

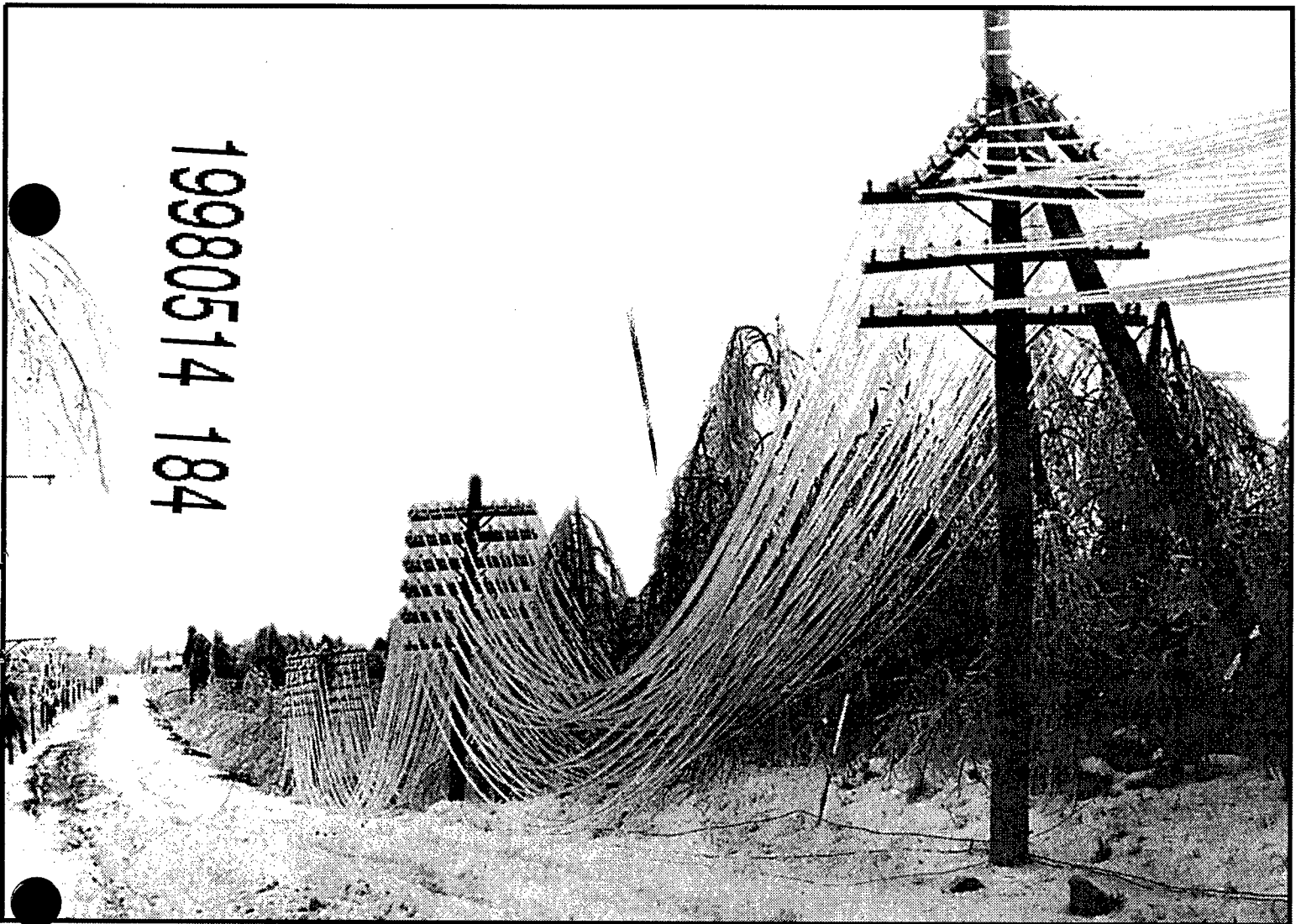


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FREEZING PRECIPITATION




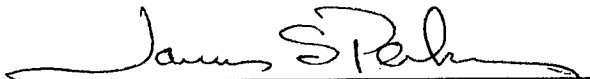
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FOREWORD

This technical note is the product of Chief Master Sergeant (USAF, Retired) Gene Weber's 46 years of practical forecasting experience in the Air Force Weather business—as an active duty forecaster until 1982, and subsequently as one of Air Force Global Weather Center's and now Air Force Weather Agency's civilian lead severe weather forecasters. His technical leadership and experience are legendary—and irreplaceable. But his legacy will live on, in this technical note, and in his previous, 1982 technical note on meteorological satellite photo interpretation. Thanks, Gene, for focusing us on the fundamentals of freezing precipitation forecasting in this publication, and for your outstanding contributions to operational meteorology.

Colonel Jack Hayes

PREFACE

The following information is the result of 11 years of research collecting and analyzing freezing precipitation occurrences over the continental United States. Approximately 500 samples were collected from the 0000Z and 1200Z data bases. The empirical information shown in this study focuses on the eastern two-thirds of the U.S., from the Rockies to the East Coast.

At the Air Force Weather Agency (AFWA) Severe Weather unit, we are responsible for forecasting freezing precipitation (along with thunderstorms, strong surface winds, heavy snow and rain) for more than 300 locations across the U.S. In addition to point forecasting, a Military Weather Advisory (MWA) is produced every 6 hours depicting the severe weather criteria mentioned above; one of the advisory criteria is freezing precipitation.

I began this study in 1985 to look at the NGM's 1,000- to 500-mb thickness and 850-mb temperature fields to arrive at some sensible rules to forecast synoptic freezing precipitation events based on model guidance. The NGM, initial to 48 hour package, is the primary tool used in daily forecasting. Other models that became operational (AVN, ETA) later on were not readily accessible on a routine basis. Additionally, other thickness levels such as surface to 1,000 feet were not routinely available.

One product that is missing throughout this study is Skew-T data. The intent of this study is for forecasters to be able to recognize "setups" for freezing precipitation using model guidance. Further investigation of the air mass(es) affecting their locations can then be looked at through Skew-Ts. It is assumed that forecasters realize that low-level inversions exist when polar air masses are present.

There has been an explosion of auxiliary weather information within the past few years through the Internet; unfortunately programs such as P.C. Grids came too late for this study. Hopefully, I have captured most freezing rain (and to a lesser degree freezing drizzle) events.

This study should help the novice forecaster; synoptic pattern recognition is still one of the most important considerations when producing a forecast. Also, it should be helpful to experienced forecasters as a review for the upcoming winter season.

ACKNOWLEDGMENTS

This technical note is dedicated to all of the men and women, past and present, whom I have worked with in the Severe Weather Unit since the early 1980s. These personnel were and are dedicated to their jobs, which can be stressful and trying at times.

Special dedication to my dear sister, Jo Ann, age 63, who died in Louisville, Ky., on December 8, 1997 from cancer. It was a difficult for me to focus on the final sections of this technical note due to her deteriorating condition.

Special thanks to Jim Rouiller (Master Sergeant, Retired) whose encouragement (and persistence) kept me on track for the past 5 years.

Special thanks also goes to Staff Sergeant Mike Taylor, whose dedication, knowledge, and expertise in the word processing and layout of this technical note, was essential to publish it in time prior to the freezing precipitation season.

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EUGENE M. WEBER

Freezing Precipitation

Chapter 1

INTRODUCTION

General. This technical note contains an orderly discussion of the atmospheric conditions favorable for the development of freezing precipitation.

Empirical Rules. There have been many good thickness and temperature rules developed over the years to forecast freezing precipitation. Some are depicted as graphs while others simply use thickness and temperature thresholds at selected millibar (mb) levels. Severe weather forecasters are often busy dealing not only with freezing precipitation but also with other severe weather events. They need a "quick and dirty" synoptic analysis program on

identifying potential freezing precipitation threat areas considering other factors such as moisture, positive vorticity advection (PVA), vertical motion, upslope, and warm air advection.

An attempt was made to identify areas across the continental United States (CONUS) where freezing precipitation is likely to occur most often (synoptic pattern recognition). Many examples are presented throughout this technical note; it is hoped they will serve as a guide to the forecaster in producing a freezing precipitation forecast.

Chapter 2

REGIME RECOGNITION

General. Synoptic scale freezing precipitation events generally begin by mid-November over the central and northern continental United States (CONUS) as continental polar (cP) air masses become the dominant anticyclonic systems. The two anticyclonic surface patterns that appear routinely on surface charts during the cold season are the receding high and prevailing high (Figures 2-1 through 2-4). These are generic models; many variations will occur. It is important for forecasters to recognize which of these two patterns will exist when a storm system is developing and moving toward their area.

Receding High. Migrating cP highs from Canada or highs that have crossed the Rockies modify and move towards the eastern CONUS. Return southerly flow and the low-level jet transport warmer and moister air northward ahead of the next developing disturbance. It is not uncommon for warm frontogenesis to appear over the Great Plains while the old warm front weakens to the south. Precipitation may develop rapidly. This pattern is often observed with zonal flow or short-wave troughs independent of long-wave systems.

Prevailing High. During January and February, a cold ridge can extend southward into southern Texas

across to southern Florida. The polar jet and primary storm tracks are located across the southern states. Widespread overrunning precipitation develops within the colder easterly low-level flow and becomes extensive when frontal disturbances intensify. This pattern is often observed with large-scale trough/ridge systems.

Autumn Patterns. During autumn, maritime pacific (mP) polar fronts and anticyclones track across the CONUS due to increased short wave activity within zonal flow. Generally the polar jet still lies in its summer position over the northern CONUS and southern Canada; it begins to migrate southward during October. Figure 2-5 depicts a typical autumn surface pattern; mP cold fronts moving across the CONUS usually bringing pleasant (usually dry) weather.

Occasionally, mP frontal systems decelerate over the Rockies and western Great Plains in response to upper-level deepening (Figures 2-6 and 2-7). This pattern is more likely to occur beginning in late October and may produce a narrow area of freezing precipitation/snow behind the surface low as continental polar air (cP) is drawn into the system (see arrow in Figure 2-6).

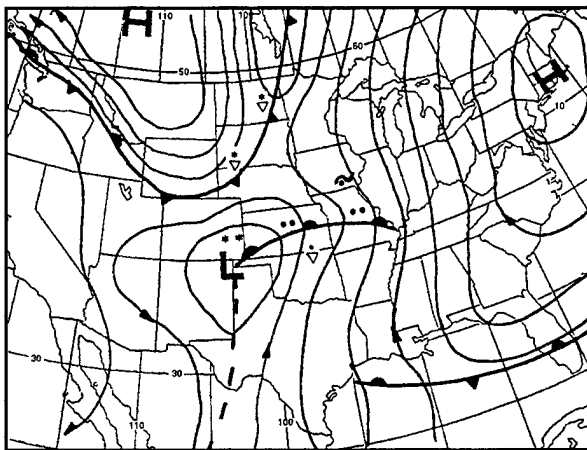


Figure 2-1. Receding High. The figure depicts a receding high pressure pattern across the central and eastern CONUS.

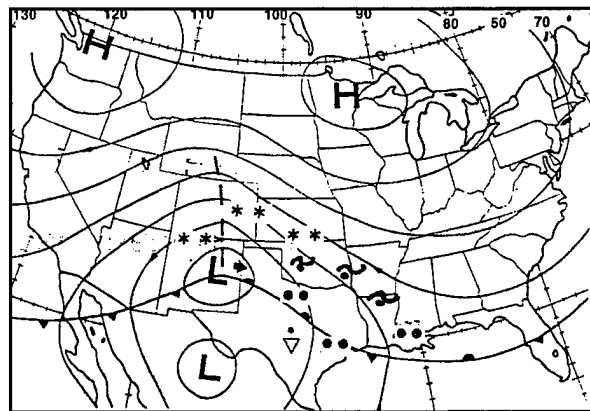


Figure 2-2. Prevailing High. A persistent zone of cold air extends west-east across a large area of the CONUS.

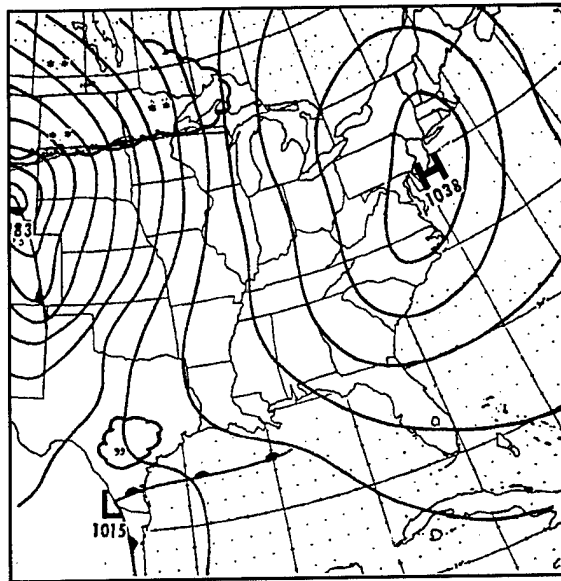


Figure 2-3. Receding High-Pressure Pattern.
The figure shows a receding high-pressure pattern that occurred at 1200Z on 10 January 1980.

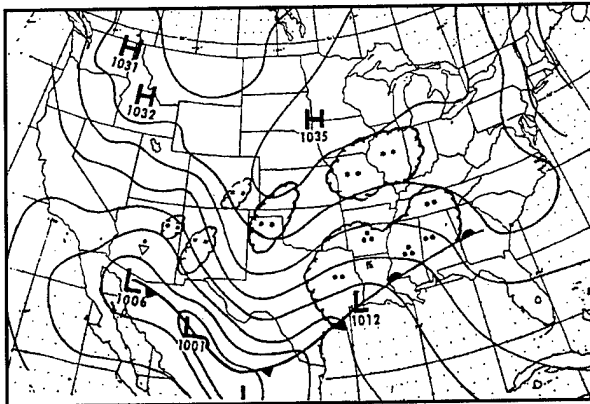


Figure 2-4. Prevailing High-Pressure Pattern.
The figure shows a prevailing high-pressure pattern that occurred at 2100Z on 8 February 1980.

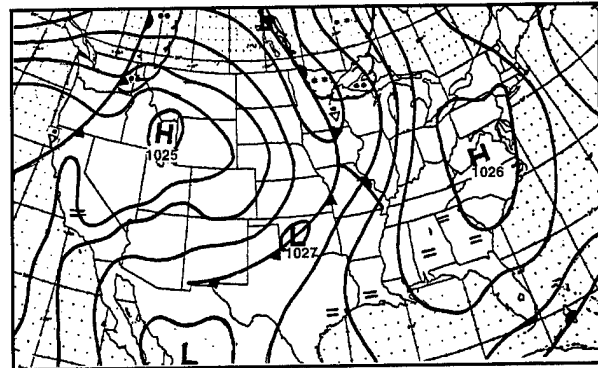


Figure 2-5. Autumn Surface Pattern. The figure depicts a typical autumn pattern, which is normally associated with pleasant weather.

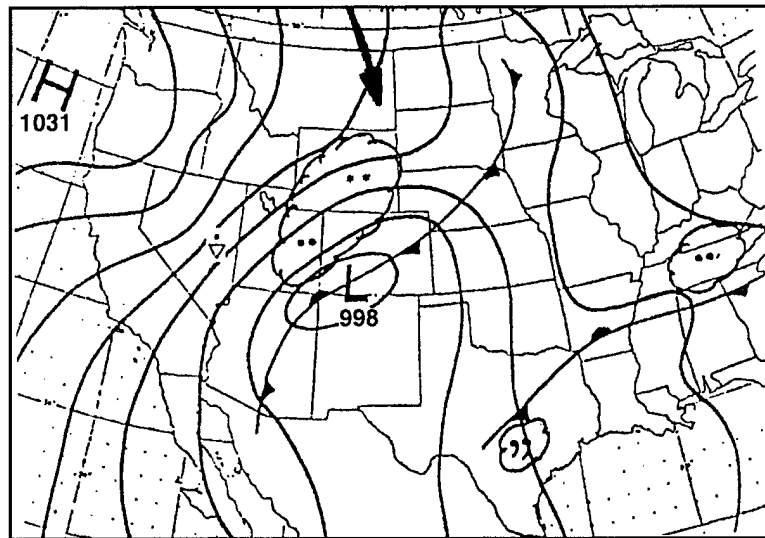


Figure 2-6. Surface Chart. Figure shows a frontal system decelerating over the Rockies and western Great Plains at 1200Z on 29 October 1979.

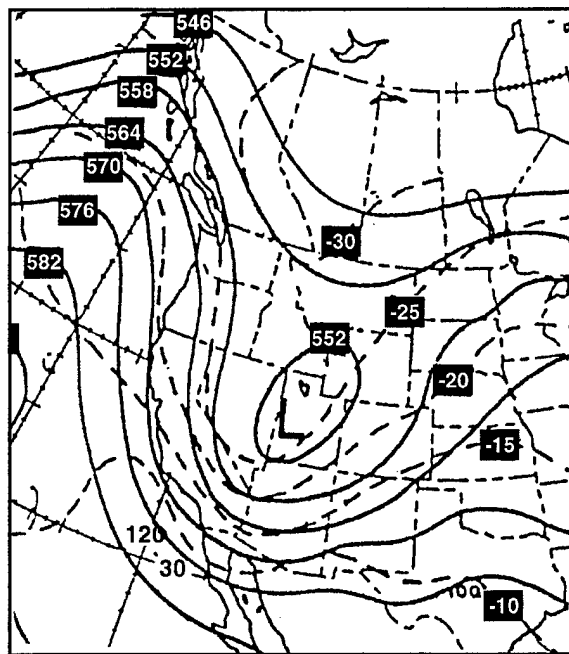


Figure 2-7. Upper-Air Chart. The figure shows a deepening 500-mb low-pressure system associated with the surface low shown in Figure 2-6.

Chapter 2

By mid-November, cP air masses continue to build over the snow fields of western and central Canada; the leading edge of these air masses often drift southward into the northern plains (Figure 2-8a).

Freezing precipitation is likely within the cold air from eastern Montana to the northern Great Lakes. This precipitation event will continue until a short wave approaches the cP front, intensifies a frontal

low, and moves the cP high southward (Figure 2-8b).

Another similar event is shown in Figure 2-9. A Pacific frontal system has moved into the Great Plains followed by a cP air mass further to the north. Clouds and precipitation will most likely be associated with the mP system while cold dry air moves rapidly southward and merges with the mP air mass.

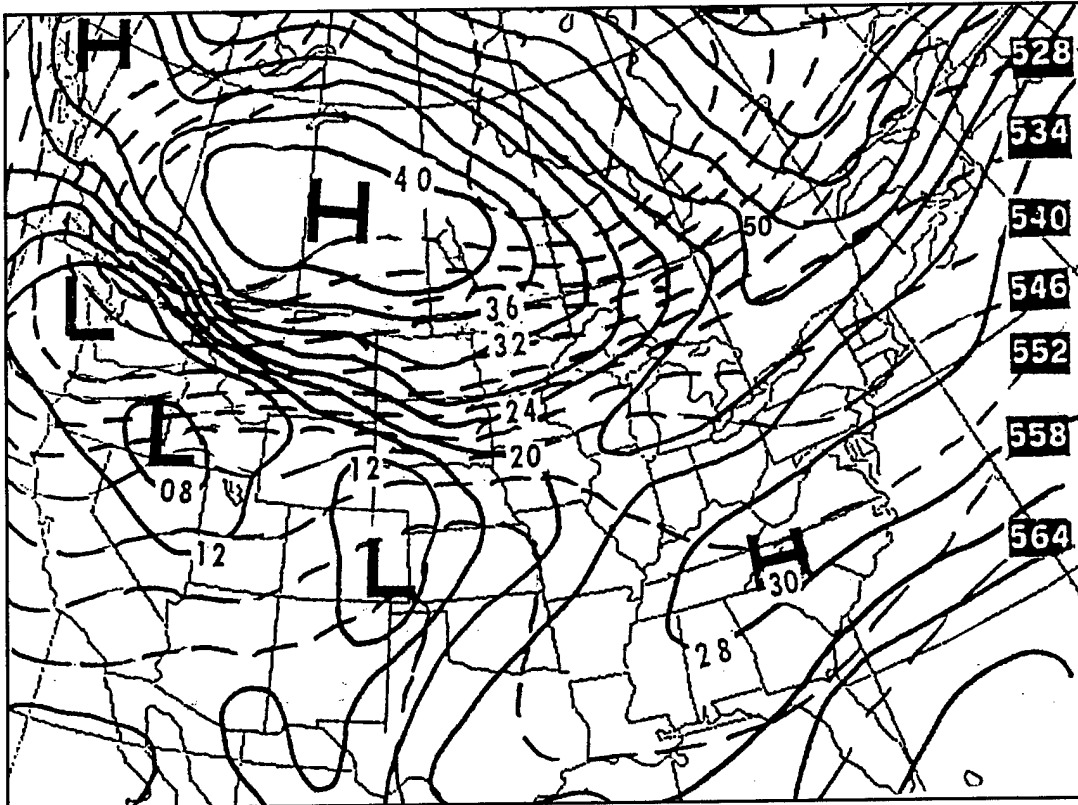


Figure 2-8a. Late Autumn High-Pressure Systems. The figure shows a building 500-mb ridge with the leading edge dropping into the northern CONUS at 1200Z on 22 November 1993.

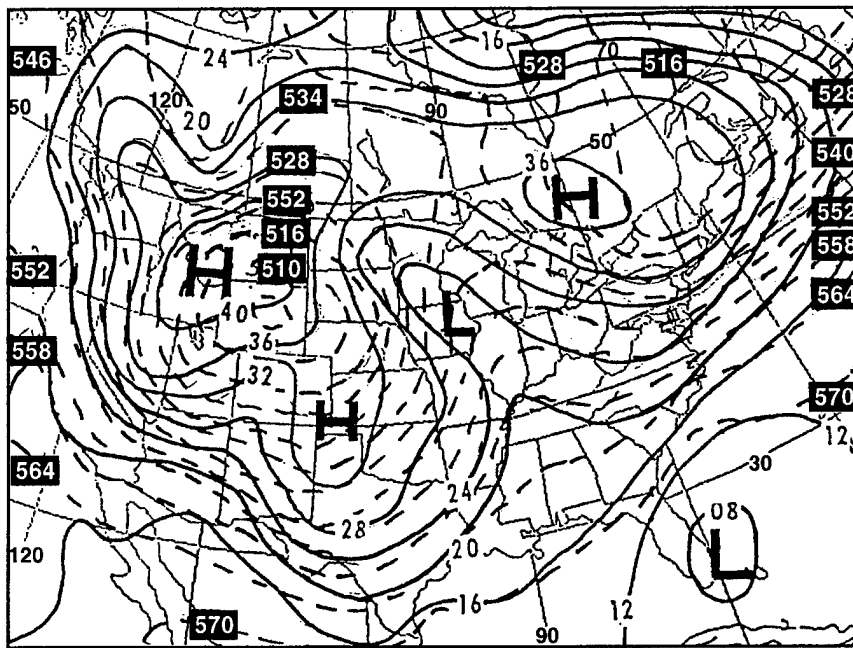


Figure 2-8b. Late Autumn High-Pressure Systems. The figure shows the southward track of the continental polar high-pressure system 3 days later at 1200Z on 25 November 1993.

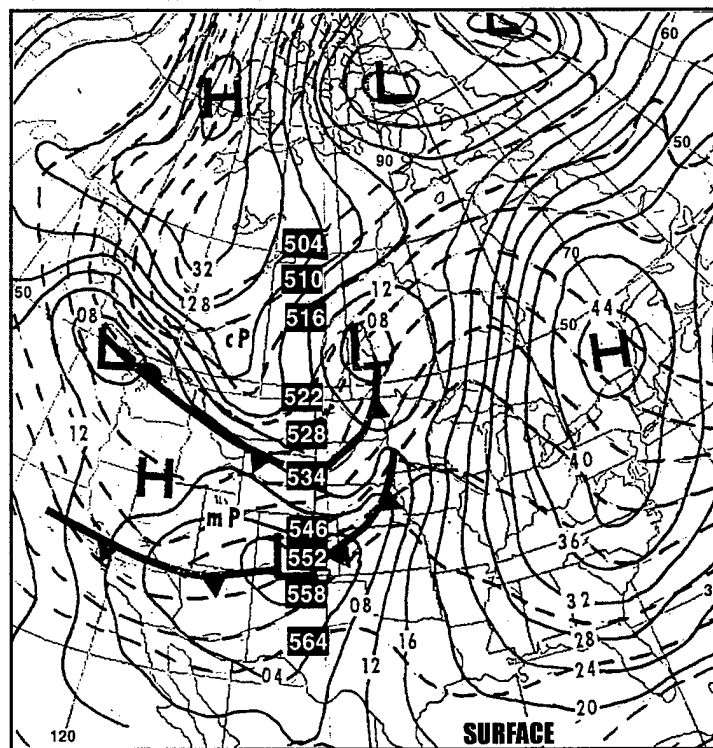


Figure 2-9. Multiple Air Mass Scenerios. The figure shows a maritime polar air mass followed quickly by a continental polar air mass at 0000Z on 16 November 1996.

Freezing Precipitation

Chapter 3

ADVECTION

General. This chapter discusses empirical rules that correlate 1,000- to 500-mb thickness and 850-mb temperature values with freezing precipitation events, identifies three advection categories (warm, neutral, and cold) that are prominent in freezing precipitation events, and illustrates how using empirical rules and advection categories can identify freezing precipitation locations.

Empirical Rules. Figures 3-1 through 3-4 show data for 503 freezing precipitation outbreaks collected over 11 years. Precipitation data was obtained from 6-hourly Military Weather Advisory verification charts and thickness/temperature data was obtained from the Nested Grid Model (NGM) initial hour charts. Patchy freezing drizzle was not considered. In Figures 3-1 and 3-2, freezing precipitation events are plotted based on 1,000- to 500-mb thickness isopleths between which freezing precipitation was observed to occur. For example, there was one event (circled) where precipitation occurred between the 528 line (on the cold side of the weather system) and the 558 line (on the warm side). The bounding isopleths establish a thickness "ribbon." Figures 3-3 and 3-4 shows a similar plot of the data versus 850-mb temperatures.

Three different patterns of precipitation events were noticed based on the study of empirical evidence. "Frontal overrunning" is the most common pattern, and represents warm air moving and lifting over a cold air mass, till the warm air cools to condensation and precipitation occurs. "Undercutting" refers to those situations where a cold air wedge is moving underneath an existing warm air mass. "Cold air stratus" refers to those situations where warm air is advecting over a shallow cold air mass, but the precipitation (always freezing drizzle) is observed from stratus within the cold air mass.

1,000- to 500-Mb Thickness Empirical Rules. In Figure 3-1, the occurrences enclosed within the dashed line represent the greatest frequency of occurrences for freezing precipitation in frontal overrunning events. Within this area, 386 out of 503 events occurred (nearly 77 percent). The maximum frequency of occurrences (150) is between the 552 and 540 thickness isopleths. There is some overlap within the fringe areas.

Table 3-1 below shows a summary of the three freezing precipitation events related to 1,000- to 500-mb thickness data shown in Figure 3-1.

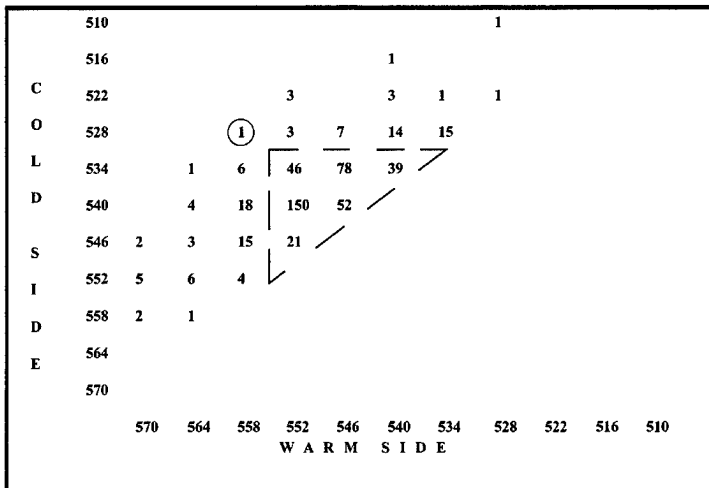


Figure 3-1. Frontal Overrunning Freezing Precipitation Events. The figure shows the correlation between events and thickness values.

| EVENT | LEVELS | THICKNESS | ADVECTION | PRECIP TYPE |
|----------------------------------|-------------|-----------|-------------------|------------------------|
| Frontal Overrunning ¹ | Low to High | 552-534 | Warm ² | ZR/ZL |
| Undercutting | Low | ≥558-540 | Cold | Mostly ZR ³ |
| Cold Air Stratus | Low | 540-≤528 | Warm | ZL |

1. Warm or stationary fronts
 2. Includes neutral advection
 3. Freezing drizzle is also likely to occur

Table 3-1. Summary of Precipitation Events Related to 1,000- to 500-Mb Thickness.

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Figure 3-2 expands on Figure 3-1 to highlight the two remaining thickness/freezing precipitation patterns, cold air stratus and undercutting.

The expanded upper-right table depicts the cold air stratus cases, with warm air advection lifting over a shallow, moist polar air mass. Most occurrences were below the 540 thickness. Thickness charts below 500-mb were not routinely available, and it is inappropriate to use 1,000- to 500-mb thickness for a shallow air mass at and below the boundary

layer. All events were associated with stratus layers within the cP air mass that produced freezing drizzle.

The expanded table in the lower left shows the thickness range for undercutting events. All thickness values are above 540. Most precipitation is freezing rain, which is occurring in warmer, moister air ahead of the approaching cP air mass. Due to the shallowness of the intruding cP air, 1,000- to 500-mb thickness does not change until deeper cold air moves and causes snow.

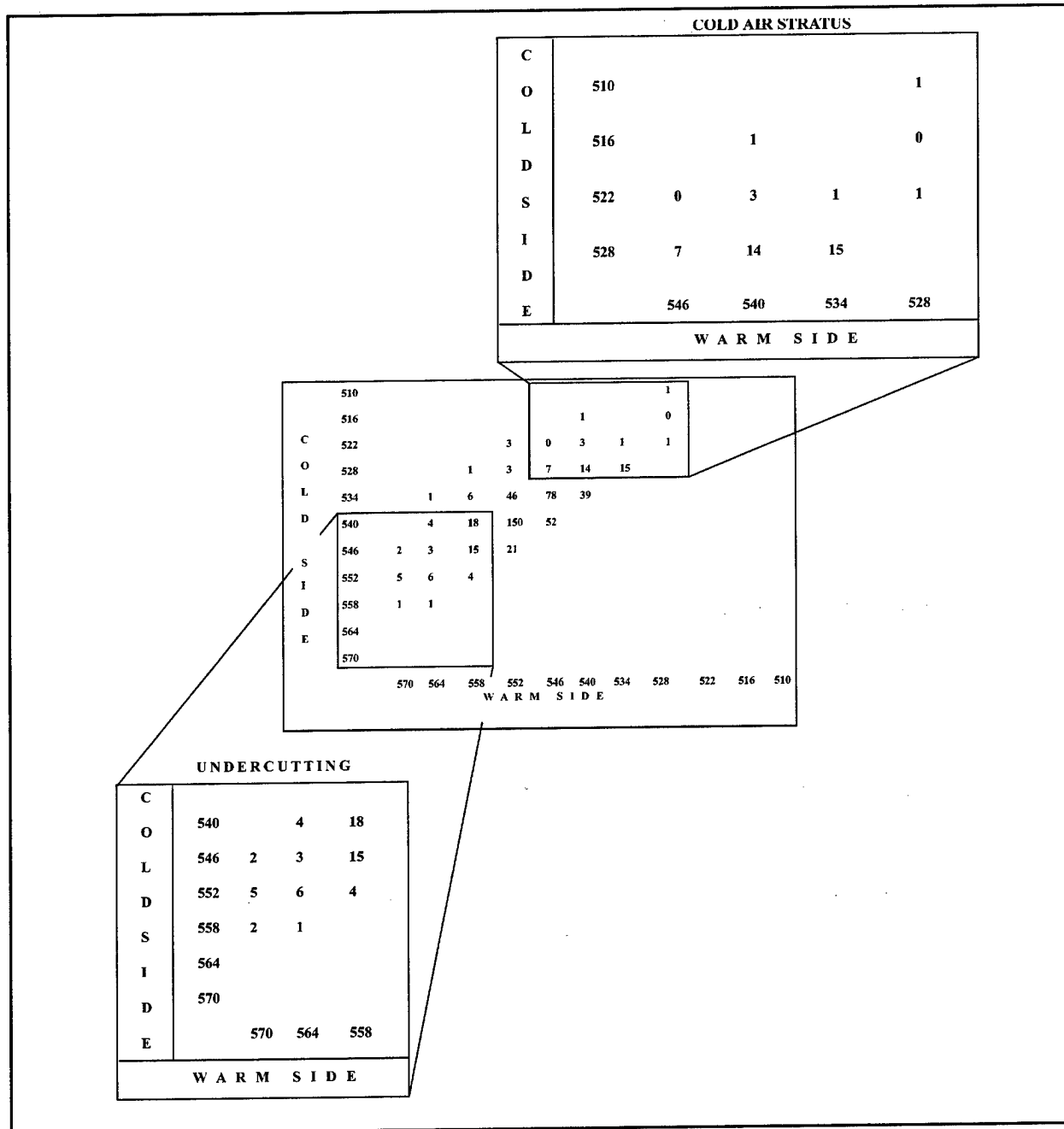


Figure 3-2. Cold Air Stratus and Undercutting Freezing Precipitation/1000- to 500-Mb Thickness Relationship. The figure shows thickness thresholds for the occurrence of freezing precipitation.

850-Mb Temperature Empirical Rules. Figures 3-3 and 3-4 correlate 850-mb temperature data and freezing precipitation occurrences, similar to the depiction in the thickness figures.

In Figure 3-3, the enclosed area represents the greatest frequency of occurrences for mostly freezing rain in frontal overrunning events. Within this area 385 out of 503 events (77 percent) occurred.

Table 3-2 shows a summary of the three freezing precipitation events related to 850-mb temperature data. The temperature range to +15°C for the “undercutting” pattern may appear to be too warm, but most occurrences were across the southern CONUS in existing rain/drizzle areas (associated with warm air advection and often a stationary frontal system). Further explanation of undercutting patterns follows later in this section.

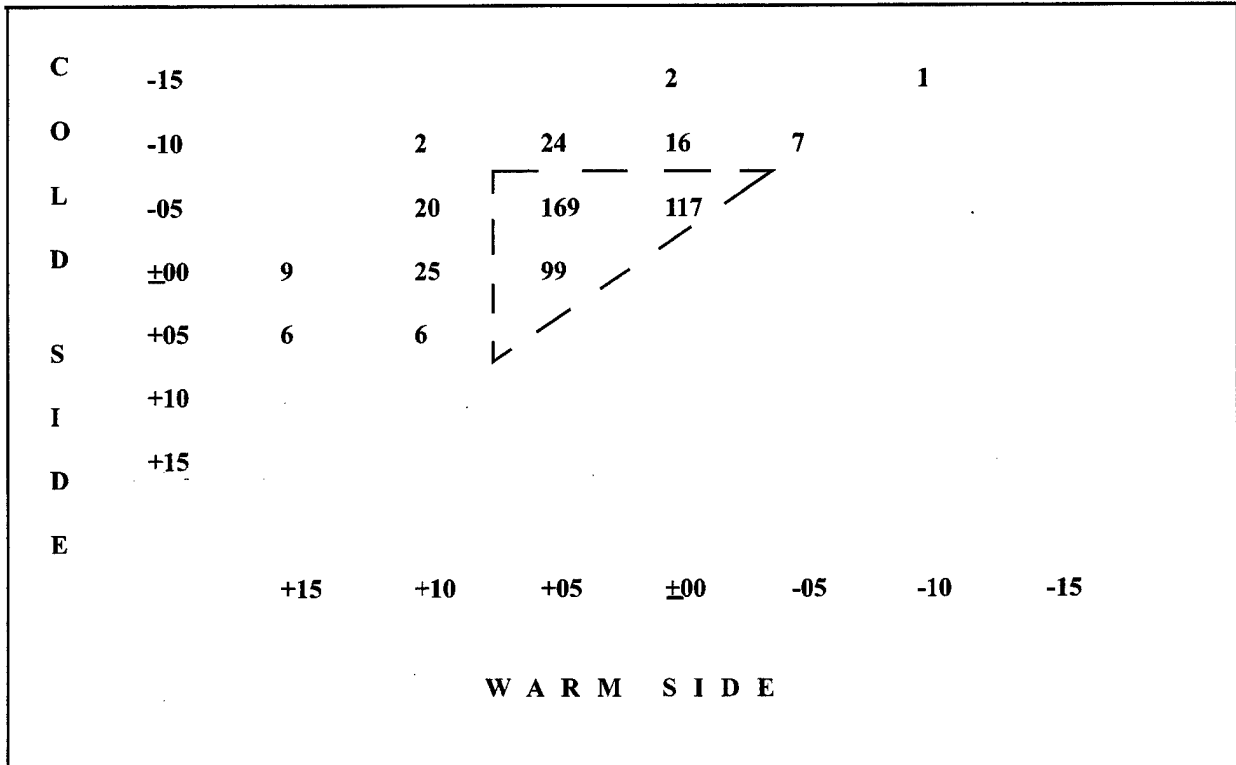


Figure 3-3. Frontal Overrunning Freezing Precipitation Events. The figure shows the correlation between events and 850-mb temperatures based on 503 events that occurred between 1985 and 1995.

Table 3-2. Summary of Precipitation Events Related to 850-Mb Temperatures.

| EVENT | TEMP RANGE | ADVECTION | PRECIP TYPE |
|----------------------------------|--------------|-------------------|------------------------|
| Frontal Overrunning ¹ | +5°C to -5°C | Warm ² | ZR/ZL |
| Undercutting | +15°C to 0°C | Cold | Mostly ZR ³ |
| Cold Air Stratus | 0°C to -10°C | Warm | ZL |

1. Warm or stationary fronts
 2. Includes neutral advection
 3. Freezing drizzle is also likely to occur

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Figure 3-4 shows the two remaining 850-mb temperature/freezing precipitation patterns. The expanded table in the upper right shows cold air stratus and freezing drizzle events. Notice that there is a greater temperature range, i.e., ± 00 to -10 with 16 occurrences. The wide range is the result of warm air lifting over a shallow cold dome; the warm air will penetrate deeper into the cold air. It was

noticed that secondary surges of cold air will move into a residual cold stratus area behind the main continental polar front. The new surge of cold air will provide the lifting and instability to produce freezing drizzle. Outbreaks of upslope freezing drizzle within cold polar air over the western Great Plains, eastern Montana, Wyoming, and Colorado also contributed to the sample occurrences.

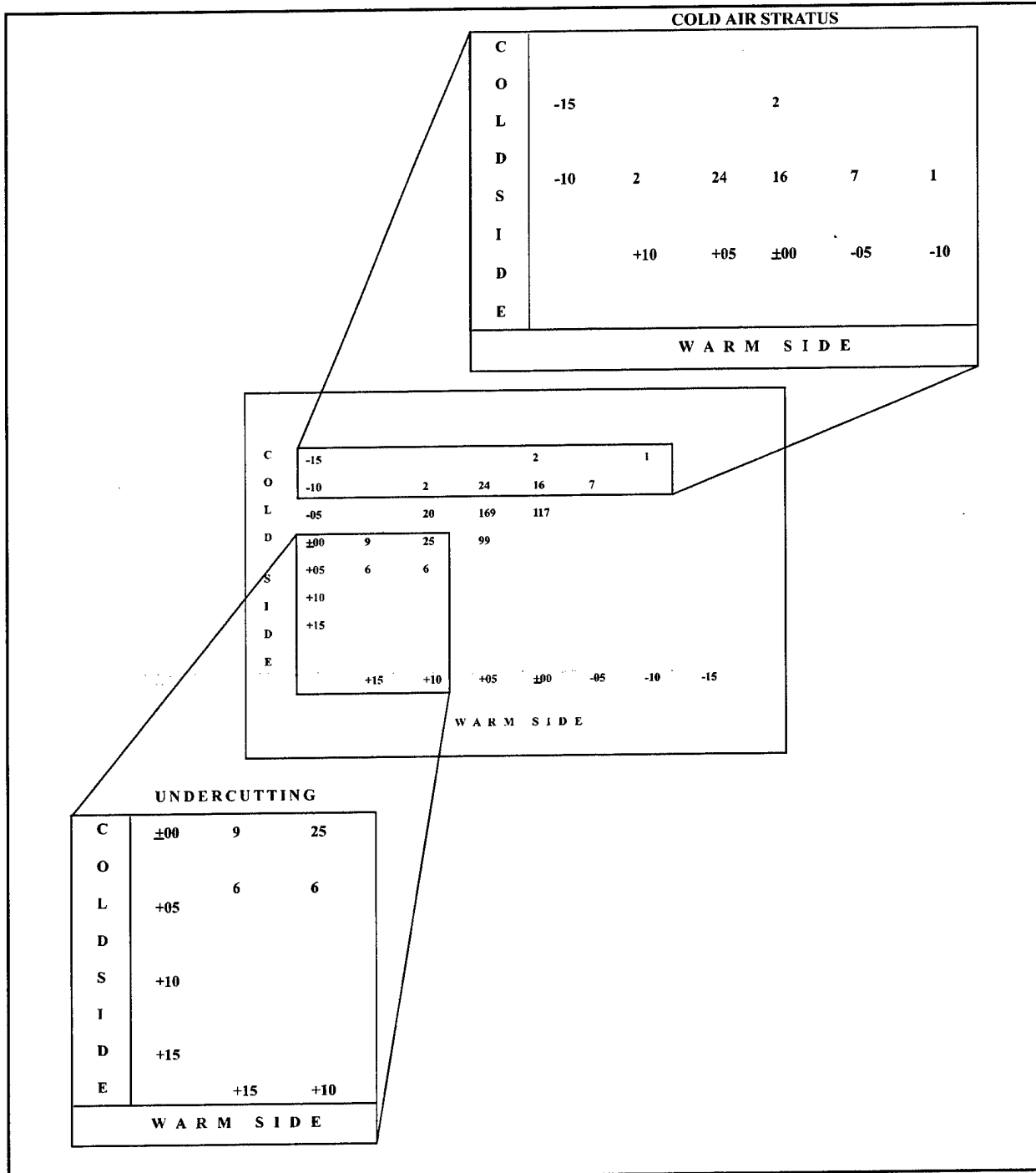


Figure 3-4. Cold Air Stratus and Undercutting Freezing Precipitation/850-Mb Temperature Relationship. The figure shows 850-mb temperature thresholds for the occurrence of freezing precipitation.

Warm Air Advection. Warmer air lifting over a shallow continental polar front (usually warm or stationary frontal overrunning) or low-level warm air advecting northward within southerly flow of a retreating polar high (no warm front exists; usually a freezing drizzle event) account for many freezing precipitation events.

In warm air advection events, the most telltale feature for development of freezing precipitation is

a thickness and temperature ridge. Increasing ridge development indicates continued warm air advection. Of course, considerations for moisture and lift should also be determined to forecast the onset of freezing precipitation.

Ridge configurations come in all sizes; freezing precipitation often occurs at the apex of thickness and temperature ridges (Figures 3-5 and 3-6) and near (usually north of) a 850-mb low (Figure 3-7).

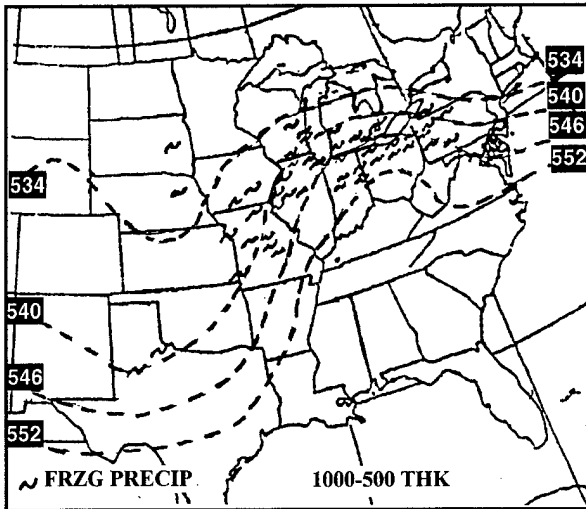


Figure 3-5. Thickness Ridge. The figure shows freezing precipitation is often observed at the apex of the thickness ridge. Chart valid at 1200Z on 11 January 1991.

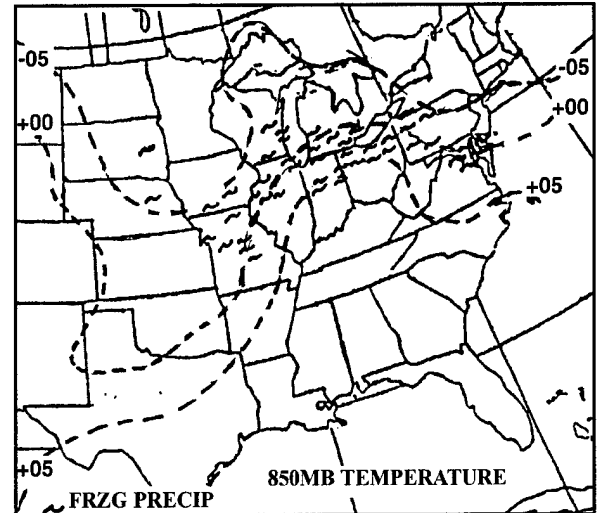


Figure 3-6. Temperature Ridge. The figure shows that freezing precipitation is often observed at the apex of the temperature ridge. Chart valid at 1200Z on 11 January 1991.

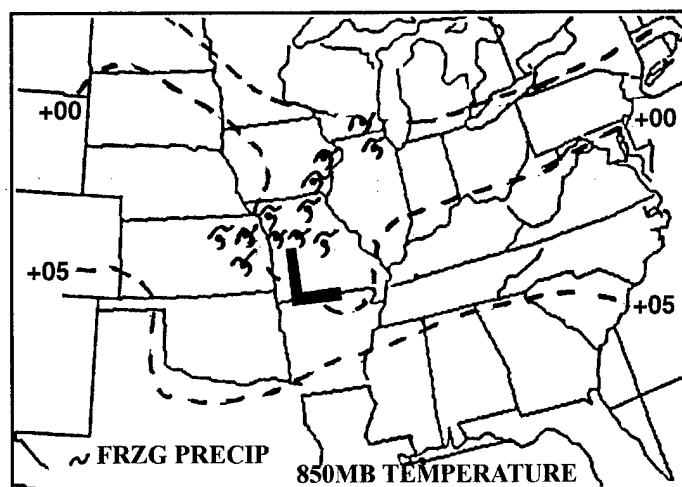


Figure 3-7. 850-Mb Low-Pressure System. The figure shows that freezing precipitation is often observed in the vicinity of a 850-mb low. Chart valid at 0000Z on 12 January 1991.

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Figures 3-8 through 3-10 depict examples of temperature and thickness ridges associated with warm air advection and their relationship with freezing precipitation. Arrows mark the freezing precipitation area within the thickness and

temperature axes on the surface (1,000- to 500-mb thickness) and 850-mb analysis. *Note: The freezing precipitation shown within all the composites in this technical note represents a 6-hour period of the data base time and is depicted as a “~”*

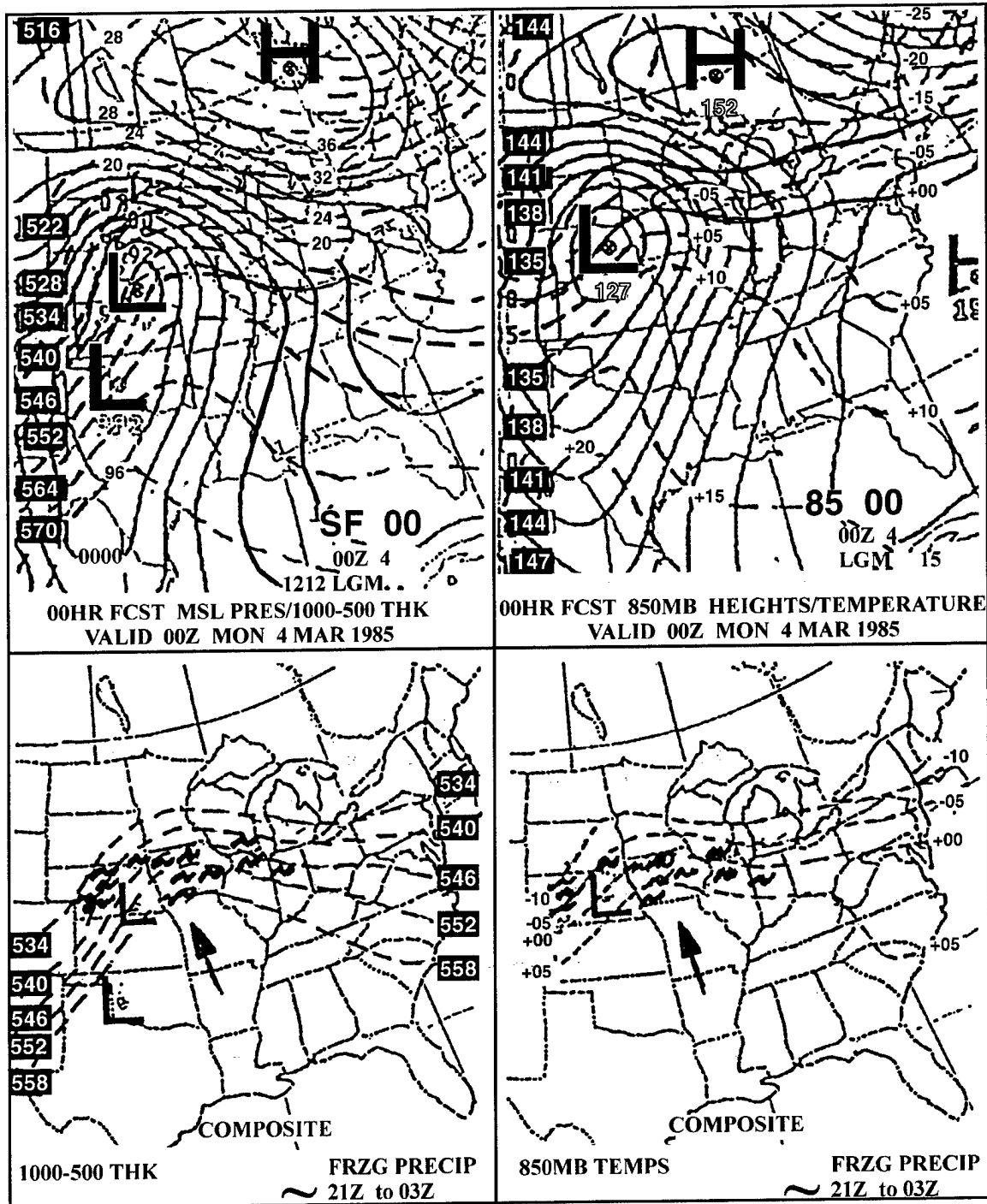


Figure 3-8. Thickness, Temperature, and Freezing Precipitation Relationships. Arrows mark the freezing precipitation area within the correlating thickness and temperature ribbons on the surface (1,000- to 500-mb thickness) and 850-mb analysis.

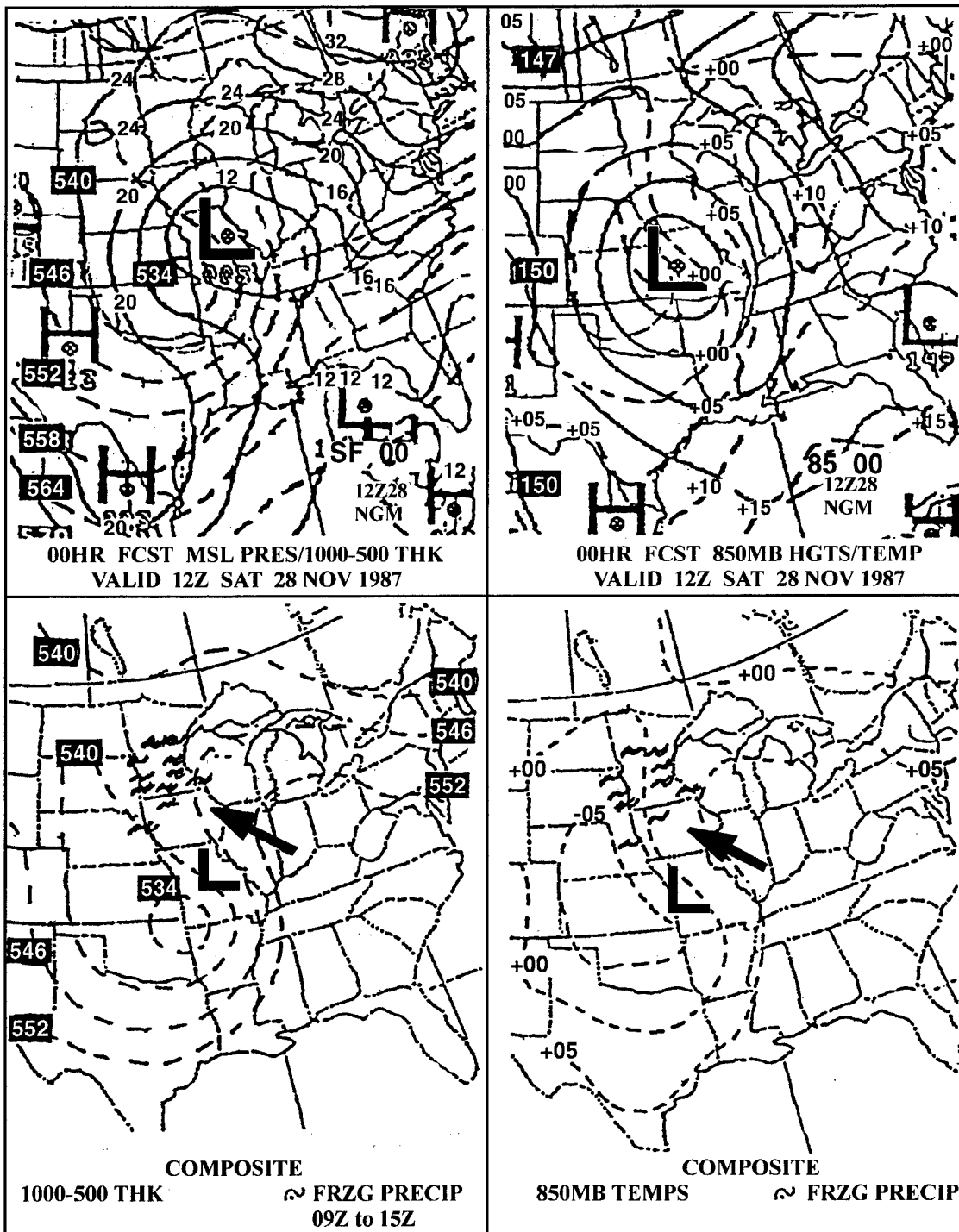


Figure 3-9. Thickness, Temperature, and Freezing Precipitation Relationships. Arrows mark the freezing precipitation area within the thickness and temperature axes on the surface (1,000- to 500-mb thickness) and 850-mb analysis.

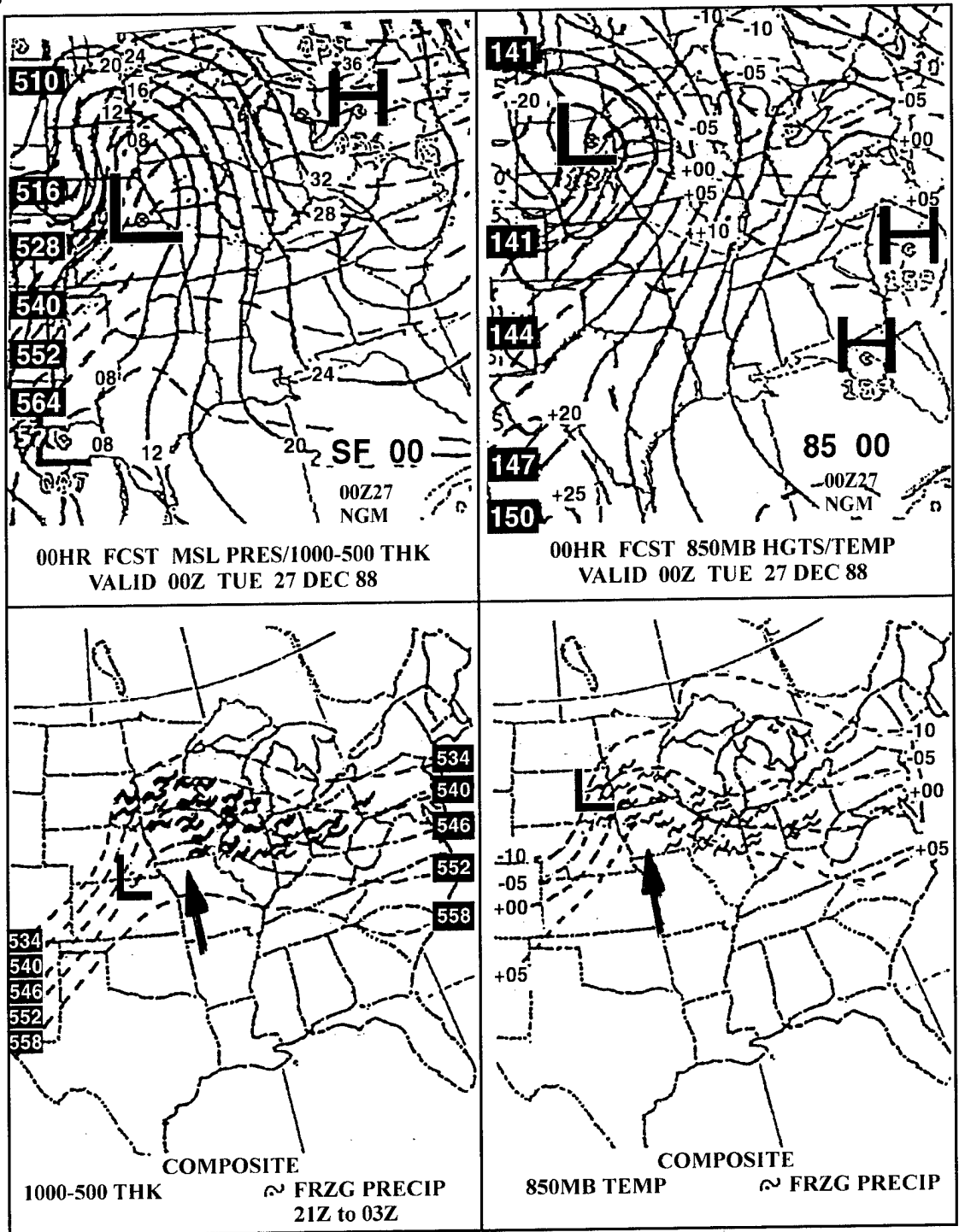


Figure 3-10. Thickness, Temperature, and Freezing Precipitation Relationships. Arrows mark the freezing precipitation area within the thickness and temperature axes on the surface (1,000- to 500-mb thickness) and 850-mb analysis.

