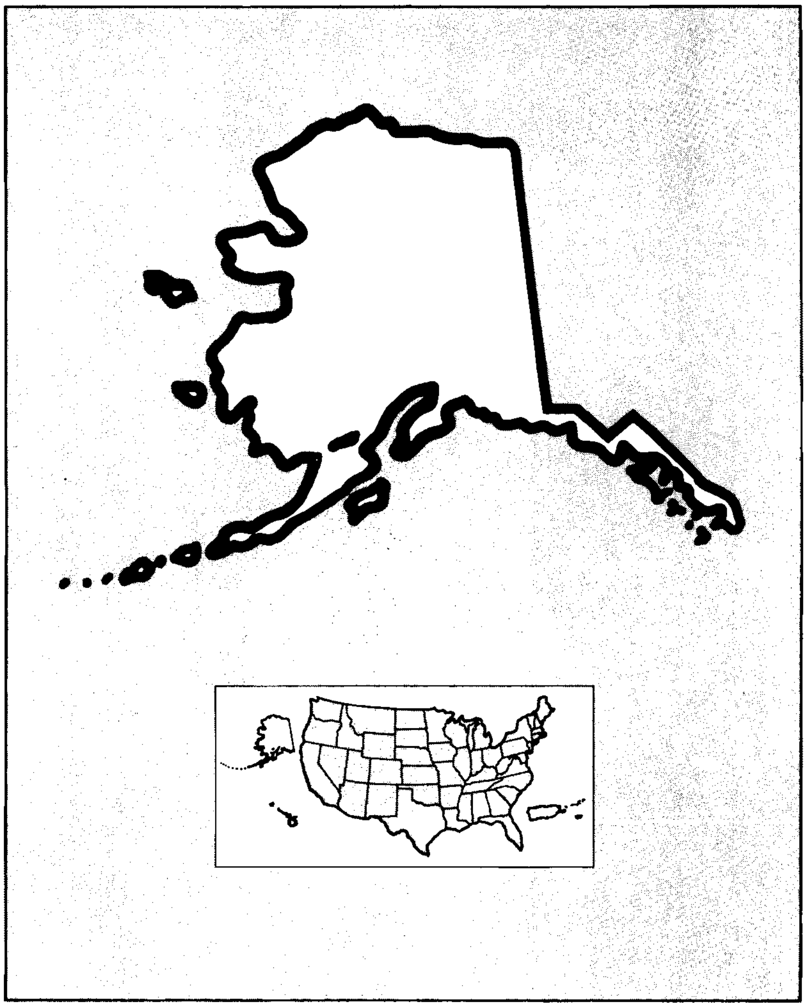
18 E

PNL-3195 WERA-10
UC-60

Wind Energy Resource Atlas: Volume 10 - Alaska



Prepared for Pacific Northwest Laboratory
Under Agreement B-87917-A-L

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

Battelle

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

Price: Printed Copy $_____ *; Microfiche $3.00

*Pages	NTIS Selling Price
001-025	$4.00
026-050	$4.50
051-075	$5.25
076-100	$6.00
101-125	$6.50
126-150	$7.25
151-175	$8.00
176-200	$9.00
201-225	$9.25
226-250	$9.50
251-275	$10.75
276-300	$11.00

PNL-3195 WERA-10
UC-60

WIND ENERGY RESOURCE ATLAS
THE ALASKA REGION

Wise, James L.
Wentink, Tunis, Jr.(a)
Becker, Richard, Jr.
Comiskey, Albert L.

D. L. Elliott(b)
W. R. Barchet(b)
R. L. George(b)

Arctic Environmental Information
and Data Center
University of Alaska
707 A Street
Anchorage, Alaska 99501

December 1980

Prepared for Pacific Northwest Laboratory
Under Agreement No. B-87917-A-L

Pacific Northwest Laboratory
Richland, Washington 99352

(a) Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

(b) Pacific Northwest Laboratory

PREFACE

For the purpose of assessing the national wind resource, the United States and its possessions have been divided into twelve regions. For each region, wind resource assessments are presented in the form of an atlas. The atlases depict in graphic, tabular and narrative form the wind resource on a regional and subregional level. The information presented in the atlases will help guide homeowners, utilities and industry in decisions concerning the use of the wind as a source of energy.

This atlas of the wind energy resource is composed of introductory and background information, a regional summary of the wind resource, and assessments of the wind resource in each subregion of Alaska. Chapter 1 provides background on how the wind resource is assessed and on how the results of the assessment should be interpreted. A description of the wind resource on a state scale is then given in Chapter 2. The results of the wind energy assessments for each subregion are assembled in this chapter into an overview and summary of the various features of the Alaska wind energy resource. Chapter 3 provides an introduction and outline to the descriptions of the wind resource given for each subregion. Assessments for individual subregions are presented as separate chapters beginning with Chapter 4. The subregion wind energy resources are described in greater detail than is the Alaska wind energy resource, and features of selected stations are discussed. This preface outlines the use and interpretation of the information found in the subregion chapters.

Much of the information in the subregion chapters is given in graphic or tabular form. As is discussed in Section 3.1, the sequence of maps, tables, and graphs is the same in each subregion chapter. References to these figures and tables are made here with an asterisk (*) in place of the chapter number (e.g., Figure *.1, Table *.2). Similar maps and tables are found in Chapter 2 on the Alaskan wind resource. References to the Alaskan maps and tables are made in brackets, [ ].

Figure *.1 shows the major geographical (mountains, rivers) and cultural (cities, towns) features in the subregion [Figure 2.1]. This map can be used to orient the reader to the subregion. Figure *.2 portrays the topography of the subregion in shaded relief [Figure 2.2]. The shaded relief allows the reader to visualize the character of the terrain surrounding locations of special interest. Superimposed on these subregion maps (but not the Alaska maps) is a grid of dashed lines one degree longitude by one-half degree (30') latitude. This grid is repeated on nearly all subsequent maps to give the reader an adequate frame of reference for locating the same feature on different maps.

Figure *.3 is a map of the land-surface form [Figure 2.3]. The information presented in Sections 1.6 and 1.8 indicates how the land-surface form is used to designate the terrain features considered to have a typical good exposure to the wind. Awareness of what constitutes well-exposed terrain features is crucial to the proper interpretation of the maps of wind power density.

Figures *.4 and *.5 identify and locate wind data sites relevant to the assessment. All locations in each subregion for which the National Climatic Center (NCC) has wind data in its archives are shown and named in Figure *.4. However, this assessment is based on a subset of NCC data augmented by data from other sources (see Sections 1.1 and 1.2). Figure *.5 shows the location of all wind data sites used in the assessment. Sections 1.3 through 1.5 briefly describe the methods used to analyze the wind data and evaluate the wind power.

The wind energy resource for a subregion is illustrated using several maps. The wind power maps represent a careful synthesis of quantitative wind data guided by state-of-the-art concepts on air flow near the earth's surface. Section 1.6 describes how the analysis of the wind data is transformed into the map of annual average wind power density found in Figure *.6 [Figure 2.4]. This map gives the annual average wind power density at typically exposed sites. A discussion of the classes of wind power density in Section 1.7 gives the relationship between mean wind power density (watts/m^2) and mean wind speed (m/s or mph).

A certainty rating is used to provide a measure of the ability to objectively evaluate the wind resource in a grid cell. The certainty ratings are given in the maps of Figure *.7. The degree of certainty with which the wind power can be estimated depends on the quality and quantity of wind data, the complexity of the terrain and concern over the variability of the wind resource over short distances. How these factors are combined to assign a certainty rating is discussed in Section 1.9.

The terrain feature with typical good exposure to the wind in a particular land-surface form provides a convenient and essential reference point on which to base the analyses of the wind resource shown in Figure *.6. However, a substantial portion of the terrain may have poorer than typical exposure to the wind and will have a lower wind resource than shown on the wind power maps. The maps of Figure *.8 provide an estimate of the percentage of area in each grid cell that may experience at least each of four different wind power classes. Section 1.10 discusses the assumptions underlying the evaluation of the areal distribution of the wind resource. The area of the subregion estimated to experience a particular wind power class is given in Table *.1 [Table 2.2]. This table summarizes the contribution made by each grid cell to the areal distribution of wind power for the subregion.

The annual average wind power density compresses into a single statistic time-varying trend on several time scales, e.g., annual, seasonal, monthly, and daily. In this atlas, the seasonal evolution of the geographical distribution of wind power is shown at the subregion level. The maps of Figure *.9 give the average wind power density for winter, spring, summer, and autumn. The interpretation of the seasonal average wind power maps is identical to that for the annual average wind power map. [For Alaska, Figure 2.5 shows only the season of maximum power.]

Additional information on the time variation and other characteristics of the wind resource in each subregion is presented for selected locations for which the National Climatic Center placed 1-hourly or 3-hourly time-series data on magnetic tape. Descriptions of the characteristics of the wind resource presented for these stations are given in Section 3.2. The urge to consider information pertaining to one of these sites as representative of some other location must be tempered with the realization that wind characteristics are extremely site-dependent. The degree of correspondence between the wind characteristics at one site and those at another site depends on the similarity between the topographical setting of the sites, the weather patterns that affect the sites and the obstructions to the wind in the vicinity of the sites.

Table *.2 identifies the stations, and gives their location (see also Figures *.4 and *.5) and annual average wind speed and power density. Figure *.10 shows how the yearly mean speed and power varied during the period of record. The monthly mean wind speed and power over the course of a year are shown in Figure *.11. The hourly mean wind speed over the course of a day is shown in Figure *.12 with a separate curve for each season. Figures *.11 and *.12 indicate the time of year and time of day, respectively, the wind resource is available. Figure *.10, on the other hand, indicates the year-to-year variability that might be expected in the yearly mean resource.

The frequency of occurrence of winds from a particular direction and of winds with a particular speed is shown in Figures *.13 and *.14, respectively. The information on wind direction may be important in assessing the availability of the wind resource relative to surrounding terrain or nearby obstructions. However, it is also important to realize that the wind direction statistics are highly dependent on the location of the instrument site relative to obstructions and major terrain features, e.g., valleys, ridges, and mountain ranges.

Figures *.15 and *.16 portray speed and power frequency statistics in the form of speed and power exceedance curves, respectively. The fraction of the total period of record the speed equals or exceeds a given value is shown in Figure *.15. The power exceedance curve in Figure *.16 gives the fraction of the period of record for which the power exceeds a given value.

As has been shown in the preceding discussion, the order of presentation of the wind resource in this atlas proceeds from an Alaskan perspective in Chapter 2, to a subregion perspective in the first part of each subregion chapter, to individual station descriptions in the last part of the subregion chapters. Attention given to Chapter 1 and Chapter 3 will make it possible for the reader to properly interpret the wind resource presentations.

ACKNOWLEDGMENTS

A number of people and organizations contributed in various ways to this program, ranging from weather observers recording the winds at individual sites to the processing and analysis of wind data. The National Climatic Center furnished most of the station summaries, and the U.S. Army Corps of Engineers and the U.S. Forest Service provided other important data. The program benefited from the close and sustained cooperation between the staff of AEIDC and the staff of the Geophysical Institute. The efforts of Coert Imstead and Celia Rohwer in the Geophysical Institute's Data Processing Section and the graphics personnel at AEIDC and PNL were especially helpful. Special appreciation goes to Deborah Topp and Lynda McAllister at AEIDC and Shelia Finch at the Geophysical Institute who patiently typed the text from initial draft through the several revisions to the finished product. Also, many thanks to Judy Brogan Murphy of AEIDC and Betsy Owzarski of PNL who edited the atlas. Finally, special acknowledgment is due to L. Divone and G. Tennyson of DOE, for their support and encouragement as well as their understanding of the many technical aspects and associated difficulties in producing this atlas.

CONTENTS

Page

CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: REGIONAL WIND ENERGY RESOURCE ASSESSMENT

Rapid development of wind as a source of commercial electric power is the principal goal of the Federal Wind Energy Program. Utility planning, wind turbine manufacturing, and marketing of wind energy conversion systems all depend on detailed wind resource assessments. This atlas of Alaska's wind resource, a product of the Wind Characteristics Program Element of the Federal Wind Energy Program, represents a major source of information for meeting these various needs.

This atlas is one of 12 being assembled to describe potential wind resources throughout the United States (see Figure 1.1). The spatial and temporal resolution of the wind resource in these regional assessments will be depicted in considerably greater detail than that in existing national assessments (Reed 1975, Coty 1976, Garate 1977, Elliott 1977). To produce the Alaska atlas in a timely fashion, only existing relevant data were used. The other atlases will use comparable data sets, analysis techniques, and presentations to ensure the comparability of the wind resource assessments.

The Alaska atlas assimilates five collections of wind resource data: one for the state and one for each of the four subregions that compose the state (northern, southcentral, southeast and southwest). At the subregional level, features of the climate, topography, and wind resource are discussed in greater detail than is provided in the state discussion, and the data locations on which the assessment is based are mapped. Variations, over several time scales, in the wind resource at selected stations in each subregion are shown on graphs of monthly average and interannual wind speed and power and hourly average wind speed for each season. Other graphs present speed, direction, and duration frequencies of the wind at these locations.

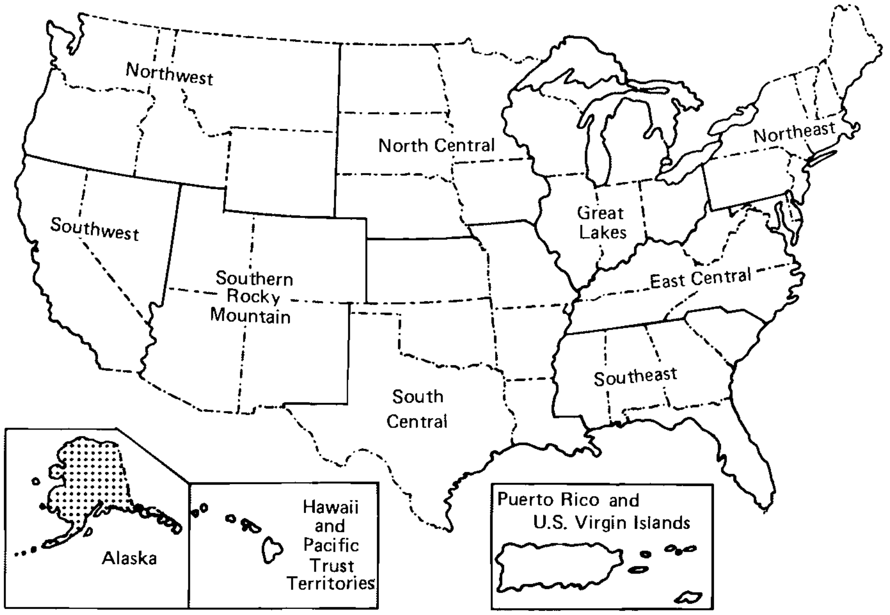


FIGURE 1.1. Geographic Divisions for Regional Wind Energy Assessments.

The methods used to identify, screen, evaluate, and analyze the various types of data and to produce the wind energy resource maps and graphs will only be described briefly. [For more detail see Wentink and Wise (1980)]. However, this discussion will provide the reader with useful background information for interpreting the wind energy resource maps for Alaska.

1.1 IDENTIFICATION OF WIND DATA SOURCES

The surface wind data on which this atlas has been based were obtained from several sources: the National Climatic Center (NCC), the U.S. Forest Service, university research projects, fossil-fuel power plants and their proposed sites, U.S. Department of Energy (DOE) candidate wind turbine sites, the Atmospheric Environment Service of Canada, and other government and private organizations. NCC has the largest collection of wind data. Surveys and indices of wind data archived there (Changery 1975, 1978; Changery et al. 1977) are extremely helpful in locating available wind data. The Index of Original Surface Weather Records, published for Alaska by the NCC, provides additional information about stations at which wind data have been taken.

The wind data available from the NCC may be in one or more of three formats: summarized, digitized, and unsummarized. Initially, all wind data are in the unsummarized format consisting of the original station weather records. For many stations, the collection of individual observations has been condensed into wind summaries. Changery et al. (1977) present examples of the various summary formats used and indices of the stations for which wind summaries are available. For still fewer stations (primarily airport stations) the NCC has put the original one- or three-hourly weather observations on magnetic tape to create a digitized time series of weather (and wind) observations. [TDF-14 (NCC 1975) describes the data on these tapes.] Table 1.1 indicates the number of stations with wind data in these various formats in Alaska.

Conventional NCC surface weather data in coastal areas were supplemented by monthly mean wind speeds summarized over coastal marine areas in the Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska (NCC and AEIDC 1977). Wind summaries at the 150-m and 300-m levels above the surface (Winds Aloft Summaries, NCC 1970) for 16 sites in Alaska supplemented the upper-air wind climatology compiled by Crutcher (1961) for the northern hemisphere.

In contrast to the NCC data, which are primarily from inhabited areas, U.S. Forest Service data in the National Fire Weather Data Library (Furman and Brink 1975) are from remote sites in mountainous and forested areas under the jurisdiction of the Federal government (i.e., national forests, national parks, Indian reservations, or Bureau of Land Management areas). Nearly 74 stations with wind data are reported in the National Fire Weather Data Library for Alaska. However, only one afternoon observation, at 2 p.m., is digitized per day during the local fire weather season.

Wind data from one fossil-fuel power plant and one potential plant site (Verholek 1977) were examined. Many other wind data sets collected by university research projects, state and local air pollution control agencies, or in support of environmental impact statements have also been identified.

1.2 WIND DATA SCREENING

Table 1.1 indicates the quantity of wind data available in Alaska. However, not all of these data need to, or should, be used in a wind resource assessment. Screening procedures were developed to identify stations with the most useful data and to eliminate stations that would not significantly contribute information on the distribution of the wind resource.

TABLE 1.1. Stations with Wind Data in Alaska and Peripheral Area Screened in Assessment

Source and Type	Screened	Retained
National Climatic Center		
Digitized	107	107
Summarized	165	152
Unsummarized	160	19
National Fire Weather Data Library	74	24
Nuclear & Fossil-Fuel Power Plants	2	2
University Research	6	2
Other	5	4
Canadian and Russian	16	16

Wind data in summarized or digitized format were chosen over unsummarized data. If stations had both summarized and digitized data, the digitized data were used for selected stations to prepare a more extensive characterization of the wind resource. Unsummarized data were used only when no summarized or digitized data were available.

In areas with a high density of stations with wind summaries, those stations appearing to have the best exposure to the wind, greatest number of daily observations, longest period of record, and longest period of unchanged anemometer height and location were usually selected over other nearby stations. When more than one type of summary (see Changery et al. 1977) was available for a given station, the summary covering the longest period of record with constant anemometer height and location, with the greatest number of wind speed and direction classes, and with the highest frequency of daily observations was chosen.

The screening of the National Fire Weather Data Library identified those stations where NCC data were not duplicated. This significantly reduced the number of U.S. Forest Service sites to be considered in the assessment. Table 1.1 shows the effect of screening on the number of sites analyzed. Only sites for which there was quality information pertaining to the wind resource were retained for the final analysis.

1.3 TIME SCALES IN REGIONAL ASSESSMENTS

Several time scales are encountered in the following discussions of the wind resource: annual, seasonal, monthly, and diurnal. Annual mean values are generally based on an average of the one- or three-hourly observations of wind speed or power in the period of record; however, a complete calendar year's data (covering January 1 to December 31) is used for calculating individual yearly means. At stations with less than 24 hourly observations or eight three-hourly observations per day, the values are only representative of the times of day for which the data were taken.

The four seasons are defined as:

- winter - December, January, and February
- spring - March, April, and May
- summer - June, July, and August
- autumn - September, October, and November.

The phrase "seasonal trends" refers to the change in monthly mean values over the course of the four seasons.

Monthly mean values are based on as many hours of data as are available for that month in each year of the period of record.

The daily or diurnal cycles of variation in the hourly mean wind power or speed are referenced to local standard time on a 24-hour clock. Midnight is both 00 and 24.

1.4 EVALUATION OF WIND DATA

For the purpose of mapping the geographical variation of the wind resource, wind power density was chosen over wind speed since the power density incorporates in a single number the combined effect of the distribution of wind speeds and the dependence of the power density on air density and on the cube of the wind speed. Quantitative wind data in three formats were evaluated for mean wind power density: digitized, summarized, and unsummarized. The average wind power density $\bar{P}$ (watts/m^2) in a vertical plane perpendicular to the wind direction for stations with one- or three-hourly digitized data was calculated from:

$$\bar{P} = \frac{1}{2n}\sum_{i=1}^{n} \rho_i \, V_i^3 \qquad (1)$$

where

n = the number of observations in the averaging period

ρ_i = the density (in kg/m^3) computed from the station pressure and temperature

V_i = the wind speed (in m/s) at the i^{th} observation time.

For stations with wind summaries, P was calculated from:

$$\bar{P} = \frac{1}{2}\,\bar{\rho}\sum_{j=1}^{c} f_j \, V_j^3 \qquad (2)$$

where

$\bar{\rho}$ = the mean air density

c = the number of wind speed classes

f_j = frequency of occurrence of winds in the j^{th} class

V_j = the median wind speed of the j^{th} class.

In those cases for which unsummarized wind data were assessed, the seasonal and annual average speeds, $\bar{V}$, were estimated from a visual examination of one year's original weather records. The wind power density, $\bar{P}$, was then estimated by assuming the speed frequency distribution followed a Weibull distribution:

$$\bar{P} = 1.07 \ \bar{\rho} \ \bar{V}^3 \qquad (3)$$

1.4.1 Vertical Adjustment

The anemometer height above the surface rarely was at either the 10-m or 50-m reference levels chosen for the presentation of the wind resource. A power law was used to adjust the long-term mean wind speed or power density to the reference level:

$$\frac{\bar{V}_r}{\bar{V}_a} = \left(\frac{Z_r}{Z_a}\right)^{\alpha} \quad \text{or} \quad \frac{\bar{P}_r}{\bar{P}_a} = \left(\frac{Z_r}{Z_a}\right)^{3\alpha} \qquad (4)$$

where

$\bar{V}_{a,r}$ and $\bar{P}_{a,r}$ = the mean wind speed or wind power density at heights $Z_{a,r}$ (the anemometer and reference level, respectively)

α = the power law exponent.

An examination of long-term mean wind speeds at airport locations at which the anemometer height was changed and at tower sites with multiple levels of anemometry indicates an $\alpha \sim 1/7$ to be widely applicable to low surface roughness and well exposed sites from which conventional NCC data are available (Elliott 1979b).

1.4.2 Estimates for Mountainous Areas

The quantitative estimation of wind power over mountains made use of the northern hemisphere upper-air wind climatologies for the 10 degree longitude meridians by Crutcher (1961). Since earlier studies had shown a strong correlation between mountaintop and free-air wind speeds (Wahl 1966), the free-air wind speed at mountain summit or ridge crest height was extrapolated (or interpolated) from the mean scalar speeds on the meridional cross sections. Estimates of the mountaintop wind speeds were made on a grid one-half degree latitude by one degree longitude. In each such cell of the grid over mountainous areas, the mean ridge crest or mountain summit elevation and appropriate mean wind speeds were estimated. Linear extrapolation provided the mean free-air wind speed at the terrain elevation and the application of a Rayleigh speed distribution gave the mean free-air wind power. The mean wind power at the 10-m and 50-m reference heights was taken to be one-third and two-thirds of the free-air value, respectively, to account for the frictional slowing of the wind near the surface.

These estimates are considered lower limits for exposed ridge crests and mountain summits. Local terrain features in these mountainous regions can enhance the wind power considerably. However, a major uncertainty in mountainous terrain is the representativeness of some of the data upon which the free-air estimates are based (e.g., sheltering by nearby mountains can bias rawinsonde winds).

Wherever possible, these estimates were compared with surface data from ridge crests and mountain summits. Over some of the mountainous areas, the estimates were adjusted based on the location of the upper-air recording station and/or the surface data from ridge crests.

1.5 QUALITATIVE WIND INDICATORS

Although more than 230 stations provided the wind resource assessment in Alaska with quantitative data, these stations were not uniformly distributed. The station location figures for each subregion show that most NCC stations are located in populated areas and along transportation corridors. Large areas in Alaska are devoid of any form of quantitative wind data suitable for this assessment, such as the western Arctic area and the Brooks Range, the eastern mainland, and all mountainous areas. Furthermore in areas of complex terrain, most observation sites (except for some U.S. Forest Service fire lookout sites) are confined to valley locations. To evaluate the distribution of the wind resource in data-sparse areas, three qualitative indicators of the wind speed or power were developed for, and employed in, the assessment.

The most widely used technique depended on certain combinations of topographical and meteorological features (Elliott 1979a) that were associated with high or low wind speeds. Those features indicative of high mean wind speeds are:

- gaps, passes, and gorges in areas of frequent strong pressure gradients
- long valleys extending down from mountain ranges
- high elevation plains and plateaus
- plains and valleys with persistent strong downslope winds associated with strong pressure gradients

- exposed ridges and mountain summits in areas of strong upper-air winds
- exposed coastal sites in areas of

  1) strong upper-air winds, or
  2) strong thermal/pressure gradients.

Features that signal rather low mean wind speeds are:

- valleys perpendicular to the prevailing winds aloft
- sheltered basins
- short and/or narrow valleys and canyons
- areas of high surface roughness, e.g., forested hilly terrain.

Areas in which the appropriate features occur were determined by examining topographic contour and shaded relief maps and synoptic and climatological maps of sea-level pressure patterns and air flow.

Evidence of persistent strong winds can also be found in wind-deformed vegetation. Mean wind speeds deduced from the extent and morphology of tree deformation by Hewson et al. (1979) provided useful qualitative indicators of wind speed in many data-sparse areas. This was used in the Portage Pass area at the east end of Turnagain Arm.

1.6 WIND POWER MAPS

The production of mean wind power density maps, such as those presented for each subregion, depended on the coherent synthesis of several pieces of information. The goal of the synthesis process was to present wind power density values representative of sites well exposed to the prevailing strong winds. Hilltops, ridge crests, mountain summits, large clearings, and other locations free of local obstructions to the wind are expected to have good exposure to the wind (see Table 1.2). In contrast, locations in narrow valleys and canyons, downwind of hills and obstructions, or in forested or urban areas are likely to have poor exposure. The wind power density shown on the maps in this atlas will not be representative of poorly exposed locations. Estimates for ridge crests and summits (the shaded areas on the maps) are lower limits to the wind power expected at exposed sites. In such areas, local terrain features can enhance the wind power considerably (e.g., by a factor of 2 or 3). By specifying the type of wind exposure to which the map values of wind power pertain, we avoid the ambiguity that typical-location or average-for-the-terrain values might introduce. In this atlas, the terms wind energy, wind power, and wind power density are used synonymously.

To represent the wind resource at well-exposed sites, it was necessary to become extremely familiar with the land-surface form and topography in the vicinity of every

TABLE 1.2. Land-Surface Form Terrain Features Representative of Exposed Locations

Land-Surface Form	Exposed Feature (Map Value)	Percentage Area[a]
Plains: A1; B1,2	Plains	93
Plains With Hills: A; B3a,b	Open Plains	79
Plains With Mountains: B4-6a,b	Plains (not shaded)[b]	67
	Ridge Crests and Mountain Summits (shaded)	10
Tablelands: B3-6c,d	Tablelands, Uplands	80
Open Hills: C2-4	Hilltops and Uplands	27
Open Mountains: C5-6	Broad Valleys (not shaded)	80
	Ridge Crests and Mountain Summits (shaded)	12
Hills: D3-4	Hilltops and Uplands	9
Mountains: D5-6	Ridge Crests and Mountain Summits (shaded)	3

(a) Percentage represents an average over the land-surface forms found in the Alaska region.

(b) Shaded areas on the wind maps emphasize that map values are estimates for ridge crests and mountain summit locations.

data site. Maps were prepared showing the location of stations, the mean wind speed and mean wind power at the reference level, the character of anemometer exposure, and the land-surface form for each subregion. On these maps, areas with the appropriate combinations of topographical and meteorological features were identified, areas with eolian landforms were outlined, and areas with wind-deformed vegetation were denoted. A great deal of attention was given to the orientation of topographic features with the prevailing wind directions. Only after all this information was assembled were the maps analyzed. The annual maps for each subregion were merged into a regional mosaic.

1.7 WIND POWER DENSITY CLASSES

The analysis of wind power maps departs from conventional isopleth analyses by showing the boundaries of wind power density classes. Each wind power class represents the range of wind power densities likely to be encountered at exposed sites within an area designated as having that wind power class. Table 1.3 gives the power density limits for the wind power classes used in the atlas for the 10-m and 50-m reference levels. The definitions of the wind power density classes are repeated with the annual wind power map for the region and for each state as a convenience for the reader.

Wind power density is proportional to the third moment of the wind speed distribution and to air density; therefore, a unique correspondence between power density and mean wind speed (the first moment of the speed distribution) does not exist. However, by specifying a Rayleigh wind speed distribution and a standard sea level air density (1.22 kg/m^3) a mean wind speed can be determined for each wind power class limit. The decrease of air density with elevation requires the mean Rayleigh speed to increase by about 3%/1,000 m elevation to maintain the same power density. If the wind speed distribution is more sharply peaked than the Rayleigh distribution, the equivalent mean speed will be slightly higher than the value in Table 1.3. Conversely, a broader distribution of wind speeds will slightly reduce the equivalent mean speed.

1.8 CLASSES OF LAND-SURFACE FORM

The physical characteristics of the land-surface form affect the number of wind turbines that can be sited in exposed places. For example, over 90% of the land area in a flat plain may be favorably exposed to the wind; whereas in mountainous terrain only the ridge crests and passes, which may be only a small percentage (<5%) of the land area, may represent exposed sites. The map of classes of land-surface form by Hammond (1964) provided information on the distribution of plains, tablelands, hills, and mountains in Alaska. Several characteristics are coded on this map:

- percentage of land area occupied by surfaces of gentle inclination (less than 8% slope)
- local relief, the maximum difference in elevation within a unit square 11 km across
- percentage of gently inclined surfaces that lie in the lower half of the local relief
- land area covered by sand, ice, and standing water
- pattern of major crests, peaks, and escarpments.

The first three characteristics are used in the classification scheme (see Table 1.4); the latter two have been omitted from the maps presented here. A three-character code, for example B3a, designates each class of land-surface form. In this example the "B" indicates that 50% to 80% of the area is occupied by gentle slopes; the "3" that the maximum local difference in elevation is 100 to 150 m; and the "a" that more than 75% of the gently sloping land is in the lowland. In areas of very little gentle slope (D) or very low relief and great smoothness (A1), the third designator is omitted.

For each land-surface form, the percentage of land area that is representative of well-exposed, moderately exposed, and poorly exposed sites has been estimated. These percentages were determined subjectively as a function of the slope, local relief, and profile type. Table 1.2 gives the average percentage of land area that is designated as exposed terrain for the different classes of land-surface form. For simplicity, the percentages shown for each class of land-surface form have been averaged over the range of categories in local relief and profile type found in Alaska. For example, the 27% for open hills is an average for C2 through C4. The average percentage of land area that is designated as exposed terrain ranges from 93% in smooth plains to 3% in mountainous areas where the exposed areas are usually the ridge crests and mountain summits.

TABLE 1.3. Classes of Wind Power Density at 10 m and 50 m(a)

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 1.4. Scheme of Classification

Slope (1st item)
A >80% of area gently sloping
B 50 to 80% of area gently sloping
C 20 to 50% of area gently sloping
D <20% of area gently sloping

Local Relief (2nd item)
1 0 to 30 m (1 to 100 ft)
2 30 to 90 m (100 to 300 ft)
3 90 to 150 m (300 to 500 ft)
4 150 to 300 m (500 to 1000 ft)
5 300 to 900 m (1000 to 3000 ft)
6 900 to 1500 m (3000 to 5000 ft)

Profile Type (3rd item)
a > 75% of gentle slope is in lowland
b 50 to 75% of gentle slope is in lowland
c 50 to 75% of gentle slope is on upland
d > 75% of gentle slope is on upland

1.9 CERTAINTY RATING

The analyses of wind power density at exposed sites shown on the wind power maps depend on the subjective integration of several factors: quantitative wind data, qualitative indicators of wind speed or power, the characteristics of exposed sites in various terrain and familiarity with the meteorology, climatology, and topography of the region. As a result, the degree of certainty with which the wind power class can be specified depends on

- the abundance and quality of wind data
- the complexity of the terrain
- the geographical variability of the resource.

A certainty rating from 1 (low) to 4 (high), of the wind energy resource estimate has been made for each cell of a one-half degree latitude by one degree longitude grid on a subregion-by-subregion basis by considering the influence of the above three factors on the certainty of the estimate of the wind power class for each cell. The definitions for the certainty ratings are adopted from those used by Voelker et al. (1979) in a resource assessment of U.S. Forest Service tracts. The certainty ratings for the wind resource assessment are defined as follows:

Rating	Definition
1	The lowest degree of certainty. A combination of the following conditions exists: 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	A low-intermediate degree of certainty. One of the following conditions exists: 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	A high-intermediate degree of certainty. One of the following conditions exists: 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.

4 The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.

The assignment of a certainty rating requires subjective evaluation of the interaction of the factors involved.

1.10 AREAL DISTRIBUTION OF THE WIND RESOURCE

As noted above, the wind power density class values shown on the maps apply only to sites well exposed to the wind. Therefore, the map area designated as having a particular wind power class does not indicate the true land area experiencing this wind power. Instead, there is a complicated and difficult-to-quantify relationship among the class of land-surface form, the land-surface area and the map value of wind power density. For each land-surface form, the fraction of land area that would be favorably exposed to the winds, i.e., have the wind power density indicated on the map, was estimated (see Table 1.2 for averages in various land-surface forms). Furthermore, to be able to establish a wind power density for the remaining area, it was also necessary to specify a factor by which the wind power shown on the map is reduced in the less-exposed areas. As an additional complication, some land-surface forms, isolated hills, and ridges that rise above a nearly flat landscape may even experience a higher power density than the map indicates.

To accommodate these various situations, the land area represented by a given land-surface form was divided into four exposure categories: 1) better exposure than typical for the terrain, 2) exposure typical for that land-surface form, 3) partially sheltered exposure, and 4) very sheltered exposure. The partitioning of the land-surface forms into the four categories was based on the parameters used to classify the land-surface forms and on the experience of the authors and their co-workers with the terrain represented by the land-surface forms.

In order to adjust the wind power density from the map value to the various exposure categories, the power density was scaled to be 1) greater than, 2) equal to, 3) slightly less than, and 4) much less than the map value power density. The factor by which the map value was adjusted to represent the wind power density in each category was determined by the magnitude of elevation relief given by the middle character of the land-surface form code. (The minimum power density allowed for a category was the median value of wind power density class 1). The scaling factors for the wind power density were based on a conservative application of a power-law type vertical adjustment with the height change specified by the terrain relief code.

In each cell of a grid one degree longitude by one-half degree latitude, the land-surface form was specified and the wind power class associated with a typically exposed site in that land-surface form was determined. By partitioning the area of the cell into the four exposure categories, and by scaling the wind power class to each category, the contribution of that cell to the areal distribution was determined.

A cell-by-cell representation of the areal distribution is given in a map that indicates the percentage land area in a cell over which the wind power class equals or exceeds a threshold value. Four maps are shown in the chapters on the subregion wind resources for threshold values of classes 2, 3, 4 and 5.

A summary table of the areal distribution that combines the contributions by each cell is provided for the state and for each subregion. For each power class, the sum of the area contributed by each exposure category is determined for each subregion and the state. Summing the area associated with each power class in each cell gives the area of the state or region over which the power class exceeds a given value. The table gives the estimated land area (km^2) and the percentage of land area associated with each power class.

Both of these presentations of the areal distribution of the wind resource are highly dependent on the estimates used to partition the land area into the four exposure categories and on the scaling of the power density for each category of exposure. Therefore, the areal distribution derived from the wind power and land-surface form maps must be considered only an approximation. The quantity and quality of wind data and topographic information required to make a highly accurate cell-by-cell appraisal of the wind resource are far beyond the scope of this regional wind resource assessment. However, as wind information becomes available through new measurement programs or through the discovery and processing of existing data sets, the evaluation of the areal distribution of the wind resource can be improved on a cell-by-cell basis.

CHAPTER 2: STATE FEATURES

In this chapter, the geography, climate, annual average wind power and seasonal variations in the wind power are described for the state of Alaska. Assessments of the wind resource for each subregion of the state were performed using the methods described in Chapter 1. These assessments were then combined to depict the wind energy potential for the state. Major areas of Alaska that are estimated to have the greatest wind resource are also described in this chapter.

2.1 GEOGRAPHY AND TOPOGRAPHY

For this analysis, Alaska has been divided into four subregions; northern, southeastern, southcentral, and southwestern (Figure 2.1). Alaska covers an area of 1,518,776 km^2 (586,400 mi^2) and had an estimated population of 428,703 in 1979 (Table 2.1). More than a third of these people (about 185,000) live in the metropolitan area of Anchorage. The major cities, towns, villages, rivers, mountain ranges, and national parks and monuments are shown in Figure 2.1.

TABLE 2.1. Land Area and Population of Alaska

Subregion	Area km^2	Area miles^2	Population in 1979	Population per km^2(mi^2)
Northern	732,310	282,672	84,627	.12 (.30)
Southcentral	574,980	221,942	265,745	.46 (1.20)
Southeastern	92,706	35,785	60,967	.66 (1.70)
Southwestern	118,780	45,849	17,364	.15 (.38)
Alaska	1,518,776	586,248	428,703	.28 (.73)

The topography of Alaska varies from subregion to subregion (see Figures 2.2 and 2.3). A large portion of the land is mountainous; the Brooks Range is in the northern subregion, the Alaska Range is in the southcentral and southwestern subregions, and the Coast and St. Elias Mountains are in the southeastern subregion. Flat coastal plains, such as those along the Arctic coast and Yukon-Kuskokwim Delta (in the northern and southcentral subregions, respectively) are also prominent features. Flat alluvial plains are found in the river valleys, such as the Yukon River valley in the southeast portion of the northern subregion. Upland plains are found throughout the state.

The lay of the land does affect the number of wind turbines that can be erected in an exposed area. For example, more than 90 percent of the land area in a flat plain may be favorably exposed to the wind, whereas in mountainous terrain only the ridge crest and passes, or less than six percent of the land area, may represent exposed sites (see Section 1.8). To determine what percentage of a given land area in Alaska is plains, tablelands, hills, or mountains, a land-surface map of the state was used.

2.2 CLIMATE

The climate of Alaska can be divided roughly into five zones. Mountain barriers form the boundaries between some of the zones, while in others such as the transition zones, there is a gradual shift from one zone to another. The climate zones are: (1) a maritime zone, which includes southeastern Alaska, the south coast, and Aleutian Islands; (2) a maritime-continental zone, which includes the north shore of the Alaska Peninsula, the Bering Sea coast inland to the Nulato Hills, the southwest Kuskokwim Mountains, Seward Peninsula, and the coastal areas of Kotzebue Sound northward to Point Hope and Cape Lisburne, (3) a transition zone between the maritime zone and the continental zone in southcentral Alaska, (4) an arctic zone from the Brooks Range to the Beaufort and Chukchi Sea coasts, and (5) a continental zone over the greater portion of the mainland.

In the maritime zone, coastal mountains and the plentiful moisture from the North Pacific Ocean and the Gulf of Alaska produce annual precipitation of up to 500 cm (200 in.) in the southeastern panhandle, and up to 380 cm (150 in.) along the northern coast of the Gulf of Alaska. Amounts decrease to near 150 cm (60 in.) on the southern side of the Alaska Range in the Alaska Peninsula and Aleutian Islands sections. Precipitation decreases rapidly to the north, with an average of 30 cm (12 inches) in the continental zone and less than 15 cm (6 in.) in the arctic zone. Snowfall makes up a large portion of the total annual precipitation. The heaviest snowfall is in the higher elevations of the mountains that rim the Gulf of Alaska coast where many large glaciers and ice fields are located. There are an estimated 54,000 km^2 (29,000 mi^2), or 5% of the state's area, composed of glaciers and ice fields. Maximum average seasonal snowfall and maximum in a single season both occurred at Thompson Pass, a highway maintenance camp on the Richardson Highway north of Valdez. The mean annual snowfall there is 1,340 cm (547 in.), and the record for a single season is 2,474 cm (974 in.).

Mean annual temperatures in Alaska range from 5°C (41°F) in the maritime zone to a chilly -12°C (10°F) in the arctic zone north of the Brooks Range. The greatest seasonal contrast in temperatures is in the continental zone. In this area average summer maximum temperatures are in the 25 to 27°C (77 to 80°F) range and temperatures around 30°C (90°F) are not uncommon. The highest recorded temperature in the state, 38°C (100°F), occurred at Fort Yukon in June 1915. Average winter minimum temperatures in this area are -35°C (-30°F); temperatures in the -45°C (-50°F) range are not uncommon. The record low temperature is -62°C (-80°F). Elsewhere in the state temperatures are much more moderate. In the maritime zone, high temperatures average near 15°C (60°F) in the summer and low temperatures average near -7°C (20°F) in winter. In the transition zone, temperatures range from 15°C (60°F) to near -18°C (0°F); in the maritime-continental zone the range is from 15°C (60°F) in summer to -24°C (-10°F) in winter. These ranges reflect the summer marine influence and the winter continental influence (in winter the Bering Sea is ice covered). The arctic zone has a range extending from 9 to 10°C (48 to 50°F) in summer to -30°C (-20°F) in winter.

2.3 WIND POWER IN ALASKA

The annual average wind power density in Alaska is shown in Figure 2.4. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as 50 to 100% from the assessment value. (See Wegley et al. 1980 for information on terrain features that may increase or reduce wind energy.) In forested or wooded areas the assessment values are representative of large clearings with good exposure to the prevailing strong winds, such as airports. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The high wind resource areas (class 4 or higher) of Alaska can be dispersed over large areas, such as on the mountain summits and ridge crests of the Alaska Range, Brooks Range, Chugach Mountains, Wrangeli Mountains, St. Elias Mountains, and the Coast Mountains. They can also be confined to particular topographic features such as Isabel Pass in the Alaska Range or Chickaloon Pass between the Talkeetna and Chugach mountains. It is convenient to refer to the latter areas as wind corridors.

A wind corridor is a passageway of lower elevation than the surrounding terrain through which the winds are channeled and sometimes enhanced. However, only those gaps, passes, valleys, gorges, or canyons in which the meteorological conditions cause high wind speeds are referred to as corridors. A corridor may vary in width from just a few km (e.g., the Isabel Pass along the Delta River) to over 100 km (e.g., Lower Cook Inlet from Iliamna Lake to the Barren Islands).

A brief description of the major (class 4 and higher) wind resource areas follows in Section 2.5. For more complete discussion of these wind resource areas, refer to the chapter on the subregion containing these areas.

2.3.1 Certainty Rating of Wind Resource

Certainty ratings of the wind power resource were assigned to each grid cell as described in Section 1.9. Maps of the certainty rating in each subregion accompany the descriptions of that subregion's wind resource.

The geographical distribution of the certainty ratings range from low (1) to high (4); only a few areas in Alaska were assigned a high certainty rating. Areas with high certainty ratings are in the northern subregion along portions of the coast of the Beaufort Sea and at Cape Lisburne, Wales, and Nome. Other high certainty rating areas are the islands in the Bering Sea, Cape Romanzof, Cape Newenham, Middleton Island in the Gulf of Alaska, and the southern portion of Kodiak Island. A high certainty rating is assigned to these areas because of the availability of existing data, low complexity of terrain, and low spatial variability of the resource. All the above-mentioned areas also have the distinction of being both high in certainty and areas of high wind resource (power class 4 or higher). Most areas with no mountainous terrain in Alaska are given certainty ratings of 2 and 3. However, a large area of Alaska has a low certainty rating, either because of sparsity of data, such as the Kuskokwim-Yukon River Delta area, or because of high complexity of terrain, such as the Aleutian Island chain and all of the southeast subregion.

Year-round data are available from only a few exposed sites in mountainous terrain. Nevertheless, the mountain summit and ridgecrest estimates were given a certainty rating of 2 because upper air wind data were used to approximate the power in these areas.

2.3.2 Areal Distribution of the Wind Resource

Through the superposition of a grid one degree longitude by one-half degree latitude over the region, the areal distribution of wind power can be computed as described in Section 1.10. Of the 717 grid cells in Alaska, 240 have exposed areas with class 4 or higher wind power. These power classes are predominantly along the coast and on mountain summits and ridge crests (shaded areas on the maps) with high topographic relief. As a result, the estimate of the actual fraction of the land area that experiences class 4 and higher wind power (about 8%) is significantly less than the 33% of the grid boxes showing class 4 and higher wind power. Many grid boxes along the coast and in island areas have only a small fraction of their areas as land (see Figure 2.4). The land area estimated to have low power densities of class 1 and 2 (about 80% of the state) is larger than the wind power maps suggest (50%) because of the highly complex terrain.

Table 2.2 summarizes the results of the computation of the areal distribution for Alaska and its subregions. The subjectivity underlying the assignment of exposure partitioning and power scaling warrants reporting the areas and percentages to only two significant digits (see Section 1.10). Thus, individual areas and percentages may not sum to their stated totals.

Of the upper four wind power classes, the largest area contributions are along the coasts in class 5 to 7. The major exception is the Yukon-Kuskokwim delta area where class 4 or higher is estimated to extend in 150 km from the coast. The only areas away from the coast estimated to have class 4 or higher wind powers are passes at the east end of Turnagain Arm in the Cook Inlet, Isabel Pass in the Alaska Range south from Big Delta, and the wind corridor from the east end of Bristol Bay to southern Cook Inlet.

2.4 SEASONAL VARIATIONS IN THE WIND RESOURCE

Throughout most of Alaska, winter is the season of maximum wind power (see Figure 2.5). Areas with winter maxima include all of the southeast and southwest subregions, all mountain areas, and the west coast of southcentral Alaska. Along the Beaufort coast, autumn is the season of maximum wind power in the west, but in the east and interior, the strongest winds occur in winter. At exposed mountain summits and ridge crests, winter is the season of maximum wind power because mean upper air wind speeds (more than 1,500 m above ground level) are strongest during the winter. However, mean wind speeds are generally low in sheltered basins and valleys. Cold air often fills the basins and valleys, resulting in a temperature profile that may remain stable throughout the day because of low solar insolation. This is most common in broad areas of southcentral and northern Alaska where strong temperature inversions form at the surface and persist for days or weeks at a time. Under these stable atmospheric conditions, the vertical mixing is restricted, and winds may be very light in a basin or valley even if winds are strong on nearby ridge crests. Winds aloft generally decrease from 50° to 65°N latitude and increase north of 65°N. Therefore, strongest winds and wind powers occur in the Aleutians, southeastern Alaska, and along the Beaufort and Chukchi Sea coasts.

In spring, the upper air flow decreases markedly over most of Alaska, and wind power at mountain summits and ridge crests also decreases. However, solar radiation increases markedly as the days become longer. The persistent arctic inversions are less frequent, and so the surface air is less stable; therefore, spring is the season of strongest winds in river valleys of interior Alaska, except in certain mountain passes where the wintertime flow is channeled and intensified by the terrain and pressure gradients.

In summer, mean upper air wind speeds are low in all areas except the Aleutians and southeastern Alaska where average wind speeds at the 1,500-m level are seven to 11 m/s (15 to 25 mph). However, lowest wind speeds occur in summer. Some isolated locations in interior Alaska, such as McGrath and Tanana, show maximum summer wind powers and speeds, but spring and summer wind speeds are close to the same at these locations.

In autumn, upper-air wind speeds increase from September to November. Autumn is the season of second highest wind power at most mountain summits and ridge crests. Along the Chukchi and western Beaufort Sea coasts, autumn is the season of strongest winds and wind powers. During this season there are more frequent migratory storms, and there is often open water early in the season. Some of the most severe storm surges on the Beaufort coast have occurred in September and October. By the middle of November, the sea ice generally has completely covered both the Chukchi and Beaufort Seas reducing the temperature contrasts (and hence storm intensities) along the coasts. Autumn is also the season of maximum wind powers at a few locations along the Yukon and Tanana Rivers from Manley Hot Springs to Galena. However, the difference from one season to another at these locations is small, and all wind powers are of class 1.

Seasonal variations in atmospheric stability affect the variation of wind speed with height in Alaska. For example, at McGrath and Fairbanks the season with highest winds above 900 mb (900 to 1,100 m) is winter, but surface and 950-mb (500 to 600-m) winds are lowest in winter and highest in spring and autumn. This seasonal trend in the profiles is typical of many of the valleys and plains in interior Alaska.

2.5 MAJOR WIND RESOURCE AREAS

Descriptions of major areas in Alaska with high annual average wind power (class 4 and above) are briefly summarized in this section. For additional details on these areas, refer to subregional assessments. For the locations of place names mentioned in this section, refer to the individual subregional maps (such as Figures 4.1 and 4.4 for northern Alaska).

2.5.1 Beaufort and Chukchi Sea Coasts

The annual average wind power for exposed coastal and offshore areas is estimated to be at least class 5. Coastal areas near Barter Island, Point Lay, and Cape Lisburne show class 7. Even through much of the area north of the Brooks Range is of low relief, wind power drops off rapidly with distance from the coast as shown by data from Sagwon and Umiat. On the eastern Beaufort coast, an area with wind power of class 4 or higher appears to extend from the coast southward to the crests of the Brooks Range. Along the Chukchi Sea coast, wind power of class 5 to 7 is probably confined to near the coast, although there are no data available inland to corroborate this assumption.

2.5.2 Bering Sea Islands and Coast

Islands in the Bering Sea, such as the Pribilofs, St. Lawrence, St. Matthew, and Nunivak, all show annual wind powers of class 7 except Savoonga, which has class 6. Along the coast from the Alaska Peninsula northward, wind power of class 5 or higher (with class 7 in exposed areas like the west end of the Seward Peninsula and the Cape Romanzof area) is shown. Wind power of class 5 or more extends eastward for 150 km (100 miles) in the Yukon-Kuskokwim Delta area, as shown by Bethel data.

2.5.3 Alaska Peninsula and the Aleutian Islands

The Alaska Peninsula west of 162°W shows annual wind power class 7 at all locations except those shielded somewhat by local terrain. The whole peninsula has class 5 or higher power. This area is along a major storm track from eastern Asia to North America. Storms generally move from west to east. Some storms also move northward through the Bering Sea, especially during the summer months. Amchitka and Asi Tanaga in the western Aleutians show mean annual wind power of over class 7 (1,000 W/m^2). Winter is the season of maximum wind power throughout the area.

2.5.4 Lower Cook Inlet

The area from Iliamna Lake to Kamishak Bay across Cook Inlet to the Barren Islands is a corridor for strong winds. This is reflected at Bruin Bay, which shows an average annual wind power of over 1,300 W/m^2. Subjective comments from mariners indicate that this lower Cook Inlet area can be very windy. Bruin Bay data and an examination of weather records from two drilling rigs operating in the area confirm this impression. There are no other permanent stations besides Bruin Bay that show this wind resource.

2.5.5 Gulf of Alaska Coast

Exposed areas of the entire Gulf of Alaska coast should experience mean annual wind power of class 4 or higher. Offshore data from Middleton Island and Brower et al. (1977) indicate class 7 wind power. Shore data such as Cape Spencer, Cape Decision, Cape Hinchinbrook, and North Dutch Island reflect class 5 or higher power. Data from more sheltered locations, such as Cordova, Sitka and Yakutat do not reflect these wind power classes. Most of this coastline is rugged and heavily wooded, so wind powers are very site-specific.

2.5.6 Exposed Mountain Ridges and Summits

At least class 4 or higher wind power is estimated for mountain summits and ridge crests in portions of the Alaska Range on the west side of the Susitna River, the Coast Mountains along the Canadian border in southeast Alaska, and portions of the eastern Brooks Range. The map analyses represent the lower limits of the wind power resource for exposed areas. Wind speeds can vary significantly from one ridge crest to another as a result of the orientation to the prevailing slope of the ridge and its closeness to other ridgelines. Winter is the season for highest wind speed and power at mountain summits and ridge crests.

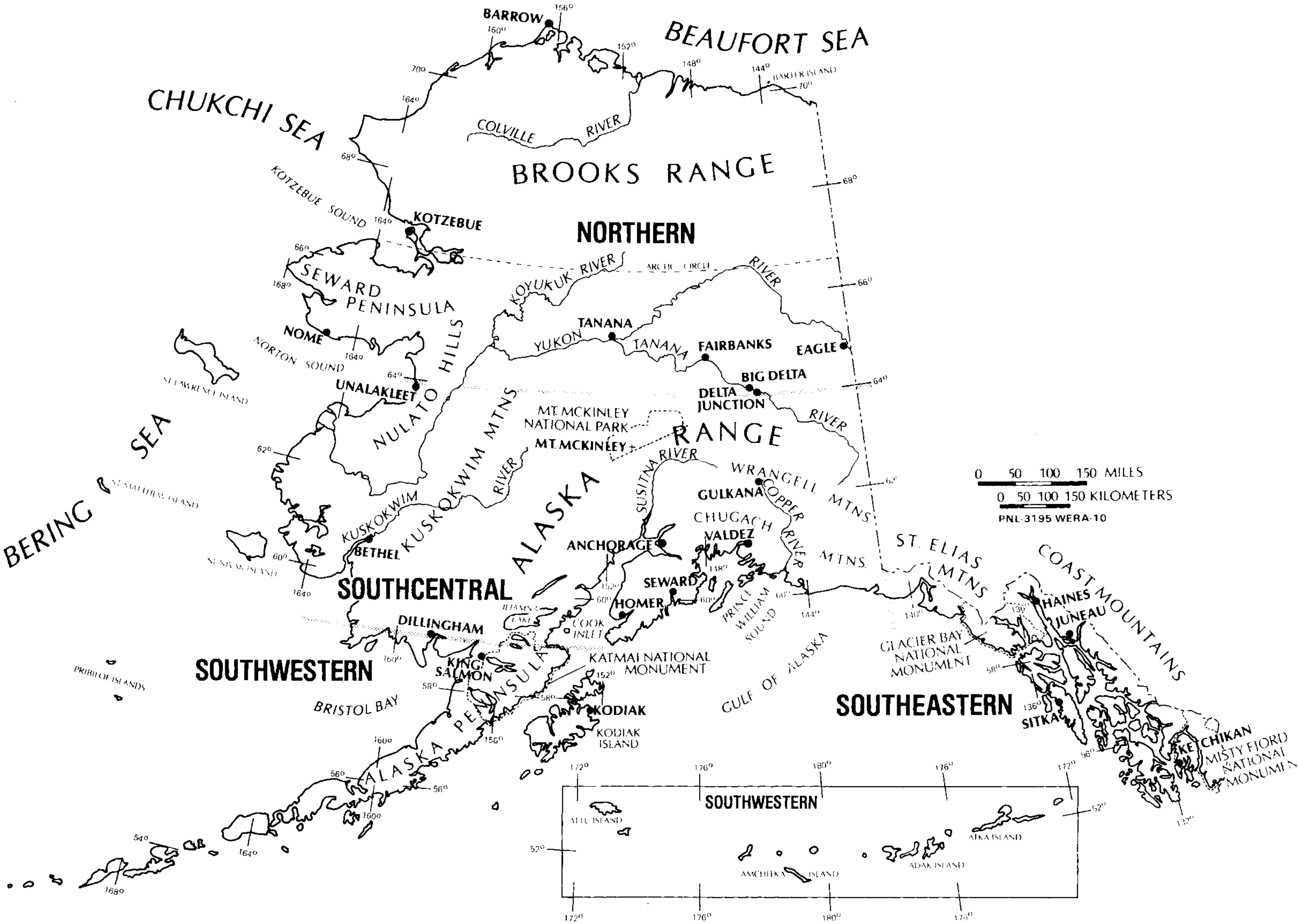


FIGURE 2.1. Geographic Map of Alaska

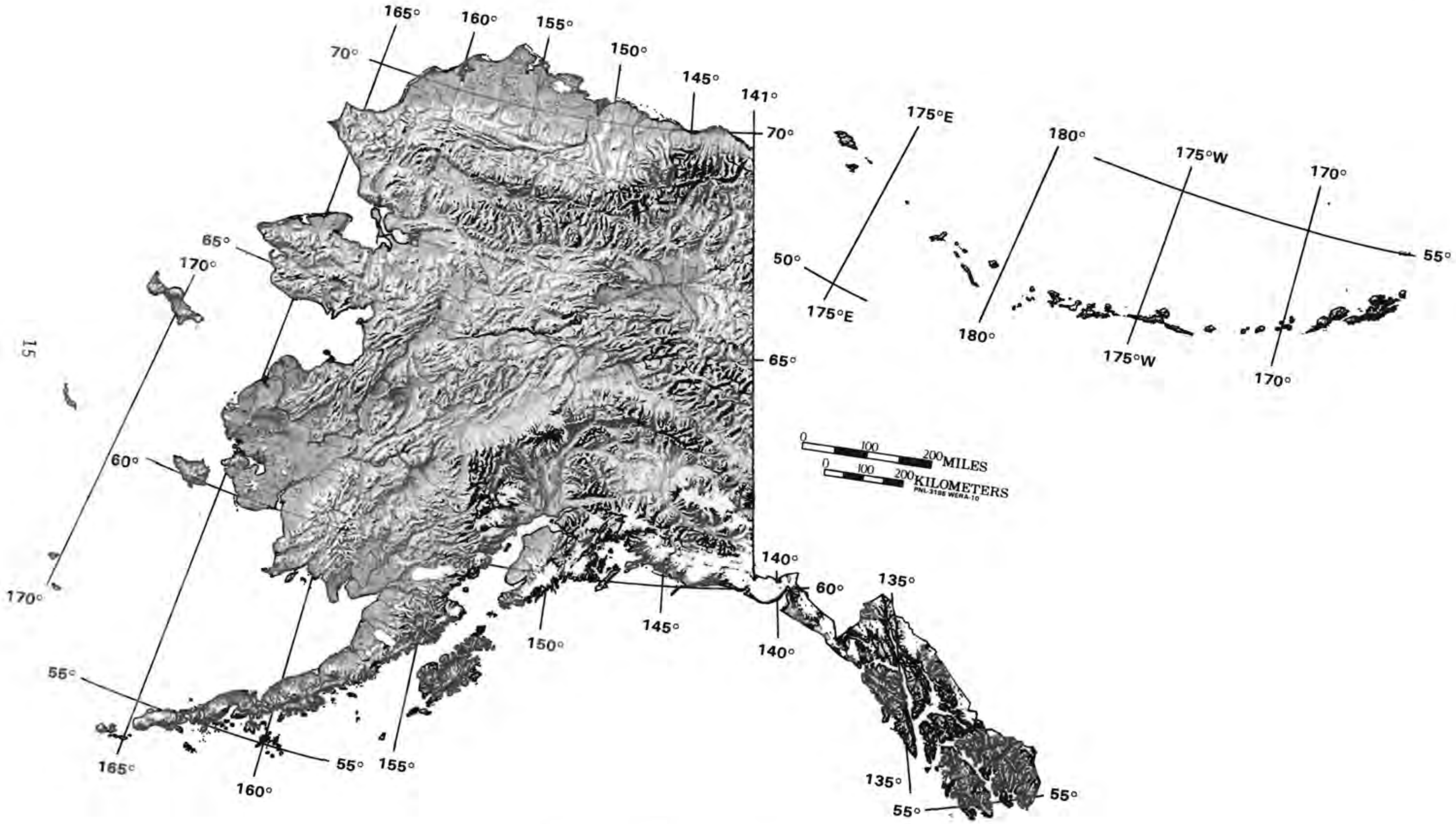


FIGURE 2.2. Topographic Map of Alaska

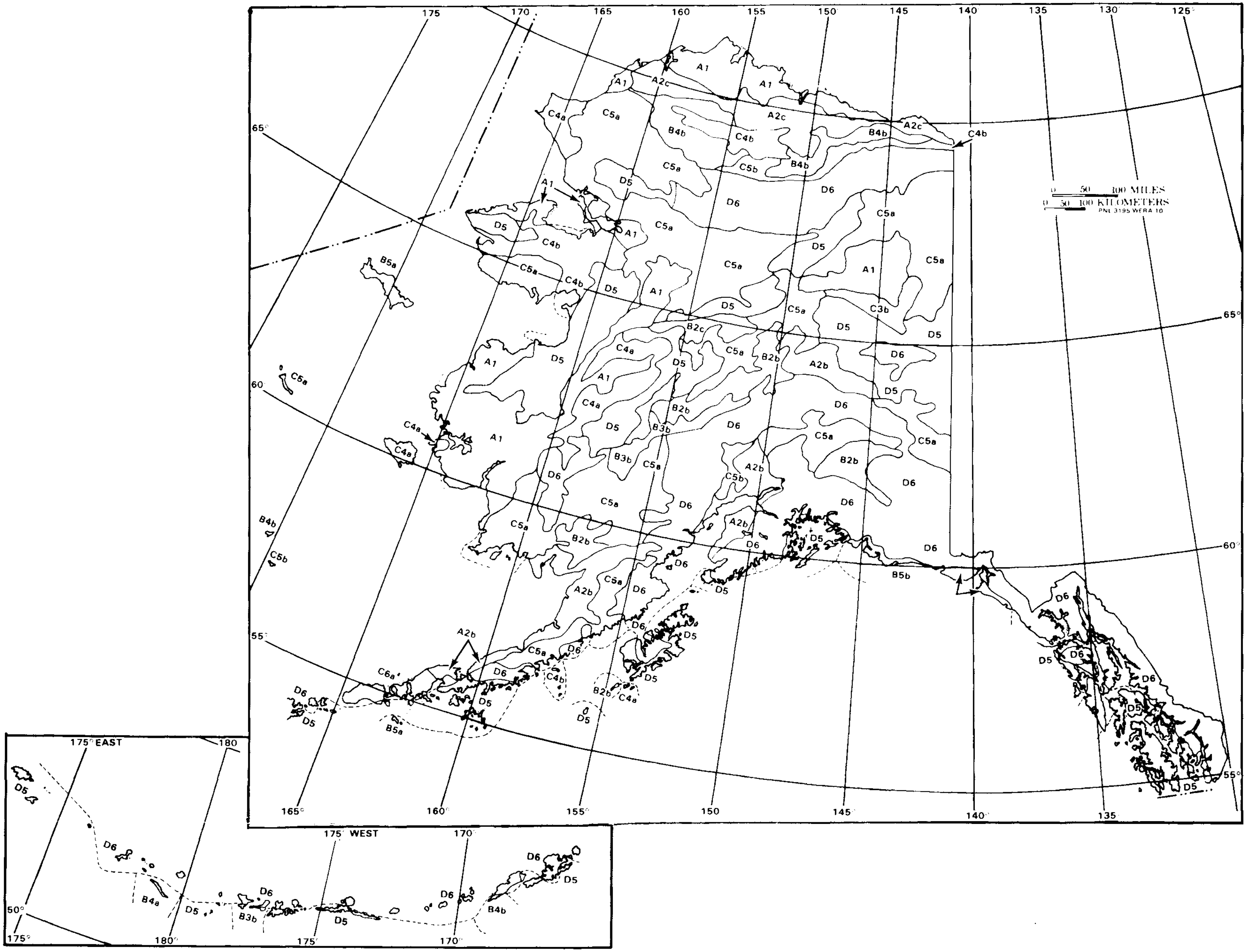


FIGURE 2.3. Classes of Land-Surface Form in Alaska

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

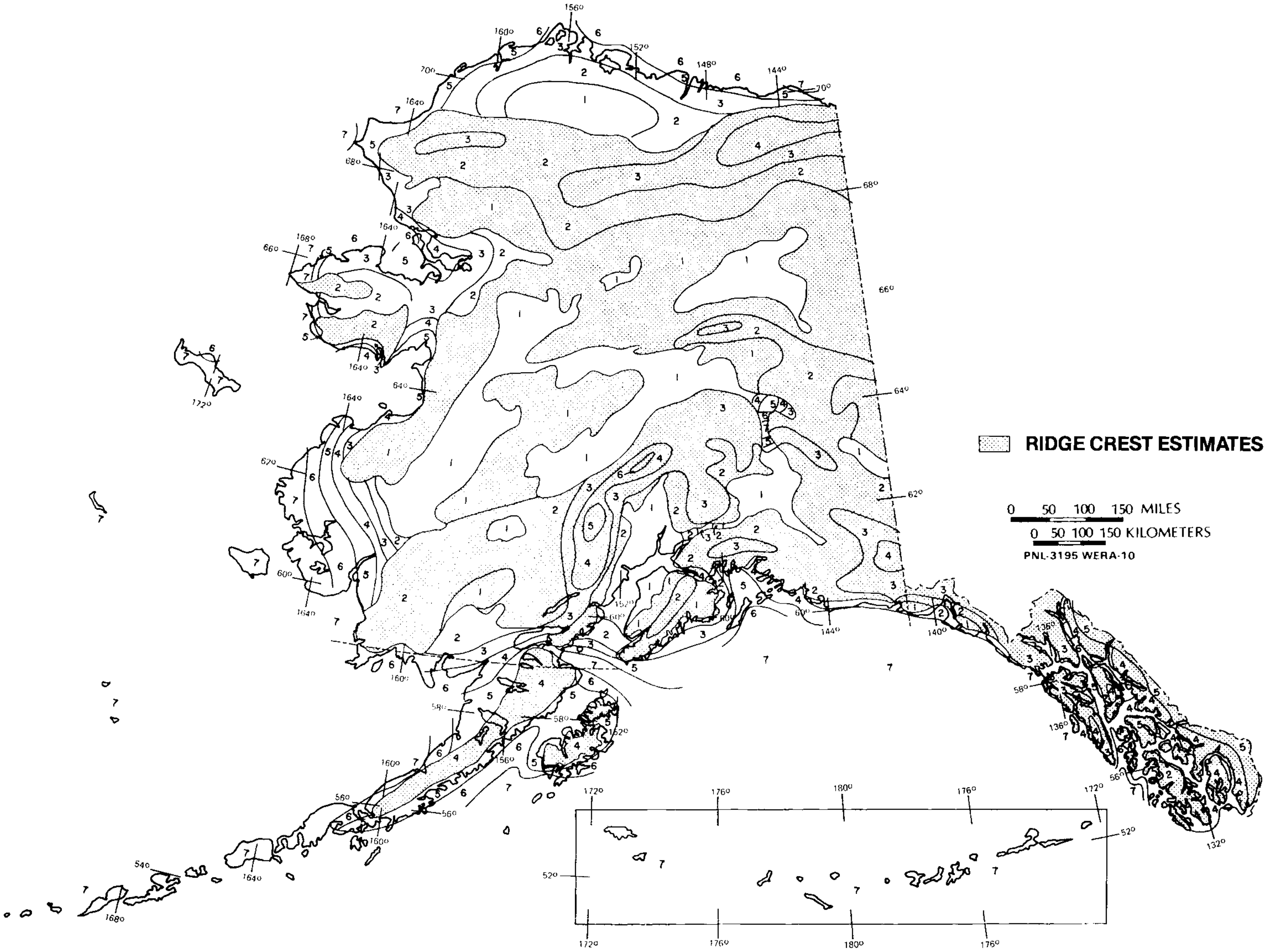


FIGURE 2.4. Annual Average Wind Power in Alaska

Classes of Wind Power Density at 10 m and 50 m(a)

Wind Power Class	10 m (33 ft) Wind Power Density, watts/m2	10 m (33 ft) Speed,(b) m/s (mph)	50 m (164 ft) Wind Power Density, watts/m2	50 m (164 ft) Speed,(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 2.2. Areal Distribution of Wind Power Classes in Alaska

Land Area (km^2) Equal or Exceeding Power Class

Power Class	Alaska	Northern Alaska	Southcentral Alaska	Southeast Alaska	Southwest Alaska
1	1,500,000	710,000	580,000	88,000	110,000
2	260,000	130,000	100,000	3,000	30,000
3	180,000	70,000	78,000	2,000	27,000
4	120,000	36,000	56,000	1,000	23,000
5	91,000	23,000	51,000	300	17,000
6	60,000	13,000	36,000	12	12,000
7	26,000	1,000	17,000	0	7,800

Percentage Land Area Equal or Exceeding Power Class

Power Class	Alaska	Northern Alaska	Southcentral Alaska	Southeast Alaska	Southwest Alaska
1	100	100	100	100	100
2	18	18	18	3.5	27
3	12	9.8	13	2.2	25
4	7.8	5.1	9.6	1.1	21
5	6.1	3.3	8.7	0.34	16
6	4.1	1.8	6.1	0.01	11
7	1.8	0.14	3.0	0.00	7.2

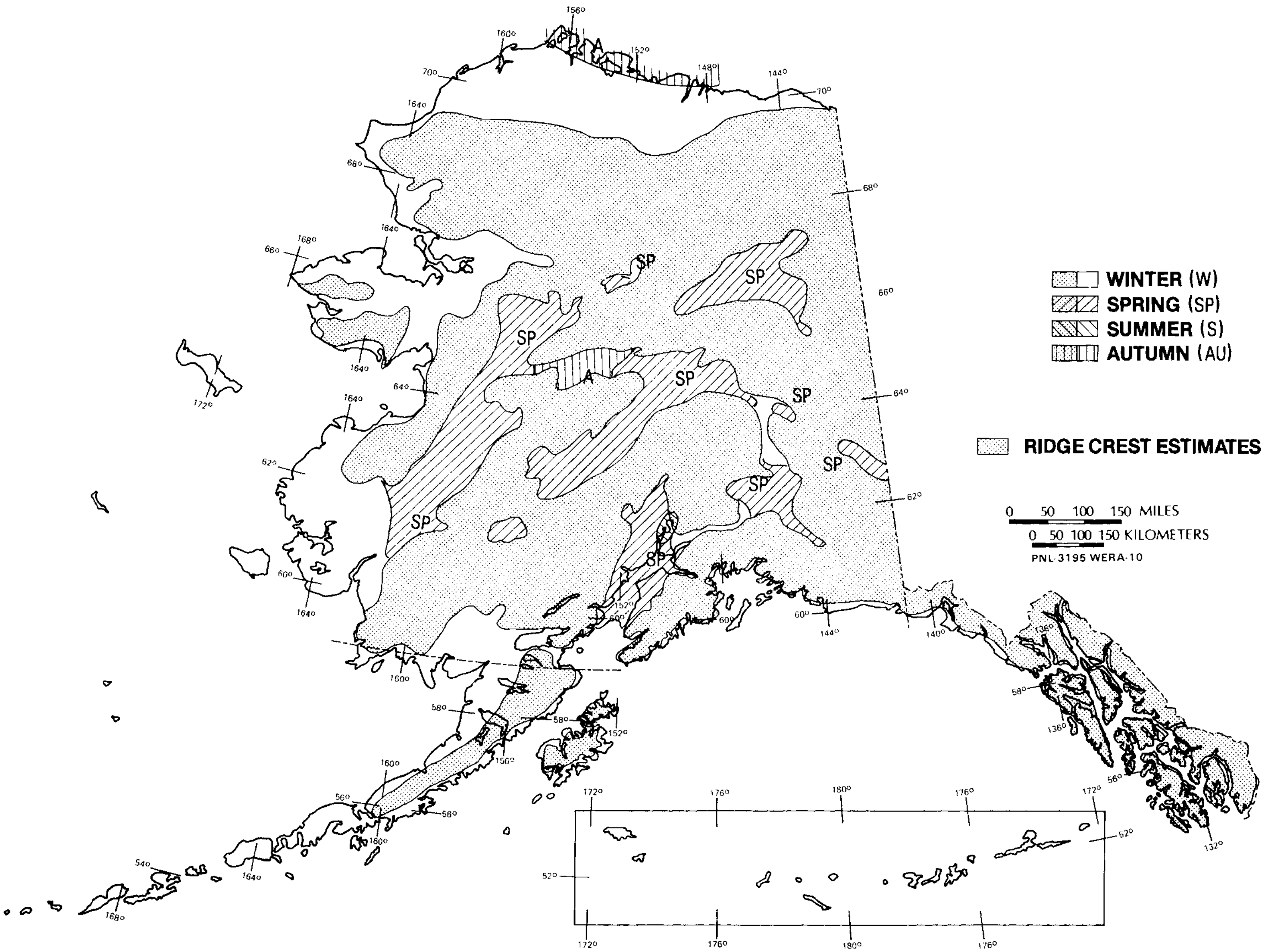


FIGURE 2.5. Seasonal Maximum Wind Power in Alaska

CHAPTER 3: SUBREGIONAL FEATURES

The wind resource for the subregions of Alaska is described in Chapters 4 through 7. The subregion descriptions are presented in a consistent format. The text of each description is followed by maps, graphs, and tables that identify features of the geography and the wind energy resource and summarize the data collected from the observation stations. The sequence of maps, tables, and graphs used to depict these features is presented below in Table 3.1. In two of the subregional descriptions, southeast and southwest, the illustrations are presented so that related information is on facing pages and can be viewed simultaneously; however, the other two subregions have numerous graphs and appear on several pages.

