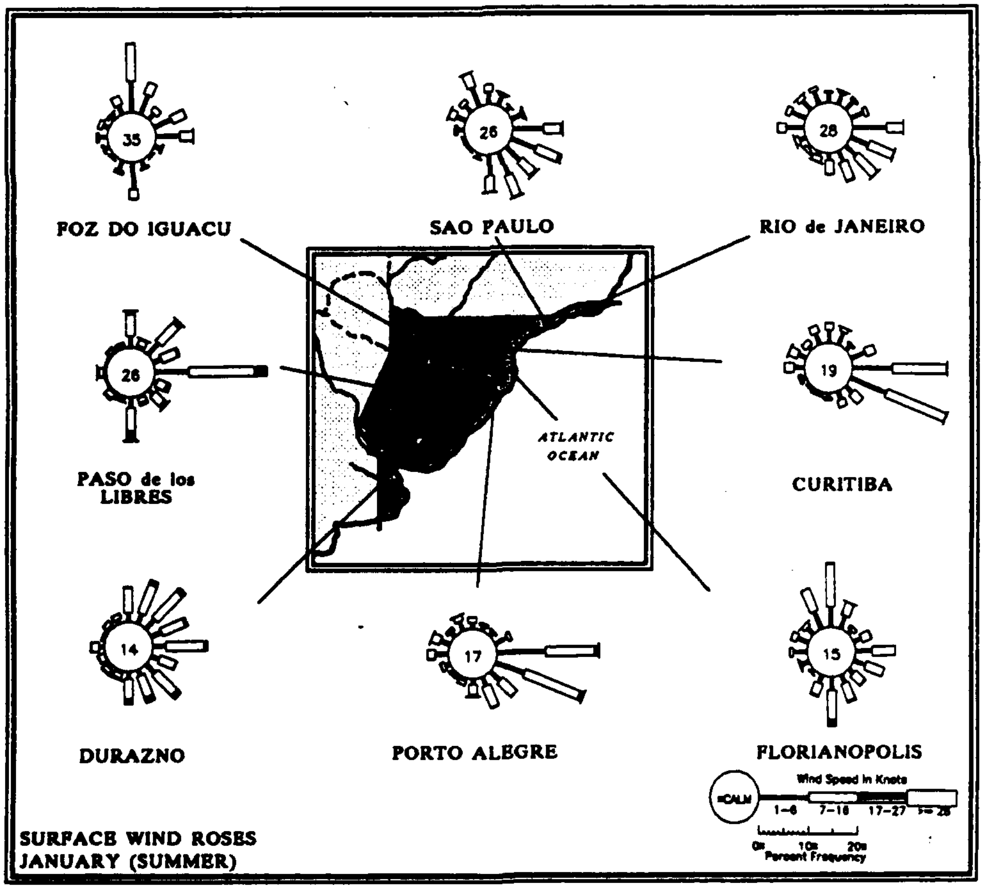


Figure 5-47. January Surface Wind Roses, Southern Brazilian Highlands & Parana Plain.

STATION	MEAN WIND SPEED		
	DEC	JAN	FEB
ASUNCION	4	5	5
BUENOS AIRES	6	6	6
CURITIBA	7	6	6
FLORIANOPOLIS	7	7	6
LONDRINA	5	5	5
MAR del PLATA	13	12	12
MONTEVIDEO	9	9	9

STATION	MEAN WIND SPEED		
	DEC	JAN	FEB
PASO de los LIBRES	8	8	7
PASO de los TOROS	7	7	7
PORTO ALEGRE	5	4	5
POSADAS	7	7	6
RIO de JANEIRO	5	5	5
SANTA MARIA	7	7	7
SAO PAULO	5	5	4

***Figure 5-48.* Mean Summer Wind Speeds, Southern Brazilian Highlands & Parana Plain.**

Winds below 10,000 feet (3,050 meters) MSL are northwest through west over the entire zone; speeds average 15 knots. Winds above 15,000 feet (4,570 meters) MSL vary from southwest to west-northwest. Speeds increase with altitude, from 15 knots at 15,000 feet (4,570 meters) MSL to 45 knots at 40,000 feet (12.2 km) MSL. Figures 5-49 through 5-51 show mean upper-level wind directions for selected stations.

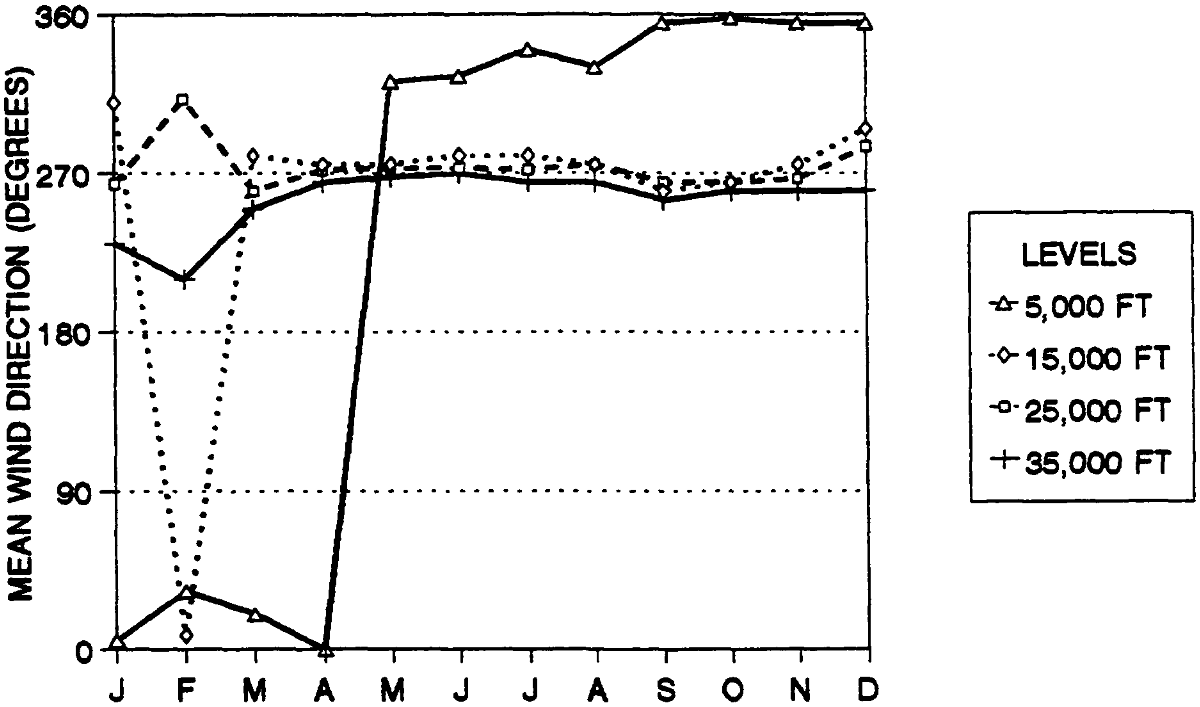


Figure 5-49. Mean Monthly Wind Directions for Various Levels at Rio De Janeiro.

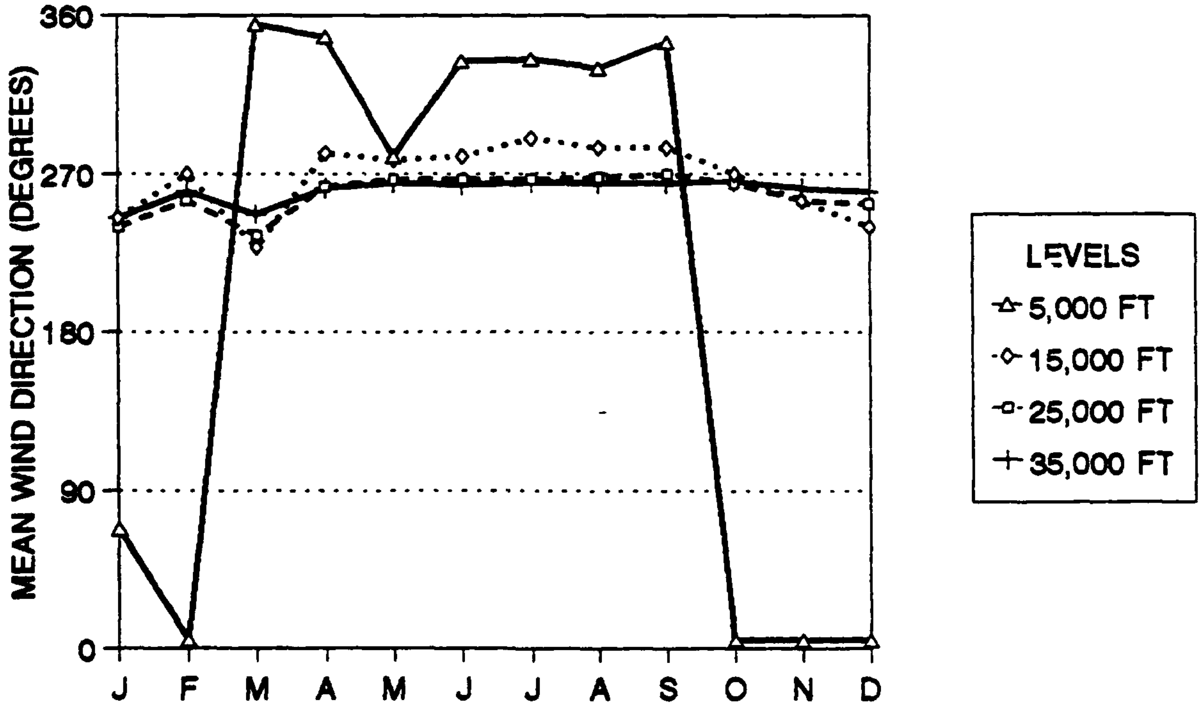


Figure 5-50. Mean Monthly Wind Directions for Various Levels at Asuncion.

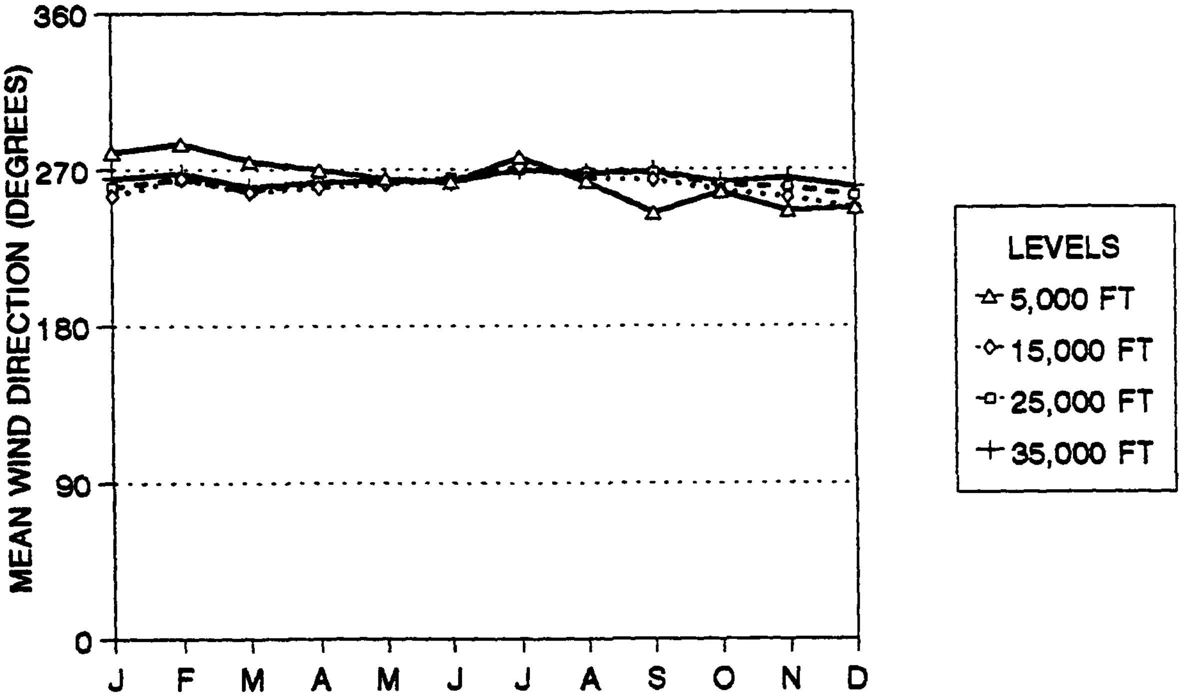


Figure 5-51. Mean Monthly Wind Directions for Various Levels at Buenos Aires.

PRECIPITATION. Showers forming in moist, unstable air produce large amounts of rainfall in a short period of time. Frontal activity and Mesoscale Convective Systems (MCSs) generate the strongest development. MCSs are most frequent over southeastern Paraguay and northeastern Argentina (see Chapter 2). They occur most often from late afternoon through evening; the heaviest rainfall occurs in the highlands. Heavy rainfall along the highlands' eastern slopes is enhanced by a combination of afternoon heating, sea breezes, and orographic lift (Figure 5-52). Precipitation occurs on an average of 12 days a month throughout the zone. Mean monthly amounts range from 2.5 inches (64 mm) at Mar de Plata on the coast to 15.6 inches (396 mm) at Sao Paulo along the highlands' eastern slopes (Figure 5-53). The extreme monthly total was at Sao Paulo (29.7 inches/754 mm).

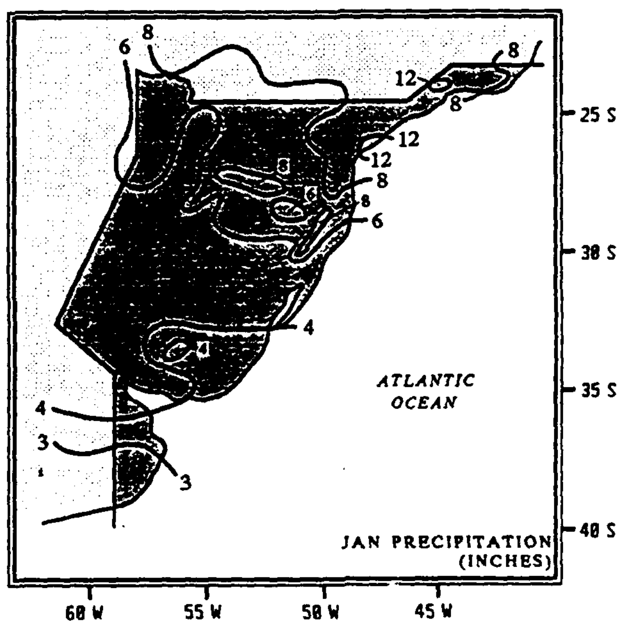


Figure 5-52. Mean January Precipitation, Southern Brazilian Highlands & Parana Plain.

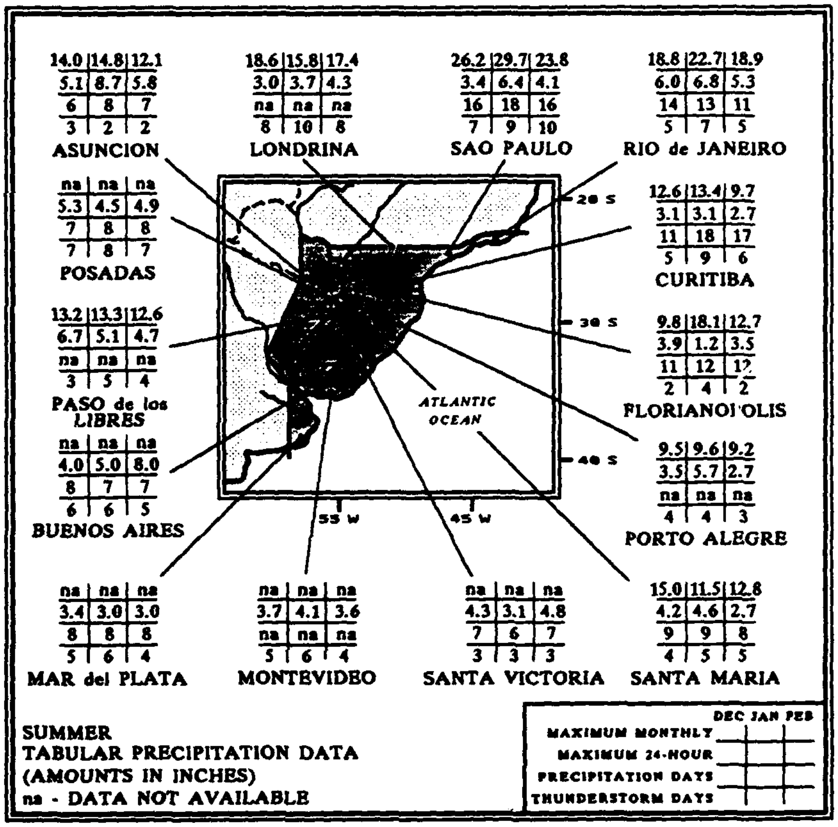


Figure 5-53. Summer Tabular Precipitation Data, Southern Brazilian Highlands & Parana Plain.

THUNDERSTORMS. The zone averages 8 thunderstorm days a month. Isolated air-mass thunderstorms occur most frequently in the afternoon and evening and generally move southeastward. Thunderstorms associated with fronts or instability lines are usually in lines or clusters; squall lines or MCSs are possible. Most thunderstorms occur along the coast from Rio de Janeiro to Curitiba and westward to Londrina. Coastal activity often correlates with land and sea breezes; cells often occur a few miles inland during the afternoon and offshore at night. Thunderstorms can be severe, producing torrential rains, winds in excess of 50 knots, hail, lightning, and tornados. Cumulonimbus bases can be below 1,000 feet (305 meters) AGL, with tops reaching 50,000 feet (15.2 km).

TEMPERATURES. Increased insolation and the maritime tropical air result in higher temperatures. Adiabatic warming along the western slopes of the highlands can pr^duce extreme temperatures. Mean daily highs range from 93° F (34° C) at Asuncion in the interior to 75° F (24° C) along the southern coast (Figure 5-54). The record high of 115° F (46° C) was recorded at Paso de los Libres in December. Temperatures along the coast are generally lower due to maritime influences. Mean daily lows range from 53° F (11° C) to 76° F (24° C). The lowest temperatures are along the southern coast; the record low (32° F/0° C) was at Mar del Plata in December.

Average relative humidity ranges from 91% at 0700L to 58% at 1300L. Humidities often average 65% or more from Florianapolis to Londrina during the afternoon due to the sea breeze, which brings in cool, moist air as well as brief, heavy showers. Figure 5-55 shows mean and maximum wet-bulb globe temperatures for selected stations.

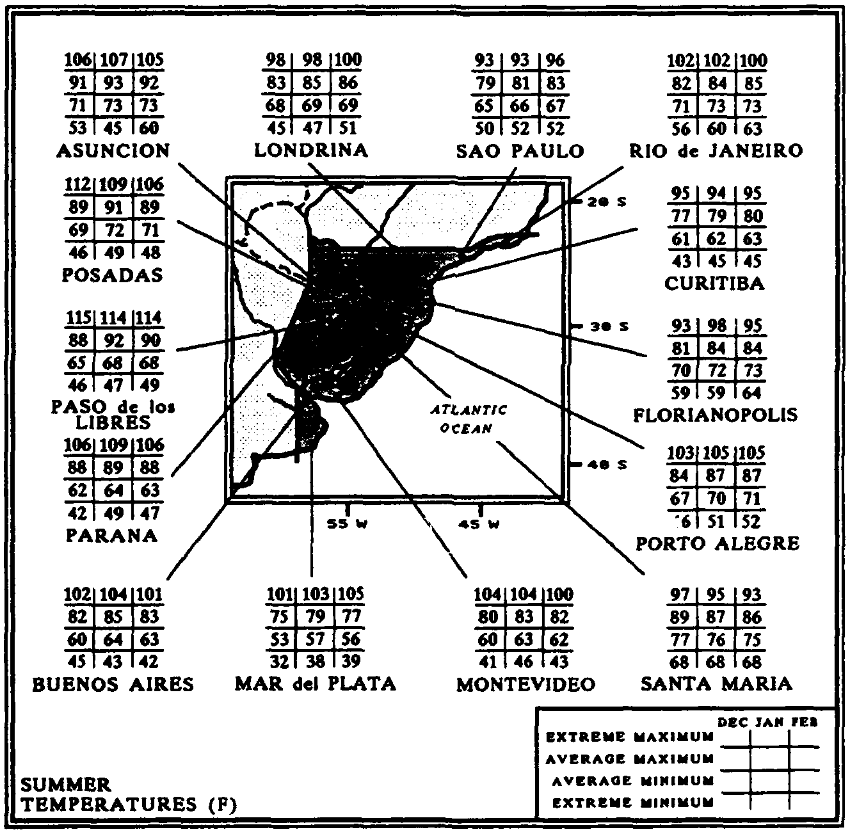


Figure 5-54. Summer Tabular Temperature Data, Southern Brazilian Highlands & Parana Plain.

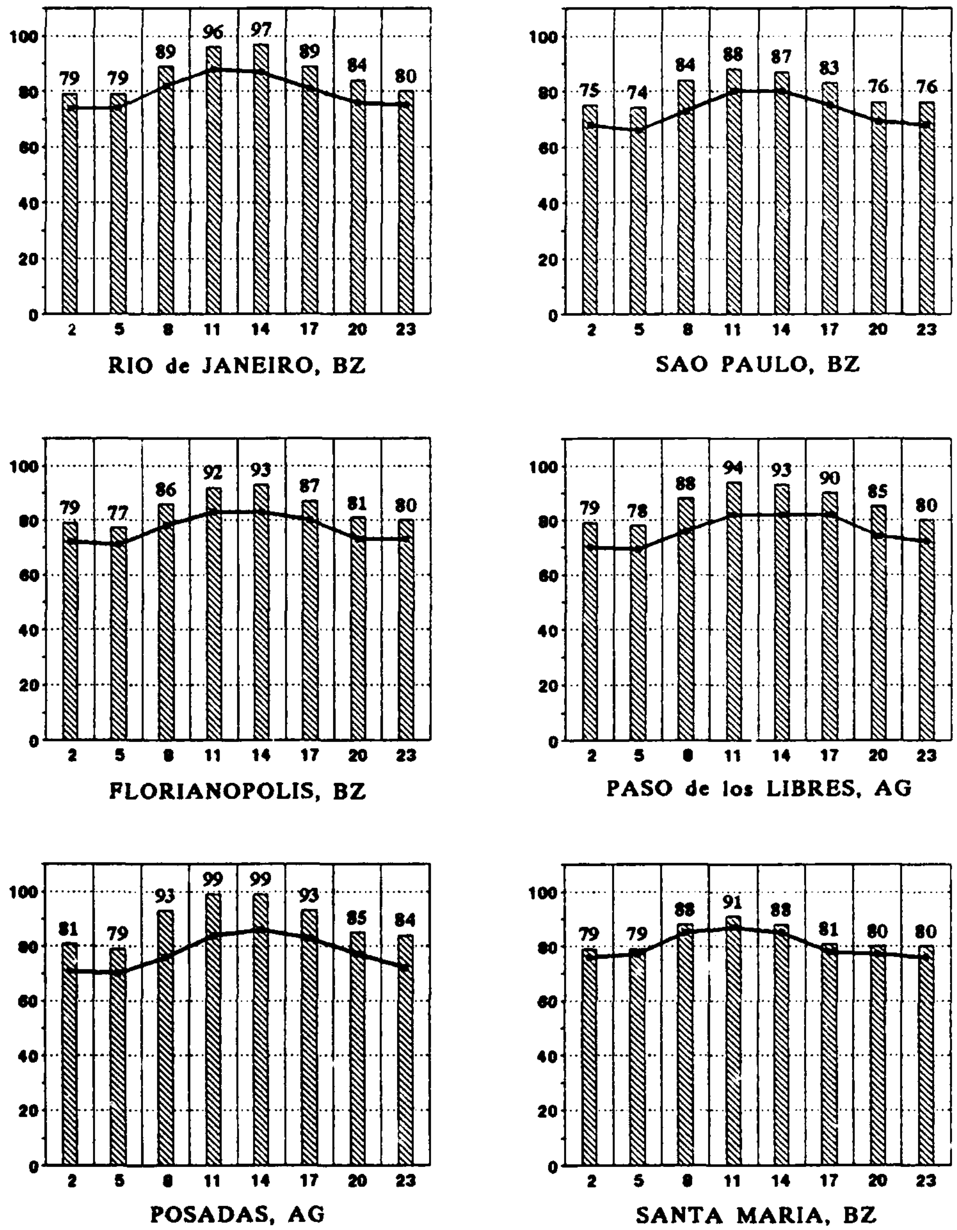


Figure 5-55. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Southern Brazilian Highlands & Parana Plain. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Turbulence is produced by thunderstorms, intense surface heating, and topography. Thunderstorms produce moderate to severe turbulence. Light to moderate, low-level turbulence is likely with strong winds over rough terrain or with convective currents rising from intense surface heating. Light rime to severe mixed icing is highly probable in clouds above 17,000 feet (5,180 meters) MSL.

GROUND HAZARDS. Thunderstorms occur more often and with greater severity during summer; they produce tornados, hail, and lightning. Heavy rain showers produce large amounts of rain in short periods, particularly in the highlands where they result in flash flooding; roads and bridges can be washed out or made impassable.

GENERAL WEATHER. As the South Atlantic High moves northwestward from its mean summer position, the easterly trade winds strengthen, subsidence increases, and Amazon moisture shifts northward. By mid-season, cloud cover, as well as the frequency and intensity of thunderstorms, decreases. Tornados, hail, and flooding are still possible, but mid-fall loosely marks the end of the wet season. Fall's poor weather is caused by fronts (see pamperos and sudestadas in summer's "General Weather"), upper-air disturbances, MCSs, squall lines, and orographic lift; local wind systems such as land/sea and mountain/valley breezes can enhance clouds and precipitation.

SKY COVER. Subsidence from the South Atlantic High generally results in decreasing cloudiness and widespread fair weather. The easterly trade winds bring moisture to the coast, but the interior is drier because moisture from the Amazon stays north. Mean cloudiness ranges from 70% in the north to 40% in the west-southwest (see Figure 5-56).

During the first half of fall, before the South Atlantic High is established, maximum cloudiness is in the afternoon. Scattered cumulus developing about noon with bases averaging 4,000 feet (1,220 meters) AGL with tops reaching 15,000 feet (4,575 meters) develop about noon. Cumulonimbus tops exceed 45,000 feet (13.7 km), with bases as low as 1,000 feet (610 meters) AGL.

Maximum cloudiness in the second half of fall occurs during the late evening and early morning, generally with stratus and stratocumulus. Bases average 2,000 feet (610 meters) AGL, while tops average 6,000 feet (1,830 meters). Altocumulus and altostratus are also common, with 12,000-foot (3,660-meter) AGL bases and tops to 15,000 feet (4,575 meters).

Sudestadas become more common by season's end, causing extensive layers of low stratus beneath nimbostratus. The resulting cloud decks often merge and reach 18,000 to 20,000 feet (5.5 to 6.1 km) MSL. Such conditions are usually confined to the Rio de la Plata, Mesopotamia, and coastal sections within 150 miles of a developing cyclone.

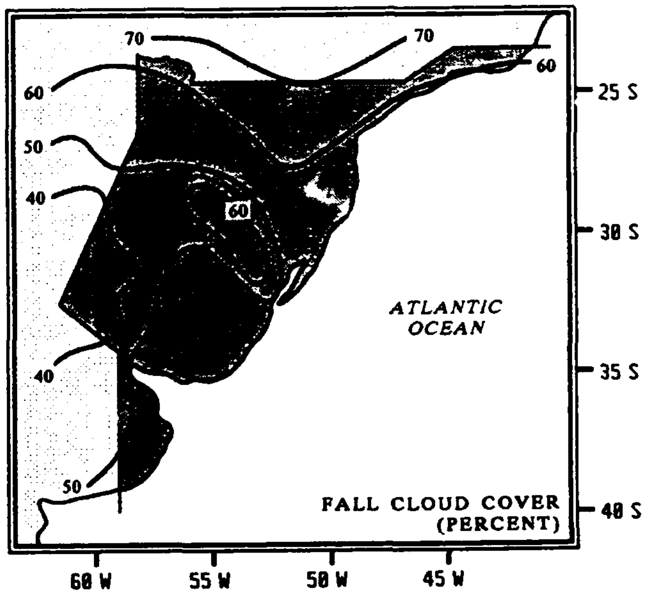


Figure 5-56. Mean Fall Cloud Cover, Southern Brazilian Highlands & Parana Plain.

Ceilings below 3,000 feet (915 meters) AGL are most frequent around sunrise, generally dissipating by mid-morning. Low-ceiling frequencies range from a mean of 11% at Posadas in the interior to 47% at Curitiba on the eastern slopes (Figure 5-57). Low ceilings are often observed near 1,000 feet (305 meters) MSL along the coast. Ceilings can be as low as 500 feet (150 meters) MSL during the afternoon with onshore flow.

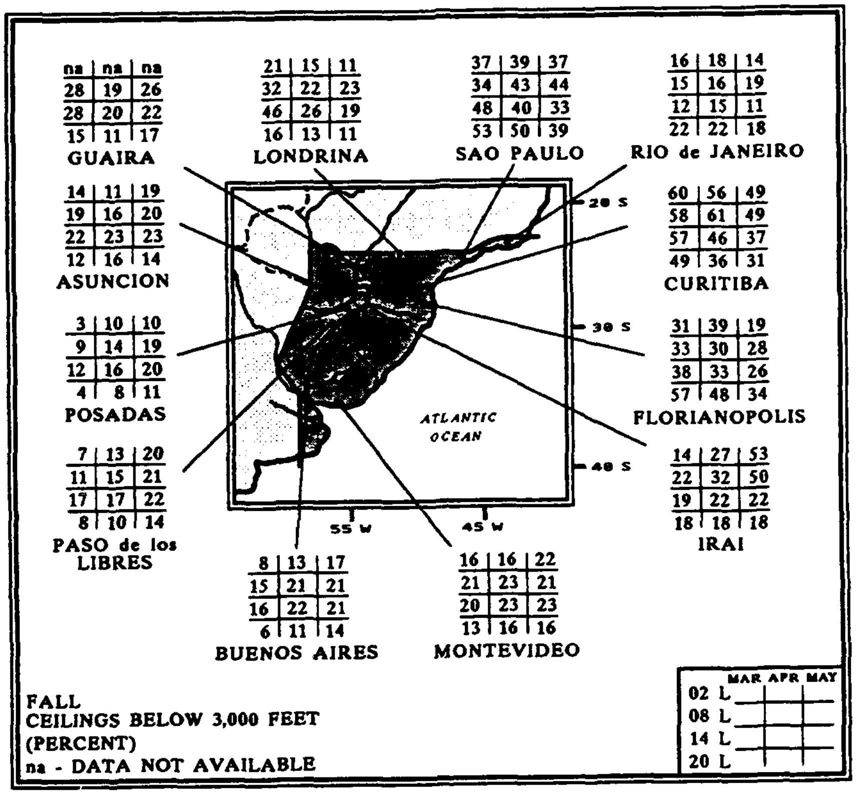


Figure 5-57. Fall Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Brazilian Highlands & Parana Plain.

VISIBILITY. The frequencies of visibility below 3 miles increase during the fall to an average of 30%. Precipitation remains the primary cause through March, but in April, subsidence from the South Atlantic High causes fog and haze to become more widespread. Stronger southeast winds significantly increase the occurrence of fog, particularly from Rio De La Plata northward along the coast. The fog is worst from predawn through 0800L (Figure 5-58); visibilities can be as low as 5/16 of mile. Fog and precipitation also combine to reduce visibilities during sudestadas. Sao Paulo, Curitiba, and Buenos Aires generally report the zone's poorest visibilities.

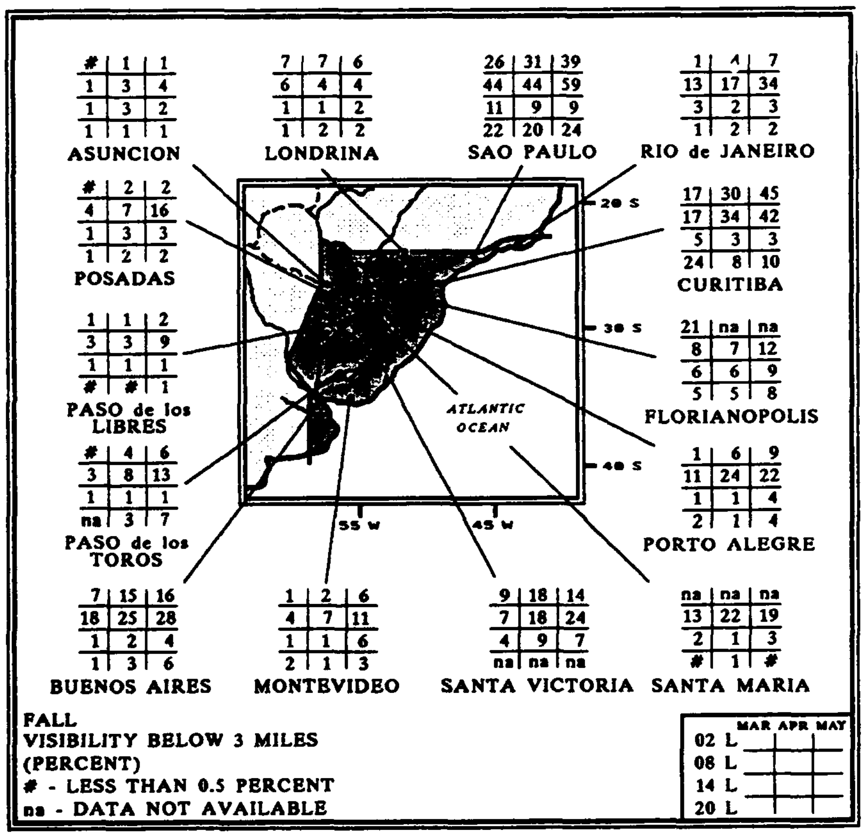


Figure 5-58. Fall Percent Frequencies of Visibility Below 3 Miles, Southern Brazilian Highlands & Parana Plain.

WINDS. South Atlantic High circulation expands, resulting in easterly trades over the northern coast. From Rio de Janeiro through Curitiba, surface winds are predominantly east through south-southeast. A land/sea breeze circulation modifies the flow at locations along the coast; it is particularly evident from Florianapolis to Porto Alegre. The rest of the coast south of Lagoa dos Patos is dominated by northerly flow. In the highlands, surface winds are primarily easterly; mountain/valley breezes modify the flow. Along the western slopes of the highlands, surface winds are light and variable, but frequently have an east-northeast to east-southeast component. Surface winds are predominantly easterly west of the highlands to the Parana River.

Mean wind speeds range from 3 to 10 knots; the highest speeds are usually during the afternoon. The strongest mean winds for the zone are at Mar del Plata (Figure 5-60). Near Rio de Janeiro, northwest squalls called "Terre Altos" can last 5 or 6 hours. The highest fall wind speed was 56 knots at Buenos Aires. Occasionally, southeasterly sudestada winds exceed 35 knots when frontal lows intensify near the coast. Rapidly intensifying systems have caused speeds to reach well over 50 knots.

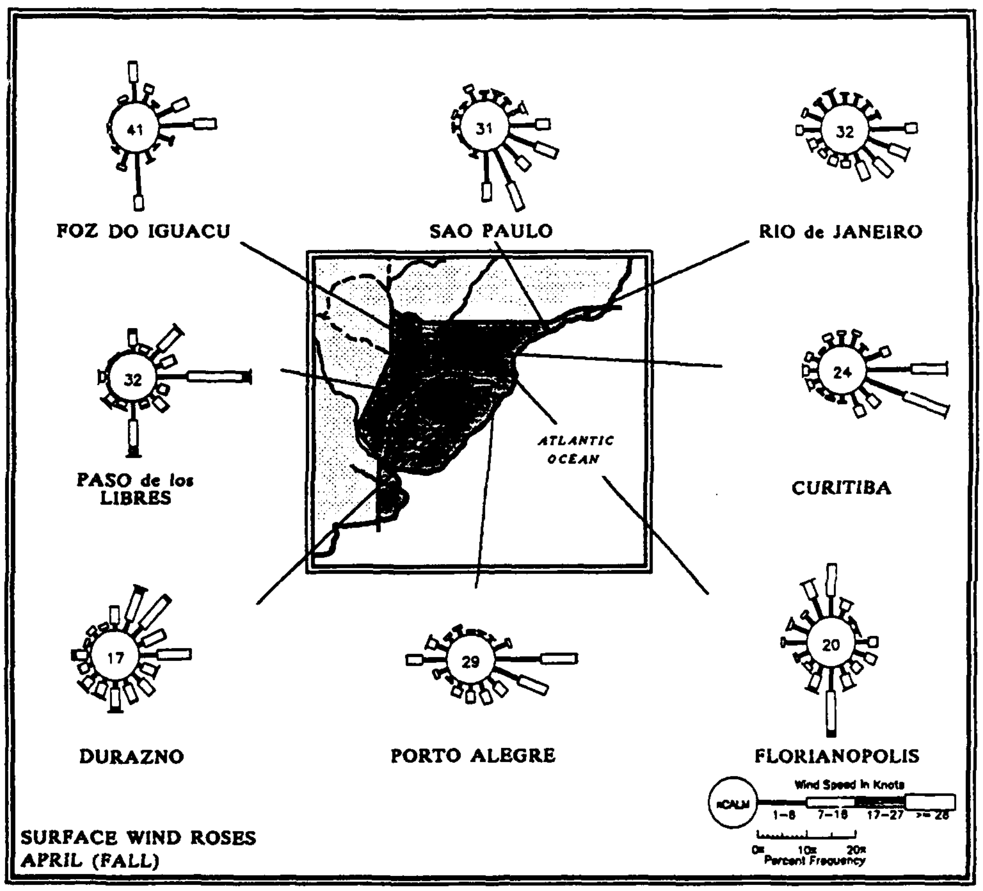


Figure 5-59. April Surface Wind Roses, Southern Brazilian Highlands & Parana Plain.

STATION	MEAN WIND SPEED MAR	APR	MAY
ASUNCION	5	5	5
BUENOS AIRES	5	5	4
CURITIBA	6	6	5
FLORIANOPOLIS	6	6	6
LONDRINA	5	5	4
MAR del PLATA	10	9	9
MONTEVIDEO	8	8	8

STATION	MEAN WIND SPEED MAR	APR	MAY
PASO de los LIBRES	7	7	7
PASO de los TOROS	7	6	6
PORTO ALEGRE	6	5	5
POSADAS	4	4	5
RIO de JANEIRO	5	4	4
SANTA MARIA	6	6	6
SAO PAULO	4	5	3

Figure 5-60. Mean Fall Wind Speeds, Southern Brazilian Highlands & Parana Plain.

Upper-level winds below 10,000 feet (3,050 meters) MSL range from southwest to northwest at 13 to 19 knots. Above 15,000 feet (4,570 meters) MSL, the prevailing direction is westerly at 20-40 knots. Speeds increase with altitude to 40,000 feet (12.2 km) MSL where they reach a mean maximum of 60 knots. The Subtropical Jet is normally located near 33° S with core speeds averaging 70 knots between 35,000 and 40,000 feet (10.6 and 12.2 km) MSL. Upper-air wind directions are shown in Figures 5-49 through 5-51.

PRECIPITATION. The wet season extends into fall, gradually tapering off by April or May depending on location. The South Atlantic High increases stability as the season progresses, but moist, convectively unstable air is still present at times. Precipitation falls primarily as showers from afternoon heating and orographic lift along the coast and highlands' eastern slopes; steady rain and drizzle become more common as it becomes cooler. Sea breezes can still enhance precipitation a few miles inland. Fall's maximum 24-hour rainfall is near the coast; 8.8 inches (225 mm) fell at Rio de Janeiro in April and an MCS caused 11.8 inches (300 mm) at Buenos Aires in May of 1985. MCSs are most common west of the highlands; they usually occur during late afternoon and through the evening (see Chapter 2). Paso de los Libres received monthly precipitation amounts of 20.6 inches (525 mm) due to MCSs. Sao Paulo has received 20.9 inches (530 mm) in March; amounts here are due to orographic lift enhancing sudestadas, sea breezes, and prevailing easterly flow. Sao Paulo also records the highest mean monthly precipitation totals, about 7.8 inches (200 mm) a month.

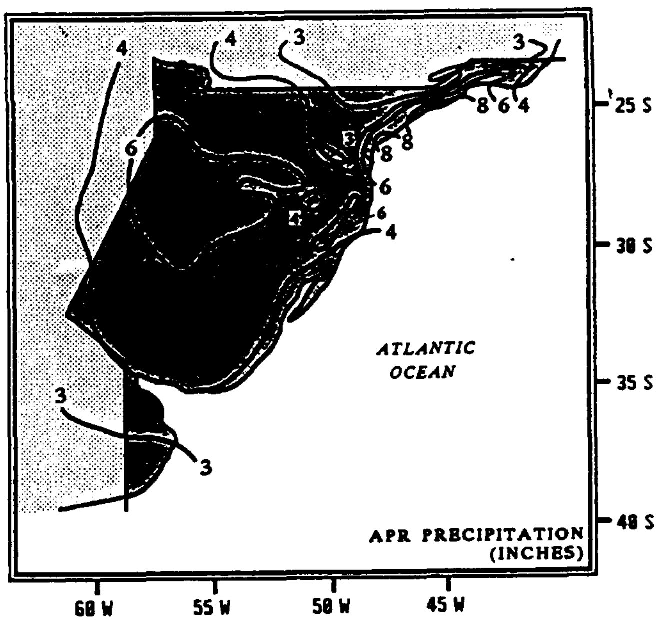


Figure 5-61. Mean April Precipitation, Southern Brazilian Highlands & Parana Plain.

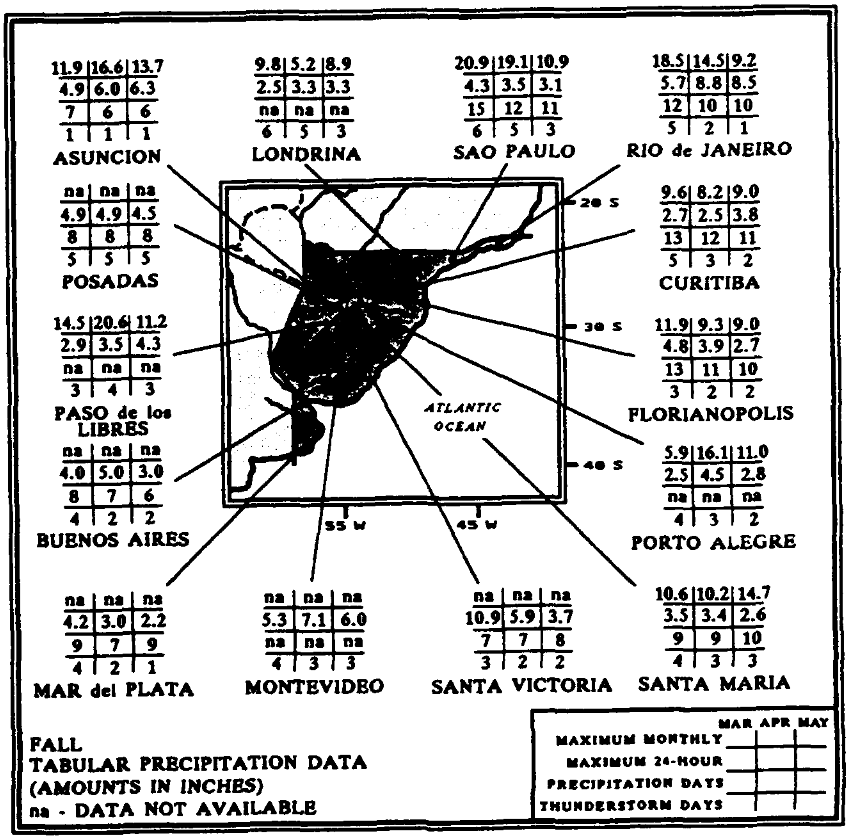


Figure 5-62. Fall Tabular Precipitation Data, Southern Brazilian Highlands & Parana Plain.

THUNDERSTORMS. Thunderstorms occur on an average of 3 days a month. They can be both air mass and frontal. Peak occurrence is from afternoon to early evening. The area around Posadas has the greatest number. Air-mass thunderstorms frequently develop on the western slopes of the highlands during the afternoon. Thunderstorms associated with fronts or instability lines are generally in lines or clusters and can cause severe weather. Early in the season, thunderstorms can produce destructive winds, hail, and tornados. Cloud tops associated with thunderstorms during this season often exceed 40,000 feet (12.2 km); bases range from 6,000 to less than 3,000 feet (1,830 to 915 meters) MSL.

TEMPERATURE. Tropical air still keeps temperatures high, but decreased insolation gradually lowers them. Mean daily highs range from 89° F (32° C) at Asuncion to 62° F (17° C) at Mar del Plata (Figure 5-63). West of the highlands, the prevailing easterlies produce adiabatic warming; an extreme high of 108° F (42° C) was recorded at Pasa de los Libres in March. Mean daily lows range from 43° F (6° C) at Mar del Plata to 76° F (24° C) at Santa Maria. The record low for this season was 25° F (-4° C) at Buenos Aires in May. Relative humidity is generally highest during this season, averaging 93% at 0700L and 61% at 1300L.

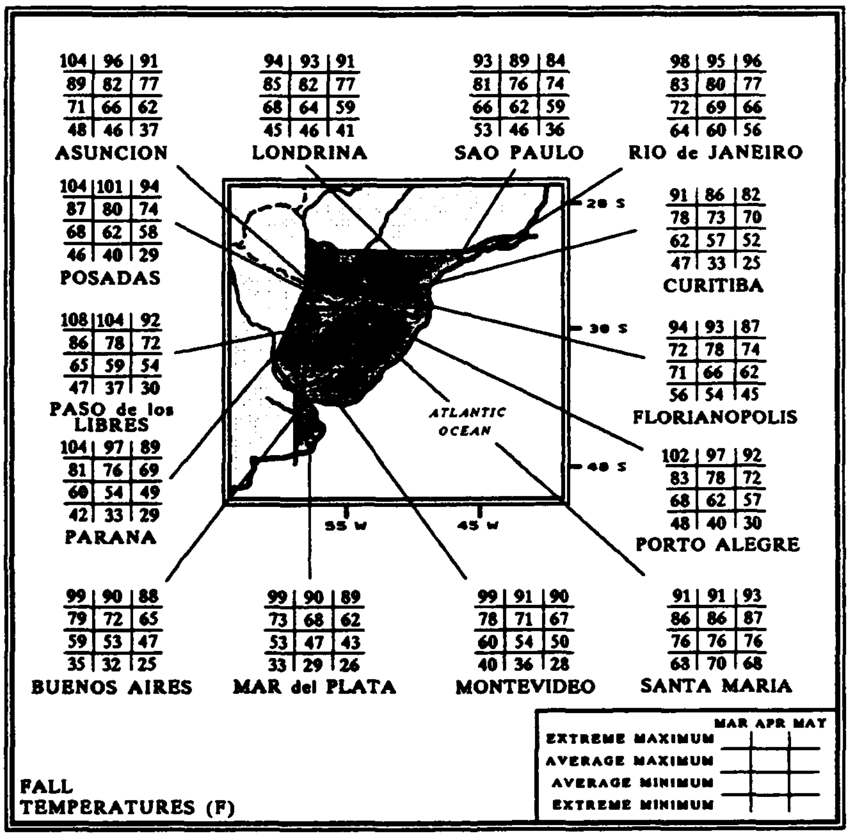


Figure 5-63. Fall Tabular Temperature Data, Southern Brazilian Highlands & Parana Plain.

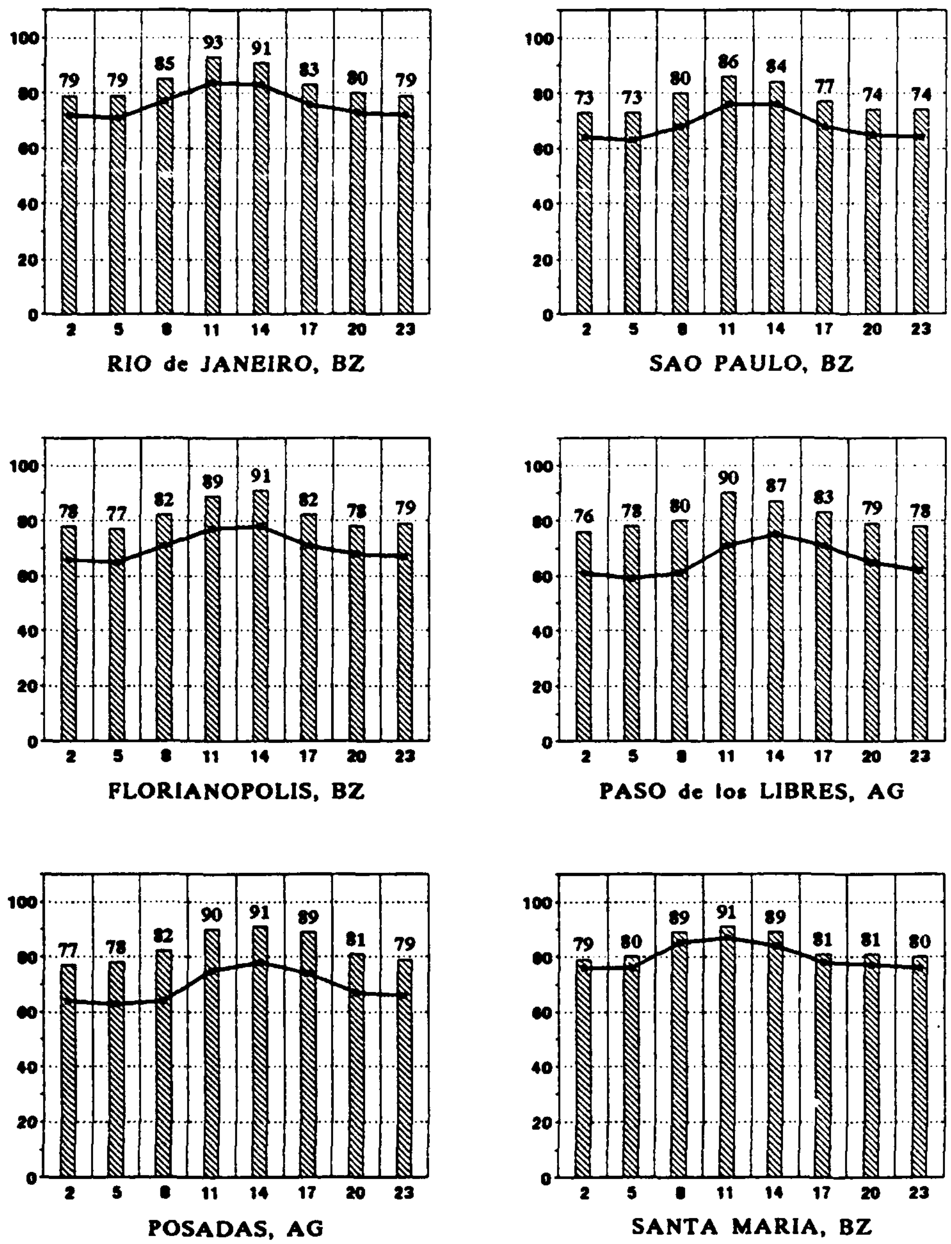


Figure 5-64. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Southern Brazilian Highlands & Parana Plain. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Moderate to severe turbulence occurs with both air-mass and frontal thunderstorms. Local winds caused by differential heating, topography, and frontal passages can also produce moderate to severe turbulence. At altitudes near 40,000 feet (12.2 km), turbulence is associated with the Subtropical Jet. Icing ranging from moderate to severe is to be expected with cold fronts and thunderstorms. Light rime to severe mixed icing occurs in clouds at and above the mean freezing level of 15,000 feet (4,570 meters) MSL. Dense haze and smoke due to widespread burning causes hazardous flying conditions in late fall at the onset of the dry season. Vertical visibility can be restricted to near zero from the surface to 13,000 feet (3,960 meters) MSL, sometimes hiding convective thunderstorms that are only visible on radar. Most haze and smoke dissipates when fronts pass through.

GROUND HAZARDS. Severe thunderstorms with tornados, hail, and intense lightning can still occur in the fall. Heavy rainshowers, particularly in the highlands, may produce flash floods that can wash out roads and bridges.

GENERAL WEATHER. Winter is relatively dry, with widespread fair weather due to subsidence from the South Atlantic High. Maritime influences are evident on the coast and adjacent slopes where clouds and morning fog are most frequent. Polar air masses stagnating over the highlands also cause some morning fog and result in early morning sub-freezing temperatures. The highlands often block Atlantic moisture from the Parana Plain; post-frontal southerly flow is the exception, as Atlantic moisture is channeled northward along the highlands' western slopes. The many swamps and rivers in the plains are sources of moisture for early morning fog and stratus.

Cyclogenesis is frequent over northeastern Argentina and Uruguay. Migratory lows develop in this area two or three times a month; they sometimes intensify and accompany a clearly defined frontal boundary. Most associated fronts may be weak and followed by a shallow maritime air mass, as with sudestadas. Conditions typical of sudestadas include: extensive stratus and stratocumulus; nimbostratus layers with tops at 18,000 to 20,000 feet (5.5 to 6.2 km) MSL; and rain, drizzle, and fog. These conditions can persist for several days, after which there are a few days of scattered stratus and layered altocumulus; amounts decrease with time. There are occasional exceptions in which strong frontal lows produce embedded showers and thunderstorms. Pamperos, on the other hand, are generally dry and characterized by brief cloudiness and precipitation. Summer's "General Weather" section discusses sudestadas and pamperos in detail.

SKY COVER. Mean cloudiness is at a minimum as subsidence from the South Atlantic High and prevailing easterly trade winds limit cloud development. Sky cover averages 50% over most of the zone and 60% along the coast (Figure 5-65). Maximum cloudiness occurs from late night through early morning (2200 to 0500L). Stratus and stratocumulus predominate; bases average 2,000 feet (610 meters) MSL; tops, about 5,000 feet (1,525 meters) MSL. Coastal stratus and stratocumulus can be blocked by (and accumulate against) low ridges. Cumulus can form from late morning through early evening; bases average 4,000 feet (1,220 meters) MSL; tops extend to 15,000 feet (4,570 meters) MSL. Broken to overcast altocumulus and altostratus are normally associated with frontal systems; they normally have bases at about 10,000 feet (3,050 meters) MSL and are 6,000 to 8,000 feet (1,830 to 2,440 meters) thick.

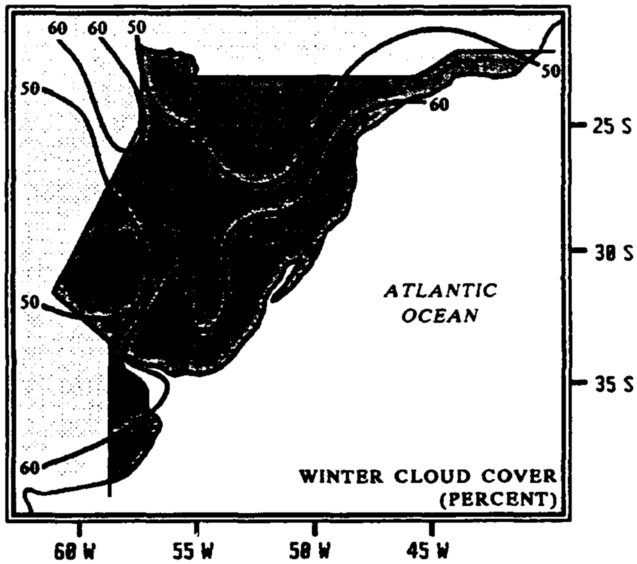


Figure 5-65. Mean Winter Cloud Cover, Southern Brazilian Highlands & Parana Plain.

Ceilings are below 3,000 feet (915 meters) AGL 25% of the time. The coast has the highest frequencies, especially from Sao Paulo to Florianapolis (Figure 5-66). Low ceilings are most common around sunrise. Stratiform ceilings at or below 1,000 feet (305 meters) AGL can occur with frontal passages; they can persist for several days with sudestadas, but may last no more than 2 or 3 hours with drier, fast-moving fronts.

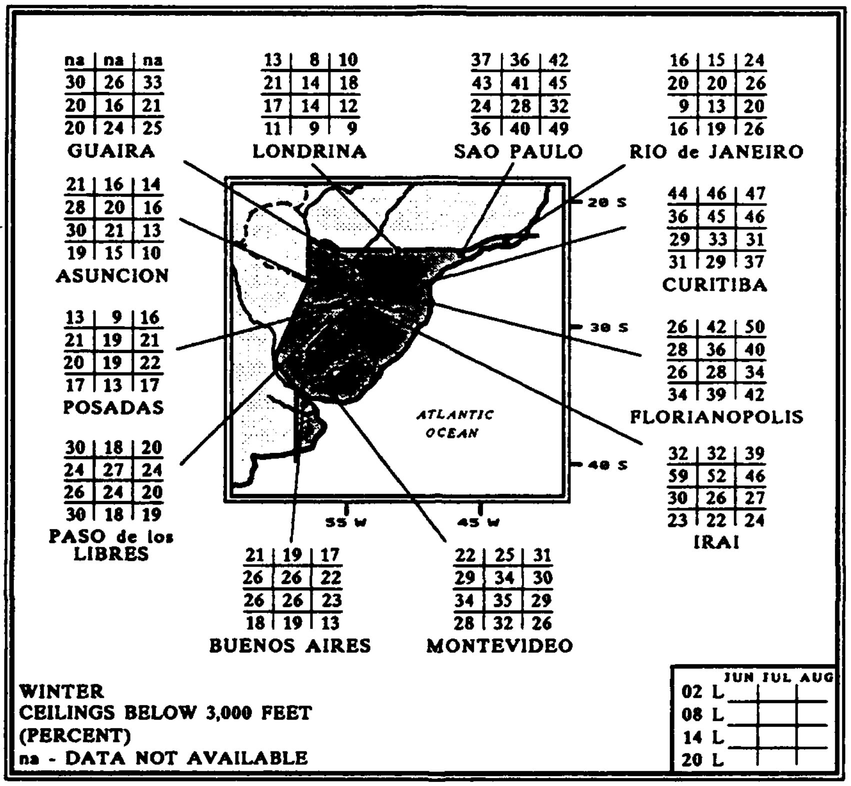


Figure 5-66. Winter Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Brazilian Highlands & Parana Plain.

VISIBILITY. Fog, both radiation and frontal, is the primary visibility restriction. Radiation fog forms in low-lying areas overnight and is generally most extensive between 0300 and 0900L. Normally, radiation fog dissipates by noon, but it can last throughout the day. Fog associated with frontal activity occurs with precipitation in the cold air. Dense fog occurs frequently in the eastern highlands where surges of cold polar air from the south often stagnate along the slopes; the coastline and eastern slopes from Rio de Janeiro to Curitiba are affected most (Figure 5-67).

Haze also significantly restricts visibility from Rio de Janeiro south to Salgado Puerto Alegre and west through Asuncion. Widespread burning of grasslands and forest, along with a stagnant circulation pattern, can produce dense haze and smoke. The haze is confined to below 13,000 feet (3,960 meters) MSL beneath a temperature inversion. As the haze accumulates, visibility can be reduced to as low as 1/4 mile. The haze is normally thinned or dissipated by frontal systems.

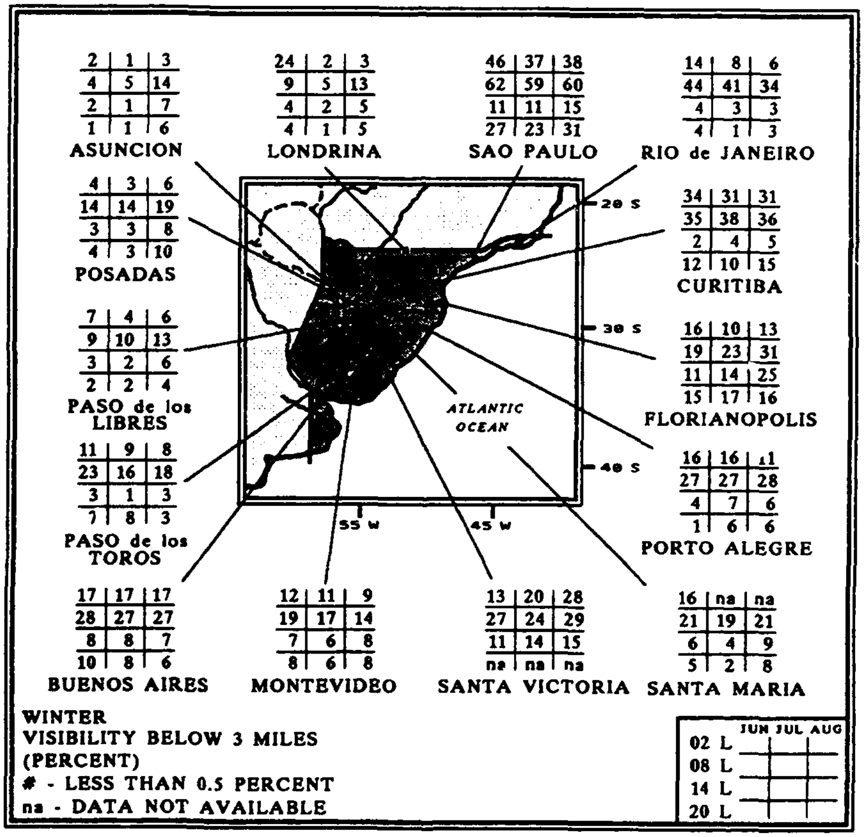


Figure 5-67. Winter Percent Frequencies of Visibility Below 3 Miles, Southern Brazilian Highlands & Parana Plain.

WINDS. The South Atlantic High extends into the zone, resulting in easterly trade winds. Although northeasterly flow is predominant, it is greatly influenced by topography; surface winds west of the highlands to the Parana River, reflect this. Winds along the western slopes of the highlands are light and variable, but the primary direction down the slopes is easterly. In the highlands, winds vary from west-northwest to east-northeast due to mountain/valley breezes. Localized land/sea breezes are found along the coast. From Rio de Janeiro to Florianapolis, winds are northwest through east-northeast. A land/sea breeze is also found south of Florianapolis near Porto Alegre. The rest of the coast south of Lagoa dos Patos is dominated by northerly flow.

Wind speeds generally range from 3 to 11 knots, with the highest speeds in the afternoon. The strongest mean winds are near Mar del Plata (Figure 5-69). Near Rio de Janeiro, northwest squalls called "Terre Altos" persist for 5 or 6 hours. The highest winter wind recorded was 65 knots at Rio de Janeiro in July. A strong southeast wind associated with sudestadas occasionally develops; lows that intensify near the coast can produce winds in excess of 50 knots. Strong winds also often accompany frontal passages; squally south-southwest winds are associated with pamperos. The stronger the pampero winds, the shorter their duration; post-frontal pampero winds can last 2-3 hours or 1-2 days.

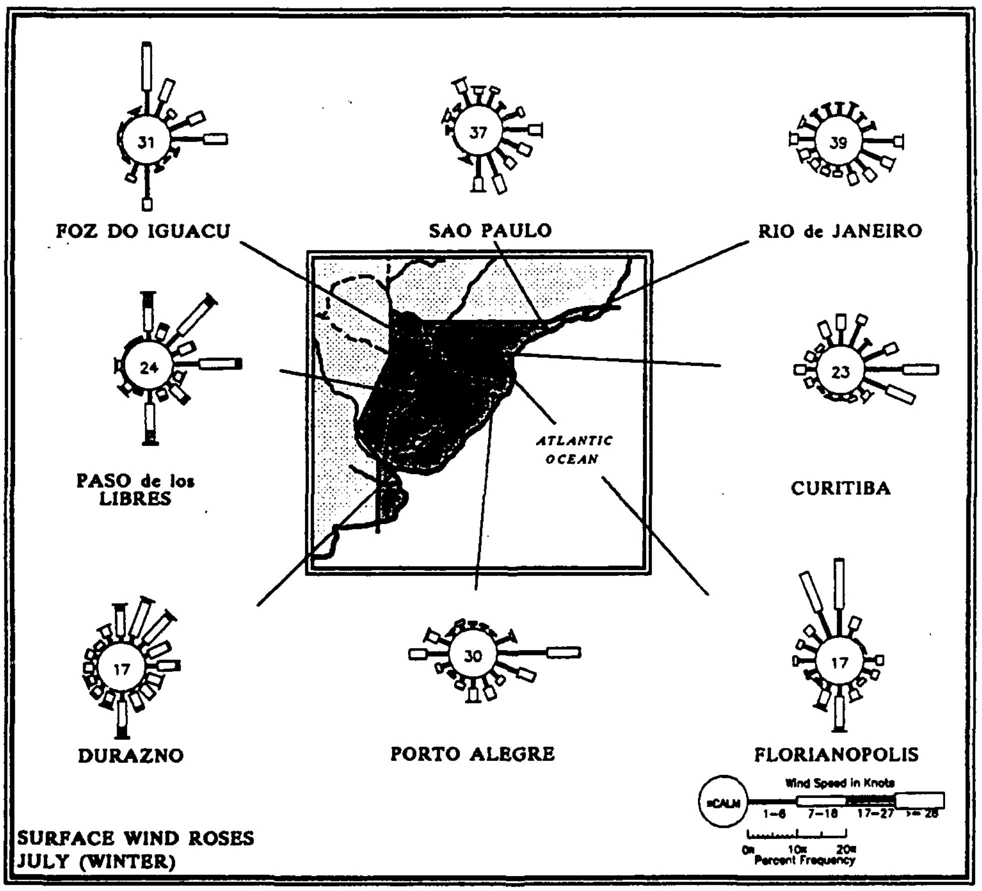


Figure 5-68. July Surface Wind Roses, Southern Brazilian Highlands & Parana Plain.

STATION	MEAN WIND SPEED JUN	JUL	AUG
ASUNCION	5	5	8
BUENOS AIRES	4	5	6
CURITIBA	5	6	6
FLORIANOPOLIS	6	7	7
LONDRINA	4	5	5
MAR del PLATA	9	10	11
MONTEVIDEO	8	8	9

STATION	MEAN WIND SPEED JUN	JUL	AUG
PASO de los LIBRES	8	9	9
PASO de los TOROS	7	7	8
PORTO ALEGRE	5	6	6
POSADAS	4	5	5
RIO de JANEIRO	3	4	4
SANTA MARIA	6	7	7
SAO PAULO	3	4	4

Figure 5-69. Mean Winter Wind Speeds, Southern Brazilian Highlands & Parana Plain.

Upper-level winds over the Parana Plain are northerly at 5,000 feet (1,525 meters) and west-southwesterly at 10,000 through 15,000 feet (3,050 through 4,570 meters). Winds over the highlands and their western slopes are northerly below 15,000 feet (4,570 meters), and westerly above. Speeds increase with altitude, averaging 10 to 25 knots through 15,000 feet (4,570 meters). Speeds increase sharply above 30,000 feet (9.1 km), reaching their mean maximum of 65 knots at 40,000 feet (12.2 km). The Subtropical Jet is generally located over the zone near 33° S between 35,000 and 40,000 feet (10.6 and 12.2 km) during winter. Maximum wind speeds associated with the jet average just over 70 knots, but occasionally exceed 100 knots. Upper-air wind directions are shown in Figures 5-49 through 5-51.

PRECIPITATION. The South Atlantic High dominates the zone during winter; prevailing dry easterly trade winds and persistent subsidence result in a "dry season," in which rain falls on an average of only 8 days a month. Rain is the primary form of precipitation, drizzle is common; they occur most often with frontal systems, but also with orographic lift. Sudestadas result in extended periods of both rain and drizzle. Snow can also occur, but is very unusual. Appreciable amounts of snow occur only in the extreme south every few years.

Mean monthly precipitation ranges from near 2 inches (25 mm) to slightly over 6 inches (150 mm) at Santa Maria (Figure 5-70). The areas receiving the greatest amounts during this period are along the eastern slopes north of Porto Alegre and the Pelotas River Valley. The monthly maximum for winter is 15.0 inches (380 mm) in June at Curitiba, which also recorded highest maximum 24-hour rainfall (6.4 inches/165 mm), also in June (Figure 5-71).

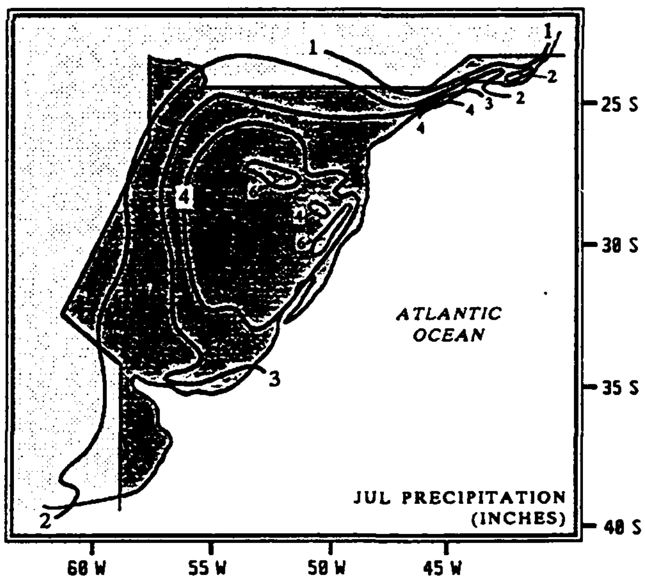


Figure 5-70. Mean July Precipitation, Southern Brazilian Highlands & Parana Plain.

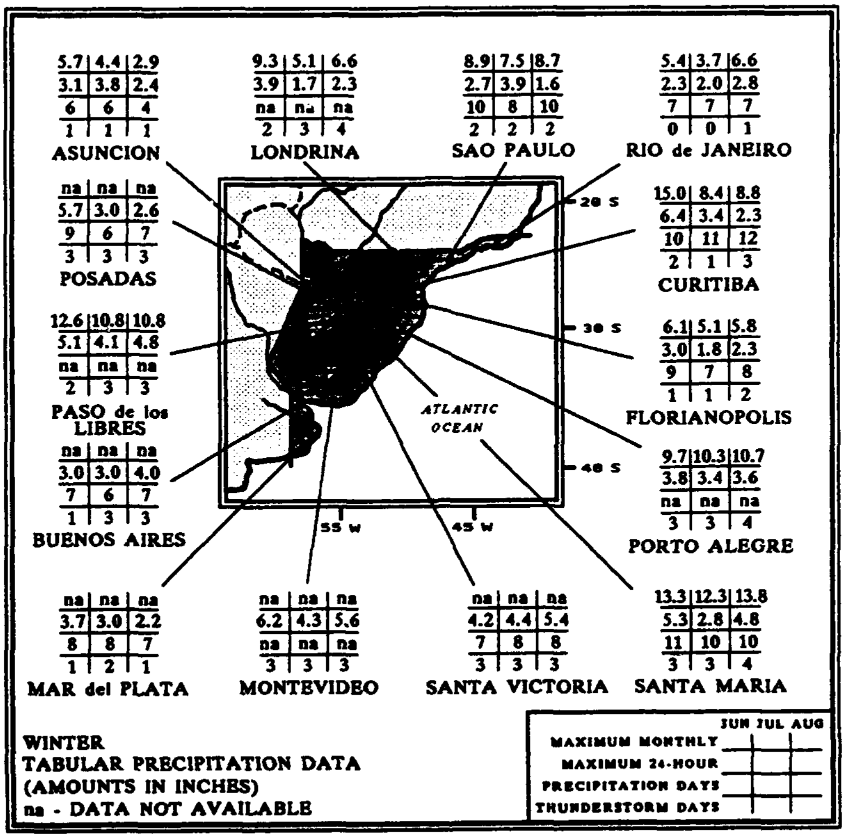


Figure 5-71. Winter Tabular Precipitation Data, Southern Brazilian Highlands & Parana Plain.

THUNDERSTORMS. Thunderstorms are least frequent in winter, averaging only 2 days a month. The highest frequency is near Posadas. Most winter thunderstorms are associated with intense northward-moving cold fronts and migratory lows. These systems are strong enough to disrupt the persistent subsidence inversion. Thunderstorms may occasionally be embedded in extensive cloudiness. Air-mass thunderstorms are rare. Wintertime thunderstorms often extend above 40,000 feet (12.2 km) with bases at or below 3,000 feet (915 meters) AGL.

TEMPERATURES. Mean daily highs range from 89° F (32° C) to 56° F (13° C) (Figure 5-72). Temperatures at sea level average 10° F (4° C) higher than in the highlands at 2,500 to 3,000 feet (760 to 915 meters) overlooking the coast. The low country west of the highlands averages 20° F warmer than the highlands. The record high for winter is 102° F (39° C) at Posadas in August. Mean daily lows range from 39° F (4° C) to 76° F (24° C). Southeasterly post-frontal flow normally brings cool, moist air to the zone, while southwesterly post-frontal winds can bring cold, dry air. The lowest temperatures occur with the invasion of polar continental air originating over southern South America. The record low is 18° F (-8° C) at Parana in July.

Relative humidity averages 90% at 0700L throughout the entire zone. Along the coast south of 25° S, RH averages 65% or better at 1300L. Afternoon relative humidities are lower in the interior.

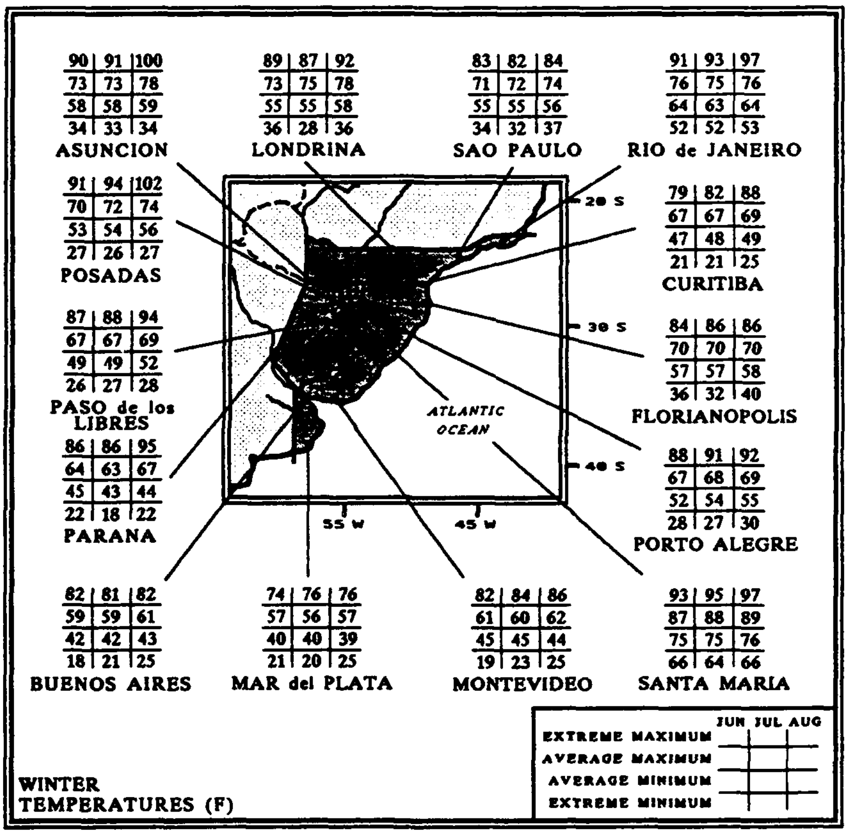


Figure 5-72. Winter Tabular Temperature Data, Southern Brazilian Highlands & Parana Plain.

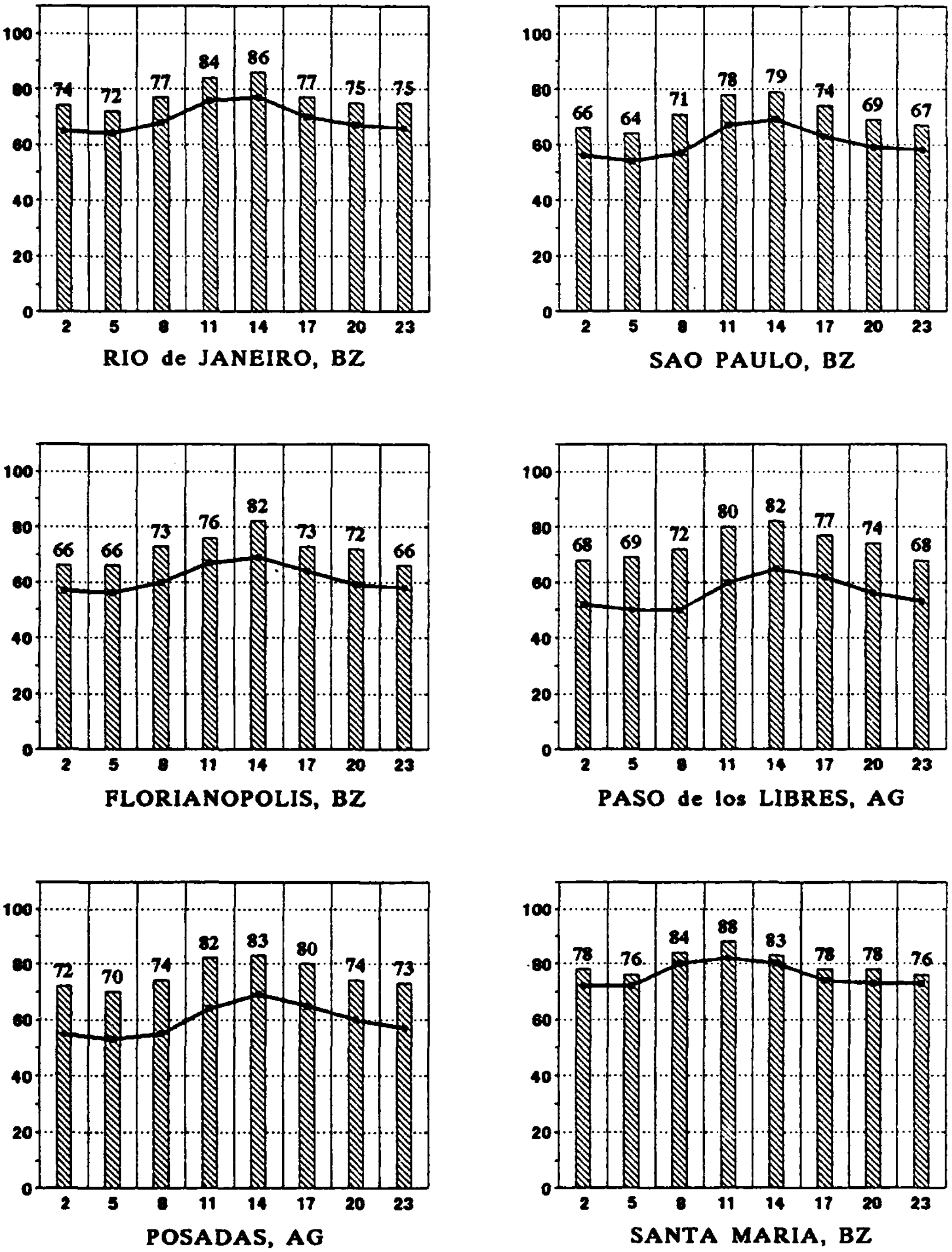


Figure 5-73. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for July, Southern Brazilian Highlands & Parana Plain. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Moderate to severe turbulence occurs in and around thunderstorms. Moderate to severe mechanical turbulence is also possible when strong winds cross rugged terrain. Winds associated with differential heating can produce light to moderate turbulence. The Subtropical Jet, with a mean position of 33° S near 40,000 feet (12.2 km) MSL, is another cause of turbulence. Cold fronts and thunderstorms produce moderate to severe mixed icing in clouds at and above the freezing level (12,000 feet/3,660 meters) MSL. Dense haze and smoke due to widespread burning causes hazardous flying conditions. Near-zero vertical visibilities extend from the surface to 13,000 feet (3,960 meters) MSL. Fronts can thin or dissipate the haze.