Freezing Precipitation Events. Many freezing precipitation events are caused by the following:

- Warm, moist air lifting above shallow continental polar or modified arctic boundaries, in conjunction with vertical motion, PVA, and a low-level jet associated with an approaching storm system (Figure 3-11a).
- Warm, perhaps moist, air moving northward within return southerly flow of a retreating high (Figure 3-11b; low clouds, fog, and freezing drizzle develops as the warm air lifts over a cold or snow-covered surface).

Freezing rain events as shown in Figure 3-11a are usually well-defined areas and are more forecastable than freezing drizzle because rain-producing cloud systems extend to the upper levels. The 1,000- to 500-mb thickness can be used with good results for forecasting freezing rain after considerations for moisture and lift are determined. Warm frontal freezing rain is not diurnal and will persist throughout the daylight hours. Warm air advection that warms surface temperatures above freezing or a warm frontal passage will end freezing rain at a particular location. It is not uncommon for freezing drizzle to be reported, along with freezing rain, within warm frontal overrunning.

Note: The thickness and temperature rules presented throughout this technical note are based on case studies and should be modified when necessary. Forecasters should determine at what thickness and temperature freezing precipitation is occurring for subsequent forecasts.

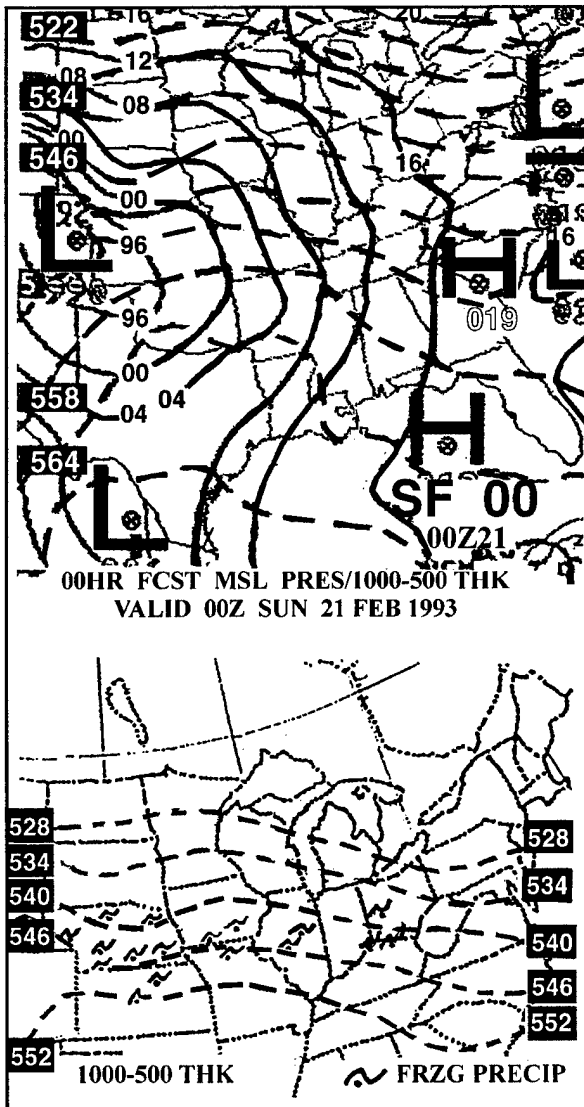


Figure 3-11a. Freezing Rain Event. Freezing rain events are usually well-defined areas.

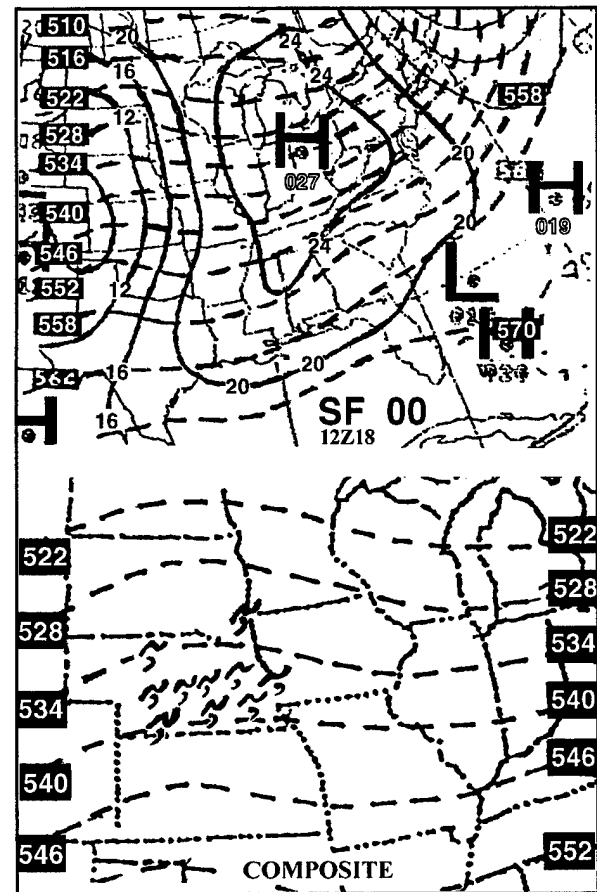


Figure 3-11b. Freezing Drizzle Event. Low clouds, fog, and freezing drizzle develops as the warm air lifts over a cold or snow-covered surface.

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Receding High—Freezing Rain. Figure 3-12 depicts a typical storm system over the central CONUS. Warm frontal freezing rain will lie between the 540 and 552 thickness isopleths when the 552 thickness isopleth is north of the warm front. It is important to decide if the 552 thickness isopleth will be located north or south of the warm front. Freezing rain will also appear between the $+5^{\circ}\text{C}$ to -5°C 850-mb temperature ribbon (not

shown). In many cases reviewed, the $+5^{\circ}\text{C}$ 850-mb temperature correlated well with the 552 thickness isopleth. A narrow band of freezing rain or drizzle may occur behind the cold front between the thickness and temperature thresholds listed above (undercutting). Post-frontal freezing precipitation is generally a short-lived event as the cold front moves eastward.

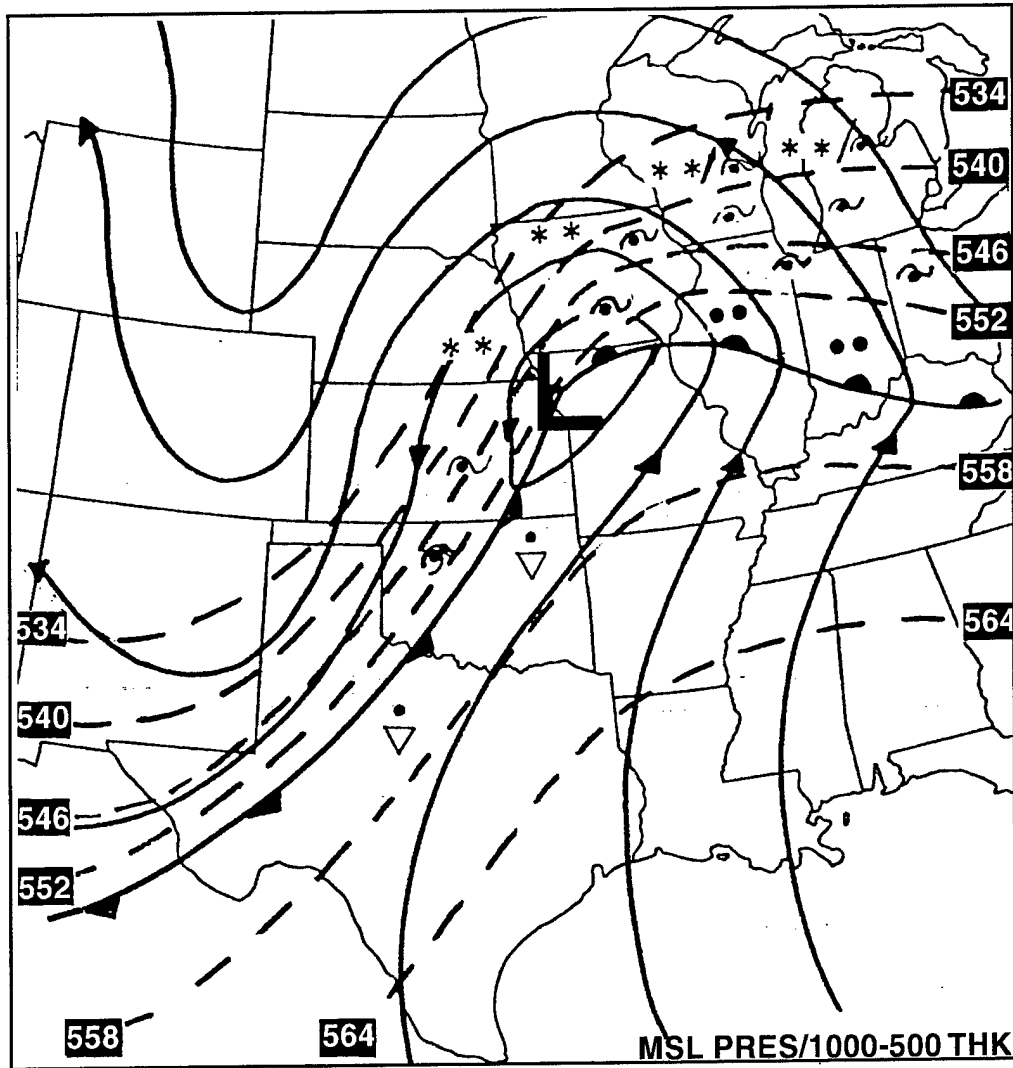


Figure 3-12. The 552 Thickness Isopleth North of Warm Front. The figure shows a warm air advection freezing rain pattern with freezing rain occurring between the 552 and 540 thickness isopleths.

Figure 3-13 shows the same general synoptic event as presented in Figure 3-12; however, the 552 thickness isopleth lies south and east of the storm system as noted by the arrows. The southern extent of freezing precipitation will be less than 552, generally either at the 546 thickness isopleth or

where the surface warm front lies between these two thickness lines. The northern extent of freezing precipitation is generally at the 534 thickness isopleth; in strong overrunning (strong low-level jet) freezing precipitation can extend northward to the 528 thickness isopleth.

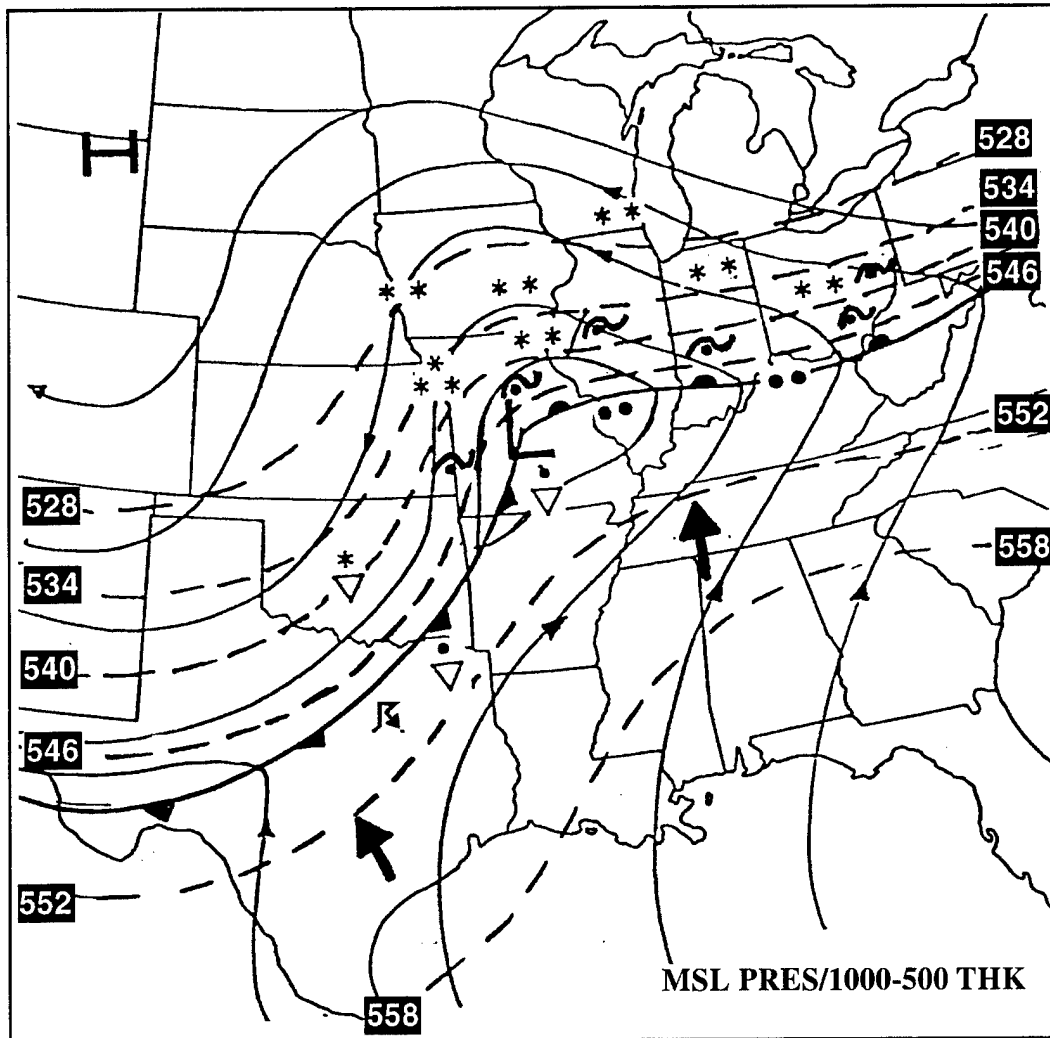


Figure 3-13. The 552 Thickness Isopleth South of Warm Front. The figure shows a warm air advection freezing rain pattern with freezing rain occurring between 540 and 546 thickness isopleths.

Chapter 3

Example 1. Figures 3-14a and 3-14b illustrate a case example, comparable to the model example in Figure 3-12, of a storm system emerging from the Rocky Mountains. Data was not available to accurately pinpoint the exact location of the surface warm front, but it is noticeable at the 850-mb level

(Figure 3-14b) where a tighter temperature gradient exists. The freezing rain shown in Figures 3-14a and 3-14b occurred during a 6-hour period from 26/0900Z to 26/1500Z. The freezing rain occurred between the 552 and 540 thickness and the +5°C to -5°C 850-mb temperature ribbons.

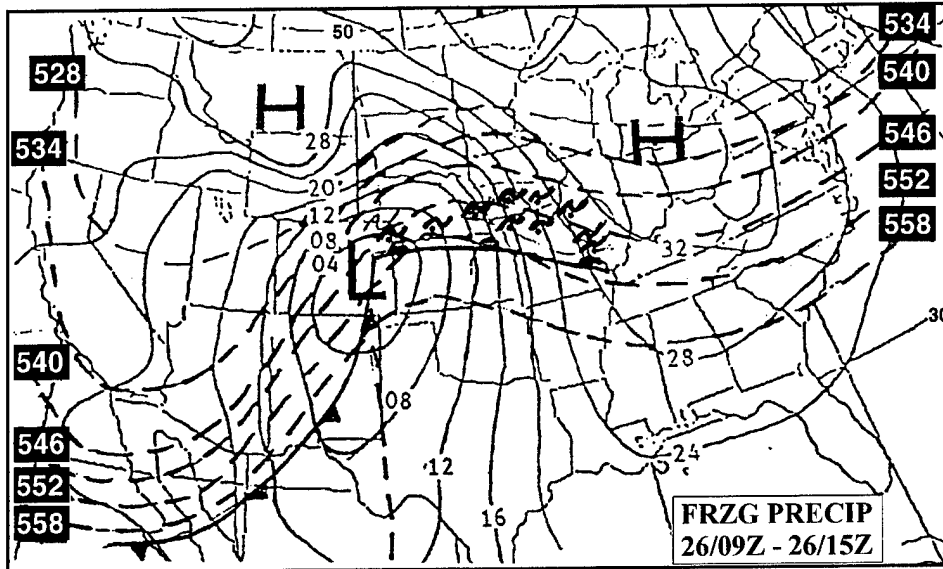


Figure 3-14a. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Figure depicts an emerging storm system from the Rocky Mountains. Chart valid at 1200Z on 26 December 1988.

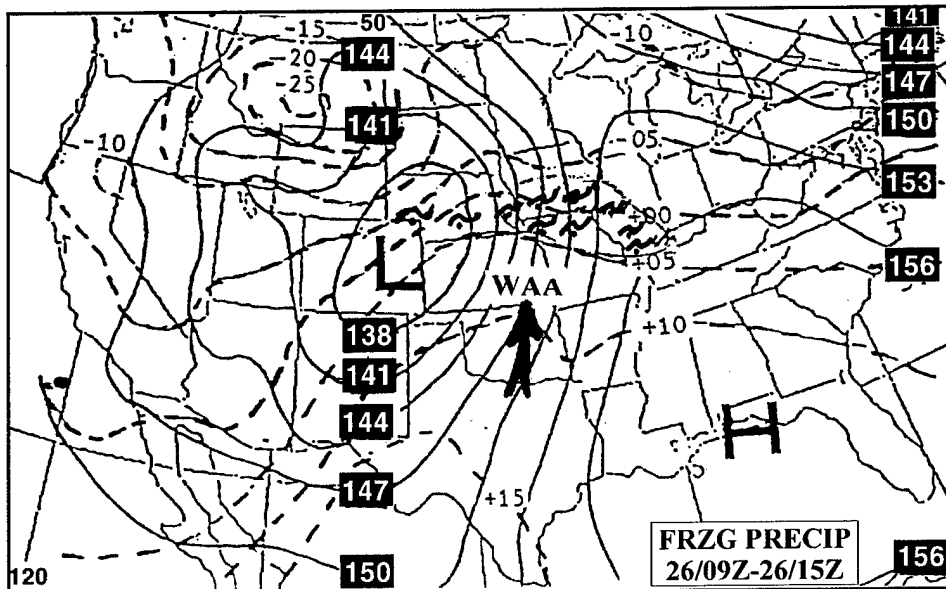


Figure 3-14b. Forecast (00HR) 850-Mb Heights/Temperature. Freezing precipitation is occurring between the +5°C to -5°C 850-mb temperature isotherms. Chart valid at 1200Z on 26 December 1988.

Example 2. Obviously, freezing rain will develop anywhere the surface temperatures are below freezing; this technical note focuses on the eastern two-thirds of the CONUS from the Rocky Mountains to the East Coast. Freezing precipitation discussions over other areas of the CONUS will be shown later in Chapter 4. The start of a freezing rain event depends on moisture, vertical motion, positive vorticity advection (PVA), lift (mainly frontal overrunning), warm air advection, and the associated low-level jet. A favorite breeding ground for the initial development of freezing rain is across the western Great Plains from Nebraska southward to west Texas. This area lies in the path of low-latitude short waves tracking across the southwestern CONUS to the southern Rocky Mountains (noted by the arrow in Figure 3-15). In receding high patterns such as shown in Figures 3-15 through 3-20, precipitation begins as low-level,

moist, southerly flow from the Gulf of Mexico, plus mid- to high-level Pacific moisture, spreads eastward in association with a short wave (along with increasing PVA).

Warm frontogenesis or strengthening of an existing warm front across the central Great Plains occurs as southerly winds and warm air advection increases ahead of the approaching storm system. Rapid development of overrunning rain/snow into the cold air leads to a large outbreak of freezing rain and snow.

Figures 3-15 through 3-17 typify development of a freezing rain and drizzle event across the central CONUS. In Figure 3-15, zonal flow prevails across the CONUS. Several PVA lobes within the flow over Utah and Arizona are evident. Mid-level moisture of 50 to 70 percent is associated with these

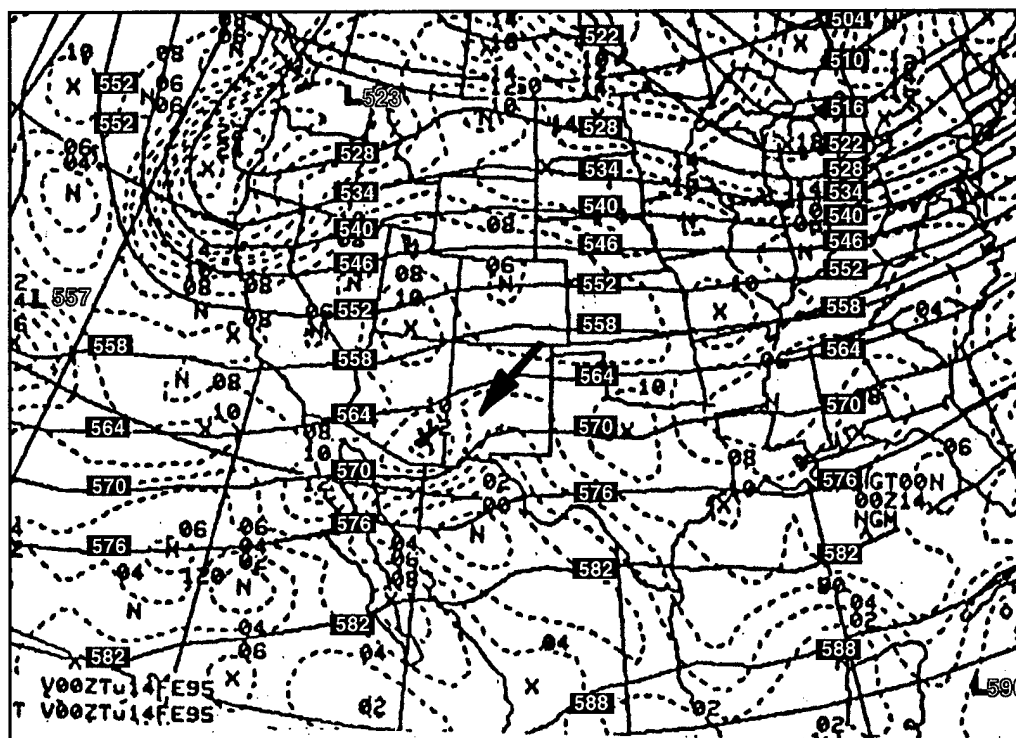


Figure 3-15. The 500-Mb Heights/Vorticity Chart. The figure shows zonal flow with a PVA lobe indicated by the arrow.

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lobes (Figure 3-16). In Figure 3-17a, a transitory high-pressure system covers the central and eastern CONUS. A strong south to north pressure gradient has set up in the lee of the Rockies and western

Great Plains. No distinct east-west warm front is evident in the vicinity of the developing freezing precipitation. The polar frontal boundary lies across the Gulf of Mexico.

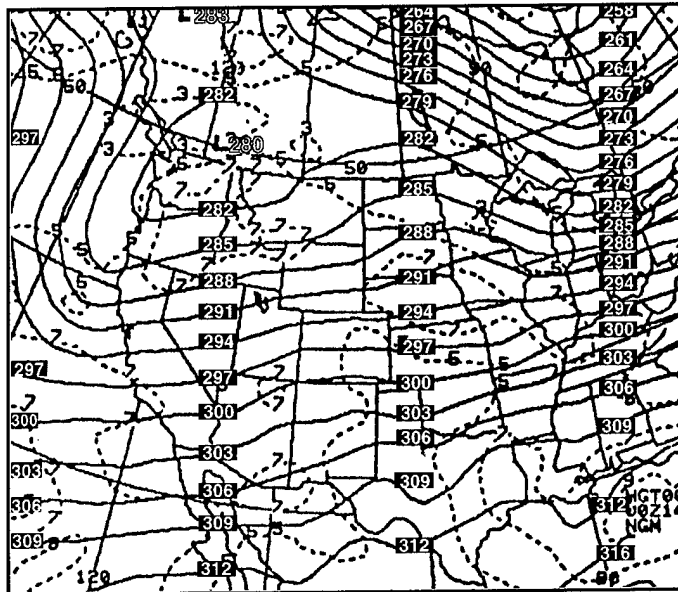


Figure 3-16. The 700-Mb Heights/Relative Humidity Chart. Seventy percent moisture is associated the PVA lobe shown in Figure 3-15. Chart valid at 0000Z on 14 February 1995.

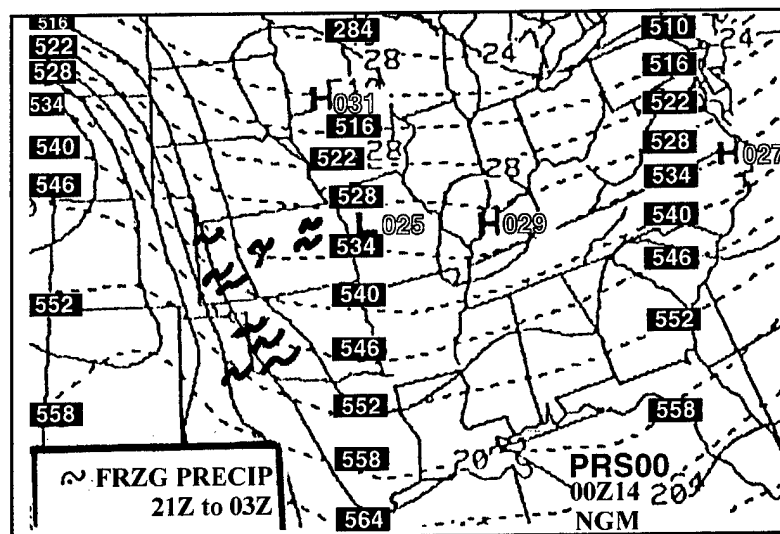


Figure 3-17a. Mean Sea-Level Pressure/1,000- to 500-mb thickness. Freezing Precipitation is occurring between the 552 and 528 thickness isopleths. Chart valid at 0000Z on 14 February 1995.

The freezing precipitation, which is most likely to be freezing drizzle in Kansas, lies between the 552 and 528 thickness and between the +00°C and -12°C

850-mb temperatures as shown in Figures 3-17a and 3-17b.

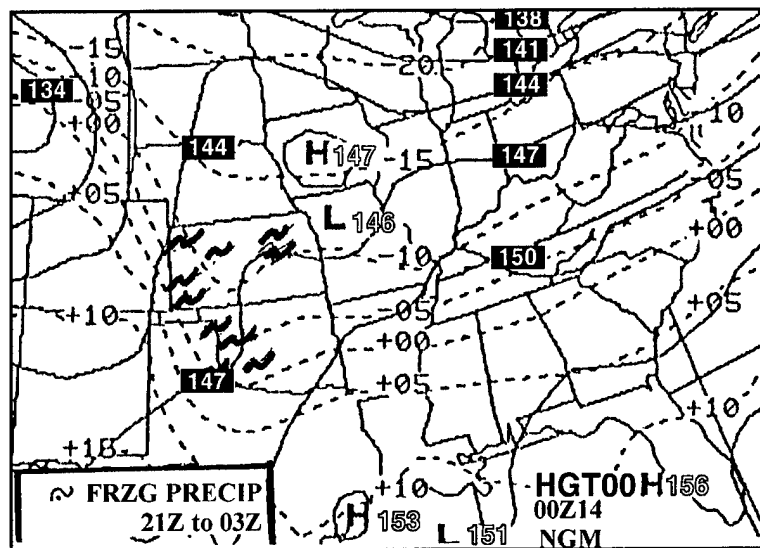


Figure 3-17b. The 850-Mb Heights/Temperature Chart. Freezing precipitation is occurring between +00°C and -12°C isotherms. Chart is valid at 0000Z on 14 February 1995.

Twenty-four hours later, in Figures 3-18 through 3-20b, a widespread freezing precipitation event is in progress from the central plains to the Ohio River valley. In Figure 3-18, a PVA lobe is shown over

the central plains; the flow is becoming oriented southwest to northeast as the trough deepens. Fifty to ninety percent moisture is shown across the freezing precipitation area (Figure 3-19).

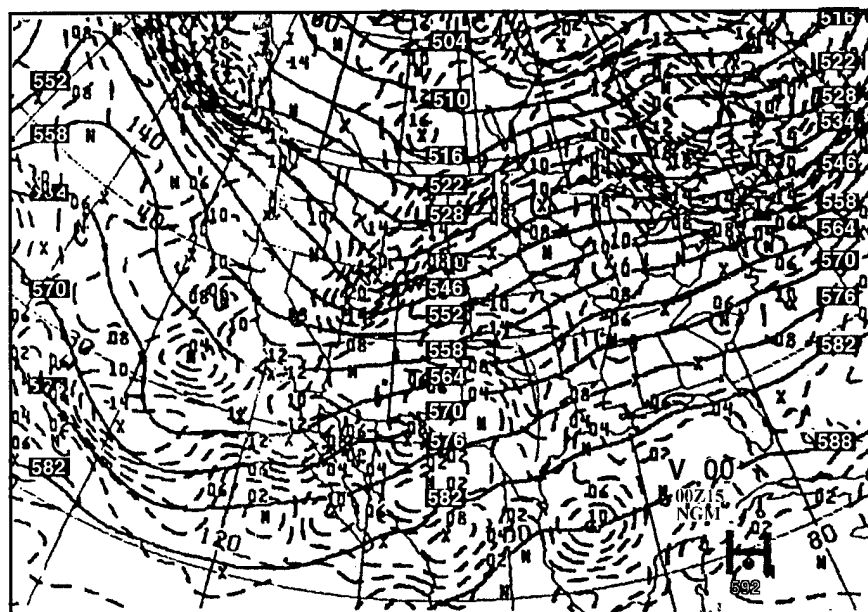


Figure 3-18. The 500-Mb Heights/Vorticity Chart. The PVA lobe has moved into the Great Plains, and the flow has become more southwest to northeast. Chart valid at 0000Z on 15 February 1995.

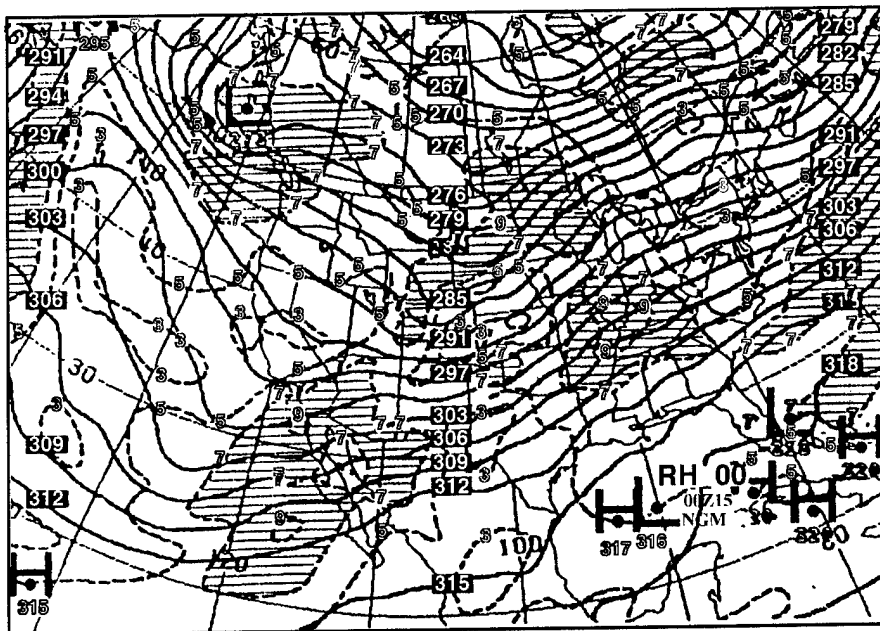


Figure 3-19. The 700-Mb Height/Relative Humidity Chart. The figure shows 50 to 90 percent relative humidity associated with the short wave moving through the central plains. The chart is valid at 0000Z on 15 February 1995.

At the surface (Figure 3-20a), a warm front appears to be developing across the southern plains to the lower Mississippi River valley area (see arrows). The freezing precipitation area is along and north of the developing warm front. It is difficult to place a warm front at the 850-mb level (Figure 3-20b); some kinking in the contours is noted over Nebraska and Missouri.

The freezing precipitation area lies between the 552 and 522 thickness and the $+5^{\circ}\text{C}$ to -12°C 850-mb temperature ribbons. Freezing precipitation, which is occurring over Wisconsin and Minnesota, is more

likely to be freezing drizzle rather than freezing rain due to strong low-level warm air advection into the cold air. Thickness values down to 522 and 850-mb temperatures to -12°C would support snow rather than rain. Freezing drizzle occurred over Minnesota, Wisconsin, Nebraska, and Iowa, while freezing rain stretched in a west to east band from Kansas to the Ohio River valley. The freezing drizzle over the northern Great Plains fell within the low thickness values of 528 and 522 and 850-mb temperatures of -10°C to -15°C . Heavy snow occurred behind the inverted trough over the Dakotas.

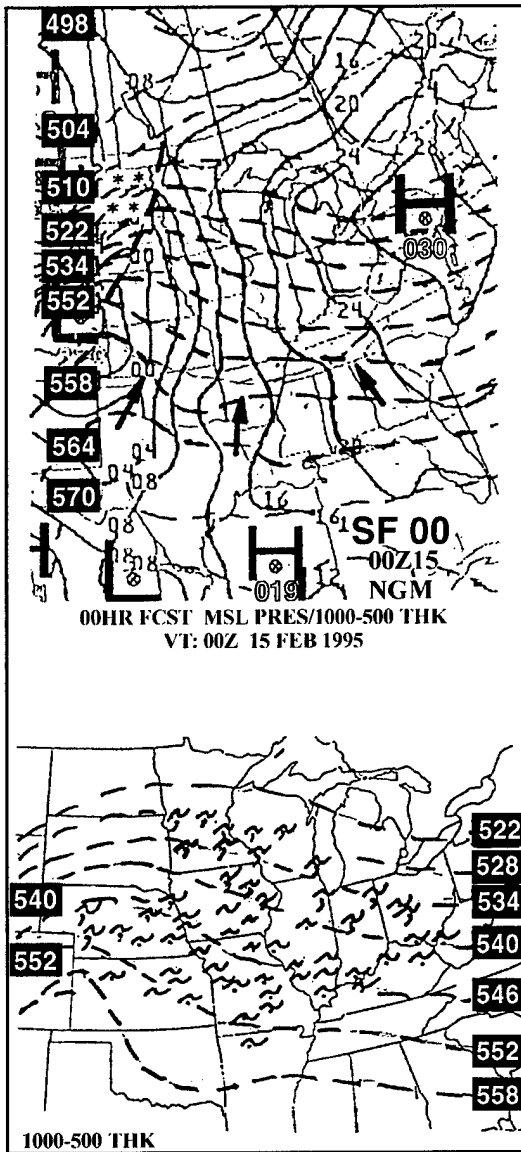


Figure 3-20a. Mean Sea-Level Pressure/1,000- to 500-mb thickness and Composite Thickness/Freezing Precipitation Charts. The arrows indicate a developing warm front (top) and the freezing precipitation area lies between the 552 and 522 thickness isopleths (bottom).

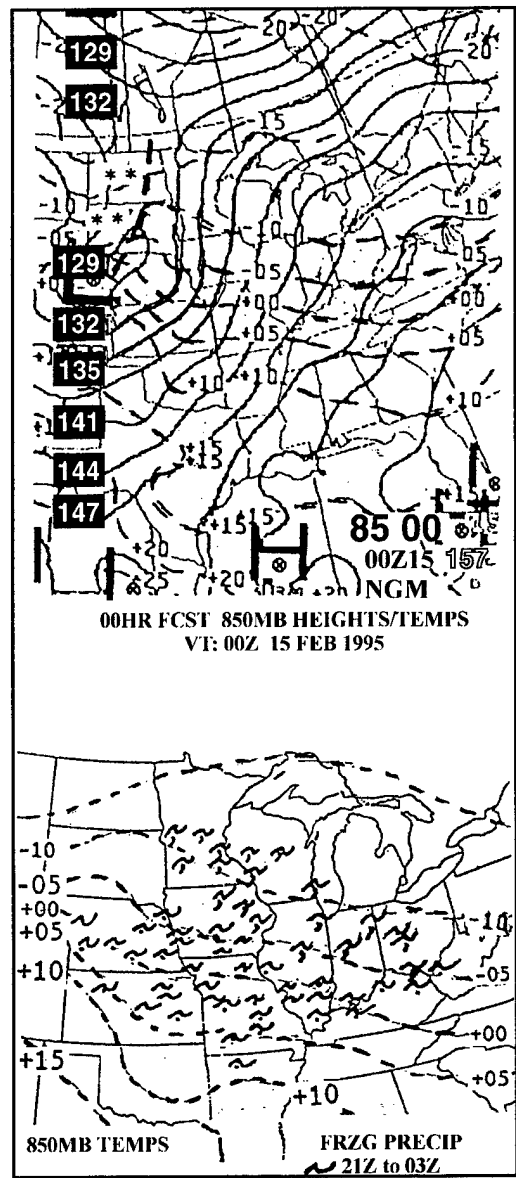


Figure 3-20b. The 850-Mb Heights/Temperatures and Composite Temperature/Freezing Precipitation Charts. The warm front is hard to place on the 850-mb chart (top) and the freezing precipitation area lies between the +5°C to -12°C 850-mb isotherms.

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Receding High - Freezing Drizzle. Warm, perhaps moist, air moving northward within return southerly flow of a retreating high can cause low clouds, fog, and freezing drizzle as the warm air lifts over a cold or snow-covered surface. The following example shows typical warm advection with the return of southerly winds in a receding high-pressure system. In this event, no noticeable warm front exists during the early stages of warm air advection (Figure 3-21a). Warm frontogenesis is likely as warmer air continues to overrun shallow cold air ahead of a developing Rocky Mountain storm system. In many gulf moisture advection occurrences into the central plains, the moisture tongue occurs below the 850-

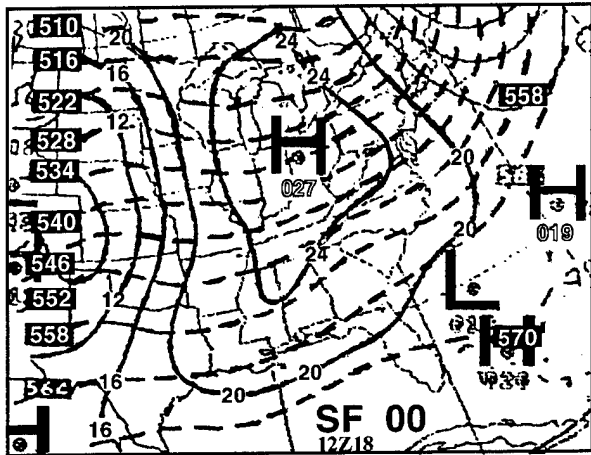


Figure 3-21a. Mean Sea-Level Pressure/1,000-to 500-mb thickness. Figure shows warm air advection due to return southerly flow. Chart is valid at 1200Z on 18 December 1992.

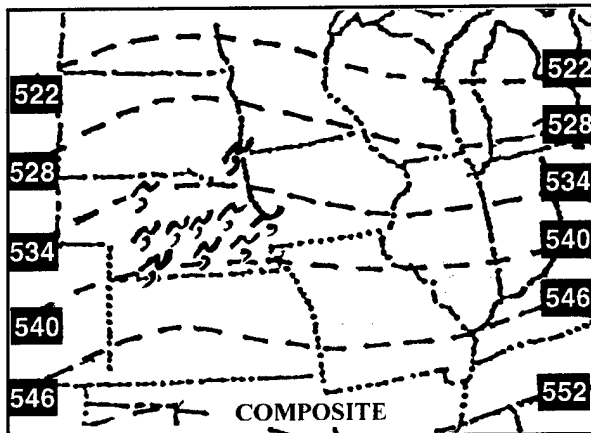


Figure 3-21c. Composite 1,000 to 500-Mb/Freezing Precipitation. Figure shows an outbreak of freezing drizzle has begun. Chart is valid at 1200Z on 18 December 1992.

mb level with tops at 3,000 to 4,000 feet and is associated with the low-level jet. In Figure 3-21b, the analysis shows dry air over the central plains; however, in Figure 3-21c, an outbreak of freezing drizzle has begun. Twelve hours later (Figure 3-21d) the 850-mb analysis shows a developing low-level jet and strong warm air advection. A warm front has developed over the southern Nebraska/northern Kansas area as shown by the arrow. It is still dry at the 850-mb level south of the warm front; the low-level jet has strengthened to 40 knots. The freezing drizzle shown in Figure 3-21c is aligned along the warm front shown in Figure 3-21d.

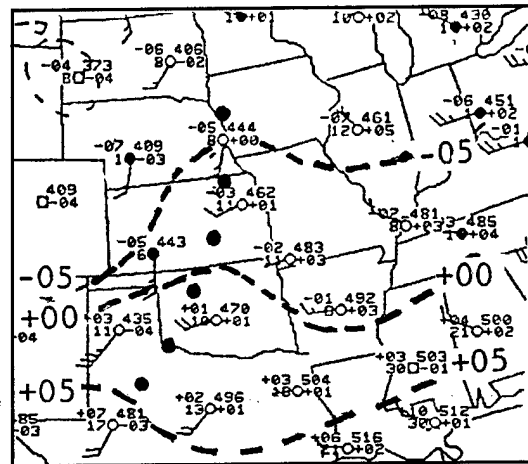


Figure 3-21b. The 850-Mb Analysis Chart. Figure shows dry air over the central plains. Chart is valid at 0000Z on 18 December 1992.

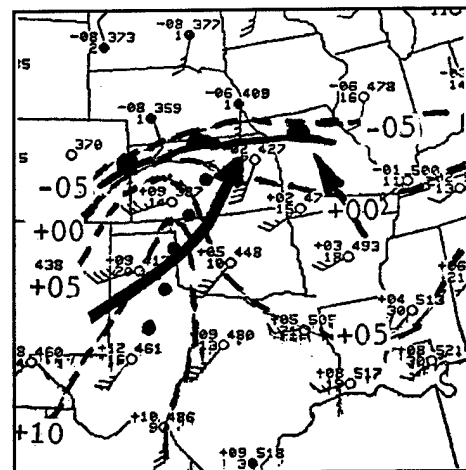


Figure 3-21d. The 850-Mb Analysis Chart. Figure shows a developing low-level jet and strong warm air advection. Chart is valid at 1200Z on 18 December 1992.

Example 1. Forecasting freezing drizzle can be a challenge during the course of winter. Drizzle is a low-level phenomenon developing in stratus layers below inversions. The 1,000- to 500-mb thickness rules would be more difficult to apply in pure warm air advection stratus, fog, and drizzle events. Forecasters must always look for warm air advection at the surface and lower layers. Wind profilers are very useful in determining wind directions and inversion layers. Also, pay attention to developing surface temperature ridges. Freezing drizzle is often a nocturnal event; drizzle is likely when stratus lowers below 1,000 feet and fog increases. On the other hand, freezing drizzle may persist for many hours especially within the cold air of frontal zones.

In most outbreaks of freezing drizzle studied, freezing drizzle occurred between the 540 and 528 thickness values and between the 0°C and -10°C temperatures as shown earlier in Figures 3-1 and 3-3. There are other thickness and temperature rules

available for forecasting freezing drizzle that may be more comfortable to forecasters (i.e. low-level thickness charts).

Figure 3-22 shows an example of low-level warm air advection (WAA) with the return of warm southerly winds and probable gulf moisture. In this example and in cases reviewed, no noticeable warm front exists during the early stages of warm air advection. Warm frontogenesis is likely as warm air continues to overrun shallow cold air ahead of a developing Rocky Mountain storm system. The 540 thickness and 0°C 850-mb isotherm usually defines the southerly boundary of freezing drizzle. Due to the shallowness of cP air being overran, warm air may overspread well into the cold air to reach the 528 thickness and -10°C 850-mb temperature fields. Often, under southerly low-level flow, gulf moisture advects northward, below the 850-mb level, over cold surfaces less than 0°C to increase moisture and subsequent widespread fog and freezing drizzle.

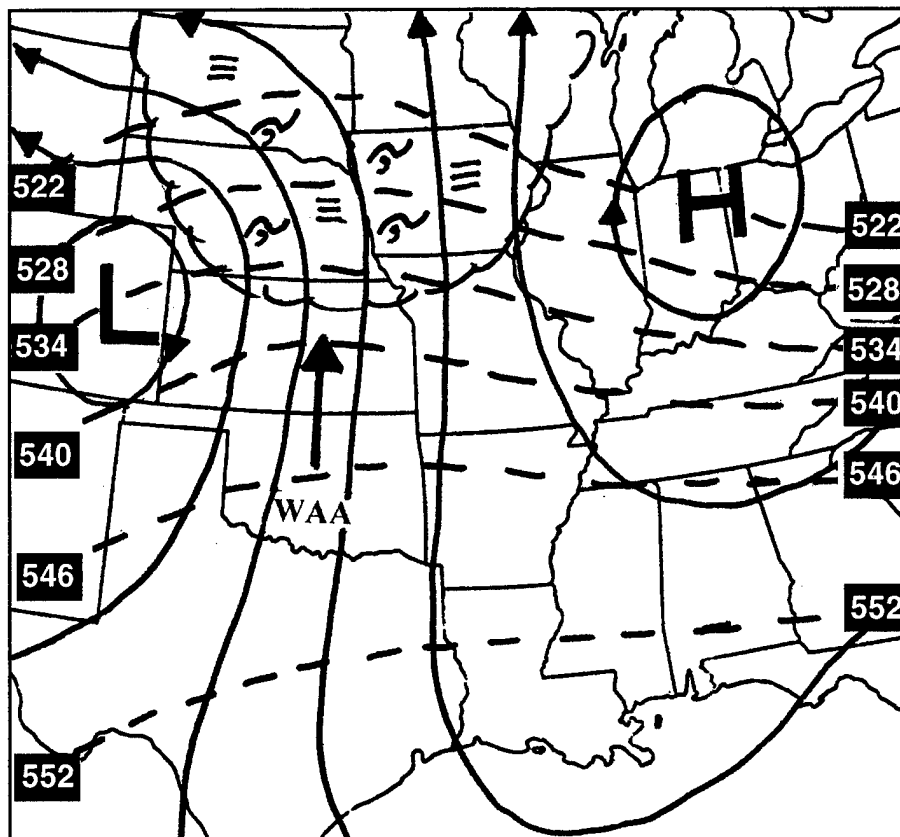


Figure 3-22. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Figure shows an example of low-level warm air advection (WAA) with the return of warm southerly winds and probable gulf moisture.

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Example 2. Figure 3-23 shows another source of low-level, warm air advecting over a Great Plains cP air mass to produce freezing drizzle. Warm, low-level westerly winds, which had developed earlier in the lee of the Rocky Mountains within a lee-side trough (or a warm front), continues eastward and lifts over a shallow cP high. Often low clouds are present over the northern plains within southerly flow. The moisture source is not necessarily from the Gulf of Mexico. Stratus layers develop within residual moisture below a strong inversion (below 850 mb) as warm air increases. With warm air advection, melting snows add moisture. Freezing drizzle begins when PVA, which adds vertical motion and instability, approaches the cold dome. Although temperatures advected eastward above the cP air mass area are often below 0°C, they are still

warmer than temperatures below the inversion. This enhances lift over the cP air mass.

The 540 thickness and 0°C 850-mb temperature defines the western extent of freezing drizzle. Several cases have shown that freezing drizzle can advect eastward into the 528 and 522 thickness values and the -10°C 850-mb isotherm. Figure 3-23 depicts a surface trough; however, north to south warm fronts extending southward from Canadian lows are often observed with these freezing precipitation events.

Although freezing drizzle occurs most often with this pattern, rain associated with warm mP fronts from the Rockies can overspread the shallow retreating cP air mass. Freezing rain may occur.

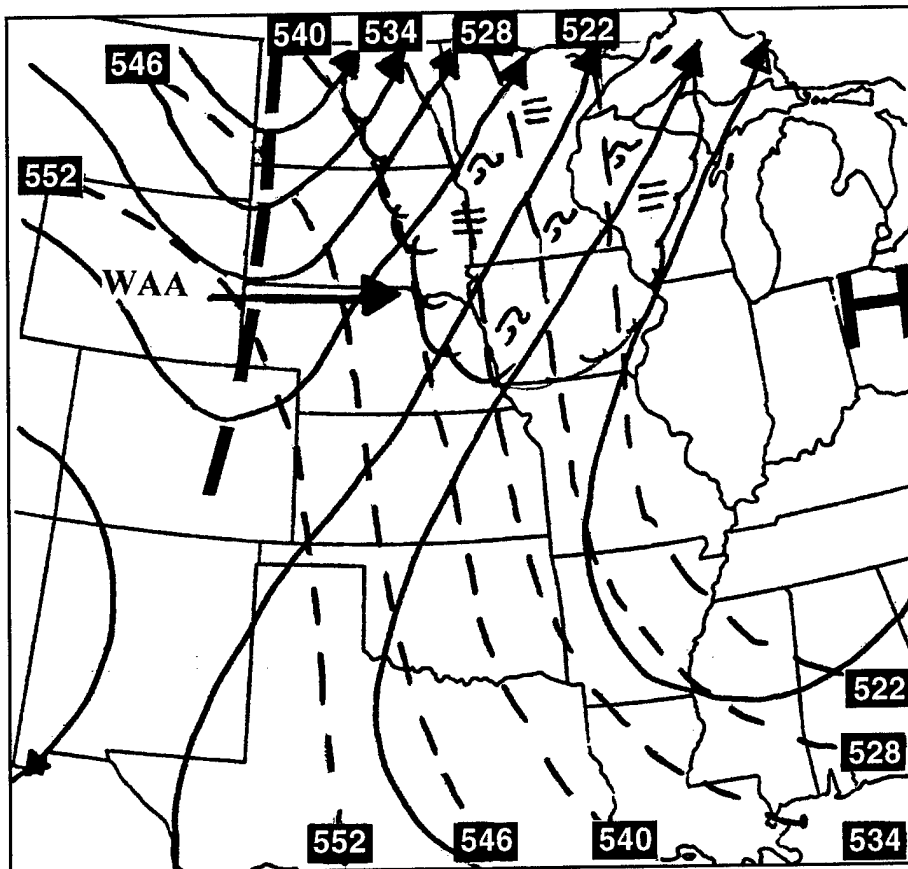


Figure 3-23. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Figure 3-23 shows another situation where low-level, warm air advection lifts over a Great Plains cP air mass to produce freezing drizzle.

Example 3. Figures 3-24 and 3-25 illustrate a freezing drizzle event that occurred 36 hours later over the Great Lakes/Ohio River valley region ahead of a surface trough. The freezing drizzle began over the central Dakotas-Nebraska area as the surface high moved east, and a lee-side trough similar to the example shown in Figure 3-23 developed. Lee-side troughs over the western Great Plains usually do not move very far to the east. Although the surface charts depicted it as a trough, a weak warm

front is suspected. The freezing drizzle spread rapidly eastward along and ahead of the surface trough within a cold air mass. The freezing drizzle extended into the 522 thickness and -10°C 850-mb temperature.

NOTE: Freezing precipitation outbreaks in a receding high-pressure pattern may occur anywhere depending on whether Gulf of Mexico or Atlantic moisture is available to feed into the system.

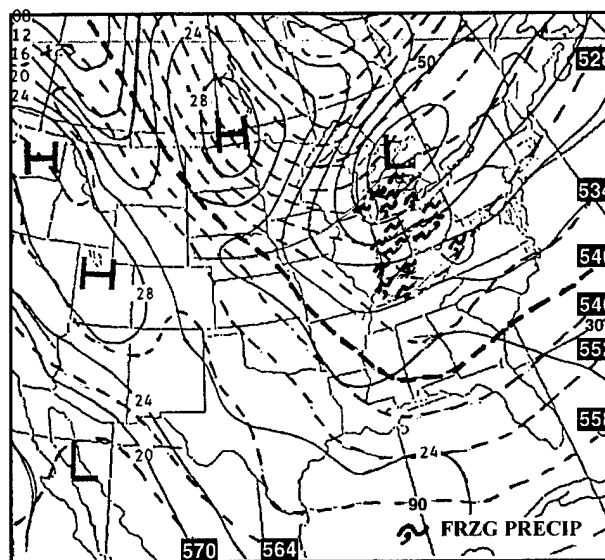


Figure 3-24. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. The freezing drizzle extended into the 522 thickness isopleth. Chart valid 0000Z on 26 December 1989.

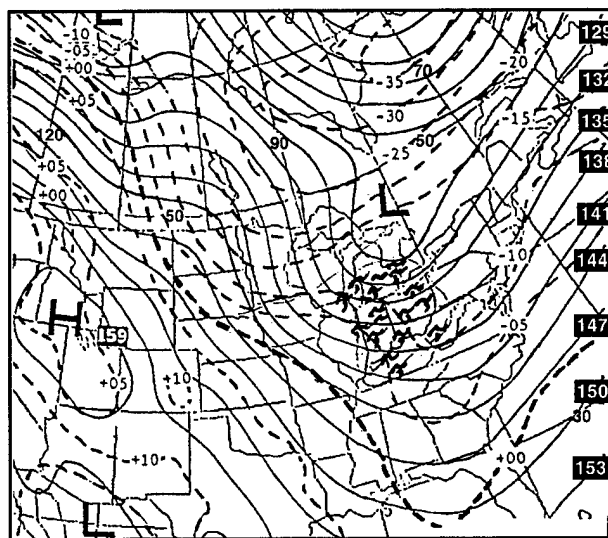


Figure 3-25. Forecast (00HR) 850-Mb Heights/Temperature. Freezing rain occurs below the -10°C temperature. Chart valid at 0000Z on 26 December 1989.

Chapter 3

Neutral Advection. Neutral advection occurs when no apparent surface cold or warm advection is occurring within the continental polar air mass. The temperature, pressure, and wind fields are in phase within a stationary pattern. In many cases, however, warm air (and moisture) advection is lifting and spreading northward above the cold dome to produce an extensive area of precipitation.

Prevailing High. Not all freezing precipitation events have an associated temperature and thickness

ridge during the initial stage of development. For example, in Figure 3-26, neither a pronounced thickness ridge nor an 850-mb temperature ridge is evident although an outbreak of freezing rain is occurring; this is a neutral advection event.

Twelve hours later, however (Figure 3-27), the pattern has changed to a warm air advection pattern with development of a thickness and temperature ridge. Figure 3-28 shows a second neutral advection event.

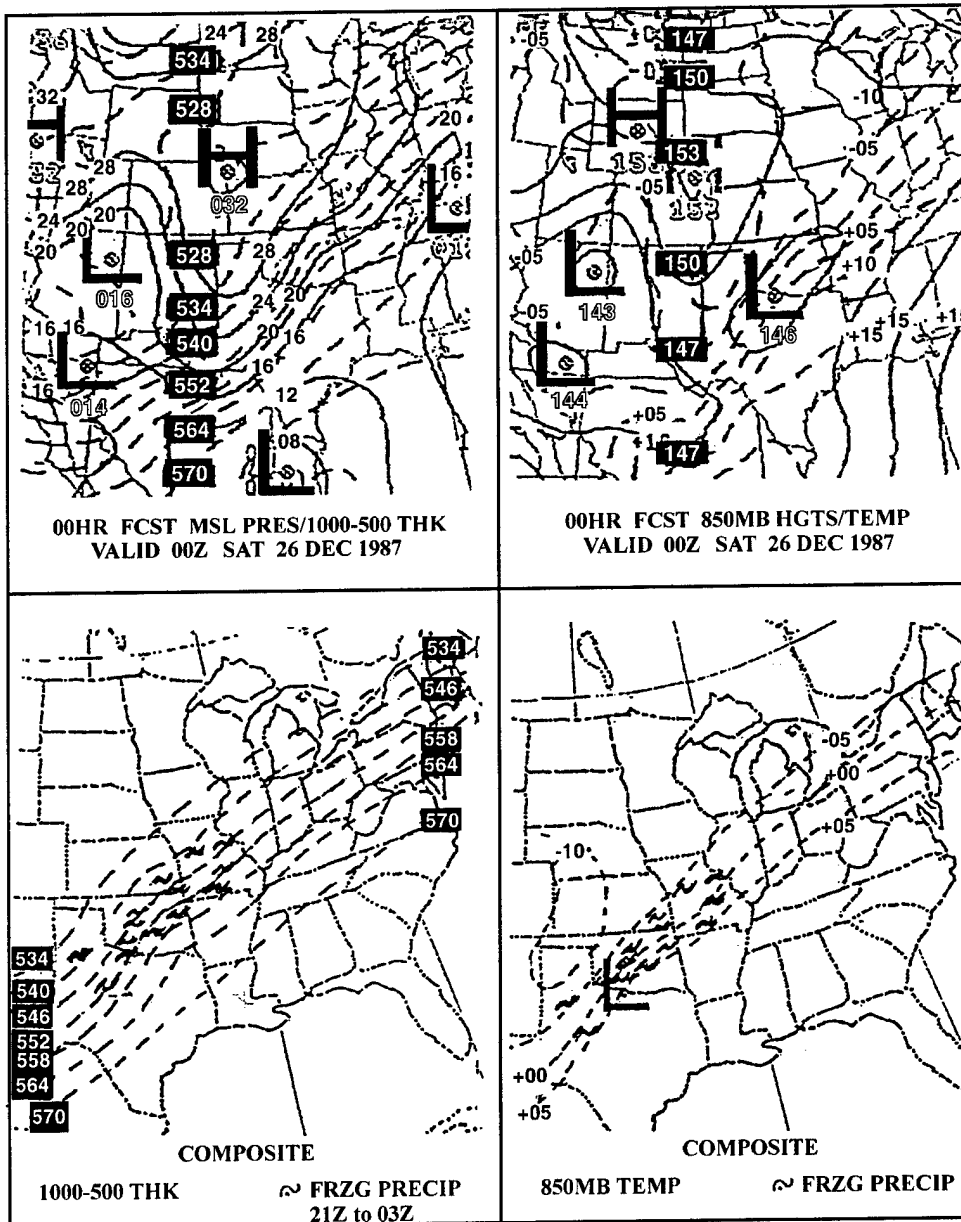


Figure 3-26. Neutral Advection/Freezing Precipitation Relationships. Although neither a pronounced thickness nor an 850-mb temperature ridge is evident, freezing rain is occurring. Chart is valid at 0000Z on 26 December 1987.

