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Learning to Forecast Wind at Remote Sites for Wind Energy Applications

Final Report

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LEARNING TO FORECAST WIND AT REMOTE SITES FOR WIND ENERGY APPLICATIONS

FINAL REPORT

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EXECUTIVE SUMMARY

As the use of large wind turbines by electrical utilities becomes more prevalent, significant penetrations of wind turbine generators (WTG) into utility power grids will introduce greater minute-to-minute variability into the power generation than has been experienced in the past. That power variability will be closely related to the variation in the wind at the WTG sites. For decades utilities have used forecasts of various weather elements in making load forecasts; however, wind forecasting for WTG operation introduces many new problems for both utility operations personnel and for the meteorologists making the forecasts. With the incorporation of wind energy into the utility generation mix, efficient unit commitment and dispatching can only occur if the availability of wind power is known several hours in advance, through preparation and dissemination of reliable wind forecasts.

In April 1979, the Pacific Northwest Laboratory (PNL) contracted with five weather consulting firms to supply 24-hour wind forecasts for eleven selected Department of Energy (DOE) candidate wind turbine sites. One conclusion drawn following this project was that more research was needed, using *a priori* knowledge, synoptic-scale weather maps and the corresponding site wind observations, in order to formulate and calibrate suitable wind-forecasting techniques. Therefore this study was initiated in February 1981 to correlate observed wind patterns with synoptic or mesoscale weather systems. Two of the organizations involved in the 1979 wind-forecasting work were selected to perform the analysis, Freese-Notis Weather and Murray and Trettel, Inc.

Six of the DOE sites were selected for analysis. The six sites include Montauk Point, New York; Boone, North Carolina; Ludington, Michigan; Clayton, New Mexico; Amarillo, Texas and San Gorgonio Pass, California. These sites were analyzed in order to accomplish the following objectives:

1. Identify synoptic and/or mesoscale weather patterns that are associated with recognizable wind events at the sites.

2. Define a set of criteria that uniquely describes such weather patterns.
3. Estimate the reliability (accuracy) of forecasting rules derived from the association of weather patterns and site winds.
4. Attempt to separate any mesoscale effects of local topography from the synoptic-scale effects.

The approach to development of a site-specific forecasting scheme led to characterization of the prevalent wind regimes at each site, formulation of forecasting guidelines and knowledge of how to learn to forecast winds for wind energy production applications.

It should be noted however, that these guidelines are the result of research on six specific sites and may not be generic to any site. Albeit the sites studied spanned the range of terrain complexity and geographic setting, it must be emphasized that the work reported herein provides an accounting of efforts to learn how to forecast wind at specific sites with sufficient accuracy and resolution to be useful to users of wind energy.

The analysis indicated that there is not a one-to-one mapping of wind regimes onto synoptic types. Examination of other wind predicators revealed that no single wind predictor appears to work well when used alone. It was concluded that four factors should be examined when stratifying wind regimes such that the regimes can be reliably forecast for wind energy applications:

- synoptic situation
- descriptive climatology
- pressure gradient vector
- winds aloft.

The wind-forecasting approach developed in this study was intended for forecasting hourly average winds out to the 24-, or possibly, 36-hour time horizon. Consequently, the forecasting technique is best suited for incorporation into utility daily load forecasts to reduce reserve generating capacity scheduled to back up the fluctuating WTG. Because the forecasting guidelines developed in this study require evaluation of weather charts prior to making and disseminating the wind forecasts, this forecasting approach is intended for use at locations where meteorologists are available who have access to National Weather Service analyses and prognoses.

The site-specific forecasting approaches developed in this study are to be tested in a subsequent wind-forecasting verification project.

Recommendations for the improvement of any future work in forecast development are:

- incorporation of the time element into forecasting guidelines (rather than "nowcasting") should be emphasized
- predictors should be specified in terms of values routinely reported at weather observing stations
- more conditional climatology should be tabulated as a forecasting aid.

Wind power forecasting problems that have yet to be addressed are:

- methods of converting hourly average speeds to WTG power output
- methods for producing wind power forecasts for WTG clusters
- methods for producing short-term (0-6 hour) high reliability wind power forecasts for dispatcher use.

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1.0 INTRODUCTION

As the use of large wind turbines by electrical utilities becomes more prevalent, significant penetrations of wind turbine generators (WTG) into utility power grids will introduce greater minute-to-minute variability into the power generation than has been experienced in the past. That power variability will be closely related to the variation in the wind at the WTG sites. For decades utilities have used forecasts of wind, temperature changes and precipitation as well as other weather elements, in making load forecasts; however, wind forecasting for WTG operation introduces many new problems for both utility operations personnel and for the meteorologists making the wind forecasts. With the incorporation of wind into the generation mix, efficient unit commitment and dispatching can only occur if the availability of wind power is known. Of primary concern is the reliability of wind forecasts produced for WTG operations.

In April 1979, the Pacific Northwest Laboratory (PNL) contracted with five weather consulting firms to supply 24-hour wind forecasts for eleven selected Department of Energy (DOE) candidate wind turbine sites. The purpose of this project was to provide a data base for evaluating the reliability of subjective wind forecasts for use in WTG operation. One conclusion drawn at the completion of this project was that more research was needed, using a priori knowledge, synoptic-scale weather maps and the corresponding site wind observations, in order to formulate and calibrate suitable wind-forecasting techniques.

As part of the verification of the subjective wind forecasts, PNL produced time-series plots of hourly average wind speed and direction. An examination of the plots revealed recurring, recognizable wind patterns at the sites. Therefore, a 10-month study was initiated in February 1981 to correlate the observed wind patterns with synoptic or mesoscale weather systems.

Two of the organizations involved in the original subjective wind-forecasting work were selected to perform the analysis. These organizations were Murray and Trettel Incorporated, a meteorological consulting firm specializing in applied weather forecasting and meteorological research, and Freese-Notis weather, a meteorological consulting firm specializing primarily in operational weather forecasting.

Six of the DOE sites were selected for analysis to accomplish the following objectives:

1. Identify synoptic and/or mesoscale weather patterns that are associated with recognizable wind events at the sites.

2. Define a set of criteria that uniquely describes such weather patterns.

3. Estimate the reliability (accuracy) of forecasting rules derived from the association of weather patterns and site winds.

4. Attempt to separate any mesoscale effects of local topography from the synoptic-scale effects.

The work performed in this study permitted formulation of rules-of-thumb and other guidelines that can be used to produce reliable forecasts of wind for WTG operations, while, at the same time, characterizing the wind events occurring at each site. In addition, the work identified approaches to the problem of learning to forecast wind for WTG operations. These approaches can be used by others faced with the problem of forecasting wind for utilities using WTG.

2.0 SITES ANALYZED

Six sites were selected for study in this project. All are either DOE candidate WTG sites or DOE sites already selected for WTG installation. The six sites--Montauk Point, New York; Boone, North Carolina; Ludington, Michigan; Clayton, New Mexico; Amarillo, Texas; and San Gorgonio Pass, California--span the entire continental United States from the East Coast to the West Coast. As the following descriptions indicate, these sites represent a broad range of topographical and climatological regimes.

Montauk Point, New York (Figure 2.1), lies on a north-northwest facing bay near the easternmost end of Long Island. The site elevation is 3 m (10 ft) above mean sea level (MSL) and the surrounding terrain is relatively flat, having no more than 9 m (30 ft) of relief within 800 m (1/2 mile) of the site. Frequent winter and spring weather disturbances move through Montauk Point making northwest the prevailing wind direction as well as the direction of strongest winds. During the warmer months, however, the sea breeze produces moderate winds from the southwest, which is the second most common wind direction. Winds from the northeast quadrant are generally light and rarely blow. The diurnal wind pattern is typical of many coastal sites, having an afternoon maximum and an early morning minimum in wind speed.

The Boone, North Carolina site (Figure 2.2) is located on the top of Howard's Knob, approximately 300 m (1000 ft) above the town of Boone, in the northwest corner of North Carolina. The knob, which is covered with hardwood trees exceeding 9 m (30 ft) in height, slopes downward on all sides. There are higher mountains in the vicinity, both to the west and to the northwest. The nearest of which is Rich Mountain, 110 m (360 ft) higher and 1.1 km (1.7 miles) northwest of the Boone site. The strongest and most frequent winds at Boone are from the northwest and generally occur as high pressure systems begin to build into the area. Easterly winds are very rare and usually very light. The diurnal wind speed cycle is typical of most mountain locations, having a maximum speed at night and a minimum about midday.

MONTAUK, NY

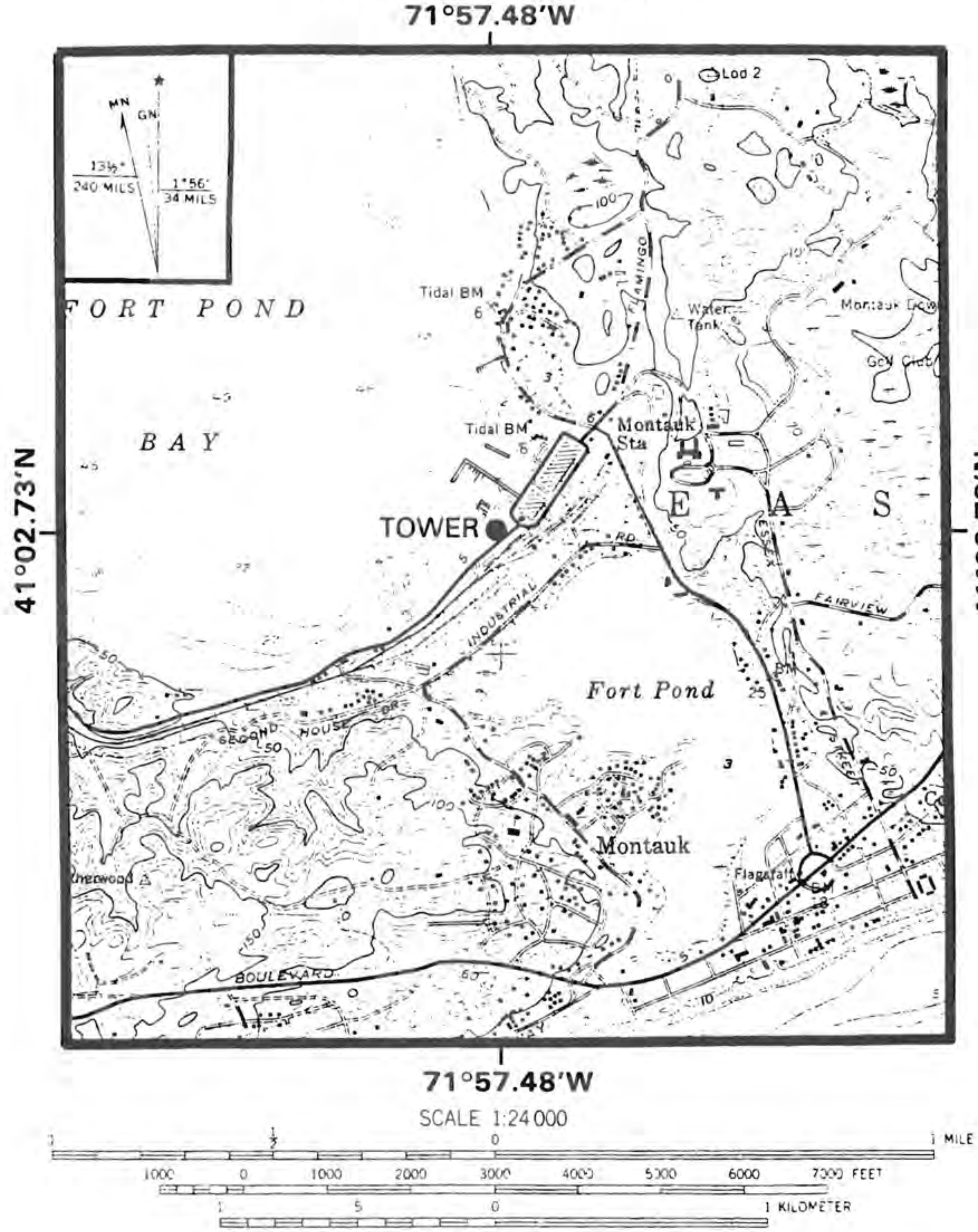


FIGURE 2.1. Montauk, New York Site Location

BOONE, N.C.

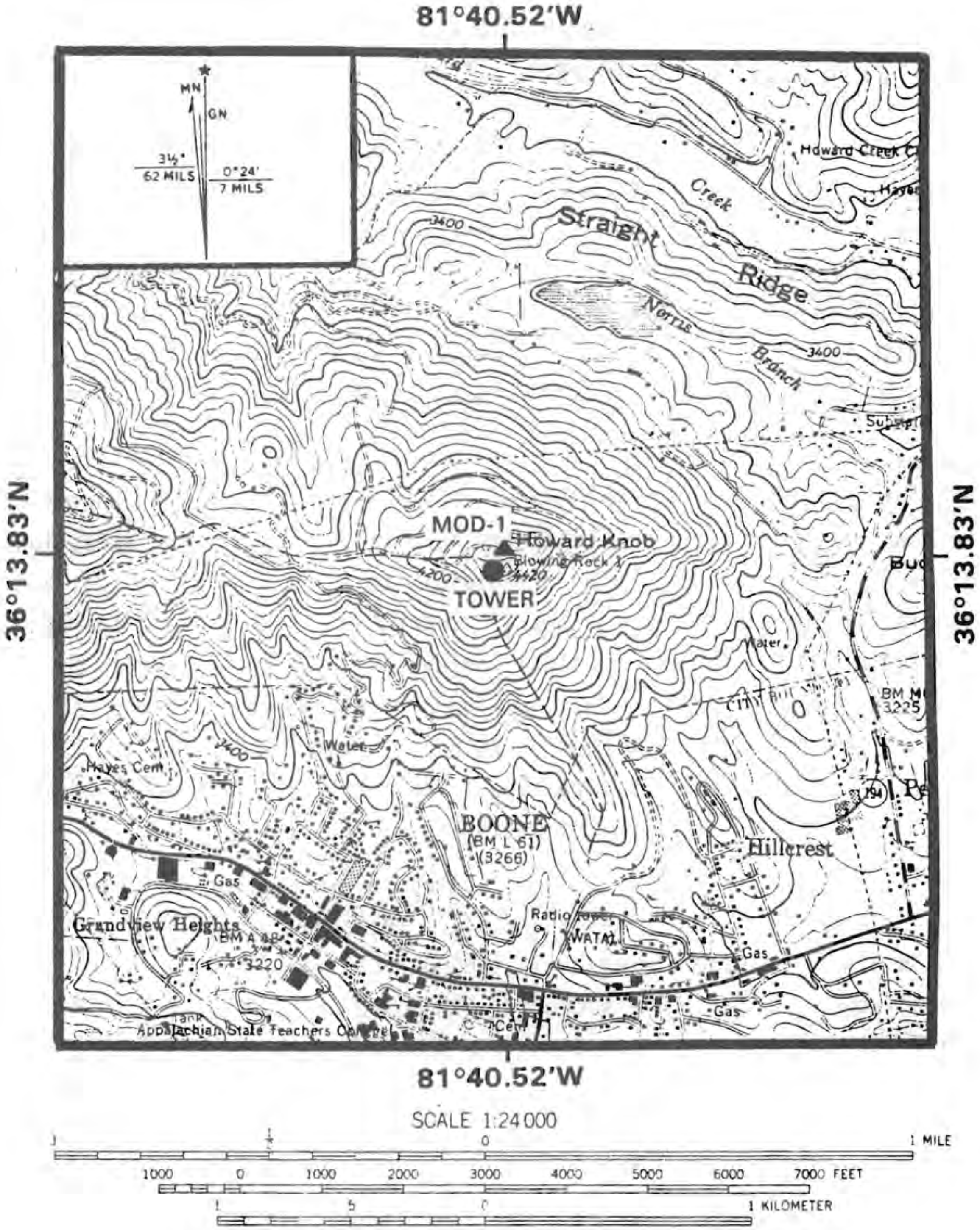


FIGURE 2.2. Boone, North Carolina Site Location

The Ludington, Michigan site (Figure 2.3) lies near a 70 m (240 ft) cliff overlooking Lake Michigan to the west. The site elevation is 250 m (815 ft) MSL. There are trees in excess of 50 ft as well as deep ravines in the vicinity of the site. The shoreline of the lake runs north-south near the site contributing to the two wind direction and speed maxima observed at south-southwest and north. The diurnal wind pattern is southeasterly flow (offshore) at night and westerly flow (onshore) during the day, with a slight nighttime speed maximum. Strong north winds are usually of short duration and associated with a frontal passage. Except for some relatively short-term phenomena the winds in the summer months are significantly reduced relative to autumn through spring.

Clayton, New Mexico (Figure 2.4) is located in the extreme northeast corner of the state. The meteorological tower site lies on the southwest edge of the town. The terrain in the vicinity is fairly flat with the exception of a 6 m (20 ft) deep creek bed lying immediately to the west of the site, and which deepens as it continues southward. Vegetation is grassy and sparse. The nearest hills are 16 km (10 miles) northwest, where the foothills of the Rocky Mountains begin. The prevailing wind directions are south and southwest, although, some strong winds do blow occasionally from the Rockies to the west and from the NE during a frontal passage. The diurnal wind speed maximum comes in mid-afternoon and the minimum in the early morning.

The Amarillo site (Figure 2.5) is located 13 km (8 miles) northeast of the city of Amarillo in the Texas Panhandle. The area primarily is a flat treeless plain. The site elevation is 1100 m (3600 ft) MSL. There are several commercial power plants in the vicinity with buildings approximately 1/2 km (1/4 mile) to the south (this is along the prevailing wind direction). The nocturnal jet produces a wind speed maximum during the middle of the night, the minimum occurs at approximately noon.

The San Gorgonio Pass site (Figure 2.6) lies near the eastern end of the east-west running pass, approximately 64 km (40 miles) east of Riverside, California. The site elevation is 335 m (1100 ft) MSL, while the pass summit is 800 m (2600 ft) MSL. The pass separates the San Jacinto Mountains to the

LUDINGTON, MI

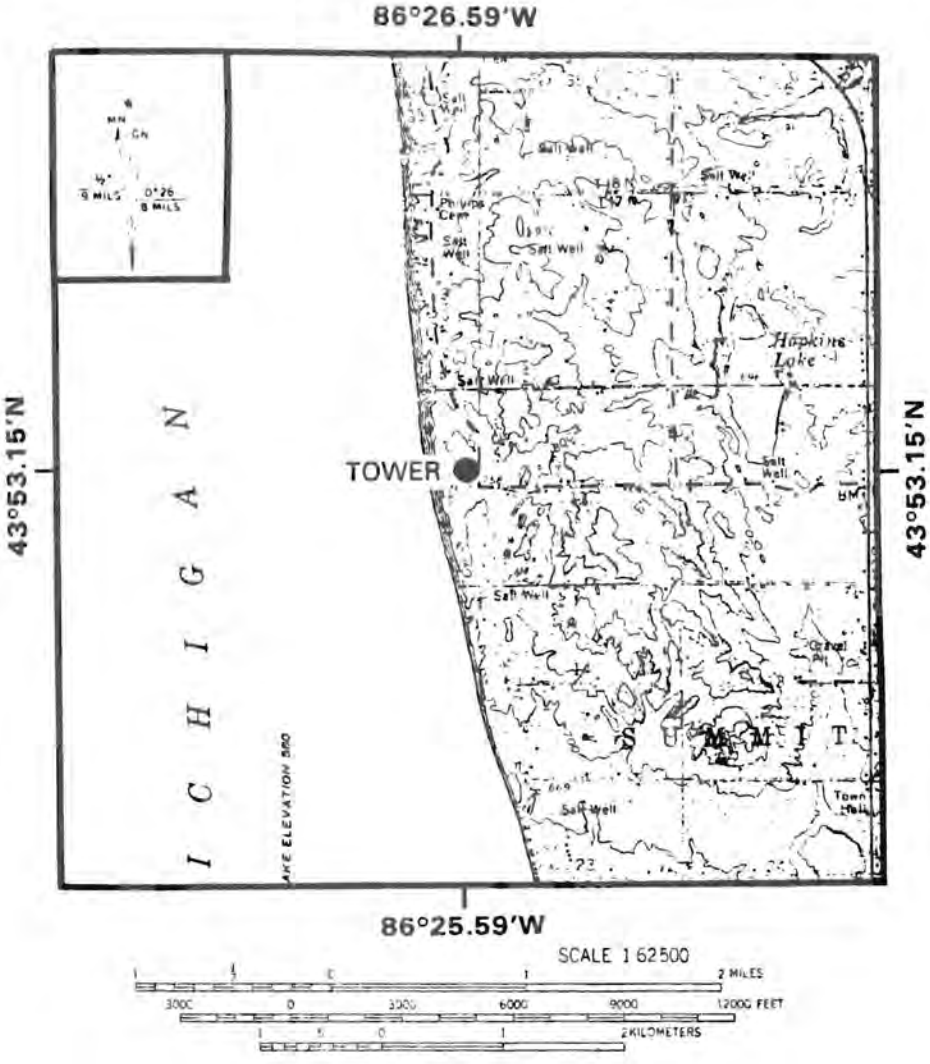


FIGURE 2.3. Ludington, Michigan Site Location

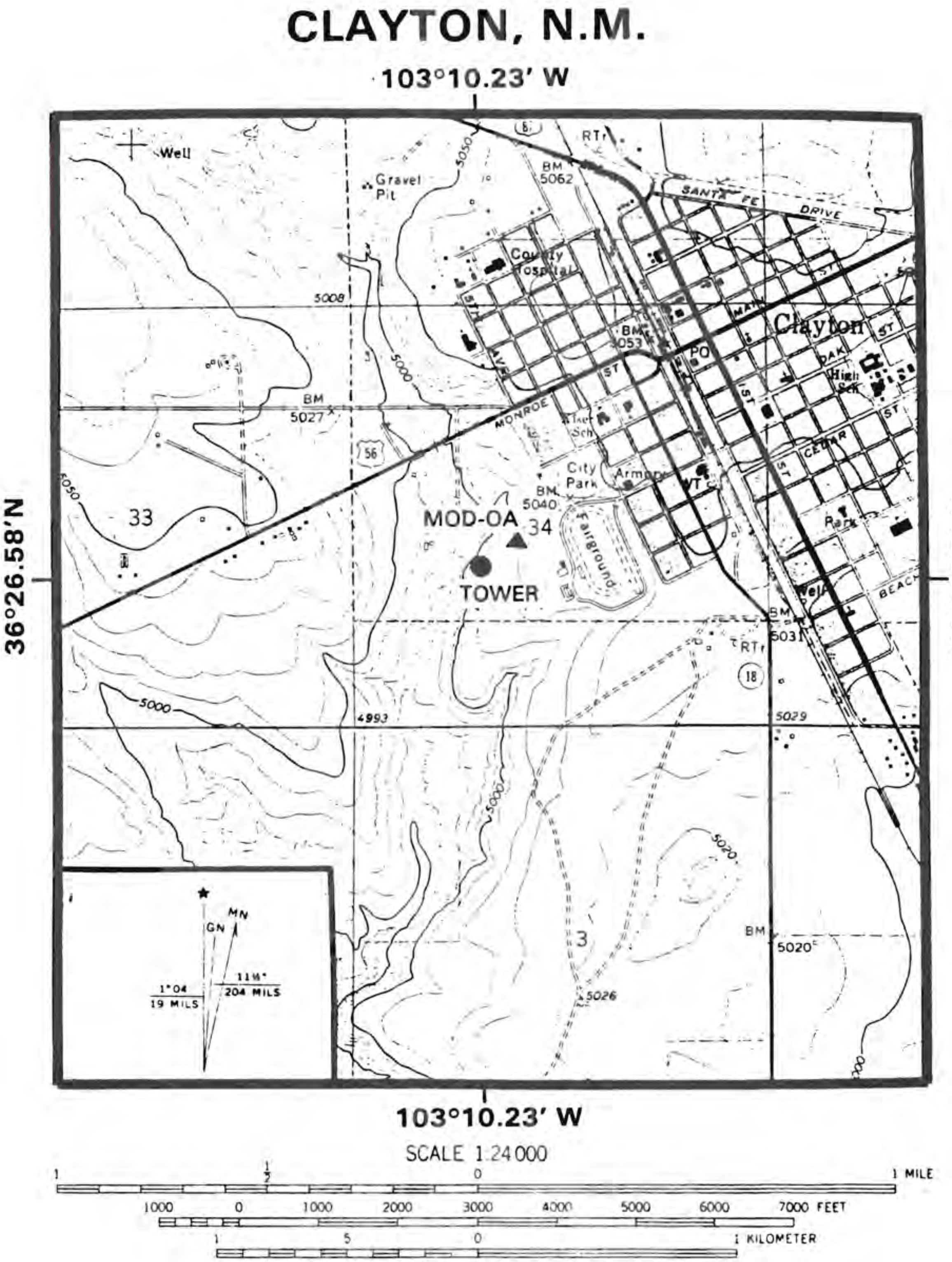


FIGURE 2.4. Clayton, New Mexico Site Location

AMARILLO, TX

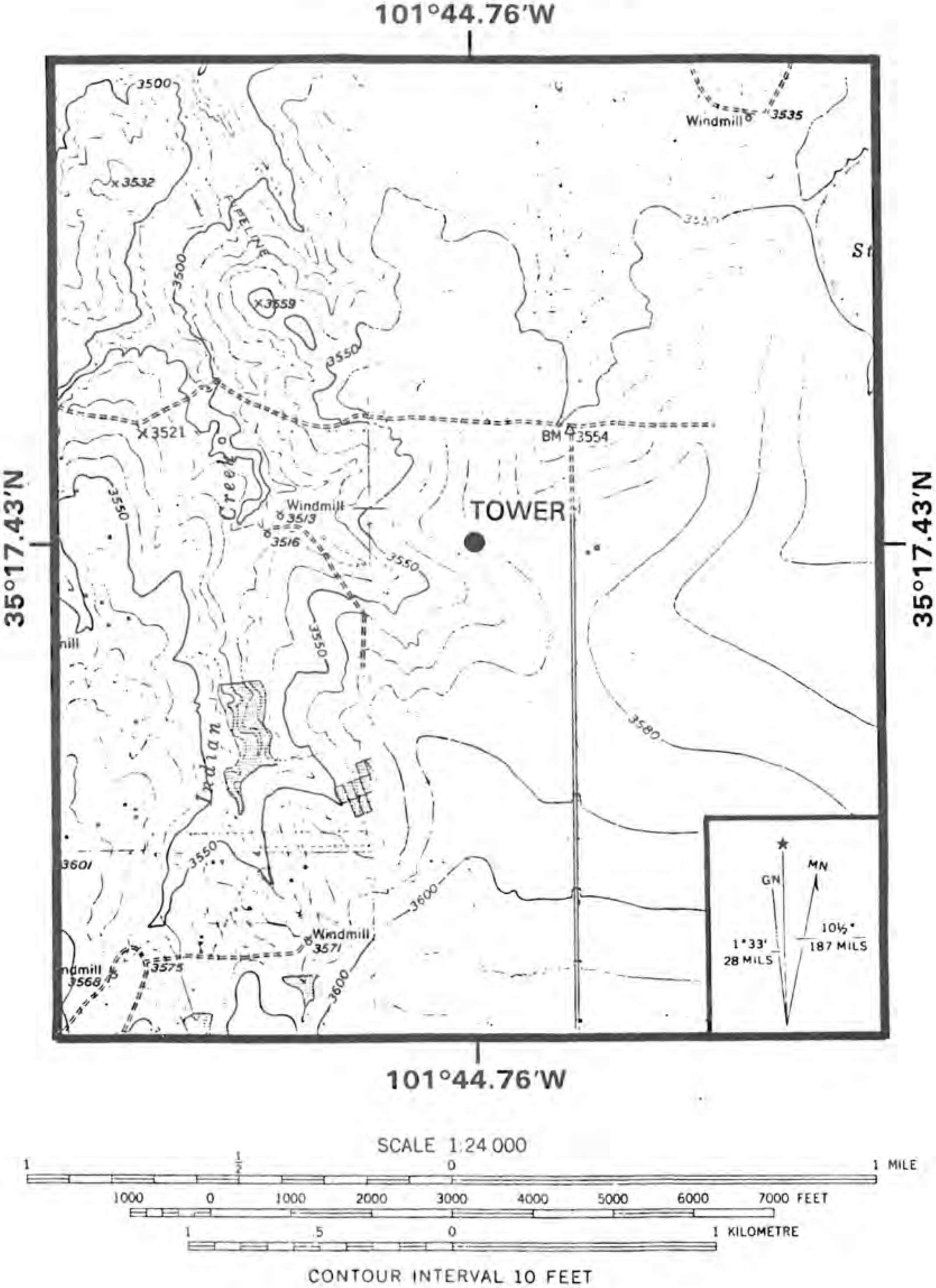


FIGURE 2.5. Amarillo, Texas Site Location

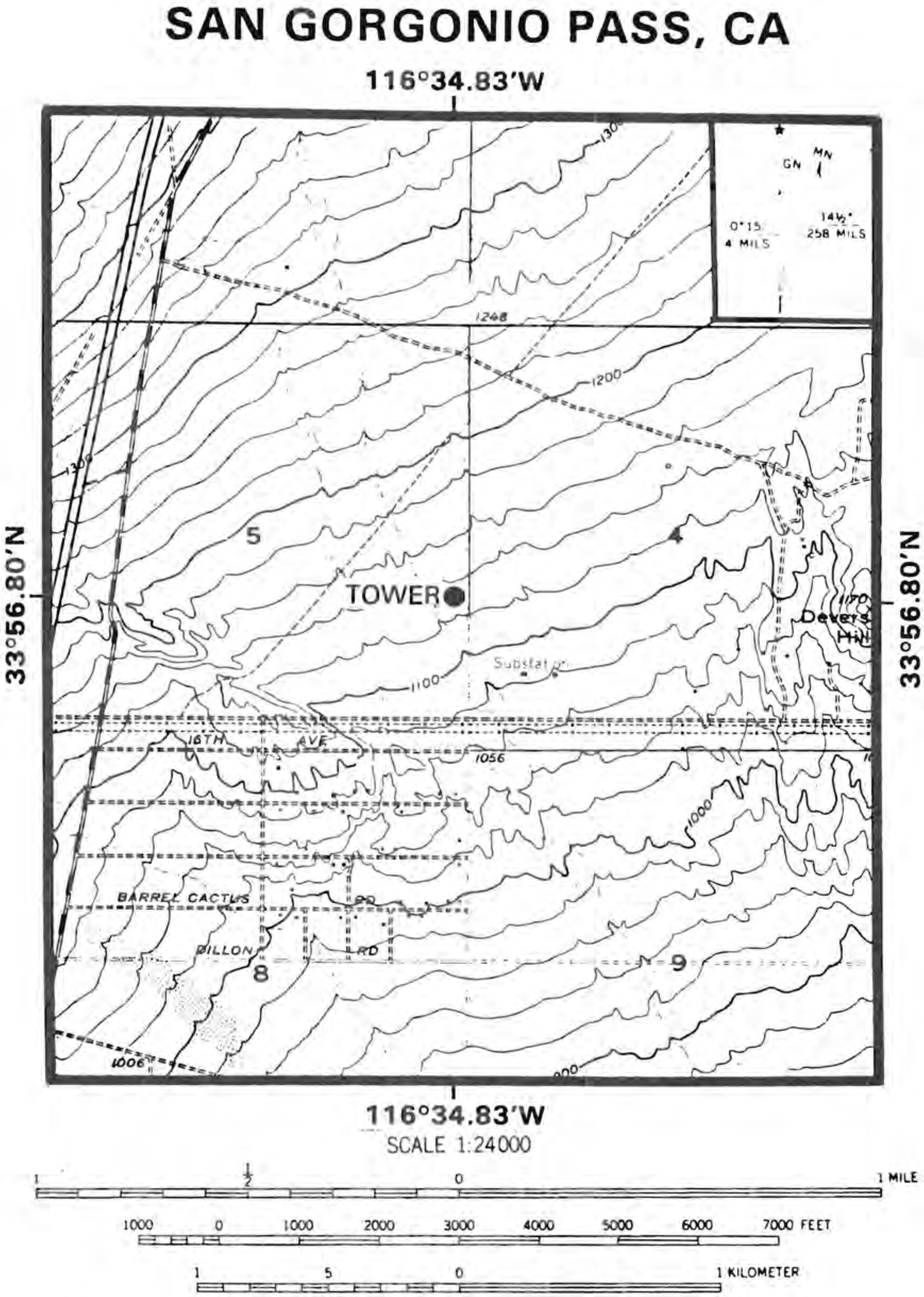


FIGURE 2.6. San Gorgonio Pass, California Site Location

south from the San Bernardino Mountains to the north. Both of these mountain ranges exceed 3050 m (10,000 ft) MSL. The pass also separates the maritime air of the Pacific Ocean from the inland desert basin. Consequently, funneling of the maritime air moving inland produces very strong westerly winds during the warm months of the year. At this time, very regular diurnal wind patterns are observed. The strongest winds occur during the evening (lagging a few hours behind the sea breeze push) and the lightest winds occur near sunrise.

The six sites studied were divided among the two research groups as shown in Table 2.1. This division of effort maximized the number of sites that could be analyzed under the operating budget and, by duplication of effort at two sites, provided for direct comparison of the effectiveness of different analytical methods used by the two organizations.

TABLE 2.1. List of Sites Studied by Investigating Organization

Site	Investigating Organization
Amarillo, TX	Murray and Trettel
Ludington, MI	Murray and Trettel
Boone, NC	Freese-Notis
Clayton, NM	Freese-Notis
Montauk Point, NY	Murray and Trettel/Freese-Notis
San Gorgonio Pass, CA	Murray and Trettel/Freese-Notis

3.0 WIND DATA PROVIDED BY PNL

The data year selected for the study was calendar year 1979. This overlapped the period for which subjective forecasts had been made, thus speeding up the site familiarization process.

Data collected at the six sites were measured using anemometry mounted on 46 m (150 ft) Rohn towers.[a] Table 3.1 summarizes the types of sensors used at each site.

TABLE 3.1. List of Wind Sensors Used at the Six Wind Sites

Site	Speed Sensor	Direction Sensor
Boone, NC	Climet 011-3*	Climet 012-15*
Clayton, NM	Climet 011-3	Climet 012-15
Amarillo, TX	MRI 1024 (cup and vane combination)**	
Ludington, MI	MRI 1024 (cup and vane combination)	
Montauk Point, NY	MRI 1024 (cup and vane combination)	
San Gorgonio Pass, CA	MRI 1024 (cup and vane combination)	

* Climet Instrument Company, P.O. Box 151, Redlands, CA 92373
** Meteorology Research, Inc., 464 W. Woodbury Road, Altadena, CA 92373

The wind speed and direction were recorded digitally on data cassettes (nearly instantaneously) at 2-minute intervals using ESC CDL700 data loggers.[b] The resultant time series of 2-minute point data was processed in three different ways to facilitate use by the two research groups.

First, time series plots of the 46 m (150 ft) wind speed and direction (see Figures 4.1-4.4) were produced to allow visual scanning of the data in order to identify various wind regimes at each site. To produce these plots, the hourly directional averages were calculated as the mean of a circular distribution (Zar 1974) using thirty 2-minute direction samples.

(a) Unarco-Rohn, P.O. Box 2000, Peoria, IL 61601
(b) Environmental Services Corp., 200 Tech Center Drive, Knoxville, TN 37919

Second, statistical analyses were performed on all sets of 30 samples representing each clock hour of the year. The results of these analyses were listed as a time series of hourly:

1. Circular mean direction (Zar 1974)
2. Circular dispersion (Zar 1974)
3. Standard deviation of direction
4. Mean hourly speed
5. Standard deviation of speed
6. Skewness of the speed distribution
7. Kurtosis of the speed distribution.

Third, monthly summaries for each site were provided. These included: monthly 46 m (150 ft) mean speed and standard deviation of speed, maximum wind speed recorded for the month (and the associated direction), a 46 m (150 ft) wind speed and direction diurnal summary for the month (listing monthly means for each hour of the day), a wind rose for the month, and wind speed duration values for selected speed categories.

Detailed site descriptions were also provided. In addition to containing information similar to that in Section 2, these contained maps of each site and, where available, photographs of the sites.

At the initial planning meeting held between the contractors and PNL personnel, D. W. Trettel suggested that as an initial attempt to stratify the data into wind regimes, the Booz-Allen surface and 500 mb classification might be a useful tool. It was adopted by the contractors who either used it in its original form or modified it to suit the task. Within this report it is usually referred to as the B-A stratification and is described in Appendix A.

4.0 LEARNING TO FORECAST WIND AT REMOTE SITES FOR WIND ENERGY APPLICATIONS: THE USE OF SURFACE MAP ANALOGUES AND PRESSURE GRADIENTS

4.1 INTRODUCTION

Three basic sources of data have been used in this study. These include:

1. Monthly time-series plots of wind speed and direction for each of the four sites for the calendar year 1979.
2. Tabulated hourly averaged wind speed and direction data.
3. Synoptic weather maps for 1979.

Time-series plots were analyzed according to various speed and direction criteria and a stratification was performed. The plots naturally fit into a few distinct groups per site. This observation alone suggests some relationships between synoptic patterns, topographic effects, and wind regimes at each site. The initial stratifications for the four sites are shown in Tables 4.1-4.4. The percentage time of occurrence for each stratification is indicated to the right of each wind type. Figures 4.1-4.4 show time-series plots for the four sites. From each of these figures examples of the stratified wind speed types for the four sites are identified.

The tabulated data were used to record the actual speed and direction at the sites for 0000 and 1200 GMT for the entire year 1979. These hours were selected to be consistent with the NCC data and to show any diurnality. Additionally, the time required to analyze 3-hourly surface maps and extract information required for this study is enormous. As will be shown later, results using 12-hourly as opposed to 3-hourly data are very similar.

Finally, the NCC microfilm data used included surface maps, 500-mb, 700-mb, and 850-mb surfaces for the United States. These maps were carefully examined and a particular synoptic pattern was noted for the sites at 0000 and 1200 GMT. In order to facilitate and simplify the description of the patterns, some kind of synoptic classification system was necessary. It was decided that a system devised by Booz-Allen (Hallanger, 1968) would be used for this purpose.

TABLE 4.1. Wind Speed and Direction Stratifications for San Gorgonio

		Wind Speed
Type 1 (16%)	=	Diurnal character with 2 or 3 day duration. Speed ranges from roughly 0-3 m/s at 0400 to 1000 Local Standard Time (LST) to 12-15 m/s at 1900 to 2300 LST.
Type 2 (42%)	=	Light wind regime lasting from a couple days to as many as 10. Speed is generally ≤ 6 m/s.
Type 3 (30%)	=	Variable in speed with peaks of 15-20 m/s and minimums between 8 and 12 m/s. Duration can be from a couple days to about 5 days. The timing of the maximum and minimum speeds tends to be similar to Type 1.
Type 4 (5%)	=	Duration of about 1 day and speed up to around 15 m/s. Quite isolated and more likely to occur in cold season.
Type 5 (7%)	=	Strongest speed type. Speeds exceed 20 m/s for a while and last from one to three days. Speed minimums are usually greater than 15 m/s.
		Wind Direction
Type 1 (37%)	=	Great diurnal variation from $0^o \rightarrow 360^o$ with no apparent direction preference. Lightest speed regime (≤ 6 m/s) lasting up to a week.
Type 2 (40%)	=	Strongest speed type with 230^o- 260^o direction. Can last a few days reaching a speed of up to 25 m/s.
Type 3 (8%)	=	Diurnal type having direction between NE veering to NW with definite preference at about 230^o- 260^o for a few hours. Can last for a few days. Speeds can reach 15 m/s and is usually associated with Type 1 speed stratification.
Type 4 (9%)	=	Direction ranges from NW backing to SE with definite preference at about 230^o-260^o and can last for a week or more. Speeds are generally ≤ 15 m/s. May be similar to Type 3.
Type 5 (6%)	=	Direction at NW for 5-10 hours then suddenly SE to NE briefly. Speeds are ≤ 7 m/s. Infrequent occurrence but when it does occur it can persist for a few days. It is usually associated with Type 2 speed stratification.

TABLE 4.2. Wind Speed and Direction Stratifications for Clayton

Wind Speed

Type 1	(1%)	=	Isolated super wind reaching 25 m/s or more.
Type 2	(7%)	=	Strong wind spikes reaching 15-20 m/sec.
Type 3	(50%)	=	Speeds range between about 5 m/s and 15 m/s and can last for days. Minimums tend to occur during early to mid morning and maximums in the late afternoon to early evening.
Type 4	(41%)	=	Light wind ranging from 2-7 m/s.

Wind Direction

Type 1	(44%)	=	Amazing diurnal range from 1° - 360° with favored position being S-SW late afternoon and early evening at which time stronger speed for this type is also occurring. Can last for up to 1 month. Speeds variable but mostly <12 m/s.
Type 2	(9%)	=	NW wind regime usually associated with strongest speeds of up to 20 or 25 m/s. Can last for a day or two. Occasionally, it can also be light speed.
Type 3	(26%)	=	S-SW regime. Can have speeds of over 15 m/s and last for a few days.
Type 4	(3%)	=	NE wind. Fairly infrequent and very light speed <7 m/s.
Type 5	(18%)	=	Ranges from WSW backing to SE and can last for 5 days or so with diurnal character. Speeds mostly <10 m/s. Highest speed with SW wind direction.

TABLE 4.4. Wind Speed and Direction Stratifications for Montauk

Wind Speed

Type 1	(10%)	=	Strongest wind type. Can reach up to 20 m/s or possibly higher and last from 1 to 4 days.
Type 2	(21%)	=	Speeds peak at about 15 m/s and usually lasts a day or so.
Type 3	(45%)	=	Speeds peak between 7 and 10 m/s and can last up to a few days.
Type 4	(24%)	=	Speeds average ≤6 m/s and can last from one to three days.

Wind Direction

Type 1	(27%)	=	NW-W regime which often has strong speed of >12 m/s.
Type 2	(24%)	=	SW regime with speed variable but generally <10 m/s.
Type 3	(12%)	=	SE wind. Can be strong reaching speeds of 15 m/s or more.
Type 4	(14%)	=	NE wind. Can occur anytime of year. Speed can be strong occasionally.
Type 5	(23%)	=	Variable wind. Can last up to 5 days especially in warm season.

Note: Very little diurnal variation is observed at Montauk.

TABLE 4.3. Wind Speed and Direction Stratifications for Boone

Wind Speed

Type 1	(2%) =	Tremendous NW wind reaching speeds in excess of 25 m/s in winter months. Duration can be a day or two.
Type 2	(15%) =	Strong wind usually reaching speeds in excess of 20 m/s in winter months. At least one or two days duration.
Type 3	(43%) =	Quite variable regime lasting from a day or two to 4 or 5 days. Speeds range from 8-18 m/s for max and about 5-10 m/s for min. There is a tendency for maximums to occur from 0000 to 0600 LST and minimums near noon.
Type 4	(40%) =	Generally quite light wind situation ranging between 2 and 8 m/s. Can last up to 4 or 5 days. Time of occurrence of maximum and minimum speeds is similar to Type 3.

Wind Direction

Type 1	(42%) =	NW wind usually associated with strong wind speed especially in cold season. Can last up to a few days. In warm season can be light speed.
Type 2	(28%) =	SW wind regime usually limited to <15 m/s.
Type 3	(13%) =	SE-S wind which is usually quite light at <8 m/s.
Type 4	(16%) =	Variable wind regime with very light speed.
Type 5	(1%) =	NE-E wind. Very infrequent and very light.

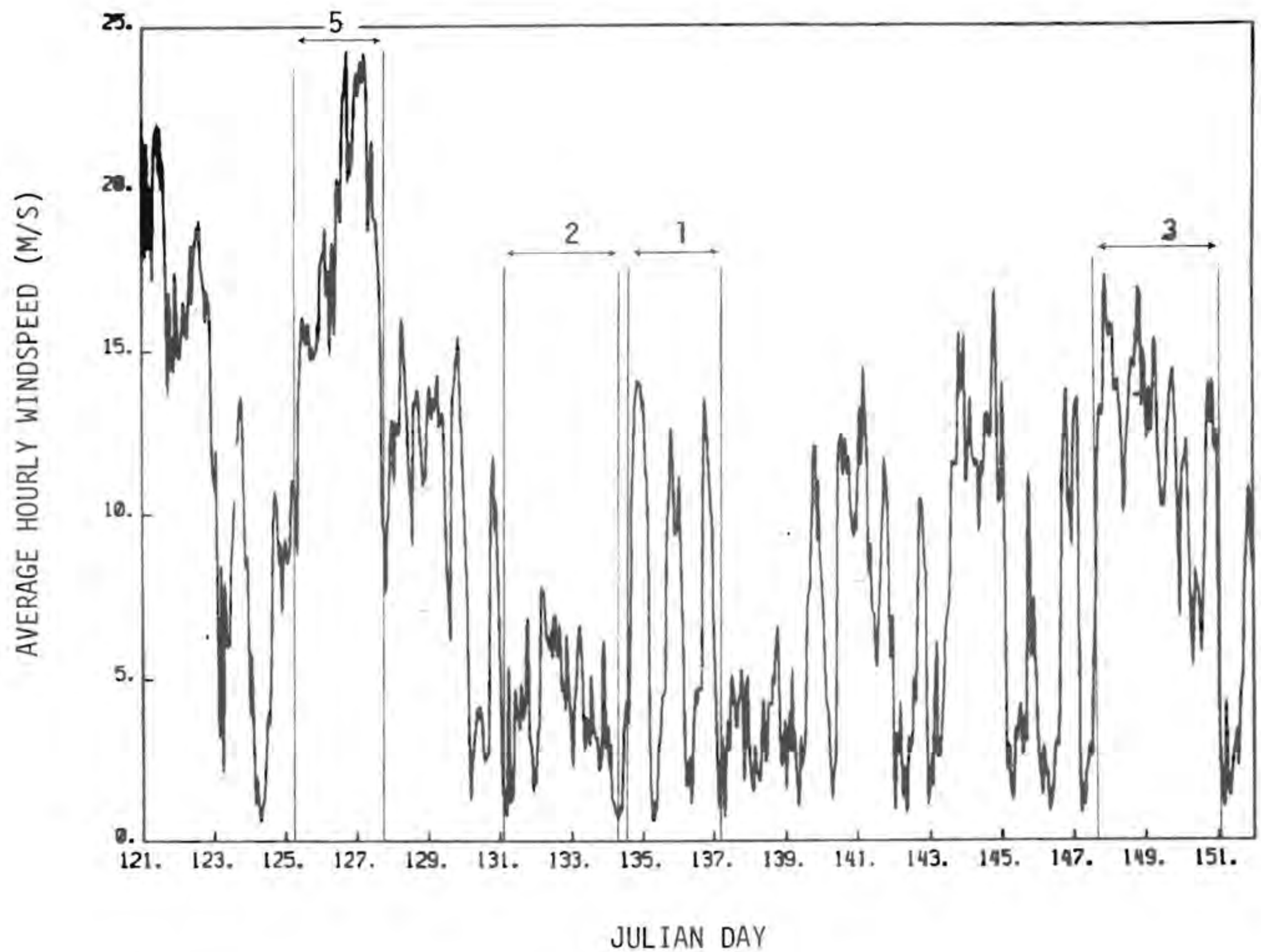


FIGURE 4.1. Time-Series Plot for San Gorgonio for May 1979 Showing Examples of Stratified Wind Speed Types

Note: Wind speed Type 4 is not shown. This type typically occurs in winter and is rare.

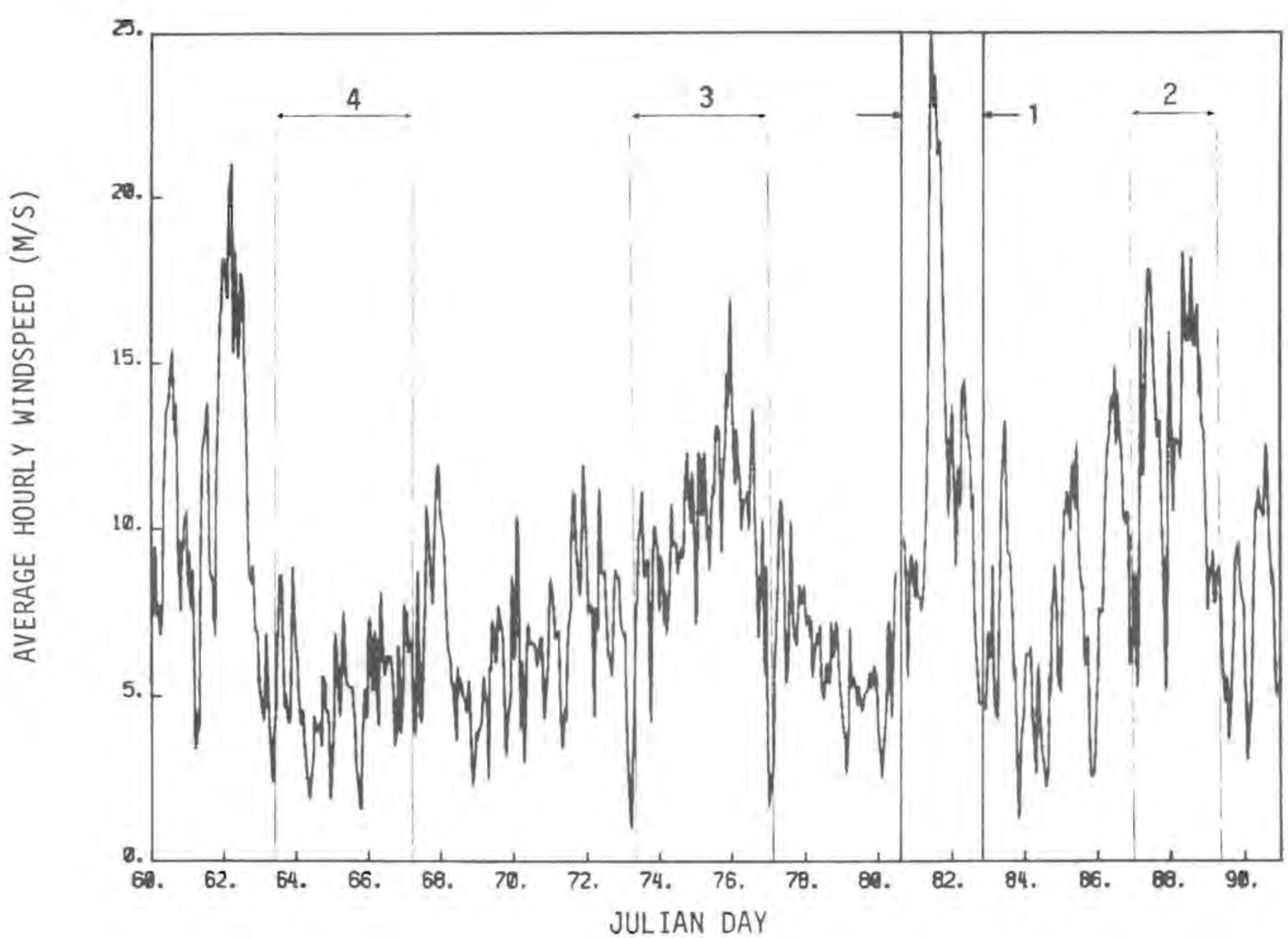


FIGURE 4.2. Time-Series Plot for Clayton for March 1979 Showing Examples of Stratified Wind Speed Types

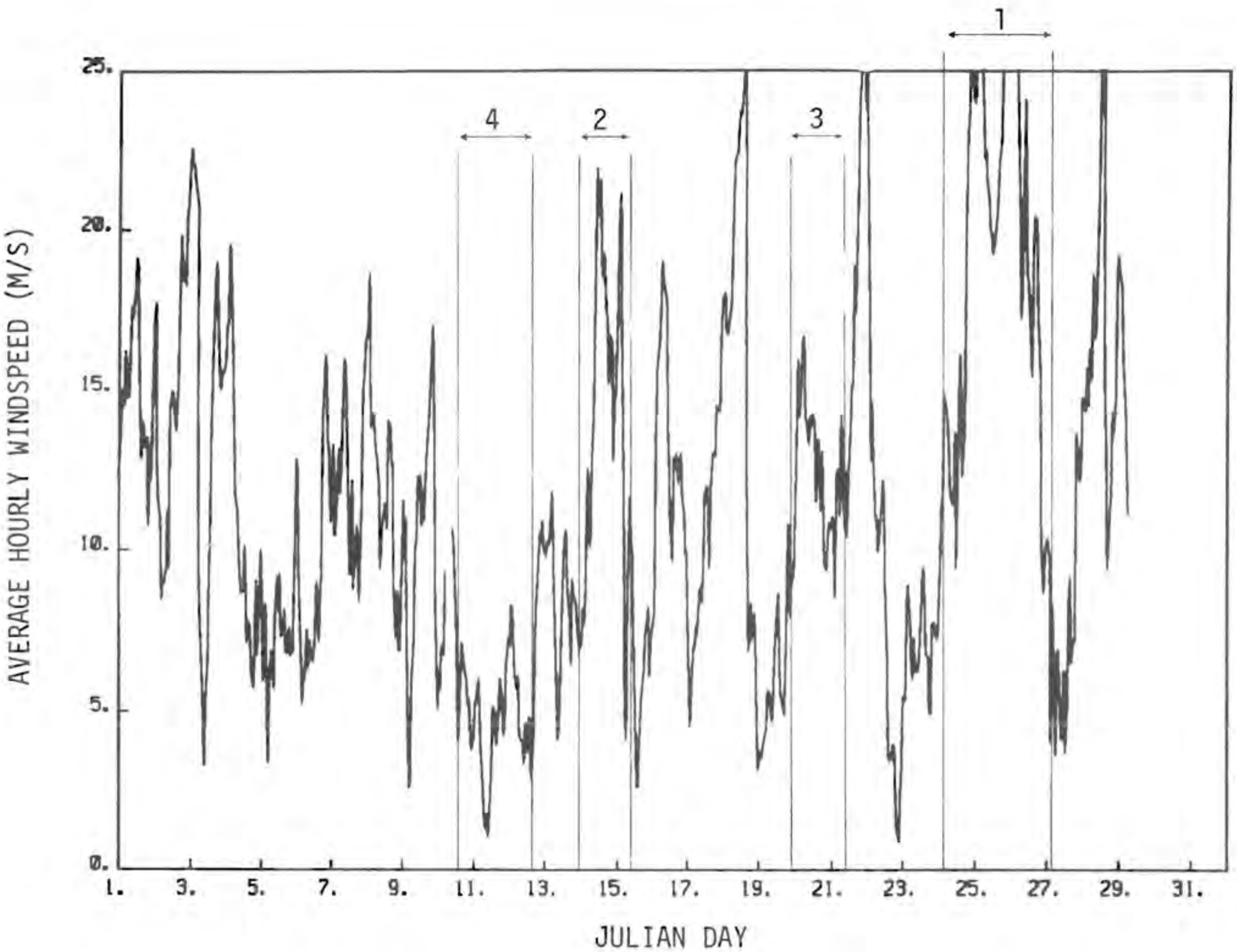


FIGURE 4.3. Time-Series Plot for Boone for January 1979 Showing Examples of Stratified Wind Speed Types

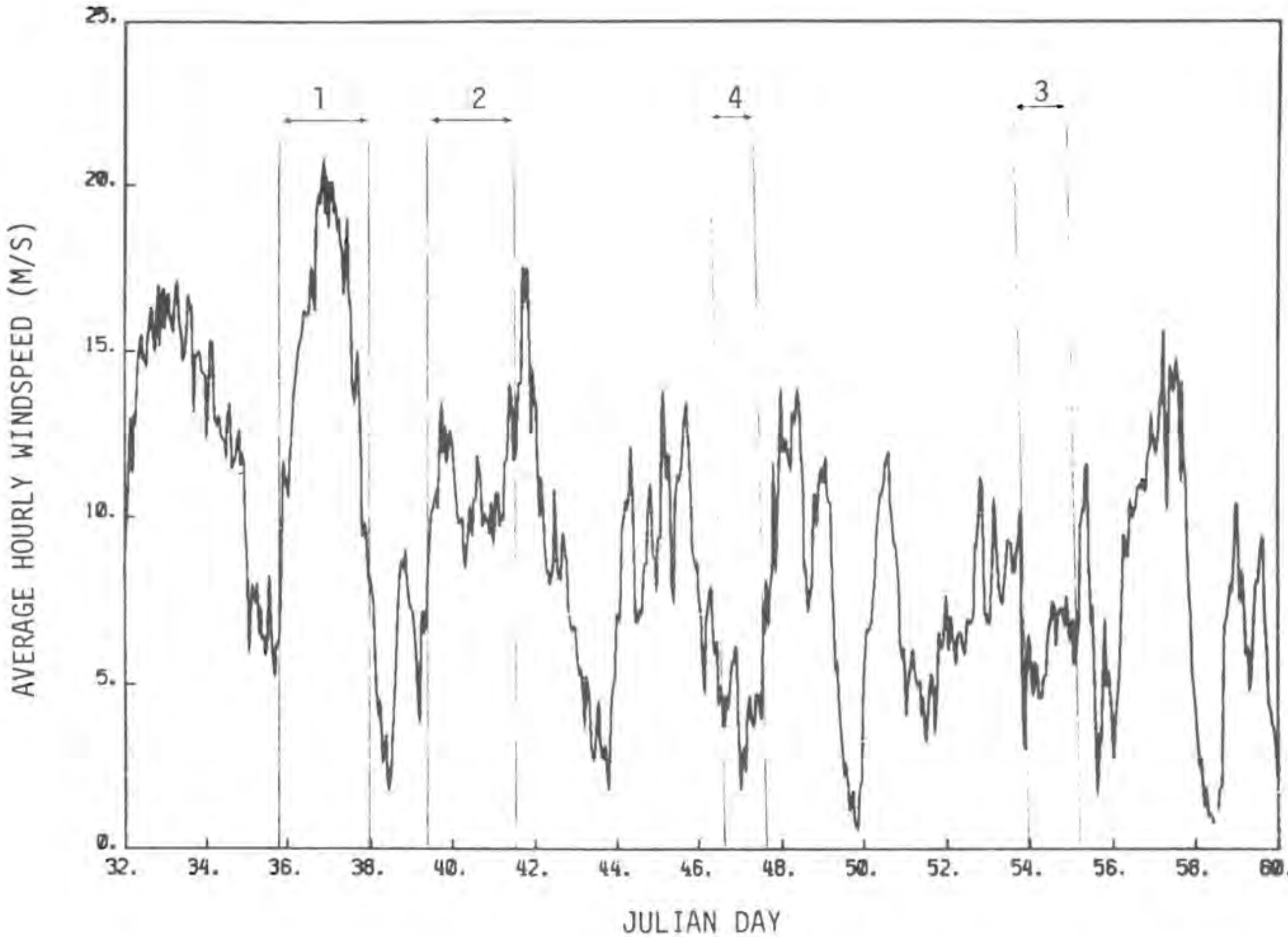


FIGURE 4.4. Time-Series Plot for Montauk Point for February 1979 Showing Examples of Stratified Wind Speed Types

The Booz-Allen (B-A) system consists of 35 surface types and 20 500-mb types. It was decided to apply the 500-mb B-A types to the 700-mb surface. For the 850-mb surface, the wind speed and direction (interpolated to the site) was recorded for later comparisons with site winds. Appendix A lists the surface and 500-mb types. At times it was rather difficult to determine which designation a particular synoptic pattern should have (i.e. pretrough, postridge, etc.). However, this is not a problem since the resulting winds in these cases are very similar. In fact, as will be shown later, combining all the B-A surface types into two large groups reveals some interesting results. Each of the B-A types for the various pressure surfaces was compared with the observed site wind speed and direction, and with the stratified wind groups. The mean and the standard deviation of the site wind speed and direction for each B-A type were calculated.

Because of the cut-in speed of 6.2 m/s (14mph) for the MOD-2 Wind Turbine Generator, considerable work has also been done on the ≥7 m/s (15.6mph) threshold and on other speed and pressure gradient relationships. For each B-A type, the percentage occurrence of wind speed ≥7 m/s was calculated. Speed and pressure gradient relationships were investigated by determining the pressure gradient across 335 kilometers (180 nautical miles) centered at the site at 0000 and 1200 GMT for each site. The isobaric orientation (I-O) was also recorded so that the relationships between I-O, pressure gradient, wind speed and wind direction could be studied. These relationships are probably the most useful forecasting tools found in this research. It should be noted here that the terms isobaric orientation, I-O, and isobaric alignment mean exactly the same thing and will be used interchangably.

The only useful relationship determined from the upper air data was the ratio between the surface wind speed and 850-mb speed. The ratio was calculated for the various B-A surface types.

4.2 WIND EVENTS COMPARED WITH SYNOPTIC TYPES

During the early stages of this research it was thought that perhaps for each wind stratification there would exist a unique synoptic type. However, it was quickly realized that this is not necessarily the case. That is, two or more synoptic patterns can result in the same wind regime. Furthermore, the same synoptic type usually is associated with several speed and direction groups. Table 4.5 shows the comparisons between the B-A synoptic types and stratified wind types at San Gorgonio. It can be seen from the table that for each B-A type there exist several speed and direction types. The results from the other sites are even more scattered and very poorly correlated. The reason for this is that the B-A types do not provide sufficient information about the intensity of the system; consequently, pressure gradient relationships also need to be examined. However, for forecasting purposes, it is very important to first predict the synoptic pattern for a given site in order to arrive at a first approximation of wind speed and direction. For example, knowing in advance that an inverted trough will lie east of San Gorgonio would lead one to forecast a rather strong southwest wind at least in the afternoon and early evening. The rest of the forecast details would be determined by the pressure gradient relationships.

It has also been determined that the 500-mb and 700-mb B-A types cannot be effectively used as short-range surface wind predictors. This is mainly due to the fact that the horizontal distance between surface systems and their corresponding upper-air systems can vary considerably. However, knowing the long wave mean trough and ridge positions assist in providing a rough estimate of the long-range (3 to 7 days) wind regime for a given site.

4.2.1 San Gorgonio

Each of the four sites studied has rather unique relationships between synoptic weather patterns and wind events; but, after reviewing the data it was quite apparent that San Gorgonio displays the most consistent relationships. As a result, San Gorgonio is probably the least difficult site in terms of forecasting wind events. Since San Gorgonio is located in an east-west mountain pass, topography plays a very important role. Due to this local

TABLE 4.5. Comparison of Booz-Allen Surface Types with Wind Speed and Direction Stratified Types

SAN GORGONIO

	Wind Speed Stratification Type					Wind Direction Stratification Type				
B-A	1	2	3	4	5	1	2	3	4	5
	Number of Observations					Number of Observations				
1	1	2	2	0	0	2	2	0	1	0
2	0	0	1	0	0	0	1	0	0	0
3	1	12	7	1	5	10	16	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	3	9	4	3	5	5	14	0	2	3
6	0	1	0	0	0	1	0	0	0	0
7	0	5	0	0	0	3	2	0	0	0
8	3	7	0	0	0	1	1	0	0	0
9	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0
12	4	3	5	2	0	3	8	1	2	0
13	0	0	6	4	3	0	10	0	0	0
14	0	1	0	0	0	1	1	0	0	0
15	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	2	1	0	0	0	1	0	0	2	0
19	0	1	3	0	0	1	3	0	0	0
20	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0
24	1	2	3	0	0	1	3	0	1	1
25	2	3	15	3	3	4	22	0	0	0
26	4	6	1	2	0	6	4	1	1	1
27	11	55	4	0	0	46	4	6	3	10
28	60	32	109	6	12	27	97	40	47	0
29	9	12	38	4	5	13	51	1	0	0
30	1	1	0	0	0	1	1	0	0	0
31	6	16	38	13	16	12	58	0	12	2
32	0	9	1	0	0	9	1	0	0	0
33	7	23	2	0	0	20	2	6	1	3
34	10	96	2	0	0	83	2	5	0	16
35	2	39	2	1	0	32	5	2	0	5

topography, the predominant wind direction is southwest (SW) to west southwest (WSW) even though the isobars are commonly oriented from northwest (NW) to southeast (SE).

Under the B-A classification scheme, the most common synoptic surface types found for San Gorgonio are generally those with the designation of posttrough or preridge. Table 4.6 statistically relates the wind speed and direction with B-A surface types. Additionally, the table gives the 850-mb wind speed and direction and the surface to 850-mb wind speed ratio for the various synoptic surface types. The percentage of time the speed is ≥ 7 m/s is also shown. Some of the B-A types display a bi-modal direction distribution. This is caused by diurnal effects when the pressure gradient is either very weak or when the I-0 is NE to SW, E to W, or S to N. Under these conditions the wind tends to be rather strong (≥ 7 m/s) SW during the day and light easterly at night and early morning. Figure 4.5 graphically shows the bi-modal phenomenon for B-A type 28 (Inverted Trough, Posttrough), the most common surface type. However, more than 80% of the time the wind is SW. Generally, the strong wind types, all having direction from 220^{o}-260^{o}, are associated synoptically with a posttrough, preridge, or post cold front. This implies a very important phenomenon at San Gorgonio. As long as the pressure is lower to the east, the wind will blow quite strongly (at least 7 m/s and often >15 m/s) between 220^{o}-260^{o}. Conversely, the speed will be very light (≤ 6 m/s) with higher pressure to the east. These pressure rules are so universal at San Gorgonio that they are only rarely violated. There are a few apparent inconsistencies to the pressure rules (see Table 4.6). Namely, synoptic types 5 (Low North, Prefrontal), 12 (Open Wave North, Prefrontal), and 24 (Meridional Trough, Pretrough) all imply lower pressure west of the site. But there are rather large average speed values (≥ 7 m/s) for these cases. However, a careful reexamination of the surface maps involving these cases provides an explanation. The key discriminant is the orientation of the isobars from W to E as a low pressure center, or meridional trough, passes north of the site. Thus, the trough axis may be west of the site, but the pressure is lower to the north rather than to the west. With this I-0 a rather strong SW wind will blow especially during the afternoon. On the other hand, if a high pressure system is located north of the site causing an E to W isobaric alignment, a very weak wind (≤5 m/s) will result even with a tight pressure gradient. This synoptic situation (B-A type 34) produces an average speed of 3.9 m/s. Figure 4.6 shows typical surface analyses of strong and weak wind situations for San Gorgonio. In the strong wind case a low is located in eastern Nevada with a NW to SE I-O over California. In the weak wind situation a strong high is centered on the Nevada-Idaho border resulting in a basically E to W I-O across Arizona and southern California.