To avoid repetition in the following chapters, the general format and content of the various maps, tables, and graphs used to describe the wind resource for each subregion are summarized here.

3.1 MAPS OF STATE FEATURES

The maps of cultural geography show the locations of major cities, rivers, and terrain features for each subregion. The maps of shaded topographic relief are reproductions of the 1:2,500,000 scale of U.S. Geological Survey maps. The land-surface form maps are reconstructions of portions of the map of classes of land-surface form by Hammond (1964; this is also available at a scale of 1:7,500,000 on Plate 62 in the National Atlas of the United States). The use of the land-surface form map was described in Section 1.8.

Two maps are used to show the locations of stations with wind data. The first map gives the locations and names of the NCC stations with wind data in any form. The other map shows the locations of NCC, fire weather, and other data stations that were utilized in this assessment of the wind resource.

The map of annual average wind power is accompanied by maps of the certainty rating of the estimated annual average wind power by grid cell, and of the areal distribution of the wind resource by grid cell. The certainty rating, which ranges from 1 (low) to 4 (high), indicates the level of confidence in the estimates of the wind resource in each cell of the grid. The rating is based on the availability of wind data, the complexity of the terrain, and the inherent geographical variability of the wind resource (see Section 1.9). The maps of areal distribution give the percentage of land area in each cell estimated to experience an annual average wind power class equal to or exceeding power classes 2, 3, 4, and 5 (see Section 1.10).

Maps of the average wind power are presented for each season: winter (December, January, and February); spring (March, April, and May); summer (June, July, and August); and autumn (September, October, and November). The legend for the power classes is found with the annual average wind power map.

TABLE 3.1. Maps, Tables and Graphs Used to Depict the Wind Resource

Maps

Left Hand	Right Hand
Cultural Geography	Topographic Shaded Relief
Land-Surface Form	Legend to Land Surface Form
NCC Station Locations	Location of Stations Used in Wind Assessment
Annual Average Wind Power	Legend to Wind Power Classes and Table on Areal Distribution
Certainty Rating	Legend for Certainty Rating
Areal Distribution (Classes 2 & 3)	Areal Distribution (Classes 4 &5)
Seasonal Average Wind Power (winter, summer)	Seasonal Average Wind Power (spring, fall)

Graphs

Summary Table of Selected Stations	Interannual Speed and Power
Monthly Speed and Power	Diurnal Speed
Directional Frequency	Speed Frequency
Speed Duration	Power Duration

3.2 FEATURES OF SELECTED STATIONS

The analysis of the wind resource on a state and subregional basis depends on information from individual stations. For those stations with one- or three-hourly data on NCC magnetic tapes, a very detailed presentation of the temporal variation and character of the wind resource can be obtained. Graphs portraying various features of the wind resource have been prepared for selected stations in each subregion and are presented in the subregion chapters. For each station presented, a brief description of the station's topographical setting and unique features is given in the text preceding the maps and graphs. The geographical area represented by a station varies, depending on the complexity of the local terrain and variability of the wind resource.

A table listing the stations for which graphs and summaries of the features of the wind resource are presented precedes the series of graphs. Height adjustments were made only to obtain estimates of the average wind speed and power at 10 m and 50 m given in this table. No attempt was made to adjust to a reference height any of the other wind characteristics (e.g., diurnal wind speeds, frequency distributions of wind speed, wind direction, speed and power duration, etc.) presented in the graphs for selected stations. Caution should therefore be used in comparing and interpreting station plots.

In the plots of interannual wind power and speed, the first line of each graph contains the station name and state. The second line contains the WBAN number. In all other plots, the first line on each station graph contains the station identification that corresponds to the name and location listed in the table and the month and year of the selected period of record. Only one period of record with constant anemometer height was plotted for most stations, even though some stations had several periods of record. However, if there was uncertainty as to which period had better anemometer exposure or if two periods with similar exposure indicated substantially different wind characteristics, two periods of record were plotted. Usually, periods when the anemometer was located on a mast directly on the ground were preferred to periods when the anemometer was located on the roof of a building.

The second line of each station graph contains the WBAN number, anemometer height (Z) in m and its location, and the annual average wind speed (V) in m/s and wind power (P) in watts/m^2 at Z. V and P are adjusted to 10 m for the graphs of interannual and monthly average wind power and speed and are at anemometer height, Z, for all other graphs.

The coded information listed with the anemometer height is one of the following (Changery 1978):

R - indicates the anemometer was located on the roof of a control tower, operations building, hangar, or other similar structure. Normal mast heights were 2 to 4 m above roof line; however, many inner city locations used considerably taller masts. The listed height is elevation above ground level, not roof level; the "R" indicates an exposure type.

G - indicates the anemometer was located on a mast attached directly to the ground. Most anemometers at airport locations changed from a roof to ground exposure by the early 1960s.

B - indicates a beacon tower exposure. For these locations, neither R nor G was considered satisfactory.

UNK - indicates that documentation on instrument heights was not available.

If information on exposure was unavailable, no exposure code is given.

On a few station plots, an E follows the annual average wind power. If a pressure or temperature observation is missing, the wind power for that observation is computed using an air density based on station elevation. If the number of missing observations exceeds 25% of the total, then an E is used to designate that the wind power is an estimated value.

Up to 12 graphs of the same type may appear on one page to allow for station-to-station comparison. The scale of each set of plots was determined by the maximum range of values found for all stations in the region.

3.2.1 Interannual Wind Power and Speed

The plots of interannual wind speed and power portray the variations of the yearly average over the period of record. The beginning and ending of each period of record with constant anemometer height and location are designated by a "plus" symbol on the wind power curve and by a "diamond" symbol on the wind speed curve. If the anemometer height was unknown, a height of 10 m was assumed. Only yearly mean wind speeds based on 12 months' data (January through December) were plotted.

Year-to-year deviations from the long-term annual average may not be a reliable indicator of the deviations at nearby sites or areas (Elliott 1979b).

3.2.2 Monthly Average Wind Power and Speed

Graphs of the monthly average wind power and speed portray the monthly and seasonal trends of the wind. Stations with less than five years of observations may not show reliable seasonal trends. Also, stations in complex terrain may not represent the seasonal trends in nearby areas because of the influence of nearby terrain. Most of the station curves are within the range of 0 to 800 watts/m^2.

3.2.3 Diurnal Wind Speed by Season

The diurnal variation in wind speed according to season is plotted on graphs containing four curves, one for each season. Local standard time (LST) is used with hour 24 as midnight and hour 1 as the beginning hour. For National Weather Service and Federal Aviation Administration stations the diurnal curves are based on 24 observations daily for periods ending before 1965 and on eight observations daily for periods ending after 1964. For Air Force stations the diurnal curves are usually based on 24 observations daily regardless of the period. The diurnal curves for Navy stations are based on 24 observations daily for periods ending before March 1972 and on eight observations for periods ending after February 1972.

3.2.4 Directional Frequency and Average Speed

Graphs of the annual average frequency of occurrence show the percentage of time that the observed wind direction was from each of 16-point compass sectors and the average wind speed of all observations in each sector. Some stations show a definite bias toward eight-point compass observations. The coincidence of peaks in the two curves indicates that the highest wind speeds occur from the prevailing directions. Caution should be used in applying these data to other sites, because nearby terrain and obstructions strongly influence the wind directions. Some of the directional data presented may not be reliable or representative because of the anemometer location.

3.2.5 Annual Average Wind Speed Frequency

Graphs of the annual average frequency of observed wind speeds are shown in 1-m/s intervals. Along with the observed distribution, a Rayleigh wind speed distribution based on the annual mean speed is shown. Some of the stations show pronounced peaks in the observed distribution; these peaks reflect observer bias toward certain wind speeds, such as 2, 5, and 8 m/s (5, 10, and 15 knots). This bias occurs more frequently in records prior to 1960. Because many of the wind instruments used had a threshold velocity of about 1.5 m/s (3 knots), the frequency of observations in the 1-m/s class is often lower than the frequency of the calm and 2-m/s classes.

3.2.6 Annual Average Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in two sets of graphs. Abrupt changes in the slope of the duration curves for speed and power usually correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold velocity. Points are plotted at 1-m/s intervals for the speed duration curves. Points are plotted every 50 watts/m^2 up to 500 watts/m^2 and every 100 watts/m^2 up to 1,000 watts/m^2 in the power duration curves.

NORTHERN ALASKA

CHAPTER 4: NORTHERN ALASKA

The northern subregion has an approximate population of 84,627 (1979 estimate). Most of the people in this subregion live along the coast or one of the major rivers. Major population centers and respective populations are: Fairbanks North Star Borough, (60,227), Nome (2,982), and Kotzebue (2,526), and Barrow (2,715). The great majority of the other communities in the subregion have populations under 500. This subregion comprises approximately one half of the total land area of the state. It includes the total width of the state from 141°W to the west coast, including Little Diomede Island, and from 64°N to the Beaufort Sea and Arctic Ocean (see Figure 4.1). The total surface area of the northern subregion is 732,310 km^2 (282,672 mi^2).

A major geographical feature of northern Alaska is the Brooks Range, which runs east and west between 69°N 141°W and 68°N 163°W (see Figure 4.2), and ranges in elevation from 1,220 to 2,750 m (see Figure 4.3). The Brooks Range divides the arctic slope north of the range from the Yukon and the northwestern portions of this subregion.

From their origins in the Brooks Range, numerous rivers such as the Colville and Sagavanirtok pass through the arctic foothills on their way to the coastal plain. The rolling uplands of moist tundra with thousands of shallow impermanent thaw lakes dominate the arctic coastal plain. The coastline is generally low and flat with occasional bluffs and sea cliffs with heights up to 15 meters. Deltas terminate the larger rivers and streams, especially east of Point Barrow. Barrier islands and spits run in a broken line a few miles offshore, enclosing long, narrow lagoons. Here and there the line is interrupted by stretches of coastline facing the open sea.

South of the Brooks Range the subregion is composed of the Yukon interior and the northwestern coast environments. Other mountains besides the Brooks Range in this subregion are the Ray Mountains, Nulato Hills and the Yukon-Tanana uplands.

Taiga forests are found extensively in the highland and river valleys below 600 m. The major rivers south of the Brooks Range are the Yukon, the longest in the state at 3,017 km; the Koyukuk; the Tanana; the Noatak; and the Kobuk.

Lakes in this portion of the subregion fall into four groups: those resulting from the regional deformation where downwarped areas along the seacoast formed large collecting basins; glacial lakes scattered throughout the mountains and foothills; tundra lakes of all shapes and sizes that occupy the bench and flat valley lands; and lakes formed by volcanic action on the central Seward Peninsula. The major lakes of the Yukon interior and northwest environments of the northern subregion are Imuruk Lake, 69 km^2 (28 mi^2); Walker Lake, 35 km^2(14 mi^2); and Shelby Lake, 20 km^2 (8 mi^2). Selawik Lake is much larger than these but is affected by tidal action.

Permafrost is found throughout the whole northern subregion and is slightly more prevalent in northern than in southern areas. The permafrost appears to be thawed near deep lakes and major rivers. A few glaciers are found in this subregion, mostly in the northeastern portion of the Brooks Range, but snowfields that last from year to year can be found in pockets throughout the northern subregion.

The wind data available from NCC are mostly from stations along the coast and major rivers in the subregion (Figure 4.4). Large areas exist in the northern subregion where no year-round data or only limited unsummarized data were available. In the absence of other reliable data, sparse fire weather data from some of the foothill and forested areas of the region (Figure 4.5) were used in the calculations.

4.1 ANNUAL AVERAGE WIND POWER IN NORTHERN ALASKA

The annual average available wind power density in northern Alaska is shown in Figure 4.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as 50 to 100% from the assessment value. (See Wegley et al. 1980 for information on terrain features that may increase or reduce wind energy.) In forested or wooded areas the assessment values are representative of large clearings with good exposure to the prevailing strong winds, such as airports. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power (Figure 4.6) is class 4 or higher all along the

Beaufort and Chukchi Sea coasts except at Barrow where class 3 occurs. Class 4 or higher wind power is estimated to be within 20 miles of these coasts and occurs only in exposed locations. Near Barter Island class 7 wind power prevails. Similarly, from Point Lay to Cape Lisburne class 7 wind power prevails.

The Kotzebue Sound area has class 4 or higher wind power. Kotzebue itself has class 6 annual average wind power.

On the Seward Peninsula, class 4 or more wind power occurs at the west end near the Bering Strait and generally along the south coast except where areas are shielded such as at Nome. Class 7 wind power occurs in the vicinity of the Bering Strait, as shown by data from Wales and Tin City, where the annual wind power is over 700 W/m^2.

Mountain summit and ridge crest wind powers are estimated to be generally class 3 along the Brooks Range except at the east end. Class 2 wind power prevails in the interior of the Seward Peninsula; the Nulato Hills are also estimated to have class 2 power.

Class 4 and higher wind power occurs in the vicinity of Big Delta, where the flow of wind through Isabel Pass affects the area. Class 2 wind power is estimated at ridge crests in the Ray Mountains, the hills between the Yukon and Tanana Rivers, and slopes of the Alaska Range to the south of the subregion.

Most of the remainder of the northern subregion has class 1 wind power. The few data in the northern Brooks Range indicate that valleys are generally sheltered. There are few passes through the range and data from Atigun, Anaktuvuk, and Wiseman indicate that low wind powers are the rule.

4.1.1 Certainty Rating of the Wind Resource

Certainty ratings in northern Alaska vary from 1 to 4 (Figure 4.7). Only three areas have class 5 or higher annual wind power and a certainty rating of 4. They are the wind corridor at the east end of the Seward Peninsula at Moses Point and Koyuk, with annual class 5; the west end of the Seward Peninsula at Wales, Tin City, and Point Spencer, with annual power class 7; and the east-central Beaufort Sea coast at McIntyre and Oliktok with annual power classes 6 and 7. The certainty rating for areas a short distance from the coast drops quickly to 2 or 1 because of the sparsity of data and complexity of the terrain.

Complexity of terrain accounts for the class 2 or 3 ratings along the north and east coast of Norton Sound, the north coast of Kotzebue Sound, the southwest Chukchi Sea coast, and the eastern Beaufort Sea coast. Lack of data over much of the Arctic north of the Brooks Range results in an extensive area with a certainty rating of 1.

The highest rating given to any interior location is 3 in the Fairbanks area and the east-central arctic plain where Umiat, Sagwan, and visually scanned data confirm a wind power class of 1. The remainder of the interior has of certainty ratings 1 and 2. Mountain summits and ridge crest estimates in the Brooks Range, Nulato Hills, and lesser mountains and hills in the interior have a certainty rating of 2 based on upper wind estimates from Crutcher (1961) and wind summaries from rawinsonde stations at Fairbanks, Nome, Barrow, and Barter Island.

4.1.2 Areal Distribution of the Wind Resource

Figure 4.8 illustrates areal distribution of the wind power in northern Alaska. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds some threshold value. Although class 4 or higher wind power is predicted in 20% of the grid cells, only about 5% of the land area is estimated to experience these power densities (see Table 4.1). High wind power resource areas are confined to the coast, where in many of the grid boxes there is only a small percentage of land and mountain summits and ridge crests of the eastern Brooks Range. In the high topographic relief of the Brooks Range, the areas with high wind resource are reduced to only the most exposed ridge crests; elsewhere wind power classes 1 to 3 prevail. The only inland areas with class 4 or higher are the wind corridors at the east end of the Seward Peninsula and in the vicinity of Big Delta. Most of northern Alaska is of wind power class 1 and 2 at both lowlands and along the mountain summits and ridge crests.

4.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 4.9. Winter is the season of maximum wind power along the Chukchi and Bering coasts, and the east end of the Beaufort Sea coast. Mountain summits and ridge crests also have winter maximum wind powers. Spring is the season of maximum wind power in sheltered valleys of the Yukon, Koyukuk, and Tanana Rivers. However, from Barrow eastward to the Sagavanirktok River, autumn is the season of maximum wind power.

4.2.1 Winter

During the winter, wind powers at exposed coastal locations such as Barter Island and the west end of the Seward Peninsula at Wales and Tin City are exceptionally high--more than 700 and 1,100 W/m^2, respectively. Nearly all of the Chukchi Sea coast, the eastern half of the Beaufort Sea, and exposed areas of Kotzebue Sound have class 7 power. As Moses Point and Koyuk data show, classes 4 to 7 wind power prevails in the relatively low relief area at the east end of the Seward Peninsula. Elsewhere along the coast, classes 3 to 6 wind power prevails.

Mountain summits and ridge crests in the Brooks Range generally have class 4 power, except in the Phillip Smith and DeLong Mountains, which have class 1; the Baird Mountains have class 2; and the Endicott Mountains, the Nulato Hills, and smaller mountain ranges in the interior and on the Seward Peninsula have classes 2 or 3 power.

Along sheltered valleys of major rivers such as the Yukon, Koyukuk, and Tanana, class 1 wind power prevails. There is also class 1 wind power over much of the area in the arctic coastal plain between the Brooks Range and the Beaufort Sea coast in winter.

4.2.2 Spring

In spring, class 4 or higher wind power occurs along the Beaufort Sea coast from Lonely Point eastward to the Canadian border, all along the Chukchi Sea coast and along the Seward Peninsula, except portions of the Norton Sound coast around Nome where class 3 prevails. Class 7 wind power occurs along the Chukchi Sea coast from Point Lay to Cape Lisburne and in the Peard Bay area. Class 7 also occurs at the west end of the Seward Peninsula, as shown by Wales and Tin City. West of Lonely Point to Barrow, classes 2 and 3 wind power prevails.

Mountain summits and ridge crests in the eastern Brooks Range have power of class 3 or 4, and those in the Yukon and Tanana uplands and the Nulato Hills are of class 2.

In the wind corridors at the east end of the Seward Peninsula wind power of class 3 to 5 occurs, and in the Isabel Pass area, power of class 2 and 3 occurs. In the spring, the remainder of northern Alaska generally has class 1 wind power.

4.2.3 Summer

In summer, class 4 or higher wind power occurs along the Beaufort Sea coast east of Harrison Bay, along the Chukchi Sea coast south of Point Lay, at the west end of the Seward Peninsula, and at the east ends of Kotzebue Sound and Norton Sound. The west end of the Seward Peninsula is the only area attaining class 7 wind power during summer; the Cape Lisburne area attains class 6. In summer there is a primary storm track through the Bering Strait. Elsewhere along the northern Alaska coast class 3 wind power prevails.

At mountain summits and ridge crests of the eastern Phillip Smith Mountains, class 4 wind power occurs. In the Nulato Hills and the western Brooks Range, class 2 prevails.

The wind corridor in the eastern Seward Peninsula has decreased to class 2 to 4 power, which is lower than the values in winter and spring. The north end of Isabel Pass also decreases to wind power class 1, indicating that high winds in this pass are primarily a winter phenomenon. Elsewhere in the subregion, class 1 wind power prevails in summer.

4.2.4 Autumn

In autumn, class 4 or higher wind power prevails all along the Chukchi and Beaufort Sea coasts. Class 7 occurs all along the Beaufort coast except around Barrow and Lonely Point, where class 4 and 6 power prevails. Along the Chukchi Sea coast, class 7 occurs in the Peard Bay area and from Point Lay to Cape Lisburne. Class 7 wind power also occurs at the west end of the Seward Peninsula, and class 6 occurs in the Kotzebue area and the east end of Norton Sound.

Mountain summits and ridge crests of the Brooks Range generally have class 3 power in the Phillip Smith, Endicott, and DeLong Mountains and only class 2 in the Baird Mountains. The Nulato Hills, Ray Mountains, and the Yukon and Tanana uplands show class 2 power in the higher elevations but for the most part are of class 1.

Wind corridors at the east end of the Seward Peninsula have class 2 to 5 wind power as shown by Moses Point and Koyuk data. The Isabel Pass area shown by Big Delta indicates class 4 wind power.

The remainder of the northern subregion is generally of wind power class 1 in autumn.

4.3 FEATURES OF SELECTED STATIONS

Graphs of wind characteristics are shown for 21 stations in northern Alaska. Twelve of these are along the coast and the remainder are in the interior of the subregion. The station characteristics are summarized in Table 4.2.

The Beaufort Sea coast is represented by the stations Barrow, Lonely Point, Oliktok, Flaxman Island, and Barter Island. All stations are well exposed to winds from all directions. Barrow and Barter Island, NWS stations, have the greatest reliability and highest frequency of observations. Lonely Point and Oliktok averaged three observations per day, and Flaxman Island averaged only one observation per day.

Barrow, Wainwright, Point Lay, and Cape Lisburne represent conditions along the Chukchi Sea coast. The most reliable stations are Barrow and Cape Lisburne, where observations averaged 24 and 18 per day, respectively. Cape Lisburne has hills from the southeast to the west quadrants. The effects of this terrain are increased frequency and enhancement of easterly winds and lesser wind speeds from the east through south. Wainwright and Point Lay are well exposed to winds from all directions.

Kotzebue Sound is well represented by Kotzebue, a NWS station on the Baldwin Peninsula. The station is exposed to winds from all directions and had an average of 21 observations per day during the summary period.

Tin City is representative of the winds in the Bering Strait and the west end of the Seward Peninsula. It is most exposed to winds from the north and south because of elevated terrain to the west (over 600 m) and to the east (over 300 m).

Nome and Moses Point experience representative winds found on the south coast of the Seward Peninsula, along the Norton Sound.

Nome is exposed to the east, south, and west. Foothills (heights ranging from 150 to 400 m) extend from northwest to northeast at a distance of 7 to 15 km and rise to 1,500 m in the Kigluaik Mountains 50 km to the north. Nome is a NWS station with a frequency of 24 observations per day.

Moses Point in the northeastern portion of Norton Sound is well exposed to winds from all directions except west through north-northwest. About 7 km to the west through north of the station, rolling hills average 500 m in elevation. To the northeast the terrain is flat and swampy for 19 to 28 km. The Koyuk and Buckland Rivers form a low pass into the Kotzebue Sound area to the north, resulting in strong northeasterly winds during the winter months. Moses Point had an average of 24 observations per day during the summary period.

Umiat on the Colville River is considered very representative of the interior of the arctic coastal plain. Winds tend to be channeled to the east and west directions by the river valley. Hills rise to more than 300 m within 10 km northwest of Umiat. The period of record is short (4.5 years), however, 24 observations per day were taken during this summary period.

Bettles is located on the Koyukuk River in the foothills of the Endicott Mountains of the Brooks Range. The river valley runs northeast to southwest, perpendicular to the prevailing winds, and is representative of winds in sheltered valleys. Peaks more than 630 m occur within 9 to 19 km to the west, north, and east. To the south, the terrain is open and marshy. The station had a frequency of 24 observations per day during the 14-year summary.

There are three stations in the Yukon River valley. From west to east they are Galena, Tanana, and Fort Yukon.

Galena is located in the broad floodplain of the Yukon just west of the Kaiyuh Mountains. There are no hills over 300 m within 20 km of the station. The most exposed directions are to the northeast and southwest. During the six-year summary for Galena there were 24 observations per day.

Tanana is located 7 km west of the confluence of the Yukon and Tanana Rivers. Hills to the north of the station rise to more than 600 m within 15 km and to 1,500 m within 50 km. To the south the terrain is flat with numerous lakes and swamps. During the 16-year summary for Tanana there was an average of 24 observations per day.

Fort Yukon is located at the confluence of the Yukon and Porcupine Rivers. It is located in a broad valley 150 km wide and 370 km long and is openly exposed in all directions. During the 12-year summary used in the analysis there was an average of 11 observations per day. It is representative of the Yukon Flats area.

The three stations along the Tanana River are Nenana, Fairbanks, and Eielson Air Force Base (AFB).

Nenana is located on the floodplain at the confluence of the Nenana and Tanana Rivers. The mountains of the Alaska Range are 50 to 75 km south of Nenana, and the White Mountains are to the northeast. There is a range of hills with elevations to 300 m within 5 km to the north-northeast of the station. The remainder of the vicinity is generally marshy with numerous lakes and swamps. During the 11-year summary used in the analysis there were 24 observations per day.

Fairbanks International Airport is located on the floodplain of the Tanana River 9 km west of Fairbanks. There are hills as high as 300 m within 4 km to the west and north of the airport. To the southwest through southeast there is generally open, gently rising terrain for 55 km to the Alaska Range with peaks to more than 5,800 m. During the 7-year summary used in this analysis there were 24 observations per day.

Eielson AFB is located 28 to 37 km southeast of Fairbanks along the Tanana River. In this area the river valley is oriented southeast to northwest; hills rise to more than 600 m within 19 km east of the air base. The area to the southeast through south to northwest is generally exposed. However, to the south the terrain rises gently toward the Alaska Range. During the 11-year summary used in this analysis there were 24 observations per day.

Indian Mountain is located in a depression in the Indian Mountains surrounded by peaks of higher elevation. It is sheltered from strong winds from all directions. During the nine-year summary used in the analysis, there were an average of 21 observations per day.

4.3.1 Interannual Wind Power and Speed

Along the Beaufort coast (Figure 4.10) annual wind power at Barter Island varies by a factor of two from 300 watts/m^2 (W/m^2) to more than 600 W/m^2. Barrow, Lonely Point, and Oliktok also vary by a factor of two, but their actual values are 120 to 250 W/m^2 at Barrow, 170 to 340 W/m^2 at Lonely Point, and 240 to 480 W/m^2 at Oliktok. With few exceptions, variations in wind power and speed are synchronous from one end of the Beaufort coast to the other. Along the Chukchi Sea coast, Cape Lisburne showed the most interannual variability, from over 700 W/m^2 in 1956 to 320 W/m^2 in 1971. At Barrow, Point Lay, Wainwright, and Cape Lisburne the interannual variations coincide from year to year. Along the west coast of Alaska, Kotzebue showed its highest wind power in 1951 of 580 W/m^2, 2.9 times the lowest power of 200 W/m^2 in 1953 and 1962. Nome and Moses Point are generally synchronous with Kotzebue; however, actual values of wind power are generally less due partly to less exposure. Though Tin City has the greatest wind power of the west coast locations, it varied more and variations did not coincide. Umiat's short record is also synchronous with coastal locations, but wind power and speed are much less. Interior locations show less variation from year to year than do the coastal locations.

4.3.2 Monthly Average Wind Power and Speed

Along the Beaufort Sea coast mean annual wind speeds (Figure 4.11) average 5.4 to 5.9 m/s; however, the wind power classes average from 3 at Barrow to 7 at Barter Island with a gradual increase from west to east. The wind speed and power vary less by season in the west, where Barrow shows an October maximum and all other stations show a pronounced November to February/March maximum.

Along the Chukchi Sea coast the wind speeds average 5.1 to 6.1 m/s, and wind power class increases from north to south--3 at Barrow to 7 at Point Lay and Cape Lisburne. All stations show a fall and winter maximum and a minimum in summer. Farther south along the coast, Kotzebue shows a mean annual speed of 5.8 m/s and a wind power class of 6. It also has a late fall and winter maximum and a minimum in summer. Tin City, at the west end of the Seward Penninsula, shows the strongest wind speed of any station in northern Alaska at 8.5 m/s and wind power class 7. There is a slight late-fall and winter maximum and summer minimum but little variation from season to season. All interior locations are of wind power class 1 with mean annual wind speeds varying from 3.8 m/s at Fort Yukon to 1.6 m/s at Fairbanks/Eielson AFB. With the exceptions of Umiat and Indian Mountain, all interior stations show a slight spring maximum and a winter minimum. Umiat, on the north slope of the Brooks Range, has a very short period of record that shows a fall minimum. Indian Mountain shows a fall and winter maximum and a summer minimum more typical of a coastal location. The reason for winter minima in interior Alaska is the prevalent temperature inversions of cold air during that time of year. With short periods of sunlight, low sun angle, and clear, or partly cloudy skies, surface cooling occurs 24 hours a day and strong inversions with dense air at the surface can persist for weeks at a time. Indian Mountain, at approximately 1,000 feet elevation, is often above the strongest inversions; therefore, it has more winter wind.

4.3.3 Diurnal Wind Speed by Season

The diurnal variation of wind speeds in northern Alaska (Figure 4.12) is generally that the strongest winds occur in the early afternoon in spring at Beaufort and Chukchi coastal locations and in spring, summer, and fall at interior stations. There is no diurnal variation in winter anywhere in the subregion. Because most of the northern Alaska subregion is north of the Arctic Circle, there are periods in winter when the sun does not rise above the horizon and periods in summer when it does not set. Since the driving mechanism for diurnal variations of a meteorological parameter is often radiational heating or cooling, the transition periods between winter and summer have the greatest day-to-night contrast. Other influences are more important than diurnal variations for most of the year.

4.3.4 Directional Frequency and Average Speed

Along the Beaufort and Chukchi Sea coasts (Figure 4.13) the most frequent wind direction is easterly with a secondary maximum from the west. The strongest winds are also mostly easterly except at Barter Island, where it is westerly and strongest, probably because the station is closer to the Brooks Range in the eastern portion. Cape Lisburne's strong south through southwest winds are enhanced by the local topography as a foehn wind. Umiat most frequently has westerly winds, with the strongest from the east-northeast along the Colville River valley. Kotzebue also has its most frequent and strongest winds from south-southeast, with secondary maximums from west-northwest. The strong south-southeast winds are caused by the intensification of low pressure systems in the Kotzebue Sound area and the strong west-northwest winds that frequently accompany or follow frontal passages from the west. Tin City's most frequent and strongest winds are northerly with a secondary maximum from south-southeast. Local terrain tends to enhance both northerly and southerly winds and very few winds occur from east or west.

Nome, on the other hand, has its most frequent and strongest winds from the east and its lightest winds from the north as a result of the blocking effects of mountains to the north. Nome is typical of locations on the south shore of the Seward Peninsula. Moses Point has its most frequent and strongest winds from the north, with a secondary maximum of south-southwest. The strong northerly winds are enhanced somewhat by local effects of north-south ridges and valleys at the east end of the Seward Peninsula. Moses Point is very representative of the area to the east as far as the Nulato Hills.

In the interior, Bettles has its most frequent winds from northerly and southerly directions. There are also winds from east-northeast and southwest along the Koyukuk River valley; however, the winds are not particularly strong from any direction (typical of many valleys in the southern Brooks Range east of the Nulato Hills). Fort Yukon is very representative of the Yukon Flats area, with northeast winds being most frequent and southwest winds the next most frequent. Wind speeds reach 4 to 5 m/s from both directions. Galena and Tanana show strongest winds from the east (along the direction of the Yukon River); however, winds from the north are the most frequent at Galena and winds from the east and southeast are most frequent at Tanana. Indian Mountain has strongest and most frequent winds from east-northeast and secondary maxima southwest through west. Nenana has a wind regime similar to that of Tanana--east-northeast winds are most frequent and strongest; southwest through northwest winds show secondary maxima. Near Fairbanks, Eielson AFB shows very little variation of speed and direction while the Fairbanks airport has north winds most frequently and strong winds from west-southwest.

4.3.5 Annual Average Wind Speed Frequency

The high incidence of calm conditions in winter at interior locations (Figure 4.14) is a result of extremely stable air and strong temperature inversions, particularly at Eielson AFB, Galena, Fairbanks, Tanana, and Nenana. Observer bias is also evident in the peaks of wind speeds at 2, 5 and 8 m/s (corresponding to 5, 10 and 15 mph) at stations with data from before 1960, such as Umiat, Barter Island, Point Lay, Oliktok, Tanana, Kotzebue, Lonely Point, Moses Point, and Flaxman Island. Speeds of 1 m/s are often not shown in recorded data before 1960 because of instrument design. There is good correlation with the Rayleigh distribution at Tin City, Nome, Moses Point, and most coastal locations where the occurrence of calm conditions is low.

4.3.6 Average Annual Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in Figures 4.15 and 4.16. Abrupt changes to the slope of the duration curves correspond to peaks in the speed frequency distribution caused by observer bias and instrument threshold speed.

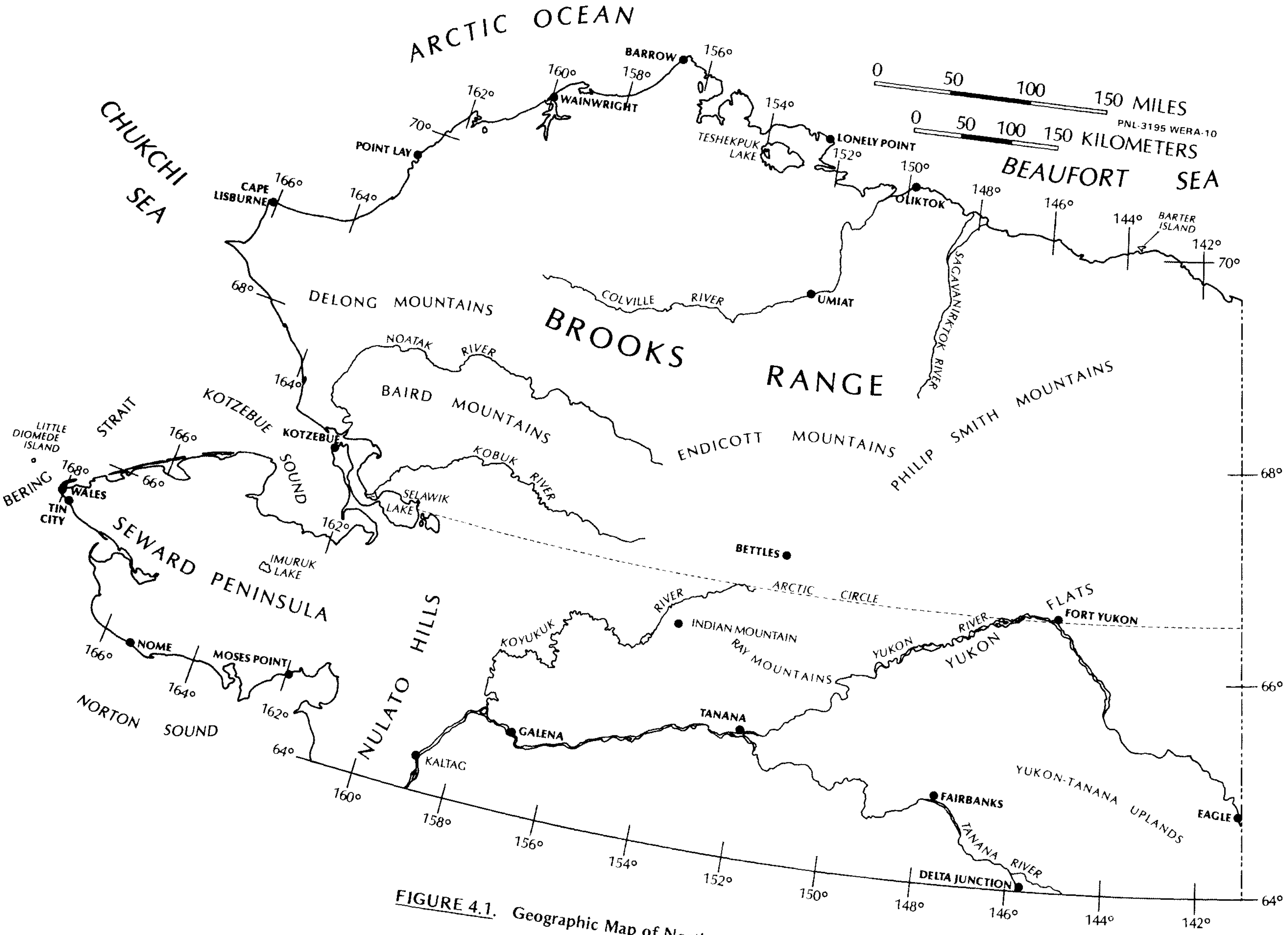


FIGURE 4.1. Geographic Map of Northern Alaska

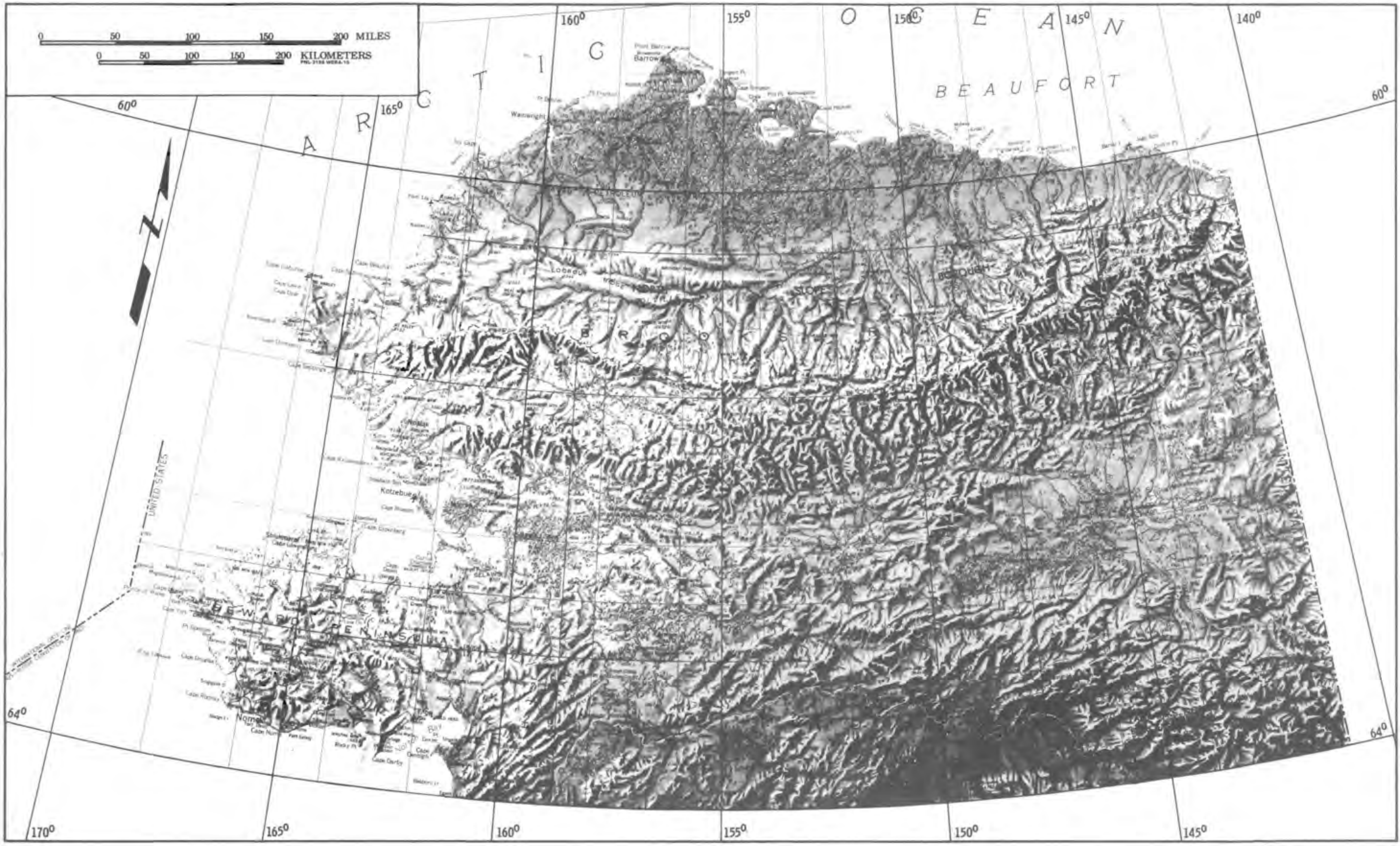


FIGURE 4.2. Topographic Map of Northern Alaska

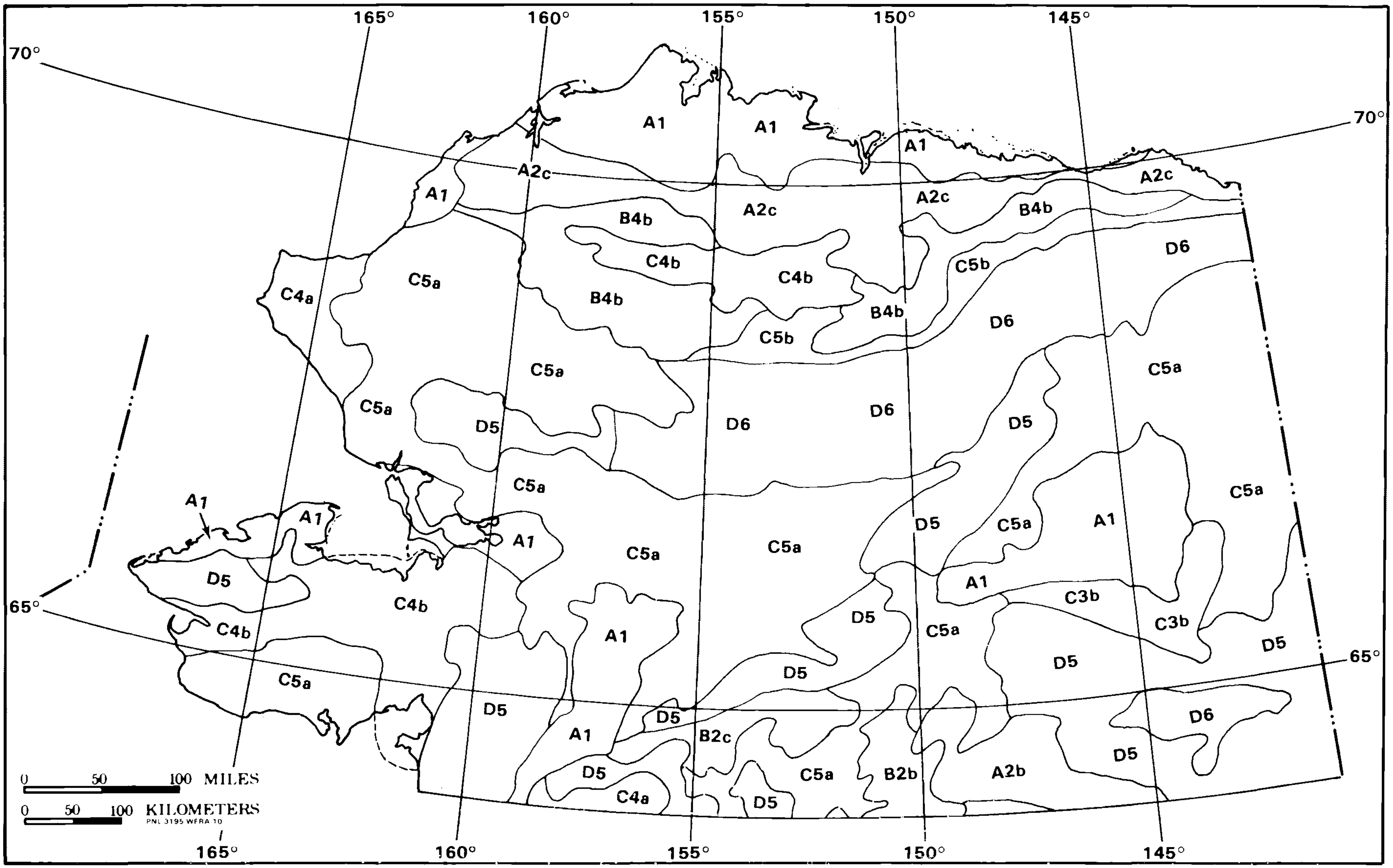


FIGURE 4.3. Land-Surface Form Map for Northern Alaska

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

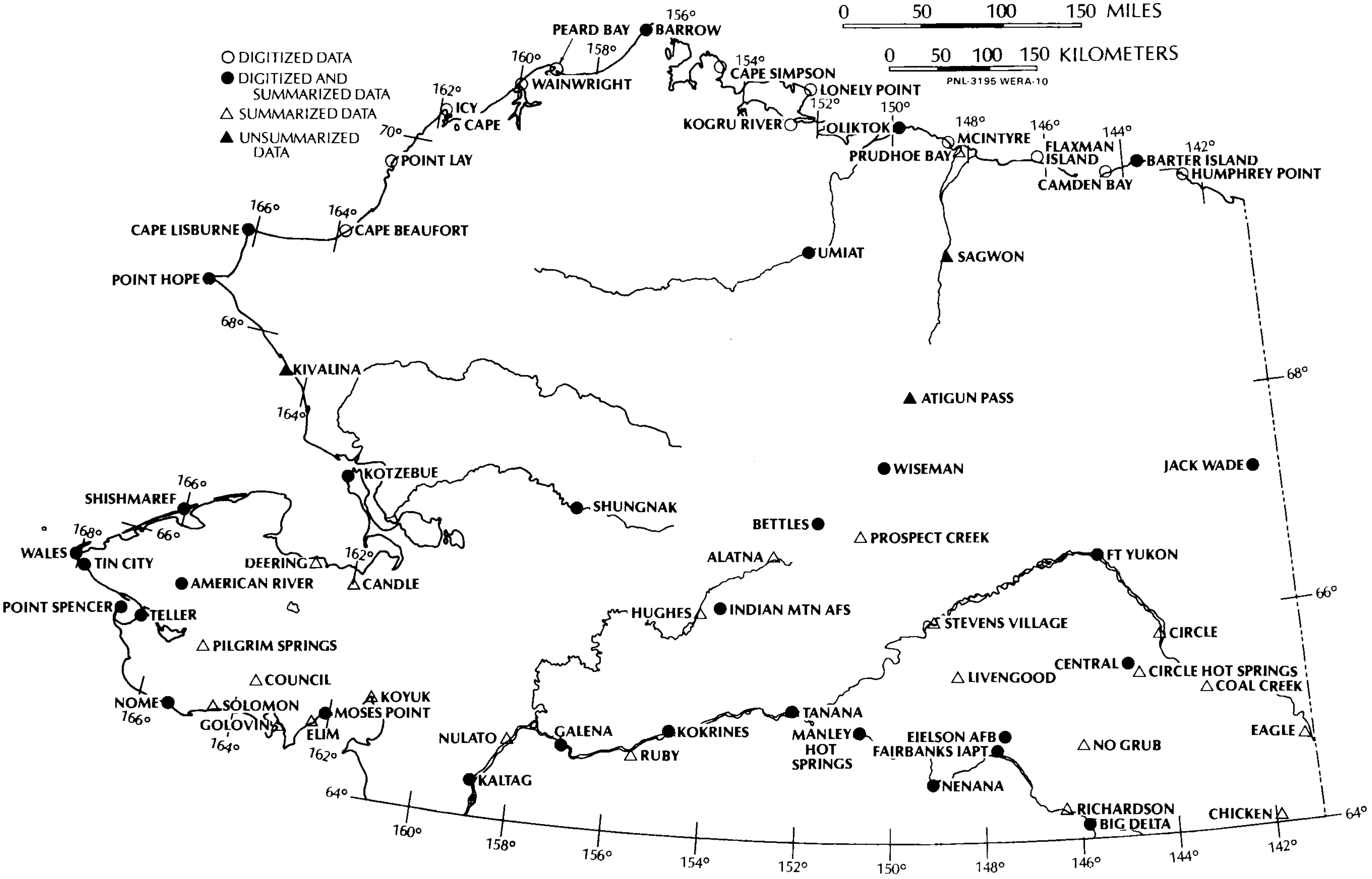


FIGURE 4.4. NCC Station Locations in Northern Alaska

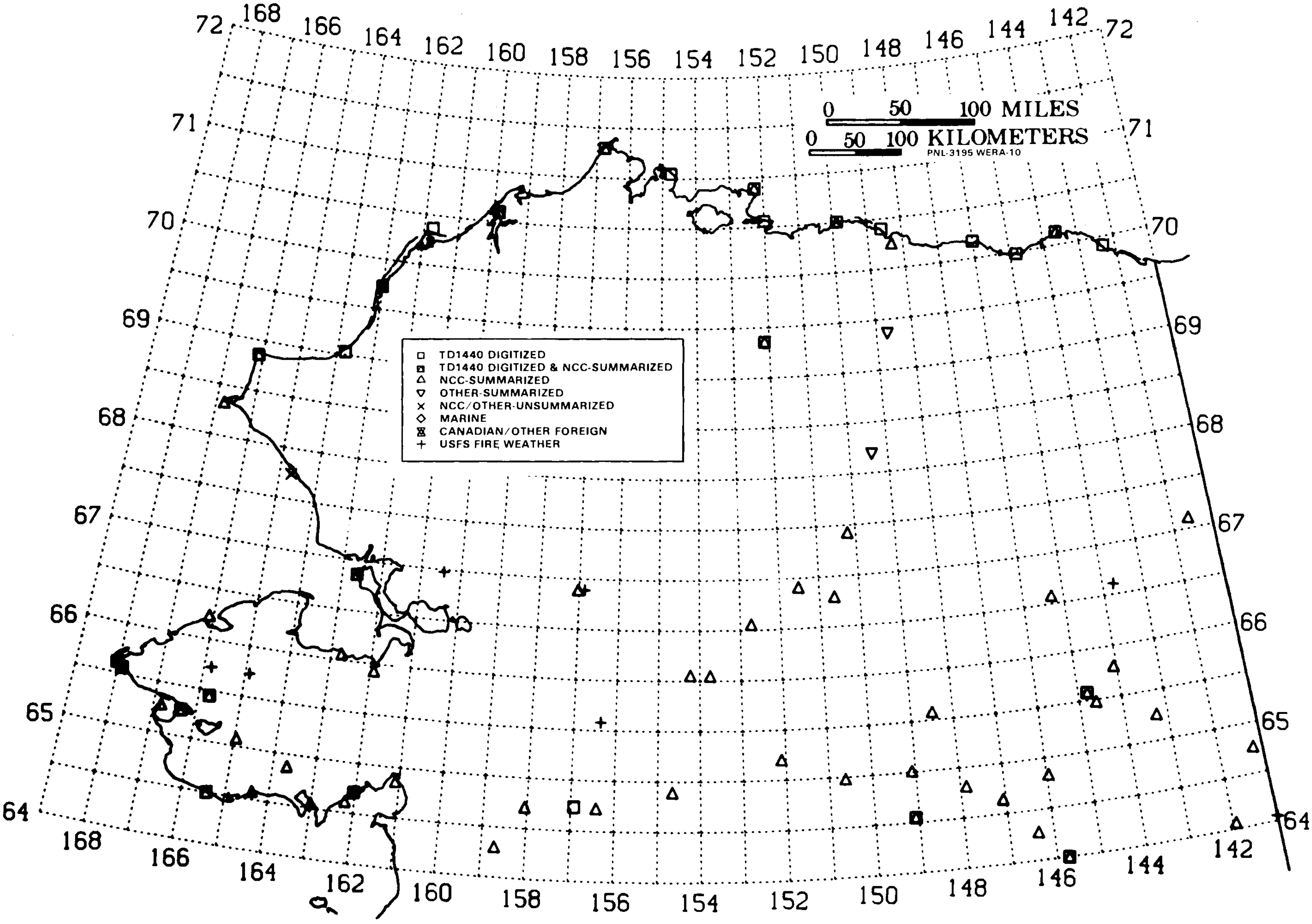


FIGURE 4.5. Location of Stations Used in Northern Alaska Resource Assessment

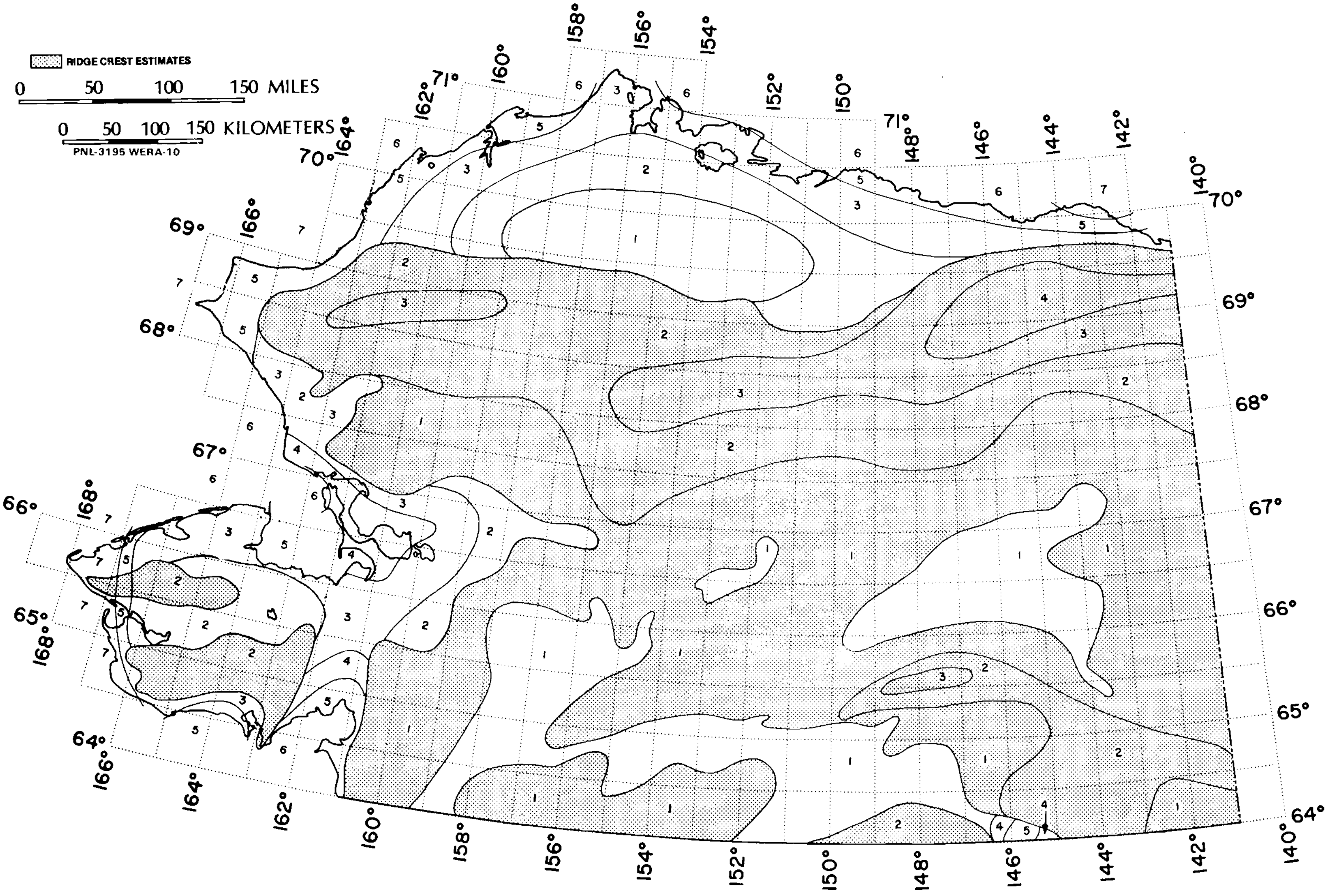


FIGURE 4.6. Northern Alaska Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m(a)

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a)Vertical extrapolation of wind speed based on the 1/7 power law.

(b)Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 4.1. Areal Distribution (km^2) of Wind Power Classes in Northern Alaska

Power Class	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	580,000	82	710,000	100
2	60,000	8.4	130,000	18
3	34,000	4.7	70,000	9.8
4	13,000	1.8	36,000	5.1
5	11,000	1.5	23,000	3.3
6	12,000	1.6	13,000	1.8
7	1,000	0.14	1,000	0.14

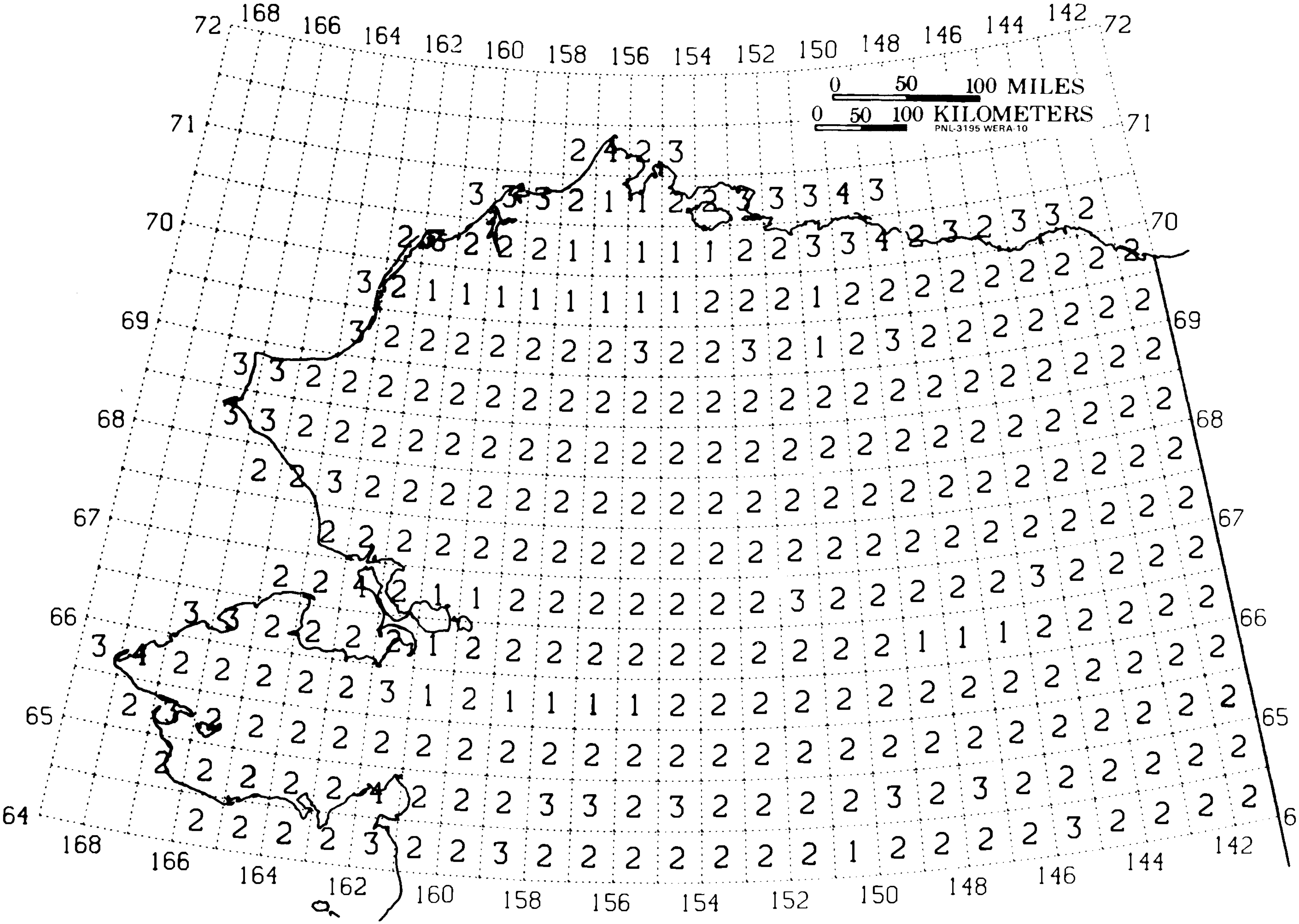
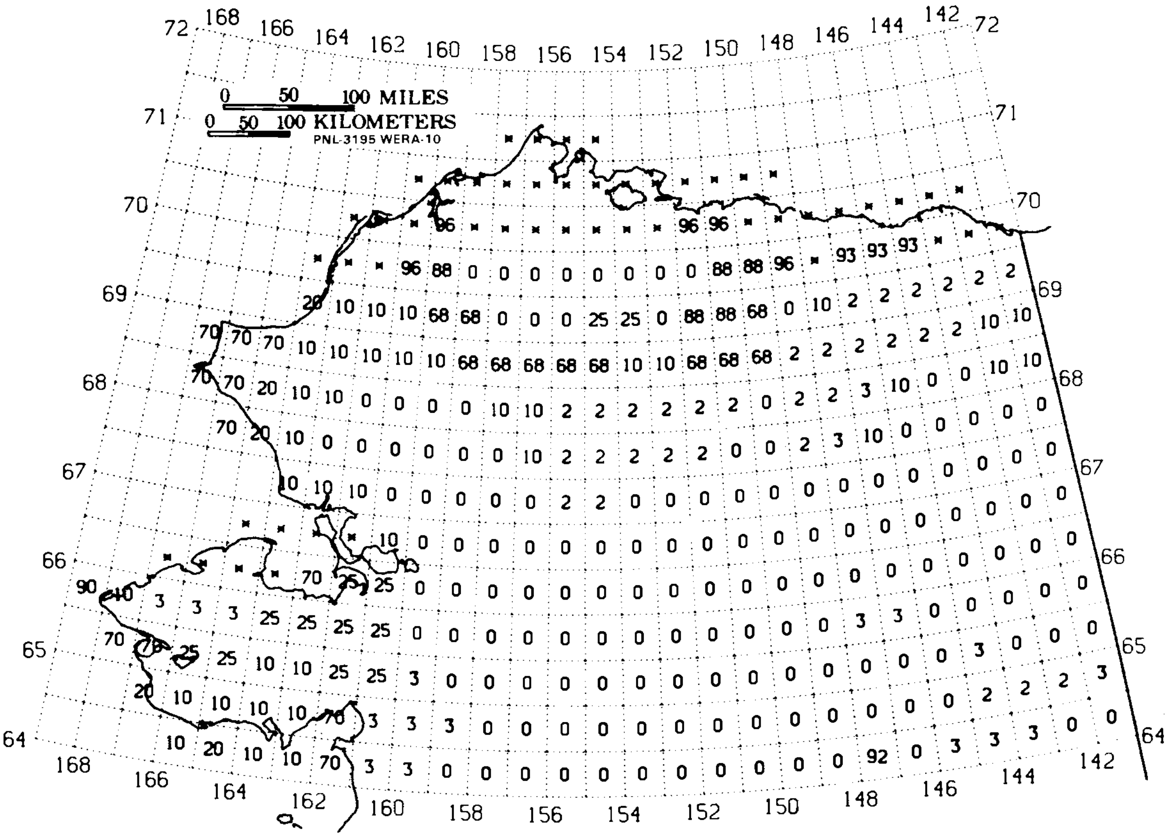


FIGURE 4.7. Certainty Rating of Northern Alaska Wind Resource.