There are those periods during winter, especially during January and February when large-scale freezing precipitation events continue for 12 to 24

hours or longer in the same general areas. These events make the headlines with phrases like "Severe Ice Storms Cause Death and Destruction." This

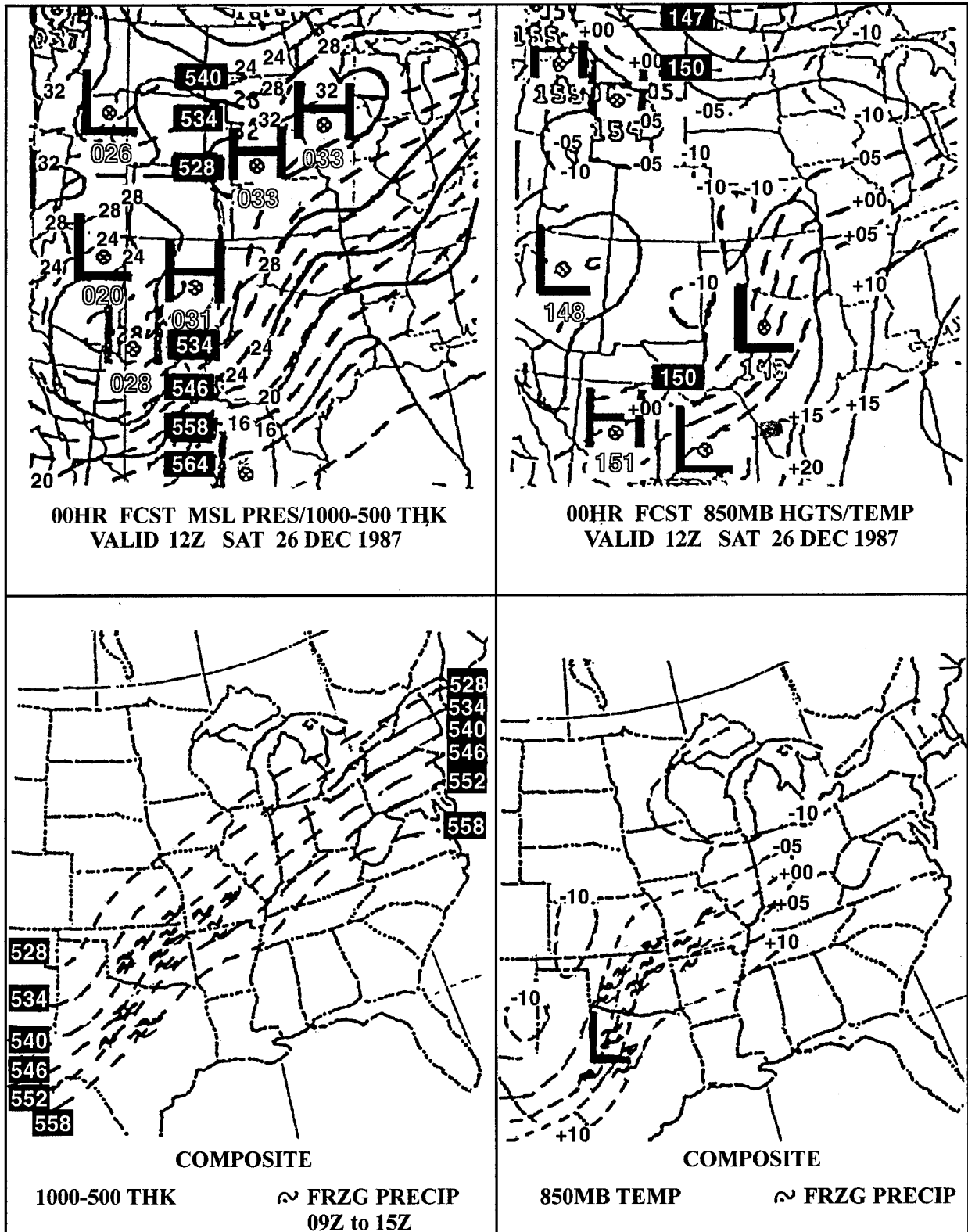


Figure 3-27. Transition to a Warm Air Advection Pattern. The figure shows development of a thickness and temperature ridge. Chart is valid at 1200Z on 26 December 1987.

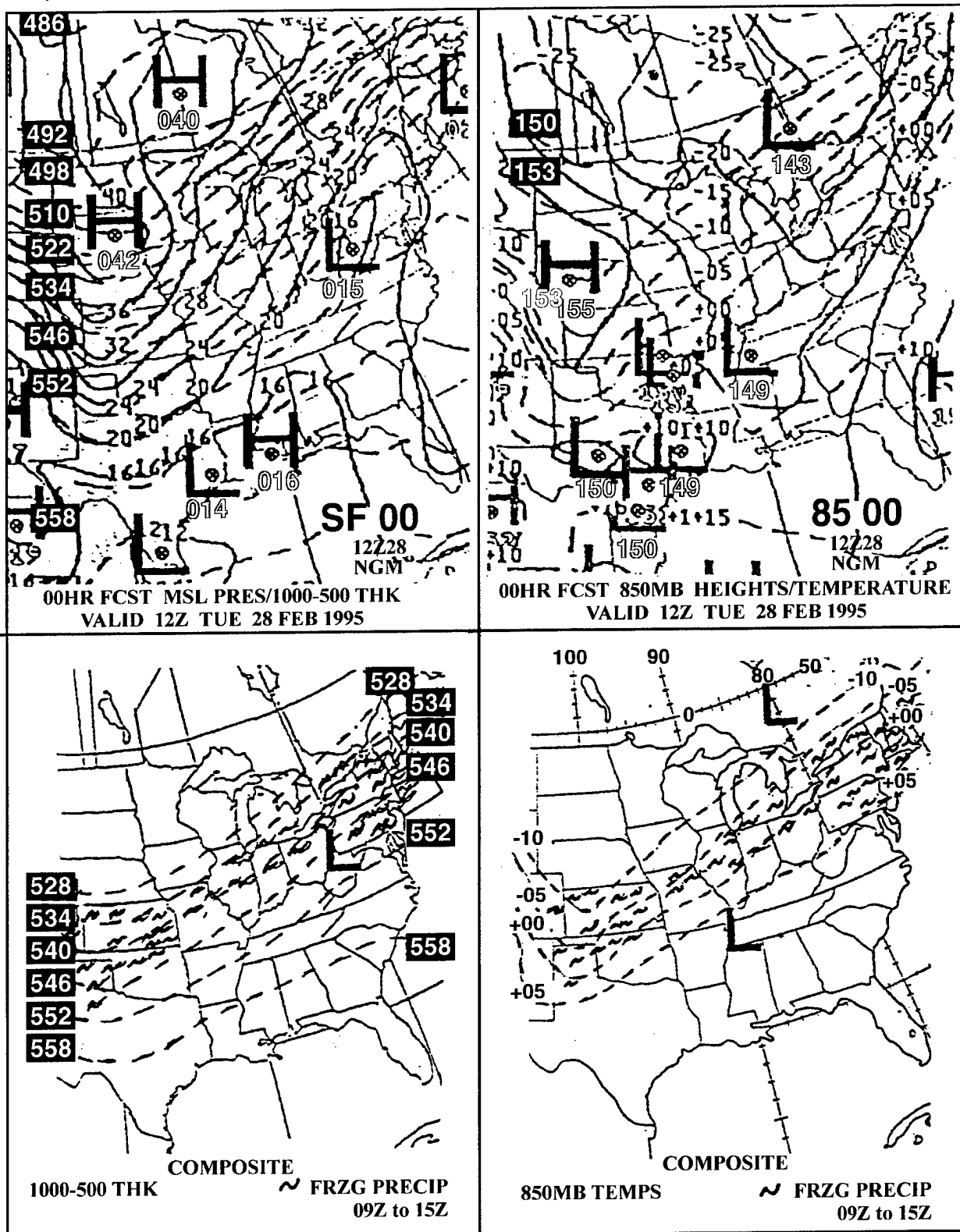


Figure 3-28. Neutral Advection/Freezing Precipitation Relationships. Although neither a pronounced thickness ridge nor an 850-mb temperature ridge is evident, an outbreak of freezing rain is occurring. Chart is valid at 1200Z on 28 February 1995.

pattern becomes established when large, stagnant or slow moving continental polar air masses prevail across the central and eastern CONUS (prevailing high-pressure system). Generally, a long-wave trough lies across the western Great Plains/Rocky Mountains area. Continental polar frontal systems slow down or become stationary over the central CONUS due to a southerly upper flow, which allows for little frontal movement. Within this southwest flow, the baroclinic cloud bands increase as gulf moisture overruns the polar boundary.

This pattern is called neutral advection because no noticeable cold or warm advection occurs at the surface. Above the shallow cold dome, however, southerly winds bring warm, moist air northward over the frontal boundary to increase cloudiness and precipitation. The pattern would likely be rain to the south, a narrow band of freezing rain, and snow to the north of the freezing rain.

Figures 3-29 and 3-30 depict two typical large-scale precipitation models. The freezing precipitation

areas are located within the 552 to 540 1,000- to 500-mb thickness ribbon. In neutral advection events, the surface isobars are nearly parallel to the thickness lines but in opposite flow. In Figure 3-29, the surface isobars are oriented east to west (easterly flow) while the thickness flow is from west to east.

The same idea appears in Figure 3-30 where the surface isobars are aligned from northeast to southwest, and the thickness flow is from southwest to northeast. The 850-mb analysis would show warm air lifting over the cold dome to produce an extensive precipitation area well into the cold air. In nearly all cases, the freezing precipitation area is located between the $+5^{\circ}\text{C}$ to -5°C thickness ribbon. In neutral advection, little or no thickness or temperature ridges are evident during the early stages. Neutral advection will eventually change to warm and/or cold advection (increased thickness and temperature ridging) when a frontal wave develops in response to an approaching short wave. Several examples will be shown later in this chapter.

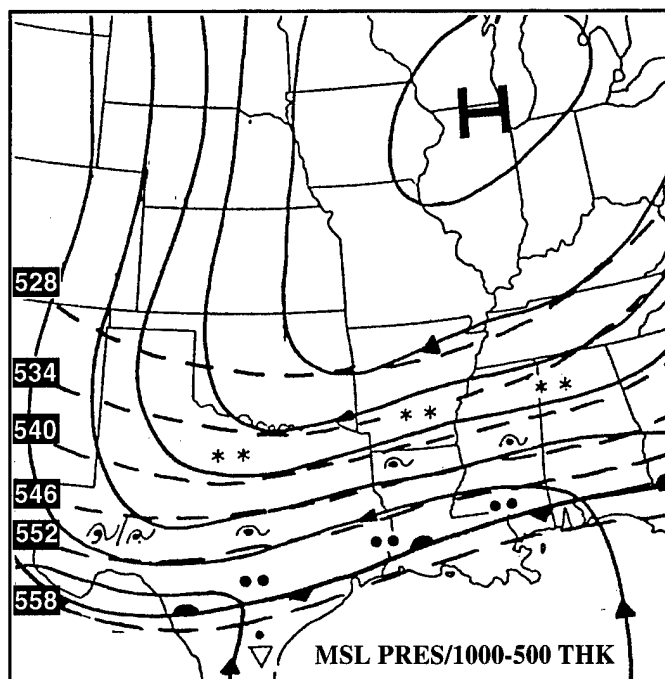


Figure 3-29. Southern CONUS Neutral Advection Pattern. The surface isobars are oriented east to west (easterly flow) while the thickness flow is from west to east. Freezing precipitation occurs between the 552 and 540 thickness isopleths and between the $+5^{\circ}\text{C}$ to -5°C 850-mb isotherms.

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Freezing precipitation associated with neutral advection may extend west to east for a considerable distance. The freezing precipitation area is narrow from south to north (less than 200 nm) but quite extensive from west to east and can extend in excess of 500 nm. Why? Precipitation increases over a slow-moving or stagnant polar air mass as gulf

moisture continues to be lifted over the cold dome. Westerly mid- and upper-level winds spread the cloudiness and precipitation eastward, and soon an extensive precipitation area develops. Short waves translating eastward over the cold dome trigger frontal cyclogenesis, which would eventually end the precipitation.

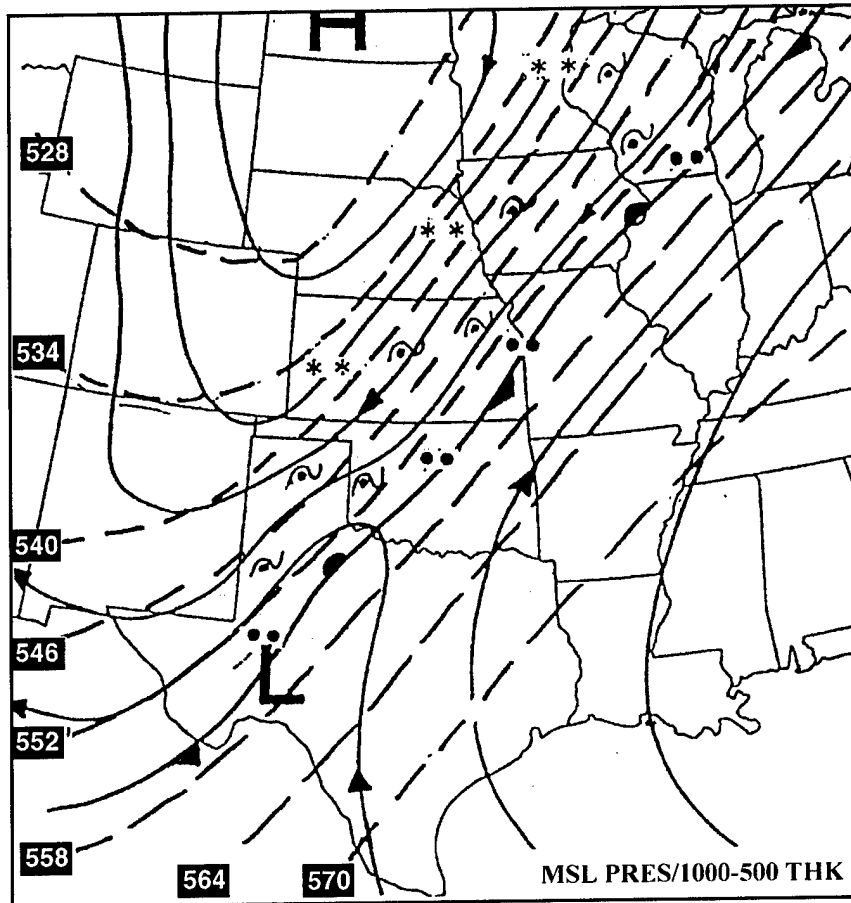


Figure 3-30. Central and Northern CONUS Neutral Advection Pattern. The surface isobars are aligned from northeast to southwest and the thickness flow is from southwest to northeast. Freezing precipitation occurs between 552 and 540 thickness isopleths and between the $+5^{\circ}\text{C}$ to -5°C 850-mb isotherms.

Two prevailing high examples for overrunning events are shown in Figure 3-31 (model) and an actual occurrence (Figure 3-32). A fetch of gulf moisture and the low-level jet intersect the stationary

boundary and establish an overrunning event. In Figure 3-31, notice the extensive freezing precipitation and snow area from Nebraska to the East Coast.

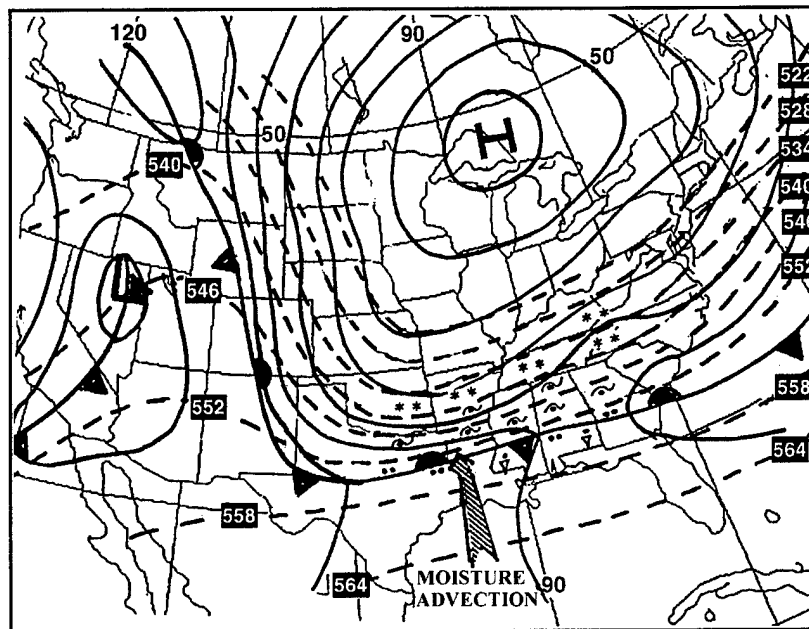


Figure 3-31. Overrunning (Model). A fetch of gulf moisture and the low-level jet intersect the stationary boundary and establishes an overrunning event.

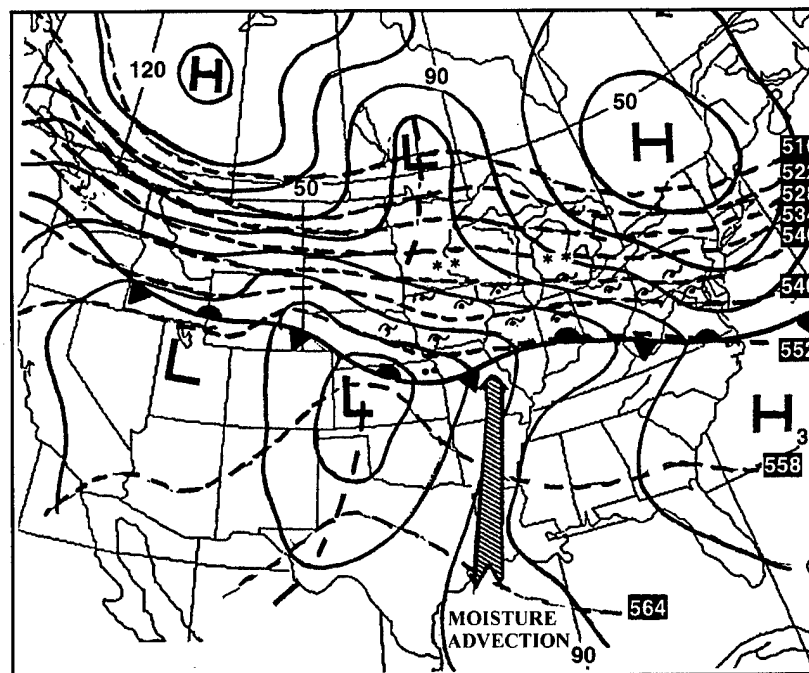


Figure 3-32. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Extensive freezing precipitation extends from Nebraska to the East Coast. Chart is valid at 0000Z on 27 Feb 1995.

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Example 1. In Figures 3-33a and 3-33b, an extensive area of freezing precipitation stretches from eastern New Mexico to South Carolina, with snow to the north. Freezing rain is occurring from central Texas eastward to South Carolina while upslope freezing drizzle has developed over west Texas and eastern New Mexico as cold air advection has begun.

In Figure 3-33a, surface inverted troughing over

Alabama and Mississippi suggests low-level warm air is eroding the ridge. The freezing rain lies between the 552 and 540 thickness ribbon.

At the 850-mb level (Figure 3-33b), there is little indication that a polar air mass exists; warm air advection and cyclonic flow with a low over Arkansas appears over the cold dome. The freezing precipitation lies within $+5^{\circ}\text{C}$ to -5°C ribbon.

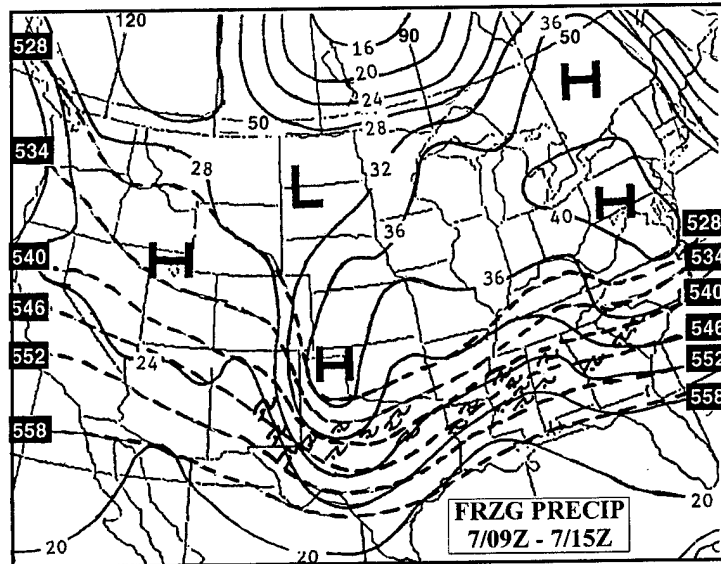


Figure 3-33a. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. The ridge begins breaking down, but freezing precipitation continues between the 552 and 540 thickness isopleths. Chart Valid at 1200Z on 7 January 1988.

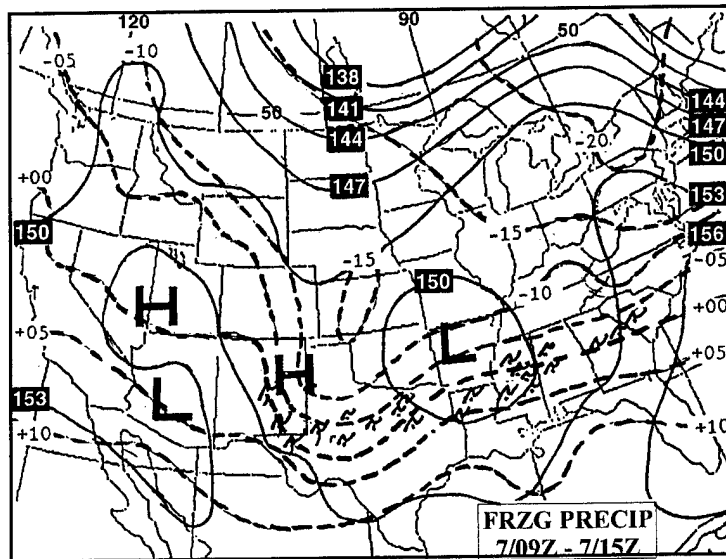


Figure 3-33b. Forecast (00HR) 850-Mb Heights/Temperature. The freezing precipitation lies within the $+5^{\circ}\text{C}$ to -5°C temperature ribbon. Chart Valid at 1200Z on 7 January 1988.

Example 2. This example and example 3 resembles the pattern shown in Figure 3-30. A long-wave trough is shown over the western CONUS with the main PVA center over southern California (Figure 3-34). A weak PVA lobe (noted by the arrow) lies across Nebraska, Kansas, and Oklahoma.

At the 700-mb level (Figure 3-35) a band of moisture (70 percent relative humidity) extends from Kansas and Oklahoma northeastward to Pennsylvania and fits perfectly with the freezing precipitation area (Figure 3-36).

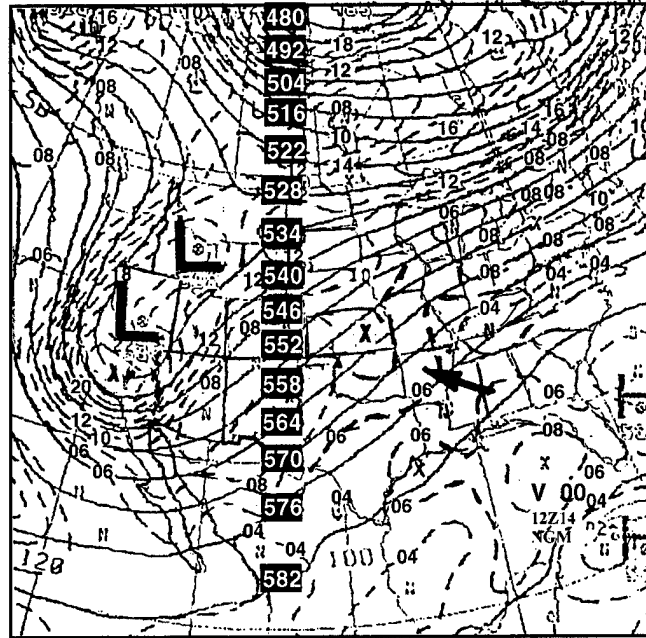


Figure 3-34. The 500-Mb Heights/Vorticity Chart. The arrow indicates a weak PVA lobe. Chart Valid at 1200Z on 14 February 1990.

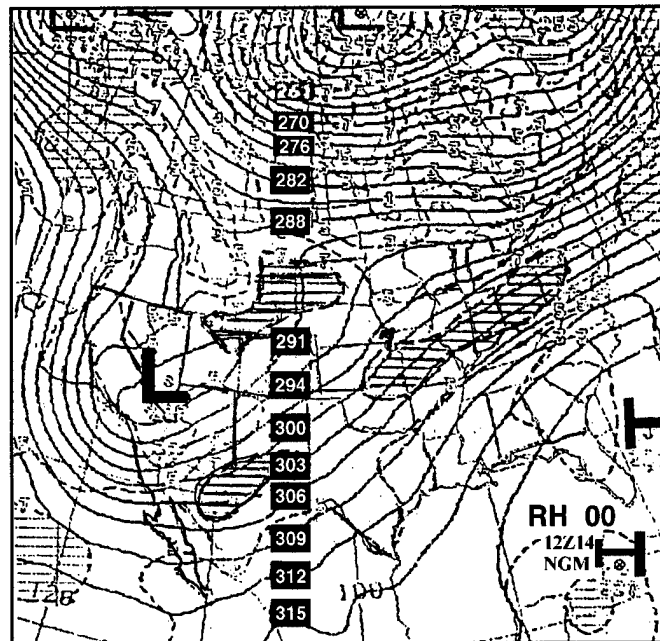


Figure 3-35. The 700-Mb Heights/Relative Humidity Chart. A band of moisture fits the freezing precipitation pattern. Chart valid at 1200Z on 14 February 1990.

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In Figure 3-36a, the cold front has become stationary across the central and eastern CONUS in response to the prevailing southwest flow aloft. In Figure 3-36b, the 850-mb front is shown from the Texas Panhandle, across southeastern Kansas, to central Indiana and Ohio. The freezing precipitation area shown in the composite lies along and to the north

of the 850-mb front. Additionally, the freezing precipitation is located within the 552/540 thickness and the +5°C/-5°C temperature ribbons. NOTE: Freezing drizzle is shown in the Lubbock area south of the 552 thickness and is likely to be drizzle in low stratus behind the cold front.

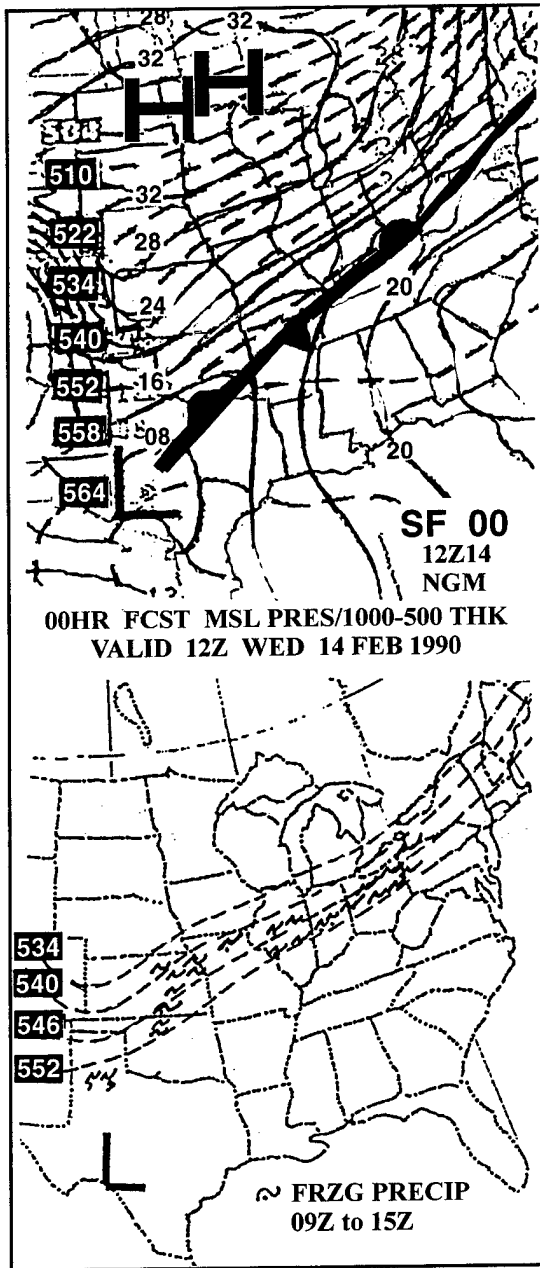


Figure 3-36a. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation. The freezing precipitation is located within the 552/540 thickness ribbon.

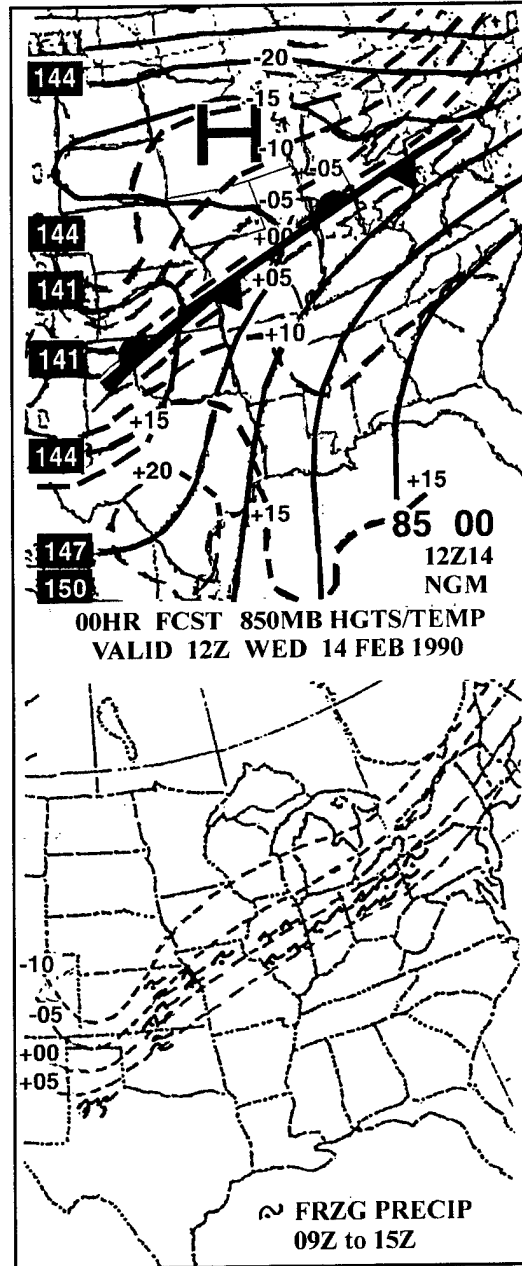


Figure 3-36b. Composite 850-Mb Temperature/Freezing Precipitation Relationship. The freezing precipitation is located within the +5°C/-5°C temperature ribbon.

Example 2 (24 hours later). The upper trough has moved eastward to the central Rockies with the main PVA center located over southern Nevada. The PVA lobe shown over the southern Great Plains in Figure 3-34 has intensified, and the center is now located near Texas. PVA is still shown over the western Great Plains (Figure 3-37).

The 700-mb relative humidity has expanded across the central and northern plains to the northeastern CONUS (Figure 3-38). A major storm system is intensifying over the southern Rockies; heavy snowfall is occurring over the mountains of northern Arizona and Colorado. This is a strong overrunning event east of the Rocky Mountains.

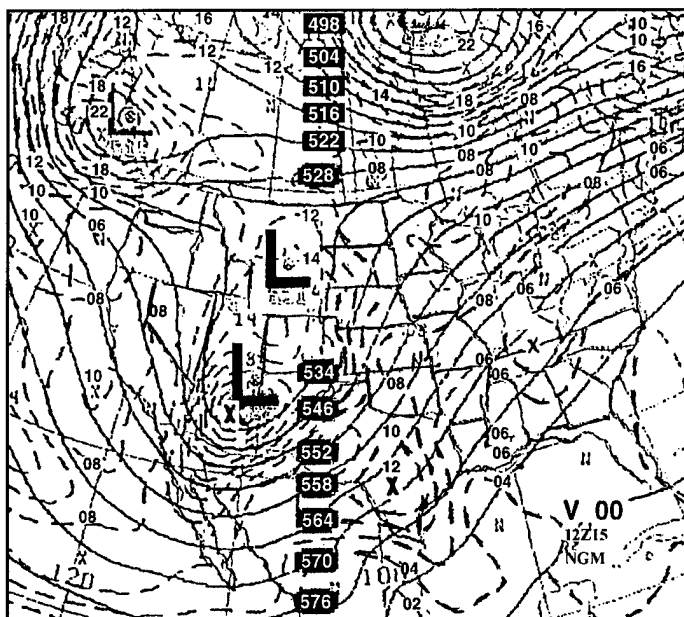


Figure 3-37. The 500-Mb Heights/Vorticity Chart. A PVA center is located over Texas. Chart valid at 1200Z on 15 February 1990.

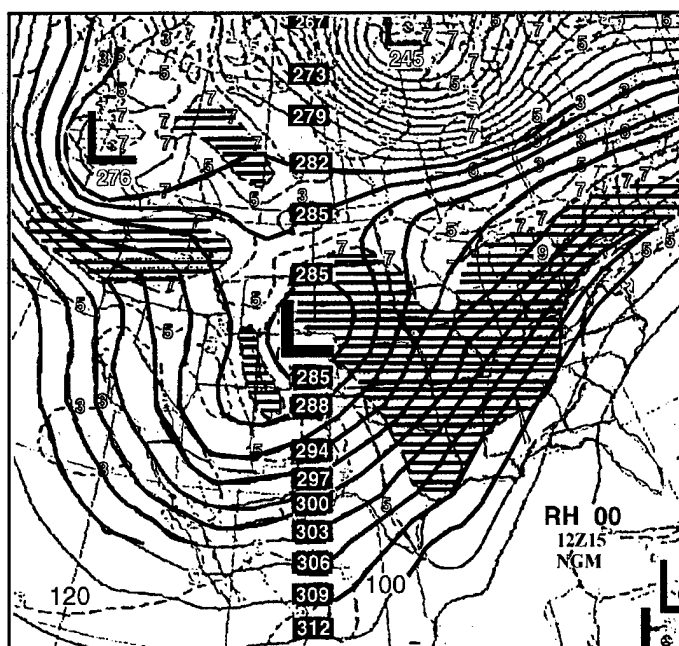


Figure 3-38. The 700-Mb Heights/Relative Humidity Chart. Moisture has expanded across the Great Plains. Chart valid at 1200Z on 15 February 1990.

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The thickness and 850-mb temperature ribbons (Figures 3-39a and 3-39b) show ridging as warm air advection increases ahead of the approaching storm system. Most of the freezing precipitation still lies within the 552 and 540 thickness and +5°C/

-5°C temperature ribbons; freezing precipitation has spread northward into the 534 thickness value, but since the freezing precipitation shown is to 1500Z the 540 thickness has most likely shifted northward.

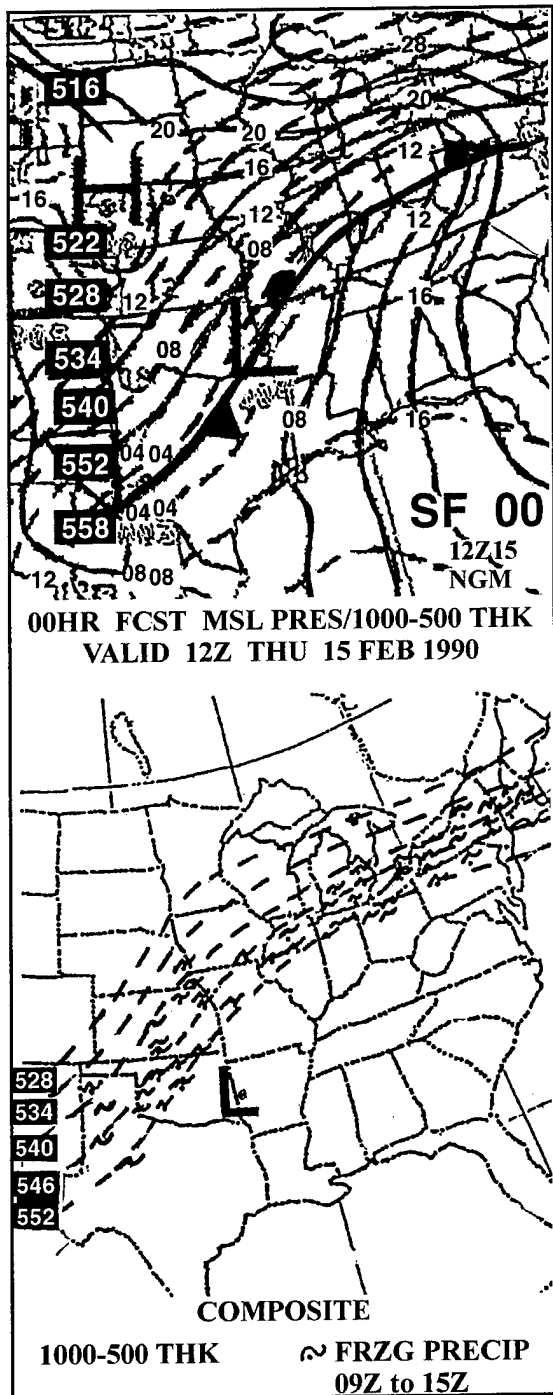


Figure 3-39a. Thickness/Freezing Precipitation Relationship. The freezing precipitation is located within the 552/540 thickness ribbon.

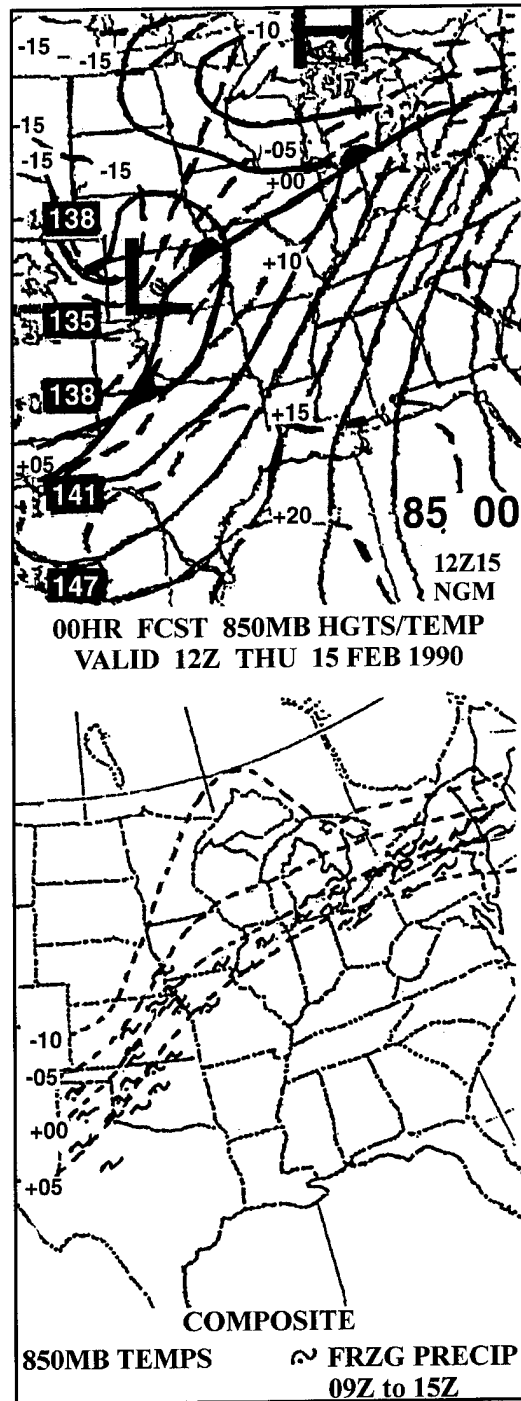


Figure 3-39b. Freezing Precipitation/850-Mb Temperature Relationship. The freezing precipitation is located within the +5°C/-5°C temperature ribbon.

As a result of these stagnant events (prevailing high) and warm fronts moving northeast (receding high), the area stretching from Kansas and Oklahoma northeastward across Missouri to Ohio, and eastward across Pennsylvania and New York to the Atlantic coast has a higher frequency of freezing precipitation; the area is shown in Figure 3-40.

Many onsets of freezing precipitation, especially rain, begin over the western Great Plains with the return of gulf moisture and moisture advection accompanying the approaching short wave. A favorite area of freezing precipitation development

within a prevailing high-pressure pattern is over the Texas Panhandle and western Oklahoma area as depicted in Figures 3-41a and 3-41b. Freezing precipitation outbreaks within a receding high-pressure pattern usually develop further to the north over western Kansas and Nebraska.

Another area favorable for freezing rain outbreaks is across the lower Mississippi River valley when inverted troughs develop northward of a Gulf of Mexico frontal low. Discussions and illustrations of the above mentioned outbreak areas will be presented later.

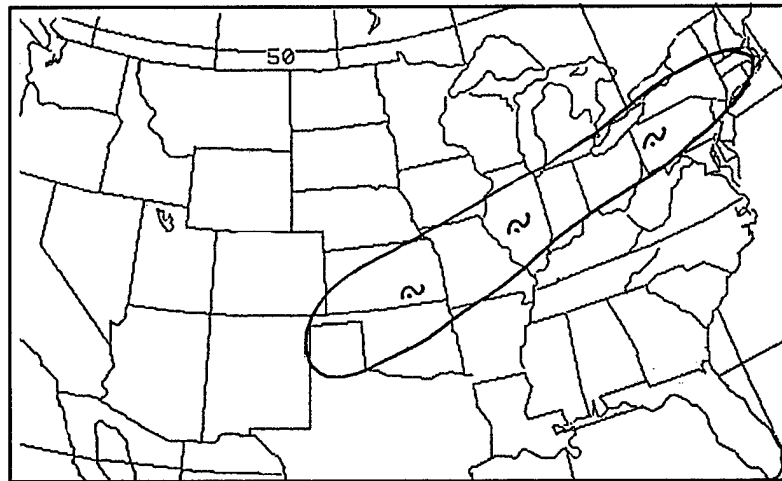


Figure 3-40. Freezing Precipitation Band. The precipitation results from warm fronts moving northeast.

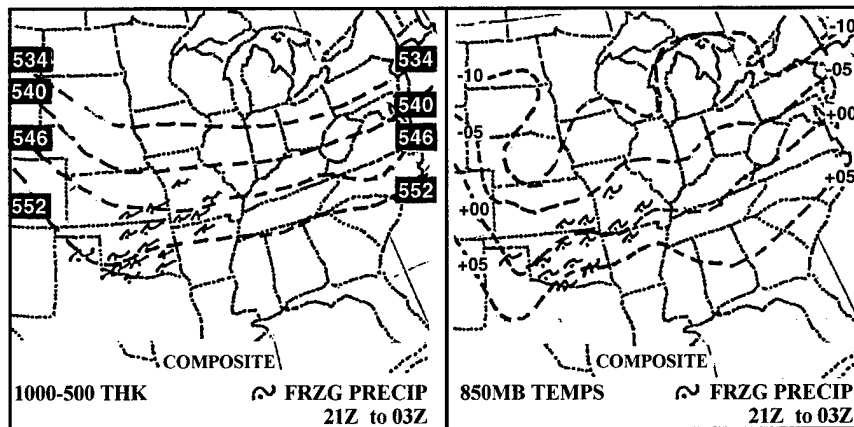


Figure 3-41a. Composite Thickness and 850-Millibar Temperatures. The figure shows a favored area for freezing precipitation development at 0000Z on 5 January 1991.

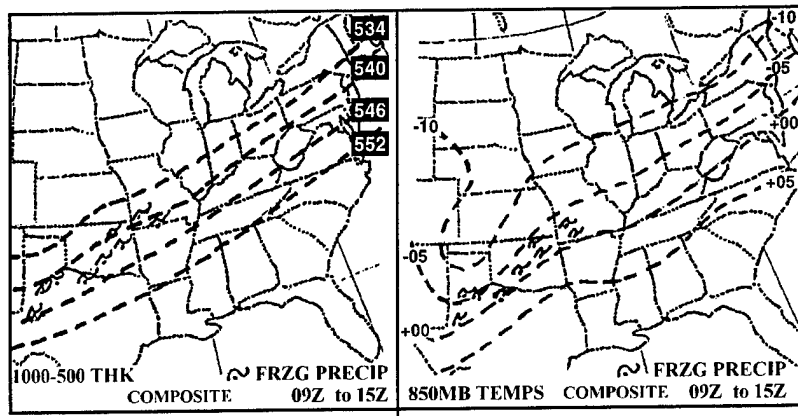


Figure 3-41b. Composite Thickness and 850-Millibar Temperatures. Figure shows another example of freezing precipitation development at 1200Z on 16 February 1987.

Cold Air Advection (Undercutting). Unlike overrunning, where warm air lifts over cP air, undercutting occurs when shallow cP air moves into an existing rain or drizzle area. The temperature drops below freezing resulting in freezing precipitation. In the northern CONUS, undercutting is a short-lived event as cold air advances eastward; however, it may last longer across the southern plains where the cold dome is shallow.

Undercutting occurs most often across the central and southern Great Plains to the Gulf Coast. Often precipitation develops with the return of gulf

moisture and/or precipitation that has moved out of the Rockies sometime before the arrival of a cP cold front. In many undercutting cases, freezing precipitation occurs between the 1,000- to 500-mb 558-540 thickness isopleths and the 850-mb +10°C to 0°C temperature ribbon.

In Figure 3-42, note the prefrontal precipitation is occurring within the 552 to 558 thickness isopleths over the central plains (noted by the arrow). A surge of cP air is moving southward. A narrow band of undercutting freezing rain is shown across the Texas panhandle and into central Kansas.

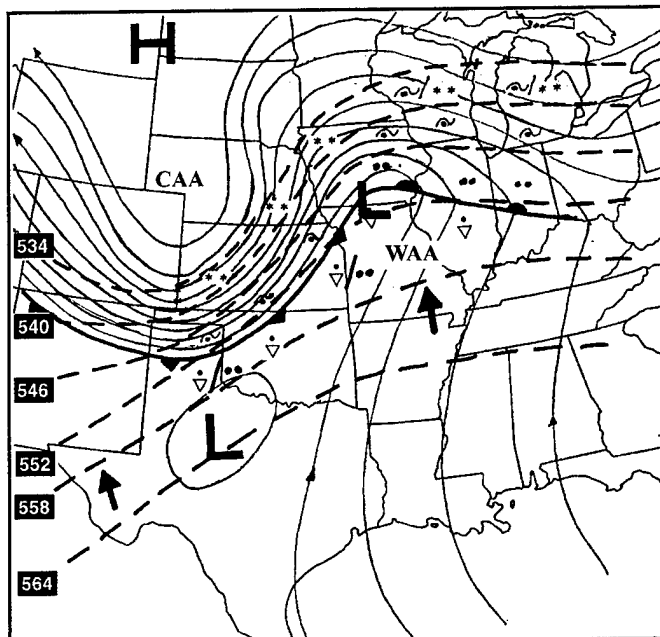


Figure 3-42. Undercutting Freezing Precipitation (Now). Prefrontal rain falls within the 552 to 558 thickness isopleths. Freezing rain occurs behind the cold front.

Later in Figure 3-43, the shallow cold air has advanced southward into central Texas and northward into Missouri. The freezing rain area has expanded as cold air moved into the previous prefrontal precipitation area shown in Figure 3-42. Since the cold air is shallow, the thickness column has not decreased sufficiently to change rain to snow. In Figure 3-43, notice that the 558 thickness isopleth is now north of the cold front as indicated by the arrows.

occurs within a narrower band after cold frontal passage. Generally, the cold front is oriented northeast-southwest, which indicates the strongest cold air advection. On the other hand, undercutting occurs often over a larger area of the southern plains to the Gulf Coast as the cold front aligns east-west, an indication of weaker cold air advection.

Generally over the upper Great Plains, undercutting

The freezing rain area shown north of the warm front in both figures is not undercutting but is associated with warm air advection presented earlier in the warm air advection pattern.

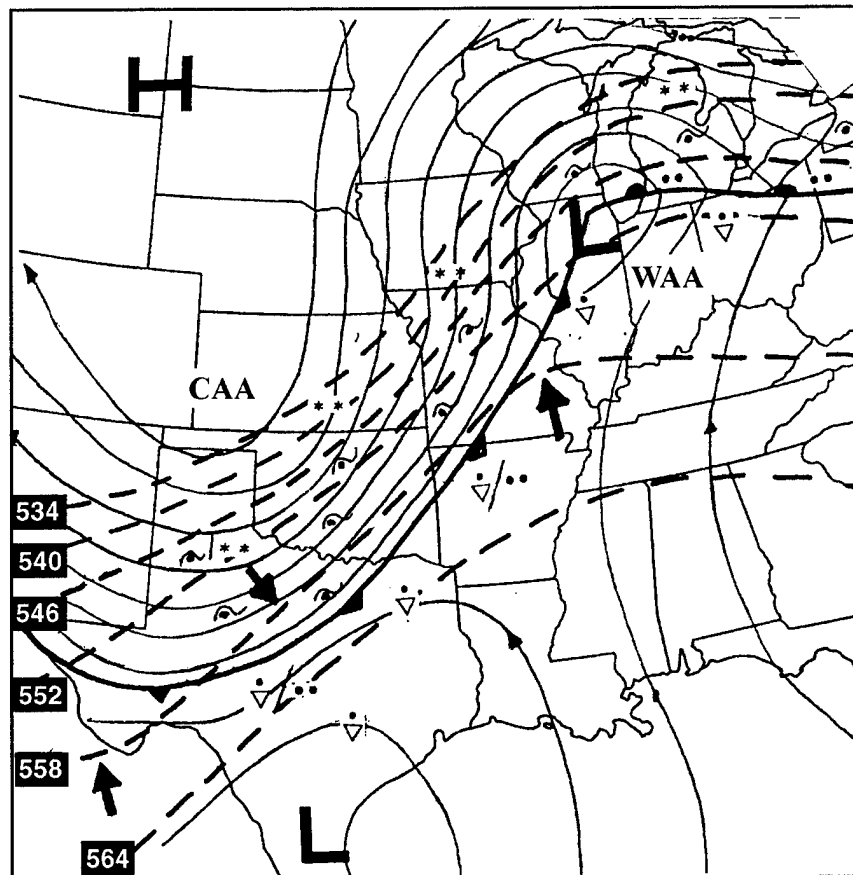


Figure 3-43. Undercutting Freezing Precipitation (Later). The 558 thickness isopleth is now located north of the cold front in the Texas and Oklahoma area (see arrow). Freezing precipitation expands northeastward.

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Figures 3-44 and 3-45 show two examples of pronounced undercutting over the central and southern Great Plains. In the model example (Figure 3-44), warm frontal rains are shown over the southern and central plains and eastward to the lower Mississippi River valley. Continental polar air is racing southward; an extensive freezing rain area has developed within the cold air.

Figure 3-45 depicts an actual occurrence of widespread undercutting freezing rain. The

thickness pattern indicates the position of the upper trough from Wisconsin to west Texas. The upper-wind flow within the baroclinic zone and across the southern and eastern CONUS is southwesterly and moist. The cP air mass has pushed rapidly southward and changed rain to freezing rain in its path. The pattern shown in Figure 3-45 will produce freezing rain to the Gulf Coast. A similar event occurred on 20 January 1985 which caused havoc over southern Louisiana, Mississippi, and the Florida panhandle.

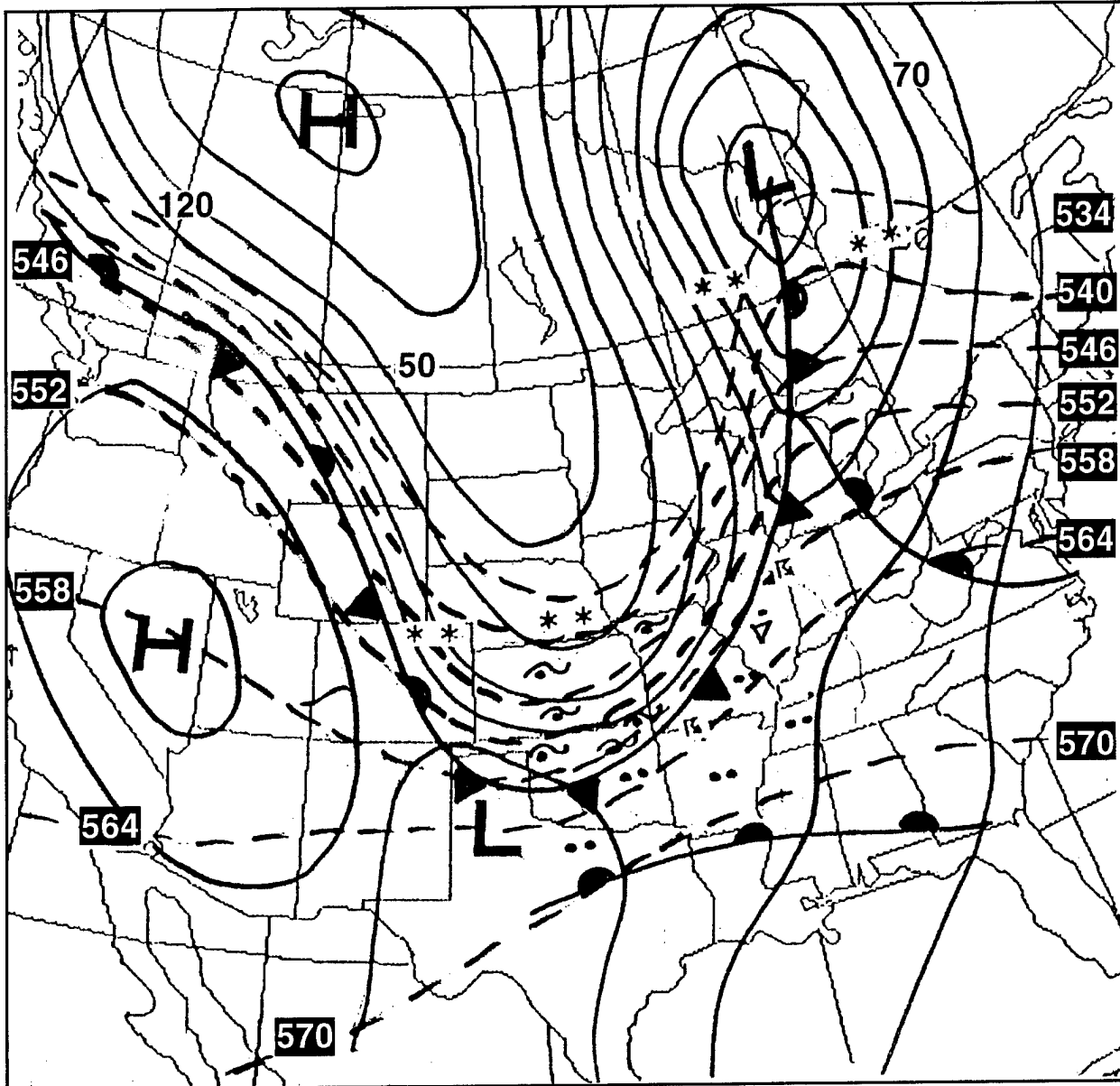


Figure 3-44. Cold Air Advection (Undercutting). As cold air rushes southward widespread freezing rain develops.