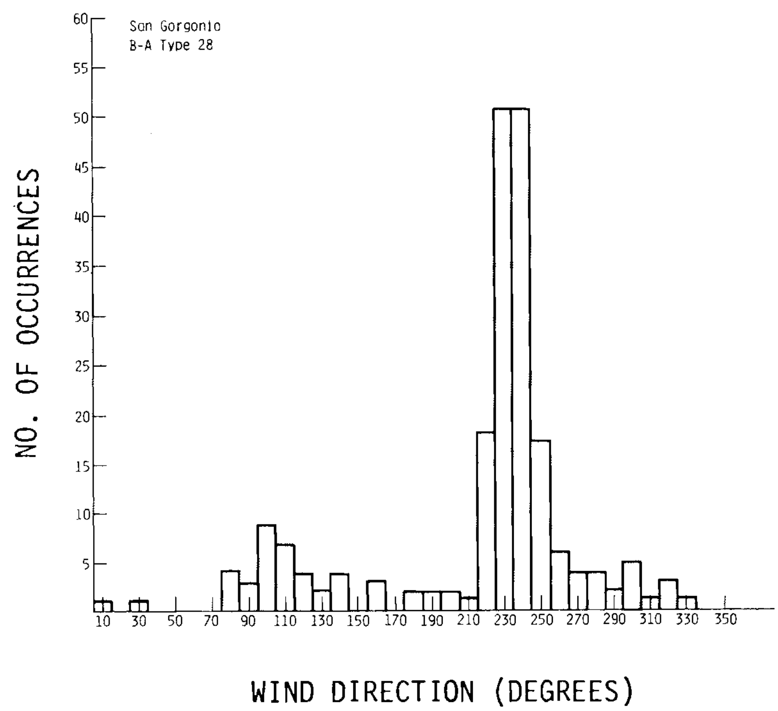
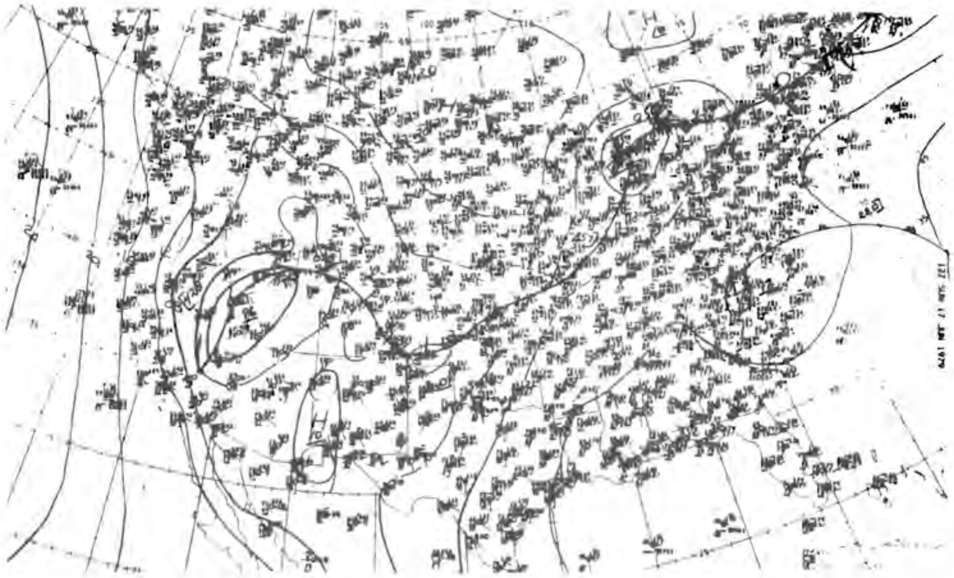


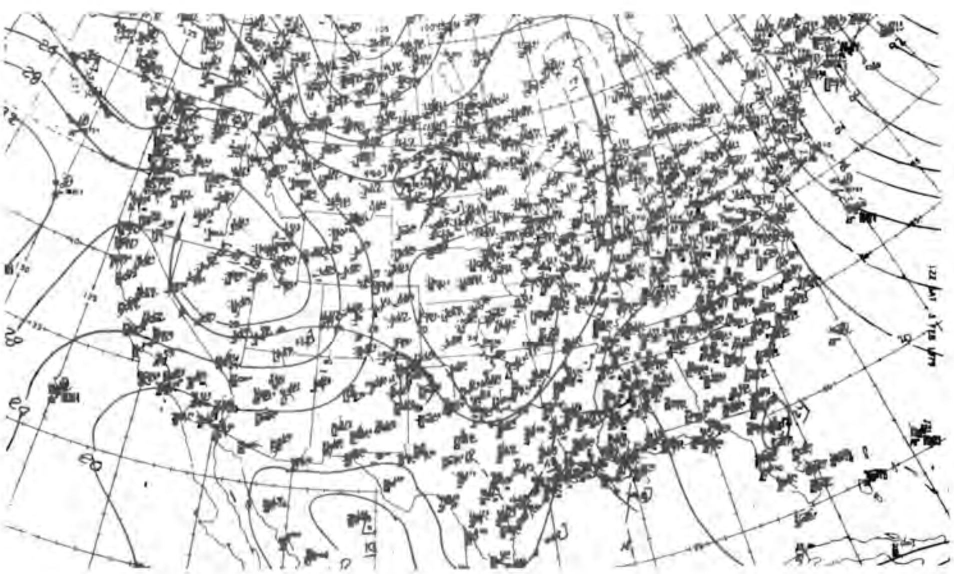
FIGURE 4.5. Wind Direction Distribution at San Gorgonio for B-A Surface Type 28 (Inverted Trough, Posttrough)

TABLE 4.6. Wind Statistics for San Gorgonio (All Speeds in m/s)

		SURFACE					850 MB				
B-A	No. of Obs.	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	≥ 7 m/s (%)	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	Sfc. to 850 Ratio
1	4	---	--	5.2	4.2	40	---	--	4.8	2.9	1.083
2	1	---	--	---	---	--	---	--	---	---	-----
3	37	257	64	8.8	6.7	60	275	57	10.4	3.7	0.846
4	1	---	--	---	---	--	---	--	---	---	-----
5	26	205	80	9.2	6.6	60	252	54	9.1	4.3	1.011
6	2	---	--	---	---	--	---	--	---	---	-----
7	5	---	--	---	---	--	---	--	---	---	-----
8	6	---	--	3.2	2.5	33	---	--	4.3	2.3	0.744
9	0	---	--	---	---	--	---	--	---	---	-----
10	0	---	--	---	---	--	---	--	---	---	-----
11	0	---	--	---	---	--	---	--	---	---	-----
12	13	228	45	8.0	4.1	67	271	47	6.7	4.0	1.194
13	11	215	41	11.6	5.0	82	305	40	11.8	3.0	0.983
14	2	---	--	---	---	--	---	--	---	---	-----
15	0	---	--	---	---	--	---	--	---	---	-----
16	0	---	--	---	---	--	---	--	---	---	-----
17	0	---	--	---	---	--	---	--	---	---	-----
18	4	---	--	---	---	--	---	--	---	---	-----
19	5	---	--	---	---	--	---	--	---	---	-----
20	0	---	--	---	---	--	---	--	---	---	-----
21	0	---	--	---	---	--	---	--	---	---	-----
22	0	---	--	---	---	--	---	--	---	---	-----
23	0	---	--	---	---	--	---	--	---	---	-----
24	7	230	73	7.5	5.6	58	266	58	8.0	1.6	0.938
25	22	215	42	10.6	5.0	76	277	44	8.1	4.9	1.309
26	13	220	69	4.5	4.7	8	263	89	8.3	4.6	0.542
27	79	79/278	38/45	3.3	2.9	16	66	69	5.1	3.1	0.647
28	231	107/228	30/60	8.1	4.9	62	306	72	5.4	3.0	1.500
29	70	234	35	10.2	5.6	74	306	52	6.8	3.6	1.500
30	4	---	--	---	---	--	---	--	---	---	-----
31	89	230	38	10.2	5.1	78	315	47	8.0	3.7	1.275
32	10	---	--	---	---	--	---	--	---	---	-----
33	34	110/288	32/34	2.8	2.3	12	---	--	2.8	2.3	1.000
34	124	90/294	43/42	3.9	3.0	23	58	72	5.1	3.4	0.765
35	44	107/288	24/34	3.3	2.8	20	248	74	4.3	3.0	0.767



(a)



(b)

FIGURE 4.6. Typical Surface Map Analyses Associated with Strong (a) and Weak Wind Speed (b) at San Gorgonio

Due to the similarity of the I-0 it was decided to combine the B-A surface types into two large groups: 1) those with designation of posttrough, preridge, and post front, 2) those with designation of pretrough, postridge, and pre-front. Figure 4.7 shows the results. Not surprisingly, the group of B-A types which implies lower pressure east of the site are remarkably similar to Figure 4.5. However, there is a great deal of scattering of wind direction for those B-A types which imply higher pressure east of the site.

Finally, Table 4.6 gives the ratio of the site wind speed to the 850-mb estimated speed. It is interesting to note that the most common B-A types implying lower pressure east (28,29,31) show stronger surface wind speed than the 850-mb wind speed. This could be used as an additional forecasting rule.

As previously mentioned the direction associated with the strong wind speed at San Gorgonio is SW. Thus the following rule was tested quantitatively (see Figure 4.8): With a wind direction of 200° - 260°, the resulting speeds will be ≥7 m/s. Using all the available 1200 and 0000 GMT data with this criteria, a forecast of ≥7 m/s would be issued 320 times and a total of 280 times or 87.5% ≥7 m/s is observed. Thus, if one anticipates that San Gorgonio will have SW winds for a given period, he can be 87.5% confident that speeds will be at least 7 m/s. On the other hand, for all other directions when a speed of ≥7 m/s is not forecast, it occurs only 30 out of 330 times or 9.1%. This rule is remarkably effective considering its simplicity. A question that may be raised here is, "How does one know when to forecast SW winds?" This is easily determined by observing the I-0. A SW wind at San Gorgonio will result with a NW to SE or N to S I-0; this implies lower pressure to the E.

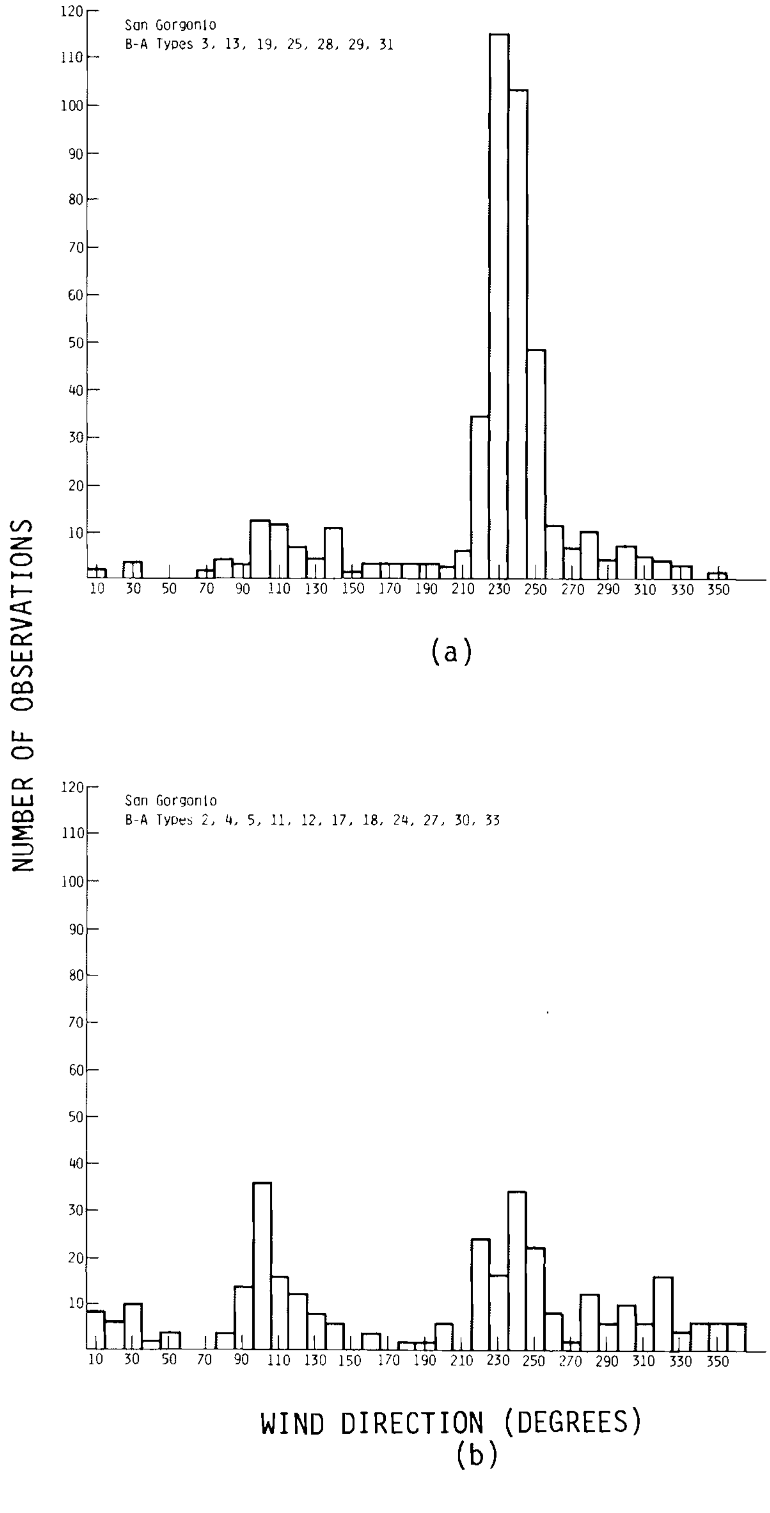


FIGURE 4.7. Wind Direction Distribution at San Gorgonio for B-A Surface Types Implying Lower Pressure East (a) and B-A Types Implying Higher Pressure East (b)

Wind Direction 220^o- 260^o

Speed ≥7 M/S		YES	NO
	YES	280	30
	NO	40	300

FIGURE 4.8. Numerical Results of the Rule: A Wind Direction of 220^o- 260^o at San Gorgonio Results in Wind Speed ≥7 M/S

4.2.2 Clayton

This site is located in the extreme northeast corner of New Mexico at an elevation of 1534 M (5030 ft.). Clayton is much more complex in terms of relating winds to synoptic patterns than San Gorgonio. Table 4.7 indicates that the most common B-A surface types are associated with the lee side trough (types 24-26) and those associated with the high center north of the site (types 31,33,34). The predominant wind direction is SW but there is a tendency for a secondary peak at W through N. However, the standard deviations for most B-A types are quite large, suggesting erratic wind behavior at this site during all seasons of the year. Except for very strong pressure gradients, the wind will blow rather strongly from the SW during the day at >7 m/s, becoming light and variable at night and early morning. Speeds can be strong at the site from all directions except for NE through SE. For this quadrant the speeds are generally <4 m/s.

The I-0 associated with the weakest speed is SE to NW. Figure 4.9 indicates that with a SE to NW I-0, 36 out of 51 forecasts (70.6%) would result in wind speeds of <7 m/s. Considering the erratic nature of the wind at Clayton, this rule holds well. The large values on the right hand side

<u>TABLE 4.7</u>. Wind Statistics for Clayton
(All Speeds in m/s)

	SURFACE						850 MB				
B-A	No. of Obs.	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	$\geq$7 m/s (%)	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	Sfc. to 850 Ratio
1	2	---	--	---	---	--	---	--	----	---	-----
2	16	212	48	9.4	2.8	88	234	37	13.1	3.0	0.718
3	23	274	52	9.5	4.9	76	307	43	13.3	4.5	0.714
4	6	225	46	10.6	2.3	100	227	48	12.8	2.8	0.828
5	11	207	45	9.2	4.8	45	244	53	12.1	5.0	0.760
6	0	---	--	---	---	--	---	--	----	---	-----
7	3	---	--	---	---	--	---	--	----	---	-----
8	16	---	--	11.4	5.6	93	---	--	12.2	3.6	0.934
9	3	---	--	---	---	--	---	--	----	---	-----
10	4	---	--	---	---	--	---	--	----	---	-----
11	20	199	56	8.5	2.5	85	260	47	10.0	4.3	0.850
12	36	193	44	8.2	3.0	64	205	65	10.6	4.6	0.734
13	30	329	63	9.4	4.1	68	356	57	10.9	5.2	0.862
14	2	---	--	--	---	--	---	--	----	---	-----
15	6	---	--	6.9	3.3	67	---	--	7.0	2.4	0.986
16	0	---	--	---	---	--	---	--	----	---	-----
17	0	---	--	---	---	--	---	--	----	---	-----
18	11	210	19	9.0	4.2	73	234	29	11.0	5.3	0.818
19	9	---	--	8.1	3.3	62	---	--	9.2	4.1	0.880
20	0	---	--	---	---	--	---	--	----	---	-----
21	0	---	--	---	---	--	---	--	----	---	-----
22	2	---	--	---	---	--	---	--	---	---	-----
23	0	---	--	---	---	--	---	--	----	---	-----
24	67	198	43	7.0	2.5	57	234	47	10.2	4.0	0.686
25	44	292	81	6.6	2.6	48	293	65	9.8	4.5	0.673
26	52	202	70	7.1	2.6	59	243	53	9.6	4.6	0.833
27	18	162	69	7.1	2.9	44	163	51	9.2	3.4	0.772
28	8	---	--	7.2	2.7	50	---	--	9.2	3.8	0.783
29	1	---	--	---	---	--	---	--	----	---	-----
30	14	188	45	6.5	2.0	43	238	43	6.6	4.3	0.985
31	99	291	75	6.7	3.0	49	---	--	8.5	4.5	0.788
32	5	---	--	---	---	--	---	--	----	---	-----
33	77	160	74	6.6	2.5	52	186	68	7.0	3.3	0.943
34	64	356	67	6.5	3.0	44	---	--	7.9	4.4	0.823
35	26	186	67	5.2	2.3	29	256	54	6.1	2.5	0.852

Speed < 7 M/S	SE-NW I-O	YES	NO
	YES	36	208
	NO	15	304

FIGURE 4.9. Numerical Results of the Rule: A SE to NW I-O at Clayton Yields Wind Speed of < 7 M/S

Direction 180^o- 260^o	NW-SE, W-E, SW-NE I-O	YES	NO
	YES	157	71
	NO	57	274

FIGURE 4.10. Numerical Results of the Rule: NW to SE, W to E, and SW to NE I-O at Clayton Causes Wind Direction From 180^o- 260^o

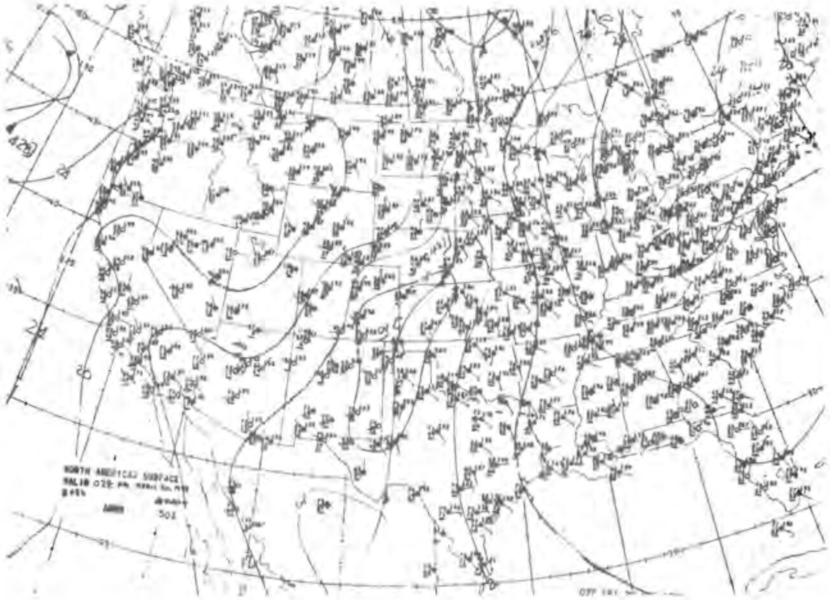
of the matrix simply show that the other isobaric alignments are also frequently associated with winds <7 m/s.

A comparison of the I-O with observed wind direction reveals that for NW to SE, W to E, and SW to NE I-O the chances are 73.4% (157 out of 214 forecasts) that the wind direction will be from the SW quadrant (180^o-260^o). The quantitative results of this rule are shown in Figure 4.10. Thus, if a forecaster knows that the I-O is one of the above three, then he is reasonably confident of a SW wind direction at Clayton. It was also determined that a wind direction between 180^o- 260^o results in speeds of ≥7 m/s 64.5% of the time.

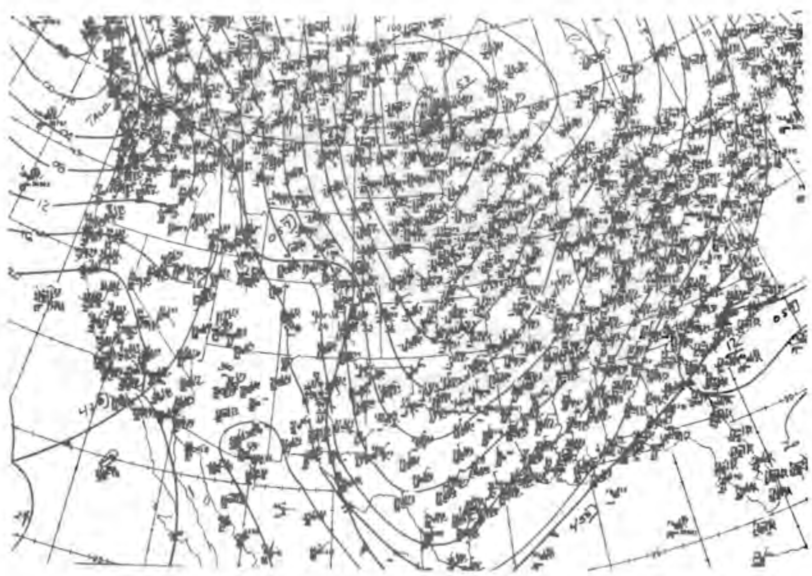
In the time-series wind plots received from PNL, one wind regime was observed to last for an extended time (up to a month). This regime consisted of speeds reaching 10-15 m/s during the day and dropping off to <4 m/s at night. After carefully analyzing the surface maps, it was determined that in a general sense the synoptic pattern is similar for all occurrences of this wind regime. Typically, a semi-permanent high (associated with an upper-level ridge) is located over the Rocky Mountains. Every few days low pressure centers track across the northern U.S. causing lee side troughing in the vicinity of Clayton. The result is the above mentioned wind regime.

At Clayton a good correlation exists between the surface wind direction and that at 850-mb for the majority of the B-A types. Generally, the two do not vary by more than 20^o- 40^o. The ratio between the surface and 850-mb speeds is generally 0.7-0.9 for all synoptic types.

Cross isobaric flow is common at Clayton. For example, an E to W isobaric alignment can result in a NW wind. In some cases, especially in the warmer half of the year, weak low pressure is located in western Kansas. With this synoptic condition, the wind will blow from the SW, directly across the isobars, at a speed often exceeding 8 m/s. Figure 4.11 shows surface analyses which correspond with strong and weak winds at the site. The I-O shown in these two examples are commonly associated with strong and light winds respectively (see Section 4.2.2 for further discussion of wind and I-O relationships). This is true even though a rather weak pressure gradient may occur with the strong wind case and a surprisingly strong pressure



(a)



(b)

FIGURE 4.11. Typical Surface Map Analyses Associated with Strong (a) and Weak Wind Speed (b) at Clayton

TABLE 4.8. Wind Statistics for Boone (All Speeds in m/s)

	SURFACE						850 MB				
B-A	No. of Obs.	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	≥7 m/s (%)	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	Sfc. to 850 Ratio
1	1	---	--	---	---	--	---	--	----	--	-----
2	16	231	58	8.0	3.3	75	230	47	11.6	8.4	0.690
3	63	307	27	11.9	5.3	90	267	49	14.2	4.9	0.838
4	36	227	47	8.3	3.8	60	222	32	12.5	3.9	0.664
5	39	239	49	10.1	3.9	87	226	36	14.9	4.5	0.678
6	3	---	--	----	---	--	---	--	----	---	-----
7	5	---	--	----	---	--	---	--	----	---	-----
8	1	---	--	----	---	--	---	--	----	---	-----
9	1	---	--	----	---	--	---	--	----	---	-----
10	2	---	--	----	---	--	---	--	----	---	-----
11	9	257	48	9.7	2.8	89	234	27	13.1	3.7	0.740
12	12	272	38	9.0	4.7	80	261	36	11.9	4.5	0.756
13	11	---	--	5.9	2.6	50	---	--	11.9	4.0	0.496
14	5	---	--	----	---	--	---	--	----	---	-----
15	6	---	--	---	---	--	---	--	----	---	-----
16	2	---	--	----	---	--	---	--	----	---	-----
17	10	235	47	7.0	3.6	60	220	41	11.5	6.7	0.609
18	21	238	50	8.0	2.9	67	232	34	11.9	6.8	0.672
19	17	313	24	10.2	3.7	94	277	38	11.8	3.9	0.864
20	4	---	--	----	---	--	---	--	----	---	-----
21	15	196	80	4.6	3.1	27	225	29	8.9	5.3	0.517
22	4	---	--	----	---	--	---	--	----	---	-----
23	4	---	--	----	----	--	---	--	----	---	-----
24	7	197	76	4.9	1.9	14	237	52	5.7	5.1	0.860
25	23	294	52	9.1	4.5	68	290	46	9.4	4.2	0.968
26	6	253	59	5.4	2.4	33	262	54	8.0	4.9	0.675
27	10	135	47	6.9	4.2	56	212	35	9.4	6.8	0.734
28	2	---	--	----	---	--	---	--	----	---	-----
29	61	312	20	10.9	5.5	90	303	31	11.6	4.2	0.940
30	74	247	50	7.6	3.9	54	244	42	6.3	3.9	1.206
31	95	322	35	8.4	4.8	57	310	41	9.9	4.7	0.848
32	36	292	61	6.2	4.1	26	266	75	7.9	2.0	0.785
33	109	192	59	5.5	2.8	26	202	60	6.7	3.9	0.821
34	192	162	--	3.5	2.2	9	---	--	4.9	3.8	0.714
35	241	99	--	4.3	3.5	16	---	--	5.2	3.1	0.827

gradient may occur with the weak wind case. However, there are good examples of either strong or light winds of long duration due to the high variability of wind speeds at Clayton.

4.2.3 Boone

The site is located on top of a 1348 m (4420 ft.) mountain in western North Carolina among the Appalachian Mountains. As can be seen from Table 4.8 the common B-A types are those associated with the passage of a low pressure center to the north of the site (3-5), those associated with a ridge or high center tracking either to the north or south of the site (29 to 34), and the type associated with a flat pressure area or col (35). The directions having the stronger speeds are SW through NW, with the peak speeds occurring with NW winds. The very strong winds (occasionally >20 m/s) (generally) occur as a low tracks from W to E with the center passing N of the site, the associated strong cold front moves east of the site, and high pressure approaches from the Midwest. This pattern is naturally more predominant in the colder months of the year. On the other hand, very light winds (<5 m/s) will result with high pressure located north of the site causing an east to west orientation of the isobars. Figures 4.12 and 4.13 respectively, show the predominance of the strong wind associated with N to S and NW to SE I-0 and weak winds associated with E to W and SE to NW I-0. With the strong wind case 114 out of 137 (83.2%) forecasts result in speeds of ≥7 m/s. On the other hand, <7 m/s results 121 out of 146 times (82.9%) with the weak wind case. Surface analyses associated with these types of wind regimes are shown in Figure 4.14. In Boone there are a large number of cases of flat pressure areas or cols resulting in light and variable winds. These occur mostly in the warmer months of the year.

The experiment of combining all the B-A types into two large groups as was done for San Gorgonio is graphically shown in Figure 4.15. The B-A types associated with lower pressure east of the site almost invariably result in winds from the NW quadrant. The types which imply higher pressure east of the site show much more scattering but most of the time the winds blow from the SW quadrant. It is suspected that most of the cases which blow from the WNW are associated with an E to W oriented high located NNW

Speed ≥7 M/S	N-S, NW-SE I-O	YES	NO
	YES	114	225
	NO	23	311

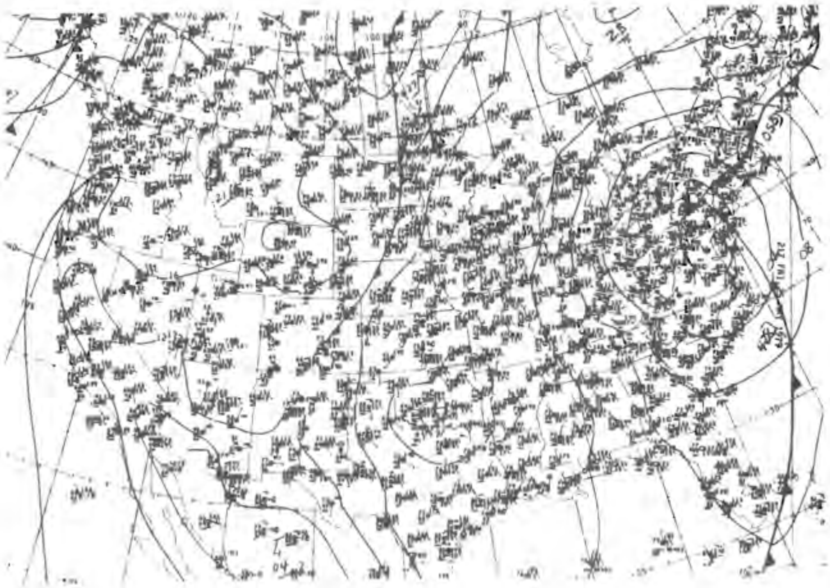
FIGURE 4.12. Numerical Results of the Rule: N to S and NW to SE I-0 at Boone Results in Speeds of ≥7 M/S

Speed <7 M/S	E-W, SE-NW I-O	YES	NO
	YES	121	213
	NO	25	314

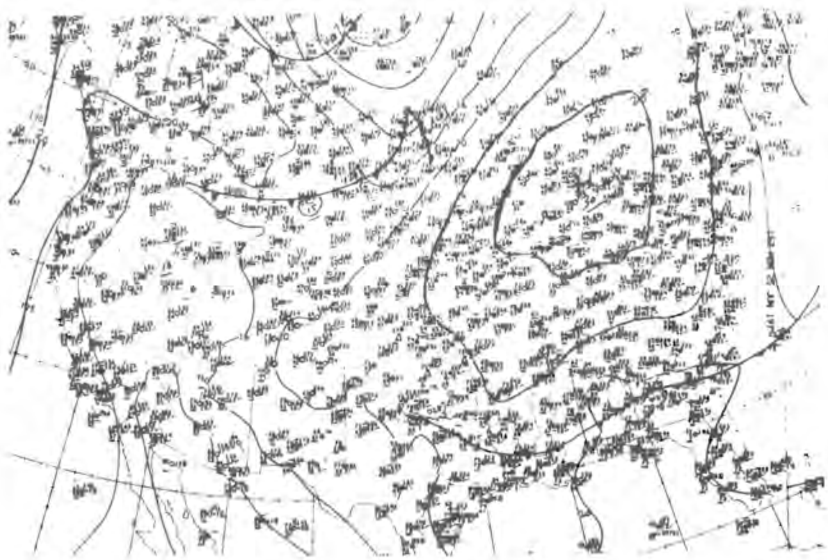
FIGURE 4.13. Numerical Results of the Rule: E to W and SE to NW I-0 at Boone Results in Speeds of <7 M/S

of the site similar to the light wind case of Figure 4.14.

Finally, the surface to 850-mb speed ratios for Boone are generally 0.7 - 0.9 for the common B-A types. The exception is B-A type 30 (high, center, south, postridge) having a ratio of about 1.2.



(a)



(b)

FIGURE 4.14. Typical Surface Map Analyses Associated with Strong (a) and Weak Wind Speed (b) at Boone

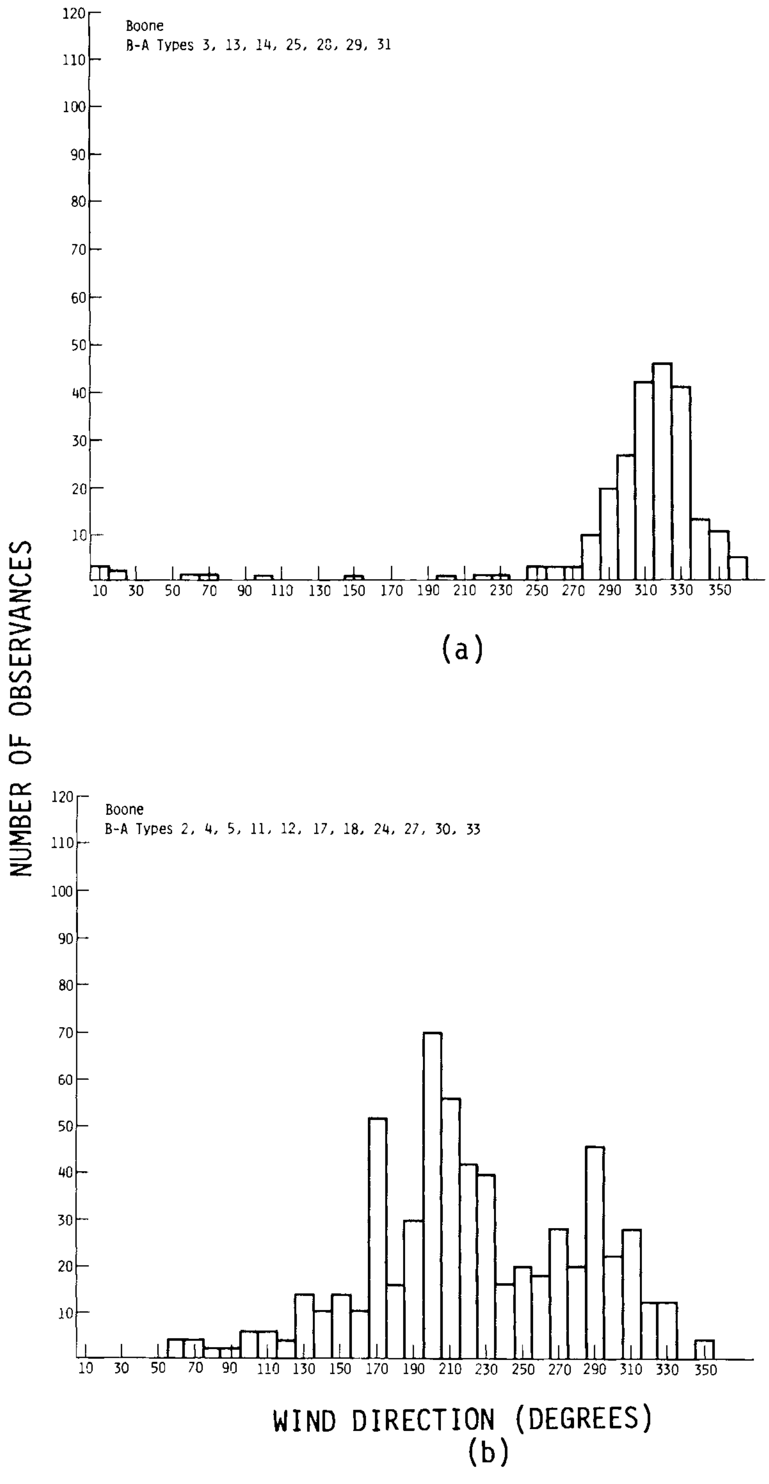


FIGURE 4.15. Wind Direction Distribution at Boone for B-A Surface Types Implying Lower Pressure East (a) and B-A Types Implying Higher Pressure East (b)

4.2.4 Montauk Point

Montauk Point is located on the eastern tip of Long Island, New York. Because it lies on the Atlantic coastal plain, the wind can blow rather strongly from any direction. Also, because it is in the northeastern United States, it is affected by many synoptic types. Table 4.9 shows that the most common B-A synoptic types are those associated with a deep closed low, center north (types 2 to 5), those associated with an open wave, center north (types 18, 19) and those associated with high pressure centers of cols (types 29 to 35).

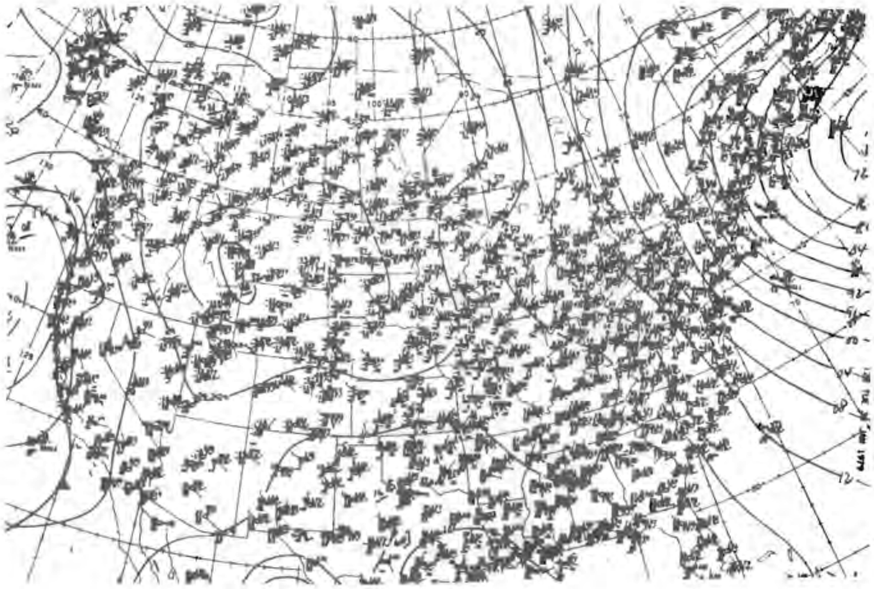
The table indicates that the strongest speeds at Montauk are generally associated with B-A types having W or NW winds (those types implying lower pressure E). The only apparent contradiction to this is B-A type 31 (high, center north, preridge) with a mean speed of only 6.5 m/s while the average direction is 292^{o}. This type has a large number of occurrences (119) but it is noted that the standard deviation is also large. Thus, in many cases it is suspected that the ridge axis is just west with the high center north of the site causing a NE to SW I-0. This I-0 results in many cases with light E through NW winds, thereby explaining the relatively low speed for this synoptic type. Without taking pressure gradients into consideration it is difficult to find reliable forecasting rules for Montauk. For example, even though the strongest winds tend to be NW, only 60.7% of the time are speeds of at least 7 m/s reached when the wind direction is between 270^{o}- 340^{o}. However, as noted in the next section, good forecasting rules do appear when one considers pressure gradients. Figure 4.16 shows the typical surface analyses associated with both strong and weak wind cases.

The combination of the B-A types into the two large groups is shown in Figure 4.17. Here again, the group associated with lower pressure to the east has the great majority of winds in the NW quadrant and the group associated with higher pressure east has over 90% of the winds in the SW and SE quadrants.

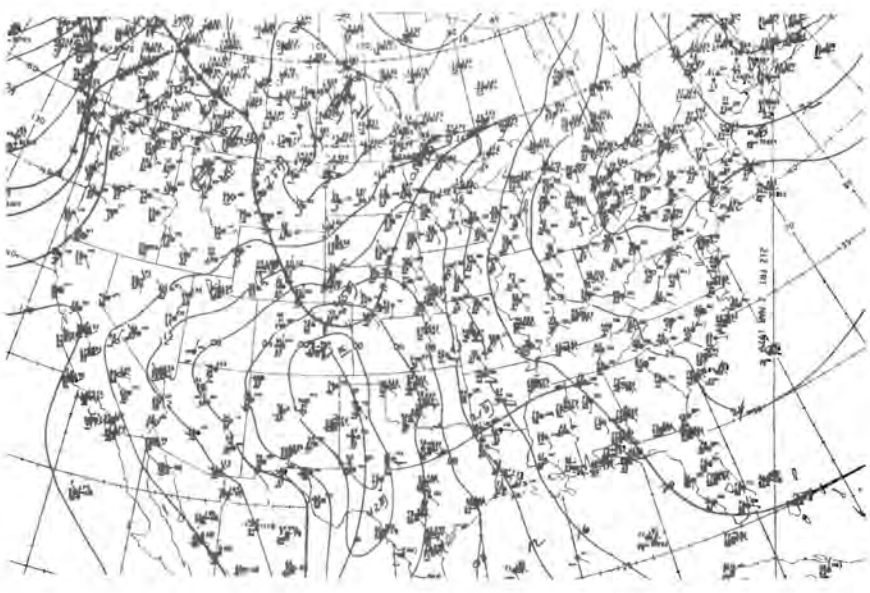
The surface to 850-mb ratio is generally between 0.4 and 0.7 for the common synoptic types. This ratio is significantly lower than the ratio for the other sites, due to differences in site elevation.

TABLE 4.9. Wind Statistics for Montauk
(All Speeds in m/s)

	SURFACE						850 MB				
B-A	No. of Obs.	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	>7 m/s (%)	Mean Dir.	St. Dev.	Mean Speed	St. Dev.	Sfc. to 850 Ratio
1	4	---	--	---	---	--	---	--	----	---	-----
2	19	153	61	6.7	3.0	42	234	29	15.4	5.1	0.435
3	84	267	57	9.1	4.4	71	292	38	14.2	3.9	0.641
4	24	195	35	7.3	2.9	61	228	37	15.7	5.4	0.465
5	49	203	48	6.5	3.6	53	230	40	19.8	9.8	0.328
6	8	101	41	10.4	3.7	88	171	33	20.0	6.8	0.520
7	10	103	75	9.4	2/8	89	171	69	14.8	8.2	0.635
8	14	337	49	6.7	3.3	57	258	104	9.8	4.3	0.684
9	14	---	--	---	---	--	---	--	----	---	-----
10	3	---	--	---	---	--	---	--	----	---	-----
11	2	---	--	---	---	--	---	--	----	---	-----
12	7	247	43	3.9	2.5	14	281	40	9.9	5.8	0.394
13	8	---	--	5.2	4.4	25	---	--	9.7	6.2	0.536
14	12	164	42	4.0	2.5	17	218	62	7.1	4.8	0.563
15	6	---	--	4.3	1.6	0	---	--	9.5	4.4	0.453
16	4	---	--	---	---	--	---	--	----	---	-----
17	9	210	51	5.5	2.7	33	240	33	12.0	5.8	0.458
18	21	204	66	6.4	2.4	53	228	30	12.2	5.9	0.525
19	20	330	52	9.7	2.3	62	276	51	10.3	6.7	0.942
20	1	---	--	---	---	--	---	--	----	---	-----
21	10	81	45	8.4	2.7	88	168	37	8.4	8.0	1.000
22	5	---	--	---	---	--	---	--	----	---	-----
23	2	---	--	---	---	--	---	--	----	---	-----
24	12	227	43	7.2	3.7	45	272	39	13.5	3.8	0.533
25	14	293	45	7.5	5.7	45	275	67	9.0	4.7	0.833
26	10	226	47	6.5	1.6	50	276	55	13.8	7.1	0.471
27	0	---	--	---	---	--	---	--	----	---	-----
28	1	---	--	---	---	--	---	--	----	---	-----
29	73	299	43	8.5	4.2	64	304	26	15.1	6.6	0.563
30	86	211	44	6.2	2.8	42	249	34	10.4	4.6	0.596
31	119	292	106	6.5	3.7	48	---	--	10.5	5.1	0.619
32	184	114	--	3.2	2.1	6	---	--	6.1	4.0	0.525
33	80	152	65	4.8	2.5	25	231	50	8.2	4.9	0.585
34	28	46	20	7.6	2.5	63	135	78	6.0	3.2	1.267
35	17	187	77	3.8	2.5	15	245	49	5.1	3.9	0.745



(a)



(b)

FIGURE 4.16. Typical Surface Map Analyses Associated with Strong (a) and Weak Wind Speed (b) at Montauk Point

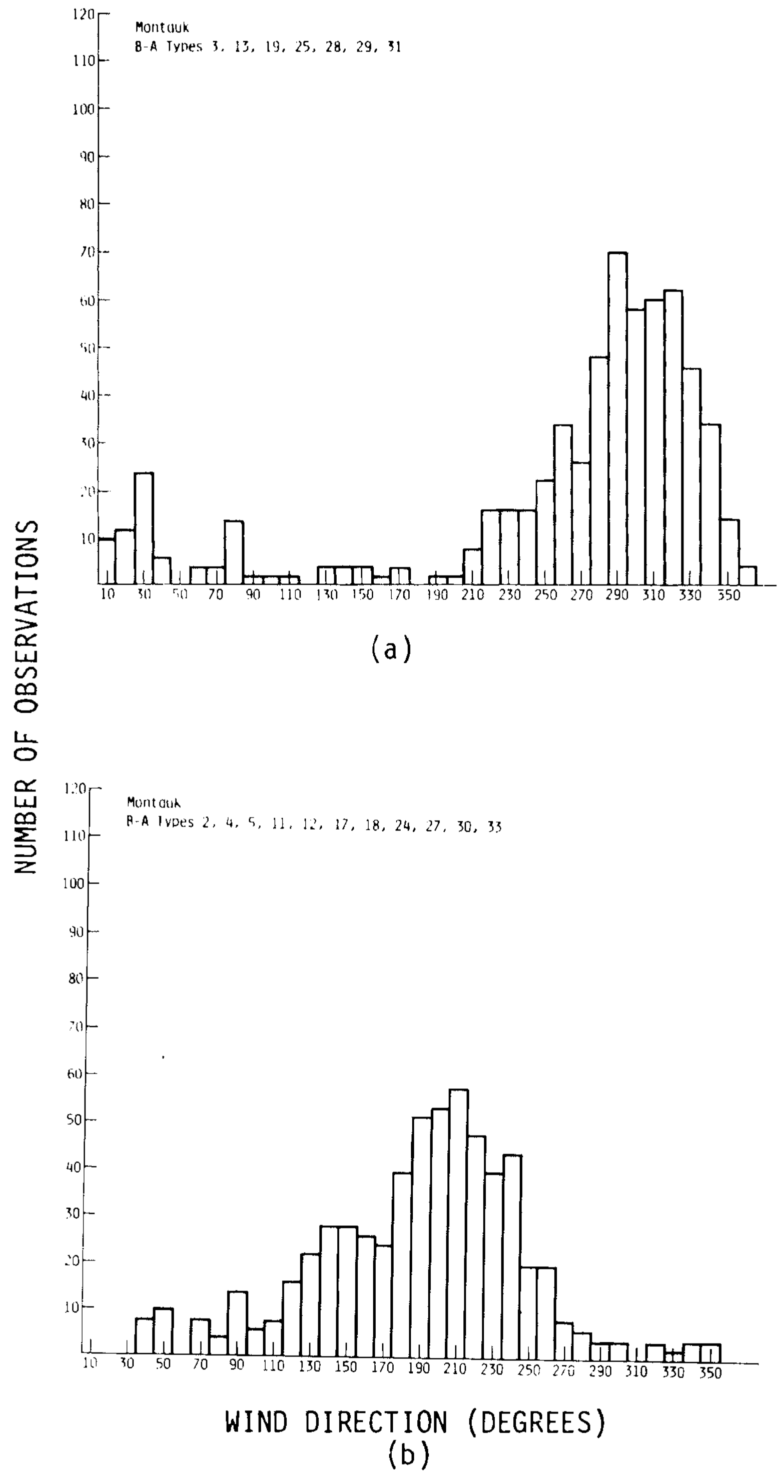


FIGURE 4.17. Wind Direction Distribution at Montauk Point for B-A Surface Types Implying Lower Pressure East (a) and B-A Types Implying Higher Pressure East (b)

4.3 PRESSURE GRADIENT RELATIONSHIPS

During the progress of this study it became increasingly obvious that in addition to recognizing the synoptic types, it is very important to know the strength of both the pressure gradient and the isobaric orientation in order to arrive at refined forecasts of wind speed and direction for a particular site. Thus a careful study of the relationships between wind speed and pressure gradient for a given I-O was made. This approach definitely helps to remove much of the guesswork involved in wind forecasting. The synoptic-type approach can be used as a first approximation and the pressure gradient relationships can be utilized to better delineate the wind forecast.

A question arose during this research regarding differences in pressure gradient, wind speed and direction relationships derived from 12-hourly rather than 3-hourly data. Therefore, three months (January, April and October) of 3-hourly surface maps per site were examined and compared to the 12-hourly data analyses. The results were similar. As an example, Figure 4.18 compares the speed and pressure gradient using 3-hourly data, as opposed to 12-hourly data, for Boone for the months of January, April and October. Note the similarity between these curves and those of Figure 4.19 which uses 12-hourly data for the year. The only I-O which seems to deviate somewhat from the 12-hourly results is the NE-SW for the 8 mb and 9 mb pressure gradients. However, as seen from Figure 4.19 only one observation is available for these pressure gradients. Thus, it was determined that data taken from 0000 and 1200 GMT provides sufficient information about site wind characteristics.

Another question which was addressed was whether or not there were synoptic differences between the very strong winds (≥20 m/s) and the moderately strong winds (10-15 m/s). After checking with the surface maps, the conclusion is that there are no major synoptic differences in these cases other than the strength of the systems. Thus, the pressure gradient can be used to discriminate between strong or very strong wind speed occurrences. The results of the pressure gradient relationships for the sites studied are discussed in the following sections.

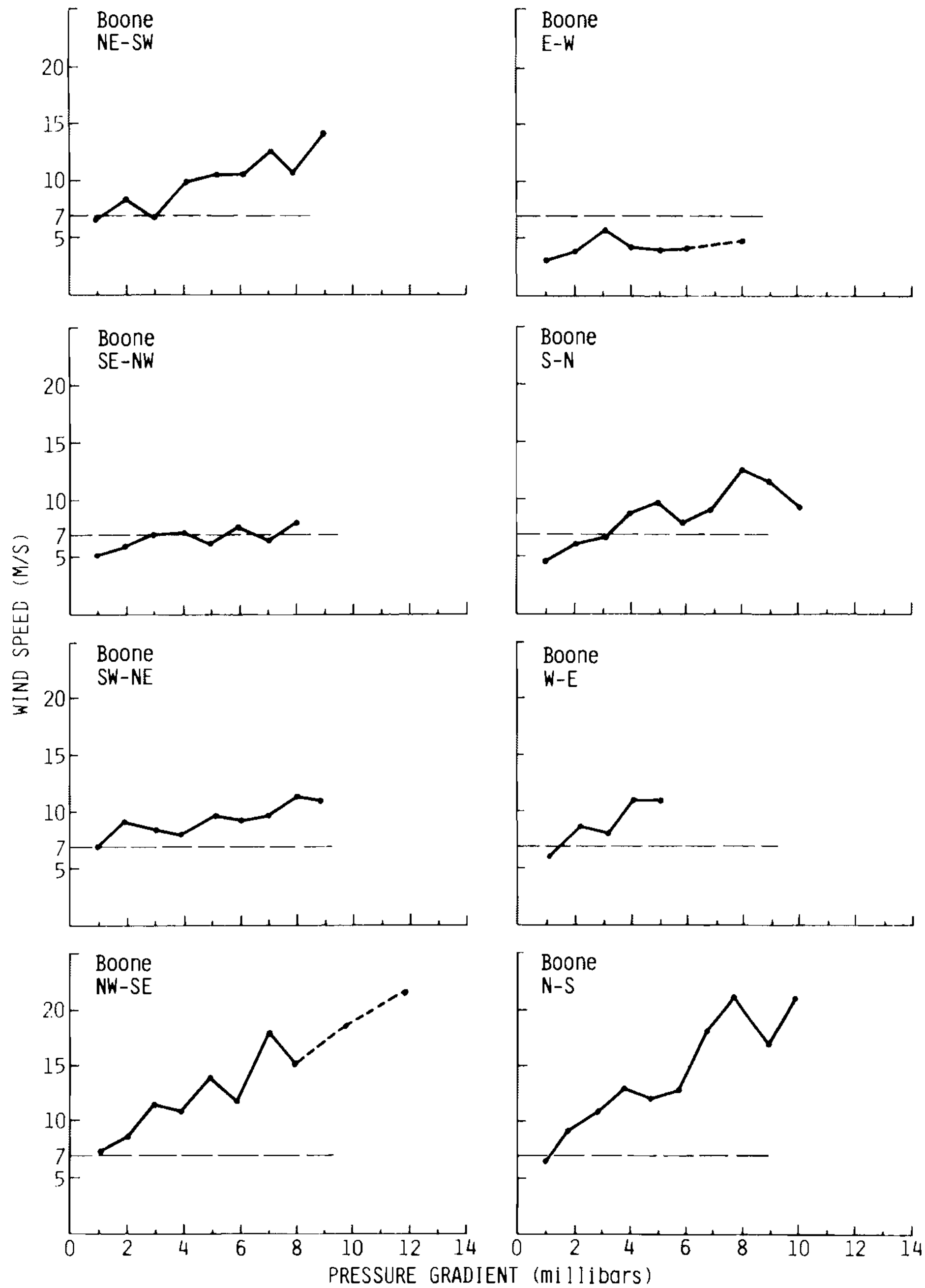


FIGURE 4.18. Wind Speed-Pressure Gradient Relationships for Boone Using 3-Hourly Data

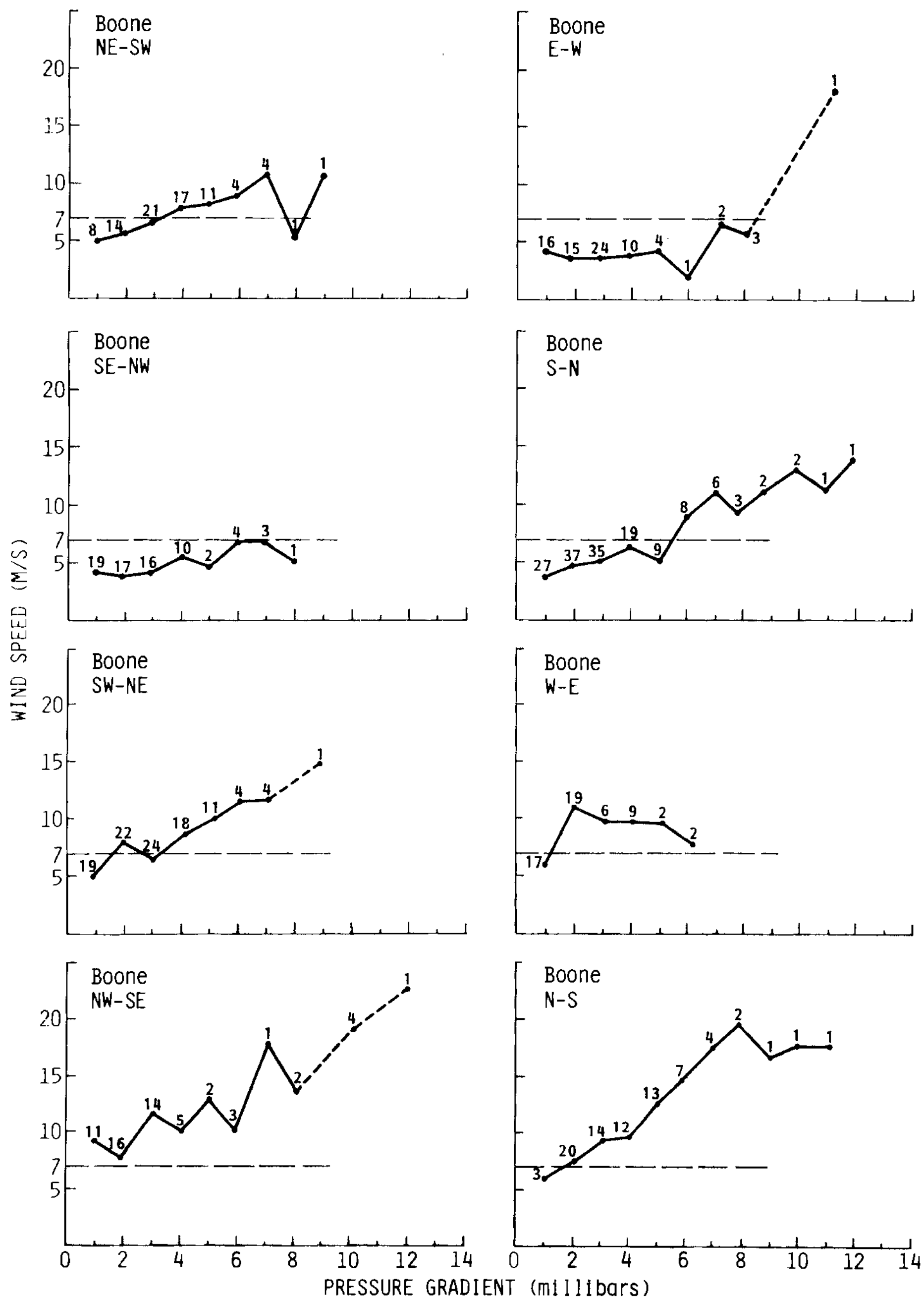


FIGURE 4.19. Wind Speed-Pressure Gradient Relationships for Boone Using 12-Hourly Data

NOTE: The numbers on the lines are the number of data which the point represents.

4.3.1 San Gorgonio

As mentioned earlier, San Gorgonio displays very consistent wind characteristics in terms of synoptic situations. This consistency is also evident when examining the relationship between wind speed and pressure gradient for a given isobaric alignment. Figure 4.20 indicates that for the NE to SW, E to W, SE to NW and S to N isobaric alignments, speeds are generally <7 m/s for nearly all pressure gradients. For the W to E isobaric alignment, the wind speed averages ≥ 8 m/s for all the available pressure gradients except for 3 mb. The minimum at 3 mb is probably due to insufficient data. This figure illustrates that a W to E and to a lesser extent a SW to NE I-O can result in strong winds at San Gorgonio. This is consistent with the San Gorgonio pressure rules discussed earlier in Section 4.2.1 (which stated that strong winds result with lower pressure to the east), for in this case, the pressure is lower to the N or NW causing a W to E I-O. However, the typical energy producing winds at San Gorgonio occur with the NW to SE and N to S I-O. These I-O's truly imply lower pressure east and higher pressure west. With these alignments the wind speeds are strong (>7 m/s) even for weak pressure gradients. For pressure gradients of ≥ 7 mb, speeds average between 17-22 m/s. From Figure 4.21, 57 out of 60 times, (95%) wind speeds are ≥ 13 m/s if the pressure gradient is ≥ 7 mb. The 13 m/s threshold was chosen because the MOD-2 Wind Turbine Generator reaches rated capacity at about 12.3 m/s (Miller 1980).

In order to study possible diurnal variations in wind speed with a given pressure gradient, the data were separated into 1200 and 0000 GMT and curves similar to Figure 4.20 were drawn. The results are shown in Figure 4.22. Given the same pressure gradient, no significant difference in speeds appeared for most isobaric orientations. The only apparent I-O which displayed a diurnal pattern at San Gorgonio is SW to NE. Here, there is a definite separation of the curves with the 0000 GMT curve showing significantly stronger speeds. However, this I-O is very infrequent at San Gorgonio.

The curves relating pressure gradient and wind direction for a particular I-O at San Gorgonio are shown in Figure 4.23. Here we see the predominance of the SW wind for the NW to SE and N to S I-O and for the most

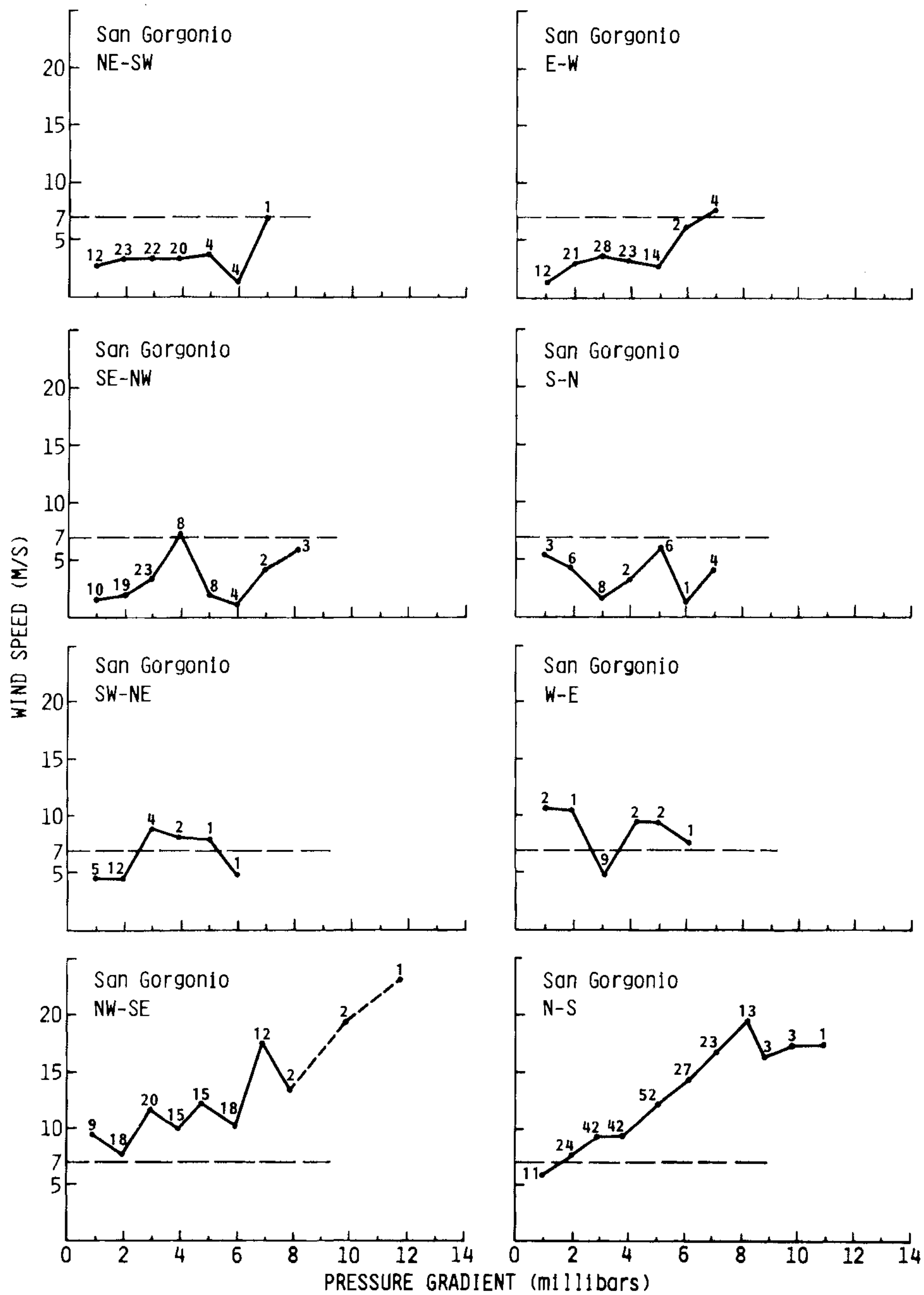


FIGURE 4.20. Wind Speed-Pressure Gradient Relationships at San Gorgonio. The Horizontal Dashed Line is the 7 M/S Threshold. Other Fine Dashed Lines Imply No Data Available Between Points.

part for the W to E I-0. As seen earlier, this SW wind is by far the strongest wind. The other isobaric alignments show very erratic wind direction behavior implying light wind speeds. Several I-0's for San Gorgonio are shown with two curves in the Figure. The shorter curve is that associated with the nocturnal light E or SE wind for a few hours with very light pressure gradients. The isobaric alignments in which this bimodal effect occurs most often are E to W, NE to SW, and N to S. This pattern occurs with a very flat pressure gradient and a weak trough over or just east of the site and only involves a small number of cases of light easterly winds.

		NW-SE, N-S I-0 And ≥7 MB: YES	NW-SE, N-S I-0 And ≥7 MB: NO
Speed ≥13 M/S	YES	57	6
	NO	3	8

FIGURE 4.21. Numerical Results of the Rule: NW to SE and N to S I-0 With ≥7 MB Pressure Gradient at San Gorgonio; Results in Speeds of ≥13 M/S

4.3.2 Clayton

Pressure gradients versus wind speeds for a given I-0 at Clayton are graphically shown in Figure 4.24. Most isobaric orientations have fairly strong winds with the exception of the SE to NW I-0. In this case, speeds almost invariably average <7 m/s regardless of the pressure gradient. The light winds associated with the SE to NW I-0 appear to be caused by local topographical influences. Because Clayton is located on a small plateau

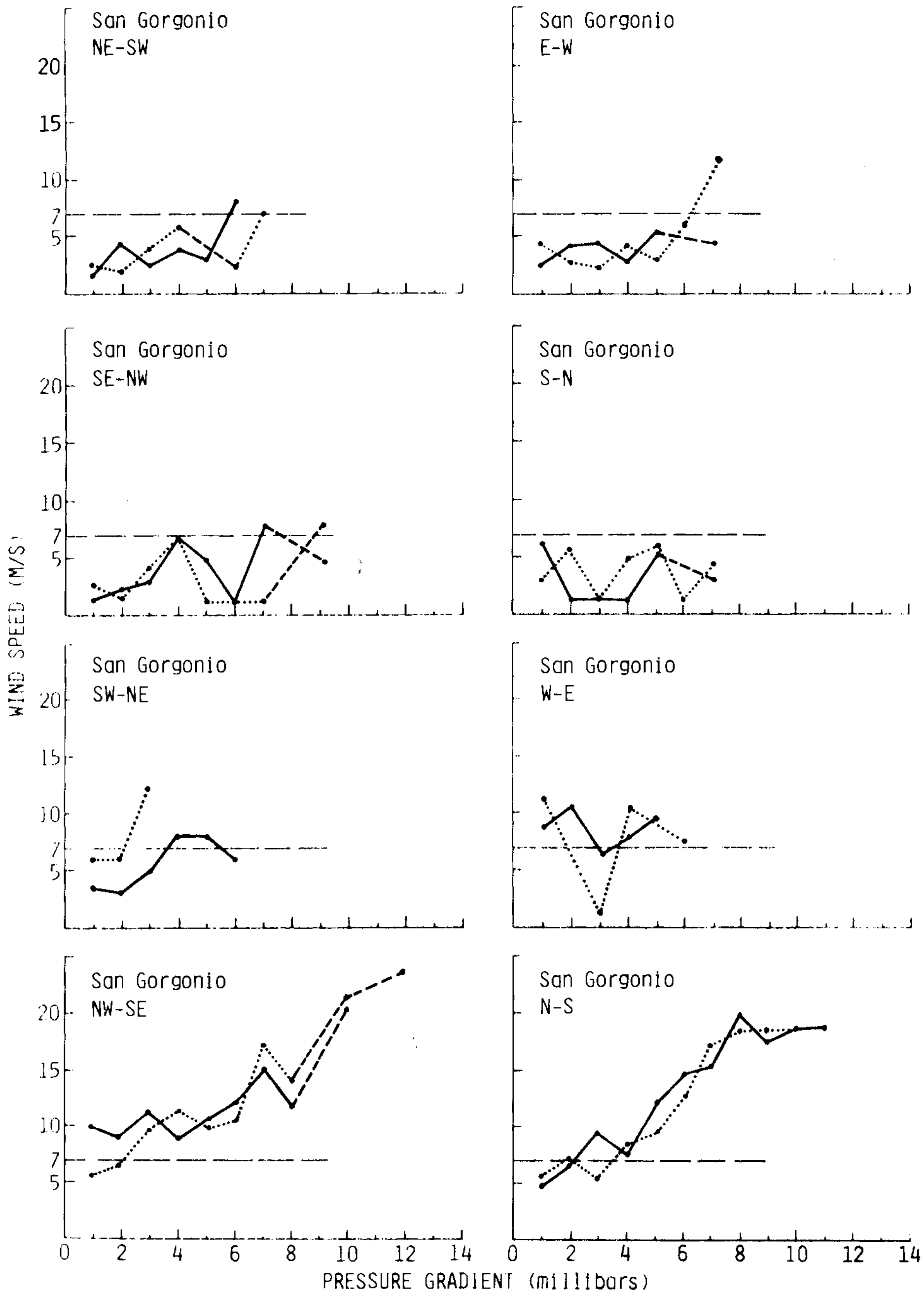


FIGURE 4.22. Wind Speed-Pressure Gradient Relationships for 1200 (•——•——•) and 0000 GMT (•····•····•) at San Gorgonio

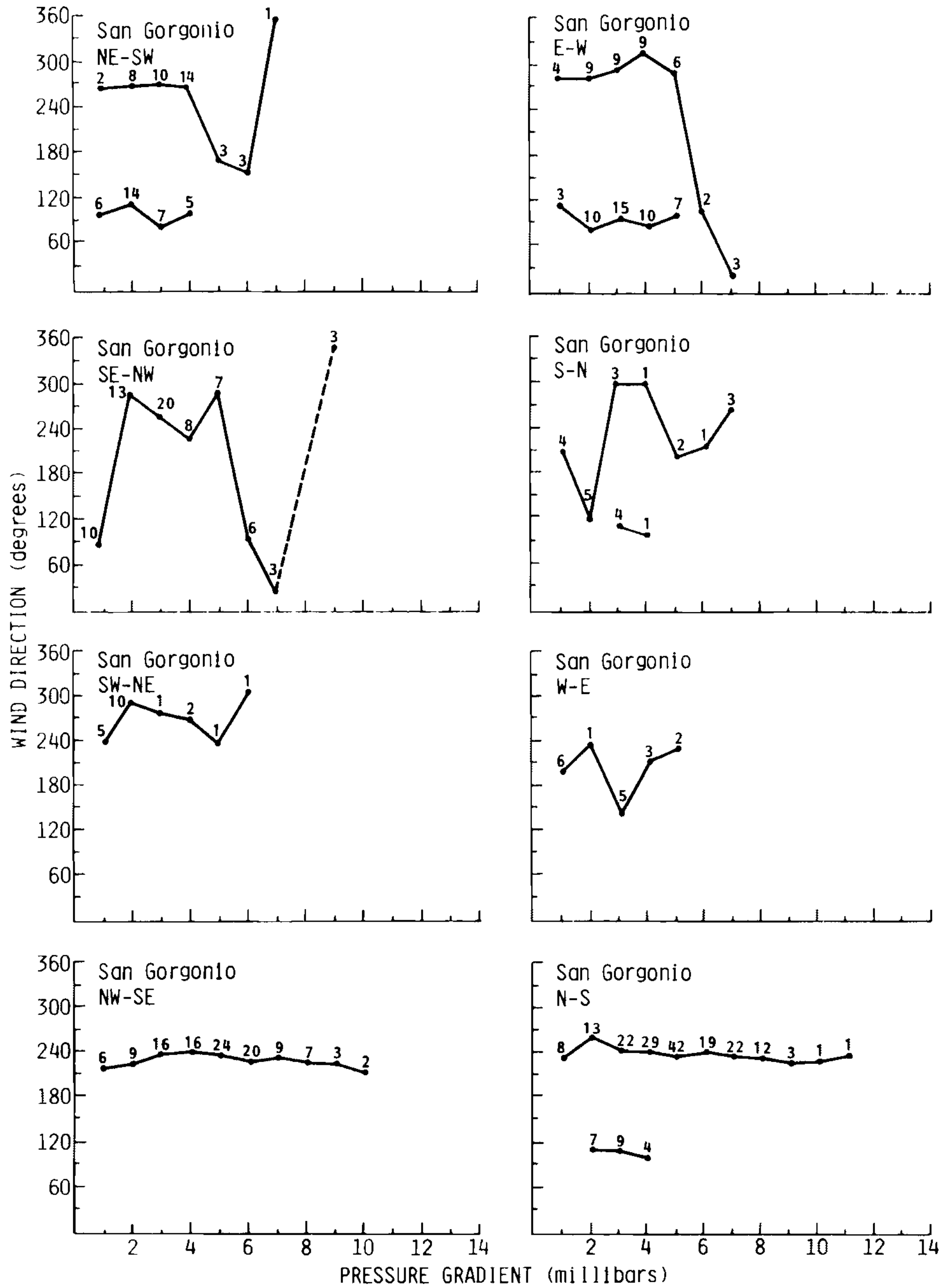


FIGURE 4.23. Wind Direction-Pressure Gradient Relationships at San Gorgonio

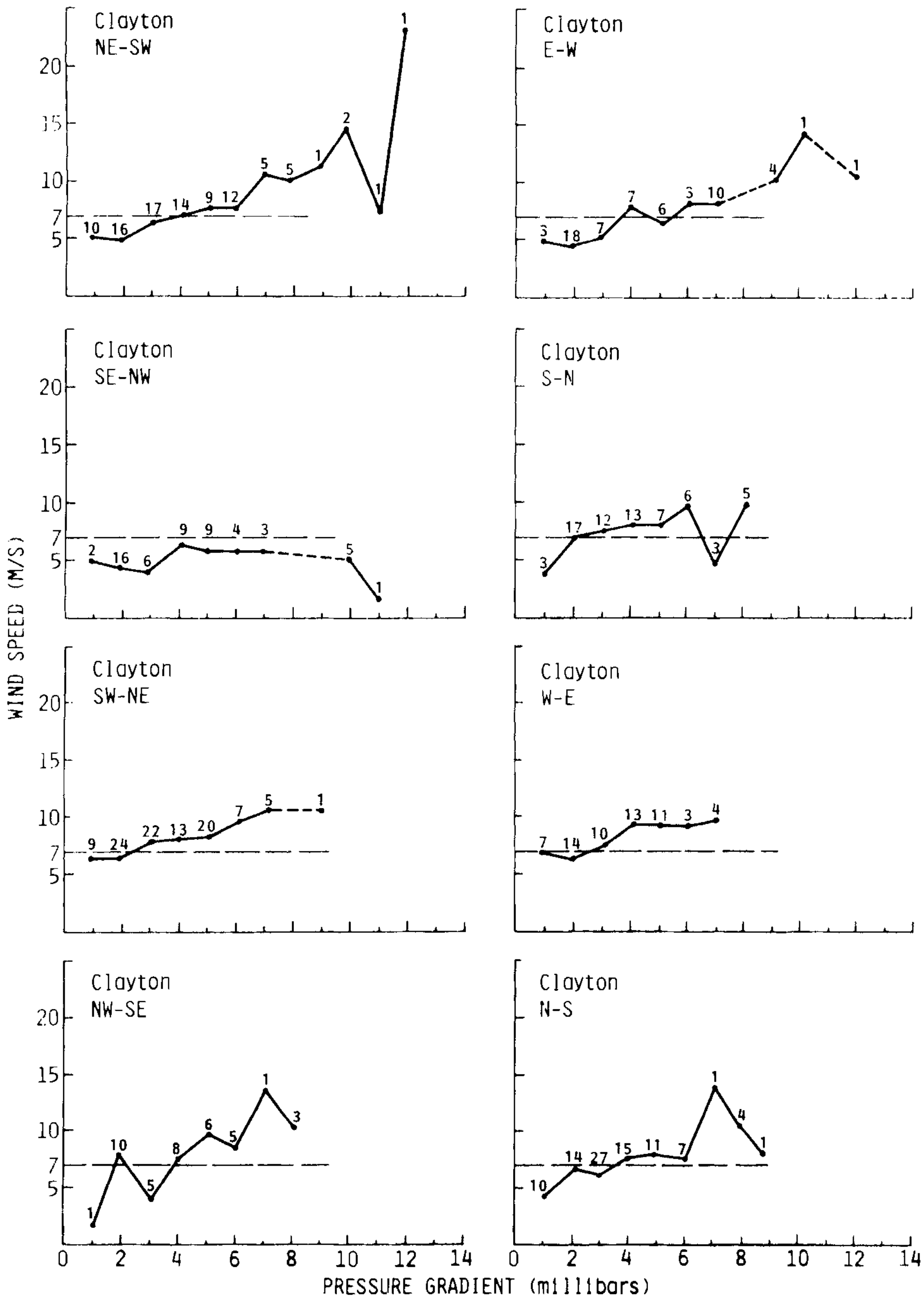


FIGURE 4.24. Wind Speed-Pressure Gradient Relationships at Clayton

near the foothills of the Rocky Mountains (which lie to the W and NW), cold stable air, well entrenched in the Great Plains will result in light winds. These light winds result from the elevated topography at Clayton opposing the easterly air flow. This conclusion is supported by the light wind case of Figure 4.12. The other alignments are generally associated with wind speeds averaging ≥7 m/s for pressure gradients of >4 mb as seen in Figure 4.25. With this criteria a forecast of ≥7 m/s would occur 75% of the time. Thus, the 4 mb pressure gradient threshold appears significant for forecasting energy-producing wind speeds at Clayton. The NE to SW I-O can have strong winds; however, this is generally a winter time phenomenon occuring when intense lows are located SSE of the site and strong high pressure is centered over the Rockies, resulting in a tight pressure gradient and a NE to SW isobaric alignment.

