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THE USEFUL POTENTIAL OF USING EXISTING DATA TO UNIQUELY IDENTIFY PREDICTABLE WIND EVENTS AND REGIMES
PART II

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ABSTRACT

Wind data from four DOE sites for the year 1979 was stratified and found to naturally fit into a few unique groups. These were compared with synoptic weather patterns using the Booz-Allen classification system. Strong relationships became evident between a particular synoptic type and wind events for each site. Statistics indicate certain patterns which result in strong winds, (> 7 m/s,15.6 mph), and some that result in weak winds. For each site there is a preferred wind direction associated with the strongest speed. Important relationships have also been found comparing 850-mb and surface wind. Additionally, comparisons between pressure gradient and wind speed for a given gradient direction show some significant relationships. It can be stated that the overall results of the study show that by using existing data for any site, the winds can be characterized and correlated with synoptic weather patterns. As a result, reliable wind forecasts can be made for utility companies for the purpose of power generation.

INTRODUCTION

During the period May through October of 1979 a few private weather consulting companies (including the author's company) were under contract with Battelle Pacific Northwest Laboratories to forecast winds up to 24 hours in the future for the various DOE wind turbine generating sites scattered throughout the United States. In some of these locations there was no National Weather Service reporting station, thus eliminating any real time data. In addition, forecast verification of any kind was unavailable until about July or August. When some forecast verification was available there was a three month lag. In other words, verifications received in July were actually the May verifications. With these severe handicaps, it was almost as if forecasting blindfolded. Therefore, the forecasts were naturally less than desirable. However, there was some skill shown, especially by several of the weather consulting companies.

It became apparent following that forecasting project that each of the sites had its own very unique wind characteristics. For example, a northwest (NW) gradient will result in a strong southwest (SW) wind at one site and a strong (NW) wind at another site. In order for forecasts to become reliable enough to be used by utility companies, it was felt that research was necessary to study the intricate relationships between synoptic and mesoscale weather patterns, topographic influences, and a particular wind event at each site. In turn, this would lead to finding forecasting rules and site characterization. Therefore, the decision was made by Battelle personnel to undertake such a study. Contracts were then awarded to two private weather consulting companies, Murray and Trettel, Inc. of Northfield, Illinois and the author's company.

Research on this project started in early February, 1981 and is expected to be completed by December, 1981 with the writting of a final report. It is the purpose of this paper to report on the progress and findings of this study up to the present time. The four sites which have been designated for study by Freese-Notis Weather include San Gorgonio, California; Clayton, New Mexico; Boone, North Carolina; and Montauk, New York.

DATA SOURCES AND PROCEDURE

There have been three basic sources of data used to conduct this research. These include Battelle - furnished time- series plots for each of the four sites for the year 1979, digitized hourly averaged observed wind speed and direction data, and National Climatic Center (NCC) - furnished synoptic weather maps on microfilm.

The time-series plots were carefully analyzed according to certain criteria for speed and direction and a stratification was performed. It was found the plots naturally fit into five or six distinct groupings per site. That alone suggests certain relationships between synoptic patterns, topographic effects and wind events at each site. An example of a time-series plot for San Gorgonio for May, 1979 is shown in Figure 1. Table 1 lists the wind speed and direction stratifications

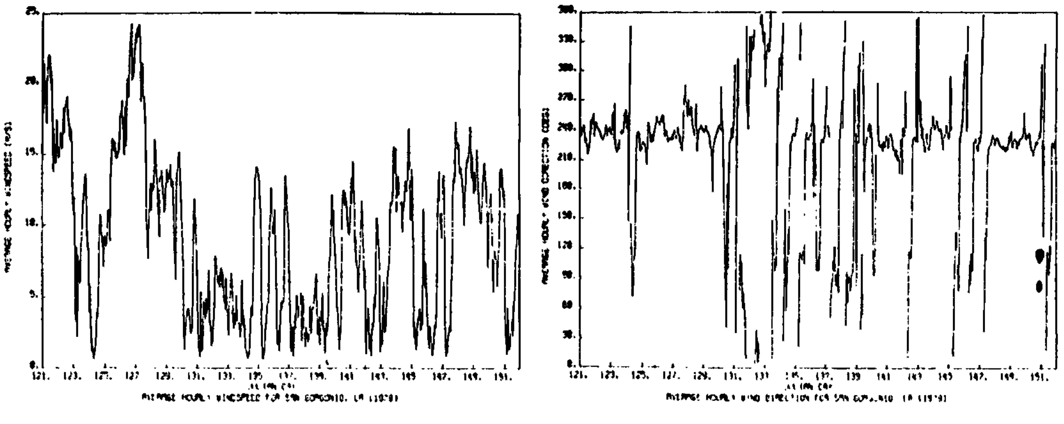

FIGURE 1. TIME-SERIES PLOTS FOR SAN GORGONIA FOR MAY, 1979
SHOWING THE AVERAGED HOURLY WIND SPEED AND WIND DIRECTION

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for San Gorgonio. The other three sites were stratified in a similar fashion.

TABLE 1. WIND SPEED AND DIRECTION STRATIFICATION
FOR SAN GORGONIO

Wind Speed	
Type 1	Diurnal character with [illegible] or 3 day duration. Speed ranges from roughly 0-1 m/s to 12-15 m/s.
Type 2	Generally light wind situation lasting from a couple days to as many as 10. Speed ranges from about 0 m/s to [illegible] m/s.
Type 3 *	Quite variable in speed with peaks of 15-20 m/s and minimums somewhere between 8-12 m/s. Duration can be from 2 to about 5 days.
Type 4 *	Duration of about 1 day and speed up to 15 m/s. Quite isolated and more likely to occur in cold season.
Type 5	Strongest 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.
Type 6	Very narrow, isolated spikes lasting a few hours at most and reaching speeds of up to 15 m/s quite rare
Wind Direction	
Type 1 *	Great diurnal variation from 0° to 360° with no apparent direction preference. Lightest speed regime (less than 6 m/s). Can last 1 week or more.
Type 2	Strongest speed type with [illegible] to 260° direction. Can last a few days reaching speeds up to 25 m/s. Frequent type.
Type 3	Diurnal type from SE veering to NW with definite preference at about 250° for a few hours. Can last for a few days. Speeds can reach 15 m/s and is usually associated with speed type 1.
Type 4	Same, from NW backing to SE with definite preference at about 250°. Can last for a week or so. Speeds generally less than 15 m/s for peaks. May be similar to type 3.
Type 5 *	Direction is SW for 5-10 hours then suddenly SE to NE for a brief time. Speeds less than [illegible] m/s for peaks. This type occurs infrequently but when it does persist for a few days. Usually occurs with a 2 speed type

The digitized data was used to record the actual speed and direction at the sites for 1200 and 0000 GMT for the entire year 1979. Those times were picked to coincide with the NCC data.