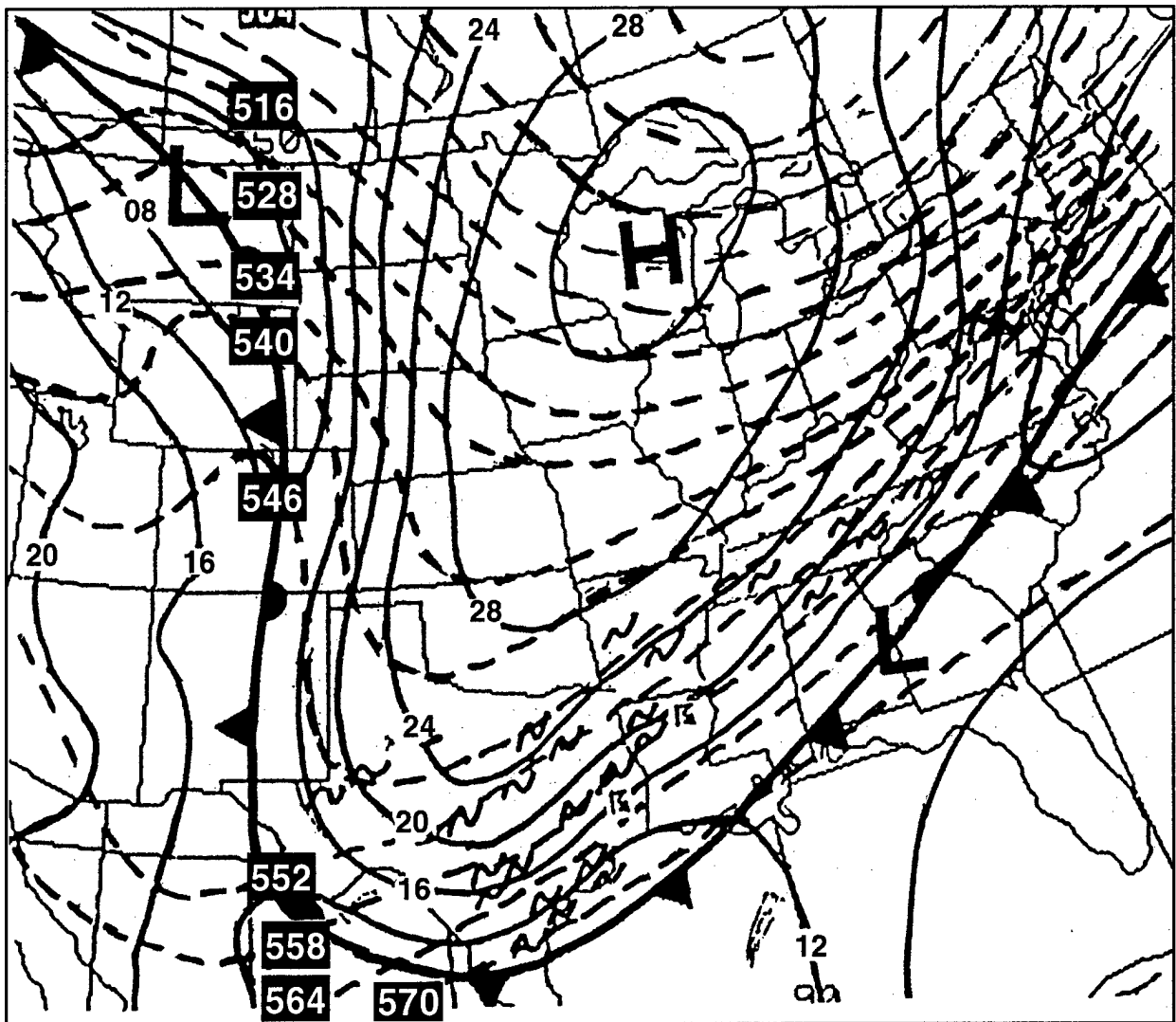


Figure 3-45. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. The pattern shown here will produce freezing rain to the Gulf Coast. Chart Valid at 0000Z on 10 February 1994.

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Cold and Warm Air Advection. Warm Figures 3-46a and 3-46b show an example of WAA (overrunning) and CAA (undercutting) occurring simultaneously across the southern and eastern CONUS. Freezing precipitation areas shown in the illustrations are for 6 hours from 5/21Z to 6/03Z with 00Z as a midpoint. The broken arrow in Figure

3-46a denotes CAA; freezing precipitation (mostly drizzle) lies between the 552 and 564 thickness. The WAA freezing precipitation (mostly rain), noted by the solid arrow, lies between the 552 and 534 thickness. The dashed line shown in Figure 3-46a extending from eastern Missouri to central Alabama is the dividing line between WAA and CAA.

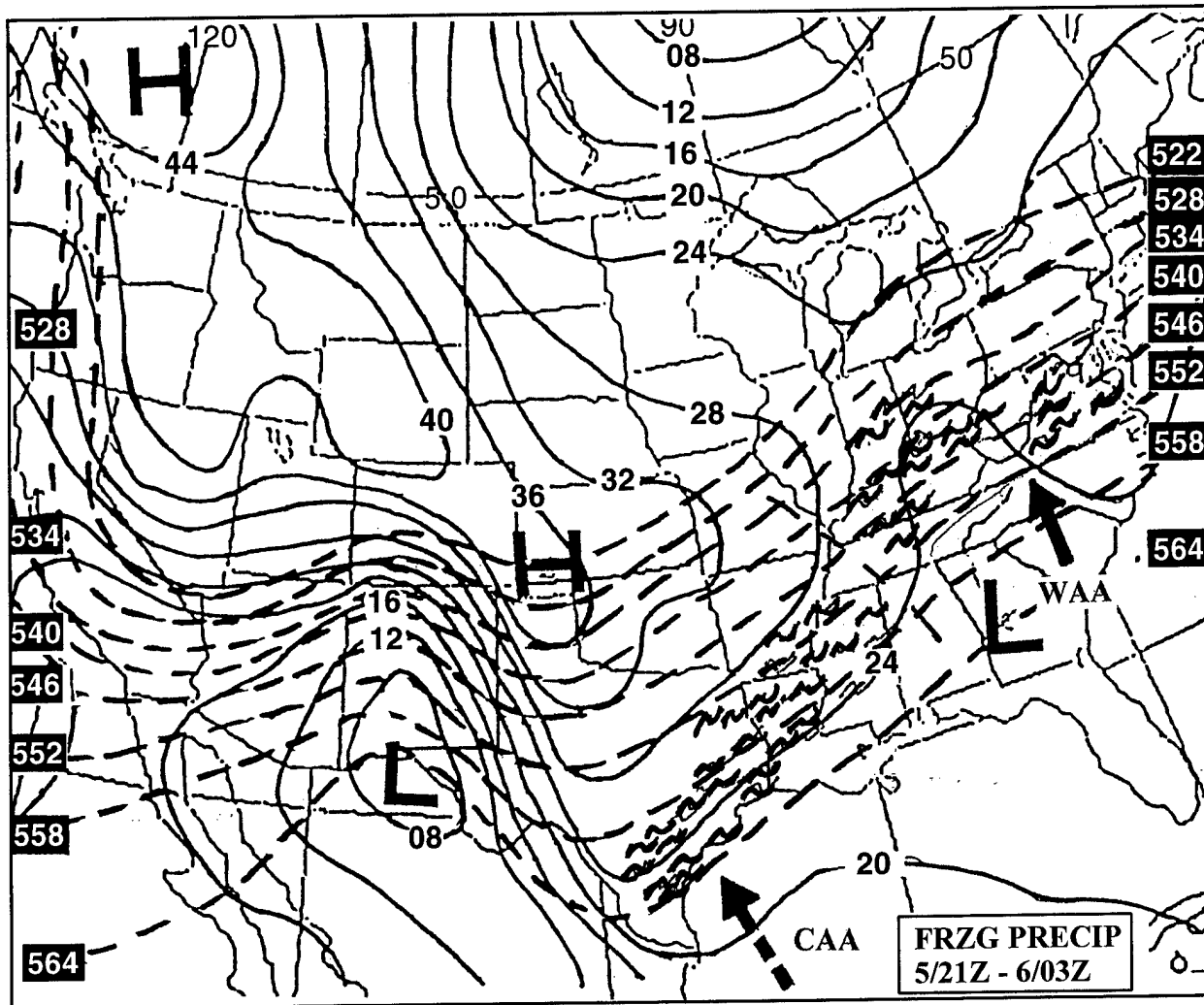


Figure 3-46a. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. The broken arrow denotes cold air advection; freezing precipitation (mostly drizzle) lies between the 552 and 564 thickness. Chart valid at 0000Z on 6 February 1989.

On the 850-mb chart (Figure 3-46b), the cold air advection precipitation appears between the +10°C and 0°C isotherms, while the WAA lies between the +5°C to -15°C isotherms. The freezing precipitation shown over Indiana and Ohio within

the -10°C to -15°C temperatures is likely to be freezing drizzle.

The depictions in Figures 3-46a and 3-46b summarize the empirical thickness and temperature rules presented throughout this section.

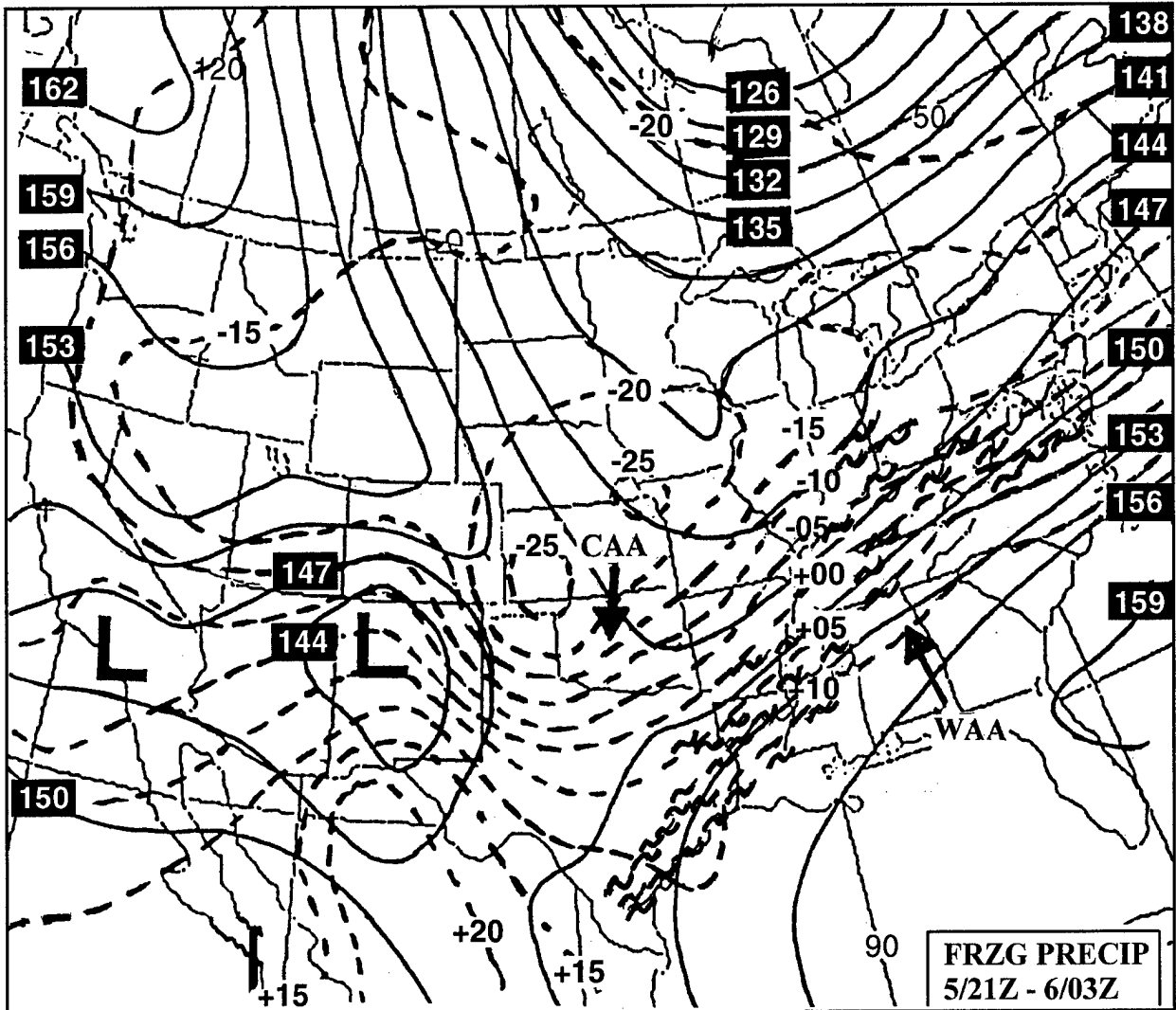


Figure 3-46b. Forecast (00HR) 850-Mb Heights/Temperatures. Cold air advection precipitation appears between the +10°C and 0°C isotherms, while the warm air advection lies between the +5°C to -15°C isotherms. Chart valid at 0000Z on 6 February 1989.

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Surface Inverted Troughs/850-Mb Lows. It was shown earlier in Figure 3-33b that the formation of lows above a cP cold dome is the result of WAA ahead of an approaching short wave whether it is in zonal flow or a short wave moving through a long-wave trough. The appearance of 850-mb lows occurs often, especially with prevailing high patterns. If there is a related surface frontal low, it will be some distance south or southwest of the 850-mb low. The freezing precipitation area will lie well to the north of the surface low in the cold air within the 552 to 540 thickness isopleths and +5°C to -5°C isotherms. In all cases studied, the freezing rain area was found to lie just to the north and/or northeast of the 850-mb low. Additionally, it was found that freezing drizzle events were observed from the southwest to the north of the 850-mb low. The development of an 850-mb low over a cold dome suggests that the associated surface low will deepen; increasing warm air advection will modify the cP air mass.

Another telltale sign of warm air advection (along with 850-mb low development) is the appearance of a surface inverted trough. A surface low either moves northward or develops within the inverted trough. Widespread freezing precipitation often lies on a northeast-southwest axis along and north of the inverted trough. Figure 3-47 depicts a freezing rain event that extends well into the cP prevailing high air mass.

Because of the importance of these features in the development of freezing rain (and snow) several examples will follow. It is hoped these examples will alert forecasters, especially across the southern CONUS, to the likelihood of freezing rain.

Figures 3-47 through 3-59 show 850-mb inverted trough and freezing precipitation relationships. The freezing precipitation areas are for a 6-hour period with either 0000Z or 1200Z being the midpoints.

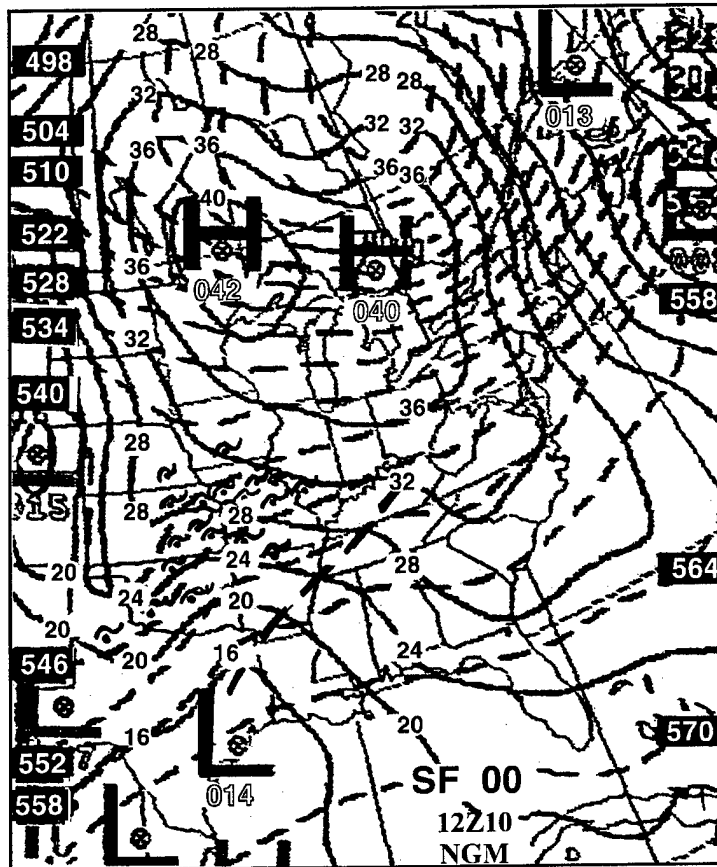


Figure 3-47. Mean Sea-Level Pressure/1,000- to 500-mb thickness. The figure depicts a freezing rain event that extends well into the cP prevailing high air mass. Chart valid at 1200Z. on 10 Jan 1991.

Example 1. Figures 3-47 through 3-59 show a typical setup for a major Great Plains storm. Figures 3-48 and 3-49 show a long-wave trough with a closed low over southern California. Closed lows that develop over the Great Basin area often bring heavy snow, freezing precipitation, and thunderstorms to the Midwest.

In Figure 3-48, several minor PVA lobes have moved out of the Rockies ahead of the major system (noted by the arrows). At the 700-mb level (Figure 3-49) a considerable amount of moisture (70 percent relative humidity) appears over the central and eastern CONUS.

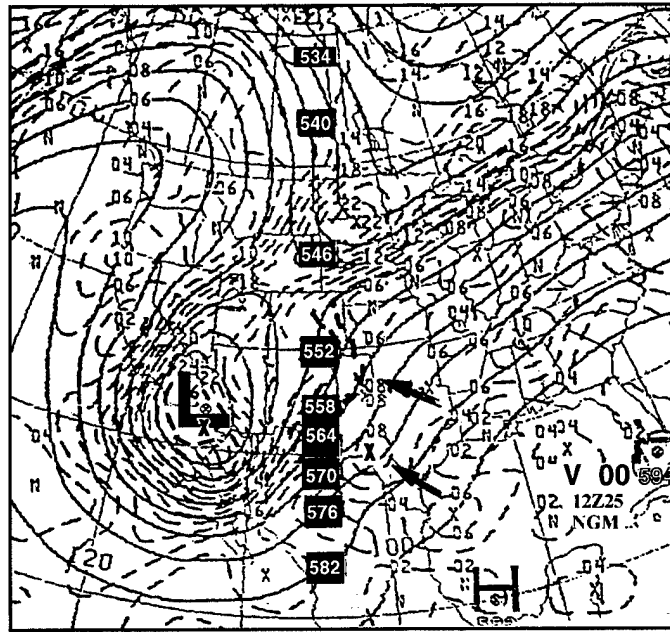


Figure 3-48. The 500-Mb Heights/Vorticity Chart. The arrows indicate PVA lobes. Chart valid at 1200Z on 25 December 1987.

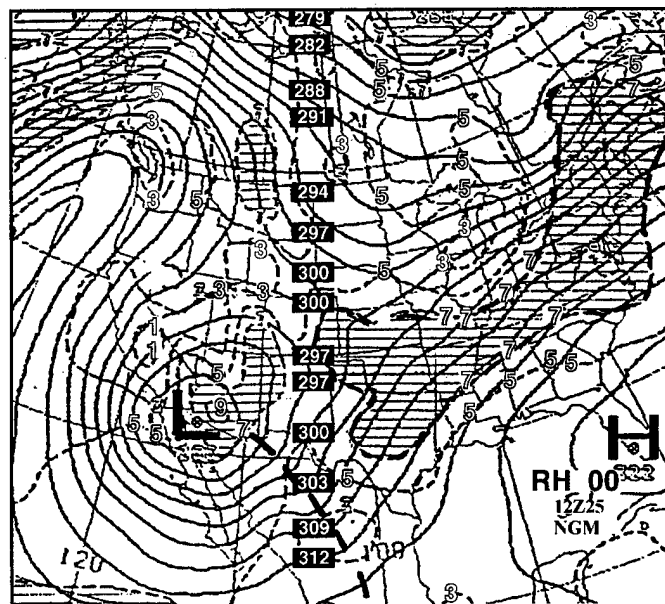


Figure 3-49. The 700-Mb Heights/Vorticity Chart. Moisture spreads across the eastern CONUS. Chart Valid at 1200Z on 25 December 1987

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At the surface (Figure 3-50a), a stationary front lies across the southern Great Plains to the Ohio River valley area. A frontal surface low is shown over southern Texas. Freezing rain has developed from Texas to Missouri as shown in the composite.

At the 850-mb level (Figure 3-50b), a low has developed on the 850-mb front over western Texas, which is northeast of the surface low (see arrow). Freezing rain lies along and to the north of the 850-mb front. Heavy snow is occurring over central and southern New Mexico (not shown).

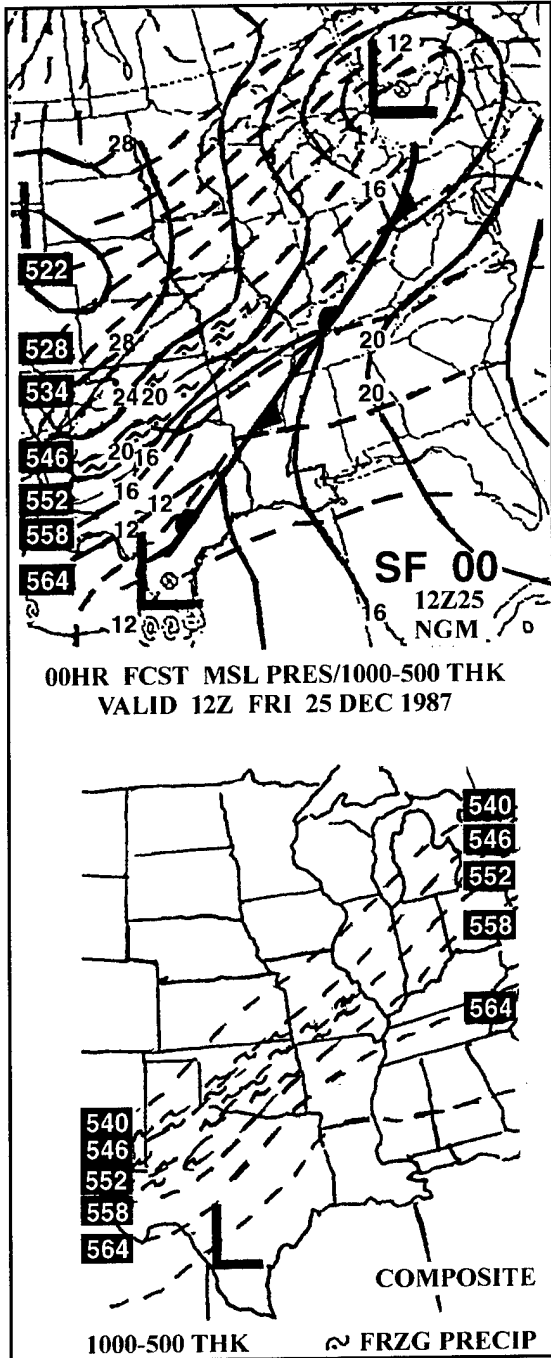


Figure 3-50a. Thickness/Freezing Precipitation Relationship. The freezing precipitation is located within the 558/546 thickness ribbon.

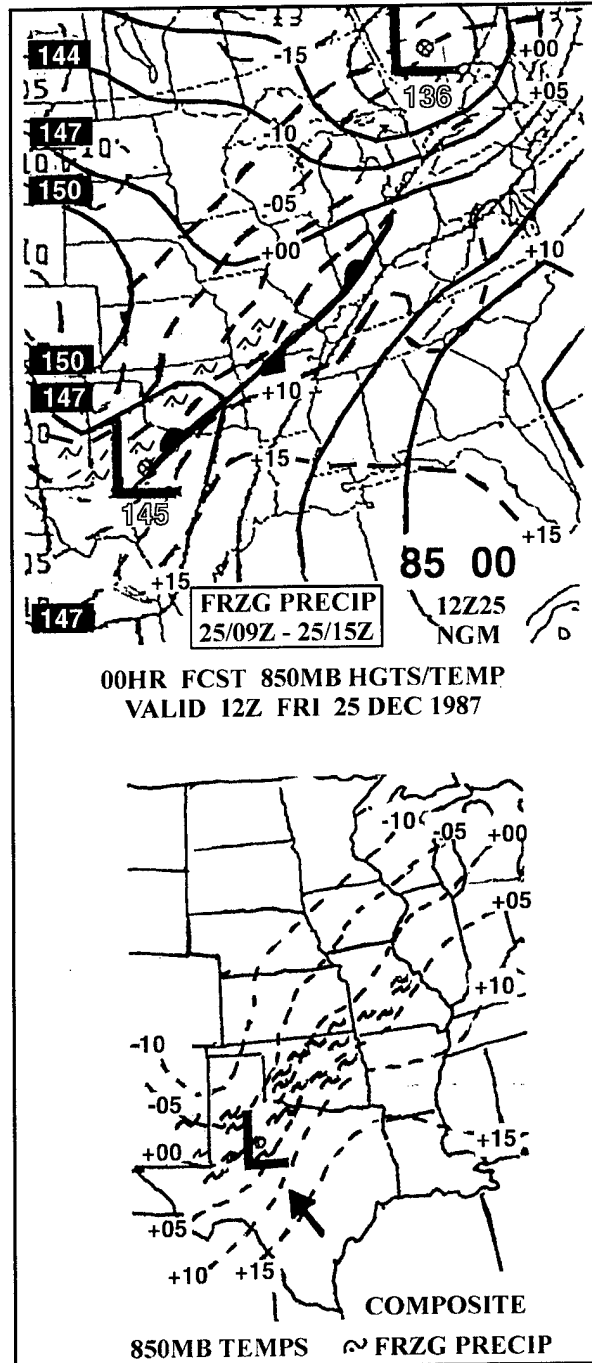


Figure 3-50b. Freezing Precipitation/850-Mb Temperature Relationship. The freezing precipitation is located within the +5°C/-5°C temperature ribbon.

Figures 3-51 through 3-53 describe the event 12 hours later. In Figure 3-51, the axis of a small negatively-tilted short wave (see arrow) within the vorticity field is shown over northern Texas. Positive vorticity advection extends northward into Kansas.

The 700-mb analysis (Figure 3-52), continues to show a moist baroclinic zone ahead of the Great Basin storm system. The relative humidity has increased to 90 percent over the southern plains (as noted by the arrow).

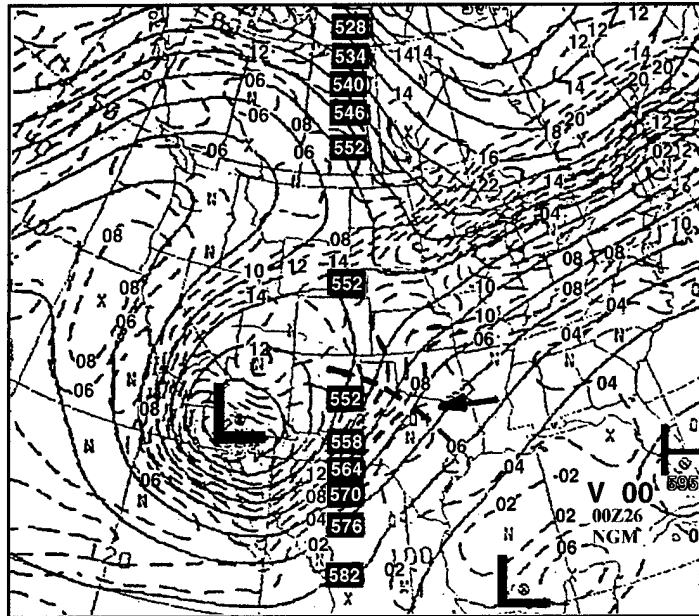


Figure 3-51. The 500-Mb Heights/Vorticity Chart. The arrow points to the axis of a small negatively-tilted short wave. Chart valid at 0000Z on 26 December 1987.

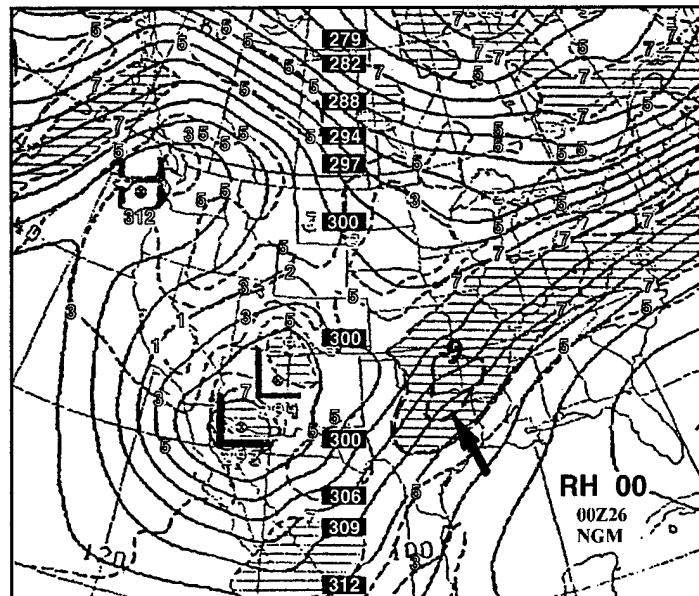


Figure 3-52. The 700-Mb heights/Relative Humidity Chart. Relative humidity has increased to 90 percent over the southern plains. Chart valid at 0000Z on 26 December 1987.

Chapter 3

At the surface (Figure 3-53a), little change in the pattern has occurred. The surface front is stationary, and freezing rain, which is associated with the short

wave, continues to expand northeastward to Illinois. Note there is no identifiable frontal surface low over the southern plains.

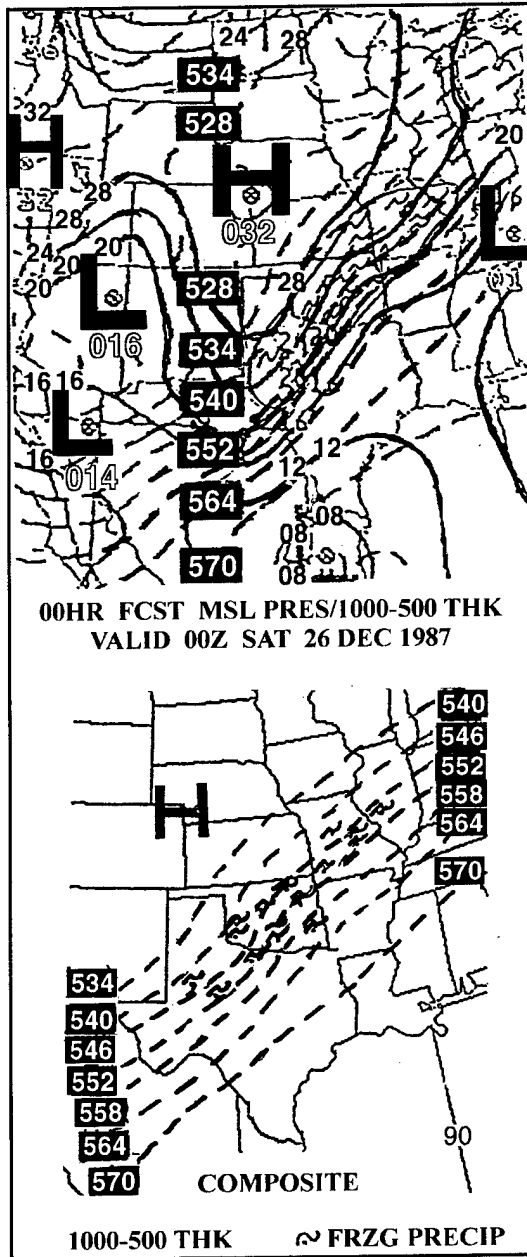


Figure 3-53a. Composite Thickness/Freezing Precipitation Relationship. The freezing precipitation is located within the 552/540 thickness ribbon.

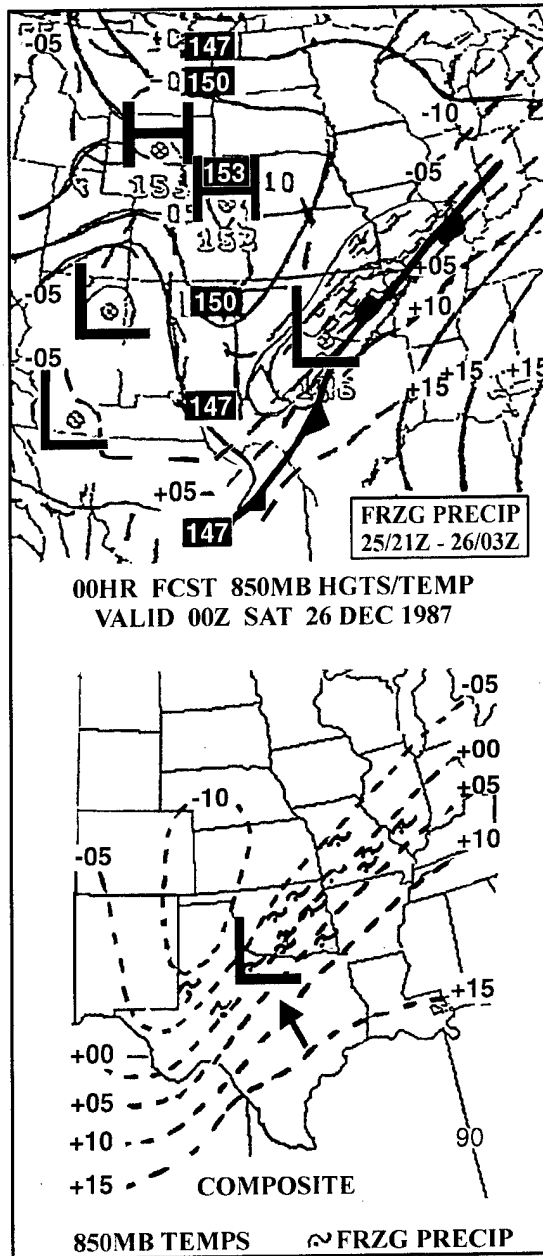


Figure 3-53b. Composite Freezing Precipitation and 850-Mb Temperature Relationship. The freezing precipitation is located within the +5°C/-5°C temperature ribbon.

Example 2. It was shown earlier that prevailing high-pressure systems are often associated with long-wave trough systems. On the other hand, prevailing high systems will occur with short waves within a zonal flow pattern. In this prevailing high example, there is no recognizable long-wave trough at the 500-mb level (Figure 3-54). If there is a long wave, it is masked by short-wave systems within the flow as shown in Figure 3-54. Several positive

vorticity systems are noted by the arrows. The vorticity system over Missouri is the system responsible for surface/850-mb cyclogenesis and freezing rain as shown in Figures 3-56a and 3-56b.

At the 700-mb level, Figure 3-55, a low appears over northern Missouri which stacks with the 850-mb low (Figure 3-56b). Plenty of mid-level moisture is available with the low.

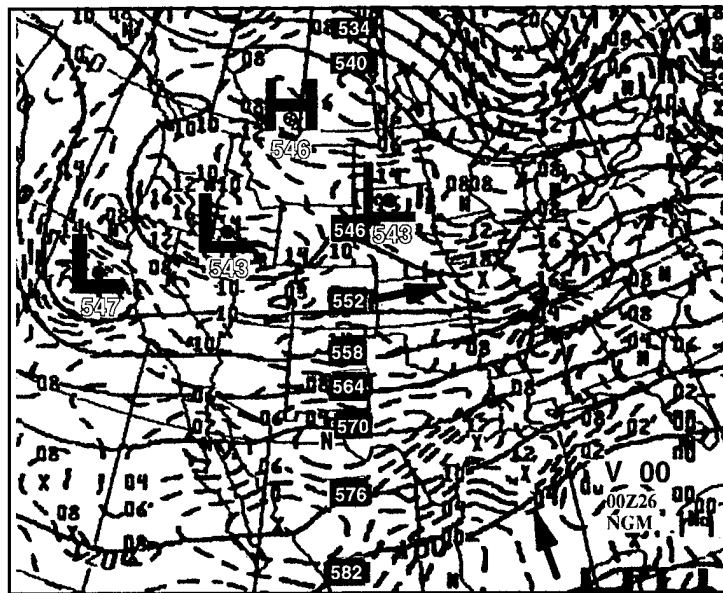


Figure 3-54. The 500-Mb Heights/Vorticity Chart. Several PVA areas are noted by the arrows. Chart valid at 0000Z on 26 February 1993.

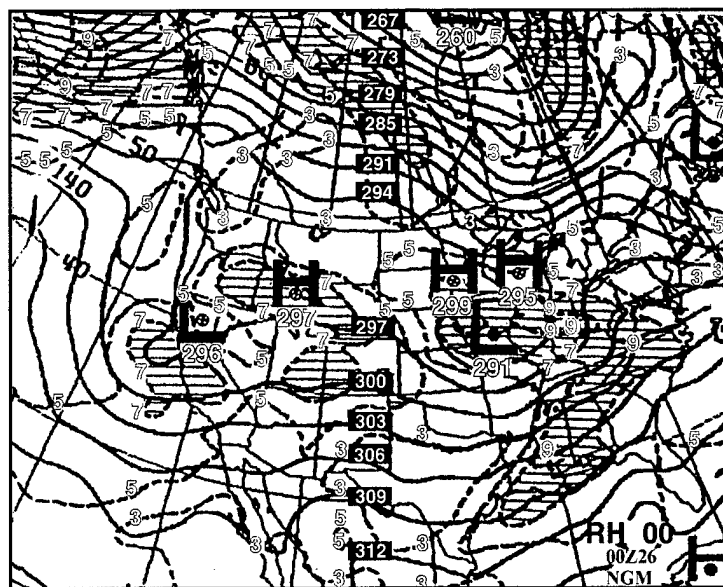


Figure 3-55. The 700-Mb Heights/Relative Humidity Chart. A low appears over northern Missouri. Chart valid at 0000Z on 26 February 1993.

Chapter 3

Figure 3-56a, depicts an inverted trough (and frontal zone) over the central CONUS. Continued warm air advection has eroded the polar air mass as evident by thickness and 850-mb temperature ridging. The developing surface low is over Louisiana (Figure 3-56a) while the 850-mb low is located over Missouri (Figure 3-56b).

In the composites, the narrow freezing rain band lies between the 546 and 534 thickness ribbon, which follows the warm air advection empirical

rules presented earlier in Figure 3-13. Also, freezing rain is located to the east of the 850-mb low and north of the 850-mb front (noted by the arrow).

The freezing precipitation shown in the composites over the northern Georgia and western North Carolina area is the result of "Appalachian Damming" where low-level cold air is trapped within a shallow ridge. This pattern will be shown and discussed later in Chapter 4.

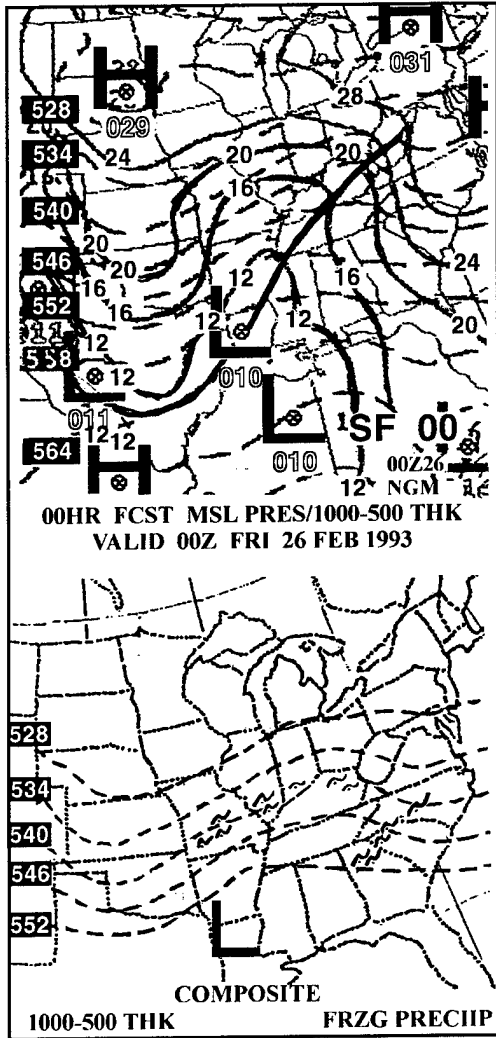


Figure 3-56a. Thickness/Freezing Precipitation Relationship. Freezing precipitation is located within the 546 and 534 thickness ribbon. An inverted trough (and frontal zone) is over the central CONUS.

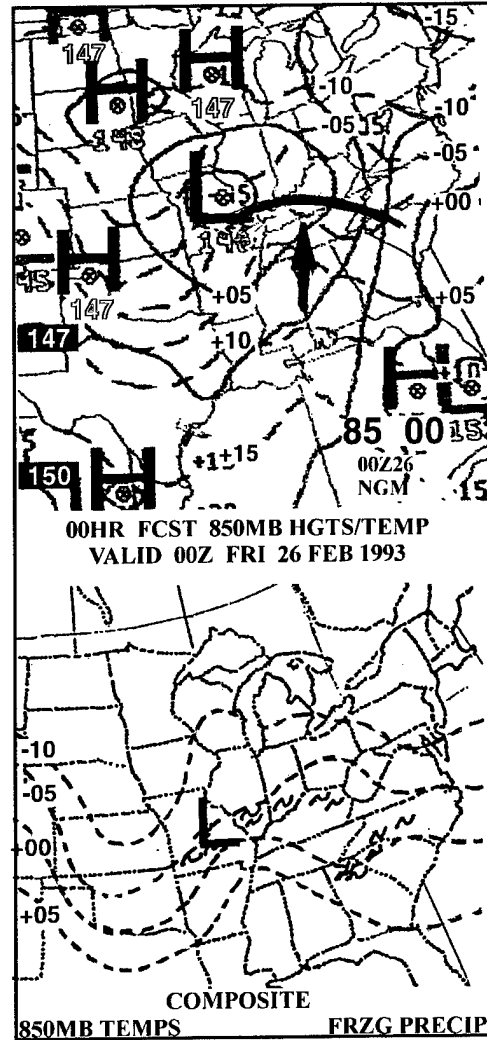


Figure 3-56b. Freezing Precipitation/850-Mb Temperature Relationship. Freezing rain is located within the +5°C/-5°C temperature ribbon. Freezing rain is located to the east of the 850-mb low and north of the 850-mb front (noted by the arrow)

Example 3. The 500-mb analysis (Figure 3-57) shows a strong short wave within the base of a long-

wave trough that is located over the southern plains states.

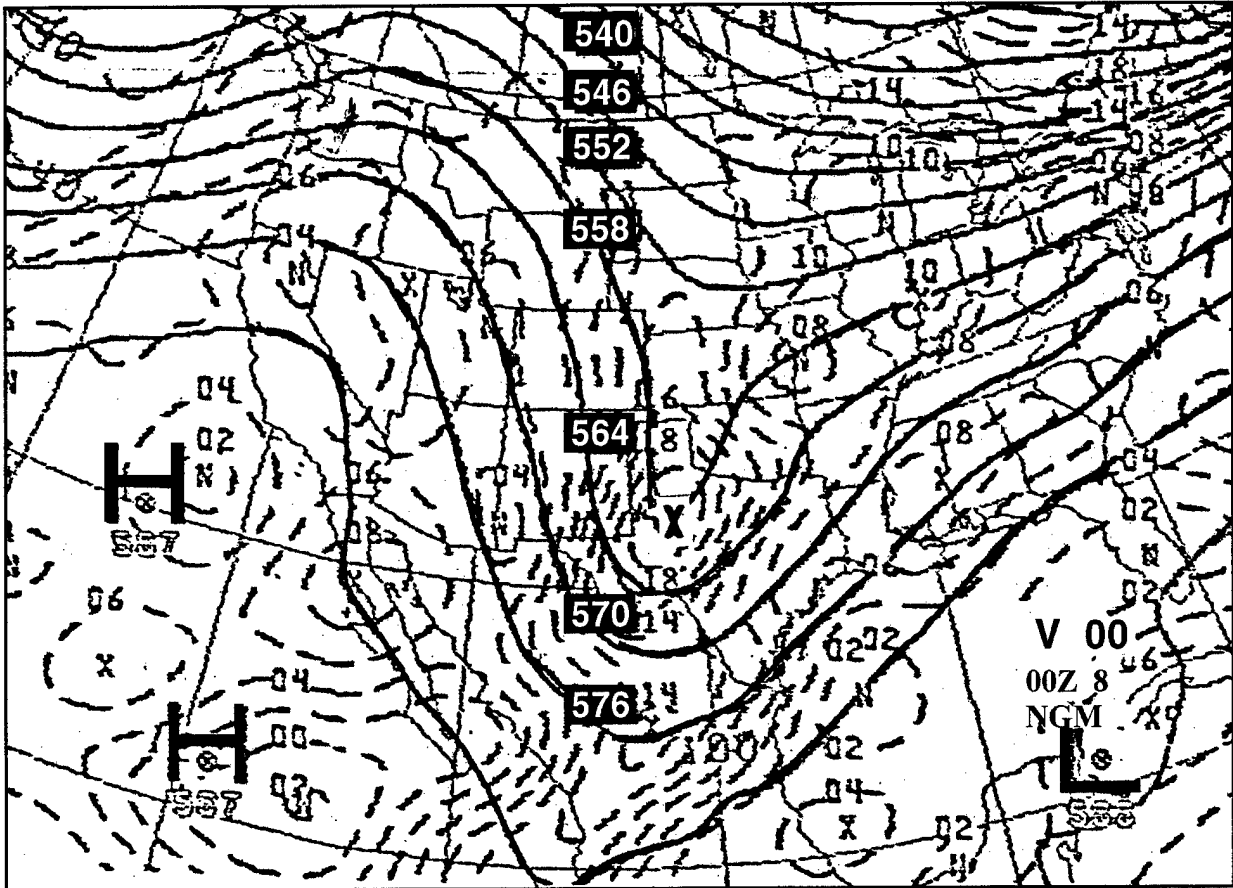


Figure 3-57. The 500-Mb Heights/Vorticity Chart. The "X" indicates a PVA maximum or short wave in the base of the long-wave trough. Chart valid at 0000Z on 8 December 1989.

Chapter 3

At the surface (Figure 3-58a), a prevailing high covers the northern and central CONUS. An inverted trough (frontal zone) is across the southeastern CONUS (broken arrow); a surface low is in the western Gulf of Mexico. The freezing rain area is some distance to the north of the inverted trough.

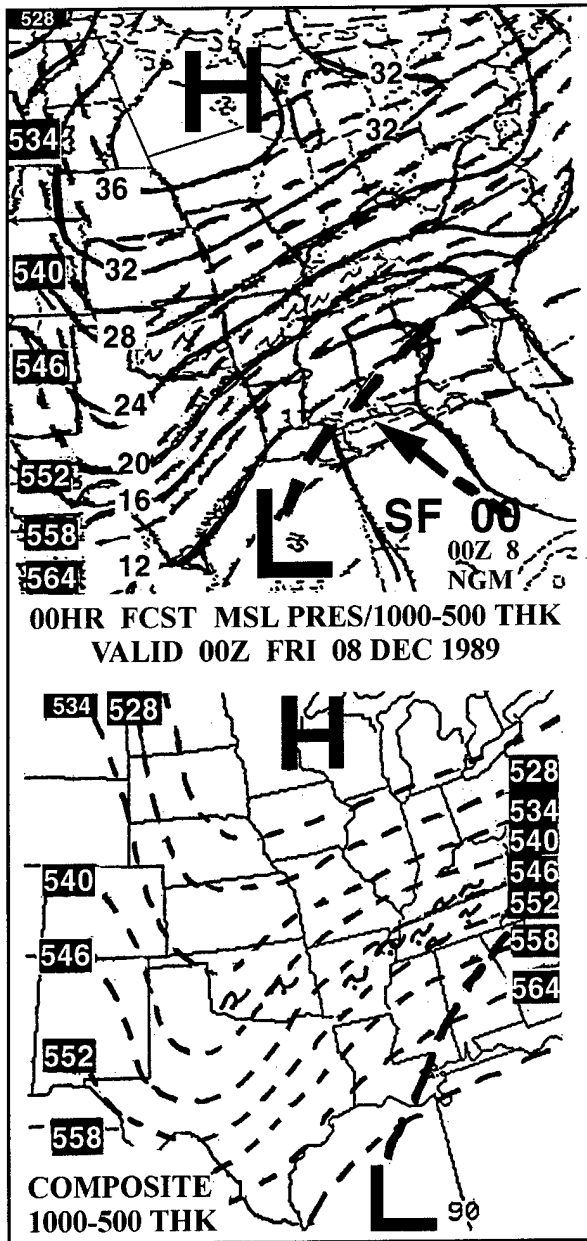


Figure 3-58a. Thickness/Freezing Precipitation Relationship. Freezing precipitation is located within the 552 and 540 thickness ribbon. An inverted trough (and frontal zone) is over the central CONUS (indicated by arrow).

In Figure 3-58b, an 850-mb low is over northern Louisiana, which is northeast of the gulf surface low. Freezing rain occurs along and north of the 850-mb front (noted by the solid arrow in Figure 3-58b), and most of the freezing precipitation is east of the 850-mb low. The freezing precipitation falls between the 552/540 thickness and the +5°C/0°C 850-mb temperature ribbons.

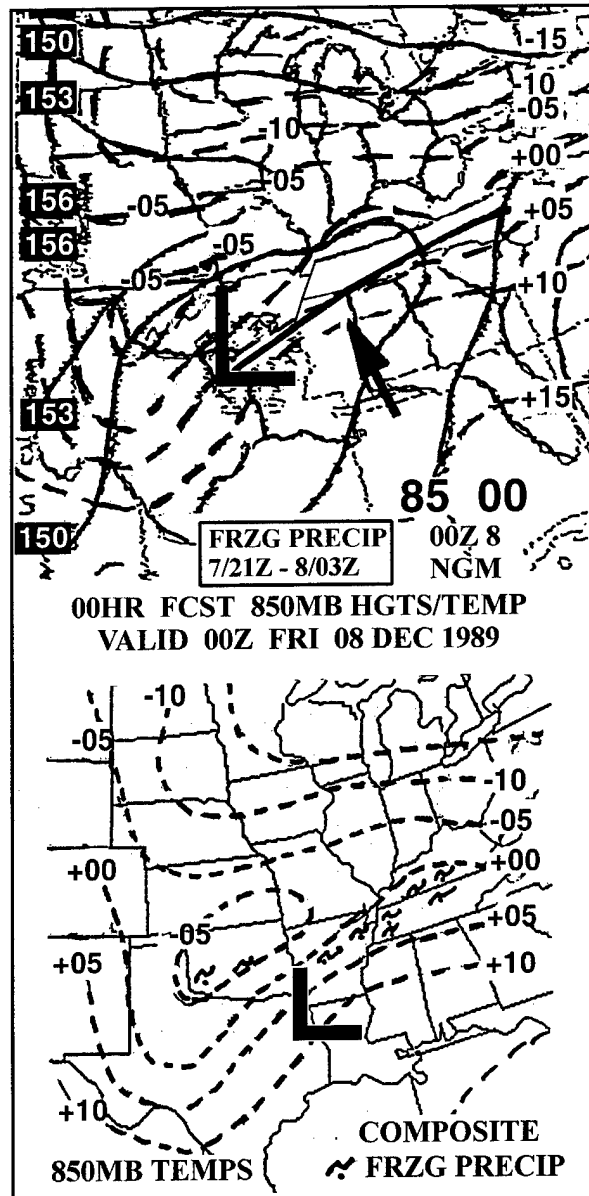


Figure 3-58b. Freezing Precipitation/850-Mb Temperature Relationship. Freezing rain is located within the +5°C/0°C temperature ribbon. Most of the freezing rain is located to the east of the 850-mb low and north of the 850-mb front (noted by the arrow)

Example 4. By now the reader should have a good idea on the synoptic pattern regarding inverted troughs and freezing precipitation. One more prevailing high example is shown below.

Freezing rain is shown over the Ohio River valley area to western Virginia in Figures 3-59a and 3-59b.

The thickness pattern shown in Figure 3-59a shows troughing over the western Great Plains. Inverted troughing extends from a Gulf of Mexico low to the Ohio River valley.

In Figure 3-59b, a 850-mb low is shown over northeastern Oklahoma; the freezing rain is along and north of the 850-mb front (noted by the arrow).

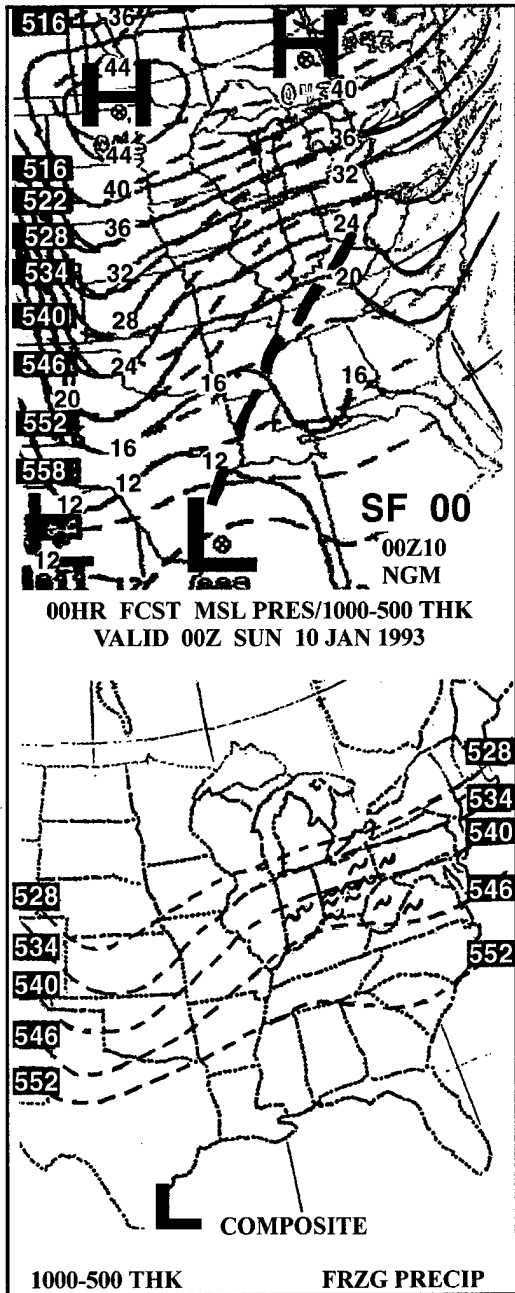


Figure 3-59a. Thickness/Freezing Precipitation Relationship. Freezing precipitation is located within the 546 and 534 thickness ribbon. An inverted trough (and frontal zone) is over the central CONUS.

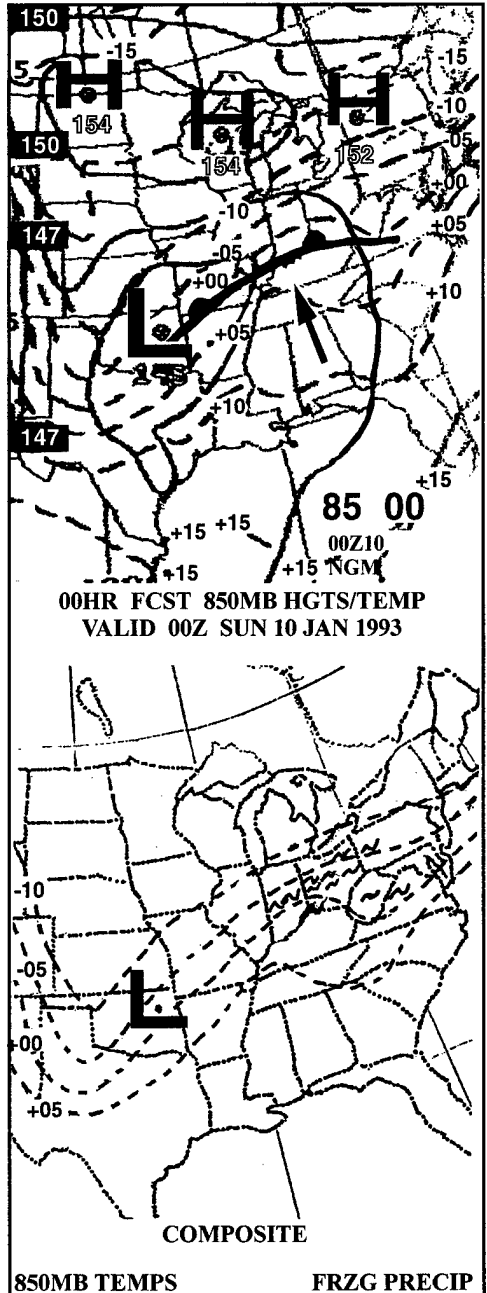


Figure 3-59b. Freezing Precipitation/850-Mb Temperature Relationship. Freezing rain is located within the +0°C/-5°C temperature ribbon.

SYNOPTIC PATTERN RECOGNITION

General. In the previous section different types of advection and empirical rules derived from over 500 samples were shown. Many of the synoptic patterns shown were over the central and southern areas of the CONUS. There are many conditions favorable for development of freezing precipitation patterns over other areas of the nation that will be shown in this section.

Eastern CONUS.

Example 1. Typically, most storm system centers approaching the eastern CONUS lift northeastward

into the New England area in response to upper-trough deepening. There are infrequent occurrences when Great Plains storm systems will not move northeastward, but move easterly; this is shown in Figure 4-1. Generally, a stationary cP high is located to the north of New England across the eastern Canada-Labrador area that prevents system movement to the northeast. Easterly, moist Atlantic air feeds into the storm system (along with gulf moisture). A long period of freezing rain within a narrow band over the same general area is likely due to little or no northward lift as shown in Figure 4-1.

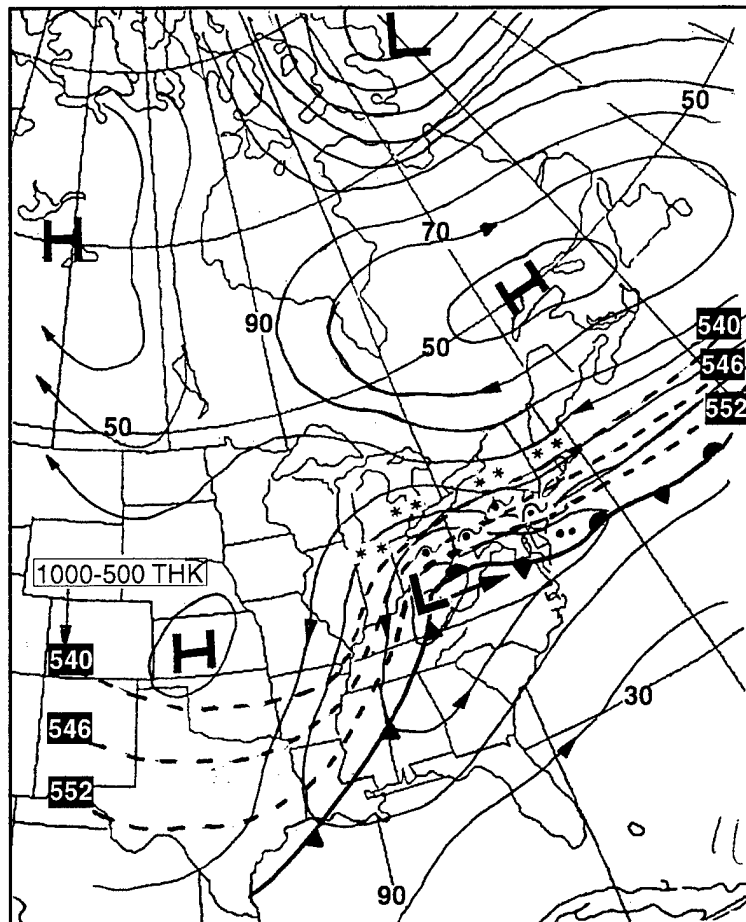


Figure 4-1. Eastern CONUS Model. The figure shows the setup for the situation where a Great Plains storm system moves easterly instead of northeastward.

