Coastal Zone Wind Energy: Part III: A Procedure to Determine the Wind Power Potential of the Coastal Zone

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March 1982

**Prepared for
Pacific Northwest Laboratory
Under Agreement B-93492-Q**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

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PACIFIC NORTHWEST LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC06-76RLO 1830

Printed in the United States of America
Available from
National Technical Information Service
United States Department of Commerce
5285 Port Royal Road
Springfield, Virginia 22151

NTIS Price Codes
Microfiche A01

Printed Copy

Pages	Price Codes
001-025	A02
026-050	A03
051-075	A04
076-100	A05
101-125	A06
126-150	A07
151-175	A08
176-200	A09
201-225	A010
226-250	A011
251-275	A012
276-300	A013

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COASTAL ZONE WIND ENERGY:
PART III: A PROCEDURE TO DETERMINE THE
WIND POWER POTENTIAL OF THE COASTAL ZONE

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March 1982

Prepared for
Pacific Northwest Laboratory
Richland, Washington 99352
Under Agreement B-93492-Q of
Prime Contract DE-AC06-76RLO 1830
With the Department of Energy
Office of Solar Power Applications
Wind Energy Technology Division

Pacific Northwest Laboratory
Richland, Washington 99352

EXECUTIVE SUMMARY

A stepwise procedure is presented for determining the seasonal and/or annual mean potential power density for any location on the East and Gulf coasts of the United States. The steps include reference to the dominant wind regimes and mean power densities already obtained to estimate the wind power potential of the location under consideration; methods to calculate the potential wind power distributions and steps to be taken to locate the best site in the area of interest. The method can be best applied where the atmospheric systems which produce most of the wind energy at the surface are relatively persistent. The method is least successful in areas where the wind field is highly variable. Application of the complete method requires the use of an existing two- or three-dimensional mesoscale numerical model.

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1. INTRODUCTION

The procedure for determining the wind power potential of a coastal location outlined in this report is designed to provide

- *an estimate of the potential wind power of a given coastal region, and
- *the location of areas as small as 10x10 km of maximum (and minimum) wind power potential.

The method cannot locate a specific site within the 10x10 km grid element. Final site determination must be based upon actual measurements which should also be used to verify the predicted power.

Previous research (Garstang et al., 1980a, 1980b) provides the foundation for the methodology which follows. The underlying principles are that the wind at a point is a function of:

- *the large scale global circulation where the relative location of the point of interest to such large scale features as the polar front and jet stream and the semi-permanent surface high pressure systems is important,
- *the frequency and duration of instabilities imbedded in the large scale circulation fields such as frontal cyclones,
- *the interaction between the larger scales of motion in the atmosphere and the local surface conditions which may convert potential to kinetic energy and transfer, in a systematic manner, the kinetic energy of the free atmosphere downward towards the surface.

The juxtaposition of land and sea at the coastline provides conditions where atmospheric density gradients may be concentrated, potential energy converted to kinetic energy and through the land-sea breeze circulation, transfer the kinetic energy of the deeper atmosphere in a persistent fashion to the surface.

Thus, the wind energy potential of the coastal zone is considered to be dependent on the type and frequency of occurrence of the atmospheric systems. Knowledge of the distribution in time and space of the atmospheric systems leads to a procedure which will allow:

- *height corrections to be made to existing wind records,
- *an estimate of annual and seasonal power density as a function of atmospheric system,

- *a determination of the potential power density as a function of atmospheric systems,
- *identification of the dominant power-producing conditions,
- *the interaction between the local coastal conditions and the large scale atmosphere which can be determined for the dominant power-producing conditions, and, finally,
- *the determination of regions of maximum and minimum power density potential over the coastal region.

The final product is a distribution of annual potential power density every 10 km over a domain of 300x300 km. The procedure is applicable to coastlines with little or no topography such as the Gulf and East coasts of the United States where the method was developed.

The method works best where the dominant energy-producing regimes of the atmosphere, such as the outbreaks of cold air behind a cold front, persist for a number of consecutive days. The method performs poorly where, for whatever reason, the meteorological conditions are changing rapidly with time. In most regions rapidly changing weather conditions occupy only a small percent of the total annual cycle. As such, the impact of the changing conditions, which would be ignored by the method, on the wind energy potential is small and can be safely omitted. In some locations, for example the Texas south coast, topography combines with the coastal effects to produce a daily imbalance of forces. This imbalance is translated, in the atmosphere, into a situation which is continually adjusting in an attempt to achieve a balance. Under these circumstances the estimates of the wind power potential are poor. We refer the interested reader to a separate publication (Garstang and Snow, 1981) which presents the results of tests of the methods described below.

In the steps described below the objective is to identify the important meteorological regimes (on a storm or synoptic scale) which govern the wind energy potential of the area or location of interest on the coast. Once the important meteorological regimes and their statistical distribution throughout the year are identified, the large scale atmospheric conditions (wind, temperature, pressure at the surface and with height) can be specified. Knowledge of the large scale atmospheric conditions allows one to specify the starting conditions for a three-dimensional mesoscale numerical model. This model (described in detail by Pielke, 1974, and its application to wind energy described by Snow, 1981), simulates the interaction between the large-scale atmospheric fields and the mesoscale influences of the region of interest, yielding wind speeds and wind directions at many heights (e.g. 10 m, 50 m, 100 m, etc. which are chosen by the user) and at grid points spaced 10 km apart in a 300 by 300 km domain. The value of the method resides largely in

the fact that a large number of wind values are generated over the entire region of interest. The information generated by the model greatly exceeds any available observations of the wind. This is particularly true over the open ocean close to the coastline and is mostly true on the mainland coast and offshore islands. The wind power potential may be assessed from the model-produced wind fields and the detailed horizontal distribution of wind speed can be examined to determine the possible optimum locations for power conversion.

The usefulness of the detailed model-predicted wind fields is predicated upon the degree to which these predictions represent the real winds. Appendix 1 provides, from the sources specified above, a summary of the skill of the model and some of the results where the model has been tested against observations. In the sections which follow we provide a step-by-step description of how this method can be applied to the East and Gulf coasts of the United States.

2. STEPWISE PROCEDURE FOR DETERMINING WIND ENERGY POTENTIAL FOR AN EAST AND GULF COAST LOCATION

Step 1:

Locate the point or area of interest in the appropriate region as designated in Figure 1.