GROUND HAZARDS. Heavy rainshowers in the highlands can produce large amounts of precipitation in short periods of time; flash floods can wash out roads and bridges.

GENERAL WEATHER. During spring, subsidence from the South Atlantic High weakens as it recedes. The easterly trades also begin to weaken, allowing maritime flow, frontal activity, and instability to increase. Rising temperatures cause intense surface heating that generates air-mass thunderstorms. Most important, frontal systems begin to encounter a great deal of moisture in their northward movement, resulting in considerable cloudiness and precipitation. Pamperos become common, they can cause squall lines and violent thunderstorms late in the season. Sudestadas occur less often than in winter, but the invading air masses tend to move farther north. Most spring sudestadas have layered stratus beneath altostratus or nimbostratus and are accompanied by drizzle, fog, and haze. Pamperos and sudestadas are discussed in detail in summer's "General Weather" section.

SKY COVER. The receding South Atlantic High allows the formation of numerous troughs and the invasion of fast-moving cold fronts. Mean cloudiness is generally similar to winter's; sky cover averages 50% throughout, except near the coast where it is closer to 60% (Figure 5-74). Early in the spring, maximum cloudiness occurs at night (2200-0500L); it is primarily stratus and stratocumulus with bases averaging 2,000 feet (610 meters) MSL. Toward the end of the season, cumulus dominates and causes cloudiness to peak in the afternoon. Bases average 5,000 feet (1,525 meters) MSL and tops extend to 15,000 feet (4,570 meters) MSL. Cumulonimbus, most often associated with frontal systems, forms with bases between 3,000 and 6,000 feet (915 to 1,830 meters) MSL and tops in excess of 45,000 feet (13.7 km) MSL. Scattered altocumulus and altostratus may occur periodically after a frontal passage; bases are about 12,000 feet (3660 meters) MSL; tops, around 15,000 feet (4,570 meters) MSL.

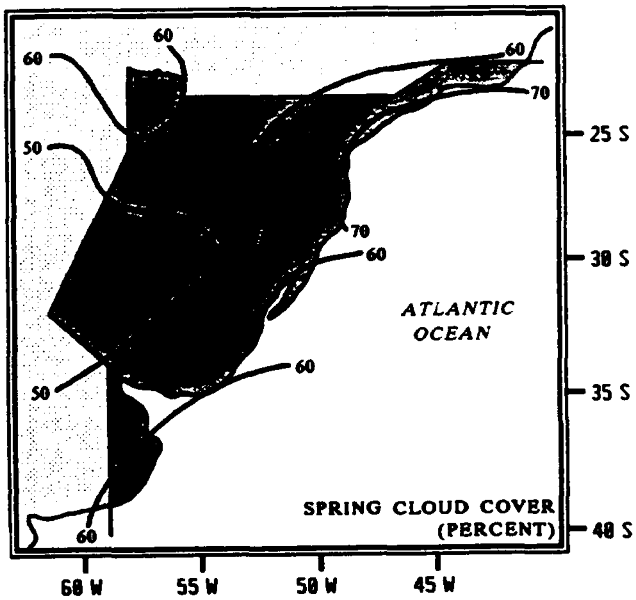


Figure 5-74. Mean Spring Cloud Cover, Southern Brazilian Highlands & Parana Plain.

Low ceilings are most frequent during the spring. The mean frequency of ceilings below 3,000 feet (915 meters) AGL ranges from 13% at Pasadas to 58% at Florianopolis (Figure 5-75). Stratus ceilings as low as 500 feet (150 meters) can develop along the coast with onshore flow, particularly around sunrise. Frontal activity can produce low ceilings averaging 1,500 feet (455 meters) AGL; occasionally, these ceilings persist into the afternoon, especially along the coast.

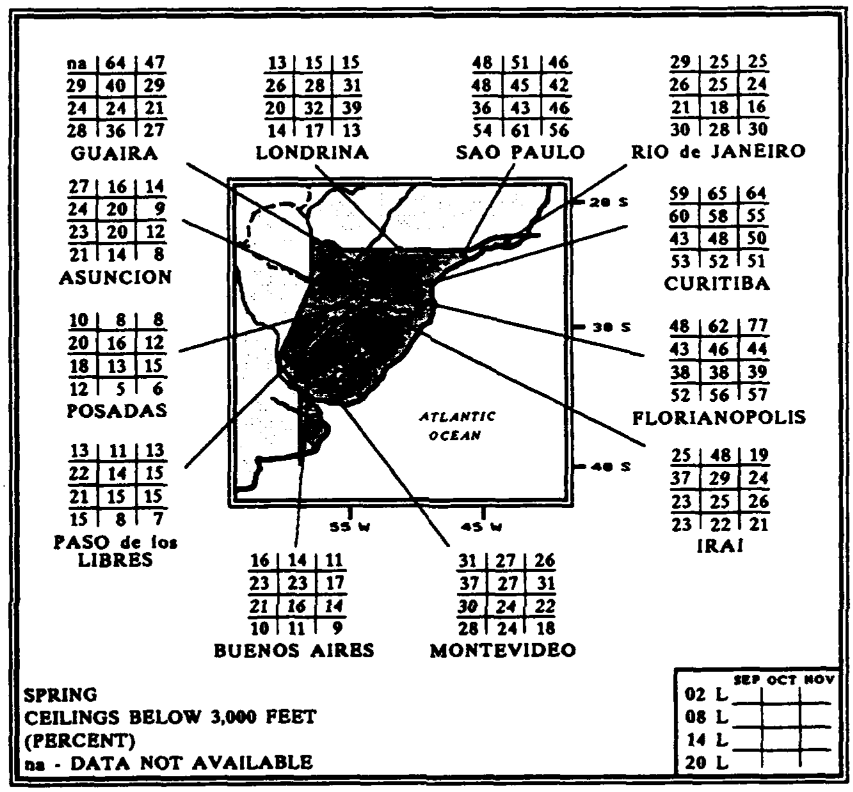


Figure 5-75. Spring Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Brazilian Highlands & Parana Plain.

VISIBILITY. Visibility is generally better on the plain west of the highlands than in the highlands themselves or along the coast. Fog and haze are still the predominant causes, but they are becoming less frequent. The South Atlantic High moves away from the coast, allowing increased instability to disperse the haze and smoke caused by burning. Toward the end of the season, precipitation restricts visibility nearly as often as fog and haze. Visibility frequencies below 3 miles average 26%. Visibilities are often reduced from predawn through 0800L (see Figure 5-76).

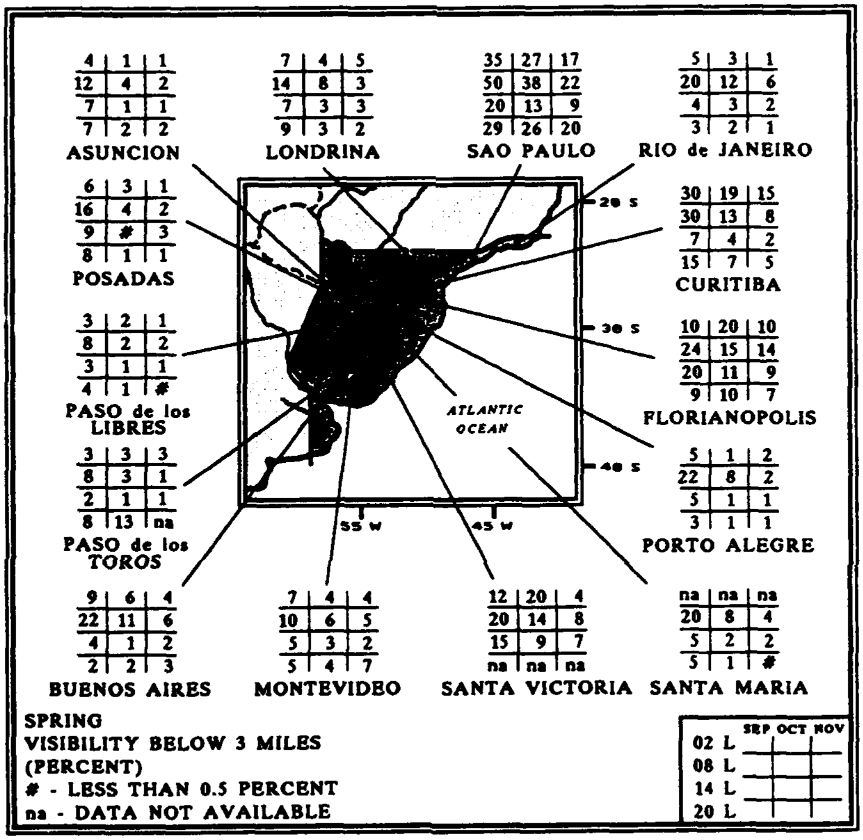


Figure 5-76. Spring Percent Frequencies of Visibility Below 3 Miles, Southern Brazilian Highlands & Parana Plain.

WINDS. Spring synoptic flow is primarily northeasterly, but topography produces many local variations. In the highlands, winds vary from west-northwest to east-northeast due to mountain/valley breezes. Surface winds become more variable west of the highlands as the South Atlantic High moves away from the continent and the Northwest Argentine Depression begins to intensify. Winds have a more easterly component along the western slopes of the highlands. South-southeasterly winds become more common from the western slopes to the Parana River. Surface winds along the coast turn counterclockwise from southeasterly at Rio de Janeiro to east-northeasterly in the south; Florianapolis, where local effects cause northerly winds to prevail, is an exception. Land/sea breezes are a factor, particularly near Porto Alegre.

The average wind speed in spring ranges from 5 knots at Rio de Janeiro to 13 knots at Mar del Plata (Figure 5-78). Winds are strongest in the afternoon. Gusty winds often accompany frontal passages; squally south-southwesterly winds associated with pamperos often exceed 30 knots and last anywhere from 2-3 hours or 1-2 days; the stronger the winds, the shorter their duration. Occasionally, strong southeasterlies occur when deep lows form near the coast. Near Rio de Janeiro, northwest squalls called "Terre Altos" persist for 5 or 6 hours. The highest wind speed recorded during the spring was 60 knots at Florianapolis.

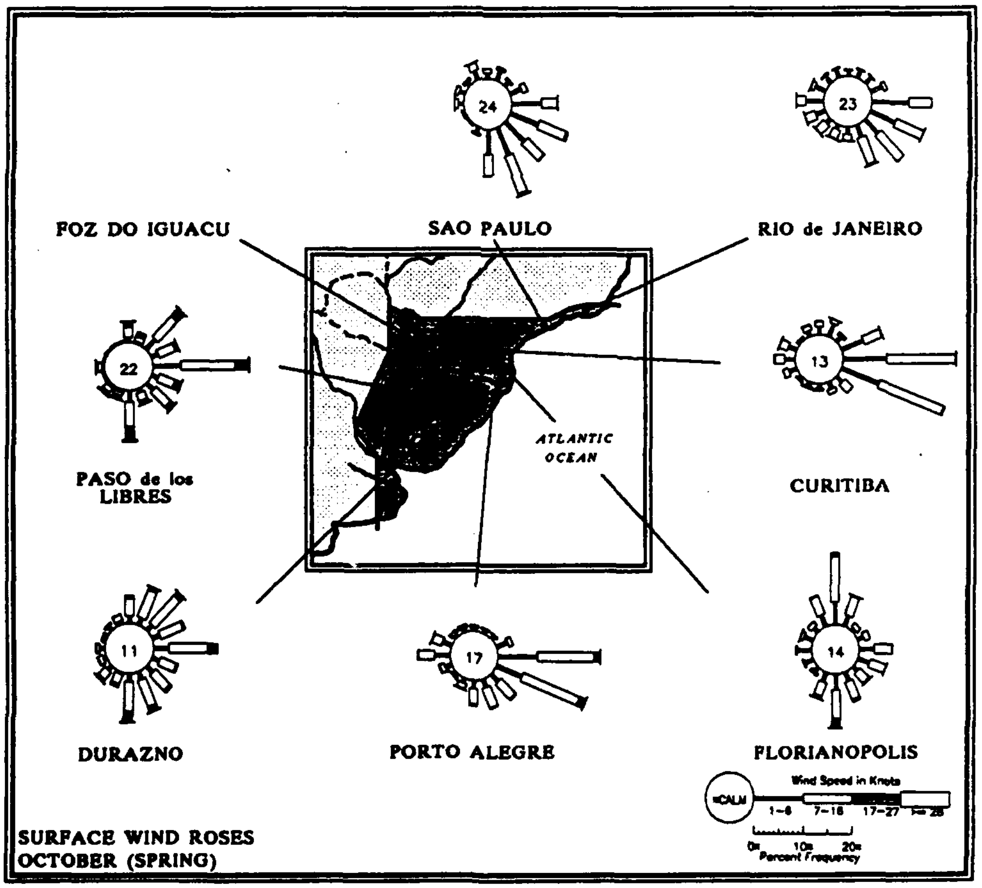


Figure 5-77. October Surface Wind Roses, Southern Brazilian Highlands & Parana Plain.

STATION	MEAN WIND SPEED SEP	OCT	NOV
ASUNCION	8	5	5
BUENOS AIRES	6	6	6
CURITIBA	7	7	7
FLORIANOPOLIS	7	8	8
LONDRINA	6	6	6
MAR del PLATA	11	12	13
MONTEVIDEO	9	9	9

STATION	MEAN WIND SPEED SEP	OCT	NOV
PASO de los LIBRES	10	9	9
PASO de los TOROS	8	7	7
PORTO ALEGRE	6	6	5
POSADAS	6	7	7
RIO de JANEIRO	5	6	6
SANTA MARIA	8	8	8
SAO PAULO	5	5	6

Figure 5-78. Mean Spring Wind Speeds, Southern Brazilian Highlands & Parana Plain.

Upper-level winds are northerly at 15 knots from 5,000 through 10,000 feet (1,525 through 3,050 meters) MSL from the Parana River to the western slopes of the highlands. Over the highlands and eastward to the coast, winds through 10,000 feet (3,050 meters) range from southwesterly to northwesterly at 18 knots. At 15,000 feet (4,570 meters) MSL and above, westerlies prevail; speeds increase with altitude. Wind speeds reach their mean maximum of 55 knots at 40,000 feet (12.2 km). Upper-air wind directions are shown in Figures 5-49 through 5-51.

PRECIPITATION. The wet season usually begins in early spring as the South Atlantic High recedes. Prevailing dry, easterly trade winds and persistent subsidence are replaced by flow from the Amazon. Precipitation occurs on an average of 11 days a month in the plains, increasing to near 16 days in the highlands. Frontal and convective activity produce rain and rainshowers. Cyclogenesis and the resulting sudestadas become more common; most lows develop off the southern Uruguay coast.

Mesoscale Convective Systems (MCSs) occur over southeastern Paraguay and northeastern Argentina in late afternoon through evening. This favored area for MCSs has an average monthly rainfall rate of more than 8 inches (200 mm) a season (Figure 5-79). In September, a maximum 24-hour rainfall of 5.9 inches (149.9 mm) was recorded at Foz do Igua within the area of frequent MCSs (Figure 5-80). Mean monthly amounts range from 2.2 inches (55 mm) at Mar de Plata to 10.0 inches (255 mm) at Sao Paulo. Sao Paulo has the highest mean monthly amounts, averaging 7 inches (180 mm) a month. It also has the maximum monthly amount, (20.0 inches/510 mm), in November. The eastern slopes of the highlands north of Porto Alegre also receive a great deal of rainfall due to orographic lift and the maritime air masses associated with sudestadas.

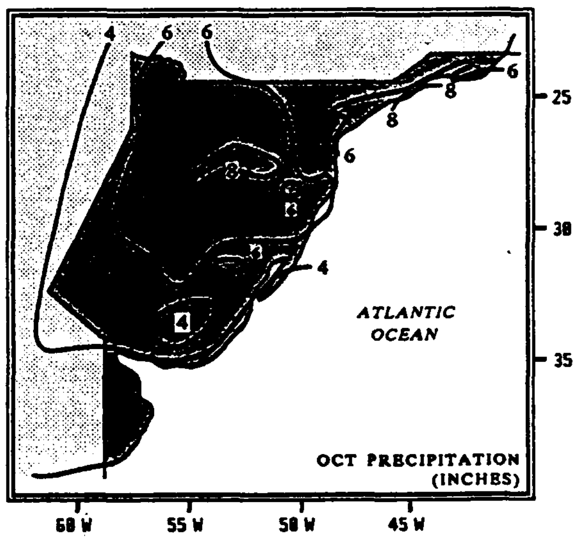


Figure 5-79. Mean October Precipitation Data, Southern Brazilian Highlands & Parana Plain.

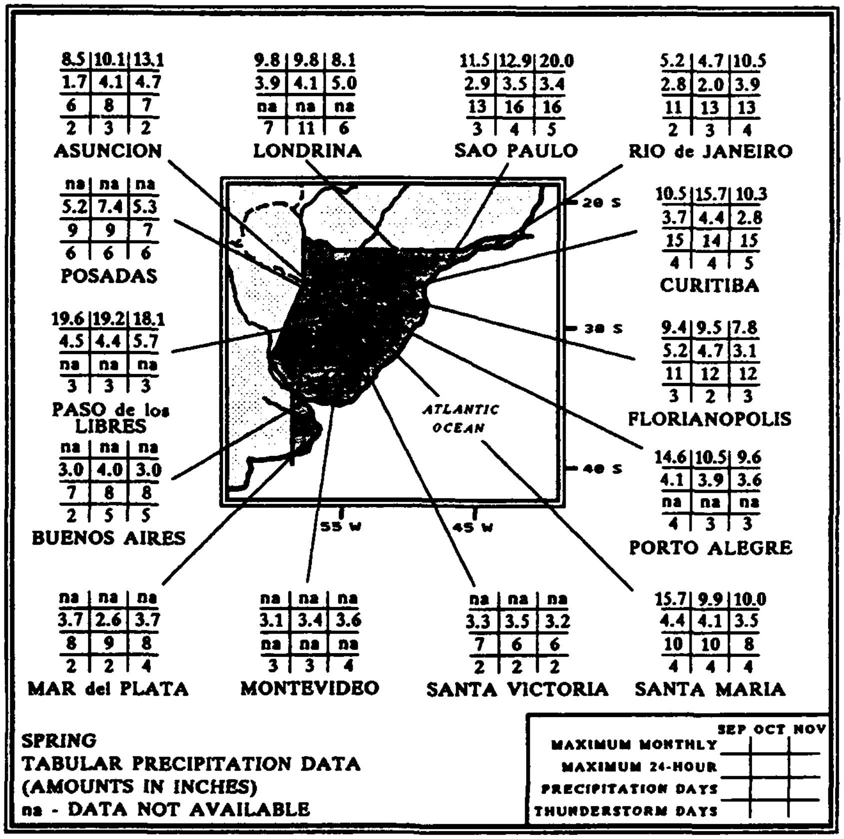


Figure 5-80. Spring Tabular Precipitation Data, Southern Brazilian Highlands & Parana Plain.

THUNDERSTORMS. The weakening subsidence inversion, along with increased surface heating, results in greater thunderstorm activity. Thunderstorms occur on an average of 5 days a month during the spring. The number of frontal thunderstorms remains constant, while air-mass types associated with MCSs increase. Air-mass thunderstorms occur most often in the afternoon and evening. Thunderstorms associated with fronts or instability lines have no diurnal preference and are generally in lines or clusters. Late in the season, thunderstorms can become severe, producing torrential rainshowers, winds in excess of 50 knots, hail, and tornados. Spring thunderstorms in the zone occur most often at Posadas. Thunderstorm tops often exceed 45,000 feet (13.7 km) MSL; bases, 3,000 feet (915 meters) AGL.

TEMPERATURE. Temperatures gradually increase during spring as invasions of polar air from the south become less frequent. Mean daily highs range from 91° F (33° C) to 59° F (15° C) (Figure 5-81). Temperatures are usually highest in the interior; easterly local winds result in adiabatic warming on western highland slopes. The record high for spring was 106° F (41° C) at Paso de los Libres in November. Mean daily lows range from 41° F (5° C) to 78° F (26° C). The record low of 22° F (-5° C) was observed at Mar del Plata in September. Relative humidity averages 88% at 0700L and 60% at 1300L throughout the entire zone.

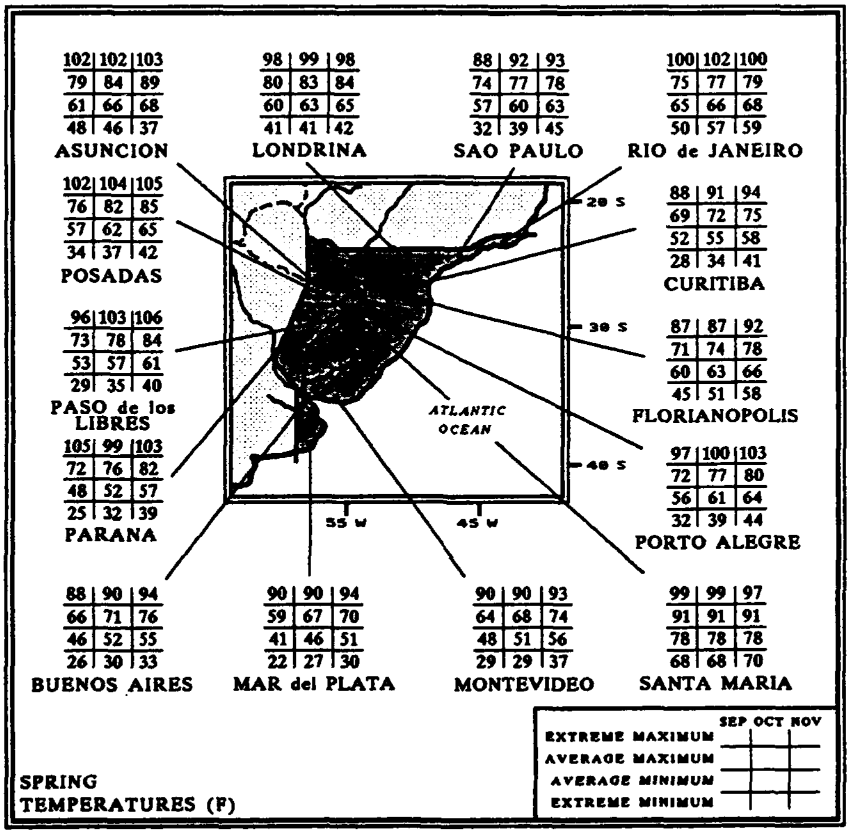


Figure 5-81. Spring Tabular Temperature Data, Southern Brazilian Highlands & Parana Plain.

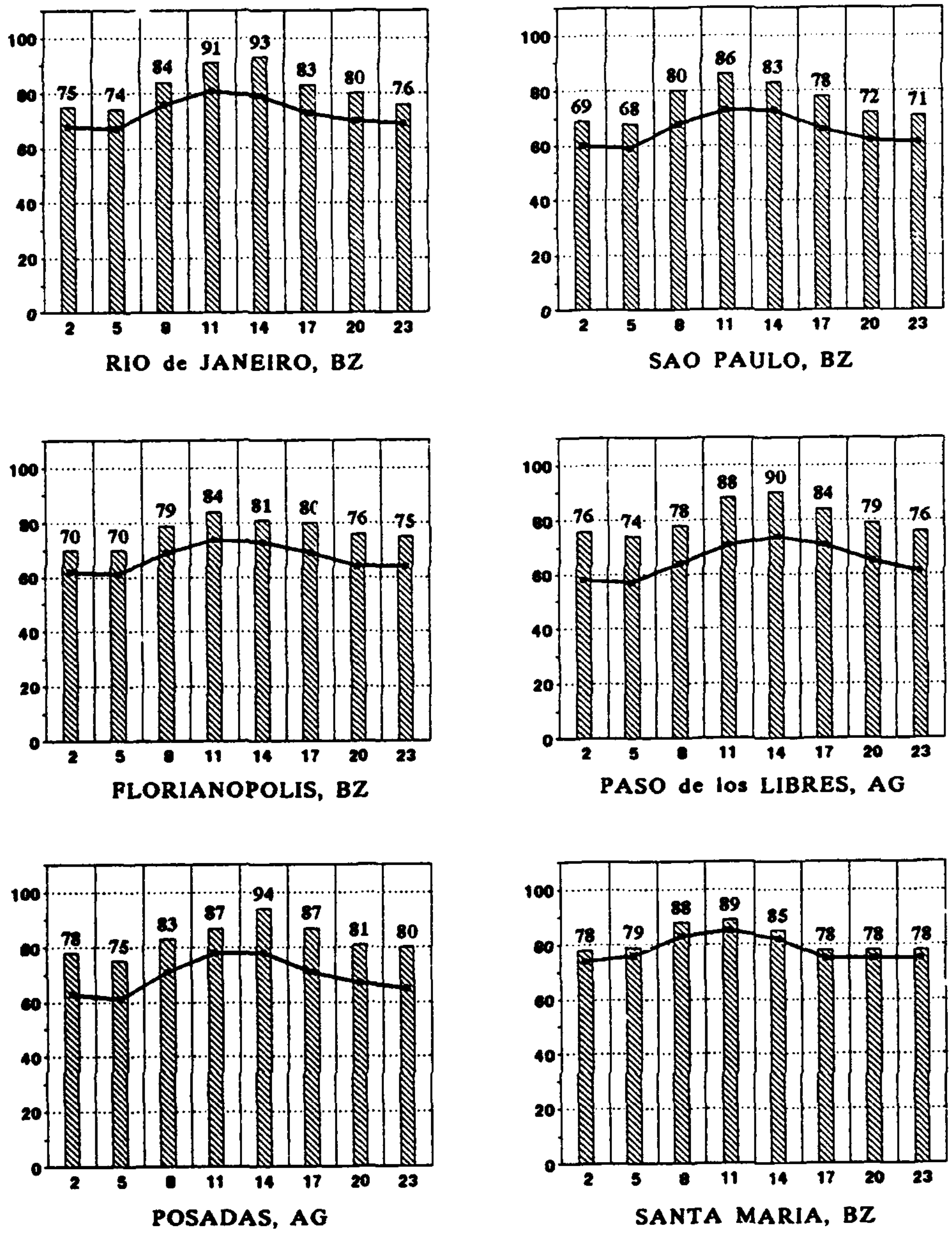


Figure 5-82. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for *October, Southern Brazilian Highlands & Parana Plain*. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Moderate to severe turbulence can occur with both air-mass and frontal thunderstorms. Several local winds caused by differential heating, topography, and frontal passage can also produce moderate to severe turbulence. The Subtropical Jet, present mainly in the early part of the season, can also cause turbulence. Moderate to severe icing occurs with cold fronts and thunderstorms. Light rime to severe mixed icing is highly probable in clouds at and above the mean freezing level of 14,000 feet (4,270 meters) MSL. Dense haze and smoke due to widespread burning causes hazardous flying conditions early in the season. Vertical visibilities near zero extend from the surface to 13,000 feet (3,960 meters) MSL, sometimes hiding convective thunderstorms that are only visible on radar. The smoke and haze is often dissipated with frontal passages.

GROUND HAZARDS. Thunderstorms occur more often, with greater severity. They can produce tornados, hail, and severe lightning. Heavy rainshowers, particularly in the highlands, often cause flooding that can wash out roads and bridges.

Chapter 6

SOUTHERN SOUTH AMERICA

This chapter describes the situation and relief, major climatic controls, and general weather of Southern South America, which includes the southern portions of Chile and Argentina and the Falkland Islands. For this study, Southern South America has been divided into four "zones of climatic and topographic commonality," as shown in Figure 6-1.

SOUTHERN SOUTH AMERICA

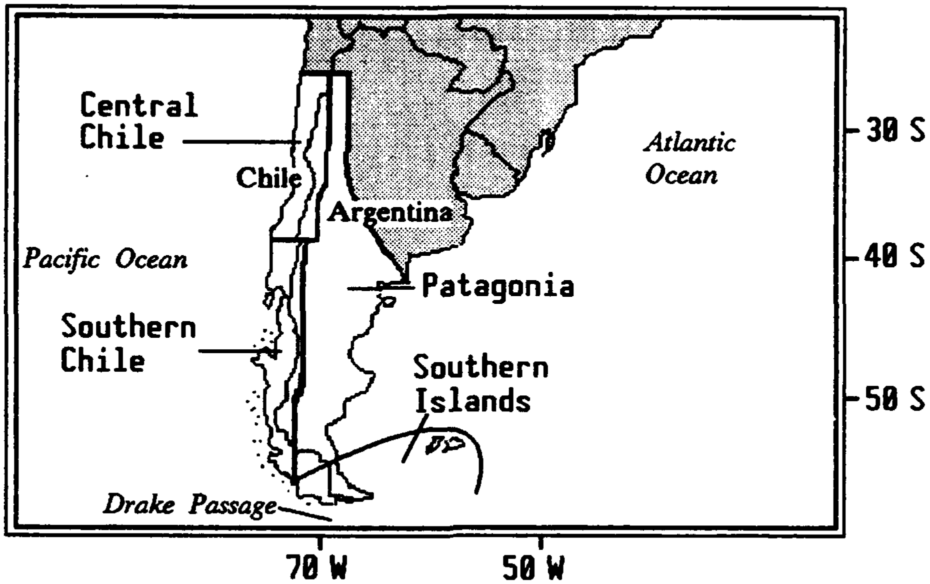


Figure 6-1. Southern South America. The region is subdivided into four "zones of climatic and topographic commonality." These are Central Chile, Southern Chile, Patagonia, and the Southern Islands.

SITUATION AND RELIEF. As shown in Figure 6-1, the Southern South America region covers a large mid-latitude area between 27 and 56° S. The landscape has great diversity. West of the Andes, estuaries with inaccessible coastlines, glaciers, and rugged mountains give way (south to north) to fertile valleys that slope gently to the Pacific Ocean. The Pacific coastline has more than 100 islands in an area sometimes called "Archipelagic Chile." The largest is the Taitao Peninsula at 46° S. East of the Andes, numerous rocky islands give way (from south to north) to rolling hills and desert plains. The Patagonian Desert (37 to 51° S), with an area of about 250,000 square miles, is the largest desert in South America. The Valdes Peninsula, located along the Atlantic coast of Argentina, is the lowest point in South America at 131 feet (40 meters) below sea level. In the southern Andes, there are numerous rivers, glacier-fed lakes, and snow-capped peaks. The Cordillera Occidental (southern Andes) forms a natural barrier between Argentina and Chile. For this study, the region is subdivided into four zones:

Central Chile runs parallel to the Pacific Ocean between 28 and 38° S. The terrain varies from narrow coastline and coastal ranges to rugged snow-capped mountain peaks at elevations above 22,000 feet (6,700 meters) MSL. The Central Valley is nestled between the coast and Cordillera Occidental, sloping southward to the Pacific Ocean.

Southern Chile extends from 38 to 53° S and the Strait of Magellan. This is a remote landscape dominated by estuaries, inlets, glaciers, and mountains. A network of islands and peninsulas extend southward along the rugged coastline; the southernmost islands have South America's wettest climate. The Cordillera Occidental forms the eastern boundary; elevations average 6,500 to 8,200 feet (1,980 to 2,500 meters) MSL.

Patagonia is a gently-sloping plain that extends from 27° S to the Strait of Magellan, and from the eastern slopes of the Andes to the Atlantic Ocean. This zone is dominated by the Patagonian Desert, which has one of the driest climates east of the Andes.

The Southern Islands comprise a group of islands separated from the continent by the Strait of Magellan. A chain of small islands extends southward into Drake passage. The Falkland Islands lie east of Tierra del Fuego. The islands are dominated by inlets, estuaries, and mountains.

MAJOR CLIMATIC CONTROLS. Southern South America's weather and climate are dominated by three major features:

The Circumpolar Trough produces strong westerly flow in the mid- and upper-levels and steers cyclonic storms through Drake Passage year-round. Upper-level flow usually ranges from 60 to 100 knots, but wind speeds occasionally reach 160 knots in Drake Passage. A quasi-stationary longwave trough axis anchors off the South American coastline between 80 and 90° W, sometimes reaching 30° S. Meridional flow is common between April and October. Secondary and/or cut-off lows usually form in the southeastern Pacific, then intensify off the Chilean coast between 35 and 45° S. These lows frequently stall along the western Andes while the upper-level trough migrates eastward into the Atlantic Ocean.

The South Pacific High is a strong, semipermanent surface circulation that migrates north and south along South America's Pacific coastline; its movement eastward is blocked by the Andes. Outflow is deflected northward below 5,000 feet (1,525 meters) MSL. Southerly flow drives the cold Humboldt Current and provides strong subsidence along the Pacific coastline north of 35° S between November and March.

Migratory Low-Pressure Systems generate heavy rainfall every 2 to 5 days. Storm tracks usually move through Drake Passage, producing uniform monthly rainfall amounts in Southern Chile and the Southern Islands. However, storm tracks oscillate from 35 and 45° S for weeks at a time between April and October, providing seasonal rainfall to the Central Chile Coast.

6.1 CENTRAL CHILE

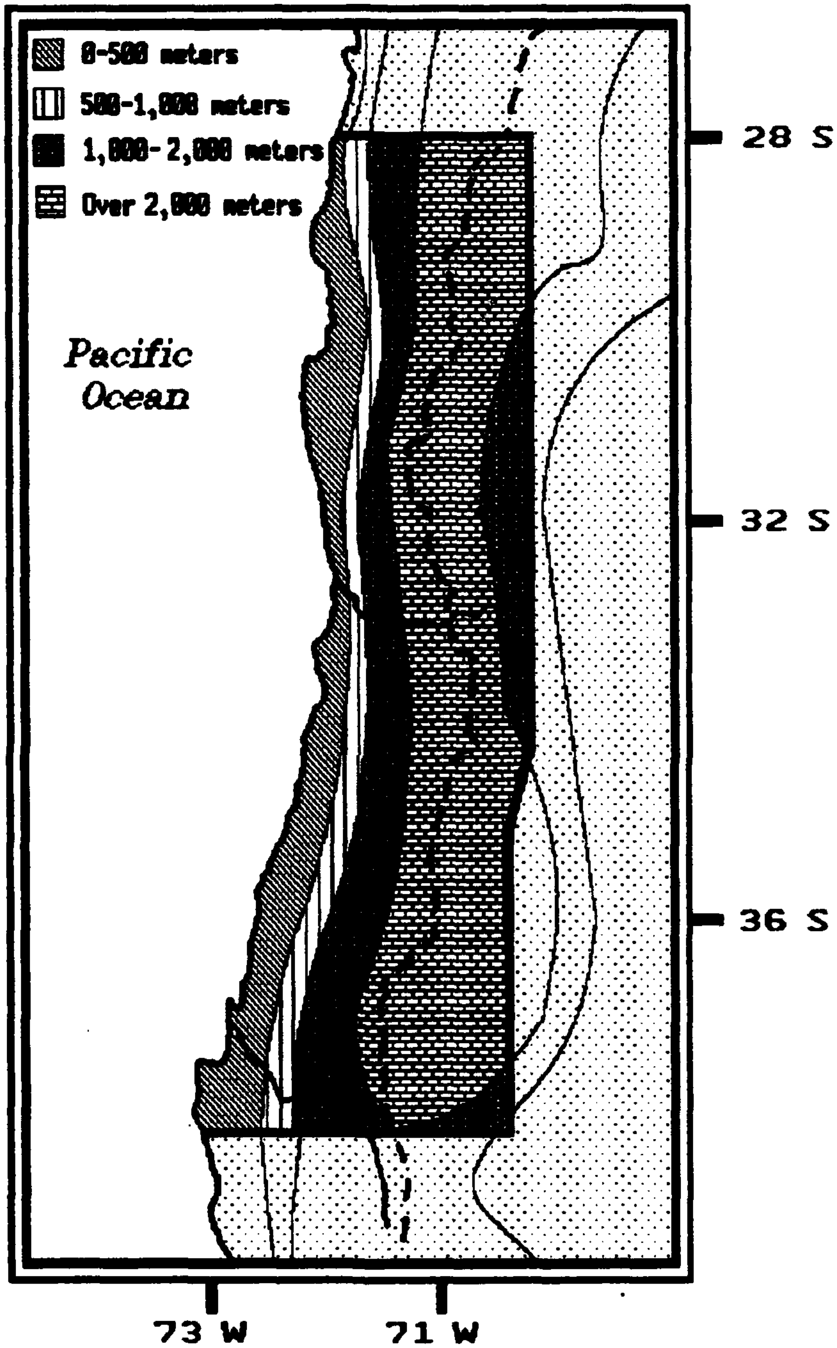
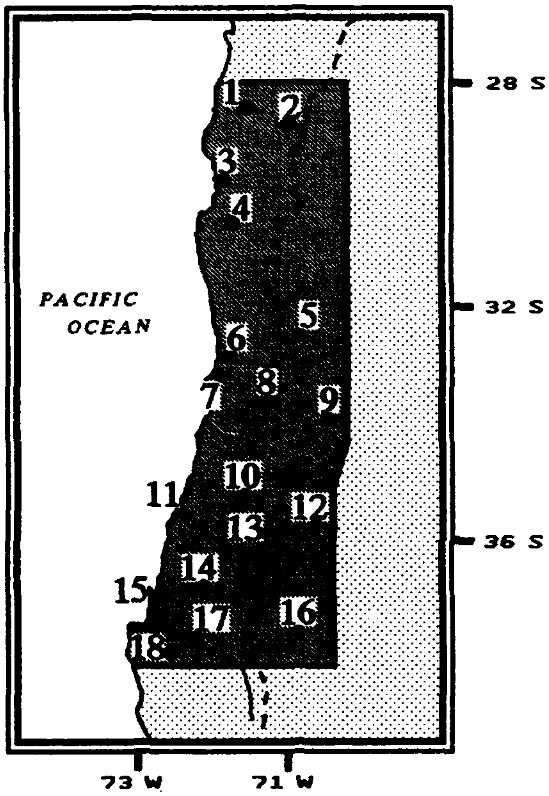


Figure 6-2. Central Chile. This zone includes sections of central Chile, the Andes Mountains, and extreme western Argentina between 28 and 38° S. It has distinctly "wet" winters and "dry" summers. The eastern boundary runs along the eastern slopes of the Andes from about 28° S, 69° W to 38° S, 69° W.



	ELEVATION (feet)
1. Vallenar	1,539
2. La Pampa	3,939
3. La Serena	105
4. Ovalle	722
5. Christ of the Andes	12,562
6. Quintero AFB	7
7. Valpariso	135
8. Santiago	1,700
9. San Carlos	3,090
10. Curico	738
11. Constitucion	7
12. Malargue	4,679
13. Talca	318
14. Chillan	387
15. Concepcion	49
16. Chos Malal	2,789
17. Los Angeles	456
18. Angol	376

Figure 6-3. Climatic Station Network, Central Chile.

CENTRAL CHILE GEOGRAPHY

TERRAIN. Central Chile (Figure 6-2) encompasses Chile and extreme western Argentina between 28 and 38° S. The main topographic features are the Cordillera Occidental (Andes Mountains), the coastal ranges (Andes foothills), and the Central Valley.

The Cordillera Occidental are volcanic ranges with several peaks reaching 20,000 feet (6,100 meters). The highest point is Mount Aconcagua (32° 42' S, 70° W) at 23,034 feet (7,021 meters). The permanent snowline averages 13,000 feet (3,960 meters) at 32° S and 10,000 feet (3,050 meters) near 38° S. Mountain passes average 7,000 feet (2,135 meters) between 28 and 33° S, and 5,000 feet (1,525 meters) from 33 to 38° S.

The Andes foothills extend westward to the coast between 28 and 33° S. Elevations average 2,000 feet (610 meters), but several peaks exceed 6,000 feet (1,830 meters). Coastal ranges rise steeply from the coast only 0.5 to 5 NM inland. The only wide coastal plains are located between 29 and 30° S. The foothills consist of terraced hills and flat-topped plateaus ranging in elevation from 2,000 to 3,200 feet (610 to 990 meters). Several isolated ranges lie next to the coastline between 35 and 38° S.

The Central Valley is an irregularly shaped depression about 60 NM inland that lies nestled between the Andes and isolated coastal ranges. It consists of a series of connected valley floors, many less than 15 NM wide. The valleys have swift-moving rivers and narrow alluvial floodplains. The Central Valley slopes southward from Santiago and the Rio Aconcagua. Valley floor elevations average 1,500 feet (455 meters) in the north (at Santiago), to 1,110 feet (370 meters) in the central part (Linares), to 515 (160 meters) feet in the south (Los Angeles).

RIVERS. Most rivers are less than 85 NM long. They flow year-round, cutting deep canyons into the Andes foothills and the extreme eastern rim of the Central Valley. Rivers meander across the Central Valley and wind through the coastal ranges before reaching the Pacific Coast.

VEGETATION in central Chile closely resembles the Pacific coast of North America at comparable latitudes. Dry steppe dominates between 28 and 31° S. A mediterranean scrub woodland (thick growths of small trees and shrubs) begins just north of the Rio Aconcagua. It extends southward 300 NM to the Rio Bio Bio (37° S) before giving way to a humid mixed forest that contains evergreen broadleaf and mixed deciduous trees. Isolated grasslands are widely scattered along south-facing slopes of coastal ranges and valley floors throughout the Central Valley. Alpine meadows can be found along the Cordillera Occidental below the tree line.

GENERAL WEATHER. A strong high-pressure ridge develops across southern South America. The South Atlantic and South Pacific Highs produce subsidence between 30 and 45° S. The South Pacific High and the cool, northward-moving Humboldt Current develop a stable low-level inversion layer along the western Cordillera Occidental between 28 and 36° S. Stratus up to 4,000 feet (1,220 feet) thick develops in the inversion layer. Deep upper-level troughs can produce significant weather in November or March. Scattered thunderstorms are possible in the Andes above 10,000 feet (3,050 meters), but they are short-lived and rarely severe.

SKY COVER. Early morning stratus and advection fog move inland from the coast to the Central Valley between 2300 and 0800L. The stratus usually develops between 1,000 and 2,000 feet (305 and 610 meters) MSL, and rarely extends above 4,000 feet (1,220 meters) MSL. Lowest ceilings are found within 20 NM of the coastline. Ceilings below 500 feet (150 meters) AGL are common. Daytime heating causes the ceiling to lift to 4,000 feet (1,220 meters) MSL by 1100L, with tops to 6,000 feet (1,830 meters) MSL. The stratus usually dissipates by 1200L along the coastline and coastal ranges; it can persist until 1500L if the low-level inversion is strong. North of 32° S, the stratus layer forms the "camanchacas", or "wet fog," between the 2,000- and 4,000-foot (610- and 1,220-meter) MSL levels. Wet fog forms every other morning between 0500 and 1000L. South of 32° S, the wet fog develops between 4,000 and 6,000 feet (1,220 and 1,830 meters) MSL.

Sky cover above the inversion layer (average inversion tops are 6,000 feet/1,830 meters MSL) is dominated by scattered diurnal cumulus between 1200 and 1900L. Clouds form at or above 7,000 feet (2,135 meters) MSL, and tops can exceed 15,000 feet (4,570 meters) MSL. On rare occasions, western slopes and ridge crests are totally obscured. On the eastern side of the Andes, cumulus forms above 9,000 feet (2,745 meters) MSL. Tops can exceed 45,000 feet (13,720 meters) MSL.

Upper-level troughs affect Central Chile about once a month. Weak troughs usually produce mid- and upper-level clouds along the coast and Central Valley. Scattered altocumulus with bases at 10,000 feet (3,050 meters) MSL form along the trough axis; the clouds are rarely more than 4,000 feet (1,220 meters) thick. Strong troughs temporarily break down the inversion layer and thick cumulus forms along the trough axis. Ceilings average 5,000 feet (1,525 meters) MSL; towering cumulus and cumulonimbus can reach 35,000 feet (10,670 meters) MSL along the Cordillera Occidental. Middle cloud layers extend 100 to 150 miles downwind of upper troughs south of 31° S; they clear almost immediately after trough passage.

Mean cloudiness (Figure 6-4) identifies the areas consistently affected by coastal stratus (the 40% isopleth), and diurnal convection (the 30% isopleth) on the eastern Andes.

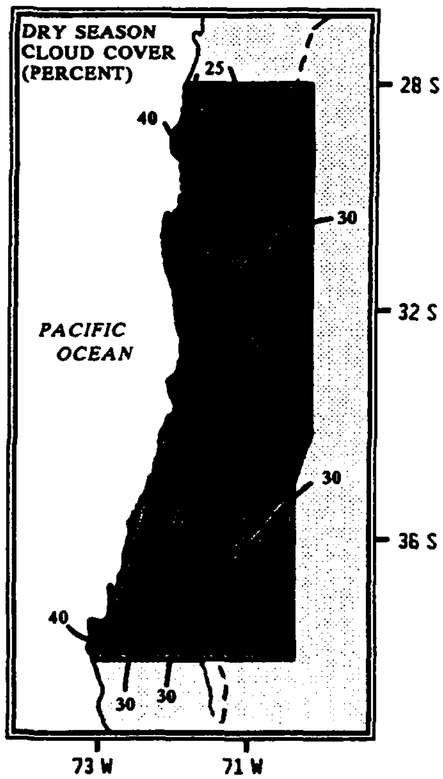


Figure 6-4. Mean Dry-Season Cloud Cover, Central Chile.

The highest frequencies of low ceilings are between 2100 and 1200L (Figure 6-5). Advection fog, radiation fog, and stratus are most common below 5,000 feet (1,525 meters); cumulus is the dominant cloud form above 5,000 feet (1,525 meters), especially between 1200 and 1800L.

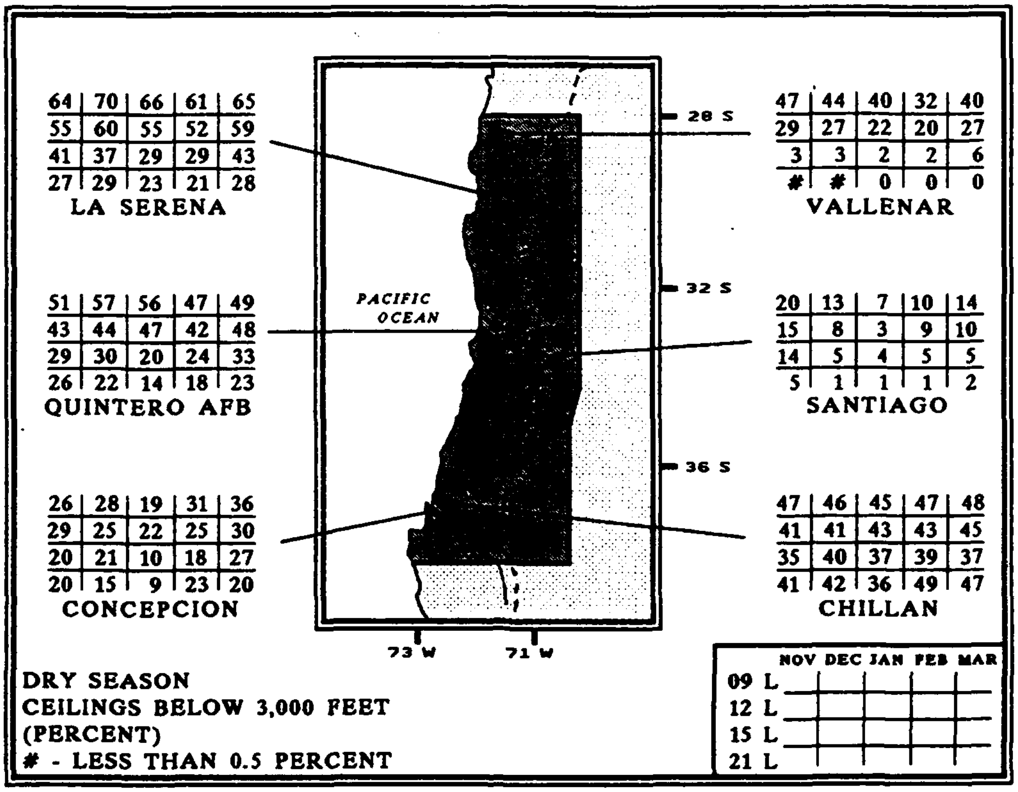


Figure 6-5. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Chile.

VISIBILITY. Early morning radiation fog in the Central Valley (and advection fog along the coastline) occur with a strong inversion. Figure 6-6 shows the frequencies of visibility below 3 miles. Santiago has the highest frequency in the Central Valley between 2100 and 0900L. Radiation fog and industrial smoke and haze accumulate during extended fair-weather periods. Low visibilities in the western foothills of the Andes above 8,000 feet (2,440 meters) are uncommon. Isolated thin radiation fog can develop by 0700L in upland valley floors of the Cordillera Occidental, but it usually burns off by 1000L. March Daytime visibilities can drop to between 3 and 6 miles along the coastline between Valparaiso and Concepcion from 1300 to 1900L and remain there until between 1900 and 0700L.

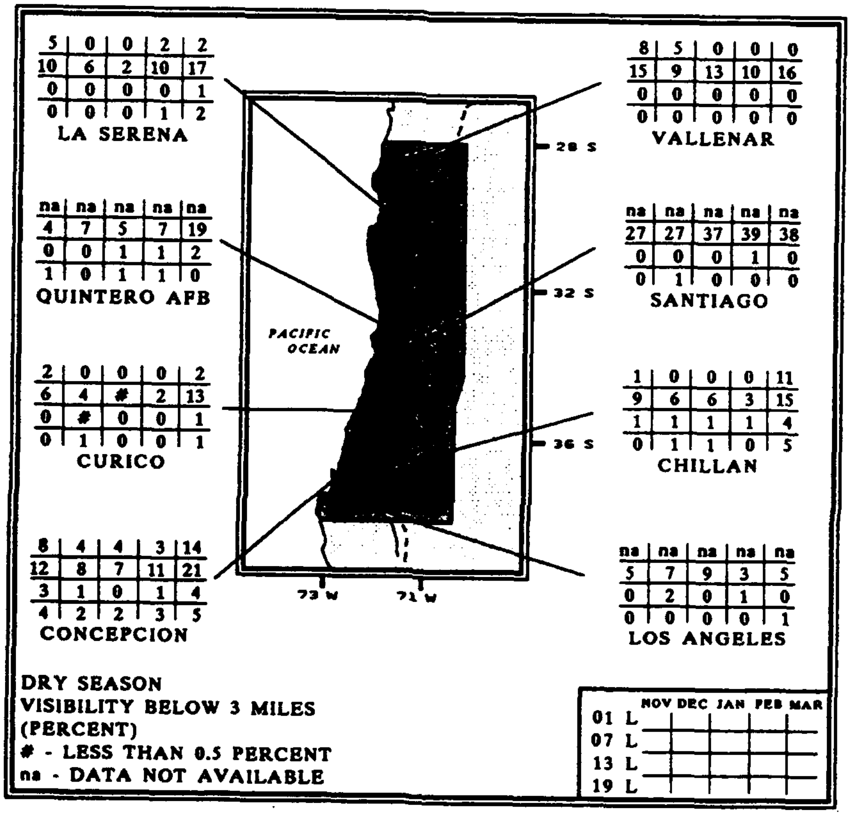


Figure 6-6. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Central Chile.

WINDS. Southerly to southeasterly winds dominate low-level flow. With extended fair weather periods, the South Pacific High intensifies the ridge over central Argentina. Tight pressure gradients produce southerlies that exceed 40 knots in the Central Valley. These strong winds are often enhanced by the valley breeze.

Upper-air troughs can replace southerly to southeasterly flow with northerly to northwesterly flow preceding them. Northerlies reach 20 knots and, in rare cases, exceed 30 knots with strong troughs. Winds are westerly and southwesterly for up to 24 hours after the trough moves onshore. South of 35° S, the sea breeze can reach 20 knots with a trough passage.

Figure 6-7 shows mean surface wind speeds. With a strong sea breeze circulation, winds along the coastline are 10-12 knots between 1200 and 1700L. In the Central Valley, valley breezes can reach 15 knots; mountain breezes north of 35° S can exceed 10 knots. Figure 6-8 gives surface wind roses for selected stations.

STATION	MEAN WIND SPEED				
	NOV	DEC	JAN	FEB	MAR
CHILLAN	5	5	6	5	5
CONCEPCION	11	11	11	10	9
CURICO	5	5	6	5	5
LA SERENA	5	6	6	6	5
MALARGUE	4	4	3	3	2
SANTIAGO	5	6	6	6	4
VALLENAR	5	5	5	5	4

Figure 6-7. Mean Dry-Season Wind Speeds, Central Chile.

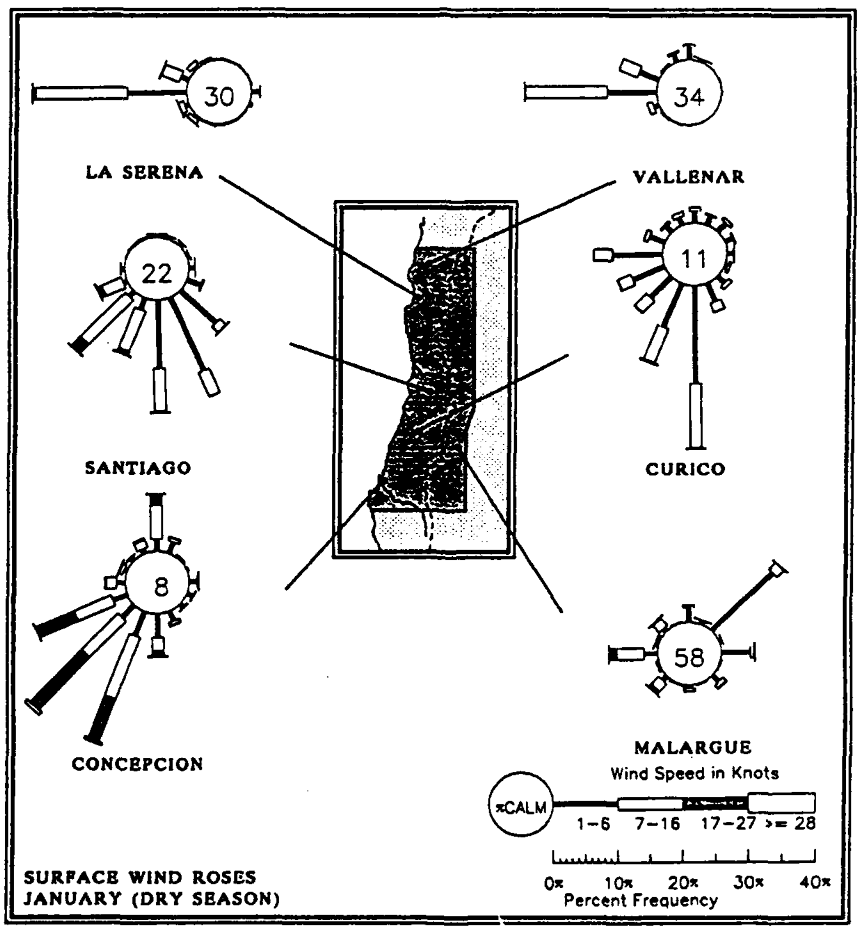


Figure 6-8. January Surface Wind Roses, Central Chile.

Mean upper-level wind speeds average 8 knots between 3,000 and 5,000 feet (915 meters and 1,525 meters) MSL, and 10 knots from 6,000 to 10,000 feet (1,830 to 3,050 meters) MSL. The Andes Mountains produce sharp contrasts in the circulation between 6,000 and 8,000 feet (1,830 and 2,440 meters) MSL. West of the Andes, flow is southeasterly between 3,000 and 6,000 feet (915 and 1,830 meters) MSL. Above 6,000 feet (1,830 meters) MSL, winds become northwesterly. Winds usually rotate clockwise with height from southwesterly to west-northwesterly. East of the Andes, winds are southeasterly between 3,000 and 7,000 feet (915 and 2,135 meters) MSL and northwesterly above 7,000 feet (2,135 meters) MSL. From 28 to 35° S, the Northwest Argentine Depression (NAD) produces an easterly to southeasterly wind component below 6,000 feet (1,830 meters) MSL between December and February. Direction rotates counterclockwise with height in February and March above 3,000 feet (915 meters) MSL. West of the Andes, mean speeds peak at 62 knots between 38,000 and 40,000 feet (11,585 and 12,190 meters) MSL. East of the Andes, the highest speed (66 knots) is near 44,000 feet (13,415 meters) MSL.

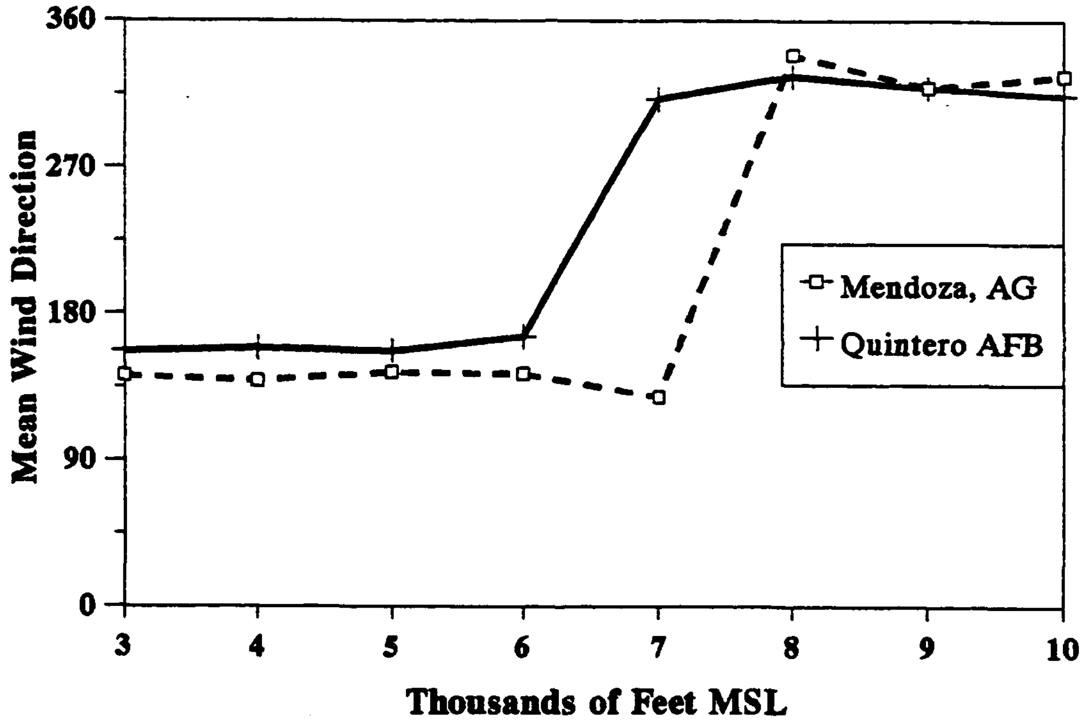


Figure 6-9. Mean Wind Direction for January Between 3,000 and 10,000 Feet (915 and 3,050 meters) MSL, Central Chile. Significant directional shear begins at 6,000 feet (1,830 meters) in the western Andes and at 7,000 feet (2,135 meters) in the eastern Andes. Solid lines represent windward locations (Quintero, Chile--33° S, 71° 30' W); dashed lines, leeward locations (Mendoza, Argentina--33° S, 69° W). Mendoza is east of the zone, but it is included because it represents downwind and lee-side conditions.

PRECIPITATION. Upper-air troughs produce nearly all the dry season precipitation. They occur once or twice a month, but very little rainfall occurs north of 31° S. Very deep troughs may produce cut-off lows along the coast; these lows produce light-to-moderate shower activity for 24 to 36 hours. Mean precipitation totals (Figures 6-10 and 6-11) show a north to south increase across Central Chile. Above normal rainfall north of 31° S is usually associated with ENSO events.

North of 31° S, mean monthly November-March precipitation averages less than 0.10 inches (2.5 mm). December and January are the driest. On very rare occasions, deep troughs penetrate to 30° S. They can produce an intense rainshower or isolated thundershower inland over the Andes foothills. These rare events occur only once every 3 or 4 years, but they can produce all the rainfall received during an entire dry season at some locations. Maximum 24-hour rainfall may exceed 1.5 inches (38 mm) in February or March, but such events are extremely rare. Wet fog ("camanchacas") occurs on every fourth or fifth morning over the coast and Andes foothills. Moisture may accumulate, but rarely totals more than 0.05 inches (1 mm).

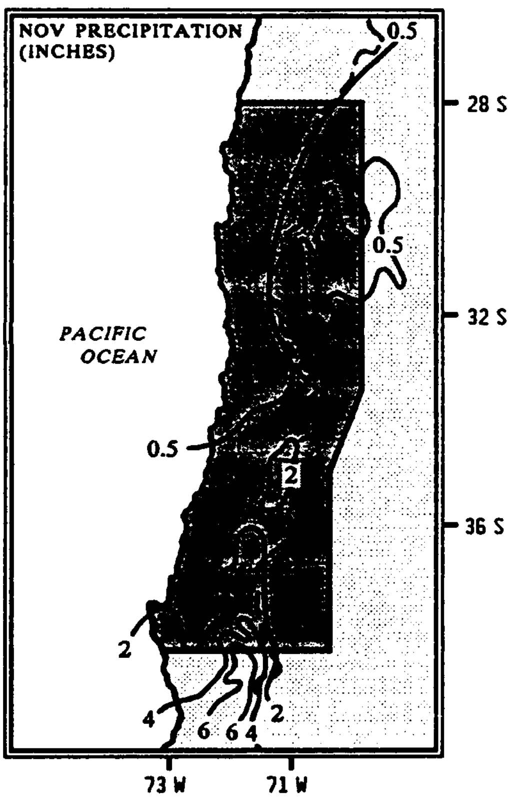


Figure 6-10. Mean November Precipitation, Central Chile.

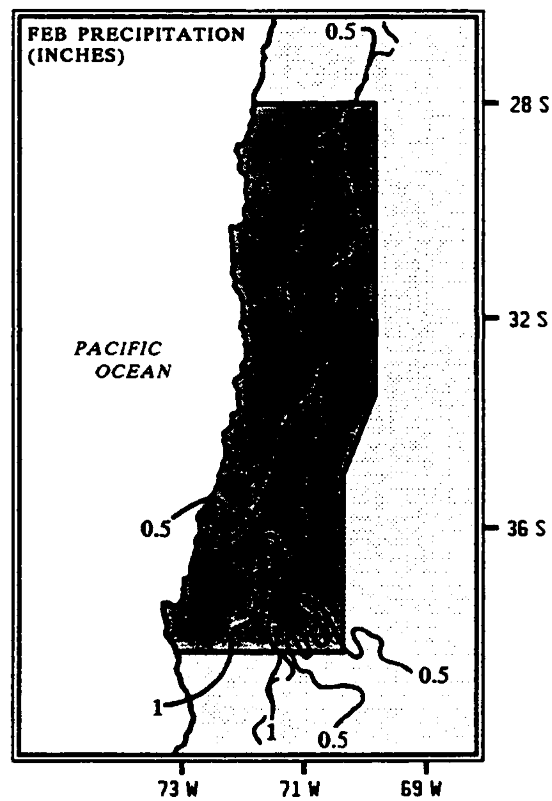


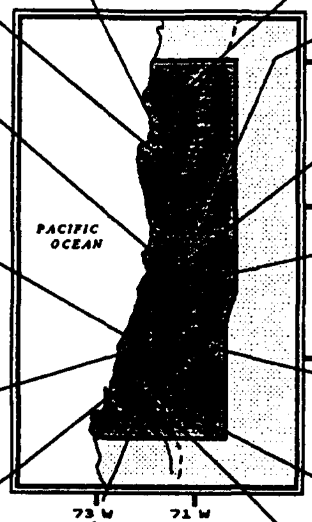
Figure 6-11. Mean February Precipitation, Central Chile.

CENTRAL CHILE
Dry Season

November-March

Between 31 and 34° S, precipitation increases with elevation. Along the coastline, fog and light drizzle occur every fifth morning in November or March. Light to moderate rainshowers are common with upper-air troughs, but rainfall amounts vary significantly. The western slopes of the coastal ranges receive more rainfall than the coastline or the Central Valley. Valparaiso receives less than 0.10 inches (2.5 mm) in January and February, but Christ of the Andes gets at least that much.

The eastern rim of the Central Valley (in the foothills above 6,000 feet/1,830 meters) and the Andes south of 34° S often have 1 inch (25 mm) of rainfall a month. Moderate rainfall is common with most trough passages. Widely-scattered thundershowers above 10,000 feet (3,050 meters) MSL occur at least once a month.



Station	Element	NOV	DEC	JAN	FEB	MAR
OVALLE	Mean monthly	#	#	0	#	#
	Maximum monthly	0.8	1.1	#	2.0	1.2
	Maximum 24-hour	0.5	1.1	#	2.0	0.9
	Thunderstorm days	0	*	*	0	0
LA SERENA	Mean monthly	#	#	#	#	#
	Maximum monthly	0.4	0.7	0.1	2.1	1.3
	Maximum 24-hour	0.4	0.7	0.1	2.1	1.1
	Thunderstorm days	*	0	*	0	*
LA PAMPA	Mean monthly	#	#	#	#	#
	Maximum monthly	0.5	0.4	0.4	0.8	1.0
	Maximum 24-hour	0.5	0.1	0.4	0.6	0.5
	Thunderstorm days	na	na	na	na	na
CHRIST OF THE ANDES	Mean monthly	0.4	0.4	0.2	0.1	1.0
	Maximum monthly	0.4	0.6	0.2	0.1	1.1
	Maximum 24-hour	0.1	0.6	0.2	0.1	0.2
	Thunderstorm days	1	2	2	1	*
VALPARISO	Mean monthly	0.2	0.1	#	#	0.2
	Maximum monthly	2.6	1.3	1.7	1.2	3.1
	Maximum 24-hour	0.9	1.3	1.0	0.9	1.5
	Thunderstorm days	*	0	*	*	*
SANTIAGO	Mean monthly	0.2	0.2	#	0.1	0.2
	Maximum monthly	2.3	2.4	0.9	3.3	1.5
	Maximum 24-hour	1.2	1.5	0.9	2.1	0.9
	Thunderstorm days	*	*	*	*	*
CONSTITUCION	Mean monthly	0.8	0.5	0.3	0.3	0.7
	Maximum monthly	5.6	3.0	2.7	2.9	5.2
	Maximum 24-hour	1.8	2.0	1.9	1.4	2.0
	Thunderstorm days	0	0	*	0	0
SAN CARLOS	Mean monthly	1.5	1.8	1.2	1.1	2.0
	Maximum monthly	7.4	7.5	4.4	3.1	5.0
	Maximum 24-hour	3.1	2.4	1.8	2.0	1.7
	Thunderstorm days	1	1	*	*	*
TALCA	Mean monthly	0.6	0.4	0.3	0.2	0.5
	Maximum monthly	3.7	2.6	3.3	2.2	2.7
	Maximum 24-hour	2.3	1.2	2.6	2.0	2.1
	Thunderstorm days	*	0	*	0	*
MALARGUE	Mean monthly	0.5	0.3	0.4	0.9	0.8
	Maximum monthly	2.1	4.9	4.0	5.8	7.7
	Maximum 24-hour	1.5	3.3	0.8	2.3	3.1
	Thunderstorm days	1	2	4	5	1
CONCEPCION	Mean monthly	1.7	1.1	0.7	0.8	2.0
	Maximum monthly	7.7	6.3	3.7	7.6	8.3
	Maximum 24-hour	1.6	2.3	3.5	2.1	3.5
	Thunderstorm days	*	*	*	*	*
LOS ANGELES	Mean monthly	1.8	0.9	1.0	1.1	1.7
	Maximum monthly	8.5	3.2	3.9	6.2	6.0
	Maximum 24-hour	3.5	1.7	[illegible]	3.1	4.2
	Thunderstorm days	0	0	[illegible]	*	0
CHILLAN	Mean monthly	1.2	0.9	0.7	0.5	1.0
	Maximum monthly	4.8	4.5	5.2	3.2	5.2
	Maximum 24-hour	2.0	2.0	3.4	2.2	3.2
	Thunderstorm days	0	0	*	0	0
CHOS MALAL	Mean monthly	0.4	0.4	0.3	0.3	0.4
	Maximum monthly	1.3	1.0	1.1	0.5	1.9
	Maximum 24-hour	0.8	0.4	0.3	0.2	0.2
	Thunderstorm days	na	na	na	na	na

DRY SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.05 INCHES
* - LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

Figure 6-12. Dry-Season Tabular Precipitation Data, Central Chile.

THUNDERSTORMS. Isolated thunderstorms are rare below 10,000 feet (3,050 meters) MSL between the coast and western Cordillera Occidental, but they can occur with intense troughs. Isolated thunderstorms can develop every 4 or 5 days a season on the Andes south of 30° S due to orographic lifting. Cloud bases average 9,000 feet (2,745 meters) MSL, with tops to 45,000 feet (13,720 meters) MSL. Small hail is possible in the Central Valley and the western Andes when strong upper-air troughs form lines of active convection along the trough axis. Cloud bases average 6,000 feet (1,830 meters) MSL; tops rarely exceed 45,000 feet (13,720 meters) MSL. Although Figure 6-12 suggests that thunderstorms are infrequent in the Cordillera Occidental, this is not the case.

TEMPERATURE. There are significant surface temperature and humidity variations along the coastal fringes/coastal ranges, in interior valleys and on plateaus, and in the Andes. Mean daily highs peak in January or February; lowest mean daily lows are in November. The highest mean relative humidities are in March. Figure 6-13 shows mean daily highs and lows for November through March.

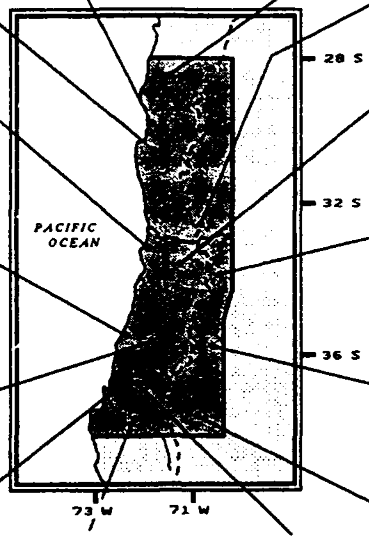
Mean daily highs along the coast range from 63 to 73° F (17 to 23° C). Mean daily lows range from 46 to 58° F (8 to 14° C); the lowest temperatures are found between 36 and 38° S. North of 32° S, record highs at most stations rarely exceed 85° F (29° C), but they can reach 95° F (35° C) south of 32° S. The record low is 36° F (2° C) at Concepcion in November, but lows rarely drop below 40° F (4° C) elsewhere on the coast.

Along the Central Valley, mean daily highs range between 74 and 87° F (23 and 31° C) from south to north. Mean daily lows range from 46 to 55° F (8 and 13° C). Record highs exceed 99° F (37° C) in any month of the season. Central Chile's highest temperature (105° F/41° C) was recorded at Angol (near Constitucion) in February. The record low of 29° F (-2° C) was also recorded at Angol in November. Most extremes range from 34 to 47° F (1 to 8° C).

In the Andes and adjacent foothills, elevation produces extremely variable diurnal temperature ranges. Above 12,000 feet (3,660 meters), highs may exceed 70° F (21° C) with cyclonic activity, while lows may go below 35° F (2° C). The record low for the dry season is -4° F (-20° C) at Christ of the Andes in November.

In the eastern foothills (Argentina), mean daily highs range from 76 to 88° F (24-31° C) below 7,000 feet (2,135 meters). Mean daily lows range from 43 to 51° F (6 to 11° C). Record highs may exceed 95° F (36° C). Record lows may go below 24° F (-5° C).

In the western Andes, the mean snow line at 33° S varies from 12,300 feet (3,750 meters) in November to 14,700 feet (4,480 meters) in February. Along the eastern Andes, the mean snow line ranges from 12,700 feet (3,870 meters) in November to 15,500 feet (4,725 meters) in February.



DRY SEASON TEMPERATURES (F)

Station		NOV	DEC	JAN	FEB	MAR
OVALLE	EXTREME MAXIMUM	97	94	97	93	94
	AVERAGE MAXIMUM	79	82	83	83	81
	AVERAGE MINIMUM	50	53	55	55	52
	EXTREME MINIMUM	36	41	44	45	42
LA SERENA	EXTREME MAXIMUM	89	88	82	86	85
	AVERAGE MAXIMUM	65	68	70	70	68
	AVERAGE MINIMUM	53	56	58	58	56
	EXTREME MINIMUM	44	46	45	42	42
VALLENAR	EXTREME MAXIMUM	88	91	85	89	88
	AVERAGE MAXIMUM	75	78	79	80	77
	AVERAGE MINIMUM	50	52	54	54	52
	EXTREME MINIMUM	43	46	47	41	41
CHRIST OF THE ANDES	EXTREME MAXIMUM	59	61	68	63	62
	AVERAGE MAXIMUM	40	46	50	49	45
	AVERAGE MINIMUM	24	28	31	30	28
	EXTREME MINIMUM	-4	7	14	9	6
VALPARISO	EXTREME MAXIMUM	91	91	91	94	89
	AVERAGE MAXIMUM	69	71	72	72	70
	AVERAGE MINIMUM	52	54	56	56	54
	EXTREME MINIMUM	44	46	46	43	45
SANTIAGO	EXTREME MAXIMUM	97	99	96	102	102
	AVERAGE MAXIMUM	76	82	85	83	79
	AVERAGE MINIMUM	48	51	54	52	49
	EXTREME MINIMUM	32	32	43	32	30
CONSTITUCION	EXTREME MAXIMUM	73	75	87	81	79
	AVERAGE MAXIMUM	64	67	69	69	67
	AVERAGE MINIMUM	46	49	51	49	48
	EXTREME MINIMUM	42	43	45	45	41
SAN CARLOS	EXTREME MAXIMUM	100	98	100	98	94
	AVERAGE MAXIMUM	81	86	86	84	79
	AVERAGE MINIMUM	46	50	53	51	46
	EXTREME MINIMUM	26	30	36	35	28
TALCA	EXTREME MAXIMUM	97	103	100	100	97
	AVERAGE MAXIMUM	78	85	87	86	81
	AVERAGE MINIMUM	50	53	55	53	50
	EXTREME MINIMUM	34	41	42	38	36
MALARGUE	EXTREME MAXIMUM	95	100	100	100	94
	AVERAGE MAXIMUM	76	81	85	83	76
	AVERAGE MINIMUM	43	47	49	48	44
	EXTREME MINIMUM	23	24	32	28	21
CONCEPCION	EXTREME MAXIMUM	88	96	98	93	82
	AVERAGE MAXIMUM	67	70	73	73	70
	AVERAGE MINIMUM	47	50	52	51	49
	EXTREME MINIMUM	36	37	39	39	32
LOS ANGELES	EXTREME MAXIMUM	93	100	99	102	91
	AVERAGE MAXIMUM	74	78	83	81	77
	AVERAGE MINIMUM	46	50	52	51	48
	EXTREME MINIMUM	36	32	43	39	36
CHILLAN	EXTREME MAXIMUM	90	99	99	100	95
	AVERAGE MAXIMUM	74	79	83	82	78
	AVERAGE MINIMUM	46	49	51	50	47
	EXTREME MINIMUM	34	36	36	39	32
CHOS MALAL	EXTREME MAXIMUM	100	103	105	105	99
	AVERAGE MAXIMUM	78	84	88	86	80
	AVERAGE MINIMUM	47	51	54	51	46
	EXTREME MINIMUM	24	31	29	36	27

Figure 6-13. Dry-Season Tabular Temperature Data, Central Chile.

Mean relative humidities are highest at locations below 1,000 feet (305 meters) MSL. At 0700L north of 33° S, they range from 76 to 94%; south of 33° S, from 69 to 83%. At 1400L, they are 55 to 73% along the entire coastline. By 1900L, they range from 41 to 82%. The highest late evening relative humidities occur south of 36° S.

In the western foothills (2,000 to 6,000 feet/610 to 1,830 meters) north of 33° S, RHs at 0700L are between 76 and 84%. Above 6,000 feet (1,830 meters), 0700L RHs are 34 to 55%.

Between 2,000 and 10,000 feet (610 and 3,050 meters), 1400L RH is 31 to 42 %. Along the eastern slopes of the Andean foothills (in Argentina) and the Central Valley, RH is 30 to 53%. Mean dry-season RH increases above 10,000 feet (3,050 meters) due to mid-afternoon orographic convection. By 1900L, only the highest ridge crests have RH above 50%. Figure 6-14 shows five stations with wet-bulb globe temperature data (° F) at specific hours in February.

