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A PRACTICAL METHOD FOR ESTIMATING WIND CHARACTERISTICS AT POTENTIAL WIND ENERGY CONVERSION SITES

By
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Solar Energy

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ABSTRACT

Terrain features and variations in the depth of the atmospheric boundary layer produce local variations in wind, and these variations are not depicted well by standard weather reports. We have developed a method to compute local winds for use in estimating the wind energy available at any potential site for a wind turbine. The method uses the terrain heights for an area surrounding the site and a series of wind and pressure reports from the nearest four or five National Weather Service stations. An initial estimate of the winds in the atmospheric boundary layer is made, then these winds are adjusted to satisfy the continuity equation. In this manner the flow is made to reflect the influences of the terrain and the shape of the boundary-layer top.

We have applied the method to seven sites in the United States for 1977. For four of the sites, the windflow model was "tuned" by altering its adjustable features and comparing the corresponding wind simulations to wind measurements that were made at the sites under the auspices of the Pacific Northwest Laboratory (PNL). For the other three sites, simulations were made without tuning the model. This report describes in detail our methodology and results, and provides descriptions of the computer programs, instructions for using them, and complete program listings.

Wind measurements are seldom available at sites under consideration for wind turbines. In this report, we describe a method for simulating a time series of winds at hub height at a potential site. Our method provides estimates of winds based on the local terrain and on standard weather reports in the general vicinity of the site. The method uses a windflow model that represents the winds in the layer from the earth's surface to the top of the atmospheric boundary layer, generally located approximately 500 m above ground during the night and 1000 to 2000 m above ground during the day.

The top of the boundary layer is chosen to be a curved surface located at a specified average distance above the ground. Its shape is controlled by appropriate values of a slope factor. Horizontally, the region of interest around a particular site covers an area having sides in the range from 100 to 200 km (60 to 120 miles). Usually four or five National Weather Service stations are located within a 200-km radius from any potential site in the United States. The data from the stations are used to derive typical wind patterns in the form of the eigenvectors of a covariance matrix. The statistical computer program used to determine the eigenvectors also gives a set of coefficients corresponding to each set of input wind observations (e.g., at three-hourly intervals). These coefficients are used later in simulating the site winds. For each wind pattern (corresponding to an eigenvector) an objective analysis program is used to determine the initial estimates of the winds at all mesh points of the model domain. In making this analysis we assume that the geostrophic wind in the region represents the wind at the top of the boundary layer. Between the anemometer level and the upper surface, smooth changes in wind speed and direction are introduced by logarithmic interpolation. The largest shear is introduced in the lowest layers, as desired. Next, the initial estimates of the wind at each mesh point are used as the input to the windflow model. By use of the continuity equation, the model alters the flow to a form that is nondivergent. The altered winds pass smoothly between the terrain and the curved boundary-layer top and reflect the influences of the terrain and the shape of the upper boundary in a realistic manner. For example, the winds tend both to increase in speed over high terrain and to deflect through lower pathways. For each representative wind pattern, the model gives the appropriate wind at the potential wind turbine site. A simulated time history of winds at the site is computed from the modeled site winds and the eigenvector coefficients appropriate to each observation. The statistical properties of these simulated winds are computed and include the annual average wind speed, seasonal and diurnal averages, frequency distributions of speed and direction, and run durations. This work represents a refinement of the previous research on this topic performed at SRI International and reported by Bhumralkar et al. (1978).

Weather data for the model are required from several stations located as close to the potential site as possible. We obtained these data from the National Climatic Center. Also, the windflow model requires terrain heights at the surface mesh points. We wrote a computer program to obtain these heights from digital tapes purchased from the National Cartographic Information Center. Information about the average boundary layer thickness was obtained from climatological sources.

The methods were applied to data for seven candidate wind turbine sites in the United States for 1977. At these same sites, wind measurements were made on towers at a level 46 m above ground under the auspices of the Pacific Northwest Laboratory (Wendell et al., 1978; Renné and Sandusky, 1979). The observations for four of the sites were used to "tune" the model, i.e., to provide guidance in selecting the parameters that control the depth of the boundary layer and the shape of the boundary-layer top. The results are shown in the first four rows of the following comparison of simulated and measured wind speeds (annual averages for 1977). At the remaining three sites, computations were made without tuning. The results (shown in the last three rows of the tabulated comparison) are of very good accuracy.

	Speed (m s^{-1})		
Site	Measured	Simulated	Difference
Boone, NC	8.0	8.1	+0.1
San Gorgonio, CA	8.0	7.2	-0.8
Block Island, RI	7.5	7.0	-0.5
Clayton, NM	7.6	5.8	-1.8
Ludington, MI	7.9	7.2	-0.7
Holyoke, MA	7.3	7.4	+0.1
Huron, SD	6.9	6.7	-0.2

We have analyzed the remaining deficiencies in the present computations and believe that assigning the geostrophic wind to a fixed height (such as 500 m above ground) instead of assigning it to the top of the boundary layer would improve the results. This change, which is straightforward to introduce, should be tested in the future.

The present model is sufficiently accurate to be a useful tool for estimating the winds at potential wind turbine sites. It can be applied to obtain the simulated winds for a year at a potential site for approximately $3,000 to $3,500, including manpower, computer time, and data acquisition.

Appendix A of this report gives instruction for using the computer programs, and Appendix B gives listings of them. Appendix C shows how weather patterns are related to the coefficients of the principal eigenvectors.

I INTRODUCTION

The recent rapid growth of interest in wind energy has created a need for economical methods of evaluating potential wind turbine sites. We must be able to determine whether a wind turbine installed at a particular location will produce electricity at prices competitive with other usual sources of energy. Wind data from the National Weather Service (NWS) network are only available at scattered locations, frequently airports, which are generally not located in the windiest places. To obtain data with instrumented towers for a year or more at numerous potential generator sites would be very expensive. The modeling approach described in this report uses existing wind observations to simulate the time history of the winds that would be expected at any potential site. We show in Section IV that the accuracy is sufficiently high to provide useful estimates.

In this study we have made significant improvements to the modeling methods developed previously at SRI International (Bhumralkar et al., 1978). The concept of modeling the flow in the lowest layer of the atmosphere using the continuity equation was originally used by Sherman (1978). We have used the available wind data gathered by NWS stations to estimate the wind flow for an atmospheric volume centered on a potential site for a wind turbine. Digital terrain data obtained from the National Cartographic Information Center are also used in the modeling process. At the top of the boundary layer where wind observations are not available, we have assumed (in general accordance with the theory of boundary-layer flow) that the geostrophic vector is a good estimate of the winds. Logarithmic interpolation is used to estimate winds between the anemometer level and the upper geostrophic layer. In general, the procedure gives smooth changes of both the wind speed and direction with height, with the largest shear near the ground.

The simulated flow around terrain obstacles is significantly affected by the values chosen for the height and shape of the boundary-layer top. We have used the heights derived from climatological data of Holzworth (1972) to define the average boundary layer depth over the area of interest. Measurements of the shape of the boundary-layer top are not available, so we have formulated a computer procedure for specifying the boundary layer top based on the average thickness and a slope factor. Appropriate values for this slope factor are discussed in Section III.E.

The windflow model operates in the so-called sigma coordinate system. In this system the terrain is the lowest sigma surface and the boundary-layer top is the uppermost sigma surface. Interior sigma surfaces have shapes that are intermediate between these boundaries. We believe that this system makes the use of the windflow model simpler and more accurate than other formulations, particularly in rough terrain.

The windflow model (COMPLEX) is used to solve the continuity equation for each set of representative winds (eigenvectors). The basic equations from Bhumralkar et al. (1978) are repeated for reference in Section II. For each eigenvector, the model gives the site wind at the hub height of a wind turbine.

Section III discusses procedures for using the windflow model. A simulated wind history at hourly or three-hourly intervals (depending on data availability) is computed by combining the results from COMPLEX with the time history of coefficients of the eigenvectors that is obtained during the statistical processing of the station data. This simulated wind history is used to derive the required statistics, including seasonal and annual mean speeds, diurnal curves, frequency distributions, and frequencies of speed as a function of direction. Wind data for a comparable period were measured for the Department of Energy (DOE) candidate wind turbine site program by the Pacific Northwest Laboratory (PNL).* Statistics based on the measured values are compared with simulated values in Section IV. Section V gives conclusions and recommendations, and Appendix A provides a guide for using the computer programs that are listed in Appendix B.

*The PNL is operated for the DOE by Battelle Memorial Institute.

II THE COMPLEX MODEL

II.A. General Features

A detailed discussion of the windflow model (called COMPLEX) has been given by Bhumralkar et al. (1978). In this section we summarize some of its more important characteristics. Its function is to adjust an initial approximate wind field so that the flow passes smoothly between the surface terrain and boundary-layer top, thereby reflecting terrain influences on the flow. This is achieved by altering the initial flow with the minimal changes needed to make it satisfy the continuity equation. The wind flow model operates in the "sigma" coordinate system. In this system the vertical coordinate sigma is defined for a certain value of height z as

$$\sigma \equiv \frac{z - h(x,y)}{H(x,y) - h(x,y)} \tag{1}$$

where h(x,y) is the height of the terrain above a certain reference level (e.g., sea level) and H(x,y) is the corresponding height of the boundary layer or elevated temperature inversion. Sigma is 0 at the ground and 1 at the top of the boundary layer. The top is generally taken as a curved surface as shown in Figure 1. In the sigma system, at each point of the grid mesh the wind components u (towards east), v (towards north), and w (upward) are replaced by the variables

$$\left.\begin{aligned} u^* &= u(H-h) \\ v^* &= v(H-h) \\ w^* &= \dot{\sigma}(H-h) \end{aligned}\right\} \tag{2}$$

The continuity equation is

$$\frac{\partial u^*}{\partial x} + \frac{\partial y^*}{\partial y} + \frac{\partial w^*}{\partial \sigma} = 0 \ , \tag{3}$$

and the remaining equations of the model are

$$
\begin{aligned}
2W_H\left(u^* - u_o^*\right) - \frac{\partial\lambda}{\partial x} &= 0 \\
2W_H\left(v^* - v_o^*\right) - \frac{\partial\lambda}{\partial y} &= 0 \\
2W_v\left(w^* - w_o^*\right) - \frac{\partial\lambda}{\partial \sigma} &= 0
\end{aligned}
\tag{4}
$$

Equations (3) and (4) comprise a complete set of equations. The quantities W_H and W_V represent the weights assigned to the modified horizontal (u^* and v^*) and vertical wind (w^*) components; these are determined through numerical experiments. Two properties of the set may be mentioned. First, through Equation (3) the mass conservation is imposed in the adjustment process. Second, the difference between the observed and the adjusted values of u^*, v^*, and w^* can be minimized on the basis of Equation (4).

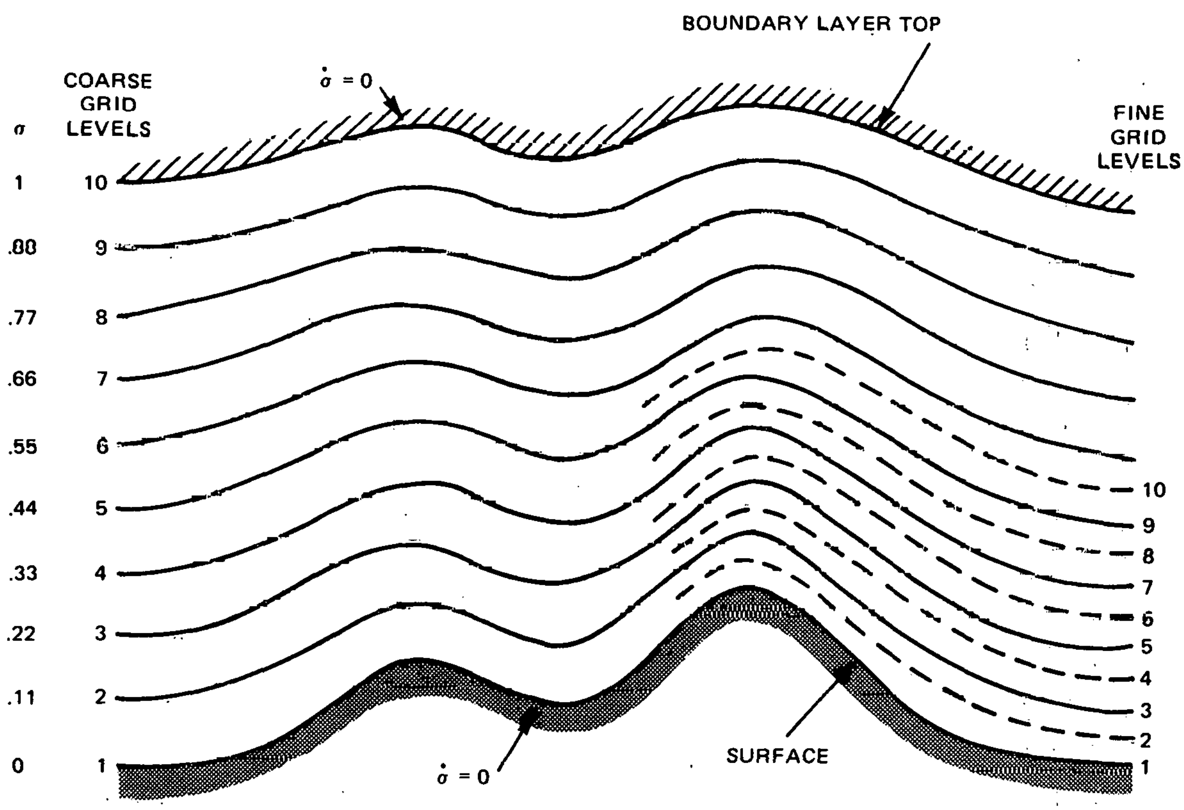


FIGURE 1 THE COARSE AND FINE GRID LEVELS OF THE WINDFLOW MODEL IN THE SIGMA SYSTEM, SHOWING CURVED UPPER AND LOWER BOUNDARIES

In applying meteorological equations to real atmospheric phenomena, numerous simplifications must be made. In the present case, the complete equations are not used for three reasons: (1) their complexity; (2) their need for accurate initial conditions of temperature, pressure, and humidity as well as wind; and (3) the high cost of computer solutions. The equations given above are a subset pertinent to the present problem. There is a simplification in our application of these equations in the x, y, σ system that makes them analogous to Sherman's (1978) equations for the x, y, z system. This simplification involves the neglect of some terms that may be of significance in areas of steep terrain but are of minor importance elsewhere. On the other hand, by using the σ system we are able to introduce variations in terrain heights and the boundary-layer top in a convenient manner. We assume a sudden transition in the depth of the boundary layer from daytime to nighttime values and vice versa, and this is, of course, only an approximation to reality. Also, there are uncertainties in analyzing flow patterns from scattered wind observations. All these assumptions and simplifications were chosen as a practical balance between theory and reality.

The basic equations of the COMPLEX model have been derived from Equations (3) and (4). For example, by eliminating v^* and w^*, and λ from these equations we obtain

$$\frac{\partial^2 u^*}{\partial x^2} + \frac{\partial^2 u^*}{\partial y^2} + \frac{W_H}{W_v}\left(\frac{\partial^2 u^*}{\partial \sigma^2}\right) = \frac{\partial^2 u_o^*}{\partial y^2} + \frac{W_H}{W_v}\left(\frac{\partial^2 u_o^*}{\partial \sigma^2}\right) - \frac{\partial}{\partial x}\left(\frac{\partial v_o^*}{\partial y} + \frac{\partial w_o^*}{\partial \sigma}\right) . \tag{5}$$

Similar equations involving v^* and w^* can be obtained by respectively eliminating (u^*, w^* and λ) from Equations (3) and (4). These equations are

$$\frac{\partial^2 v^*}{\partial x^2} + \frac{\partial^2 v^*}{\partial y^2} + \frac{W_H}{W_v}\left(\frac{\partial^2 v^*}{\partial \sigma^2}\right) = \frac{\partial^2 v_o^*}{\partial x^2} + \frac{W_H}{W_v}\left(\frac{\partial^2 v_o^*}{\partial \sigma^2}\right) - \frac{\partial}{\partial y}\left(\frac{\partial u_o^*}{\partial x} + \frac{\partial w_o^*}{\partial \sigma}\right) , \tag{6}$$

$$\frac{\partial^2 w^*}{\partial x^2} + \frac{\partial^2 w^*}{\partial y^2} + \frac{W_H}{W_v}\left(\frac{\partial^2 w^*}{\partial \sigma^2}\right) = -\frac{W_H}{W_v}\left(\frac{\partial}{\partial \sigma}\right)\left(\frac{\partial u_o^*}{\partial x} + \frac{\partial v_o^*}{\partial y}\right) + \frac{\partial^2 w_o^*}{\partial x^2} + \frac{\partial^2 w_o^*}{\partial y^2} . \tag{7}$$

Equations (3), (5), (6), and (7) constitute the working equations of the COMPLEX model. The right-hand sides of Equations (5), (6), and (7) are evaluated from the initial estimates of the wind components (denoted by the subscript zero), and the adjusted values are computed by relaxation.

The flow is first adjusted over a fairly large volume using a relatively coarse mesh size with the site at or near the center of the horizontal mesh. A typical grid spacing is 8 km. Then, to gain better accuracy and detail at the site, the same equations are solved for a smaller grid using a horizontal grid spacing such as 2 km and for closer spacing in the vertical as shown in Figure 1. The adjusted flow for the coarse grid is used as the initial data in the solution for the fine grid.

II.B. Modifications and Tests

II.B.1. Density Variation in the Vertical

In the previous work at SRI, we assumed that the air density was constant within the atmospheric boundary layer. In the present study, we introduced a variable density that decreases with height according to standard atmospheric values. The decrease in density from the surface to 1500 m above is approximately 10 percent. Appropriate values of density are computed for each sigma surface. To determine the effect of the variable density on the model output, runs were made with constant and variable density; all other conditions in the runs were identical. Although we found that the differences in the results were barely detectable, the variable density has been retained because it is more physically realistic than using a constant value.

II.B.2. Effects of Varying the Vertical and Horizontal Weighting Factors

Experiments were also carried out to determine the sensitivity of the model to the values of W_H and W_V in Equation (4). If a relatively high value is assigned to W_V compared to W_H, the wind alterations made by COMPLEX tend to minimize changes to the vertical wind components and to maximize changes to the horizontal components. This causes the horizontal winds to adjust to the terrain in a realistic manner that is in accord with the stable thermal stratification that is usually observed. The value of the ratio W_H/W_V that gives appropriate results is 1×10^{-12}, which is the same as that used previously (Bhumralkar et al., 1978).

II.B.3. Reduced Number of Iterations

In the relaxation subroutine of the windflow model, we investigated the effect of varying the upper limit on the number of relaxations performed in the adjustment process. Previously, the limit was set at 40, and this large number required substantial computer time. We found that the computed site winds changed by very insignificant amounts after 30 iterations or less. Therefore, we have reduced the upper limit to 30 and have consequently effected a modest reduction in computer costs.

III PROCEDURES

III.A. Grid Layout

For reasons of convenience and economy in solving the windflow model, the quasi-horizontal grid is taken as an array of 21 × 21 points or less and the vertical grid as 10 levels. With a 10-km grid spacing, the coarse grid covers an area 210 by 210 km, and the potential wind turbine site is taken at a grid point near the center. The spacing between the vertical levels depends on the values selected for the mixing depth and for the shape of the boundary-layer top, as discussed later. The fine grid distance is chosen as a fraction (such as one-fourth) of the coarse grid, causing some of the horizontal mesh points of the fine grid to coincide with coarse grid points. Also, the vertical separation of the fine grid mesh is half that of the coarse mesh. Hub-height winds (46 m) are interpolated from the nearest levels of the fine mesh. The mesh sizes used for the various sites treated in this study are shown in Table 1.

III.B. Wind Data

As discussed by Bhumralkar et al. (1978), standard weather reports from four or five stations in the vicinity of each wind turbine site are used as the basic observations for the windflow model. Current data are generally available at three-hourly intervals, whereas before 1964 they had been available at hourly intervals. The results from the model are, of course, dependent upon the degree to which the stations represent the approximate windflow at the site. Stations too far away are likely to be unrepresentative, especially in mountainous terrain or at coastlines.

In recent years, the wind data have been given in terms of direction and speed at a standard height 10 m above the ground. The station weather data were obtained on magnetic tape in a card image format in synoptic order: stations A, B, C, D, and E at time 1; stations A, B, C, D, and E at time 2, etc. This arrangement has eliminated the need for some of the data processing routines used by Bhumralkar et al. (1978) and facilitates the use of the data by the program XFORM that obtains eigenvectors and their coefficients.

As mentioned previously, a geostrophic wind computed from the values of sea-level pressure at the reporting stations is used to obtain a suitable estimate of wind at the top of the boundary layer. The computation is made from pressure values at three stations. The location of the three stations forms a regular triangle whose center is near the site. The computation follows the triangle method described by Endlich and Clark (1963).

Table I

INFORMATION CONCERNING WIND TURBINE SITES, DATA STATIONS, AND GRIDS

Site	Grid Sizes (km)	Day/Night Boundary Layer: Average Thickness (m)	Slope Factor	Minimum Thickness (m)	Thickness at Site (m)	Data Stations
Boone, NC 36.25°N, 81.67°W, 1348 m ASL	4.0, 1.0	1500/450	0.0/0.1	300/250	966/250	Asheville, NC; Greensboro, NC; Roanoke, VA; Bristol, TN; Charlotte, NC
Block Island, RI 41.17°N. 71.57°W, 9 m ASL	9.0, 3.0	1000/700	2.0/1.0	300/300	932/832	Windsor Locks, CN; Providence, RI; Bridgeport, CN; JFK International Airport, NY
San Gorgonio, CA 33.93°N, 116.58°W, 335 m ASL	10.0, 2.5	1200/500	0.7/0.9	300/200	1616/539	Daggett, CA; Los Angeles International Airport, CA; Sandberg, CA; Yuma, AZ
Clayton, NM 36.44°N, 103.20°W, 1533 m ASL	8.0, 2.0	2600/450	1.2/1.0	500/250	2608/450	Dodge City, KA; Amarillo, TX; Tucumcari, NM; Pueblo, CO
Ludington, MI 43.88°N, 86.43°W 250 m ASL	10.0, 2.5	1200/500	2.0/-2.0	300/200	1235/430	Milwaukee, WI; Green Bay, WI; Muskegon, MI; Traverse City, MI
Holyoke, MA 42.25°N, 72.65°W 323 m ASL	6.0, 1.5	1300/600	0.5/0.0	400/250	1246/493	Albany, NY; Windsor Locks, CN; Concord, NH; Worcester, MA
Huron, SD 44.42°N, 98.14°W, 402 m ASL	10.0, 2.5	1400/400	2.0/1.0	400/300	1318/400	Fargo, ND; Sioux Falls, SD; Bismarck, ND; Pierre, SD (Huron, SD)

III.C. Computation of Representative Patterns (Eigenvectors)

III.C.1 General Approach

The wind information used in this study consists of u and v wind components computed from the direction and speed at the reporting stations and a geostrophic wind for the area, all available at three-hourly intervals. The computer program XFORM computes the covariance matrix of all the input wind components (including the geostrophic wind) and gives the eigenvectors of that matrix. For n reporting stations and one geostrophic wind there are 2(n+1) eigenvectors. Also, the coefficients of each eigenvector are computed for each input data set (observation time). The coefficients are used later to reconstruct the time history of site winds. The percent of the total variance explained by each eigenvector is also computed.

In all cases examined, a few eigenvectors explain most of the variance. For example, at Boone, North Carolina the percent of variance explained by the eigenvectors in decreasing order is 46, 32, 10, 2.5, 2.0, etc. We found that the neglect of about half the eigenvectors (those having individual contributions of less than 2 percent of the variance) caused no discernible difference in the simulated site wind statistics. This shortcut reduces the required computer time and lowers costs. The use of eigenvectors has given an accurate and efficient method for handling the voluminous wind data. The method has been described by Bhumralkar et al. (1978) and Ludwig and Byrd (1980).

III.C.2. Examples of Eigenvectors

Figure 2 shows the mean winds and the two principal eigenvectors for San Gorgonio, California. The mean station winds are quite weak (3.2 m s^{-1} or less) but the mean geostrophic speed (shown at San Gorgonio) is quite strong, having a speed of 9.4 m s^{-1} from the north. The principal eigenvector has opposite flow, and the second eigenvector is at approximately right angles to the mean flow. Figure 3 shows that at Ludington, Michigan the mean speeds are less than 2 m s^{-1} and the station winds are directed toward the low pressure side of the mean geostrophic vector. The winds of the principal eigenvector are approximately perpendicular to the mean winds, and the second eigenvector is approximately opposite to the mean flow.

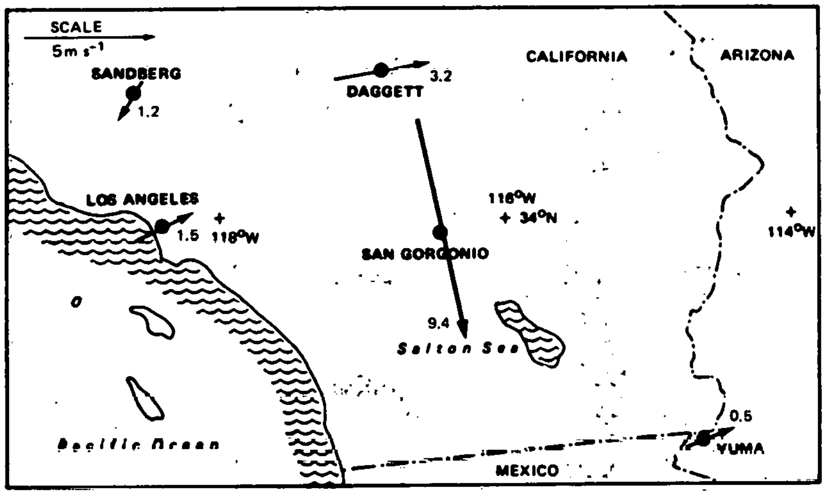
In our study of the use of eigenvectors to represent weather patterns, we also considered how the coefficients of the eigenvectors could be used as climatological indicators. For example, at Ludington the two principal eigenvectors represent 87 percent of the variance. The coefficients of these two eigenvectors were categorized and compared with weather maps. The results, described in Appendix C, show that the coefficients of the eigenvectors can be associated with typical weather patterns in the vicinity of the site.

III.D. Initial Winds

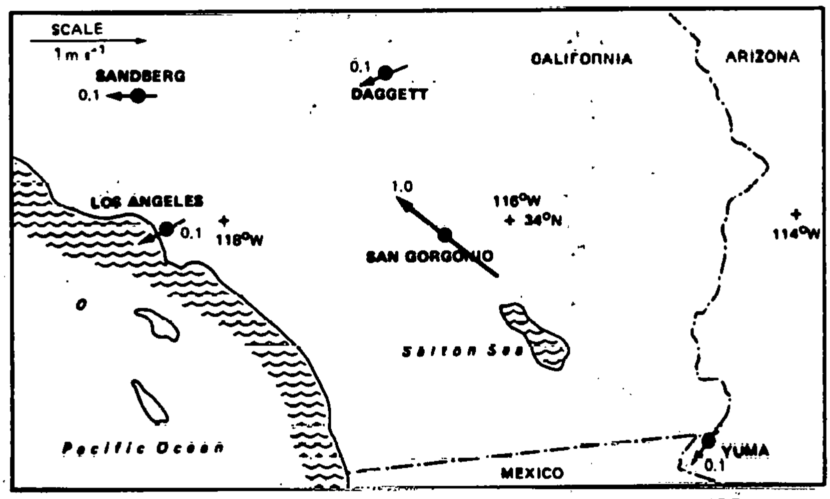
We generated initial winds for the windflow model for the mean winds and each set of eigenvectors. This was done by first making an analysis at the anemometer height (10 m). (If the anemometers were not at uniform height it would be necessary to correct the data to a constant level.) The method for obtaining grid point values of u and v station reports is that described by Mancuso and Endlich (1973). The output is a smooth field of winds near the ground. As mentioned earlier, we assume that at the top of the boundary layer the geostrophic wind applies over all the grid. At the interior points, wind values along vertical lines are interpolated from the upper and lower values using the following logarithmic formula, which puts the strongest shear in the lowest layers:

$$u = u_a + (u_g - u_a)\,\frac{\log z - \log z_a}{\log z_g - \log z_a} \qquad (8)$$

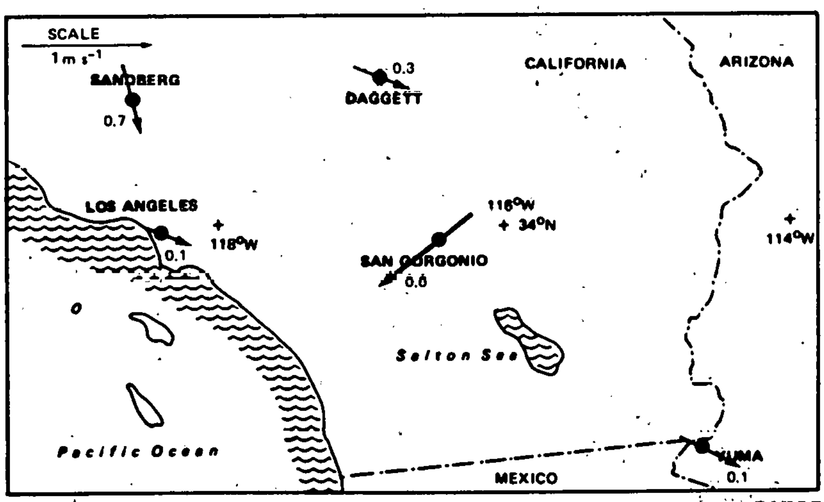
$$v = v_a + (v_g - v_a)\,\frac{\log z - \log z_a}{\log z_g - \log z_a} \qquad (9)$$



(a) THE MEAN OBSERVED WINDS AND THE MEAN GEOSTROPHIC WIND

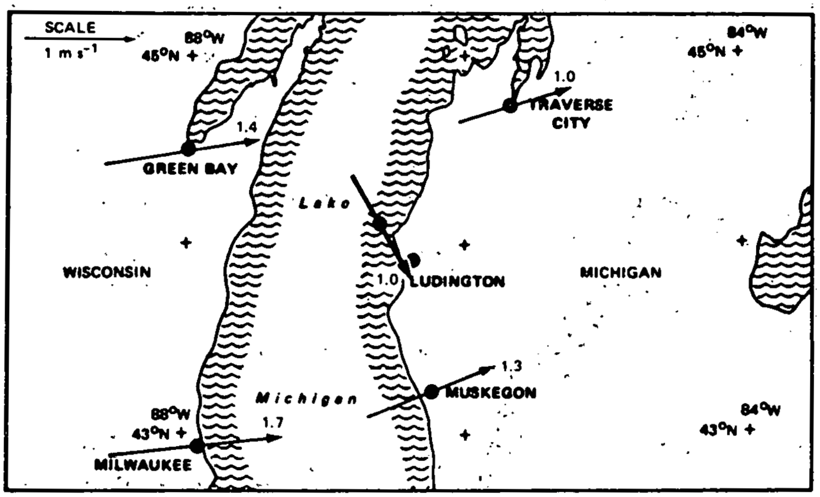


(b) THE WINDS DESCRIBED BY THE PRINCIPAL EIGENVECTOR

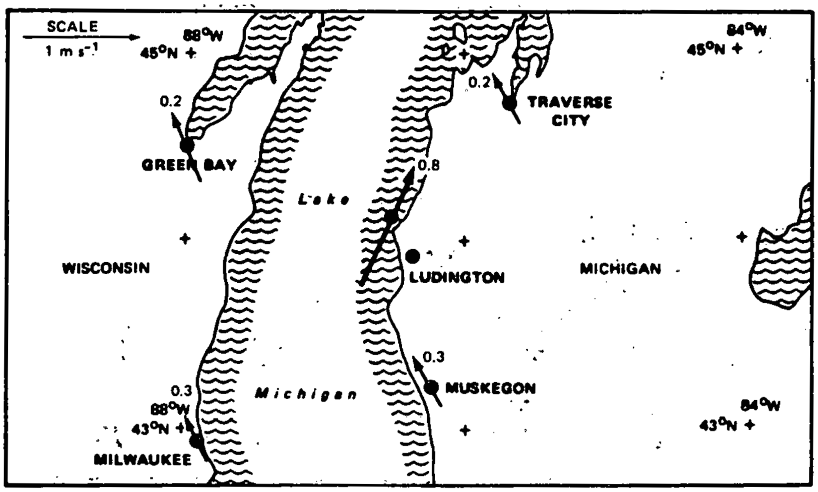


(c) THE WINDS DESCRIBED BY THE SECOND MOST IMPORTANT EIGENVECTOR

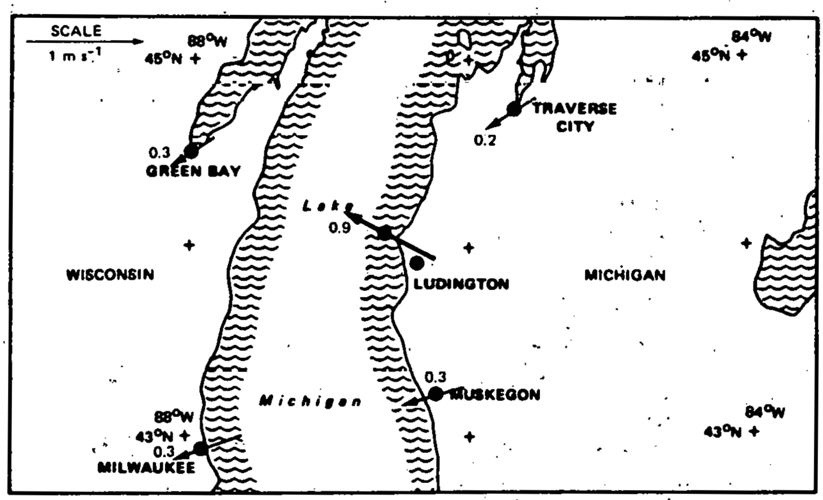
FIGURE 2 WIND PATTERNS IN THE VICINITY OF SAN GORGONIO, CALIFORNIA



(a) THE MEAN OBSERVED WINDS AND THE MEAN GEOSTROPHIC WIND



(b) THE WINDS OF THE PRINCIPAL EIGENVECTOR



(c) THE WINDS OF THE SECOND MOST IMPORTANT EIGENVECTOR

FIGURE 3 WIND PATTERNS IN THE VICINITY OF LUDINGTON, MICHIGAN

The subscript a denotes the anemometer height and g denotes the geostrophic level. This type of interpolation permits the wind to change in direction as well as in speed with height; in contrast, power law interpolation permits only a variation in speed.

III.E. Specification of the Boundary-Layer Top

Since the top of the boundary layer is not a directly observed meteorological variable, information about it is incomplete, particularly in regard to variations in its height over complex terrain. It is known, however, from indirect information such as radiosonde reports, that the top of the boundary layer is relatively flat at night, but tends to conform approximately to the terrain shape during the daytime. We based our treatment of the boundary-layer top (which is needed in the COMPLEX model) on the parameters of thickness and slope in a subroutine called SETBLT. The height of the boundary-layer top at a particular point of the grid being used is denoted by BLT; the average thickness of the boundary layer in the area of interest (surrounding a wind generator site) is denoted by AVTHK; h is the terrain height at the point of interest; h_s is the terrain height at the site; and k is the slope factor. Then the basic equation is

$$BLT = AVTHK + kh + (1 - k)\, h_s \,. \qquad (10)$$

If k is set equal to zero, the boundary-layer top is flat; if k equals one, the top parallels the terrain. Values between zero and one give intermediate slopes, and values greater than one give slopes steeper than the terrain slope. Negative values give slopes opposite to the terrain slopes. Figure 4 shows typical boundary-layer tops for a nighttime case (AVTHK = 500 m, k = 0.2) and a daytime case (AVTHK = 1500 m, k = 0.8). The parameters AVTHK and k can be treated as functions of time of day and season.

For terrain that has some high, rather sharp peaks, the use of Equation (10) can give unrealistically low values of the boundary-layer top height over the highest terrain, unless an additional parameter is introduced. This parameter specifies the minimum thickness (STHK) of the boundary layer over any point. STHK is set to be 200 m or more and is also set to be less than AVTHK. The complete solution for the boundary-layer top is obtained iteratively in the following way. First, the values of BLT are computed using Equation (10). Then each point of the grid is tested, and if the condition for STHK is not met, BLT is corrected accordingly. After corrections are made, the actual average thickness over the area is computed and compared with the desired value AVTHK. If the average computed value differs from AVTHK, all values of BLT are corrected by the difference in the second iteration, and other steps are repeated. Within six iterations, the average thickness differs from AVTHK by 1 m (or less) and the computation is stopped. The amount of computation required in SETBLT is insignificant from the cost standpoint.

III.F. The Use of Digitized Terrain Data

Our methodology requires that terrain heights at grid points be supplied for use in solving the COMPLEX model equations. Previously, the heights had been laboriously read from U.S. Geological Survey maps and then punched on cards. To automate this time-consuming step for the sites of interest, we purchased magnetic tapes of terrain data from the National Cartographic Information Center (NCIC) and wrote a program to obtain the desired terrain heights.

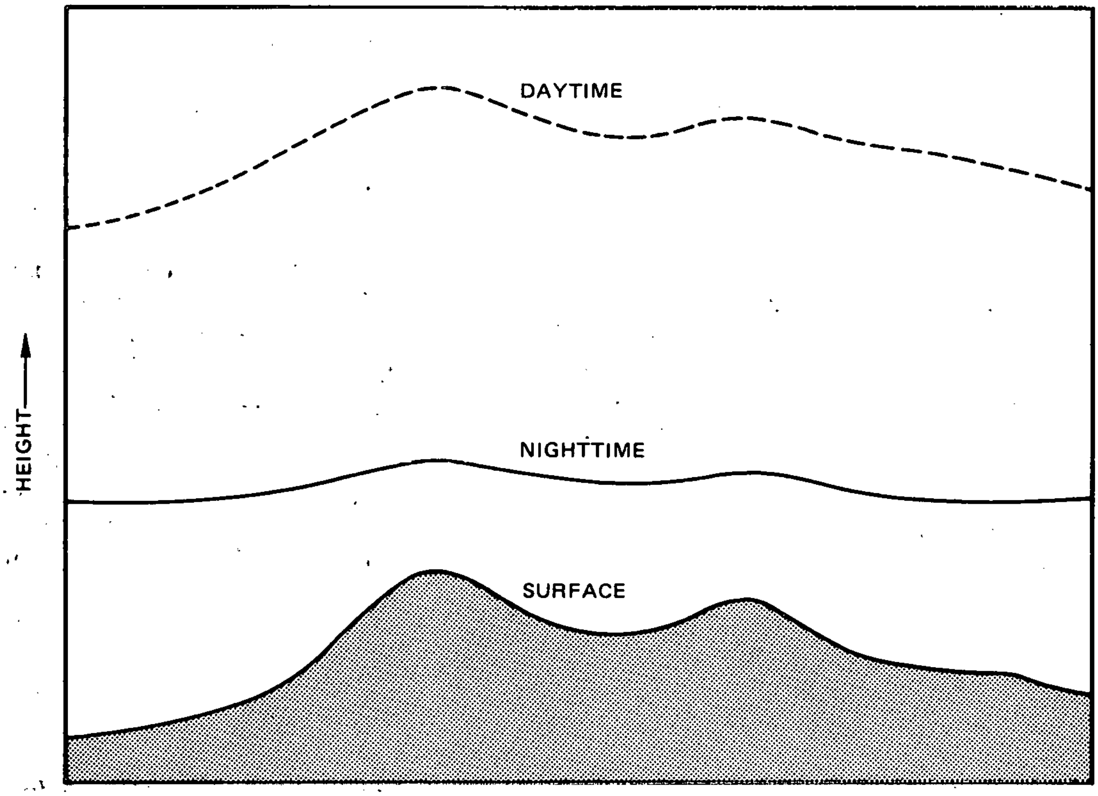


FIGURE 4 TYPICAL CONFIGURATIONS OF THE BOUNDARY LAYER TOP FOR DAYTIME (AVERAGE THICKNESS = 1500 m, SLOPE FACTOR = 0.8) AND NIGHTTIME (AVERAGE THICKNESS = 500 m, SLOPE FACTOR = 0.2)

The original NCIC data contain approximately 2.4 million height values in each 1° lat. by 1° long. region. (This data density is approximately 200 times greater than that needed for the 1-km grid used in the COMPLEX model.) The basic terrain heights that are required to match this grid can be taken at 0.01° lat./long. increments. Obtaining these 0.01° height values by decoding and averaging all of the original NCIC heights would require extensive processing and would be prohibitively expensive. The format of the NCIC data is such that it is efficient to decode height values at latitude increments of approximately 0.005° and then to average six of these values to obtain the desired values. Figure 5 is a computer plot of the smoothed height values for the area from 33° to 34°N, 116° to 117°W. Each symbol represents the average height value for a 0.01° area. A blank indicates a height below 1000 ft, a printed "1" represents a height between 1000 and 2000 ft, "2" represents 2000 to 3000 ft, and so on. The plot enables us to check the computed values by comparing them to ordinary terrain maps. The area covered in Figure 5 includes part of the Salton Sea (represented by blanks); the San Gorgonio Pass runs through the northwestern part of the map. Height values for use in COMPLEX are selected at appropriate points from these 0.01° values by the computer program GRIDHT.

FIGURE 5 COMPUTER-PRINTER PLOT OF TERRAIN HEIGHTS FOR A 1-DEGREE LATITUDE/LONGITUDE REGION THAT INCLUDES THE SAN GORGONIO WIND TURBINE SITE (INDICATED BY A STAR)

Symbols represent heights in 1000-ft increments.

III.G. Selection of Site Parameters

The information about the sites, the data stations, and the grid sizes used in the windflow model is given in Table 1. The wind observations for the reporting stations are for the period 1 January 1977 through 31 December 1977. Many of the routinely reporting weather stations listed in this table are quite far from the sites, and this tends to limit the accuracy of the results. The year 1977 was chosen so the simulated winds could be compared with wind data measured at the sites as part of the DOE candidate site program.

The values of boundary layer thickness and slope were chosen using generally accepted principles discussed below:

- The boundary-layer thickness is least at night and largest in the early afternoon.
- In regions of low mountains or hills, the boundary-layer top tends to be flat at night and to slope less steeply than the terrain during the day, except during the afternoon in summer when convection may be occurring over the higher terrain.
- In regions of high mountains, the nocturnal boundary layer is relatively thin and the top tends to slope slightly less than the terrain. In the daytime, the boundary layer is thick and tends to slope less than the terrain, except for cases of convection over the peaks.
- Over islands and coastal locations, the boundary layer thickness remains relatively constant from day to night, but over the adjacent land it is relatively high during the day and low at night. Therefore, at Block Island and Ludington the slope factor is positive during the day and negative at night.
- In relatively flat terrain the boundary layer top is also flat, i.e., the boundary layer thickness is approximately constant in space but the thickness varies diurnally.

To keep the methodology simple, we divided the boundary layer parameters into two classes, i.e., day and night. The corresponding values of the parameters used to control the boundary layer's thickness and top were derived from Holzworth's (1972) morning and afternoon climatological values. These are given in Table 1. The transition between the daytime and nighttime boundary layers was assumed to take place at 1700 and 0900 LST. Seasonal changes in this transition could be introduced. Furthermore, seasonal differences in the average mixing height for both day and night are not considered in the present version of the model. Inasmuch as Holzworth (1972) provides values for each season, the necessary information would be available to make the change; however, the amount of computation required by the COMPLEX model would be increased substantially.

III.H. The Windflow Model (COMPLEX)

We applied COMPLEX (described in Section II) to the initial winds corresponding to each set of eigenvectors (except those that explained less than two percent of the variance). The output of COMPLEX was interpolated to give u an v components at hub height over the grid, and the site values of winds were saved for use in the next step.

III.I. Simulation of the Site Winds

The program REWIND computes the site winds at each time from the hub height winds corresponding to the eigenvectors, and the time series of the eigenvector coefficients that were computed earlier by the XFORM program. The output of site winds at three-hourly intervals is treated by two statistical programs that compute

- A frequency distribution of wind speed
- A joint frequency distribution of wind speed and direction
- Seasonal variability in wind speed
- Diurnal variability in wind speed
- Run duration analysis for wind speeds:
  - Above or below 6 m s^{-1}
  - Between 6 and 20 m s^{-1}.

The first three requirements are quite standard and we have chosen to use available computer program packages (Nie, 1975) to calculate frequency distributions and joint frequency distributions. The speeds have been averaged as scalars rather than vectors.

III.J. The Tuning Process

As mentioned earlier, at four of the sites the observations were used to tune the windflow model. The basic structure of the analysis methods and the model suggested that the results would be sensitive primarily to the boundary layer thickness and the slope of the boundary-layer top. (These parameters were discussed earlier in Section III.E.) Several numerical experiments were carried out. These showed that decreasing the average thickness of the boundary layer and making the top relatively flat (i.e., using a slope factor less than 0.5) tended to increase the simulated wind speeds at the sites. Seasonal average speeds, annual average speeds and diurnal curves were computed from the simulated winds. We compared these statistics to comparable statistics of the measured winds, and identified the most accurate values of thickness and slope. The sensitivity to these parameters proved to be greatest for sites on mountain tops (such as Boone and Holyoke) or in complicated terrain (San Gorgonio), somewhat less at coastlines, and least of all for uniform, flat terrain (Huron).

The values of average boundary-layer thickness and slope factor given in Table 1 should be used as a guide in selecting appropriate values for other locations. The sites used in the tuning process represent a variety of geographical setting—flat terrains, rough terrain with sites located on peaks and in valleys, shoreline settings, and maritime locations. The principles used to derive the slope factors have given satisfactory results, except at Boone where a flat boundary-layer top in the daytime gave realistic wind speeds at the site, whereas positive values of slope gave winds that were too weak in the afternoon.