Step 2:

For the region identified in Step 1, look up the frequency distribution of weather categories¹ in Table 1a-g. Note the dominant weather category(s) by season and for the annual cycle. Between 1 and 3 categories should account for 75% or more of the mean annual potential power density ($W m^{-2}$). For example, for Region I (Table 1a) Categories II, III and IV contribute 82.65% of the annual power at 50 m. In winter, however, Category III (behind the cold front) contributes more than half (55.07%) of the power although it occurs only 40.06% of the time.

Step 3:

Decide whether, for the application under consideration, the magnitude and seasonal distribution of potential power density is adequate or not. Note that (a) potential power density is listed in Table 1. The potential power available in each region must be modified to reflect the hub-height of the wind turbine(s) being considered by the user.

¹

Appendix 2 defines each of the five weather categories listed in Table 1.

(b) Since the purpose of the subsequent steps is to determine the optimum wind power locations, the optimum power density can be substantially greater (up to 3 times) than the power density values provided for guidance in Table 1.

If the decision by the user in Step 3 is that either adequate wind power potential exists or is likely to exist then proceed to Step 4.

Step 4:

Note the geographical location of the point or area of interest relative to the three coastal test regions shown in Figure 2 and in detail in Figures 3a, b and c.

If you are dealing with a point which falls in one of the test regions shown in Figures 3a, b and c, simply determine the annual potential power density by reading the value nearest your site by locating the appropriate grid element on Figure 3 and reading the annual potential power for that grid element from Table 2.

If you are dealing with an area which falls in one of the test regions, locate the grid element (10x10 km) in your area which has the highest annual potential power.

If your point or area falls outside of one of the test regions intercept the likely annual power density by examining the adjacent test region(s) and making a qualitative interpolation. For example, if your area of interest is on the Louisiana offshore island, then your annual power density is likely to be similar to that of western Apalachee Bay (Figure 3b). There would be some confidence in this interpolation whereas if your area lay on the South Carolina coast you would, by reference to the Chesapeake Bay test region (Figure 3a), have to be cautious as to the potential power density.

Confidence in the interpolation of the first example lies in the fact that the meteorological regimes and, therefore, the region as depicted in Figure 1, is the same for the Louisiana offshore island as for test region AB. In contrast, the second example crosses boundaries between regions from any two of the test sites. Thus one would not be justified in assuming similar wind conditions to either test region CB or test region AB.

On the basis of the above steps decide whether the annual potential power density is likely to be locally enhanced or diminished for your area of interest. Where your area falls in a test region this should be an easy decision and if positive you can proceed to Step 6.

If your area falls outside of the test areas but still looks promising proceed to Step 5 which is designed to provide the same information as is available in the test regions.

Step 5:

Depending upon the complexity of the coastline in your area, i.e., no major embayments or estuaries versus a region of marked coastal indentations, you may proceed with 2-D or 3-D model calculations. Computer programs and documentation which will allow the running of either the 2-D or 3-D models are available (at a nominal cost of providing tape, copying and shipping) from the U.Va. and probably from other users of the University of Virginia mesoscale model. The 2-D model can be run at most computer facilities. The 3-D model in the complex form as used by us, can be run at the National Center for Atmospheric Research, Boulder, Colorado. A simplified version of the 3-D model could be run at other computer facilities. Assistance in simplifying the 3-D model can be provided by the U.Va. Wind Energy group.

- a) 2-D Calculations: Choose a line normal to the coastline that intersects the point or points which are of greatest interest to you. From Step 2 above, designate the major weather categories.

From local climatology and vegetation determine the input variables for the models for the dominant weather categories. The input variables and other model parameters required are listed in Appendix 3. Run the 2-D model for the dominant weather categories and determine the annual potential power density by following the methods outlined in Appendix 4.

- b) 3-D Calculations: Choose the model domain (300x300 km) to include your area or point of interest. Include any alternative areas or sites in the domain. Determine the input variables as specified in Appendix 3. Run the 3-D calculations for the dominant weather categories and determine the annual potential power density by following the methods outlined in Appendix 4.

The numerical model results will provide an assessment of the local enhancement for your area. A decision can now be made as to the probable optimum location within 5 km on a line normal to the coastline or within a grid element of 10x10 km. The next step is the final site selection and check on the model estimates.

Step 6:

Site selection and verification: A minimum of two fixed anemometers (at 10 m) and a series of profile measurements made from different locations is recommended. One anemometer (A-1) should be chosen at the probable wind generator site. The other anemometer (A-2) should be located on a line intersecting the site or bisecting the grid element in the direction of the greatest predicted gradient in potential power density. A-2 should be 5 km (2-D case) to 10 km (3-D case) from A-1. For intermediate (100-500 kW) and large (> 500 kW) WECS, soundings are recommended to a height of 1 rotor diameter above the projected rotor

height. (Thus for a 100-ft rotor mounted at a hub height of 100 ft, soundings should be made to 250 ft.) The soundings should be taken at the anemometer sites and at locations between the anemometers with a spacial resolution of not greater than 1 km. Observations from the fixed anemometers and from the mobile sounding system should be made for a period during each of the dominant weather categories. Observations are continued until a valid statistical sample of each dominant synoptic regime is obtained. Normally this should not require more than 6 months over an annual cycle (1 year).

The observations at the anemometer sites are compared with the model predicted observations and the wind distribution along the line or in the grid element is confirmed with the model-predicted distribution. Both the magnitude and the horizontal distributions of the predicted and observed wind must be compared. The model-predicted field should be adjusted to fit the observations.

Step 7:

Optimum potential power densities can now be calculated and the final decision on the wind machine location can be made.

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TABLE 1. Occurrence of weather categories in each of the 7 coastal regions (Figure 1) for representative stations showing the percent of occurrence of each category, the average power and percent of power at 10 m and 50 m for each season and for the year for each category.

