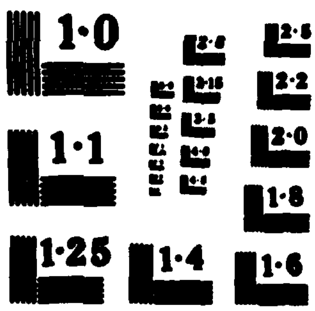
AD-A148 108 THE VISIBILITY CLIMATOLOGY OF MCMURDO SOUND/WILLIAMS FIELD ANTARCTICA(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA C G SOUDERS MAR 84 1/2

UNCLASSIFIED F/G 4/2 NL


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5

(2)

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE VISIBILITY CLIMATOLOGY
OF MCMURDO SOUND/WILLIAMS FIELD,
ANTARCTICA

by

Cheryl G. Souders

March 1984

Thesis Advisor: R. J. Renard

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A148108

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
The Visibility Climatology of McMurdo Sound/ Williams Field, Antarctica

5. TYPE OF REPORT & PERIOD COVERED
Master's Thesis;
March 1984

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
Cheryl G. Souders

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93943

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
Naval Postgraduate School
Monterey, California 93943

12. REPORT DATE
March 1984

13. NUMBER OF PAGES
150

14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
visibility, Antarctica, climatology, weather in the Antarctic, flight operations in the Antarctic

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

dee

Accurate forecasting of visibility at McMurdo/Williams Field, Antarctica is essential for the air operations involving the resupply of United States bases and the conduct of research on the Antarctic continent. McMurdo, located at 77° 51' S 166° 40' E, receives all supplies destined for use by the United States Antarctic Research Program scientists. The Williams Field skiway and the adjacent ice runway are approximately 4.5 mi southeast of McMurdo. Weather observations are taken

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

at both McMurdo and the operational airfield. The visibility climatology, August through March, for McMurdo (1956-1983) and Williams Field skiway/runway (1968-1983) was prepared using four operational visibility categories, as well as the seven important weather parameters which reduce visibility, namely, blowing snow, light snow, moderate to heavy snow, the three types of fog and ice crystals. A wind speed/direction climatology was also prepared because of its relation to both blowing snow and fog.

Accession For		
NTIS CRA&I		☑
DTIC TAB		☐
Unannounced		☐
Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

The Visibility Climatology of McMurdo Sound/Williams Field, Antarctica

by

Cheryl G. Souders
Captain, United States Air Force
B.A., Coe College, 1976
B.S., University of Utah, 1977

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY

from the

NAVAL POSTGRADUATE SCHOOL
March 1984

Author: Cheryl G. Souders

Approved by: ______________________________
Thesis Advisor

____
Second Reader

____
Chairman, Department of Meteorology

____
Dean of Science and Engineering

ABSTRACT

Accurate forecasting of visibility at McMurdo/Williams Field, Antarctica is essential for the air operations involving the resupply of United States bases and the conduct of research on the Antarctic continent. McMurdo, located at 77° 51' S 166° 40' E, receives all supplies destined for use by the United States Antarctic Research Program scientists. The Williams Field skiway and the adjacent ice runway are approximately 4.5 mi southeast of McMurdo. Weather observations are taken at both McMurdo and the operational airfield. The visibility climatology, August through March, for McMurdo (1956-1983) and Williams Field skiway/ice runway (1968-1983) was prepared using four operational visibility categories, as well as the seven important weather parameters which reduce visibility, namely, blowing snow, light snow, moderate to heavy snow, the three types of fog and ice crystals. A wind speed/direction climatology was also prepared because of its relation to both blowing snow and fog.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENTS

The author wishes to express her sincere appreciation to Dr. R. J. Renard, Department of Meteorology, for his assistance, interest and guidance during this study. Dr. Renard's effort was supported in part by the Naval Support Force, Antarctica. Also, Dr. C. H. Wash, Department of Meteorology is sincerely thanked for his critical review of the study. In addition, the author thanks Mr. W. J. Thompson, without whose guidance the computer work would not have been completed on time.

Appreciation is due to: Mr. M. McDermet, Department of Meteorology, for drafting the wind roses; the personnel of the Meteorology Division, Naval Support Force, Antarctica, Port Hueneme, CA, for providing information on the official observations at McMurdo and Williams Field; and the Naval Oceanography Command Detachment, Asheville, NC, especially Mr. B. Wallace, for furnishing information on the McMurdo and Williams Field data used in the study.

I. INTRODUCTION AND OBJECTIVES

A. IMPORTANCE OF MCMURDO/WILLIAMS FIELD

Accurate forecasting of visibility at McMurdo/Williams Field, Antarctica is essential for the air operations involving the resupply of United States bases and conduct of research on the Continent. Direct and indirect transportation costs (mainly air) account for about half the total annual cost of carrying out the United States Antarctic Research program, managed and funded by the National Science Foundation.

McMurdo station is located at 77° 51' S 166° 40' E (Fig. 1), on the southern end of Hut Point Peninsula on Ross Island (Fig. 2). McMurdo, the Continent's largest station, was constructed in 1955 as a staging base for all inland research projects. Today, all supplies destined for use by United States scientists on the Continent (except Palmer on the Antarctic Peninsula) are received at McMurdo and redistributed to inland stations and remote field camps (United States Naval Support Force Antarctica, 1982).

Each year, by early October, the United States Navy begins resupplying the United States bases on the Antarctic continent. Ships are used for bulk cargo; however, the initial resupply must be completed by air, since the pack ice generally precludes ship operations until late in the operating season.

The United States is one of only three countries that routinely employ long-range aircraft for passenger and priority cargo transport to Antarctica. There are only two airfields suitable for wheeled aircraft, one of which is near McMurdo (Central Intelligence Agency, 1978). United States Air Force and Navy aircraft carry cargo and personnel from Christchurch, New Zealand (the main staging base outside of the Continent) over a 2,100 nautical mile route to McMurdo. The supplies and personnel are then transferred to Navy ski-equipped aircraft for flights to inland bases (Biter, 1965).

McMurdo Sound lies between Ross Island and Victoria Land. The southern portion of McMurdo Sound is covered with landfast ice ten months of the year and is the site of the skiway complex named Williams Field (National Science Foundation, 1983). Williams Field is located approximately four and one-half miles to the southeast of McMurdo and because of Observation Hill cannot be seen from McMurdo. The airfield facilities actually consist of two landing areas, one permanently located on the Ross Ice Shelf (Williams Field Skiway) and the second, used during the cold months, on the annual sea ice (ice runway). See Fig. 3. (Central Intelligence Agency, 1978). The runway, constructed on sea ice, is used between October and December for the United States C-141 Starlifter and LC-130 Hercules aircraft which fly men and women, engaged in American and New Zealand scientific programs, to the ice. While the surface of the annual ice runway is still firm, LC-130 Hercules aircraft from the Royal New Zealand Air Force also fly to Williams Field. By late summer, the ice runway begins to deteriorate and ski-equipped aircraft, operating off prepared snow skiways, must be utilized. C-141's cannot use the snow runway because they are not ski-equipped (United States Naval Support Force Antarctica, 1982). Transportation to the interior stations is provided by both aircraft and surface vehicles.

Traditionally, New Zealand has been the jumping off point for U.S. expeditions to the Antarctic. The U.S. Navy maintains a small year round facility at Christchurch's International Airport. From there, personnel and supplies are readied for the long flight south to Williams Field.

B. LOCATION AND TOPOGRAPHY VICINITY OF MCMURDO

McMurdo is located approximately 730 n mi from the South Pole. The main city is located on the southwest extremity of Hut Point Peninsula, which extends southward from Ross Island for 10 mi (Fig. 3). Hut Point (59 ft high) is about 0.4 mi to the west of the station. From Hut Point, the land rises fairly steeply to Harbour Hill (525 ft high) due north of the station. Approximately one mile to the east of the station, Crater Hill rises to a height of 987 ft, and about 0.6 mi to the southeast lies Observation Hill, 747 ft high. Between these two hills, there is a pronounced gap or pass to the east-southeast of the station (Mercer, 1961).

Ross Island is located about 40 mi off the Victoria Land coast on the extreme western boundary of the Ross Sea and along the edge of the Ross Ice Shelf. The area to the southeast of McMurdo is a flat (Ross) ice shelf extending south for several hundred miles, broken only by White and Black Islands. To the west, across McMurdo Sound, and through the north to northeast, lies the Ross Sea. Although covered by annual sea ice most of the year, the Ross Sea becomes largely open water in middle and late summer. Therefore, McMurdo is affected by moisture laden marine air for part of the year (Sallee and Snell, 1970).

C. ANTARCTIC WEATHER

Antarctica is the world's largest and driest desert. Precipitation, mostly in some form of ice or snow, occurs frequently over much of Antarctica, but is light. Average accumulations of snow on the continent are less than two inches per year; however, along the coast the marine influence causes higher temperatures and greater amounts of snowfall. Once snow falls, it is blown about the surface until the flakes are compressed and gradually turned to ice (United States Support Force Antarctica, 1982).

The Antarctic climate is distinguished by extremely low temperatures and a permanent ice sheet. A large part of the surface of the continent, 55%, lies at an elevation of more than 2000 m and about 25% at more than 3000 m above sea level. Of the total area of the continent, about 14,000,000 km^2, less than 3%, are estimated to be free of a permanent ice sheet. Most of the meteorological data for Antarctica have been obtained since the beginning of the International Geophysical Year (IGY) in 1957 (Orvig, 1970).

Another unique feature of Antarctica is the strength of the wind. Katabatic winds often exceed hurricane force near the edge of the continent. As air on the polar plateau cools, it begins to flow seaward, due in part to gravitational pull. In areas where the continent is relatively formless, the airflow is unimpeded. Once it reaches the outer edge of the continent, the already swift wind races down the jagged mountain ranges to the sea. These winds lift large amounts of snow and are associated with low visibilities.

In addition to falling snow and blowing snow, ice fog and water fog act to deteriorate the visibility, although this is not a serious problem at McMurdo/Williams Field.

D. OBJECTIVES

The objectives of this study are: (1) to update the visibility climatology for McMurdo, Antarctica, stratifying the statistics by weather type and wind, (2) to develop a visibility climatology for Williams Field, Antarctica, and (3) to intercompare the McMurdo and Williams Field visibility climatologies and relate results to previous studies for McMurdo.

II. DATA

A. ACQUISITION

McMurdo data, August through March, were obtained on magnetic tape from the National Climatic Data Center (NCDC), Asheville, North Carolina. These data cover the period from 1 March 1956 to 31 January 1983 and consist of hourly airways surface observations on tape.

The Williams Field data[1] were derived from hard copy forms archived by the NCDC, the Naval Postgraduate School, Monterey, California, and the Naval Support Force Antarctica, Port Hueneme, California. This data set, representing the total known amount of archived Williams Field data, also covers the period from August through March, but only for the years 1968-1983. There are data from parts or all of only 54 months in this period of 124 months. Data for the months of August, September, February and March are extremely limited. Therefore, greater emphasis was placed on the McMurdo data archive, since it is the longer and more complete record, and it is transmitted via the meteorological data network. The four months of austral fall/early winter

---

[1]For the purpose of this thesis, the Williams Field data refers to data observed from either the skiway or the annual ice runway.

(April through July) were not considered since Antarctic flights are not scheduled during this period.

B. PROBLEMS

There was an initial problem associated with both McMurdo and Williams Field data sets. The McMurdo data initially forwarded from NCDC were available in three forms: (1) synoptic surface observations on magnetic tape (2) synoptic surface observations on hard copy forms and (3) airways surface observations on magnetic tape; however, all data were eventually made available in airways surface observation code. The advantage of airways over synoptic code is that the former allows reporting more than one current weather parameter, while the latter is limited to one such parameter. The Williams Field data, in addition to being all hard copy, also suffered from a change in format of the temperature and pressure during the period under consideration. After transcribing the data to the computer, the weather parameters had to be changed from alphabetic to numeric representations for processing. Also, in some cases it was necessary to change local standard time to Greenwich Mean Time. McMurdo local standard time is Greenwich Mean Time plus 12 hours.

III. CLIMATOLOGY OF MCMURDO

Climatology is usually defined as being the description of average atmospheric conditions using a 30-year period for the average value of various elements (Orvig, 1970). This study includes 26 2/3 years of McMurdo data. Previous studies of McMurdo climatology by Mercer (1961), Thompson (1972), and Sinclair (1982), cover the period 1957-1960, 1956-1961 and 1956-1972, respectively. Section III E addresses comparisons of this research to the previous studies. The McMurdo, and Williams Field (Section IV), climatologies are compared in the Conclusion Section (V).

A. VISIBILITY BY TIME PERIOD

Visibility was divided into four categories, based on flight filing restrictions: Cat 1, less than one mi - airfield closed, therefore no departures from Christchurch, New Zealand; Cat 2, one mi to less than three mi - aircraft cannot land without navigational aides (e.g., GCA, TACAN); Cat 3, three mi to less than five mi - all aircraft can land except for the C-141's during initial mainbody[2] fly-in; and Cat 4, five mi or greater - no restrictions (Table I).

---

[2]First fly-in with personnel and cargo, usually in October.

Fig. 4 shows the categorized restricted visibility by the month for August to March (49,100 observations). Low visibility problems are maximized in the austral winter and early spring period (August-October) and again in the late summer/early fall (March); Cat 1 dominates these months. In the late spring/early summer months of December and January Cat 2 dominates, while Cat 2 equals Cat 1 in November and February. Cat 3 is less than both Cat 1 and Cat 2 for all months.

To determine any diurnal patterns in the visibility at McMurdo, the percentage occurrence of the visibility categories was determined for the three-hourly observations. There doesn't appear to be a consistent pattern through all the months.

In August (Fig 5), the most likely visibility restriction category is 1, followed by 2 and then 3. The difference in the probability of occurrence of Cat 1 and Cat 2 at 0900 GMT and of Cat 2 and Cat 3 at 1500 GMT is negligible.

Again in September (Fig. 6), a restriction to visibility would most likely produce Cat 1, followed by 2 and then 3. However, in September, there is a significant increase in the percent of Cat 1 compared to Cat 2 or 3. At 2100 GMT, the difference between Cat 1 and 2 is smaller than between Cat 2 and 3. There is not any general increasing or decreasing trend through the hours.

October (Fig. 7) is a transitional month; however, the overall trend in the most likely category of occurrence continues. Unlike August and September, in October the hourly average of the differences between Cats 1 and 2 and Cats 2 and 3 is approximately the same (Table I).

In November (Fig. 8) visibility less than one mile occurs more than Cats 2 or 3 during the afternoon and evening hours (0000 to 0900 GMT), while Cat 2 is more prevalent from 1500 to 2100 GMT. However, at 1200 GMT Cat 1 is only slightly higher than Cat 2. There is a significant reduction in the frequency of restricted visibility from October.

For December (Fig. 9), the pattern is basically reversed with Cat 2 occurring more than Cat 1 or 3 in the afternoon and evening hours (0000 to 1200 GMT), while the lowest visibility category dominates only from 1500 to 1800 GMT. Also at 1800 GMT, the occurrence of Cat 2 equals that of Cat 3 and six hours later the occurrence of Cat 1 equals that of Cat 3.

In January (Fig. 10), the distribution is more uneven than either November or December, with visibility less than one mile dominating only at midnight (1200 GMT) and Cat 2 dominating most of the rest of the day. The occurrence of Cat 3 edges higher than Cat 1 only one hour (0000 GMT), with the two categories being approximately equal for the remainder of the time between 2100 and 0600 GMT.

The trend in February (Fig. 11) is definitely systematically related to the time of day. The nighttime and early morning hours (1200 to 2100 GMT) are dominated by Cat 2, while Cat 1 dominates during the day (0000 to 0900 GMT). The occurrence of Cat 3 is slightly greater than Cat 1 at 1500 GMT and higher than Cat 2 at 0300 GMT.

In March (Fig. 12), the visibility restrictions are not as great as in the austral winter (August and September); however, they are significantly higher than late spring and summer (November through February). The occurrence of Cat 2 is greater than both Cat 1 and 3 during three of the eight time periods, an interesting difference from the austral winter/early spring months. Also, the occurrence of Cat 3 increases during the early morning hours (1200 to 1800 GMT) and then drops until early afternoon (1800 to 0300 GMT).

B. VISIBILITY BY WEATHER PARAMETER

Air operations at McMurdo are restricted at times by low visibility due to blowing snow, falling snow, or fog, occurring alone or in any combination. Blowing and falling snow must be ranked before fog in order of importance due to their frequent occurrence. It should be noted that the snow category in this thesis includes all falling frozen precipitation, i.e. snow, snow pellets and grains, sleet, and snow showers.

The percentage occurrence of each of seven weather parameters (light snow, moderate or heavy snow, blowing snow, fog, ice fog, ground fog and ice crystals) was determined first by the month (Fig. 13) and then by the hour for each month (Figs. 14-21). Although many consider Antarctica to have only two months of summer (December and January), the McMurdo data indicate little difference in the percentage of occurrence of the various weather parameters in the three months, November through January. Thompson (1972) shows a marked deterioration in visibility outside the period of November through February. In all months, fog (all types) occurs significantly less than falling snow. The same is true for blowing snow relative to fog, except in the months of December and January. During the austral mid/late winter and early spring months of August through October, and the late summer month of March, the percentage of blowing snow and falling snow is approximately the same. In August and September, blowing snow occurs more often than light snow. For the remaining months, observations with falling snow exceed considerably those with blowing snow. Ice fog dominates the other types of fog in August. The occurrence of ice and water fog is approximately equal in September, while water fog dominates significantly in January and March.

In August (Fig. 14), blowing snow occurs more than falling snow at most hours. Ice fog exceeds water fog and ground fog during all hours. From early night through early morning (0600 to 2100 GMT), ice crystals occur more often than moderate and heavy snow. In September (Fig. 15), blowing snow also occurs more than falling snow at most hours. A more random pattern of fog occurs in September than in August - ice fog exceeds water fog at two time periods, equals water fog at two time periods and is dominated by water fog during four time periods. Ice crystals occur more often than moderate and heavy snow at all hours but 0600 and 0900 GMT.

October (Fig. 16) is a transitional month with three time periods when light snow exceeds blowing snow and five periods with the situation reversed. Unexpectedly, the greatest percentage difference between the two (light snow and blowing snow) occurs at 1200 GMT (2.3%) and the least difference occurs only three hours later. Ice fog dominates water fog only at 0000 GMT. The occurrence of ice crystals exceeds 1% only at 2100 GMT.

November (Fig. 17) is the beginning of the austral summer, according to weather occurrences. The drop in blowing snow from October is very noticeable (at least 50% for all time periods except 1800 GMT). Ice fog is the dominant type of fog reported in November.

In December (Fig. 18), light snow is predominant, much as it is in November. The amount of blowing snow drops from an average of 4.6% in November to an average of 1.9% in December. Reversing November's trend, ice fog is nonexistent in December. In addition, fog occurs mostly in the morning hours (1200 to 2100 GMT) with water fog predominating.

Midsummer is considered the period of maximum occurrence of nocturnal snow (Sallee and Snell, 1970); however, this is discernible only in January. More fog occurs in January (Figs. 13 and 19) than in December and it is primarily water fog. There is an increasing trend in the occurrence of fog in the late night/early morning hours of January (1200 to 1800 GMT) with a maximum of 2.7% at 1800 GMT.

Precipitation in the form of snow, sleet, or snow pellets occurs throughout the year with a maximum amount occurring in February (Sallee and Snell, 1970). During February (Figs. 13 and 20), light snow occurs 17.8% of the time (2.8% more than in any other month); the average for all months is 12.7%.

March (Figs. 13 and 21) begins the transition into winter. Immediately noticeable is the strong increase in blowing snow from February. Also interesting is the sudden increase in the occurrence of fog. March has a greater occurrence of fog than any other month and it occurs primarily as water fog.

C. VISIBILITY BY COMBINED WEATHER PARAMETERS

It must be noted that two or more weather parameters affecting visibility may coexist. Therefore, the percentage occurrences are not mutually exclusive. For example, in the month of January, light snow occurs during 68% of the blowing snow observations; the figure is 18% for the occurrence of moderate or heavy snow during blowing snow (Table II). Thus, although the visibility is significantly reduced to less than one mile in 37% of the blowing snow observations, it is not possible to assign the predominant cause. Simpson (1919) describes this clearly in his excellent discussion of blizzard conditions around McMurdo during the British Antarctic Expedition of 1910-1913.

Frequently, fog occurs in conjunction with falling snow at McMurdo. Both parameters can occur for several hours, producing a rapid reduction in visibility to values below airport minimums. The snow is believed to initially produce saturation of the layer of air below the surface inversion. As the inversion weakens or disappears, the fog dissipates due to vertical mixing (Sallee and Snell, 1970). For five of the eight months studied, light snow occurs simultaneously with at least 20% of the fog occurrences (Table III). In February, the figure is 62% of the time. Usually fog is not expected with blowing snow since the strong winds produce considerable vertical mixing. For all months but March, the percentage occurrence of blowing snow with fog is less than 17%, and averages 12%. The maximum of 33% occurs in March (which has the greatest occurrence of fog).

Once the forecaster has determined which weather parameter (or parameters) to forecast, it is necessary to determine the associated visibility. To facilitate this procedure, a visibility climatology has been compiled which gives the restricted visibilities associated with seven weather parameters. As mentioned before, in some cases it is nearly impossible to tell if only one weather parameter is occurring (for example, is there just blowing snow or is snow falling also). Therefore, the seven categories selected for this portion of the climatology were blowing snow, blowing snow and falling snow, blowing snow and fog, light snow, moderate to heavy snow, fog and ice crystals.

Blowing snow (Fig. 22) shows the greatest annual variation in the percentage occurrence in comparison with the seven parameters discussed here. The number of observations of blowing snow clearly shows a peak in the August through October time frame, then a dip to a minimum in January, and finally rising toward another peak in March. The largest percentage occurrence of restricted visibility during blowing snow is Cat 1 for all months. The smallest percent occurrence is Cat 3. For the months of August through October, Cat 1 exceeds Cat 2 by a two to one margin. In all other months Cat 1 and 2 are within 8% of each other, except February, where it is 16%. More Cat 1 occurs in February than in March, which is unexpected since there is nearly three times more blowing show observations in March than in February. The restricted visibility category resulting from blowing snow relates primarily to the wind speed; however, the wetness of snow, the time since the last snowfall and the topography are also important.

Although there are less observations of blowing snow and snow (Fig. 23) than snow (approximately one-half), the same trend holds - namely the most observations are in the austral winter/early spring (August-October) and again in March, with a minimum of occurrences in January. Cat 1 exceeds Cat 2 and 3 in all months, but by a larger margin (approximately three to one; nearly five to one in September). For blowing snow and snow, Cat 1 is more nearly equal to Cat 2 during the period from November to January than for blowing snow. Cat 1 occurs more in March than in February by a small amount.

For fog (Fig. 24), the general pattern of more occurrences in the austral winter/early spring and again in the early fall holds. However, the lowest occurrences are in November and February with a small secondary peak in January. Cat 2 predominates with Cat 2 equal to Cat 1 in November. A significant exception occurs in December, where

Cat 1 exceeds Cat 2 by nearly a three to one margin. Also in October, Cat 3 edges higher than Cat 1 or 2.

For blowing snow and fog (Fig. 25), Cat 1 dominates for August through November with Cat 1 equal to Cat 3 in December. In January there are no occurrences, in February only Cat 2 occurs, and in March Cat 2 dominates. Blowing snow and fog occur seldom together, ranging from a percentage occurrence of zero in January (lowest occurrence of blowing snow) to a high of 83 in March (greatest occurrence of fog).

While blowing snow shows an annual cycle (902 observations in August and 81 observations in January), light snow (Fig. 26) varies from month to month with much weaker amplitudes (maximum in February of 914 observations and minimum in November with 659 observations). Cat 1 dominates from August to October, while Cat 2 dominates from November through March. In December and January, Cat 3 exceeds Cat 1.

As expected, the number of moderate to heavy snow observations (Fig. 27) is far less than the number for light snow. The variation in occurrence through the year is quite small (71 in March to 38 in November and January). The smallest occurrence of Cat 1 is 97%, not unexpected since moderate to heavy snow literally requires Cat 1 visibility (the Cat 2 and Cat 3 observations are probably errors).

Cat 2 occurs in August and September, and again in January and February, with Cat 3 occurring only in February.

According to Huffman and Ohtake (1971), the diameter of ice crystals decreases with decreasing temperature and the smaller the size of the particles, the greater the visibility restriction. However, this does not appear to hold at McMurdo, although the sample size is very small (267 observations) (Fig. 28). For example, the maximum occurrence of ice crystals is in August, but the greatest restriction to visibility occurs in November (Fig. 24). All three categories occur the same number of times in November, and in December, Cats 1 and 2 occur equally, without any Cat 3. In October, there was not any Cat 3 and in January only Cat 3 occurs.

D. WIND STATISTICS

The wind direction and speed are included in this study because of their importance to the visibility, especially in relation to blowing snow and fog.

The wind statistics for all visibility categories (Table IV) show an easterly wind about 30% to 50% of the time. The most likely wind speed is 11 to 20 kt, except 1 to 10 kt in November, December and January. The strongest winds occur during the austral winter/early spring and are predominately from the south. The maximum ten-minute average of 60 kt occurs in September. In the summer months, the maximum wind averages about 40 kt. In most months the least likely wind directions are those from the south to west. The number of observations range from a low of 5546 in March to a high of 6696 in January.

When visibilities less than one mi occur (Table V), the most likely wind speed is 11 to 20 kt for four of the months and 21 to 30 kt for three of the months. The strong winter winds show a preference for a southerly to southwesterly direction. In six of the eight months, the maximum wind occurs with Cat 1 visibilities. The predominant wind direction is now southeasterly or easterly. The least likely wind direction is in the range southwest to north. January has the smallest number of observations (106) and September has the highest (545).

When visibilities of one to less than three mi (Table VI) occur, the most likely wind speed is 11 to 20 kt from the east. There is a higher percentage of calm days in all months, except November and December, than for Cat 1. There is a larger variation in the wind direction for the stronger winds (from the north to northeast and the south to southeast) with Cat 2 than Cat 1. Both the overall maximum wind speed and the maximum associated with the predominant direction is lower than for Cat 1 for August through December.

Again, for visibilities of three but less than five mi (Table VII), 11 to 20 kt is the most likely wind speed for all months, except January, and the predominant wind direction is easterly. The stronger winds vary from north through southeast, but are weaker than the winds associated with the two lower visibility categories.

The most likely wind speed during blowing snow (Table VIII) is 11-20 kt. The maximum wind speeds occur in the winter with the directions variable. The predominant wind direction is easterly with southerly winds in December and southeasterly winds in November.

Lower maximum winds occur with blowing snow and snow (Table IX) than with just blowing snow and the direction of the maximum wind speed is more southerly. The maximum wind speeds are about the same as for blowing snow alone. The predominant wind is easterly to southeasterly, and has higher wind speeds associated in the winter and lower wind speeds in the summer, than during blowing snow alone. There are no observations with winds from the southwest to north from December through March.

There are fewer calm winds in the winter for fog (Table X) than for ice crystals, but there are more calm winds in the summer. The most likely wind speed is 1-10 kt for four of the eight months. The predominant wind is easterly. The maximum winds are easterly in the summer and southeasterly in the winter. The maximum wind speeds are higher than those for ice crystals but less than those for snow.

For blowing snow and fog (Table XI), the maximum wind is usually from the east through south, while the predominant direction is northeasterly to southerly.

For light snow (Table XII), the most likely wind speed is 11 to 20 kt in the winter months; however, there are a large number of calm winds. The maximum wind speed and direction is about the same as for blowing snow. There is a minimum in the occurrence of light snow with winds from the southwest to north. The predominant wind direction is easterly.

The maximum wind speed for moderate to heavy snow (Table XIII) is less for all months than for light snow. The maximum winds are from the southwest to southeast and the predominant winds shift to a more southeasterly direction. For three of the eight months, there are no observations for wind directions from the southwest to northwest.

Ice crystals (Table XIV) occur with predominantly calm winds in the winter/spring season (ranging from 37.5% in November to 74.1% in October), but during the rest of the year calm winds do not occur. there are no observations for wind directions from the south to southwest in the winter. The predominant wind direction is easterly, except in October. Both the maximum and predominant wind speeds are lower than for other weather categories.

Selected wind roses for McMurdo, for various weather conditions and months, are shown in Figs. 55 to 65.

E. COMPARISON TO PREVIOUS MCMURDO STUDIES

Sinclair's (1982) study of weather in the Ross Island area covers the period from 1956 to 1972. A comparison of the frequency of snow and fog reported by this study and that presented by Sinclair shows reasonable agreement for snow. The difference in the percentage occurrence of all snow is significant only in January, with 25% less for the shorter record of Sinclair. In all other months, but November, Sinclair's data have more percentage occurrence of snow. However, there are significant differences in the percentage occurrence of fog in the months of October through December. For these months, the shorter record has 25% to 54% more occurrences of fog (Table XV). This may imply that in the last decade there has been a significant decrease in the amount of fog at McMurdo. However, Sinclair rounded all percentage occurrence figures to the next highest number.

Thompson's (1972) climatology uses six-hourly observations and covers the period from October 1957 to March 1960. A comparison with the data presented by Thompson (1972) shows a trend similar to the comparison with Sinclair (1982). The Thompson and Sinclair studies have the same values for fog in all months, except August, where

Thompson's data shows a drop (41% less fog than this study). Thompson's percentage occurrence of falling snow is smaller for five of the months, especially from January through March (24% to 32%) (Table XV). Thompson also rounded his percentage occurrence figures up to the next highest number.

Mercer (1961) presents, in tabular and graphical form, the existing climatological data for McMurdo Sound which was derived (with few exceptions) from the three-hourly surface observations recorded during the period March 1956 through December 1960. Table XVI presents the pertinent wind data compared with this study.

Although Mercer's data are of instantaneous wind speeds rather than averaged winds, it is interesting to note that in most cases the wind direction is very close. The primary exception is in November, when the maximum instantaneous wind is from the south while the maximum ten-minute averaged wind occurs from several directions. Sinclair (1982) also indicates that the strongest winds are from the south and more common during the winter. In Table XVI, the strongest winds (both averaged and instantaneous) occur in the austral winter/early spring (August through October). Fig. 29 is a wind rose for McMurdo (data:March 1956-December 1972) (Sinclair, 1982), showing the strong preference for a wind from the southeast to northeast. This study gives basically the same results with a slightly higher preference for easterly and southeasterly winds. A comparison of the percentage of calm days is within 2%. Although the surface wind at McMurdo is usually easterly, the winds aloft (300 m to 3000 m) are predominantly southerly off the Antarctic plateau. The surface wind direction appears to be due to the local topographic influences of a 300 m ridge to the south of McMurdo (Sinclair, 1982).

Compared to Mercer, the data from this study (Tables I and XVII) have a greater percentage of visibilities Cat 3 or less in only three months: August, November and February (Table XVII). It is to be noted that Mercer's data are in nautical miles, which gives the following statute mile values for the various categories: (1) Mercer's Cat 1 is less than 1.15 mi, (2) Mercer's Cat 2 is greater than 1.15 to 3.45 mi, and (3) Mercer's Cat 3 is greater than 3.45 to 5.75 mi.

IV. CLIMATOLOGY OF WILLIAMS FIELD

A. VISIBILITY BY TIME PERIOD

The previously defined categories are used for the Williams Field visibility climatology. Fig. A.30 shows the categorized restricted visibility by the month for August through March (9314 observations). Low visibility problems are maximized in September and October; however, Cat 1 dominates all months except March and December. Cat 3 exceeds Cat 2 in August, and in March Cat 3 dominates with both Cat 2 and Cat 3 exceeding Cat 1 by a seven to one margin. The largest percentage of visibilities less than five mi occur in March and the smallest percentage in December. Unexpectedly, February and November have less restricted visibility occurrences and less Cat 1 than January.

To determine any diurnal patterns in the visibility at Williams Field, the percentage occurrence of the visibility categories was determined for the three-hourly observation (for parts of March and August only six-hourly observations were taken). There does not appear to be a consistent pattern through all the months.

In August (Fig. 31), there is not a prevailing category (partially due to only 225 observations). Cat 1 dominates only two time periods (0300 to 0600 GMT) and Cat 3 dominates at 1500 GMT. At 1200 GMT, there were not any observations.

For the remaining four time periods, at least two categories occur equally.

In September (Fig. 32), visibilities of less than five mi do not occur in the early morning hours (1200 to 1800 GMT). In the late morning hours (2100 to 0000 GMT), all categories are equal. During the late evening hours (0600 to 0900 GMT), Cat 1 dominates. At 0300 GMT, only Cat 2 occurs. There are only 94 observations for September.

In October (Fig. 33), low visibilities occur at all hours, with Cat 1 dominating, except at 0000 GMT, where Cat 1 equals Cat 3. More Cat 1 occurs during the late night and morning hours (0900 to 2100 GMT) than in the afternoon (0000 to 0600 GMT). Cat 3 occurs less than the other two categories most of the time; the exceptions are at 1200 and 1800 GMT (Cat 3 equals Cat 2).

Again in November (Fig. 34), Cat 1 dominates all hours except 2100 GMT, when Cat 1 equals Cat 2. The occurrences of Cat 1 peak at noon (0000 GMT) and then decrease through the evening hours, until midnight, and then rise to a secondary (smaller) peak in the early morning hours (1800 GMT). Cat 3 exceeds Cat 2 only at 1200 GMT and equals Cat 2 at 0300 and 1500 GMT.

In December (Fig. 35), Cat 1 and Cat 2 are equally dominant; Cat 1 dominates in the evening and night hours (0900 to 1800 GMT), and Cat 2 dominates during the late morning and afternoon (2100 to 0600 GMT). When Cat 1 dominates, Cat 2 exceeds Cat 3, except at 1800 GMT, where they are equal. When Cat 2 dominates, Cat 1 exceeds Cat 3 for two time periods, equals Cat 3 for one time period, and is exceeded by Cat 3 for one time period.

For January (Fig. 36), Cat 1 dominates all hours except noon (0000 GMT). The number of occurrences of Cat 1 rise from a low in the early afternoon (0300 GMT) to a peak in the early morning (1800 GMT), and then declines slightly by 2100 GMT. Cat 2 exceeds Cat 3 for all hours, except 0300 GMT. For the one hour Cat 2 dominates (0000 GMT), Cat 1 exceeds Cat 3. Cat 3 shows a generally increasing trend from midnight to early morning (1800 GMT), then there is a general decrease through the day until the minimum at midnight is reached again (except at noon, 0000 GMT).

In February (Fig. 37), Cat 1 dominates in the morning and early afternoon hours (1800 to 0300 GMT). Cat 1 equals Cat 2 at 0600 GMT and at 0900 GMT Cat 2 dominates (Cat 1 equals Cat 3). Cat 2 does not occur at noon.

In March (Fig. 38), the predominant categories are much higher than in the other months; this is due in part to the limited amount of data (49 observations). At two time periods, no visibilities less than five mi occur. For four time periods only one category occurs.

B. VISIBILITY BY WEATHER PARAMETER

Air operations at Williams Field are restricted by the same types of weather parameters as at McMurdo, but not necessarily in the same frequency of occurrence. Again, snow includes all falling frozen precipitation.

The percentage occurrence of each of the seven weather parameters was determined first by the month (Fig. 39) and then by the hour (Figs. 40-47). Table XVIII shows the limited number of observations available in August, September, and March; therefore, any conclusions for these months must be carefully considered. The Williams Field data validate the traditionally held view of a two-month summer (December and January) with two transitional months (November and February). Blowing snow dominates the winter months of August through October, while in November the percentage occurrence of blowing snow equals that of light snow, and light snow dominates in December through March (the highest percentage of light snow occurs in March). Moderate to heavy snow appears to have a maximum percentage occurrence in September (94 observations), although it occurs more often in the summer months than in the other two winter months (August and October). Ice crystals occur in three months with the maximum percentage in March (over 4%) and less than 1% in August and November. The percentage occurrence of ice fog is greater than either water fog or ground fog from August through November. For fog and ice fog, the percentage occurrence is approximately equal in December and fog occurs twice as much as ice fog in January and February.[3] Only water fog occurs in March.

In August (Fig. 40), blowing snow dominates, except at 0000 GMT (blowing snow equals light snow) and at 1800 GMT (light snow dominates). The highest percentage of occurrence of blowing snow is at 1500 GMT (20%). Moderate to heavy snow is reported only at 0900 and 1800 to 2100 GMT. At 1800 GMT, moderate to heavy snow and light snow occur equally. Fog occurs only in the afternoon and evening hours, with ice fog predominating, except at 0300 GMT, when ice fog equals water fog (only time water fog occurs). No ice crystals occur in August. There are only 225 observations in August.

In September (Fig. 41), blowing snow predominates. Any other conclusion is not valid due to the limited amount of observations for the month (94 observations).

In October (Fig. 42), blowing snow dominates all hours, with light snow second. Moderate to heavy snow occurs at 0900 GMT and in the middle to late morning (1800 to 0000 GMT). Ice fog dominates the other two types of fog, except at 1200 GMT, when water fog has a two to one lead. Ice fog occurs more than moderate to heavy snow at all hours.

---

[3] See comments on inconsistent observations in Section V, Conclusions and Recommendations.

In November (Fig. 43), blowing snow dominates five of the time periods and light snow dominates the other three (1800 to 2100 and 0900 GMT). Moderate to heavy snow is not reported at 1800 GMT. Ice fog occurs more than the other types of fog at all hours. Ground fog occurs only in the morning (1500 to 1800 GMT), and from 0900 to 1200 GMT only ice fog occurs.

In December (Fig. 44), light snow becomes the dominant weather parameter, exceeding all others by 50% or more (except at 1200 GMT). There is a slight increase in the occurrence of moderate to heavy snow from November. Ice crystals occur only at 1500 GMT. Ice fog exceeds the other types of fog in the afternoon and evening hours (0000 to 0900 GMT), while water fog dominates in the morning hours (1200 to 2100 GMT). Ground fog occurs only at 0600 GMT.