CERTAINTY RATING LEGEND

Rating	Definition
1	The lowest degree of certainty. A combination of the following conditions exists: 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	A low-intermediate degree of certainty. One of the following conditions exists: 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	A high-intermediate degree of certainty. One of the following conditions exists: 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.

Class 2



Class 3

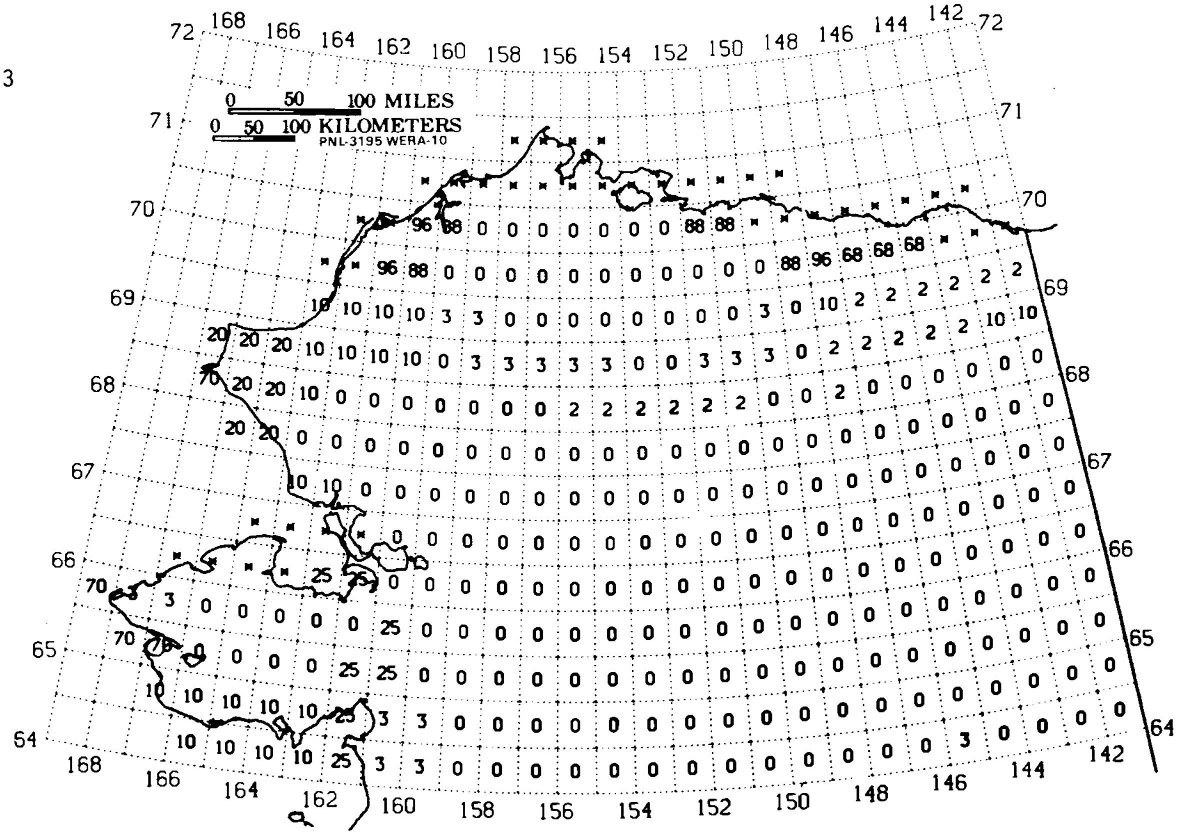
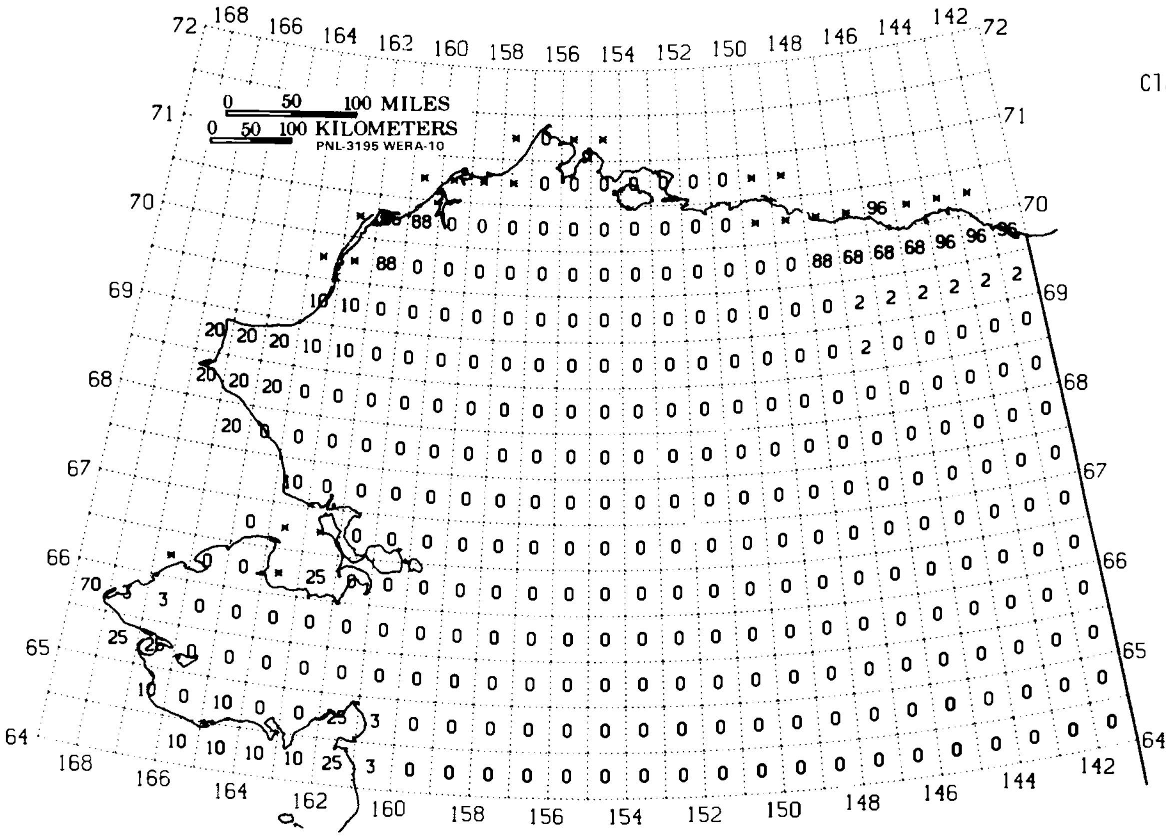
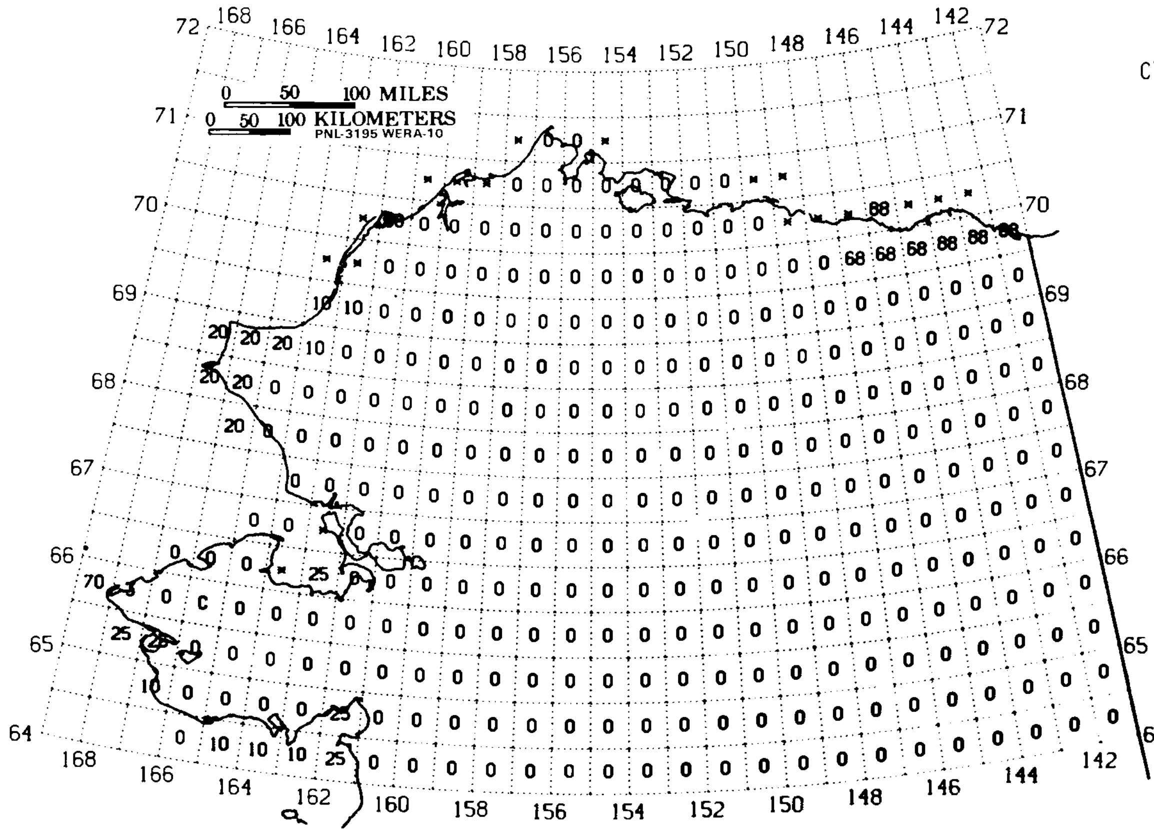


FIGURE 4.8 (Continued). Areal Distribution of Wind Resource in Northern Alaska (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown.



Class 4



Class 5

FIGURE 4.8. Areal Distribution of Wind Resource in Northern Alaska (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown.

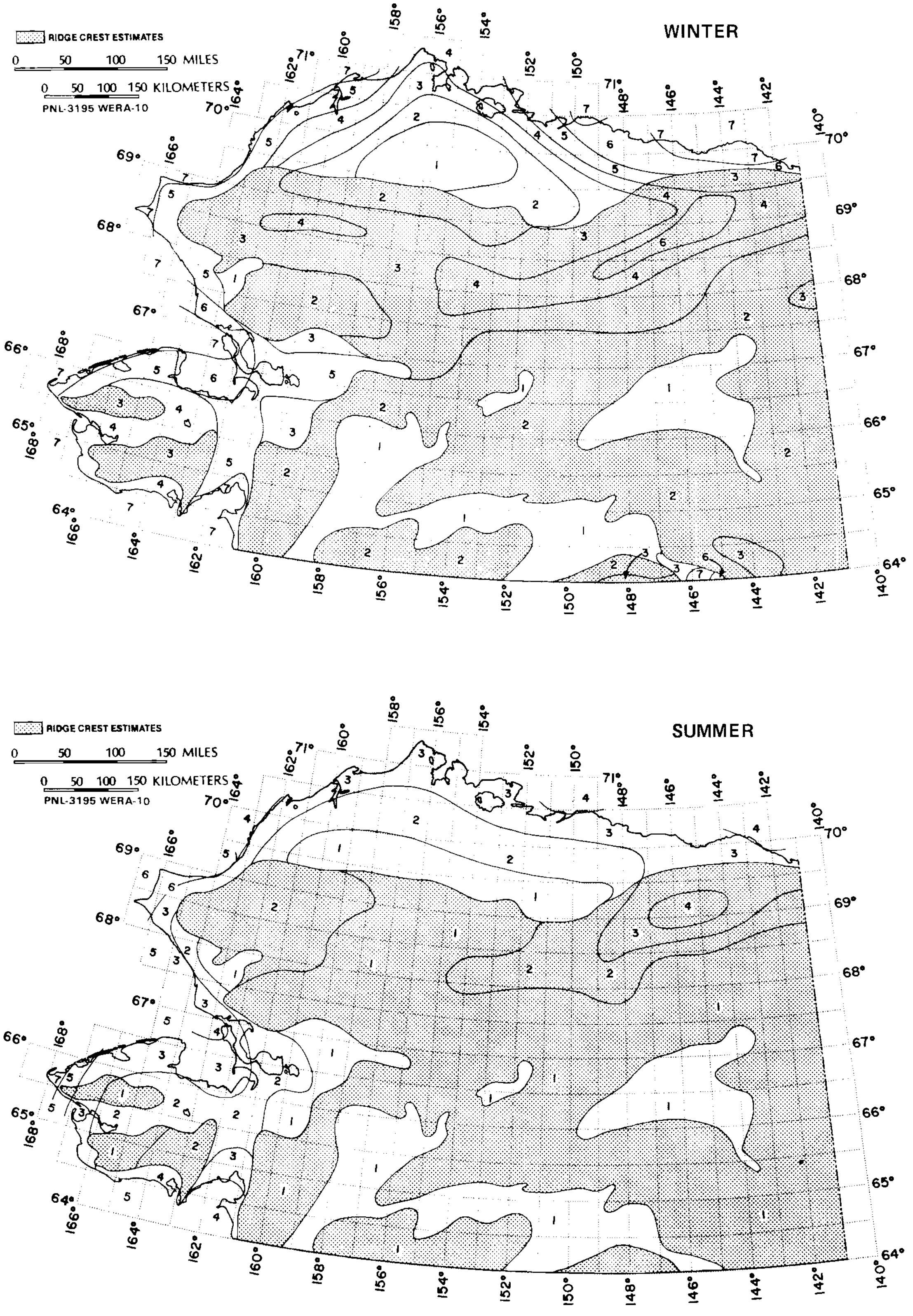
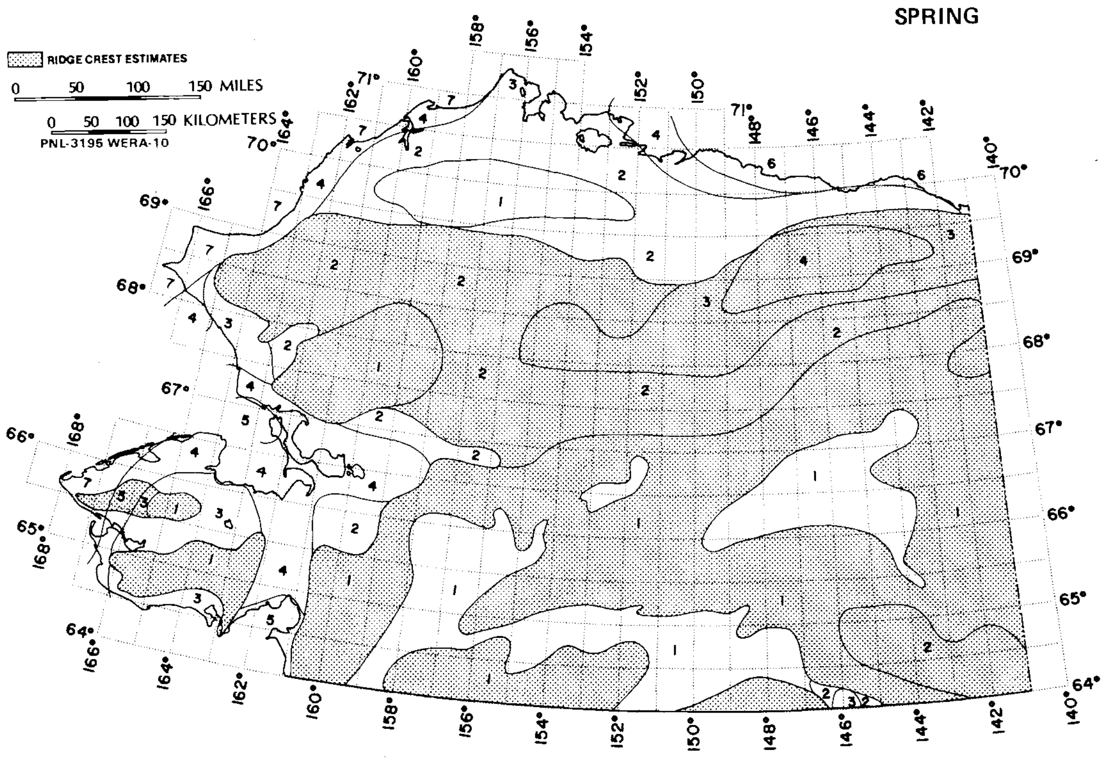


FIGURE 4.9. Seasonal Average Wind Power in Northern Alaska (Winter, Summer)



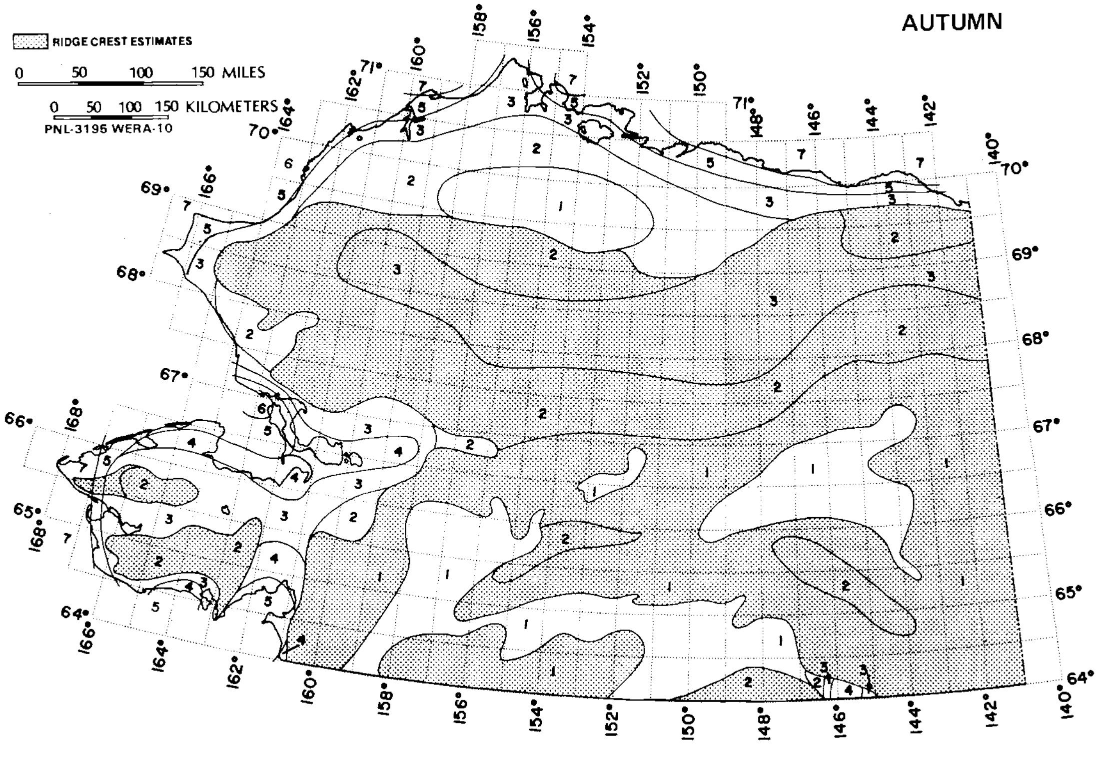


FIGURE 4.9 (Continued). Seasonal Average Wind Power in Northern Alaska (Spring, Autumn)

TABLE 4.2. Northern Alaska Stations with Graphs of the Wind Characteristics.

							Annual Average Wind Speed, m/s			Annual Average Wind Power, W/m²		
Station ID	Station Name	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Barrow	Wiley Post - Will Rogers Airport	71.3	156.78	9.4	04/55-12/64	11.9	5.6	5.4	6.8	213	198	394
Barter Island	Barter Island Airport	70.1	143.63	11.9	01/49-08/55	7.6	5.6	5.8	7.3	370	416	829
Bettles	Bettles CAA	66.9	153.5	203.0	05/51-12/64	8.2	2.9	3.0	3.8	37	40	80
Cape Lisburne	Cape Lisburne AFS	68.9	166.1	16.1	04/61-12/71	4.0	5.3	6.0	7.5	272	404	806
Fairbanks EIE	Eielson AFB	64.7	140.1	173.4	08/59-12/70	4.0	1.4	1.6	2.0	13	19	39
Fairbanks INT	Fairbanks International Airport	64.8	147.9	134.1	09/57-12/64	10.1	2.5	2.5	3.2	26	26	52
Flayman Island	Flayman Island Air Field	70.2	158.0	7.0	08/57-12/70	4.3	5.0	5.7	7.1	232	334	666
Fort Yukon	Fort Yukon CAA	66.6	145.3	129.5	01/52-09/63	7.6	3.7	3.8	4.8	69	78	155
Galena	Galena AFS	64.7	156.9	45.4	04/62-11/68	6.1	2.2	2.4	3.0	28	35	69
Indian Mountain	Indian Mountain AFS	66.0	153.7	288.3	04/61-12/70	4.0	2.6	2.9	3.7	56	83	166
Kotzebue	Ralph Wein Memorial Airport	65.9	163.0	6.1	01/45-12/64	9.4	5.8	5.8	7.3	309	317	631
Lonely Point	Lonely Point Air Field	70.9	152.3	9.0	07/37-11/75	4.3	4.5	5.0	6.3	171	246	491
Moses Point	Moses Point AAF	64.7	162.1	6.4	06/52-07/64	8.2	5.4	5.6	7.0	241	262	522
Nenana	Nenana AAF	66.6	149.1	110.9	07/53-12/64	8.5	2.7	2.8	3.5	38	41	81
Nome	Nome Airport	64.5	165.4	5.5	08/58-12/64	21.3	5.4	4.9	6.1	247	179	356
Oliktak	Oliktok Air Field	70.5	149.9	5.0	08/57-11/75	4.3	5.2	5.9	7.4	254	366	729
Point Lay	Point Lay Air Field	69.7	163.0	6.0	08/57-11/75	4.3	5.4	6.1	7.7	281	405	807
Tanana	Tanana FSS	65.2	152.1	73.2	07/48-12/64	10.1	2.5	2.5	3.2	42	42	84
Tin City	Tin City AFS	65.6	167.9	78.6	06/60-12/71	4.0	7.4	8.4	10.6	519	772	1538
Umiat	Umiat Airport	69.4	152.1	102.7	07/48-12/52	10.7	3.3	3.3	4.1	91	89	176
Wainwright	Wainwright Air Field	70.6	160.1	27.0	08/57-11/75	4.3	4.5	5.1	6.5	192	277	551

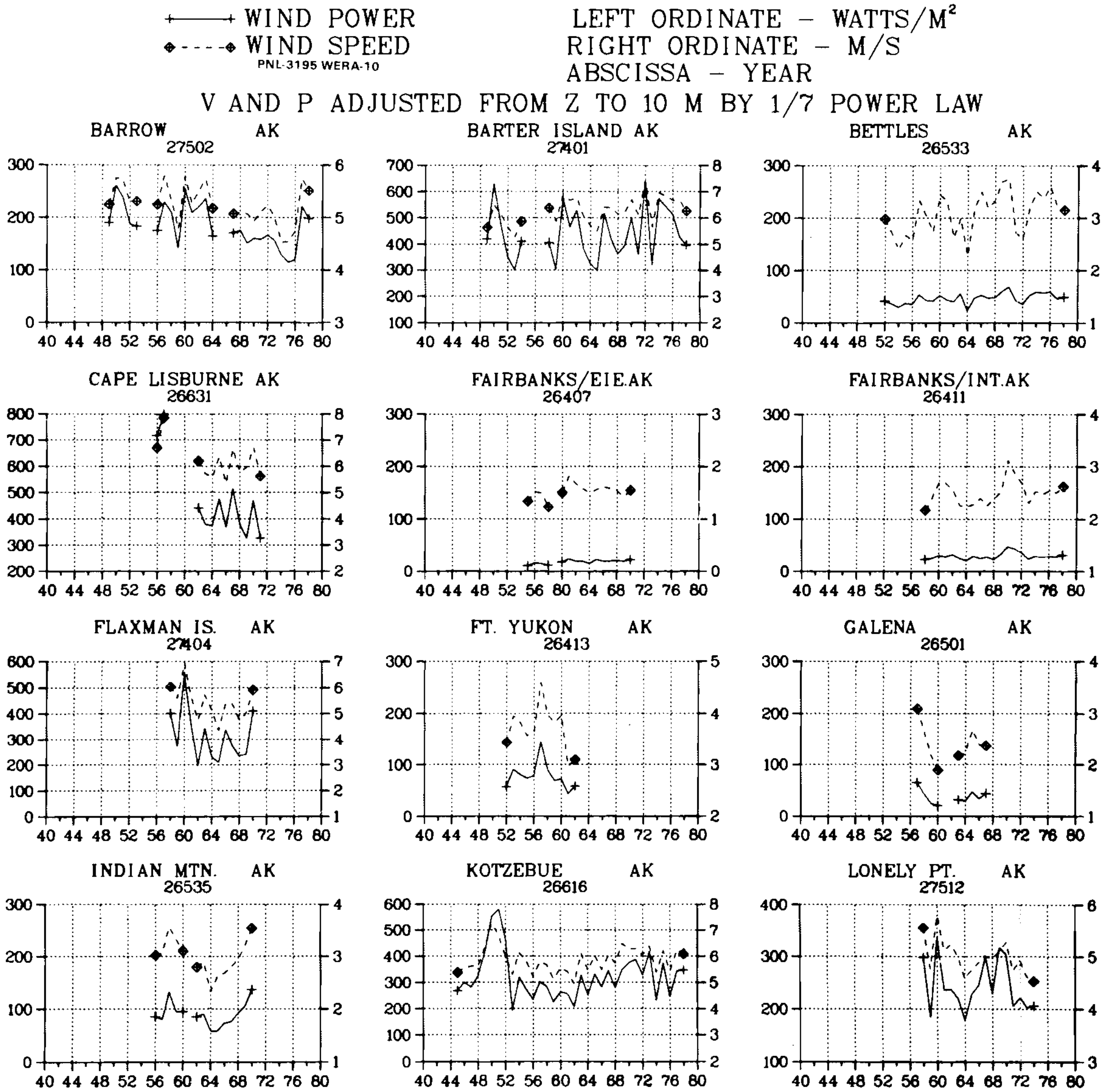


FIGURE 4.10. Interannual Wind Power and Speed for Northern Alaska.

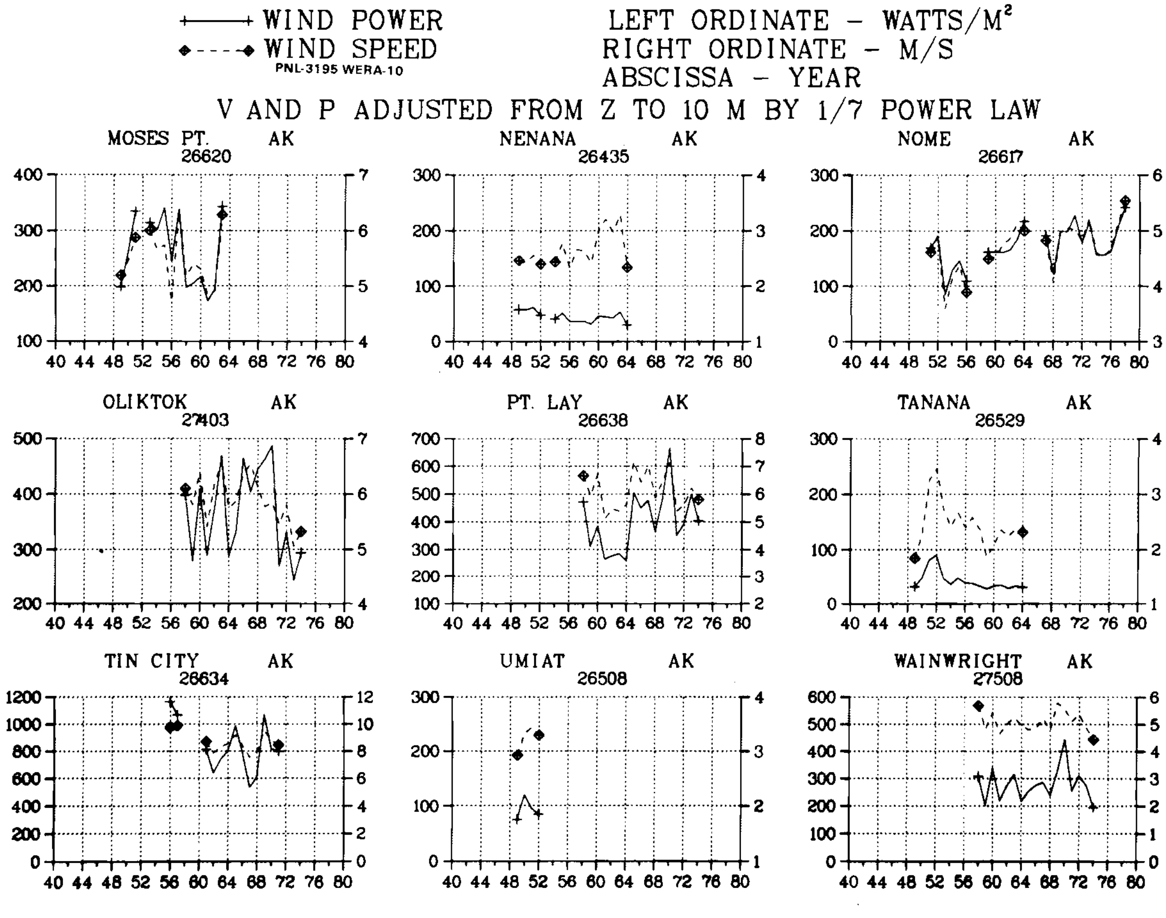


FIGURE 4.10 (Continued). Interannual Wind Power and Speed for Northern Alaska.

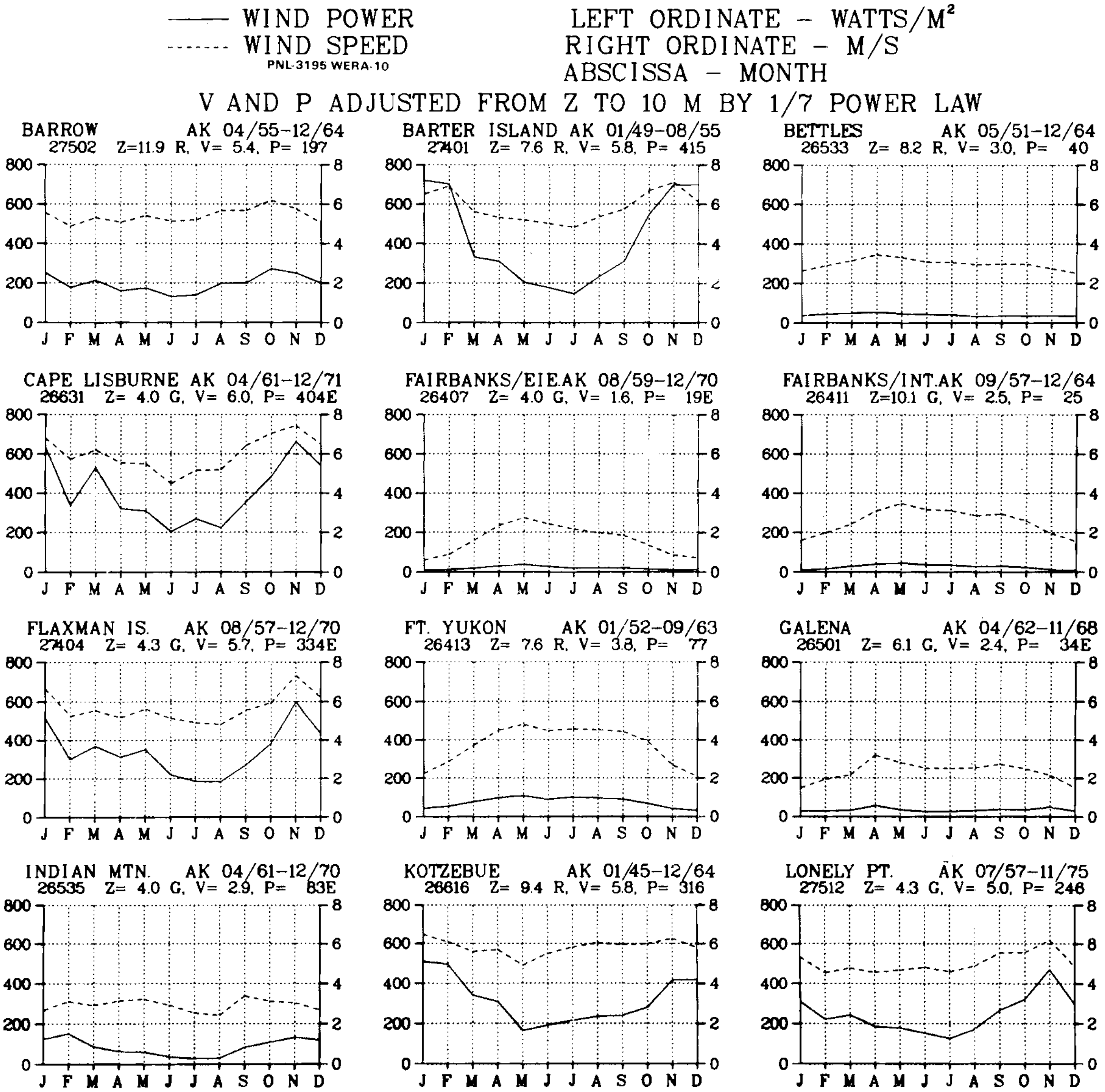


FIGURE 4.11. Monthly Average Wind Power and Speed for Northern Alaska.

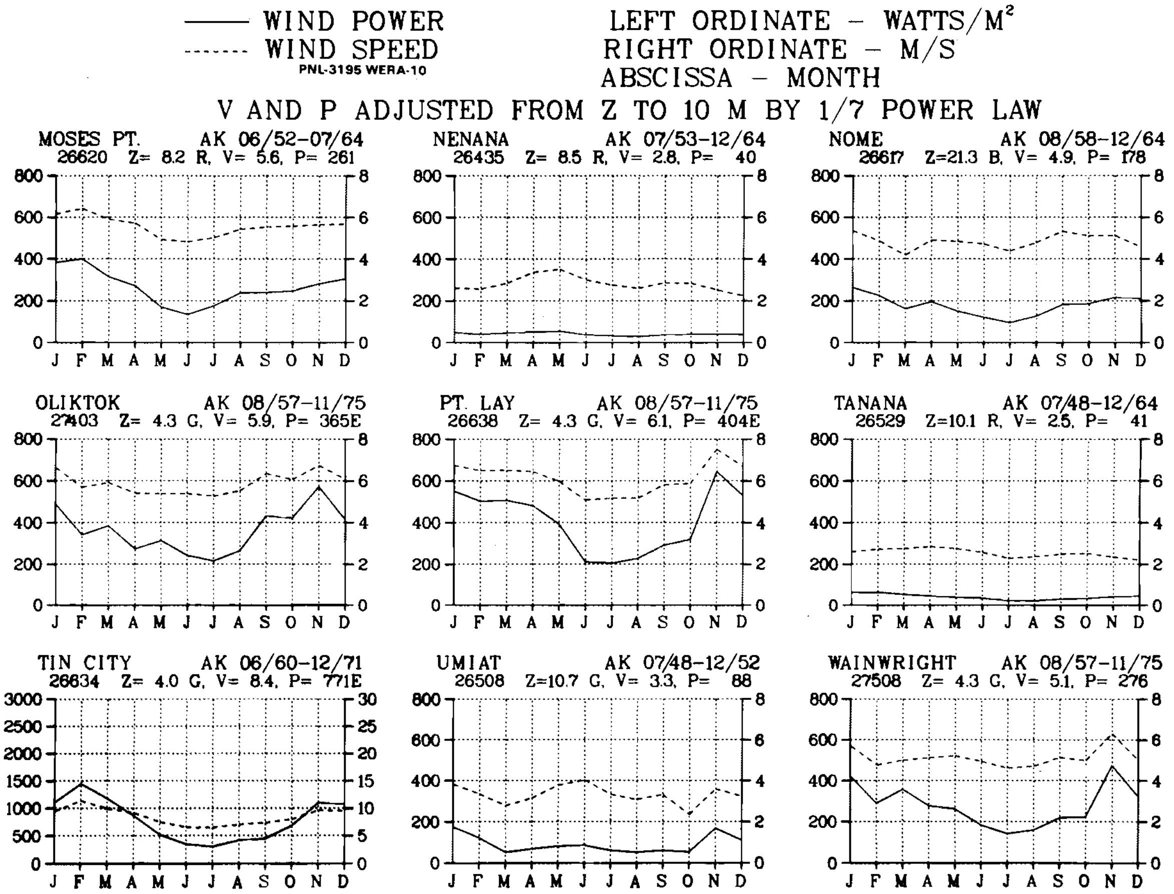


FIGURE 4.11 (Continued). Monthly Average Wind Power and Speed for Northern Alaska.

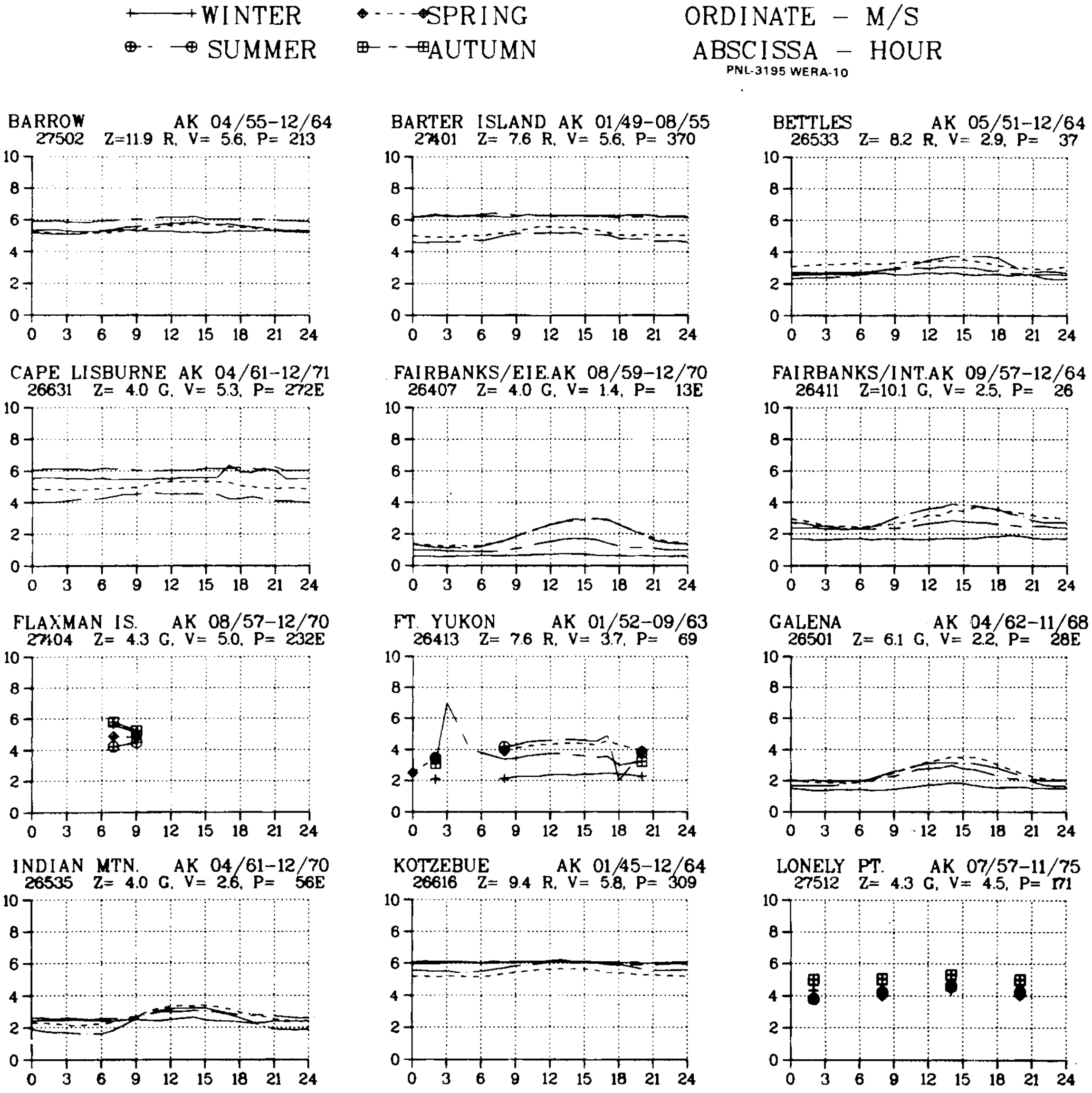


FIGURE 4.12. Diurnal Wind Speed by Season for Northern Alaska.

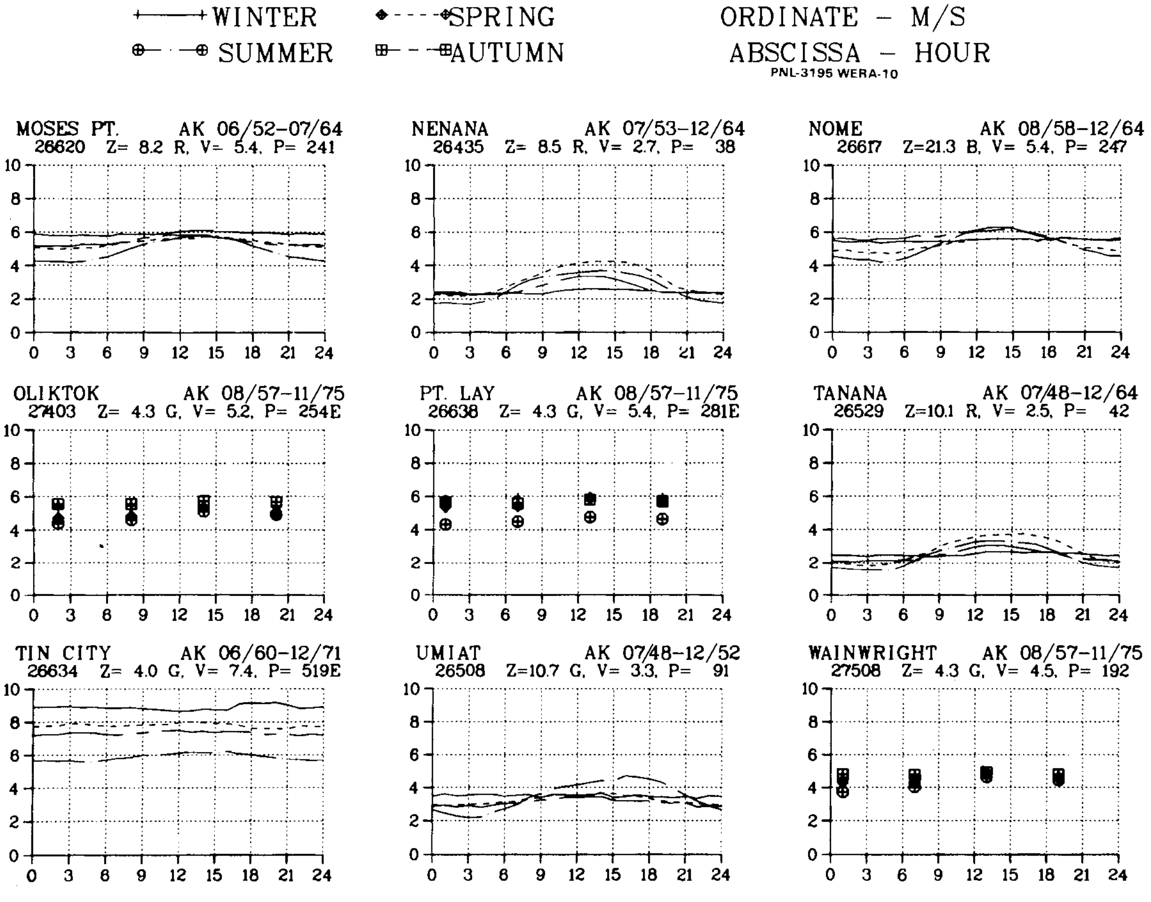


FIGURE 4.12 (Continued). Diurnal Wind Speed by Season for Northern Alaska.

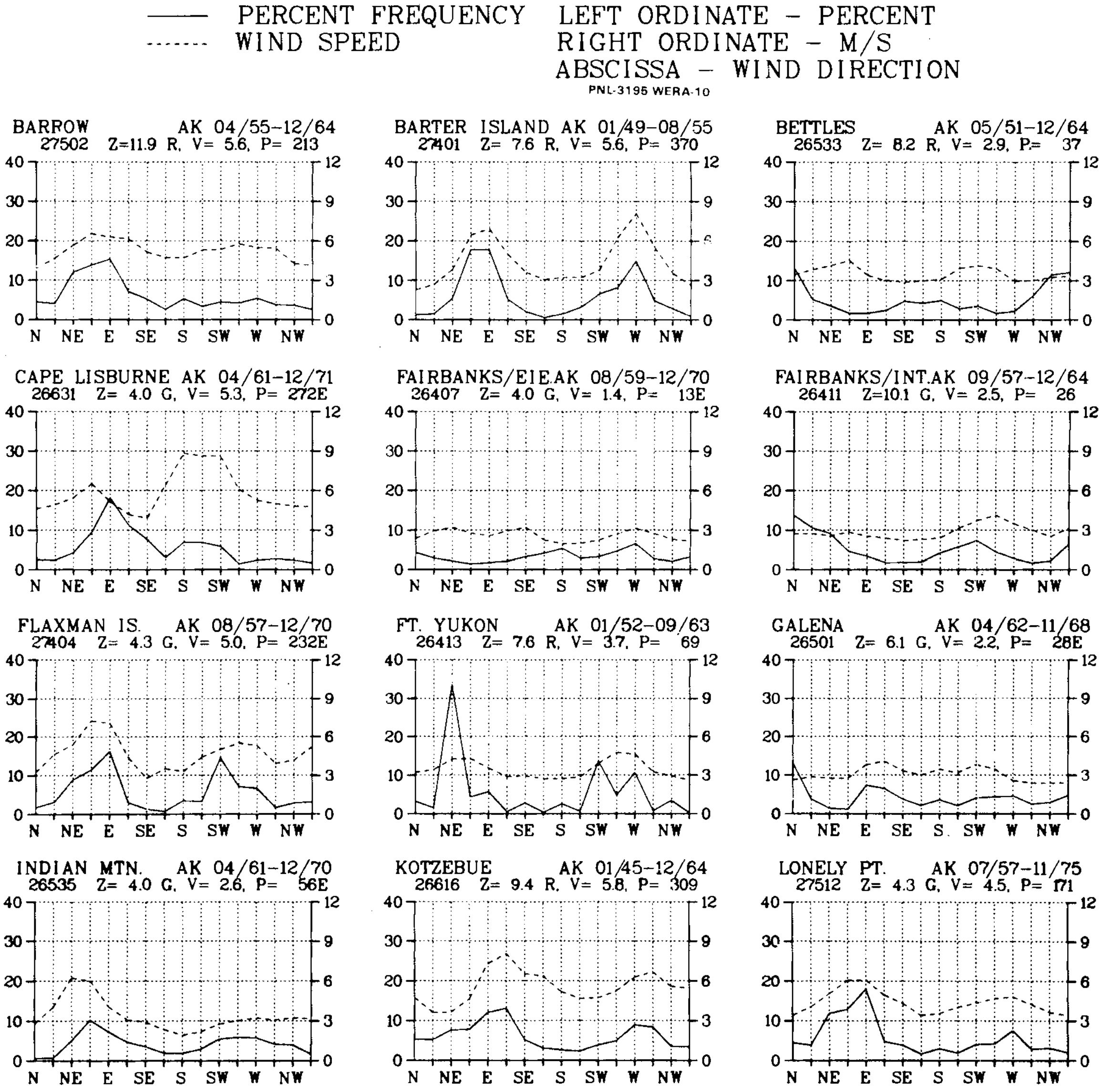


FIGURE 4.13. Directional Frequency and Average Wind Speed for Northern Alaska.

—— PERCENT FREQUENCY LEFT ORDINATE - PERCENT
------- WIND SPEED RIGHT ORDINATE - M/S
ABSCISSA - WIND DIRECTION

PNL-3195 WERA-10

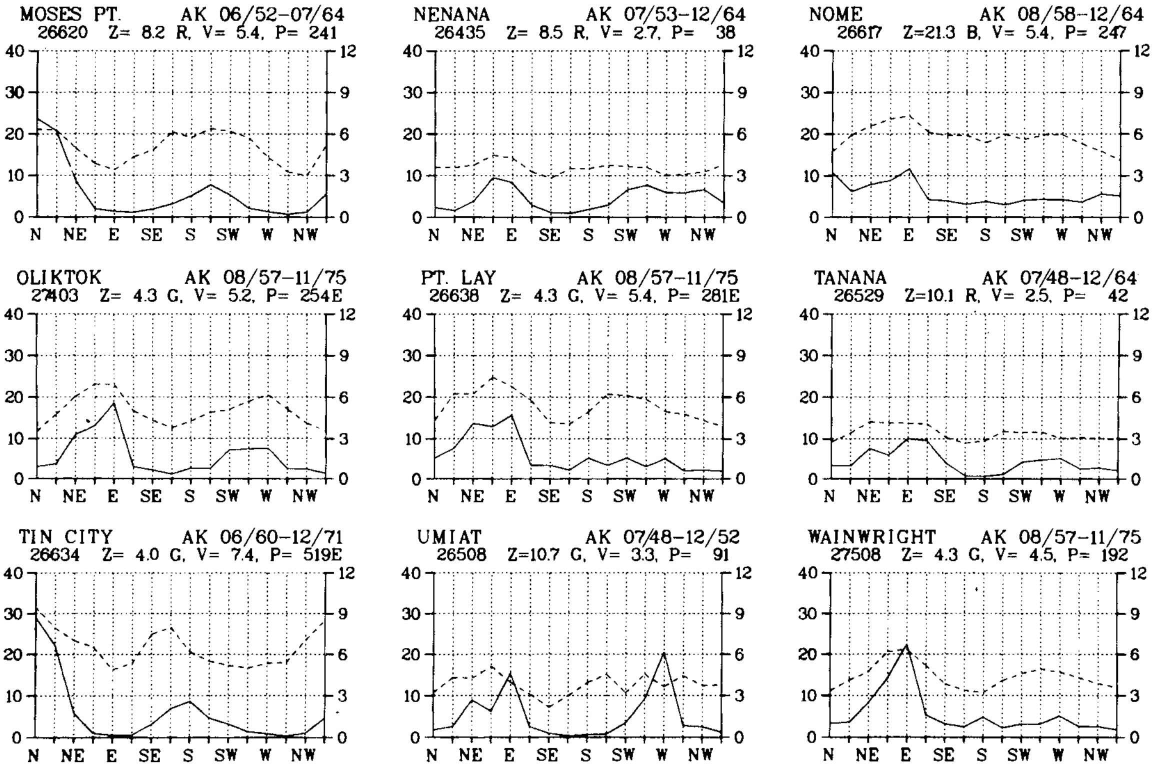


FIGURE 4.13 (Continued). Directional Frequency and Average Wind Speed for Northern Alaska.

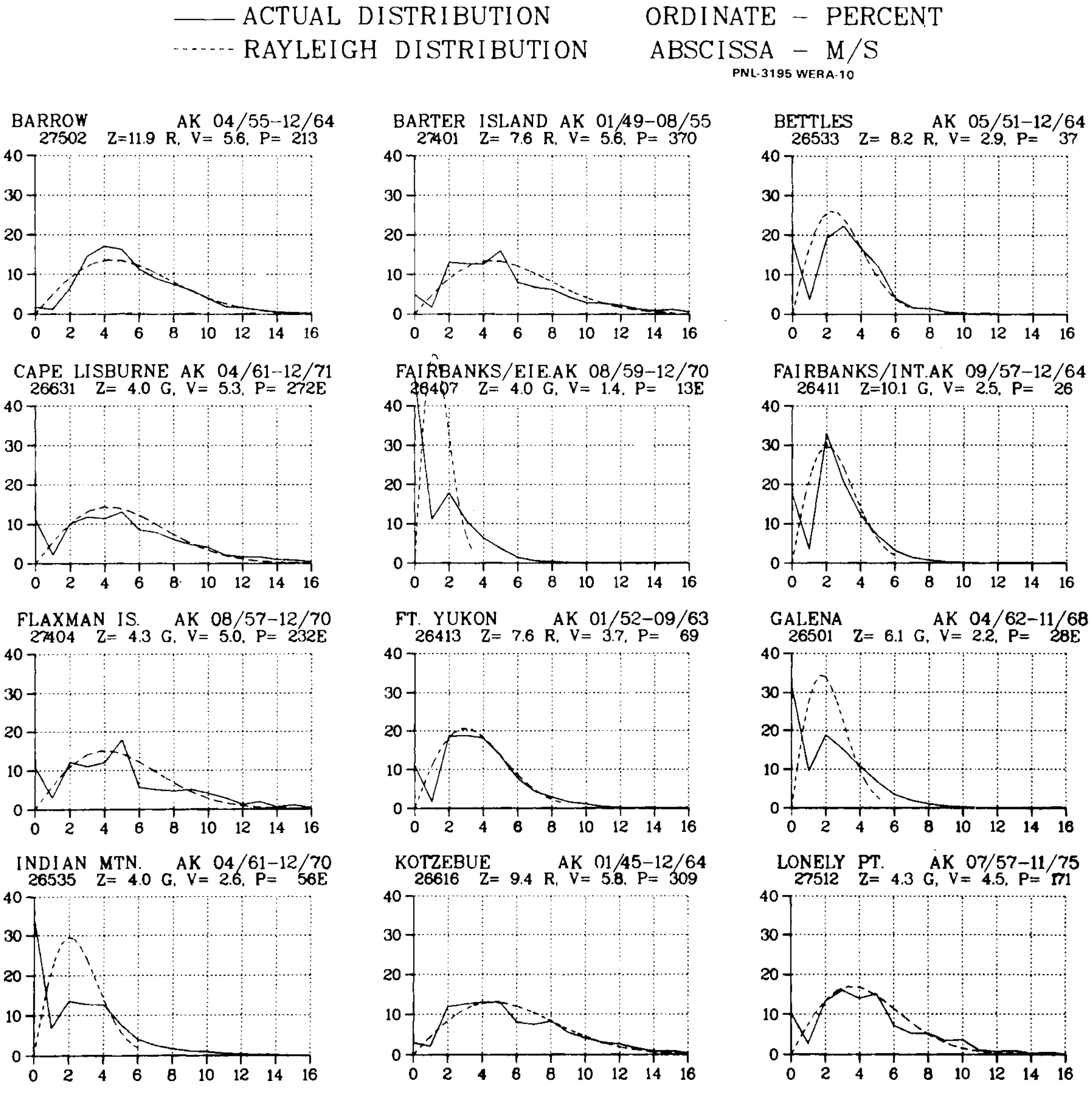


FIGURE 4.14. Annual Average Wind Speed Frequency for Northern Alaska.

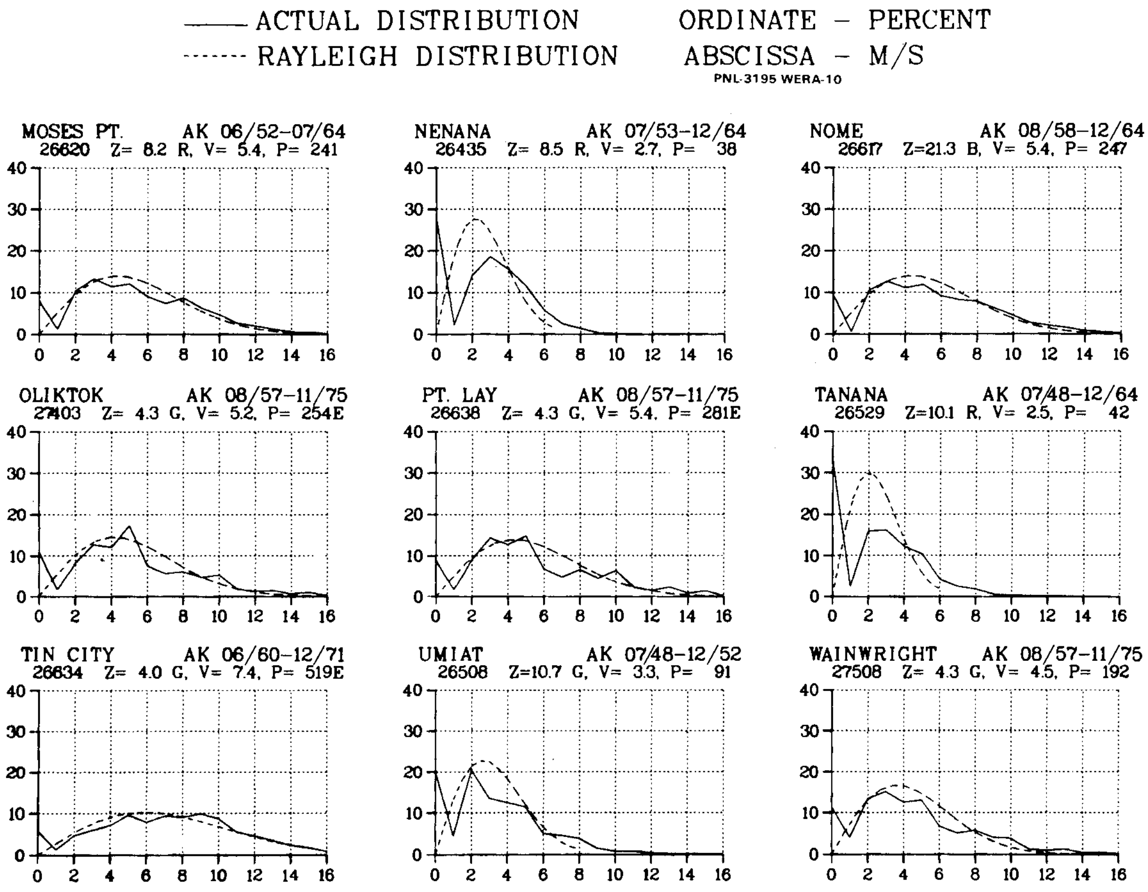


FIGURE 4.14 (Continued). Annual Average Wind Speed Frequency for Northern Alaska.

ORDINATE - PERCENT
ABSCISSA - M/S
PNL-3195 WERA-10

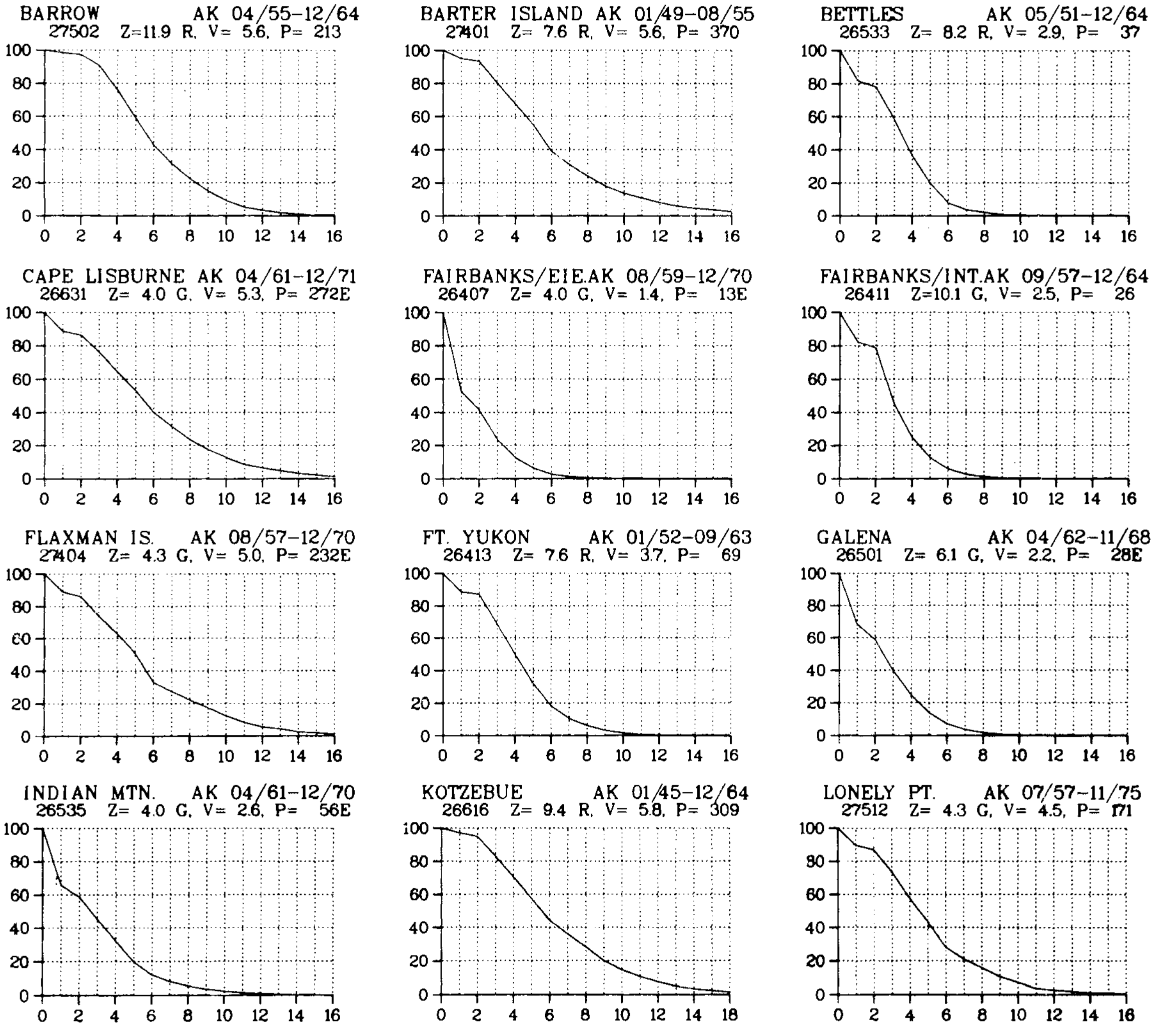


FIGURE 4.15. Annual Average Wind Speed Duration for Northern Alaska.

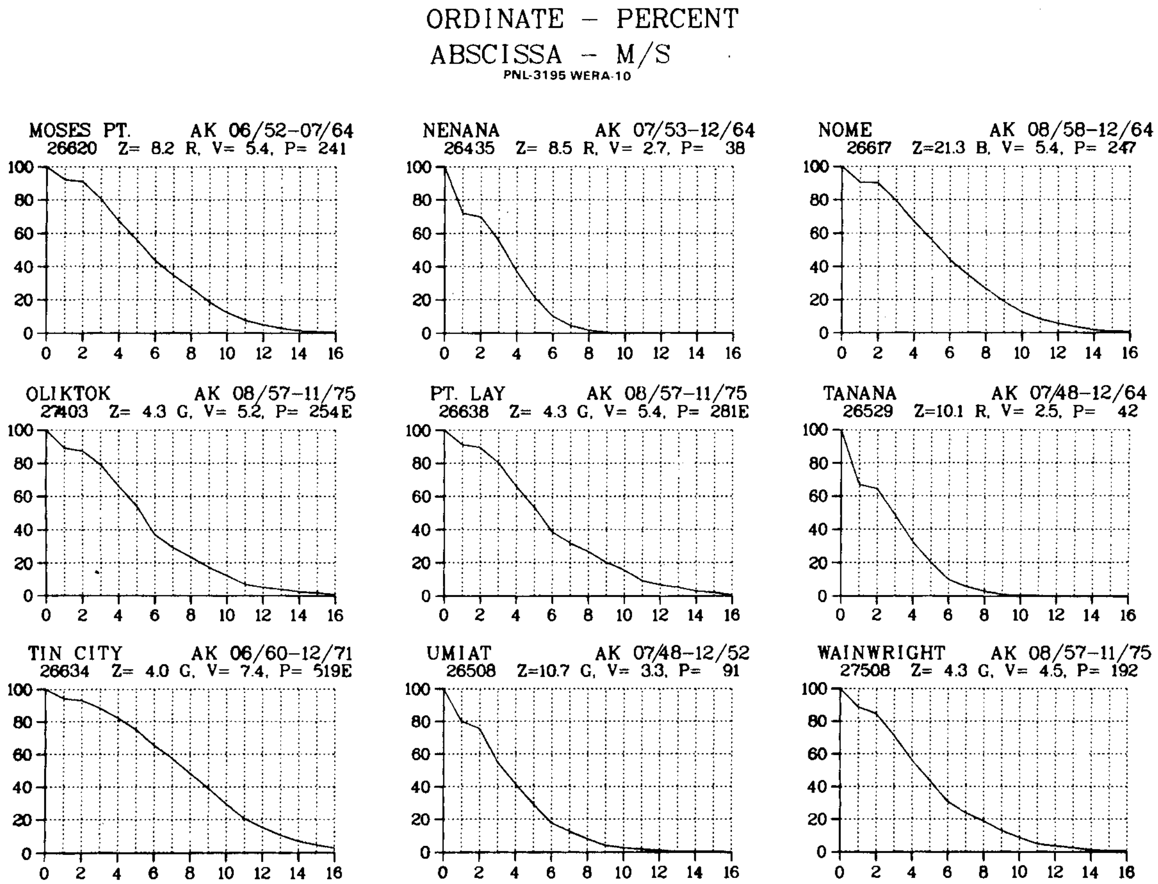


FIGURE 4.15 (Continued). Annual Average Wind Speed Duration for Northern Alaska.