All I-O's Except SE-NW And ≥4 MB

Speed ≥7 M/S		YES	NO
	YES	192	9
	NO	64	18

FIGURE 4.25. Numerical Results of the Rule: All Isobaric Orientations Except the SE to NW Result in Speeds of ≥7 M/S at Clayton if the Pressure Gradient is ≥4 MB

Figure 4.26 shows the curves relating pressure gradient and wind direction for a given I-0 at Clayton. A NE to SW I-0 results in NW winds for pressure gradients ≥7 mb. A N to S I-0 has WSW through NW winds. The NW to SE, W to E, SW to NE, and S to N isobaric alignments are all associated with S to SW winds. The SE to NW I-0 is extremely erratic in direction as seen in Figure 4.26 suggesting the light and variable regime for this I-0. The E to W I-0 is somewhat perplexing. The wind direction is mostly NE through SW for ≥6 mb pressure gradient, but the direction is basically due N for ≥6 mb (see Figure 4.26). From Figure 4.24 speeds are mostly in the range between 7-12 m/s for ≥6 mb pressure gradient. Synoptically, this case is very similar to the NE to SW I-0 described above.

Figure 4.27 shows the pressure gradient versus speed curves separated into 1200 GMT and 0000 GMT for Clayton. Diurnal wind speed variations appear as significantly stronger speeds at 0000 GMT for the SW to NE, W to E, SE to NW, and S to N isobaric alignments. For these isobaric alignments, the speed at 0000 GMT appears to be 2-5 m/s stronger for the same pressure gradient. The remaining four I-0's do not show a stronger speed pattern at 0000 GMT.

4.3.3 Boone

As seen in Figure 4.28, Boone can have strong winds with any I-0 except E to W and SE to NW (see also Figures 4.13 and 4.14). The alignments associated with the strongest speeds are those from N to S and NW to SE. Speeds occurring with these I-0's often exceed 20 m/s. The S to N, SW to NE, and W to E alignments also have rather strong winds. From Figure 4.29, it is seen that with a NW to SE and N to S I-0 with ≥6 mb pressure gradient, 19 out of 22 times (86.4%) the wind speed reached at least 13 m/s. For the other isobaric alignments the reverse is true. Speeds were <13 m/s 52 out of 70 times (74.3%). Figure 4.30 reveals that the S to N, SW to NE, and W to E isobaric alignments result in speeds of ≥7 m/s with >4 mb pressure gradient 78.6% of the time, or 44 out of 56 cases.

Figure 4.31 shows that the NE to SW, N to S, and NW to SE alignments result in NW winds for all pressure gradients. Generally, the wind direction at Boone is very nicely correlated to the I-0. The W to E I-0 has

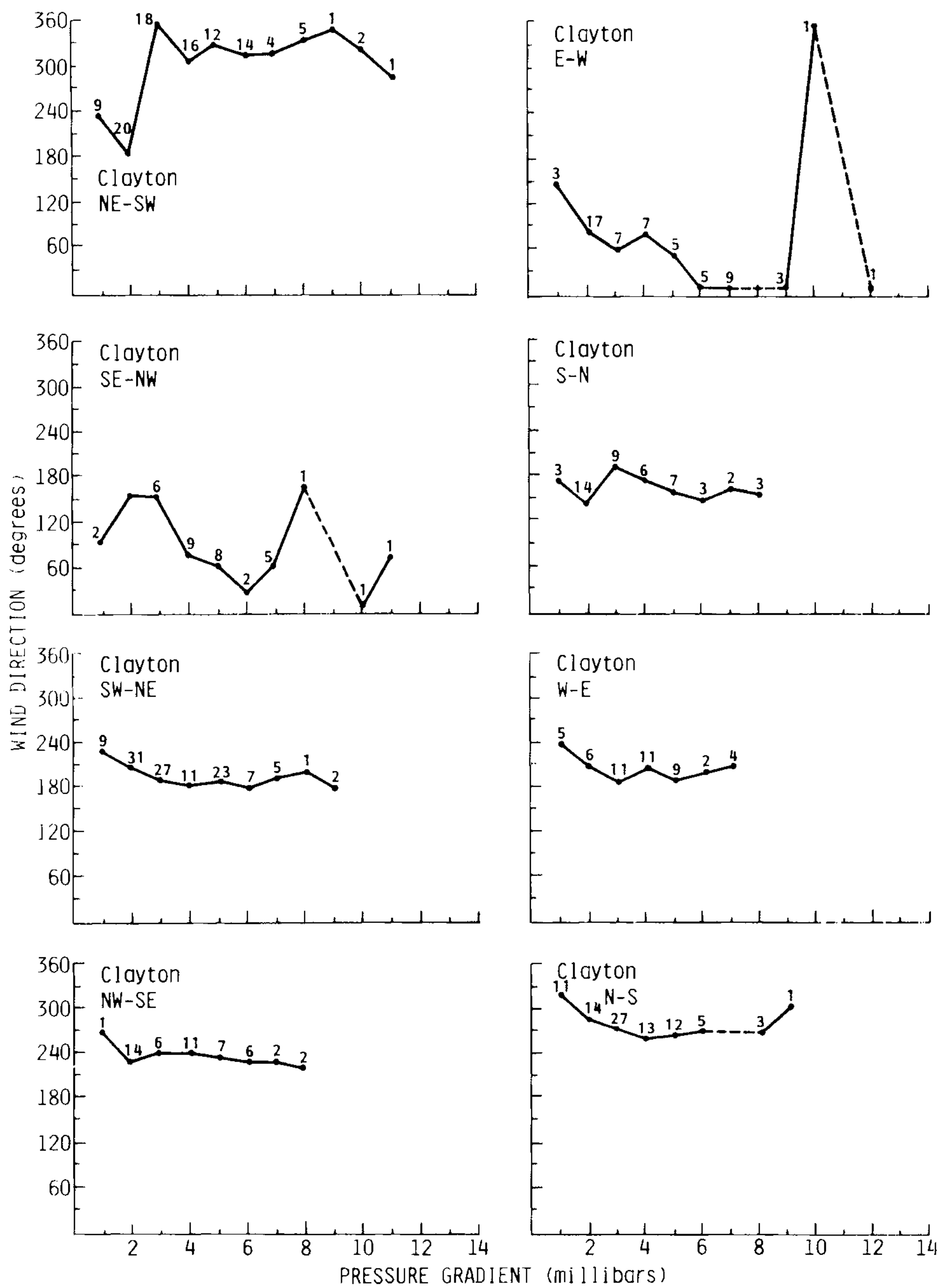


FIGURE 4.26. Wind Direction-Pressure Gradient Relationships at Clayton

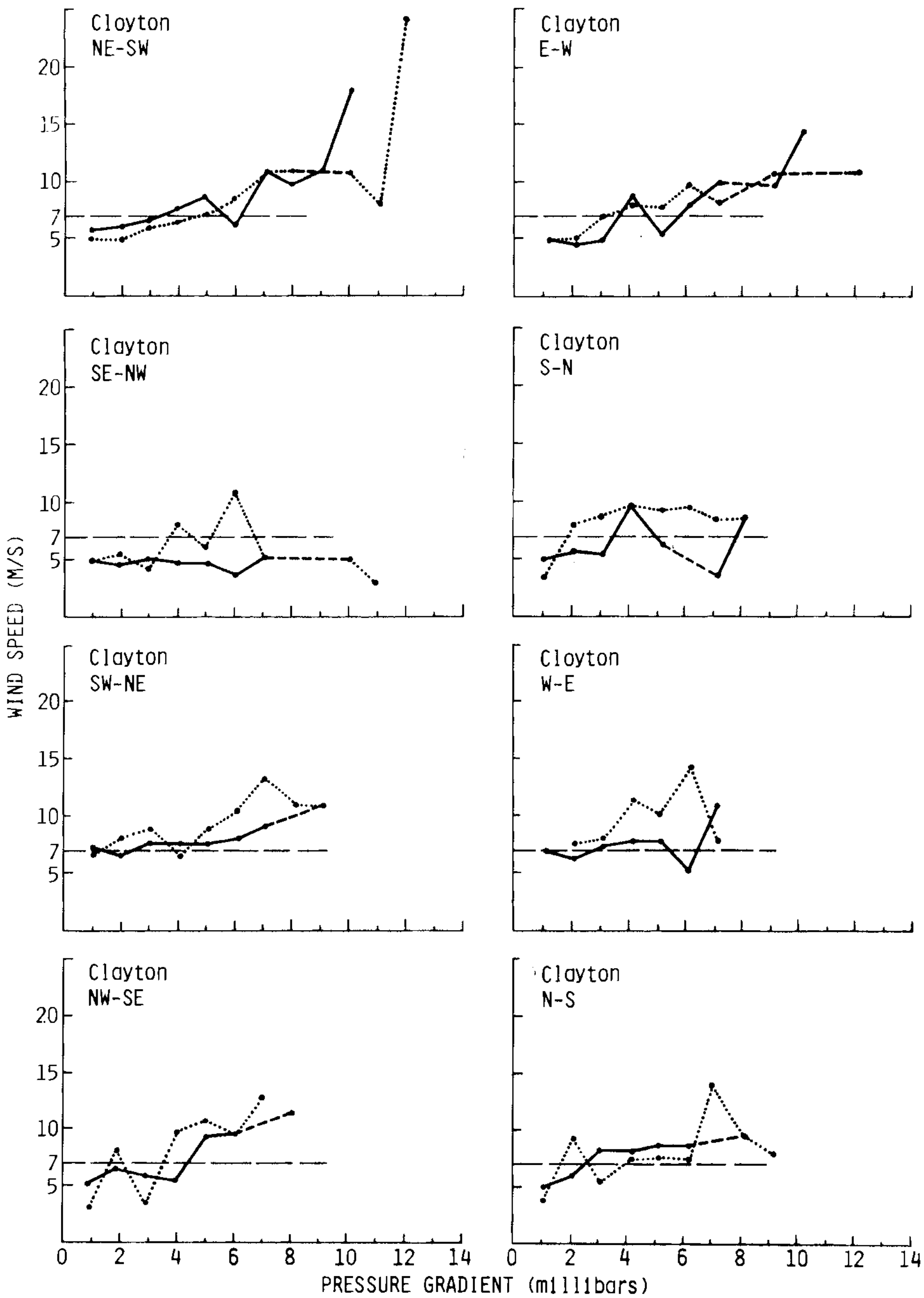


FIGURE 4.27. Wind Speed-Pressure Gradient Relationships for 1200 and 0000 GMT at Clayton

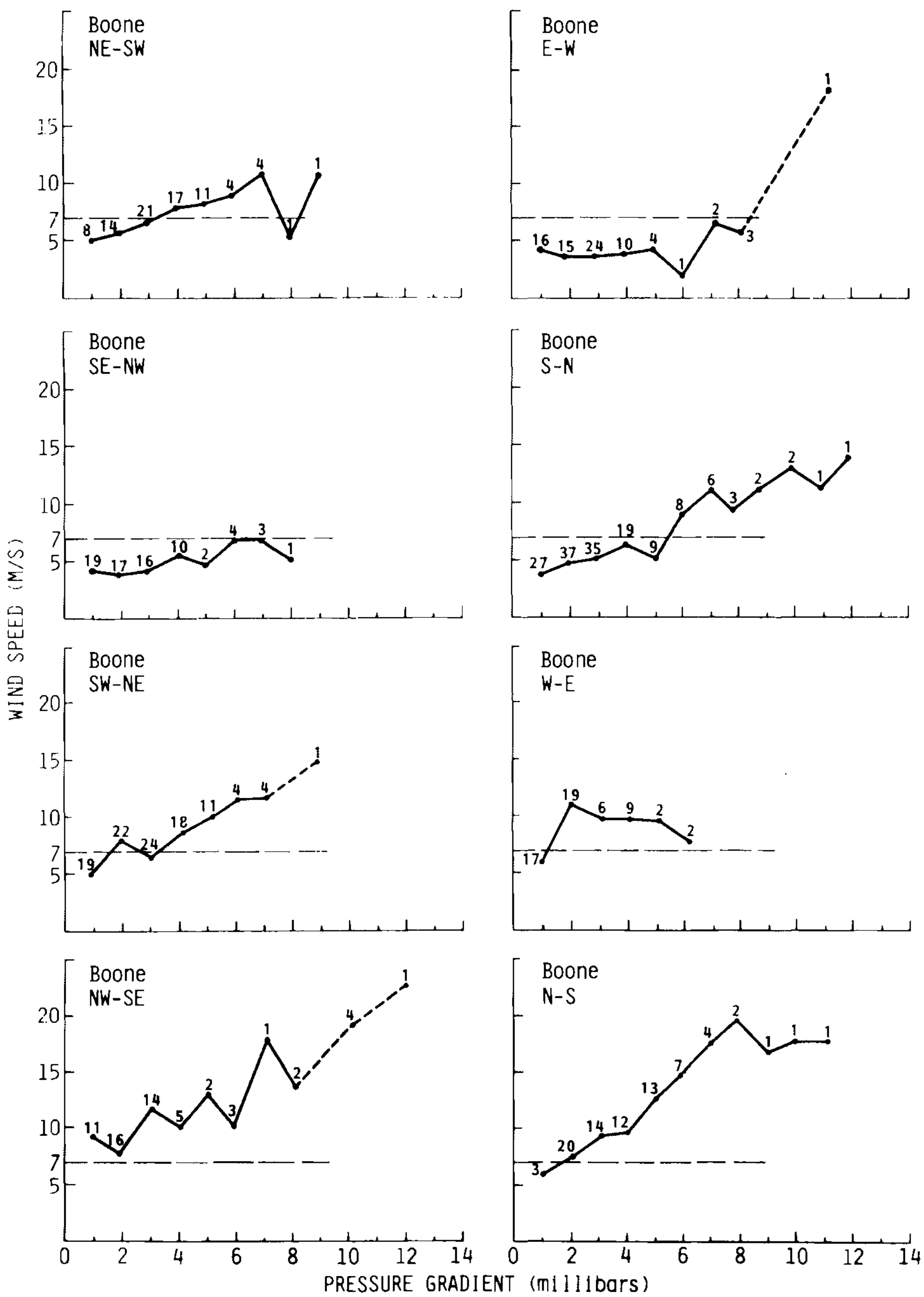


FIGURE 4.28. Wind Speed-Pressure Gradient Relationships at Boone

NW-SE, N-S I-O
And ≥6 MB

Speed ≥13 M/S		YES	NO
	YES	19	18
	NO	3	52

FIGURE 4.29. Numerical Results of the Rule: NW to SE and N to S I-O with ≥6 MB Pressure Gradient Results in ≥13 M/S at Boone

S-N, SW-NE, W-E
And >4 MB

Speed ≥7 M/S		YES	NO
	YES	44	69
	NO	12	19

FIGURE 4.30. Numerical Results of the Rule: S to N, SW to NE and W to E I-O with >4 MB Pressure Gradient Results in Speeds of ≥7 M/S at Boone

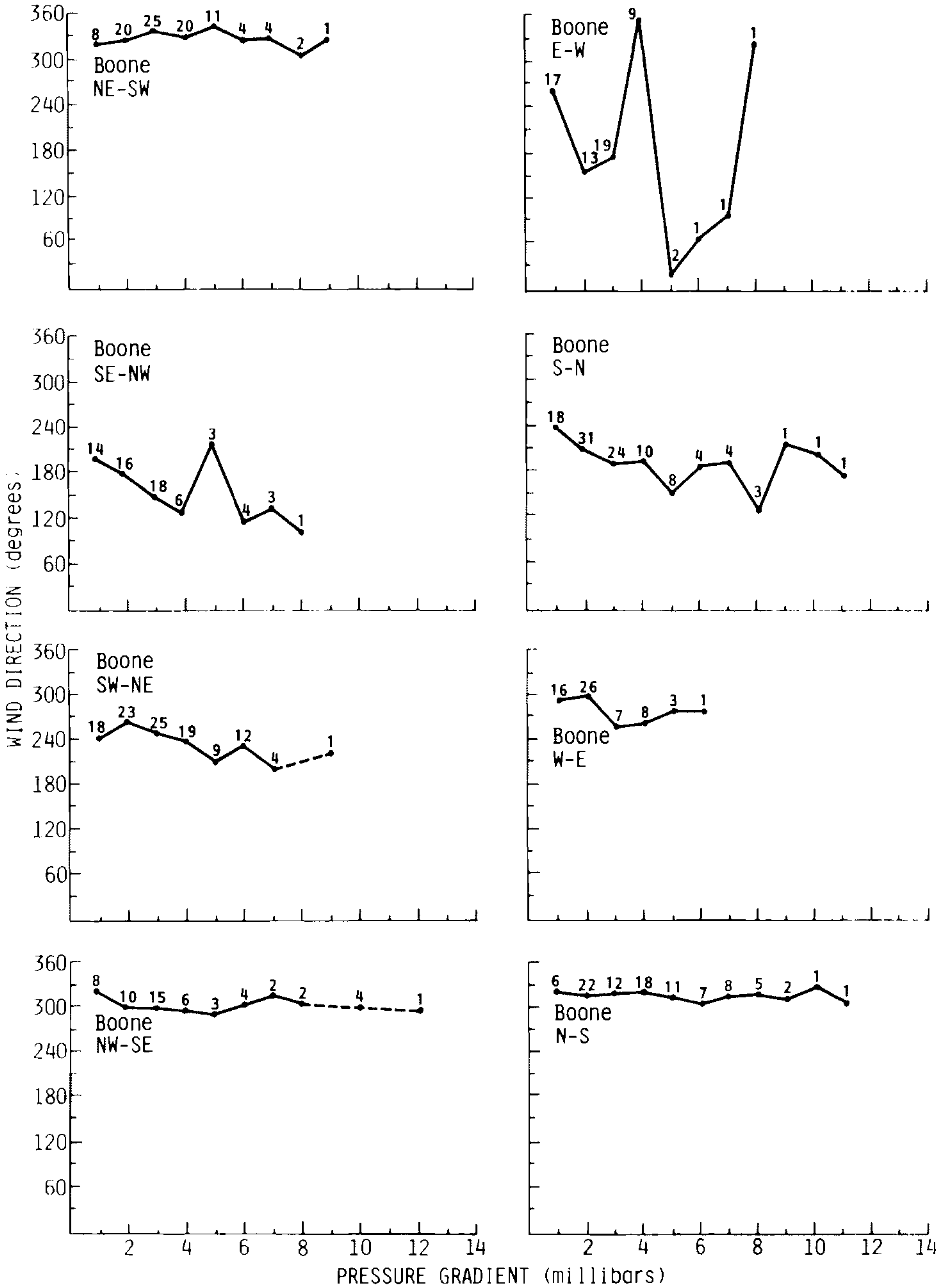


FIGURE 4.31. Wind Direction-Pressure Gradient Relationships at Boone

winds between 250^{o} and 290^{o}, the SW to NE I-0 results in 200^{o}- 250^{o} winds, the S to N I-0 in generally 160^{o}- 220^{o} winds, and the SE to NW I-0 in 120^{o}- 200^{o} winds. However, the E to W I-0 is extremely erratic.

Large cross-isobaric flow is observed with I-0's of NE to SW, E to W and SE to NW at Boone. Such flow is usually indicative of increased surface friction which occurs when the air flow encounters local topographical influences. Consequently, the cross-isobaric flows of 50^{o}- 100^{o} (for the above-mentioned I-0's), occurring with even large pressure gradients show the effects of surface topography at Boone.

4.3.4 Montauk Point

Due to its coastal location in the Northeast United States, Montauk can have strong wind with any I-0. However, Figure 4.32 indicates that it generally takes a pressure gradient of >4 mb for all isobaric alignments to result in speeds of ≥7 m/s. In fact, this is an excellent forecasting rule as seen in Figure 4.33. Of the forecasts, 86% result in speeds of ≥7 m/s regardless of the I-0. With NW to SE and N to S I-0, 63.3% of the forecasts would result in wind speeds of ≥13 m/s with >7 mb pressure gradient (see Figure 4.34). The isobaric alignments associated with the stronger speeds are those from NW to SE and N to S. These alignments can have speeds approaching 20 m/s. The large pressure gradient range here is attributed to the rather frequent occurrence of strong storm systems in the Northeast.

As seen in Figure 4.35, Montauk has a very strong correlation between wind direction and I-0 due to the coastal topography. The two generally do not vary by more than 10^{o}- 30^{o} for any I-0. When the data were separated into 1200 and 0000 GMT there appears to be some speed differences for the SW to NE, W to E and SE to NW I-0. Otherwise, no significant speed differences are noted between early morning and late afternoon wind speed for a given pressure gradient.

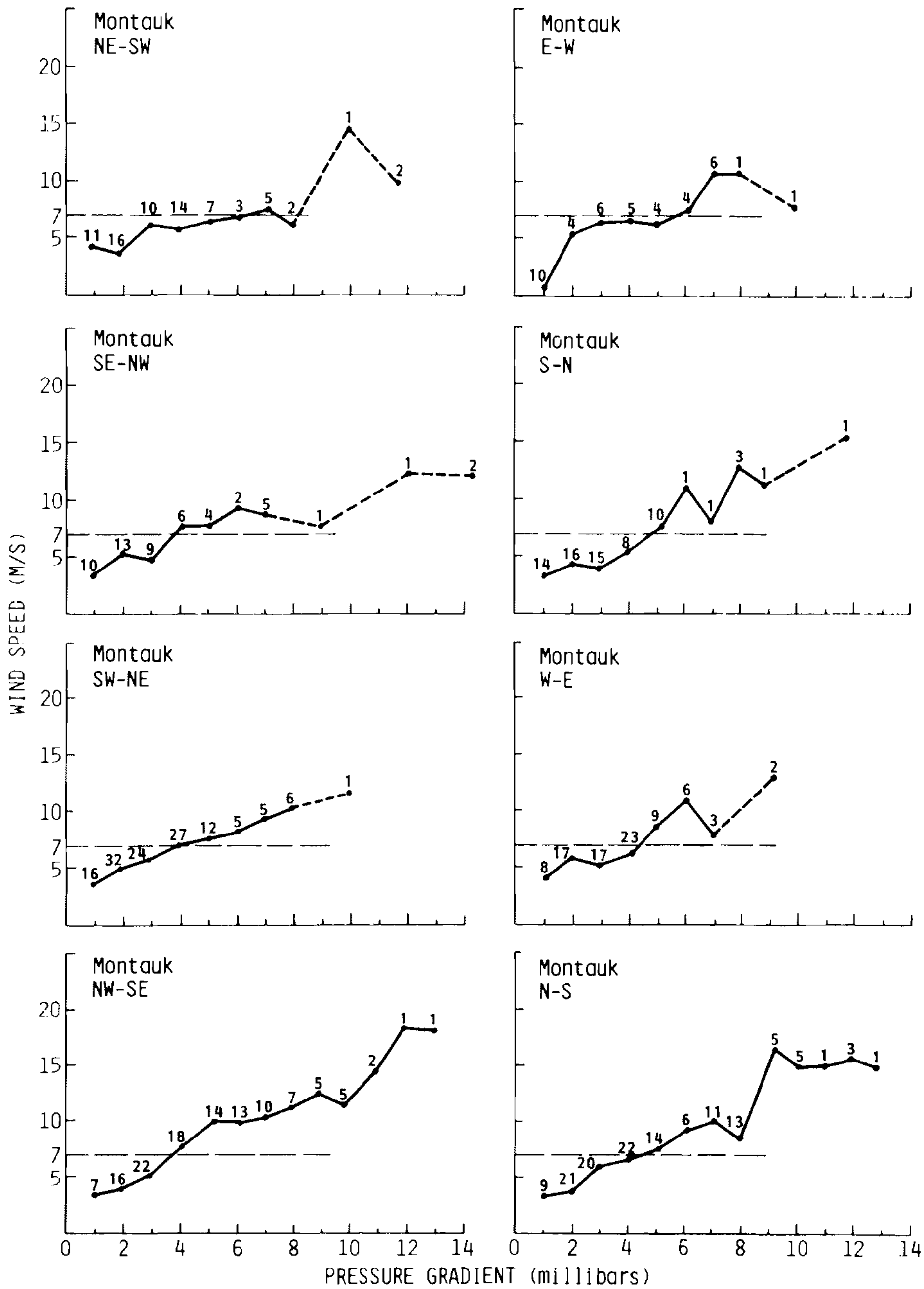


FIGURE 4.32. Wind Speed-Pressure Gradient Relationships at Montauk Point

Speed ≥7 M/S		>4 MB YES	>4 MB NO
	YES	202	138
	NO	33	327

FIGURE 4.33. Numerical Results of the Rule: A Pressure Gradient of >4 MB at Montauk Results in Speeds of ≥7 M/S

Speed ≥13 M/S		NW-SE, N-S I-O And >7 MB YES	NW-SE, N-S I-O And >7 MB NO
	YES	31	8
	NO	18	23

FIGURE 4.34. Numerical Results of the Rule: A NW to SE and N to S I-O with a Pressure Gradient of >7 MB at Montauk Results in Speeds of ≥13 M/S

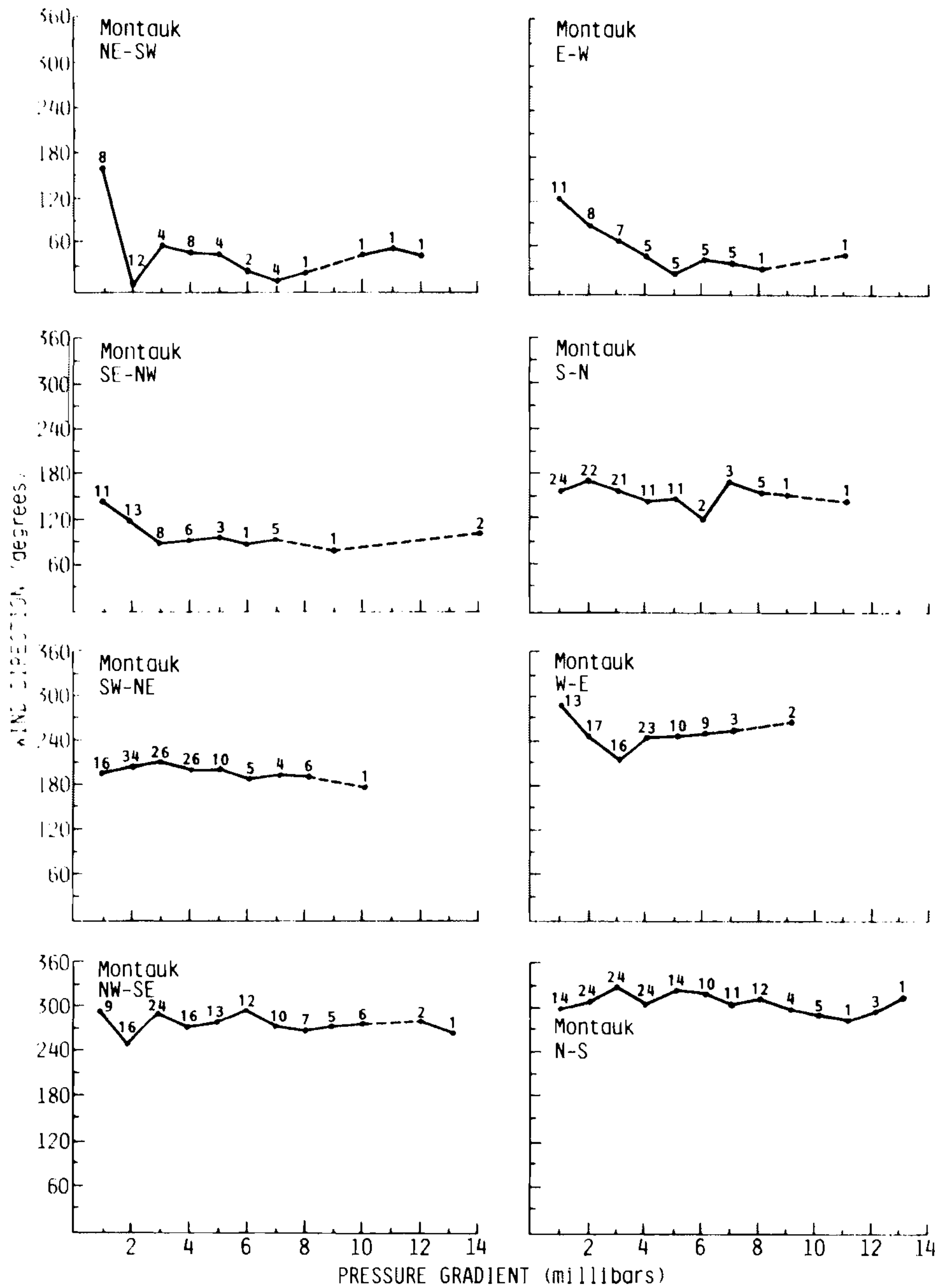


FIGURE 4.35. Wind Direction-Pressure Gradient Relationships at Montauk Point

4.4 APPLICATIONS

The method used in this study can be easily applied to forecast winds for any site. However, local topography would play a very important role in determining certain wind peculiarities. These can usually be isolated from synoptic scale features by recognition of wind events which are in contradiction to geostrophic relationships. A N to S I-O producing a consistent SW wind would be an example of such a contradiction caused by the local topographic features. Another example is the absence of strong wind speeds from certain directions, even with a strong pressure gradient.

The following steps should be taken prior to the initiation of operational forecasts for utilities using WTG:

1. Examine time-series of wind speed and direction for any recognizable wind regimes,

2. Determine what synoptic patterns are associated with these regimes. This step will result in a general idea of what is happening synoptically at the site and is necessary in order to arrive at the refined and detailed wind forecast. This step will also reveal any topographic influence.

3. Determine pressure gradient relationships similar to those described in the preceeding section. When used in conjunction with step 2, these relationships can give a close approximation of the expected wind events.

The following hypothetical example of an operational wind forecast for Boone is given to illustrate the forecasting procedure to be applied once the research is complete.

Suppose that a forecast is to be issued to the utility company at 8:00 A.M. (local time) and cover the period 9:00 A.M. today to 12:00 P.M. (noon) tomorrow. Also assume that the initial surface analysis (1200 GMT) shows a rather intense low that is centered over north-central Kentucky with a warm front extending eastward to Virginia and a cold front stretching south-south-westward into the Gulf of Mexico. The initial conditions for Boone include a SW to NE I-O with a pressure gradient of 7 mb across 335 km centered at Boone. Comparison of Figures 4.36-4.38, combined with the meteorologist's

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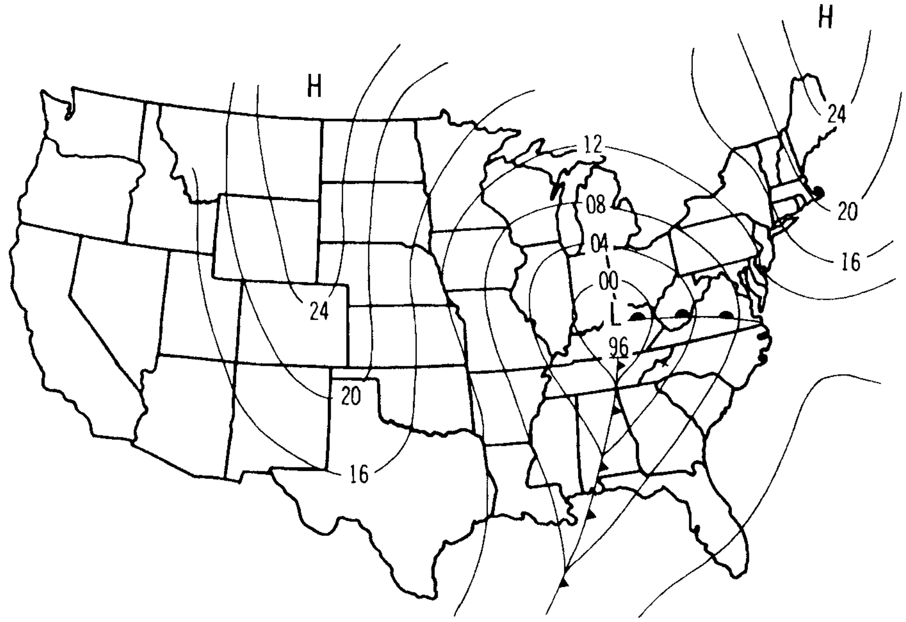

FIGURE 4.36. Initial Surface Analysis for a Hypothetical Case of Strong Wind at Boone

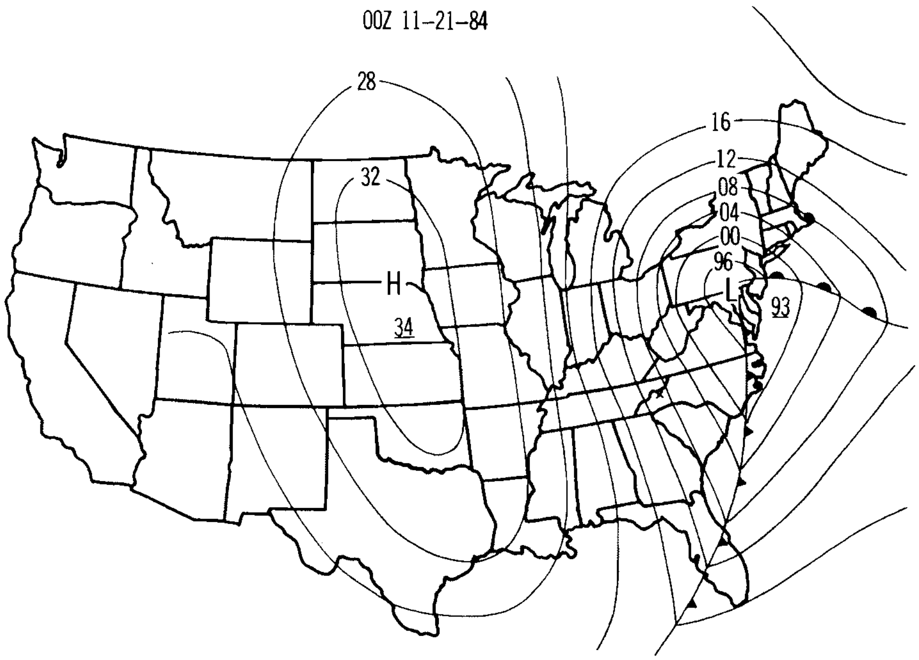

FIGURE 4.37. 12-Hour Surface Prognostication for the Strong Wind Hypothetical Case at Boone

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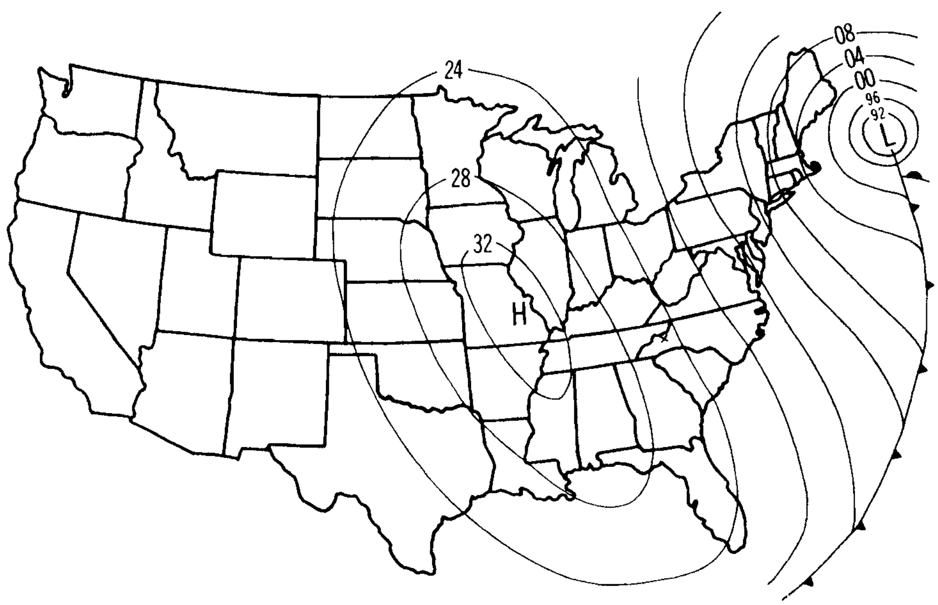

FIGURE 4.38. 24-Hour Surface Prognostication for the Strong Wind Hypothetical Case at Boone

expertise, suggests that the intensifying low will move rapidly ENE and that the associated cold front will pass Boone at about noon of the current day. From the figures it is also evident that the pressure gradient is expected to increase to about 9 mb during the afternoon and remain at about 9 or 10 mb until near midnight. A gradual decrease in pressure gradient starts at this time and the value reaches 5 mb by about 7:00 A.M. (Figure 4.38). A high pressure center is forecast just west of Boone by noon and the pressure gradient relaxes to 3 mb. The I-O during the forecast period goes from SW to NE to N to S following the frontal passage. This isobaric alignment gradually becomes more NW to SE after midnight. The NW to SE alignment persists through the end of the forecasting period.

With the above initial conditions and forecast surface features, one should be able to produce the wind forecast. Based on this synoptic pattern, Boone will obviously be associated initially with rather strong winds. The isobaric orientations and the pressure gradient are based on the surface systems forecast position and strength. If this general part of the forecast is erroneous, then the detailed wind forecast will also be in error.

Use of the pressure gradient, wind speed, and wind direction relationships determined in this study, will now give the detailed wind forecast for Boone. From Figure 4.31, the wind direction with 7 mb pressure gradient and a SW to NE I-O is about 200^{0}. Figure 4.28 gives a speed of about 12 m/s for the appropriate I-O and pressure gradient. This speed and direction should hold until noon, at which time conditions will change abruptly due to the frontal passage. Starting around noon, Figures 4.31 and 4.28 predict a wind direction of 320^{0} and speed of about 18 m/s, respectively. This will hold well into the evening. In fact, speeds could exceed 20 m/s at times since this synoptic type is associated with the strongest speeds at Boone. As the pressure gradient gradually relaxes after midnight, wind speeds will also decrease slightly. One must also consider that the I-O becomes NW to SE after midnight. Looking at the appropriate section of the figures, will now give a wind direction of about 290^{0} and speed that gradually decreases to about 12 m/s by 1200 GMT. The pressure gradient continues to relax to only 3 mb, but the graph still suggests rather strong speeds of 10-12 m/s from about 290^0 by noon. Table 4.10 shows this sample forecast on an hourly basis. Naturally, the most reliable portion of the forecast will be the first 6 to 12 hours with skill slowly decreasing with time. A careful hour-by-hour monitoring of the conditions is essential for any subtle or abrupt changes.

The method of learning how to forecast wind described in this paper is particularly useful for sites having no nearby National Weather Service observation station to provide the hour-by-hour feedback of data.

TABLE 4.10. Sample Wind Forecast for Boone

Time Issued: 8:00 A.M.
Date: 11-20-1984

Local Time	Wind Direction (Degrees)	Wind Speed M/S
9:00 AM	200	12
10:00 AM	200	12
11:00 AM	210	8
12:00 PM	300	16
1:00 PM	320	18
2:00 PM	320	18
3:00 PM	320	19
4:00 PM	320	19
5:00 PM	320	20
6:00 PM	320	20
7:00 PM	320	19
8:00 PM	320	19
9:00 PM	320	19
10:00 PM	320	18
11:00 PM	310	18
12:00 AM	310	17
1:00 AM	300	17
2:00 AM	290	16
3:00 AM	290	16
4:00 AM	290	15
5:00 AM	290	15
6:00 AM	290	14
7:00 AM	290	12
8:00 AM	290	12
9:00 AM	290	12
10:00 AM	290	12
11:00 AM	290	11
12:00 PM	290	11

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5.0 LEARNING TO FORECAST WIND AT REMOTE SITES FOR WIND ENERGY APPLICATIONS: THE USE OF METEOROLOGICAL/SYNOPTIC AND STATISTICAL ANALYSES

5.1 INTRODUCTION

The Murray and Trettel (M/T) approach to wind forecasting was divided into two concepts: statistical and meteorological/synoptic. In each concept the general approach, the procedures used and the reasons for choosing that approach are described. Examples are included in the text. In Appendix C there are numerous other examples of similar cases but with minor and subtle differences that are important to a forecaster.

The project was to accomplish the four objectives enumerated in Section 1. However, it was not limited to these objectives. The site wind data were analyzed based upon M/T experience in working with utility company management in planning decisions and load dispatchers' day-by-day, hour-by-hour operational decisions. The statistical summaries presented will answer such operational questions as in which months can power from wind turbines be expected; how much power, how many days in those months, how many hours in those days? Similar questions could be answered by this type of approach. Although this was not specified as part of this contract M/T felt it would be basic, useful information for an electric utility.

The second concept approached the objectives of this project in a more direct manner, namely, the viewpoint of a forecaster. An attempt was made to make any forecasting rules as objective as practical. The result was to develop semi-objective techniques that could readily be used even by a nonmeteorologist and then use the skill of the professional meteorologist to increase the forecast effectiveness. The semi-objective techniques were based upon a set of existing conditions. This approach implicitly assumes there is no significant change in those conditions that will affect the forecast for the next 12 to 24 hours. As all meteorologists know, this is simply a first step and in many cases will not give a satisfactory forecast particularly when systems are moving and/or changing intensity rapidly.

This is where the skill of the forecaster comes into play. In addition, if the forecaster can construct a prognostic chart and then use the semi-objective techniques once again as a second approximation, this approach could be used a number of times throughout the forecast period.

The results are expressed in a series of tables and figures. The figures include synoptic maps and verification matrices of forecasting rules. Time is expressed in Greenwich Mean Time (GMT) unless otherwise indicated. These two approaches combined (statistical and meteorological/synoptic) will be of maximum use to both the electric utility and the meteorologist.

5.2 GENERAL PROCEDURE

Although there was necessarily some variation in the data stratification procedures due to the location and topography of the four (4) sites, a general procedure was used at all the sites.

5.2.1 Data Stratification - Statistical

The data were tabulated from the computer printout furnished by PNL (Section 1) according to wind speed, duration of certain wind speeds (7 and 10 m/s), maximum speed for the day along with its direction and time of occurrence. The bulk of this report deals with a threshold wind speed equal to or greater than 7 m/s; a small part deals with wind speeds equal to or greater than 10 m/s.

The data were stratified based on the following reasoning. The critical wind speed chosen was 7 m/s (14 kts). This is just above the 6.26 m/s that activates the MOD-2 generator. The number of days for each month that had at least one hourly wind speed equal to or greater than 7 m/s was logged. The number of consecutive hours of speeds equal to or greater than 7 m/s was also logged. The logged data were further stratified into four types:

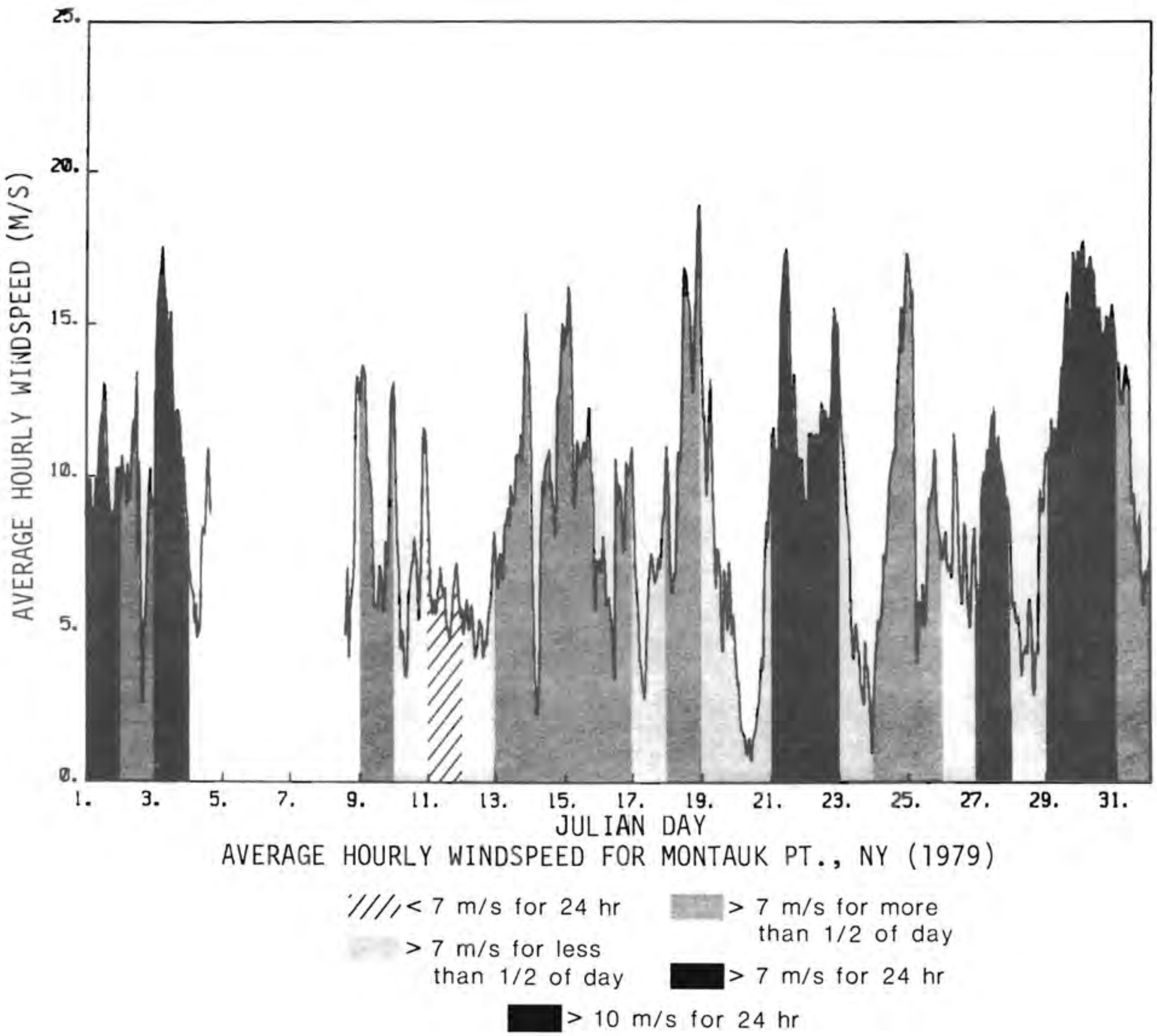


FIGURE 5.1. Average Hourly Wind Speed for Montauk Point for Julian Days 1 to 31

Type 0 (zero): no hourly reports equal to or greater than 7 m/s.

Type 1: 1 to 2 consecutive hours of wind speeds equal to or greater than 7 m/s.

Type 2: 3 to 7 consecutive hours of wind speeds equal to or greater than 7 m/s.

Type 3: 8 or more consecutive hours of wind speeds equal to or greater than 7 m/s.

The rationale for this breakdown was based upon M/T experience in working with electric load dispatchers since 1959. Type 0 would indicate that no generation could be expected; Type 1 would produce a limited amount of generation; Type 2 would produce a more significant amount; Type 3 would produce a sustained period of generation.

5.2.2 Data Stratification - Meteorological/Synoptic

The time-series plots of hourly average wind speed and direction and tabulated wind data were examined and classified into five (5) types A, B, C, D and E. An example for the period Julian Days 1 to 31 for Montauk Point, New York (MTP) is shown in Figure 5.1. There is some similarity and duplication with types 0, 1, 2 and 3 described above. However, the alphabetical types were based on synoptic maps used in normal forecasting procedures. Again 7 m/s was used as the critical wind speed.

Type A: no wind speeds equal to or greater than 7 m/s observed during the 24-hour period midnight to midnight local standard time (same as Type 0).

Type B: less than 12 hours equal to or greater than 7 m/s.

Type C: 12 to 23 hours equal to or greater than 7 m/s.

Type D: equal to or greater than 24 hours equal to or greater than 7 m/s.

Type E: equal to or greater than 24 hours equal to or greater than 10 m/s.

A listing of the dates of occurrence of each type for Ludington, Michigan (LDM), Montauk Point, New York (MTP), Amarillo, Texas (AMA) and San Gorgonio, California (SAG) is contained in Appendix B.

5.2.3 Booz-Allen (B-A) Classification

Each day of the year the B-A classification scheme was used to describe the 1200 GMT surface and 500-mb synoptic charts. A copy of these classifications is found in Appendix A (Hallanger et al. 1968).

The B-A scheme was viewed as only a preliminary step. The advantage of the B-A classification is that it gives a quick and easy description of a synoptic map. However, it has the disadvantage that pressure gradients are not directly specified. Pressure gradients are important in forecasting wind speeds. In addition, the classification is subject to the interpretation of the individual meteorologist. For example B-A Surface Type 24 is pretrough, Type 29 is postridge; the distinction between the two is often arbitrary.

The B-A index was tabulated for each day rather than just certain selected situations. There were two reasons for this: 1) there was interest not only in the occurrence of strong winds but also periods of persistent, light winds when wind turbine operations would be at a minimum, and 2) it was more efficient to accomplish the entire tabulation at one time. This tabulation was accomplished using the Daily Weather Map Weekly Series for all four sites.

5.2.4 850-mb Wind Data

The 850-mb wind speeds and directions were tabulated for 1200 GMT for each day. There was some disadvantage in using 850-mb data because of the difference in elevation of the four sites. However, the 850-mb data and other selected levels (UW/US North America-TTAA) come in on the 604 teletype circuit earlier (1255 GMT) than the complete sounding. Furthermore, using this selected-level data would enable the meteorologist to make his forecast without waiting for the complete 850-mb chart on the DIFAX circuit (1433 GMT). This is a difference of almost two hours, and is a significant time period in load forecasting.

The radiosonde stations used were Amarillo, Texas (363) for AMA; Green Bay, Wisconsin (645) for LDM; New York, New York (486) for MTP; and Vandenberg AFB, California (393) and Las Vegas, Nevada (387) for SAG.

5.2.5 Second Standard Level Wind Data

As the data logging progressed and some preliminary analyses were begun, the difference in elevation of the various sites led to the conclusion that the wind data at the second standard level (approximately 2000 ft above the ground) should be examined. This would overcome the disadvantage of the elevation differences mentioned above. But it should also be noted that this information is not available until 1356 GMT is identified as UJ1 PPBB on the 604 line (high speed teletype circuit) and even later on the DIFAX circuit (1549 GMT).

Because of the greater degree of usefulness found with the 850-mb data, the second standard level wind data were not analyzed in detail and are not a part of this report.

5.2.6 Pressure Gradient Analysis

The pressure gradients were measured across the selected sites in two ways. In the first method, the pressure difference between two representative stations was logged. For example in the case of San Gorgonio, the pressure difference between Los Angeles (LAX) and Las Vegas (LAS) was used. This worked very well, particularly for the summer months, because the changes in the pressure patterns were minor. However, it became apparent that although this method worked well for San Gorgonio, it did not work well for Montauk Point. In the second method, using the synoptic surface maps, the pressure gradient across the site was measured for a distance of 150 nautical miles (75 miles on either side). The orientation of the isobars was also logged. It was felt that the isobaric orientation (IO) direction would be important due to local effects.

For clarification the following description is given. If the isobars were oriented in a northeast, southwest line and the general airflow was from the NE toward the SW, the IO was labeled NE-SW. However, if the IO was as just described and the airflow was from the SW toward the NE, the IO was labelled SW-NE. The same type of reasoning was used for other directions of IO. For example, a general wind flow from west to east would be W-E IO. This method worked well for MTP and LDM but did not work well for AMA.

In addition to the above information, the pressure gradient in millibars per 150 nautical miles was measured on the 1200 GMT surface map. The average site wind speed for each pressure gradient category was calculated for all directions. This was further divided into each of four quadrants.

5.2.7 Conclusions

Preliminary conclusions when appropriate are given along with the discussion in the text and at the end of each section; further conclusions are presented at the end of each site. Final conclusions are given at the end of the presentation of all the data for all four sites.

5.3 SITE 1: MONTAUK POINT, NY (MTP)

5.3.1 Data Stratification - Statistical

The hourly wind data furnished by PNL were analyzed. Particular emphasis was placed upon a speed threshold of 7 m/s because of its impact relative to the MOD-2 wind turbine start up speed. The data were stratified and summarized by months for 1) the number and percentage of hours the wind speeds were equal to or greater than 7 m/s, (A) and 2) the number and percentage of the type of windpower day, (B). These data are tabulated in Table 5.1.

TABLE 5.1. Stratification of Wind Speeds at MTP Types 0, 1, 2 and 3

	(A)				(B)									
					Days									
	Hours Avail	Winds Poss	>7 mps Actual		Avail	Type 0		Type 1		Type 2		Type 3		
Mon	Obs	Obs	Obs	%	Obs	No	%	No	%	No	%	No	%	
Jan	652	744	442	68	28	0	0	3	11	2	7	23	82	
Feb	672	672	437	65	28	2	7	0	0	5	18	21	75	
Mar	744	744	277	37	31	6	19	6	19	5	16	14	45	
Apr	720	720	293	41	30	5	17	4	13	6	20	15	50	
May	744	744	299	40	31	3	10	4	13	7	23	17	55	
Jun	720	720	174	24	30	15	50	2	7	6	20	7	23	
Jul	427	744	77	18	19	10	53	3	16	2	11	4	21	
Aug	744	744	154	21	24	8	33	6	25	2	8	8	33	
Sep	720	720	188	26	30	10	33	4	13	7	23	9	30	
Oct	744	744	311	42	31	4	13	5	16	3	10	19	61	
Nov	720	720	328	46	30	7	23	3	10	3	10	17	57	
Dec	744	744	456	61	31	3	10	2	6	3	10	23	74	
TOT	8351	8760	3436	41	343	73	21	42	12	51	15	177	52	

In 1979 there was a total of 3,436 hours of winds speeds equal to or greater than 7 m/s. This represents 41% of the available hours. The percentages ranged from a maximum of 68% in January to a minimum of 18% in July. It was not surprising that the cold weather season (Dec-Feb) showed the highest values (averages of 65%) with the lowest values (average 22%) in the warm months (June-September).

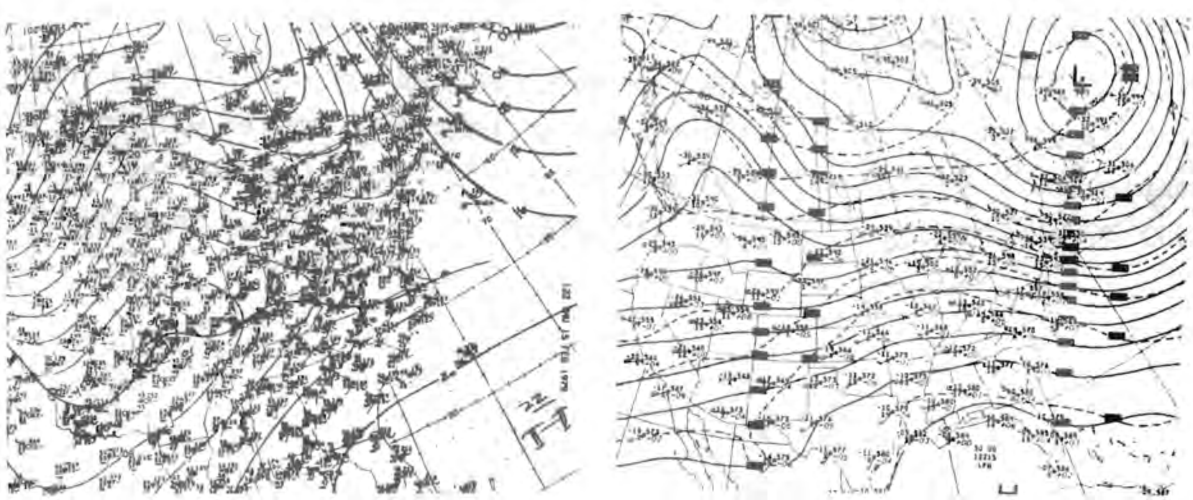
Although the total hours of wind speeds strong enough to activate a MOD-2 generator were of interest it was felt that the number of consecutive hours of speeds equal to or greater than 7 m/s would be more significant. The data were therefore further stratified into Type 0, 1, 2 and 3 'days' as described above. The Type 3 days (speeds equal to or greater than 7 m/s for 8 or more consecutive hours) were of particular interest. The values ranged from an average high of 22 days (77%) in the period December through February to an average low of 7 days (27%) in the four month period June through September.

This leads to the conclusion that wind speeds at MTP were strong enough to activate a MOD-2 generator an average of 52% of the days in 1979 with values ranging from 82% in January to 21% in July. Wind power could have a significant impact on the cold weather heating load but minimal impact on the summer air conditioning requirements.

5.3.2 Booz-Allen (B-A) Classification

The B-A classification was poorly correlated with the wind types and was not considered a highly useful tool in this application except in a general way. As discussed earlier this was not too surprising due to the lack of direct consideration of pressure gradients.

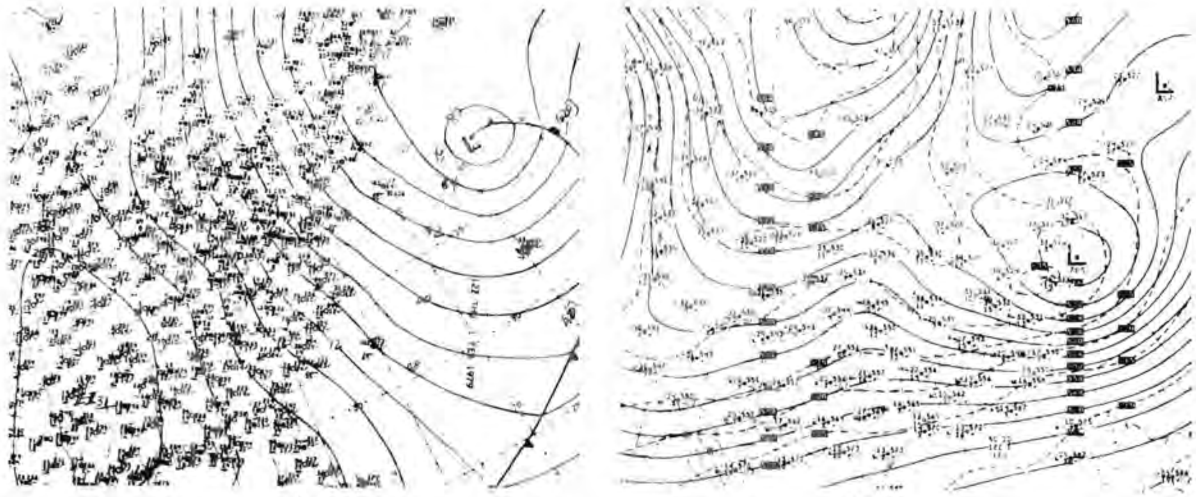
A Type 1 day (light winds) occurred on February 15 and is shown in Figure 5.2. Note the weak gradient in part A of the figure due to the ridge of high pressure (B-A type = 33, post-inverted ridge). The 500-mb chart shows strong NW flow (B-A type = 14, preridge). These maps are good examples of the need for judgment by the forecaster. The B-A surface type could have been 33, 34 or 35; the 500-mb could have been 10 or 14.



(A) (B)

FIGURE 5.2. Example of a Type 1 Day (Light Winds) at MTP at 1200 GMT on February 15, 1979. (A)Surface Map (B)500-mb

A Type 3 (strong winds) occurred on February 1 and is shown in Figure 5.3. The surface B-A type was 3, (deep-closed low postfrontal); the 500-mb B-A type was 4 (deep-closed low posttrough).



(A) (B)

FIGURE 5.3. Example of a Type 3 Day (Strong Winds) at MTP at 1200 GMT on February 1, 1979. (A) Surface Map (B) 500-mb

5.3.3 850-mb Wind Data

The 850-mb wind data at New York were compared with the PNL data from MTP. In particular the 850-mb speed was analyzed and compared with the maximum hourly wind speed in the twelve hours following the 1200 GMT and 0000 GMT observations. These data are presented in Tables 5.2 through 5.4.

TABLE 5.2. Maximum Hourly Wind Speed at Montauk Point As a Percentage of 850-mb Wind Speed at New York

Month	Monthly Average	Distribution By Direction							
		S	SW	W	NW	N	NE	E	SE
Jan	101	58	87	106	135	101	--	--	--
Feb	87	90	--	68	96	69	--	--	90
Mar	90	43	93	129	104	83	64	--	68
Apr	89	74	104	92	86	70	--	--	--
May	107	107	104	108	120	--	100	133	100
Jun	123	113	170	127	77	110	--	--	--
Jul	102	--	71	130	93	240	--	--	--
Aug	93	--	83	95	92	111	--	108	--
Sep	114	109	130	103	125	109	--	180	140
Oct	108	82	120	100	200	160	--	--	--
Nov	105	--	61	92	128	84	--	350	--
Dec	97	88	63	67	106	155	--	--	--
Avg.	101	85	99	101	114	117	82	193	100

The maximum hourly wind speed at MTP for 1979 was 101% of the average 850-mb speed for the year. The values ranged from 123% in June to 87% in February. The distribtuion of the comparison by months and direction was also tabulated. However, these values should be viewed only as guides because of the size of this sample. It appears that the largest difference between the observed maximum hourly wind speed and the 850-mb speed occurs with a NW and N wind. East was discounted because of the small sample and the unusually high single value in November.

The 850-mb wind speed was also compared to the type of day (0, 1, 2 and 3). These data are presented in Table 5.3. When the 850-mb wind speed was equal to or greather than 20 kts, a Type 3 day occurred 72% of the time; equal to or greater than 25 kts, 79%; equal to or greater than 30 kts, 79 percent.

TABLE 5.3 Montauk Point 850-mb Wind Speed versus Surface Wind Type All Directions

Type		850-mb Wind Speed - Kts 1200 GMT 5	10	15	20	25	30	35	40	Total
0	No. of Occurrences	8	18	14	1	2	1		1	45
	% of Occurrences*	53	45	32	3	4	4		4	
1	No. of Occurrences	2	7	4	4	1		1		19
	% of Occurrences	13	18	9	12	2		9		
2	No. of Occurrences	3	9	10	14	9	4	2	1	52
	% of Occurrences	20	23	23	41	20	17	18	4	
3	No. of Occurrences	2	6	16	15	34	18	8	22	121
	% of Occurrences	13	15	36	44	74	78	73	92	
Total No. of Occurrences		15	40	44	34	46	23	11	24	237

* % of Occurrences refers to the columns rather than rows.

The data for 850-mb wind speeds equal to or greater than 20 kts is also shown in a 2 x 2 matrix in Figure 5.4.

The 1200 GMT 850-mb wind speed was compared with the consecutive hours of speeds equal to or greater than 7 m/s and the peak hourly wind for the next 24 hours. There was a wide scatter of the data but a general trend was evident. The wide scatter did not lend itself to a specific forecast, but in general, as the 1200 GMT 850-mb wind speed increased so did the peak wind and the number of consecutive hours of surface wind speeds equal to or greater than 7 m/s.

The conclusion is that the 850-mb wind speed at 1200 GMT or 0000 GMT is a good first approximation of the maximum hourly wind in the succeeding 12 hours.

5.3.4 Pressure Gradient Analysis

The pressure gradients on the surface maps were measured daily at 1200 GMT in mb per 150 nautical miles (nm). The pressure difference and the IO were logged and compared with the wind type (0, 1, 2 or 3). There were 327 cases (instead of 365) in this analysis due to missing data.

MTP Pressure Gradient vs. Type 3 Days

Pressure gradient ≥3-mb	Yes	No
Yes	140	31
No	47	113

$$\text{Yes-Yes} = \frac{140}{187} = 75\%$$

$$\text{No-No} = \frac{113}{144} = 78\%$$

MTP 850-mb Wind Speed vs. Type 3 Days

Speed ≥20 kts	Yes	No
Yes	107	28
No	41	75

$$\text{Yes-Yes} = \frac{107}{148} = 72\%$$

$$\text{No-No} = \frac{75}{103} = 73\%$$

FIGURE 5.4. Verification Matrices for Type 3 Days at MTP Using Pressure Gradients

Table 5.4 shows the number of occurrences for each pressure difference and the percentage of the total for each type of day.

TABLE 5.4. Montauk Point Pressure Gradient Versus Surface Wind Type All Directions

Type		Pressure Gradient-mb/150 nm						
		1	2	3	4	5	6	TOTAL
0	No. of Occurrences	22	28	9	4	1	1	65
	% of Occurrences	38	34	13	9	3	2	
1	No. of Occurrences	10	8	2	3			23
	% of Occurrences	17	10	3	7			
2	No. of Occurrences	22	19	13	7	5	2	68
	% of Occurrences	38	23	19	16	17	4	
3	No. of Occurrences	4	27	42	30	23	45	171
	% of Occurrences	6	33	63	68	79	94	
	Totals	58	82	66	44	29	48	327

The table shows that when the pressure gradient is equal to or greater than 3 mb, a Type 3 day occurred 75% of the time. This percent is calculated as follows: (42 + 30 + 23 + 45 = 140), the number of Type 3 days divided by (15 + 5 + 27 + 140 = 187), the number of occurrences equal to or greater than 3 mb. This gives 140 divided by 187 or 75 percent. A more detailed analysis, by quadrants, is presented for LDM in Table 5.6.

These data are also presented in a 2 x 2 matrix in Figure 5.4 along with the 850-mb matrix described in Section 5.2.3.

The pressure gradient was measured at 1200 GMT each day and compared with the surface wind speed at 1200 GMT. An average wind speed was computed for each pressure gradient category. This computation was subdivided into octants. The results are shown graphically in Figure 4.32.

5.3.5 Data Stratification - Meteorological/Synoptic

Using both the time series wind plots and the tabulated data, hourly wind speeds for each day were classified as Types A through E. These data are shown in Table 5.5 which gives the frequency of occurrence of each type by month. (Note that the stratification in Table 5.1 refers to the tabulated hourly wind data furnished by PNL; the stratification in Table 5.5 refers to synoptic weather patterns.)