TABLE 1a. Region I, representative station: Portland, ME

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power $W\ m^{-2}$	% Contribution to Power	Average Power $W\ m^{-2}$	% Contribution to Power
Spring	I	13.59	93.9	14.03	318.7	19.10
	II	13.83	74.8	11.59	250.3	15.27
	III	31.88	106.2	37.95	224.3	31.53
	IV	37.89	79.8	33.89	187.1	31.26
	V	1.95	103.9	2.27	330.1	2.84
Summer	I	20.91	62.8	23.50	212.4	30.82
	II	9.28	41.2	6.84	140.5	9.05
	III	27.31	69.3	33.88	146.1	27.69
	IV	35.63	51.7	32.97	116.0	28.68
	V	4.04	38.8	2.81	134.6	3.77
Fall	I	12.88	66.5	10.79	240.5	15.21
	II	8.88	79.8	7.81	251.5	10.96
	III	26.63	122.7	41.18	269.2	35.19
	IV	46.63	66.4	39.02	162.0	37.08
	V	2.38	40.06	1.20	133.5	1.56
Winter	I	6.87	88.5	6.20	327.4	8.78
	II	11.16	125.5	14.27	468.3	20.41
	III	40.06	134.9	55.07	298.8	46.75
	IV	39.81	59.3	24.06	150.7	23.43
	V	0.32	124.5	0.41	500.3	0.63
Annual	I	12.70	75.0	11.55	262.2	15.61
	II	10.84	88.7	11.66	320.4	16.28
	III	33.52	113.8	46.27	248.4	39.03
	IV	39.03	61.7	29.21	149.4	27.34
	V	1.89	57.0	1.31	196.3	1.74

TABLE 1b. Region II, representative station: New York, NY (JFK)

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power W m^{-2}	% Contribution to Power	Average Power W m^{-2}	% Contribution to Power
Spring	I	20.17	176.5	24.12	612.9	30.07
	II	10.09	128.6	8.79	439.3	10.78
	III	24.22	178.6	29.30	396.1	23.33
	IV	41.29	127.9	35.78	331.2	33.26
	V	2.84	104.5	2.01	371.1	2.56
Summer	I	25.22	115.5	29.26	420.4	36.47
	II	5.71	95.5	5.48	336.1	6.60
	III	21.12	127.9	27.13	280.1	20.35
	IV	35.76	86.5	31.07	225.1	27.69
	V	7.81	90.1	7.07	330.8	8.89
Fall	I	15.66	147.2	14.78	569.1	19.48
	II	7.70	262.0	12.93	1032.8	17.38
	III	23.20	228.4	33.97	522.5	26.50
	IV	48.52	117.5	36.55	322.8	34.24
	V	2.95	93.8	1.77	372.9	2.40
Winter	I	9.50	193.6	8.03	751.3	11.39
	II	10.69	227.3	10.61	852.7	14.55
	III	32.40	362.0	51.22	825.2	42.68
	IV	44.95	152.8	29.99	435.1	31.22
	V	0.26	125.6	0.14	394.6	0.16
Annual	I	17.04	147.8	15.34	547.2	20.22
	II	8.57	187.1	9.76	696.9	12.95
	III	26.11	257.1	40.88	581.9	32.94
	IV	42.15	124.9	32.06	242.7	31.32
	V	3.44	93.5	1.96	343.9	2.57

TABLE 1c. Region III, representative station: Hampton, VA

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power $W m^{-2}$	% Contribution to Power	Average Power $W m^{-2}$	% Contribution to Power
Spring	I	26.25	96.3	27.81	385.3	36.60
	II	6.84	110.0	8.28	416.7	10.31
	III	21.40	136.4	32.11	307.6	23.82
	IV	36.32	65.8	26.29	171.5	22.54
	V	6.76	74.0	5.50	274.9	6.72
Summer	I	34.43	67.2	44.08	214.9	18.22
	II	4.49	84.6	7.24	509.2	10.64
	III	16.96	50.0	30.63	285.5	22.10
	IV	25.32	41.8	39.41	187.8	35.27
	V	13.35	48.6	6.66	226.2	13.78
Fall	I	17.50	121.4	18.04	484.0	24.73
	II	4.31	98.4	8.83	381.5	11.77
	III	15.97	154.5	37.16	351.6	29.08
	IV	38.75	65.6	35.04	181.2	33.28
	V	12.57	72.0	0.94	253.3	1.13
Winter	I	14.05	121.4	18.04	484.0	24.73
	II	8.48	98.4	8.83	381.5	11.77
	III	22.74	154.5	37.16	351.6	29.08
	IV	50.50	65.6	35.04	181.2	33.28
	V	1.23	72.0	0.94	253.3	1.13
Annual	I	21.41	85.9	23.18	341.1	30.79
	II	6.49	104.8	8.57	391.3	10.71
	III	19.90	127.5	31.97	288.3	24.19
	IV	40.10	62.9	31.78	170.2	28.78
	V	7.12	50.1	4.50	184.3	5.53

TABLE 1d. Region IV, representative station: Charleston, SC

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power W m ⁻²	% Contribution to Power	Average Power W m ⁻²	% Contribution to Power
Spring	I	24.73	136.0	28.54	509.2	36.66
	II	3.27	178.4	4.95	653.1	6.22
	III	18.09	179.4	27.54	382.8	18.56
	IV	24.36	85.0	17.57	195.6	13.87
	V	24.09	104.6	21.39	352.1	24.69
Summer	I	30.40	69.0	38.49	247.9	43.67
	II	1.65	67.9	2.06	218.7	2.09
	III	12.55	65.7	15.13	143.6	10.44
	IV	8.80	71.3	11.51	164.8	8.40
	V	36.35	49.2	32.81	168.0	35.39
Fall	I	16.34	54.2	14.40	198.1	18.75
	II	4.20	115.9	7.91	396.2	9.64
	III	13.21	88.2	18.94	198.1	15.16
	IV	25.89	78.9	37.12	200.9	30.13
	V	27.32	48.7	21.63	166.4	26.33
Winter	I	15.14	187.2	24.25	709.5	32.05
	II	5.96	112.7	5.75	420.8	7.48
	III	22.76	183.7	35.77	403.3	27.39
	IV	44.44	70.9	26.96	183.4	24.32
	V	7.13	119.3	7.28	411.2	8.75
Annual	I	20.94	115.2	26.49	429.3	33.57
	II	4.11	116.2	5.24	422.6	6.49
	III	17.80	149.4	29.20	326.6	21.71
	IV	28.82	73.8	23.35	185.8	20.00
	V	20.78	68.9	15.72	235.1	18.24