IV RESULTS

IV.A. Examples of Tuned Results

IV.A.1. Boone, North Carolina

Figure 6 shows the generator site at Boone, North Carolina and the surrounding weather stations. The site is on Howards Knob in mountainous terrain at a height of 1350 m (4420 ft). The weather stations in the area (listed in Table 1) are located at low elevations, and the nearest one (Asheville, North Carolina) is approximately 150 km away. Thus, the data distribution is unfavorable. The results of our methods are shown in Figure 7. The annual-average wind speed given by observations is 8.0 m s^{-1}, and the model value is 8.1 m s^{-1}. The seasonal curves are in reasonably good agreement, except that the model values have less variation than the observations. With regard to the diurnal curve, the model values overemphasize the change in speeds from night to day. This is probably because of our use of a sudden transition in mixing depth from day to night. Also, the climatological data used to select the average mixing depths may not be representative of the mountaintop location of the site.

Figure 8 shows the cumulative frequency distribution of wind speeds for the observations and the model. The agreement is excellent. In the distribution of wind directions, cases of weak winds having speeds less than 4 m s^{-1} are omitted. Curves are given in Figure 8 for the simulations and observations for moderate speeds (between 4 and 12 m/s) and for high speeds (greater than 12 m/s). The observations show high frequencies of directions from the north and west-northwest, but the model does not reproduce these peaks well, perhaps because of the large distances of the reporting stations from the site.

Table 2 shows the run durations for Boone for both the model simultations and the site observations in terms of a one-year interval. Since the observed data were incomplete, the counts were normalized to a year to permit comparison with the simulated values. The duration increments (column 1) are in 3-hour steps because of the 3-hour interval used in the simulations. The values of 6 m s^{-1} and 20 m s^{-1} are used because they are representative of recent designs of large machines. The numbers in Table 2 (and in subsequent run duration tables for other sites) have the following meanings:

- On 157 occasions during 1977 the simulated data had wind speeds that were less than 6 m s^{-1} for exactly 1 hour (column 2).
- On 67 occasions the wind speed was less than 6 m s^{-1} for exactly 4 hours (2 successive simulated speeds).
- On 59 occasions it was less than 6 m s^{-1} for exactly 7 hours (3 successive simulated speeds), etc.

Comparable values for the site observations are given in column 3. The next two columns give similar counts for speeds equal to or greater than 6 m s^{-1}. The entries in column 4 mean that speeds equal to or greater than 6 m s^{-1} persisted for exactly 1 hour on 124 occasions, for exactly 4 hours on 58 occasions, etc. The last two columns pertain to speeds between 6 and

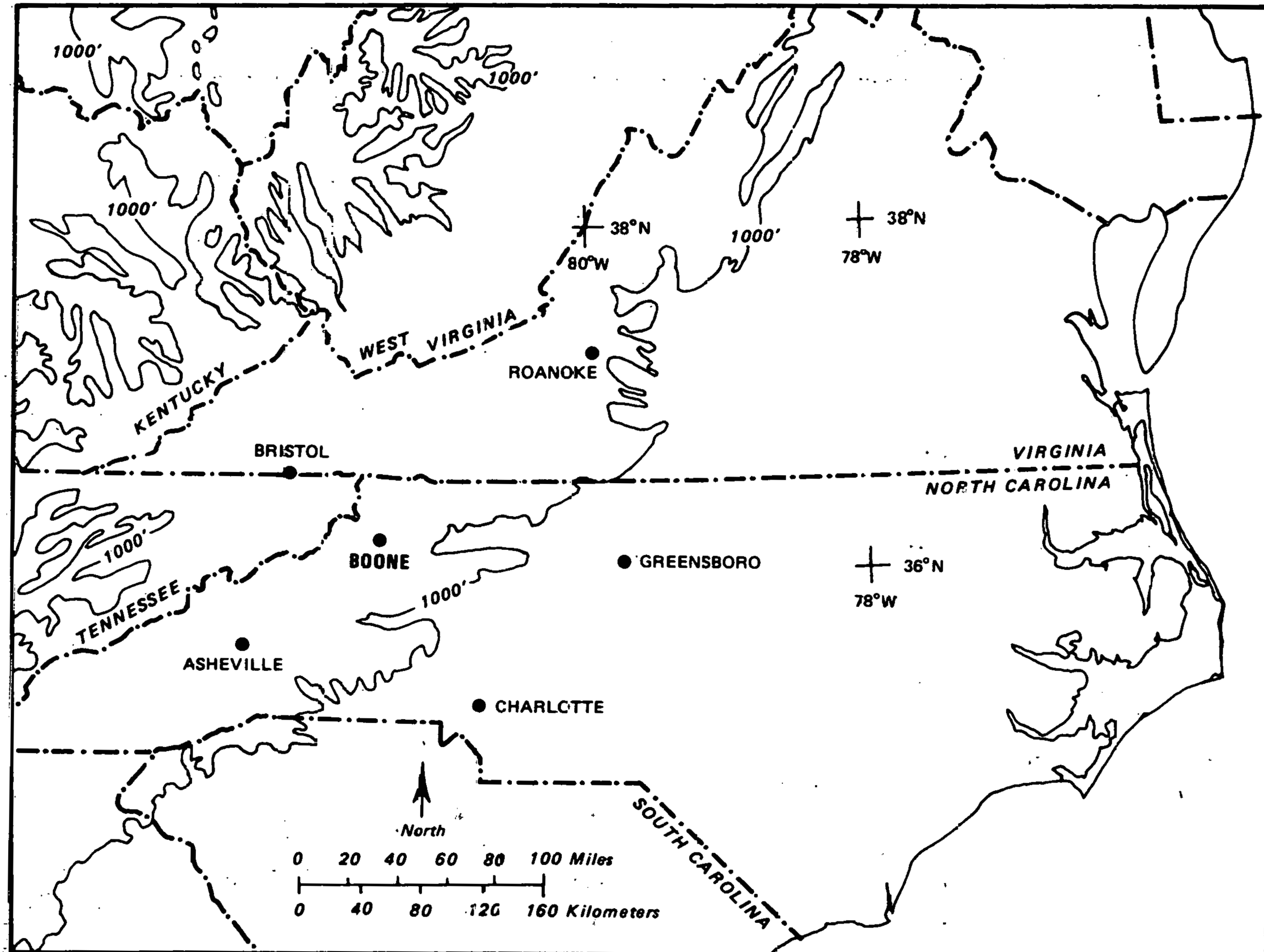


FIGURE 6 MAP SHOWING THE LOCATION OF BOONE, NORTH CAROLINA AND THE NEAREST WEATHER STATIONS

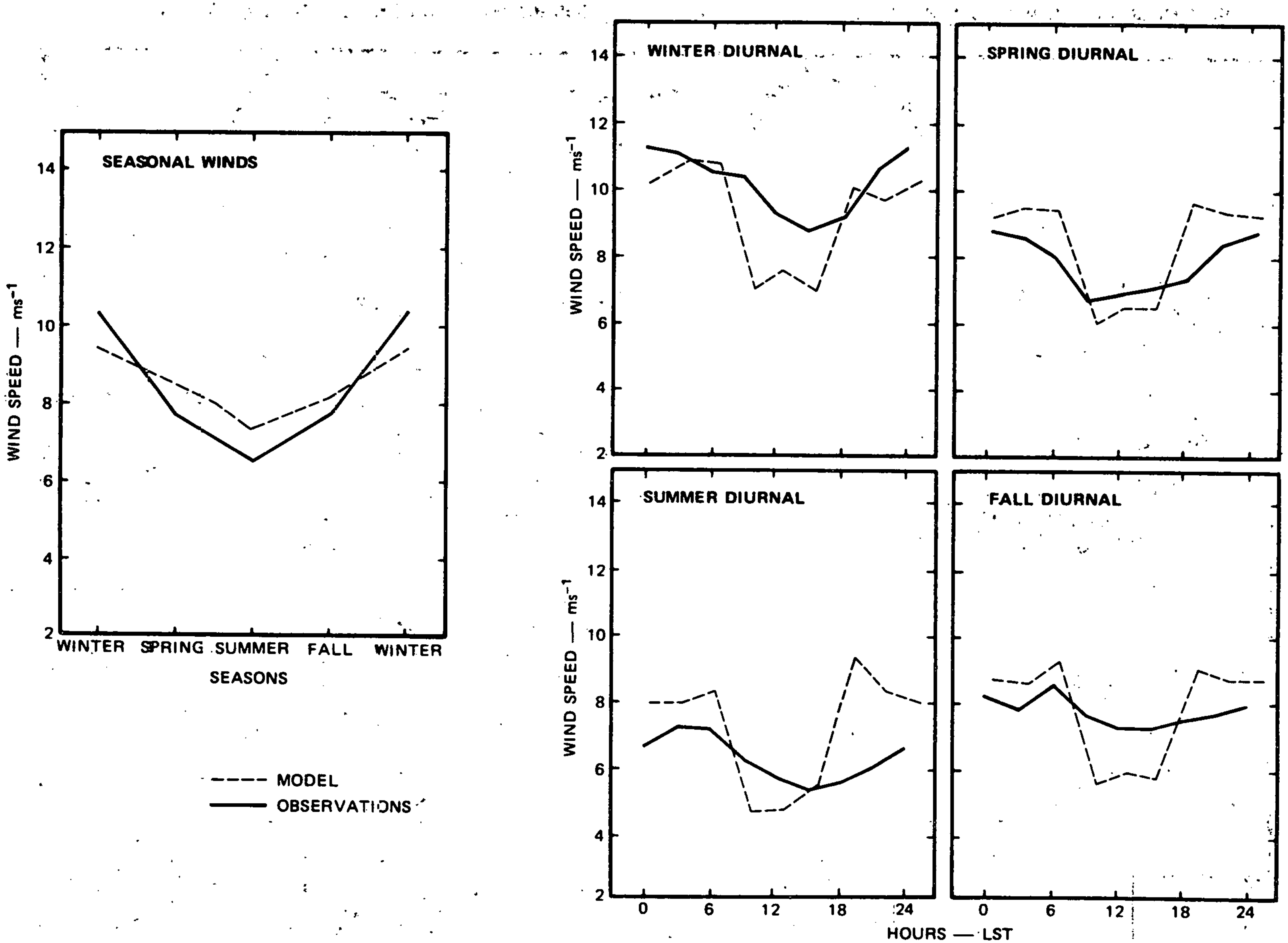


FIGURE 7 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR BOONE, NORTH CAROLINA AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

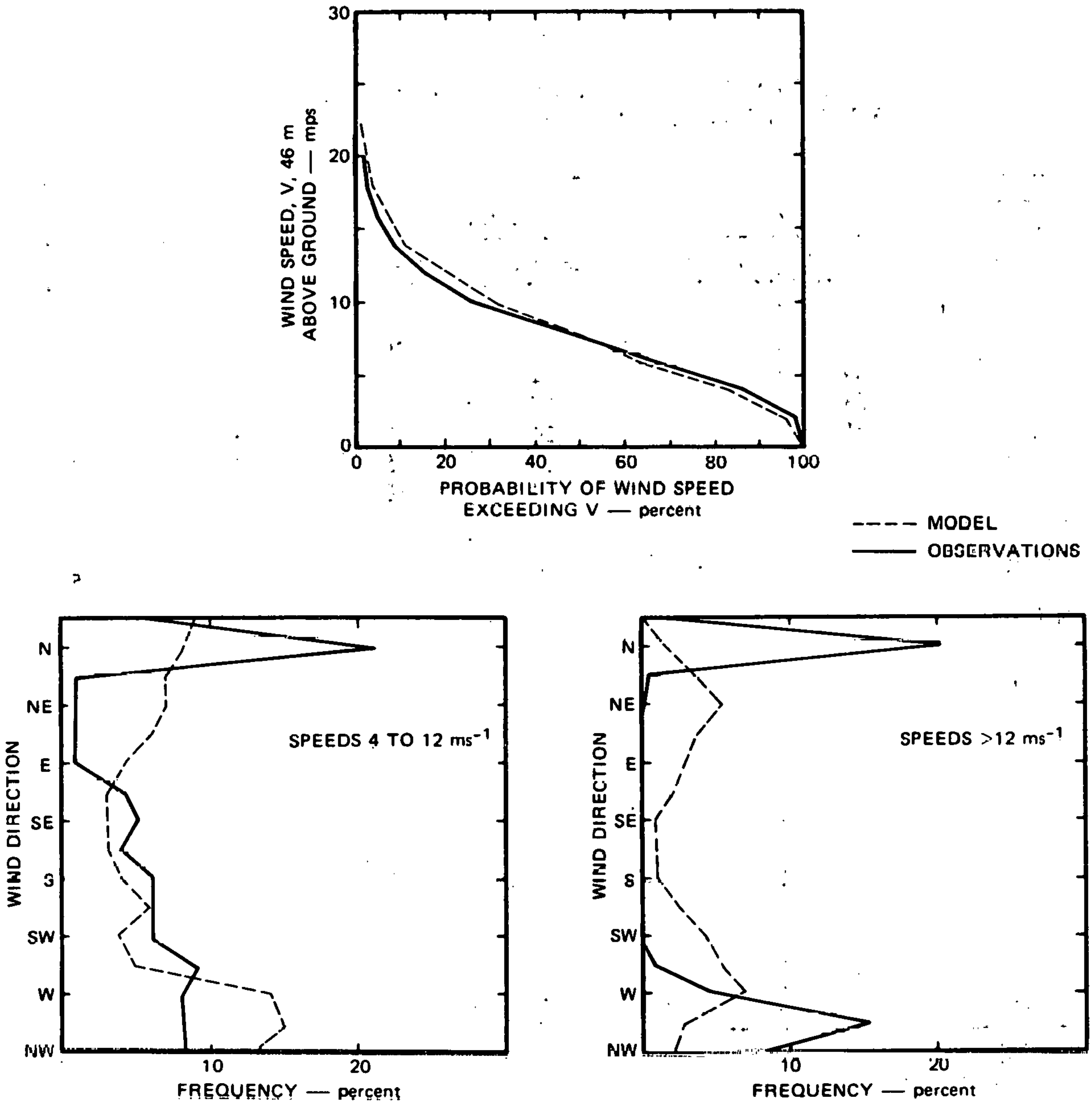


FIGURE 8 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR BOONE, NORTH CAROLINA FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 2

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT BOONE, NORTH CAROLINA FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		≥ 6 m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	157	95	124	90	133	97
4	67	46	58	39	65	41
7	59	36	34	29	39	32
10	26	27	21	13	27	18
13	21	18	34	13	39	15
16	10	14	19	15	22	13
19	14	11	17	10	23	14
22	3	5	5	9	9	10
25	4	4	8	2	7	4
28	2	5	7	5	11	5
31	2	4	6	4	3	4
34	1	1	7	5	6	5
37	2	1	4	5	4	4
40	1	3	3	5	4	6
43	0	0	7	4	3	3
46	1	2	2	2	2	1
49	2	1	0	0	2	1
52	0	0	2	0	1	1
55	0	0	2	3	2	2
58	0	0	1	1	2	2
61	1	0	2	2	1	3
64	1	2	1	2	1	3
67	0	1	0	3	1	3
70	0	0	2	1	2	0
73	0	0	2	2	1	1

20 m s^{-1}. The tabulated values in these columns are not identical to those in the previous two columns because the speeds occasionally exceeded 20 m s^{-1}, causing the end of sequence that was often followed shortly afterward by the beginning of a new sequence of speeds between 6 and 20 m s^{-1}. For Boone, the simulated speeds show strong winds persisting for somewhat longer times than the observations show.

Overall, we consider the results for Boone to be excellent, considering that the terrain is complex and no nearby weather data were used.

IV.A.2. Block Island, Rhode Island

Block Island is a small island (approximately 10 km long) that lies about 25 km off the Rhode Island coast, as shown in Figure 9. The site is at an elevation of 9 m. The nearest weather station, at Providence, is approximately 100 km to the north. None of the nearby stations is exposed to oceanic influences to the same extent as Block Island. Nevertheless, the model gives fairly accurate results. The observed annual average wind speed is 7.5 m s^{-1} as compared to 7.0 m s^{-1} for the simulations. Figure 10 shows that the simulated data had a seasonal curve similar to that of the real data. The diurnal curves of the model peak earlier in the day than do the observations. This is probably because of land/sea effects that are not well represented by the available station data. Figure 11 shows that the speed and direction distributions of the simulations agree fairly well with the observations. The run durations in Table 3 show good agreement between the simulated and observed speeds.

Considering that the nearest wind observations are for non-island stations, we feel that the results are satisfactory.

IV.A.3. San Gorgonio, California

The wind turbine site at San Gorgonio is on the eastern side of San Gorgonio Pass. The weather stations for this site were shown in Figure 2 and the terrain features were shown in Figure 5. The pass is oriented approximately west-to-east with large mountains to the north and a somewhat lower range to the south. The land in the immediate vicinity of the site is flat and slopes gradually downward to the southeast. During 1977, the nearest weather station (listed in Table 1) was Daggett, California, approximately 100 km to the north-northwest. Unfortunately, none of the stations reflects the location variations in wind that are directly associated with San Gorgonio Pass.

The annual-average wind speed for the three-hourly site winds simulated by the model is 7.2 m s^{-1} and the average of the measured winds is 8.0 m s^{-1}. Although the model estimate is low, it is considerably more accurate than the earlier result reported by Bhumralkar et al. (1978). Figure 12 shows the seasonal and diurnal curves. The model winds were approximately 3 m s^{-1} too low in spring and 1.5 m s^{-1} too strong in winter; however, site wind measurements were missing during much of February and March, so the observed average may be somewhat unrepresentative. The diurnal curves of the model have the correct shape with maximum speeds at approximately 1900 LST, but the peaks in the observed speeds are higher, particularly in spring. Evidently the strong thermal influences that act locally in the vicinity of the site in spring and summer are not properly included when the reporting stations are outside this regime.

The cumulative frequency distributions of wind speed for the model (Figure 13) show that the model calculates too few cases at 8 m s^{-1} and above, as noted in the previous discussion of diurnal curves. The wind direction curves for the model (Figure 13) indicate that northwest winds have the highest frequency. However, the observations show that the most frequent direction is from the west, particularly for wind speeds above 12 m s^{-1}. This discrepancy may be because of the smoothing of terrain in the model or the unrepresentativeness of the available wind data used by the model.

Table 4 shows the run durations for the simulations and the observations. The agreement is reasonably good except that the observations show more runs of strong winds than the simulations show for periods of up to 10 hours.

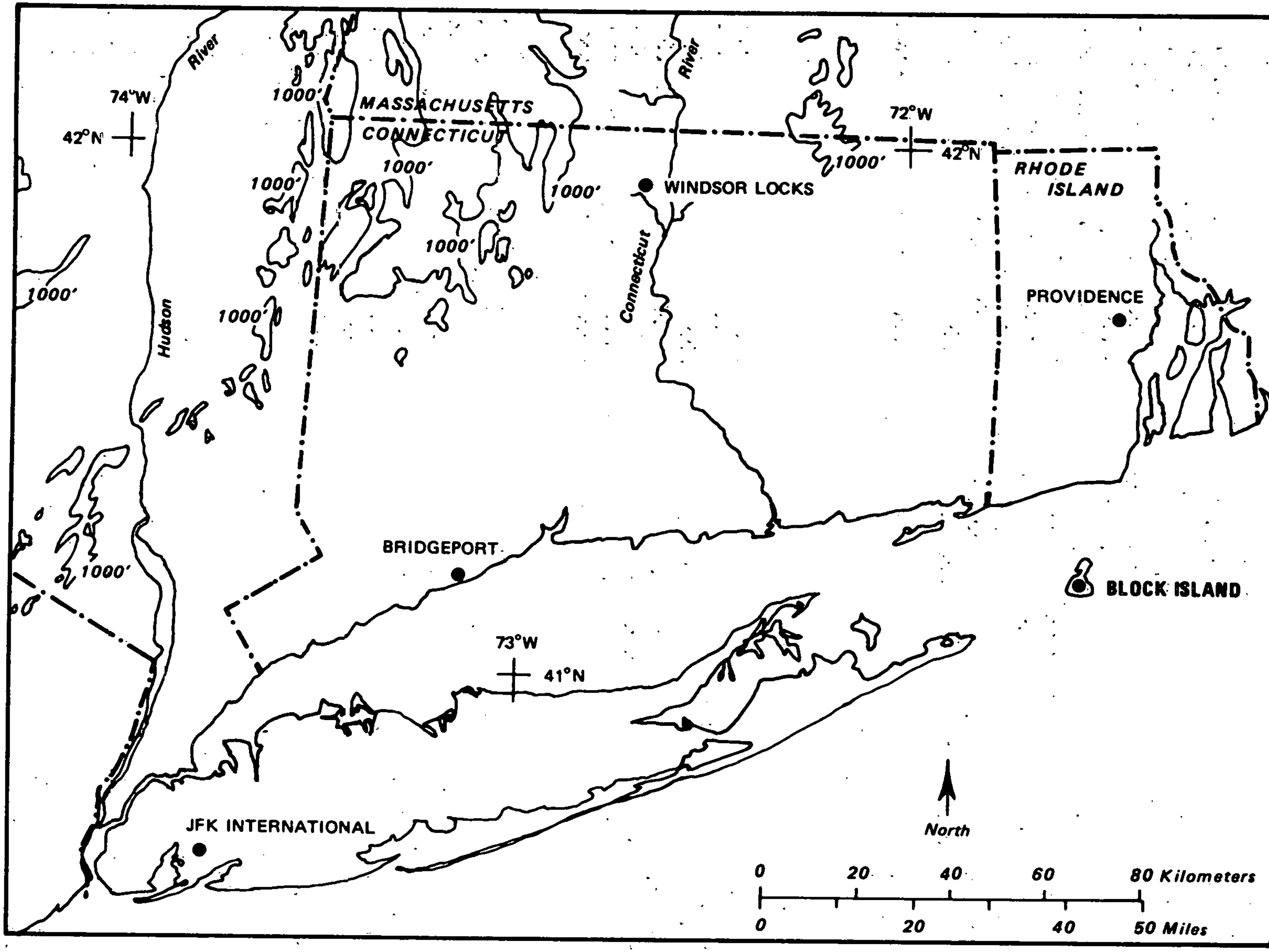


FIGURE 9 MAP SHOWING THE LOCATION OF BLOCK ISLAND, RHODE ISLAND AND THE NEAREST WEATHER STATIONS

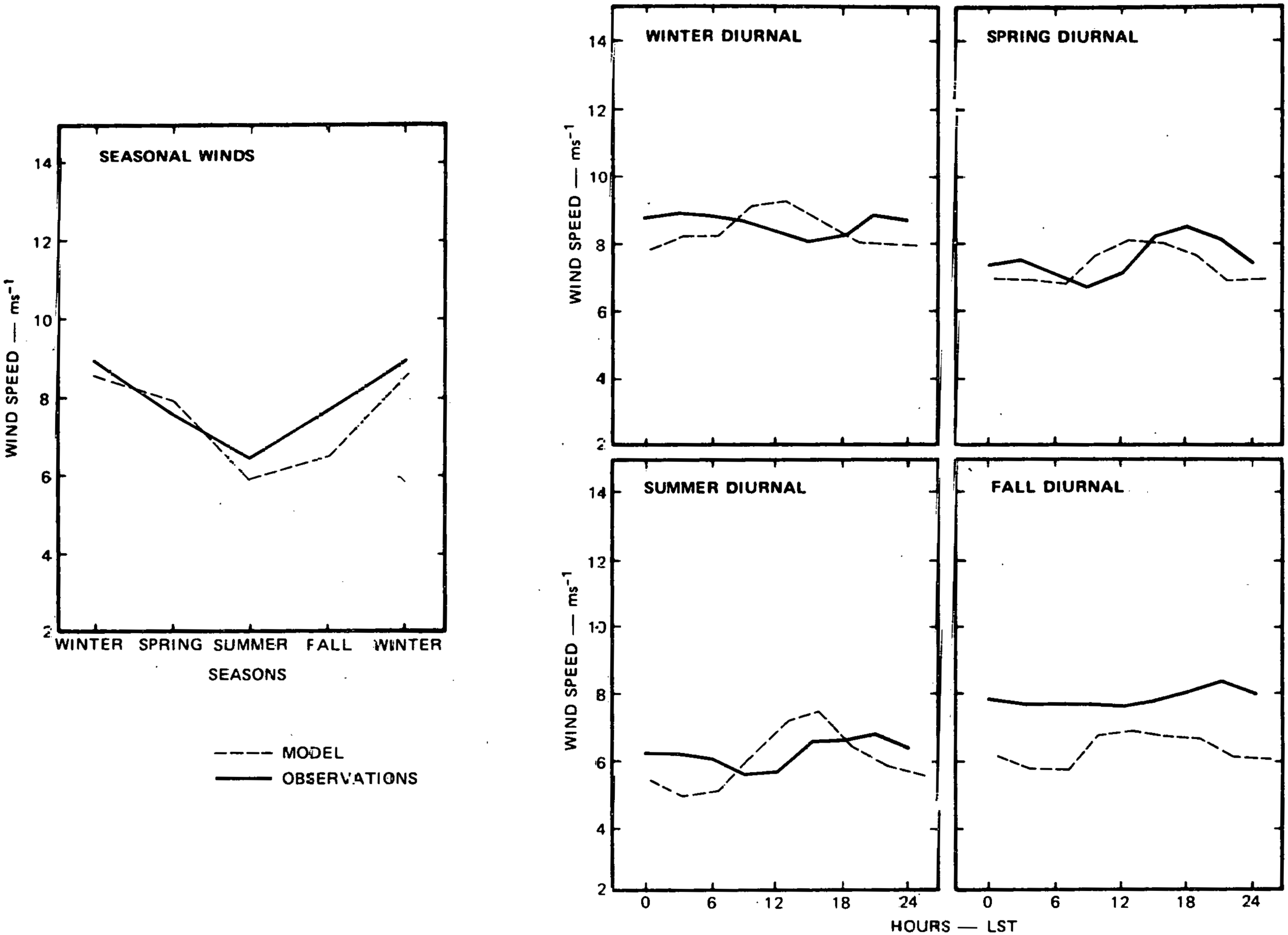


FIGURE 10 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR BLOCK ISLAND, RHODE ISLAND AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

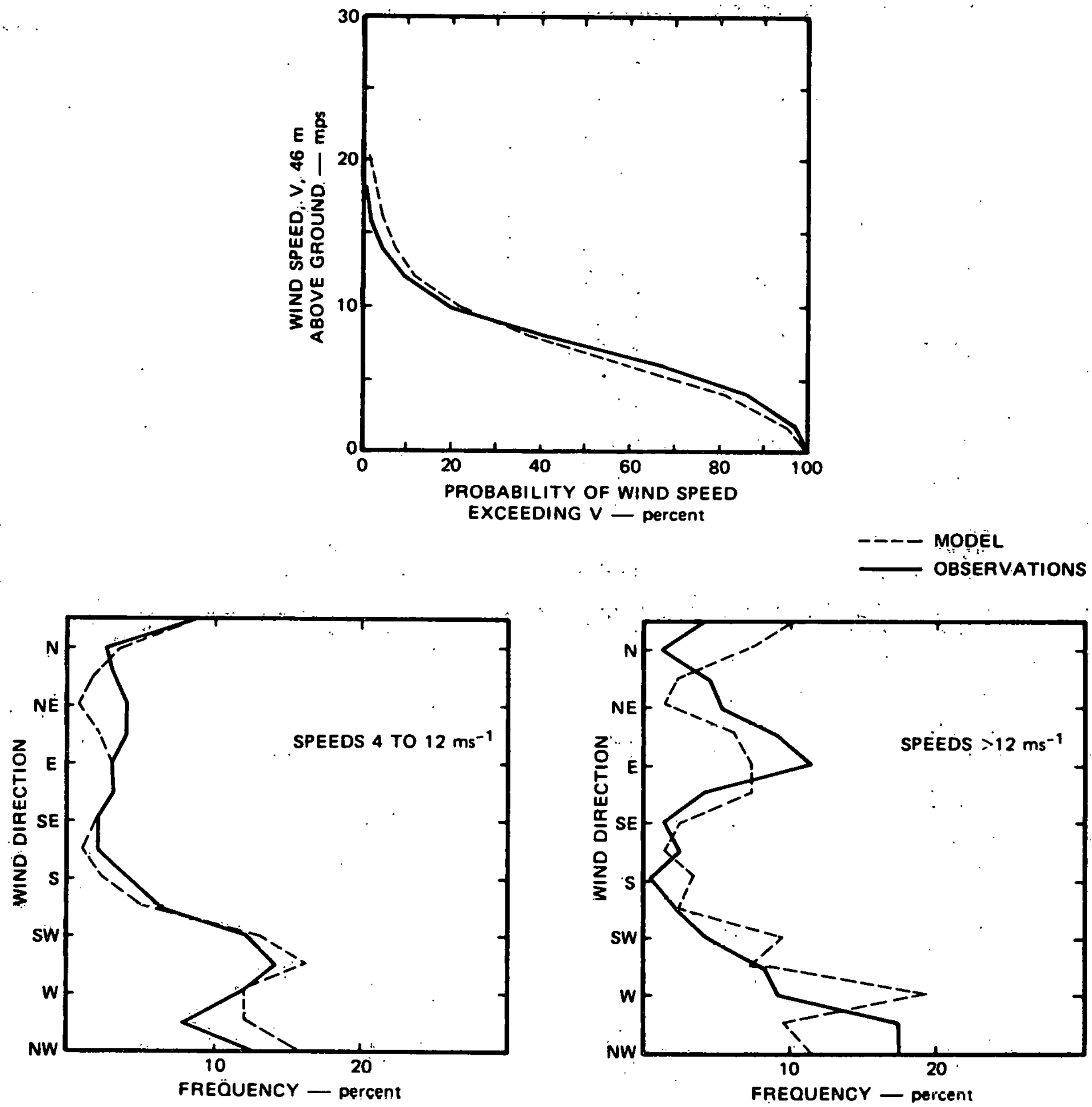


FIGURE 11 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR BLOCK ISLAND, RHODE ISLAND FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 3

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT BLOCK ISLAND, RHODE ISLAND FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		≥ 6 m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	103	97	89	52	93	54
4	41	27	31	29	36	31
7	26	35	32	27	34	29
10	32	18	23	21	26	19
13	20	12	18	15	18	16
16	18	16	14	11	15	15
19	7	9	10	11	10	10
22	7	7	8	10	9	9
25	2	4	2	6	5	7
28	6	3	10	6	8	6
31	3	4	6	3	6	4
34	2	3	2	9	2	9
37	2	2	6	4	6	3
40	2	5	6	5	6	6
43	5	1	5	5	6	6
46	4	1	2	2	1	1
49	1	0	4	2	5	3
52	0	1	2	2	2	2
55	1	1	1	3	2	2
58	1	0	3	2	2	1
61	2	0	2	1	2	2
64	2	0	2	2	1	1
67	0	0	1	5	1	5
70	0	0	1	0	1	0
73	2	0	2	0	0	1

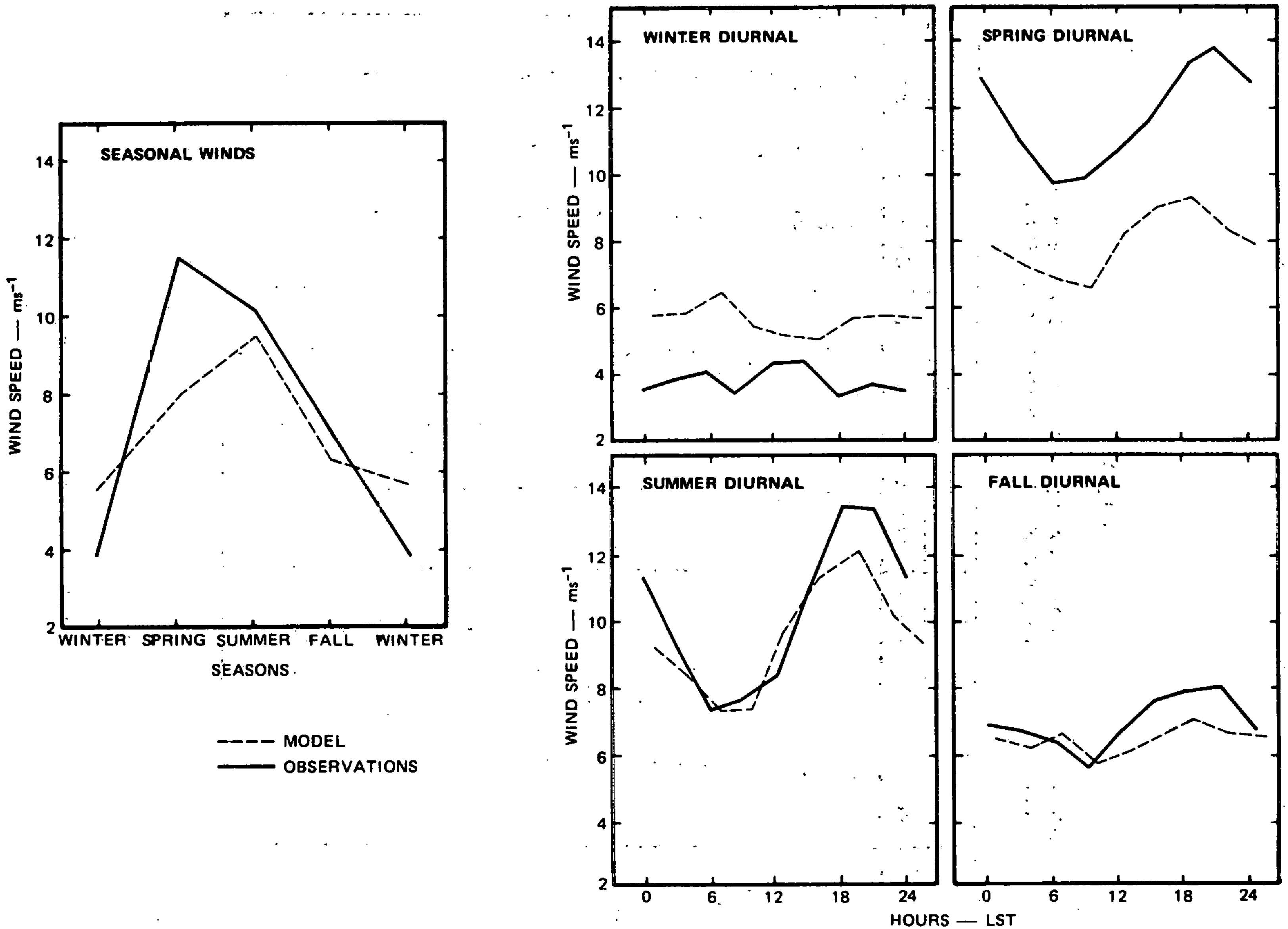


FIGURE 12 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR SAN GORGONIO, CALIFORNIA AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

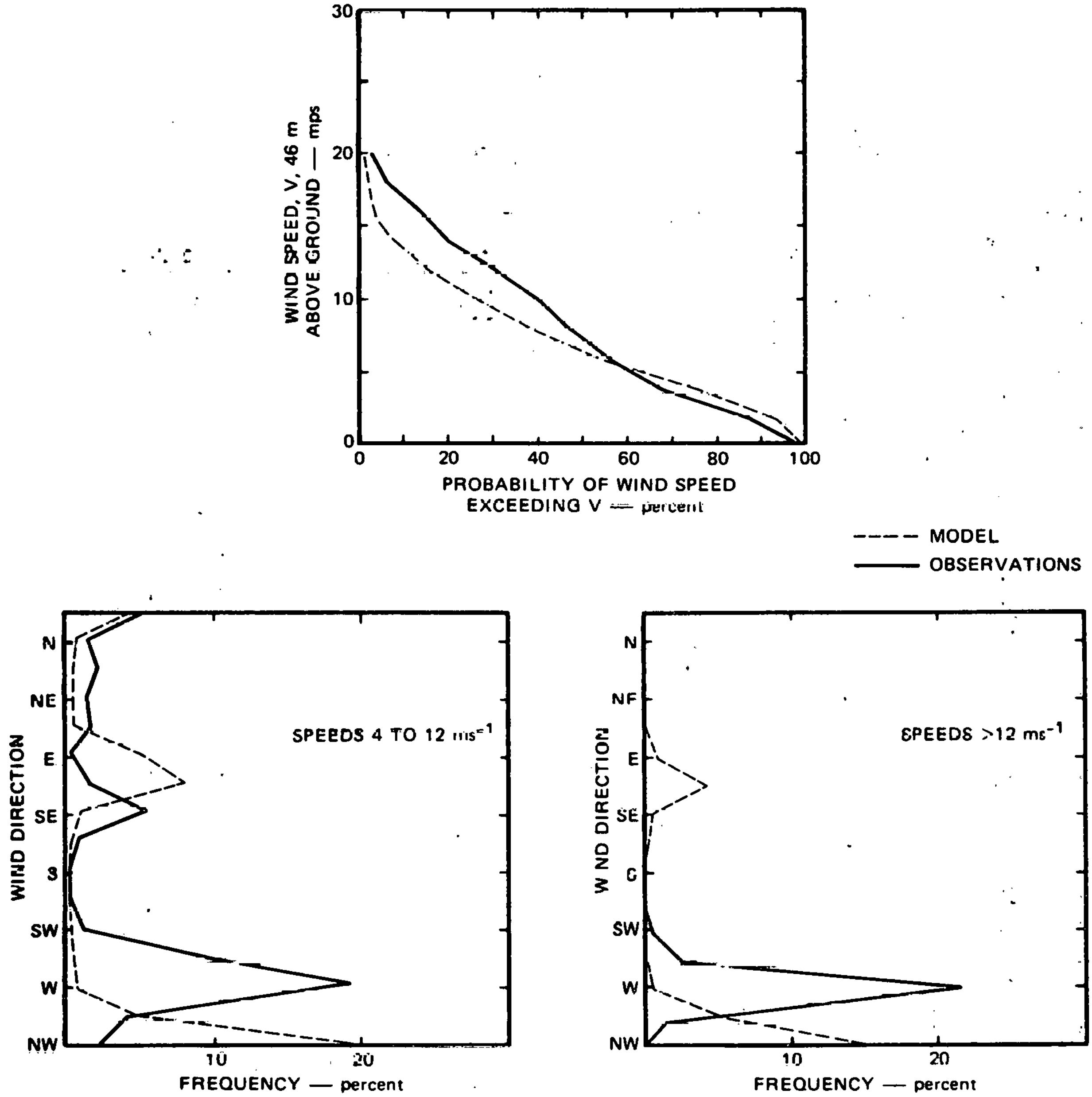


FIGURE 13 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR SAN GORGONIO, CALIFORNIA FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 4

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT SAN GORGONIO, CALIFORNIA FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		≥ 6 m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	44	42	43	61	43	53
4	26	32	34	41	34	43
7	22	31	26	24	26	23
10	18	26	12	17	12	23
13	10	23	13	14	14	16
16	12	9	16	9	16	10
19	8	10	8	7	9	9
22	4	3	2	1	2	5
25	5	7	2	1	2	3
28	8	3	5	0	6	3
31	3	5	5	6	5	2
34	2	0	1	3	1	3
37	2	6	4	2	4	3
40	8	3	5	3	4	5
43	2	3	3	1	3	1
46	1	0	2	0	2	0
49	3	0	1	1	1	2
52	3	2	1	1	1	5
55	0	1	1	1	0	1
58	4	1	1	2	1	3
61	1	1	2	1	2	2
64	0	0	2	1	2	0
67	1	0	1	1	1	3
70	0	1	0	0	0	0
73	1	1	1	0	1	0

The improvements made in our methodology have produced much greater accuracy in the simulations for San Gorgonio than was obtained previously, even though the weather stations used before were nearer to the site.

IV.A.4. Clayton, New Mexico

The terrain in the vicinity of the wind turbine site at Clayton is flat as shown in Figure 14. About 15 km to the northwest there are foothills, and approximately 100 km to the northwest there are peaks above 2400 m. In 1977, the two nearest weather stations were at Amarillo, Texas, and Tucumcari, New Mexico, both approximately 150 km away (to the southeast and south-southwest, respectively). To the north the nearest stations were at Dodge City, Kansas, and Pueblo, Colorado, both far outside the local influences that probably affect Clayton.

The annual-average wind speed given by the model is 5.8 m s^{-1}. Observed data were available only for the period from 1 May through 31 December, with occasional missing reports interspersed within this period; therefore the site values may be unrepresentative during winter and spring. Ignoring this problem, the apparent observed annual average speed is 7.6 m s^{-1}. The simulated winds were too weak in all seasons, as shown in Figure 15. The simulated diurnal curves indicate maximum winds in late afternoon in spring and summer, while the observations show a strong late afternoon maximum at all seasons. We believe that this difference is because of the unrepresentativeness of the input winds, which are far from Clayton.

The wind speed distribution of the model shown in Figure 16 has too few high speeds, as mentioned above. The wind direction frequencies of the simulation (Figure 16) show that the winds were most frequent from the south-southwest, and the observations show a slightly stronger peak for the same direction. The run durations for the simulations and the observed data are given in Table 5. The simulations show more long runs of weak winds than observations do, while for strong winds the reverse is true. This is, of course, in agreement with the frequency distributions of Figure 16.

We believe that our present methodology may be deficient in using the same boundary-layer thickness values at all seasons for Clayton, instead of showing a change in depth from winter to summer. Another deficiency is probably due to using the geostrophic wind to represent the flow at the boundary-layer top even when the mixing depth is very deep, as at Clayton in the daytime. It would probably be more accurate to adjust the winds at the boundary-layer top with the depth of the boundary layer to reflect the usual increase of pressure gradients with height. Further numerical experiments concerning these points would be desirable.

IV.B. Examples of Results Without Tuning

IV.B.1. Ludington, Michigan

The wind turbine site at Ludington is on a 73-m cliff overlooking Lake Michigan to the west; otherwise the general terrain in the area is rather flat. The locations of the site and the weather stations are shown in Figure 3.