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 during 0000 and 1200 GMT for the sites. In order to facilitate and simplify the description of the patterns, some kind of classification system was necessary. It was decided that a classification system devised by Booz-Allen (Hollanger, 1968) would be used for this purpose. The Booz-Allen (B-A) system consists of 35 surface types and 20- 500-mb types. It was decided to also apply the 500-mb B-A types to the 700-mb surface. For the 850-mb surface, the wind speed and direction (estimated at that level) was recorded for later comparisons with site winds. Table 2 lists the B-A surface types. The B-A 500-mb types are not shown here because research on the upper air patterns is not complete. This classification system proved to be very beneficial to the project. At times it was rather difficult to decide what B-A designation a particular synoptic pattern should have. i.e. "pretrough" or "postridge", etc. But the resulting winds in these cases are quite similar. In fact, some thought may be given to combine these B-A types into one, later in the project.

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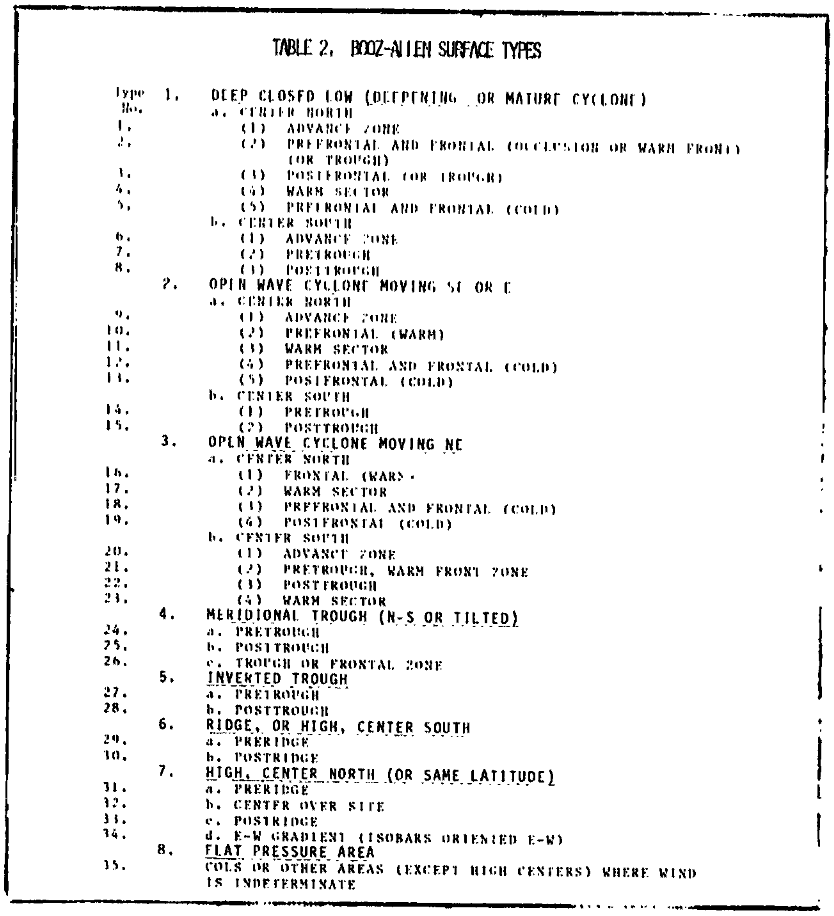

TABLE 2. BOOZ-ALLEN SURFACE TYPES

Type No.		
	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)
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
29.		a. PRERIDGE
30.		b. POSTRIDGE
	7.	HIGH, CENTER NORTH (OR SAME LATITUDE)
31.		a. PRERIDGE
32.		b. CENTER OVER SITE
33.		c. POSTRIDGE
34.		d. E-W GRADIENT (ISOBARS ORIENTED E-W)
	8.	FLAT PRESSURE AREA
35.		COLS OR OTHER AREAS (EXCEPT HIGH CENTERS) WHERE WIND IS INDETERMINATE

Each of the B-A types for the various pressure surfaces was compared with the observed wind speed and direction and with the stratified wind groups. Naturally, in some cases certain B-A types occurred so infrequently that it was decided to ignore them. The means and standard deviations were calculated for each relationship to get an idea of how each sample was distributed.

Due to the importance of the cut-in speed of 6.2m/s (14mph) for the MOD-2 Wind Turbine Generator, considerable work has also been done on the ≥ 7m/s (15.6mph) threshold. For each B-A type, the number of occurrences of ≥7m/s wind speed was calculated in percent. To further study speed relationships, the perpendicular pressure gradient across 335 kilometers (180 nautical miles) centered at the site was determined for 0000 GMT and 1200 GMT for each site. The gradient direction was also recorded so that the relationship between gradient direction, gradient strength, and wind speed could be studied. Finally, the ratio between the surface wind speed and 850-mb speed was calculated and compared with B-A types.

DISCUSSION AND RESULTS

San Gorgonio

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Prior to the start of this research it was the consensus that this site would be the most difficult in terms of forecasting. However, after a brief glance at the data, it became quite obvious that San Gorgonio displays the most consistent relationships between synoptic weather patterns and wind events. In order to better understand the wind characteristics at this site, a brief topographic description is helpful. The site is located in a basically east-west mountain pass in southeastern California. The elevation is approximately 341m (1120 ft.) and 5000-8000 foot mountains lie to the north and south. Needless to say this topography plays a very important role in determining the wind events at the site.

It does not take much investigation to see that by far the favorite wind direction at the site is southwest (SW) to west southwest (WSW), whenever speeds exceed 6m/s. The typical time series plot shown in Figure 1 clearly demonstrates this characteristic. Furthermore, a study of Table 3 also shows this relationship. In this Table the mean direction and its standard deviation (σ), the mean speed and σ , and the % ≥ 7m/s are recorded for the appropriate B-A type. The B-A types which have two mean directions recorded is due to the bi-modal character of these types. The bi-modal character is caused by diurnal effects when the pressure gradient is very weak or when the gradient direction is northeast (NE) through south (S). Under these conditions the wind tends to be strong SW during the day and light easterly (E) later at night and early morning. Figure 2 graphically shows this bi-modal phenomenon for B-A type 28. However, note the predominance of the SW direction. More than 80% of the time the wind is SW for this B-A type. Generally, the strong wind types, all with direction from 220°- 260°, are associated with a posttrough, a preridge , or a post cold frontal situation. This implies a very