TABLE 1e. Region V, representative station: Mobile, AL

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power W m^{-2}	% Contribution to Power	Average Power W m^{-2}	% Contribution to Power
Spring	I	14.40	109.8	19.93	432.4	24.50
	II	2.50	111.3	3.51	477.7	4.70
	III	11.98	117.9	17.80	259.5	12.23
	IV	24.57	72.9	22.57	188.0	18.17
	V	40.34	71.2	36.20	254.5	40.40
Summer	I	15.19	32.5	16.98	123.8	19.36
	II	0.73	43.1	1.08	146.9	1.10
	III	7.09	45.0	10.98	99.3	7.25
	IV	3.30	40.8	4.63	104.6	3.55
	V	61.99	31.1	66.33	107.7	68.73
Fall	I	9.69	42.4	9.27	176.8	12.63
	II	3.52	81.1	6.44	284.4	7.38
	III	11.80	93.2	24.82	225.1	19.58
	IV	25.47	61.8	35.53	161.0	30.23
	V	38.28	27.7	23.93	106.9	30.17
Winter	I	10.62	138.2	14.19	530.0	17.84
	II	7.02	131.3	8.91	535.6	11.91
	III	13.73	161.5	21.44	375.4	16.33
	IV	54.65	82.0	43.32	225.6	39.07
	V	11.09	113.3	12.15	422.5	14.85
Annual	I	12.35	83.1	15.03	322.4	18.71
	II	3.92	116.7	6.70	469.8	8.66
	III	11.24	120.8	19.88	279.1	14.75
	IV	30.28	76.6	33.96	207.6	29.55
	V	34.85	47.9	24.44	173.0	28.34

TABLE 1f. Region VI, representative station: Miami, FL

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power W m ⁻²	% Contribution to Power	Average Power W m ⁻²	% Contribution to Power
Spring	I	21.25	125.1	21.55	421.7	22.76
	II	1.14	125.7	1.16	378.2	1.10
	III	9.20	107.5	8.02	242.2	5.66
	IV	15.23	185.0	22.85	452.7	17.51
	V	45.80	125.0	46.42	455.4	52.97
Summer	I	17.54	59.1	18.21	201.1	18.34
	II	0.08	51.7	0.07	144.6	0.06
	III	1.67	93.1	2.73	196.1	1.70
	IV	0.56	28.2	0.28	68.7	0.20
	V	66.19	67.7	78.71	231.6	79.70
Fall	I	24.49	70.6	22.42	239.9	24.44
	II	1.99	170.3	4.40	621.4	5.15
	III	8.01	69.6	7.23	148.2	4.94
	IV	16.99	120.2	26.50	299.0	21.13
	V	32.50	93.5	39.44	328.0	44.34
Winter	I	26.21	100.8	26.83	344.0	30.46
	II	3.30	99.6	3.34	385.8	4.30
	III	9.55	107.2	10.40	237.5	7.66
	IV	36.58	98.6	36.63	245.9	30.34
	V	19.06	120.5	23.32	422.0	27.18
Annual	I	22.30	86.1	23.05	292.9	24.97
	II	1.68	116.4	2.35	432.9	2.78
	III	6.50	97.4	7.60	214.1	5.32
	IV	17.93	110.5	23.79	274.5	18.81
	V	41.04	87.7	43.21	306.7	48.12

TABLE 1g. Region VII, representative station: Brownsville, TX

	Weather Category	% Occurrence of Category	10 meters		50 meters	
			Average Power W m ⁻²	% Contribution to Power	Average Power W m ⁻²	% Contribution to Power
Spring	I	24.82	197.8	25.57	735.2	28.38
	II	1.14	365.6	2.17	1178.1	2.09
	III	4.82	109.4	2.75	234.5	1.76
	IV	24.74	154.9	19.96	365.0	14.04
	V	40.35	235.7	49.54	856.2	53.73
Summer	I	19.11	108.0	19.93	400.2	21.76
	II	0.00	0.0	0.00	0.0	0.00
	III	1.36	87.6	1.15	181.3	0.70
	IV	3.46	81.6	2.73	177.1	1.74
	V	67.85	116.3	76.19	392.5	75.79
Fall	I	18.60	101.0	21.59	344.8	25.28
	II	0.61	52.3	0.37	228.6	0.55
	III	7.19	119.1	9.84	269.5	7.64
	IV	28.33	102.4	33.34	233.7	26.10
	V	35.53	85.4	34.87	288.7	40.43
Winter	I	23.02	177.3	26.79	633.4	33.69
	II	2.29	155.7	2.34	507.7	2.69
	III	8.60	144.7	8.17	329.8	6.55
	IV	56.67	142.1	52.87	345.4	45.23
	V	6.59	227.2	9.83	777.7	11.84
Annual	I	21.46	152.6	24.43	552.0	28.63
	II	1.18	179.0	1.58	586.3	1.67
	III	5.67	130.9	5.54	294.8	4.04
	IV	31.68	136.2	32.19	326.8	25.02
	V	34.32	141.6	36.26	490.0	40.64

TABLE 2. Mean annual power density (W m^{-2}) for the layer 10-100 m shown for each 100 km^2 (10 km north-south x 10 km east-west) for each grid area corresponding to

- a) Chesapeake Bay, Figure 3a
- b) Apalachee Bay, Figure 3b
- c) South Texas Coast, Figure 3c

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
A	194	194	194	195	194	205	215	226	230	218	200	196	200	211	207	207	193	191	191	192	194
B	194	194	195	198	206	221	235	229	216	206	199	195	195	209	226	218	204	191	195	198	199
C	195	195	196	201	217	241	250	229	210	202	197	194	194	205	236	231	234	220	210	206	212
D	195	195	196	201	217	244	257	237	213	200	195	194	193	203	235	267	272	262	234	221	234
E	195	195	197	201	218	242	254	238	213	200	195	192	192	198	224	265	291	280	235	231	268
F	197	196	197	202	220	248	252	232	211	199	194	192	192	194	211	254	292	288	264	269	292
G	199	197	197	204	226	255	254	232	210	198	194	191	190	192	200	227	269	291	294	298	306
H	199	197	197	205	233	262	256	233	218	199	194	191	190	190	190	206	205	276	304	312	315
I	200	197	197	206	250	266	265	238	215	202	195	191	190	189	191	198	220	261	310	317	320
J	199	197	199	207	233	264	258	234	216	201	195	191	190	190	190	198	210	280	296	318	322
K	211	198	201	208	228	255	246	225	210	210	195	192	191	189	190	194	209	241	295	318	324
L	211	205	202	207	222	201	241	221	209	203	198	194	191	191	191	193	211	254	299	319	325
M	221	221	213	211	216	236	252	239	226	221	207	197	194	192	193	193	217	263	304	322	328
N	216	230	231	225	219	238	263	268	258	244	220	202	196	195	198	210	239	279	311	326	332
O	207	213	220	227	231	239	266	284	277	258	239	207	198	199	209	233	263	296	319	330	336
P	202	204	206	213	228	249	271	282	274	250	234	211	202	200	226	251	285	310	325	335	340
Q	201	206	205	205	214	234	263	279	260	242	239	228	211	211	230	269	300	320	330	338	343
R	200	240	209	208	209	219	241	283	277	252	257	246	220	223	254	289	312	325	334	341	344
S	200	202	208	216	212	218	219	287	298	289	270	244	227	247	283	307	321	330	337	342	345
T	201	201	204	212	216	223	254	290	316	299	282	232	238	272	302	317	327	334	339	343	346
U	201	202	201	205	211	226	259	292	305	286	249	233	252	288	312	323	331	336	340	343	346
V	200	201	202	202	206	220	201	289	300	271	245	247	272	301	319	328	333	337	340	343	346
W	200	200	203	205	208	215	241	283	295	262	202	272	296	314	324	331	335	338	341	353	345
X	203	203	204	208	214	230	257	286	285	257	257	286	311	323	329	333	336	338	341	343	345
Y	204	208	208	208	216	200	272	292	281	256	262	296	319	327	332	335	337	339	341	343	345
Z	198	202	208	214	214	225	259	291	291	274	285	307	323	330	334	336	338	339	341	343	344
a	196	197	203	219	222	232	242	282	301	302	305	316	325	332	335	337	339	340	351	343	344
b	197	197	200	209	223	228	234	258	284	301	313	321	328	333	336	338	340	341	342	344	345
c	197	198	199	202	211	217	217	223	240	274	308	324	330	335	337	339	340	341	342	344	344
d	197	197	198	200	203	204	205	206	219	284	302	326	332	336	338	340	341	341	343	344	345
e	197	197	198	199	201	200	201	204	216	250	300	326	335	339	340	341	341	342	343	344	344
f	197	197	197	199	201	200	201	204	217	250	293	323	337	341	343	343	343	343	344	344	345
g	196	197	197	198	199	199	200	200	220	245	286	319	337	343	345	345	345	344	345	345	345