In January (Fig. 45), light snow and blowing snow occur with the same general relationship as in December. Moderate to heavy snow occurs more than blowing snow for three time periods. Ice crystals occur at all but two of the time periods. There is a significant increase in the amount of water fog compared to December, which dominates the other types of fog. Ice fog occurs at all hours with about the same frequency as in December. There is an increase in the occurrence of ground fog from the previous month (occurs at six of the eight time periods).

In February (Fig. 46), light snow still dominates and there is an increase in the frequency of occurrence over January. For the general trend, the maximum light snow occurs in the late night to early morning hours; however, the largest peak is at 2100 GMT. Blowing snow is the second most frequently occurring weather parameter and exceeds moderate to heavy snow at all hours. Moderate to heavy snow is *not* reported at 2100 GMT. The amount of fog drops significantly from January (approximately one-third less), and is not reported at 0000 or 1500 GMT. Water fog dominates the three types of fog at 0600 and 1200 GMT. Ice fog occurs in the morning hours (1800 to 2100 GMT), and again at 0600 GMT. At 0300 GMT, only ground fog occurs (the only time during the day).

In March (Fig. 47), there are only 49 observations, so any trends distributed over eight time periods are suspect.

C. VISIBILITY BY COMBINED WEATHER PARAMETERS

As mentioned before, weather parameters often occur simultaneously, making it impossible to determine which one is most responsible in reducing the visibility. A visibility climatology was developed for Williams Field using the same combined weather parameters as for McMurdo.

The maximum number of occurrences of blowing snow (Fig. 48) are in October and November (138 occurrences) with the minimum in September (13 occurrences). For all months in which blowing snow occurs, Cat 1 dominates (about twice as many occurrences as the next highest occurring category), with the exception of December (lowest monthly percentage of Cat 1). In August and February, Cat 3 is the second highest occurring category, while Cat 2 is the second highest in all other months.

Cat 1 dominates all months for blowing snow and snow (Fig. 49), except September when Cat 1 equals Cat 2; however, there are only two occurrences. In October, November, January and February, Cat 1 occurs at least 60% of the time. Also, in August, Cat 1 occurs 100% of the time, but again, there are only two occurrences. Cat 2 exceeds Cat 3 in all the rest of the months, except November, where Cat 2 equals Cat 3. There are no occurrences of blowing snow with falling snow in March.

Fog (Fig. 50) occurs all months, but no single category dominates. In December through February, Cat 1 dominates, followed by Cat 2 and then Cat 3. In March and September, only Cat 2 and 3 occur and in March Cat 3 dominates, while in September, Cat 2 dominates. In October and November, Cat 2 dominates. The five observations in August are not enough to make conclusions.

Blowing snow and fog (Fig. 51) occur in only five months with Cat 2 dominating in August and November, and Cat 2 dominating in January (only category occurring). This distribution results from the number of occurrences (only one in August, December and January).

For light snow (Fig. 52), Cat 2 predominates, with Cat 2 equaling Cat 3 in August, and Cat 1 dominating in October. There are no occurrences of Cat 1 in March. However, there are less than ten occurrences of light snow in August, September and March respectively, with the maximum occurrences in January (172).

With moderate and heavy snow (Fig. 53), Cat 1 dominates all months except February, where Cat 1 equals Cat 2 and August, where Cat 2 exceeds Cat 1. Cat 3 occurs only from November to January. Again, there are less than ten occurrences in August (3), September (7) and March (1), while the maximum occurs in January (53).

Ice crystals (Fig. 54) occur in only three months with 25 occurrences. This is not a sufficient amount to analyze.

D. WIND STATISTICS

The wind statistics were compiled for Williams Field by visibility categories and by combined weather parameters.

For all visibilities combined (Table XIX), the most likely wind speed is 1 to 10 kt in all months. The maximum average wind speed of 59 kt occurs in November. The wind directions associated with the maximum speeds vary, while the predominant wind is generally from the northeast through east. The maximum wind speed from the predominant direction is less than the maximum wind speed for most months. Winds occur from all directions but the least likely directions are southwesterly to northwesterly; however, in March the least likely direction is northeasterly. The minimum number of observations occurs in March (49) and the maximum number occurs in January (2430).

When the visibility is less than one mi (Table XX), the most likely wind speed is 11 to 20 kt in the winter and 1 to 10 kt in the summer. The maximum wind speed occurs with visibilities less than one mile, except December, February and March. The maximum winds are from the southwest to southeast, while the predominant winds are from the south to southeast (more southerly than the combined visibility figures). The wind speed associated with the predominant direction in the winter is higher than for the combined visibilities, and approximately equal in the summer. There is one observation in March and 127 in January.

For Cat 2 visibilities (Table XXI), the most likely wind speed is 1 to 10 kt for all months. The maximum wind speed is significantly less in the winter (August to October) and slightly lower in the summer than Cat 1; the same pattern occurs for the predominant winds. The maximum wind direction is variable, with the predominant winds varying mostly from southerly to easterly. There are five observations in March and 76 in January.

For Cat 3 (Table XXII), the most likely wind speed is also 1 to 10 kt, but the maximum speeds are approximately one-half the maximum speeds for the combined visibilities. The directions of the maximum speed are variable. The predominant wind direction is northeasterly to easterly. The least likely wind directions include northerly and northwesterly winds.

The calm wind association with blowing snow in Table XXIII is considered an error. The most likely wind speed is 11 to 20 kt, except in September. The maximum winds at Williams Field generally occur with blowing snow. The directions of the maximum winds are southwesterly to southeasterly with west being the least likely wind direction.

For blowing snow and falling snow (Table XXIV), the most likely wind speed is 1 to 10 kt in August and September (two occurrences each) and 11 to 20 kt the rest of the months. The maximum winds are mostly from the south, while the predominant winds are slightly more easterly. The maximum wind speeds are generally lower than when blowing snow occurs alone.

When fog occurs (Table XXV), the most likely wind speed is less than 10 kt. The strongest wind directions are variable; the predominant winds are generally from the northeast to east. The maximum wind speeds are one-half or less compared to the maximum wind speed for the combined visibilities category. Fog occurs in all months.

Blowing snow and fog (Table XXVI) occurs in only five of the eight months and only once in August, December and January with a high of five in November.

For light snow (Table XXVII), the most likely wind speed is 1 to 10 kt. The maximum wind speed is 45 kt in November and the wind directions associated with the maximum speed are generally southeasterly to southwesterly. The predominant wind directions are easterly except in March, and the speed is approximately the same as the maximum (in the winter). There are only five observations in September and 172 in January.

During moderate to heavy snowfall (Table XXVIII), the most likely wind speed is 1 to 10 kt. The maximum wind is 59 kt in November (higher than for light snow) with monthly maxima from the southeast to southwest. For most months the maximum speeds and the maximum speeds associated with the predominant direction are the same. The number of observations range from a low of one in March to a high of 52 in November.

Ice crystals (Table XXIX) occur in only four of the months with a total of 25 observations. January is the only month with a significant number of occurrences (16). In January the maximum winds are mostly from the east and the predominant winds are from northeast to southeast. The most likely wind speed is 1 to 10 kt.

Selected wind roses for Williams Field, for various weather conditions and months, are shown in Figs. 55, 56, 58, 59, 61, 62 and 63.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The percentage occurrence of restricted visibility (i.e. < 5 mi) at McMurdo shows a definite four-month minimum in the spring/summer season November to February. During the winter months Cat 1 dominates; during November and February Cat 1 equals Cat 2; and in December and January Cat 2 dominates. Snow and blowing snow (the main visibility restrictants) are at a minimum from November to February.

The visibility climatology for Williams Field validates the traditional view of a two-month summer (December and January) in the Antarctic, with November and February being transitional months. Cat 1 dominates all months, except December and March, when Cat 1 equals Cat 2. Blowing snow and snow have a minimum in December and January.

For the weather parameters, the trends are similar at both stations. Blowing snow at McMurdo shows a strong peak in August and a minimum in January, while at Williams Field, the strong peak is in October to November and the minimum is in March. Williams Field experiences less blowing snow in the summer than McMurdo. For blowing snow and snow occurring simultaneously, Cat 1 predominates at both locations. The trend of Cat 1 dominating in the winter, and Cat 2 dominating in the summer for blowing snow and fog, also holds at both locations. Light snow is less of a visibility deterrent at Williams Field, with Cat 2 dominating all months; at McMurdo, Cat 1 dominates in the winter months. Also, McMurdo experiences twice as much light snow in the summer as Williams Field. Although moderate to heavy snow occurs at both Williams Field and McMurdo, it occurs from three to seven times more often at Williams Field. More ice crystals occur at Williams Field in March, but the distribution for the rest of the year is the same as at McMurdo. The general trend of water fog dominating in the summer occurs at both locations; however, there is a dramatic increase in the amount of ice fog that occurs at Williams Field over that experienced at McMurdo.

In general, at McMurdo, the stronger winds are from the south with the predominant winds from the east. At Williams Field, there is more variation in the direction of the stronger winds (southeasterly to south-southwesterly), and the predominant winds are more southeasterly. The wind speeds at Williams Field are usually higher than at McMurdo.

If the only observations available to the forecaster are from McMurdo, they can be considered to indicate the general trend occurring at Williams Field. However, the forecaster must give careful consideration to the type of weather parameter to be forecast and the season of the year before making a forecast for Williams Field. A comparison of the winds at Williams Field and those at McMurdo is difficult except for the months of October through January because of the extremely small number of observations in the other months. Also, certain weather parameters do not occur enough in any month for a comparison.

No attempt was made to correct inconsistent observations. For example, the large number of ice fog observations in November at McMurdo, and through the summer months at Williams Field, is suspect, considering temperature. And, westerly wind directions associated with maximum wind speeds at Williams Field (Tables XXV, XXVI, XXVII) are considered highly unlikely. There are other less obvious inconsistencies.

B. RECOMMENDATIONS

1. The Antarctic ice pack experiences a great annual variation. It grows from an average minimum 2.6 million km^2 in March to about 18.8 million km^2 in September (a greater than seven-fold increase). In addition, 85% of the ice pack melts each year (Central Intelligence Agency, 1978). Since the large variation of sea ice affects the amount of moisture which reaches the McMurdo/Williams Field area, research should be done to determine the importance of this seasonal process.

2. The data available from the remote automatic weather stations in the vicinity of McMurdo, Antarctica should be

compared to that at McMurdo/Williams Field in relation to the occurrence of low visibility and weather type associated with low visibility.

3. The visibility climatology should be completed for the remaining four months not considered here.

4. Inconsistent reported data at McMurdo and Williams Field should be corrected, as appropriate.

TABLE I

Percentage Occurrence of Restricted Visibility Categories at McMurdo

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Cat 1	8.2%	9.3%	7.2%	2.7%	2.1%	1.5%	3.1%	5.8%
Cat 2	5.7%	5.0%	4.6%	2.7%	2.5%	2.4%	3.1%	5.3%
Cat 3	3.9%	3.4%	2.3%	1.3%	1.3%	1.3%	1.9%	2.9%
Total	17.8%	17.7%	14.1%	6.7%	6.9%	5.2%	8.1%	14.0%

TABLE II

Percentage Occurrence of Weather Parameters during Blowing Snow Observations

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
LT SNOW	42	35	35	42	48	68	57	36
MODERATE TO HEAVY SNOW	4	3	7	6	13	18	12	5
FOG	2	3	3	2	4	0	1	13

TABLE III

Percentage Occurrence of Weather Parameters for Fog Observations

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
BLSN	9	16	15	11	6	0	4	33
LT SN	5	25	17	34	13	30	62	21
MOD TO HVY SN	1	0	0	0	2	0	0	0

TABLE IV

Wind Statistics for All Visibilities at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	21.8	19.9	17.2	11.3	8.3	10.3	5.8	5.9
1-10KT	27.8	27.6	35.0	45.7	54.6	54.1	37.9	29.7
11-20KT	34.9	37.4	37.4	38.5	34.0	32.7	47.5	44.7
21-30KT	13.1	12.4	9.5	3.9	2.9	2.8	8.0	18.2
> 30KT	2.4	2.7	1.0	.3	.2	.1	.5	1.7
Average Speed	11	12	11	10	9	9	12	14
Resultant Speed	8	8	7	6	5	6	9	11
Resultant Direction	82	89	88	86	91	84	93	85
Max Speed	58	60	55	40	43	39	47	48
Max Speed Dir	SE	S	S/SW	NE-SE SW	S	E	S	S
% Max Speed Dir	10.3	5.2	6.9	65.3	6.8	39.8	6.4	4.1
Max Speed Pred Dir	43	44	33	40	29	39	36	40
Predominant Dir	E	E	E	E	E	E	E	E
% Predominant Dir	31.5	32.8	33.1	35.7	34.1	39.9	46.6	48.4
No Observations Obs Less Than 5%	S-W	SW-N	SW-W	S-W	S-W	S-W	SW-N	S-W
Total Observations	5774	5847	6604	6479	6668	6696	5453	5546

TABLE V

Wind Statistics when Visibility is less than One Mi at McMurdo Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	3.4	3.5	3.3	5.5	4.2	.9	2.9	1.2
1-10KT	3.5	6.6	6.3	21.7	41.3	40.5	16.2	8.2
11-20KT	35.2	34.1	42.9	43.1	36.4	45.2	54.3	37.8
21-30KT	41.6	35.1	35.5	21.1	16.1	13.2	24.3	42.9
> 30KT	16.2	21.0	11.6	.8.8	2.1	0	2.3	9.9
Average Speed	23	23	21	17	13	13	17	21
Resultant Speed	15	16	15	11	9	9	10	16
Resultant Direction	118	131	131	143	137	112	129	105
Max Speed	58	60	55	40	43	26	42	48
Max Speed Dir	SE	S	S/SW	SE/SW	S	S	S	S
% Max Speed Dir	25.2	23.1	28.0	32.0	23.0	20.8	23.1	14.4
Max Speed Pred Dir	43	44	50	40	30	25	26	35
Predominant Dir	E	E	E/SE	SE	SE	E	E	E
% Predominant Dir	28.4	32.3	57.4	28.7	27.3	43.4	31.8	48.8
No Observations								W
Obs Less Than 5%	SW-N	SW-N	SW-N	SW-N	SW-N	SW-N	SW-N	SW-N
Total Observations	476	545	479	181	143	106	173	326

TABLE VI

Wind Statistics when Visibility is greater than One but less than Three Mi at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	9.3	6.1	4.6	2.2	2.9	4.4	4.1	3.4
1-10KT	12.0	13.1	20.5	32.2	42.4	35.2	27.3	9.4
11-20KT	43.3	53.2	50.0	49.6	41.2	51.0	55.2	45.6
21-30KT	30.8	25.4	24.0	11.9	11.9	9.5	10.5	36.2
> 30KT	4.8	2.4	.9	3.6	1.8	0	3.0	5.4
Average Speed	18	17	16	14	13	13	14	19
Resultant Speed	13	13	12	9	9	10	10	17
Resultant Direction	84	96	106	124	129	109	103	86
Max Speed	42	44	39	40	38	30	47	37
Max Speed Dir	NE/E	SE	SE	NE/E	S	S	S	N/NE
% Max Speed Dir	62.7	17.2	21.2	41.5	20.0	13.8	10.5	78.7
Max Speed Pred Dir	42	40	30	40	26	29	36	37
Predominant Dir	E	E	E	E	E	E	E	E
% Predominant Dir	39.1	47.6	44.0	28.4	35.9	50.3	41.3	58.1
No Observations							SW	W
Obs Less Than 5%	SW-N	SW-N	SW-N	SW-N	SW-N	SW-N	SW-NW	S-N
Total Observations	335	296	307	183	170	159	172	296

TABLE VII

Wind Statistics when Visibility is greater than Three but less than Five Mi

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	13.9	4.4	11.4	4.7	3.4	0	3.8	1.8
1-10KT	16.9	13.4	22.1	37.7	36.7	45.4	22.6	18.8
11-20KT	38.9	50.9	46.2	47.2	48.1	41.9	51.9	40.9
21-30KT	26.0	25.6	20.3	8.3	11.4	11.3	21.7	35.3
> 30KT	4.0	6.0	0	2.4	0	1.1	0	3.0
Average Speed	15	18	14	12	13	13	15	19
Resultant Speed	11	12	10	9	10	10	11	15
Resultant Direction	82	87	101	106	121	101	104	85
Max Speed	35	45	30	31	28	32	30	35
Direction	NE/E	SE	S/SE	S/SE	SE	E	E-S	E
% Direction	54.2	15.8	31.6	34.1	31.0	44.6	78.3	53.7
Max Speed Pred Dir	35	33	28	26	27	32	30	35
Predominant Dir	E	E	E	E	E	E	E	E
% Predominant Dir	32.7	41.4	35.4	35.3	34.5	44.6	38.7	53.7
No Observations					SW-W	N	SW/NW	
Obs Less Than 5%	SW-W N	W/N	SW-N	SW-N	N	SW-N	W/N	S-N
Total Observations	223	203	158	85	87	88	106	164

TABLE VIII

Wind Statistics when Blowing Snow Occurs
at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	0	0	0	0	0	0
1-10KT	1.9	2.4	2.4	6.1	10.6	6.1	1.9	2.3
11-20KT	41.6	44.6	52.5	56.4	50.9	53.6	57.9	42.4
21-30KT	45.2	38.1	37.1	31.2	32.6	35.4	34.5	47.3
> 30KT	11.4	14.8	7.8	10.3	6.1	4.9	5.9	8.2
Average Speed	23	23	22	20	20	20	21	22
Resultant Speed	15	16	15	15	17	15	13	18
Resultant Direction	100	116	124	142	150	121	123	93
Max Speed	58	60	55	40	43	39	47	48
Max Speed Dir	SE	S	S/SW	NE/SE SW	S	E	S	S
% Max Speed Dir	21.8	17.8	24.5	71.4	45.5	42.7	24.4	8.5
Max Speed Pred Dir	43	44	32	40	43	39	36	37
Predominant Dir	E	E	E	SE	S	E	E	E
% Predominant Dir	35.1	39.4	34.1	38.9	45.5	42.7	38.9	54.8
No Observations				NW	W-N	W-N	NW-N	
Obs Less than 5%	SW-N	SW-N	SW-N	SW-N	SW/NE	SW/NE	SW-W	SW-N
Total Observations	908	897	751	265	132	82	221	650

TABLE IX

Wind Statistics when *Blowing Snow* and *Snow* Occurs at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	0	0	0	0	0	0
1-10KT	2.3	2.1	2.8	8.8	15.8	7.2	2.0	4.1
11-20KT	50.7	47.9	58.6	71.0	61.7	60.9	68.0	52.1
21-30KT	36.7	36.2	32.2	17.7	23.4	29.0	28.7	37.6
> 30KT	9.9	13.8	6.2	2.4	0	2.9	1.3	6.4
Average Speed	22	23	21	18	17	19	19	21
Resultant Speed	14	16	14	12	14	14	12	16
Resultant Direction	111	119	123	129	141	118	125	103
Max Speed	56	60	55	35	30	32	42	47
Max Speed Dir	S/SW	S	S/SW	S	S/SE	E	S	S
% Max Speed Dir	16.6	20.4	25.9	16.4	76.7	43.5	23.0	11.9
Max Speed Pred Dir	35	40	32	40	30	32	30	36
Predominant Dir	E	E	E	SW	S	E	E	E
% Predominant Dir	32.2	38.2	36.3	3.2	35.8	43.5	39.5	52.8
No Observations		W		NW	SW-N	SW-N	NW-N	W-N
Obs Less Than 5%	SW-N	SW-N	SW-N	SW-N			SW-W	SW
Total Observations	410	343	317	124	81	69	152	269

TABLE X

Wind Statistics when Fog Occurs at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	41.9	18.1	22.1	10.4	9.1	.8	8.5	5.1
1-10KT	26.3	26.7	30.4	46.0	44.4	37.4	42.6	12.6
11-20KT	29.1	41.5	27.8	37.6	39.8	55.4	36.2	41.4
21-30KT	2.8	13.3	18.7	6.3	6.7	6.3	12.7	35.6
> 30KT	0	.5	0	0	0	0	0	5.5
Average Speed	6	12	11	10	11	12	12	19
Resultant Speed	5	9	9	3	7	10	10	15
Resultant Direction	80	84	89	86	87	95	88	83
Max Speed	25	38	40	26	29	26	28	40
Max Speed Dir	SE	SE	S	S/SE	E	E	E	SE
% Max Speed Dir	7.8	12.9	1.9	35.4	36.4	62.5	55.3	12.5
Max Speed Pred Dir	22	24	26	26	29	26	28	36
Predominant Dir	E	E	E	E	E	E	E	E
% Predominant Dir	25.7	42.4	31.8	27.1	36.4	62.5	55.3	50.8
No Observations Obs Less Than 5%	S-N	S-N	S-N	S-SW/N	S-SW/N	SW-N	SW-W NW	S-N
Total Observations	179	210	154	48	88	128	47	256

TABLE XI

Wind Statistics when Blowing Snow and Fog Occurs at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	0	0	0		0	0
1-10KT	6.3	0	4.2	0	0		0	1.2
11-20KT	75.1	57.6	33.3	80.0	20.0		100.0	35.7
21-30KT	18.8	39.4	58.3	20.0	80.0		0	49.3
> 30KT	0	3.0	4.2	0	0		0	11.9
Average Speed	17	20	22	18	24		17	24
Resultant Speed	14	18	18	12	24		16	19
Resultant Direction	85	89	110	148	100		83	81
Max Speed	25	38	40	24	29		19	40
Max Speed Dir	SE	SE	S	S	E		E	SE
% Max Speed Dir	25.0	15.2	4.2	40.0	80.0		100.0	15.5
Max Speed Pred Dir	22	24	26	19	29		19	33
Predominant Dir	E	E	E	S/E	E		E	NE
% Predominant Dir	50.0	63.6	41.7	40.0	80.0		100.0	41.7
No Observations	SW-N		SW-N					SW-NW
Obs Less Than 5%			S					S/N
All Obs from		NE-SE		E/S/W	E-SE		E	
Total Obs	16	33	24	5	5	0	2	84

TABLE XII

Wind Statistics when Light Falling Snow
Occurs at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	12.5	8.4	10.1	7.6	4.4	5.4	3.7	5.3
1-10KT	21.4	22.9	34.1	46.0	45.0	44.4	33.1	29.5
11-20KT	42.0	43.6	41.1	43.1	43.1	44.8	54.4	47.6
21-30KT	19.1	18.3	12.2	3.0	4.6	5.2	8.5	15.5
> 30KT	5.0	6.6	2.4	.3	0	.3	.2	1.7
Average Speed	15	16	13	10	24	11	13	14
Resultant Speed	9	10	8	7	24	9	10	11
Resultant Direction	98	105	103	93	100	100	99	91
Max Speed	56	60	55	35	30	32	42	47
Max Speed Dir	S/SW	S	S/SW	S	SE/S	E	S	S
% Max Speed Dir	8.5	11.0	11.6	7.9	34.5	48.9	7.8	5.8
Max Speed Pred Dir	35	40	32	30	27	32	30	36
Predominant Dir	E	E	E	E	E	E	E	E
% Predominant Dir	31.7	38.6	35.7	38.2	38.2	49.9	48.0	50.1
No Observations Less Than 5%								
Obs Less Than 5%	SW-N	SW-N	SW-N	SW-NW	SW-N	SW-N	SW-N	SW-N
Total Observations	783	682	733	723	765	753	950	812

TABLE XIII

Wind Statistics when Moderate to Heavy Snow Occurs at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	4.4	14.6	7.2	9.3	0	2.3	3.0	0
1-10KT	8.8	8.4	12.9	32.7	40.8	37.2	24.0	17.3
11-20KT	51.2	46.0	46.2	44.2	40.9	44.2	46.3	45.3
21-30KT	31.0	25.1	30.3	11.7	18.4	16.3	26.4	30.7
> 30KT	4.4	6.3	2.9	2.3	0	0	1.5	6.7
Average Speed	19	16	18	14	13	13	16	18
Resultant Speed	10	11	13	5	10	10	9	14
Resultant Direction	146	131	120	134	135	133	126	113
Max Speed	40	48	38	30	26	26	35	34
Max Speed Dir	SW	SW	S	SW	SE	S	S	S/SE
% Max Speed Dir	8.9	4.2	23.2	5.1	38.8	34.9	22.4	31.4
Max Speed Pred Dir	35	30	28	20	26	25	35	32
Predominant Dir	S	SE	E	E	SE	E	S	E
% Predominant Dir	33.3	31.3	42.0	23.1	38.8	39.5	22.4	44.0
No Observations	W-N	NW-N	SW-NW		SW-W	SW-N		SW-N
Obs Less Than 5%		SW-W	N	SW-NW	NW-N	NE	SW-N	
Total Observations	45	48	69	43	49	43	67	75

TABLE XIV

Wind Statistics when Ice Crystals Occur at McMurdo, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	63.1	58.6	74.1	37.5	0	0	0	0
1-10KT	21.9	36.1	18.5	25.0	28.6	15.8	20.0	25.0
11-20KT	11.4	5.1	7.4	37.5	70.5	68.5	80.0	25.0
21-30KT	3.5	0	0	0	0	15.5	0	50.0
> 30KT	0	0	0	0	0	0	0	0
Average Speed	4	3	3	7	12	17	14	10
Resultant Speed	3	2	1	6	11	16	13	13
Resultant Direction	66	77	57	84	77	88	101	77
Max Speed	25	17	20	16	18	26	18	24
Max Speed Dir	NE/E	E	E	E	E	E	E	E
% Max Speed Dir	28.3	17.2	3.7	50.0	57.1	64.8	80.0	75.0
Max Speed Pred Dir	25	17	10	16	18	26	18	24
Predominant Dir	E	E	N	E	E	E	E	E
% Predominant Dir	18.4	17.2	7.4	50.0	57.1	68.4	80.0	74.0
No Observations	S-SW	S-SW	S-SW					
Obs Less Than 5%	SE/W-N	W-NW	W-NW					
All Obs From		SE	NE-SE	E/NW	NE-E SW	NE-SE	E-SE	N/E
Total Observations	141	58	27	8	7	19	5	[illegible]

TABLE XV

Monthly Percentage Occurrence of Snow and Fog

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Sinclair								
Snow	19	15	13	11	13	10	19	17
Fog	3	2	3	1	2	2	1	4
This study								
Snow	16.7	13.4	12.4	11.8	12.0	13.3	18.5	15.9
Fog	2.9	3.6	2.3	.8	1.3	1.8	.8	4.7
Diff Snow	13.7	11.9	4.8	-6.7	8.3	-24.8	2.7	6.9
Diff Fog	3.4	-44.4	30.4	25.0	53.8	11.1	25.0	-14.9
Thompson								
Snow	18	15	12	11	13	9	14	12
Fog	2	2	3	1	2	2	1	4
Diff Snow	7.8	11.9	-3.2	-6.7	8.3	-32.3	-24.3	-24.5
Diff Fog	-31.0	-44.4	30.4	25.0	53.8	11.1	25.0	-14.9

TABLE XVI

Monthly Maximum Averaged and Instantaneous Wind Speeds by Direction and Month

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Mercer								
Speed	74	80	72	67	46	47	56	52
Direction	S	SE	SSW	S	S	SE	S	S
This study								
Speed	58	60	55	40	43	39	47	48
Direction	SE	S	S/SW	NE/E SE/SW	S	E	S	S

TABLE XVII

Monthly Restricted Visibility by Category in Nautical Miles

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Mercer								
Cat 1	8.4	12.3	5.6	2.3	3.2	1.8	1.3	5.6
Cat 2	4.4	6.2	5.7	2.1	3.0	2.7	3.1	6.3
Cat 3	4.1	3.8	3.9	1.2	1.4	1.7	1.8	3.5
Total	16.9	22.3	15.2	6.6	7.6	6.3	6.2	15.4

TABLE XVIII

Percentage Occurrence of Restricted Visibility Categories at Williams Field

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Cat 1	4.9%	11.7%	6.9%	4.7%	2.8%	5.3%	4.0%	2.0%
Cat 2	2.2%	5.3%	4.2%	2.7%	2.6%	3.1%	2.6%	10.2%
Cat 3	3.5%	1.1%	3.4%	1.7%	1.1%	1.7%	2.1%	10.2%
Total	10.6%	18.1%	14.5%	9.2%	6.5%	10.1%	8.7%	22.4%
# Obs	225	38	1213	2301	2356	2430	941	49

TABLE XIX

Wind Statistics for All Visibilities at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	7.6	5.3	14.0	12.0	11.0	8.8	8.2	4.1
1-10KT	69.0	76.4	62.3	60.3	70.1	73.7	70.3	65.2
11-20KT	22.2	16.0	22.0	24.2	18.1	16.8	19.1	30.6
21-30KT	.8	2.1	3.7	2.3	.8	.6	1.7	0
> 30KT	.4	2.1	1.0	.5	.1	0	.7	0
Average Wind	8	8	8	8	7	7	8	9
Resultant Speed	4	4	3	4	3	4	3	8
Resultant Direction	76	101	100	90	80	80	91	254
Max Speed	40	50	50	59	45	35	40	20
Max Speed Dir	SW	S	SE	S	S	S	S	W
% MAx Speed Dir	5.8	11.7	12.4	6.2	25.5	4.4	6.9	40.8
Max Speed Pred Dir	20	15	40	30	25	30	20	20
Predominant Dir	NE	NE	E	E	E	E	E/NE	W
% Predominant Dir	38.7	37.2	24.4	26.0	25.5	29.6	50.1	40.8
No Observations		W						NE
Obs Less Than 5%	W-NW	SW/NW	NW	SW-W	S-SW	S-NW	SW	N-S
Total Observations	22[illegible]	94	1218	2001	2356	2430	941	49

TABLE XX

Wind Statistics when Visibility is less than One Mi
at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	2.4	1.1	0	5.5	0	0
1-10KT	18.2	36.4	20.4	18.6	61.5	63.8	26.2	100.0
11-20KT	54.6	27.3	27.5	41.3	24.6	21.3	36.9	0
21-30KT	18.2	18.2	36.9	26.0	13.8	8.7	23.7	0
> 30KT	9.1	18.2	13.2	12.1	0	.8	13.2	0
Average Wind	21	22	21	20	11	10	17	3
Resultant Speed	16	17	10	13	6	4	15	3
Resultant Direction	157	165	153	159	131	98	168	203
Max Speed	40	50	50	59	30	35	38	3
Max Speed Dir	SW	S	SE	S	SW	S	S	SW
% Max Speed Dir	9.1	45.5	21.4	37.0	7.7	12.6	44.7	100.0
Max Speed Pred Dir	30	50	50	59	25	15	38	3
Predominant Dir	S	S	SE	S	E	NE	S	SW
% Predominant Dir	45.5	45.5	21.4	37.0	26.2	32.3	44.7	100.0
No Observations	W-NW/NE	W-NE					SW	
Obs Less Than 5%			W/N	W-NW	W-NW	SW-NW	W-N	
All Obs From								SW
Total Observations	11	11	84	92	65	127	38	1

TABLE XXI

Wind Statistics when Visibility is greater than One but less than Three Mi at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	13.5	3.7	4.9	10.5	16.7	20.0
1-10KT	60.0	60.0	51.9	48.2	57.3	59.2	45.9	80.0
11-20KT	40.0	40.0	28.7	40.8	34.4	28.9	37.5	0
21-30KT	0	0	5.7	13.1	3.2	1.3	0	0
> 30KT	0	0	0	0	0	0	0	0
Average Wind	10	11	10	13	10	9	8	3
Resultant Speed	7	4	3	6	5	5	5	0
Resultant Direction	106	119	101	127	114	94	94	312
Max Speed	15	15	30	30	27	23	20	4
Max Speed Dir	E	E/S	NW	S	S-SE	S	E	N/S
% Max Speed Dir	40.0	60.0	9.6	16.7	22.9	7.9	29.2	80.0
Max Speed Pred Dir	15	15	22	25	15	18	20/13	4
Predominant Dir	E	S	E	SE	E	E	E/SE	N/S
% Predominant Dir	40.0	40.0	32.7	29.6	41.0	32.9	58.4	80.0
No Observations	NW-NE SW	SW-NW SE					S-SW N	
Obs Less Than 5%			S/N-NE	SW-W	SW/N	W-NW	W	
All Obs From								S/N
Total Observations	5	5	52	54	61	76	24	5

TABLE XXII

Wind Statistics when Visibility is greater than Three but less than Five Mi at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	2.4	14.7	18.5	2.4	10.0	20.0
1-10KT	25.0	100.0	58.4	32.3	55.5	70.6	45.0	80.0
11-20KT	75.0	0	38.2	44.1	25.9	24.3	40.0	0
21-30KT	0	0	2.4	8.8	0	2.4	0	0
> 30KT	0	0	0	0	0	0	5.0	0
Average Wind	14	5	11	11	8	10	11	4
Resultant Speed	12	5	3	8	4	7	2	3
Resultant Direction	78	33	92	99	119	100	195	203
Max Speed	20	5	25	25	20	24	40	10
Max Speed Dir	NE	NE	NW	S/NE	S	S	S	SW
% Max Speed Dir	37.5	100.0	4.8	26.4	11.1	7.3	10.0	40.0
Max Speed Pred Dir	20	5	20	18	14	15	20/12	10
Predominant Dir	NE	NE	E	SE	E	E	E/W	SW
% Predominant Dir	37.5	100.0	33.3	20.6	33.3	41.5	40.0	40.0
No Observations	S-SW NW-N			W-NW	N	W-NW	SW	W-NE
Obs Less Than 5%			S/NW		SW-NW	SW/N		E-SE
All Obs From		NE						SW
Total Observations	8	1	42	34	27	41	20	[illegible]

TABLE XXIII

Wind Statistics when Blowing Snow Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	.7	0	0	0	0	
1-10KT	4.3	69.3	16.1	3.5	27.1	11.7	13.6	
11-20KT	82.4	15.4	43.8	62.4	55.8	63.4	49.9	
21-30KT	8.6	15.4	30.6	25.8	17.2	23.4	22.7	
> 30KT	4.3	0	8.7	8.4	0	1.7	13.6	
Average Wind	20	23	20	21	15	18	20	
Resultant Speed	10	17	8	13	8	8	15	
Resultant Direction	135	164	139	148	135	145	177	
Max Speed	40	50	50	59	30	35	40	
Direction	SW	S	SE	S	SE/SW	S	S	
% Direction	8.7	61.5	19.0	37.5	20.0	38.3	52.3	
Max Speed Pred Dir	30	50	40	59	25	35	40	
Predominant Dir	S	S	E	S	E	S	S	
% Predominant Dir	34.8	61.5	27.0	37.5	38.6	38.3	52.3	
No Observations	W/N	SW-NW NE			W	W	SW/NE	
Obs Less Than 5%			N	SW-N	NW-N	SW/NE NW	N	
Total Observations	23	13	137	144	70	60	44	0

TABLE XXIV

Wind Statistics when Blowing Snow and Snow
Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	2.5	0	0	0	0	
1-10KT	0	0	22.5	5.6	38.5	15.9	17.7	
11-20KT	100.0	100.0	55.0	47.4	48.8	56.8	58.9	
21-30KT	0	0	15.0	16.7	12.8	25.1	23.5	
> 30KT	0	0	5.0	30.5	0	2.3	0	
Average Wind	18	18	16	24	13	18	17	
Resultant Speed	18	13	9	15	7	6	10	
Resultant Direction	113	136	134	177	132	146	159	
Max Speed	18	20	34	59	30	35	30	
Max Speed Dir	SE	S	S	S	SW	S	S	
% Max Speed Dir	100.0	50.0	22.5	47.2	10.3	34.1	35.3	
Max Speed Pred Dir	18	15/20	25	59	17	35	30	
Predominant Dir	SE	S/E	E	S	E	S	S	
% Predominant Dir	100.0	100.0	35.0	47.2	35.9	34.1	35.3	
No Observations			NW		W-NW	W/NE	N-NE SW	
Obs Less Than 5%			W/N	NW	N	NW/SW		
All Obs From	SE	S/E						
Total Observations	2	2	40	39	36	44	17	0

TABLE XXV

Wind Statistics when Fog Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	16.9	8.6	8.2	6.5	7.7	20.0
1-10KT	80.0	100.0	71.8	65.8	69.7	81.0	77.0	80.0
11-20KT	20.0	0	11.2	20.0	21.9	12.3	15.4	0
21-30KT	0	0	0	5.8	0	0	0	0
> 30KT	0	0	0	0	0	0	0	0
Average Wind	7	6	6	9	7	7	6	4
Resultant Speed	3	6	3	5	4	5	5	2
Resultant Direction	158	59	72	103	87	74	84	237
Max Speed	20	10	18	24	20	19	13	10
Max Speed Dir	S	E	W	S	SE	SE	SE	SW
% Max Speed Dir	20.0	33.3	8.5	11.4	17.8	9.1	15.4	20.0
Max Speed Pred Dir	6	9	15	22	15	18	12	10/8
Predominant Dir	NE	NE	E	E	E	NE	E	SW/W
% Predominant Dir	40.0	66.7	28.2	34.3	35.6	38.3	38.5	40.0
No Observations	SE/SW NW-N		S	NW		S	S-NW	NE-E
Obs Less Than 5% All Obs From		NE-E	N	SW/N	S-W	SW-N		
Total Observations	5	6	71	35	73	154	13	10

TABLE XXVI

Wind Statistics when Blowing Snow and Fog Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0		0	0	0	0		
1-10KT	0		66.7	0	0	0		
11-20KT	100.0		33.3	80.0	100.0	100.0		
21-30KT	0		0	20.0	0	0		
> 30KT	0		0	0	0	0		
Average Wind	20		13	17	15	15		
Resultant Speed	20		1	16	15	15		
Resultant Direction	183		73	167	293	123		
Max Speed	20		18	24	15	15		
Max Speed Dir	S		W	S	NW	SE		
% Max Speed Dir	100.0		33.3	80.0	100.0	100.0		
Max Speed Pred Dir	20		10	24	15	15		
Predominant Dir	S		E	S	NW	SE		
% Predominant Dir	100.0		66.7	80.0	100.0	100.0		
No Observations								
Obs Less Than 5%								
All Obs From			E/SW	S/SE	NW	SE		
Total Observations	1	0	3	5	1	1	0	0

TABLE XXVII

Wind Statistics when Light Falling Snow Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	4.3	6.7	12.5	4.7	10.5	25.0
1-10KT	28.6	100.0	60.9	61.2	59.9	65.2	47.8	75.0
11-20KT	71.5	0	27.2	23.8	27.1	27.3	39.7	0
21-30KT	0	0	5.5	3.7	.7	2.9	2.3	0
> 30KT	0	0	2.2	4.4	0	0	0	0
Average Wind	13	8	11	10	8	10	9	3
Resultant Speed	11	8	5	.4	5	6	6	2
Resultant Direction	93	70	109	109	88	95	110	220
Max Speed	18	10	34	45	25	25	25	10
Max Speed Dir	SE	NE-E	S	W	S	S	S	SW
% Max Speed Dir	28.6	100.0	14.1	.7	5.9	8.1	3.5	12.5
Max Speed Pred Dir	15	10	25	18	17	15	20	4
Predominant Dir	E	E	E	E	E	E	E	S
% Predominant Dir	42.9	60.0	27.2	31.3	36.8	40.1	31.4	25.0
No Observations	NW-N S-SW				SW		SW	NW/SE
Obs Less Than 5%			W-NW	W-NW		SW-N	W/N	
All Obs From		NE-E						
Total Observations	7	5	92	134	152	172	86	8

TABLE XXVIII

Wind Statistics when Moderate to Heavy Snow
Occurs at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm	0	0	7.7	6.3	0	9.6	5.9	0
1-10KT	100.0	71.5	46.2	40.8	59.1	32.6	47.1	100.0
11-20KT	0	28.6	38.5	31.2	29.5	44.1	35.4	0
21-30KT	0	0	7.7	6.2	11.3	11.5	11.8	0
> 30KT	0	0	0	15.6	0	1.9	0	0
Average Wind	8	10	11	16	10	13	11	3
Resultant Speed	3	5	6	8	5	5	6	3
Resultant Direction	129	129	145	168	143	133	147	203
Max Speed	9	20	25	59	30	35	30	3
Max Speed Dir	S	S	SW	S	SW	S	S	SW
% Max Speed Dir	33.3	28.6	15.4	25.0	9.1	25.0	23.5	100.0
Max Speed Pred Dir	8	15	20	59	14	35	30	3
Predominant Dir	N/SE/S	E	E	S	E	S	S/SE/NE	SW
% Predominant Dir	100.0	42.9	38.5	25.0	31.8	25.0	20.5	100.0
No Observations		NE/SE W-NW	NW-N			W	SW/N	
Obs Less Than 5%					W-NW	SW/NW		
All Obs From	N/S/SE							SW
Total Observations	3	7	13	32	44	52	17	1

TABLE XXIX

Wind Statistics when Ice Crystals Occur
at Williams Field, Antarctica

	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR
Calm			0		0	0		0
1-10KT			100.0		100.0	75.0		100.0
11-20KT			0		0	25.0		0
21-30KT			0		0	0		0
> 30KT			0		0	0		0
Average Wind			5		4	8		4
Resultant Speed			3		4	7		3
Resultant Direction			53		93	72		181
Max Speed			10		4	15		5
Max Speed Dir			E		E	E		SW
% Max Speed Dir			33.3		100.0	31.3		50.0
Max Speed Pred DIr			6/10		4	14		3/5
Predominant Dir			E-NE		E	NE		SE/SW
% Predominant Dir			66.7		100.0	56.3		100.0
No Observations			NW-N SE-S			SW-N		
Obs Less Than 5%			NE-NW					
All Obs From					E			
Total Observations	0	0	6	0	1	16	0	[illegible]

Figure 1. Antarctica.