TABLE 3. WIND STATISTICS FOR SAN GORGONIO
SAN GORGONIO

		Surface					850 mb				
Class No.	No. of Obs.	Average Direction	Sigma	Average Speed	Sigma	[illegible] Surface	Average Direction	Sigma	Average Speed	Sigma	Surface to 850 Ratio
1	4			5.2	5.2	40			4.8	5.9	1.081
2	1										
3	17	25[illegible]	64	8.8	6.[illegible]	60	225	52	10.4	1.[illegible]	.846
4	1										
5	26	205	80	9.2	6.6	60	252	54	9.1	4.1	1.011
6	2										
7	5										
8	6			1.2	2.5	11			4.1	2.1	.[illegible]
9	0										
10	0										
11	0										
12	11	228	45	8.0	4.1	62	2[illegible]1	4[illegible]	6.[illegible]	4.0	1.19[illegible]
13	11	215	51	11.6	5.0	82	105	40	11.8	1.0	.981
14	2										
15	0										
16	0										
17	0										
18	4										
19	5										
20	0										
21	0										
22	0										
23	0										
24	[illegible]	210	[illegible]	[illegible]	5.6	58	266	58	8.0	1.6	.919
25	[illegible]	215	4[illegible]	10.6	5.0	[illegible]	[illegible]	4[illegible]	8.1	4.9	1.100
26	1[illegible]	220	69	4.5	4.[illegible]	8	264	89	8.3	4.6	.5[illegible]
27	2[illegible]	[illegible]0:2[illegible]8	18:45	1.1	2.9	16	66	69	5.1	1.1	.64[illegible]
28	241	102:228	40:60	8.1	4.9	6[illegible]	100	[illegible]	5.[illegible]	1.0	1.5[illegible]0
29	[illegible]	2[illegible]	15	10.2	5.6	[illegible]	106	5[illegible]	6.8	1.6	1.500
30	4										
31	89	210	18	10.[illegible]	5.1	[illegible]8	115	4[illegible]	8.0	1.[illegible]	1.[illegible]
32	10										
33	[illegible]	110 288	12 [illegible]	[illegible].8	[illegible]	1[illegible]			[illegible].8	[illegible]	1.[illegible]0
34	12[illegible]	90, 29[illegible]	61:4[illegible]	1.9	1.0	[illegible]	58	[illegible]	[illegible].1	1.[illegible]	.[illegible]6[illegible]
35	4[illegible]	10[illegible]:288	[illegible]	1.1	[illegible].8	[illegible]0	248	[illegible]	[illegible].1	1.0	.[illegible]6

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important phenomenon regarding pressure for this site. As long as the pressure is lower to the east of the site, the wind will blow quite strong (generally at least 7m/s and quite often >15m/s) between 220°-260° . The exact strength is generally dependent upon the pressure gradient. On the other hand, the odds for a very light wind (≤6m/s) are very high with low pressure to the west of the site. A mesoscale feature that sometimes occurs is a weak trough of low pressure just west of the site followed by the usually strong Pacific High. If not analyzed carefully, this weak trough might be missed. This will result in an over estimate of the wind speed. The above pressure rules are so universal at San Gorgonio that one has to double check for possible error if something contradictory to the rules is observed.

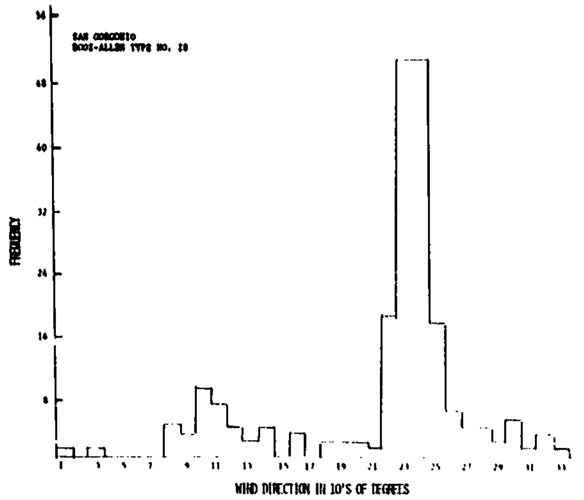

FIGURE 2. TYPICAL WIND DIRECTION FOR SAN GORGONIO
FOR BOOZ-ALLEN SURFACE TYPE 28.

Referring to Table 3 once again, note that with a few B-A types a mean speed and σ is given without any direction. This is due either to the very small number of observations, or the great scattering of the data in some cases making the mean direction meaningless. This occurs with very light gradients. The most frequent B-A types are generally numbers 27-29, 31, and 34. The Table also shows the 850-mb mean direction and σ , the mean speed and σ , and the ratio of the surface speed to the estimated 850-mb speed for the appropriate B-A surface type. It is interesting to note quite a few occurrences of stronger surface winds than 850-mb winds especially for the posttrough or postfront types. Finally, the Table also shows the % ≥ 7m/s for the particular B-A surface type. Not surprisingly, large percentage values appear for the typical and frequent B-A types for the site and small values are common for the pretrough types. The author suspects this correlation would be even stronger, but in some cases it was rather difficult for the researcher to decide which B-A type should be assigned for a particular synoptic situation. A great deal of individual judgement went into the decision. We are currently in the process of combining some of the B-A surface types. For example, we are combining B-A types 3, 13, 19, 25, 28, 29, and 31 due to the similarity in isobaric orientation for these types. In a similar manner numbers 2, 4, 12, 18, 24, 27, 30 and 33 are being combined.

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We are designating the first group as postfrontal or posttrough and the second group as prefrontal or pretrough. Preliminary indications with this approach give encouraging results. Another glance at the Table still suggests some inconsistencies however. There appear to be a significant number of cases with the designation of "pretrough" or "prefrontal" that have winds >7m/s. The secret here is the orientation of the isobars from west to east as a low pressure center or meridional trough passes off to the north of the site. Under this situation, a fairly strong southwest wind can result. On the other hand if a high is located to the north (east to west pressure gradient of B-A number 34) the result is very weak wind of < 5m/s (< 11.2mph) even with a fairly tight pressure gradient. Typical surface analyses of a strong and weak wind situations are shown in Figure 3.

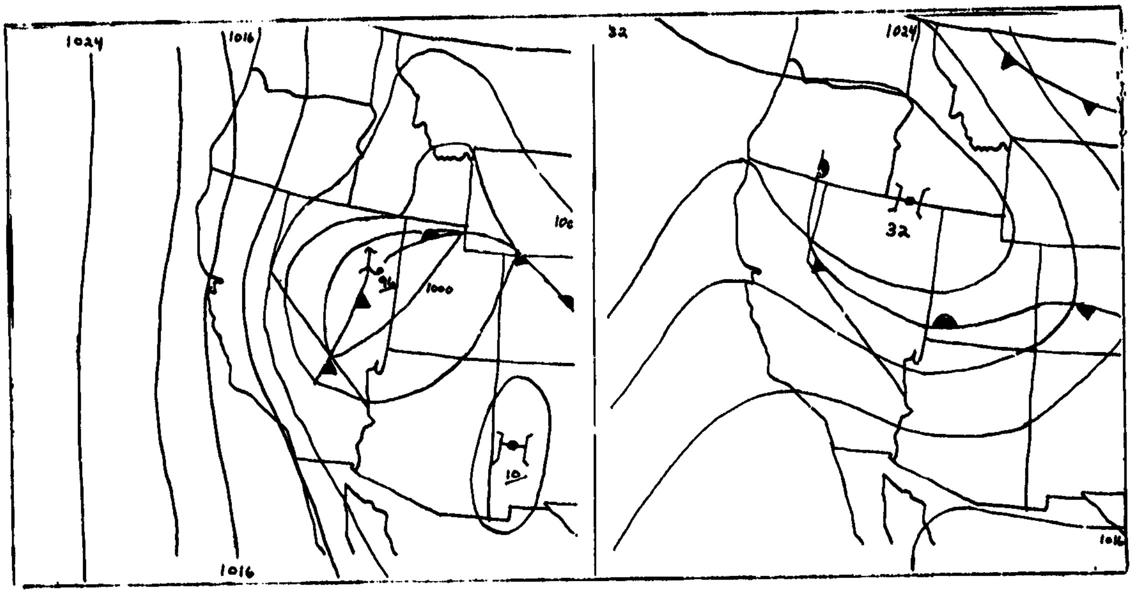

FIGURE 3. TYPICAL SURFACE MAP DESCRIPTION ASSOCIATED WITH STRONG WIND (LEFT) AND WEAK WIND (RIGHT) FOR SAN GORGONIO.