TABLE 2a. Chesapeake Bay

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
A	74	73	74	74	73	72	71	71	71	71	71	73	74	76	77	77	76	78	78	77	78	76	76	74	75	75	72	71	71	70	69	69	68	68	67	66
B	76	76	76	75	74	73	72	71	70	69	70	71	72	74	75	76	77	77	77	77	76	75	76	74	73	73	72	72	71	70	69	68	68	67	67	66
C	78	78	77	76	75	74	72	71	71	70	70	71	72	72	73	74	75	75	76	76	76	75	76	74	73	73	72	72	71	70	69	68	68	67	67	66
D	80	79	78	77	76	74	73	72	71	72	72	72	72	72	72	73	75	74	75	75	75	75	74	74	73	72	71	71	70	70	68	68	67	66	66	
E	83	82	80	78	78	74	73	73	73	73	73	73	73	73	73	74	74	74	74	74	74	74	74	74	73	72	72	71	70	70	68	68	68	67	66	66
F	84	86	83	78	76	74	74	73	74	74	74	74	74	74	75	76	77	76	76	75	73	73	73	73	73	72	71	71	70	70	68	68	67	66	65	65
G	86	92	88	81	76	74	78	74	74	74	74	75	75	77	77	80	83	80	84	80	77	74	73	72	71	71	71	71	70	70	69	68	67	66	65	65
H	97	98	94	85	78	76	74	74	74	76	77	79	79	81	86	94	98	98	91	84	78	78	72	71	70	70	70	70	70	69	68	68	68	65	65	64
I	96	97	97	92	83	76	75	76	78	79	81	82	85	87	92	99	103	105	104	98	88	80	74	71	70	70	69	69	69	69	69	68	67	66	65	64
J	93	94	96	97	89	80	78	80	81	83	85	88	93	96	96	98	101	102	105	108	104	90	78	73	70	69	69	69	68	68	67	66	66	64	64	63
K	93	94	95	97	93	86	83	85	88	90	92	95	97	98	98	98	100	101	104	107	110	102	87	75	71	69	68	68	67	68	67	67	66	65	64	63
L	94	94	95	96	95	92	90	91	93	95	96	97	97	97	97	97	98	99	101	103	105	109	110	100	84	75	69	68	67	68	67	67	66	65	64	63
M	93	94	95	96	97	97	96	95	95	96	97	96	97	96	96	97	98	100	103	105	108	111	109	95	80	72	68	67	67	67	67	67	66	66	65	64
N	95	95	96	96	96	95	94	94	93	93	93	94	94	96	96	98	99	101	103	105	107	110	112	111	102	86	74	68	67	67	67	67	67	65	65	64
O	95	95	96	96	96	95	94	94	93	93	93	94	94	96	96	98	99	101	103	105	107	110	112	111	113	112	100	82	71	67	67	67	67	66	66	65
P	93	94	94	94	94	95	94	94	94	95	95	96	97	97	99	100	101	103	104	106	109	110	111	113	114	114	111	96	79	71	68	67	67	66	66	65
Q	95	95	96	96	97	97	98	98	98	98	99	100	100	101	101	102	103	105	107	108	110	111	113	114	114	111	96	79	71	68	67	67	66	66	65	64
R	98	98	99	100	100	101	101	101	101	101	101	102	102	102	103	104	105	106	107	109	110	111	113	114	115	115	114	107	92	81	72	67	66	66	66	64
S	99	99	100	101	101	102	102	103	106	104	103	104	105	105	106	107	108	110	111	112	114	115	116	117	117	116	113	106	95	80	69	66	66	66	65	64
T	100	100	100	101	102	103	103	104	104	105	105	106	107	107	109	110	111	113	114	115	116	118	119	119	119	118	117	113	107	91	74	67	66	66	66	65
U	101	101	101	102	102	103	104	104	105	106	107	107	109	110	111	112	113	115	117	118	119	120	121	121	122	122	120	118	114	101	81	68	66	67	67	66
V	102	101	102	102	103	104	104	105	106	107	108	109	110	111	113	114	116	118	119	121	122	123	124	125	125	125	125	124	122	119	110	88	71	66	67	67
W	102	102	102	103	104	104	105	106	107	108	110	111	112	114	115	117	118	120	121	123	124	126	126	127	128	128	128	126	124	117	95	79	67	67	67	67
X	104	103	103	104	104	105	106	107	108	109	111	112	113	115	117	118	120	122	123	125	126	128	129	130	130	131	130	130	128	124	105	76	67	68	67	67
Y	104	104	104	104	105	106	107	108	109	110	111	113	115	116	118	120	122	123	125	127	129	129	131	132	133	133	133	132	132	129	107	78	67	68	68	67