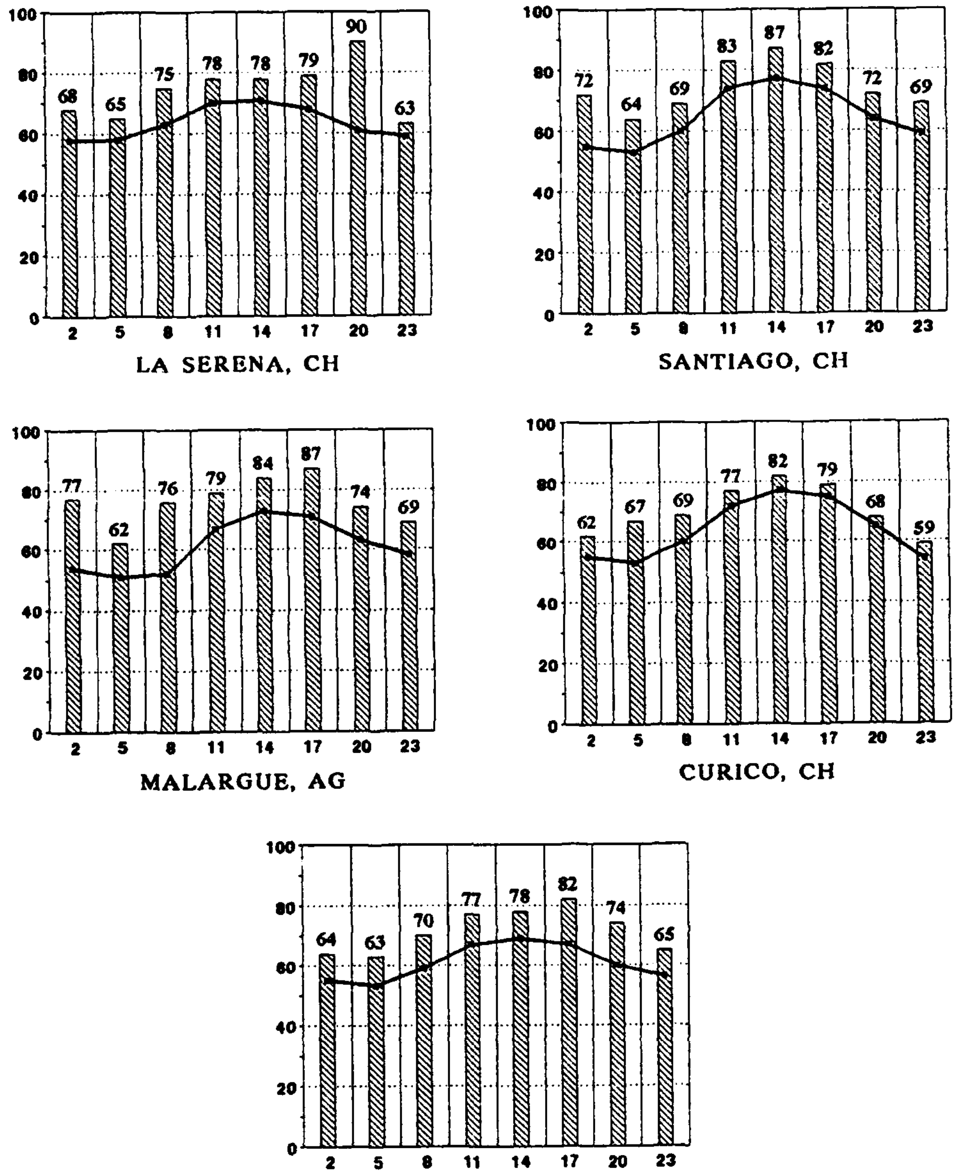


Figure 6-14. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for February, Central Chile. Mean WBGT is a line graph superimposed over the bar graphs (maximum WBGT).

FLIGHT HAZARDS. Directional wind shear from surface to 8,000 feet (2,440 meters) MSL is common during the dry season. Moderate to severe turbulence is possible for light aircraft and helicopters. Above 7,000 feet (2,135 meters) MSL, occasional moderate turbulence between 1200 and 1900L is found between 34 and 38° S. Severe turbulence along the entire eastern Andes is possible with strong downslope winds and strong upper-air troughs. Clear air turbulence (light to occasional moderate and isolated severe) occurs between 28 and 33° S with mountain waves in the eastern Andes foothills above 10,000 feet (3,050 meters) MSL. In and around thunderstorms, 50-knot wind gusts, small hail, and severe turbulence is possible in the eastern Andes between 33 and 38° S. Ridge crests can be totally obscured by clouds. Light to moderate mixed icing occurs in trough-associated middle cloud layers as far north as 31° S. From 0400 to 0800L, stratus can totally obscure Andes foothills and coastal ranges between 4,000 and 8,000 feet (1,220 and 2,440 meters) MSL.

GROUND HAZARDS. Upper-air troughs can produce isolated thunderstorms, heavy rain, and flash flooding in the upper valleys of the Rio Aconcagua and Rio Bio Bio river basins. Flash flooding also occurs along the eastern Andes between 34 and 38° S where narrow upper valleys widen out onto the Patagonia of western Argentina. Radiation or advection fog reduces visibility between 2200 and 0900L. Visibilities can be below 1 mile between 0400 and 0900L along the coast, coastal ranges, Central Valley, and interior valley connecting the coast with the Central Valley. Visibilities below 3 miles can be expected at these locations for at least 2 hours every other day.

GENERAL WEATHER. The South Pacific High produces a strong inversion over the entire coastline, producing extended fair-weather periods and light winds. The inversion, which is confined to the coast and Central Valley, varies in height from 500 to 8,000 feet (160 to 2,440 meters) MSL. Stratus up to 4,000 feet (1,220 meters) thick usually develops beneath the inversion layer. Winds below 8,000 feet (2,440 meters) MSL are controlled by outflow from the high-pressure cells over both oceans during fair weather periods. The highs are separated by the Andes.

Frontal activity and upper-air troughs affect Central Chile every 3 to 6 days. Most significant weather occurs along the trough axis, but when the trough and associated cold front stall against the western Andes, rainfall, strong winds, and heavy convection are widespread. Strong downslope winds (the "zonda") may exceed 50 knots along the eastern Andes with intense surface lows. The coastline, the Central Valley, and the Andes foothills are covered with thick fog when a warm, moist air mass precedes the cold front.

SKY COVER. Cold fronts usually produce multilayered cloud cover, low ceilings, and/or embedded convective cumulus along the trough axis north as far as 31° S. Heavy cumulus buildups are found above 6,000 feet (1,830 meters) MSL along the western Andes south of 34° S. On rare occasions, mid-level moisture is sufficient to produce heavy cumulus north of 34° S. Tops often exceed 20,000 feet (6,100 meters) MSL.

Figure 6-15 shows the high incidence of stratus cloud cover along the coastline which, along with the Central Valley, is usually dominated by stratus and stratocumulus. Sky cover exceeds 6/8ths every second or third day (8 to 14 days each April) between 0700 and 1300L. Stratus is the primary cloud type, particularly north of 32° S, because the Humboldt Current and inversion layer are both well established; cold fronts rarely reach this far north. Cumulus is common with troughs; thin cirrus is frequent during fair weather periods. Cumulus is common along the Cordillera Occidental above 7,000 feet (2,135 meters) MSL. Higher terrain may be shrouded in convective cumulus between 1200 and 1800L, while stratus and stratocumulus is frequent in the upland valleys between 0600 and 1100L.

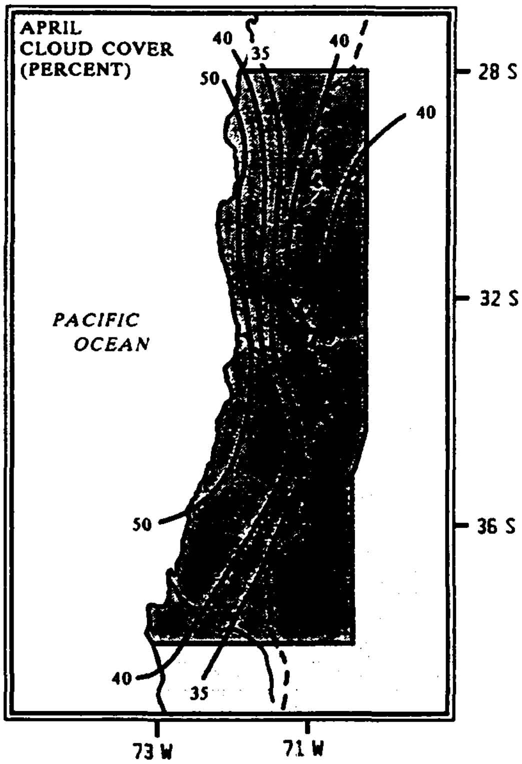


Figure 6-15. Mean Dry-to-Wet Transition Cloud Cover, Central Chile.

Low ceilings, usually stratus mixed with thin fog/haze, are most frequent between 2100 and 0900L (Figure 6-16). By 1100L, most stratus dissipates or lifts to 4,000 feet (1,220 meters) MSL and becomes stratocumulus (2-4/8ths coverage) along the coastline, coastal ranges, and in the Central Valley. If the inversion layer is strong, stratus can persist until 1500L along the coastline. By 1400L, the Andes can develop scattered cumulus with bases at or above 6,000 feet (1,830 meters) MSL. Tops rarely exceed 20,000 feet (6,100 meters) MSL, but if they are associated with a trough, they can exceed 35,000 feet (10,670 meters) MSL. Extensive lines of cumulus can form along the western Cordillera Occidental above 10,000 feet (3,050 meters), obscuring ridge crests south of 33° S. Middle clouds extend 100 to 150 miles downwind of upper troughs south of 31° S; they clear almost immediately after trough passage.

Ceilings below 1,000 feet (305 meters) AGL can persist for up to 12 hours with strong cold fronts on the western side of the Andes. Scud with bases at or below 500 feet (150 meters) AGL occurs along the coastline and coastal ranges south of 34° S. Embedded towering cumulus and cumulonimbus are possible when an upper-air trough is superimposed over the surface trough. Thick cumulus usually forms along or just ahead of the surface trough axis at or below 6,000 feet (1,830 meters) MSL south of 34° S. Surface troughs usually weaken along the Andes; the eastern foothills rarely have cumulus bases below 7,000 feet (2,135 meters) MSL; tops rarely exceed 25,000 feet (7,620 meters) MSL.

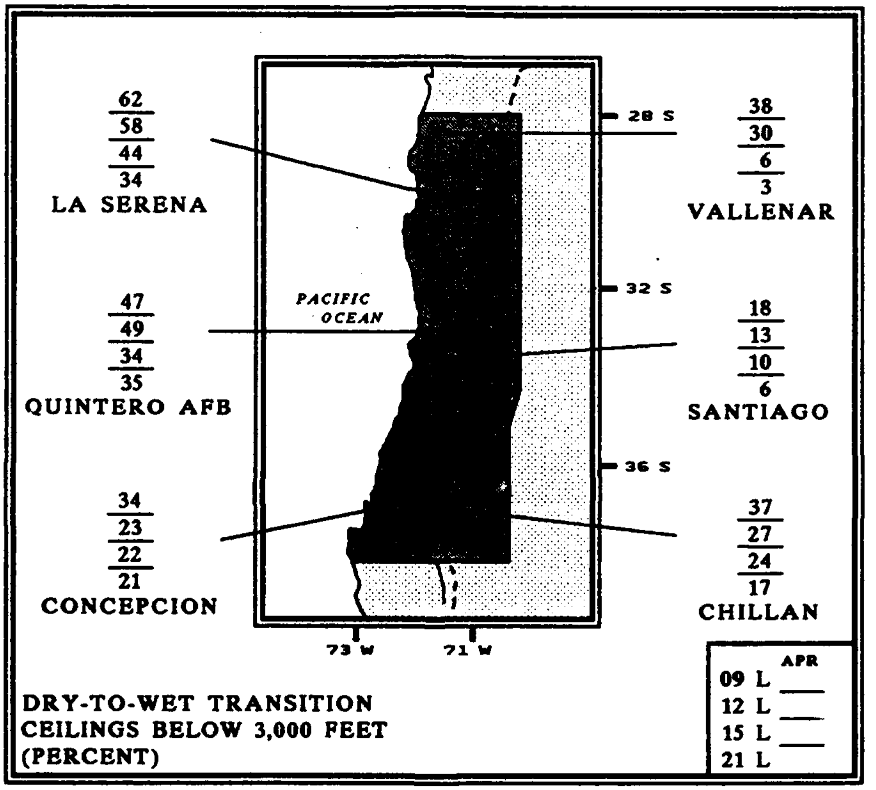


Figure 6-16. Dry-to-Wet Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Chile.

VISIBILITY below 3 miles (see Figure 6-17) is usually associated with slow-moving cold fronts. Advection fog is common with warm fronts. Low visibility is also common with radiation fog in the Central Valley and the Cordillera Occidental's upper-valley floors between 0100 and 0900L. Early morning fog and stratus can also produce low visibilities over the coastal ranges and coastline when the inversion layer is well-developed. Fog and stratus usually burn off by 1100L; visibility improves to 6 miles over 90% of the time between 1200 and 2100L.

Reduced visibility is most frequent between 0100 and 0900L. The frequency of visibility below 6 miles ranges from 39% at La Serena (0100L) to 56% at Valparaiso (0700L). Visibility below 3 miles ranges from 7% at La Serena (0100L) to 32% at Valparaiso (0700L).

In the Central Valley, visibility frequencies between 3 and 6 miles range from 7% at Curico (0100L) to 86% at Santiago (0700L). Visibility below 3 miles ranges from 2% at Curico (0100L) to 46% at Santiago (0700L). At Santiago, Los Cerrillos Airport reports significantly more radiation fog and stratus than El Bosque Airport. Industrial smoke and haze contribute to lower visibility in the Santiago area in the early morning hours.

In the Cordillera Occidental and the foothills above 3,000 feet (915 meters), visibilities are rarely below 6 miles during fair weather. The upper valleys of the Rio Aconcagua and Rio Bio Bio river basins may have isolated patches of dense radiation fog and stratus between 0100 and 0900L. Blowing dust is rare, with less than 5% frequency, but it is possible along the eastern foothills in Argentina with frontal systems or strong drainage winds.

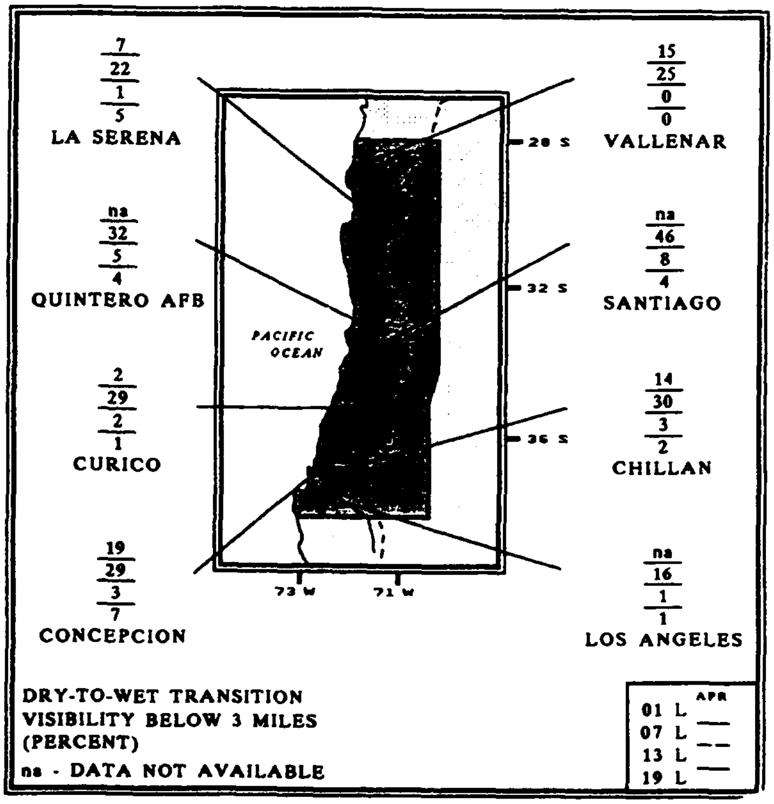


Figure 6-17. Dry-to-Wet Transition Percent Frequencies of Visibility Below 3 Miles, Central Chile.

WINDS. Winds during fair weather are generally southerly due to the South Pacific High. Mean surface wind speeds (Figure 6-18) and directions vary with terrain. West of the Andes, wind speeds reach 15 knots along the coast between 1200 and 1700L. A strong sea breeze develops when southerly flow is weak. In the Central Valley, valley winds average 7 knots between 1100 and 1900L. On rare occasions, mountain breezes can exceed 10 knots between 2000 and 0100L along the eastern rim of the Central Valley. Along the eastern Andean foothills, surface winds are usually northeasterly to southeasterly. Westerlies develop for 24 to 48 hours when fronts and upper-air troughs cross the Andes. Wind speeds range from 2 to 8 knots. Figure 6-19 shows surface wind roses for selected stations.

Northwesterlies or northerlies precede most troughs for up to 36 hours south of 33° S. Wind speeds may exceed 25 knots along the coastline and in the Central Valley. Westerlies and southwesterlies prevail behind the trough axis. Wind speeds often exceed 20 knots and, with intense cold fronts, have exceeded 60 knots at Concepcion, Chillan, and in most mountain passes.

STATION	APR
CHILLAN	5
CONCEPCION	8
CURICO	4
LA SERENA	4
MALARGUE	2
SANTIAGO	3
VALLENAR	3

Figure 6-18. Mean Dry-to-Wet Transition Wind Speeds, Central Chile.

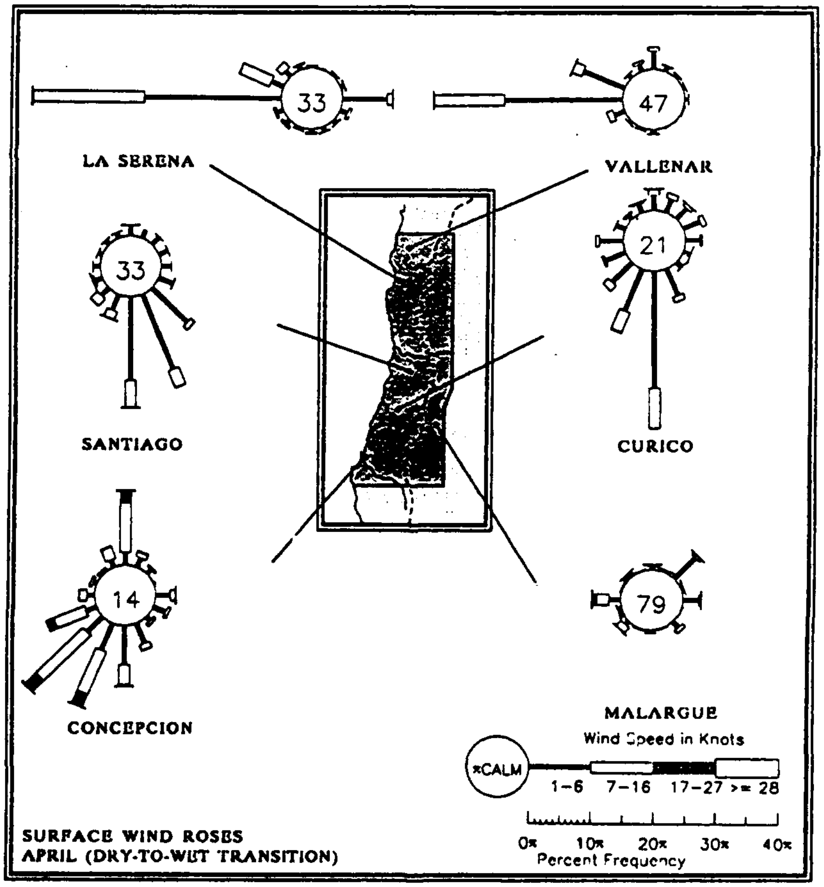


Figure 6-19. April Surface Wind Roses, Central Chile.

Winds are south-southeasterly or southerly from 1,000 to 5,000 feet (305 to 1,525 meters) MSL. Above 6,000 feet (1,830 meters) MSL, winds rotate clockwise with height from southwesterly to northwesterly. Figure 6-20 shows mean April wind directions between 3,000 and 10,000 feet (915 and 3,050 meters) MSL for two upper-air stations. Mean wind speeds average 7 knots between 3,000 and 5,000 feet (915 and 1,525 meters) MSL, and 10 knots from 6,000 to 10,000 feet (1,830 to 3,050 meters) MSL.

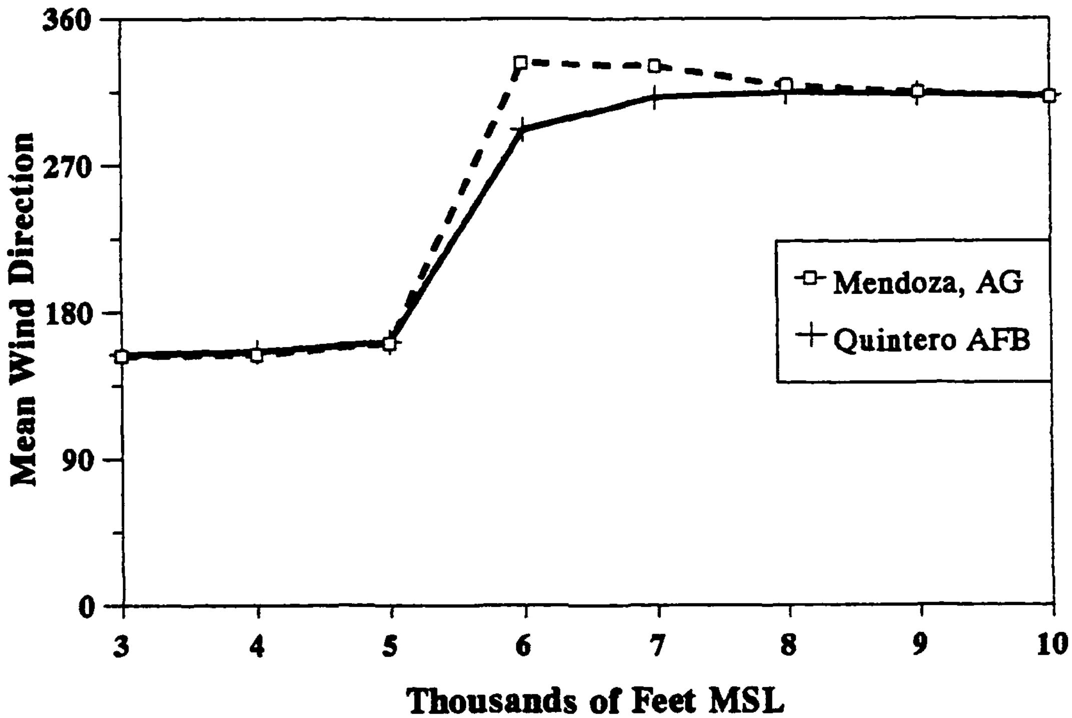


Figure 6-20. Mean Wind Direction for April From 3,000 to 10,000 Feet (915 to 3,050 meters) MSL, Central Chile. There is directional shear between 5,000 and 6,000 feet (1,525 and 1,830 meters) MSL on either side of the Andes. The solid line represents Quintero, Chile (33° S, 71° 30' W); the dashed line, Mendoza, Argentina (33° S, 69° W). Mendoza, east of the zone, is included because it represents downwind and lee-side conditions accurately.

Mean wind speeds between 15,000 and 45,000 feet (4,570 and 13,720 meters) MSL range from 20 to 54 knots. West of the Andes, highest mean wind speeds average 57 knots between 38,000 and 39,000 feet (11,585 and 11,890 meters) MSL. East of the Andes, maximum wind speeds average 54 knots at 44,000 (13,415 meters) MSL.

PRECIPITATION. Mean April rainfall is greater than 1 inch (25 mm) south of 35° S along the coastline (see Figure 6-21). Rainfall amounts decrease abruptly along the eastern Andes and north of 31° S. Snowfall can exceed 6 inches (152 mm) above the 10,000-foot (3,050-meter) level south of 32° S with extremely cold air aloft.

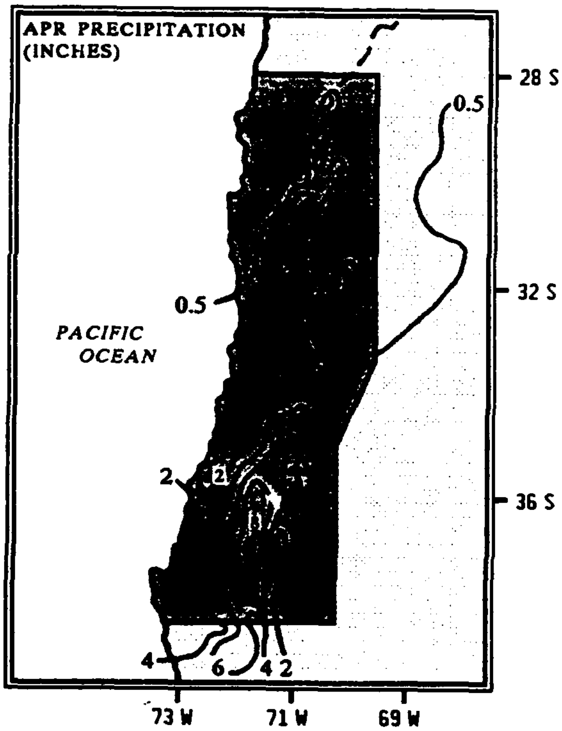


Figure 6-21. Mean April Precipitation, Central Chile.

Light rain and drizzle from stratus is most frequent on the coast. On rare occasions, slow-moving cold fronts generate isolated moderate-to-heavy rainfall with thundershowers along its axis. Orographic lifting along the Andes accelerates cloud development and increases rainfall amounts. Maximum 24-hour rainfall exceeds 1.5 inches (38 mm) except for stations north of 31° S and Argentine stations south of 34° S. Heaviest convection and rainfall with fronts occur along the western Andes and southern Central Valley south of 36° S where extreme 24-hour rainfalls exceed 3.5 inches (89 mm), and monthly rainfall totals can exceed 10 inches (254 mm)--three to ten times the mean April rainfall (Figure 6-22). Wet fogs (or "camanchacas") develop along the western Andean foothills in the stratus layer, but they rarely produce more than a trace.

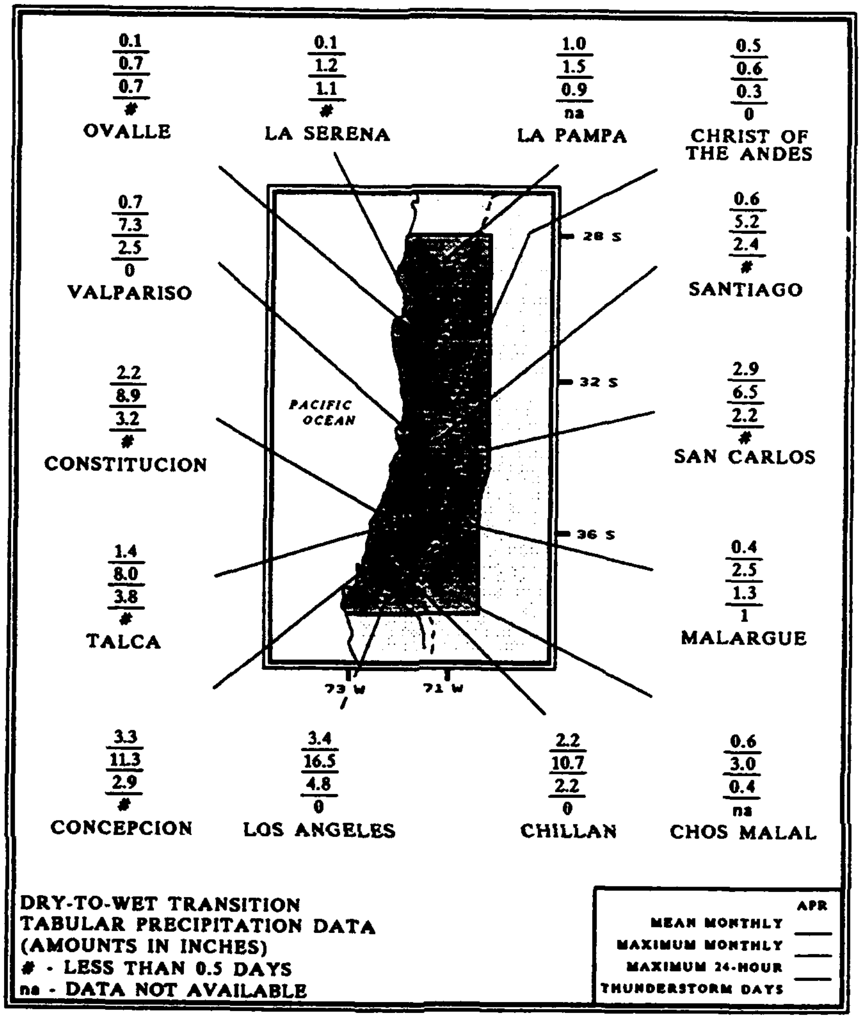


Figure 6-22. Dry-to-Wet Transition Tabular Precipitation Data, Central Chile.

THUNDERSTORMS occur about once every April along the northeastern rim of Chile's Central Valley and the Andes between 32 and 38° S above 10,000 feet (3,050 meters) MSL (Figure 6-22). Cloud bases average 5,000 feet (1,525 meters) AGL in the northeastern Central Valley, north of 33° S, and 3,500 feet (1,070 meters) AGL in the Central Valley and western Andes south of 33° S. Tops can exceed 40,000 feet (12,190 meters) MSL. Below 10,000 feet (3,050 meters) MSL, thunderstorms are rarely severe, but small hail has fallen near Santiago, Talca (in the Central Valley), and El Teniente (in the western Andes foothills).

TEMPERATURE. Along the coast, mean daily highs range from 62 to 67° F (17 to 19° C) in April (Figure 6-23), and mean daily lows are 45-53° F (7-12° C). Record April highs rarely exceed 80° F (27° C) north of 32° S, but Valparaiso has reached 87° F (31° C). The record low is 30° F (-1° C) at Concepcion, but lows are rarely below 38° F (3° C) elsewhere. In the Central Valley, mean daily highs range from 69 to 76° F (18 to 25° C), while mean daily lows range from 43 to 47° F (6 to 8° C). The record high is 91° F (33° C); the record low, 27° F (-3 C), both at Talca. Most record lows are from 30 to 37° F (-1 to 3° C).

In the western Andean foothills between 2,000 and 7,000 feet (610 and 2,135 meters), April mean daily highs decrease with height from 74° F (23° C) to 61° F (16° C). Mean daily lows average 45° F (7° C). Record highs exceed 85° F (29° C) and record lows reach 18° F (-8° C). In the Andes Mountains and adjacent foothills, intense mountain/valley winds produce extremely variable daytime temperatures. The mean snow line at 33° S is found near 12,800 feet (3,900 meters) along the western Andes, and 13,800 feet (4,210 meters) along the eastern Andes. Above 12,000 feet (3,660 meters), mean daily highs rarely exceed 51° F (11° C), while the mean daily low is rarely above 26° F (-3° C). The record low for April is 7° F (-14° C) at Christ of the Andes (on the Argentina-Chile border).

In the eastern foothills of Argentina, mean daily highs range from 70 to 73° F (21 to 23° C) below 7,000 feet (2,135 meters). Mean daily lows are from 38° F (3° C) to 41° F (5° C). Record highs exceed 90° F (32° C) and record lows reach 20° F (-7° C).

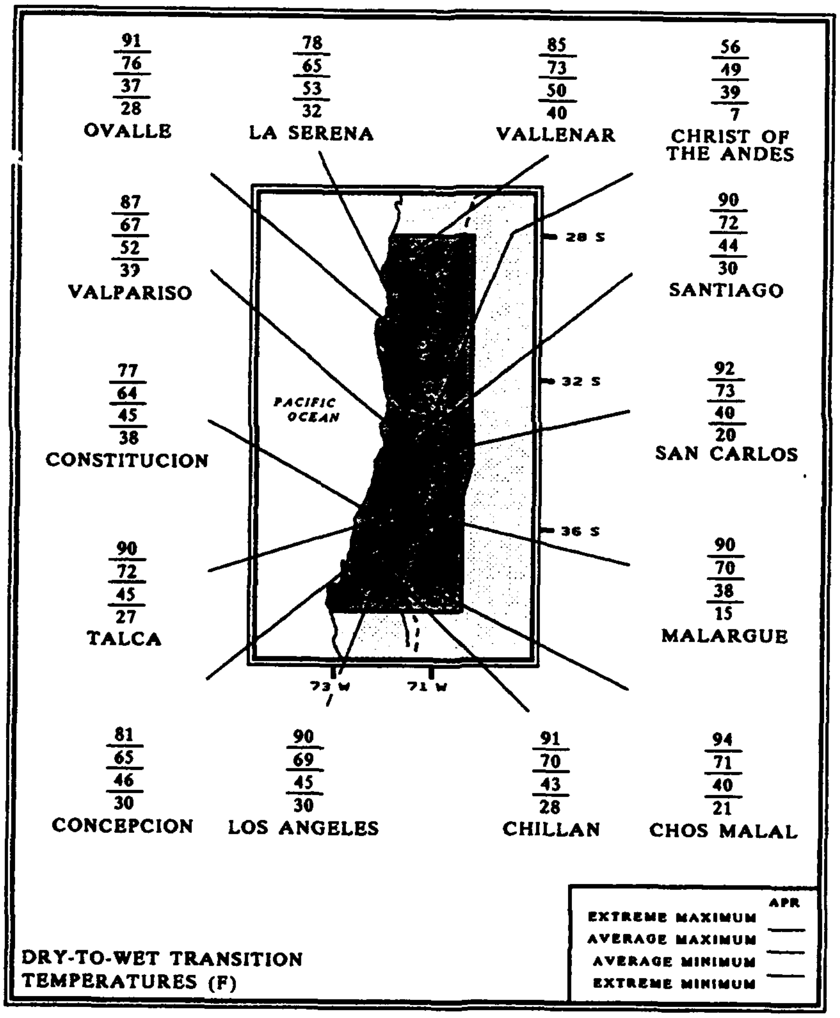


Figure 6-23. Dry-to-Wet Transition Tabular Temperature Data, Central Chile.

Mean relative humidities along the immediate coast and coastal ranges below 1,000 feet (305 meters) at 0700L range from 84% (La Serena) to 89% (Concepcion). At 1400L, they range from 72 to 78%. By 1900L, they are 80 to 85%.

Over interior valleys and plateaus, mean RHs at 0700L are 78 to 90%. By 1400L, they are 46 to 62%. Lowest RHs at 1400L are along the northern edges of the Central Valley; by 1900L, they range from 59 to 75%. The highest RHs in late evening are south of 36° S.

In the Andes above 6,000 feet (1,830 meters), mean RHs at 0700L range from 34 to 77% because of the large differences in terrain. Enclosed upland valleys can have light radiation fog, while exposed sites upwind may be cloud free. The western foothills (2,000 to 6,000 feet/610 to 1,830 meters) north of 33° S have 0700L RHs between 77 and 86%. At 1400L, RH increases above 10,000 feet (3,050 meters) with mid-afternoon orographic convection. Between 2,000 and 10,000 feet (610 and 3,050 meters), RH is 37 to 57%. By 1900L, only the highest ridge crests have RHs above 50%.

Figure 6-24 shows five stations with wet-bulb globe temperature data (° F) at specific hours in April.

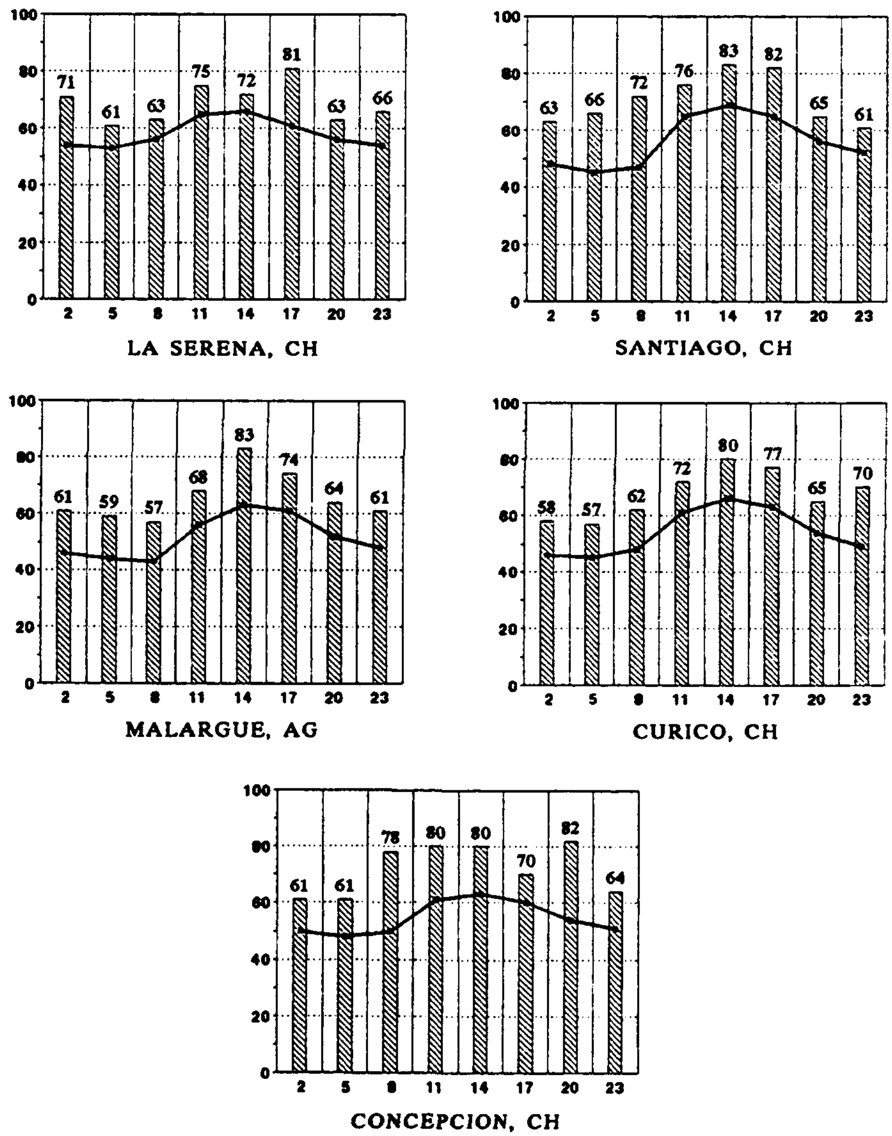


Figure 6-24. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Central Chile. Mean WBGT is shown by a line graph superimposed over the bar graphs (maximum WBGT).

FLIGHT HAZARDS. Strong directional wind shear between the surface and 8,000 feet (2,440 meters) MSL is possible in the stratus layer. Light to moderate turbulence is common for small aircraft and helicopters. Along the western foothills, the stratus layer can obscure terrain. Visibility below 3 miles in fog and stratus is most frequent between 2300L and 0900L. Low ceilings can persist throughout the day with a strong low-level inversion.

Cyclonic activity produces significant low-level crosswinds and wind shear, as well as scattered thunderstorms along the western Andes and Central Valley. Along the trough axis, low ceilings and moderate rain can reduce visibility to less than 3 miles for up to 3 hours. Ridge crests above 10,000 feet (3,050 meters) MSL may be totally obscured by cloud. Stalled cold fronts produce heavy cumulus and isolated thunderstorms with 40-knot wind gusts in and around individual cells. Along the eastern Andes, upper-air troughs can produce mountain waves, severe turbulence, and strong downslope winds at the surface. Moderate clear air turbulence is possible when troughs are not present. Light to moderate mixed icing occurs in trough-associated middle cloud layers as far north as 31° S.

GROUND HAZARDS. Flash flooding is possible along the Rio Aconcagua Valley and Rio Bio Bio basin within 48 hours after heavy thunderstorms. Upper-valley locations that open into the eastern Central Valley are immediately affected with little warning. Along the eastern Andes, prolonged drought can produce blowing dust. The "zonda," or chinook-type wind, can exceed 50 knots with strong troughs. Thick fog is possible in the Central Valley between 0100 and 0900L. Fog is most likely to occur after a night of moderate-to-heavy rainfall. Visibility can be below 1 mile for several hours between 0400 and 0900L. Fog occurs between 2 and 15 days every April.

GENERAL WEATHER. The South Pacific High weakens, allowing low-pressure systems to reach the zone every 2 to 4 days during the wet season. Fronts normally extend northward along the coast to between 33 and 38° S. Intense systems produce sudden wind shifts, moderate to heavy rainshowers, isolated thundershowers or thunderstorms (above 6,000 feet/1,830 meters MSL), and low ceilings near the low and cold front. In rare cases, cold fronts extend to 25° S and affect the entire zone.

A broad upper-air trough, a transient wet-season feature, is often well-developed off the Chilean coast by June or early July. The trough base usually extends to 32° S between 75 or 80° W. It tilts southeastward toward the Drake Passage, crossing the Andes between 37 and 42° S. The Subtropical Jet is usually found near the trough base. This upper-air pattern is frequently observed during periods of intense cyclonic activity.

SKY COVER. Early morning low clouds and low-pressure systems are responsible for the 50% or greater mean cloudiness south of 33° S (Figure 6-25). North of 33° S, the coast is affected by early morning stratus, while the mountains have afternoon cumulus.

Warm front "overrunning" produces stratus and stratocumulus over the coastline and Central Valley, cumulus in the higher terrain. Bases usually range from 500 to 4,000 feet (160 to 1,220 meters) AGL. The warm front stratus can be 4,000 feet (915 to 1,220 meters) thick, but is rarely above the top of the inversion layer. Cumulus is common with warm fronts south of 32° S along the western Andean foothills and ridge crests. Extensive lines of orographic cumulus form, usually at 4,000 to 5,000 feet (1,220 to 1,525 meters) MSL with 10- to 20-knot northwesterly winds. The cumulus can extend continuously in a north-south band for 50 to 100 NM; tops can exceed 20,000 feet (6,100 meters). Warm-front cloud development on the leeward slopes of the Andes is usually found south of 34° S; cumulus and stratocumulus bases are usually between 5,000 and 8,000 feet (1,525 and 2,440 meters) MSL. Cloud cover dissipates rapidly along the eastern Andes once the trough moves across the area. Middle-cloud layers extend 100 to 150 miles downwind of upper troughs south of 31° S; they clear almost immediately after trough passage. Subtropical Jet cirrus precedes most lows; it extends northward to 28° S with deep troughs.

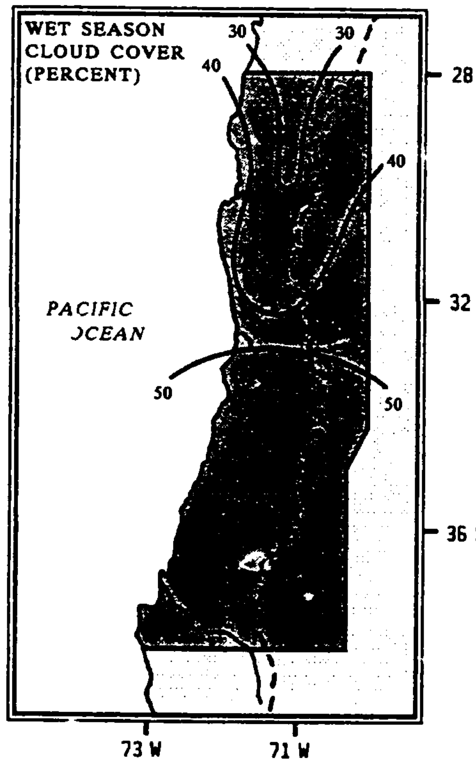


Figure 6-25. Mean Wet-Season Cloud Cover, Central Chile.

Figure 6-26 shows wet-season frequencies of ceilings below 3,000 feet (915 meters) AGL. The highest frequencies are between 2100 and 0900L with fog and early morning stratus or stratocumulus, but low ceilings with stratus are possible through 1700L whenever the inversion layer remains strong during the day.

Most surface lows and their cold fronts produce thick stratus layers with embedded cumulus. Scud is common along the coast, in coastal ranges, and in the Central Valley south of 36° S with strong surface lows. Ceilings are below 1,000 feet (305 meters) AGL between 10 and 20% of the time in July and August south of 34° S. Stratus and stratocumulus dominate below 6,000 feet (1,830 meters) MSL along the cold front. Embedded cumulus with bases at 3,000 feet (915 meters) AGL and tops to 15,000 feet (4,570 meters) MSL develop along the coast and coastal ranges between 32 and 38° S when deep mid-level troughing extends northward to 28° S.

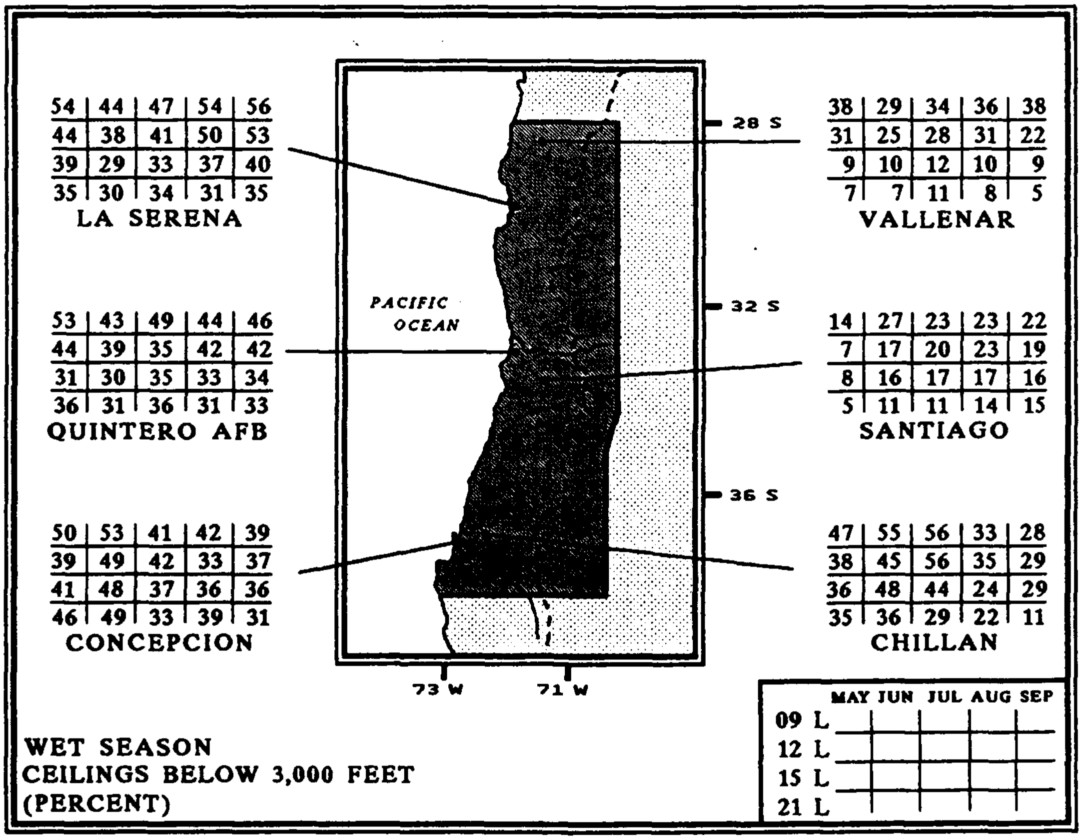


Figure 6-26. Wet-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Chile.

VISIBILITY. Early morning radiation fog in the Central Valley and advection fog along the coastline forms when the South Pacific High produces a strong low-level subsidence inversion during fair-weather periods. Coastal stratus can be advected inland against the western Andes south of 32° S if the subsidence inversion is strong. Visibility usually improves immediately after a trough passage except in areas where moderate to heavy rainfall has occurred. Visibility is below 1 mile in the Central Valley and western Andes foothills in the early morning after moderate nighttime rainfalls. The thick fog or low ceilings linger throughout the day if light winds allow a subsidence inversion to strengthen behind the trough. Visibility averages 2 to 4 miles by 1200L.

Early morning (0700L) visibility frequencies below 6 miles along the coastline range from 12 to 55%, with the highest frequencies south of 32° S. North of 32° S, visibility improves to greater than 6 miles at La Serena 84% of the time in May and 95% of the time in September as the sun burns off the low cloud and fog by 1300L. South of 32° S, visibility improves to greater than 6 miles 70 to 88% of the time at Valparaiso, and 73 to 80% of the time at Concepcion.

Cool maritime air masses regularly penetrate to 32° S from May through August, lowering visibilities below 3 miles. Santiago has the highest frequencies of visibility below 3 miles, particularly between 2100 and 0900L, due to radiation fog and industrial smoke and haze accumulations during fair weather periods.

Low visibility during fair weather is uncommon in the western Andes above 4,000 feet (1,220 meters). Low visibility occurs most frequently with low-pressure systems and moderate to heavy rainfall. Advection fog can lower visibility below 1 mile for 3 to 9 hours with slow-moving cold fronts. Isolated radiation fog can develop by 0700L on upland-valley floors; it usually burns off by 1000L.

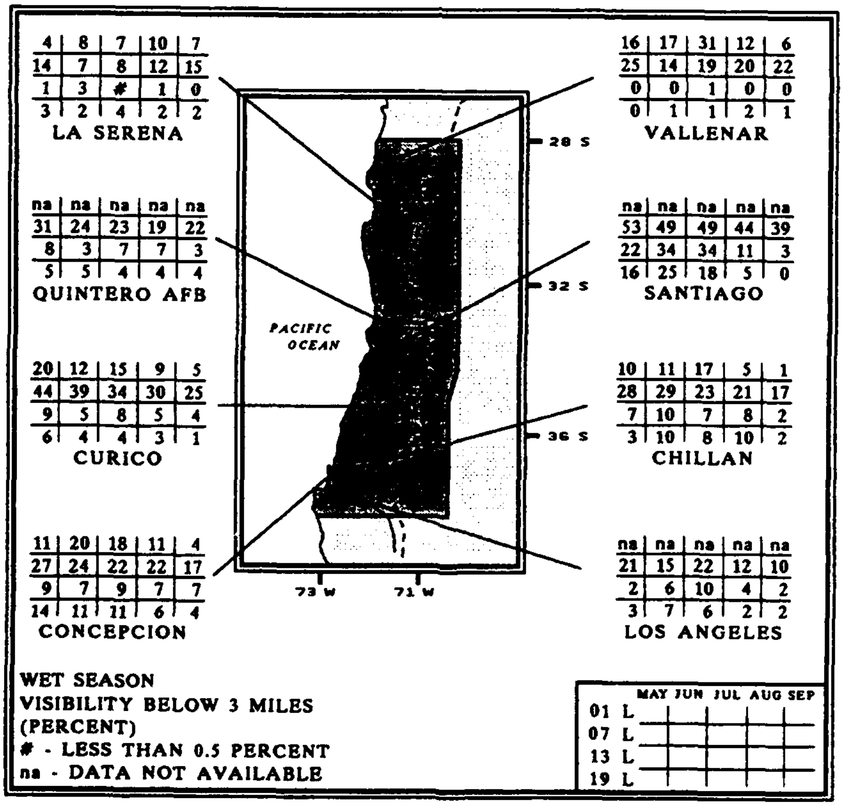


Figure 6-27. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Central Chile.

WINDS. Because storm systems are more frequent, wind directions vary more in the wet season than during the rest of the year. Southerly flow from the South Pacific High is replaced by 10- to 20-knot north to northwesterly winds preceding troughs for up to 36 hours. Winds can exceed 50 knots in rare cases. Westerlies and southwesterlies can persist below 8,000 feet (2,440 meters) MSL for up to 24 hours after the trough crosses the eastern Andes and can exceed 30 knots in some cases. This accelerates the sea breeze along the coastline from 5 to 20 knots between 1000 and 1800L.

The South Pacific High produces subsidence, clearing skies, and light/variable winds in the Central Valley. Prolonged fair weather is rare from mid-June to late-August.

The eastern Andes' slopes are usually sheltered from lows, but wind speeds can exceed 75 knots between 34 and 38° S with deep troughs. Strong westerlies and southwesterlies descend onto the foothills when the mid- or upper-level trough remains organized over the Andes.

Mean surface wind speeds (Figure 6-28) are affected by terrain. Along the coastline, 12-knot winds are common between 1200 and 1700L with a strong sea breeze. In the Central Valley, large-scale upslope valley winds are accentuated by synoptic flow during the day. Downslope mountain breezes at night are well-defined south of 35° S. Figure 6-29 shows surface wind roses for selected stations.

STATION	MEAN WIND SPEED				
	MAY	JUN	JUL	AUG	SEP
CHILLAN	5	5	5	5	5
CONCEPCION	9	10	10	8	9
CURICO	4	5	5	5	5
LA SERENA	4	4	4	4	5
MALARGUE	3	3	3	3	4
SANTIAGO	3	2	3	3	4
VALLENAR	2	2	3	3	4

Figure 6-28. Mean Wet-Season Wind Speeds, Central Chile.

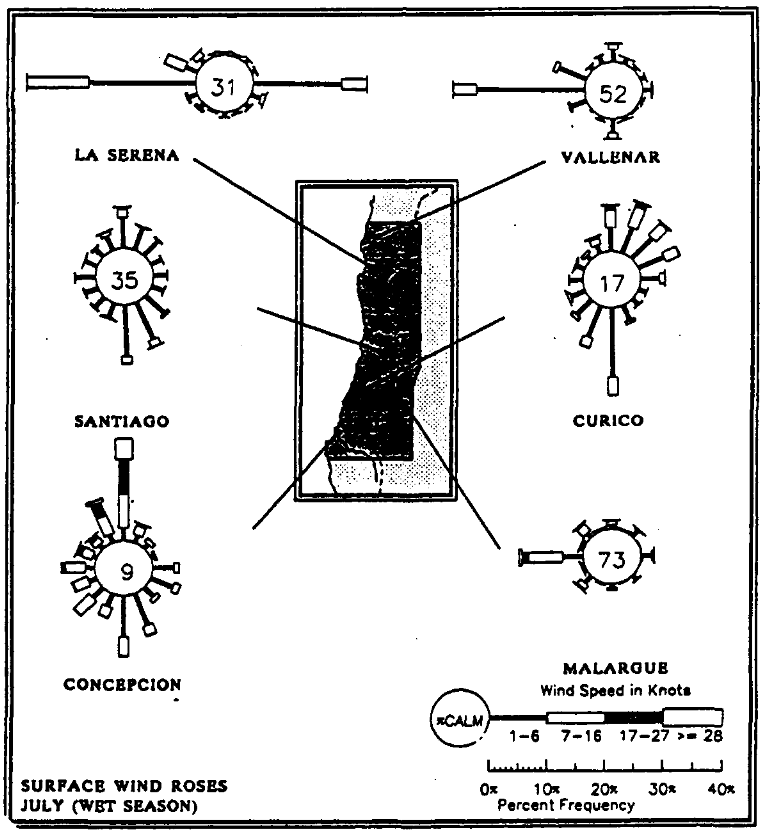


Figure 6-29. July Surface Wind Roses, Central Chile.

The Andes Mountains produce sharp contrasts in low-level circulation between the windward and leeward sides below 5,000 feet (1,525 meters) MSL (Figure 6-30). East of the Andes, the mean wind direction rotates clockwise from south-southwesterly to west-northwesterly. West-northwesterly winds dominate below 5,000 feet (1,525 meters) on the Pacific coastline. Mean wind speeds average 10 knots between 3,000 and 5,000 feet (915 and 1,525 meters) MSL. Wind direction from 6,000 to 10,000 feet (1,830 to 3,050 meters) MSL is west-northwesterly on both sides. By the end of the wet season, southerlies reappear in the lowest layers on the Pacific coast.

Mean wind speeds between 15,000 and 45,000 feet (4,570 and 13,720 meters) MSL range from 25 to 65 knots. The jet core is usually found at 39,000 (11,890 meters) MSL throughout the wet season; maximum speeds average 65 knots.

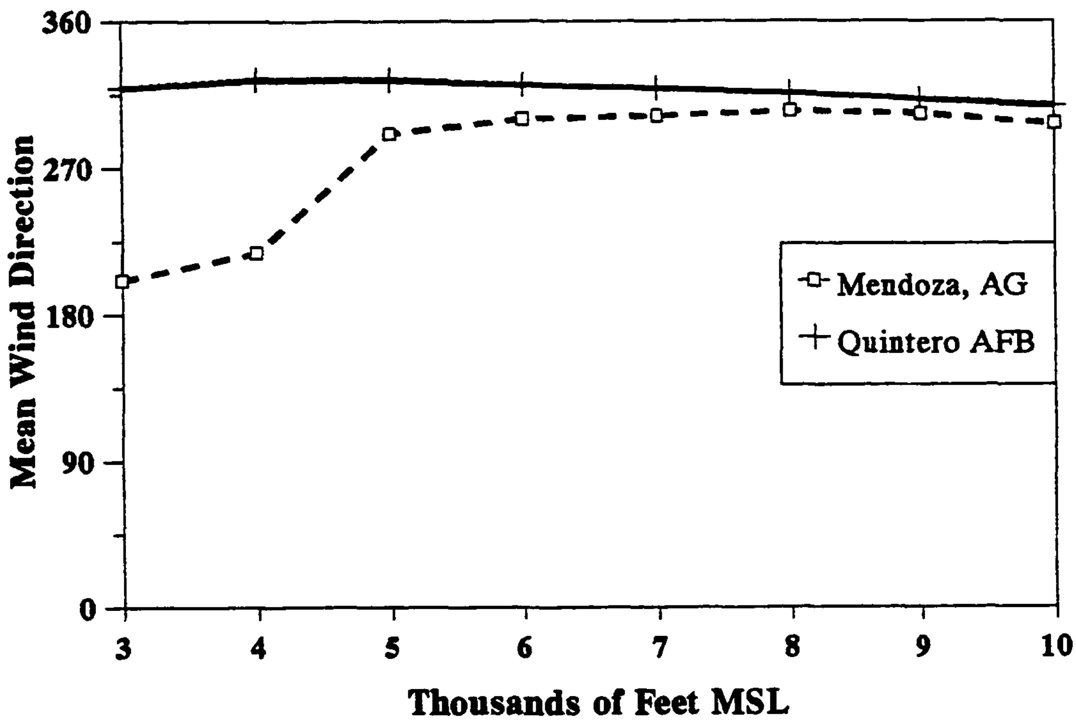


Figure 6-30. Mean Wind Direction for July Between 3,000 and 10,000 Feet (915 and 3,050 meters) MSL, Central Chile. Directional shear between 3,000 and 5,000 feet (915 and 1,525 meters) MSL is found only on the leeward slopes of the Andes.

PRECIPITATION. June is the wet season's wettest month with few exceptions. Average rainfall is over 8 inches (203 mm) in the Central Valley (Figure 6-31), and 12 inches (308 mm) in the Valley's southern end. June rainfall along the western Andes averages more than 4 inches (100 mm) between 3,000 and 6,000 feet (915 and 1,830 meters) from 33 to 38° S, and above 10,000 feet (3,050 meters) between 30 and 33° S. The coastline between 28 and 29° S is the exception in June, averaging only 0.4 inches (10 mm).

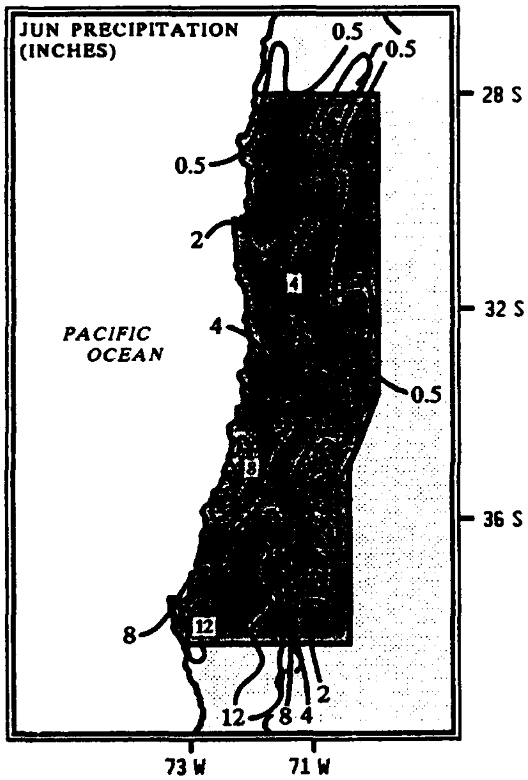


Figure 6-31. Average June Precipitation, Central Chile.

Maximum monthly and 24-hour rainfall totals (Figure 6-32) are extremely variable from year to year depending on the upper-air flow pattern.

Low-pressure systems normally affect the zone every second or third day from June to August, but every fourth day in May and September. Intense surface lows may stall along the Andes and remain stationary for 24 to 48 hours before dissipating. Heaviest rainfall is usually concentrated between 36 and 38° S.

Some surface lows form over the eastern Pacific Ocean between 33 and 35° S below deep 500-millibar troughs. These lows, blocked by the Andes, move slowly eastward while the 500-mb trough continues east toward the Atlantic Ocean. Coastal and mountain stations can receive over 20 inches (508 mm) of rain in a month with continuous low-level moisture pushed inland. Some 24-hour rainfall totals exceed 3 inches (76 mm) west of the Andes, but rarely exceed 1 inch (25 mm) east of the mountains.

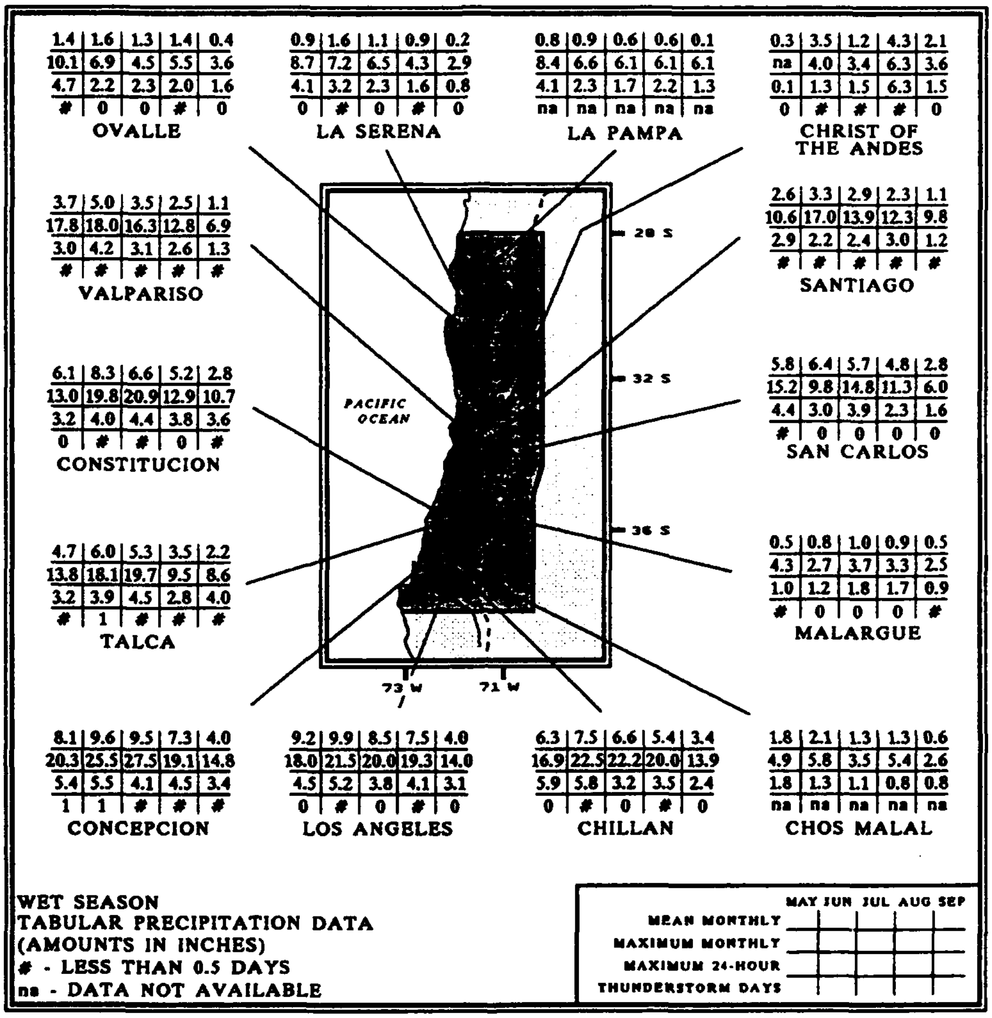


Figure 6-32. Wet-Season Tabular Precipitation Data, Central Chile.

The heaviest snowfall occurs above 8,000 feet (2,440 meters). It can reach 36 inches (810 mm) between 36 and 38° S. The snow line can be as low as 2,000 feet (610 meters) in extreme cases; snow can fall at sea level in July and August. Light snow and ice pellets have been recorded at Santiago and Valparaiso, but snow rarely remains on the ground for more than 3 hours along the coast and below 2,000 feet (610 meters) north of 32° S. Accumulations rarely exceed 1 inch (25 mm) below 2,000 feet (610 meters), or north of 32° S. These events may occur once or twice in an average wet season.

Heavier snowfalls usually occur with intense thunderstorms that develop along the cold front in the Central Valley. This is similar to what occurs in the northern Sierra Nevada of California when deep polar troughs remain stationary for 36 to 72 hours along the Pacific coastline. Mountain passes can be closed south of 33° S. Snowfall can be expected above 10,000 feet (3,050 meters)with most systems, regardless of strength.

THUNDERSTORMS occur on less than 1 day a month throughout the zone, most along intense cold fronts with deep upper-air troughs. Cloud bases average 3,000 feet (915 meters) AGL with tops to 30,000 feet (9,145 meters) MSL over the coast and Central Valley; tops can exceed 40,000 feet (12,190 meters) MSL along the Andes. Heavy wet snow is common above 10,000 feet (3,050 meters) MSL with thunderstorms in the Central Valley. Small hail is possible below 6,000 feet (1,830 meters) MSL.

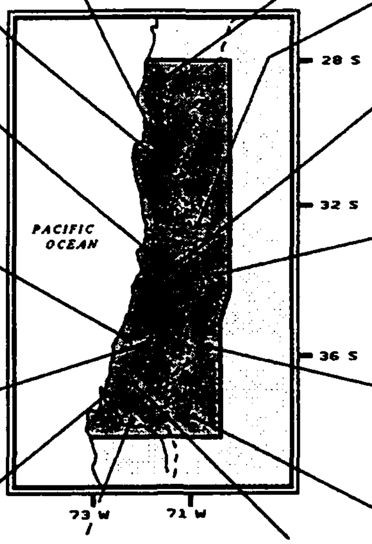
TEMPERATURE. Along the coast, mean daily highs range from 55 to 65° F (13 to 18° C); mean daily lows range from 40 to 50° F (4 to 10° C) (Figure 6-33). Record highs range from 64 to 84° F (19 to 29° C) at Valparaiso. Record lows reach 21° F (-6° C) at Concepcion.

Mean daily highs range from 54 to 65° F (12 to 18° C) in the Central Valley, while mean daily lows range from 37 to 43° F (3 to 6° C). Santiago's record highs range from 80° F (27° C) in June to 88° F (31° C) in September. South of 35° S, record highs range from 64° F (18° C) in the coastal mountains in June, to 82° F (28° C) at Talca and Los Angeles in both May and September.

In the western Andes foothills between 2,000 and 7,000 feet (610 and 2,135 meters), mean daily highs decrease with height from 64° F (18° C) at 2,000 feet (610 meters) to 50° F (10° C) at 7,000 feet (2,135 meters). Mean daily lows usually range from 36 to 41° F (2 to 5° C) between 2,000 and 5,000 feet (610 and 1,525 meters). Between 5,000 and 7,000 feet (1,525 and 2,135 meters), mean daily lows range from 33 to 35° F (1 to 2° C).

In the Andes Mountains and adjacent foothills, the mean snow line in May and September is near 11,500 feet (3,500 meters) at 33° S. From June to August, the mean snow line ranges from 10,200 to 10,600 feet (3,110 to 3,230 meters). Along the eastern Andes, it decreases from 12,500 feet (3,810 meters) in May to 10,600 feet (3,230 meters) in September. The mean daily high rarely exceeds 35° F (2° C), while the mean daily low is rarely above 21° F (-6° C). The record low is -23° F (-31° C) at Christ of the Andes (on the Argentina-Chile border).

In the eastern foothills of Argentina, mean daily highs range from 57 to 65° F (14 to 19° C) below 7,000 feet (2,135 meters). Mean daily lows range from 26 to 37° F (-3 to 3° C). Record highs may exceed 90° F (33° C), and the record low is -12° F (-24° C) at Malargue, Argentina, below 5,000 feet (1,525 meters).



WET SEASON TEMPERATURES (F)

Station		MAY	JUN	JUL	AUG	SEP
OVALLE	EXTREME MAXIMUM	86	83	86	88	90
	AVERAGE MAXIMUM	71	66	65	68	71
	AVERAGE MINIMUM	46	44	42	44	46
	EXTREME MINIMUM	32	32	27	32	34
LA SERENA	EXTREME MAXIMUM	75	76	74	76	79
	AVERAGE MAXIMUM	62	59	59	59	61
	AVERAGE MINIMUM	50	47	47	48	49
	EXTREME MINIMUM	34	32	32	35	37
VALLENAR	EXTREME MAXIMUM	86	85	86	86	91
	AVERAGE MAXIMUM	70	67	65	67	69
	AVERAGE MINIMUM	47	45	44	45	45
	EXTREME MINIMUM	37	35	35	34	37
CHRIST OF THE ANDES	EXTREME MAXIMUM	52	48	47	49	50
	AVERAGE MAXIMUM	33	27	26	26	30
	AVERAGE MINIMUM	21	15	13	14	15
	EXTREME MINIMUM	-1	-17	-23	-10	-7
VALPARISO	EXTREME MAXIMUM	81	76	82	82	84
	AVERAGE MAXIMUM	63	60	60	61	62
	AVERAGE MINIMUM	50	48	47	47	48
	EXTREME MINIMUM	39	32	36	39	37
SANTIAGO	EXTREME MAXIMUM	87	88	81	84	88
	AVERAGE MAXIMUM	64	57	56	60	64
	AVERAGE MINIMUM	42	38	38	39	42
	EXTREME MINIMUM	26	21	21	24	24
CONSTITUCION	EXTREME MAXIMUM	77	71	64	69	67
	AVERAGE MAXIMUM	61	58	56	57	59
	AVERAGE MINIMUM	44	42	40	40	40
	EXTREME MINIMUM	32	29	33	32	34
SAN CARLOS	EXTREME MAXIMUM	84	88	80	86	90
	AVERAGE MAXIMUM	65	59	57	61	68
	AVERAGE MINIMUM	34	27	26	29	35
	EXTREME MINIMUM	17	11	10	11	15
TALCA	EXTREME MAXIMUM	82	72	72	75	82
	AVERAGE MAXIMUM	62	56	56	60	65
	AVERAGE MINIMUM	42	40	39	39	42
	EXTREME MINIMUM	25	25	23	24	28
MALARGUE	EXTREME MAXIMUM	85	81	81	89	88
	AVERAGE MAXIMUM	61	54	53	57	63
	AVERAGE MINIMUM	32	27	26	27	32
	EXTREME MINIMUM	6	-10	-12	0	11
CONCEPCION	EXTREME MAXIMUM	80	75	72	74	79
	AVERAGE MAXIMUM	60	56	56	57	59
	AVERAGE MINIMUM	45	43	41	41	42
	EXTREME MINIMUM	30	28	21	27	27
LOS ANGELES	EXTREME MAXIMUM	73	73	64	79	82
	AVERAGE MAXIMUM	60	55	54	56	61
	AVERAGE MINIMUM	43	40	38	39	40
	EXTREME MINIMUM	27	21	19	25	25
CHILLAN	EXTREME MAXIMUM	77	73	66	75	77
	AVERAGE MAXIMUM	61	54	54	57	61
	AVERAGE MINIMUM	41	40	38	39	40
	EXTREME MINIMUM	23	19	23	21	25
CHOS MALAL	EXTREME MAXIMUM	87	78	77	81	93
	AVERAGE MAXIMUM	62	55	55	58	64
	AVERAGE MINIMUM	37	34	32	33	36
	EXTREME MINIMUM	13	10	7	15	16

Figure 6-33. Wet-Season Tabular Temperature Data, Central Chile.

Along the coast, mean relative humidities at 0700L range from 93% along the central coast in May to 81% in the extreme south in August. At 1400L, they range from 69% (La Serena) to 85% (Punta Lavapie). By 1900L, RH is 79 to 88%.

Over the interior valleys and plateaus, mean RHs at 0700L ranges from 56 to 76% south of 35° S it averages 87% north of 35° S. By 1400L, RHs is from 58 to 80%. The lowest RH at 1400L is along the northern edges of the Central Valley. By 1900L, RH is 73 to 89%. The highest late evening RHs occur south of 35° S.

In the Andes above 6,000 feet (1,830 meters), RHs at 0700L range from 76 to 85% because of the uniform moisture over high terrain during the wet season. Moderate fog and heavy cumulus within contained upland valleys are common. The western foothills (2,000 to 6,000 feet/610 to 1,830 meters) have 0700L RHs between 77 and 89%. At 1400L, RHs increase because of mid-afternoon convection. Between 2,000 and 10,000 feet (610 and 3,050 meters), RHs are from 50 to 71%. By 1900L, they range from 35 to 55%. Since wet-bulb globe temperatures (WBGTs) rarely exceed 70° F (21° C) during the wet season, they are not provided here.

FLIGHT HAZARDS. Strong wind shear, downburst winds, small hail, and lightning are possible in and around thunderstorms. Above 6,000 feet (1,830 meters) MSL, the western Andes can be totally obscured by clouds, mist, and/or fog for days at a time. Moderate icing in heavy cumulus buildups can occur along the Andes above 10,000 feet (3,050 meters) MSL. Moderate to severe mixed icing occurs in trough-associated middle cloud layers as far north as 31° S. Freezing levels average 500 to 1,000 feet lower than the permanent snow line.

Wind shear may be found between 3,000 and 6,000 feet (915 and 1,830 meters) MSL with prolonged periods of fair weather from June to August on the western side of the Andes. East of the mountains, wind shear below 8,000 feet (2,440 meters) MSL occurs between 0700 and 1900L. Moderate to severe turbulence can be expected for light aircraft and helicopters with strong upper-air troughs and, with mountain waves, for all aircraft.

GROUND HAZARDS. Heavy snowfalls close mountain passes above 5,000 feet (1,525 meters) for weeks at a time between 33 and 38° S along the western Andes. In the eastern Andes, snow is common above 7,000 feet (2,135 meters). In September, melting snow can flood upper-valley floors between 33 and 38° S. Landslides also occur.

GENERAL WEATHER. Cold fronts pass every 4 or 5 days, producing moderate rainfall along the trough axis south of 34° S. Isolated thunderstorm activity develops along the trough axis in the Central Valley and western Andes. Heavy cumulus buildups are usually found above 6,000 feet MSL (1,830 meters) MSL. Cloud tops along the western Andes can exceed 45,000 feet (13,720 meters) MSL. Ceilings below 1,000 feet (305 meters) AGL can last for up to 12 hours with strong cold fronts on the western side of the Andes. Scud with bases at or below 500 feet (150 meters) AGL is common along the coastline and coastal ranges south of 34° S. Strong wind shear and low visibility are common along the trough axis in the Central Valley. Coastal stratus and early morning fog dominate calm periods along the coastline.

SKY COVER. The South Pacific High forms a strong inversion over the entire coastline producing extended fair weather periods and light winds. This inversion varies in height from 500 to 6,000 feet (150 to 1,830 meters) MSL. Thick stratus usually develops beneath the inversion; stratus rarely develops above 6,000 feet (1,830 meters) MSL. Wet fogs, or "camanchacas," occur along the western Andes foothills within the stratus layer.

Mean cloud cover reflects the high amounts of stratus along the coastline and Central Valley north of 30° S (Figure 6-34). Stratus is the primary cloud type, but there is cumulus along the eastern foothills. High terrain can be shrouded in stratus and convective cumulus south of 32° S. The coastline and Central Valley are usually dominated by stratus and stratocumulus during early morning hours. Bases average 2,000 feet (610 meters) AGL; tops are rarely above 4,000 feet (1,200 (1,220 meters) MSL. Average sky cover exceeds 6/8ths every second or third day (7 to 16 days each October) between the western Andes and the Pacific coast. Thin cirrus is also common during fair weather.

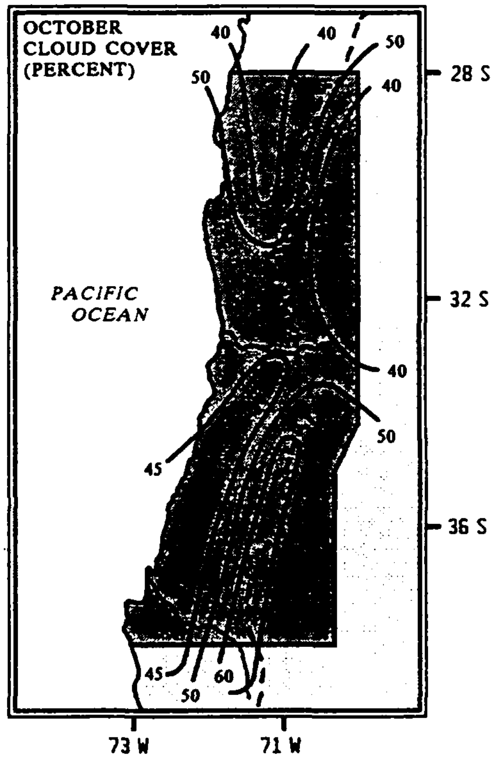


Figure 6-34. Mean Wet-to-Dry Transition Cloud Cover, Central Chile.