Finally, Figure 4 shows the relationship between pressure gradient and wind speed for a given gradient direction for all sites. As far as San Gorgonio is concerned, the curves beautifully demonstrate the very light wind conditions for the gradient directions NE through SW. For the westerly (W) gradient, we do notice a speed average of ≥8m/s for 1,2,4,5, and 6-mb gradients. The dip at 3-mb is probably due to an insufficient data sample. This Figure helps to explain the above mentioned inconsistencies. For, if low pressure is to the N or NW of the site, the gradient direction is more than likely to be W. For the NW and N gradients which truly imply lower pressure to east and high pressure west, the speed increases dramatically as the pressure gradient increases. As of the writting of this paper, similar graphs showing the relationship between pressure gradient and wind direction for a given gradient direction are not completed. Also, the 500-mb and the 700-mb data has not been fully analyzed yet but it is suspected that this data will not be as useful as that of the surface and 850-mb.

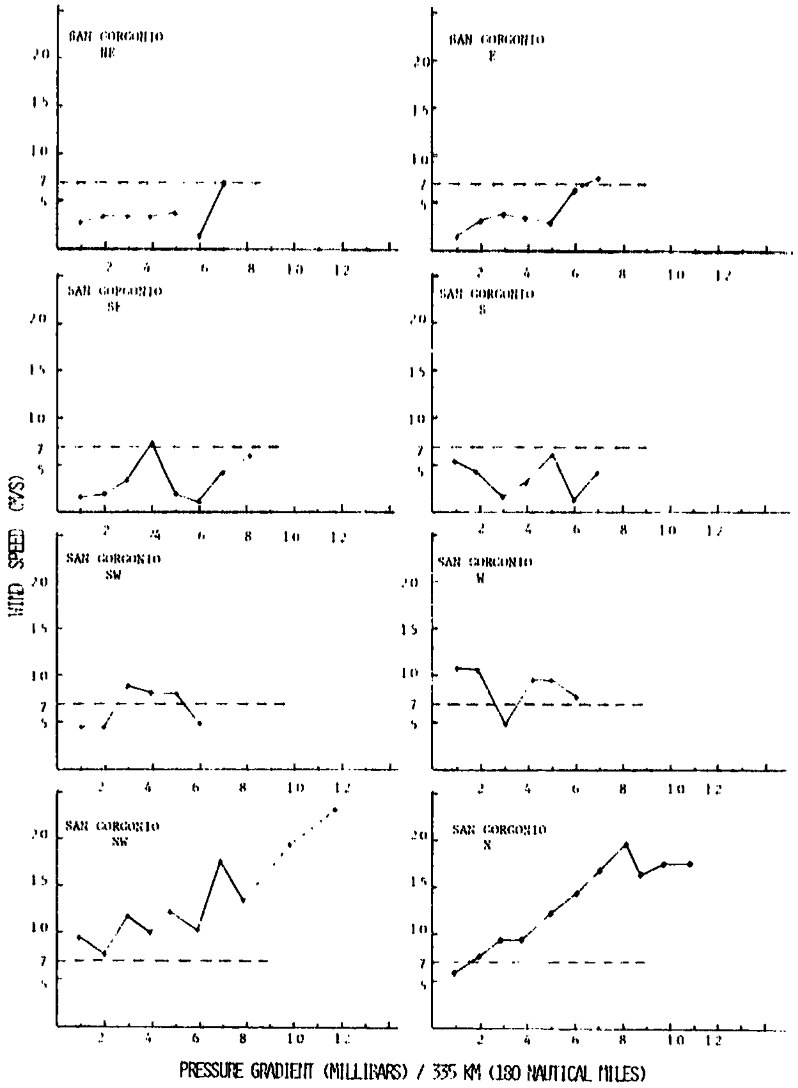

FIGURE 4. CURVES RELATING PRESSURE GRADIENT AND WIND SPEED FOR SAN GORGONIO FOR 8 GRADIENT DIRECTIONS. THE HORIZONTAL DASHED LINE IS THE 7 M/S THRESHOLD. OTHER FINE DASHED LINES IMPLY NO DATA AVAILABLE BETWEEN POINTS.

Clayton

Clayton is located in the extreme northeast corner of New Mexico and has an elevation of 1534m (5030 ft). The foot hills of the Rocky Mountains begin 10 miles west of the site. This site is considerably more complex in terms of weather regimes and site wind events than the San Gorgonio site. However, after a careful examination of the data the "secrets" of the site are being revealed.

As can be seen from Table 4, the most common B-A types are 24-26, 31, 33, and 34. All types have mean direction between 160° and 230° except for types 3, 13, 25, and 31 which show a W to NW direction. However, the standard deviations are quite large suggesting the great variability and erratic character of this site. In fact, there is a great diurnal effect going on at any time of the year. The preferred direction at Clayton is somewhere between 180°- 360° for the strongest speeds with the prevailing wind being SW. Except for quite strong pressure gradients, the wind will generally blow quite strong from the SW during the day at > 7m/s and light and variable at night and early morning. A good correlation exists between the surface direction and 850-mb direction for the great majority of the B-A types. Generally, the two don't vary by more than 20°-40°. The ratio between the surface and 850-mb speeds is generally between 0.7 and 0.9 for all the synoptic types. Speeds can be strong at the site from all directions except for NE through ESE. In these cases the speeds are generally < 4m/s.