ORDINATE – PERCENT
ABSCISSA – WATTS/M^2
PNL-3195 WERA-10

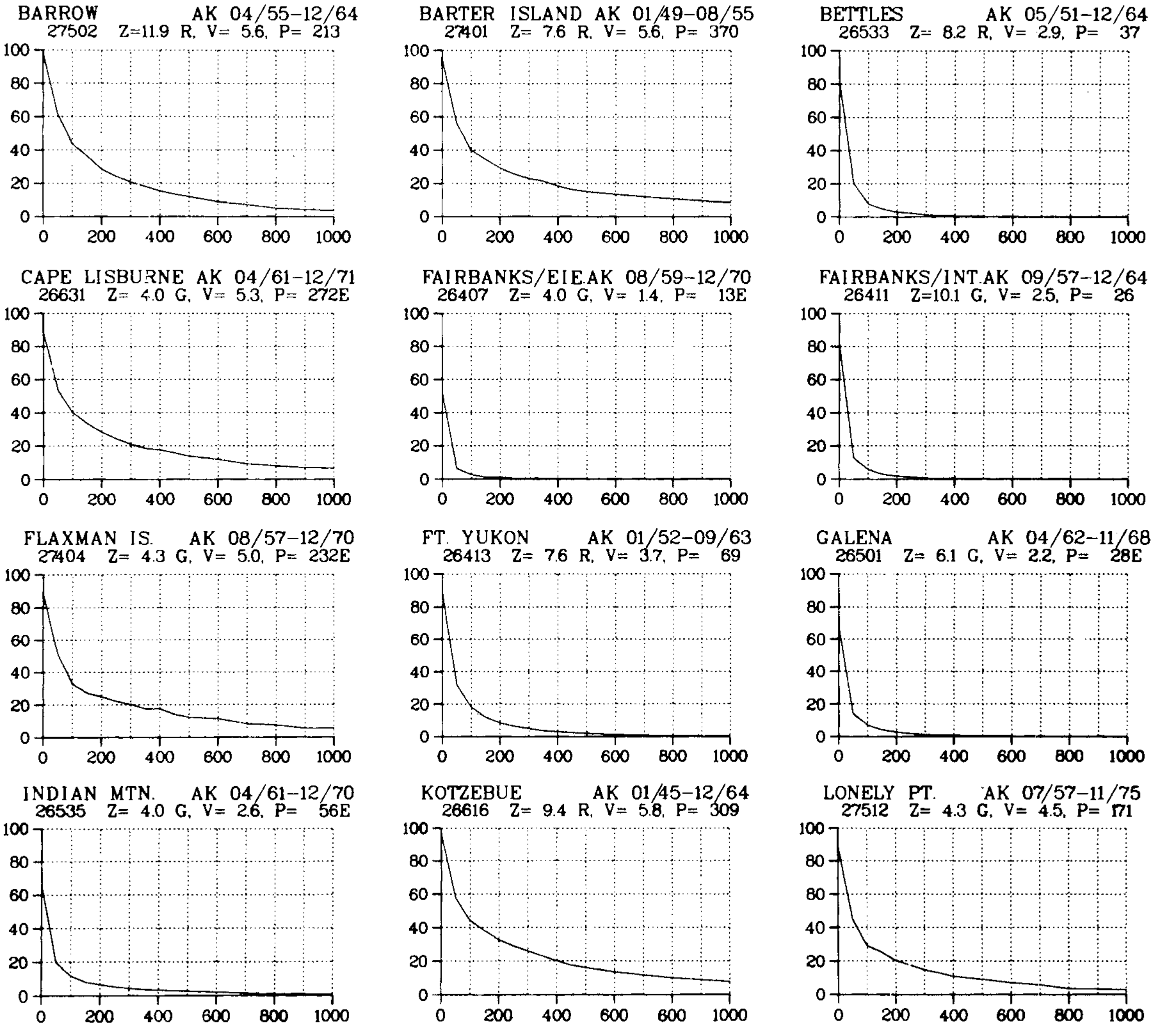


FIGURE 4.16. Annual Average Wind Power Duration for Northern Alaska.

ORDINATE - PERCENT
ABSCISSA - WATTS/M^2
PNL-3195 WERA-10

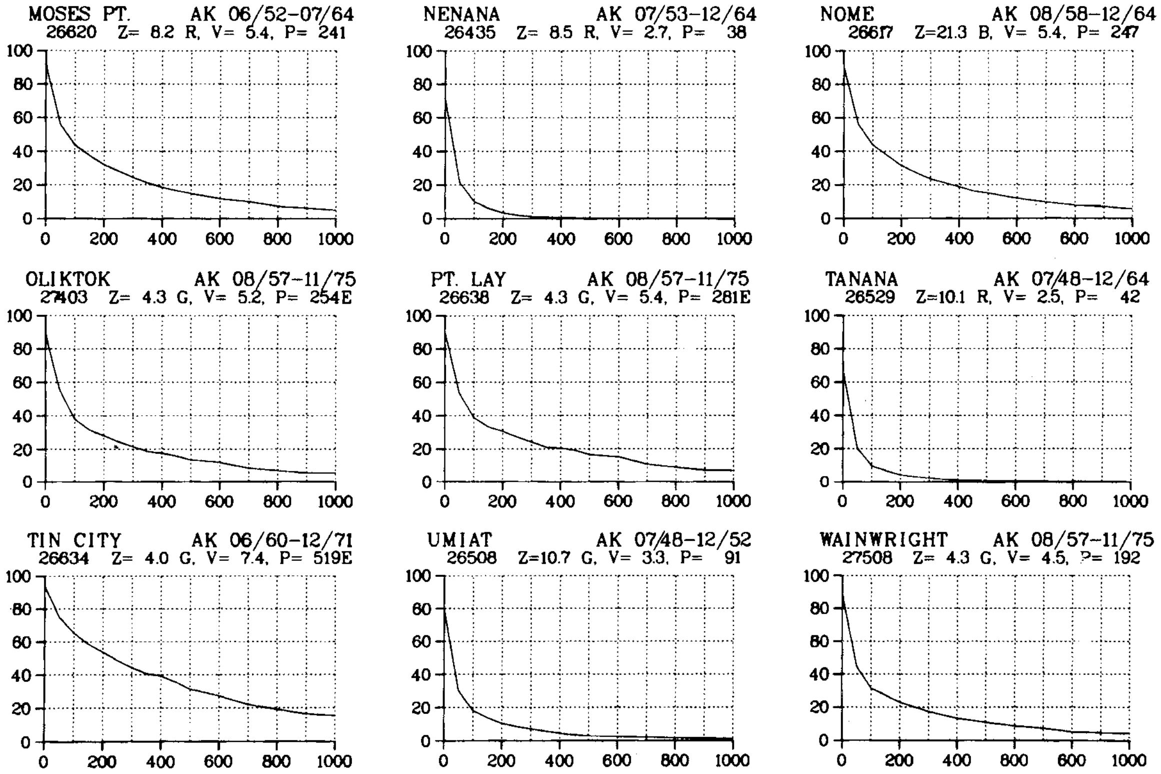


FIGURE 4.16 (Continued). Annual Average Wind Power Duration for Northern Alaska.

SOUTHCENTRAL ALASKA

CHAPTER 5: SOUTHCENTRAL ALASKA

The southcentral subregion had an estimated population of 265,745 in 1979. The major population centers of this subregion are the Matanuska-Susitna Borough, the Kenai Peninsula Borough, and the Municipality of Anchorage (formerly the Greater Anchorage Area Borough). With a population of 185,280, Anchorage is the largest population center in the state.

This subregion extends from 141°W on its east end to 176°06' in the Bering Sea on the west. Its northern boundary is 64°N and its southern boundary is 59°N and the Gulf of Alaska. The southcentral subregion covers an area of 574,980 km^2 (222,000 mi^2). Geographic and topographic features of southcentral Alaska are shown in Figures 5.1 and 5.2.

The subregion is characterized by rugged, mountainous terrain (Figure 5.3). Important exceptions are in the lowlands bordering Cook Inlet, the Kuskokwim River valley, the lower Susitna Valley, the Copper River plateau, and intermittent lowlands along the coast. The borders of this subregion encompass the southern portion of the Nulato Hills, the Kuskokwim Mountains, the Alaska Range (including the 6,194 m high Mt. McKinley, the tallest peak in North America), and the Talkeetna, Wrangell, Chugach, and Kenai mountain ranges.

The subregion experiences great tectonic activity. It is subject to frequent violent movements of the earth's crust that cause severe earthquakes, and it exhibits all the manifestations of the Pacific Rim's "Ring of Fire," including the following active volcanoes--Augustine, Iliamna, Redoubt, Spurr, and the Wrangells.

Great glaciers abound in the Alaska, Wrangell, Chugach, and Kenai mountain ranges. Meltwater from glaciers contributes huge quantities of water and silt to many of the large rivers in the southcentral subregion.

The subregion has three of the largest river systems in the state: the Kuskokwim, Susitna, and Copper. It also includes the lower third and delta region of the Yukon River, the longest river in Alaska. Their drainage basins account for more than half the total area of the subregion. Next in size is the Matanuska River with a drainage area of 5,672 km^2 (2,190 mi^2).

Lakes abound in this subregion. Iliamna Lake covers 2,590 km^2(2,190 mi^2) and is the largest in the state; others are just large enough for floatplanes to land and take off. Major lakes in the subregion are Tustumena, 303 km^2 (117 mi^2); Lake Clark, 285 km^2 (110 mi^2); Wood River/Tikchik Lakes area; Skilak Lake and Kenai Lake.

The coastal areas of this subregion vary from the fjords, inlets, and islands of Prince William Sound, the Kenai Peninsula, and Cook Inlet to the delta portions of the Yukon and Kuskokwim rivers.

Wind data stations in the southcentral subregion (identified in Figures 5.4 and 5.5) are primarily along the coast, major rivers, the railroad, and the few highways. Fire weather data (Figure 5.5) from the forested foothill and the lowland areas were used for calculations where other reliable data were absent.

5.1 ANNUAL AVERAGE WIND POWER IN SOUTHCENTRAL ALASKA

The annual average wind power density in southcentral Alaska is shown in Figure 5.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as 50 to 100% from the assessment value. (See Wegley et al. 1980 for information on terrain features that may increase or reduce wind energy.) In forested or wooded areas the assessment values are representative of large clearings with good exposure to the prevailing strong winds, such as airports. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power (Figure 5.6) is class 4 or higher all along the Bering Sea coast, at islands in the Bering Sea, in wind corridors in lower Cook Inlet and Isabel Pass, and at mountain summits and ridge crests of the Alaska Range and the Wrangell Mountains. St. Lawrence Island shows class 7 power at the east and west ends and class 6 along the north shore; however, St. Matthew Island, Nunivak Island, and the Bering Sea coast all show class 7 wind powers. Class 4 or higher wind power extends eastward in the Yukon-Kuskokwim delta for more than 150 km (100 mi), as shown by Bethel data. These high wind powers reflect the frequent storms that occur in the Bering Sea year round.

Off the Gulf of Alaska coast and Middleton Island class 7 wind power occurs. However, most coastal data are in sheltered locations and thus reflect annual power of class 2 or 3. Exposed locations should be class 4 or higher.

There are wind corridors with class 4 and higher power in the lower Cook Inlet from Kamishak Bay to the Barren Islands. Bruin Bay shows class 7 for all seasons of the year. Isabel Pass along the Delta River through the Alaska Range shows annual wind power of class 4 to 7. Other wind corridors with no objective data have a significant wind resource. A few examples of these are: Portage Pass, which connects the Turnagain Arm of Cook Inlet with Prince William Sound; the lower Copper River; Windy Pass near Mt. McKinley National Park; and several other passes through the Alaska Range.

Mountain summits and ridge crests of the Alaska Range east of 150°W reach wind power class 6 in the vicinity of Mt. McKinley; class 4 or higher occurs north of 60°N along this range. In the Wrangell Mountains along the Canadian border, class 4 wind power also occurs. However, other mountain summits and ridge crests are generally estimated to have class 3 power.

Annual wind power of class 1 prevails in interior regions along the Yukon, Kuskokwim, and Tanana rivers; in the source region of the Copper River, in the relatively low relief area between the Talkeetna, Chugach, Wrangell, and Alaska mountain ranges; and in the sheltered areas of Cook Inlet and the Susitna River valley.

5.1.1 Certainty Rating of the Wind Resource

Certainty ratings in southcentral Alaska vary from 1 to 4 (Figure 5.7). There are only two areas with class 4 or higher wind power and a certainty rating of 4--southern St. Matthew Island and Middleton Island, both with an annual wind power of class 7. Elsewhere in the subregion, certainty ratings of 3 or less predominate.

There are several areas where data are adequate but the certainty rating is reduced because of terrain complexity. These are the vicinities of Cook Inlet, St. Lawrence Island, the Bering Sea coast, and the inner mountain region around Gulkana. Most of the subregion is of certainty rating 2 because the powers are based on mountain summit and ridge crest estimates in the Nulato Hills, the Alaska Range, and the Kuskokwim, Talkeetna, Wrangell, Chugach, and Kenai mountains.

Stations along the Gulf of Alaska coast and in the Prince William Sound area that represent exposed locations are North Dutch Island, Cape Hinchinbrook, and Middleton Island. The certainty rating at all of these stations except Middleton Island is reduced to 2 or 3 because of the complexity of the terrain in the vicinity. Other Gulf of Alaska coast stations, such as Valdez, Cordova, and Yakataga, are not favorably exposed to the prevailing winds.

5.1.2 Areal Distribution of the Wind Resource

The areal distribution of the wind power in southcentral Alaska is illustrated in Figure 5.8. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds some threshold value. Although class 4 or higher is predicted in 18% of the grid cells, only about 10% of the land area is estimated to experience these power densities (see Table 5.1). High wind energy resource areas are along the Bering Sea coast and its islands, lower Cook Inlet, and the coast of the Gulf of Alaska from Prince William Sound eastward, mountain summits and ridge crests of the Alaska Range west of Cook Inlet, and the Wrangell Mountains. The most exploitable high wind resource areas are the Bering Sea coast, the Yukon-Kuskokwim Delta, the wind corridor from Bristol Bay to lower Cook Inlet, Isabel Pass south of Big Delta, and Portage Pass at the east end of the Turnagain Arm. High wind resource areas along the Gulf of Alaska coast are estimated to be in a narrow strip along the coast and the Copper River delta. The remainder of southcentral Alaska is estimated to be of class 1 or 2.

5.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 5.9. Generally, winter is the season of maximum wind power along the coastlines, the mountain ranges, and in passes where pressure differences in winter cause strong winds in the passes. Maximum wind power along major inland rivers and the upper Cook Inlet coasts generally occurs in spring.

5.2.1 Winter

Class 7 wind power occurs all along the Bering coast in winter except along the south shore of Norton Sound and Kvichak Bay at the northeast end of Bristol Bay. Class 4 or higher wind power is estimated to occur over the western 150 km of the Yukon-Kuskokwim Delta, as shown by Bethel data that indicate class 5 wind power. Along the Gulf of Alaska coast, class 5 or 6 wind power generally occurs with class 7 over the open waters and in the Middleton Island area.

At mountain summits and ridge crests in the Alaska Range, class 7 wind power is estimated in the vicinity of Mt. McKinley and west of the Susitna River valley. In the Wrangell Mountains along the Canadian border class 7 is estimated at the highest peaks, and class 4 or higher is estimated for most of the Chugach Range and the Talkeetna Mountains.

Wind corridors in lower Cook Inlet from Kamishak Bay to the Barren Islands and in Isabel have class 7 power for part of their lengths, as shown by Bruin Bay and Big Delta data. Other passes with high wind powers that are primarily a winter phenomenon resulting from strong pressure gradients are Portage Pass, which connects the Turnagain Arm of Cook Inlet to Prince William Sound, with class 5 to 7 wind power; Isabel Pass, with class 6 and 7, Windy Pass, with class 5 and 6; Chickaloon Pass, along the Matanuska River, with class 6 power as shown by Palmer and Sheep Mountain; and the lower Copper River, estimated to experience class 6 wind power.

Class 1 wind power occurs along major rivers, such as the Yukon, Kuskokwim, Tanana, Susitna, and the source region of the Copper River where extremely stable air at the surface may persist for weeks at a time with intense temperature inversions.

5.2.2 Spring

Class 4 or higher wind power prevails all along the Bering Sea coast and at islands in the Bering Sea in the spring. Class 7 only occurs at the most exposed areas of the western coast of St. Lawrence Island at Gambell and at Cape Romanzof and Platinum on the mainland coast. The remainder of the Bering Sea islands are of class 6 and the remainder of the coast is class 6, decreasing to class 4 at the east end of Bristol Bay and along the shore of Norton Sound. Class 7 wind power still occurs in the wind corridor from Kamishak Bay to the Barren Islands in lower Cook Inlet. Along the Gulf of Alaska coast class 4 and 5 wind power is the rule; power generally increases to class 6 at Middleton Island and class 7 over the more open waters of the Gulf of Alaska.

Mountain summits and ridge crests with class 4 or higher wind power are restricted to the Alaska Range in the vicinity of Mt. McKinley and the Wrangell Mountains along the Canadian border. The remainder of the mountain summits and ridge crests are primarily class 2, with a few estimated at class 3.

Wind corridors at Isabel Pass have of class 3 or 4 power, and Chickaloon has class 3. Other wind corridors shown in the winter season are not significant in spring because of the seasonal decrease in pressure gradients. Class 1 wind power covers most of the interior west of the Alaska Range, the major river valleys, the Cook Inlet area, and the low relief area between the Talkeetna, Wrangell, Chugach, and Alaska mountains.

5.2.3 Summer

In summer, locations with class 4 or higher wind power are St. Lawrence and Nunivak Islands in the Bering Sea and the wind corridor from Kamishak Bay to the Barren Islands. This corridor shows class 7 wind power at the west end of Kamishak Bay, which diminishes rapidly to class 3 in both directions. The Bering Sea coast is predominantly class 3, and the Gulf of Alaska coast is class 2 as far out as Middleton Island.

Mountain summits and ridge crests have up to class 4 power in the vicinity of Mt. McKinley, and class 3 in the Wrangell Mountains along the Canadian border and portions of the Alaska Range southwest of Mt. McKinley. The remainder of mountains summits are of class 2 or 1.

Class 1 prevails over the rest of south-central Alaska in summer.

5.2.4 Autumn

In autumn, class 4 or higher wind power occurs along the Bering Sea coast and at islands in the Bering Sea. Class 7 occurs along the Bering coast from Cape Romanzof to Kuskokwim Bay and at St. Matthew, St. Lawrence, and Nunivak Islands. Class 4 or higher occurs over the western Yukon-Kuskokwim Delta up to 160 km from the coast. The Norton Sound coast has class 4 or 5 power, as does the north shore of Bristol Bay.

The wind corridor from Iliamna Lake through the lower Cook Inlet to the Barren Islands has class 7 power. Other wind corridors show wind powers as follows: Isabel Pass, class 5 and 4; Chickaloon Pass, class 2 and 3; Portage Pass, class 4 and 3; and the lower Copper River corridor, class 3.

Mountain summits and ridge crests in the Alaska Range and the Wrangells near the Canadian border reach class 6. Class 3 wind power occurs in the Chugach Range north and east of Prince William Sound. Elsewhere in the Talkeetna, Kenai, and Kuskokwim mountains, class 2 power is the rule.

Class 1 power prevails over the remainder of the subregion west of the Alaska Range; in the Susitna River valley and vicinity of Cook Inlet; and in the inner mountain region at the headwaters of the Copper, Delta, Susitna, and Matanuska rivers.

5.3 FEATURES OF SELECTED STATIONS

Graphs of wind characteristics are shown for 23 stations in southcentral Alaska. Nine of these are along the coast and 14 are inland. The station characteristics are summarized in Table 5.2.

Northeast Cape is located on the extreme northeastern coast of St. Lawrence Island. It is well exposed to the open sea to the north, east, and south with the terrain to the west gradually rising to 300 to 450 m elevation about 8 km west of the station. During the six-year summary used in this analysis there was an average of 22 observations made per day.

Unalakleet is at the east end of Norton Sound about 100 m from the shoreline and 400 m north northwest of the mouth of the Unalakleet River. The country in the immediate vicinity is flat beach and tideland. Low, rolling hills rise to 200 to 300 m about 3 km northeast of the station and extend from north-northwest to east. Mountains 800 to 1,100 m high and 16 to 64 km distant extend from southeast to south. The Unalakleet River valley extends inland in an easterly direction and forms a low pass into the Yukon River basin. Strong easterly winds are common down this valley during the winter months. During the seven-year summary used in this analysis there were 24 observations per day.

Cape Romanzof on the Bering coast is surrounded on three sides by hills up to 700 m within a few kilometers of the station. It is exposed to winds from the southwest toward Kokechik Bay. Prevailing winds are along the direction of the valley, either southwest or northeast. During the seven-year period of record used in the analysis, there was an average of 22 observations per day.

There are three stations along the Kuskokwim River: Bethel, Aniak, and McGrath.

Bethel is about 80 km from the coast on the Kuskokwim River. Surrounding terrain is flat tundra except for the Kilbuck Mountains about 65 km southeast of the station. Bethel is very representative of the Yukon-Kuskokwim delta area. There was an average of eight observations per day coded during the 16-year summary used in the analysis.

Aniak is located at the confluence of the Aniak and Kuskokwim Rivers, where the wind direction is from east to west. The surrounding terrain is generally level to the south with low brush vegetation. To the north there are rolling hills with elevations over 300 m within 16 km of the station. Aniak is typical of a sheltered valley wind regime. There were 24 observations per day during the 11-year summary used in the analysis.

McGrath is located in a relatively flat drainage basin in the upper portion of the Kuskokwim River. Elevations in the Kuskokwim Mountains from northeast to southwest of the station are more than 500 m within 8 km of the station and 1,000 to 1,300 m within 30 km. McGrath had 24 observations per day during the 16-year summary used in the analysis.

There are four stations in the western slopes of the Alaska Range: Iliamna, Farewell, Lake Minchumina, and Sparrevohn.

Iliamna is located near the north shore of Iliamna Lake along the Newhalen River, which connects Lake Clark to Iliamna Lake. The area immediately surrounding the station is relatively level and covered with muskeg, and slopes gently southward to the lake. To the northeast and northwest on both sides of the Newhalen River there are peaks over 600 m within 15 km of the station. This station is exposed to winds from Cook Inlet across the lake from the east-southeast and also from the north from the direction of Lake Clark. During the 16-year summary used in this analysis there were 24 observations per day.

Farewell is located on the south fork of the Kuskokwim River, a few miles from the foothills of the Alaska Range and about 45 km from the entrance to Rainy Pass. At 500 m elevation, it is one of the few stations higher than 300 m in Alaska. The surrounding terrain is generally level or rolling tundra. Frequent gusty southeast winds from the direction of Rainy Pass occur in winter. During the 16-year summary used in this analysis, there was an average of 24 observations per day.

Lake Minchumina is located on the north shore of the lake in a broad valley between the Kuskokwim Mountains and the Alaska Range. It is sheltered from all except the east-northeast and south-southwest. To the north of the station, thickly wooded slopes begin about 80 m from the station and extend into the Kuskokwim Mountains, providing a very effective block to northerly winds. During the 16-year summary used in the analysis there were 24 observations per day.

Sparrevohn is in a very sheltered location with ridges to the north, east, and southeast rising to about 600 m above the station within 10 km of the station. During the 10-year summary used in the analysis, there was an average of 21 observations per day.

The eastern shore of Cook Inlet is represented by Homer, Kenai, and two locations in the Anchorage area.

Homer, located on the shore of Kachemak Bay, is sheltered from all except southwest and northeast winds. The terrain in the immediate vicinity is flat or gently rolling with alternating wooded and open, swampy patches. A bluff 300 to 500 m high and oriented east-west rises sharply about 3 km north of the station. The Kenai Mountains on the south shore of Kachemak Bay protect the station from the southwest to east direction. During the 16-year summary used in the analysis, there were 24 observations per day.

Kenai is located about 3 km from the shore of Cook Inlet. Terrain is flat, there are swampy areas, and it is covered with a moderate growth of trees and brush. During the 16-year summary used in the analysis, there were 24 observations per day.

Anchorage International Airport is on a point of land that separates the Knik Arm from the Turnagain Arm of Cook Inlet. The terrain in the immediate vicinity is gently rolling. To the south, west, and north are the open waters of Cook Inlet. Peaks of the Chugach Mountains rise to more than 1,600 m within 30 km to the southeast through northeast. Three-hour synoptic observations were used in the 17-year summary in this analysis.

Elmendorf AFB is located on a 65-m high bluff on the Knik Arm of Cook Inlet. It is sheltered somewhat by a 200-m high glacial moraine that lies parallel to the runway and is oriented east-northeast to west- southwest less than one kilometer to the north. The mountains of the Chugach Range with elevations higher than 600 m are 30 km to the southeast through northeast. During the 10-year period of the summary used in this analysis, there were 24 observations per day.

The Susitna River valley between the Alaska Range and the Talkeetna Mountains is well represented by Skwentna, Summit, and Talkeetna.

Skwentna is located in a broad valley at the confluence of the Skwentna and Yentna Rivers in the eastern foothills of the Alaska Range. The immediate area around the station is very flat swampy ground with numerous ponds and small lakes. There are dense patches of birch and spruce trees 7 to 10 m high. The area is open to the east, but mountains and hills are nearby in other directions. During the six-year summary used in the analysis there were 24 observations per day.

Summit is located on a plateau that lies in a northeast-southwest direction and averages about 15 km in width. Mountains are 6 km away to the north and south and 15 km away to east and west. Much of the immediate vicinity is swampy and covered with brush and a few small trees. During the eight-year summary used in the analysis, there were 24 observations per day.

Talkeetna is located on the Susitna River near the confluence with the Chulitna River. The area in the vicinity is slightly rolling, with considerable swampland and a moderate growth of brush and trees on the higher elevations. The mountains of the Alaska Range are about 100 km to the west and north and the Talkeetna Mountains are within 20 km to the east. During the period of the 16-year summary used in the analysis, there were 24 observations per day.

The Tanana River valley is represented by Big Delta and Northway.

Big Delta is located on the Delta River about 15 km southeast of its confluence with the Tanana River. This station is affected by flow through Isabel Pass, one of the few passes through the Alaska Range. In the immediate vicinity the terrain is gently rolling for 15 to 20 km in all directions. However, the mountains of the Alaska Range reach altitudes to near 3,000 m within 50 km to the southwest to southeast. During the 16-year summary used in this analysis, there were 24 observations per day.

Northway is located on the Nabesna River 8 km from its confluence with the Tanana River. The terrain in the vicinity is gently rolling, with numerous lakes and swamps and moderate growth of trees on the higher ground. There is a range of hills across the Tanana River oriented southeast to northwest up to 1,000 m elevation within 15 km of the station. The mountains of the Alaska Range are within 30 km to the southwest of the station. During the seven-year period of the summary used in the analysis, there were 24 observations per day.

Gulkana is located in a broad valley about 15 km wide, 3 km from the Copper River. The terrain is nearly level in the vicinity, sloping slightly toward the Copper River to the east. The area is heavily wooded with spruce and alder. The Wrangell Mountains are to the east and south of the station about 30 km and the Alaska Range is to northeast and north about 40 km. Toward the west and northwest there are no obstructions for 80 km. During the 16-year period of the summary used in this analysis, there were 24 observations per day.

The Gulf of Alaska coast is represented by Cordova and Yakataga.

Cordova is located in a sheltered area of the gulf coast 20 km east of the town of Cordova and 15 km west of the Copper River delta. There are mountains up to 1,000 m within 15 km of the station and the Chugach Mountains rise to more than 2,200 m within 40 km from northeast to northwest of the station. The station's immediate vicinity is gently rolling and heavily wooded. During the 16-year period of the summary used in the analysis, there were 24 observation per day.

Yakataga is located on a narrow strip of relatively level land bounded on the south by the Gulf of Alaska near the mouth of the Yakataga River. To the north the Chugach Mountains rise to more than 1,000 m within 8 km. The immediate vicinity has been cleared of a dense growth of timber to allow for moderate exposure. There were 24 observations per day during the nine-year summary used in the analysis.

Middleton Island lies in the Gulf of Alaska about 120 km south of Cordova. The station is 400 m from the island's west edge, 520 m from its east edge and 1,300 m from its northern tip. The island is about 8 km long and about 1.5 km at the widest part. It has no trees and is covered with a dense growth of heavy grass. There are no obstructions. During the eight-year period of the summary used in the analysis, there were 24 observations per day.

5.3.1 Interannual Wind Power and Speed

The three locations exposed to the open Bering Sea (Cape Romanzof, Northeast Cape, and Unalakleet) are highly variable from one year to another (Figure 5.10). Northeast Cape and Unalakleet varied by a factor of more than 2 and Cape Romanzof by 1.5. Interannual variations coincide at these three locations. Along the Kuskokwim River, Bethel showed wind power values of class 2 or 3 from 1948 to 1957, but varied between class 4 and 6 wind power for the remainder of its period of record. In 1958 the anemometer was moved 8 km and from an elevation of 5 to 42 m and the height above ground changed from 12 to 20 m. During the last 16 years the wind power varied by a factor of 1.5 from minimum to maximum. Aniak and McGrath, with class 1 wind power, show very little variability from year to year. Between the Kuskokwim Mountains and the Alaska Range, Lake Minchumina and Sparrevohn show very little interannual variation while Iliamna and Farewell vary by a factor of more than 2, from wind power classes 1 to 4. In the Cook Inlet area, Anchorage, Homer, and Kenai vary little from year to year, remaining in wind power class 1 at all times. These sites do not reflect the wind powers that occur at more exposed locations or passes in the Cook Inlet area. Skwentna and Talkeetna, in the Susitna River drainage, show very little change in wind power from year to year while Summit, at a more exposed location, varies between class 1 and 4 wind power . In the Tanana River valley, Northway shows very little interannual variation; however, Big Delta at the north end of Isabel Pass varies from class 1 to class 7 wind power from one year to another. Gulkana, on the upper Copper River, shows very little variation from year to year, which is typical of an interior location. Along the Gulf of Alaska coast, Cordova, in a sheltered location, and Cape Yakataga show very little interannual variation in wind power or speed, remaining in wind power classes 1 and 2. Middleton Island varied from class 6 to 7 wind power over the seven-year record.

5.3.2 Monthly Average Wind Power and Speed

At coastal and island stations in south-central Alaska, wind power class 7 dominates in autumn and winter and minimum wind powers occur in summer (Figure 5.11). Two exceptions are Cordova and Yakataga, where there is very little seasonal change in wind power. Cordova is class 1 and Yakataga is class 2 most of the time Unalakleet shows wind power class 7 in winter only. Along the Kuskokwim River, Bethel is typical of inland areas of the Yukon and Kuskokwim Deltas, with class 6 wind power occurring in late autumn and winter, decreasing to class 3 in summer. Aniak, with class 1 wind power, shows a March maximum and a July minimum. McGrath is typical of much of the interior area, with a winter minimum and spring/summer maximum. In the area between the Kuskokwim Mountains and the Alaska Range, Sparrevohn, with wind power class 2, shows a March maximum and June minimum. Farewell and Iliamna both show summer minima and maxima in autumn and winter, with annual wind powers of class 2 and 3, respectively. Lake Minchumina shows very little change in wind power and speed throughout the year.

All stations in the Cook Inlet area show an annual wind power class 1, with minima in summer at Kenai and Homer and in winter at Anchorage. However, there is very little change during the year. In the Susitna drainage area, Skwentna and Talkeetna show annual wind power class 1, with very little seasonal variation, summer minima, and winter or spring maxima. Summit, on the other hand, with annual wind power class 2, reaches class 3 in winter and class 1 from April to December. Summit, at 770 m, is less affected by the persistent arctic temperature inversion that generally affects more sheltered locations during the wintertime.

Big Delta, along the Tanana River valley at the north end of Isabel Pass, shows a winter maximum and summer minimum. Big Delta is only representative of a small area affected by this local phenomenon. Northway, with annual class 1 wind power, is more typical of the broad Tanana Valley; it has a winter minimum and summer maximum, reflecting the influence of the persistent winter temperature inversions. Gulkana, at 510 m elevation, is very representative of the broad, rolling plain that forms the divide between rivers flowing north, south, and west. Wind power class 1, a winter minimum, and small spring maximum are reflected in Gulkana's data.

5.3.3 Diurnal Wind Speed by Season

All 22 stations showed maximum winds between noon and late afternoon (local time) (Figure 5.12). The season with greatest diurnal variation was spring at seven stations and summer at the remainder. All stations showed the least diurnal variation during winter, when there is very little warming by the sun. Coastal stations tend to experience maximum winds earlier in the afternoon than do island stations.

5.3.4 Directional Frequency and Average Speed

In the Bering Sea and along the coast inland to Bethel, the prevailing winds are north through east and southwest through south (Figure 5.13). These are also the quadrants of strongest winds, averaging 9 m/s at Northeast Cape from south-southeast and 6 to 8 m/s at Cape Romanzof and Bethel. Unalakleet has a high frequency of strong easterly winds from a pass through the Nulato Hills and a pressure gradient from a high in the interior to a low over the Bering Sea. Migrating storms are responsible for the strong southerly winds along the coast. Prevailing winds at Aniak are along the direction of the Kuskokwim River valley, with no real peak in wind speed. McGrath shows predominant north and northwest winds, but the strongest winds (4 to 5 m/s) are from the south-southwest. Farewell and Iliamna show prevailing east-southeast and southeast winds, averaging 6 m/s. Along the broad valley in which Lake Minchumina is located, winds from east-northeast and west-southwest average 3 to 4 m/s.

Stations along Cook Inlet show prevailing north to northeast winds; however, strongest winds are most likely to be south-southeast to southwest. There are light winds in the Susitna drainage; Skwentna's winds are from the west-northwest and Talkeetna's from the north. Summit shows prevailing winds from the northeast and southwest. The strongest winds average 6 m/s from east-northeast and originate in the high plain around Summit.

Big Delta shows strong east-southeast winds and mean speeds of 8 to 9 m/s from that direction. The strong winds at Big Delta are affected by flow through Isabel Pass. Northway, more typical of locations in the Tanana River valley, has prevailing winds from northwest along the direction of the Tanana River; however, speeds only average 4 m/s from northwest. Gulkana's stongest winds tend to come from south to southeast; the wind speed averages less than 6 m/s. The winds at Cordova average less than 4 m/s. Yakataga winds occur most often from southeast through south and average 6 m/s. Middleton Island's prevailing and strongest winds are east-southeast, averaging 6 to 8 m/s. This station is more representative of exposed areas of the coast than either Yakataga or Cordova.

5.3.5 Annual Average Wind Speed Frequency

Many interior stations have a high percentage of calm winds and do not follow the Rayleigh distribution (Figure 5.14). The Rayleigh distribution in these cases tends to put too high a percentage of winds in the 1 to 4 m/s range and not enough above 4 m/s. Coastal stations like Northeast Cape, Unalakleet, Middleton Island, and Cape Romanzof tend to follow the Rayleigh distribution. There is also observer bias shown in the preference for 2, 5, 8, and 10 m/s (corresponding to 5, 10, 15, and 20 mph) in the data at Aniak, Cape Romanzof, Cordova, Homer, Iliamna, Middleton Island, Northeast Cape, Summit, Unalakleet, and Yakataga.

5.3.6 Annual Average Wind Speed and Power Duration

The percent of time that a given wind speed or power is exceeded is shown in Figures 5.15 and 5.16. Evidence of observer bias and instrument response is indicated by abrupt changes in the shape of the wind speed duration curves. Note that wind power class 7 occurs 20 percent of the time at Cape Romanzof, Middleton Island, and Northeast Cape, all coastal or island locations. Bethel data indicate that the Yukon-Kuskokwim Delta also has a substantial potential for wind power development.

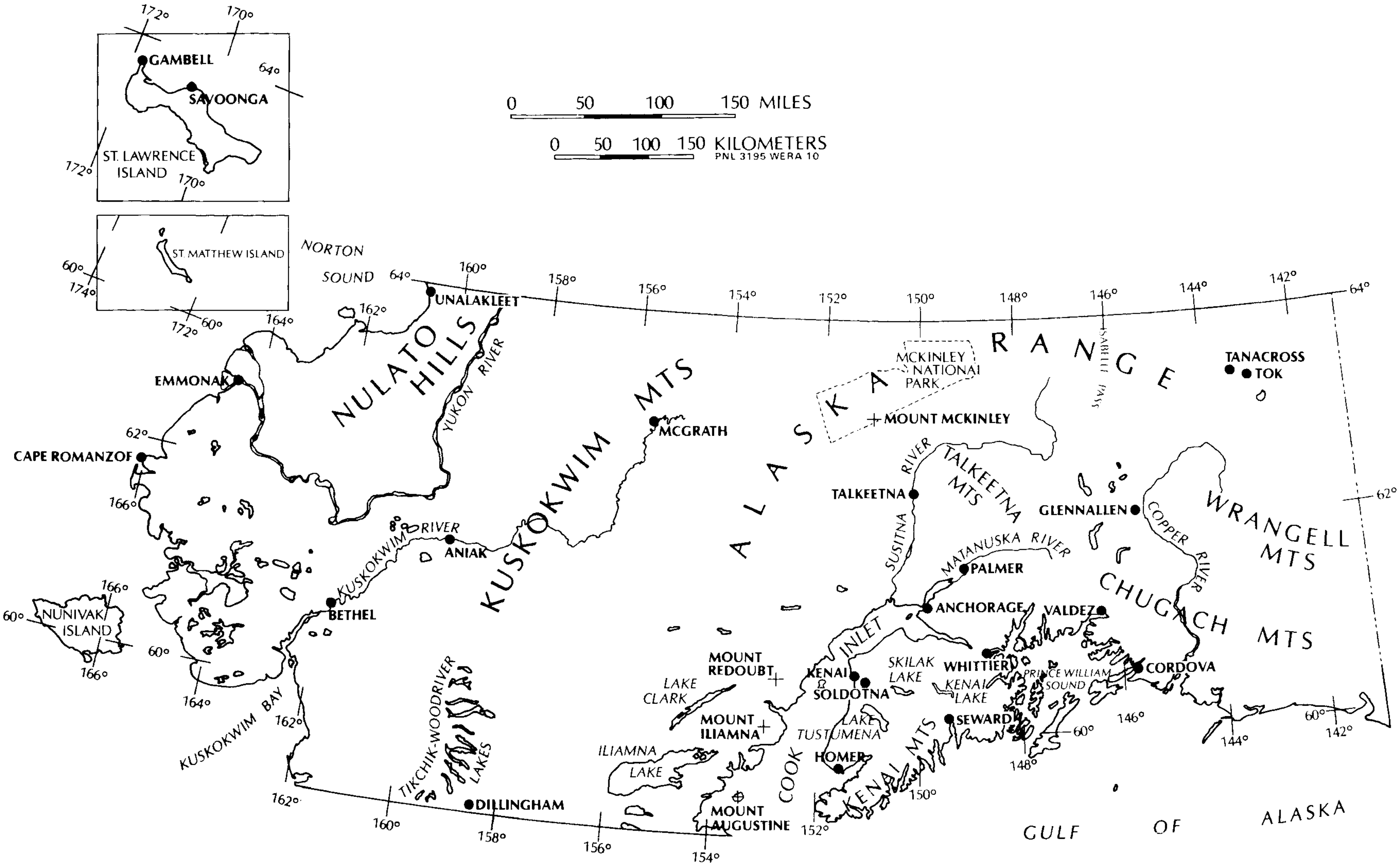


FIGURE 5.1. Geographic Map of Southcentral Alaska

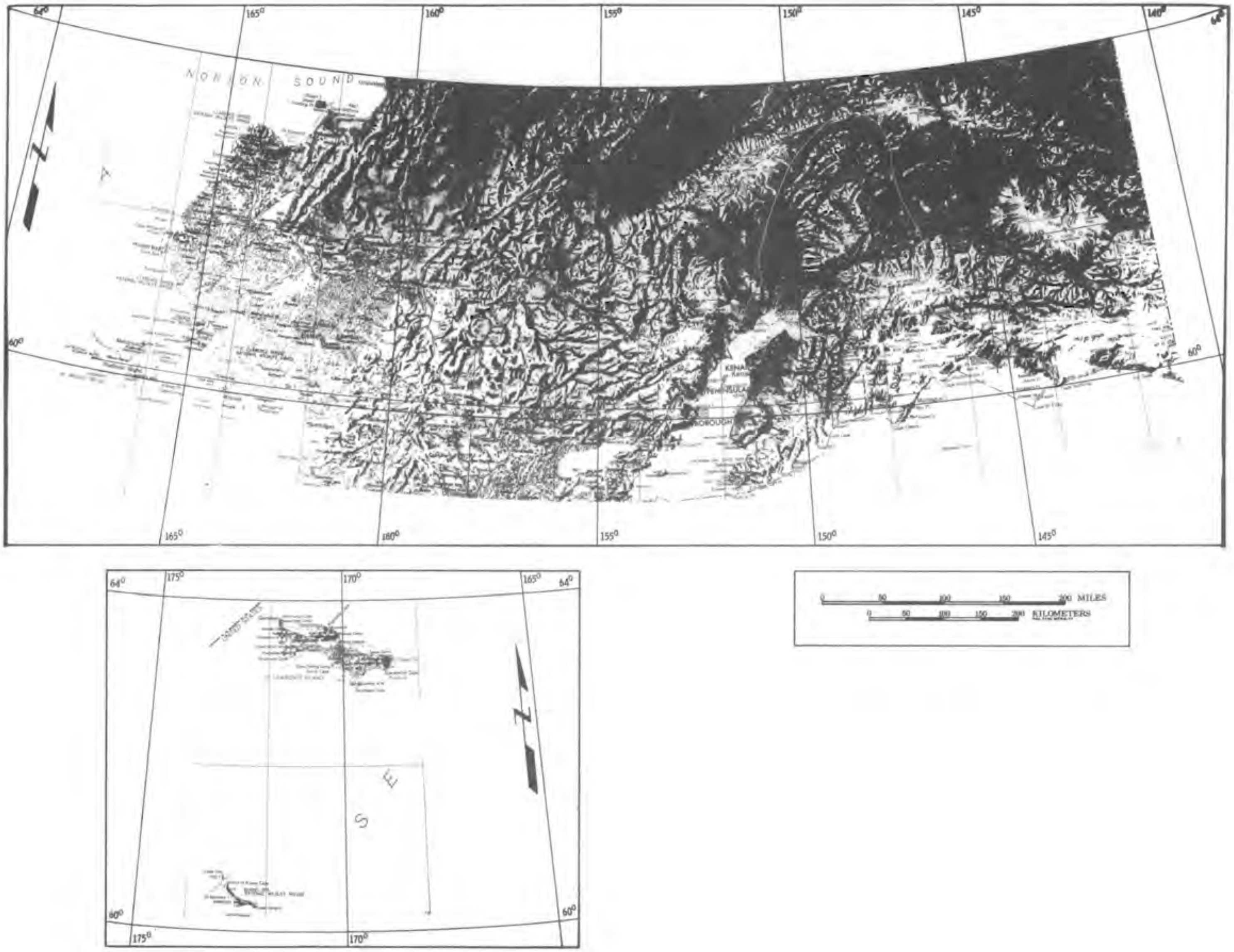


FIGURE 5.2. Topographic Map of Southcentral Alaska

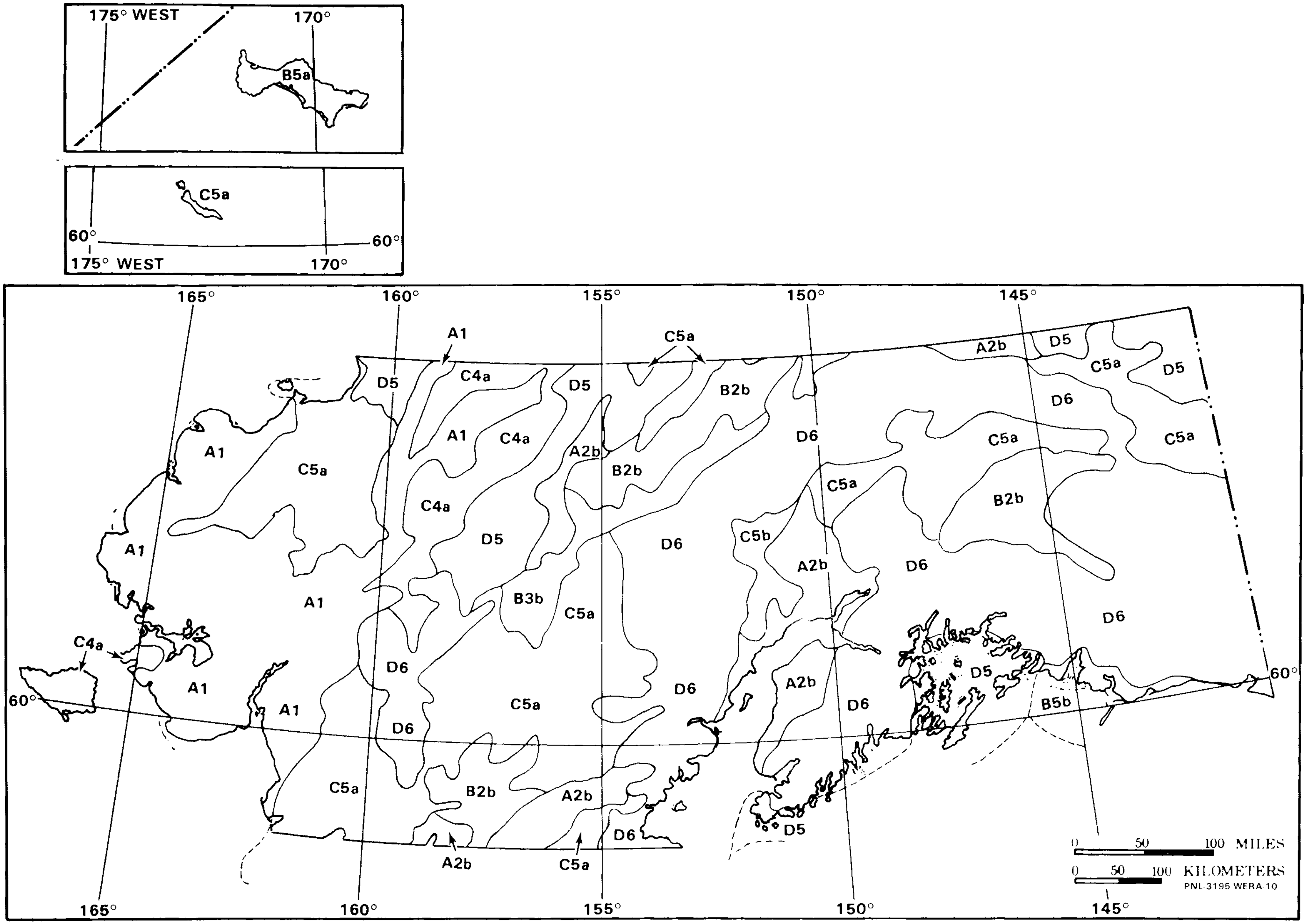


FIGURE 5.3. Land-Surface Form Map of Southcentral Alaska.

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

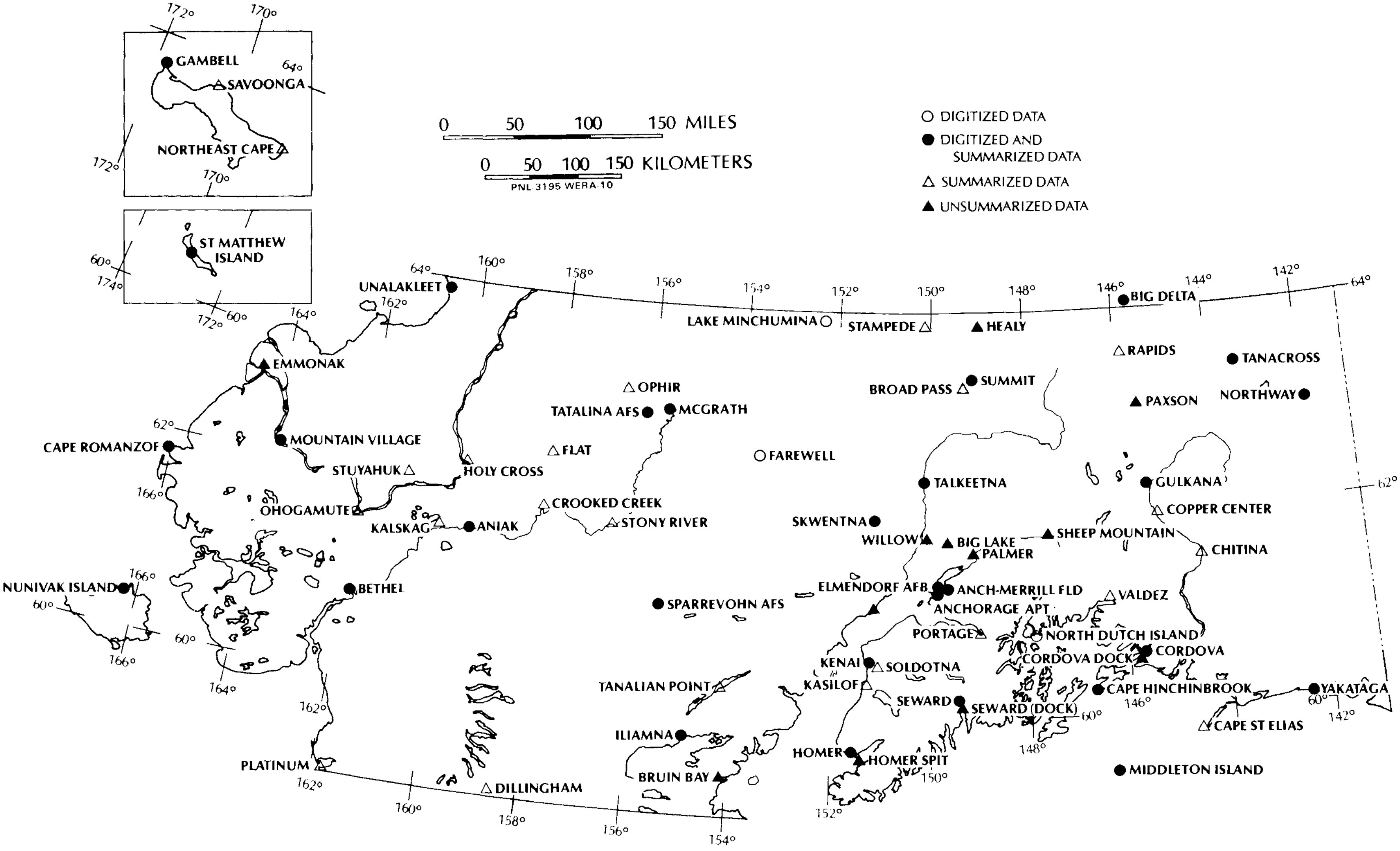


FIGURE 5.4. NCC Station Locations in Southcentral Alaska

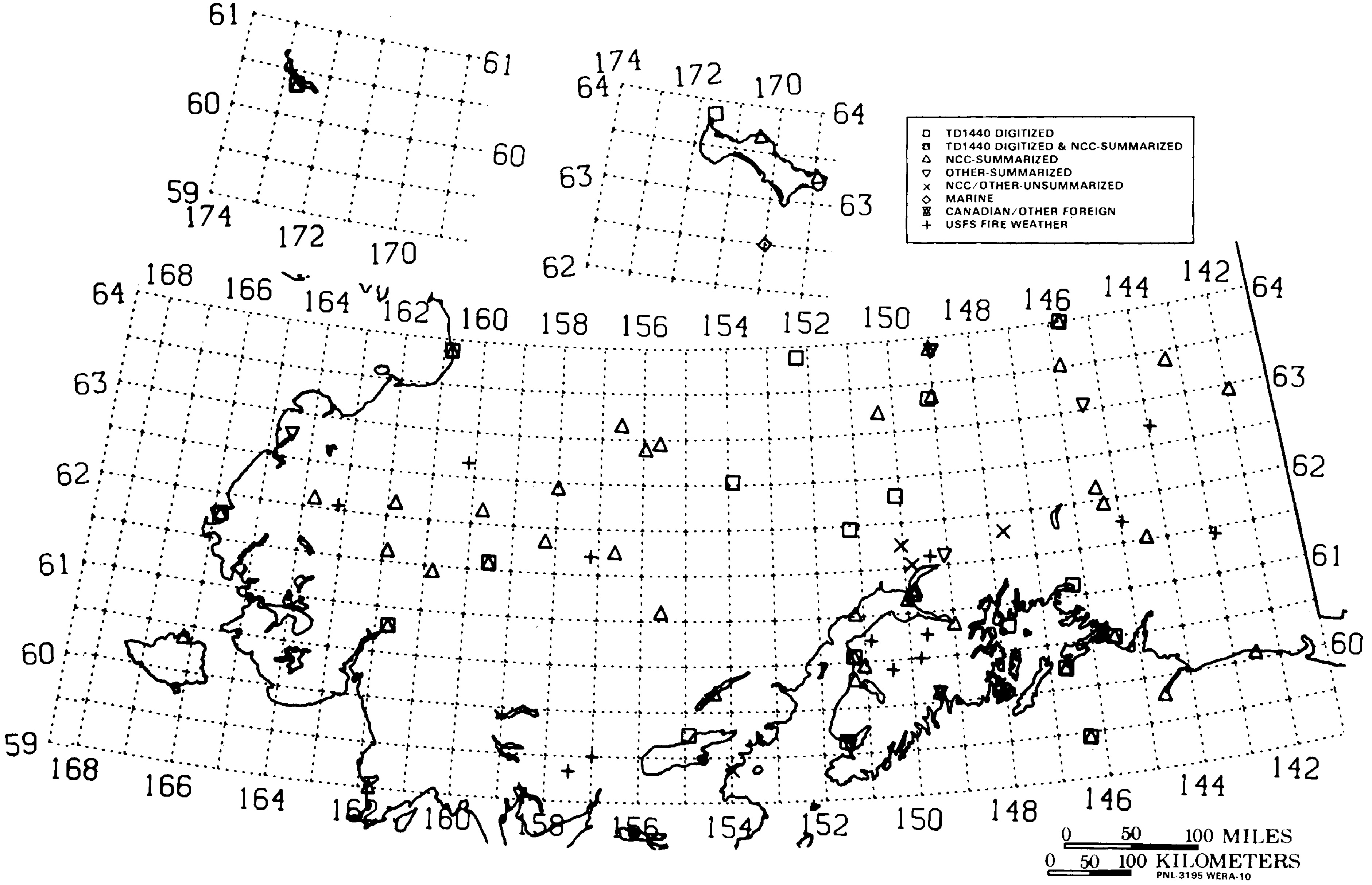


FIGURE 5.5. Location of Stations Used in Southcentral Alaska Assessment.

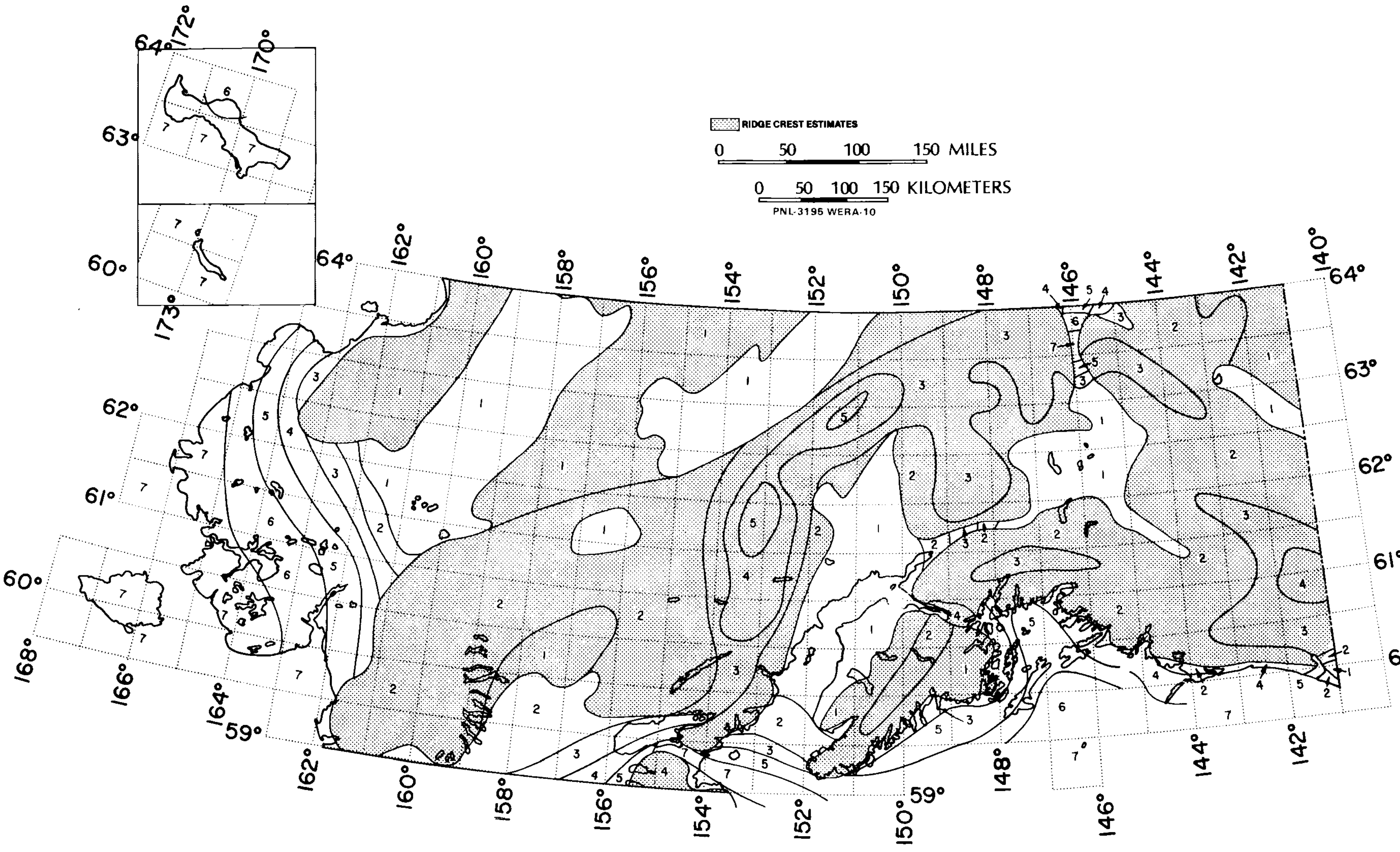


FIGURE 5.6. Southcentral Alaska Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m[a]

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, watts/m^2	Speed,[b] m/s (mph)	Wind Power Density, watts/m^2	Speed,[b] m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

---

[a] Vertical extrapolation of wind speed based on the 1/7 power law.

[b] Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 5.1. Areal Distribution (km^2) of Wind Power Classes in Southcentral Alaska

Power Class	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	480,000	82	580,000	100
2	25,000	4.2	100,000	18
3	22,000	3.8	78,000	13
4	5,000	0.85	56,000	10
5	15,000	2.6	51,000	8.7
6	18,000	3.2	36,000	6.1
7	17,000	3.0	17,000	3.0

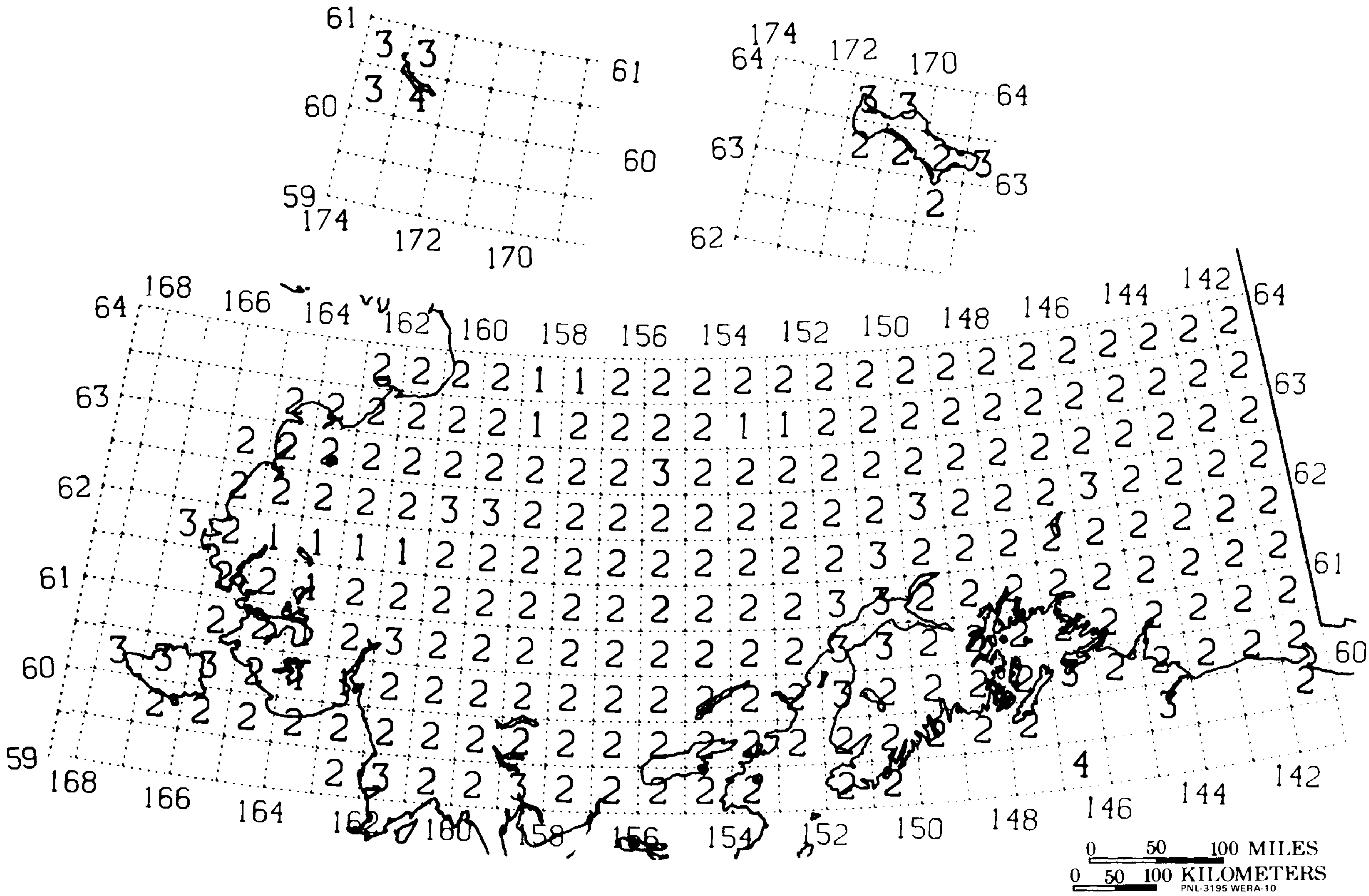


FIGURE 5.7. Certainty Rating of Southcentral Alaska Wind Resource.

CERTAINTY RATING LEGEND

Rating	Definition
1	The lowest degree of certainty. A combination of the following conditions exists: 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	A low-intermediate degree of certainty. One of the following conditions exists: 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	A high-intermediate degree of certainty. One of the following conditions exists: 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.

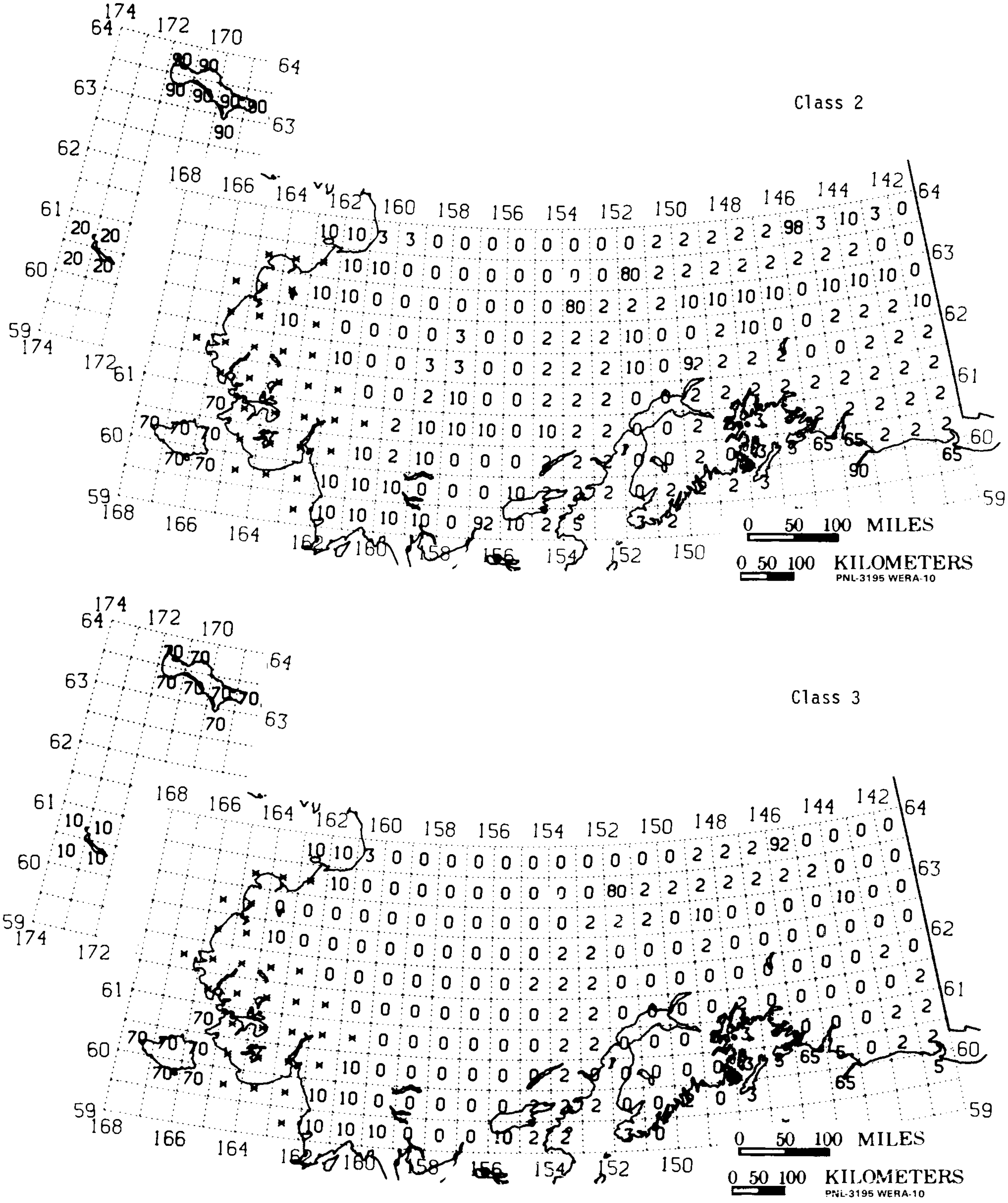


FIGURE 5.8. Areal Distribution of Wind Resource in Southcentral Alaska (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown.