TABLE 5.5. Stratification of Synoptic Types A, B, C, D and E at MTP

Mon	Avail Days	Poss Days	Type A No.	Type A %	Type B No.	Type B %	Type C No.	Type C %	Type D No.	Type D %	Type E No.	Type E %	Msg
Jan	27	31	2	7	8	30	10	37	3	11	4	15	4
Feb	28	28	2	7	11	39	7	25	2	7	6	21	0
Mar	31	31	6	19	14	45	7	23	4	13	0	0	0
Apr	30	30	5	16	11	37	11	37	3	10	0	0	0
May	31	31	6	19	16	52	7	23	2	7	0	0	0
Jun	30	30	16	53	12	40	2	7	0	0	0	0	0
Jul	19	31	11	58	7	37	1	5	0	0	0	0	12
Aug	23	31	7	30	11	48	4	17	1	4	0	0	8
Sep	30	30	13	43	13	43	3	10	1	3	0	0	0
Oct	30	31	4	13	14	47	7	23	5	17	0	0	1
Nov	30	30	8	27	11	37	9	30	2	7	0	0	0
Dec	31	31	6	19	8	27	8	26	7	23	2	6	0
TOT	340	365	86	25	136	40	76	22	30	9	12	4	25

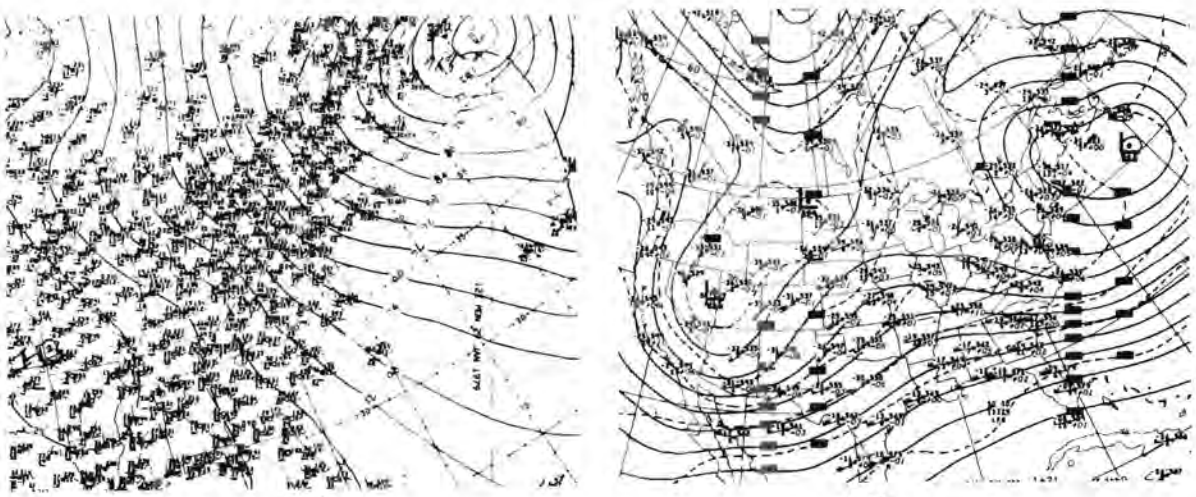
These types are not listed alphabetically in the following text but in a sequence which shows the development of the reasoning associated with each type.

Types A and E showed definite synoptic patterns. Type D was less definite and more variable but still easily recognizable. Types B and C were associated with many different and varied synoptic situations which made any classification unwieldy. This is not surprising since MTP is affected by many and varied weather patterns.

Type A (no hourly winds equal to or greater than 7 m/s) was generally associated with the weak pressure gradients of less than 3 mb. The synoptic situations were weak ridges or centers of high pressure systems located over or near MTP. At times a weak warm front to the south was noted.

5.3.5.1 Type E

All cases of Type E (wind speed equal to or greater than 10 m/s for a period equal to or greater than 24 hr) occurred with a deep stagnant low off the northeast coast and a typical deep 500-mb vortex. Because of the two factors of strong gradient and slow movement, a Type 3 situation persisted for a number of days. Such a Type 3 occurred in the period from January 29 through February 5. Maps for January 29 are shown in Figure 5.5. Note the vertical "stacking" of the surface and 500-mb lows and the tight pressure gradient. Further examples are included in Appendix C.



(A) (B)

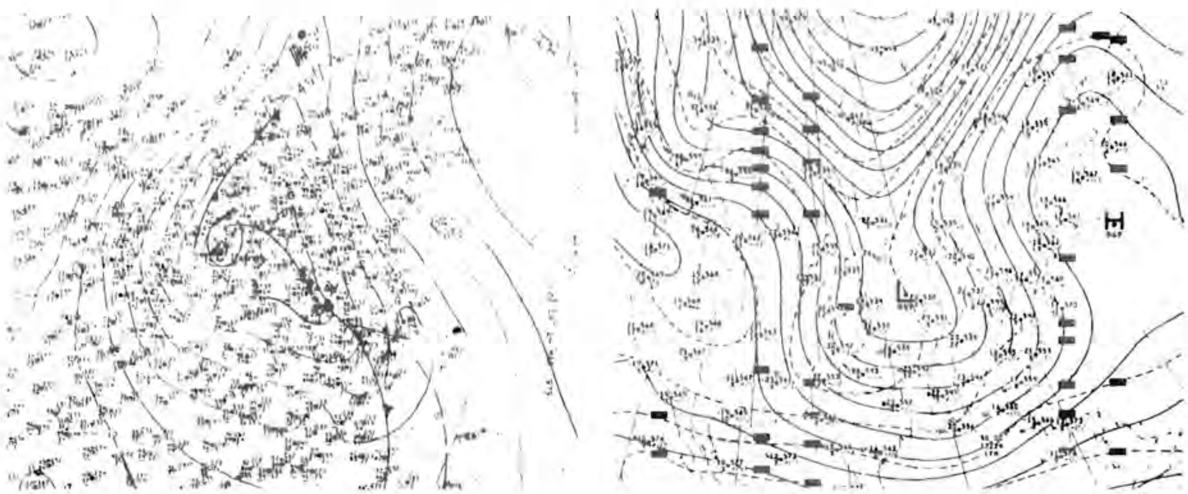
FIGURE 5.5. Example of a Type E Day at MTP at 1200 GMT on January 29, 1979. (A)Surface Map (B)500-mb

5.3.5.2 Type D

Type D (wind speeds equal to or greater than 7 m/s for a period equal to or greater than 24 hr) was similar to Type E in some respects but had a variety of synoptic patterns and was generally associated with a strong, moving system. The duration of the Type 3 situation was less - on the order of one to three days. However, both Type D and E could be counted on to produce Type 3 days with a high probability of an extended period of wind power generation.

Type D was further subdivided and is illustrated by examples.

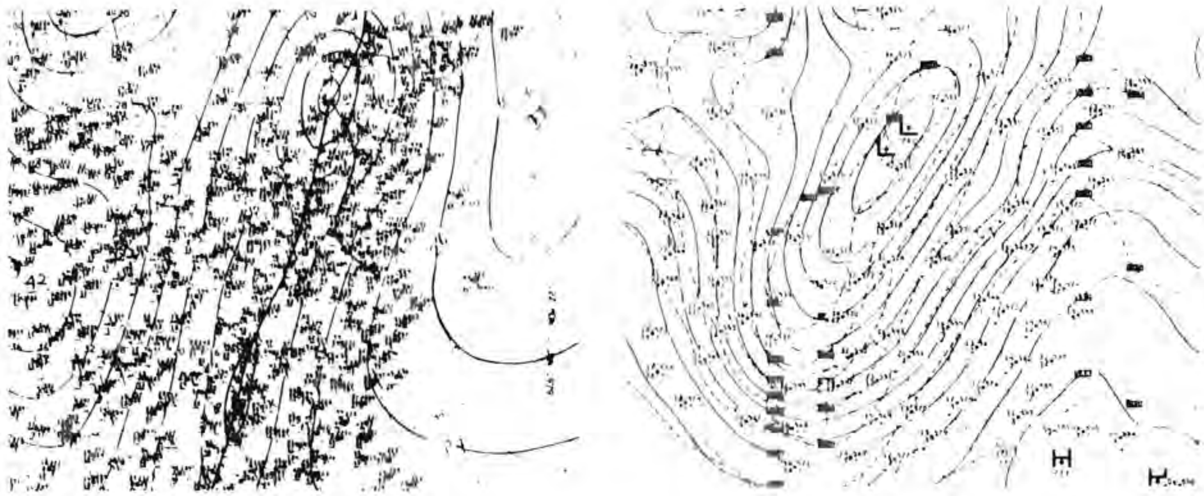
D1a. Pre-cold front with a low to the west, moving N or NE, and a southerly (S-N) orientation of isobars over MTP. An example is shown in Figure 5.6. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.6. Example of a Type D1a Day at MTP at 1200 GMT on March 24, 1979. (A) Surface Map (B) 500-mb

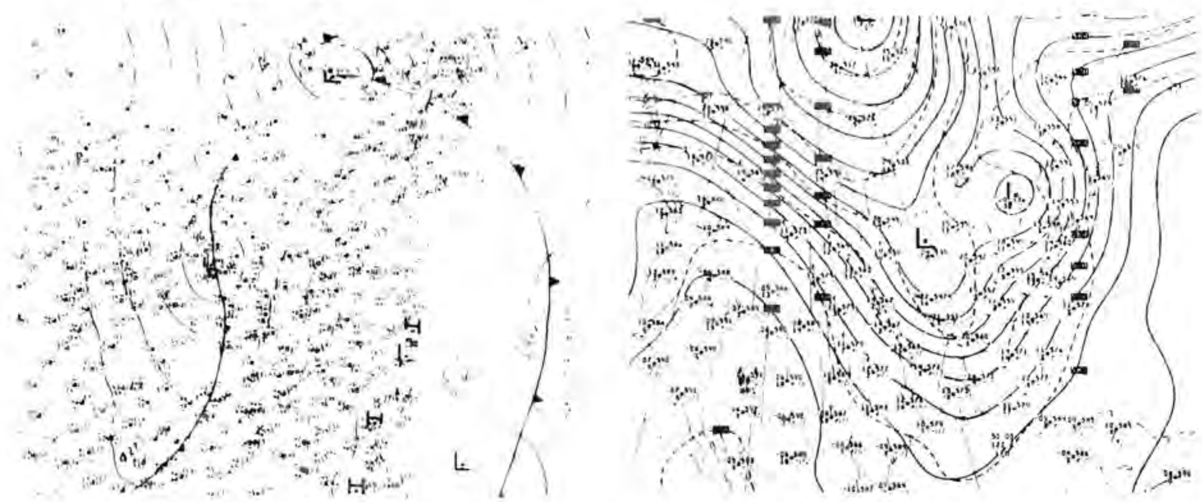
D1b. Pre-cold front, with a low in southeastern Canada moving NE and a southwesterly (SW-NE) orientation of isobars over MTP. An example is shown in Figure 5.7. An additional example is shown in Appendix C.



(A) (B)

FIGURE 5.7. Example of a Type Dlb Day at MTP at 1200 GMT on January 1, 1979. (A)Surface Map (B)500-mb

Dlc. Pre-cold front with a low in southeastern Canada moving N or NE and a westerly orientation of isobars (W-E) across MTP. An example is shown in Figure 5.8 dated October 6. An additional example is shown in Appendix C.

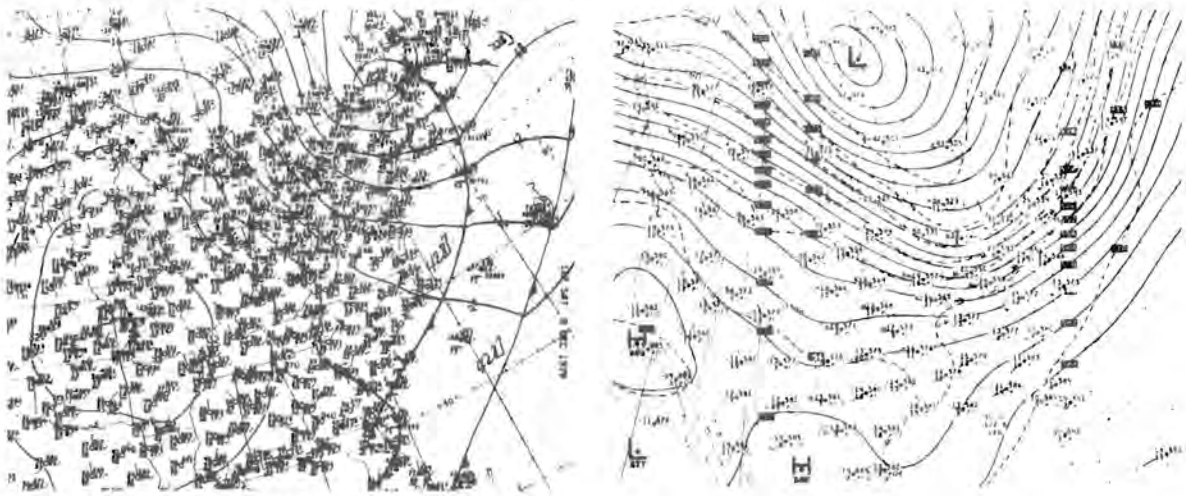


(A) (B)

FIGURE 5.8. Example of Type Dlc Day at MTP at 1200 GMT on October 6, 1979. (A)Surface Map (B)500-mb

Note the primary difference in the various Type Dl's is the direction of the orientation of the isobars over MTP (S-N, SW-NE, W-E).

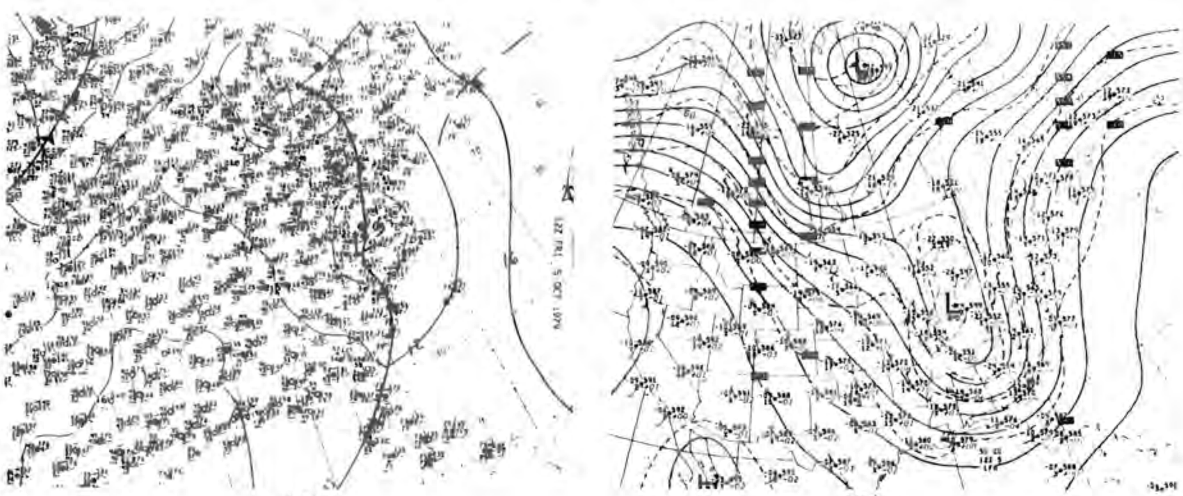
D2. Post-cold front with a deep low to the NE. An example is shown in Figure 5.9. Note that Type D2 is very similar to Type E. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.9. Example of a Type D2 Day at MTP at 1200 GMT on December 8, 1979. (A)Surface Map (B)500-mb

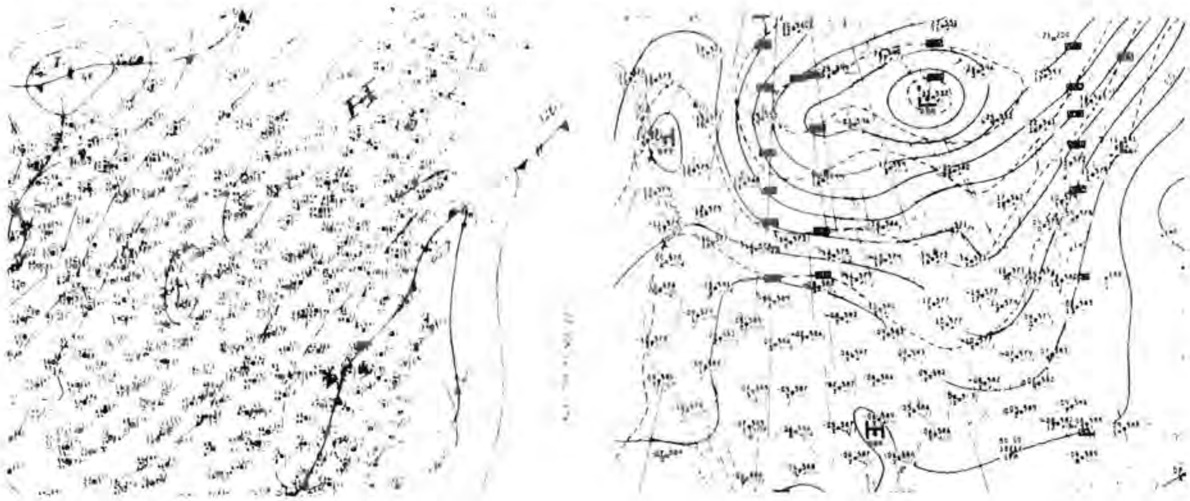
D3. Low over Virginia moving NE and deepening. An example is shown in Figure 5.10. An additional example is shown in Appendix C.



(A) (B)

FIGURE 5.10. Example of a Type D3 Day at MTP at 1200 GMT on October 5, 1979. (A)Surface Map (B)500-mb

D4. Inverted ridge to the north and east of MTP extending southward over Ohio or Michigan with a developing low over the Carolinas or off the Carolina coast. An example is shown in Figure 5.11. Additional examples are shown in Appendix C.



(A) (B)

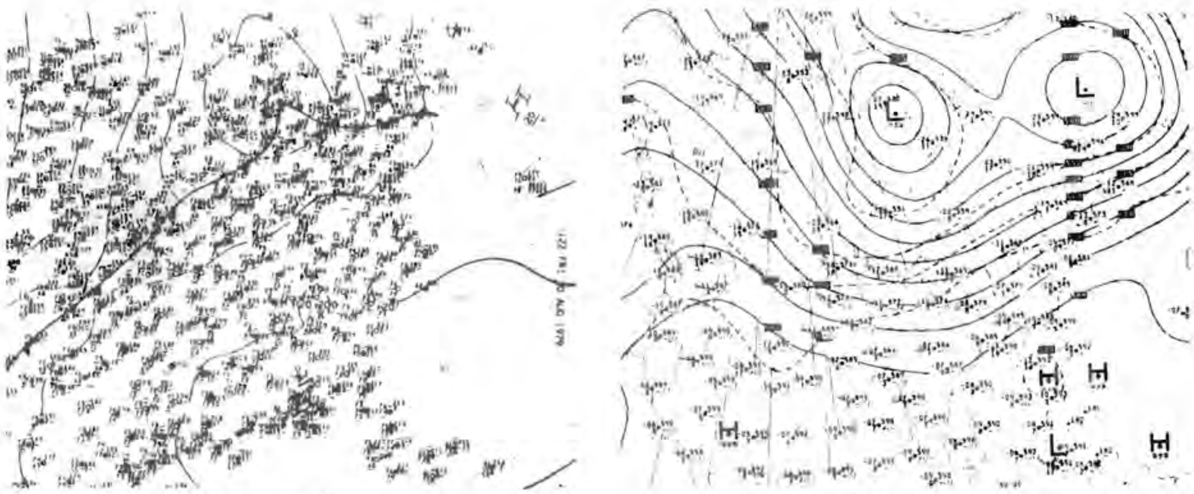
FIGURE 5.11. Example of a Type D4 Day at MTP at 1200 GMT on August 12, 1979. (A)Surface Map (B)500-mb

5.3.5.3 Type B

As discussed above, Types B and C were associated with many different synoptic situations. A list of all the Type B and C days is presented in Appendix B. Various Type B synoptic situations are given below.

Type B could be classified as pre-cold front, post-cold front, etc. as in Type D. The primary difference between Types B and C and D was the strength of the pressure gradient. This simply emphasizes the importance of that parameter.

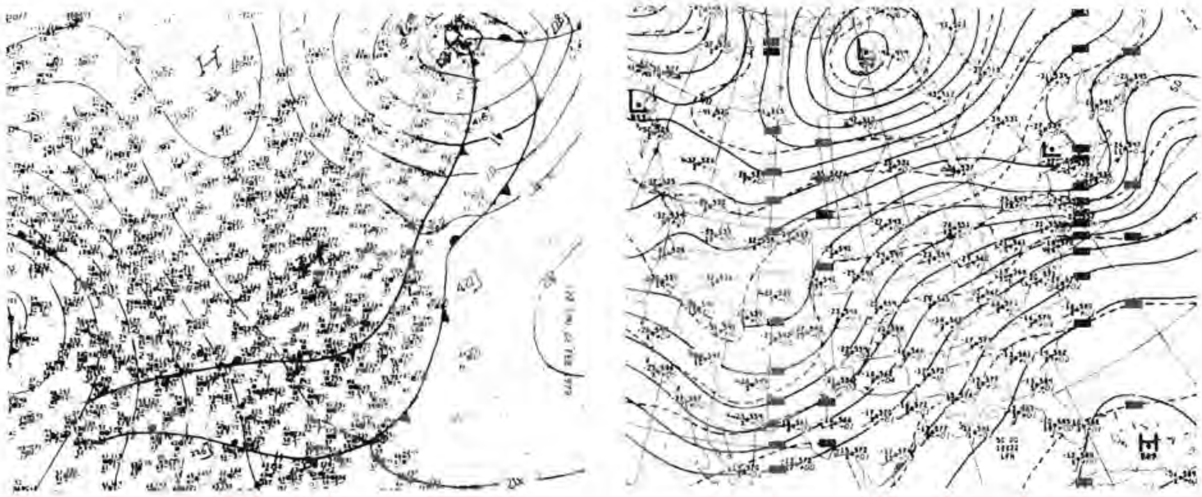
An example of a Type B situation is shown in Figure 5.12. This is a pre-cold front situation with a SW-NE orientation of isobars. The pressure gradient was less than 2 mb but with the low moving toward MTP, the gradient was increasing and was enough to give a Type B day (less than 12 hours of 7 m/s). Note the 500-mb low is far to the north of the surface low and is not stacked vertically as in the case of a Type E situation.



(A) (B)

FIGURE 5.12. Example of a Type B Day at MTP at 1200 GMT on August 10, 1979. (A)Surface Map (B)500-mb

Another example of a Type B situation is shown in Figure 5.13. A deep low to the NE of MTP was moving rapidly to the NE. The pressure gradient was approximately 3 mb. This would normally produce a Type C or D situation. However, the pressure gradient was weakening rapidly due to the movement of the low away from MTP. This resulted in a Type B situation. Note the rapidly moving short wave trough (SWT) at 500-mb. This case is similar to Type D2 and shows the subtle differences between various types. With a stronger gradient this case could have been a Type C or D. Although a Type 0, 1, 2 or 3 day can be forecast rather well from the objective techniques such as pressure gradient, 850-mb wind speed, etc.; it takes a more subtle synoptic approach to further break down a Type 2 or 3 situation into a Type B, C or D. Although knowing a situation will produce a Type 3 day is useful information, a further breakdown into Types B, C and D is more useful. A Type 3 day simply indicates that the wind speed will be equal to or greater than 7 m/s for a period equal to or greater than 8 hours. A further breakdown into a Type B indicates a time period less than 12 hours; Type C indicates 12 to 23 hours; Types D and E indicate a time period equal to or greater than 24 hours. Types D and E may indicate several days of continuous wind generation.

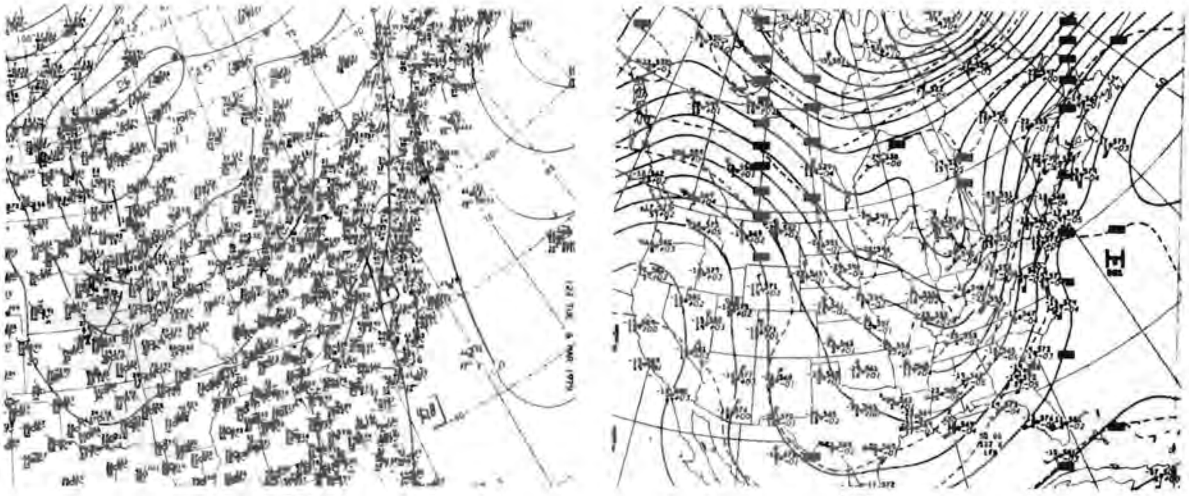


(A) (B)

FIGURE 5.13. Example of a Type B Day at MTP at 1200 GMT on February 22, 1979. (A)Surface Map (B)500-mb

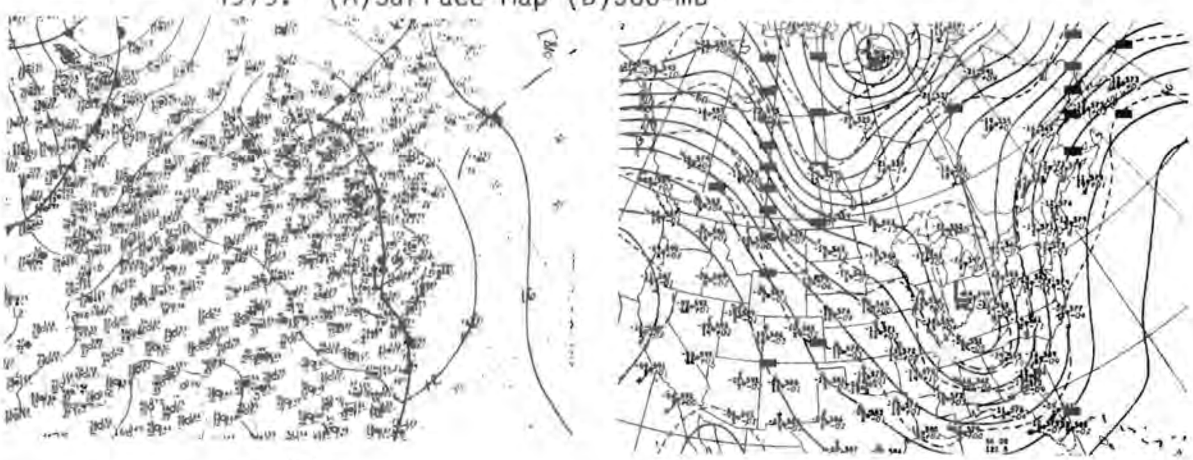
A third example is shown in Figure 5.14. There was a weak trough in the area of MTP with a low over Virginia. This example is included because of its similarity to the map of October 5 shown in Figure 5.15. Although the surface maps are similar, the 500-mb chart for October 5 shows a deep trough to the west which is being acted upon by a vigorous SWT coming into the Great Lakes region. This resulted in a strong deepening of the surface low as the low moved NNE into Canada. The resulting increase in the pressure gradient produced a Type D situation. This strengthening can be clearly seen on the October 6 maps previously shown in Figure 5.8. In the current example of March 6, deepening did not occur as the low and front moved off the coast with little change in intensity resulting in a Type B situation.

The above examples are further illustrations of the complete analysis that is necessary for an accurate wind forecast. The objective techniques are a useful first step but must be supplemented with the above type of analysis.



(A) (B)

FIGURE 5.14. Example of a Type B Day at MTP at 1200 GMT on March 6, 1979. (A) Surface Map (B) 500-mb



(A) (B)

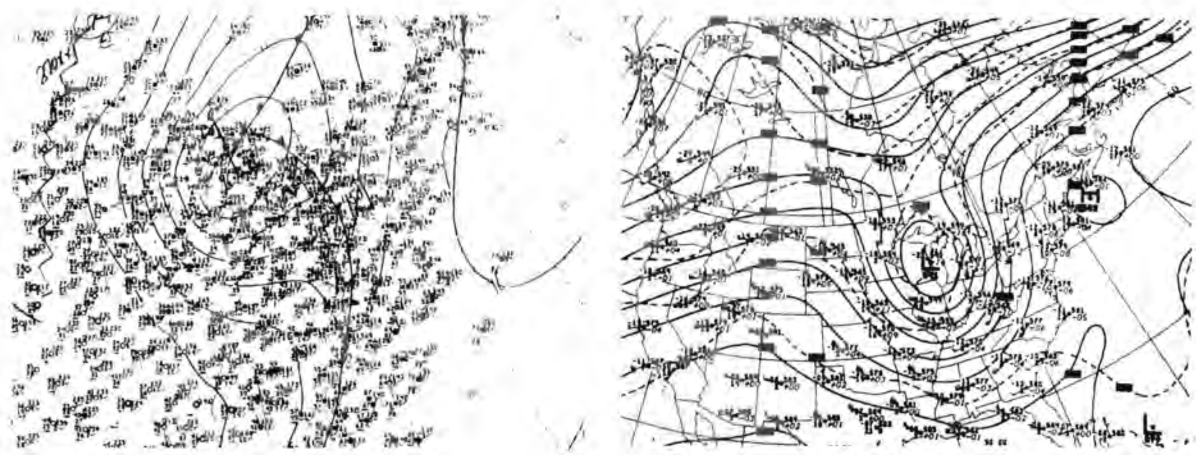
FIGURE 5.15. Example of a Type D Day at MTP at 1200 GMT on October 5, 1979. (A) Surface Map (B) 500-mb

5.3.5.4 Type C (wind speed equal to or greater than 7 m/s for a period of 12 to 23 hours)

Type C was subdivided into categories similar to Type B. Again the primary difference between B and C was the length of the period of the winds equal to or greater than 7 m/s. The length of the period was dependent on the strength of the pressure gradient and the intensity and speed of the synoptic systems.

C1a. Pre-cold front or pretrough with a S-N orientation of isobars.

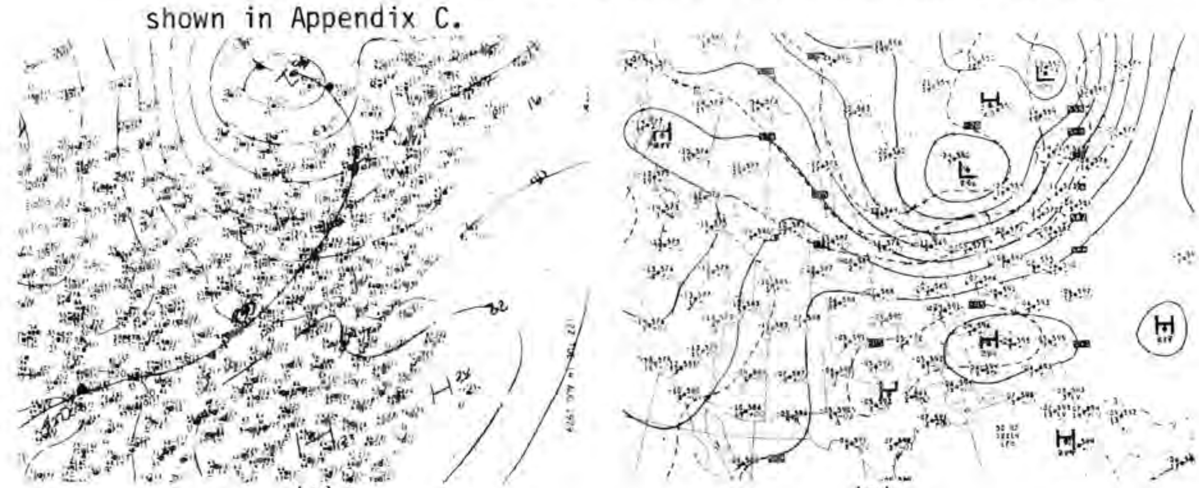
C1b. Pre-cold front or pretrough with a SW-NE orientation of isobars. An example is shown in Figure 5.16. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.16. Example of a Type C1b Day at MTP at 1200 GMT on October 23, 1979. (A)Surface Map (B)500-mb

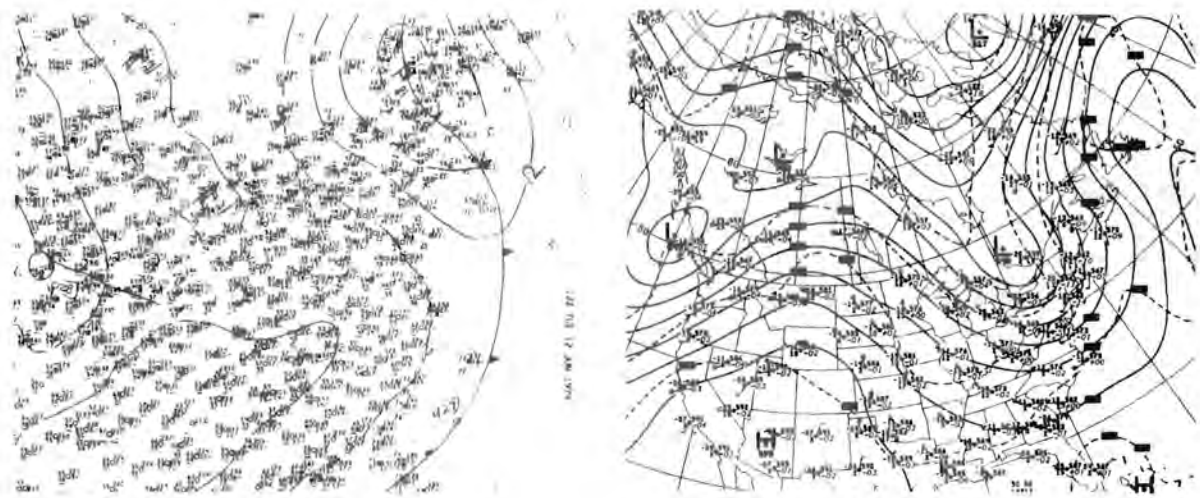
C1c. Pre-cold front or pretrough with a W-E orientation of isobars. An example is shown in Figure 5.17. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.17. Example of a Type C1c Day at MTP at 1200 GMT on August 14, 1979. (A)Surface Map (B)500-mb

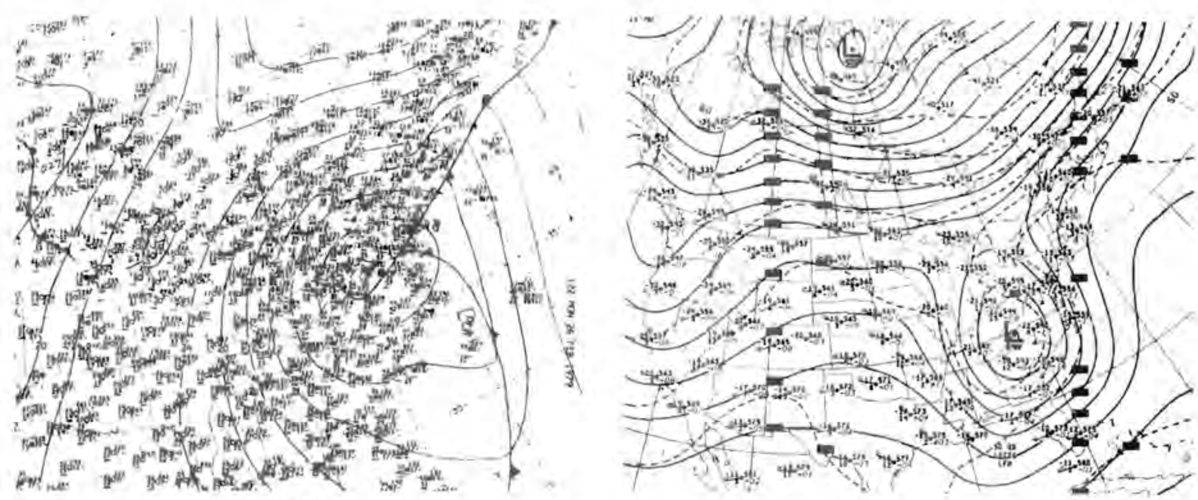
C2. Post-cold front. An example is shown in Figure 5.18. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.18. Example of a Type C2 Day at MTP at 1200 GMT on June 12, 1979. (A)Surface Map (B)500-mb

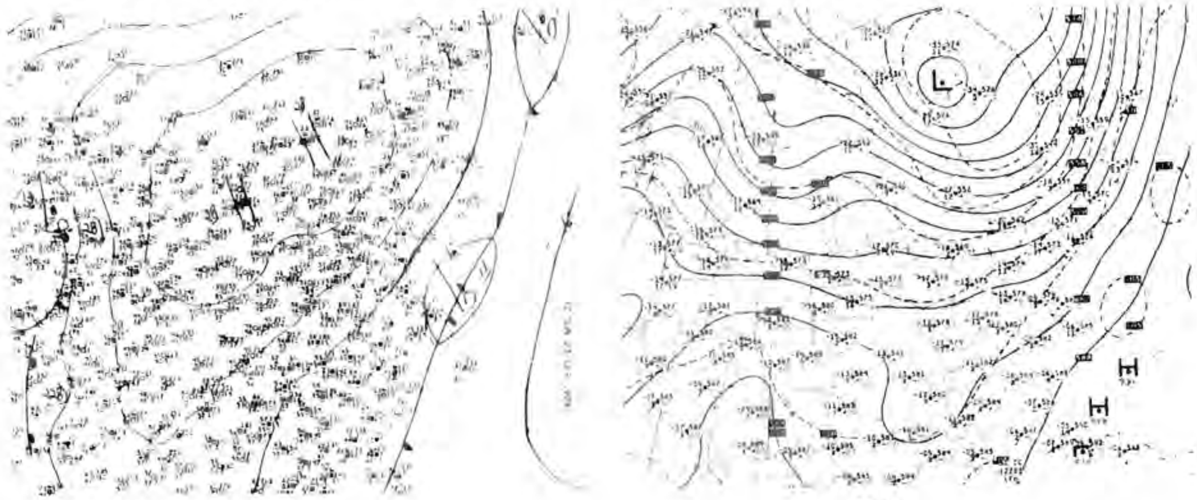
C3. Low to the south moving NE. An example is shown in Figure 5.19. Further examples are shown in Appendix C.



(A) (B)

FIGURE 5.19. Example of a Type C3 Day at MTP at 1200 GMT on February 26, 1979. (A)Surface Map (B)500-mb

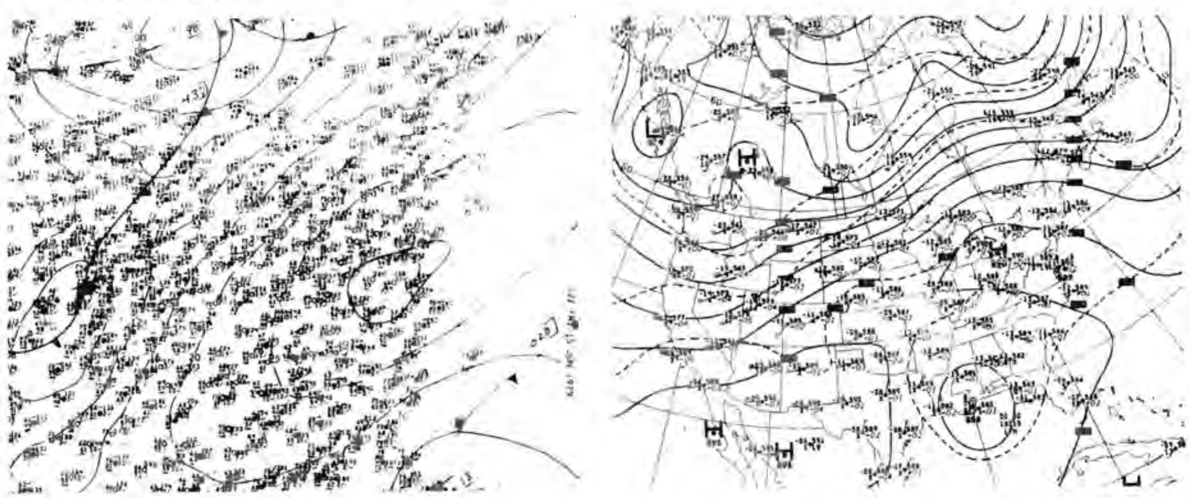
C4. Inverted ridge or high to the north (N-E IO). An example is shown in Figure 5.20. Further examples are shown in Appendix C.



(A) (B)

FIGURE 5.20. Example of a Type C4 Day at MTP at 1200 GMT on September 23, 1979. (A)Surface Map (B)500-mb

C5. Strong ridge or high to the south primarily with an E-W IO. An example is shown in Figure 5.21. Further examples are shown in Appendix C.



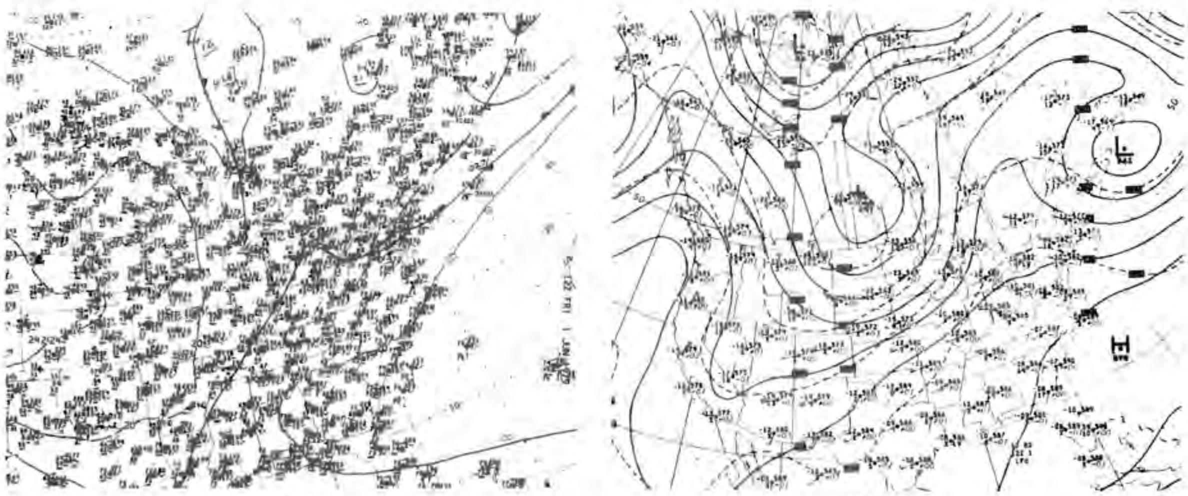
(A) (B)

FIGURE 5.21. Example of a Type C5 Day at MTP at 1200 GMT on June 15, 1979. (A)Surface Map (B)500-mb

5.3.5.5 <u>Type A</u> (no hourly wind speeds equal to or greater than 7 m/s)

The synoptic patterns associated with Type A were also varied as in the previous types but were mostly associated with highs, ridges or very weak troughs. A number of examples are shown, but a classification similar to Types B, C and D was not made.

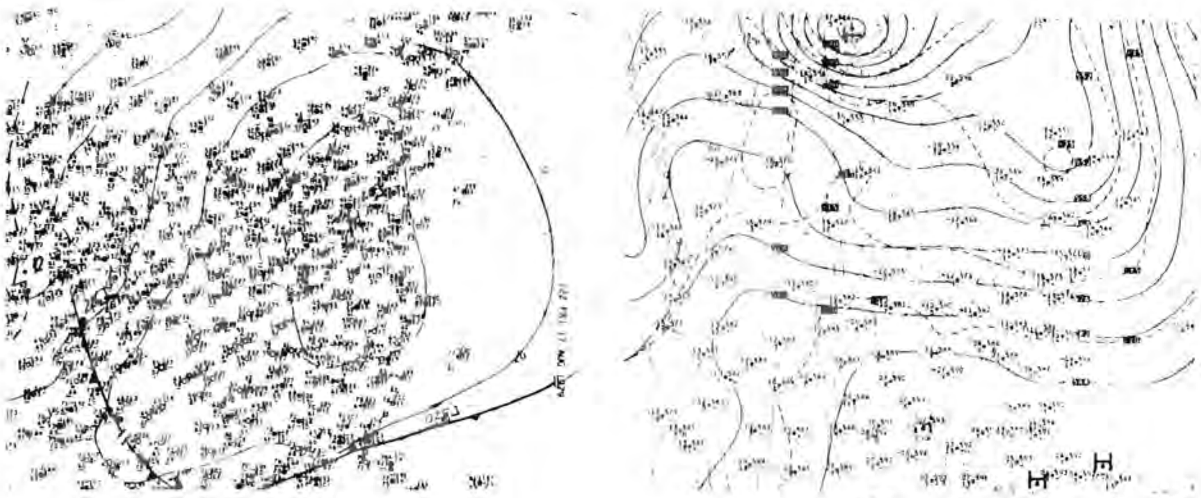
Example 1: An example of a Type A situation is shown in Figure 5.22. The weak warm front to the south and weak gradient are typical of this type. Further examples are shown in Appendix C.



(A) (B)

FIGURE 5.22. Example of a Type A Day at MTP at 1200 GMT on June 1, 1979. (A) Surface Map (B) 500-mb

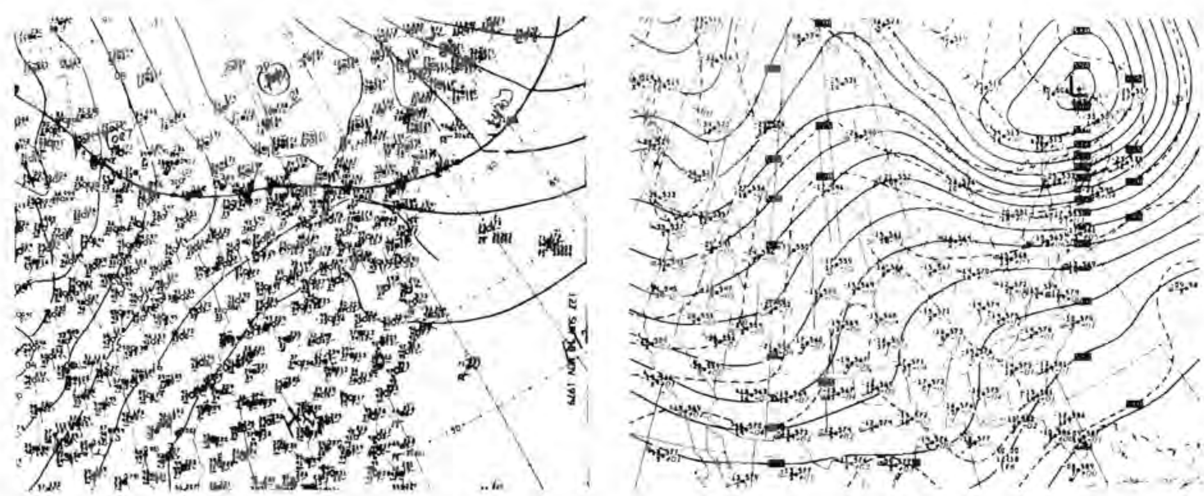
Example 2: A second example of a Type A situation is shown in Figure 5.23. A stagnant high over the area was oriented N-S. Further examples are shown in Appendix C.



(A) (B)

FIGURE 5.23. Example of a Type A Day at MTP at 1200 GMT on August 17, 1979. (A)Surface Map (B)500-mb

Example 3: A third example is shown in Figure 5.24. Here MTP is in a col area with a weak gradient. Additional examples are shown in Appendix C.



(A) (B)

FIGURE 5.24. Example of a Type A Day at MTP at 1200 GMT on November 18, 1979. (A)Surface Map (B)500-mb

The reason that the large number of examples was given was to provide the forecaster with a series of analogs that he could compare with his current map. The maps were chosen to show similar synoptic situations but with minor differences that made a major difference in the forecast. It is evident that the use of the combination of the semi-objective techniques plus the analogs will result in the best wind forecast.

5.4 SITE 2: LUDINGTON, MI (LDM)

5.4.1 Data Stratification - Statistical

As in MTP the data were stratified and summarized by months for 1) the number and percentage of hours the wind speeds were equal to or greater than 7 m/s, (A) and 2) the number and percentage of the type of windpower day, (B). These data are presented in Table 5.6.

TABLE 5.6. Stratification of Wind Speeds at LDM in 1979, Types 0, 1, 2 and 3

	(A)				(B)								
	Hours	Winds	≥7 mps		Days								
	Avail	Poss	Actual		Avail	Type 0		Type 1		Type 2		Type 3	
Mon	Obs	Obs	Obs	%	Obs	No	%	No	%	No	%	No	%
Jan	744	744	508	68	31	2	6	1	3	2	6	26	84
Feb	648	672	348	54	27	1	4	3	11	4	15	19	70
Mar	696	744	407	58	29	4	14	0	0	3	10	22	76
Apr	504	720	232	46	21	4	19	1	5	5	24	11	52
May	744	744	333	45	31	7	23	0	0	3	10	21	68
Jun	720	720	349	48	30	5	17	3	10	4	13	18	60
Jul	744	744	181	24	31	12	39	6	19	3	10	10	32
Aug	744	744	298	40	31	5	16	2	6	9	29	15	48
Sep	720	720	399	55	30	6	20	0	0	5	17	19	63
Oct	744	744	451	61	31	0	0	1	3	7	23	24	77
Nov	480*	720	284	59	20	1	5	1	5	4	20	14	70
Dec	552*	744	406	74	23	0	0	0	0	2	9	21	91
TOT	8040	8760	4196	52	335	47	14	18	5	51	15	220	66

*1978 data

The same general pattern as observed at MTP was also noted at LDM. The maximum percentage (hours) of Type 3 winds occurred in December (74%) and the minimum in July (24%). The annual average was 66 percent.

Type 3 winds ranged from a maximum of 26 days (84%) in January and October to a minimum of 10 days in July (32%).

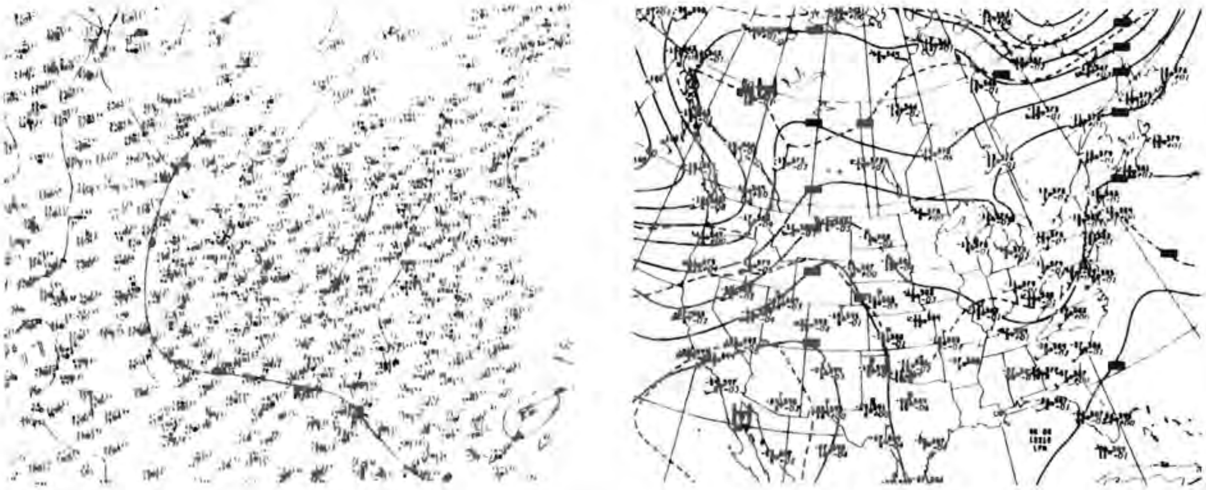
5.4.2 Booz-Allen (B-A) Classification

As in the case of MTP the B-A classification was useful in only a limited way.

Two synoptic situations illustrating the use of the B-A classification are shown. The first example, a Type 1 day (light winds), is shown in Figure 5.25. The B-A classifications are: surface type = 35 (flat pressure area); 500-mb type = 10 (meridional trough-posttrough).

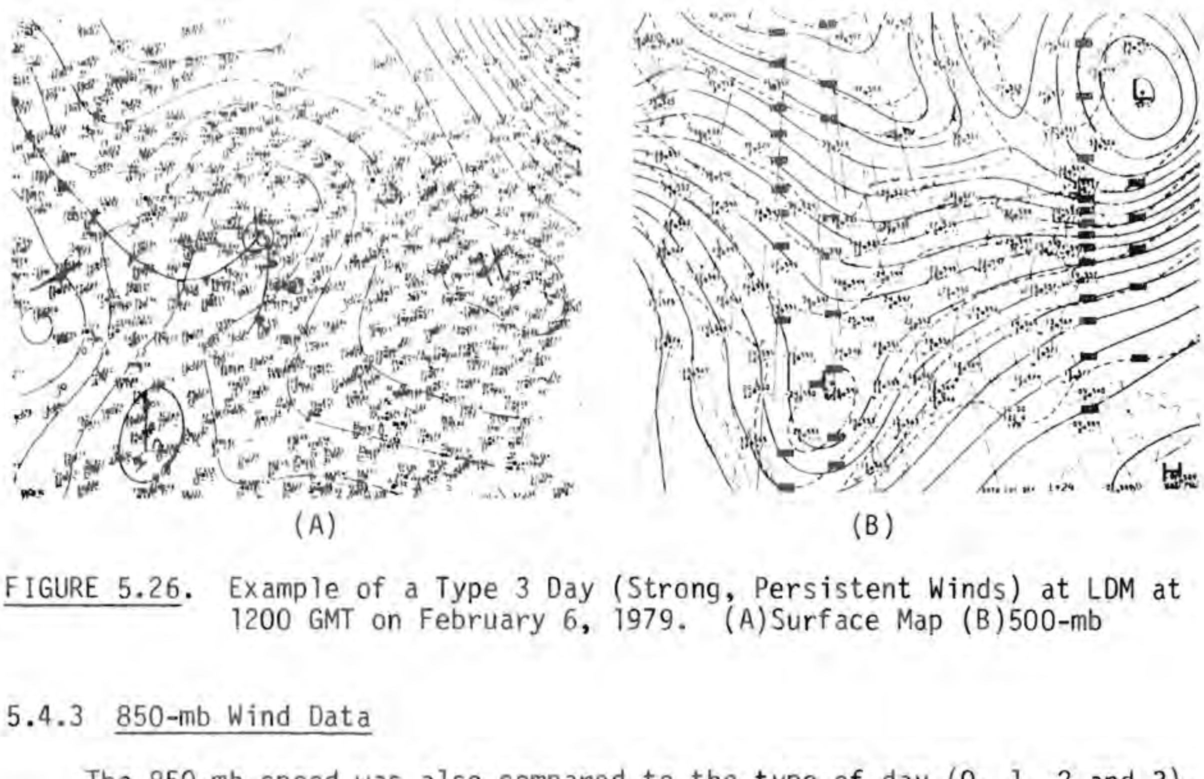
The second example, a Type 3 day (strong, persistent winds), is shown in Figure 5.26. The B-A classifications are: surface type = 14 (open wave cyclone moving SE or E, center S, pretrough); 500-mb type = 15 (meridional ridge, postridge).

Stagnant high pressure systems are most favorable for Type 1; strong, moving systems with shifting winds favor Type 3.



(A) (B)

FIGURE 5.25. Example of a Type 1 Day (Light Winds) at LDM at 1200 GMT on July 10, 1979. (A)Surface Mape (B)500-mb.



(A) (B)

FIGURE 5.26. Example of a Type 3 Day (Strong, Persistent Winds) at LDM at 1200 GMT on February 6, 1979. (A)Surface Map (B)500-mb

5.4.3 850-mb Wind Data

The 850-mb speed was also compared to the type of day (0, 1, 2 and 3). These data are presented in Table 5.7.

Table 5.8 shows the tabulation of the number of occurrences for each pressure difference and the percentage of the total for each type of day.

TABLE 5.7. LDM 850-mb Wind Speed Versus Surface Type Wind

All Directions

		850-mb Wind Speed - Kts 1200 GMT								
Type		5	10	15	20	25	30	35	40	Total
0	No. of Occurrences	3	9	4		1				17
	% of Occurrences	14	24	8		3				
1	No. of Occurrences	3	5	8	2	1				19
	% of Occurrences	14	14	16	3	3				
2	No. of Occurrences	8	10	10	14	6	2			50
	% of Occurrences	36	27	20	24	17	17			
3	No. of Occurrences	8	13	29	43	27	10	7	7	144
	% of Occurrences	36	35	57	73	77	83	100	100	
	Totals	22	37	51	59	35	12	7	7	230

Quadrant 000-090°

		850-mb Wind Speed - Kts 1200 GMT								
Type		5	10	15	20	25	30	35	40	Total
0	No. of Occurrences	1	2	1						4
	% of Occurrences	20	40	13						
1	No. of Occurrences									
	% of Occurrences									
2	No. of Occurrences	2	1	3	2	1	1			10
	% of Occurrences	40	20	38	50	25	50			
3	No. of Occurrences	2	2	4	2	3	1			14
	% of Occurrences	40	40	50	50	75	50			
	Totals	5	5	8	4	4	2			28

Quadrant 090-180°

		850-mb Wind Speed - Kts 1200 GMT								
Type		5	10	15	20	25	30	35	40	Total
0	No. of Occurrences		1	1						2
	% of Occurrences		17	50						
1	No. of Occurrences	1								
	% of Occurrences	100								
2	No. of Occurrences		2	1	1					4
	% of Occurrences		33	50	25					
3	No. of Occurrences		3		3	1		1		8
	% of Occurrences		50		75	100		100		
	Totals		6	2	4	1		1		14

Quadrant 180-270°

		850-mb Wind Speed - Kts 1200 GMT								
Type		5	10	15	20	25	30	35	40	Total
0	No. of Occurrences		5							5
	% of Occurrences		50							
1	No. of Occurrences	1	2	1	1					5
	% of Occurrences	11	20	7	5					
2	No. of Occurrences	5	1	4	3	3				16
	% of Occurrences	56	10	31	15	21				
3	No. of Occurrences	3	2	8	16	11	3	4	3	50
	% of Occurrences	33	20	62	80	79	100	100	100	
	Totals	9	10	13	20	14	3	4	3	76

Quadrant 270-360°

		850-mb Wind Speed - Kts 1200 GMT								
Type		5	10	15	20	25	30	35	40	Total
0	No. of Occurrences	2	1	2	0	1				6
	% of Occurrences	29	6	7		6				
1	No. of Occurrences	1	3	7	1	1				13
	% of Occurrences	14	19	25	3	6				
2	No. of Occurrences	1	6	2	8	2	2			21
	% of Occurrences	14	38	7	26	12	25			
3	No. of Occurrences	3	6	17	22	12	6	2	4	72
	% of Occurrences	43	38	61	71	75	75	100	100	
	Totals	7	16	28	31	16	8	2	4	112

TABLE 5.8. LDM Pressure Gradient Versus Surface Wind Type

All Directions

		Pressure Gradient-mb						
Type		1	2	3	4	5	6	Total
0	No. of Occurrences	9	6	1	4			20
	% of Occurrences	21	9	2	7			
1	No. of Occurrences	9	6	6	2			23
	% of Occurrences	21	9	10	4			
2	No. of Occurrences	13	25	13	5	3	2	61
	% of Occurrences	31	37	22	9	11	5	
3	No. of Occurrences	11	30	38	44	24	35	182
	% of Occurrences	26	45	66	80	89	95	
	Totals	42	67	58	55	27	37	286

Quadrant 000-090°

		Pressure Gradient-mb						
Type		1	2	3	4	5	6	Total
0	No. of Occurrences		2		1			3
	% of Occurrences		14		8			
1	No. of Occurrences	1	2	2	1			6
	% of Occurrences	11	14	15	8			
2	No. of Occurrences	6	6	3	3	2	1	21
	% of Occurrences	67	43	23	23	33	13	
3	No. of Occurrences	2	4	8	8	4	7	33
	% of Occurrences	22	29	62	62	67	88	
	Totals	9	14	13	13	6	8	63

Quadrant 090-180°

		Pressure Gradient-mb						
Type		1	2	3	4	5	6	Total
0	No. of Occurrences	2			1			3
	% of Occurrences	2			9			
1	No. of Occurrences	1	1	2	1			5
	% of Occurrences	10	8	11	9			
2	No. of Occurrences	3	8	5	1			17
	% of Occurrences	30	62	26	9			
3	No. of Occurrences	4	4	12	8	6	11	45
	% of Occurrences	40	31	63	73	100	100	
	Totals	10	13	19	11	6	11	70

Quadrant 180-270°

		Pressure Gradient-mb						
Type		1	2	3	4	5	6	Total
0	No. of Occurrences	6	0	1				7
	% of Occurrences	30		6				
1	No. of Occurrences	6	2	2				10
	% of Occurrences	30	10	13				
2	No. of Occurrences	3	6	2			1	12
	% of Occurrences	15	30	13			25	
3	No. of Occurrences	5	12	11	13	8	4	53
	% of Occurrences	25	60	69	100	100	75	
	Totals	20	20	16	13	8	5	82

Quadrant 270-360°

		Pressure Gradient-mb						
Type		1	2	3	4	5	6	Total
0	No. of Occurrences	1	4		2			7
	% of Occurrences	33	20		11			
1	No. of Occurrences	1	1					2
	% of Occurrences	33	5					
2	No. of Occurrences	1	5	3	1	1		11
	% of Occurrences	33	25	30	6	14		
3	No. of Occurrences		10	7	15	6	13	51
	% of Occurrences		50	70	83	86	100	
	Totals	3	20	10	18	7	13	71

When the 850-mb wind speed was greater than 20 kts, a Type 3 day occurred 78% of the time. When the 850-mb speed was greater than 15 kts, Type 3 occurred 71% of the time. The above applies to all directions.

These data are presented in a 2 x 2 matrix in Figure 5.27. Using an 850-mb wind speed equal to or greater than 20 kts, a forecast of a Type 3 day occurred 94 times (43 + 27 + 10 + 7 + 7); and did not occur 26 times (1 + 3 + 22). This parameter gave the correct forecast 78% of the time (94 divided by 120). However, using a wind speed less than 20 kts, a 'NO' forecast verified 'NO' 60 times (16 + 16 + 28) while YES occurred 50 times (8 + 13 + 29). Thus, if the 850-mb wind was equal to or greater than 20 kts, it was a good predictor of a Type 3 day. However, if the 850-mb wind speed was less than 20 kts it was not a good predictor of the type of day that occurred. This is further evidence that more than one parameter is needed to give an accurate wind forecast.

The data were then divided into four quadrants. When the 850-mb speed was greater than 20 kts in the 190°-270° quadrant, Type 3 occurred 84% of the time; in the 000°-090° quadrant Type 3 occurred 60% of the time. This difference is believed to be due to the effect of the difference in friction over the land compared to Lake Michigan (180°-270°). Note also that for 850-mb speeds greater than 15 kts, the highest percentage (79%) of Type 3 days occurred with the 180°-270° quadrant.

These data are also in the 2 x 2 matrix in Figure 5.27.

LDM 850-mb Wind Speeds vs. Type 3 Days

All directions

Speeds ≥20 kts	Yes	No
Yes	94	50
No	26	60

Yes-Yes = $\frac{94}{120}$ = 78%

No-No = $\frac{60}{110}$ = 55%

000°-090° Quadrant

Speeds ≥20 kts	Yes	No
Yes	6	8
No	4	10

Yes-Yes = $\frac{6}{10}$ = 60%

No-No = $\frac{10}{18}$ = 55%

180°-270° Quadrant

Speeds ≥20 kts	Yes	No
Yes	37	13
No	7	18

Yes-Yes = $\frac{37}{44}$ = 84%

No-No = $\frac{18}{31}$ = 58%

180°-270° Quadrant

Speeds ≥15 kts	Yes	No
Yes	45	13
No	12	19

Yes-Yes = $\frac{45}{57}$ = 79%

No-No = $\frac{19}{32}$ = 59%

FIGURE 5.27. Verification Matrices for Type 3 Days at LDM Using 850-mb Wind Speeds

The 1200 GMT 850-mb wind speed was compared with the consecutive hours of speeds equal to or greater than 7 m/s and the peak hourly wind for the next 24 hours. As in the case of MTP there was a wide scatter, but a trend was evident. In general as 1200 GMT 850-mb wind speed increased, so did the peak wind and the number of consecutive hours of wind speeds equal to or greater than 7 m/s.

The conclusion is that the 1200 GMT 850-mb wind at Green Bay, Wisconsin (GRB) is a good approximation of a Type 3 day at LDM. Based upon the analysis at MTP the 0000 GMT 850-mb wind speed is also a good predictor of a Type 3 day.

5.4.4 Pressure Gradient Analysis

The pressure gradients on the surface maps in mb per 150 nautical miles were measured daily at 1200 GMT. The pressure difference and the orientation of the isobars were logged and compared with the wind type (0, 1, 2 or 3). There were 286 cases (instead of 365) in this analysis due to missing data. (The LDM data for November and December 1979 were missing entirely. November and December 1978 data were obtained and have been included in the final report in order to complete an entire year.)

Note that when the pressure gradient is equal to or greater than 3 mb, a Type 3 day occurs 80%; equal to or greater than 4 mb, 87%; equal to or greater than 5 mb, 92% of the time.

The 80% value was arrived at by dividing 141 (38 + 44 + 24 + 35), the number of Type 3 occurrences by 177 (5 + 8 + 23 + 141), the total number of occurrences of pressure gradient equal to or greater than 3 mb. Similar analyses gave values of 87% (for 4 mb) and 92% (for 5 mb).

All four of the Type 0 days that occurred with the pressure gradient of 4 mb were with a weak front, low or col area over the Great Lakes rather than with ridges or a high.

These data were further subdivided into quadrants. The results are included in Table 5.8. Note that when the pressure gradient was equal to or greater than 3 mb a Type 3 day occurred 82 percent of the time for the 000^{0}-090^{0} quadrant. But the same pressure gradient for the 180^{0}-270^{0} quadrant gave a Type 3 day 68 percent of the time. This is believed to be due to the difference in friction over land and water. As the pressure gradient increased to equal to or greater than 4 mb and 5 mb, there was little difference in the number of Type 3 days for the 000^{0}-090^{0} quadrant and the 180^{0}-270^{0} quadrant. This indicated that as the pressure gradient became stronger the impact of friction was less.

The data in Table 5.8 are also presented in a series of 2 x 2 matrices in Figure 5.28.

The conclusion is that when a pressure gradient of equal to or greater than 3 mb exists at 1200 GMT across LDM a Type 3 day is expected to occur at least 68 percent of the time and more likely to occur 82-86 percent of the time.

The pressure gradient was measured at 1200 GMT each day and compared with the surface wind speed at 1200 GMT. An average wind speed was computed for each pressure gradient category. This computation was subdivided into quadrants. The results are shown graphically in Figure 5.29.

5.4.5 Data Stratification - Meteorological/Synoptic

In addition to the data presented in Table 5.8 a further tabulation was made for Types A through E. This is presented in Table 5.9.