The highest frequencies of low ceilings are between 2100 and 0900L except along the immediate coastline (Figure 6-35). Most stratus dissipates or lifts to 4,000 feet (1,220 meters) MSL to become 2-4/8ths stratocumulus by 1100L away from the coastline. By 1400L, the Andes regularly develop lines of cumulus with bases at or above 6,000 feet (1,830 meters) MSL. Tops rarely exceed 20,000 feet (6,100 meters) MSL, unless associated with a trough. These cumulus lines contain embedded thunderstorms. They can obscure ridge crests above 10,000 feet (3,050 meters) MSL. Scattered rainshowers/thundershowers usually dissipate by 1800L at these elevations.

Troughs that break up along the Andes produce less significant weather in the eastern Andean foothills. Cumulus buildups with bases below 6,000 feet (1,829 meters) MSL, and tops to 20,000 feet (6,100 meters) MSL can develop up to 48 hours after a trough breaks down. Middle-cloud layers extend 100 to 150 miles downwind of upper troughs south of 31° S; they clear almost immediately after trough passage.

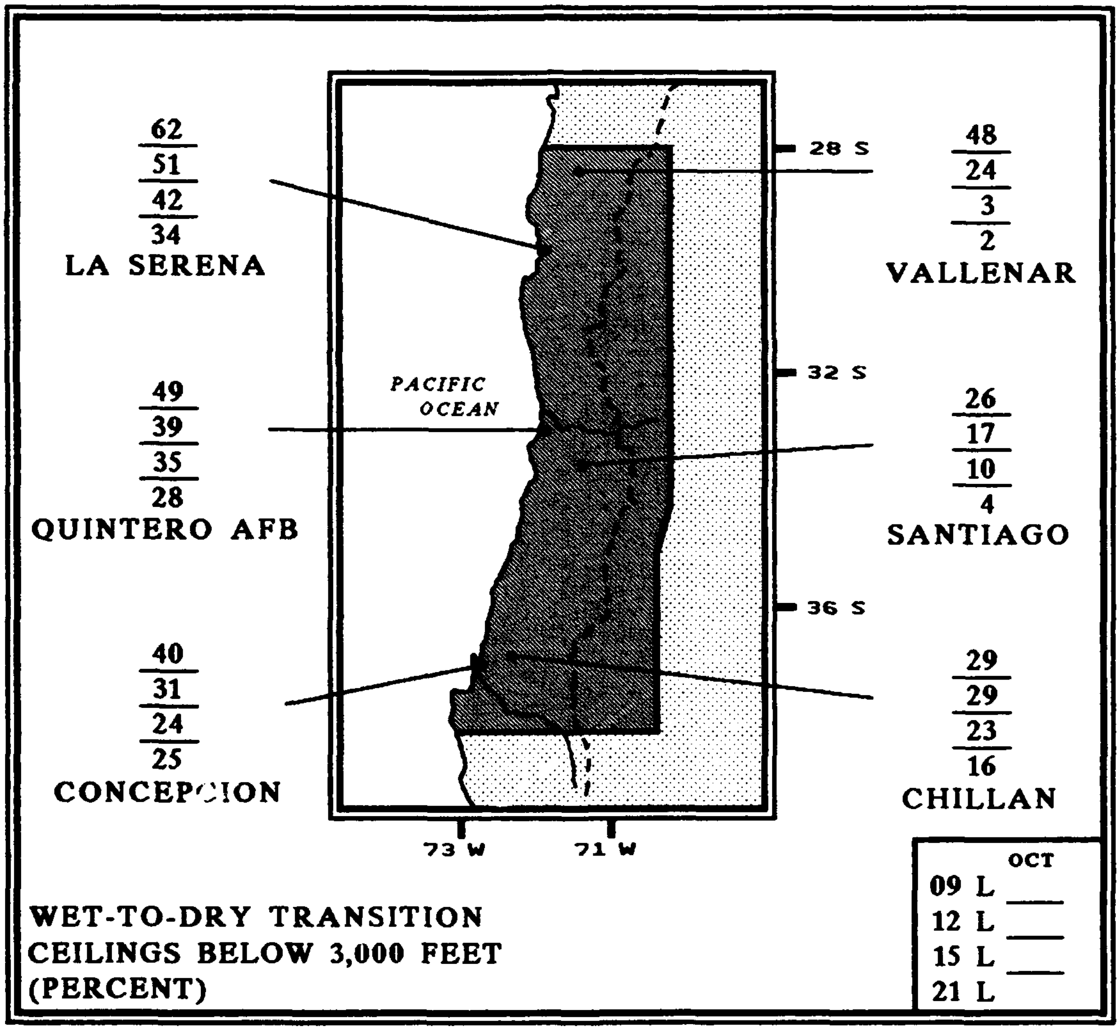


Figure 6-35. Wet-to-Dry Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Central Chile.

VISIBILITY below 3 miles (Figure 6-36) is caused by advection fog along the immediate coastline and by slow-moving fronts in the Central Valley. Radiation fog is common throughout the Central Valley and on upper-valley floors along the western and eastern Andes. Early morning stratus produces low visibilities over terrain below 3,000 feet (915 meters) MSL. Cyclonic activity lowers visibility to 1 mile with heavy rain; thick fog can form after a night of heavy rain. Fog and low stratus decks usually burn off by 1100L. Visibilities are greater than 6 miles over 85% of the time between 1200 and 2100L.

The highest frequencies of low visibility occur between 0100 and 0900L. Frequencies of early morning visibility below 6 miles along the coast range from 9% at La Serena to 35% at Valparaiso. Visibility below 3 miles ranges from 4% at La Serena to 13% at Valparaiso.

In the Central Valley, visibility frequencies below 6 miles range from 3% at Chillan to 80% at Santiago. Visibility below 3 miles ranges from less than 1% at Chillan to 38% at Santiago. At Santiago, Los Cerrillos Airport (in the west) reports significantly more radiation fog and stratus than El Bosque Airport (in the southwest). Smoke and haze contribute significantly to lower visibility in the Santiago metropolitan area during fair weather periods.

The Andes and adjacent foothills above 3,000 feet (915 meters) rarely have visibilities below 6 miles during fair weather periods. Only the upper mountain valleys can expect isolated, dense radiation fog and thin stratus during early mornings in October. Intense cold fronts produce heavy rain and visibility below 2 miles for up to an hour.

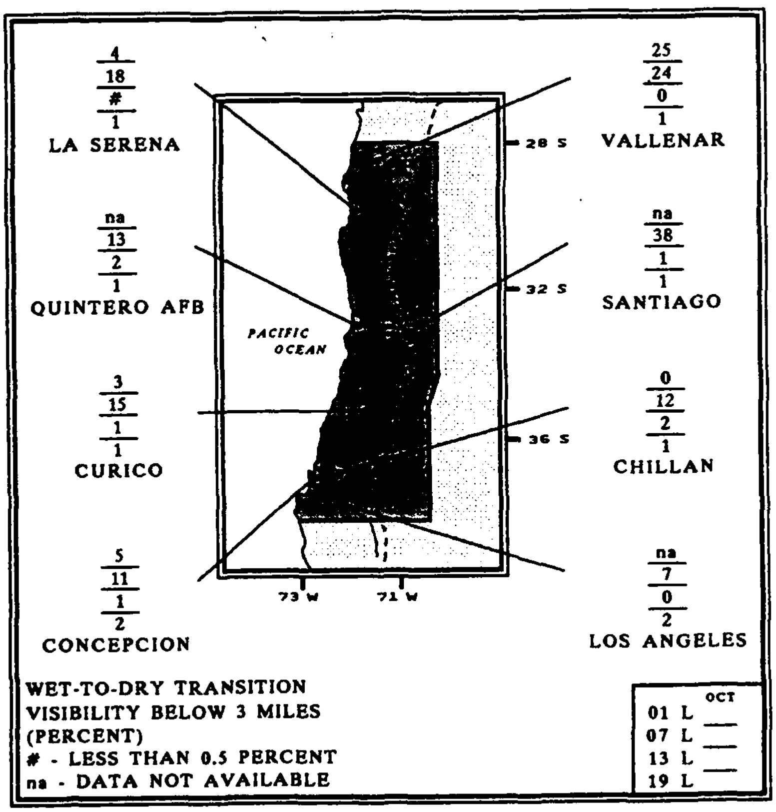


Figure 6-36. Wet-to-Dry Transition Percent Frequencies of Visibility Below 3 Miles, Central Chile.

WINDS. Warm northwesterlies or northerlies precede most troughs for up to 36 hours; they can exceed 40 knots. Behind the troughs, westerlies and southwesterlies prevail; highest wind speeds reach 50 knots at Malargue, Argentina, and in most mountain passes above 8,000 feet (2,440 meters). Along the eastern Andean foothills, surface winds are usually northeasterly or easterly during daylight hours in fair weather.

Mean surface wind speeds (Figure 6-37) are affected by terrain and range from 4 to 10 knots. Along the coastline, 10-to 12-knot winds are common between 1200 and 1700L with a strong sea breeze. In the Central Valley, large-scale upslope valley winds are strong during daylight hours, as are downslope mountain breezes at night.

Upslope daylight wind speeds average 4 to 8 knots; these southerly winds prevail from Santiago southward to Los Angeles, in the extreme south. Mountain breezes can exceed 20 knots along the eastern foothills of the Andes. Lighter mountain breezes (2 to 4 knots) affect the eastern rim of the Central Valley. Figure 6-38 shows surface wind roses for selected stations.

STATION	OCT
CHILLAN	6
CONCEPCION	10
CURICO	5
LA SERENA	5
MALARGUE	4
SANTIAGO	4
VALLENAR	5

Figure 6-37. Mean Wet-to-Dry Transition Wind Speeds, Central Chile.

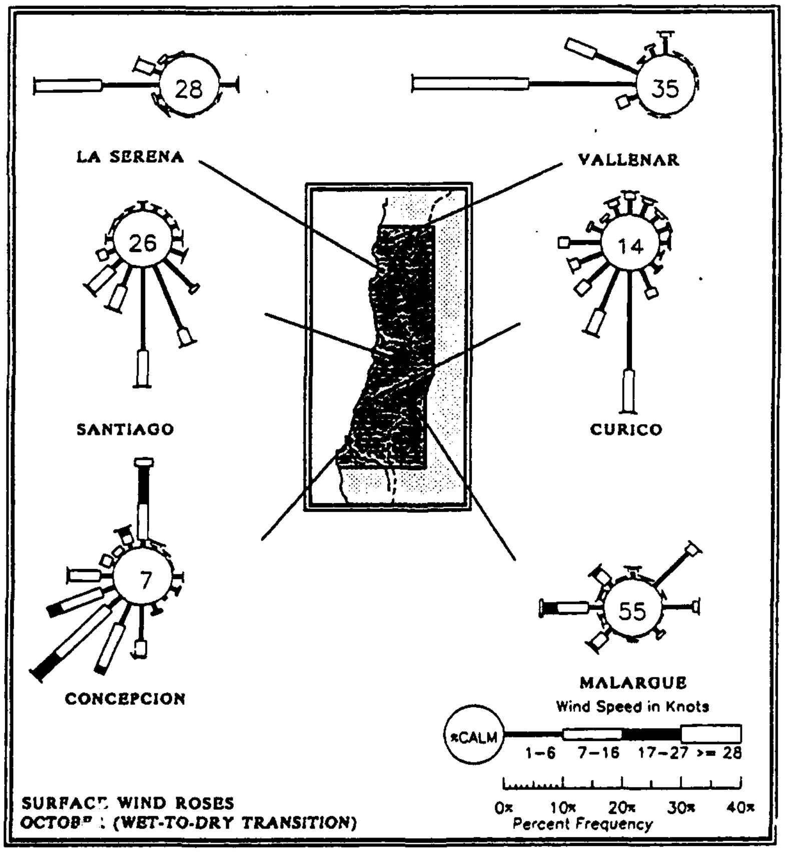


Figure 6-38. October Surface Wind Roses, Central Chile.

Winds in the lower layers are controlled by semipermanent high-pressure cells during fair weather periods. West of the Andes, the prevailing wind direction between 1,000 and 5,000 feet (305 and 1,525 meters) MSL is south-southeasterly or southerly; east of the Andes, these winds extend to 6,000 feet (1,830 meters) MSL. In both areas, winds rotate clockwise with height from southwesterly to west-northwesterly.

Figure 6-39 shows mean October wind directions for two upper-air stations between 3,000 and 10,000 feet (915 and 3,050 meters) MSL. Mean wind speeds average 8 knots between 3,000 and 5,000 feet (915 and 1,525 meters) MSL, and 10 knots from 6,000 to 10,000 feet (1,830 to 3,050 meters) MSL.

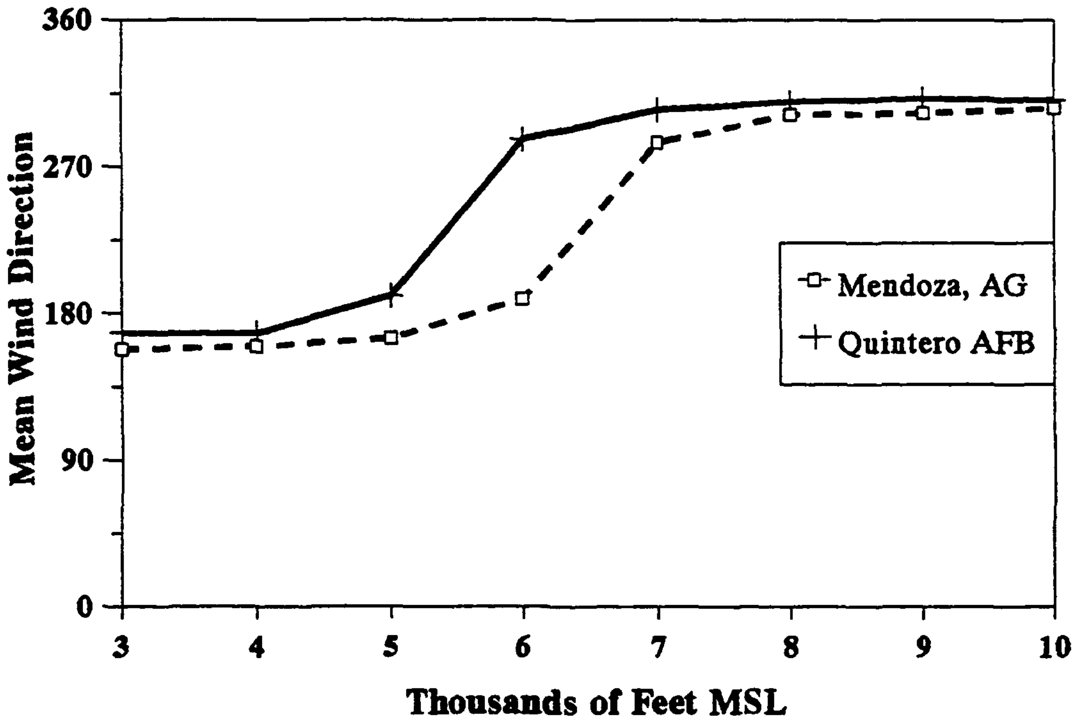


Figure 6-39. Mean Wind Direction for October Between 3,000 and 10,000 Feet (915 and 3,050 Meters) MSL, Central Chile. The figure clearly shows uniform directional shear between 5,000 and 7,000 feet (1,525 and 2,135 meters) MSL depending on location (leeward or windward).

Mean wind speeds between 15,000 and 45,000 feet (4,570 and 13,720 meters) MSL range from 19 to 65 knots. West of the Andes, highest speeds average 65 knots near 37,000 feet (11,285 meters) MSL. East of the Andes, maximum wind speeds average 65 knots at 44,000 (13,415 meters) MSL.

PRECIPITATION increases from north to south due to the seasonal storm track. Frontal-type light rain and rainshowers are the most frequent. Early morning mist and fog are common along the coastline and coastal ranges north of 31° S during fair weather periods, but this moisture rarely produces measurable accumulations. South of 31° S, heavy rainfall is concentrated along the western Andes foothills above 6,000 feet (1,830 meters) and in the southern Central Valley.

North of 33° S, maximum October rainfall rarely exceeds 4 inches (102 mm); maximum 24-hour rainfall rarely exceeds 1.5 inches (38 mm). The only exceptions are stations along the western Andes above 7,000 feet (2,135 meters). In the Central Valley and western Andes south of 33° S, maximum monthly rainfall can exceed 7 inches (178 mm) at lower elevations and 15 inches/381 mm above 6,000 feet (1,830 meters). Mean October rainfall is more than 2 inches (50 mm) south of 37° S. Snow is possible above 6,000 feet (1,830 meters) along the western Andes between 34 and 38° S. Figures 6-40 and 6-41 gives October precipitation data.

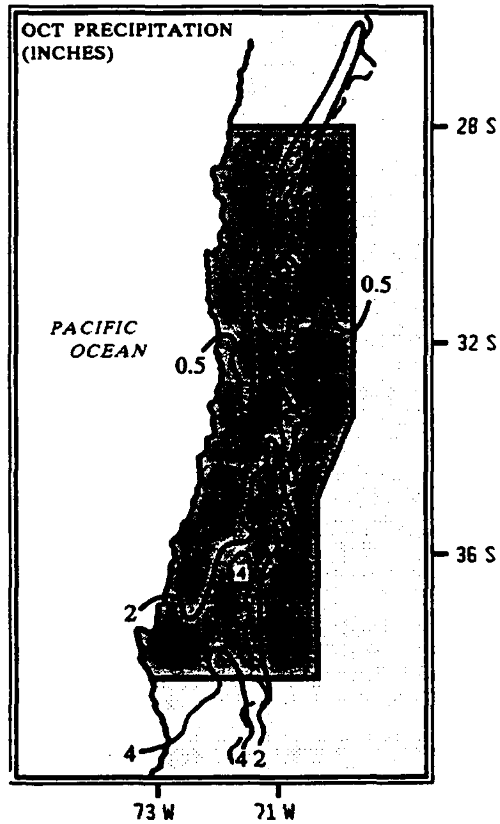


Figure 6-40. Mean October Precipitation, Central Chile.

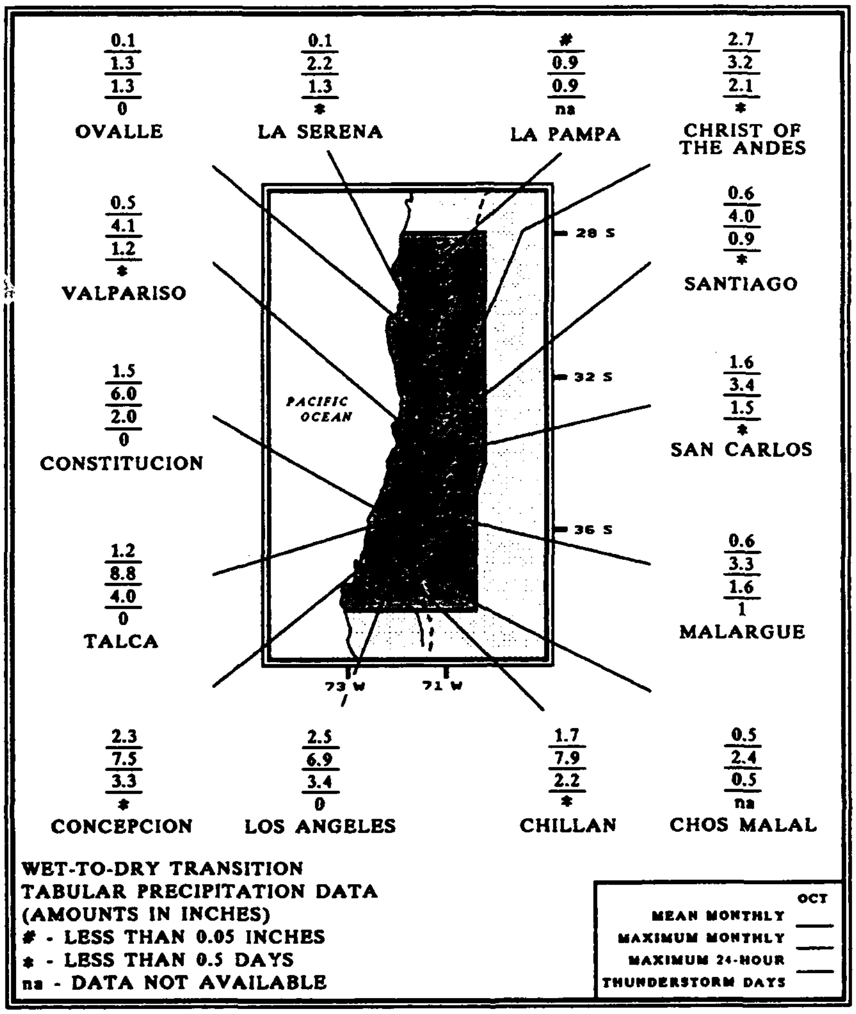


Figure 6-41. Wet-to-Dry Transition Tabular Precipitation Data, Central Chile.

THUNDERSTORMS are rare, but they can develop along the western Andes with intense cold fronts. Severe thunderstorms are possible with small hail, lightning, and heavy rainfall; cloud tops can exceed 45,000 feet (13,720 meters) MSL. Ceilings can drop below 3,000 feet (915 meters) AGL.

TEMPERATURE. Along the coast, mean daily highs range from 60 to 65° F (16 to 18° C) in October (Figure 6-42). Mean daily lows range from 42 to 51° F (6 to 11° C). Most record highs don't exceed 80° F (27° C), but Valparaiso has reached 90° F (32° C). The record low is 28° F (-2° C) at Concepcion, but elsewhere, lows rarely drop below 36° F (2° C).

Across the Central Valley, mean daily highs range from 66 to 75° F (19 to 24° C); mean daily lows, from 42 to 48° F (6 to 9° C). Record highs reach 92° F (33° C) at Santiago, but only 86° F (30° C) at Los Angeles. The record low is 28° F (-2° C) at Angol (in the far south), but most extremes are from 30 to 37° F (-1 C to 3° C).

The mean snow line at 33° S is found near 11,500 feet (3,500 meters) along the western Andes, and 12,500 feet (3,810 meters) along the eastern Andes. Above 12,000 feet (3,660 meters), mean daily highs rarely exceed 51° F (11° C), while the mean daily low is rarely above 32° F (0° C). The record low in October is -1° F (-18° C) at Christ of the Andes on the Argentina-Chile border.

In the western Andes foothills between 2,000 and 7,000 feet (610 and 2,135 meters), mean daily highs decrease with height from 72 to 57° F (22 to 14° C). Mean daily lows also decrease with height, from 45 to 39° F (7 to 4° C). Record highs may exceed 95° F (35° C); record lows may reach 28° F (-2° C).

In the eastern foothills of Argentina, mean daily highs range from 70 to 75° F (21 to 24° C) below 7,000 feet (2,135 meters). Mean daily lows range from 38 to 41° F (3 to 5° C). Record highs rarely exceed 90° F (32° C); record lows may reach 21° F (-6° C).

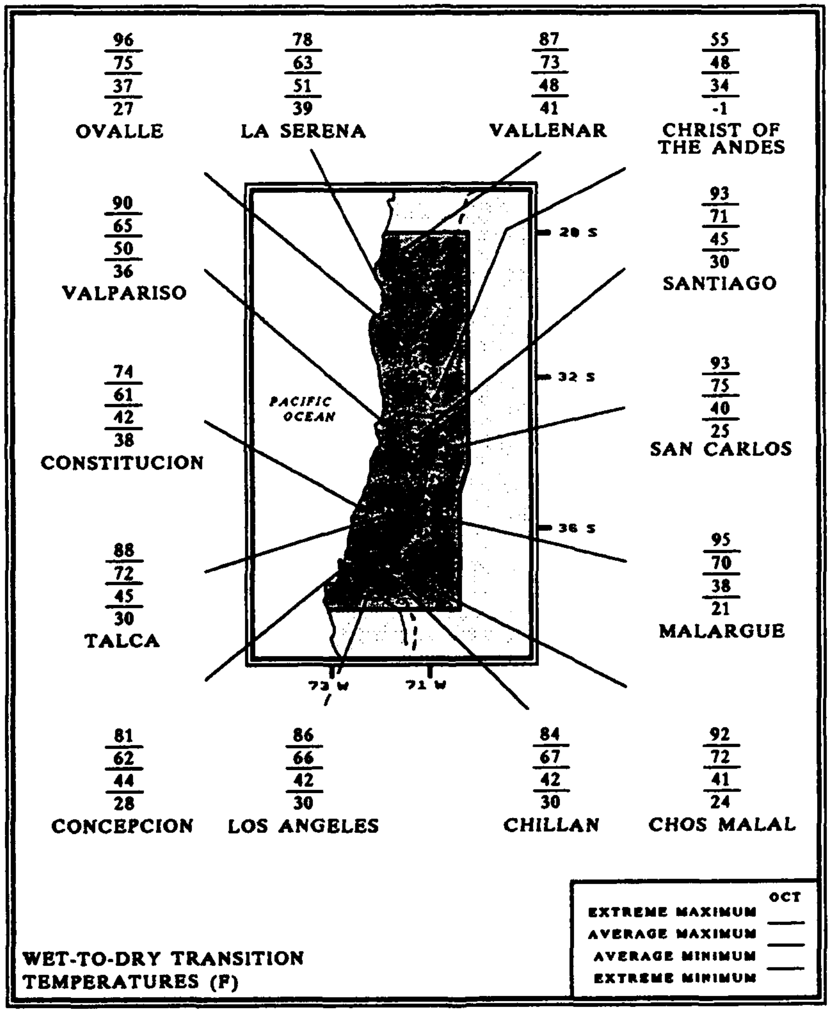


Figure 6-42. Wet-to-Dry Transition Tabular Temperature Data, Central Chile.

Mean relative humidities at 0700L are about 85% along the coast and in coastal ranges below 1,000 feet (305 meters). At 1400L, they range from 67 to 77% along the entire coastline. By 1900L, RH is 77 to 83%.

Over the interior valleys and plateaus, mean relative humidities at 0700L range from 73 to 88%; the highest early morning values are in the northern half of the Central Valley. By 1400L, they are from 50 to 59%; by 1900L, from 65 to 69%.

In the Andes above 6,000 feet (1,830 meters), mean RH at 0700L ranges from 51 to 77% because of the large terrain variations across the limited observation network. Upland valleys can have light radiation fog, while exposed sites upwind may be cloud-free. At 1400L, the western foothills (2,000 to 6,000 feet/610 to 1,830 meters) have RHs between 38 and 51%, increasing above 10,000 feet (3,050 meters) due to mid-afternoon orographic convection. Between 2,000 and 10,000 feet (610 and 3,050 meters), RH averages 40 to 57%. By 1900L, only the highest ridge crests have RHs above 50%.

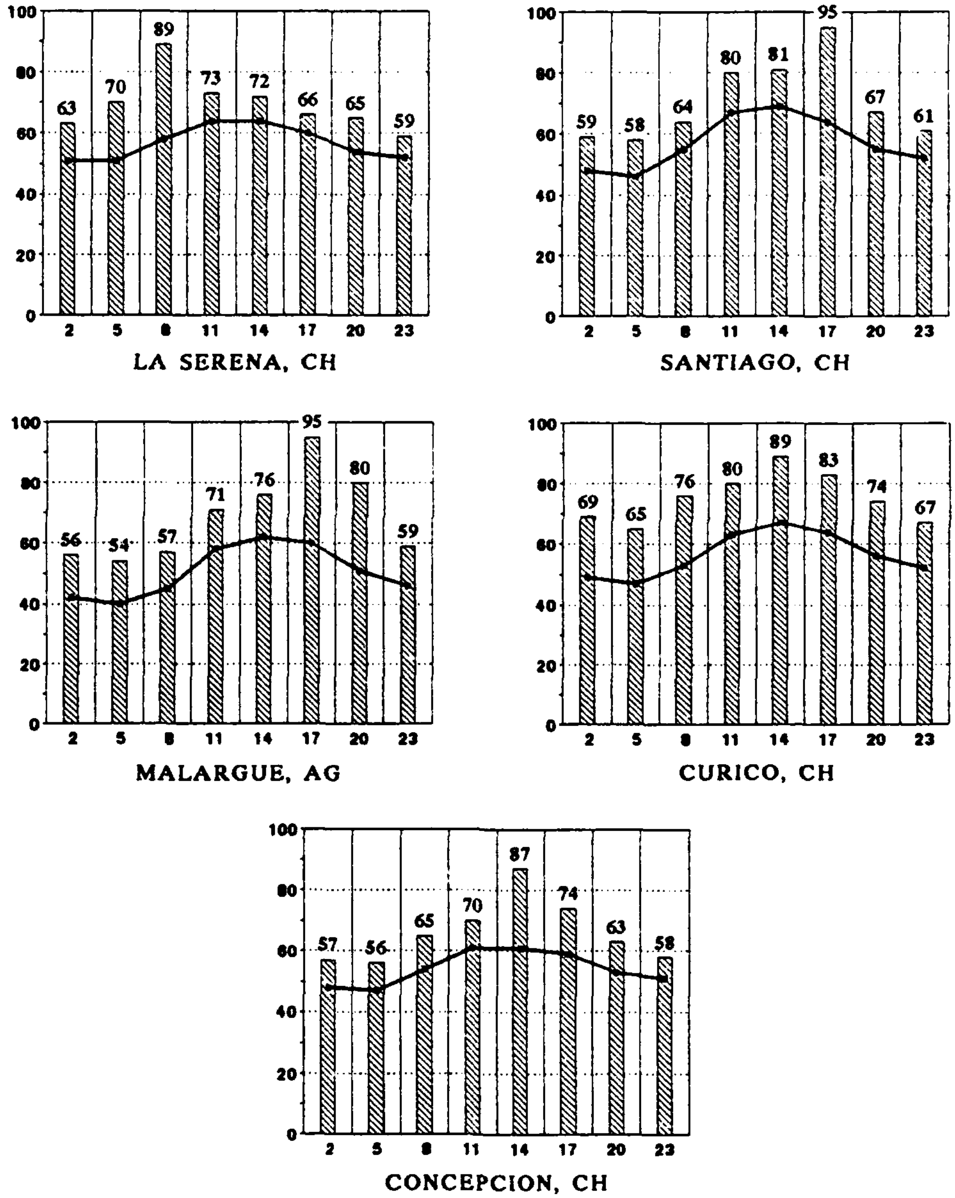


Figure 6-43. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Central Chile.

FLIGHT HAZARDS. The usual thunderstorm hazards apply. Light to moderate turbulence for light aircraft and helicopters is possible in the stratus layer. Upper-valley slopes may be totally obscured in fog and low cloud with cold fronts. Moderate to severe turbulence is possible along the eastern Andes with intense cold fronts. Moderate to severe mixed icing occurs in trough-associated middle cloud layers as far north as 31° S. Freezing levels average 500 to 1,000 (150 to 305 meters) feet lower than the permanent snow line.

GROUND HAZARDS. Upper-valley floors can flood without warning between 34 and 38° S when storms stall along the western Andes. With heavy snow, mountain passes may be closed for up to a week. Snow accumulations can exceed 12 inches in 24 hours. Early morning fog can develop between 0400 and 0900L and lower visibility below 3 miles for several hours.

6.2 SOUTHERN CHILE

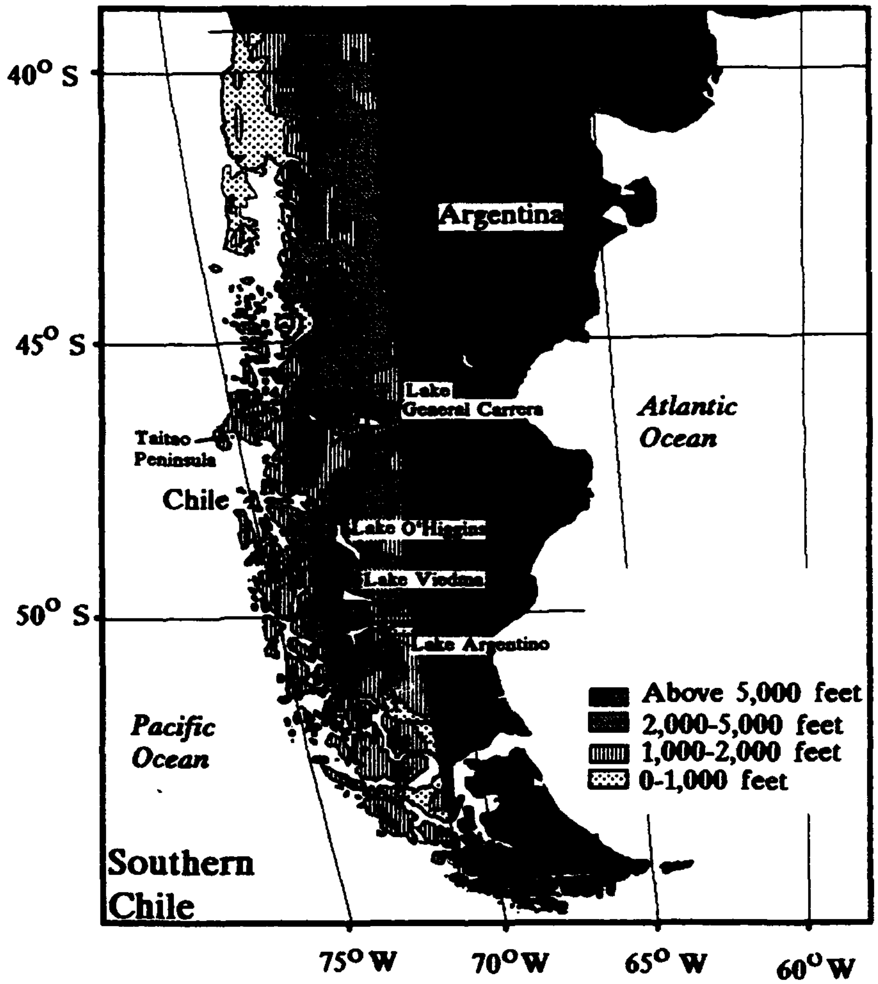
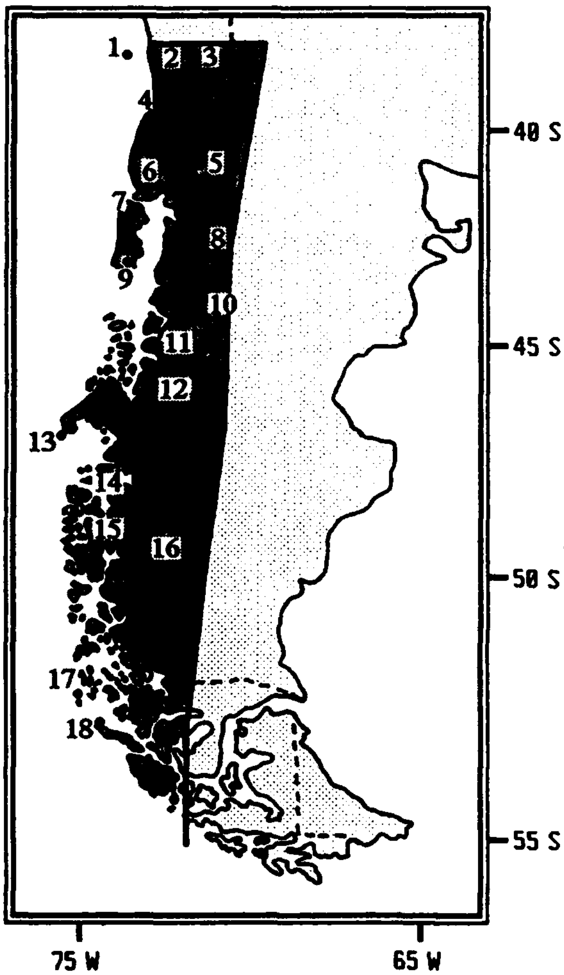


Figure 6-44. Southern Chile. This zone comprises Chile between 38 and 53° S, as well as the eastern Andes of southern Argentina south of 38° S to the Strait of Magellan. Southern Chile's eastern boundary is marked by a line along which more than 1.95 inches (50 mm) of rain falls at least 1 month a year. This line is established by drawing a line along the following points: 38° S, 70° W; 43° S, 71° W; 47° S, 71° W; 49° S, 72° W; and 53° S, 72° W.



	ELEVATION (FEET)
1. ISLA MOCHA	20
2. TEMUCO	350
3. LONGQUIMAY	6220
4. VALDIVA	62
5. SAN CARLOS de BARILOCHE	3092
6. PUERTO MONTT	295
7. ANCUD	375
8. ESQUEL	2605
9. QUELLON	10
10. RIO CISNES	2297
11. PUERTO AISEN	32
12. BALMACEDA	1697
13. CABO RAPER	131
14. ISLA SAN PEDRO	72
15. PUERTO EDEN	66
16. MONTE FITZROY	1378
17. ISLA EVANGELISTA	181
18. BAHIA FELIX	49

Figure 6-45. Climatic Station Network, Southern Chile.

SOUTHERN CHILE GEOGRAPHY

TERRAIN. The southern third of Chile and the extreme southwestern part of Argentina are very rugged and sparsely populated. Extensive glaciers and permanent snow-capped peaks are separated in some places by glacier-carved river valleys and thick boreal forests. Glaciers are common above 7,000 feet (2,135 meters) as far north as 42° S. The Great Patagonian Ice Field begins in the Andes at 46° S and extends more than 270 NM southward. Glaciers reach the Pacific Ocean south of 50° S. Numerous glacial lakes are found between 42 and 51° S and 70 and 72° W. The largest are Lake General Carrera (Chilean name)/Lake Buenos Aires (Argentine name) at 46° 30'S, 72° W; Lake O'Higgins (Chilean name)/Lake San Martin (Argentine name) at 49° S, 72° W; Lake Viedma at 49° 30'S, 72° W; and Lake Argentino at 50° 12'S, 72° 30'W.

Between 42 and 53° S, numerous islands, called "Archipelagic Chile" are linked to the mainland by an intricate network of deep channels and estuaries. The Taitao Peninsula breaks the island chain at 46° 30' S. These islands are covered by thick broadleaf forests.

The widest coastal plains lie between 38 and 40° S. They narrow to less than 1/4 mile south of 42° S. In the long and narrow estuaries, forest-covered hillsides often rise to 3,000 feet (915 meters) within 1 or 2 miles of the sea.

VEGETATION. The temperate rain forest consists primarily of broadleaf evergreens mixed with broadleaf deciduous and evergreen coniferous trees. The coastal lowlands and hillsides between 38 and 46° S have dense forests with vines, shrubs, and mosses on the forest floor. Cool, moist conditions south of 46° S produce bogs in some coastal lowlands. There are lichens and mosses, but little forest or grassland. Agriculture is limited to sheltered inland locations. Vegetation along the eastern slopes of the Andes transitions from the broadleaf evergreen forest to low brush and bunch grass between 5,000 and 8,000 feet (1,525 and 2,440 meters).

GENERAL WEATHER. Synoptic high-pressure cells migrate through Drake Passage at 36- to 72-hour intervals, resulting in temporarily dry conditions. The mean storm track shifts poleward, reducing storm frequency and strength over the zone. Lows pass through Southern Chile near 50° S every 4 to 5 days with central pressures that are 5 to 8 millibars higher than during the wet season. Cold fronts are weak north of 46° S and only affect these areas every 5th or 6th day.

Rainshowers and scattered thundershowers usually occur above 7,000 feet (2,135 meters), while light rain or drizzle along the trough axis dominates the coastline, coastal inlets, and coastal ranges below 7,000 feet (2,135 meters). Strong cold fronts and brisk westerlies at 15 to 25 knots usually pass quickly. The eastern Andes remain dry; most precipitation falls along the windward slopes. Adiabatic warming and foehn winds in the eastern Andes are common with intense troughs south of 46° S. High temperatures exceed 95° F (35° C).

SKY COVER. Cloud cover amounts are high year-round, but slightly lower in the dry season, primarily in the northern half of the zone (Figure 6-46). The storm track shifts south during the dry season and fronts don't penetrate as far north.

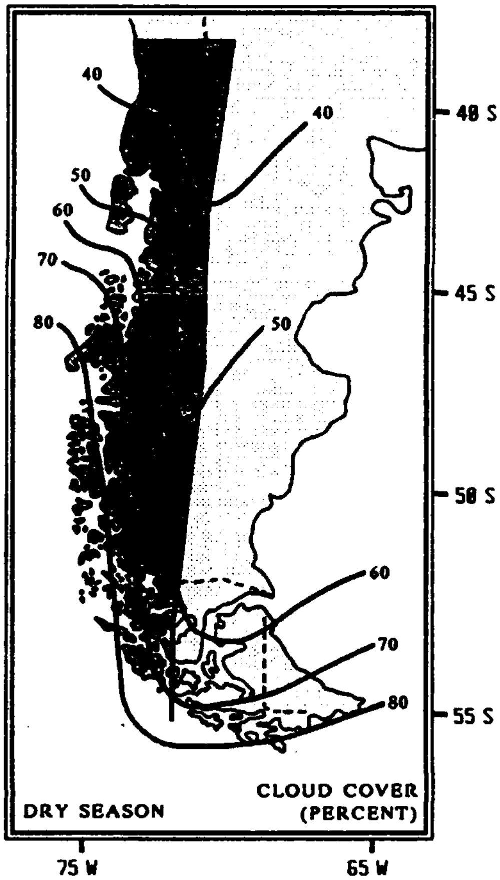


Figure 6-46. Mean Dry-Season Cloud Cover, Southern Chile.

Broken stratus and stratocumulus between 2,000 and 4,000 feet (610 or 1,220 meters) MSL are common. Ceilings can drop to 500 feet (150 meters) MSL near the surface low. Most ceilings below 1,000 feet (305 meters) MSL don't extend northward along the trough axis more than 50 NM from the low. Scattered towering cumulus and cumulonimbus develop along the western Andes. Bases average 6,000 feet (1,830 meters) MSL; tops rarely exceed 20,000 feet (6,100 meters) MSL. Broken cumulus decks are common along fast-moving troughs; they normally obscure ridge crests. Broken middle and high clouds form as far as 300 miles ahead of frontal systems. These merge with low clouds on the windward slopes, totally obscuring ridges above 6,000 feet (1,830 meters). Such middle-cloud decks end with passage of the upper-air low or trough. Eastern Andean slopes above 8,000 feet (2,440 meters) have scattered cumulus that usually dissipates 10 to 30 NM downwind of the highest ridge crests. Middle clouds form over and just downwind of the highest ridges ahead of frontal systems; they clear within 4 to 6 hours of upper-trough passage as upper-level ridging builds.

Fair-weather stratus and stratocumulus form along the coast, coastal inlets, and hillsides between 0400 and 1000L near sheltered local moisture sources during periods dominated by quasi-stationary high-pressure cells. Lowest ceilings develop before 0800L (Figure 6-47); bases average 3,000 feet (915 meters) MSL. On occasion, ceilings drop to 1,000 feet (305 meters) MSL. Stratus and stratocumulus that are rarely more than 1,000 feet (305 meters) thick become scattered cumulus along coastal hillsides by 1100L. Bases near 5,000 feet (1,525 meters) are common as moderate sea breezes push into narrow coastal inlets. Tops rarely exceed 8,000 feet (2,440 meters) MSL except where local convergence favors orographic lifting. Isolated tops to 12,000 feet (3,660 meters) are possible.

Diurnal cumulus is common after 1400L in the western Andes above 7,000 feet (2,135 meters) MSL. Bases range from 10,000 to 13,000 feet (3,050 to 3,960 meters) MSL; tops rarely exceed 16,000 feet (4,880 meters) MSL except along the highest ridge crests south of 45° S. Cloud development and movement is usually east-southeastward over the highest ridge crests. Clouds dissipate along the eastern Andes near 8,000 feet (2,440 meters) MSL. Bases can be as low as 5,000 feet (1,525 meters) with southeasterly surface flow behind cold fronts; tops rarely exceed 12,000 feet (3,659 meters) MSL.

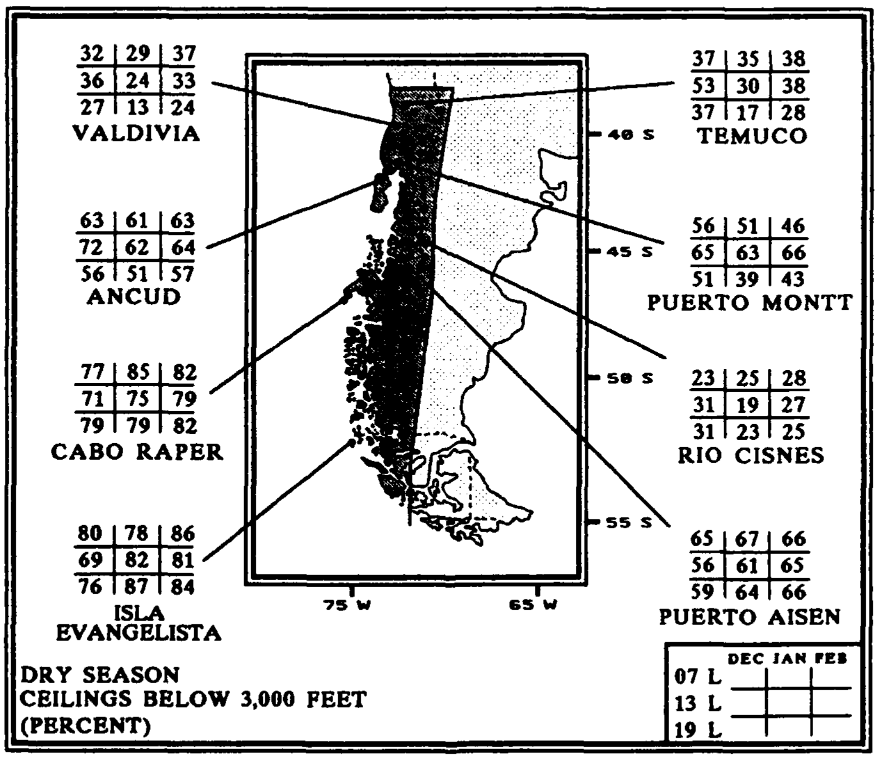


Figure 6-47. Dry-Season Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Chile.

VISIBILITY. Fog, mist, and showers are the main visibility restrictions. Heavy frontal precipitation reduces visibility below 2 miles for up to 1 hour south of 46° S. Rainfall associated with strong westerlies can lower visibility to 1 mile. Post-frontal fog lowers visibility below 1 mile occasionally along the coast, in coastal inlets, and on hillsides. Visibility can be below 3 miles for up to 12 hours in extreme cases. Early morning fog is common along the coast with quasi-stationary highs. Visibilities below 3 miles (Figure 6-48) are usually confined to sheltered inlets between 2300 and 0700L. The sea breeze often pushes fog inland. Visibility usually improves to 4 miles by 1000L. Occluded or stationary fronts produce localized advection fog (sea fog) and heavy mist along the coastline and coastal inlets. These conditions are usually accompanied by low ceilings and visibility below 3 miles for up to 18 hours.

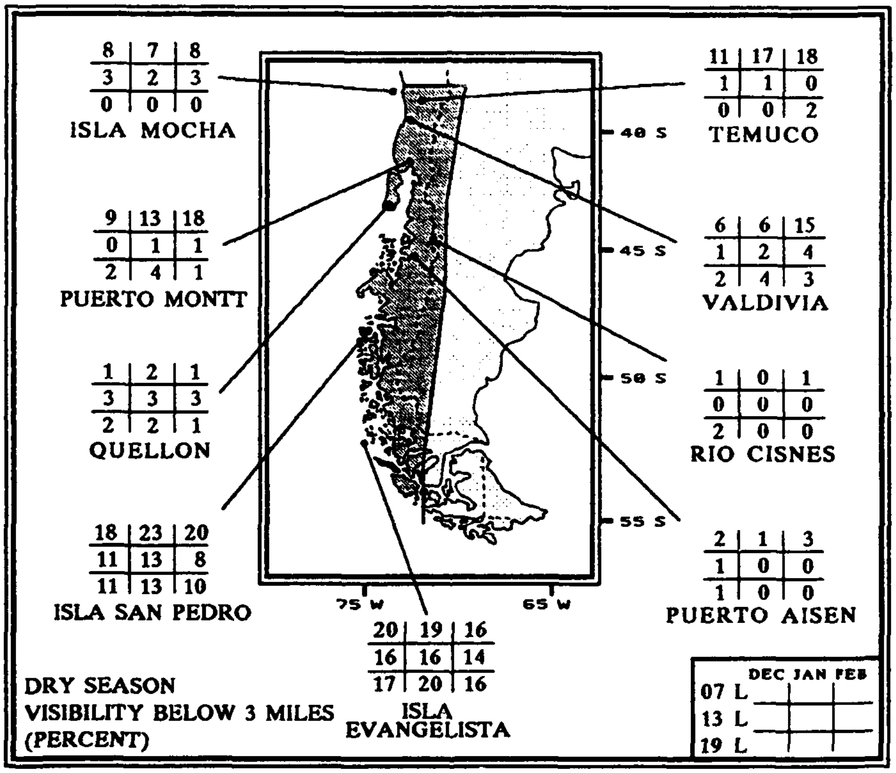


Figure 6-48. Dry-Season Percent Frequencies of Visibility Below 3 Miles, Southern Chile.

WINDS. Winds from the surface to 3,000 feet (915 meters) MSL are controlled by quasi-stationary highs, local terrain, and latitude with respect to the storm track.

South of 46° S, surface winds are westerly except for brief periods of northerlies associated with lows. Southerlies shift back to westerlies within 24 hours. Warm-front winds are northwesterly; they rarely exceed 15 knots west of the continental divide, and usually don't persist for more than 18 hours. Westerlies behind cold fronts often exceed 25 knots, but occasionally reach 50 knots. Westerlies associated with quasi-stationary highs rarely exceed 20 knots between 1000 and 2000L and decrease to 9 knots after 2000L. Winds are rarely calm unless a high's center moves directly over Southern Chile.

North of 46° S, South Pacific High outflow produces southerly to southwesterly flow that is deflected northward by the Andes. Lows can produce northwesterlies, but they are normally too weak or too rare to break down the ridging. Land and sea breezes become important near the coast. Wind speeds vary diurnally, ranging from 5 to 15 knots.

Southerly flow can strengthen during extended fair-weather periods. Winds exceed 15 knots south of 46° S for 24 to 36 hours. Southerlies intensify northward if the ridge continues to build. By the 4th or 5th day, southerlies at 15 knots extend northward to 38° S. These southerly winds often enhance orographic lifting over nearby terrain--winds can exceed 35 knots.

Mean surface wind speeds (Figure 6-49) range from 5 knots (at Chaiten in December) to 17 knots (at Balmaceda in December). Surface wind direction (Figure 6-50) varies with terrain. Prevailing monthly wind direction is westerly to southerly. With strong low-pressure systems, 20- to 25-knot westerlies are common along the coast. Upslope valley winds can be enhanced by synoptic flow during daylight hours south of 43° S along the western Andes. Sudden 30-knot gusts along these western foothills are common above 5,000 feet (1,525 meters) MSL between 1300 and 1600L.

Strong north-to-northwesterly winds at 15 to 20 knots can precede intense cold fronts for up to 36 hours in the higher elevations. Behind the fronts, west-to-southwesterly winds can exceed 40 knots. Along the eastern Andes, speeds can exceed 70 knots in upland valleys and canyons.

STATION	MEAN WIND SPEED DEC	JAN	FEB
BALMACEDA	17	17	15
CHAITEN	5	5	6
CHILE CHICO	17	17	15
COYHAIQUE	9	9	8
ESQUEL	12	15	14
PUERTO AISEN	9	8	8
PUERTO MONTT	8	8	7
QUELLON	7	7	7
SAN CARLOS de BARILOCHE	16	16	14
TEMUCO	6	5	5
VALDIVIA	9	9	8

Figure 6-49. Mean Dry-Season Wind Speeds, Southern Chile.

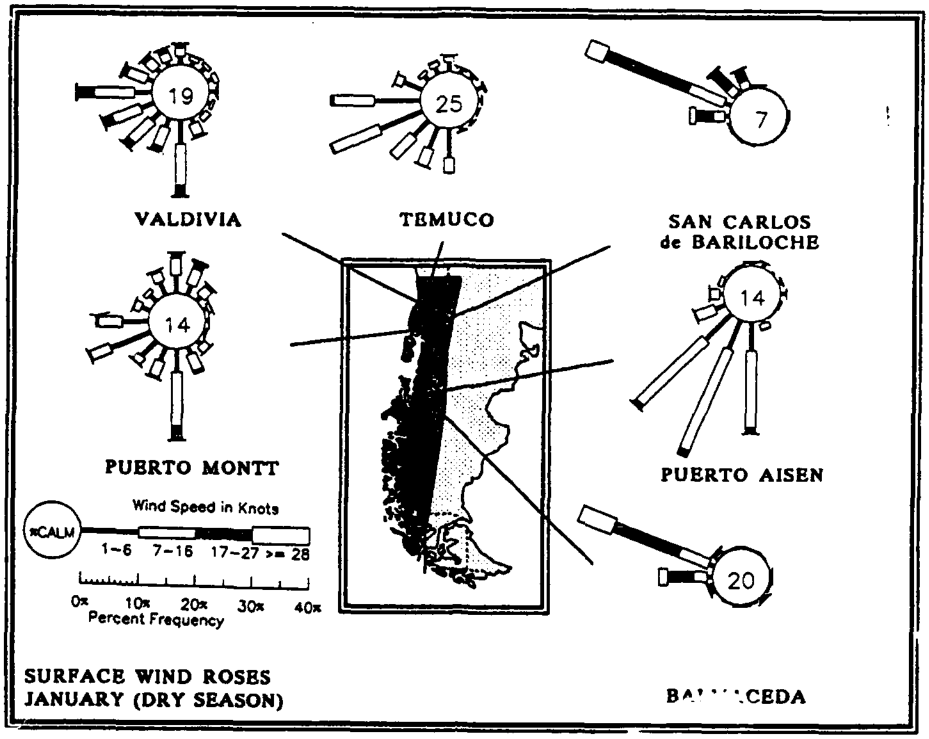


Figure 6-50. January Surface Wind Roses, Southern Chile.

Except for strong low-pressure systems, wind direction varies little with height. It shifts from west-southwesterly at 5,000 feet (1,525 meters) MSL to westerly above 15,000 feet (4,570 meters) MSL. Mean maximum speeds are 58 knots (in January) at 37,000 feet (11,285 meters) MSL; peak speeds of 80 knots are possible.

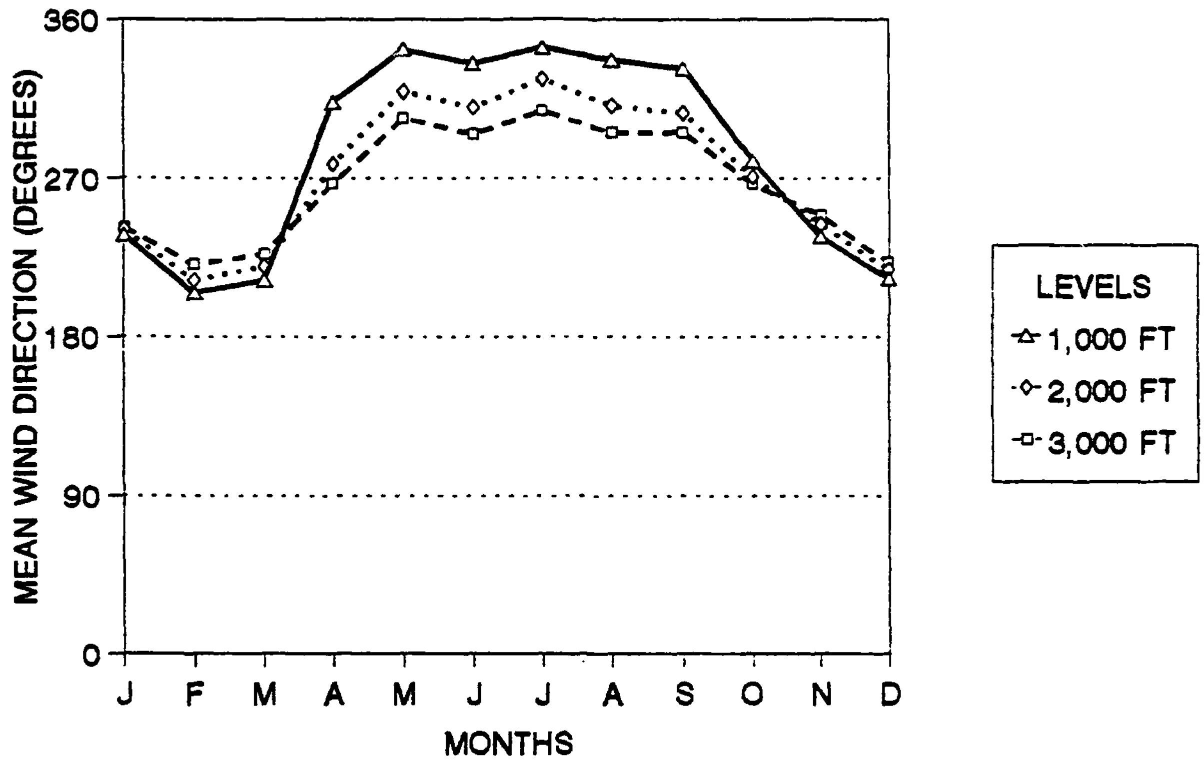


Figure 6-51. Mean Monthly Wind Directions for Various Levels at Puerto Montt, Southern Chile. Note how the low-level winds change direction in April and November. Between May and September, wet-season low-level winds are consistently from the west-northwest and west.

PRECIPITATION. Coastal terrain causes rainfall to vary over short distances. Topography produces large precipitation gradients (see Figure 6-52) from west to east. A north-south gradient reflects the southward shift in the storm track and the influence of the South Pacific High. Precipitation can be extremely variable from year to year with changes in the upper-air flow patterns.

South of 45° S, mean monthly rainfall amounts range from 5.7 inches (145 mm) at Cabo Raper to 17 inches (432 mm) at Bahia Felix (Figure 6-53). Frontal precipitation is moderate to heavy every 4th or 5th day. January and February have the lowest frequencies of low-pressure systems. Storm tracks are fast-moving and at very high latitudes (58 to 65° S); this significantly reduces rainfall along the trailing cold front. Isolated thunderstorms along the western Andes above 7,000 feet (2,135 meters), can produce more than 4 inches (102 mm) of rain in 24 hours. Snow falls above 12,000 feet (3,660 meters) with very cold polar troughs, but rarely exceeds 6 inches (152 mm).

North of 45° S, the driest month is usually February; mean rainfall ranges from 1 to 3 inches (25 to 76 mm). Weak cold fronts seldom produce more than scattered showers and may not reach the coastline north of 48° S as they move southeastward through Drake Passage.

In the eastern Andes, mean monthly rainfall rarely exceeds 2 inches (51 mm) a month between 3,000 and 7,000 feet (915 and 2,135 meters). South of 42° S, mean February rainfall is less than 1 inch (25 mm) at some locations. The moisture is often squeezed out west of the Divide. Only the isolated ridge crests south of 45° S above 7,000 feet/2,135 meters receive 2 to 4 inches/51 to 102 mm.

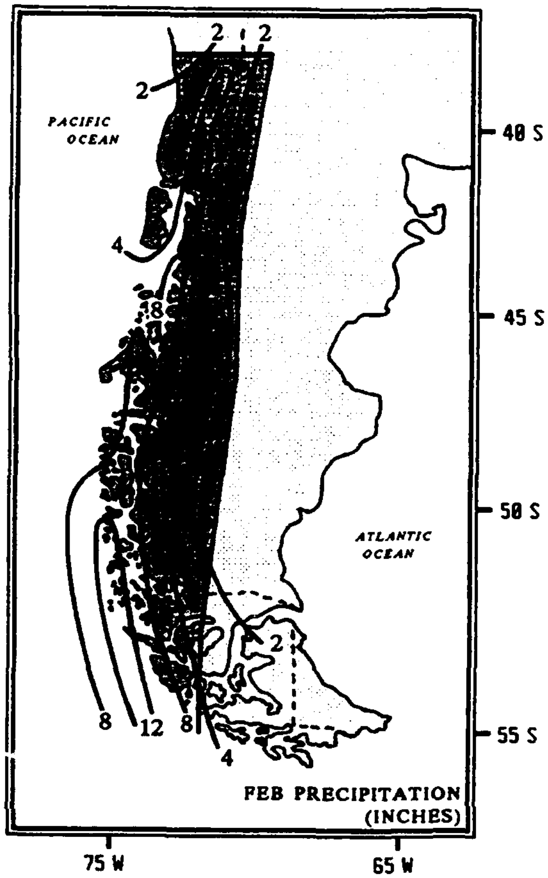


Figure 6-52. Mean February Precipitation, Southern Chile.

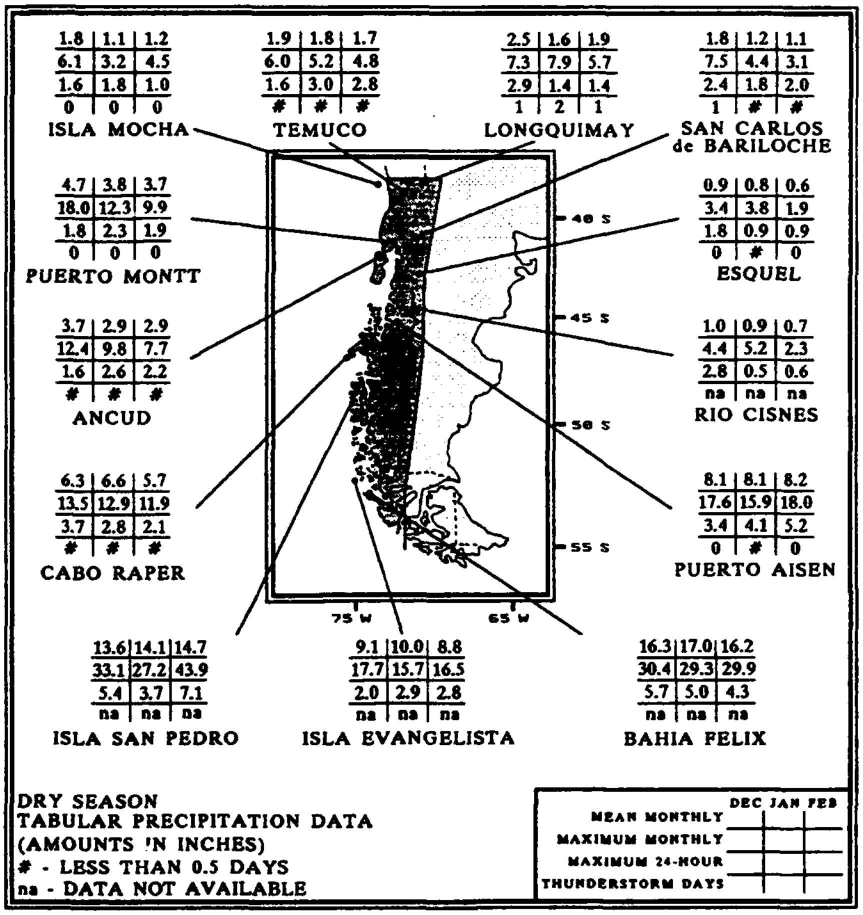


Figure 6-53. Dry-Season Tabular Precipitation Data, Southern Chile.

THUNDERSTORMS occur less than 1 day a month except at Ancud and Cabo Raper, where they occur more than twice a dry season because of local terrain influences. Most thunderstorms develop along intense cold fronts with cold-air support from deep upper-air troughs and localized divergence from the Subtropical Jet. These storms are rarely severe. Intense troughing can produce thunderstorm bases at or below 1,000 feet (305 meters) AGL on the coast, but bases overall average 6,000 feet (1,830 meters) MSL. Tops rarely exceed 20,000 feet (6,100 meters) MSL, but have reached 45,000 feet (13,720 meters) MSL along the Andes' highest ridge crests. Heavy wet snow is rare below 10,000 feet (3,050 meters) with thunderstorms. With deep lows, thundershowers can produce 1 inch (25 mm) an hour rainfalls. Thunderstorms along the eastern Andes are rare.

TEMPERATURE. Moist and cool boundary layer air moderates air temperature below 2,000 feet (610 meters). Temperatures generally increase to the north due to the influence of the subtropical ridge. Mean daily highs are 69 to 81° F (21 to 7° C) north of 43° S, and 60 to 69° F (16 to 21° C) between 43 and 46° S. South of 46° S, coastal sites have a small diurnal temperature range (6 to 10° F/4 to 6° C). Highs range from 48 to 58° F (9 to 14° C); lows, from 40 to 44° F (4 to 7° C). Around glaciers and higher terrain, highs and lows may vary by 5 to 10° F (4 to 6° C) from those along the coastline. Record highs north of 43° S exceed 95° F (35° C) with strong ridging. On the eastern Andes, intense adiabatic warming with strong fronts and troughs produce strong downslope winds. South of 43° S, coastal locations rarely exceed 85° F (30° C). Over higher terrain, record highs rarely exceed 80° F (27° C); record highs along the extreme southern coastal fringes rarely reach 75° F (23° C). Record lows are below 32° F (0° C) except along the coastal fringes north of 41° S. Above 5,000 feet (1,525 meters), record lows are below 22° F (-6° C).

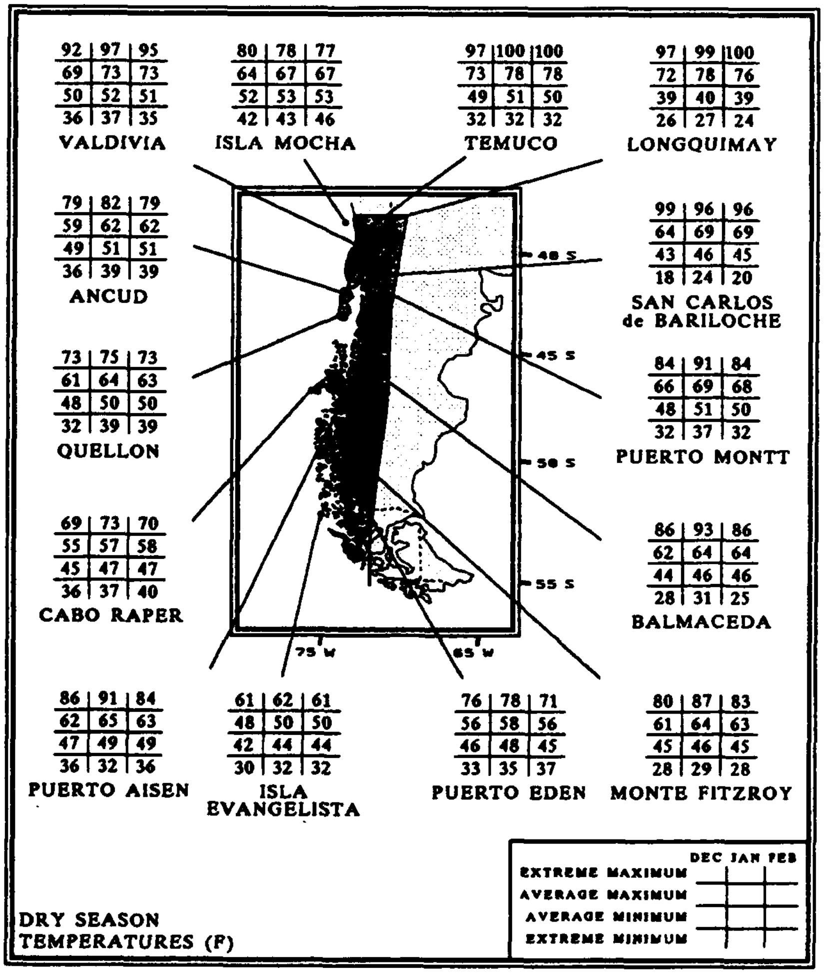


Figure 6-54. Dry-Season Tabular Temperature Data, Southern Chile.

Below 2,000 feet (610 meters), relative humidity at 0700Z consistently ranges between 80 and 92%. Inland, RH ranges from 40 to 60% between 0800 and 2000L. Along the coast, RH rarely drops below 70%. East of the Andes, it ranges from 50 to 65% at 0700L, but can drop to less than 35% by 1300L.

The mean snow line at 41° S ranges from 9,800 feet (2,990 meters) in December to 10,900 feet (3,320 meters) in February. At 45° S, the mean snow line lowers to 8,400 feet (2,560 meters) in December, and to 9,300 feet (2,835 meters) in February.

Figure 6-55 shows maximum and mean wet-bulb globe temperatures (WBGT) for selected stations. With extended periods of fair weather, WBGTs may average 80 to 85° F (27 to 30° C) as air stagnation results in higher daytime temperatures and relative humidities during January and February.

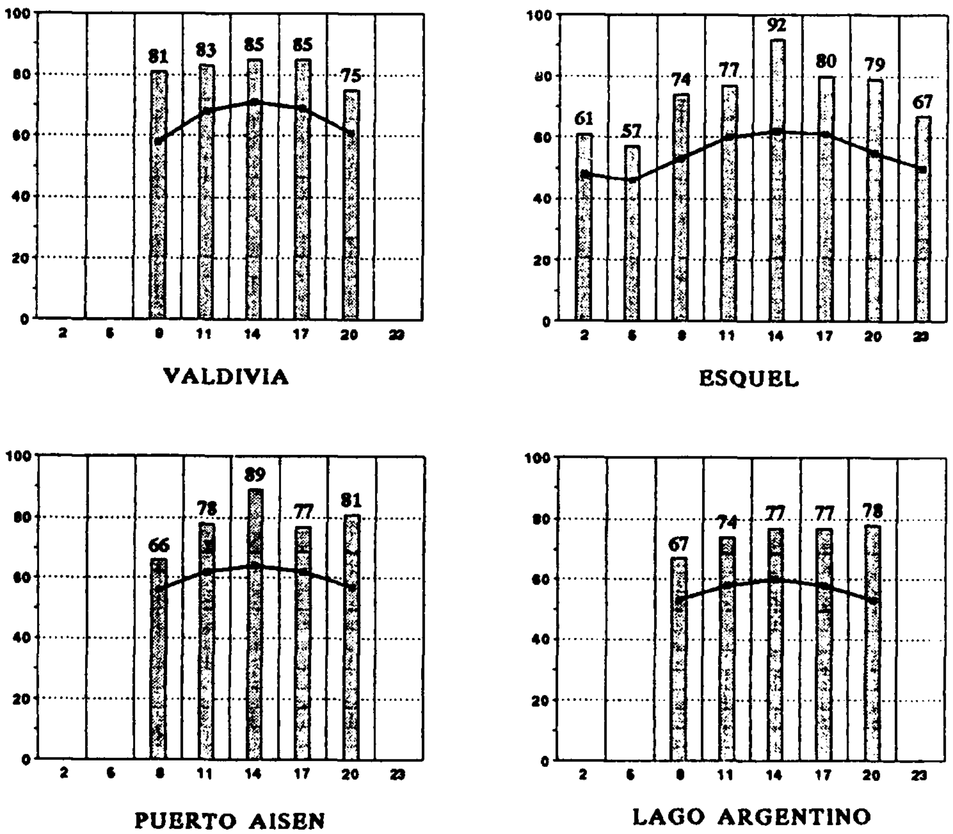


Figure 6-55. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Southern Chile.

FLIGHT HAZARDS. Wind gusts to 50 knots, moderate turbulence for light aircraft, lightning, and small hail are possible in and around thunderstorms along the Andes above 7,000 feet (2,135 meters) MSL. Strong wind shear and moderate turbulence are common with most frontal passages along the Andes above 5,000 feet (1,525 meters) MSL. Moderate to severe mixed icing also occurs in and near thunderstorms; light to moderate mixed icing is also found in layered prefrontal cloud decks. Freezing levels average 500 to 1,000 feet lower than the permanent snow line.

GROUND HAZARDS. Heavy rains, thick fog, and heavy mist affect the coast south of 48° S. Visibilities below 3 miles with fog and mist are very likely between 0500 and 0900L along the coast and coastal inlets.

GENERAL WEATHER. By mid-April, low-pressure systems affect the entire zone every 4th day. Moderate to heavy rainshowers are common along most cold fronts. Rain usually changes over to snow above 7,000 feet (2,135 meters). April snowfall can exceed 12 inches (305 mm) south of 46° S along the western Andes above 10,000 feet (3,050 meters). The storm track intensifies in the Drake Passage and several "cut-off" or secondary lows can be expected to reach the Southern Chile coast between 42 and 48° S. During fair weather, strong westerlies dominate the zone at all levels.

SKY COVER. Cloud cover increases as fronts become more frequent and reach farther north (Figure 6-56). Thick stratus and stratocumulus can form along the coast throughout the day. Cloud bases range from 1,000 to 4,000 feet (305 to 1,220 meters) MSL. Tops rarely exceed 7,000 feet (2,135 meters) MSL. The thickest and lowest cloud is concentrated south of 45° S and can push inland to the western Andes with a strong cold front.

Highest low-ceiling frequencies form along the coast, but early morning low cloud is possible north of 41° S within interior valleys far from marine influences (Figure 6-57). Heavy mist, early morning fog, and patchy stratus or stratocumulus during fair weather form along the coast and narrow coastal inlets leading to the sea between 2200 and 0900L. Cloud bases can be below 1,000 feet (305 meters) MSL in the moist marine layer until 1300L south of 50° S. Most cloud cover burns off by 1000 or 1100L or, with a sea breeze, reforms into shallow cumulus with bases of 4,000 feet (1,220 meters) MSL and tops to 6,000 or 7,000 feet (1,830 or 2,135 meters) MSL. Along the western Andes, diurnal cumulus usually forms above 5,000 feet (1,525 meters) MSL by 1300L. With troughs, tops can reach 15,000 feet (4,575 meters) MSL along higher terrain bordering coastal inlets, but they seldom reach 10,000 feet (3,050 meters) MSL otherwise. Isolated cumulus and altocumulus along the trough axis can exceed 20,000 feet (6,100 meters) MSL south of 45° S along a jet axis. Broken middle and high clouds occur as far as 300 miles ahead of frontal systems. These merge with low clouds on windward slopes, totally obscuring ridges above 6,000 feet (1,830 meters). Such middle-cloud decks end with passage of the upper-air low or trough. Middle clouds occur over and just downwind of the highest ridges ahead of frontal systems; they clear within 4 to 6 hours of upper-trough passage as upper-level ridging builds.

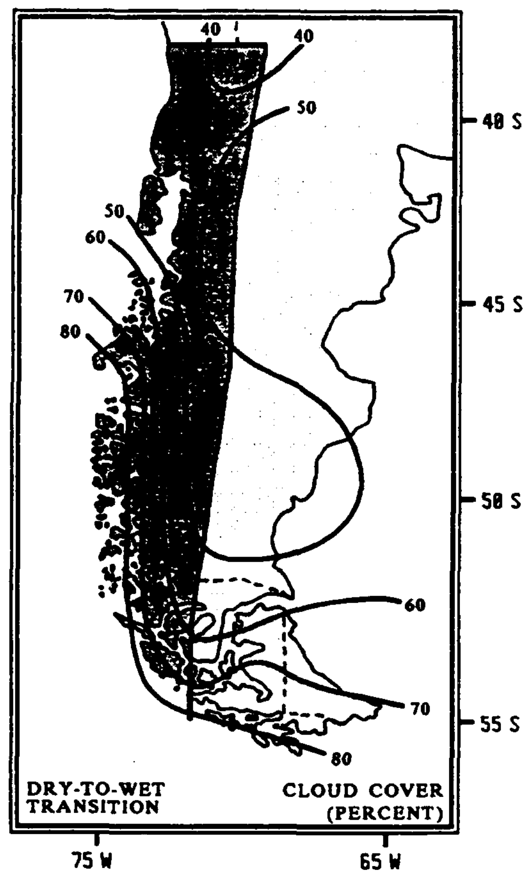


Figure 6-56. Mean Dry-to-Wet Transition Cloud Cover, Southern Chile.

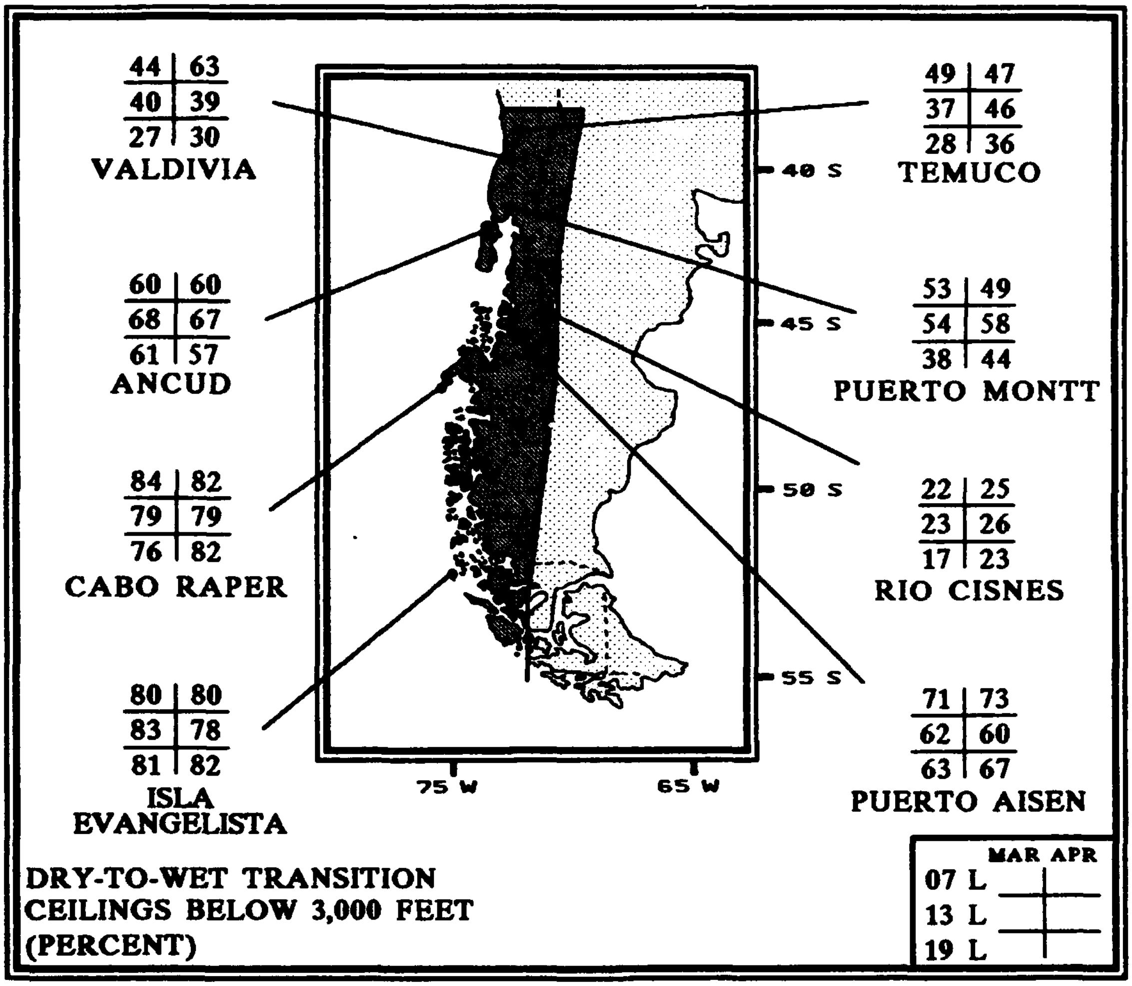


Figure 6-57. Dry-to-Wet Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Chile.