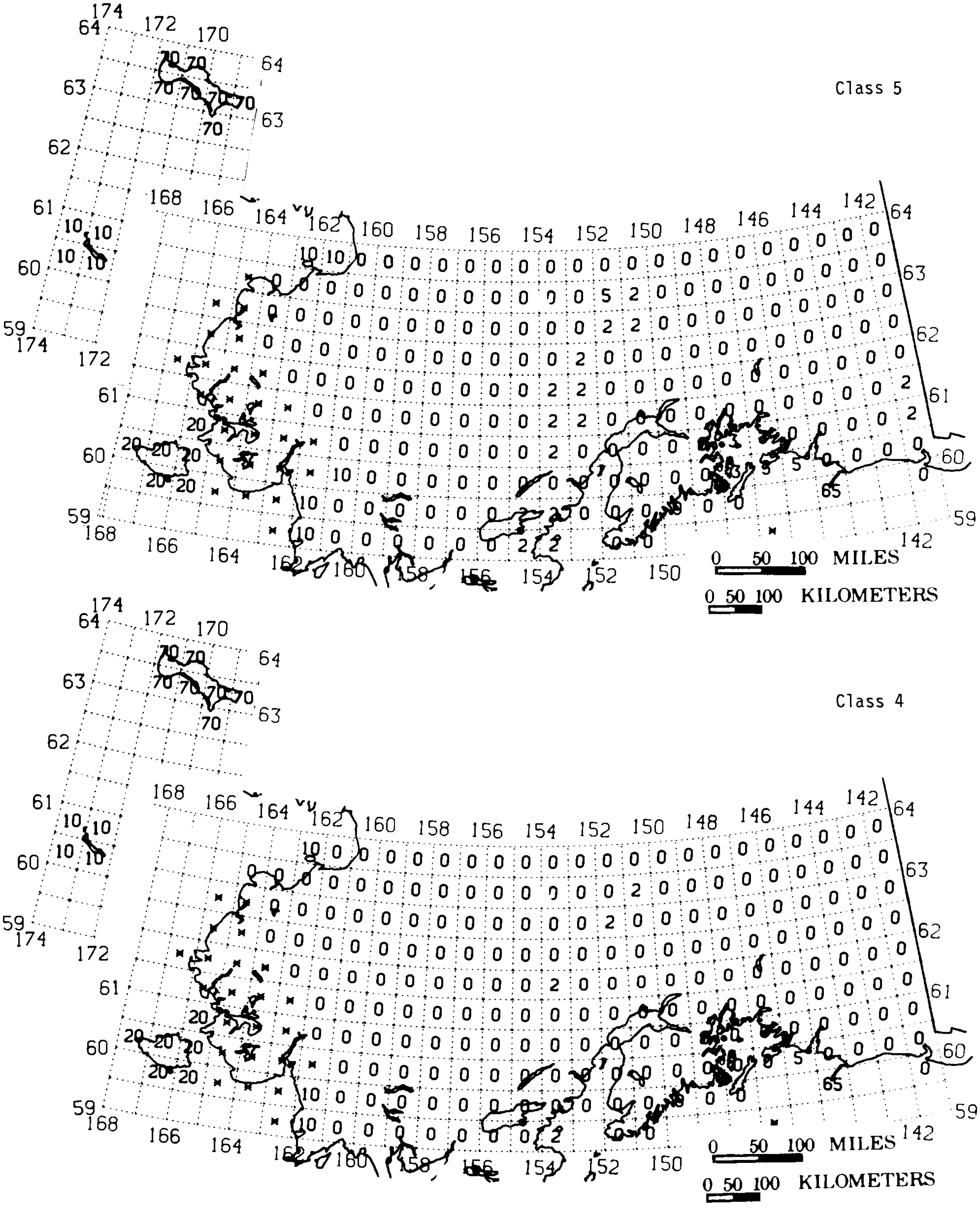


FIGURE 5.8 (Continued). Areal Distribution of Wind Resource in Southcentral Alaska (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown.

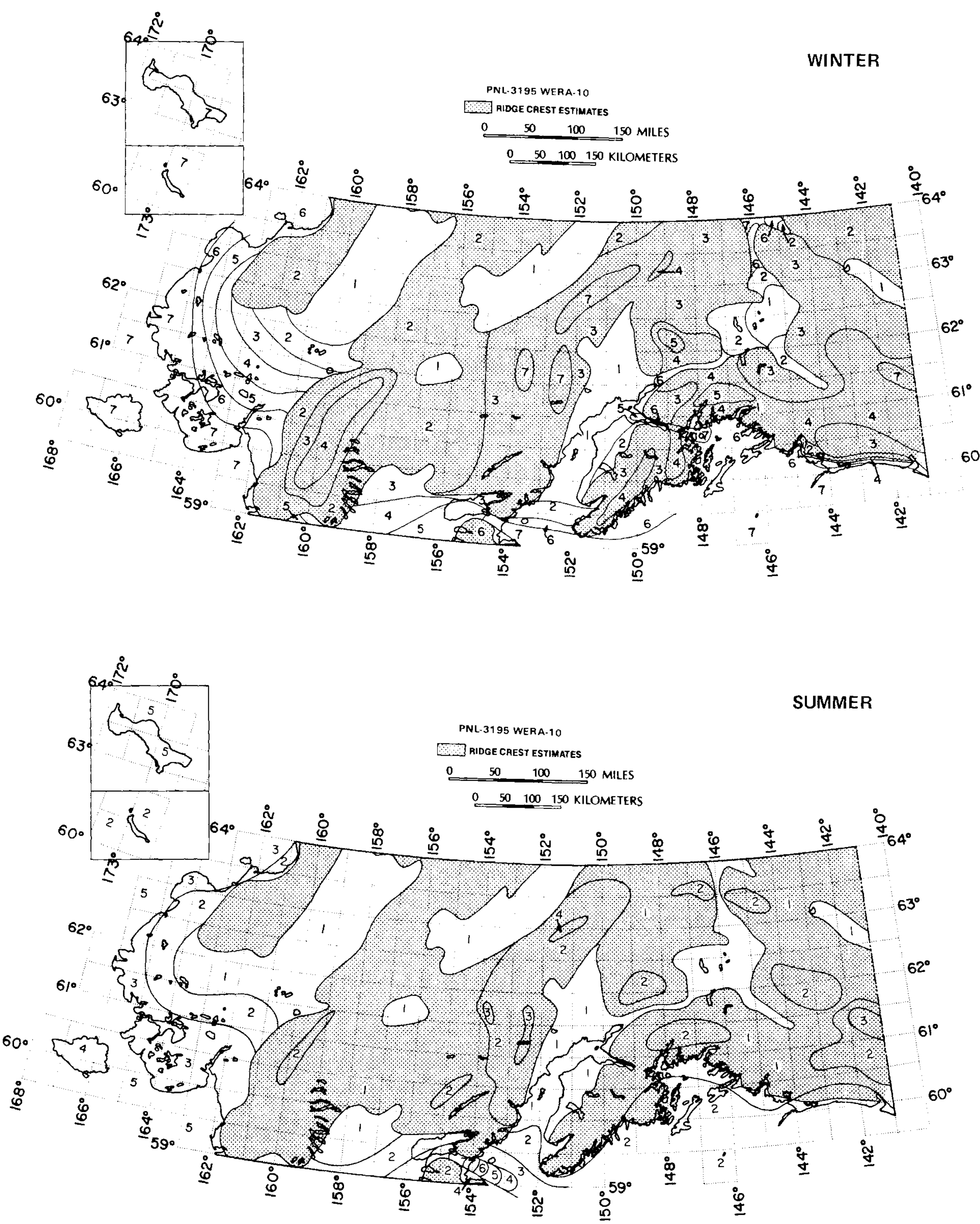
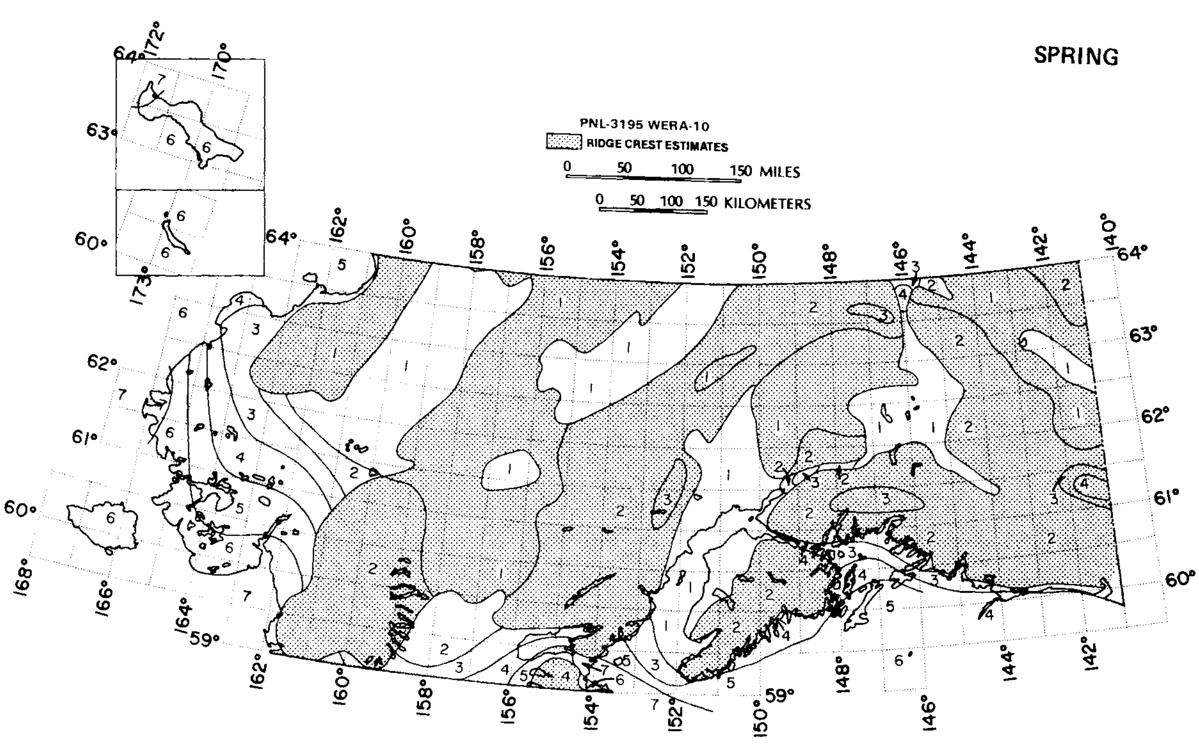
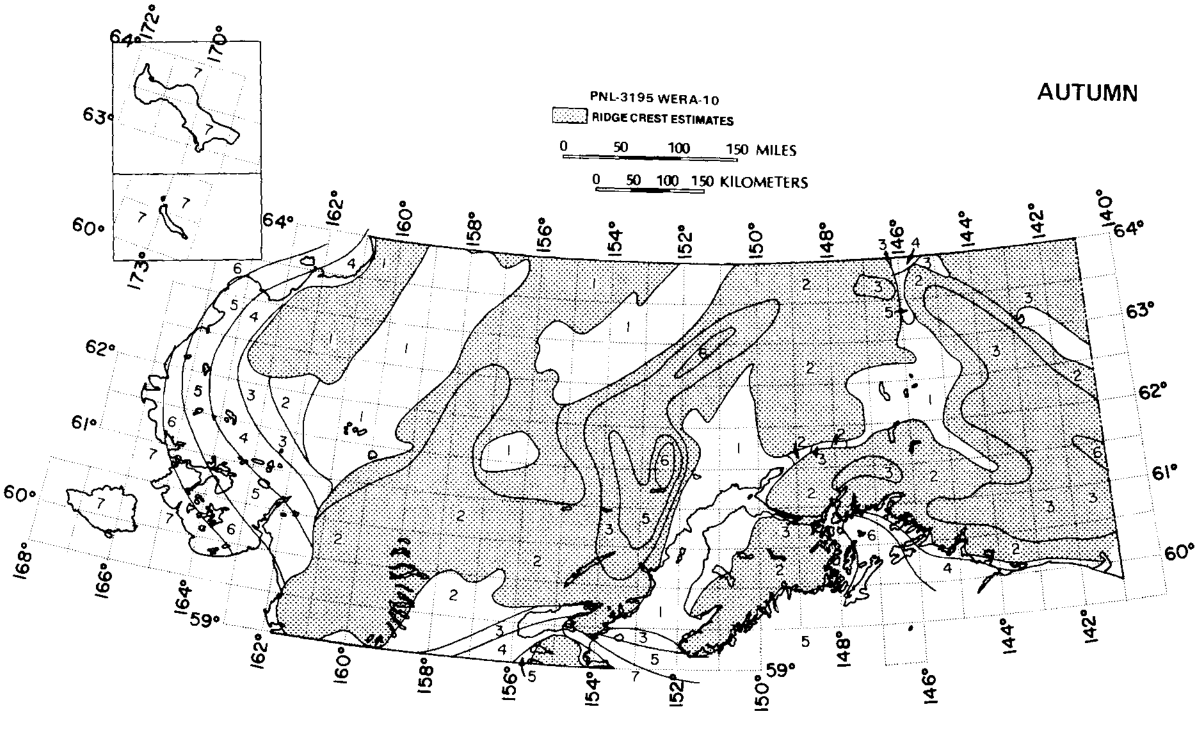


FIGURE 5.9. Seasonal Average Wind Power in Southcentral Alaska (Winter, Summer)



SPRING



AUTUMN

FIGURE 5.9 (Continued). Seasonal Average Wind Power in Southcentral Alaska (Spring, Autumn)

TABLE 5.2. Southcentral Alaska Stations with Graphs of the Wind Characteristics

							Annual Average Wind Speed, m/s			Annual Average Wind Power, W/m^2		
Station ID	Station Name	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Anchorage/ ELM	Elmendorf AFB	61.3	149.8	53.6	10/53-04/56	13.7	2.2	2.1	2.6	31	27	54
Anchorage/ INT	Anchorage International Airport	61.2	150.0	32.0	03/61-12/78	6.7	3.2	3.4	4.2	52	62	123
Aniak	Aniak CAA	61.6	159.5	8.5	07/48-02/59	9.8	3.0	3.1	3.8	50	51	101
Bethel	Bethel WBAS	60.8	161.8	39.9	10/62-12/78	6.1	5.6	6.1	7.6	209	258	515
Big Delta	Big Delta CAA	64.00	145.7	388.2	07/48-12/64	8.8	4.2	4.3	5.4	215	227	452
Cape Romanzof	Cape Romanzof AFS	61.8	166.0	123.4	04/61-11/68	4.0	5.8	6.6	8.3	346	514	1026
Cordova	Cordova WBAS	60.5	145.5	13.4	07/48-12/64	10.4	2.3	2.3	2.9	38	37	75
Farewell	Farewell CAA	62.5	153.9	458.1	07/48-07/64	9.1	3.8	3.8	4.8	124	129	257
Gulkana	Gulkana CAA	62.2	145.5	481.3	07/48-12/64	9.1	3.1	3.1	3.9	76	79	157
Homer	Homer CAA	59.6	151.5	22.3	07/48-12/64	9.1	3.0	3.0	3.8	52	54	108
Iliamna	Iliamna CAA	59.8	154.9	46.3	07/48-09/64	9.8	4.6	4.6	5.8	151	153	304
Kenai	Kenai CAA	60.6	151.3	27.7	07/48-12/64	10.7	3.5	3.4	4.3	73	71	142
L. Minchumina	Minchumina CAA	63.9	152.3	65.2	07/48-09/64	9.8	2.3	2.3	2.9	41	41	83
McGrath	McGrath WBAS	63.0	155.6	103.9	07/48-12/64	8.5	2.2	2.3	2.9	27	29	58
Middleton Island	Middleton Island CAA	59.5	146.3	13.7	07/48-08/56	9.1	6.2	6.3	8.0	389	404	806
Northeast CP	Northeast Cape AFS	63.3	169.0	9.1	04/62-12/68	4.0	5.6	6.4	8.1	295	439	874
Northway	Northway FAA	63.0	141.9	523.6	10/57-12/64	9.4	1.8	1.8	2.3	24	25	49
Skwentna	Skwentna CAA	62.0	151.2	46.6	06/53-02/28	10.1	1.4	1.4	1.8	14	14	28
Sparrevohn	Sparrevohn AFS	61.1	155.6	529.1	06/58-11/68	4.3	2.4	2.7	3.4	55	79	158
Summit	Summit CAA	63.3	149.1	733.7	03/51-12/59	9.8	4.2	4.2	5.3	112	113	226
Talkeetna	Talkeetna CAA	62.3	150.1	107.0	07/48-12/64	10.4	2.2	2.2	2.8	29	29	57
Unalakleet	Unalakleet CAA	63.9	160.8	6.4	07/52-06/59	7.6	5.3	5.5	6.9	240	270	537
Yakataga	Yakataga CAA	60.1	142.5	10.1	01/53-06/62	9.4	3.7	3.7	4.7	108	111	221

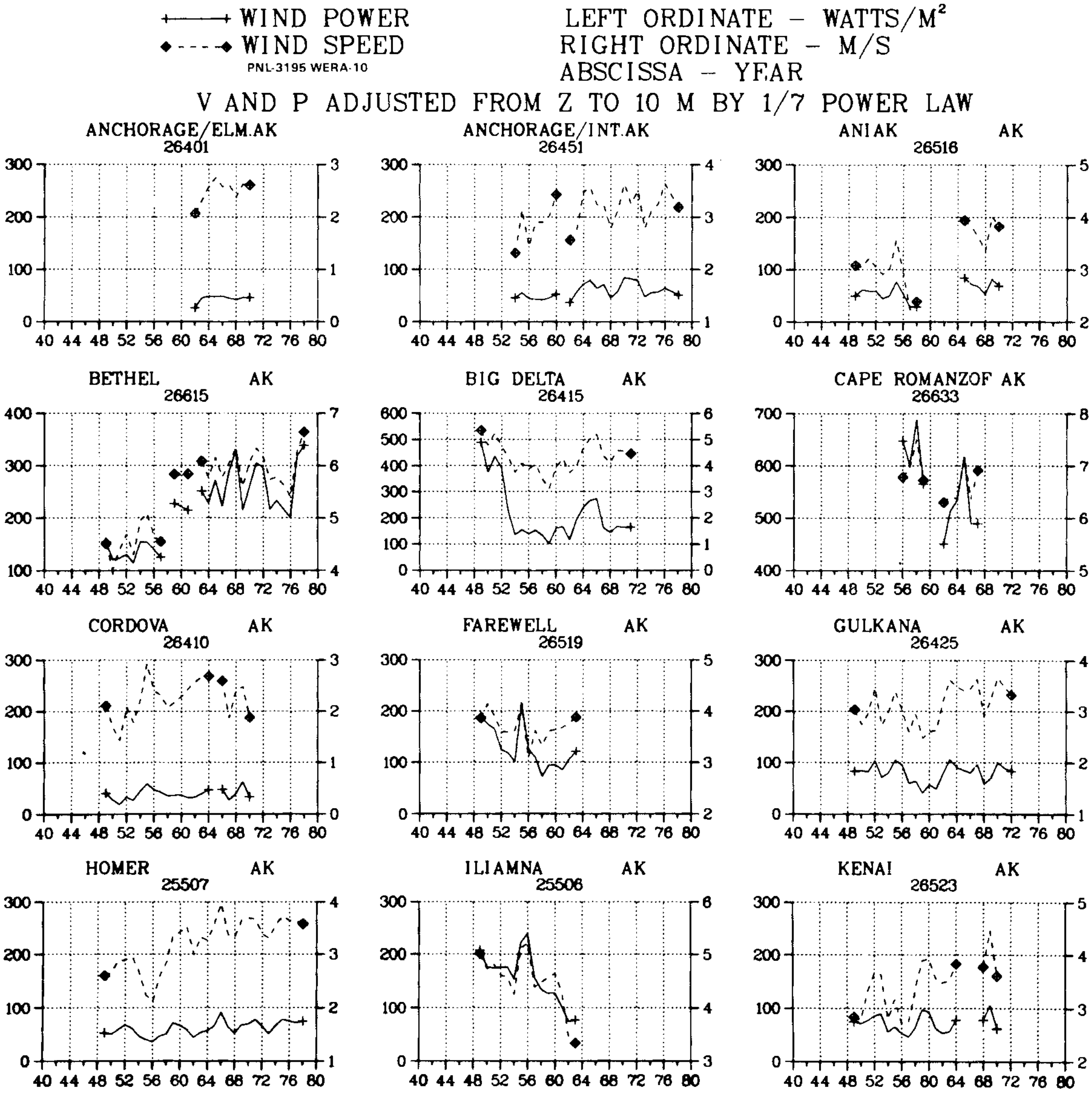


FIGURE 5.10. Interannual Wind Power and Speed for Southcentral Alaska.

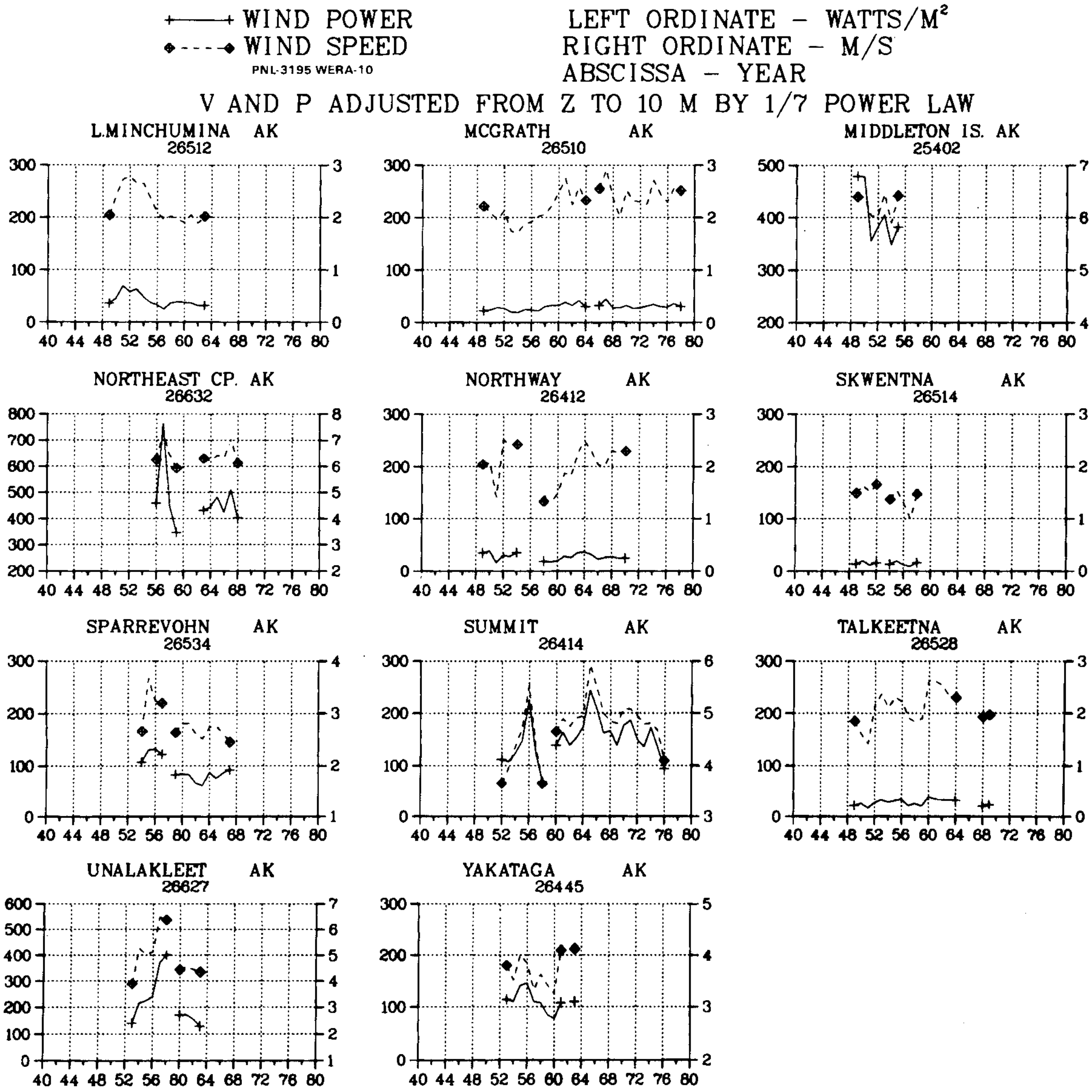


FIGURE 5.10 (Continued). Interannual Wind Power and Speed for Southcentral Alaska.

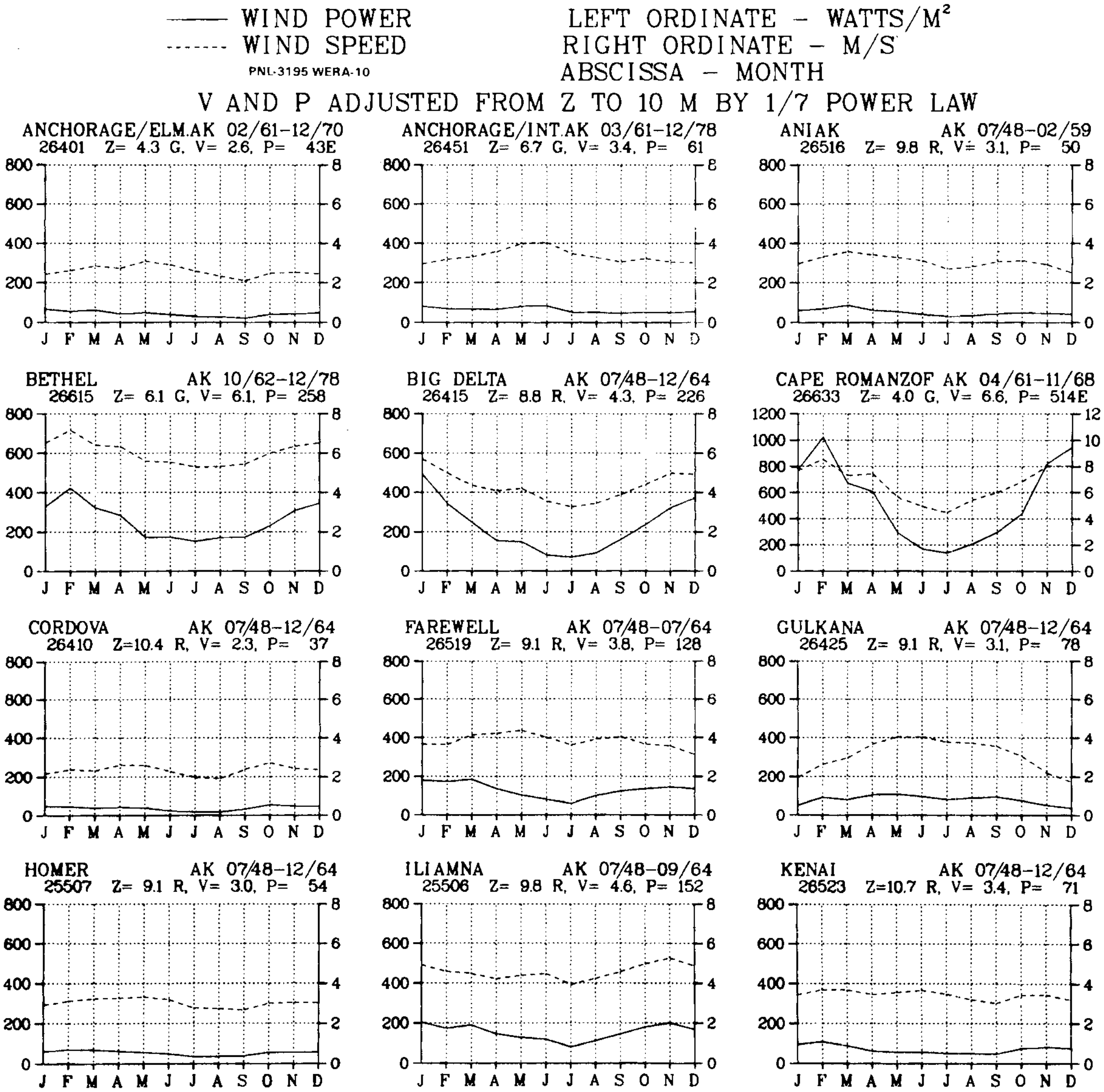


FIGURE 5.11. Monthly Average Wind Power and Speed for Southcentral Alaska.

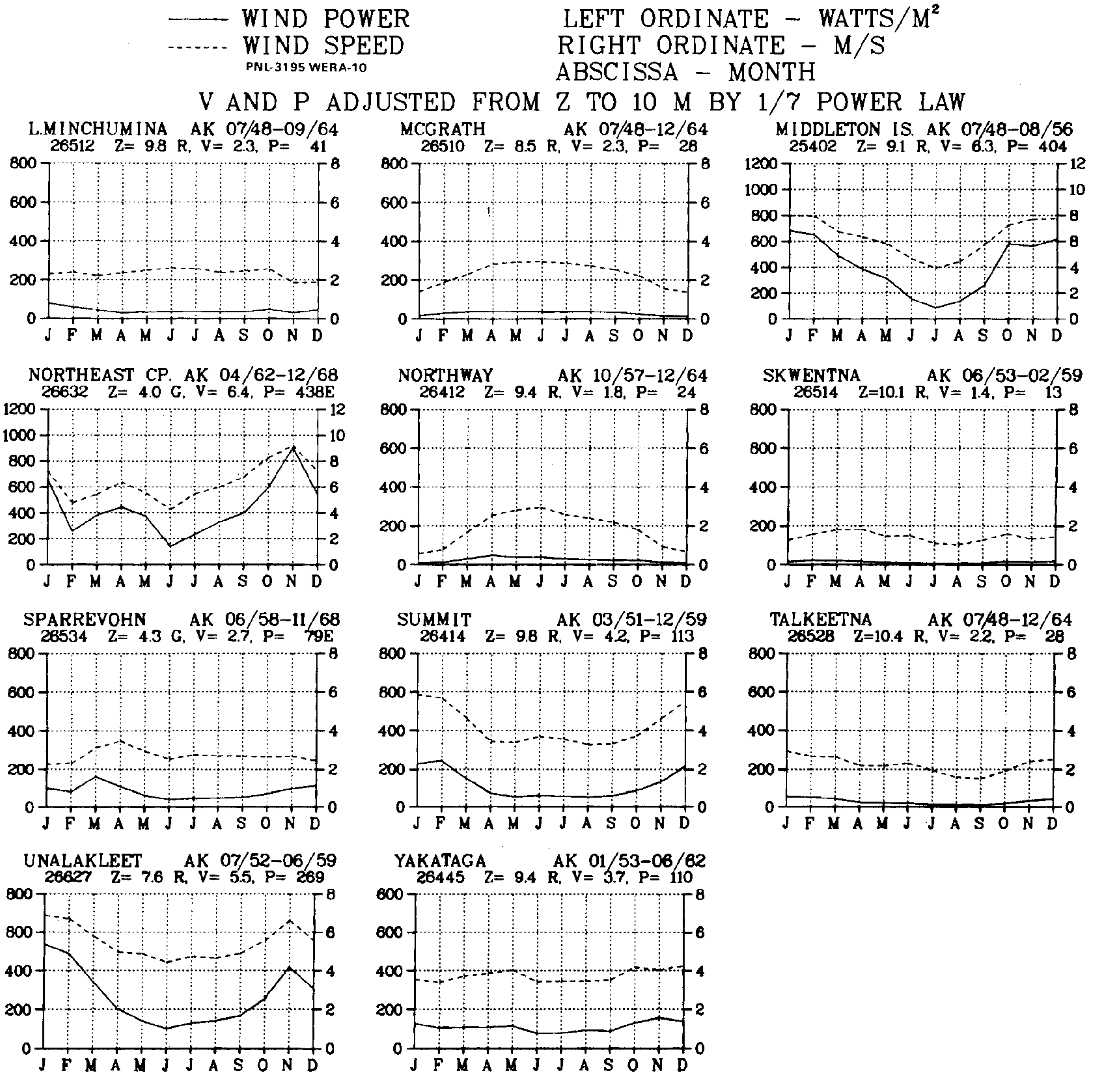


FIGURE 5.11 (Continued). Monthly Average Wind Power and Speed for Southcentral Alaska.

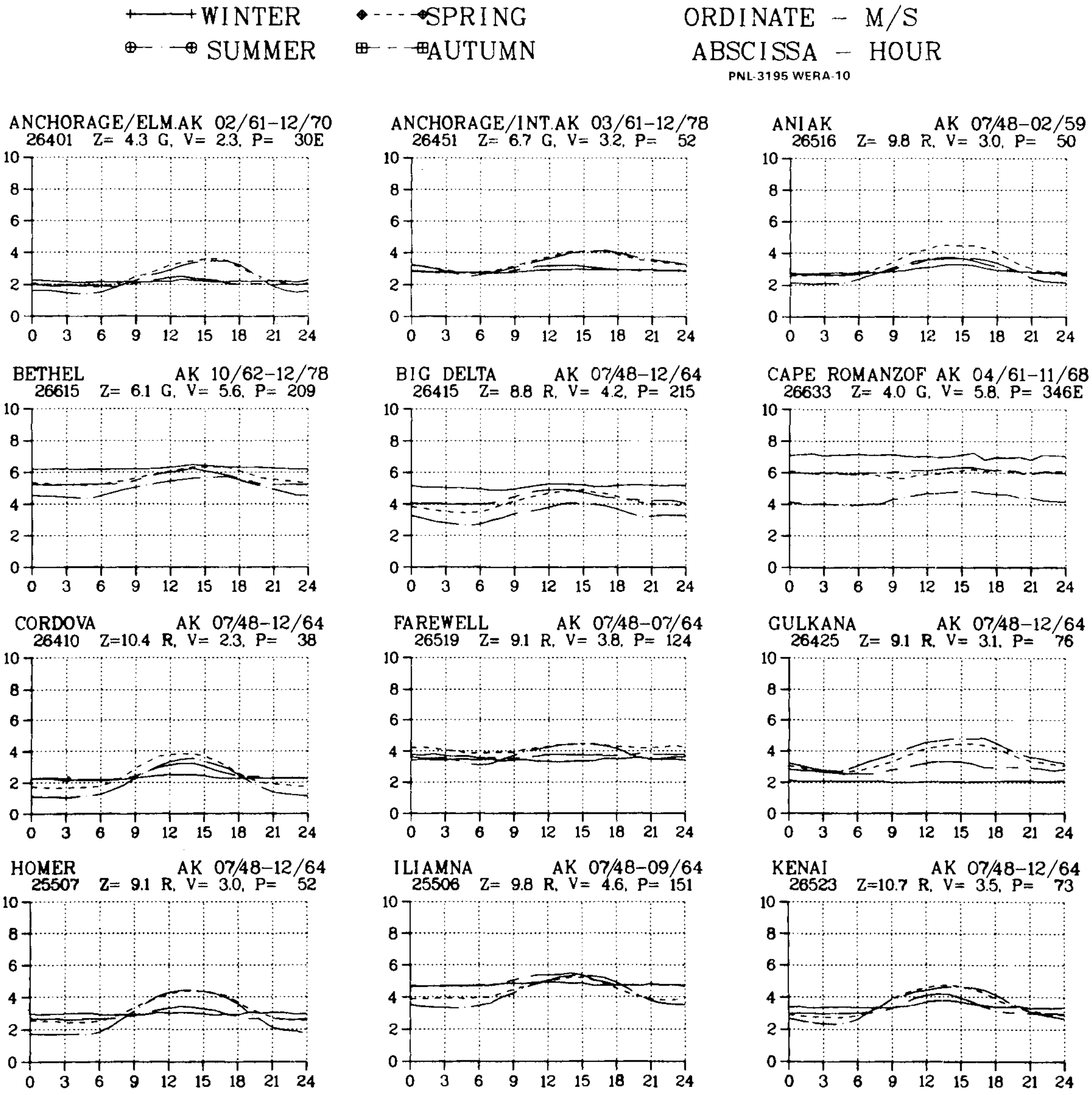


FIGURE 5.12. Diurnal Wind Speed by Season for Southcentral Alaska.

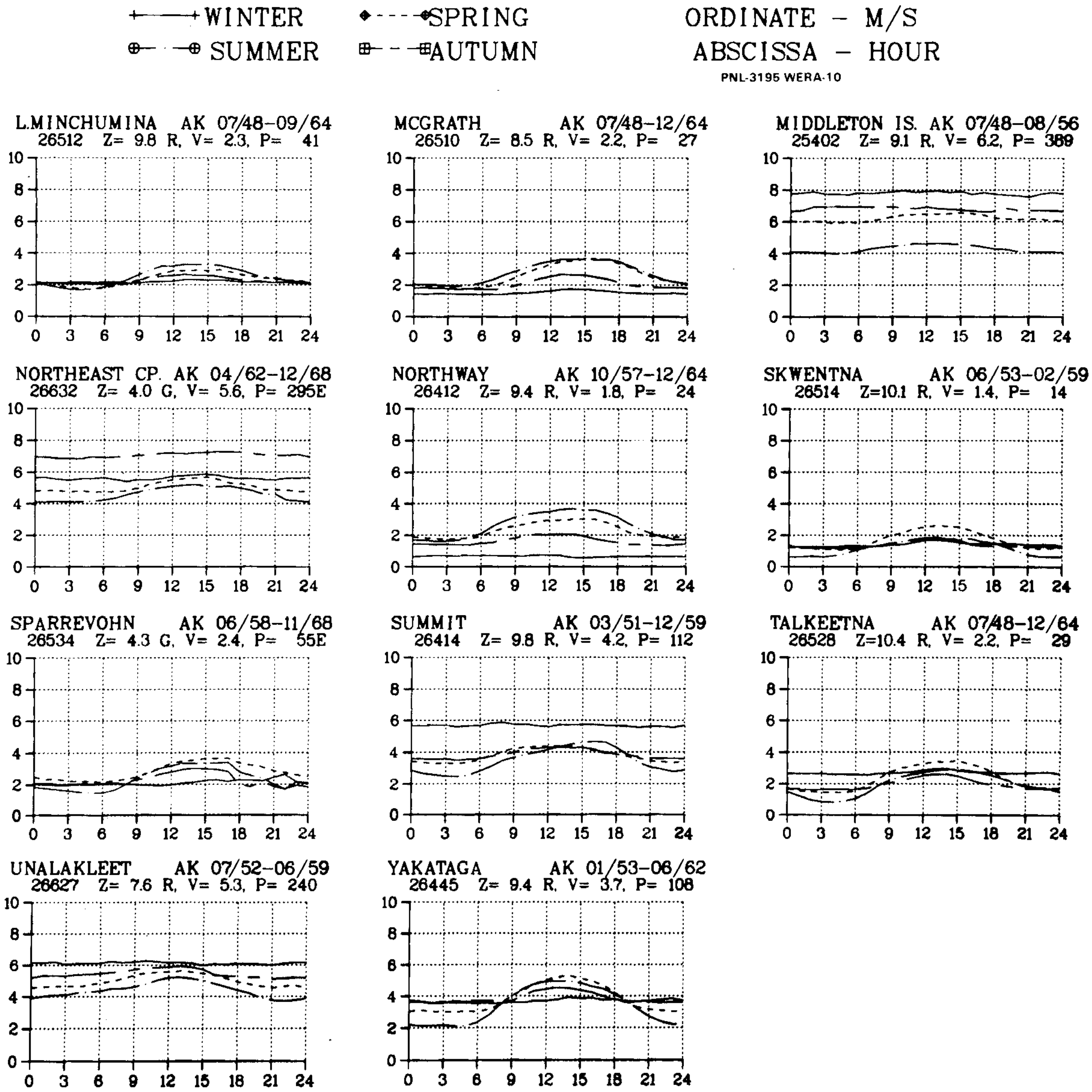


FIGURE 5.12 (Continued). Diurnal Wind Speed by Season for Southcentral Alaska.

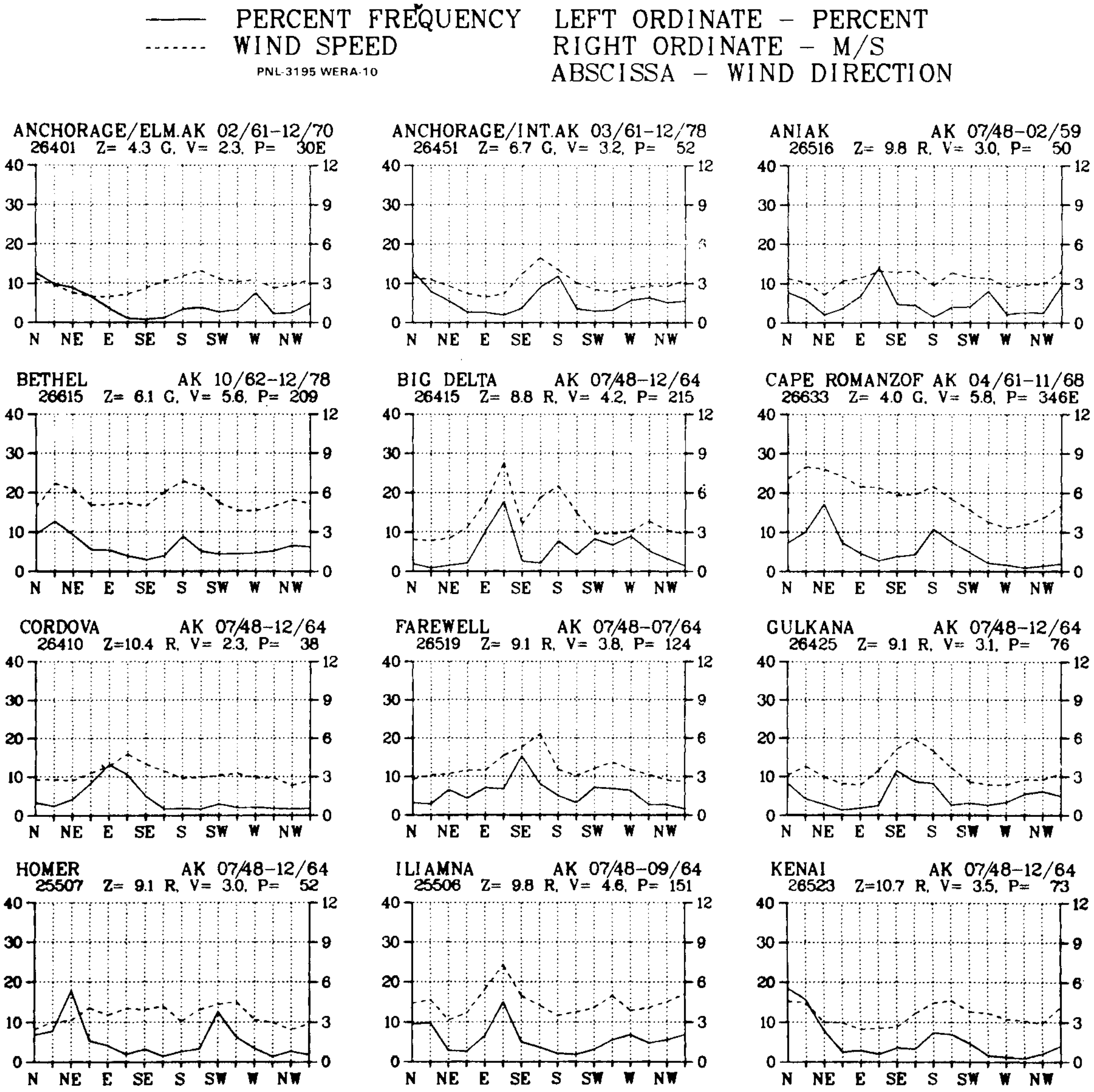


FIGURE 5.13. Directional Frequency and Average Wind Speed for Southcentral Alaska.

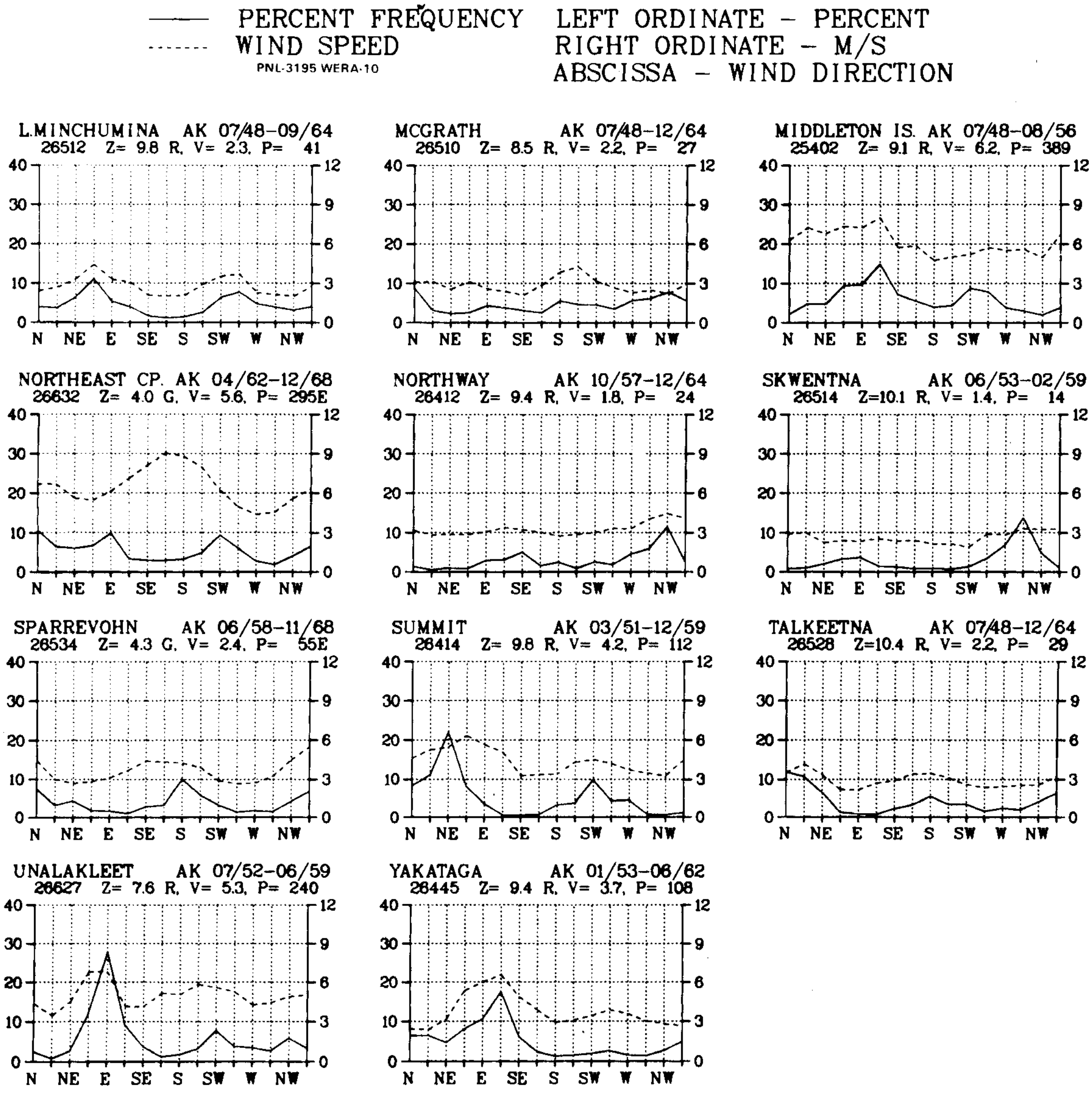


FIGURE 5.13 (Continued). Directional Frequency and Average Wind Speed for Southcentral Alaska.

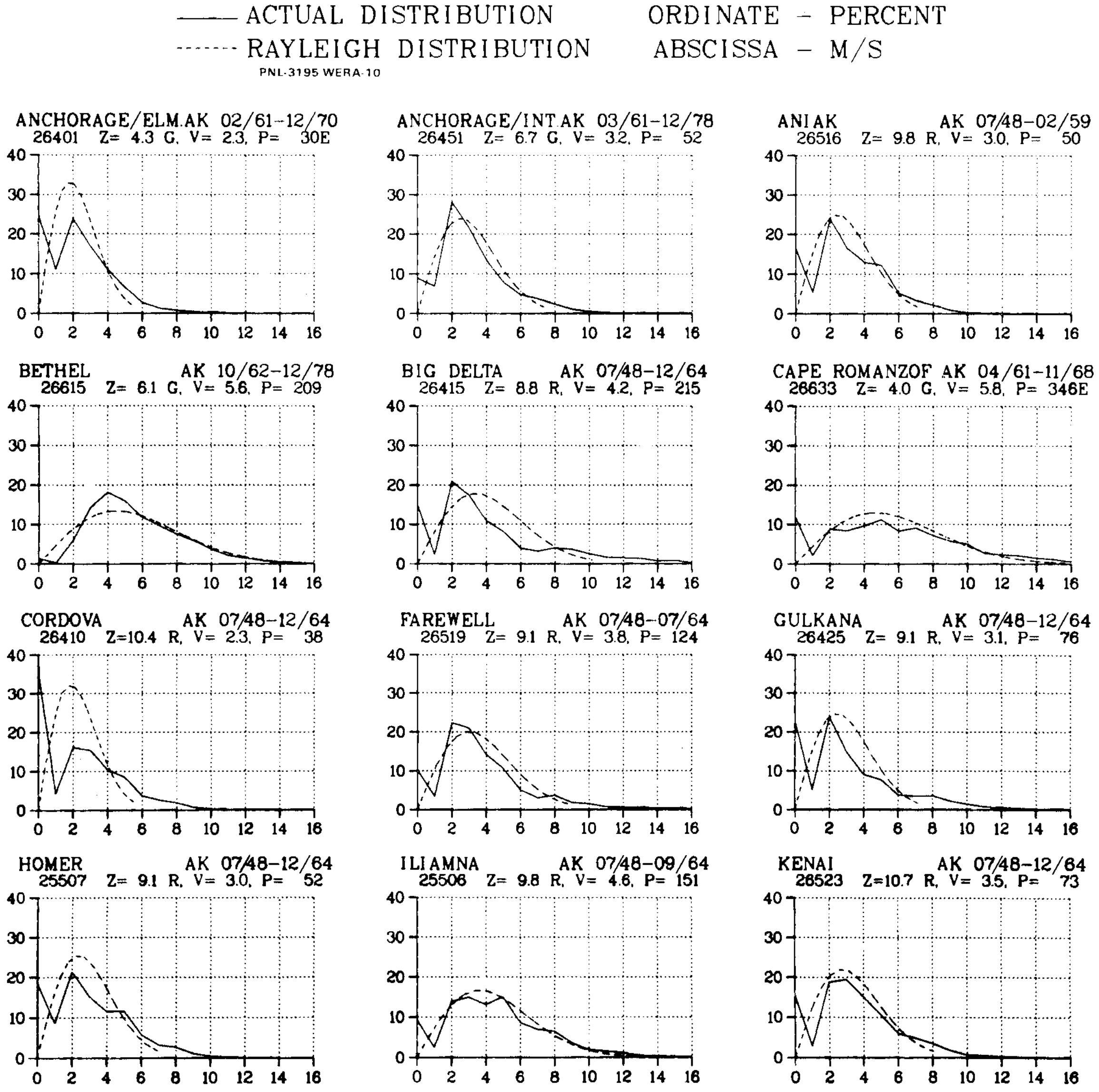


FIGURE 5.14. Annual Average Wind Speed Frequency for Southcentral Alaska.

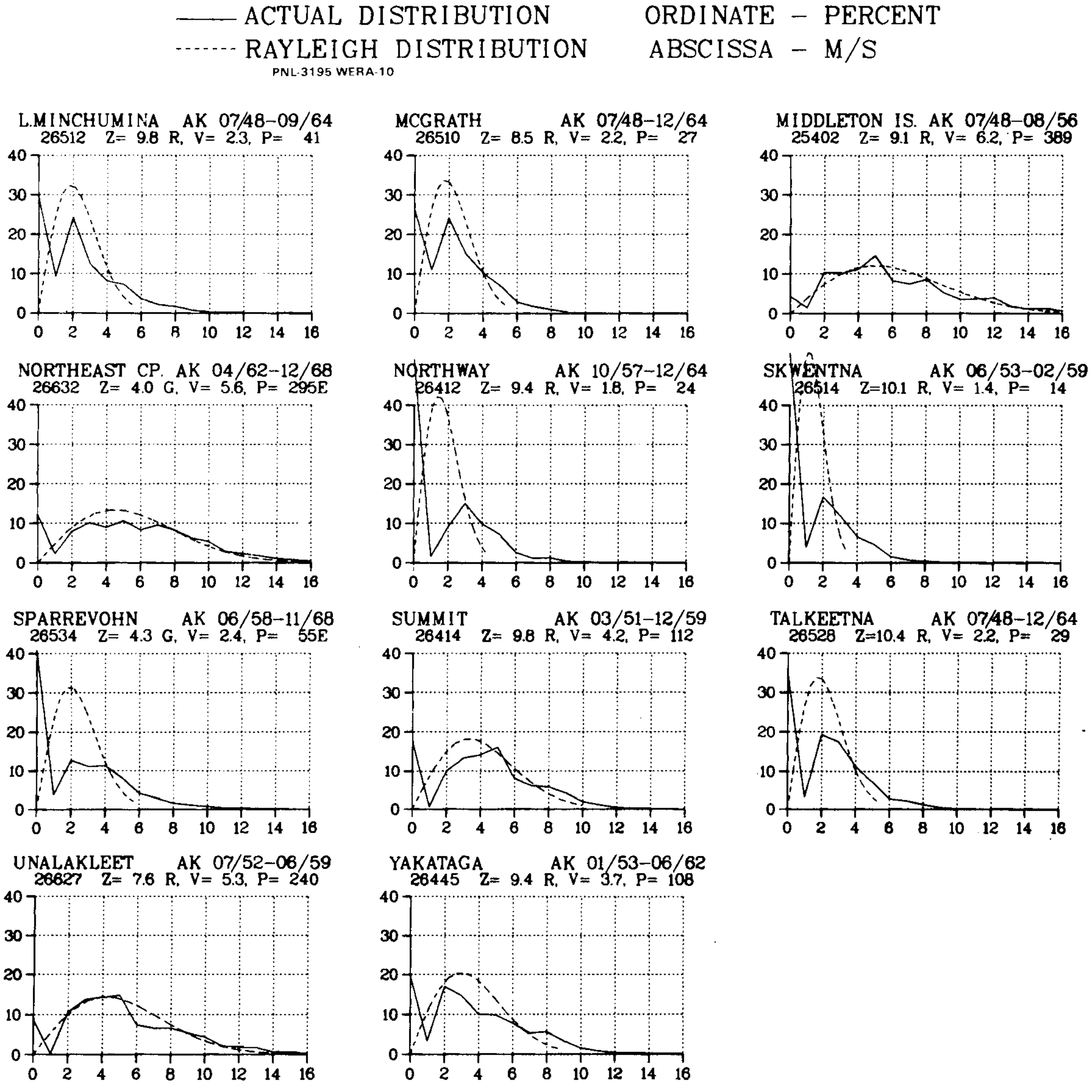


FIGURE 5.14 (Continued). Annual Average Wind Speed Frequency for Southcentral Alaska.

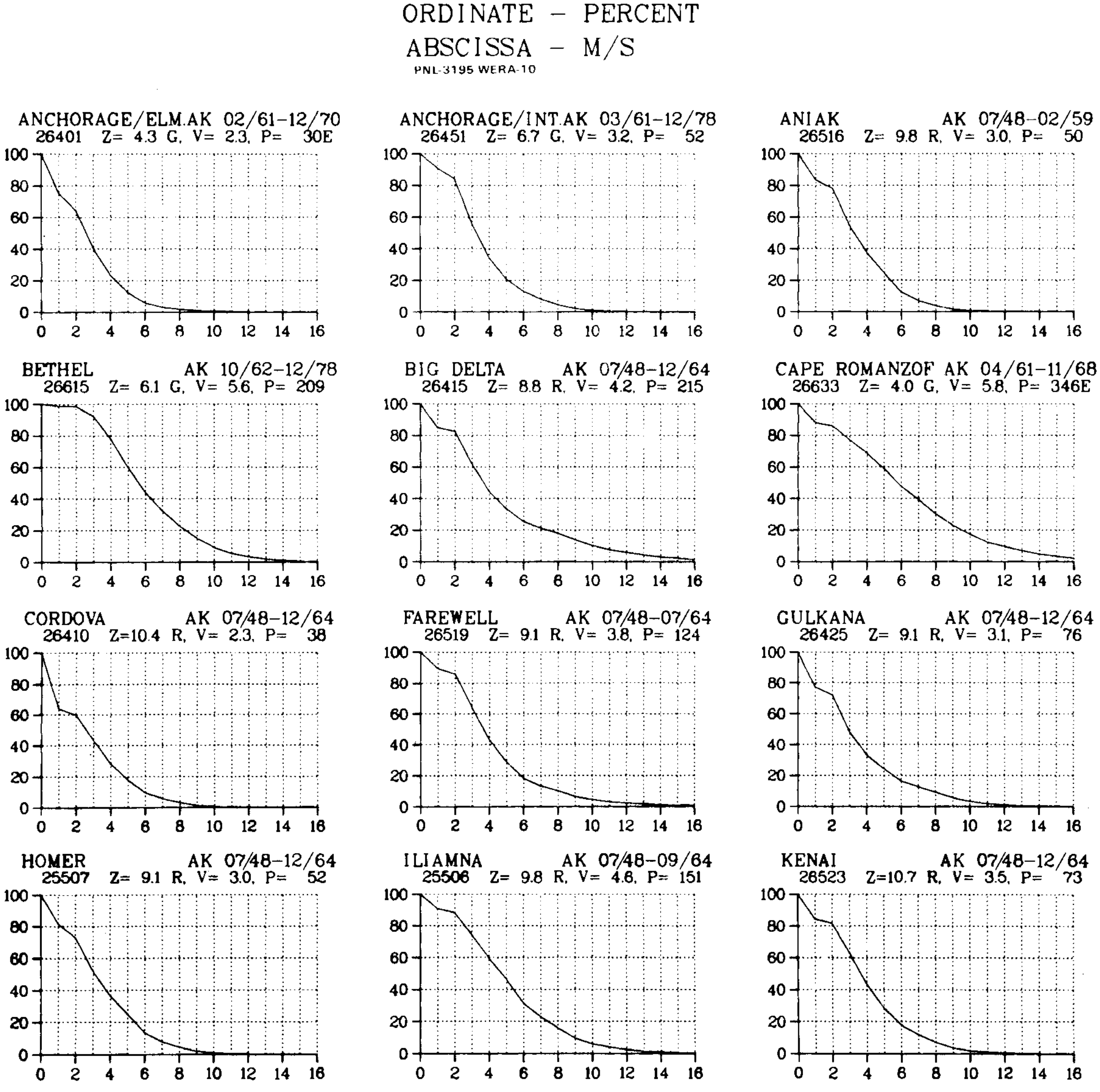
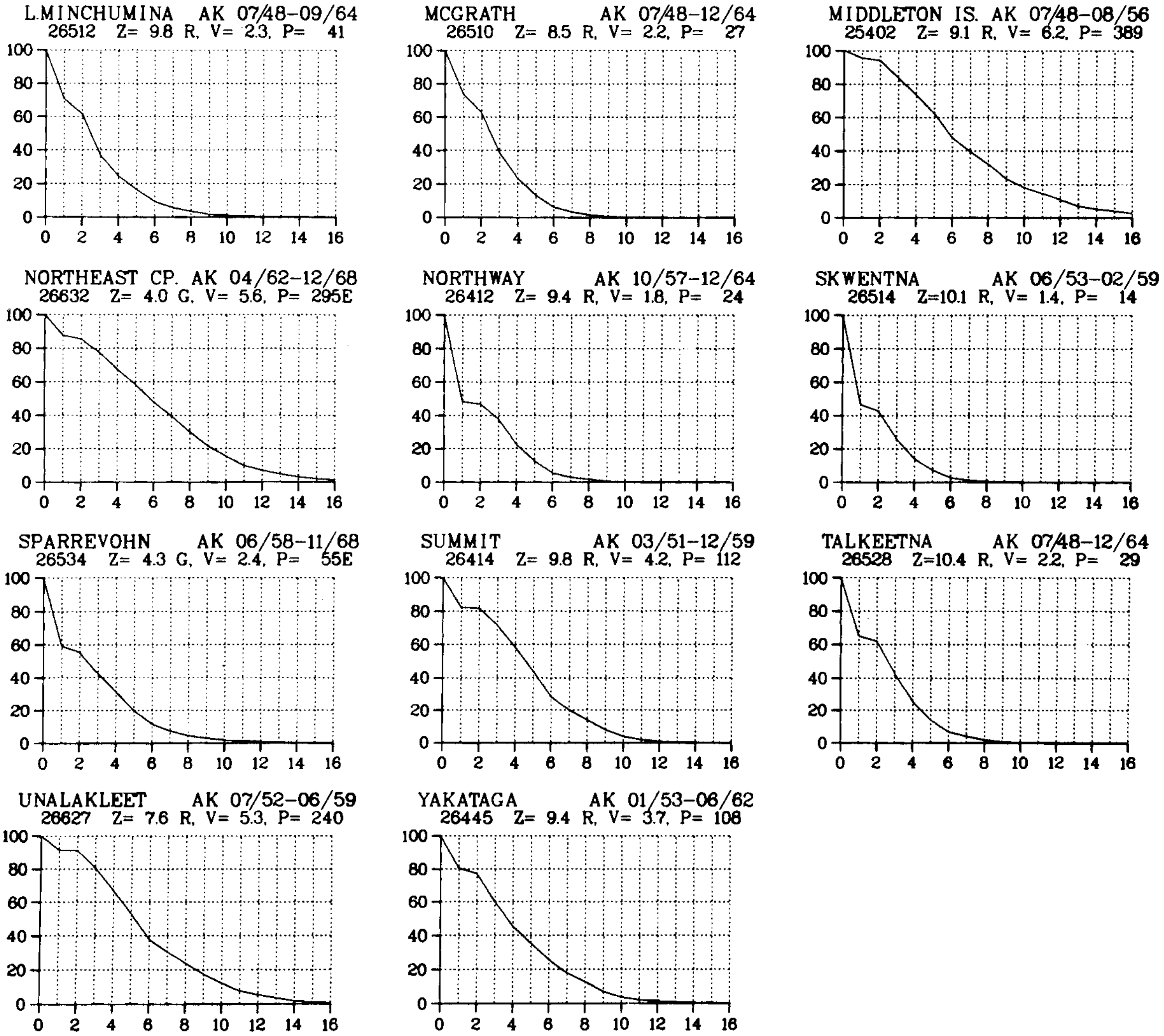


FIGURE 5.15. Annual Average Wind Speed Duration for Southcentral Alaska.

ORDINATE – PERCENT
ABSCISSA – M/S
PNL-3195 WERA-10


L.MINCHUMINA AK 07/48-09/64
26512 Z= 9.8 R, V= 2.3, P= 41

MCGRATH AK 07/48-12/64
26510 Z= 8.5 R, V= 2.2, P= 27

MIDDLETON IS. AK 07/48-08/56
25402 Z= 9.1 R, V= 6.2, P= 389

NORTHEAST CP. AK 04/62-12/68
26632 Z= 4.0 G, V= 5.6, P= 295E

NORTHWAY AK 10/57-12/64
26412 Z= 9.4 R, V= 1.8, P= 24

SKWENTNA AK 06/53-02/59
26514 Z=10.1 R, V= 1.4, P= 14

SPARREVOHN AK 06/58-11/68
26534 Z= 4.3 G, V= 2.4, P= 55E

SUMMIT AK 03/51-12/59
26414 Z= 9.8 R, V= 4.2, P= 112

TALKEETNA AK 07/48-12/64
26528 Z=10.4 R, V= 2.2, P= 29

UNALAKLEET AK 07/52-06/59
26627 Z= 7.6 R, V= 5.3, P= 240

YAKATAGA AK 01/53-06/62
26445 Z= 9.4 R, V= 3.7, P= 108

FIGURE 5.15 (Continued). Annual Average Wind Speed Duration for Southcentral Alaska.

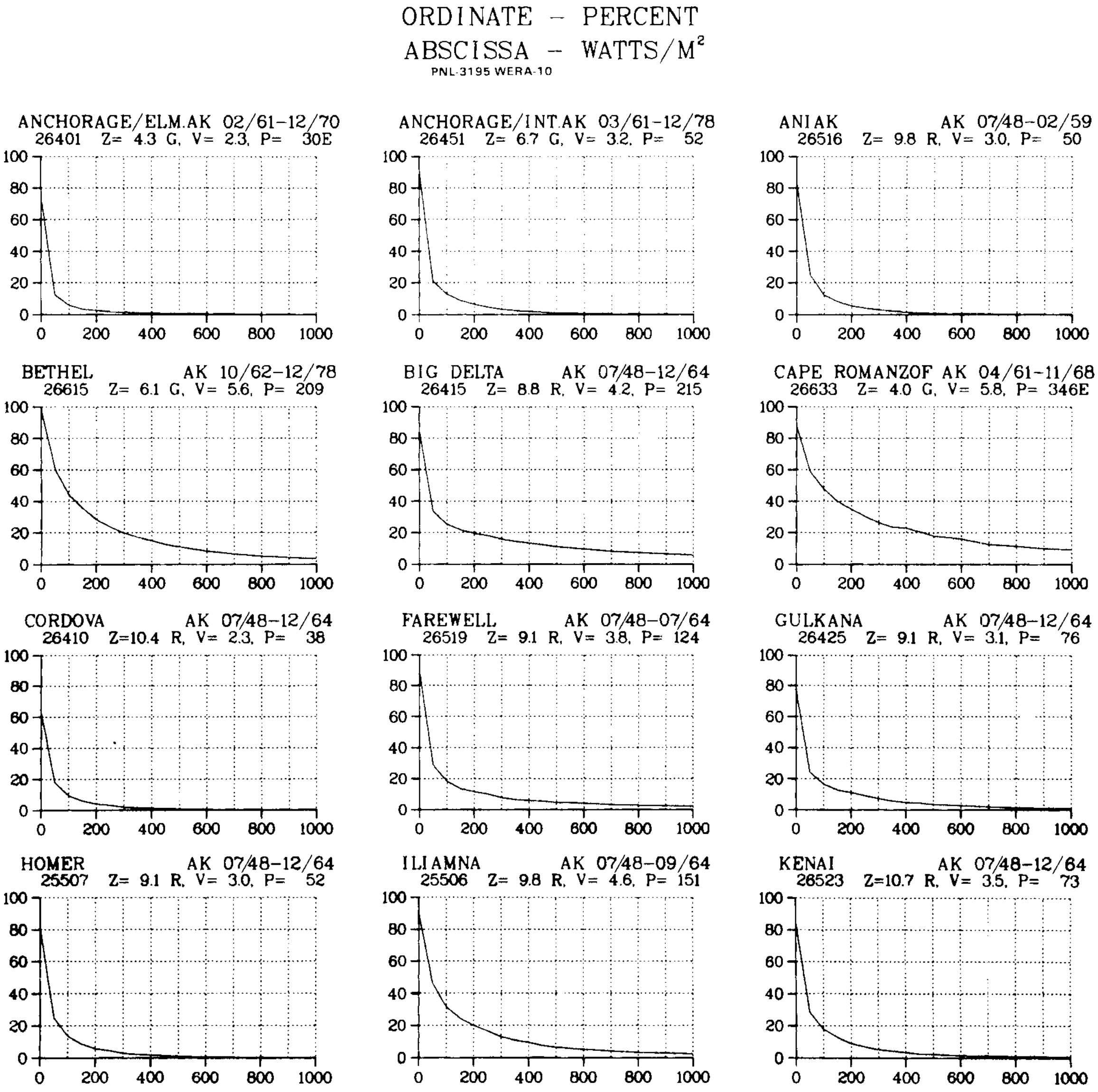


FIGURE 5.16. Annual Average Wind Power Duration for Southcentral Alaska.