Chapter 4

Example 2. Figures 4-3 and 4-4 depict two surface analysis 12 hours apart. A persistent cP high is shown over Labrador and Maine. Two frontal low-pressure systems are shown; the primary low is located over Georgia, and is associated with the positive vorticity center centered over central

Alabama (Figure 4-2). In Figure 4-4, 12 hours later, the Georgia low has moved northeastward to northeast Virginia and deepened by 12 millibars. The high-pressure system north of the low has been flattened but is still providing cold air across New England.

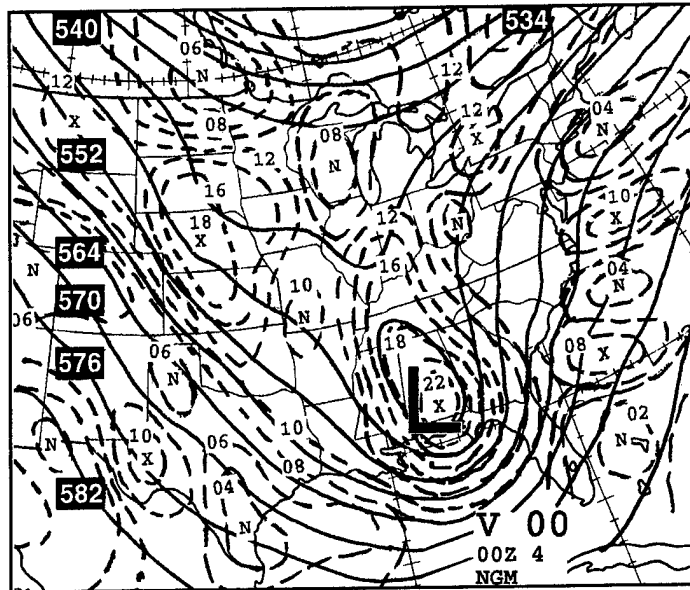


Figure 4-2. The 500-Mb Heights/Vorticity Chart. A PVA center is located over Alabama. Chart valid at 0000Z on 4 January 1994.

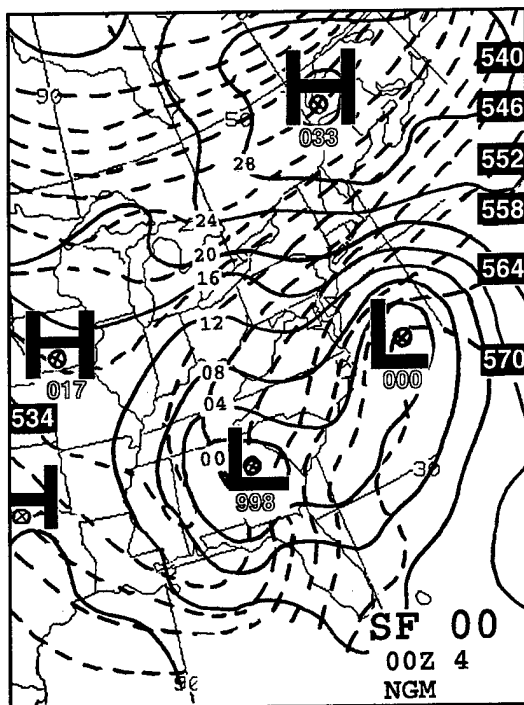


Figure 4-3. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The primary frontal low is located over Georgia. Chart valid at 0000Z on 4 January 1994.

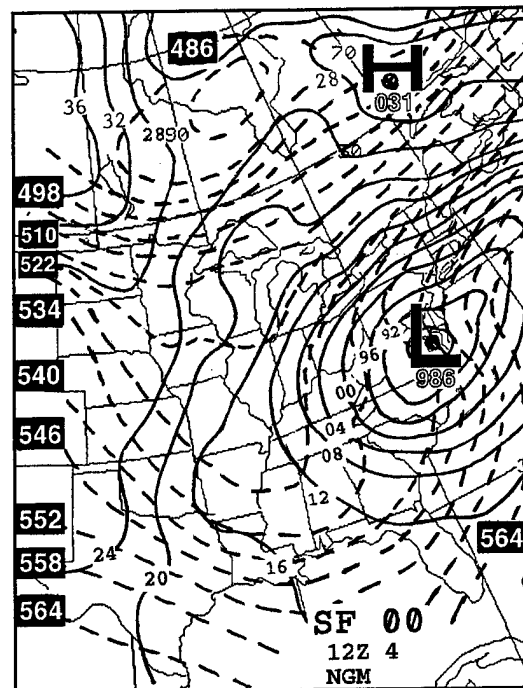


Figure 4-4. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The primary frontal low has moved northeast of Virginia. Chart valid at 1200Z on 4 January 1994.

The composites (Figures 4-5a and 4-5b) show the associated precipitation with this deepening storm. The freezing rain event shown in Figures 4-5a and 4-5b lasted over 15 hours; the storm system moved

eastward into the Atlantic. Heavy snow occurred from Pennsylvania to Maine. The freezing rain area was mostly between the 552/540 thickness and the 850-mb +5°C/-5°C temperature ribbons.

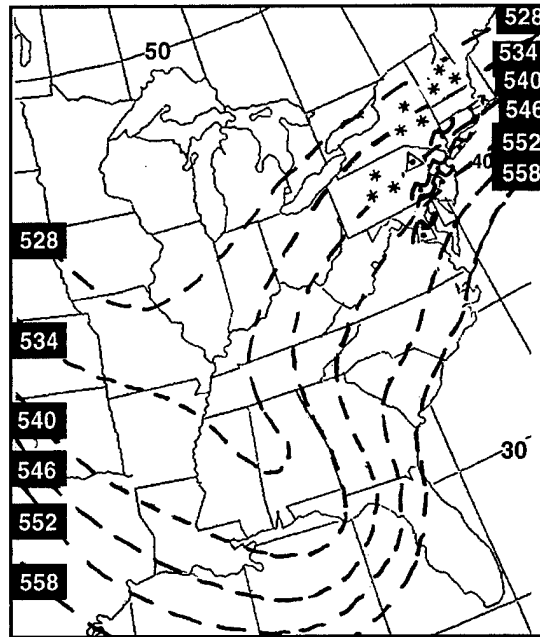


Figure 4-5a. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation Chart. The freezing rain area was mostly between the 552/540 thickness isopleths.

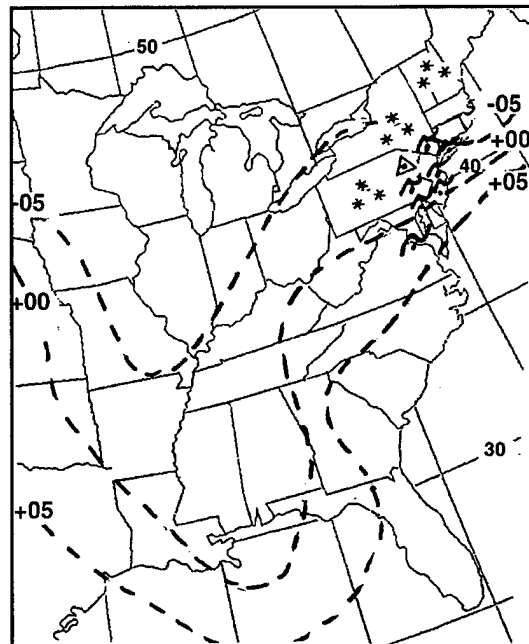


Figure 4-5b. Composite 850-Mb Temperature/Freezing Precipitation Chart. Freezing precipitation occurred in the 850-mb +5°C/-5°C temperature ribbon.

Chapter 4

Example 3. Explosive cyclogenesis off the New Jersey coast (triple-point cyclogenesis) will produce an extensive freezing rain event over the interior areas where it is still cold. Generally, an old decaying low is located over the Great Lakes/southern Canada area with an occluded front extending eastward to the coast (Figure 4-6). A strong easterly flow north of the warm/occluded front will advect moist Atlantic air westward as shown in the figure.

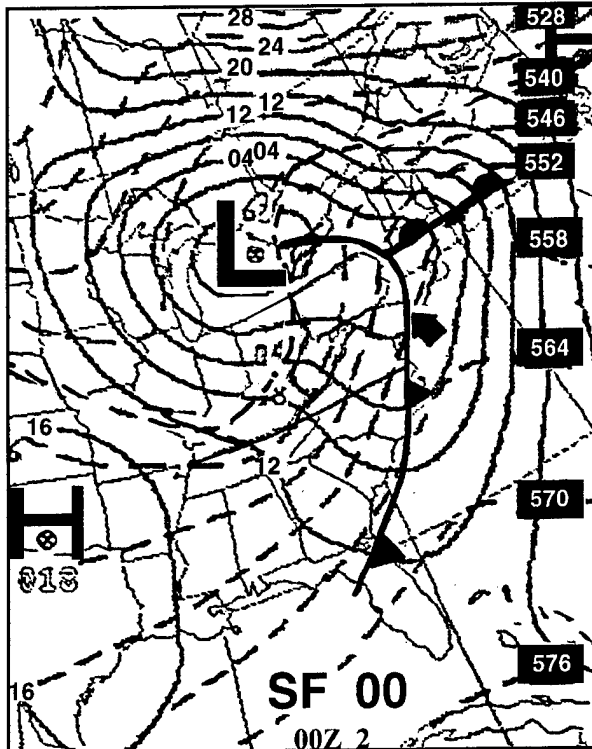


Figure 4-6. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The heavy arrow indicates a wide isobaric gradient that has the potential for cyclogenesis and rapid deepening. Chart valid at 0000Z on 2 March 1987.

Also in Figure 4-6, a wide isobaric gradient appears over the Delaware, Maryland, and Virginia region and across Pennsylvania and New York (noted by the heavy arrow). This widening of the isobaric gradient should always be suspect for potential cyclogenesis and rapid deepening. Usually, a secondary positive vorticity lobe located south of the old low system moves toward the weak isobaric area and triggers cyclogenesis (see arrow in Figure 4-7).

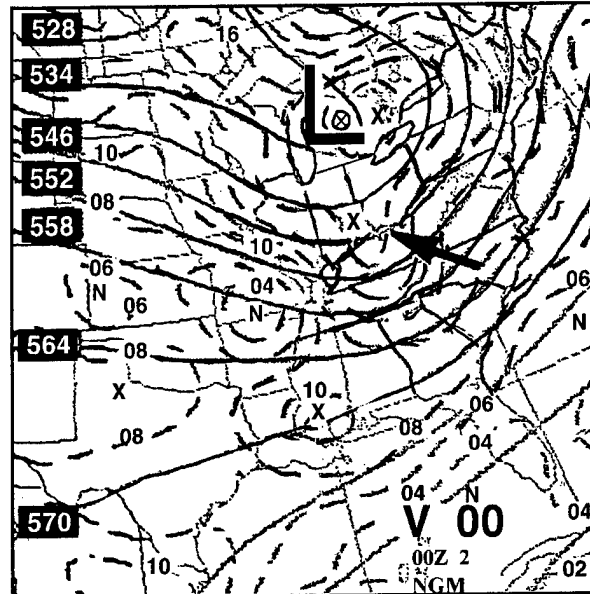


Figure 4-7. The 500-Mb Heights/Vorticity Chart. The arrow indicates a secondary positive vorticity area that may trigger cyclogenesis. Chart valid at 0000Z on 2 March 1987.

SYNOPTIC PATTERN RECOGNITION

The associated freezing rain area is shown in Figures 4-8a and 4-8b. The freezing rain is shown between the 552/540 thickness and the 850-mb +5°C/-5°C temperature ribbons. Twelve hours later (Figure 4-9), an intense low is shown off the Maine coastal

area. This pattern produces a variety of precipitation during its formative and deepening stages. At the 500-mb level (Figure 4-10), the related vorticity system has lifted northeastward (see arrow) and stacks with the surface system.

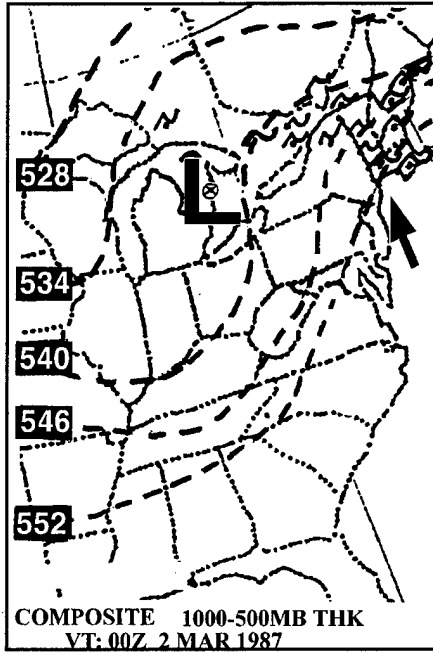


Figure 4-8a. Composite Thickness/Freezing Rain Relationship. Freezing precipitation is occurring between 552/540 thickness isopleths.

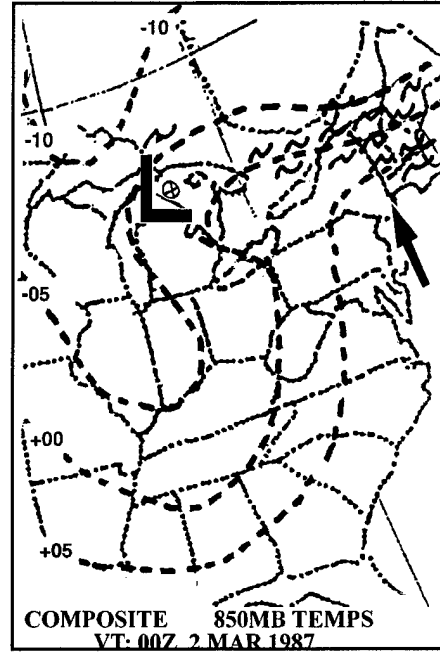


Figure 4-8b. Temperature/Freezing Rain Relationship. Freezing rain is occurring between the 850-mb +5°C and -5°C temperature isotherms.

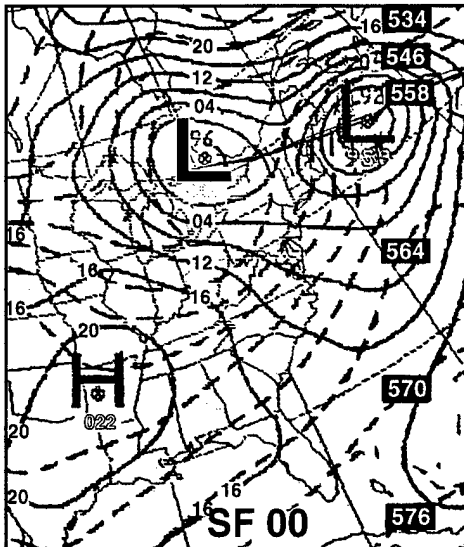


Figure 4-9. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. This pattern produces a variety of precipitation during its formative and deepening stages. Chart valid at 1200Z on 2 March 1987.

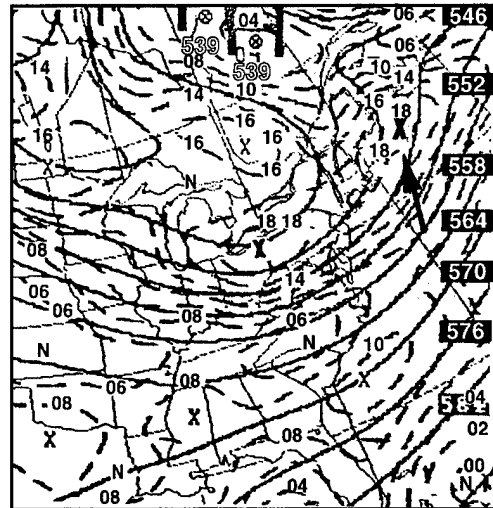


Figure 4-10. The 500-Mb Heights/Vorticity Chart. The related vorticity system has lifted northeastward (see arrow) and stacks with the surface system. Chart valid on 1200Z on 2 March 1987.

Chapter 4

Southern Plains and Gulf Coast

Example 1. Nearly all freezing rain events affecting the southern and southeastern CONUS are associated with prevailing high-pressure systems. Temperatures usually warm up to 32°F on the return flow of a receding high-pressure system, which prevents freezing rain. There is one exception: freezing rain will occur over the higher terrain of the southern and central Appalachians while low lying areas will receive rain. Appalachian freezing rain events, which occur under southerly flow, are short-lived events; persistent freezing rain/drizzle occurs in the Appalachians under a synoptic pattern called "Appalachian Damming" (discussed later).

Figure 4-11 depicts a favorable synoptic pattern for extensive freezing precipitation across the southern and southeastern CONUS (prevailing high). Some discussion on southern plains and Gulf Coast freezing precipitation synoptic patterns were presented earlier. The model shown here represents a typical setup for Gulf of Mexico frontal cyclogenesis and the accompanying extensive overrunning precipitation. The surface pattern shown in Figure 4-11 may remain stationary for some time until a low-latitude impulse from the southern Rockies initiates frontal cyclogenesis in the Gulf. This stationary pattern would be classified as neutral advection at the surface.

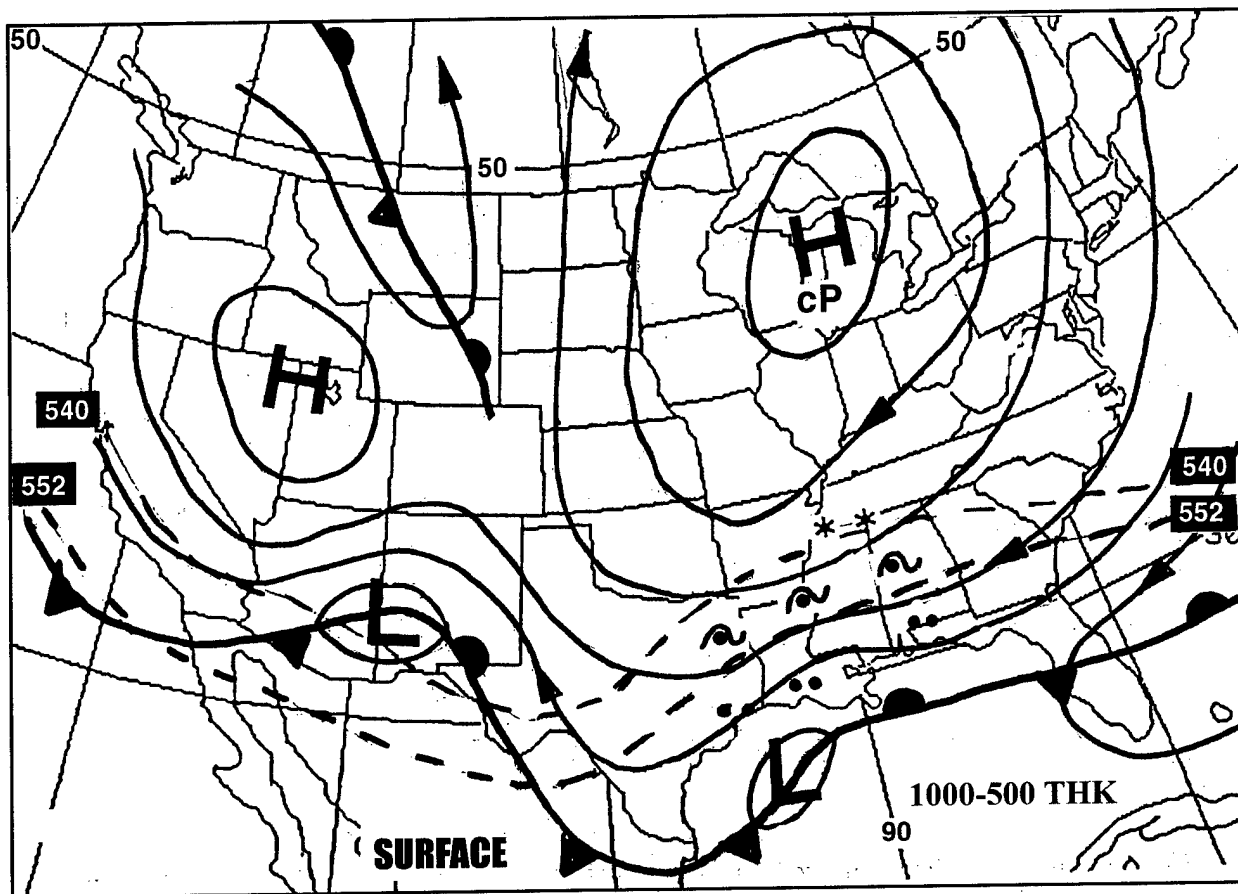


Figure 4-11. Southern Plains/Gulf Coast Model. The figure depicts a favorable synoptic pattern for extensive freezing precipitation across the southern and southeastern CONUS.

SYNOPTIC PATTERN RECOGNITION

Example 2. Figures 4-12a and 4-12b show an example of southern Texas/western Gulf of Mexico cyclogenesis. In the upper levels, a long-wave trough is often located over the central CONUS (Figure 4-12a). The southern branch of the Polar jet is positioned across the southern CONUS, which causes frontal lows to track across Arizona and New Mexico. Surface lows west of the Rockies are often associated with a deepening upper low and often do not move out of the mountains (these actions may occur anywhere over the western Great Plains).

In this pattern, the new frontal low develops in the western Gulf of Mexico while the old low dissipates as the upper low and PVA moves across western and central Texas; these two lows are noted by the arrows in Figure 4-12b. Strong moisture, temperature, and low-level wind discontinuities exist over the open waters. Freezing precipitation would occur between the 552/540 thickness and the 850-mb +5°C/-5°C temperature ribbon. It is noteworthy that elevated convection to the north of the Gulf frontal system is not uncommon.

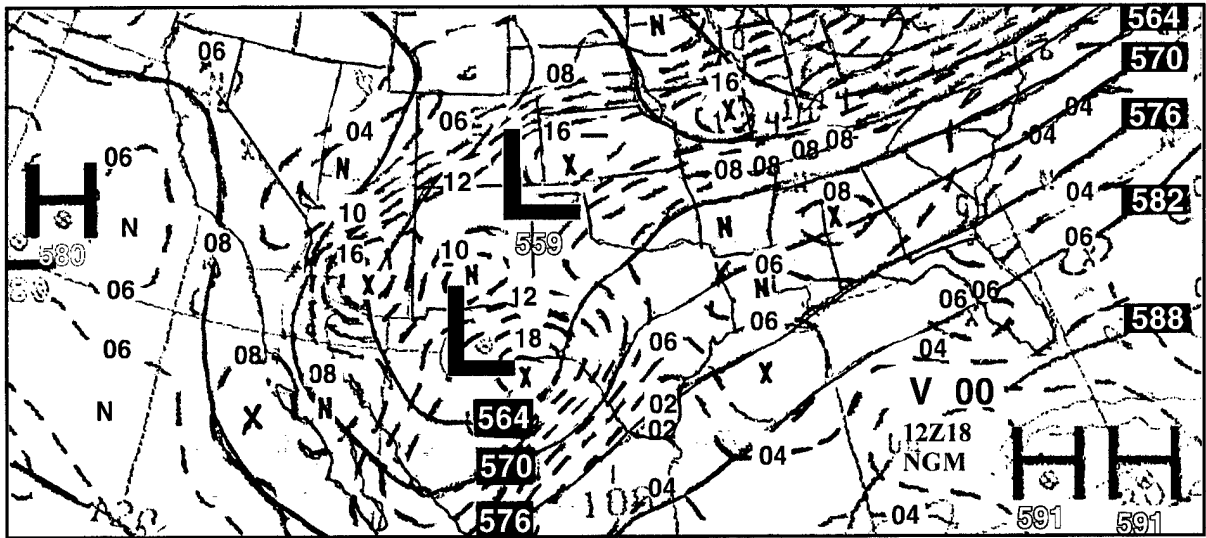


Figure 4-12a. Forecast (00HR) 500-Mb Heights/Vorticity. A long-wave trough is often located over the central CONUS during southern Texas/western Gulf of Mexico cyclogenesis. Chart valid at 1200Z on 18 January 1991.

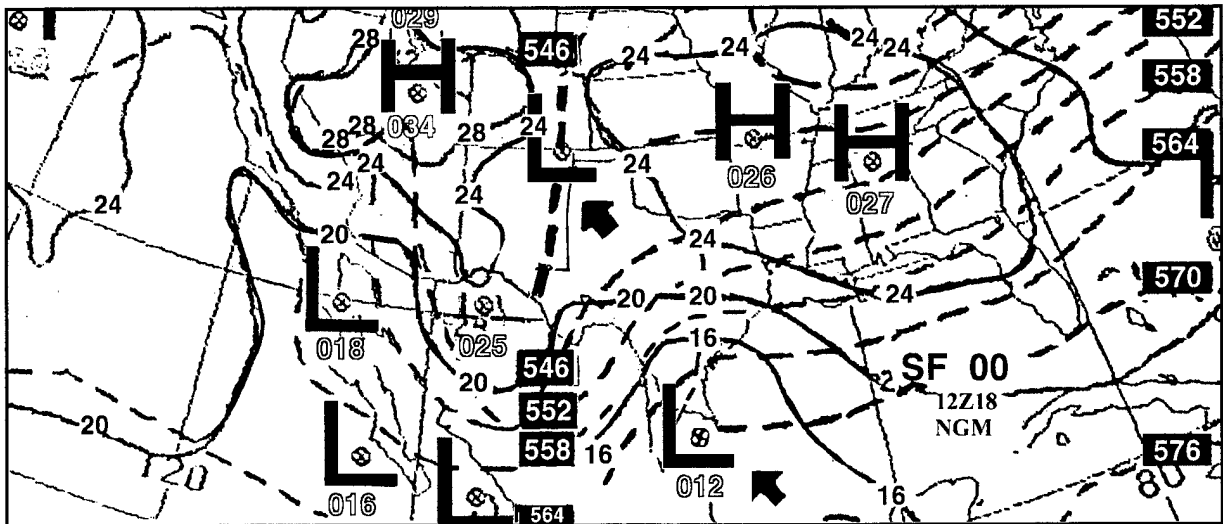


Figure 4-12b. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. A new frontal low develops in the western Gulf of Mexico while the upper low and PVA lobe moves across western and central Texas; these two lows are noted by the arrows. Chart valid at 1200Z on 18 January 1991.

Chapter 4

Southeastern and Eastern CONUS.

Example 1. Once a gulf frontal low develops with favorable upper-level support (previous example) then the typical storm moves eastward for a while then lifts northeastward due to upper-trough deepening. The storm often moves across northern Florida as shown in Figure 4-13. The system continues to deepen as it moves into the Atlantic; the thickness and temperature fields begin to show ridging as warm air feeds into the storm.

These gulf frontal lows produce extensive areas of

precipitation back into the cold air as overrunning increases. The typical transition from rain, freezing rain, and ice pellets to snow can be followed by eastern CONUS forecasters upstream as the deepening low moves northeastward (Figure 4-14). Ice storms (sometimes severe) occur east of the Appalachian mountains from northern Georgia to New England with the model pattern shown in Figures 4-13 and 4-14. A stationary cP high, usually located over the Great Lakes area, provides cold air that advects into the system. Thunderstorms (sometimes severe) develop south of the frontal wave across the Florida peninsula.

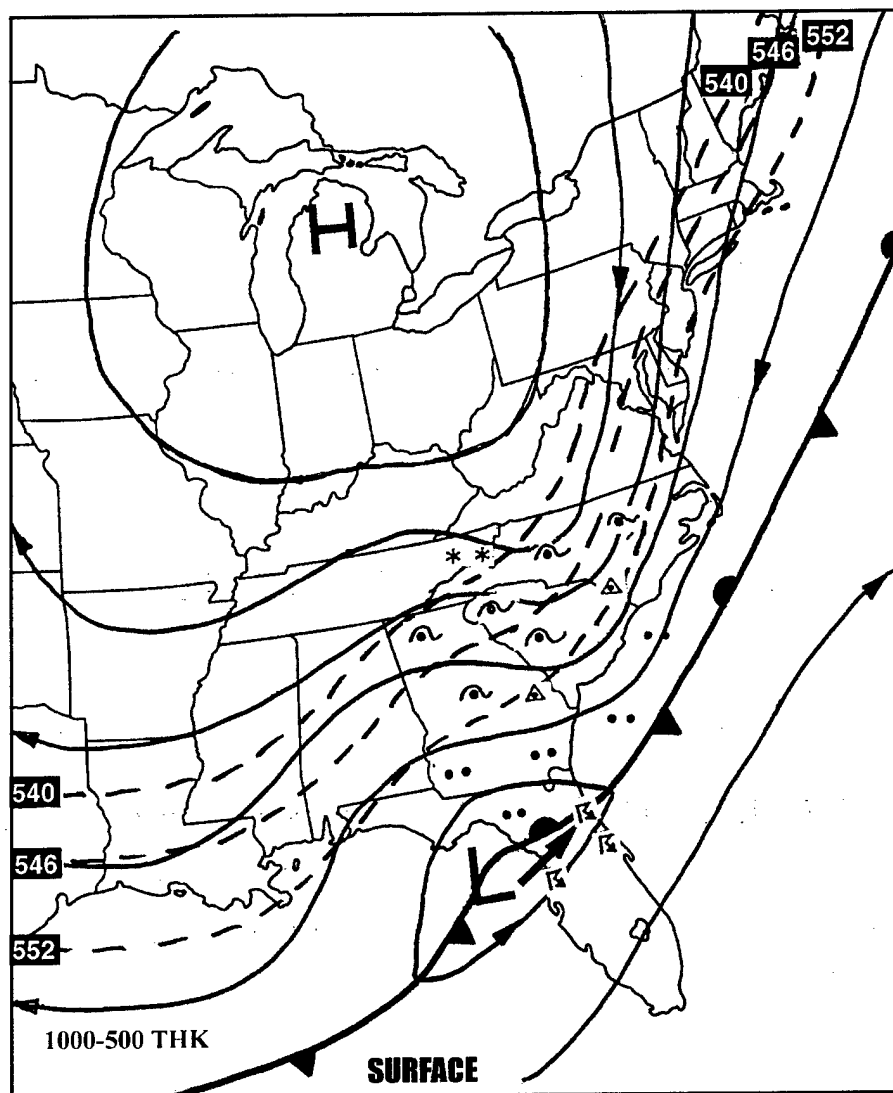


Figure 4-13. Gulf Frontal Lows. These storms often move across northern Florida into the Atlantic Ocean where they continue to deepen.

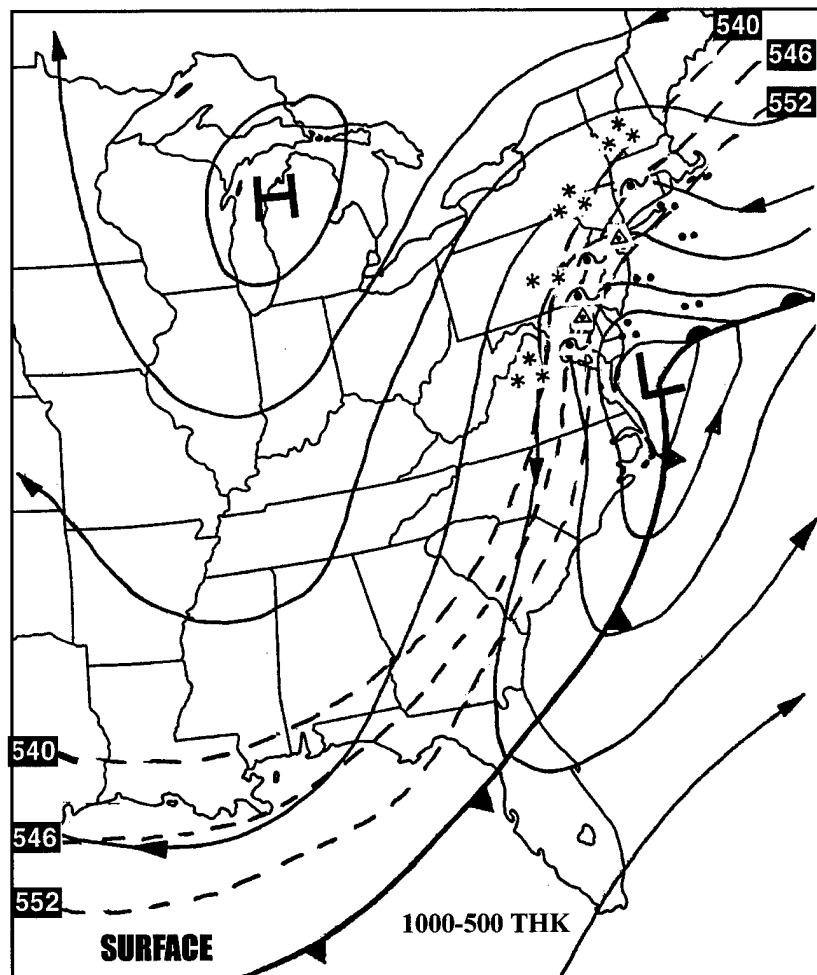


Figure 4-14. Gulf Frontal Low Progression. The deepening low moves northeastward spreading rain, freezing rain, and snow.

On day 2 (Figure 4-14), the deepening surface low moves northeastward parallel to the coastline. Intensification is often noted in the Cape Hatteras area. The accompanying precipitation shown in Figure 4-14 is typical with these coastal lows. Moderate-to-heavy rain will occur in the warmer air along the coastal areas while a few miles west in the cold air a narrow swath of ice pellets and freezing rain is likely. Further to the west, moderate-to-heavy snow is the rule. One or two of these storms may evolve into a “Nor’easter” depending on system deepening and subsequent strong cold air advection.

As discussed in a previous example, the southern branch of the Polar jet lies across the southern CONUS/northern Gulf of Mexico area. Usually a

long-wave trough lies across the central CONUS. Short waves bottom out in the long wave anywhere from the Ohio River valley southward into the lower Mississippi River valley areas and provide the upper support for coastal low deepening.

At the surface and in the lower levels abundant Atlantic moisture borne on easterly winds advects into the storm system. Strong coastal winds are not uncommon. The freezing precipitation areas shown in Figures 4-13 and 4-14 will generally lie between the 552/540 thickness and the 850-mb $+5^{\circ}\text{C}/-5^{\circ}\text{C}$ temperature ribbons. It has been observed in some of the strongest storms (strong warm air advection) that freezing rain will extend into the 534 thickness.

Chapter 4

Example 2. This case study shows a severe ice storm event that occurred in North Carolina and southern Virginia on December 8-9, 1989.

Figures 4-15 through 4-18b depict conditions at onset time. At the 500-mb level (Figure 4-15), a trough with a developing low is shown over the

central and southern Great Plains. Seventy to ninety percent relative humidity ahead of the trough covers the entire southeastern CONUS as seen in the 700-mb analysis (not shown). At the 850-mb level (Figure 4-16), the related low is seen over northern Alabama while the surface low is located further to the south in the Florida panhandle (Figure 4-17).

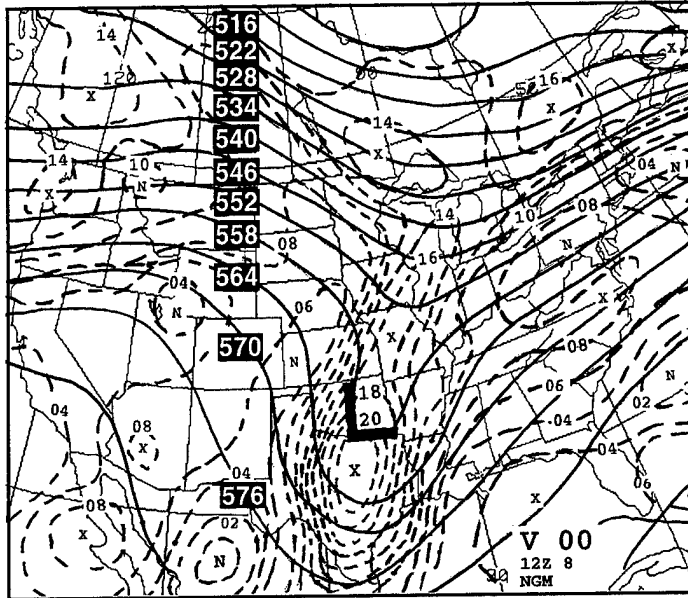


Figure 4-15. The 500-Mb Heights/Vorticity Chart. A trough with a developing low is shown. Chart valid at 1200Z on 8 December 1989.

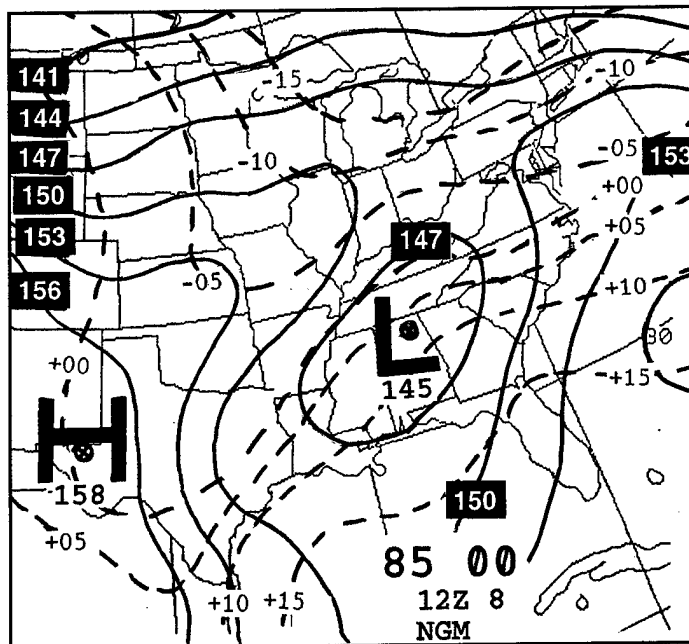


Figure 4-16. The 850-Mb Heights/Temperature Chart. The related 850-mb low is seen over northern Alabama. Chart valid at 1200Z on 8 December 1989

SYNOPTIC PATTERN RECOGNITION

The developing surface low-pressure system is along a stationary cP frontal boundary. A large stationary cP high is shown over the Great Lakes/Great Plains area (Figure 4-17). Figures 3-57 through 3-58b show the 0000Z, 8 December 1987 analysis.

Figures 4-18a and 4-18b depict the ongoing freezing rain, which lies between the 552/540 thickness and the +5°C/-5°C temperature corridors.

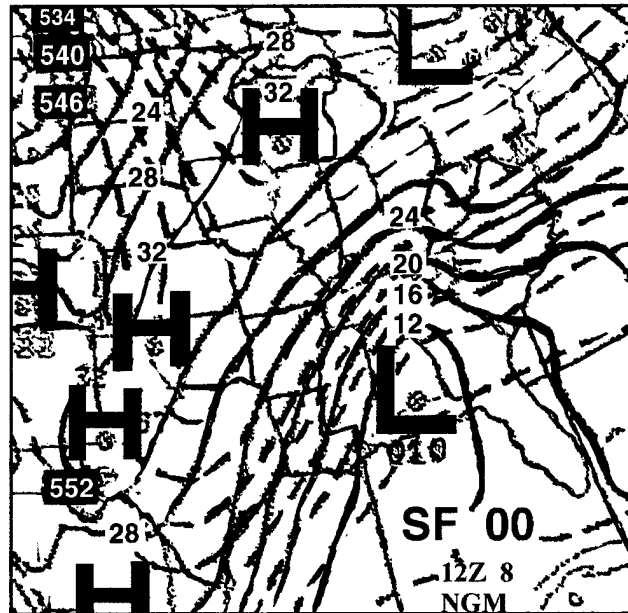


Figure 4-17. Mean Sea-Level/1,000- to 500-Mb Thickness Chart. A low is developing over the Florida Panhandle. Chart valid at 1200Z on 8 December 1989.

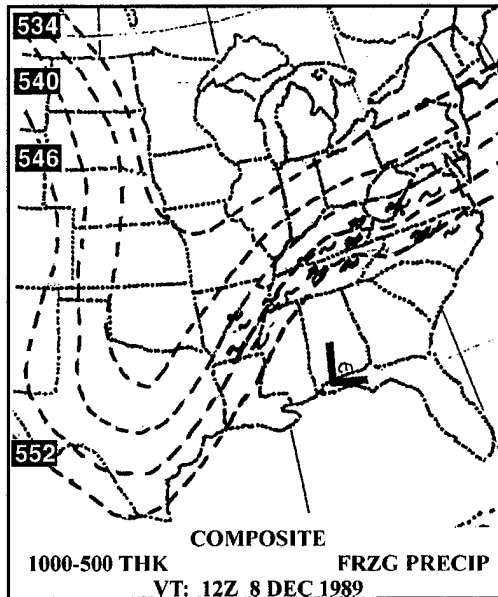


Figure 4-18a. Composite Thickness/Freezing Precipitation Chart. Freezing precipitation is occurring between 552/540 thickness isopleths.

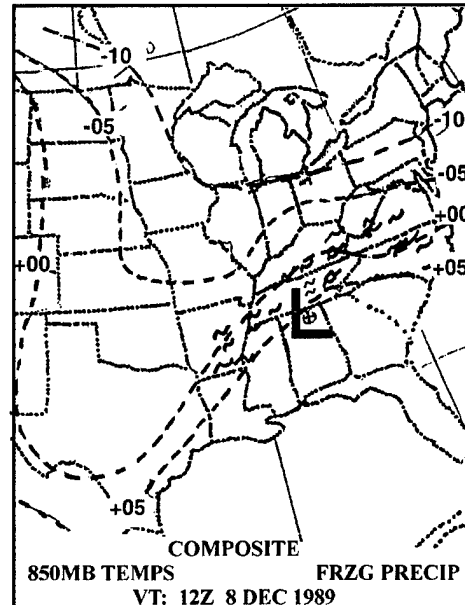


Figure 4-18b. Composite Temperature/Freezing Rain Chart. Freezing rain is occurring between the 850-mb +5°C and -5°C isotherms.

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Twenty-four hours later (Figures 4-19 through 4-22), freezing rain is falling heavily over North Carolina. The 500-mb low (Figure 4-19), has moved into western Alabama; strong PVA is shown over Alabama and Georgia.

In Figure 4-20, the 850-mb low has deepened; the 0°C isotherm has dipped southward into Tennessee and western North Carolina indicating cold air advection continues to be drawn into the storm system.

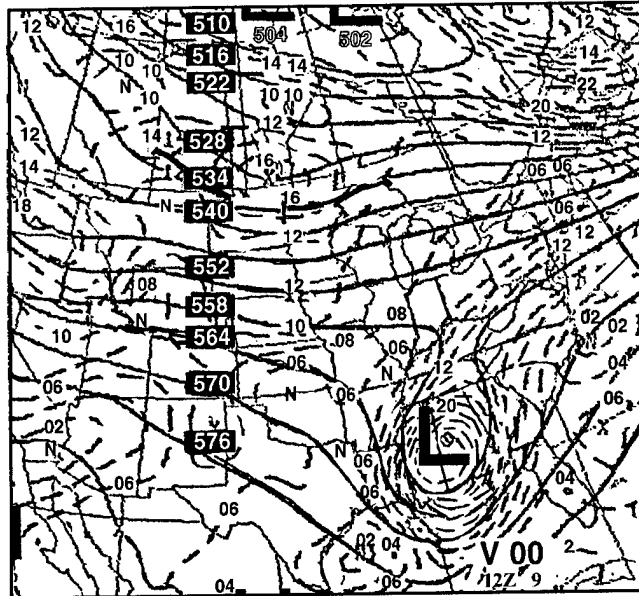


Figure 4-19. The 500-Mb Heights/Vorticity Chart. The 500-mb low has moved to western Alabama. Chart valid at 1200Z on 9 December 1989.

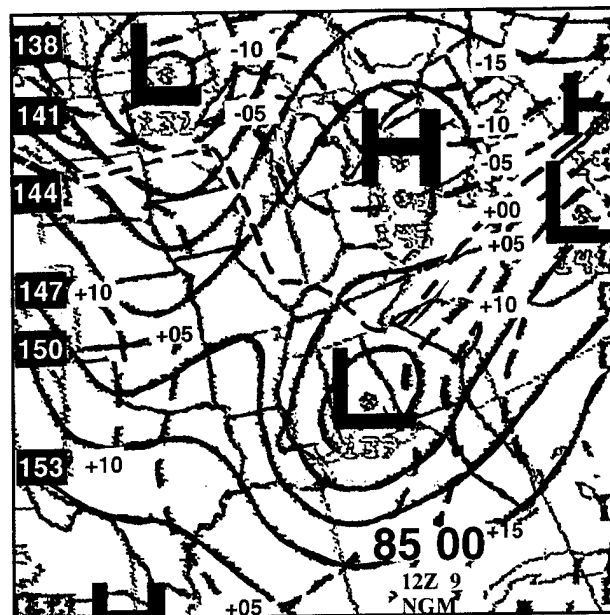


Figure 4-20. The 850-Mb Heights/Temperature Chart. The 850-mb low has deepened. Chart valid at 1200Z on 9 December 1989.

SYNOPTIC PATTERN RECOGNITION

At the surface (Figure 4-21), the Nested Grid Model (NGM) did not show the associated low over southern Georgia or northern Florida (noted by the arrow). Forecasters should not ignore these pressure system omissions. One is justified in placing a surface low within this area based on the isobars

and the low's position from the previous surface analysis. The cP ridge north of the low maintains cold air over the southern Appalachians to the coast.

The freezing rain swatch is shown in Figures 4-22a and 4-22b; this event lasted 24 hours.

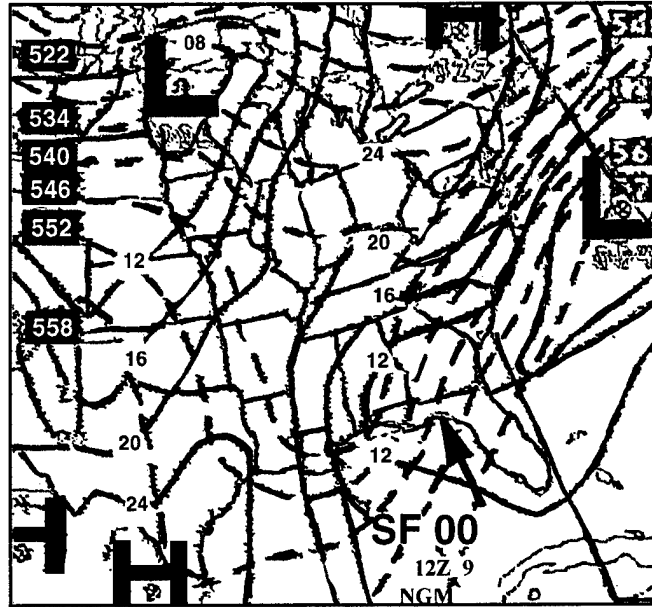


Figure 4-21. Mean Sea-Level/1,000- to 500-Mb Thickness Chart. The arrow indicates the position of a low-pressure system that was omitted on the NGM run. Chart valid at 1200Z on 9 December 1989.

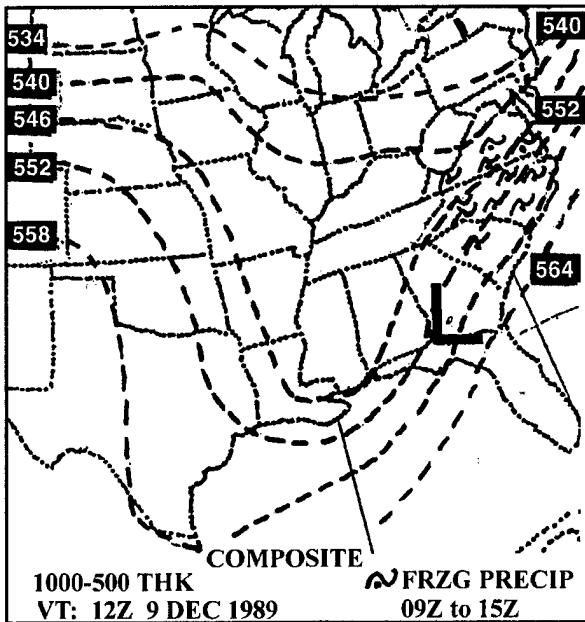


Figure 4-22a. Composite Thickness/Freezing Rain Chart. Freezing precipitation is occurring between 558/540 thickness isopleths.

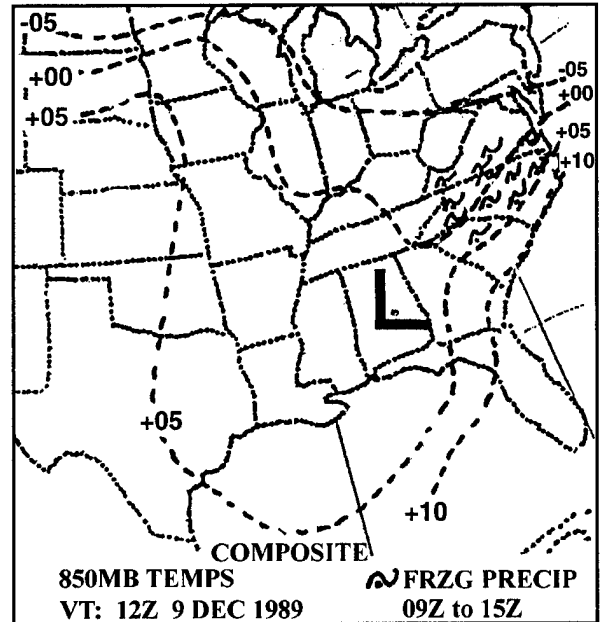


Figure 4-22b. Temperature/Freezing Rain Chart. Freezing rain is occurring between the 850-mb +5°C and -5°C isotherms.

Chapter 4

Example 3. This event is similar to the event just presented. These patterns should give southeastern CONUS forecasters a good idea on the synoptic pattern favorable for widespread freezing rain across the Carolinas and Virginia.

Figure 4-23 shows the 500-mb pattern. A long-wave trough is positioned over the central CONUS; two positive vorticity systems appear over the southern plains and the Georgia/South Carolina area. Freezing rain associated with the first PVA lobe is occurring over North Carolina and Georgia. A second, stronger PVA system is located over Texas and Louisiana.

The 850-mb analysis (Figure 4-24) shows a weak

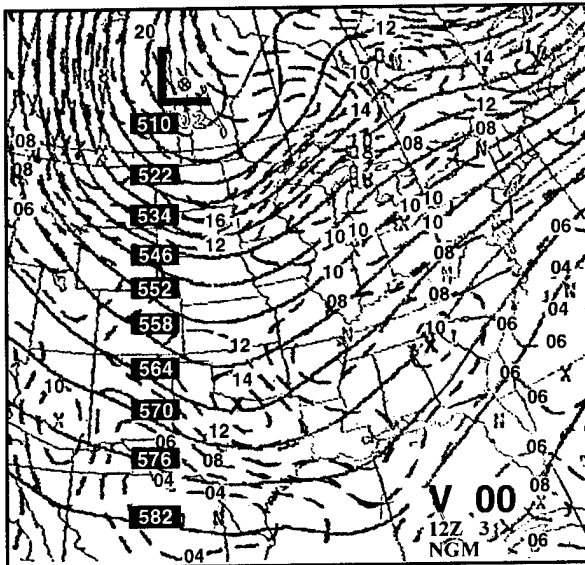


Figure 4-23. The 500-Mb Heights/Vorticity Chart. Freezing rain associated with the first PVA lobe is occurring over North Carolina and Georgia. Chart valid at 1200Z on 3 January 1988.

contour gradient over the southeastern states. A low is suspected in the Gulf of Mexico as indicated by the cyclonic isobar. The $+5^{\circ}\text{C}/-5^{\circ}\text{C}$ temperature ribbon is located over North Carolina and Virginia.

The surface features (Figure 4-25) shows no low-pressure systems associated with the freezing rain. A prevailing high-pressure pattern exists across the northern and central CONUS. A surface low does appear in the Gulf of Mexico with inverted troughing extending northward into Alabama and Mississippi. The gulf low is along a weak, modified cP front.

The freezing rain area shown in Figures 4-26a and 4-26b, falls within the expected thresholds of 552/540 and $+5^{\circ}\text{C}/-5^{\circ}\text{C}$.

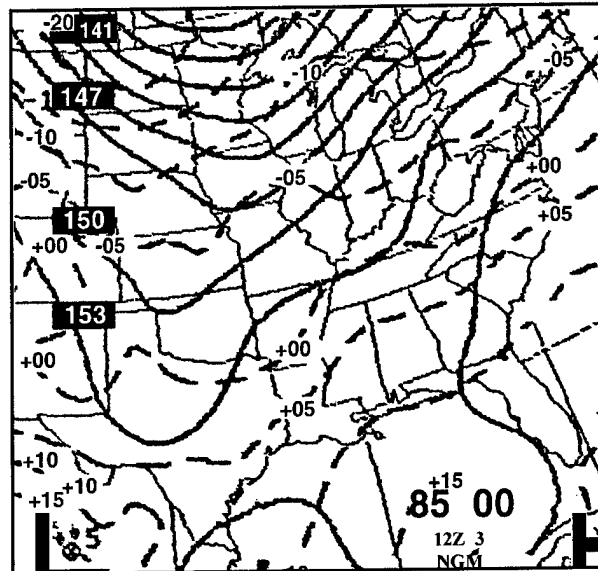


Figure 4-24. The 850-Mb Heights/Temperature Chart. A low is suspected in the Gulf of Mexico as indicated by the cyclonic isobar. Chart valid at 1200Z on 3 January 1988.

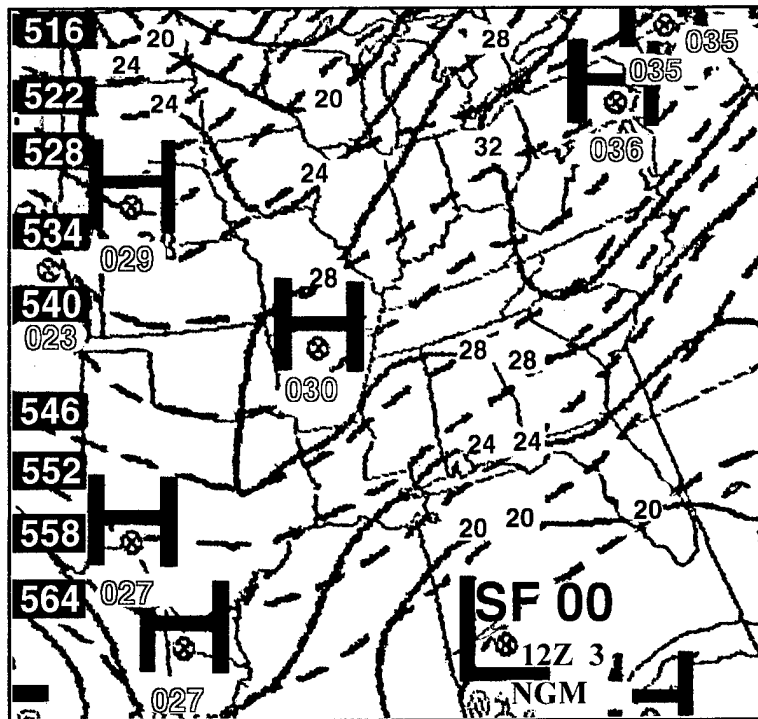


Figure 4-25. Mean Sea-level Pressure/1,000- to 500-Mb Thickness. The figure shows no low- pressure systems associated with the freezing rain. Chart valid at 1200Z on 3 January 1988.

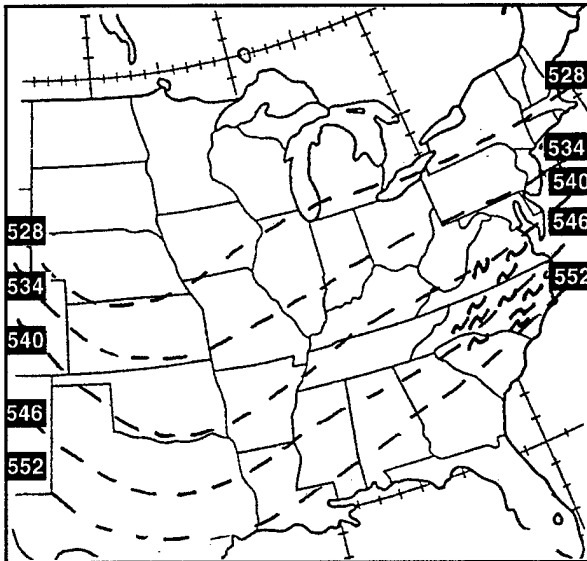


Figure 4-26a. Composite Thickness/Freezing Rain Relationship. Freezing precipitation is occurring between 552/540 thickness isopleths.

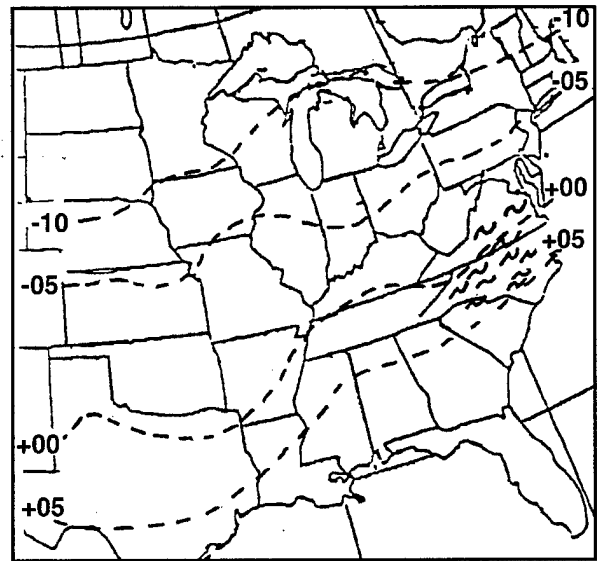


Figure 4-26b. Composite Temperature/Freezing Rain Relationship. Freezing rain is occurring between the 850-mb +5°C and -5°C isotherms.