LDM Pressure Gradient vs. Type 3 Days

All directions

Pressure gradient ≥3-mb	Yes	No
Yes	141	41
No	36	68

Yes-Yes $= \frac{141}{177} = 80\%$

No-No $= \frac{68}{109} = 62\%$

All directions

Pressure gradient ≥4-mb	Yes	No
Yes	103	79
No	16	88

Yes-Yes $= \frac{103}{119} = 87\%$

No-No $= \frac{88}{167} = 53\%$

000°-090° Quadrant

Pressure gradient ≥3-mb	Yes	No
Yes	27	6
No	13	17

Yes-Yes $= \frac{27}{40} = 68\%$

No-No $= \frac{17}{23} = 74\%$

180°-270° Quadrant

Pressure gradient ≥3-mb	Yes	No
Yes	36	17
No	6	23

Yes-Yes $= \frac{36}{42} = 80\%$

No-No $= \frac{23}{40} = 58\%$

FIGURE 5.28. Verification Matrices for Type 3 Days at LDM Using Pressure Gradients

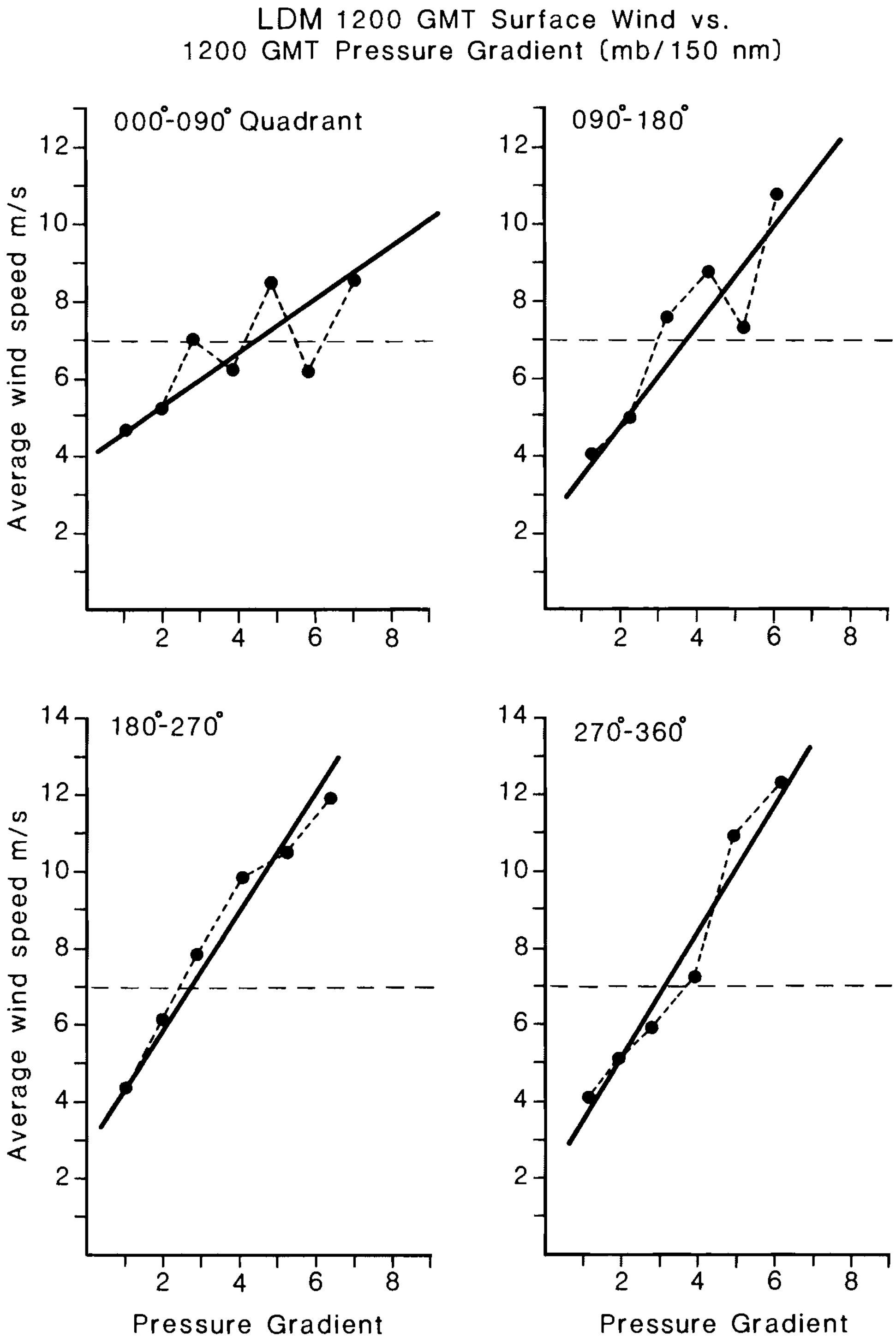


FIGURE 5.29. Surface Wind Speed Versus Pressure Gradient at 1200 GMT at LDM

TABLE 5.9. Stratification of Synoptic Types A, B, C, D and E at LDM

Mon	Avail Days	Poss Days	Type A No.	Type A %	Type B No.	Type B %	Type C No.	Type C %	Type D No.	Type D %	Type E No.	Type E %	Msg
Jan	31	31	2	6	9	29	9	29	8	26	3	10	0
Feb	27	28	1	4	12	44	9	33	4	15	1	4	1
Mar	29	31	4	14	7	24	11	38	5	17	2	7	2
Apr	21	30	4	19	9	43	4	19	4	19	0	0	9
May	31	31	7	23	13	42	7	23	4	13	0	0	0
Jun	30	30	5	17	12	40	7	23	5	17	1	3	0
Jul	31	31	12	39	14	45	4	13	1	3	0	0	0
Aug	31	31	5	16	14	45	9	29	3	10	0	0	0
Sep	30	30	6	20	7	23	9	30	8	27	0	0	0
Oct	31	31	0	0	12	39	11	36	6	19	2	6	0
Nov	20	30	1	5	7	35	7	35	2	10	3	15	10
Dec	23	31	0	0	3	13	12	52	3	13	5	22	8
TOT	335	365	47	14	119	36	99	30	53	16	17	5	30

Type A had a maximum value of 39% in July, a minimum of zero in December. Type B had a rather even distribution without a distinct maximum and a minimum of 13% in December. Type C had a maximum value of 52% in December and a minimum of 13% in July. Type D had a maximum of 27% in September and 26% in January and a minimum of 3% in July. Type E had a maximum of 22% in December. The minimum value was zero in a number of months.

It was expected that Types A and E would have a definite type of synoptic pattern while B, C and D would be less distinct. The following discussion and rules-of-thumb are a result of the analysis of these types. (A complete list of the dates of each type is presented in Appendix B.)

5.4.5.1 Type A (no hourly winds equal to or greater than 7 m/s)

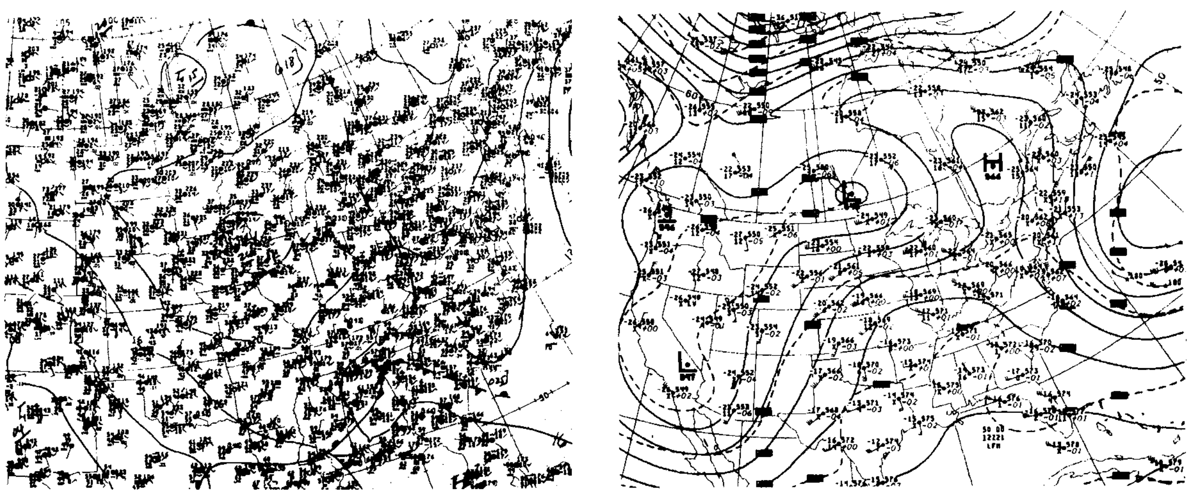
Out of forty-five cases forty were characterized by a ridge or a closed high center moving across the Great Lakes. The remaining five cases were associated with a weak, slow moving or stationary low center or frontal system.

All but six of these forty-five cases had pressure gradients at 1200 GMT of two mb or less. Four of these six exceptions were associated with a weak low or stationary front over the Great Lakes. In all cases except one the 850-mb wind speed was twenty kts or less. The one exception was associated with a col area.

The above leads to the following rules-of-thumb for Type A.

1. A slow moving high or ridge over the Great Lakes will give a Type A (and a Type O) day.
2. The pressure gradient should be 2 mb or less. Conversely, if the pressure gradient is equal to or greater than 3 mb do not forecast a Type A day.
3. The 850-mb wind speed should be 20 kts or less. Conversely, if the 850-mb speed is equal to or greater than 25 kts do not forecast a Type A day.

An example of a closed high is shown in Figure 5.30. Further examples are in Appendix C.



(A) (B)

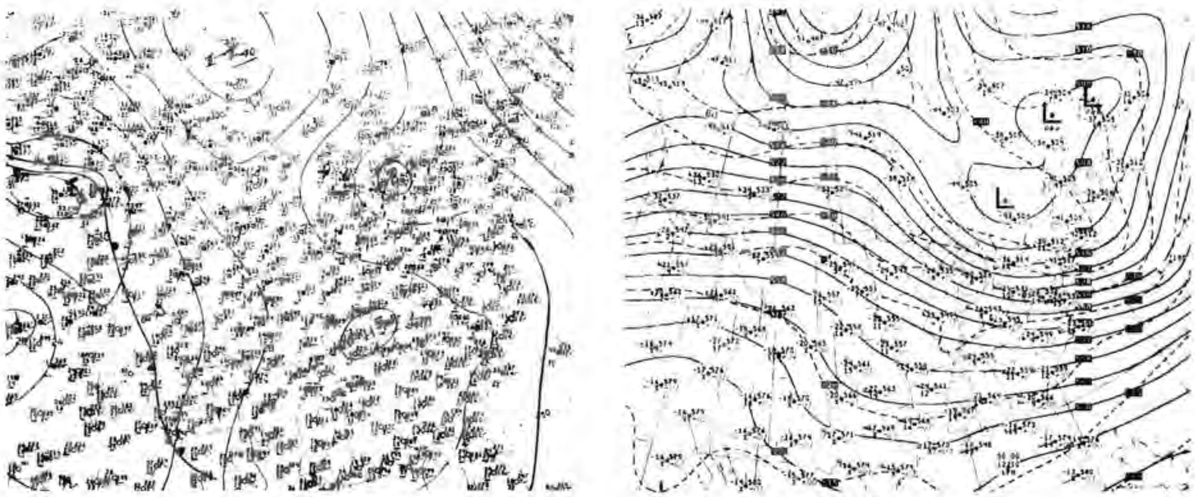
FIGURE 5.30. Example of a Type A Day at LDM at 1200 GMT on March 21, 1979. (A)Surface Map (B)500-mb

5.4.5.2 <u>Type B</u> (1-11 hours of wind speed equal to or greater than 7 m/s)

The following synoptic situations were typical of Type B.

1. Weak trough/front/low moving across Great Lakes or just east of LDM
2. Ridge over Minnesota-Wisconsin
3. High or ridge east of LDM
4. A weak or weakening low moving E or NE out of the Great Plains or the Midwest
5. A high or ridge north of LDM moving E
6. A high or ridge south of LDM moving E
7. A low or Col area nearly stationary over Michigan

An example of a Type B day is shown in Figure 5.31. A further listing of dates for Type B is in Appendix B. Additional examples are in Appendix C.

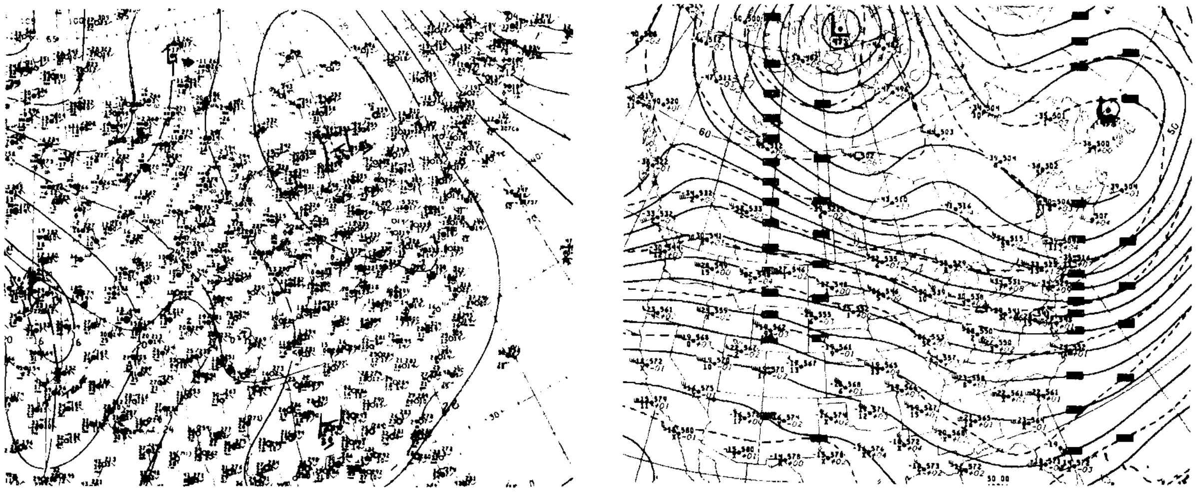


(A) (B)

FIGURE 5.31. Example of a Type B Day at LDM at 1200 GMT on February 10, 1979. (A)Surface Map (B)500-mb

5.4.5.3 <u>Type C</u> (12-23 hours of wind speed equal to or greater than 7 m/s)

Type C also occurred with a wide variety of synoptic situations. An example of Type C is shown in Figure 5.32. A complete list of Type C days is in Appendix B. Additional examples are shown in Appendix C.

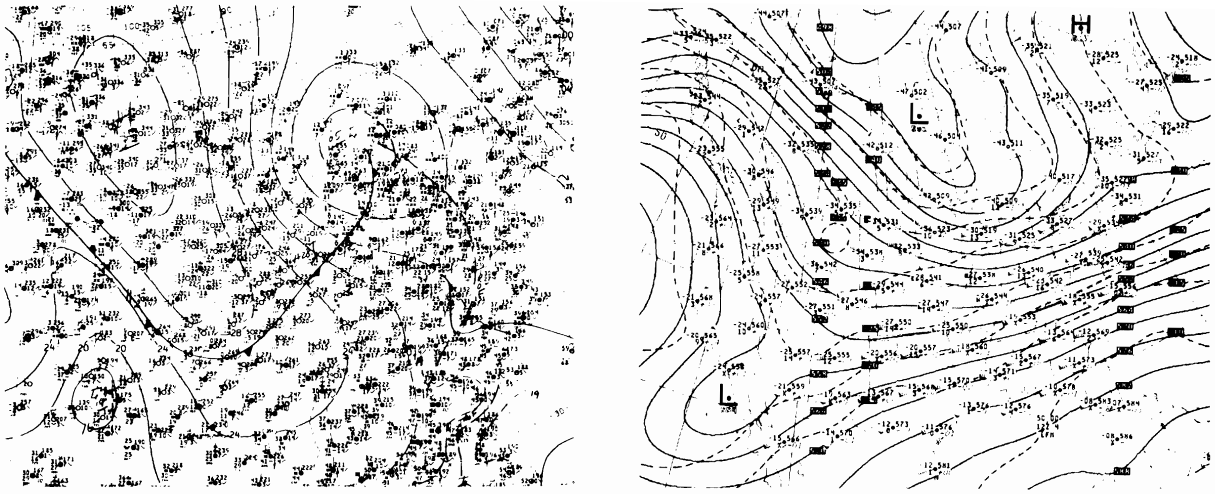


(A) (B)

FIGURE 5.32. Example of a Type C Day at LDM at 1200 GMT on February 11, 1979. (A)Surface Map (B)500-mb

5.4.5.4 <u>Type D</u>

This type includes only those days on which the surface wind was equal to or greater than 7 m/s for a period equal to or greater than 24 hours. An example of a Type D situation is shown in Figure 5.33. Further examples are shown in Appendix C.



(A) (B)

FIGURE 5.33. Example of a Type D Day at LDM at 1200 GMT on February 4, 1979. (A)Surface Map (B)500-mb

There was a large number of cases with a surface low moving across the northern Midwest, Great Lakes or Southern Canada (Manitoba, Ontario) either deepening or with little change in intensity. Another large number of cases involved a low moving out of the Great Plains to the NE with its track west of LDM.

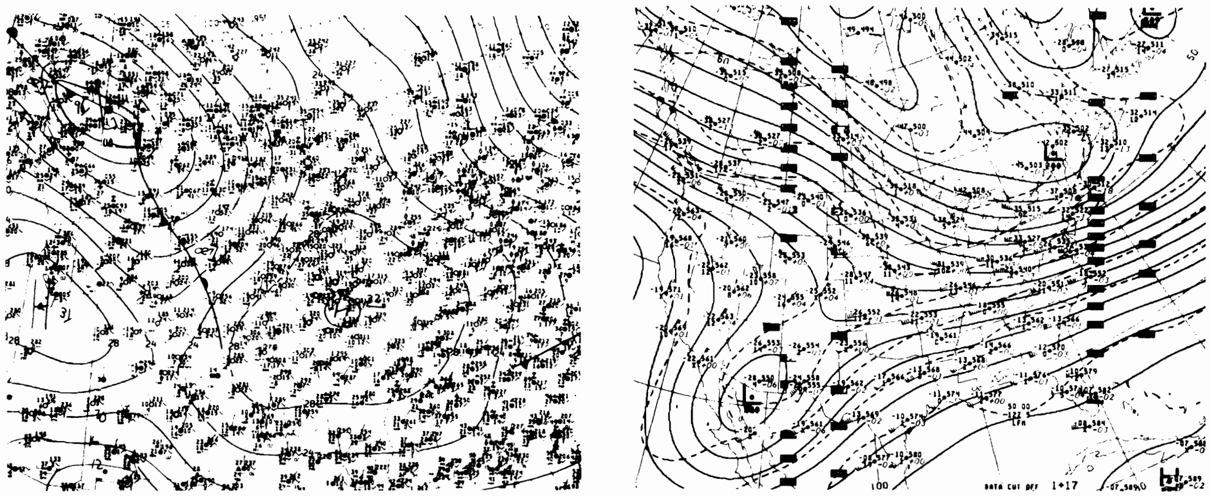
There were only nine out of fifty cases which did not fall into the above. Three involved deep storm centers that moved south or east of LDM. Three others involved deep lows over central Canada.

The pressure gradients were generally equal to or greater than 4 mb. However, on fourteen days out of fifty the pressure gradient was 2 or 3 mb. Of these fourteen days eleven days had 850-mb wind speeds at 1200 GMT equal to or greater than 20 kts, indicating a Type 3 day.

The above discussion leads to the following rule-of-thumb. If you have (1) a significant low pressure system (deepening or with little change in intensity) moving across the northern Great Lakes or southern Canada or (2) a low moving from the Great Plains to the NE with the track west of LDM, (3) the pressure gradient at 1200 GMT is equal to or greater than 4 mb and/or 850-mb 1200 GMT wind speed is equal to or greater than 20 kts - forecast at least equal to or greater than 24 hours of wind generation (winds equal to or greater than 7 m/s).

5.4.5.5 Type E

This type includes only those days which the surface wind was equal to or greater than 10 m/s for a period equal to or greater than 24 hours. An example of Type E is shown in Figure 5.34. Additional examples are given in Appendix C.



(A) (B)

FIGURE 5.34. Example of a Type E Day at LDM at 1200 GMT on February 5, 1979. (A)Surface Map (B)500-mb

All seventeen of Type E cases involved a strong or deepening surface low moving NE across northern Great Lakes or Canada. Pressure gradients were all equal to or greater than 4 mb at 1200 GMT. All but three of the seventeen Type E cases were equal to or greater than 6 mb. Those three had 850-mb wind speeds at 1200 GMT equal to or greater than 30 kts.

The above leads to the following rules of thumb. 1) If, (a) there is a deep or deepening surface low, located anywhere from the Great Plains to the Appalachians, moving NE or, (b) a deep or deepening low moving across the northern Great Lakes or southern Canada and, (c) the pressure gradient is equal to or greater than 6 mb, forecast an extended period of high winds at LDM. 2) If the pressure gradient is equal to or greater than 6 mb and the 1200 GMT 850-mb wind speed is equal to or greater than 30 kts, forecast a Type E situation.

The series of February maps shown in Figures 5.31 to 5.34 illustrates the large day-to-day variation that can occur across the LDM area.

5.5 SITE 3: AMARILLO, TX (AMA)

5.5.1 Data Stratification - Statistical

The data were stratified and summarized by months for 1) the number and percentage of hours the wind speeds were equal to or greater than 7 m/s (A) and 2) the number and percentage of the type of windpower day (B). These data are presented in Table 5.10

In 1979 there was a total of 4946 hours of wind speeds equal to or greater than 7 m/s. This represents 60% of the available reports. The percentages ranged from a maximum of 71% in August to a minimum of 47% in September.

TABLE 5.10. Stratification of Wind Speeds at AMA in 1979, Types 0, 1, 2 and 3

	(A)				(B)								
	Hours	Winds	≥7 mps		Days								
	Avail	Poss	Actual		Avail	Type 0		Type 1		Type 2		Type 3	
Mon	Obs	Obs	Obs	%	Obs	No	%	No	%	No	%	No	%
Jan	384	744	264	63	16	0	0	0	0	3	19	13	81
Feb	672	672	420	63	28	1	4	0	0	3	10	24	86
Mar	624	744	384	62	26	1	4	1	4	3	11	21	81
Apr	720	720	483	67	30	0	0	0	0	5	17	25	83
May	744	744	462	62	31	0	0	2	6	5	17	24	77
Jun	720	720	415	58	30	1	3	1	3	4	14	24	80
Jul	744	744	394	53	31	2	6	0	0	10	32	19	62
Aug	744	744	530	71	31	0	0	1	4	2	6	28	90
Sep	648	720	302	47	27	1	4	3	11	6	22	17	63
Oct	744	744	509	68	31	0	0	1	3	2	6	28	90
Nov	720	720	405	56	30	1	3	0	0	8	27	21	70
Dec	744	744	378	51	31	1	3	1	3	7	23	22	71
TOT	8208	8760	4946	60	342	8	2	10	3	58	17	266	78

A Type 3 day occurred 78% of the total observations for 1979 ranging from a maximum of 90% in August and October to a minimum of 62% in July. Note there was not the wide monthly and seasonal variation noted at the other sites. Despite the fact that data for only sixteen days were reported in January it is thought to be representative because it corresponds well with December and February. Note that a Type 0 'day' occurred only 2 percent of the observed days. This indicates that some power generation could be expected during 98 percent of the days. Combining Types 2 and 3 would give three or more consecutive hours of power generation on 95 percent of the days.

5.5.2 Booz-Allen (B-A) Classification

Each day was classified for both the surface map and 500-mb chart. Four analyses of the B-A classifications and their correlation (or lack of correlation) to wind speeds at AMA were made. Types 0, 1, 2 and 3 were plotted against the B-A surface and the 500-mb types for the entire year. Although some groupings were apparent no obvious correlation was noted.

5.5.3 850-mb Wind Data

Since AMA is situated 3945 feet above sea level there was some concern about using the 850-mb level. Consideration was given to using the second standard level (4000 ft) but the 850-mb data was examined first because of its earlier availability as discussed above in Section 5.1.

The 850-mb 1200 GMT wind speed was correlated with Type 0, 1, 2 and 3 days. These data are present in Table 5.11.

On the 326 days when the 1200 GMT 850-mb data were available a Type 3 day occurred 254 times (78 percent). Of these 254 times, a Type 3 day occurred 224 times (88 percent) when the 850-mb wind speed was equal to or greater than 15 kts. These data are also shown in a 2 x 2 matrix in Figure 5.35.

The 1200 GMT 850-mb wind speed was equal to or greater than 25 kts on 154 days. A Type 3 day occurred 152 times or 99 percent of the time.

TABLE 5.11. AMA 850-mb Wind Speed Versus Surface Wind Type in All Directions

Type		850-mb Wind Speed - Kts 1200 GMT							
		5	10	15	20	25	30	35	40
0	No. of Occurrences	6	1			1			
	% of Occurrences	24	2			2			
1	No. of Occurrences	2	2	4	1	1			
	% of Occurrences	8	5	8	2	2			
2	No. of Occurrences	9	14	18	13		2		
	% of Occurrences	36	36	35	24		17		
3	No. of Occurrences	8	22	29	41	43	45	44	22
	% of Occurrences	32	56	57	75	96	83	100	100

The conclusion reached is that the 1200 GMT 850-mb wind speed is an excellent parameter for forecasting the occurrence of a Type 3 day.

The relation between the 1200 GMT 850-mb wind speed and the maximum hourly wind for the next 24 hours was logged. Although there was a substantial amount of variation from day to day there was a trend to show that as the 850-mb speed increased the maximum hourly wind also increased. The data also indicated that the maximum hourly wind is approximately 81 percent of the 1200 GMT 850-mb wind speed. The conclusion reached was that the 1200 GMT 850-mb wind speed was an acceptable parameter for forecasting the maximum hourly wind for the next 24 hours.

The 850-mb data were analyzed in a third manner relating the 1200 GMT 850-mb speed to the number of consecutive hours of surface wind speeds equal to or greater than 7 m/s. A diagram showing this relationship is shown in Figure 5.36. Although there is substantial scatter there is a clear trend. As the 850-mb speed increases the number of consecutive hours of surface winds equal to or greater than 7 m/s also increases. It further shows that in all cases when 850-mb wind speeds were equal to or greater than 25 kts a period of at least 8 consecutive hours of surface speeds averaging 7 m/s or higher occurred. This is defined above as a Type 3 day and relates well to the data presented earlier regarding 850-mb wind speed

AMA 850-mb Wind Speeds vs. Type 3 Days

Speeds ⩾15 kts	All directions Yes	All directions No
Yes	224	30
No	30	34

Yes-Yes=$\frac{224}{254}$=88%

No-No=$\frac{34}{64}$=53%

Speeds ⩾20 kts	All directions Yes	All directions No
Yes	195	59
No	18	56

Yes-Yes=$\frac{195}{213}$=92%

No-No=$\frac{56}{115}$=49%

FIGURE 5.35. Verification Matrices for Type 3 Days at AMA Using 850-mb Wind Speed

AMA Pressure Gradient vs. Type 3Days

Pressure gradient ⩾3-mb	Yes	No
Yes	147	129
No	32	53

Yes-Yes=$\frac{147}{179}$=82%

No-No=$\frac{53}{182}$=29%

FIGURE 5.37. Verification Matrix for Type 3 Days at AMA Using Pressure Gradients

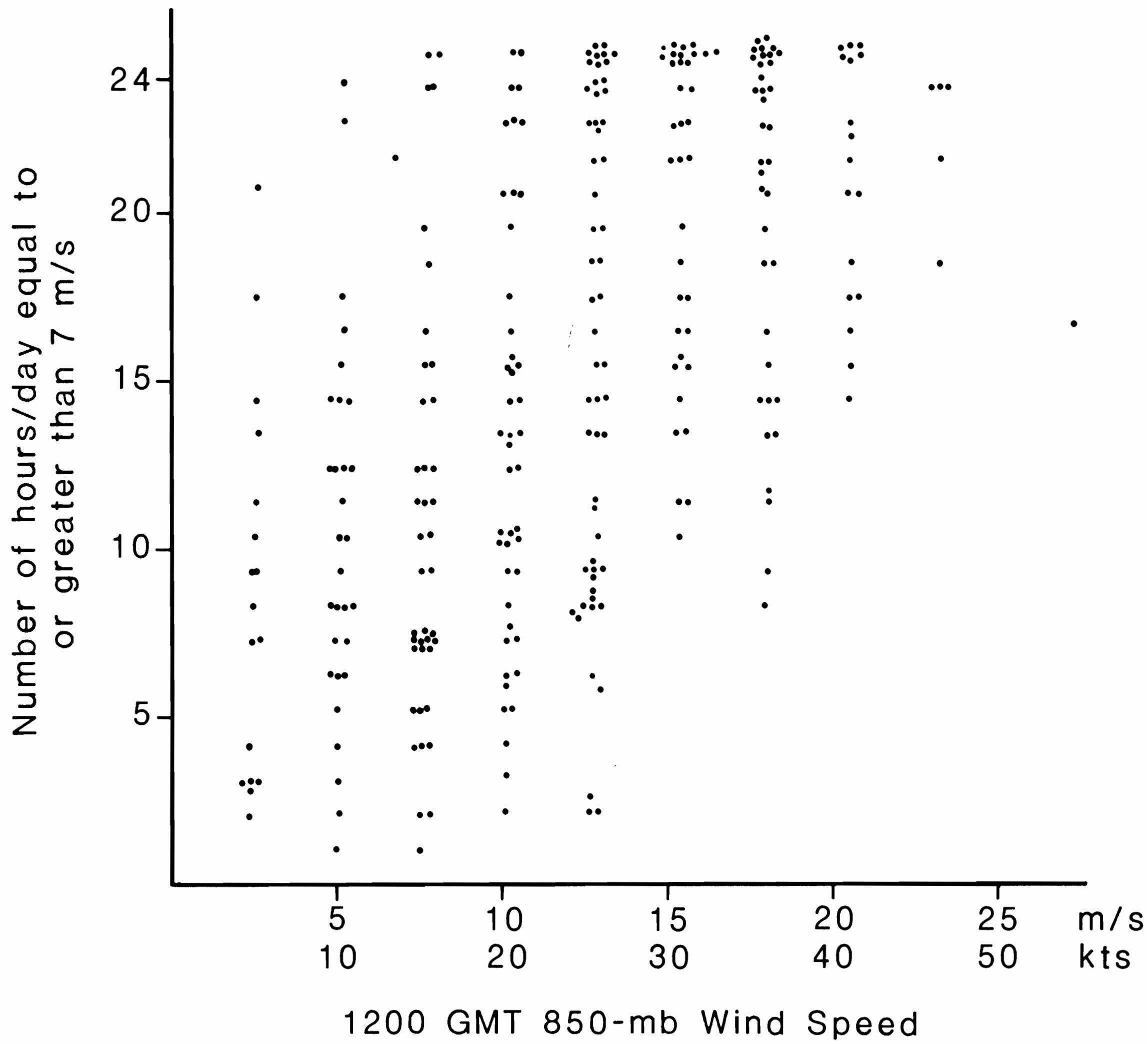


FIGURE 5.36. 850-mb Wind Speed at 1200 GMT Versus the Number of Consecutive Hours of Winds Equal to or Greater than 7 m/s at AMA

and type of day. However, this analysis goes one step further and gives a more specific number of consecutive hours rather than simply equal to or greater than 8 hours.

5.5.4 Pressure Gradient Analysis

An attempt was made to correlate the surface pressure gradient and occurrence of Types 0, 1, 2 and 3 days. These data are displayed in Table 5.12.

TABLE 5.12. AMA Pressure Gradient Versus Surface Wind Type in All Directions

Type		Pressure Gradient-mb 1	2	3	4	5	6	Total
0	No. of Occurrences	3	2	2	9			16
	% of Occurrences	4	2	4	10			
1	No. of Occurrences	4	5	2	0			11
	% of Occurrences	5	5	4				
2	No. of Occurrences	20	19	9	10	0	0	58
	% of Occurrences	26	20	16	11			
3	No. of Occurrences	50	69	44	74	21	8	266
	% of Occurrences	65	73	77	80	100	100	
	Totals	77	95	57	93	21	8	351

This table shows that there was no pattern for a Type 3 day as compared with the 1200 GMT surface pressure gradient. For example a Type 3 day occurred 50 times (out of 77 cases) with a gradient of 1 mb; 69 times (out of 95) with a gradient of 2 mb; 44 times (out of 57) with a gradient of 3 mb; 74 times (out of 85) with a gradient of 4 mb; and 21 times (out of 21) with a gradient of 5 mb.

The data showed that a Type 3 day could occur with any pressure gradient. The data did show that a Type 0 and 1 day did not occur at all if the pressure gradient exceeded 4 mb but this was not considered a useful forecast tool.

These data are also displayed in a 2 x 2 matrix in Figure 5.37.

The preliminary conclusion was that the pressure gradient at AMA was not a useful tool in forecasting the wind power type.

Because of the poor results the isobaric orientation was divided into four quadrants. Once again the results confirmed the above preliminary conclusion. The 000^{o}-090^{o} direction occurred 64 times or 19%; 090^{o}-180^{o}, 63 times or 18%; 180^{o}-270^{o}, 157 times or 46%; 270^{o}-360^{o}, 57 times or 17%.

The surface wind at 1200 GMT was logged along with the 1200 GMT pressure gradient and IO. The average hourly wind speed was determined and plotted against the pressure gradient. These data are presented in Figure 5.38.

The data show that as the 1200 GMT pressure gradient increases the 1200 GMT surface wind also tends to increase. Furthermore if the pressure gradient is equal to or less than 3 mb, the 1200 GMT surface wind is equal to or less than 7 m/s for all quadrants except 180^{o}-270^{o}.

This can be used as a forecast parameter as long as the synoptic pattern remains unchanged. This concept is discussed more fully in Section 4.

At this point no further effort was spent on the pressure gradient analysis. It is useful to note that this parameter, the pressure gradient, was one of the best forecast parameters for both MTP and LDM and yet a very poor forecast parameter for AMA.

5.5.5 Data Stratification - Meteorological/Synoptic

The data for AMA was stratified using synoptic Types A, B, C, D and E in a manner similar to the description given earlier in this report (Data Stratification-Meteorological/Synoptic) and discussed further in Section 5.3.5. These data are presented in Table 5.13.

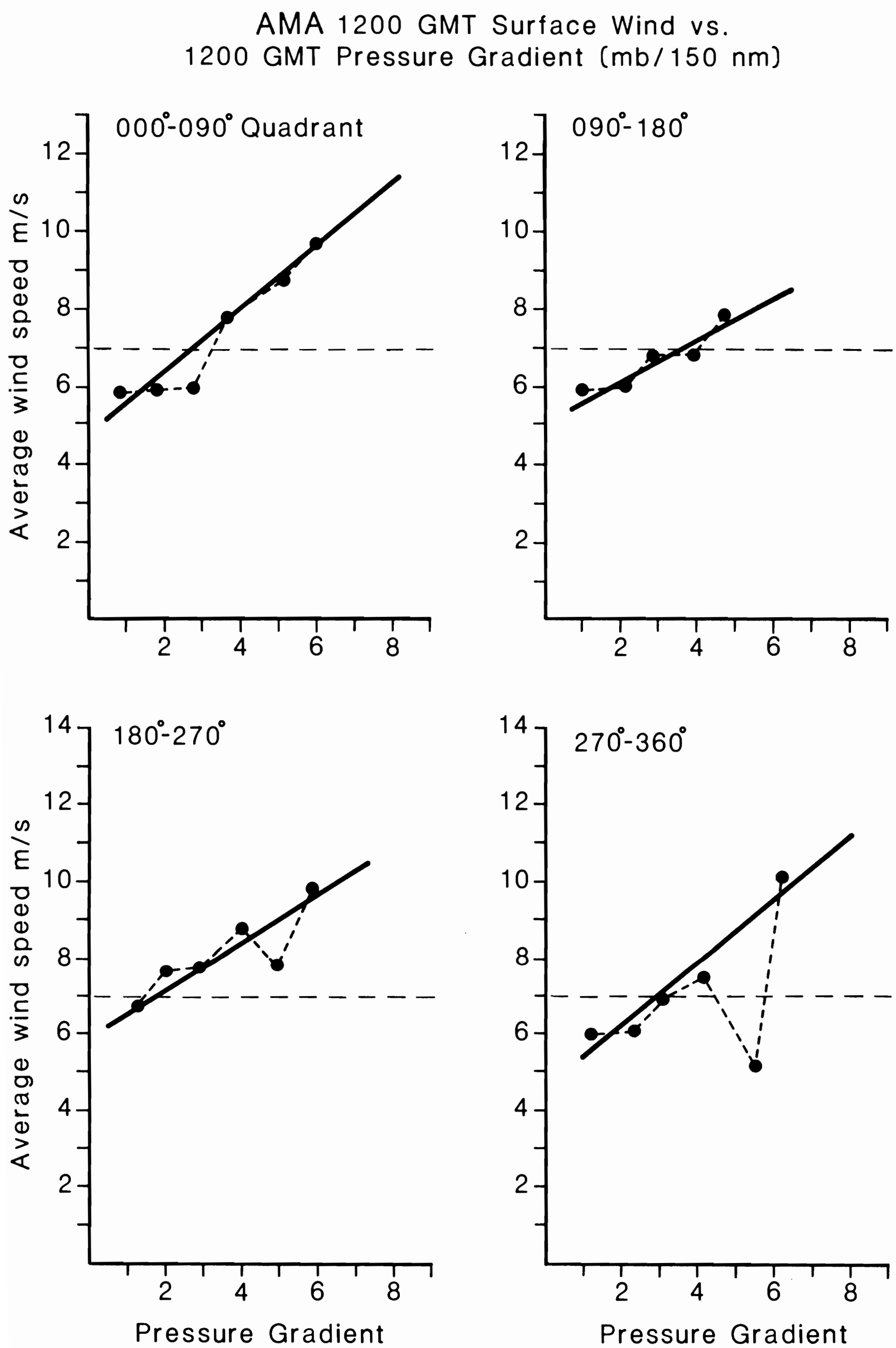


FIGURE 5.38. Surface Wind Speed Versus Pressure Gradients at 1200 GMT at AMA

TABLE 5.13. Stratification of Synoptic Types A, B, C, D and E at AMA

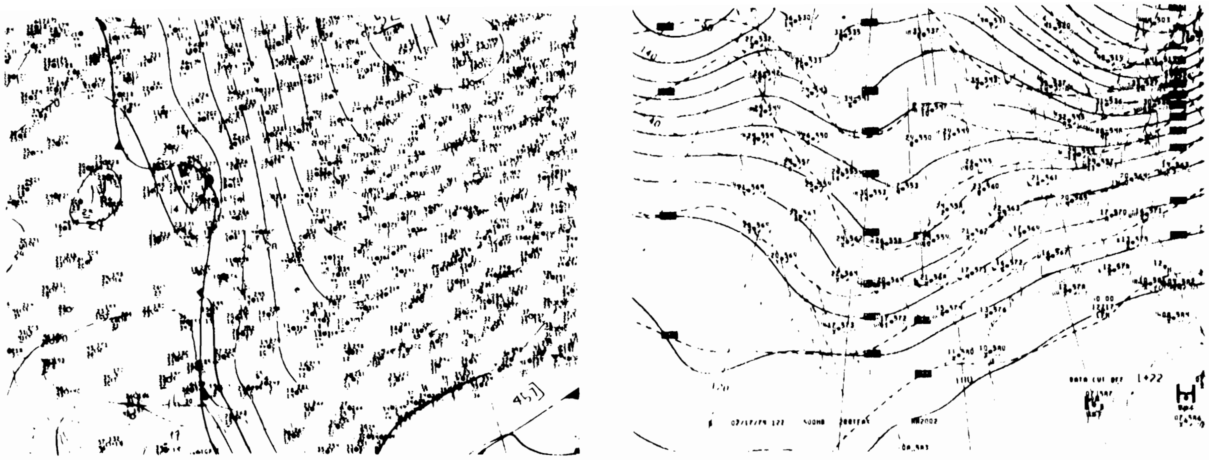
Mon	Avail Days	Poss Days	Type A No.	Type A %	Type B No.	Type B %	Type C No.	Type C %	Type D No.	Type D %	Type E No.	Type E %	Msg
Jan	18	31	0	0	7	39	7	39	4	22	0	0	13
Feb	28	28	1	4	10	36	9	32	8	28	0	0	0
Mar	25	31	1	4	7	28	15	60	1	4	1	4	6
Apr	30	30	0	0	10	33	17	57	3	10	0	0	0
May	31	31	0	0	8	26	16	52	6	19	1	3	0
Jun	30	30	1	3	13	43	14	47	2	7	0	0	0
Jul	31	31	2	6	13	42	14	45	2	6	0	0	0
Aug	31	31	0	0	8	26	14	45	9	29	0	0	0
Sep	27	30	1	4	11	41	14	52	1	4	0	0	3
Oct	31	31	0	0	5	16	21	68	3	10	2	6	0
Nov	30	30	1	3	14	47	10	33	5	17	0	0	0
Dec	31	31	1	3	16	52	11	35	2	6	1	3	0
TOT	343	365	8	2	122	36	162	47	46	13	5	1	22

The table shows that Type A and Type E rarely occurred and that Type C occurred 47% of the observed cases. Examples of each type are listed below with additional cases in Appendix C.

5.5.5.1 Type A

All eight situations that produced a Type A day were associated with weak ridges or a high centered near AMA.

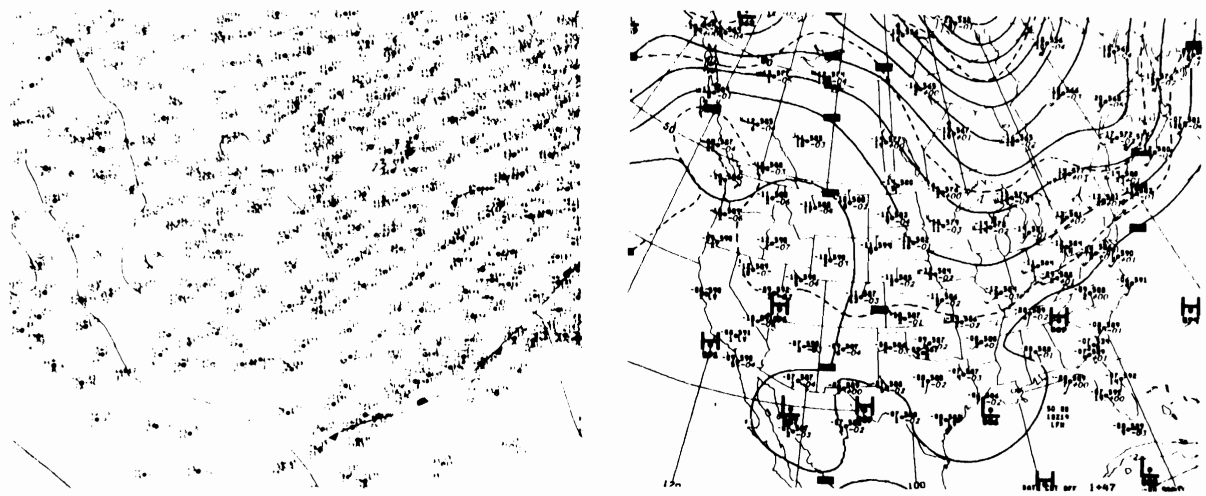
An example of a Type A day is shown in Figure 5.39. A weak ridge was located east of AMA with a low in Wyoming.



(A) (B)

FIGURE 5.39. Example of a Type A Day at AMA at 1200 GMT on February 17, 1979. (A)Surface Map (B)500-mb

A further example of a Type A day is shown in Figure 5.40. A high pressure system extended from northern New Mexico to New England.



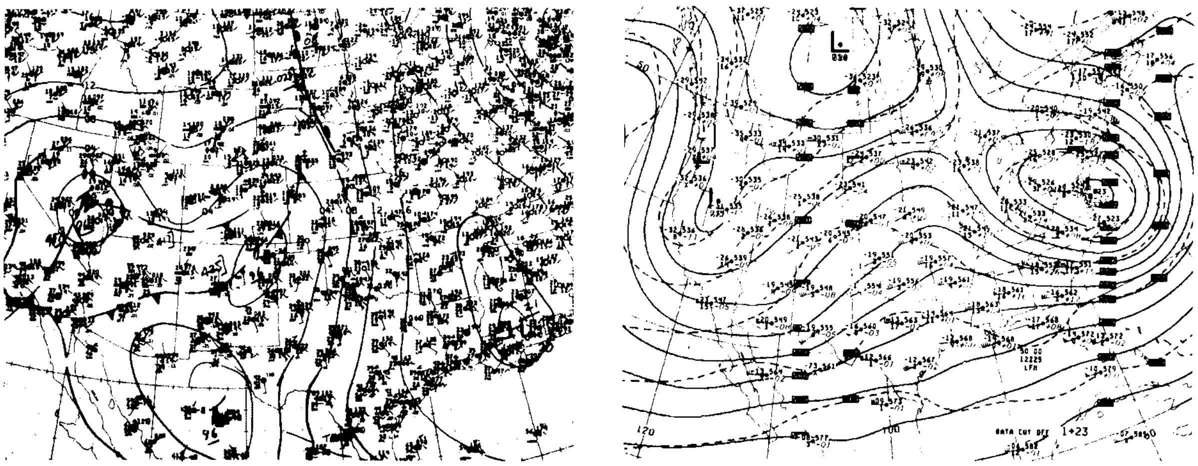
(A) (B)

FIGURE 5.40. Example of a Type A Day at AMA at 1200 GMT on July 19, 1979. (A)Surface Map (B)500-mb

Additional examples are shown in Appendix C.

5.5.5.2 Type B

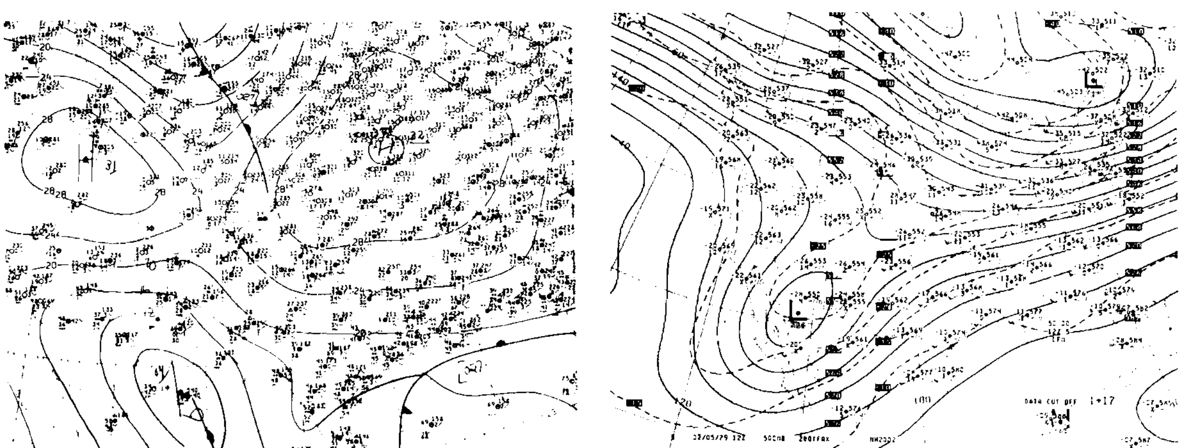
There were a wide variety of synoptic situations including highs, lows and frontal systems which were typical of Type B days. An example of a Type B day is shown in Figure 5.41. A cold front was located west of AMA with a high over Mississippi giving a southerly gradient across the AMA area.



(A) (B)

FIGURE 5.41. Example of a Type B Day at AMA at 1200 GMT on January 25, 1979. (A)Surface Map (B)500-mb

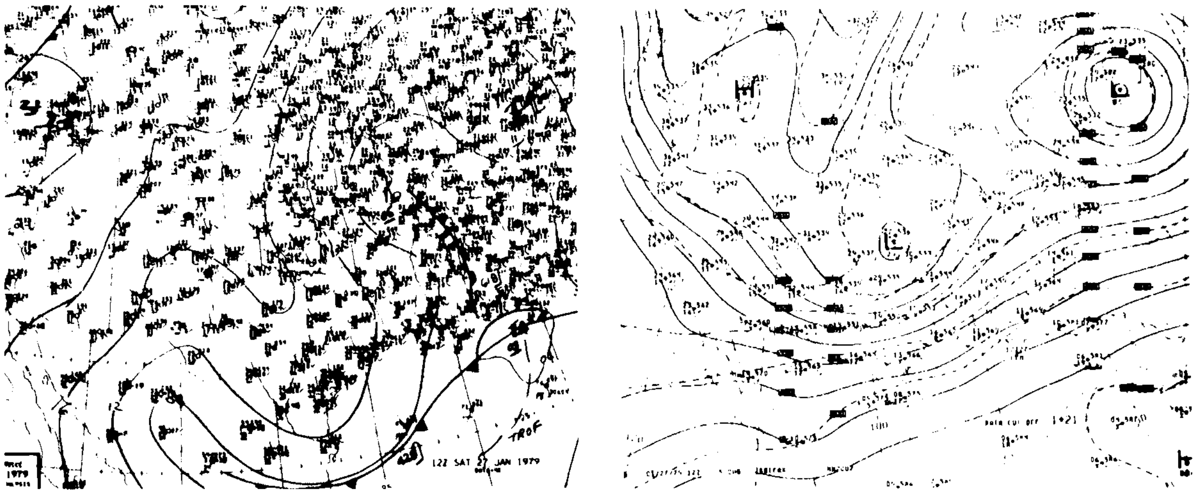
A second example of a Type B day is shown in Figure 5.42. A 1033 mb high was centered over Missouri with an easterly flow of air over the Texas- Oklahoma Panhandle.



(A) (B)

FIGURE 5.42. Example of a Type B Day at AMA at 1200 GMT on February 5, 1979. (A)Surface Map (B)500-mb

A third example of a Type B day is shown in Figure 5.43. A ridge of high pressure extended southward from North Dakota into western Oklahoma and central Texas. There was a weak inverted trough over New Mexico. A closed low at 500-mb was located over southeast Kansas.



(A) (B)

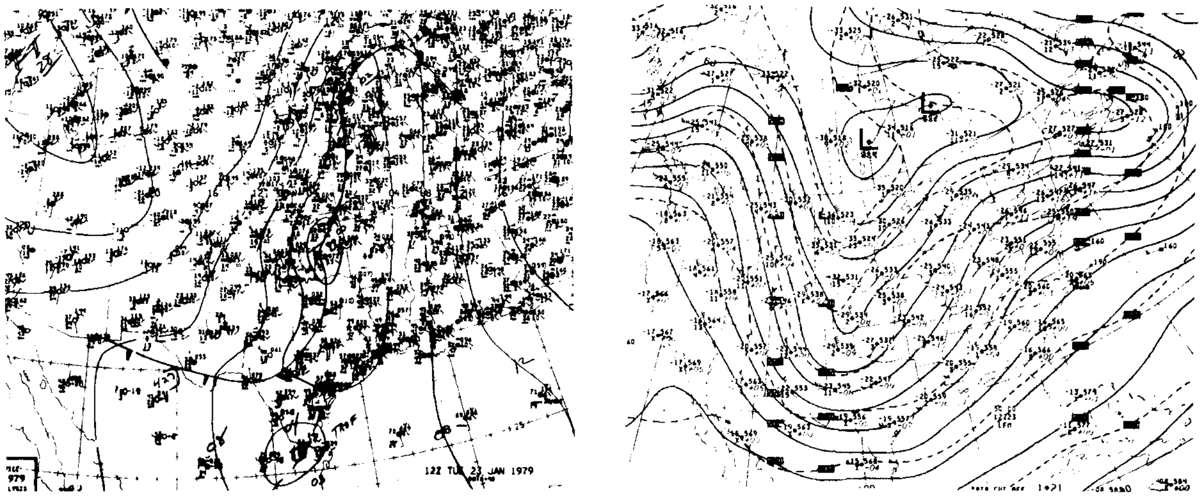
FIGURE 5.43. Example of a Type B Day at AMA at 1200 GMT on January 27, 1979. (A)Surface Map (B)500-mb

Additional examples are given in Appendix C.

5.5.5.3 Type C

Type C days also included a wide variety of synoptic situations.

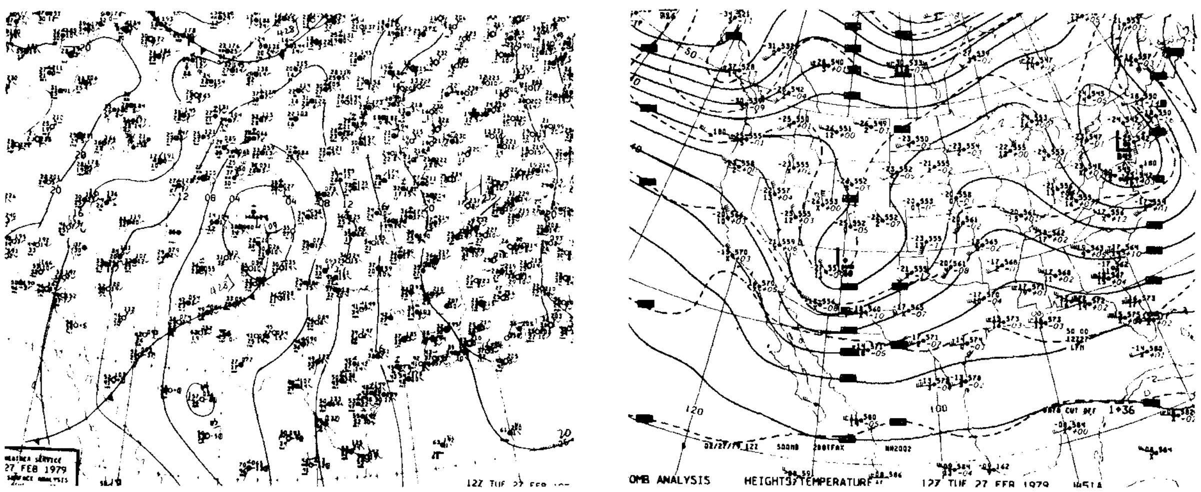
An example of a Type C day is shown in Figure 5.44. There was a deepening low over eastern Oklahoma with a northeast IO over AMA. A 500-mb trough was oriented N-S through the Texas Panhandle.



(A) (B)

FIGURE 5.44. Example of a Type C Day at AMA at 1200 GMT on January 23, 1979. (A)Surface Map (B)500-mb

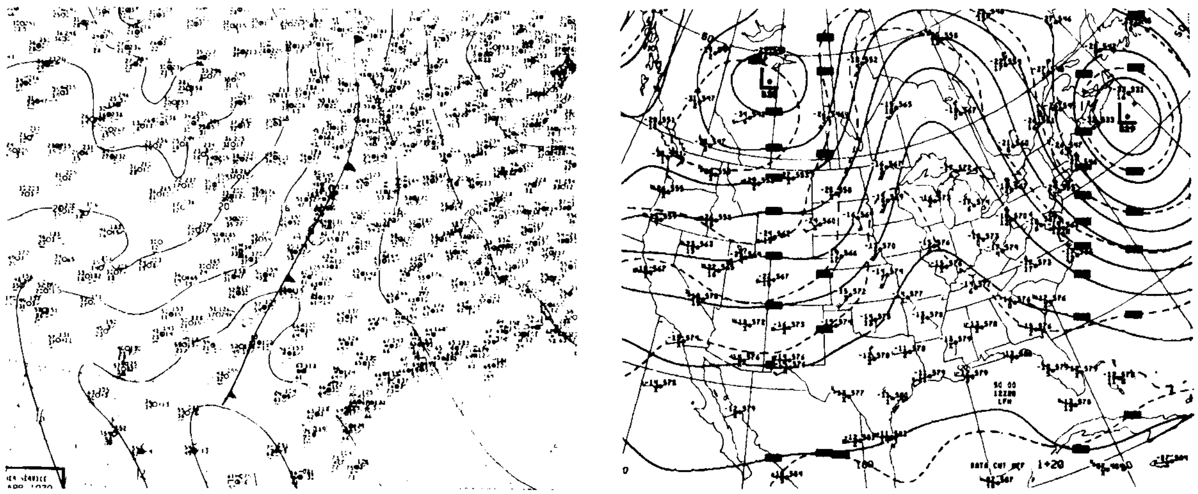
A second example of a Type C day is shown in Figure 5.45. A low was centered over southeastern Colorado giving a southerly IO over AMA. The low had been moving toward the SE. A 500-mb trough extended from Montana to New Mexico.



(A) (B)

FIGURE 5.45. Example of a Type C Day at AMA at 1200 GMT on February 27, 1979. (A)Surface Map (B)500-mb

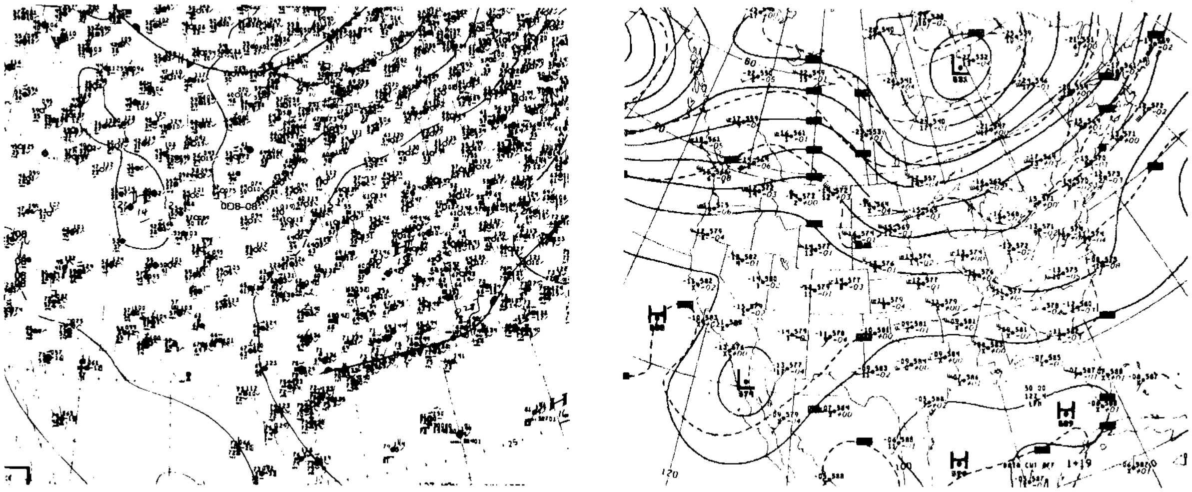
A third example of a Type C day is shown in Figure 5.46. A cold front was located from Minnesota into Texas just to the east of AMA. A high was centered over Wyoming resulting in a NE-SW IO over AMA. At 500-mb there was a SWT from Montana to New Mexico.



(A) (B)

FIGURE 5.46. Example of a Type C Day at AMA at 1200 GMT on April 20, 1979. (A)Surface Map (B)500-mb

A fourth example of a Type C day is shown in Figure 5.47. A weak trough was located west of AMA with a weak high over Arizona and another weak high over Tennessee. At 500-mb there was a closed low over the Baja Peninsula and a ridge over AMA.



(A) (B)

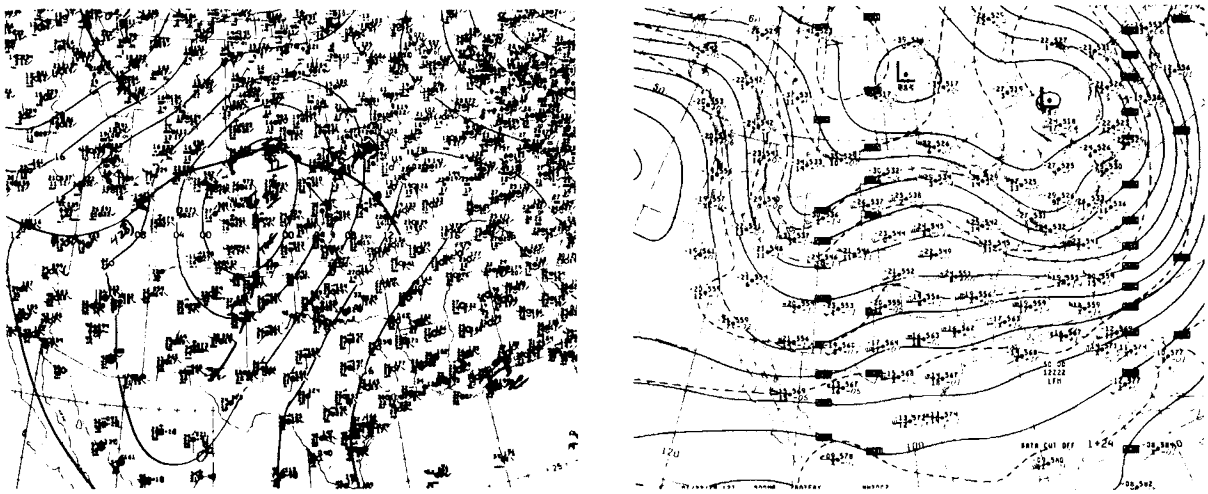
FIGURE 5.47. Example of a Type C Day at AMA at 1200 GMT on June 4, 1979. (A)Surface Map (B)500-mb

These four examples illustrate the wide variety of synoptic situations that can produce a Type C day at AMA.

5.5.5.4 Type D

Type D was frequently (but not always) associated with a low over the Rocky Mountains and a ridge over Mississippi Valley.

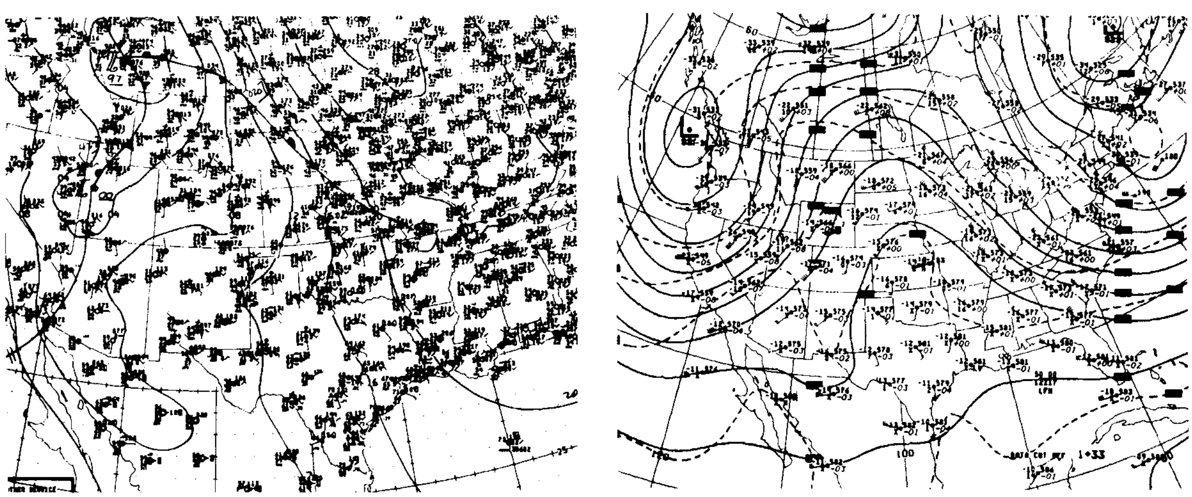
An example of a Type D situation is shown in Figure 5.48. A strong low was centered in northeastern Colorado with a strong SW-NE IO over the Texas Panhandle. At 500-mb there was a SWT from Montana to Arizona. Note that this situation is similar to the February 27 situation in Figure 5.45 except that the pressure gradient is greater in this case.



(A) (B)

FIGURE 5.48. Example of a Type D Day at AMA at 1200 GMT on January 22, 1979. (A)Surface Map (B)500-mb

A second example of a Type D situation is shown in Figure 5.49. There was a ridge of high pressure from Minnesota southward into Alabama. A low was centered over western Montana with a secondary low over Utah. These two systems combined to give an increasing southerly IO across AMA. At 500-mb there was a weak SWT over New Mexico with a strong trough approaching the California coast.



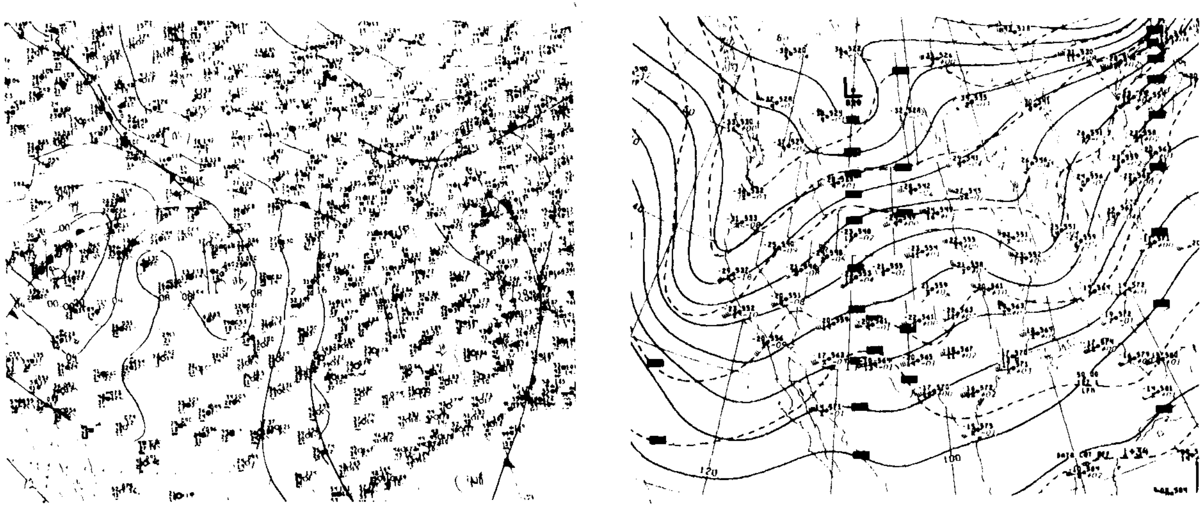
(A) (B)

FIGURE 5.49. Example of a Type D Day at AMA at 1200 GMT on April 17, 1979. (A)Surface Map (B)500-mb

5.5.5.5 Type E

All five cases of Type E were associated with a deep surface low and its associated strong pressure gradient.

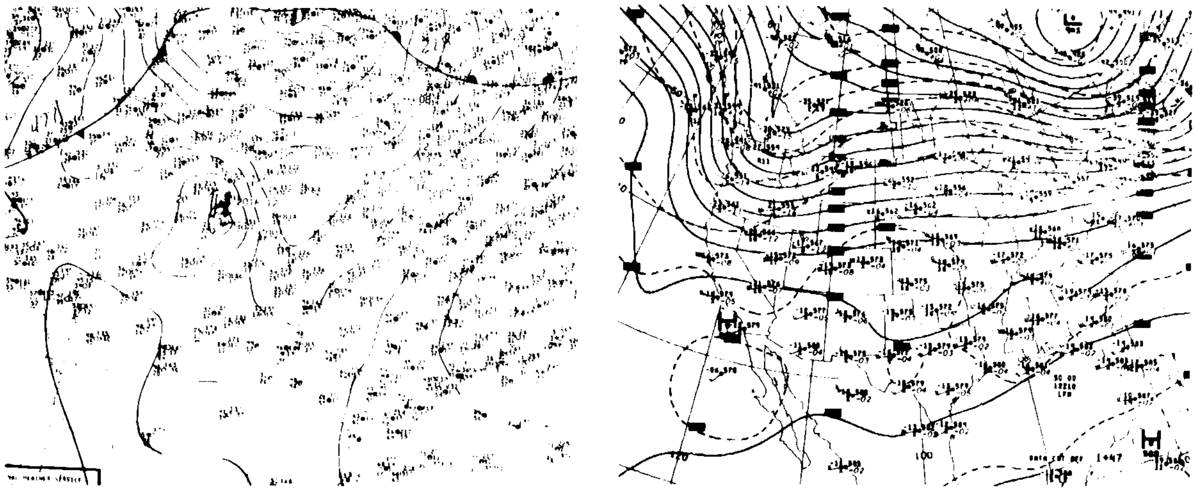
An example of a Type E situation is shown in Figure 5.50. There was a weak trough over Colorado along with a deepening low over Nevada. At 500-mb a vigorous SWT was entering the California coast. The pressure gradient increased during the next 24 hr period and continued to indicate a strong gradient as the low moved eastward into the Great Plains. This resulted in a prolonged period of strong winds typical of a Type E situation.



(A) (B)

FIGURE 5.50. Example of a Type E (extended period of strong winds) at AMA at 1200 GMT on March 1, 1979. (A)Surface Map (B)500-mb

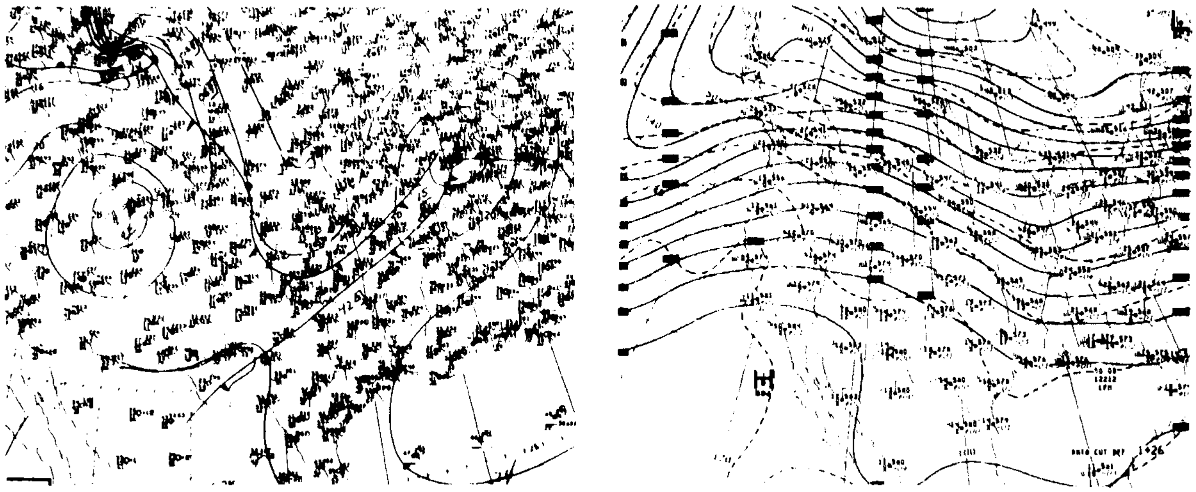
A second example is shown in Figure 5.51. An elongated deep low was stretched from Montana to North Dakota with a strong SW-NE IO over AMA. A weak high was located over western Colorado. At 500-mb a vigorous SWT extended from Washington to California. As the SWT moved eastward and deepened the surface low increased the pressure gradient over AMA. The result was an extended period of strong winds. This example illustrates that the familiar deepening low moving into Colorado is not the only synoptic pattern to produce a Type E situation at AMA.



(A) (B)

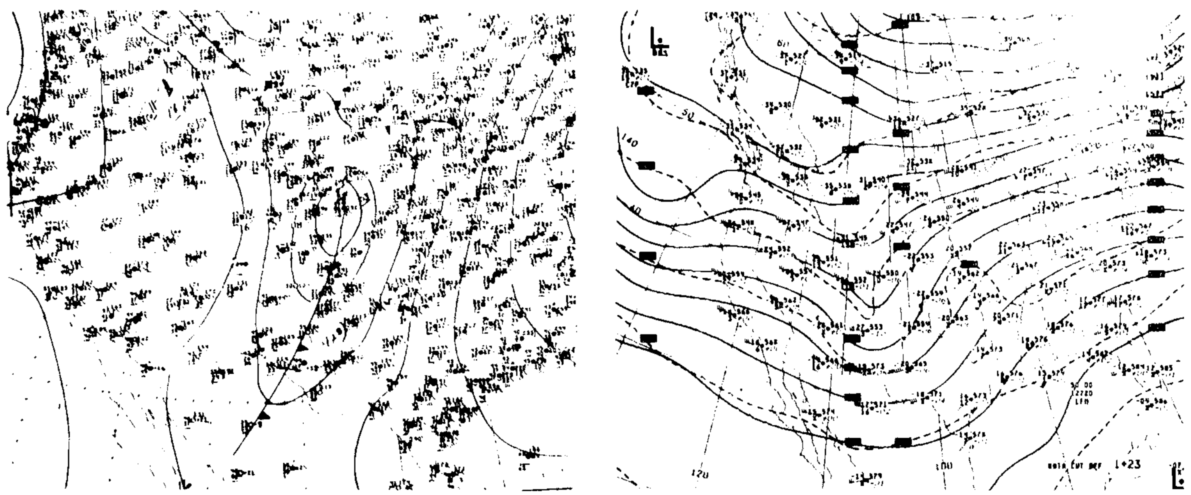
FIGURE 5.51. Example of a Type E Day at AMA at 1200 GMT on December 10, 1979. (A)Surface Map (B)500-mb

In addition to the above examples two further examples are given. An example of a Type 1 (and Type A) situation (light winds) is shown in Figure 5.52. The surface B-A type = 35 (flat pressure area); the 500-mb B-A = 14 (meridional ridge, preridge). An example of a Type 3 situation (strong, persistent winds) is shown in Figure 5.53. The surface B-A = 24 (meridional trough, pretrough); the 500-mb B-A = 9 (meridional trough, pretrough). The February 20 situation was one of a series of systems moving across the AMA area. Type 3 winds persisted for ninety-six consecutive hours from February 19 through February 22.