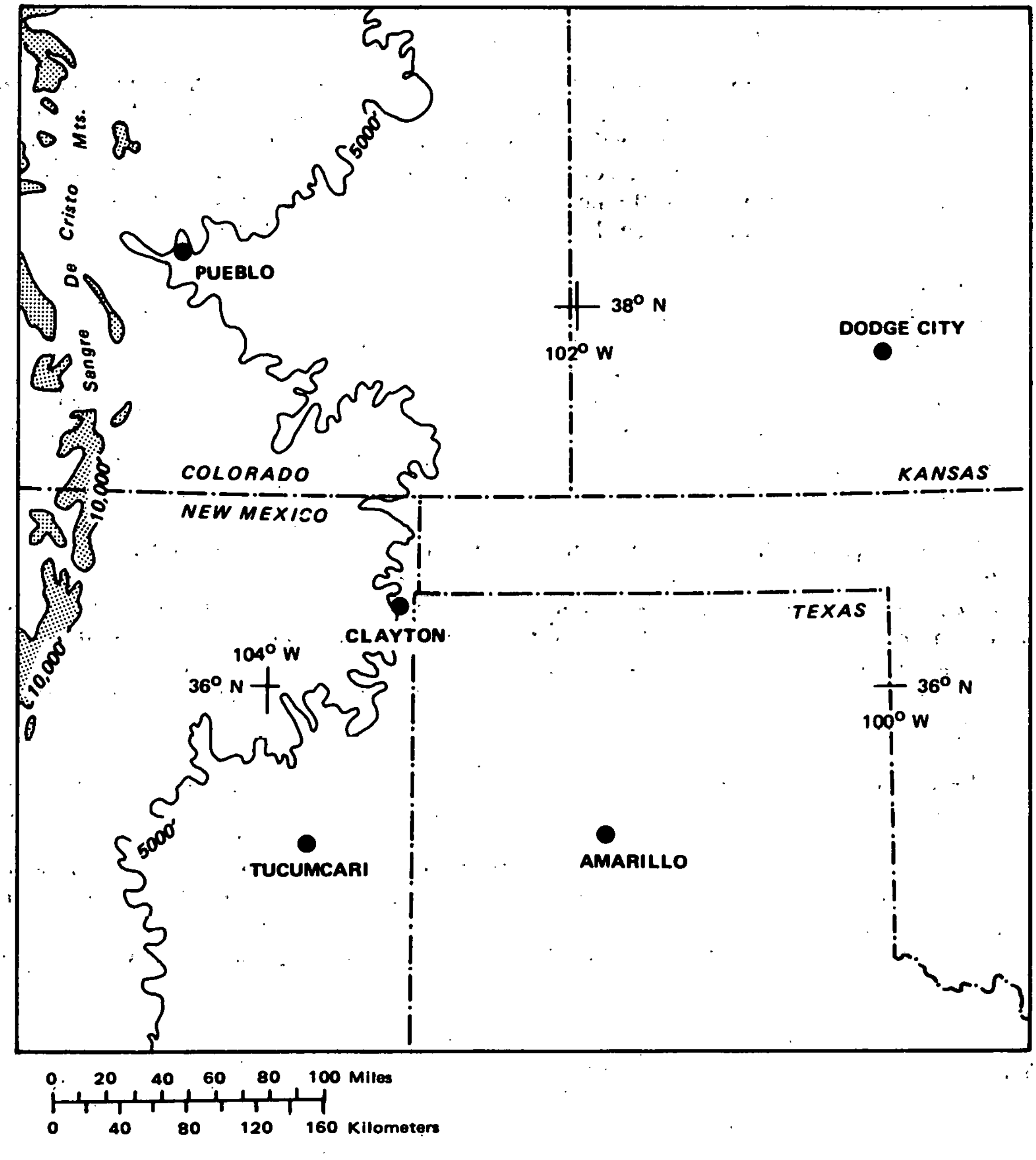


FIGURE 14 MAP SHOWING THE LOCATION OF CLAYTON, NEW MEXICO AND THE NEAREST WEATHER STATIONS

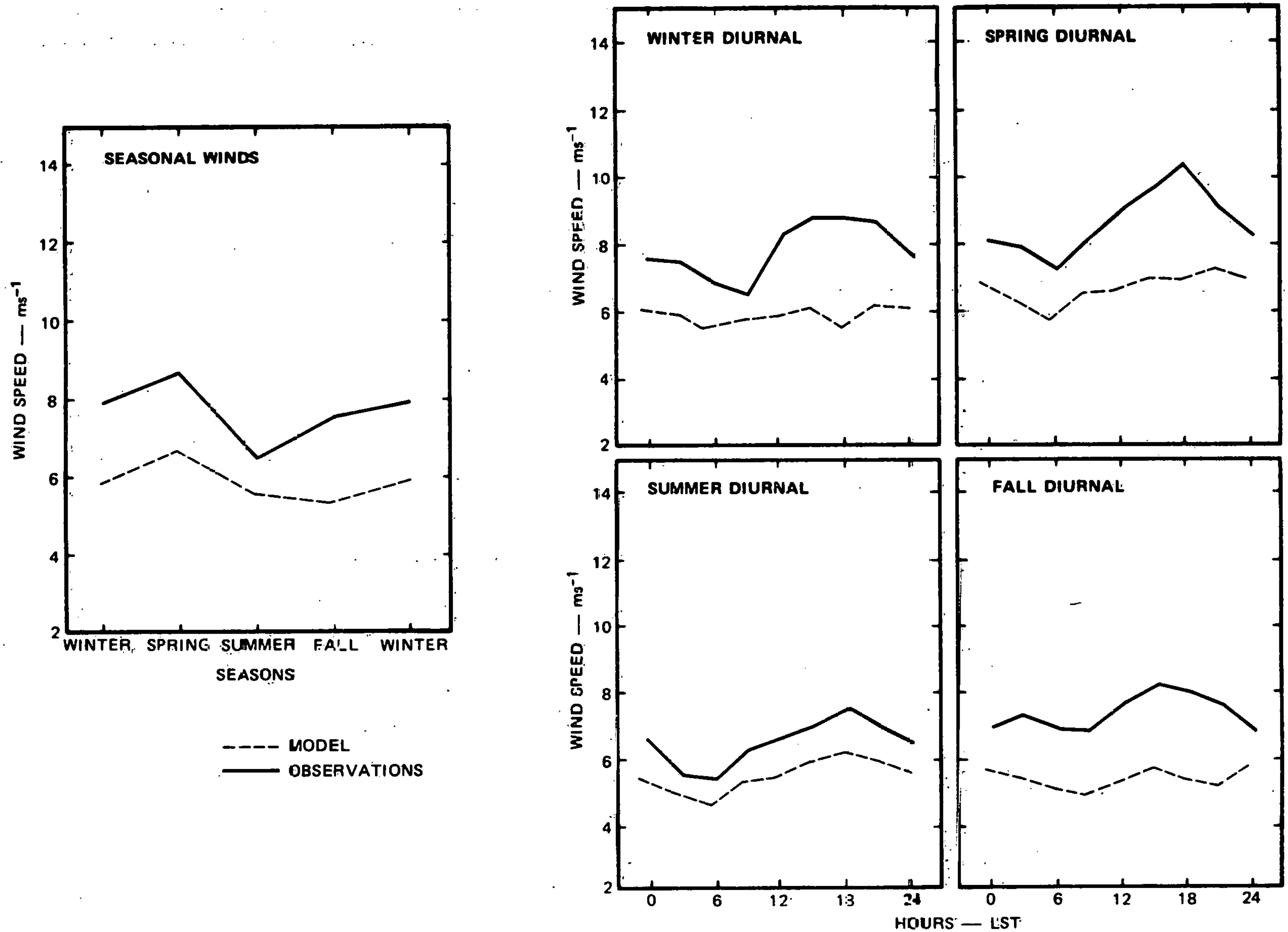


FIGURE 15 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR CLAYTON, NEW MEXICO AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

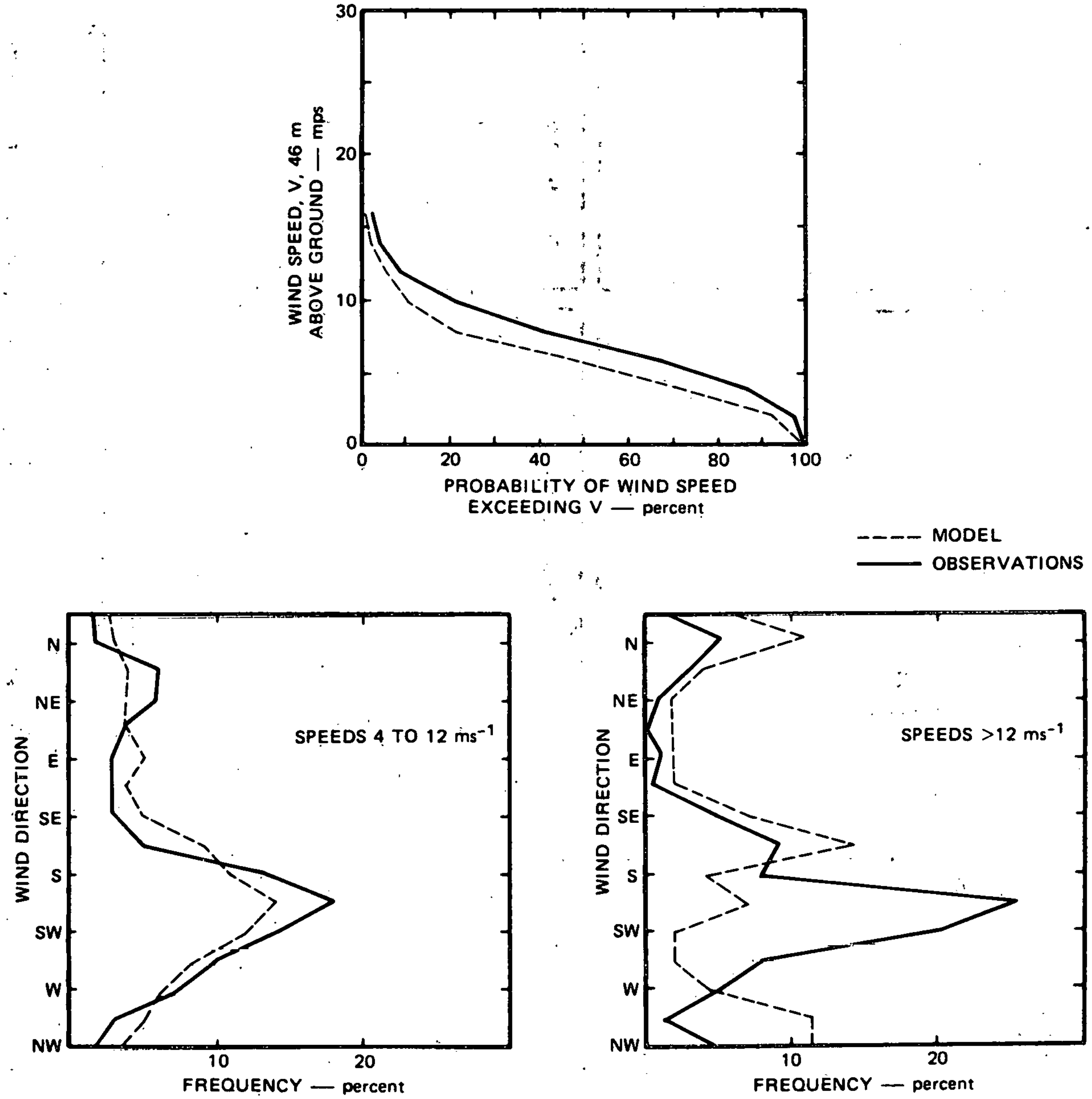


FIGURE 16 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR CLAYTON, NEW MEXICO FOR MODEL SIMULATION AND SITE MEASUREMENTS

Table 5

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT CLAYTON, NEW MEXICO FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		≥ 6 m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	92	153	135	113	135	123
4	66	82	55	62	55	73
7	36	60	50	45	50	45
10	34	32	26	27	27	23
13	21	27	19	28	20	33
16	17	18	14	25	14	25
19	13	5	11	22	11	18
22	7	4	10	3	10	7
25	12	2	4	13	4	12
28	9	2	6	2	6	2
31	6	3	0	8	0	8
34	4	0	2	12	2	12
37	3	0	4	7	3	7
40	5	0	0	8	0	5
43	2	0	1	5	1	3
46	4	0	0	2	0	2
49	2	0	1	3	1	2
52	1	0	1	2	1	2
55	3	0	2	2	2	2
58	2	0	1	2	1	2
61	1	0	0	0	0	0
64	1	2	2	0	2	0
67	0	0	2	0	2	0
70	2	2	0	0	0	0
73	3	0	0	0	0	0

The annual-average wind speed given by the model is too low, 7.2 m s^{-1} compared to the observed values of 7.9 m s^{-1} (for the period April through December). The simulated seasonal progression is quite accurate as shown in Figure 17. The simulated diurnal curves show that variations from night to day are too large, probably because of the assumed sharp transition in boundary-layer depth and slope. Diurnal variations are small in the observations.

Figure 18 shows the distribution of wind speed and direction. The wind speed distributions for the simulations and observations are quite similar. For speeds from 4 to 12 m s^{-1} the direction distributions are similar, but for speeds above 12 m s^{-1} the observations have a peak for west-southwest winds that is not very well simulated.

The run durations are shown in Table 6. Compared to the simulations, the observations show a larger number of runs of speeds greater than 6 m s^{-1} extending to 24 hours. In summary, we believe that these untuned simulations for Ludington are reasonably accurate.

IV.B.2. Holyoke, Massachusetts

The wind turbine site at Holyoke is at the top of Mt. Tom, which lies on a north-south ridge line. There is a steep slope (250 m within 0.5 km) to the west and a more gradual slope to the east. The site and the nearest weather stations are shown in Figure 19.

Because this site is at the top of a mountain, the simulated winds are quite sensitive to the values chosen for the average thickness of the boundary layer and the slope of the boundary-layer top. We used the values shown in Table 1. The annual average of the simulated wind speeds is 7.4 m s^{-1} and agrees well with the observed value (7.3 m s^{-1}). The simulated and observed seasonal speeds agree well as shown in Figure 20. The simulated diurnal patterns in winter and spring show larger variations than the observations, while in summer and fall the agreement is good.

Figure 21 shows the speed and direction distributions. The simulated speeds have somewhat more values above 10 m s^{-1} than the observations, otherwise the curves are similar. For speeds in the range from 4 to 12 m s^{-1}, the observed winds have higher frequencies from the northwest. Table 7 shows the run durations. The observations show more short runs of speeds equal to or greater than 6 m s^{-1} than the simulations and the reverse for longer runs. We consider that the untuned simulations for Holyoke are in good agreement with the observations.

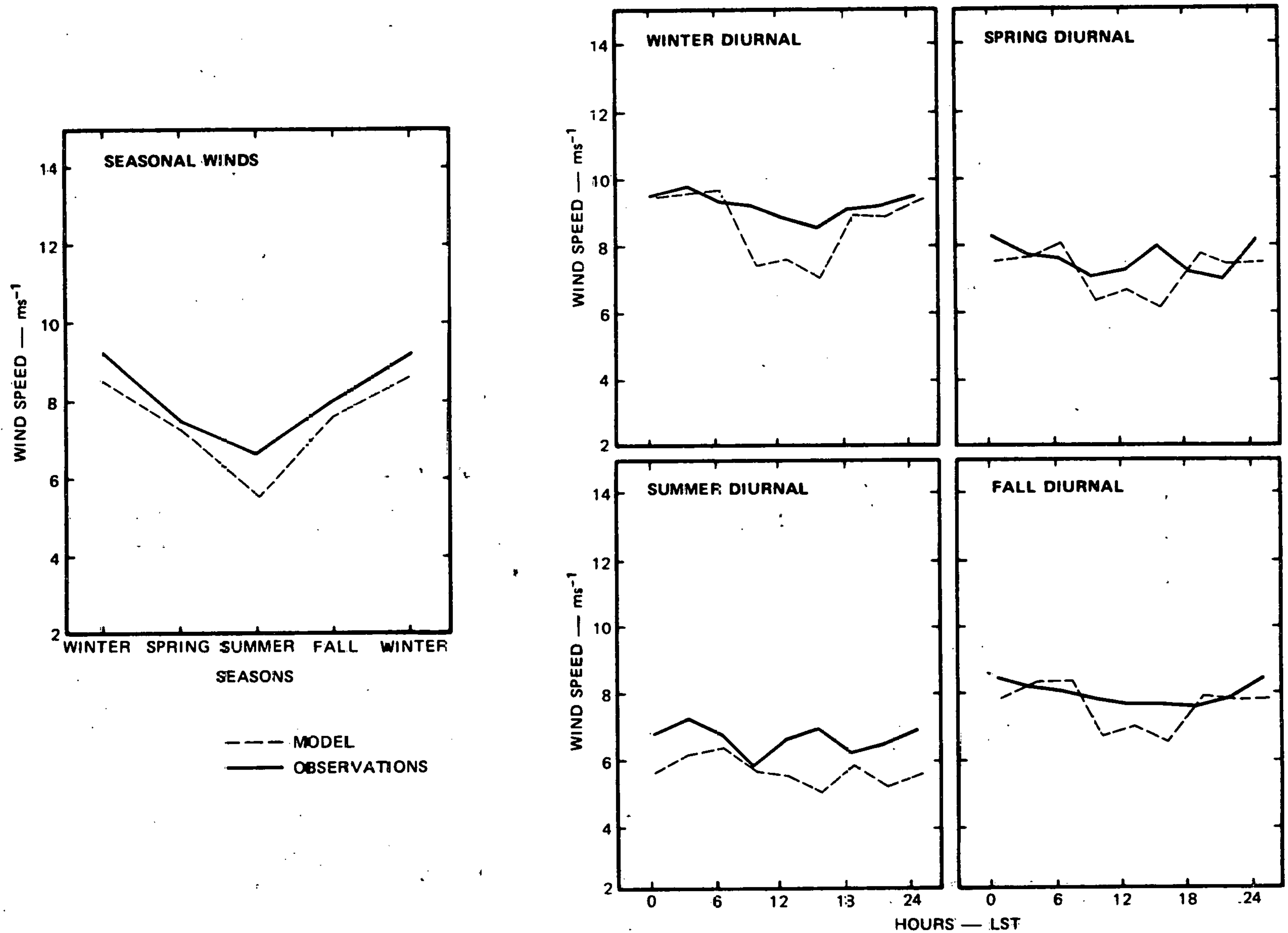


FIGURE 17 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR LUDINGTON, MICHIGAN AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

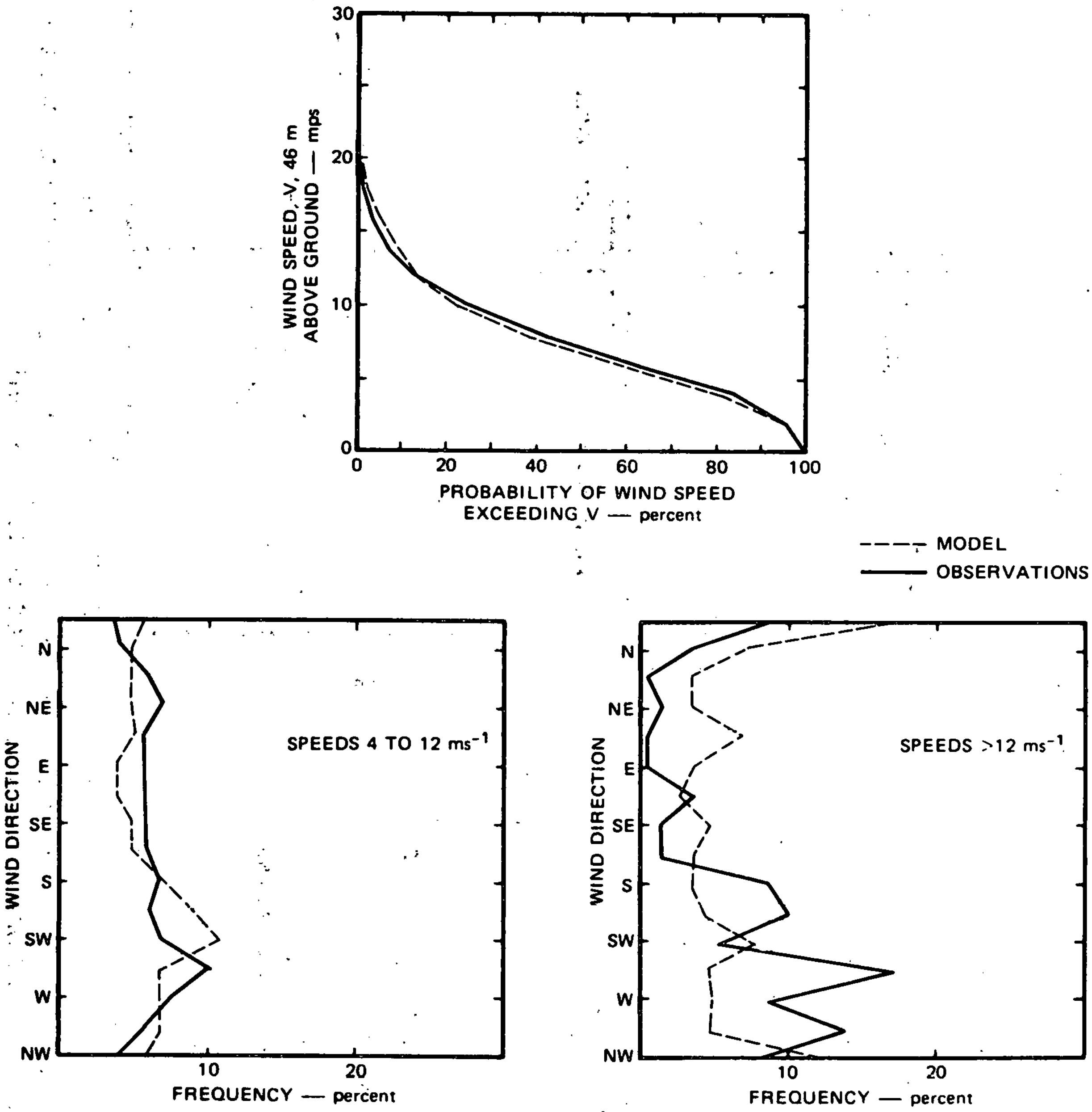


FIGURE 18 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR LUDINGTON, MICHIGAN FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 6

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT LUDINGTON, MICHIGAN FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		$\geqslant 6$ m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	56	104	71	85	71	85
4	35	78	29	34	30	35
7	28	26	25	22	27	22
10	27	17	11	31	14	33
13	19	25	11	13	17	13
16	14	16	8	29	10	30
19	14	14	14	20	15	22
22	7	8	10	12	12	13
25	10	10	8	8	10	8
28	5	9	5	8	5	10
31	7	1	6	13	7	12
34	6	1	8	5	10	5
37	2	3	7	5	9	5
40	2	0	6	0	6	0
43	0	0	3	1	3	1
46	4	0	2	7	0	7
49	2	0	4	4	4	4
52	2	0	1	1	2	3
55	0	0	2	3	1	3
58	1	0	1	0	1	0
61	0	0	4	0	2	0
64	2	0	3	3	2	3
67	2	0	2	1	2	3
70	1	0	0	0	1	0
73	0	0	1	1	1	1

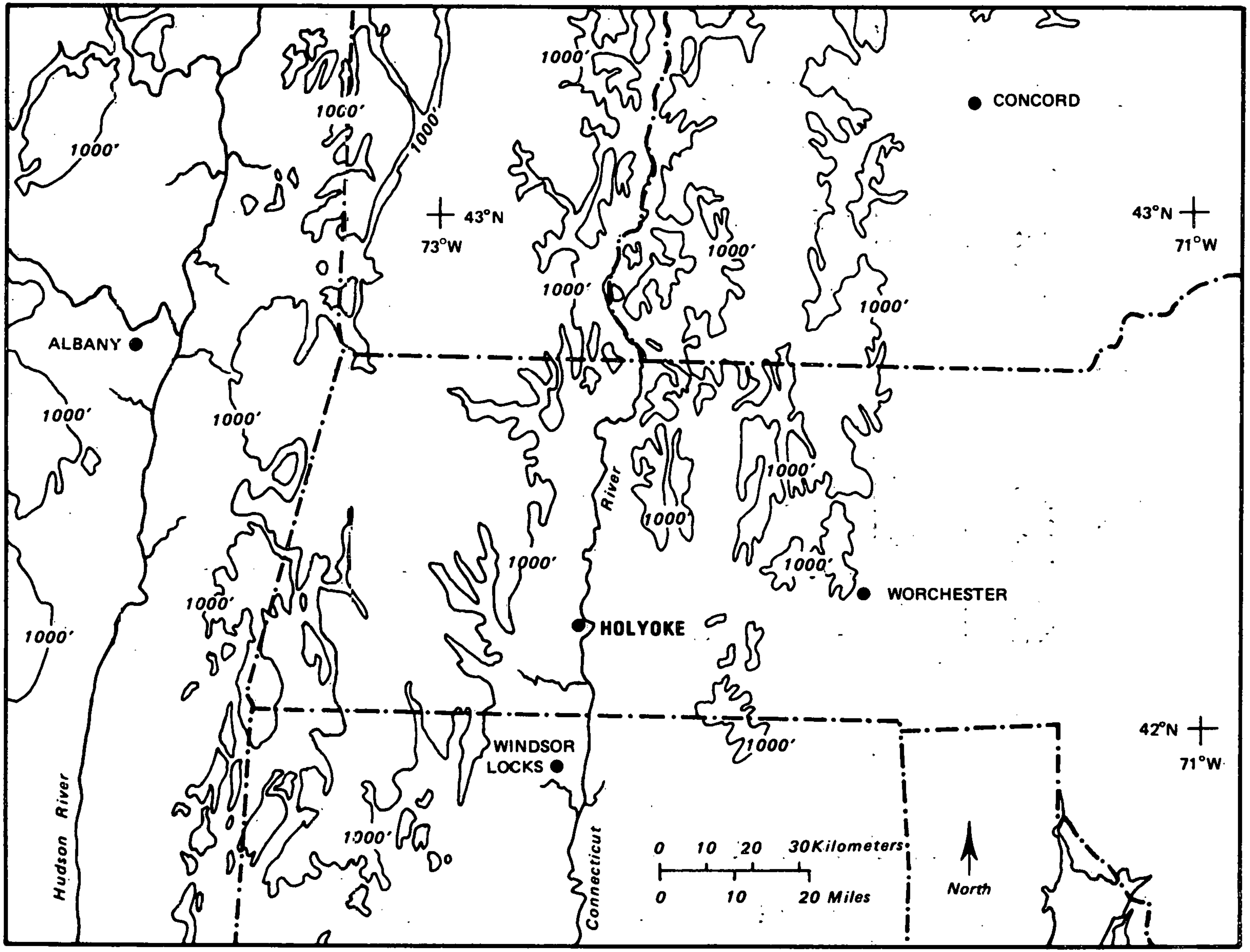


FIGURE 19 MAP SHOWING THE LOCATION OF HOLYOKE, MASSACHUSETTS AND THE NEAREST WEATHER STATIONS

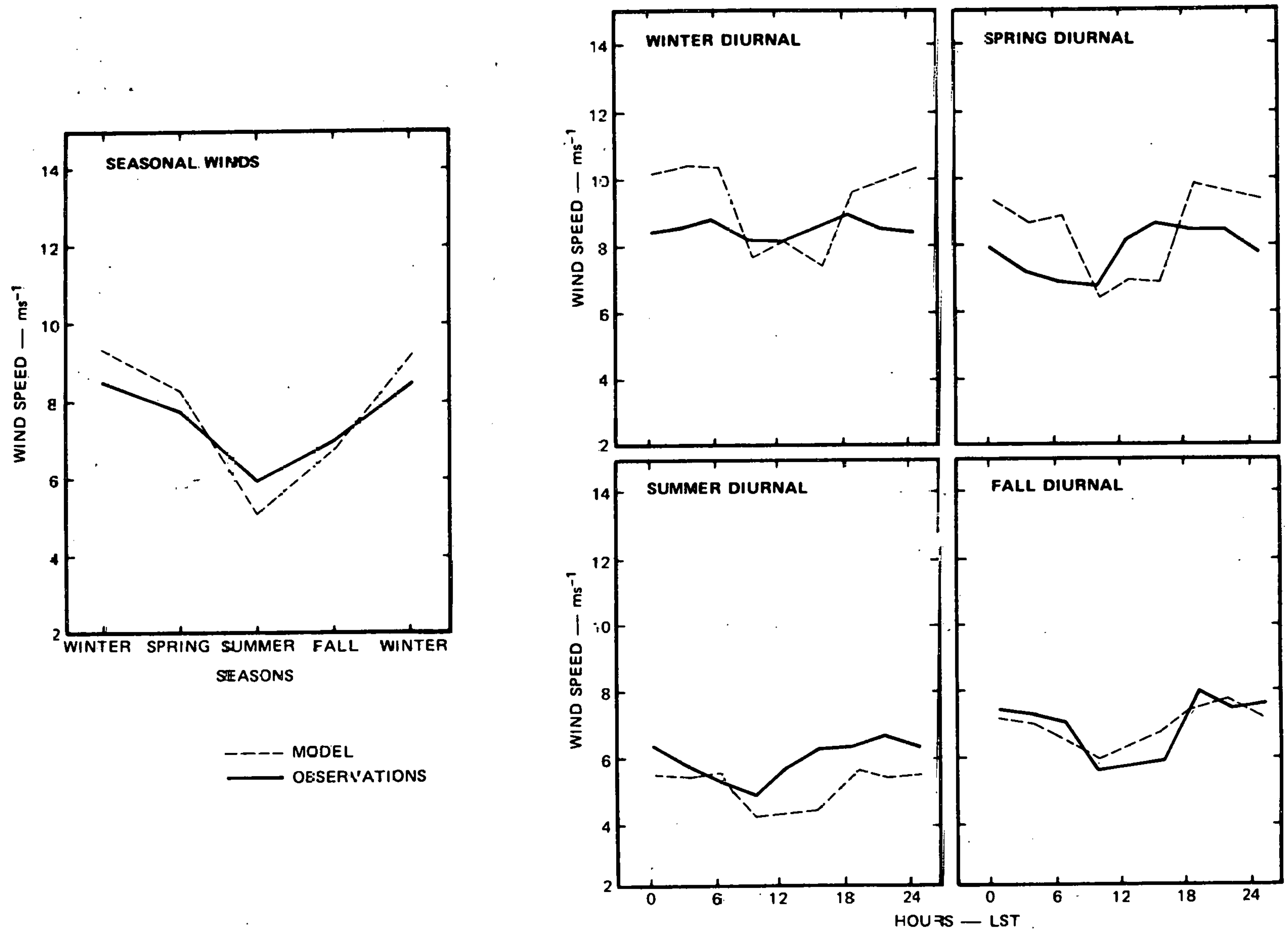


FIGURE 20 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR HOLYOKE, MASSACHUSETTS AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

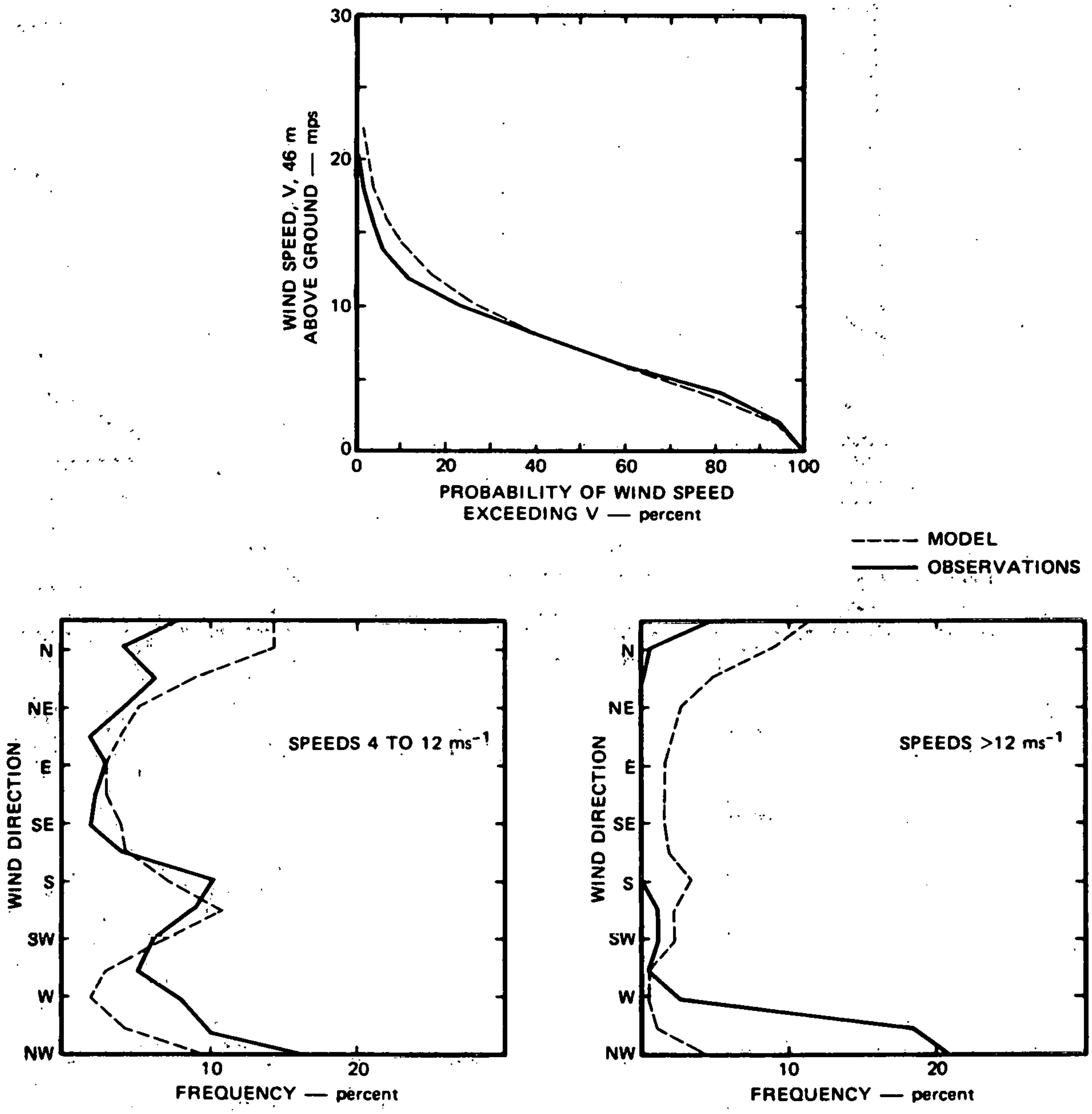


FIGURE 21 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR HOLYOKE, MASSACHUSETTS FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 7

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT HOLYOKE, MASSACHUSETTS FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		≥ 6 m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	74	92	63	86	66	89
4	31	49	26	42	34	43
7	29	30	29	29	39	30
10	20	30	21	22	27	25
13	17	28	19	22	21	25
16	16	16	14	9	19	12
19	11	12	16	8	17	12
22	6	9	10	5	15	6
25	11	5	12	6	13	7
28	9	5	2	7	4	5
31	3	2	7	11	8	11
34	1	4	4	7	5	8
37	8	6	4	9	4	9
40	3	2	2	4	2	1
43	0	1	2	6	2	6
46	1	1	1	2	1	2
49	2	0	3	0	3	0
52	2	0	4	2	4	5
55	0	0	2	5	0	5
58	1	0	2	2	0	2
61	1	1	2	1	0	1
64	4	1	0	1	0	1
67	1	1	2	2	0	1
70	1	0	2	2	1	2
73	0	0	0	1	0	0

IV.C.3. Huron, South Dakota

The terrain around the wind turbine site at Huron is generally flat. As shown in Figure 22, the site is located on the eastern side of the James River. In 1977 there was a weather station at Huron, approximately 8 km to the southwest. Simulations were made with and without this station and the results differed by only insignificant amounts. The remaining stations are quite far from the site—Sioux Falls is approximately 130 km to the southeast, Pierre is approximately the same distance to the west, and both Bismarck and Fargo are more than 225 km away.

The annual-average wind speed of the simulated winds is 6.7 m s^{-1}. Without using the Huron NWS wind data, the comparable value is 6.6 m s^{-1}. Because of this small difference, all remaining statistics are given for the simulations that included Huron.

The annual-average observed speed is slightly stronger than the simulated value (6.9 m s^{-1}). The simulated and observed seasonal curves are very similar as shown in Figure 23. The diurnal variations are very small in both the simulations and observations. Figure 24 shows the speed and direction distributions. The simulated and observed frequencies are in good agreement.

Table 8 shows the run durations. For speeds equal to or greater than 6 m s^{-1}, the observations show more runs extending to 13 hours than the simulations show. We believe that the simulations for Huron are accurate because of the uniformity of the terrain and the absence of terrain-induced mesoscale wind patterns in this region.

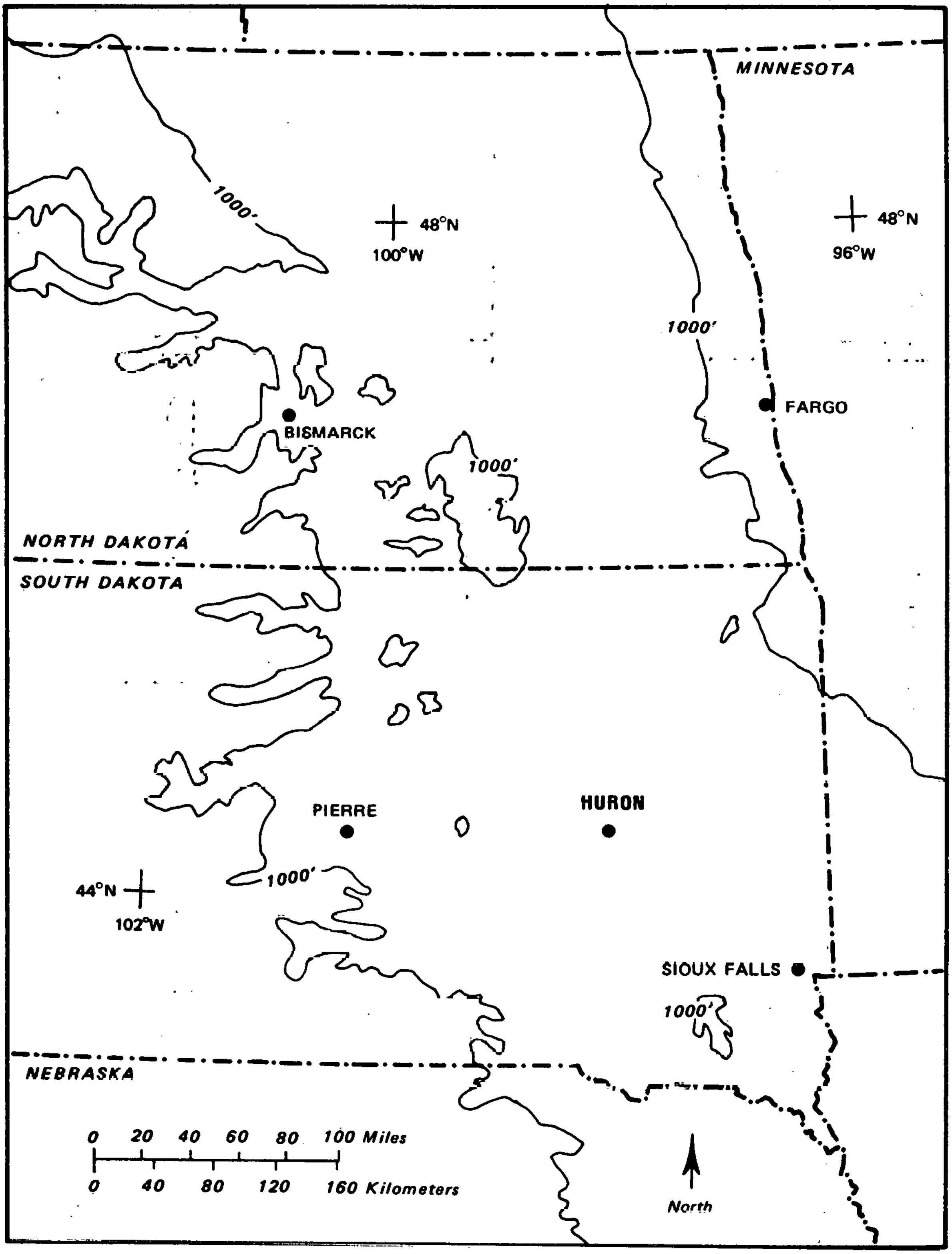


FIGURE 22 MAP SHOWING THE LOCATION OF HURON, SOUTH DAKOTA AND THE NEAREST WEATHER STATIONS

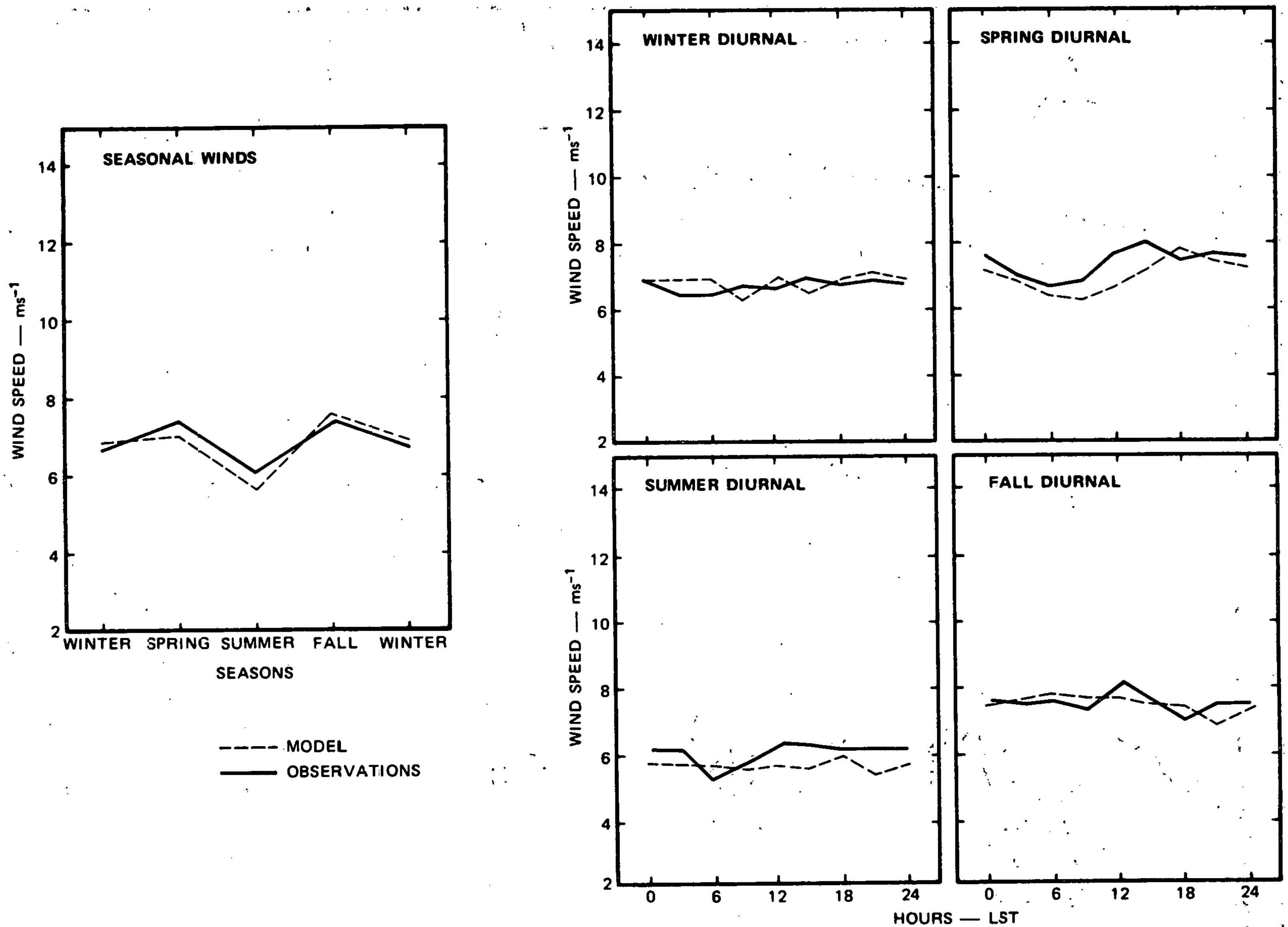


FIGURE 23 SEASONAL AND DIURNAL WIND-SPEED CURVES FOR HURON, SOUTH DAKOTA AS SIMULATED BY THE WINDFLOW MODEL AND AS MEASURED AT THE SITE

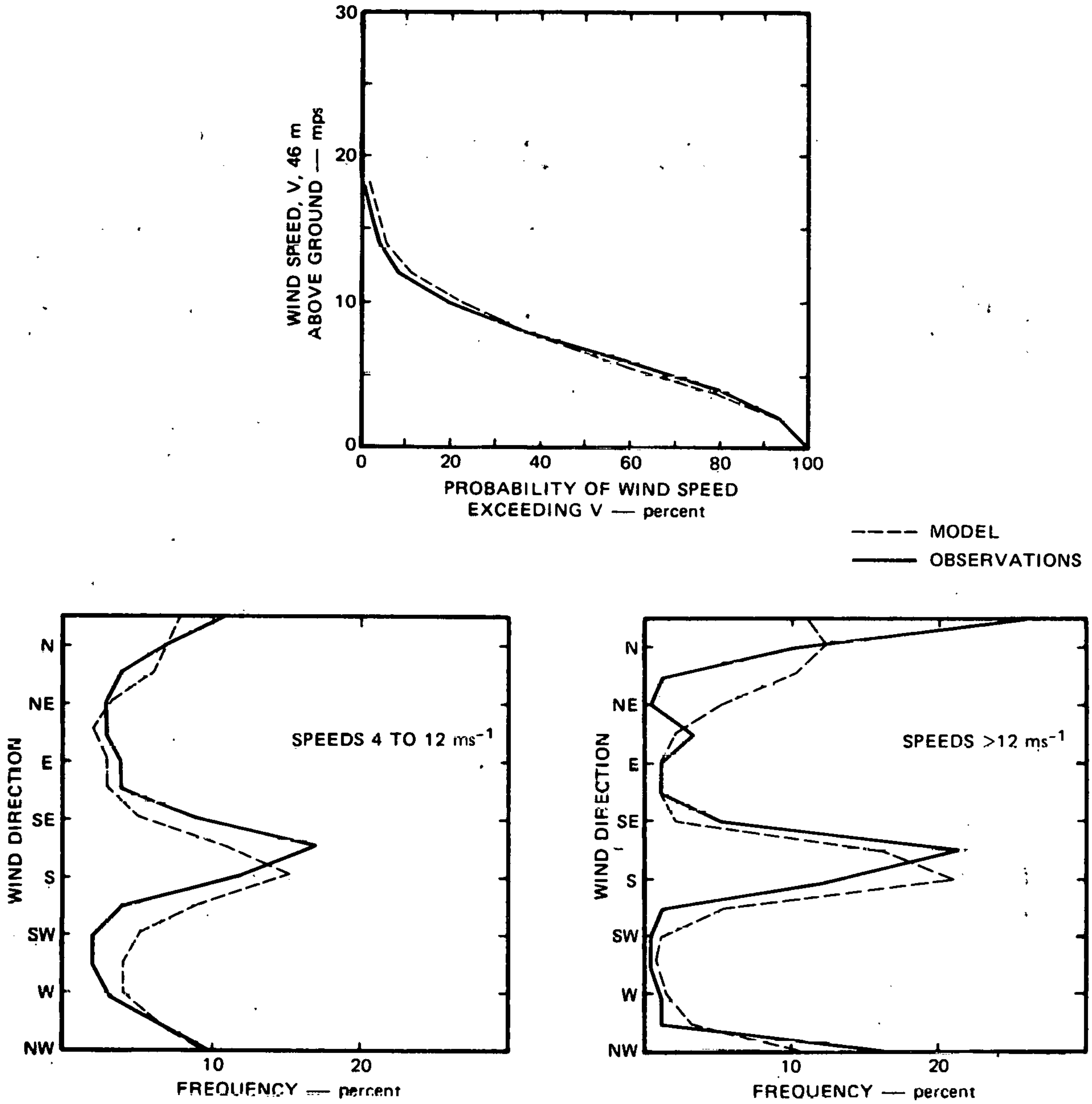


FIGURE 24 FREQUENCY DISTRIBUTIONS OF WIND SPEED AND DIRECTION FOR HURON, SOUTH DAKOTA FOR MODEL SIMULATIONS AND SITE MEASUREMENTS

Table 8

RUN DURATIONS OF SIMULATED AND OBSERVED HUB-HEIGHT WIND SPEEDS AT HURON, SOUTH DAKOTA FOR 1977

Run Duration (Hours)	< 6 m s^{-1}		$\geqslant 6$ m s^{-1}		6 to 20 m s^{-1}	
	Simulated	Observed	Simulated	Observed	Simulated	Observed
1	30	99	51	89	51	91
4	22	46	19	40	20	40
7	22	44	10	32	11	32
10	19	32	14	30	14	30
13	17	25	13	24	14	24
16	14	19	15	13	16	13
19	12	11	14	16	14	17
22	14	10	12	14	13	14
25	10	5	9	11	8	11
28	6	6	4	5	5	5
31	7	2	6	5	6	5
34	7	3	5	1	5	1
37	3	1	5	10	6	10
40	5	3	4	2	4	2
43	2	1	3	4	3	4
46	2	2	2	3	2	2
49	2	1	6	1	5	1
52	2	0	2	1	2	1
55	4	0	1	2	1	2
58	1	2	2	2	2	2
61	2	0	2	0	2	0
64	0	0	2	2	2	2
67	0	0	0	1	0	1
70	1	1	0	1	0	1
73	2	0	2	0	2	0

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V CONCLUSIONS AND RECOMMENDATIONS

Bhumralkar et al. (1978) used wind data for the 1950s to estimate annual-average wind speeds (and other statistics) for eight sites. These simulated average values differed from site measurements for 1977 by amounts ranging from 0.1 to 4.3 m s^{-1}, with an average difference of 1.7 m s^{-1}. In the present study the difference between the simulations and measurements range from 0.1 to 1.8 m s^{-1}, with an average value of 0.6 m s^{-1}. We consider this to be a major improvement in the results, especially because in 1977 the weather stations were generally far from the sites.