Chapter 4

The 500-mb analysis 12 hours later (Figure 4-27) shows the short wave has moved into the Mississippi/Alabama area and PVA extends eastward to the southeast coastal area.

No low appears at the 850-mb level (Figure 4-28), and the contour gradient remains relatively weak. The tighter temperature gradient over the Carolinas support an 850-mb front that exists over that area.

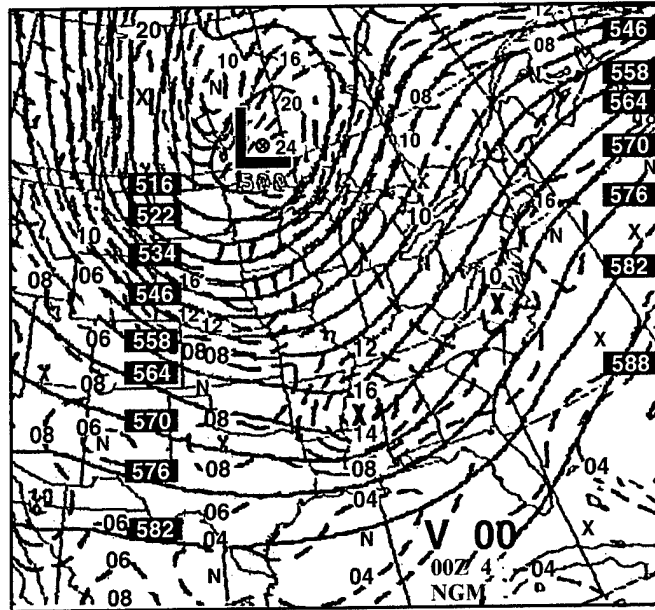


Figure 4-27. The 500-Mb Heights/Vorticity Chart (12 Hours Later). The figure shows a short wave has moved into the Mississippi/Alabama area. Chart valid 0000Z on 4 January 1988,

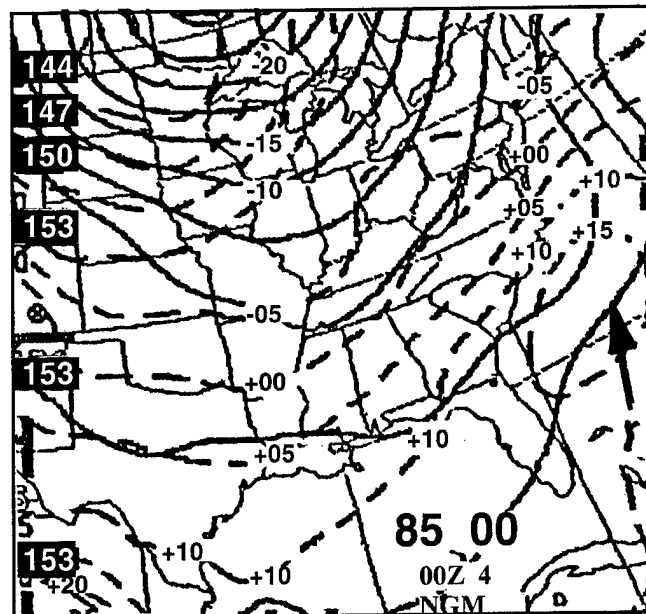


Figure 4-28. The 850-Mb Heights/Temperature Chart (12-Hours Later). The arrow denotes a thermal axis. Chart valid at 0000Z on 4 January 1988.

At the surface (Figure 4-29) a frontal low appears off the Carolinas' coast and has developed within the thermal axis shown in Figure 4-28 (noted by the arrow).

Freezing rain continues over the colder interior areas of North Carolina to southern New Jersey as shown in Figures 4-30a and 4-30b. The freezing rain continues in the 552/540 thickness and the 850-mb +5°C/-5°C temperature corridors.

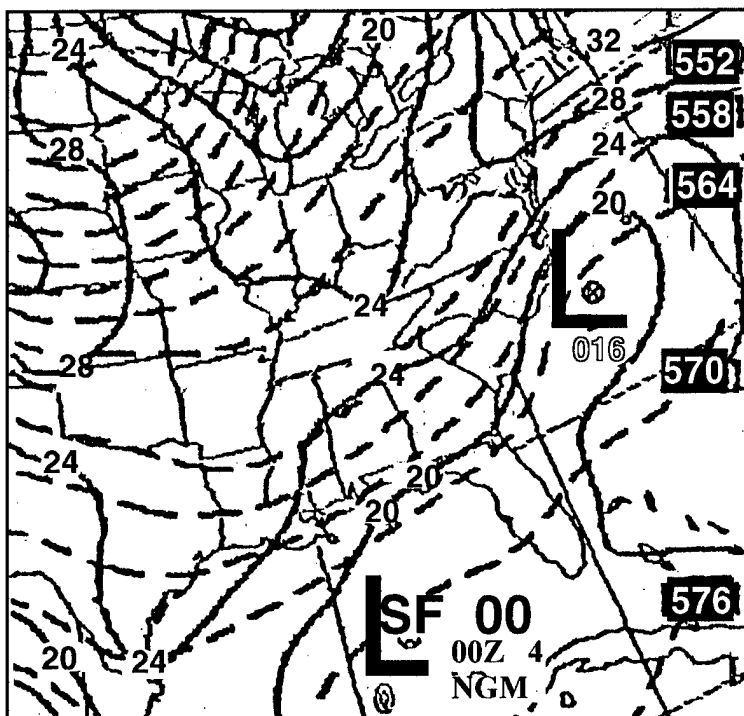


Figure 4-29. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. A low is developing in the thermal axis off the Carolinas' coast. Chart valid at 0000Z on 4 January 1988.

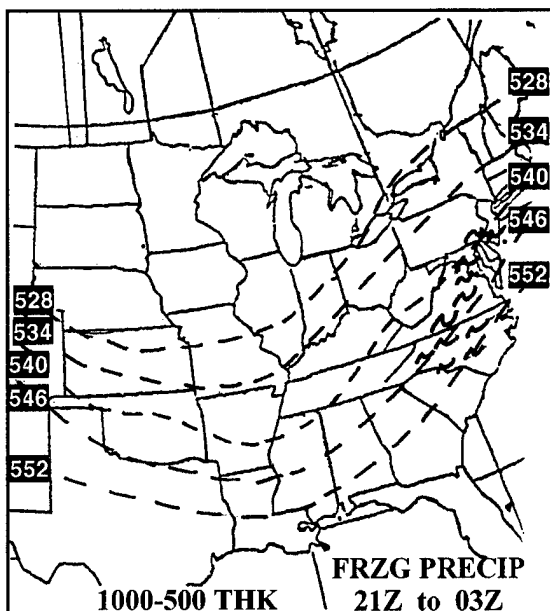


Figure 4-30a. Composite Thickness/Freezing Rain Relationship. Freezing precipitation is occurring between 552/540 thickness isopleths.

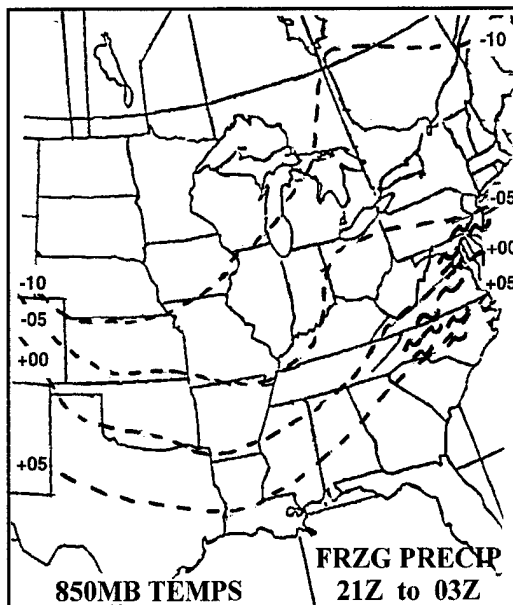


Figure 4-30b. Composite Temperature/Freezing Rain Relationship. Freezing rain occurs between the +5°C and -5°C isotherms.

Chapter 4

Appalachian Damming.

Example 1. Occasionally during the winter months, a slow moving cP high-pressure system located over Maine and northward into the Newfoundland/Labrador area will extend an elongated, shallow ridge southward across New England to the southern Appalachians. The ridge is usually along and east of the mountains; this pattern is shown in Figure 4-

31. A strong low-level inversion and an easterly moist Atlantic flow produces upslope stratus along with fog; this stagnant pattern can persist for several days until strong warm air advection erodes the shallow ridge. A rain area associated with an approaching disturbance will overrun the shallow air mass and produce freezing rain for a few hours. A stationary front is usually along the Appalachian Mountain region as illustrated in Figure 4-31.

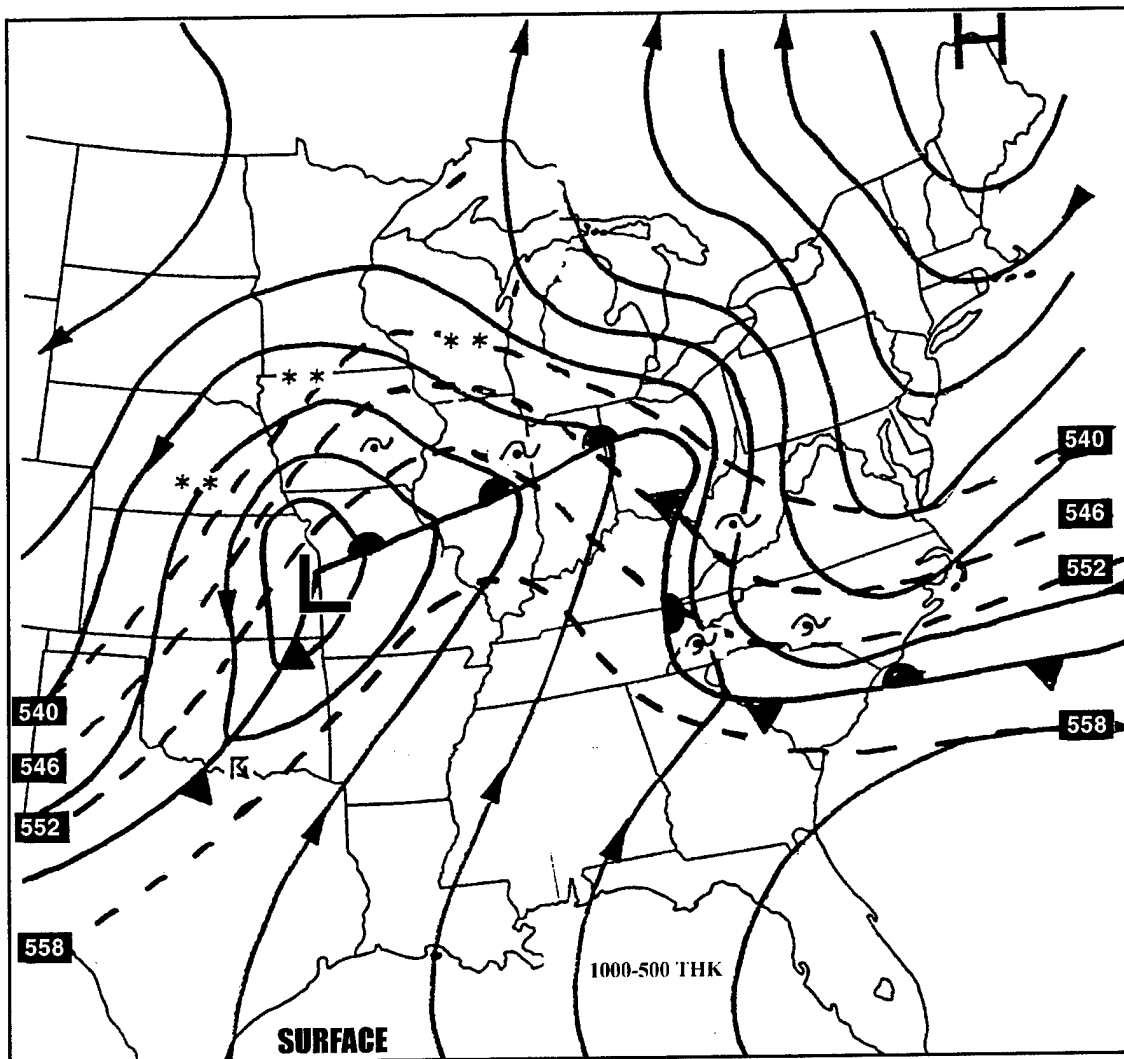


Figure 4-31. Appalachian Damming Pattern. The figure shows the ridging along the east side of the Appalachian Mountains.

An approaching storm and its warm air advection will eventually destroy the shallow ridge. The Appalachian front will undergo frontolysis and a

new frontal boundary will appear further north where the better temperature and moisture discontinuities exist as shown in Figure 4-32.

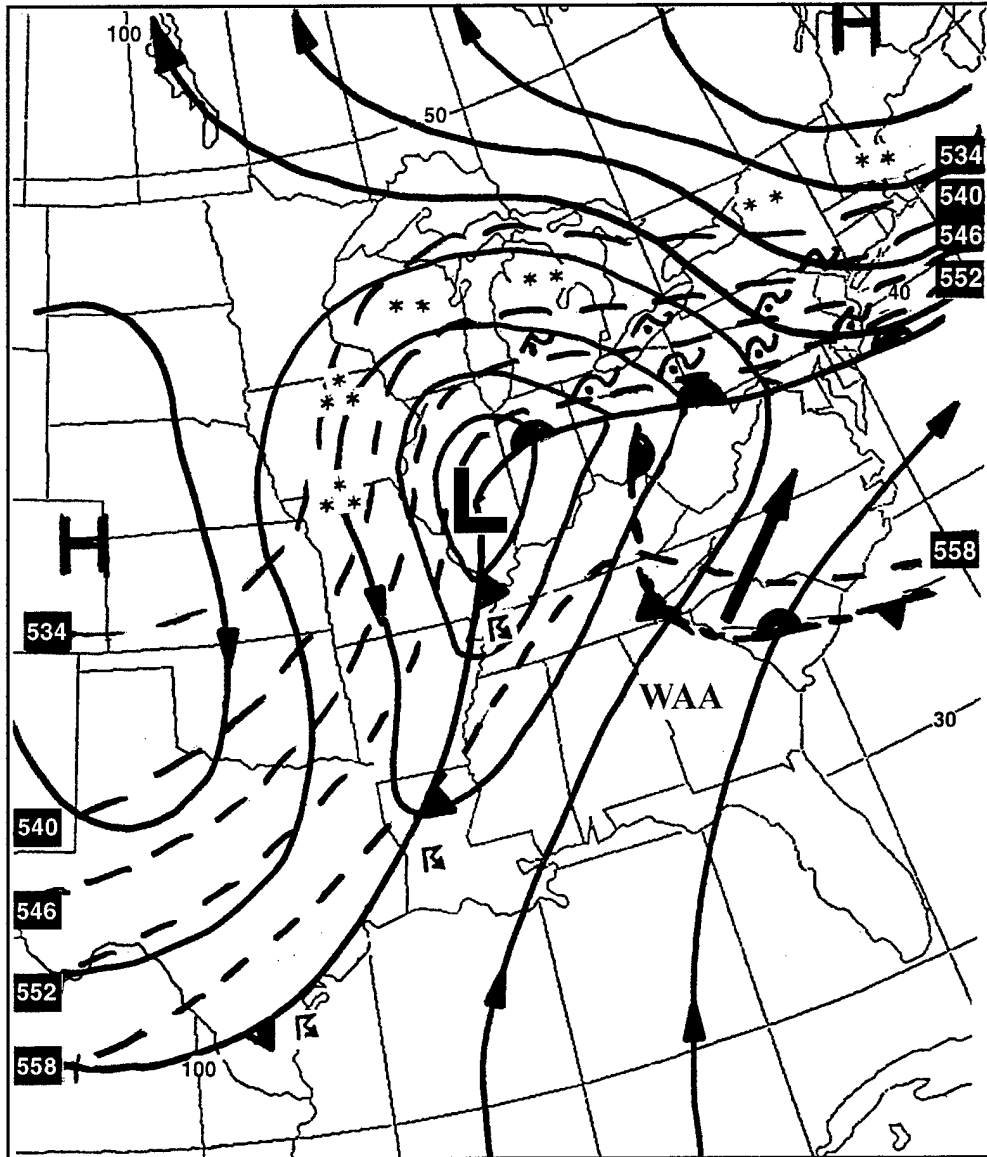


Figure 4-32. Appalachian Damming Progression. Figure shows the stationary front washing out and the boundary reestablishing itself further north.

Chapter 4

Example 2. A strong, shallow ridge that extended southward from a Canadian high (>1050 mb) affected all of New England to North Carolina (Figure 4-33). This was a pronounced damming precipitation event across western North Carolina, eastern West Virginia, and nearly all of Virginia that lasted over a 36-hour period. Many of these events are much weaker than this example; however, the shallow cP inversion is likely to occur along and east of the Appalachians and produce low ceilings, fog, and light freezing precipitation.

Within the mid-levels, a short wave with a closed

low was centered over southern Nebraska and was moving towards the Great Lakes area (not shown). Figures 4-33 and 4-34 depict the mean sea-level pressure/1,000- to 500-mb and composite analysis. In Figure 4-33, a surface warm front lies across southern Missouri eastward into Kentucky and Tennessee, but it is lost in the shallow ridge over Virginia and North Carolina.

Figure 4-34 shows an extensive freezing precipitation area (mostly rain) from Nebraska to the East Coast. Most of the freezing rain lies between the 552 and 534 thickness area.

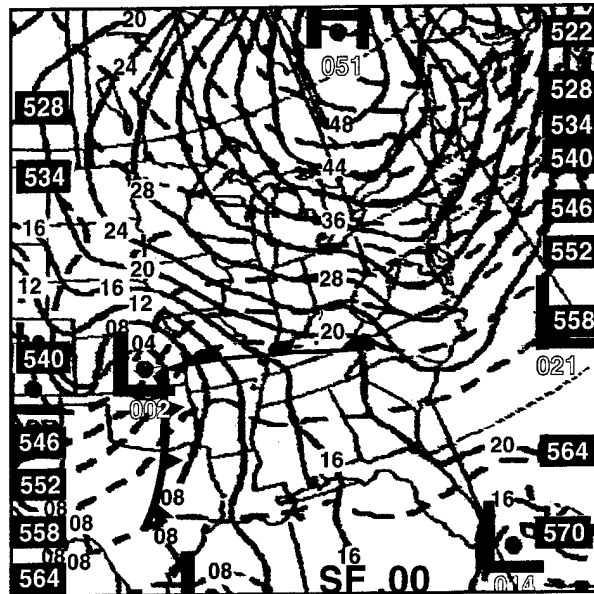


Figure 4-33. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. A shallow ridge extends southward east of the Appalachians. Chart valid at 0000Z on 27 January 1991.

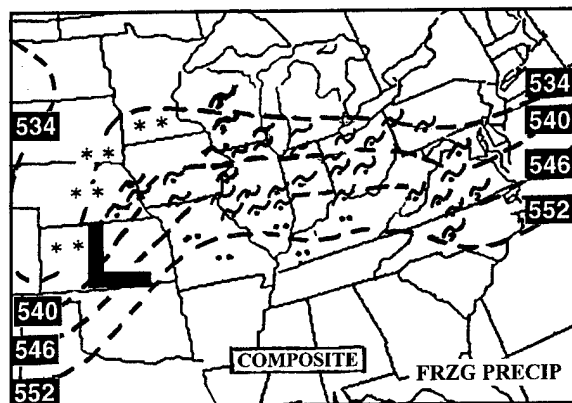


Figure 4-34. Composite 1,000- to 500-mb thickness/Freezing Precipitation Chart. Freezing rain falls between the 534 and 552 thickness isopleths.

The related 850-mb analysis and composite are shown in Figures 4-35 and 4-36, respectively. Notice that the freezing precipitation is further to the north from the surface warm front shown in Figure 4-33. The southern boundary of the freezing

precipitation is along and north of the 850-mb warm front shown in Figures 4-35 and 4-36 (noted by the arrows). The freezing precipitation lies between the +5°C/-5°C temperature ribbon.

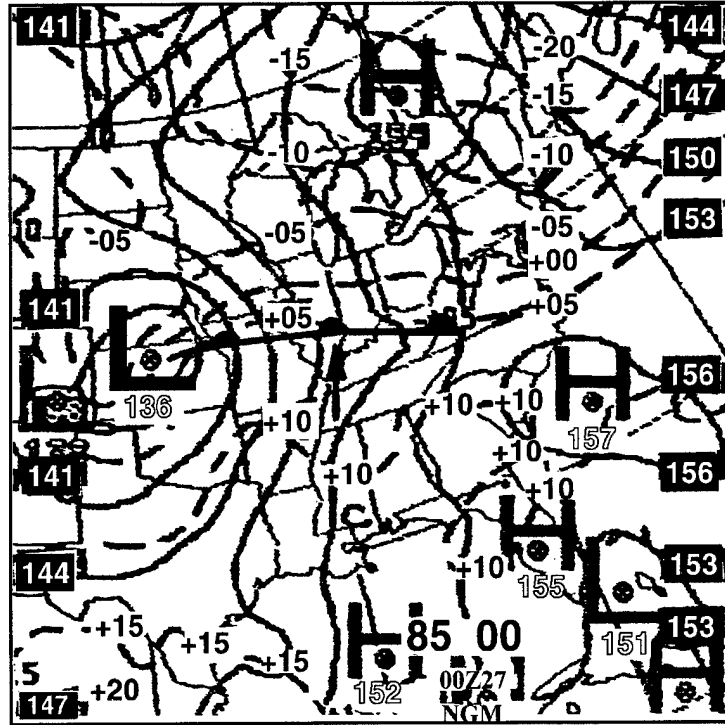


Figure 4-35. The 850-Mb Heights/Temperature Chart. The 850-mb warm front (indicated by the arrow) lies to the north of the surface front. Chart valid at 0000Z on 27 January 1991.

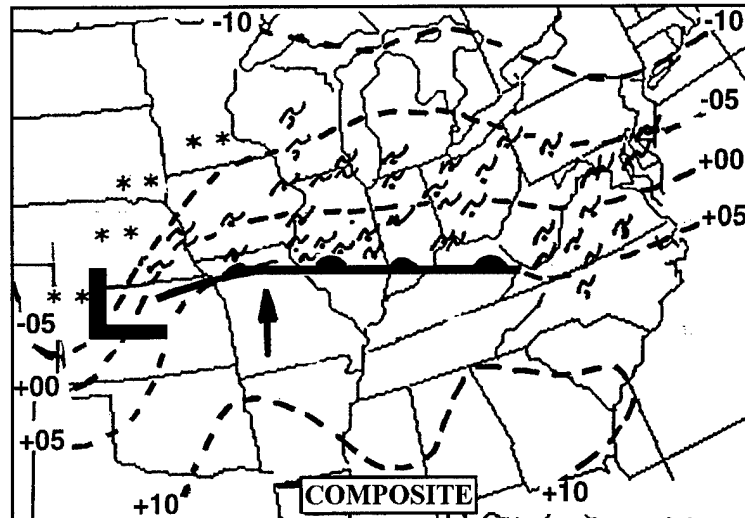


Figure 4-36. Composite 850-Mb Temperature/Freezing Rain Chart. Freezing rain is occurring between the 850-mb +5°C and -5°C isotherms. The arrow indicates the southern boundary of the freezing precipitation.

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Figures 4-37 through 4-40 show the pattern 12 hours later. In Figure 4-37, the Canadian high has shifted slightly eastward but continues to dominate the eastern CONUS. The ridge east of the Appalachians remains strong.

plains and Ohio Valley has moved northward as the upper low and surface warm front shifted northeastward. In the cold air damming area over the Delaware, Maryland, and Virginia region the freezing precipitation extends further to the south as the low-level inversion remains strong.

In Figure 4-38, the freezing precipitation over the

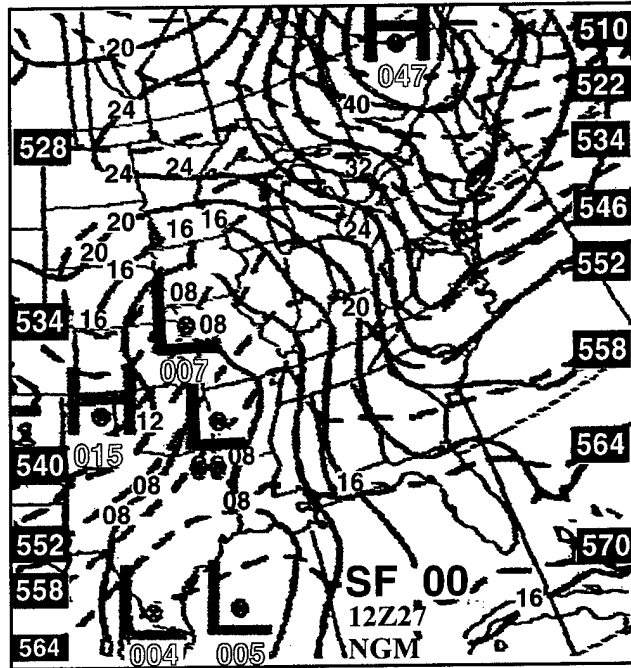


Figure 4-37. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-mb thickness. The ridge east of the Appalachians remains strong. Chart valid at 1200Z on 27 January 1991.

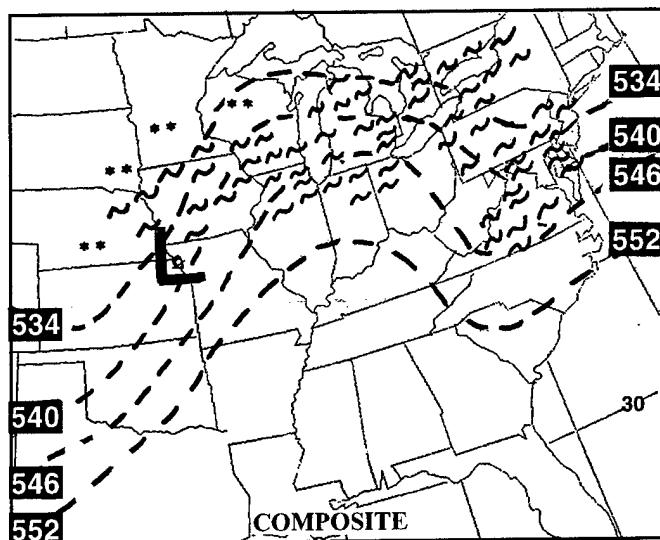


Figure 4-38. Composite 1,000- to 500-mb thickness/Freezing Precipitation Chart. Freezing precipitation has moved northward with the warm front.

SYNOPTIC PATTERN RECOGNITION

Figures 4-39 and 4-40 depict the 850-mb data. The 850-mb warm front continues to move northward and lies across northern Illinois to southern Pennsylvania. The associated upper low over Nebraska is headed for the western Great Lakes. The damming effect is still noticeable in the curvature of the isotherms east of the Appalachians.

In Figure 4-40, most of the freezing rain lies along and north of the 850-mb warm front. Freezing rain/drizzle continues within the damming area over Virginia and northward. Most of the freezing precipitation lies within the $+5^{\circ}\text{C}/-5^{\circ}\text{C}$ temperature ribbon.

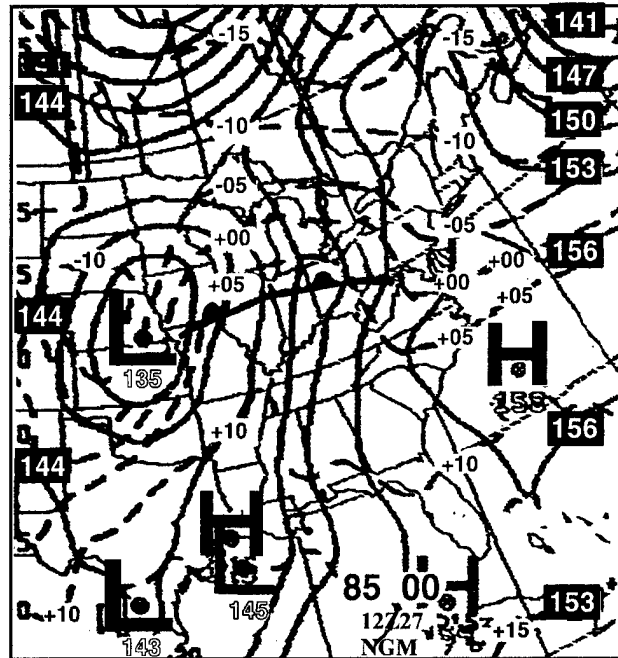


Figure 4-39. The 850-Mb Heights/Temperature Chart. The warm front continues its northward movement. Chart valid at 1200Z on 27 January 1991.

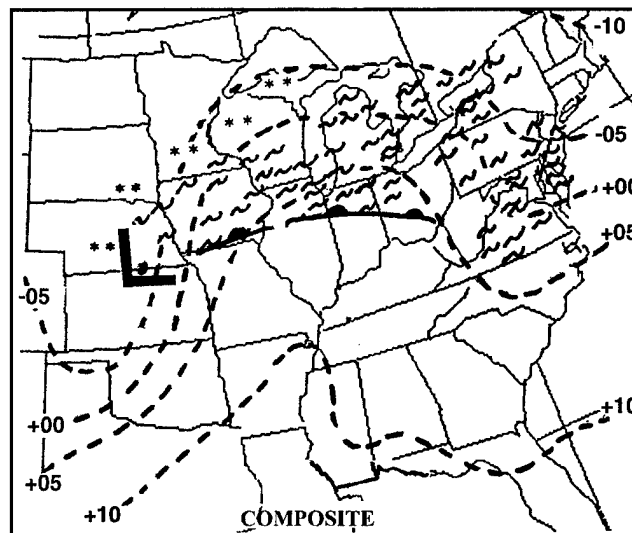


Figure 4-40. Composite Temperature/Freezing Rain Chart. Most of the freezing rain is occurring between the 850-mb $+5^{\circ}\text{C}$ and -5°C isotherms.

Chapter 4

Western Great Plains.

Example 1. This pattern occurs mostly during January through early March when a slow moving or a stationary cP prevailing high-pressure system dominates the central and eastern CONUS (Figure 4-41). In conjunction with this cP high, the Great Basin high is also present over the western CONUS which results in an anticyclonic regime across the entire CONUS. An inverted trough is generally located over the southern and central Rockies; this trough separates the transitory cP high over the central CONUS from the stationary mP or modified cP Great Basin high.

In prevailing-high occurrences, large areas of upslope stratus east of the Rocky Mountains and across the western Great Plains develop as gulf moisture overruns the shallow air mass. The 850-mb analysis would likely show a moist southeast flow from the Gulf of Mexico across southern and western Texas. The upslope precipitation type would likely be freezing drizzle and/or light snow. The precipitation area seldom moves too far east and will persist until the upslope flow breaks down. This event is often diurnal, however, under a very cold air mass where the low-level inversion is strong, the freezing drizzle will persist throughout the day.

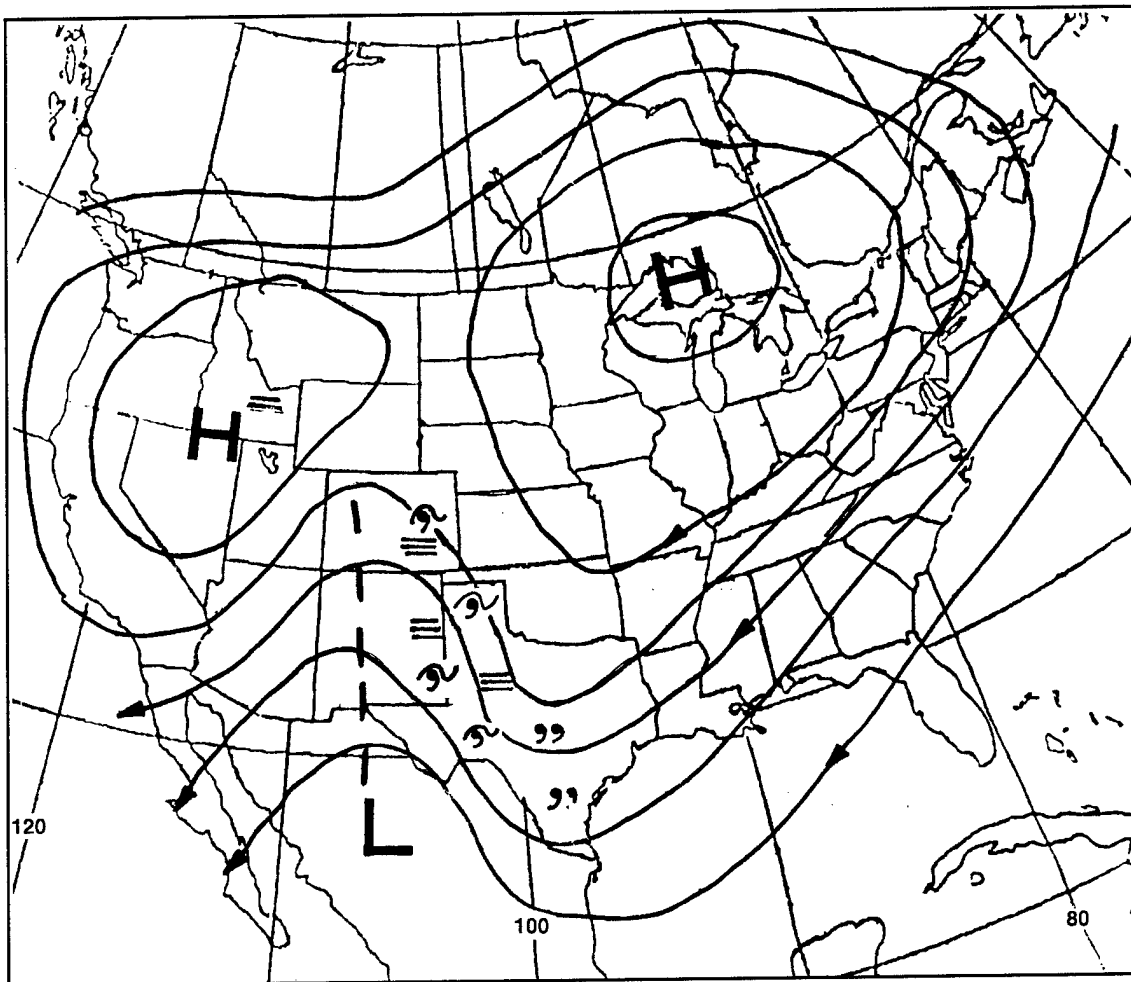


Figure 4-41. Western Great Plains Pattern. The figure depicts a slow moving or a stationary cP prevailing high-pressure system that dominates the central and eastern CONUS

Example 2.

Figures 4-42 through 4-44 depict a strong cP outbreak which covers a majority of the CONUS. The cP frontal system is located across the central Gulf of Mexico.

Gulf of Mexico (Figure 4-42). At the 850-mb level, (Figure 4-43) a weak thermal axis is shown over eastern Texas and Oklahoma. Low-level moisture is spreading northward within a weak southerly flow across the southern plains.

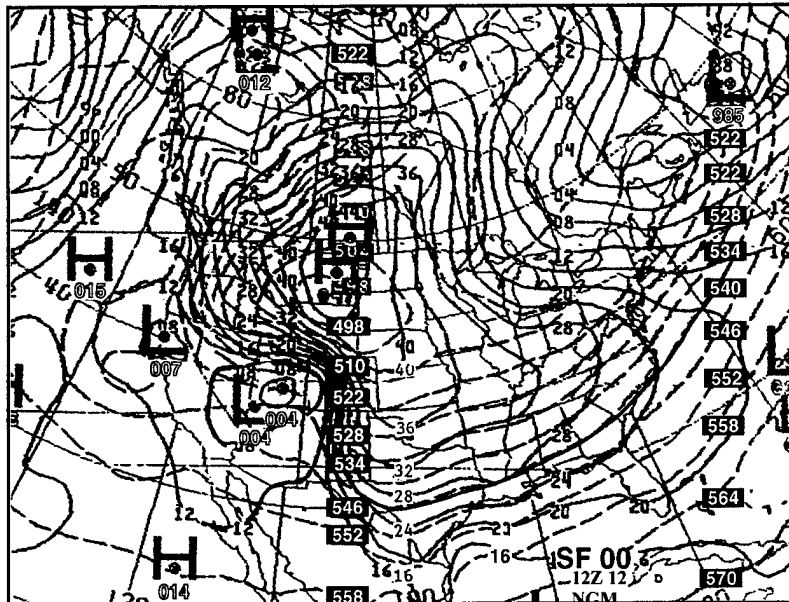


Figure 4-42. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The cP frontal system is located across the central Gulf of Mexico. Chart valid at 1200Z on 12 January 1997.

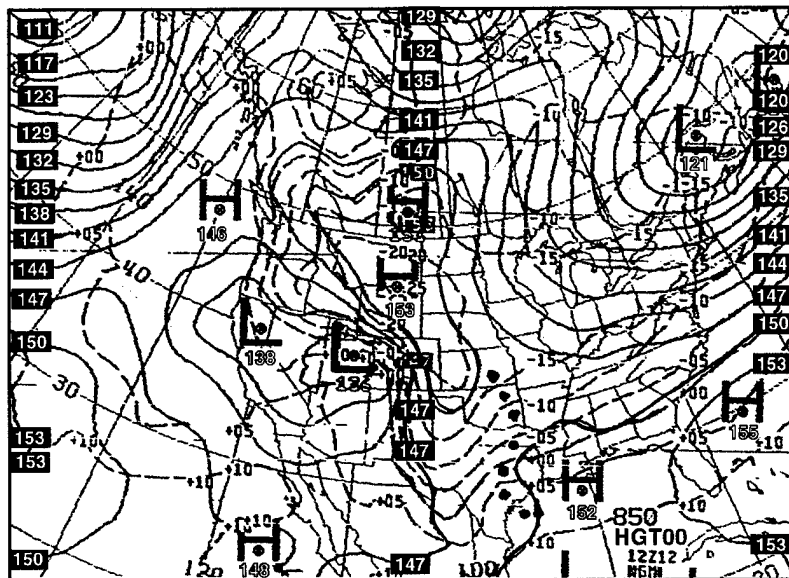


Figure 4-43. Forecast (00HR) 850-Mb Heights/Temperatures. A weak thermal axis is indicated by dots over eastern Texas and Oklahoma. Chart valid at 1200Z on 12 January 1997.

Chapter 4

The visible satellite picture (Figure 4-44), which is approximately 5 hours after the information in Figures 4-42 and 4-43, shows an extensive stratus cloud system from the Gulf of Mexico to Colorado and Kansas. No freezing precipitation occurs with

this event since it was too cold; snow occurred. However, this would be the satellite signature for upslope freezing precipitation. Notice the grayer shade comma tail that overlies the stratus layer over northern Texas and Oklahoma (noted by the arrow).

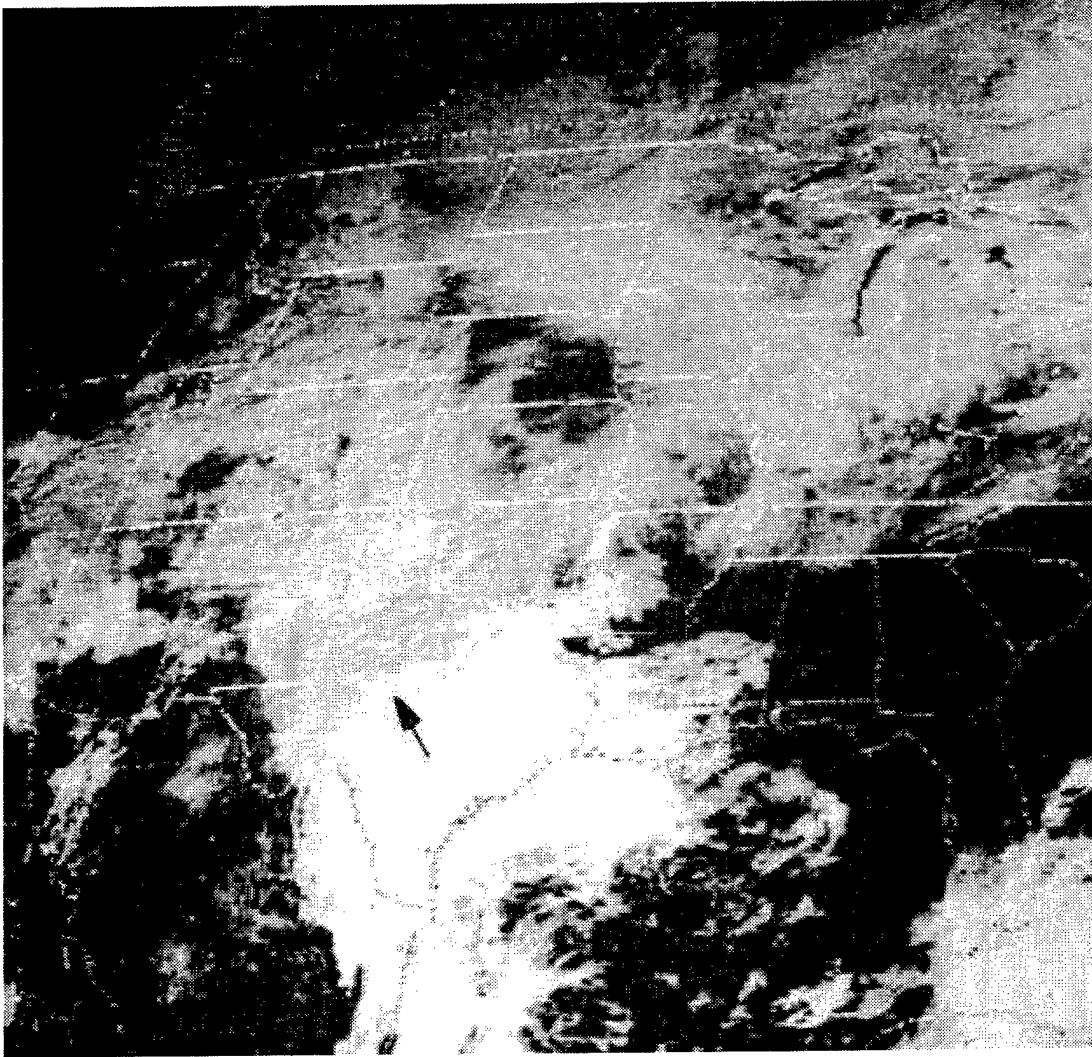


Figure 4-44. Visible Satellite Imagery. The figure shows the satellite signature for upslope freezing precipitation. Notice the grayer shade comma tail that overlies the stratus layer over northern Texas and Oklahoma (noted by the arrow).

Southern Great Plains.

Inverted Troughs. In the previous example, the inverted trough separating a transitory cP high east of the Rockies from the Great Basin high is oriented south to north across the southern and central Rockies. When these inverted troughs become aligned northeast to southwest (Figure 4-45), then

forecasters should suspect a warm front is developing in association with an approaching southern Rockies short wave (Figure 4-46). Unlike the previous example, the precipitation area is generally rain rather than drizzle and will spread eastward. Snow will increase north of the freezing rain as the short wave emerges from the mountains.

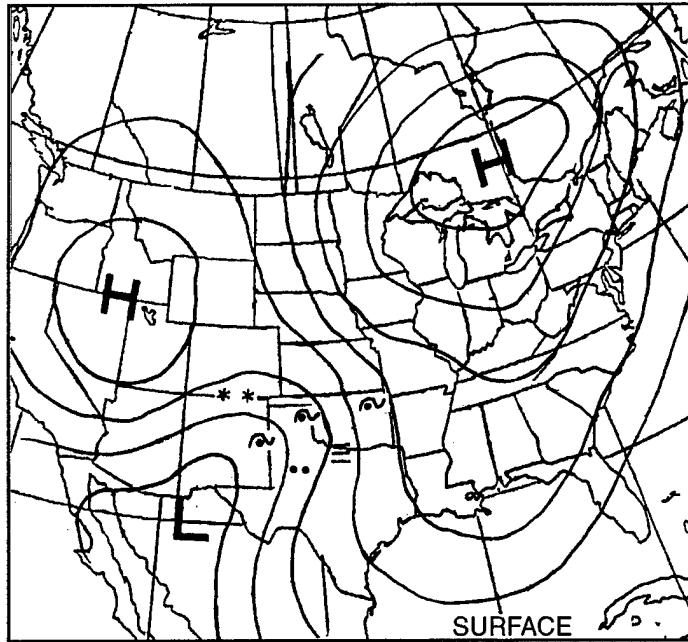


Figure 4-45. Inverted Surface Trough. The figure depicts an inverted trough aligned northeast to southwest.

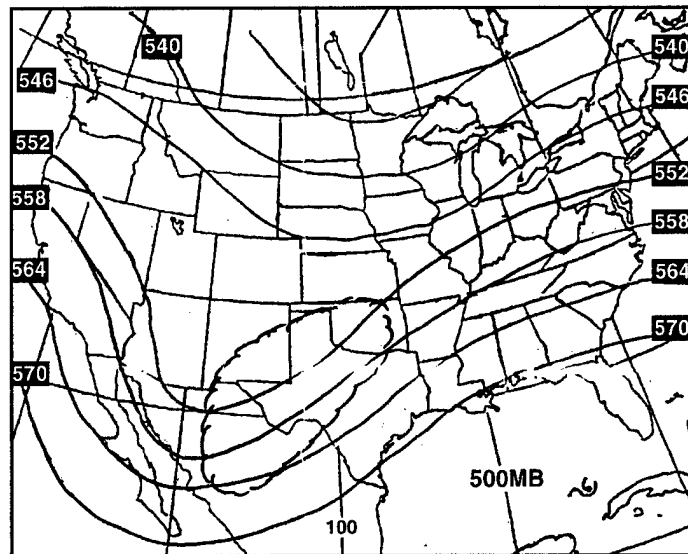


Figure 4-46. The 500-Millibar Analysis. The pattern shows a short wave moving out of the southern Rocky Mountains.

Chapter 4

Northern Great Plains

Warm Fronts. Southern Canadian lows tracking eastward within zonal flow with the Polar jet often have a warm front extending southward into the northern Great Plains such as shown in Figure 4-47. The moisture source associated with these warm fronts is Pacific moisture within a fast moving

westerly flow. Moisture that manages to survive the mountains moves into the northern plains and overruns shallow cP air. Unlike a similar pattern (see Figure 3-23) where a more extensive area of freezing drizzle develops in low stratus layers under return southerly flow, warm frontal freezing rain is often patchy in areal coverage, is of light intensity, and generally falls from mid-level cloud layers.

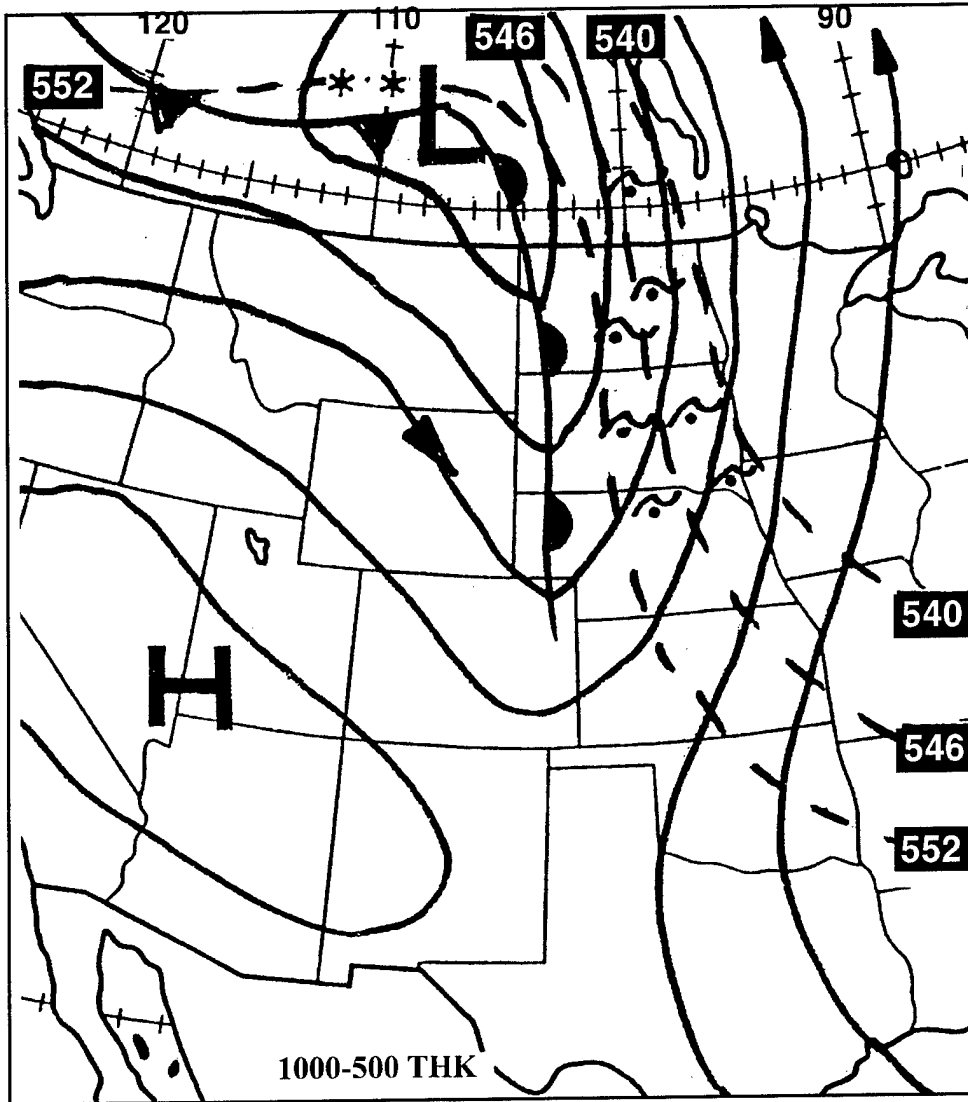


Figure 4-47. Northern Great Plains Warm Fronts. The figure shows a warm front extending southward from a southern Canadian low.

Stationary Fronts. Polar air masses occasionally remain stationary over western and central Canada but continue to build. The upper flow is generally from the southwest. The southern boundary of the cP air mass is often observed from eastern Montana extending eastward across the northern plains as shown in Figure 4-48. Within the cold air behind the front, an extensive area of low stratus and fog (easterly flow) often forms. Freezing drizzle occurs

frequently in this stationary event, especially in the upslope flow over the western Dakotas and eastern Montana area. Sometimes an east-west trough is depicted on the surface chart rather than a stationary front. This pattern will end when a low moves out of the Rockies into the central plains, and the cold air and ridging moves rapidly southward behind the low

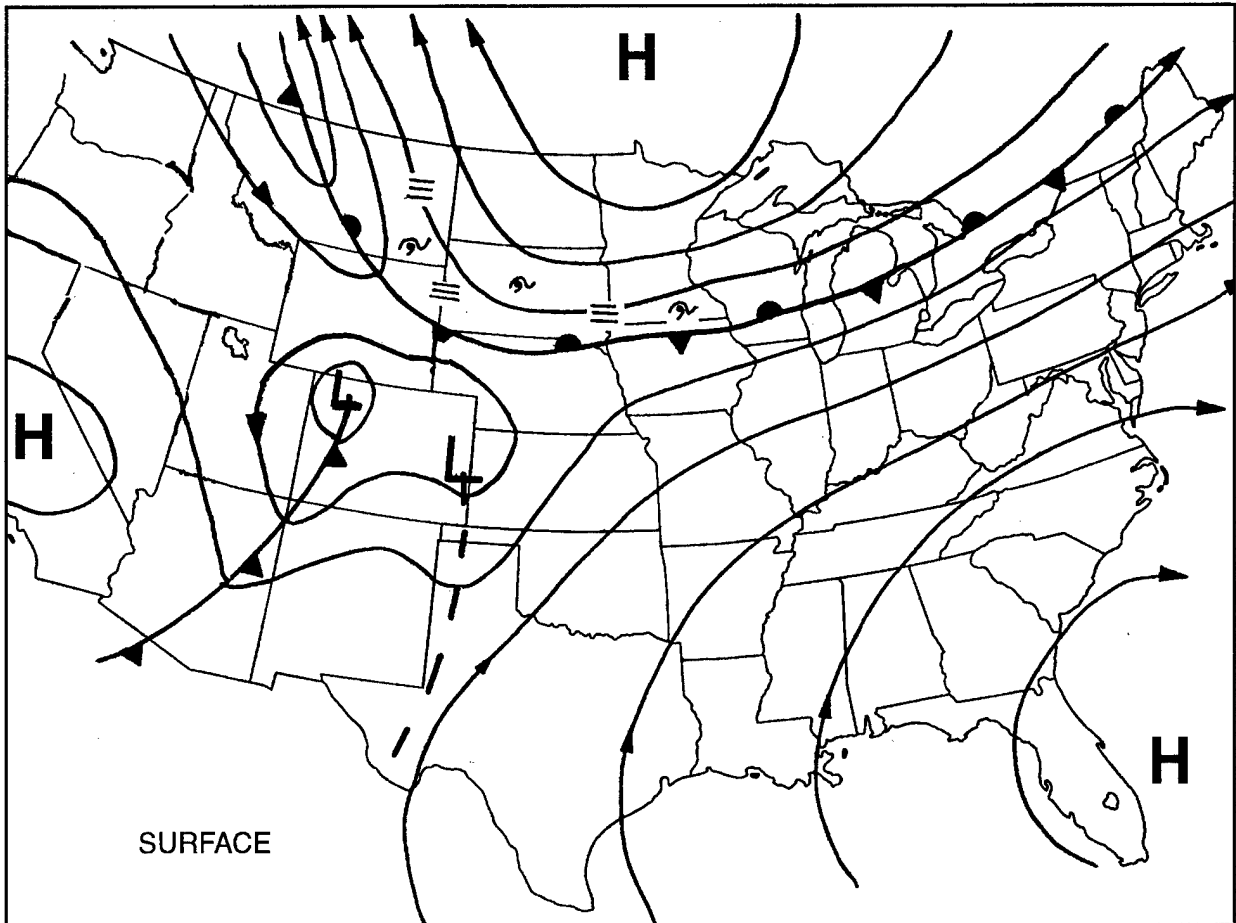


Figure 4-48. Northern Great Plains Stationary Fronts. The stationary front extending across the northern Great Plains indicates the southern boundary of the cP air mass and frequently leads to freezing drizzle.

Chapter 4

Great Lakes/Ohio Valley. Forecasting freezing drizzle can be a challenge during the course of winter. Drizzle is a low-level phenomenon developing in stratus layers below inversions. The 1,000- to 500-mb thickness rules would be more difficult to apply in pure warm air advection stratus, fog, and drizzle events. Forecasters must always look for warm air advection at the surface and lower layers. Freezing drizzle is often a nocturnal event; drizzle is likely when stratus lowers below 1,000 feet and fog increases. Warm air advection freezing drizzle was presented earlier in Figures 3-21 through 3-25. On the other hand, freezing drizzle may persist for many hours especially within the cold air of frontal zones. In most freezing drizzle cases studied, freezing drizzle occurred between the 540 and 528 thickness and between the 0°C and -10°C isotherms.

The upper Great Plains eastward across the Great Lakes/Ohio Valley region to the hilly terrain of West Virginia, Pennsylvania and New York are favorable areas for mostly random nocturnal occurrences of freezing drizzle where persistent residual stratus prevails. Air flowing across the warmer waters of the Great Lakes lifts above the shallow, cold air over land and produces enough instability to develop freezing drizzle. Often the air mass has not been "cleaned out" after cold frontal passage, or clouds persist within the large scale circulation of a decayed low that has become stationary over the Great Lakes and southern Canada area (Figure 4-49).

NOTE: The pattern shown in Figure 4-49 is an infrequent event; most residual stratus events are associated with stationary frontal systems which will be shown in the next example.

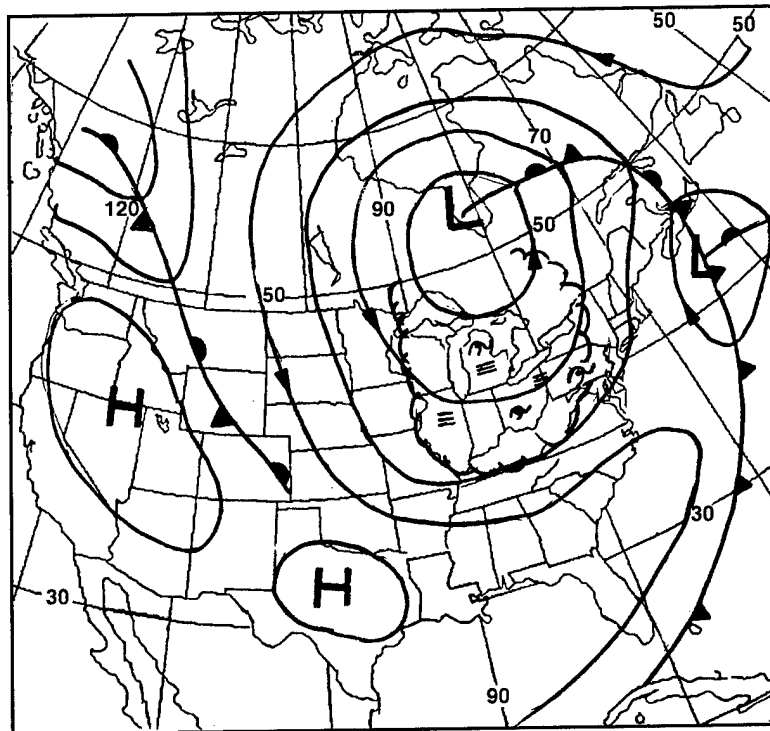


Figure 4-49. Decaying Low-Pressure System. The figure shows clouds that occasionally persist within the large scale circulation of a decayed low that has become stationary over the Great Lakes and southern Canada area.