ORDINATE – PERCENT
ABSCISSA – WATTS/M^2
PNL-3195 WERA-10

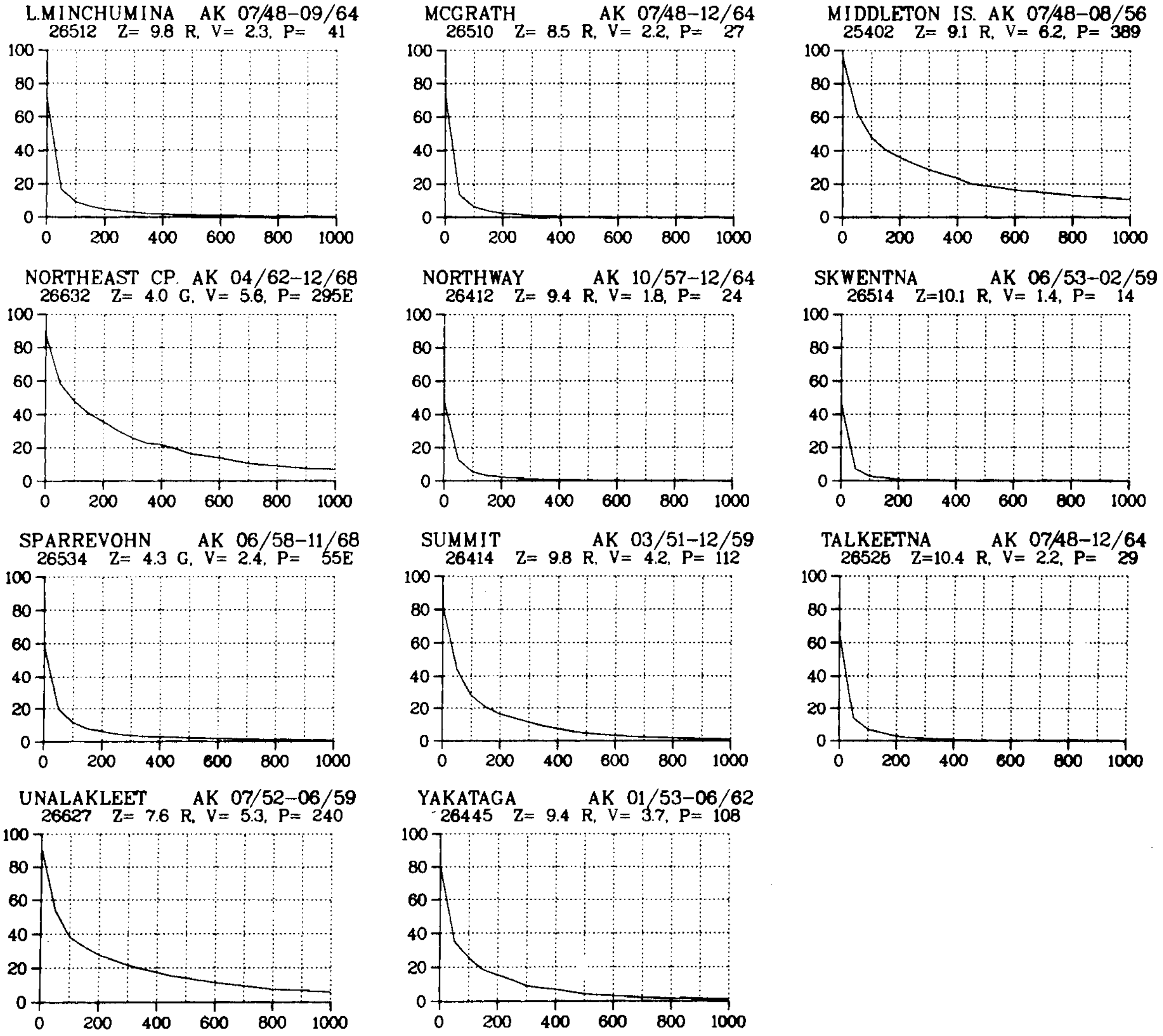


FIGURE 5.16 (Continued). Annual Average Wind Power Duration for Southcentral Alaska.

SOUTHEASTERN ALASKA

CHAPTER 6: SOUTHEASTERN ALASKA

In 1979 southeastern Alaska had an estimated population of 60,967, which is about 1.7 persons per square mile. Most of the population is found along the coast and on the islands that make up about 40 percent of this subregion. (See Figure 6.1). The major population centers are Juneau, Sitka, and Ketchikan. This subregion is 200 km (125 mi) wide and stretches approximately 966 km (590 mi) north from the southern tip of Prince of Wales Island to 141°W, which runs through the Malaspina Glacier. Total surface area is about 92,706 km^2 (35,785 mi^2).

Cross Sound divides the subregion into two parts. To the north the coast is regular but is bordered by a low, hummocky, irregular coastal plain less than 61 m high and covered in part by the Malaspina Glacier, which separates the Coast Mountains from the Gulf of Alaska. South of Cross Sound, the mainland of southeastern Alaska is dissected by an intricate system of fjords forming a complex of mountainous islands with summits 700 to 1,100 m high (see Figure 6.2). These spectacular fjords are believed to be former drainage courses that were eroded and deepened by glaciers and ice currents. On the mainland strip, peaks as high as 3,000 m are frequently found.

The Alexander Archipelago, an extension of the coastal mountains to the north, is about 500 km long and has hundreds of islands. Sixty-five of these exceed 10 km^2 (4 mi^2) and six exceed 2,600 km^2 (1,000 mi^2). From largest to smallest they are Prince of Wales, Chichagof, Admiralty, Baranof, Revillagigedo, and Kupreanof. The islands are separated by a system of marine features such as sounds, straits, canals, narrows, and channels. There are nearly 17,000 km (10,000 mi) of shoreline along the islands and mainland.

The Chatham Trough divides the coastal St. Elias Mountains from the irregularly incised Coast Mountains along the U.S.-Canada border. The Coastal Mountains in southeast Alaska consist of the Fairweather Range, the Alsek Ranges, the Glacier Bay Section, the Chichagof Highland, and the Baranof Mountains (see Figure 6.3). The Fairweather Range, the most rugged in southeastern Alaska, is the coastal extension of the St. Elias Mountains.

The major rivers of the region originate in Canada, apparently as antecedent streams that were able to maintain their courses as the Coastal Mountains were thrust upward. The principal rivers are the Alsek, Chilkat, Klehini, Taku, Whiting, Chichamin, Unuk, Bradfield, Speel, Stikine, and Taiya. The largest drainages are the Stikine River 51,036 km^2 (19,700 mi^2), Alsek River 24,611 km^2 (19,700 mi^2), Taku River 17,358 km^2 (6,700 mi^2), and the Chilkat 3,187 km^2 (1,230 mi^2). Many of these rivers have glaciers at their headwaters. Freshwater lakes vary in size from a few to several thousand acres and in type from coastal marsh to high alpine cirque lakes. Only Harlequin Lake exceeds 25 km^2 (10 mi^2). Water storage is principally in the glaciers and winter snowpack.

Although no permafrost exists at lower elevations, the region contains extensive glaciers. The Malaspina Glacier, one of the largest ice masses on the North American continent, lies at the northwestern extremity of the region. The mountains of the St. Elias Range rise to elevations of 4,267 to 5,791 m from a jagged mass of peaks having elevations of 2,438 to 3,048 m. Interconnected valleys between the peaks are filled with glaciers and ice fields. These ice fields and smaller ones to the southeast feed many streams.

Wind data available from NCC are mostly from stations along the waterways of the inland passage (Figure 6.4). Data from three fire weather stations were used in the calculations for this subregion (Figure 6.5); two from Prince of Wales Island and the other from Chichagof Island. Fire weather data were used only where other reliable data were absent.

6.1 ANNUAL AVERAGE WIND POWER IN SOUTHEASTERN ALASKA

The annual average wind power density in southeastern Alaska is shown in Figure 6.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as 50 to 100% from the assessment value. (See Wegley et al. 1980 for information on terrain features that may increase or reduce wind energy.) In forested or wooded areas the assessment values are representative of large clearings with good exposure to the prevailing strong winds, such as airports. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

In the major portion of the southeast subregion, from Cape Fairweather and Skagway in the north to Dixon Entrance in the south, wind powers range between class 3 and 6 with a small area of class 7 in Lynn Canal (Figure 6.6). In general, there is class 3 and 4 power over the relatively low, wooded islands. Class 5, 6, and 7 powers are located along the outer coast, over the major channels and over high terrain, the latter being generally inaccessible and extremely hostile to both people and equipment. It is suspected that the Taku River valley, the Stikine River valley, Behm Canal, and Portland Canal also have high wind classes, but no data exist from these areas and they are too narrow to depict on Figure 6.6.

Most of the wind power is generated by atmospheric pressure gradients with lowest pressure associated with storms in the Gulf of Alaska and relatively higher pressures over the mainland. The pressure gradient winds tend to blow along the isobars--mostly from the southeast--but in areas of rough terrain the wind will blow almost directly from high to low pressure. Consequently the winds in southeast Alaska tend to blow parallel to the axis of a channel, strait, passage, or valley. In addition to the winds induced by pressure gradients, gravity winds are found in the passes and valleys leading into the interior. Gravity winds are caused by dense (cold) air flowing into an area of less dense air. Gradient winds and gravity winds can work together to create very strong winds. These conditions account for the class 7 winds in Lynn Canal and the probable strong but unconfirmed winds in the Taku Inlet, Stikine River, Behm Canal, and Portland Canal.

6.1.1 Certainty Rating of the Wind Resource

The wind power estimates of southeast Alaska have a rather uniform certainty rating of 2 (Figure 6.7). The three major criteria for determining certainty ratings are data quantity, terrain complexity, and resource variability. The entire subregion has extremely complex terrain; surface data are mostly from sheltered locations and the analysis is primarily based on ridge crest estimates.

6.1.2 Areal Distribution of the Wind Resource

The areal distribution of wind power in southeast Alaska is illustrated in Figure 6.8. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds some threshold value. Wind power class 4 or higher is estimated to occur in 48% of the grid cells in southeast Alaska, primarily along the Gulf of Alaska coast and in the mountain summits and ridge crests of the Coast Mountains paralleling the Alaska-Canada border, and the higher elevations of Baranof, Admiralty, and Kupreanof Islands. Since the entire subregion has high relief, only about 1% of the area is estimated to have wind power class 4 or higher (see Table 6.1). U.S. Coast Guard stations in Lynn Canal and Frederick Sound indicate that exposed areas along these waterways and Chatham Strait will have the higher wind power classes. Exposed locations all along the coast of the Gulf of Alaska are estimated to have class 4 to 7 wind power. More than 98% of the subregion is estimated to be of wind power class 1 to 3 because of the high topographic relief.

6.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 6.9. Winter is the season of maximum wind power, and autumn is a close second. Juneau and Ketchikan report an autumn maximum, but all other sites report a winter maximum. The highest to lowest wind power seasons are winter, autumn, spring, and summer.

6.2.1 Winter

Wind power is highest during the winter; class 4 to 7 powers are encountered. The highest classes (6 and 7) occur near sea level because of the combined effects of gravity and pressure gradients and stronger pressure gradient winds from above 1,520 m. The intermediate area has power between class 4 and 6 in exposed areas, primarily as a result of pressure gradient winds. Winter conditions in southeastern Alaska are almost completely opposite those in interior Alaska. In interior Alaska the valleys fill with very cold, stable, and stagnant air because of radiation and drainage. In southeastern Alaska the valleys are mostly filled with relatively warm seawater, causing unstable conditions in the lower portion of the atmosphere and, consequently, stronger surface winds. As a result some of the highest wind powers occur over and adjacent to waterways. The most notable waterways for high wind power are Chatham Strait and Lynn Canal. Others are Icy Strait, Cross Sound, Sumner Strait, Frederick Sound, Clarence Strait, and Dixon Entrance. Although no data are available, Taku Inlet, Stikine River, Behm Canal, and Portland Canal probably experience similar wind conditions.

6.2.2 Spring

In the spring wind power ranges between class 2 and 6; class 5 and 6 is generally restricted to terrain above 900 m. Thus, the effective class range is generally from

2 to 4. Pressure gradient winds and drainage winds are less frequent than in winter, but some low level maxima are still evident over the waterways. These low-level maxima are considerably less than winter maxima but still account for class 4 power. In fact a few small areas of class 5 exist at the seaward entrances to Chatham Strait, Sumner Strait, Clarence Strait, and Cross Sound. In summary, spring wind power, lower than that found in winter, can be attributed to the weaker pressure gradients, very weak gravity winds, and more stability in the low layers of the atmosphere that occur in spring.

6.2.3 Summer

Summer wind power classes are mostly 1 or 2 with a possiblity of a class 3 on very exposed locations along the outer coast and near Dixon Entrance. The low classes are a result of low pressure gradients, stable conditions, and very weak and erratic gravity winds. Average wind power is less than that in spring and much less than that in autumn.

6.2.4 Autumn

Autumn wind classes are high--generally 4 to 7--with a few areas of class 3 in the northern portion. The class average is about one class lower than winter. The highest powers (class 5 to 7) are over the higher terrain. Classes 4 to 6 prevail over the major waterways and adjacent exposed locations. The exposed areas near Dixon Entrance may experience class 7. The high wind powers can be attributed mainly to strong pressure gradients associated with autumn storms.

6.3 FEATURES OF SELECTED STATIONS

Graphs of wind characteristics are shown for seven stations. Characteristics of these stations are summarized in Table 6.2.

Annette Island Airport winds are quite representative of winds over southern southeast Alaska because the airport is on a relatively large piece of flat land in an exposed location. This station would not accurately represent the wind power available at nearby Ketchikan, which is relatively sheltered, or at other communities that are quite sheltered. Strongest and most frequent winds are from the southeast.

Juneau Airport wind speeds are reasonably representative of the Juneau-Gastineau Channel area. The most frequent sustained winds are from the southeast and east-southeast, caused by funneling through Gastineau Channel. Because of the extremely rough terrain in the Juneau area, winds and wind powers vary from a little higher than those at the airport to considerably lower than those at the airport.

Gustavus Airport, although on an unusually large tract of flat land, is quite sheltered by high mountains in all directions except from the south. The most common strong winds are from the southeast. It is representative of the habitable area from Icy Strait northward. Icy Strait and Pleasant Island, which lie to the south, have much higher wind values although the values are not known. Icy strait is subjected to strong sustained easterly and southeasterly winds.

Petersburg is in a very sheltered location and is not representative of the stronger winds found on nearby ridges or exposed locations along Frederick Sound. Wind speeds on nearby ridges and exposed locations are probably a little higher than those at the Juneau Airport. Strong winds tend to be south-southeasterly.

Haines, located in the northern, inside portion of southeast Alaska, is in a relatively well protected area and is not representative of wind speeds nearby. Chilkat Inlet, oriented approximately north-south on either side of Haines, is subjected to strong northerly winds in the winter and to brisk southerly sea breezes in the summer. The terrain is very rough. The most frequent and sustained winds at Haines are from the south-southeast.

Sitka, although close to the outer coast of central southeast Alaska, is in a relatively sheltered area. Sitka Sound lies to the south and west and rough terrain lies to the east and north. Wind values are lower than one might expect. Higher wind values probably occur on the numerous small islands in Sitka Sound, and considerably higher values probably occur on nearby ridges. Strongest winds are from the southeast.

Yakutat Airport is representative of most of the habitable land along the east coast of the Gulf of Alaska between Dry Bay and Icy Cape. The wind speeds are much lower than one might expect. This is caused by the very high mountain range that parallels the coast and rises from sea level to 3,000 m within 48 km of the coast. Mountain peaks rise to nearly 6,000 m. Exposed areas along the immediate coast may have higher wind speeds. The strongest winds at Yakutat are from the southeast.

6.3.1 Interannual Wind Power and Speed

The interannual wind power and speed (Figure 6.10) varied considerably between stations; Annette Island has the highest values and Petersburg has the lowest. This variability is attributed more to the differences in exposure of the two locations than to a difference in climatic conditions. In addition, peak years of wind power did not necessarily coincide between stations. For instance, Annette had high values of wind power between the years 1952 and 1956 with a peak in 1954. Yakutat had high wind values in 1952 and 1956 but had a minimum in 1954. The ratio of highest annual wind power to lowest annual wind power at any one station was greatest at Juneau (2.66); however, the greatest interannual variability at any one station was at Annette, where it varied between a minimum of 130 W/m^2 to a maximum of 270 W/m^2 for a difference of 140 W/m^2. Wind powers approaching those at Annette and Juneau are probably attainable over most of southeast Alaska in exposed locations.

6.3.2 Monthly Average Wind Power and Speed

At most locations, maximum wind power and speed occurred from October through March (Figure 6.11). All stations exhibited relatively constant values during those months except Yakutat and Haines, which had sharp peaks during January. The monthly wind and power averages from Annette and Juneau should be considered the most representative of exposed areas throughout southeast Alaska. At those stations the wind reaches a near maximum during the month of October and remains high through December, drops off a little during January, rises to another peak in February, and then drops steadily to a minimum in July.

6.3.3 Diurnal Wind Speed by Season

Diurnal variations of wind speed (Figure 6.12) are greatest during the summer months with maximum variations of near 2 m/s at Juneau, Gustavus, Haines, and Sitka. Yakutat varied by 3 m/s. The maximum winds occurred at 1500 hours, and the minimum winds occurred between midnight and 0500 hours. Winter variations were the least; no station reported a diurnal variation of 1 m/s or more. Spring and autumn had some significant diurnal variations, ranging between 1 and 2 m/s at all locations.

6.3.4 Directional Frequency and Average Speed

The prevailing direction at all stations except Petersburg is southeasterly, varying from easterly at Yakutat to south-southeast at Haines (Figure 6.13). Average wind speed was highest from these directions. Petersburg reported prevailing winds from the west-southwest and from the east-southeast, with the west-southwest winds being slightly more predominant. However, the maximum wind speeds were reported to be from the south-southeast. Petersburg is in a very unusual topographic location, and it is this location to which we can attribute wind records quite different from those of other stations.

6.3.5 Annual Average Wind Speed Frequency

The actual wind speed distribution (Figure 6.14) clearly depicts one of the shortcomings of the wind speed observational program in that speeds of 1 m/s are rarely reported. This can be attributed to observer bias and low instrument threshold speeds. Consequently the actual wind speed curve does not approximate well with the Rayleigh speed distribution curve in the lower wind ranges between 0 and 2 m/s. Disregarding the low-level anomalies in the actual distribution curve, the actual curve at Annette Island approximates very closely the Rayleigh curve. Juneau, Yakutat, Gustavus, and Petersburg are also reasonably close to the Rayleigh curve. However, both Haines and Sitka are considerably below Rayleigh curve estimates in the 3 and 4 m/s range. There is no obvious explanation for the anomalies at this particular speed range. Wind speeds of 2 m/s are reported with the greatest frequency, and this is particularly true of Petersburg, which reports a 2 m/s wind speed about 40 percent of the time. Here again, it seems obvious that Petersburg should not be used as guidance for determining general wind power availability in southeast Alaska.

6.3.6 Annual Average Wind Speed and Power Duration

Annette, Juneau, and Haines have the highest percent of stronger winds (Figure 6.15 and 6.16), and since wind energy is generated most effectively above 8 m/s, the wind power duration curves at these locations are quite favorable. In fact, in terms of wind power duration, Haines is the most effective, generating 200 W about 20% of the time and 400 W approximately 10% of the time. This is slightly better than both Annette and Juneau and considerably better than all the other locations. The wind power duration results at Haines indicate that favorable locations for wind generators would be in exposed areas along major channels and passages such as Chilkat Inlet, Lynn Canal, and Chatham Strait. Annette Island and Juneau indicate that wind power generation is favorable in most of southeastern Alaska in exposed locations.

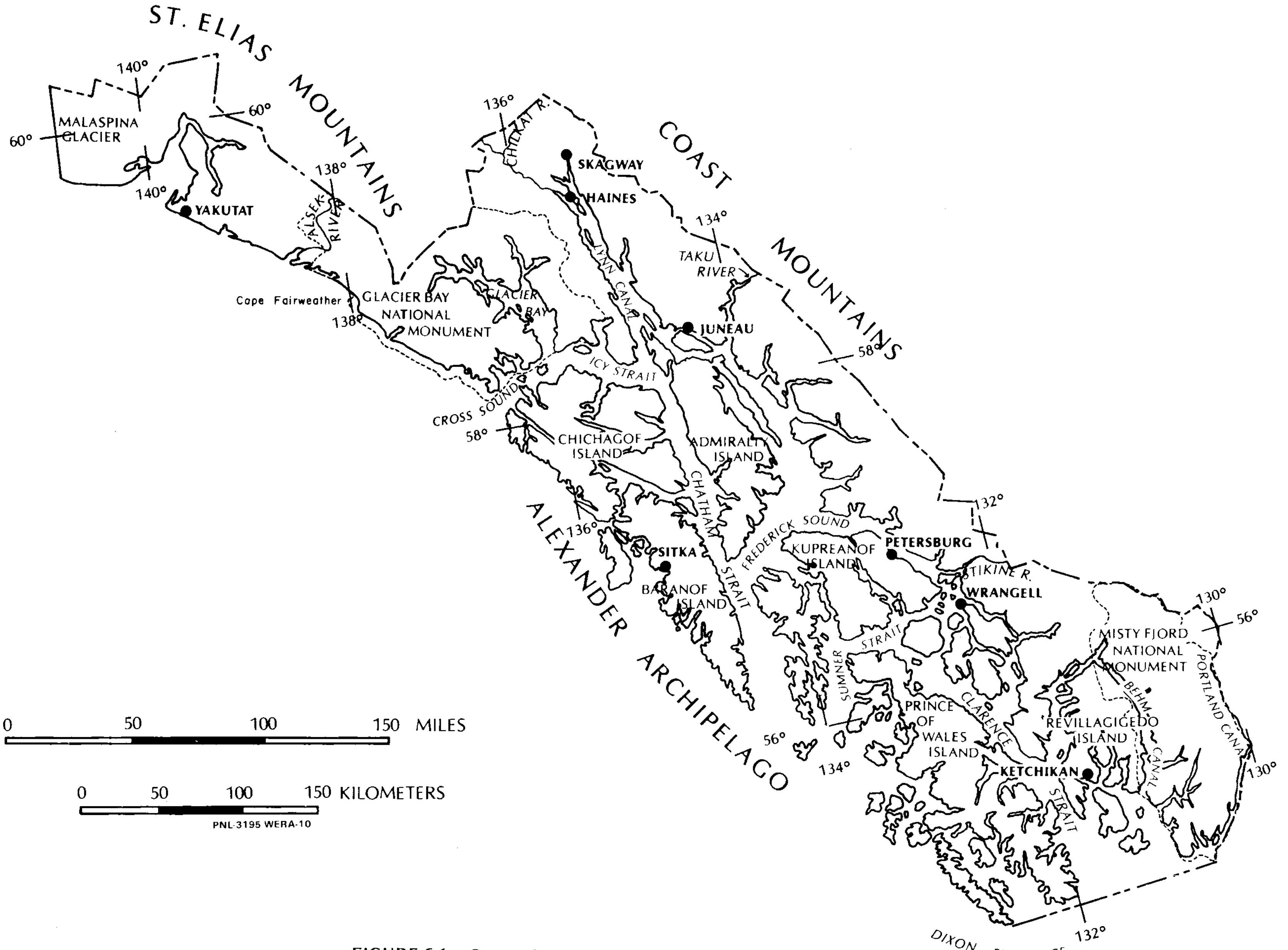


FIGURE 6.1. Geographic Map of Southeastern Alaska

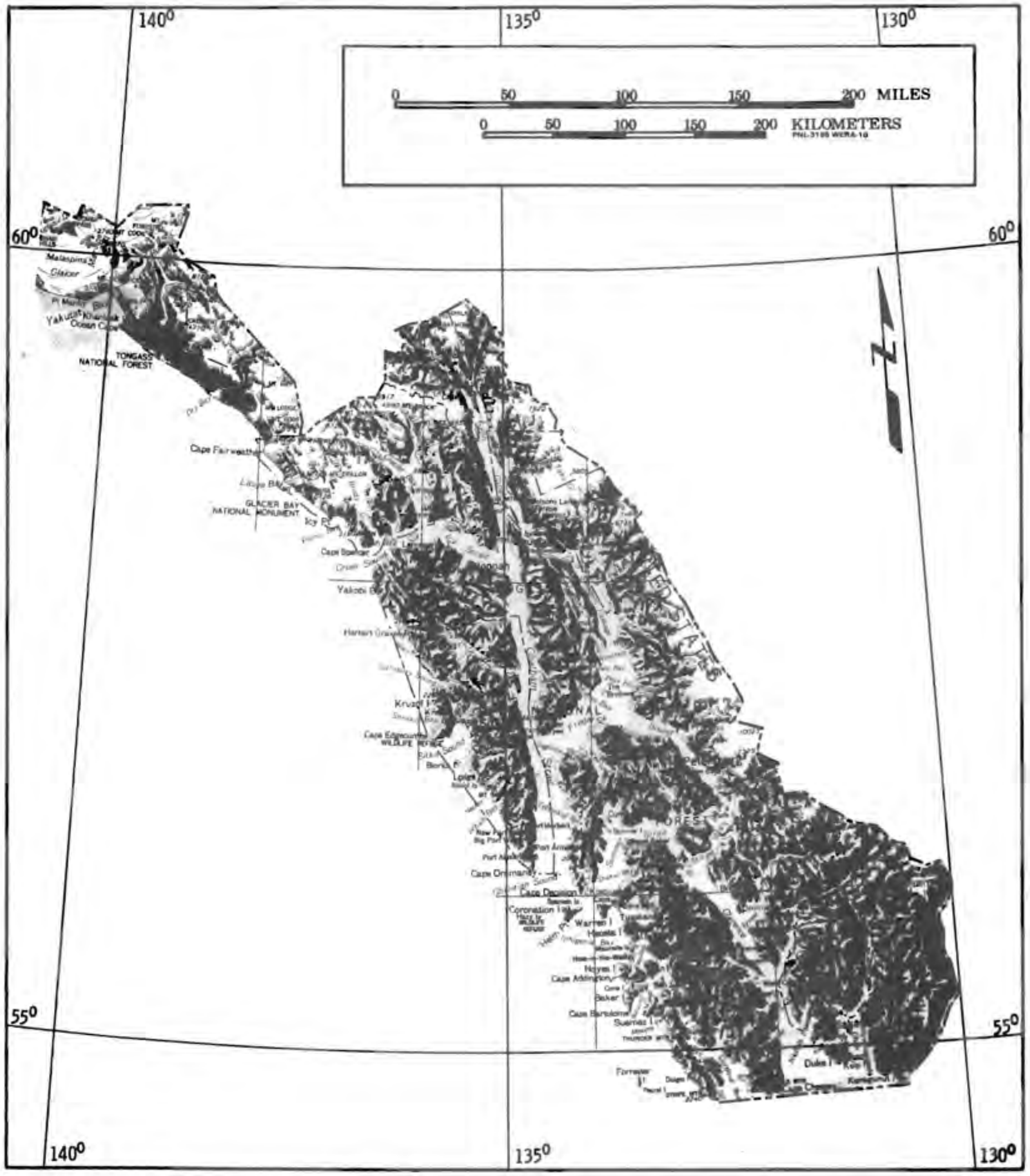


FIGURE 6.2. Topographic Map of Southeastern Alaska

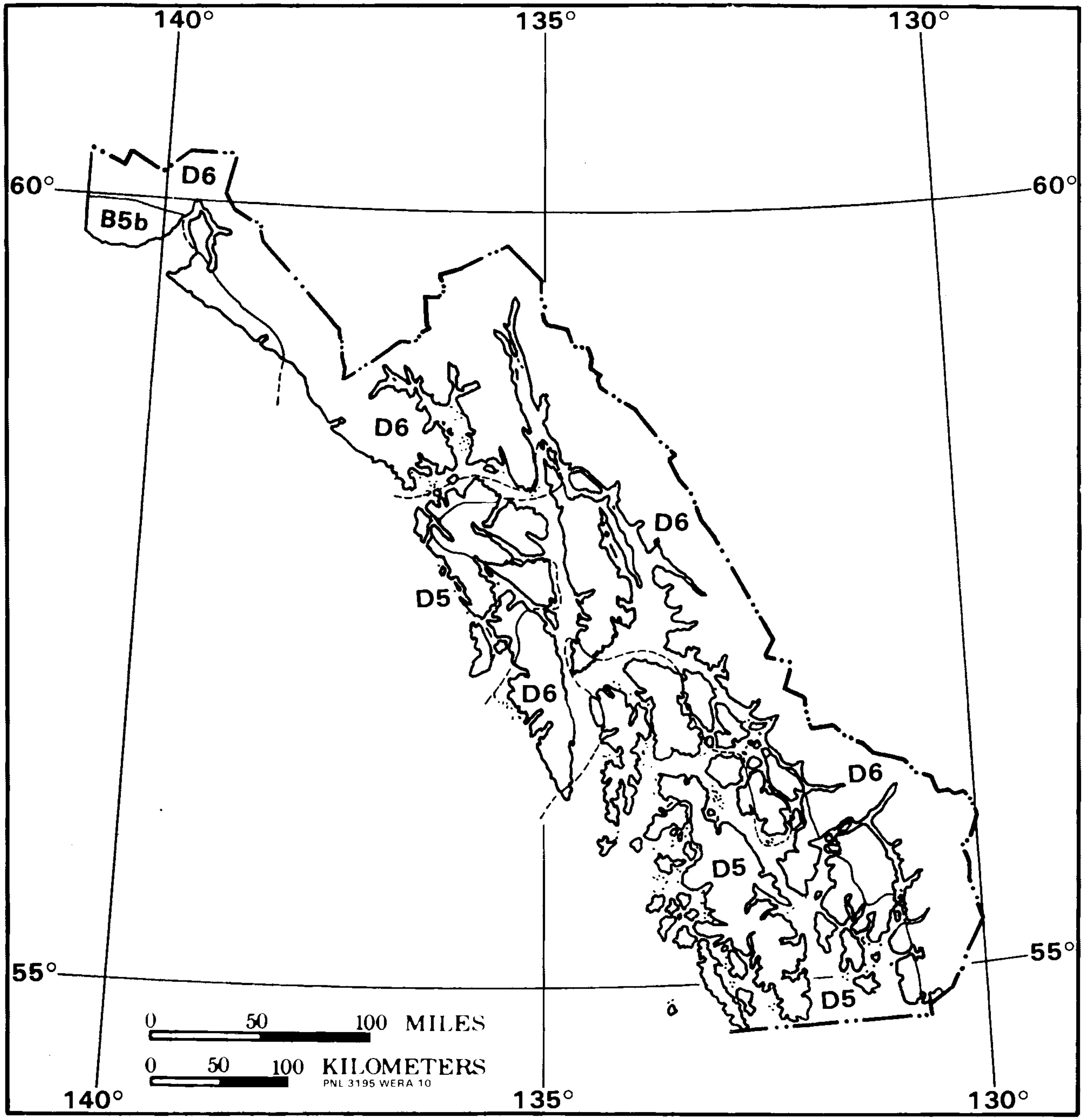


FIGURE 6.3. Land-Surface Form Map for Southeastern Alaska

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

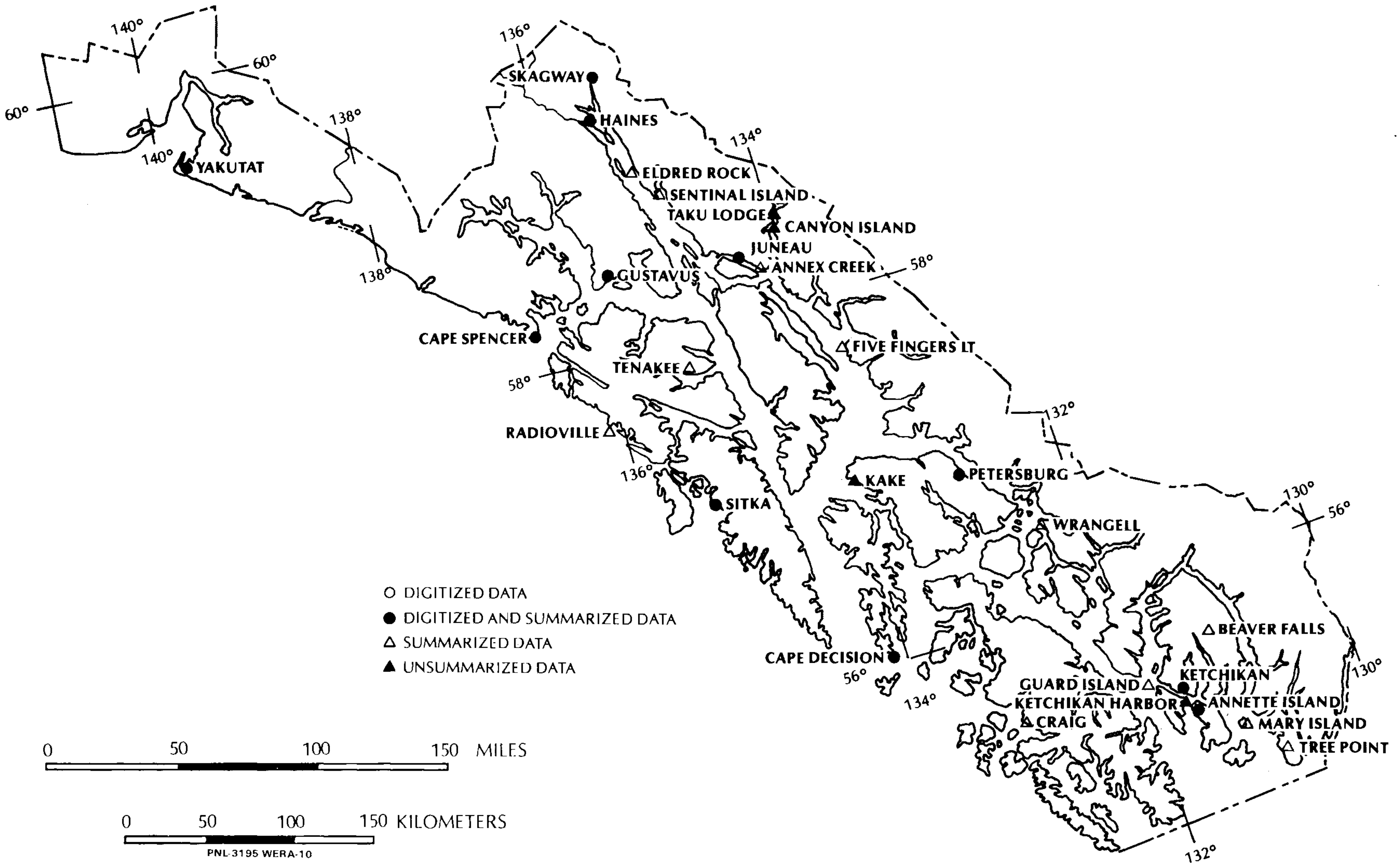


FIGURE 6.4. NCC Station Locations in Southeastern Alaska

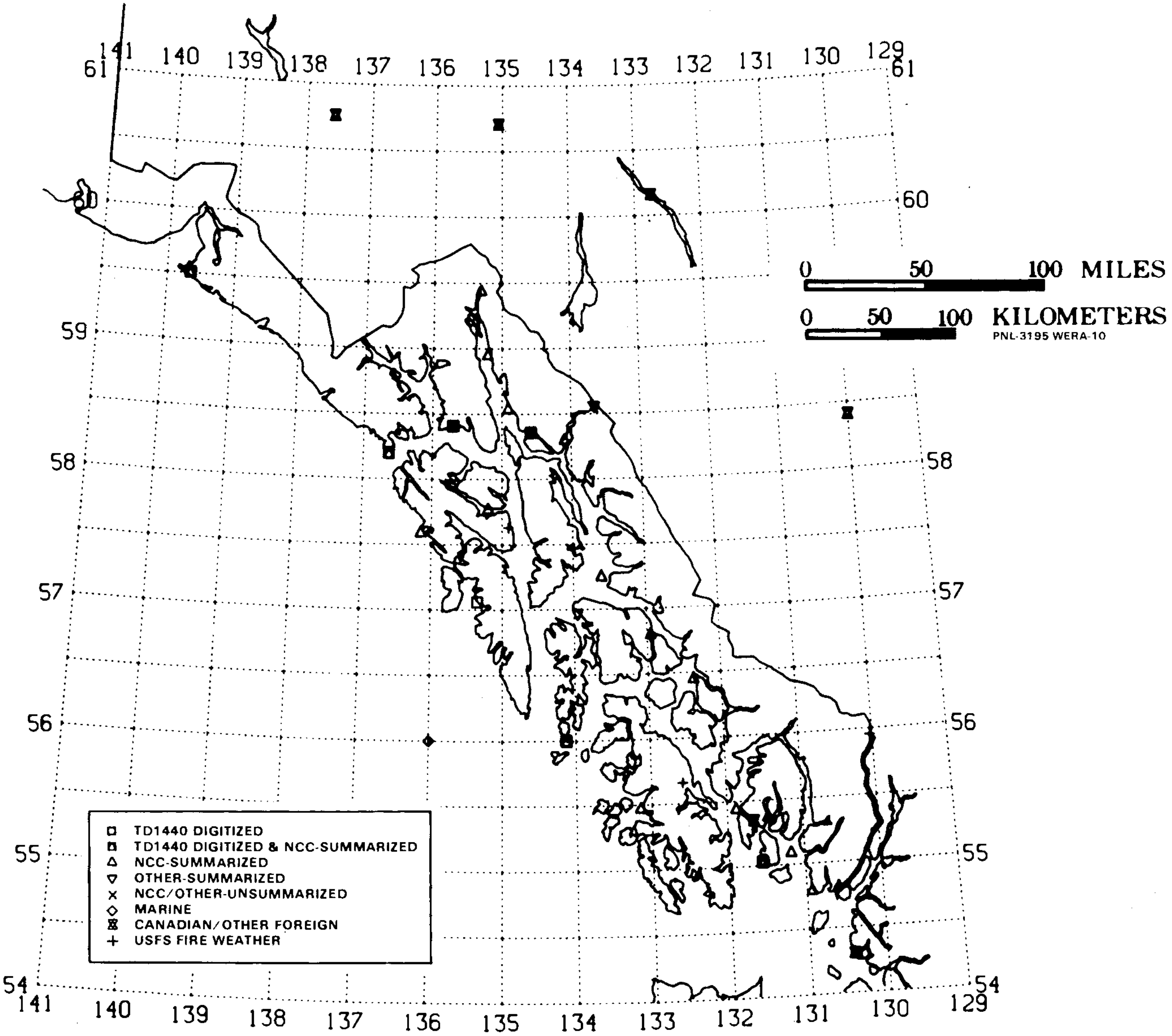


FIGURE 6.5. Location of Stations Used in Southeastern Alaska Resource Assessment

Classes of Wind Power Density at 10 m and 50 m(a)

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, $watts/m^2$	Speed,(b) m/s (mph)	Wind Power Density, $watts/m^2$	Speed,(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a) Vertical extrapolation of wind speed based on the 1/7 power law.

(b) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 6.1. Areal Distribution (km^2) of Wind Power Classes in Southeast Alaska

Power Class	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	85,000	97	88,000	100
2	1,100	1.2	3,000	3.5
3	900	1.1	2,000	2.2
4	700	0.80	1,000	1.1
5	300	0.33	300	0.34
6	12	0.01	12	0.01
7	0	0.00	0	0.00

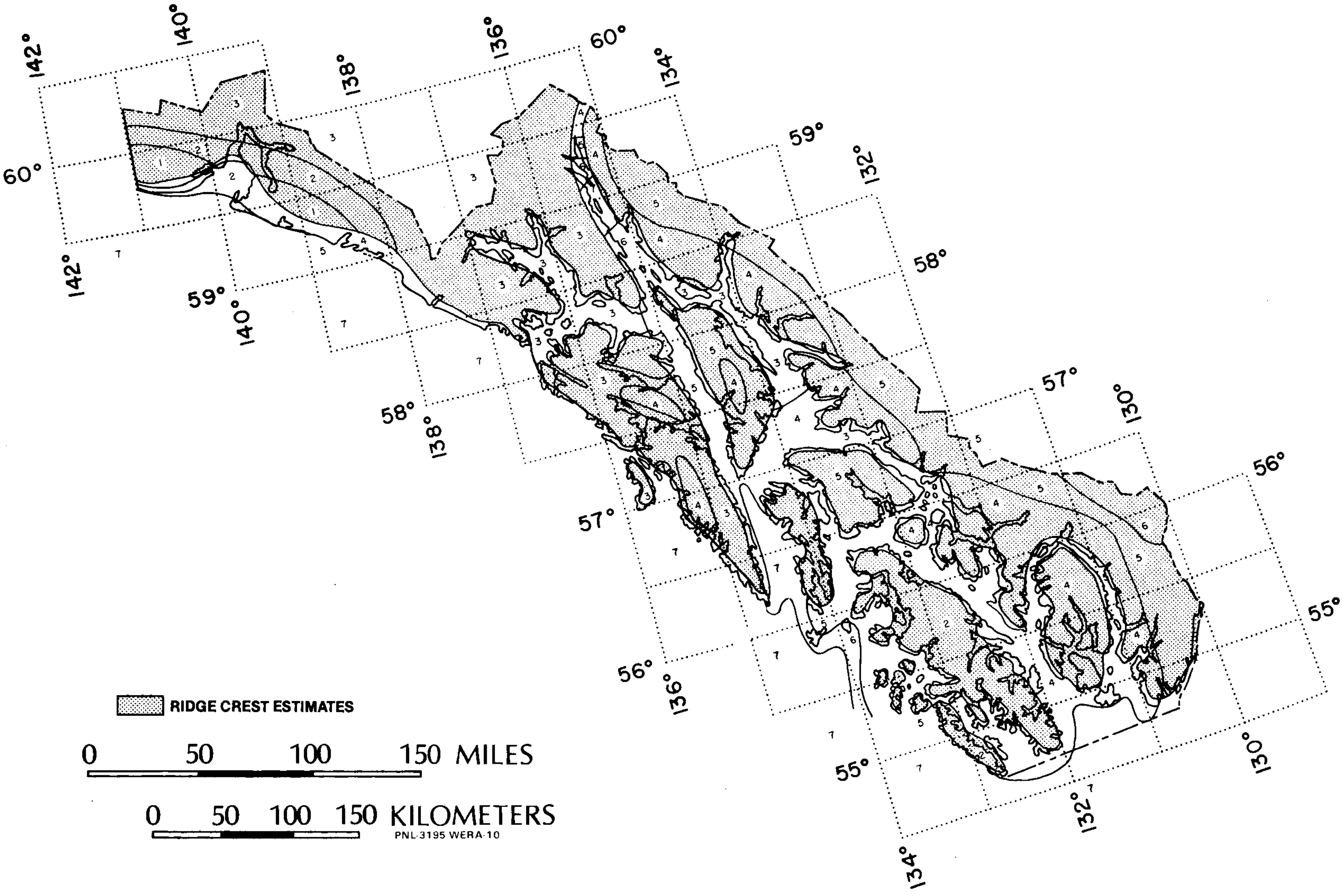


FIGURE 6.6. Southeastern Alaska Annual Average Wind Power

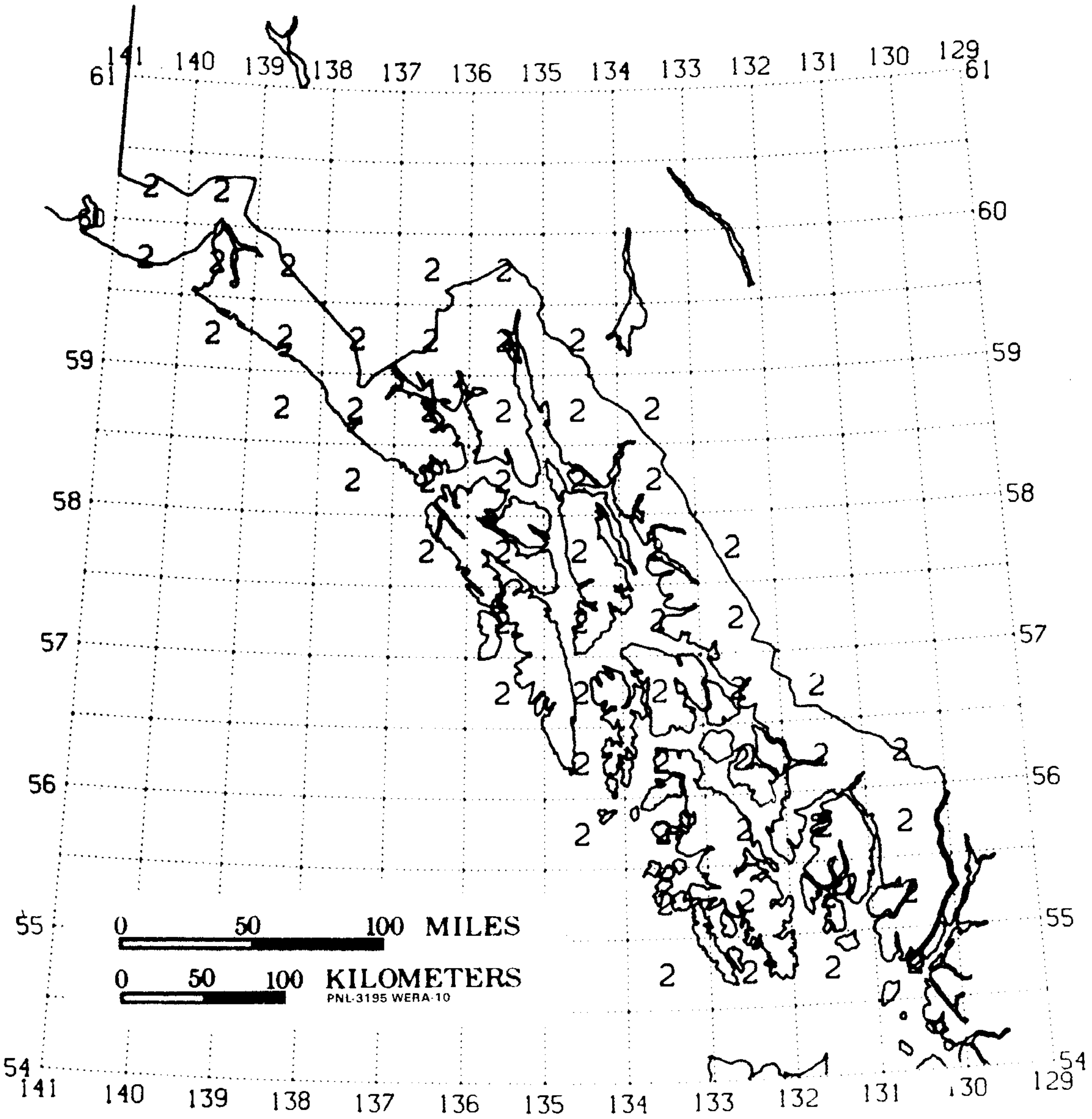
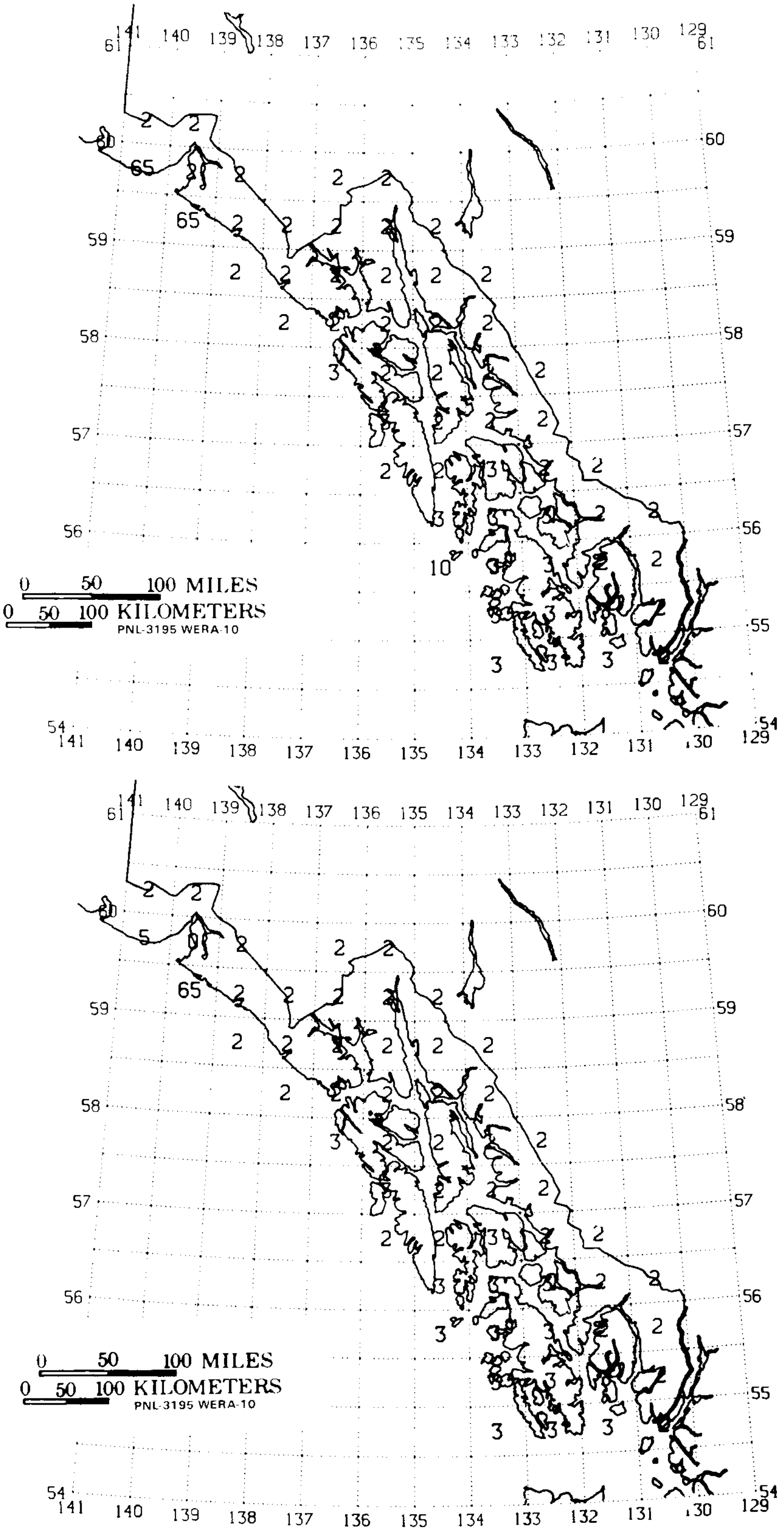


FIGURE 6.7. Certainty Rating of Southeast Alaska Wind Resource.

CERTAINTY RATING LEGEND

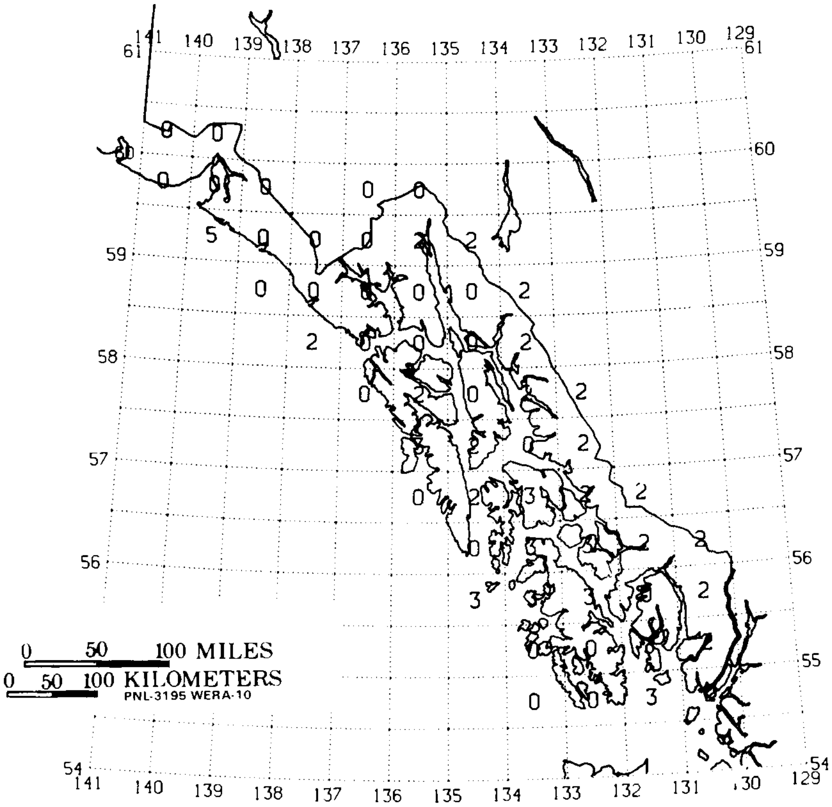
Rating	Definition
1	The lowest degree of certainty. A combination of the following conditions exists: 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	A low-intermediate degree of certainty. One of the following conditions exists: 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	A high-intermediate degree of certainty. One of the following conditions exists: 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.



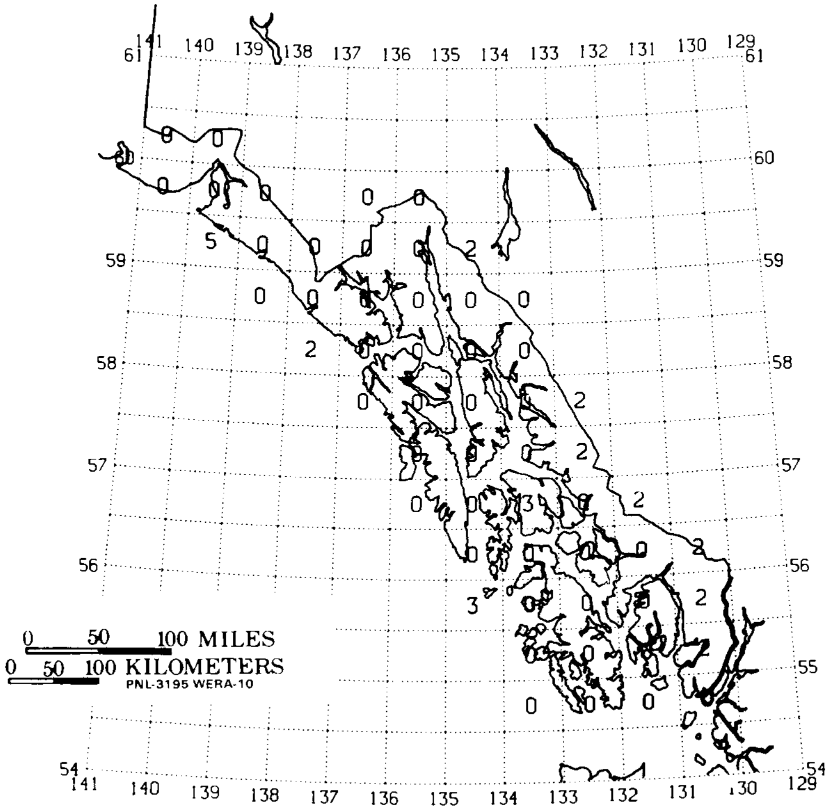
Class 2

Class 3

FIGURE 6.8. Areal Distribution of Wind Resource in Southeast Alaska (Power Classes 2 and 3); Percent of Land Area With or Exceeding Power Class Shown.



Class 4



Class 5

FIGURE 6.8 (Continued). Areal Distribution of Wind Resource in Southeast Alaska (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown.

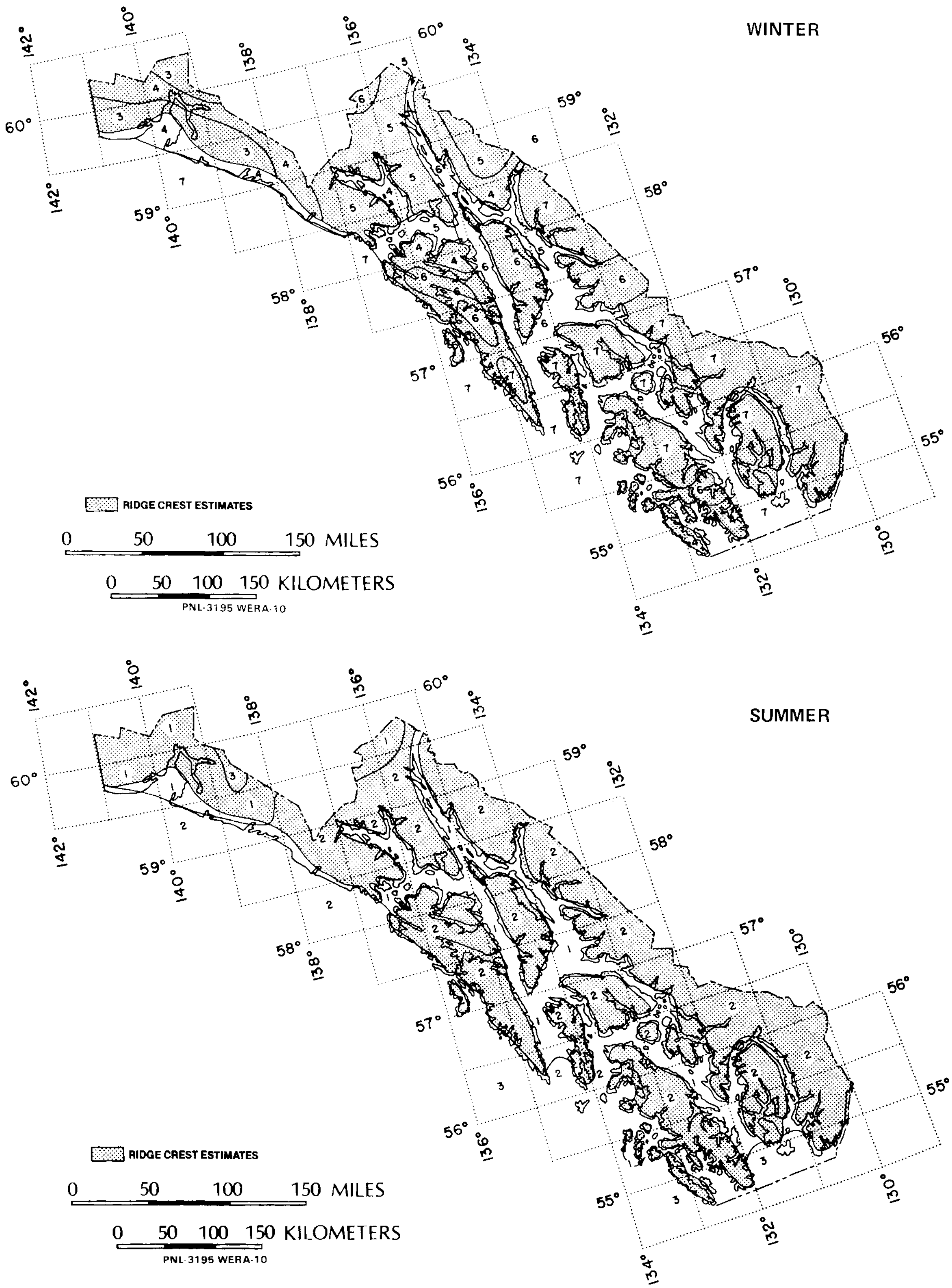


FIGURE 6.9. Seasonal Average Wind Power in Southeastern Alaska (Winter, Summer)

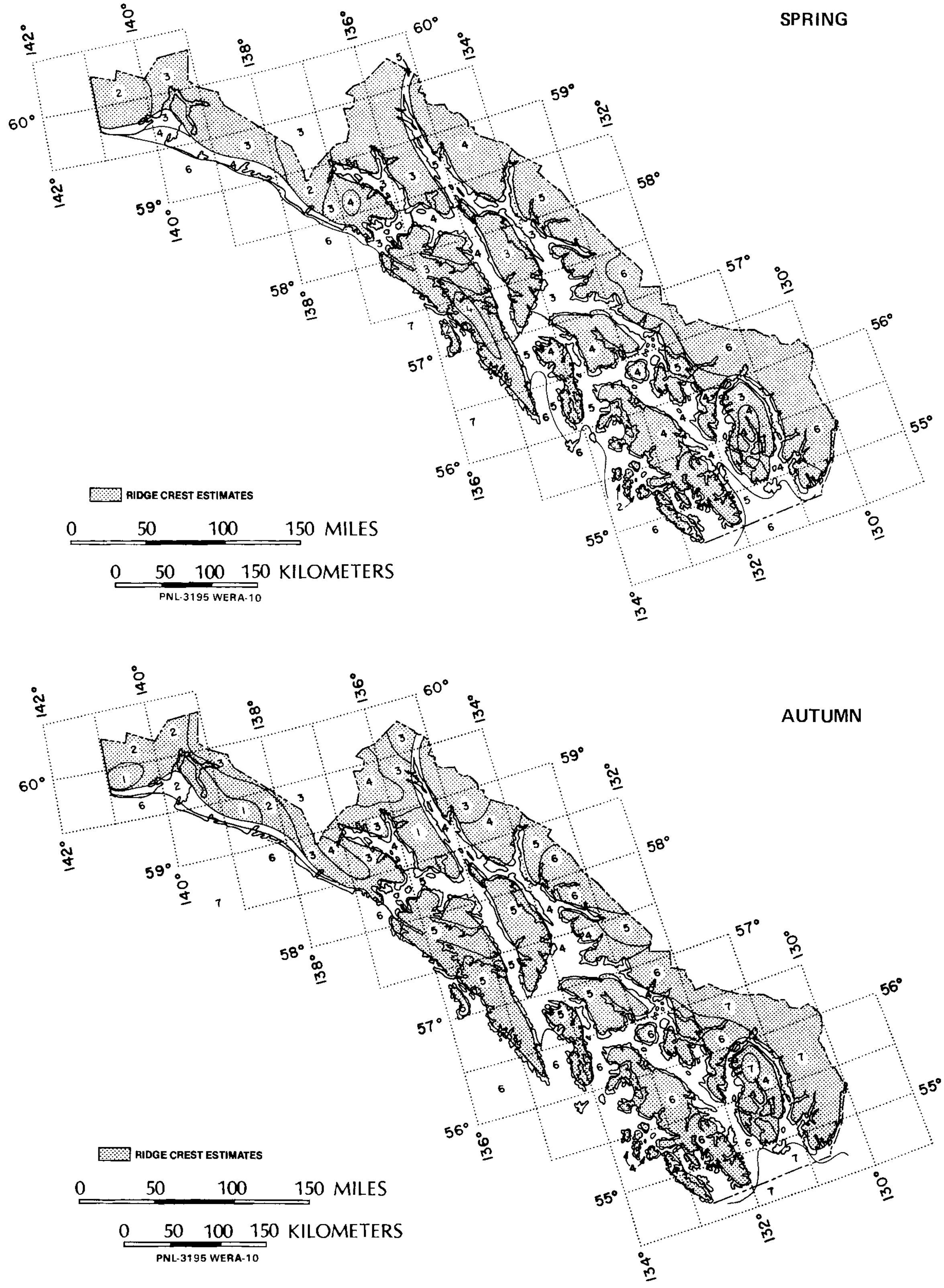


FIGURE 6.9 (Continued). Seasonal Average Wind Power in Southeastern Alaska (Spring, Autumn)

TABLE 6.2. Southeastern Alaska Stations with Graphs of the Wind Characteristics.