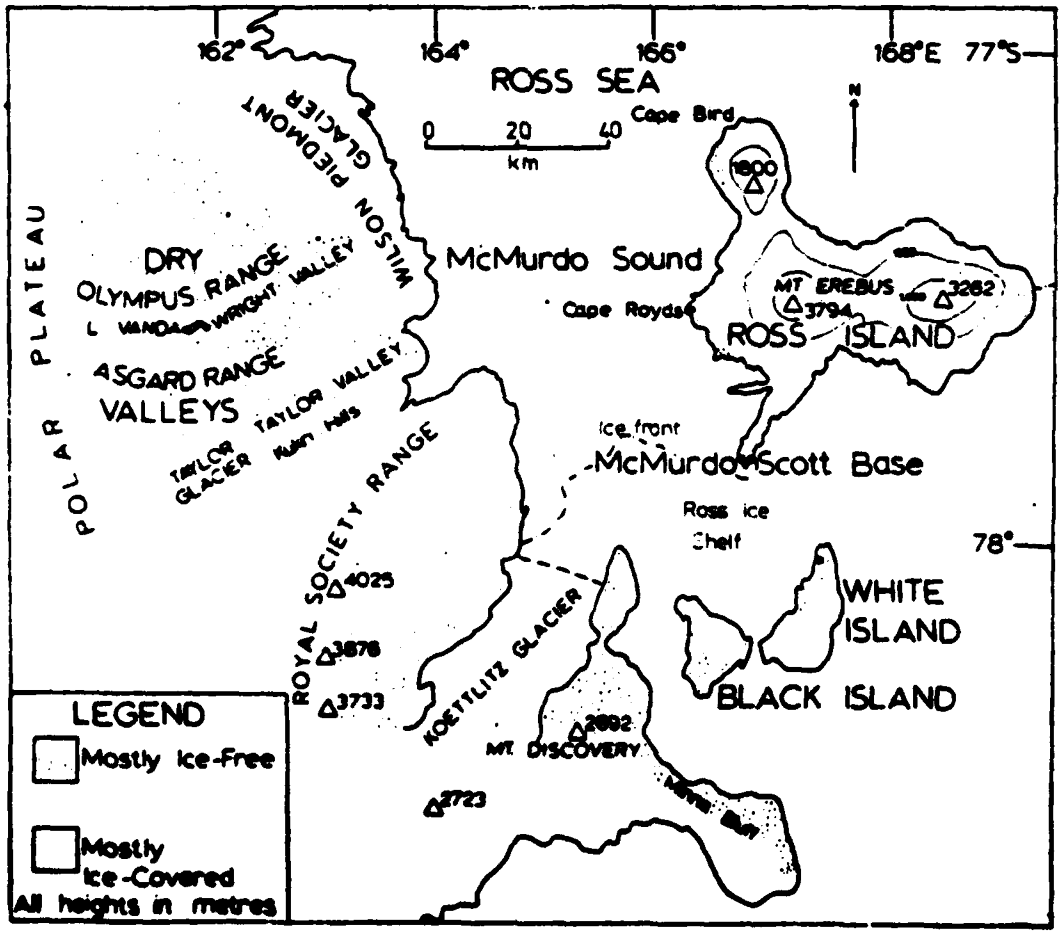


Figure 2. McMurdo Local Area

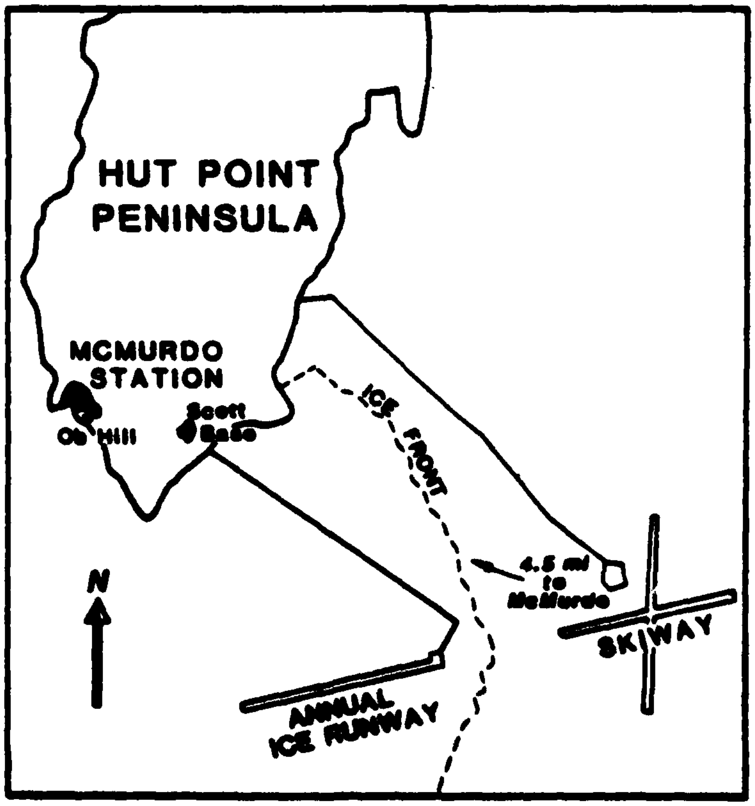


Figure 3. Williams Field Complex

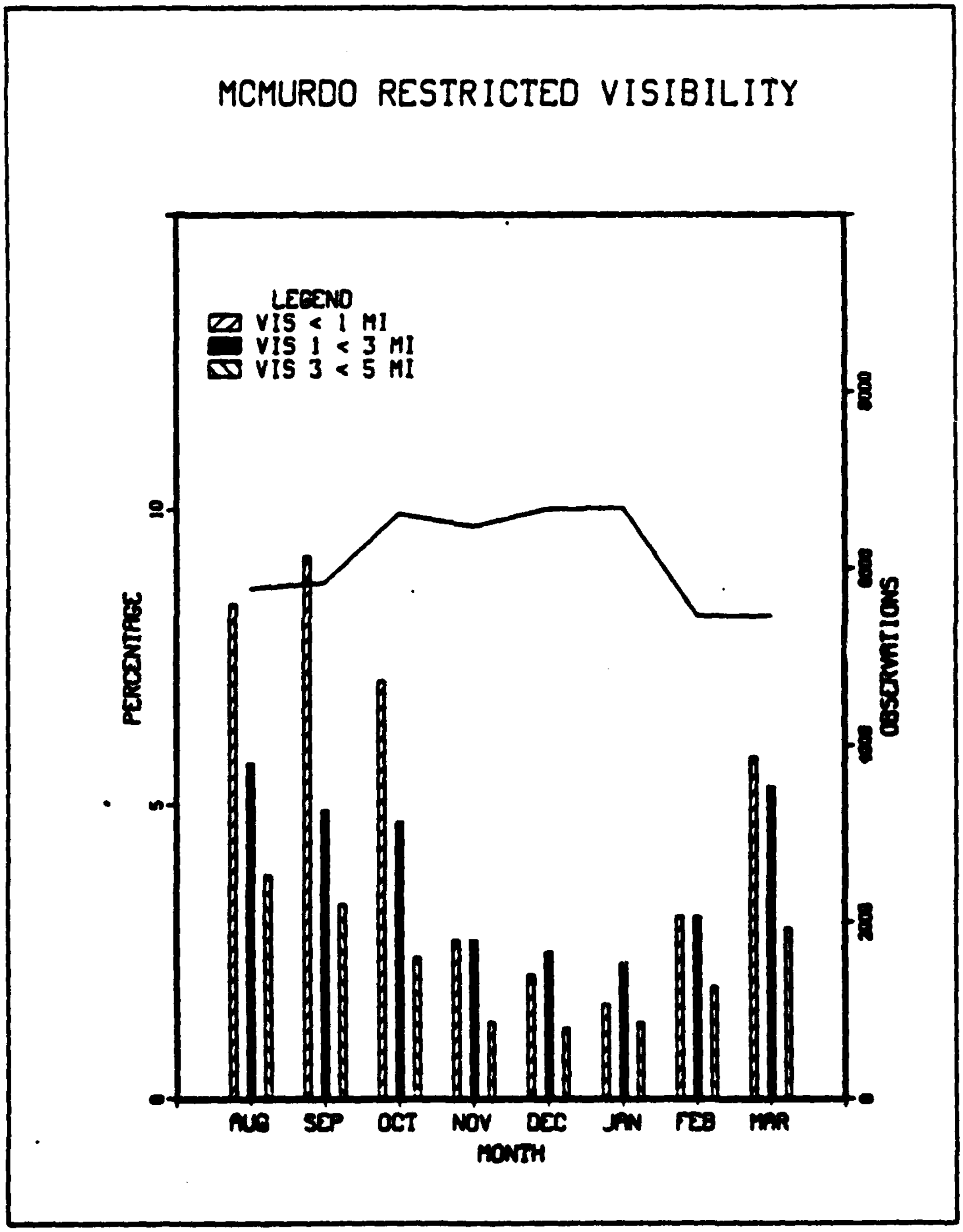


Figure 4. Monthly Climatology of Restricted Visibility at McMurdo, Antarctica.

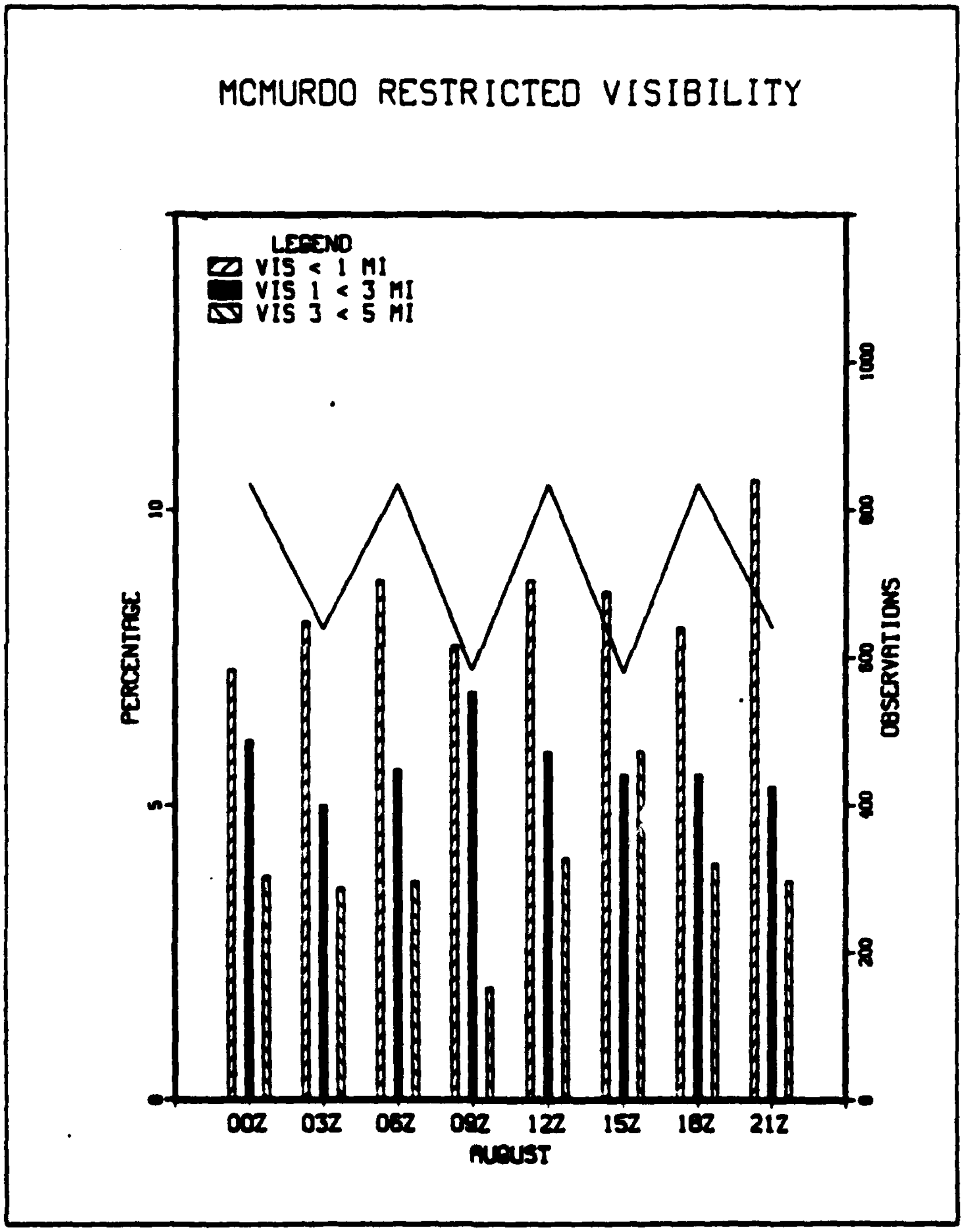


Figure 5. Diurnal Climatology of Restricted Visibility by Category for August, at McMurdo, Antarctica.

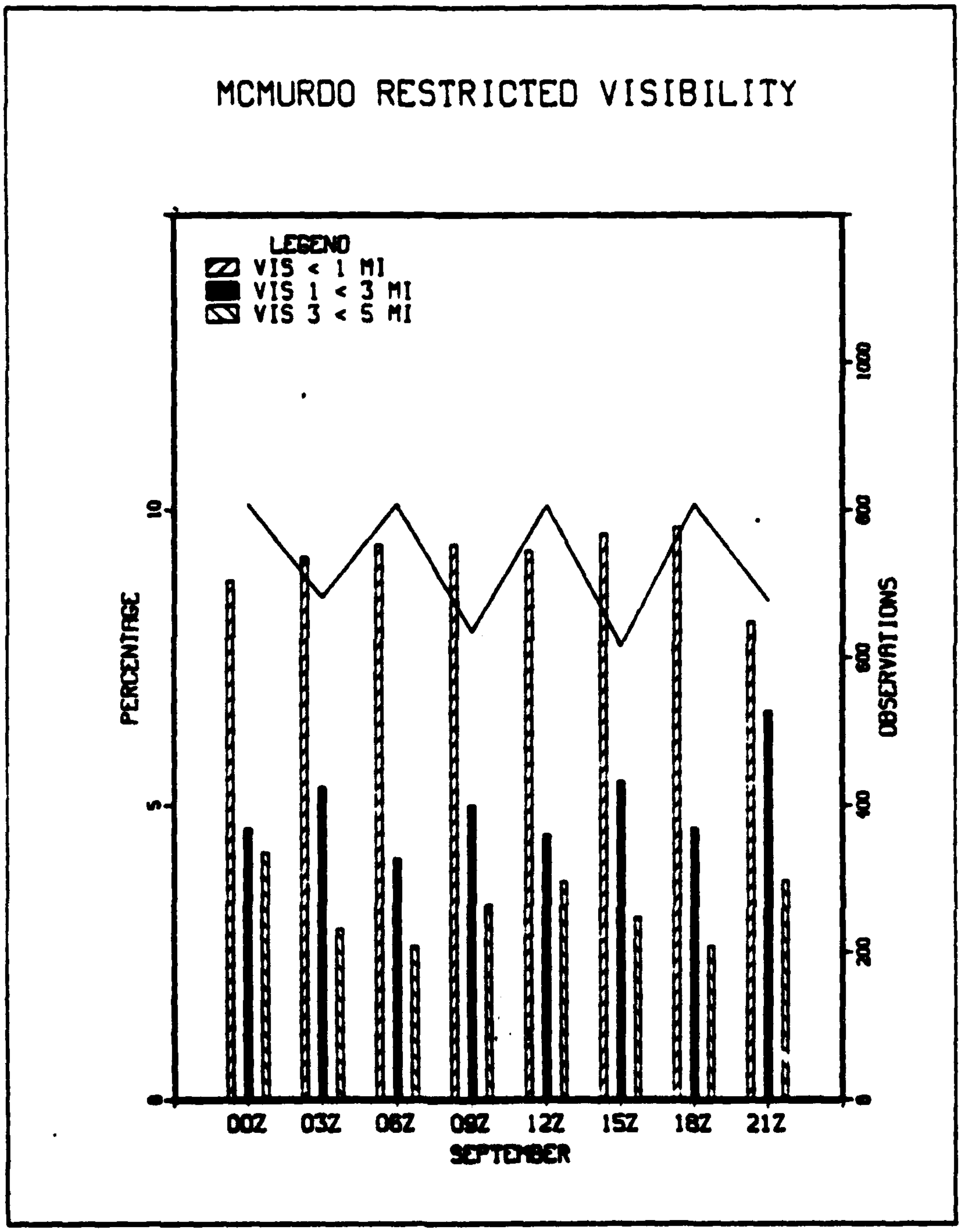


Figure 6. Diurnal Climatology of Restricted Visibility by Category for September, at McMurdo, Antarctica.

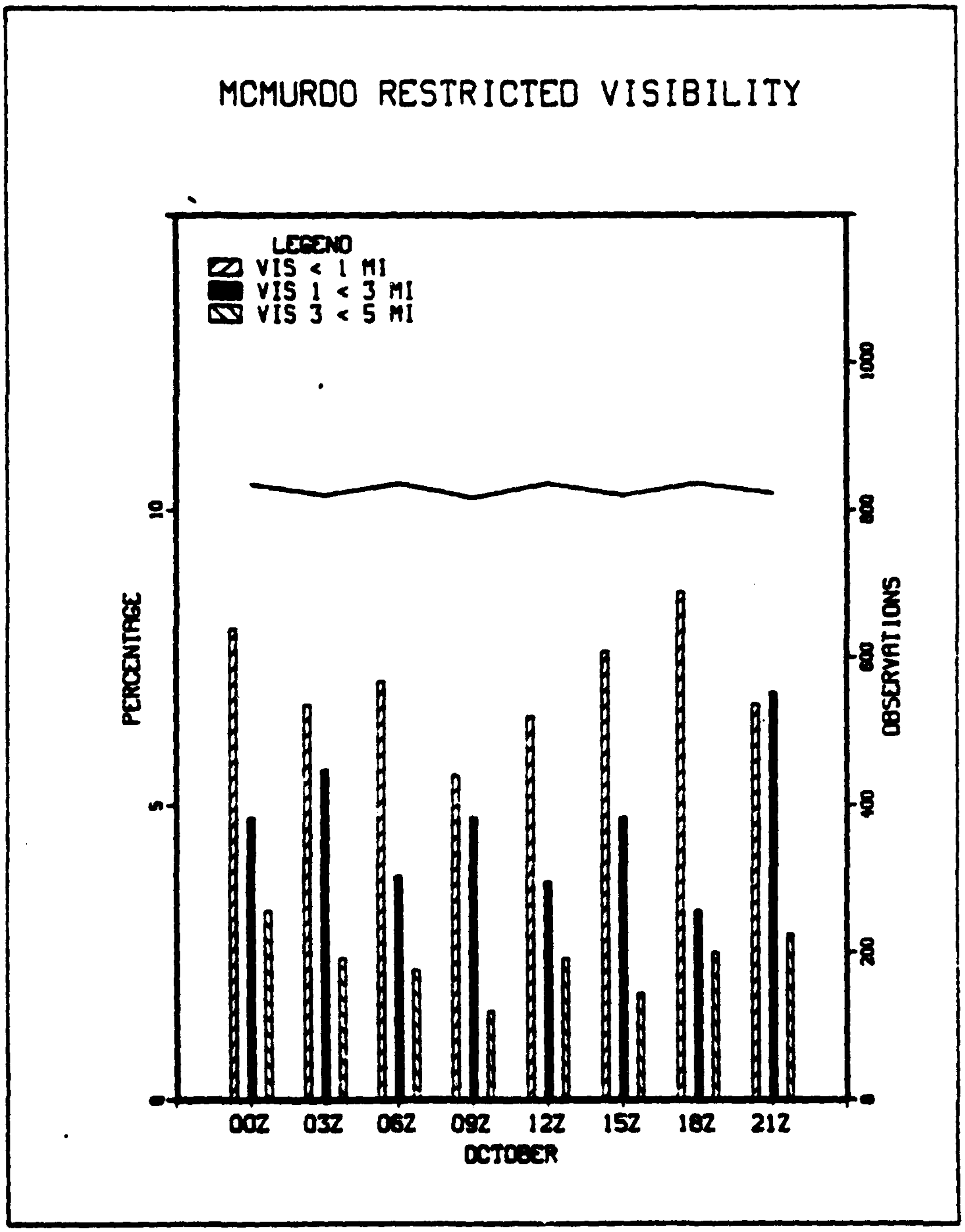


Figure 7. Diurnal Climatology of Restricted Visibility by Category for October, at McMurdo, Antarctica.

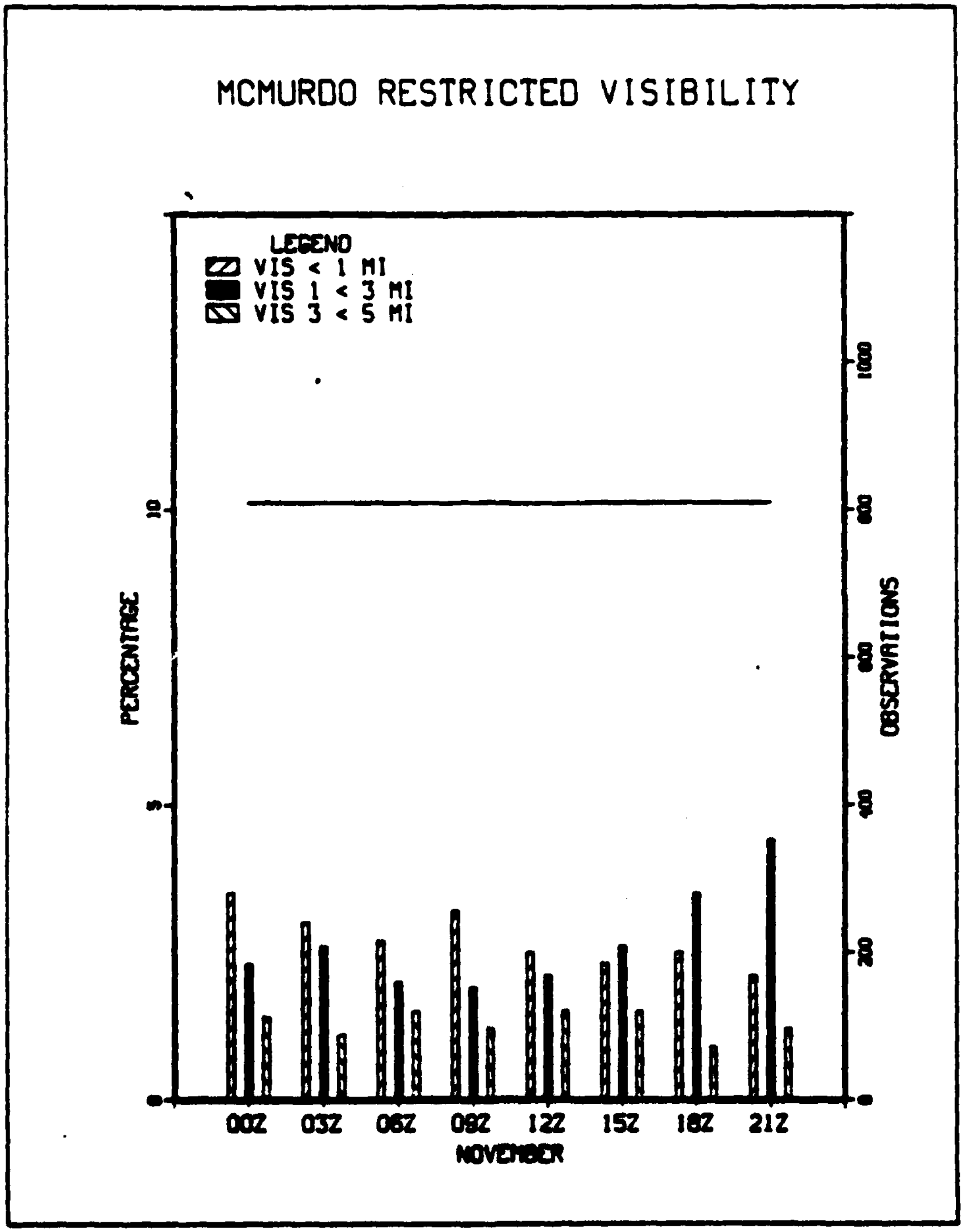


Figure 8. Diurnal Climatology of Restricted Visibility by Category for November, at McMurdo, Antarctica.

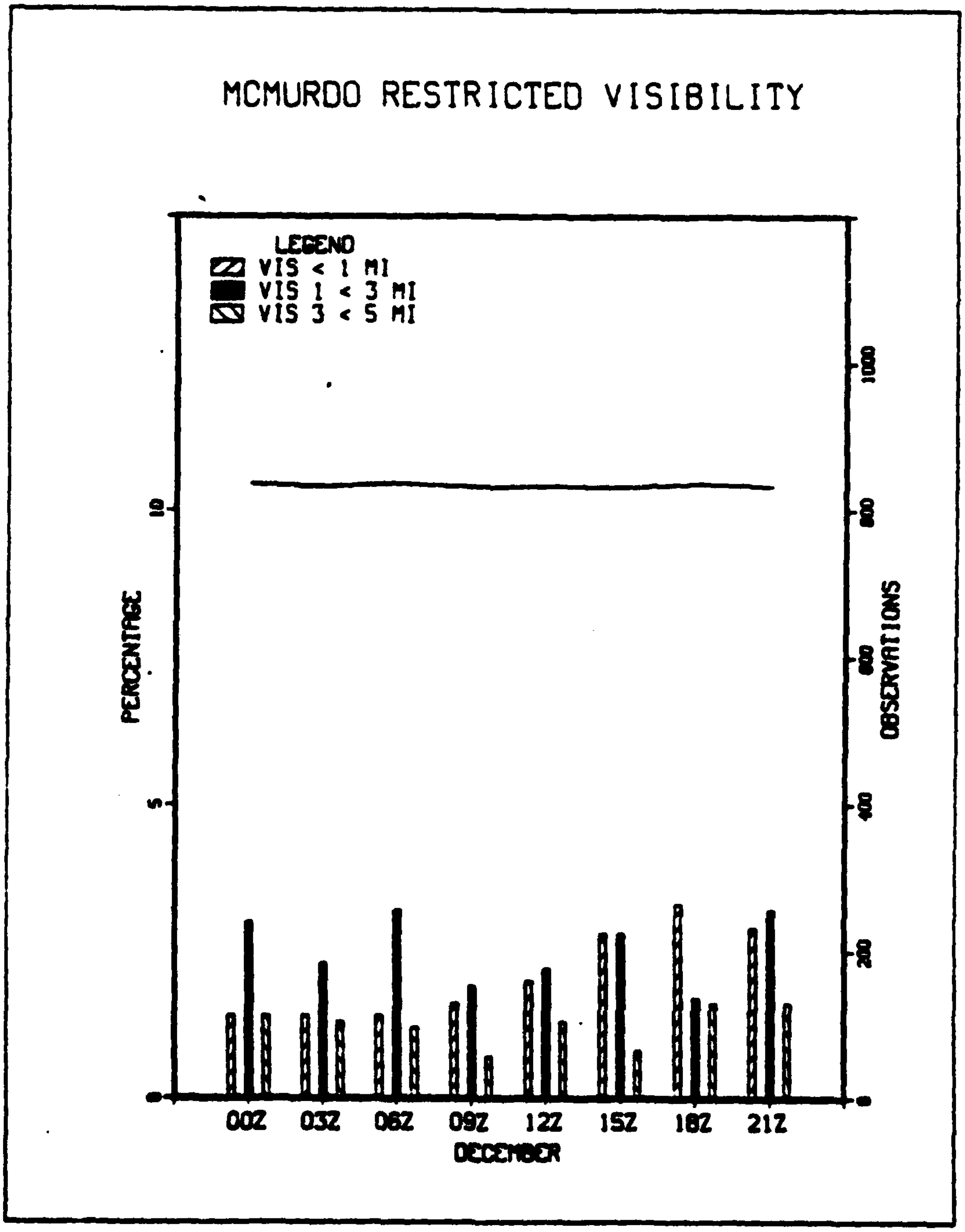


Figure 9. Diurnal Climatology of Restricted Visibility by Category for December, at McMurdo, Antarctica.

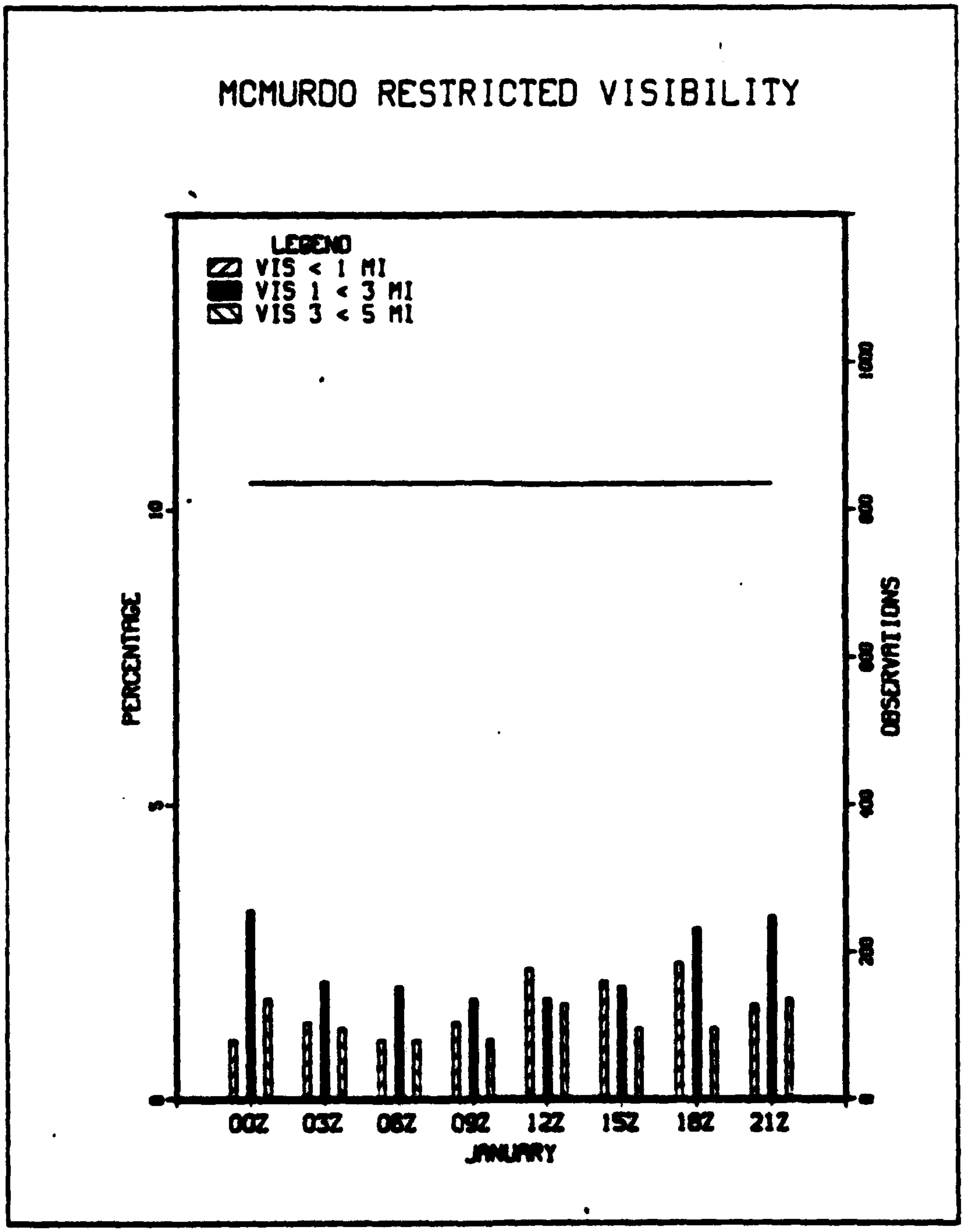


Figure 10. Diurnal Climatology of Restricted Visibility by Category for January, at McMurdo, Antarctica.

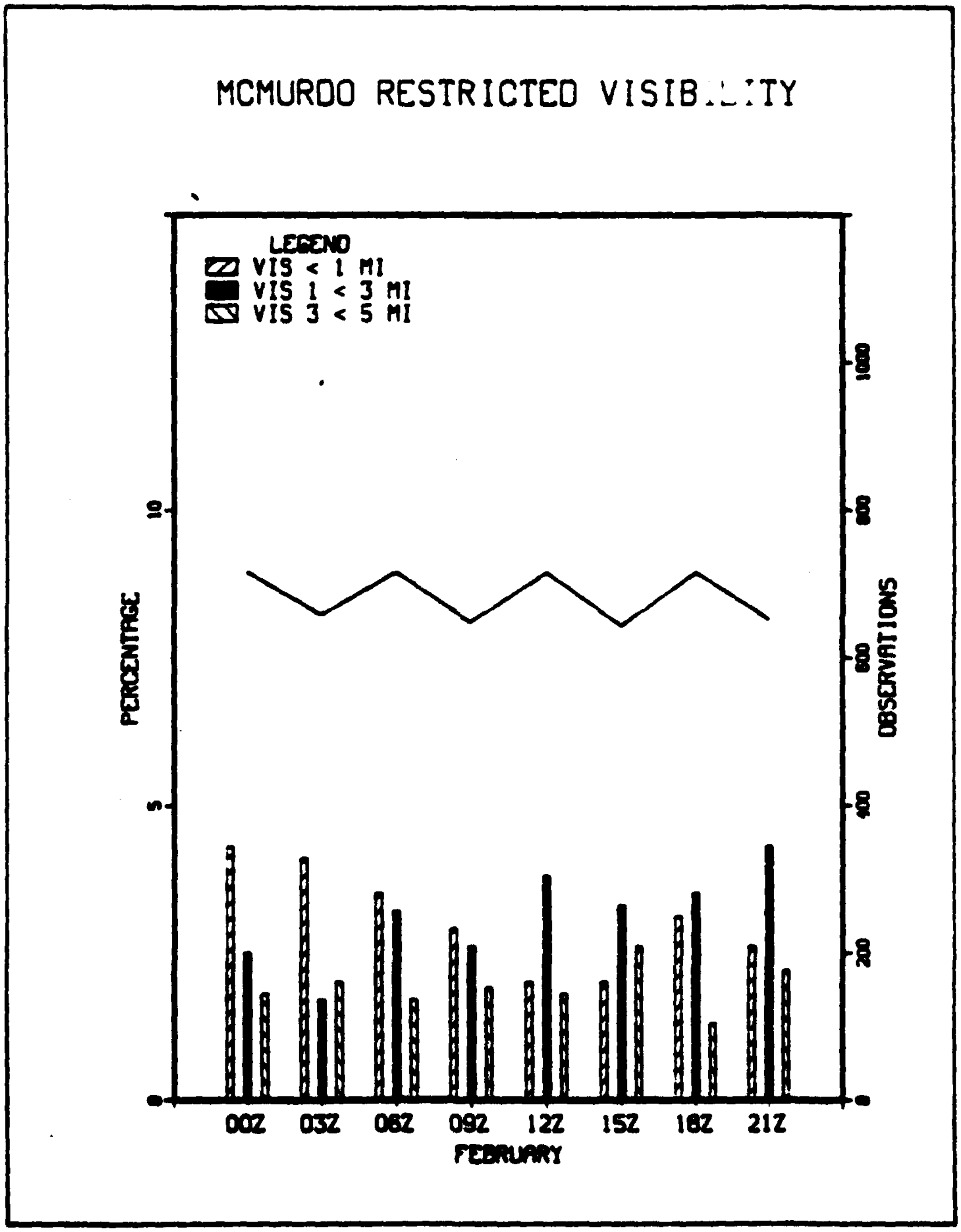


Figure 11. Diurnal Climatology of Restricted Visibility by Category for February, at McMurdo, Antarctica.