TABLE 2b. Apalachee Bay

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
A	130	132	135	135	139	133	132	130	127	125	123	122	123	134	126	131	132	137	148	156	159	162	170	181
B	130	133	135	133	135	133	132	130	128	126	124	123	124	139	136	130	141	151	155	168	172	177	181	185
C	131	134	135	136	135	130	132	131	129	127	128	125	126	132	141	147	152	157	166	177	183	184	186	188
D	132	134	135	136	130	134	132	131	125	128	126	126	127	132	140	147	146	155	175	182	183	184	186	188
E	132	134	136	136	135	133	132	131	130	129	129	130	130	132	138	159	162	173	180	182	183	185	187	190
F	132	138	137	136	135	136	132	130	125	129	131	135	138	139	145	156	169	177	181	182	184	186	188	191
G	133	136	137	136	135	131	132	130	124	128	130	135	143	148	155	165	174	179	181	184	186	188	190	192
H	133	134	138	137	136	138	132	130	129	128	127	130	137	148	161	170	176	180	183	185	187	190	191	194
I	134	137	139	138	136	135	135	131	124	128	128	129	135	141	164	172	176	181	184	187	190	191	193	195
J	134	137	139	139	137	136	134	132	131	131	130	131	139	153	165	172	177	182	186	189	192	194	195	197
K	134	137	139	139	138	136	135	134	135	134	134	134	142	156	166	172	178	183	188	192	194	196	197	199
L	134	136	139	139	138	136	135	135	138	139	139	138	144	156	166	173	179	185	190	194	196	197	199	200
M	134	136	138	138	138	137	134	134	136	139	140	143	148	157	166	173	181	188	193	197	199	200	200	202
N	132	135	138	138	138	316	314	138	130	134	138	144	151	158	165	174	183	190	196	199	201	202	202	203
O	132	135	137	138	137	136	134	133	132	134	140	145	151	158	166	175	185	193	199	202	204	204	204	205
P	132	134	136	137	136	135	134	136	132	137	146	149	151	158	166	177	187	196	202	205	206	205	206	206
Q	131	134	135	136	135	134	138	132	131	137	147	151	153	158	167	179	191	198	205	208	208	207	207	207
R	131	133	134	135	134	133	132	131	130	134	144	152	153	158	169	181	194	203	208	210	210	209	208	208
S	131	133	134	134	135	132	130	129	129	130	140	152	154	158	171	184	197	205	210	212	211	210	209	209
T	131	132	133	135	132	131	129	127	127	128	136	140	155	159	171	186	198	208	212	214	212	211	209	209
U	130	132	133	132	132	130	127	126	124	126	133	148	155	158	171	188	201	210	214	214	213	211	209	209
V	130	131	132	132	130	129	126	124	120	124	129	143	155	159	171	189	202	211	215	215	213	210	209	209
W	129	131	132	132	130	128	126	123	121	121	128	137	150	159	171	189	204	213	215	214	212	209	208	208
X	129	131	132	131	129	127	128	122	120	119	121	131	145	157	170	188	205	213	215	213	211	208	207	206
Y	129	131	131	131	129	127	124	122	120	119	121	128	141	155	168	188	206	213	214	212	209	207	205	205
Z	128	130	131	130	129	127	124	122	120	119	120	126	137	149	163	188	206	212	212	210	207	204	203	203
a	128	130	131	130	128	126	124	121	119	119	121	126	134	143	163	189	206	210	209	207	205	202	201	201
b	127	130	130	130	128	126	123	120	119	119	122	128	137	148	166	190	205	207	206	204	202	201	199	199
c	127	129	130	130	128	126	124	121	119	118	121	129	140	151	168	192	204	205	204	202	200	198	197	198
d	127	125	130	130	129	127	125	128	120	119	121	128	148	152	175	195	201	202	201	199	198	196	195	196
e	127	129	130	130	129	127	126	124	122	121	113	129	139	158	183	197	199	199	198	197	196	195	194	195
f	127	129	130	130	129	126	127	126	126	126	128	133	147	171	188	195	196	197	196	195	195	193	193	194
g	127	129	130	130	129	128	128	129	132	134	134	139	158	180	189	192	195	195	195	194	194	192	192	193
h	127	129	130	130	129	129	129	132	136	141	140	148	169	183	188	192	193	194	194	193	192	191	192	192
i	128	130	130	130	129	129	129	133	141	142	142	167	175	184	188	191	192	193	192	192	191	191	191	192
j	128	130	131	130	130	129	129	133	142	144	148	164	178	184	188	191	192	192	192	191	191	190	190	191
k	128	130	131	130	130	131	131	136	142	146	156	170	179	185	188	191	191	192	191	191	190	190	190	191
l	128	130	131	130	130	131	133	137	140	148	159	173	180	185	188	191	191	191	191	190	190	190	190	191
m	128	130	131	130	129	129	130	134	140	147	160	173	181	186	189	191	191	191	191	190	190	189	189	191
n	127	130	130	130	128	128	127	132	142	161	162	173	181	186	189	191	191	191	191	190	190	189	189	190

TABLE 2c. South Texas Coast

TABLE 3. Coastal Stations Used in the Verification of 100 m Layer-Mean Annual Average Power Density.

Station Name	Anemometer* Height (m)	Years of Data	Single-Level	Exponent (a)	100 m Layer-Mean Annual Average Power Density (Wm^{-2}):	
			Annual Average Power Density (Wm^{-2})		From Data	From Figs. 5, 9 or 13
CHESAPEAKE BAY AREA						
Dover (AFB), DE	<u>4.6</u>	1957-64	85	0.124**	196	203
Wallops Island (X-85), VA	<u>10.0</u>	1967-76	99	0.209**	250	254
Hampton (Langley AFB), VA	<u>29.3</u>	1955-59	160	0.209	210	223
Virginia Beach Oceana NAS), VA	<u>4.0</u>	1960-64	57	0.240	313	274
	<u>12.8</u>	1955-59	122			
	<u>4.0</u>	1960-64	73			
APALACHEE BAY AREA						
Tampa (McDill AFB), FL	<u>22.9</u>	1955-57	66	0.061	73	67
Panama City (Tyndall AFB), FL	<u>4.0</u>	1958-64	47	0.066	86	88
	<u>3.0</u>	1958-64	51			
SOUTH TEXAS COAST AREA						
Corpus Christi (NAS), TX	<u>19.2</u>	1955-60	259	0.213	455	151
Brownsville (Int. Airport), TX	<u>6.7</u>	1961-64	160	0.213**	362	141
	<u>17.1</u>	1955-60	191			

*Underlined heights used as basis for computing layer-mean values.