The present results indicate the importance of making an accurate initial estimate of the winds in the boundary layer. To achieve this accuracy the National Weather Service wind reports must be generally representative of the flow in the vicinity of the site. In mountainous terrain, at coastlines, or other locales of pronounced mesoscale wind variations, data as close to the site as possible should be available. We believe that the lack of nearby stations in the 1977 NWS data has been the major limitation on the accuracy of the present results. In future simulations, it may be desirable to use the more dense network of NWS stations that was available prior to 1964. Another factor of importance in estimating initial winds is the technique for assigning winds at the top of the boundary layer. We believe that the use of the geostrophic wind to represent the actual wind at the upper boundary and logarithmic interpolation between the anemometer level and the upper boundary have given satisfactory results.

The finding that the methodology does not require the use of the minor eigenvectors (those that individually account for less than 2 percent of the variance) means that only 4 to 6 eigenvectors (instead of 10 to 12) must be treated by the windflow model. This results in a substantial saving in computer costs.

The windflow model is quite sensitive to the parameters related to the boundary-layer top, i.e., the average thickness of the boundary layer, the slope of the top, and in mountainous terrain the minimum thickness of the boundary layer. As mentioned earlier, the average thickness can be determined with acceptable accuracy from climatological data. On the other hand, climatological data are not available for the other parameters, and the general principles for selection of the slope factor and minimum thickness given in Section III.E should be followed. If the results obtained do not appear to agree with expected meteorological conditions in the boundary layer, numerical experimentation may be required to improve them.

The costs for applying the methodology to any potential wind turbine site in the United States using the SRI CDC-6400 computer are listed in Table 9 for each of the component computer programs. These costs apply to the use of three-hourly National Weather Service weather reports for a one-year period, which is the minimum period needed to obtain reliable results. In addition to these direct costs, approximately 40 man hours of professional effort are required to obtain data, set up grids, run the program, monitor the results, etc. The total costs are approximately $3500 per site.

Table 9

COSTS FOR APPLYING THE METHODOLOGY TO ESTIMATE WINDS
AT A POTENTIAL WIND TURBINE SITE
USING THREE-HOURLY WIND DATA FOR A PERIOD OF ONE YEAR

Computer Programs	Data Cost	Computer Cost	Remarks
TERRAIN	$ 90	$ 195	Magnetic tapes of terrain heights are obtained from the NCIC
GRIDHT		16	For two grids
GEOCAL	270	54	Magnetic tapes of weather data are obtained from the NCC
XFORM		48	
COMPLEX		190	
REWND		22	
WINDY		9	
SPSS		18	
Total	$360	$502	

It is probable that further improvements can be made to the windflow model, and we recommend that the following experiments be tried:

- Adjust the wind at the top of the boundary layer as a function of the boundary layer depth to incorporate the usual increase of pressure gradients with height.
- Include thermal influences on the flow produced by strong summertime heating of certain terrain features, such as mountains and deserts.
- Add a finer grid mesh for a third set of windflow computations at sites in complex terrain to attempt to account for influences produced by smaller terrain features than those previously included.

In summary, we believe that the accuracy achieved by the present methods, which use terrain heights, a boundary-layer model based on standard weather data, and a wind flow controlled by the continuity equation, represents a significant improvement over the results obtained previously. Although the methodology is intricate and computer programs are lengthy, the method as it now exists can be applied rather quickly and directly to standard data to obtain simulated winds at a potential site for a wind turbine.

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Appendix A

USER'S GUIDE AND PROGRAM DESCRIPTIONS

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Appendix A

USER'S GUIDE AND PROGRAM DESCRIPTIONS

A block diagram showing the steps required to derive wind statistics and the computer programs used is given in Figure A-1.

1. Program TERRAIN

This program reads digital terrain data obtained on magnetic tape (nine track, 1600 bpi) from the National Cartographic Information Center, Reston, Virginia 22092 (telephone 703-860-6045). Each tape contains data for up to seven 1° lat.-long. regions These data are read from logical unit 1. The program selects part of the original dense data and averages it to produce smoothed height values for small areas having sides of 0.01° in lat. and long.

The output is an array HT(101,101) of smoothed height values with point (1,1) at the southwest corner. The array is written in a file on logical unit 2. We will refer to this information as output AO.

The program also gives a printout of the smoothed height data in a form similar to Figure 5. The height interval of the symbols is controlled by the parameter HTINT, which is read from logical unit 5 in the format F6.1. To obtain prints like Figure 5 use HTINT = 1000 ft.

The listing of this program is given in Appendix B.

2. Program GRIDAT

This program selects grid point values of terrain height from tapes of type AO (see Program TERRAIN). The grid point values of terrain height are assembled in the array GHT(22,22). GHT(1,1) is at the southwest corner of the array. The input parameters are:

MX—Number of columns in the terrain height array.

NY—Number of rows in the terrain height array.

NGCX, NGCY—Column on row of the site.

GINCX, GINCY—Grid increments (km) in the x and y directions.

NFILES—Number of files of data on the input tape.

SLAT, SLNG—Latitude and longitude of the site in degrees and hundredths.

SHGT—Actual height of the site.

NFILES—Number of files of data on the input tape.

Table A-1 gives the formats of the input parameters.

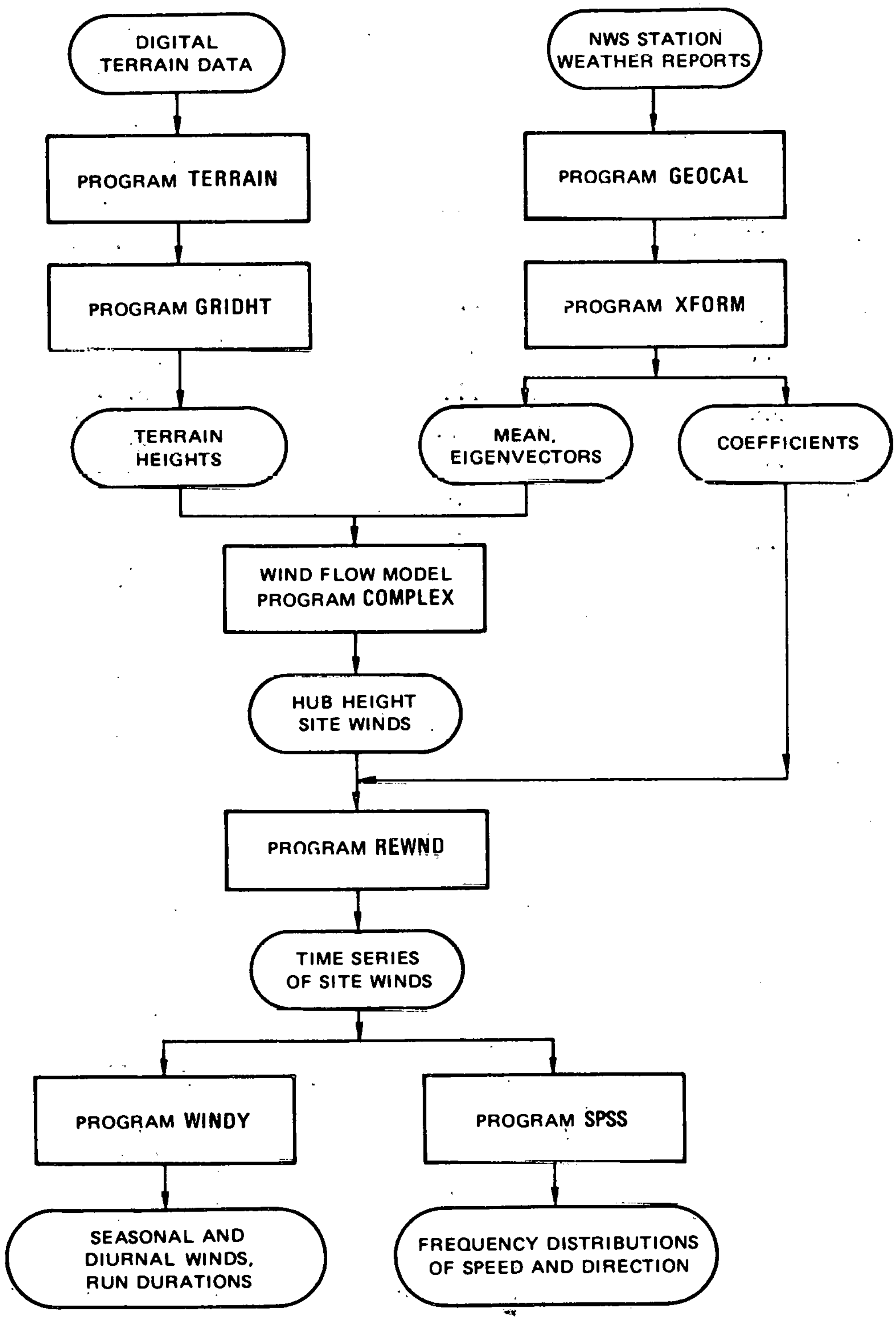

FIGURE A-1 BLOCK DIAGRAM OF THE WIND ENERGY COMPUTER PROGRAMS

Table A-1

INPUT CARDS FOR PROGRAM GRIDHT

Card No.	Variables	Format
1	MX, NY, NGCX, NGCY, GINCX, GINCY	4I5, 2F6.1
2	SLAT, SLONG, SHOT	3F10.3
3	NFILS	I5

The array GHT is punched on cards in the format 11F6.0 for use by the windflow model (COMPLEX). The listing of this program is given in Appendix B.

3. Program GEOCAL

This program creates a file of weather data for groups of weather stations. The file includes u and v components (m s^{-1}) and a geostrophic wind computed from sea-level pressure data. A stability index is also computed from cloud and temperature data. The file is written on logical unit 2.

The input data are National Weather Service TD-1440 Airways Surface Observations, Card Deck 144, on nine-track, 1600 bpi, EBCDFC magnetic tapes. They are read on logical unit 2. Each tape contains a year of data for 4 to 6 stations (see Table 1). The weather data may be obtained from the National Climatic Center, Federal Building, Asheville, North Carolina 28801 (telephone 704-258-2850). The program fills in missing or garbled data with the last available reliable observation.

The input parameters are:

NSTA—Number of weather stations used.

IU1, IU2, IU3—Indices of stations used in geostrophic wind computation.

IDATES—Starting date in terms of year, month, day (example 770101).

IGHS—Starting hour (GMT).

ISTA—Weather station identification numbers used NCFC.

IGMT—Time corrections to convert local time to GMT for weather stations.

ALAT—Latitude of weather stations.

ALONG—Longitude of weather stations.

IFMT2—Header format for data printout.

IFMT5—Data format for printout.

Table A-2 gives the formats for the input cards.

Table A-2

INPUT CARDS FOR PROGRAM GEOCAL

Card No.	Variables	Format
1	NSTA, IU1, IU2, IU3, IDATES, IGHS	10I8
2	ISTA(L)	10I8
3	IGMT(L)	10I8
4	ALAT(L)	10F8.2
5	ALON(L)	10F8.2
6	IFMT2	8A10
7	IFMT5	8A10

The output is a file on logical unit 2 of wind components and stability at each station, and a geostrophic wind for the area. The data are in synoptic order. For 1977, the data are at three-hourly intervals. This output is referred to as CO.

The listing of this program is given in Appendix B.

4. *Program XFORM*

This program makes use of subroutines from the International Mathematical and Statistical Library (IMSL). A detailed description of its use in wind energy evaluation was given by Bhumralkar et al. (1978). The program calls IMSL subroutines to compute a covariance matrix of the input data, the eigenvectors of the covariance matrix, and the coefficients of the eigenvectors. Other subroutines could be substituted to perform these functions. The calling parameters are described in detail in the listing of this program given in Appendix B.

The input data are station wind data in terms of u and v components and geostrophic wind components at three-hourly intervals from tapes of type CO (see program GEOCAL).

The output includes a listing of the mean winds, the eigenvectors, and the percentage of variance explained by each eigenvector. The means and eigenvectors are punched on cards for use by the windflow model. Also, the coefficients of each eigenvector at each time are written in a file on tapes designated DO.

5. *Program COMPLEX*

This program comprises the windflow model, which is a modified version of the COMPLEX model described by Bhumralkar et al. (1978). The model computes nondivergent winds that conform to the terrain and to the shape of the boundary-layer top. The program requires terrain heights for a coarse grid and a fine grid as given by Program GRIDHT. It also requires the mean winds and the significant eigenvectors from Program XFORM. The input parameters are:

JSITE—Site identification number.

NWIND—Number of wind patterns (data sets) to be treated.

NGRID—Number of grids to be used.

IXZ, JYZ—Column, row of the site in the coarse grid.

IXSS, JYSS—Column, row of the site in the fine grid.

HSITE—Elevation of the site in feet.

MI, NI—Number of columns, rows in the coarse grid.

MR, NR—Number of columns, rows in the fine grid.

IZ—Ratio of coarse grid spacing to fine grid spacing in the x direction.

JZ—Ratio of coarse grid spacing to fine grid spacing in the y direction.

DSI—Coarse grid increment (km).

DSR—Fine grid increment (km).

AVTHK—Average thickness of the boundary layer (m).

SLFAC—Slope factor for the boundary-layer top (see Section III-E).

STHK—Minimum boundary layer thickness over high terrain (m).

NREL—Upper limit on the number of relaxations permitted (see Section II-B).

RATIO—Ratio of vertical to horizontal wind alterations.

IPNCH—Punch control (> 20 punches output).

Additional parameters used in output are:

IV—Eigenvector number

UV—U component of site wind

VA—V component of site wind.

The card formats are shown in Table A-3.

Table A-3

CARDS FOR PROGRAM COMPLEX

Card No.	Variables	Format
Input		
1	JSITE	I15
2	NWIND, NGRID	2I5
3	IXZ, JYZ, IXSS, JYSS, HSITE	4I5, F10.2
4	MI, NI, MR, NR, IZ, JZ, DSI, DSR	6I5, 2F10.2
5	AVTHK, SLFAC, STHK, DNI	F10.1, F10.2, F10.1, I15
6	NREL, Ratio, IPNCH	I5, E10.1, I5
Output		
1	JSITE, IV, UA, VA, DNI, AVTHK, SLFAC, STHK	2I5, 2F10.2, I5, F10.0, F5.1, F8.0

The output of COMPLEX is a hub-height field of u and v wind components corresponding to the input wind pattern. The site wind is punched on a card designated EO for use by the REWND program.

The principal subroutines used in COMPLEX are:

TOPO—Reads in the terrain heights (input of the form BO) and computes the relative heights of the sigma surfaces at each mesh point.

SETBLT—Computes the height of the boundary-layer top based on the input values of thickness and slope.

INWND—Computes the initial estimate of winds for COMPLEX based on the station winds at anemometer height for a wind pattern (i.e., the mean winds or an eigenvector) and the associated geostrophic wind at the upper boundary. Interior values of wind are determined by logarithmic interpolation. The subroutine also interpolates initial winds for the fine grid from the altered winds of the coarse grid.

NET—Interpolates grid-point values of wind components at anemometer height from the station values for each wind pattern being processed.

RELAX3—Alters the initial winds to a nondivergent condition.

6. *Program REWND*

This program computes a time series of winds at hub height at the wind turbine site using the site winds that correspond to the representative wind patterns (the mean and the significant eigenvectors) and the time series of coefficients of the eigenvectors. The site winds are the output (designated EO) from the CMPLX program, and the coefficients are part of the output (designated DO) from the XFORM program. The input variables that must be specified are:

NEIC—Number of significant eigenvectors to be used

NTYPE—Number of classes of solutions (i.e., 2 for day and night).

These two parameters are read from Card 1 on logical unit 8 in I5 format. The next series of cards (NEIG in number) is the output (designated EO) from the COMPLEX Program and is followed by a blank card. The final card indicates whether each hour of the day (GMT) is to be treated as a daytime (ITYPE = 1) or nighttime (ITYPE = 2) hour. The format is 24I3.

The coefficients (designated DO) from the XFORM program are read on logical unit 3. The output (designated FO) is a file on logical unit 2 consisting of a time series of values of u and v wind components, and also wind speed and direction.

The listing for this program is given in Appendix B.

7. *Program WINDY*

This program computes average seasonal and diurnal values of wind speed from site winds (designed FO) from the REWND program. These are read on logical unit 1. In addition, the program computes the run durations, i.e., the number of consecutive hours that the wind speeds remain below or above certain limits. The input parameters required are:

JULIAN—Julian date of the first observation of the series

SPLOW—Generator cutin speed (m s^{-1})

SPHI—Cutin speed or an intermediate speed

TOPSPD—Generator cut-out speed

UNITS—100.0 for model output; 1.0 for observed data

INCT—Time interval (hours) between records used

K—Program uses every Kth record for calculations.

These parameters are read in order from a card in the format I3, 4F7.2, 2I3. The output is a listing of seasonal and diurnal wind speed values and tabulated run durations.

Program WINDY is listed in Appendix B.

8. *Program SPSS*

A standard statistical package, the Statistical Package for the Social Sciences (SPSS; see Nie et al., 1975), has been used to obtain some of the statistical information. There are many other easily used packages that can provide similar outputs by using the time-series tape that is output by the program REWND.

The SPSS program given in Appendix B computes wind speed distributions and joint distributions of wind speed and direction. The wind speeds are tabulated in 2 m s^{-1} classes. The joint distributions are tabulated in 4 m s^{-1} classes for speed and 16 compass points for direction. The input is the file of site winds (designated FO) from program REWND. The output is a listing of the pertinent tables.

Appendix B

PROGRAM LISTINGS

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1. Program TERRAIN

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```
      PROGRAM TERRAIN(INPUT,OUTPUT,TAPE1,TAPE2,TAPE5=INPUT)
C**FOR READING DIGITAL TERRAIN DATA AT .005 DEG INTERVALS AND SMOOTHING
C  TO GET .01 DEG VALUES
C**TAPE 1 IS INPUT FROM NCIC, TAPE 2 IS SMOOTHED OUTPUT
C* PT(1,1) IS AT SW CORNER OF 1 DEG BLOCK. DATA EXTEND TO NEXT WHOLE
C  LAT AND LONG.
C* TERRAIN HEIGHT DATA ARE HT(KY,JX). KY IS COUNTER S TO N, JX IS W TO E
C** BY R. ENDLICH , SRI, MAY 79
      DIMENSION  IX(2),IY(2)
      DIMENSION  IA(1800),IUNPK(14)
      DIMENSION KHAR(10),LINE(12)
      COMMON /C1/ RT(4370)
      COMMON /C2/ PR(202,2)
      COMMON /C3/ HT(101,101)
      COMMON /C4/ IXSWC, DELX
      DATA KHAR/10H 123456789,10H ABCDEFGHI,10H JKLMNOPQR,10H STUVWXYZ+,
     +10H 123456789,10H ABCDEFGHI,10H JKLMNOPQR,10H STUVWXYZ+,10H 123456
     +789,10H ABCDEFGHI/
C       READ 9010, NMAREA,TAPEID,SECTN,IFILE
C       PRINT 9015,NMAREA,TAPEID,SECTN,IFILE
        REWIND 1
      NUMREC = 0   $  JX = 1    $  K12 = 2
C READ HEADER RECORD
 200   BUFFER IN (1,1) (RT(1),RT(4370))
        ERROR=1H      $  NUMREC = NUMREC +1
        IF (UNIT(1))  230,210,220
 210     PRINT 22
        CALL REMARK(20HEOF AT HEADER RECORD)
       GO TO 600
 220   ERROR =4HP.E.
C  HEADER RECORD IS OK
 230    LAST = 4370
        LENREC = LENGTH(1)
        K12 = 3 - K12
        IF (NUMREC .EQ. 1) CALL APRINT(RT,NAME,IFILE,8)
C       PRINT 331, NUMREC, LENREC, ERROR, (RT(I),I=1,LENREC)
       IBYTE = 9  $  IF (NUMREC .EQ.1) IBYTE = 91
       CALL UNPK8(RT,IBYTE ,IUNPK(1),14)
       IX(K12)=SHIFT(IUNPK(1),8) .OR.IUNPK(2)
       IY(K12) = SHIFT(IUNPK(3),8) .OR.IUNPK(4)
       IDX = SHIFT(IUNPK(5),8) .OR.IUNPK(6)
       IDY = SHIFT(IUNPK(7),8) .OR.IUNPK(8)
       NPTS     = SHIFT(IUNPK(9),8) .OR.IUNPK(10)
       IH1  = SHIFT(IUNPK(11),8) .OR.IUNPK(12)
       IH2  =  SHIFT(IUNPK(13),8) .OR.IUNPK(14)
      PRINT 332, NUMREC,LENREC,IX(K12),IY(K12),IDX,IDY,NPTS     ,IH1,IH2
     +     ,ERROR
      IF (JX .LT. 2 .AND. NPTS .LT. 1740) GO TO 200
        IF (NPTS .LT. 1740) GO TO 235
       CALL UNPK16(RT,(IBYTE+10)/2+1,IA(1),NPTS)
C*     PRINT 9027, (IA(L),L=1701,1800)
C*     PRINT 9027, (IA(L),L=   1, 100)
       CALL SELECT(NPTS,K12,(IBYTE+10)/2)
        IF (JX .GT. 1)  GO TO 245
  235   CONTINUE
```

```
                DO 240 KY1 = 1,202
                  PR(KY1,3-K12) = PR(KY1,K12)
    240       CONTINUE
                  GO TO 250
    245      CONTINUE
            NSX = IXSWC + (JX -1) * DELX
            PRINT 9026, NUMREC,JX,K12,IX(K12),NSX
             IF (NSX .GT. IX(K12) ) GO TO 200
C*          PRINT 9026, NUMREC,JX,K12,IX(K12),NSX
    250     CALL AVERG(JX)
C           PRINT 9028, (HT(KY,JX),KY=91,101)
             JX = JX + 1
              IF (JX .GT. 101) GO TO 600
            GO TO 200
   600       CONTINUE
   602       IF (JX .GT. 101) GO TO 605
               DO 603 KY = 1,101
                 HT(KY,JX) = HT(KY,JX-1)
   603         CONTINUE
               JX = JX +1
             GO TO 602
   605       CONTINUE
           WRITE(2) ((HT(K,J),K=1,101),J=1,101)
           READ(5,15) HTINT
            PRINT 9032, HTINT
              SCFC = 1.0/HTINT
            PRINT 9040
            DO 615 KY = 1,101
             KYP = 101 - KY +1
            DO 610 JX = 1,101
             HTD = HT(KYP,JX)
             K = SCFC * HTD +1
             IF (HTD .GT. 0.0 .AND. HTD .LE. 25.0) K =32  ; FOR SHORELINE
             IF (K .LT.1) K =1 $  IF (K .GT. 100) K = 100
             CALL CHAR(KHAR,K,LINE,JX,1)             ; USUAL ORDER REVERSED
    610     CONTINUE
             PRINT 9030,KYP,LINE
    615     CONTINUE
            PRINT 9040
   10      FORMAT (A10)
   15      FORMAT (F5.1)
   21      FORMAT (*0ERROR 110 - CANT RECOGNIZE NAME*A11,/,(10X,10A11))
   22      FORMAT (*0ERROR 210 - EOF AT HEADER RECORD*)
   23      FORMAT (2X,I6,2A10,I6)
   331     FORMAT (*0RECORD *2I5,A12,/,(10X,5O22))
   332     FORMAT (1X,I4,I6,2X,2I6,2X,2I6,I7,2X,2I6,5X,A10)
   9010    FORMAT  (3A10,I5)
   9015    FORMAT (2X,3A10,* FILE =*I6)
   9026    FORMAT (2X,6I5)
   9027    FORMAT  (1X,4(2X,5I5))
   9028    FORMAT (1X,4(1X,5F6.0))
   9030    FORMAT (4X,I5,2X,12A10)
   9032    FORMAT (1H1,*  HEIGHT INTERVAL = *F6.1)
   9040    FORMAT(/11X,9(1H0),10(1H1),10(1H2),10(1H3),10(1H4),10(1H5),
          +10(1H6),10(1H7),10(1H8),10(1H9),1H0/11X,
```

```
     +10(10H1234567890)/)
9042 FORMAT (100(1X,30(1X,O3)/))
     END
```

```
          SUBROUTINE AVERG(JCOL)
C* AVERAGE PR(X,1) AND PR(X,2) TO GIVE SMOOTHED TERRAIN AT .01 DEG INCR
          COMMON /C2/ PR(202,2)
          COMMON /C3/ HT(101,101)
             HT(1,JCOL) = 0.5 *(PR(1,1) + PR(1,2))
           DO 100  KY2 = 3,201,2
             KY1 = (KY2 +1)/2
             HT(KY1,JCOL) = .16667 * (PR(KY2-1,1) +PR(KY2,1) + PR(KY2+1,1)
     +                      + PR(KY2-1,2) + PR(KY2,2) + PR(KY2+1,2))
      100  CONTINUE
           RETURN
           END
```

```
      SUBROUTINE SELECT(NN,JCOL,I16)
C* IUNPK IS RAW TERRAIN DATA, NN IS NO. OF PTS IN PROFILE, JCOL IS COL.
      COMMON /C1/ RT(4370)
      COMMON /C2/ PR(202,2)
         CALL UNPK16(RT,I16+1,IB,1)
         PR(1,JCOL) = IB
         DELY = (NN-1)/200.0
         KBEG = 2    $  KEND = 202  $  KSKIP = 1
       DO 50 KN = KBEG,KEND,KSKIP
         NSY = 1.0 + (KN-1) * DELY
         IF (NSY .GT. NN) GO TO 45
         CALL UNPK16(RT,I16+NSY,IB,1)
         PR(KN,JCOL) = IB
         GO TO 48
 45      PR(KN,JCOL) = PR(KN-1,JCOL)
C48    IF (KN .LT.  6 .OR. KN .GT. 195) PRINT 9002, KN,NSY,PR(KN,JCOL)
 48    CONTINUE
 50    CONTINUE
 9002 FORMAT (3X,2I8,F10.0)
       RETURN
       END
```

```
      SUBROUTINE UNPK16(PACK,IB,I16,N16)
C         REVISION DATE:  JULY 24, 1978
C  UNPACK *N16* 16-BIT BYTES FROM *PACK*, STARTING WITH THE IB-TH ONE,
C    AND STORE INTO *I16*.
C  USES *UNPK8* TO FIRST UNPACK INTO 8 BIT BYTES.
C---------------------------------------------------------------------
      DIMENSION PACK(1),I16(1),I8BB(2)
C---------------------------------------------------------------------
          I8  =  2*IB - 3
          DO 10  I=1,N16
            I8  =  I8 + 2
            CALL UNPK8(PACK,I8,I8BB,2)
         I16(I) = SHIFT(I8BB(1) .AND. 177B,8) .OR. I8BB(2)
C           CHECK FOR SIGN BIT
            IF ((I8BB(1).AND.200B) .EQ. 0)  GO TO 10
         I16(I) = -I16(I) -1
   10     CONTINUE
          RETURN
C---------------------------------------------------------------------
      END
```

```
      SUBROUTINE APRINT(DATA,NAME,IFIL,IBEG)
C         REVISION DATE:  APRIL 24, 1979
C  PRINT THE CONTENTS OF A TYPE A LOGICAL RECORD FROM A DIGITAL TERRAIN TAPE
C     USES UNPK8 AND CHAR (FROM LIBRARY-WINDLIB/UN=DEBJF)
C-----------------------------------------------------------------------
      LOGICAL DEBUG
      DIMENSION DATA(1),IUNPK(16),CORNER(4),SHEET(2),UNITS(2)

      COMMON /C4/ IXSWC, DELX
      DATA  DEBUG/.FALSE./     ;NO DEBUGGING PRINTOUT
      DATA  DEBUG/.TRUE./      ;DELETE THIS CARD WHEN THIS SUBROUTINE WORKS
      DATA  UNITS/6HMETERS,5H FEET/
      DATA  CORNER/9HSOUTHWEST,9HNORTHWEST,9HNORTHEAST,9HSOUTHEAST/
C-----------------------------------------------------------------------
      N32BIT(I1,I2,I3,I4)  =  SHIFT(SHIFT(I1,52).OR.SHIFT(I2,44)
     +                          .OR.SHIFT(I3,36).OR.SHIFT(I4,28),-28)
C-----------------------------------------------------------------------
    1     FORMAT (" SUBAREA"A11"FILE:"I2)
    2     FORMAT (35X," MAP    PROJ   ELEVATION"
     +       /3X"S H E E T     SERIES  EDITION   PROJ   ZONE   U N I T S"
     +       /"  N U M B E R"5X"I D        I D     CODE    NUM   CODE TYPE"
     +       /1X,A10,A2,3X,A6,3X,A6,3X,I4,3X,I4,2X,I4,1X,A6)
    3     FORMAT (13X"I N C H E S   D E G R E E S"7X"DEG.MIN.SEC"
     +           ,11X"ARC-SECONDS"
     +           /15X"X       Y"8X"LON    LAT"6X"L O N      L A T"
     +           ,8X"L O N  L A T")
    4     FORMAT (1X,A9,2X,2F6.2,3X,F7.2,F6.2,3X,I4"."I2"."I2
     +           ,I3"."I2"."I2,4X,2I7)
C-----------------------------------------------------------------------
C    BYTES 1-12:  SHEET NUMBER (EBCDIC CODE)
   10     CALL UNPK8(DATA,IBEG+1,IUNPK,12)
   11     FORMAT ("OBYTES  1-12:"12(1X,O3))
          IF (DEBUG)  PRINT 11, (IUNPK(I),I=1,12)
          DO 12  I=1,12
            CALL KEB264(IUNPK(I),SHEET,I)
   12     CONTINUE
C    BYTES 13-18:  SERIES ID (EBCDID CODE)
   20     CALL UNPK8(DATA,IBEG+13,IUNPK,6)
   21     FORMAT ("OBYTES 13-18:"12(1X,O3))
          IF (DEBUG)  PRINT 21, (IUNPK(I),I=1,6)
          DO 22  I=1,6
            CALL KEB264(IUNPK(I),SERIES,I)
   22     CONTINUE
C    BYTES 19-24:  EDITION ID (EBCDIC CODE)
   30     CALL UNPK8(DATA,IBEG+19,IUNPK,6)
   31     FORMAT ("OBYTES 19-24:"12(1X,O3))
          IF (DEBUG)  PRINT 31, (IUNPK(I),I=1,6)
          DO 32  I=1,6
            CALL KEB264(IUNPK(I),EDITION,I)
   32     CONTINUE
C    MAP PROJECTION CODE, PROJECTION ZONE NUMBER, AND ELEVATION UNITS CODE
   40     CALL UNPK8(DATA,IBEG+25,IUNPK,6)
   41     FORMAT ("OBYTES 25-30:"12(1X,O3))
          IF (DEBUG)  PRINT 41, (IUNPK(I),I=1,6)
          IPROJ   =  SHIFT(IUNPK(1),8).OR.IUNPK(2)     ;BYTES 25-26
```

```
                IZONE   =  SHIFT(IUNPK(3),8).OR.IUNPK(4)      ;BYTES 27-28
                IUNITS  =  SHIFT(IUNPK(5),8).OR.IUNPK(6)      ;BYTES 29-30
C    BYTES 31-46:   (X,Y) OF MAP CORNERS -- INCHES
   50           CALL UNPK8(DATA,IBEG+31,IUNPK,16)
   51           FORMAT ("0BYTES 31-46:"16(1X,O3))
                IF (DEBUG)  PRINT 51, (IUNPK(I),I=1,16)
                XSW = 0.01*FLOAT((SHIFT(IUNPK( 1),8).OR.IUNPK( 2)))
                YSW = 0.01*FLOAT((SHIFT(IUNPK( 3),8).OR.IUNPK( 4)))
                XNW = 0.01*FLOAT((SHIFT(IUNPK( 5),8).OR.IUNPK( 6)))
                YNW = 0.01*FLOAT((SHIFT(IUNPK( 7),8).OR.IUNPK( 8)))
                XNE = 0.01*FLOAT((SHIFT(IUNPK( 9),8).OR.IUNPK(10)))
                YNE = 0.01*FLOAT((SHIFT(IUNPK(11),8).OR.IUNPK(12)))
                XSE = 0.01*FLOAT((SHIFT(IUNPK(13),8).OR.IUNPK(14)))
                YSE = 0.01*FLOAT((SHIFT(IUNPK(15),8).OR.IUNPK(16)))
           DELX = XSE - XSW
                IXSWC = 100 * XSW
C    BYTES 47-78:  LON-LAT OF CORNERS OF AREA COVERED BY THE MAP
   60           CALL UNPK8(DATA,IBEG+47,IUNPK,16)
   61           FORMAT ("0BYTES 47-62:"16(1X,O3))
   62           FORMAT ("0BYTES 63-78:"16(1X,O3))
                IF (DEBUG)  PRINT 61, (IUNPK(I),I=1,16)
                LONSW  =  N32BIT(IUNPK( 1),IUNPK( 2),IUNPK( 3),IUNPK( 4)) -1
                LATSW  =  N32BIT(IUNPK( 5),IUNPK( 6),IUNPK( 7),IUNPK( 8))
                LONNW  =  N32BIT(IUNPK( 9),IUNPK(10),IUNPK(11),IUNPK(12)) -1
                LATNW  =  N32BIT(IUNPK(13),IUNPK(14),IUNPK(15),IUNPK(16))
                CALL UNPK8(DATA,IBEG+63,IUNPK,16)
                IF (DEBUG)  PRINT 62, (IUNPK(I),I=1,16)
                LONNE  =  N32BIT(IUNPK( 1),IUNPK( 2),IUNPK( 3),IUNPK( 4)) -1
                LATNE  =  N32BIT(IUNPK( 5),IUNPK( 6),IUNPK( 7),IUNPK( 8))
                LONSE  =  N32BIT(IUNPK( 9),IUNPK(10),IUNPK(11),IUNPK(12)) -1
                LATSE  =  N32BIT(IUNPK(13),IUNPK(14),IUNPK(15),IUNPK(16))
                PRINT 1, NAME,IFIL
                PRINT2,SHEET,SERIES,EDITION,IPROJ,IZONE,IUNITS,UNITS(IUNITS+1)
                PRINT 3
                X=XSW $ Y=YSW $ LON=LONSW $ LAT=LATSW $ IGOTO=1   $  GO TO 80
   71           X=XNW $ Y=YNW $ LON=LONNW $ LAT=LATNW $ IGOTO=2   $  GO TO 80
   72           X=XNE $ Y=YNE $ LON=LONNE $ LAT=LATNE $ IGOTO=3   $  GO TO 80
   73           X=XSE $ Y=YSE $ LON=LONSE $ LAT=LATSE $ IGOTO=4   $  GO TO 80
   74           RETURN
C    PRINT A LINE FOR THE LOCATIONS OF A CORNER
   80           DLON  =  LON/3600.0   $   DLAT = LAT/3600.0
                LOND  =  ISIGN(IABS(LON)/3600,LON)
                LATD  =  LAT/3600
                LONM  =  MOD((IABS(LON)/60),60)
                LATM  =  MOD(LAT/60, 60)
                LONS  =  MOD(IABS(LON), 60)
                LATS  =  MOD(LAT,60)
          CALL DATEX(DATE1,DATE2)
          PRINT 9005, DATE1,DATE2
 9005     FORMAT(1X,A10,A2)
                PRINT 4, CORNER(IGOTO),X,Y,DLON,DLAT,
         +                LOND,LONM,LONS, LATD,LATM,LATS, LON,LAT
          WRITE(2) DATE1,DATE2,CORNER(IGOTO),X,Y,DLON,DLAT,
         1             LOND,LONM,LONS,LATD,LATM,LATS,LON,LAT
                GO TO (71,72,73,74),IGOTO
```

```
      C-------------------------------------------------------------------
            END
```

```
      SUBROUTINE GO2EOF(LUN,NEOF,NREC)
C          REVISION DATE:  AUGUST 1, 1977
C     SKIP TO THE NEOF-TH END OF FILE ON LOGICAL UNIT NUMBER *LUN*.
C       NOTE THAT THIS VERSION USES *BUFFER IN* TO READ THE DATA.

   10      IF (NEOF .LT. 1)  GO TO 90
           IEOF  =  0

   20      BUFFER IN (LUN,1)  (NULL,NULL)
           NREC  =  NREC + 1
           IF (UNIT(LUN))  20,30,20

   30      IEOF  =  IEOF + 1
           IF (IEOF .LT. NEOF)  GO TO 20

   90      RETURN

      END
```

```
      SUBROUTINE KEB264(I8BIT,STRING,K)
C         REVISION DATE:  JULY 21, 1978
C  BY TABLE LOOKUP, CONVERT *I8BIT* FROM AN 8-BIT, RIGHT JUSTIFIED, EXTERNAL BCD
C    CODED (EBCDIC) CHARACTER TO A CDC-6400 INTERNAL DISPLAY CODED CHATACTER
C    STORED IN THE PROPER CHARACTER POSITION OF *STRING*.
C  USE SUBROUTINE *CHAR* TO TRANSFER THE PROPER SIX BIT CHATACTER FROM THE
C    PACKED CONVERSION TABLE INTO THE K-TH CHARACTER OF *STRING*.
C-----------------------------------------------------------------------
      DIMENSION TABLE(26)
      DATA  TABLE/
     +       0          ,  0          ,  0          ,  0
     +    ,  0          ,  0          ,  0          ,10H     .<(+
     +    ,  0          ,10H $*);¬-/  ,10H       ,   ,10H>
     +    ,10H  :   "=" A,10HBCDEFGHI  ,10H     JKLMN,10HOPQR
     +    ,10H  STUVWXYZ,  0          ,  0          ,10H   ABCDEFG
     +    ,10HHI        J,10HKLMNOPQR  ,10H      STUV,10HWXYZ
     +    ,10H0123456789,  0                                   /
C-----------------------------------------------------------------------
          CALL CHAR(TABLE,I8BIT+1,STRING,K,1)
          RETURN
C-----------------------------------------------------------------------
      END
```

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2. Program GRIDHT

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```
      PROGRAM  GRIDHT(INPUT,OUTPUT,TAPE1,PUNCH)
C* USE SMOOTHED .01 DEG TERRAIN HEIGHTS. PICKS OUT PROPER VALUES
C  FOR GRID PTS.  SMOOTHES FURTHER FOR AREAS EQUIVALENT TO GRID SPACING
C* BY R  ENDLICH, SRI 7/79
     DIMENSION ALAT(22,22),ALNG(22,22),GHT(22,22),GX(22,22),GY(22,22)
     DIMENSION HT(101,101)
     READ 9001, MX,NY,NGCX,NGCY,GINCX,GINCY
     PRINT 9002, MX,NY,NGCX,NGCY,GINCX,GINCY
      READ   9003, SLAT, SLNG, SHGT
      PRINT  9004, SLAT, SLNG, SHGT
C*  HEIGHT DATA ARE HT(IX,IY) IN FEET
C* NGCX, NGCY ARE COLUMN AND ROW OF SITE.  IX GOES 1,MX  IY GOES 1,NY
C   (1,1) IS SW CORNER.  GRID INCREMENTS AREIN KM.
C*  GX( , ) HAS X VALUES OF GRID PTS.  X=0 IS AT NGCX, THE SITE.
C* COMPUTE LAT AND LONG OF GRID PTS
      DO 100  IX =1,MX    $  DO 100 IY = 1,NY
        GX(IX,IY) = (IX -NGCX) * GINCX
        GY(IX,IY) = (IY - NGCY) * GINCY
        ALAT(IX,IY) = SLAT + GY(IX,IY)/111.0
        COSS = COS(SLAT/57.2958)
        ALNG(IX,IY) = SLNG + GX(IX,IY)/(111.0 * COSS)
        IF (IX .EQ. 1 .OR. IX .EQ. MX)
    +   PRINT 9010,GX(IX,IY),ALNG(IX,IY),GY(IX,IY),ALAT(IX,IY)
  100 CONTINUE
          CALL MEMSETX(0.0,GHT,22*22)
     READ 9001, NFILES
      PRINT 9006, NFILES
      NCOUNT = 0
  140 CONTINUE
C*  READ AREA LIMITS AND THE 0.01 DEG HEIGHTS
      PRINT 3
      DO 160 IC = 1,4
  150 CONTINUE
      READ (1) DATE,DATE2,CORNER,X,Y,DLON,DLAT,LOND,LONM,LONS,LATD,
     + LATM,LATS,LON,LAT
        IF (EOF(1))  150,155
  155   CONTINUE
      PRINT 4, CORNER,X,Y,DLON,DLAT,LOND,LONM,LONS,LATD,LATM,LATS,LON,
    +    LAT
        IF (IC .GT. 1) GO TO 160
        WLNG= DLON
        ASLAT = DLAT
        ELNG = WLNG + 1.0
        ANLAT = ASLAT + 1.0
 160   CONTINUE
      PRINT 9014, ANLAT,ASLAT,ELNG,WLNG
      NCOUNT = NCOUNT + 1
      READ (1) ((HT(K,J),K=1,101),J=1,101)
C*  HT(1,1) IS AT SW CORNER.  K INCREASES TO N. J INCREASES TO EAST.
       DO 165  J =1,5
  165 PRINT 9012,  (HT(K,J),K=1,20)
C* SEARCH THE AREA TO SEE IS A GRID PT IS ENCLOSED.  IF IT IS PICK
C   THE HEIGHT VALUE.
      DO 200 IX =1,MX    $  DO 200 IY = 1,NY
        IF (ALAT(IX,IY) .GT. ANLAT .OR. ALAT(IX,IY) .LT. ASLAT) GO TO
```

```
     + 200
        IF (ALNG(IX,IY) .GT. ELNG .OR. ALNG(IX,IY) .LT. WLNG) GO TO
     +  200
        AX =  (ALNG(IX,IY) -WLNG) + .005
        LX = 100 * AX
        AY = (ALAT(IX,IY) - ASLAT) + .005
        LY = 100 * AY
C*  LX AND LY ARE INDICES TO PICK OUT HT( ) VALUES
C* COMPUTE SMOOTHING INTERVAL
        IS = GINCY/(2.5 * 1.11)
        LYN = LY + IS
        IF (LYN .GT. 101) LYN = 101
        LYS = LY - IS
        IF (LYS .LT. 1) LYS = 1
        LXE = LX + IS
        IF (LXE .GT. 101) LXE = 101
        LXW = LX - IS
        IF (LXW .LT. 1) LXW = 1
        GHT(IX,IY) = 0.2 * (HT(LY,LX) + HT(LYN,LX) + HT(LYS,LX) +
     +    HT(LY,LXE) + HT(LY,LXW))
        IF (IX .EQ. 1 .OR. IX .EQ. MX)
     + PRINT 9021, AX,LX,AY,LY,GHT(IX,IY),IS,IX,IY
  200 CONTINUE
      PRINT 9015
      DO 220 IY = 1,NY
       IP = NY + 1 - IY
  220 PRINT 9012, (GHT(IX,IP),IX=1,MX)
        IF (NCOUNT .LT. NFILES) GO TO 140
C* INSERT HEIGHT AT SITE
      GHT(NGCX,NGCY) = SHGT
C* PUNCH THE SOUTHERN ROW FIRST FOR USE BY TOPO
      DO 225 IY = 1,NY
  225 PUNCH 9016, (GHT(IX,IY),IX=1,MX)
    3     FORMAT (13X*I N C H E S   D E G R E E S*7X*DEG.MIN.SEC*
     +            ,11X*ARC-SECONDS*
     +            /11X*X     Y*8X*LON   LAT*6X*L O N     L A T*
     +            ,8X*L O N  L A T*)
    4     FORMAT (1X,A9,2X,2F6.2,3X,F7.2,F6.2,3X,I4*.*I2*.*I2
     +            ,I3*.*I2*.*I2,4X,2I7)
 9001 FORMAT  (4I5,2F6.1)
 9002 FORMAT (/*  NO. PTS W-E =*I3,*  N-S =*I3,* SITE COL =*I3,* SITE
     +ROW =*I3,* GRID INCREMENTS X =*F5.1,* Y =*F5.1)
 9003 FORMAT  (4F10.3)
 9004 FORMAT (/*  SITE LAT =*F8.2,*  LONG =*F8.2,* HEIGHT IN FT=*F9.0)
 9006 FORMAT (/*   NO. OF FILES FOR 1 BY 1 DEG AREAS =*I5)
 9010 FORMAT (10F10.2)
 9012 FORMAT (20F6.0)
 9013 FORMAT (/20F6.1)
 9014 FORMAT (/*   NORTHERN LAT =*F6.1,*  SOUTHERN LAT = *F6.1,* EASTERN
     + LNG =*F7.1,* WESTERN LONG =*F7.1/)
 9015 FORMAT  (/*    HEIGHT VALUES AT GRID POINTS*/)
 9016 FORMAT (11F6.0)
 9021 FORMAT (/2(F8.3,I4),F10.1,3I4)
      STOP
      END
```