VISIBILITY. Highest frequencies of visibilities below 3 miles (Figure 6-58) are along the coastline and coastal inlets. Heavy mist, advection fog, and low ceilings with heavy rain produce most visibilities below 3 miles, but south of 48° S, heavy rain and low cloud are the main restrictions. Inland valleys have early morning radiation fog between 0400 and 0800L. Advection fog is common near large ice fields and glaciers. Visibility below 3 miles lasts up to 6 hours with post-frontal fog formation.

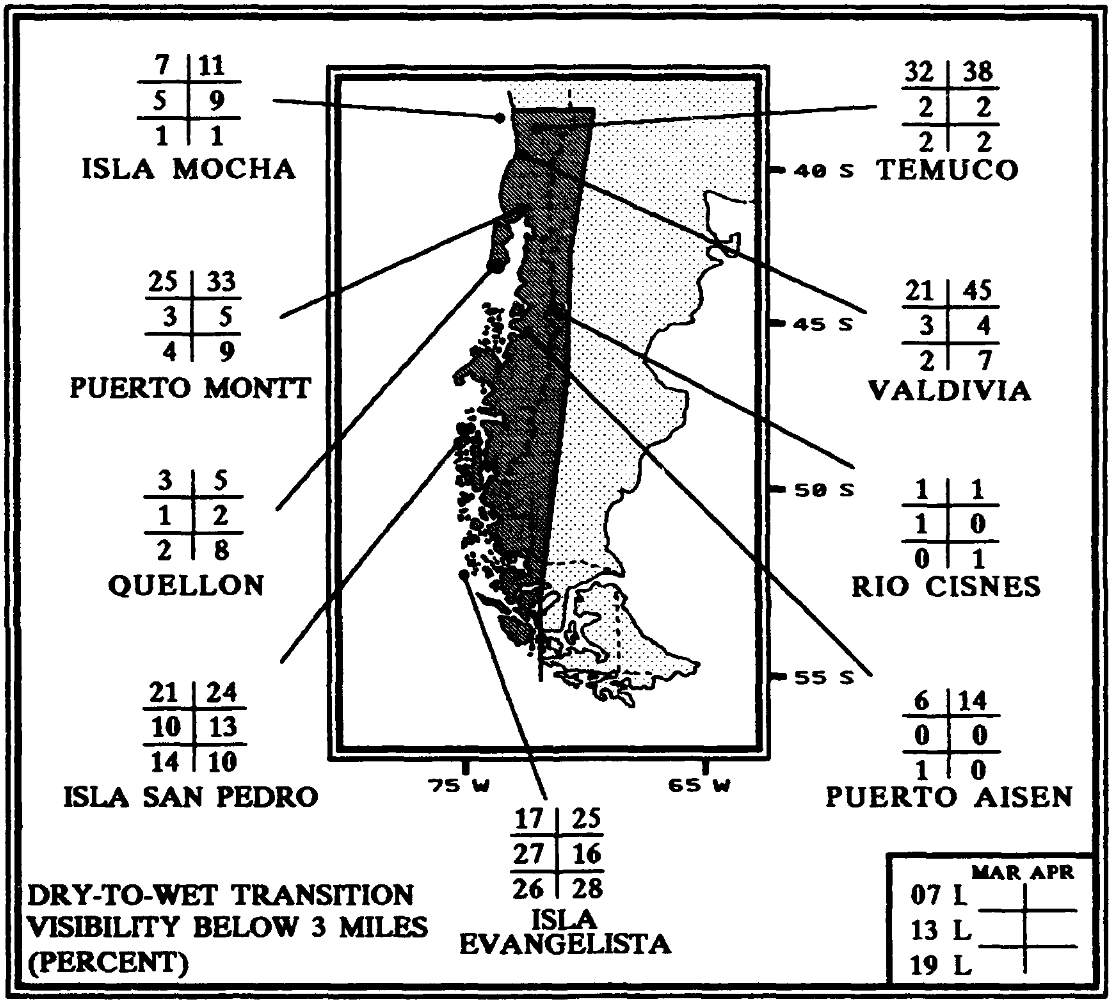


Figure 6-58. Dry-to-Wet Transition Percent Frequencies of Visibility Below 3 Miles, Southern Chile.

WINDS. Strong westerlies dominate at all levels during fair weather. Surface wind speeds can exceed 20 knots. Light northwesterlies at 3 to 9 knots precede intense fronts and can extend southward to 46° S before shifting to westerly. Westerlies at 20 to 30 knots can last up to 12 hours before shifting to southwesterly.

Once or twice a month, a secondary low forms off the coast between 42 and 48° S and moves east-northeastward. Rare southeasterly or easterly winds south of 48° S can last up to 6 hours. Acceleration across the western Andes can produce easterlies exceeding 20 knots.

Figure 6-59 shows mean monthly surface wind speeds ranging from 4 to 14 knots. Frontal passages produce northwest to northeast winds at 7 to 12 knots, but they occasionally exceed 40 knots. Behind the cold front, westerlies and southwesterlies have exceeded 50 knots. Figure 6-60 shows surface wind roses for April.

STATION	MEAN WIND SPEED MAR	APR
BALMACEDA	14	13
CHAITEN	4	5
CHILE CHICO	14	11
COYHAIQUE	8	7
ESQUEL	12	10
PUERTO AISEN	7	5
PUERTO MONTT	6	6
QUELLON	5	6
SAN CARLOS de BARILOCHE	12	11
TEMUCO	4	4
VALDIVIA	6	5

Figure 6-59. Mean Dry-to-Wet Transition Wind Speeds, Southern Chile.

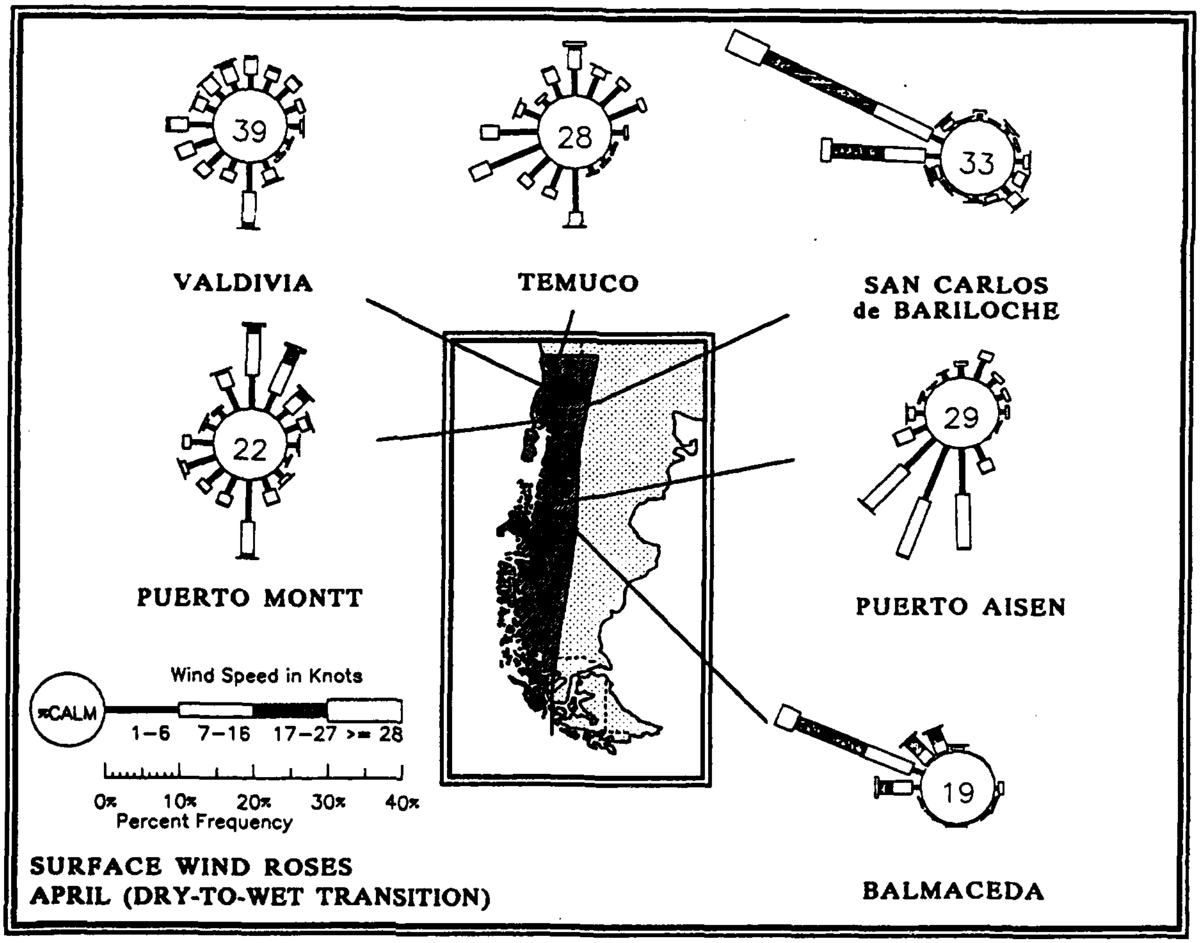


Figure 6-60. April Surface Wind Roses, Southern Chile.

In March, mean winds rotate clockwise with height from southwesterly (1,000 feet/305 meters MSL) to west-southwesterly (30,000 feet/9,145 meters MSL). In April, mean winds rotate counterclockwise from northwesterly to west-southwesterly from 1,000 to 4,000 feet (305 to 1,220 meters) MSL (Figure 6-51). Mean wind direction is consistently 260° above 5,000 feet (1,525 meters) MSL except with throughs. At 15,000 feet (4,575 meters) MSL, speeds average 30 knots in March and 34 knots in April. At 30,000 feet (9,145 meters) MSL, speeds average 56 knots in March and 66 knots in April. Mean maximum wind speeds are 60 knots near 36,000 feet (10,975 meters) MSL in March, and 68 knots near 34,000 feet (10,365 meters) MSL in April. The difference in maximum wind height between March and April is caused by a lowering of the tropopause over Southern Chile.

PRECIPITATION. Fast-moving cold fronts bring short periods of heavy rain. Heaviest rainfall is concentrated above 5,000 feet (1,525 meters) along the western Andes south of 41° S in March and north of it by by mid-April.

Mean March rainfall ranges from 0.9 inches/23 mm (Esquel, Argentina) to 20.3 inches/516 mm (Bahia Felix). April's mean rainfall amounts are greater than March's because of the northward shift in cyclonic activity; exceptions are Bahia Felix, the Evangelista Islands, and Puerto Aisen. Mean April rainfall (Figure 6-61) ranges from 1.4 inches/36 mm (Esquel) to 17.4 inches/442 mm (Bahia Felix).

Monthly and maximum 24-hour rainfall totals for March and April (Figure 6-62) can be extremely variable from year to year depending on the number of storms affecting the zone. Light snow and ice pellets are possible above 7,000 feet (2,135 meters) in late March; intense polar troughs by mid-April can produce 1-inch (25-mm) an hour snowfalls.

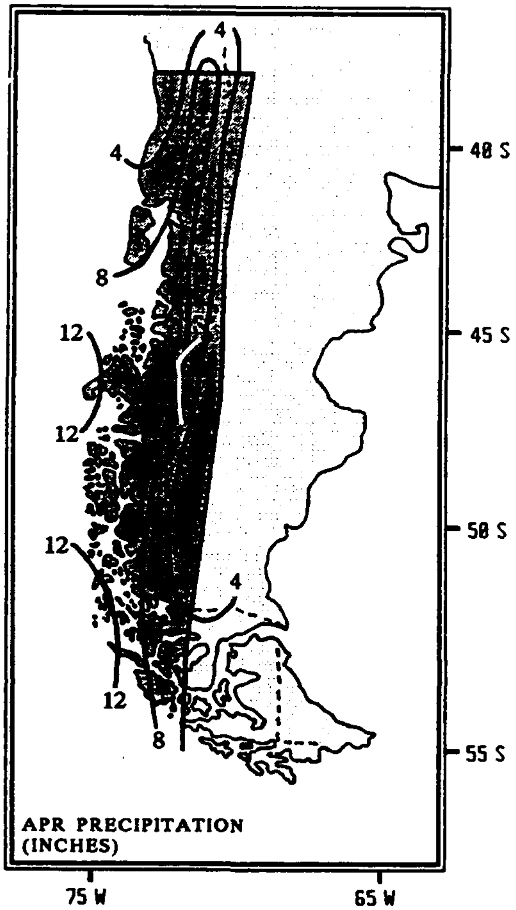


Figure 6-61. Mean April Precipitation, Southern Chile.

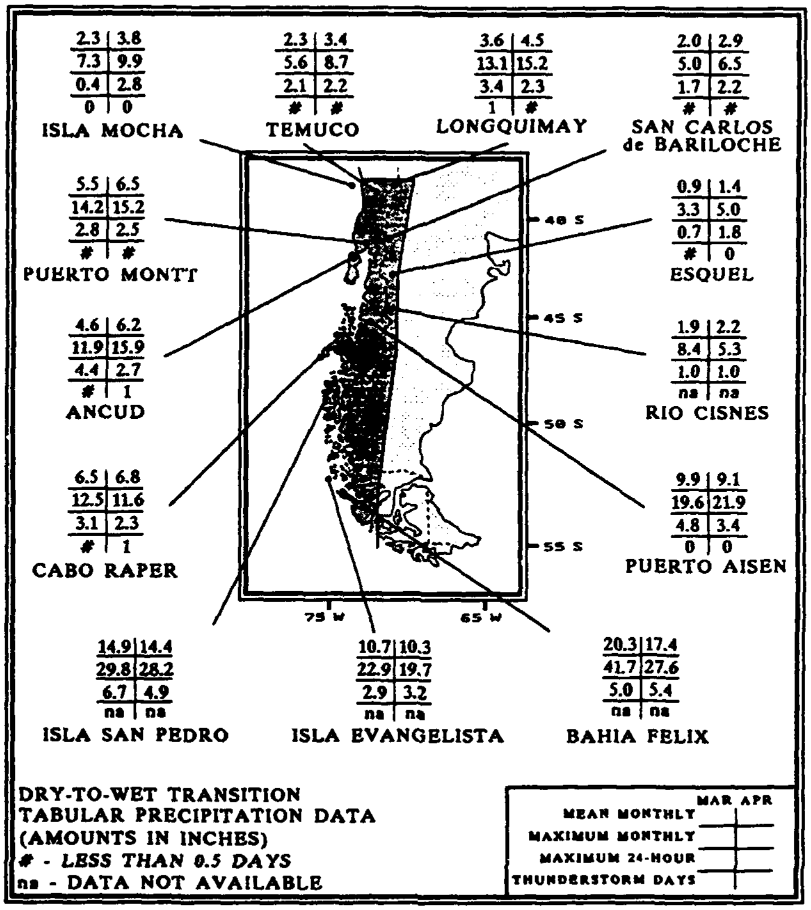


Figure 6-62. Dry-to-Wet Transition Tabular Precipitation Data, Southern Chile.

THUNDERSTORMS occur less than 1 day a month. Rarely severe, they develop near secondary lows that have cold-air support aloft. Bases average 3,000 feet (915 meters) MSL with tops to 35,000 feet (10.7 km) MSL north of 40° S. When the Subtropical Jet is associated with an intense upper-air trough, tops can exceed 45,000 feet (13,720 meters) MSL along the Andes' highest ridge crests. On the eastern slopes of the Andes, cloud bases average 4,000 feet (1,220 meters) MSL; tops are similar to those on the western Andes. With deep lows, thunderstorms can produce rainfall of 0.5 inch (13 mm) an hour, and snowfall up to 12 inches (305 mm) above 10,000 feet (3,050 meters) MSL.

TEMPERATURE. Temperatures become lower through the season as solar insolation decreases. Terrain and insolation produce large variations in temperatures from east to west and from north to south (Figure 6-63). Mean daily highs range from 48 to 78° F (9 to 26° C); the higher temperatures are in the western Andean foothills in the northern end of the zone. Mean daily lows range from 29 to 52° F (-2 to 11° C); the lowest temperatures are in the higher elevations. Daytime temperatures near glaciers stay below 40° F (4° C) except where the ice reaches the sea. Record highs in March exceed 90° F (32° C) north of 42° S, but rarely reach the 70's° F (21° C) south of 48° S. Record lows range from 40° F (4° C) at Isla Mocha off the coast to 9° F (-13° C) at Monte Fitzroy in the mountains. Diurnal temperature changes are smallest near the coast and highest in the higher elevations. The mean snow line ranges from 10,400 feet (3,170 meters) in March to 8,700 feet (2,650 meters) in April at 41° S. At 45° S, it ranges from 9,700 feet (2,955 meters) in March to 7,700 feet (2,345 meters) in April.

Mean relative humidity is consistently above 87% along the coast and coastal inlets. Over the interior, it is usually 80 to 90% at 0700L west of the Andes, but decreases to between 55 and 85% east of the mountains. By 1300L, RH over the entire interior ranges from 45 to 75%. By 1900L along western interior stations, it ranges from 60 to 75%, but is between 45 and 60% east of the Andes. Figure 6-64 shows maximum and mean wet-bulb globe temperatures (° F) for selected stations.

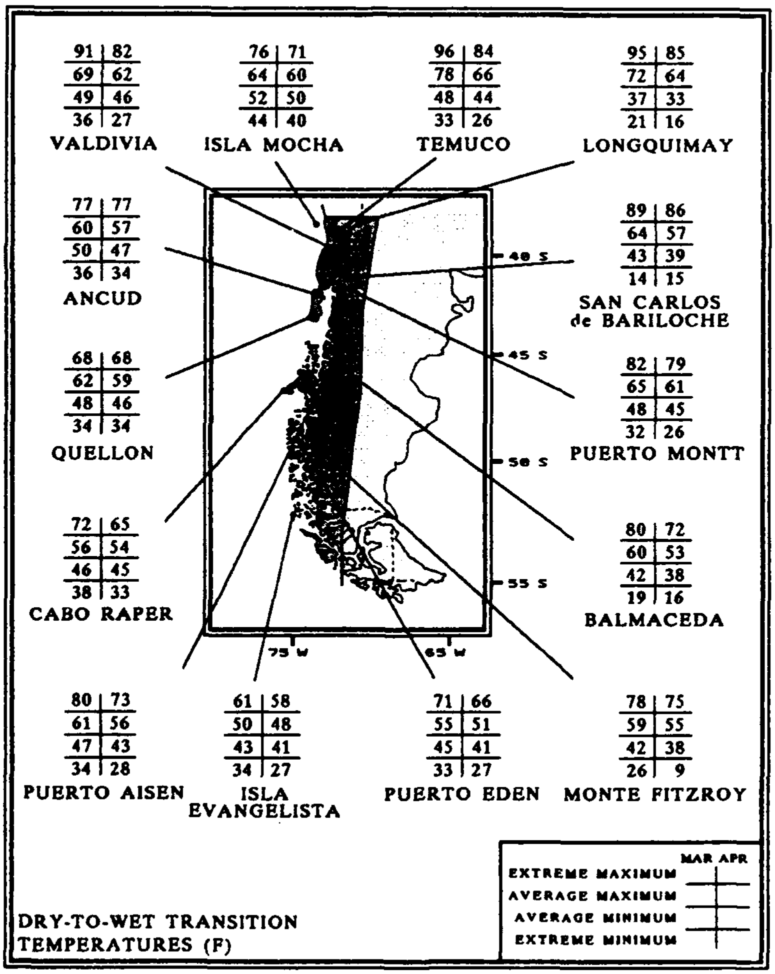


Figure 6-63. Dry-to-Wet Transition Tabular Temperature Data, Southern Chile.

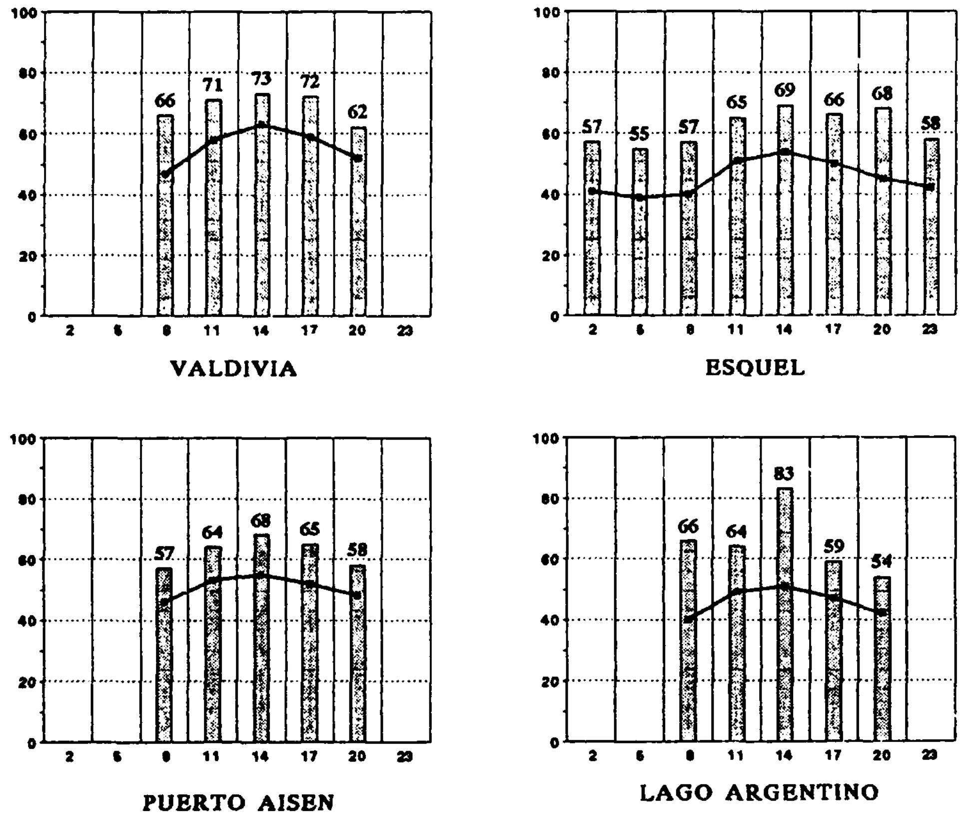


Figure 6-64. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Southern Chile.

FLIGHT HAZARDS. Moderate turbulence, wind gusts exceeding 50 knots, heavy rain with visibilities below 2 miles, and moderate mixed icing are possible in and around thunderstorms. Along the Andes and upland valleys (above 7,000 feet/2,135 meters) MSL, light to moderate turbulence for light aircraft and helicopters is possible with mountain/valley winds. Wind gusts exceed 35 knots after 1300L, but usually weaken by 1900L. In the eastern Andes, southwesterly winds can produce adiabatic warming and 60- to 70-knot wind gusts with associated mountain-wave turbulence. Moderate to severe mixed icing occurs in and near thunderstorms; light to moderate mixed icing can be found in layered prefrontal cloud decks. Freezing levels average 500 to 1,000 feet (150 to 305 meters) lower than the permanent snow line.

GROUND HAZARDS. By mid-April, heavy rain and/or snowfall above 7,000 feet (2,135 meters) MSL can close mountain passes for several days. Flash flooding often washes out roadways. On rare occasions, freezing rain and/or sleet occurs with intense storms. Thick fog with visibility below 1 mile is possible along the coastline and interior valleys between 2300 and 0900L.

GENERAL WEATHER. Southern Chile is often referred to as the "Roaring Forties" because of the intense low-pressure systems and strong westerly winds. Surface lows can affect Southern Chile south of 43° S every 2nd or 3rd day. The South Pacific High is normally too weak to block storms from reaching the coast for more than 2 consecutive days between May and September. By late June, cold fronts can bring rain or snow on 7 or more consecutive days before there is a temporary break in the flow pattern. Flow often becomes northwesterly south of 43° S because a stationary trough develops in the eastern South Pacific from late June to late August between 75 and 90° W. "Polar lows"--similar to those of the northern hemisphere--may affect the extreme southern portion of this zone three to four times during August and September; their effects are concentrated in The Drake Passage. Ceilings and visibilities drop rapidly to near zero; winds increase dramatically to gale or even hurricane force. Effects rarely last beyond 12 hours. As of spring 1992, satellite imagery was the only detection method available.

Most frontal passages produce low ceilings, low visibilities, liquid and/or frozen precipitation, sudden wind shifts, and high wind speeds. On occasion, cut-off lows form along the Southern Chile coast north of 38° S and propagate slowly eastward into the western Andes. Remnants of these lows continue to produce poor flying conditions for up to 72 hours. Heavy rains below 2,000 feet (610 meters) fall from isolated thunderstorms, and significant snowfalls (6 to 24 inches/152 to 610 mm) above 7,000 feet (2,135 meters) are common.

SKY COVER. Mean cloud cover is at its maximum (Figure 6-65), mainly due to the constant stream of storms that cross the zone. The South Pacific High is too far north and too weak to keep storms to the south. Stratus and stratocumulus are common along cold fronts and diurnally between 2300 and 0900L. Fair weather periods and clear skies seldom persist for more than 24 hours between late June and late August south of 43° S.

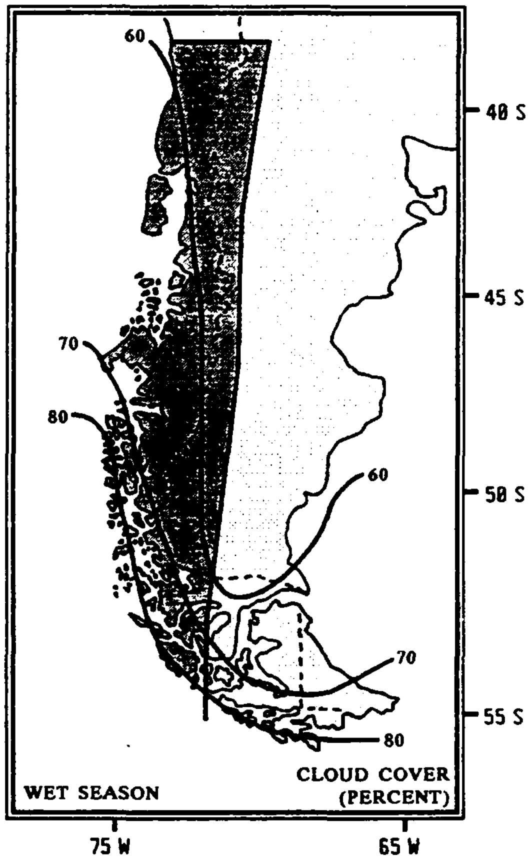


Figure 6-65. Mean Wet-Season Cloud Cover, Southern Chile.

Ceilings are below 3,000 feet most of the time west of the Andes (Figure 6-66), again because of the frequent storms. Frequencies gradually decrease northward, away from the main storm track. Diurnal variations are small except in the far north where nighttime and early morning stratus is a factor.

South of 43° S, stratus and stratocumulus ceilings average 4,000 feet (1,220 meters), but can be 500 feet (150 meters) AGL for up to 12 hours with slow-moving systems. These clouds are rarely more than 2,000 feet (610 meters) thick. Embedded cumulus and altocumulus have bases near 4,000 feet (1,220 meters) MSL with tops to 15,000 feet (4,573 meters) MSL. Along the western Andes, the stratus and cumulus clouds can obscure terrain above 3,000 feet (915 meters).

North of 43° S, warm fronts sometimes produce solid stratus decks with bases below 4,000 feet (1,220 meters) MSL and tops to 8,000 feet (2,440 meters) MSL. Scattered cumulus is often embedded in the stratus layer with bases near 5,000 feet (1,525 meters) MSL and tops to 10,000 feet (3,050 meters) MSL. Multilayered clouds are common along the cold front. Stratus and stratocumulus ceilings can be below 1,000 feet (305 meters) MSL along the coast and coastal inlets. Cumulus is concentrated along the trough axis; tops rarely exceed 17,000 feet (5,180 meters) MSL except along the western Andes where they reach 30,000 feet (9,145 meters) MSL. Broken middle and high clouds occur as far as 300 miles ahead of frontal systems; they merge with low clouds on the windward slopes, totally obscuring ridges above 6,000 feet (1,830 meters). These middle clouds end with passage of the upper-air low or trough. Middle clouds occur over and just downwind of the highest ridges ahead of frontal systems; they clear within 4 to 6 hours of upper-trough passage as upper-level ridging builds.

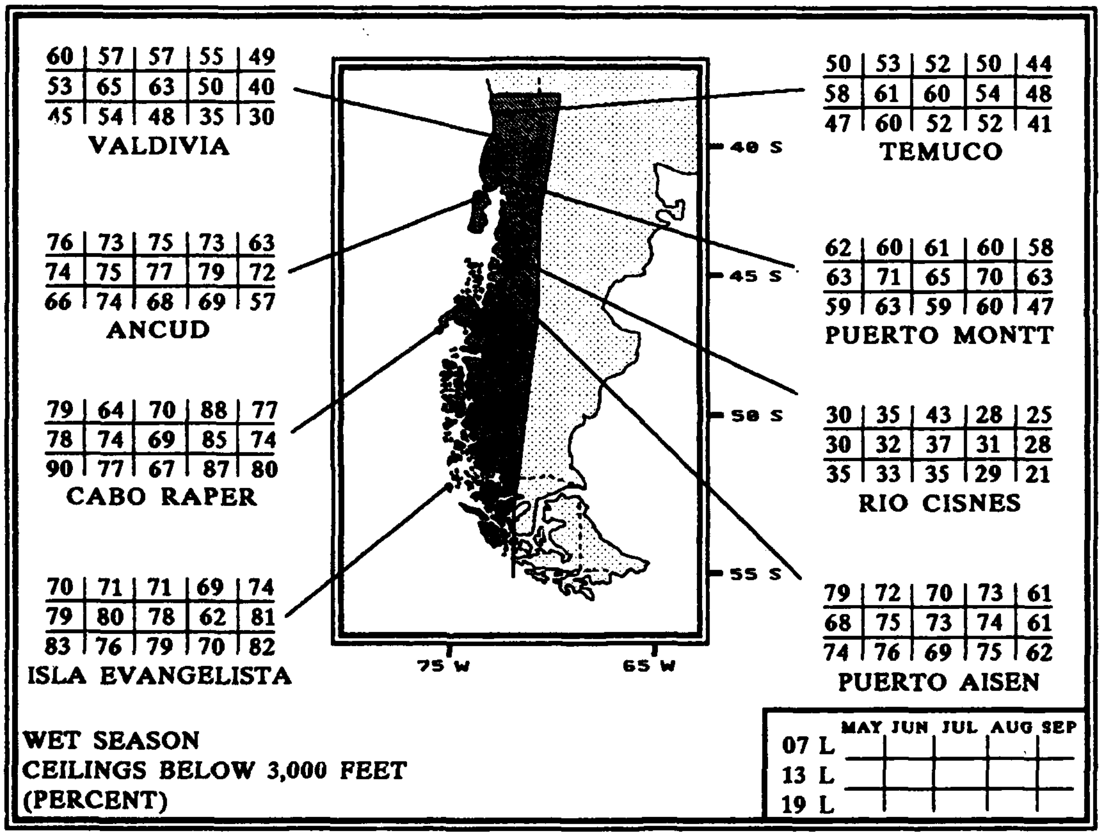


Figure 6-66. Wet-Season Percent Frequencies of Ceilings Below 3,000 feet (915 meters), Southern Chile.

VISIBILITY. Low visibilities are most frequent in the wet season due to heavy rains and early morning fog/mist in sheltered coastal inlets and valleys (Figure 6-67). Frontal passages produce isolated fog, heavy mist, and/or steady drizzle along the archipelago and coastline. Advection fog sometimes moves onshore in the warm sector of strong lows, particularly between 0900 and 1800L. South of 46° S, slow-moving warm and occluded fronts can produce visibilities below 1 mile for up to 12 hours below 2,000-foot (610-meter) elevations; heavy mist can persist throughout the day. Isolated radiation fog develops by 0700L on wide upland valley floors, but usually burns off by 1000L along the eastern and western Andes. Upland valleys can be shrouded in fog after a night of heavy rain. Advection fog occurs nearly every morning near glaciers and major ice fields; visibility can remain below 2 miles for up to 6 hours.

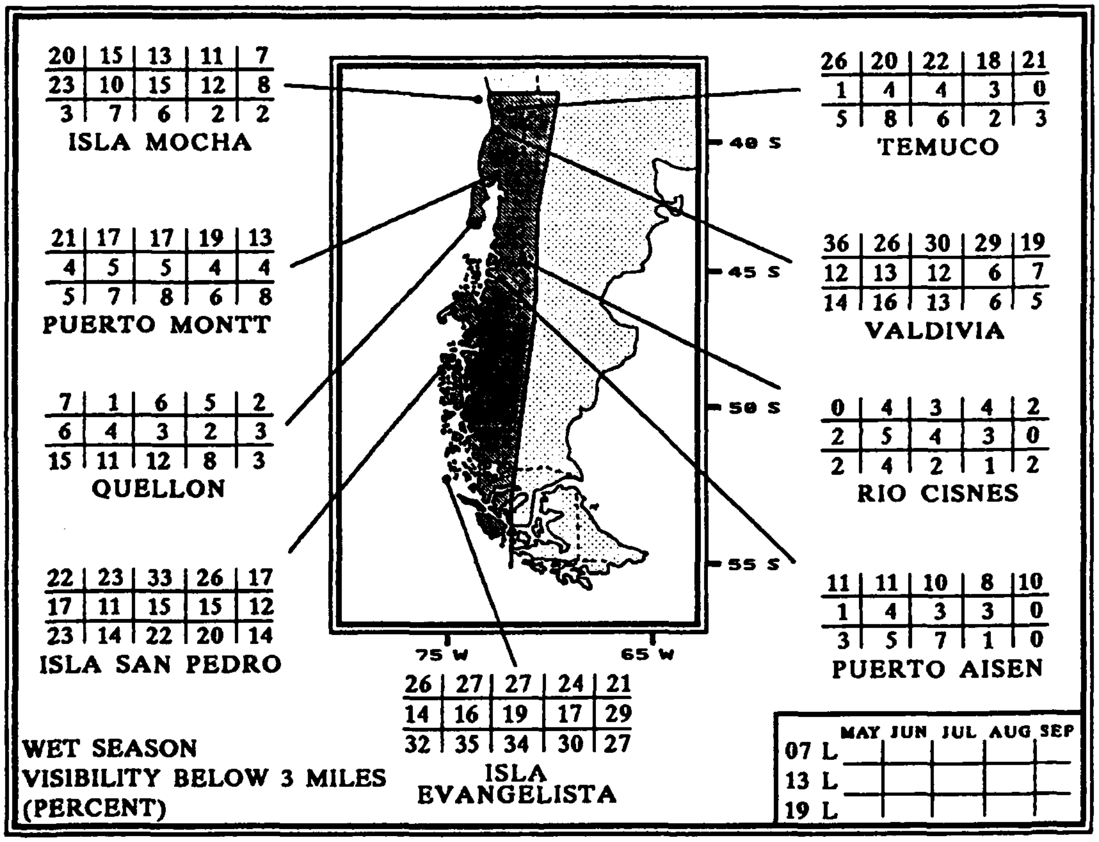


Figure 6-67. Wet-Season Percent Frequencies of Visibility Below 3 Miles, Southern Chile.

WINDS. Strong mid-latitude westerlies bring in one storm system after another; storms are virtually uninterrupted across the eastern South Pacific. Mean surface wind speeds (Figure 6-68) range from 3 to 13 knots. Speeds are highest at exposed southern locations.

Along the coastline, 15- to 25-knot winds are common with frontal passages. Strong north to northwest winds at 10 to 20 knots can prevail ahead of cold fronts for up to 36 hours. Behind the trough, westerly to southwesterly winds exceeding 55 knots are common. Northwesterlies can persist south of 43° S for several days between late June and late August when a stationary 500-mb trough develops in the eastern South Pacific.

Along the eastern Andes, storms can produce winds exceeding 70 knots in upland valleys and canyons. Upslope valley winds are enhanced by synoptic flow during the day south of 43° S along the western Andes. A 30-knot wind along the western foothills is common by 1300L. Figure 6-69 shows surface wind roses for several stations in mid-season (July).

STATION	MEAN WIND SPEED				
	MAY	JUN	JUL	AUG	SEP
BALMACEDA	10	9	10	13	13
CHAITEN	5	6	6	5	5
CHILE CHICO	6	6	8	12	12
COYHAIQUE	5	5	6	7	8
ESQUEL	8	9	8	11	11
PUERTO AISEN	4	3	4	5	5
PUERTO MONTT	9	8	9	8	8
QUELLON	6	7	7	8	7
SAN CARLOS de BARILOCHE	11	11	11	13	13
TEMUCO	6	6	9	6	6
VALDIVIA	7	7	7	7	8

Figure 6-68. Mean Wet-Season Wind Speeds, Southern Chile.

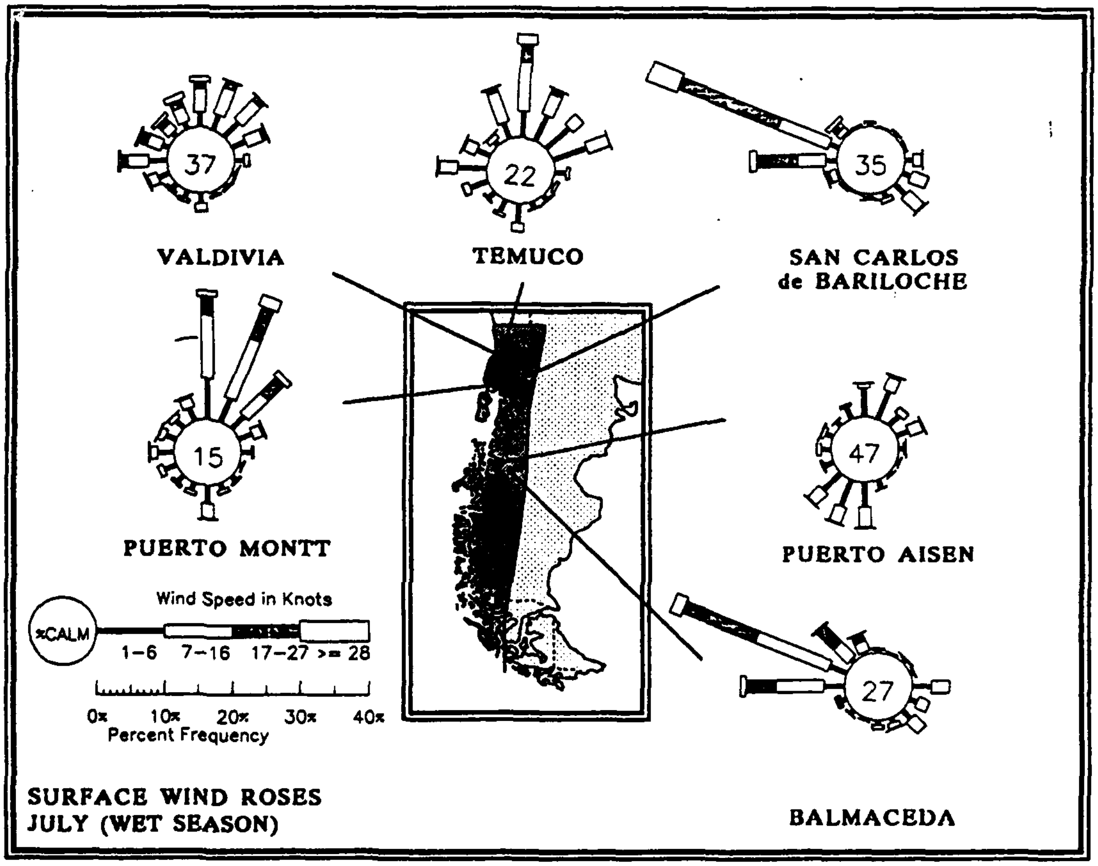


Figure 6-69. July Surface Wind Roses, Southern Chile.

Figure 6-51 shows the mean May-September northwesteries from 1,000 to 3,000 feet (305 to 915 meters) MSL at Puerto Montt (41° S), associated with the troughs. Mean directions vary little with height from month to month; they are 270° at 5,000 feet (1,525 meters) MSL and 255° at 30,000 feet (9,145 meters) MSL. At 15,000 feet (4,575 meters) MSL, speeds range from 39 knots (June/July) to 34 knots (September). Maximum speeds range from 69 knots (June) at 34,000 feet (10,365 meters) MSL to only 56 knots (September) at 31,000 feet (9,450 meters) MSL.

PRECIPITATION. Widespread moderate rain usually falls along cold fronts below 3,000 feet (915 meters). A single cold front can produce more than 4 inches (102 mm) of rain over remote sections of the coastal islands and the western Andes above 7,000 feet (2,135 meters). Steady drizzle and patchy fog dominate warm front and post-cold-front weather along the coast; scattered moderate to heavy rainfall or snowshowers dominate above 3,000 feet (915 meters). Mixed precipitation is common between 3,000 and 7,000 feet (915 and 2,135 meters). A mix of sleet, freezing drizzle/rain, and/or ice pellets occurs with deep troughs in coastal inlet and adjacent hillsides. An isolated thundershower is possible along the western Andes.

Mean July rainfall (Figure 6-70) exceeds 12 inches (308 mm) in the extreme southern fringes of the archipelago south of 50° S and in the western Andes above 7,000 feet (2,135 meters). In the eastern Andes, precipitation amounts decrease rapidly below 8,000 feet (2,440 meters). July averages at least 7 inches (178 mm) west of the Divide, but only 3 inches (76 mm) or less below 5,000 feet (2,135 meters) east of the Andes.

Low-pressure systems affect Southern Chile every 2nd or 3rd day in June, July, and August, and every 3rd or 4th day in May and September.

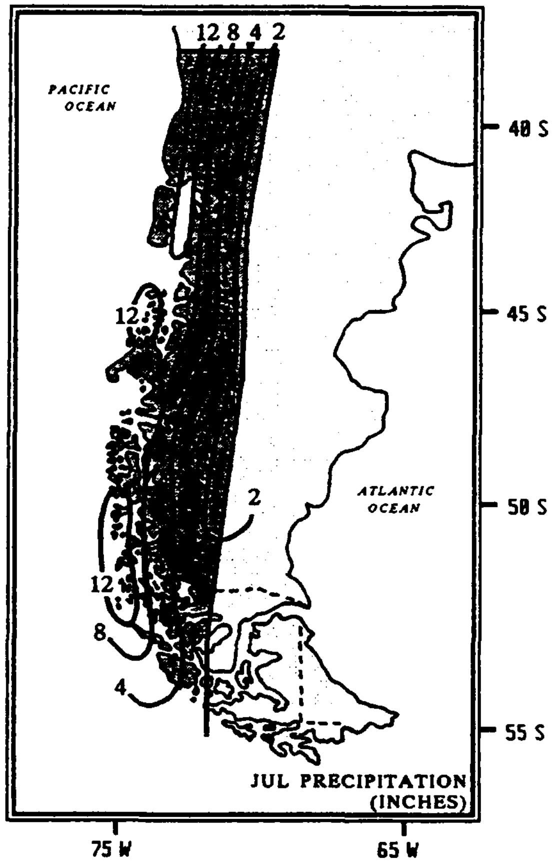
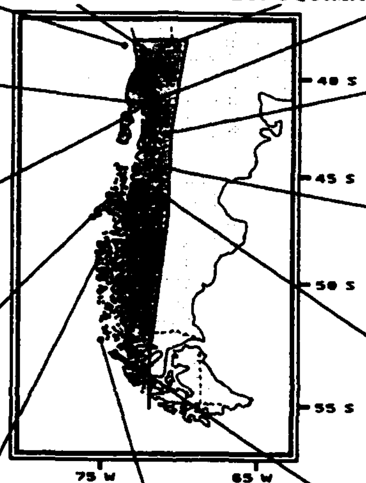


Figure 6-70. Mean July Precipitation, Southern Chile.

Cut-off lows produce about 1 inch (25 mm) of rainfall. On rare occasions, a surface low, supported by a deep 500-mb trough, forms over the eastern Pacific north of 38° S and moves slowly eastward, its movement blocked by the Andes, as the 500-mb trough continues eastward into the Atlantic. Stations north of 42° S have received more than 20 inches (508 mm) of liquid precipitation in a month (Figure 6-71). Maximum 24-hour rainfall can exceed 6 inches (152 mm) west of the Andes, but rarely exceeds 2 inches (51 mm) east of the mountains.

Snowfall can exceed 12 inches (305 mm) above 3,000 feet (915 meters); snow of 24 inches (610 mm) or more fall on the western Andes above 7,000 feet (2,135 meters). Snowfall can exceed 30 inches (662 mm) above 8,000 feet (2,440 meters). The heaviest snows are usually south of 44° S. In extreme cases, the snow line lowers to 2,000 feet (610 meters). Light snow and ice pellets have fallen at Temuco, but they rarely remain on the ground for more than 3 hours. This is similar to what occurs along the western Sierra Nevada of California when deep polar troughs combine with a upper-level wind maxima over the Pacific coast. Snowfall can be expected with most systems, regardless of strength, above 10,000 feet (3,050 meters); however, 6-inch snowfalls are usually produced only once or twice a season east of the Andes below 7,000 feet (2,135 meters) and north of 40° S.



Station		MAY	JUN	JUL	AUG	SEP
ISLA MOCHA	MEAN MONTHLY	7.5	8.3	7.7	6.1	3.9
	MAXIMUM MONTHLY	19.2	17.5	22.9	13.8	10.5
	MAXIMUM 24-HOUR	3.9	3.2	2.4	2.1	1.4
	THUNDERSTORM DAYS	0	#	0	#	0
TEMUCO	MEAN MONTHLY	7.5	7.8	6.8	5.5	3.7
	MAXIMUM MONTHLY	15.1	13.3	12.0	10.6	8.8
	MAXIMUM 24-HOUR	3.7	4.5	2.3	3.1	4.0
	THUNDERSTORM DAYS	#	#	#	0	0
LONGQUIMAY	MEAN MONTHLY	12.1	12.7	12.0	9.5	6.6
	MAXIMUM MONTHLY	27.7	26.7	24.6	27.3	16.6
	MAXIMUM 24-HOUR	4.7	5.1	4.8	2.9	2.8
	THUNDERSTORM DAYS	#	#	#	0	#
SAN CARLOS de BARILOCHE	MEAN MONTHLY	5.8	6.4	5.7	4.8	2.8
	MAXIMUM MONTHLY	15.2	9.8	14.8	11.3	6.0
	MAXIMUM 24-HOUR	4.4	3.0	3.9	2.3	1.6
	THUNDERSTORM DAYS	#	0	0	0	0
PUERTO MONTT	MEAN MONTHLY	9.1	9.1	9.3	8.1	6.0
	MAXIMUM MONTHLY	20.5	26.9	20.4	18.5	12.8
	MAXIMUM 24-HOUR	3.3	3.3	4.6	3.3	2.9
	THUNDERSTORM DAYS	0	0	#	#	0
ESQUEL	MEAN MONTHLY	2.7	2.6	3.2	2.3	1.2
	MAXIMUM MONTHLY	5.4	6.6	7.2	4.7	4.1
	MAXIMUM 24-HOUR	1.8	4.4	2.9	1.7	0.9
	THUNDERSTORM DAYS	0	0	0	0	0
ANCUD	MEAN MONTHLY	9.3	10.3	9.3	8.6	6.3
	MAXIMUM MONTHLY	23.5	22.6	23.4	20.0	17.5
	MAXIMUM 24-HOUR	3.3	3.1	5.1	3.7	3.6
	THUNDERSTORM DAYS	1	1	1	#	#
RIO CISNES	MEAN MONTHLY	3.2	2.2	2.7	2.7	1.5
	MAXIMUM MONTHLY	8.6	6.7	9.7	8.1	5.3
	MAXIMUM 24-HOUR	2.2	1.6	1.9	5.0	1.3
	THUNDERSTORM DAYS	na	na	na	na	na
CABO RAPER	MEAN MONTHLY	7.2	7.3	7.4	6.6	5.1
	MAXIMUM MONTHLY	23.2	18.4	17.1	12.8	10.0
	MAXIMUM 24-HOUR	5.4	2.1	3.4	1.9	1.4
	THUNDERSTORM DAYS	#	#	1	#	#
PUERTO AISEN	MEAN MONTHLY	12.9	10.9	12.8	12.4	8.3
	MAXIMUM MONTHLY	24.1	21.4	42.1	27.8	16.0
	MAXIMUM 24-HOUR	3.9	5.0	3.9	6.7	4.2
	THUNDERSTORM DAYS	0	0	0	0	#
ISLA SAN PEDRO	MEAN MONTHLY	13.9	13.5	14.2	11.3	10.6
	MAXIMUM MONTHLY	28.0	30.7	32.1	23.1	23.1
	MAXIMUM 24-HOUR	7.1	4.3	5.6	4.6	3.9
	THUNDERSTORM DAYS	na	na	na	na	na
ISLA EVANGELISTA	MEAN MONTHLY	8.5	8.5	8.5	8.4	8.6
	MAXIMUM MONTHLY	16.2	22.2	18.8	18.8	21.1
	MAXIMUM 24-HOUR	3.2	3.8	3.3	5.4	4.8
	THUNDERSTORM DAYS	na	na	na	na	na
BAHIA FELIX	MEAN MONTHLY	14.1	13.4	14.9	14.7	14.3
	MAXIMUM MONTHLY	31.1	29.2	31.1	30.6	27.6
	MAXIMUM 24-HOUR	5.5	3.6	5.3	4.8	4.2
	THUNDERSTORM DAYS	na	na	na	na	na

WET SEASON
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

Figure 6-71. Wet-Season Tabular Precipitation Data, Southern Chile.

THUNDERSTORM days average 1 or less a month across the zone. Cut-off lows forming in the cold-air pools over the Pacific Ocean at the mid- and upper-levels produce most thunderstorms. Heavy wet snow is common above 3,000 feet (915 meters) from thunderstorms along the coast. Strong lifting produces isolated thundershowers with 1 inch (25 mm) an hour rainfalls along the coast. Some isolated thunderstorms produce small hail. Cloud bases average 3,000 feet (915 meters) MSL with tops to 30,000 feet (9,145 meters) MSL north of 40° S. Cloud tops exceed 40,000 feet (12,190 meters) MSL along the Andes' highest ridge crests. On the eastern slopes of the Andes, cloud bases average 4,000 feet (1,220 meters) MSL. Tops are similar to those in the western Andes.

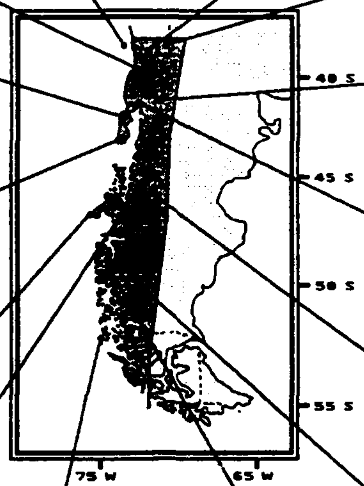
TEMPERATURE. Temperatures are generally highest in May and September. The highest are in the western Andes foothills and lowland valleys away from the coastline and coastal inlets. Mean highs are generally in the 50's (° F) or 10's (° C), dropping into the 40's (5-10° C) over the southern portions of the zone. Lows range from 37 to 43° F (3 to 6° C). Temperatures are a few degrees lower above 2,000 feet (610 meters).

Temperatures are generally lowest in mid-season (July). The highest are along the coast, where highs are in the low 50's (10 to 12° C) over the northern half, and 40's (5-10° C) over the southern half. In the interior, highs are in the low to mid 40's (4 to 8° C). Daily lows are generally near 40° F (4° C) in the north, dropping into the 30's (-1 to 4° C) over the south; mean lows reach 26° F (-3° C) above 2,000 feet (610 meters). Sub-freezing temperatures are also found near glaciers and major ice fields. The daytime temperature rarely reaches 32° F (0° C) near glaciers except where the ice field reaches the sea.

Record highs only exceed 80° F (31° C) north of 40° S and in September; elsewhere, record highs seldom reach 70° F (21° C). South of 48° S, record highs rarely exceed 55° F (21° C). Record lows range from -17° F (-27° C) at Monte Fitzroy to 28° F (-2° C) at Valdivia. Terrain and cold drainage winds cause wide variations in record lows over short distances. Most all-time record lows are in July.

The mean snow line at 41° S ranges from 6,900 feet (2,105 meters) in May to 5,400 feet (1,645 meters) in July. By September, it has moved back above 5,600 feet (1,710 meters). At 45° S, the mean snow line is 5,800 feet (1,770 meters) in May, 4,700 feet (1,430 meters) in July, and 5,500 feet (1,675 meters) in September.

Mean relative humidity along the coastline rarely drops below 80% during a 24-hour period. Inland, RH rarely drops below 50% west of the Andes, and then only between 1300 and 1600L. East of the Andes, RH ranges from 30 to 50% at 1300L, and from 50 to 70% at 1900L. RH is highest in July and August, lowest in May. No maximum and mean wet-bulb globe temperatures are given because temperatures rarely exceed 65° F (18° C).



WET SEASON TEMPERATURES (F)

Station		MAY	JUN	JUL	AUG	SEP
VALDIVIA	EXTREME MAXIMUM	71	66	66	68	79
	AVERAGE MAXIMUM	56	52	52	54	58
	AVERAGE MINIMUM	43	42	41	40	41
	EXTREME MINIMUM	26	19	23	25	27
ISLA MOCHA	EXTREME MAXIMUM	67	63	61	67	68
	AVERAGE MAXIMUM	58	56	54	54	56
	AVERAGE MINIMUM	48	46	44	44	45
	EXTREME MINIMUM	37	34	34	35	36
TEMUCO	EXTREME MAXIMUM	76	68	75	73	86
	AVERAGE MAXIMUM	58	54	54	56	60
	AVERAGE MINIMUM	42	41	39	39	41
	EXTREME MINIMUM	25	23	20	24	24
LONGQUIMAY	EXTREME MAXIMUM	77	73	63	68	82
	AVERAGE MAXIMUM	53	44	44	48	56
	AVERAGE MINIMUM	31	29	27	28	31
	EXTREME MINIMUM	13	-3	-6	-2	16
ANCUD	EXTREME MAXIMUM	64	61	57	61	66
	AVERAGE MAXIMUM	53	51	50	50	52
	AVERAGE MINIMUM	45	43	42	42	43
	EXTREME MINIMUM	32	28	30	30	32
SAN CARLOS de BARILOCHE	EXTREME MAXIMUM	73	70	64	66	73
	AVERAGE MAXIMUM	50	45	44	46	50
	AVERAGE MINIMUM	36	33	31	32	33
	EXTREME MINIMUM	12	0	-6	2	1
QUELLON	EXTREME MAXIMUM	64	66	57	66	63
	AVERAGE MAXIMUM	55	50	50	50	52
	AVERAGE MINIMUM	43	41	40	40	41
	EXTREME MINIMUM	32	27	28	30	30
PUERTO MONTT	EXTREME MAXIMUM	73	68	67	68	74
	AVERAGE MAXIMUM	57	52	51	53	55
	AVERAGE MINIMUM	44	41	40	40	40
	EXTREME MINIMUM	23	21	20	24	24
CABO RAPER	EXTREME MAXIMUM	64	60	65	60	72
	AVERAGE MAXIMUM	51	49	46	48	49
	AVERAGE MINIMUM	43	40	39	39	39
	EXTREME MINIMUM	33	28	32	29	29
BALMACEDA	EXTREME MAXIMUM	63	56	60	61	70
	AVERAGE MAXIMUM	45	40	39	43	49
	AVERAGE MINIMUM	33	30	28	31	34
	EXTREME MINIMUM	11	-9	-8	-3	14
PUERTO AISEN	EXTREME MAXIMUM	66	59	55	61	72
	AVERAGE MAXIMUM	50	45	43	47	51
	AVERAGE MINIMUM	40	35	34	36	37
	EXTREME MINIMUM	25	19	16	19	25
ISLA EVANGELISTA	EXTREME MAXIMUM	55	54	53	52	53
	AVERAGE MAXIMUM	46	44	43	43	44
	AVERAGE MINIMUM	38	36	36	36	38
	EXTREME MINIMUM	25	19	24	25	26
PUERTO EDEN	EXTREME MAXIMUM	59	53	51	54	60
	AVERAGE MAXIMUM	46	42	41	44	47
	AVERAGE MINIMUM	38	35	33	36	37
	EXTREME MINIMUM	22	19	19	24	24
MONTE FITZROY	EXTREME MAXIMUM	69	68	64	64	67
	AVERAGE MAXIMUM	47	44	43	45	49
	AVERAGE MINIMUM	33	30	30	30	35
	EXTREME MINIMUM	6	-4	3	5	12

Figure 6-72. Wet-Season Tabular Temperature Data, Southern Chile.

FLIGHT HAZARDS. Moderate to severe turbulence, mixed icing, and wind shear occur with intense frontal passages. Clear-air and mountain-wave turbulence can occur with trough passages along the eastern Andes; strong adiabatic winds have gusted to 70 knots. Low ceilings/visibilities with rain and fog occur every 3 days south of 45° S. Moderate to severe mixed icing occurs in and near thunderstorms; light to moderate mixed icing also occurs in layered prefrontal cloud decks. Freezing levels average 500 to 1,000 feet (150 to 305 meters) lower than the permanent snow line. Moderate to severe mountain-wave turbulence occurs over and downwind of higher Andean ranges. Mountain waves, are relatively common along and east of the highest ranges.

GROUND HAZARDS. Heavy snows can close mountain passes. Along the coast (41 to 50° S), thick fog can reduce visibility to below 1/2 mile for up to 12 hours prior to a frontal passage. Heavy rains in the Andes produce flash flooding along the adjacent foothills and upland river valleys. Heavy wet snow or sleet/freezing rain make road travel hazardous.

GENERAL WEATHER. The primary storm track moves poleward. Most locations north of 45° S rarely see moderate rain or rain showers along a trailing cold front. The South Pacific High begins to re-establish itself, producing south-southwesterly winds for stations north of 44° S.

SKY COVER. Extensive cloud cover is common south of 45° S with most frontal passages (Figure 6-73). Stratus and stratocumulus extend along the coastline as far north as 40° S within a storm's warm sector. Cloud bases slope upward from 1,000 feet (305 meters) MSL near 42° S to 4,000 feet (1,220 meters) MSL at 48° S. Tops reach 7,000 feet (2,135 meters) MSL along the trough axis, but the layer is seldom more than 3,000 feet (915 meters) thick. The thickest and lowest clouds sometimes move inland to the western Andes. Stratus/stratocumulus bases average 4,000 feet (1,220 meters) MSL near the Andes and usually lift into cumulus by 1300L above 7,000 feet (2,135 meters). Tops rarely reach 10,000 feet (3,050 meters) MSL. Cumulus and altocumulus along the trough axis have bases at or above 9,000 feet (2,745 meters) AGL, with tops exceeding 20,000 feet (6,100 meters) MSL south of 45° S. Broken middle and high clouds occur as far as 300 miles ahead of frontal systems; they merge with low clouds on the windward slopes, totally obscuring ridges above 6,000 feet (1,830 meters) and ending with passage of the upper-air low or trough. Middle clouds occur over and just downwind of the highest ridges ahead of frontal systems; they clear within 4 to 6 hours of upper trough passage as upper-level ridging builds.

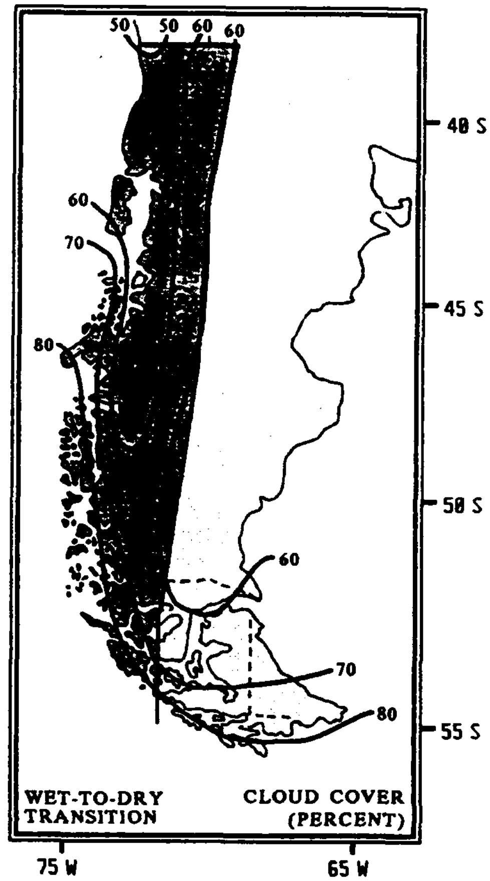


Figure 6-73. Mean Wet-to-Dry Transition Cloud Cover, Southern Chile.

Heavy mist, early morning fog, and patchy stratus or stratocumulus form between 2200 and 0900L during fair weather periods (Figure 6-74). Most cloud cover burns off by 1000 or 1100L; north of 43° S, it reforms into shallow cumulus with bases at 4,000 feet (1,220 meters) MSL and tops to 6,000 feet (1,830 meters) MSL. Bases can go below 1,000 feet (305 meters) MSL within the moist marine layer until 1300L south of 43° S. Along the western Andes, diurnal cumulus usually forms above 5,000 feet (1,525 meters) MSL with a strong sea breeze. Tops average 10,000 feet (3,050 meters) MSL. Scattered diurnal cumulus develops along the eastern Andes near 8,000 feet (2,440 meters) MSL; tops rarely exceed 11,000 feet (3,350) MSL.

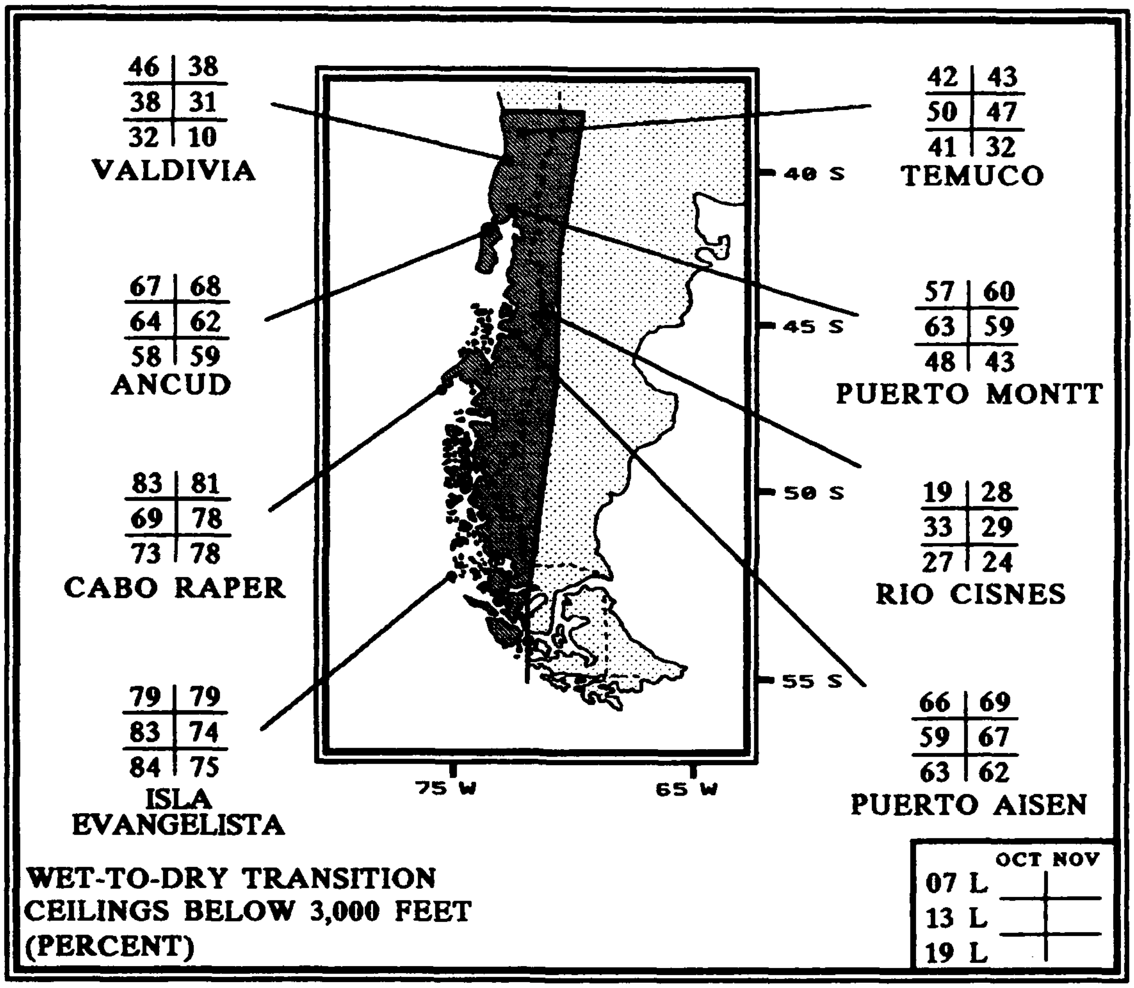


Figure 6-74. Wet-to-Dry Transition Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Chile.

VISIBILITY. Fog and heavy mist lower visibilities below 3 miles between 2200 and 0900L along the coastline and in inlets. A moist marine boundary layer and light nighttime winds produce radiation fog north of 40° S in the wide inland valleys. Stations like Temuco, Traiguen, and Longuimay (Figure 6-75) have the highest frequencies of early morning radiation fog between 0100 and 0900L. These stations lie within the Central Valley (38 to 40° S). Visibilities between 1 and 3 miles are common with cold fronts for up to 12 hours prior to passage. Thick, localized early morning fog is possible where there is residual moisture from heavy rain. Good visibility can be expected along the Andes above 5,000 feet (1,524 meters) MSL.

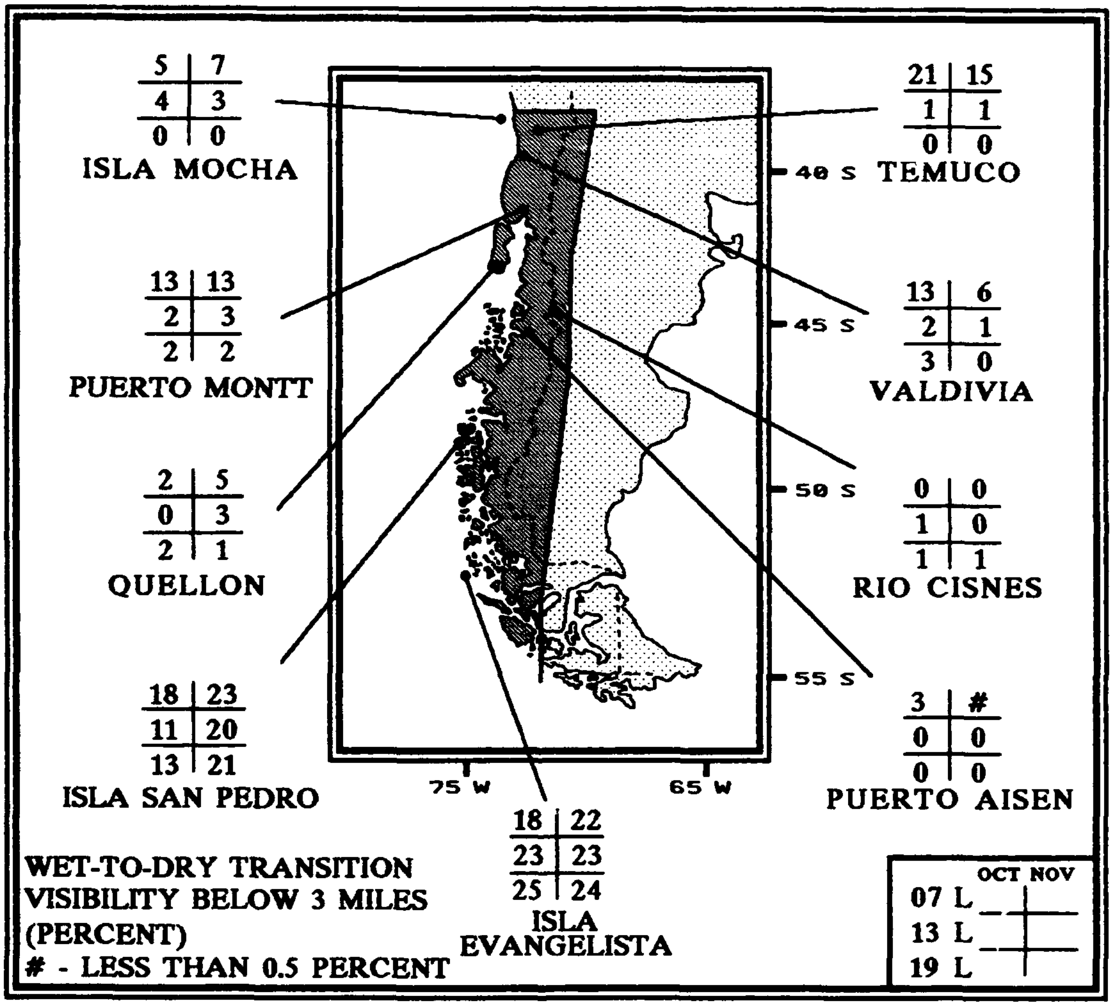


Figure 6-75. Wet-to-Dry Transition Percent Frequencies of Visibility Below 3 Miles, Southern Chile.

WINDS. Westerlies dominate initially, but by late November, the South Pacific High begins to generate light southerly surface flow north of 44° S. Directions are most variable along the archipelago and coastline because of land/sea breezes. Ahead of cold fronts, northwest to northeast winds average 6 knots, but can exceed 25 knots with intense lows. Behind the cold front, westerly to southwesterly winds can exceed 35 knots. Along the Andes, valley breezes rarely exceed 20 knots; nighttime mountain breezes rarely exceed 10 knots. Mean wind speeds range from 5 to 16 knots (Figure 6-76), reflecting the changing conditions. Figure 6-77 shows surface wind roses for October.

STATION	MEAN WIND SPEED OCT	NOV
BALMACEDA	15	17
CHAITEN	5	5
CHILE CHICO	16	16
COYHAIQUE	8	8
ESQUEL	13	15
PUERTO AISEN	7	9
PUERTO MONTT	8	8
QUELLON	7	7
SAN CARLOS de BARILOCHE	14	16
TEMUCO	5	5
VALDIVIA	8	9

Figure 6-76. Mean Wet-to-Dry Transition Wind Speeds, Southern Chile.

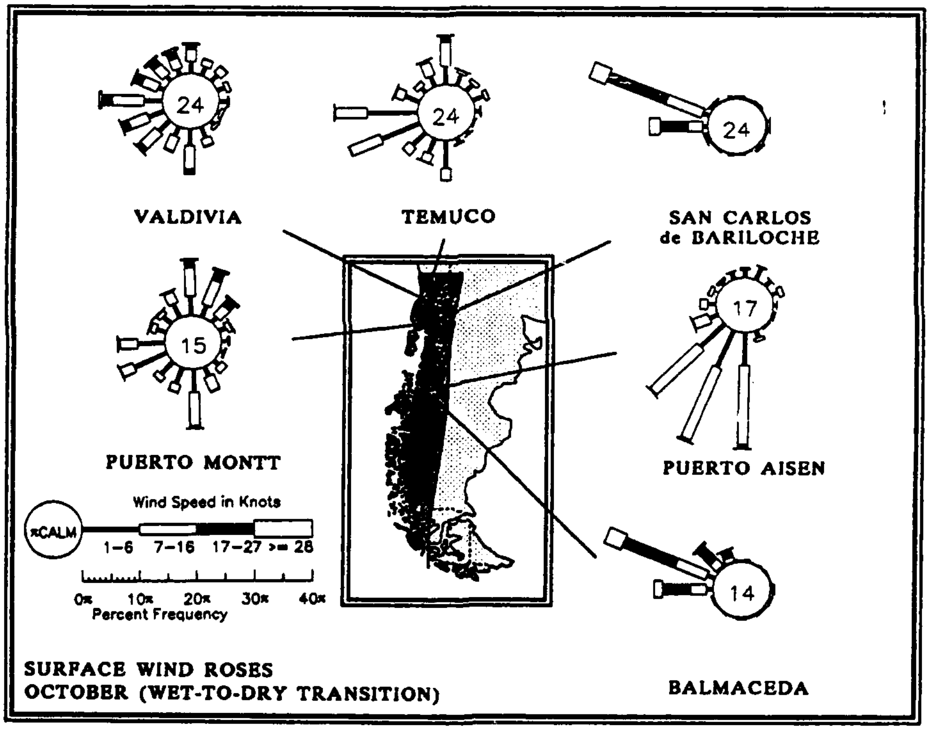


Figure 6-77. October Surface Wind Roses, Southern Chile.

Mean wind direction varies little with height. In October, winds are from 260 to 280° at all levels. In November, they range from 240 to 260°. Mean maximum wind speeds are 54 knots near 31,000 feet (9,450 meters) MSL in October, and near 34,000 feet (10,365 meters) MSL in November. The change shows the rise in the tropopause.

PRECIPITATION. Low-pressure systems affect Southern Chile every 3rd or 4th day south of 46° S. Frontal-type precipitation is common, producing moderate to heavy rainshowers. Along the western Andes above 2,000 feet (610 meters) MSL, thunderstorms can develop along the trough axis and produce isolated heavy downpours. Snow can fall at lower elevations, but the heaviest snowfalls (12-inch/305 mm or greater) are found above 10,000 feet (3,050 meters) MSL with thunderstorm activity; heavy wet snow is rare below 5,000 feet (1,525 meters) MSL.

Most November precipitation is concentrated south of 45° S between Puerto Aisen and Bahia Felix. North of 45° S, scattered light rain or rainshowers occur along frontal boundaries. Rain or drizzle can persist for 24 to 36 hours with slow-moving systems. Along the Andes, orographic effects produce scattered thundershowers and isolated heavy downpours. Mean monthly rainfall averages less than 2 inches (51 mm) a month east of the Andes below 7,000 feet (2,135 meters) (Figure 6-78).

Maximum monthly rainfall ranges from 2.3 to 34.3 inches (58 to 871 mm) at Esquel (October) and Bahia Felix (November), respectively, depending on local topography and proximity to the primary storm track. The record maximum 24-hour rainfall is 12.6 inches (320 mm) at San Pedro in November; other stations have had 5 inches (127 mm). The highest amounts fall along the Archipelagic Chile; the smallest, east of the Andes in the north.

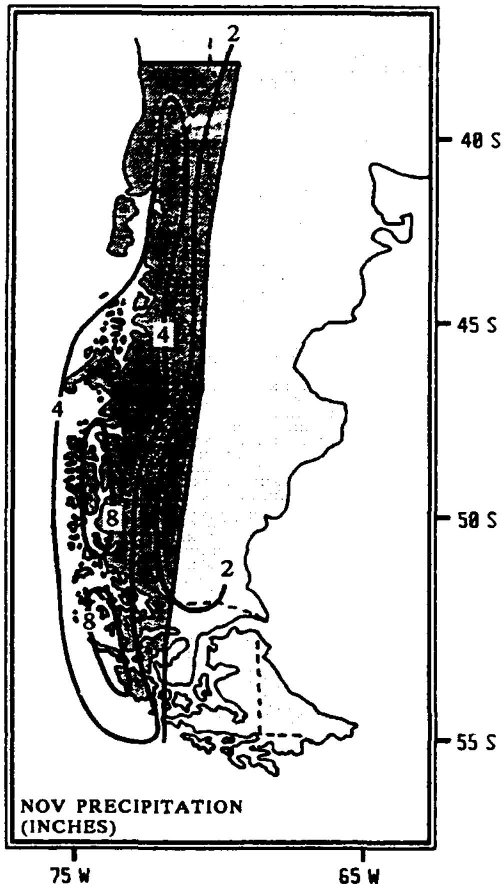


Figure 6-78. Mean November Precipitation, Southern Chile.

