Wind Energy Resource Atlas Of The Philippines

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Executive Summary

We conducted a wind resource analysis and mapping study for the Philippine archipelago to identify potential wind resource areas and to quantify the value of that resource within those areas. This is a major study and the first of its kind undertaken for the Philippines. The key to the successful completion of the study is an automated wind resource mapping program recently developed at the National Renewable Energy Laboratory (NREL).

The wind resource mapping program uses an advanced computerized mapping system known as the Geographic Information System (GIS). The two primary inputs to the mapping system are gridded 1-square kilometer (km^2) terrain data and meteorological data. The meteorological data sources include surface (land and open-ocean) and upper-air data sets. These data are screened to select representative stations and data periods for use in the mapping system. The final meteorological inputs to the mapping system are vertical wind profile(s), wind power rose(s) (the percentage of total potential power from the wind by direction sector), and the open-ocean wind power density, where appropriate. The GIS determines any required adjustments to these composite distributions for each 1-km^2 grid cell. The factors that have the greatest influence on the adjustment for a particular grid cell are the topography in the vicinity and a combination of the absolute and relative elevation of the grid cell. The primary output of the mapping system is a color-coded map containing the estimated wind power, and equivalent wind speed, for each individual grid cell.

To portray the mapping results, the Philippine archipelago was divided into 13 regions. Each region is approximately 300 km by 300 km. The regional divisions were determined principally on the geography of the archipelago and the desire to maintain the same map scale for each region. Surface, satellite, and upper-air data were assembled, processed, and analyzed. These data sets included information provided by the Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA), the Philippine National Power Corporation (NPC), data sets from the United States National Climatic Data Center (NCDC), and other U.S. data. The satellite data sets of calculated wind speed at 10-meter (m) heights over ocean areas were extremely useful in this analysis because of the large expanse of ocean surrounding the archipelago and the limited number and value of land-based observations. The mapping system was applied to each of these 13 regions, and the wind resource maps for each region were generated.

A combination of wind characteristics helps determine the wind energy resource in a particular area. Factors such as the annual and monthly average wind speeds and the seasonal and diurnal wind patterns affect the suitability of an area. In general, locations with an annual average wind speed of 6.5 to 7.0 meters per second (m/s) or greater at turbine hub height, are the most suitable for utility grid-connected wind energy systems. Rural power applications are typically viable at lower wind speeds (5.5 to 6.0 m/s), and, in some cases, at wind speeds as low as 4.5 m/s.

The average wind speed is not the best indicator of the resource. Instead, the level of the wind resource is often defined in terms of the wind-power-density value, expressed in watts per square meter (W/m^2). This value incorporates the combined effects of the wind speed frequency distribution, the dependence of the wind power on air density, and the cube of the wind speed. Thus, six wind power classifications, based on ranges of wind-power-density values, were established in each of two categories: one for utility-scale applications (ranging from marginal to excellent) and one for rural power applications (ranging from moderate to excellent). This classification scheme is presented in Table S-1.

Table S-1. Wind Power Classification

Class	Resource Potential Utility	Resource Potential Rural	Wind Power Density (W/m^2) @ 30 m	Wind Speed [a] (m/s) @ 30 m
1	Marginal	Moderate	100 – 200	4.4 – 5.6
2	Moderate	Good	200 – 300	5.6 – 6.4
3	Good	Excellent	300 – 400	6.4 – 7.0
4	Excellent	Excellent	400 – 600	7.0 – 8.0
5	Excellent	Excellent	600 – 800	8.0 – 8.8
6	Excellent	Excellent	800 – 1200	8.8 – 10.1

[a] Mean wind speed is estimated assuming a Weibull distribution of wind speeds with a shape factor (k) of 2.0 and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20 percent, depending on the actual wind speed distribution (or Weibull k value) and the elevation above sea level.

The wind resource in the Philippines is strongly dependent on latitude, elevation, and proximity to the coastline. In general, the best wind resource is in the north and northeast, and the worst resource is in the south and southwest of the archipelago.

The wind mapping results show many areas of good-to-excellent wind resource for utility-scale applications or excellent wind resource for village power applications, particularly in the northern and central regions of the Philippines. The best wind resources are found in six regions: (1) the Batanes and Babuyan islands north of Luzon; (2) the northwest tip of Luzon (Ilocos Norte); (3) the higher interior terrain of Luzon, Mindoro, Samar, Leyte, Panay, Negros, Cebu, Palawan, eastern Mindanao, and adjacent islands; (4) well-exposed east-facing coastal locations from northern Luzon southward to Samar; (5) the wind corridors between Luzon and Mindoro (including Lubang Island); and (6) between Mindoro and Panay (including the Semirara Islands and extending to the Cuyo Islands).

More than 10,000 km^2 of windy land areas are estimated to exist with good-to-excellent wind resource potential. Using conservative assumptions of about 7 MW per km^2, this windy land could support more than 70,000 MW of potential installed capacity. Considering only the areas of good-to-excellent wind resource, there are 47 provinces out of 73 with at least 500 MW of wind potential and 25 provinces with at least 1,000 MW of wind potential. However, to accurately assess the wind electric potential will require additional studies, considering such factors as the existing transmission grid and accessibility.

The wind mapping results also show numerous additional areas of moderate wind resource for utility-scale applications or good wind resource for village power applications. If these additional areas are considered, the estimated total land area increases to more than 25,000 km^2. Using conservative assumptions of about 7 MW per km^2, this land could support more than 170,000 MW of potential installed capacity. On a provincial basis, there are 51 provinces out of 73 with at least 1,000 MW of wind potential and 64 provinces with at least 500 MW of wind potential.

The seasons have a pronounced effect on the wind resource. The best resource is in the winter during the northeast monsoon, and the poorest resource is in the summer during the southwest monsoon. Throughout most of the Philippines, the highest wind resource occurs from November through February, and the lowest from April to September. However, there are some regional differences in the seasonal variability. For example, in the northern Philippines, the months with the highest wind resource are October through February; and in much of the central and southern Philippines, November through March are the months with the highest wind resource. Two areas of the Philippines (the southeastern Mindanao coast and the western coast of Palawan) have a relatively high wind resource from June through September during the southwest monsoon.

The wind resource maps and other wind resource characteristic information will be useful in identifying prospective areas for wind-energy applications. However, very limited data of sufficient quality were available to validate the wind resource estimates. Therefore, we strongly recommend that wind measurement programs be conducted to validate the resource estimates and to refine the wind maps and assessment methods where necessary.

1.0 Introduction

Upon learning of the National Renewable Energy Laboratory's (NREL) capability in regional- or national-scale wind energy resource assessment, the Winrock International Philippines Renewable Energy Project Support Office (REPSO) and Preferred Energy, Inc. (PEI), worked with other interested parties in the Philippines to propose and fund the development of a national-level Wind Energy Resource Atlas. The Philippine Council for Industry and Energy Research and Development (PCIERD), of the Department of Science and Technology (DOST), and the Philippines National Oil Company (PNOC) each provided funding for the study through Winrock International. The U.S. Department of Energy (DOE) provided significant funding for the development of the Wind Energy Resource Atlas, and the U.S. Agency for International Development (USAID) supported the overall coordination and data gathering for the Wind Atlas development effort. The project was intended to facilitate and accelerate the use of wind energy technologies—both for utility-scale generation and off-grid wind energy applications—in the Philippines, by providing the best possible estimates of wind energy resources over the entire national territory. The Philippines National Power Corporation (NPC) supported the project by contributing wind-monitoring data collected at 14 prospective wind energy sites and by providing other technical assistance.

Winrock International and REPSO had the lead responsibility in administering this project and in collaborating with the Philippine organizations and NREL on project activities. NREL had the technical lead for the wind resource analysis and mapping activities. The primary goal was to develop detailed wind resource maps for all regions of the Philippines and to produce a comprehensive wind-resource atlas documenting the mapping results.

This document, the "Wind Energy Resource Atlas of the Philippines," presents the wind-resource analysis and mapping results for the Philippines. The maps identifying the wind resource were created using a Geographic Information System- (GIS) based program developed at NREL. The mapping program, which combines high-resolution terrain data and formatted meteorological data, is designed to highlight areas possessing a favorable wind resource where specific wind energy projects, both for utility-grid applications and rural power applications, are likely to be feasible. The entire Philippines archipelago was mapped as part of this study. This is the first detailed national-scale wind energy resource atlas for a developing country, and one of the very first in the world. In addition to the Philippines, NREL has applied its new wind mapping system to produce wind resource assessments of the Dominican Republic (Elliott, 1999) and Mongolia (Elliott et al., 1998), and specific regions of Chile, China, Indonesia, Mexico, and the United States (Schwartz, 1999; Elliott et al., 1999).

The report is divided into six sections. An overview of the geography and climate of the Philippines is presented in Section 2.0. The wind resource information used to create the meteorological input files is highlighted in Section 3.0. A description of the mapping system is presented in Section 4.0. The wind resource characteristics of the Philippines and the wind mapping results are presented in Sections 5.0 and 6.0, respectively.

Appendices are included that highlight the analysis results from the NPC monitoring sites and selected surface-based sites from the DATSAV2 database, summarize data for three of the upper-air stations, and show maps and monthly summaries of wind speed and wind power from the satellite ocean wind data.

2.0 Geography and Climate of the Philippines

2.1 Geography

The Philippines is an archipelago consisting of 7,107 islands in the western Pacific. Figure 2-1 is a political base map of the Philippines and includes the names of major islands and cities. Boundaries of the 73 provinces are also shown in the figure. The population of the Philippines is 76,103,564 (July 1997 est.). The land area is approximately 299,000 square kilometers (km) (116,610 square miles), and there is approximately 36,289 km of coastline. The Philippines archipelago is centered at approximately 13 degrees north latitude and 122 degrees east longitude. Taiwan is north of the archipelago, Indonesia is south, and Eastern Malaysia and Brunei are southwest. Of all the islands in the archipelago, only 2,000 are inhabited. Luzon and Mindanao are the largest islands and comprise 66% of the total area of the country.

The terrain, shown in Figure 2-2, is largely mountainous with narrow coastal plains and interior plains and valleys. The principal valleys are in Central Luzon and include the northeastern Cagayan Valley and the Agusan Basin in the far south. There are numerous dormant and active volcanoes, such as Mt. Pinatubo on Luzon. The highest point in the archipelago is Mt. Apo on Mindanao at 2,954 meters (9,689 feet).

2.2 Climate

The Philippines has a tropical marine climate dominated by a wet season and a dry season. Prevailing winds govern the seasons. The southwest monsoon brings heavy rains to the archipelago from May to October, while the northeast monsoon brings cooler and drier air from December to February. The easterly trade winds induce hot, dry weather in March and April. However, the climate varies somewhat by region.

The northeast monsoon affects the northern part of the Philippines in October and reaches the southern portion of the archipelago by November. This wind flow attains its maximum strength in December throughout much of the Philippines and generally weakens by late March. The southwest wind first affects the northern part of the archipelago by early May and reaches the southern portion by June, attaining maximum intensity in August and gradually disappearing in October.

Mean annual sea-level temperatures rarely fall below 27 degrees Centigrade (°C). Annual rainfall is quite heavy in the mountains, but is much less in some sheltered valley areas. Typhoons, or eastern Pacific hurricanes, frequently hit the Philippines during the hurricane season, which extends from July through October, especially in northern and eastern Luzon, Bicol, and the eastern Visayas.

Philippines
Political Base Map

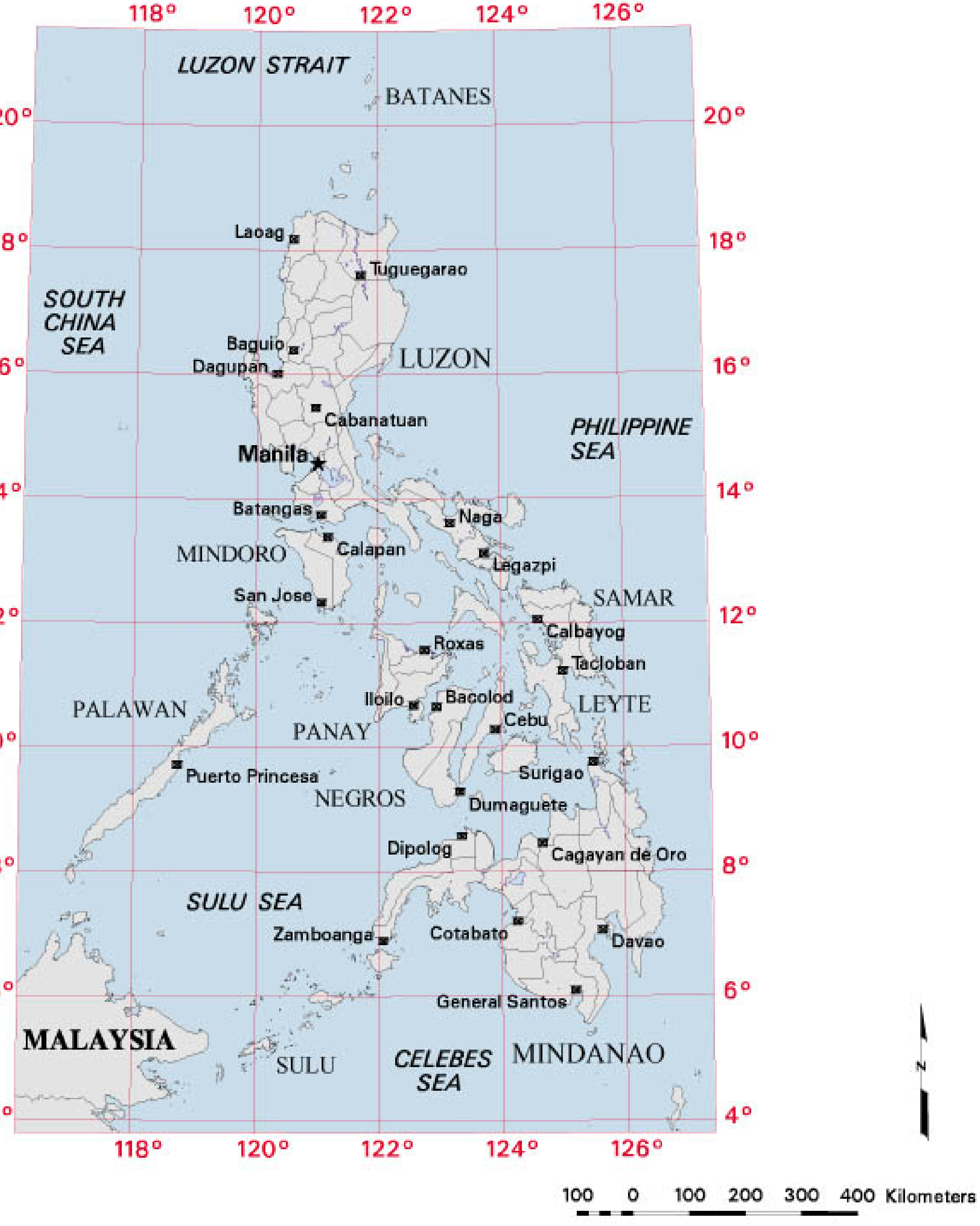

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Figure 2-1

Philippines
Elevation Map

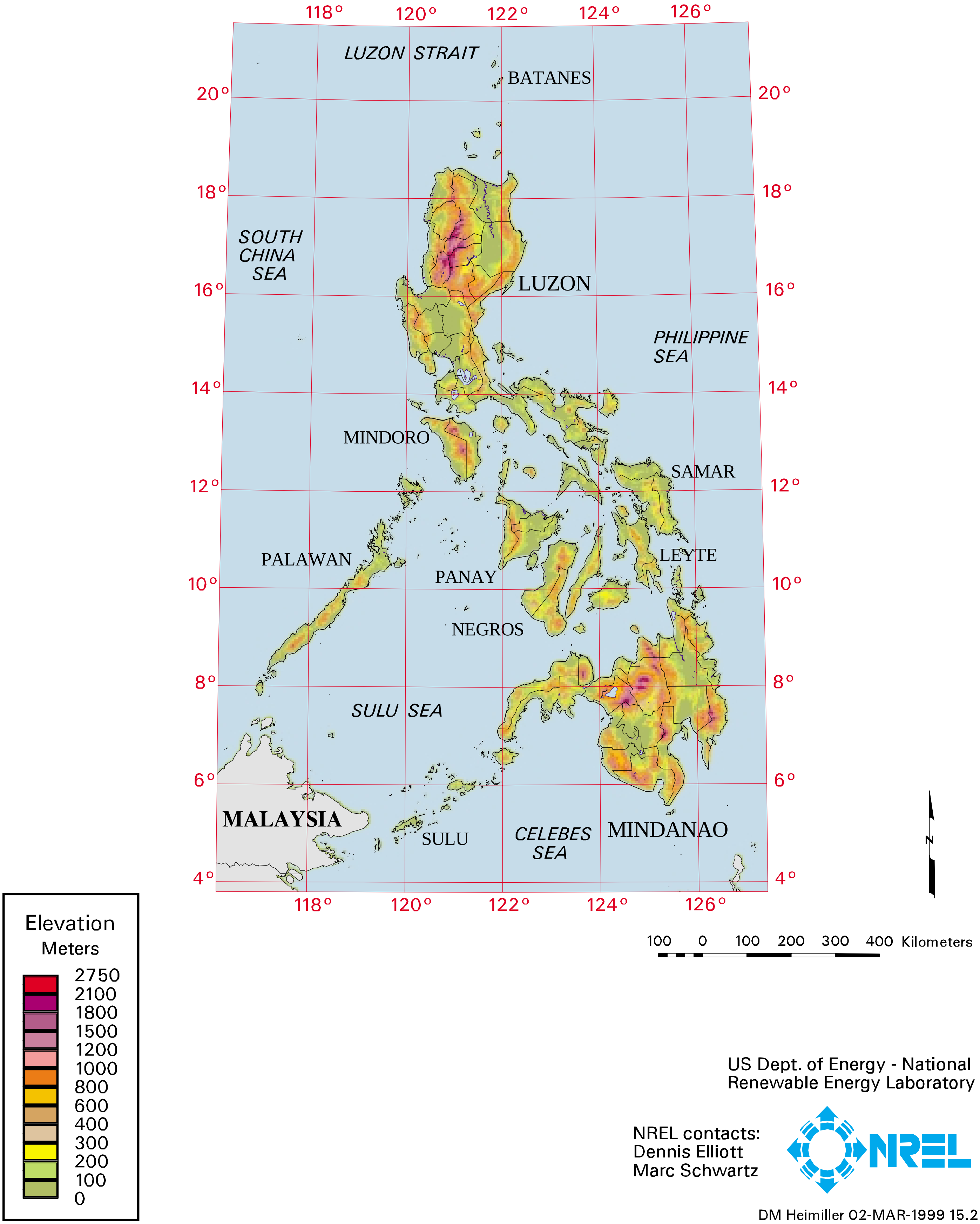

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Figure 2-2

3.0 Wind Resource Information

3.1 Introduction

An accurate wind resource assessment is highly dependent on the quantity and quality of the input data. NREL reviews numerous sources of wind speed data and previous wind energy assessments as part of its overall evaluation. We used several global wind data sets that have recently become available in this assessment. These data sets included land surface observations, marine data, and upper-air data. Multiple data sets are used because the quality of data in any particular data set can vary, and because high-quality data can be quite sparse in many regions of the world. Each data set plays an integral role in the overall assessment. This chapter summarizes the data sets analyzed in the wind resource mapping effort for the Philippines.

3.2 Surface Data

High-quality surface wind data from well-exposed locations can provide the best indication of the magnitude and distribution of the wind resource in the analysis region. The locations of meteorological stations in the Philippines where surface wind speed data were available are presented in Figure 3-1. The following sections present a summary of the surface data sets used in the assessment.

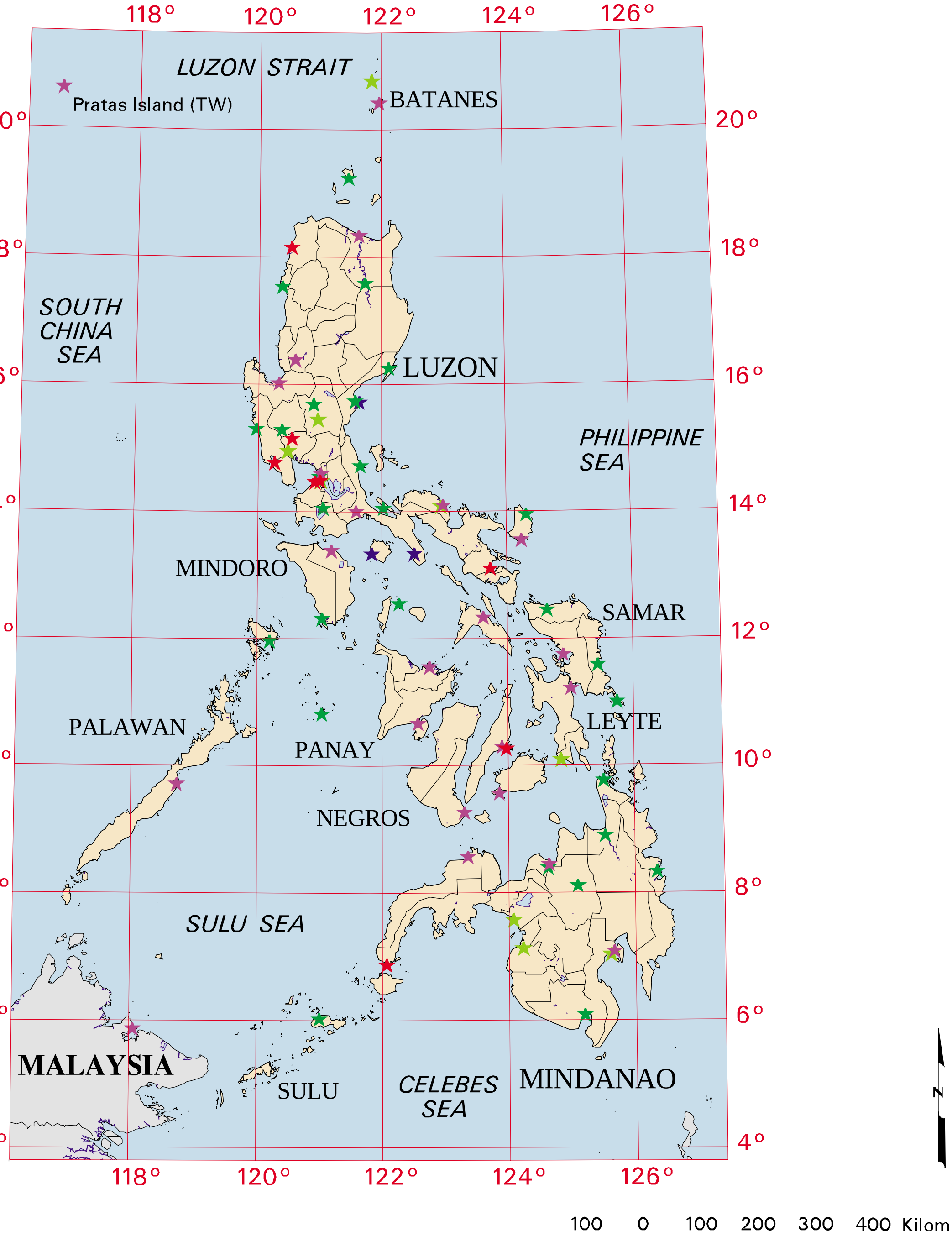
3.2.1 PAGASA

The National Institute of Climatology, Philippine Atmospheric, Geophysical, and Astronomical Services Administration (PAGASA) provided summarized data and several reports for this study. The summarized data included average wind speed and prevailing direction, by month, for 44 stations covering the period from 1961 to 1992. The two reports provided for this study included *Climatological Normal of Surface Winds in the Philippines,* prepared by the National Institute of Climatology, PAGASA, in January 1988, and *Solar Radiation and Wind Mapping of the Philippines,* also prepared by the National Institute of Climatology, PAGASA, in October 1986.

3.2.2 National Power Corporation

The NPC provided data from several wind-resource monitoring programs operated by NPC from 1994 to 1997, including hourly average wind speed and prevailing direction from nine sites, using 30-m-tall towers and state-of-the-art data acquisition equipment. The period of record at these nine sites varied from 9 months to 20 months. Monthly average wind speeds from five additional sites employing shorter towers were also provided.

Philippines - GTS Meteorological Stations With Surface Wind Data



The Global Telecommunications System (GTS) meteorological stations with surface wind data are part of NREL's global database.

Meteorological Stations Total Observations
★ 100,000 to 315,000
★ 50,000 to 100,000
★ 20,000 to 50,000
★ 5,000 to 20,000
★ 1,000 to 5,000

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Figure 3-1

3.2.3 DATSAV2

This global climatic database, obtained from the U.S. National Climatic Data Center (NCDC), contains the hourly surface weather observations from first-order meteorological stations throughout the world. This data set is the primary source of surface wind information used in the analysis. NREL currently has 24 years of DATSAV2 data in its archive, spanning the period 1973 to 1996. Additional years of data, in some cases back to the 1940s, were available in DATSAV2 for many stations in the Philippines. Meteorological parameters such as wind speed, wind direction, temperature, pressure, and altimeter setting are extracted from the hourly observations and used to create statistical summaries of wind characteristics. Most of the stations in the Philippines transmitted synoptic observations every 3 hours; many stations did not transmit during late-night hours. At many stations, the transmission frequency changed over the years. Some stations transmitted more frequently (hourly) or less frequently (such as every 6 hours) during some time periods. Each station in the DATSAV2 data set is identified by a unique six-digit number based on the World Meteorological Organization (WMO) numbering system for the stations in the Philippines.

3.2.4 Marine Climatic Atlas of the World

This is one of two global marine wind data sets used by NREL to provide estimates of the wind resource for offshore areas as well as coastal and inland sites that are well-exposed to the ocean winds. This data set, compiled from historical ship observations, presents summarized wind statistics for a 1-degree-latitude by 1-degree-longitude grid. Measurements are concentrated along the major shipping routes. Included are summaries of the monthly means and standard deviations of wind speed, pressure, temperature, and wind direction frequency and speed.

3.2.5 Special Sensor Microwave Imager (SSMI)

The SSMI, which is part of the Defense Meteorological Satellite Program, provides 10-m ocean wind speed measurements. This data set provides much more uniform and detailed coverage of oceanic wind speeds than the Marine Climatic Atlas of the World. Comparisons of satellite-derived winds with ship observations along major shipping routes indicate consistent results. NREL currently has 9 years of SSMI data covering the period 1988 to 1996.

3.3 Upper-Air Data

Upper-air data can provide an estimate of the wind resource at low levels in the atmosphere and contribute to the understanding of the vertical distribution of the wind resource. This is useful in estimating the winds on elevated terrain features and for estimating the wind resource at exposed locations in areas without reliable surface wind observations. The following two upper-air data sets were employed in the assessment.

3.3.1 Automated Data Processing Reports (ADP)

This data set contains upper-air observations from rawinsonde instruments and pilot balloons for approximately 1,800 stations worldwide. Observation times include 00, 06, 12, and 18 Greenwich Mean Time (GMT). Wind information is available from the surface, from mandatory pressure levels (1,000 mb, 850 mb, 700 mb, and 500 mb), from significant pressure levels (as determined by the vertical profiles of temperature and moisture), and from specified geopotential heights above the surface. The significant pressure levels and geopotential heights are different for each upper-air observation. The data set housed at NREL has approximately 25 years of observations, beginning in 1973.

3.3.2 Global Gridded Upper-Air Statistics

This data set contains monthly means and standard deviations of climatic elements for 15 atmospheric levels on a 2.5-degree global grid. We obtained the data, which covers the period 1980 to 1991, from the NCDC. This data set is used to supplement the ADP information in areas where upper-air data are scarce.

3.4 Data Screening

The reliability of the meteorological input data is the most important factor in creating an accurate wind resource map. A recent NREL paper (Schwartz and Elliott, 1997) describes the integration, analysis, and evaluation of different meteorological data sets for use in wind resource assessment. Known problems associated with observations taken at many meteorological stations around the world include a lack of information on anemometer height, exposure, hardware, maintenance history, and observational procedures. In addition, many areas of the world with the potential to have good or excellent wind resource sites have very little or no meteorological stations to provide guidance on assessing the wind magnitude and characteristics.

An analysis of the meteorological data is performed using techniques developed by NREL specifically for wind resource analysis. We used a comprehensive data-processing package to convert the surface and upper-air data to statistical summaries of the wind characteristics. The summaries, presented as a series of graphs and tables in the appendices, were used to highlight the regional wind characteristics. The DATSAV2 summaries include the interannual variability of the wind speed and wind power, the average wind speed and power on a monthly basis, the diurnal distribution of the wind resource, and the mean wind speed and frequency by direction sector. The wind power density is also computed and analyzed because it provides a truer indication of the wind resource potential than wind speed. We generated similar types of summaries for the upper-air data at specific geopotential heights or pressure levels of interest. We also generated monthly and annual average vertical profiles of wind speed by geopotential height or pressure level from the upper-air data.

Site-specific products are screened for consistency and reasonableness. For example, the interannual wind speeds are evaluated to identify obvious trends in the data, or periods of questionable data. Only representative data periods are selected from the entire record for the assessment. The summarized products are also cross-referenced against each other to select sites that apparently have the best exposure and to develop an understanding of the wind characteristics of the study region. This is important because of the variable quality of the data and, in most cases, the lack of documentation of the anemometer height and exposure. For assessment purposes, NREL assumes an anemometer height of 10 m (the WMO standard height) unless specific height information is provided. When there is a conflict among the information as to certain wind characteristics in the analysis region, the preponderance of meteorological evidence from the region serves as the basis of the input. The goal of the data analysis and screening process is to develop a conceptual model of the physical mechanisms, both regional and local in scale, that influence the wind flow.

3.5 Weibull Distribution Function

The Weibull Distribution Function is a generally accepted methodology used to estimate the wind speed frequency distribution. The Weibull Function is defined as follows:

$$f(V) = (k/c)(V/c)^{k-1} \exp(-V/c)^{k}$$

where *f(V)* is the Weibull probability density function where the probability of encountering a wind speed of V m/s is *f(V)*; *c*, expressed in m/s, is the Weibull scale factor, which is typically related to the average wind speed through the shape factor; and *k* is the Weibull shape factor, which describes the distribution of the wind speeds. Detailed explanations of the Weibull Distribution Function and its application are available in many texts, such as that by Rohatgi and Nelson (1994).

3.6 Wind Power Density

The wind resource at a site can be described by the mean wind speed, but the wind power density (WPD) provides a truer indication of a site's wind energy potential. The power density is proportional to the sum of the cube of the instantaneous or short-term average wind speed and the air density. The wind power density, in units of W/m^2, is computed by the following equation:

$$\boldsymbol{WPD} = \frac{\mathbf{1}}{\mathbf{2n}} \sum_{\mathbf{i=1}}^{\mathbf{n}} \rho \times \mathrm{v}_{\mathbf{i}}^{\mathbf{3}} \quad (\mathbf{W / m^2})$$

where

n = the number of records in the averaging interval;
ρ = the air density (kg/m^3) at a particular observation time; and
v_i^3 = the cube of the wind speed (m/s) at the same observation time.

This equation should only be used for instantaneous (n = 1) or multiple average wind speed values (n>1) and not for a single long-term average, such as a yearly value.

The air density term is dependent on temperature and pressure and can vary by 10% to 15% seasonally. If the site pressure is known, the hourly air-density values, with respect to air temperature, can be calculated using the following equation:

$$\rho = \frac{\mathbf{P}}{\mathbf{R \times T}} (\mathbf{kg / m^3})$$

where

> P = the air pressure (Pa or N/m^2);
> R = the specific gas constant for air (287 J/kg·K); and
> T = the air temperature in degrees Kelvin (°C+273).

If site pressure is not available, air density can be estimated as a function of site elevation (z) and temperature (T) as follows:

$$\rho = \left(\frac{\mathbf{P_0}}{\mathbf{R \cdot T}}\right) \varepsilon^{\left(\frac{-\mathbf{g \cdot z}}{\mathbf{R \cdot T}}\right)} \ \mathbf{(kg / m^3)}$$

where

> P_0 = the standard sea level atmospheric pressure (101,325 Pa), or the actual sea-level adjusted pressure reading from a local airport;
> g = the gravitational constant (9.8 m/s^2); and
> z = the site elevation above sea level (m).

Substituting in the numerical values for P_0, R, and g, the resulting equation is:

$$\rho = \left(\frac{\mathbf{353.05}}{\mathbf{T}}\right) \varepsilon^{-0.034\left(\frac{z}{t}\right)} \ \mathbf{(kg / m^3)}$$

This air density equation can be substituted into the WPD equation for the determination of each instantaneous or multiple average value.

3.7 Wind Shear and the Power Law

The wind shear is a description of the change in horizontal wind speed with height. The magnitude of the wind shear is site-specific and dependent on wind direction, wind speed, and atmospheric stability. By determining the wind shear, one can extrapolate existing wind speed or wind-power-density data to other heights. The following form of the power law equation is used to make these adjustments:

$$\mathbf{U = U_0 \, (z/z_0)^{\alpha}} \qquad \text{[Wind Speed]}$$

$$\mathbf{P = P_0 \, (z/z_0)^{3\alpha}} \qquad \text{[Wind Power Density]}$$

where

U = the unknown wind speed at height z above ground;
U_0 = the known speed at a reference height z_0;
P = the unknown wind power density at height z above ground;
P_0 = the known wind power density at a reference height z_0;
α = the power law exponent.

An exponent of 1/7 (or 0.143), which is representative of well-exposed areas with low surface roughness, is often used to extrapolate data to higher heights.

4.0 Wind Resource Assessment and Mapping Methodology

4.1 Introduction

NREL has been developing its GIS-based wind resource mapping technique since 1996. This technique replaces the manual analysis techniques employed in previous mapping efforts, such as the *Wind Energy Resource Atlas of the United States* (Elliott et al., 1987) and the "Mexico Wind Resource Assessment Project" (Schwartz and Elliott, 1995). NREL developed the system with the following two primary goals in mind:

1) To produce a more consistent and detailed analysis of the wind resource, particularly in areas of complex terrain; and,
2) To generate user-friendly high-quality map products.

4.2 Description of Mapping System

The mapping procedure uses GIS advanced computerized mapping system. The main GIS software is ARC/INFO, a powerful and complex package featuring a large number of routines for scientific analysis. None of the ARC/INFO analysis routines is specifically designed for wind resource assessment work, so NREL's mapping technique requires extensive programming in ARC/INFO to create combinations of scientific routines that mimic direct wind-resource assessment methods. The mapping system is divided into three main components: input data, wind power calculations, and the output section that produces the final wind resource map. These components are described below.

4.2.1 Input Data

The two primary model inputs are digital terrain data and formatted meteorological data. The elevation information consists of Digital Elevation Model (DEM) terrain data that are used to divide the analysis region into individual grid cells, each having its own unique elevation value. The United States Geological Survey (USGS) and the Earth Resource Observing Satellite Data Center (EROS) recently produced updated DEMs for most of the world from previously classified Department of Defense data and other sources. The new data sets have a resolution of 1 km^2 and are available for large parts of the world. This represents a significant improvement in elevation data used by the mapping system. It previously relied on 1:1,000,000 scale maps and 305-m (1,000 ft) elevation contours. Most of the final wind resource maps are gridded to 1 km^2.

The final meteorological inputs to the mapping system, following the data screening process, are vertical wind profile(s), wind power rose(s) (the percentage of total potential power from the wind by direction sector), and the open-ocean wind-power density, where appropriate. The data are brought in as ARC/INFO-compatible files and used in the power calculation algorithms. The vertical profiles are broken down into 100-m intervals centered every 100 m above sea level (asl), except for the lowest layer, which is at 50 m asl. The wind power rose is used to determine the degree of exposure of a particular grid cell to the power-producing winds. The open-ocean wind power density is derived from the SSMI and ship wind speed observations, converted to wind power density, and extrapolated to 30 m for use by the model.

4.2.2 Wind Power Calculations

The wind-power-calculation methodology is presented in Section 3.6. The factors that either decrease or increase the base wind power value for a particular grid cell are terrain considerations, relative and absolute elevation, aspect (the slope of the terrain relative to the prevailing wind direction), distance from ocean or lake shorelines, and influence of small-scale wind flow patterns. The factors that have the greatest influence on the adjustment of the base wind power for a particular grid cell are the topography of the area in the vicinity and a combination of the absolute and relative elevation. The wind-power-calculation modules use the wind power rose and vertical wind profile of a region to account for the effects of short-range (less than 10 km), medium-range (10-50 km), and long-range (greater than 50 km) blocking of the ambient wind flow by the terrain; the slope and aspect of the terrain surrounding a particular grid cell; and the relative elevation of a grid cell compared to its surroundings.

The wind power calculations are performed in three modules, depending upon the existence or proximity of oceans or large lakes to the mapping region. These include "land," "ocean," and "lake" modules. The land module is run for the entire area only if there is no ocean present in the mapping region. Likewise, the ocean module is run for the entire area in instances where there is an ocean shoreline present in the mapping region. The lake module is run only if there are lakes, estuaries, or fjords with an area of 50 km^2 or greater. This module only calculates the wind power for the area within 5 km of any non-ocean body of water in the mapped region. If more than one module is run for a particular region, the results are combined to produce the final wind map. Each of the three modules contains identical routines that use a general topographical description to adjust the base wind power density. The topographical description can be classified as either complex terrain (hills and ridges), complex terrain with large flat areas present, or areas that are designated as flat. The adjustment to the base wind-power density depends on which terrain routine is activated during the mapping run.

4.2.3 Mapping Products

The primary output of the mapping system is a color-coded wind power map in units of W/m^2 and the equivalent mean wind speed for each individual grid cell. The wind power classification scheme for the Philippines maps is presented in Table 4-1. We used the one-seventh-power law (see Section 3.7) to adjust the power densities to a height of 30 m above ground, used as the reference height in the classification. The 30-m height was chosen as a compromise hub height between large utility-scale wind turbines (which may range between 30 m to 60 m) and small wind turbines (which may range between 15 m and 30 m) for rural power applications.

Wind power is calculated only for those grid cells that meet certain exposure and slope requirements. As a result, only the most favorable wind resource areas are highlighted. For example, a grid cell is excluded if there is major blocking of the ambient wind flow by local terrain features. The exposure must be at least 70% to be included. A grid cell can also be excluded if the slope of the terrain is too steep. To be included, the slope must not exceed 20%. The wind resource values presented are estimates for low surface roughness (e.g., grassland with no major obstructions, such as trees or buildings).

Table 4-1. Wind Power Classification

Class	Resource Potential Utility	Resource Potential Rural	Wind Power Density (W/m^2) @ 30 m	Wind Speed [a] (m/s) @ 30 m
1	Marginal	Moderate	100 - 200	4.4 - 5.6
2	Moderate	Good	200 - 300	5.6 - 6.4
3	Good	Excellent	300 - 400	6.4 - 7.0
4	Excellent	Excellent	400 - 600	7.0 - 8.0
5	Excellent	Excellent	600 - 800	8.0 - 8.8
6	Excellent	Excellent	800 -1200	8.8 -10.1

[a] Mean wind speed is estimated assuming a Weibull distribution of wind speeds with a shape factor (k) of 2.0 and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20 percent, depending on the actual wind-speed distribution (or Weibull k value) and elevation above sea level.

The output portion of the mapping system also includes software to produce the proper map projection for the region. It labels the map with useful information, such as a legend, latitude and longitude lines, locations of meteorological stations, prevailing wind direction(s), important cities, and a distance scale. The DEM data can also be used to create a color-coded elevation map, a hill-shaded relief map, and a map of the elevation contours. When combined with the wind power maps, these products enable the user to obtain a feel for the three-dimensional distribution of the wind power in the analysis region.

4.3 Limitations of Mapping Technique

There are several limitations to the mapping technique, the first being the resolution of the DEM data. Significant terrain variations can occur within the DEM's 1 km^2 area; thus, the wind resource estimate for a particular grid cell may not apply to all areas within the cell. A second potential problem is the development of the conceptual model of the wind flow and its extrapolation to the analysis region. There are many complexities in the wind flow that make this an inexact methodology, including the structure of low-level jets and their interaction with the boundary layer, and localized circulations, such as land-sea breezes, mountain-valley flows, and channeling effects in steeply sloped areas. Finally, the power estimates are valid for areas with low surface roughness. Estimates for areas with a higher surface roughness need to be adjusted accordingly.

5.0 Wind Resource Characteristics of the Philippines

5.1 Introduction

This section presents and discusses both surface and upper-air data, collected for this study. These data sources include those data archives available at NREL and the data provided by local agencies in the Philippines.

5.2 Surface Data

5.2.1 PAGASA

PAGASA provided NREL a summary of the average wind speed and prevailing direction for 44 surface-based stations and two reports: *Climatological Normal of Surface Winds in the Philippines (January 1988)* and *Solar Radiation and Wind Mapping of the Philippines (October 1986).*

The Climate Data Section, the Climatology and Agrometeorology Branch of PAGASA, prepared a summary of monthly average wind speeds and prevailing directions for 44 stations in the Philippines. These are principally the synoptic reporting stations managed by PAGASA, listed in Table 5-1 and shown in Figure 5-1. Wind speed and direction is collected nominally at 10 m (33 feet) above ground level. The annual average wind speeds at these stations are quite low, ranging from 1.0 to 5.0 m/s.

The PAGASA Report *Climatological Normal of Surface Winds In the Philippines* presents a series of maps with average wind speed and prevailing wind direction, by month, for the archipelago. Samples of the maps are included as Figures 5-2 and 5-3. These maps are based on a variety of data sources, including stations where winds are estimated using the Beaufort Scale of Wind. This report included a table of the highest wind speeds recorded in the Philippines, by month. The highest wind gust recorded in the country was 77 m/s at Virac Synop on October 13, 1970, associated with the landfall of Typhoon "Sening".

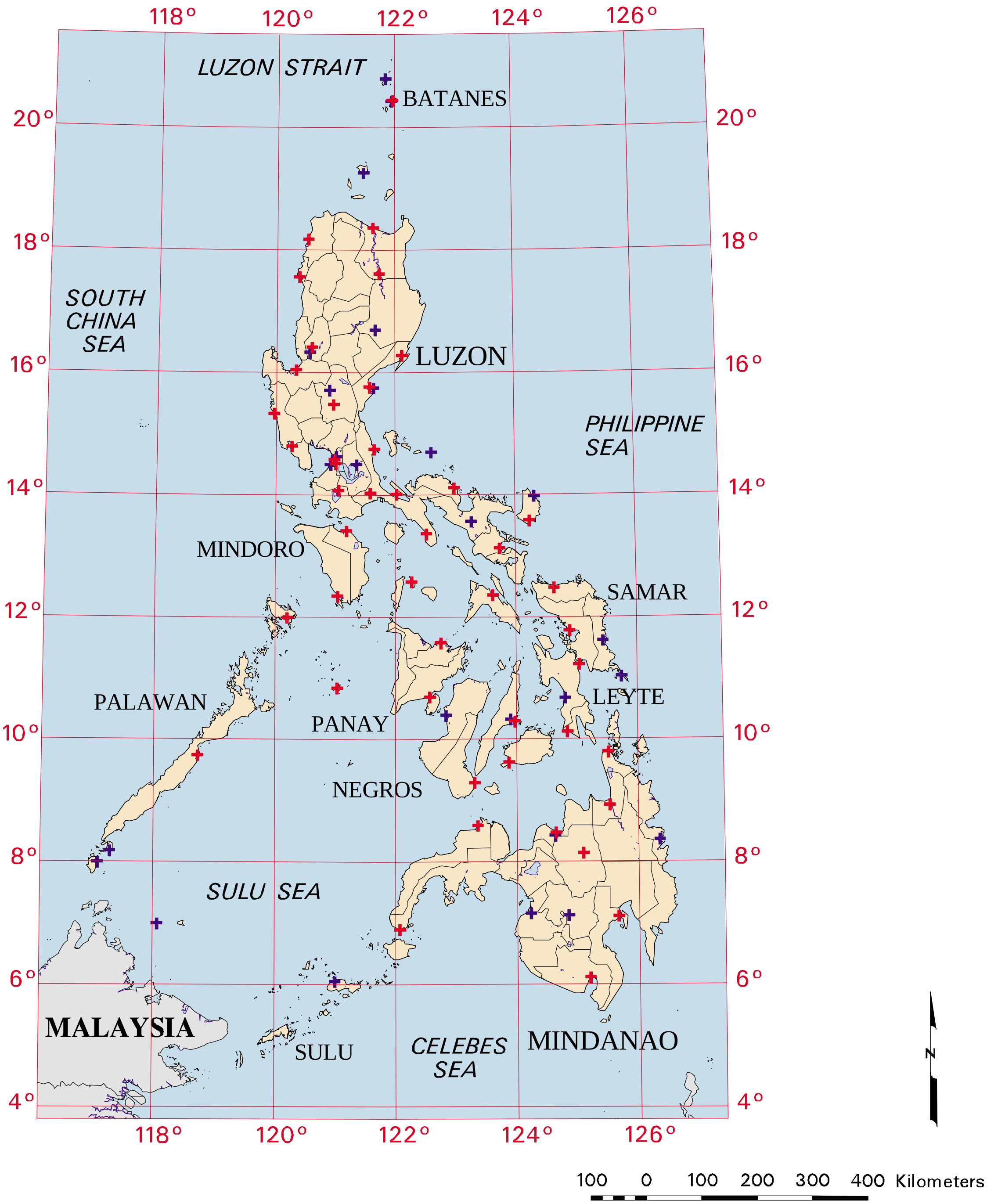
The PAGASA Report *Solar Radiation and Wind Mapping of the Philippines* presents wind flow maps, but also includes, by month, an analysis of the shape and scale parameters (both related to the Weibull distribution), the mean wind speed, and the mean wind-power density. The conclusions are based on two data sets. The first set consists of 30 years (1951–1980) of surface wind data at 10 m for 23 synoptic stations. These data were observed using a 3–5-minute averaging period from a wind instrument indicator or the Beaufort Scale Wind Force method taken every 3 hours. The second set of surface wind data is based on data extracted from chart recorders. The period of record covers mid-1981 to mid-1984 (approximately 3 years).

These data were then plotted and analyzed. The highest annual average wind speeds and corresponding high wind-power density occurred along the north coast of Luzon and the northern islands, the east and west central parts of the archipelago, and on a ridgeline overlooking the Taal Volcano. Mean monthly wind speeds are highest in the winter during the northeast monsoon and lower during the summer. The diurnal variation of the wind speeds showed significant variability. For example, some sites showed the highest wind speeds were during midday, other sites showed a peak at midnight.