3. Program GEOCAL

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```
      PROGRAM GEOCAL (INPUT,OUTPUT,TAPE1,TAPE2,TAPE5=INPUT,TAPE6=
     *OUTPUT)
C
C          THIS PROGRAM CREATES A DATA FILE OF WEATHER DATA FOR GROUPS
C      OF WEATHER STATIONS IN VARIOUS U.S. AREAS DURING 1977-1978.  THE
C      GEOSTROPHIC WINDS AND STABILITY INDICES ARE ALSO COMPUTED.
C
      COMMON /REC/ ID(80),NF,NR,NP,LEN,IEOF
      COMMON /CSTAB/SP180,CP180,DAY
      COMMON /DAT/ SP(10),ALAT(10),ALON(10),IU1,IU2,IU3,C1,C2,FC,
     1AVLAT,AVLON,DENOM,STLT1,STLT2,STLT3,STLN1,STLN2,STLN3,COSLAT
      DIMENSION ISTA(10),STAN(10),IGMT(10),SI(10),WD(10),WS(10),OC(10),
     1SPS(10),WDS(10),OCS(10),WSS(10),U(10),V(10),P180S(10),P180C(10),
     2IFMT2(6),IFMT5(4),STANS(10),US(10),VS(10),SIS(10),MODA(12)
      DATA (MODA=31,28,31,30,31,30,31,31,30,31,30,31)
      DATA ACR /0.0174533/
      DATA SPS,WDS,WSS,OCS/10*1013.0,10*270.0,10*1.0,10*5.0/
      DATA US,VS,SIS,UGS,VGS /10*1.0,10*1.0,10*3.0,0.0,0.0/
 1    FORMAT (1H1,10X*CREATION OF A DATA FILE OF SURFACE METEOROLOGICAL
     1DATA, GEOSTROPHIC WINDS AND STABILITY INDICES.*/)
 3    FORMAT (10I8)
 4    FORMAT (10F8.0)
 6    FORMAT (A2,I1,R7)
 7    FORMAT (A9,I1)
 8    FORMAT (/1H ,*END OF FILE, TAPE2 ... NO. OF RECORDS =*I5)
 9    FORMAT (3X*SFC P:*5(F6.1,17X))
 10   FORMAT (8A10)
 11   FORMAT (1H ,8A10)
 12   FORMAT (A2)
 13   FORMAT (8X,A2)
 14   FORMAT (1X,A4)
 15   FORMAT (8X,A1)
 16   FORMAT (1H ,*WS MISSING FOR SITE*I6,* ON*I7,I2)
 17   FORMAT (1H ,*WD MISSING FOR SITE*I6,* ON*I7,I2)
 18   FORMAT (1H ,*SP MISSING FOR SITE*I6,* ON*I7,I2)
 19   FORMAT (1H ,*OC MISSING FOR SITE*I6,* ON*I7,I2)
C
C     INPUT ...
C
C     IFMT2 = HEADER FORMAT FOR DATA PRINTOUT.
C     IFMT5 = DATA FORMAT FOR PRINTOUT.
C     NSTA = NO. OF STATIONS IN THE AREA.
C     IU1, IU2, IU3 = INDICIES OF STATIONS FOR GEOS WIND COMPUTATIONS.
C     ISTA = STATION NUMBERS.
C     IGMT = GMT TIME CORRECTION  FOR EACH STATION.
C     ALAT = LATITUDE FOR EACH STATION
C     ALON = LONGITUDE  FOR EACH STATION.
C     IDATES = STARTING DATE OF INTEREST
C     IGHS = STARTING GMT HOUR.
C
      READ (5,3) NSTA,IU1,IU2,IU3,IDATES,IGHS
      WRITE (6,3) NSTA,IU1,IU2,IU3,IDATES,IGHS
      READ (5,3) (ISTA(L),L=1,NSTA) $ READ (5,3) (IGMT(L),L=1,NSTA)
      WRITE(6,3) (ISTA(L),L=1,NSTA) $ WRITE(6,3) (IGMT(L),L=1,NSTA)
      READ (5,4) (ALAT(L),L=1,NSTA) $ READ (5,4) (ALON(L),L=1,NSTA)
      WRITE (6,4) (ALAT(L),L=1,NSTA) $ WRITE (6,4) (ALON(L),L=1,NSTA)
      READ (5,10) IFMT2 $ WRITE (6,11) IFMT2
      READ (5,10) IFMT5 $ WRITE (6,11) IFMT5
      ENCODE (10,6,IFMT2(2))IFMT2(2),NSTA,IFMT2(2)
      ENCODE (10,7,IFMT5(1)) IFMT5(1),NSTA
      WRITE (6,1) $ WRITE (6,IFMT2) $ IS=NRW=0
```

```
      DO 50 I=1,NSTA
      P180=ACR*ALAT(I)
      P180S(I)=SIN(P180) $ P180C(I)=COS(P180)
      STANS(I)=ISTA(I)
 50   CONTINUE
      C1=1.0 $ RHO=1.1 $ C2=100.0/(RHO*1.11) $ IOK=3H NO
      STLT1=ALAT(IU1) $ STLN1=ALON(IU1)
      STLT2=ALAT(IU2) $ STLN2=ALON(IU2)
      STLT3=ALAT(IU3) $ STLN3=ALON(IU3)
       AVLAT = ( 0.333 *(STLT1 + STLT2 + STLT3))/57.2958
       AVLON = ( 0.333 *(STLN1 + STLN2 + STLN3))/57.2958
       FC = 14.584 * SIN(AVLAT) $ COSLAT=COS(AVLAT)
       DENOM = (STLT2 -STLT1) * (STLN3 - STLN1) - (STLT3 -STLT1) *
     +      (STLN2 - STLN1)
 100  CALL RECORD
      IF (IEOF.EQ.3HYES) GO TO 200
C
C          PROCESS ONE RECORD OF DATA.
C
      DO 175 I=1,80,8
C
C          CHECK FOR STATION OF INTEREST.
C
      ISITE=INTXX(ID(I),1,5)
      DO 105 J=1,NSTA
      IF (ISITE.NE.ISTA(J)) GO TO 105
      JS=J $ GO TO 110
 105  CONTINUE
      GO TO 175
C
C          PROCESS DATA FOR ONE STATION.
C
 110  IYR=INTXX(ID(I),6,2) $ IMO=INTXX(ID(I),8,2)
      IDA=INTXX(ID(I),10,2) $ IHOUR=INTXX(ID(I+1),2,2)
      DAY=30.5*(IMO-1)+IDA
      IGH=IHOUR+IGMT(JS)
C
C          CHANGE THE DATES TO BE CONSISTENT WITH THE GMT TIMES.
C
      IF (IGH.LE.24) GO TO 111
      IGH=IGH-24 $ IDA=IDA+1
      IF (IDA.LE.MODA(IMO)) GO TO 111
      IDA=1 $ IMO=IMO+1
      IF (IMO.LE.12) GO TO 111
      IMO=1 $ IYR=IYR+1
 11   IDATE=IYR*10000+IMO*100+IDA
C
C          SKIP NON-3-HOURLY OBSERVATION.
C
      IF (MOD(IGH,3).NE.0) GO TO 175
      IS=IS+1
      IF (IGH.NE.IGHS) GO TO 180
 112  STAN(JS)=ISITE $ IOK=3H NO
      IDATES=IDATE $ IGHS=IGH
      DECODE (2,12,ID(I+4)) IWS
      IF (IWS.EQ.2H  ) GO TO 115
      WS(JS)=INTXX(ID(I+4),1,2)
      GO TO 120
 115  WS(JS)=WSS(JS) $ WRITE (6,16) ISITE,IDATE,IGH
 120  DECODE (10,13,ID(I+3)) IWD
      IF (IWD.EQ.2H  ) GO TO 125
```

```
      WD(JS)=INTXX(ID(I+3),9,2)*10.0
      GO TO 130
 125  WD(JS)=WDS(JS) $ WRITE (6,17) ISITE,IDATE,IGH
 130  DECODE (5,14,ID(I+3)) ISP
      IF (ISP.EQ.4H    ) GO TO 135
      SP(JS)=INTXX(ID(I+3),2,4)*0.1
      IF (SP(JS).LT.500.0) SP(JS)=SP(JS)+1000.0
      GO TO 140
 135  SP(JS)=SPS(JS) $ WRITE (6,18) ISITE,IDATE,IGH
 140  DECODE (9,15,ID(I+7)) IOC
      IF (IOC.EQ.1H ) GO TO 145
      IF (IOC.EQ.1HX) GO TO 150
      OC(JS)=INTXX(ID(I+7),9,1)
      GO TO 155
 145  OC(JS)=OCS(JS) $ WRITE (6,19) ISITE,IDATE,IGH
      GO TO 155
 150  OC(JS)=10.0
C
C          CHECK TO SEE IF ALL SITES ARE ACCOUNTED FOR.
C
 155  IF (IS.NE.NSTA) GO TO 175
C
C          CALCULATE THE STABILITY INDICES.
C
      DO 160 J=1,NSTA
      SP180=P180S(J) $ CP180=P180C(J)
      CALL STABLE (IHOUR,SAL,SI(J),WS(J),OC(J))
C
C          CONVERT WIND SPEED UNITS FROM KTS TO M/S.
C
      WS(J)=WS(J)*0.5148
      ANGLE=ACR*WD(J) $ U(J)=-WS(J)*SIN(ANGLE) $ V(J)=-WS(J)*COS(ANGLE)
 160  CONTINUE
C
C          CALCULATE THE GEOSTROPHIC WINDS.
C
      CALL GWINDS (UG,VG)
      WRITE (2) IDATE,IGH   ,NSTA,(STAN(L),SP(L),WD(L),WS(L),OC(L),U(L),
     1V(L),SI(L),L=1,NSTA),UG,VG
      NRW=NRW+1
C     IF (IDA.NE.15) GO TO 165
      IF (IDA.NE.15) GO TO 165
      WRITE(6,IFMT5) IDATE,IGH,(STAN(L),U(L),V(L),SI(L),L=1,NSTA),UG,VG
      WRITE (6,9) (SP(L),L=1,NSTA)
C
C          SAVE THE 3-HOURLY OBSERVATIONS.
C
 165  DO 170 J=1,NSTA
      SPS(J)=SP(J) $ WDS(J)=WD(J) $ WSS(J)=WS(J) $ OCS(J)=OC(J)
      STANS(J)=STAN(J) $ US(J)=U(J) $ VS(J)=V(J) $ SIS(J)=SI(J)
 170  CONTINUE
      UGS=UG $ VGS=VG
      IS=0 $ IOK=3HYES
 175  CONTINUE
      GO TO 100
 180  IS=1
      IF (IOK.EQ.3HYES) GO TO 112
      WRITE (2) IDATES,IGHS,NSTA,(STANS(L),SPS(L),WDS(L),WSS(L),OCS(L),
     1US(L),VS(L),SIS(L),L=1,NSTA),UGS,VGS
      NRW=NRW+1
      IF (IDA.NE.15) GO TO 112
```

```
      WRITE(6,IFMT5) IDATES,IGHS,(STANS(L),US(L),VS(L),SIS(L),L=1,NSTA),
     1UGS,VGS
      GO TO 112
 200  WRITE(6,IFMT5)IDATE,IGH  ,(STAN(L),U(L),V(L),SI(L),L=1,NSTA),UG,
     1VG
      END FILE 2 $ WRITE (6,8) NRW
      STOP200
      END
      SUBROUTINE GWINDS (UGS,VGS)
      COMMON /DAT/ PRS(10),STLAT(10),STLON(10),IU1,IU2,IU3,C1,C2,FC,
     1AVLAT,AVLON,DENOM,STLT1,STLT2,STLT3,STLN1,STLN2,STLN3,COSLAT
        PR1 = PRS(IU1)*C1
        PR2 = PRS(IU2)*C1
        PR3 = PRS(IU3)*C1
C* CORIOLIS FORCE IN UNITS 10 -5 SEC -1
C*  DENSITY IN UNITS 10 -3 G/CM3, PRESSURE IN MB
        DPDLT = (( STLN2 -STLN1) * (PR3 - PR1) - (STLN3 - STLN1) *
     +       (PR2 - PR1))/(-DENOM)
        DPDLN = (( STLT2 -STLT1) * (PR3 -PR1) - (STLT3 - STLT1) *
     +       (PR2 - PR1))/DENOM
        UGS = -(C2/FC) * DPDLT
        VGS =  (C2/FC) * (DPDLN/COSLAT)
C*  SPEED UNITS ARE  M PER SEC
      RETURN
      END
```

```
      SUBROUTINE STABLE (J,SAL,SI,WSP,OC)
C
C          THIS SUBROUTINE DETERMINES A STABILITY INDEX THROUGH A SERIES
C     OF CRITERIA CONCERNING CLOUD COVER, WIND SPEED, AND SOLAR ELEVATION
C     (SI=IJ=STABILITY INDEX, I=J=HOUR, SAL=SIN OF SOLAR ELEVATION.
C     WSP=WIND SPEED (KTS), OC=OPAQUE CLOUD COVER (TENTHS) )
C
      DIMENSION IX(15),HCOS(24)
      COMMON /CSTAB/SP180,CP180,DAY
      DATA HCOS /-0.9695,-0.866,-0.7071,-0.5,-0.2588,0.0,0.2588,0.5,
     10.7071,0.866,0.9659,1.0,0.9659,0.866,0.7071,0.5,0.2588,0.0,-0.2588
     2,-0.5,-0.7071,-0.866,-0.9659,-1.0/
      DATA IX /1,2*2,1,2,3,2,4*3,4,3,2*4/
      I=J
      CC=OC*0.1
      IJ=4
C
C          CALCULATE THE SIN OF THE SUNS ELEVATION ANGLE (SAL)
C
      XT=-.43378*COS(0.0172142*(10.0+DAY))
      XS=XT/SQRT(1.0+XT*XT)
      XC=XS/XT
      XSP=XS*SP180 $ SCP=XC*CP180
 102  HC=HCOS(I)
      SAL=XSP+HC*XCP
C
C          IS IT OVERCAST (CC.GE.0.9)
C
      IF (CC.GE.0.9) GO TO 310
C
C          IS IT NIGHT (SAL.LT.0)
C
      IF  (SAL.LT.0.0) GO TO 305
C
C          CALCULATE DAYTIME STABILITY
C
C          IS THE SUN WITHIN 15 DEGREES OF HORIZON (SAL.LT.0.26)
C
      IF (SAL.LT.0.26) GO TO 310
C-
C          RADIATION AND CLOUD AMOUNT EFFECT (XSOL=INSOLATION)
C-
      XSOL=(1.0-0.5*CC)*SAL
      IF (XSOL.GT.0.30) GO TO 120
      IRAD=3
      GO TO 200
 120  IF (XSOL.GT.0.55) GO TO 130
      IRAD=2
      GO TO 200
 130  IRAD=1
C
C          WIND SPEED EFFECT
C
 200  IF (WSP.GT.3.0) GO TO 210
      IWS=1 $ GO TO 300
 210  IF (WSP.GT.6.0) GO TO 220
      IWS=2$ GO TO 300
 220  IF(WSP.GT.10.0) GO TO 230
      IWS=3 $ GO TO 300
 230  IF (WSP.GT.12.0) GO TO 240
      IWS=4 $ GO TO 300
```

```
 240  IWS=5
 300  IEX=(IWS-1)*3+IRAD
      IJ=IX(IEX)
      GO TO 310
C
C         CALCULATION OF NIGHTTIME STABILITY
C
 305  IF (WSP.GT.6.0) GO TO 310
      IF (CC.GE.0.5.A.WSP.GT.3.0) GO TO 310
      IJ=5
 310  SI=IJ
      RETURN
      END
```

```
      SUBROUTINE RECORD
      COMMON /REC/ ID(80),NF,NR,NP,LEN,IEOF
      DATA IEOF /3H NO/
1     FORMAT (/1H ,*EOF NO. **I3/)
2     FORMAT (1H ,*REC. NO. **I5/)
3     FORMAT (1H ,*P.E. NO. **I5/)
      BUFFER IN (1,0) (IDAT(1),IDAT(80))
      IF (UNIT(1)) 120,100,110
100   NF=NF+1 $ PRINT 1,NF $ IEOF=3HYES $ RETURN
110   NP=NP+1 $ PRINT 3,NP
120   NR=NR+1
      LEN=LENGTH(1)
      RETURN
      END
```

```
          IDENT     CHAR
*
*   CHARACTER STRING TRANSFER ROUTINE
*      USE FROM FORTRAN (FTN COMPILER ONLY)
*      CALL CHAR(SOURCE, I, DESTIN, J, N)
*   TRANSFER A STRING OF -N- CHARACTERS, STARTING WITH THE I-TH CHARACTER
*   OF -SOURCE- TO CHARACTER POSITIONS J,J+1,...,J+N-1 OF -DESTIN-.
*      NOTE THAT THE ARRAYS -SOURCE- AND -DESTIN- MAY BE THOUGHT OF AS
*   CHARACTER STRINGS OF ARBITRARY LENGTH, 6 BITS PER CHARACTER, 10
*   CHARACTERS PER WORD.  THUS THE 11-TH CHARACTER OF THE STRING IS
*   ACTUALLY THE 1-ST CHARACTER OF WORD 2 OF THE ARRAY, ETC.
*
          ENTRY     CHAR
CHAR      DATA      0
          SA2       A1+4
          SA2       X2
          SB1       X2
          EQ        B1,B0,CHAR
          SA4       =1RA
          SA5       =1.0E+1P0
          NX3       B0,X5
          SA2       A1+1
          SA2       X2
          IX2       X2-X4
          PX2       B0,X2
          FX1       X2/X3
          UX1       B7,X1
          LX1       B7,X1
          SB3       X1
          PX1       B0,X1
          DX1       X1*X5
          FX1       X2-X1
          SA4       =6.0P0
          DX1       X1*X4
          SB4       X1
          SA4       =1RA
          SA2       A1+3
          SA2       X2
          IX2       X2-X4
          PX2       B0,X2
          FX1       X2/X3
          UX1       B7,X1
          LX1       B7,X1
          SB5       X1
          PX1       B0,X1
          DX1       X1*X5
          FX1       X2-X1
          SA4       =6.0P0
          DX1       X1*X4
          SB6       X1
          SA2       A1
          SA4       X2+B3
          SA3       A1+2
          SA1       X3+B5
          BX7       X1
          LX4       B4,X4
          LX7       B6,X7
          MX5       6
          SB2       B0+60
TRAS      BX6       X4*X5
          BX7       -X5*X7
```