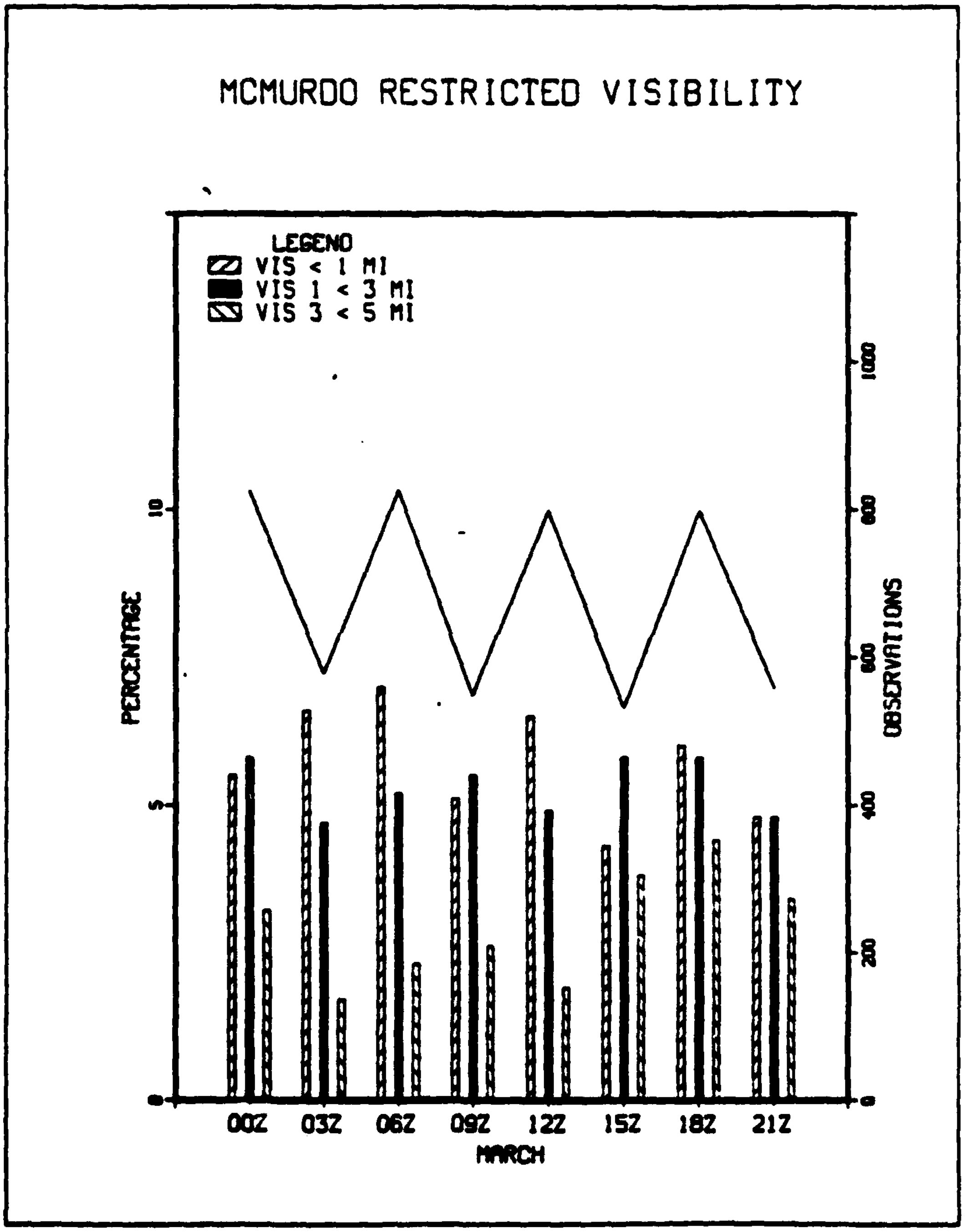


Figure 12. Diurnal Climatology of Restricted Visibility by Category for March, at McMurdo, Antarctica.

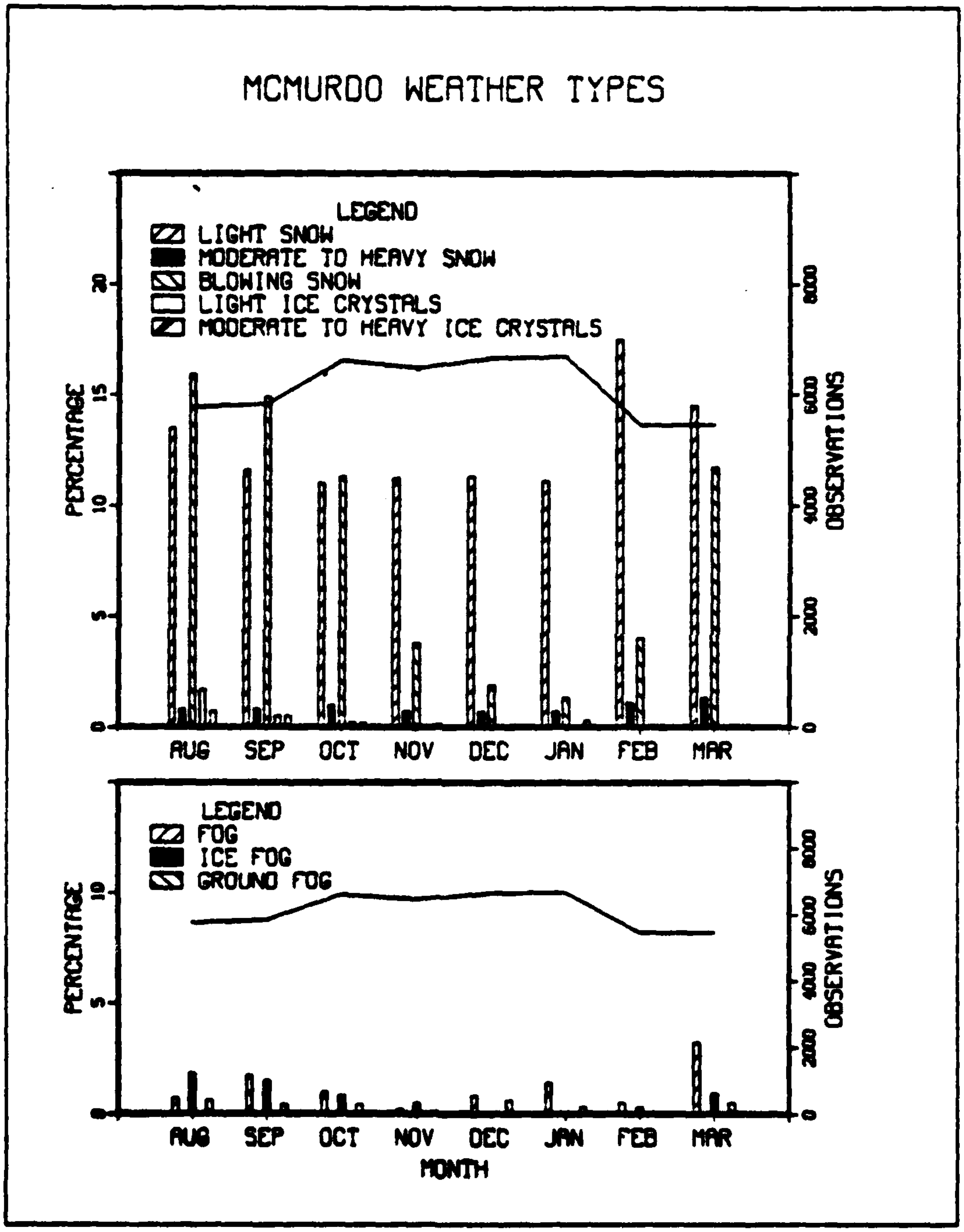


Figure 13. Monthly Climatology of Weather Types at McMurdo, Antarctica.

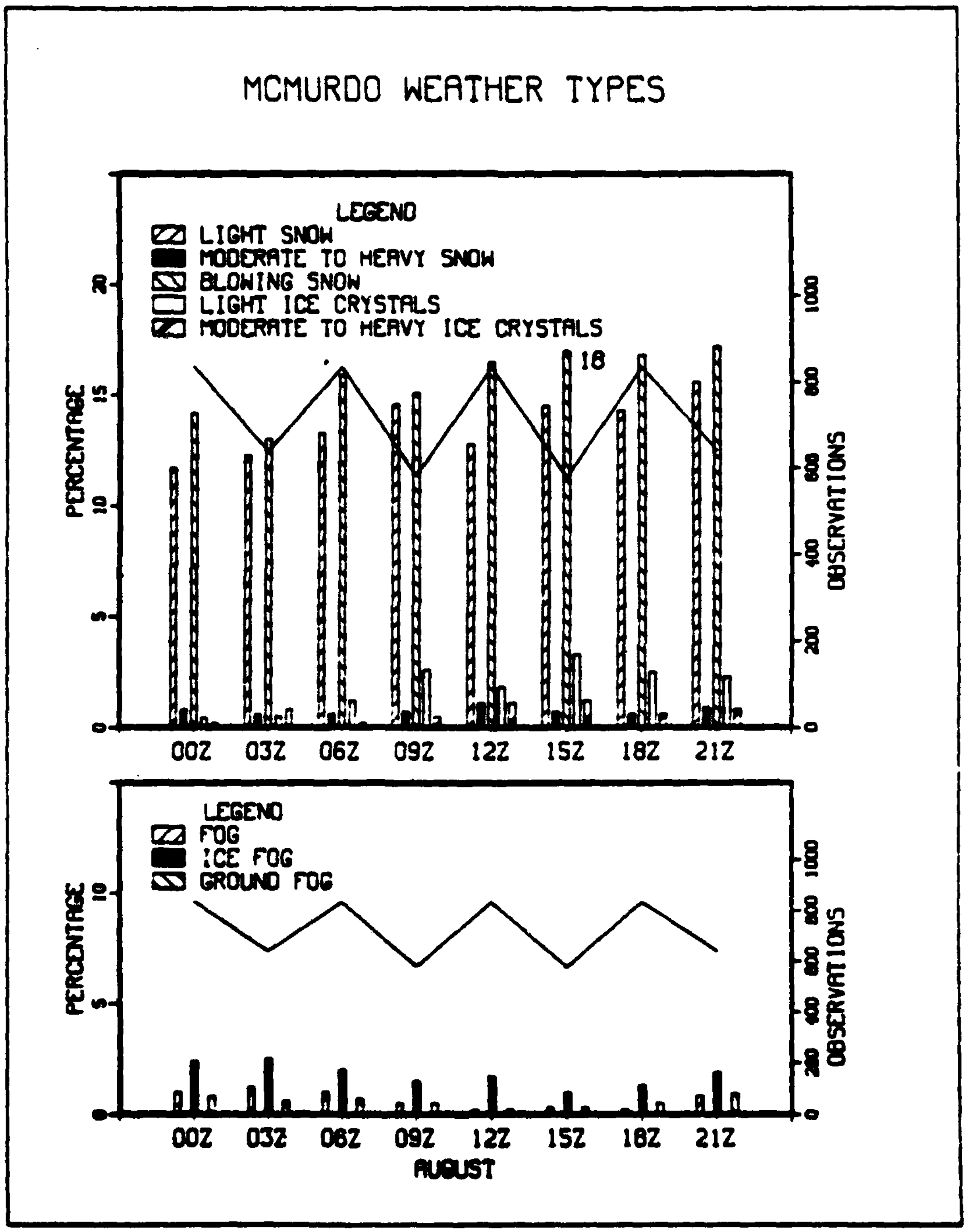
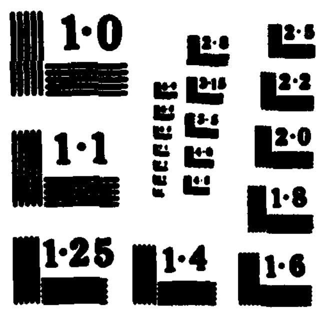


Figure 14. Diurnal Climatology of Weather Types For August at McMurdo, Antarctica.

AD-A148 108 THE VISIBILITY CLIMATOLOGY OF MCMURDO SOUND/WILLIAMS FIELD ANTARCTICA(U) NAVAL POSTGRADUATE SCHOOL MONTEREY CA C G SOUDERS MAR 84 2/2

UNCLASSIFIED F/G 4/2 NL

END


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5

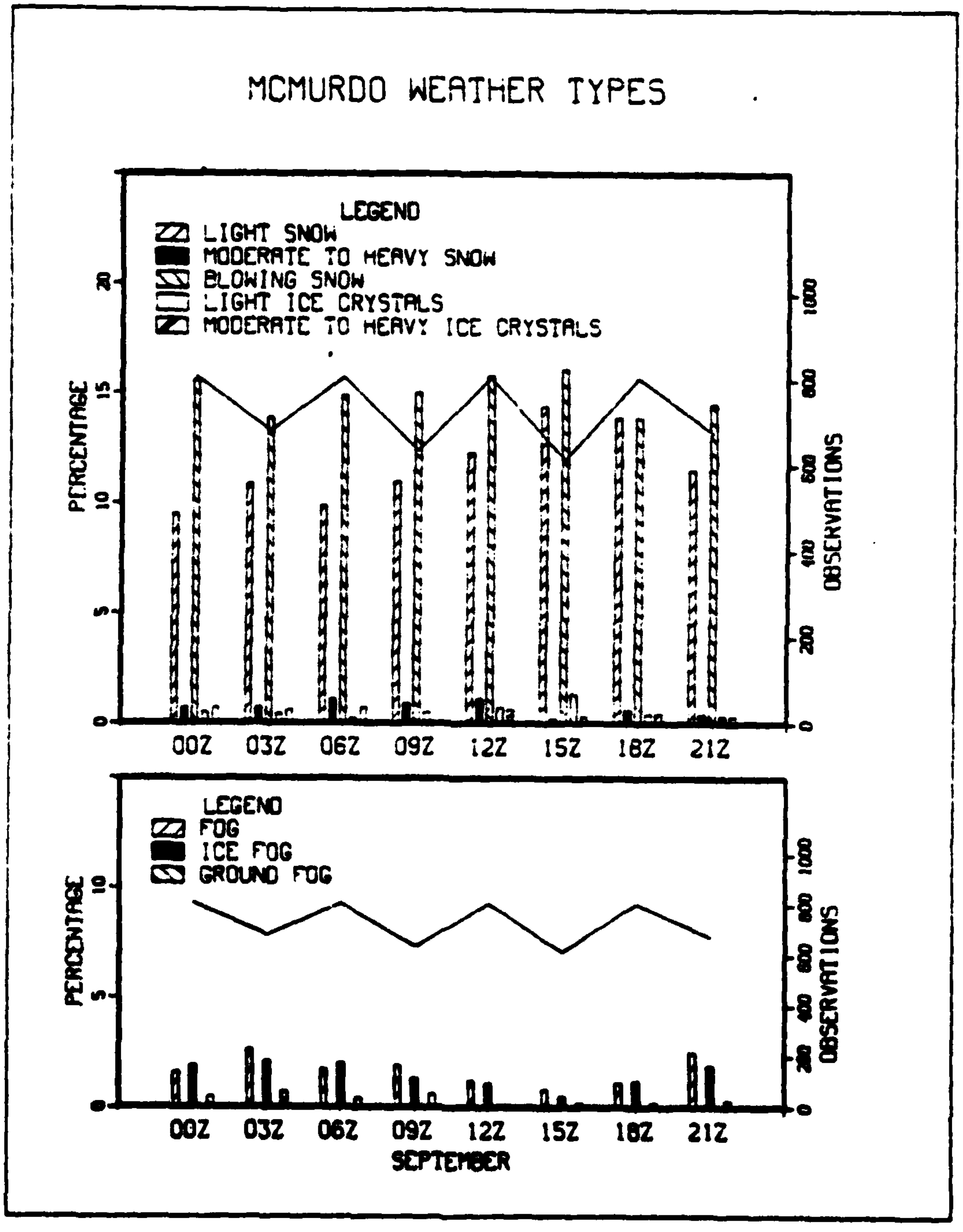


Figure 15. Diurnal Climatology of Weather Types For September at McMurdo, Antarctica.

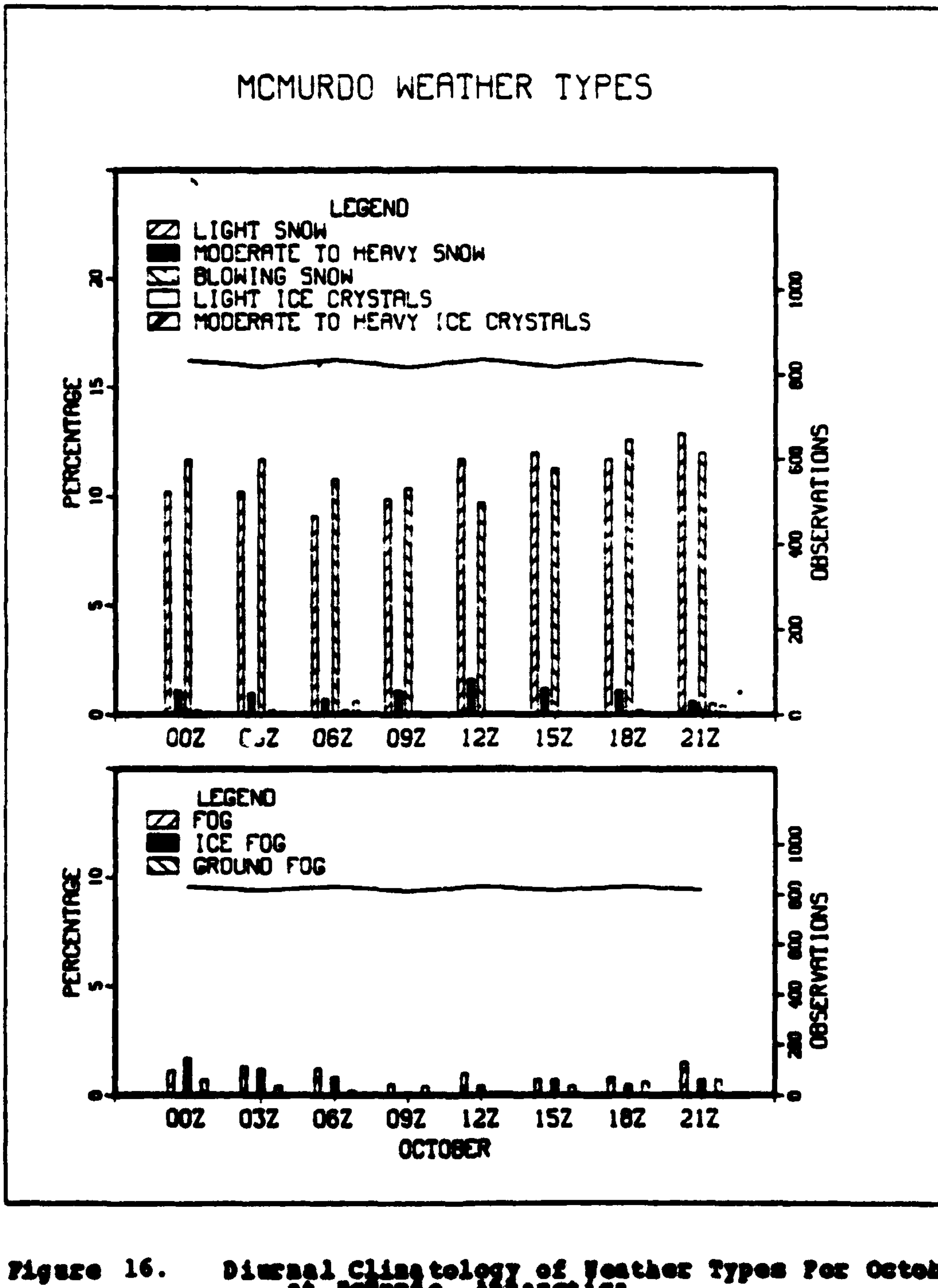


Figure 16. Diurnal Climatology of Weather Types For October at McMurdo, Antarctica.

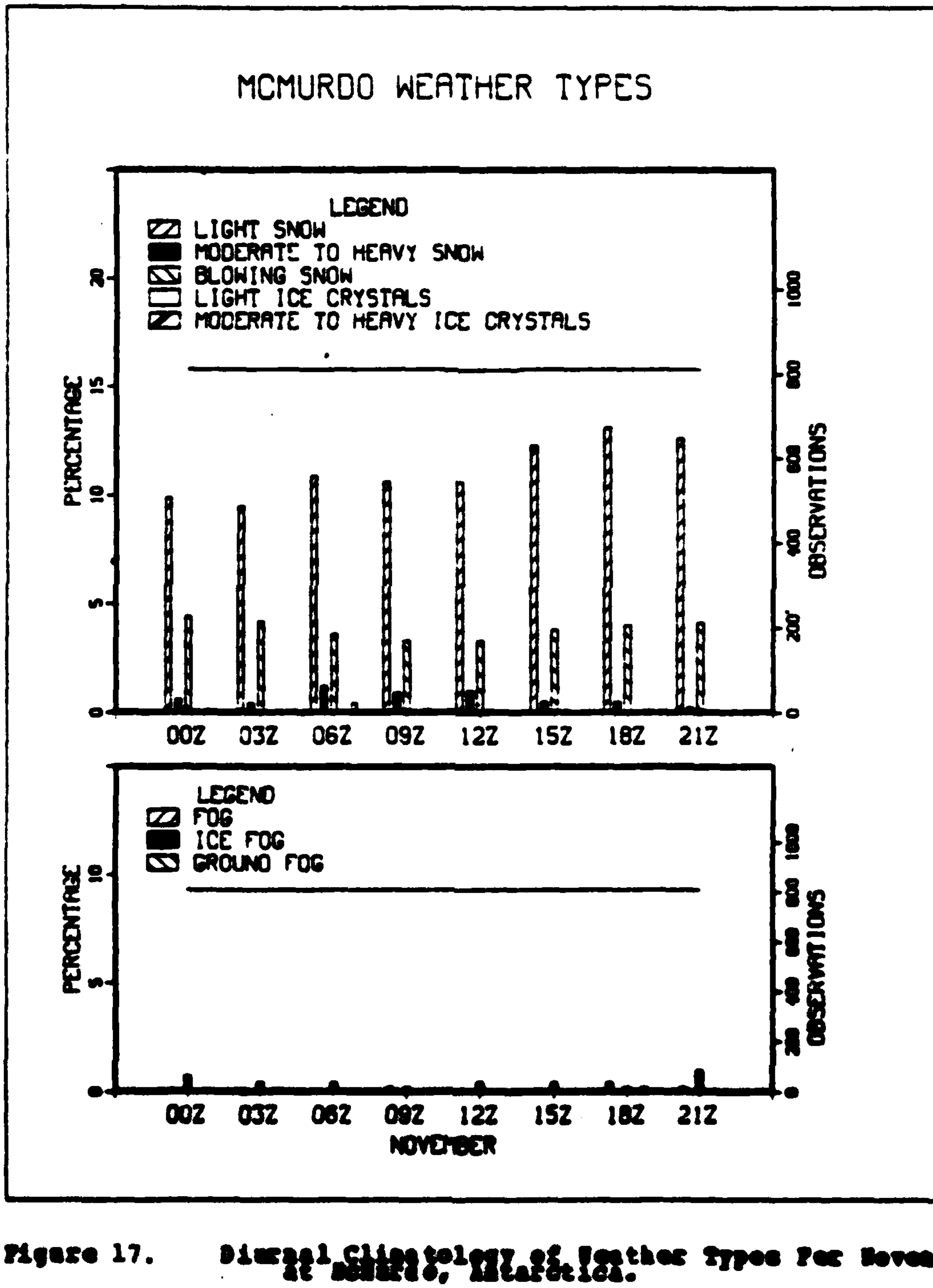


Figure 17. Diurnal Climatology of Weather Types For November at McMurdo, Antarctica.

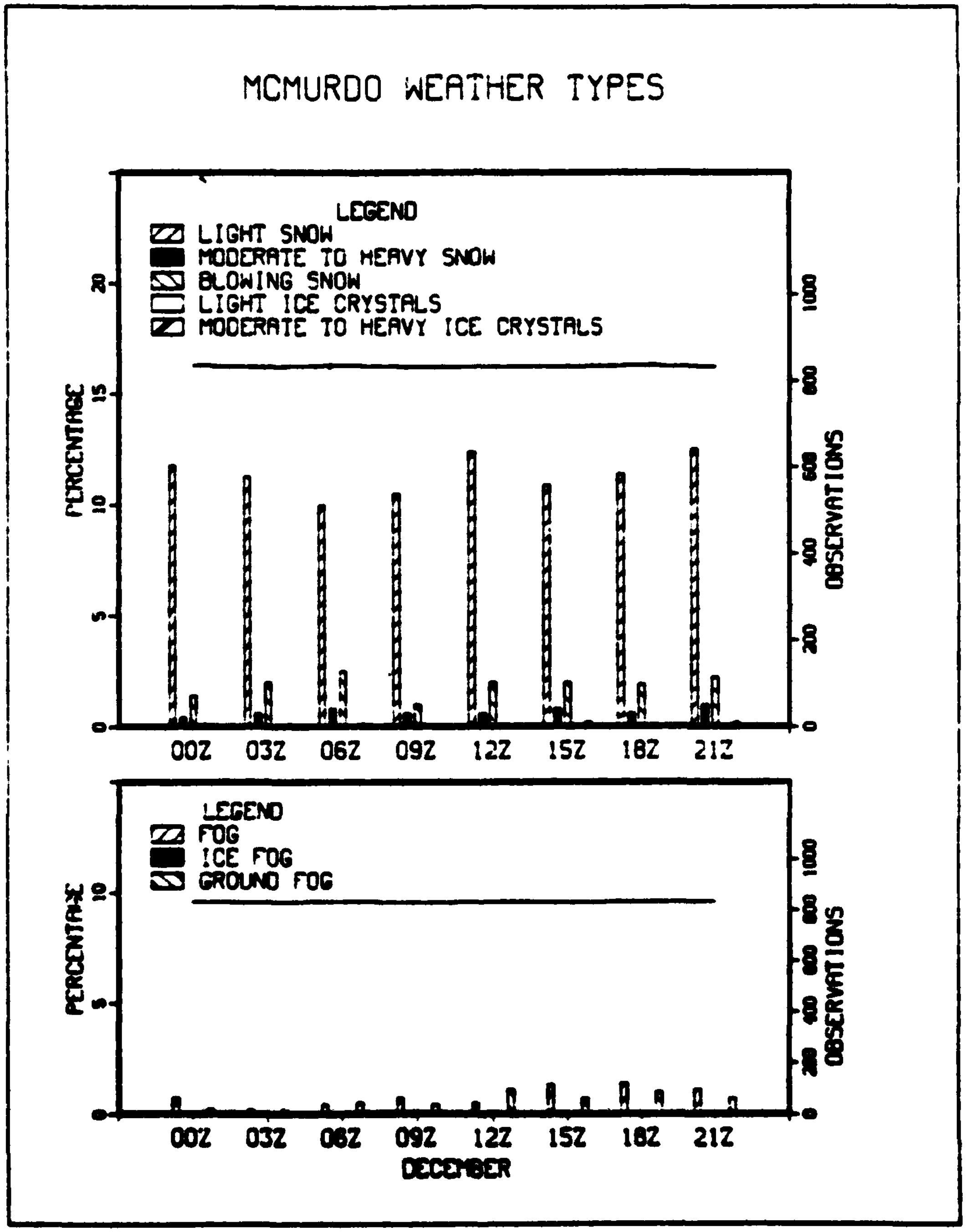


Figure 18. Diurnal Climatology of Weather Types For December at McMurdo, Antarctica.

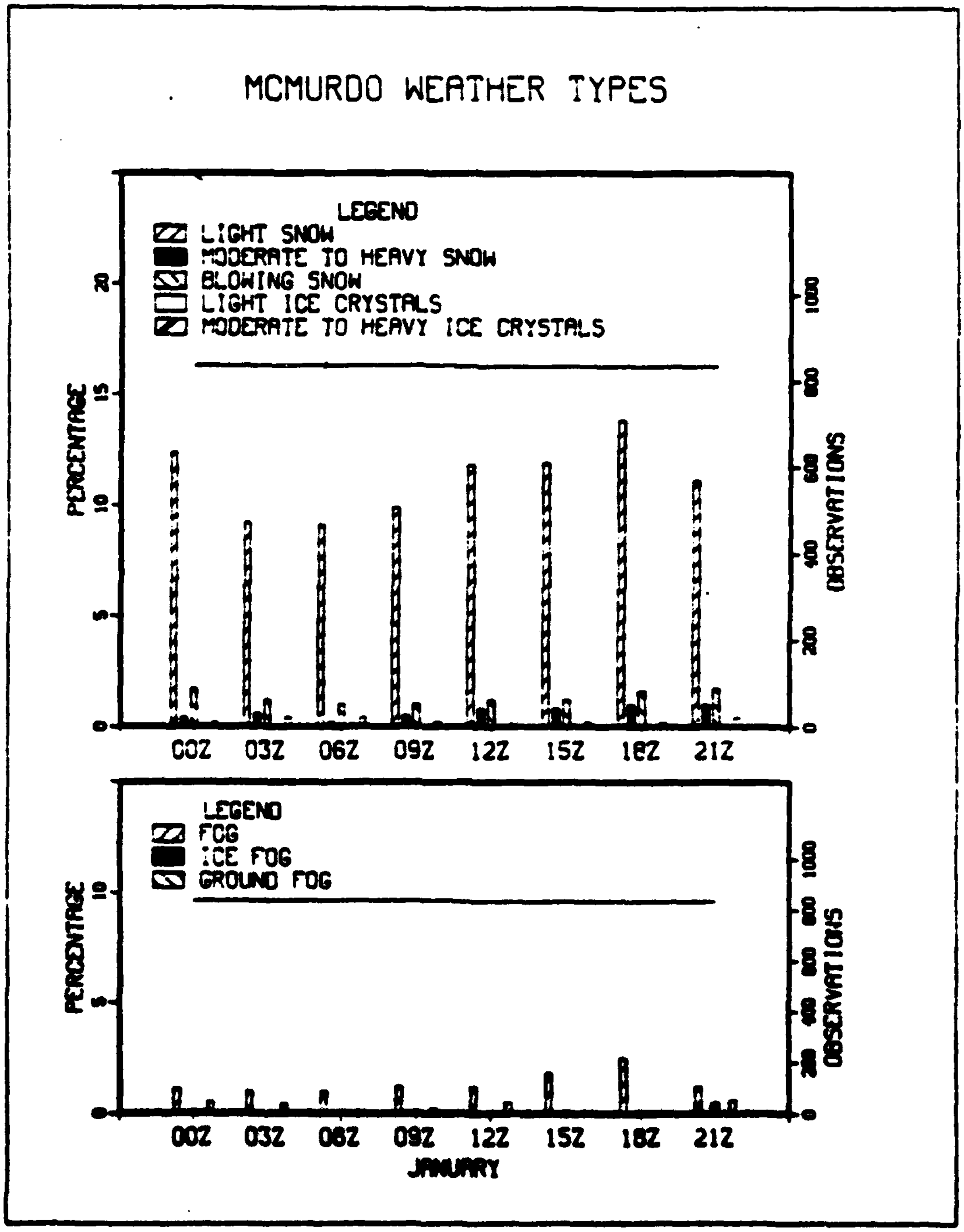


Figure 19. Diurnal Climatology of Weather Types For January at McMurdo, Antarctica.

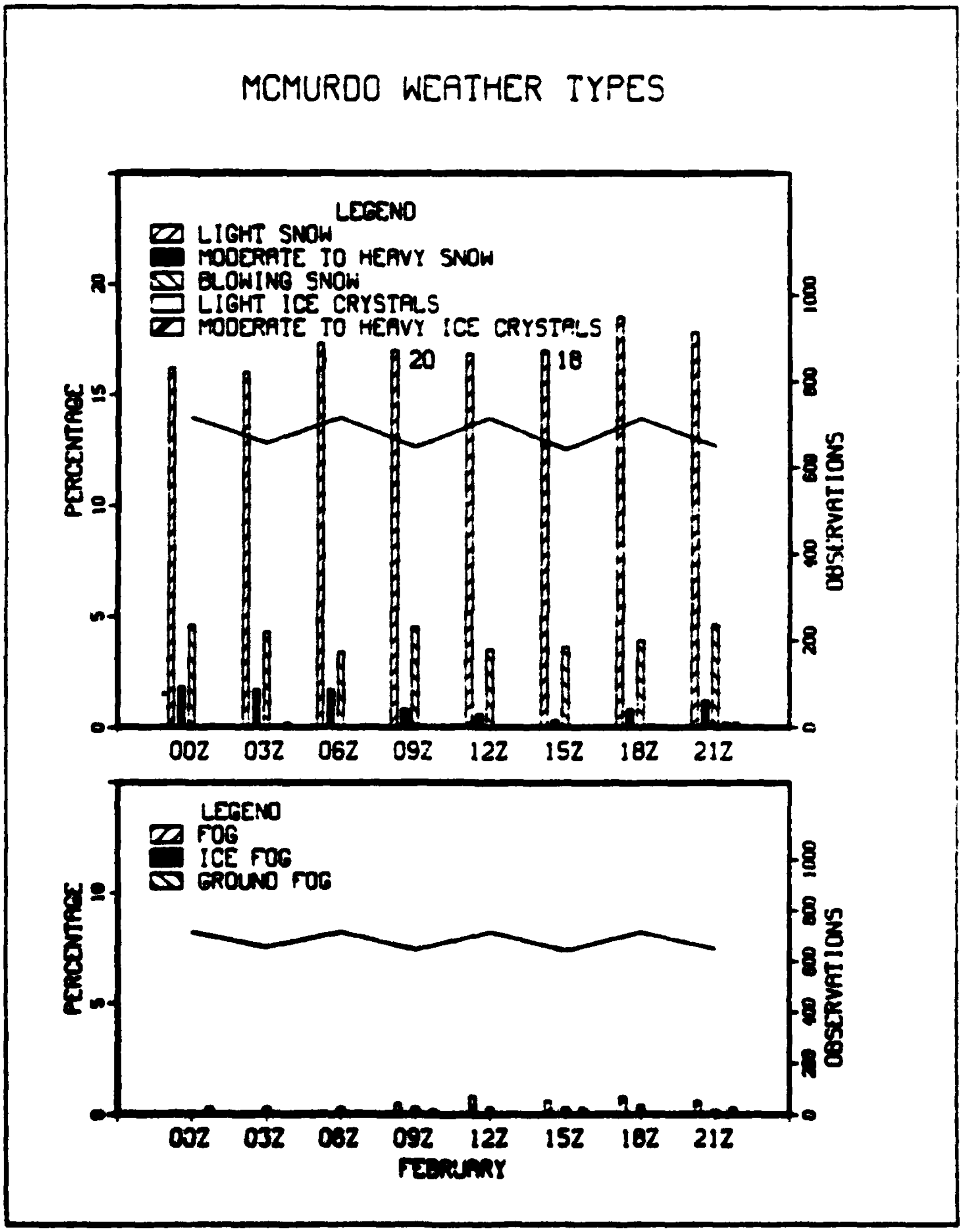


Figure 20. Diurnal Climatology of Weather Types For February at McMurdo, Antarctica.