TABLE 4. WIND STATISTICS FOR CLAYTON

CLAYTON

		Surface					850 mb				
Class. No.	No. of Obs.	Average Direction	Sigma	Average Speed	Sigma	% 7m/s Surface	Average Direction	Sigma	Average Speed	Sigma	Surface to 850 Ratio
1	2										
2	16	212	40	9.4	2.8	88	216	17	11.1	3.0	.718
3	3	224	52	9.5	4.9	26	307	41	13.1	4.5	.715
4	6	235	36	10.6	2.3	100	227	48	12.8	2.8	.828
5	11	202	45	9.7	4.8	45	244	51	12.1	5.0	.760
6	0										
7	3										
8	16			11.4	5.6	93			12.2	3.6	.934
9	3										
10	4										
11	20	199	56	8.5	2.5	85	260	47	10.0	4.3	.850
12	16	193	44	8.2	3.0	64	205	65	10.6	4.6	.774
13	10	170	63	9.4	4.1	68	156	57	10.9	5.2	.862
14	2										
15	6			6.9	1.3	67			7.0	2.4	.986
16	0										
17	0										
18	11	210	19	9.0	4.2	73	216	29	11.0	5.3	.818
19	4			8.1	3.3	62			9.2	4.1	.880
20	0										
21	0										
22	2										
23	0										
24	62	198	43	7.0	2.5	57	215	47	10.2	4.0	.686
25	44	207	81	6.6	2.6	48	291	65	9.8	4.5	.673
26	52	202	70	7.1	2.6	59	243	53	9.6	4.6	.833
27	18	162	69	7.1	2.9	44	163	51	9.2	3.4	.772
28	8			7.2	2.7	50			9.2	3.8	.783
29	1										
30	14	188	45	6.5	2.0	43	238	43	6.6	4.3	.985
31	44	201	55	6.7	3.0	49	---	--	8.5	4.5	.788
32	5										
33	22	160	73	6.6	2.5	52	186	68	7.0	3.3	.943
34	64	156	67	6.5	3.0	44	--	--	7.9	4.4	.823
35	26	186	67	5.2	2.3	29	256	54	6.1	2.5	.852

Clayton is notorious for blowing against the gradient. For example, an E gradient can result in a NW wind. In some cases, especially in the summer half of the year, weak low pressure is located in western Kansas. With this situation, Clayton will blow from the SW right across the isobars into the low. If one had to choose the most common synoptic pattern for Clayton it would have to be the lee-side trough either just west, over, or just east of the site. Figure 5 shows a strong and a weak synoptic type for Clayton.

Figure 6 for Clayton graphically shows a fairly strong wind for most gradient directions. The outstanding exception is the SE gradient which shows light winds for all pressure gradient strengths. E and S gradients are also fairly weak.

During the progress of this research the following "rules of thumb" have been observed for Clayton:

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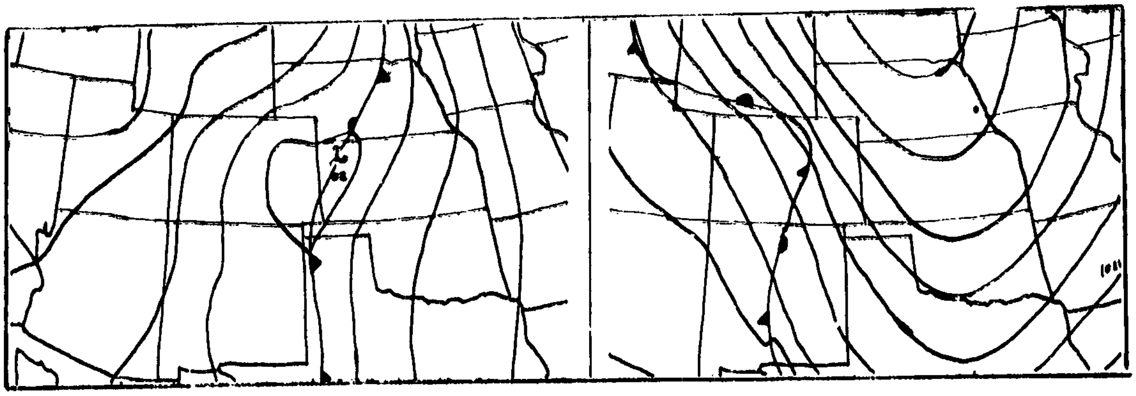

FIGURE 5. TYPICAL SURFACE MAP DESCRIPTION ASSOCIATED WITH STRONG WIND (LEFT) AND WEAK WIND (RIGHT) FOR CLAYTON.

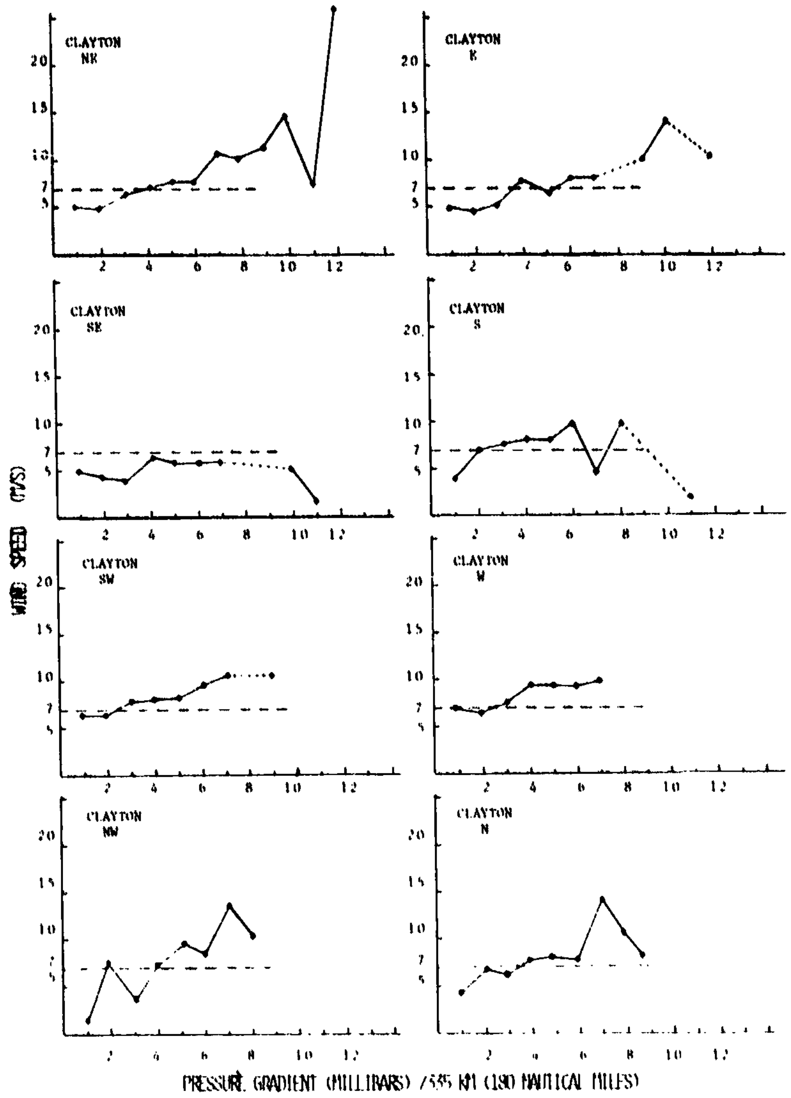

FIGURE 6. SAME AS FIGURE 4 EXCEPT THESE CURVES FOR CLAYTON.