**Exponent not determinable for this station; value of nearest station used. (In the case of Dover, DE, Atlantic City, NJ was used.)

FIGURE 1. Regional demarcations of coastal zone and seven representative stations.

FIGURE 2. Location of test regions.

CB - Chesapeake Bay
 AB - Apalachee Bay
 ST - South Texas coast

Annual average wind speed (m s^{-1}) normalized to 10 m above the ground for 36 coastal locations is also shown.

FIGURE 3. Mean annual power density (W m^{-2}) for the layer 10-100 m for each of the test regions shown in Figure 2. Centers of relative maximum (X) and minimum (N) are indicated along with solid isolines drawn at 50 W m^{-2} intervals. Values of mean annual power density for each $10 \times 10 \text{ km}$ grid area can be obtained by referring grid location to Table 2.

- a) Chesapeake Bay: Intersections of 75° , 76° and 77°W with 37° , 38° and 39°N are marked. Table 2(a) gives the $10 \times 10 \text{ km}$ grid of mean annual power density values.
- b) Apalachee Bay: Intersections of 83° , 84° and 85°W with 29° and 30°N are marked. Table 2(b) gives the $10 \times 10 \text{ km}$ grid of mean annual power density values.
- c) South Texas Coast: Intersections of 97° and 98°W with 25° , 26° , 27° and 28°N are marked. Table 2(c) gives the $10 \times 10 \text{ km}$ grid of mean annual power density values.

FIGURE 3a. Chesapeake Bay

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Figure 3c.
South Texas
Coast

APPENDIX 1

THE SKILL OF THE MODEL

Measurements of wind speed and direction were made over a 30x120 km rectangle lying across the Delmarva Peninsula in late January and early February, 1980. Two days representing weather category III (see Table 1 and Appendix 2) were selected to test the ability of the model to reproduce the observed winds.

The mesoscale numerical model of the atmosphere is used to produce the "predicted" winds. The initialization of the model was accomplished using pre-dawn meteorological conditions. The integration of the model encompassed all daylight hours of each day.

Approximately 200 two-minute average (based on 120 observed values) wind speeds were "observed" on each day. These are compared to the spatially and temporally coincident values produced by the model. (Only wind-speeds are compared. Wind directions are not considered because no model produced direction differed from its coincident measured value by more than 15°. For wind power purposes this departure is not regarded as important.) On 30 January and 3 February a total of 409 wind speed measurements were made. Of the model predictions 308 were within the measurement error. Therefore, based upon the criterion that error in excess of that attributable to measurement is due to poor predictive ability, the model has a 75% skill in reproducing observed wind speeds.

The skill of any numerical simulation is not solely due to the integrations performed. The representativeness of the initialization procedure has a comparable impact upon the resulting predictions. The separation of the two skills is difficult without the expenditure of considerable computer resources on sensitivity tests. Nevertheless, it is approximately true to ascribe the spatial and temporal variations to the model's operations and the mean values to the initialization. The computation of the coefficient of linear correlation between predicted and observed wind speeds emphasizes the variations. On 30 January the coefficient was 0.79, on the 3rd of February 0.75. The correlation analysis thus suggests a 77% skill for the model itself.

An analysis of the departures between prediction and observed wind speeds, when the bias due to differing means is removed, also serves to evaluate the model's skill. This analysis gives a value of 81% skill for the 30th and 76% for the 3rd, i.e. 78% overall. It is therefore concluded that the model's ability to reproduce wind speeds in the vicinity of a coastline is most likely 77%.

A skill rating of 77% implies a percent error in predictions of 23%. Since wind power varies on the cube of wind speed, it is anticipated that the percent error in wind power predictions will be three times that in wind speed, i.e. approximately 70%. In Figures 1.A and 1.B the cube of the observed wind speeds is plotted against predicted wind speed. Various percent error isolines are plotted.

The set (+) of isolines which contains 68% of all points, i.e. the + 1 standard deviation limit, is 33%. The set which contains 95%, the + 2 standard deviation limit, is 70%. Therefore, if a one-in-three chance of being wrong is acceptable, the percent error in wind power predictions by the model is 33%. If only a one-in-twenty chance can be tolerated, then the percent error is 70%.

Error analysis of the observations can be carried out in terms of the measurement platform used. Known sources of error can be explicitly included (e.g. for the aircraft drift in the inertial navigation system). Unknown sources of error cannot be accounted for. Most routine (operational) field measurements of wind speed probably do not reproduce the theoretical true wind by more than 90% and many as low as or lower than 75%. We conclude that for the conditions measured, the model has a skill comparable to that of routine observations.

FIGURE 1.A. Scatter diagram of the cube of measured wind speed, U_m^3 , versus predicted wind speed, U_p , for 30 January 1980. Isolines of percent error in predicted wind power, $(U_p^3 - U_m^3)/U_m^3 = \ell\ell$, where $\ell\ell = -50, -25, +0, +25$ and $+50\%$, are plotted. (Actually, U^3 is specific kinetic energy flux and not wind power. Since the percent error in atmospheric density contributes little to the percent error in power, the $\ell\ell$ values are essentially the percent errors in power.) Over-predictions are below, under-predictions above the $+0\%$ error, the solid line.

FIGURE 1.B. Scatter diagram of the cube of measured wind speed, U_m^3 , versus predicted wind speed, U_p , for 3 February 1980. Isolines of percent error in predicted wind power, $(U_p^3 - U_m^3)/U_m^3 = \ell\ell$, where $\ell\ell = -50, -25, +0, +25$ and $+50\%$, are plotted. (Actually, U^3 is specific kinetic energy flux and not wind power. Since the percent error in atmospheric density contributes little to the percent error in power, the $\ell\ell$ values are essentially the percent errors in power.) Over-predictions are below, under-predictions above the $+0\%$ error, the solid line.

APPENDIX 2

DEFINITION OF WEATHER CATEGORIES

Figure 2.A shows the frontal cyclone and surface low and high pressure systems with the associated regions labelled I-V for each of the five weather categories.

Each category is defined below together with a description of the physical state of the atmosphere represented by that category:

Category I: in the warm sector, i.e., ahead of the cold front and/or behind the warm front, with generally a straight isobaric pattern.

This region is generally characterized by an overlying upper-level ridge. The subsidence associated with this ridge will favor a relatively stable thermal stratification. The low-level pressure gradient is usually weak or moderate. The air mass type is maritime tropical (mT).

Category II: ahead of the warm region in the region of cyclonic curvature of the isobars.