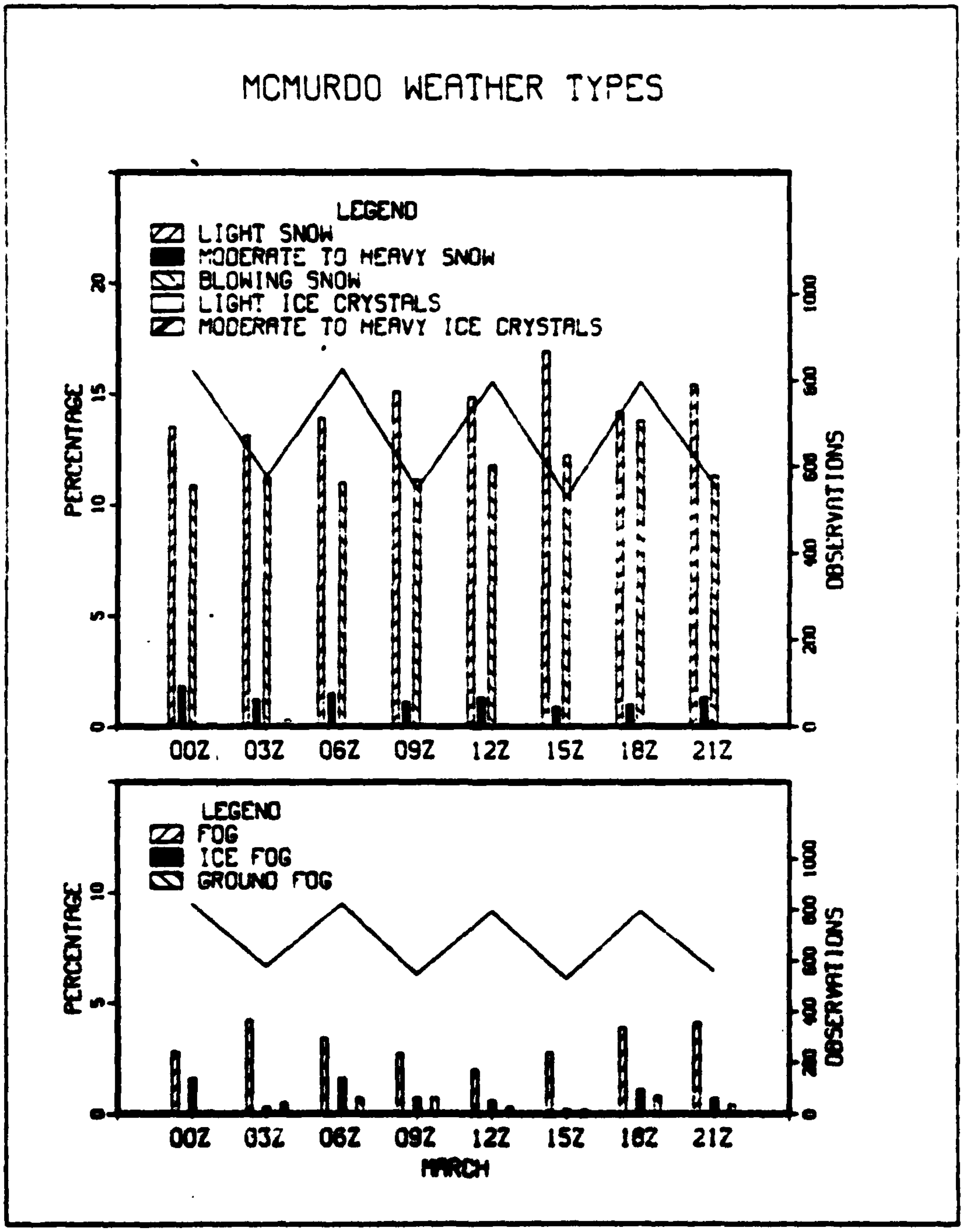


Figure 21. Diurnal Climatology of Weather Types For March at McMurdo, Antarctica.

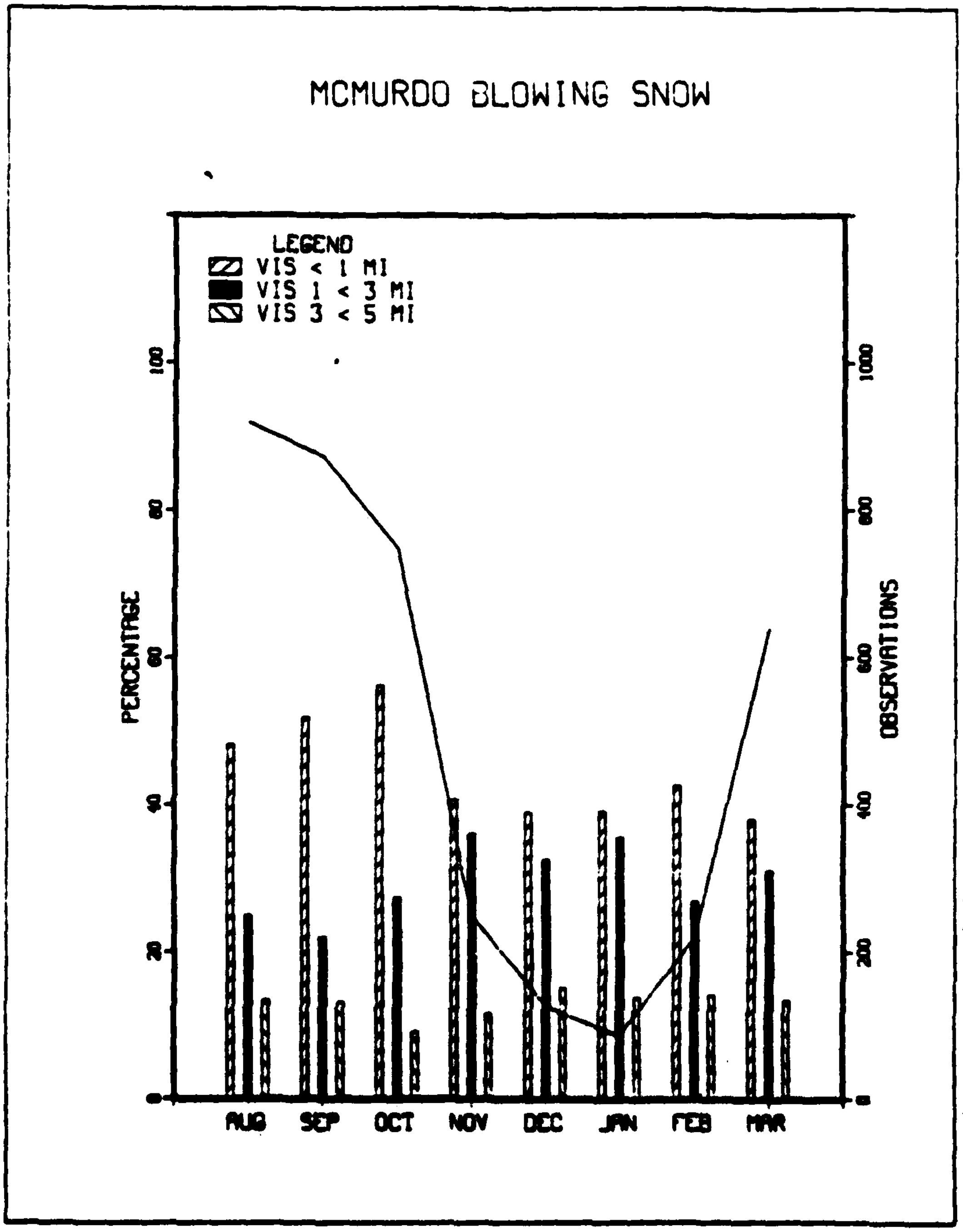


Figure 22. Monthly Climatology of Blowing Snow at McMurdo, Antarctica.

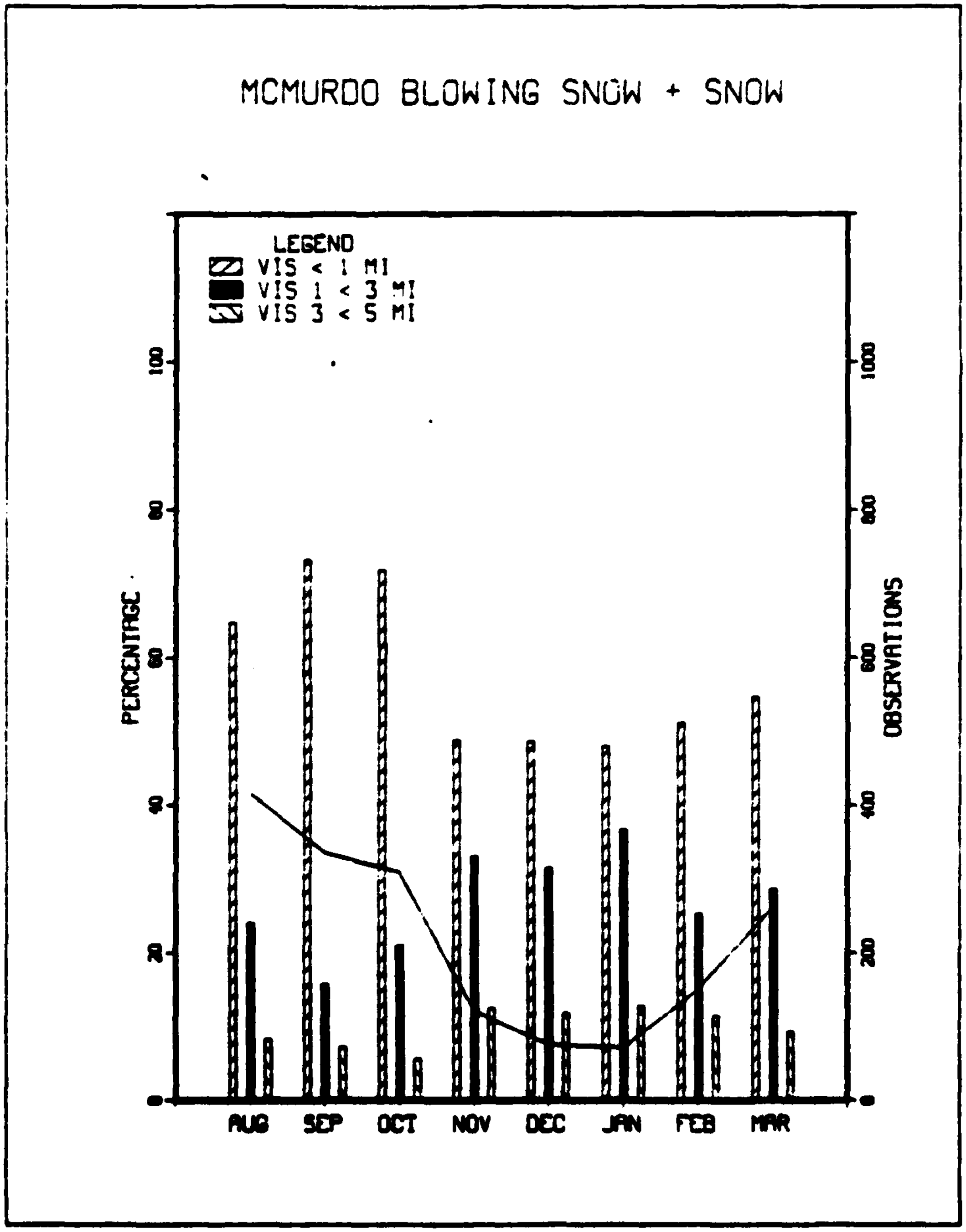


Figure 23. Monthly Climatology of Blowing Snow and Snow at McMurdo, Antarctica.

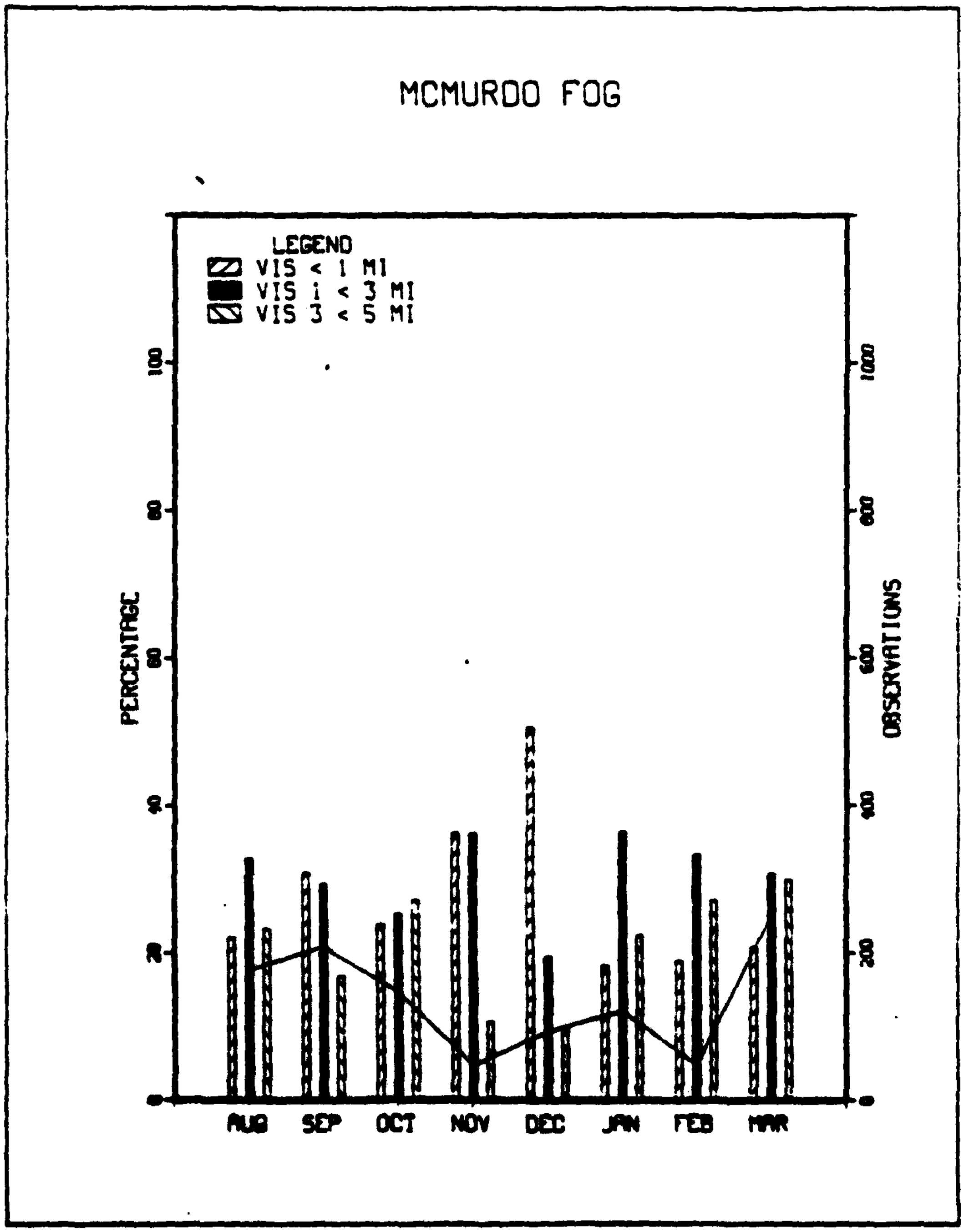


Figure 24. Monthly Climatology of Fog at McMurdo, Antarctica.

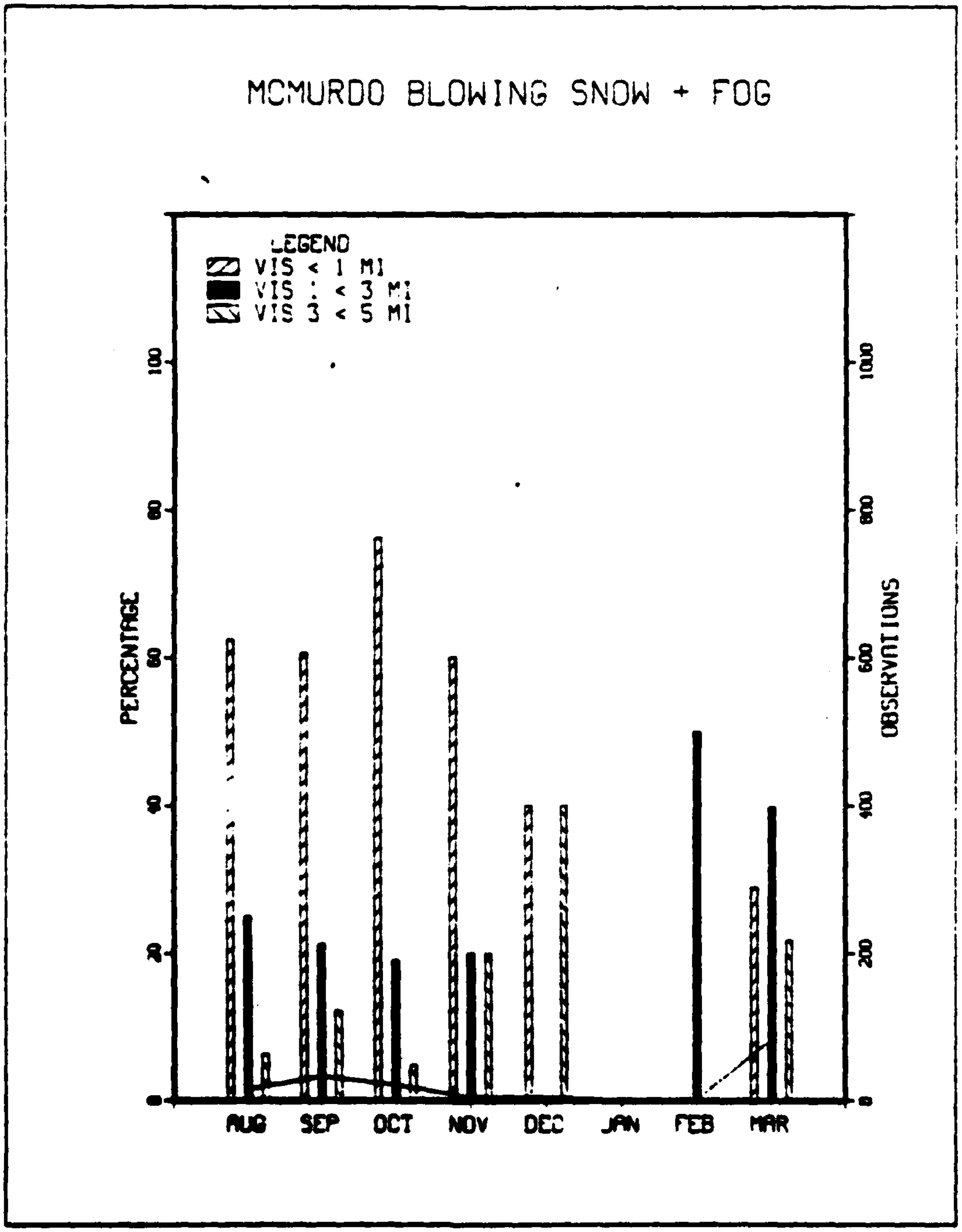


Figure 25. Monthly Climatology of Blowing Snow and Fog at McMurdo, Antarctica.

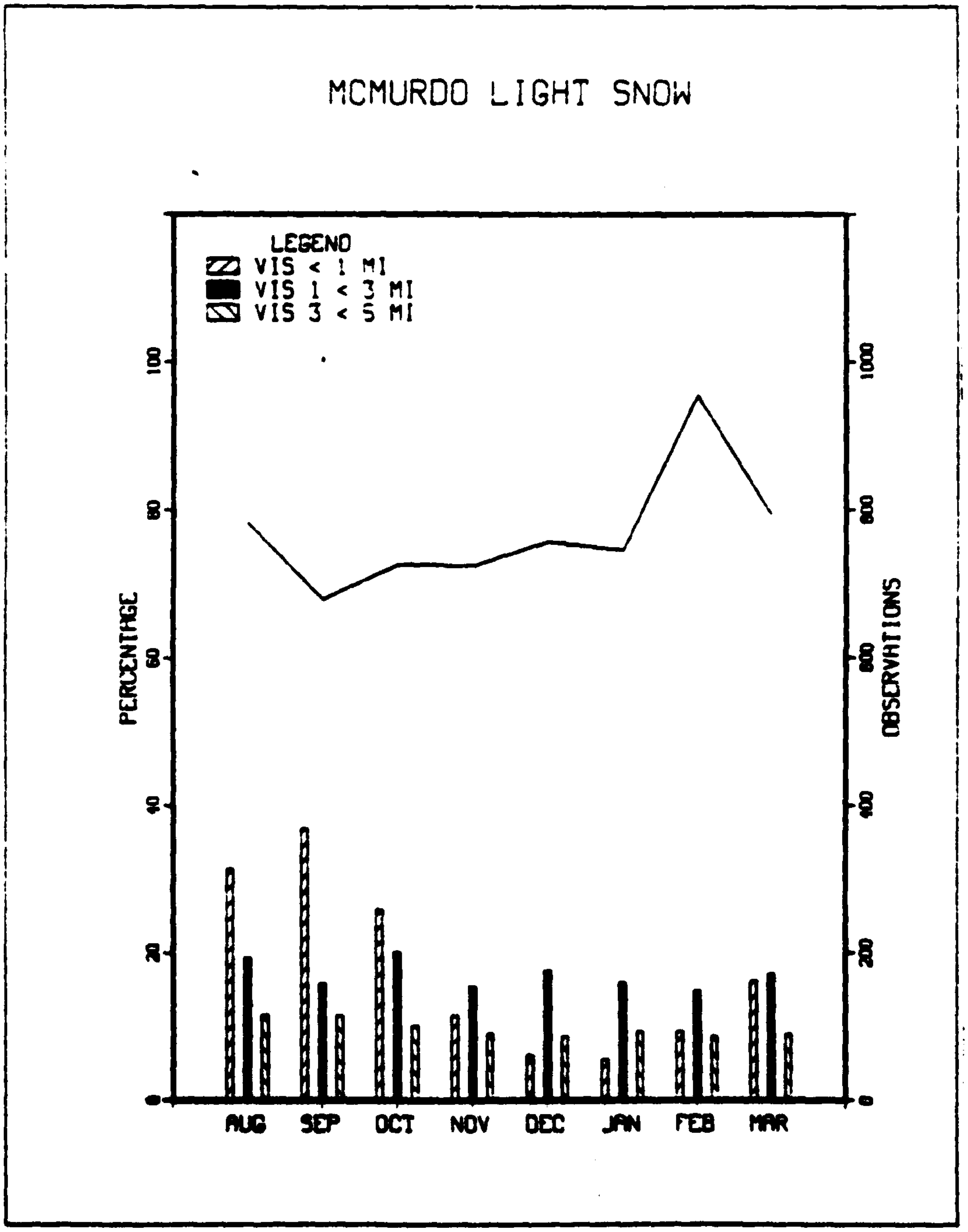


Figure 26. Monthly Climatology of Light Snow at McMurdo, Antarctica.

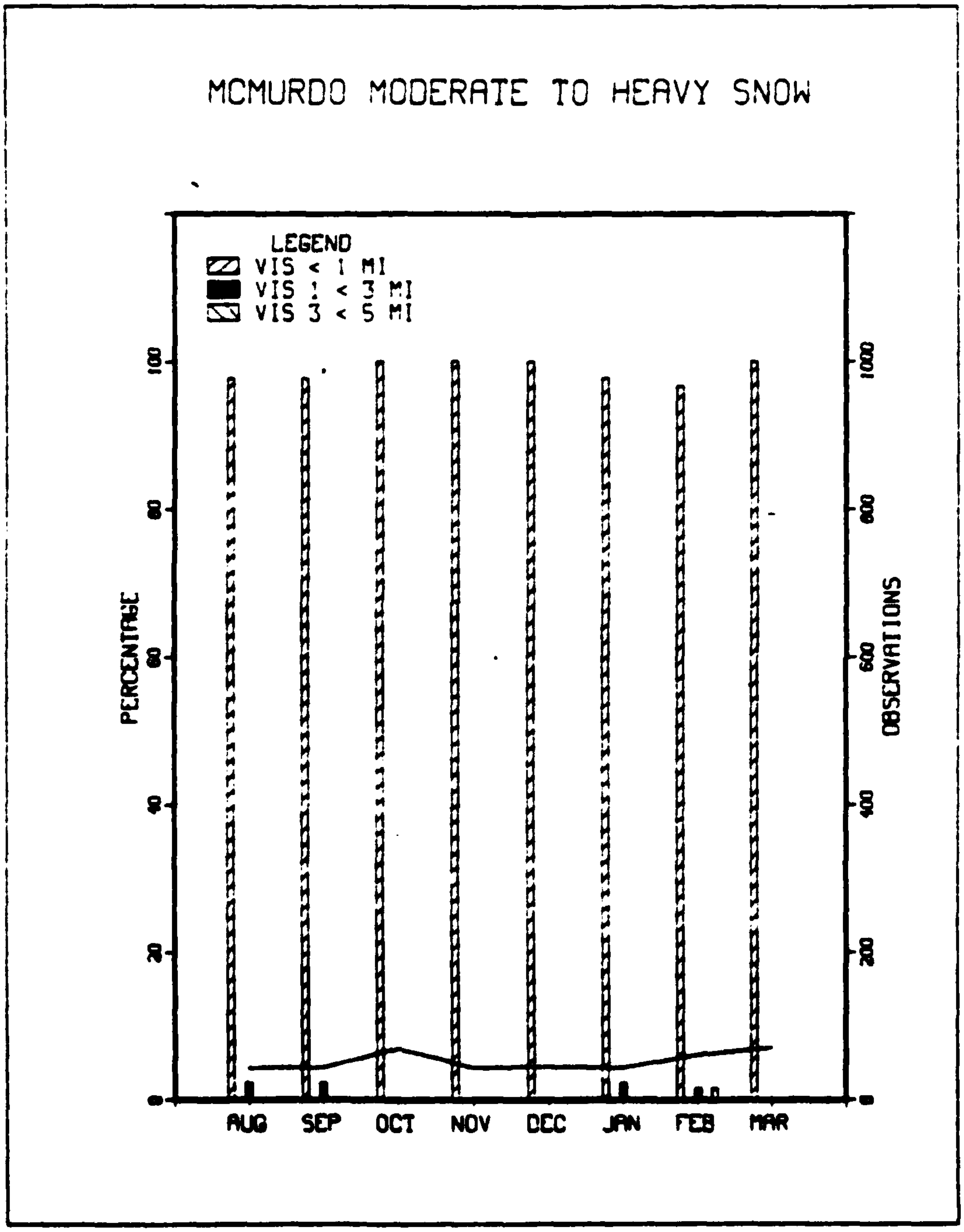


Figure 27. Monthly Climatology of Moderate to Heavy Snow at McMurdo, Antarctica.

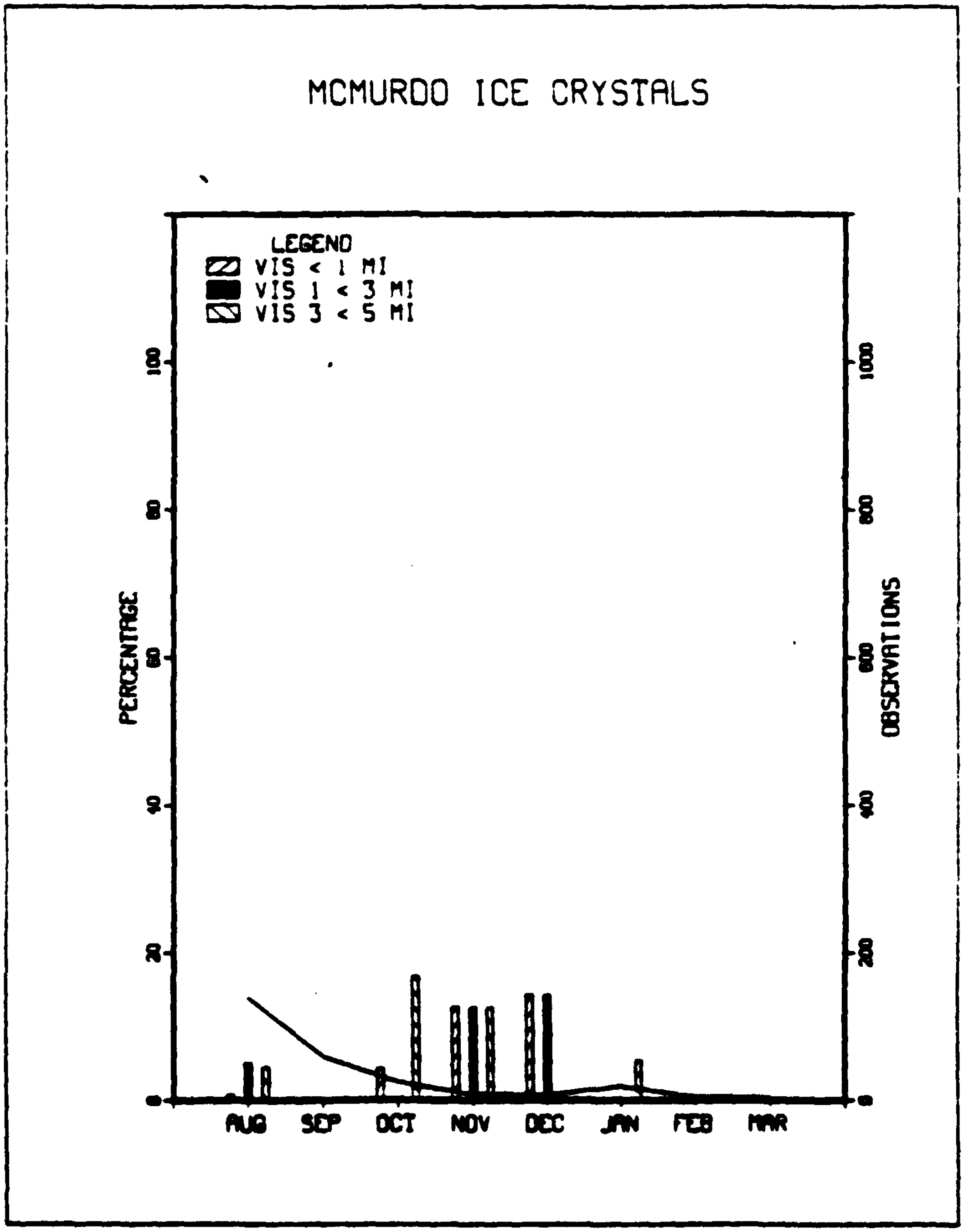


Figure 28. Monthly Climatology of Ice Crystals at McMurdo, Antarctica.

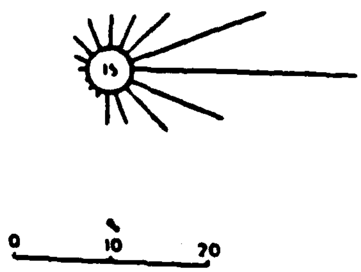


Figure 29. McMurdo Wind Rose (data base, March 1956-December 1972) (Sinclair, 1982).

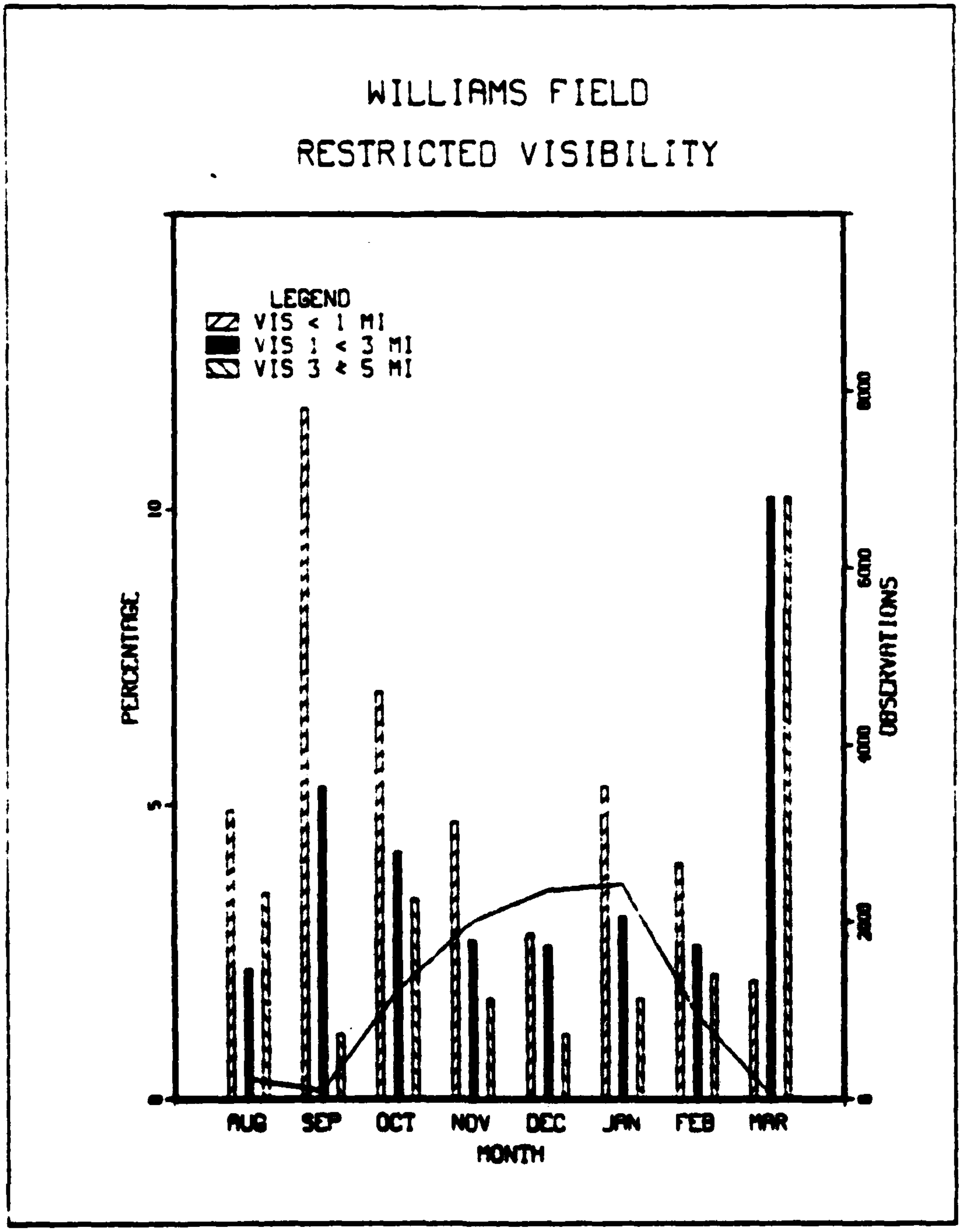


Figure 30. Monthly Climatology of Restricted Visibility at Williams Field, Antarctica.

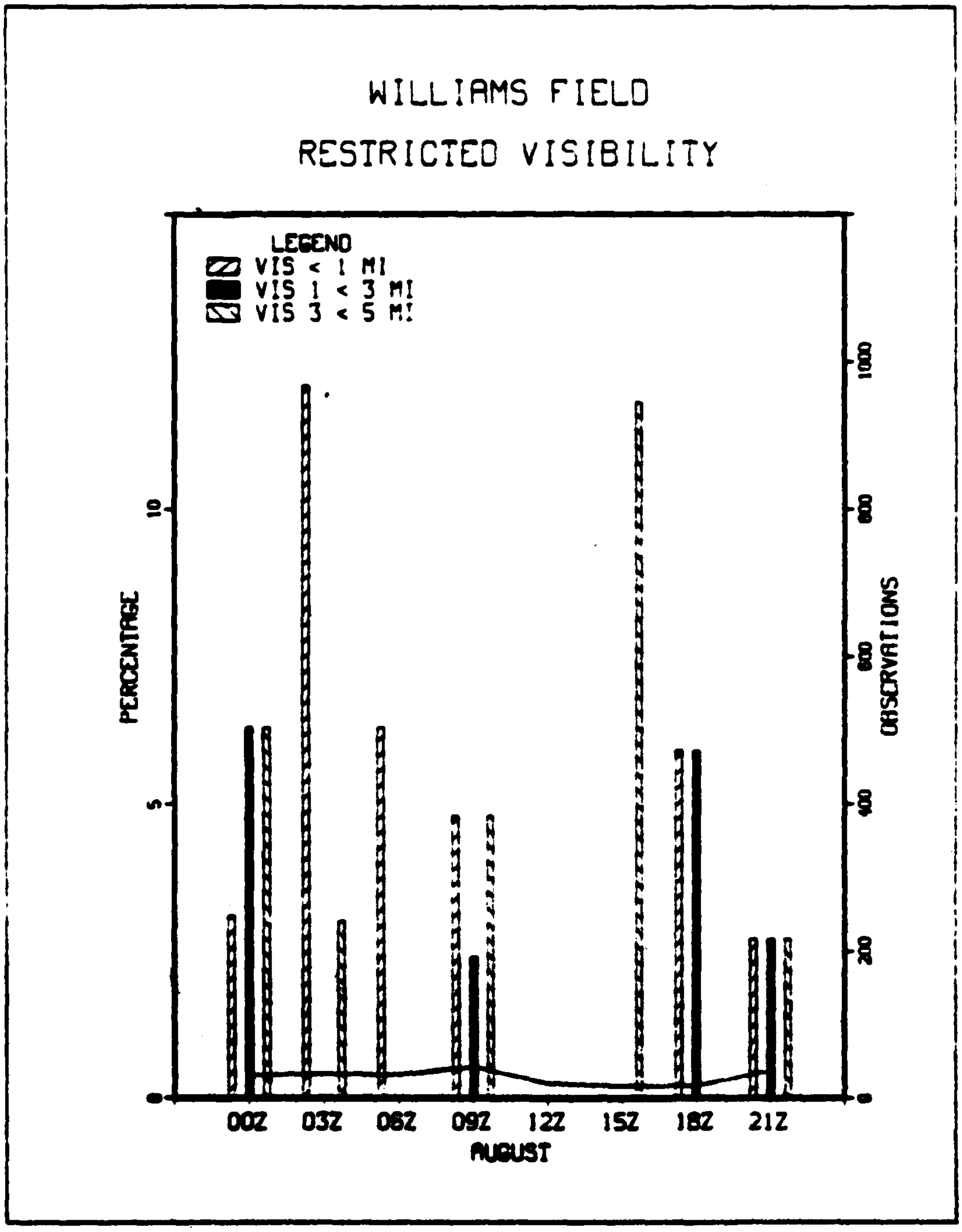


Figure 31. Diurnal Climatology of Restricted Visibility by Category for August at Williams Field, Antarctica.