1. A NE gradient generally results in 300°-350° direction and >10 m/s if gradient is >5mb.
2. Speeds can be often light with NE gradient unless the pressure gradient is strong or is under the influence of strong "post front" type.
3. An E gradient of ≤3mb results in variable direction and ≤7m/s
4. A SE gradient yields winds of <7m/s often blowing 02° -08°.
5. If high ridges southward into the site the direction will be 130°-150° with a SE gradient.
6. For a S gradient speeds are generally >7m/s even for very weak gradients (2mb in 180 nautical miles). Direction is generally 160°- 220° depending on the low position.
7. For a SW gradient, if trough is near the site, speed will be quite strong (>7m/s) from the S or SW regardless of gradient strength.
8. With a W gradient, speed is generally >7m/s from 180° to 220°.
9. With a NW gradient wind blows 270°-300° if no low pressure is in the vicinity. If a low is located northeast of Clayton, the wind will blow from about 240°.

Boone

This site is located on top of a 1348m (4420 ft.) mountain in far western North Carolina on the Apalachian Chain. The statistics of Table 5 show the most common B-A gypes to be 3-5 and 29-35. The direction with the stronger speeds are SW through NW with the peak speeds occurring with NW winds as is common in the eastern U.S. At Boone the super strong winds (occasionally >20m/s) occur as a low passes off to the north, the associated strong cold front pushes east of the site, and the high pressure center approaches from the middle part of the country. The B-A synoptic types with that regime are 3, 29, and 31. These types are naturally more predominant in the winter half of the year. From Table

TABLE 5. WIND STATISTICS FOR BOONE

BOONE

		Surface					850 mb				
Class No.	No. of Obs.	Average Direction	Sigma	Average Speed	Sigma	% [illegible] Surface	Average Direction	Sigma	Average Speed	Sigma	Surface to 850 Ratio
1	1										
2	16	[illegible]	58	8.0	[illegible]	[illegible]	210	[illegible]	11.6	[illegible]	[illegible]
3	61	[illegible]	[illegible]	11.9	5.1	90	[illegible]	19	[illegible]	[illegible]	.818
4	16	[illegible]	[illegible]	9.1	1.8	60	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
5	19	210	[illegible]	10.1	[illegible]	[illegible]	[illegible]	16	[illegible]	[illegible]	[illegible]
6	[illegible]										
[illegible]	[illegible]										
8	1										
9	1										
10	[illegible]										
11	[illegible]	[illegible]	48	[illegible]	[illegible]	80	[illegible]	[illegible]	11.1	[illegible]	[illegible]
12	12	[illegible]	18	9.0	[illegible]	80	[illegible]	16	[illegible]	[illegible]	[illegible]
13	11			[illegible]	[illegible]	[illegible]			11.9	[illegible]	[illegible]
[illegible]	[illegible]										
[illegible]	[illegible]										
16	[illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]
18	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19	1	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	18	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]										
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]										
[illegible]	[illegible]										
[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]											
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	11.6		[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
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[illegible]	[illegible]			[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]
[illegible]		[illegible]		[illegible]	[illegible]	[illegible]			[illegible]	[illegible]	[illegible]

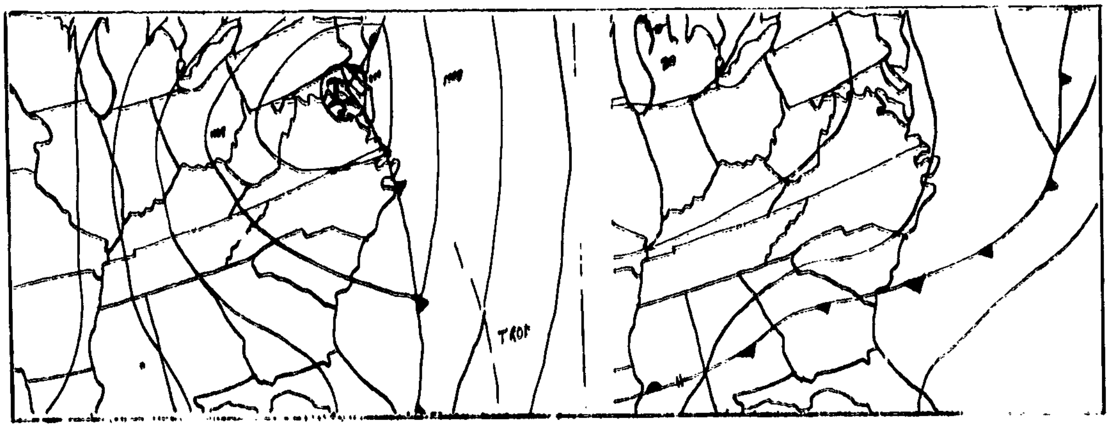

FIGURE 7. TYPICAL SURFACE MAP DESCRIPTION ASSOCIATED WITH STRONG WIND (LEFT) AND WEAK WIND (RIGHT) FOR BOONE.