Table 5-1
List of Synoptic Stations Provided By PAGASA

Station Name	Latitude	Longitude	Elevation (m)	Period of Record	Annual Average Wind Speed (m/s)
Alabat, Quezon	14 01	122 01	5.0	1961-92	3.0
Ambulong, Batangas	14 05	121 03	10.0	1961-92	2.0
Aparri, Cagayan	18 22	121 38	3.0	1961-92	3.0
Baguio City, Benguet	16 25	120 36	1,500.0	1961-92	2.0
Baler, Quezon	15 46	121 34	6.0	1961-92	2.0
Basco, Batanes	20 27	121 58	11.0	1961-92	5.0
Butuan City, Agusan Del Norte	08 56	125 31	18.0	1981-92	1.0
Cabanatuan, Nueva Ecija	15 29	120 58	32.0	1961-92	2.0
Cagayan De Oro, Misamis Oriental	08 29	124 38	6.0	1961-92	1.0
Calapan, Oriental Mindoro	13 25	121 11	40.5	1961-92	2.0
Casiguran, Quezon	16 17	122 07	4.0	1961-92	2.0
Catarman, Northern Samar	12 29	124 38	50.0	1961-92	2.0
Catbalogan, Western Samar	11 47	124 53	5.0	1961-92	2.0
Coron, Palawan	12 00	120 12	14.0	1961-92	2.0
Cuyo, Palawan	10 51	121 02	4.0	1961-92	5.0
Dagupan City, Pangasinan	16 03	120 20	2.0	1961-92	3.0
Davao City, Davao Del Sur	07 07	125 39	18.0	1961-92	2.0
Dipolog, Zamboanga Del Norte	08 36	123 21	4.0	1961-92	2.0
Dumaguete City, Negros Oriental	09 18	123 18	8.0	1961-92	2.0
General Santos, South Cotabato	06 07	125 11	15.0	1961-92	2.0
Iba, Zambales	15 20	119 58	4.7	1961-92	3.0
Iloilo City, Iloilo	10 42	122 34	8.0	1961-92	4.0
Infanta, Quezon	14 45	121 39	7.0	1961-92	2.0
Laoag City, Ilocos Norte	18 11	120 32	5.0	1961-92	3.0
Legaspi City, Albay	13 08	123 44	17.0	1961-92	3.0
Maasin, Southern Leyte	10 08	124 50	71.8	1971-92	2.0
Mactan, Cebu	10 18	123 58	12.8	1972-92	3.0
Malaybalay, Bukidnon	08 09	125 05	627.0	1961-92	1.0
Masbate, Masbate	12 22	123 37	6.0	1961-92	2.0
Naia, Pasay City	14 31	121 01	21.0	1961-92	3.0
Port Area, Manila	14 35	120 59	16.0	1961-92	3.0
Puerto Princesa, Palawan	09 45	118 44	16.0	1961-92	2.0
Romblon, Romblon	12 35	122 16	47.0	1961-92	3.0
Roxas City, Aklan	11 35	122 45	4.0	1961-92	3.0
San Francisco, Quezon	13 22	122 31	45.0	1961-92	3.0
San Jose, Occidental Mindoro	12 21	121 02	0.3	1981-92	3.0
Surigao, Surigao De Norte	09 48	125 30	39.0	1961-92	3.0
Tacloban City, Leyte	11 14	125 02	3.0	1961-92	2.0
Tagbilaran City, Bohol	09 36	123 52	6.0	1961-92	2.0
Tayabas, Quezon	14 02	121 35	157.7	1971-92	2.0
Tuguegarao, Cagayan	17 37	121 44	61.8	1961-92	2.0
Vigan, Ilocos Sur	17 34	120 23	33.0	1961-92	3.0
Virac Synop, Catanduanes	13 35	124 14	40.0	1961-92	3.0
Zamboanga City, Zamboanga Del Sur	06 54	122 04	6.0	1961-92	2.0

Philippines - PAGASA Meteorological Stations With Surface Wind Data



Station locations provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA).

Meteorological Stations

- + Wind data provided by PAGASA
- + No wind data provided by PAGASA

US Dept. of Energy - National Renewable Energy Laboratory

NREL contacts:
Dennis Elliott (303) 384-6935
Marc Schwartz (303) 384-6936

NREL

DM Heimiller 02-MAR-1999 6.2

Figure 5-1

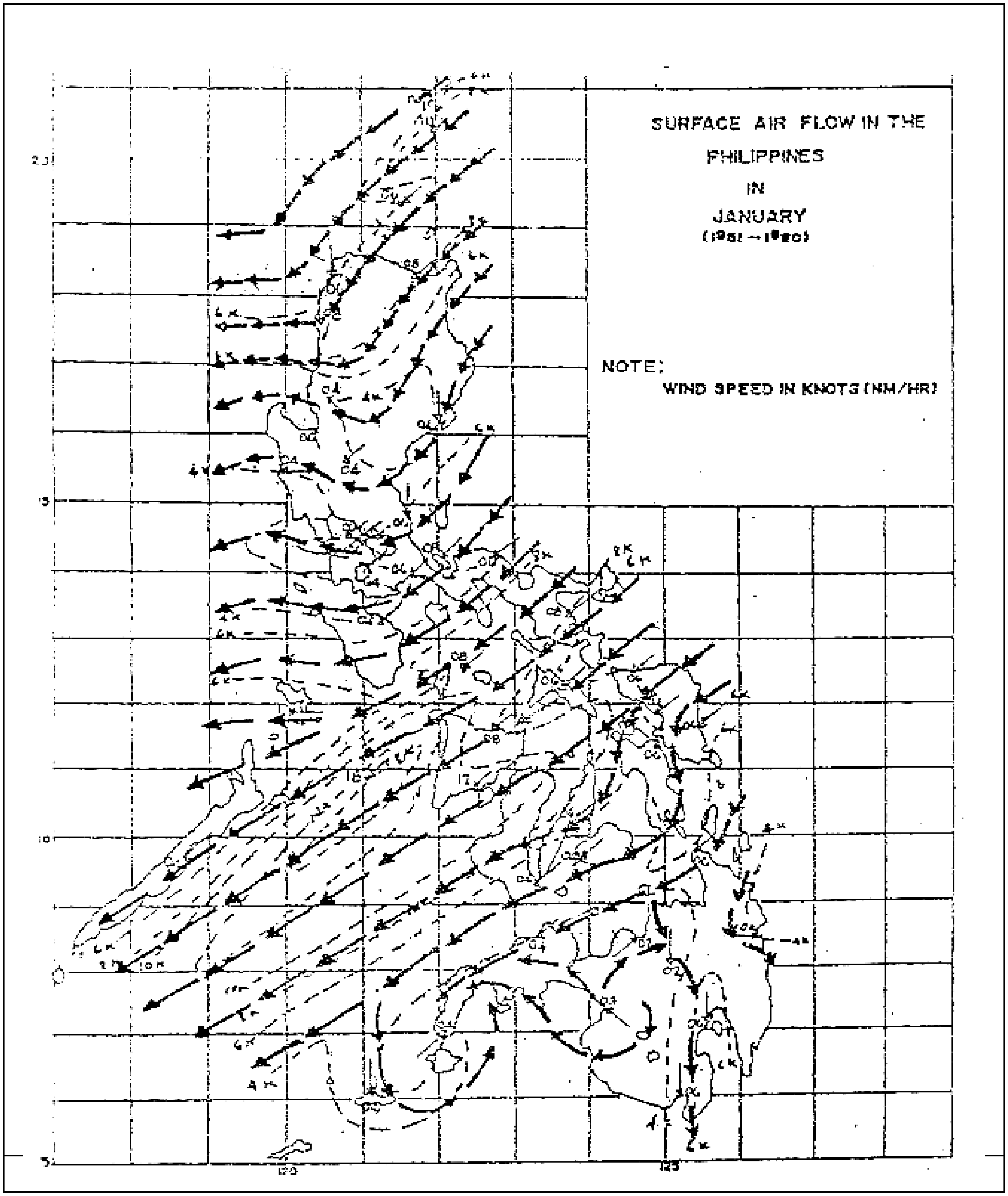


Figure 5.2 Surface Air Flow (January) in the Philippines

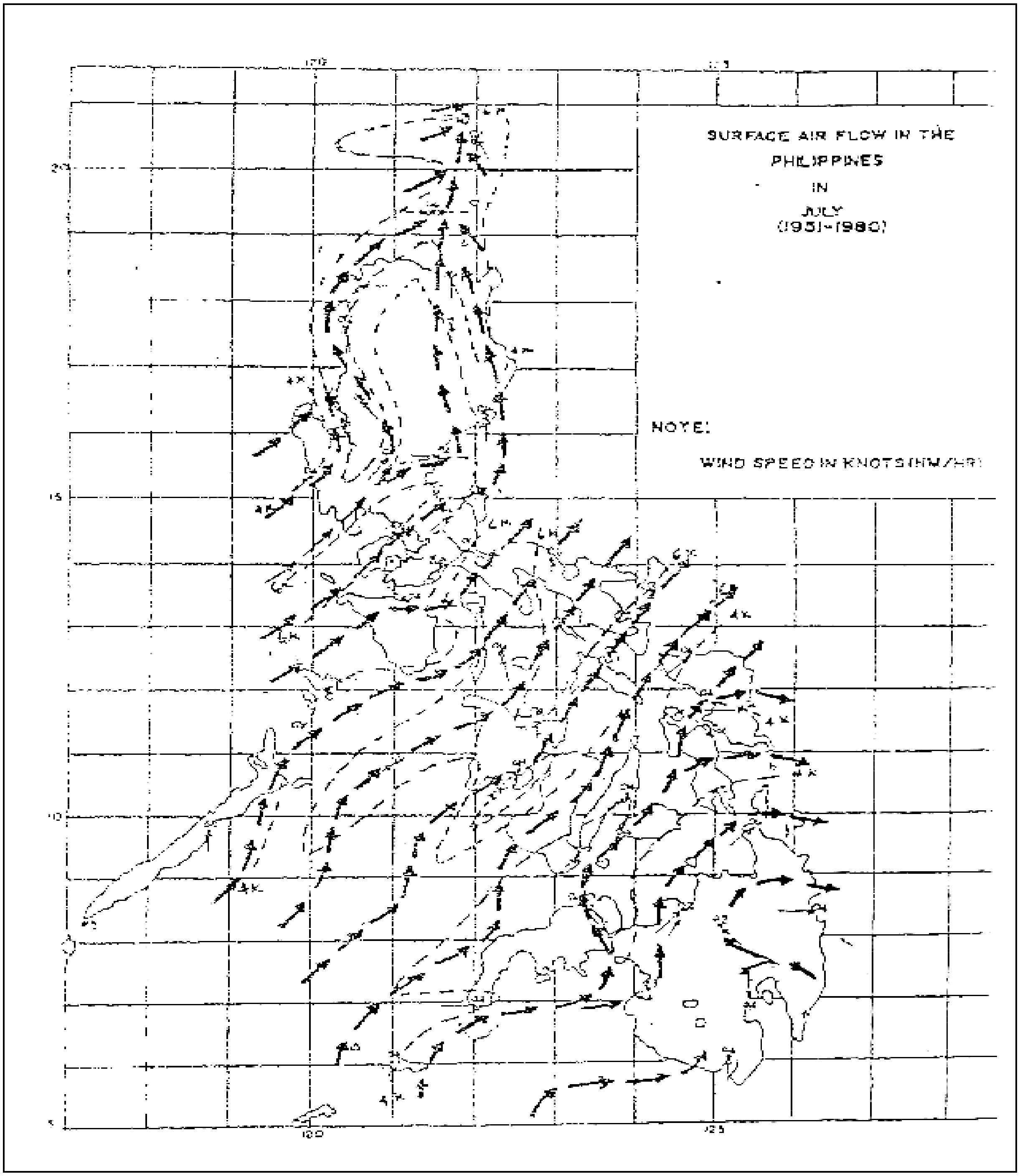


Figure 5.3 Surface Air Flow (July) in the Philippines

These reports represent a good starting point in understanding the wind resource in the Philippines; however, the studies do have some significant limitations:

- The conclusions are based on the data from only 35 stations.
- There is no information on the exposure of the instruments at these 35 stations. This type of knowledge is extremely useful in judging the quality of the data used in the study.
- There is no information regarding the quality of the measurements at each of the sites. Failure to properly maintain the anemometer, location changes, urbanization, and vegetation changes surrounding the anemometer site affect the measurements.
- The analysis did not take into account the topography of the archipelago or other factors that may accelerate or retard the wind.

5.2.2 National Power Corporation

NPC conducted a wind-resource-measurement program by placing towers with wind-speed-measurement equipment at various sites in Luzon, Batanes, Catanduanes, Romblon Island, Cuyo Island, and Guimaras Island. These were the general locations of the better wind resource areas from the previous PAGASA studies. At nine of the sites, the wind-resource-measurement equipment consisted of NRG Systems 30-m-tall towers, NRG Systems 9200 data loggers, Maximum #40 wind speed sensors, and #200P wind direction sensors. The general location of the monitoring sites is presented in Figure 5-4. Two levels of wind speed and two levels of wind direction (20 m and 30 m) were installed on each tall tower. The sampling rate was every 2 seconds, and the data were averaged into hourly values. For the other five sites, we used a shorter tower, either 12-m or 15.5-m, and the data acquisition equipment is not identified. The monitoring sites are installed in eight specific areas: Ilocos Norte (7 sites), Mountain Province (1 site), Guimaras Island (1 site), Romblon Island (1 site), Catanduanes (1 site), Cuyo Island (1 site), and Batanes (1 site). A description of each site is presented in Table 5-2.

Seven of the sites are in the northwestern portion of Luzon, along the coast and in the coastal hills. The hourly wind speed and wind direction data were available for Bayog, Pagali, Saoit, Agaga, Bangui, Caparispisan, Subec, Sagada, and Guimaras. NREL processed these data to produce estimates of monthly average power and monthly average wind speed, as well as average speed and power by hour of the day, and joint frequencies of wind speed and wind direction (see Appendix A). The annual average wind speed and power for the 30-m sites are presented in Table 5-3. The monthly average wind speed and wind power for three sites—Pagali, Sagada, and Guimaras Island—are presented in Figures 5-5 to 5-7. Due to the short collection period at all NPC sites, some months are underrepresented relative to others (see plots of 'Observations by Month' in Appendix A). Averaging all records can bias the average towards those months with more records. To eliminate this bias, all annual averages reported here were computed by averaging the 12 monthly values. Some of these monthly values may have been derived from data from 2 years, while others represent only a single year.

The sites at Bayog, Pagali, and Saoit are located on the northwest coast of Luzon near the town of Burgos. The site maps provided by NPC indicate that Bayog and Pagali are along the coast, while Saoit is located on the inland hills. Annual wind speeds at 30 m above ground level were 5.6 m/s at Saoit, 6.9 m/s at Bayog, and 7.2 m/s at Pagali. There are significant differences in the magnitude of the wind speed between the months with the highest and lowest average wind speeds. For example, at Bayog the highest monthly average wind speed is 12.4 m/s (December), while the lowest value is 4.0 m/s (June). At Saoit, the highest value is 9.0 m/s (December), and the lowest is 3.7 m/s (June). At Pagali, the highest value is 11.9 m/s (December), and the lowest is 3.6 m/s (June). For Bayog, Pagali, and Saoit, the annual average wind powers are 510 W/m^2, 569 W/m^2, and 266 W/m^2, respectively, with the highest values occurring in December and the lowest values in June.

The sites at Agaga, Caparispisan, and Subec are also located in northwestern Luzon, north of the town of Laoag. The Agaga and Subec sites are located on interior hills, while Caparispisan is on

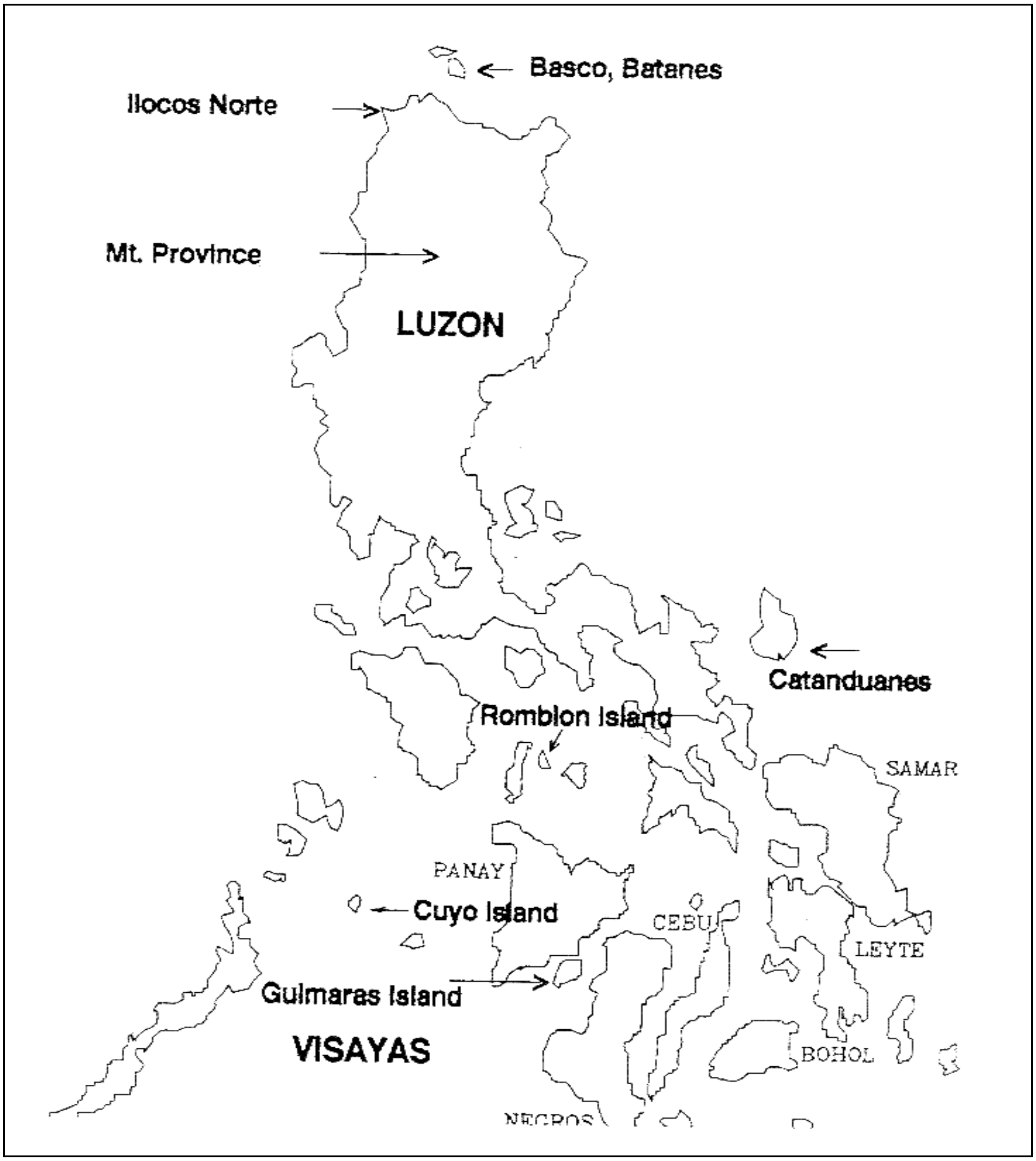


Figure 5.4 General location of the National Power Corporation monitoring sites in the Philippines

Table 5-2. Wind Monitoring Sites for National Power Corporation

Region	Site	Tower Height (m)	Latitude	Longitude	Elevation (m)	Period Of Record	Wind Speed (m/s)
Ilocos North	Bayog	30	18 30	120 35	5	05/95-10/96	6.9
	Pagali	30	18 32	120 37	1	07/95-04/97	7.2
	Saoit	30	18 31	120 37	80	06/95-03/97	5.6
	Agaga	30	18 27	120 39	280	07/95-03/97	6.2
	Bangui	20	18 31	120 43	175	07/95-04/96	6.6
	Caparispisan	30	18 36	120 47	140	05/95-02/97	7.6
	Subec	30	18 36	120 49	80	06/95-03/97	7.7
Mt. Province	Sagada	30	17 06	120 52	1871	06/95-12/96	6.7
Guimaras Is.	Guimaras	30	10 32	122 39	160	06/95-05/97	5.0
Romblon Is.	Romblon	12	N/A	N/A	N/A	10/91-07/93	4.6
Catanduanes	Catanduanes	12	N/A	N/A	N/A	11/93-04/95	5.2
Cuyo Is.	Cuyo	12	N/A	N/A	N/A	11/93-03/95	4.7
Guimaras Is.	Guimaras	15.5	N/A	N/A	N/A	03/94-06/95	4.9
Batanes	Basco	12	N/A	N/A	N/A	04/94-08/94	6.3

Table 5-3. Average Wind Speed (m/s) and Power (W/m^2)

Site	Average Wind Speed (m/s)	Average Wind Power (W/m^2)	Highest Monthly Average Wind Power (W/m^2)	Lowest Monthly Average Wind Power (W/m^2)
Bayog	6.9	510	1474 (Dec)	98 (Jun)
Pagali	7.2	569	1378 (Dec)	79 (Jun)
Saoit	5.6	266	623 (Dec)	83 (Jun)
Agaga	6.2	393	1006 (Dec)	72 (Jun)
Bangui*	6.6	425	1139 (Dec)	51 (Aug)
Caparispisan	7.6	516	1001 (Dec)	179 (Jun)
Subec	7.7	669	1813 (Dec)	110 (Jun)
Sagada	6.7	356	977 (Dec)	67 (Apr)
Guimaras	5.0	143	437 (Feb)	38 (Jun)

* Bangui had insufficient data at the 30-m tower height. Values are based on 9 months of data at 20-m tower height.

the coastal bluffs overlooking the ocean. Annual wind speeds at 30 m above ground level were 7.7 m/s at Subec, 7.6 m/s at Caparispisan, and 6.2 m/s at Agaga. Again, there are significant differences in magnitude between the months with the highest and lowest average wind speeds. For example, at Subec, the highest monthly average wind speed is 13.2 m/s (December), while the lowest value is 3.8 m/s (June). At Caparispisan, the highest value is 11.3 m/s (December), and the lowest is 4.7 m/s (June). At Agaga, the highest value is 9.8 m/s (December), and the lowest is 3.6 m/s (June). For Subec, Caparispisan, and Agaga, the annual average wind powers are 669 W/m^2, 518 W/m^2, and 393 W/m^2, respectively, with the highest values occurring in December and the lowest values in June.

The frequency of occurrence of wind speed and direction for these six sites shows the predominant northeast flow in the late fall through early spring months (October to April) and the increased variability of wind directions in the summer months. The diurnal trend at these six sites shows a daytime maximum and nighttime minimum.

The site at Sagada is also in northern Luzon; however, as a high-elevation, interior site, it has a very different exposure than the other sites. The site is northwest of the town of Sagada at an elevation of 1,871 m, and is on a north–south-oriented mountain range. The annual wind speed at 30 m above ground level is 6.7 m/s, and the annual wind power is 356 W/m^2. The monthly wind power ranges from 977 W/m^2 in December to 67 W/m^2 in April. The wind direction is predominantly from the northeast during the winter. However, during the summer, except for September, the wind direction is split evenly between east-northeast and west-southwest. The diurnal wind speed pattern is typical for a mountain site with, on average, little change from hour to hour. There is a slight increase in wind speeds during the nighttime hours during stable conditions and a decrease during the daytime, most likely due to instability and increased mixing.

A 30-m tower was installed on Guimaras Island. The island is in the Guimaras Strait, southeast of Panay. The tower was installed on a small hill on the southeast quarter of the island, well away from the coast. The annual average wind speed and annual average wind power are marginal (5.0 m/s and 143 W/m^2, respectively) for utility-scale power. However, the resource at this site may be sufficient for rural power applications. The frequency distribution of wind directions shows the typical predominance of northeast winds during the winter and the variability in wind directions during the summer. This particular site does show a pronounced peak in southwesterly wind directions during the late summer and early fall.

NPC also provided monthly average wind speeds for five other sites. These data were measured on either 12-m- or 15.5-m-tall towers. The sites: Romblon Island in the Sibuyan Sea in the central part of the archipelago, Catanduanes on the eastern side of the archipelago, Cuyo Island in the Cuyo East Pass, and Basco on Batan Island north of Luzon, appear to have good wind resources. However, the relatively low measurement heights, poor data recovery, and missing months of data undermine the usefulness of the information.

The NPC data has significant value for this study. The results of the 30-m-tower program indicate that there is good wind resource in the coastal region and higher interior mountains of northern Luzon. These data also yield valuable information on the diurnal trends in the wind speed and, consequently, the wind power.

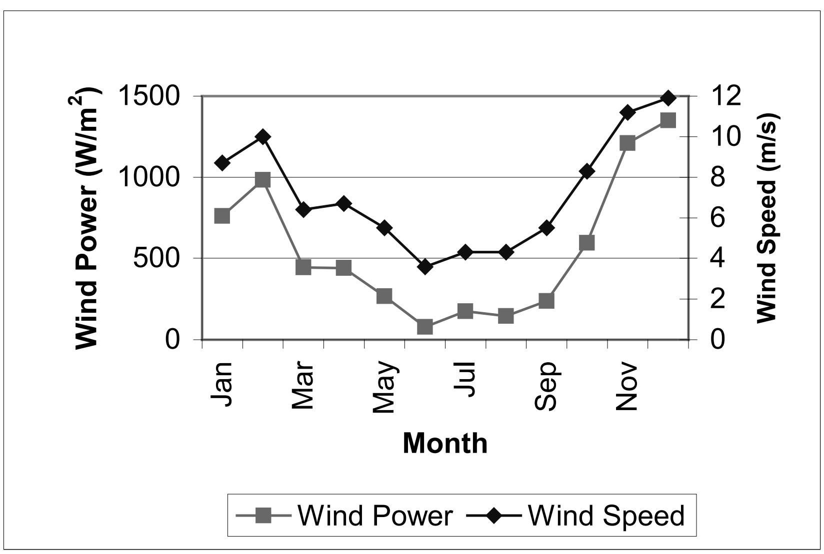


Figure 5.5 Monthly wind speed and power—Pagali

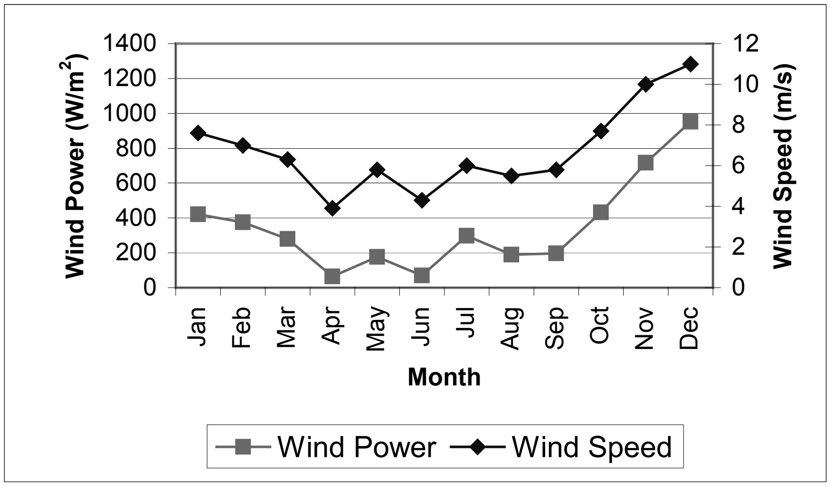


Figure 5.6 Monthly wind speed and power—Sagada

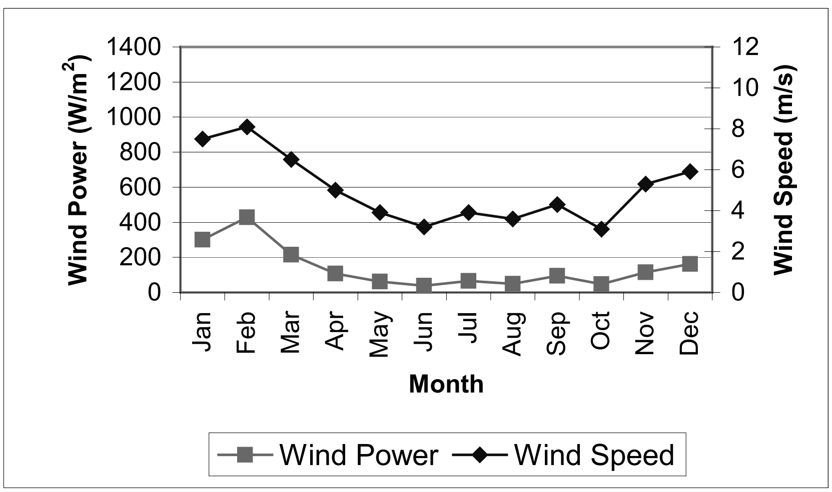


Figure 5.7 Monthly wind speed and power – Guimaras Island

5.2.3 DATSAV2

There are data for 67 stations in the Philippine archipelago available from the climatic data set known as DATSAV2. We obtained the data set from the NCDC; it consists of hourly surface observations of meteorological variables. These observations were transmitted, for the most part, via the Global Telecommunications System (GTS). A map of the station locations, and the total number of observations for each station, was previously shown in Figure 3-1.

The number of hourly observations within each year and from year to year for the individual sites is highly variable. Some stations, such as Clark Air Force Base (AFB), Olongapo, and Mactan International Airport, have approximately 8,760 hourly observations in each year. Other sites, such as Maasin on Leyte Island, have no more than 2,000 observations in any year and sometimes less than 500 observations.

The data records for each of these stations were processed to produce monthly and annual averages of wind speed and power. The summarized data are presented in Table 5-4, and copies of the processed files are presented in Appendix B for selected stations. These data are useful for evaluating the inter-annual, monthly, and diurnal variability of wind speed and power, and the joint frequency of wind speed and wind direction.

Visual inspection of the plots of the various wind characteristics data for each station sometimes revealed trends and peculiarities, particularly in the inter-annual variability. For example, the long-term average wind speed and power density at Cuyo Island from 1973 to 1996 was 3.5 m/s and 123 W/m^2, respectively. However, an inspection of the yearly wind speeds and power densities from 1973 to 1996 reveals that the average wind speeds were about 5 m/s in the 1970s and had decreased to about 2 m/s by the mid-1990s. The wind power was in the range of 200 to 300 W/m^2 in the 1970s and decreased to less than 20 W/m^2 by the mid-1990s. A long-term downward trend in wind speed and power at a station frequently indicates that either the site is becoming less exposed to the prevailing wind because of an increase in obstructions around the site or there is a degradation of the anemometer. Similar types of trends and peculiarities were found at many other stations in the Philippines.

Although the average wind speeds and power densities are presented in Table 5-4 for each station, these data may not be a reliable indicator of the area’s wind resource because of problems with the data. Unfortunately, information on exposure of the wind measurement equipment and maintenance of the equipment is not available for meteorological stations in the Philippines, (nor most countries of the world, for that matter). With the various inherent problems in the reliability of the surface data from meteorological stations, using the appropriate upper-air data and ocean satellite data to characterize the ambient wind-flow characteristics and to develop the meteorological inputs for the wind mapping system becomes even more important. Nevertheless, screening the available surface data helps identify the most reliable data for evaluating the wind characteristics and helps validate the resource estimates generated by the mapping system.

5.3 Upper-Air Data

The upper-air data, consisting of wind speed and direction profiles, are an important component in the development of the wind resource projections. These data are available in either the ADP database or the Global Upper Air Climatic Atlas (GUACA).

The upper-air database consists of information obtained from surface-launched meteorological instrument packages. These packages are usually launched once or twice daily, at 0000 GMT and 1200 GMT, via balloon, and are managed under WMO guidance and procedures. There are 11 locations in the Philippine archipelago where upper-air wind data are available from the ADP Database: Basco, Laoag, Baguio, Crow Valley, Clark AFB, Olongapo, Legaspi, Cebu, Puerto Princesa, Davao, and Zamboanga. These locations are shown in Figure 5-8.

The GUACA data consist of monthly means and standard deviations of upper-air parameters for the mandatory pressure levels on a 2.5-degree global grid. The mandatory levels of interest include surface, 850 millibar (mb), 700 mb, and 500 mb.

Vertical profiles of wind speed and direction are an important meteorological input parameter for the wind mapping. Therefore, the vertical profiles must reflect ambient regional atmospheric flow and not be subject to major blocking effects from terrain features. Unfortunately, of these 11 stations, only the data from one (Legaspi) meet this particular requirement and could be used. Most of the stations could not be used because the local mountain ranges blocked the ambient flow. Some stations, such as Batanes, had insufficient data. Upper-air data from two stations near the Philippines were useful in estimating regional ambient vertical profiles. These stations were Pratas Island, located about 500 km west of Batanes, and Palau Island, located about 800 km east of Mindanao. Summaries of the upper-air data for the three stations—Legaspi, Palau Island, and Pratas Island—are presented in Appendix C.

The ADP data yielded profiles of monthly and annual average wind speed and frequency distributions of wind speed and direction for a number of pressure levels and height levels from the surface through 700 mb, or approximately 3,000 m. The ADP data was supplemented by the GUACA data, which expanded the analysis to cover the entire archipelago.

5.4 Satellite Ocean Wind Data

Because the Philippines is an archipelago, there is a large amount of water surface surrounding the country. The SSMI data set contains estimates of 10-m ocean wind speed measurements. These data also provide an excellent overview of the ambient wind conditions around the islands.

The annual wind speeds for the 7-year period from 1988 to 1994, based on satellite data, are presented in Figure 5-9. The best wind speeds are along the northern Luzon coast, the Batanes and Babuyan Islands, the northeast coastal areas, and the southeast coast of Mindanao. The lowest annual average wind speeds occur in the Celebes Sea, west of Mindoro, and the west-southwest coast of Luzon. The annual data imply the presence of wind corridors in the straits between Luzon and Mindoro, Mindoro and Panay, and Panay and Negros.

The wind power density map (Figure 5-10) parallels the annual wind speeds with the highest density off the northwest coast of Luzon and the lowest density in the Celebes Sea. The SSMI data was also used to determine the Weibull k (shape) factor for the ocean areas. The k-value, shown in Figure 5-11, has a magnitude of 2.4–2.7 in the Batanes and Babuyan islands off the north coast of Luzon, a magnitude of 1.8–2.2 along the northeast coast, and a magnitude of 1.8-2.2 off the north and east coasts of much of the Philippines from northern Luzon southward to northern Mindanao.

The seasonal variation in wind speed and power density is dramatically illustrated for some areas in Figures 5-12 and 5-13. Plots for all of the areas are included in Appendix D. In December, monthly average wind speeds off the northern coast of Luzon exceed 11.0 m/s, and wind speeds are in the range of 8.0 to 10.0 m/s off the east and northeast coast of the archipelago. The wind corridors between the islands of Luzon and Mindoro, Mindoro and Panay, and Panay and Negros appear to have December monthly wind speeds in excess of 8.0 m/s. Also, the southeast corner of Mindanao Island appears to have December monthly average wind speed of 7.5 m/s.

Table 5-4. Philippines' Stations from DATSAV2 Files

Station WMO No.	Station Name	Latitude dd mm	Longitude dd mm	Period of Record	Average WS (m/s)	Average Wind Power (W/m^2)
984350	Alabat Is.	14 05	122 01	1973-96	2.9	49
984320	Ambulong/Luzon	14 05	121 03	1973-96	1.6	14
982320	Aparri/Luzon	18 22	121 38	1973-96	3.6	86
983280	Baguio/Luzon	16 25	120 36	1973-96	2.0	24
983330	Baler/Luzon	15 46	121 34	1973-96	2.1	36
983260	Basa	14 59	120 29	1973-85	2.6	24
981350	Basco/Batan Is.	20 27	121 58	1973-96	4.1	125
985530	Borongan/Samar Is.	11 37	125 26	1973-87	2.2	26
987520	Butuan/Mindanao is.	8 56	125 31	1981-96	1.2	12
983300	Cabananatuan/Luzon	15 29	120 58	1990-96	1.7	17
987480	Cagayan de Oro	8 29	124 38	1973-96	1.1	7
984310	Calapan/Mindoro Is.	12 21	121 02	1973-96	2.1	26
981330	Calayan Is.	19 16	121 28	1973-96	3.0	54
983360	Casiguran /Luzon	16 17	122 07	1973-96	1.7	30
984470	Cataduanes Radar	13 59	124 19	1973-96	3.7	71
985460	Catarman/Samar	12 29	124 38	1973-96	2.1	36
985480	Catbalogan/Samar Is.	11 47	124 53	1973-96	1.1	11
983270	Clark	15 11	120 33	1973-91	1.9	16
985260	Coron/Calamin	12 00	120 12	1973-96	1.6	13
987460	Cotabato	7 10	124 13	1986-96	2.2	24
983220	Crow Valley	15 19	120 23	1975-90	2.2	17
986300	Cuyo Is.	10 51	121 02	1973-96	3.5	123
984390	Daet	14 07	122 57	1973-93	2.0	18
984400	Daet	14 08	122 59	1974-96	3.4	80
983250	Dagupan/Luzon	16 03	120 20	1973-96	2.6	45
987540	Davao	7 04	125 36	1973-75	2.2	31
987530	Davao	7 07	125 39	1974-96	1.5	12
987410	Dipolog/Mindanao	8 36	123 21	1973-96	1.6	14
986420	Dumaguette.Negros Is.	9 18	123 18	1973-96	1.6	18
988510	General Santos	6 07	125 11	1973-96	1.4	12
985580	Guiuan/Samar Is.	11 02	125 44	1974-96	3.7	102
987550	Hinatuan/Mindanao	8 22	126 20	1973-96	2.1	23
983240	Iba/Luzon	15 20	119 58	1973-96	3.0	52
986370	Iloilo/Panay Is.	10 42	122 34	1973-96	3.1	49
984340	Infanta/Luzon	14 45	121 39	1973-96	1.8	23
981320	Itbayat Is.	20 48	121 51	1973-96	3.6	70
988300	Jolo Is.	6 03	121 00	1973-90	1.1	11
982230	Laoag	18 11	120 32	1973-96	2.6	37
984440	Legaspi/Luzon Is.	13 08	123 44	1973-96	2.8	42
987470	Lumbia Airport	8 26	124 17	1977-96	2.1	17
986480	Maasin/Leyte Is.	10 08	124 50	1973-96	2.3	22
985430	Macatan/Masbate	12 22	123 37	1973-96	2.3	27
986460	Mactan	10 18	123 58	1973-96	2.5	30

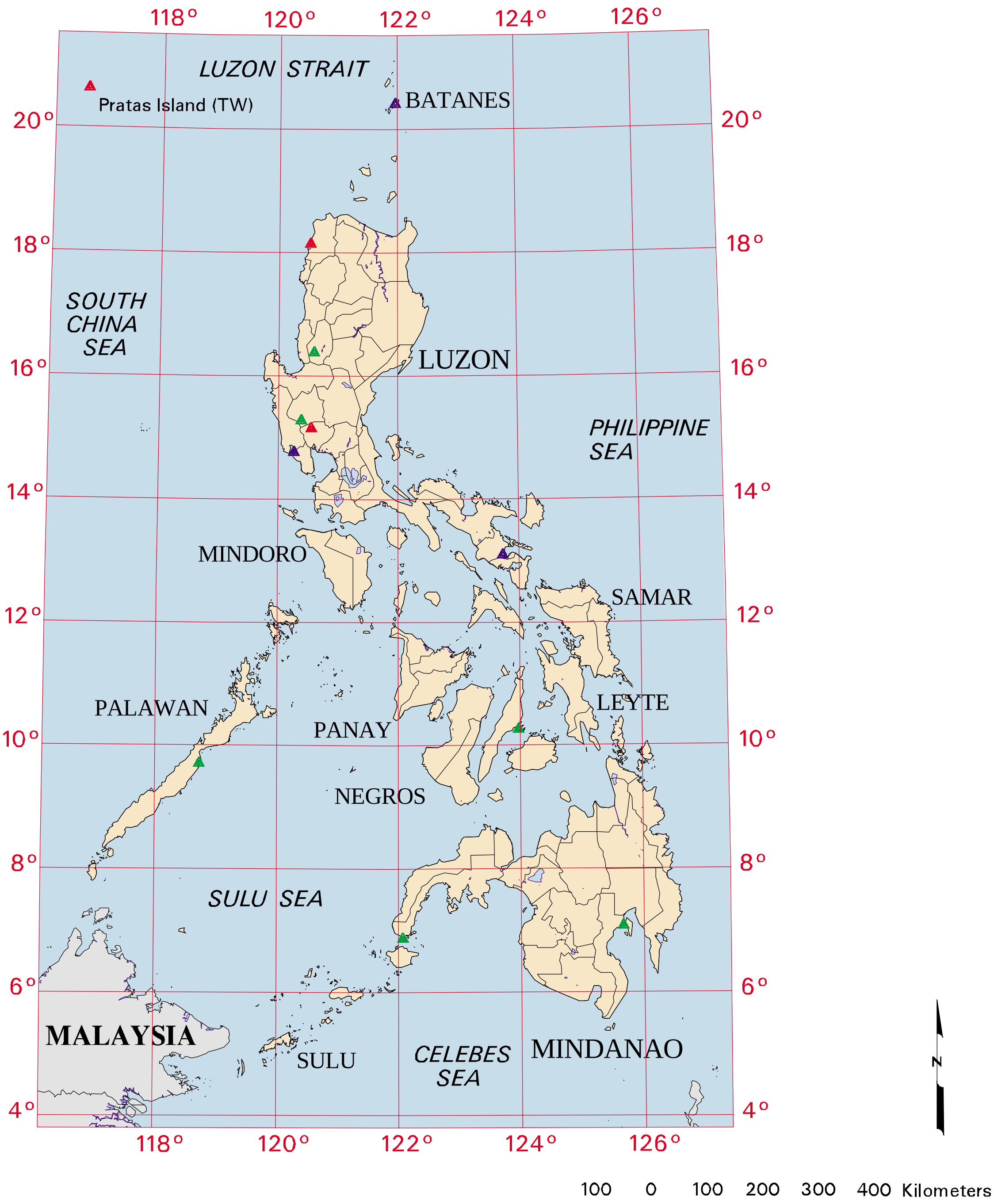
Table 5-4 Philippines' Stations from DATSAV2 Files (continued)

Station WMO No.	Station Name	Latitude dd mm	Longitude dd mm	Period of Record	Average WS (m/s)	Average Wind Power (W/m^2)
987510	Malaybalay Is./Mindanao	8 09	125 05	1973-96	0.9	5
984250	Manila	14 35	120 59	1978-96	2.7	49
984375	Marinduque Is.	13 22	121 50	1984-91	6.3	242
983290	Munoz/Luzon	15 43	120 54	1973-96	2.2	29
986020	Nanshan Is.	10 43	115 49	1983-89	4.4	131
984295	Nichols	14 31	121 01	1973-85	3.2	48
984290	Ninoy Aquino	14 31	121 00	1973-96	3.6	165
984260	Olongapo	14 48	120 16	1973-96	3.2	52
985010	Pagasa Is.	11 01	114 10	1979-81	4.3	114
986180	Puerto Princesa	9 45	118 44	1973-96	1.8	22
984300	Quezon City	14 38	121 01	1973-96	1.4	18
985360	Romblon/Tablas Is.	12 35	122 16	1973-96	2.8	47
985380	Roxas/Panay Is.	11 35	122 45	1973-96	3.3	51
984370	San Francisco	13 22	122 31	1985-96	2.7	45
984310	San Jose/Mindoro Is.	12 21	121 02	1981-96	3.0	58
984280	Sangley Point	14 30	120 55	1974-96	2.7	41
986530	Surigao/Mindanao	9 48	125 30	1973-96	2.4	26
985500	Tacloban/Leyte Is.	11 15	125 00	1973-96	1.8	23
986440	Tagbilaran	9 36	123 51	1973-96	1.4	13
984270	Tayabas	14 02	121 35	1973-96	1.6	19
982330	Tuguegardo/Luzon	17 37	121 44	1973-96	1.9	42
982220	Vigan/Luzon	17 34	120 23	1973-96	2.6	44
984460	Virac/Catanduanes Is.	13 35	124 14	1973-96	3.1	60
988360	Zamboanga	6 54	122 04	1973-96	1.7	18

The wind power density in December exceeds 1200 W/m^2 off the northwest tip of Luzon. The wind power density in December is also quite good along the northeastern and eastern coast of the archipelago and along the wind corridors between the islands.

In August, under the southwest monsoon conditions, the wind resource is substantially less across the archipelago. The northwest coast of Luzon continues to have a good wind resource with wind speeds of 6.5–7.0 m/s. There are also good areas of wind resource in August off the southeast Mindanao coast, with wind speeds of 7.0–8.0 m/s. The wind resource along the northeast Luzon coast is substantially less in August, because the terrain blocks the prevailing southwest monsoon flow. The analysis of the satellite wind-speed data indicates the highest wind power density in August is off the southeast coast of Mindanao and the northern portion of the Sibuyan Sea.

Philippines - GTS Meteorological Stations With Upper Air Wind Data



The Global Telecommunication System (GTS) meteorological stations with upper air wind data are part of NREL's global database.