```
         BX7      X6-X7
         SB1      B1-1
         NE       B1,B0,SHIFT
         SB6      B2-B6
         LX7      B6,X7
         SA7      X3+B5
         JP       CHAR
SHIFT    LX4      6
         LX7      6
         SB4      B4+6
         SB6      B6+6
         EQ       B4,B2,IWD
OWD      NE       B6,B2,TRAS
         SA7      X3+B5
         SB5      B5+1
         SA1      X3+B5
         BX7      X1
         SB6      B0
         JP       TRAS
IWD      SB3      B3+1
         SA4      X2+B3
         SB4      B0
         JP       OWD
          END
```

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4. Program XFORM

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```
/JOB
/NOSEQ
AR1,CM50000,T100,P30.
ACCOUNT(HSHIG,HISAO)
SETID(OUTPUT=47)
MAP(PART)
FTN(R=2)
ATTACH,TAPE16=AREA01/PN=PUBLIC,NA.
DEFINE,TAPE3=WIND1.
GETLIB(SUBLIB)
LDSET(LIB=SUBLIB)
LGO.
EXIT.
EXIT.
/EOR
      PROGRAM XFORM (INPUT, OUTPUT, TAPE16, TAPE3, PUNCH)
C
C     THIS PROGRAM CALLS OTHER ROUTINES FOR MAJOR OPERATIONS
      DIMENSION X(1000,20),XM(20),NBR(6),TEMP(20),A(20)
     1,D(20),Z(20,20),WK(20)
C
C     NVAR  =  NUMBER OF VARIABLES (TWICE THE NUMBER OF WINDS
C              (INCLUDING GEOSTROPHIC))
C     NREC  =  NUMBER OF RECORDS (HOURS OF DATA)
C    NSITE  =  NUMBER OF SITES (NVAR/2)-1
      READ 31,NRECS
 31   FORMAT(3I4)
      PRINT 32, NRECS
 32   FORMAT(1X,8H NRECS=  ,I4)
      READ(16) IDATE,IHR,NSITE
      REWIND 16
      NVAR=2*(NSITE+1)
      PRINT 1601, NVAR,NSITE
 1601 FORMAT(1X,7H NVAR=  ,I6,8H NSITE=  ,I6)
C
C     SETTING CONTROL PARAMETER FOR MATRIX OPERATING ROUTINES IN SUB1
      NBR(1)=NVAR
      NBR(2)=NRECS
      NBR(3)=732
      NBR(4)=1
      NBR(5)=1
      NBR(6)=0
      IX=732
C
C     SUB1 READS INPUT DATA, CALCULATES EIGENVECTORS, INNER PRODUCTS, ETC.
      CALL SUB1(X,XM,NBR,NVAR,NSITE,NRECS,IX,A,D,Z,WK,TEMP)
      STOP
      END
```

```
      SUBROUTINE SUB1(X,XM,NBR,NVAR,NSITE,NRECS,IX,A,D,Z,WK,TEMP)
      DIMENSION X(732,NVAR),XM(NVAR),NBR(6),TEMP(NVAR),
     1VCV(100),A(20),D(NVAR),Z(NVAR,NVAR),WK(20)
      DIMENSION SUMU(10),SUMV(10),ISTAB(10)
C
C     THIS SUBROUTINE READS INPUT WIND AND STABILITY DATA, CALCULATES
C     COVARIANCE MATRIX, OBTAINS EIGENVECTORS OF COVARIANCE MATRIX, AND
C     CALLS A ROUTINE TO OBTAIN TRANSFORMED DATA.
C
C     MATSUB=NO. OF SUBMATRICES READ--GENERAL 4/YEAR
      MATSUB=4
      MVP=NSITE+1
      NCASES=0
      IPRINT=0
      DO 150 NN=1,MATSUB
C
C     AT 8 OBS/DAY THERE ARE 2928 OBS/LEAP YEAR. 2928/4=732
      DO 100 L=1,732
      READ(16) IDATE,IHR,NSITE,(DUM1,DUM2,DUM3,DUM4,DUM5,
     1SUMU(J),SUMV(J),ISTAB(J),J=1,NSITE),UG,VG
      IF(L.LE.10)
     1PRINT 1600, IDATE,IHR,NSITE,(SUMU(J),SUMV(J),ISTAB(J),J=1,92),
     1UG,VG
 1600 FORMAT(1H0,I6,I2,I3/(3F10.2))
C
C     READING INPUT DATA
C         IDATE = DATA (YR/MO/DA)
C         IHR   = HOUR OF DAY (LST)
C         SUMU,SUMV = U,V COMPONENTS OF WIND (M/S)
C         ISTAB = PASQUILL/GIFFORD STABILITY
C         UG,VG = GEOSTROPHIC WIND COMPONENTS (M/S)
      IF (EOF(16).NE.0)GOTO 99
      IF(NCASES .GT. NRECS)GOTO 99
      NCASES=NCASES+1
      SUMU(MVP)=UG
      SUMV(MVP)=VG
      DO 100 I=1,MVP
C
C     ENTERING WIND DATA INPUTS IN MATRIX X
      NPI=2*(I-1)+1
      NPIP1=NPI+1
      X(L,NPI)=SUMU(I)
      X(L,NPIP1)=SUMV(I)
C     PRINT 2003, L,NPI,NPIP1,I,X(L,NPI),X(L,NPIP1)
C2003 FORMAT(1X,*L=*,I4,* NPI=*,I4,* NPIP1=*,I4,*    I=*,I4,*   X=*,
C    12F10.2)
      IPRINT=IPRINT+1
 100  CONTINUE
 99   CONTINUE
      CALL BECOVM(X,IX,NBR,TEMP,XM,VCV,IER)
C     ****************************************************************************
C
C     THE FOLLOWING DESCRIPTION OF SUBROUTINE BEVCOVM(X,IX,NBR,TEMP,XM,VC
C     V,IER) IS FROM THE IMSL MANUAL.
C
C     CALCULATES MEANS AND VARIANCE/COVARIANCE MATRIX
C     X---ON INPUT X IS A NBR(3) BY NBR(1) SUBMATRIX OF THE MATRIX (CALL
C     XX) OF DATA FOR WHICH MEANS, VARIANCES AND COVARIANCES, OR CORREC
C     TED SUMS OF SQUARES AND CROSS-PRODUCTS ARE DESIRED. THE LAST SUBMATR
C     IX IN XX MAY HAVE FEWER THAN NBR(3) ROWS.
C     ON  OUTPUT, THE ROWS OF X HAVE BEEN ADJUSTED BY THE TEMPORARY MEANS
```

```
C     IX---ROW DIMENSION OF X EXACTLY AS DIMENSIONED IN THE CALLING PROGRAM.
C     NBR---INPUT VECTOR OF LENGTH 6. NBR(I) CONTAINS, WHEN
C           I=1, NUMBER OF VARIABLES
C           I=2, NUMBER OF OBSERVATIONS PER VARIABLE IN XX
C           I=3, NUMBER OF OBSERVATIONS PER VARIABLE IN EACH SUBMATRIX X,
C                NOT INCLUDING THE LAST SUBMATRIX WHERE THE NUMBER MAY BE
C                LESS THAN OR EQUAL TO NBR(3). HOWEVER, NBR(3) SHOULD BE
C                THE SAME FOR ALL CALLS.
C           I=4, THE NUMBER OF THE SUBMATRIX STORED IN X.
C           I=5, THE TEMPORARY MEAN INDICATOR. IF NBR(5)=0, THE USER SUPPL
C                LIES  TEMPORARY MEANS IN TEMP.  OTHERWISE, THE 1ST ROW OF
C                XX (OR FIRST OF X WHEM NBR(4)=1) IS USED.
C           I=6, THE VCV OPTION. IF NBR(6)=0, VCV CONTAINS THE VARIANCE-
C                COVARIANCE MATRIX. OTHERWISE VCV CONTAINS THE CORRECTED
C                SUMS OF SQUARES AND CROSS-PRODUCTS MATRIX.
C     TEMP---INPUT VECTOR OF LENGTH NBR(1). IF NBR(5)=0 TEMP MUST CONTAIN
C           THE  TEMPORARY MEANS WHEN NBR(4)=1 OTHERWISE TEMP IS WORK STOR
C           AGE.
C     XM---OUTPUT VECTOR OF LENGTH NBR(1) CONTAINING THE VARIABLE MEANS.
C     VCV---OUTPUT NBR(1) BY NBR(1) MATRIX STORED IN SYMMETRIC STORAGE
C            MODE REQUIRING (NBR(1)*NBR(1)+1))/2 STORAGE LOCATIONS. VCV CONT
C           AINS THE VARIANCE/COVARIANCE MATRIX OR THE CORRECTED SUM OF SQ-
C           UARES AND CROSS PRODUCTS MATRIX, AS CONTROLLED BY VCV OPTION,
C           NBR(6).
C     IER---ERROR PARAMETER,  TERMINAL ERROR =128+N.  N=1 INDICATES THAT
C           NBR(4) IS LESS THAN 1 OR THAT NBR(3)*(NBR(4)-1) EXCEEDS NBR(2)
C           N=2 INDICATES THAT NBR(1) IS LESS THAN 1 OR NBR(2) IS LESS THA
C               N 2 OR THAT NBR(3) EXCEEDS NBR(2).
C     *******************************************************************$$$$$$
C
      NBR(4)=NN+1
 150  CONTINUE
C
C     PRINTING MEANS AND NUMBER OF INPUT DATA SETS
      PRINT 12,(XM(I),I=1,NVAR)
 12   FORMAT(1HO,16HVECTOR OF MEANS ,8E12.5)
      PRINT 88,NCASES
 88    FORMAT(1HO,16HNUMBER OF CASES ,I5)
C
C     OBTAINING (FROM SYMMETRIC STORAGE) AND PRINTING THE VARIANCE/COVARIANCE
C     MATRIX (VCV) AND THE ERROR PARAMETER
      DO 10 I=1,NVAR
      DO 1000 K=1,NVAR
 1000 A(K)=0.
      DO 111 J=1,NVAR
      IF (J .GT.I)K=(J*(J-1)/2)+I
      IF (J .LE.I)K=(I*(I-1)/2)+J
 111  A(J)=VCV(K)
 10   PRINT 14,(A(K),K=1,NVAR)
 14   FORMAT(1HO,18HCOVARIANCE MATRIX ,8E12.5)
      PRINT 15,IER
 15   FORMAT(1HO,21HERROR PARAMETER IS = ,I5)
C     COVARIANCE MATRIX HAS BEEN WRITTEN, NOW DO EIGENVECTORS
      N=IZ=NVAR
      IJOB=1
      CALL EIGRS(VCV,N,IJOB,D,Z,IZ,WK,IER)
C     *****************************************************************
C
C     THE FOLLOWING DESCRIPTION OF SUBROUTINE EIGRS(A,N,IJOB,D,Z,IZ,WK,IE
C     R) WAS EXTRACTED FROM THE IMSL MANUAL.
C
```

```
C     IT CALCULATES EIGENVALUES AND EIGENVECTORS
C     OF A REAL SYMMETRIC MATRIX.
C     VCV---THE INPUT SYMMETRIC MATRIX OF ORDER N, STORED IN SYMMETRIC STOR
C          AGE MODE (OBTAINED FROM BEVCOVM).
C     N---ORDER OF INPUT MATRIX VCV.
C     IJOB---INPUT OPTION PARAMETER, WHEN
C     IJOB=0, COMPUTE EIGENVALUES ONLY.  IJOB=1--EIGENVALUES AND EIGEN V
C     ECTORS.  IJOB=2--E-VALUES,E-VECTS AND PERFORMANCE INDEX.  IJOB=3--
C     PERFORM INDEX ONLY. PERFORM INDX RETURNED IN WK(1)--LT 1 = WELL, 1
C     TO 100 = SATISFACT., GT 100 = POORLY.
C     D---N-DIMENSIONAL VECTOR OF E-VALUES.
C     Z---N BY N MATRIX OF E-VECTORS OF VCV. E-VECTOR IN COLUMN J CORRESPO
C     NDS TO E-VALUE J, D(J).
C     IZ---ROW DIMEN. OF Z IN CALLING PROGRAM. IZ MUST BE GE 0.
C     WK---WORK AREA. LENGTH DEPENDS ON IJOB.  IJOB=1 OR 2, LENGTH GE N.
C     IJOB=2, LENGTH GE N(N+1)/2+N
C     IER---ERROR PARAMETER.  TERMINAL ERROR   IER=128+J, INDICATES FAILU
C     RE TO CONVERGE ON EIGENVALUE J. E-VALUES AND E-VECTORS TO J-1 ARE C
C     ORRECT, BUT E-VALUES ARE UNORDERED.
C
C     *******************************************************************
C
C      PRINTING AND PUNCHING EIGENVECTORS
       DO 16 I=1,N
 16    PRINT 32,(Z(I,J),J=1,N)
 32    FORMAT(1H0,23HMATRIX OF EIGENVECTORS ,8E12.5/20X,8E12.5)
       DO 310 I=1,N
       PUNCH 3001, I
       PRINT 3001, I
C
C      PRINTING AND PUNCHING EIGENVECTORS (X100 TO CONVERT TO CM/SEC)
 3001  FORMAT (8X,I2)
       DO 310 J=2, N, 2
       JMONE = J-1
       UCMPS = 100. * Z(JMONE,I)
       VCMPS = 100. * Z(J,I)
       PUNCH 3002, UCMPS, VCMPS
       PRINT 3002, UCMPS, VCMPS
 3002  FORMAT (2F10.2)
  310  CONTINUE
       I = N+1
       PUNCH 3001, I
       PRINT 3001, I
       DO 320  J=2,N,2
C      PRINTING AND PUNCHING MEAN VECTORS (X100 TO CONVERT TO CM/SEC)
       JMONE = J-1
       UCMEAN = 100.*XM( JMONE )
       VCMEAN = 100.*XM( J )
       PUNCH 3002, UCMEAN, VCMEAN
       PRINT 3002, UCMEAN, VCMEAN
  320  CONTINUE
C
C      PRINT EIGENVALUES
       PRINT 112,(D(K),K=1,NVAR)
 112   FORMAT(1H0,16HEIGENVALUES ARE  8E12.5)
       PRINT 15,IER
C      EIGENVECTOR MATRIX HAS BEEN WRITTEN, NOW DO INNER PRODUCTS
       REWIND 16
C
C      SUB2 CALCULATES INNER PRODUCTS OF INPUT DATA SETS WITH EIGENVECTORS.
       CALL SUB2(Z,NVAR,NSITE,XM,NRECS)

       RETURN
       END
```

```
      SUBROUTINE SUB2(Z,NVAR,NSITE,XM,NRECS)
C
C        Z = MATRIX OF EIGENVECTORS OF DATA COVARIANCE MATRIX
C     NVAR = NUMBER OF ELEMENTS IN INPUT DATA SETS (WIND COMPONENTS)
C       XM = MEANS OF INPUT DATA
C    NRECS = NUMBER OF INPUT DATA SETS
C    NSITE = NUMBER OF SITES USED
C    SUMU,SUMV = OBSERVED WIND COMPONENTS
      DIMENSION ISTAB(10),Z(NVAR,NVAR),XM(NVAR),
     1C(20),SUMU(10),SUMV(10),XD(20)
      DATA C/20*(-999.)/
      NCASES=0
      DO 150 L=1,NRECS
C
C     READING INPUT DATA--DATE, HOUR (LOCAL TIME) AND NSITE GROUPS
C     OF THREE (U,V,STABILITY CLASS), FINAL PAIR OF DATA ARE GEOSTROPHIC
C     U AND V.
      READ(16) IDATE,IHR,NSITE,(DUM1,DUM2,DUM3,DUM4,DUM5,
     1SUMU(J),SUMV(J),ISTAB(J),J=1,NSITE),UG,VG
      IF (EOF(16).NE.0)GOTO 99
      NSP1 = NSITE+1
      SUMU(NSP1)=UG
      SUMV(NSP1)=VG
      NCASES=NCASES+1
      DO 100 I=1,NSP1
      J=2*(I-1)+1
      JP1=J+1
C
C     GETTING DEVIATION FROM MEAN FOR EACH INPUT WIND DATUM
      XD(J)=SUMU(I)-XM(J)
      XD(JP1)=SUMV(I)-XM(JP1)
 100  CONTINUE
C     COMPUTE INNER PRODUCTS.  C(K) = INNER PRODUCT OF INPUT WIND DATA
C     (DEVIATIONS FROM MEAN) SET WITH KTH EIGENVECTOR
      DO 120 K=1,NVAR
      TERM=0.
      DO 130 J=1,NVAR
      TERM=TERM+XD(J)*Z(J,K)
 130  CONTINUE
      C(K)=TERM
 120  CONTINUE
      CONTINUE
C     WRITE DATE,HOUR,INNER PRODUCTS AND STABILITIES
      WRITE(3) IDATE,IHR,NVAR,NSITE,(C(J),J=1,NVAR),
     1(ISTAB(J),J=1,NSITE)
      IF(L.LT.30) PRINT 75,(C(LF),LF=1,NVAR)
 75   FORMAT(1X,10F10.2)
 150  CONTINUE
      PRINT 18,NCASES
 18   FORMAT(1H0,22HNUMBER OF DAYS READ = ,I5)
   99 END FILE 3
      REWIND 3
      RETURN
      END
/EOR
3936
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5. Program COMPLEX

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      PROGRAM CMPLX(INPUT=65,OUTPUT=65,PUNCH=65,
     2              TAPE3=OUTPUT,TAPE6=OUTPUT,TAPE5)
C* LAST REVISION 8/1/79
C* *   * * * * * PROGRAM TO COMPUTE TOPOGRAPHICALLY INDUCED WINDS
C
      DIMENSION B(21,21),LPRNT(10)
      COMMON /CISV/ ISV(21,21), NREL
      COMMON/RARS/RHS(21,21,10)
      COMMON/CSFC/SFCHT(21,21),SIGMA(10),RHO(10),X(21),Y(21)
      COMMON/UARS/U(21,21,10),UA(21,21,10),V(21,21,10),VA(21,21,10)
      COMMON/WARS/W(21,21,10),WA(21,21,10)
      COMMON /PARMS/ ZTOP,DS,DSIGMA,MM1,NM1,LM1,XHT1,XHT2,X1,Y1,X2,Y2,UG
     1 ,VG,EDDYK,ZO,CORIO,ALPHA,AS,RI,PIHALF,WTH,WTV,RATIO,TDSI
      COMMON/ZETA/ZETA(10),F1(10),F2(10),F3(10),DZETA
      COMMON /CDRAW/ RTD
      COMMON /CVOS/ IB,JB,IZ,JZ,IV,DSI,IXZ,JYZ
      COMMON/CTOP/ MI,NI,MR,NR,NGRID,HTOP
      COMMON/MNL/M,N,L
      COMMON /BLHT/ BLT(21,21),HSITE, AVTHK, SLFAC,STHK
      COMMON /SITE/ IXS, JYS, THSITE, IGRID
      DATA L,NMAX,MX,NX/10,21,21,21/
      DATA ALPHA,AS,RI,PIHALF/ 3.0, 1.0, 1.E10, 1.57/
C*  IN ALL ARRAYS POINT (1,1) IS AT SW CORNER.  X INCREASES TO EAST, Y
C  INCREASES TO N. INDICES ARE I,J,K -(COL,ROW,LYR) WITH LIMITS M,N,L
C*  UNITS USED IN COMPUTATION ARE CM, G, SEC.
    1 FORMAT(4I5,F10.2)
  2   FORMAT   (/*     FINAL RESULTS*/11X,*K         UA         VA         WA
     +     SIGMADOT    REL. HTS.*/)
    3 FORMAT(2X,I10,2X,2F10.2,F11.7,F10.1)
    4 FORMAT(10X,*TOTAL TIME =*,E12.3)
   5  FORMAT (2X,I10,2X,3F10.2,F11.7,F10.1)
    7 FORMAT(2X,5E12.3)
    8 FORMAT(6I5,2F10.2)
    9 FORMAT (2I5,2F10.2,I5,F10.0,F5.1,F8.0)
      CALL SECOND(RTB)
      RTD=0.0
      READ 1,JSITE
       PRINT 9011,JSITE
      READ 1,NWIND,NGRID
       PRINT 9012,NWIND,NGRID
      READ 1,IXZ,JYZ,IXSS,JYSS,HSITE
       PRINT 9015, IXZ,JYZ,IXSS,JYSS,HSITE
      READ 8,MI,NI,MR,NR,IZ,JZ,DSI,DSR
       IB = ((IXZ-1)*IZ +2) -IXSS
       JB = ((JYZ -1) * JZ +2) -JYSS
C* (IB-1)= FINE GRID X UNITS FROM SW CORNER COARSE GRID TO SW CORNER
C  OF FINE GRID
       PRINT 9013, MI,NI,MR,NR,IB,JB
       PRINT 9014,IZ,JZ,DSI,DSR
      HSITE=30.48*HSITE
      LM1=L-1
C
       READ 9022, AVTHK, SLFAC, STHK, DNI
      PRINT 9025, AVTHK, SLFAC, STHK, DNI
          AVTHK = 100.0 * AVTHK
          STHK = 100.0 * STHK
C* READ PRINT INDICATORS. TO PRINT LEVEL K USE LPRNT(K) = 1.
       READ 9030, (LPRNT(K),K=1,L)
       PRINT 9035
       PRINT 9030, (LPRNT(K),K=1,L)
       READ 9060, NREL, RATIO, IPNCH
```

```
        PRINT 9062, NREL, RATIO, IPNCH
C*   SET F1,F2,F3.
       DO 916 K=1,L
       F1(K) = 1.0
       F2(K) = 0.0
       F3(K) = 1.0
  916 CONTINUE
C  LOOP THRU NWIND SETS.
       CALL TOPO(0)
        DO 1050 IWIND = 1,NWIND
       IXS=IXZ
       JYS=JYZ
       M=MI
       N=NI
       DS=DSI
C  LOOP THRU NGRID SYSTEMS,
       CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
        DO 1040 IGRID = 1,NGRID
         IF (IGRID .GT. 1)  PRINT 9040
       DS=DS*1.0E5
       MM1=M-1
       NM1=N-1
       TDSI = 1./(2.0*DS)
C ESTABLISH GRID COORDINATES
       X(1)=0.0
       DO 12 I = 1,MM1
          X(I+1) = X(I) + DS
   12  CONTINUE
       Y(1)=0.0
       DO 13 J = 1,NM1
          Y(J+1) = Y(J) + DS
   13  CONTINUE
C* USE SIGMA, MAKE ZETA = SIGMA.
       SIGMA(1)= 0.0   $  ZETA(1)= 0.0
       DSIGMA = 1.0/FLOAT(LM1)
       DZETA = DSIGMA
       DO 14  K =2,L
       SIGMA(K) = SIGMA(K-1) + DSIGMA
       ZETA(K) = SIGMA(K)
   14  CONTINUE
C*   SET UP VERTICAL COORD. FOR FINE GRID
       IF (IGRID .LT. 2) GO TO 19
       DSIGMA = 0.5/FLOAT(LM1)
       DZETA = DSIGMA
       DO 17  K =2,L
       SIGMA(K) = SIGMA(K-1) + DSIGMA
       ZETA(K) = SIGMA(K)
  17   CONTINUE
  19   CONTINUE
C COMPUTE DENSITY DISTRIBUTIONS
       DO 50 K=1,L
        RHO(K) = 1.0 - DSIGMA *0.1 *K
   50  CONTINUE
C OBTAIN HEIGHT OF TERRAIN(SFCHT)
       CALL TOPO(IGRID)
C OBTAIN DATA FOR VELOCITIES
C    VELOCITIES SHOULD BE EXTRAPOLATED( WITH POWER LAW ) AT ZETA(K) LEVELS
       IF (IGRID.EQ.1.AND.IWIND.EQ.1) CALL INWND(0)
        CALL INWND(IGRID)
C PRINT + PLOT SURFACE HEIGHT
       PRINT 171
```

```
  171 FORMAT (1H1,*     TERRAIN HEIGHT, M,  1ST ROW IS TO NORTH*/)
        DO 53 JP = 1,N
        DO 53 IP = 1,M
        B(IP,JP) = .01 * SFCHT(IP,JP)
  53    CONTINUE
        DO 54 JP =1,N
       JR = N + 1 -JP
  54    PRINT 9100,  (    B(IP,JR),IP=1,M )
C
  55   CONTINUE
C* SET ISV FOR POSSIBLE USE IN KEEPING VALUES UNCHANGED IN RELAX
      DO 15  I =1,M
      DO 15  J =1,N
        ISV(I,J) = 0
   15 CONTINUE
C * * * * * *PLOT  OBSERVED VELOCITY COMPONENTS AT SELECTED LEVELS * *
       DO 211  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 211
      PRINT 271,K
  271 FORMAT(1H1,*  U COMPONENT CM PER SEC, LVL = *I4/)
        DO 56 JP =1,N
       JR = N + 1 -JP
  56    PRINT 9100,  (    U(IP,JR,K),IP=1,M )
  211 CONTINUE
       DO 212  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 212
      PRINT 272,K
  272 FORMAT(1H1,*  V COMPONENT CM PER SEC, LVL = *I4/)
        DO 58 JP =1,N
       JR = N + 1 -JP
  58    PRINT 9100,  (    V(IP,JR,K),IP=1,M )
  212 CONTINUE
  214 CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
C*  INITIALLY SET SIGMADOT (CALLED W HERE) = 0
       IF (IGRID .GT. 1)  GO TO 226    ; 6/29
      DO 220  I =1,M
      DO 220  J =1,N
      DO 220  K =1,L
        W(I,J,K) = 0.0          ;  6/29
  220 CONTINUE
  226  CONTINUE
       IF (IGRID .EQ. 1) PRINT 9050
       IF (IGRID .GT. 1) PRINT 9055
      PRINT 9020
 9020 FORMAT (/*  ORIGINAL U, V, SIGMADOT, REL. HTS AT SITE*/)
      PRINT 3,(K, U(IXS,JYS,K), V(IXS,JYS,K), W(IXS,JYS,K),
     2         RHS(IXS,JYS,K),K=1,L)
       DO 213  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 213
      PRINT 273,K
  273 FORMAT(1H1,*  SIGMADOT TIMES 10 TO 6TH, LVL =*I3/)
      DO 60  JP = 1,N
      DO 60  IP = 1,M
        B(IP,JP) = 1000000.* W(IP,JP,K)
  60  CONTINUE
      DO 65  JP = 1,N
       JR = N + 1 -JP
  65  PRINT 9100,  ( B(IP,JR),IP=1,M)
  213 CONTINUE
C * * * *  * * * CONVERT VELOCITY COMPONENTS INTO STARRED FORM *
      DO 225 I =1,M
```

```
      DO 225 J =1,N
      DO 225 K =1,L
      ZVAR = BLT(I,J) - SFCHT(I,J)
      U(I,J,K) = RHO(K) * U(I,J,K) * ZVAR
      V(I,J,K) = RHO(K) * V(I,J,K) * ZVAR
      W(I,J,K) = RHO(K) * W(I,J,K) * ZVAR
  225 CONTINUE
      DO 240  I =1,M
      DO 240  J =1,N
      DO 240  K =1,L
      UA(I,J,K) = U(I,J,K)
      VA(I,J,K) = V(I,J,K)
      WA(I,J,K) = W(I,J,K)
  240 CONTINUE
C  * * * * * * * * * * VELOCITY COMPONENTS ARE IN STARRED FORM
C COMPUTE FORCING FOR W OR RHO*SIGMADOT EQUATION
C COMPUTE FIRST TERM ON RIGHT HAND SIDE
      FDSDI=1./(4.0*DS*DZETA)
      DSSI = 1./(DS*DS)
      DO 80 I=2,MM1
      DO 80 J=2,NM1
      DO 80 K=2,LM1
C COMPUTE DIVERGENCE OF WIND SHEAR
      DUDZE=U(I+1,J,K+1)-U(I+1,J,K-1)
      DUDZW=U(I-1,J,K+1)-U(I-1,J,K-1)
      DSUDX=(DUDZE-DUDZW)*FDSDI
      DSUDX=DSUDX*F1(K)
      DVDZN=V(I,J+1,K+1)-V(I,J+1,K-1)
      DVDZS=V(I,J-1,K+1)-V(I,J-1,K-1)
      DSVDY=(DVDZN-DVDZS)*FDSDI
      DSVDY=DSVDY*F1(K)
      FIRST=RATIO*(DSUDX+DSVDY)
C COMPUTE LAPLACIAN
      WLAP=W(I,J+1,K)+W(I,J-1,K)+W(I+1,J,K)+W(I-1,J,K)-4.0*W(I,J,K)
      SECON =WLAP*DSSI
      RHS(I,J,K)=SECON -FIRST
   80 CONTINUE
C
      CH=RATIO
      CALL RELAX3(WA,RHS,CH)
      CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
C   BOUNDARY CONDITIONS FOR UA AND VA ARE SET * * * * * * * * * * *
C**********    TEMPORARY      **********
C    * * * COMPUTATION OF UA, AND VA BY RELAXATION
      DO 680 I=2,MM1
      DO 680 J=2,NM1
      DO 680 K=2,LM1
      VXN=V(I+1,J+1,K)-V(I-1,J+1,K)
      VXS=V(I+1,J-1,K)-V(I-1,J-1,K)
      DSVDY=(VXN-VXS)*DSSI/4.0
      WXB=W(I+1,J,K-1)-W(I-1,J,K-1)
      WXT=W(I+1,J,K+1)-W(I-1,J,K+1)
      DSWDZ=(WXT-WXB)*FDSDI
      DSWDZ=DSWDZ*F1(K)
      FIRST=DSVDY+DSWDZ
      UYY=U(I,J+1,K)+U(I,J-1,K)-2.0*U(I,J,K)
      UYY=UYY*DSSI
      UZZ=U(I,J,K+1)+U(I,J,K-1)-2.0*U(I,J,K)
      UZZ=UZZ*RATIO/(DZETA*DZETA)
      UZZ=UZZ*F3(K)
      UZ=U(I,J,K+1)-U(I,J,K-1)
```

```
      UZ=UZ*F2(K)/(2.0*DZETA)
      UZZ=UZZ+UZ*RATIO
      SECON =UYY+UZZ
      RHS(I,J,K)=SECON -FIRST
  680 CONTINUE
      CALL RELAX3(UA,RHS,CH)
      CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
      DO 780 I=2,MM1
      DO 780 J=2,NM1
      DO 780 K=2,LM1
      UYE=U(I+1,J+1,K)-U(I+1,J-1,K)
      UYW=U(I-1,J+1,K)-U(I-1,J-1,K)
      DSUDX=(UYE-UYW)*DSSI/4.0
      WYT=W(I,J+1,K+1)-W(I,J-1,K+1)
      WYB=W(I,J+1,K-1)-W(I,J-1,K-1)
      DSWDZ=(WYT-WYB)*FDSDI
      DSWDZ=DSWDZ*F1(K)
      FIRST=DSUDX+DSWDZ
      VXX=V(I+1,J,K)+V(I-1,J,K)-2.0*V(I,J,K)
      VXX=VXX*DSSI
      VZZ=V(I,J,K+1)+V(I,J,K-1)-2.0*V(I,J,K)
      VZZ=VZZ*RATIO/(DZETA*DZETA)
      VZZ=VZZ*F3(K)
      VZ=V(I,J,K+1)-V(I,J,K-1)
      VZ=VZ*F2(K)/(2.0*DZETA)
      VZZ=VZZ+VZ*RATIO
      SECON =VXX+VZZ
      RHS(I,J,K)=SECON -FIRST
  780 CONTINUE
      CALL RELAX3(VA,RHS,CH)
      CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
C   END OF COMPUTATION OF UA AND VA BY RELAXATION
C**********    TEMPORARY      **********
C COMPUTE GEOMETRIC HEIGHTS OF GRIDPTS ABOVE TERRAIN,RHS
      DO 10 I=1,M
      DO 10 J=1,N
      DO 10 K=1,L
C RHS IS THE HEIGHT ABOVE THE TERRAIN SURFACE
      ZVAR = BLT(I,J) - SFCHT(I,J)
      RHS(I,J,K)=SIGMA(K)*ZVAR
   10 CONTINUE
C * * * *PLOT GEOMETRIC HEIGHTS OF  SELECTED SIGMA SURFACES
        DO 511  K =1,L
        IF (LPRNT(K) .NE. 1) GO TO 511
         DO  627  JP = 1,N
         DO 627 IP = 1,M
         B(IP,JP) = .01 * RHS(IP,JP,K)
  627    CONTINUE
      PRINT 571,K
  571 FORMAT (1H1,*   HEIGHT ABOVE TERRAIN, M,  LVL=*I3/)
         DO 628 JP=1,N
        JR = N + 1 -JP
  628    PRINT 9100,  (B(IP,JR),IP=1,M )
  511 CONTINUE
C CONVERT MOMENTUM INTO WIND
      DO 600  I =1,M
      DO 600  J = 1,N
      DO 600  K = 1,L
      ZVAR = BLT(I,J) - SFCHT(I,J)
      UA(I,J,K)=UA(I,J,K)/(RHO(K)*ZVAR)
      VA(I,J,K)=VA(I,J,K)/(RHO(K)*ZVAR)
```

```
      WA(I,J,K)=WA(I,J,K)/(RHO(K)*ZVAR)
C UA AND VA ARE IN VELOCITY UNITS, WA IS SIGMADOT
 600  CONTINUE
C CONVERT WA(SIGMADOT) INTO VERTICAL VELOCITY
       DO 604  I = 2,MM1
       DO 604  J = 2,NM1
       DO 604  K =2,L
      TEMP1=WA(I,J,K)*(BLT(I,J) - SFCHT(I,J))
      HSIGE = SFCHT(I+1,J)   + RHS(I+1,J,K)    ;  7/9
      HSIGW = SFCHT(I-1,J)   + RHS(I-1,J,K)
      HSIGN = SFCHT(I,J+1)   + RHS(I,J+1,K)
      HSIGS = SFCHT(I,J-1)   + RHS(I,J-1,K)
      DHDX = (HSIGE - HSIGW) * TDSI
      DHDY = (HSIGN - HSIGS) * TDSI
      TEMP3=UA(I,J,K)*DHDX+VA(I,J,K)*DHDY
C* TEMP3 IS W ALONG THE SIGMA SURFACE
       W(I,J,K)=TEMP1+TEMP3           ;   TOTAL W   7/9
C  W IS NOW IN VELOCITY UNITS
 604  CONTINUE
C PRINT + PLOT ADJUSTED WIND AT SELECTED LEVELS
C   APPROXIMATE BOUNDARY VALUES AT LATERAL BOUNDARIES
C * * * *PLOT ADJUSTED VELOCCTY COMPONENTS  AT SELECTED LEVELS
       DO 611  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 611
      PRINT 671,K
  671 FORMAT (1H1,*   ADJUSTED U COMPONENT, CPS,  LVL=*I3/)
        DO 622 JP=1,N
       JR = N + 1 -JP
 622    PRINT 9100,  (  UA(IP,JR,K),IP=1,M )
  611 CONTINUE
       DO 612  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 612
      PRINT 672,K
  672 FORMAT (1H1,*   ADJUSTED V COMPONENT, CPS,  LVL=*I3/)
        DO 624 JP=1,N
       JR = N + 1 -JP
 624    PRINT 9100,  (  VA(IP,JR,K),IP=1,M )
  612 CONTINUE
       DO 613  K =1,L
       IF (LPRNT(K) .NE. 1) GO TO 613
      PRINT 673,K
  673 FORMAT (1H1,*   ADJUSTED W COMPONENT, CPS,  LVL=*I3/)
        DO 626 JP=1,N
       JR = N + 1 -JP
 626    PRINT 9100,  (   W(IP,JR,K),IP=1,M )
       DO 640  JP = 1,N
       DO 640  IP = 1,M
        B(IP,JP) = 1000000.*WA(IP,JP,K)
  640  CONTINUE
      PRINT 273,K
       DO 645  JP = 1,N
       JR = N + 1 -JP
 645    PRINT 9100,  (   B(IP,JR),IP=1,M )
  613 CONTINUE
C REPLACE COARSE GRID PARAMETERS WITH FINE GRID PARAMETERS
  614 M=MR
      N=NR
      DS=DSR
       IF (IGRID .EQ. 1) PRINT 9050
       IF (IGRID .GT. 1) PRINT 9055
      PRINT 2
```

```
      PRINT 5,(K,UA(IXS,JYS,K),VA(IXS,JYS,K), W(IXS,JYS,K),
     + WA(IXS,JYS,K),RHS(IXS,JYS,K),K=1,L)
      IXS=IXSS
      JYS=JYSS
      CALL SECOND(RTE)$ RTT=RTE-RTB-RTD$  PRINT 4,RTT
      CALL SECOND(RTX)$  PRINT 7,RTB,RTD,RTX
       IF (IGRID .NE. NGRID) GO TO 1040
C*  COMPUTE WINDS AT HUB HT, PUT IN UA(I,J,1)
        HUBHT = 4570.0
       DO 900 I =1,M
        DO 900 J =1,N
        IF (RHS(I,J,2) .LT. HUBHT) GO TO 855
          Z3 = ALOG(RHS(I,J,3))
          Z2 = ALOG(RHS(I,J,2))
          ZHB= ALOG(HUBHT)
          UA(I,J,1) =((UA(I,J,3) -UA(I,J,2))/(Z3-Z2))
     +      *(ZHB-Z2) + UA(I,J,2)
          VA(I,J,1) =((VA(I,J,3) -VA(I,J,2))/(Z3-Z2))
     +      * (ZHB-Z2) + VA(I,J,2)
          GO TO 900
 855   CONTINUE
        KUP = 3
        IF (RHS(I,J,3) .GE. HUBHT)  GO TO 860
        KUP = 4
        IF (RHS(I,J,4) .GE. HUBHT ) GO TO 860
        KUP = 5
        IF (RHS(I,J,5) .GE. HUBHT)  GO TO 860
 860   CONTINUE
        KLWR = KUP - 1
        UA(I,J,1) = UA(I,J,KLWR) +(HUBHT -RHS(I,J,KLWR))
     +    *(UA(I,J,KUP)-UA(I,J,KLWR))/(RHS(I,J,KUP)-RHS(I,J,KLWR))
        VA(I,J,1) = VA(I,J,KLWR) +(HUBHT  -RHS(I,J,KLWR))
     +   *(VA(I,J,KUP)-VA(I,J,KLWR))/(RHS(I,J,KUP)-RHS(I,J,KLWR))
 900   CONTINUE
C* PUNCH RESULTS- SITE, E. VECTOR NO, U, V, DAY-NITE INDICATOR, AV. B L
C  THICKNESS, SLOPE, MIN  THICKNESS
      IF (IPNCH .GT. 0)
     +PUNCH 9,JSITE,IV,UA(IXS,JYS,1),VA(IXS,JYS,1),DNI,AVTHK,SLFAC,STHK
        PRINT 9045
        DO 910 JP = 1,N
        JR = N + 1 - JP
 910   PRINT 9100, (UA(IP,JR,1),IP=1,M)
        PRINT 9046
        DO 915 JP = 1,N
        JR = N + 1 - JP
 915   PRINT 9100, (VA(IP,JR,1),IP=1,M)
       PRINT 9065
 9065 FORMAT (//*   PRINT FINAL OUTPUT CARD*)
      PRINT 9,JSITE,IV,UA(IXS,JYS,1),VA(IXS,JYS,1),DNI,AVTHK,SLFAC,STHK
 1040  CONTINUE
 1050  CONTINUE
 9011 FORMAT (/* SITE NUMBER = *I5)
 9012 FORMAT (/* NO. WIND SETS =*I5,*   NO. GRIDS =*I5)
 9013 FORMAT (/* COARSE GRID E-W*I5,* S-N*I5,*   FINE GRID E-W*I4,*  S-N
     +*I4,* DISTANCE, X*I4,*  Y*I4)
 9014 FORMAT (/* RATIO, COARSE -FINE, IZ*I5,* JZ*I5,*   COARSE INCR*F6.1
     +,*   FINE INCR*F6.1)
 9015 FORMAT (/* SITE, COARSE GRID X*I5,* Y*I5,* SITE, FINE GRID X*I5,*
     +Y*I5,* SITE ELEVATION, FEET =*F8.1)
 9022 FORMAT (F10.1,F10.2,F10.1,I5)
 9025 FORMAT (//*   AVER. BNDY. THICKNESS IN M =*F8.1,
```

```
     + *SLOPE FACTOR FOR BL TOP=*F6.1,* MIN. THICKNESS=*F8.1,
     +  /*    DAY1 NITE 2 INDICATOR=*I3/)
9030 FORMAT (12I5)
9035 FORMAT (/*    INDICATORS, LPRNT(K), FOR PRINTING FIELDS*/)
9040 FORMAT (1H1,*    BEGIN COMPUTATIONS FOR FINE GRID*/)
9045  FORMAT (1H1,*     U COMP. AT HUB HT.*/)
9046   FORMAT (1H1,*     V COMP. AT HUB HT. CPS*/)
9050 FORMAT (1H1,*     COARSE GRID*)
9055 FORMAT (1H1,*      FINE GRID*)
9060 FORMAT (I5,E10.1,I5)
9062 FORMAT (/*  THE LIMIT ON RELAX ITERATIONS =*I4,* THE RATIO OF VERT
     +ICAL TO HORIZ ADJUSTMENTS=*E10.1,*  IPUNCH=*I3)
9100 FORMAT (/5X,22F5.0)
     STOP
     END
```

```
      SUBROUTINE BOUNDS(MER,MT,NT,YMAX,XMIN,YD,XD,Y,X)
      DIMENSION Y(1),X(1)
      DO 10 M=1,MT
      YM=YMAX+(1-M)*YD
      Y(M+MT)=YM
   10 Y(M)=YM
      DO 20 N=1,NT
      XN=XMIN+(N-1)*XD
      X(N+NT)=XN
   20 X(N)=XN
      RETURN
      END
```

```
      SUBROUTINE INWND(NUM)
C*   THIS IS A MODIFIED NERSION OF VOBSER. IT USES ANEMOM. WINDS AND
C    GEOSTROPHIC WINDS AT UPPER BNDY.  IT INTERPOLATES LOGARITHMICALLY.
C    FOR FINE GRID IT INTERPOLATES FROM COARSE GRID OUTPUT.
C* LAST REVISION 8/17/79
C
      COMMON/MNL/M,N,L
      COMMON /CVOS/ IB,JB,IZ,JZ,IV,DSI,IXZ,JYZ
      COMMON/RARS/RHS(21,21,10)
      COMMON/UARS/U(21,21,10),UA(21,21,10),V(21,21,10),VA(21,21,10)
      COMMON/WARS/W(21,21,10),WA(21,21,10)
      COMMON/CSFC/SFCHT(21,21),SIGMA(10),RHO(10),X(21),Y(21)
      COMMON /PARMS/ ZTOP,DS,DSIGMA,MM1,NM1,LM1,XHT1,XHT2,X1,Y1,X2,Y2,UG
     1 ,VG,EDDYK,Z0,CORIO,ALPHA,AS,RI,PIHALF,WTH,WTV,RATIO,TDSI
      COMMON/CTOP/ MI,NI,MR,NR,HTOP
      COMMON /BLHT/ BLT(21,21),HSITE, AVTHK, SLFAC
      DIMENSION  A(28,21),B(28,21),C(28,21)
      DIMENSION UX(450),VX(450),Z(450),IS(2220),XG(5),YG(5)
       DIMENSION XS( 5),YS( 5),US( 5),VS( 5),ZS( 5),ES( 5),YX(40),XX(40)
      DATA WGHT,AHS,LL4/2.0,150.0,4/
      DATA ESS/304.8/
    2 FORMAT(4X,13F4.0)
    3 FORMAT(4X,-2P13F5.0)
    4 FORMAT(I10,F10.4)
    5 FORMAT(3F10.2)
    6 FORMAT(4X,-2P14F6.2)
    7 FORMAT(1H )
    8 FORMAT(4X,-5P3F10.2)
    9 FORMAT(2X,*EIGENVECTOR NO*,I3)
       PRINT 9001
 9001 FORMAT (/* BEGIN SUBROUTINE INWND*/)
      IF (NUM.GT.0) GO TO 100
      LT=L
      MT=N
      NT=M
      IT=MT*NT
      DSS=DS
      YMIN=Y(1)
      XMIN=X(1)
      YD=DSS
      XD=YD
      YMAX=(MT-1)*DSS+YMIN
      CALL BOUNDS(0,MT,NT,YMAX,XMIN,YD,XD,YX,XX)
       READ 5, SLAT, SLNG
       PRINT 9007, SLAT, SLNG
C  READ IN NO OF DATA POINTS.
       READ 4, JT
       PRINT 9003, JT
C* READ LAT YS, LONG XS OF STATIONS (DEG) AND CONVERT TO XS YS (CM)
C  MEASURED FROM SW CORNER OF COARSE GRID
       READ    9015, (YS(J), XS(J),J=1,JT)
       PRINT 9004
       PRINT   9015, (YS(J), XS(J),J=1,JT)
      DO 15J=1,JT
       XS(J) = (XS(J) - SLNG)*(111.0 *COS(SLAT/57.295))
       YS(J) = (YS(J) - SLAT)*111.0
       XS(J) = XS(J) + IXZ * DSI
       YS(J) = YS(J) + JYZ * DSI
       XG(J) = XS(J)/DSI
       YG(J) = YS(J)/DSI
       XS(J) = XS(J) * 100000.0
```

```
      YS(J) = YS(J) * 100000.0
   15 CONTINUE
      PRINT 9008
      PRINT 9011, (XS(J), YS(J),XG(J),YG(J),J=1,JT)
C  INITIATE SUBROUTINE NET (GRID POINT ANALYSIS)
      CALL NET  (JT,JT,WGHT,JT,MT,NT,YS,XS,VS,US,ZS,YX,XX,VX,UX,Z,IS)
      GO TO 300
  100 IF (NUM.GT.1) GO TO 200
C  READ IN WIND COMPONENTS FOR EACH DATA POINT.
      READ 4,IV
      PRINT 9,IV
      READ 9015, (US(J),VS(J),J=1,JT)
      PRINT9015, (US(J),VS(J),J=1,JT)
      READ 5, UGEOS, VGEOS
      PRINT 9006, UGEOS, VGEOS
C     WRITE (5) VS,US
      DO 27 J=1,JT
   27 ZS(J)=SQRT(US(J)*US(J)+VS(J)*VS(J))
C* USE NET TO GET GRID PT SURFACE WIND ANALYSIS
      CALL NET(1,1,0.05,JT,MT,NT,YS,XS,VS,US,ZS,YX,XX,VX,UX,Z,IS)
      CALL NET(2,1,0.05,JT,MT,NT,YS,XS,VS,US,ZS,YX,XX,VX,UX,Z,IS)
        PRINT 9015, (UX(I),I=1,IT)
        PRINT 9016, (VX(I),I=1,IT)
 9016 FORMAT (/5X,21F5.0)
C* MAKE A LOG INTERPOLATION BETWEEN SFC AND GEOSTROPHIC WINDS
       DO 50  J =1,MT
       DO 50  I =1,NT
        IR = (MT-J) *NT +I
C* ASSIGN EFFECTIVE ANEM. HT FOR LOWEST POINT
       AH = 1000.0 * (RHS(I,J,LT)/AVTHK)
       AA = ALOG(AH)
       BB = 1.0/(ALOG(RHS(I,J,LT)) -AA)
       UBB = BB * (UGEOS - UX(IR))
       VBB = BB * (VGEOS - VX(IR))
       UAA = UX(IR)- UBB * AA
       VAA = VX(IR)- VBB * AA
      DO 40 LV = 2,LT
       ZL = ALOG( RHS(I,J,LV))
       U(I,J,LV) =   UAA + UBB* ZL
       V(I,J,LV) =   VAA + VBB * ZL
   40 CONTINUE
   50 CONTINUE
      GO TO 250
  200 CONTINUE
C  INTERPOLATES VALUES OF FINE GRID FROM VALUES OF COARSE GRID.
      IZ1=IZ-1
      XD=(IB-1.0)/IZ
      YD=(JB-1.0)/JZ
      IG=XD
      JG=YD
      ID=(XD-IG)*IZ+0.00001+ 1
      IE=IB+M-1
      JE=JB+N-1
      IBB=IG*IZ+1
      IEE=(IE+IZ-2)/IZ
      IEE=IEE*IZ+1
  176 FORMAT(2X,5I10,2F10.2)
      L1=L+1
      K=0$ DO 180 KX=1,L1,2$ K=K+1$KY=KX$ IF (KX.EQ.L1) KY=KX-1
      DO 170 I=IBB,IEE,IZ
      IO=(I-1)/IZ+1
```

```
      IX=I-IBB+1
      DO 170 J=JB,JE
      JX=J-JB+1
      Y1=(J-1.0)/JZ+1.0
      J1=Y1
      J2=J1+1
      FJ=Y1-J1
      A(IX,JX)   =FJ*(UA(IO,J2,K)-UA(IO,J1,K))+UA(IO,J1,K)
      B(IX,JX)   =FJ*(VA(IO,J2,K)-VA(IO,J1,K))+VA(IO,J1,K)
      C(IX,JX)   =FJ*(WA(IO,J2,K)-WA(IO,J1,K))+WA(IO,J1,K)
  170 CONTINUE
      IX=0
      DO 175 IYT=IBB,IEE,IZ$ IY=IYT-IBB+1
      IX=IX+1
      DO 175 IYY=1,IZ1
      IX=IX+1
      FJ=IYY*1.0/IZ
      DO 175 JX=1,N
      A(IX,JX) =FJ*(A(IY+IZ,JX)-A(IY,JX))+A(IY,JX)
      B(IX,JX) =FJ*(B(IY+IZ,JX)-B(IY,JX))+B(IY,JX)
      C(IX,JX) =FJ*(C(IY+IZ,JX)-C(IY,JX))+C(IY,JX)
  175 CONTINUE
      MID=M+ID-1
      DO 177 JX=1,N
      IX=0
      DO 177 IY=ID,MID
      IX=IX+1
      U(IX,JX,KY)=A(IY,JX)
      V(IX,JX,KY)=B(IY,JX)
      W(IX,JX,KY)=C(IY,JX)
C     IF (JX.EQ.1.AND.K.EQ.4) PRINT 176,MID,JX,IY,IX,K,U(IX,JX,K)
C    2              ,A(IY,JX)
  177 CONTINUE
  180 CONTINUE
      FIG=0.5**0.142
      DO 240 K=2,L,2$ KP1=K+1$ IF (K.EQ.L) KP1=K
      DO 240 JX=1,NS  DO 240 IX=1,MS IF (K.GT.2) GO TO 235
C* USE LOG EXTRAPOLATION FOR LEVEL 2
       Z5 = ALOG(RHS(IX,JX,5))
       Z3 = ALOG(RHS(IX,JX,3))
       Z2 = ALOG(RHS(IX,JX,2))
       U(IX,JX,2) =((U(IX,JX,5)-U(IX,JX,3))/(Z5-Z3))*(Z2-Z3)+U(IX,JX,3)
       V(IX,JX,2) =((V(IX,JX,5)-V(IX,JX,3))/(Z5-Z3))*(Z2-Z3)+V(IX,JX,3)
       W(IX,JX,2) =((W(IX,JX,5)-W(IX,JX,3))/(Z5-Z3))*(Z2-Z3)+W(IX,JX,3)
      GO TO 240
  235 U(IX,JX,K)=0.5*(U(IX,JX,K-1)+U(IX,JX,KP1))
      V(IX,JX,K)=0.5*(V(IX,JX,K-1)+V(IX,JX,KP1))
      W(IX,JX,K)=0.5*(W(IX,JX,K-1)+W(IX,JX,KP1))
  240 CONTINUE
  250 CONTINUE
       PRINT 9002
  300 RETURN
 9002 FORMAT (/* END OF SUBROUTINE INWND*/)
 9003 FORMAT (//*  THE NUMBER OF INPUT WINDS =*I3/)
 9004 FORMAT (//*   LATITUDE AND LONG OF STATIONS*/)
 9003 FORMAT (/*   GEOSTROPHIC WIND, CPS, U COMP. =*F8.1,*       V COMP.
     +=*F8.1/)
 9007 FORMAT (//*  THE SITE IS AT LAT =*F9.3,*  AND LONG=*F9.3)
 9008 FORMAT (//*   X AND Y OF STATIONS IN CM AND IN GRID UNITS FROM SW
     +CORNER*)
 9011 FORMAT (/4X,2F11.0,8X,2F10.1)
 9015 FORMAT (2F10.2)
      END
```

```
      SUBROUTINE NET(KQ,IDS,WIN,JJ,M9,N9,YS,XS,VS,US,HS,Y,X,V,U,H,IS)
      DIMENSION DS(150),JS(150),IQ(150)
      DIMENSION YS(1),XS(1),VS(1),US(1),HS(1)
      DIMENSION Y(1),X(1),V(1),U(1),H(1),IS(1)
      DATA KSW,ALPH,UNIL/4,2.5,5000.0/
      DATA DYL,DCK/1.0E12,3.2E7/
      IF(KQ.GT.2) GO TO 18
      KQ5=KQ-1+KSS5
      L=0
      M=L
      I=0
   75 M=M+1
      IF (M-M9)77,77,100
   77 N=0
      YLM=Y(M)
   80 N=N+1
      IF (N-N9)81,81,75
   81 L=L+1
      NOD=0
      K=NOD
      XLN=X(N)
      IF (KQ-1)82,82,83
   82 U(L)=0.0
      V(L)=U(L)
      H(L)=V(L)
      NOD=0
      DVH=0.0
      DUH=DVH
      DHH=DUH
      DNH=DHH
      GO TO 84
   83 DYVH=0.0
      DYUH=DYVH
      DYHH=DYUH
      DXVH=DYHH
      DXUH=DXVH
      DXHH=DXUH
      DYYH=DXHH
      DXXH=DYYH
      DXYH=DXXH
      DYH=DXYH
      DXH=DYH
      W=WIN
      DNH=W
      NOD=1
      K=0
      DHH=H(L)*W
      DUH=U(L)*W
      DVH=V(L)*W
   84 K=K+1
      IF (K-KS)85,85,90
  384 I=I+KS-K
      GO TO 90
   85 I=I+1
      IF (NOD-KQ5)86,384,384
   86 J=IS(I)
      IF (J)84,84,87
   87 IF (ABS(US(J)).GT.UNIL)GO TO 84
      XSJ=XS(J)
      YSJ=YS(J)
      USJ=US(J)
```

```
      VSJ=VS(J)
      HSJ=HS(J)
      DYS=YSJ-YLM
      DXS=XLN-XSJ
      DYS2=DYS*DYS+DXS*DXS
      DXS2=0.5*DYS2
      IF (IDS.EQ.0)GO TO 385
      USK=USJ
      VSK=VSJ
      IF (KQ.EQ.1)GO TO 388
      USK=USJ+U(L)
      VSK=VSJ+V(L)
  388 DXS1=USK*USK+VSK*VSK+0.01
      DXS2=(USK*DYS-VSK*DXS)
      DXS2=DXS2*DXS2/DXS1
  385 W=DYL/(DYS2+DXS2*ALPH+DYL)
      NOD=NOD+1
      DNH=DNH+W
      HSJ=HSJ*W
      USJ=USJ*W
      VSJ=VSJ*W
      DHH=DHH+HSJ
      DUH=DUH+USJ
      DVH=DVH+VSJ
      IF (KQ-1)89,84,89
   89 DYH=DYH+DYS*W
      DXH=DXH+DXS*W
      DXYH=DXYH+DXS*DYS*W
      DXXH=DXXH+DXS*DXS*W
      DYYH=DYYH+DYS*DYS*W
      DXHH=DXHH+HSJ*DXS
      DYHH=DYHH+HSJ*DYS
      DXUH=DXUH+USJ*DXS
      DYUH=DYUH+USJ*DYS
      DXVH=DXVH+VSJ*DXS
      DYVH=DYVH+VSJ*DYS
      GO TO 84
   90 CONTINUE
      IF (KQ-1)94,91,94
   91 IF (NOD-2)80,92,92
   92 IF (DNH)80,80,93
   93 DNH=1.0/DNH
      H(L)=DHH*DNH
      U(L)=DUH*DNH
      V(L)=DVH*DNH
      GO TO 80
   94 IF (NOD-3)80,80,95
   95 D=DYH*DYH-DNH*DYYH
      E=DXYH*DYH-DXH*DYYH
      A=DXH*DYH-DNH*DXYH
      B=DXXH*DYH-DXH*DXYH
      BDAE=B*D-A*E
      IF (BDAE)97,80,97
   97 BI=1.0/BDAE
      C=DXHH*DYH-DHH*DXYH
      F=DYHH*DYH-DHH*DYYH
      CU=DXUH*DYH-DUH*DXYH
      FU=DYUH*DYH-DUH*DYYH
      CV=DXVH*DYH-DVH*DXYH
      FV=DYVH*DYH-DVH*DYYH
      H(L)=(B*F-C*E)*BI
```

```
      U(L)=(B*FU-CU*E)*BI
      V(L)=(B*FV-CV*E)*BI
      GO TO 80
100   CONTINUE
      RETURN
 18   CONTINUE
      KS=KQ
      KSS5=IDS
      DLCK=DCK*DCK
      JCT=150
      JS(JCT)=-1
      DS(JCT)=DLCK
      JC2=JCT-2
      L=0
      M=L
      I=0
 20   M=M+1
      N=0
      YLM=Y(M)
 25   N=N+1
      L=L+1
      J=0
      JT=JJ
      XLN=X(N)
      XLCK=DLCK
 29   JC=0
      J=JC
 30   J=J+1
      DYS=YS(J)-YLM
      DXS=XLN-XS(J)
      DLS=DYS*DYS+DXS*DXS
      IF (DLS-XLCK)32,33,33
 32   JC=JC+1
      IF (JC.LT.JCT)GO TO 31
      XLCK=XLCK*0.75
      GO TO 29
 31   DS(JC)=DLS
      JS(JC)=J
      IYS=0
      IXS=1
      IF (DXS.LT.0)IXS=2
      IF (DYS.LT.0)IYS=2
      IQ(JC)=IYS+IXS
 33   IF (J-JT)30,34,34
 34   KP=0
      K=0
      ISW=1
      JQ=ISW
      JX=JC
      IF (KSW.LT.1)ISW=2
 35   K=K+1
      SIL=DLCK
      J=0
      I=I+1
      KP=KP+1
      JC=JCT
 40   J=J+1
      IF (J.LE.JX)GO TO (41,42)ISW
      GO TO 45
 41   IF (IQ(J).NE.JQ)GO TO 40
 42   IF (DS(J)-SIL)44,40,40
```

```
44 SIL=DS(J)
   JC=J
   GO TO 40
45 DS(JC)=DLCK
   IS(I)=JS(JC)
   JQ=JQ+1
   IF (JQ.GT.4)JQ=1
   IF (KP.EQ.KSW)ISW=2
   IF (JC.LT.JCT)GO TO 49
   IF (KP.GT.KSW)GO TO 49
   K=K-1
   I=I-1
   GO TO 35
49 IF (K-KS)35,50,50
50 IF (N-N9)25,55,55
55 IF (M-M9)20,60,60
60 CONTINUE
   RETURN
   END
```

```
      SUBROUTINE RELAX3(FA,RHT,WDW)
      COMMON/MNL/M,N,L
      COMMON /CISV/ ISV(21,21), NREL
      COMMON/RARS/RHS(21,21,10)
      COMMON/UARS/U(21,21,10),UA(21,21,10),V(21,21,10),VA(21,21,10)
      COMMON/WARS/W(21,21,10),WA(21,21,10)
      COMMON/CSFC/SFCHT(21,21),SIGMA(10),RHO(10),X(21),Y(21)
      COMMON /PARMS/ ZTOP,DS,DSIGMA,MM1,NM1,LM1,XHT1,XHT2,X1,Y1,X2,Y2,UG
     1 ,VG,EDDYK,Z0,CORIO,ALPHA,AS,RI,PIHALF,WTH,WTV,RATIO,TDSI
      COMMON/ZETA/ZETA(10),F1(10),F2(10),F3(10),DZETA
      DIMENSION FA(21,21,10),RHT(21,21,10)
      DATA FACTOR, EPS /1.5, 1.0E-02/
      DM=1.0/(DS*DS)
      DM4=4.0*DM
      DPI=1.0/(DZETA*DZETA)
      WDP=WDW*DPI
      DZI=0.5*WDW/DZETA
       PRINT 9001
 9001 FORMAT (/* BEGIN SUBROUTINE RELAX*)
      NSC=0
   88 REMX=0.0
      DO 1 K=2,LM1
      F2K=F2(K)*DZI
      F3K=F3(K)*WDP
      PK=1.0/(DM4+F3K+F3K)
      DO 1 I=2,MM1
      DO 1 J=2,NM1
      IF (ISV(I,J).EQ.1) GO TO 1
      FA1=FA(I,J,K)
      FA2=FA1+FA1
      BB=(FA(I+1,J,K)+FA(I-1,J,K)+FA(I,J+1,K)+FA(I,J-1,K)-FA2-FA2)*DM
     1   +(FA(I,J,K+1)-FA(I,J,K-1))*F2K
      CC=    F3K*(FA(I,J,K+1)+FA(I,J,K-1)-FA2)
      RE=(RHT(I,J,K)-BB-CC)*PK
      FA(I,J,K)=FA1-FACTOR*RE
      IF (ABS(RE).GT. REMX) REMX = ABS(RE)
    1 CONTINUE
      NSC=NSC+1
      PRINT 9,   NSC,REMX
      IF(REMX-EPS) 89,89,85
   85  IF (NSC .LT. NREL) GO TO 88
   89 CONTINUE
    9 FORMAT(2X,13HSCAN COUNT = ,I5,5X,15HMAX RESIDUAL = ,E11.3)
       PRINT 9002
 9002 FORMAT (/* END OF SUBROUTINE RELAX*)
      RETURN
      END
```

```
      SUBROUTINE SETBLT
C** THIS SUBROUTINE SETS THE HEIGHT OF THE BNDY LAYER TOP.  AVTHK IS
C  AVER. BL THICKNESS OVER AREA. SLFAC CONTROLS THE SLOPE, IF 0 THE
C  TOP IS FLAT, IF 1 THE BL TOP FOLLOWS THE TERRAIN.
C    BY R  ENDLICH,  JULY 79.
C* LAST REVISION 8/1/79
      DIMENSION B(21,21)
      COMMON/MNL/M,N,L
      COMMON /SITE/ IXS, JYS, THSITE, IGRID
      COMMON /BLHT/ BLT(21,21),HSITE, AVTHK, SLFAC,STHK
      COMMON /CSFC/ SFCHT(21,21),SIGMA(10),RHO(10),X(21),Y(21)
      PRINT 9001
      THK = AVTHK
        IF (IGRID .GT. 1)  THK = THSITE
        ITER = 0
 10    ITER = ITER + 1
        SUM1 = 0.0
         Q1 = 0.0
       DO 50  I =1,M
       DO 50 J = 1,N
         BLT(I,J) = THK + (SLFAC * SFCHT(I,J)) + (1.0 -SLFAC) *HSITE
         IF (SFCHT(I,J) .GT. (BLT(I,J)-  STHK )) BLT(I,J) = SFCHT(I,J)
     +          + STHK
       SUM1 = SUM1 + (BLT(I,J) - SFCHT(I,J))
        Q1 = Q1 + 1.0
 50    CONTINUE
       ATH = SUM1/Q1
       THK = THK + (AVTHK - ATH)
       THSITE = BLT(IXS,JYS) - SFCHT(IXS,JYS)
       PRINT 9010, AVTHK,ATH, THSITE
        DIFF = ABS(AVTHK - ATH)
        IF (ITER  GT.  9) GO TO 52
        IF (IGRID .EQ. 1 .AND. DIFF .GT. 100.0) GO TO 10
 52    CONTINUE
       DO 55  JP = 1,N
       DO 55  IP = 1,M
         B(IP,JP) = .01 * BLT(IP,JP)
 55    CONTINUE
       PRINT 9115
       DO 60  JP = 1,N
       JR = N + 1 -JP
 60    PR.NT 9100,  ( B(IP,JR),IP=1,M)
      PRINT 9002
 9001 FORMAT (1H1,*     BEGIN SUBROUTINE SETBLT*/)
 9002 FORMAT (//*    END OF SUBROUTINE SETBLT*/)
 9010 FORMAT  (/*   INITIAL AV. THICKNESS, CM=*F10.1,
     +  *    ACTUAL AV. THICKNESS =*F10.1,
     + *   SITE THICKNESS =*F10.1/)
 9100 FORMAT (/5X,22F5.0)
 9115 FORMAT (//*   HEIGHT OF BNDY LAYER TOP, M   */)
         RETURN
         END
```

```
      SUBROUTINE   TOPO(NUM)
C
CC   READ  AND  COMPUTE TOPOGRAPHY AT GRID POINTS
C* LAST REVISION 7/27/79
C
      COMMON/MNL/M,N,L
      COMMON/CTOP/ MI,NI,MR,NR,NGRID,HTOP
      COMMON/RARS/RHS(21,21,10)
      COMMON/CSFC/SFCHT(21,21),SIGMA(10),RHO(10),X(21),Y(21)
      COMMON /BLHT/ BLT(21,21),HSITE, AVTHK, SLFAC
      DIMENSION XF(23,23),YF(23,23)
    2 FORMAT(11F6.0)
    3 FORMAT(4X,-2P14F5.0)
    4 FORMAT(2X,21F5.0)
    6 FORMAT(4X,-2P19F5.0)
       PRINT 9001
 9001 FORMAT (/* BEGIN SUBROUTINE TOPO*)
      IF (NUM.GT.0) GO TO 10
C  READS TERRAIN HEIGHT VALUES AT GRID POINTS IN FEET
C     COARSE GRID.
      N2=NI+1
      M2=MI+1
       PRINT 9006
       PRINT 9003
      DO 8 J=2,N2
      READ  2, (XF(I,J),I=2,M2)
    8 CONTINUE
       DO 118 J = 2,N2
      JR = N2 + 2 -J
      PRINT 4, (XF(I,JR),I =2,M2)
  118  CONTINUE
      IF (NGRID.LT.2) GO TO 150
C     FINE GRID (IF NGRID EQ 2)
      M2=MR+1
      N2=NR+1
       PRINT 9004
      DO 9 J=2,N2
      READ  2, (YF(I,J),I=2,M2)
    9 CONTINUE
       DO 119 J = 2,N2
      JR = N2 + 2 -J
      PRINT 4, (YF(I,JR),I =2,M2)
  119  CONTINUE
       GO TO 150
   10 J=1
      DO 12 JX=1,N
      I=1
      J=J+1
      DO 12 IX=1,M
      I=I+1
      IF (NUM.GT.1) GO TO 11
      SFCHT(IX,JX)=XF(I,J)
      GO TO 12
   11 CONTINUE
      SFCHT(IX,JX)=YF(I,J)
   12 CONTINUE
C  CONVERTS TERRAIN HEIGHT VALUES AT GRID POINTS TO CENTIMETERS.
      DO 22J=1,N
      DO 22I=1,M
   22 SFCHT(I,J)=30.48*SFCHT(I,J)
   25 CONTINUE
```

```
C** SET BNDY LAYER TOP.
       CALL SETBLT
C DENOTE GEOMETRIC HEIGHT ABOVE TERRAIN BY RHS
      DO 67 I=1,M
      DO 67 J=1,N
      DO 67 K=1,L
      ZVAR = BLT(I,J) - SFCHT(I,J)
   67 RHS(I,J,K)=SIGMA(K)*ZVAR
  150  PRINT 9002
 9002 FORMAT (/* END OF SUBROUTINE TOPO*/)
 9003 FORMAT (/* TERRAIN HTS, COARSE GRID, FEET*/)
 9004 FORMAT (/* TERRAIN HTS, FINE GRID, FEET*/)
 9006 FORMAT (/*   PRINTOUT IS REVERSE OF INPUT - HAS NORTH ROW 1ST*/)
       RETURN
      END
```

6. Program REWND

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```
      PROGRAM REWND (INPUT,OUTPUT, TAPE3, TAPE2, TAPE8=INPUT)
C
C  THIS PROGRAM CALCULATES HOURLY WINDS FROM EIGENVECTOR SOLUTIONS AND
C  HOURLY TRANSFORMED OBSERVATIONS AT SURROUNDING SITES.
C
      DIMENSION ITYPE(24),USOL(5,20),VSOL(5,20),UMN(5),VMN(5),A(20)
     1,NNDAY(5),ISTAB(10), AVTHK(5),SFAC(5),STHK(5)
      READ   (8,3) NEIG,NTYPE
 3    FORMAT(2I5)
C
C     NUMBER OF TYPES OF SOLUTION (INTYPE).
C     NUMBER OF EIGENVECTORS TO BE USED (NEIG)
C     NUMBER OF VARIABLES (NVAR)
C     NUMBER OF SITES (NSITE=NVAR/2)
C
      READ(3) IDATE,IHOUR,NVAR,NSITE
      PRINT 3333, IDATE,IHOUR,NVAR,NSITE
 3333 FORMAT(1X,5I10)
C
C     READING TAPE TO GET NVAR=NO. OF VARIABLES,
C     WHICH IS = TOTAL NO. OF EIGENVECTORS, BUT NOT
C     NECESSARILY TO NUMBER USED TO CONSTRUCT WINDS
C     (NEIG).
C
      BACKSPACE 3
      INVEIG=NVAR-NEIG+1
C
C     READING COMPLEX SOLUTIONS FOR EIGENVECTORS (J) AND MEANS--
C     AS DERIVED FOR EACH TYPE (I) OF MIXING DEPTH.
C
 2    READ (8,1000) JSITE,IV,UDUM,VDUM,NTDAY,AVA,SLS,STS
C
C     BLANK CARD STOPS READING
      IF(JSITE.EQ.0) GO TO 7
 1000 FORMAT (2I5,2F10.2,I5,F10.0,F5.1,F8.0)
      AVTHK(NTDAY)=AVA
      SFAC(NTDAY)=SLS
      STHK(NTDAY)=STS
      NNDAY(NTDAY)=NTDAY
C
C     JSITE=SITE IDENTIFIER (NOT USED)
C     IV=EIGENVECT NO. (=0 FOR MEANS)
C     UDUM,VDUM=COMPLEX MODEL SOLUTIONS FOR THIS EIGENVECT
C                 NO. AND SOLUTION TYPE (NTDAY)
C     NTDAY=CASE TYPE E.G. DAY=1, NIGHT =2
C     AVTHK,SFAC,STHK= AV.MIX.LAYER THICKNESS (M), SLOPE
C                         FACTOR, AND MINIMUM LAYER THICKNESS(M)
C                         USED FOR THIS CASE---NOT USED.
C
C     SOLUTIONS FOR VARIOUS CASE TYPES AND EIGENVECTORS ASSIGNED
C     TO ARRAYS BELOW
C
      IF(IV.EQ.0) GO TO 5
      USOL(NTDAY,IV)=UDUM
      VSOL(NTDAY,IV)=VDUM
      GO TO 6
C
C     COMPLEX MODEL SOLUTIONS FOR MEAN INPUTS
C
 5    UMN(NTDAY)=UDUM
      VMN(NTDAY)=VDUM
```

```
 6     GO TO 2
 7     CONTINUE
C
C      DEFINE TYPE OF MIXING FOR EACH HOUR OF THE DAY
C
       READ(8,2000) (ITYPE(IHR),IHR=1,24)
 2000  FORMAT(24I3)
       NCASE=1
       PRINT 1001
 1001  FORMAT(1H1,*EIGVECT. *,3X,*TYPE*,5X,*U*,9X,*V*,
      12X,*D/N IND*,4X,*AV THK*,5X,*SLOPE*,3X,*MIN THK*)
       DO 1100 I=1,NTYPE
       PRINT 1002, I,UMN(I),VMN(I),NNDAY(I),AVTHK(I),SFAC(I),STHK(I)
 1002  FORMAT(1X,*MEAN *,I8,2F10.3,I5,6X,F9.1,3X,F6.2,F7.1)
       DO 1100 J=INVEIG,NVAR
       PRINT 1003, J,I,USOL(I,J),VSOL(I,J)
 1003  FORMAT(1X,I5,I7,2F10.3)
 1100  CONTINUE
       PRINT 1004, ((K),K=1,24),(ITYPE(L),L=1,24)
 1004  FORMAT(1H0,*CASE TYPES*/1X,*HOUR=*,24I3/
      *1X,*TYPE=*,24I3)
C
C      READING THE INNER PRODUCTS (A) OF THE OBSERVED DATA SETS
C      AND THE EIGENVECTORS FOR EACH DATE (IDATE) AND HOUR (IHOUR)
 30    READ(3) IDATE,IHOUR,LVAR,LSITE,(A(J),J=1,NVAR),(ISTAB(J),
      1J=1,NSITE)
       IF(EOF(3).NE.0) GO TO 99
C
C      SELECTING SOLUTION TYPE APPROPRIATE TO THE HOUR
       II=ITYPE(IHOUR)
C
C      GETTING U,V COMPONENTS FOR MEAN SOLUTIONS
       U=UMN(II)
       V=VMN(II)
C
C      SUMMING WEIGHTED (*A) SOLUTIONS FOR EACH EIGENVECTOR
       DO 35 K=INVEIG,NVAR
       U=U+A(K)*USOL(II,K)
 35    V=V+A(K)*VSOL(II,K)
C
C      GETTING SPEED AND DIRECTION
       S=SQRT(U*U+V*V)
       IF (S.EQ.0.0) GO TO 40
       D=(ATAN2(V,U))*57.2719
       GO TO 45
 40    D=270.0
 45    D=270.0-D
       IF(D.LT.0.) D=D+360.0
       D=AMOD(D,360.)
       XJ=IDATE
       HOUR=IHOUR
C
C      WRITING RECONSTRUCTED WIND INFORMATION.  PRINT RESULTS
C      ONCE PER 100 CASES (3-HR DATA) FOR INSPECTION
       WRITE(2) XJ,HOUR,U,V,S,D
       IMPRNT=MOD(NCASE,15)
       IF (IMPRNT.EQ.1)
      1PRINT 3005, NCASE, IDATE, IHOUR,U,V,S,D,(A(KK),KK=1,NVAR)
 3005  FORMAT(*0*,*CASE =*,I8,*DATE =*,I10,* HOUR =*,I8/
      1* U  =*,F10.3,* V =*,F10.3/1X,
      1*SPEED=*,F10.3,* DIRECT=*,F10.3
```