Stationary Fronts/Residual Moisture. Figure 4-50 depicts a typical stationary front with post-frontal residual stratus and drizzle within the colder air. Northward stratus advection (often rapid; noted by the arrow) within return southerly low-level flow is

likely. Forecasters located upstream should always be on the alert for lowering ceilings, fog, and drizzle. Warm air advection over snow cover or surfaces below 0°C will produce low ceilings, fog, and freezing drizzle, especially at night.

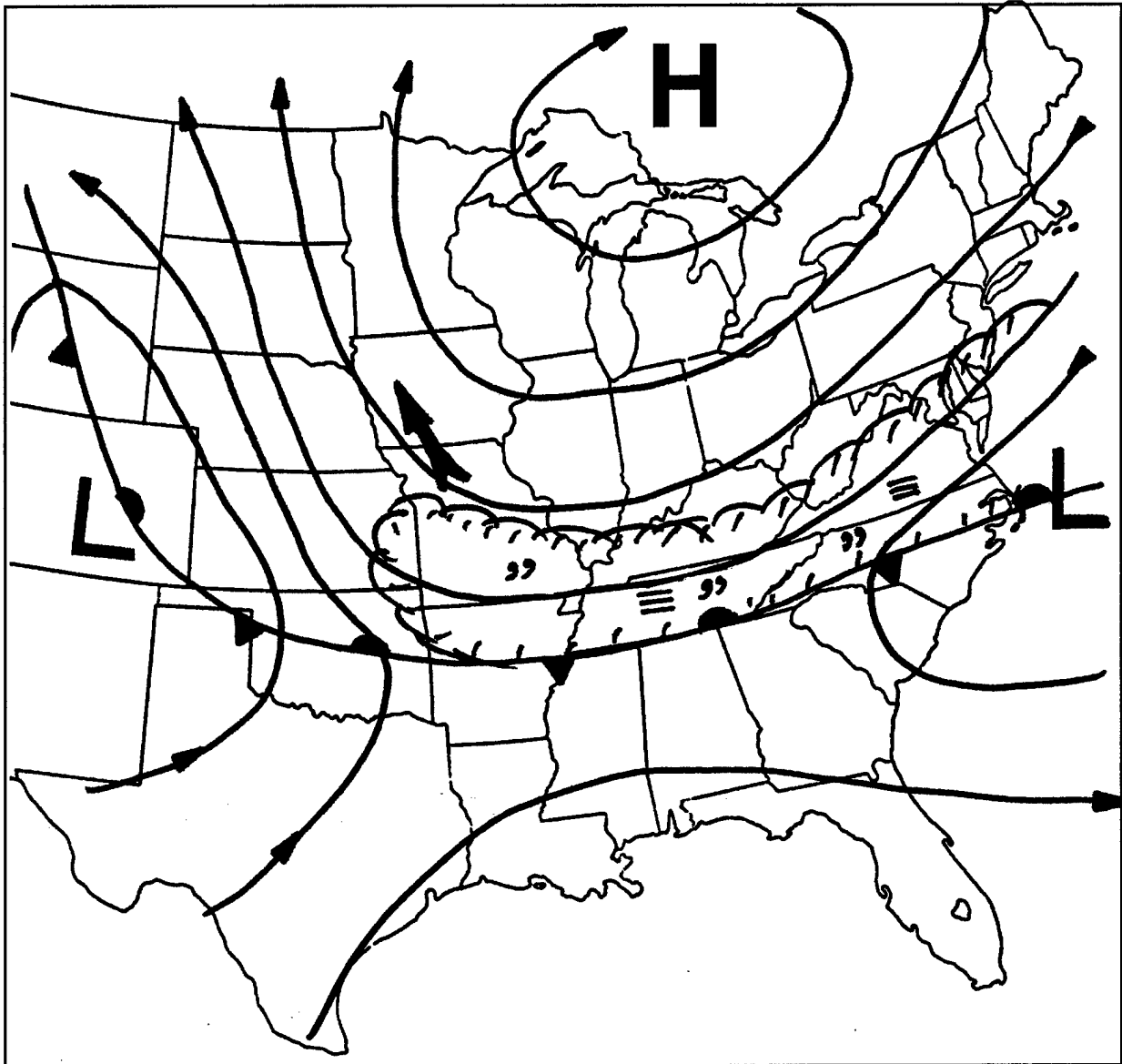


Figure 4-50. Postfrontal Residual Stratus and Drizzle. The arrow indicates northward stratus advection in the return southerly flow.

Chapter 4

Figures 4-51 through 4-60 depict a widespread residual moisture advection event which occurred over the Ohio Valley/Great Lakes area.

The 500-mb analysis (Figure 4-51) shows a short wave moving across the southeastern CONUS. PVA stretches from Alabama to Ohio and Pennsylvania.

The surface analysis (Figure 4-52) shows several frontal lows over the southeastern CONUS. The frontal system becomes ill-defined over the central plains due to a weak ridge. Another short wave is approaching the Rockies; an associated surface low is noted over Wyoming.

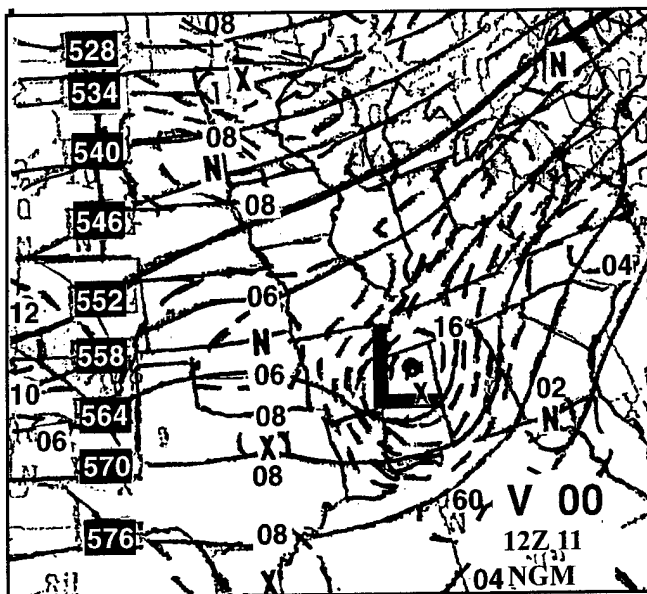


Figure 4-51. The 500-Mb Heights/Vorticity Chart. Figure shows a short wave moving across the southeastern CONUS. Chart valid at 1200Z on 11 February 1994.

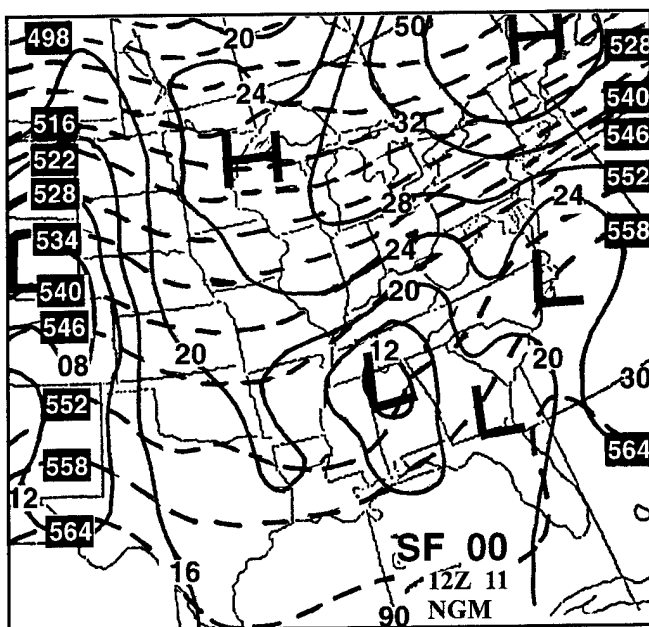


Figure 4-52. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The figures shows several frontal lows. Chart valid at 1200Z on 11 February 1994.

An extensive cloud and precipitation area over the eastern CONUS is shown in Figure 4-53. Indiana, Illinois, Missouri, and most of Iowa are cloud-free within the ridge; this entire area will be under low ceilings, fog, and freezing drizzle within 24 hours.

the 558 and 552 thickness ribbon with snow falling within the 552 and 546 thickness ribbon over Virginia and the Carolinas. This area lies within a surface ridge (Figure 4-52), and cold air advection is occurring, which is probably an undercutting event. The rest of the freezing precipitation over the Ohio and Tennessee Valleys lies between the 552/540 thickness as shown in Figure 4-54.

Figure 4-54 shows the snow and freezing precipitation associated with the southeastern storm system. Note that freezing rain is occurring within

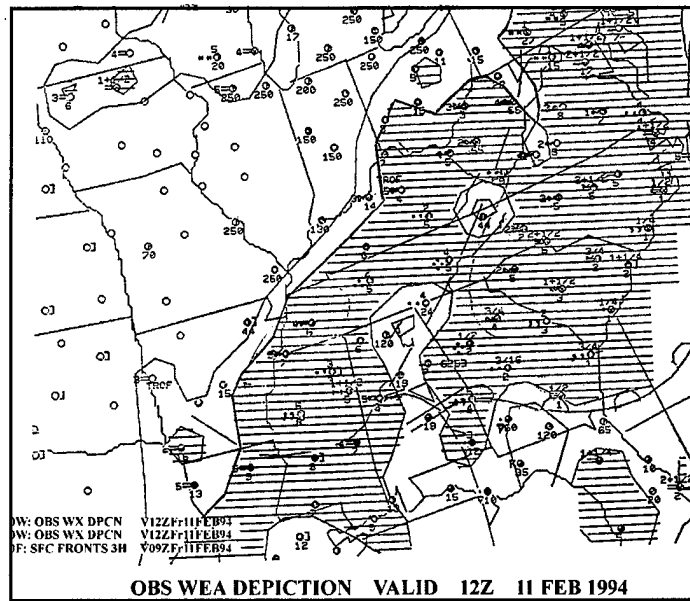


Figure 4-53. Cloud and Precipitation Pattern. The figure depicts widespread clouds and precipitation over the eastern CONUS.

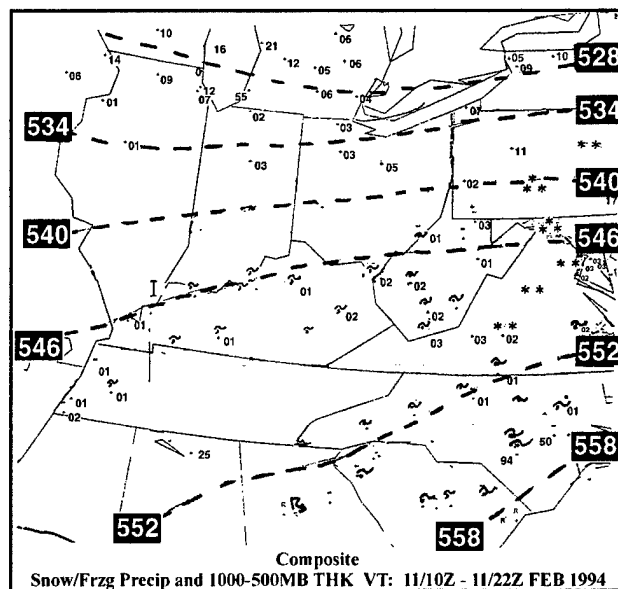


Figure 4-54. Thickness and Freezing/Frozen Precipitation Relationship. The separate freezing rain events are due to different synoptic features.

Chapter 4

The NGM 12-hour, 500-mb and surface forecasts are shown in Figures 4-55 and 4-56. Besides the eastern CONUS short wave, another short wave is approaching the western Great Plains.

The surface forecast (Figure 4-56) shows the two related surface lows. Ridging is shown from the Great Lakes to the Tennessee Valley area.

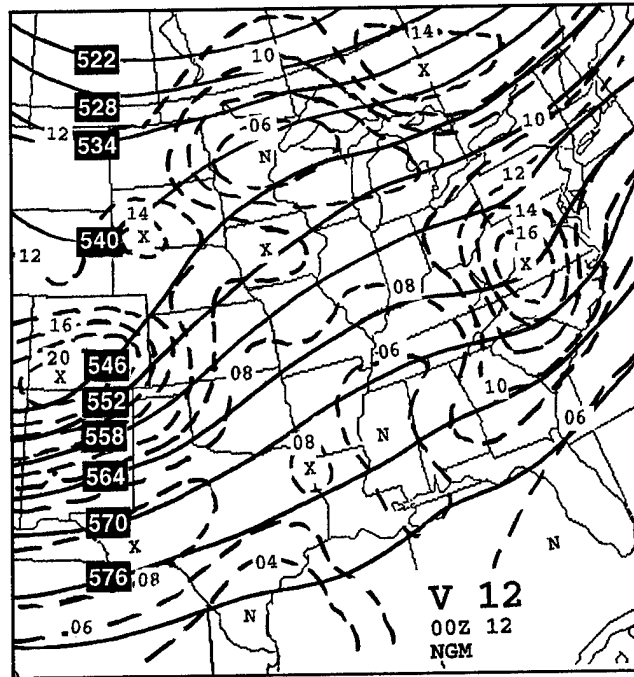


Figure 4-55. The 500-Mb Heights/Vorticity Chart. Two short waves are shown. Chart valid at 0000Z on 12 February 1994.

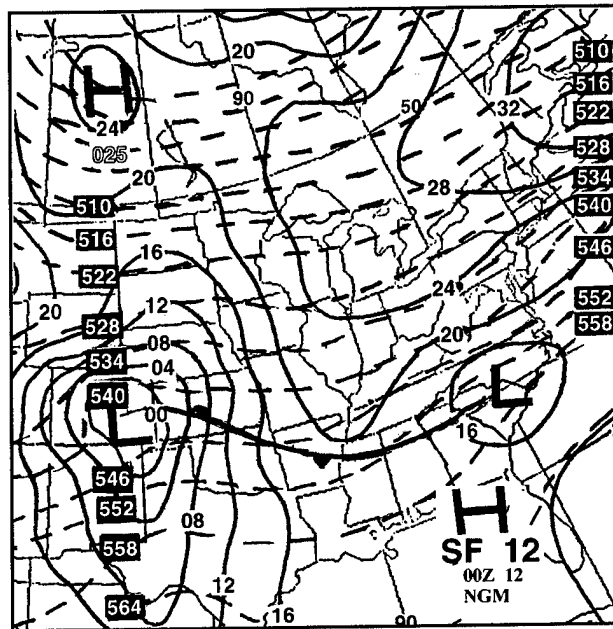


Figure 4-56. Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The figure shows ridging from the Great Lakes to the Tennessee valley. Chart valid at 0000Z on 12 February 1994.

SYNOPTIC PATTERN RECOGNITION

The surface geostrophic wind/vorticity analysis, Figure 4-57 (approximately 8-10 hours before northward advection began), depicts the easterly flow across the Ohio Valley/Great Lakes area hindering any northward stratus advection. The apex of the surface ridge is narrow, therefore, the wind flow will eventually become southeasterly within a few hours as the Georgia low moves offshore. Advection began after 0800Z lowering ceilings below 1,000 feet with fog and freezing drizzle. Selected observations follow:

- IND: 0300Z: 250 -BKN
0907Z: 3 OVC 1ZL-F
- DAY: 0300Z: CLEAR
0744Z: 5 OVC 7ZL-F
- DEC: 0300Z: 160 SCT 7
1050Z: 3 OVC 2ZL-F

- FWA: 0300Z: 300 BKN
1341Z: 3 OVC 1ZL-F
- PIA: 0300Z: 160 SCT
1150Z: 5 OVC 3ZL-F
- LAF: 0300Z: 250 BKN
1142Z: 5 OVC 1/2ZL-F

NOTE: The sky conditions and visibilities at the above locations remained above VFR conditions from 0300Z until the stratus moved in.

The 12-hour, 700-mb prognosis valid at 0000Z, 12 February 1994 (not shown), forecasted 30 percent relative humidity over the area affected by low ceilings and freezing precipitation. This indicates the models have a difficult time forecasting low-level advection events.

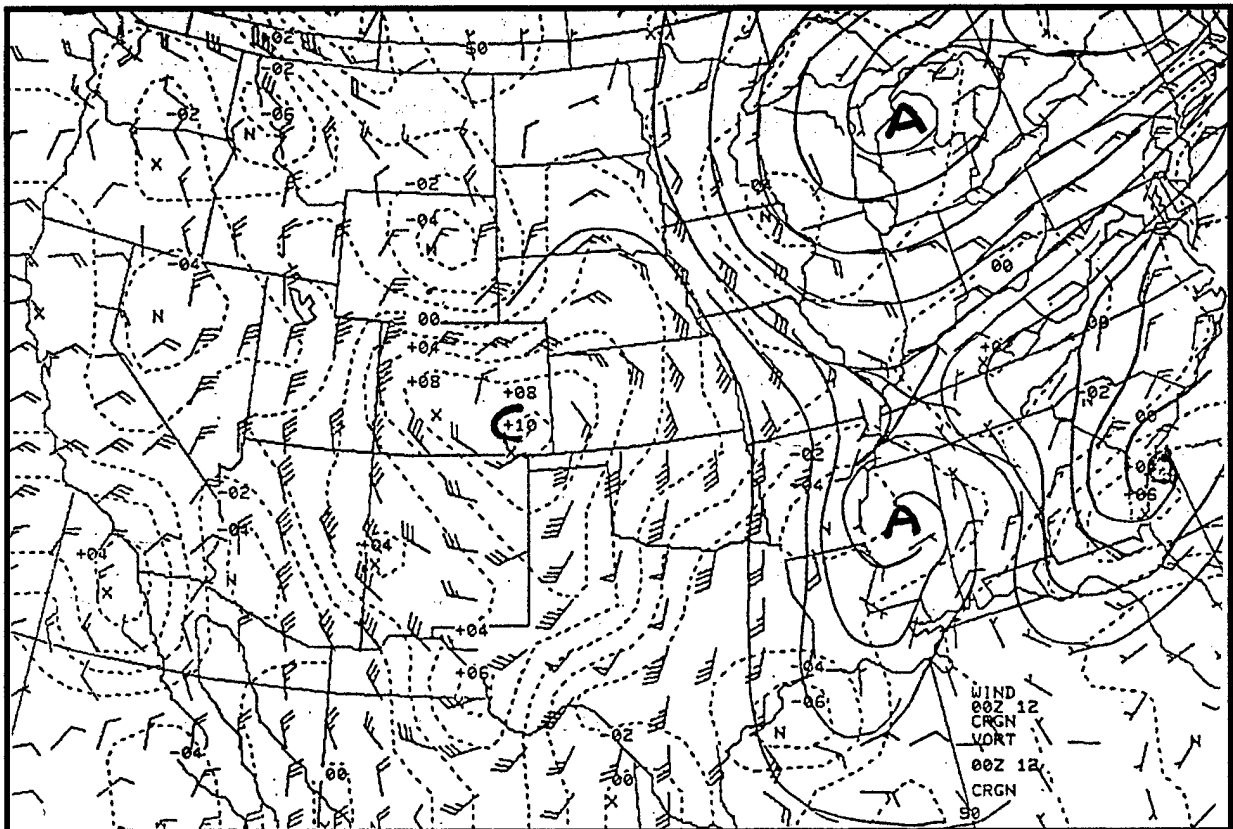


Figure 4-57. Surface Geostrophic Wind/Vorticity. The chart is valid at 0000Z on 12 February 1994. Easterly flow across the Ohio Valley/Great Lakes area is hindering any northward stratus advection.

Chapter 4

Figures 4-58 through 4-60 show the northward progression of warm air stratus advection over the southern Great Lakes area (this area was snow covered). In Figures 4-58 and 4-59, notice that

nearly all of the freezing drizzle is below the 1,000- to 500-mb 540 thickness (see previous discussions relating to warm air freezing drizzle in Figure 3-21 and Figures 3-25).

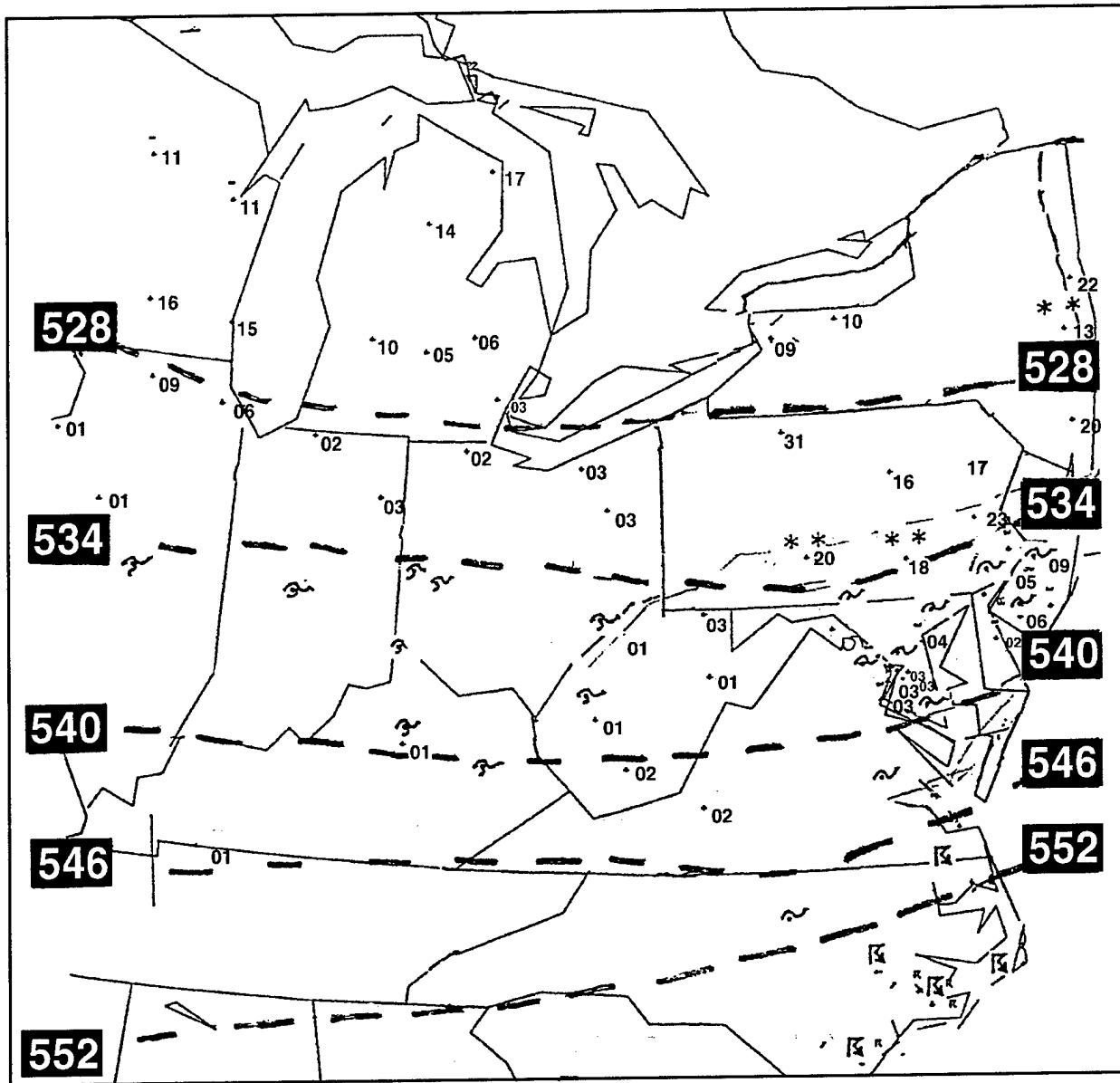


Figure 4-58. Composite Snow/Freezing Precipitation and 1,000- to 500-Mb Thickness. The chart is valid from 2200Z on 11 February 1994 to 1000Z on 12 February 1994. Nearly all the freezing drizzle is on the cold side of the 1,000- to 500-mb 540 thickness isopleth.

SYNOPTIC PATTERN RECOGNITION

In Figures 4-59 and 4-60, moderate to heavy snowfall is occurring over the northern Great Plains and is associated with the Great Plains short wave.

In Figure 4-60, freezing drizzle has advected into southern Michigan.

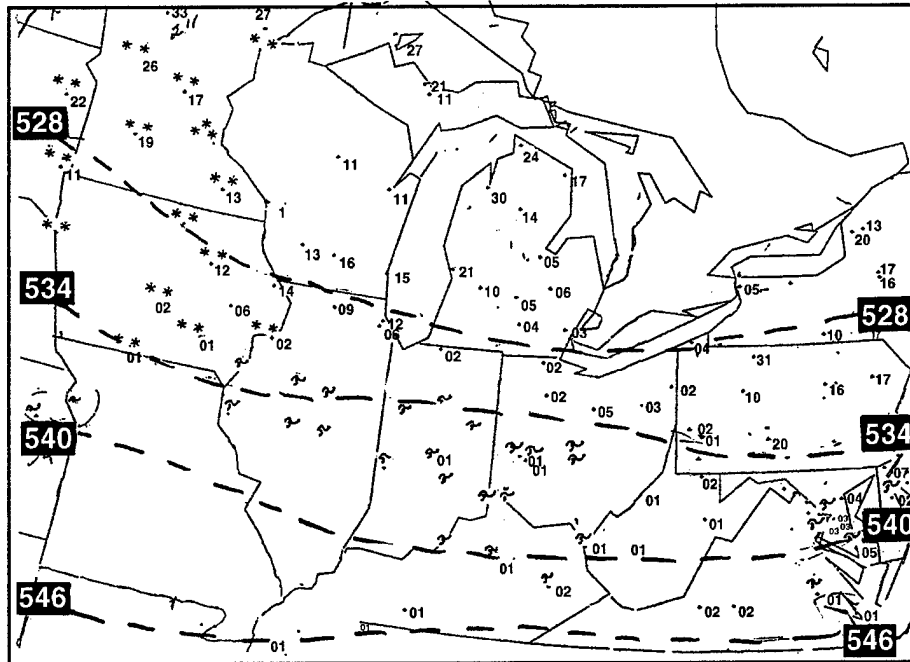


Figure 4-59. Composite Snow/Freezing Precipitation and 1,000- to 500-Mb Thickness Relationship. The chart is valid from 0400Z on 12 February 1994 to 1600Z on 12 February 1994.

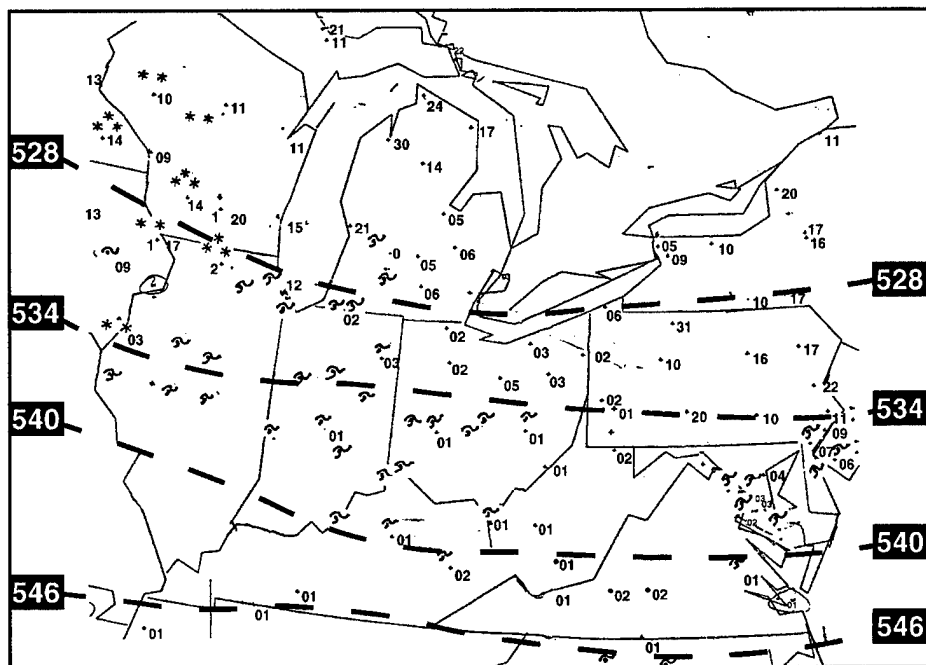


Figure 4-60. Composite Snow/Freezing Precipitation and 1,000- to 500-Mb Thickness Relationship. The chart is valid from 1000Z on 12 February 1994 to 2200Z on 12 February 1994.

Chapter 4

Great Basin High.

During the cold season, a major Rocky Mountain feature is the continued intensification of anticyclonic activity over the Great Basin area. The Great Basin high begins to appear in September and reaches a maximum frequency of occurrence in December. This mountain-confined high is caused by cold air which has been trapped by the mountains (Rockies on the east and Sierras on the west). Sea-

level pressures rise as the cold air strengthens, which results in anticyclogenesis. Typical development occurs when a ridge, following a Pacific mP front, is pinched off the North Pacific high system along the West Coast (mP air). Persistent stratus, fog, and drizzle continues to be a problem over many valley and river areas due to minimal solar insolation and a day-to-day strengthening of low-level inversions (Figure 4-61).

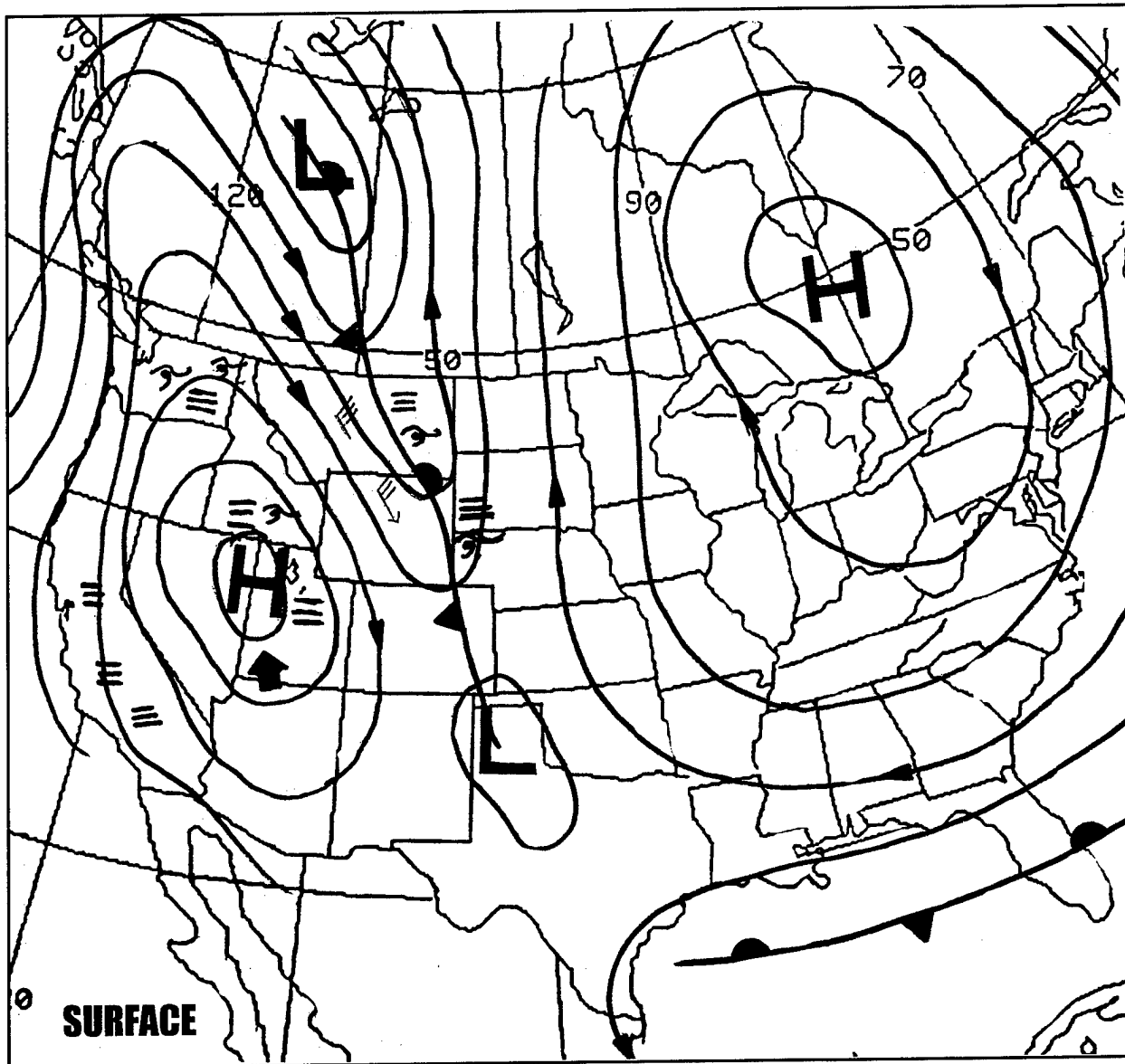


Figure 4-61. Great Basin High. The figure shows the development of a Great Basin high and the persistent stratus, fog, and drizzle that occurs due to minimum solar insolation and a day-to-day strengthening of low-level inversions.

SYNOPTIC PATTERN RECOGNITION

A second pattern occurs when ridging from western Canada drops southward across the Pacific Northwest and settles over the Great Basin area (cP air; see Figure 4-69). It is important to recognize the source region of the Great Basin high to determine the strength and persistence of low-level inversions (stratus, fog and freezing drizzle).

Although named the Great Basin high because of its frequent appearance in that area (Figure 4-61), the high system's center may wander across the western CONUS. The system may move eastward, but it never moves out of the mountains into the western Great Plains as an entity. *NOTE: Transitory postfrontal highs will develop over the Great Plains as ridging increases behind the cold front.* Great Basin highs are strongest and most persistent when supported by a ridge aloft over the western CONUS. Conversely, these highs gradually weaken or

dissipate over the mountains as increased low-level warming ahead of an approaching disturbance weakens the anticyclone (Figure 4-62). The high will reappear after the front moves into the Great Plains.

The Great Basin high is responsible for a variety of winter weather over the western CONUS. Significant events such as persistent fog in the San Joaquin/Sacramento Valley areas; low ceilings, fog, and freezing drizzle over the Columbia Basin and the Snake River valley area; and strong downslope winds east of the Montana and Wyoming Rockies all frequently occur. The stationary front shown in Figure 4-61 separates warm, westerly, usually dry, downslope flow (west side) from a colder, easterly, moist, upslope, low-level flow (east side; transitory cP highs).

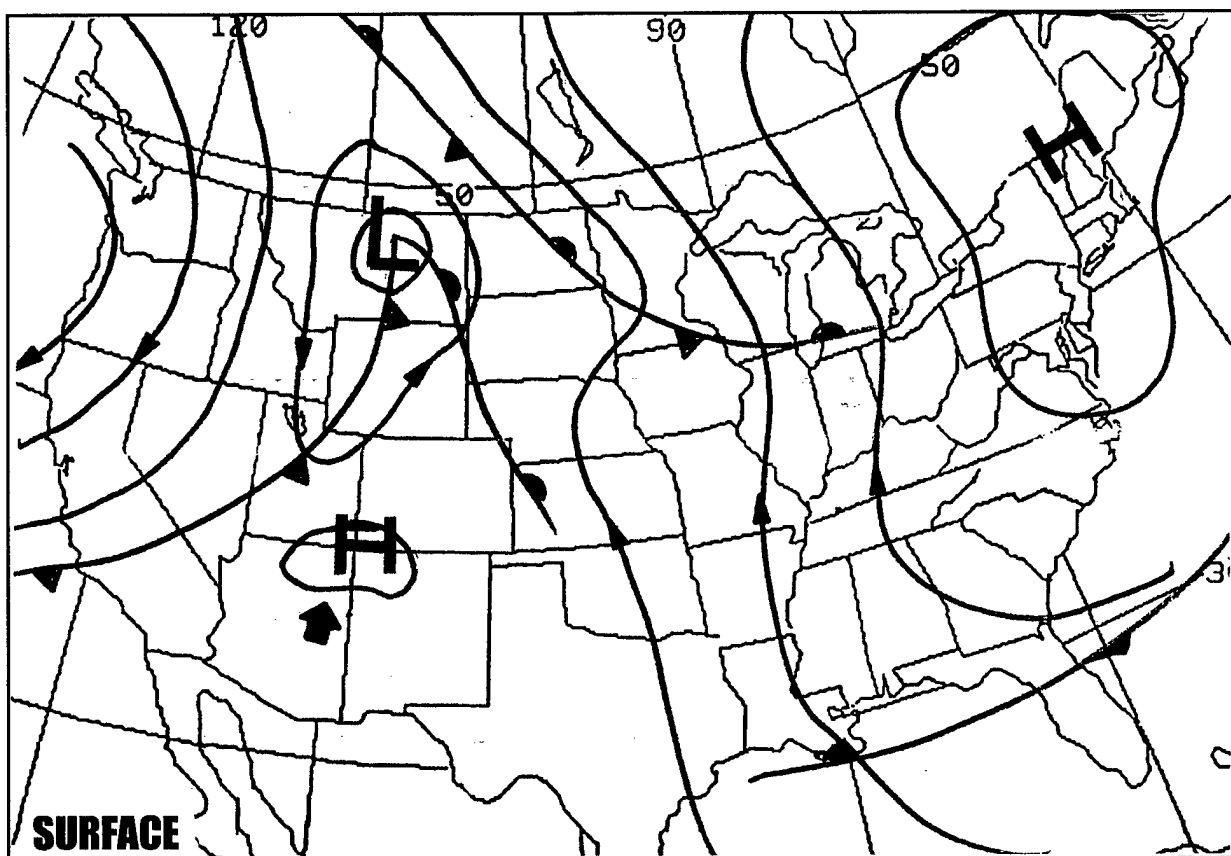


Figure 4-62. Weakening Great Basin High. The figure shows the weakening of the Great Basin high due to increased low-level warming ahead of an approaching disturbance.

Chapter 4

Pacific Northwest.

Example 1. The Great Basin high frequently plays an important role in the winter weather across the Pacific Northwest. The Columbia Basin area east of the Washington Cascades may experience continuous days of low ceilings, fog, and drizzle when a ridge, extending northwestward from the Great Basin high, lies across the basin (Figure 4-63). The ridge becomes more pronounced when supported by an upper-level ridge such as shown in

Figure 4-64. Warmer maritime Pacific air, borne on southwesterly winds, spreads over the basin ridge creating a strong inversion. When the source region is continental Polar air from western Canada then the inversion becomes very strong and will persist for days until there is an air mass change. Freezing drizzle is a common occurrence and generally is diurnal. Freezing rain associated with an offshore disturbance will persist until the system moves into western Canada as shown in Figure 4-64.

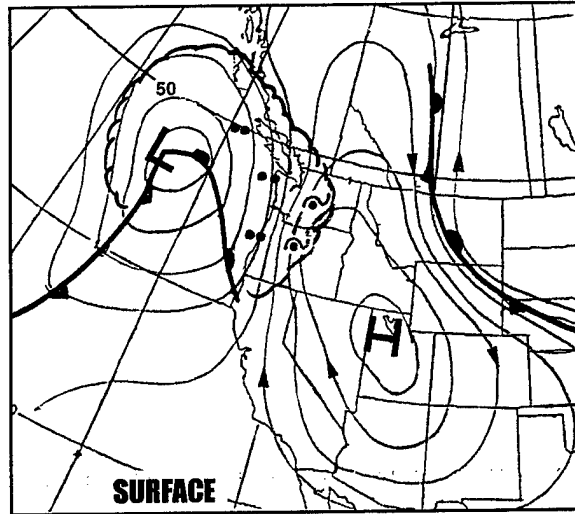


Figure 4-63. Great Basin High and Pacific Northwest Weather. The figure shows the low ceilings, fog, and drizzle when a ridge extends northwestward from the Great Basin high.

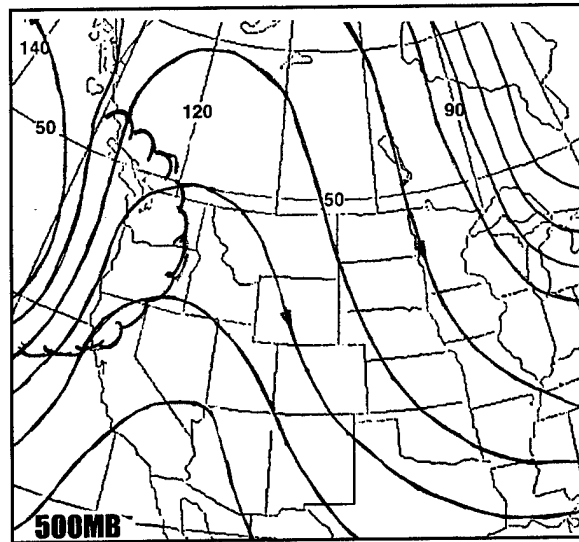


Figure 4-64. Upper-Level Ridge Impact on the Great Basin High. The Great Basin high becomes stronger when supported by an upper-level ridge.

SYNOPTIC PATTERN RECOGNITION

Example 2. In Figure 4-65, the Great Basin high appears over northern Nevada and Utah. A weak surface ridge extends northward over eastern Washington and Oregon and western Montana. Columbia Basin temperatures are below 0°C within this weak ridge. The coastal area remains much warmer within a strong southwest flow. No distinct frontal systems such as depicted in Figure 4-63 is distinguishable. However, the mid- and upper-level flow should be watched closely for short waves

moving towards the coast through a moist, westerly flow (Figures 4-65 and 4-66). At the 500-mb level (Figure 4-66), a positively-tilted PVA lobe extending southeastward from the cold core Aleutian low has brought moisture (700 mb; Figure 4-67), relatively warmer air, and vertical lift across most of Washington. Freezing rain was reported at all interior locations as shown in Figure 4-68. The freezing rain area occurred at or slightly below the 5,400-meter 1,000- to 500-mb thickness.

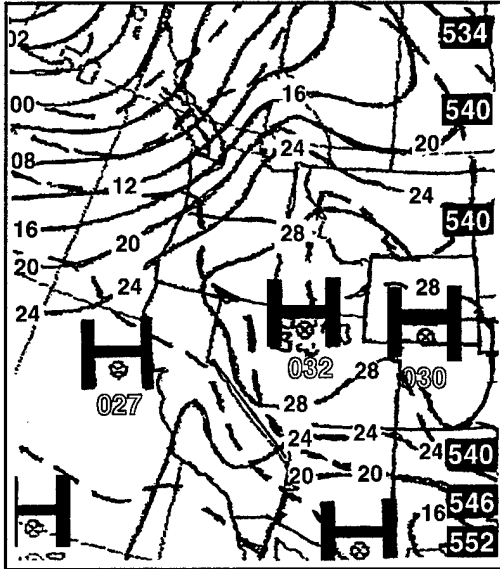


Figure 4-65. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Chart valid at 1200Z on 4 March 1993.

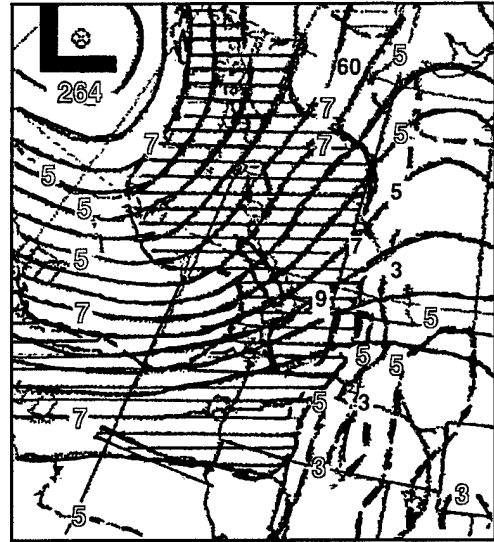


Figure 4-67. The 700-Mb Heights/Relative Humidity Chart. Moisture moves into the Northwest. Chart valid at 1200Z on 4 March 1993.

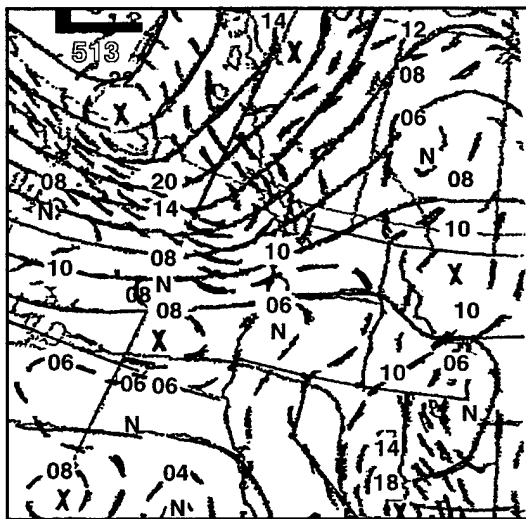


Figure 4-66. The 500-Mb Heights/Vorticity Chart. A PVA lobe is entering the Northwest. Chart valid at 1200Z on 4 March 1993.

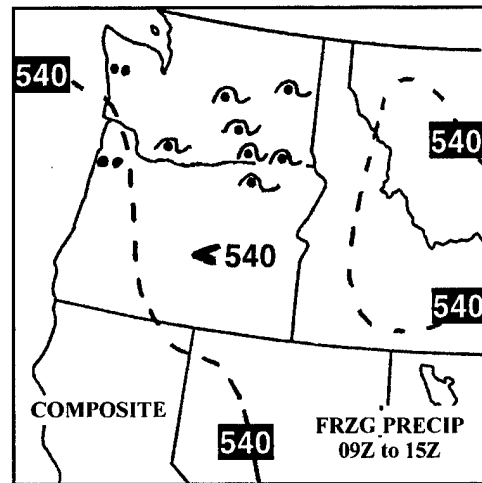


Figure 4-68. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation. Freezing precipitation occurs at or below the 5,400-meter thickness isopleth.

Chapter 4

Example 3. Occasionally, strong outbreaks of continental Polar air will spread southwestward and westward to the Oregon and Washington coastal areas. This uncommon event may bring significant precipitation over the Pacific Northwest. Heavy snowfall in the Columbia Basin and ice storms over western Washington and Oregon develop as Pacific

moisture interacts with cP air along and north of a cP frontal boundary (Figure 4-69).

A long-wave trough is located over the central CONUS. Short waves either drop southeastward from western Canada or move in from the west enhancing precipitation (Figure 4-70).

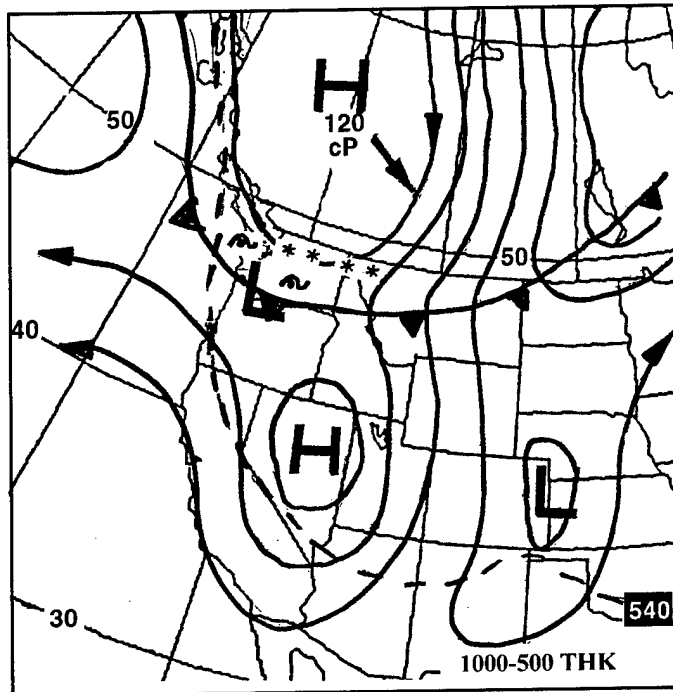


Figure 4-69. Pacific Moisture Advection. Freezing precipitation develops as moisture interacts with the cP air mass.

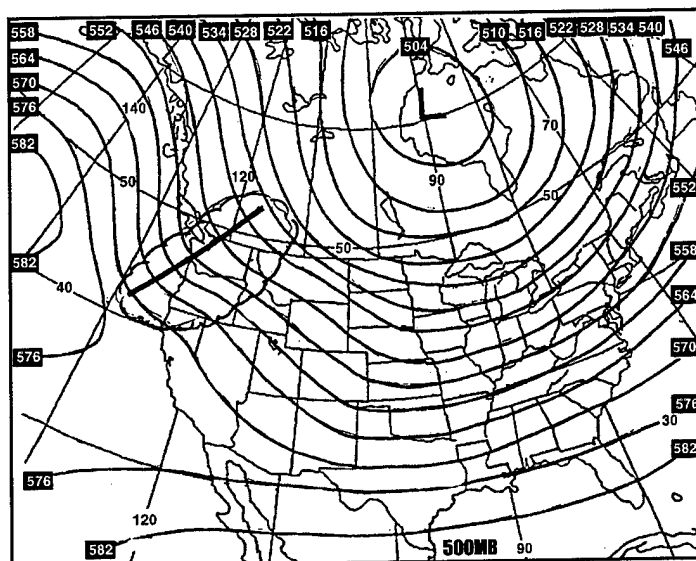


Figure 4-70. Short-Wave Trough. A short-wave trough within the long-wave trough drops southward from Canada.

Example 4. A significant ice storm and heavy interior snowfall event occurred in late December 1996 over a large area of the Pacific Northwest. The 500-mb analysis (Figure 4-71) shows the pattern a few hours before the freezing rain began. A long-

wave trough lies across the central CONUS with a series of short waves traveling through the long wave (noted by the arrows). The short wave upstream from Washington will be the culprit for the freezing precipitation event later in the evening.

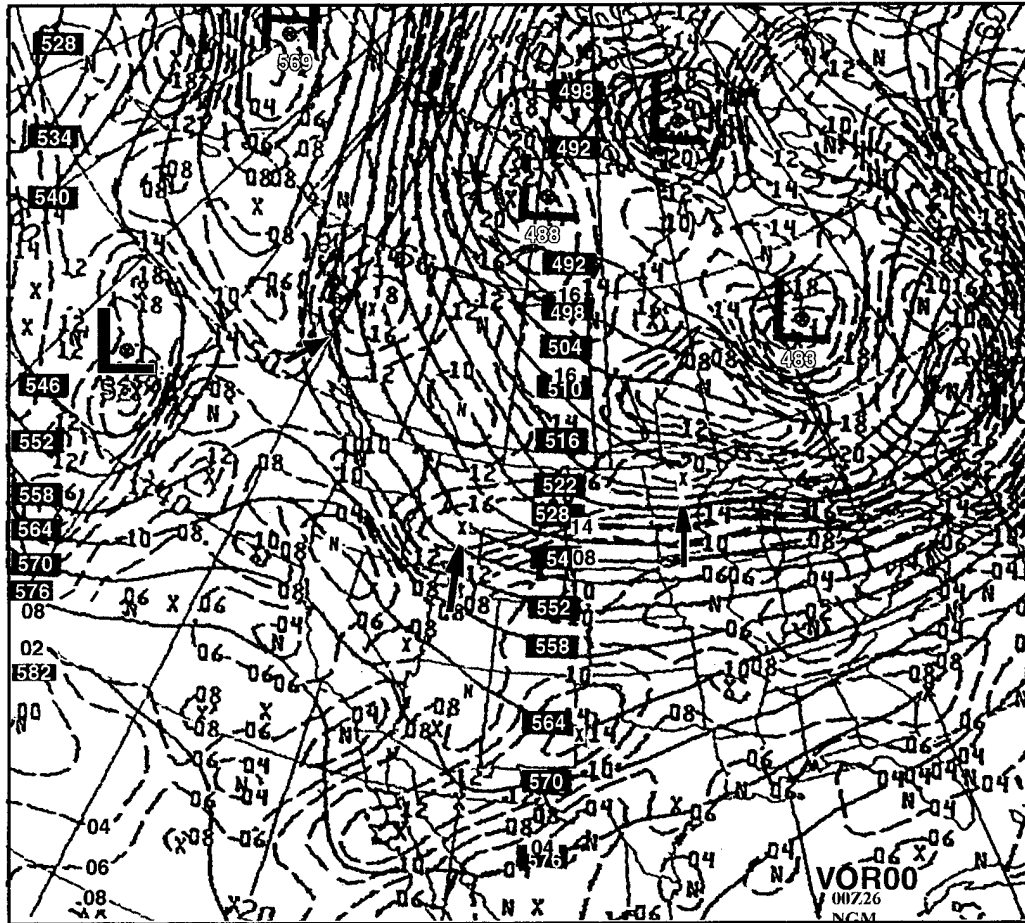


Figure 4-71. Forecast (00HR) 500-Mb Heights/Vorticity. A long-wave trough lies across the central CONUS with a series of short waves traveling through the long wave (noted by the arrows). Chart valid at 0000Z on 26 December 1996.

Chapter 4

The 850-mb analysis (Figure 4-72) depicts strong temperature packing over Washington behind the cP front that is located over Oregon to a low in Wyoming. The surface analysis (Figure 4-73) shows

a strong cP ridge from Alaska across western Canada into the northern Rockies. The surface front lies from central Oregon to Colorado.

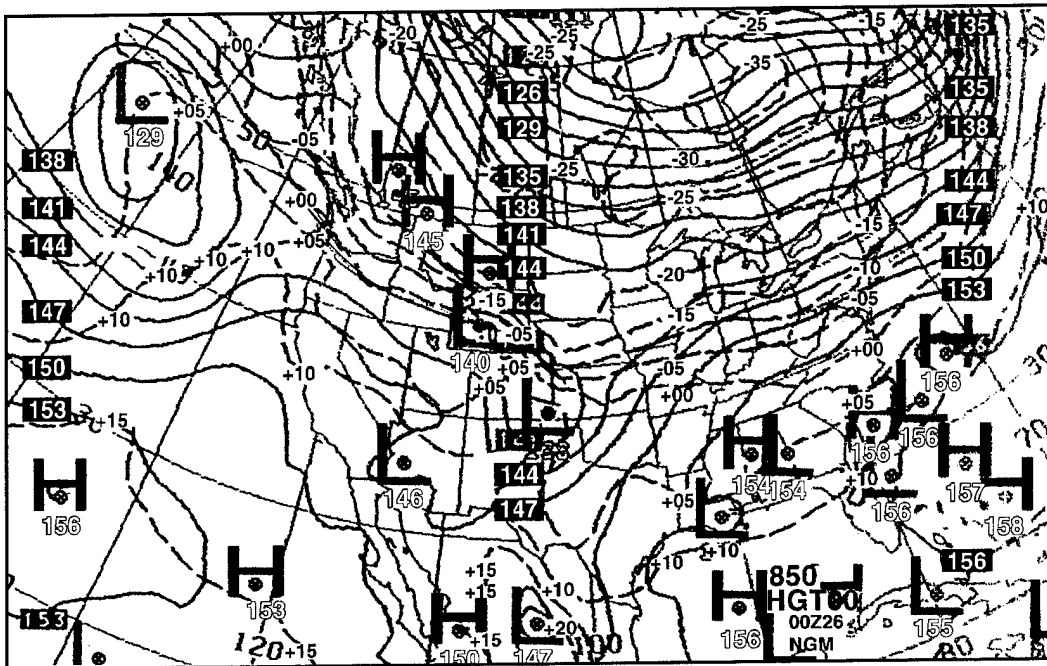


Figure 4-72. Forecast (00HR) 850-Mb Heights/Temperatures. Figure shows strong temperature packing over Washington. Chart valid at 0000Z on 26 December 1996.

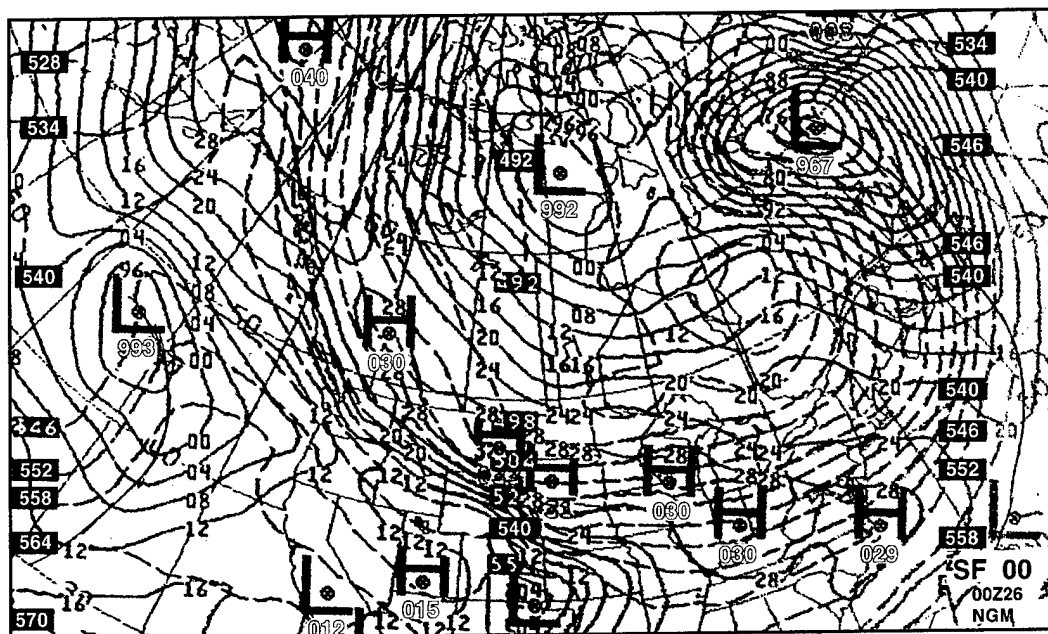


Figure 4-73. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. A strong ridge extends from Alaska to the Rocky Mountains. Chart valid at 0000Z on 26 December 1996.