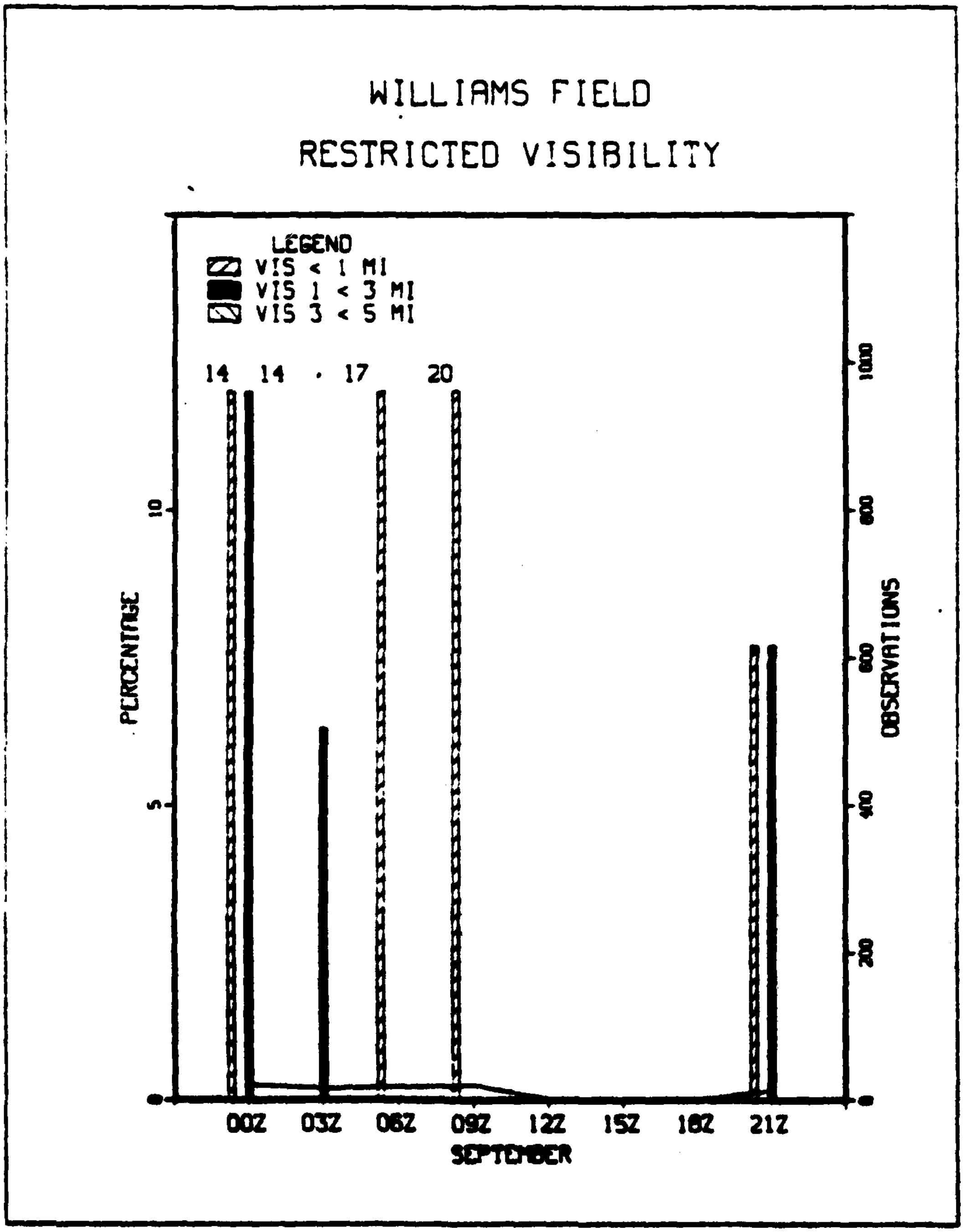


Figure 32. Diurnal Climatology of Restricted Visibility by Category for September, at Williams Field, Antarctica.

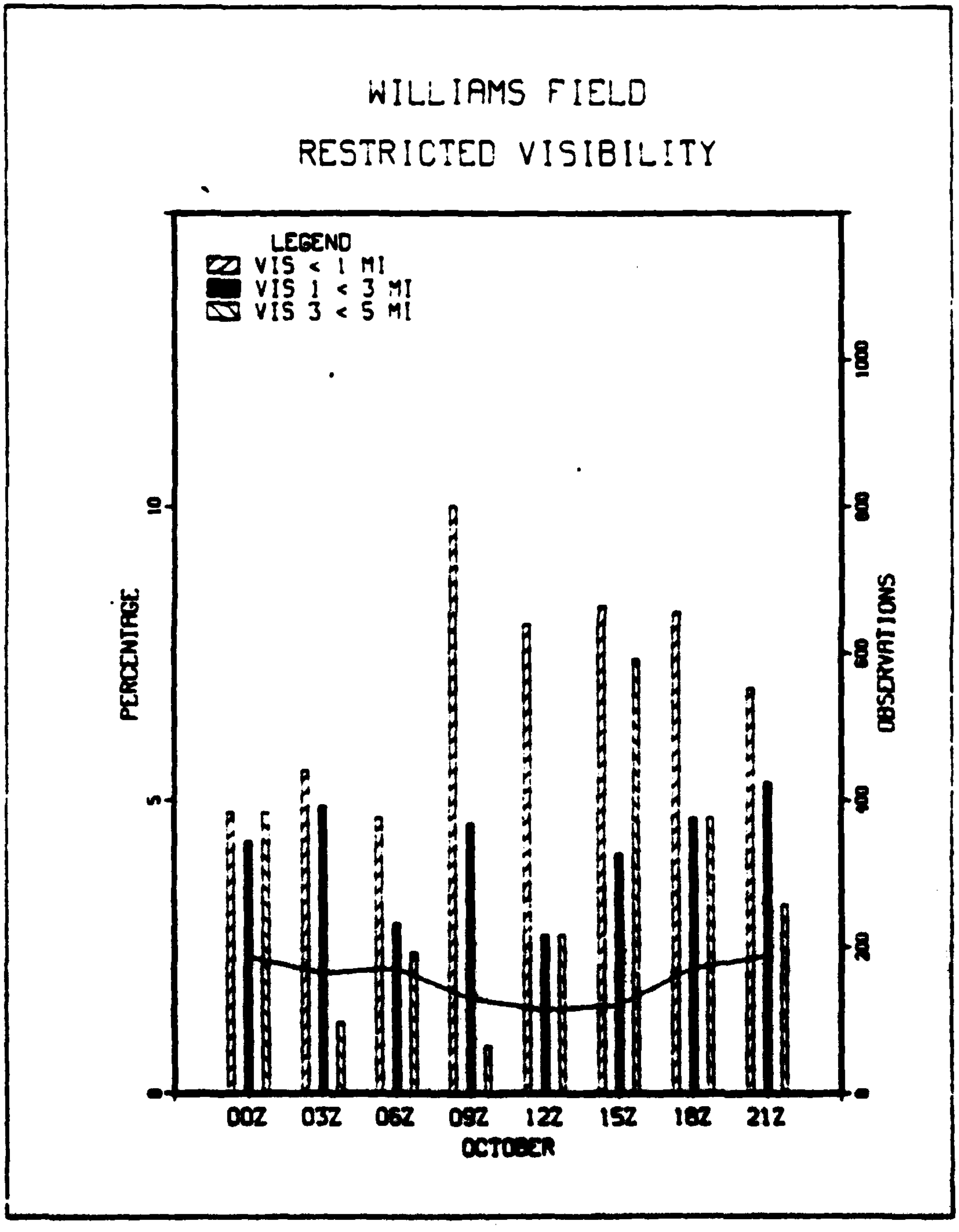


Figure 33. Diurnal Climatology of Restricted Visibility By Category for October at Williams Field, Antarctica.

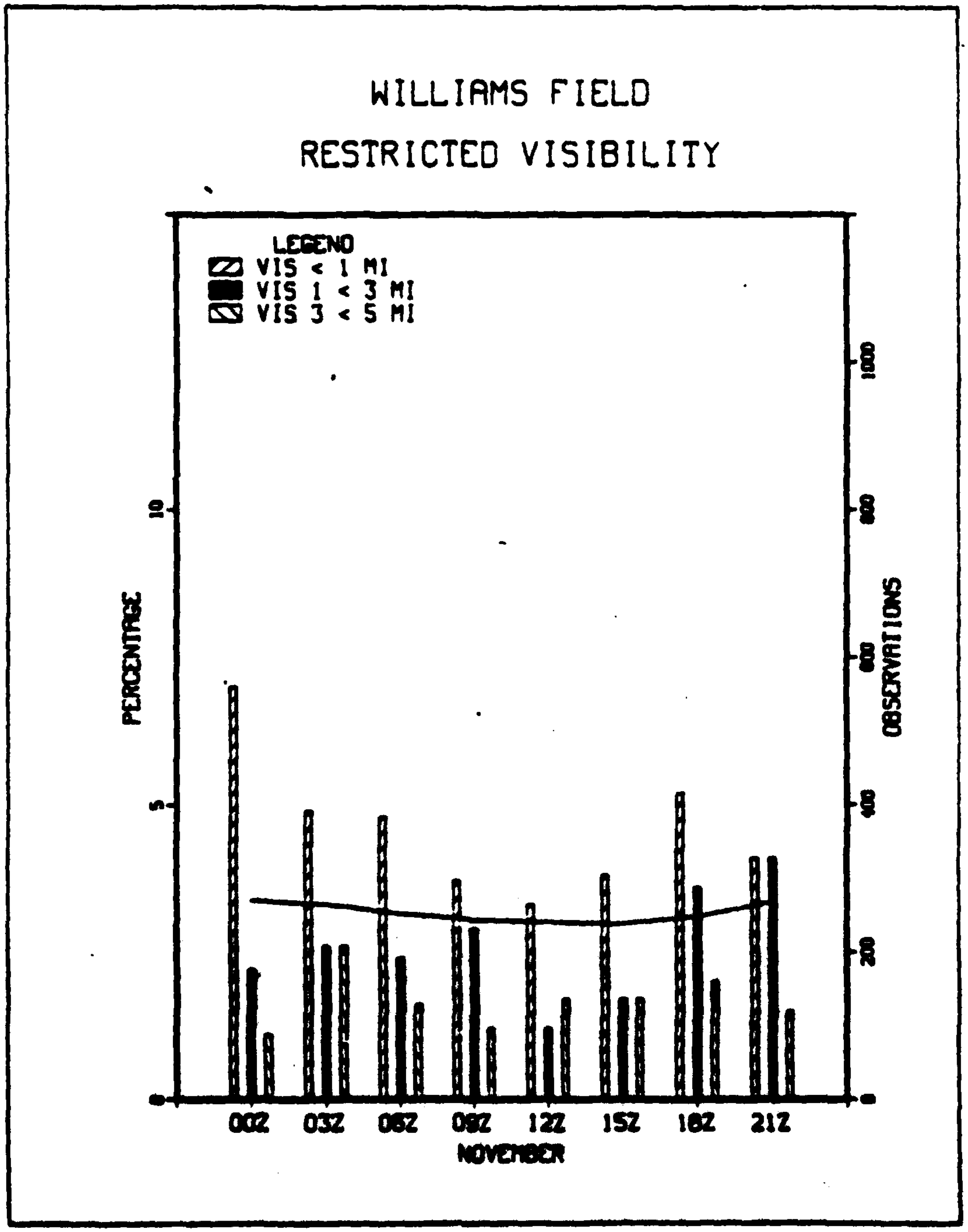


Figure 34. Diurnal Climatology of Restricted Visibility by Category for November at Williams Field, Antarctica.

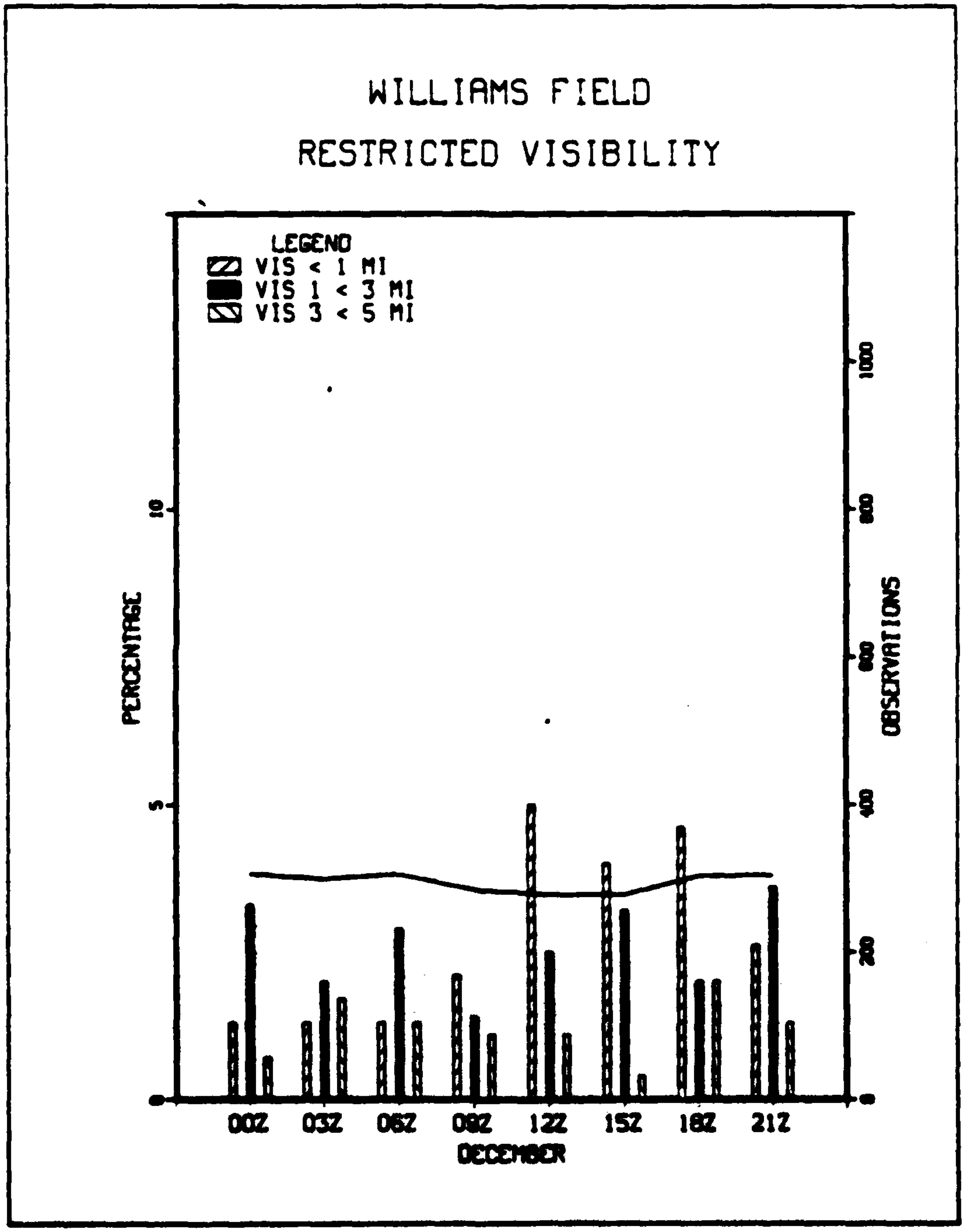


Figure 35. Diurnal Climatology of Restricted Visibility by Category for December at Williams Field, Antarctica.

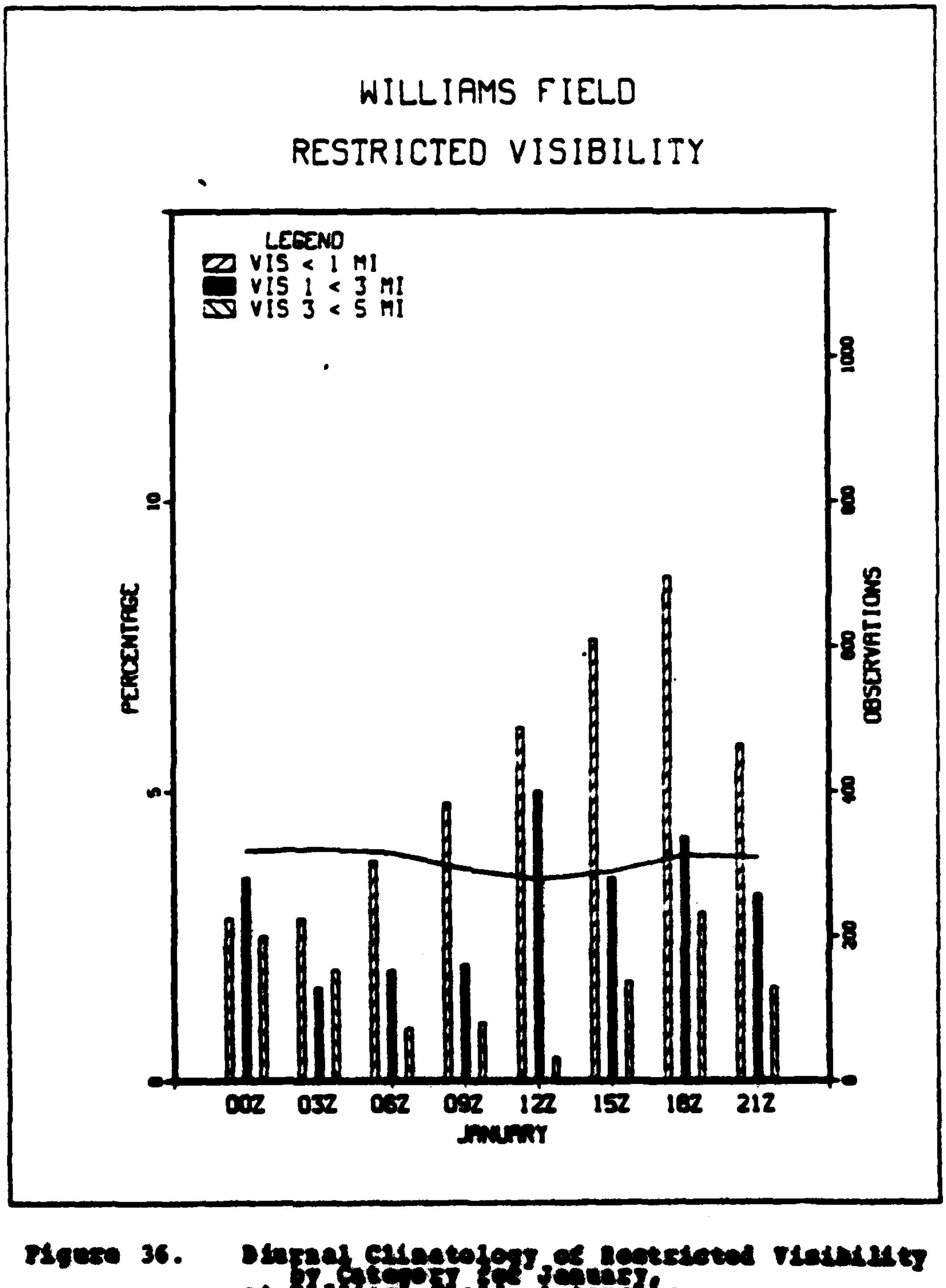


Figure 36. Diurnal Climatology of Restricted Visibility by Category for January, at Williams Field, Antarctica.

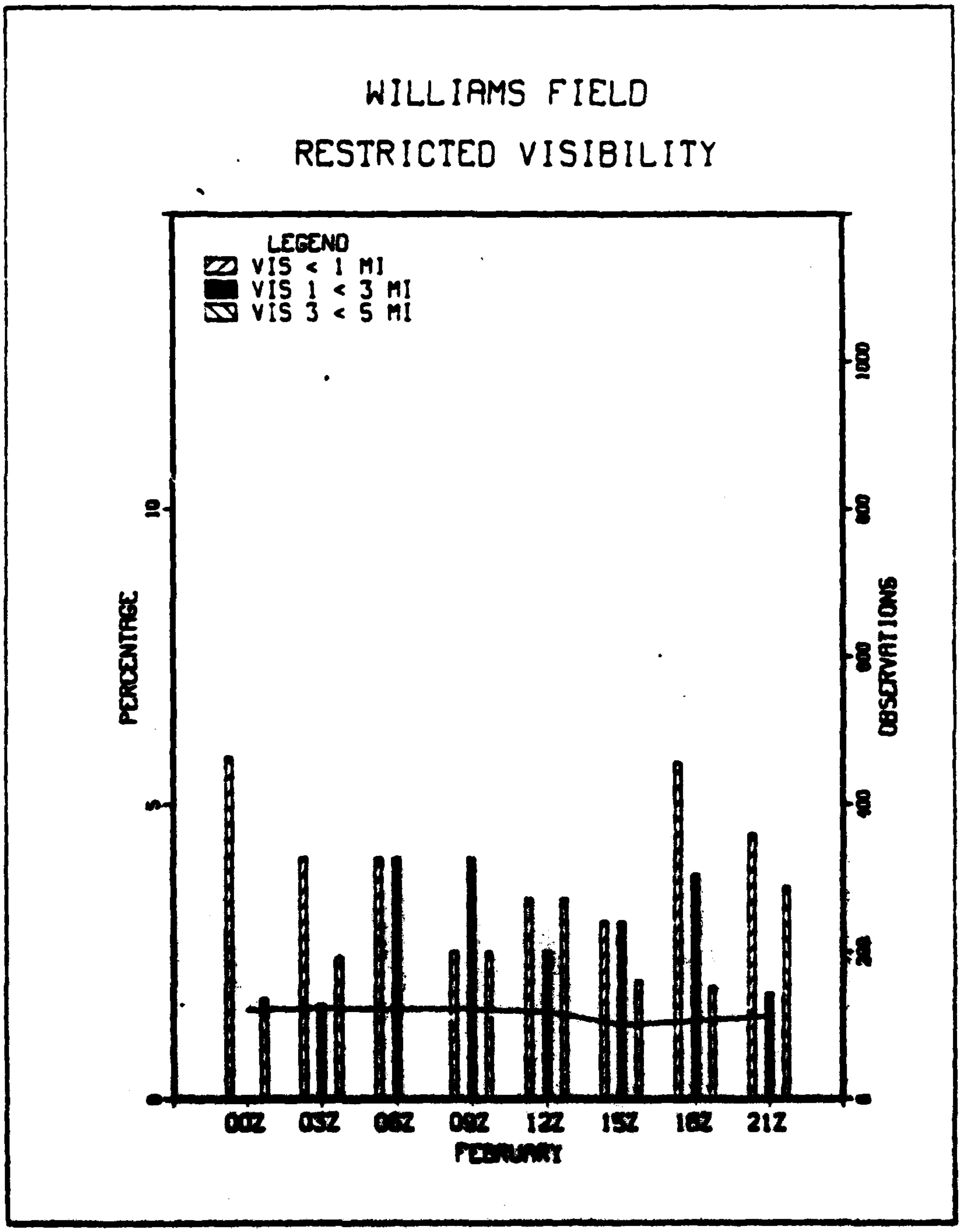


Figure 37. Diurnal Climatology of Restricted Visibility at Williams Field, Antarctica.

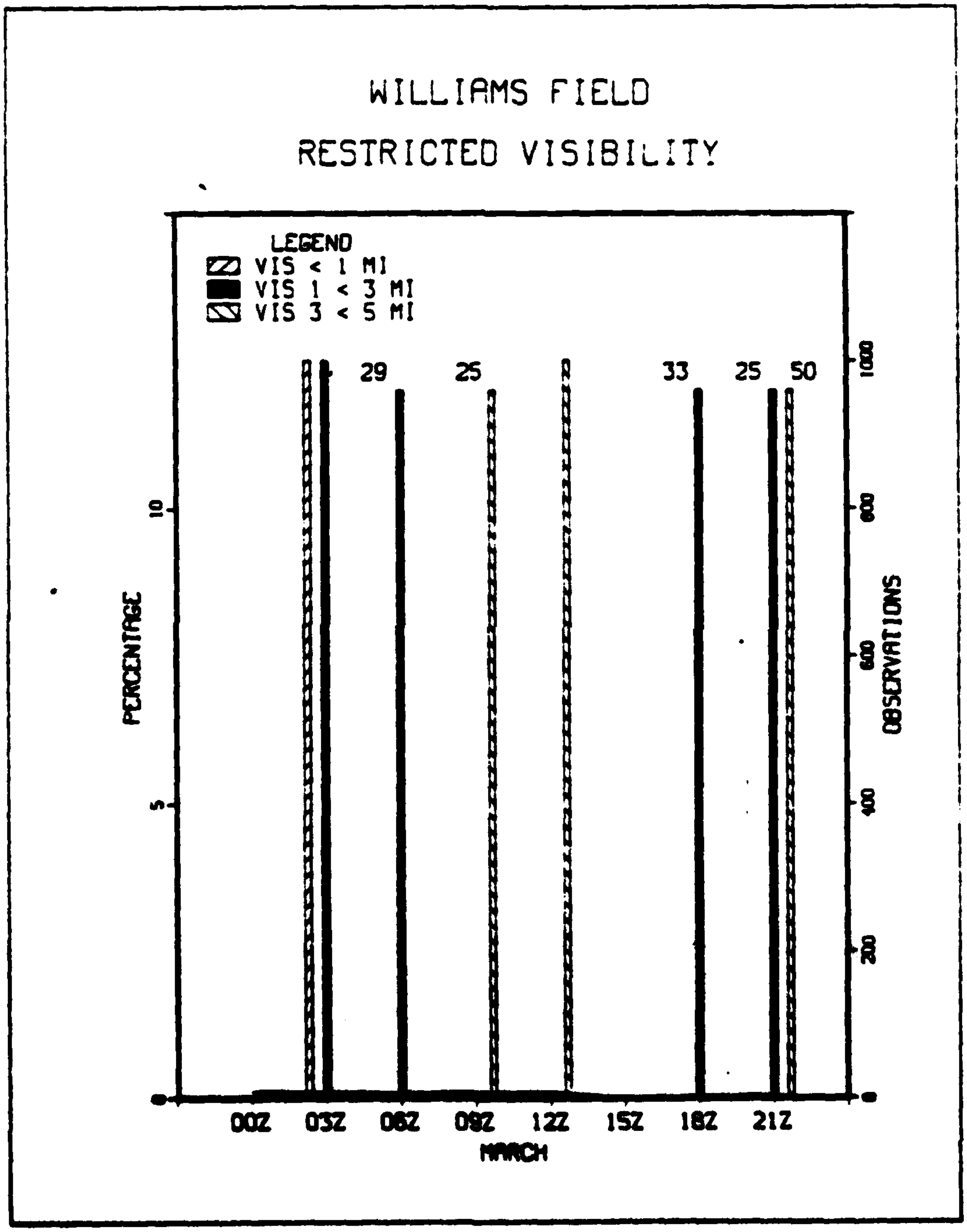


Figure 38. Diurnal Climatology of Restricted Visibility by Category for March, at Williams Field, Antarctica.

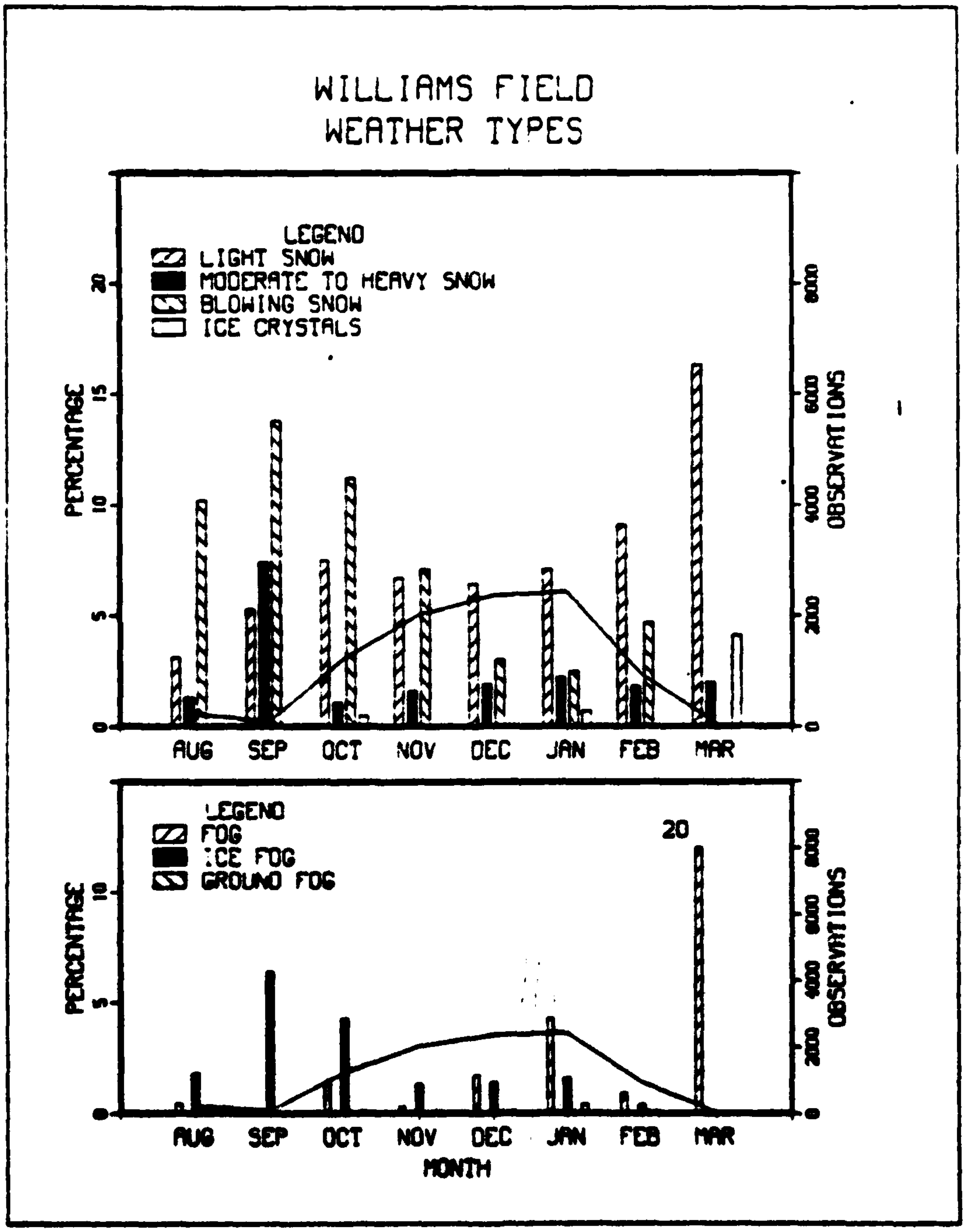


Figure 39. Monthly Climatology of Weather Types at Williams Field, Antarctica.

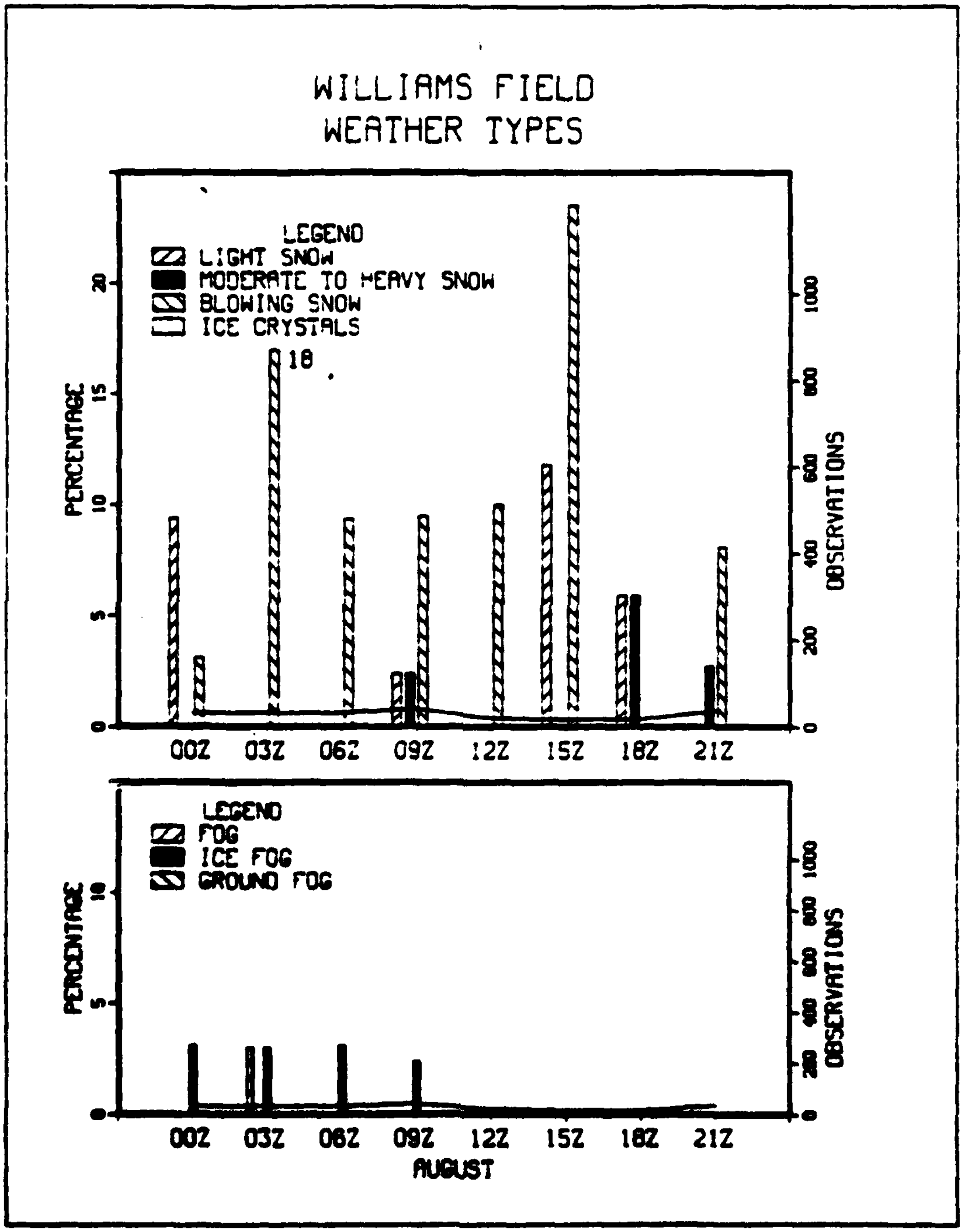


Figure 40. Diurnal Climatology of Weather Types For August at Williams Field, Antarctica.

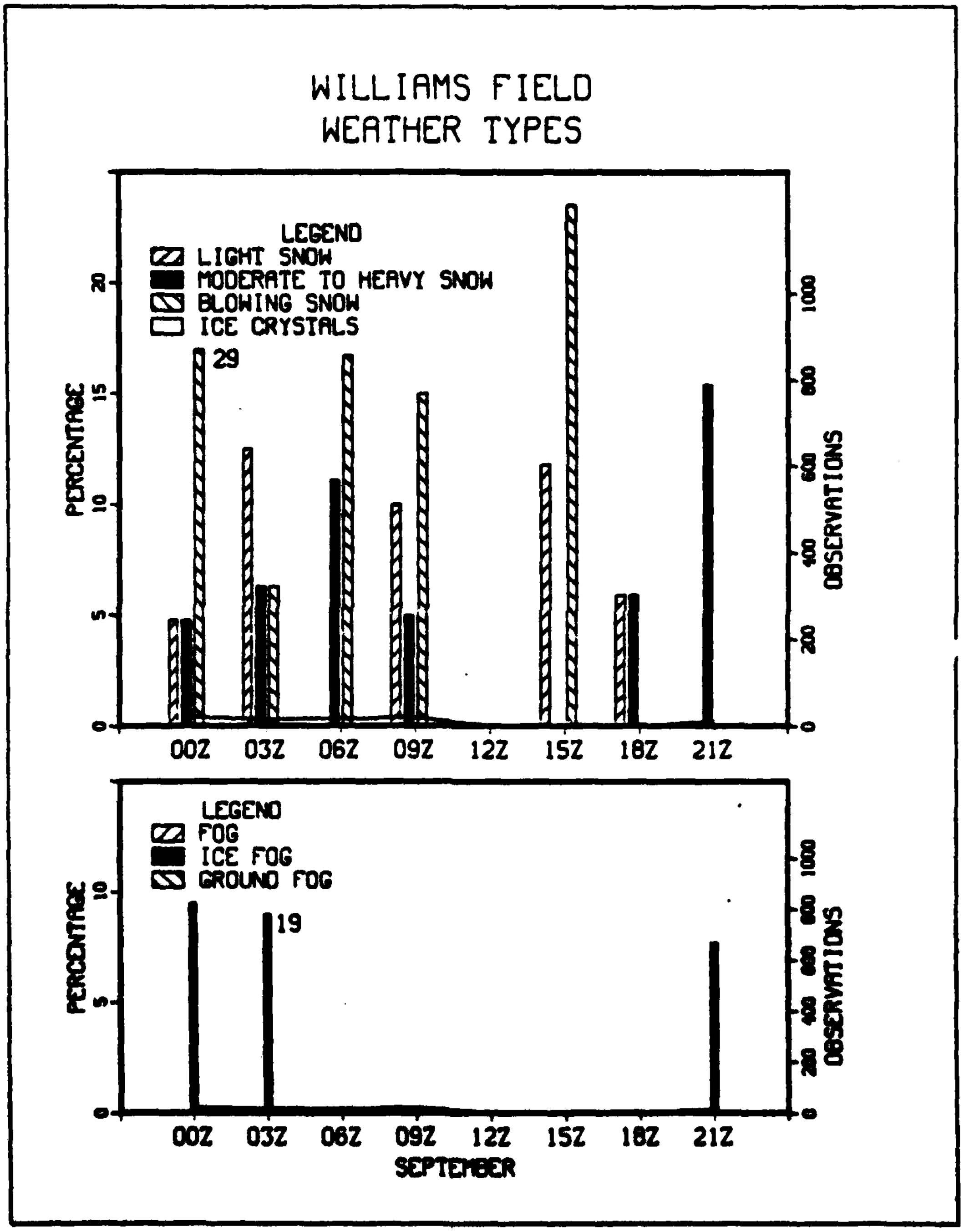


Figure 41. Diurnal Climatology of Weather Types For September at Williams Field, Antarctica.