```
     1 /1X,*COEFFICIENTS:*, 12F9.3)
      NCASE=NCASE+1
      GO TO 30
C
C     WRITE END FILE ON TAPE, PRINT NUMBER OF CASES TREATED,
C     REWIND TAPES AND END.
 99   END FILE 2 $ PRINT 9000, NCASE
 9000 FORMAT(1X,*EOF FILE 2*,5X,*NO. OF CASES =*,2X,I6)
      REWIND 2
      REWIND 3
      STOP
      END
```

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7. Program WINDY

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```
      PROGRAM WINDYN(OUTPUT,INPUT, TAPE1)
C
C   CALCULATES RUN DURATIONS IN SPECIFIC CATEGORIES AND SEASONAL AND
C   HOURLY AVERAGE SPEEDS.
C
      DIMENSION LOWS(80),MIDS(80),MOSTS(80),SPDS(24,4),XN(24,4)
     1          , SEA(4),SON(4),SEASUM(4),SEANO(4)
      DATA ALL /3HALL/
      DATA SEA/3HDEC,3HMAR,3HJUN,3HSEP/
      DATA SON/3HFEB,3HMAY,3HAUG,3HNOV/
      SPAST=4.
      N=0
       USED = 0.0
C  USED IS A COUNTER FOR NO. OF HRS USED IN COMPUTATIONS

C
C   SETTING RUNS AND SUMS=0.
C
      DO 50 I = 1,79
         LOWS(I) = 0
         MIDS(I) = 0
         MOSTS(I) = 0
   50 CONTINUE
      DO 52 I = 1,4
         SEASUM(I) = 0.0
         SEANO(I) = 0.0
   52 CONTINUE
      DO 55 J=1,4
      DO 55 I=1,24
      SPDS(I,J) = 0.0
      XN(I,J) = 0.0
   55 CONTINUE
      NMID = 0
      NLO = 0
      NHI = 0
C
C  JULIAN = JULIAN DATE AT START OF RUN THEN CONVERTED TO DAYS SINCE DEC 1.
C
C  SPLOW = LOWEST SPEED AT WHICH GENERATOR OPERATES (M/S)
C  SPHI,TOPSPD = RANGE OF MAXIMUM GENERATED POWER (M/S)
C  UNITS = FACTOR TO CONVERT GIVEN UNITS TO M/S
C  AT= TIME INTERVAL, HRS, BETWEEN RECORDED DATA
C  K --PROGRAM USES EVERY K TH RECORD FOR CALCULATIONS
C  INCT=K*AT,IS INTERVAL HRS BETWEEN RECORDS ACTUALLY USED
C  FOR COMPARISONS USE K=3, INCT=3 FOR REAL HOURLY DATA
C  AND K=1, INCT=3 FOR MODEL (3 HR) DATA
      READ 5000, JULIAN,SPLOW,SPHI,TOPSPD,UNITS,INCT,K
 5000 FORMAT(I3,4F7.2,2I3)
      IF(INCT.EQ.0) INCT=1
      PRINT 5001, JULIAN, SPLOW,SPHI,TOPSPD,UNITS,INCT,K
 5001 FORMAT(1H1,*JULIAN = *,I3,*  SPLOW = *,F7.2,*  SPHI  = *,F7.2,
     1*  TOPSPD = *,F7.2,*  UNITS = *,F7.2,*  TIME STEP = *,I3,
     2*  K =*,I3)
      JULIAN = (JULIAN + 31)
C
  100 READ(1) CASE,HOUR,U,V,S,D
      IF (EOF(1)) 86,120
  120 CONTINUE
      IF(K.EQ.1) GO TO 125
      N = N + 1
      IF(MOD(N,K).NE.1) GO TO 100
```

```
  125 CONTINUE
C  MISSING SPEED = 99.9
      IF(S.EQ.99.9) PRINT 6007, CASE,HOUR
      IF(S.EQ.99.9) GO TO 100
 6007 FORMAT(8H MISSING,2F8.0)
C
C   GETTING HOUR INDEX (IH) AND SEASON INDEX (LSEA-- 1=DEC-FEB,...,4=
C    COUNT NO. OF HOURS USED
C
      USED = USED + 1.0
      IH = HOUR
      S=UNITS*S
      SPAST=S
      ICASE = CASE
      LLL = ICASE/100
      LLL = MOD(LLL,100)
      LSEA = LLL/3 + 1
      IF(LSEA.EQ.5) LSEA = 1
      SEASUM(LSEA) = SEASUM(LSEA) + S
      SEANO(LSEA) = SEANO(LSEA) + 1.0
      SPDS(IH,LSEA) = SPDS(IH,LSEA)+S
      XN(IH,LSEA) = XN(IH,LSEA)  +1.0
C
C    GETTING RUN CATEGORIES AND INCREMENTING
C
      IF (S .GE. SPLOW) GO TO 130
      NHI = 0
      NMID = 0
      NLO = NLO + 1
      GO TO 200
  130 NMID = NMID + 1
      NLO = 0
      IF (S .GT. SPHI .AND. S .LT. TOPSPD) GO TO 140
      NHI = 0
      GO TO 210
  140 NHI = NHI + 1
      GO TO 210
  200 J = 1 + (NLO-1)*INCT
      IF (J .GT. 79) J = 79
      LOWS(J) = LOWS(J) + 1
      GO TO 100
  210 J = 1 + (NMID-1)*INCT
      IF (J .GT. 79) J = 79
      MIDS(J) = MIDS(J) + 1
      IF(NHI.EQ.0) GO TO 100
      J = 1 + (NHI-1)*INCT
      IF (J .GT. 79) J = 79
      MOSTS(J) = MOSTS(J) + 1
      GO TO 100
   86 CONTINUE
       PRINT 6009, USED
 6009 FORMAT (//*  NO. OF OBSERVATIONS =*F9.0//)
C
C   PRINT RUN DURATIONS, CALCULATE AND PRINT AVERAGE SPEEDS.
C
      PRINT 6000
 6000 FORMAT(1H0,*RUN DURATION*,3X,*LT*,5X,*GE*,3X,*BETWEEN*/
     1         3X,*(HOURS)*,4X,*SPLOW*,1X,*SPLOW*,1X,*SPHI-TOPSPD*,
     2*     NORMALIZED TO A YEAR*)
      INSTRT=INCT+1
      DO 300 I = INSTRT,79,INCT
```

```
      J = I-INCT
C     GETTING NUMBER OF TIMES THAT MAXIMUM RUN LENGTH = J FOR
C     THE THREE CRITERIA
      LOW = LOWS(J) - LOWS(I)
      MID = MIDS(J) - MIDS(I)
      MOST = MOSTS(J) - MOSTS(I)
C NORMALIZE HOURS TO A YEAR OF 3 HRLY OBSERVATIONS
       XL = LOW
       XM = MID
       XT = MOST
       PLOW =  8.0 * 365. * XL/USED
       PMID = 8.0 * 365. * XM/USED
       PMOST = 8.0 * 365. * XT/USED
       PRINT 6001, J, LOW, MID, MOST, PLOW,PMID,PMOST
 6001 FORMAT (4X,I2,8X,I4,2X,I4,4X,I4,3(4X,F8.0))
  300 CONTINUE
      PRINT 6005
 6005 FORMAT(/////,1HO*SEASONAL MEANS--*)
      DO 325 I = 1,4
      AVER = SEASUM(I)/SEANO(I)
      PRINT 6006, SEA(I),SON(I),AVER
 6006 FORMAT(10X,A3,* THROUGH *,A3,F6.2,* M/S*)
  325 CONTINUE
      DO 375 LSEA=1,4
      SUM = 0.0
      ZNUM= 0.0
      PRINT 6002
 6002 FORMAT (////,1HO,*HOURLY MEANS--*,/,4X,*HR*, 3X, *MEAN (M/S)* )
      PRINT 6008, SEA(LSEA), SON(LSEA)
 6008 FORMAT (3H    ,A3,* THROUGH *,A3)
      DO 350 IH = 1,24
      SUM = SUM + SPDS(IH,LSEA)
      ZNUM = ZNUM + XN(IH,LSEA)
      IF(XN(IH,LSEA).EQ.0) GO TO 225
      SPEED = SPDS(IH,LSEA)/XN(IH,LSEA)
      GO TO 230
  225 SPEED = -99.9
  230 CONTINUE
      PRINT 6003, IH, SPEED
 6003 FORMAT (4X, I2, F10.3)
  350 CONTINUE
      SUM = SUM/ZNUM
      PRINT 6004, ALL,SUM
 6004 FORMAT (3HO    ,A3, F10.3)
  375 CONTINUE
      STOP
      END
```

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8. Program SPSS

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RUN NAME        FREQUENCIES,CROSSTABS FOR SOUTH DAKOTA(HURON)
FILE NAME       WIND1
VARIABLE LIST   CASENO,HOUR,U,V,SPEED,DIRECT
VAR LABELS      DIRECT,DIRECTION--16 DEGREE BINS/SPEED,
                SPEED--IN CM PER SECOND
INPUT MEDIUM    DISK
INPUT FORMAT    BINARY
N OF CASES      UNKNOWN
COMPUTE         SPEED2=SPEED
COMPUTE         SPEED2=TRUNC(SPEED2/200)
COMPUTE         DIRECT=TRUNC((DIRECT+11.25)/22.5+1)
IF              (DIRECT GT 16)DIRECT = 1
COMPUTE         SPEED4=TRUNC(SPEED/100)
RECODE          SPEED4(0 THRU 3=1)(4 THRU 7=2)
                (8 THRU 11=3)(12 THRU 15=4)(16 THRU HI=5)/
VAR LABELS      SPEED2,SPEED--2 METER PER SECOND BINS/
                SPEED4,SPEED--4 METER PER SECOND BINS
VALUE LABELS    SPEED4(1)0 - 3.99(2)4-7.99(3)8-11.99
                (4)12-15.99(5)16 AND OVER/
TASK NAME       FREQUENCY SPEED--2 METER BINS
FREQUENCY       INTEGER=SPEED2(0,30)
OPTIONS         8
READ INPUT DATA
```