Meteorological Stations
Total Observations

- ▲ 5,000 to 12,500
- ▲ 2,000 to 5,000
- ▲ 500 to 2,000

US Dept. of Energy - National Renewable Energy Laboratory

NREL contacts:
Dennis Elliott (303) 384-6935
Marc Schwartz (303) 384-6936

DM Heimiller 02-MAR-1999 4.2

Figure 5-8

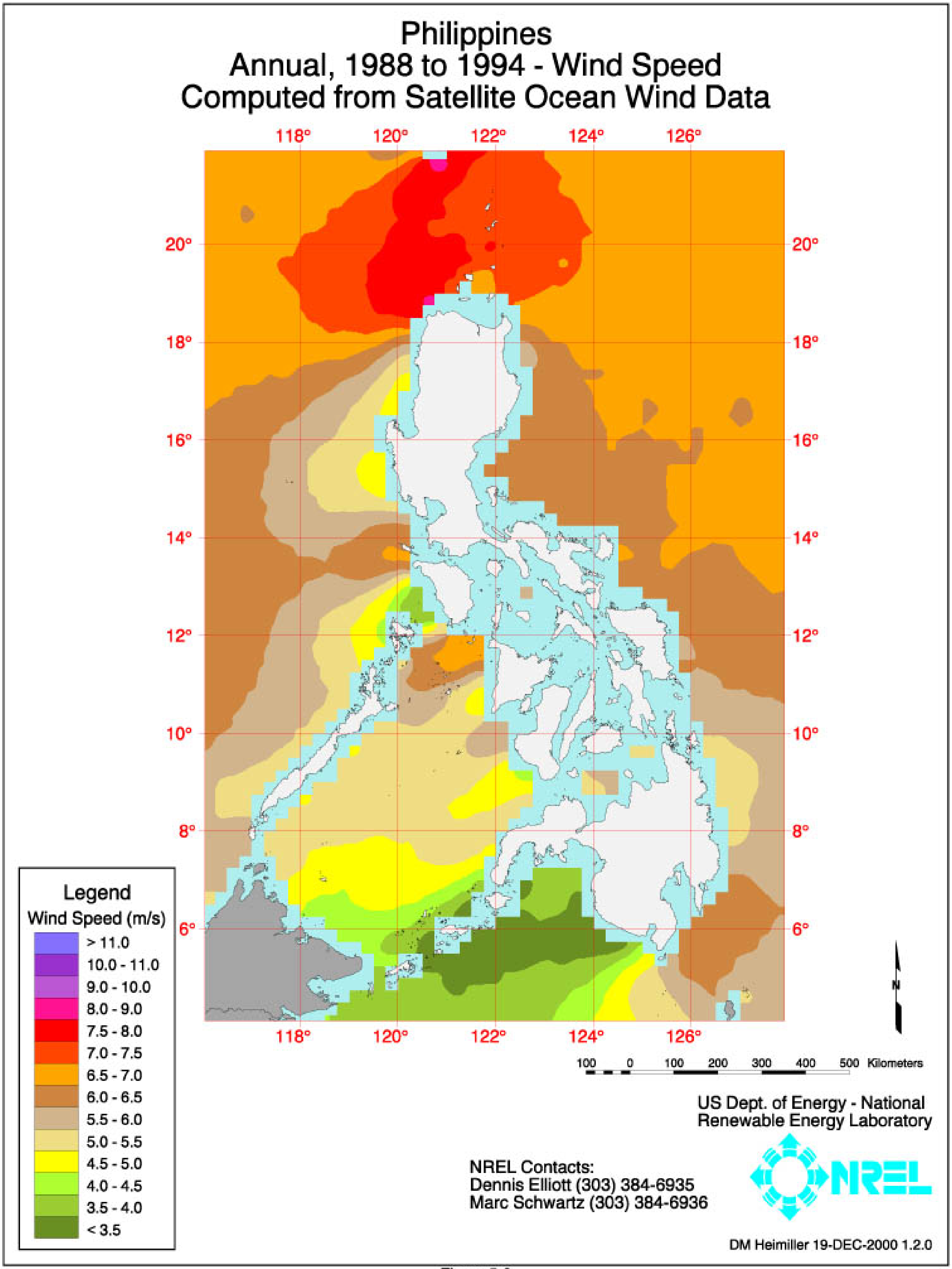
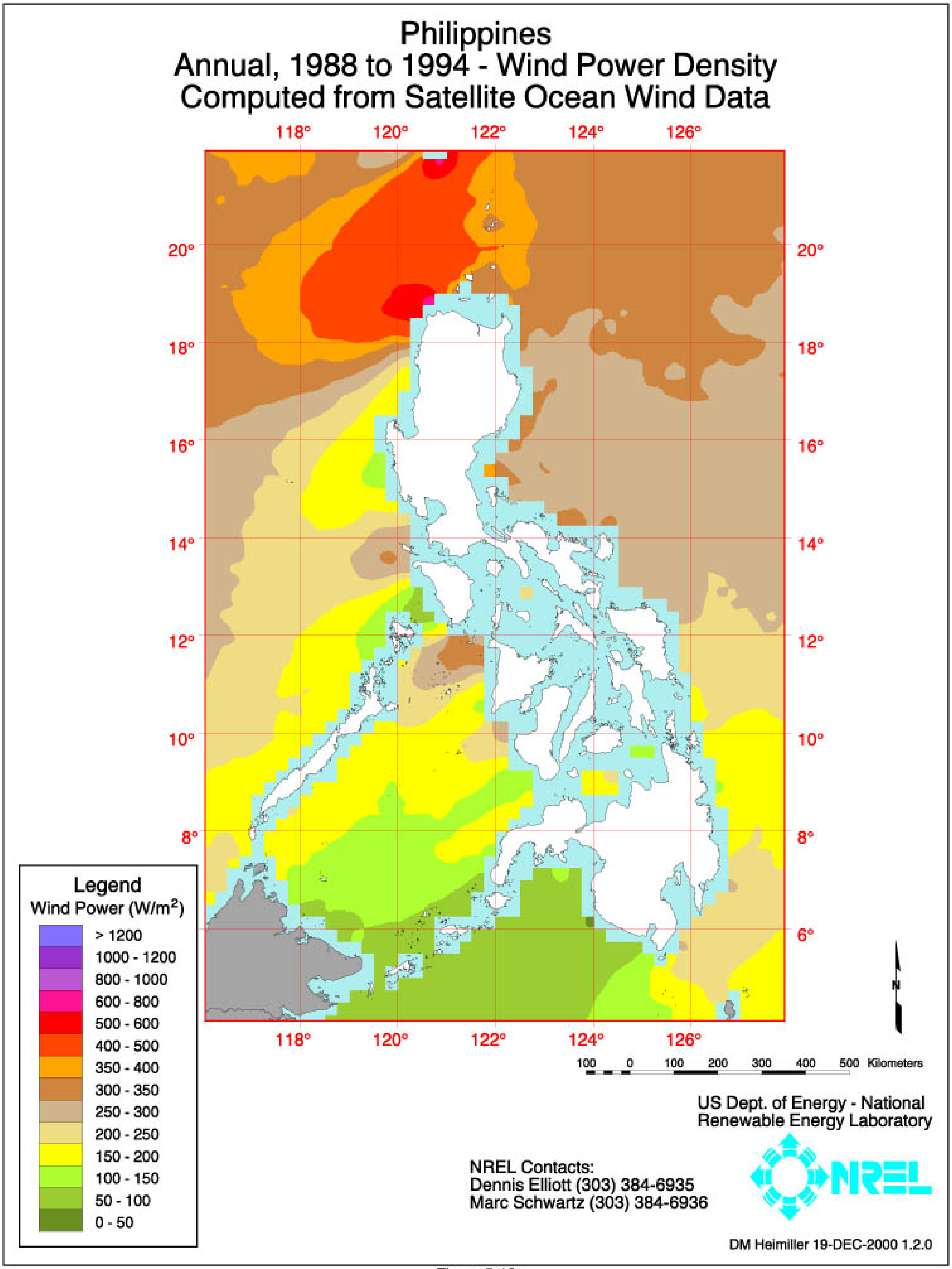

Philippines
Annual, 1988 to 1994 - Wind Speed
Computed from Satellite Ocean Wind Data
118°
120°
122°
124°
126°
20°
18°
16°
14°
12°
10°
8°
6°
Legend
Wind Speed (m/s)
> 11.0
10.0 - 11.0
9.0 - 10.0
8.0 - 9.0
7.5 - 8.0
7.0 - 7.5
6.5 - 7.0
6.0 - 6.5
5.5 - 6.0
5.0 - 5.5
4.5 - 5.0
4.0 - 4.5
3.5 - 4.0
< 3.5
N
100 0 100 200 300 400 500 Kilometers
US Dept. of Energy - National Renewable Energy Laboratory
NREL Contacts:
Dennis Elliott (303) 384-6935
Marc Schwartz (303) 384-6936
DM Heimiller 19-DEC-2000 1.2.0

Figure 5-9


Philippines
Annual, 1988 to 1994 - Wind Power Density
Computed from Satellite Ocean Wind Data
118°
120°
122°
124°
126°
20°
18°
16°
14°
12°
10°
8°
6°
Legend
Wind Power (W/m²)
> 1200
1000 - 1200
800 - 1000
600 - 800
500 - 600
400 - 500
350 - 400
300 - 350
250 - 300
200 - 250
150 - 200
100 - 150
50 - 100
0 - 50
N
100 0 100 200 300 400 500 Kilometers
US Dept. of Energy - National
Renewable Energy Laboratory
NREL Contacts:
Dennis Elliott (303) 384-6935
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NREL
DM Heimiller 19-DEC-2000 1.2.0

Figure 5-10

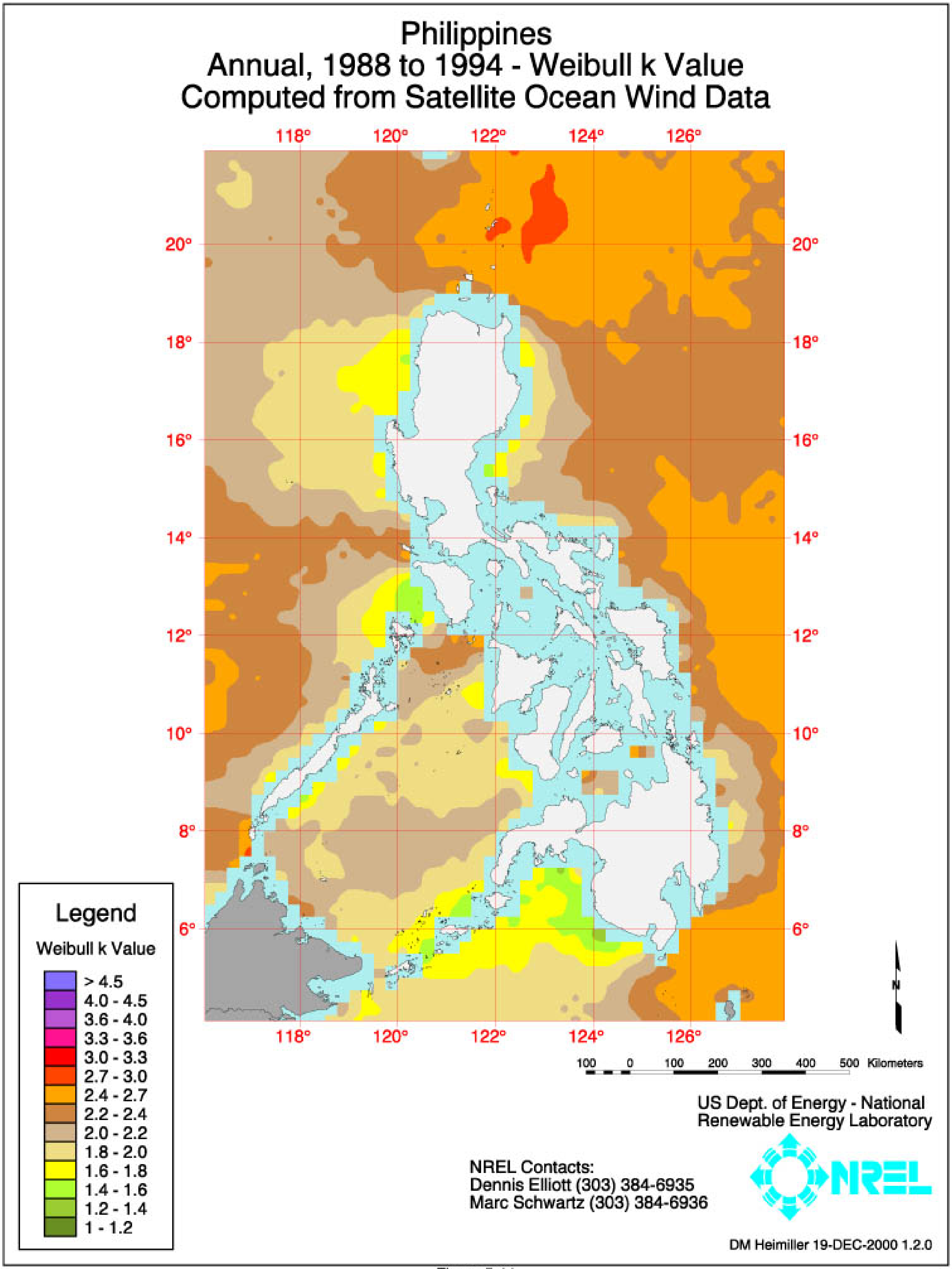
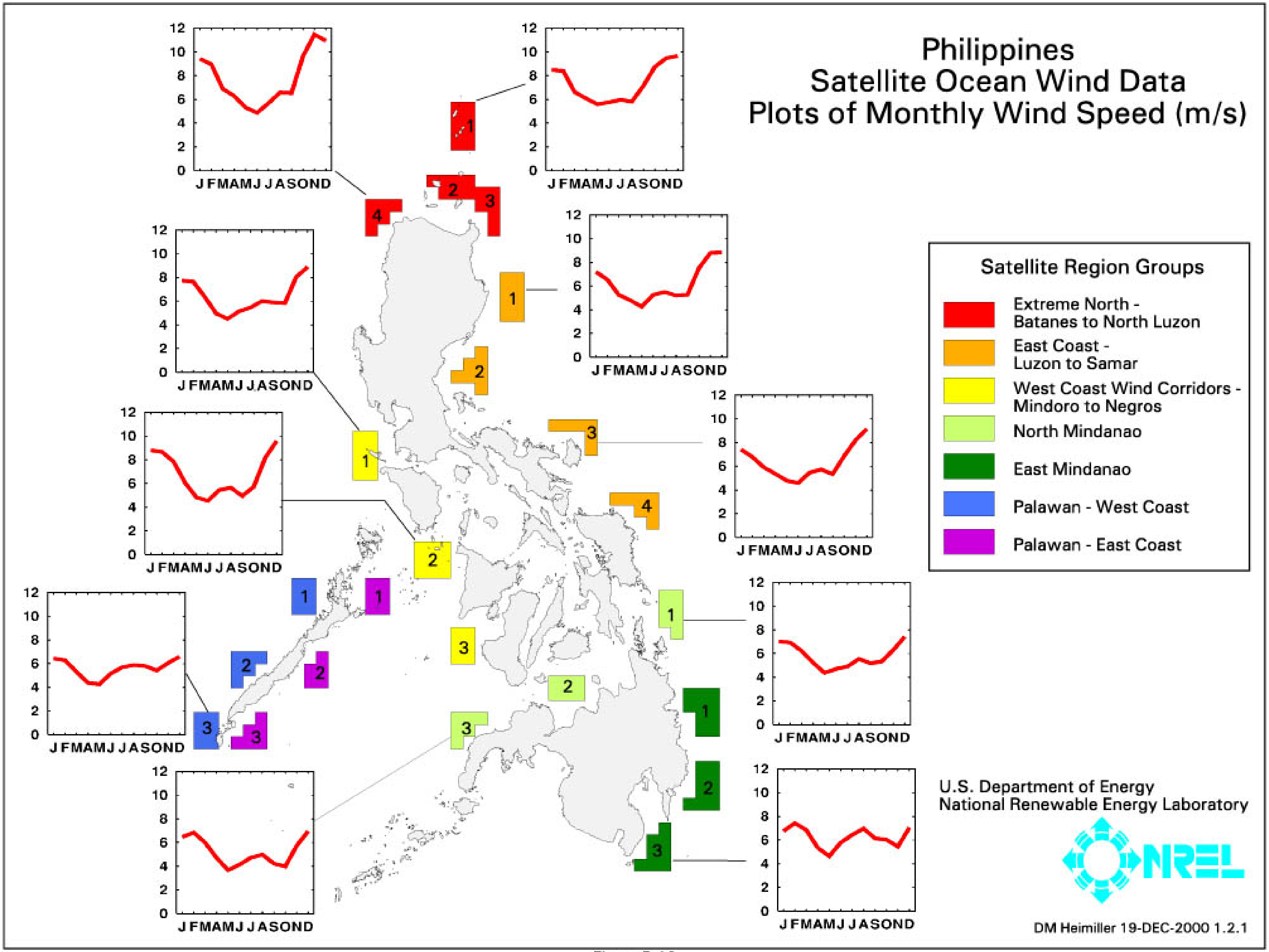

Philippines
Annual, 1988 to 1994 - Weibull k Value
Computed from Satellite Ocean Wind Data
118°
120°
122°
124°
126°
20°
18°
16°
14°
12°
10°
8°
6°
Legend
Weibull k Value
> 4.5
4.0 - 4.5
3.6 - 4.0
3.3 - 3.6
3.0 - 3.3
2.7 - 3.0
2.4 - 2.7
2.2 - 2.4
2.0 - 2.2
1.8 - 2.0
1.6 - 1.8
1.4 - 1.6
1.2 - 1.4
1 - 1.2
N
100 0 100 200 300 400 500 Kilometers
US Dept. of Energy - National
Renewable Energy Laboratory
NREL Contacts:
Dennis Elliott (303) 384-6935
Marc Schwartz (303) 384-6936
DM Heimiller 19-DEC-2000 1.2.0

Figure 5-11


Philippines
Satellite Ocean Wind Data
Plots of Monthly Wind Speed (m/s)
Satellite Region Groups
Extreme North - Batanes to North Luzon
East Coast - Luzon to Samar
West Coast Wind Corridors - Mindoro to Negros
North Mindanao
East Mindanao
Palawan - West Coast
Palawan - East Coast
J F M A M J J A S O N D
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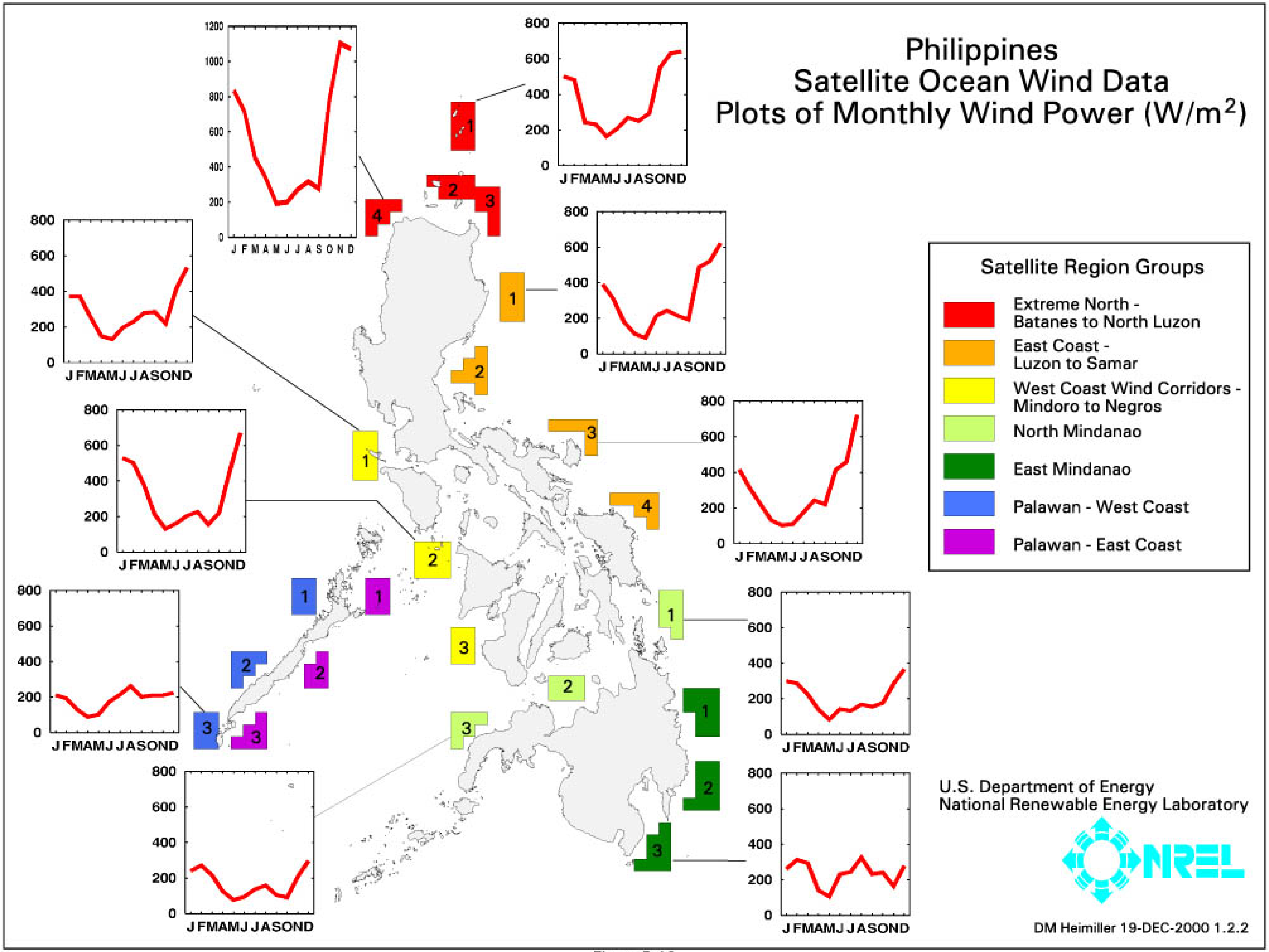
National Renewable Energy Laboratory
NREL
DM Heimiller 19-DEC-2000 1.2.1

Figure 5-12



Philippines
Satellite Ocean Wind Data
Plots of Monthly Wind Power (W/m2)
Satellite Region Groups
Extreme North - Batanes to North Luzon
East Coast - Luzon to Samar
West Coast Wind Corridors - Mindoro to Negros
North Mindanao
East Mindanao
Palawan - West Coast
Palawan - East Coast
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National Renewable Energy Laboratory
DM Heimiller 19-DEC-2000 1.2.2

Figure 5-13

5.5 Wind Resource Distribution and Characteristics

5.5.1 Annual Wind Resource Distribution

The wind resource over the Philippines varies considerably and is strongly dependent on three main factors: latitude, topography or elevation, and proximity to the coastline.

According to the wind speed and power density computed from the satellite ocean wind data, the best annual wind resource is in the islands of Batanes Province north of Luzon; the north and northwest coast of Luzon; the northeast- and east-facing coasts of Luzon and Samar; the southeast coast of Mindanao; and the straits between Mindoro and Luzon, Mindoro and Panay, and Panay and Negros. The satellite wind data and wind power density shows, in general, a strong relationship between latitude and the resource (Figure 5-9). Wind power density ranges from 500–600 W/m^2 along the northwest Luzon coast (Figure 5-10) to 250-350 W/m^2 between Mindoro and Panay, 250–300 W/m^2 along the eastern coast of Luzon and the northern coast of Samar, and less than 100 W/m^2 off the southwest coast of Mindanao.

The NPC wind data, presented in Tables 5-2 and 5-3, show that hilly areas along the immediate coast of northern Luzon in Ilocos Norte, and at one interior ridge top in Mountain Province, have a good annual wind resource. At the seven monitoring sites in Ilocos Norte, the annual average wind speed over the period of record ranges from 5.7 m/s (Saoit) to 7.7 m/s (Subec). The average annual wind power density ranges from 267 W/m^2 to 669 W/m^2. At the ridge top site (Sagada), with an elevation of 1,871 m, the annual average wind speed at 30 m above ground level was 7.1 m/s, and the power density was 393 W/m^2.

5.5.2 Seasonal Wind Resource Distribution

The satellite ocean wind data were processed to compare the seasonal distribution of the wind resource among the different regions of the Philippines. Plots of the monthly average wind speeds and power densities are shown for some areas in Figures 5-12 and 5-13 and for all areas in Appendix D. Through an examination of these plots, some conclusions can be made regarding patterns for the seasonal wind resource in the coastal regions and offshore islands of the Philippines.

Throughout most of the Philippines, the highest wind resource occurs from November through February and the lowest from April through September. However, there are some significant regional differences in the seasonal variability. For example, the months with the highest wind resource are October through February in the northern Philippines, and November through March in much of the central and southern Philippines. Two regions of the Philippines—the southeastern Mindanao coast and the western coast of Palawan—have a relatively high wind resource during the southwest monsoon, about as high as that of the northeast monsoon. In all other regions with significant wind resource potential, the wind resource during the northeast monsoon is considerably greater than that during the southwest monsoon.

The analysis of surface wind-resource data from meteorological stations may or may not provide reliable indications of the seasonal variation at exposed sites in the area. For example, long-term wind data (1973–1996) from the meteorological station at Basco in Batanes Province indicate that the month with the highest wind resource is August, during the peak of the southwest monsoon. However, the seasonal pattern of wind resource at the meteorological station is substantially different from that of the ocean satellite wind data for the Batanes region. The satellite data indicate that the wind-power density during the northeast monsoon (October through February) is in the range of 400–600 W/m^2, whereas, during the southwest monsoon (July and August), the wind power density is in the range of 200–300 W/m^2. The wind power measured at the Basco meteorological station is almost as great as that indicated by the satellite data during the southwest monsoon. However, during the northeast monsoon, the wind power at the meteorological station averages only about one-fourth that of the satellite data. From an inspection of topographic maps, it appears that the meteorological station is blocked from the northeast monsoon flow by a mountain upwind. This probably explains the peculiar seasonal pattern observed at the meteorological station and the severely reduced wind power during the northeast monsoon season.

The pronounced seasonal variation in the wind resource is also seen in Figures 5-5 to 5-7 (previously presented). These data, from the NPC sites at Pagali (coastal) and Sagada (inland, elevated) clearly show that both wind speed and power reach their minimums in the late spring to late summer, with June having the lowest values. The wind resource increases beginning in October, reaches a peak in December, and gradually decreases through the spring. For Guimaras Island, the peak wind speeds occur in February, later than they do in northern Luzon.

5.5.3 Diurnal Wind Speed Distribution

The diurnal wind speed distribution, or wind speed versus time of day, is influenced by site elevation and proximity to the Pacific Ocean. The distribution at low-elevation, inland sites in simple terrain typically reveals a maximum wind speed during the afternoon and a minimum near sunrise. The primary forcing mechanism for this pattern is the daytime heating, which destabilizes the lower levels of the atmosphere, resulting in a downward transfer of momentum to the surface. The near-surface winds tend to peak in the early afternoon, which corresponds to the time of maximum heating. In the late afternoon and evening, the declining supply of sunshine leads to surface cooling and a decoupling of the thermally forced momentum exchange. Surface winds begin to decelerate, while winds aloft, previously restrained by friction, are free to accelerate. The minimum in surface wind speed near sunrise corresponds to the time of maximum atmospheric stability. The chart of speed and power by hour in Appendix A for the NPC sites in Ilocos Norte shows this phenomenon. From an early morning minimum, wind speeds increase rapidly following sunrise, reaching a peak during the mid-afternoon. Winds decrease until after sunset and then remain steady during the late night and early morning hours.

Mountaintop diurnal distributions differ from those of low-elevation sites. The strongest winds at mountain locations occur at night, while the lowest wind speeds are observed during the midday hours. The chart for Sagada, showing speed and power by the hour, is included in Appendix A. The chart shows a well-defined maximum late at night and a minimum during the mid-afternoon.

Over the ocean, the diurnal variation of the atmospheric instability is typically reversed, resulting in a wind speed maximum at night and a minimum in the afternoon. However, diurnal wind speed changes are more complicated on the islands. The curves of average diurnal wind speed for island sites are often flatter than those observed over land. The plots of wind speed and power by hour for Guimaras and Cuyo Islands show a general peak during the early afternoon and a relative minimum during the night. The distribution is relatively flat for Cuyo Island, varying by less than 3 m/s, but is much more pronounced for Guimaras Island.

The magnitude of the diurnal variation is a function of the season, elevation, and influence of the ocean. From the NPC data, the seven stations in Ilocos Norte show a more pronounced diurnal variation in the winter and slightly less in the summer. For the high elevation site, the diurnal variation is also more pronounced during the winter and less so in the summer. For the island sites, Cuyo and Guimaras, the diurnal variations are greater during the winter than the summer.

5.5.4 Wind Direction Frequency Distribution

The wind speed frequency distribution at a site in the Philippines is influenced principally by the northeast and southwest monsoons and secondarily by latitude and elevation.

Appendix B contains data from the DATSAV2 database, including the hourly wind speed and wind direction data for Daet on Luzon, Guiuan on Samar Island, and Cuyo Island. On an annual basis, the wind is from the northeast nearly 25% of the time at Daet, 28% of the time at Guiuan, and more than 40% at Cuyo Island. The wind direction is southwest approximately 20% of the time at Cuyo Island; however, the southwest wind direction is not as pronounced at Daet or Guiuan. On a monthly basis, the predominance of the monsoon flow can clearly be seen. For Daet on Luzon, the wind direction is either northeast or east from December to April and south or southwest in August. The other months are transitional months with a mix of wind directions as the different monsoon flows become established. The pattern is slightly different at Guiuan, with a predominant northeast or east wind direction extending from November to May and southwest or west winds from July through September. For Cuyo Island, the wind direction is exclusively northeast from November to March and principally southwest from June through September.

The NPC data (Appendix A) from the stations in Ilocos Norte show a slightly different distribution of wind directions. On an annual basis, four stations—Bayog, Caparispisan, Pagali, and Saoit—show that nearly 30% of the time the wind is from the northeast or east. On a monthly basis, these four sites show that northeast wind directions predominate from October through April and then become much more variable from May through September. The northeast wind direction is associated with the best wind resource; that is, the highest monthly wind speeds and highest wind power density, for Ilocos Norte. For two other stations, Agaga and Subec, a predominately north component is indicated. This could be due to a local effect or, more likely, to faulty wind direction data in the data set. At Sagada, the interior mountain site in Mountain Province, on an annual basis, the wind directions are from the north 20% of the time, northeast 25% of the time, and west 7.5% of the time. On a monthly basis, the wind direction is predominately east-northeast from January to March with a secondary peak from the west. From April to August, the wind directions are evenly distributed, either east-northeast or west 35% to 40 % of the time, with the remainder spread over the other directions. This site also indicated a significant northerly component to the wind direction distribution from September to December. Again, this could be due to a local effect, or more likely, to faulty wind direction data in the data set.

6.0 Wind Mapping and Identification of Resource Areas

6.1 Introduction

This section presents an overview of the input data files, the results of the wind mapping, and wind-power density estimates for the Philippines. Two classification schemes for wind power density are used: one for wind power technology in rural areas and one for utility-scale applications. A description of the detailed meteorological data files is also presented. We used 22 different wind profiles in the modeling study, because of the large variability of the meteorological attributes across the archipelago.

To portray the mapping results, the Philippine archipelago was divided into 13 regions. Each region covered an area approximately 300 km by 300 km. The regional divisions were determined principally on the geography of the archipelago and the desire to maintain the same map scale for each region.

6.2 Wind Power Classifications

The wind power classifications for the Philippines are presented in Table 6-1. Two different classifications are used in the analysis: one for utility-scale applications and one for rural power applications. For utility-scale applications, areas with a Class 2 and higher resource potential are considered suitable for wind power development. For rural applications, areas with a Class 1 or higher are considered suitable for wind power development. In reviewing the mapping results, it is important to keep these classifications separate, because an area considered marginal from a utility-scale-application point of view is considered moderate from a rural power application point of view.

Table 6-1. Wind Power Classification

Class	Resource Potential		Wind Power Density (W/m^2) @ 30 m	Wind Speed [a] (m/s) @ 30 m
	Utility	Rural		
1	Marginal	Moderate	100 - 200	4.4 - 5.6
2	Moderate	Good	200 - 300	5.6 - 6.4
3	Good	Excellent	300 - 400	6.4 - 7.0
4	Excellent	Excellent	400 - 600	7.0 - 8.0
5	Excellent	Excellent	600 - 800	8.0 - 8.8
6	Excellent	Excellent	800 -1200	8.8 -10.1

[a] Mean wind speed is estimated assuming a Weibull distribution of wind speeds with a shape factor (k) of 2.0 and standard sea-level air density. The actual mean wind speed may differ from these estimated values by as much as 20%, depending on the actual wind speed distribution (or Weibull k value) and elevation above sea level.

6.3 Approach

We previously presented the description of the mapping methodology in Section 4.0. NREL prepared the digital terrain data set from the DEM information for the Philippines. NREL also prepared the meteorological data files necessary for the modeling analysis. These meteorological data files included vertical wind profiles, wind power roses that express the percentage of total wind-power density by direction sector, and open-ocean wind power density. The vertical profiles are broken down into 100-m intervals and centered every 100 m above sea level, except for the lowest layer, which is at 50 meters.

The vertical profiles were carefully determined, based primarily on the upper-air data, and then subjectively modified to derive the final profiles for 22 specific geographic zones. Wind roses were developed to account for the effects of short-range (less than 10 km), medium-range (10–50 km), and long-range (>50 km) blocking of the ambient wind flow by terrain. For this analysis, we incorporated the medium- and short-range blocking into one wind rose and the long-range blocking into a second wind rose.

6.4 Mapping Regions

The Philippine archipelago is divided into 13 regions. These regions are presented in Figure 6-1. The regions are:

1) Batanes and Babuyan
2) Northern Luzon
3) Central Luzon
4) Mindoro, Southern Luzon, Romblon, and Marinduque
5) Southeastern Luzon, Catanduanes, and Masbate
6) Samar and Leyte
7) Panay, Negros, Cebu, and Siquijor
8) Northern Mindanao and Bohol
9) Southern Mindanao
10) Western Mindanao and Basilan
11) Northern Palawan
12) Southern Palawan
13) Sulu, Basilan, and Tawi-Tawi

6.5 Mapping Results

6.5.1 Batanes and Babuyan

This region is the northernmost land area in the Philippines and consists of eight large islands—Itbayat, Batan, Sabtang, Babuyan, Calayan, Dalupiri, Fuga, and Camiguin—and numerous smaller islands. There are areas with good-to-excellent wind resource on each of these islands for both rural and utility-scale applications. Figures 6-2, 6-3, and 6-4 illustrate the significant political features, topography, and potential wind resource of this region.

On Itbayat Island, the wind resource is rated excellent (500–700 W/m^2) at the northeast tip of the island and good elsewhere. On Batan Island, there is an area of excellent resource at Rocavato Point and the higher terrain on the south end of the island. Coastal areas along the southeast and south end of the island are considered to have a good wind resource. The inland area at the north end of the island, north and east of the town of Basco, is considered to have a poor wind resource.

In a similar fashion, the higher terrain in the north-central part of Sabtang Island has an excellent resource, and the north-, east-, and south-facing coastal areas have a good wind resource. The only area considered to have a poor wind resource is the central-west side of the island, which is sheltered from the prevailing easterly flow. For Babuyan Island, an excellent wind resource exists in the higher, central portion of the island, while a good-to-excellent wind resource exists on the coastal portions of the northeast cape, the southern tip, and the western cape.

For Camiguin Island, an excellent wind resource exists on the interior high terrain and at the southern tip (Genlous Point). A moderate-to-good wind resource exists along all coastal sections with better resources at Machibat Point and Nagayaman Point. For Calayan Island, the interior hills and ridges have an excellent wind resource with good-to-excellent resources along the northern and eastern coastline including Priddan Point, Batang Point, and Tumulod Point. The wind resource on Dalupiri Island and Fuga Island is rated excellent on the interior elevations and good to excellent across the coastal and interior areas of each island.

6.5.2 Northern Luzon

The significant political features, topography, and potential wind resource of northern Luzon are illustrated in Figures 6-5, 6-6, and 6-7. The wind resource in northern Luzon is confined to the eastern, northern, and northwestern coastal sections; coastal hills; and interior high-elevation areas. The flat coastal sections, from the coastline to several kilometers inland, are classified as having a marginal wind resource for utility-scale applications and a good resource for rural power applications. The area inland (south) from Aparri along the Cagayan River is also classified as moderate for rural wind power applications.

For the coastal sections, areas with a better wind resource include the capes at Bangui Bay and Pasaleng Bay, Palaui Island, the coastline between Escarpada Point and Matador Point, Palanan Bay, and the peninsula on the east coast near Casiguran.

Good-to-excellent wind resources exist in Ilocos Norte in the coastal hills extending from Agaga to Dumalneg. This resource is generally confirmed by the NPC sites installed in this area. The wind-power-density measurements ranged from 267 W/m^2 at Saoit to 669 W/m^2 at Subec. Good-to-excellent wind resources are found in the Sierra Madre Mountains extending north to south along the eastern coast of northern Luzon and the Cordillera Central Mountains in the interior of Luzon. An area of moderate-to-good wind resource potential is found in the lake region northwest of Cabarroquis. The interior plains along the Cagayan River and from Lingayen Gulf past Tarlac have a poor wind resource, even for rural power applications.

Other areas with a moderate wind resource for rural power applications are the western and northern coastal plains of the Province of Pangasinan in the southwest part of northern Luzon. The hills and mountains extending south-southeast from Burgos to Mt. Iba are classified as having a good-to-excellent resource.

6.5.3 Central Luzon

The significant political features, topography, and wind mapping results for Central Luzon are illustrated in Figures 6-8, 6-9, and 6-10. The Central Luzon region encompasses the area from 16.5 degrees to 13.5 degrees north latitude and includes metropolitan areas surrounding Manila. The wind resource in the flat interior and coastal sections of this area is generally moderate to good for rural power applications and marginal to moderate for utility-scale applications. The area surrounding Manila Bay and extending north to Cabanatuan fits this description. Good-to-excellent wind resources are evident in the mountain chain running north–south into Bataan, the high terrain north and southeast of Lake Taal, and the higher terrain southeast of Batangas. Good-to-excellent wind resources are evident in the mountains in the provinces of Bulacan, Rizal, and Quezon. The east-to-west-oriented ridgelines near Lamon Bay are also classified as having a good-to-excellent resource. Both Polillo Island, to the east of Central Luzon, and Lubang Island, to the southwest, have extensive areas of moderate-to-good wind resource. The majority of the coastal and interior areas of the isthmus and peninsula between Tayabas Bay and Ragay Gulf, as well as Alabat Island, have a marginal-to-moderate wind resource (utility scale) and a moderate-to-good resource (rural power scale). A good-to-excellent wind resource exists in the higher terrain at the southern end of the peninsula east of San Francisco, at Dapdap Point, and the higher terrain surrounding Mt. Cadig.

6.5.4 Mindoro, Southern Luzon, Romblon, and Marinduque

The significant political features, topography, and wind mapping results for this region are illustrated in Figures 6-11, 6-12, and 6-13. Mindoro, a large island in the Philippines archipelago, centered at 13 degrees north and 121 degrees east, is divided into two provinces, Occidental Mindoro and Oriental Mindoro. The topography consists of a coastal plain and a high mountain interior. Except in certain specific locations, the island has a limited developable wind resource. However, good-to-moderate wind resources for rural power applications can be found in several areas of the region: the northeast portion near Balingawan Point and Dumali Point, the northwest corner of the island at Calisurigan Point, along the southeast coastal sections from Soguicay Bay to Buruncan Point, and around Ilin Island on the south-southwest. Good-to-excellent wind resources are evident along the central mountain range from Tandrac Peak in the north to just north of Bulalakao in the south. Another area of good-to-excellent wind resource is evident in the high terrain north of Mamburao in the northwest and near Tusk Peak in the southwest. The Semirara Islands south of Mindoro have a uniformly good-to-excellent wind resource across all three islands.

A similar wind resource pattern is evident in the Romblon Island group—Sibuyan, Tablas, Carabao and Romblon. On Sibuyan Island, a good-to-excellent wind resource is evident on the high terrain in the eastern and central part of the island. A limited area of moderate-to-good wind resource for rural power applications exists on the immediate north coast. On Romblon Island itself, a moderate-to-good wind resource extends from north to south along the central part of the island. On Tablas Island, a moderate-to-good wind resource exists on the southwest and southern plains extending from Odiongan to Cabalian Point. A good-to-excellent wind resource occurs in the high mountains along the eastern side of the island. On Carabao Island, the wind resource across the entire island is classified as excellent for rural power applications.

The northwest, north, and east coastal sections of Marinduque have a moderate-to-good wind resource for rural power applications and marginal to moderate for utility-scale power applications. Good-to-excellent wind resources are evident from Mogpog in the north to Suban Point in the south, along the interior mountain ranges on the eastern and southwestern sides of the island.

The wind resource in the portion of Luzon presented in Figure 6-13 was previously discussed in Section 6.5.4.

6.5.5 Southeastern Luzon, Catanduanes and Masbate

The significant political features, topography, and wind mapping results for Southeastern Luzon, Catanduanes, and Masbate are illustrated in Figures 6-14, 6-15, and 6-16. Southeastern Luzon includes the provinces of Camarines Norte, Camarines Sur, Albay, and portions of Sorsogon. The coastal areas, including several kilometers inland, as well as the plains south of San Miguel Bay and the plains west and south of Legaspi, have a marginal-to-moderate resource for utility-scale power applications and a moderate-to-good resource for rural power applications. Other areas in Sorsogon having a similar resource include the coastal area and interior plains from Prieto Diaz to Barcellona, westward to Casiguran.

The best wind resource in the coastal areas is found at Gumaus Point in Camarines Norte, near Daet; on Camarines Sur, at Quinabucasan Point southeast to Maslog; at the far eastern end of the province at Rungus Point; and at Prieto Diaz and San Jose in Sorsogon. Good-to-excellent wind resources exist in the high interior areas of the provinces near Mt. Cadig, Mt Labo, the mountains west of San Miguel Bay, Mt Isarog, the east–west-oriented mountain chain from Buludan to Bitaogan in Camarines Sur, and the mountains in Albay and Sorsogon.

The wind resource on San Miguel Island, Gagrary Island, Batan Island, and Rapu Rapu Island are also rated moderate to good for rural power applications and marginal to moderate for utility-scale power applications. The best resources are found on the higher terrain of Batan Island and Rapu Rapu Island.

The Province of Catanduanes is located directly east of Camarines Sur. A moderate-to-good wind resource for rural power applications and marginal-to-moderate for utility-scale power applications exists along the north, east, and south coastal sections of the province. The best coastal resources appear to be at Binorong Point and Nagumbuaya Point, in the southeast part of the island, and at Virac Point in the south. A good-to-excellent wind resource exists on the higher terrain in the north-central part of the island, on the eastern side of the island west of Gigmoto, at the southern end in the higher terrain north of Virac, and in the terrain east of Codon in the southwest part of the island.

Masbate includes three separate islands—Burias, Ticao, and Masbate. The distribution of wind resource is very similar to other areas of the Philippines: the best resource is on the highest terrain. For Burias Island, the north-, east- and south-facing coastal sections have, in general, a moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications. The coastal and interior plains at the north end of the island and in the center have a similar resource. A good-to-excellent resource for rural power applications (moderate to good for utility-scale applications) is indicated at the far north end of the island and in the northwest. The best wind resource is associated with the higher terrain in the central part of the island near Dancalan and in the south around Mt. Enganoso and Maputing Baybay.

Ticao Island has a similar distribution of resources with a moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications along east-facing coastal sections. However, the best wind resource is on the highest terrain in the northwest part of the island, but this only ranks as good for utility-scale applications.

Masbate also has large areas classified as moderate to good for rural power applications and marginal to moderate for utility-scale power applications. This includes all coastal sections and the plains in the southwestern and northwestern parts of the island. A moderate-to-good resource exists at Cadurnan Point at the southern tip of the island, the high terrain northwest of Cataingan, and the high terrain directly south of the town of Masbate. The best resource on the island is the high terrain directly west of Masbate and north of Milagros.

6.5.6 Samar and Leyte

The significant political features, topography, and wind mapping results for Samar and Leyte are illustrated in Figures 6-17, 6-18, and 6-19. As in Southeastern Luzon, there is a good distribution of wind resources across the island. The coastal sections, including inland areas across the interior plains and the islands on the western side of Samar in the Samar Sea, have a moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications. In the coastal sections, the best wind resource, classified as good for utility-scale applications and excellent for village power applications, is on the northwest tip of the island, near and including Biri Island, and the northern tip of the island, including Batag Island. Good resources at coastal locations are also found at Bunga Point on the eastern side of the island, Tugnug Point on the southeastern part of the island, and near the Town of Mercedes and Calicon Island in the south. The best wind resources on Samar, good to excellent from the utility-scale classification, are found in the northwest on the high terrain southwest of Catarman and the mountains in the central interior (Mt. Bingo, Mt. Canyaba, and Mt. Cabalantina). A good wind resource is also found on the interior high terrain in the southern part of the island.

Compared to Samar, the coastal sections of Leyte generally have less wind resource, as can be seen in Figure 6-19. A moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications exists in the plains at the north end of Leyte, the north coast around Capoocan, the northeast corner near Rizal, and the southern end of Leyte, near Himayanan and Liloan. The best wind resource, much like on Samar, exists in the interior high terrain extending through the center of the island from the area north of Mt. Lobi to the high terrain west of Sogod Bay at the south end.

6.5.7 Panay, Negros, Cebu, and Siquijor

The significant political features, topography, and wind mapping results for Panay, Negros, Cebu, and Siquijor are illustrated in Figures 6-20, 6-21, and 6-22. A moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications exists along the north coastline along Jintotolo Channel and southeast coastlines of the island along Guimaras Strait, including Guimaras Island. A better wind resource in the coastal areas includes Potol Point in the far northwest, the areas east and south of Roxas, the northeast point near Balasam, southeast near Concepcion, north of Iloilo City, and in the far south at Naso Point. A good wind resource is found in the mountains (Mt. Agudo and Mt. Lantuan) in the northeast and the east (Mt. Caniapasan). The best wind resource on Panay is in the north-south-oriented mountain range along the western side of the island.

On Negros, a moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications exists along the northwest coastline of Guimaras Strait, including the area around Bacolod; the northeast area near Sagay Point; the east-west coastline in the Panay Gulf from Sojoton Point to Diut Point; and the west-facing coastline from Binigsian Point to Matatindoe Point. Moderate-to-good wind resources occur in the hilly terrain in the southwest part of the island; however, the best wind resources occur in the high terrain in the north end of the island and along the eastern interior. This includes the areas around

Mt. Silay, Mt. Mandalagan, and Canlaon Volcan in the north; from Razor Back Mountain along the eastern side of the island to just southwest of Bais; and in the southern part of the island around Cuemos de Negros and Dome Peak.

For Cebu, a moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications exists across the north end of the island from Bulalquit Point south to the beginning of the higher terrain near Sogod; east of Cebu City, including Mactan Island; and in selected areas on the west coast along the Tanon Strait, especially around Alcantara. A good-to-excellent wind resource exists in the hills and mountains, including Mt. Lanibga, Mt. Cabalasan, and Mt. Uling, which run north to south along the length of the island.

Siquijor Island sits at the confluence of the Bohol Strait, the Cebu Strait, and the Tanon Strait. The indicated wind resource on the island is very similar to the nearby islands except that it does not have the higher terrain needed to accelerate the wind power density from the marginal-to-moderate classification into a higher category. A moderate-to-good wind resource for rural power applications and a marginal-to-moderate resource for utility-scale power applications exists at Tongo Point to the west, Sandagan Point in the north, Daquit Point in the east, and east of Minalulan. The best wind resource, classified as good for utility-scale applications, occurs on the hills that run generally west to east across the island.

6.5.8 Northern Mindanao and Bohol

The significant political features, topography, and wind mapping results for Northern Mindanao and Bohol are illustrated in Figures 6-23, 6-24, and 6-25. For Bohol, a good-to-excellent wind resource is present on the high terrain in the southeast part of the island. Good wind resources occur in the high terrain at the eastern end of the island, near Talisay, and in the southwestern part of the island, east of Cruz Point. A moderate-to-good wind resource for rural power applications and marginal-to-moderate for utility-scale power applications exists in the northern third of Bohol, from Mahanay Island in the west to Lapining Island in the east, and south to Dagohoy in the central interior. A similar resource exists across most of the southern interior plains extending southwestward to Panglao Island.

Northern Mindanao lacks a consistent, widespread wind resource, principally due to the latitude and the resultant lower wind speeds over the ocean. However, because of the accelerating effects of the terrain, there are a limited number of areas with a usable wind resource. A good-to-excellent wind resource occurs at the crest of a long, narrow mountain range that extends from Macopa in Surigao del Norte to west of Lake Mainit in Agusan del Norte. A good wind resource also exists in the higher terrain east of Lake Mainit in Surigao del Norte, Surigao del Sur, Agusan del Norte, and Agusan del Sur.

The high terrain extends from Mt Legaspi in the north to Mt. Divata in the south and east-northeast to Canit Point. Other good wind resource areas are scattered in the higher terrain on the eastern side of northern Mindanao. The resource is considered marginal (utility-scale) to moderate (rural power), on the successive ridgelines progressing from east to west. Siargao Island, Dinagat Island, the area around Surigao, the east coast from Tandag to Jobo Point and from Bakulin Point to Lamon Point, and Taglo Point, northeast of Dipolog, all exhibit a marginal-to-moderate wind resource. For other areas in northern Mindanao, the wind resource is classified as poor.

6.5.9 Southern Mindanao

The significant political features, topography, and wind mapping results for Southern Mindanao are illustrated in Figures 6-26, 6-27, and 6-28. This region, defined as Southern Mindanao, extends from Lanao del Sur on the west to Davao Oriental on the east, and from northern Cotabato in the north to Davao del Sur in the south. A marginal (utility-scale) wind resource exists in some east-facing coastal sections in Davao Oriental from Pusan Point to Tugubun Point near Mayo Bay and Cape San Augustin. The best wind resource areas, principally good (utility-scale) to excellent (rural scale), in Southern Mindanao are the higher terrain areas east of Davao Gulf, along the mountains that separate Davao del Sur from southern Cotabato, west of Sarangani Bay, and west of Isulan. Two locations, Sharp Peak and Saddle Peak, in Davao del Sur, are classified as having an excellent wind resource. The large interior valley, extending from Cotabato City, Maguindanao, in the northwest to Koronadal, southern Cotabato, in the southeast, is considered to have a poor wind resource for either rural or utility applications.