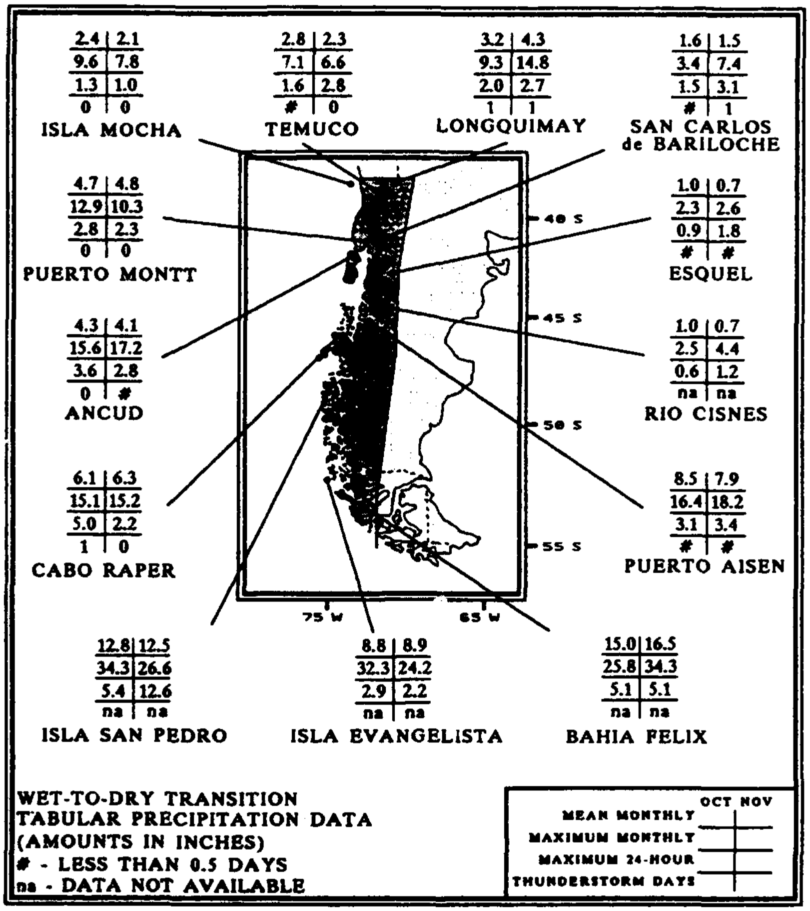


Figure 6-79. Wet-to-Dry Transition Tabular Precipitation Data, Southern Chile.

THUNDERSTORMS occur 1 day or less a month, most often north of 41° S. Most occur along intense cold fronts with cold-air support from deep upper-air troughs, but some are generated by orographic lifting and sea-breeze moisture. Thunderstorm bases average 3,000 feet (915 meters) MSL with tops to 35,000 feet (10,670 meters) MSL. Cloud tops can exceed 45,000 feet 13,720 meters) MSL along the Andes' highest ridge crests by mid-November. Although the eastern slopes of the Andes get far less rainfall, cloud bases average 4,000 feet (1,220 meters) MSL, and tops are similar to those on the western Andes. Thunderstorms generated by deep lows can produce 0.5 inch (13 mm) an hour rainfall and small hail.

TEMPERATURE. Temperatures generally increase during the transition. North of 44° S, mean daily highs range from 53 to 69 F° (12 to 21° C); the western Andes foothills and interior valleys are warmest. Mean daily lows on the coast range from 40 to 49° F (4 to 9° C). Above 2,000 feet (610 meters) MSL, they drop to 33-40° F (1-4° C), and go below freezing above 10,000 feet (3,050 meters) MSL.

South of 44° S, highs range from 45-55° F (7-13° C) along the coast to from 56-61° F (13-16° C) above 2,000 feet (610 meters). Lows range from 39-43° F (4-6° C) on the immediate coast and from 32-38° F (0 to 3° C) above 2,000 feet (610 meters). Temperatures are much lower above the permanent snow line and near glaciers; daytime temperatures may never reach 40° F (4° C) near glaciers except where the ice field reaches the sea.

Record highs in October exceed 90° F (32° C) at some locations north of 42° S. South of 48° S, record highs rarely exceed 70° F (21° C). Record lows range from 29° F (-2° C) at Puerto Aisen (sea level) to 12° F (-11° C) at San Carlos de Bariloche, Argentina (2,772 feet/845 meters). Terrain and cold drainage winds cause wide variations in record low temperatures over short distances.

The mean snow line at 41° S ranges from 6,300 feet (1,920 meters) in October to 7,800 feet (2,380 meters) in November. At 45° S, it ranges from 6,200 feet (1,890 meters) in October to 7,500 feet (2,285 meters) in November.

Along the coastline, relative humidities rarely drop below 75%. Inland, mean RHs at 0700L range from 65 to 80% on both sides of the Andes. By 1300L, it can drop to 40% east of the Andes, but stays high to the west. Figure 6-81 shows maximum and mean wet-bulb globe temperatures (° F) for selected stations.

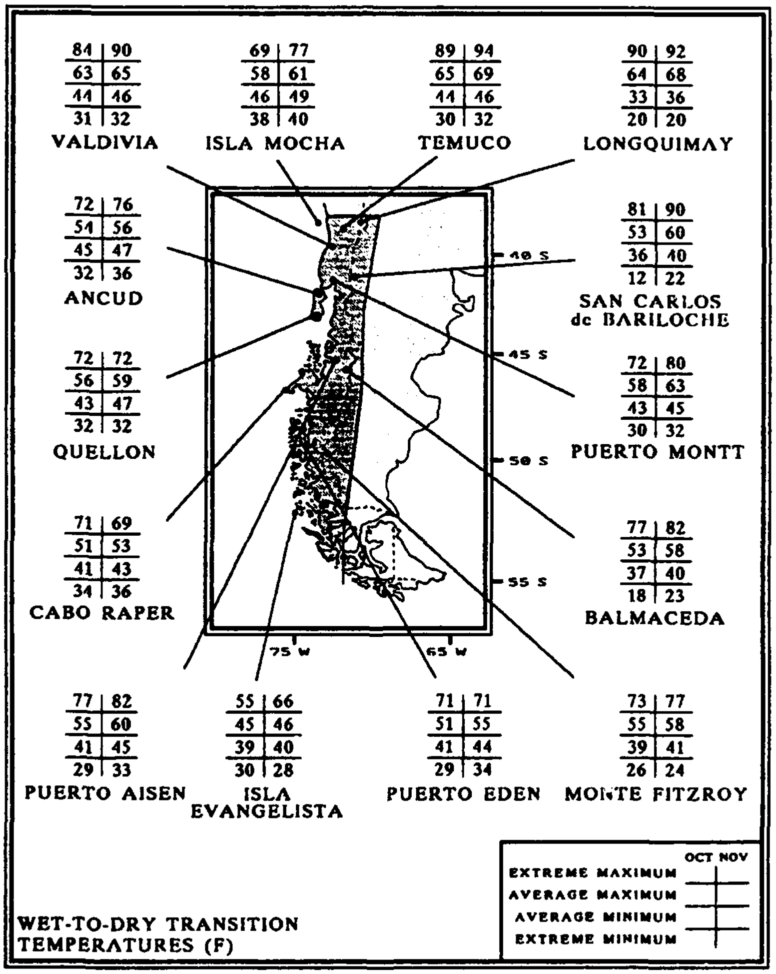


Figure 6-80. Wet-to-Dry Transition Tabular Temperature Data, Southern Chile.

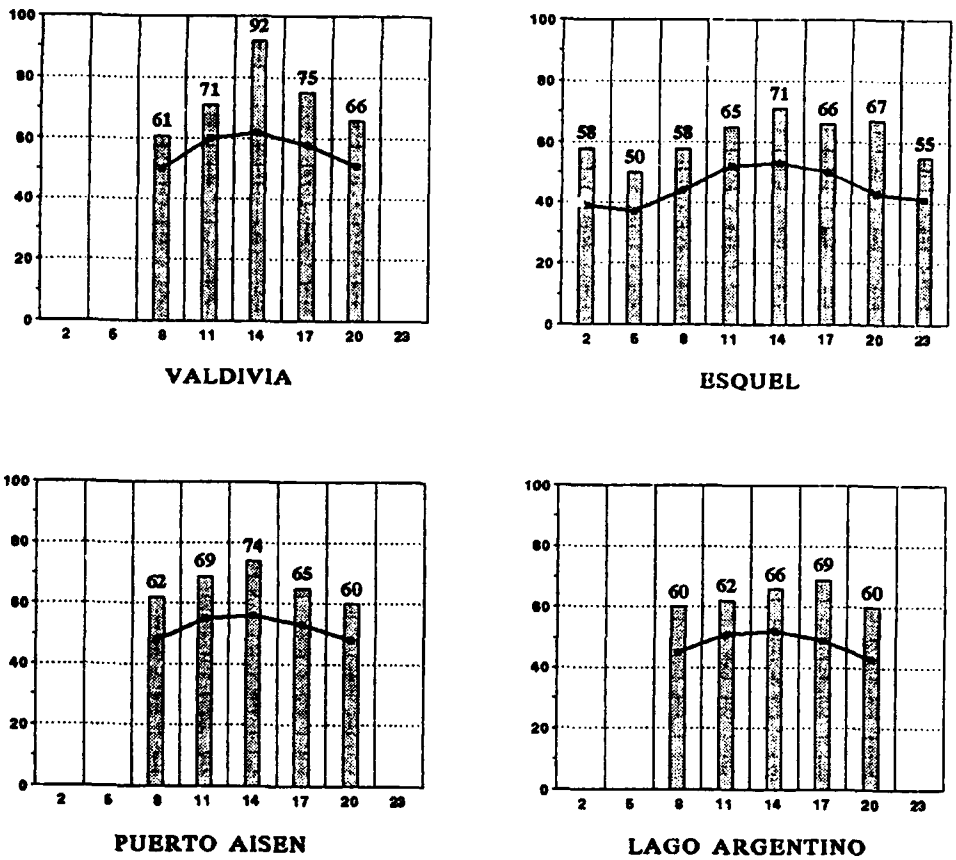


Figure 6-81. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Southern Chile.

FLIGHT HAZARDS. Moderate turbulence, gusts over 50 knots, heavy rain with visibility less than 2 miles, and mixed icing are possible in and around thunderstorms. Light to occasional moderate turbulence occurs for light aircraft and helicopters along the Andes and in upland valleys above 7,000 feet (2,135 meters) due to wind shear from mountain/valley winds. Gusts may exceed 25 knots after 1300L, but they usually weaken by 1900L. Light to moderate mixed icing in layered prefrontal cloud decks is possible. Freezing levels average 500 to 1,000 feet (150-305 meters) lower than the permanent snow line.

GROUND HAZARDS. Heavy rain and/or snowfall (in early October only) above 8,000 feet (2,440 meters) can close mountain passes for several days or produce flash flooding. Freezing rain occurs on rare occasions. Thick fog produces visibilities below 1 mile along the coastline and in coastal inlets between 2300 and 0900L less than 3% of the time.

6.3 PATAGONIA

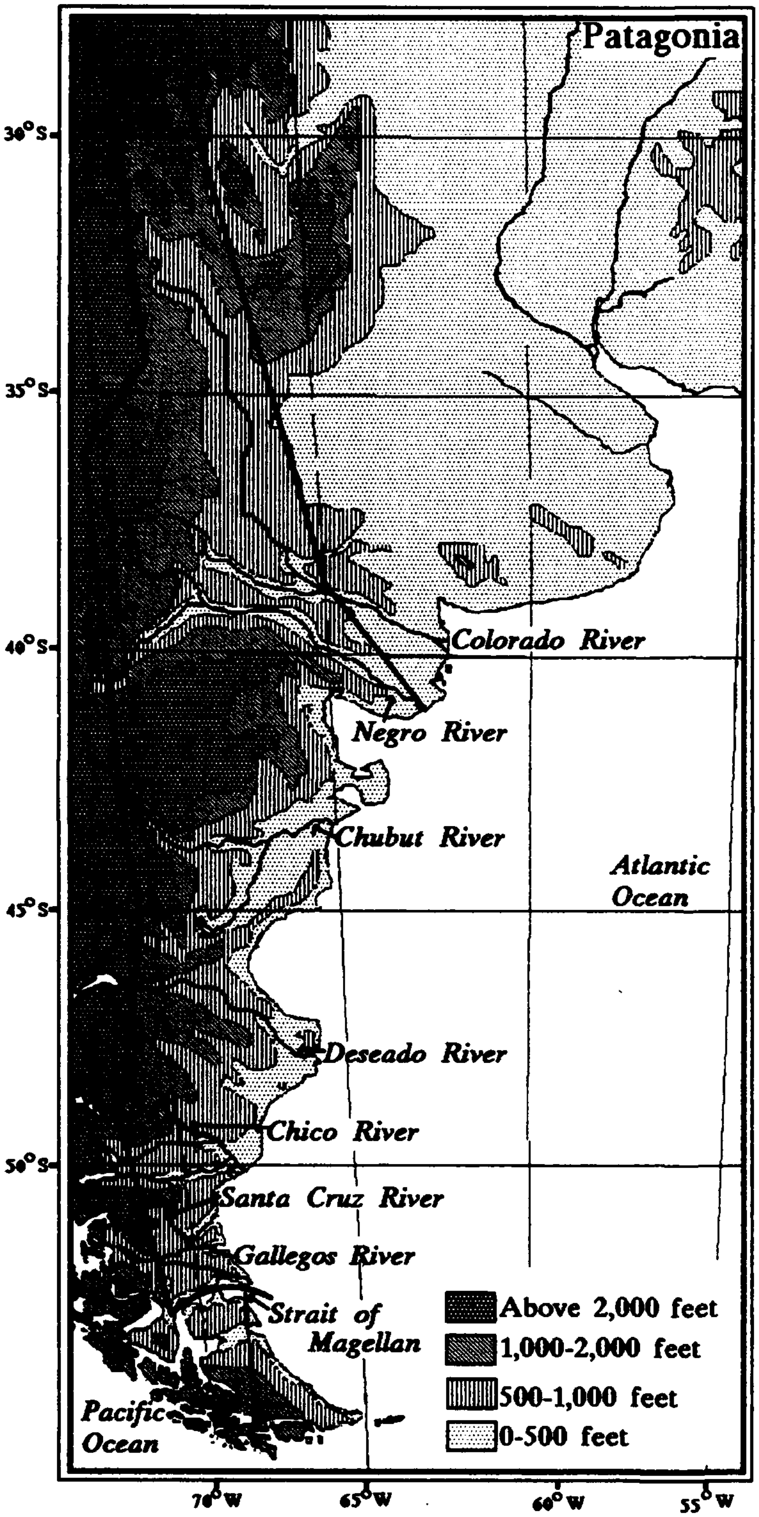
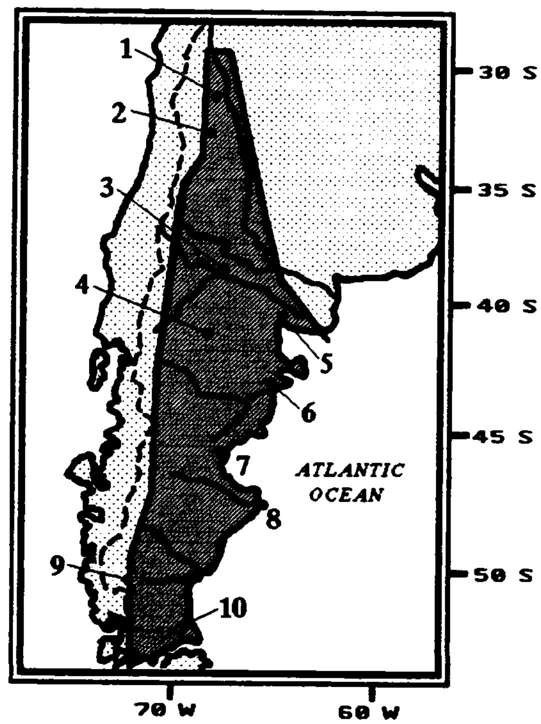


Figure 6-82. Patagonia. Semiarid/Arid Patagonia covers nearly 300,000 square miles, all in Argentina.



	ELEVATION (FEET)
1. SAN JUAN	2,067
2. MENDOZA	2,313
3. NEUQUEN	870
4. MAQUINCHAO	2,849
5. SAN ANTONIO OESTE	22
6. TRELEW	138
7. COMODORO RIVADAVIA	148
8. PUERTO DESEADO	257
9. CALAFATE	732
10. RIO GALLEGOS	61

Figure 6-83. Climatic Station Network, Patagonia.

PATAGONIA GEOGRAPHY

BOUNDARIES.
The zone is bounded:

On the north: by a line from 29° S, 69° W to 30° S, 67° 30'W.

On the east: by a line from 30° S, 67° 30'W south to 33° S, 67° W, following the Desaguadero and Salodo rivers to the Colorado River, continuing along the Colorado south to Choele Choel (39° S, 65° W), then southeastward paralleling the Negro River to near Viedma (41° S, 62° W), then following the Atlantic coast to the Strait of Magellan.

On the south: by the Strait of Magellan from the Atlantic coast to 53° S, 71° W.

On the west: by a line from 53° S, 72° W northward along the eastern slopes of the Andes to 29° S, 69° W.

TERRAIN. A series of steppe-like plateaus extends from the Atlantic Ocean to the eastern slopes of the Andes. Elevations vary from 300 feet (91 meters) near the coast to more than 3,000 feet (914 meters) at the base of the Andes. In southern Patagonia, glacial and volcanic formations dominate; glaciers sometimes reach the Atlantic Ocean. The cool, temperate Patagonian Desert extends from 37° S to the Strait of Magellan. The east coast generally has high cliffs separated from the sea by a narrow coastal plain. West of the Patagonian Desert are the low-lying Patagonian Andes and plateaus with a succession of steep cliffs and deep, wide valleys. The mountains, although low, are often snow-covered in winter. Many of the valleys are beds of former rivers that once flowed from the Andes to the Atlantic; others contain perennial and intermittent rivers.

WATERWAYS AND DRAINAGE. Rivers flow from the Andes eastward across the plateau in broad, low valleys. Among the most important (and their lengths) are the Colorado (597 NM) and the Negro (395 NM). The Negro is formed by the junction of the Neuquen and Lemay rivers. Both supply water for irrigation. The Chubut River, 503 NM in length, has been dammed and is used for irrigation. Most other rivers, which include the Santa Cruz, Chico, and Gallegos, are intermittent. The Deseado River is completely dry except for salt ponds that remain in deeper depressions and provide surface evidence that a river once flowed there.

VEGETATION. Vegetation is primarily low brush, bunch grass, or cropland. The northern portion is open bushland covered with widely spaced thickets between 3 and 7 feet high. Scattered throughout this area are several centers of agriculture produced by extensive irrigation. Fruit orchards and vegetable farms are common. To the south of the Negro River, grasses flourish in sandy areas. Vegetation is generally low and very sparse.

PATAGONIA CLIMATIC PECULIARITIES

THE "ROARING FORTIES." The zone is affected by winds from the South Pacific; air loses most of its moisture crossing the Andes and is therefore dry when it reaches Patagonia. As a result, a well-defined rain shadow extends along the lee side of the central and southern Andes to the coast of southern Argentina. The strong westerlies are Patagonia's most important meteorological factor. Often cold and dry, they blow unimpeded across the barren plateaus. They are strongest from about 40° S to the Strait of Magellan; these westerlies are so persistent that they're known as the "Roaring Forties."

MIGRATORY FRONTAL SYSTEMS. Migratory low-pressure systems from the South Pacific pass near the southernmost part of Argentina every few days throughout the year. Warm fronts normally move southeastward across southern Patagonia with little effect; at most, low clouds increase. Cold fronts, however, sweep northeastward and can bring a sudden drop in temperature, isolated showers, and gusty winds. Cyclogenesis is common along the Atlantic coast between 25 and 50° S; it usually enhances cloud cover and spreads light precipitation, especially south through west of the low's center where southeasterly flow advects Atlantic moisture into the area. There is a major frontogenesis area just beyond the zone's northeast border, but it has little or no effect on Patagonia.

PRECIPITATION AMOUNTS are highest in the higher elevations due to upslope flow, and possibly because evaporation of falling precipitation lessens amounts reaching lower elevations. Precipitation amounts along the immediate northern and southern coasts are slightly higher than the adjacent interior; the central coast is as dry as the interior.

FOEHN WINDS. Foehns occurring along the Andes slopes are locally referred to as "zondas." They're most frequent in winter, but can occur in any season. Winds range from westerly to northerly and are very warm and dry; temperatures can rise more than 50° F (28° C) and relative humidities can fall to less than 10%. Unlike foehns in some parts of the world, zondas can cause abnormally turbulent air and duststorms. The duststorms normally don't reduce visibilities for more than a few hours, but dust can remain suspended for a few days and prevent distinctly good visibilities.

SQUALL LINES. Squall line formation during late spring, summer, and early fall is common in the extreme northeast portion of the zone. Squall lines can produce severe convective weather the equal of that on the North American western Great Plains. Large hail, damaging winds and even isolated tornadoes have been reported north of Mendoza. Mesoscale Convective Systems (MCS) often form in this area before moving east.

NORTH AND SOUTH PATAGONIA. Patagonia can be divided into north and south sectors from near Neuquen to a point just south of the Valdes Peninsula. In the north, mean annual temperatures range from 55° F (13° C) to 65° F (18° C), and mean annual precipitation is from 4 to 9 inches (102 to 229 mm). The southern half has a cold, dry climate, with higher mean annual temperatures along the coast than inland; they range from 44° F (7° C) to 57° F (14° C). Mean annual precipitation ranges from 6 to 10 inches (153 to 254 mm).

GENERAL WEATHER. Summers are hot and windy; thunderstorms and precipitation are at their annual maximums. MCS formation north of Mendoza reaches its yearly peak. The South Pacific High steers moist air toward the area, but low-level moisture is lost over the Andes. Along the Andes' eastern slopes, the Northwest Argentine Depression (NAD) draws in warm air and some moisture from the north. High-pressure systems often stagnate off the east coast; these, along with occasional frontal lows, can advect Atlantic moisture into the zone. Frontal passages are common in southern Patagonia. Cold fronts can sweep northeastward and bring showers and gusty winds. Squall lines are relatively common ahead of such systems east and north of Neuquen; they are often severe. Conditions are similar to those of eastern Colorado. Surface hail in excess of 1 inch (2.5 cm) and gusts above 70 knots have been reported.

SKY COVER. Sky cover averages 40% in the north, 50% along the coast, and 70% in the south (see Figure 6-84); maximum cloudiness occurs in mid-morning. The predominant cloud types in the north range from stratus and stratocumulus in the morning to cumulus and towering cumulus afternoons. Most low ceilings are caused by post-frontal stratus, stratocumulus, and thunderstorms. Stratus and stratocumulus form with onshore flow produced by northeasterly winds from offshore blocking highs and from post-frontal southeasterly winds. Figure 6-85 shows percent frequencies of ceilings below 3,000 feet (915 meters) AGL for selected stations.

In the south, stratus and stratocumulus cause most low ceilings. Easterly flow associated with some blocking highs and occasional frontal lows bring in the moisture. Clouds develop by morning with radiation cooling and dissipate by noon. Their formation may also be orographically enhanced along eastward-facing slopes. Bases average 2,000 feet (610 meters) MSL, with tops to 6,000 feet (1,830 meters).

Towering cumulus affects the entire zone during afternoons; bases average 8,000 feet (2,440 meters); tops, 18,000 feet (5,490 meters). Cumulonimbus bases average 8,000 feet (2,440 meters) MSL, but can be as low as 2,500 feet (760 meters) MSL; tops can reach 50,000 feet (15.2 km).

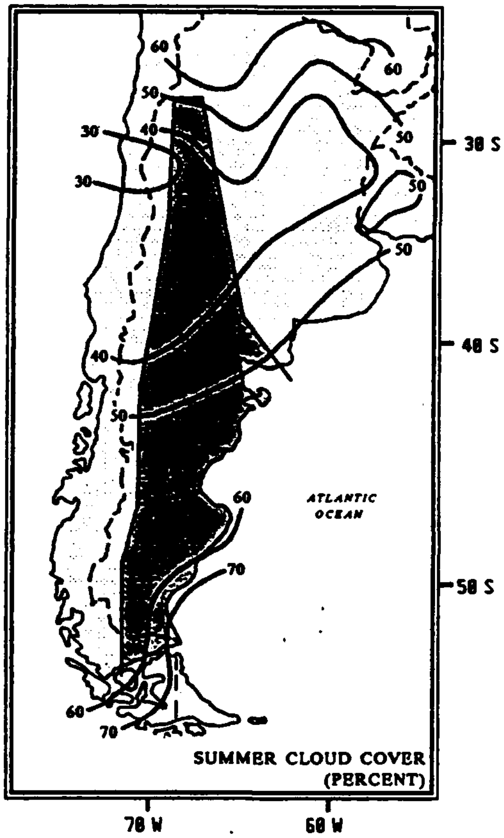
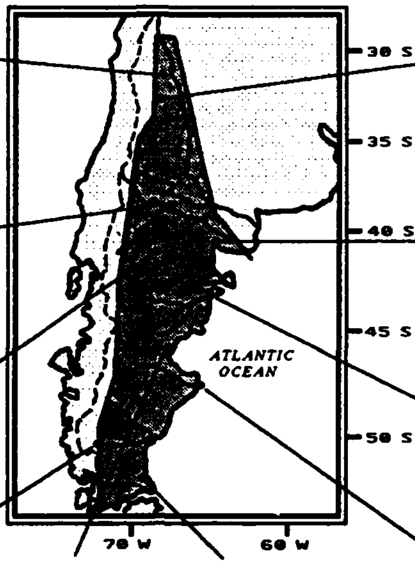


Figure 6-84. Mean Summer Cloud Cover, Patagonia.



SAN JUAN

5	4	5
11	7	9
10	5	10
7	3	4

MENDOZA

5	4	6
6	5	5
4	3	4
6	4	5

NEUQUEN

2	0	2
2	#	3
3	0	3
#	1	1

S. ANTONIO OESTE

5	3	4
5	18	0
4	5	8
3	3	6

MAQUINCHAO

10	6	9
10	7	8
17	12	15
15	9	10

TRELEW

2	2	3
4	3	5
5	4	7
3	2	4

CALAFATE

10	17	19
14	11	17
18	15	14
13	13	7

COMODORO RIVADAVIA

4	2	5
4	2	5
5	3	5
2	3	5

RIO GALLEGOS

14	13	8
9	9	8
9	8	6
25	21	14

PUERTO DESEADO

13	0	0
14	38	na
9	9	11
12	12	7

SUMMER
CEILINGS BELOW 3,000 FEET
(PERCENT)
- LESS THAN 0.5 PERCENT
na - DATA NOT AVAILABLE

	DEC	JAN	FEB
03 L			
09 L			
15 L			
21 L			

Figure 6-85. Summer Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Patagonia.

VISIBILITY. Summer visibilities are above 6 miles over 98% of the time and below 3 miles only about 1% of the time (see Figure 6-86). The chief restriction to visibility is precipitation; blowing dust is second. They usually reduce visibilities to below 3 miles for less than 3 hours. Thick pockets of overnight ground fog form near glaciers in the western foothills of southern Patagonia; visibilities below 1 mile can last through mid-morning. Radiation fog or mist near the coast can briefly reduce visibilities, generally near sunrise.

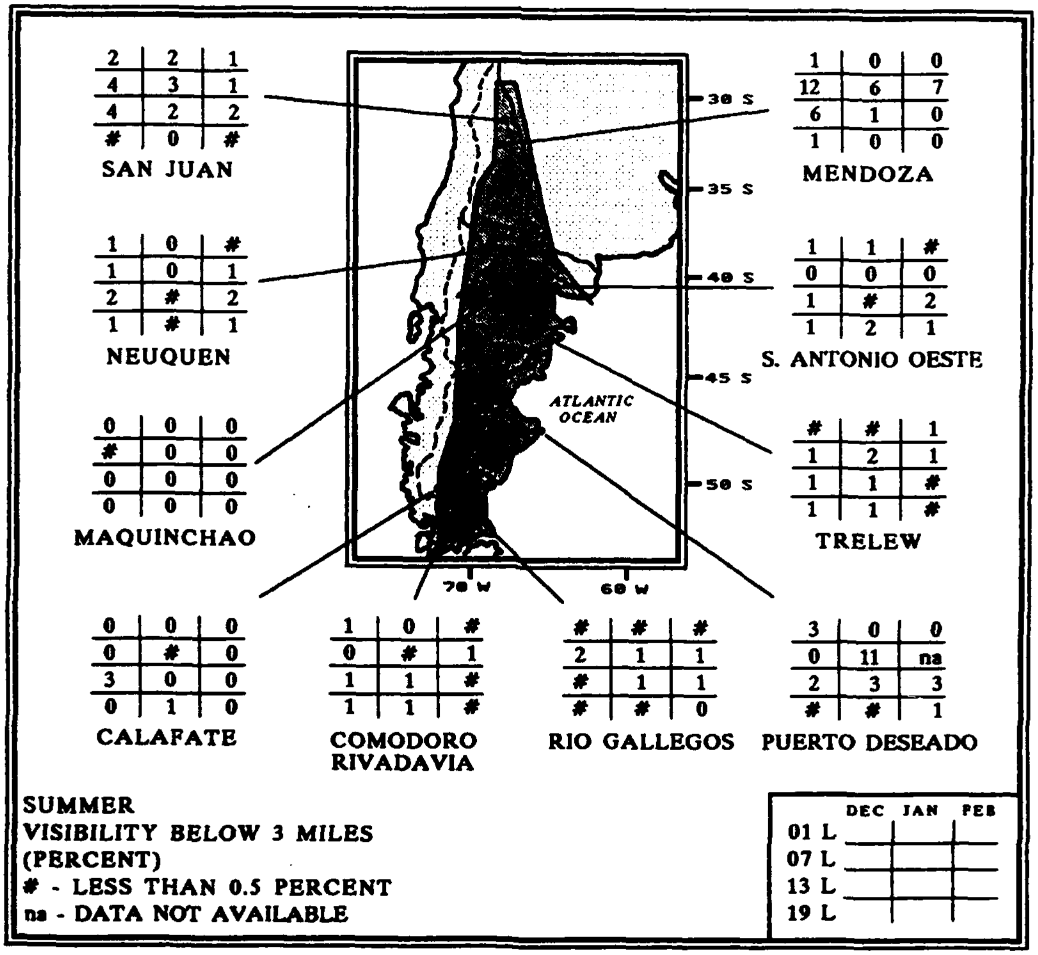


Figure 6-86. Summer Percent Frequencies of Visibility Below 3 Miles, Patagonia.

WINDS. Winds are generally strong and westerly; most variations are due to terrain, passing fronts, and the NAD). Although land/sea breeze circulations are minimal, they affect the coast in the north; a sea breeze accounts for San Antonio Queste's prevailing southeasterly wind in summer. Wind speeds are higher in open areas and more than double where funneled through mountain passes. Mean speeds range from 5 to 10 knots north of 41° S and from 10 to 20 knots south of 41° S (see Figure 6-87). Fronts and thunderstorms produce the strongest winds. A peak gust of 72 knots occurred at Perito Moreno from funneling. Figure 6-88 shows that mean surface wind directions north of 41° S range from south to west-northwest and from south-southwest to west south of 41° S.

STATION	MEAN WIND SPEED DEC	JAN	FEB
COMMODORO RIVADAVIA	17	18	15
MAQUINCHAO	10	10	9
MENDOZA	6	5	5
NEQUEN	10	9	9
PERITO MORENO	20	20	19
PUERTO DESEADO	20	21	19
RIO GALLEGOS	21	18	18
SAN ANTONIO OESTE	10	10	10
SAN JUAN	8	7	6
TRELEW	16	15	14

Figure 6-87. Mean Summer Wind Speeds, Patagonia.

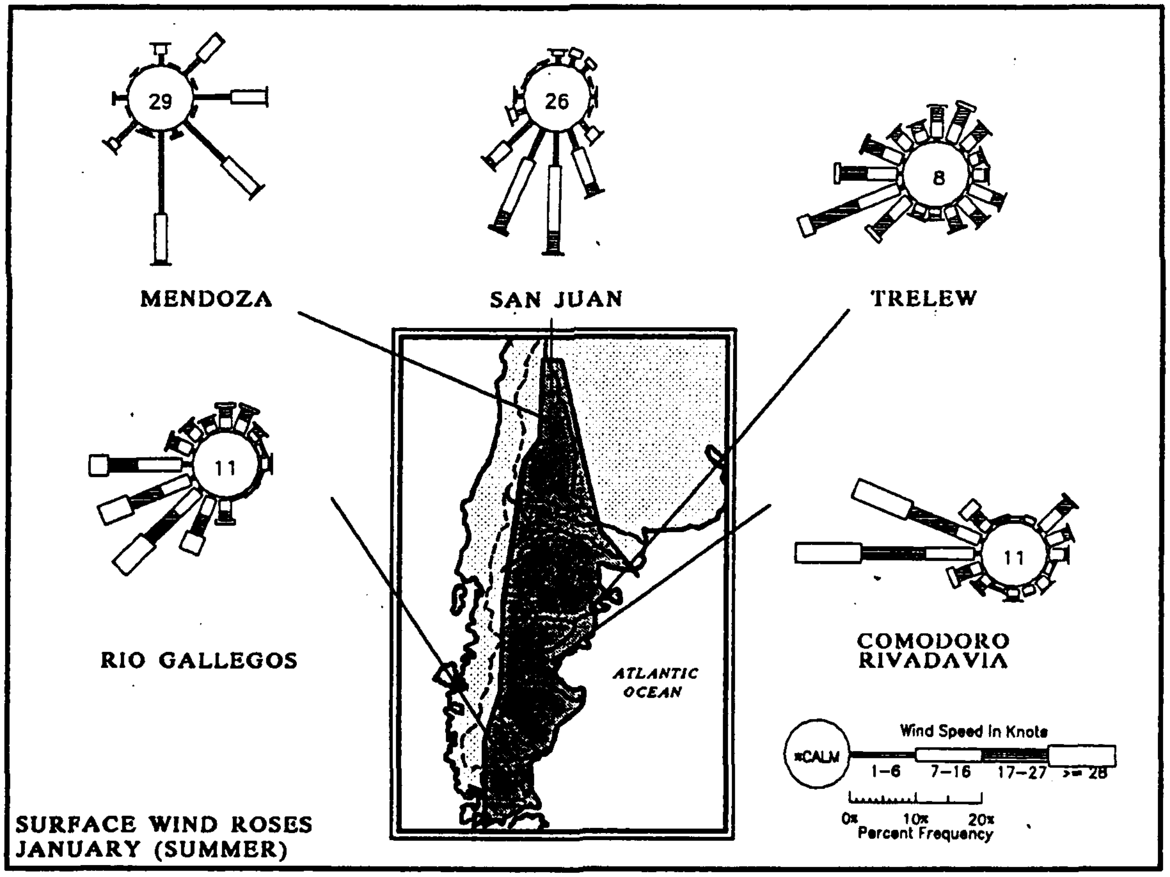


Figure 6-88. January Surface Wind Roses, Patagonia.

Mean upper-level wind speeds range from 25 knots in the north at 10,000 feet (3,050 meters) MSL to 55 knots in the south at 30,000 feet (9.2 km). Figures 6-89 through 6-92 give mean monthly wind directions at various heights for four representative stations.

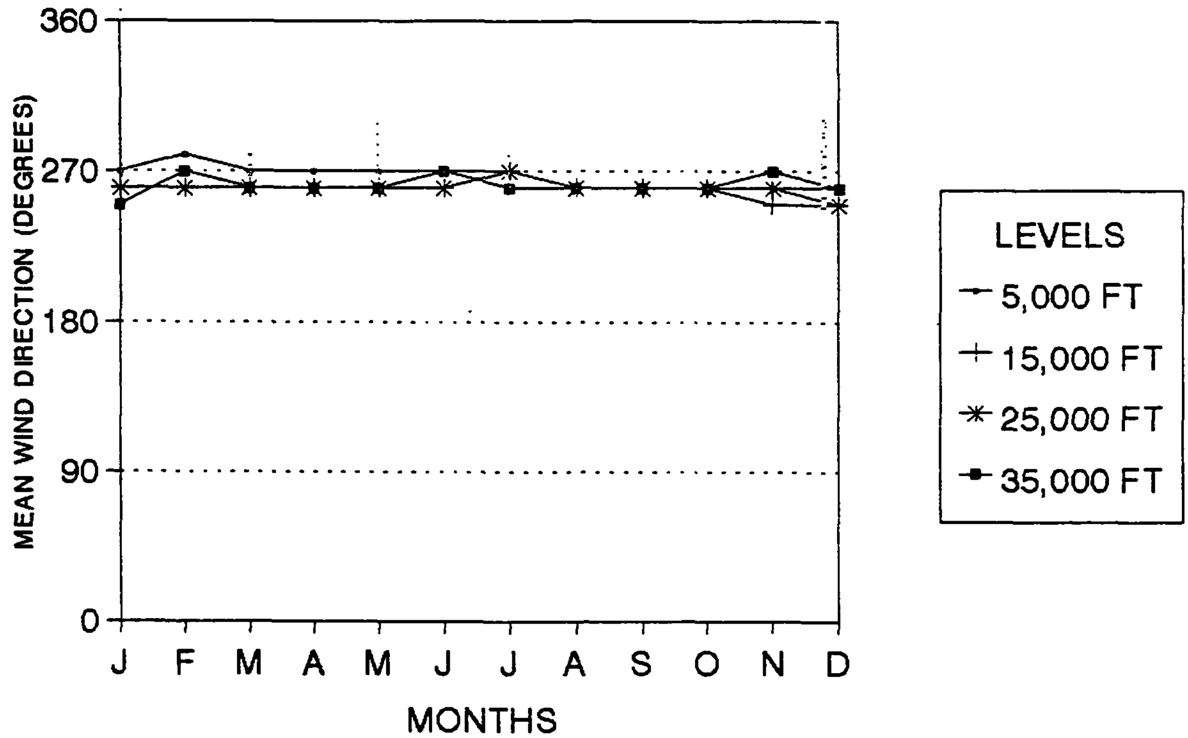


Figure 6-89. Mean Monthly Wind Directions for Various Levels at Bahia Blanca, Gran Chaco.

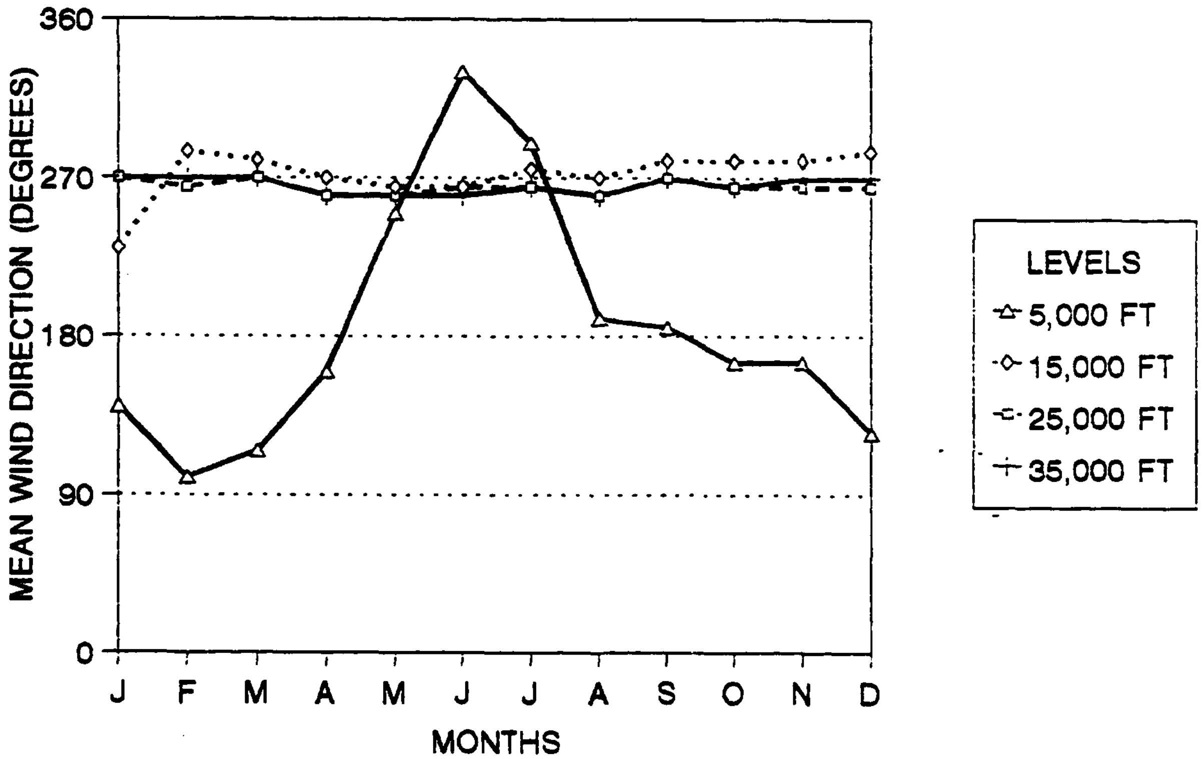


Figure 6-90. Mean Monthly Wind Directions for Various Levels at Mendoza/El Plumerillo, Patagonia.

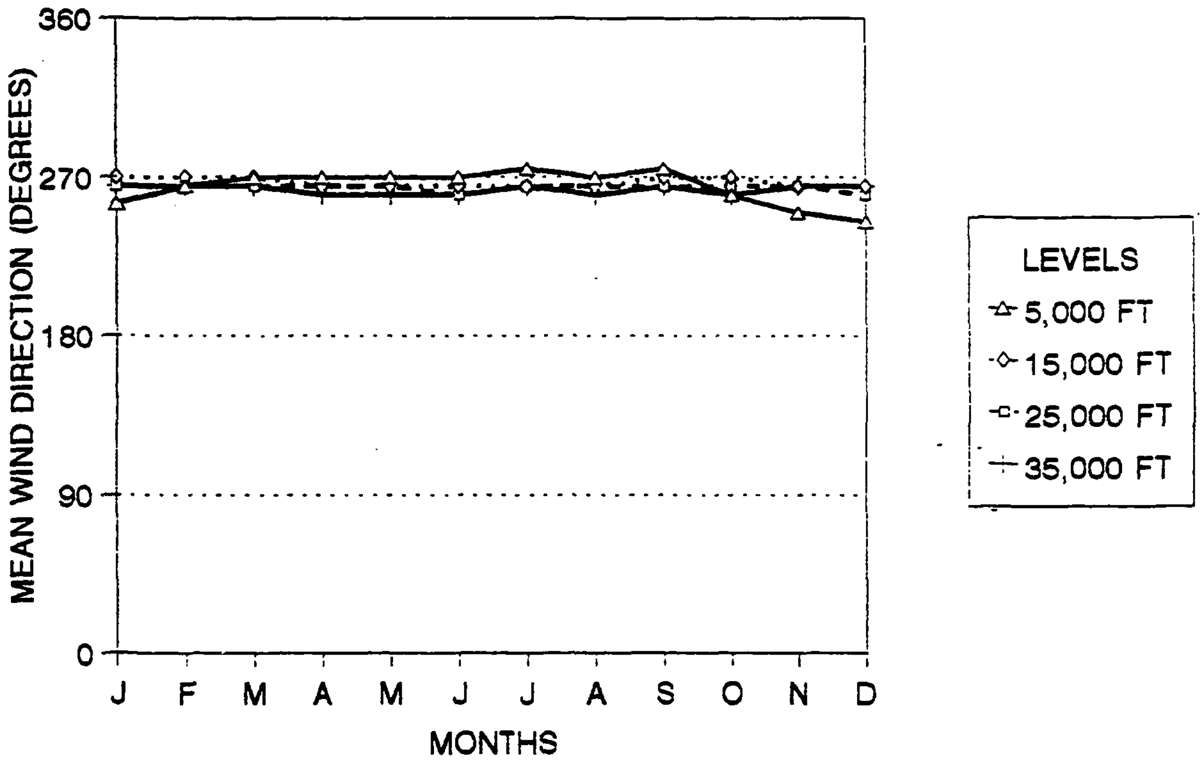


Figure 6-91. Mean Monthly Wind Directions for Various Levels at Neuquen, Patagonia.

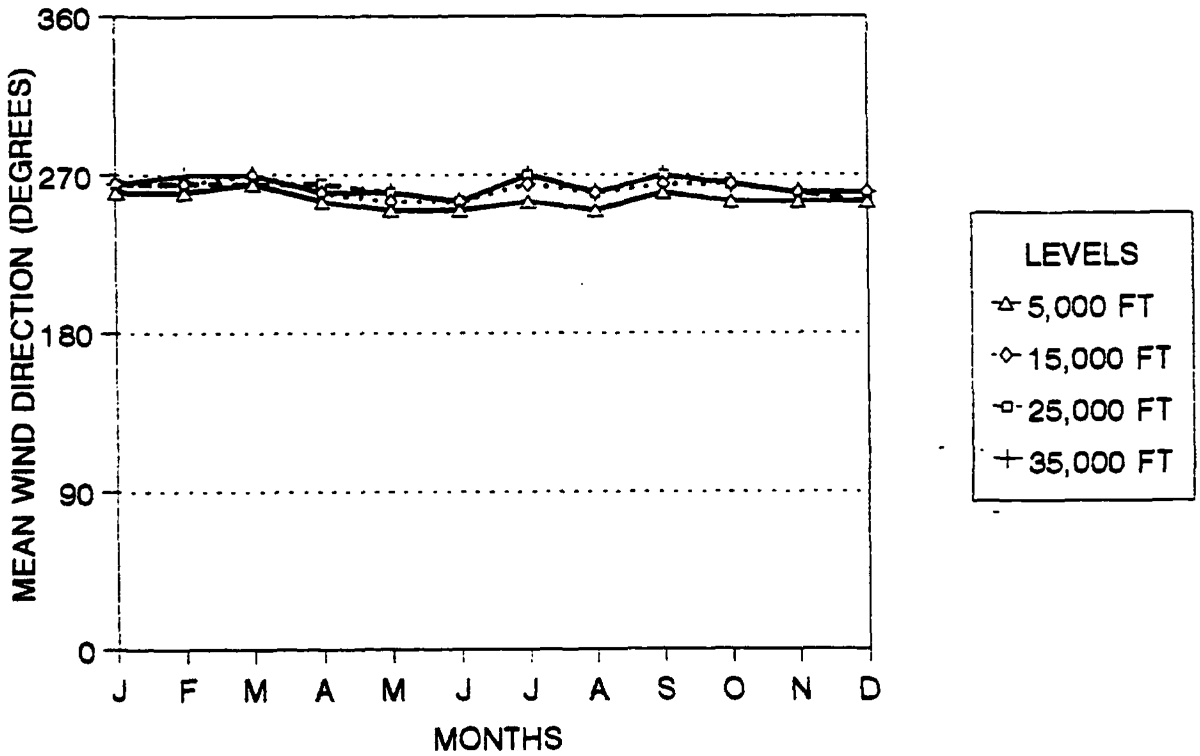


Figure 6-92. Mean Monthly Wind Directions for Various Levels at Comodoro Rivadavia, Patagonia.

PRECIPITATION. Northerly flow, common in the north, brings moist tropical air from the Amazon Basin. Blocking highs and frontal lows off the east coast create easterly flow that also bring in moisture. Mean precipitation ranges from 0.4 inch (10 mm) in south-central Patagonia to 2 inches (50 mm) in the interior southwest. The coast averages about 0.6 inch (15 mm) since it has lower terrain, but much of the rainfall evaporates before it reaches the ground (see Figure 6-93). Precipitation is primarily rain; virga is common. Snow occurs at higher elevations in the south, but it is very rare and light. In central Patagonia from about 40° S to 47° S, precipitation amounts are low. In the north, precipitation is highest during summer, averaging 0.8 inch (20 mm). Precipitation falls on 2 to 5 days a month except in the extreme south, where it falls on 10 days a month (Figure 6-94).

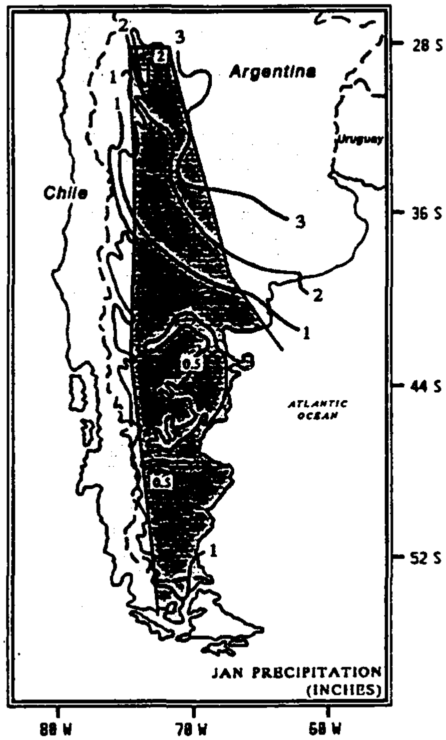


Figure 6-93. Mean January Precipitation, Patagonia.

SAN JUAN

0.34	0.95	0.60
1.70	3.60	3.50
0.80	1.50	1.40
3	4	4

MENDOZA

0.81	1.10	0.83
3.34	3.70	4.10
3.34	2.16	1.77
5	6	5

NEUQUEN

0.37	0.26	0.37
1.17	0.34	1.82
0.64	0.54	1.54
1	2	2

S. ANTONIO OESTE

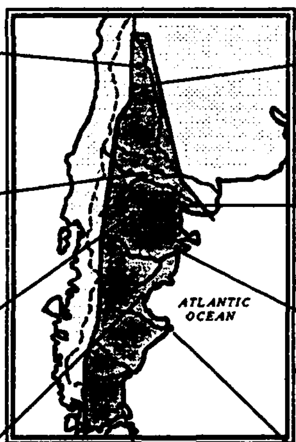
0.63	0.75	0.75
1.15	1.79	2.39
0.69	1.06	1.95
2	1	2

MAQUINCHAO

0.72	0.25	0.45
1.76	0.87	1.44
0.98	0.82	1.18
1	1	#

TRELEW

0.80	0.40	0.55
3.70	3.94	3.80
1.40	3.90	3.20
2	2	1



COMODORO RIVADAVIA

0.50	0.50	0.60
3.70	2.00	1.50
2.00	1.50	1.00
#	#	#

RIO GALLEGOS

0.90	1.15	0.85
2.10	2.40	2.80
0.80	1.30	1.20
#	0	#

PUERTO DESEADO

0.64	0.53	0.93
1.04	1.08	2.67
0.59	0.54	1.10
#	#	#

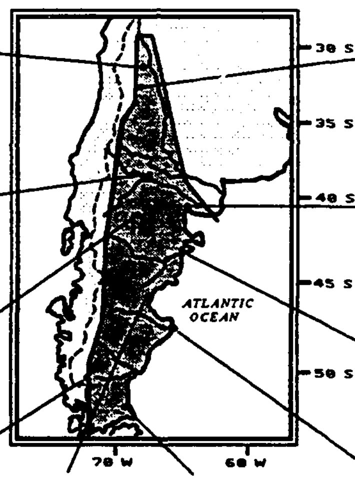
SUMMER
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS

	DEC	JAN	FEB
MEAN MONTHLY			
MAXIMUM MONTHLY			
MAXIMUM 24-HOUR			
THUNDERSTORM DAYS			

Figure 6-94. Summer Tabular Precipitation Data, Patagonia.

THUNDERSTORMS. Thunderstorm frequency is highest during summer; they occcur on 1 to 6 days a month in the north, 1 to 2 days in central Patagonia, and less than 1 day in the south. Thunderstorms occur with frontal pa ;sages and occasio.ally from local convective heating. Cloud tops reach 50,000 feet 15.2 km); bases average 8,000 feet (2,440 meters) MSL. Storms occasionally produce strong downrush winds. Hail in excess of 1 inch (2.54 cm) and tornadoes have occurred in northern Patagonia near San Juan and Mendoza.

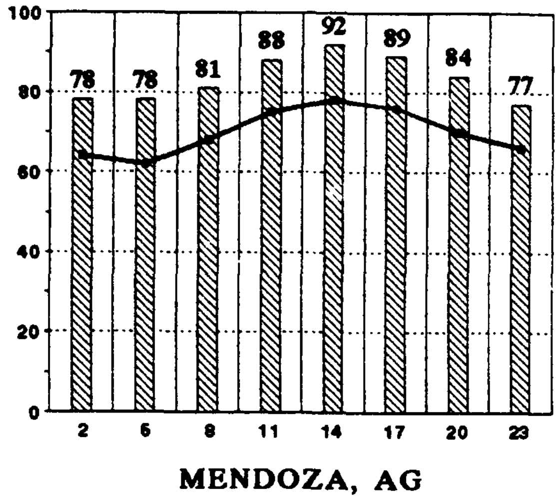
TEMPERATURE. The highest temperatures occur at lower elevations in the northern interior where there is minimal maritime influence. Zondas (foehn winds) increase temperatures. The northerly zonda often precedes cold fronts; the cool southerly wind behind the front can suddenly drop temperatures by 25° F (14° C). Mean daily highs range from 95° F (35° C) in the north to 65° F (18° C) in the south. The record high is 113° F (45° C), recorded east of Mendoza in January. Mean daily lows range from 65° F (18° C) to 43° F (6° C). A record low of 18° F (-8° C) was observed in January in the Andes Foothills west of Maquinchao (see Figure 6-95). The freezing level over northern Patagonia during summer ranges from 10,000 to 12,000 feet (3,050 to 3,660 meters) MSL; over southern Patagonia, 3,000 feet (915 meters) MSL. Mean relative humidity is lowest during summer, ranging from 40 to 60% in the mornings and from 23 to 42% in the afternoons. Figure 6-96 shows wet-bulb globe temperature data for selected stations.



SUMMER TEMPERATURES (F)

Station		DEC	JAN	FEB
SAN JUAN	EXTREME MAXIMUM	109	109	110
	AVERAGE MAXIMUM	91	93	90
	AVERAGE MINIMUM	65	68	66
	EXTREME MINIMUM	46	39	42
MENDOZA	EXTREME MAXIMUM	103	111	102
	AVERAGE MAXIMUM	87	88	86
	AVERAGE MINIMUM	64	66	64
	EXTREME MINIMUM	40	49	44
NEUQUEN	EXTREME MAXIMUM	103	104	101
	AVERAGE MAXIMUM	84	89	86
	AVERAGE MINIMUM	55	58	55
	EXTREME MINIMUM	39	36	36
S. ANTONIO OESTE	EXTREME MAXIMUM	107	108	99
	AVERAGE MAXIMUM	80	83	80
	AVERAGE MINIMUM	65	68	66
	EXTREME MINIMUM	43	50	46
MAQUINCHAO	EXTREME MAXIMUM	97	100	100
	AVERAGE MAXIMUM	76	80	78
	AVERAGE MINIMUM	45	48	47
	EXTREME MINIMUM	21	28	28
TRELEW	EXTREME MAXIMUM	106	106	108
	AVERAGE MAXIMUM	79	83	80
	AVERAGE MINIMUM	56	59	57
	EXTREME MINIMUM	29	35	31
CALAFATE	EXTREME MAXIMUM	81	83	87
	AVERAGE MAXIMUM	63	65	65
	AVERAGE MINIMUM	43	46	44
	EXTREME MINIMUM	32	30	32
COMODORO RIVADAVIA	EXTREME MAXIMUM	100	103	100
	AVERAGE MAXIMUM	74	77	75
	AVERAGE MINIMUM	55	58	57
	EXTREME MINIMUM	36	41	37
RIO GALLEGOS	EXTREME MAXIMUM	85	91	92
	AVERAGE MAXIMUM	67	68	66
	AVERAGE MINIMUM	47	48	47
	EXTREME MINIMUM	23	30	28
PUERTO DESEADO	EXTREME MAXIMUM	91	115	96
	AVERAGE MAXIMUM	66	69	68
	AVERAGE MINIMUM	57	60	58
	EXTREME MINIMUM	33	42	37

Figure 6-95. Summer Tabular Temperature Data, Patagonia.



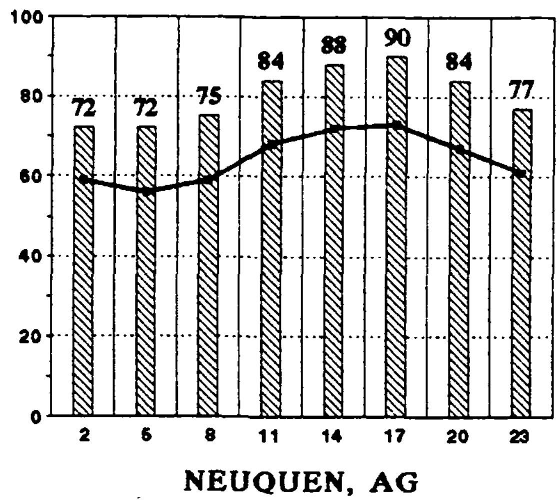


Figure 6-96. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for January, Patagonia. Mean WBGT is shown as a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Thunderstorms cause severe turbulence and icing. Sudden, strong downrush winds or downbursts are found near thunderstorms with high bases. Lightning and small hail occur; large hail and tornados can occur in extreme northern Patagonia. The strong westerly winds over the central and southern Andes form mountain waves that can extend to 35,000 feet (10,670 meters) MSL north of 39° S and to 30,000 feet (9,145 meters) south of 39° S. In southern Patagonia, moderate to severe low-level turbulence can reach 5,000 feet (1,525 meters) above the highest terrain feature. Other topographic features such as mountain passes cause speed shear due to funneling or directional shear. Light to moderate thermal turbulence is possible below 5,000 feet (1,525 meters) AGL.

GROUND HAZARDS. Duststorms occasionally reduce visibilities below 3 miles for 1 to 3 hours. Thick pockets of ground fog form overnight near the glaciers in the western foothills of southern Patagonia. MCS-caused heavy rains can cause flooding in extreme northern Patagonia; thunderstorm-related flash floods occur in canyons immediately east of the main Andes ranges.

GENERAL WEATHER. Fall is normally cool, with less active weather than summer; the South Pacific High begins to move away from the west coast toward its mean winter position. The highs off the east coast tend to be stationary less often. Migratory lows and their associated fronts occur a little less often than in summer. Cooling causes increased stability; cumuliform weather begins to give way to more stratiform outbreaks and cold temperatures. Squall line incidence and severity decreases rapidly.

SKY COVER. Sky cover ranges from less than 40% in the north to 55% in the central part of the zone (see Figure 6-97). Altostratus and altocumulus dominate, occurring primarily in the morning and near the coast. Bases average 12,000 feet (3,660 meters) MSL with tops of 15,000 feet (4,570 meters) MSL. Stratus and stratocumulus also occur, but with decreasing frequency as the season progresses; low-level moisture is limited since frontal systems and blocking highs are not as common. Bases average 2,000 feet (610 meters) MSL. Low stratiform clouds dissipate with daytime heating, forming cumulus in the afternoon. Cumulus bases average 8,000 feet (2,440 meters) MSL, often building to 15,000 feet (4,570 meters) MSL. Cumulonimbus associated with frontal passages have bases ranging from 2,500 to 8,000 feet (760 to 2,440 meters) MSL and tops exceeding 40,000 feet (12.2 km) MSL. Squall lines still occur north and east of Neuquen, but they are rarely severe.

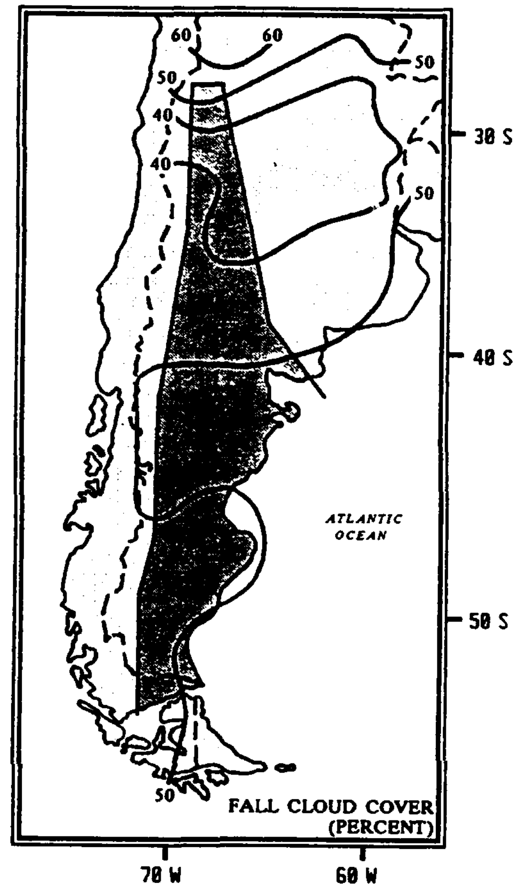
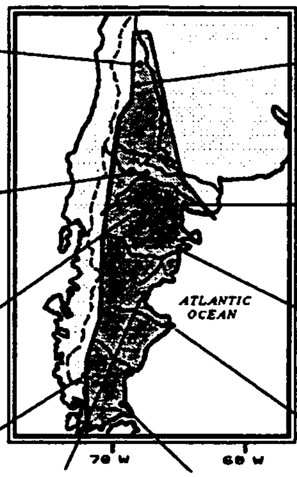


Figure 6-97. Mean Fall Cloud Cover, Patagonia.

Low ceilings at most locations in northern Patagonia occur with frontal systems; southeasterly winds behind some cold fronts produce stratus and stratocumulus. Post-frontal southeasterly flow can also produce low stratus and stratocumulus ceilings in southern Patagonia. Melting glaciers in the southwest also produce low ceilings. Low ceilings are more frequent from early evening through mid-morning with the added influence of radiation cooling. Figure 6-98 shows percent frequency of ceilings below 3,000 feet (915 meters) AGL for selected stations.



Station	Hour	MAR	APR	MAY
SAN JUAN	03 L	10	13	19
	09 L	16	24	31
	15 L	13	17	18
	21 L	9	11	17
MENDOZA	03 L	12	11	12
	09 L	12	17	23
	15 L	7	8	7
	21 L	12	10	10
NEUQUEN	03 L	1	4	4
	09 L	2	7	7
	15 L	3	7	9
	21 L	2	3	5
S. ANTONIO OESTE	03 L	3	12	9
	09 L	na	na	0
	15 L	8	12	10
	21 L	6	9	10
MAQUINCHAO	03 L	7	12	14
	09 L	8	14	19
	15 L	11	15	15
	21 L	8	15	14
TRELEW	03 L	3	6	6
	09 L	3	7	7
	15 L	8	7	9
	21 L	8	7	9
CALAFATE	03 L	23	34	37
	09 L	9	16	20
	15 L	12	16	19
	21 L	9	17	18
COMODORO RIVADAVIA	03 L	3	4	9
	09 L	5	5	8
	15 L	5	6	8
	21 L	3	4	9
RIO GALLEGOS	03 L	12	10	16
	09 L	10	12	14
	15 L	10	11	15
	21 L	13	14	17
PUERTO DESEADO	03 L	13	17	29
	09 L	na	na	na
	15 L	12	11	19
	21 L	13	13	23

FALL
CEILINGS BELOW 3,000 FEET
(PERCENT)
na - DATA NOT AVAILABLE

Figure 6-98. Fall Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Patagonia.

VISIBILITY. Restricted visibilities become more common during fall. Visibilities are below 6 miles 5% of the time and below 3 miles 2% of the time (see Figure 6-99). Precipitation is the primary cause. Dust or duststorms associated with zondas and frontal passages also reduce visibility below 3 miles for short periods of time. Strong thunderstorm downbursts can also raise dust. Visibility is restricted most frequently in the early morning. Thick pockets of ground fog form overnight near glaciers in the western foothills of southern Patagonia; visibilities below 1 mile can last through mid-morning. Elsewhere, patchy ground fog forms overnight and usually dissipates shortly after sunrise; near the coast, it can last through mid-morning.

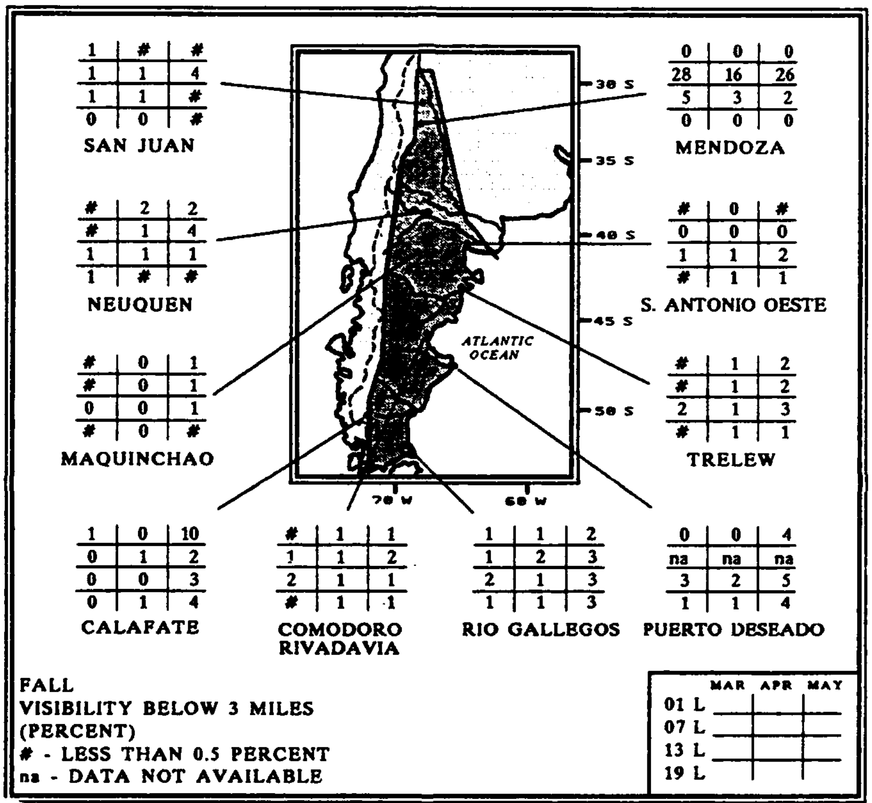


Figure 6-99. Fall Percent Frequencies of Visibility Below 3 Miles, Patagonia.

WINDS. Wind speeds decrease during fall. They average 8 knots in the north and 12 knots in the south (see Figure 6-100). Winds are strongest along the coast and during the afternoon. The highest speeds occur when strong frontal winds are channeled. The maximum gust in the fall was 70 knots, recorded at Trelew. Severe thunderstorm downrush winds still occur in the extreme north, but frequency decreases dramatically as the season progresses.

STATION	MEAN WIND SPEED MAR	APR	MAY
COMMODORO RIVADAVIA	14	14	13
MAQUINCHAO	9	9	9
MENDOZA	4	3	3
NEQUEN	8	7	7
PERITO MORENO	15	12	11
PUERTO DESEADO	19	17	15
RIO GALLEGOS	16	15	12
SAN ANTONIO OESTE	8	8	8
SAN JUAN	6	5	4
TRELEW	13	11	10

Figure 6-100. Mean Fall Wind Speeds, Patagonia.

Mean wind directions show no significant seasonal change. Over Patagonia's northern half, mean surface wind directions range from south to west-northwest (see Figure 6-101); over the southern half, from south-southwest to west. In mountainous areas, channeled winds more than double speeds.

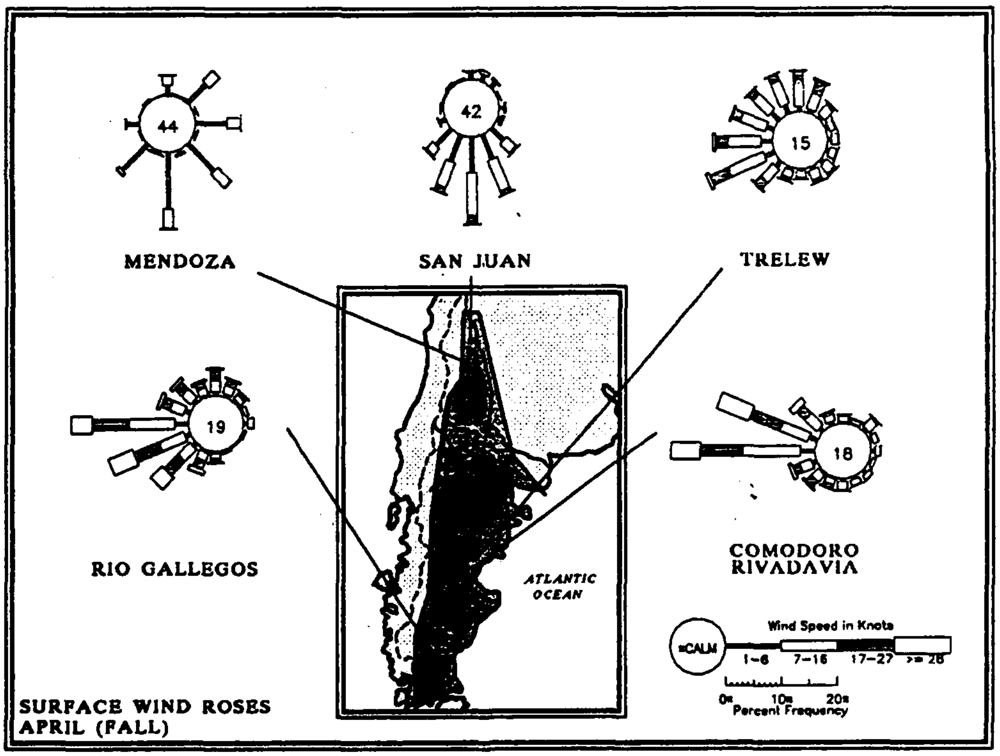


Figure 6-101. April Surface Wind Roses, Patagonia.

Upper-level winds are westerly. Speeds below 20,000 feet (6,100 meters) MSL are 20-40 knots. At 30,000 feet (9,145 meters) MSL, speeds vary between 45 and 60 knots. Mean monthly upper-air wind directions are shown in Figures 6-89 through 6-92.

PRECIPITATION. Mean monthly precipitation is less than 1 inch (25 mm), except in the southwest, where it is 2 inches (50 mm) (see Figure 6-102). Rainfall occurs on 3 to 8 days a month except in extreme southern Patagonia where rain or drizzle occurs on 8 to 12 days a month (see Figure 6-103). Snowfall is possible as early as April in the extreme south and in May over central Patagonia at elevations near the freezing level. Normally there is little or no accumulation. Virga occurs occasionally.

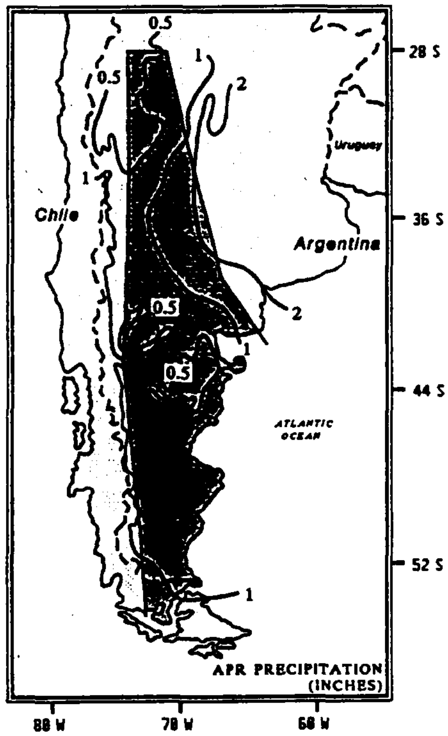


Figure 6-102. Mean April Precipitation, Patagonia.

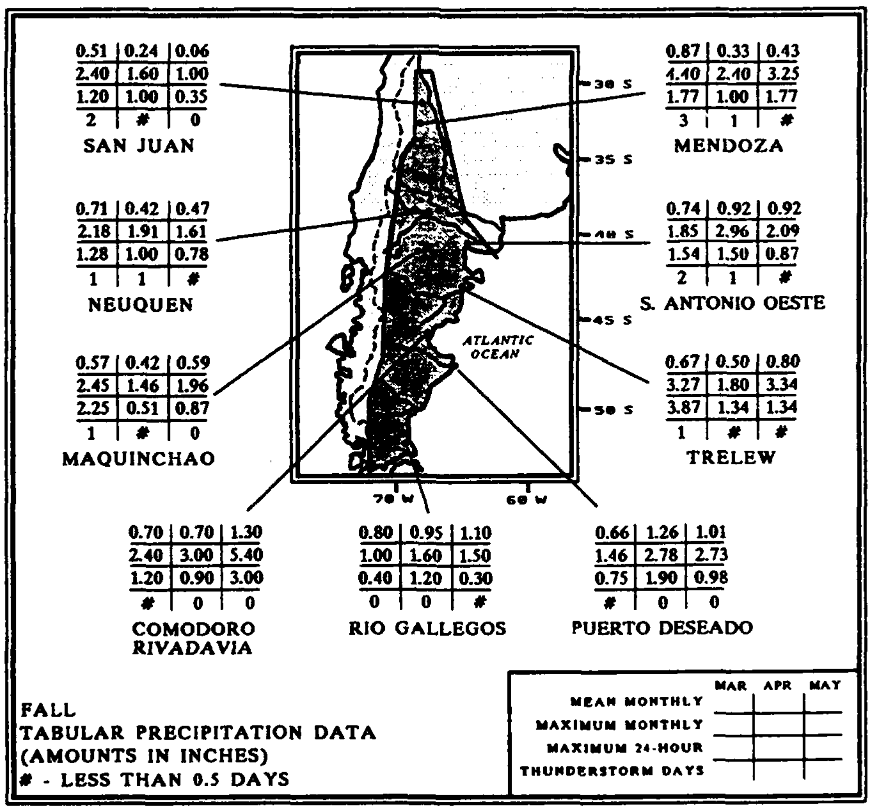
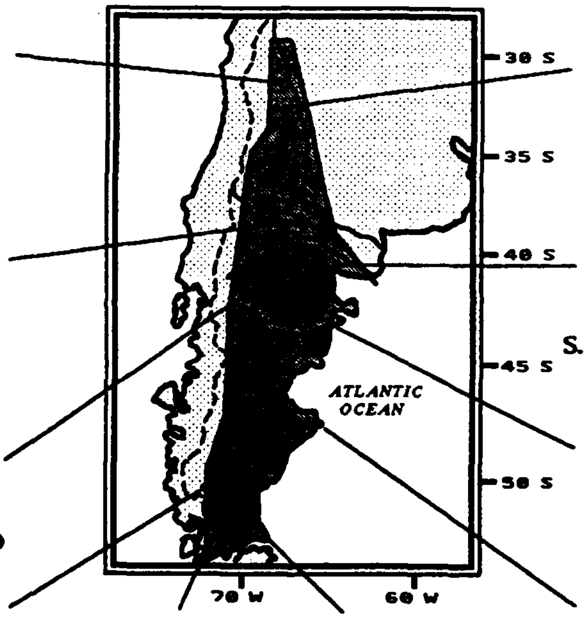


Figure 6-103. Fall Tabular Precipitation Data, Patagonia.

THUNDERSTORMS. Thunderstorm frequencies decrease; they occur about 2 days a month in the north and less than 1 day a month in the south. Thunderstorms occur primarily with fronts and, on rare occasions in the north, withafternoon heating. Thunderstorm tops can exceed 40,000 feet (12.2 km) MSL; most bases are at 8,000 feet (2,440 meters) MSL, but can be as low as 2,500 feet (760 meters) MSL.

TEMPERATURE. Temperatures gradually decrease through fall; the southern half of Patagonia changes the least. Figure 6-104 shows mean highs ranging from 85° F (29° C) in the north to 60° F (15° C) in the south. Mean daily lows range from 44° F (6° C) in the north and along the coast to 29° F (-2° C) in the southern interior. A record high of 101° F (38° C) was recorded in northern Patagonia. A record low of 1° F (-17° C) occurred in the Andes east of Calafate. The freezing level averages 10,000 feet (3,050 meters) MSL over northern Patagonia, but fluctuates between the surface and 2,500 feet (760 meters) MSL in the south. Mean relative humidity ranges from 56 to 83% mornings and from 36 to 54% afternoons. Figure 6-105 provides wet-bulb globe temperature data for selected stations.



SAN JUAN

101	95	91
85	77	68
61	53	43
30	26	23

MENDOZA

98	94	88
80	73	66
60	52	44
37	27	21

NEUQUEN

102	90	82
81	71	63
50	42	36
22	26	19

S. ANTONIO OESTE

97	88	82
75	68	60
61	54	47
36	35	28

MAQUINCHAO

95	80	73
71	63	53
42	36	32
20	12	1

TRELEW

103	96	85
75	68	59
53	47	41
26	18	14

CALAFATE

32	84	69
60	54	45
42	38	32
25	16	18

COMODORO RIVADAVIA

99	88	84
71	65	56
53	49	43
30	25	22

RIO GALLEGOS

90	88	78
62	55	45
43	39	34
23	18	11

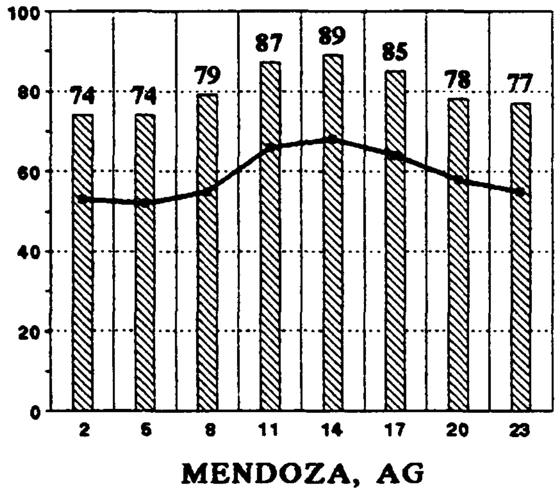
PUERTO DESEADO

90	79	66
63	57	49
53	47	41
32	33	23

	MAR	APR	MAY
EXTREME MAXIMUM			
AVERAGE MAXIMUM			
AVERAGE MINIMUM			
EXTREME MINIMUM			

FALL TEMPERATURES (F)

Figure 6-104. Fall Tabular Temperature Data, Patagonia.



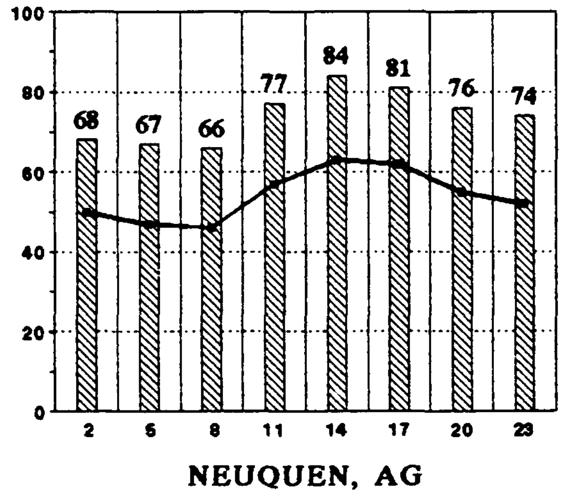


Figure 6-105. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for April, Patagonia. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. The usual thunderstorm hazards apply. Sudden, strong downrush winds can occur from thunderstorms with high bases. Over northern Patagonia, moderate to severe mixed icing occurs in towering cumulus and cumulonimbus. Over southern Patagonia, most clouds form above the freezing level; light rime icing can be expected. Strong winds produce mountain waves over the central and southern Andes. These waves can extend to 35,000 feet (10,670 meters) MSL north of 39° S and to 30,000 feet (9,145 meters) MSL south of 39° S. Strong winds over rough terrain cause moderate to severe low-level turbulence for light aircraft up to 5,000 feet (1,525 meters) above the highest surface feature. Other topographic features, such as mountain passes, cause speed shear due to funneling or directional shear.