							Annual Average Wind Speed, m/s			Annual Average Wind Power, W/m^2		
Station ID	**Station Name**	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Annette Island	Annette Airport	55.0	131.6	33.5	03/60-12/78	6.1	4.5	4.8	6.0	128	158	315
Gustavus	Gustavus FAA	58.4	135.7	8.8	07/48-09/64	9.8	3.2	3.2	4.0	68	69	132
Haines	Haines CAA	59.2	135.4	78.3	07/48-07/53	10.7	4.1	4.1	5.1	124	121	240
Juneau	Juneau Airport	58.4	134.6	6.1	04/59-12/78	11.3	4.0	4.0	5.0	121	115	229
Petersburg	Petersburg Airport	56.8	133.0	33.8	07/48-04/56	10.7	2.6	2.6	3.2	37	36	72
Sitka	Sitka FAA	57.1	135.4	20.1	07/48-05/58	21.6	3.4	3.0	3.8	113	81	162
Yakutat	Yakutat WBAS State Airport	59.5	139.7	9.4	11/58-12/64	10.4	3.5	3.4	4.3	82	81	161

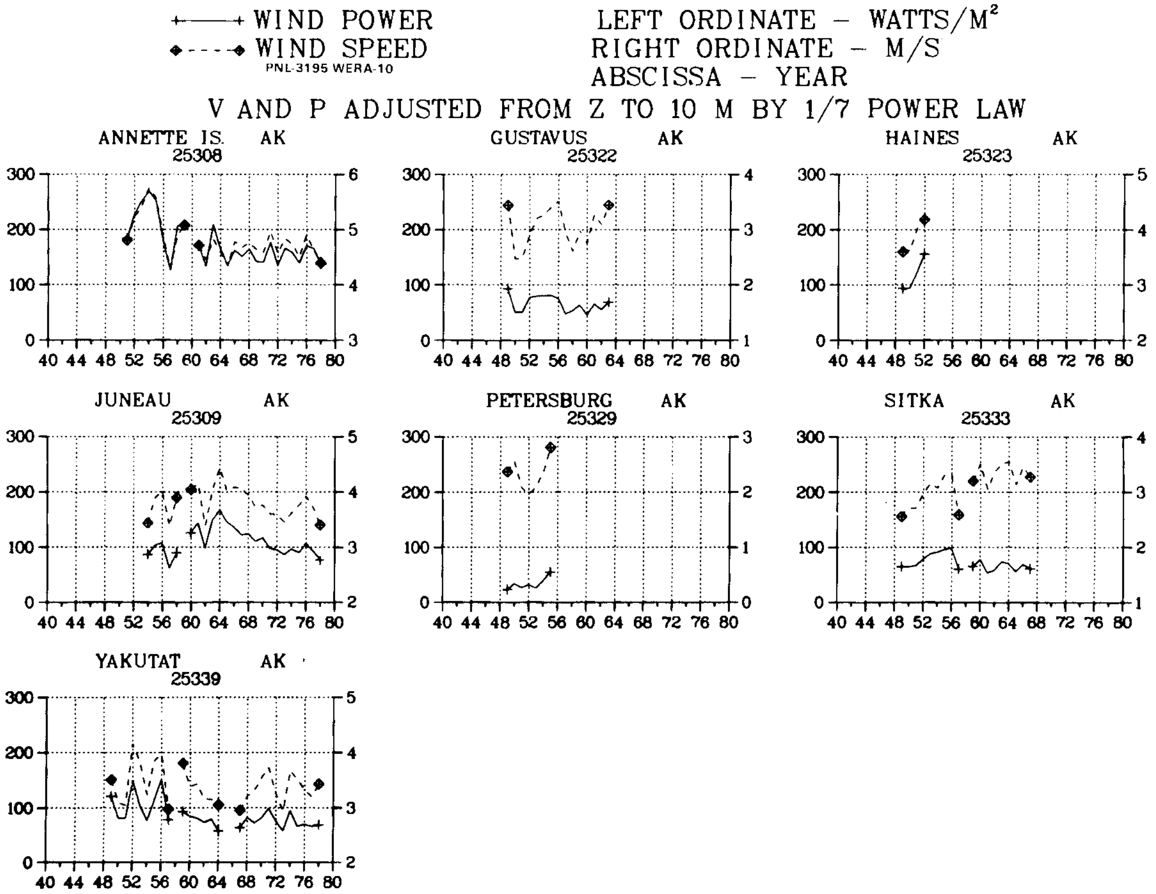


FIGURE 6.10. Interannual Wind Power and Speed for Southeastern Alaska

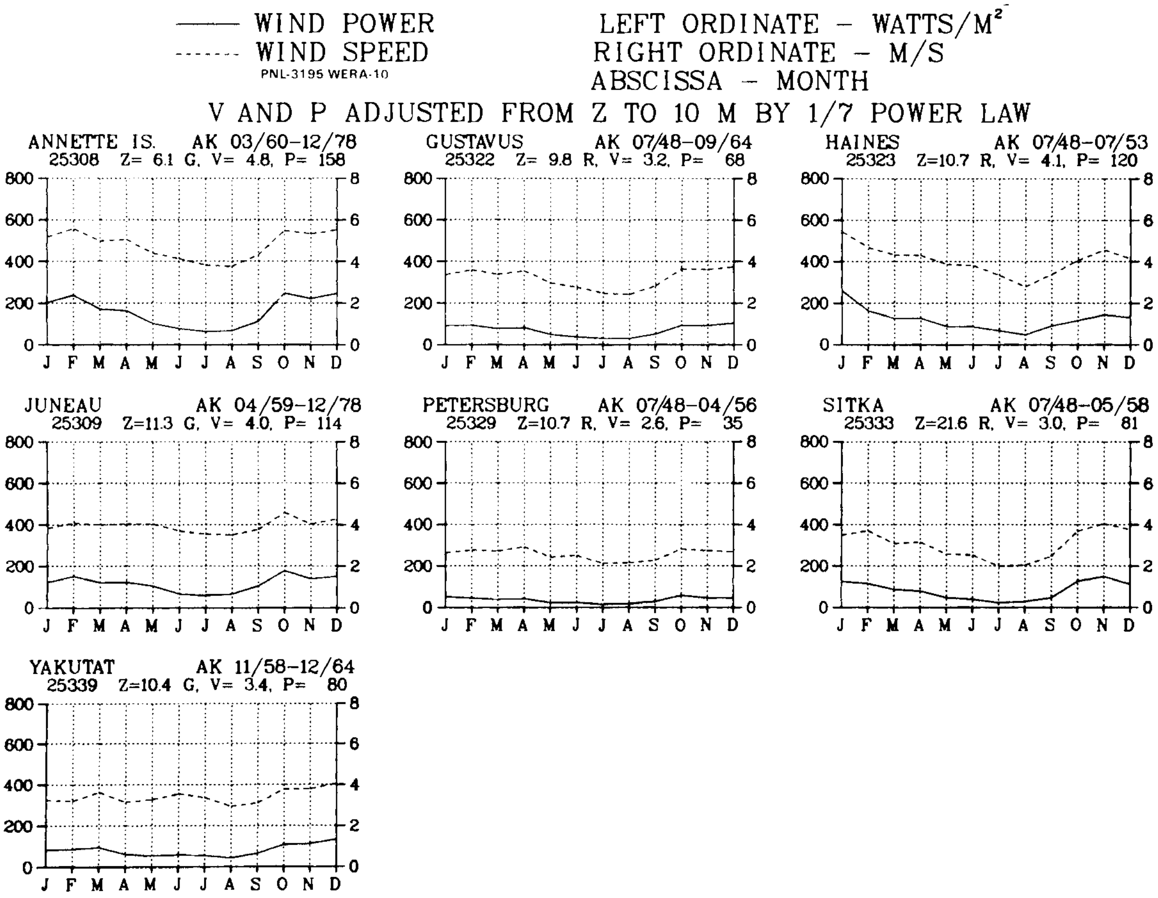


FIGURE 6.11. Monthly Average Wind Power and Speed for Southeastern Alaska

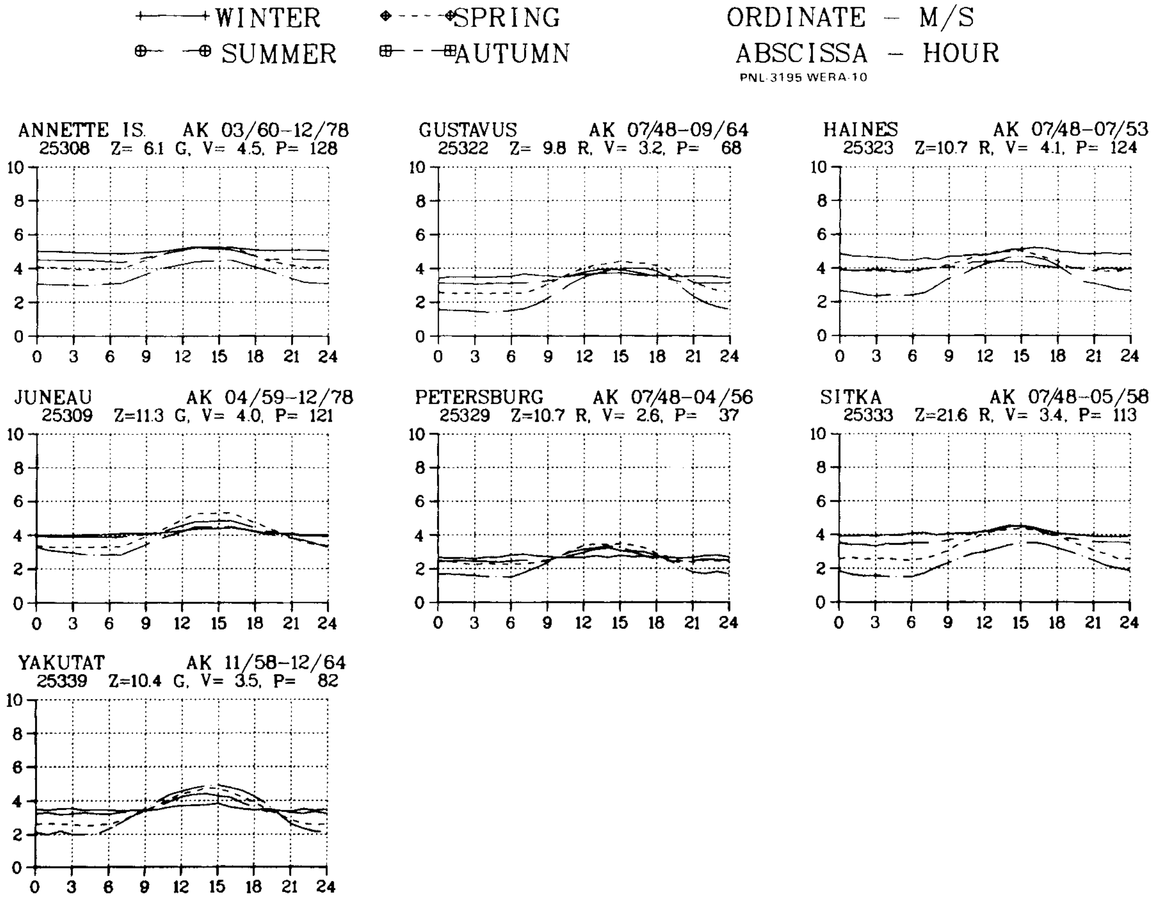


FIGURE 6.12. Diurnal Wind Speed by Season for Southeastern Alaska

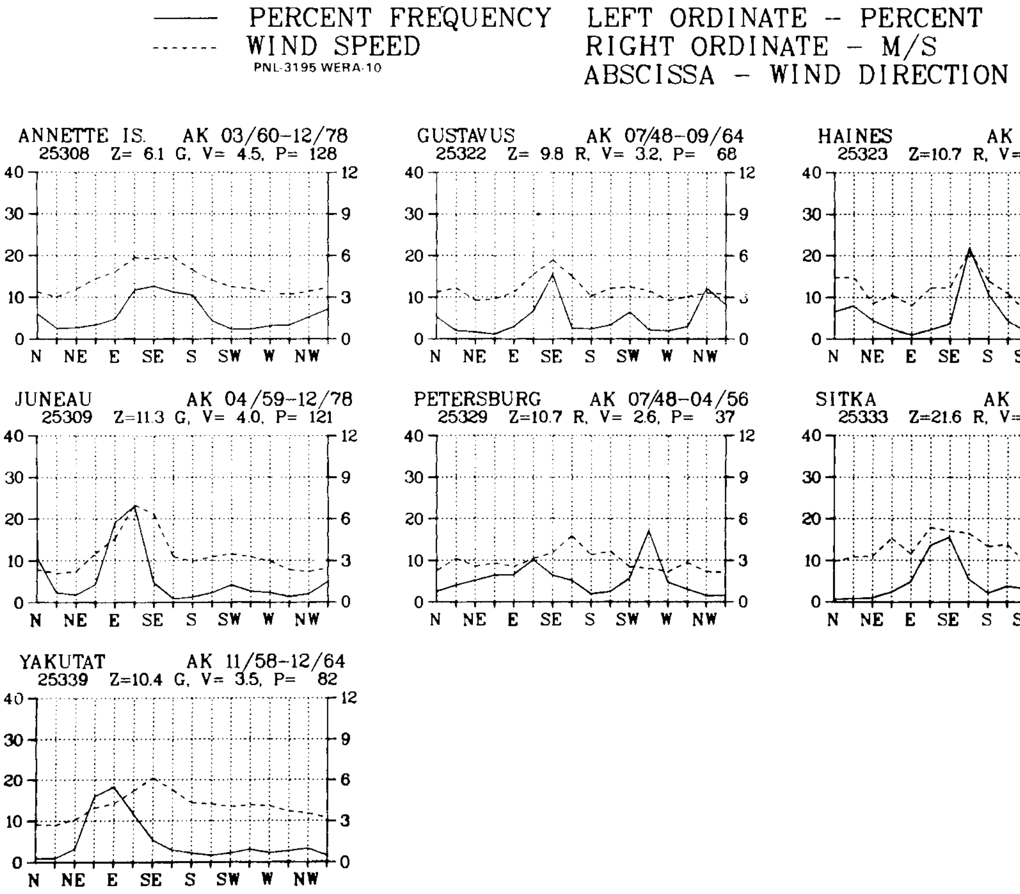


FIGURE 6.13. Directional Frequency and Average Wind Speed for Southeastern Alaska

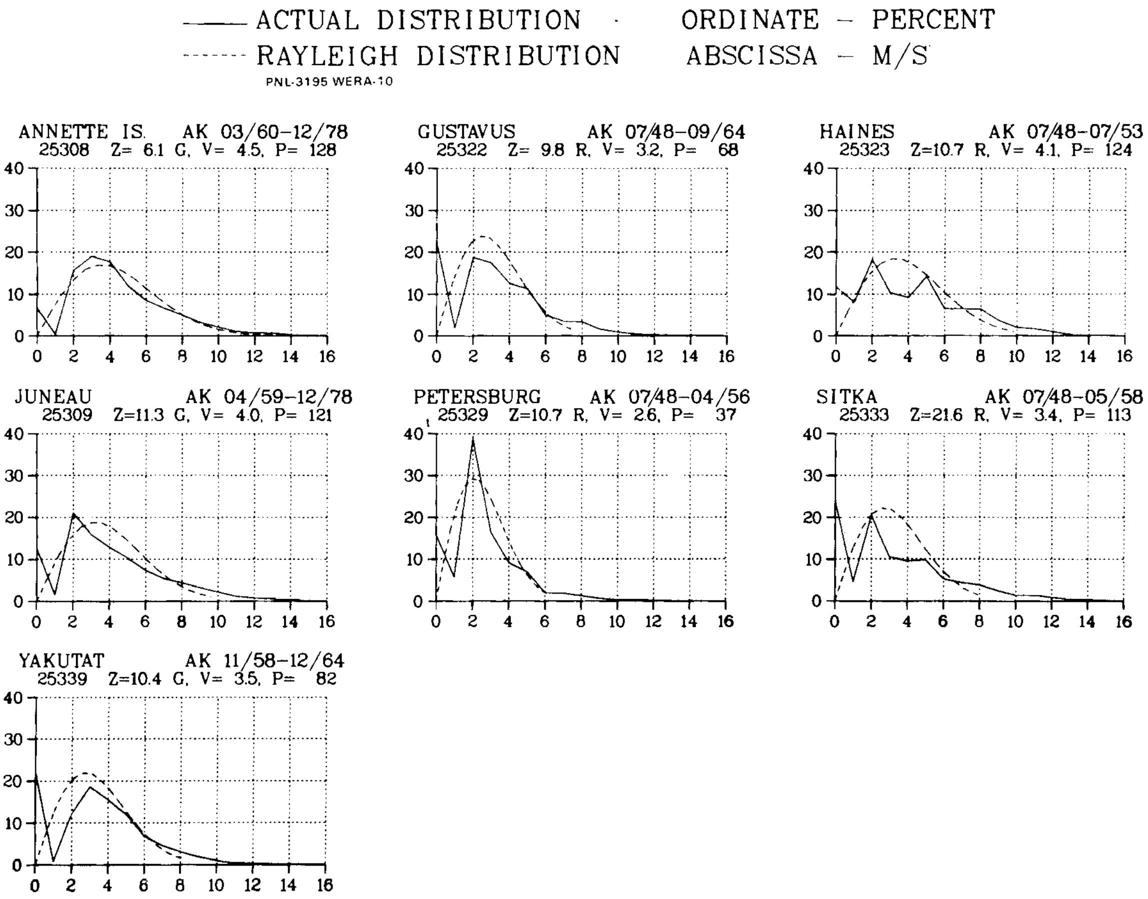


FIGURE 6.14. Annual Average Wind Speed Frequency for Southeastern Alaska

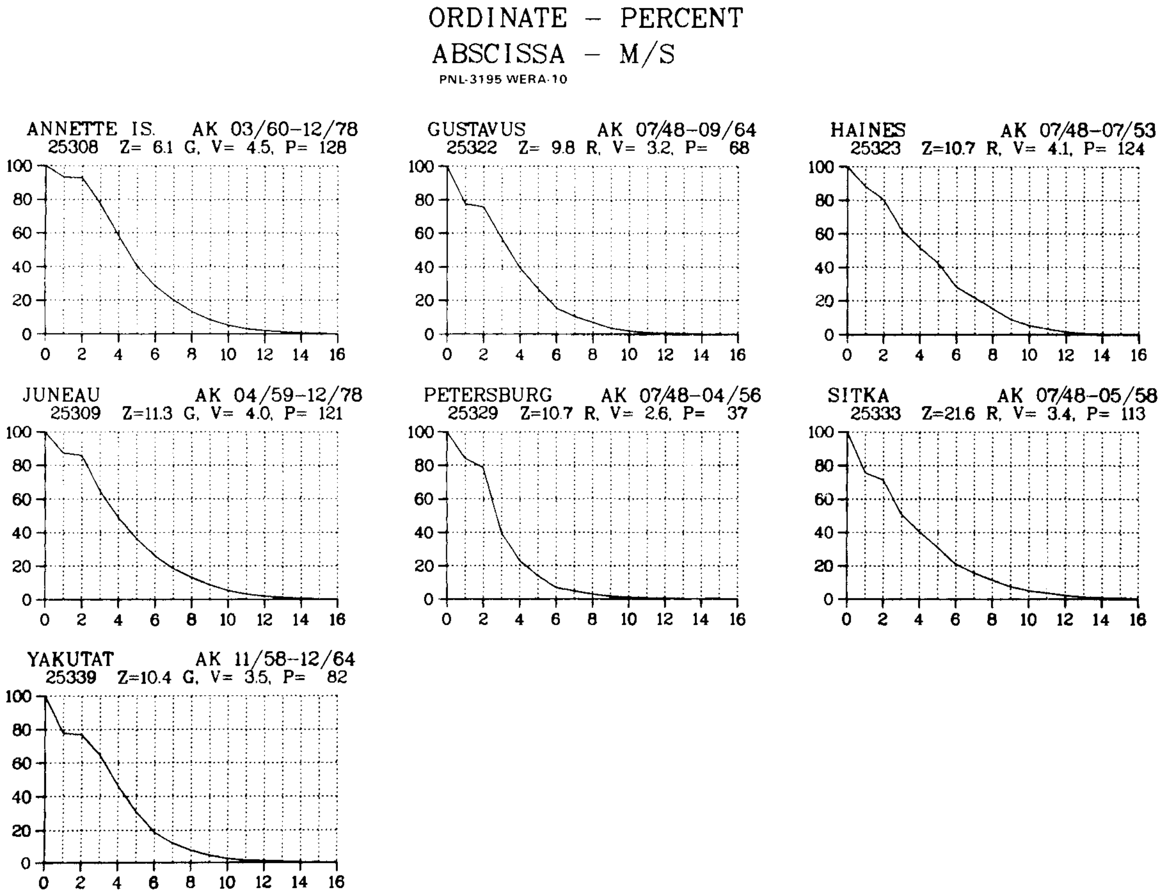
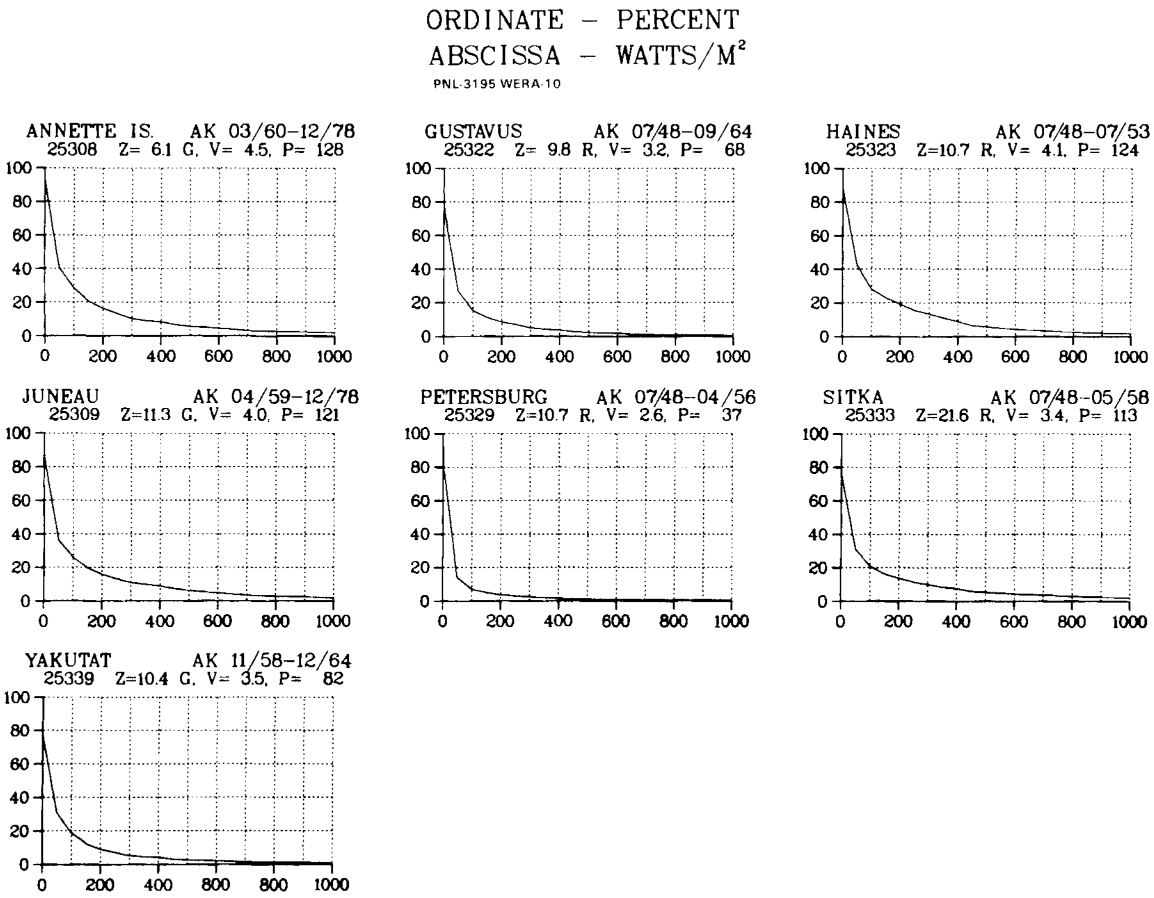


FIGURE 6.15. Annual Average Wind Speed Duration for Southeastern Alaska



ORDINATE - PERCENT
ABSCISSA - WATTS/M^2
PNL-3195 WERA-10

ANNETTE IS. AK 03/60-12/78
25308 Z= 6.1 G, V= 4.5, P= 128

GUSTAVUS AK 07/48-09/64
25322 Z= 9.8 R, V= 3.2, P= 68

HAINES AK 07/48-07/53
25323 Z=10.7 R, V= 4.1, P= 124

JUNEAU AK 04/59-12/78
25309 Z=11.3 G, V= 4.0, P= 121

PETERSBURG AK 07/48-04/56
25329 Z=10.7 R, V= 2.6, P= 37

SITKA AK 07/48-05/58
25333 Z=21.6 R, V= 3.4, P= 113

YAKUTAT AK 11/58-12/64
25339 Z=10.4 G, V= 3.5, P= 82

FIGURE 6.16. Annual Average Wind Power Duration for Southeastern Alaska

SOUTHWESTERN ALASKA

CHAPTER 7: SOUTHWESTERN ALASKA

Southwestern Alaska had an estimated population of 17,364 in 1979, which is approximately 0.62 persons per square mile. The major population centers of the subregion are the Bristol Bay Borough, Kodiak Island, and Adak Island. As shown in Figure 7.1, this subregion has a northern boundary of 59°N and includes the Alaska Peninsula, the Aleutian Chain, the Pribilof Islands, and the Kodiak Islands. Its southern boundary is the Pacific Ocean and the western boundary is the western tip of Attu Island, which is approximately 173°30'E. With a total area of 118,780 km^2, (45,849 mi^2), the southwestern area is the smallest subregion in the state.

The Aleutians are the only major mountain range in the southwestern subregion (Figure 7.2, 7.3). The Alaska Peninsula and the more than 50 islands of the Aleutian Island chain form an arc separating the north Pacific Ocean and the Bering Sea and are part of one of the world's most active seismic zones. There are many small streams in the subregion but no major rivers. Three lakes on the Alaska Peninsula are of noteworthy size: Becharof Lake and upper and lower Ugashik Lakes. One very significant physical feature of the Aleutian Islands is that they are treeless.

Wind data from NCC were available for stations along the coast of the Alaska Peninsula, Kodiak Islands, and the Aleutian Islands (Figure 7.4). Data from one fire weather station on the peninsula were used in the calculations for this subregion (Figure 7.5) because other reliable data were absent.

7.1 ANNUAL AVERAGE WIND POWER IN SOUTHWESTERN ALASKA

The annual average available wind power density in southwestern Alaska is shown in Figure 7.6. The analyses of mean wind power apply to terrain features that are favorably exposed to the wind, such as mountain summits, ridge crests, hilltops and uplands. However, nearby terrain features may interact with the windfield to cause the wind power at some exposed sites to vary as much as 50 to 100% from the assessment value. (See Wegley et al. 1980 for information on terrain features that may increase or reduce wind energy.) In forested or wooded areas the assessment values are representative of large clearings with good exposure to the prevailing strong winds, such as airports. In mountainous regions, the analyses also reflect major valleys. The percentage of land area that is favorably exposed to the wind strongly depends on the land-surface form (Section 1.8).

The annual average wind power (Figure 7.6) is class 4 or higher throughout southwestern Alaska. Class 7 wind power prevails in the Pribilof Islands, the Aleutian Islands, the west end of the Alaska Peninsula, and the islands south of the Alaska Peninsula southwest of Kodiak Island. Several stations show annual wind powers of over 1,000 W/m^2 including Amchitka, Shemya, Asi Tanaga, and Scotch Cap. Individual stations with annual wind power classes less than 7 in the Aleutians are sheltered somewhat from a part of the strong winds. All open waters in the Bering Sea and Pacific Ocean have class 7 power.

Mountain summits and ridge crests on the Alaska Peninsula and Kodiak Island are estimated at class 4 for the most part and 5 at the higher elevations. Mountain summits and ridge crests in the Aleutians are isolated peaks and the estimates were much lower than surface data for the most part, so the wind power classes discussed for the Aleutians are exclusively based on surface data at exposed locations. It is assumed that for the purposes of wind energy conversion systems (WECS), these surface data reflect the wind powers to expect for WECS installations.

Kodiak Island's exposed locations are estimated to experience class 6 and 7 wind power; however, the Kodiak station shows annual class 4 power because of its sheltered location.

The only wind corridors in the subregion for which there are data are Cold Bay (where south-southeast winds, enhanced by surrounding terrain, are of class 7 wind power) and the wind corridor from Kamishak Bay to the Barren Islands in the northeast corner of the subregion (also with class 7 power). Other major wind corridors may exist along the Alaska Peninsula at Dry Bay, Puale Bay, and Port Heiden, based on examination of satellite imagery and subjective meteorological considerations, but no data have been gathered at these sites.

7.1.1 Certainty Rating of the Wind Resource

The wind power estimates for most of the subregion have a certainty rating of 2 (Figure 7.7). In the Aleutians, even though there was a fair amount of data, many of the locations were shielded from at least one direction and the land-surface forms are moderately to highly complex. A certainty rating of 3 was assigned to the Pribilof and Chirikof Islands.

Mainland areas of the Alaska Peninsula have generally class 2 power, because most of the area consists of mountain summit and ridge crest estimates. Data are sparse on the mainland in the Bristol Bay area where land-surface forms are less complex, but the certainty rating is still 2 or 1.

7.1.2 Areal Distribution of the Wind Resource

Figure 7.8 illustrates the areal distribution of wind power in southwest Alaska. The numbers identify the percentage of area in each cell of the grid in which the wind power equals or exceeds some threshold value. Wind power class 4 or higher is estimated to occur in 98% of the grid cells including all of the Aleutian Islands, Kodiak Island, all other islands in the Gulf of Alaska and the Bering Sea, the Trinity Islands, and the Alaska Peninsula. The only area not of class 4 or higher is inland from the north shore of Bristol Bay and is estimated to be class 3. Following the assumptions and computations described in Section 1.10 and because of the high relief in most of this region, only 21% of the land area is estimated to be of class 4 or higher (see Table 7.1). This subregion, located along a storm track that generally affects Alaska and much of North America, reflects an annual wind power class 7 (approximately 55% of the grid cells). However, the assumption that there is a reduction of wind power class in high topographic relief may be too general for this subregion, particularly for land forms D5 and D6 where entire islands consist of one or two mountain peaks with only a few sheltered valleys. Using the same reasoning, the estimated 72% of wind power class 1 is most likely high.

7.2 SEASONAL WIND POWER

Wind power maps for each season are shown in Figure 7.9. The season of maximum wind power is generally winter in the entire subregion. There are few sheltered valleys where stable air is present for any period of time in southwestern Alaska. Summer is the season of minimum wind power in the entire subregion.

7.2.1 Winter

In winter class 7 wind power occurs in all coastal areas of the subregion except the eastern Bristol Bay area, where class 5 or 6 occurs, and the Kodiak Island coasts, where class 6 occurs for the most part. Winter wind power over 1,000 W/m^2 occurs in the open waters of the southern Bering Sea, the north Pacific Ocean, and the Gulf of Alaska. Land stations in the Aleutians with over 1,000 W/m^2 are Shemya, Kiska, Amchitka, Ogliuga, Asi Tanaga, and Sitkinak.

Mountain summits and ridge crests of the Aleutian Mountains on the Alaska Peninsula generally have class 6 power; however, the higher peaks experience class 7 power, and those of Kodiak Islands have class 5 (also class 7 at highest elevations). The wind corridor from Kamishak Bay to the Barren Islands (affecting the northeast corner of the subregion) also has wind power class 7.

7.2.2 Spring

Class 4 or higher wind power occurs throughout southwest Alaska in the spring. The Pribilof Islands, Aleutians, and the islands south of the Alaska Peninsula west of Kodiak all have class 7 power. Bristol Bay coastal areas vary from class 7 in the west as shown by Cape Newenham and Port Heiden, to class 4 in the east, shown by King Salmon. Kodiak Island has class 5 or 6 along the coast at exposed locations and 4 elsewhere.

Mountian summits and ridge crest estimates show mostly class 4 for Kodiak Island and the northeastern Alaska Peninsula and increase to class 6 farther west along the peninsula. In the Aleutian Islands the mountain peaks were considered to be well represented by surface data and are class 7. The wind corridor from Kamishak Bay to the Barren Islands also experiences class 7 power.

7.2.3 Summer

In summer, the wind resource is more variable in southwestern Alaska than in any other season. Class 4 or higher wind power occurs in the Pribilof Islands, the Aleutians, and the west end of the Alaska Peninsula. However, the Pribilofs are of class 4 and the Aleutians are of class 4 to 6, except for Amchitka, which is class 7. The open waters of the Bering Sea have class 6 power, as does the western north Pacific. Wind power class in the Gulf of Alaska decreases from 7 in the southwest to 3 in the north. The Trinity Islands still have class 7 power, as shown by Sitkinak. The wind corridor from Kamishak Bay to the Barren Islands is reduced to class 3 power by the time it affects southwestern Alaska.

Mountain summit and ridge crest estimates vary from class 2 to 4 on the Alaska Peninsula and are class 3 on Kodiak. Isolated summits in the Aleutians are assumed to be of the same power as the surface data, varying from class 4 to 7.

7.2.4 Autumn

Class 4 or higher wind power occurs throughout the subregion in autumn. The Pribilof, Aleutian, Trinity, and Chirikof Islands are all estimated to have class 7 power. Bristol Bay coastal areas vary from class 7 at Port Heiden and class 6 at Cape Newenham to class 4 along the shores of Kvichak Bay. Kodiak Island is class 5 or 6 along the coast depending on the degree of exposure. Open waters of the Bering Sea, the North Pacific and Gulf of Alaska experience class 7.

Mountain summits and ridge crests are estimated at class 4 to 6 on the Alaska Peninsula and class 4 on Kodiak Island. The wind corridor from Kamishak Bay to the Barren Islands experiences class 7 power as it affects the northeast portion of southwestern Alaska.

7.3 FEATURES OF SELECTED STATIONS

Graphs of wind characteristics are shown for 13 stations in southwest Alaska. All stations are near the coast or on an island. The station characteristics are summarized in Table 7.2.

The Bristol Bay area is represented by Cape Newenham and King Salmon.

Cape Newenham is on a rugged point of land at the northwest end of Bristol Bay. It is sheltered on the east, south and west by a ridge that extends to more than 610 m. It is open to the northwest, and there is a saddleback in the ridge to the southeast. The terrain slopes steeply upward toward the southeast in the vicinity of the station. During the nine-year period of record used in the summary, there was an average of 22 observations per day.

King Salmon is located about half a kilometer (one-fourth mile) from the Naknek River, 29 km inland from the shores of Kvichak Bay at the east end of Bristol Bay. The terrain surrounding the station is gently rolling, barren tundra for 50 to 100 km in the north through east to south-southwest. Some 100 km to the east are the mountains of the Aleutian Range with peaks to more than 2,260 m. During the summary period of used in this analysis, there were eight observations per day digitized.

There are two stations on the Alaska Peninsula, Cold Bay and Port Moller.

Cold Bay is located on the northwest side of the bay that bears its name. Ten miles southwest of the station Frosty Peak rises to 1,870 m. Across the bay to the east, several peaks rise to elevations of approximately 1,610 m. The station is sheltered from strong southwesterly and easterly winds. The open bay area to the south-southeast tends to provide a funneling effect on all winds of consequence from the southwest through southeast to produce strong south-southeasterly winds. From west-northwest to the northeast the land is relatively flat with much swampland and numerous small lakes. During the 16-year summary used in the analysis, there was an average of six observations per day.

Port Moller is located on a sand spit between Moller Bay and the Bering Sea. It is exposed to west, north, and northeast winds but is sheltered somewhat from the east through south to southwest by the Aleutian Range, which rises to more than 2,260 m within 8 km of the station. During the period of the summary used in the analysis, there were an average of eight observations per day.

Kodiak, the only station on Kodiak Island, is located on the western shore of Women's Bay. The area around the station is heavily wooded and steep in all directions except northeast through east-southeast, where it is exposed to the open water of the Gulf of Alaska. Mountain peaks rise to more than 800 m within 5 km to the west of the station. During the summary period used in the analysis, there were 24 observations per day.

St. Paul is located on the south shore of St. Paul Island, which is 11 by 14 km in size, of low relief, and has no trees. The station is well exposed to winds from all directions. St. Paul's winds are considered to be representative of other islands in the Pribilofs. During the three-year summary used in the analysis, there were 24 observations per day.

The Aleutian Islands are represented by seven stations: Adak, Amchitka, Asi Tanaga, Attu, Driftwood Bay, Nikolski, and Shemya.

Adak Naval Station is located on Adak Island. It is shielded to the northwest, north-northwest, and south by mountains more than 610 m high within 8 km of the station. However, there are no obstructions to the north, west, or east. During the nine years of the summary used in the analysis, there were 24 observations per day.

Amchitka is located at the southeast end of Amchitka Island where the terrain is gently rolling. There are no elevations within 25 km more than 300 m high. At the northwest end of the island there are a few peaks. During the seven-year period of the summary used in the analysis, there were 24 observations per day.

Asi Tanaga is located at the south end of Tanaga Island on a gently rolling portion of the island. The station is shielded somewhat to the northwest to northeast by a mountain, with an elevation more than 1,600 m, about 19 km from the station. There are no obstructions in any other directions. During the two years of the summary used in the analysis, there was an average of 21 observations per day.

Attu is located at the east end of Attu Island on the west shore of Massacre Bay. It is shielded from all directions except south to east. The island is mountainous, with elevations to more than 610 m. During the two-year period summary used in the analysis, there were 24 observations per day.

Driftwood Bay is located on the north shore of Unalaska Island. The terrain south of the station slopes upward to 1,060 m within a mile of the station. The location is sheltered from strong winds from northeast through south to southwest but is exposed to the west and north. During the five-year summary period used in the analysis, there was an average of eight observations per day.

Nikolski is located at the southwest end of Umnak Island. The terrain around a 3-km radius of the station is gently rolling hills or open water. There are mountains with elevations more than 1,800 m 15 to 25 km northeast of the station. All other directions are free of obstructions. During the summary period used in the analysis, there was an average of eight observations per day.

Shemya AFS is on Shemya Island, a small island about 5 by 5 km with very little relief. There are no trees or hills of any size on the island, and it is open in all directions. Only observations taken every three hours were used in the analysis.

7.3.1 Interannual Wind Power and Speed

The only stations with long periods of record in this subregion are Adak, Cape Newenham, Cold Bay, King Salmon, Kodiak, St. Paul Island, and Shemya (Figure 7.10). The greatest interannual variability is at Attu, Adak, Cape Newenham, and Kodiak. These locations are all shielded from a particular direction by surrounding terrain. Less interannual variability of wind power was shown at St. Paul Island, Shemya, and Nikolski where no obstructions exist. Many of the stations' periods of record are not simultaneous; however, 1964 and 1965 appear to be maximum years for wind power for most locations except Cold Bay and Kodiak, which show somewhat less wind resource during those years. The year 1976 was a relatively low wind power year at all stations reporting then except Kodiak, which was high. Kodiak is more exposed to storms from the southwest than other stations. The most prevalent storm track is west to east along the Aleutians to the Gulf of Alaska. Attu varied by a factor of two in wind power from 300 to 600 W/m^2 whereas St. Paul, Shemya, and Nikolski varied by a fraction of only 1.1 to 1.2. Most other stations have too few years to make a comparision of long-term trends in interannual variability.

7.3.2 Monthly Average Wind Power and Speed

Class 7 mean annual wind power occurs at all locations west of Driftwood Bay except Adak and Attu (Figure 7.11). Since both of these stations are shielded to some extent by local terrain, class 7 appears to be the normal for the entire west end of the subregion. Class 7 wind power also occurs at St. Paul in the Pribilofs and at Cold Bay. The winds at Cold Bay are enhanced somewhat by local terrain, so this station is high in reference to the rest of the Alaska Peninsula. Driftwood Bay and Port Moller are somewhat sheltered from the strongest winds, so their annual power (class of 4 and 3) is somewhat low. King Salmon, with class 4 annual power is representative of the broad relatively flat area of the southern and eastern Bristol Bay area. Cape Newenham, with class 6 annual power, is characteristic of an exposed location even though it is sheltered from all except southeast and northwest winds. Kodiak's annual power (class 4) is low for exposed areas on Kodiak Island and adjacent islands.

The season for maximum wind speed and wind power is winter at all except Shemya, Attu, Adak, Nikolski, and Port Moller. Attu's maximum wind power occurs in March, and the remainding stations have maximum wind power in October and November. Class 7 wind power occurs during some months at Amchitka, Asi Tanaga, Attu, Cape Newenham, Cold Bay, Nikolski, St. Paul, and Shemya. Summer is the season of minimum wind power except Cold Bay where the minimum occurs in May. The greatest seasonal variation occurs in the western Aleutians, the Pribilofs, and Cape Newenham.

7.3.3 Diurnal Wind Speed by Season

There is very little diurnal variation of wind speeds (Figure 7.12) at any location. The highest diurnal variation is at King Salmon in spring with about 2 m/s. The rest of the stations showed the greatest diurnal variation in summer with the variation 1 m/s or less. Since King Salmon is the farthest from the coast of any location in the subregion, it also has the greatest diurnal temperature change particularly in spring and autumn. Strongest winds tend to occur from 1200 to 1500 hours.

7.3.4 Directional Frequency and Average Speed

Only Cold Bay has its strongest winds and its most frequent winds from the south-southeast direction (Figure 7.13). Most of the remaining stations show very little directional prominence. Only Adak, Asi Tanaga, Attu, Cape Newenham, Cold Bay, King Salmon, Kodiak, and Port Moller show more than 10 percent of the winds from any one direction. The most frequent directions of wind are west-southwest through north. However, exceptions are Cold Bay, Cape Newenham, and Port Moller. At Cold Bay winds are most frequently from the south-southeast. At Cape Newenham they are from the south; strong winds occur most often from the southeast. At Port Moller, south winds are most frequent, but the strongest winds are from the south-southeast.

7.3.5 Annual Average Wind Speed Frequency

There is some observer bias in favoring speeds of 2, 5, 8 and 10 m/s (5, 10, 15, and 20 mph) at the older stations such as Amchitka, Asi Tanaga, Nikolski, Port Moller, and Cape Newenham (Figure 7.14). Actual wind speed distributions agree quite well with the Rayleigh distribution except at Attu, Asi Tanaga, Cape Newenham, Driftwood Bay, Kodiak, and Nikolski. Some of the disagreement is the result of observer bias, but at other stations (such as Attu, Kodiak, and Cape Newenham) the disagreement is more from local peculiarities of terrain.

7.3.6 Annual Average Wind Speed and Power Duration

The percentage of time that a given wind speed or power is exceeded is shown in Figures 7.15 and 7.16. Wind power class 7 occurs more than 40 percent of the time at Amchitka, Asi Tanaga, Cold Bay, Nikolski, St. Paul, and Shemya. Some abrupt changes in the shapes of the wind speed duration curve are due to observer bias and instrument threshold velocity.

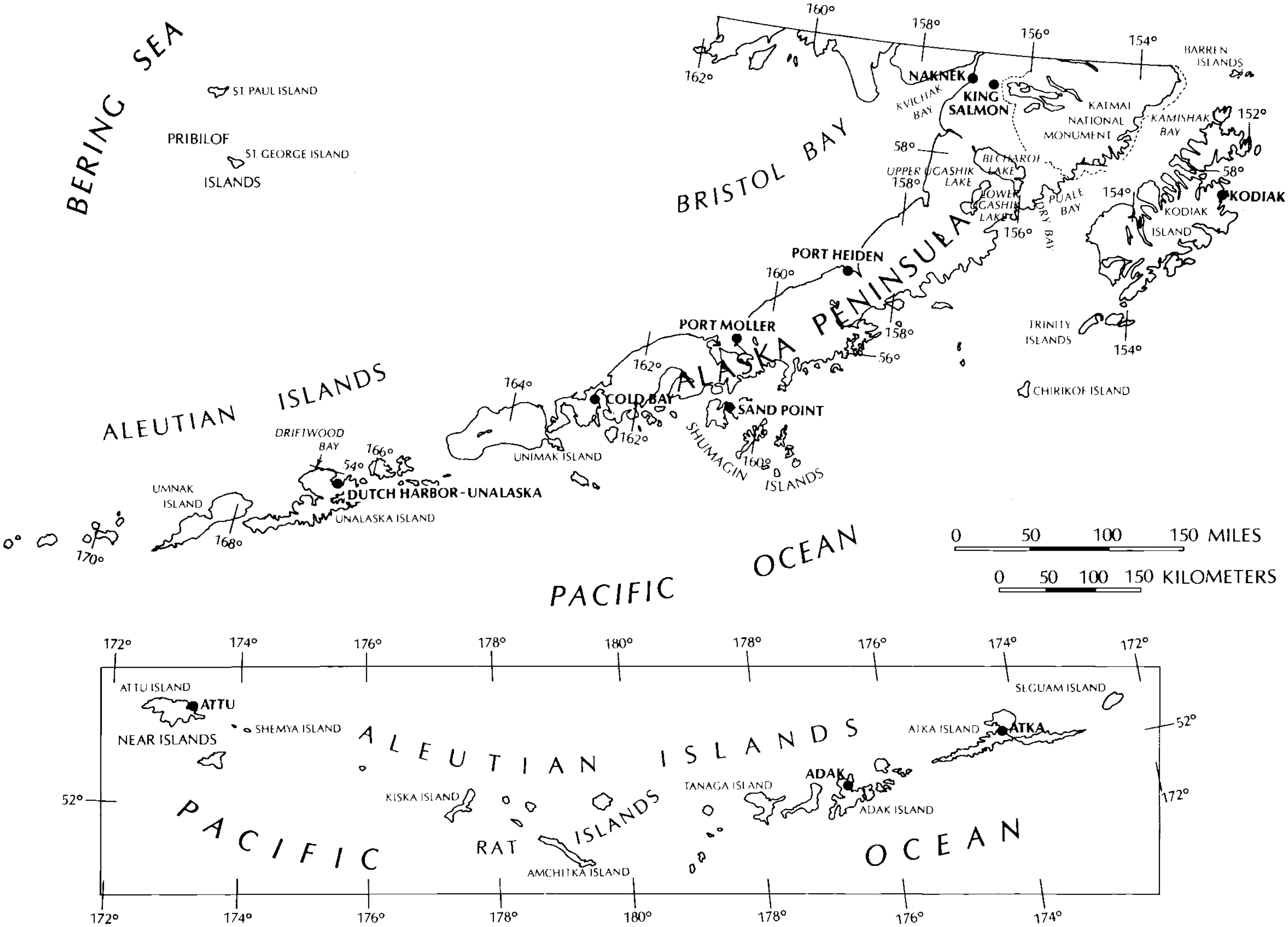


FIGURE 7.1. Geographic Map of Southwestern Alaska

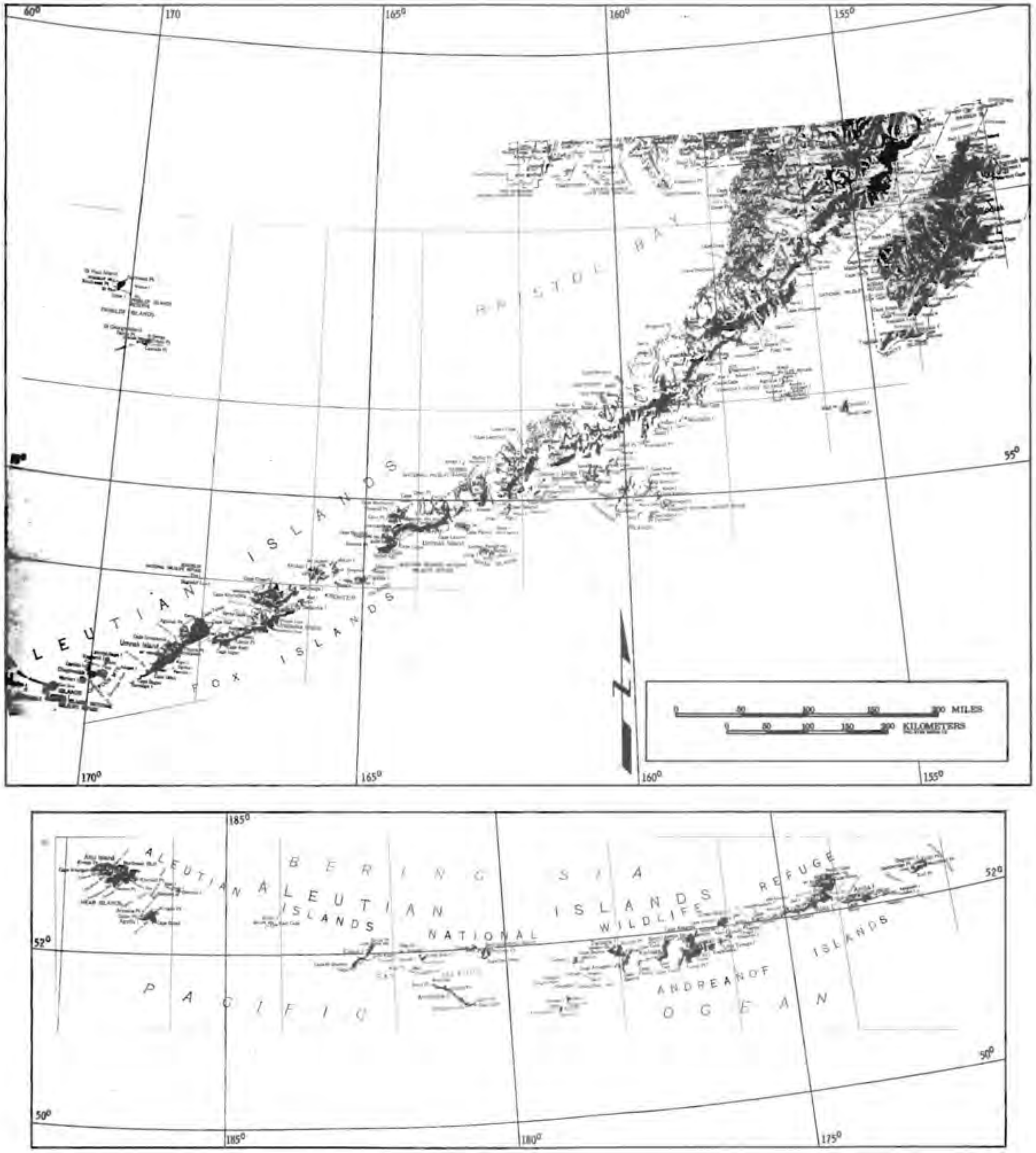


FIGURE 7.2. Topographic Map of Southwestern Alaska

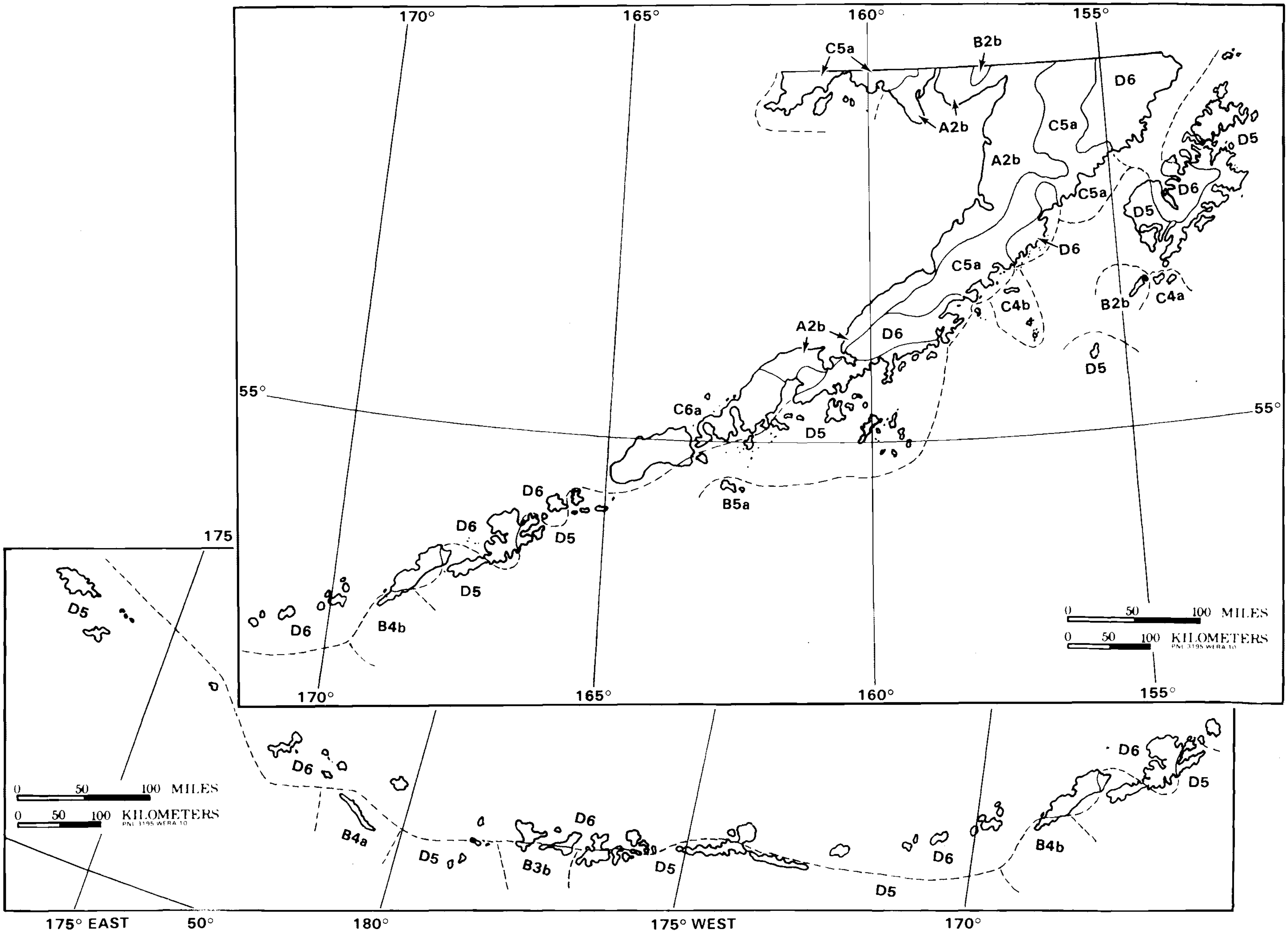


FIGURE 7.3. Land-Surface Form Map for Southwestern Alaska

LAND-SURFACE FORM LEGEND

PLAINS

A1	FLAT PLAINS
A2	SMOOTH PLAINS
B1	IRREGULAR PLAINS, SLIGHT RELIEF
B2	IRREGULAR PLAINS

PLAINS WITH HILLS OR MOUNTAINS

A,B3a,b	PLAINS WITH HILLS
B4,a,b	PLAINS WITH HIGH HILLS
B5a,b	PLAINS WITH LOW MOUNTAINS
B6a,b	PLAINS WITH HIGH MOUNTAINS

OPEN HILLS AND MOUNTAINS

C2	OPEN LOW HILLS
C3	OPEN HILLS
C4	OPEN HIGH HILLS
C5	OPEN LOW MOUNTAINS
C6	OPEN HIGH MOUNTAINS

HILLS AND MOUNTAINS

D3	HILLS
D4	HIGH HILLS
D5	LOW MOUNTAINS
D6	HIGH MOUNTAINS

TABLELANDS

B3c,d	TABLELANDS, MODERATE RELIEF
B4c,d	TABLELANDS, CONSIDERABLE RELIEF
B5c,d	TABLELANDS, HIGH RELIEF
B6c,d	TABLELANDS, VERY HIGH RELIEF

SCHEME OF CLASSIFICATION

SLOPE (1st LETTER)

A	>80% OF AREA GENTLY SLOPING
B	50-80% OF AREA GENTLY SLOPING
C	20-50% OF AREA GENTLY SLOPING
D	<20% OF AREA GENTLY SLOPING

LOCAL RELIEF (2nd LETTER)

1	0 TO 30m (1 TO 100 ft)
2	30 TO 90m (100 TO 300 ft)
3	90 TO 150m (300 TO 500 ft)
4	150 TO 300m (500 TO 1000 ft)
5	300 TO 900m (1000 TO 3000 ft)
6	900 TO 1500m (3000 TO 5000 ft)

PROFILE TYPE (3rd LETTER)

a	>75% OF GENTLE SLOPE IS IN LOWLAND
b	50-75% OF GENTLE SLOPE IS IN LOWLAND
c	50-75% OF GENTLE SLOPE IS ON UPLAND
d	>75% OF GENTLE SLOPE IS ON UPLAND

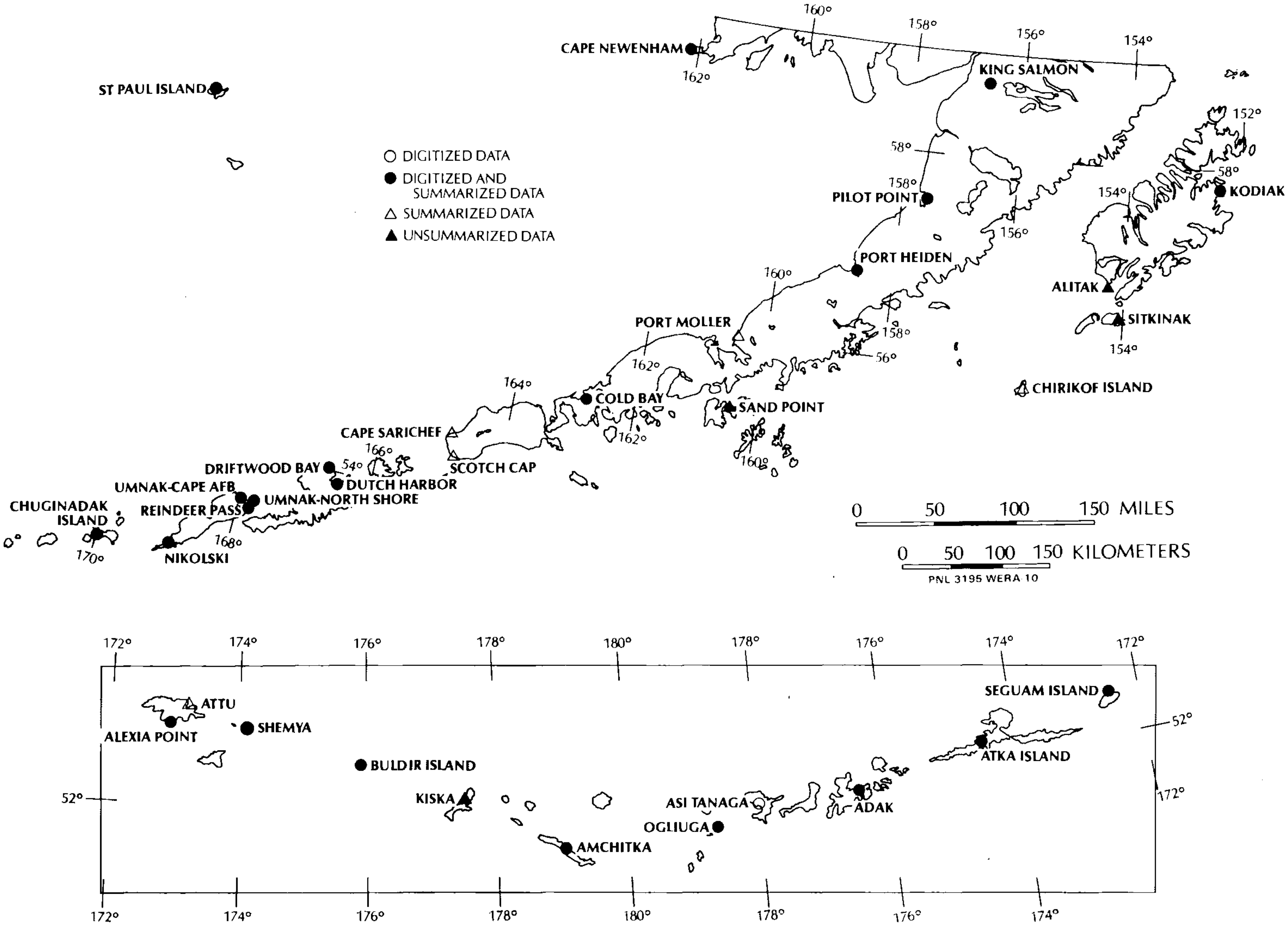


FIGURE 7.4. NCC Station Locations in Southwestern Alaska

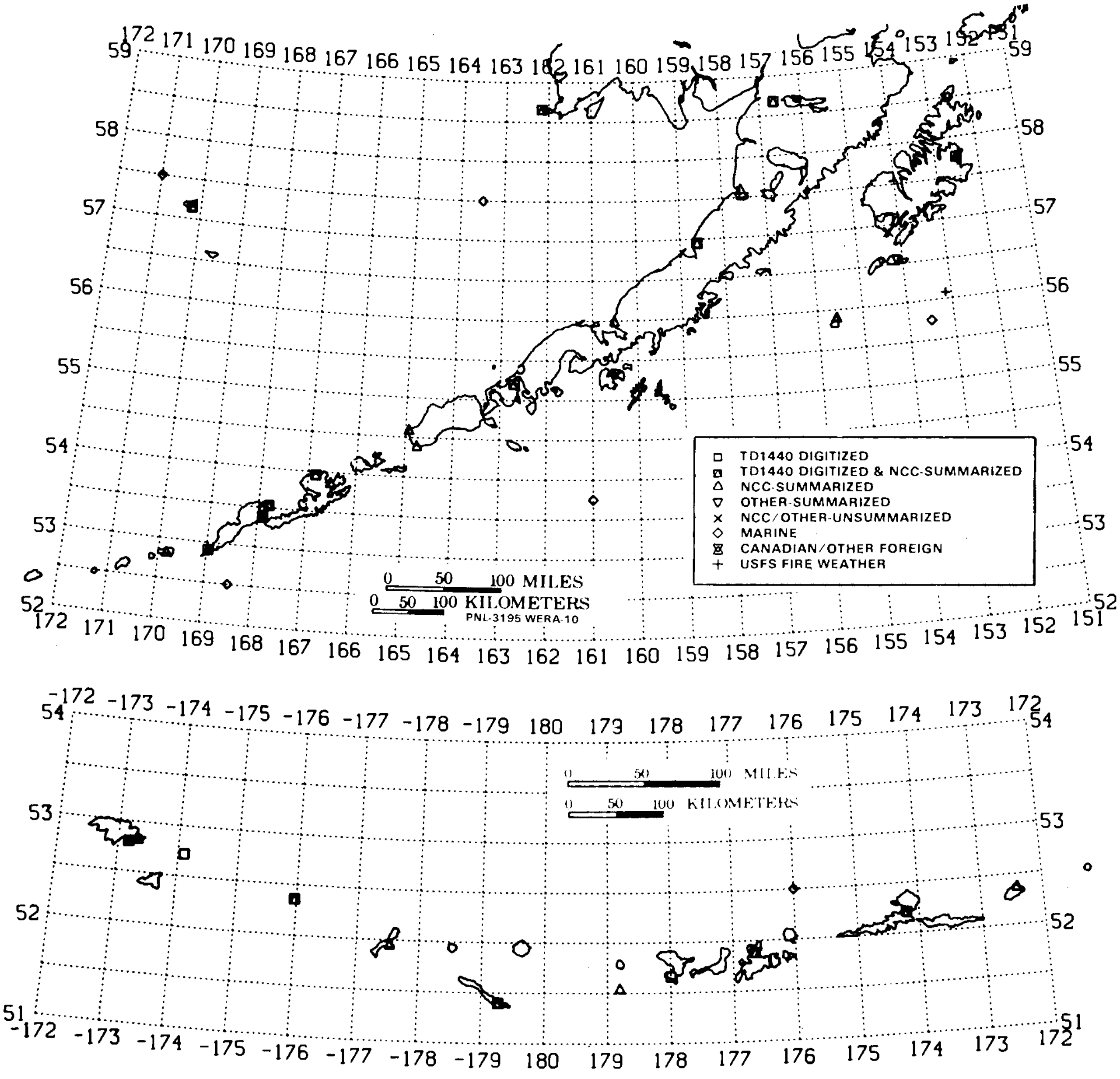


FIGURE 7.5. Location of Stations Used in Southwestern Alaska Resource Assessment.

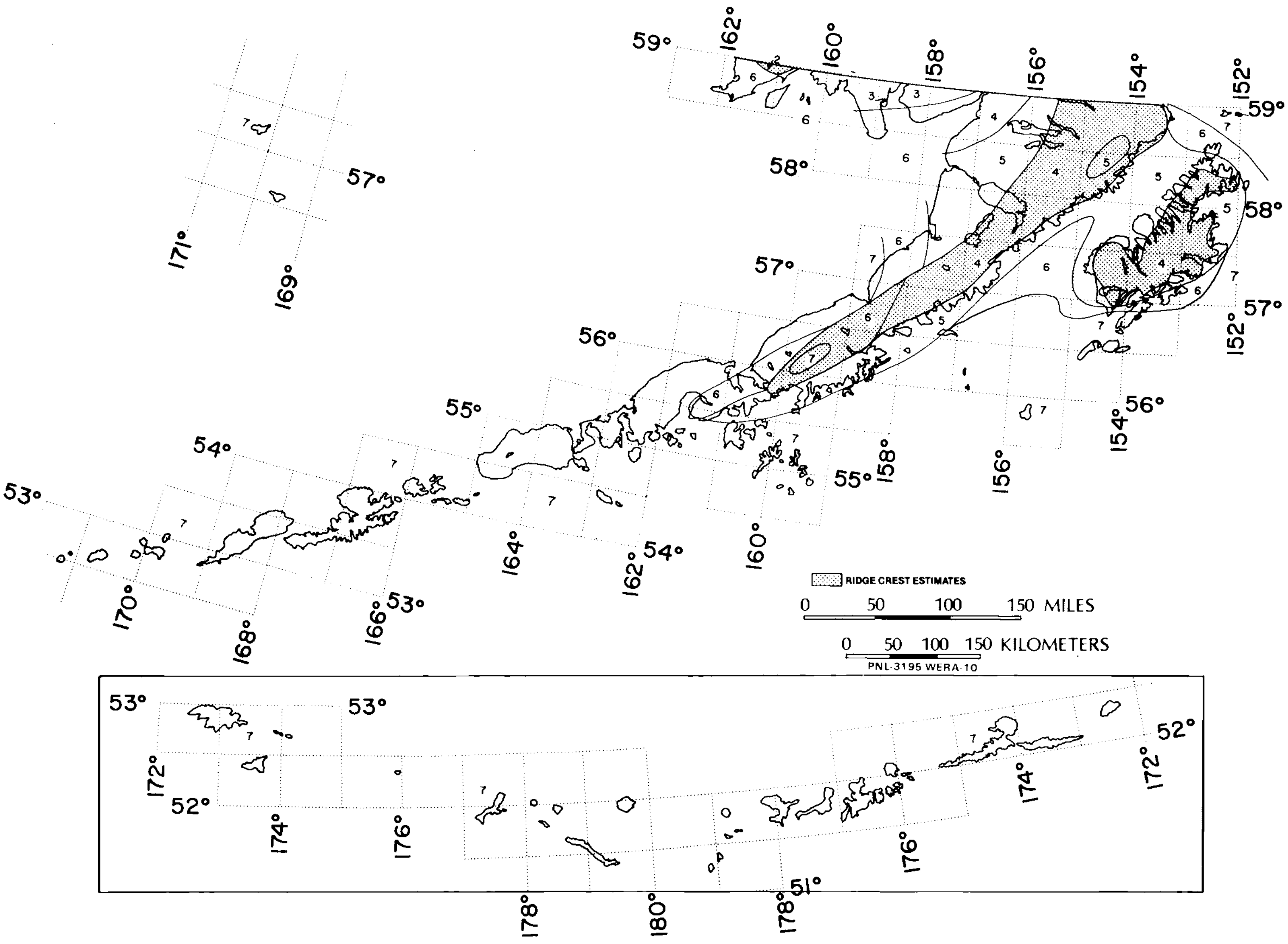


FIGURE 7.6. Southwestern Alaska Annual Average Wind Power

Classes of Wind Power Density at 10 m and 50 m(a)

	10 m (33 ft)		50 m (164 ft)	
Wind Power Class	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)	Wind Power Density, watts/m^2	Speed,(b) m/s (mph)
	0	0	0	0
1	100	4.4 (9.8)	200	5.6 (12.5)
2	150	5.1 (11.5)	300	6.4 (14.3)
3	200	5.6 (12.5)	400	7.0 (15.7)
4	250	6.0 (13.4)	500	7.5 (16.8)
5	300	6.4 (14.3)	600	8.0 (17.9)
6	400	7.0 (15.7)	800	8.8 (19.7)
7	1000	9.4 (21.1)	2000	11.9 (26.6)

(a)Vertical extrapolation of wind speed based on the 1/7 power law.

(b)Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, speed increases 5%/5000 ft (3%/1000 m) of elevation.