(A) (B)

FIGURE 5.52. Example of a Type 1 Day (Light Winds) at AMA at 1200 GMT on February 12, 1979. (A)Surface Map (B)500-mb



(A) (B)

FIGURE 5.53. Example of a Type 3 Day (Strong, Persistent Winds) at AMA at 1200 GMT on February 20, 1979. (A)Surface Map (B)500-mb

5.5.6 Conclusions

1. The 1200 GMT 850-mb wind speed is an excellent parameter for forecasting the occurrence of a Type 3 day. When the 850-mb speed was equal to or greater than 15 kts a Type 3 day occurred 88% of the time. When the 850-mb speed was equal to or greater than 20 kts a Type 3 day occurred 99% of the time.

2. The 1200 GMT 850-mb wind is a useful tool for forecasting the maximum wind in the next 24 hours. Although there was considerable variation, the average maximum wind was 81% of the 850-mb wind.

3. The 1200 GMT pressure gradient showed little correlation to the occurrence of a Type 3 day. Furthermore, it showed little correlation to any surface wind speed at AMA.

5.6 SITE 4: SAN GORGONIO PASS, CA (SAG)

Although an attempt was made to follow the general outline used above with MTP, LDM and AMA, some changes were made in the SAG presentation. This was due to the unique location and resulting wind patterns at SAG.

5.6.1 Data Stratification - Statistical

As in the above three sites the data were stratified and summarized by months for 1) the number and percentage of hours the wind speeds were equal to or greater than 7 m/s, (A); and 2) the number and percentage of the type of windpower day, (B). These data are presented in Table 5.14.

TABLE 5.14. Stratification of Wind Speeds at SAG, Types 0, 1, 2 and 3

Mon	Hours Avail Obs	(A) Winds Poss Obs	≥7 mps Actual Obs	%	(B) Days Avail Obs	Type 0 No	Type 0 %	Type 1 No	Type 1 %	Type 2 No	Type 2 %	Type 3 No	Type 3 %
Jan	744	744	116	16	31	18	58	4	13	2	6	7	23
Feb	.672	672	266	40	28	7	25	5	18	1	4	15	53
Mar	720	744	328	46	30	5	17	5	17	3	10	17	56
Apr	690	720	483	70	29	0	0	0	0	8	28	21	72
May	744	744	415	56	31	2	6	2	6	6	19	21	68
Jun	469	720	301	64	20	0	0	1	5	2	10	17	85
Jul	727	744	431	59	31	1	3	3	10	5	16	22	71
Aug	345	744	229	66	16	1	6	2	12	2	12	11	69
Sep	662	720	214	34	29	6	21	3	10	9	31	11	38
Oct	744	744	406	55	31	2	6	3	10	6	19	20	65
Nov	688	720	239	35	29	6	21	2	7	9	31	12	41
Dec	744	744	146	20	31	15	52	3	10	6	19	6	19
TOT	7949	8760	3574	45	336	64	19	33	10	59	18	180	53

The maximum number of hours of wind speeds equal to or greater than 7 m/s occurred at SAG in the spring and summer with a second peak in October. April showed 70%; August, 66%; October, 55%. The minimum of 16% occurred in January with 20% in December.

The same pattern occurred when the data were classified as Type 0, 1, 2 and 3 days. For example in June 85% of the days were Type 3. In January, 64% of the days were Type 0.

The data were also classified in a more meteorological manner with less consideration given to wind turbine operation. The SAG wind types are similar to those of MTP, LDM and AMA with respect to speed but have some differences due to the unique topography surrounding the site.

5.6.1.1 Type A

All Type A wind speeds were less than 7 m/s for a period equal to or greater than 24 hours.

5.6.1.2 Type B

All Type B wind speeds were equal to or greater than 7 m/s for less than 24 hours with the direction remaining WSW throughout and after the episode.

5.6.1.3 Type C

Wind speeds for Type C were equal to or greater than 7 m/s for less than 24 hours. The wind direction was SW or WSW when the speed was equal to or greater than 7 m/s but the direction shifted to an easterly component when wind speed was light. The wind shift and speed dropoff usually occurred in the morning.

5.6.1.4 Type D

Wind speeds were equal to or greater than 7 m/s for a period equal to or greater than 24 hours with the direction remaining SW or WSW. Brief periods (3 hours or less) where winds were less than 7 m/s were permissable but direction must remain SW or WSW.

5.6.1.5 Type E

All Type E wind speeds were equal to or greater than 7 m/s with direction from NW to NE.

A list of the dates and times of occurrence of Types B, C, D and E is contained in Appendix B.

Table 5.15 summarizes the results of the synoptic classification for SAG.

TABLE 5.15. Summary of Synoptic Classification, Types B, C, D, E at SAG

Month	Hrs. Data Avail.	Number of Hours Occurred							
		Type D	%	Type B	%	Type C	%	Type E	%
Jan	744	0		104		0		24	
Feb	672	230		16		0		10	
Mar	720	312		35		10		4	
Apr	690	417		8		54		3	
May	744	324		0		84		3	
Jun	469	222		0		70		0	
Jul	727	323		0		100		0	
Aug	345	218		12		6		0	
Sep	662	149		0		95		0	
Oct	744	341		13		47		1	
Nov	688	134		4		3		74	
Dec	744	100		8		0		16	
TOTAL	7949	2770	7	200	6	469	13	135	4

Type D clearly dominates with 77% of the total hours equal to or greater than 7 m/s falling into this category. Type D dominates in every month except January, when the closely related Type B predominates. Type D peaks in spring with a secondary maximum in October. Type C peaks in summer while Type E occurs mostly in the winter.

An analysis by direction was made of the maximum hourly wind for each day and is shown in Table 5.16.

TABLE 5.16. SAG Average Monthly Maximum Wind Speed by Directions (m/s)

Month	Southwest # Days	Southwest %	Southwest Speed	Northwest # Days	Northwest %	Northwest Speed	East # Days	East %	East Speed	# Days Reported
Jan	13	42	10	10	32	6	8	26	5	31
Feb	17	61	15	7	25	6	4	14	5	28
Mar	25	81	13	4	13	6	2	6	7	31
Apr	28	97	15	1	3	9	0	0	-	29
May	28	90	15	2	7	6	1	3	6	31
Jun	20	100	15	0	0	-	0	0	-	20*
Jul	28	90	14	1	3	6	2	7	7	30
Aug	15	100	13	0	0	-	0	0	-	15*
Sep	22	73	11	4	13	6	4	13	5	30
Oct	25	81	14	4	13	7	2	6	7	31
Nov	10	34	14	17	59	7	2	7	7	29
Dec	8	26	14	22	71	6	1	3	5	31
Annual	239	71	14	72	21	7	26	8	6	

* Southwest would have been a bit more predominant since most missing data were in summer months.

The predominance of SW winds was again apparent. NW and E winds are mainly a winter phenomena. The average speed of the maximum wind was 14 m/s for SW winds, 7 m/s for NW and 6 m/s for E.

5.6.2 Booz-Allen (B-A) Classification

The number of hours when the wind speed was equal to or greater than 7 m/s was compared with the B-A surface and 500-mb types. Surface and 500-mb charts were analyzed at 1200 GMT and the number of hours equal to or greater than 7 m/s for the subsequent 24 hours were logged for that surface and 500-mb B-A type. These data were examined by months. The surface maps showed a predominance of pre- and post-frontal B-A Types 12 and 13 and Type 28, inverted troughs centered east of SAG. Together these three types accounted for 87% of the hours when the speed was equal to or greater than 7 m/s. Frontal types were predominant in winter. The inverted trough was predominant in the summer with a mixture in the spring and fall. The 500-mb types showed a preference for pretrough situations (B-A Types 1, 3, 5, 7, 9 and 12). These types occurred 58% of the time. Posttrough (Types 2, 4, 6, 8, 10 and 13) accounted for 31% of the time; westerly flow (Type 11), 11%; and post-meridional ridge (Type 15), 8%.

These B-A types were also compared with the data stratification system consisting of Types 0, 1, 2 and 3. Since surface Type 28 (inverted trough, posttrough) occurred frequently, a comparison of B-A 500-mb types for Type 28 was made. The upper-air types were divided at Type 13 (post minor trough) to see if the upper-air pattern had an effect on the surface wind speed. B-A 500-mb Type 13 or less was associated with stronger upper-air patterns. The comparison is summarized below:

500-mb B-A Type	Type 0-1	Type 2	Type 3
equal to or less than 13	7 (7%)	13 (13%)	81 (80%)
greater than 13	13 (31%)	9 (21%)	20 (48%)
TOTAL	20 (14%)	22 (15%)	101 (71%)

When the surface B-A type was 28, a strong preference for Type 3 occurred. The influence of the upper-air pattern is evident with stronger patterns (B-A Type 13 or less) giving a high percentage (80%) of Type 3.

Surface Type 28 was also compared with its opposite Type 27 (inverted trough, pretrough) and with weak surface patterns Types 29 through 35. The results are summarized below:

Surface B-A Type	Type 0-1	Type 2	Type 3
27 (pretrough)	28 (67%)	6 (14%)	8 (19%)
28 (posttrough)	20 (14%)	22 (15%)	101 (71%)
29-35	35 (65%)	8 (15%)	11 (20%)

B-A Type 27 is unfavorable for a Type 3 day. B-A Types 29 through 35 (which occur with weak pressure gradients) are also unfavorable for a Type 3 day.

The synoptic Types A, B, C, D and E were classified according to the B-A system. The results are discussed below.

For Type D (at least 24 hours equal to or greater than 7 m/s with direction of wind from the SW) surface B-A Type 12 (open wave cyclone moving SE or S, center North, pre-cold frontal and cold frontal), Type 13 (post-cold front) and Type 28 (inverted post-trough) were predominant. These three types accounted for ninety percent of the Type D occurrence. Strong 500-mb patterns also were predominant with 500-mb B-A Type 10 or less accounting for seventy-seven percent of the Type D occurrences.

Type B had only 15 occurrences so no conclusions were drawn.

Type C showed a strong preference for surface Type 28 with 86% of the Type B occurrences. Type C occurred much more frequently with weak 500-mb patterns than did Type D. B-A types 10 or less accounted for only thirty-eight percent of the Type C occurrences.

There were twenty-two Type E situations. B-A surface Type 27 accounted for forty-five percent of the cases. The 500-mb types were about evenly split between strong and weak types.

The B-A classification for days when the average hourly wind did not exceed 7 m/s was analyzed. Weak surface patterns predominated with Types 27 and Types 31 through 35 accounting for 66% of the total days. Weak upper-air patterns were common with the B-A types greater than 13 accounting for sixty-six percent of the total days.

5.6.3 Pressure Gradient Analysis

The value of the surface pressure gradient as a predictor of occurrence of Type 3 wind conditions was tested. The pressure gradient was measured by determining the difference in pressure between Los Angeles (LAX) and Las Vegas (LAS). This method was chosen because almost all strong wind cases had a pressure gradient in that direction. The period of prediction was the 24 hours beginning at noon local time. This period was chosen to most closely approximate the actual diurnal wind pattern at SAG, i.e. minimum wind speed in the morning hours, maximum wind speed in evening hours. The pressure gradient was determined for 1200 GMT, 1500 GMT, 1800 GMT, 2100 GMT and 0000 GMT (0400, 0700, 1000, 1300 and 1600 LST); 2 x 2 matrices for 1500 GMT and 2100 GMT are presented in Figure 5.54.

SAG Pressure Gradient vs. Type 3 Days

Time = 1500 GMT

Pressure gradient ≥1-mb	Yes	No
Yes	130	25
No	29	99

Yes-Yes $= \frac{130}{159} = 82\%$

No-No $= \frac{99}{124} = 80\%$

Pressure gradient ≥3-mb	Yes	No
Yes	89	66
No	8	120

Yes-Yes $= \frac{89}{97} = 92\%$

No-No $= \frac{120}{186} = 65\%$

Time = 2100 GMT

Pressure gradient ≥1-mb	Yes	No
Yes	154	13
No	48	85

Yes-Yes $= \frac{154}{202} = 76\%$

No-No $= \frac{85}{98} = 87\%$

Pressure gradient ≥3-mb	Yes	No
Yes	132	35
No	13	120

Yes-Yes $= \frac{132}{145} = 91\%$

No-No $= \frac{120}{155} = 77\%$

FIGURE 5.54. Verification Matrices for Type 3 Days at SAG Using Pressure Gradients

The diurnal change in the pressure pattern shows clearly that a smaller pressure gradient is needed to produce a Type 3 in the late morning than in the late afternoon. The percent of correct forecasts rises slightly through the day. For example at 1200 GMT the best forecast for a Type 3 day occurred with a pressure gradient equal to or greater than 2 mb; at 1500 GMT, equal to or greater than 1 mb; at 1800 GMT, equal to or greater than 1 mb; at 2100 GMT, equal to or greater than 3 mb; at 0000 GMT, equal to or greater than 3 mb. This shows that 1 mb will produce a Type 3 situation at 1500 GMT and 1800 GMT but it takes at least 3 mb to produce a Type 3 situation at 2100 GMT and 0000 GMT. This is further illustrated in a series of figures in Appendix C.

The 850-mb height gradient for 1200 GMT (0400) was also tested. The gradient was determined by finding the difference in heights between Vandenburg AFB (72393) and Las Vagas (72387). The correlation was significantly lower than the surface pressure gradient.

The 850-mb wind speed, 700-mb wind speed and 500-mb wind speeds were tested to see if they correlated with the occurrence of Type 3 days but no apparent correlation was observed.

The 1200 GMT surface pressure gradient between LAX and LAS was tested to see if any correlation existed between it and the maximum hourly wind for the 24-hour period beginning at 0000 LST (0800 GMT). The correlation was only fair but a rule-of-thumb was developed for positive pressure gradients:

$$\text{Max wind} = 11 + \text{pressure gradient} \ (\pm 2 \text{ m/s}).$$

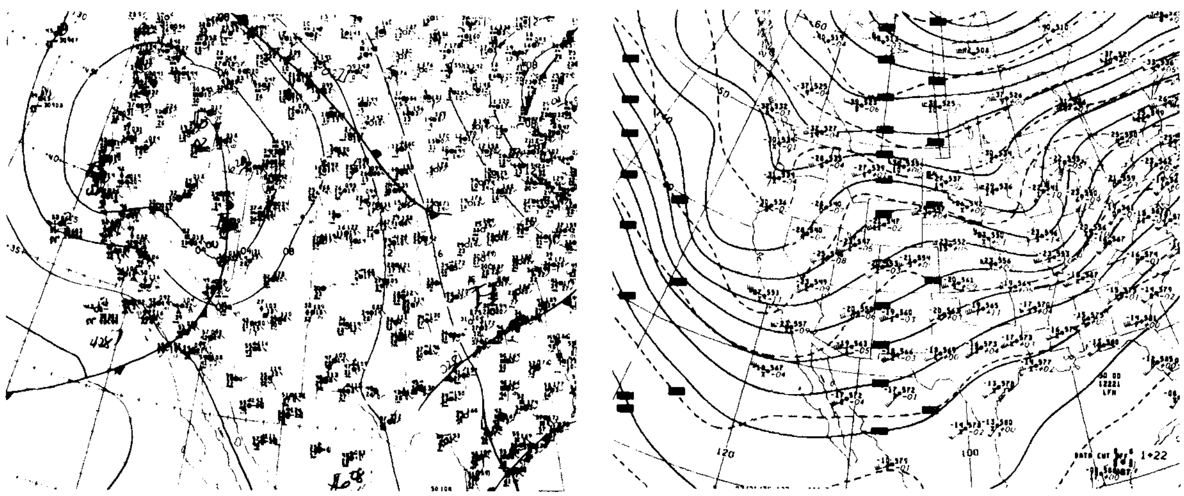
Seventy percent of the days were covered by this approximation.

Examples are given below to show synoptic applications of Types A, B, C, D and E.

5.6.3.1 <u>Type D</u> (wind speed equal to or greater than 7 m/s for a period equal to or greater than 24 hours with WSW wind)

Type D occurred 2770 hours or 78% of the time.

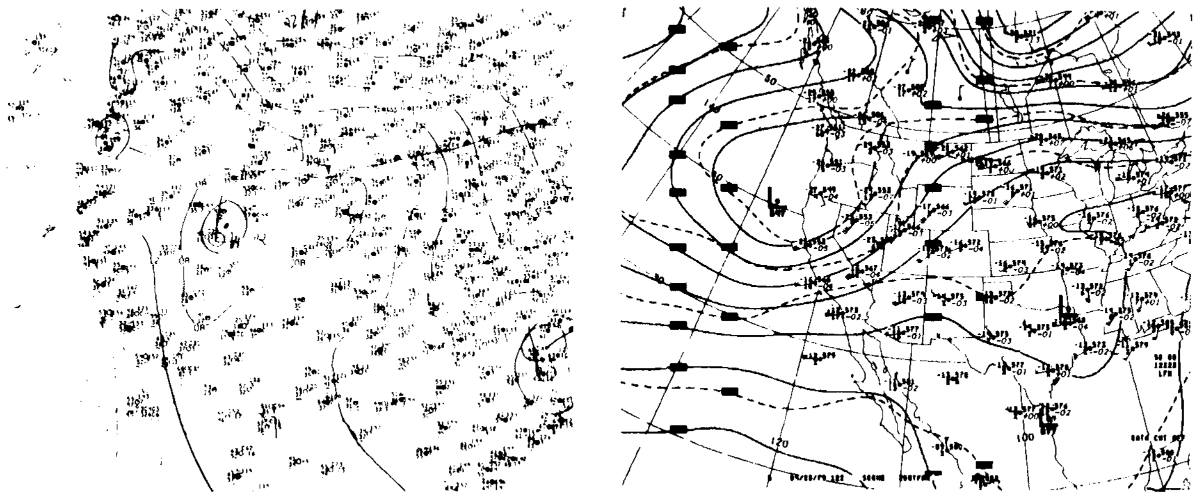
An example of a Type D situation is shown in Figure 5.55. This is a typical moving winter situation. A low extended from Oregon to Nevada with a cold front between LAX and SAG. The pressure gradient between LAX and LAS was 6 mb. SWT at 500-mb was located over California. This situation resulted in one hundred sixteen (116) consecutive hours, 0200 LST February 19 through 2300 LST February 23, of wind speeds equal to or greater than 7 m/s.



(A) (B)

FIGURE 5.55. Example of a Type D Day (Typical Moving Winter Situation) at SAG at 1200 GMT on February 21, 1979. (A)Surface Map (B)500-mb

A second example of a Type D situation is shown in Figure 5.56. This is a typical stagnant spring pattern. A weak low was centered over Utah with a trough east of SAG over Arizona. The pressure gradient between LAX and LAS was 8 mb. There was a 500-mb low off the California coast. This situation resulted in an extended period of 254 hours, 0800 LST April 22 through 0300 LST May 3, of wind speeds equal to or greater than 7 m/s.



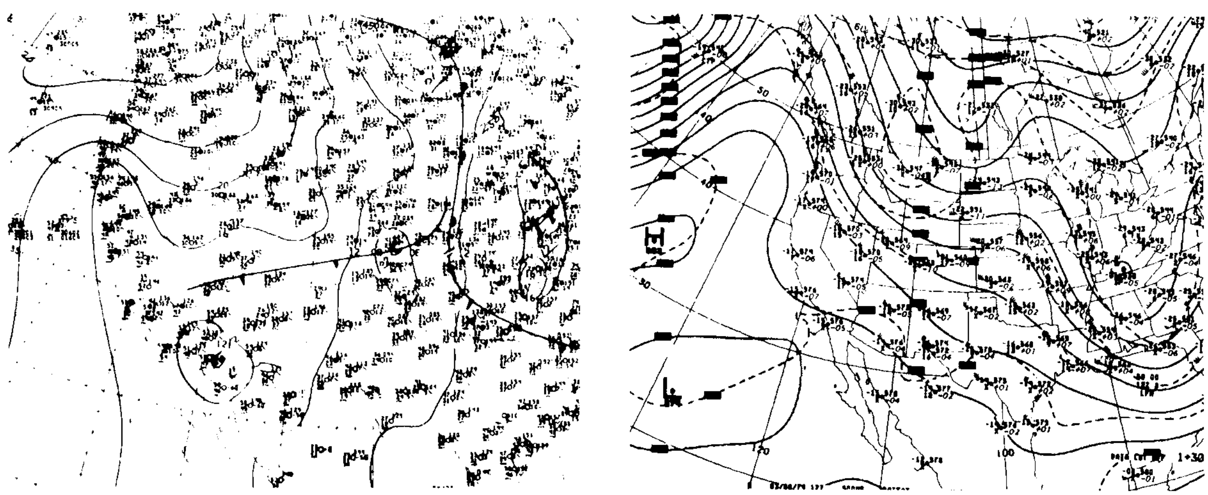
(A) (B)

FIGURE 5.56. Example of a Type D Day (Typical Stagnant Spring Pattern) at SAG at 1200 GMT on April 23, 1979. (A)Surface Map (B)500-mb

5.6.3.2 Type B (wind speed equal to or greater than 7 m/s for less than 24 hours with WSW wind)

Type B occurred 200 hours or approximately 6% of the time.

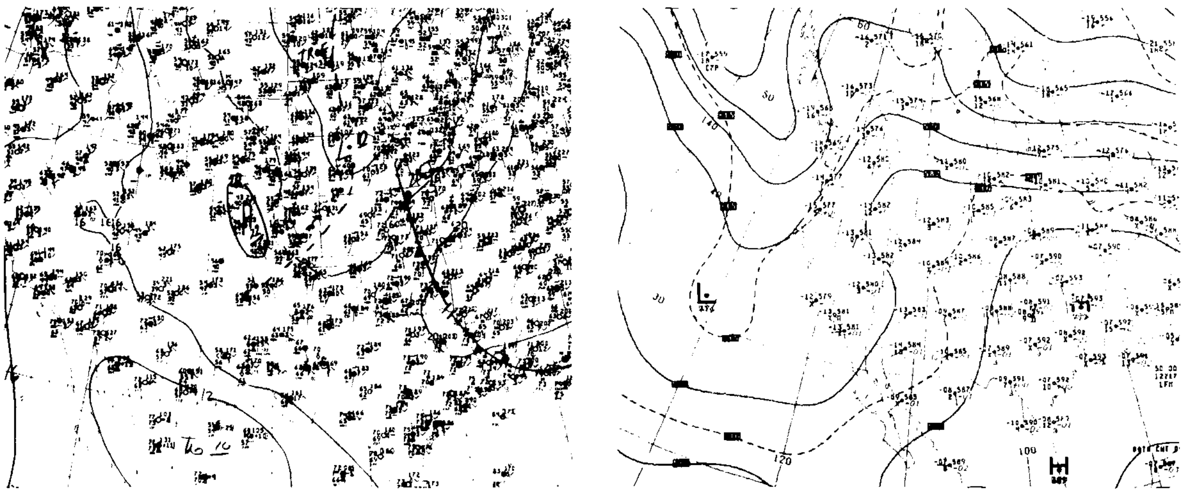
An example of a Type B situation is shown in Figure 5.57. There was a week low over Uma, Arizona. The pressure at LAX was slightly higher than LAS. The flow at 500-mb was light. The wind speed increased to equal to or greater than 7 m/s at 1600 LST. Five hours later at 2000 LST the speed decreased to less than 7 m/s.



(A) (B)

FIGURE 5.57. Example of a Type B Day at SAG at 1200 GMT on March 8, 1979. (A)Surface Map (B)500-mb

A second example of a Type B situation is shown in Figure 5.58. The surface trough was east of SAG with the pressure slightly higher at LAX. At 500-mb there was a weak trough off the California coast. The wind speed increased to equal to or greater than 7 m/s at 1900 LST and decreased to less than 7 m/s at 0600 LST the next morning.



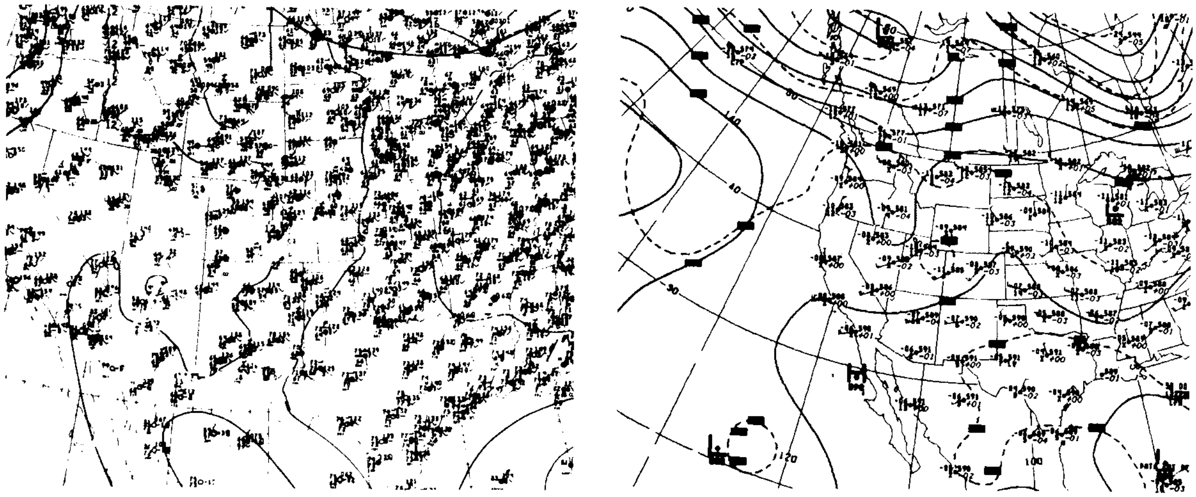
(A) (B)

FIGURE 5.58. Example of a Type B Day at SAG at 1200 GMT on August 17, 1979. (A)Surface Map (B)500-mb

5.6.3.3 Type C (wind speeds equal to or greater than 7 m/s for less than 24 hours - with a wind shift to the E)

Type C occurred for 469 hours or 13% of the time with a peak in the summer months.

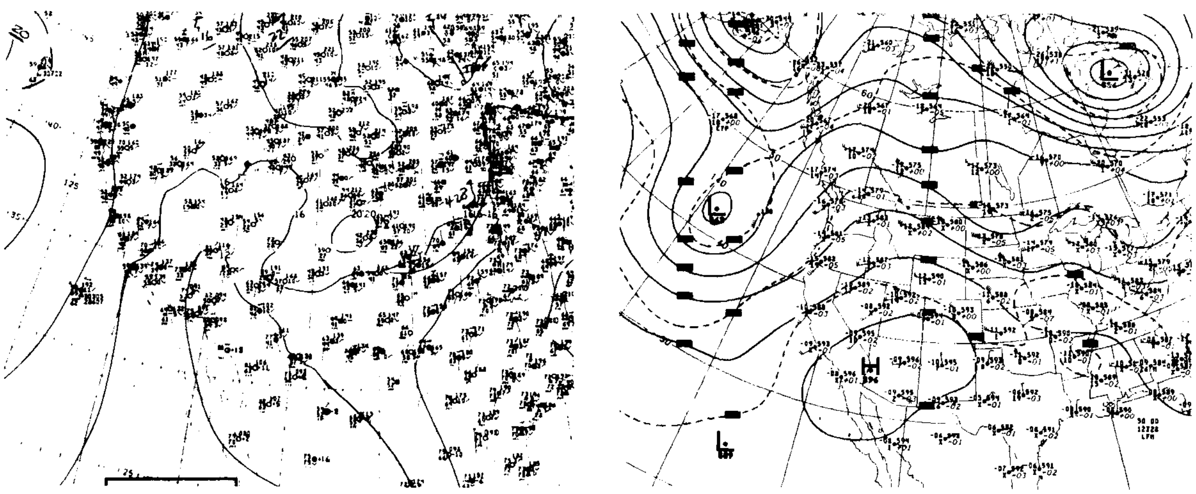
An example of a Type C situation is shown in Figure 5.59. This is a typical example of the wind increasing in the late afternoon, continuing into the night and decreasing early the next morning. There was an inverted trough to the east of SAG with a weak ridge over Utah. At 500-mb there was a weak SWT over Nevada. The wind speed increased to 7 m/s or greater at 1300 LST July 22 and decreased to less than 7 m/s at 0600 LST July 23. There were eighteen consecutive hours of wind speeds equal to or greater than 7 m/s. The wind increased again at 1700 LST July 23.



(A) (B)

FIGURE 5.59. Example of a Type C Day (Wind Increasing in the Early Afternoon and Continuing into the Next Morning) at SAG at 1200 GMT on July 22, 1979. (A)Surface Map (B)500-mb

A second example of a Type C situation is shown in Figure 5.60. There was an inverted trough east of SAG, a weak ridge over Utah and a 500-mb high over Arizona. There were twenty-one consecutive hours of wind speeds equal to or greater than 7 m/s beginning at 1000 LST June 28 and continuing through 0600 LST June 29.



(A) (B)

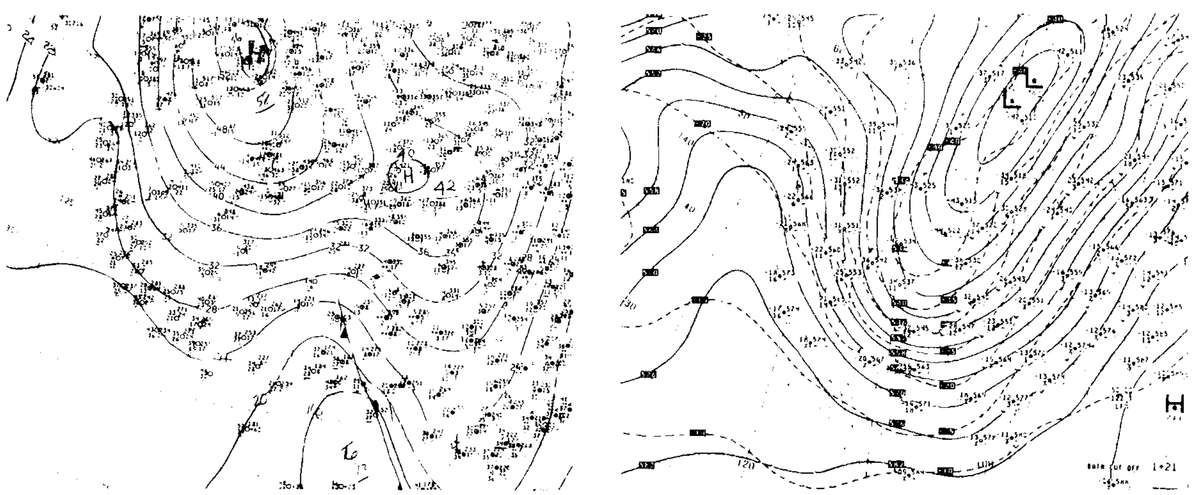
FIGURE 5.60. Example of a Type C Day at SAG at 1200 GMT on June 28, 1979. (A)Surface Map (B)500-mb

Both of these examples are typical situations where the wind increased in the late morning or early afternoon, continued into the night and then decreased the following morning. Type B would give a substantial period of wind speeds strong enough to activate a MOD-2 turbine.

5.6.3.4 Type E (wind speed equal to or greater than 7 m/s - direction NW to NE)

Of the 3574 hours when the wind speed was equal to or greater than 7 m/s, Type E occurred for 135 hours or 4% of the time. It occurred primarily in the months of Nov-Dec-Jan-Feb. Type E was generally associated with a High over the Rocky Mountains.

An example of a Type E situation is shown in Figure 5.61. There was a strong high centered over the Idaho Panhandle with a ridge over SAG. A weak surface trough was off the California coast. The pressure was higher at LAS than LAX. A deep 500-mb trough was located over the Great Plains with a strong ridge off the California coast. There were 24 hours of wind speeds equal to or greater than 7 m/s beginning 0100 LST January 1 and continuing through 0000 LST January 2.

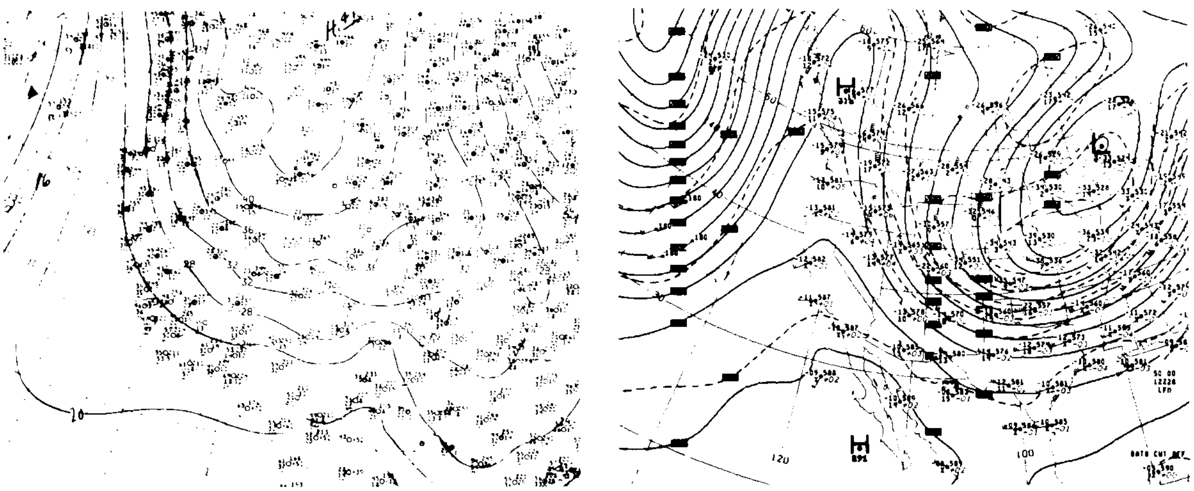


(A) (B)

FIGURE 5.61. Example of a Type E Day (NW to NE winds) at SAG at 1200 GMT on January 1, 1979. (A)Surface Map (B)500-mb

A second example of a Type E situation is shown in Figure 5.62. There was a strong high centered over western Montana with a ridge line extending in Texas. A weak inverted trough was located over Mexico. The surface pressure at LAS was about 10 mb higher than LAX. At 500 mb there was a deep low over Wisconsin and a strong ridge along the west coast. There were thirty consecutive hours of wind speeds equal to or greater than 7 m/s beginning at 1600 LST November 27 and continuing through 0600 LST November 29.

These two examples show the typical Type E situation with a strong high to the north over the Rocky Mountains and a higher pressure at LAS than LAX.



(A) (B)

FIGURE 5.62. Example of a Type E Day at SAG at 1200 GMT on November 28, 1979. (A)Surface Map (B)500-mb

5.6.3.5 Type A (wind speed less than 7 m/s for a period equal to or greater than 24 hours)

An excellent example of a series of Type A days is shown in the graphical wind display in Figure 5.63. The graph indicates that strong winds (15 m/s) were recorded on Julian Day 33 (February 2). The following period from Julian Day 34 (February 3) through Julian Day 44 (February 13) was a prolonged period of light winds. On Julian Day 45 (February 14) winds increased once again and reached 20 m/s.

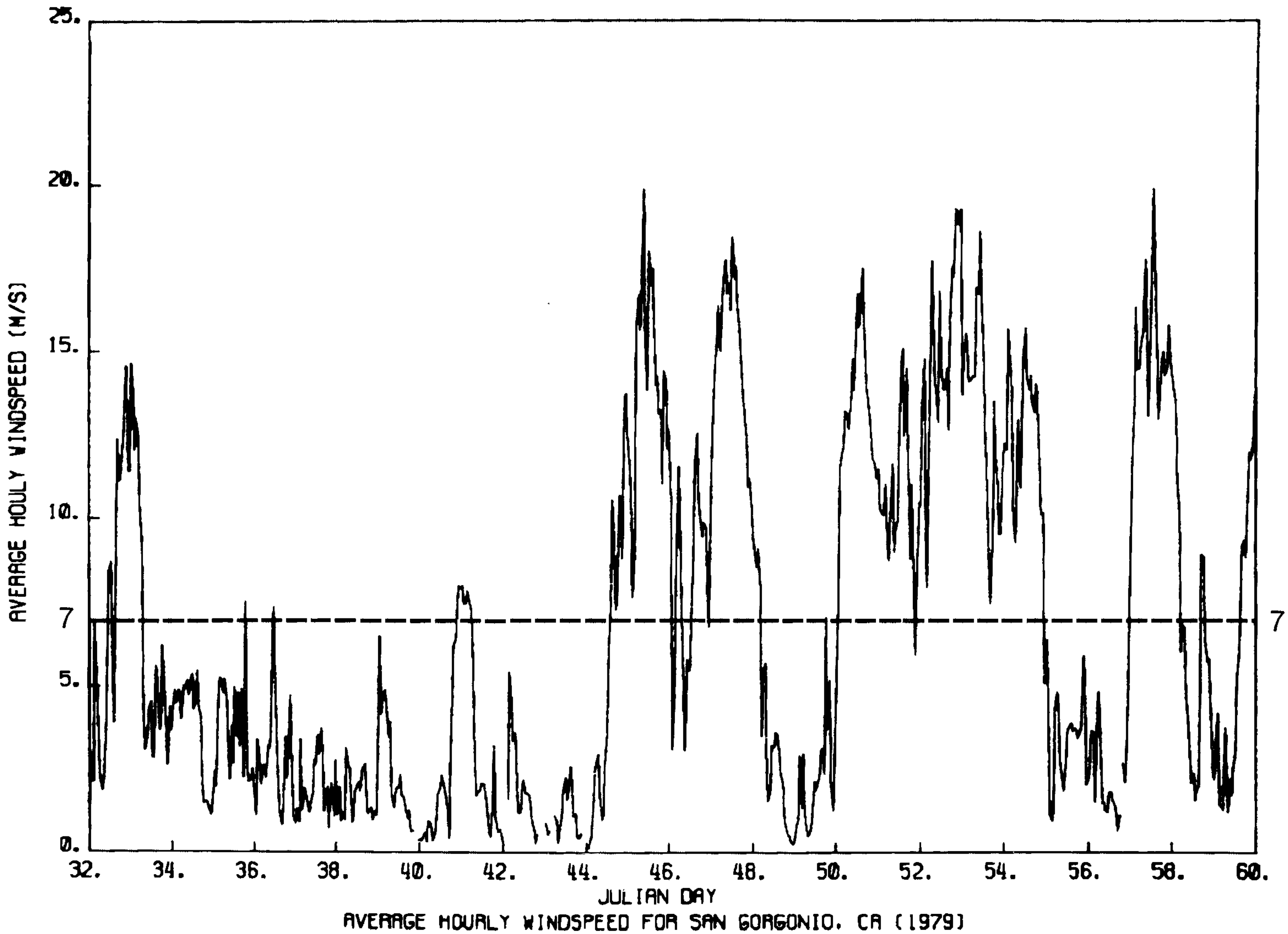
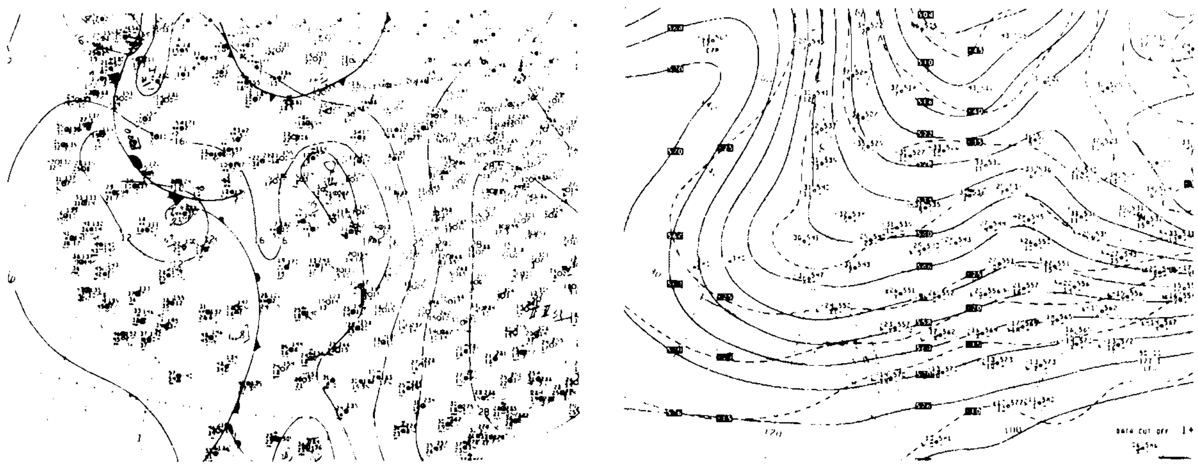


FIGURE 5.63. Average Hourly Wind Speed for San Gorgonio for Julian Days 32-60 Showing an Example of Light Winds from Julian Day 34 (February 3) through Julian Day 44 (February 13, 1979).

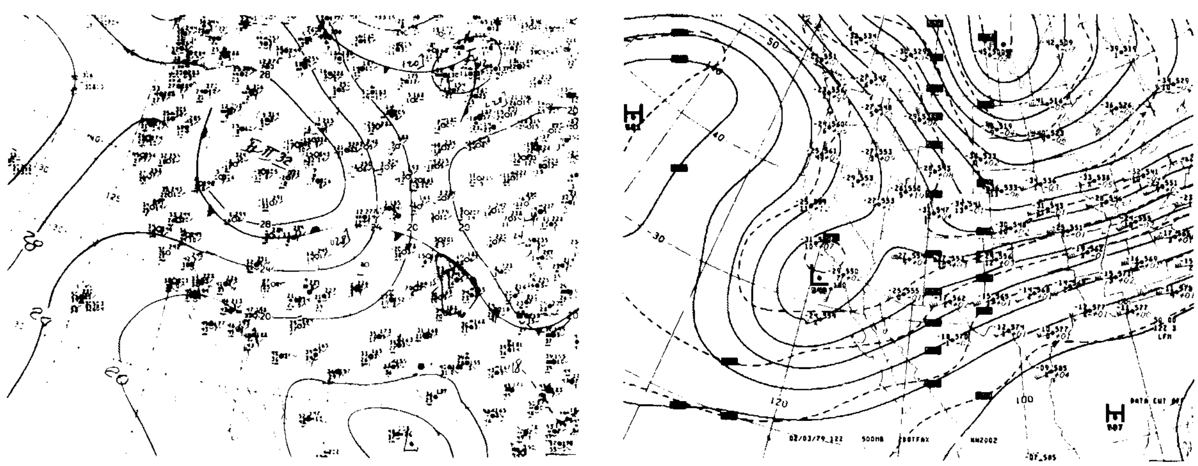
A series of synoptic maps beginning February 1 is shown in Figures 5.64 through 5.67.

Note the low to the north of SAG with a trough extending to the south on February 1 and the location of a ridge of high pressure that replaced the low on February 3. This general pattern of high pressure to the north prevailed through February 13. During this entire period, light winds were observed at SAG. Also note that the pressure was higher at LAS than at LAX during the period of light winds. When the pressure at LAX became higher than that at LAS, strong winds returned to SAG.



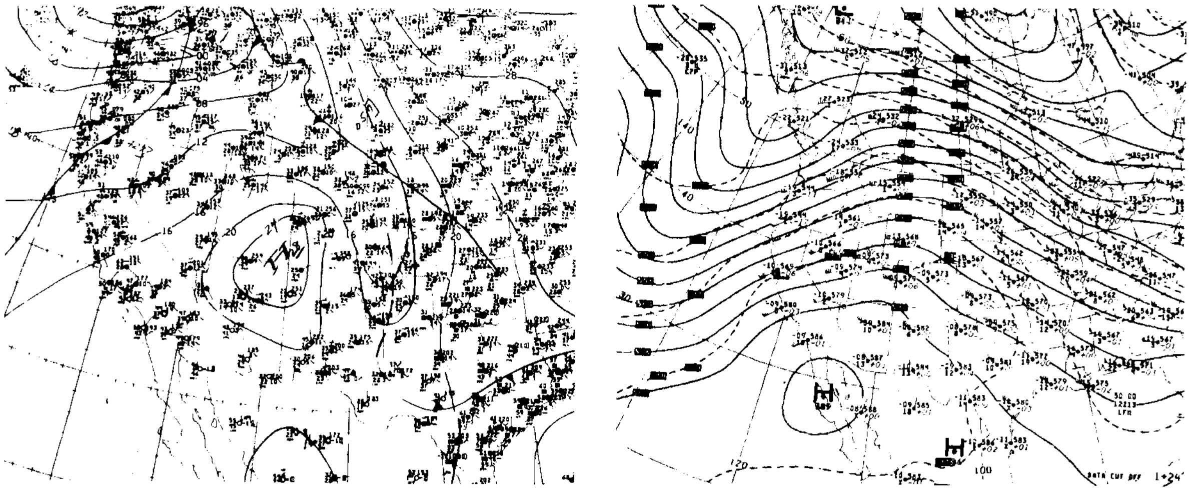
(A) (B)

FIGURE 5.64. Example of Strong Winds at SAG at 1200 GMT on February 1, 1979. (A) Surface Map (B) 500-mb



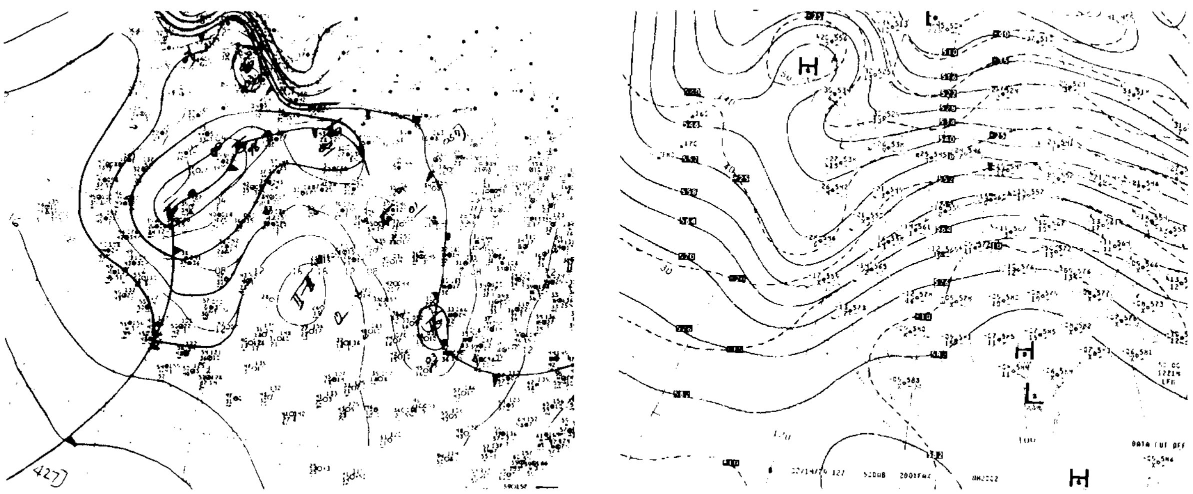
(A) (B)

FIGURE 5.65. Example of a Type A Day (Light Winds) at SAG at 1200 GMT on February 3, 1981. (A) Surface Map (B) 500-mb



(A) (B)

FIGURE 5.66. Example of a Type A Day Continuing (Light Winds) at SAG at 1200 GMT on February 13, 1979. (A)Surface Map (B)500-mb



(A) (B)

FIGURE 5.67. Example of a Change from a Type A Day (Light Winds) to a Strong Wind Situation at SAG at 1200 GMT on February 14, 1979. (A)Surface Map (B) 500-mb

On February 14 the high gave way to a new low and associated trough. The winds increased once again. This leads to the conclusion that when a ridge of high pressure is to the north of SAG with a trough off the west coast of California giving an easterly direction to the wind flow, the winds at SAG will be light (less than 7 m/s) for an extended period.

ACKNOWLEDGMENTS

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6.0 COMPARISON OF ANALYTICAL APPROACHES

The analytical approaches used by the two contractors Freese-Notis and Murray and Trettel are presented in Sections 4 and 5 respectively. Two sites were analyzed in common by the two contractors; San Gorgonio Pass and Montauk Point. In Section 6 the two analytical approaches are compared to determine similarities/differences in approaches and the results obtained from each as well as to compare the strengths and weaknesses of both approaches so that recommendations for improvements can be made.

Five descriptors/predictors were used by the two contractors in their respective analyses:

B/A synoptic classification
Contractor-defined wind regime types
Map analogs
Pressure gradients and isobaric orientations
850-mb wind speeds.

Similarities and differences in the uses of these five potential wind predictors/descriptors are discussed in the following sections.

6.1 GENERAL COMPARISON OF THE ANALYTICAL APPROACHES USED BY THE TWO CONTRACTORS

A description of the analytical techniques used by Freese-Notis and Murray and Trettel, as well as observed strengths and weaknesses, are contained in this section. Observations are of a general nature only; comparisons of the sites analyzed in common are contained in Sections 6.2 and 6.3.

6.1.1 Use of the B/A Classification

Though both contractors used the B/A synoptic classification scheme, the scheme was used in very different manners. Freese-Notis discussed general features of site winds associated with the B/A types. B/A types were treated as predictors of the wind in their analysis. On the other hand, Murray and

Trettel discussed predefined wind regimes in terms of the associated synoptic situation(s). The B/A types were used primarily as an aid to describing the synoptic pattern rather than as a predictor of wind (see Section 5.1.3).

6.1.2 Use of Wind Regime Types

Both contractors defined wind regime types based upon analysis of time-series of wind speed and direction supplied by PNL (Section 3). Freese-Notis defined wind types using observed diurnal variations in speed; observed wind speed ranges generally were used to delimit categories of speed (see Tables 4.1 to 4.4). Murray and Trettel defined four wind types based upon the number of consecutive hours of speeds greater than the cut-in of the MOD-2 wind turbine generator (WTG) (Linscott et al. 1981), rather than classifying site wind speeds according to naturally occurring wind regimes.

Though the Freese-Notis wind types provided better descriptions of site wind regimes, their wind types were not integrated into the discussion of site wind characteristics. Reference to the wind types in the discussion as well as rules for forecasting the wind types would have been helpful to the reader/forecaster.

The Murray and Trettel wind classifications provided less information about site-specific winds due to the use of an artificial 7 m/2 delimiter; but, the wind types were thoroughly integrated into the discussion of site wind characteristics so that the reader was provided with sufficient information to forecast them.

6.1.3 Use of Map Analogs

The contractors both used map analogs in their respective analyses, but for different purposes. Freese-Notis presented typical strong and weak wind cases for each site analyzed. Extension of this approach to cover more wind types would have been helpful. Murray and Trettel presented numerous examples of synoptic surface and 500-mb charts associated with the wind types. Their discussion often is aimed at showing subtle differences between maps associated with the same wind category. This can be confusing, particularly for an uninitiated forecaster who is looking for the similarities between maps associated with one type of winds rather than differences.

The Freese-Notis discussion could have benefited from more map types to cover the entire set of wind types described, while Murray and Trettel perhaps should have limited the number of maps and concentrated on salient features that differentiate the defined wind types. The use by Murray and Trettel of the 500-mb chart, in addition to the surface chart, was useful in providing a more complete picture of the state of the atmosphere.

6.1.4 Use of 850-mb Wind Speeds

Both Freese-Notis and Murray and Trettel used 850-mb winds to determine the maximum surface wind speed during the forecast period. Both found this to be of some value. Neither discussed methods of estimating the actual influence of 850-mb winds upon the surface winds when making a wind forecast (this would entail expressing momentum transfer to the surface as a function of stability or some other related parameter).

6.1.5 Use of Pressure Gradients

Both contractors concluded that pressure gradient vectors (magnitude and direction of the pressure gradient) were necessary to specify system intensity and thus to make wind forecasts once the synoptic map type has been determined. Though both used pressure gradients as a predictor of wind, there are significant differences in the way in which the pressure gradient was applied to forecast production.

In both cases the magnitude of the pressure gradient was evaluated using the surface pressure analysis. Freese-Notis evaluated the pressure gradient (to the nearest mb) as the pressure difference measured over 180 nautical miles miles in a direction normal to the isobars and centered on the site. Murray and Trettel used the same approach but measured the pressure change over 150 nautical miles. Both contractors used the direction of the isobars through the site to denote direction of the pressure gradient. Furthermore, both expressed directions (for example east-to-west) corresponding to the direction of flow of the geostrophic wind (see Sections 4.1 and 5.1.6). Directions of the pressure gradient were categorized by octant (Freese-Notis) and by quadrant (Murray and Trettel).

The differences in the two contractors use of pressure gradients are large enough that forecasting rules based upon pressure gradients can only be compared for similarities in a qualitative sense.

The times for which pressure gradients were tabulated and their subsequent use in wind prediction vary significantly between the two contractors. Freese-Notis tabulated pressure gradients at 0000 GMT and 1200 GMT daily for the period of the study. Their wind forecasts are actually "nowcasts" based upon existence of a particular pressure gradient at a specific time. To use their pressure gradient rules, one must forecast the magnitude of the pressure gradient as well as the isobaric orientation (IO) and then look up the tabulated wind speed associated with that combination of pressure gradient and IO. In this application there is an inherent assumption that no significant correlation exists between time-of-day and wind speed for a given pressure gradient. The tabulation of 3 months of 3-hour pressure gradients for each site (Section 4.3) does tend to support this conclusion (see Figures 4.18 and 4.19); however, this assumption may not hold at all sites for all months of the year (see Section 5.5.3 which discusses pressure gradients at San Gorgonio). Factors such as the dependency of wind speed upon momentum transfer to the surface (which is partially dependent on time-of-day) may become important at some sites.

Murray and Trettel tabulated pressure gradients observed at 1200 GMT only. They then used these pressure gradients to predict wind speed based upon the tabulated climatological wind speeds. This approach avoids the need to forecast future pressure gradients and IO's, but is limited by the degree of correlation between the single predictor, pressure gradient at 1200 GMT, and the predictands, wind speeds from 1 to 24 hours in the future.

The Murray and Trettel approach works fairly well when predicting broad categories of wind speed (such as their type 3 wind which is forecast in Figure 5.5.4); however, it can never be highly accurate for narrow wind speed categories; for, without incorporating information on time changes of the pressure gradient, it seems unlikely that this method will ever explain much of the variance in the wind speed. This approach is further limited by the fact that the forecast cannot be updated when later information becomes available, because the forecasting rules are based upon the 1200 GMT pressure gradient only and not on pressure gradients observed at any other time. The Freese-Notis approach, on the other hand, permits forecast updating. Furthermore, as the method of forecasting pressure gradients improves (through better numerical models of the atmosphere and the resultant improved prognostic charts), so will the wind forecasts.

6.2 COMPARISON OF THE TWO SITE ANALYSES FOR SAN GORGONIO

Though the approach to analysis of site wind characteristics varied as noted in Section 6.1, the conclusions drawn by both contractors for the analysis of San Gorgonio Pass are nearly identical.

Both contractors agreed that San Gorgonio displays more consistent relationships between synoptic map type and wind than any of the sites analyzed. Hence, Freese-Notis concludes that it should not be difficult to forecast the wind at San Gorgonio. This conclusion is yet to be proven as all previous efforts to forecast winds in this pass have produced large forecast errors (Wegley 1982).

The B/A surface types found to be associated with strong winds at San Gorgonio are listed in Table 6.1. The reader should note that B/A types 25, 28 and 29 are equivalent in a synoptic sense and differ only in the features used to describe the situation (i.e., in one case the upstream features are used and in the other the downstream features are used to describe the synoptic situation). The use of different B/A types to describe similar weather patterns denotes the subjectivity in assigning B/A types and suggests that the scheme for identifying map type for wind forecasting need not be as elaborate as the B/A classification.

TABLE 6.1. Surface Synoptic Types Associated With Moderate-to-Strong Winds at San Gorgonio Pass, California

B/A Synoptic Type		B/A Type
Freese-Notis	Murray and Trettel	Description
	12	Open wave cyclone passing north
13	13	Post-cold front
25		Posttrough
	27	Inverted pretrough
	28	Inverted posttrough
29		Preridge

Table 6.2 lists the B/A classifications selected as being associated with weak winds at San Gorgonio. Though different B/A classifications were used they all have in common at least one of three factors:

- high pressure to the north is denoted (B/A 8, 31, 33, 34)
- a flat pressure gradient (B/A 35)
- low pressure to the west (B/A 27).

TABLE 6.2. Surface Synoptic Types Associated With Light Winds at San Gorgonio Pass, California

B/A Synoptic Type		B/A Type
Freese-Notis	Murray and Trettel	Description
8		Low to the south; posttrough
27	27	Inverted pretrough
	31	High to the north; pre-inverted ridge
33		High to the north; post-inverted ridge
34		High to the north; E-W gradient
35	35	Col (flat pressure gradient)

The analysis of pressure gradients resulted in nearly identical conclusions. Freese-Notis pressure gradient analysis shown in Figure 4.22 indicates that a 3-mb pressure gradient through the pass will produce winds $\geq$ 7 m/s. Murray and Trettel note (Section 5.5.3) that a 3-mb pressure gradient between Los Angeles and Palm Springs at 2100 to 2400 GMT will produce moderate-to-strong winds ($\geq$ 7 m/s for at least 8 hours).

Upper air winds (850-mb or above) were not found by either contractor to be strongly correlated with surface winds. Freese-Notis indicates that for the stronger wind cases, the surface wind funneling through the pass generally exceeds the 850-mb wind speed. Murray and Trettel also note that strong upper air flow is not always required for strong surface flow. They state that only half of the time is a strong upper air pattern associated with the strong wind situation.

6.3 COMPARISON OF THE TWO SITE ANALYSES FOR MONTAUK POINT

Montauk Point lies near the point of intersection of two climatological storm tracks. Consequently, many different synoptic situations occur giving rise to a variety of wind regimes. The analysis of Montauk Point by both contractors was rather tentative and produced fewer solid conclusions then for other sites studied in this project. Perhaps the diversity of synoptic situations and wind regimes is the cause of the difficulty in recognizing patterns at this site.

The wind types defined by Freese-Notis (Figure 4.4) reflect the difficulty in stratifying the Montauk Point wind data. Freese-Notis stratified wind speeds by defining peak wind speed and duration of the event in days. No minimum speed or wind speed range was associated with any wind type. Apparently, due to the lack of descriptiveness in the wind type definitions, they were not used in the discussion of the Montauk Point analysis. Murray and Trettel used the same wind types as those used for the other sites analyzed (i.e., stratification in terms of number of hours above or below 7 m/s). Wind types in this stratification were not in general forecast well by the predictors used.

The analysis of Montauk Point suggests that wind types should be precise (descriptive) enough to be referred to when discussing surface winds associated with synoptic patterns, pressure gradients, winds aloft, etc.

The methods of data analysis of the two contractors differed sufficiently that important observations were made by one contractor but missed by the other. For example, since Freese-Notis emphasized scanning plots of time series of wind speeds and since they tabulated data for both 0000 GMT and 1200 GMT, they observed a lack of diurnality in the winds. This was not mentioned by Murray and Trettel. The lack of diurnality at Montauk Point is further supported by Sandusky and Renné (1981). Murray and Trettel produced monthly summaries of wind statistics (not produced by Freese-Notis). Consequently, they noted that the strongest winds at Montauk Point occur in the cold months (Dec-Feb) and the lightest winds occur in the warm months (July-Sept).

These examples illustrate the need for outlining a method of data stratification and tabulation that enables recognition of wind patterns on all pertinent time scales as well as recognition of wind patterns associated with all synoptic events.

Both contractors noted the generally poor correlation of B/A map type with wind type and both attributed this to the lack of association with pressure gradient inherent in the B/A scheme. However, Murray and Trettel noted that both very strong and very light wind episodes were recognizable by the associated synoptic pattern. For example, very strong wind episodes with long duration occur with a deep, very slow-moving low pressure system NE of Montauk Point.

Tables 6.3 and 6.4 list the B/A classifications found by the two contractors to be associated with moderate-to-strong and light winds respectively. Moderate-to-strong winds appear to blow whenever a storm system is near Montauk Point or moves by to the north or south. Light winds are associated with flat-pressure gradients or E-W gradients. These basic patterns were recognized by both organizations.

Freese-Notis tabulated surface to 850-mb wind ratios by B/A synoptic type. From this analyses they concluded that the surface winds were generally 40 to 70% of the 850-mb wind and that the 850-mb wind tends to be upper-bound for the surface wind. On the other hand, Murray and Trettel tabulated maximum hourly surface to 850-mb wind ratios (as a percentage) by month and by wind direction rather than by B/A type. This appears to be a better scheme to

TABLE 6.3. Surface Synoptic Types Associated With Moderate-to-Strong Winds at Montauk Point, New York

B/A Synoptic Type Freese-Notis	Murray and Trettel	B/A Type Description
3	3	Deep low to the north
6		Deep low to the south
7	7	Pretrough; low to the south
19		Prefrontal; open wave to the north
21		Pretrough; open wave to the south
29		Preridge; high west or south

TABLE 6.4. Surface Synoptic Types Associated With Light Winds at Montauk Point, New York

B/A Synoptic Type Freese-Notis	Murray and Trettel	B/A Type Description
30		Postridge
32		High center over station
33	33	Post-inverted ridge
34	34	E-W gradient
35	35	Flat-pressure gradient or col

relate surface and 850-mb winds as Murray and Trettel show that surface winds frequently exceed the 850-mb wind by as much as 100%. This means that stronger peak hourly winds should be forecast than is indicated by the Freese-Notis analysis.

Murray and Trettel also found that the 850-mb wind speed was fairly well correlated with wind type and, consequently, suggested guidelines for using the 850-mb wind to forecast surface wind speeds at Montauk Point.

Both contractors offered similar rules for forecasting wind speeds $\geq$ 7 m/s at Montauk Point. For example, Murray and Trettel (using the pressure gradient over 150 nm) observed that a pressure gradient of $\geq$ 3 mb would produce winds $\geq$ 7 m/s while Freese-Notis (using the pressure gradient over 180 nm) concluded that $\geq$ 4 mb were required.

Freese-Notis arrived at some unique conclusions based upon their analysis of wind speed and direction versus pressure gradient for eight isoboric orientations (see Figures 4.32 and 4.35). They observed that the topography (which is low-relief) near Montauk has a minimal affect upon wind direction. This is true because the IO is strongly correlated with wind direction (see Figure 4.35). In addition, their analysis of 3 months of 3-hourly data (Section 4.3) and 12 months of twice-daily data indicated that the wind speed associated with a particular pressure gradient does not vary significantly with time-of-day at Montauk Point.

Murray and Trettel emphasized the importance of considering time changes in the pressure gradient based upon their rather detailed analysis of surface and 500-mb charts. They pointed out that slowly changing pressure gradients associated with deep, <u>slow-moving</u> lows produce sustained strong winds at Montauk.

7.0 CONCLUSIONS AND RECOMMENDATIONS

In April 1979, PNL initiated a 6-month wind forecasting study in which subjective hour-by-hour wind forecasts for 24 hours were produced for 11 DOE candidate wind turbine sites. An analysis of forecasting errors revealed a basic lack of understanding of the wind characteristics of these very windy sites. For example, mean forecast errors exceeded 5 m/s at some sites and large negative biases (often exceeding 4 m/s) were observed indicating severe under-forecasting of the wind speeds. Such errors indicate that forecasters must be familiar with the wind characteristics of a site in order to produce meaningful forecasts.

Two primary objectives of the current study were to relate identified wind regimes to synoptic events at each site analyzed in order to 1) gain sufficient understanding of the site wind characteristics, and 2) to forecast the wind at these sites. As mentioned in Sections 4 and 5, through use of the B/A map classification scheme, it soon became apparent that there was not a one-to-one mapping of the identified wind regimes onto the set of synoptic types. Furthermore, though the B/A classification is detailed to the point of becoming cumbersome to use, it provides little information about the intensity of a weather system.

Examination of other wind predictors revealed that no single predictor appears to work well alone for forecasting the wind. It was concluded that four factors should be examined to stratify wind regimes in such a way that they can be reliably forecast for wind energy applications. First, consideration should be given to the synoptic situation. Using appropriate meteorological theory, the synoptic situation provides a general idea of what winds might be expected. Second, some descriptive climatology is needed to help relate statistics of the wind regimes to the synoptic situation. In this climatology, synoptic patterns need not be described in as much detail as the B/A classification provides, because such "overclassification" dilutes the data to the point that no salient features appear.

Third, since it is the pressure force that generally initiates air movement, some measure(s) of the pressure gradient vector should be considered.

That is, the measure(s) should include both the direction of the pressure gradient and its magnitude. This approach provides information about a weather system's intensity (magnitude of the pressure gradient) and allows effects of local topography to be considered (by examining the direction of the gradient).

A fourth consideration is that near-surface winds are often affected by momentum imparted from stronger winds aloft. Both winds aloft and some measure of the degree of momentum transfer (possibly atmospheric stability) should be considered. As was noted in Section 5, the 850-mb wind is often useful in predicting maximum wind speeds for the following 24-hour period. Again, any modifying effects of local topography should be considered (such as acceleration of flow over and around ridges, funneling through passes, etc.).

The four factors discussed above provide a means of learning to forecast winds, using semi-objective techniques, at new and perhaps remote sites.

The wind forecasting approach developed in this study was intended for forecasting hourly average winds out to the 24- or possibly 36-hour time horizon. Consequently, the forecasting technique is best suited for incorporation into utility daily load forecasts to reduce reserve generating capacity that might be scheduled to back up the fluctuating wind generators (see Goldenblatt et al. 1982). Because the forecasting rules in this study require evaluation of weather charts prior to making and disseminating the wind forecasts, this forecasting approach is intended for use at locations where meteorologists are available who have access to National Weather Service synoptic analyses and prognoses.

Subsequent to completion of the analyses presented in Sections 4 and 5, a wind forecasting project (ongoing at the time of this report) was initiated in which forecasting procedures for each site were extracted from the two sections. Several recommendations for the improvement of any future work in site wind characteristic analysis are made based upon the forecasting project as well as knowledge gained during the wind data stratification.

First, more of the forecasting rules and guidelines developed should incorporate the time element. That is, more of the rules should forecast future events based upon observed initial conditions rather than be of a "nowcasting" nature. Furthermore, the forecasting guidelines should provide more definition of the wind speed in the forecast. One or two speed thresholds (such as 7 m/s and 13 m/s) are not adequate to produce a sufficiently detailed wind power forecast.

Pressure gradients and, as much as possible, other predictors should be specified in terms of values routinely reported from weather observing stations. Use of these data removes the subjectivity from the extraction of predictors from weather charts, thus producing more consistent forecasts. If all predictors can be evaluated from reported numbers, then totally objective forecasting schemes can be implemented based upon statistical or dynamical-statistical methods. Dynamical-statistical methods such as Model Output Statistics (Crisci et al. 1977) have been shown to be more accurate than subjective forecasts at many sites.

Finally, the climatological summaries should present more conditional climatology (such as diurnal wind speed patterns by month and by daily average sky cover). This type of climatology requires more effort to tabulate, but provides the forecaster with much more useful information and results in more realistic forecasts.

If the results of the work in developing 24-hour forecasts of hourly average wind speeds are to be made useful to utilities, methods of converting hourly average speeds to WTG power output are needed. Analysis of either actual or simulated WTG power output versus wind speed must be performed in order to establish the needed relationships. Work performed in this area should attempt to identify categories of wind speed that are of operational significance to a utility operating a particular type(s) of WTG(s). Identification of such categories of wind speed will define the manner in which the wind speed data should be stratified when implementing the forecasting technique.

As the use of wind energy grows from the use of individual test machines to clusters of wind turbines, short-term (0-6 hour) high reliability wind power forecasts for the WTG clusters will become very useful to dispatchers. It is therefore recommended that work, analogous to that done in this study, be performed to learn to forecast the power output of clusters of WTGs. This will require actual cluster power output data, or wind data sufficient to simulate a cluster of WTGs. It will also require the selection and testing of appropriate short-term forecasting techniques as well as close coordination with utility operations personnel to insure that the content and format of such forecasts meet utilities' needs.

8.0 REFERENCES

Crisci, R. L., G. M. Carter and G. W. Hollenbaugh. 1977. Comparative Verification of Guidance and Local Aviation/Public Forecasts--No. 2 (April-September 1976, TDL Office Note 77-5, Techniques Development Laboratory, National Oceanic and Atmospheric Administration, Silver Springs, Maryland.

Daily Weather Maps, Weekly Series. 1979. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data and Information Service. Available from the U.S. Government Printing Office, Washington, DC.

Goldenblatt, M. K., H. L. Wegley and A. H. Miller. 1982. Analysis of the Effects of Integrating Wind Turbines Into a Conventional Utility: A Case Study, PNL-3962, JBF Scientific Coporation, Wilmington, Massachusetts and Pacific Northwest Laboratory, Richland, Washington.

Hallanger, N. L., D. A. Griffith and K. Gray. 1968. Development of the C/B Forecast System for a Mid-Latitude Location. Booz-Allen Applied Research, Inc. Report No. 9004-075-R1, Vol. 1. Available from the National Technical Information Service, Springfield, Virginia.

Linscott, B. S., J. T. Dennett and L. H. Gordon. 1981. The MOD-2 Wind Turbine Development Project, DOE/NASA/20305-5, NASA/Lewis Research Center, Cleveland, Ohio.

Miller, A. H. 1980. "Implications of the Effects of Wind Characteristics on the Operation of Large Wind Turbines." In Proceedings of the 15th Intersociety Energy Conversion Engineering Conference, Seattle, Washington.