6.5.10 Western Mindanao and Basilan

The significant political features, topography, and wind mapping results for Western Mindanao and Basilan are illustrated in Figures 6-29, 6-30, and 6-31. The wind resource is classified as moderate for rural power applications and marginal for utility-scale applications. The areas with this limited resource include the coastal areas immediately northeast of Dipolog, the coastal areas near Patauag, and the higher terrain in the interior of Mindanao. A similar, limited wind resource exists on the higher terrain on Basilan.

6.5.11 Northern Palawan

We divided the province of Palawan into two regions—Northern Palawan and Southern Palawan. The significant political features, topography, and wind mapping results for Northern Palawan are illustrated in Figures 6-32, 6-33, and 6-34. This region includes the northern part of Palawan Island and the islands at the northern end of Palawan, including Lincapan Island and Dumaran Island. The wind resource on the northern part of Palawan Island is generally classified as moderate to good for rural power applications and marginal for utility-scale applications. There are a very limited number of areas with a good-to-excellent resource in the higher terrain areas southwest of Roxas.

The wind power on Lincapan and Dumaran islands is classified as moderate to good for rural power applications and marginal to moderate for utility-scale applications. The immediate coastline and high terrain in the far northern portion of Palawan is classified as having a good-to-excellent resource for rural power applications and a moderate-to-good resource for utility-scale applications. There are two small areas with the best resource (good to excellent). These are the high terrains east of El Nido and the high terrain northwest of San Vincente. Other areas with a good-to-excellent wind resource include the high terrain west of Caramay and southwest of Roxas. The wind resource in the immediate vicinity of Puerto Princesa is marginal for utility-scale applications, but moderate for rural power applications. However, the higher terrain west of Puerto Princesa is characterized as having a good to excellent resource.

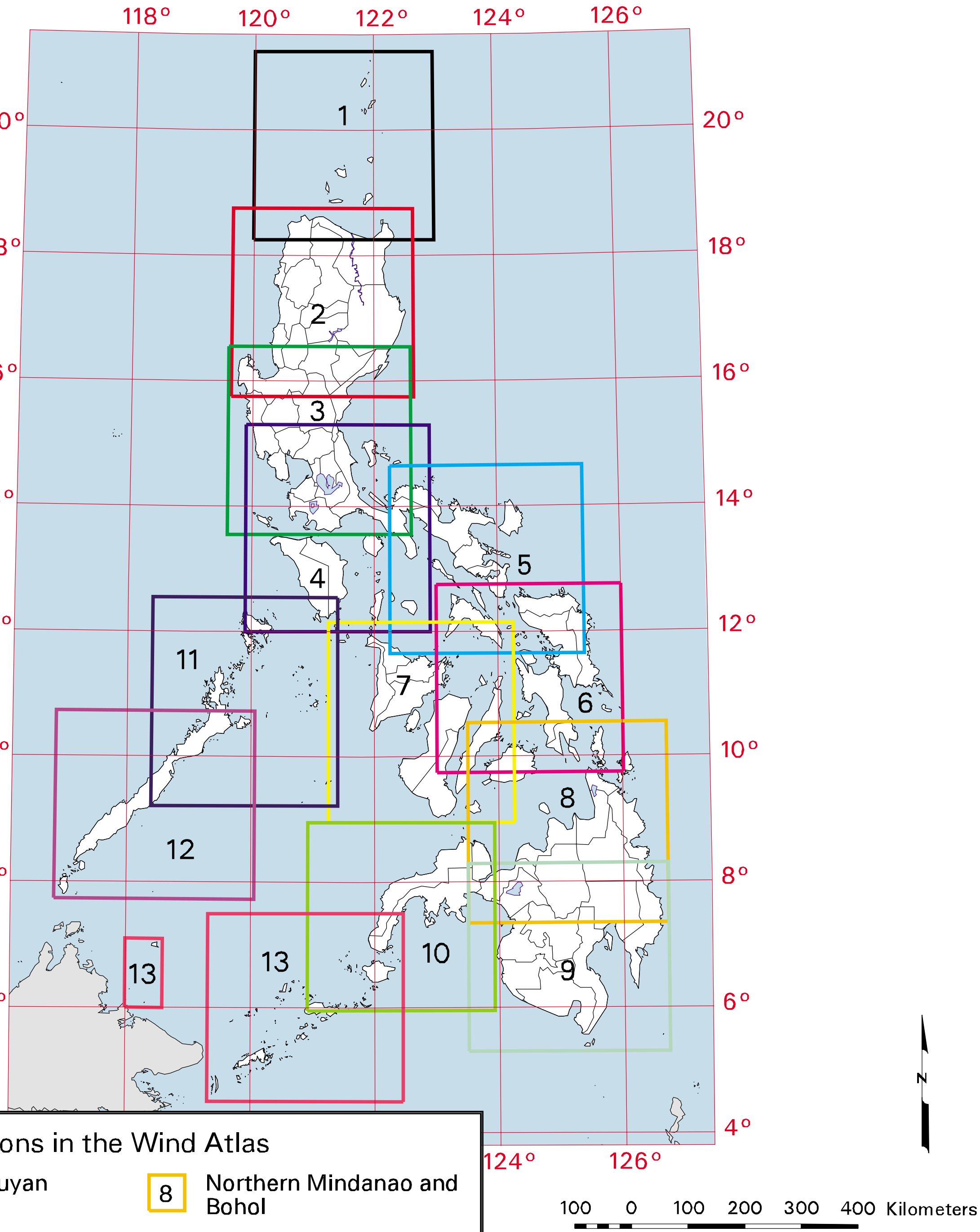
6.5.12 Southern Palawan

The significant political features, topography, and wind mapping results for Northern Palawan are illustrated in Figures 6-35, 6-36, and 6-37. A moderate-to-good resource for rural power applications is evident in the coastal areas at the far southern end of Palawan, including Bugsuk Island, Balabac Island, and areas along the eastern coast near Bivouac Point. A limited area, characterized by a good-to-excellent wind resource, extends along the higher terrain in the center of Palawan. These areas are principally west of Aborian, Panacan, and Tacbolubu, and north of Rio Tuba.

6.5.13 Sulu, Basilan, and Tawi-Tawi

The significant political features, topography, and wind mapping results for the Sulu Archipelago, including Basilan and Tawi-Tawi, are illustrated in Figures 6-38, 6-39, and 6-40. The Sulu Archipelago extends from the western tip of Mindanao southwest toward Malaysia. This group of islands is bracketed by the Sulu Sea to the northwest and the Celebes Sea to the southeast. Based on the satellite-computed wind speed information presented previously, the wind resource in this area is quite low. There is a small area of moderate wind resource associated with the higher terrain in the south-central part of Basilan, on the eastern tip and north central part (east of Jolo) of Sulu, and on the islands of the Jolo and Tapul groups.

Philippines
Key to the Regions in the Wind Atlas



Regions in the Wind Atlas

1	Batanes and Babuyan
2	Northern Luzon
3	Central Luzon
4	Southern Luzon, Mindoro, Romblon and Marinduque
5	Southeastern Luzon, Catanduanes and Masbate
6	Samar and Leyte
7	Panay, Negros, Cebu and Siquijor
8	Northern Mindanao and Bohol
9	Southern Mindanao
10	Western Mindanao and Basilan
11	Northern Palawan
12	Southern Palawan
13	Basilan, Sulu and Tawi-Tawi

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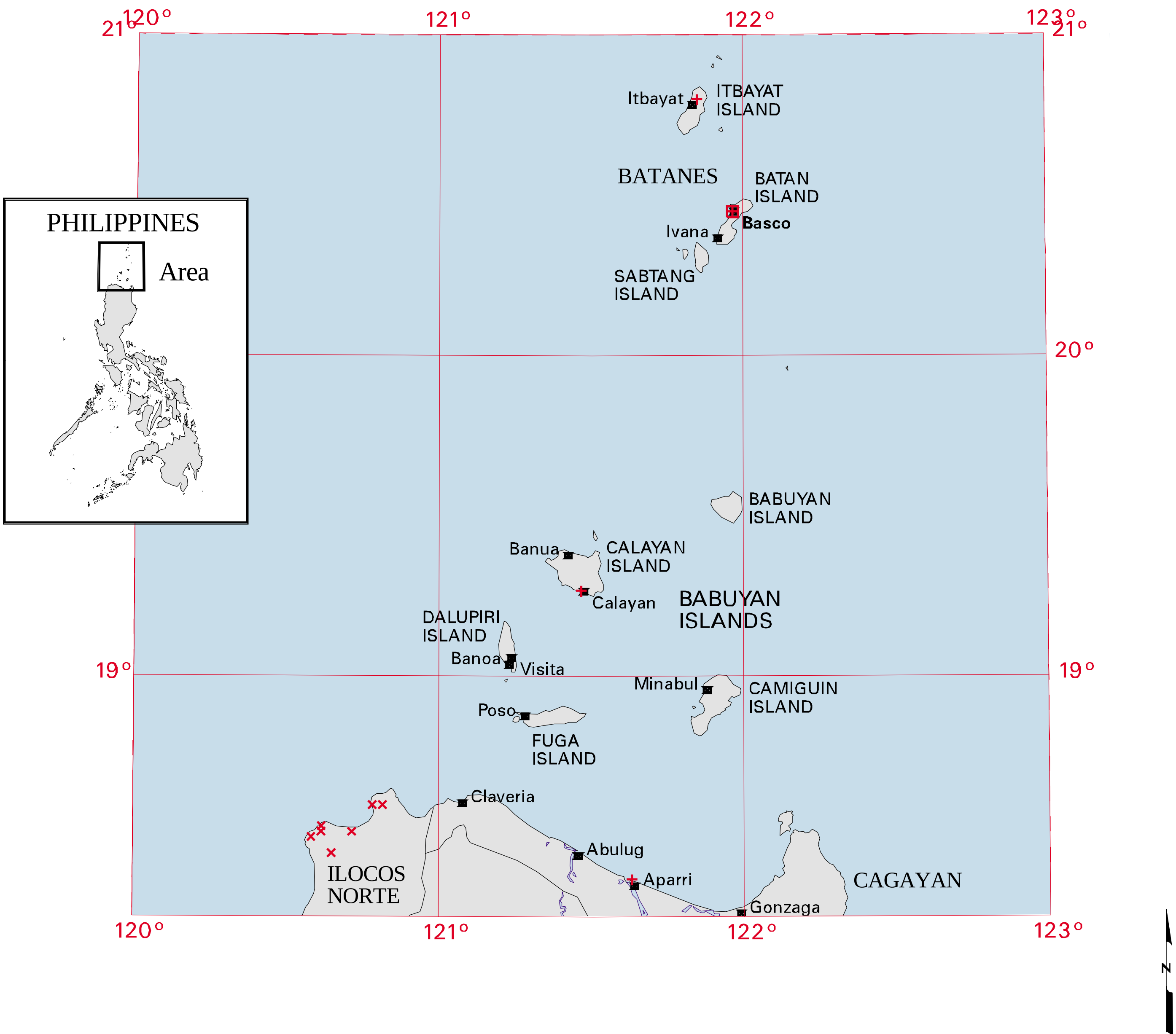
Figure 6-1

Philippines - Batanes and Babuyan
Political Base Map



20 10 0 20 40 60 80 100 Kilometers

The Global Telecommunications System (GTS) meteorological stations are part of NREL's global database. Additional data for many of the meteorological stations were provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The data for the wind monitoring sites were provided by the Philippine National Power Corporation (NPC).

Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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Philippines - Batanes and Babuyan
Elevation Map

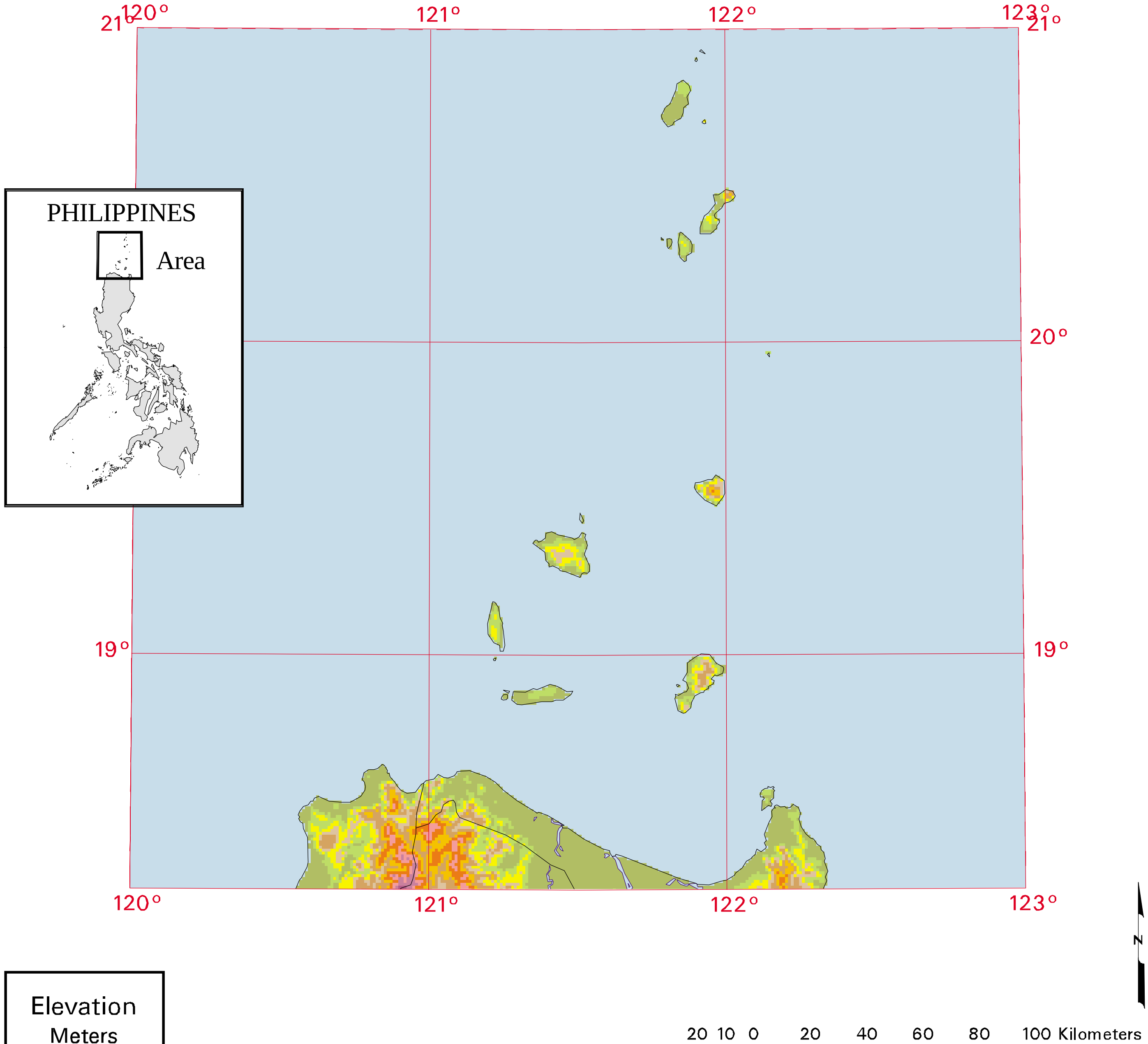

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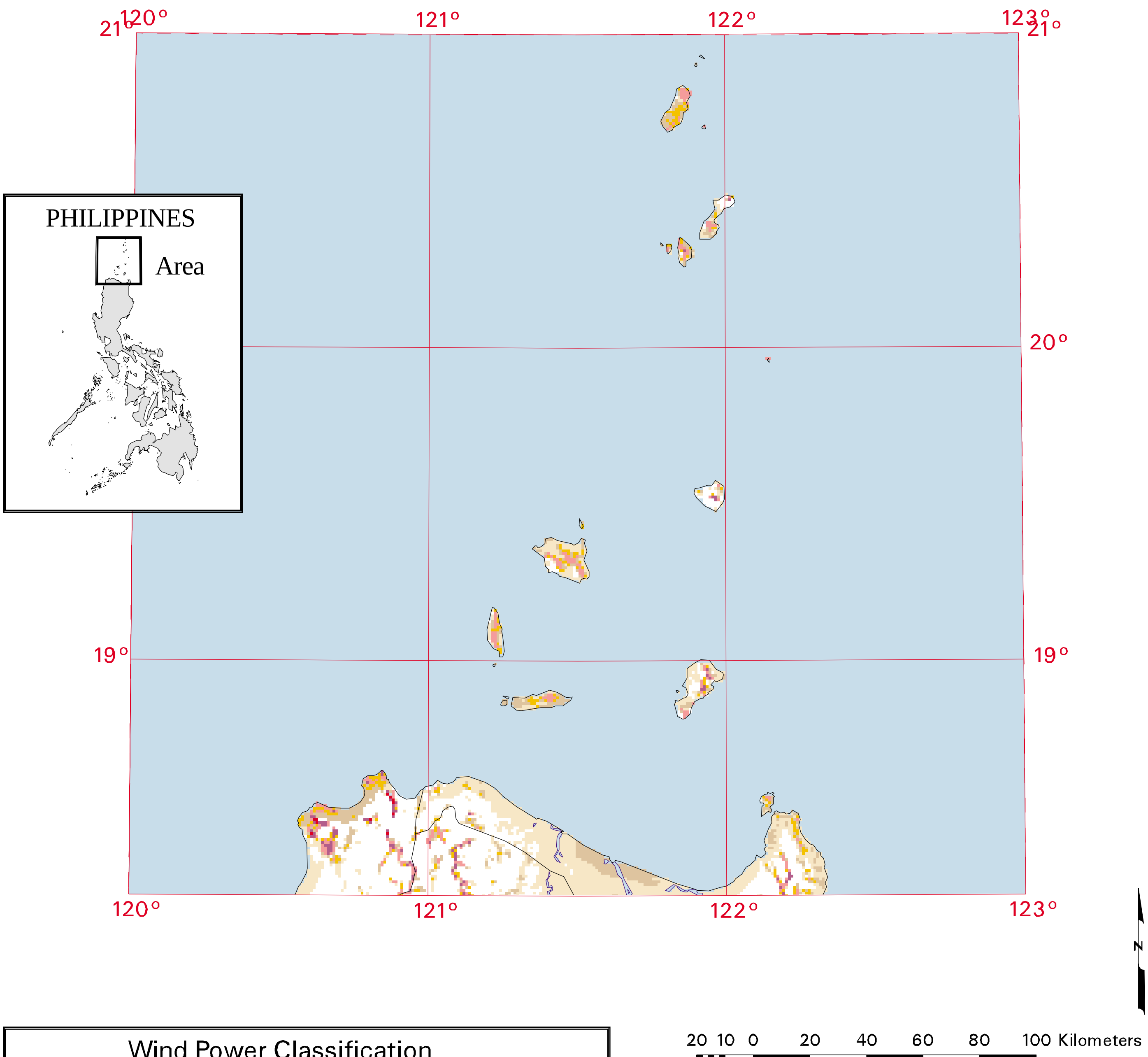
Figure 6-3

Philippines - Batanes and Babuyan
Most Favorable Wind Resource Areas



Wind Power Classification

	Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
	Marginal	Moderate	100 - 200	4.4 - 5.6
	Moderate	Good	200 - 300	5.6 - 6.4
	Good	Excellent	300 - 400	6.4 - 7.0
	Excellent		400 - 600	7.0 - 8.0
			600 - 800	8.0 - 8.8
			800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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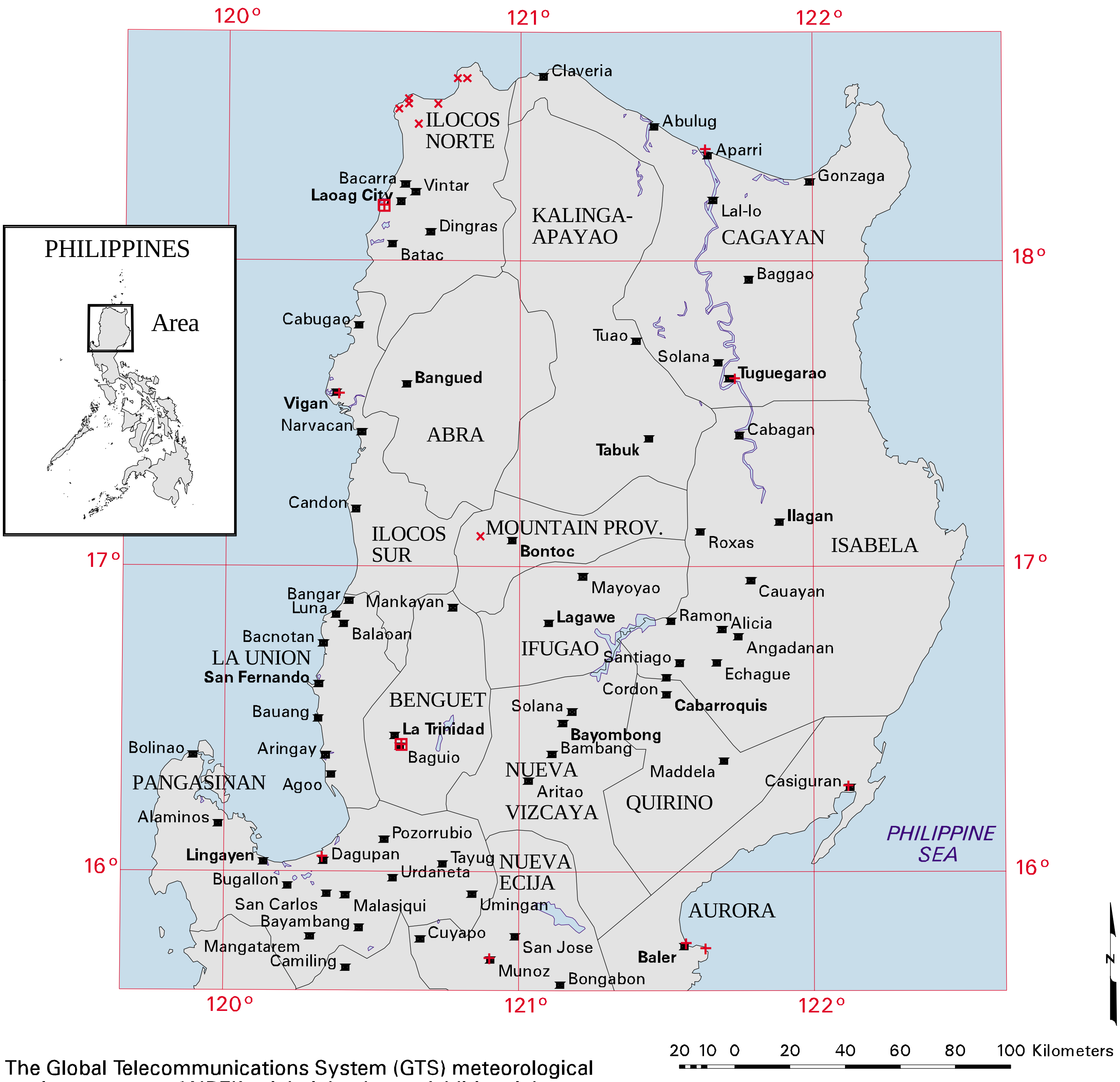
Figure 6-4

Philippines - Northern Luzon
Political Base Map



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Legend

- + GTS Surface Meteorological Station with Wind Data
- ☐ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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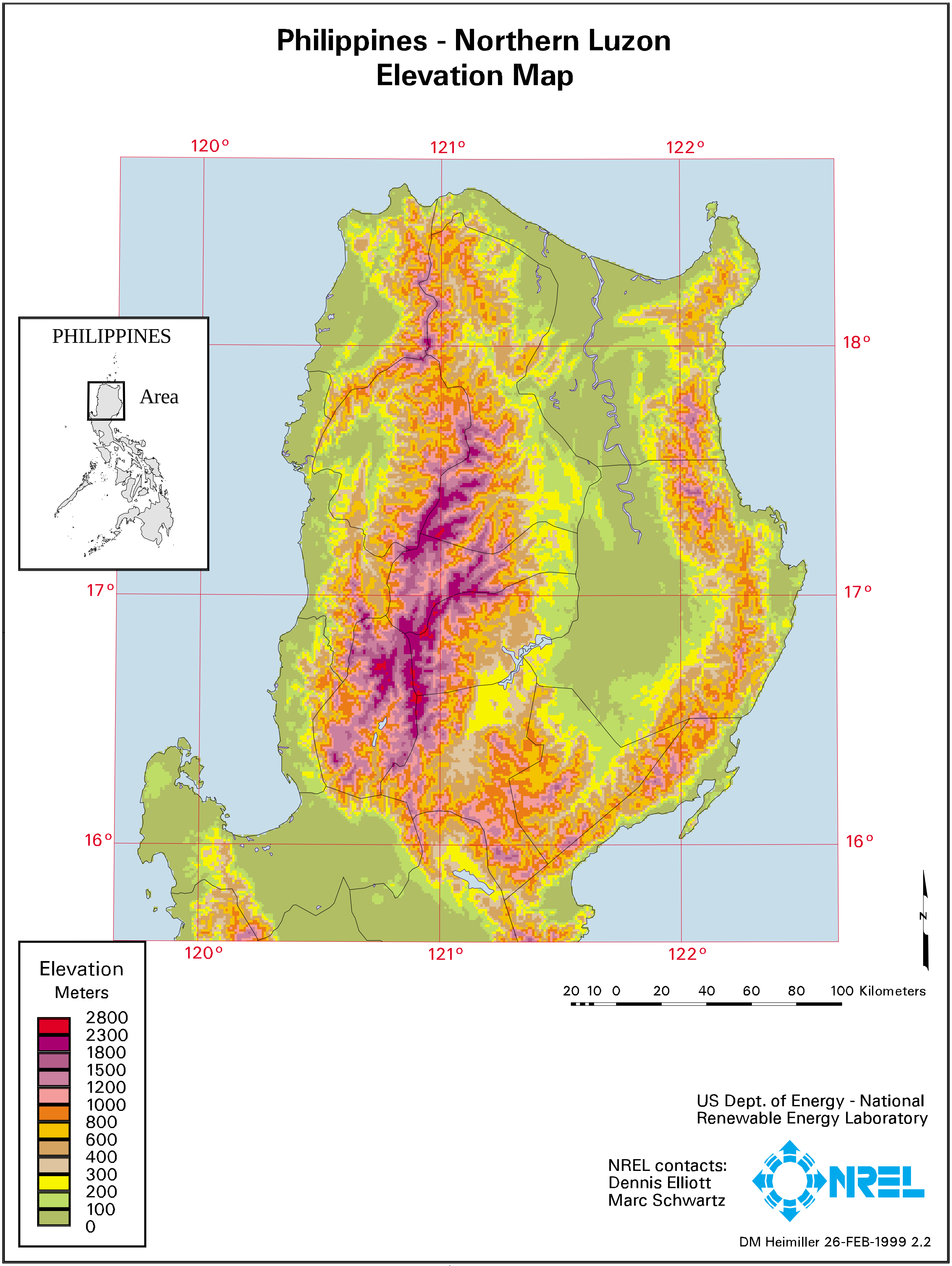
Figure 6-5



Philippines - Northern Luzon
Elevation Map
120°
121°
122°
18°
17°
16°
PHILIPPINES
Area
Elevation
Meters
2800
2300
1800
1500
1200
1000
800
600
400
300
200
100
0
N
20 10 0 20 40 60 80 100 Kilometers
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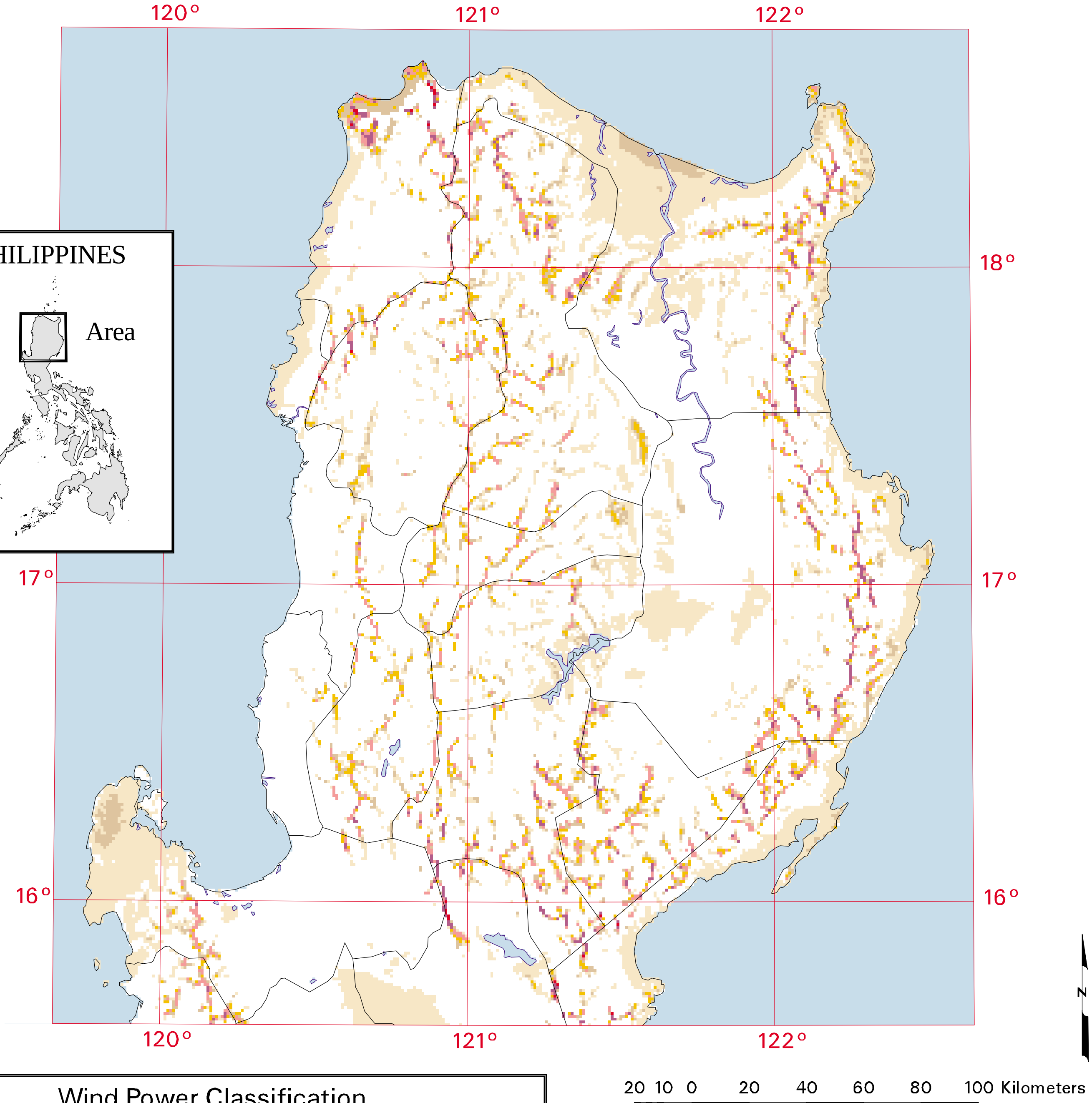
Figure 6-6

Philippines - Northern Luzon
Most Favorable Wind Resource Areas



Wind Power Classification

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Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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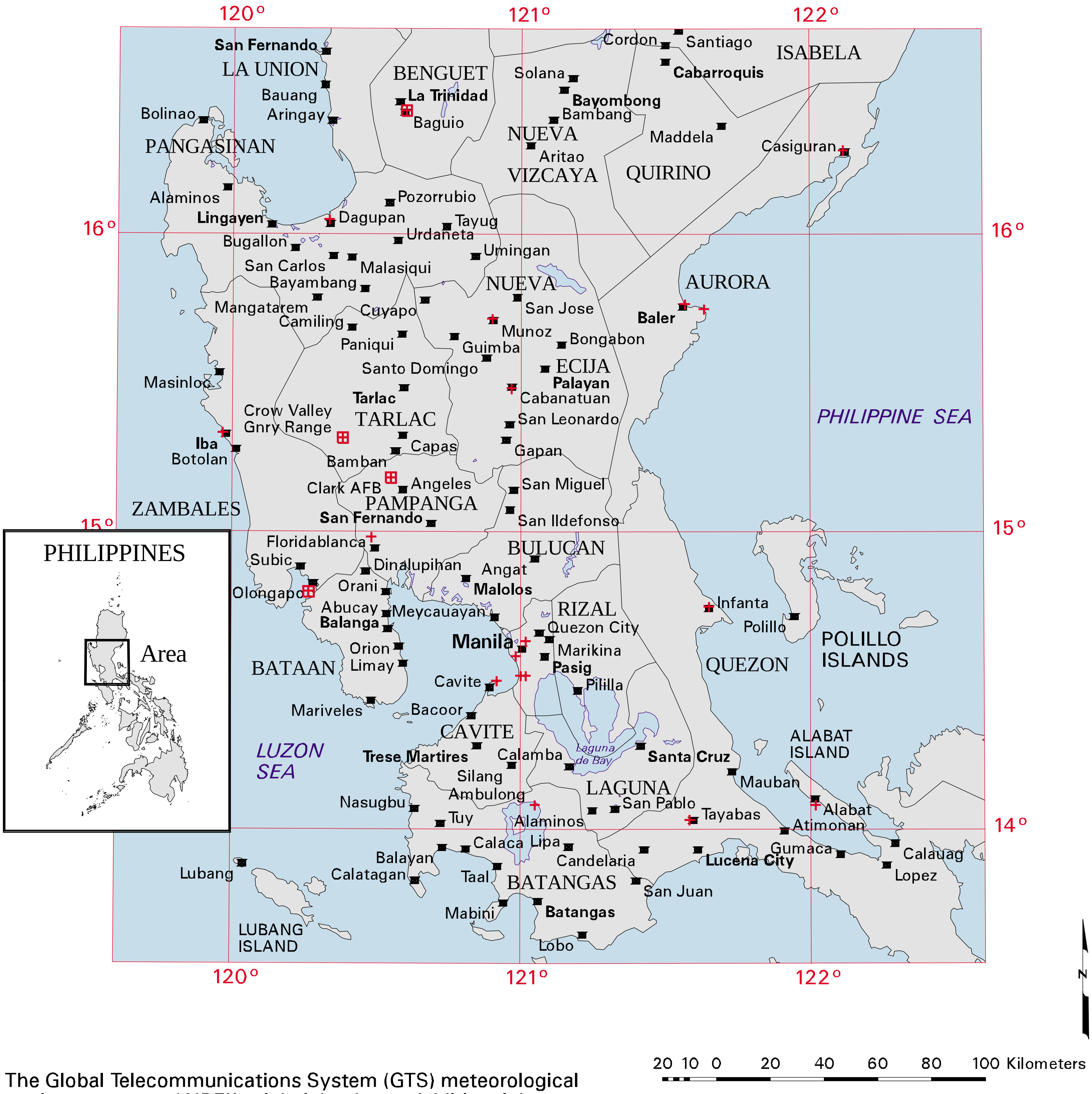
Figure 6-7

Philippines - Central Luzon
Political Base Map



The Global Telecommunications System (GTS) meteorological stations are part of NREL's global database. Additional data for many of the meteorological stations were provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The data for the wind monitoring sites were provided by the Philippine National Power Corporation (NPC).

Legend

- + GTS Surface Meteorological Station with Wind Data
- ☐ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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Figure 6-8

Philippines - Central Luzon
Elevation Map

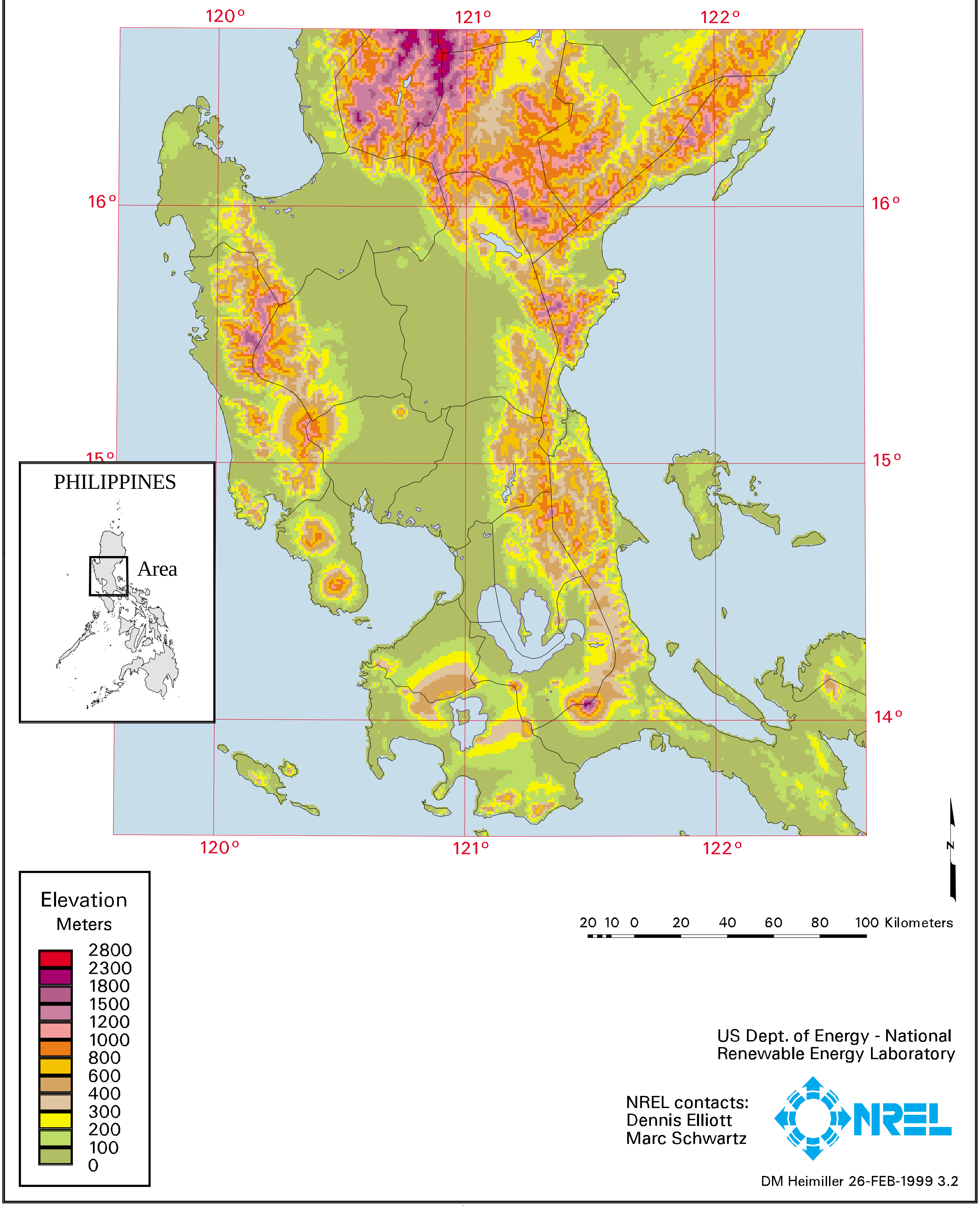
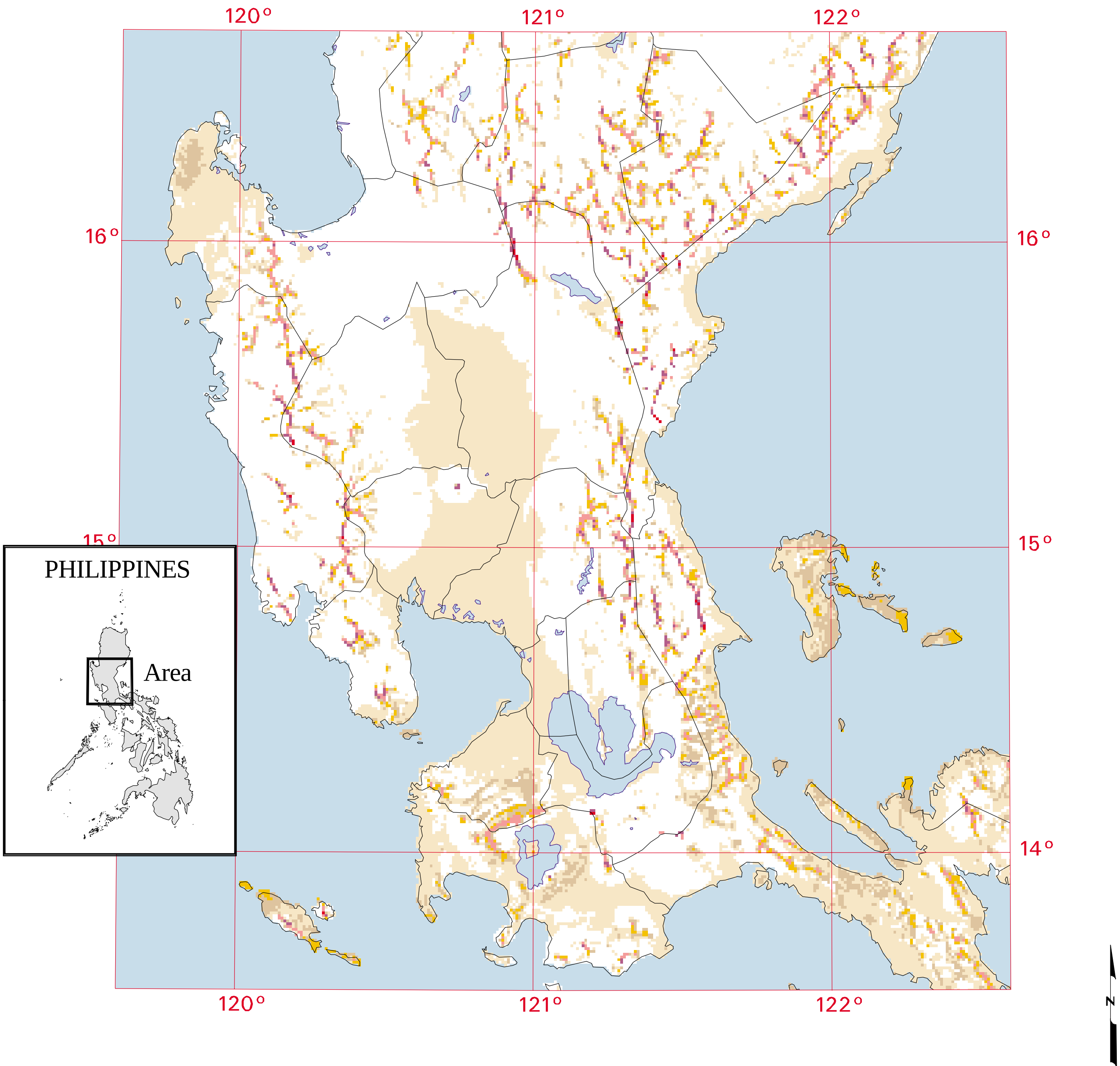


Figure 6-9

Philippines - Central Luzon
Most Favorable Wind Resource Areas



20 10 0 20 40 60 80 100 Kilometers

Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m2	Wind Speed [a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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Marc Schwartz

NREL

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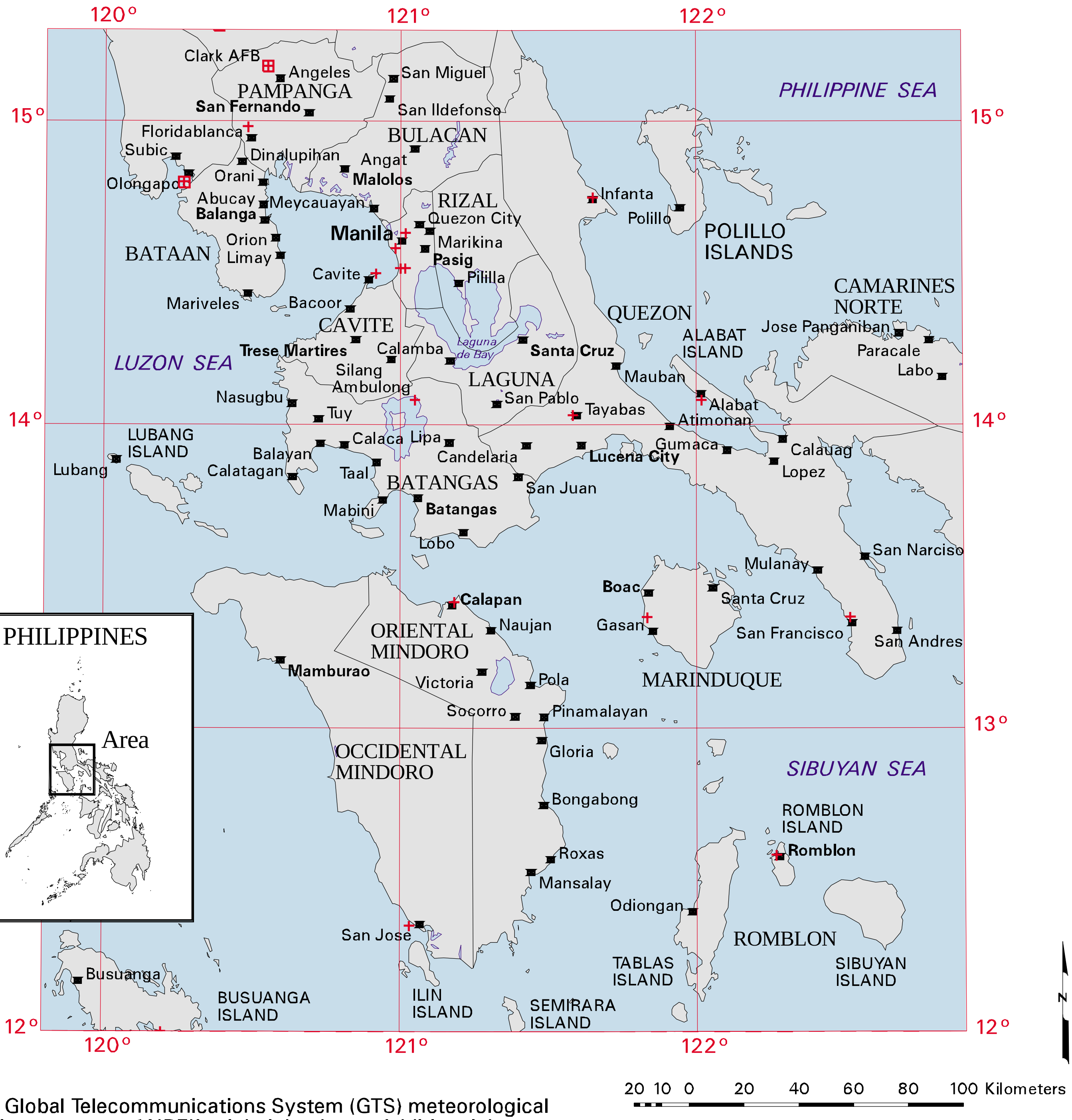
Figure 6-10

Philippines - Southern Luzon, Mindoro, Romblon and Marinduque - Political Base Map



The Global Telecommunications System (GTS) meteorological stations are part of NREL's global database. Additional data for many of the meteorological stations were provided by the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA). The data for the wind monitoring sites were provided by the Philippine National Power Corporation (NPC).