Figures 4-74 through 4-77 show the pattern 12 hours later. In the 500-mb analysis (Figure 4-74), the western Canada short wave continues southeastward. Little PVA is noted over the Washington freezing rain area. The 700-mb analysis

(Figure 4-75) shows a strong fetch of Pacific moisture over most of the Pacific Northwest. In this event, warm, moist Pacific air overran the shallow cP air mass to produce an extensive area of precipitation.

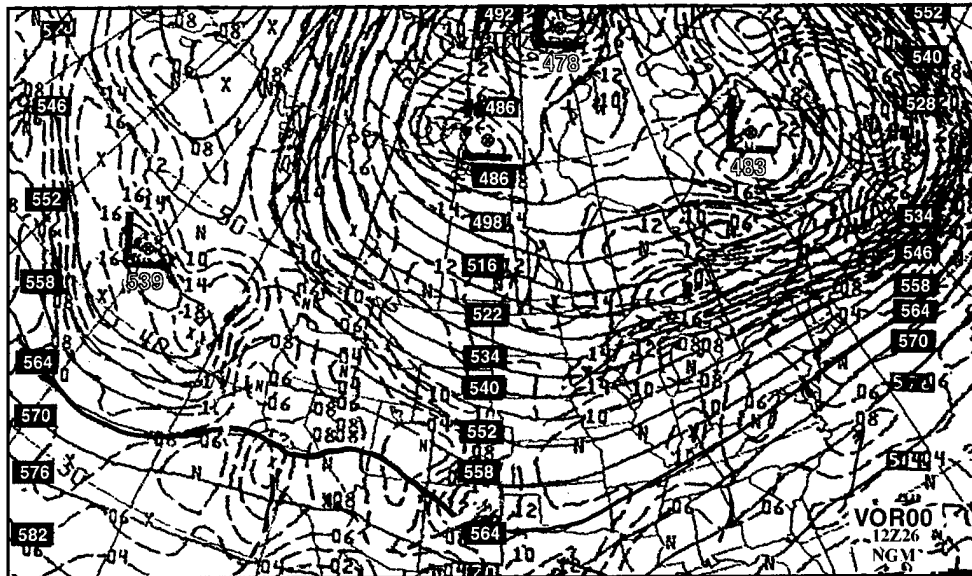


Figure 4-74. Forecast (00HR) 500-Mb Heights/Vorticity. A long-wave trough lies across the central CONUS with a series of short waves traveling through the long wave (noted by the arrows). Chart valid at 0000Z on 26 December 1996.

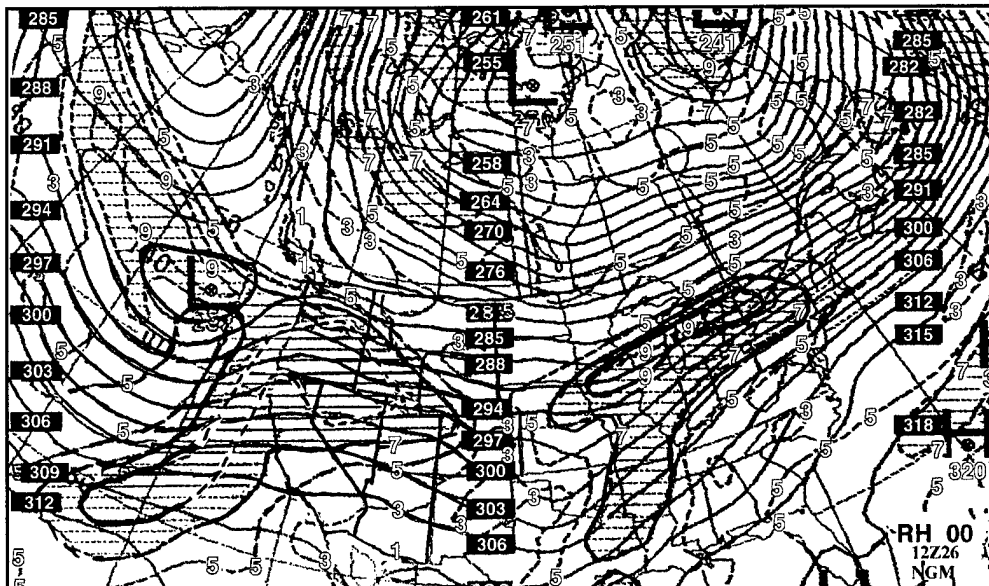


Figure 4-75. Forecast (00HR) 700-Mb Heights/Relative Humidity. The figure shows a strong fetch of Pacific moisture over most of the Pacific Northwest. Chart valid at 1200Z on 26 December 1996.

Chapter 4

The 850-mb analysis (Figure 4-76) still shows the strong thermal packing over Washington and northern Oregon. The 850-mb cP front has shifted southward.

The surface front is evident across Oregon to Colorado as shown in Figure 4-77. Abundant Pacific moisture continues to overrun the shallow cP air mass.

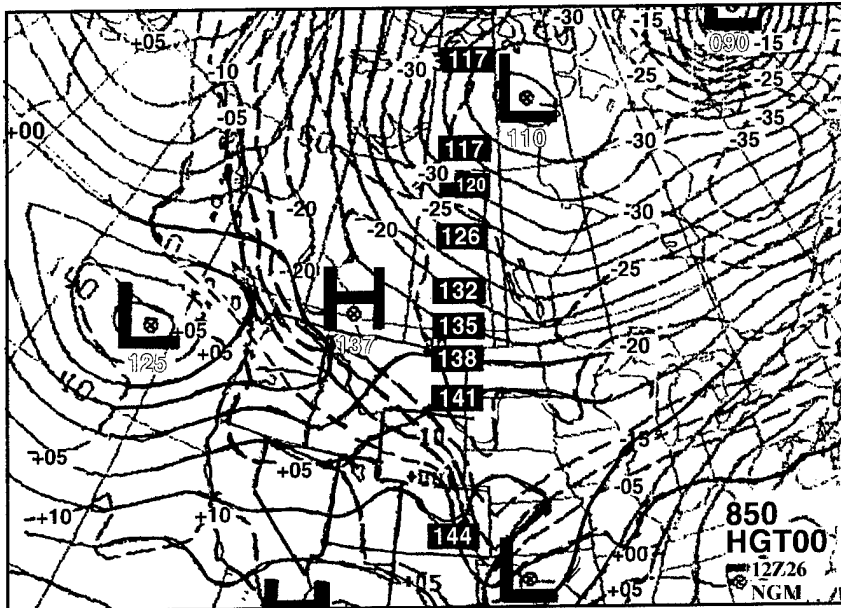


Figure 4-76. The 850-Mb Heights/Temperature Chart. Thermal packing is occurring over the Northwest. Chart valid at 1200Z at 26 December 1996.

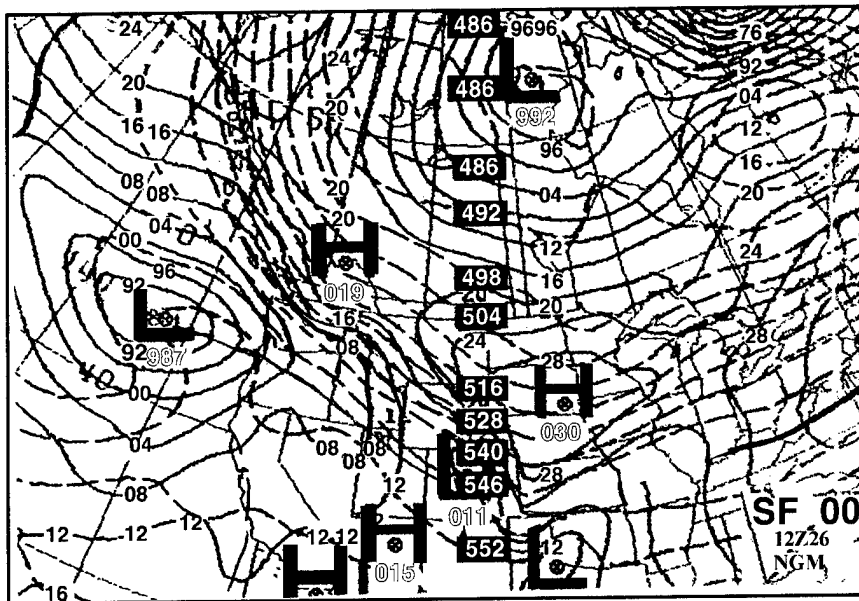


Figure 4-77. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. A frontal boundary stretches between Oregon and Colorado. Chart valid at 1200Z on 26 December 1996.

Figure 4-78 depicts the freezing rain and snow areas. The freezing rain event ended by late afternoon on

December 27, 1966, as the cP front moved northward into northern Washington.

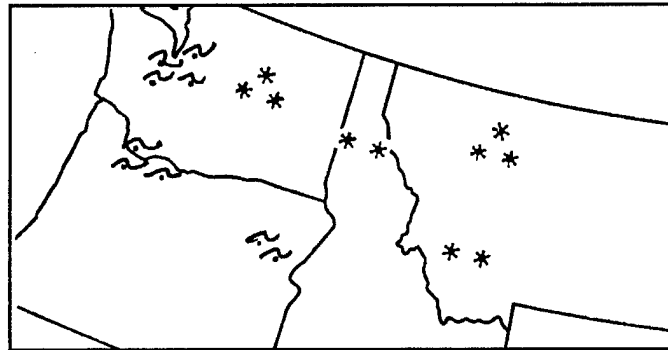


Figure 4-78. Freezing Rain and Snow Areas. Figure shows the track of freezing precipitation versus snow.

Example 5. On December 29, 1966, a second freezing rain episode occurred. Figure 4-79 shows the pattern had not changed much from the previous pattern. Very cold Polar air remained in place in Canada, northern Washington, and the northern

Rockies. The cP front shifted back to the south, and the pressure gradient strengthened over the entire area (Figure 4-79). This tightened pressure gradient undoubtedly increased overrunning of Pacific moisture over the shallow air mass.

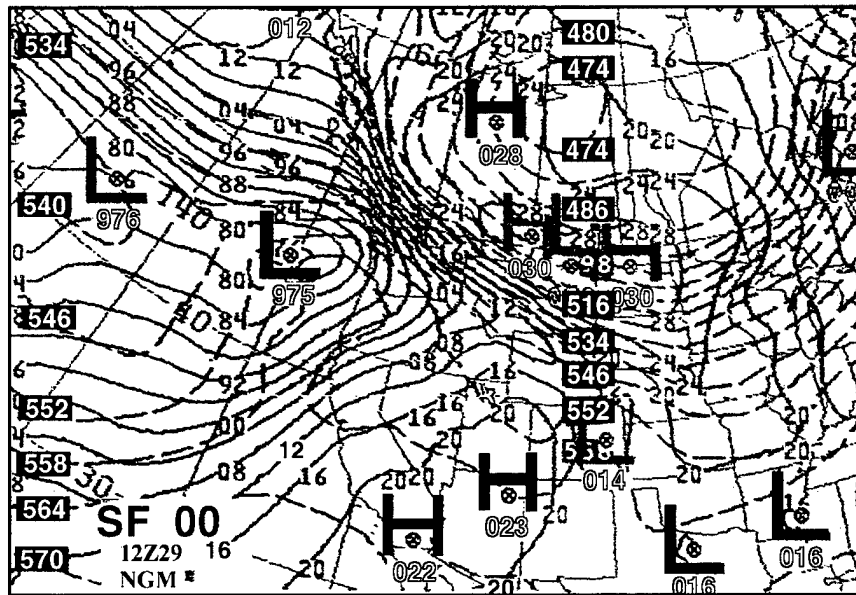


Figure 4-79. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. Chart valid at 1200Z on 29 October 1991.

Chapter 4

The 700-mb analysis (Figure 4-80) shows 70 to 90 percent relative humidity over the entire Pacific Northwest. Again, as in the previous example, little

PVA was associated with this event. Figure 4-81 shows the freezing rain and mountain snows.

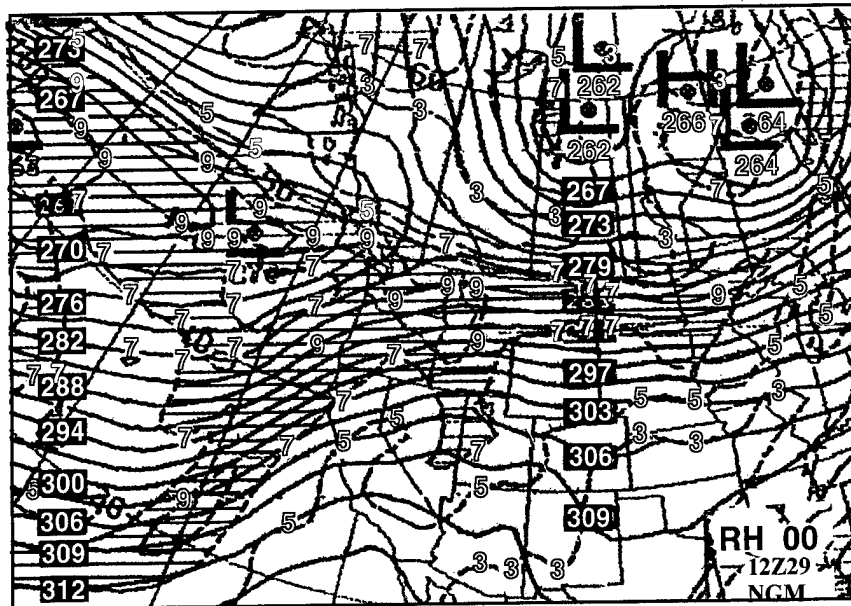


Figure 4-80. Forecast (00HR) 700-Mb Heights/Relative Humidity. Ninety percent relative humidity values are located over the Northwest. Chart valid at 1200Z on 29 December 1996.

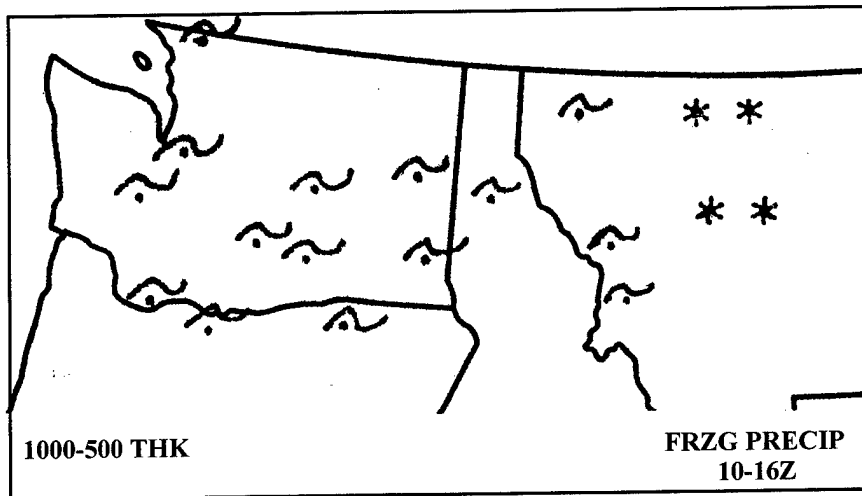


Figure 4-81. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation. Freezing precipitation extends across the Northwest.

Chapter 5

CASE STUDY

General. This case study is presented at this time to show and discuss some of the features and empirical rules within this technical note (page references are noted when appropriate).

This storm system produced a swath of heavy freezing rain from the Texas panhandle northeastward across western Oklahoma, central and eastern Kansas, and eastern Nebraska to northern Wisconsin. The freezing rain began during the afternoon on 30 October 1991 and spread

northeastward throughout the day on 31 October 1991. Kids were disappointed on Halloween night across eastern Kansas and Nebraska; it was impossible to walk on ice accumulations of an inch or more; therefore, "Trick or Treat" was canceled.

System Development. The storm system began over the southwestern CONUS when an upper low developed within the base of a major trough (split-flow in Figure 5-1). The southern polar jet branch supported the developing low-latitude system.

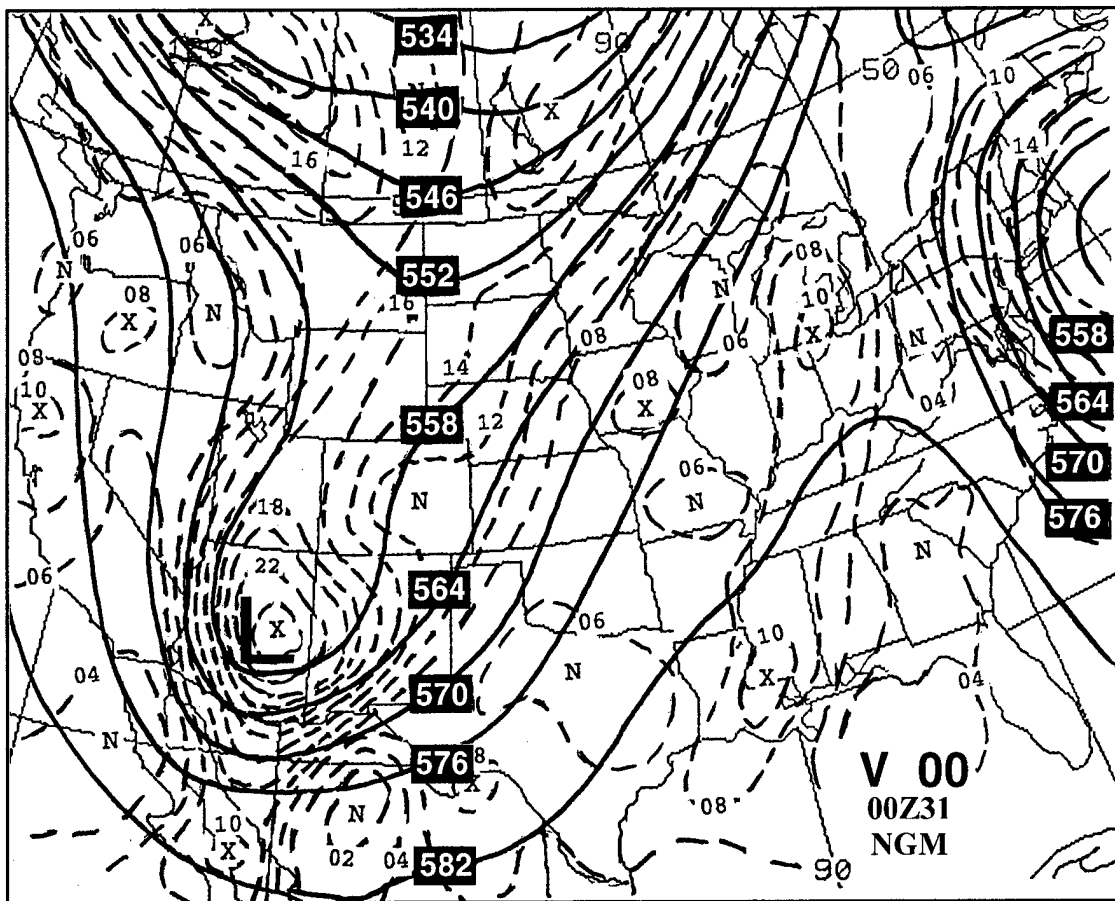


Figure 5-1. The 500-Mb Heights/Vorticity Chart. The system begins with an upper low-pressure system developing in the base of a major trough. Chart valid at 0000Z on 31 October 1991.

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At the surface (Figure 5-2), a high-pressure system dominates the central Great Plains and Great Lakes area (prevailing high). The leading edge of the air mass is shown as a stationary front since little eastward frontal movement occurred; the intense low located off the northeastern CONUS coastal area affected its eastward movement. The isobars behind the front are in phase with the thickness isopleths, which closely resembles the neutral

advection model shown in Figure 3-30 on page 3-26.

In Figure 5-2, the Great Basin high is shown over Idaho. Notice the south to north inverted trough over western New Mexico to western Colorado (noted by the heavy arrow). This trough separates the two anticyclonic systems (Figure 4-41, page 4-24). The surface low over southern Arizona is associated with the developing upper low.

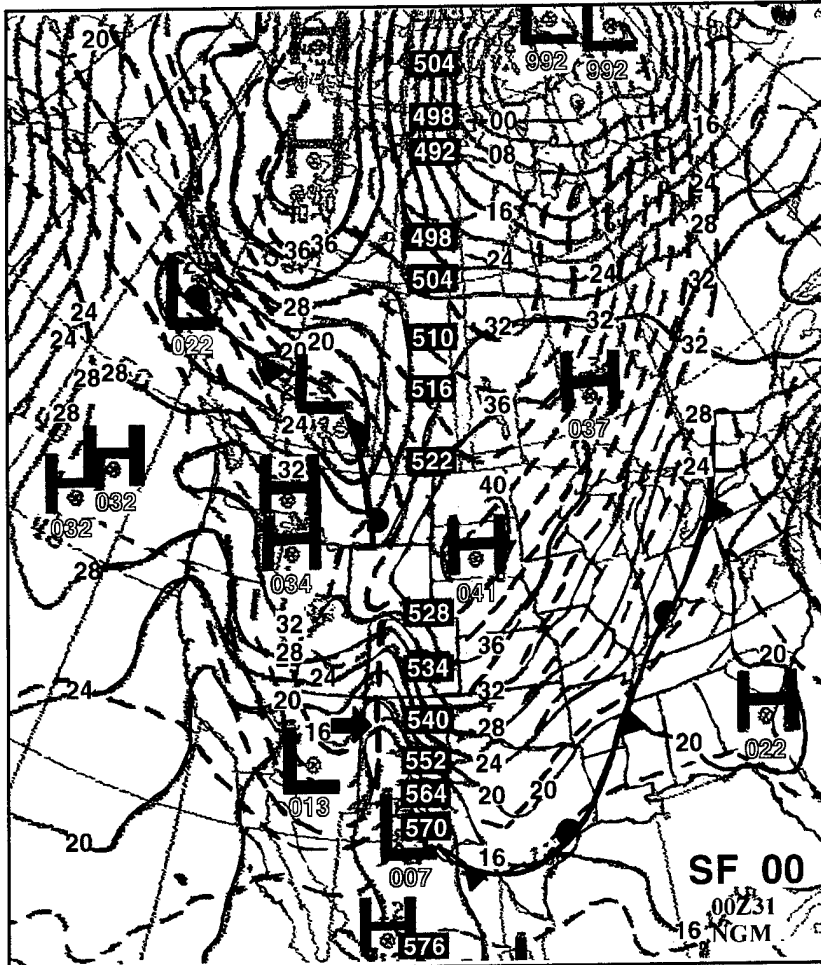


Figure 5-2. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. High pressure dominates the central Great Plains. Chart valid at 1200Z on 31 October 1991.

Figure 5-3 shows freezing rain has either developed over or moved into the Texas panhandle. Significant snow fall is occurring over eastern Colorado.

The 850-mb analysis (Figure 5-4) shows a tight temperature gradient across western Texas,

Oklahoma, and extending northeastward to the Great Lakes region. Based on the 850-mb empirical temperature rules (page 3-3), the freezing rain area over the Texas panhandle should spread northeastward and fall between the +5°C to -5°C temperature ribbon. Forecasters at Tinker, McConnell, and Offutt AFBs fall within the +5°C/-5°C temperature ribbon, and they should be prepared for a freezing rain event. Since the storm system is not moving eastward very fast, the freezing rain should persist rather than change to snow since no cold air advection is occurring (neutral advection, page 3-22).

The 850-mb front lies further north in the cold air. The southern boundary of the freezing rain should lie along the 850-mb front which correlates with the +5°C isotherm (see pages 3-48 through 3-57). Figure 5-5 depicts freezing rain location in relation to the 850-mb temperatures.

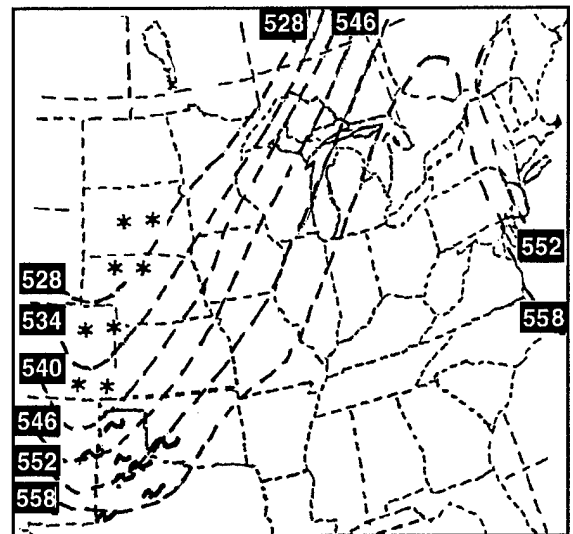


Figure 5-3. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation. Freezing rain develops between the 546 and 558 thickness isopleths. Chart valid at 0000Z on 31 October 1991.

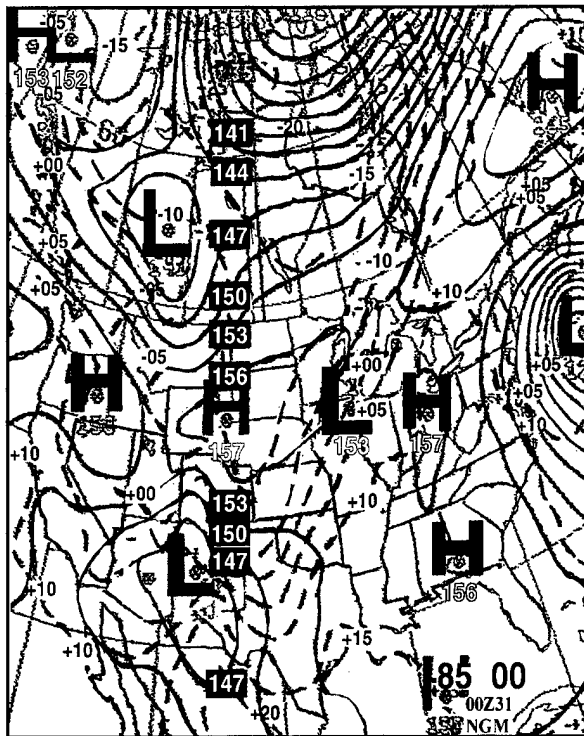


Figure 5-4. The 850-Mb Heights/Temperature Chart. A tight temperature gradient occurs across the Great Plains. Chart valid at 0000Z on 31 October 1991.

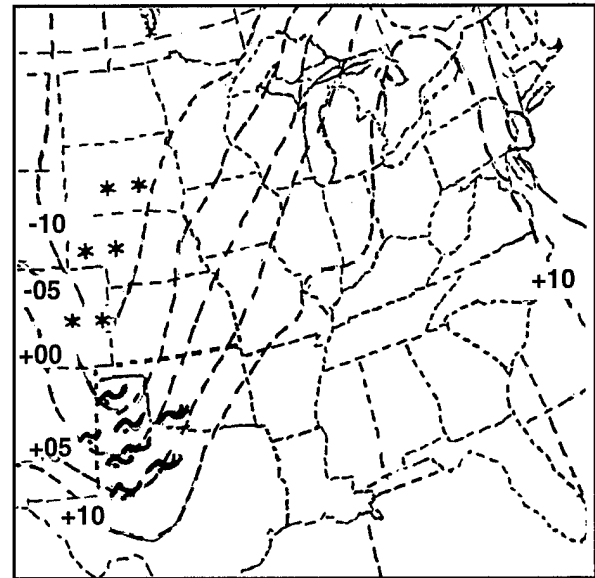


Figure 5-5. Temperature/Freezing Rain Relationship. Freezing rain develops between the 850-mb +5°C and -5°C isotherms. Chart valid at 0000Z on 31 October 1991.

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Figures 5-6 through 5-9 illustrate the developing storm system and its associated precipitation 12 hours later. At the 500-mb level (Figure 5-6), a closed low within the split-flow pattern appears over central New Mexico and is following the favorable track for a major storm system.

percent relative humidity over the western Great Plains.

NOTE: The storm system shown in this case study follows the empirical rules presented and discussed in 3WW TN 79-2 entitled "Major Midwest Snowstorms."

The 700-mb analysis (Figure 5-7) shows 70 to 90

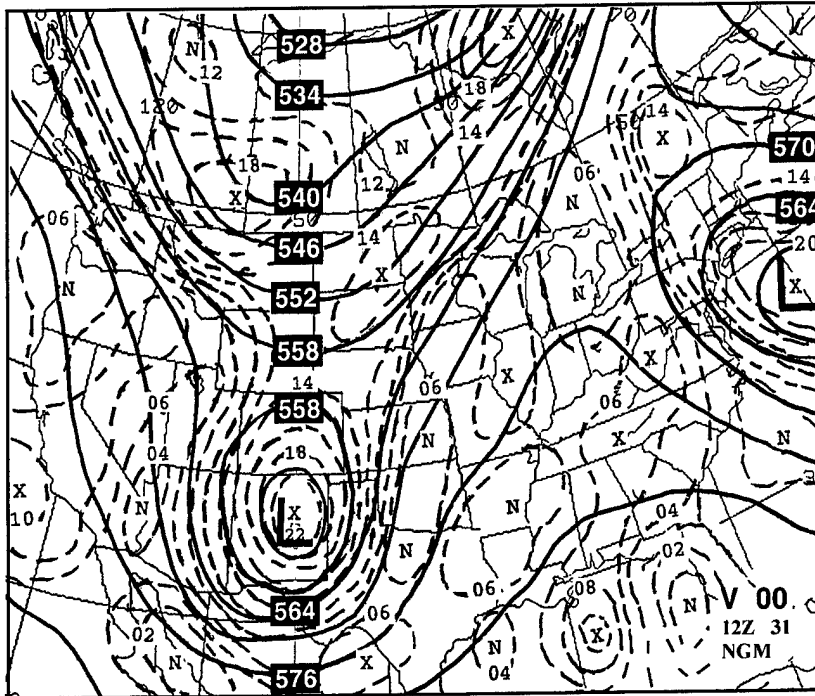


Figure 5-6. The 500-Mb Heights/Vorticity Chart. The figure shows a closed low-pressure system developing over New Mexico. Chart valid at 1200Z on 31 October 1991.

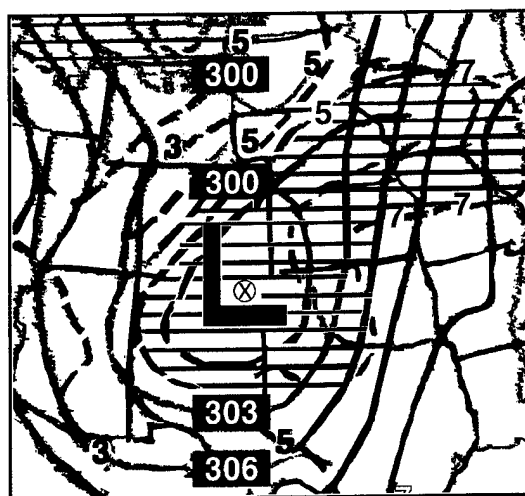


Figure 5-7. The 700-Mb Heights/Relative Humidity Charts. The figure shows moisture associated with the low-pressure system. Chart valid at 1200Z on 31 October 1991.

The surface analysis (Figure 5-8) shows little eastward frontal movement except over the Ohio Valley. The front is beginning to show waving over the lower Mississippi Valley. An inverted trough has developed north of the front (see heavy arrow); the thickness and isobar pattern shows northward bulging, which indicates warm air advection ahead of the approaching storm. Surface cyclogenesis often occurs within the inverted trough; the 850-mb analysis (Figure 5-10) already shows a developing low over Oklahoma.

The weak surface low noted over southern Colorado

by the long arrow (Figure 5-8), is associated with the 500-mb low over New Mexico (Figure 5-6). The Arizona low is most likely a thermal low with no upper support. It was discussed earlier (page 4-7; Figures 4-12a/4-12b) that the related surface low west of the Rocky Mountains will dissipate while a new low develops on the front over the Great Plains. This action is occurring with this system. The Great Basin high is shown over its favorite location over Nevada and Utah. A surge of cP air is advancing towards Montana and Idaho and eventually will provide cold air for the developing Great Plains storm.

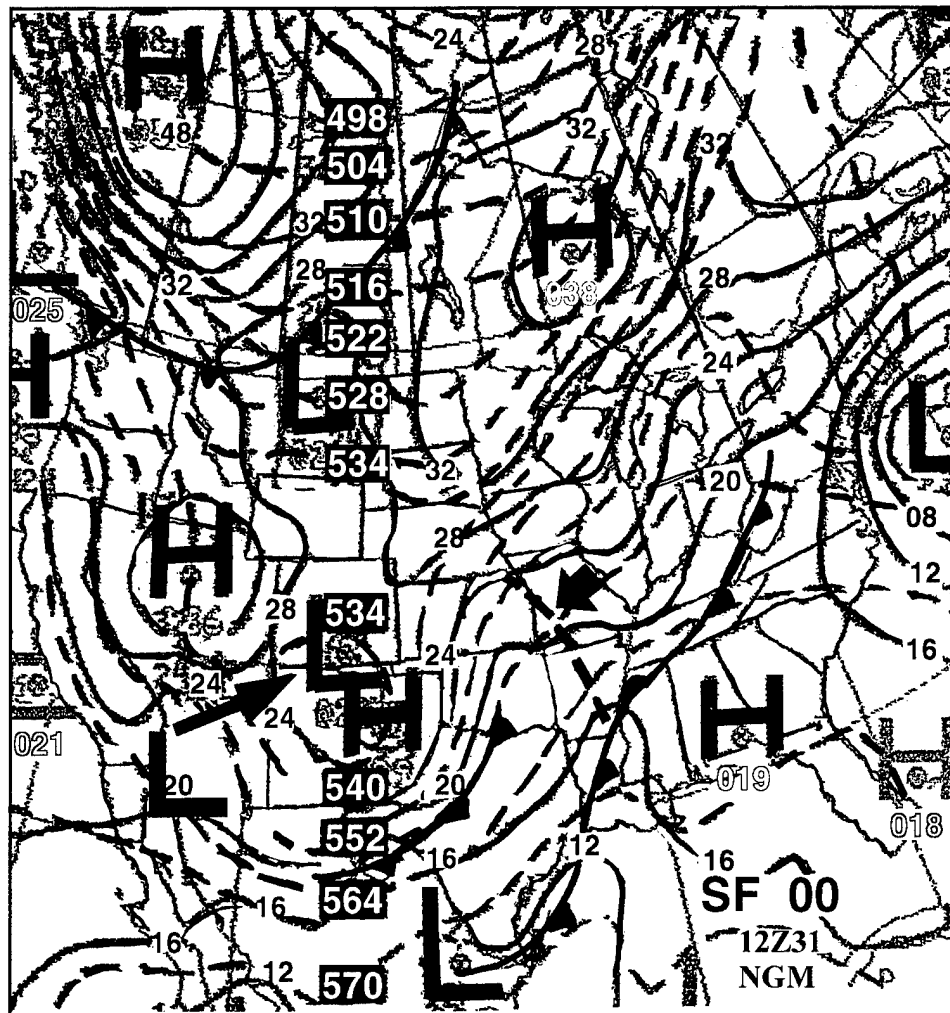


Figure 5-8. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. The long arrow indicates the location of the surface low-pressure system, and the wide arrow indicates the developing inverted trough. Chart valid at 1200Z on 31 October 1991.

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The related 1,000- to 500-mb thickness and freezing rain composite is shown in Figure 5-9. The freezing rain has spread northeastward to eastern Nebraska and Iowa. The freezing rain from Oklahoma to Iowa falls within the favorable 552/540 thickness ribbon; the freezing rain over the Abilene - San Angelo, Texas area lies within the 558/552 thickness and is most likely undercutting. In Figure 5-8, a surface

high is developing over the Texas Panhandle resulting in cold air advection over west Texas. Light to moderate snow is shown further to the west.

The 850-mb analysis (Figure 5-10) shows a low over Oklahoma, which lies on the 850-mb front, although a surface low was not evident in Figure 5-8. See pages 3-48 through 3-57 for discussion of inverted

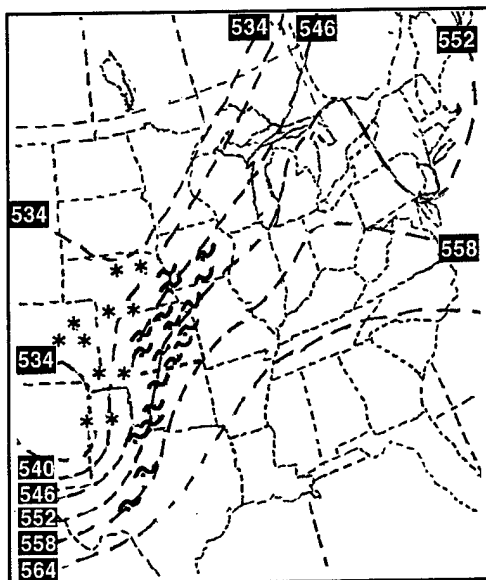


Figure 5-9. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation Chart. Freezing rain falls between the 540 and 552 thickness isopleths.

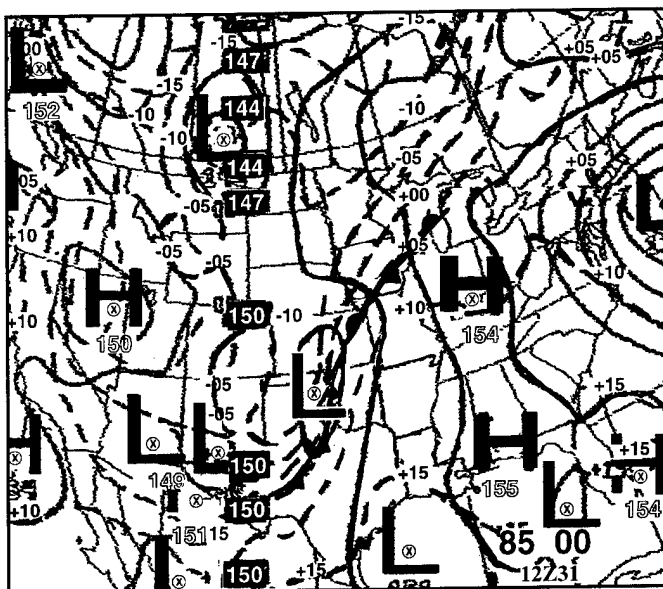


Figure 5-10. The 850-Mb Heights/Temperature Chart. A low-pressure system has developed on the 850-mb front. Chart valid at 1200Z at 31 October 1991.

troughs. The temperature gradient over the southern plains has tightened as cold air advects in from the west. Gulf moisture continues to feed into the developing storm as noted by the south to north contours over eastern Texas and the Mississippi Valley area.

The composite (Figure 5-11) depicts the 850-mb temperature and precipitation relationship. Nearly all of the freezing rain lies in the narrow $+5^{\circ}\text{C}/-5^{\circ}\text{C}$ temperature ribbon. The freezing rain is along and west of the 850-mb front as seen in Figure 5-10.

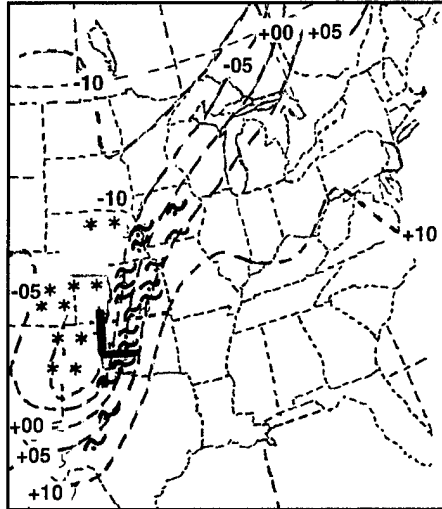


Figure 5-11. Composite 850-Mb Temperature/Freezing Rain Relationship. Freezing rain falls between the 850-mb $+5^{\circ}\text{C}$ and -5°C isotherms.

Intermediate Stage. Figures 5-12 through 5-16 shows the continued evolution of the deepening storm. The upper-level low has moved into the Great

Plains as shown in Figure 5-12. The 500-mb low is located over southwestern Oklahoma; data is difficult to read due to the tight gradients.

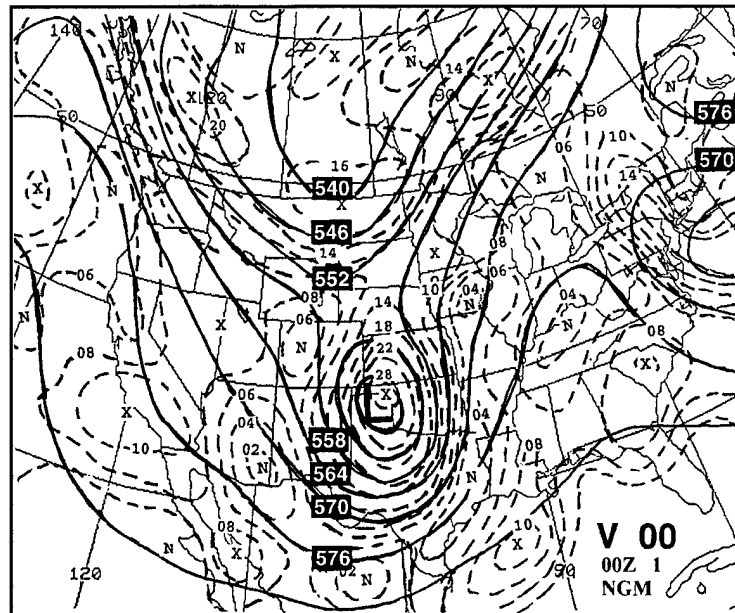


Figure 5-12. The 500-Mb Heights/Vorticity Chart. By 0000Z on November 1, 1991, the 500-mb low has moved into the plains.

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At the surface (Figure 5-13), a low now appears along the front over southern Missouri. Ridging and cold air advection has moved swiftly eastward across Oklahoma to southern Texas. The fresh outbreak of cP air has moved into western Nebraska and the Dakotas.

The 1,000- to 500-mb thickness composite (Figure 5-14) shows the persistent freezing rain area across eastern Kansas and Nebraska to Wisconsin; the freezing rain continues to lie between the 552/540 thickness ribbon. Heavy freezing rain accumulated more than one inch of surface ice (Halloween night).

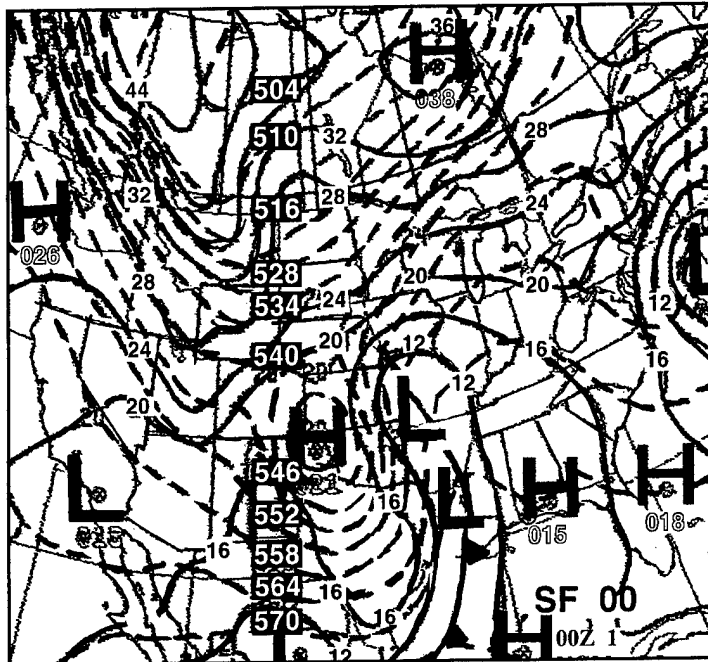


Figure 5-13. Forecast (00HR) Mean Sea-Level Pressure/1,000- to 500-Mb Thickness. A low-pressure system has developed on the front in Missouri. Chart valid at 0000Z on 1 November 1991.

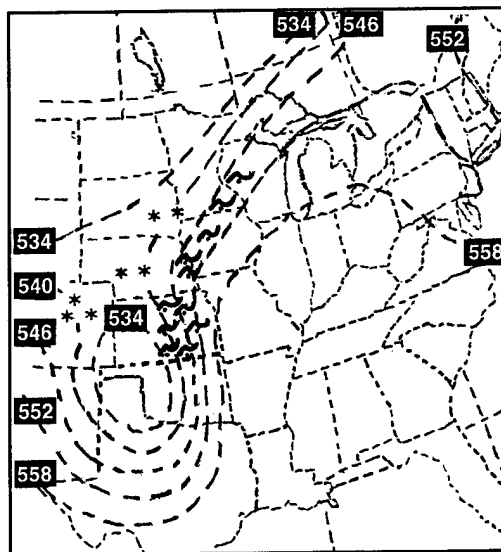


Figure 5-14. Composite 1,000- to 500-Mb Thickness/Freezing Precipitation Relationship. Freezing rain develops between the 540 and 552 thickness isopleths.

The 850-mb data is shown in Figures 5-15 and 5-16. A well developed low is centered over eastern Kansas.

The swath of freezing rain shown in Figure 5-16 lies along and west of the 850-mb front and between the $+5^{\circ}\text{C}/-5^{\circ}\text{C}$ temperature corridor.

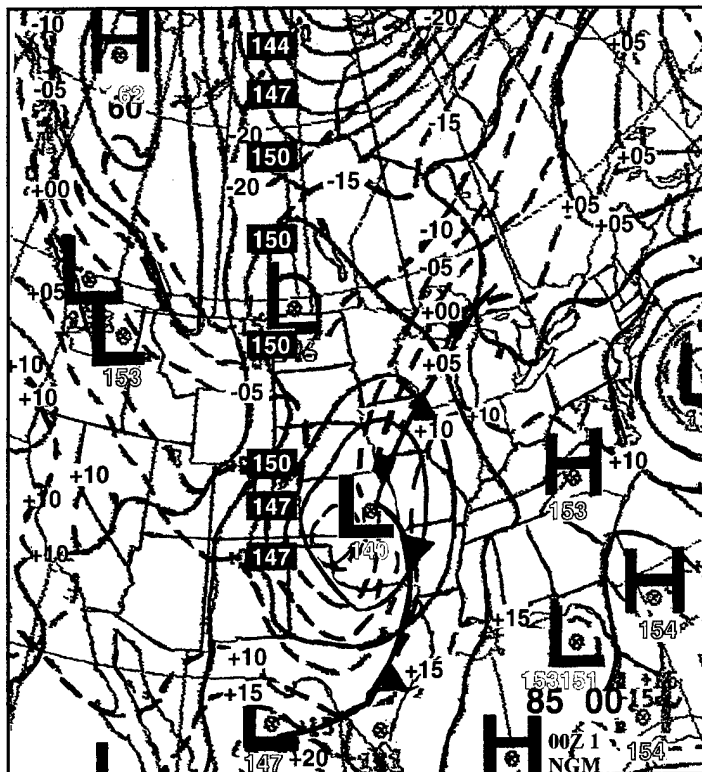


Figure 5-15. Forecast (00HR) 850-Mb Heights/Temperature. A well-developed low is centered over Kansas. Chart valid at 0000Z on 1 November 1991.

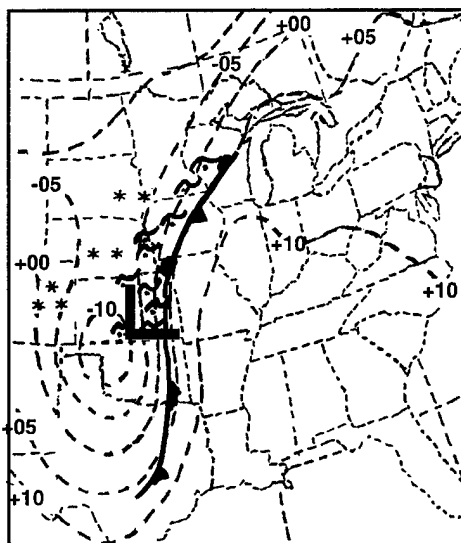


Figure 5-16. Composite 850-Mb Temperature/Freezing Rain Relationship. Freezing rain develops between the 850-mb $+5^{\circ}\text{C}$ and -5°C isotherms.

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Mature Stage. Figures 5-17 through 5-21 depict the final sequence of this case study. The 500-mb

low has bottomed out over Oklahoma and is centered over eastern Kansas as shown in Figure 5-17.

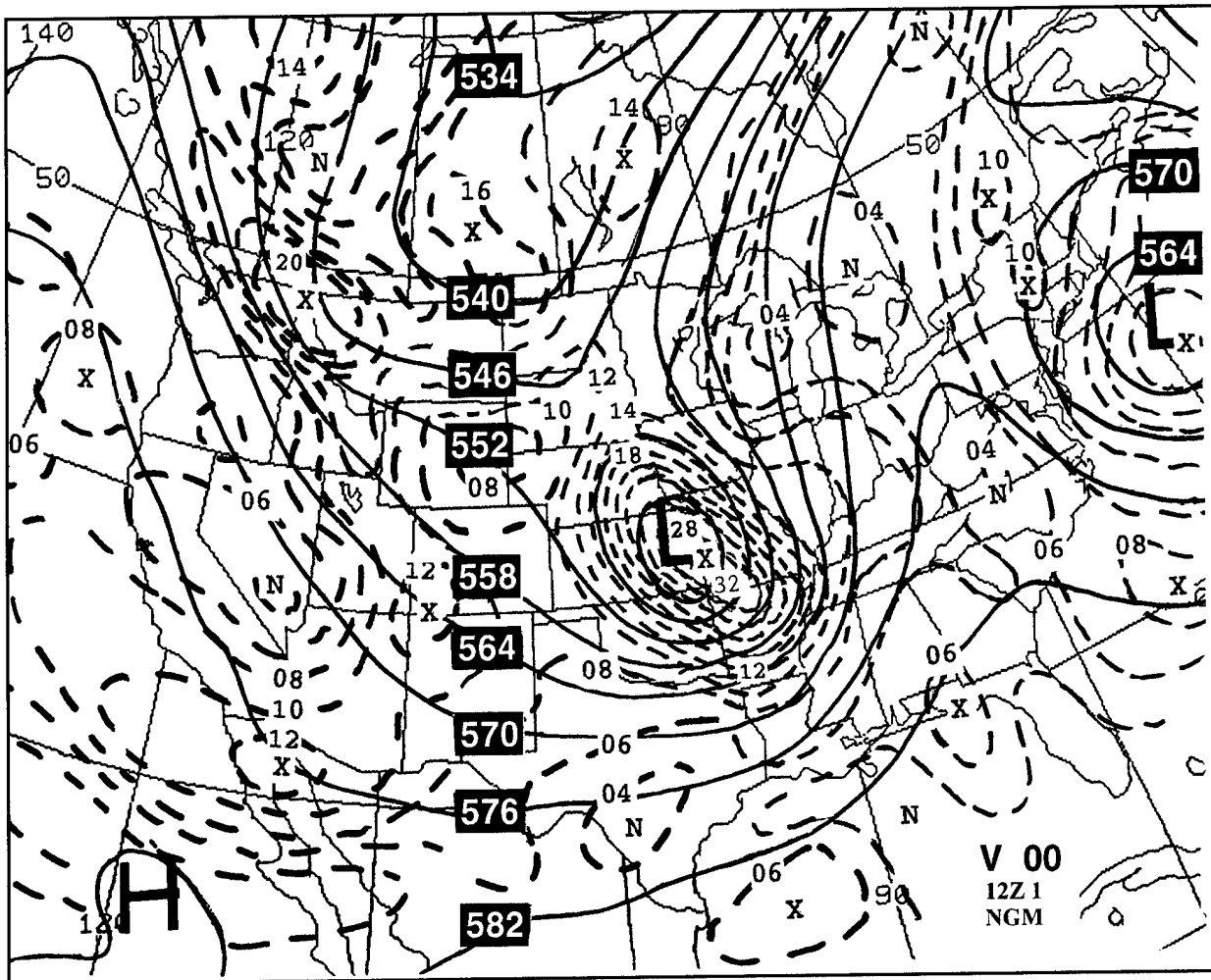


Figure 5-17. NGM 1200Z 500-Mb Heights/Vorticity. The figure shows an intense 500-mb low-pressure system has developed by November 1, 1991 over eastern Kansas

An intense storm system now appears over the Great Plains as depicted in Figures 5-18 (Surface) through

5-21 (850 mb). The new surge of cP air has entered into the storm system over the western Great Plains.

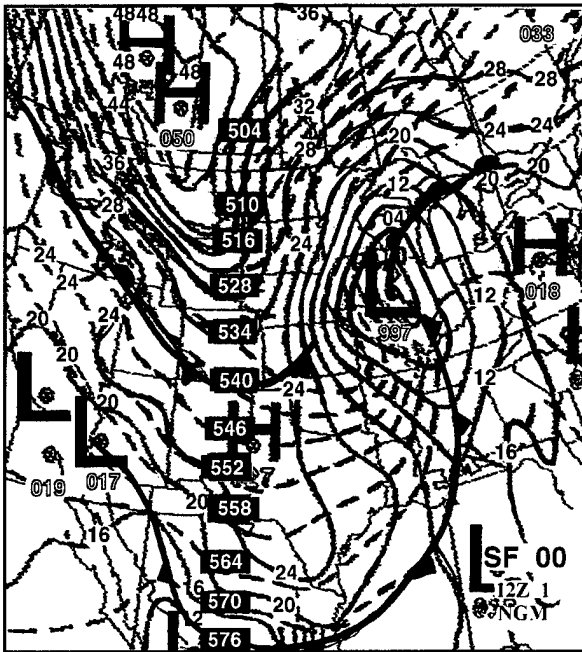


Figure 5-18. Mean Sea-Level Pressure/1000- to 500-Mb Thickness. An intense storm system appears over the Great Plains. Chart valid at 1200Z on 1 November 1991.

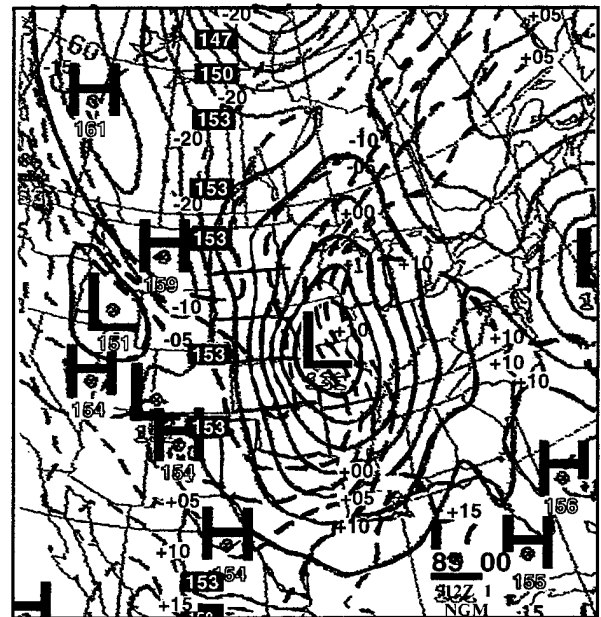


Figure 5-20. Forecast (00HR) 850-Mb Heights/Temperature. A new surge of cP air has entered into the storm system. Chart valid at 1200Z on 1 November 1991.

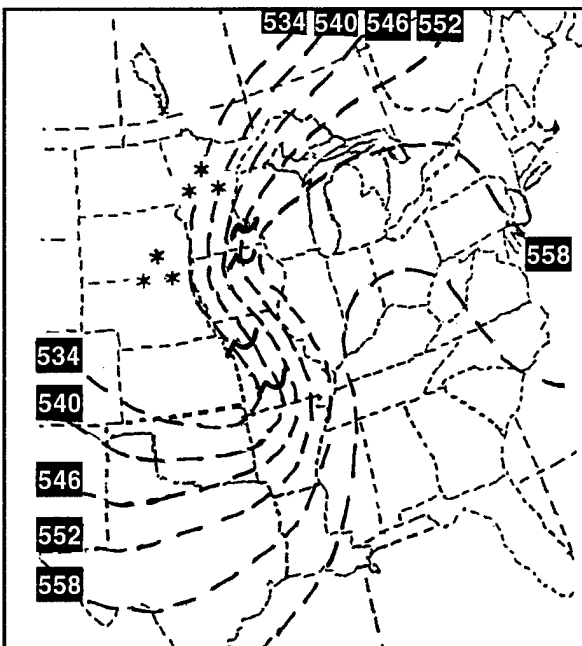


Figure 5-19. Composite 1000- to 500-Mb Thickness/Freezing Precipitation Relationship. Freezing precipitation is occurring in the 534/552 thickness ribbon.

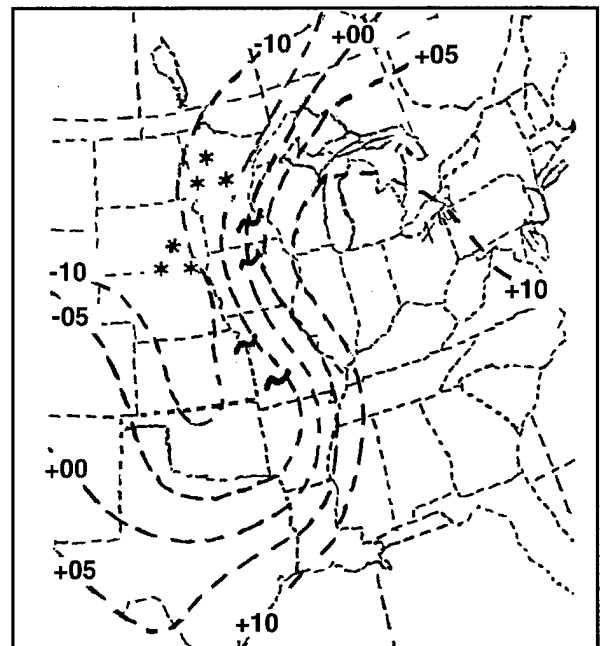


Figure 5-21. Composite 850-Mb Temperature/Freezing Precipitation Relationship. Freezing precipitation is occurring within the 850-mb +5°C and -5°C isotherms.

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