TABLE 7.1. Areal Distribution (km^2) of Wind Power Classes in Southwest Alaska

Power Class	Land Area	% Land Area	Cumulative Land Area	% Cumulative Land Area
1	78,000	72	110,000	100
2	2,700	2.5	30,000	27
3	3,800	3.4	27,000	25
4	6,100	5.6	23,000	21
5	4,800	4.4	17,000	16
6	4,400	4.0	12,000	11
7	7,800	7.2	7,800	7.2

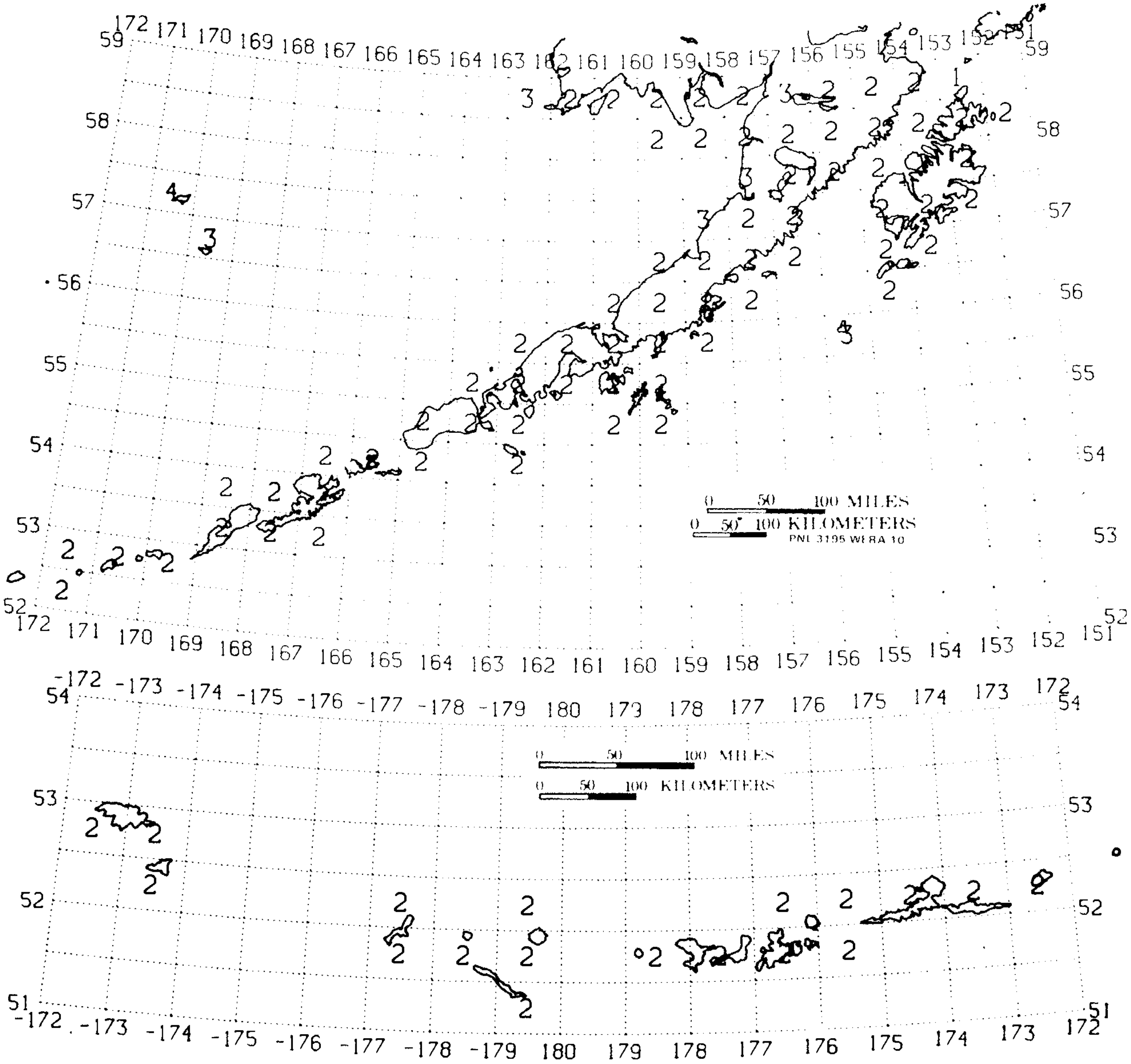


FIGURE 7.7. Certainty Rating of Southwestern Alaska Wind Resource

CERTAINTY RATING LEGEND

Rating	Definition
1	The lowest degree of certainty. A combination of the following conditions exists: 1) No data exist in the vicinity of the cell. 2) The terrain is highly complex. 3) Various meteorological and topographical indicators suggest a high level of variability of the resource within the cell.
2	A low-intermediate degree of certainty. One of the following conditions exists: 1) Little or no data exist in or near the cell, but the small variability of the resource and the low complexity of the terrain suggest that the wind resource will not differ substantially from the resource in nearby areas with data. 2) Limited data exist in the vicinity of the cell, but the terrain is highly complex or the mesoscale variability of the resource is large.
3	A high-intermediate degree of certainty. One of the following conditions exists: 1) There are limited wind data in the vicinity of the cell, but the low complexity of terrain and the small mesoscale variability of the resource indicate little departure from the wind resource in nearby areas with data. 2) Considerable wind data exist but in moderately complex terrain and/or in areas where moderate variability of the resource is likely to occur.
4	The highest degree of certainty. Quantitative data exist at exposed sites in the vicinity of the cell and can be confidently applied to exposed areas in the cell because of the low complexity of terrain and low spatial variability of the resource.

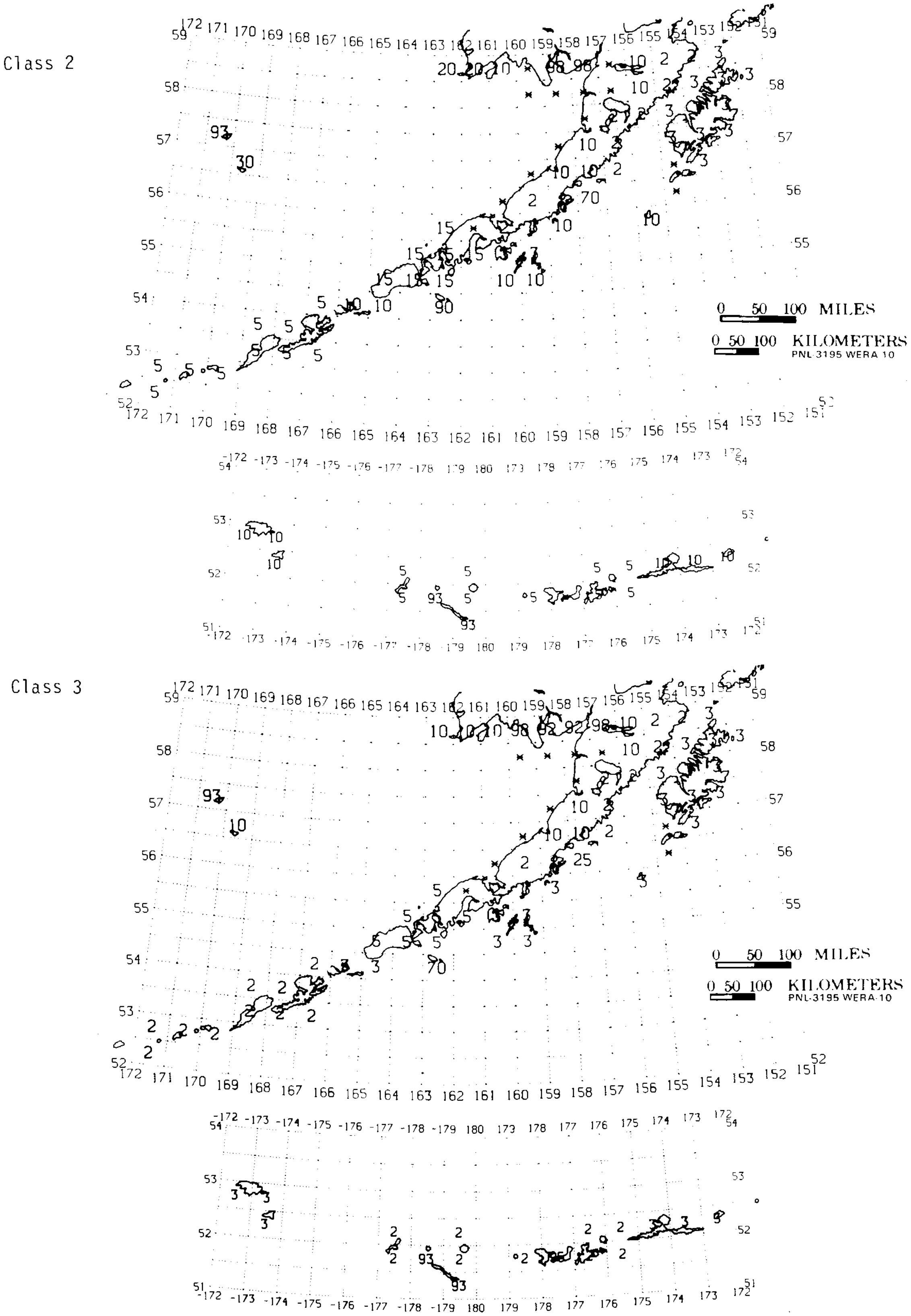
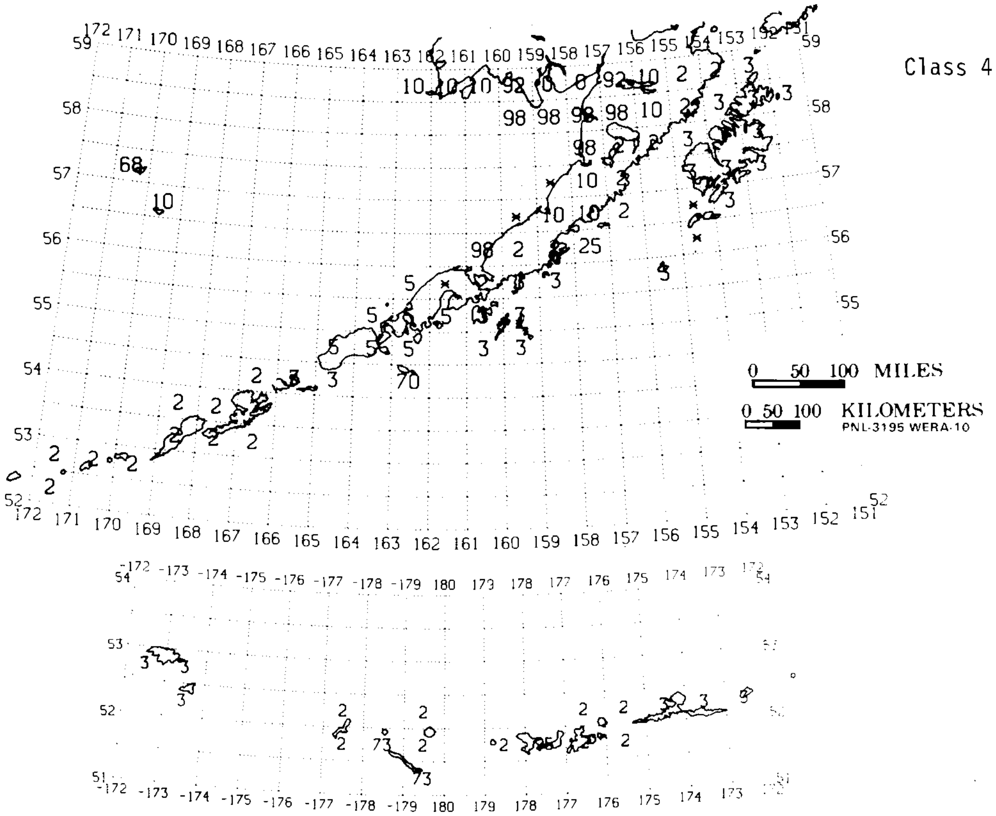


FIGURE 7.8. Areal Distribution of Wind Resource in Southwestern Alaska (Power Classes 2 and 3); Percent of Land Area with or Exceeding Power Class Shown.



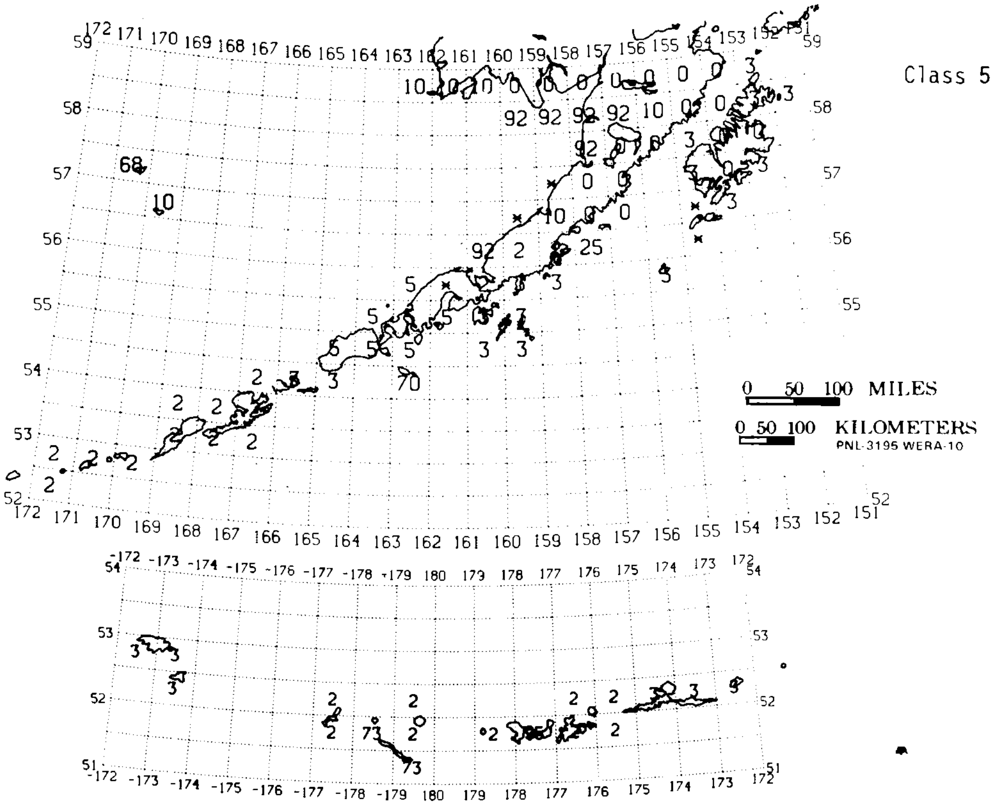


FIGURE 7.8 (Continued). Areal Distribution of Wind Resource in Southwestern Alaska (Power Classes 4 and 5); Percent of Land Area With or Exceeding Power Class Shown.

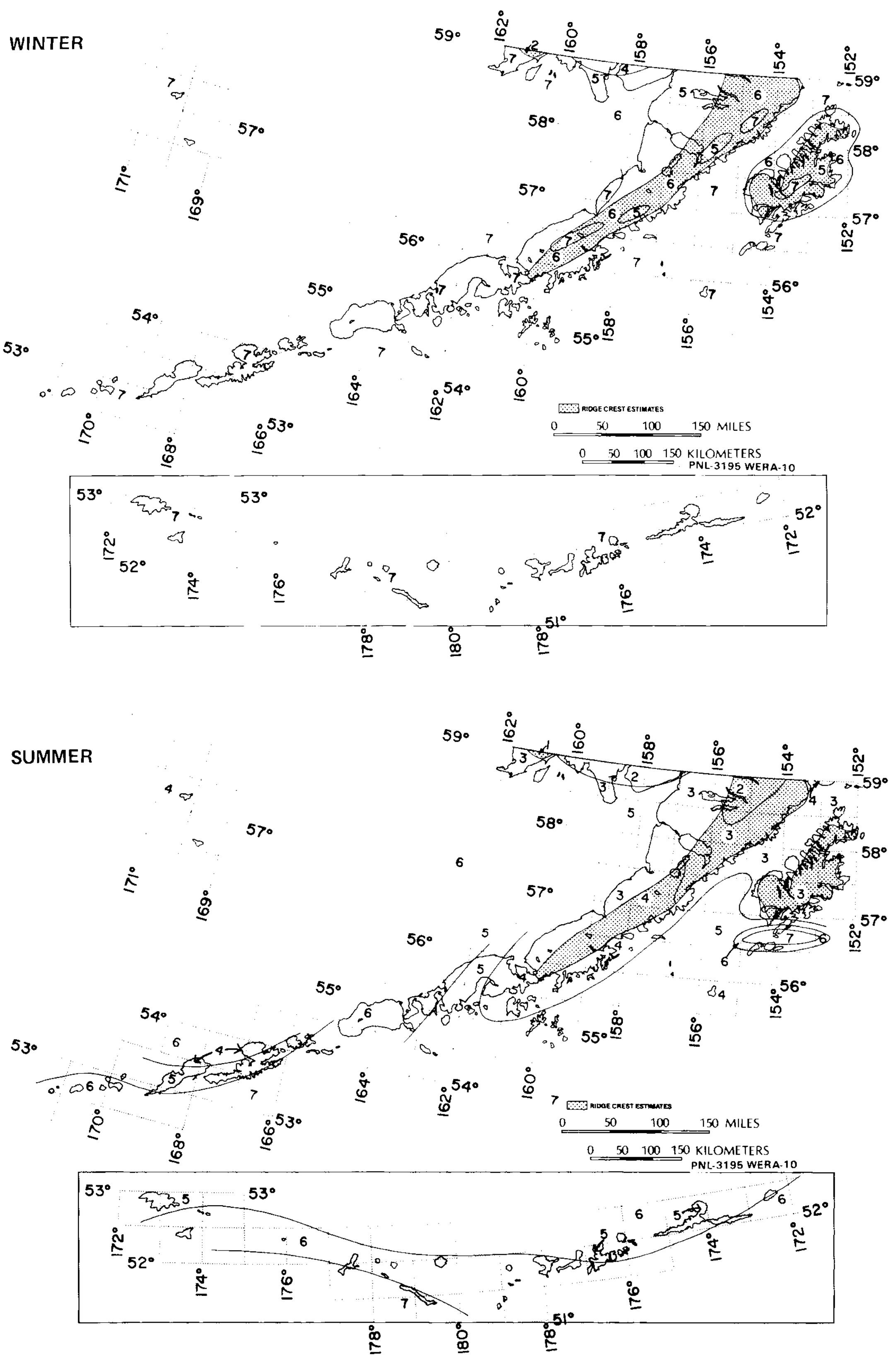


FIGURE 7.9. Seasonal Average Wind Power in Southwestern Alaska (Winter, Summer)

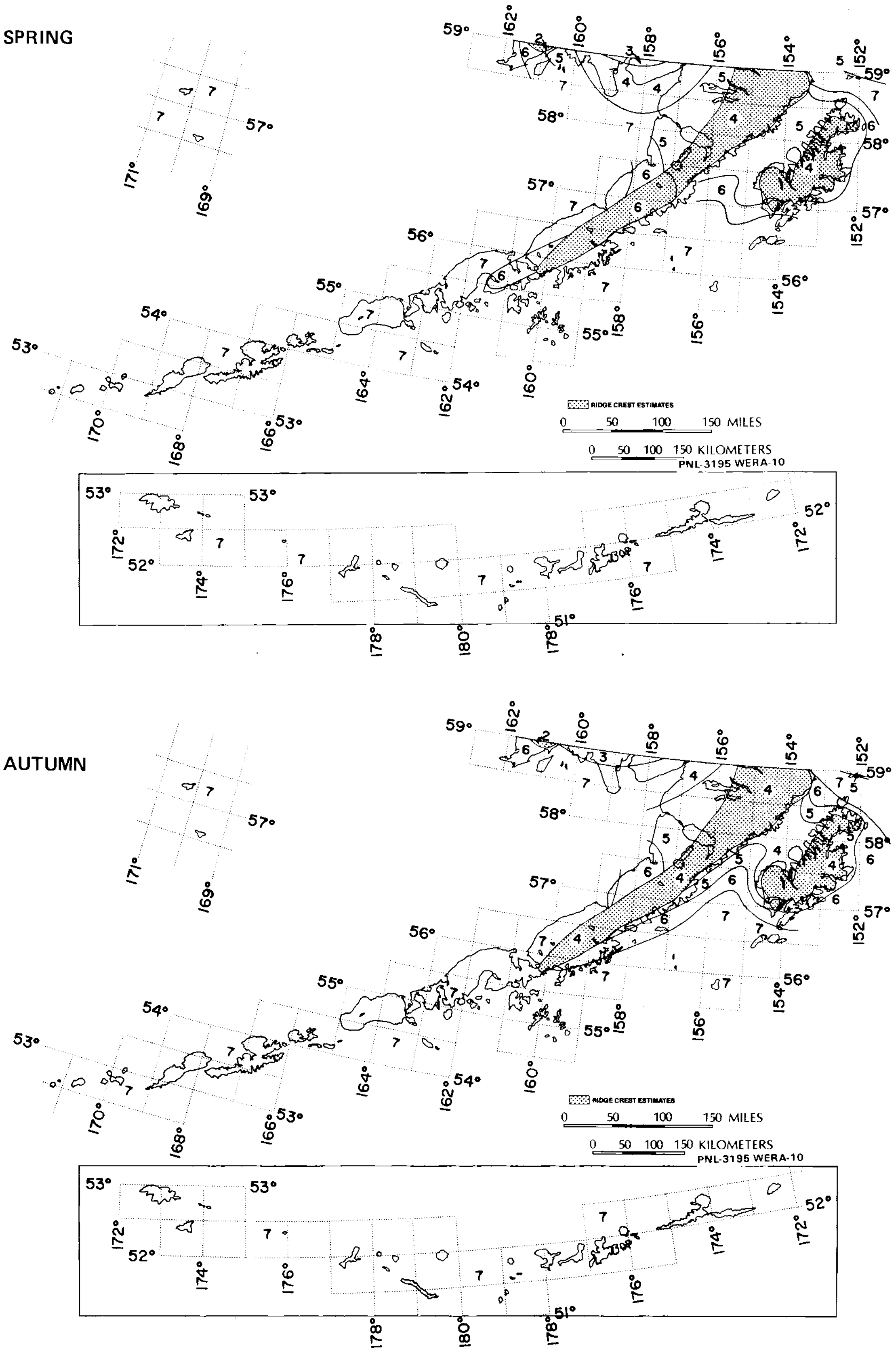


FIGURE 7.9 (Continued). Seasonal Average Wind Power in Southwestern Alaska (Spring, Autumn)

TABLE 7.2. Southwestern Alaska Stations with Graphs of the Wind Characteristics.

							Annual Average Wind Speed, m/s			Annual Average Wind Power, W/m^2		
Station ID	Station Name	Latitude, Degrees North	Longitude, Degrees West	Elevation of Station, m	Period of Record, Month/Year	Anemometer Height, m	At Anemometer Height, m	At 10 m	At 50 m	At Anemometer Height, m	At 10 m	At 50 m
Adak	Adak Naval Station	51.9	176.7W	4.9	04/62-02/72	7.6	5.4	5.7	7.1	255	287	571
Amchitka	Amchitka Island AFB	51.4	179.3E	62.3	01/44-11/50	10.7	9.7	9.6	12.1	1219	1186	2363
ASI Tanaga	ASI Tanaga Naval Station	51.7	178.0W	45.1	02/47-03/49	10.1	8.5	8.5	10.7	1028	1025	2044
Attu	Attu Naval Station	52.8	173.3E	28.0	08/54-12/56	10.4	5.3	5.3	6.6	330	325	648
Cape Newenham	Cape Newenham AFS	58.7	162.2W	71.6	04/61-12/70	4.0	5.1	5.8	7.3	342	360	717
Cold Bay	Cold Bay WBAS	55.2	162.7W	30.2	11/62-12/78	6.4	7.5	8.0	10.1	517	626	1248
Driftwood Bay	Driftwood Bay AFS	53.9	166.9W	395.6	05/64-05/69	4.0	4.3	4.9	6.2	153	228	453
King Salmon	King Salmon WBAS	58.7	156.7W	14.3	06/62-12/78	6.1	4.8	5.2	6.5	163	202	402
Kodiak	Kodiak Naval Air Facility	57.8	152.5W	33.8	08/58-05/73	4.9	4.4	4.8	6.1	171	233	464
Nikolski	Nikolski AFS	52.9	168.8W	214.9	01/61-02/67	9.1	7.2	7.3	9.1	497	516	1029
Port Moller	Port Moller AFS	56.0	160.5W	316.4	06/59-02/64	9.1	4.4	4.4	5.6	160	166	331
St. Paul Island	St. Paul Island WBAS	57.2	170.2W	8.5	08/61-12/64	19.5	8.0	7.2	9.1	612	410	916
Shemya	Shemya WBAS	52.7	174.1E	39.0	11/61-04/73	6.1	8.7	9.4	11.8	810	1001	1996

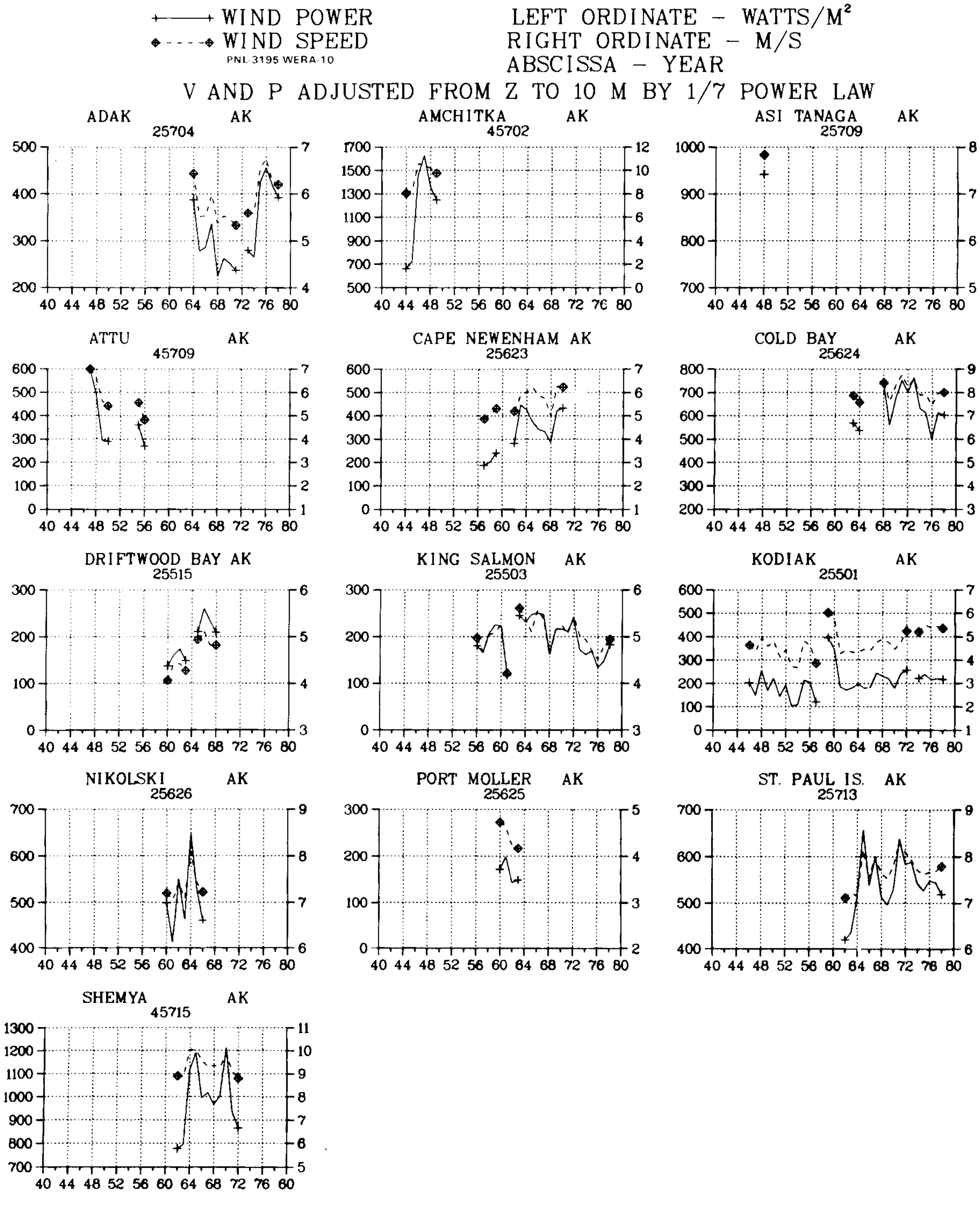


FIGURE 7.10. Interannual Wind Power and Speed for Southwestern Alaska

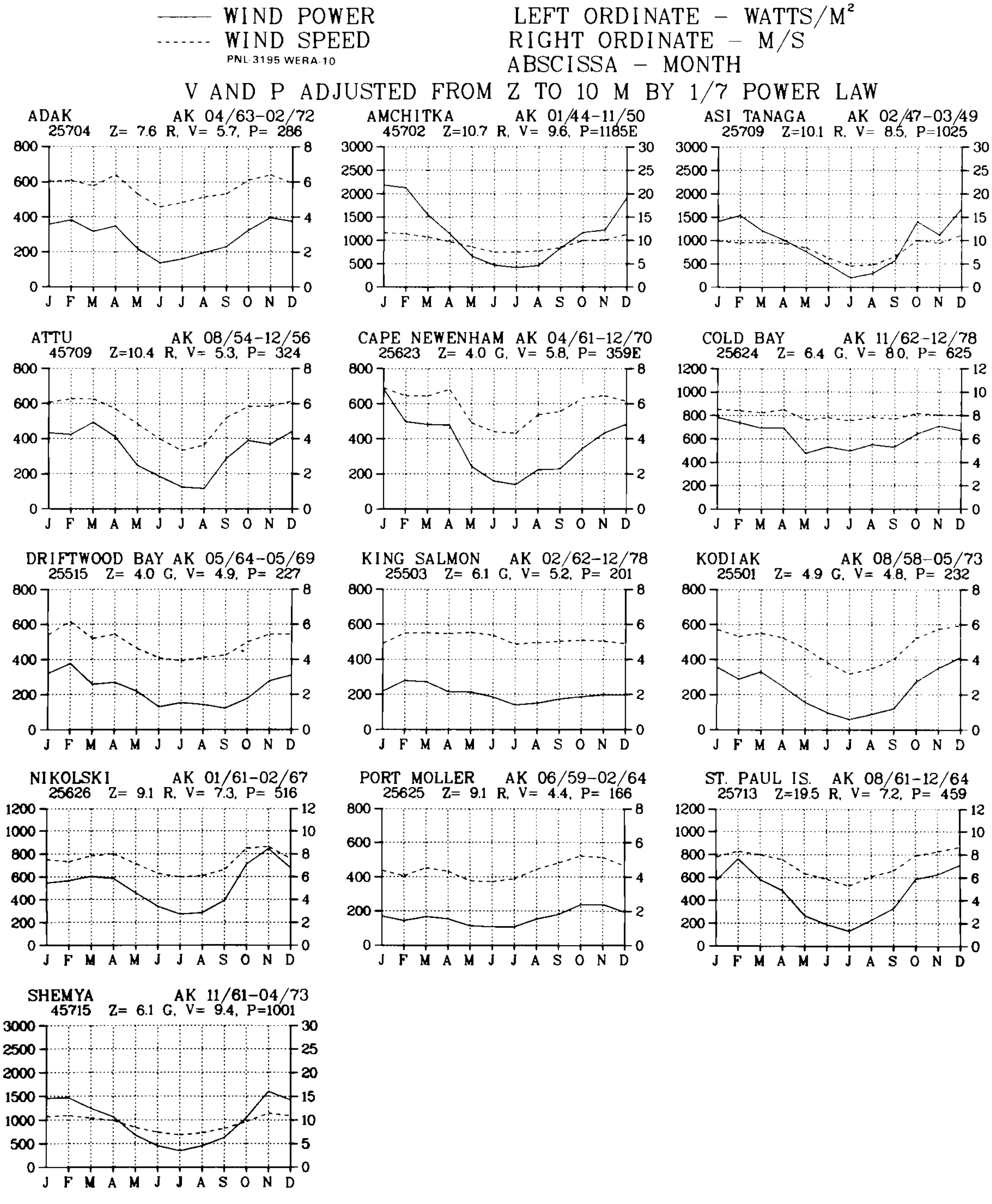


FIGURE 7.11. Monthly Average Wind Power and Speed for Southwestern Alaska

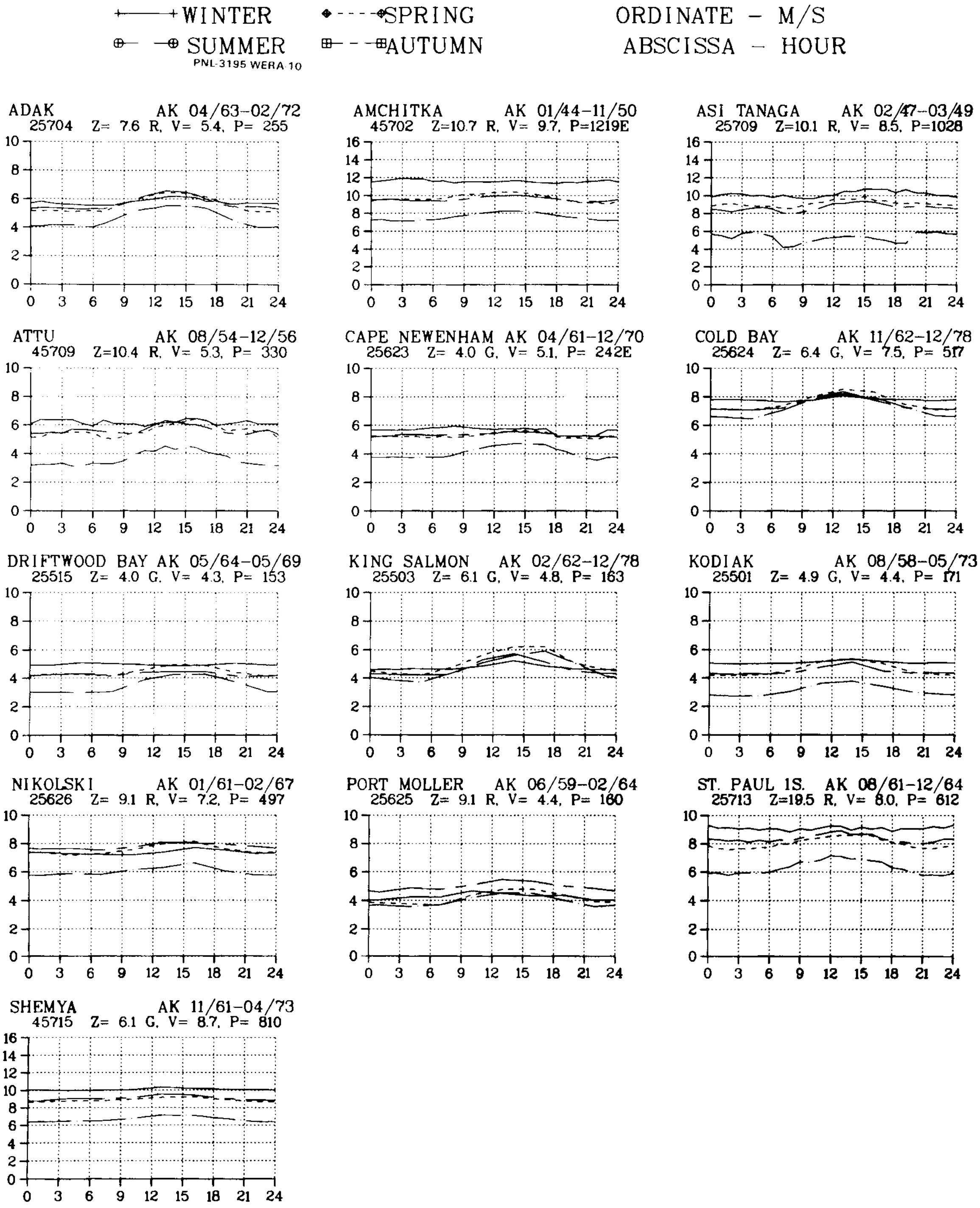


FIGURE 7.12. Diurnal Wind Speed by Season for Southwestern Alaska

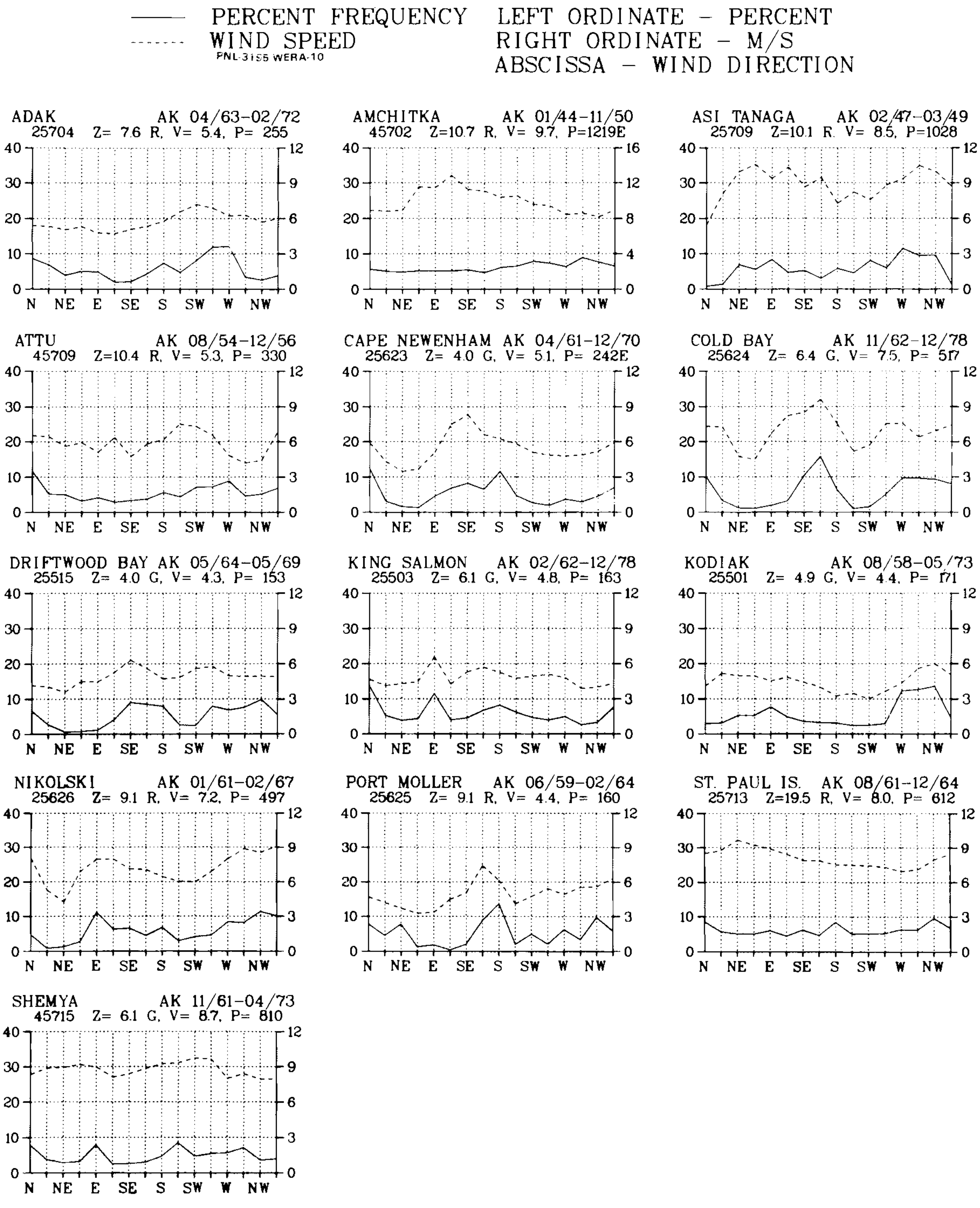


FIGURE 7.13. Directional Frequency and Average Wind Speed for Southwestern Alaska

ORDINATE - PERCENT
ABSCISSA - M/S
PNL-3195 WERA-10

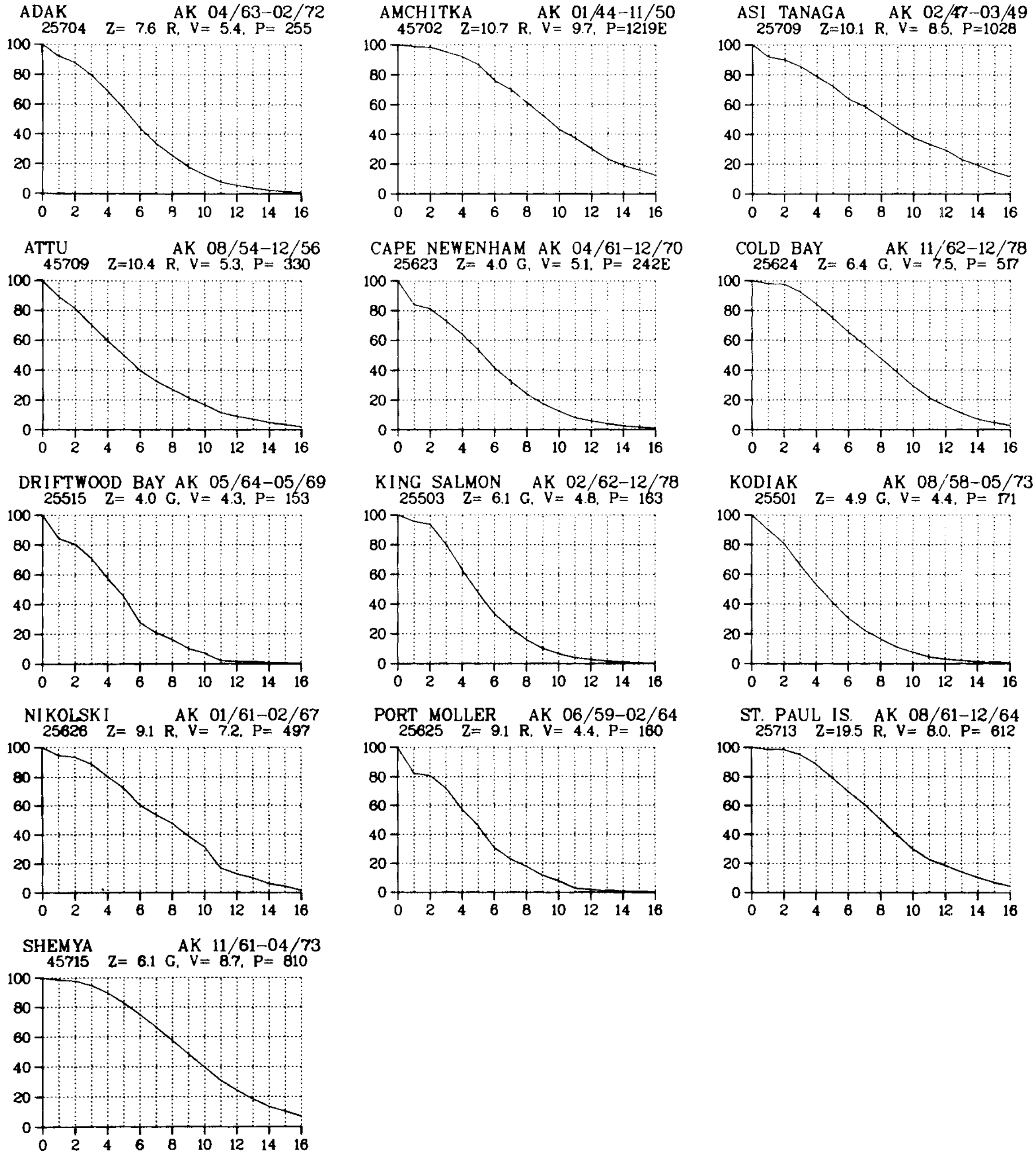


FIGURE 7.15. Annual Average Wind Speed Duration for Southwestern Alaska

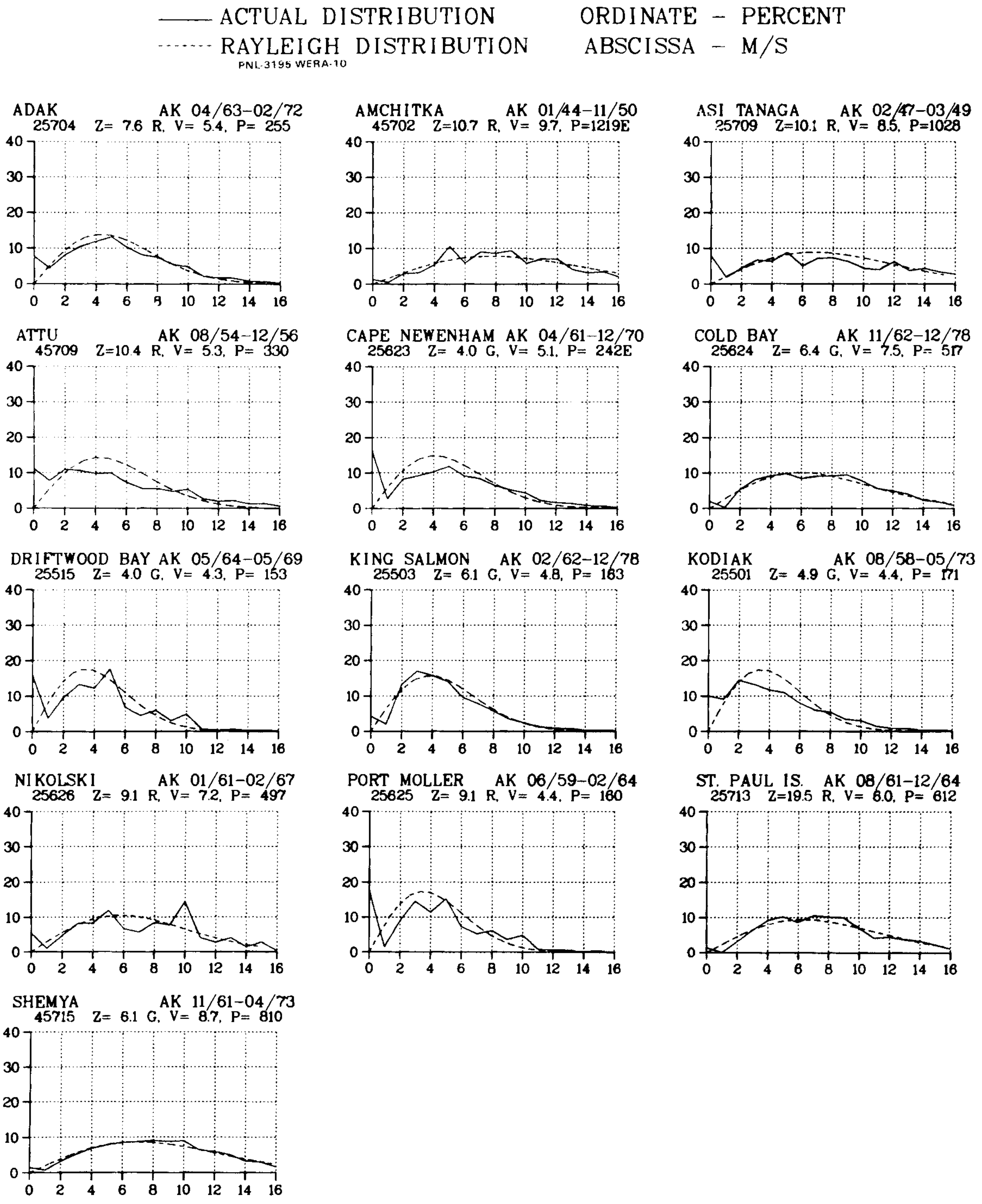
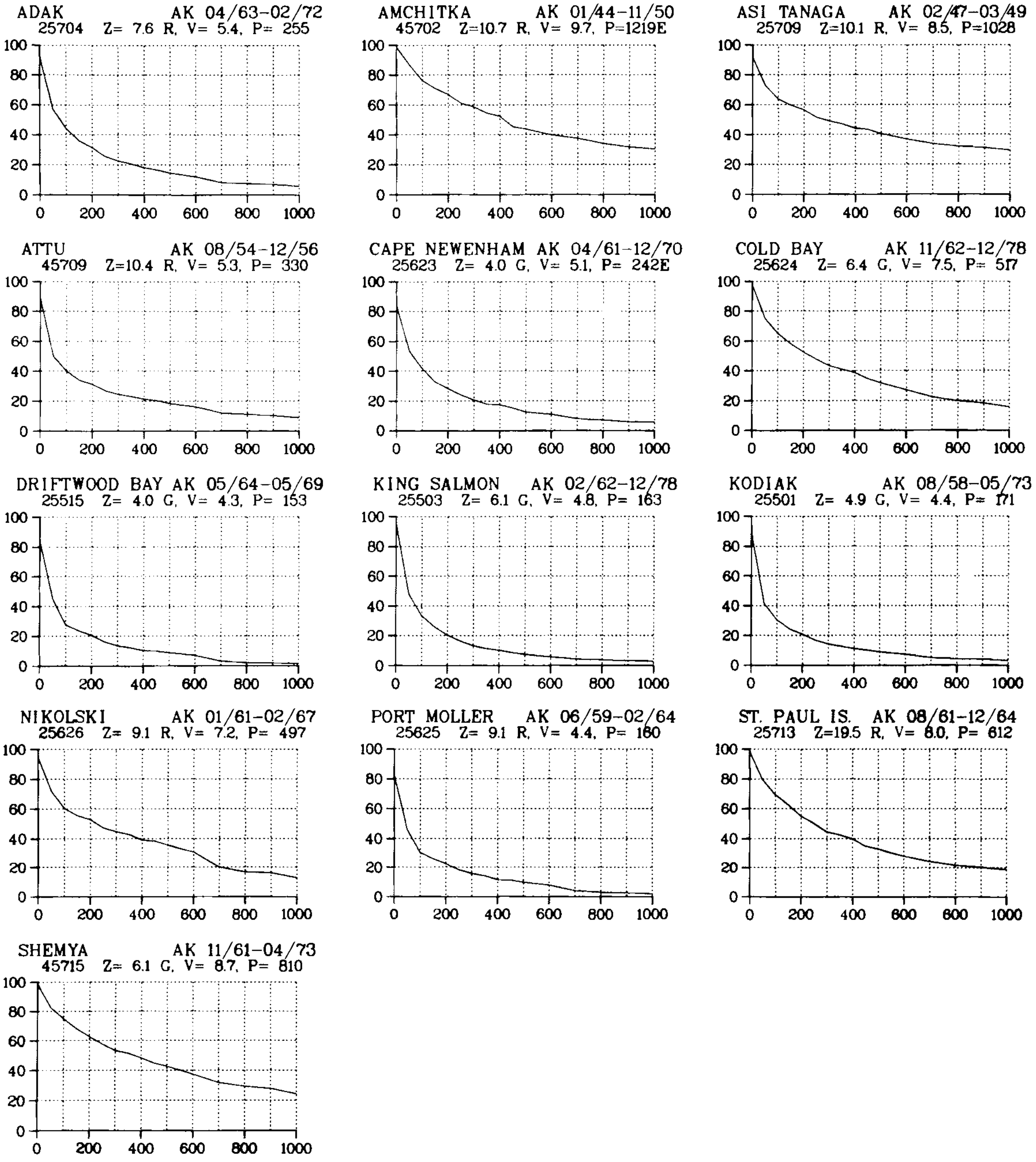


FIGURE 7.14. Annual Average Wind Speed Frequency for Southwestern Alaska

ORDINATE - PERCENT
ABSCISSA - WATTS/M^2
PNL-3195 WERA-10



ADAK AK 04/63-02/72
25704 Z= 7.6 R, V= 5.4, P= 255

AMCHITKA AK 01/44-11/50
45702 Z=10.7 R, V= 9.7, P=1219E

ASI TANAGA AK 02/47-03/49
25709 Z=10.1 R, V= 8.5, P=1028

ATTU AK 08/54-12/56
45709 Z=10.4 R, V= 5.3, P= 330

CAPE NEWENHAM AK 04/61-12/70
25623 Z= 4.0 G, V= 5.1, P= 242E

COLD BAY AK 11/62-12/78
25624 Z= 6.4 G, V= 7.5, P= 517

DRIFTWOOD BAY AK 05/64-05/69
25515 Z= 4.0 G, V= 4.3, P= 153

KING SALMON AK 02/62-12/78
25503 Z= 6.1 G, V= 4.8, P= 163

KODIAK AK 08/58-05/73
25501 Z= 4.9 G, V= 4.4, P= 171

NIKOLSKI AK 01/61-02/67
25626 Z= 9.1 R, V= 7.2, P= 497

PORT MOLLER AK 06/59-02/64
25625 Z= 9.1 R, V= 4.4, P= 160

ST. PAUL IS. AK 08/61-12/64
25713 Z=19.5 R, V= 8.0, P= 612

SHEMYA AK 11/61-04/73
45715 Z= 6.1 G, V= 8.7, P= 810

FIGURE 7.16. Annual Average Wind Power Duration for Southwestern Alaska

REFERENCES

Arctic Meteorology Research Group. 1960a. *Temperature and Wind Frequency Tables for North America and Greenland. Vol. 1, January-June*. McGill University, Montreal, Quebec, Canada.

Arctic Meteorology Research Group. 1960b. *Temperature and Wind Frequency Tables for North America and Greenland. Vol. 2, July-December*. McGill University, Montreal, Quebec, Canada.

Atmospheric Environment Canada. 1976a. *Climatological Station Data. The North Yukon Territory and Northwest Territory*. Downsview, Ontario, Canada.

Atmospheric Environment Canada. 1976b. *Climatological Station Data. British Columbia*. Downsview, Ontario, Canada.

Atmospheric Environment Canada. No date. *Canadian Normals, 1955-1972*.

Changery, M. J. 1975. *Initial Wind Energy Data Assessment Study*. NSF/NOAA, NSF-RA-N-75-020, National Climatic Center, Asheville, North Carolina.

Changery, M. J., W. T. Hodge, and J. V. Ramsdell. 1977. *Index-Summarized Wind Data*. BNWL-2220 WIND-11, NOAA/Pacific Northwest Laboratory, National Climatic Center, Asheville, North Carolina.

Changery, M. J. 1978. *National Wind Data Index*. HCO/T1041-01, DOE/NOAA, E(49-26)-1041, National Climatic Center, Asheville, North Carolina.

Cliff, W. C. 1977. *The Effect of Generalized Wind Characteristics on Annual Power Production Estimates from Wind Turbine Generators*. PNL-2436, Pacific Northwest Laboratory, Richland, Washington.

Coty, U. A. 1976. *Wind Energy Mission Analysis*. SAN/1075-1/1,2,3; Lockheed-California Company, Burbank, California.

Crutcher, H. L. 1961. *Meridonal Cross-Sections, Upper Winds over the Northern Hemisphere*. Technical Paper No. 41, National Weather Records Center, U.S. Weather Bureau, Asheville, North Carolina.

Elliott, D. L. 1977. *Synthesis of National Wind Energy Assessments*. BNWL-2220 WIND-5, Pacific Northwest Laboratory, Richland, Washington.

Elliott, D. L. 1979a. "Meteorological and Topographical Indicators of Wind Energy for Regional Assessments." *Proceedings of the Conference on Wind Characteristics and Wind Energy Sitting*. PNL-3214, Pacific Northwest Laboratory, Richland, Washington.

Elliott, D. L. 1979b. "Adjustment and Analysis of Data for Regional Wind Energy Assessments." Paper presented at the Workshop on Wind Climate, Asheville, North Carolina, November 12-13, 1979.

Furman, R. W. and G. E. Brink. 1975. *The National Fire Weather Data Library*. USDA For. Ser. Gen. Techn. Rep. RM-19, Rocky Mt. Fo. and Range Exp. Stn., Fort Collins, Colorado.

Garate, J. A. 1977. *Wind Energy Mission Analysis*. COO/2578-1/1,2,3, General Electric Company, Philadelphia, Pennsylvania.

Hammond, E. H. 1964. "Analysis of Properties in Landform Geography: An Application to Broadscale Landform Mapping," *Annals*, Association of American Geographers, 54:11-19, Map Supplement Number 4.

Hewson, E. W. and R. W. Baker. 1978. *Windpower Network Over the Pacific Northwest*. BPA-77-2, Oregon State University, Corvallis, Oregon.

Hewson, E. W. et al. 1978. *Vegetation as an Indicator of High Wind Velocity*. RLO/2227-T24-78-2. Available from National Technical Information Service, Springfield, Virginia.

Hewson, E. W. et al. 1979. *A Handbook on the Use of Trees as an Indicator of Wind Power Potential*. RLO/2227-79/3. Available from National Technical Information Service, Springfield, Virginia.

Kolm, L. E. and R. W. Marrs. 1977. *Predicting the Surface Wind Characteristics of Southern Wyoming from Remote Sensing and Eolian Geomorphology*. RLO/2343-78/1, University of Wyoming, Laramie, Wyoming.

Marlatt, W. E., P. Tierney, P. Meikle, M. Baer, and J. Childs. 1979. *Assessment of the Applicability of the National Fire Weather Library to Wind Energy Analyses*. PNL-2538. Prepared for Pacific Northwest Laboratory, Richland, Washington.

Marrs, R. W. and D. R. Gaylord. 1979. A Guide to Interpretation of Windflow Characteristics from Eolian Landforms. RLO/2343-79/2. Available from National Technical Information Service, Springfield, Virginia.

National Climatic Center (NCC). 1970. Winds Aloft Summaries, by Month. Available from National Weather Records Center, Federal Building, Asheville, North Carolina.

National Climatic Center (NCC). 1975. TDF-14: Surface Observations. Available from the National Climatic Center, Asheville, North Carolina.

National Climatic Center (NCC) and University of Alaska. 1977. Climatic Atlas of the Outer Continental Shelf and Coastal Regions of Alaska. Available from Arctic Environmental Information and Data Center, University of Alaska, 707 A Street, Anchorage, Alaska and NTIS.

National Climatic Center. 1977. Index of Original Surface Weather Records for Stations in Alaska. Available from the National Climatic Center, Asheville, North Carolina.

Reed, J. W. 1975. Wind Power Climatology of the U.S. SAND 74 0348, Sandia Laboratories, Albuquerque, New Mexico.

Voelker, A. H. et al. 1979. A Systematic Method for Resource Rating with Two Applications to Potential Wilderness Areas. ORNL/TM-6759, Oak Ridge National Laboratory, Oak Ridge, Tennessee.

Wahl, E. W. 1966. Windspeed on Mountains. No. AF19(628)-3873, USAF-CRL, Bedford, Massachusetts.

Wegley, H. L. et al. 1980. A Siting Handbook for Small Wind Energy Conversion Systems. PNL-2521 Rev. 1, Pacific Northwest Laboratory, Richland, Washington.

Yansky, G. R., E. H. Markee, Jr., and A. P. Richter. 1966. Climatography of the National Reactor Testing Station. IDO-12048, Air Resources Field Research Office, Idaho Falls, Idaho.

INDEX

DISTRIBUTION

No. of
Copies

OFFSITE

A. A. Churm
DOE Chicago Patent Group
9800 S. Cass Ave.
Argonne, IL 60439

D. F. Ancona
Department of Energy
600 E St. NW
Washington, DC 20545

Ted Ankrum
Office of Commercialization
Department of Energy
Room 6A081, M/S 6B025
Washington, DC 20585

5 C. I. Aspliden
Department of Energy
600 E. St. NW
Washington, DC 20545

Ernie Chabot
Department of Energy
GMTA, CS-74, M/S 2H027
Forrestal Building
Washington, DC 20585

5 L. V. Divone
Department of Energy
600 E St. NW
Washington, DC 20545

5 W. C. Reddick
Department of Energy
600 E St. NW
Washington, DC 20545

Robert San Martin
Department of Energy
600 E St. NW
Washington, DC 20545

20 G. P. Tennyson
Department of Energy
Albuquerque Operations Office
Suite 151
4501 Indian School Rd. NE
Albuquerque, NM 87110

27 DOE Technical Information Center

50 U.S. Government Printing Office
Documents Warehouse
8610 Cherry Ln.
Laurel, MD 20810

No. of
Copies

20 Tunis Wentink
University of Alaska
Geophysical Institute
Fairbanks, AK 99701

62 J. L. Wise
Arctic Environmental Information and Data Center
University of Alaska
707 A St.
Anchorage, AK 99501

Richard Katzenburg
American Wind Energy Association
2820 Upton St. NW
Washington, DC 20008

Ben Wolff
American Wind Energy Association
1621 Connecticut Ave. NW
Fifth Floor
Washington, DC 20009

AWEA Windletter
1609 Connecticut Ave. NW
Washington, DC 20009

Bruce B. Hicks
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439

D. L. Sisterson
Argonne National Laboratory
9700 S. Cass Ave.
Argonne, IL 60439

P. A. Taylor
Atmospheric Environmental Service
4505 Dufferin St.
Downsview, Ontario, CANADA

M. J. Berger
Bonneville Power Administration
P.O. Box 3621
Portland, OR 97208

Edgar De Meo
Electric Power Research Institute
3412 Hillview Ave.
Palo Alto, CA 94303

Ken Bosley
Energy Unlimited
2 Aldwin Center
Villanova, PA 19085

No. of
Copies

Stanley Macklis
General Electric Company
P.O. Box 8661
Philadelphia, PA 19101

Ken Pickering
GEOMET, Inc.
15 Firstfield Rd.
Gaithersburg, MD 20760

Joe Zabransky
GEOMET, Inc.
15 Firstfield Rd.
Gaithersburg, MD 20760

G. T. Norman
Global Weather Consultants, Inc.
2301 Hanover St.
Palo Alto, CA 94306

Alain Streicher
Hagler, Bailly and Co.
Suite 350
2020 K St. NW
Washington, DC 20006

T. A. Schroeder
Department of Meteorology
University of Hawaii
2525 Correa Rd.
Honolulu, HI 96822

Leon Graves
Institute for Storm Research
4104 Mt. Vernon
Houston, TX 77006

J. B. Knox
Lawrence Livermore Laboratory
P.O. Box 808
Livermore, CA 94550

Barbara Luxemburg
Library of Congress/CRS
Washington, DC 20540

R. J. Templin
National Research Council
Montreal Rd.
Ottawa, Ontario, CANADA
K1A 0R6

J. Estes
NASA Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135

Ron Thomas
NASA Lewis Research Center
21000 Brookpark Rd.
Cleveland, OH 44135

No. of
Copies

Phillip French
NASA Scientific and Technical
Information Facility
P.O. Box 8757
Baltimore/Washington International
Airport
Baltimore, MD 21240

Tom Potter
National Oceanic and Atmospheric
Administration/EDIS
National Climatic Center
Federal Building
Asheville, NC 28801

Malcom Reid
National Oceanic and Atmospheric
Administration
EDIS/CEAS
Room 416 Page 1
Washington, DC 20235

M. J. Changery
National Oceanic and Atmospheric
Administration
National Climatic Center
Federal Building
Asheville, NC 28801

5 Daniel Mitchell
National Oceanic and Atmospheric
Administration
National Climatic Center
Federal Building
Asheville NC 28801

Roger Brode
NUS Corporation
4 Research Pl.
Rockville, MD 20850

Ron Stoner
NUS Corporation
4 Research Pl.
Rockville, MD 20850

R. L. Simon
Pacific Gas and Electric
Rm 455
215 Market St.
San Francisco, CA 94106

E. L. Luther
PRC Energy Analysis Co.
7600 Old Springhouse Rd.
McLean, VA 22102

R. Cingo
Rockwell International
Rocky Flats Plant
Golden, CO 80401

No. of
Copies

C. Hansen
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401

Terry Healy
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401

R. Moment
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401

J. Sherman
Rockwell International
Rocky Flats Plant
P.O. Box 464
Golden, CO 80401

Ted Kornreich
SAI
1710 Goodridge Dr.
McClean, VA 22102

Richard Braasch
Division 4715
Sandia Laboratory
Albuquerque, NM 87185

E. Kadlec
Division 5443
Sandia Laboratory
Albuquerque, NM 87115

J. A. Bereny
Solar Energy Information Service
P.O. Box 204
San Mateo, CA 94401

Roland Hulstrom
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

Information Library
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

Ken Olsen
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

No. of
Copies

Irwin Vas
Solar Energy Research Institute
1617 Cole Blvd.
Golden, CO 80401

Noland Clark
U.S. Department of Agriculture
Agriculture Research Service
Bushland, TX 79012

R. Case
U.S. Bureau of Land Management
Building 50, Dept. D-440
Denver Federal Center
Denver, CO 80225

S. Hightower
U.S. Bureau of Reclamation
Building 67, Code 254
Denver Federal Center
Denver, CO 80225

S. Jennings
U.S. Department of Justice/INS
Room 6307, COENG
425 I St. NW
Washington, DC 20534

Steve Anderson
Western Scientific Services, Inc.
328 Airpark Dr., P.O. Box 1965
Ft. Collins, CO 80522

Dan Freeman
Western Scientific Services, Inc.
328 Airpark Dr., P.O. Box 1965
Ft. Collins, CO 80522

Farrell Smith Seiler
Wind Energy Report
Box 14
104 X. Village Ave.
Rockville Centre, NY 11571

Earl Davis
Wind Farms Ltd.
639 Front St.
San Francisco, CA 94111

Alaska Center for the Environment
1069 West Sixth Avenue
Anchorage, AK 99501

Ernst Mueller
State of Alaska
Department of Environmental Conservation
Pouch O
Juneau, AK 99811

No. of
Copies

Neil Davis
Geophysical Institute
University of Alaska
Fairbanks, AK 99701

John Zarling
Mechanical Engineering Dept.
University of Alaska
Fairbanks, AK 99701

Chris Noah, Executive Director
Alaska Council Science and Technology
Pouch AV
Juneau, AK 99811

Jeff Wilson
Alaska Chapter AIA
201 East Fireweed Lane
Anchorage, AK 99503

Richard Straty
Auke Bay Fisheries Lab
U.S. Dept. of Commerce (NOAA)
P.O. Box 155
Auke Bay, Alaska 99821

Nils P. Sara
AVCP
Box 767
Bethel, AK 99559

Mim Dixon
P.O. Box 81585
College, AK 99701

Frank DeLong
Earth Resources Company
1200 One Energy Square
Dallas, TX 74026

Robert Burkett
F.R.E.D. Division
Dept. of Fish & Game
Subport Building
Juneau, AK 99801

Emil Remus
4 Winds of Alaska
5100 Vi Street
Anchorage, AK 99507

Kent Grinage
P.O. Box 69
Barrow, AK 99723

Byron Hollembaek
Mile 1403-1/2, Alaska Highway
Delta Junction, AK 99737

Sara and Chuck Hornberger
P.O. Box 69
Iliamna, AK 99606

No. of
Copies

Bill Leighty
P.O. Box 993
Juneau, AK 99802

Jay Hogan
Legislative Finance Division
Legislative Affairs
Pouch FW
Juneau, AK 99811

Harvey Laborn
Local 72
Sheet Metal Workers
315 5th Avenue
Fairbanks, AK 99701

Byron D. Ruppel
Lockheed Missiles and
Space Company, Inc.
Sunnyvale, CA 94086

John A. Pursley
Heatloss Analysis
536 Bonanza Avenue
Anchorage, AK 99502

Jerry D. Plunkett
Managing Director
Montana Energy and MHD
Research and Development Institute
P.O. Box 3980
Butte, MT 59701

Bill Bartlett
National Oceanic and Atmospheric
Administration
National Climatic Center
Federal Building
Asheville, NC 28801

Jack T. Sanderson
Asst. Director for Engineering
and Applied Science
National Science Foundation
1800 "G" Street N.W. Room 537
Washington, DC 20550

Harold Sparch
Director
Nunam Kitlutsisti
P.O. Box 267
Bethel, AK 99559

Walter B. Parker
3724 Campbell Airstrip Road
Anchorage, AK 99504

Leslie Griffiths
Rand M. Consultants
P.O. Box 6087
Anchorage, AK 99502

No. of
Copies

Phil Smith
c/o Rural CAP
327 Eagle Street
Anchorage, AK 99501

Bob Roggasch
529 6th Avenue
Fairbanks, AK 99701

Richard D. Seifert
P.O. Box 8014
Fairbanks, AK 99708

Mark Newell
Wind Systems Engineering, Inc.
1551 Tudor Road
Anchorage, AK 99507

Michael Edds
WSUN
Pioneer Park Building, Suite 800
715 S.W. Morrison
Portland, OR 97205

G. A. McKay
Director
Climatological Applications Branch
Canadian Climate Centre
4905 Dufferin Street
Downsview, Ontario M3H 5T4
CANADA

ONSITE

2 DOE Richland Operations Office
P.O. Box 550
Richland, WA 99352

H. E. Ransom
R. K. Stewart

75 Pacific Northwest Laboratory
Battelle Boulevard
Richland, WA 99352

W. R. Barchet (10)
J. C. Barnard
N. J. Cherry
J. R. Connell
J. C. Doran
R. L. Drake
K. Drumheller
C. E. Elderkin
D. L. Elliott (20)
R. L. George
D. Hadley
S. K. Heflick
T. R. Hiester
G. A. Jensen

No. of
Copies

A. H. Miller
E. L. Owzarski
W. T. Pennell
E. H. Phinney
D. C. Powell
J. M. Proud (15)
J. V. Ramsdell
D. S. Renne
H. L. Wegley
L. L. Wendell
R. K. Woodruff
R. Zengerle
Technical Information (5)
Publishing Coordination (2)

* GPO 797-416 1981