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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ▪ City or **Provincial Capital**

NREL contacts:
Dennis Elliott
Marc Schwartz

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Figure 6-11

Philippines - Southern Luzon, Mindoro, Romblon and Marinduque - Elevation Map

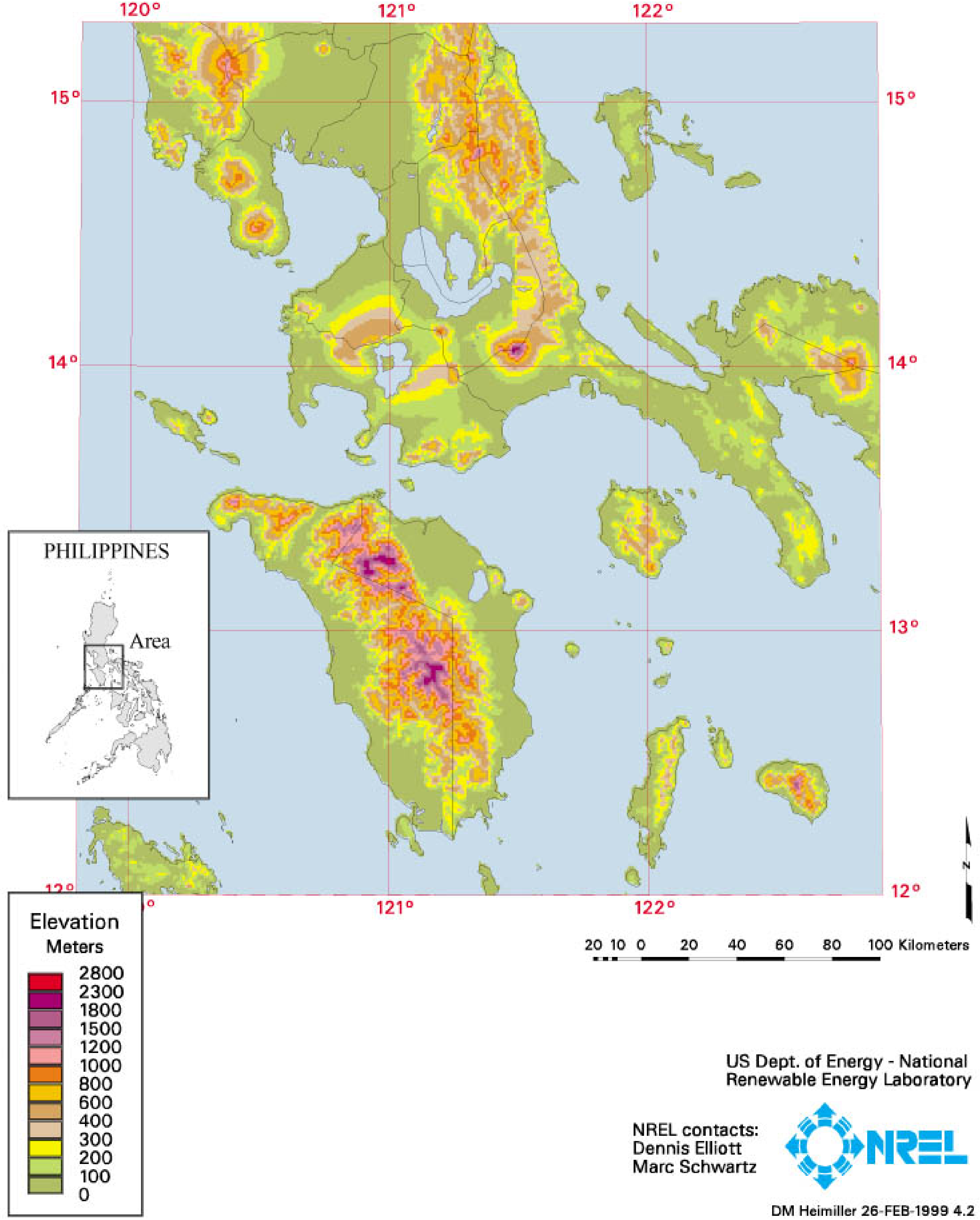
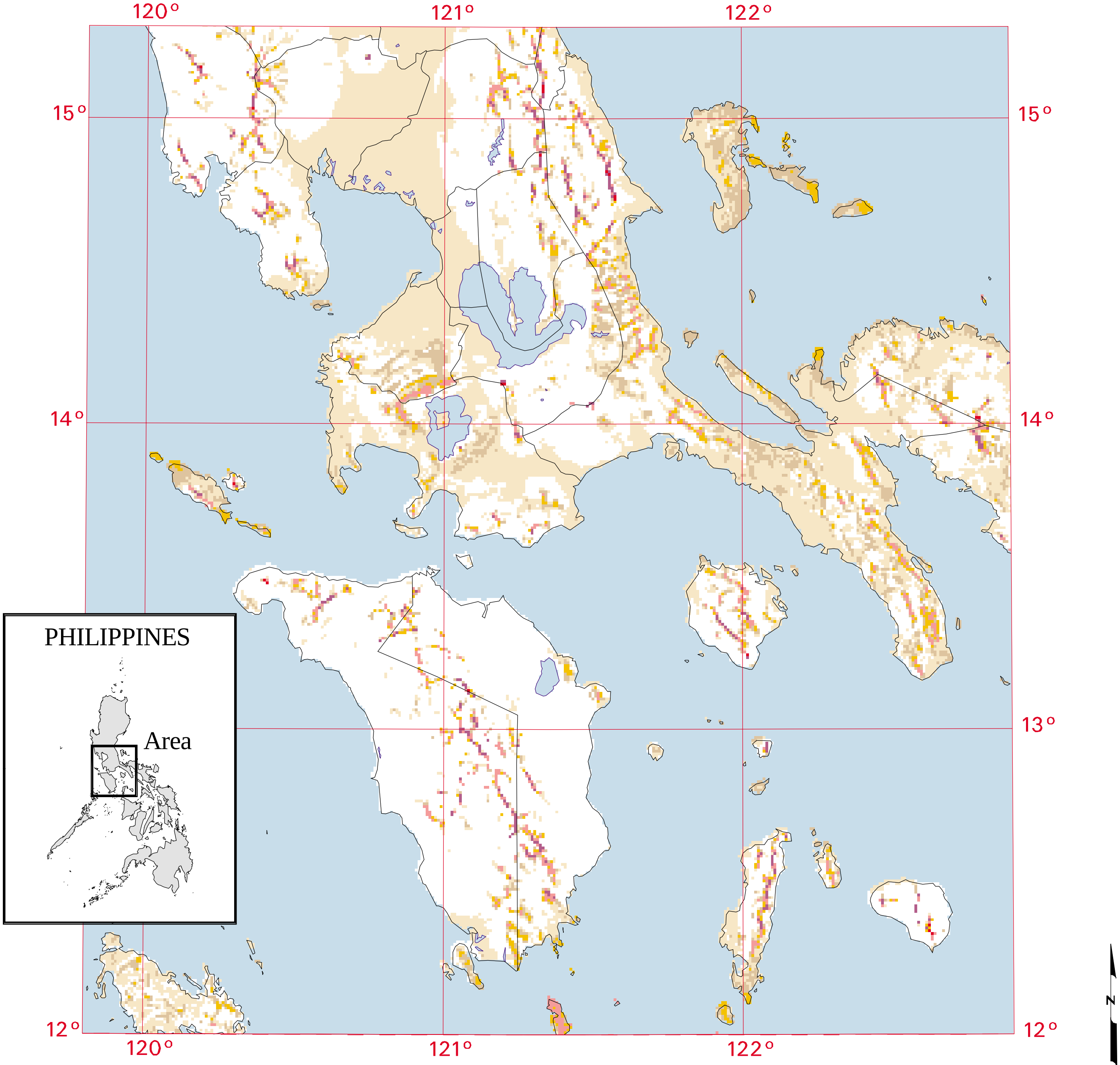


Figure 6-12

Philippines - Southern Luzon, Mindoro, Romblon and Marinduque - Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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Figure 6-13

Philippines - Southeastern Luzon, Catanduanes and Masbate Political Base Map

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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

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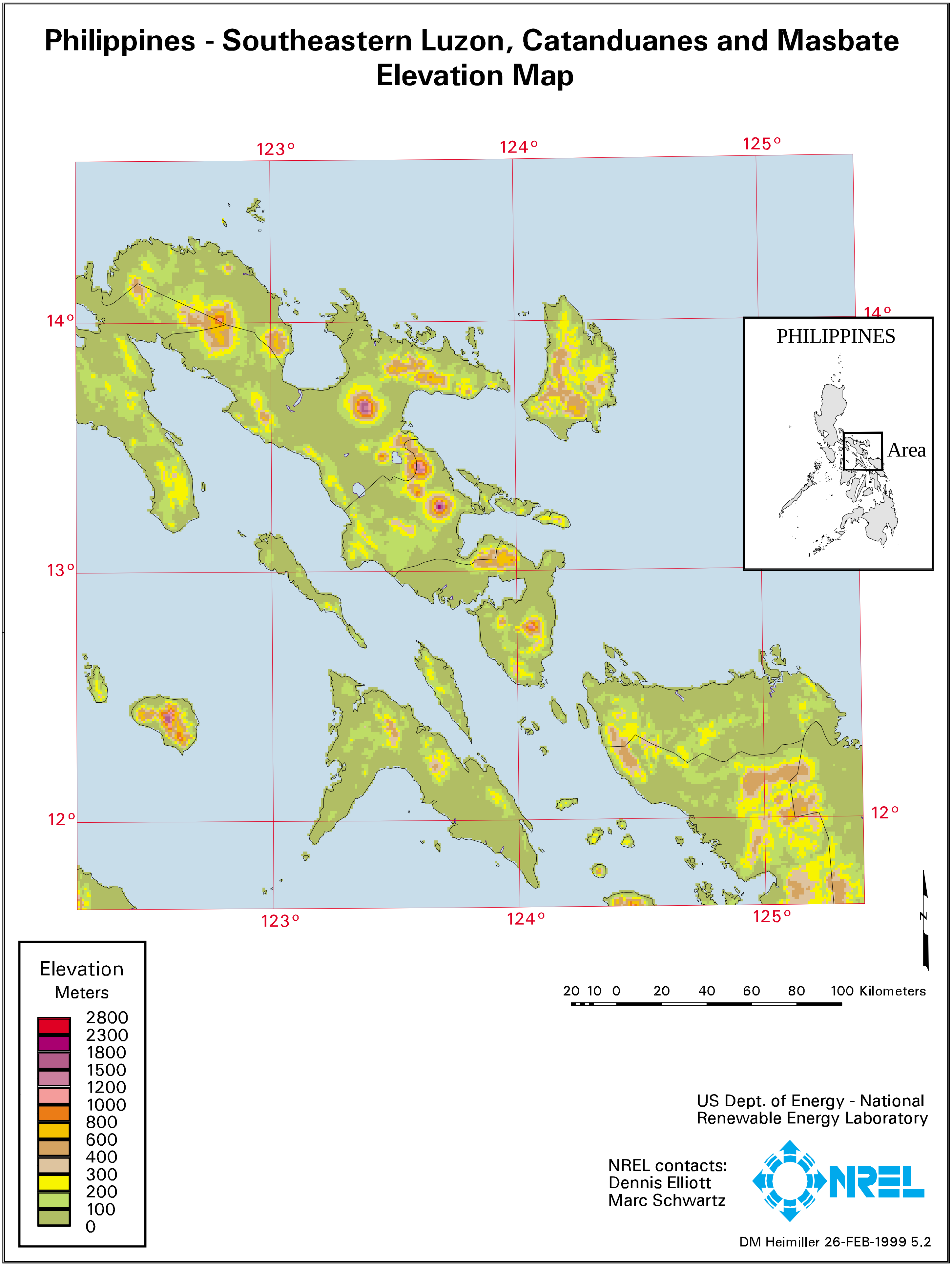
Figure 6-14


Philippines - Southeastern Luzon, Catanduanes and Masbate
Elevation Map
123°
124°
125°
14°
13°
12°
PHILIPPINES
Area
Elevation
Meters
2800
2300
1800
1500
1200
1000
800
600
400
300
200
100
0
20 10 0 20 40 60 80 100 Kilometers
US Dept. of Energy - National Renewable Energy Laboratory
NREL contacts:
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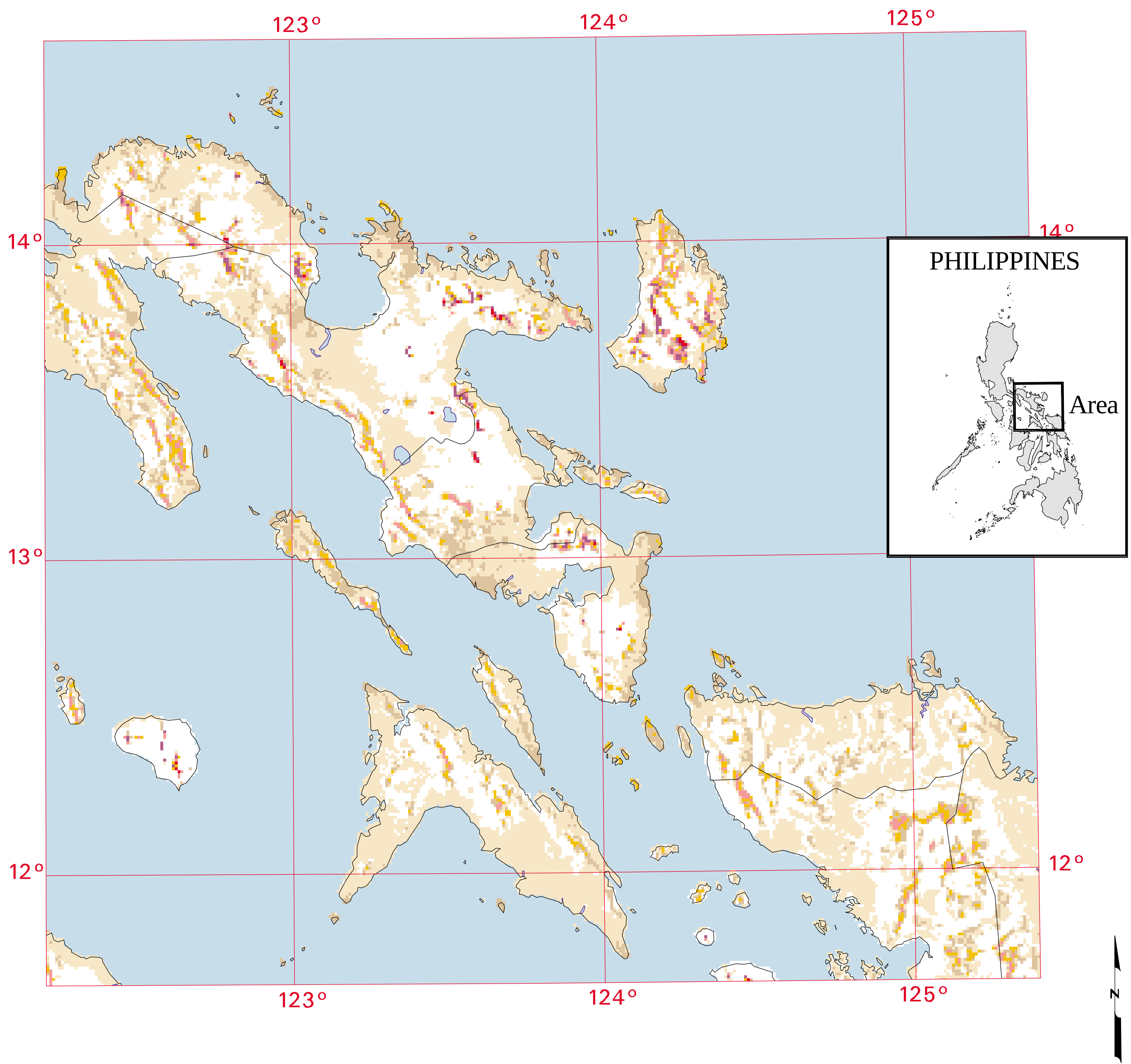
NREL
DM Heimiller 26-FEB-1999 5.2

Figure 6-15

Philippines - Southeastern Luzon, Catanduanes and Masbate
Most Favorable Wind Resource Areas



20 10 0 20 40 60 80 100 Kilometers

Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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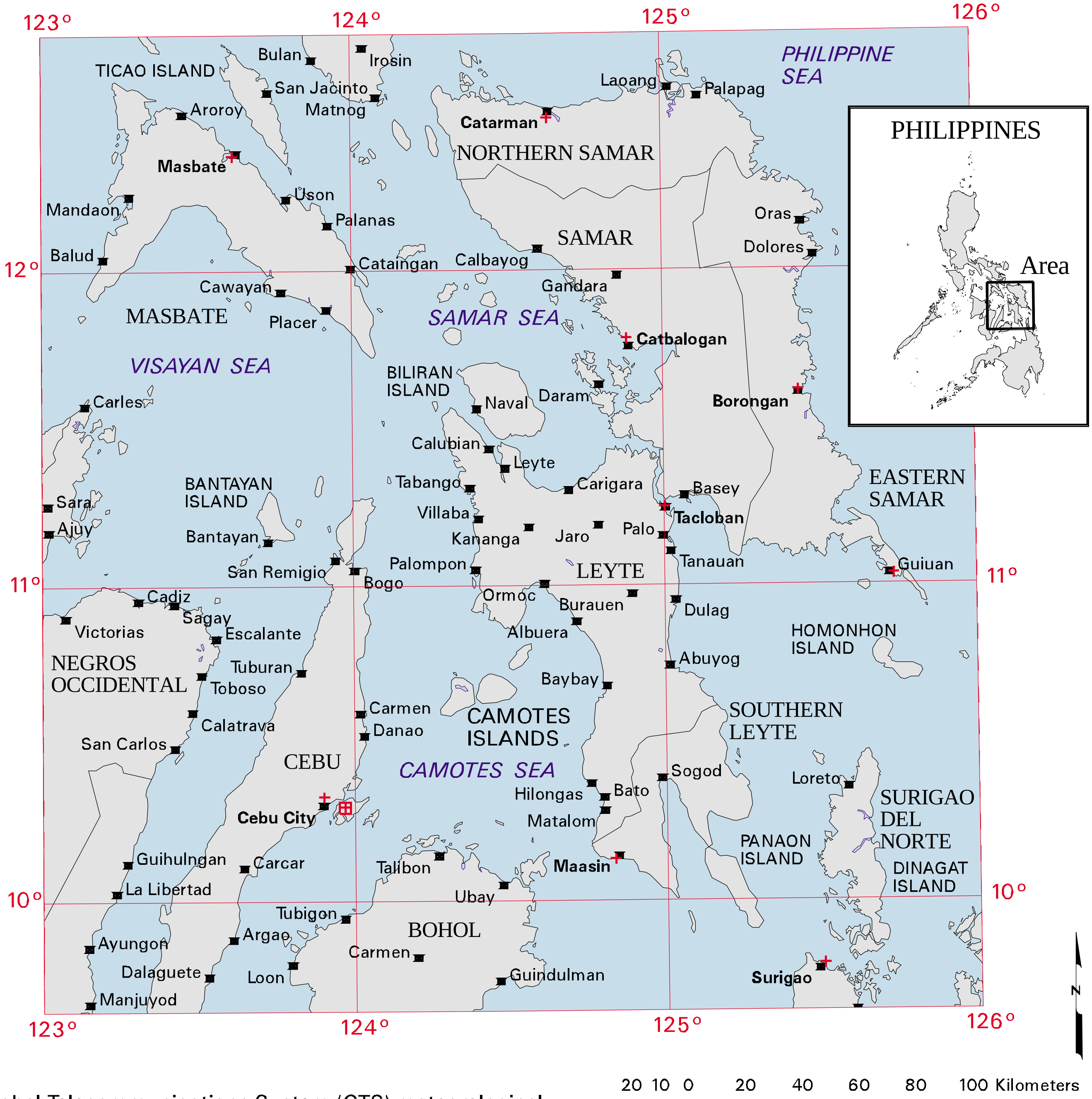
Figure 6-16

Philippines - Samar and Leyte
Political Base Map



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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

NREL

DM Heimiller 26-FEB-1999 6.2

Figure 6-17

Philippines - Samar and Leyte
Elevation Map

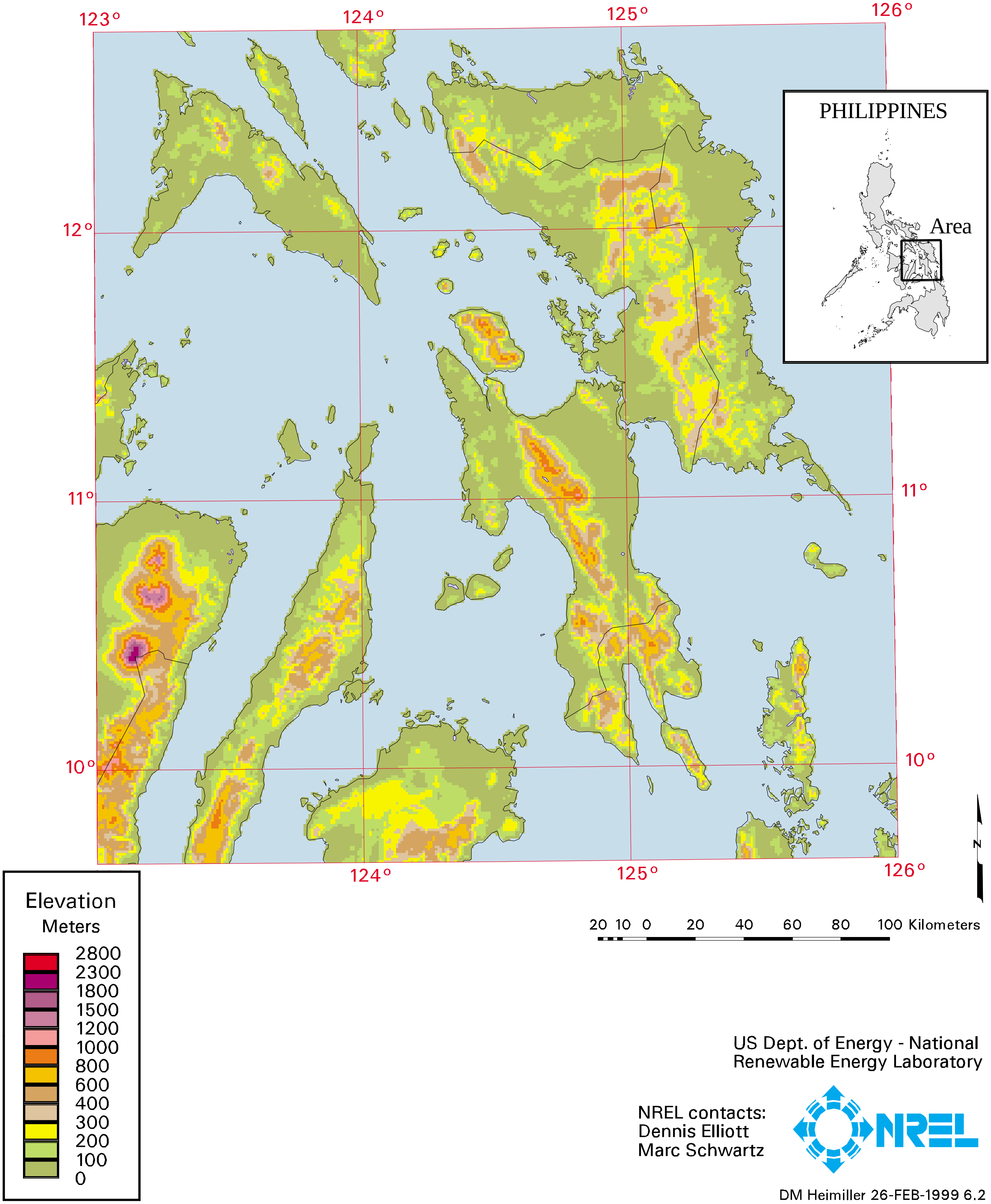
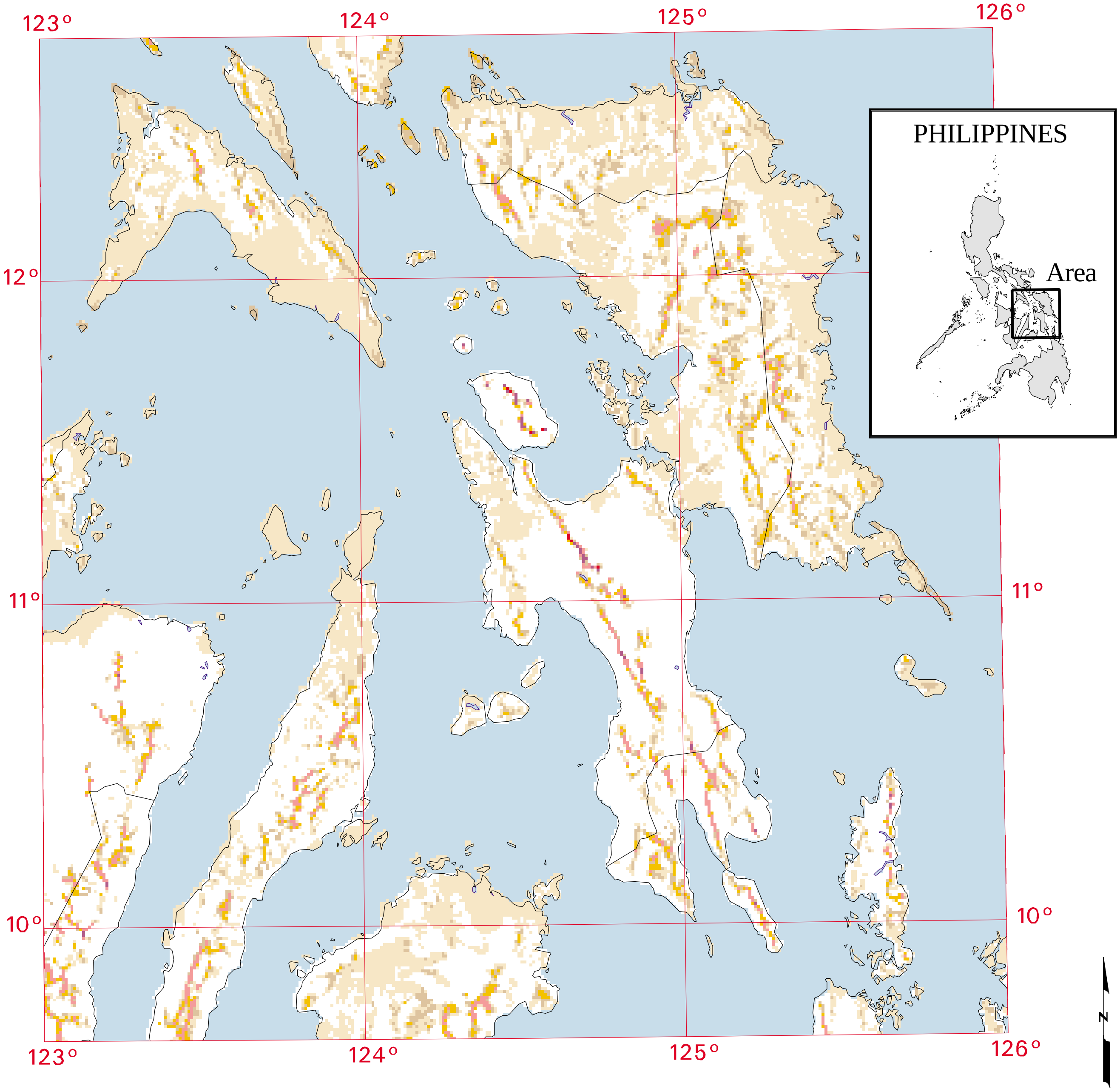


Figure 6-18

Philippines - Samar and Leyte
Most Favorable Wind Resource Areas



Wind Power Classification

	Resource Potential Utility	Rural	Wind Power Density at 30 m W/m²	Wind Speed[a] at 30 m m/s
(Marginal colour)	Marginal	Moderate	100 - 200	4.4 - 5.6
(Moderate colour)	Moderate	Good	200 - 300	5.6 - 6.4
(Good colour)	Good	Excellent	300 - 400	6.4 - 7.0
(Excellent colour)	Excellent		400 - 600	7.0 - 8.0
			600 - 800	8.0 - 8.8
			800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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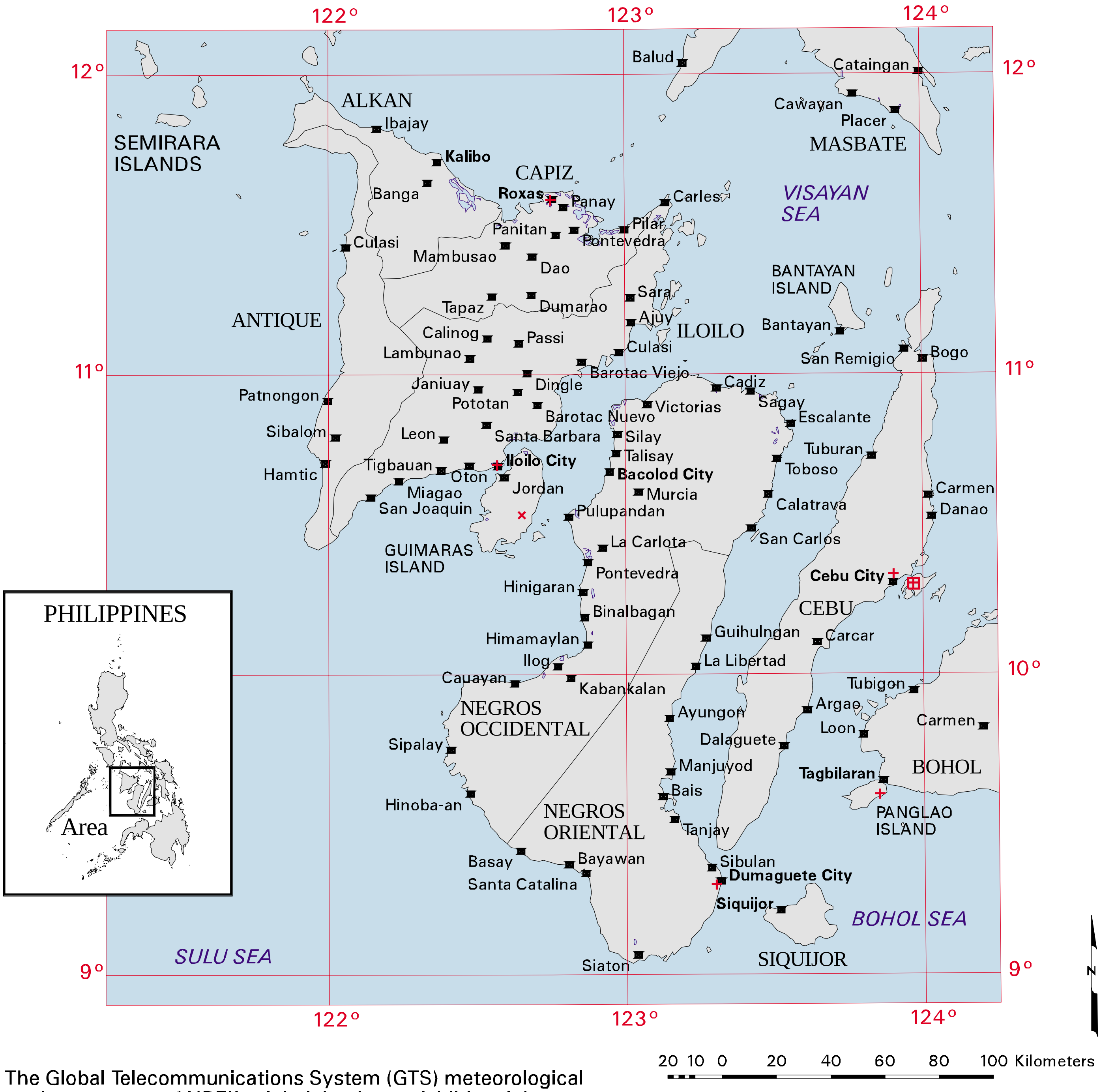
Figure 6-19

Philippines - Panay, Negros, Cebu and Siquijor
Political Base Map



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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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Marc Schwartz

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Figure 6-20

Philippines - Panay, Negros, Cebu and Siquijor
Elevation Map

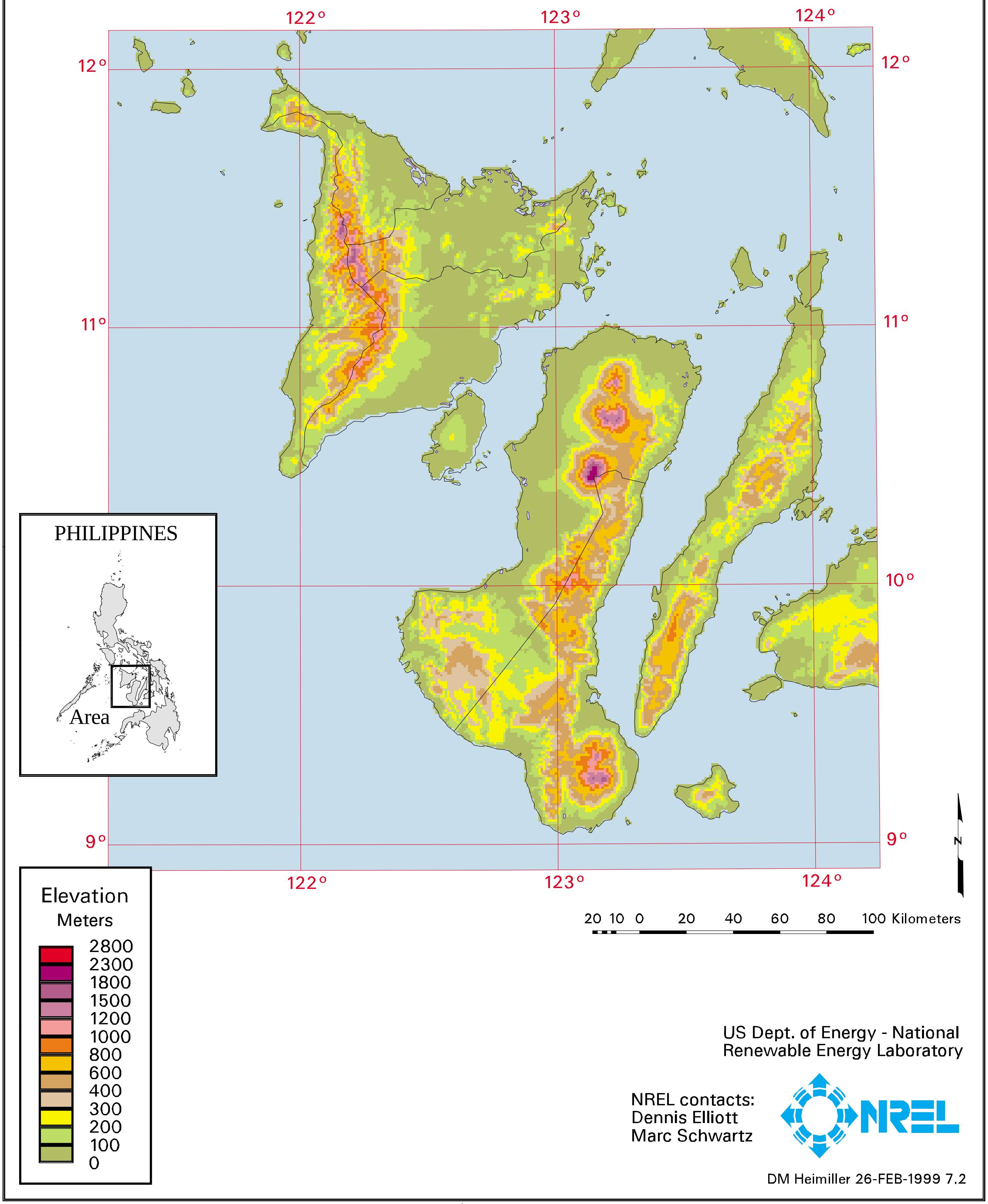
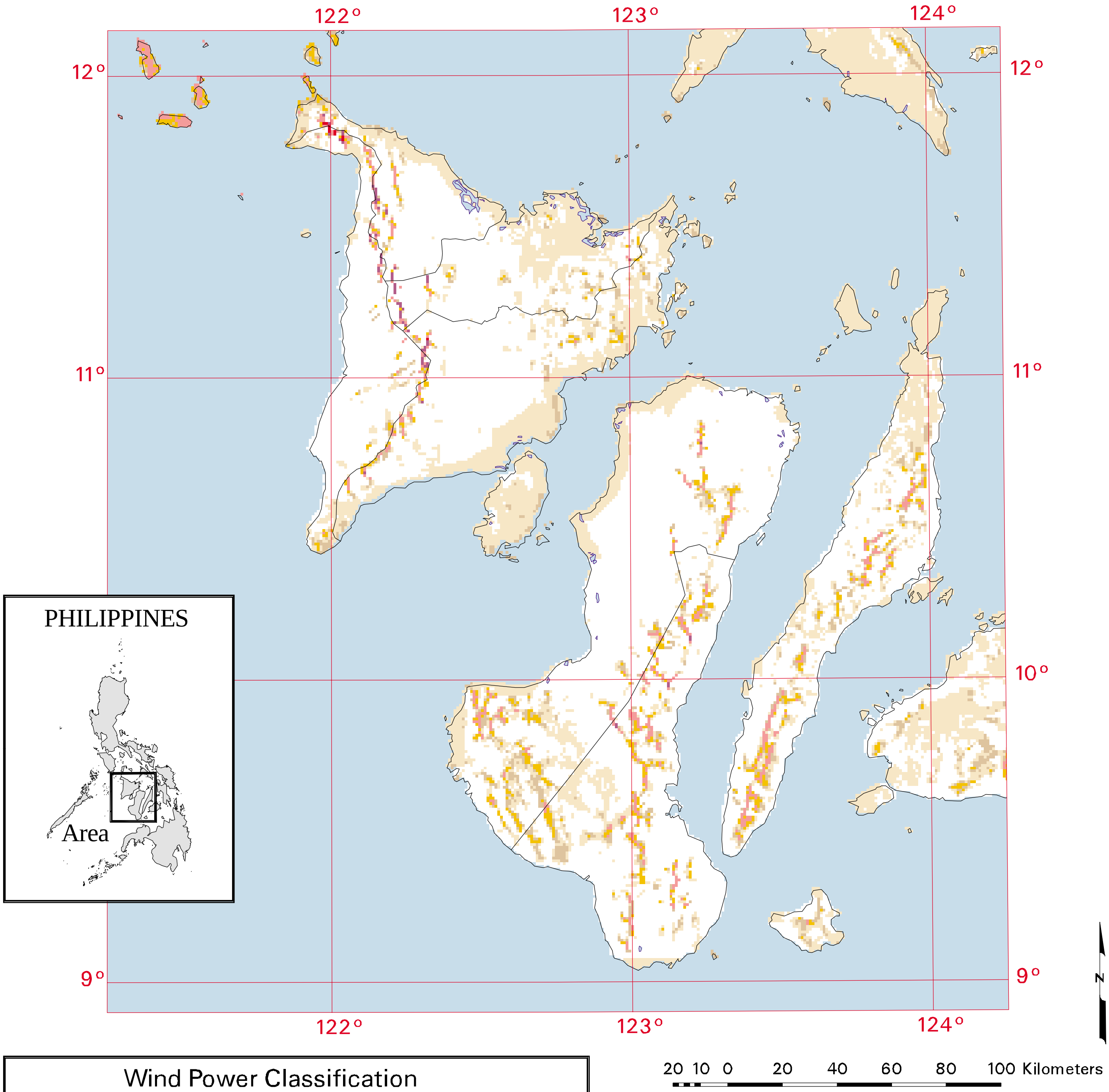


Figure 6-21

Philippines - Panay, Negros, Cebu and Siquijor
Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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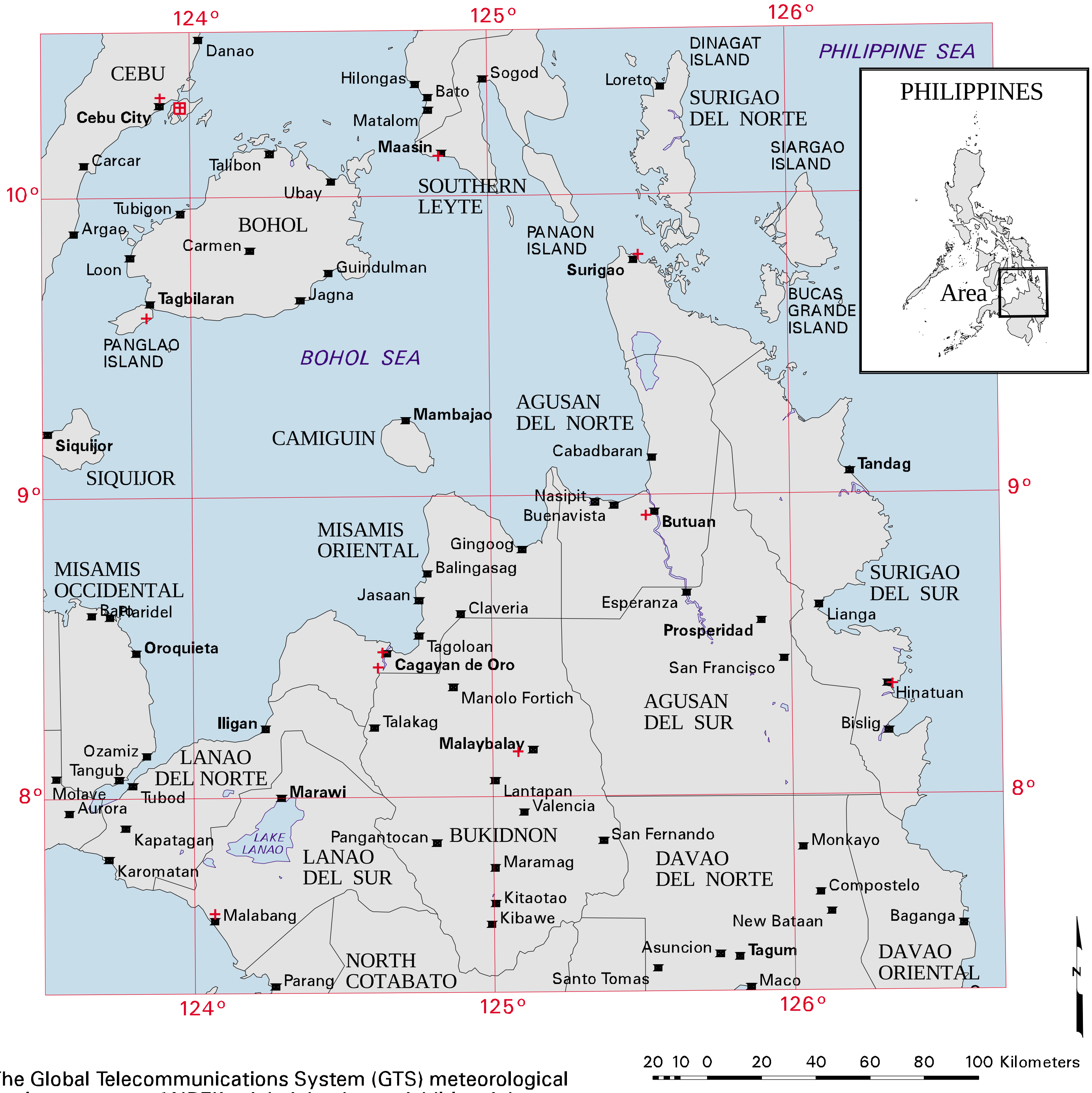
Figure 6-22

Philippines - Northern Mindanao and Bohol Political Base Map



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Legend

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- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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NREL contacts:
Dennis Elliott
Marc Schwartz