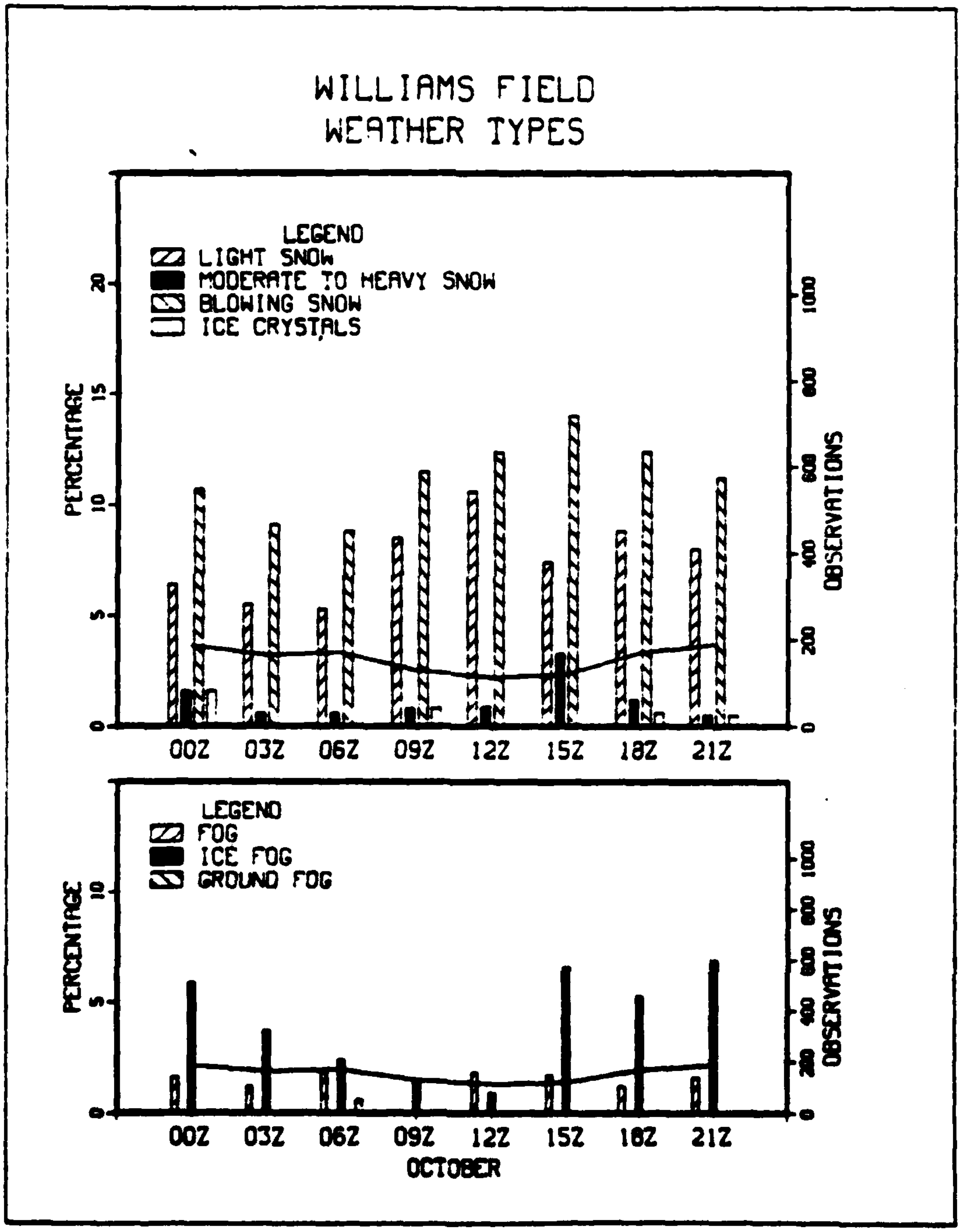


Figure 42. Diurnal Climatology of Weather Types For October at Williams Field, Antarctica.

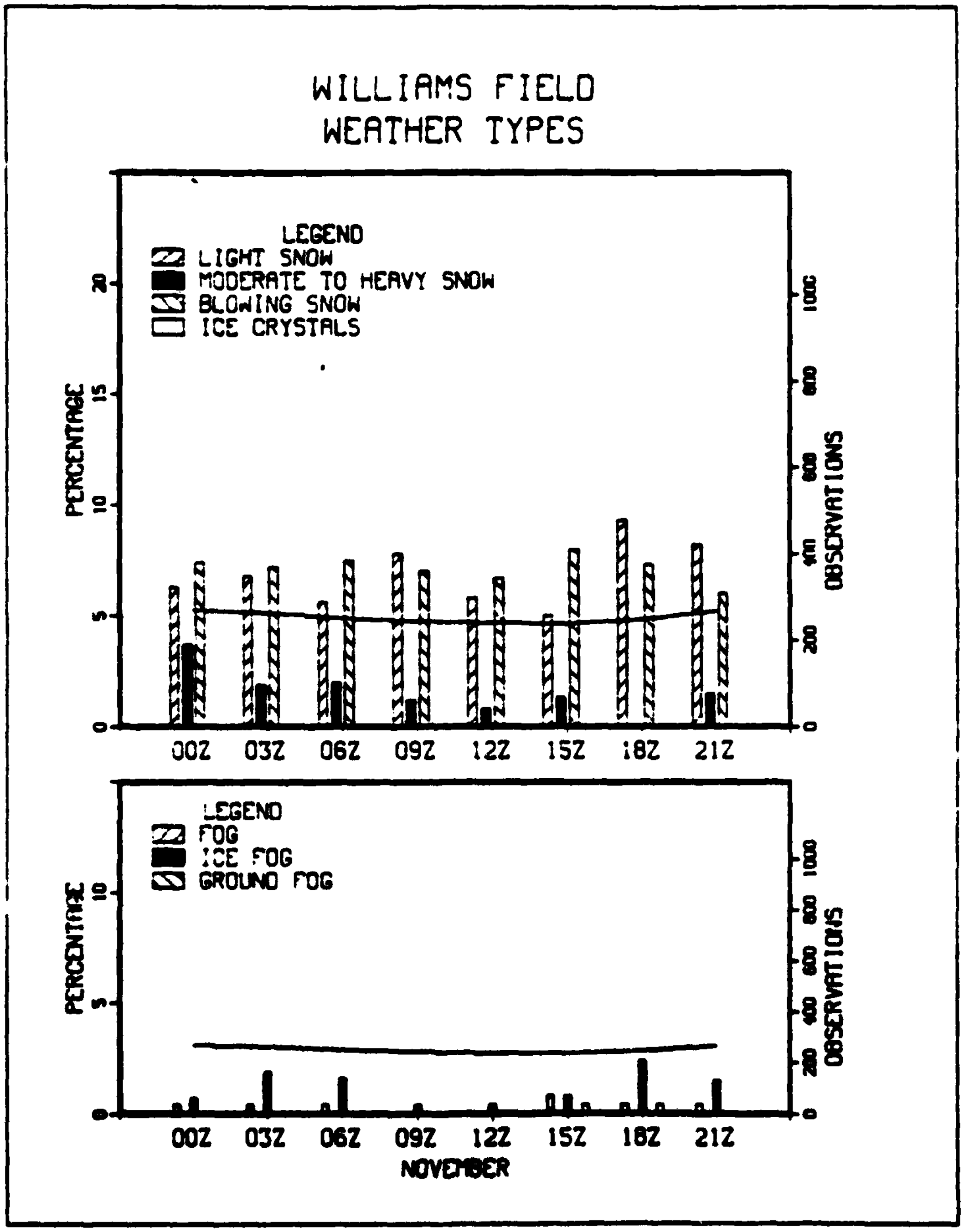


Figure 43. Diurnal Climatology of Weather Types For November at Williams Field, Antarctica.

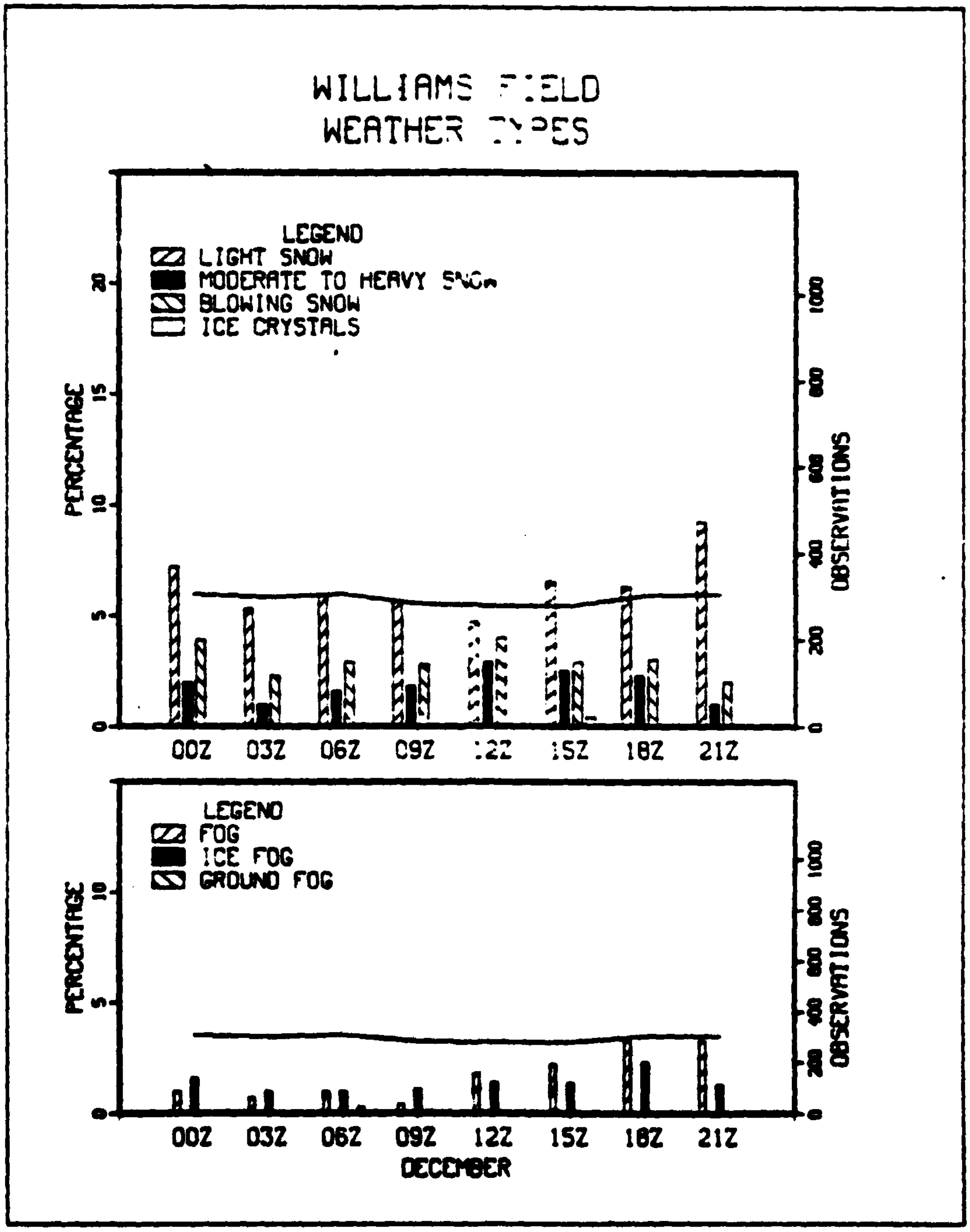


Figure 44. Diurnal Climatology of Weather Types For December at Williams Field, Antarctica.

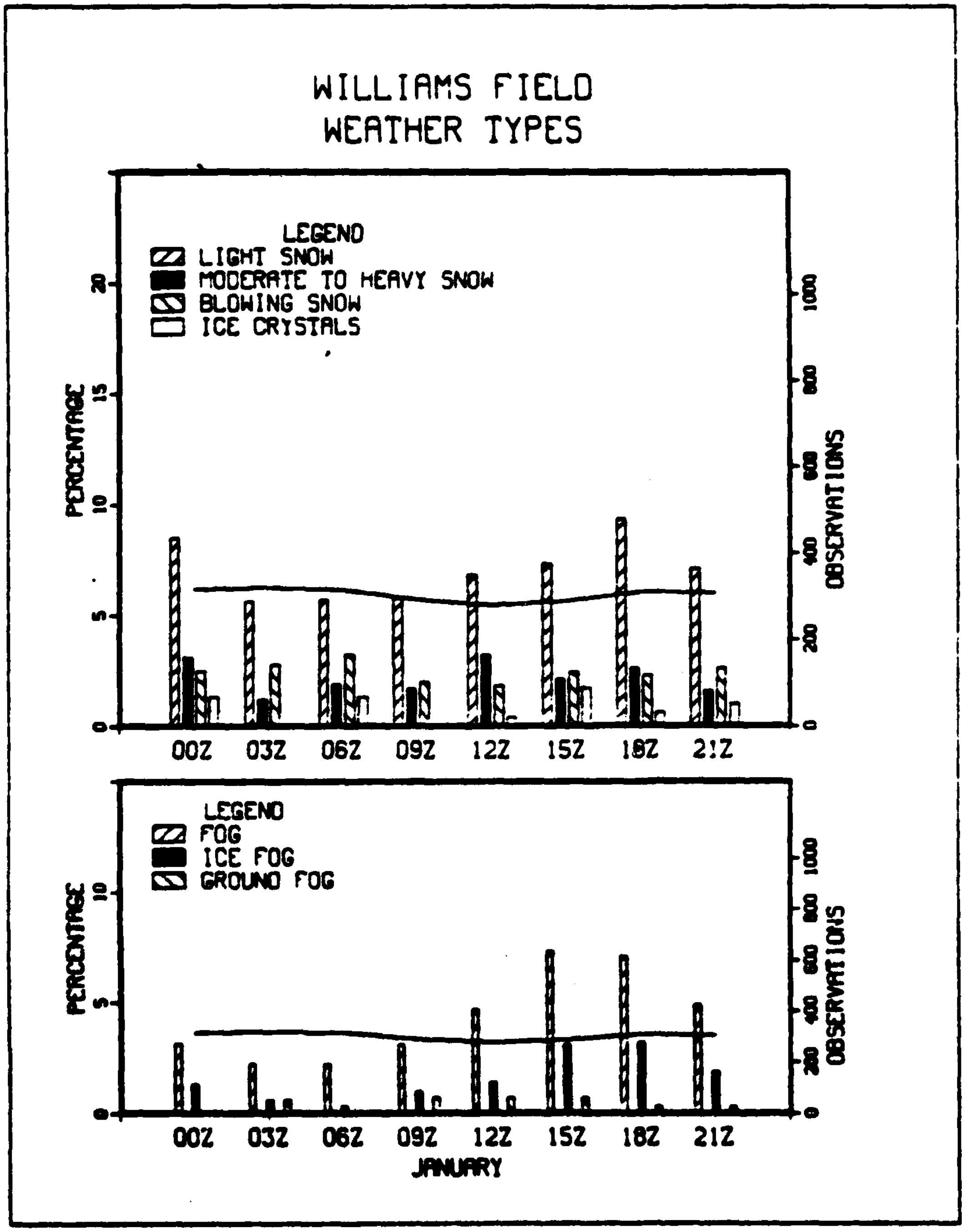


Figure 45. Diurnal Climatology of Weather Types For January at Williams Field, Antarctica.

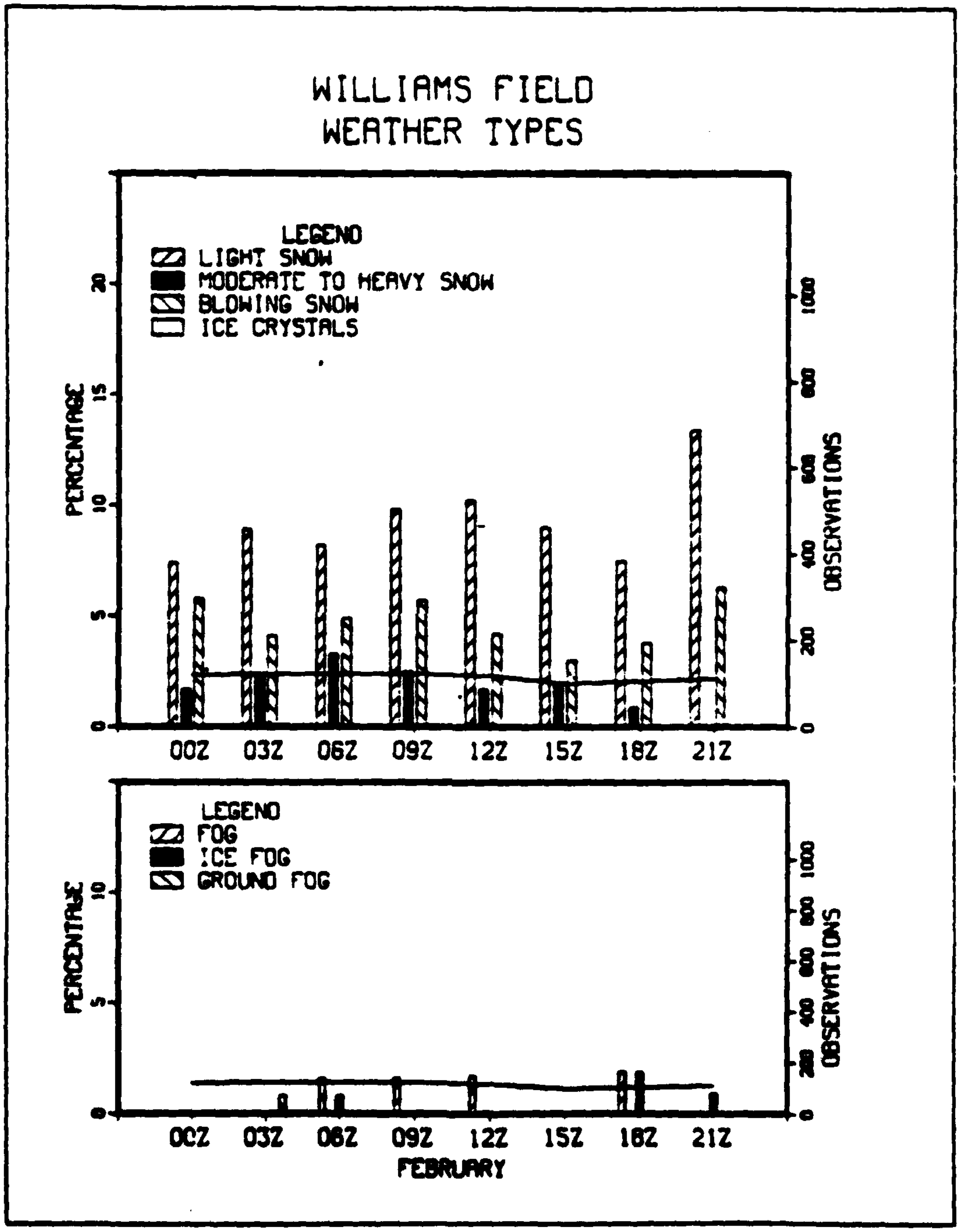


Figure 46. Diurnal Climatology of Weather Types For February at Williams Field, Antarctica.

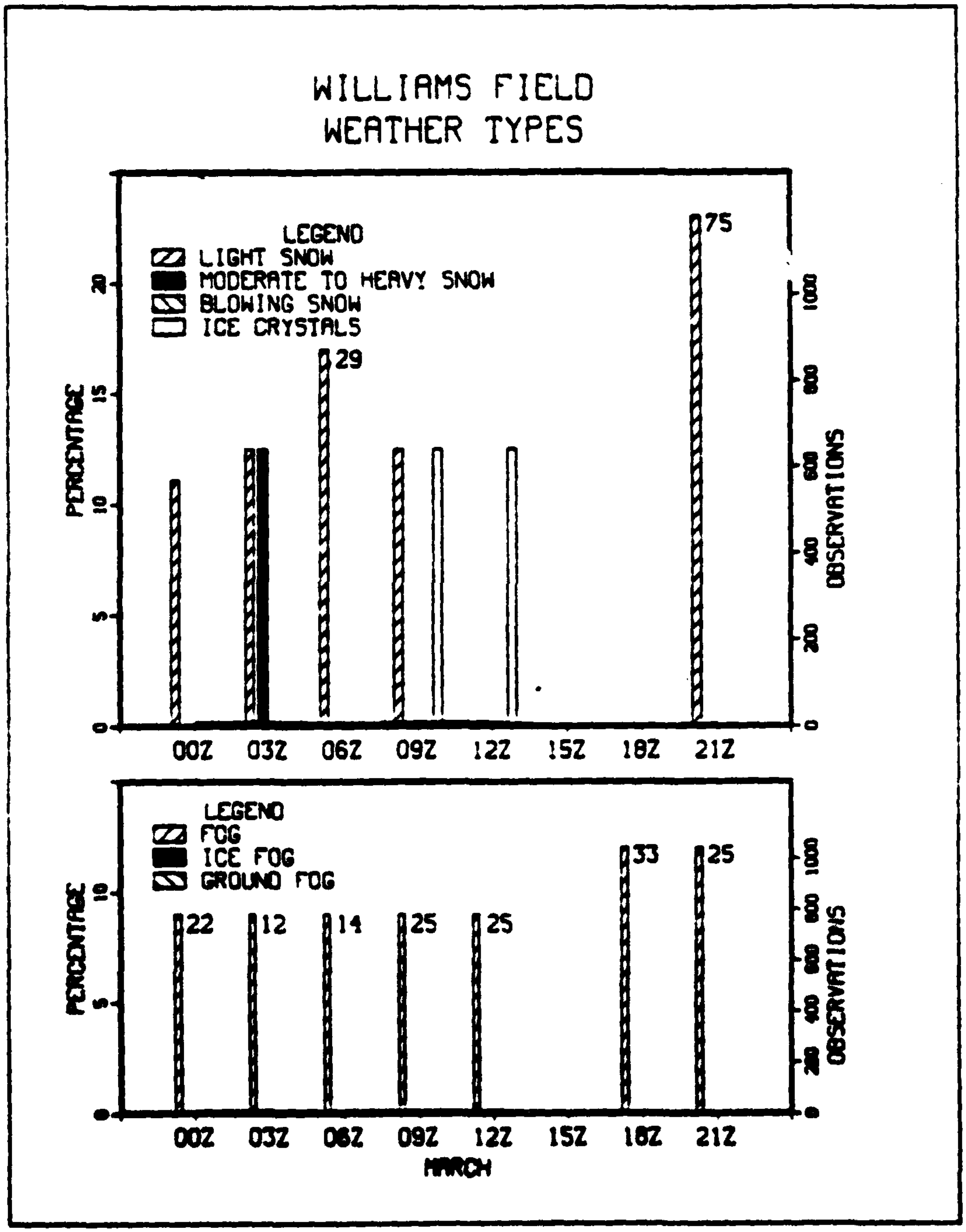


Figure 47. Diurnal Climatology of Weather Types For March at Williams Field, Antarctica.

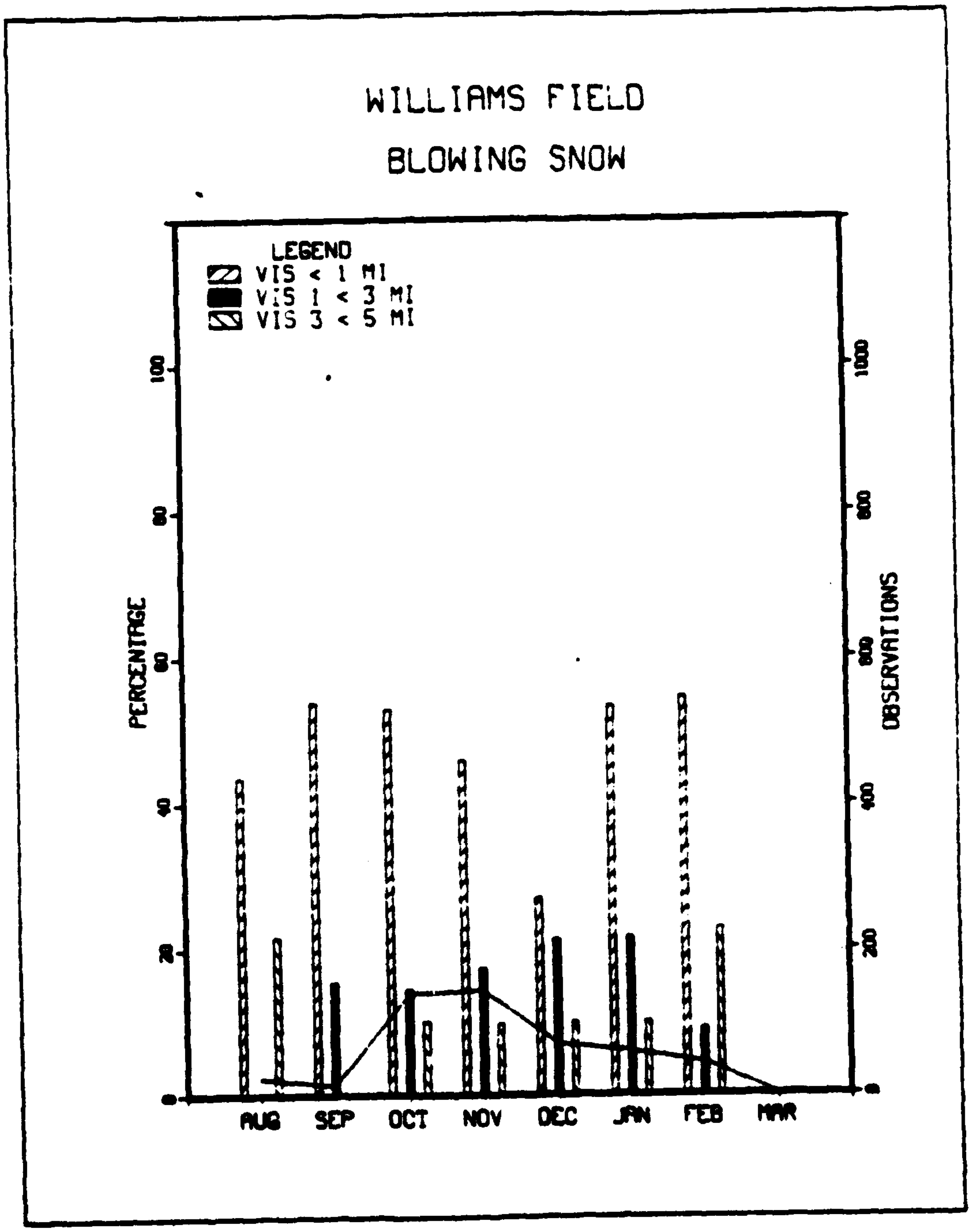


Figure 48. Monthly Climatology of Blowing Snow at Williams Field, Antarctica.

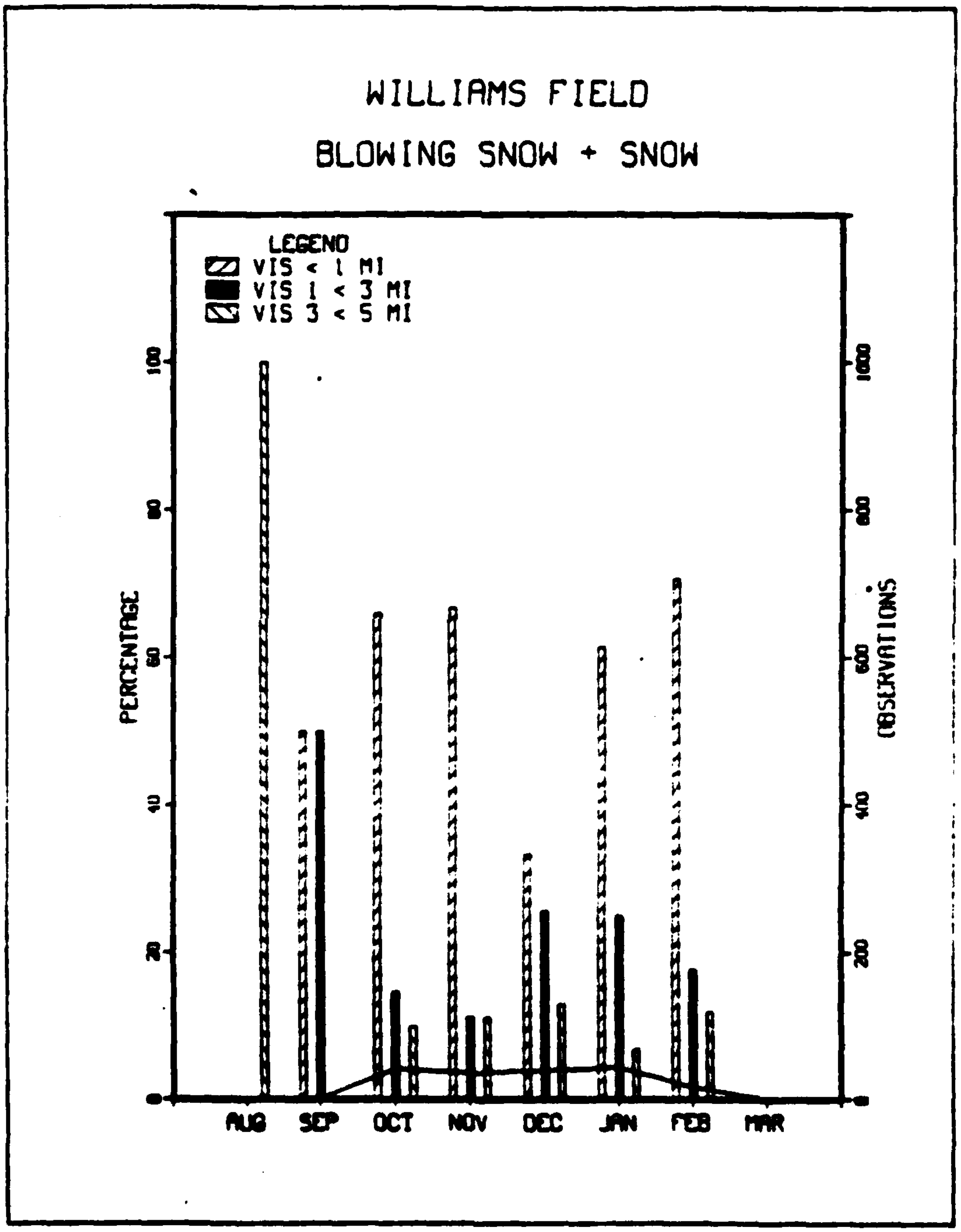


Figure 49. Monthly Climatology of Blowing Snow and Snow at Williams Field, Antarctica.

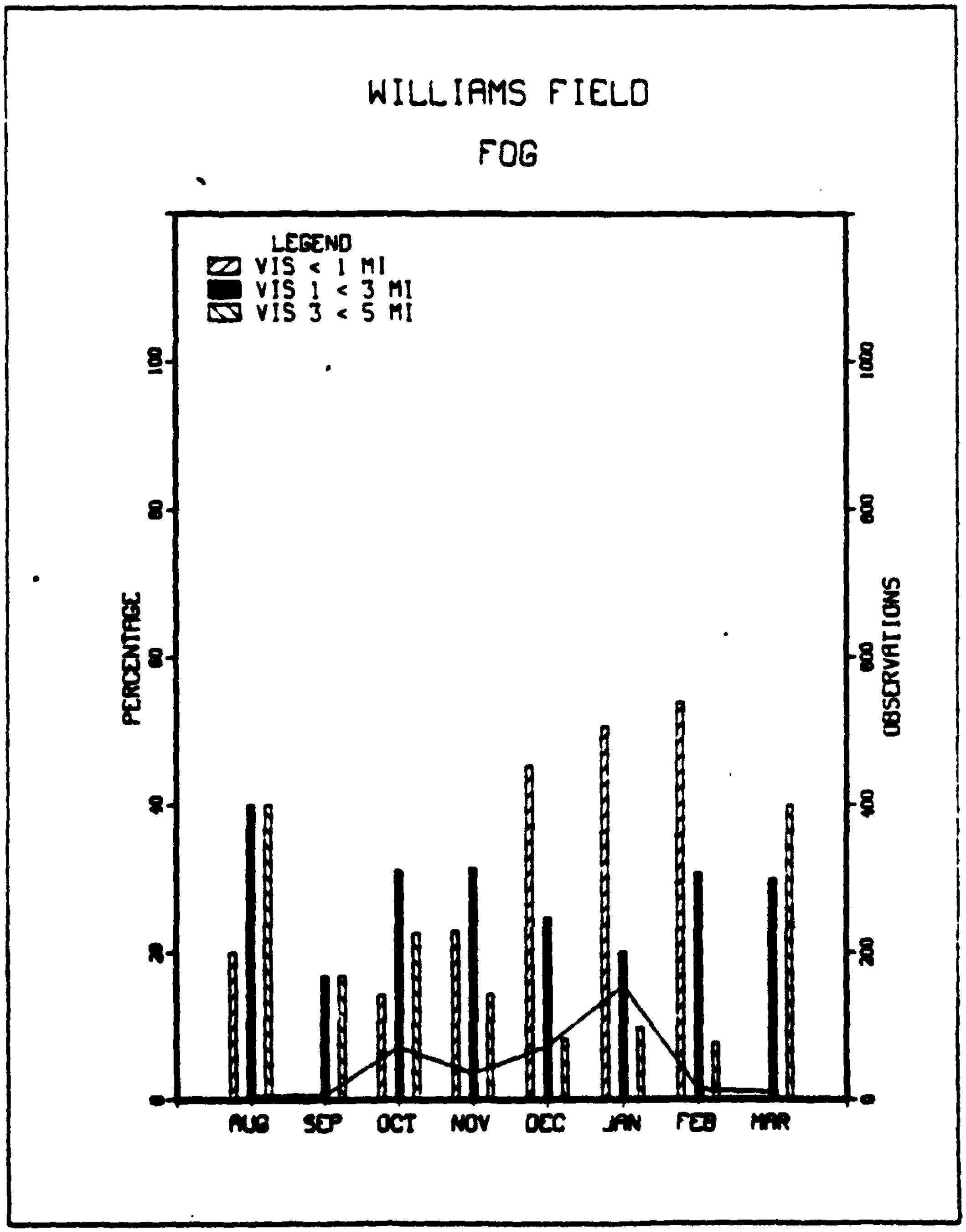


Figure 50. Monthly Climatology of Fog at Williams Field, Antarctica.

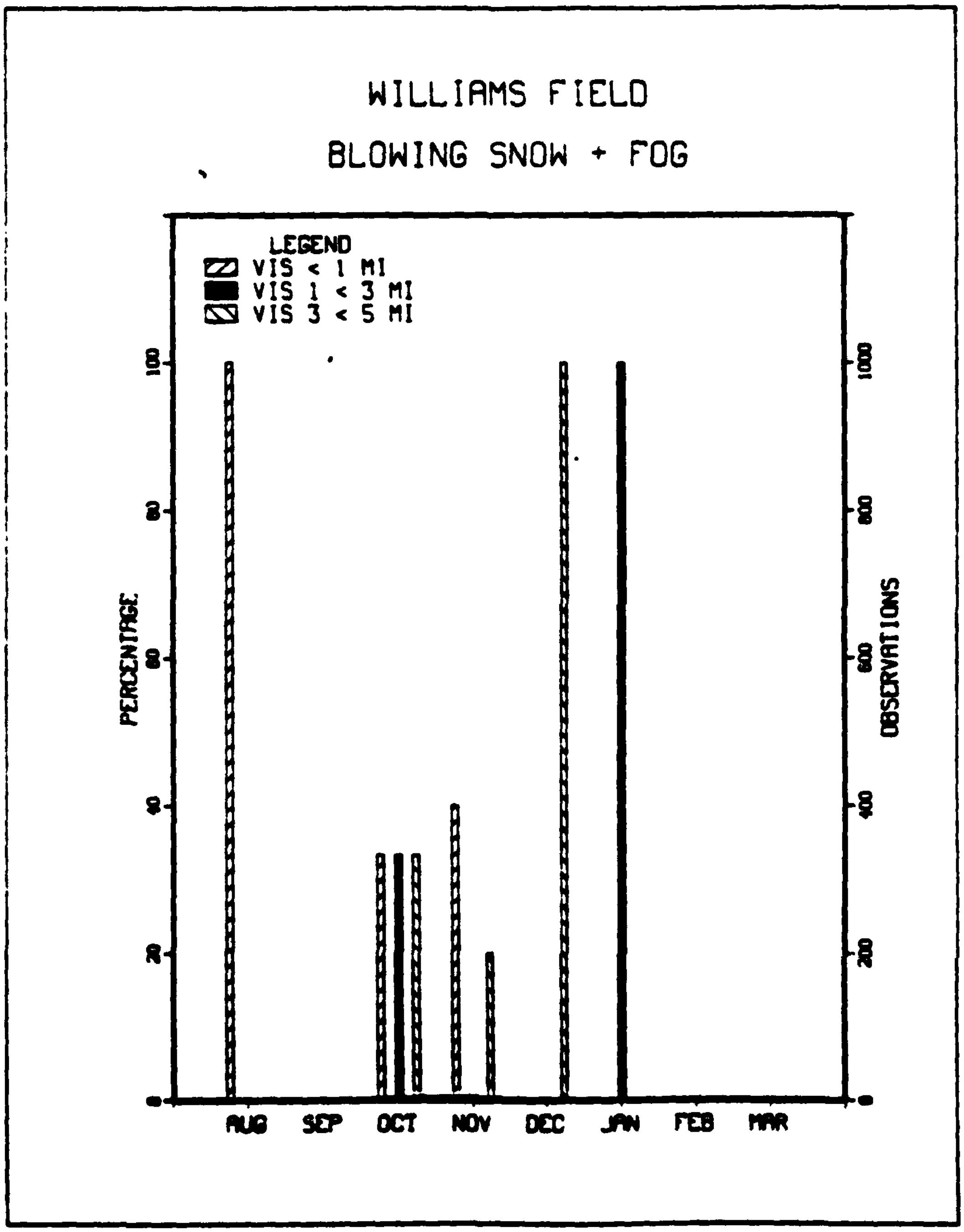


Figure 51. Monthly Climatology of Blowing Snow and Fog at Williams Field, Antarctica.