This region is generally characterized by warmer air overriding colder air near the ground, thereby favoring a comparatively stable thermal stratification. The cyclonic curvature of the isobars, with its associated low-level frictional convergence, will compensate somewhat for the stabilizing influence of the overlying warm air, but the vertical thermal gradient is expected to be dominant in general. The low-level pressure gradient is usually moderate to strong. The air mass is maritime polar, continental polar or continental arctic with maritime tropical above $\frac{mT}{mP}$, $\frac{mT}{cP}$, $\frac{mT}{cA}$.

Category III: behind the cold front in the region of cyclonic curvature of the isobars.

This region is generally characterized by an upper level trough, which, with its comparatively cold temperatures, will enhance mixing and thereby favor less stable stratification. The cyclonic curvature of the isobars will cause low-level frictional convergence and, therefore, upward motion, which will further aid the mixing. The low-level pressure gradient is usually moderate or strong. The air mass is continental polar or arctic (cP, cA).

Category IV: under a continental polar or arctic high with anticyclonic curvature to the surface isobars.

This region is generally characterized by an upper level trough, which will enhance vertical mixing, while the low level isobaric pattern is oriented so as to somewhat reduce this mixing through boundary layer divergence with its resultant subsidence. The low-level pressure gradient is usually weak or moderate. The air mass is continental polar or arctic (cP, cA).

Category V: in the vicinity of the subtropical ridge with anticyclonic curvature to the surface isobars.

This region is generally characterized by an overlying upper-level ridge and boundary layer frictional divergence. Both effects will act to promote a relatively stable thermal stratification. The low-level pressure gradient is usually weak or moderate. The air mass is maritime tropical (mT).

Categories I through IV are associated with the polar and arctic fronts. Category V is characteristic of the broad region of high pressure which circles the globe equatorward of the polar front. The number of times a site is north of the polar front (in categories II through IV) and south of the front (in categories I and V) is used to estimate the Winter, Spring, Summer and Fall seasons at those locations.

FIGURE 2.A. The observed synoptic weather map over the United States for 9 January 1964, along with the typing of particular weather feature characteristics. The numbers plotted on the Figure illustrate the method of binning these features.

APPENDIX 3

MODEL PARAMETERS

Required meteorological input is based upon:

1. A characterization of the dominant weather categories determined from Figure 1 and Table 1. This may be done either by
 - a) determining the mean conditions for each of the chosen categories for the location of interest.

or

- b) choosing a day typical of each of the chosen categories.

Choice of b) is simplest and is the method recommended.

2. Upper air structure:

Select the nearest rawinsonde station to the location of interest and for the days chosen as typical of each category determine the quantities listed in Table 3.A for either the 2- or 3-dimensional model.

3. Surface parameters:

For the location of interest determine from measurements available from such sources as the nearest National Weather Service (NWS) station and from the NWS files the parameters listed in Table 3.A.

4. Other model specifications as listed in Table 3.A.

TABLE 3.A. Required measurements and parameters to initialize the 2 or 3-D models. (✓ required, x not required)

Element	2-D	3-D	Source
<u>Upper Air</u>			
1) geostrophic wind (meteor deg. and m/sec)	✓	✓	NWS rawinsonde nearest location and time of start: geostrophic level chosen at height where a) wind shear approaches zero and b) where marked decrease in moisture begins.
38 2) wind shear to 6 km ($\text{m s}^{-1} \text{ km}^{-1}$)	✓	✓	NWS rawinsonde nearest location and time of start: a) take 6 km wind vector, b) subtract geostrophic wind vector, c) divide by 6 km minus geostrophic height
a) u-component	✓	✓	
b) v-component	✓	✓	
3) initial depth of initial boundary layer (m)			Same as height of geostrophic level
4) free atmosphere lapse rate of potential tempera- ture (K km^{-1})	✓	✓	NWS rawinsonde determined 5 to 6 km
<u>Surface</u>			
1) initial shelter height temperature ($^{\circ}\text{C}$)	✓	✓	Nearest NWS observation or NWS weather chart nearest time of start

Table 3.A. (cont.)

Element	2-D	3-D	Source
2) initial surface pressure (mb)	✓	✓	NWS weather chart nearest time of start
3) sea surface temperature (C)	✓	✓	NWS weather chart or satellite information for day of interest
4) soil characteristics			Nearest agricultural station or by direct observation
a) density (g cm^{-3})	x	✓	
b) specific heat ($\text{cal g}^{-1} \text{K}^{-1}$)	x	✓	
c) diffusivity (cm s^{-1})	x	✓	
d) wetness (%)	x	✓	
5) surface albedo	✓	✓	From textbook based on inspection
6) surface roughness length (cm)	✓	✓	From textbook based on inspection or by calculation (see Snow, 1981)
<u>Other Specifications</u>			
1) mean latitude ($^{\circ}\text{N}$)	✓	✓	USGS map
2) horizontal grid interval (km)	2 to 10	5 to 15	Users choice
3) length of section or size of domain (km)	50 to 300	100 to 300 on side	Users choice
4) number of vertical levels	up to 17	up to 17	Users choice

Table 3.A. (cont.)

Element	2-D	3-D	Source
5) spacing of vertical levels (m)	down to 5 m	down to 5 m	Users choice
6) time steps of model (sec)	60 to 300	60 to 300	Users choice
7) time of day at which model is started	open	open	Users choice

APPENDIX 4

NORMALIZING THE POWER ESTIMATES

The potential wind power of a given site or location is based upon an estimate derived from model calculation for one, two or three dominant weather categories which represent 75% or more of the annual wind power potential. The reason for not performing model calculations for all situations is the cost of the model runs.

When 2-D calculations are used, many estimates can be made and little adjustment (normalizing) will be necessary. If 3-D calculations are made, the cost of the model runs is high. To obtain an annual power estimate, the percent of the year for which no estimates are made must be accounted for by normalizing the estimate to one.

To normalize, obtain the total percent occurrence of the dominant categories chosen from Table 1. For example for Region II, Table 1b, Categories I, III and IV occur just over 85% of the year, each category occurring 17%, 26% and 42% of the time. Thus the weighting factors to be applied to obtain the annual power estimate are

I	$17/85 = 0.20$
III	$26/85 = 0.31$
IV	$42/85 = \underline{0.49}$

1.00

and the annual power distribution at 50 m would be

I	547.2 W m^{-2} , 20% of time
III	581.9 W m^{-2} , 31% of time
IV	242.7 W m^{-2} , 49% of time

for a mean annual wind power potential of just over 400 W m^{-2} .

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