Sandusky, W. F. and D. S. Renné. 1981. Candidate Wind Turbine Site Annual Data Summary for January 1979 Through December 1979, PNL-3703, Pacific Northwest Laboratory, Richland, Washington.

Trettel, D. W., J. T. Aquino, T. R. Piazza, L. E. Taylor and D. C. Trask. 1981. "The Useful Potential of Using Existing Data to Uniquely Identify Predictable Wind Events and Regimes, Part I." In Proceedings of the DOE/NASA LHWT or Workshop and Conference, Cleveland, Ohio.

Wegley, H. L. 1982. "The Development and Evaluation of Wind Forecasts for Wind Energy Applications." PNL-SA-10351. Presented at the American Meteorological Society Tenth Conference on Weather Forecasting and Analysis, Seattle, Washington.

Zar, J. H. 1974. Biostatistical Analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

APPENDIX A

<u>BOOZ-ALLEN SURFACE</u>

<u>AND</u>

<u>UPPER AIR TYPES</u>

The Booz-Allen Surface Types

Type No.	Description
	1. Deep Closed Low (deepening or mature cyclone)
	a. Center North
1	(1) Advance Zone
2	(2) Prefrontal and frontal (occlusion or warm front) (or trough)
3	(3) Postfrontal (or trough) (cold front or occlusion)
4	(4) Warm sector
5	(5) Prefrontal and frontal (cold)
	b. Center South
6	(1) Advance Zone
7	(2) Pretrough
8	(3) Posttrough
	2. Open Wave Cyclone Moving SE or E
	a. Center North
9	(1) Advance Zone
10	(2) Prefrontal (warm)
11	(3) Warm sector
12	(4) Prefrontal and frontal (cold)
13	(5) Postfrontal (cold)
	b. Center South
14	(1) Pretrough
15	(2) Posttrough
	3. Open Wave Cyclone Moving NE
	a. Center North
16	(1) Frontal (warm)
17	(2) Warm sector
18	(3) Prefrontal and frontal (cold)
19	(4) Postfrontal (cold)
	b. Center South
20	(1) Advance Zone
21	(2) Pretrough, warm front zone
22	(3) Posttrough
23	(4) Warm sector
	4. Meridional Trough (N-S or tilted)
24	a. Pretrough
25	b. Posttrough
26	c. Trough or frontal zone
	5. Inverted Trough
27	a. Pretrough
28	b. Posttrough
	6. Ridge, or High Center South (or same latitude)
29	a. Preridge
30	b. Postridge

The Booz-Allen Surface Types (Continued)

Type No.		Description
	7.	<u>High, Center North (or same latitude)</u>
31		a. Pre-inverted ridge
32		b. Center
33		c. Post-inverted ridge
34		d. E-W gradient
	8.	<u>Flat Pressure Area</u>
35		Cols or other areas (except high centers) where wind is indeterminate

The Booz-Allen 500-millibars Types

Type No.		Description
	1.	<u>Deep Closed Low</u>
		a. Center North
1		(1) Pretrough
2		(2) Posttrough
		b. Center South
3		(1) Pretrough
4		(2) Posttrough
	2.	<u>Weak Closed Low</u>
		a. Center North
5		(1) Pretrough
6		(2) Posttrough
		b. Center South
7		(1) Pretrough
8		(2) Posttrough
	3.	<u>Meridional Trough (N-S or tilted) (including transitional)</u>
9		a. Pretrough
10		b. Posttrough
	4.	<u>Basically Zonal</u>
11		a. Westerly flow
12		b. Pre-minor trough
13		c. Post-minor trough
	5.	<u>Meridional Ridge</u>
14		a. Preridge
15		b. Postridge
	6.	<u>High, Center North (or same latitude)</u>
16		a. Pre-inverted ridge
17		b. Center
18		c. Post-inverted ridge
19		d. E-W gradient
	7.	<u>Flat Pressure Area</u>
20		Cols or other transitional areas (except highs) where wind is indeterminate and there is no convergence

APPENDIX B

LIST OF DATES FOR VARIOUS TYPES OF WEATHER PATTERNS FOR

MONTAUK POINT, NY (MTP)

LUDINGTON, MI (LDM)

AMARILLO, TX (AMA)

SAN GORGONIO, CA (SAG)

MONTAUK POINT, NY (MTP) 1979
Type A
Less Than 7 m/s for 24 Hours

Date	1200 GMT - Pressure gradient	Date	1200 GMT - Pressure gradient
Feb 12	1	Jul 15	1
Feb 20	3	Jul 16	1
Mar 1	1	Jul 17	2
Mar 3	1	Jul 18	1
Mar 7	2	Jul 19	1
Mar 8	3	Aug 11	2
Mar 19	3	Aug 17	3
Mar 31	2	Aug 18	2
Apr 15	2	Aug 20	2
Apr 16	1	Aug 23	2
Apr 25	2	Aug 26	2
Apr 28	2	Aug 28	2
May 14	2	Sep 1	1
May 15	2	Sep 12	2
May 16	2	Sep 13	1
May 20	3	Sep 16	2
May 22	2	Sep 17	2
May 29	1	Sep 20	3
Jun 1	2	Sep 25	2
Jun 2	1	Sep 26	3
Jun 3	1	Sep 27	2
Jun 4	1	Sep 28	2
Jun 5	2	Oct 2	1
Jun 6	1	Oct 4	2
Jun 8	3	Oct 18	2
Jun 9	1	Oct 30	3
Jun 10	2	Nov 1	1
Jun 20	2	Nov 5	3
Jun 21	2	Nov 6	2
Jun 22	2	Nov 18	2
Jun 26	1	Nov 19	2
Jun 27	2	Nov 21	2
Jun 28	2	Nov 22	2
Jun 29	2	Nov 25	2
Jul 4	2	Dec 1	1
Jul 7	2	Dec 15	1
Jul 10	2	Dec 22	1
Jul 11	1	Dec 23	2
Jul 12	1	Dec 24	2
Jul 14	1	Dec 31	3

MONTAUK POINT, NY (MTP) 1979
Type B
Less Than 12 Hours of 7 m/s

Date	1200 GMT - Pressure gradient	Date	1200 GMT - Pressure gradient
Jan 4	2	May 24	3
Jan 23	3	May 25	6
Jan 24	4	May 26	3
Jan 26	3	May 27	4
Jan 28	2	May 28	3
Feb 4	2	May 30	1
Feb 7	2	May 31	2
Feb 15	2	Jun 7	1
Feb 16	2	Jun 11	2
Feb 18	3	Jun 13	2
Feb 21	3	Jun 14	2
Feb 22	4	Jun 16	3
Feb 23	2	Jun 17	2
Feb 24	2	Jun 18	2
Feb 27	2	Jun 19	4
Feb 28	4	Jun 23	2
Mar 2	2	Jun 24	3
Mar 4	3	Jun 25	4
Mar 5	4	Jun 30	2
Mar 6	3	Jul 1	2
Mar 9	4	Jul 2	3
Mar 10	3	Jul 5	4
Mar 17	2	Jul 6	4
Mar 21	5	Jul 8	2
Mar 22	3	Jul 9	2
Mar 23	2	Jul 13	2
Mar 25	2	Aug 9	5
Mar 28	3	Aug 10	2
Mar 29	3	Aug 16	5
Mar 30	2	Aug 19	2
Apr 1	2	Aug 21	2
Apr 11	2	Aug 22	2
Apr 12	5	Aug 24	3
Apr 13	3	Aug 25	4
Apr 18	4	Aug 29	3
Apr 19	4	Aug 30	2
Apr 20	4	Aug 31	2
Apr 21	1	Sep 2	1
Apr 24	6	Sep 10	1
Apr 29	4	Sep 11	2
May 17	5	Sep 15	4
May 21	2	Sep 18	3
May 23	1	Sep 21	3

MONTAUK POINT, NY (MTP) 1979
Type B (cont)

Date	1200 GMT - Pressure gradient	Date	1200 GMT - Pressure gradient
Sep 22	2	Nov 3	2
Sep 24	5	Nov 4	4
Sep 29	2	Nov 7	1
Sep 30	2	Nov 8	2
Oct 10	3	Nov 9	1
Oct 12	3	Nov 11	3
Oct 13	3	Nov 12	5
Oct 15	3	Nov 15	3
Oct 16	2	Nov 20	2
Oct 17	2	Nov 23	3
Oct 19	2	Dec 5	2
Oct 20	2	Dec 7	4
Oct 22	2	Dec 10	5
Oct 26	2	Dec 16	2
Oct 27	2	Dec 19	2
Oct 28	3	Dec 21	4
Oct 29	4	Dec 25	7
Nov 2	3	Dec 26	6

MONTAUK POINT, NY (MTP) 1979
Type C
Greater Than 7 m/s for 12-23 Hours

Date	1200 GMT - Pressure gradient	Date	1200 GMT - Pressure gradient
Jan 2	5	Aug 15	5
Jan 25	5	Aug 27	4
Jan 26	6	Sep 19	6
Feb 8	4	Sep 23	5
Feb 11	4	Oct 1	4
Feb 13	6	Oct 3	5
Feb 17	8	Oct 7	4
Feb 19	10	Oct 9	5
Feb 25	4	Oct 21	4
Feb 26	5	Oct 23	4
Mar 11	3	Oct 24	3
Mar 12	7	Nov 10	5
Mar 13	3	Nov 13	3
Mar 14	8	Nov 14	4
Mar 16	4	Nov 17	7
Mar 18	5	Nov 24	5
Mar 20	6	Nov 27	5
Apr 9	4	Nov 28	6
Apr 14	6	Nov 29	4
Apr 17	4	Nov 30	5
Apr 22	3	Dec 2	5
Apr 23	3	Dec 3	4
Apr 26	4	Dec 6	5
Jun 12	5	Dec 9	4
Jun 15	4	Dec 11	5
Jul 3	4	Dec 13	4
Aug 13	7	Dec 14	6
Aug 14	4	Dec 20	6

MONTAUK POINT, NY (MTP) 1979
Type D
Greater Than 7 m/s for 24 Hours

Date	1200 GMT - Pressure gradient
Jan 1	6
Feb 9	5
Feb 14	6
Mar 15	8
Mar 24	7
Mar 26	6
Mar 27	5
Apr 10	9
May 18	4
May 19	6
Aug 12	6
Sep 14	5
Oct 5	5
Oct 6	6
Oct 14	5
Oct 25	5
Nov 16	6
Nov 26	7
Dec 4	5
Dec 8	6
Dec 12	5
Dec 18	6
Dec 28	6
Dec 29	7
Dec 30	8

MONTAUK POINT, NY (MTP) 1979
Type E
Greater Than 10 m/s for Equal to or Greater Than 24 Hours

Date	1200 GMT - Pressure gradient
Jan 3	8
Jan 22	7
Jan 29	8
Jan 30	9
Feb 1	9
Feb 2	9
Feb 3	8
Feb 5	8
Feb 6	10
Feb 10	7
Dec 17	10
Dec 27	7

LUDINGTON, MI (LDM) 1979
Type A
Less Than 7 m/s for 24 Hours

Date	1200 GMT - Pressure gradient	Date	1200 GMT - Pressure gradient
Jan 26	4	Jul 3	1
Jan 27	2	Jul 6	1
Feb 27	2	Jul 7	1
Mar 1	4	Jul 8	1
Mar 2	1	Jul 9	1
Mar 21	2	Jul 11	1
Mar 27	2	Jul 12	1
Apr 1	2	Jul 18	1
Apr 7	2	Jul 19	1
Apr 10	1	Jul 20	1
Apr 19	1	Jul 22	1
May 1	2	Jul 29	1
May 4	2	Aug 16	1
May 15	2	Aug 18	1
May 16	1	Aug 19	2
May 27	2	Aug 26	2
May 28	2	Aug 28	1
May 29	1	Sep 4	1
Jun 8	4	Sep 8	1
Jun 9	1	Sep 19	1
Jun 11	3	Sep 22	3
Jun 12	1	Sep 23	1
Jun 18	2	Sep 30	4
		Nov 22 1978	1

LUDINGTON, MI (LDM) 1979
Type B
Less Than 12 Hours of 7 m/s

Date	1200 GMT - Pressure gradient
Jan 7	2
Jan 11	3
Jan 16	2
Jan 18	3
Jan 20	3
Jan 21	6
Jan 28	5
Jan 30	4
Jan 31	3
Feb 2	3
Feb 3	1
Feb 9	2
Feb 10	3
Feb 12	4
Feb 13	3
Feb 15	6
Feb 17	3
Feb 19	1
Feb 22	1
Feb 24	4
Feb 28	2
Mar 6	3
Mar 7	3
Mar 8	3
Mar 12	3
Mar 20	3
Mar 24	8
Mar 29	2
Apr 2	4
Apr 4	3
Apr 9	5
Apr 17	2
Apr 18	1
Apr 28	3
Apr 29	1
Apr 30	4
May 5	1
May 6	3
May 9	5
May 10	2
May 12	1
May 13	1
May 14	2

Date	1200 GMT - Pressure gradient
May 20	3
May 22	1
May 24	6
May 26	4
May 30	3
May 31	3
Jun 1	3
Jun 2	3
Jun 3	2
Jun 5	2
Jun 13	2
Jun 22	2
Jun 24	1
Jun 25	2
Jun 27	3
Jun 28	1
Jun 29	2
Jun 30	4
Jul 2	2
Jul 5	1
Jul 10	1
Jul 13	2
Jul 14	2
Jul 15	2
Jul 17	2
Jul 21	1
Jul 26	1
Jul 27	2
Jul 28	1
Jul 31	4
Aug 1	3
Aug 2	2
Aug 4	2
Aug 5	1
Aug 6	1
Aug 8	3
Aug 9	1
Aug 20	3
Aug 21	2
Aug 23	2
Aug 24	2
Aug 25	3
Aug 27	4

LUDINGTON, MI (LDM) 1979
Type B (cont)

Date	1200 GMT - Pressure gradient
Aug 30	1
Sep 5	2
Sep 6	2
Sep 13	4
Sep 16	5
Sep 25	2
Sep 26	2
Sep 29	3
Oct 1	1
Oct 4	2
Oct 5	2
Oct 8	4
Oct 9	3
Oct 10	3
Oct 15	3
Oct 16	2
Oct 17	2
Oct 25	3
Oct 26	3
Oct 29	2

LUDINGTON, MI (LDM) 1979
Type C
Greater Than 7 m/s for 12-23 Hours

Date	1200 GMT - Pressure gradient
Jan 8	4
Jan 9	5
Jan 10	4
Jan 12	3
Jan 13	5
Jan 22	6
Jan 23	4
Jan 24	7
Jan 29	5
Feb 1	5
Feb 4	8
Feb 7	3
Feb 8	4
Feb 11	4
Feb 16	6
Feb 20	5
Feb 25	7
Feb 26	7
Mar 4	5
Mar 5	3
Mar 9	4
Mar 11	3
Mar 15	5
Mar 17	4
Mar 18	4
Mar 22	2
Mar 23	5
Mar 28	6
Mar 31	4
Apr 5	3
Apr 8	4
Apr 26	4
Apr 27	2
May 2	4
May 3	2
May 11	3
May 18	6
May 19	3
May 21	4
May 23	4

Date	1200 GMT - Pressure gradient
Jun 4	4
Jun 6	3
Jun 7	4
Jun 14	5
Jun 17	4
Jun 21	5
Jun 26	4
Jul 1	5
Jul 16	3
Jul 25	2
Jul 30	2
Aug 3	3
Aug 7	6
Aug 10	4
Aug 11	2
Aug 12	3
Aug 15	4
Aug 22	4
Aug 29	2
Aug 31	3
Sep 1	4
Sep 2	3
Sep 3	4
Sep 7	4
Sep 9	2
Sep 10	4
Sep 14	4
Sep 15	4
Sep 21	3
Oct 2	5
Oct 3	2
Oct 6	4
Oct 7	5
Oct 11	5
Oct 13	6
Oct 14	2
Oct 18	3
Oct 19	6
Oct 23	4
Oct 28	4

LUDINGTON, MI (LDM) 1979
Type D
Greater Than 7 m/s for 24 Hours

Date	1200 GMT - Pressure gradient
Jan 1	6
Jan 2	4
Jan 5	6
Jan 6	6
Jan 15	6
Jan 17	6
Jan 19	6
Jan 25	8
Feb 6	6
Feb 14	6
Feb 18	5
Feb 23	6
Mar 3	6
Mar 10	6
Mar 14	7
Mar 16	4
Mar 30	6
Apr 6	13
Apr 11	3
Apr 12	8
Apr 25	4
May 7	3
May 8	2
May 17	3
May 25	7
Jun 10	2

Date	1200 GMT - Pressure gradient
Jun 16	2
Jun 19	4
Jun 20	3
Jun 23	3
Jul 24	2
Aug 13	5
Aug 14	5
Aug 17	3
Sep 11	4
Sep 12	2
Sep 17	5
Sep 18	3
Sep 20	4
Sep 24	4
Sep 27	3
Sep 28	2
Oct 12	4
Oct 20	6
Oct 22	5
Oct 24	6
Oct 27	6
Oct 30	4
Nov 18 1978	5
Nov 24 1978	6
Dec 3 1978	6
Dec 8 1978	4
Dec 10 1978	4

LUDINGTON, MI (LDM) 1979
Type E
Greater Than 10 m/s for Equal to or Greater Than 24 Hours

Date	1200 GMT - Pressure gradient
Jan 3	6
Jan 4	6
Jan 14	10
Feb 5	5
Mar 13	6
Mar 19	6
Jun 15	5
Oct 21	4
Oct 31	6
Nov 13 1978	7
Nov 14 1978	7
Dec 4 1978	8
Dec 5 1978	6
Dec 9 1978	7
Dec 12 1978	4
Dec 22 1978	6
	8

AMARILLO, TX (AMA) 1979
Type A
Less Than 7 m/s for 24 Hours

Date
Feb 17
Mar 4
Jun 2
Jul 19
Jul 26
Sep 15
Nov 30
Dec 30

AMARILLO, TX (AMA) 1979
Type B
Less Than 12 Hours of 7 m/s

Date

Jan 1
Jan 2
Jan 11
Jan 19
Jan 25
Jan 27
Jan 28
Feb 3
Feb 5
Feb 10
Feb 11
Feb 12
Feb 13
Feb 16
Feb 18
Feb 25
Feb 28
Mar 5
Mar 6
Mar 7
Mar 10
Mar 11
Mar 14
Mar 20
Apr 2
Apr 4
Apr 5
Apr 12
Apr 13
Apr 14
Apr 21
Apr 26
Apr 29
Apr 30
May 11
May 12
May 18
May 22
May 23
May 24
May 27
May 31
Jun 1
Jun 3
Jun 5
Jun 9
Jun 10
Jun 11
Jun 12
Jun 20
Jun 24
Jun 25
Jun 26
Jun 28
Jun 29
Jul 3
Jul 4
Jul 6
Jul 7
Jul 10
Jul 16
Jul 17
Jul 18
Jul 20
Jul 25
Jul 27
Jul 30
Jul 31
Aug 1
Aug 3
Aug 11
Aug 15
Aug 22
Aug 23
Aug 25
Aug 27
Sep 2
Sep 16
Sep 17
Sep 18
Sep 19
Sep 21
Sep 22
Sep 23
Sep 24
Sep 25
Sep 28
Oct 4
Oct 5
Oct 8
Oct 10
Oct 28
Nov 1
Nov 2
Nov 6
Nov 8
Nov 10
Nov 11
Nov 12
Nov 13
Nov 14
Nov 15
Nov 16
Nov 23
Nov 24
Nov 29
Dec 1
Dec 4
Dec 9
Dec 12
Dec 13
Dec 14
Dec 15
Dec 18
Dec 19
Dec 20
Dec 21
Dec 24
Dec 26
Dec 27
Dec 29
Dec 31

AMARILLO, TX (AMA) 1979
Type C
Greater Than 7 m/s for 12-23 Hours

Date

Jan 13
Jan 17
Jan 20
Jan 21
Jan 23
Jan 24
Jan 26
Feb 2
Feb 6
Feb 7
Feb 8
Feb 9
Feb 23
Feb 24
Feb 27
Mar 2
Mar 3
Mar 8
Mar 9
Mar 12
Mar 13
Mar 15
Mar 16
Mar 17
Mar 18
Mar 19
Mar 21
Mar 23
Mar 30
Mar 31
Apr 1
Apr 3
Apr 7
Apr 8
Apr 9
Apr 10
Apr 11
Apr 15
Apr 16
Apr 18
Apr 20
Apr 22
Apr 23
Apr 24
Apr 25
Apr 27
Apr 28
May 1
May 2
May 4
May 7
May 9
May 10
May 13
May 14
May 15
May 19
May 20
May 21
May 26
May 28
May 29
May 30
Jun 4
Jun 6
Jun 7
Jun 8
Jun 13
Jun 14
Jun 15
Jun 16
Jun 17
Jun 19
Jun 21
Jun 22
Jun 23
Jun 27
Jul 1
Jul 2
Jul 5
Jul 8
Jul 9
Jul 11
Jul 12
Jul 13
Jul 14
Jul 15
Jul 21
Jul 22
Jul 24
Jul 28
Aug 2
Aug 8
Aug 10
Aug 14
Aug 16
Aug 17
Aug 18
Aug 19
Aug 20
Aug 21
Aug 24
Aug 26
Aug 30
Aug 31
Sep 1
Sep 3
Sep 7
Sep 8
Sep 9
Sep 11
Sep 12
Sep 13
Sep 14
Sep 20
Sep 26
Sep 27
Sep 29
Sep 30
Oct 1
Oct 2
Oct 3
Oct 6
Oct 7
Oct 9
Oct 11
Oct 12
Oct 13
Oct 14
Oct 15
Oct 16
Oct 17
Oct 18
Oct 22
Oct 23
Oct 24
Oct 25
Oct 26
Oct 29
Oct 31
Nov 3
Nov 5
Nov 9
Nov 19
Nov 20
Nov 22
Nov 25
Nov 26
Nov 27
Nov 28
Dec 2
Dec 3
Dec 5
Dec 6
Dec 7
Dec 8
Dec 16
Dec 17
Dec 23
Dec 25
Dec 28

AMARILLO, TX (AMA) 1979
Type D
Greater Than 7 m/s for 24 Hours

Date
Jan 12
Jan 16
Jan 18
Jan 22
Feb 1
Feb 14
Feb 15
Feb 19
Feb 20
Feb 21
Feb 22
Feb 26
Mar 22
Apr 4
Apr 17
Apr 19
May 3
May 5
May 8
May 16
May 17
May 25
Jun 18
Jun 30
Jul 23
Jul 29
Aug 5
Aug 6
Aug 7
Aug 8
Aug 9
Aug 12
Aug 13
Aug 28
Aug 29
Sep 10
Oct 21
Oct 27
Oct 30
Nov 4
Nov 7
Nov 17
Nov 18
Nov 21
Dec 11
Dec 22

AMARILLO, TX (AMA) 1979
Type E
Greater Than 10 m/s for Equal to or Greater Than 24 Hours

Date
Mar 1
May 6
Oct 19
Oct 20
Dec 10

SAN GORGONIO, CA (SAG) 1979
Type B

Equal to or greater than 7 m/s for less than 24 hours - direction remains WSW through and after episode.

Time Began	Time Ended	Hours Equal to/Greater than 7 m/s
1-09/0900	1-09/2200	14
1-12/0300	1-12/2300	21
1-14/1600	1-14/1700	2
1-18/0600	1-19/1500	21
1-21/2300	1-22/2100	23
1-25/1500	1-26/0700	17
1-28/1100	1-28/1600	6
2-01/1700	2-02/0800	16
3-08/1600	3-08/2000	5
3-17/1800	3-19/0700	18
3-24/1700	3-25/0500	12
4-15/1700	4-16/0000	8
8-17/1900	8-18/0600	12
10-16/1600	10-17/0400	13
11-23/0600	11-27/0900	4
12-10/0400	12-10/0600	3
12-26/2000	12-27/0000	5
	TOTAL	200 = 5.5%

SAN GORGONIO, CA (SAG) 1979
Type C

Equal to or greater than 7 m/s for less than 24 hours - winds shift to east when light usually in morning.

Time Began	Time Ended	Hours Equal to/Greater than 7 m/s
3-19/1600	3-19/1800	2
3-27/1600	3-27/2200	5
3-31/1900	3-31/2100	3
4-02/1100	4-03/0100	15
4-13/1600	4-13/2100	6
4-14/1700	4-15/0400	12
4-20/1700	4-20/2300	7
4-21/1500	4-22/0400	14
5-03/1300	5-04/0000	12
5-14/1700	5-15/0500	13
5-15/1700	5-16/0300	11
5-16/1700	5-17/0000	8
5-19/1600	5-20/0100	10
5-22/1700	5-22/2200	6
5-25/1800	5-25/2200	5
5-26/1600	5-27/0300	12
5-31/1800	6-01/0000	7
6-01/1800	6-02/0000	7
6-03/1900	6-04/0000	6
6-19/1900	6-20/0400	10
6-26/1500	6-27/0100	11
6-27/1100	6-28/0100	15
6-28/1000	6-29/0600	21
7-14/2000	7-14/2200	3
7-15/1800	7-16/0200	9
7-16/1900	7-16/2200	4
7-17/1300	7-18/0100	12
7-18/1900	7-18/2300	5
7-21/2000	7-21/0300	8
7-22/1300	7-23/0600	18
7-23/1700	7-24/0500	12
7-28/1500	7-29/0600	16
7-29/1900	7-29/2300	5
7-31/2000	8-01/0300	8
8-17/2100	8-17/2200	2
8-27/2000	8-27/2300	4
9-04/1100	9-05/0100	15
9-05/1800	9-06/0200	9
9-10/2100	9-10/2200	2
9-11/1900	9-12/0200	8

San Gorgonio, CA (SAG) 1979
Type B (Cont)

Time Began	Time Ended	Hours Equal to/Greater than 7 m/s
9-20/1900	9-21/0500	11
9-21/1800	9-22/0500	12
9-22/1400	9-22/2200	9
9-23/1800	9-23/2200	5
9-28/1700	9-29/0100	9
9-29/1500	9-29/2200	8
9-30/1700	10-01/0000	7
10-01/1900	10-01/2100	3
10-03/1600	10-04/0000	8
10-04/1600	10-05/0600	15
10-05/1800	10-06/0500	12
10-24/1900	10-24/2100	3
10-27/1900	10-28/0000	6
11-10/1600	11-10/1800	3
	TOTAL	469 = 13.1%

SAN GORGONIO, CA (SAG) 1979
Type D

Equal to or greater than 7 m/s for at least 24 hours - direction remains WSW - brief periods equal to or less than 7 m/s permissable but direction must not change

Time Began	Time Ended	Hours Equal to/Greater than 7 m/s
2-13/1500	2-15/0800	38
2-15/1400	2-17/0500	38
2-19/0200	2-23/2300	116
2-26/0100	2-27/0500	28
2-28/1500	3-02/2300	57
3-11/2300	3-13/2000	46
3-14/1200	3-17/0600	69
3-20/2300	3-22/1200	36
3-25/1300	3-27/0700	43
3-28/0300	3-31/0100	71
4-06/0200	4-12/0400	143
4-16/0900	4-19/0400	68
4-22/0800	5-03/0300	254
5-04/1700	5-10/0300	130
5-20/1200	5-21/2200	31
5-23/1300	5-25/0300	39
5-27/1500	5-31/0000	82
6-15/0800	6-19/0200	91
6-20/1600	6-23/1000	60
6-24/1700	6-26/0600	37
6-29/1400	7-07/0600	185
7-07/1400	7-12/0300	101
7-24/1500	7-26/0500	38
7-26/1400	7-28/0300	34
8-20/1600	8-23/0500	51
8-23/1200	8-26/2300	84
8-28/1400	9-04/0600	160
9-24/2300	9-26/0600	29
9-26/1100	9-28/0800	43
10-06/2000	10-09/0400	52
10-10/1800	10-16/0700	126
10-17/1100	10-21/1100	92
10-25/1000	10-26/2100	36
10-28/0500	10-29/1500	35
11-03/1700	11-04/2300	31
11-07/1500	11-09/2300	57
11-17/0400	11-19/0700	46
12-10/1100	12-12/0100	34
12-20/1000	12-23/0400	66

TOTAL 2770 = 77.5%

SAN GORGONIO, CA (SAG) 1979
Type E

Winds equal to or greater than 7 m/s with direction NW to NE

Time Began	Time Ended	Hours Equal to/Greater than 7 m/s
1-01/0100	1-02/0000	24
2-04/2000		1
2-09/2300	2-10/0700	9
3-06/1200	3-06/1300	2
3-10/0600	3-10/0700	2
4-01/0400	4-01/0600	3
5-12/0500	5-12/0700	3
10-29/2100		1
11-01/0800		1
11-05/0400	11-05/0800	5
11-11/2200	11-12/0700	10
11-12/1900	11-13/0700	13
11-14/		11
11-15/		13
11-19/1000	11-19/1200	3
11-20/0000	11-20/0300	4
11-20/1300	11-20/1400	2
11-21/1000	11-21/1400	5
11-27/1600	11-29/0600	30
11-30/0000		1
12-05/1000	12-05/1600	6
12-12/1300	12-12/1400	2
12-14/0700		1
12-17/0100	12-17/0700	7
	TOTAL	135 = 3.7%

APPENDIX C

FURTHER EXAMPLES OF

VARIOUS TYPES OF WEATHER PATTERNS

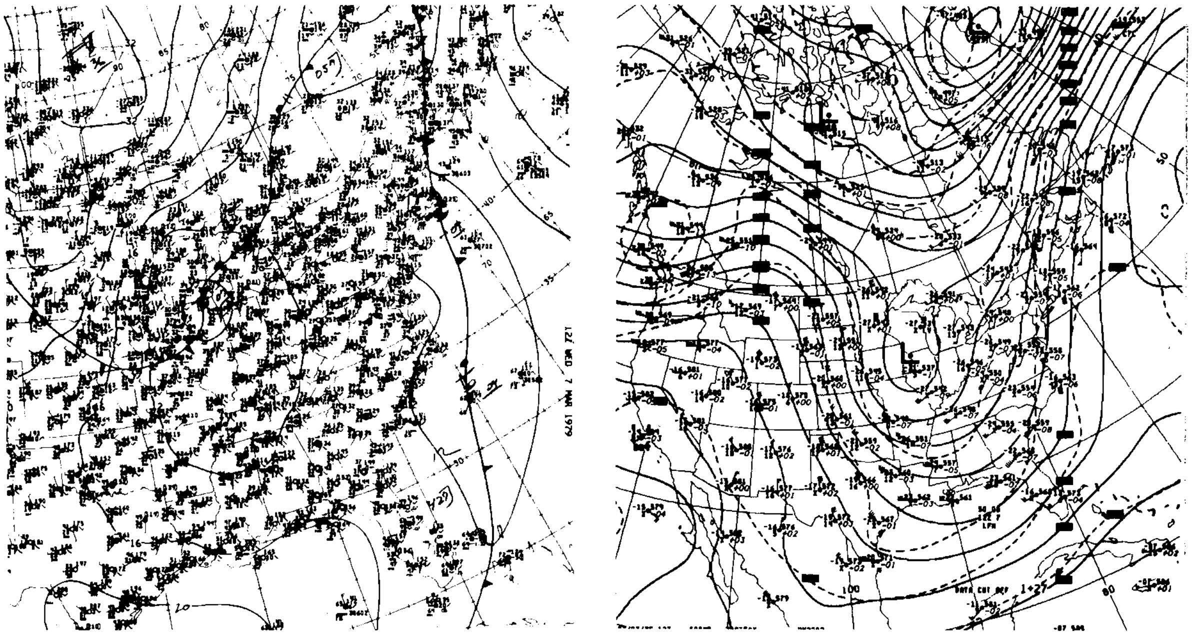
FOR

MONTAUK POINT, NY (MTP)

LUDINGTON, MI (LDM)

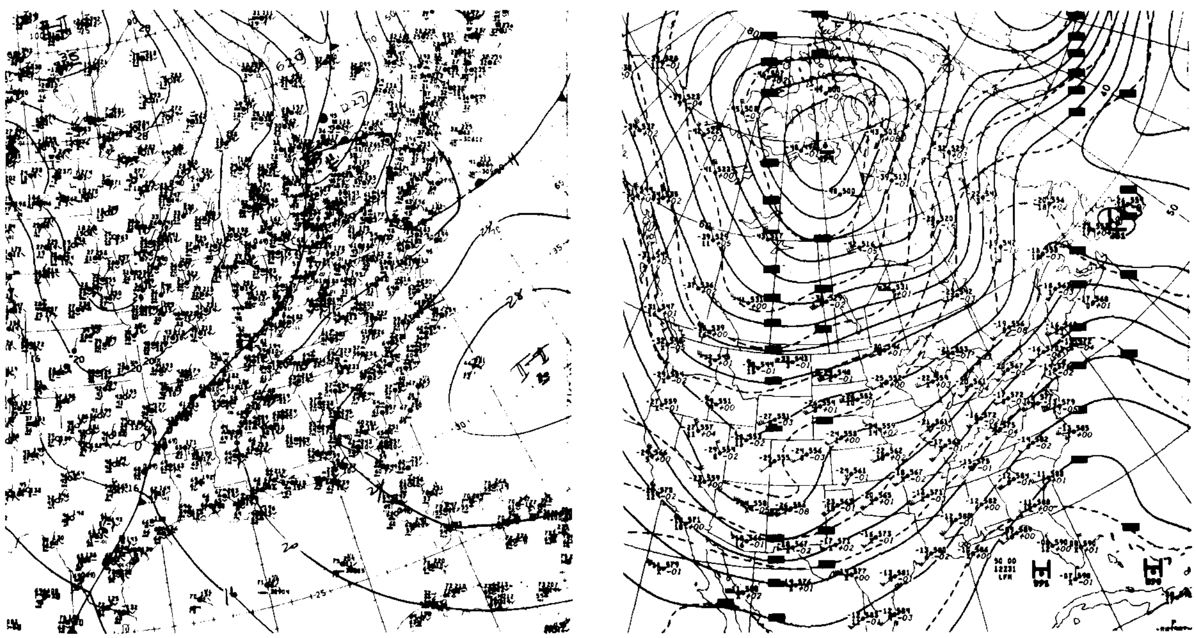
AMARILLO, TX (AMA)

SAN GORGONIO, CA (SAG)



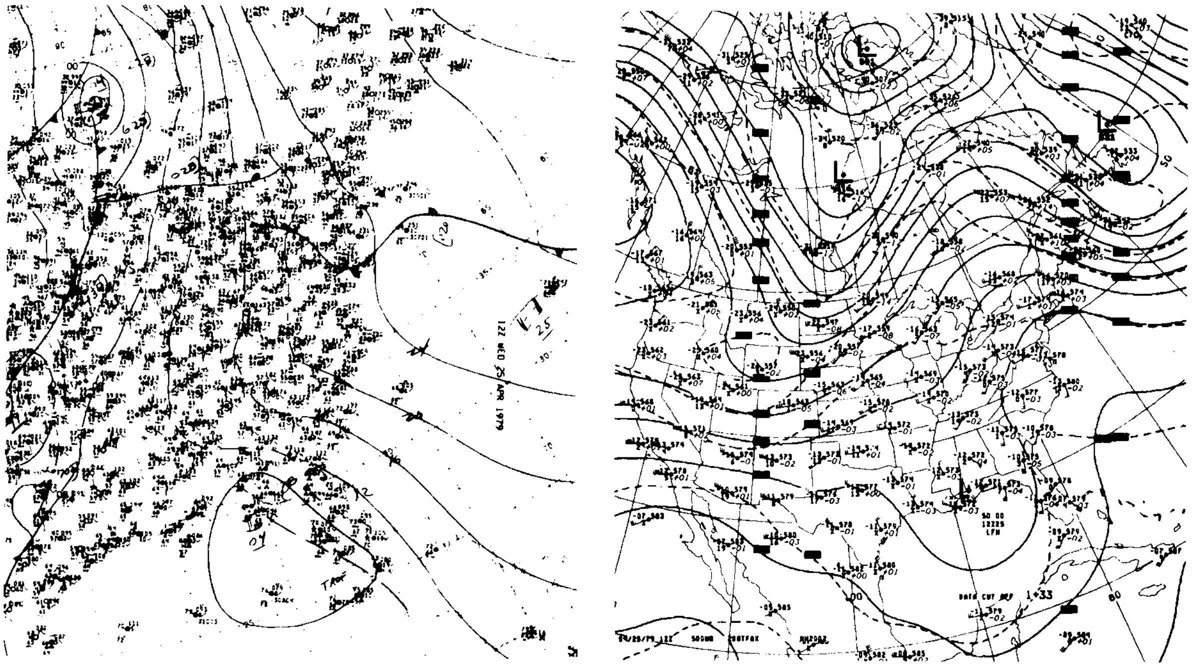
(A) (B)

FIGURE C-1. Example of a Type A Day at MTP at 1200 GMT on March 7, 1979. (A)Surface Map (B)500-mb



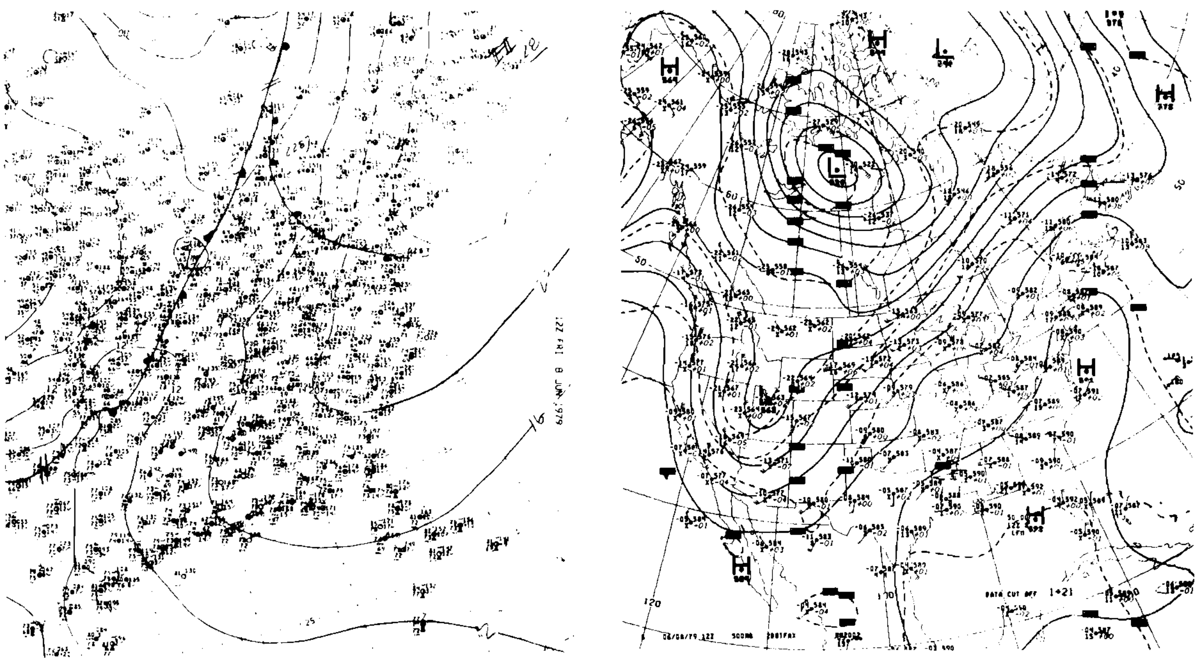
(A) (B)

FIGURE C-2. Example of a Type A Day at MTP at 1200 GMT on March 31, 1979. (A)Surface Map (B)500-mb



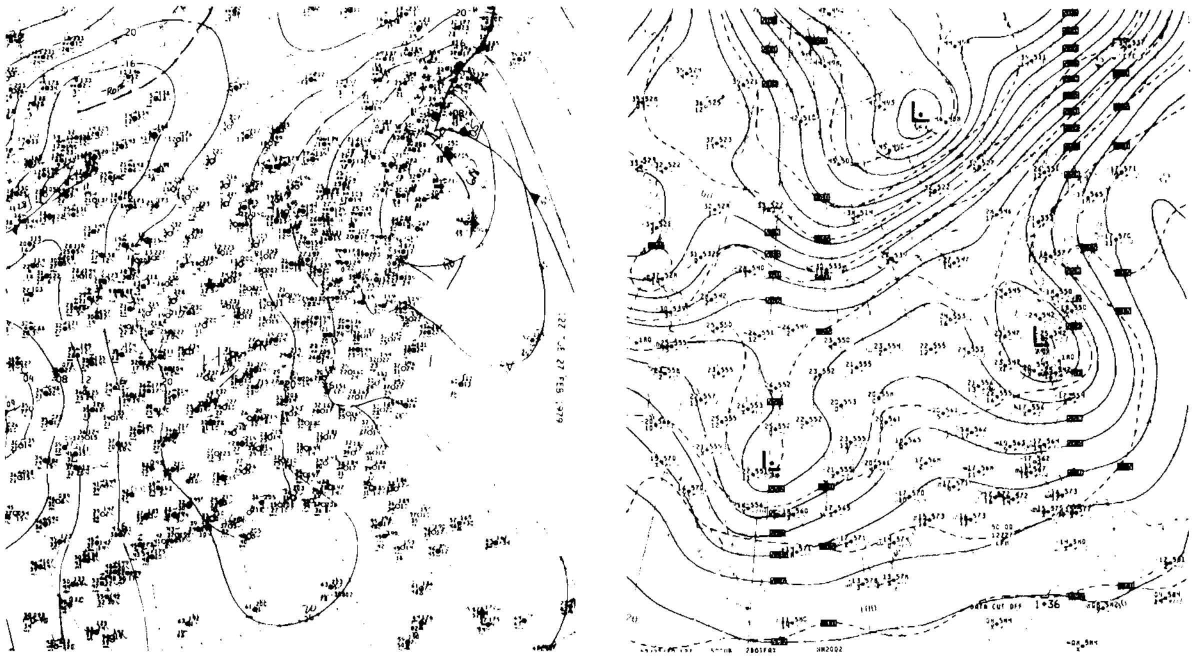
(A) (B)

FIGURE C-3. Example of a Type A Day at MTP at 1200 GMT on April 25, 1979. (A)Surface Map (B)500-mb



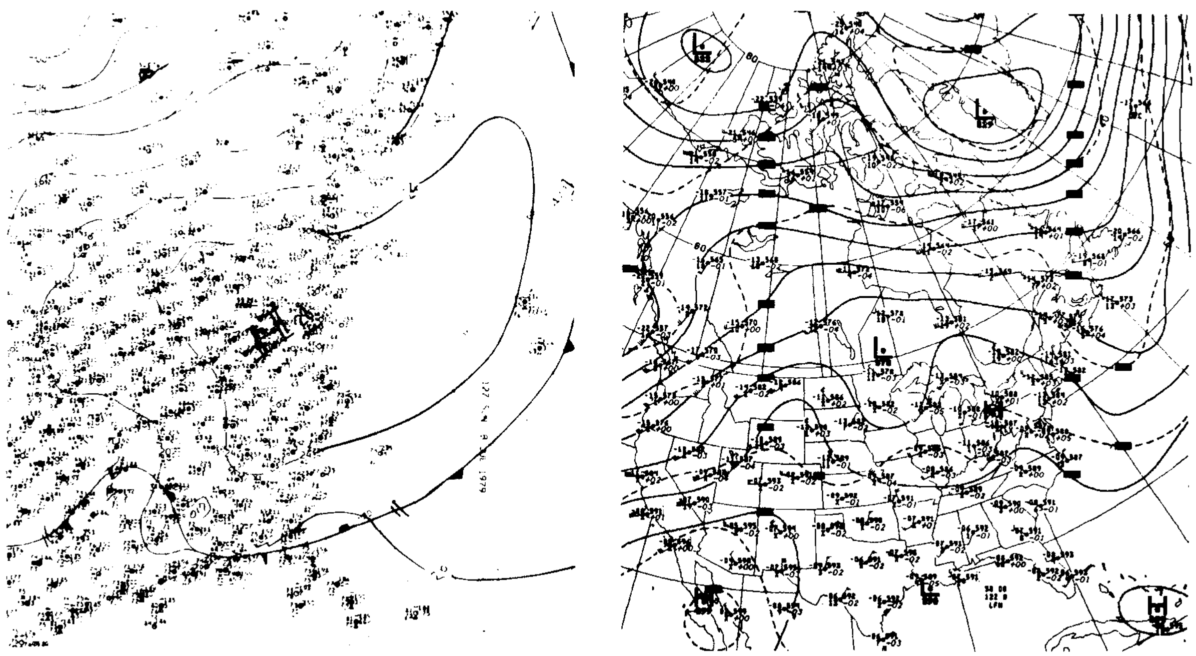
(A) (B)

FIGURE C-4. Example of a Type A Day at MTP at 1200 GMT on June 8, 1979. (A)Surface Map (B)500-mb



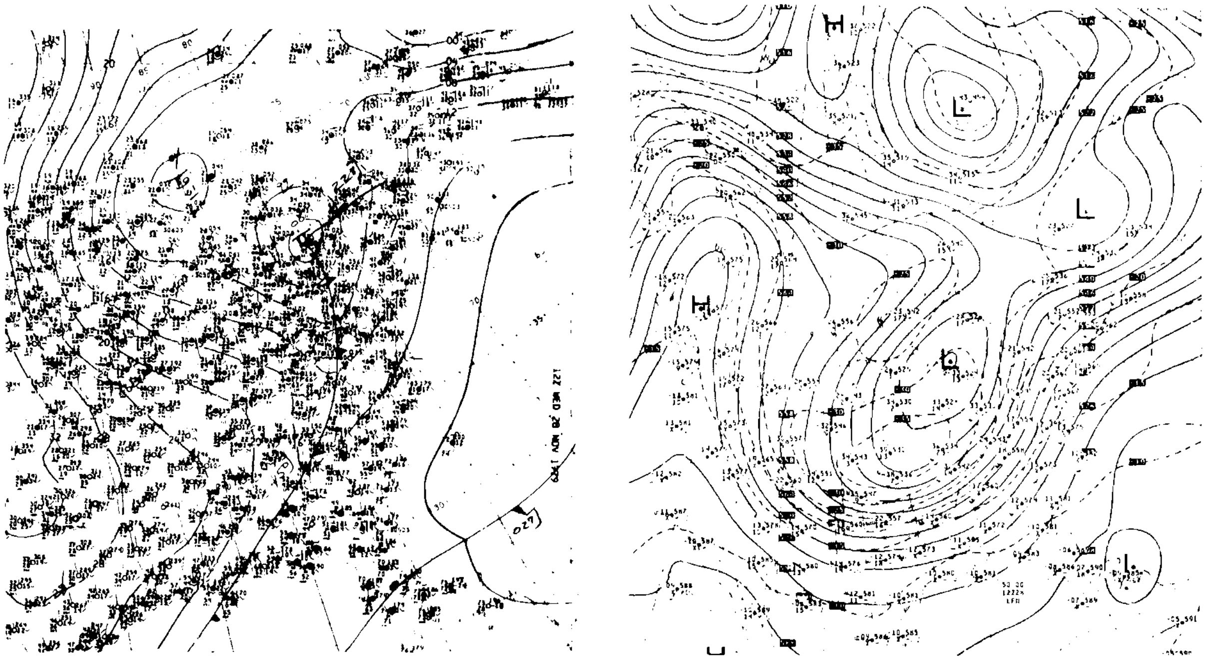
(A) (B)

FIGURE C-5. Example of a Type B Day at MTP at 1200 GMT on February 27, 1979. (A)Surface Map (B)500-mb



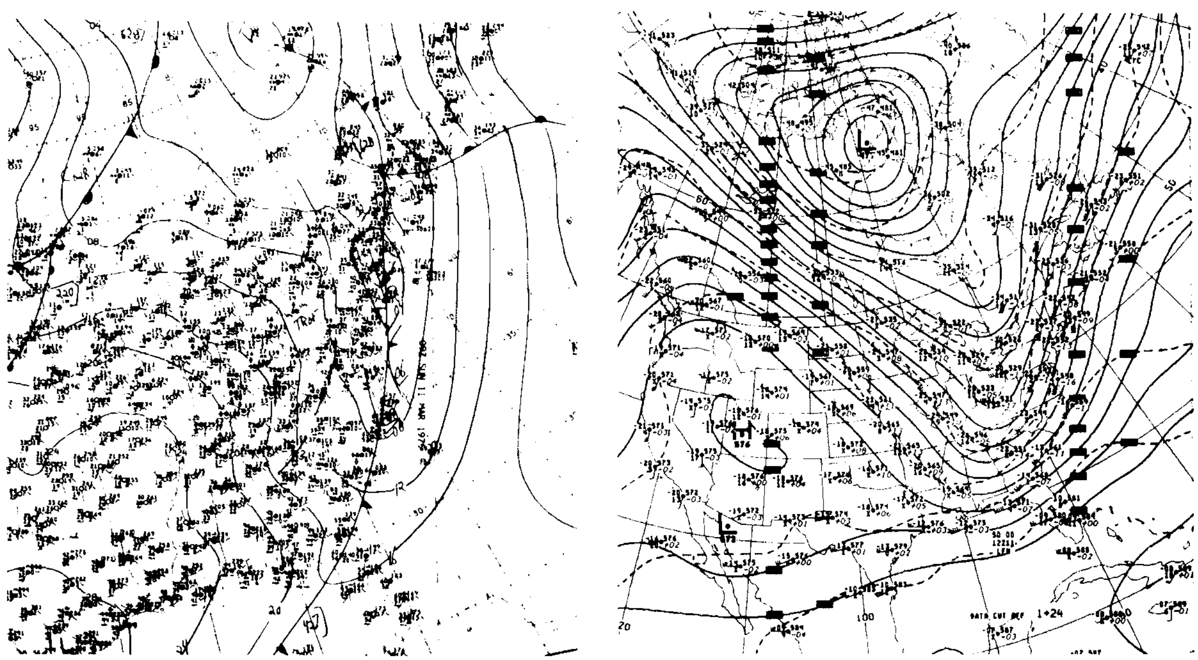
(A) (B)

FIGURE C-6. Example of a Type B Day at MTP at 1200 GMT on July 8, 1979. (A)Surface Map (B)500-mb



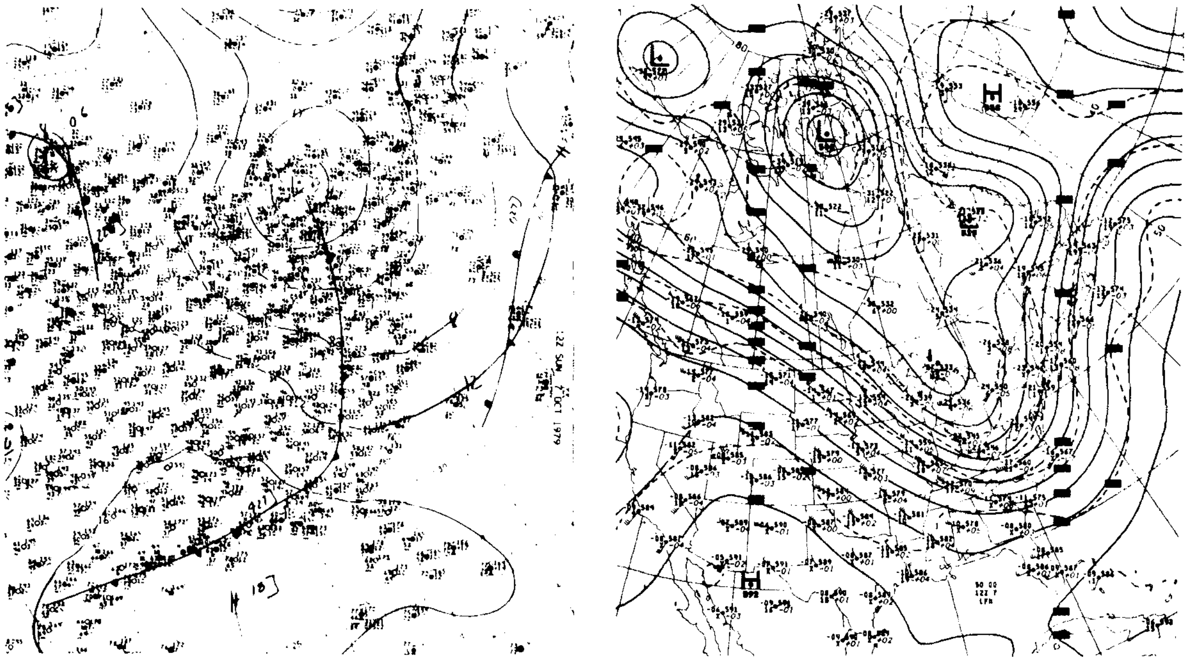
(A) (B)

FIGURE C-7. Example of a Type C1b Day at MTP at 1200 GMT on November 28, 1979. (A)Surface Map (B)500-mb



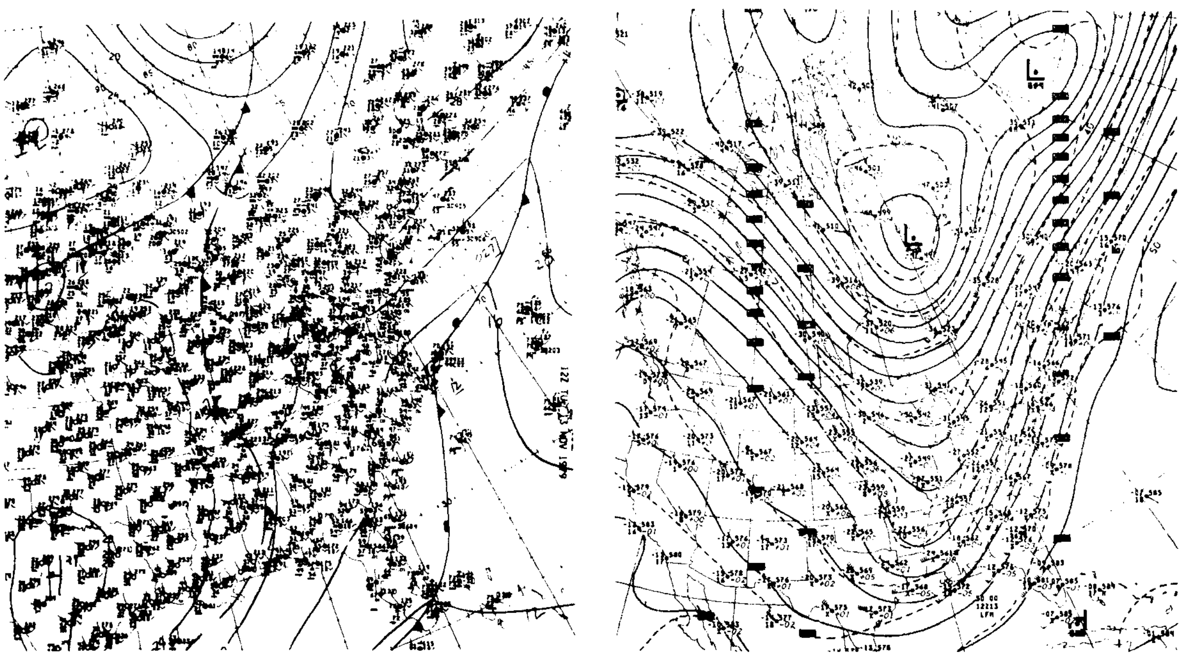
(A) (B)

FIGURE C-8. Example of a Type C2 Day at MTP at 1200 GMT on March 11, 1979. (A)Surface Map (B)500-mb



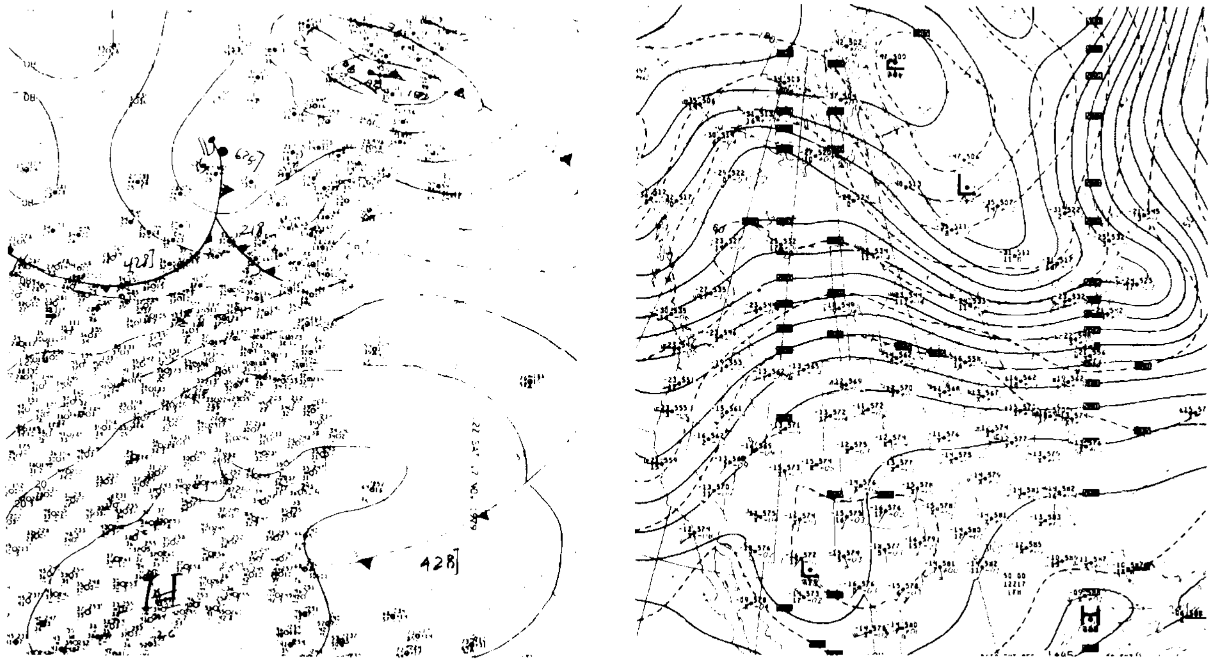
(A) (B)

FIGURE C-9. Example of a Type C3 Day at MTP at 1200 GMT on October 7, 1979. (A)Surface Map (B)500-mb



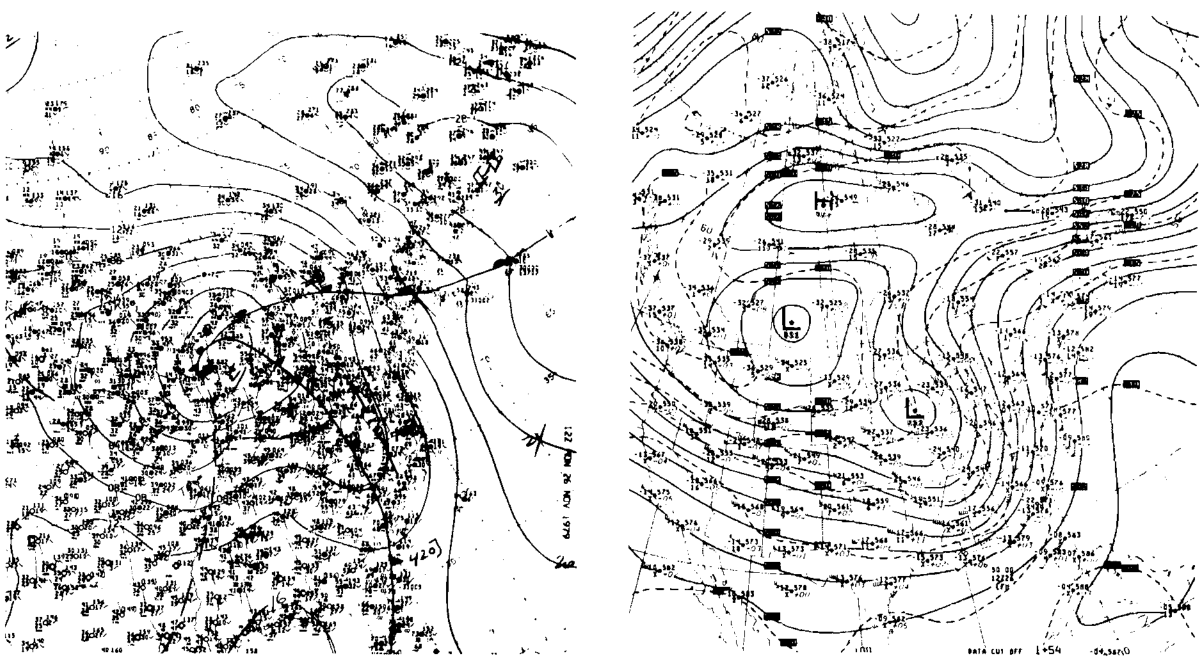
(A) (B)

FIGURE C-10. Example of a Type C4 Day at MTP at 1200 GMT on November 13, 1979. (A)Surface Map (B)500-mb



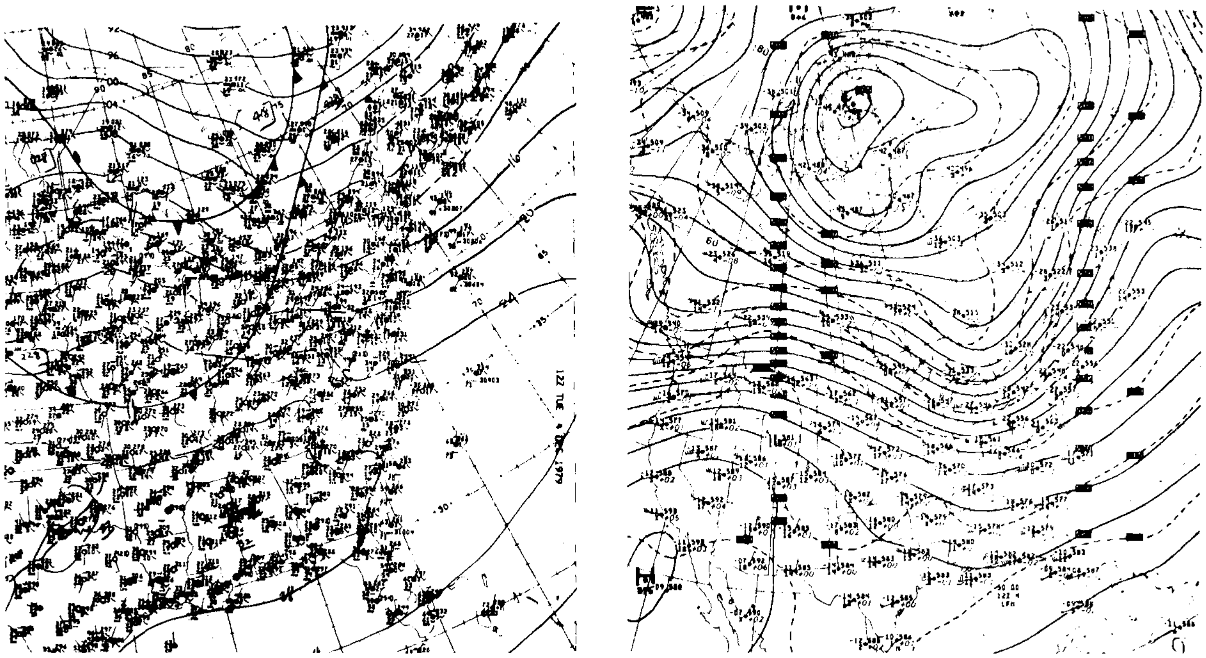
(A) (B)

FIGURE C-11. Example of a Type C5 Day at MTP at 1200 GMT on November 17, 1979. (A)Surface Map (B)500-mb



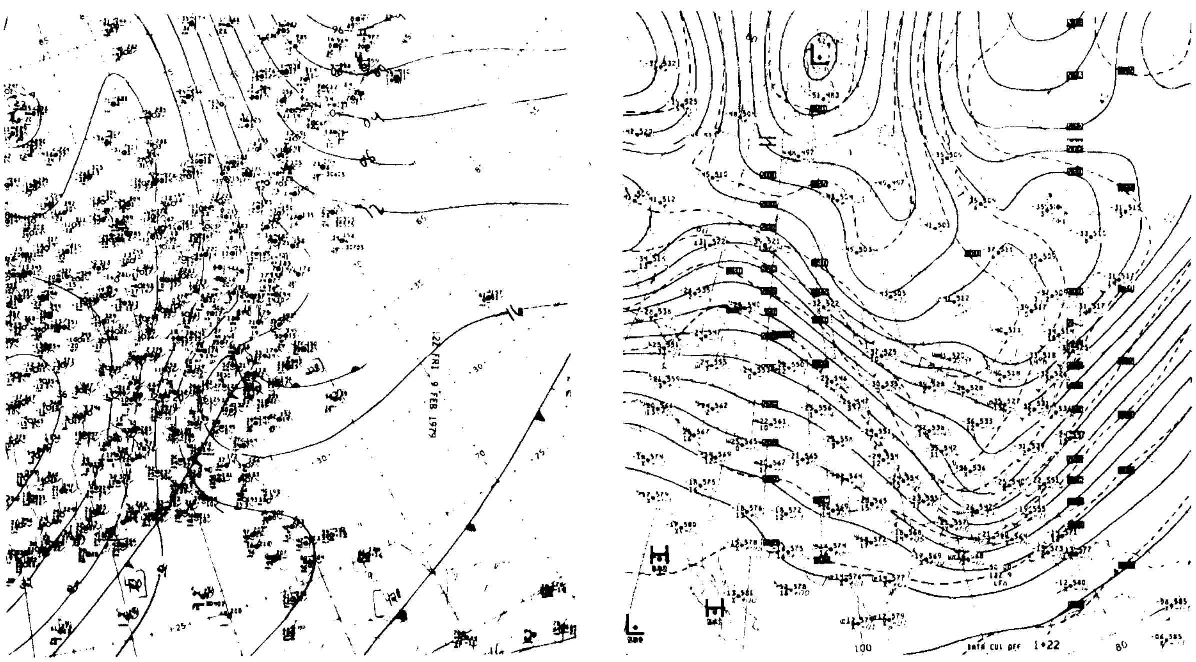
(A) (B)

FIGURE C-12. Example of a Type D1a Day at MTP at 1200 GMT on November 26, 1979. (A)Surface Map (B)500-mb



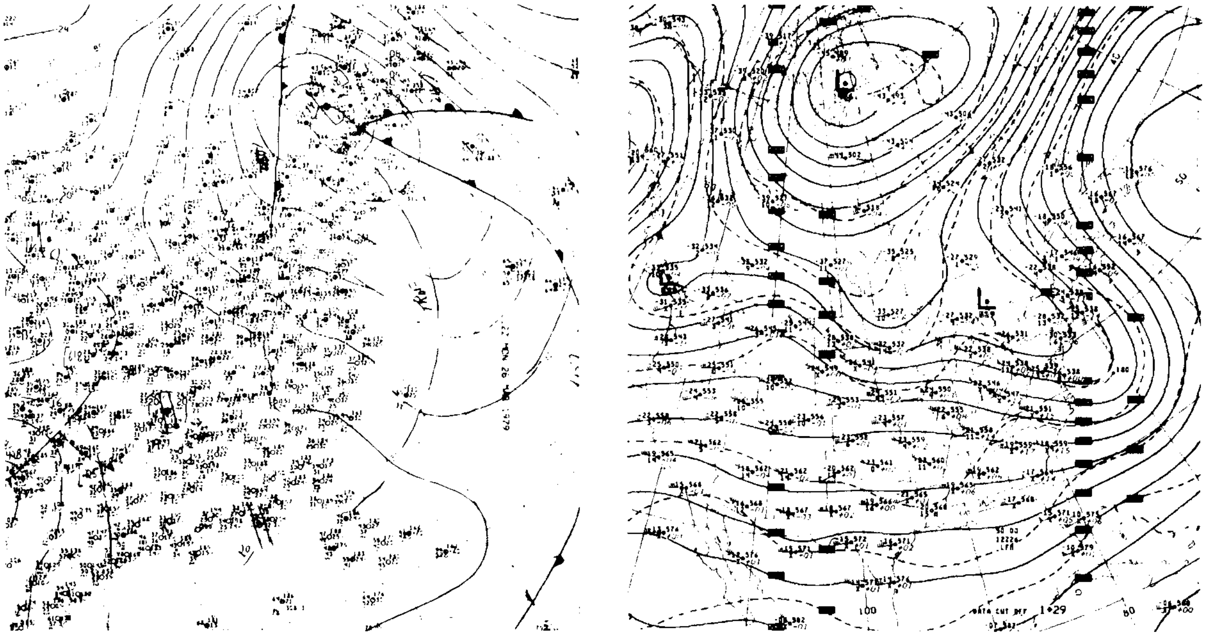
(A) (B)

<u>FIGURE C-13.</u> Example of a Type D1c Day at MTP at 1200 GMT on December 4, 1979. (A)Surface Map (B)500-mb