GROUND HAZARDS. Duststorms reduce visibility below 3 miles for 1 to 3 hours. Thick fog can form overnight near glaciers in the western foothills of southern Patagonia.

GENERAL WEATHER. Patagonia winters are cold, cloudy, and dry. The South Pacific High steers moist winds toward the area, but low-level moisture is lost in the Andes. A well-defined rain shadow extends from the lee side of the central and southern Andes to the eastern coast of Patagonia.

SKY COVER. Sky cover averages 40% in the north, 50% in the south, and 60% along the coast (see Figure 6-106). Maximum cloud cover occurs during mid-morning. The predominant types are altostratus and altocumulus. Bases average 12,000 feet (3,660 meters) MSL. Clouds are normally 3,000 to 5,000 feet (915 to 1,525 meters) thick.

Stratus and stratocumulus form overnight in the south and during mid-morning in the north; bases average 2,000 feet (610 meters) MSL. They account for winter's comparatively high frequency of low ceilings (see Figure 6-107). Moisture comes from onshore flow, occurring with blocking highs and strong frontal lows, and from surface water provided by glaciers in the southwest. Stratus and stratocumulus form through radiation cooling, lifting of fog, orographic lift, and onshore flow lifted by a shallow cold dome of land-based air. Clouds generally dissipate by early afternoon, but continued onshore flow can cause them to persist through the day.

South Pacific lows approaching the coast of southern Chile sometimes cross the southern Andes. These lows and their associated frontal systems bring extensive cloudiness to southern Patagonia; isolated cumulonimbus is possible along the cold front. Thunderstorm tops average 40,000 feet (12.2 km), with bases generally ranging from 5,000 to 9,000 feet (1,525 to 2,740 meters) MSL. Bases as low as 2,500 feet (760 meters) MSL are possible.

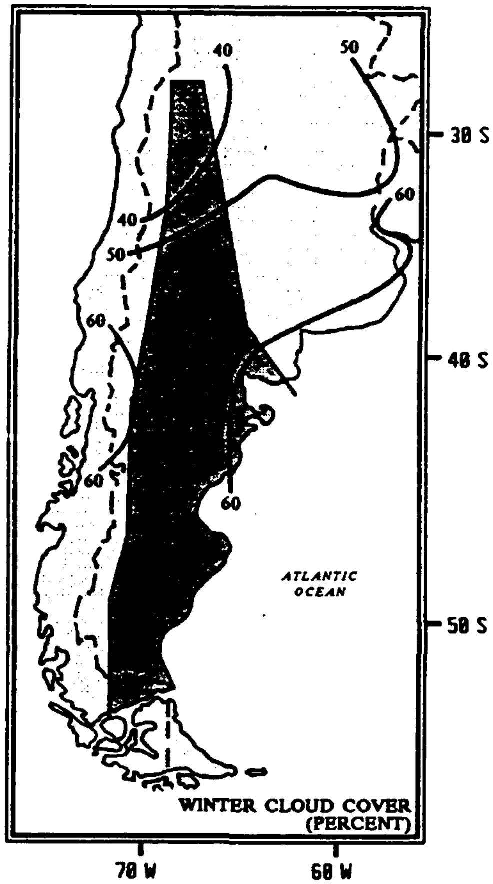


Figure 6-106. Mean Winter Cloud Cover, Patagonia.

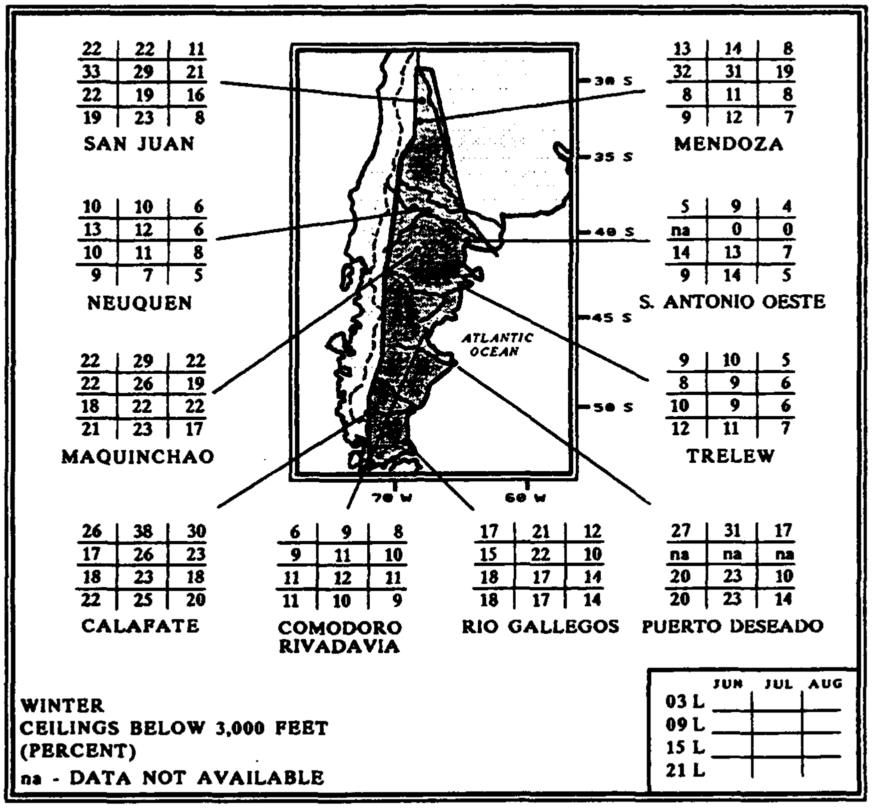


Figure 6-107. Winter Percent Frequencies of Ceilings Below 3,000 Feet (915 meters) MSL, Patagonia.

VISIBILITY. Visibilities are below 3 miles about 3% of the time during winter (see Figure 6-108). The primary cause is precipitation, generally rain. Dust is raised by fronts that have little or no precipitation. Fog can occur with precipitation and can lower visibility to below 3 miles for several hours. Thick pockets of ground fog form overnight near glaciers in the western foothills of southern Patagonia; visibilities below 1 mile can last through morning. Elsewhere, ground fog occasionally forms overnight, generally in low-lying or partially sheltered areas. The fog usually dissipates rapidly after sunrise; however, it can last through the day along the coast and immediately inland when onshore flow persists.

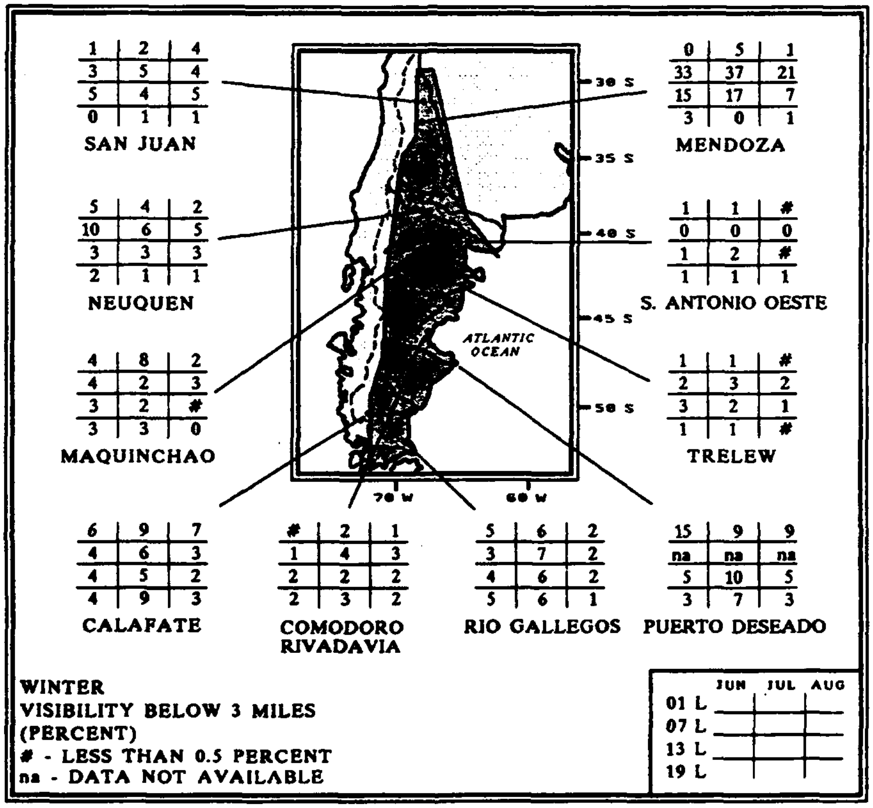


Figure 6-108. Winter Percent Frequencies of Visibility Below 3 miles, Patagonia.

WINDS. Mean surface wind speeds are generally lighter in winter, ranging from 7 to 11 knots (see Figure 6-109). Locally, surface wind directions are altered by mountain barriers, and speeds are reduced in sheltered locations. Wind speeds increase in open areas and more than double when channeled through mountain passes. Winds are stronger during the day with radiation inversions forming at night. Frontal systems cause the highest winds; the highest recorded during winter was 65 knots at Trelew and Rio Gallegos.

Mean surface wind directions range from southerly to west-northwesterly north of 41° S and from southwesterly to westerly south of 41° S (see Figure 6-110). At coastal locations, land/sea breezes rarely develop due to the persistence of westerly winds. Northeast winds occur with some regularity due to the blocking action of high-pressure systems over the western South Atlantic Ocean.

STATION	MEAN WIND SPEED		
	JUN	JUL	AUG
COMMODORO RIVADAVIA	14	14	15
MAQUINCHAO	9	9	9
MENDOZA	3	3	4
NEQUEN	7	7	8
PERITO MORENO	8	10	11
PUERTO DESEADO	15	15	18
RIO GALLEGOS	13	13	15
SAN ANTONIO OESTE	9	9	9
SAN JUAN	4	5	6
TRELEW	10	10	12

Figure 6-109. Mean Winter Wind Speeds, Patagonia.

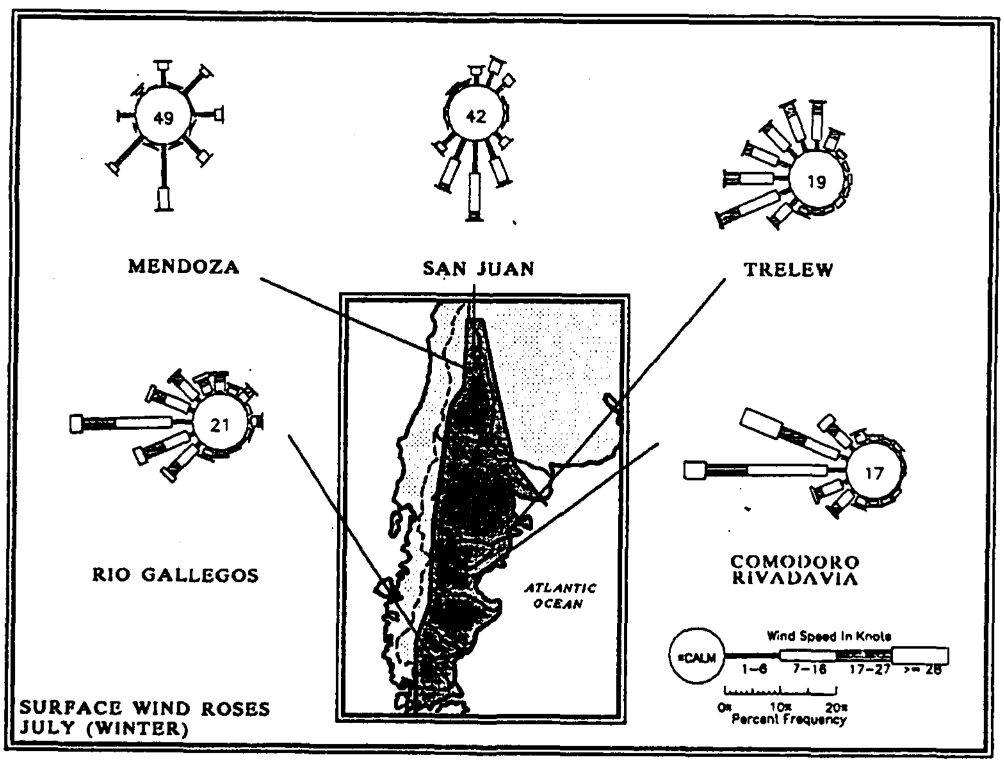


Figure 6-110. July Surface Wind Roses, Patagonia.

Upper-level winds are westerly. Below 20,000 feet (6,100 meters) MSL, speeds range from 20 to 35 knots. At 30,000 feet (9,145 meters) MSL, speeds are 50 knots. Maximum wind speeds occur near 40,000 feet (12.2 km) MSL, with the Subtropical Jet. Mean monthly upper-air wind directions are shown in Figures 6-89 through 6-92.

PRECIPITATION. Frontal systems occasionally bring extensive cloudiness across the southern Andes, but precipitation is sparse. Much of the moisture from the Pacific is lost in crossing the Andes. Moist, southeasterly flow occurs southwest of some frontal lows; light rain or drizzle often falls, especially when the moisture reaches the Andes' eastern slopes. Northern Patagonia is similarly affected by moist, northeasterly flow associated with blocking highs over the western South Atlantic.

Precipitation falls on 1 to 4 days a month in the north and 3 to 6 days a month in the south, highest in the higher elevations. Most falls as light rain or drizzle. Snow falls above 5,000 feet (1,525 meters) MSL on 1 to 3 days a month, but there is little accumulation.

There is little information available on snow in southern Patagonia even though it is the main type of precipitation in Patagonia's southern interior, where it falls on 3 to 5 days a month. Available data suggests that total monthly amounts remain less than 5 inches, even at higher elevations. Argentine sources state that snow cover generally lasts no more than 3 days in all but the highest elevations.

Precipitation amounts are lowest during winter. Mean monthly amounts range from 0.1 to 1 inch (2.5 to 25 mm). Precipitation is lowest in the north where the Andes' rain shadow effect is most pronounced (Figure 6-111). Mean monthly amounts are highest at the coast due to Atlantic moisture. A 24-hour precipitation maximum of 3.7 inches (94 mm) was recorded in July at Comodoro (see Figure 6-112).

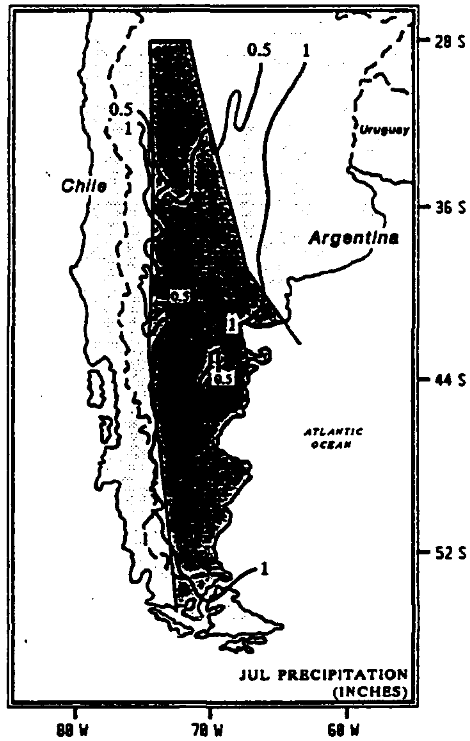


Figure 6-111. Mean July Precipitation, Patagonia.

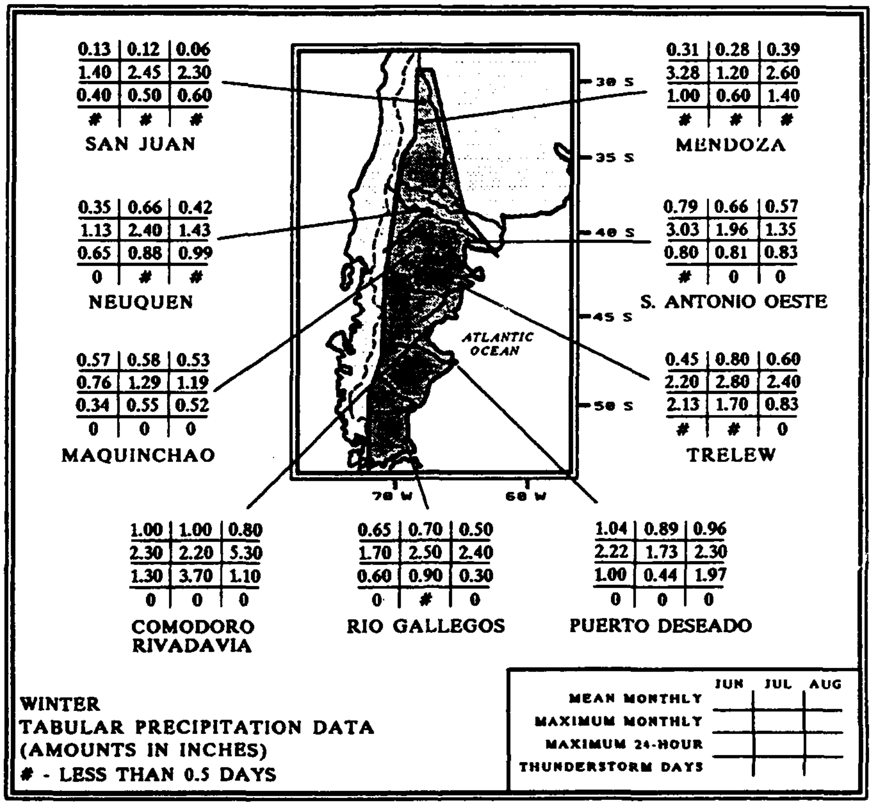
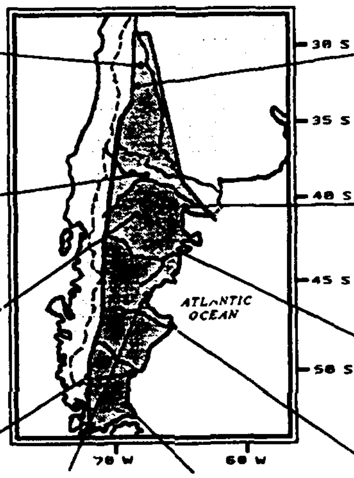


Figure 6-112. Winter Tabular Precipitation Data, Patagonia.

THUNDERSTORMS. Thunderstorms are very rare during winter, occurring only with frontal passages. Thunderstorm days average less than 1 a month throughout the zone. Well-developed cumuliform clouds become sheared by strong upper-level winds and rarely reach thunderstorm intensity. When thunderstorms do occur, their bases range from 5,000 to 9,000 feet (1,525 to 3,740 meters) MSL, with tops as high as 40,000 feet (12.2 km).

TEMPERATURE. Temperatures get lower as cold, dry, southwest winds sweep over the region. Mean daily highs range from near 70° F (21° C) in the north to 45° F (7° C) in the south (see Figure 6-113). Most extreme highs are cause by adiabatic warming off the Andes by zonda winds. A high of 91° F (33° C) occurred at San Juan. Temperatures can take a sudden and significant drop when cold fronts sweep northeastward over the zone. The lowest temperatures occur in the southern interior. Mean daily lows range from 40° F (4° C) along the northern coast to 25° F (-4° C) in the southern interior. An extreme low of -12° F (-24° C) was recorded in the southern foothills in July. Locations north of 41° S have the greatest diurnal temperature range, averaging 25° F (14° C). Relative humidity is highest in the morning, averaging 75%. During the afternoon, it ranges from 45% in the north to 70% in the south. Wet-bulb globe temperatures do not fall below 70° F in winter--no data is presented.



	JUN	JUL	AUG
EXTREME MAXIMUM			
AVERAGE MAXIMUM			
AVERAGE MINIMUM			
EXTREME MINIMUM			

SAN JUAN

90	90	91
61	61	66
35	36	39
18	17	21

MENDOZA

84	85	90
59	59	63
37	37	40
21	19	20

NEUQUEN

80	79	81
56	55	60
32	32	33
9	12	13

S. ANTONIO OESTE

79	77	86
53	53	58
41	41	43
22	25	23

MAQUINCHAO

69	63	67
46	44	48
28	25	27
1	-11	2

TRELEW

82	73	82
53	53	57
36	35	37
9	10	14

CALAFATE

66	63	65
42	41	44
29	28	29
14	11	9

COMODORO RIVADAVIA

75	71	76
51	50	53
39	38	39
17	18	21

RIO GALLEGOS

65	68	70
40	39	45
31	29	33
-1	0	3

PUERTO DESEADO

60	61	86
42	42	47
36	35	38
14	17	16

WINTER TEMPERATURES (F)

Figure 6-113. Winter Tabular Temperature Data, Patagonia.

FLIGHT HAZARDS. Severe turbulence occurs in or near thunderstorms. Strong winds over the central and southern Andes produce mountain waves that can reach 35,000 feet (10.7 km) MSL. Strong winds over southern Patagonia's rugged terrain also cause moderate to severe low-level turbulence to 5,000 feet (1,525 meters) above the highest terrain. Mountain passages cause speed shear due to funneling or mountain barriers that produce directional shear.

Towering cumulus or cumulonimbus extends above 10,000 feet (3,000 meters) MSL over the northern half of Patagonia and contains moderate to severe mixed icing. Over southern Patagonia, the freezing level ranges from the surface to 2,000 feet (600 meters) MSL; light rime icing is common in clouds above those levels.

GROUND HAZARDS. Duststorms reduce visibility below 3 miles for 1 to 3 hours. They generally occur with frontal passages that have little or no precipitation. Thick pockets of ground fog form overnight near glaciers in the western foothills of southern Patagonia. Coastal fog can also reduce visibilities well below 3 miles.

GENERAL WEATHER. Spring is warmer with a little more precipitation than winter. The South Pacific High moves closer to the west coast. Stationary highs become more common off the east coast. These highs, along with occasional strong frontal lows to the northeast and east, bring Atlantic moisture into the area. Precipitation and thunderstorms are more likely during spring, fueled by frontal passages and convective instability due to increasing temperatures. By late November, squall lines occur north and east of Neuquen, often reaching severe proportions; conditions are similar to those of eastern Colorado. Surface hail in excess of 1 inch (2.5 cm) and gusts above 70 knots have been reported.

SKY COVER. There is little change in mean cloudiness between winter and spring. Sky cover averages 40% in the north, 50% along the coast, and near 60% in the south (see Figure 6-114). Maximum cloud cover occurs during mid-morning; minimum cloud cover occurs during the evening. Stratus and stratocumulus are the main cloud types. Stratocumulus can occur with southeasterly post-frontal flow. Both form most often in the north during mornings and in the south between late evening and mid-morning; they usually dissipate or form cumulus during the day. Moisture sources are onshore flow or, in the south, surface water from the melting of ice and snow in the Andes. Most bases range from 1,000 to 2,000 feet (305 to 610 meters) MSL. Stratus and stratocumulus are also the primary causes of low ceilings, but afternoon cumulonimbus is also important. Cumulonimbus occurs most often with frontal systems. Bases range from 5,000 to 9,000 feet (1,525 to 2,740 meters) MSL, but may be as low as 1,500 feet (455 meters) MSL. Cumulonimbus tops often extend to 40,000 feet (12.2 km). Cumulus develops in the interior during the afternoon, with 8,000-foot (2,440-meter) MSL bases and 15,000-foot (4,570 meter) tops.

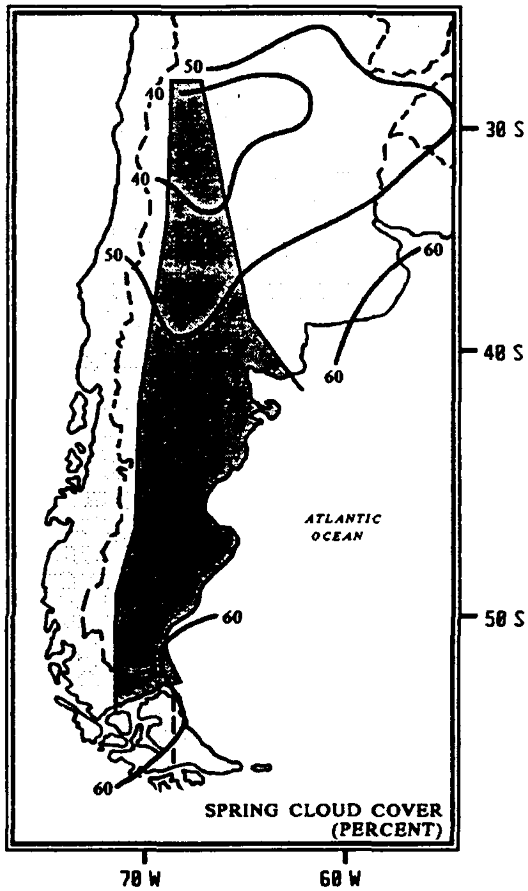
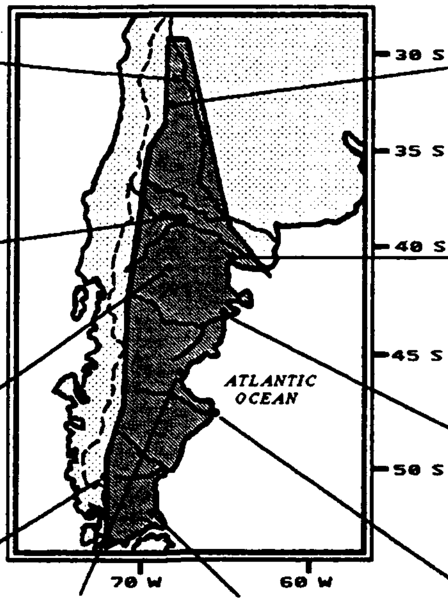


Figure 6-114. Mean Spring Cloud Cover, Patagonia.



SAN JUAN

8	10	8
16	16	12
17	15	15
8	8	8

MENDOZA

9	4	5
16	6	5
7	5	4
7	4	5

NEUQUEN

6	5	3
8	6	4
9	7	4
6	4	2

S. ANTONIO OESTE

4	5	6
0	0	0
8	7	3
6	6	5

MAQUINCHAO

20	12	16
18	12	12
29	23	23
21	17	18

TRELEW

6	3	3
8	4	6
10	8	4
8	5	5

CALAFATE

22	21	24
12	11	12
15	16	13
13	13	19

COMODORO RIVADAVIA

6	6	4
8	7	6
9	8	5
7	5	4

RIO GALLEGOS

12	12	15
9	12	10
12	11	8
17	17	20

PUERTO DESEADO

25	12	14
na	na	na
14	10	10
13	11	9

SPRING
CEILINGS BELOW 3,000 FEET
(PERCENT)
na - DATA NOT AVAILABLE

	SEP	OCT	NOV
03 L			
09 L			
15 L			
21 L			

Figure 6-115. Spring Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Patagonia.

VISIBILITY. Spring visibilities are good. They are below 6 miles only 3% of the time, and below 3 miles only 1.5% of the time (see Figure 6-116). The primary restrictions to visibility are precipitation, dust, and fog. Brief rains or rainshowers cause visibility to drop below 6 miles for short periods; in southern Patagonia this precipitation can be snow. Duststorms occurring from frontal passages can reduce visibility below 3 miles for 1 to 3 hours. Thunderstorms can also raise dust. Radiation fog forms overnight throughout the zone, particularly in low-lying or partially sheltered areas. Radiation fog normally dissipates rapidly after sunrise.

3	2	1
1	4	2
5	3	2
#	#	1

SAN JUAN

0	0	0
18	16	2
4	6	2
1	0	0

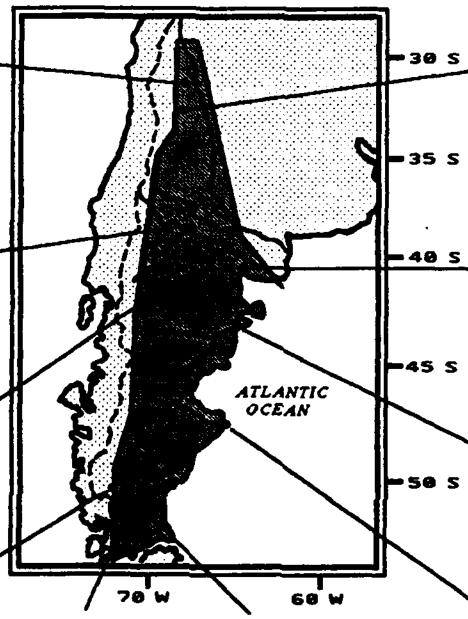
MENDOZA

1	2	1
1	2	#
1	3	#
0	1	1

NEUQUEN

1	1	1
#	#	0
1	1	1
1	1	#

S. ANTONIO OESTE



1	0	0
1	#	0
1	0	1
#	0	0

MAQUINCHAO

1	#	#
1	1	1
3	1	#
#	#	1

TRELEW

3	1	1
#	#	#
#	2	1
2	#	0

CALAFATE

1	1	1
1	1	2
#	1	2
0	1	2

COMODORO RIVADAVIA

2	#	#
4	1	#
3	2	#
1	1	#

RIO GALLEGOS

5	9	3
na	na	0
6	4	1
3	3	1

PUERTO DESEADO

SPRING
VISIBILITY BELOW 3 MILES
(PERCENT)
- LESS THAN 0.5 PERCENT
na - DATA NOT AVAILABLE

	SEP	OCT	NOV
01 L			
07 L			
13 L			
19 L			

Figure 6-116. Spring Percent Frequencies of Visibility Below 3 Miles, Patagonia.

WINDS. Wind speeds average 10 knots in the north and 15 knots in the south. Figure 6-117 provides mean wind speed data for several locations. Diurnally, winds are strongest during the day. Speeds are highest in the south due to the stronger pressure gradient associated with intense spring lows. At some locations, such as Comodoro, surface winds are persistently controlled by local terrain. In mountainous areas, wind speeds more than double if there is channeling. In the south, winds are generally strongest in the afternoon near the coast. Frontal systems and thunderstorms cause the highest winds; the maximum gust during spring was 65 knots at Rio Gallegos.

Mean gradient-level winds are westerly. North of 41° S, mean surface wind directions range from south to west-northwest; south of 41° S, from southwest to west. Northeasterly winds occur with some regularity when blocking highs settle over the western South Atlantic. Southeasterly winds occur with strong frontal lows northeast of the zone. Figure 6-118 shows wind roses for selected stations.

STATION	MEAN WIND SPEED SEP	OCT	NOV
COMMODORO RIVADAVIA	14	15	17
MAQUINCHAO	9	10	10
MENDOZA	5	5	6
NEQUEN	7	9	9
PERITO MORENO	12	16	17
PUERTO DESEADO	18	19	20
RIO GALLEGOS	16	16	18
SAN ANTONIO OESTE	9	10	11
SAN JUAN	7	8	9
TRELEW	13	13	15

Figure 6-117. Mean Spring Wind Speeds, Patagonia.

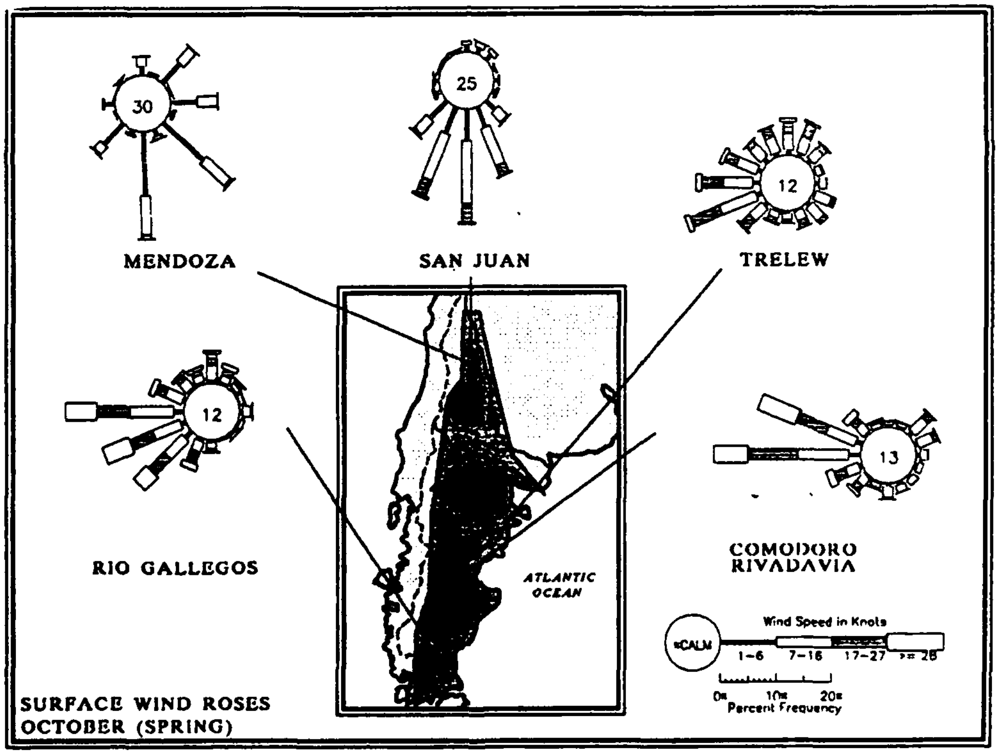


Figure 6-118. October Surface Wind Roses, Patagonia.

Upper-level winds are westerly at from 20 to 40 knots. Speeds increase with height and from north to south. Mean monthly upper-level wind directions are shown in Figures 6-89 through 6-92.

PRECIPITATION. Spring frontal activity tends to be more intense than that of winter. Precipitation is rain, except at elevations above 2,500 feet (760 meters) MSL in central and extreme southern Patagonia. Mean monthly precipitation amounts range from less than 0.40 inch (10 mm) to 1 inch (25 mm), as shown in Figure 6-119. MCS-caused heavy rains can cause flooding in extreme northern Patagonia by late November; thunderstorm-caused flash floods occur, on rare occasions, in canyons immediately east of the main Andes ranges.

Westerly flow becomes less persistent over northern Patagonia, reducing the rain shadow effect caused by the Andes. Easterly winds created by blocking highs bring moisture to the Andes' eastern foothills; orographically-enhanced rain showers can be significant. Precipitation occurs on an average of 5 days a month in the north.

Westerly flow continues to be predominant over southern Patagonia. Some low-level moisture enters the south with easterly flow associated with blocking highs and frontal lows. South of 44° S, snowfall occurs on an average of 2 days a month, with little accumulation.

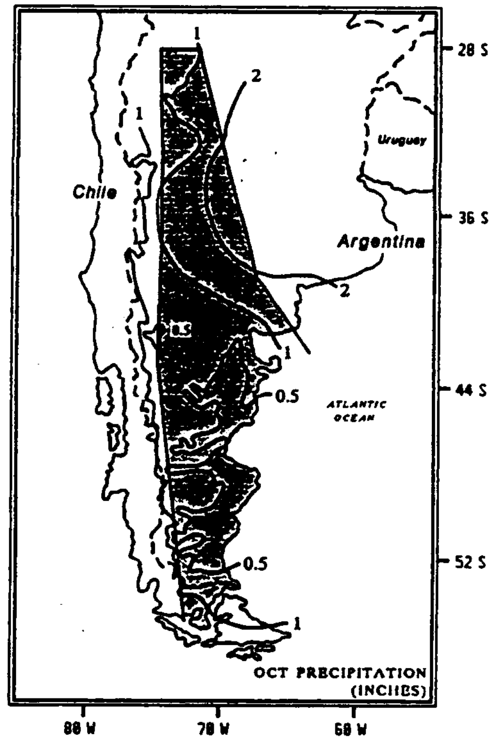


Figure 6-119. Mean October Precipitation, Patagonia.

0.19	0.24	0.35
2.00	2.30	2.70
0.63	1.20	1.80
#	1	1

SAN JUAN

0.55	0.91	0.79
2.80	3.90	2.40
1.40	1.77	1.77
1	1	2

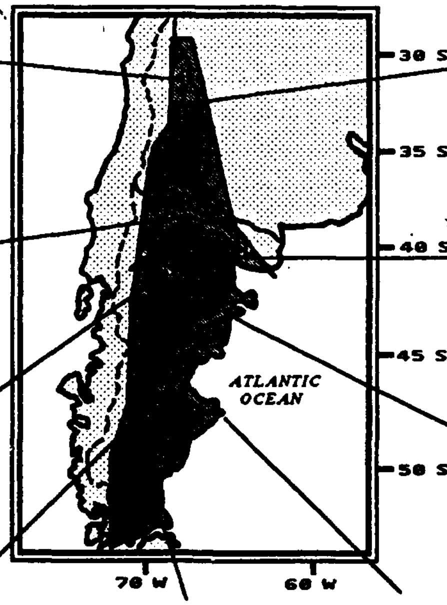
MENDOZA

0.60	0.82	0.51
2.32	2.38	1.46
0.74	1.24	0.58
#	1	2

NEUQUEN

0.69	0.69	0.90
2.55	2.49	1.79
0.79	0.71	1.26
#	1	2

S. ANTONIO OESTE



0.37	0.44	1.11
1.02	1.82	3.07
0.41	0.39	1.18
0	#	1

MAQUINCHAO

0.58	0.66	0.70
2.40	2.87	4.20
1.37	1.22	2.80
#	1	1

TRELEW

0.60	0.40	0.60
1.90	0.80	3.50
0.60	0.50	1.50
0	0	#

COMODORO RIVADAVIA

0.50	0.50	0.90
2.00	1.50	2.20
0.40	0.30	1.60
0	0	0

RIO GALLEGOS

0.77	0.39	0.49
3.07	1.19	1.15
0.78	0.67	0.75
#	0	0

PUERTO DESEADO

SPRING
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS

	SEP	OCT	NOV
MEAN MONTHLY			
MAXIMUM MONTHLY			
MAXIMUM 24-HOUR			
THUNDERSTORM DAYS			

Figure 6-120. Spring Tabular Precipitation Data, Patagonia.

THUNDERSTORMS. Thunderstorms become more common during spring. They occur on an average of 2 days a month in the north and less than 1 day a month toward the south. Thunderstorms occur most often with fronts and occasionally with afternoon heating in late spring. Tops generally exceed 40,000 feet (12.2 km), with bases averaging 8,000 feet (2,440 meters) MSL. Springtime thunderstorms typically include brief rainshowers, occasional lightning, and gusty surface winds. Thunderstorms with high bases can produce strong downrush winds.

TEMPERATURE. Temperatures increase substantially with increased surface heating. Adiabatic warming also contributes to higher temperatures near the Andes' eastern slopes. Mean daily highs range from 90° F (32° C) to 60° F (15° C) (Figure 6-121). The extreme high is 106° F (41° C) at San Juan. Mean daily lows range from 45° F (7° C) to less than 30° F (-1° C). The coldest temperatures occur in the foothills of southern Patagonia. The record low of 5° F (-15° C) occurred at Maquinchao in September. Over northern Patagonia the mean freezing level is 10,000 feet (3,050 meters) MSL, while over southern Patagonia it averages 2,000 feet (610 meters MSL).

Mean relative humidities aren't as high as in winter, averaging 65% in the morning and 40% in the afternoon. Figure 6-122 gives wet-bulb globe temperature data for selected stations.

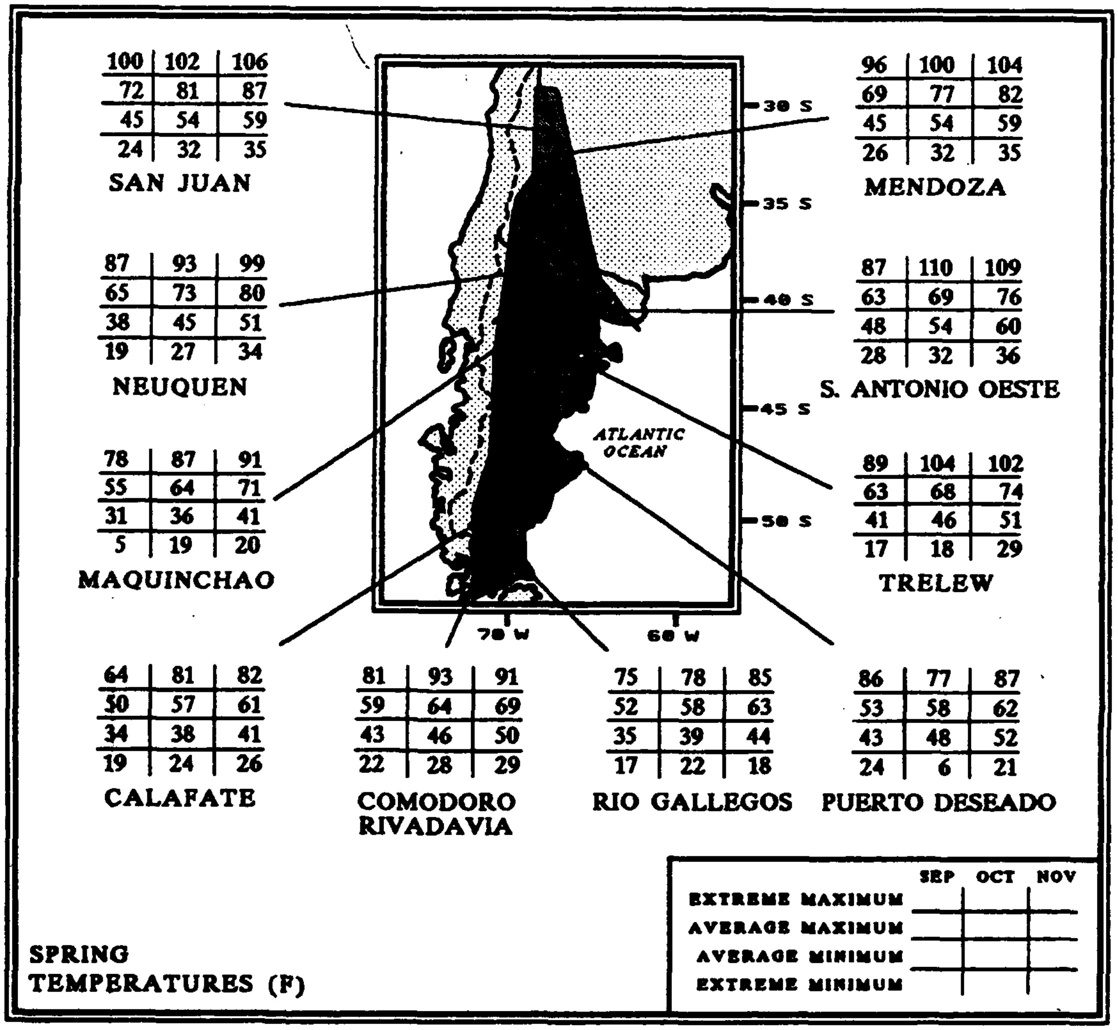
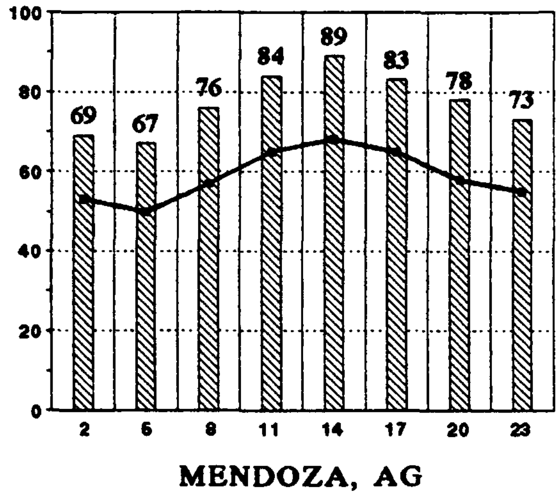


Figure 6-121. Spring Tabular Temperature Data, Patagonia.



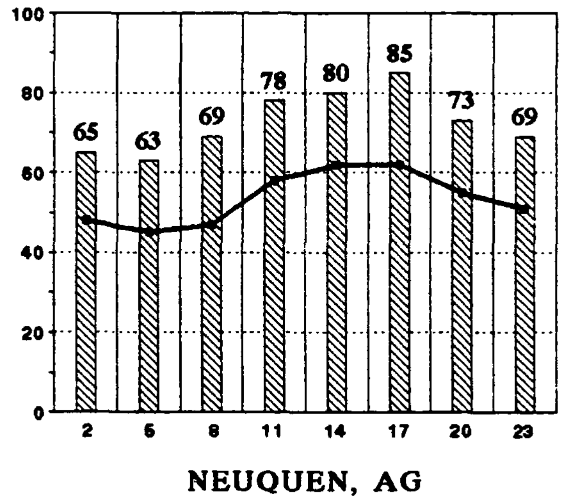


Figure 6-122. Mean and Maximum Diurnal Wet-Bulb Globe Temperature (WBGT) Data (° F) for October, Patagonia. Mean WBGT is shown by a line graph superimposed over a bar graph (maximum WBGT).

FLIGHT HAZARDS. Severe turbulence occurs near thunderstorms. Strong winds over the central and southern Andes produce mountain waves that can extend to 35,000 feet (10.7 km) MSL north of 39° S and to 30,000 feet (9,145 meters) MSL south of 39° S. In southern Patagonia, strong winds over rugged terrain cause moderate to severe low-level turbulence for light aircraft up to 5,000 feet (1,525 meters) above the highest terrain. Funneling causes speed shear in mountain passes; mountain barriers cause directional shear. Squall lines north and east of Neuquen in late November can reach severe proportions; conditions are similar to those of eastern Colorado. Surface hail in excess of 1 inch (2.5 cm) and gusts above 70 knots have been reported. Icing over the northern half of Patagonia is normally associated with towering cumulus or cumulonimbus. Over southern Patagonia, most clouds form at or above the freezing level, providing the potential for icing in almost any cloud.

GROUND HAZARDS. Duststorms reduce visibility below 3 miles for 1 to 3 hours. Thick pockets of ground fog can form overnight near glaciers in the western foothills of southern Patagonia. By late November, MCS-caused heavy rains can cause flooding in extreme northern Patagonia; thunderstorm-caused flash floods occur in canyons immediately east of the main Andes ranges.

6.4 THE SOUTHERN ISLANDS

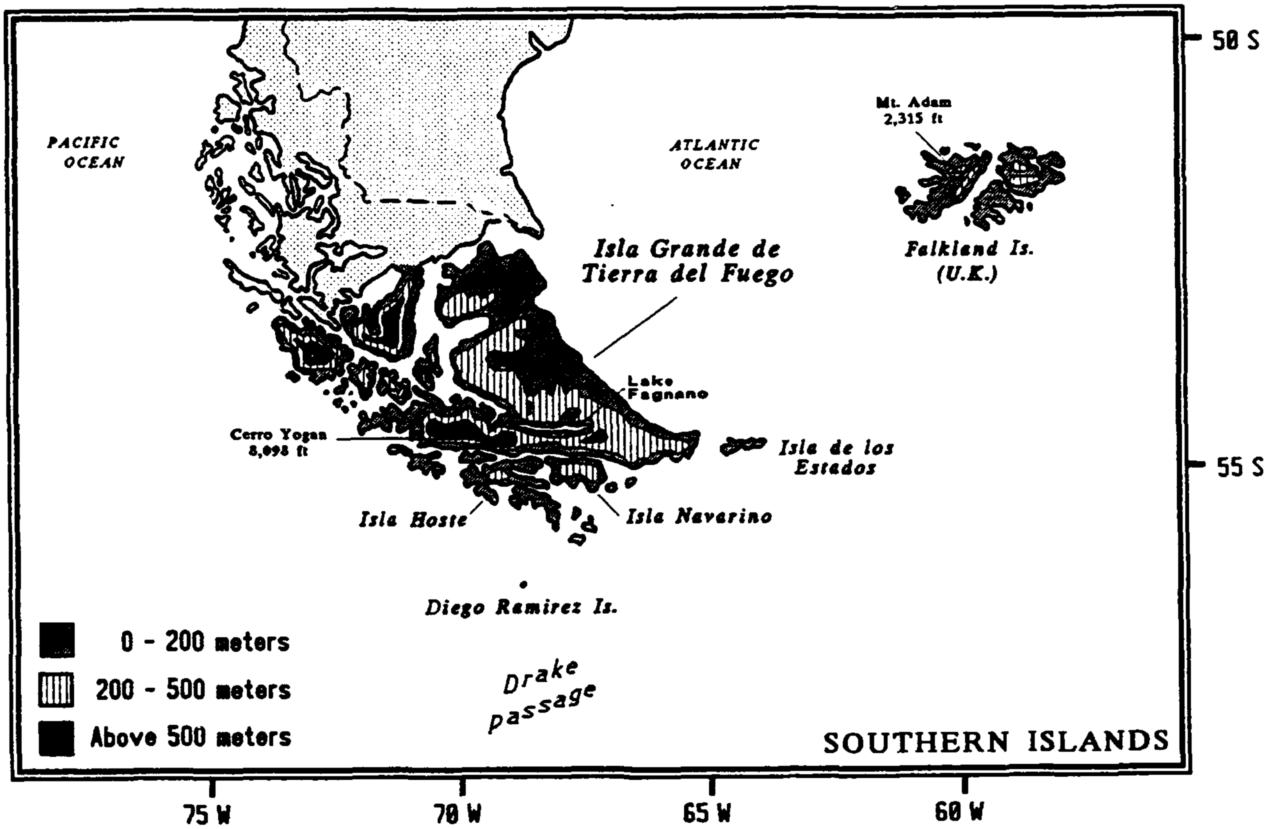
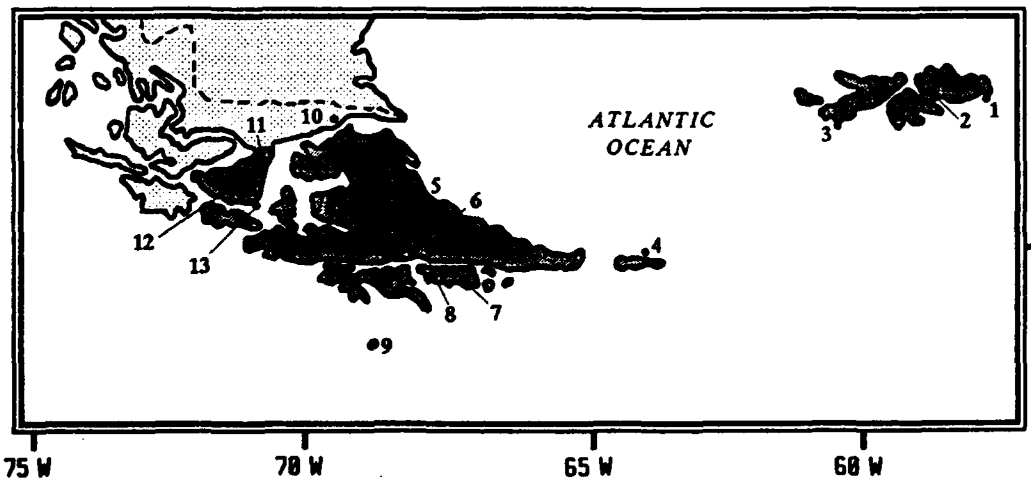


Figure 6-123. The Southern Islands. The Southern Islands comprise the southern fringes of Chile and Argentina, as well as the Falkland (Malvinas) Islands. The largest island is Tierra Del Fuego. The Falkland Island group lies 300 NM northeast of the southern tip of Tierra Del Fuego.



1.	PORT STANLEY	173
2.	DARWIN	13
3.	FOX BAY	45
4.	ISLA OBSERVATORIO	164
5.	RIO GRANDE	33
6.	USHUAIA	52
7.	PUERTO WILLIAMS	26
	55 S	
8.	CALETA WULAIA	26
9.	DIEGO RAMIREZ Is.	138
10.	PUNTA DELGADA	16
11.	CHABUNCO AIRPORT	108
12.	PUNTA ARENAS	66
13.	CABO SAN ISIDRO	66

Figure 6-124. Climatic Station Network, Southern Islands.

SOUTHERN ISLANDS GEOGRAPHY

TERRAIN. The landscape consists of rolling hills, low mountain chains, and glaciers. Tierra del Fuego has several ridges with elevations near 8,000 feet (2,440 meters). On Isla de los Estados (Staten Island), peaks reach 3,700 feet (1,130 meters). Hoste Island has the largest glacier. Of the 200 islands in the Falkland group, East and West Falkland account for 90% of the land area. Two small valleys run east-west across the northern half of the islands. The valleys are enclosed by rolling hills that rise to 2,300 feet (700 meters).

WATERWAYS AND DRAINAGE. Many of the islands, which are separated by channels and coastal inlets, have small streams, rivers, and lakes. The largest lake is Lake Fagnano, located on Tierra Del Fuego. Short winding creeks dominate the landscape of the Falklands.

VEGETATION. Vegetation in the Southern Islands is mostly grassland and shrubs, but the southern fringes are dominated by forest. Short grasses grow in the Falklands.

SOUTHERN ISLANDS CLIMATIC PECULARITIES

This area has long been known to sailors as having the worst weather on the planet. High winds--often above hurricane force--poor visibilities, rain/snow squalls, spray, superstructure icing, and monster waves are all common here. Conditions are worst in August and early September due to the proximity of the mean northern edge of polar ice only 180 miles southeast of Cape Horn. Severe conditions, however, can occur at any time of year. As of spring 1992, meteorological satellite imagery was the only reliable forecasting tool for this area.

GENERAL WEATHER. Fast-moving but weak cold fronts affect the Southern Islands every 2 to 3 days. The primary storm track is south of 60° S in Drake Passage, but weak cold fronts produce rain showers and isolated thundershowers in narrow bands along the southern and southwestern fringes of Tierra del Fuego. Surface highs migrate eastward between systems, producing subsidence and shallow fair-weather cumulus. Although the Southern Islands have 15 to 20 hours of daylight, cool coastal waters keep air temperatures in the mid-60s° F (16-17° C) to low 70s (21-22° C). During ENSO years, the South Pacific High weakens, allowing low-pressure systems to penetrate farther north than usual.

SKY COVER. Summer cloud cover averages 70% on Tierra Del Fuego and 60% in the Falklands (Figure 6-125). Fair weather produces stratocumulus with bases at 3,000-4,000 feet (915-1,220 meters) AGL and scattered cumulus between 3,000 and 5,000 feet (915 and 1,525 meters) AGL. Moderate cumulus development with isolated towering cumulus occurs along frontal boundaries. Bases range from 3,000 to 5,000 feet (915 to 1,525 meters) AGL; tops occasionally exceed 20,000 feet (6,100 meters) MSL. High terrain can be totally obscured. Thin stratocumulus and stratus are localized within sheltered inlets and along coastal hills during the short (4-9 hour) periods of darkness. Bases can be below 1,000 feet (305 meters) AGL between 2300 and 0800L in northern Drake Passage and the western Strait of Magellan.

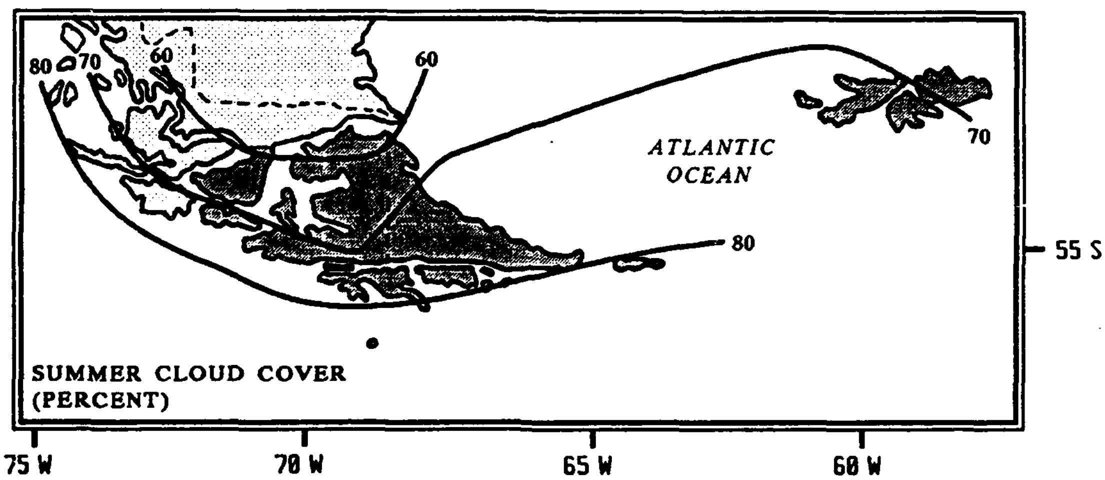


Figure 6-125. Mean January Cloud Cover, Southern Islands.

Tierra Del Fuego ceilings are below 3,000 feet (915 meters) 36% of the time; the Falklands, about 40% of the time (Figure 6-126). Many small islands along the zone's southern fringes have higher frequencies of low ceilings than shown in the figure. Frequent frontal systems produce low ceilings. At some sheltered inland locations, there are low ceilings of thin stratus at night. Layered middle and high clouds occur within 200 miles of frontal systems.

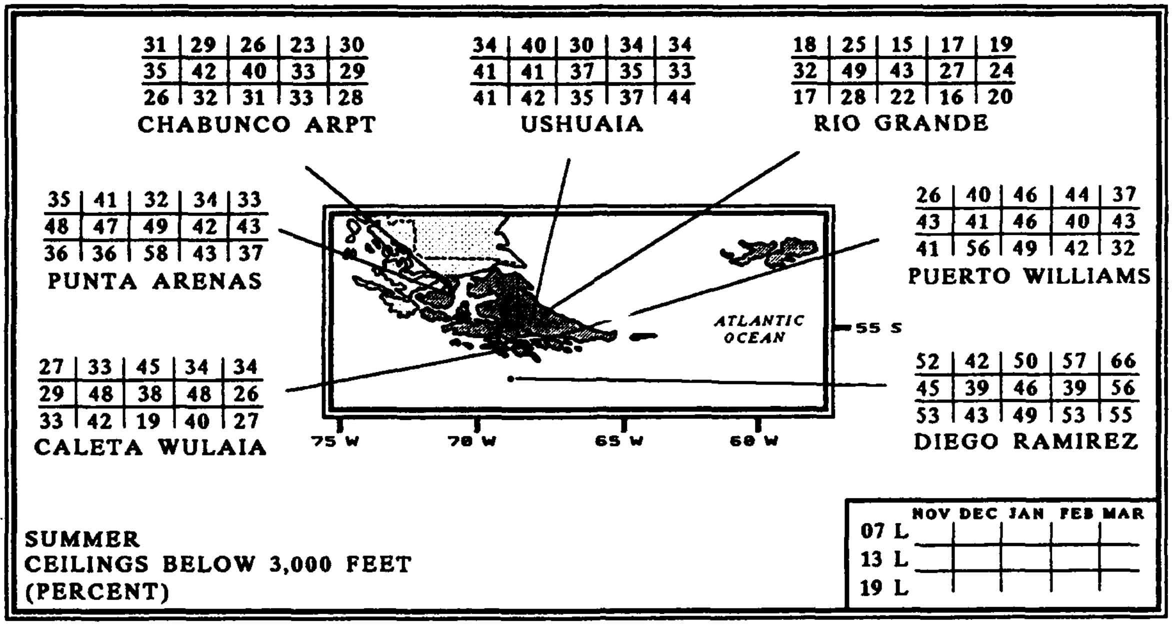


Figure 6-126. Summer Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Islands.

VISIBILITY. Heavy precipitation from passing cold fronts results in isolated areas with visibilities below 3 miles along coastal ranges; visibilities below 1 mile are rare. The many smaller islands along Drake Passage and coastal locations near the Strait of Magellan have higher frequencies (Figure 6-127) of low visibility due to maritime influences. Sea fog often occurs during calm conditions, but the frequency of visibility below 6 miles averages only 10% (and below 3 miles only 3%) as extended hours of daylight inhibit extensive fog formation.

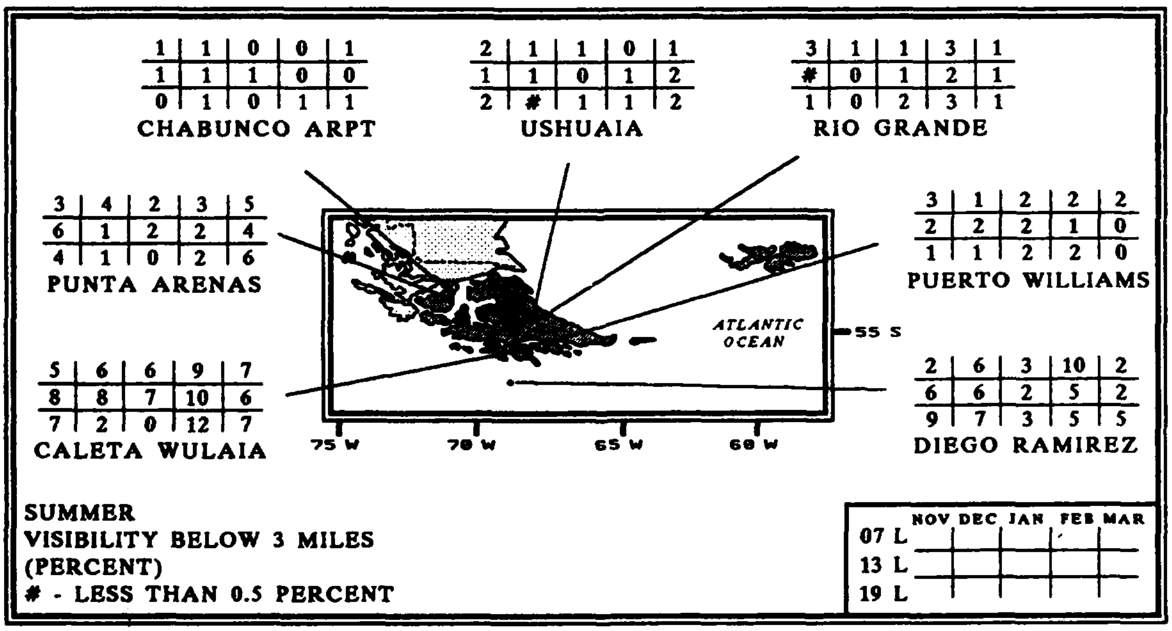


Figure 6-127. Summer Percent Frequencies of Visibility Below 3 Miles, Southern Islands.

WINDS. Strong westerlies dominate. Wind speeds average 15 to 25 knots during fair weather over open water, but are often only 9 to 15 knots in sheltered coves and inlets. Migratory lows produce northwesterlies or northerlies that exceed 30 knots. In rare cases, the northerlies may precede a cold front for 24 to 36 hours before shifting to southerly with frontal passage. Sustained wind speeds of 35 to 45 knots and gusts to 55 knots (or even higher) occur with southerlies; these are generated by strong high-pressure cells moving in behind the cold front. Land/sea breezes produce localized wind shifts in the Falklands and coastal stations of southeastern Tierra del Fuego. Figure 6-128 shows mean surface wind speeds for several stations on Tierra del Fuego. Along the coastline, consistently strong winds reach their peak by 1400L. Wind roses for January (Figure 6-129) also show the strong westerly winds and infrequent calm conditions at most unsheltered locations.

STATION	MEAN WIND SPEED				
	NOV	DEC	JAN	FEB	MAR
CALETA WULAIA	8	7	7	6	7
DARWIN	20	19	20	19	18
DIEGO RAMIREZ	19	17	16	15	18
FOX BAY	22	19	20	19	19
PORT STANLEY	21	19	19	20	20
PUNTA ARENAS	9	10	11	10	8

Figure 6-128. Mean Summer Wind Speeds, Southern Islands.

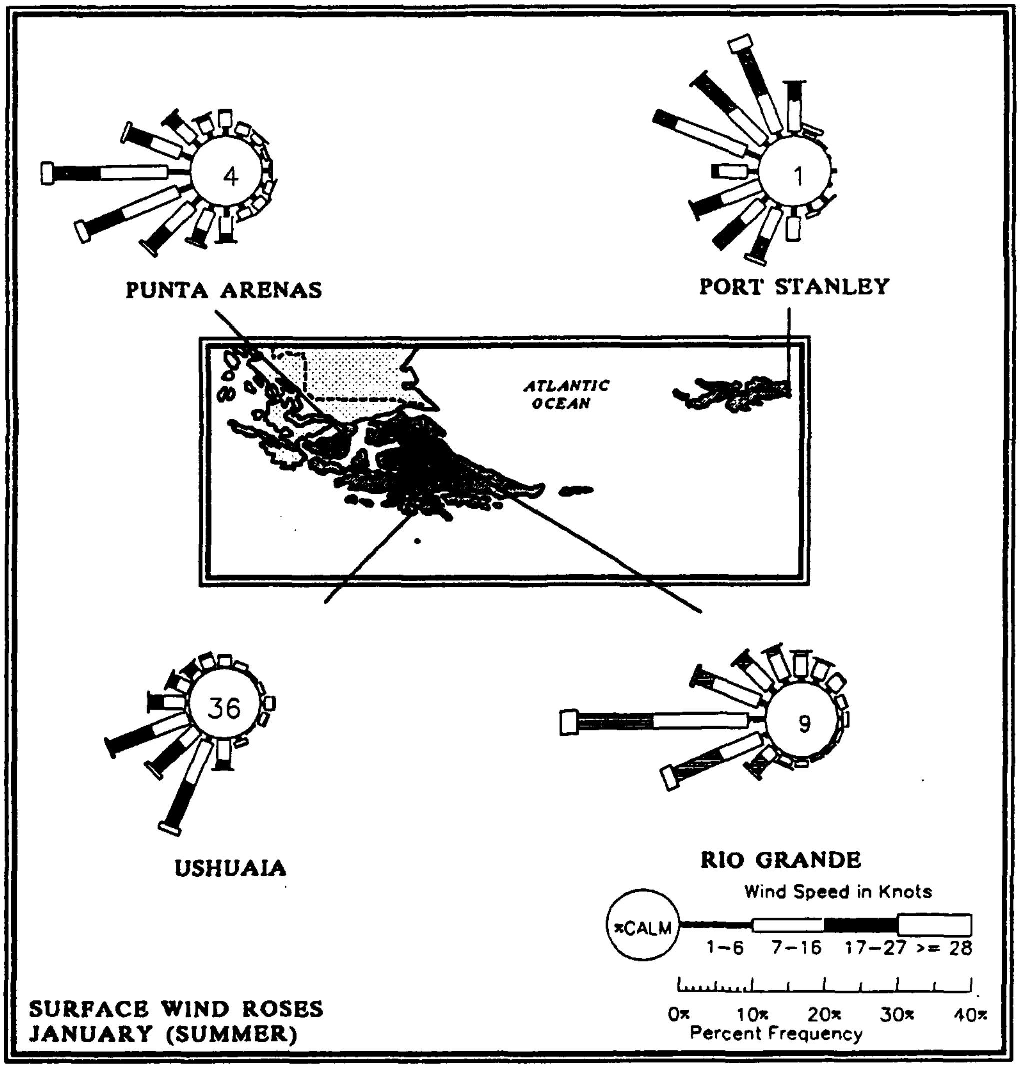


Figure 6-129. January Surface Wind Roses, Southern Islands.

Mid- and upper-level wind directions are west-southwesterly to westerly. The circumpolar trough (see Chapter 2), which drives the westerly flow over the oceans surrounding Antarctica, actually produces stronger mid- and upper-level westerlies in summer because the thermal gradients between 35° and 55° S are greater. Wind speeds average 25 knots at 5,000 feet (1,525 meters) MSL and 65 knots at 30,000 feet (9,145 meters) MSL. A 120-knot jet maximum is possible as far north as 50° S with intense upper-air troughs.

PRECIPITATION. Summer rainfall is usually convective, produced by weak, fast-moving cold fronts. Migratory lows rarely pass through Drake Passage north of 57° S, but their trailing cold fronts extend northward into Tierra del Fuego. Weak cold fronts usually produce isolated convection along the trough axis, while strong fair-weather westerlies produce scattered diurnal convective precipitation along coastal terrain in the extreme southern islands. In both cases, light-to-moderate rain showers often develop when afternoon heating is greatest (1300 to 1700L). Widely scattered air-mass thundershowers can occur once or twice a summer when a strong high pressure ridge settles over Patagonia. In this case, widespread convection develops along coastal terrain within localized areas of sea-breeze convergence. Convective showers rarely produce more than 0.75 inches (19 mm) of rain.

Figure 6-130 is representative of the summer rainfall pattern. Greatest January precipitation is concentrated along the many southwestern islands near Drake Passage. Figure 6-131 shows precipitation data for several locations in the Southern Islands. Highest rainfall is found at Diego Ramirez Island, where surface lows move across the island every 2 to 3 days and produce moderate rain showers along the trough axis.

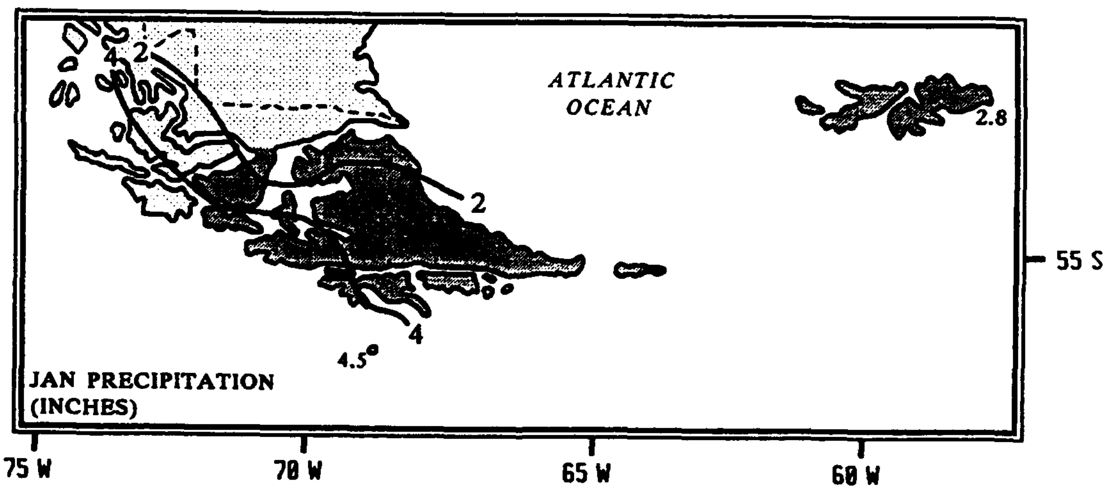


Figure 6-130. Mean January Precipitation, Southern Islands. Station data for Diego Ramirez Island and Stanley (the Falklands) is insufficient to draw representative isohyets.

PUNTA ARENAS

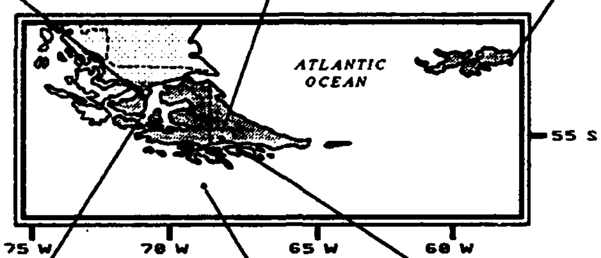
	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	3.5	5.5	5.7	3.2	5.5
MAXIMUM 24-HOUR	1.3	0.7	1.6	1.2	3.9
THUNDERSTORM DAYS	0	#	0	0	#
SNOW DAYS	na	na	na	na	na

USHUAIA

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	5.4	4.3	4.8	4.8	4.1
MAXIMUM 24-HOUR	5.0	2.0	1.0	1.8	1.6
THUNDERSTORM DAYS	#	#	0	#	0
SNOW DAYS	4	3	1	#	2

PORT STANLEY

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	na	na	na	na	na
MAXIMUM 24-HOUR	1.4	1.6	1.2	1.7	1.1
THUNDERSTORM DAYS	na	na	na	na	na
SNOW DAYS	0	0	0	0	0



CABO SAN ISIDRO

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	6.2	9.7	13.3	6.6	6.2
MAXIMUM 24-HOUR	1.9	0.9	1.9	0.9	1.9
THUNDERSTORM DAYS	0	0	0	#	0
SNOW DAYS	na	na	na	na	na

DIEGO RAMIREZ

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	6.8	5.7	6.7	5.2	7.1
MAXIMUM 24-HOUR	0.7	1.2	1.1	1.0	1.1
THUNDERSTORM DAYS	#	#	0	0	#
SNOW DAYS	na	na	na	na	na

PUERTO WILLIAMS

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY	3.6	5.0	2.1	3.0	3.5
MAXIMUM 24-HOUR	1.0	0.7	0.4	1.1	0.8
THUNDERSTORM DAYS	0	#	0	1	#
SNOW DAYS	na	na	na	na	na

SUMMER
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	NOV	DEC	JAN	FEB	MAR
MAXIMUM MONTHLY					
MAXIMUM 24-HOUR					
THUNDERSTORM DAYS					
SNOW DAYS					

Figure 6-131. Summer Tabular Precipitation Data, Southern Islands.

THUNDERSTORMS are triggered by surface heating and fueled by strong sea breezes and orographic lifting along coastal terrain. They are infrequent and short-lived because strong mid-level winds often shear them off. Stanley, with 1 a month, has the most summertime thunderstorm days in the Southern Islands. Tops are normally under 25,000 feet 7.6 km) MSL. Hail seldom occurs with summer thunderstorms.

TEMPERATURE. Mean daily lows range from 37 to 56° F (3 to 13° C); highs, from 46 to 74° F (8 to 24° C). Summer cold fronts produce the lowest temperatures; the lowest was 21° F (-6° C) at Rio Grande and Ushuaia. The record high is 99° F (37° C) at Punta Delgada (December). Extreme high temperatures occur when blocking high-pressure ridges keep storms to the south. Relative humidity is fairly uniform throughout the Southern Islands, averaging 82% at 0700L and 67% at 1300L.

SUMMER TEMPERATURES (F)

Station		NOV	DEC	JAN	FEB	MAR
PUNTA DELGADA	EXTREME MAXIMUM	74	78	83	82	78
	AVERAGE MAXIMUM	55	57	60	58	56
	AVERAGE MINIMUM	41	45	45	44	43
	EXTREME MINIMUM	24	25	25	27	23
USHUAIA	EXTREME MAXIMUM	74	84	85	79	78
	AVERAGE MAXIMUM	54	56	58	58	54
	AVERAGE MINIMUM	38	40	42	41	38
	EXTREME MINIMUM	21	25	28	25	24
RIO GRANDE	EXTREME MAXIMUM	65	72	75	75	71
	AVERAGE MAXIMUM	53	58	59	59	55
	AVERAGE MINIMUM	37	42	42	40	38
	EXTREME MINIMUM	25	27	27	27	21
PUNTA ARENAS	EXTREME MAXIMUM	76	79	86	79	75
	AVERAGE MAXIMUM	54	57	59	58	55
	AVERAGE MINIMUM	40	43	45	44	43
	EXTREME MINIMUM	23	23	26	28	23
PORT STANLEY	EXTREME MAXIMUM	71	71	76	74	70
	AVERAGE MAXIMUM	52	54	56	55	53
	AVERAGE MINIMUM	37	39	42	41	40
	EXTREME MINIMUM	26	29	30	30	27
CABO SAN ISIDRO	EXTREME MAXIMUM	67	66	71	67	67
	AVERAGE MAXIMUM	51	53	54	54	51
	AVERAGE MINIMUM	39	41	42	42	40
	EXTREME MINIMUM	25	32	32	32	28
ISLA OBSERVATORIO	EXTREME MAXIMUM	60	63	62	64	59
	AVERAGE MAXIMUM	48	51	52	52	50
	AVERAGE MINIMUM	37	40	42	42	41
	EXTREME MINIMUM	24	32	32	33	32
DIEGO RAMIREZ	EXTREME MAXIMUM	59	64	59	65	55
	AVERAGE MAXIMUM	46	49	50	50	49
	AVERAGE MINIMUM	38	39	40	41	40
	EXTREME MINIMUM	28	25	32	34	23
PUERTO WILLIAMS	EXTREME MAXIMUM	72	68	72	73	72
	AVERAGE MAXIMUM	56	56	57	57	56
	AVERAGE MINIMUM	37	40	40	41	39
	EXTREME MINIMUM	25	28	30	25	28

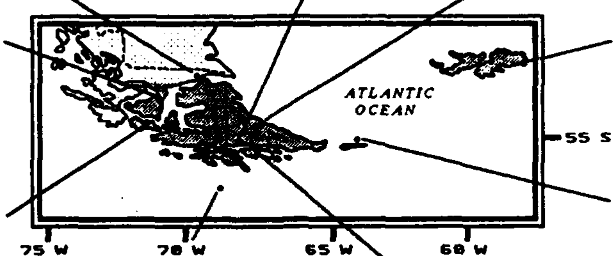


Figure 6-132. Summer Tabular Temperature Data, Southern Islands.

FLIGHT HAZARDS. Moderate to severe mountain wave turbulence is common because of the strong westerly winds. Lenticular and rotor clouds are common along Tierra Del Fuego and, in rare cases, over the Falklands. Moderate-to-severe turbulence usually occurs from 5,000 to 10,000 feet (1,525 to 3,050 meters) MSL, but has also been reported near 40,000 feet (12.2 km) MSL, associated with the jet stream. Low-level turbulence occurs several miles downwind of hills and mountains. Intense surface heating and foehn winds are possible over Tierra Del Fuego. Moderate to severe turbulence occurs near strong downslope winds. Icing is possible above 4,000 feet (1,220 meters) MSL in convective clouds along cold fronts. Light to moderate rime icing is likely in stratiform clouds. Moderate to severe mixed icing can be expected in towering cumulus and thunderstorms.

GROUND HAZARDS. Fog and isolated heavy downpours can reduce visibility for several hours, but visibility is rarely below 1 mile for more than an hour. Open ocean wave heights exceed 15 feet; extreme heights associated with storm fetches may exceed 30 feet.