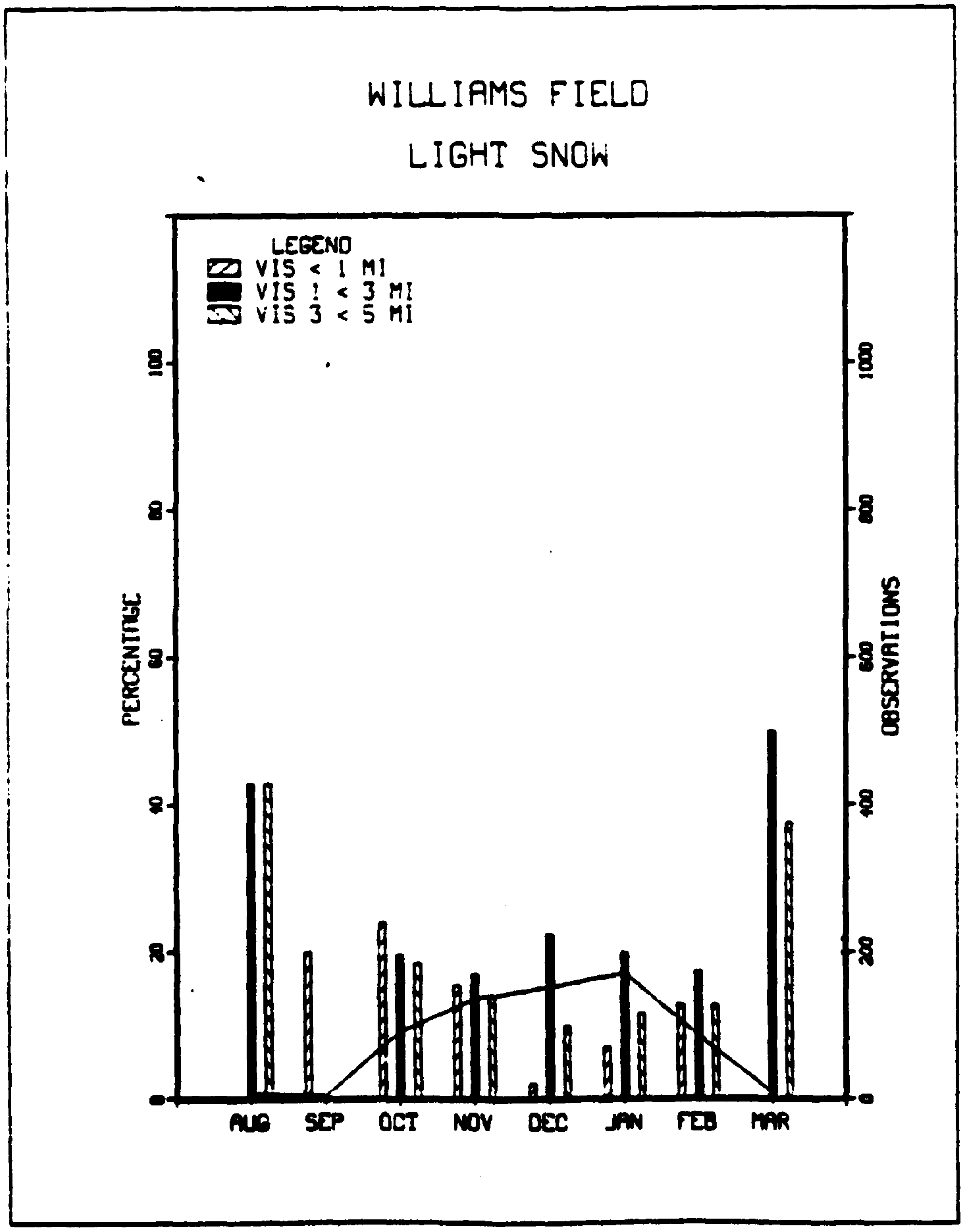


Figure 52. Monthly Climatology of Light Snow at Williams Field, Antarctica.

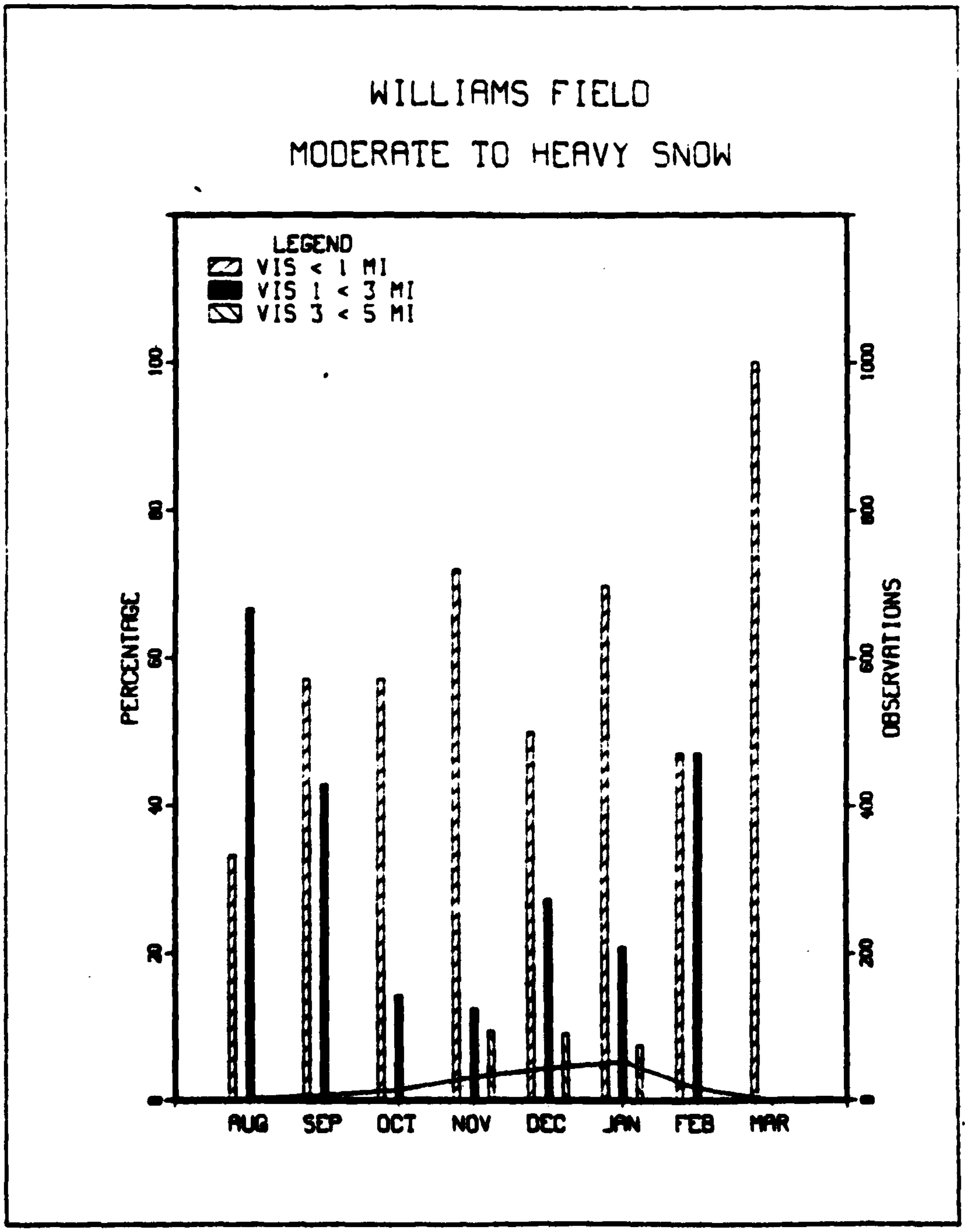


Figure 53. Monthly Climatology of Moderate to Heavy Snow at Williams Field, Antarctica.

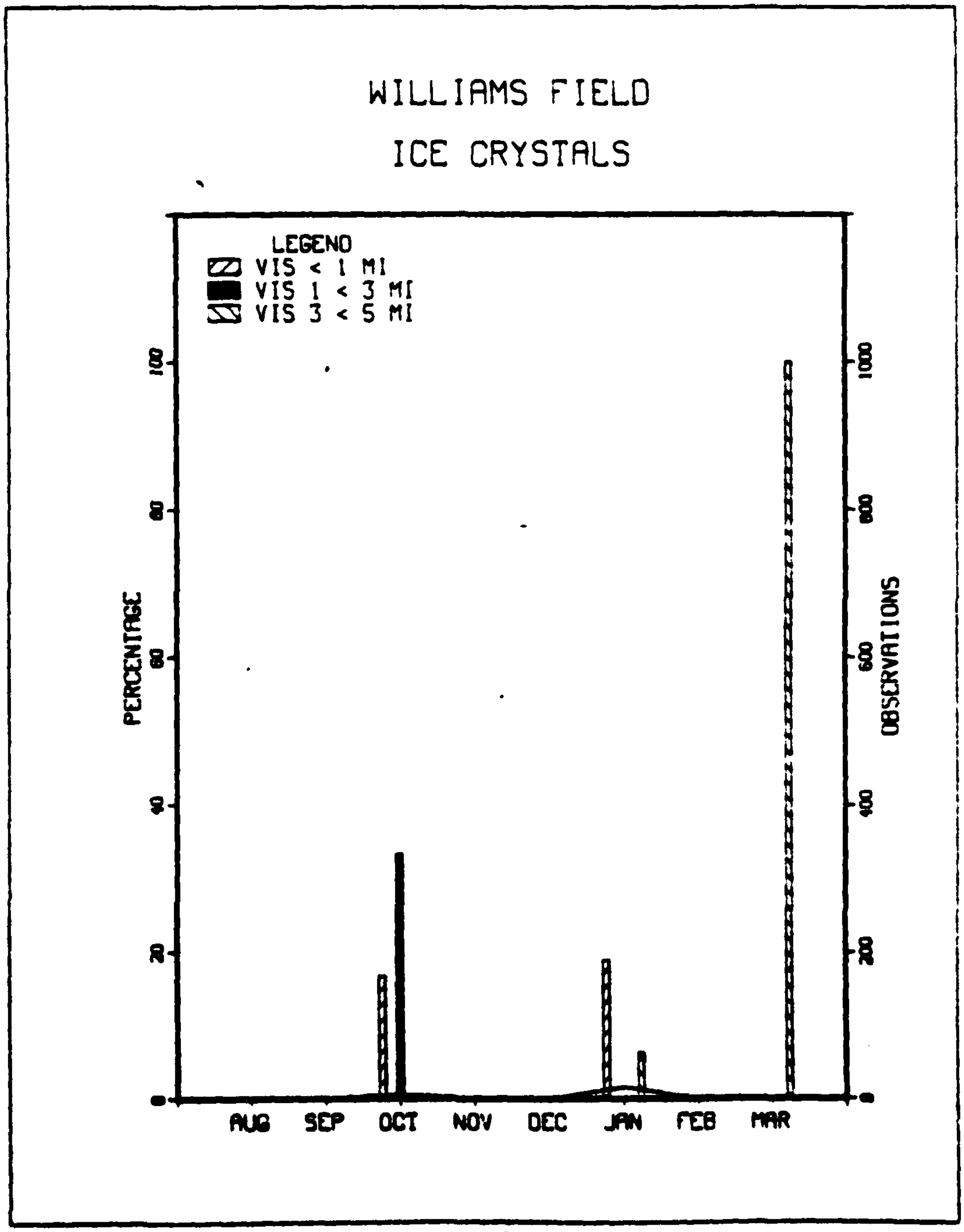


Figure 54. Monthly Climatology of Ice Crystals at Williams Field, Antarctica.

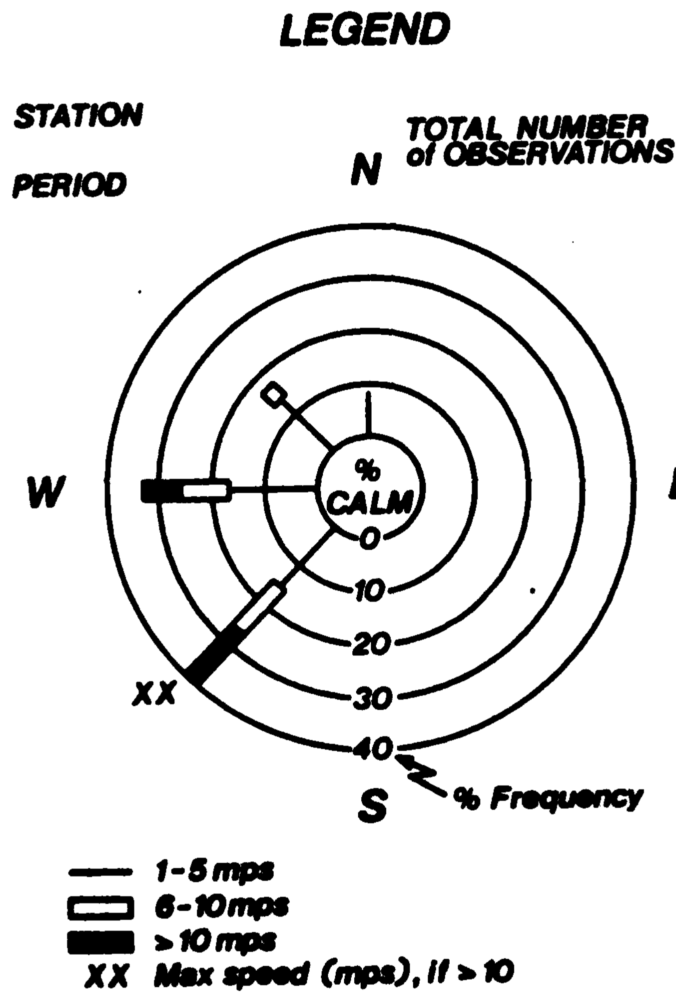


Figure 55. Legend for Wind Roses.

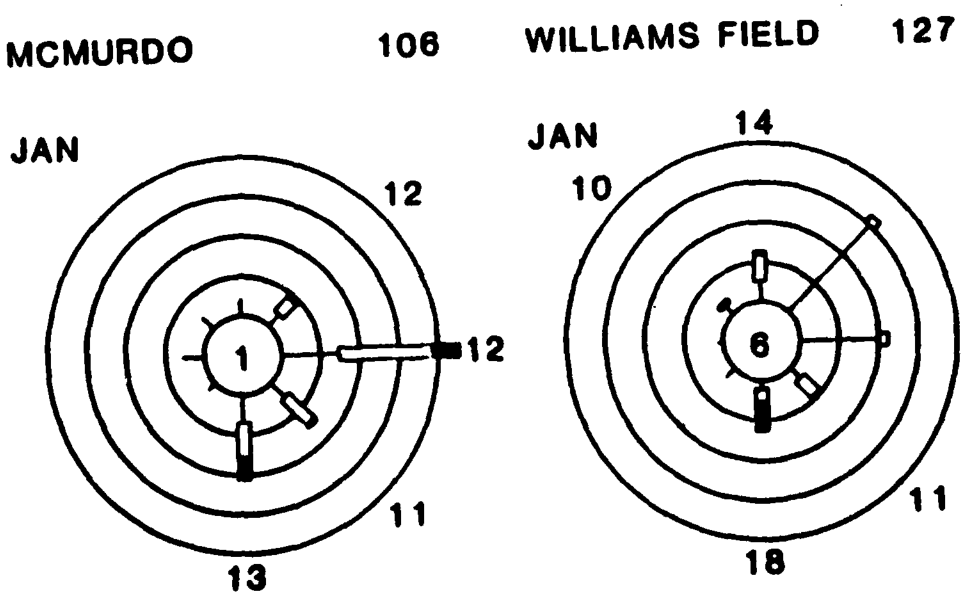


Figure 56. Wind Roses for Cat 1 Visibility in January at McMurdo/Williams Field, Antarctica.

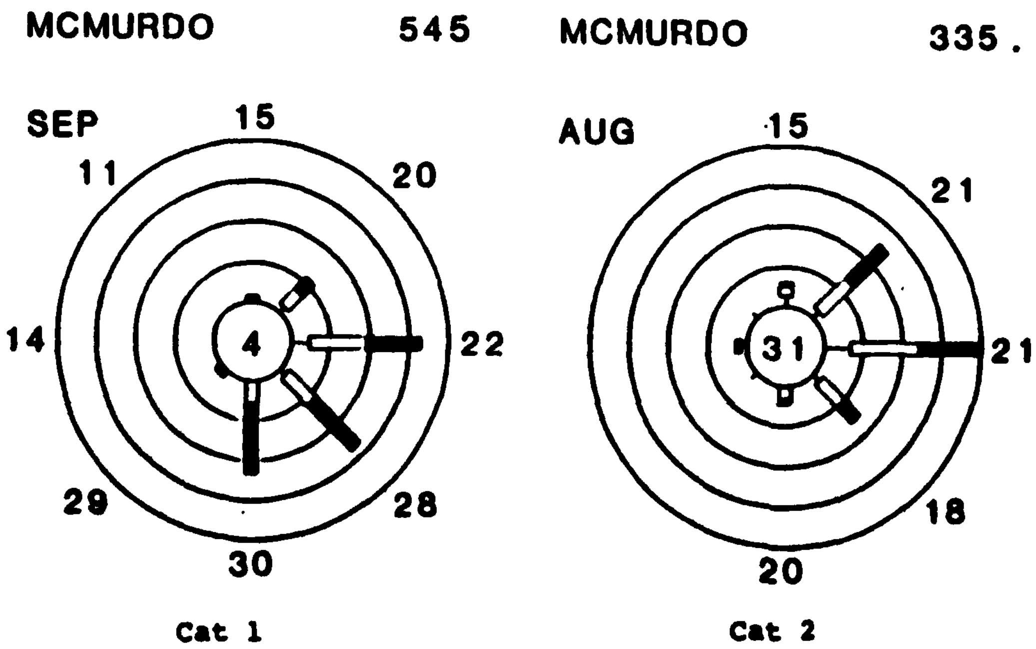


Figure 57. Wind Roses for Cat 1 Visibility in September and Cat 2 Visibility in August at McMurdo, Antarctica

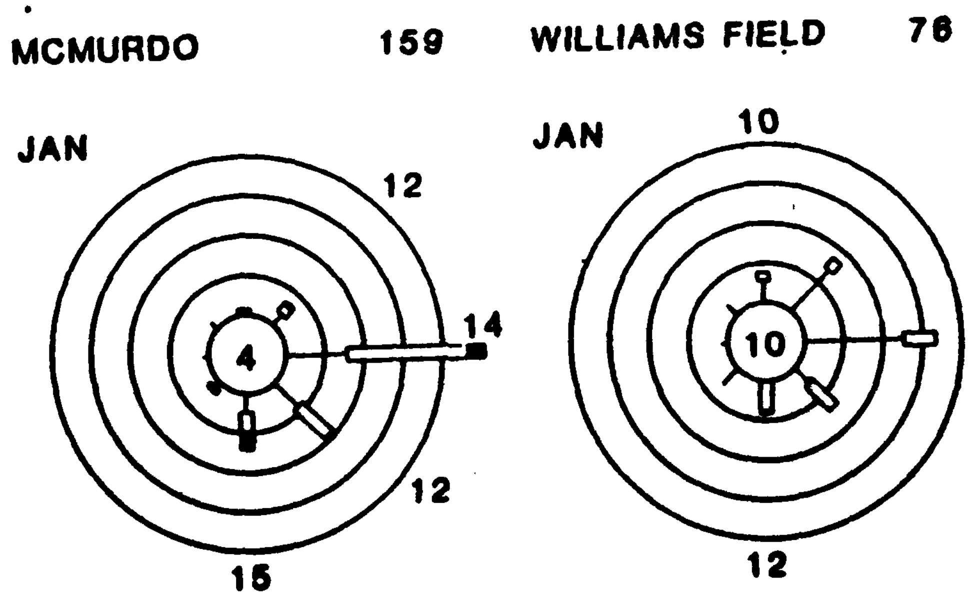


Figure 58. Wind Roses for Cat 2 Visibility in January at McMurdo/Williams Field, Antarctica.

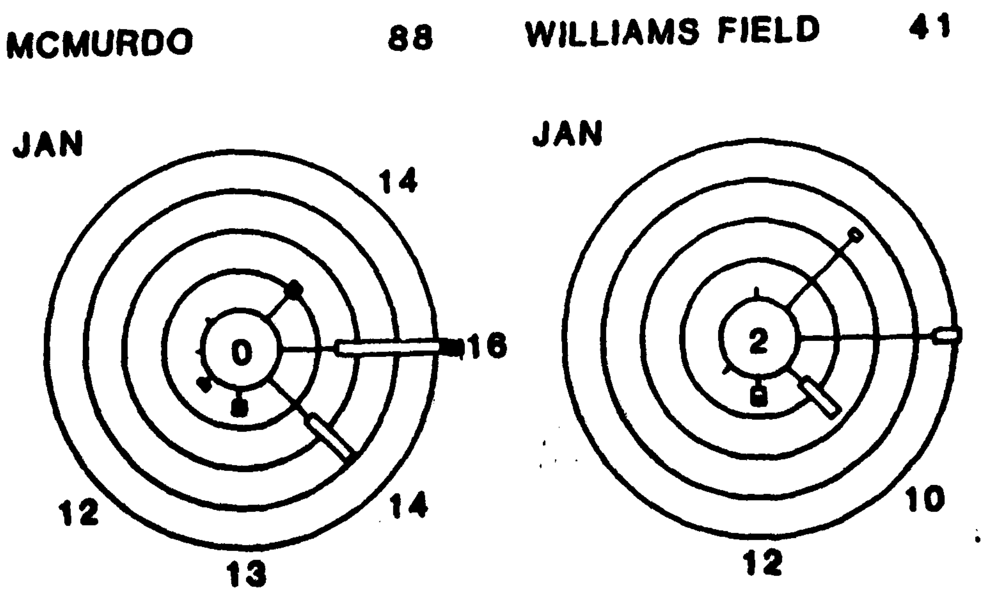


Figure 59. Wind Roses for Cat 3 Visibility for January at McMurdo/Williams Field, Antarctica.

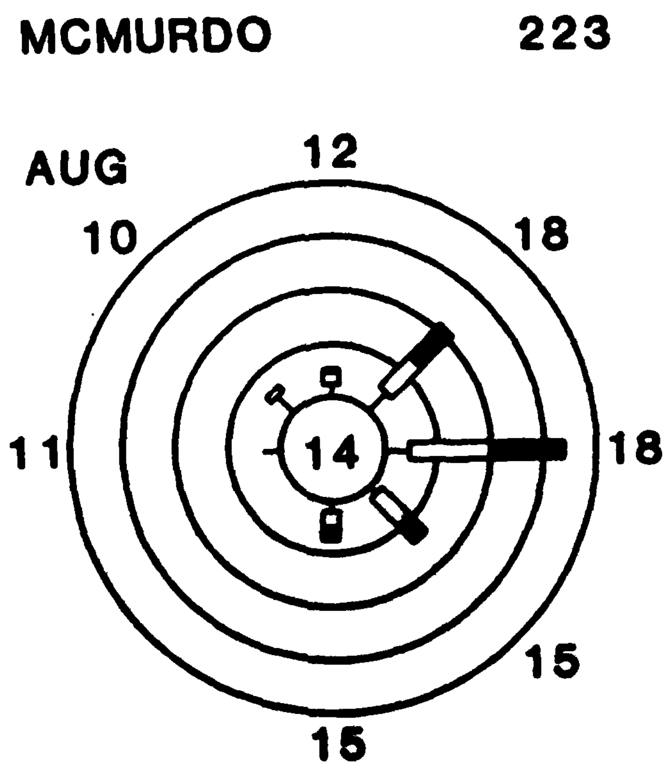


Figure 60. Wind Roses for Cat 3 Visibility for August at McMurdo, Antarctica.

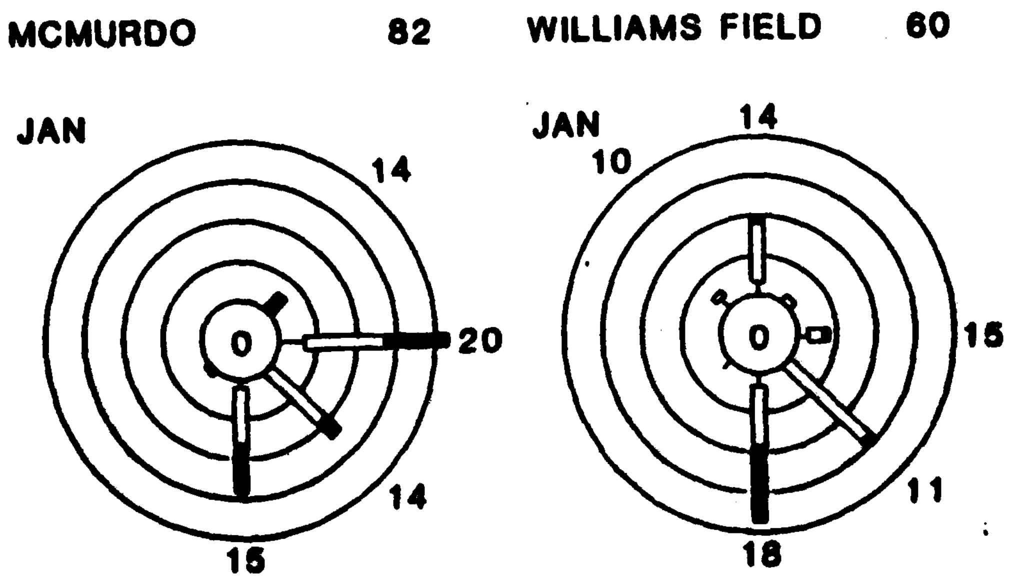


Figure 61. Wind Roses for Blowing Snow for January at McMurdo/Williams Field, Antarctica.

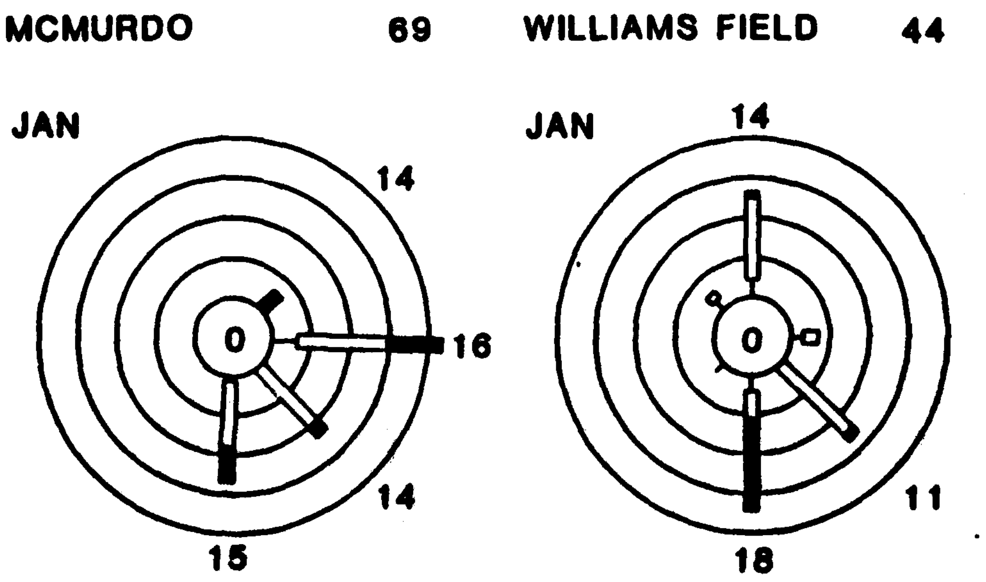


Figure 62. Wind Roses for Blowing Snow and Snow for January at McMurdo/Williams Field, Antarctica.

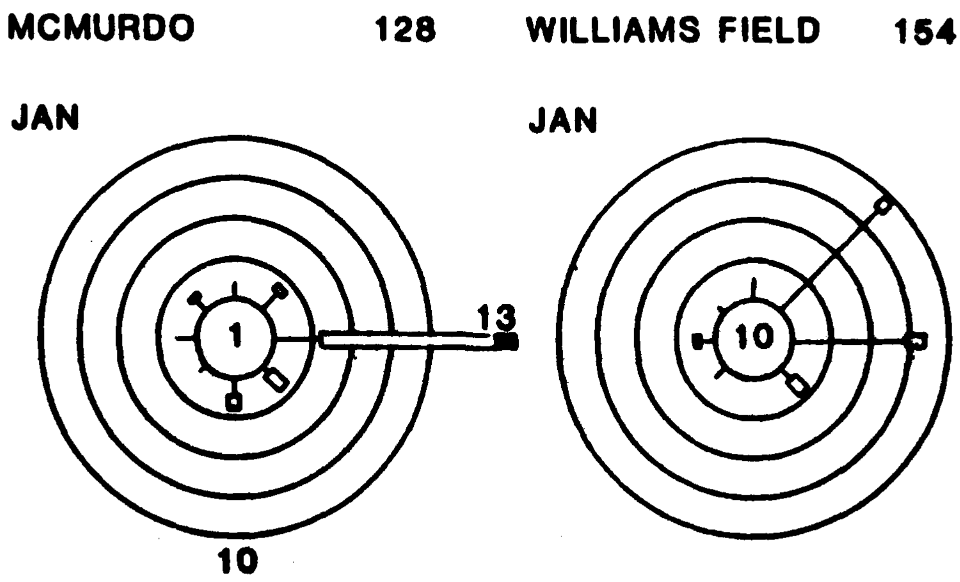


Figure 63. Wind Roses for Fog for January at McMurdo/Williams Field, Antarctica.

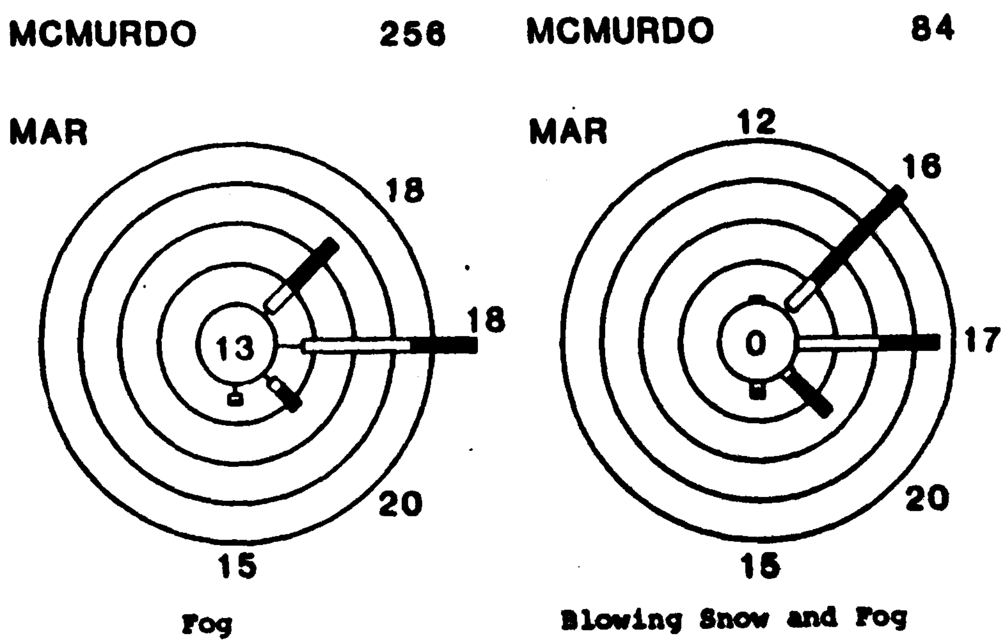


Figure 64. Wind Roses for Fog, and Blowing Snow and Fog for March at McMurdo, Antarctica.

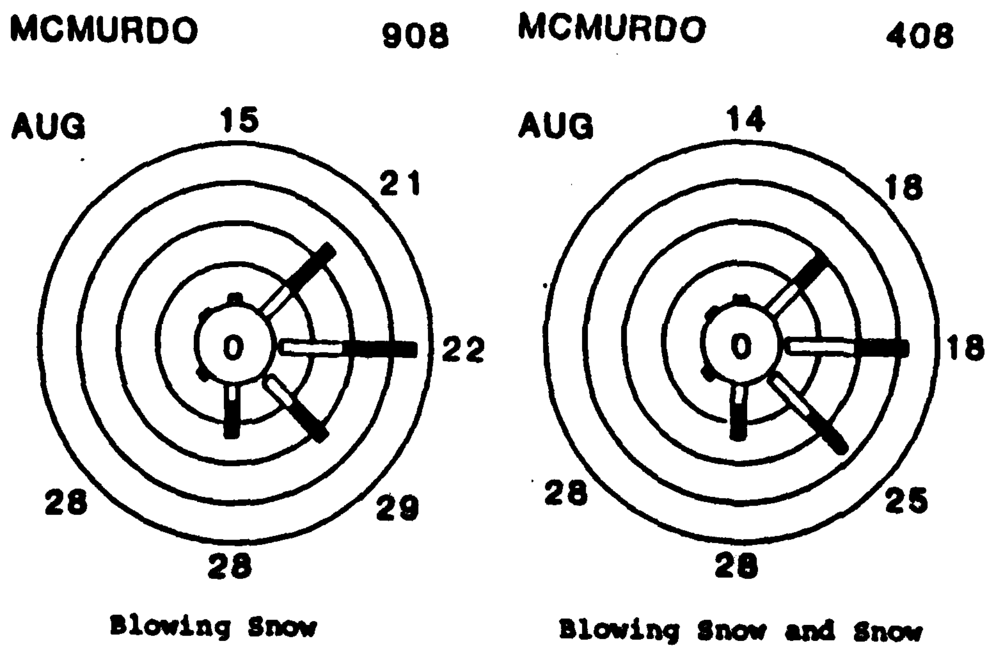


Figure 65. Wind Roses for Blowing Snow, and Blowing Snow and Snow for August at McMurdo, Antarctica.

LIST OF REFERENCES

Biter, C. J., 1965: A study of some hydrometers that affect visibility at McMurdo Sound, Antarctica, NWRF Technical Paper No. 14-65, Navy Weather Research Facility, Norfolk, Virginia, 28 pp.

Central Intelligence Agency, 1978: Polar Regions Atlas, Superintendent of Documents, U.S. Government Printing Office, Washington, DC, 20402, 66 pp., Stock Number 041-015-00094-2.

Huffman, P. J. and T. Ohtake, 1971: Formation and growth of ice fog particles at Fairbanks, Alaska, Journal of Geophysical Research, 76, No. 3, January, pp. 657-665.

Mercer, J. M., 1961: Climatology of McMurdo Sound, U.S. Navy Weather Research Facility, Building R-48, U.S. Naval Air Station, Norfolk, Virginia, Dec 1961, NWRF 16-1261-052, pp. 67.

National Science Foundation, 1983: Williams Field: the history of an icy aerodrome, Antarctic Journal of the United States, 18, No. 2, June 1983, pp. 1-7.

Orvig, S., 1970: World Survey of Climatology, 14, Climates of the Polar Regions, Elsevier Publishing Company, 52 Vanderbilt Ave., New York, New York, 10017, 370 pp.

Sallee, R. W. and A. W. Snell, 1970: Antarctic Forecasters Handbook, Antarctic Support Activities, Detachment CHARLIE, Fleet Post Office, New York, New York, 09501.

Simpson, G. C., 1919: Meteorology, 1: Discussion, British Antarctic Expedition 1910-1913, Thacker, Spink and Co., Calcutta, 326 pp.

Sinclair, M. K., 1982: Weather observations in the Ross Island Area, Antarctica, New Zealand Meteorological Service, Technical Note No. 253, P.O. Box 722, Wellington, New Zealand, 36 pp.

Thompson, D. C., 1972: Adverse weather conditions for flying operations at McMurdo Sound and Cape Hallett, Antarctica, Technical Note 214, New Zealand Meteorological Service, P.O. Box 722, Wellington, New Zealand, 9 pp.

United States Naval Support Force Antarctica (NSFA), 1982: United States Antarctic Program Welcome Aboard Manual, Public Affairs Office, NSFA, Fleet Post Office, San Francisco, California, 96601, 74 pp.

INITIAL DISTRIBUTION LIST

		No. Copies
1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22314	2
2.	Library, Code 0142 Naval Postgraduate School Monterey, California 93943	2
3.	Chairman, Code 63Rd Department of Meteorology Naval Postgraduate School Monterey, California 93943	6
4.	Chairman, Code 63Mr Department of Oceanography Naval Postgraduate School Monterey, California 93943	1
5.	Professor Carlyle Wash, Code 63Wx Department of Meteorology Naval Postgraduate School Monterey, California 93943	1
6.	Captain Cheryl G. Souders USAF PSC Box 1905 APO, New York 09127	2
7.	Naval Support Force Antarctica Code 33 FPO, San Francisco 96601	2
8.	Mr. Ben Fogle Polar Programs Manager National Science Foundation Washington, DC 20550	1
9.	Director Naval Oceanography Division Naval Observatory 34th and Massachusetts Avenue NW Washington, DC 20390	1
10.	Mr. William J. Thompson, Code 63Th Department of Meteorology Naval Postgraduate School Monterey, California 93943	1

11. Commander 1
Naval Oceanography Command
NSTL Station
Bay St Louis, Mississippi 39522

12. Commanding Officer 1
Fleet Numerical Oceanography Center
Monterey, California 93943

13. Commanding Officer 1
Naval Environmental Prediction
Research Facility
Monterey, California 93943

14. Chairman, Oceanography Department 1
U.S. Naval Academy
Annapolis, Maryland 21402

15. Chief of Naval Research 1
800 N. Quincy Street
Arlington, Virginia 22217

16. Commander (AIR-370) 1
Naval Air Systems Command
Washington, DC 20360

17. Program Manager (CIRF) 1
Air Force Institute of Technology
Wright-Patterson AFB, Ohio 45433

18. Commander 1
Air Weather Service
Scott Air Force Base, Illinois 62225

19. Commanding Officer 2
Air Force Global Weather Central
Offutt Air Force Base, Nebraska 68113

20. Mr. Mark K. Sinclair, Code 63Si 1
Department of Meteorology
Naval Postgraduate School
Monterey, California 93943

DATE
FILMED