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Figure 6-23

Philippines - Northern Mindanao and Bohol
Elevation Map

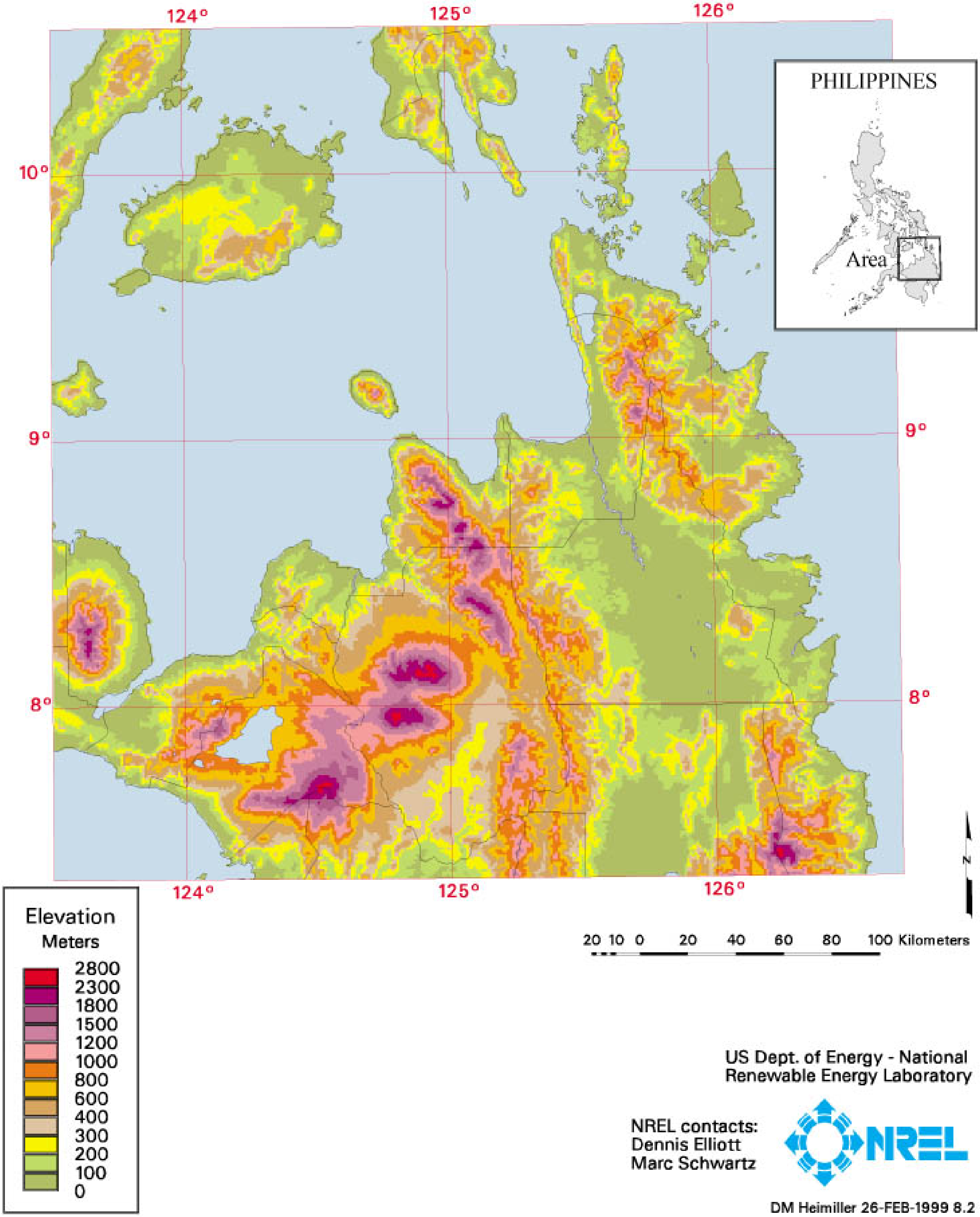
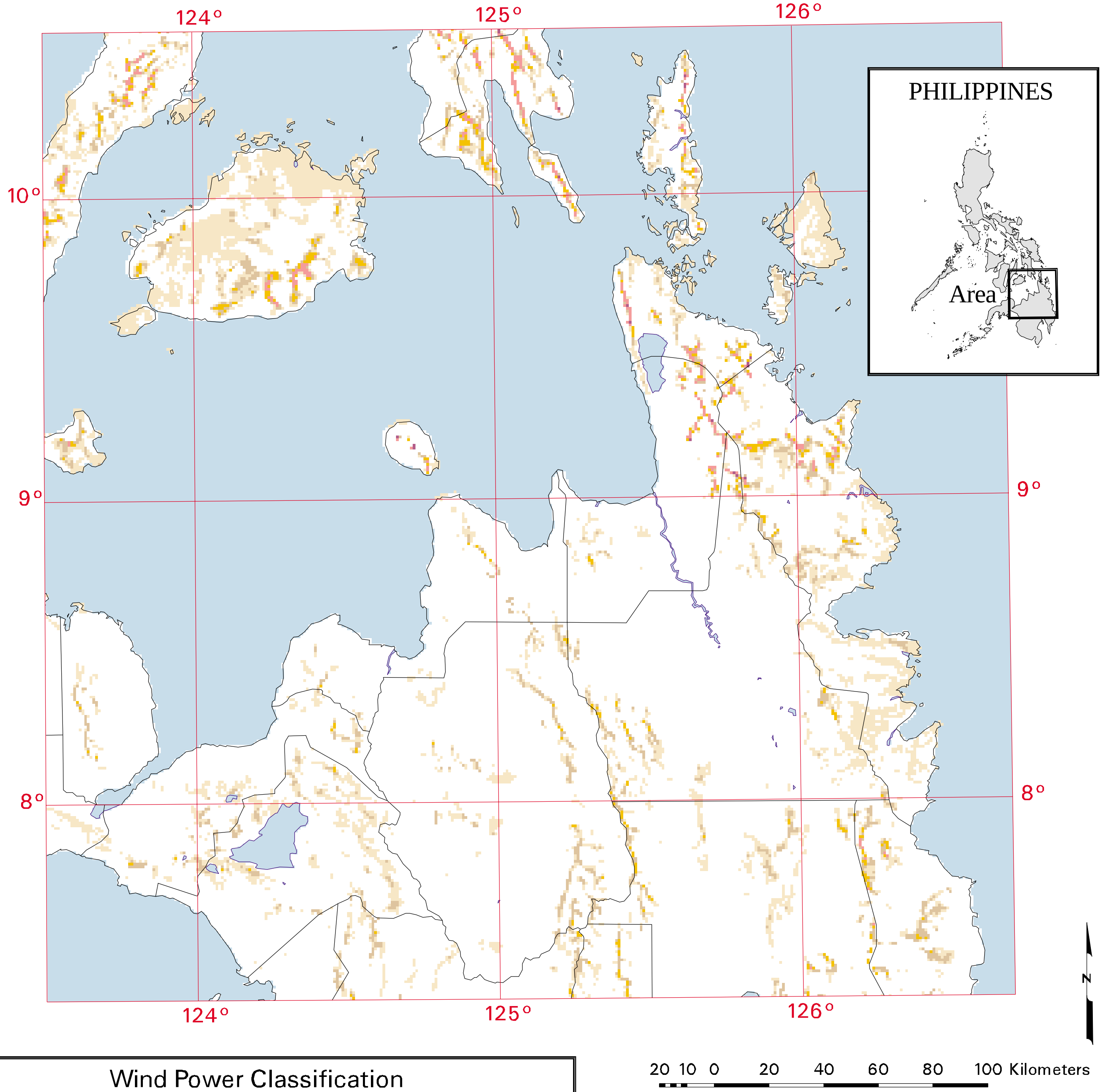


Figure 6-24

Philippines - Northern Mindanao and Bohol
Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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NREL contacts:
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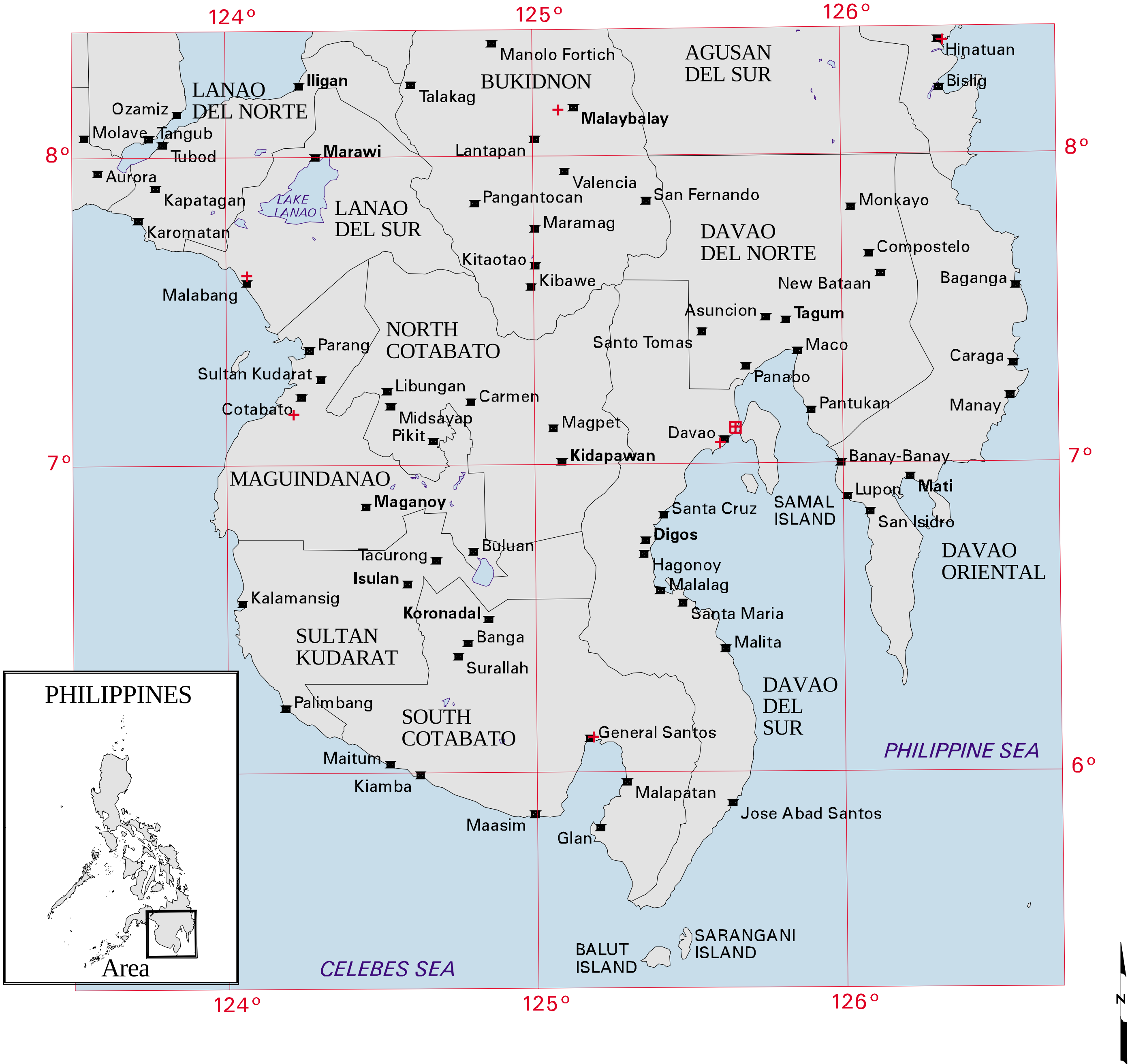
Figure 6-25

Philippines - Southern Mindanao
Political Base Map



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- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ▪ City or **Provincial Capital**

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NREL contacts:
Dennis Elliott
Marc Schwartz

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Figure 6-26

Philippines - Southern Mindanao
Elevation Map

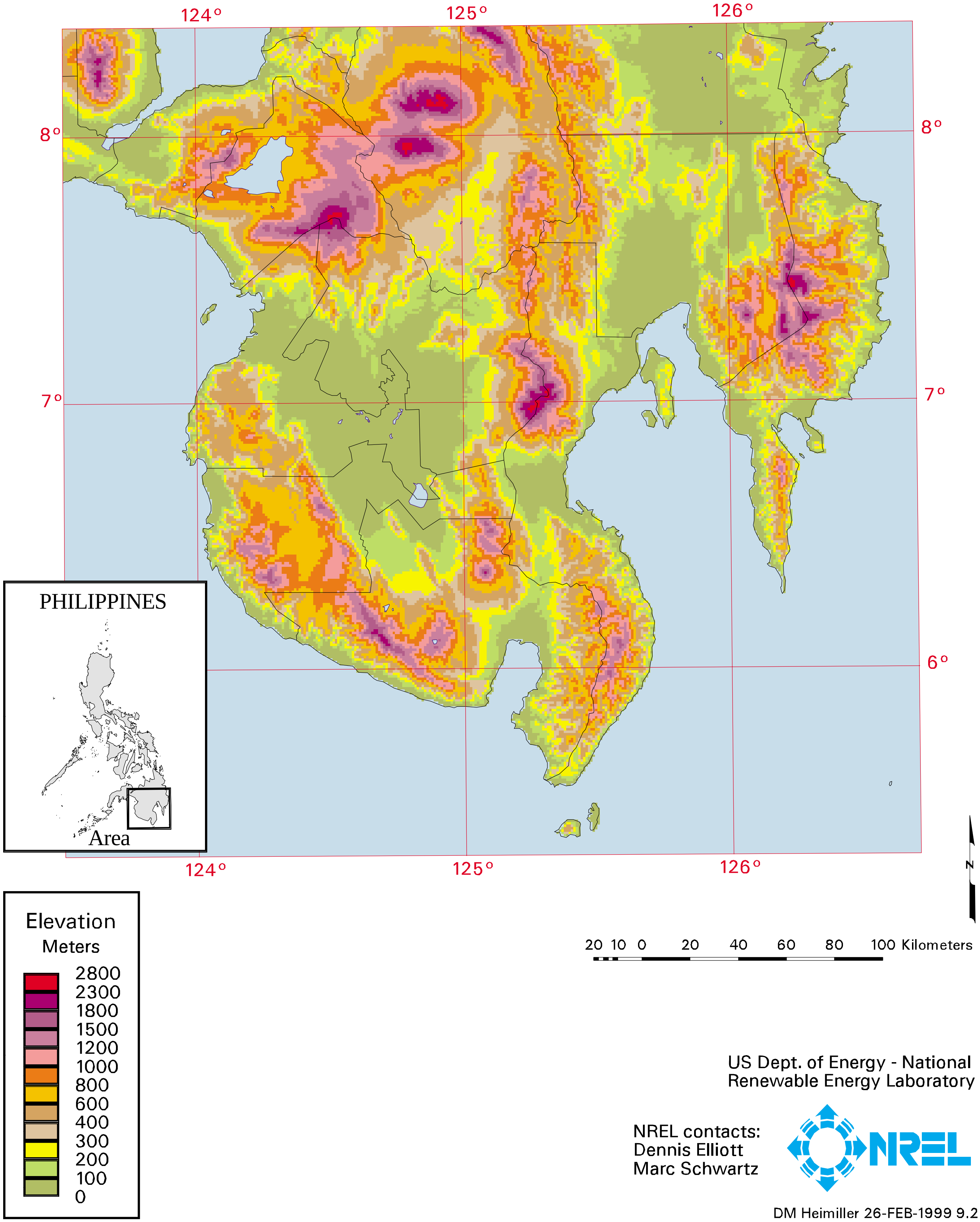
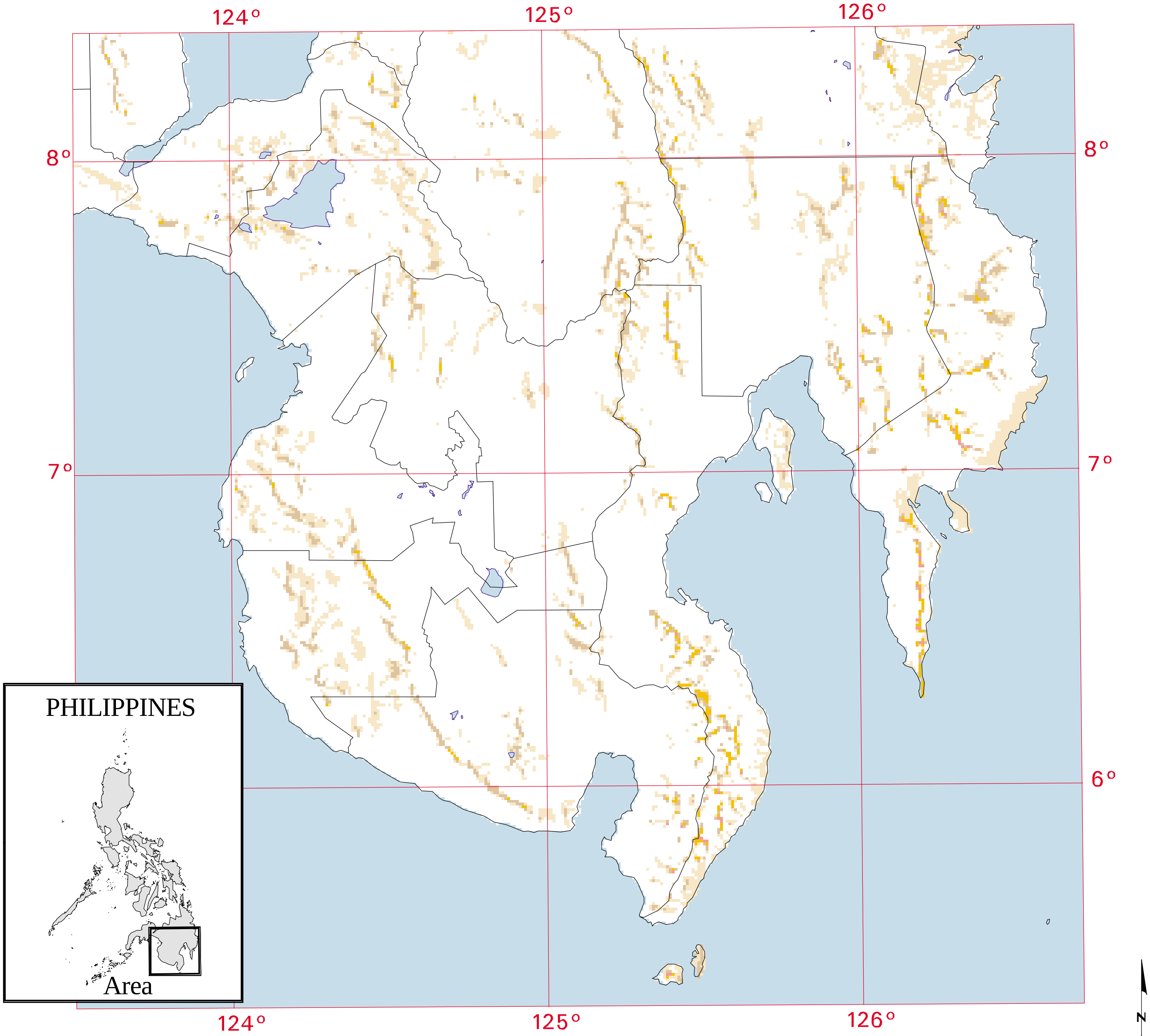


Figure 6-27

Philippines - Southern Mindanao
Most Favorable Wind Resource Areas



Wind Power Classification

	Resource Potential Utility	Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
	Marginal	Moderate	100 - 200	4.4 - 5.6
	Moderate	Good	200 - 300	5.6 - 6.4
	Good	Excellent	300 - 400	6.4 - 7.0
	Excellent		400 - 600	7.0 - 8.0
			600 - 800	8.0 - 8.8
			800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

20 10 0 20 40 60 80 100 Kilometers

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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NREL contacts:
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Marc Schwartz

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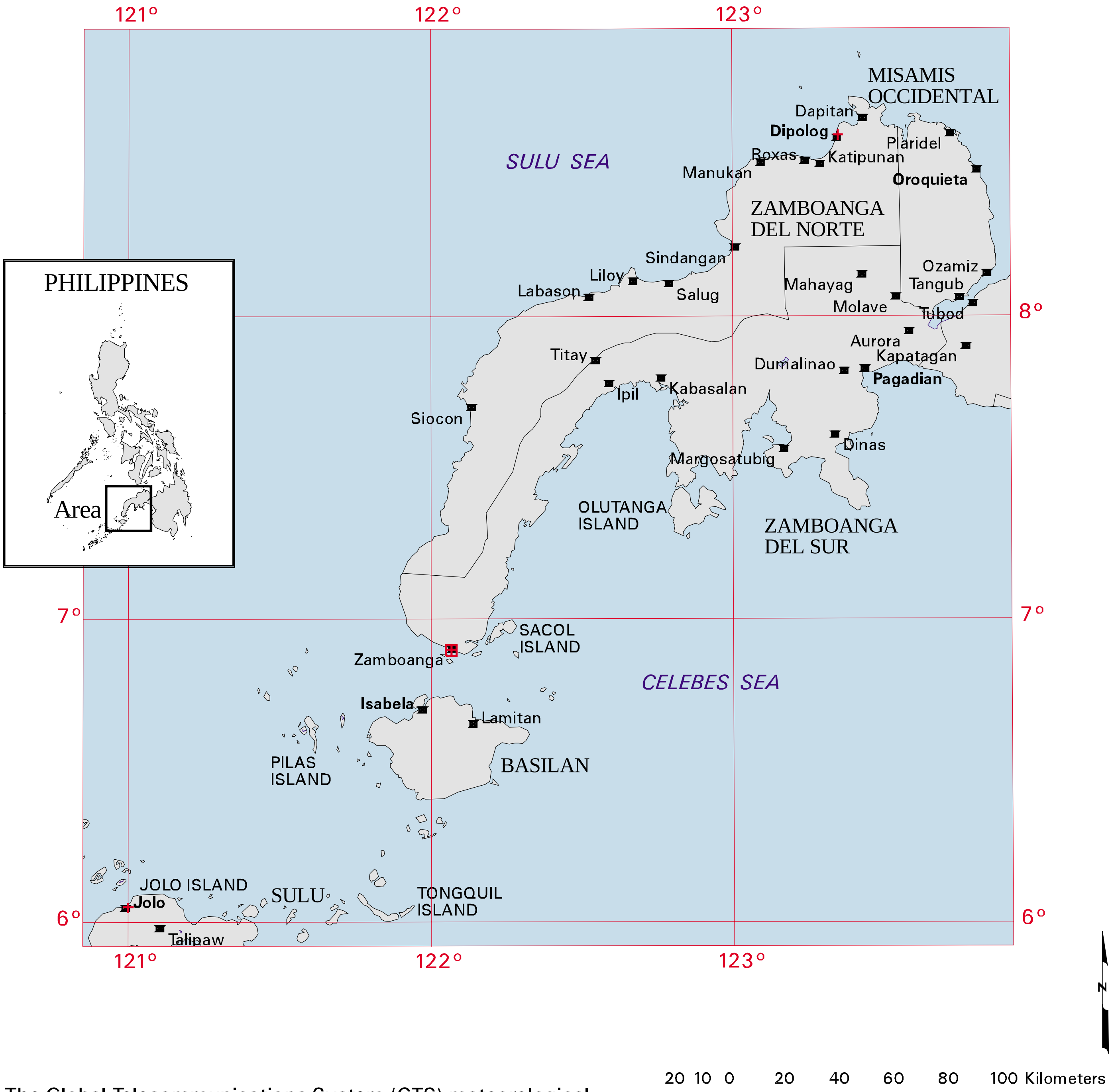
Figure 6-28

Philippines - Western Mindanao and Basilan
Political Base Map



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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ■ City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

NREL

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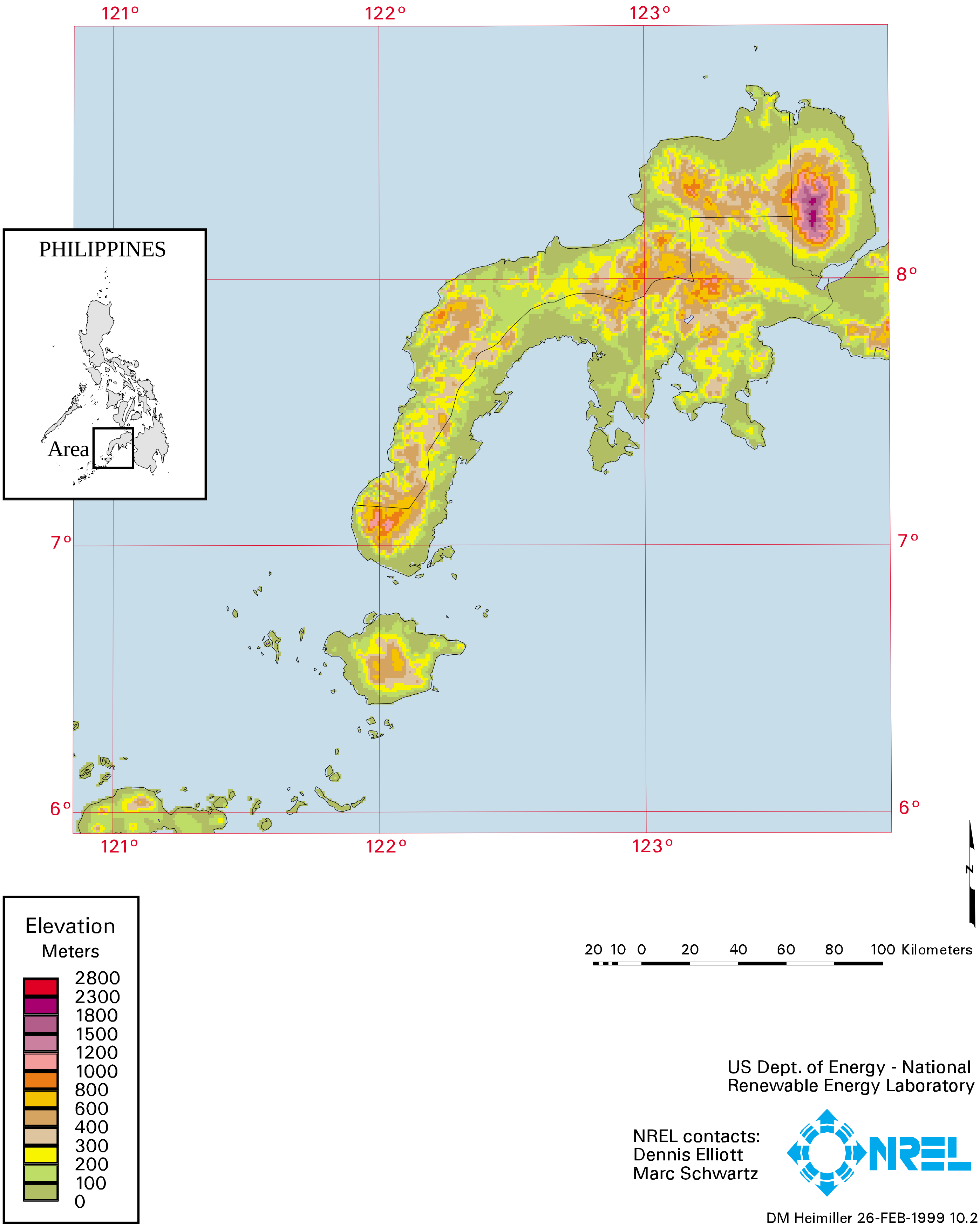
Figure 6-29

Philippines - Western Mindanao and Basilan
Elevation Map



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Marc Schwartz

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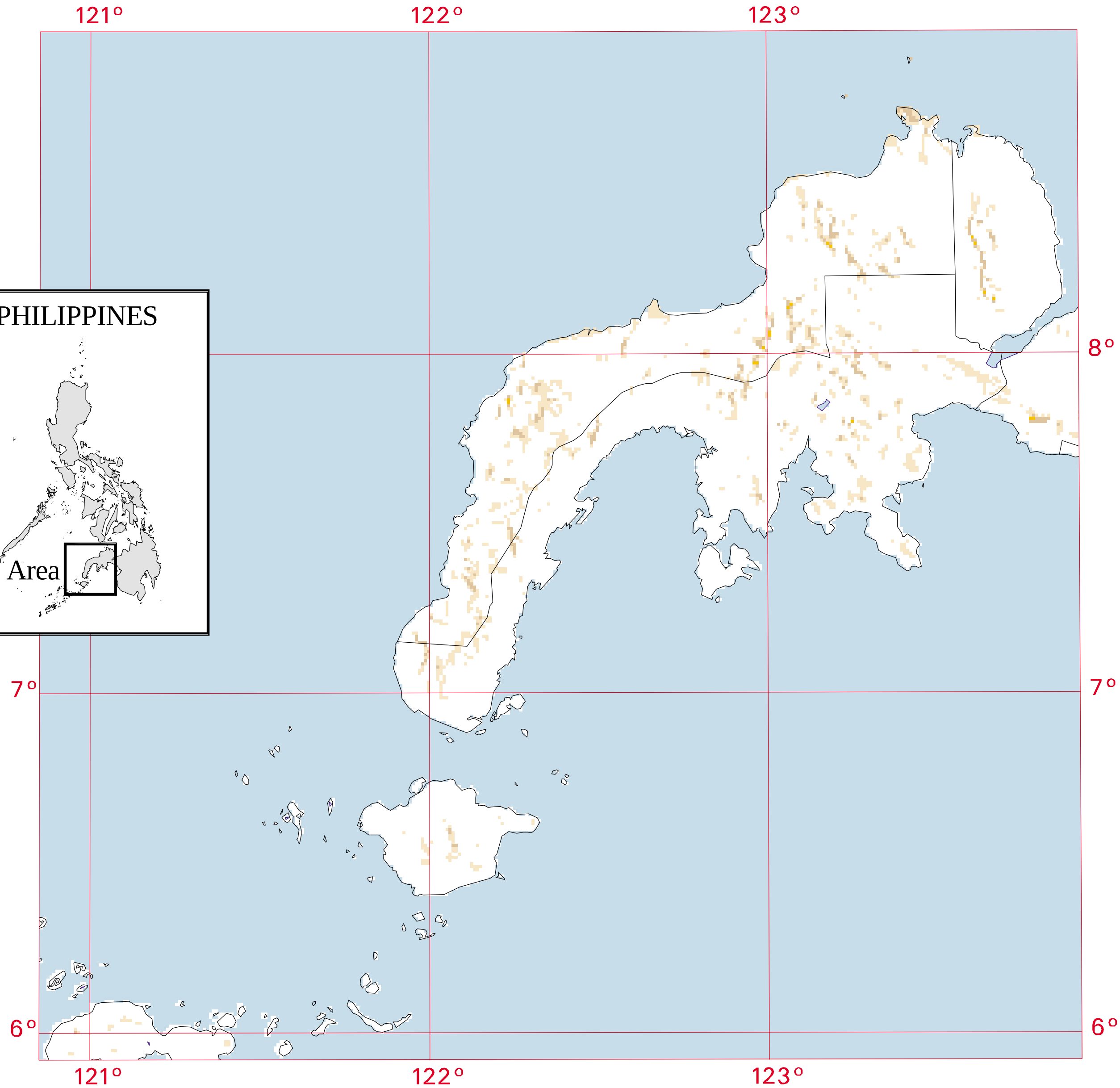
Figure 6-30

Philippines - Western Mindanao and Basilan
Most Favorable Wind Resource Areas



20 10 0 20 40 60 80 100 Kilometers

Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m2	Wind Speed [a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

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NREL contacts:
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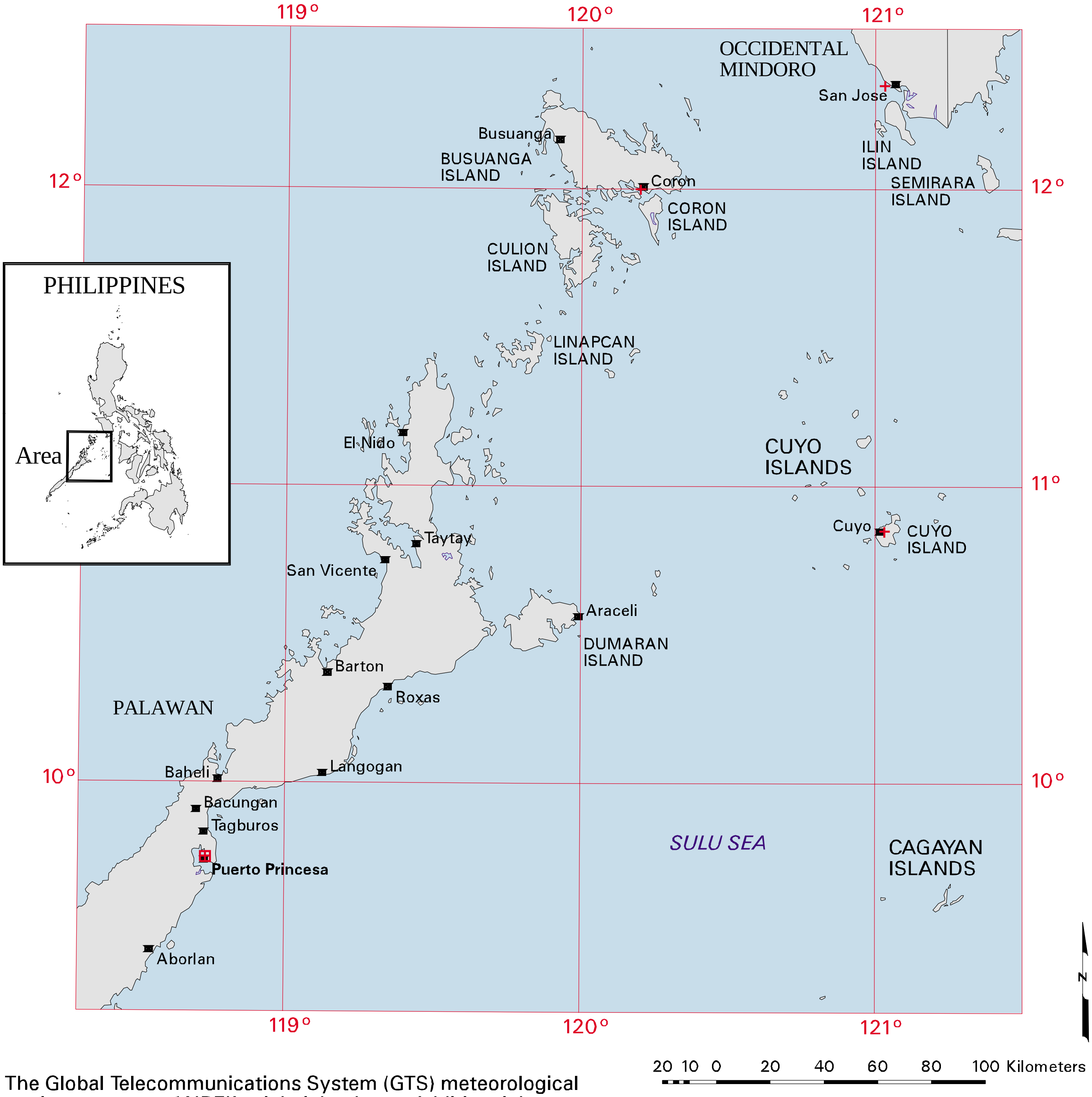
Figure 6-31

Philippines - Northern Palawan
Political Base Map



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Legend

- + GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- ▪ City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

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Figure 6-32

Philippines - Northern Palawan
Elevation Map

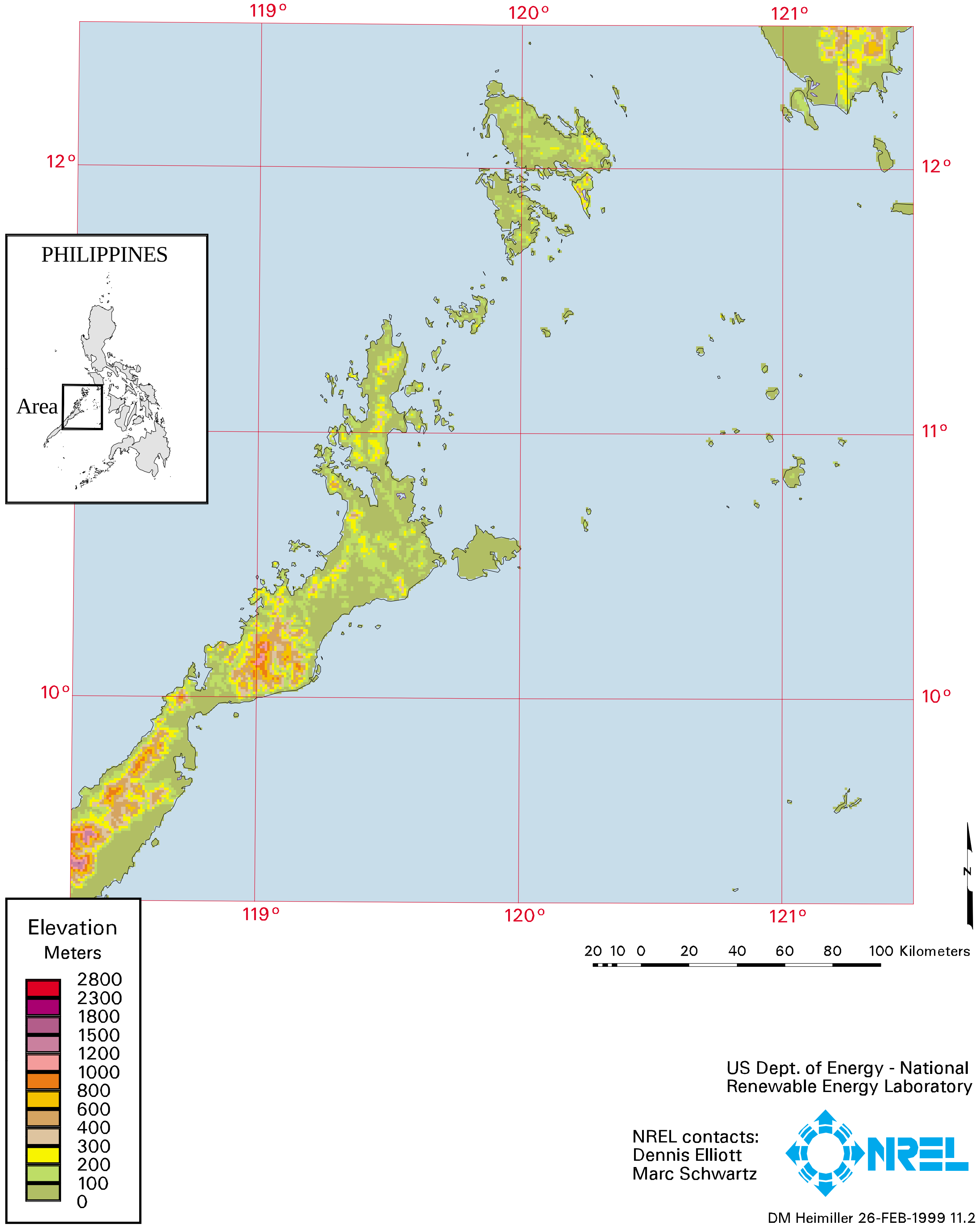
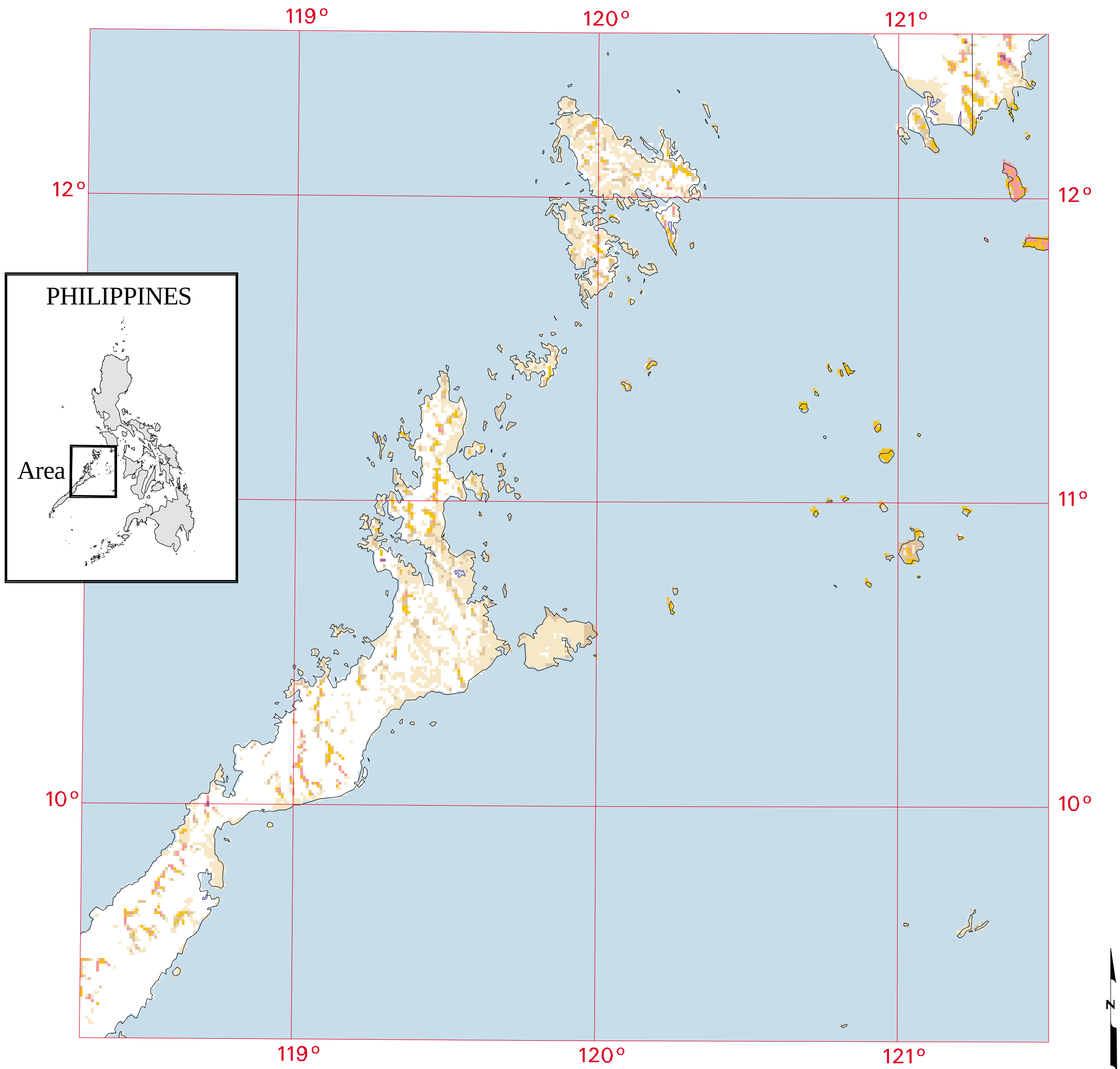


Figure 6-33

Philippines - Northern Palawan
Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

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NREL contacts:
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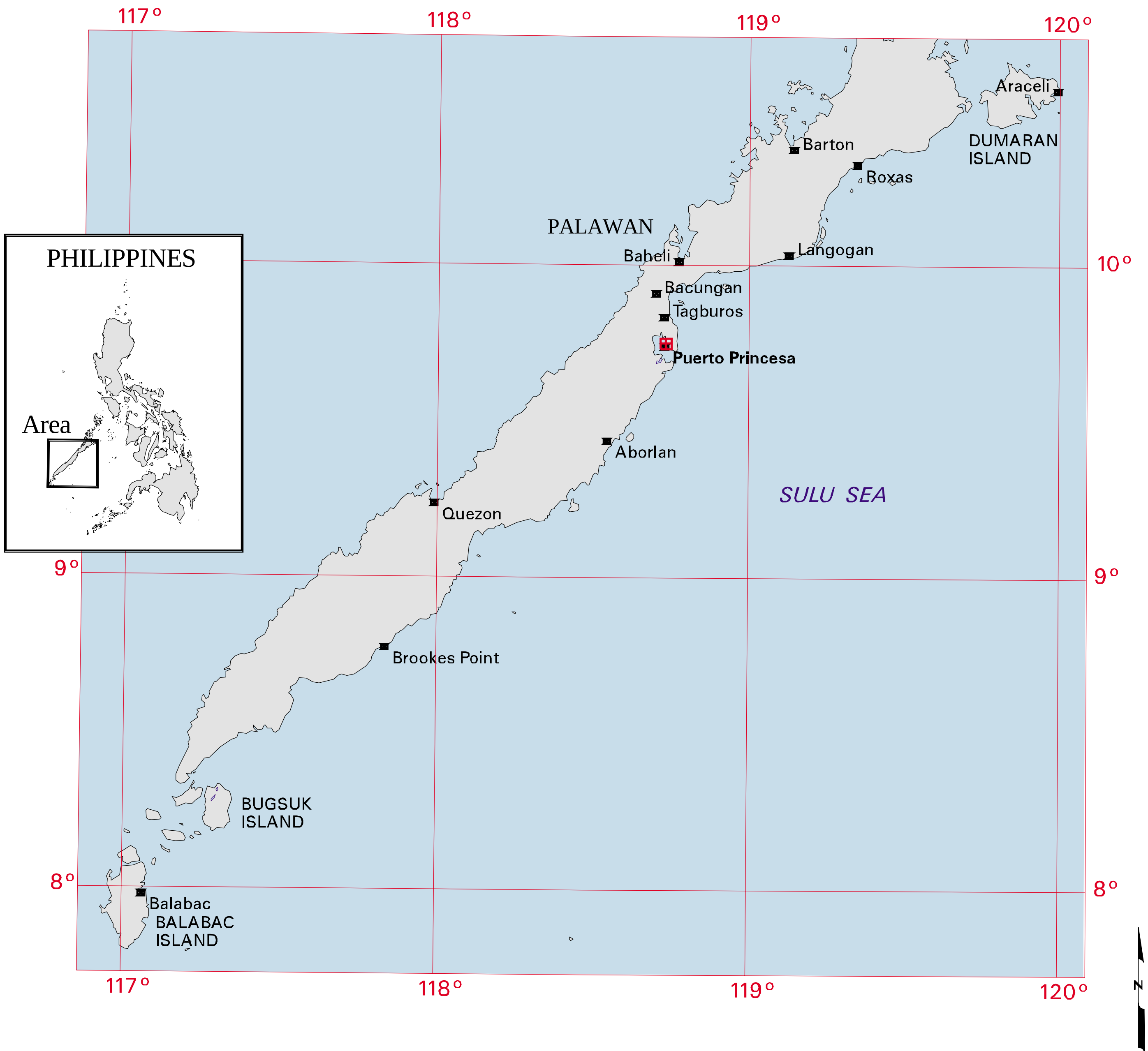
Marc Schwartz

SR Haymes 01-MAR-1999 11.2

Figure 6-34

Philippines - Southern Palawan
Political Base Map



20 10 0 20 40 60 80 100 Kilometers

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Legend

- \+ GTS Surface Meteorological Station with Wind Data
- ☐ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

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Figure 6-35

Philippines - Southern Palawan
Elevation Map

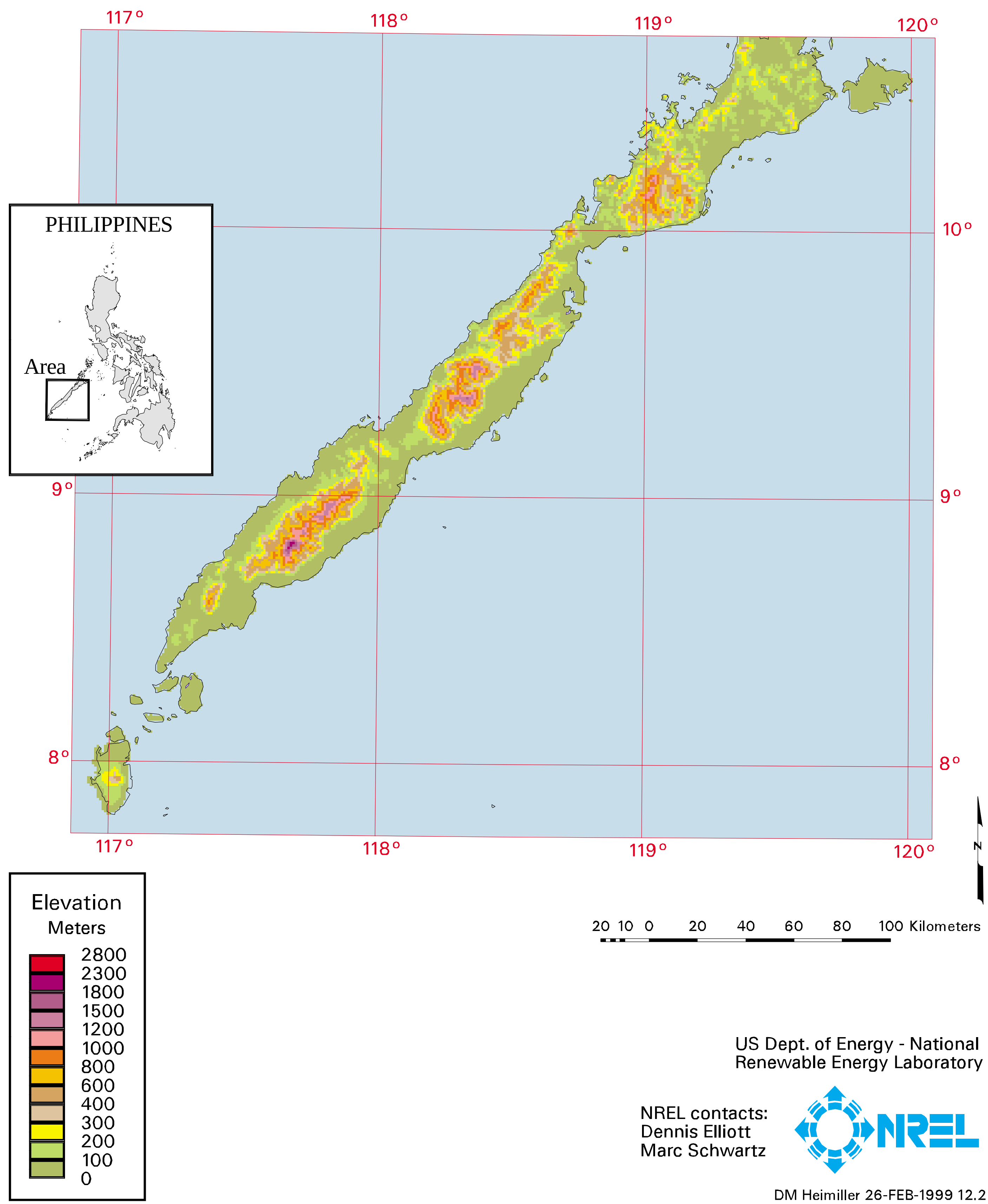
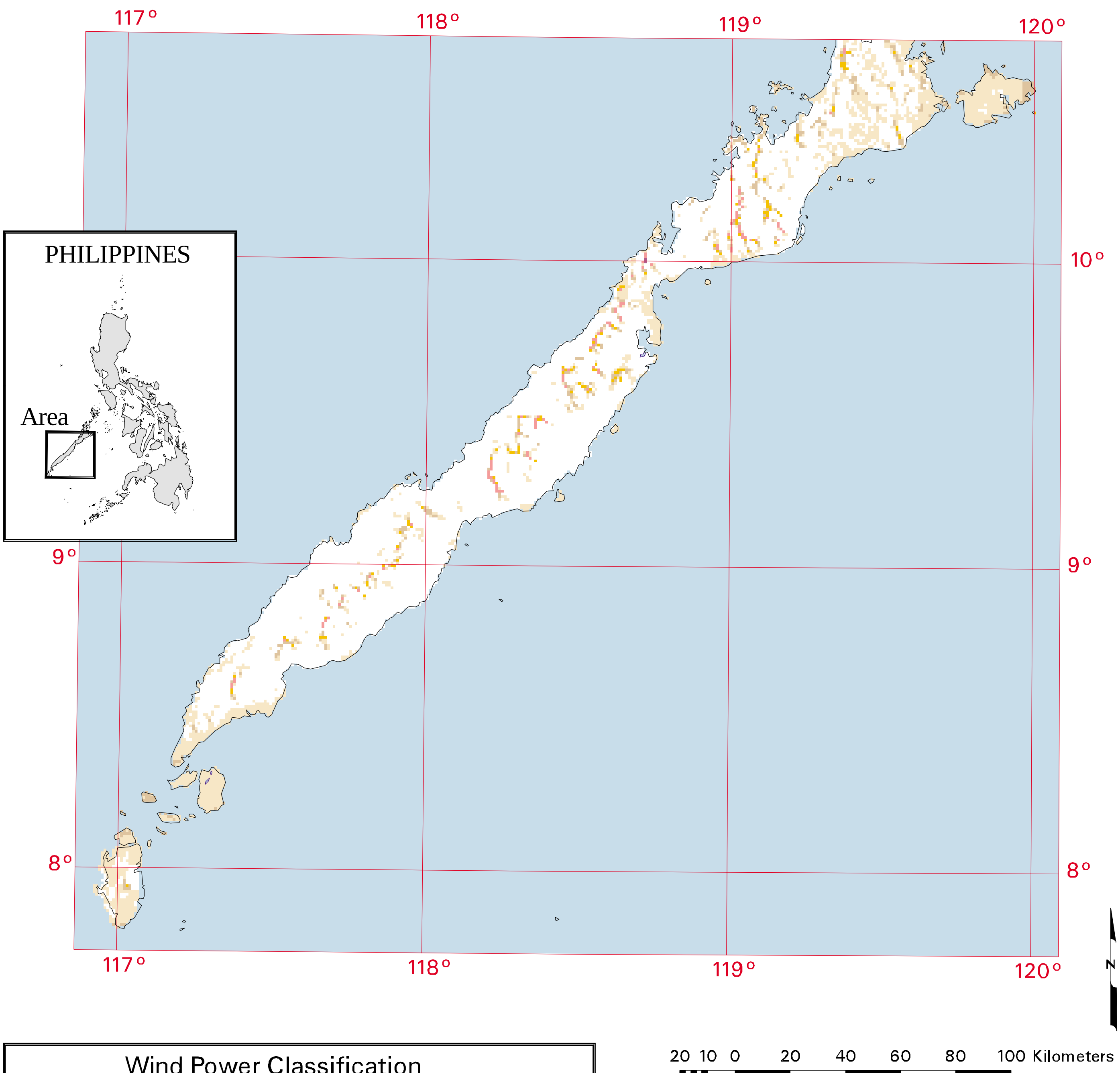