GENERAL WEATHER. Low-pressure systems affect the Southern Islands every 2 to 4 days. Storms intensify in Drake Passage. A 500-mb trough begins to re-form off the Chilean coast; it can produce a secondary or cut-off low once or twice every April. Light to moderate rainfall is common along most cold fronts. Snow is possible with slow-moving cold fronts supported by deep upper-air troughs. Snowfall rarely exceeds 2 inches below 2,000 feet (610 meters) MSL.

SKY COVER. Mean cloud cover ranges from 50 to 60% in April (Figure 6-133). Stratocumulus is common between sunrise and noon, while moderate cumulus buildups along coastal terrain dominate late afternoon skies. Stratocumulus bases average 3,000 feet (915 meters) AGL; tops rarely exceed 5,000 feet (1,525 meters) MSL. Stratocumulus can obscure coastal hills until an hour or two after sunrise. Cumulus bases are usually from 4,000 to 6,000 feet (1,220 to 1,830 meters) AGL with tops to 10,000 feet (3,050 meters) MSL. Nimbostratus and stratocumulus dominate the lower levels of most cold and occluded fronts, while cumulus, altocumulus, and occasionally altostratus, dominate the middle levels.

Along cold fronts, towering cumulus can exceed 20,000 feet (6,100 meters) MSL. Altocumulus bases are near 7,000 feet (2,135 meters) MSL with tops to 16,000 feet (4,880 meters) MSL along the trough axis; altostratus tops rarely exceed 13,000 feet (3,965 meters). Cirrus is common above 30,000 feet (9,145 meters) MSL with strong upper-level westerlies. Clouds 150 miles downstream of frontal systems merge into solid layers above 5,000 feet (1,525 meters) MSL.

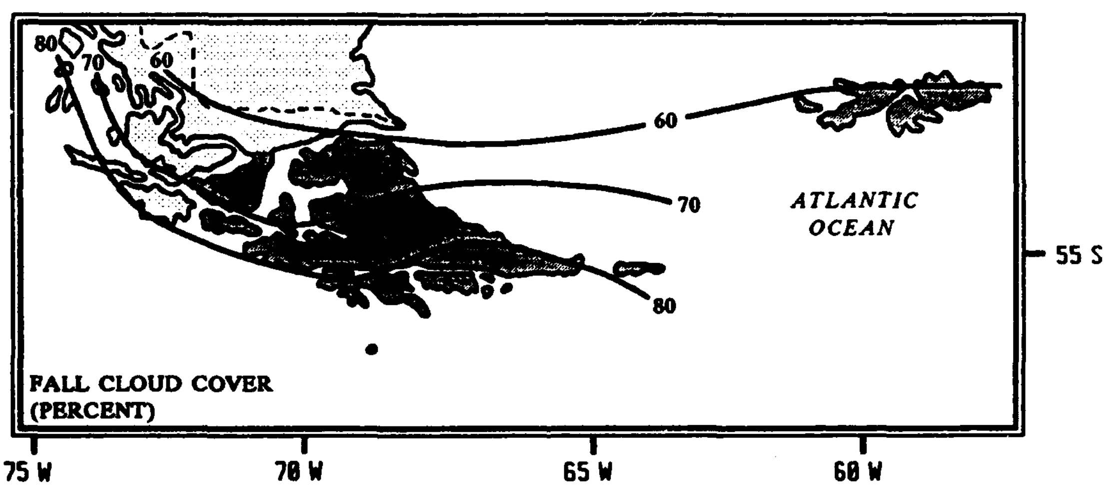


Figure 6-133. Mean April Cloud Cover, Southern Islands.

The frequency of ceilings below 3,000 feet (915 meters) AGL averages 37% across the Southern Islands (Figure 6-134). Lower ceilings can occur along coastal terrain when fronts enhance orographic lift. Isolated areas of heavy cumulus can obscure higher mountain peaks.

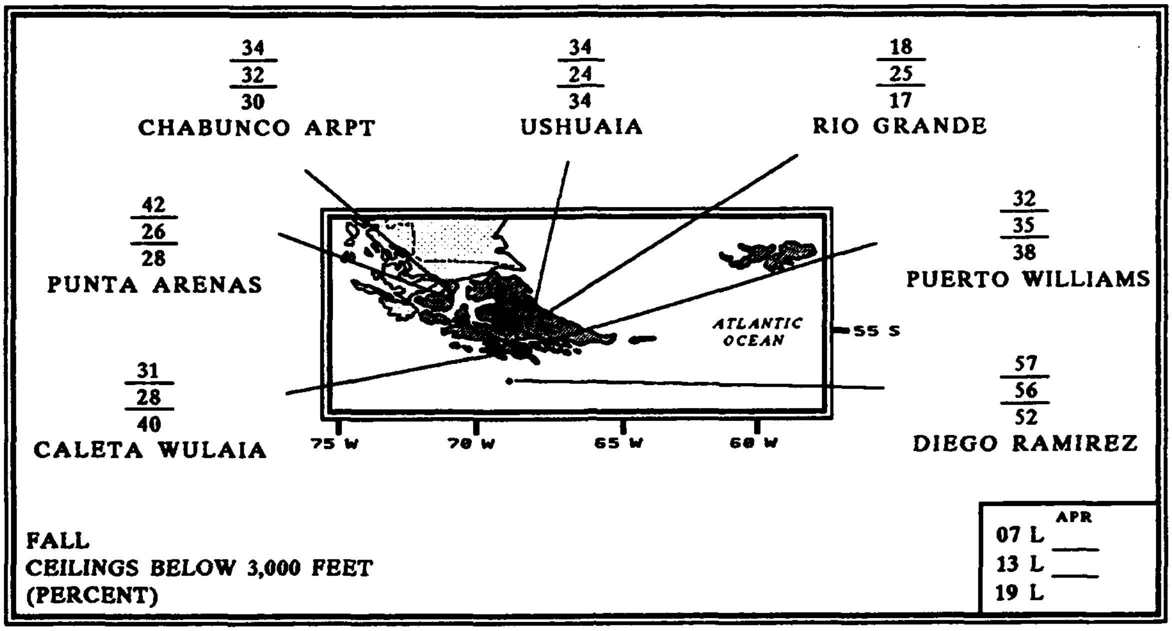


Figure 6-134. Fall Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Islands.

VISIBILITY. The frequency of visibility below 3 miles increases slightly as fronts become more common, but the average is still only 7% (Figure 6-135). Visibilities below 1 mile are extremely rare. Fog is the most common visibility restriction along the southern islands of Tierra Del Fuego and the waters separating the two main Falkland Islands. Heavy rainfall accounts for a large percentage of mid-day and late-afternoon low visibilities. Over Drake Passage and the South Atlantic, wind-whipped spray can reduce visibility to less than 1 mile.

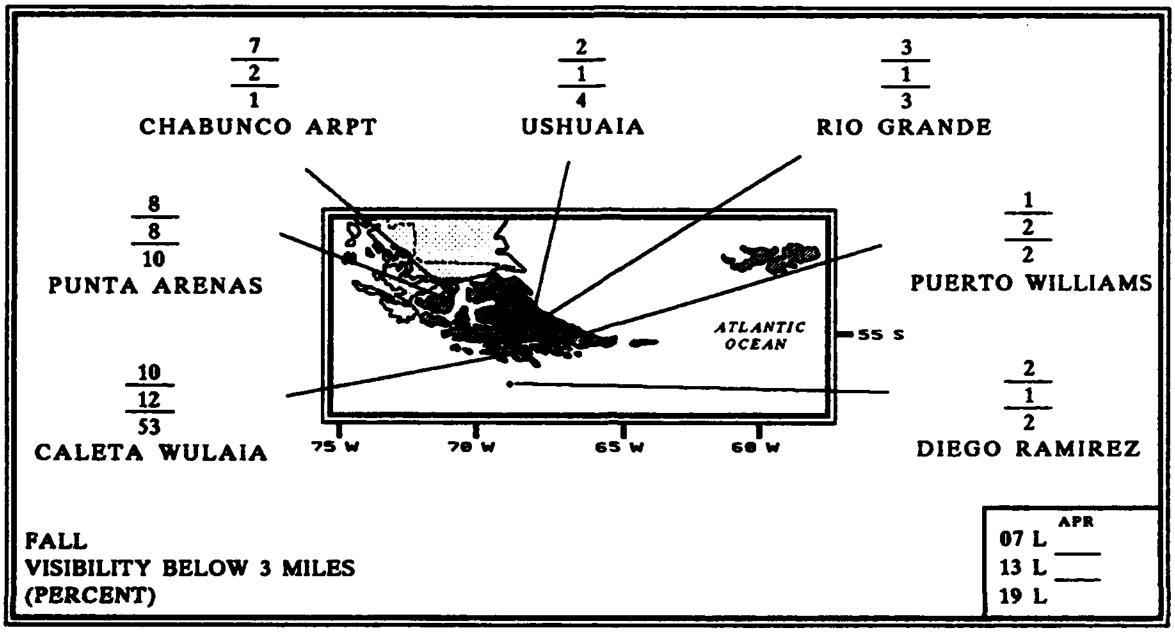


Figure 6-135. Fall Percent Frequencies of Visibility Below 3 Miles, Southern Islands.

WINDS. Westerlies average 17 to 23 knots. Speeds drop to less than 15 knots only in sheltered coves and inlets between 1900 and 0800L. Northwesterlies or southerlies occur with migratory lows. When lows pass north of Tierra del Fuego, 25- to 35-knot easterlies can affect the Southern Islands up to 24 hours before the frontal passage. Gusts to 50 knots accompany strong frontal passages; Fox Bay in the Falkland Islands reported an easterly wind of 63 knots. Open ocean gusts associated with strong lows exceed hurricane force.

STATION	APR
CALETA WULAIA	7
DARWIN	17
DIEGO RAMIREZ	18
FOX BAY	17
PORT STANLEY	19
PUNTA ARENAS	9

Figure 6-136. Mean Fall Wind Speeds, Southern Islands.

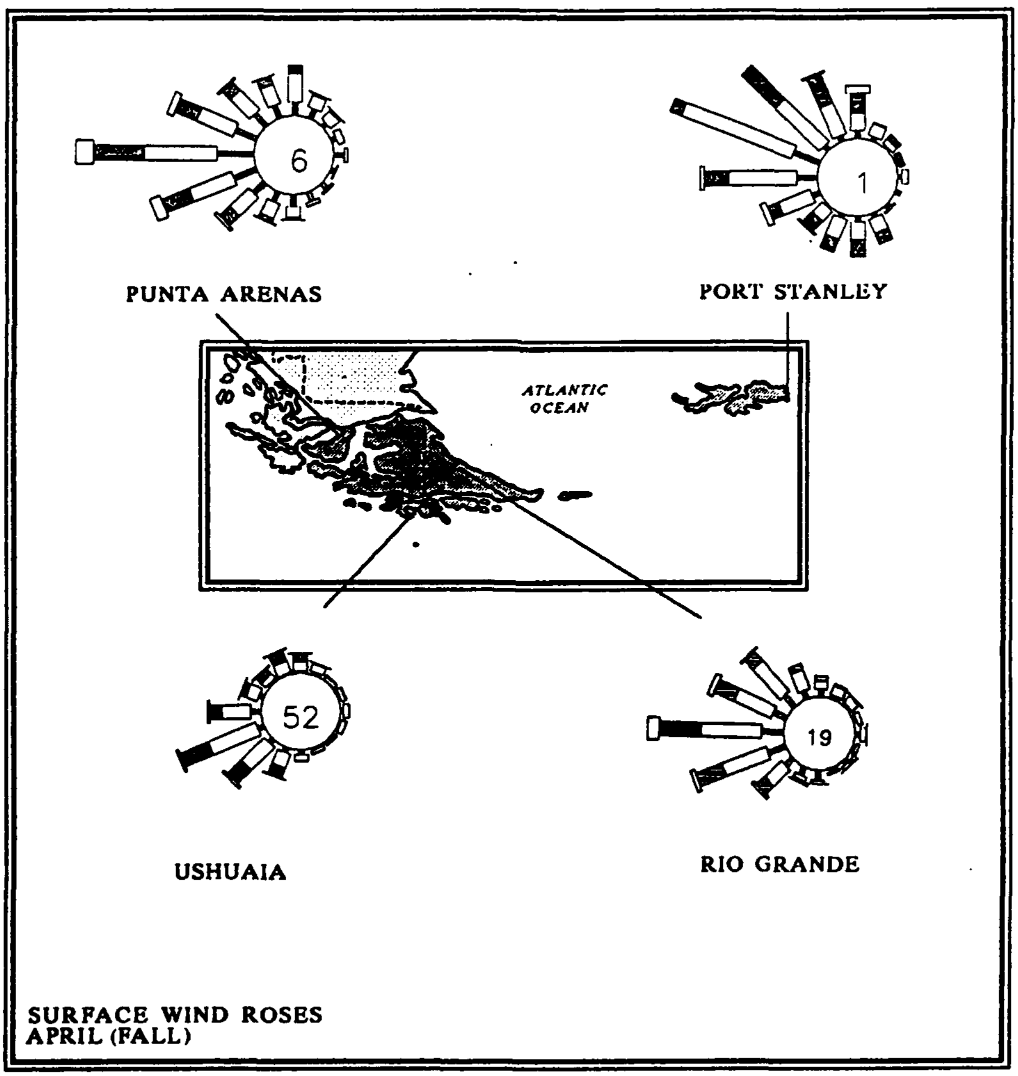


Figure 6-137. April Surface Wind Roses, Southern Islands.

Most mid- and upper-level winds are southwesterly to west-northwesterly; the exception is with deep upper-level transitory troughs. Mean winds at 5,000 feet (1,525 meters) are westerly at 30 knots. At 10,000 feet (3,050 meters) MSL, winds are westerly at 35 knots. Highest mean wind speeds (60 knots) are found between 30,000 and 34,000 feet (9,145-10,365 meters) MSL. Maximum jet stream wind speeds occasionally reach 130 knots, and can exceed 160 knots.

PRECIPITATION. Storms produce rain and rain showers across the Southern Islands. In April, upper-air patterns in the eastern South Pacific and Drake Passage become more meridional than zonal. Cold upper-air troughs and deep surface lows produce rain, rain showers, and occasional snow as they move eastward into the South Atlantic. Rain is concentrated along the trough axis, while snow, sleet, and freezing rain occur south of the low. Widely scattered snow flurries are possible when a cold surface high slides northward behind the cold front.

Most locations in the Southern Islands get at least 2 inches (51 mm) of precipitation each April (Figures 6-138 and 6-139). The coastal island chain in extreme southwestern Tierra del Fuego normally receives more than 4 inches (102 mm). Snowfall rarely exceeds 2 inches (51 mm) and seldom remains on the ground for more than 24 hours.

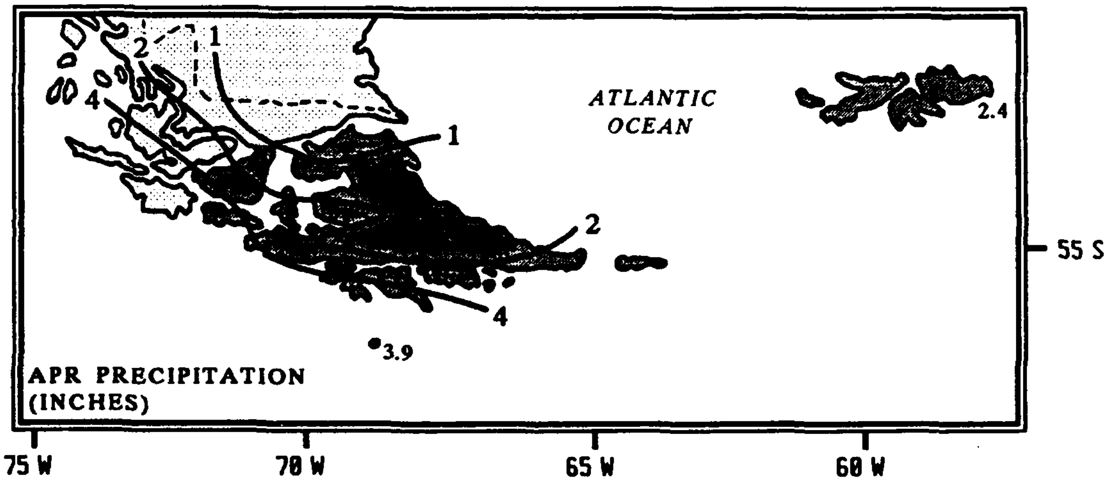


Figure 6-138. Mean April Precipitation, Southern Islands. Station data for Diego Ramirez Island and Stanley (The Falklands) is insufficient to draw representative isopleths.

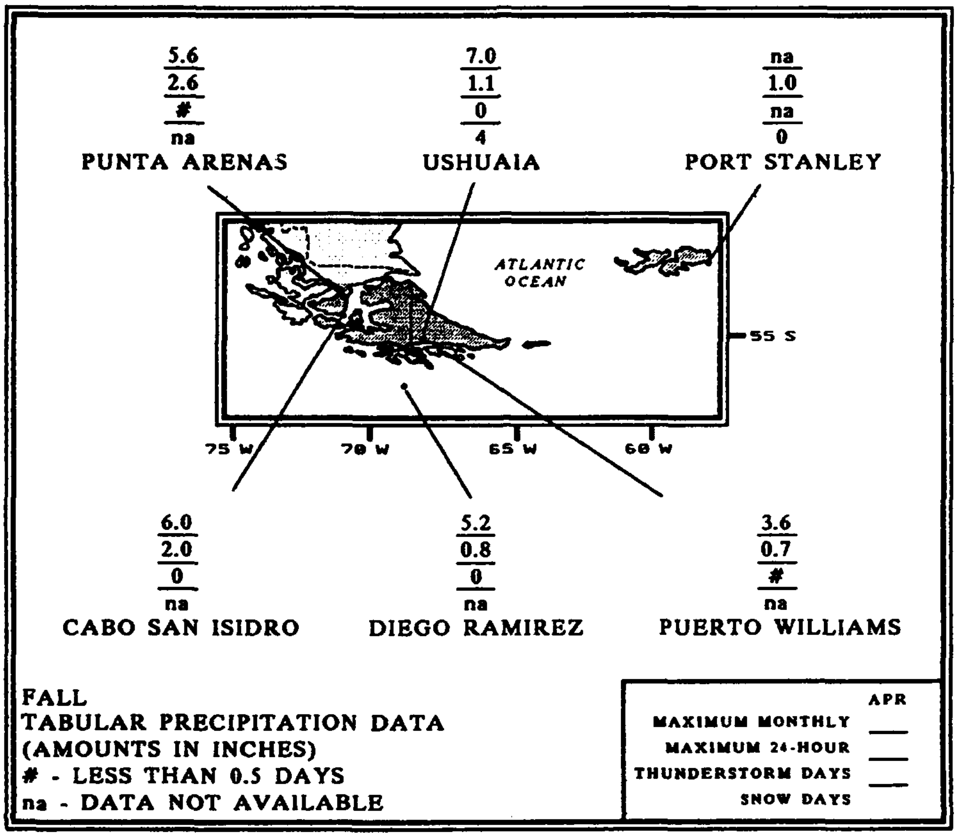


Figure 6-139. Fall Tabular Precipitation Data, Southern Islands.

THUNDERSTORMS are rare in April. Deep, slow-moving troughs must be accompanied by a strong upper-level jet and fueled by a long day of intense surface heating before isolated thunderstorms can develop. Thunderstorms are found most often along the trough axis. Tops are rarely above 25,000 feet (7.6 km) MSL.

TEMPERATURE. Mean daily highs and lows decrease as the days grow shorter. Maritime polar air masses behind cold fronts also help lower temperatures. Mean daily lows range from 35 to 50° F (2 to 10° C); mean daily highs, from 46 to 65° F (8 to 18° C).

The record high in April is 95° F (35° C) at Punta Delgada; the record low is 11° F (-12° C) at Ushuaia. Relative humidity is generally uniform throughout the Southern Islands, averaging 85% at 0700L and 72% at 1300L.

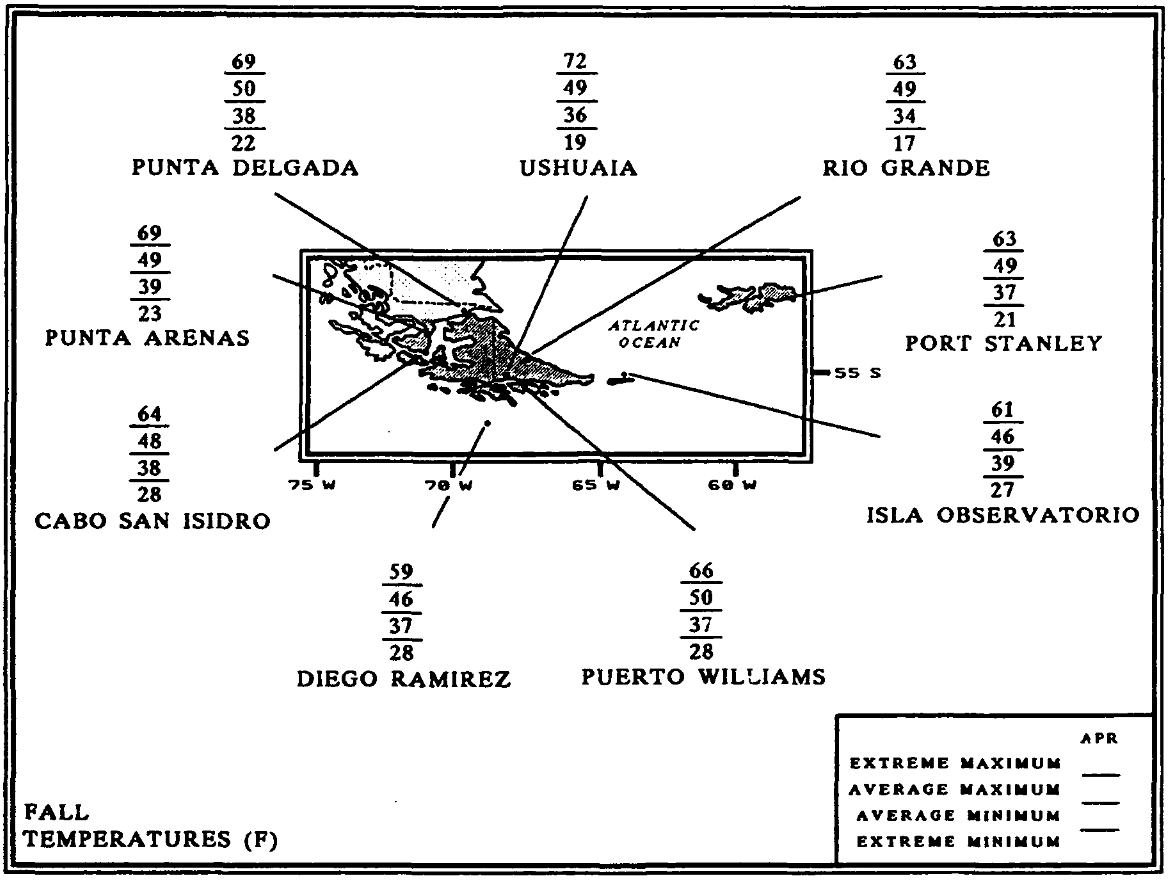


Figure 6-140. Fall Tabular Temperature Data, Southern Islands.

FLIGHT HAZARDS. Mountain-wave turbulence is common on the lee sides of major coastal ranges and the eastern Andes. Lenticular and rotor clouds signify moderate to severe turbulence between 5,000 and 10,000 feet (1,525 and 3,050 meters) MSL. Light to moderate turbulence below 5,000 feet (1,525 meters) occurs along coastal terrain with cold fronts and strong westerly flow. Severe turbulence is possible between 23,000 and 45,000 feet (7,015 and 13,720 meters) MSL with a strong upper-level jet. Icing is common with cold fronts and in heavy cumulus above 2,000 feet (610 meter) MSL. Light to moderate rime icing frequently occurs in stratiform clouds, while moderate to severe mixed icing is found in convective clouds.

GROUND HAZARDS. Patchy ground fog on coastal hillsides and within sheltered inlets reduces visibilities below 3 miles. On occasion, heavy rain reduces visibilities below 3 miles for several minutes to an hour along the southern fringes of Tierra Del Fuego. Building and ship superstructures rapidly accrete rime ice--often to the point of endangering a ship's stability and seaworthiness. Over Drake Passage and the South Atlantic, wind-whipped spray can reduce visibility to less than 1 mile with the strongest storm winds. Open-ocean wave heights associated with intense lows can exceed 40 feet.

GENERAL WEATHER. By early June, intense migratory lows produce moderate to heavy rainfall, snow/snowshowers, and strong winds every 2nd or 3rd day. Drake Passage is the primary storm track for fast-moving winter lows. Intense surface lows with deep 500-mb troughs often produce a secondary surface low between 45 and 55° S in the southeastern Pacific. These secondary lows move slowly eastward into southwestern Tierra del Fuego, while the primary low moves rapidly eastward or southeastward with the mid-level trough. Most surface lows pass several hundred miles south of the Falklands.

Secondary lows can stall for 24 to 48 hours, reorganizing and intensifying along Tierra del Fuego's southwestern coastline. Heavy rains, low ceilings, and wind gusts exceeding 50 knots are possible. Frequently, the secondary low begins to track eastward in advance of the next storm system. Moving rapidly into Drake Passage, these surface lows may overtake the secondary low and form an "instant occlusion" over central and eastern Tierra del Fuego (see Chapter 2). Poor weather can continue for another 24 to 36 hours.

Strong blocking highs occasionally develop southeast of the Southern Islands between 50 and 60° S and 35 to 45° W. This causes the primary storm track to deviate northeastward toward the Falklands and cold fronts to slow down or stall. Two to four times a month, a polar high surges northward into Patagonia behind a deep, slow-moving surface low. Snow showers, sleet, and ice pellets are common with the strong southerly winds and low temperatures behind the cold front. Within 36 hours, the snow/rain mix changes back to rain within the marine boundary layer, and surface temperatures rise into the high 30s° F (3-4° C) or low 40s (5-6° C).

A special type of polar low forms along the sea/ice interface. Local drainage winds from Antarctica produce these intense lows in the Weddell and Bellingshausen Seas from May to September. Their circulation is usually small and the clouds low-level, but they produce strong winds and heavy precipitation. They usually move along the ice edge, but they can pass through Drake Passage. They can last for 12 to 24 hours before dissipating. Conditions associated with these systems are extremely poor; little advance warning is possible unless they are detected in satellite imagery.

SKY COVER. Mean cloudiness for mid-winter ranges from 50 to 70% over most of the Southern Islands (Figure 6-141). During most winters, several surface lows move in succession through Drake Passage, causing multilayered skies over Tierra Del Fuego for 10 to 20 consecutive days. Low clouds are usually in a broken deck of stratus or stratocumulus with bases between 2,000 and 4,000 feet (610 and 1,220 meters) AGL. Ceilings below 500 feet (160 meters) AGL are not uncommon in Drake Passage. Embedded cumulus can develop along a cold front with bases between 1,000 and 5,000 feet (305 and 1,525 meters) AGL; tops rarely exceed 10,000 feet (3,050 meters) MSL.

With deep lows, nimbostratus is the predominant cloud type; bases average 3,000 feet (915 meters) AGL and tops merge with the middle clouds above. Altostratus and altocumulus form at 12,000 feet (3,660 meters) MSL; tops reach 15,000 feet (4,570 meters) MSL. Cirrus and cirrostratus develop above 20,000 feet (6,100 meters) MSL with the upper-level jet.

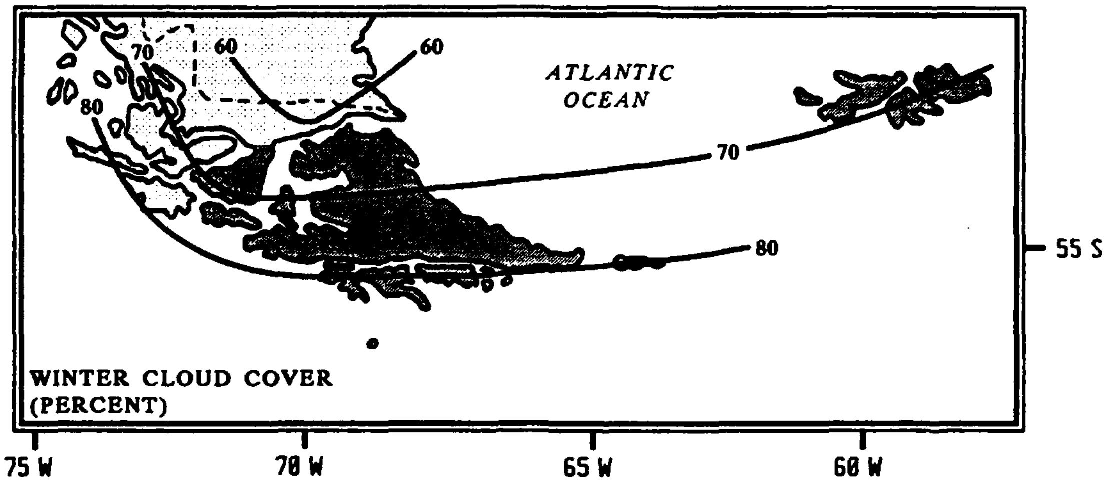


Figure 6-141. Mean July Cloud Cover, Southern Islands.

Ceilings below 3,000 feet (915 meters) occur every 3rd day across Tierra Del Fuego and every other day in the Falkland (Malvinas) Islands. Along Tierra Del Fuego's southern fringes, ceilings below 3,000 feet (915 meters) can develop in the coastal hills for several hours every day. Drake Passage has the highest frequency of low ceilings in winter because it is in the primary storm track (Figure 6-142). Low ceilings last for 12 to 24 hours before cloud bases temporarily lift between storms.

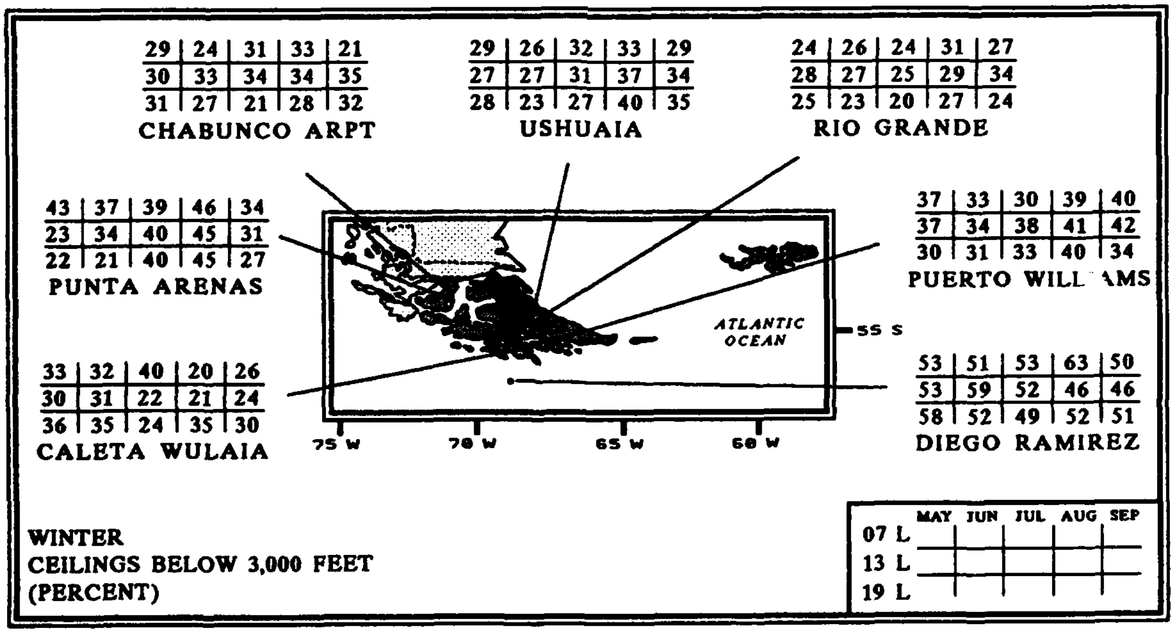


Figure 6-142. Winter Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Islands.

VISIBILITY. Visibility falls below 3 miles with moderate to heavy rain and snow produced by migratory lows. Blowing snow occurs when polar highs move into southern South America. Fog is possible in sheltered inlets and coastal hillsides with slow-moving systems. Caleta Wulaia, located on a windward coast near hilly terrain, has the highest frequency of low visibility (Figure 6-143). Over Drake Passage and the South Atlantic, wind-whipped spray can reduce visibility to less than a half-mile.

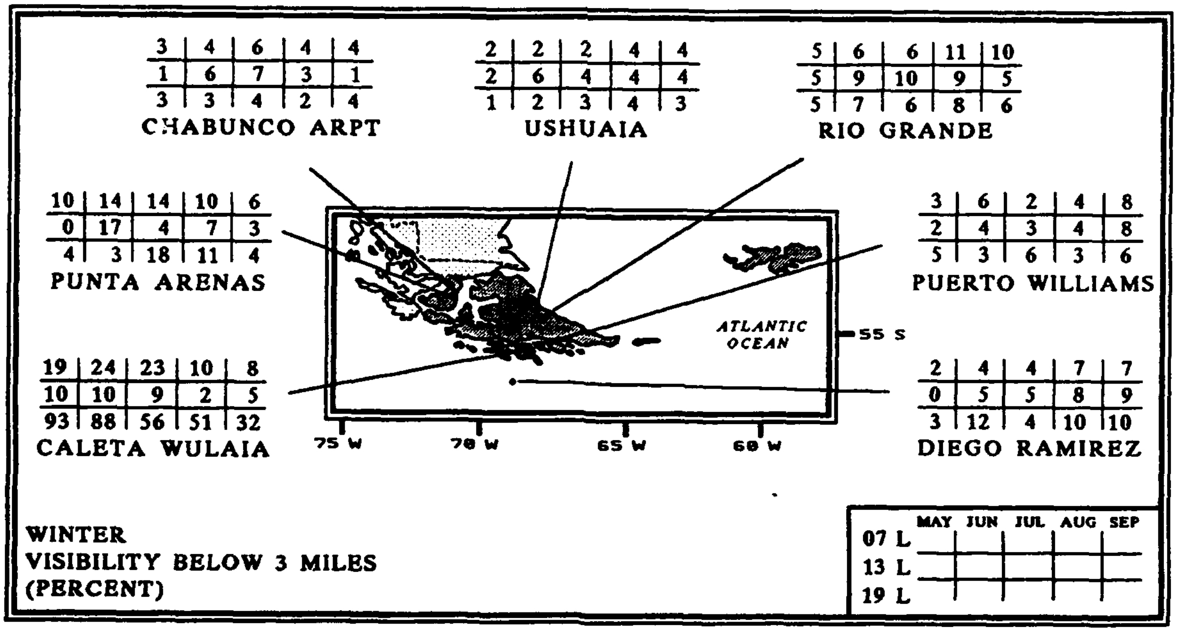


Figure 6-143. Winter Percent Frequencies of Visibility Below 3 Miles, Southern Islands.

WINDS. Westerlies are very strong in Drake Passage, even during fair-weather periods; speeds rarely drop below 15 knots. Migratory lows frequently produce strong winds. Secondary low formation is common along active cold fronts northwest of Tierra del Fuego between 35 and 45° S. Northwesterly to easterly surface flow into these lows is common for up to 24 hours across Tierra del Fuego. Wind speeds average 20 knots and occasionally exceed 40 knots. After frontal passage, southeasterly to westerly winds dominate; strong high-pressure cells move northeastward toward the Falklands. The winds shift to northerly when the high migrates northward. Wind speeds intensify away from the high's center to 45 or 50 knots on the western side of these northward-moving cells; maximum gusts exceed hurricane force. Typical winter storm movements are shown in Figure 6-144; northward-moving polar highs are shown in Figure 6-145.

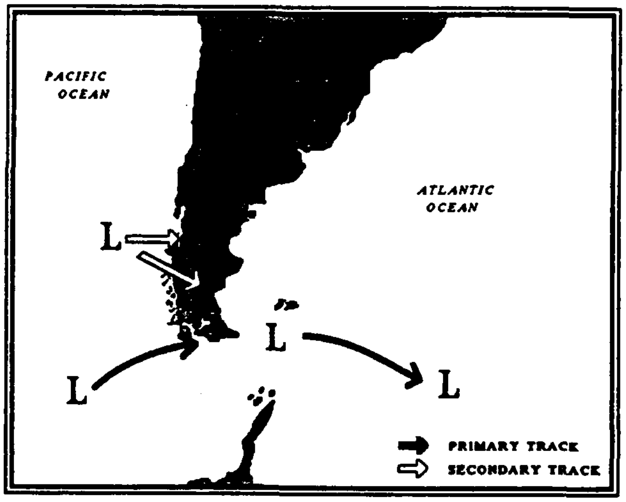


Figure 6-144. Primary and Secondary Low Movement Across the Southern Islands, Winter. Two surface, are commonly associated with a polar jet and deep upper-level troughs extending southeast to northwest across Drake Passage.

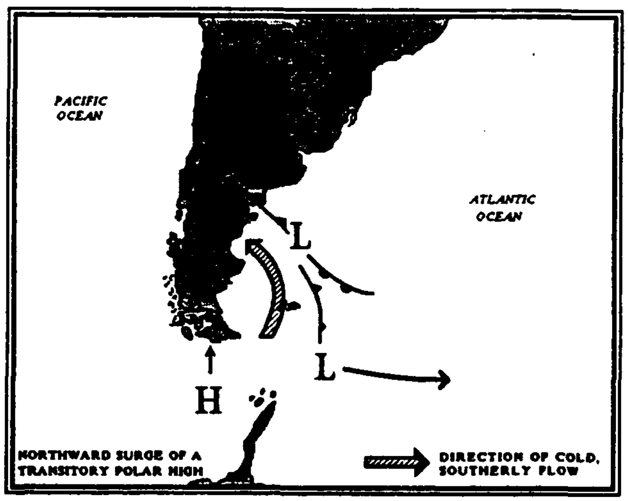


Figure 6-145. Northward Surge of Transitory Polar Highs Across Southern South America. Polar highs may enter Tierra Del Fuego two to four times a month in some winters. Cold southerly flow exceeds 35 knots and produces heavy snows and poor visibility.

Mean surface wind speeds (Figure 6-146) for the Southern Islands depend on terrain. East-central Tierra Del Fuego is sheltered from the strong winds through Drake Passage by hills and narrow coastal waterways. Winds are consistently strong and westerly over open water and the Falklands. Note the percentage of calm conditions (number within circles) over the landlocked and southernmost island chains of Tierra del Fuego in Figure 6-147). Calm conditions are extremely rare over open water, where winds associated with migratory lows can exceed hurricane force.

STATION	MEAN WIND SPEED				
	MAY	JUN	JUL	AUG	SEP
CALETA WULAIA	10	8	7	7	9
DARWIN	14	15	14	14	17
DIEGO RAMIREZ	18	18	17	18	21
FOX BAY	17	17	17	18	19
PORT STANLEY	19	20	20	19	18
PUNTA ARENAS	7	6	8	9	9

Figure 6-146. Mean Winter Wind Speeds, Southern Islands.

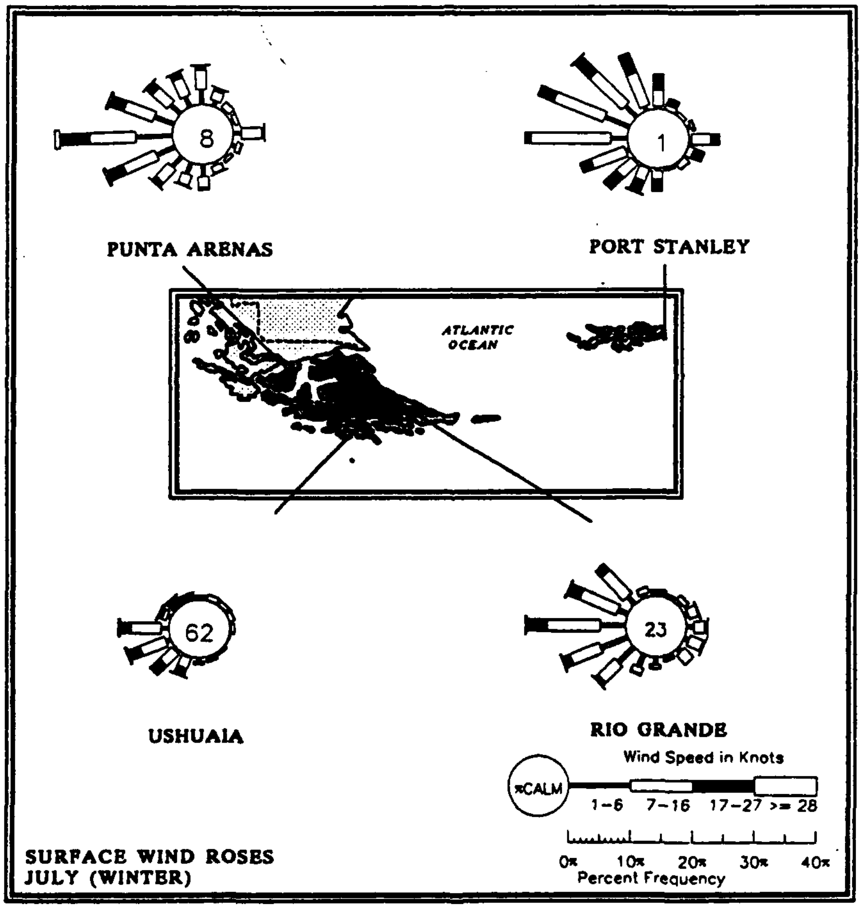


Figure 6-147. July Surface Wind Roses, Southern Islands.

The mean mid- and upper-level wind direction is west-southwesterly, but this flow can be dramatically altered by throughs. Intense troughs often produce a southeasterly or southerly branch of the jet with speeds exceeding 120 knots along the upwind side of the trough. The jet can turn abruptly northeastward and intensify at the trough base rather than continuing northward and weakening.

PRECIPITATION. Mean monthly winter rainfall decreases from southwest to northeast (Figure 6-148). Four inches (102 mm) is normal along the western island chain, with 1 inch (25 mm) or less in the extreme northeast. Storm tracks and terrain influences produce the rain shadow.

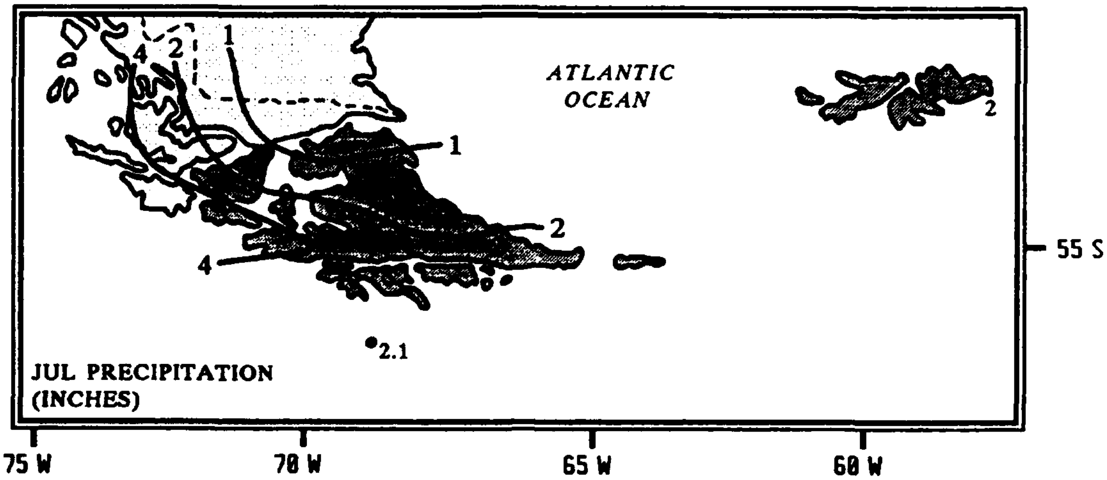


Figure 6-148. Mean July Precipitation, Southern Islands. Station data for Diego Ramirez Island and Stanley (The Falklands) is insufficient to draw representative isohyets.

Moderate rain usually falls along the cold front. Rain bands usually move southwest to northeast with a migratory low moving eastward through Drake Passage. Scattered rain bands occasionally move northwest to southeast when associated with a secondary low off the Chilean coast north of 45° S. Rainfall is lighter in this case, since most of the moisture is lost along the western Andes. In rare cases, a flow pattern produces numerous secondary lows north of Tierra del Fuego for several weeks to a month. This flow produces a drier winter (less than 1 inch/25 mm each month) everywhere on Tierra Del Fuego.

Warm fronts rarely develop significant overrunning precipitation unless the primary storm track is established through Drake Passage. Warm fronts form with downsloping northwesterlies along the eastern Andes when secondary lows cross the Andes between 35 and 45° S. Overrunning precipitation is light and widely scattered.

Drizzle and scattered light showers can persist for 24 to 36 hours if a secondary surface low forms along a cold front, or if the primary cold front stalls along the southern Andes. Heavy rain is possible in rare cases if a stationary front forms along the stalled cold front. If the stationary front oscillates between 40 and 50° S, the upper-air trough supporting the surface low has weakened or sheared away from the surface trough. Usually the upper-level flow is transitioning from meridional to zonal flow, causing the stationary front to stagnate along Tierra del Fuego's northern edge. In this case, maritime polar air combines with strong mid-latitude flow to produce heavy rainfall. On even rarer occasions, the stationary front pushes southward into Drake Passage and eastward to the Falklands.

Snowfall is common every 4th or 5th day from June to August; it is associated with cold fronts and the massive cloud shields south of the eastward-moving surface lows in Drake Passage. These lows often produce an initial cold front dominated by maritime polar air. Light or moderate rain mixed with sleet, freezing rain, and snow flurries is common. Following the polar front is an Antarctic front that trails several hundred miles behind the maritime polar air mass. These fast-moving Antarctic fronts can produce moderate snow showers over a 3- to 9-hour period. The air mass is 10 to 15° F (4 to 8° C) colder than the polar front. The Antarctic front may catch the polar front between Tierra del Fuego and the Falklands. Six-inch (152-mm) snowfall is rare on the coasts, but common in the coastal hills above 2,000 feet (610 meters). The Falklands usually get snow when these cold fronts occlude.

PUNTA ARENAS

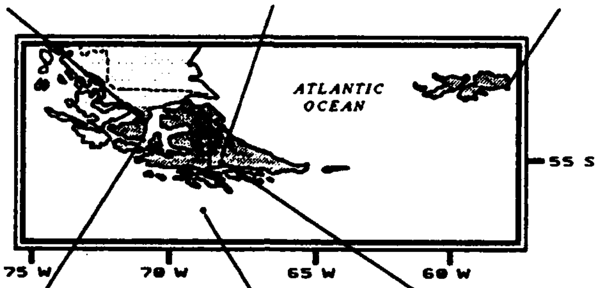
5.7	5.4	5.0	3.6	4.4
1.3	1.7	1.6	1.8	1.2
0	0	0	0	0
na	na	na	na	na

USHUAIA

4.1	5.2	3.9	7.7	7.7
2.0	1.3	1.7	0.8	0.8
0	0	0	#	0
5	11	10	10	7

PORT STANLEY

na	na	na	na	na
1.5	1.1	1.2	1.0	0.5
na	na	na	na	na
2	2	2	3	1



CABO SAN ISIDRO

6.3	6.9	6.5	5.4	6.1
1.6	1.0	0.8	1.1	1.1
0	0	0	0	0
na	na	na	na	na

DIEGO RAMIREZ

6.9	24.1	27.5	39.5	20.4
1.3	4.9	6.5	6.2	2.8
0	#	0	0	0
na	na	na	na	na

PUERTO WILLIAMS

3.2	2.8	3.3	1.9	5.2
1.5	0.7	0.9	0.4	2.1
0	#	0	#	#
na	na	na	na	na

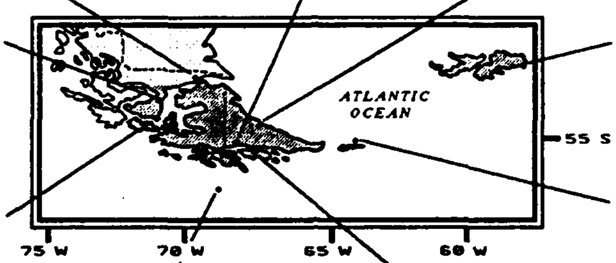
WINTER
TABULAR PRECIPITATION DATA
(AMOUNTS IN INCHES)
- LESS THAN 0.5 DAYS
na - DATA NOT AVAILABLE

	MAY	JUN	JUL	AUG	SEP
MAXIMUM MONTHLY					
MAXIMUM 24-HOUR					
THUNDERSTORM DAYS					
SNOW DAYS					

Figure 6-149. Winter Tabular Precipitation Data, Southern Islands.

THUNDERSTORMS are rare. They require a persistent high-pressure ridge in Drake Passage advecting warm, moist air poleward while a deep, cold trough digs to the west of the ridge. The ridge must stall over Drake Passage for 7 to 10 days. A thunderstorm may produce small hail and a moderate rain/snow mix in Drake Passage.

TEMPERATURE. Mean daily highs range from 54° F (12° C) at Punta Delgada to 38° F (3° C) at Isla Observatorio (Figure 6-150). The record high is 71° F (22° C) at Punta Delgada in August. Mean daily lows range from 40° F (4° C) at Punta Delgada to 28° F (-2° C) at Rio Grande and Ushuaia. The record low is -6° F (-21° C) at Ushuaia in July. Antarctic air masses produce the record lows, which are not as extreme as in the northern hemisphere at the same latitudes because of the moderating influence of the oceans.



WINTER TEMPERATURES (F)

Station		MAY	JUN	JUL	AUG	SEP
PUNTA DELGADA	EXTREME MAXIMUM	65	56	57	56	64
	AVERAGE MAXIMUM	46	42	40	41	46
	AVERAGE MINIMUM	35	35	34	32	35
	EXTREME MINIMUM	23	20	19	16	22
USHUAIA	EXTREME MAXIMUM	69	66	64	59	72
	AVERAGE MAXIMUM	44	40	40	42	46
	AVERAGE MINIMUM	32	28	28	29	33
	EXTREME MINIMUM	-4	-1	-6	-3	13
RIO GRANDE	EXTREME MAXIMUM	59	51	49	52	59
	AVERAGE MAXIMUM	41	38	38	40	46
	AVERAGE MINIMUM	29	28	28	29	32
	EXTREME MINIMUM	9	6	2	14	14
PUNTA ARENAS	EXTREME MAXIMUM	63	52	55	55	61
	AVERAGE MAXIMUM	43	40	38	40	45
	AVERAGE MINIMUM	35	33	33	33	35
	EXTREME MINIMUM	16	11	12	15	19
PORT STANLEY	EXTREME MAXIMUM	58	51	50	52	59
	AVERAGE MAXIMUM	44	41	40	41	45
	AVERAGE MINIMUM	34	31	31	31	33
	EXTREME MINIMUM	20	12	16	12	13
CABO SAN ISIDRO	EXTREME MAXIMUM	57	55	53	52	61
	AVERAGE MAXIMUM	44	40	40	42	44
	AVERAGE MINIMUM	36	33	32	34	35
	EXTREME MINIMUM	24	20	17	22	23
ISLA OBSERVATORIO	EXTREME MAXIMUM	56	46	46	51	53
	AVERAGE MAXIMUM	42	39	38	39	42
	AVERAGE MINIMUM	36	33	33	33	34
	EXTREME MINIMUM	23	22	17	20	18
DIEGO RAMIREZ	EXTREME MAXIMUM	54	50	48	48	50
	AVERAGE MAXIMUM	43	41	40	41	42
	AVERAGE MINIMUM	36	35	34	34	35
	EXTREME MINIMUM	21	25	21	23	25
PUERTO WILLIAMS	EXTREME MAXIMUM	63	54	50	55	61
	AVERAGE MAXIMUM	44	41	40	42	46
	AVERAGE MINIMUM	32	31	30	32	32
	EXTREME MINIMUM	21	16	18	16	21

Figure 6-150. Winter Tabular Temperature Data, Southern Islands.

FLIGHT HAZARDS. Moderate, isolated severe turbulence is common with most frontal systems that approach Tierra del Fuego from the west and southwest. Lenticular and rotor clouds have been observed as far east as the Falklands. Downslope winds along the eastern Andes can produce moderate to severe turbulence between 5,000 and 10,000 feet (1,525 and 3,050 meters) MSL with fronts. Severe turbulence is possible between 20,000 and 40,000 feet (6.1 and 12.2 km) MSL with the jet stream. Moderate to severe icing is possible in most storms. Light to moderate rime icing is common above 1,000 feet (305 meters) MSL. expect moderate to severe mixed icing in heavy cumulus buildups.

GROUND HAZARDS. Above 1,000 feet (305 meters) MSL, freezing rain, sleet, and ice pellets are possible with most fronts. Heavy snowfall (more than 12 inches/315 mm) has occurred along many peaks above 3,000 feet (915 meters). Dense fog is not uncommon in sheltered coastal inlets and along coastal terrain. Building and ship superstructures rapidly accrete rime ice--often to the point of endangering the ship's stability. Over open ocean, wave heights associated with intense lows can exceed 40 feet; "rogue" wave heights in excess of 60 feet have been reported.

GENERAL WEATHER. By late October, the 500-mb trough in the southeastern Pacific weakens; secondary low formation off the Chilean coast no longer occurs routinely. The primary storm track shifts southward in Drake Passage, but individual storms still affect Tierra del Fuego every 3rd day. Most cloud cover, precipitation, and low visibilities are concentrated along the cold front and around the low.

A secondary source of cyclogenesis is found near the Rio de la Plata valley in eastern Argentina. These storms track southeastward to the north and east of the Falkland (Malvinas) Islands every 4 or 5 days when deep upper-level troughs develop in the southwestern Atlantic. Warm fronts contain moist northwesterly to northeasterly winds and showery precipitation, while cold fronts produce moderate rainfall and strong westerly or southwesterly winds.

SKY COVER. Mean cloudiness is most extensive along Tierra Del Fuego's southern fringes (Figure 6-151). Stratus, nimbostratus, stratocumulus, and embedded cumulus associated with frontal systems dominate. Stratiform cloud bases range from 1,000 to 3,000 feet (305 and 915 meters) AGL, while cumuliform clouds have bases between 2,000 and 5,000 feet (610 and 1,525 meters) AGL. Stratiform cloud tops rarely exceed 7,000 feet (2,135 meters), while cumuliform clouds seldom extend above 10,000 feet (3,050 meters) MSL. Mid-level cumuliform clouds produce broken decks between 8,000 and 12,000 feet (2,440 and 3,660 meters) MSL. Altocumulus tops normally reach 16,000 feet (4,570 meters). Cirrus/cirrostratus bases start at 20,000 feet (6,100 meters) MSL and are layered to 30,000 feet (9.2 km).

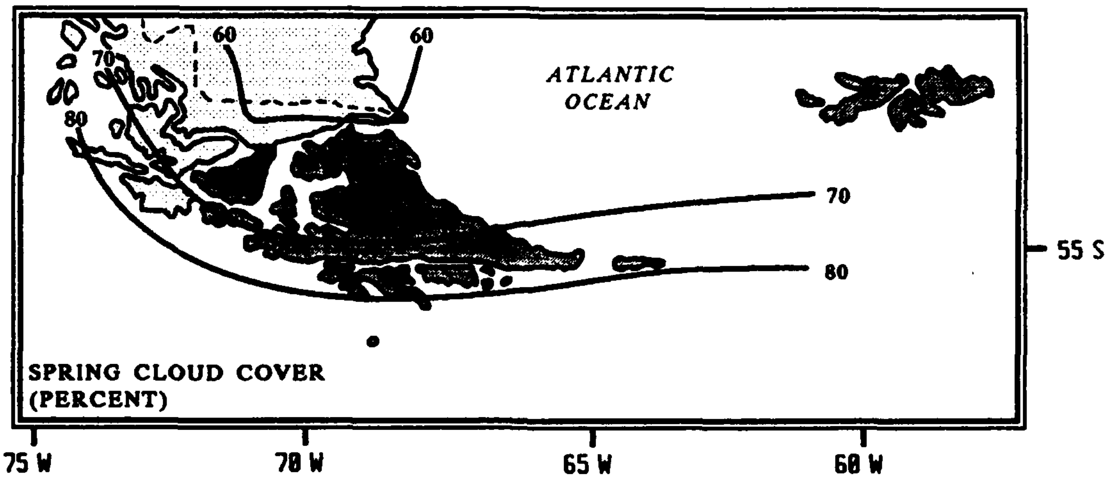


Figure 6-151. Mean October Cloud Cover, Southern Islands.

Low-pressure systems, modified by local terrain, determine the frequency of low ceilings. The highest frequencies are on upwind slopes, while the lowest are in the rain shadow on the northeastern portions of the islands. Diurnally, the highest frequencies of ceilings below 3,000 feet (915 meters) occur between 1400 and 1800L (Figure 6-152) except along Tierra Del Fuego's southern fringes, where frontal passages are so frequent in Drake Passage that any diurnal variation is masked.

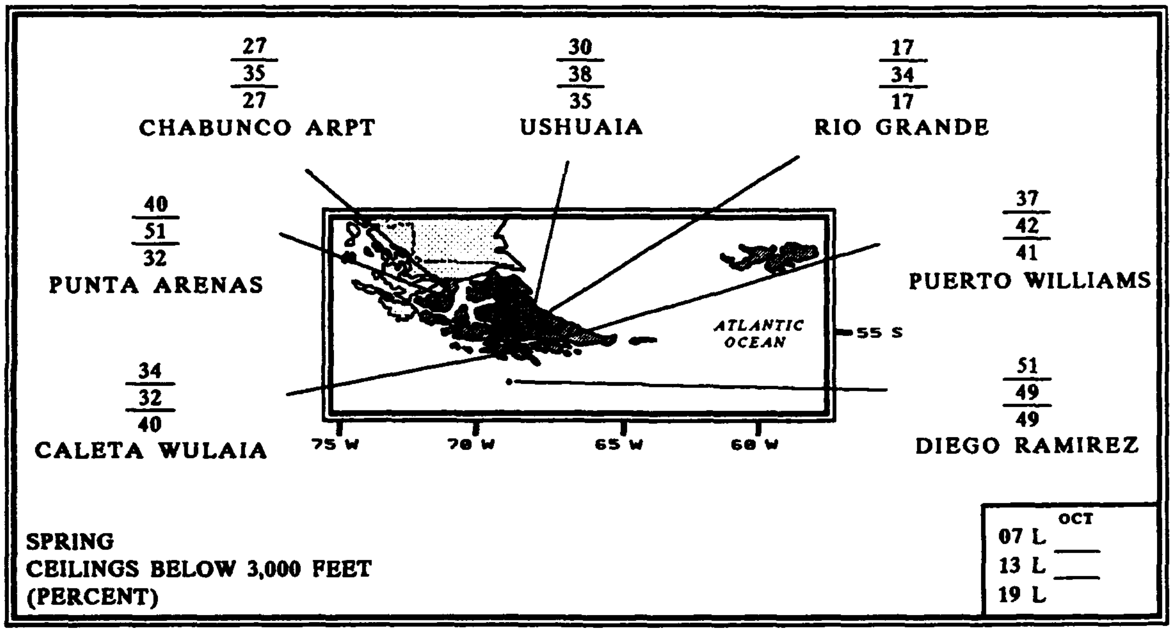


Figure 6-152. Spring Percent Frequencies of Ceilings Below 3,000 Feet (915 meters), Southern Islands.

VISIBILITY. Visibilities below 3 miles are due primarily to moderate or heavy precipitation. Strong winds accompanying heavy rain can lower visibility to 1 mile for several hours. Post-frontal fog is common in the narrow waterways and inlets of the Strait of Magellan, but visibilities below 3 miles are usually confined to the sheltered inlets and coastal hillsides surrounding the strait. Blowing snow and blizzard conditions are extremely rare after mid-October in the coastal ranges, but visibilities can approach zero for up to 6 hours with early spring storms. Over Drake Passage and the South Atlantic, wind-whipped spray can reduce visibility to less than 1 mile.

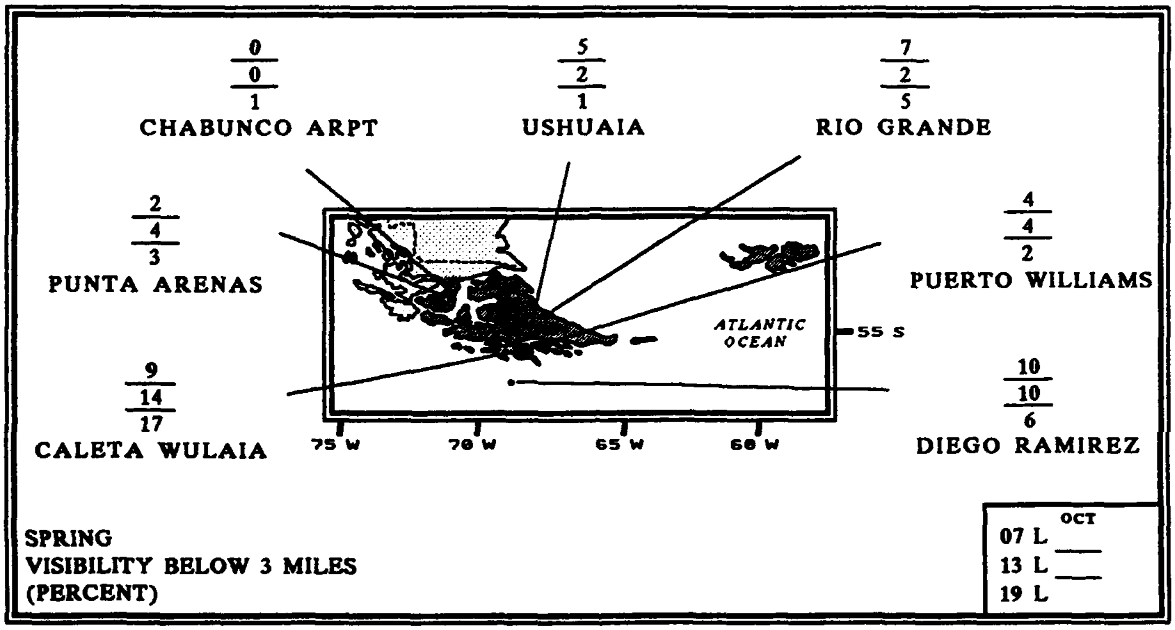


Figure 6-153. Spring Percent Frequencies of Visibility Below 3 Miles, Southern Islands.

WINDS. Westerlies dominate, with frequent northwesterly and southwesterly winds produced by migratory systems. Migratory troughs affect Tierra del Fuego every 2 to 4 days, producing northwesterly winds ahead of them and southwesterlies behind. Northwesterlies average 15 knots; southwesterlies, 20 knots. On rare occasions, these troughs become stationary north of Tierra del Fuego. Southeasterly to easterly flow can exceed 35 knots across the Falkland Islands with a strong gradient. Fair-weather periods are dominated by westerlies.

Surface winds average 18 knots in Drake Passage, while wind speeds in sheltered inlets and coastlines average 11 knots (Figure 6-154).

Coastal terrain reduces wind speeds and modifies directions. In Figure 6-155, the sheltered stations are evident by the high percent frequencies of calm conditions (number within circles). Port Stanley reports no calm conditions in October. Over open ocean, the strongest winds associated with intense lows can exceed hurricane force.

STATION	OCT
CALETA WULAIA	8
DARWIN	19
DIEGO RAMIREZ	17
FOX BAY	20
PORT STANLEY	20
PUNTA ARENAS	9

Figure 6-154. Mean Spring Wind Speeds, Southern Islands.

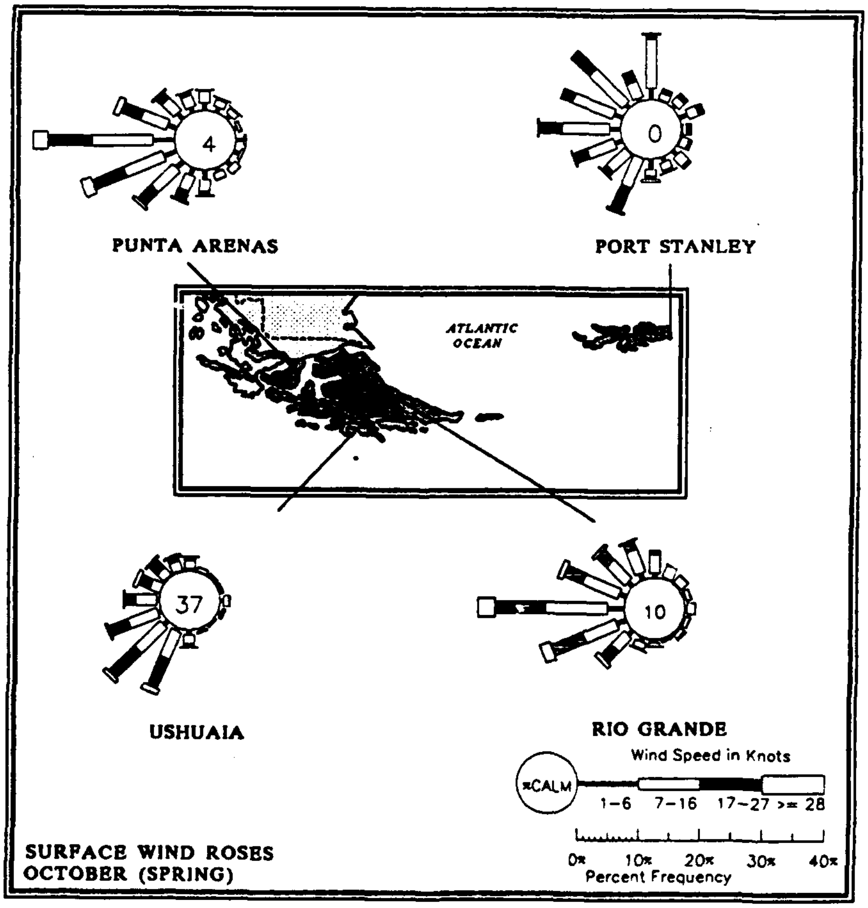


Figure 6-155. October Surface Wind Roses, Southern Islands.

Mid- and upper-level flow is westerly, modified by migratory systems. Mean wind speeds vary from 26 knots at 5,000 feet (1,525 meters) MSL to 53 knots at 30,000 feet (9,145 meters) MSL. The polar jet can affect the zone with 100- to 120-knot winds when strong troughs are present, but much less frequently when zonal flow is established.

PRECIPITATION. Mean October rainfall shows a distinct dry zone over the northeastern half of Tierra del Fuego, as represented by the 1-inch (25-mm) isohyet (Figure 6-156). The South Atlantic High begins to migrate southward, bringing increased subsidence and dry northwesterly outflow into the Southern Islands. The intensity of lows between 35 and 45° S decreases. Surface lows nearly always track through Drake Passage without forming secondary lows in the eastern South Pacific. Strong zonal flow above 700 mb inhibits mid-level trough formation in the southeastern Pacific.

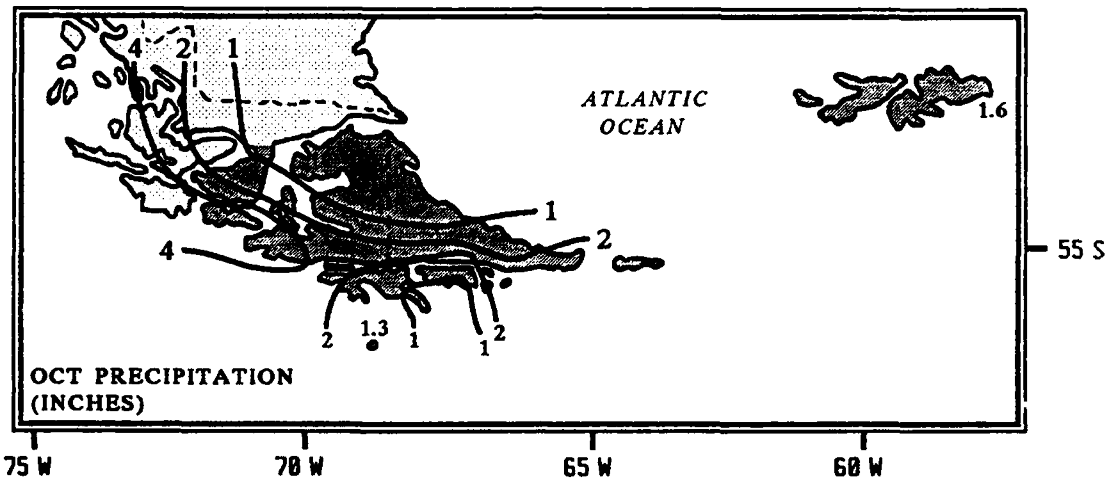


Figure 6-156. Mean October Precipitation, Southern Islands. Station data for Diego Ramirez Island and Stanley (The Falklands) is insufficient to draw representative isohyets.

Moderate and heavy rainshowers are confined to the frontal boundaries. Slow-moving systems with upper-level support can produce widespread areas of precipitation due to overrunning along the warm front. Along the cold front, an isolated thundershower can develop on the upwind side of the upper-air trough. Snowfall is possible on the poleward side of the surface low within a 50-NM radius of the low. Snowfalls of more than 4 inches (102 mm) are not uncommon with slow-moving surface lows.

Fair-weather periods produce isolated convective showers along the coastal hills, but they are short-lived. Strong surface winds permit isolated areas of diurnal convection. Showers rarely produce more than 0.25 inches (6 mm) of rainfall.

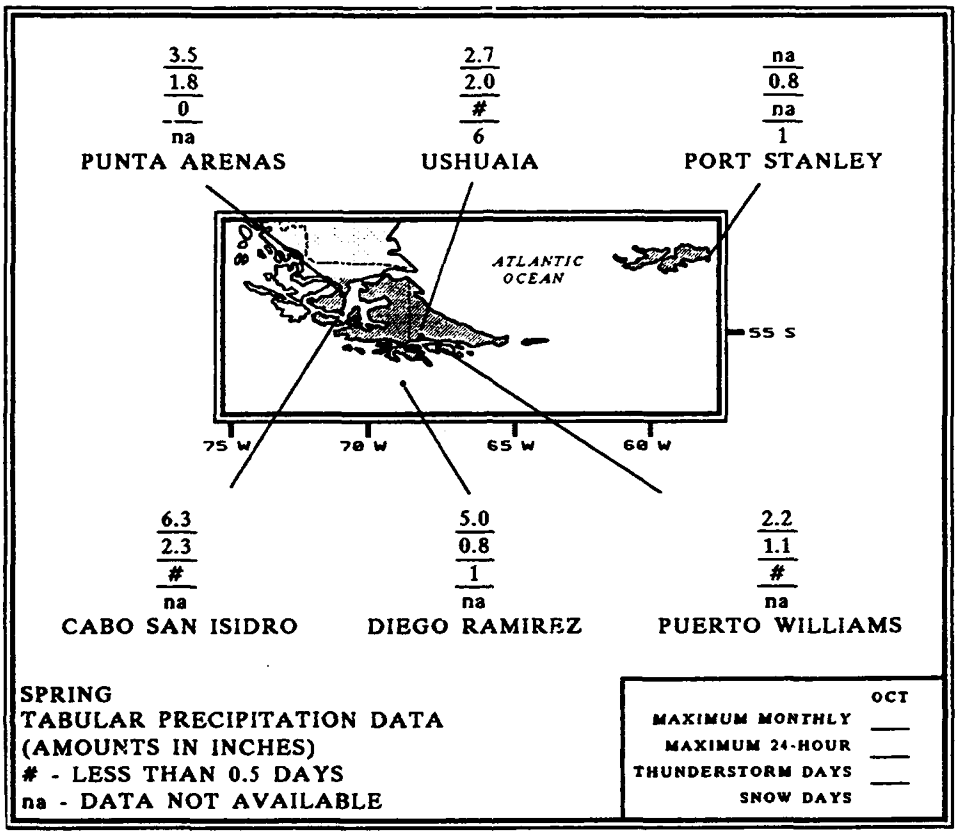


Figure 6-157. Spring Tabular Precipitation Data, Southern Islands.

THUNDERSTORMS occur most often in October, but thunderstorm days still average less than 1 at most locations. The longer periods of daylight increase instability. Deep mid- and upper-level troughs trigger isolated thunderstorms ahead of and along cold fronts. Thunderstorms are rarely severe, but surface winds can exceed 35 knots along the cold front. A strong polar jet often accompanies these troughs, producing moderate turbulence near isolated convective cells. Tops rarely exceed 25,000 feet (7.6 km) MSL.

TEMPERATURE. Mean daily lows range from 34 to 45° F (1 to 7° C); highs, from 44 to 63° F (7 to 17° C). The record high in October is 87° F (31° C) at Punta Delgada; the record low; 20° F (-7° C), at Rio Grande. Relative humidity is generally uniform, averaging 75 to 85% at 0700L and 70 to 75% at 1300L.

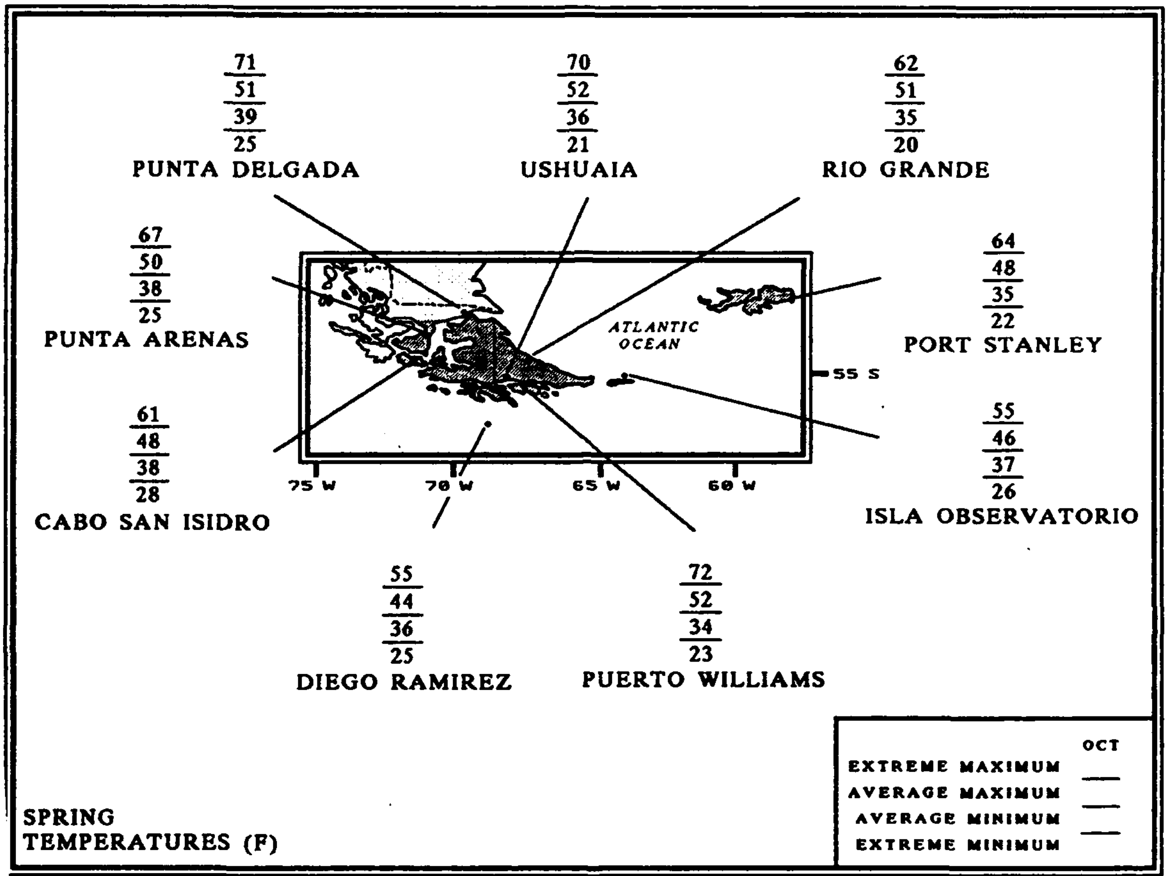


Figure 6-158. Spring Tabular Temperature Data, Southern Islands.

FLIGHT HAZARDS. With strong westerlies, moderate to severe low-level turbulence is common near higher terrain. Standing mountain waves are common along the eastern Andes between 5,000 and 10,000 feet (1,525 and 3,050 meters) MSL. Wind shear is possible below 5,000 feet (1,525 meters) MSL with cold fronts. At jet-stream levels, moderate turbulence is not uncommon over Drake Passage. Mean freezing levels are near 2,000 feet (610 meters) MSL. Light to moderate rime icing is likely in stratiform clouds, while moderate to severe mixed icing can be expected in convective clouds with most frontal passages.

GROUND HAZARDS. Freezing rain, sleet, fog, and occasional heavy snow are possible. Building and ship superstructures rapidly accrete rime ice--often to the point of endangering a ship's stability. Over Drake Passage and the South Atlantic, wind-whipped spray can reduce visibility to less than 1 mile.

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SOUTH AMERICA

South of the Amazon River

A Climatological Study

Make the following pen & ink corrections:

Page iv, para 6, line 2: Change "brach" to "branch."

Page 3-54, para 2, line 6: Change "fsorm" to "forms."

Page 3-57, para 3, line 5: Change "ispronounced" to "is pronounced."

Page 3-59, 2nd column, line 4: Delete "Maximum speeds are."

Page 3-70, caption, Figure 3-41: Delete "(mm)."

Page 3-79, caption, Figure 3-50: Delete "(mm)."

Page 4-73, para 3, line 8: Change "of shear line" to "or shear line."

Page 4-217, under "Strong ENSO Events," para 2, change lines 1and 2 to read: "Research into this phenomenon by both South and North American meteorologists continues; the ..."

Page BIB-3, third and fourth entries: Change "BRAS IL IA" to "BRASILIA."

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