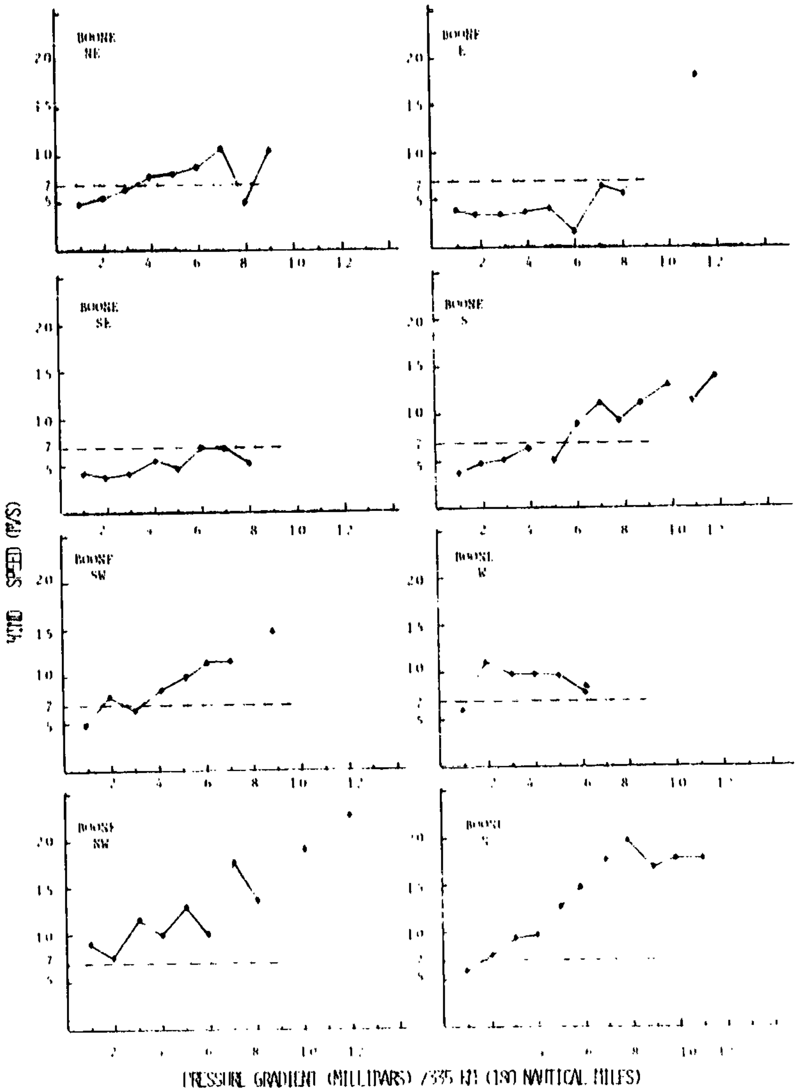

FIGURE 8. SAME AS FIGURE 4 EXCEPT THESE CURVES FOR BOONE

5, the surface to 850-mb speed ratios are generally between 0.7 and 0.9 for the common B-A types. The exception is B-A number 30 having a ratio of about 1.2. The strong wind B-A types also have high percentage values of ≥7m/s. Typical strong and weak synoptic types for Boone are shown in Figure 7.

On Figure 8 it is seen that the only gradients resulting in very light wind are the E and SE and in some respects the NE and S with gradient strength <4mb. The dashed lines in some of these curves indicate lack of data between points. The SW and N gradients result in strong wind events as seen in the graphs.

A few "rules of thumb" for Boone include the following for the NE through S gradients (tricky gradients for this site):

1. With a NE gradient, direction is generally 320°- 340° except with an E to W high pressure to the north or a low to the S or SE in which case the direction is 010°-040°. Speeds are generally fairly strong if gradient strength is ≥4mb.
2. The direction with an E light gradient is 300°-330°. Stronger gradients result in 070°-110° wind direction. In just about all cases the speed is rarely over 5 or 6m/s.
3. The SE gradient results in light speed (generally <6m/s) and often has 290°-330° direction.
4. With a weak S gradient (≤4mb) wind tends to blow with the 850-mb direction and be ≤7m/s. When a wave or trough [illegible] the vicinity of Tennessee-Kentucky area a SE direction will result. If gradient is strong, wind will blow with the gradient. The speed is quite strong (>10m/s) when a front is near the site with the S gradient.

Montauk

This site is located on the southeastern tip of Long Island, N.Y. The most common synoptic types for this site are B-A numbers 2-5, 18-19, 29-35 as seen in Table 6. Because of its location in the northeastern U.S., it is affected by quite a few synoptic types. This is not necessarily the case for San Gorgonio, Clayton, and in some respects Boone. The table shows the strongest speeds tending to be associated with B-A types having W or NW winds. About the only apparent contradiction to this is B-A type 31 with mean speed of 6.5m/s. This type has a large number of occurrences (119) but it is also noted that the σ is astronomical. Thus, in many of these cases it is suspected that the ridge axis is just west with the high center to the north. This can cause a considerable number of cases with light E through NW winds explaining the rather low speed for B-A number 31. 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, but on the other hand the 850-mb speed is stronger for this site as is common for the northeast U.S. Figure 9 shows the typical strong wind and weak wind pattern for Montauk.

Glancing at Figure 10 for Montauk, one thing that should be pointed out is that it generally takes ≥4mb gradient strength for all gradient directions to result in speeds of ≥7m/s. The gradients with the

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OF POOR QUALITY

TABLE 6. WIND STATISTICS FOR MONTAUK

MONTAUK

Class No.	No. of Obs.	Surface Average Direction	Sigma	Average Speed	Sigma	%≥7/MS Surface	Average Direction	Sigma	850 mb Average Speed	Sigma	Surface to 850 Ratio
1	4	.	--	.	.	.	--	.	.	.	--
2	19	151	61	6.7	1.0	42	214	29	15.4	5.1	.335
3	84	167	57	9.1	4.4	71	202	38	14.2	3.9	.641
4	24	195	35	7.3	2.9	61	226	17	15.7	5.4	.465
5	49	201	48	6.5	3.6	33	210	40	19.8	9.8	.328
6	8	101	41	10.4	3.7	88	171	13	20.0	6.8	.520
7	10	101	75	9.4	2.8	80	171	69	14.8	8.2	.635
8	14	137	49	6.7	3.3	57	258	104	9.8	4.3	.684
9	14	---		---		..	..	..	..		-
10	1	.	.	...	...	.	--	--		....	..
11	2		.	..	-	...	.	..	.	.	..
12	7	247	43	3.9	2.5	14	281	40	9.9	5.8	.394
13	8	.		5.2	4.4	25	...	--	9.7	6.2	.536
14	12	164	42	4.0	2.5	17	218	62	7.1	4.8	.561
15	6	...	--	4.3	1.6	0	--	--	9.5	4.4	.453
16	5	.	--	.	..	..	---	--	--	---	.
17	9	210	51	5.5	2.7	33	240	33	12.0	5.8	.458
18	21	204	66	6.4	2.4	53	228	30	12.2	5.9	.525
19	20	330	52	9.7	2.3	62	276	51	10.3	6.7	.942
20	1	---	--	---	---	---	---	--	---	---	--
21	10	81	45	8.4	2.7	88	168	37	8.4	8.0	1.00
22	5	---	--	---	---	--	---	--	---	---	----
23	2	---	--	---	---	--	---	--	---	---	----
24	12	227	43	7.2	3.7	45	272	39	13.5	3.8	.533
25	14	293	45	7.5	5.7	45	275	67	9.0	4.7	.833
26	10	226	47	6.5	1.6	50	276	55	13.8	7.1	.471
27	0	---	--	---	---	--	---	--	----	---	---
28	1	---	--	---	---	--	---	--	----	---	----
29	73	299	43	8.5	4.2	64	304	26	15.1	6.6	.563
30	86	211	44	6.2	2.8	42	249	34	10.4	4.6	.596
31	119	292	106	6.5	3.7	48	---	--	10.5	5.1	.619
32	184	114	--	3.2	2.1	6	---	--	6.1	4.0	.525
33	80	152	65	4.8	2.5	25	231	50	8.2	4.9	.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	.745

weaker speeds seem to be NE, E, and S but note the large range for this site. The gradients associated with the highest speeds are the NW and N.

The "rules of thumb" observed for this site include the following:

1. NE gradient is not generally good for strong wind. A high percentage of cases are <7m/s. This is especially true for gradients < 7mb.
2. E gradient is likewise not a strong wind gradient but is a bit stronger than NE. A gradient strength 3 or 4 mb usually produces wind of ≥ 7m/s.
3. SE gradient is not very frequent. For a gradient strength of >3mb the speed is ≥7 m/s.
4. S gradient is not a strong wind gradient. It usually takes ≥ 5mb to result in wind of ≥ 7m/s
5. SW gradient is fairly common. 4mb or higher gradient gives wind of ≥ 7m/s but even smaller gradient strength can result in quite a few cases of ≥ 7.
6. The W gradient is also common. Any gradient can produce wind of ≥ 7m/s but gradients of >5mb results in speed ≳ 7 consistently.
7. The NW gradient produces some of the strongest winds of up to 20 m/s consistently.
8. The N gradient also produces speeds up to 20 m/s and a lot in the range of 10-20 m/s. A strength ≥5mb results in speed of ≥7m/s consistently.
9. Of the four sites studied Montauk by far has the best correlation between wind direction and gradient. The direction is generally within 10°-30° of the gradient direction.