Figure 6-36

Philippines - Southern Palawan
Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

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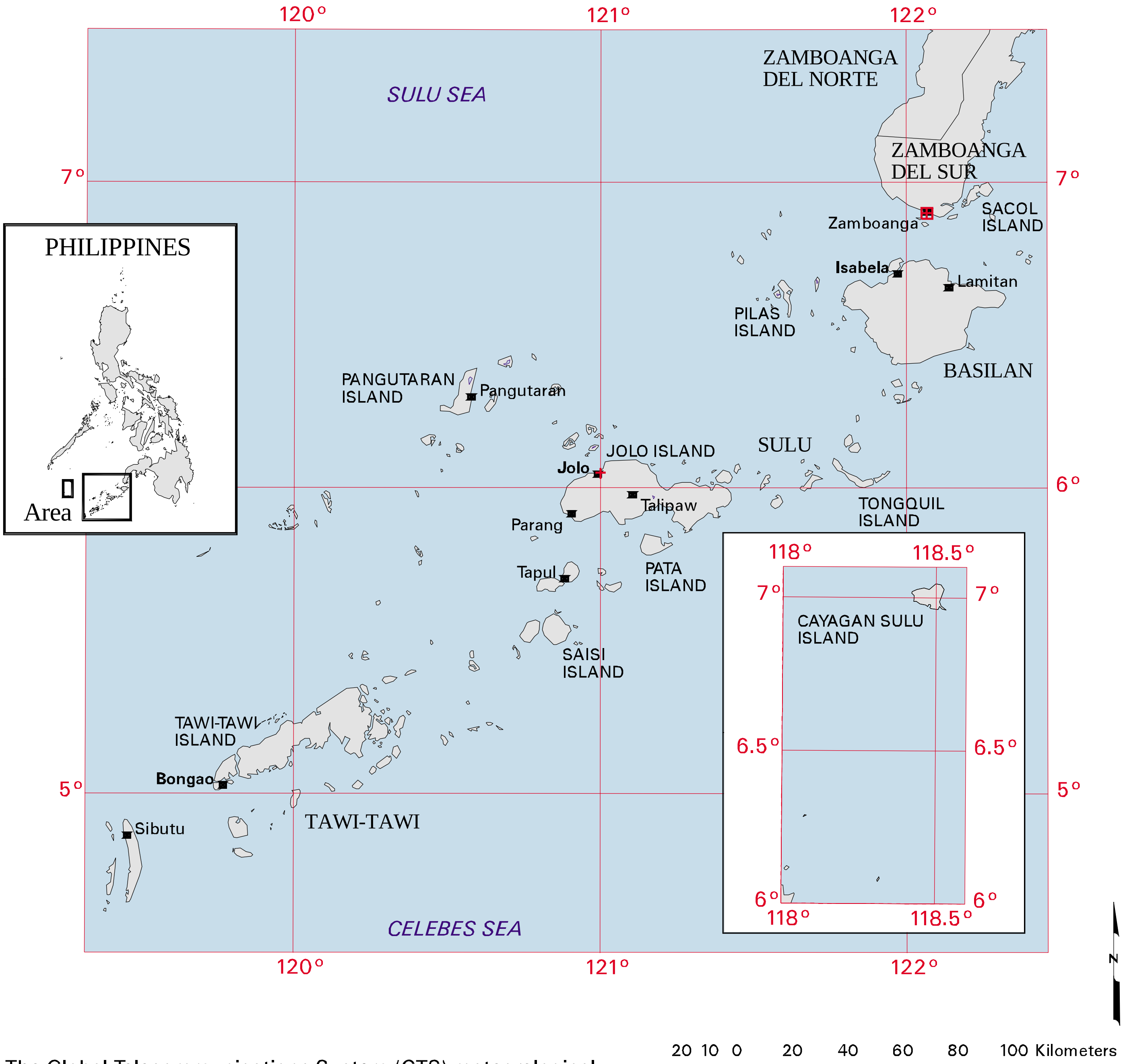
Figure 6-37

Philippines - Basilan, Sulu and Tawi-Tawi
Political Base Map



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Legend

- \+ GTS Surface Meteorological Station with Wind Data
- □ GTS Upper-Air Meteorological Station
- × NPC Wind Measurement Site
- City or **Provincial Capital**

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NREL contacts:
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Marc Schwartz

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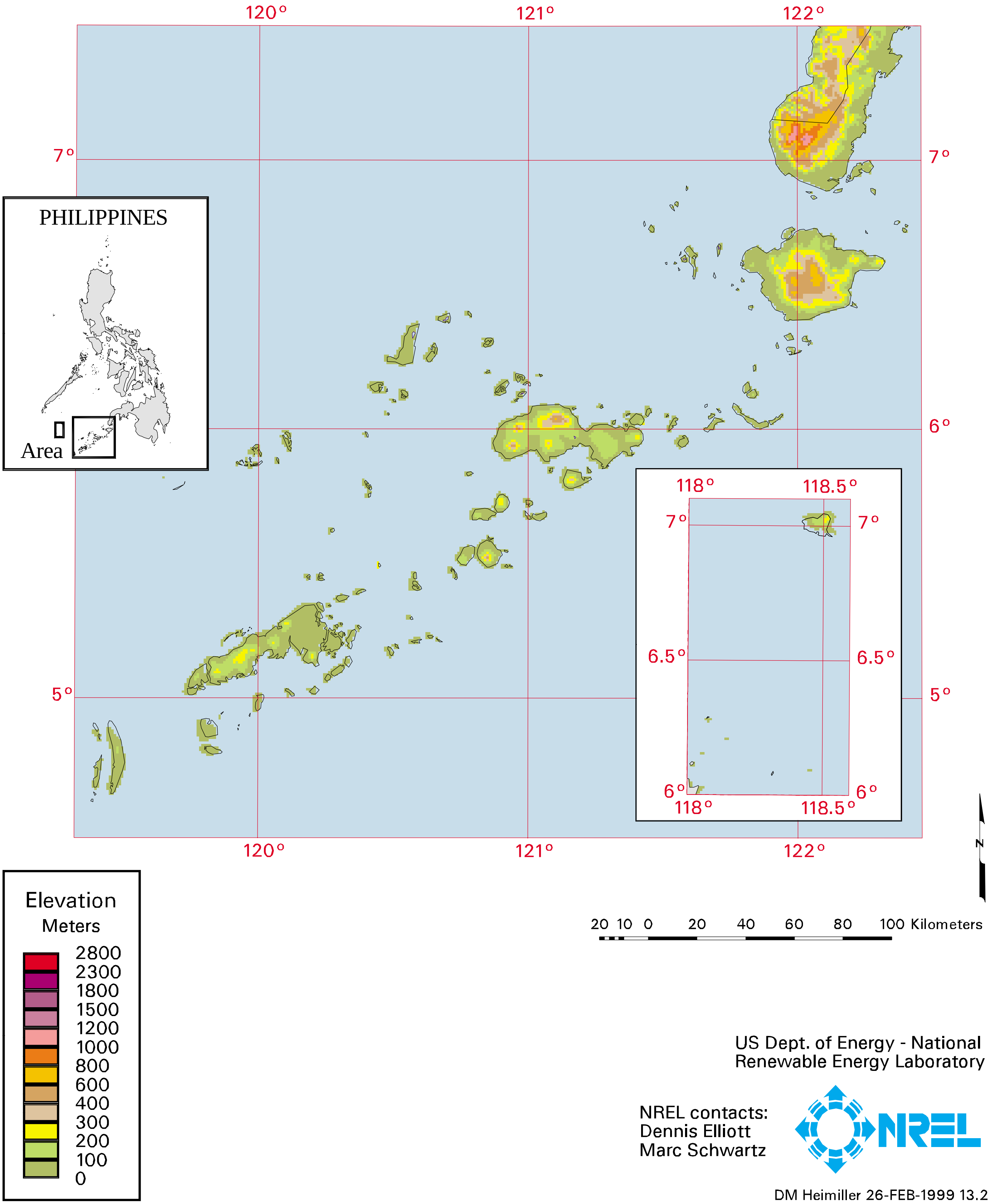
Figure 6-38

Philippines - Basilan, Sulu and Tawi-Tawi
Elevation Map



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NREL contacts:
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Marc Schwartz

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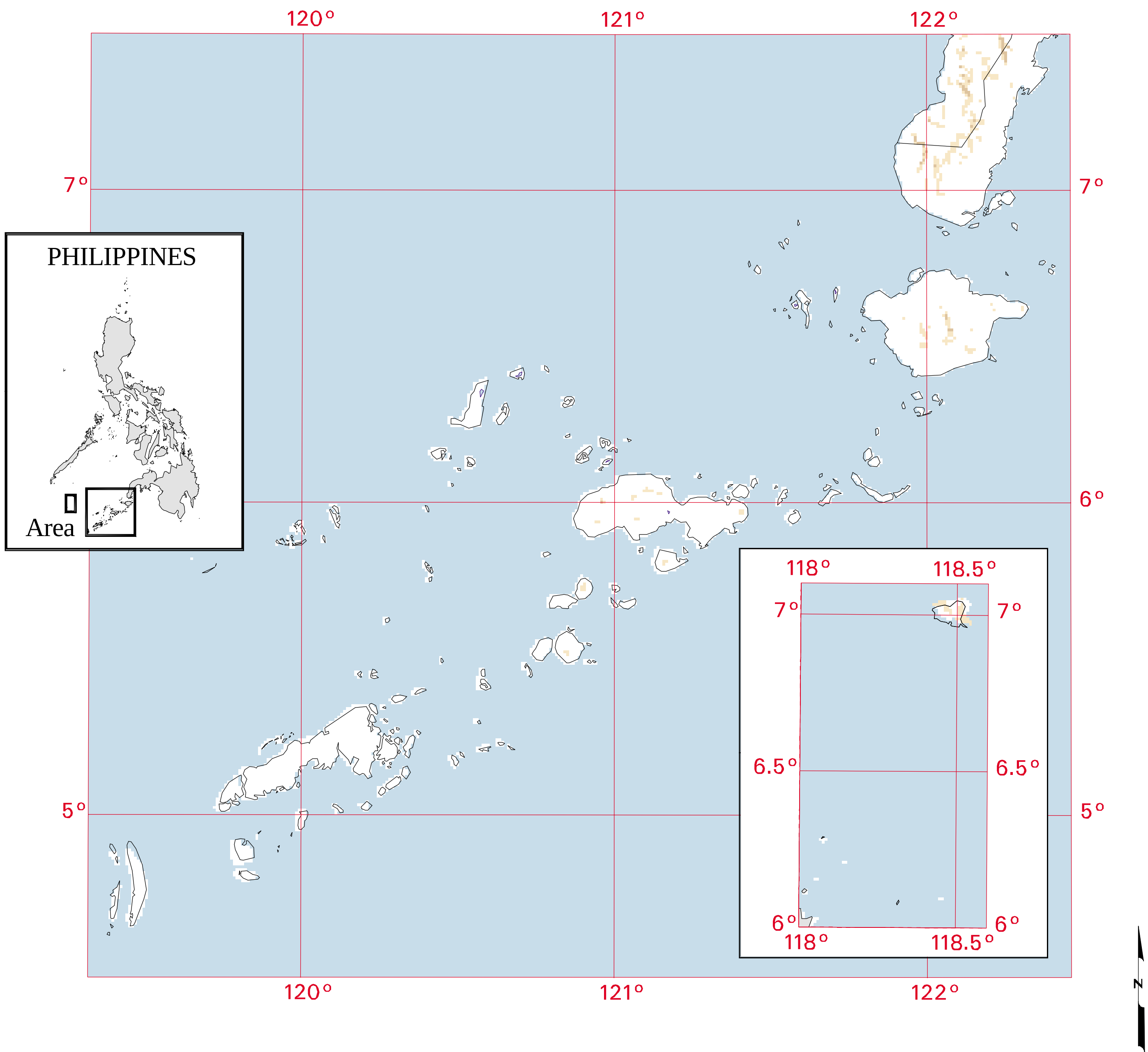
Figure 6-39

Philippines - Basilan, Sulu and Tawi-Tawi
Most Favorable Wind Resource Areas



Wind Power Classification

Resource Potential: Utility	Resource Potential: Rural	Wind Power Density at 30 m W/m^2	Wind Speed[a] at 30 m m/s
Marginal	Moderate	100 - 200	4.4 - 5.6
Moderate	Good	200 - 300	5.6 - 6.4
Good	Excellent	300 - 400	6.4 - 7.0
Excellent		400 - 600	7.0 - 8.0
		600 - 800	8.0 - 8.8
		800 - 1200	8.8 - 10.1

[a] Wind speeds are based on a Weibull k value of 2.0

The wind resource classification is specific for both utility scale and rural applications and applies to areas with low surface roughness.

US Dept. of Energy - National Renewable Energy Laboratory

NREL contacts:
Dennis Elliott
Marc Schwartz

SR Haymes 01-MAR-1999 13.2

Figure 6-40

7.0 Wind Electric Potential

7.1 Introduction

The assumptions and methods for converting the wind resource to wind energy potential are based on those in the report *"Renewable Energy Technology Characterizations"* (DeMeo and Galdo, 1997) and are listed at the bottom of Table 7-1. Each square kilometer on the map has an annual average wind power density, in W/m^2, at a 30-m height. We developed an equation to compute the total net annual energy delivery for each square kilometer of grid cells with an annual average wind power density of 200 W/m^2 or greater. If the wind power density was less than 200 W/m^2, the net energy potential was set equal to zero, because these grid cells have insufficient wind potential for the economic development of utility-scale wind energy. Although the areas with lower wind resource (100-200 W/m^2) are not economic for utility-scale wind and thus have been discounted, these areas have the potential for isolated use of small wind for rural electrification projects. Under another scenario (good-to-excellent resource levels) only grid cells with an annual average wind power of 300 W/m^2 or greater were included.

The wind resource levels in Table 7-1 are consistent with those on the wind resource maps for the Philippines. The numbers in the table represent total net wind-energy potential, and they have not been reduced by factors such as land-use exclusions. The net energy is already reduced by about 15%–20% because of expected losses from downtime, wake-effects, etc. When the wind energy potential is computed, the wind power density to the turbine-hub-height level is adjusted so the total wind energy potential is not dependent on the height used in our wind resource classification.

7.2 Wind Electric Potential Estimates

More than 10,000 km^2 of windy land area is estimated to exist with a good-to-excellent wind resource potential. The proportion of windy land and potential wind capacity in each wind power category is listed in Table 7-1. These windy land areas represent less than 4% of the total land area (299,000 km^2) in the Philippines. Using conservative assumptions of about 7 MW per km^2, these windy areas could support more than 70,000 MW of potential installed capacity, delivering more than 195 billion kWh per year. Considering only these areas of good-to-excellent wind resource, Figure 7-1 shows there are 47 provinces out of 73 in the Philippines with at least 500 MW of wind potential and 25 provinces with at least 1,000 MW of wind potential. However, to assess the wind electric potential more accurately, additional studies, considering factors such as the existing transmission grid and accessibility, are required.

If we consider additional areas that have a moderate wind resource potential or that have a good wind resource for rural power applications, the estimated total land area increases to more than 25,000 km^2 (slightly more than 8% of the total land area of the Philippines, as shown in Table 7-1). This land could support over 170,000 MW of potential installed capacity, delivering 361 billion kWh per year. Figure 7-2 shows 51 provinces out of 73 with at least 1,000 MW of wind potential and 64 provinces with at least 500 MW of wind potential.

Table 7-1
Philippines - Wind Electric Potential
Good-to-Excellent Wind Resource at 30 m (Utility Scale)

Wind Resource Utility Scale	Wind Power W/m^2	Wind Speed m/s*	Total Area km^2	Total Cap Installed MW	Total Power GWh/yr
Good	300 – 400	6.4 – 7.0	5,541	38,400	85,400
Excellent	400 – 500	7.0 – 8.0	2,841	19,700	52,200
Excellent	500 – 700	8.0 – 8.8	2,258	15,600	47,900
Excellent	700 – 1250	8.8 – 10.1	415	2,900	9,700
Total			11,055	76,600	195,200

Moderate-to-Excellent Wind Resource at 30 m (Utility Scale)

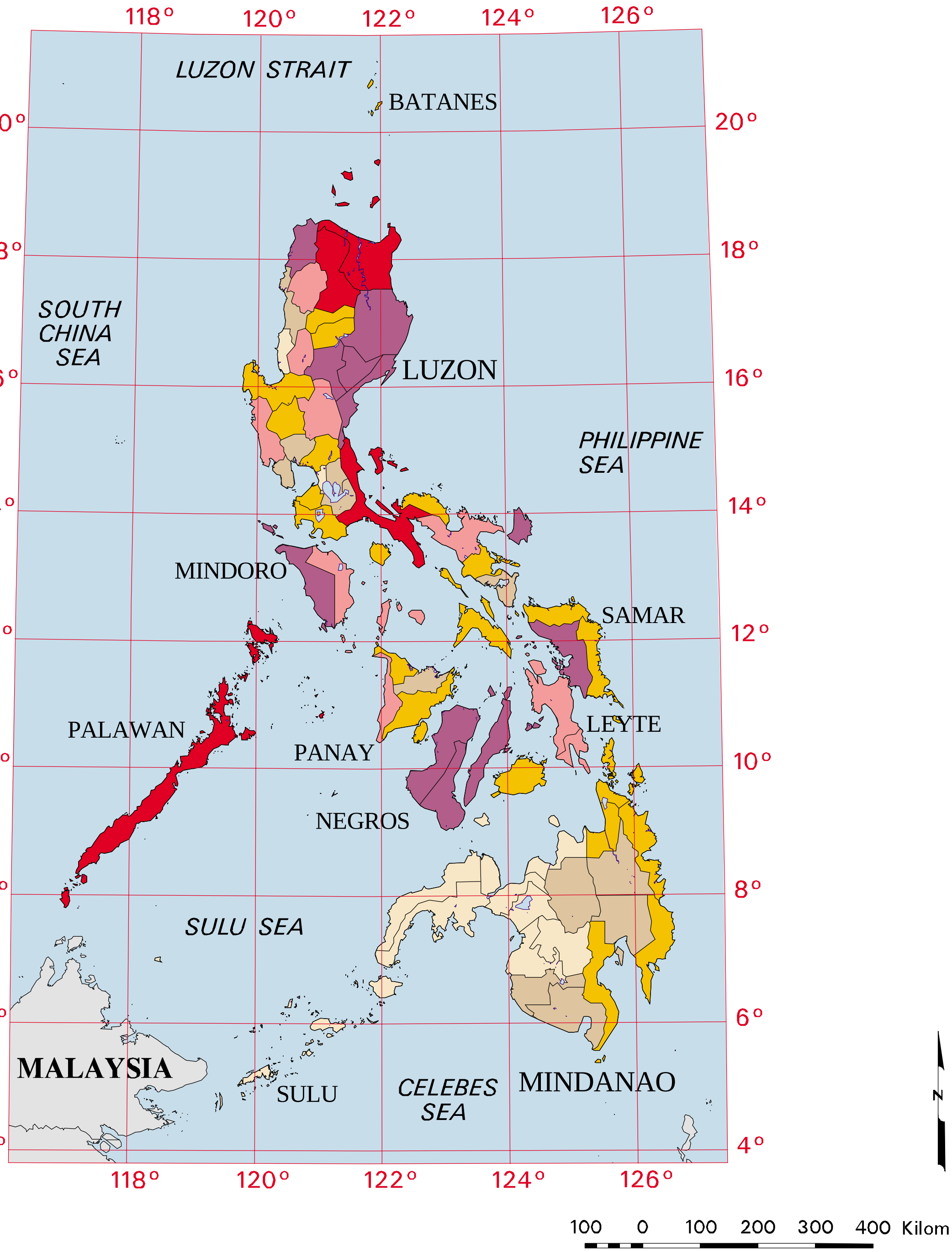
Wind Resource Utility Scale	Wind Power W/m^2	Wind Speed m/s*	Total Area km^2	Total Capacity Installed MW	Total Power GWh/yr
Moderate	200 – 300	5.6 – 6.4	14,002	97,000	165,800
Good	300 – 400	6.4 – 7.0	5,541	38,400	85,400
Excellent	400 – 500	7.0 – 8.0	2,841	19,700	52,200
Excellent	500 – 700	8.0 – 8.8	2,258	15,600	47,900
Excellent	700 – 1250	8.8 – 10.1	415	2,900	9,700
Total			25,057	173,600	361,000

* Wind speeds are based on a Weibull k value of 2.0

<u>Assumptions</u>
Turbine Size – 500 kW
Hub Height – 40 m
Rotor Diameter – 38 m
Turbine Spacing – 10D by 5D
Capacity/km^2 – 6.9 MW

Philippines - Wind Electric Potential

Good-to-Excellent Wind Resource (Utility Scale Classification)



Philippines Total - 76,600 MW

Wind Electric Potential Megawatts
< 100
100 - 500
500 - 1,000
1,000 - 2,000
2,000 - 3,000
3,000 - 5,200

The following assumptions were used in calculating the total potential wind electric capacity installed:

Minimum wind power - 300 W/m2
Turbine size - 500 kW
Hub height - 40 m
Rotor diameter - 38 m
5D Side-to-side spacing - 190 m
10D Front-to-back spacing - 380 m
Swept area - 1134 m2
Turbines/km2 - 13.9
Capacity/km2 - 6.9 MW

US Dept. of Energy - National Renewable Energy Laboratory

NREL contacts:
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Marc Schwartz

NREL

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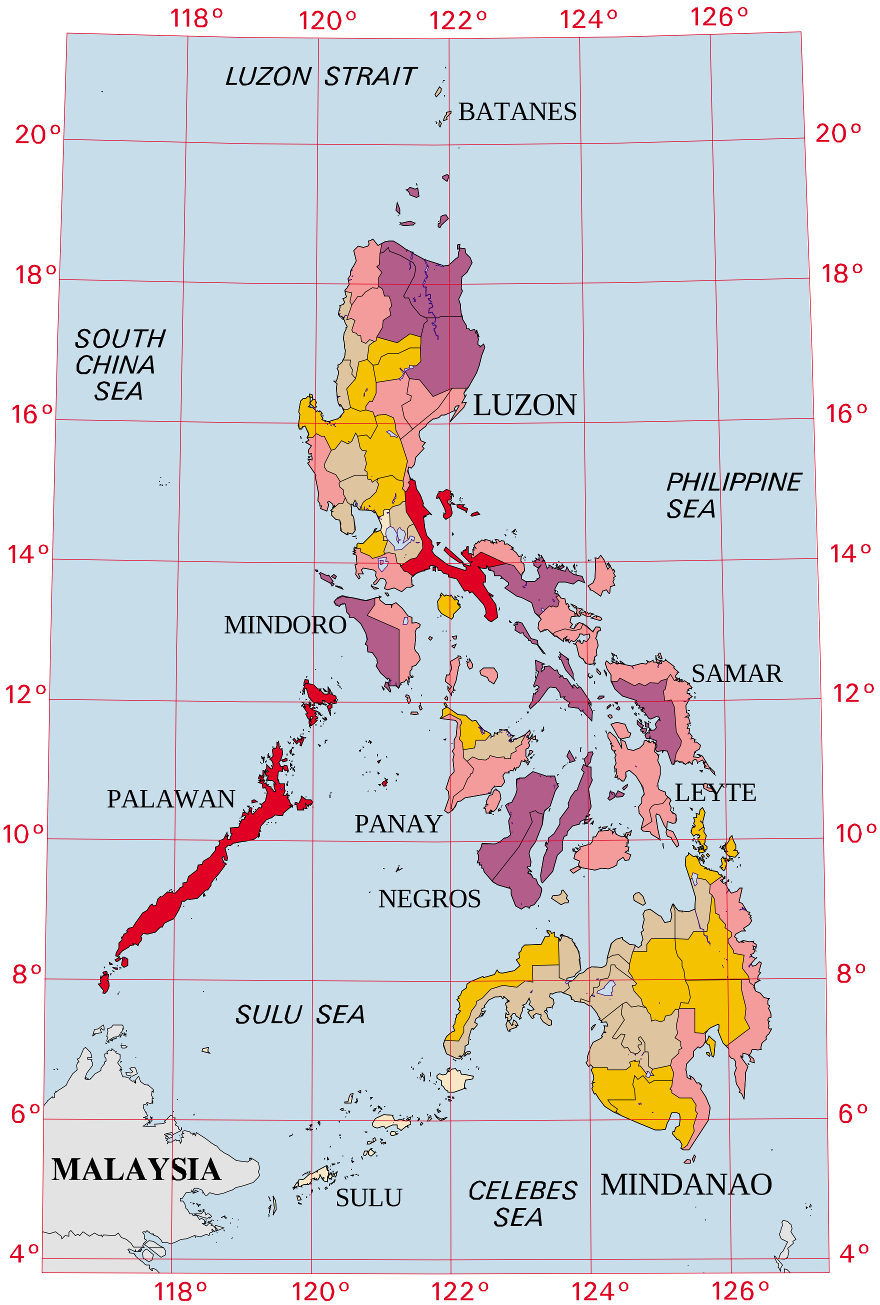
Figure 7-1

Philippines - Wind Electric Potential

Moderate-to-Excellent Wind Resource (Utility Scale Classification)



100 0 100 200 300 400 Kilometers

Philippines Total - 173,650 MW

Wind Electric Potential
Megawatts

- < 100
- 100 - 1,000
- 1,000 - 2,000
- 2,000 - 4,000
- 4,000 - 8,000
- 8,000 - 15,100

The following assumptions were used in calculating the total potential wind electric capacity installed:

Minimum wind power - 200 W/m2
Turbine size - 500 kW
Hub height - 40 m
Rotor diameter - 38 m
5D Side-to-side spacing - 190 m
10D Front-to-back spacing - 380 m
Swept area - 1134 m2
Turbines/km2 - 13.9
Capacity/km2 - 6.9 MW

US Dept. of Energy - National Renewable Energy Laboratory

NREL contacts:
Dennis Elliott
Marc Schwartz

SR Haymes 07-JUN-1999 15.3

Figure 7-2

References

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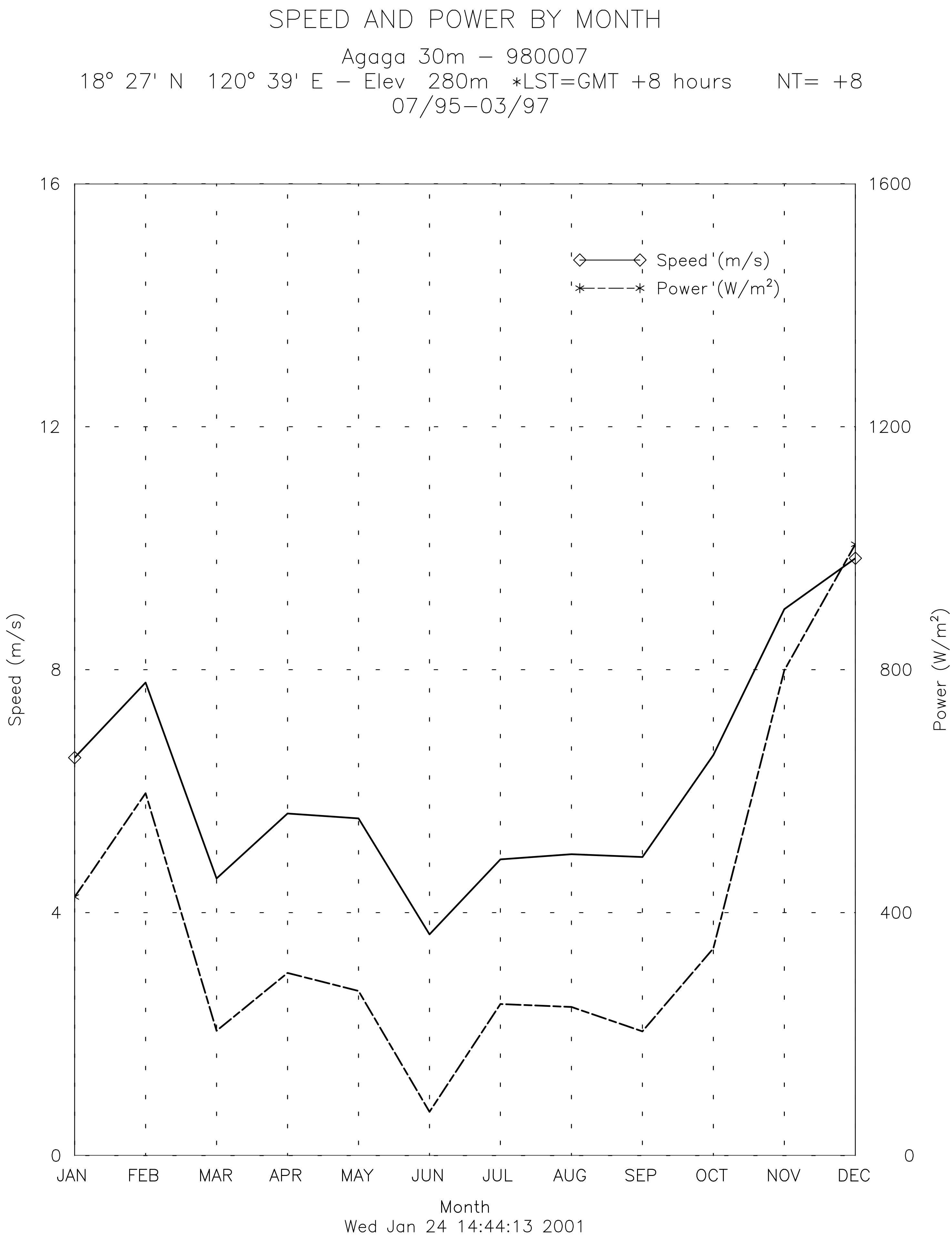
Appendix A

Data Summaries
National Power Corporation Sites

Agaga
Bangui
Bayog
Caparispisan
Guimaras
Pagali
Sagada
Saoit
Subec


SPEED AND POWER BY MONTH
Agaga 30m - 980007
18° 27' N 120° 39' E - Elev 280m *LST=GMT +8 hours NT= +8
07/95-03/97
Speed (m/s)
Power (W/m²)
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
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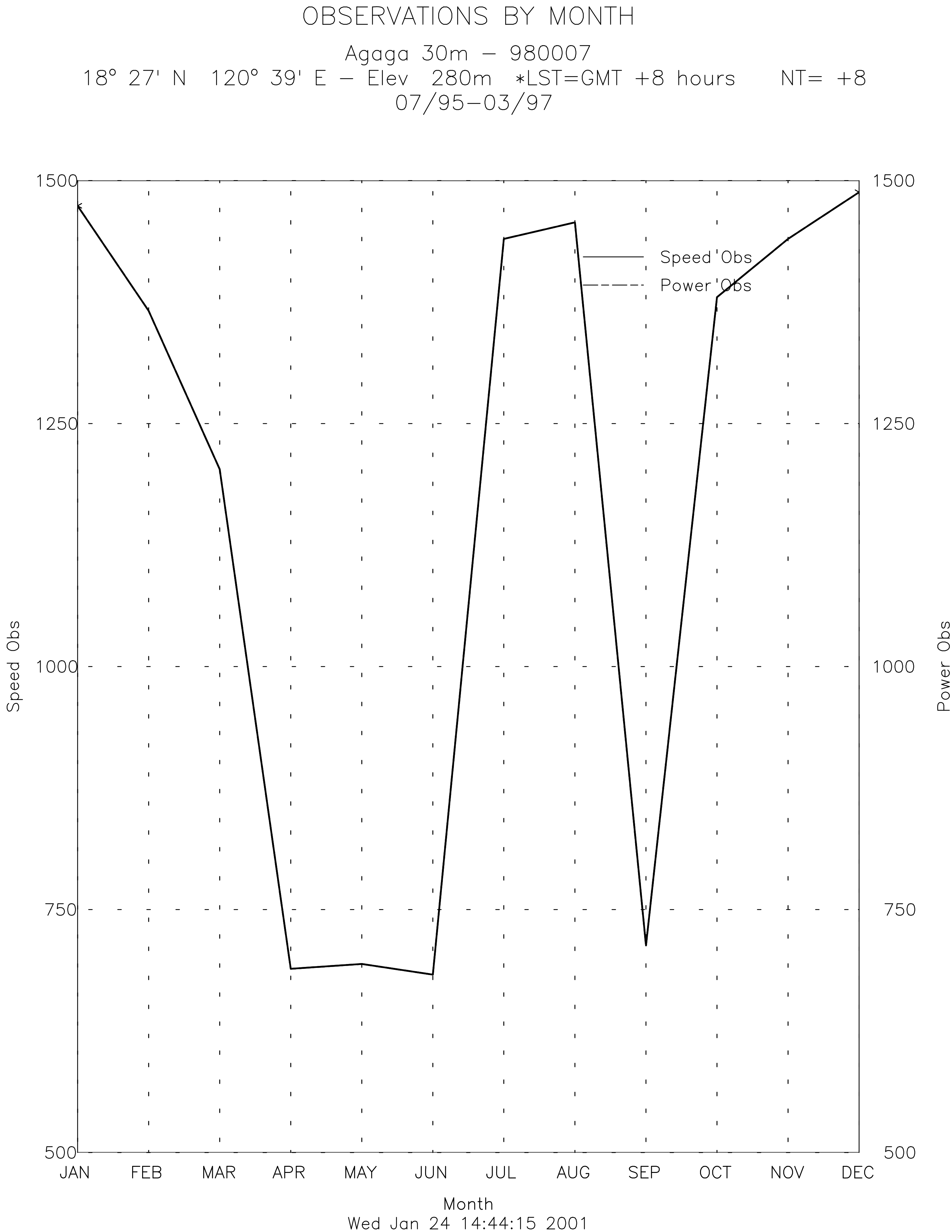
OBSERVATIONS BY MONTH
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07/95-03/97
Speed Obs
Power Obs
1500
1250
1000
750
500
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:44:15 2001

SPEED AND POWER BY HOUR

Agaga 30m - 980007

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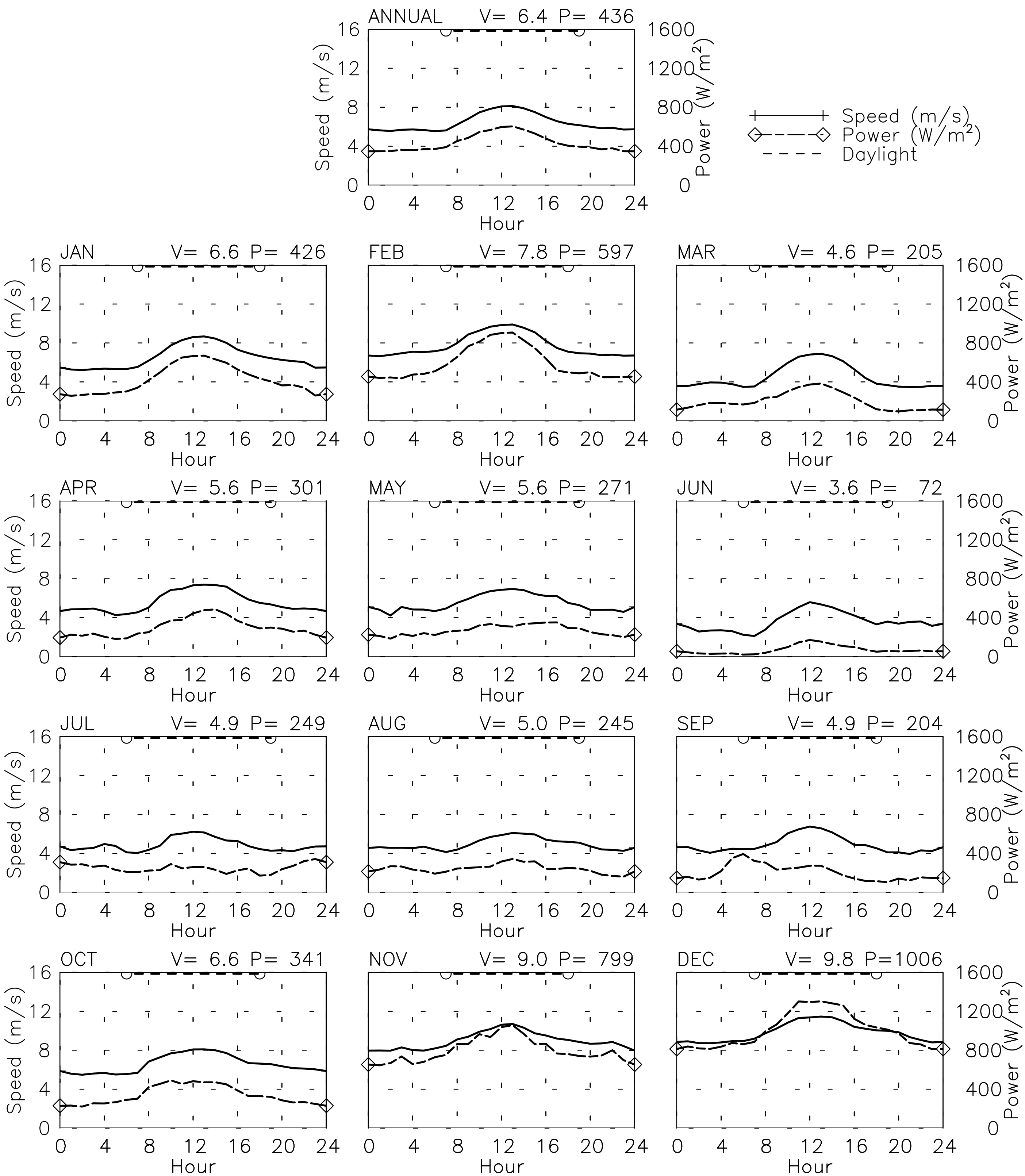
07/95-03/97



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FREQUENCY AND SPEED BY DIRECTION

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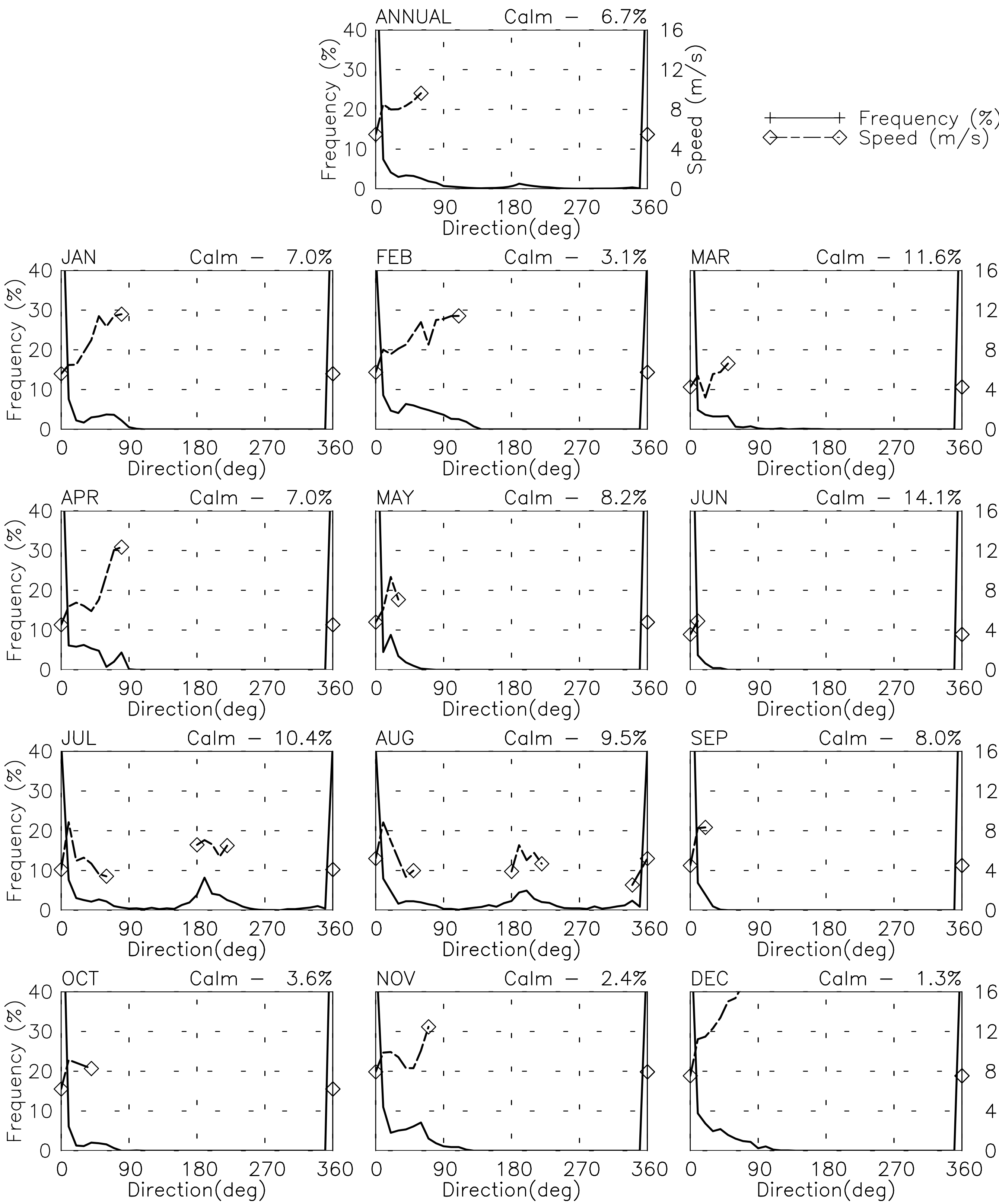
07/95–03/97