```
RUN NAME         FREQUENCIES,CROSSTABS FOR CALIFORNIA(SAN GORGONIO)
FILE NAME        WIND1
VARIABLE LIST    CASENO,HOUR,DUM1,DUM2,SPEED,DIRECT
VAR LABELS       DIRECT,DIRECTION--22.5 DEGREE BINS/SPEED,
                 SPEED--IN METERS PER SECOND/
INPUT MEDIUM     TAPE
INPUT FORMAT     BINARY
N OF CASES       UNKNOWN
MISSING VALUES   SPEED(99.9)/DIRECT(999.)
COMPUTE          SPEED2=SPEED
COMPUTE          SPEED2=TRUNC(SPEED2/2)
COMPUTE          DIRECT2=TRUNC((DIRECT+11.25)/22.5+1)
ASSIGN MISSING   DIRECT2(-1)
IF               (DIRECT2 GT 16)DIRECT2 = 1
COMPUTE          SPEED4=TRUNC(SPEED)
ASSIGN MISSING   SPEED2,SPEED4(-1)
RECODE           SPEED4(0 THRU 3=1)(4 THRU 7=2)
                 (8 THRU 11=3)(12 THRU 15=4)(16 THRU HI=5)/
VAR LABELS       SPEED2,SPEED--2 METER PER SECOND BINS/
                 SPEED4,SPEED--4 METER PER SECOND BINS/
                 DIRECT2,DIRECTION--22.5 DEGREE BINS/
VALUE LABELS     SPEED4(1)0 - 3.99(2)4-7.99(3)8-11.99
                 (4)12-15.99(5)16 AND OVER/
TASK NAME        FREQUENCY SPEED--2 METER BINS
FREQUENCY        INTEGER=SPEED2(0,30)
OPTIONS          8
READ INPUT DATA
TASK NAME        CROSSTAB SPEED--BINS OF 4 BY DIRECT
CROSSTABS        VARIABLES=SPEED4(1,5),DIRECT2(0,16)/
                 TABLES=SPEED4 BY DIRECT2
STATISTICS       ALL
FINISH
/EOF
```

Appendix C

AN EXAMPLE OF THE RELATIONSHIPS BETWEEN WEATHER PATTERNS AND EIGENVECTORS

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Appendix C

AN EXAMPLE OF THE RELATIONSHIPS BETWEEN WEATHER PATTERNS AND EIGENVECTORS

1. *General*

As shown by Bhumralkar et al. (1978) and also in Section III.C of this report, it is possible to calculate the wind for any given hour from a linear combination of the individual eigenvectors of the data set and the associated coefficients at that time. In this appendix we show how the coefficients are related to different weather patterns to illustrate the significance of the eigenvectors and their coefficients.

For all the sites examined, the most important few eigenvectors can be used to explain the majority of the variance in the data sets. In fact, at several sites the single most important eigenvector accounted for about 2/3 of the total variance. This was not true of Ludington, Michigan, but nearly 90 percent of the variance was explained by the two most important eigenvectors. Each accounted for about half that figure, 45 and 43 percent, respectively.

The coefficient of the principal eigenvector is denoted by a_{10}, and the coefficient of the next most important eigenvector is denoted by a_9. The coefficients a_9 and a_{10} provide a good description of the entire input data set and we can use this fact to classify the data. In the following section, we show how the weather patterns in the vicinity of Ludington vary according to the values of a_9 and a_{10}.

The wind patterns associated with the mean flow and the two principal eigenvectors for Ludington were shown in Figure 3 in the body of this report. In this figure the surface winds are plotted at their appropriate locations and the geostrophic wind appears in the middle of the figure. Wind speeds are indicated by the number near the arrows. It can be seen that the mean flow at the surface is from the west-southwest with speeds on the order of 2 m s^{-1}. The mean geostrophic wind shows the expected clockwise rotation relative to the surface winds.

The two most important eigenvectors describe deviations from the mean that are at approximately right angles to the mean flow or parallel to it. A large positive value of a_{10} will generally rotate the winds counterclockwise toward the north and increase speeds, and a large negative value would cause a clockwise rotation. A large negative value of a_9 would cause the winds to be stronger, but generally from the same direction. A large positive value of a_9 would cause the winds to be weaker than the mean flow, and if sufficiently large would turn the winds in the opposite direction. When a_9 and a_{10} are both small, winds will be near their means. In the next section, the weather maps associated with the various combinations of a_9 and a_{10} are examined.

2. *Weather Patterns Associated with Various Combinations of* a_9 *and* a_{10}

a. *Selection of Cases*

For convenience, the weather maps published by the National Oceanographic and Atmospheric Administration (1978) as part of the daily weather map series were used to define weather patterns. These daily weather maps describe conditions at 1200 GMT (0700 EST). The values of a_9 and a_{10} were examined for this hour for all available dates. All dates were identified when either a_9 or a_{10} were near 0 (an absolute value less than 1) and the other had a value that was either near 0 or large (positive or negative with an absolute value greater than 15). Days when both a_9 and a_{10} were large (positive or negative) were also identified. The weather patterns associated with the various combinations of values of a_9 and a_{10} are presented and discussed in the following sections.

b. *Near Zero Values of* a_9 *and* a_{10}

Four dates in the period from January 1977 through March of 1978 were identified when both a_9 and a_{10} were near zero. For these four dates, a_9 averaged -0.65 and a_{10} averaged -0.175. The dates were 7 March, 7 July, and 14 September 1977, and 16 March 1978. Figure C-1 shows the winds based on the average a_9 and a_{10} values. One would expect that the winds

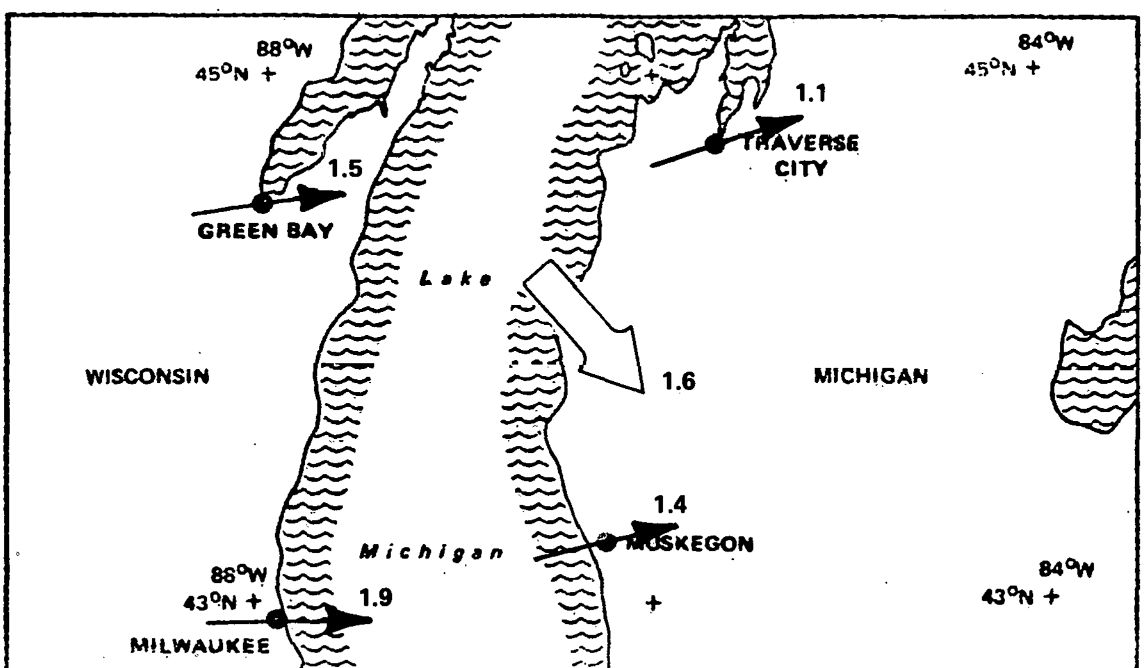


FIGURE C-1 WIND PATTERN FOR NEAR-ZERO VALUES OF a_9 AND a_{10}

would be quite near their mean values and they are. Figure C-2 shows the weather maps associated with these cases. They all have very weak pressure gradients over the northern part of Lake Michigan. As would be expected from the geostrophic wind, the pressure gradients, although light, tend to be from the southwest toward the northeast. In these light wind cases, the surface winds do not always match those reconstructed from the two eigenvectors, especially at the two more northerly sites. As will be seen in subsequent sections, the conditions are better defined for larger values of a_9 and a_{10}.

c. *Large Positive or Negative Values of* a_{10} *With a Small Value of* a_9

On 6 December 1977 the eigenvectors were characterized by a small value of a_9 (0.6) and a large negative value of a_{10} (-20.2). Figure C-3 shows the expected strong northerly component; the geostrophic wind has a speed of nearly 18 m s^{-1}. The surface winds are around 4 to 6 m s^{-1}, (about 10 knots) which is in good agreement with the observed surface wind shown on the weather map for this time. It can be seen from the weather map that the directions actually observed were in generally good agreement with those specified by the values of a_9 and a_{10}.

The weather map shows that this combination of values of a_9 and a_{10} was associated with very strong west-to-east pressure gradient in the vicinity of Ludington. This pressure gradient was the result of a fairly strong low pressure area over central New York and a well defined ridge in the Great Plains states. One could expect the gradient and winds to be reversed if the sign of a_{10} were reversed. Two days were characterized by such conditions, 13 March 1977 and 20 March 1978 (Figure C-4). For these two days, a_9 averaged 0.85 and a_{10} averaged 16.45. This figure also shows the reconstructed winds for these values. The geostrophic wind is relatively strong, approximately 14 m s^{-1}, and from the south-southwest. The surface winds are southerly from about four to five m s^{-1} or about 10 knots. The weather maps for these two days were generally the reverse of those seen on 6 December 1977; the pressure gradient was from east-southeast to the west and northwest. The observed winds were approximately five to ten knots from the south except at the two southerly sites on 7 March 1977.

No days were found in the set when the value of a_{10} at 0700 EST was near 0 at the same time that the value of a_9 was less than -15. However, there were three days with a value of greater than 15 (averaging 18.3) while a_{10} was near 0 (averaging 0.1). Figure C-5 shows the reconstructed winds based on the average values for a_9 and a_{10}. The surface winds are generally from the east-northeast at speeds from about 2 to 4 m s^{-1} (about 5 knots). The geostrophic wind is from the east-southeast at about 15 m s^{-1}. Figure C-6 shows the three weather maps for this wind field type, 28 March and 29 and 30 May 1977. In each case the pressure gradient is toward the south-southwest over central and northern Lake Michigan. This is the appropriate direction for the geostrophic winds shown in Figure C-5. The pressure gradient on 30 May 1977 was somewhat weaker than on the other two dates. The generally easterly or east-northeasterly winds on 30 May 1977 at the surface are in reasonable agreement with those shown in Figure C-6, except at Traverse City, where the wind was calm rather than the expected light east-northeasterly. On 29 May 1977 surface winds are all in reasonably good agreement with those reconstructed using just the two most important eigenvectors. The 28 March 1977 surface winds at the northern sites have a larger than expected northerly component.

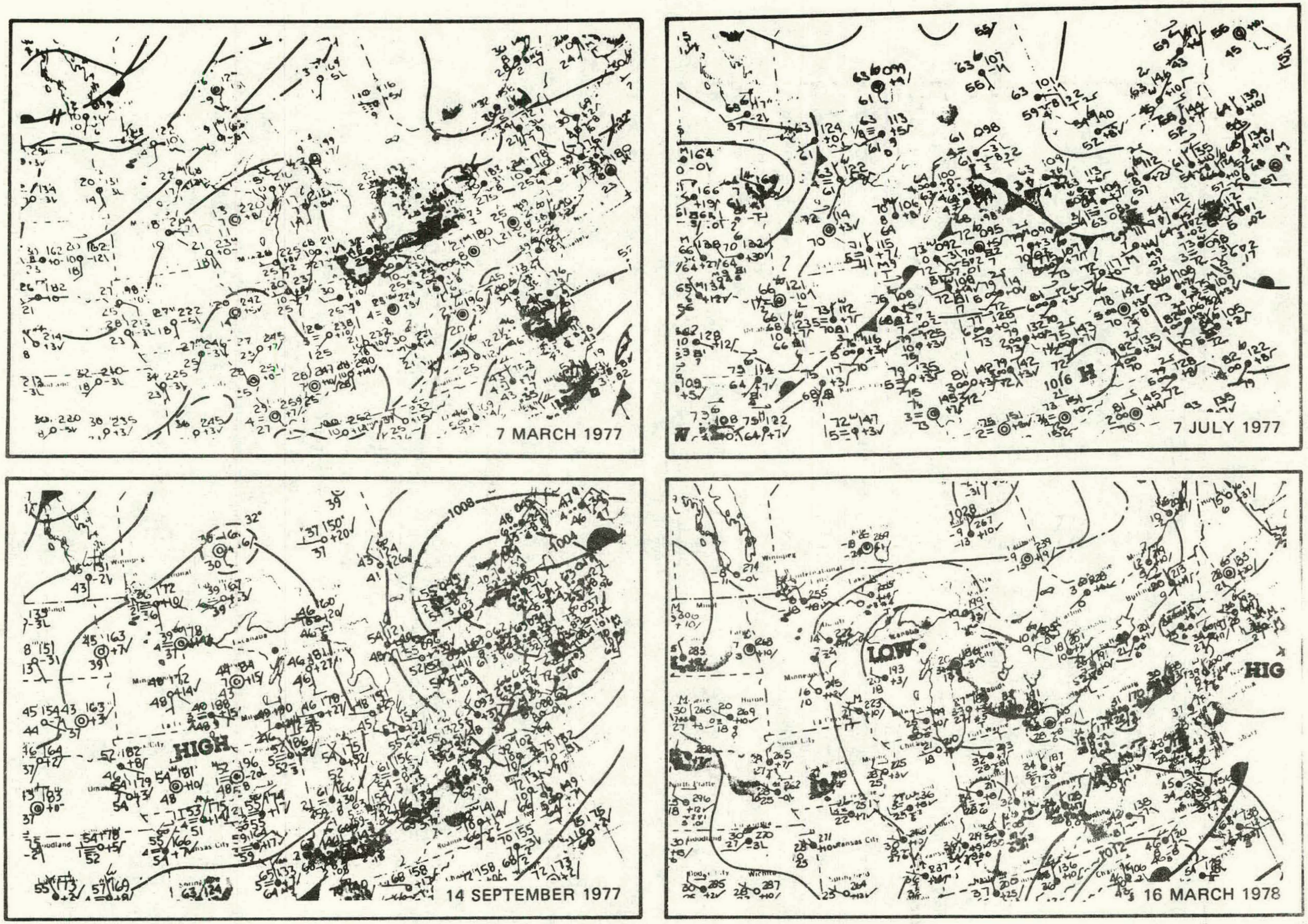
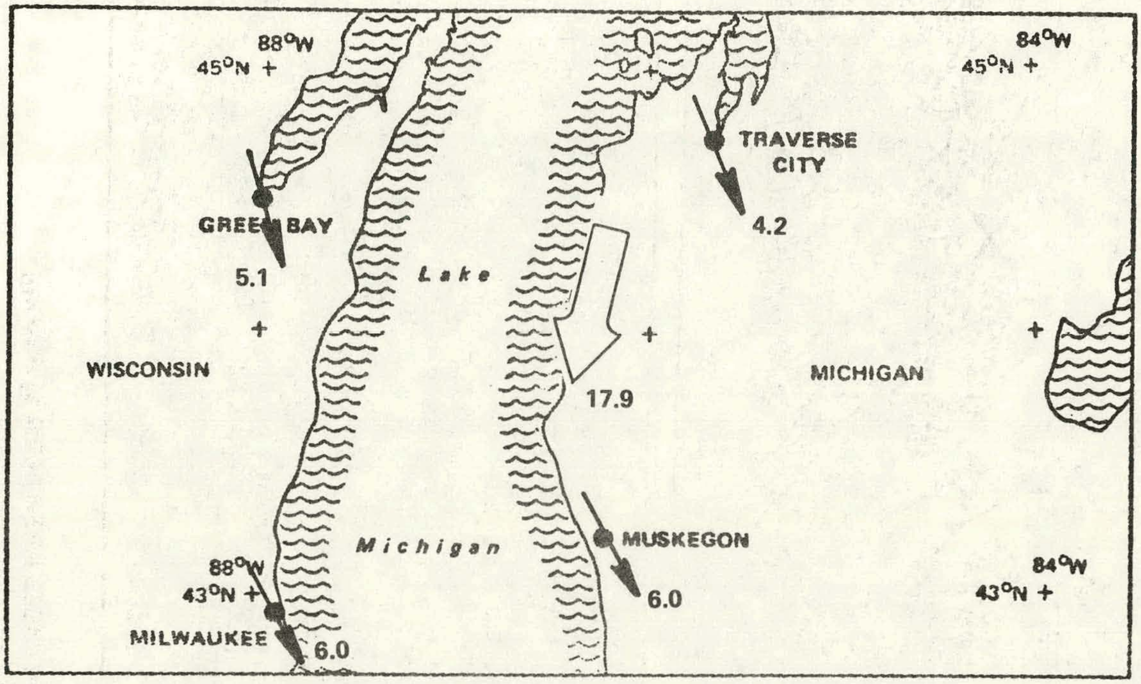


FIGURE C-2 WEATHER MAPS FOR CASES WHEN BOTH a_9 AND a_{10} HAD VALUES NEAR ZERO



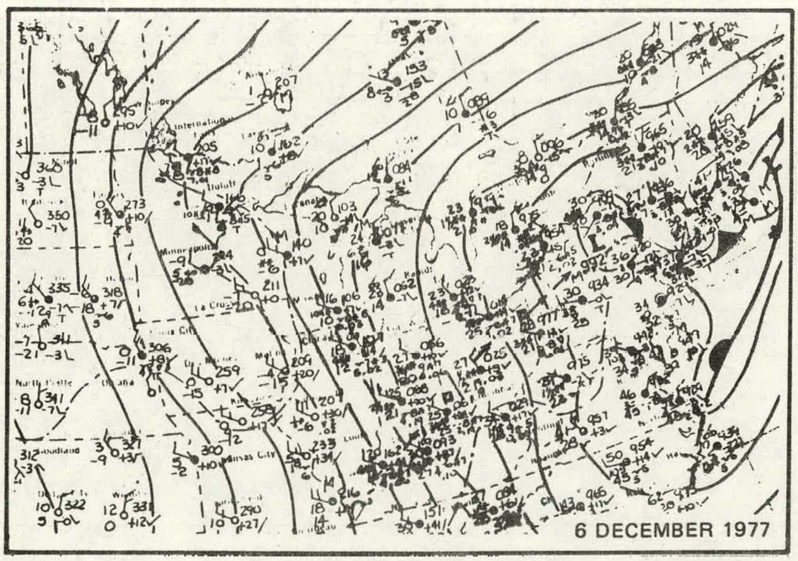


FIGURE C-3 WIND PATTERN FOR A NEAR-ZERO VALUE OF a_9 AND A LARGE POSITIVE VALUE OF a_{10}, AND THE CORRESPONDING WEATHER MAP OF 6 DECEMBER 1977

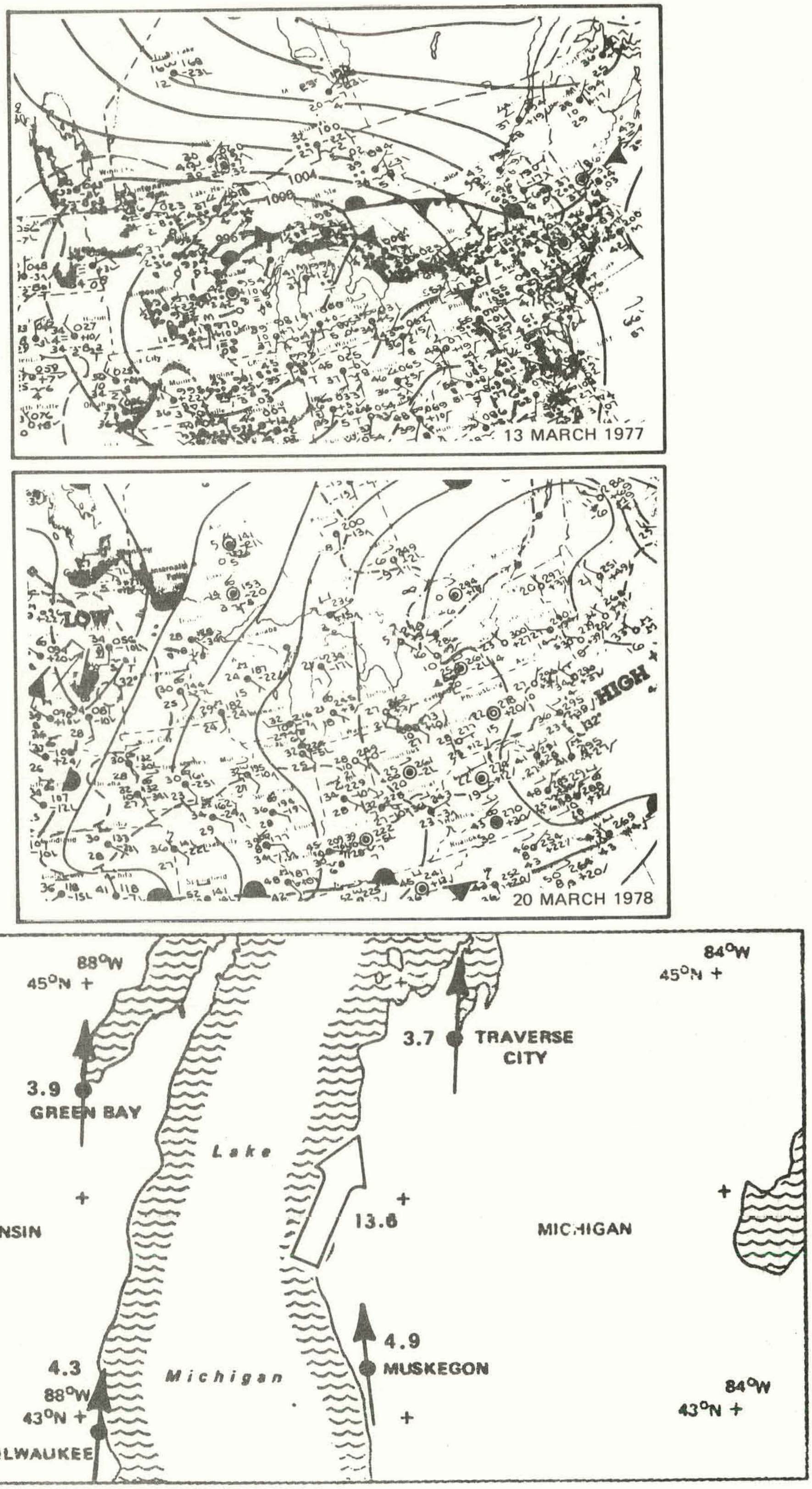


FIGURE C-4 WEATHER MAPS FOR 13 MARCH 1977 AND 20 MARCH 1978, WITH CORRESPONDING WIND PATTERNS FOR a_9 = 0.85 AND a_{10} = 16.45

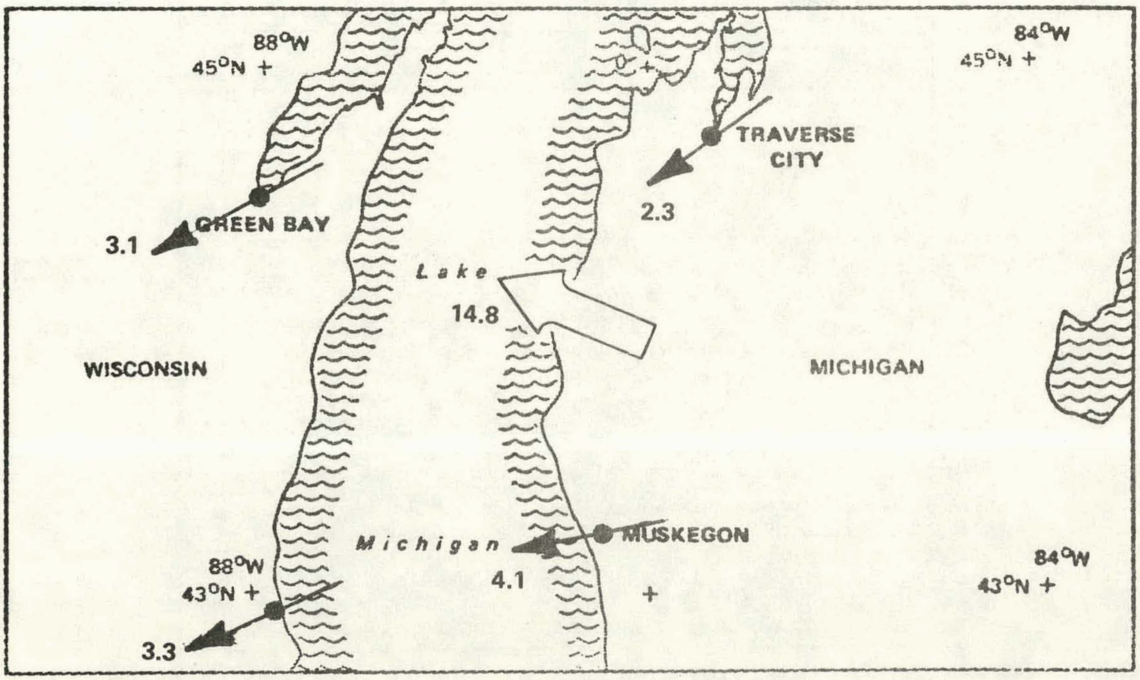


FIGURE C-5 WIND PATTERN FOR a_9 = 0.1 AND a_{10} = 18.3

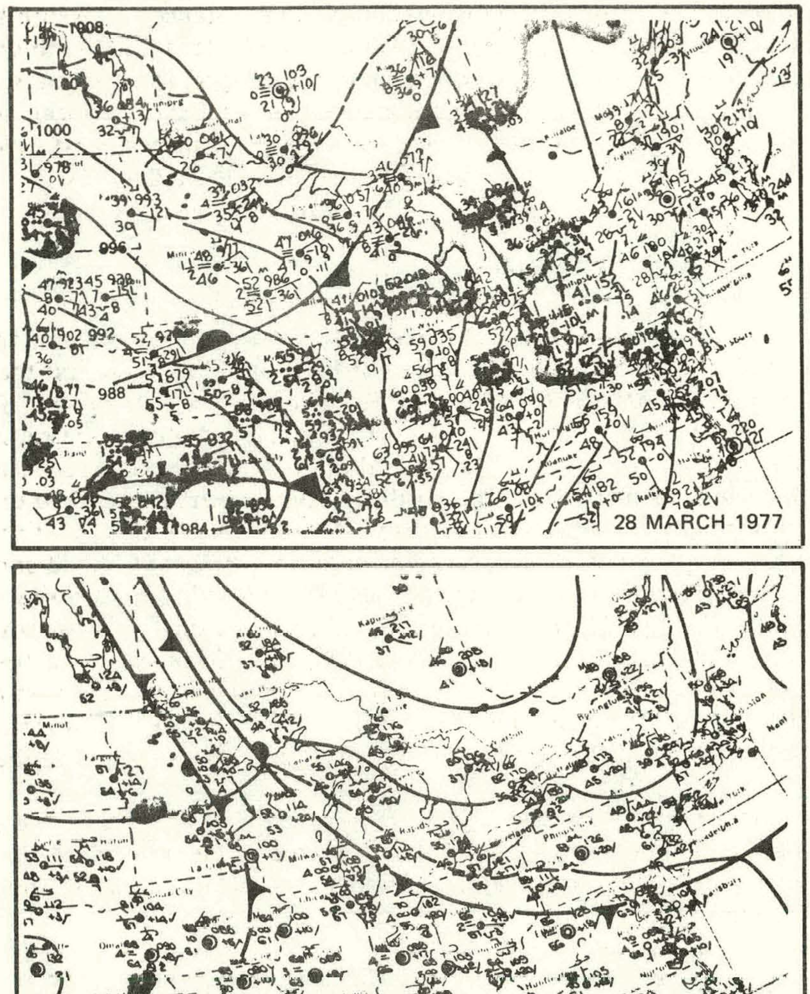


FIGURE C-6 WEATHER MAPS FOR CASES WITH A LARGE POSITIVE a_9 AND a_{10} NEAR ZERO

Figure C-7 shows the reconstructed winds for the one instance, 22 December 1977, when a_{10} was small (0.6) and a_9 had a large negative value (-18.4). It is nearly the exact reversal of Figure C-5, except that the surface winds are somewhat stronger, from about 4 1/2 to 6 1/2 m s^{-1}. The surface chart shows that the pressure gradient in the Lake Michigan area is generally the reverse of those seen in Figure C-6, being toward the north-northeast. Not surprisingly, the surface winds are in quite good agreement with the reconstructed winds.

d. Large Negative Values of Both a_9 *and* a_{10}

On 10 days (1, 12, and 16 January, 13 February, 5 April, 11 November, and 9 December 1977; and 9, 10, and 27 January 1978) the values of both a_9 and a_{10} were less than -15. On two of these days (9 and 10 January 1978) the value of a_{10} was less than -30. On one day (9 December 1977) the value of a_9 was less than -30. Figure C-8 shows the reconstructed wind field based on the average values of a_9 (-20.5) and a_{10} (-23.4) for these seven days. The very strong geostrophic wind, 28 m s^{-1} from the north-northwest, would lead us to expect quite pronounced pressure gradients toward the east-northeast over Lake Michigan. The weather maps in Figure C-9 verify that appropriate pressure gradients were always observed and surface winds were also as expected. Figure C-10 shows the reconstructed wind field based on the average values of a_9 (-20.0) and a_{10} (-37.0) for those days (9 and 10 January 1978) when a_{10} was less than -30. The very strong geostrophic wind from the north (37.5 m s^{-1}) in the reconstructed wind field is consistent with the very strong west to east pressure gradient seen on the weather maps over northern Lake Michigan. The reconstructed surface winds of about 8 to 13 m s^{-1}, or about 15 to 25 knots, are in fair agreement with those actually observed on these two dates.

Figure C-11 shows the reconstructed wind field for 9 December 1977, the one case found where a_9 was less than -30 (-35.4); a_{10} was -21.3. The reconstructed wind field is quite similar to that shown in Figure C-10, except all the vectors are rotated about 30° counterclockwise. Thus, one might expect to find a strong pressure gradient toward the northeast which the weather map shows to be the case.

e. Large Positive Values of a_9 *and* a_{10}

Four dates were identified when the 0700 EST values of a_9 and a_{10} both exceeded 15. These dates were 24 February, 12 March, 24 September, and 17 December 1977. None of the positive values of a_9 or a_{10} exceeded 30. Figure C-12 shows the reconstructed wind field based on the average values of a_9 (24.2) and a_{10} (20.4) for the four dates. As expected, the vectors shown in Figure C-12 are approximately the reverse of those shown in Figure C-8 for the cases where both a_9 and a_{10} had large negative values. The magnitudes tend to be about 2 m s^{-1} less than for the negative values. The pressure gradients shown on the corresponding weather maps in Figure C-13 are all strong and directed toward the west-southwest over Lake Michigan. In all cases, the Ludington area lies in the strong pressure gradient along the eastern side of a low pressure center associated with an approaching frontal system.

The cases represented by the weather maps in Figure C-13 are reasonably easy to identify, as were those cases shown earlier for wind categories associated with large negative values of a_9 and a_{10}. Furthermore, they tend to be associated with high winds which are of considerable interest to the wind energy generating program. It should not be difficult to identify such patterns subjectively. Their frequency of occurrence during a year would provide a measure of the

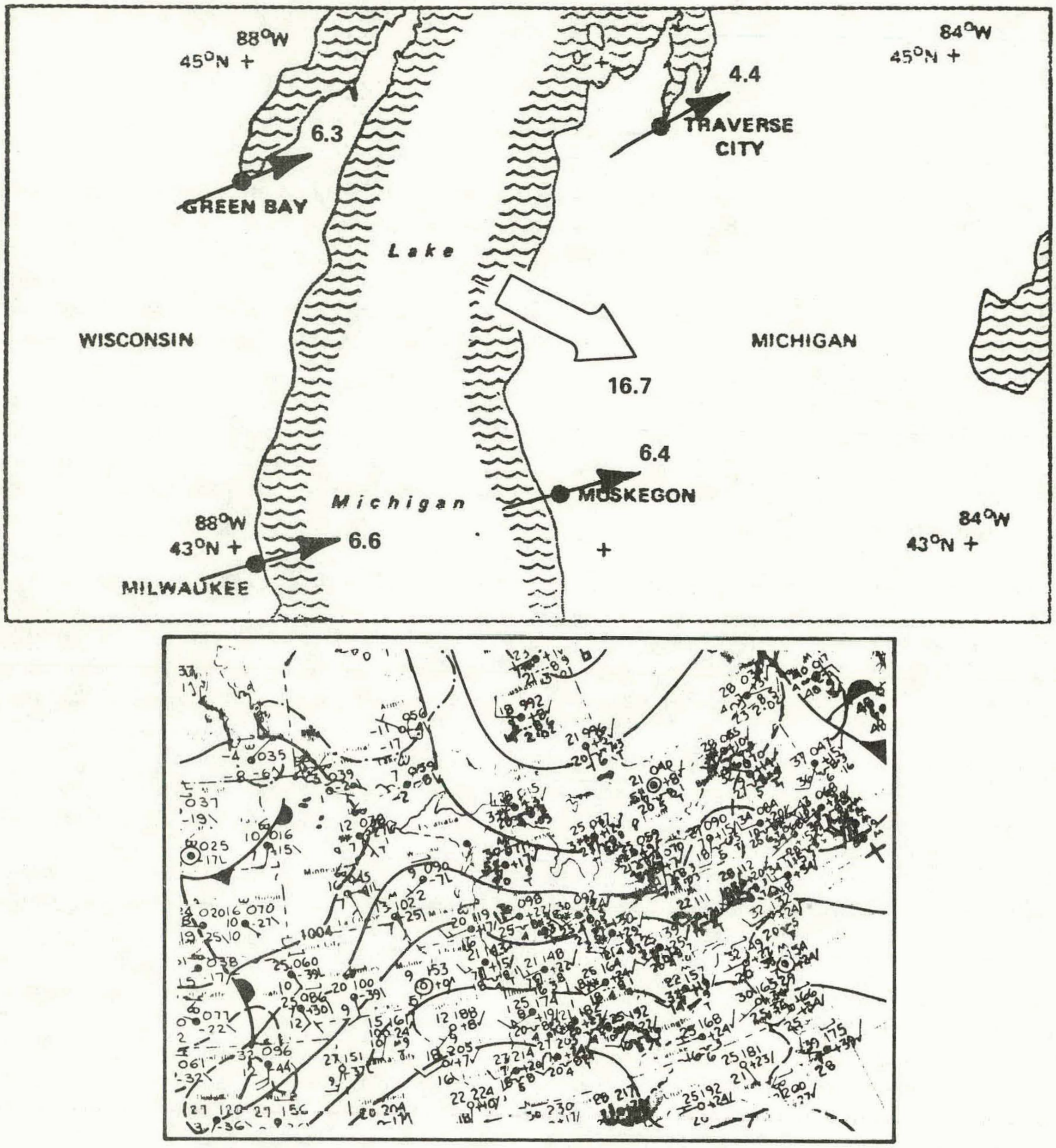


FIGURE C-7 WIND PATTERN FOR a_9 = -18.4 AND a_{10} = 0.6, AND THE CORRESPONDING WEATHER MAP OF 22 DECEMBER 1977

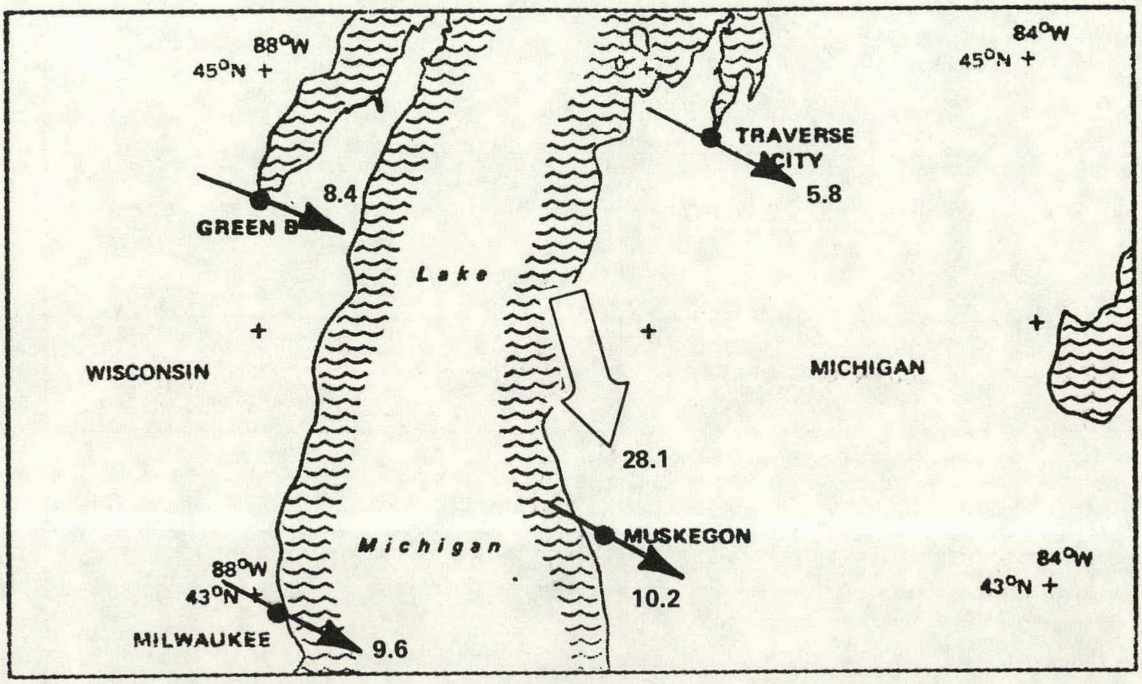


FIGURE C-8 WIND PATTERN FOR $a_9 = -20.5$ AND $a_{10} = -23.4$

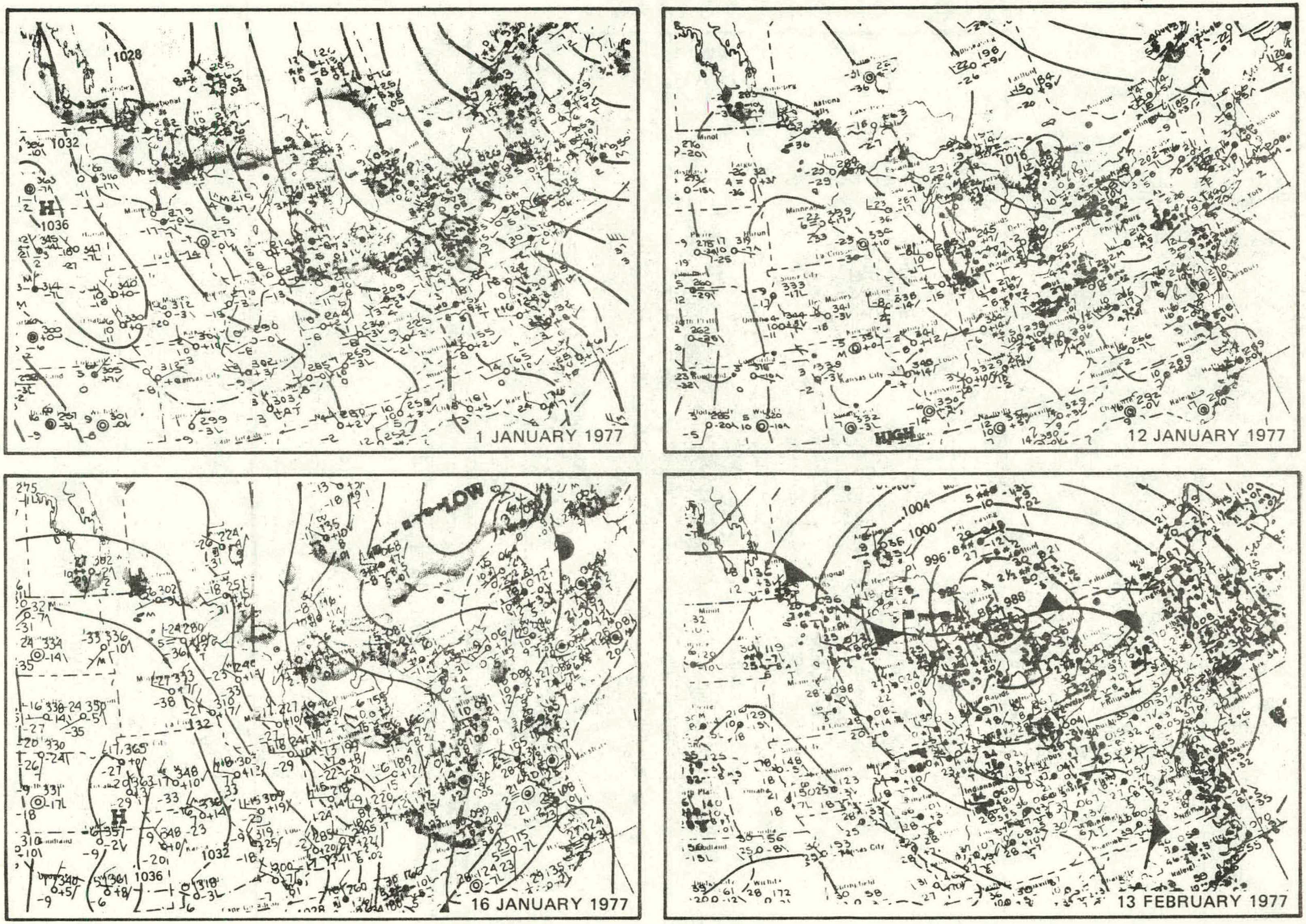


FIGURE C-9 WEATHER MAPS FOR DAYS WITH LARGE NEGATIVE VALUES OF a_9 AND a_{10}

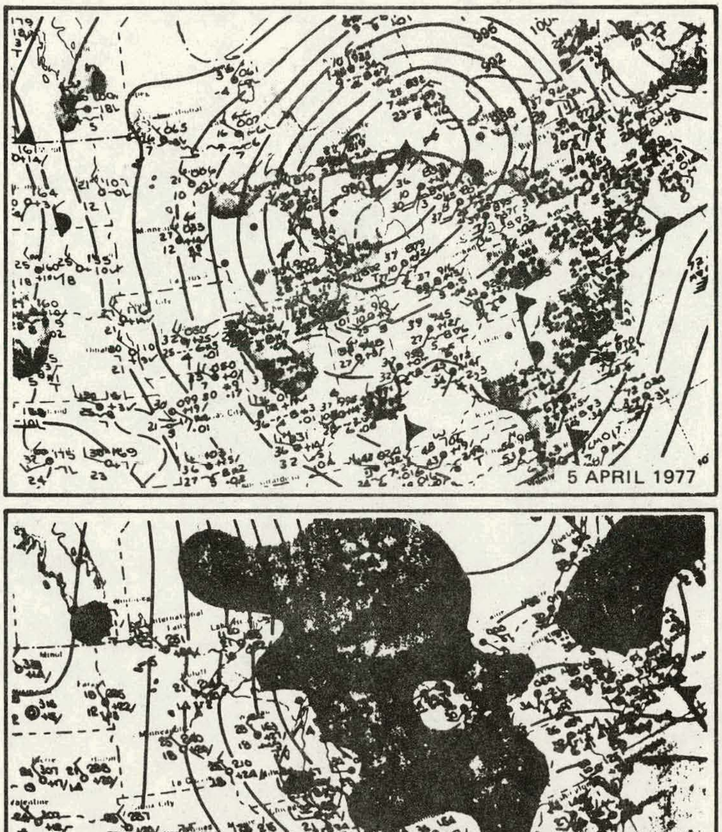


FIGURE C-9 WEATHER MAPS FOR DAYS WITH LARGE NEGATIVE VALUES OF a_9 AND a_{10} (CONCLUDED)

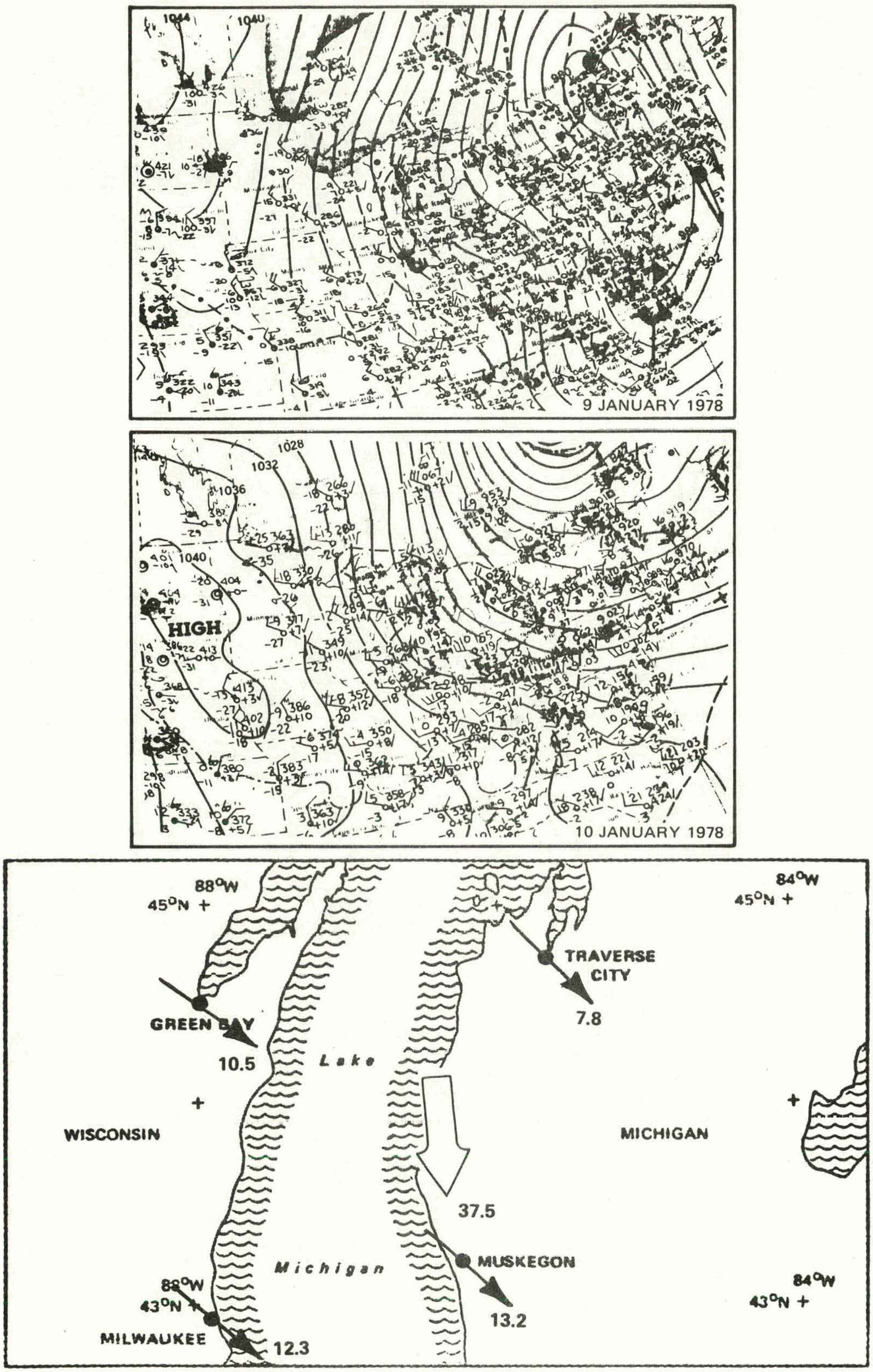


FIGURE C-10 WEATHER MAPS FOR 9 AND 10 JANUARY 1978
WITH CORRESPONDING WIND PATTERN FOR $a_9 = -20$ AND $a_{10} = -37.0$

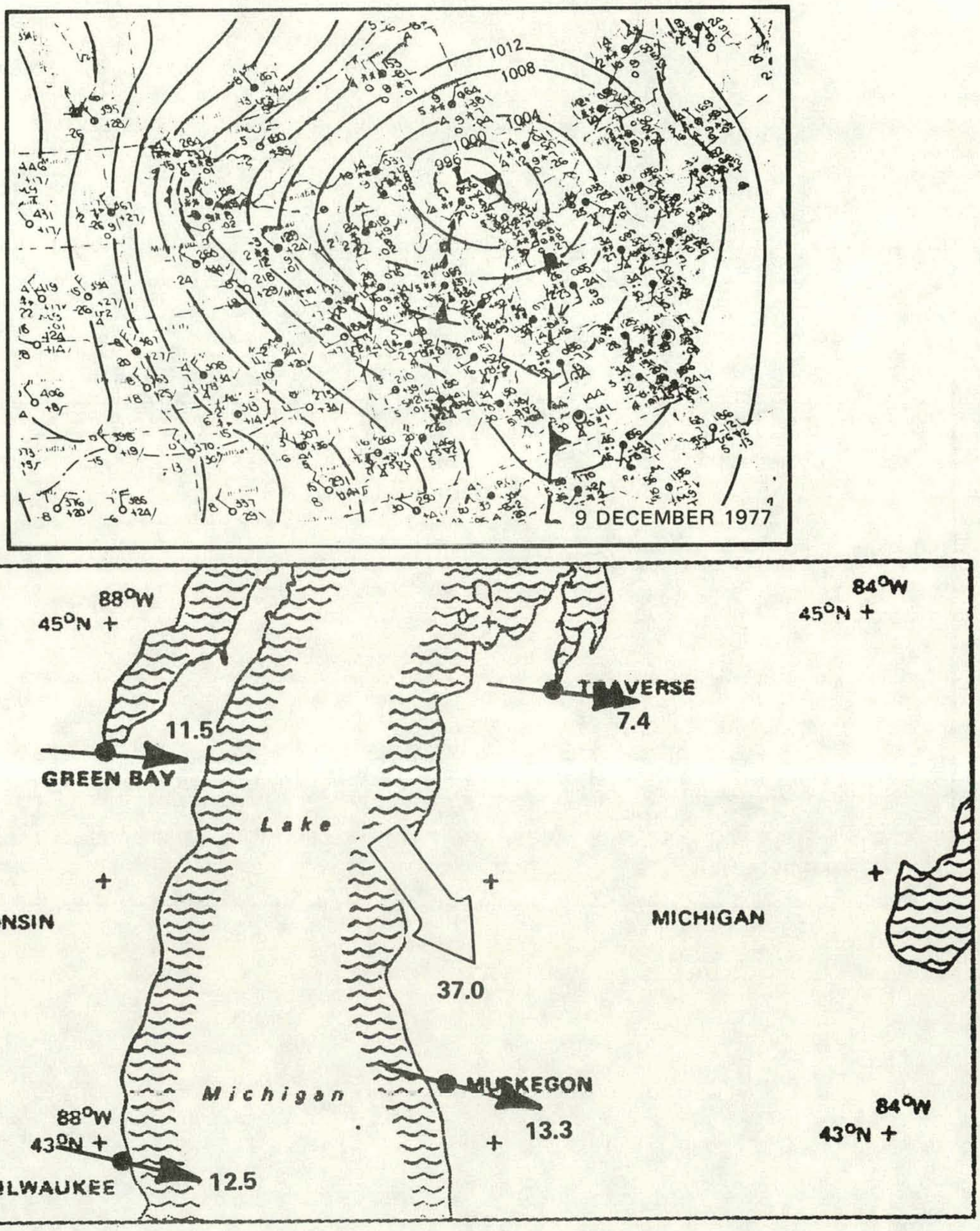


FIGURE C-11 WEATHER MAP FOR 9 DECEMBER 1977 AND THE WIND PATTERN FOR a_9 = -35.4 AND a_{10} = -21.3

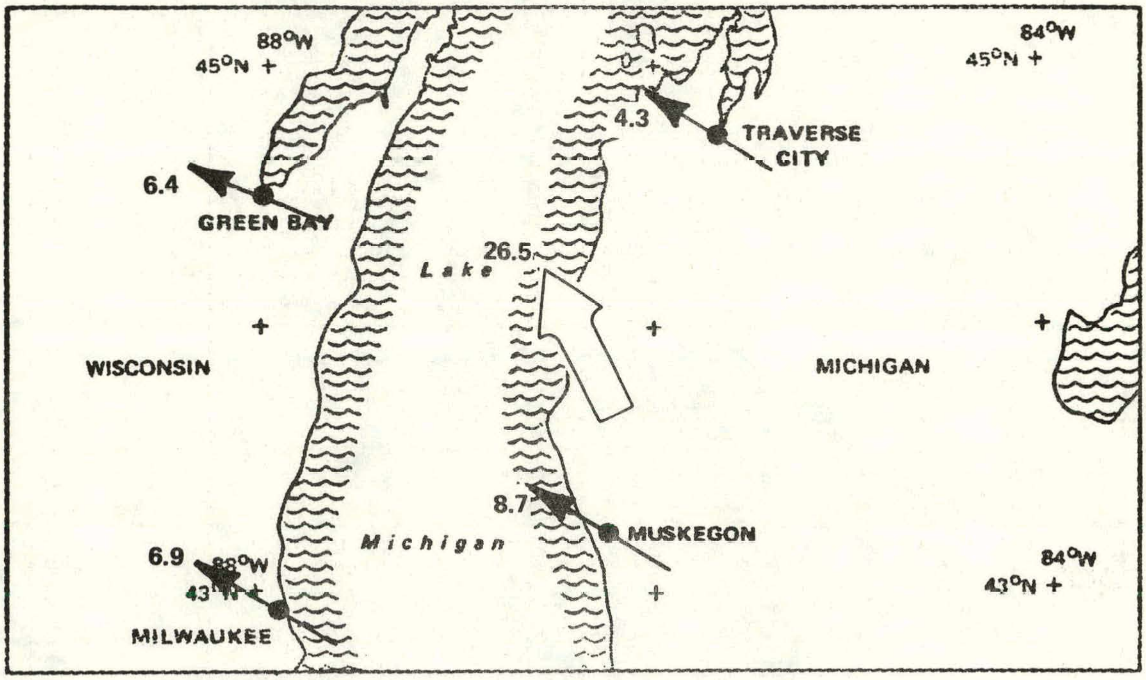


FIGURE C-12 WIND PATTERN FOR a_9 = 24.2 AND a_{10} = 20.9

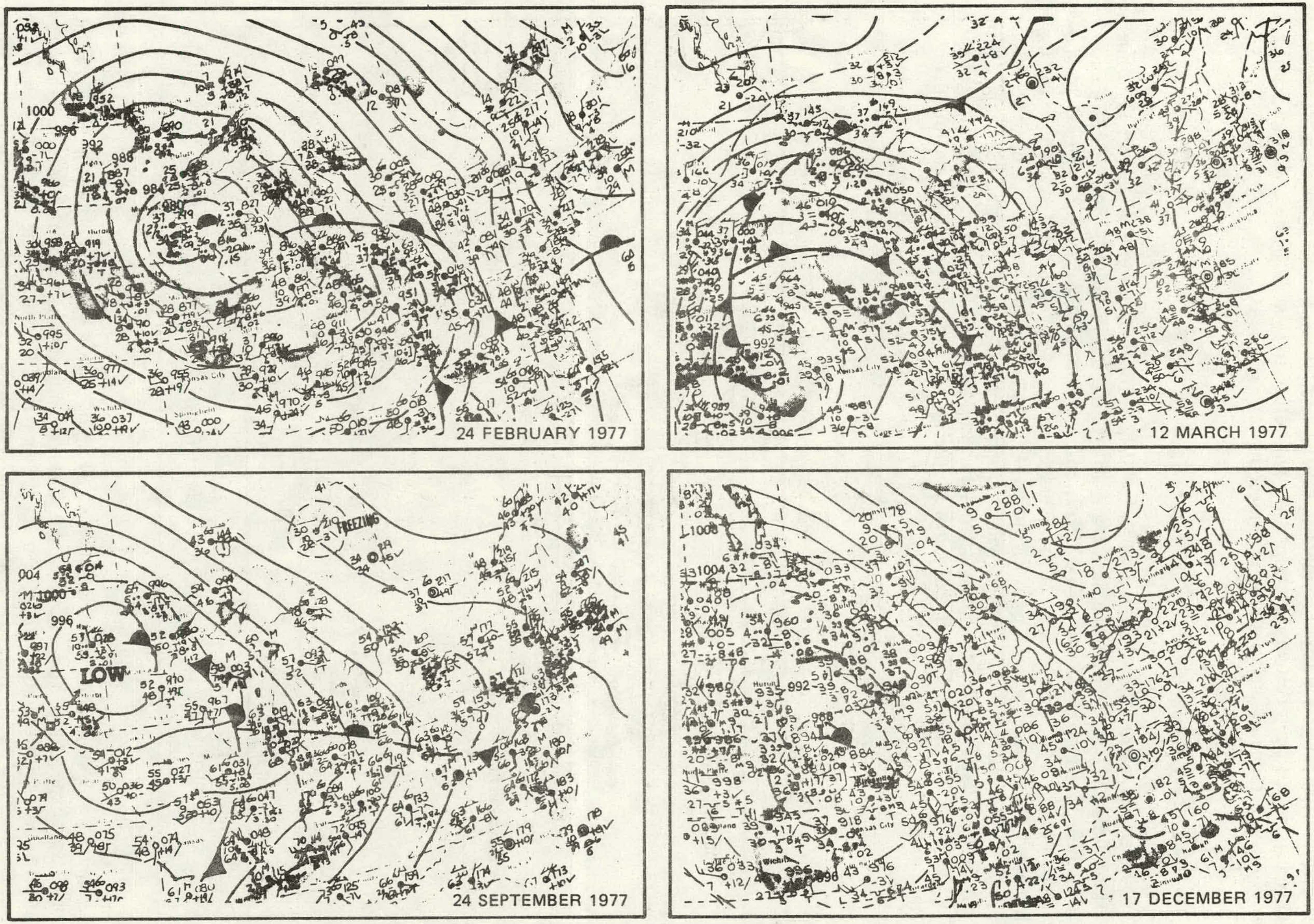


FIGURE C-13 WEATHER MAPS FOR DAYS WITH LARGE POSITIVE VALUES OF a_9 AND a_{10}

degree to which that year was comparable to other years, at least with regard to the occurrence of very high winds from certain directions. We will return to this later when we discuss the frequency of occurrence of such patterns in some other recent years.

f. Large Values of a_9 *and* a_{10} *of Opposite Signs*

There were eight days identified when the value of a_9 at 0700 EST exceeded 15, while at the same time the value of a_{10} was less than -15. These days were 10 January, 18 March, 28 April, 6 June, 1 October, 25 November 1977; and 1 and 14 January 1978. Figure C-14 shows the reconstructed wind field based on the average values of a_9 (24.8) and a_{10} (-20.3) for those eight days. These cases, according to Figure C-14, should be characterized by relatively strong, 6 to 8 m s^{-1} (about 15 knots), surface winds from the north-northeast. The geostrophic wind shown in this figure is about 27 m s^{-1} from the east-northeast, so strong pressure gradients from the north-northwest toward the south-southeast would be expected to be found on the weather maps.

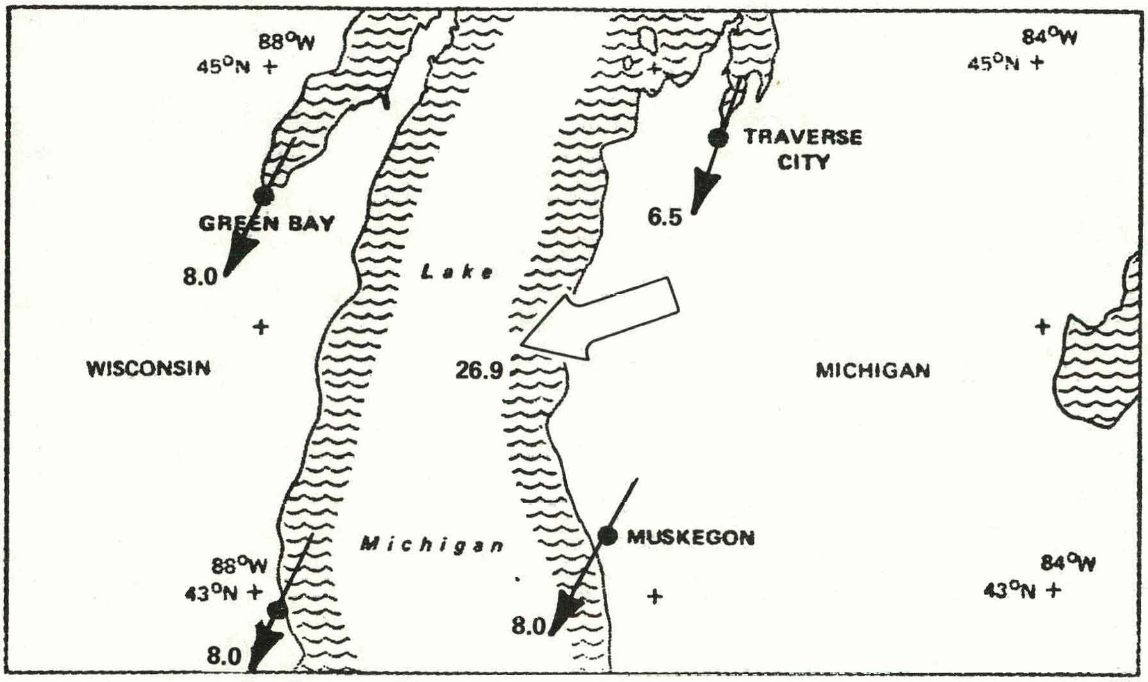


FIGURE C-14 WIND PATTERN FOR a_9 = 24.8 AND a_{10} = -20.3

Figure C-15 shows the eight weather maps of this type represented by Figure C-14 and confirms the expectation with regard to pressure gradient. As a general rule, Ludington was located in the northwest quadrant of a deep low pressure system on the eight days shown in Figure C-15. This location was generally in the cold air behind an advancing front farther to the south. Local conditions were often characterized by precipitation. Observed surface winds

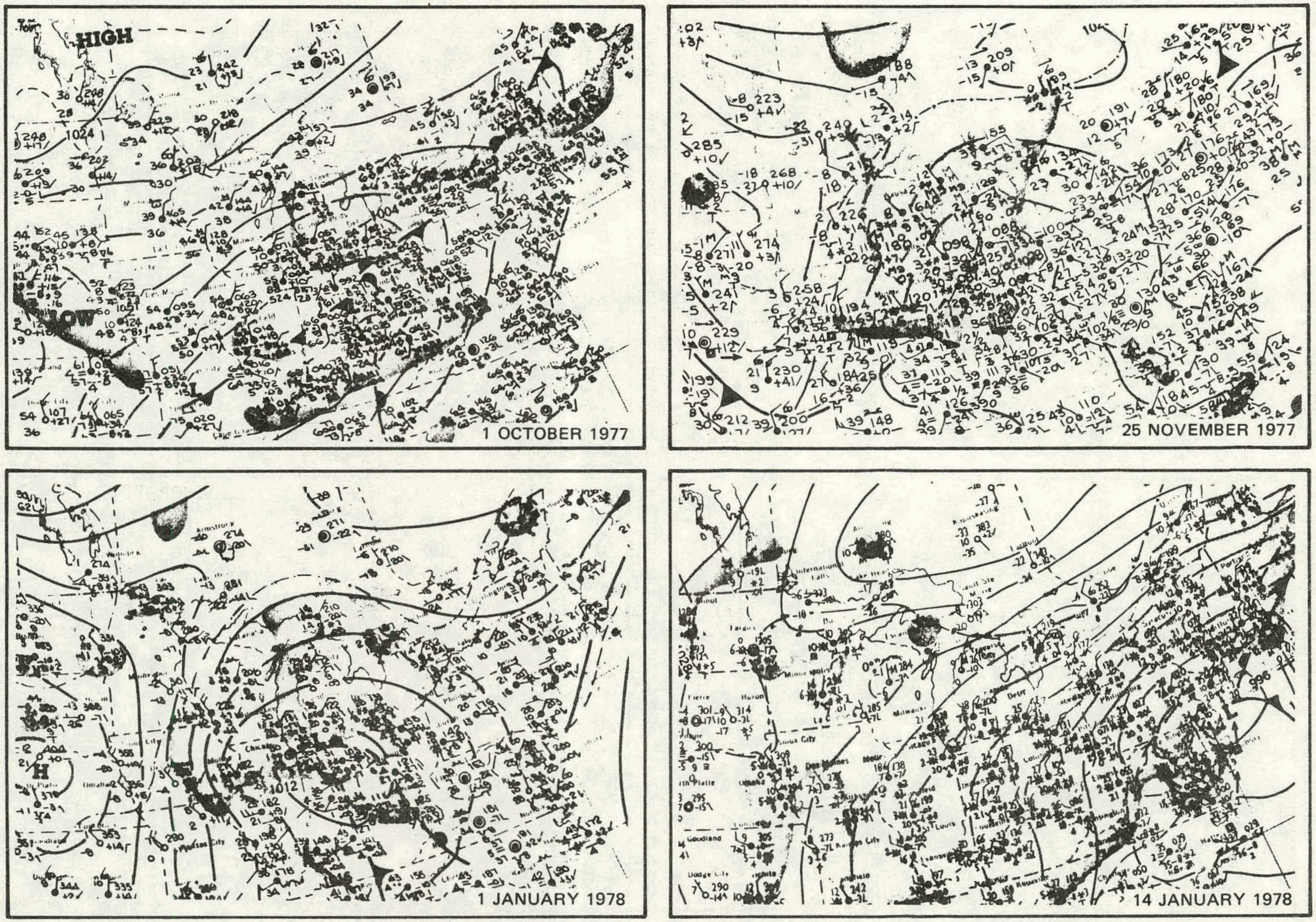


FIGURE C-15 WEATHER MAPS FOR DAYS WITH LARGE POSITIVE VALUES OF a_9 AND LARGE NEGATIVE VALUES OF a_{10}

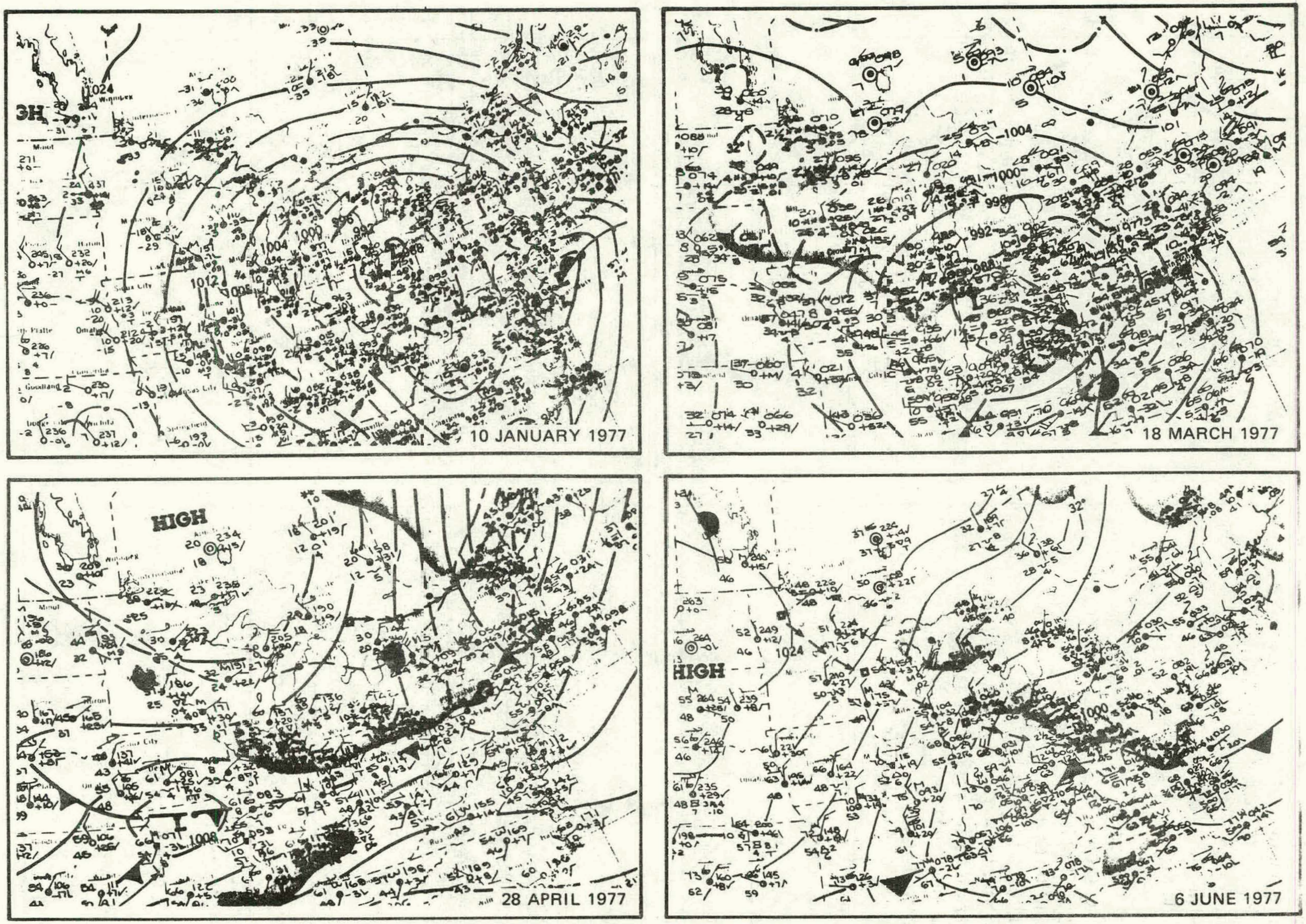


FIGURE C-15 WEATHER MAPS FOR DAYS WITH LARGE POSITIVE VALUES OF a_9 AND LARGE NEGATIVE VALUES OF a_{10} (CONCLUDED) were in good agreement with those shown by the reconstructed winds in Figure C-14. It should be remembered that disagreements between observed winds and the reconstructed winds shown in Figure C-14 cannot be attributed entirely to the fact that only two eigenvectors were used to construct the wind field. Figure C-14 is based on average values of a_9 and a_{10} and there was considerable variation in the individual values about the means; a_9 varied from -31.4 to -15.5 while a_{10} varied from 15.2 to 39.8

Three days were identified when a_9 was less than -15 and a_{10} was greater than 15. Figure C-16 shows the reconstructed wind field based on the averages of a_9 (-17.0) and a_{10} (19.4). Figure C-17 shows the weather maps for these days, 9 March, 11 April, and 9 September 1977. In all three cases there was a strong pressure gradient toward the north-northwest in the area of interest. In two of the three cases, Ludington was in the warm sector of a frontal system. In the third case (11 April 1977), the daily weather map analysis does not show a warm front, but there is evidence of a trough and very strong temperature contrasts, which suggest that Ludington may well have been in the warm sector of a frontal system in this case too. The reconstructed winds in Figure C-16 are seen to represent the observed winds quite well.

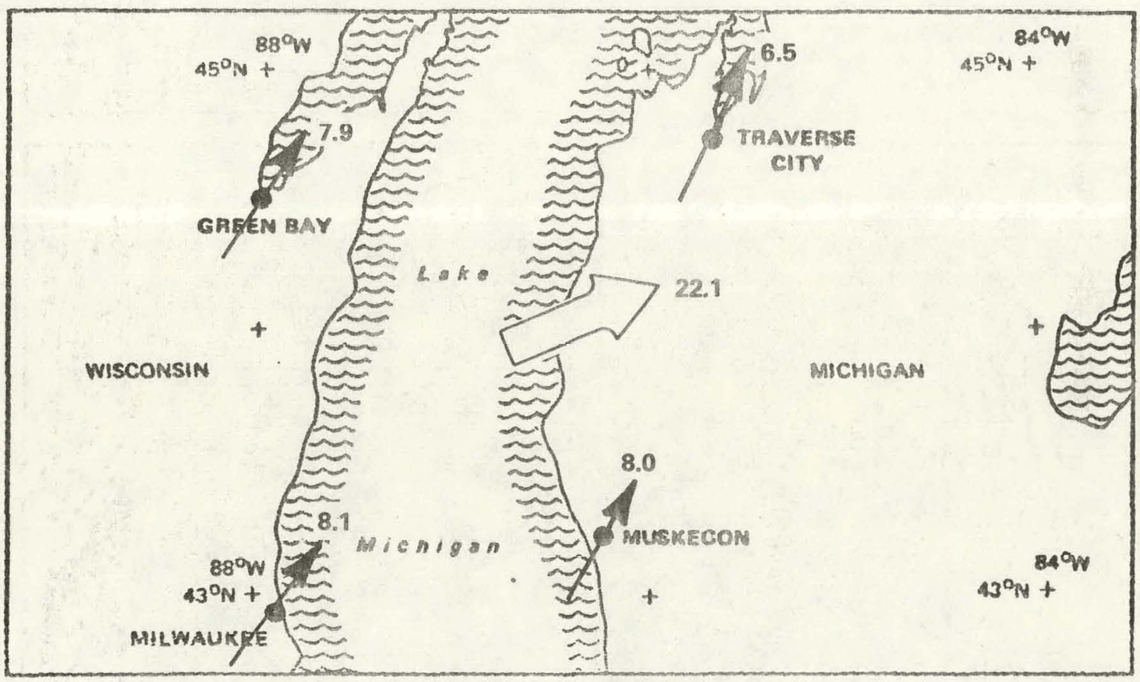


FIGURE C-16 WIND PATTERN FOR a_9 = -17.0 AND a_{10} = 19.4

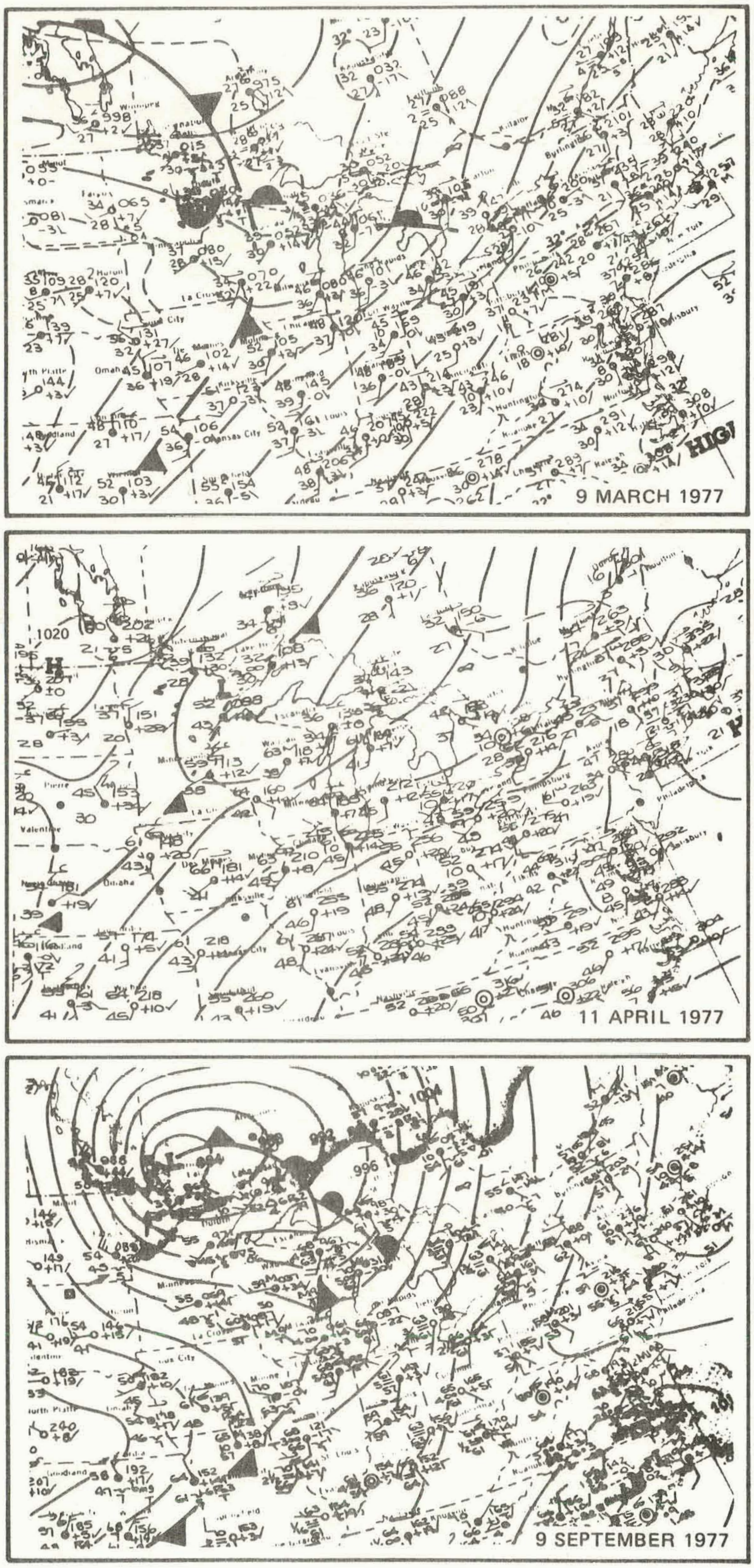


FIGURE C-17 WEATHER MAPS FOR DAYS WITH LARGE NEGATIVE VALUES OF a_9 AND a_{10}

3. *A Look At Some Recent Years*

As noted before, those instances over the Lake Michigan area where both a_9 and a_{10} have the same sign and are relatively large in magnitude are associated with weather patterns, especially pressure gradients area that are reasonably distinct. Therefore, we have chosen to identify such cases subjectively for a few recent years and compare their frequencies of occurrence from year to year. This is done in the following sections.

a. *Frequency of Occurrence During Recent Years of Days When Both a_9 and a_{10} Had Large Positive Values at 0700 EST*

Table C-1 shows the dates during 1976, 1977, and 1978 that were identified subjectively as being of the type where both a_9 and a_{10} should have been positive and fairly large, i.e. greater than about 15. Those days during 1977 that were identified by the objective method as being of this type are indicated with asterisks. It can be seen from Table C-1 that two days during 1977 were misidentified, but those days that were actually in the category were all selected.

In 1976, all but one of the five selected days were in March. The other day was in January. For 1978, two of the four selected days were in April, one in September, and one in

Table C-1

DAYS FOR WHICH 0700 EST WEATHER MAPS WERE SUBJECTIVELY JUDGED TO BE OF A TYPE HAVING A_9 AND A_{10} BOTH > 15

Year	Date
1976	23 January 12 March 26 March 29 March 30 March
1977	23 February 24 February* 11 March 12 March* 24 September* 17 December*
1978	6 April 18 April 18 September 17 November

*Also identified by objective analysis.

November. Judging by 1976 and 1978, there is a tendency for this type of pattern to occur in the Ludington area a few times per year, mostly in the spring or fall with an occasional winter occurrence. Thus, 1977 was reasonably typical; six days were selected subjectively and two of these were in a spring month, March, and one in an autumn month, September. Two selected dates were in late February and one was in December.

b. Occurrences of Days During Recent Years When 0700 EST Values of a_9 *and* a_{10} *Had Large Negative Values*

Table C-2 shows those dates during 1976 through 1978 that were identified as having weather patterns that were of the type associated with large negative values of a_9 and a_{10}. Those days during 1977 and early 1978 that had been identified as falling in this category by the objective methods are marked with asterisks. Two other dates, 13 February and 5 April 1977, that have been identified objectively were not identified by the subjective scanning of the weather maps. In general, the subjective identification of weather patterns in this category produced a larger number of cases than the objective method.

Examination of Table C-2 shows that by far the greatest frequency of occurrence of this type of pattern was in the winter, with a few cases in the fall (especially late fall) and early spring. There appear to have been more instances of this type of pattern in the Ludington area during 1977 than during either the year before or the following year. It appears that the data set used for these analyses contains more than the usual number of days when the morning air flow was quite strong from the northeast. Obviously, the small sample and the uncertainty of the subjective classification method make this conclusion uncertain.

c. Discussion and Remarks Concerning the Results

The preceding results show that it is possible to identify many of the more extreme weather patterns subjectively and in a fashion that is relatively consistent with the objective method based on the eigenvector analysis. It is not surprising that the analyst misclassified some of the cases. An average of only a few seconds was spent deciding whether or not a particular weather map fell into one of the two categories being considered. Obviously, many of the cases could be classified almost immediately as not being of the proper type so that more time was spent on those that came close to fitting the pattern. However, even in the latter cases, decisions were generally made in only a fraction of a minute.

One important point needs to be reiterated. While the method demonstrated in the preceding sections can be used to identify some of the more extreme weather patterns quickly and to make determinations concerning whether or not those patterns were occurring with more or less frequency during some year for which data were available, the efficiency of the objective methods that have been developed are now so great as to make it a rather moot point. If the appropriate surface weather data are available, the winds at the potential wind energy site can be quantitatively and objectively estimated much more quickly than the weather maps can be classified subjectively. Although it is interesting and instructive to see the correspondence of eigenvector coefficients and weather patterns, it should never be necessary to resort to subjective classifications of wind patterns. The combination of the COMPLEX model and the eigenvector analysis of the input data can supply the complete statistics for a number of years, so that the typicality of any given year can be determined with much greater rigor through standard statistical comparison techniques.

Table C-2

DAYS FOR WHICH 0700 EST WEATHER MAPS WERE SUBJECTIVELY JUDGED TO BE OF A TYPE HAVING A_9 AND A_{10} BOTH ≤ -15

Year	Date
1976	8 January
	11 January
	29 January
	8 February
	23 September
	22 November
	23 November
	17 December
	21 December
	23 December
	31 December
1977	1 January*
	7 January
	12 January*
	16 January*
	17 January
	1 February
	23 February
	24 February
	12 March
	24 September
	9 October
	31 October
	11 November*
	18 November
	9 December*
	25 December
	26 December
1978	9 January*
	10 January*
	27 January*
	28 January
	19 March
	24 November
	13 December
	17 December

*Also identified by objective analysis.

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