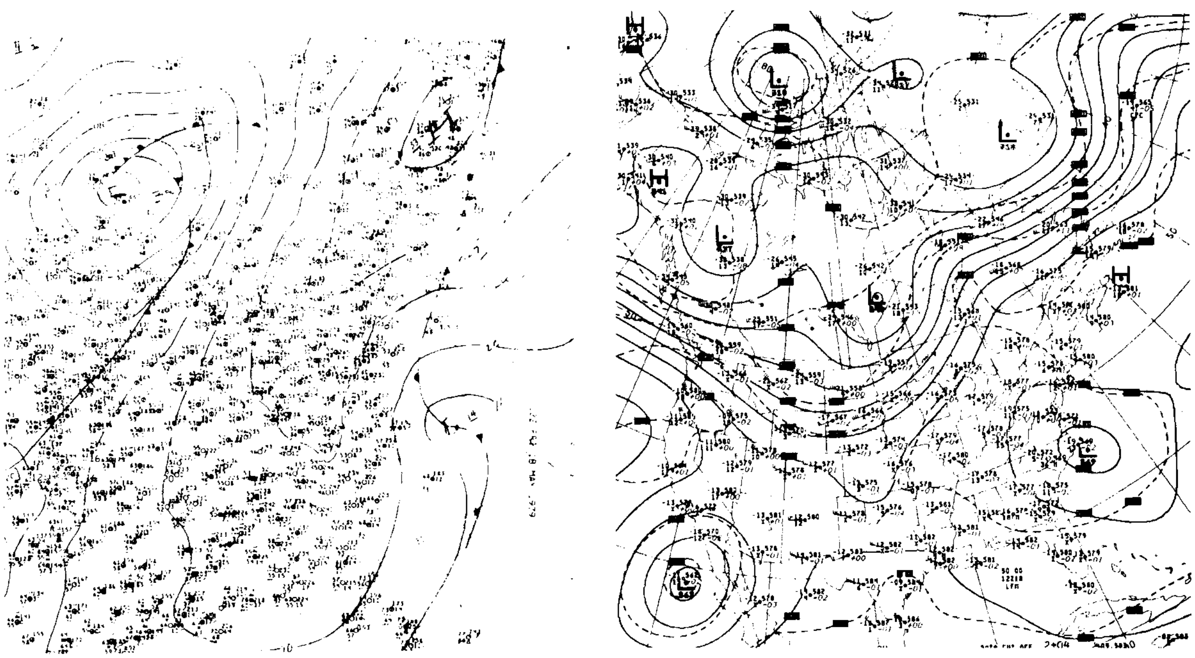
(A) (B)

<u>FIGURE C-14.</u> Example of a Type D2 Day at MTP at 1200 GMT on February 9, 1979. (A)Surface Map (B)500-mb



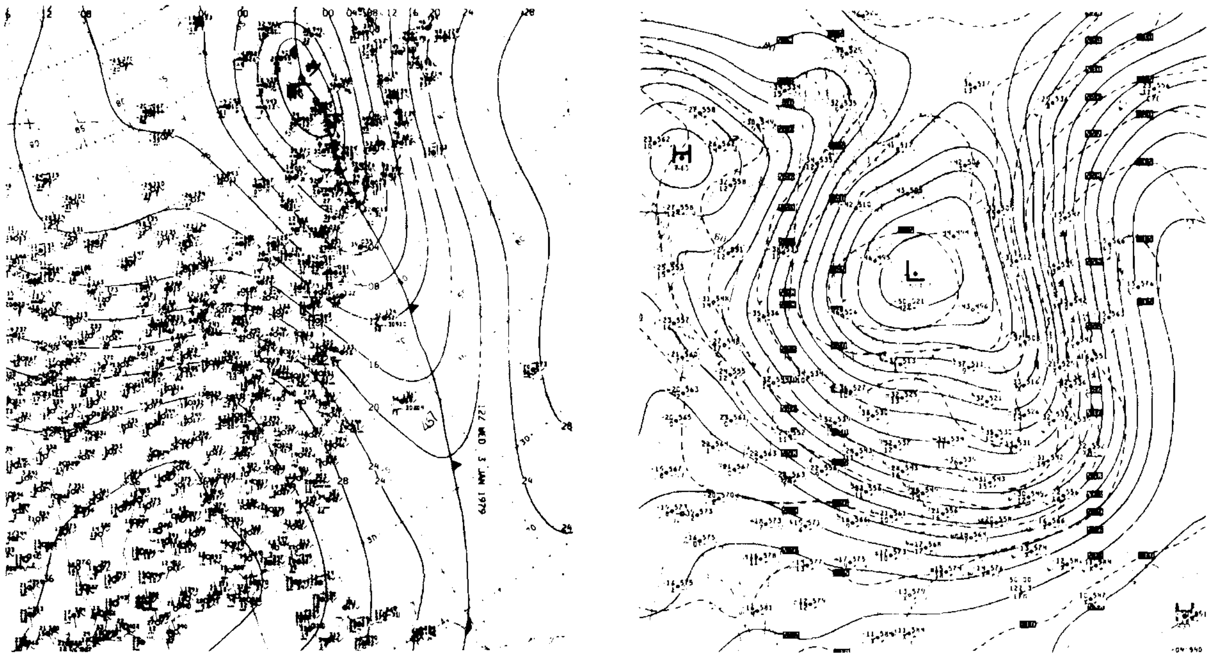
(A) (B)

FIGURE C-15. Example of a Type D3 Day at MTP at 1200 GMT on March 26, 1979.
(A)Surface Map (B)500-mb



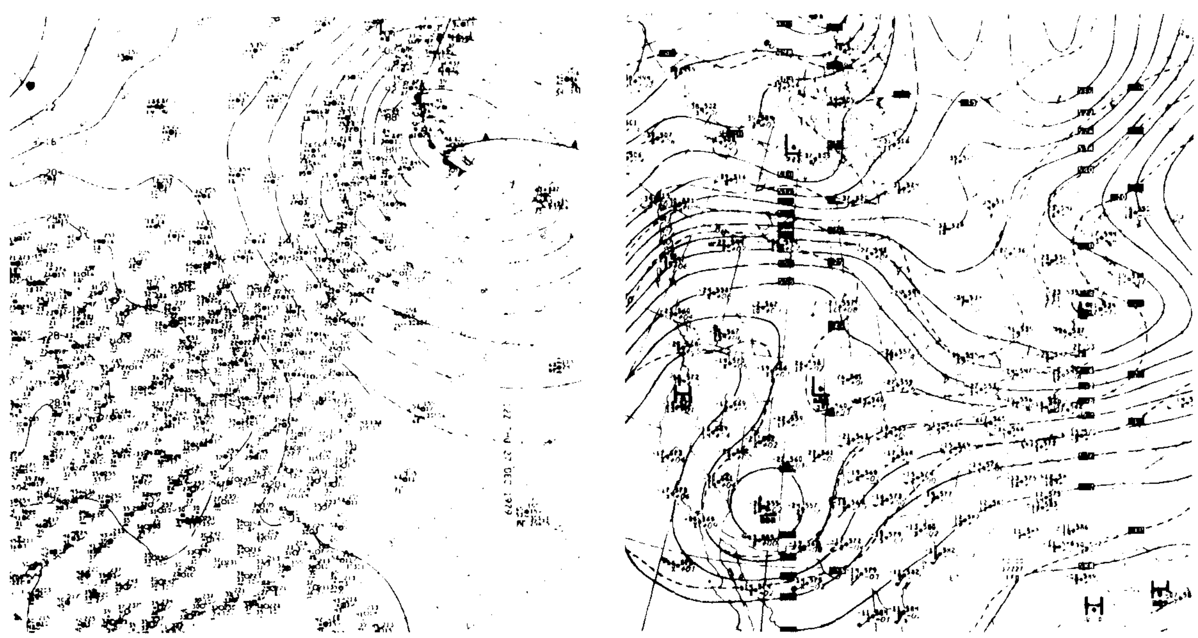
(A) (B)

FIGURE C-16. Example of a Type D4 Day at MTP at 1200 GMT on May 18, 1979.
(A)Surface Map (B)500-mb



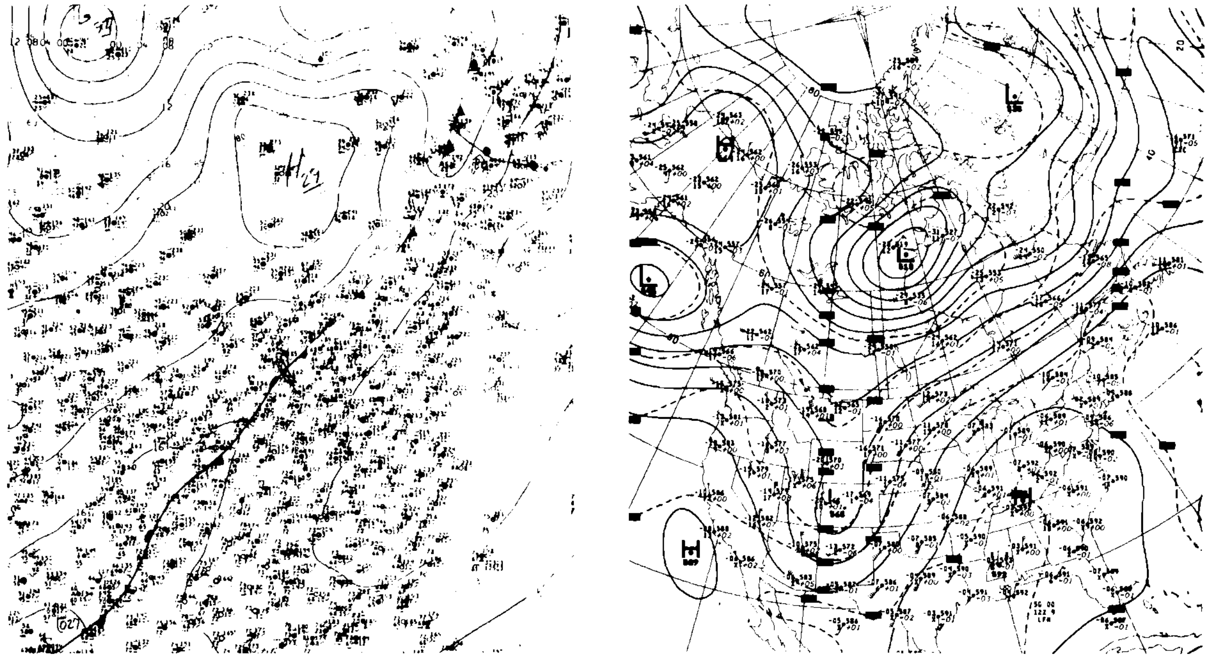
(A) (B)

FIGURE C-17. Example of a Type E Day at MTP at 1200 GMT on January 3, 1979. (A)Surface Map (B)500-mb



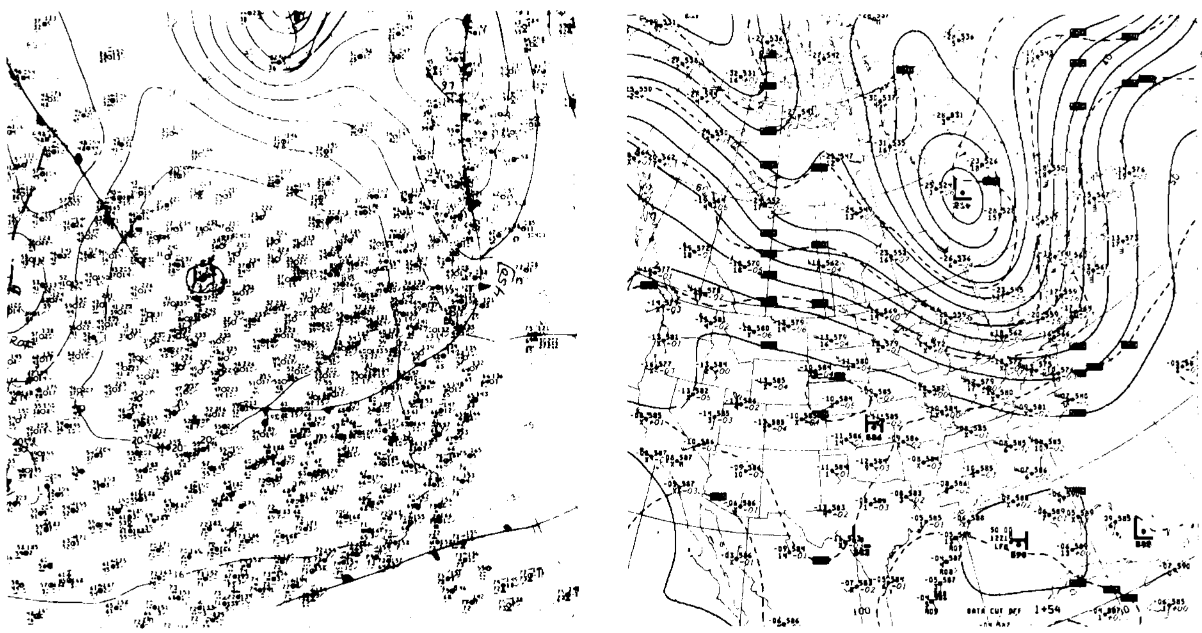
(A) (B)

FIGURE C-18. Example of a Type E Day at MTP at 1200 GMT on December 27, 1979. (A)Surface Map (B)500-mb



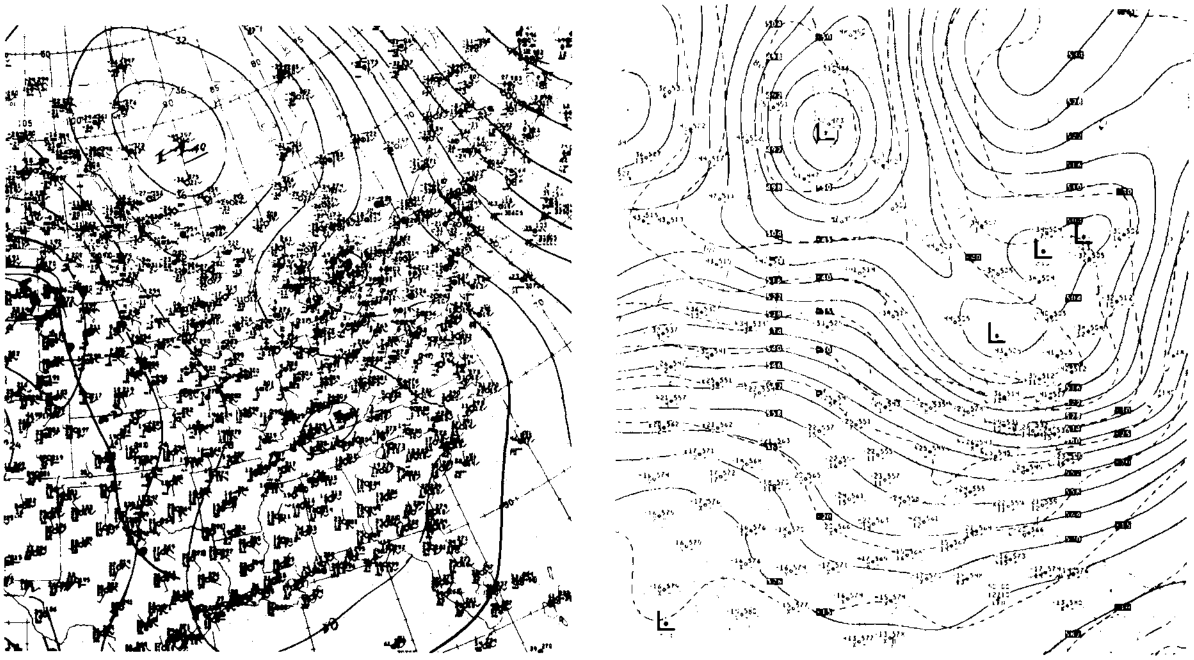
(A) (B)

FIGURE C-19. Example of a Type A Day at LDM at 1200 GMT on June 9, 1979. (A)Surface Map (B)500-mb



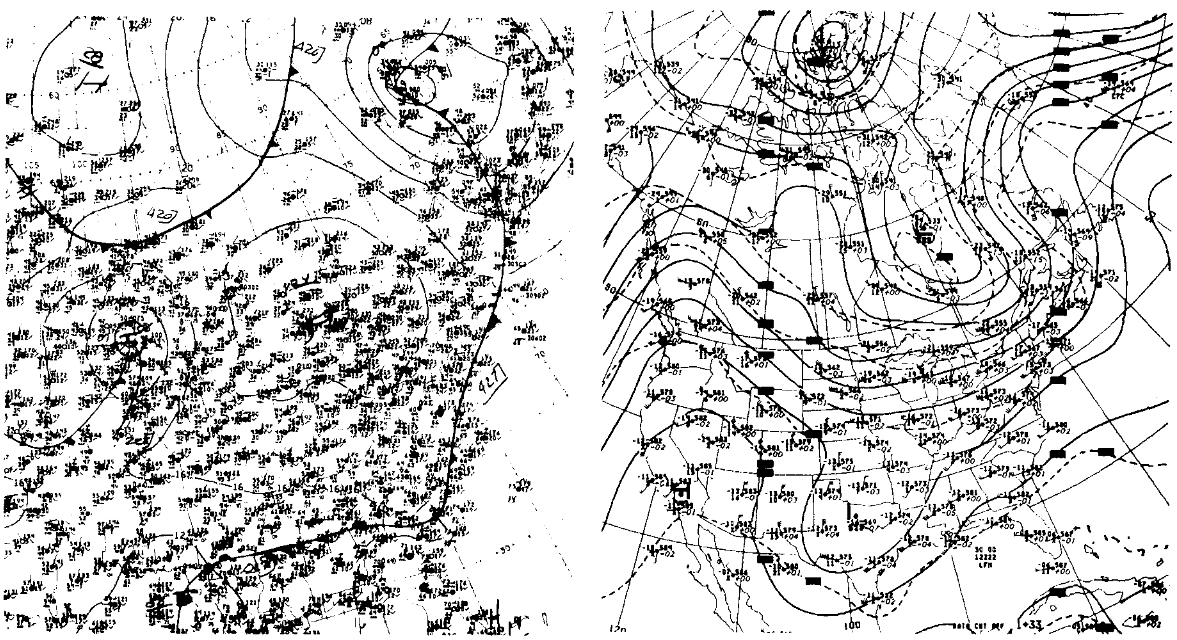
(A) (B)

FIGURE C-20. Example of a Type A Day at LDM at 1200 GMT on September 19, 1979. (A)Surface Map (B)500-mb



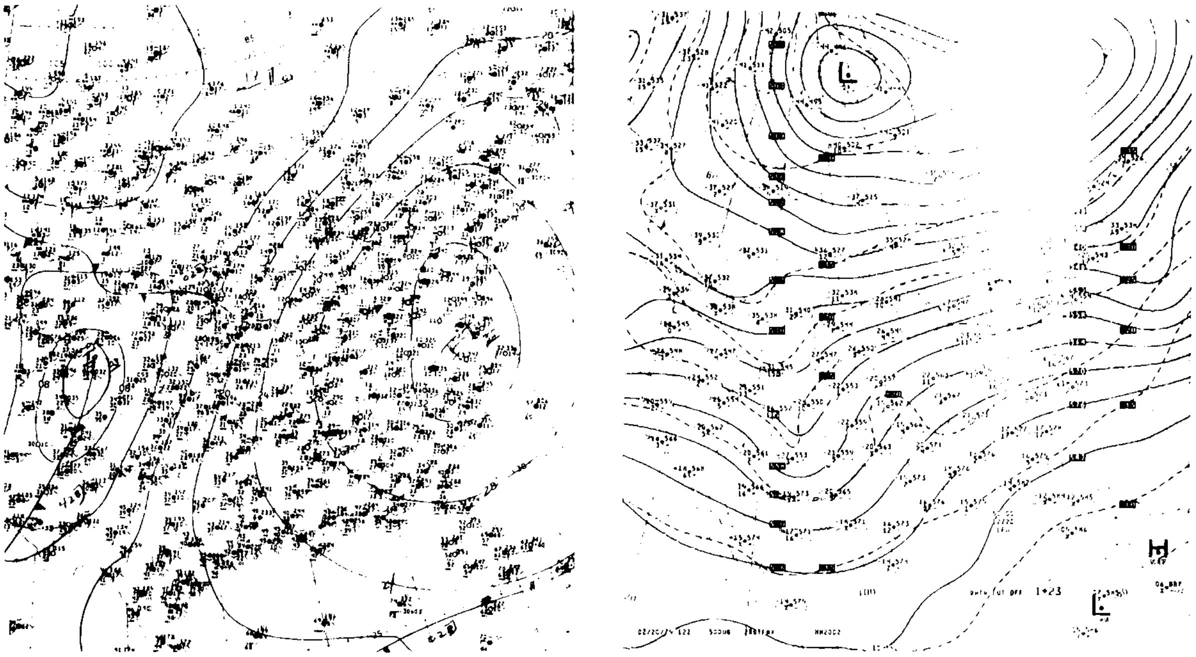
(A) (B)

FIGURE C-21. Example of a Type B Day at LDM at 1200 GMT on February 10, 1979. (A)Surface Map (B)500-mb



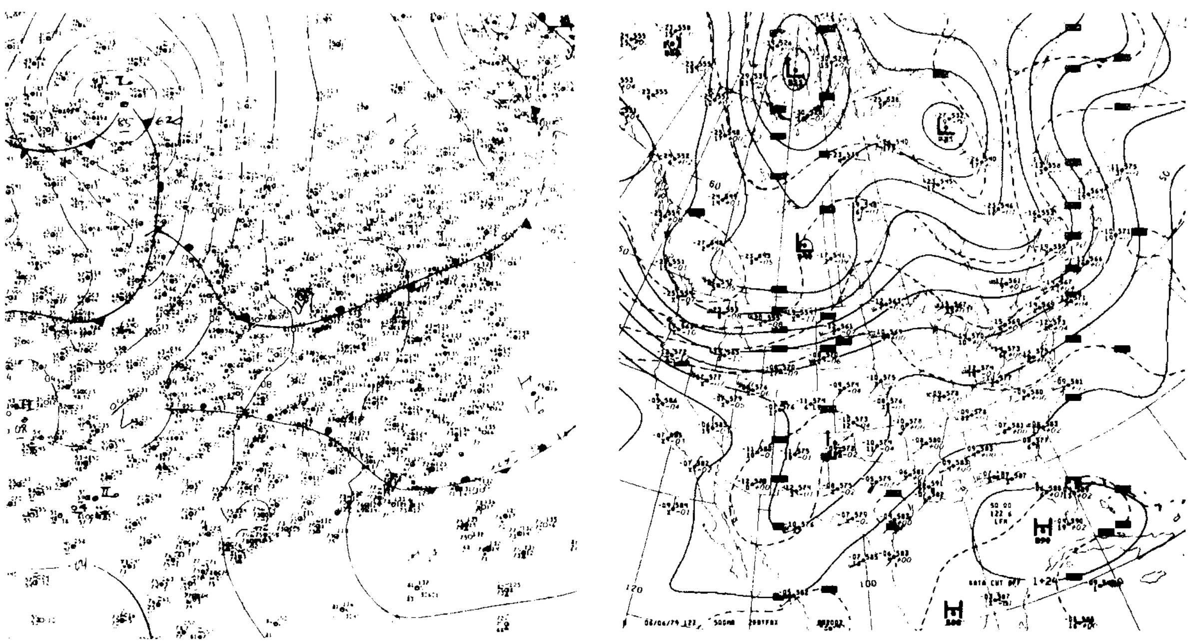
(A) (B)

FIGURE C-22. Example of a Type B Day at LDM at 1200 GMT on May 22, 1979. (A)Surface Map (B)500-mb



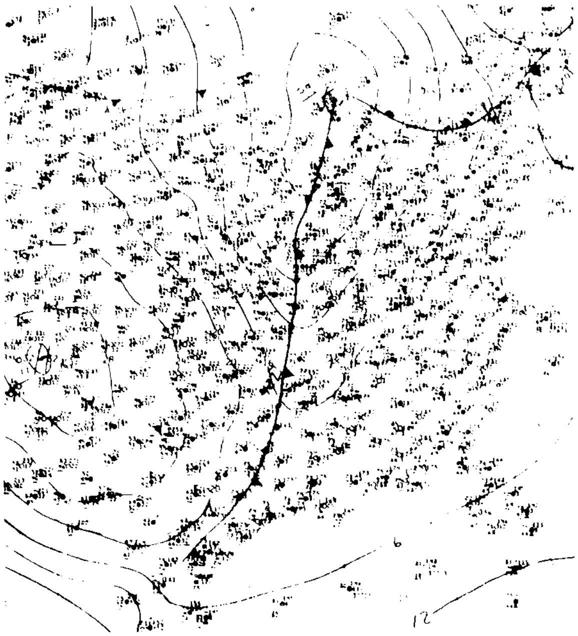
(A) (B)

FIGURE C-23. Example of a Type C Day at LDM at 1200 GMT on February 20, 1979. (A)Surface Map (B)500-mb

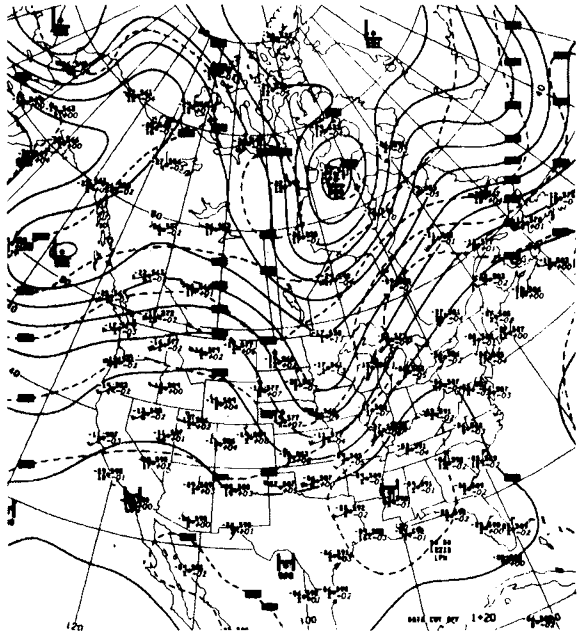


(A) (B)

FIGURE C-24. Example of a Type C Day at LDM at 1200 GMT on June 6, 1979. (A)Surface Map (B)500-mb

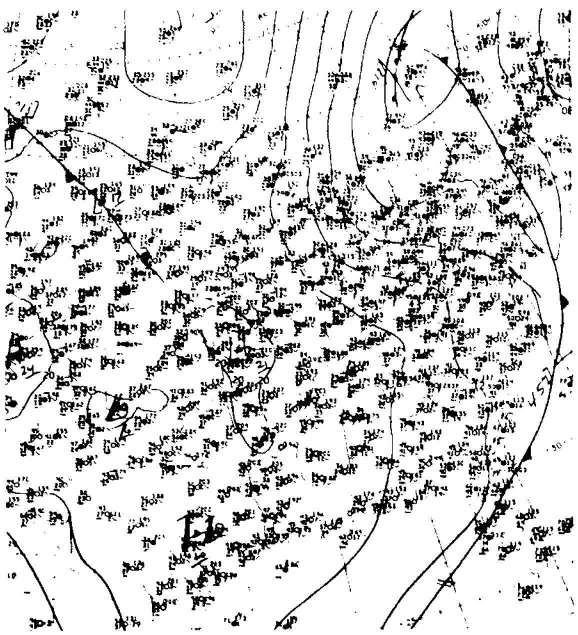


(A)

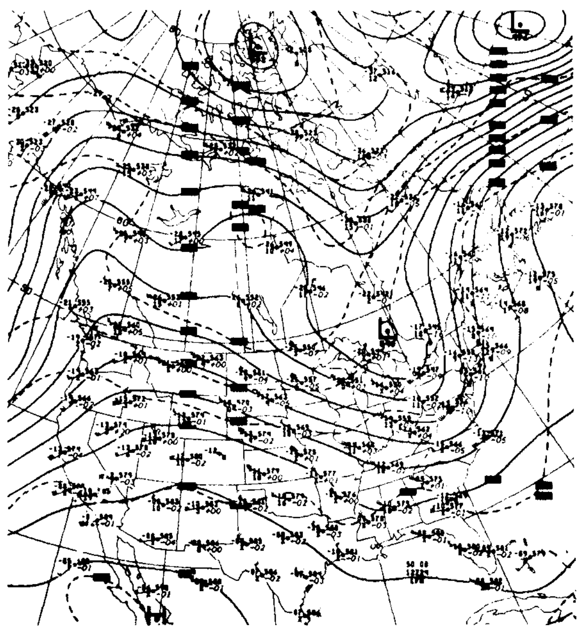


(B)

FIGURE C-25. Example of a Type D Day at LDM at 1200 GMT on June 10, 1979. (A)Surface Map (B)500-mb

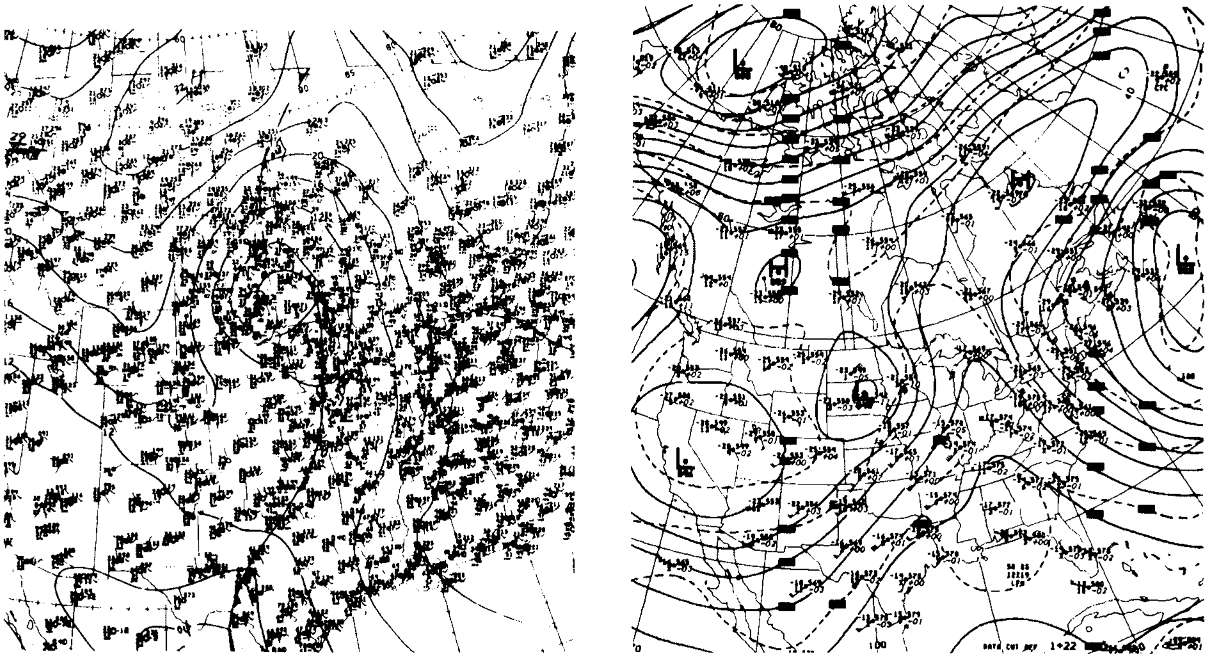


(A)



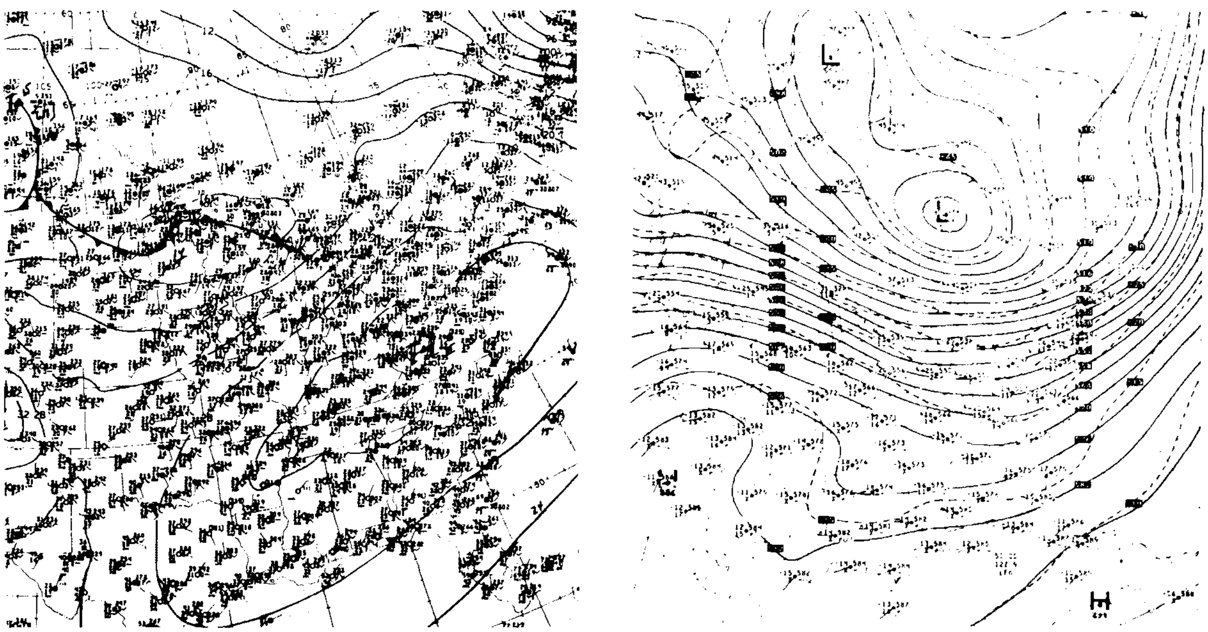
(B)

FIGURE C-26. Example of a Type D Day at LDM at 1200 GMT on October 24, 1979. (A)Surface Map (B)500-mb



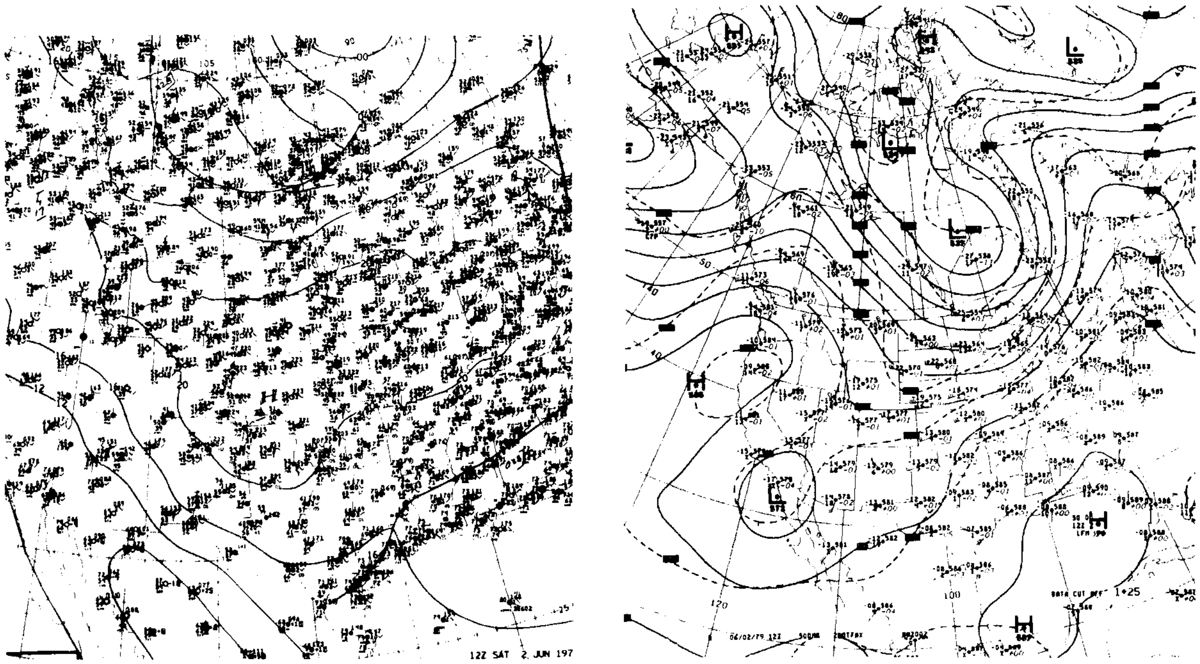
(A) (B)

FIGURE C-27. Example of a Type E Day at LDM at 1200 GMT on March 19, 1979. (A)Surface Map (B)500-mb



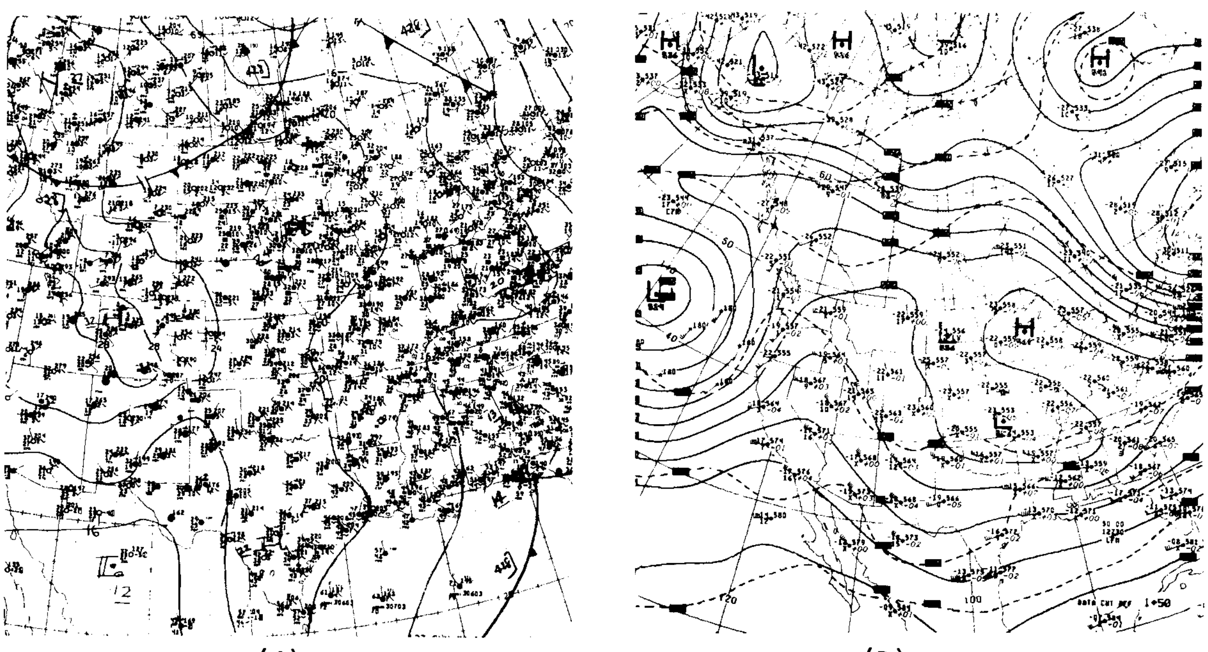
(A) (B)

FIGURE C-28. Example of a Type E Day at LDM at 1200 GMT on December 9, 1979. (A)Surface Map (B)500-mb



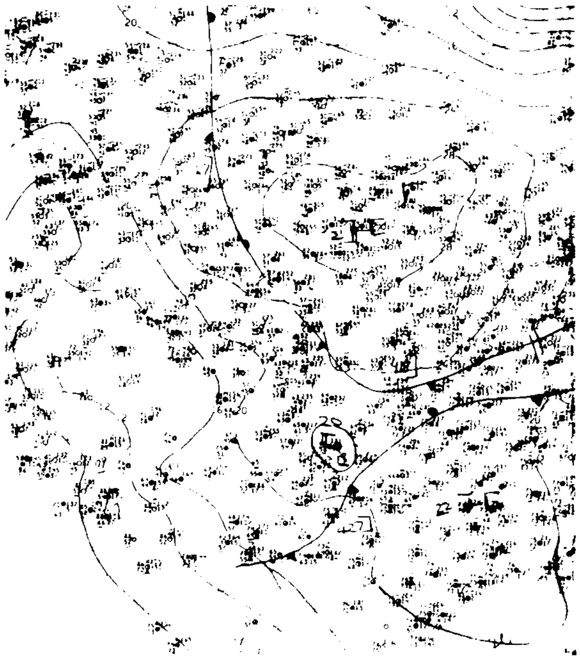
(A) (B)

FIGURE C-29. Example of a Type A Day at AMA at 1200 GMT on June 2, 1979. (A)Surface Map (B)500-mb

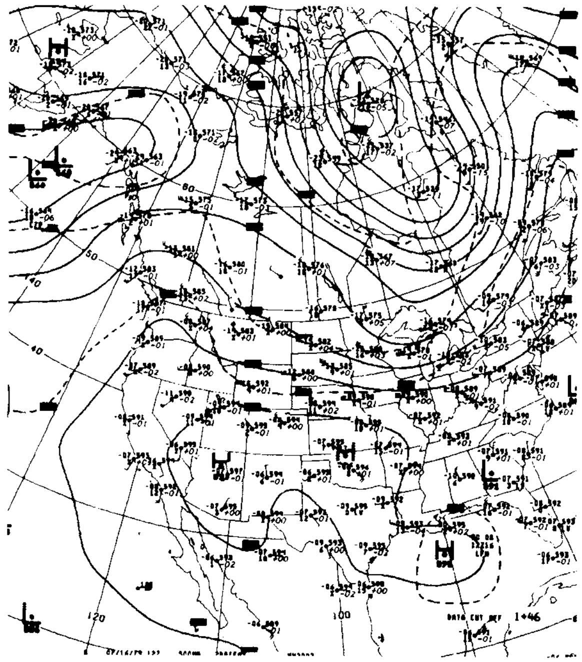


(A) (B)

FIGURE C-30. Example of a Type A Day at AMA at 1200 GMT on December 30, 1979. (A)Surface Map (B)500-mb

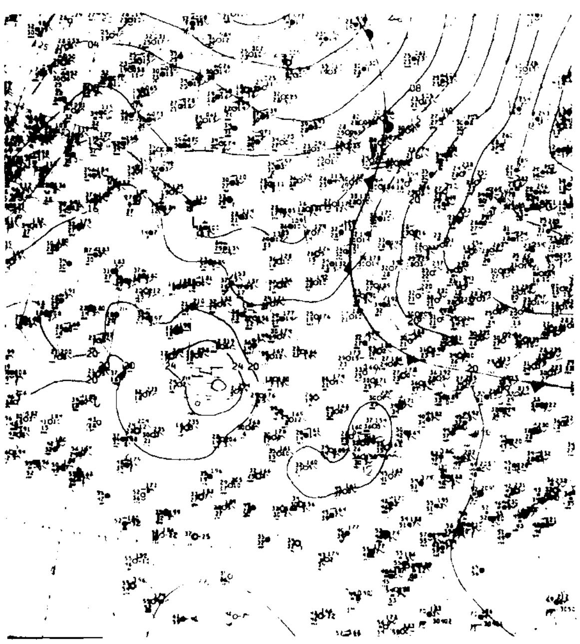


(A)

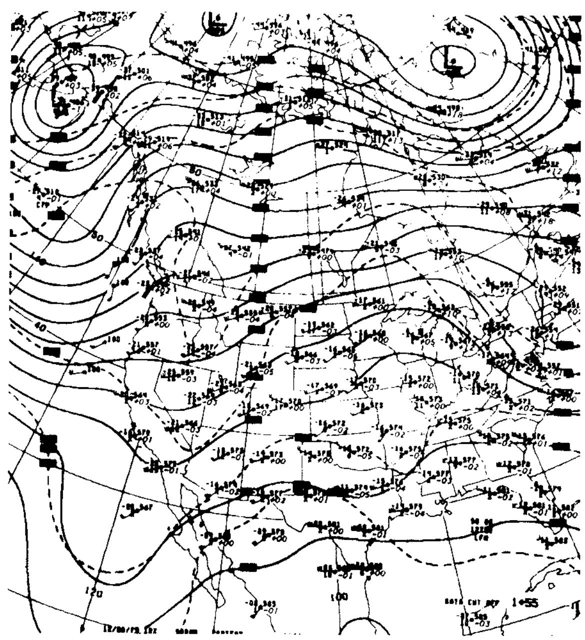


(B)

FIGURE C-31. Example of a Type B Day at AMA at 1200 GMT on July 16, 1979. (A)Surface Map (B)500-mb

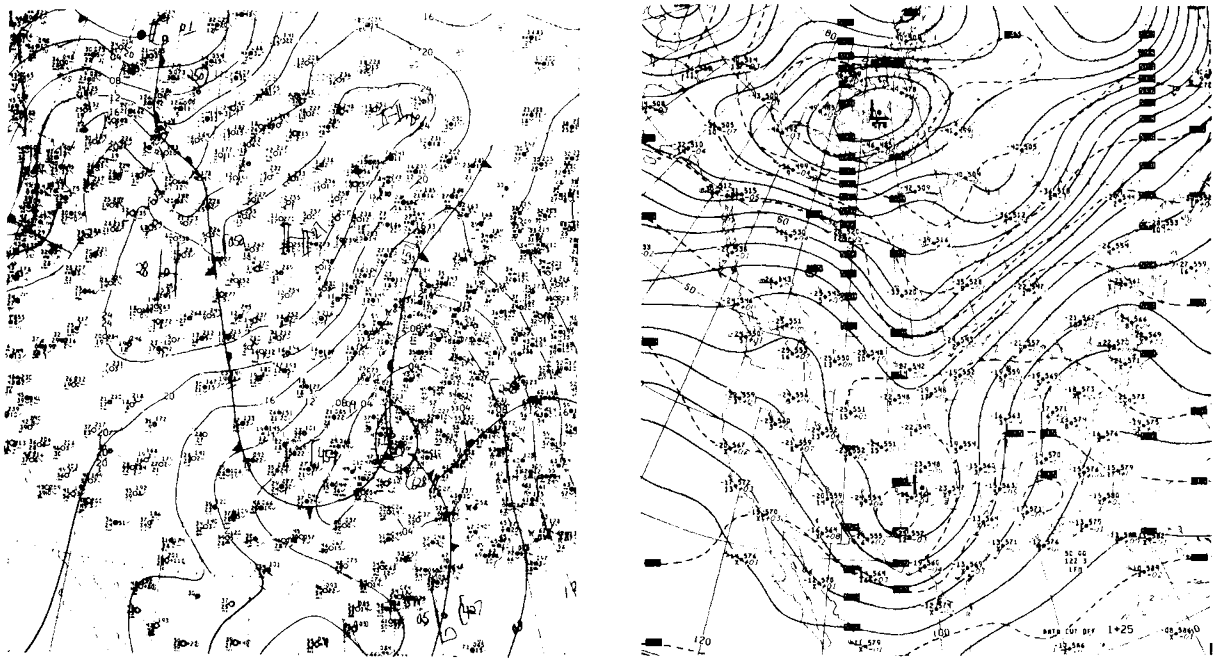


(A)



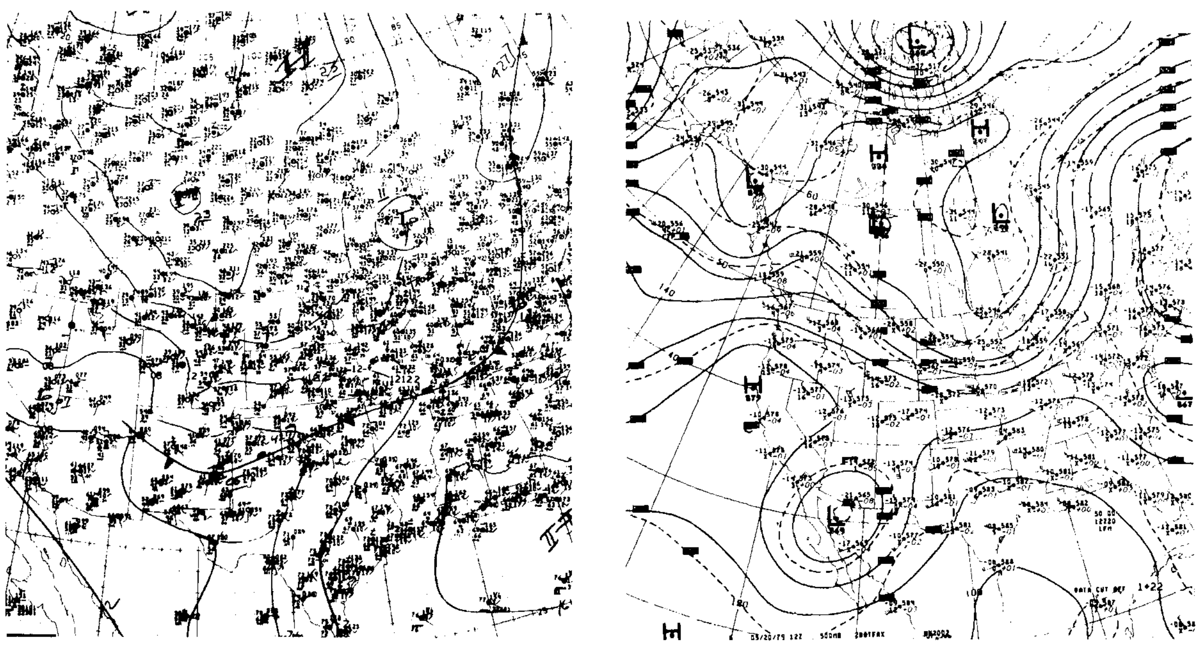
(B)

FIGURE C-32. Example of a Type B Day at AMA at 1200 GMT on December 20, 1979. (A)Surface Map (B)500-mb



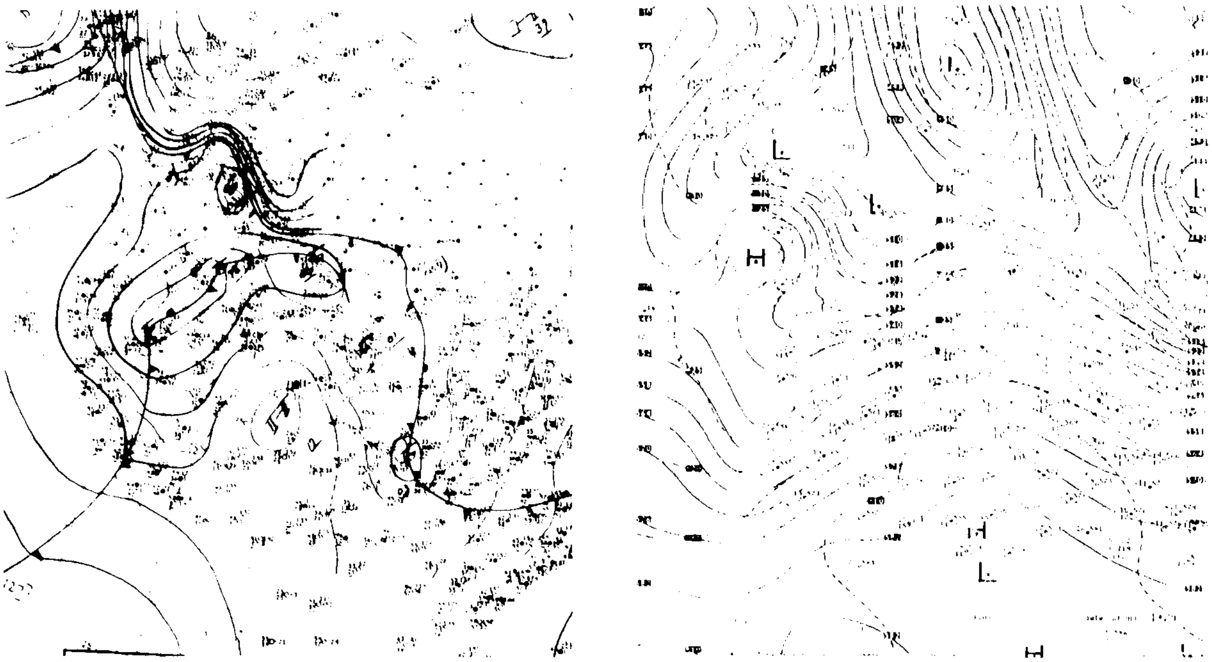
(A) (B)

FIGURE C-33. Example of a Type C Day at AMA at 1200 GMT on March 3, 1979. (A)Surface Map (B)500-mb



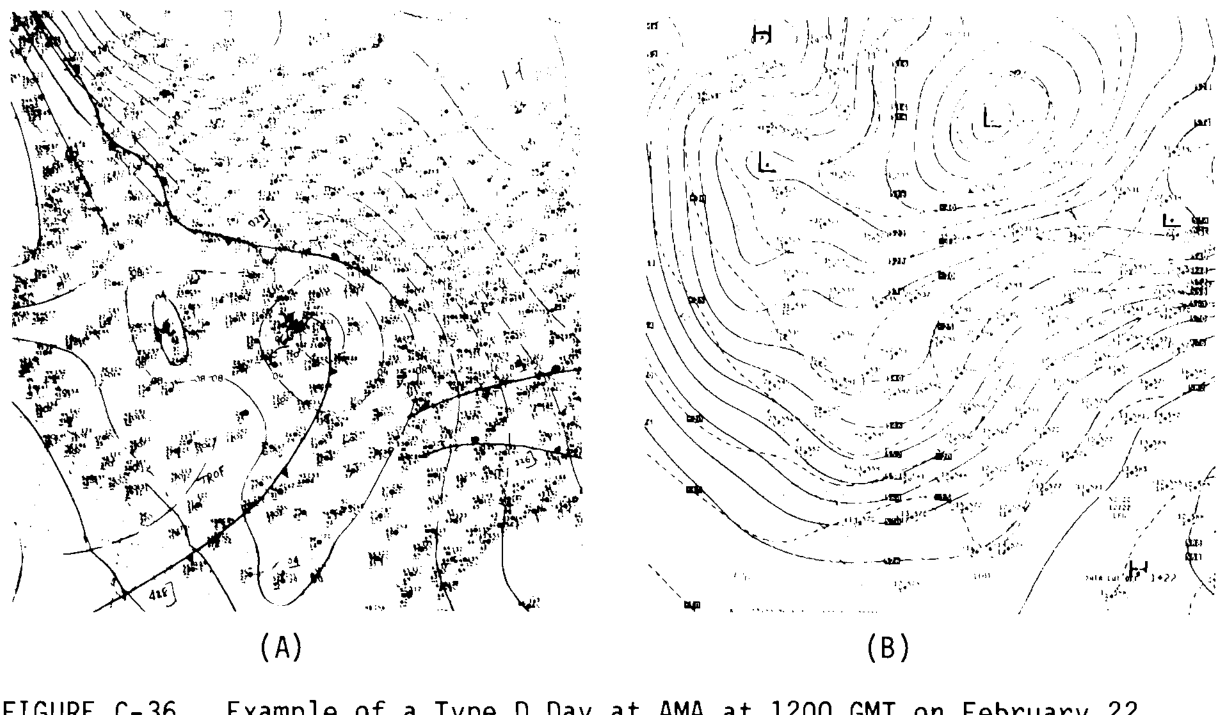
(A) (B)

FIGURE C-34. Example of a Type C Day at AMA at 1200 GMT on May 20, 1979. (A)Surface Map (B)500-mb



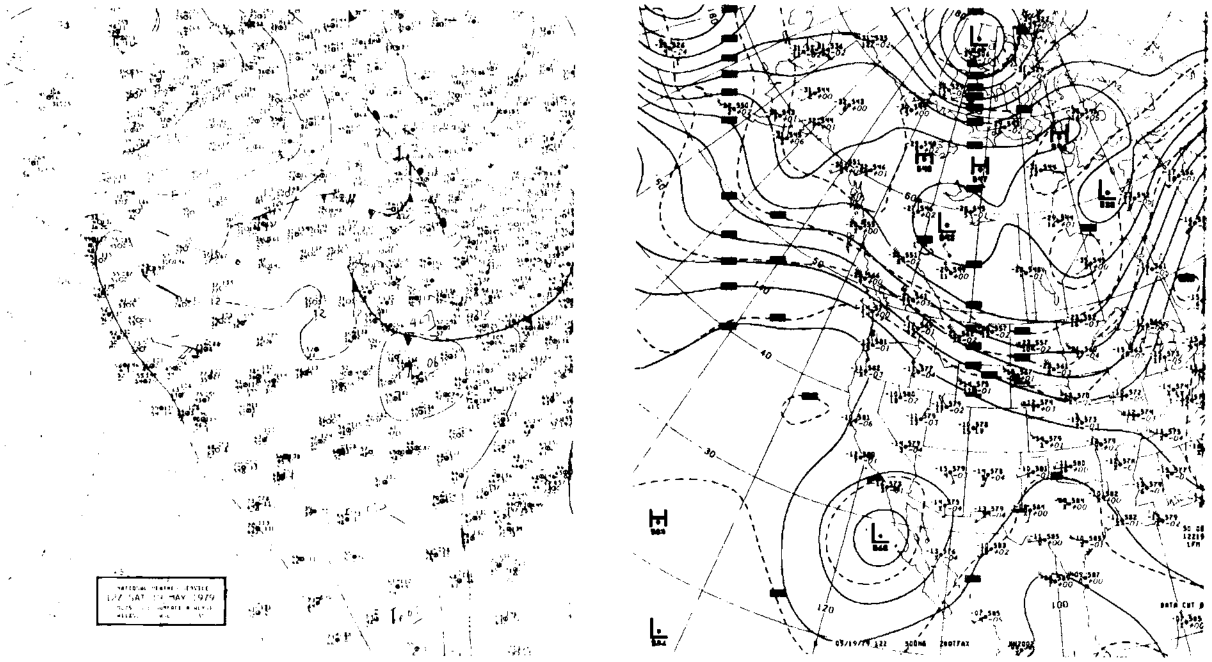
(A) (B)

FIGURE C-35. Example of a Type D Day at AMA at 1200 GMT on February 14, 1979. (A)Surface Map (B)500-mb



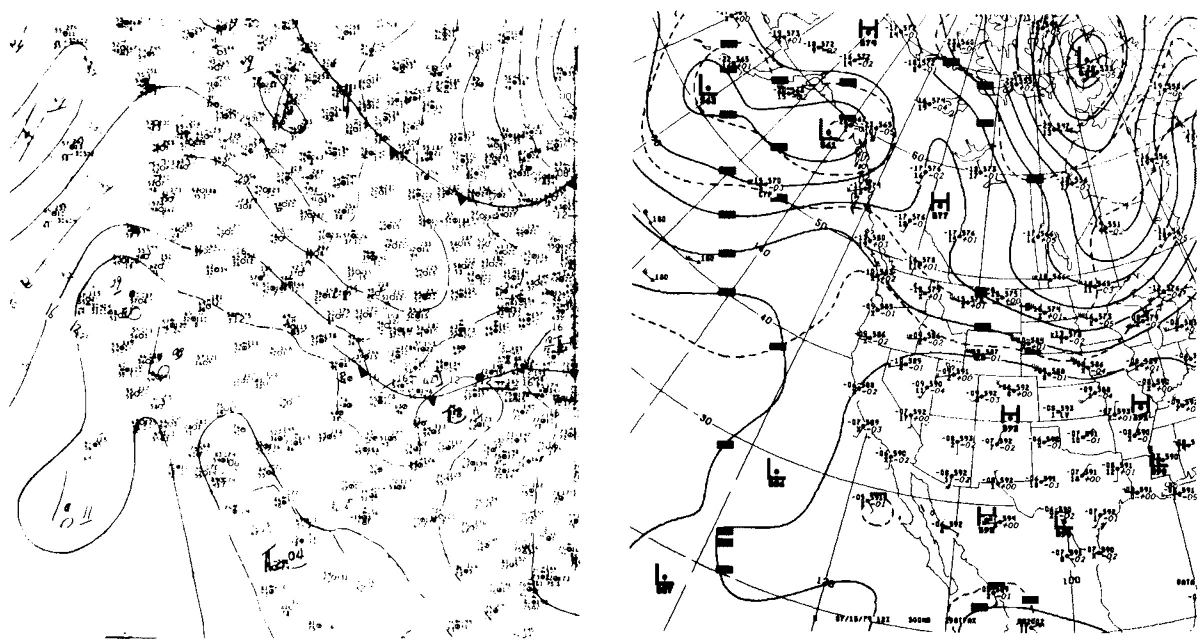
(A) (B)

FIGURE C-36. Example of a Type D Day at AMA at 1200 GMT on February 22, 1979. (A)Surface Map (B)500-mb



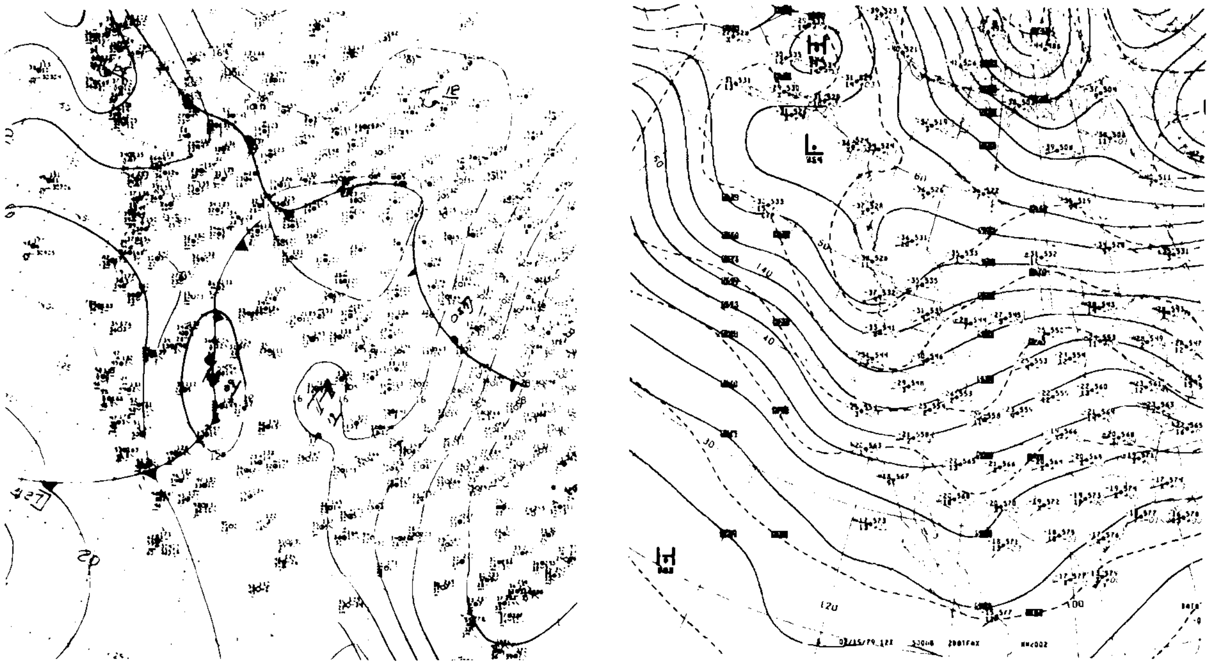
(A) (B)

FIGURE C-37. Example of a Type C Day at SAG at 1200 GMT on May 19, 1979. (A)Surface Map (B)500-mb



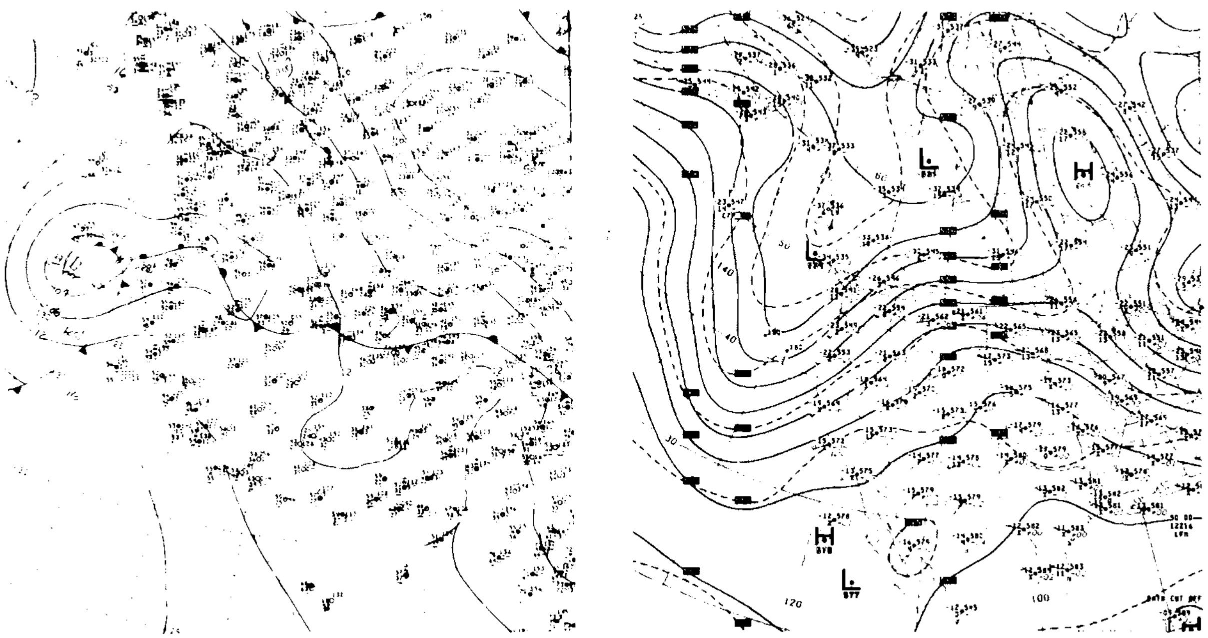
(A) (B)

FIGURE C-38. Example of a Type C Day at SAG at 1200 GMT on July 15, 1979. (A)Surface Map (B)500-mb



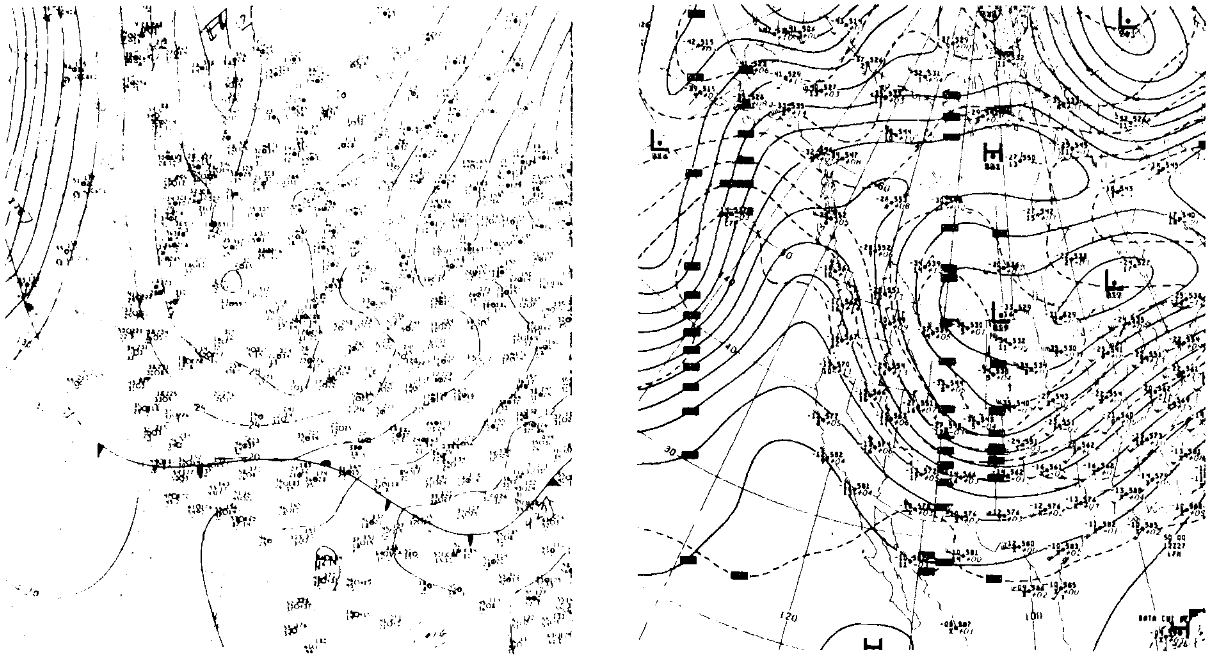
(A) (B)

FIGURE C-39. Example of a Type D Day at SAG at 1200 GMT on February 19, 1979. (A)Surface Map (B)500-mb



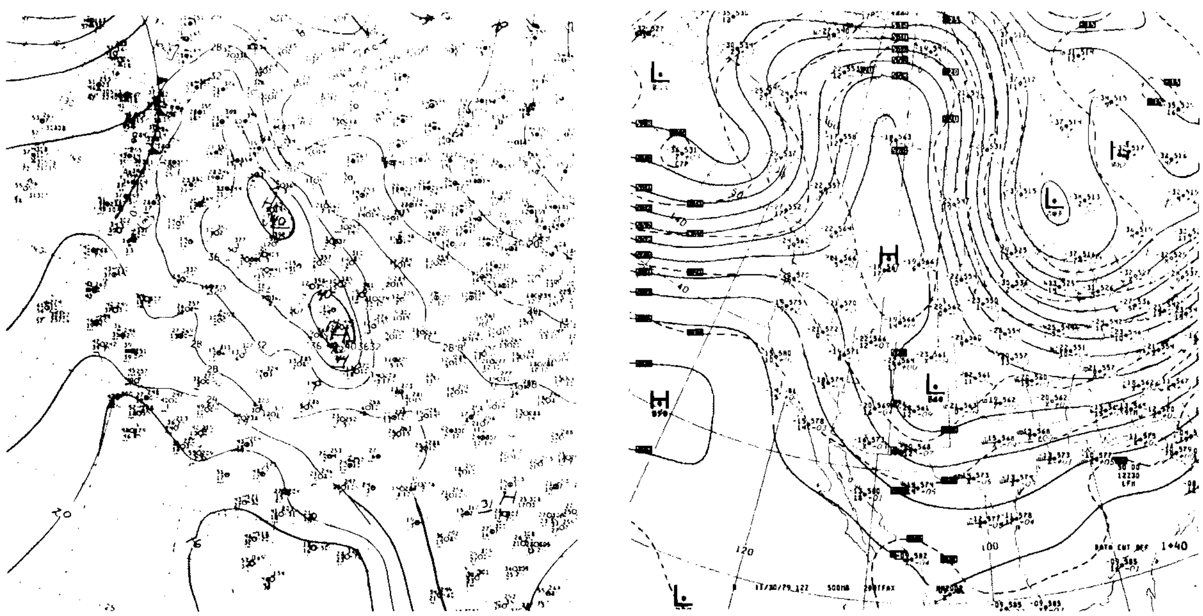
(A) (B)

FIGURE C-40. Example of a Type D Day at SAG at 1200 GMT on April 16, 1979. (A)Surface Map (B)500-mb



(A) (B)

FIGURE C-41. Example of a Type E Day at SAG at 1200 GMT on November 27, 1979. (A)Surface Map (B)500-mb



(A) (B)

FIGURE C-42. Example of a Type E Day at SAG at 1200 GMT on November 30, 1979. (A)Surface Map (B)500-mb

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