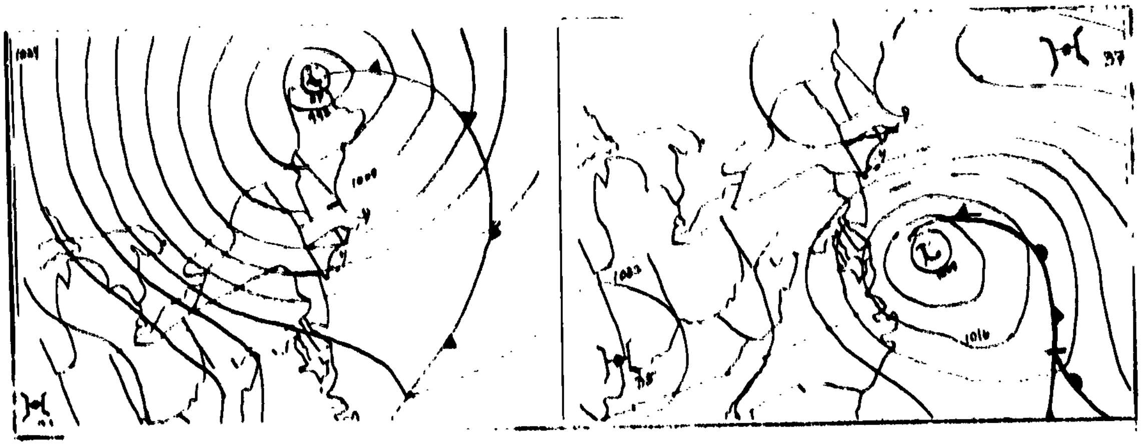

FIGURE 9. TYPICAL SURFACE MAP DESCRIPTION ASSOCIATED WITH STRONG WIND (LEFT) AND WEAK WIND (RIGHT) FOR BOONE.

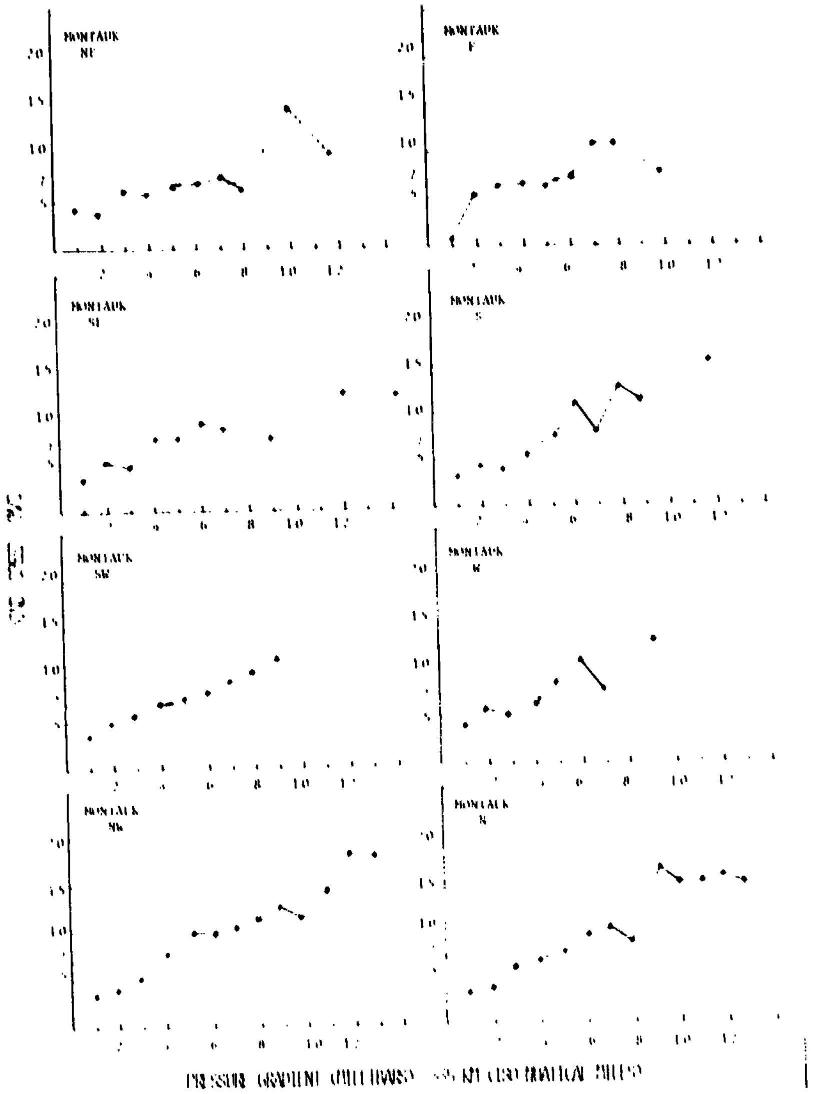

FIGURE 10. SAME AS FIGURE 4 EXCEPT THESE CURVES FOR MONTAUK.

SUMMARY

Research on this project is by no means complete, but the results and findings to this point are very encouraging. There are strong correlations between synoptic features and wind events. The wind events are obviously also influenced by the local topography. When this study began, there were three major questions to be answered:

1. Are there synoptic or subsynoptic scale weather patterns evident at the sites in such a recognizable pattern, that they can be used to more accurately predict wind events for the purposes of power generation?
2. Given a set of criteria with unique characteristics, can one then recognize the weather patterns with which they are associated?
3. Using the site winds and archived analyses, can characterization of the site winds in terms of apparent mesoscale effects of local topography be separated from synoptic scale effects?

The answers to all of these are positive. The results clearly show that by using existing data for a given site, the winds can be characterized and correlated with synoptic weather patterns.
When this is accomplished, there is no doubt that forecasts of wind events for the large wind power generators will be quite reliable and very useful to utility companies. If given the opportunity to once again forecast for these sites following the completion of this research, the author strongly believes that these forecasts will be much more accurate, than those during the forecasting project of 1979.

As previously mentioned the current research is not complete. More work is needed to study in greater detail diurnal and seasonal effects. Further investigation is also necessary on gradient, speed, and direction relations. Finally, some refinement of the findings is also needed.

ACKNOWLEDGMENTS

The author is greatly indebted to Alan H. Miller and Harry Wegley of Battelle, Northwest Laboratories for their tremendous assistance in this project. The effort of Freese-Notis Weather meteorologists, Dan Hicks, Miles Schumacher, and Ryan Tilley, who devoted many hundreds of hours in research for this project, is much appreciated.

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