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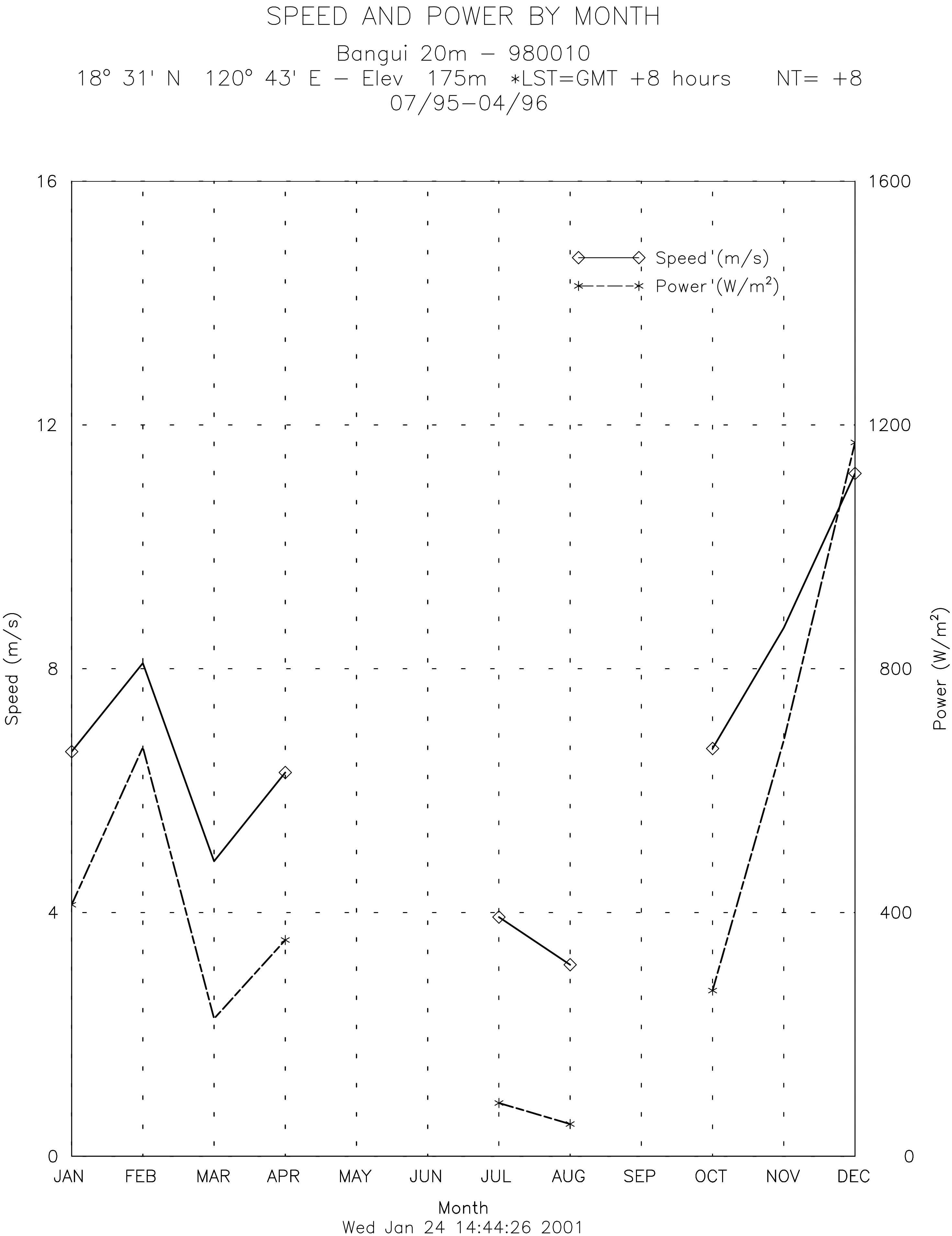
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Bangui 20m - 980010
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07/95-04/96
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
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JUL
AUG
SEP
OCT
NOV
DEC
Month
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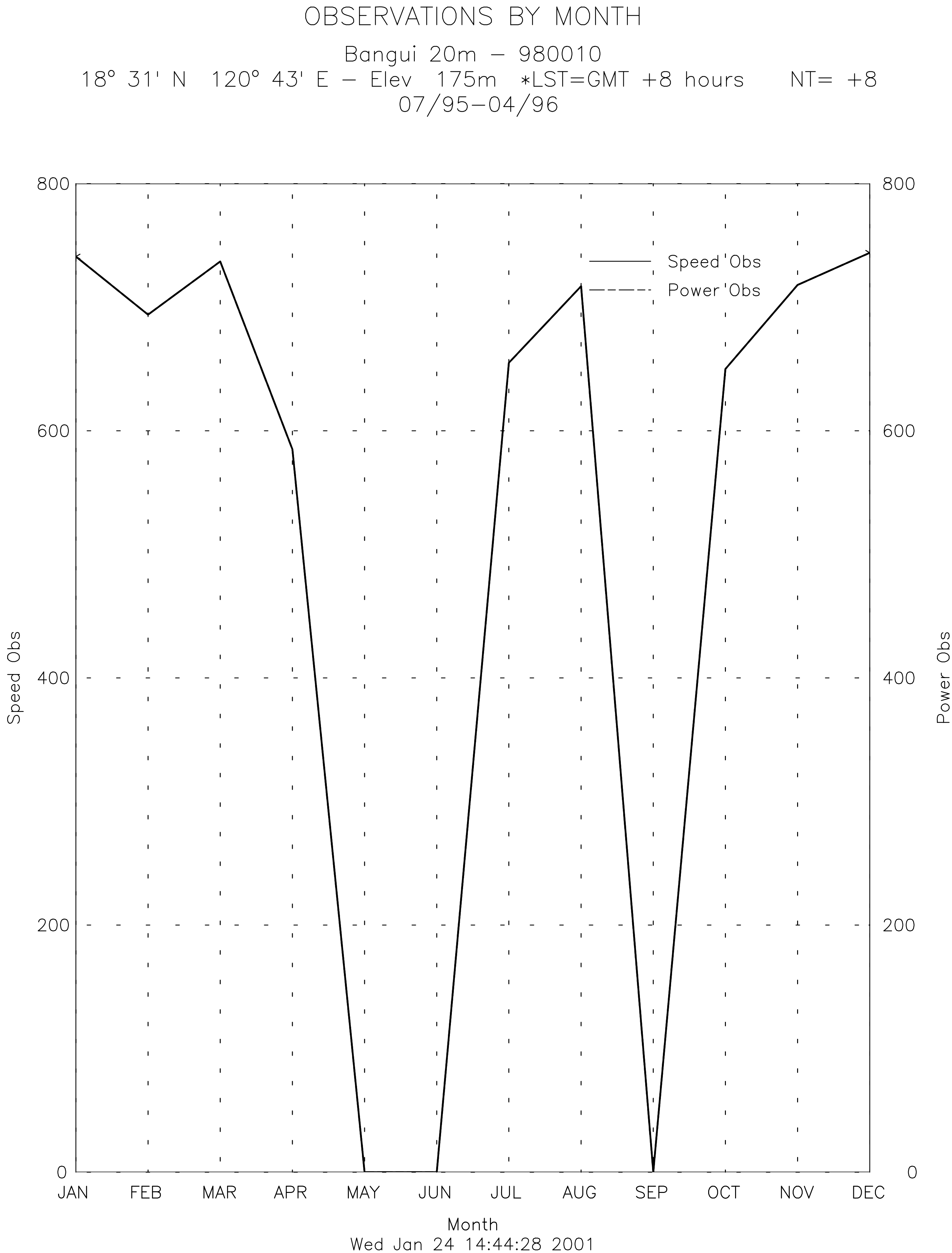
OBSERVATIONS BY MONTH
Bangui 20m - 980010
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07/95-04/96
Speed'Obs
Power'Obs
Speed Obs
Power Obs
0
200
400
600
800
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:44:28 2001

SPEED AND POWER BY HOUR

Bangui 20m – 980010
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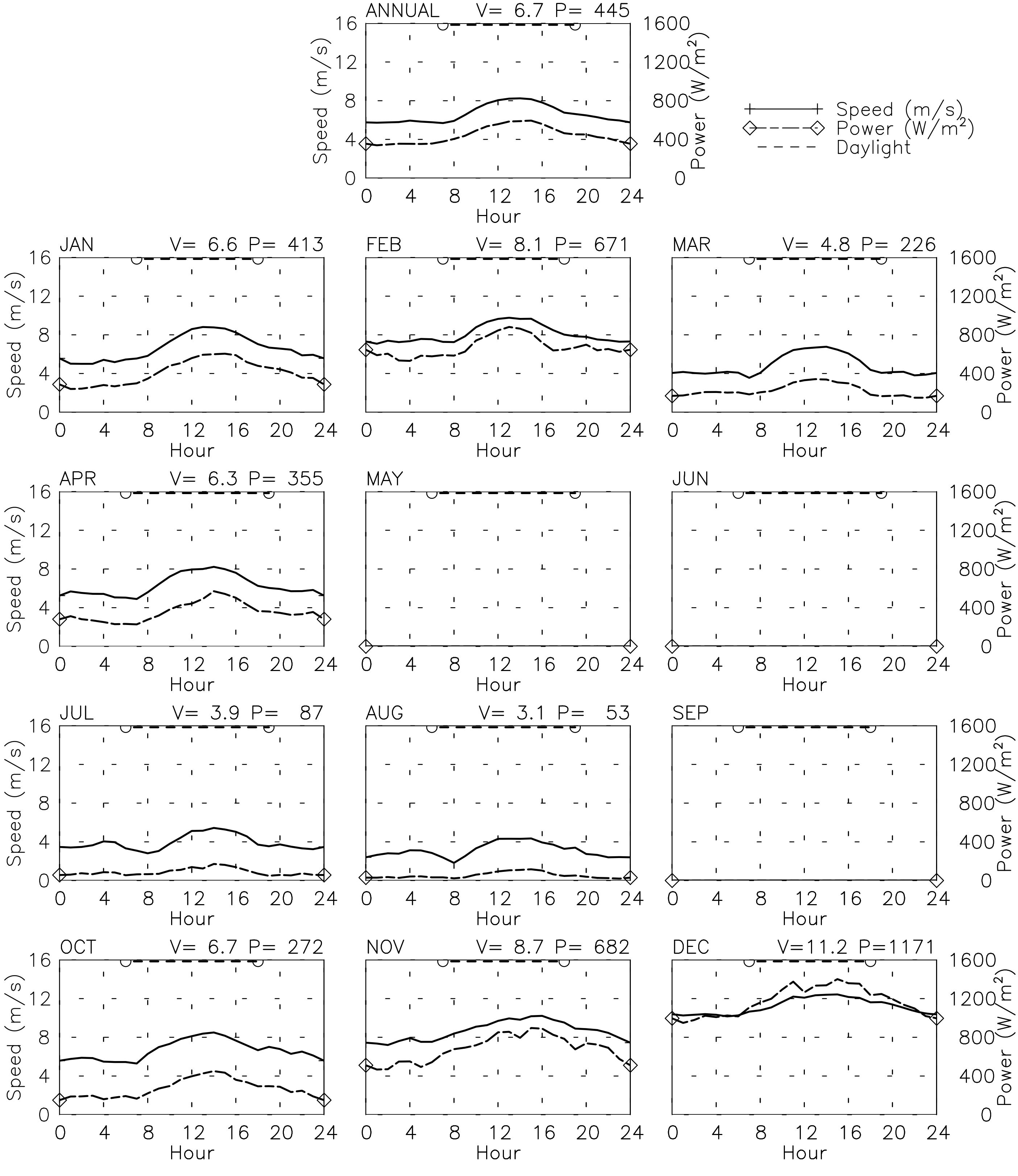
07/95–04/96



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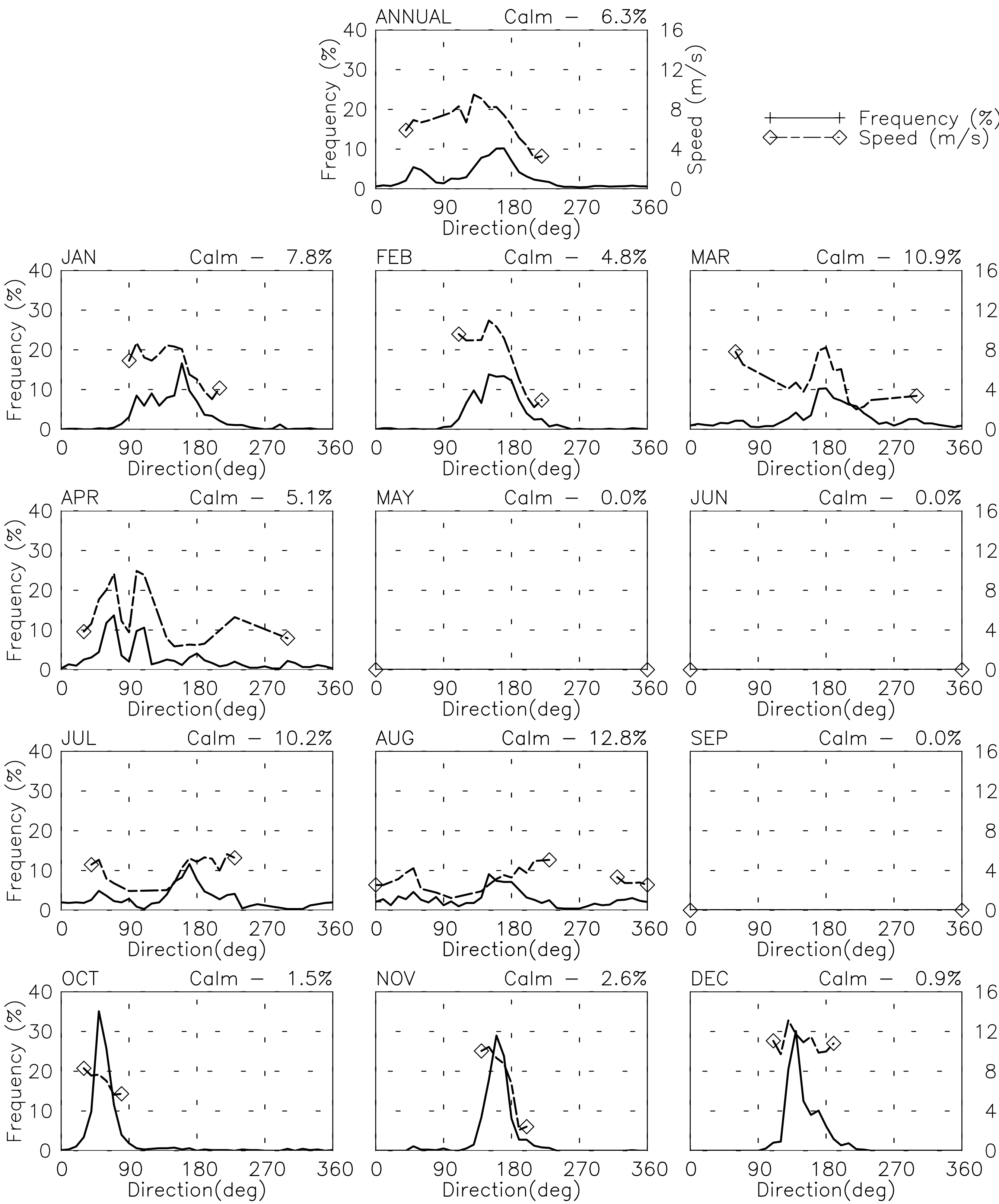
07/95–04/96



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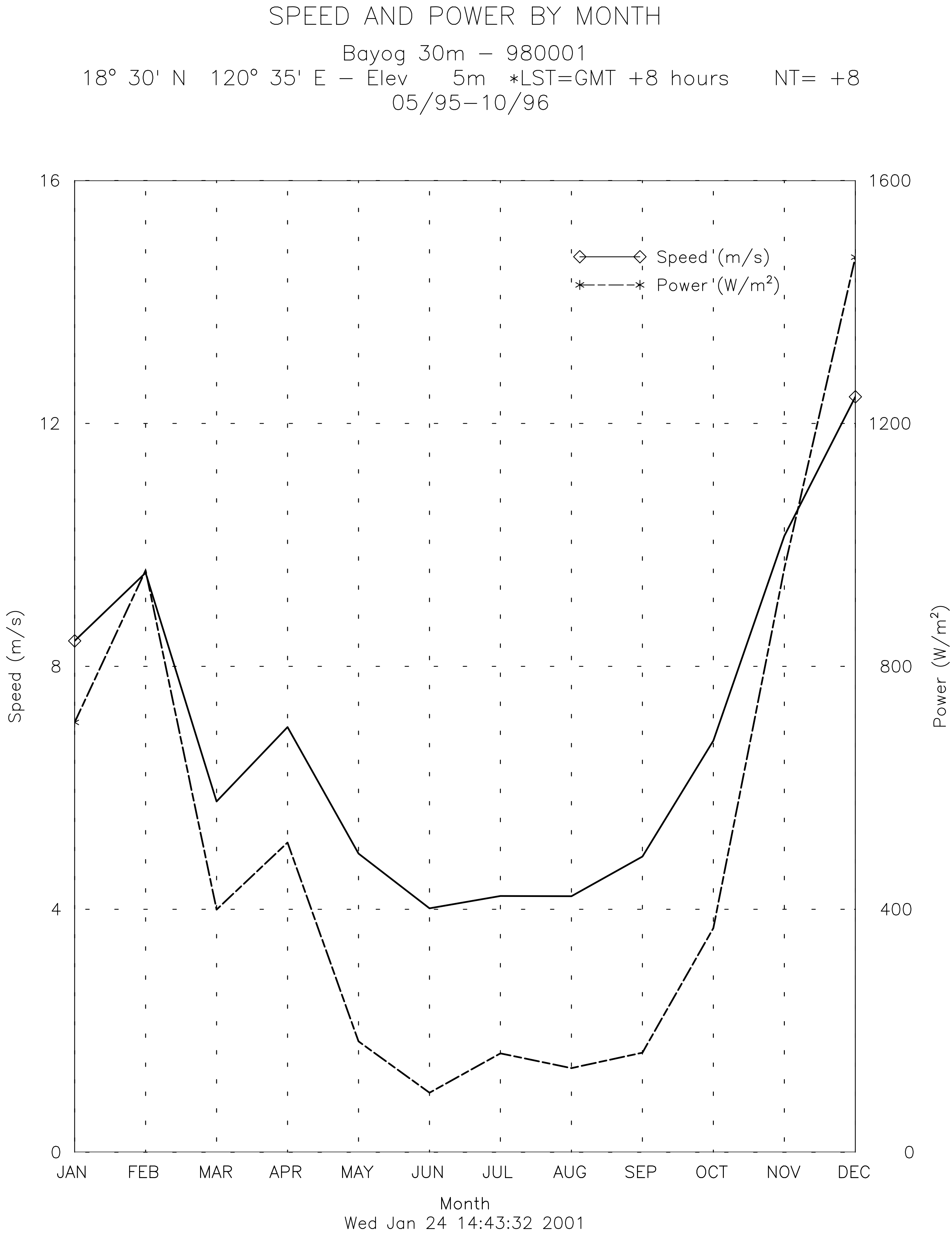
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05/95-10/96
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
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FEB
MAR
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MAY
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OCT
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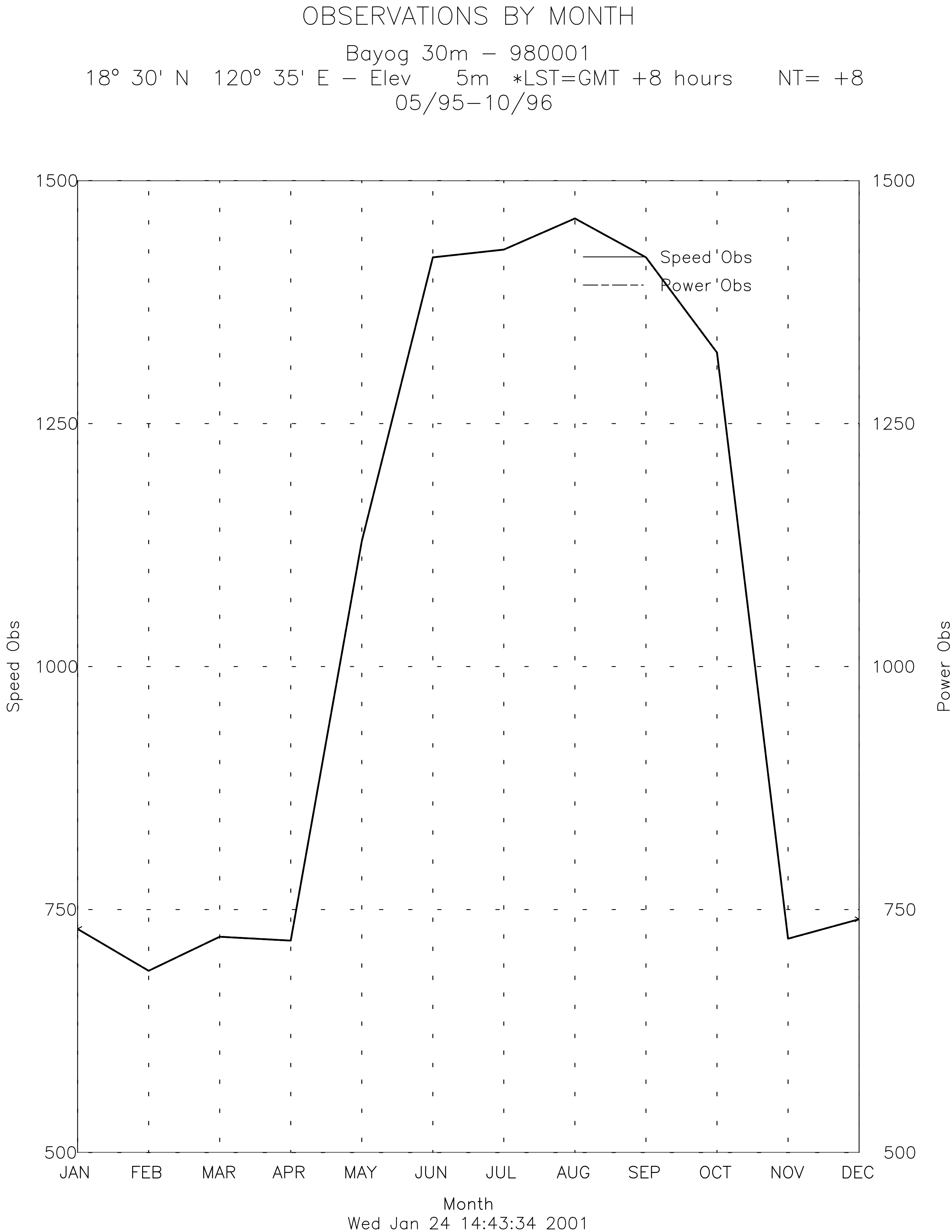
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05/95-10/96
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1250
1000
750
500
Speed Obs
Power Obs
Speed'Obs
Power'Obs
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:43:34 2001

SPEED AND POWER BY HOUR

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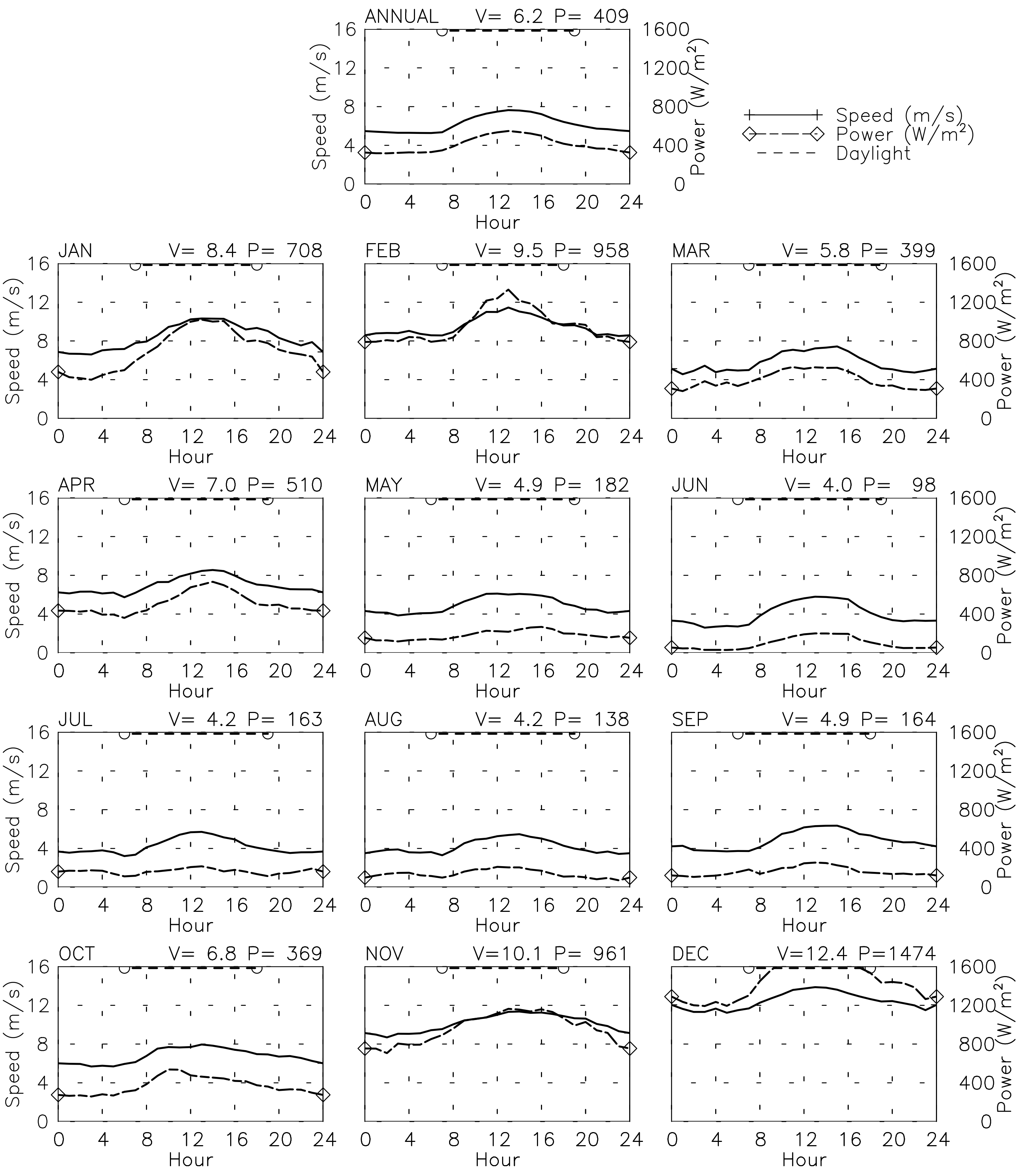
05/95-10/96



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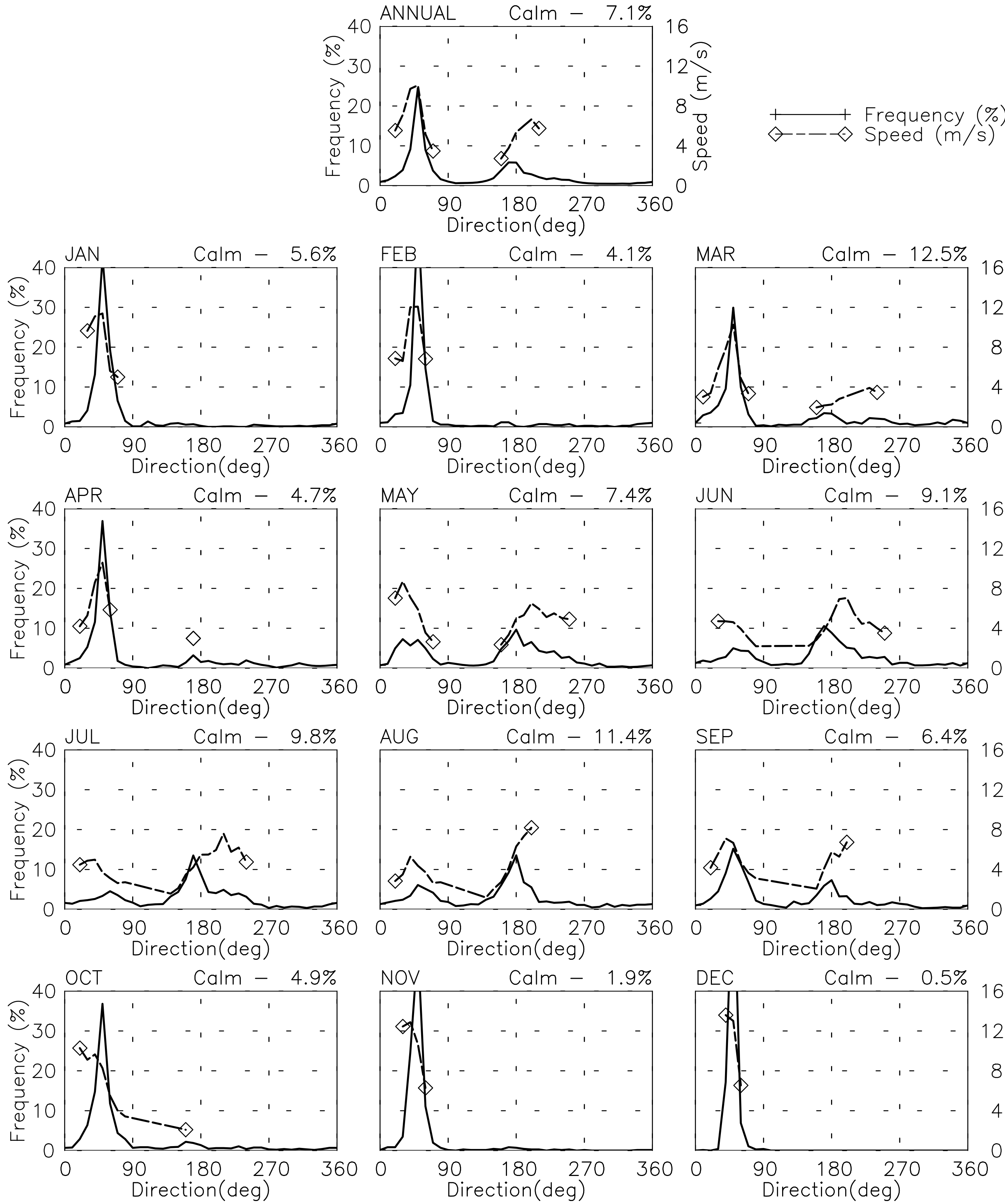
05/95-10/96



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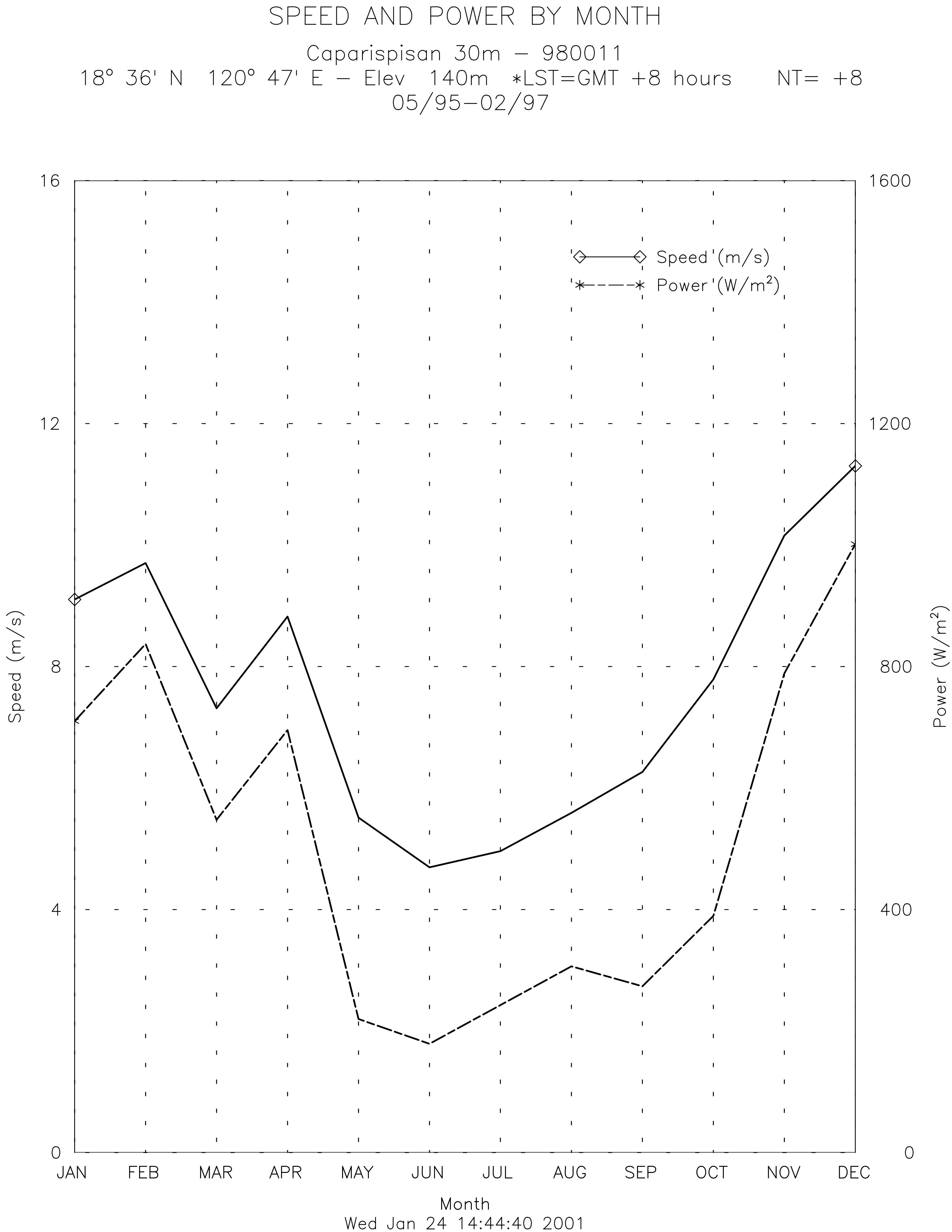

SPEED AND POWER BY MONTH
Caparispisan 30m - 980011
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05/95-02/97
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:44:40 2001

OBSERVATIONS BY MONTH

Caparispisan 30m - 980011

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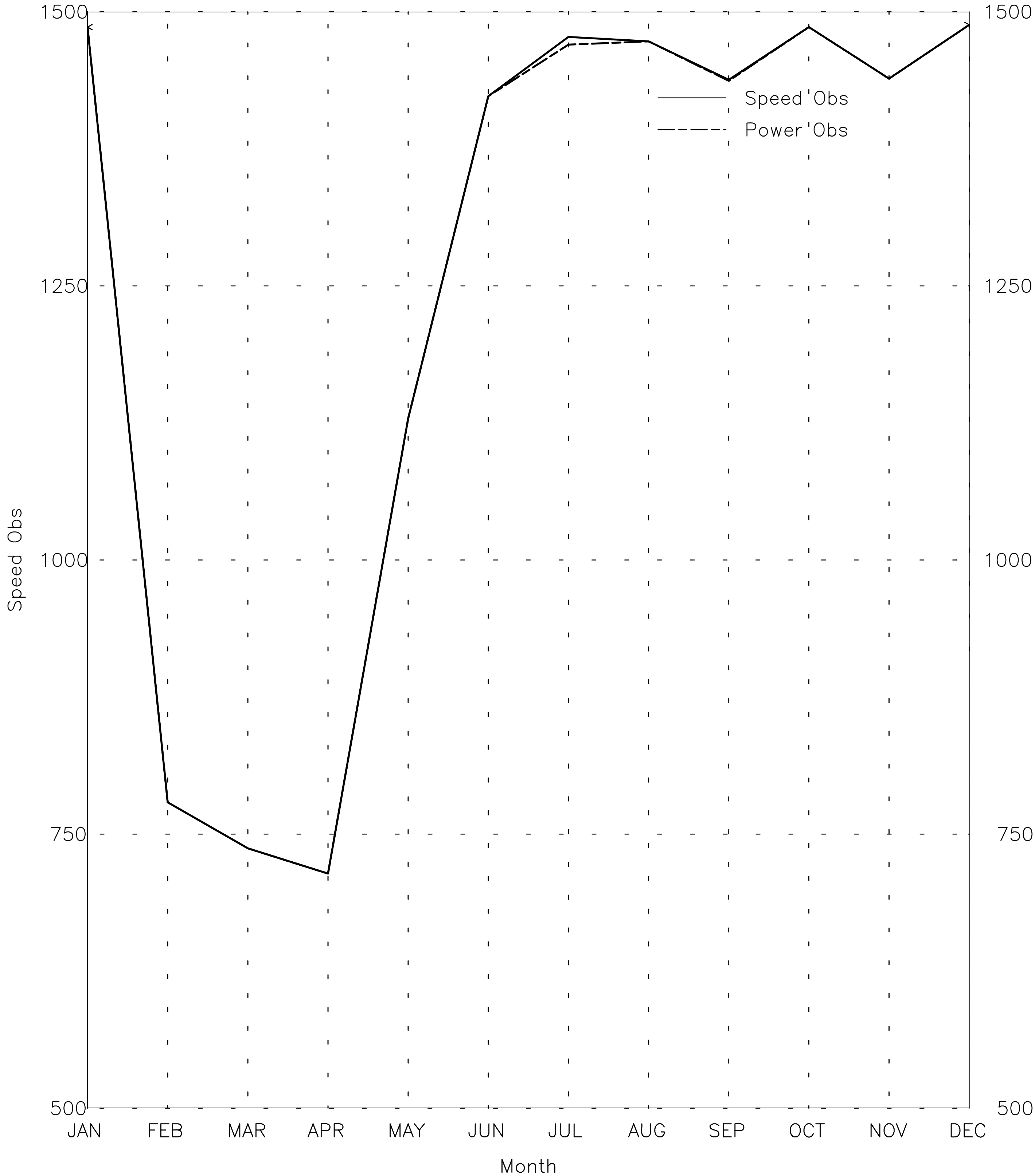
05/95-02/97



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SPEED AND POWER BY HOUR

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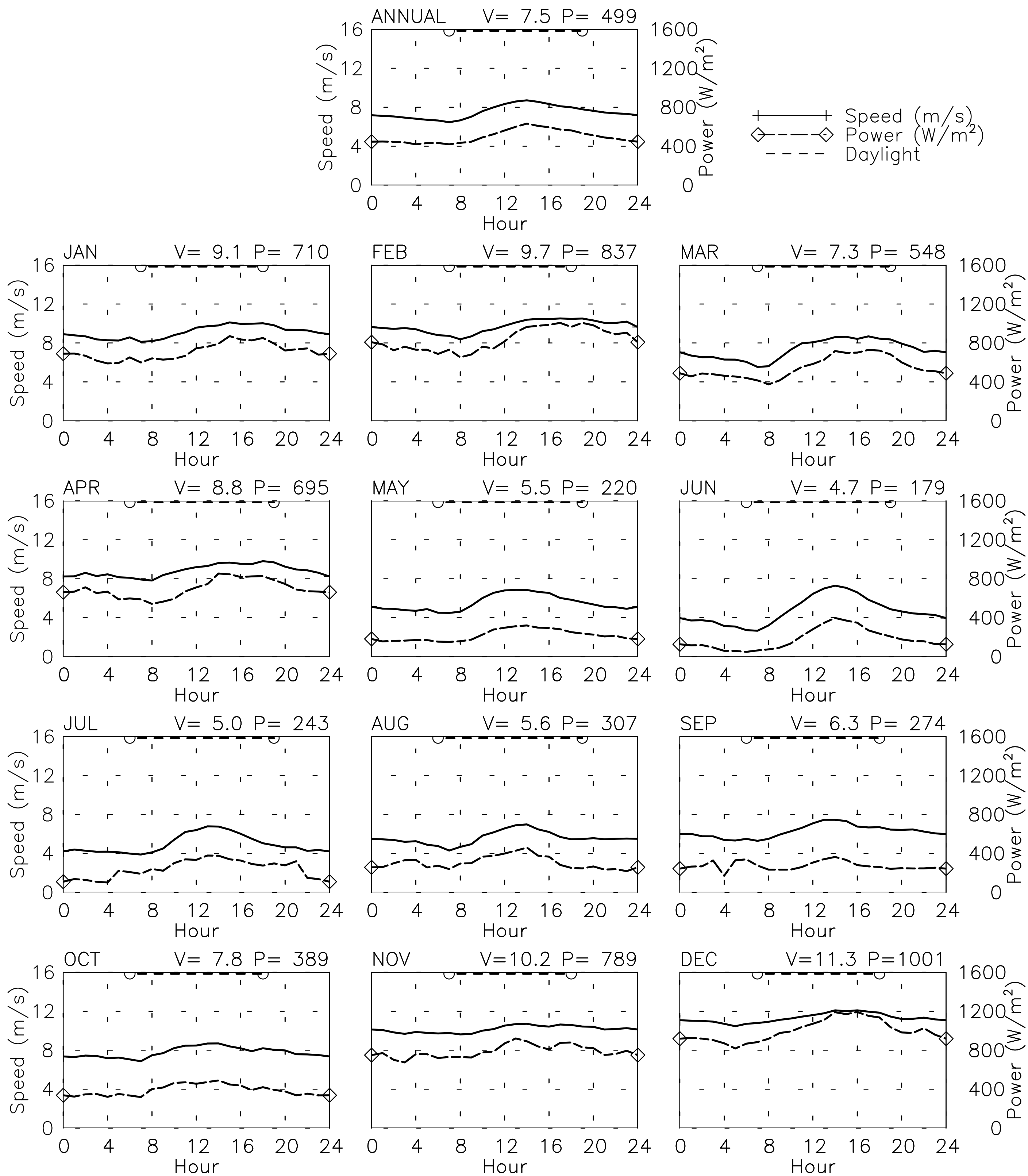
05/95–02/97



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FREQUENCY AND SPEED BY DIRECTION

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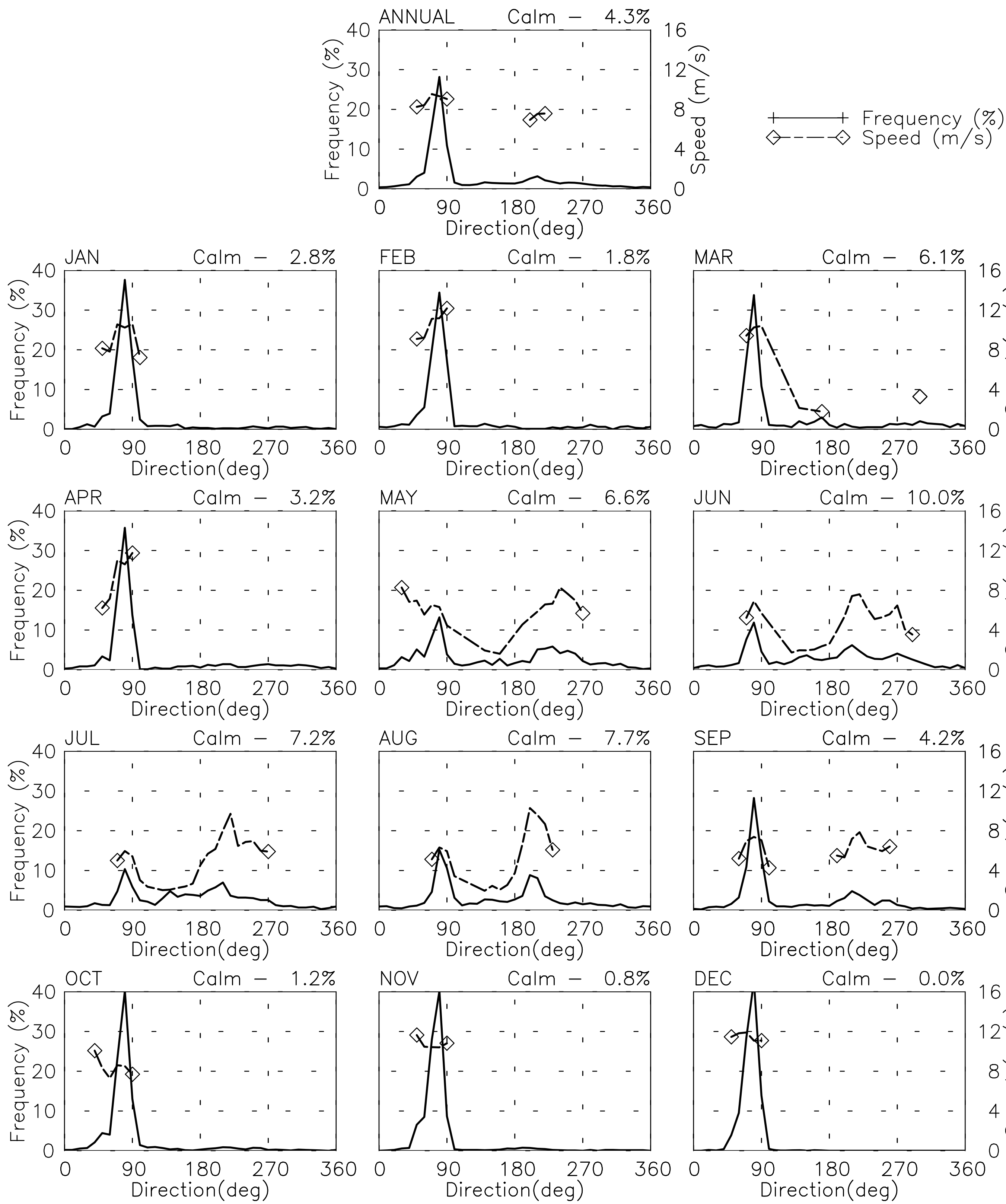
05/95–02/97



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SPEED AND POWER BY MONTH

Guimaras 30m – 980017

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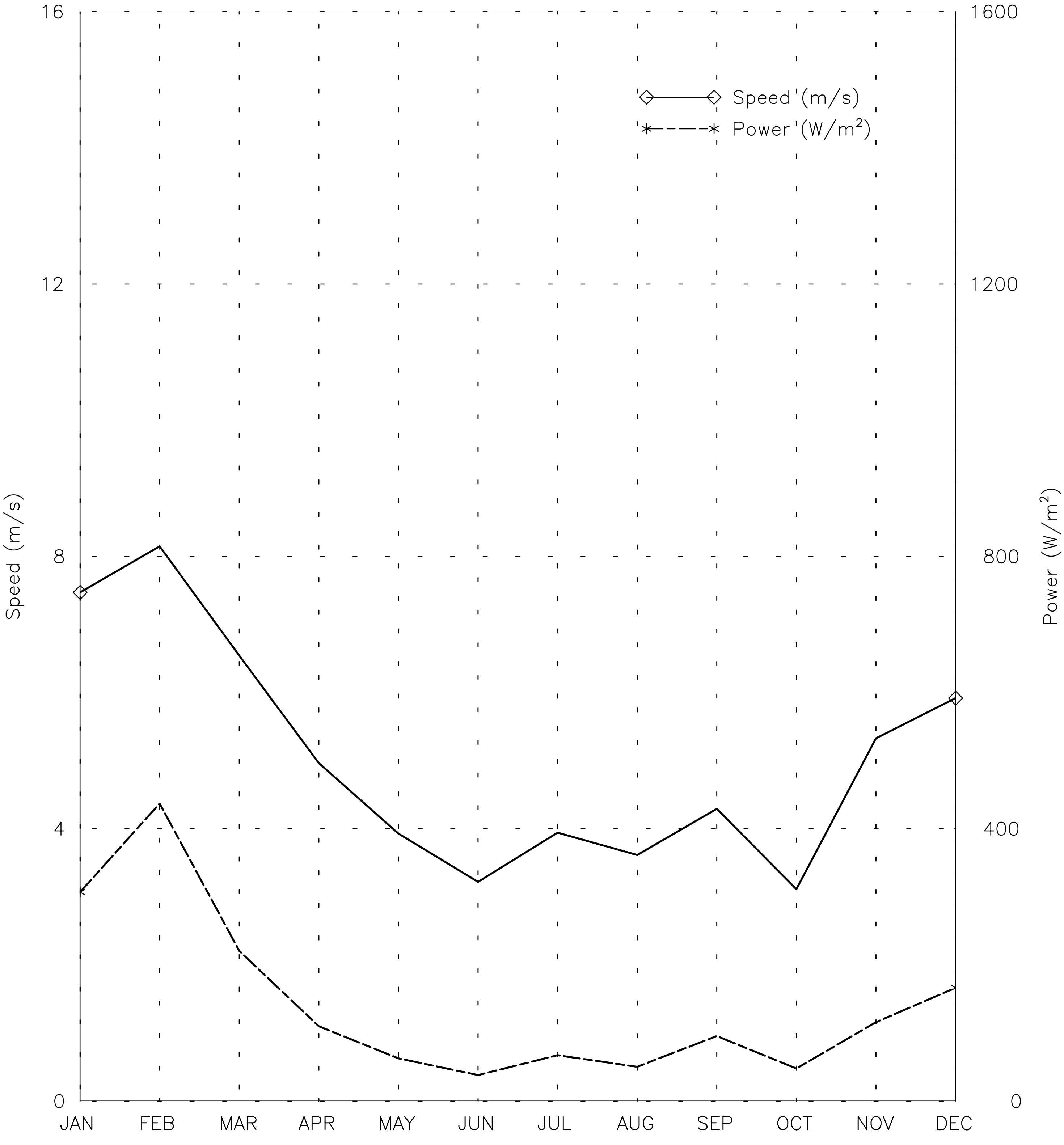
06/95–05/97



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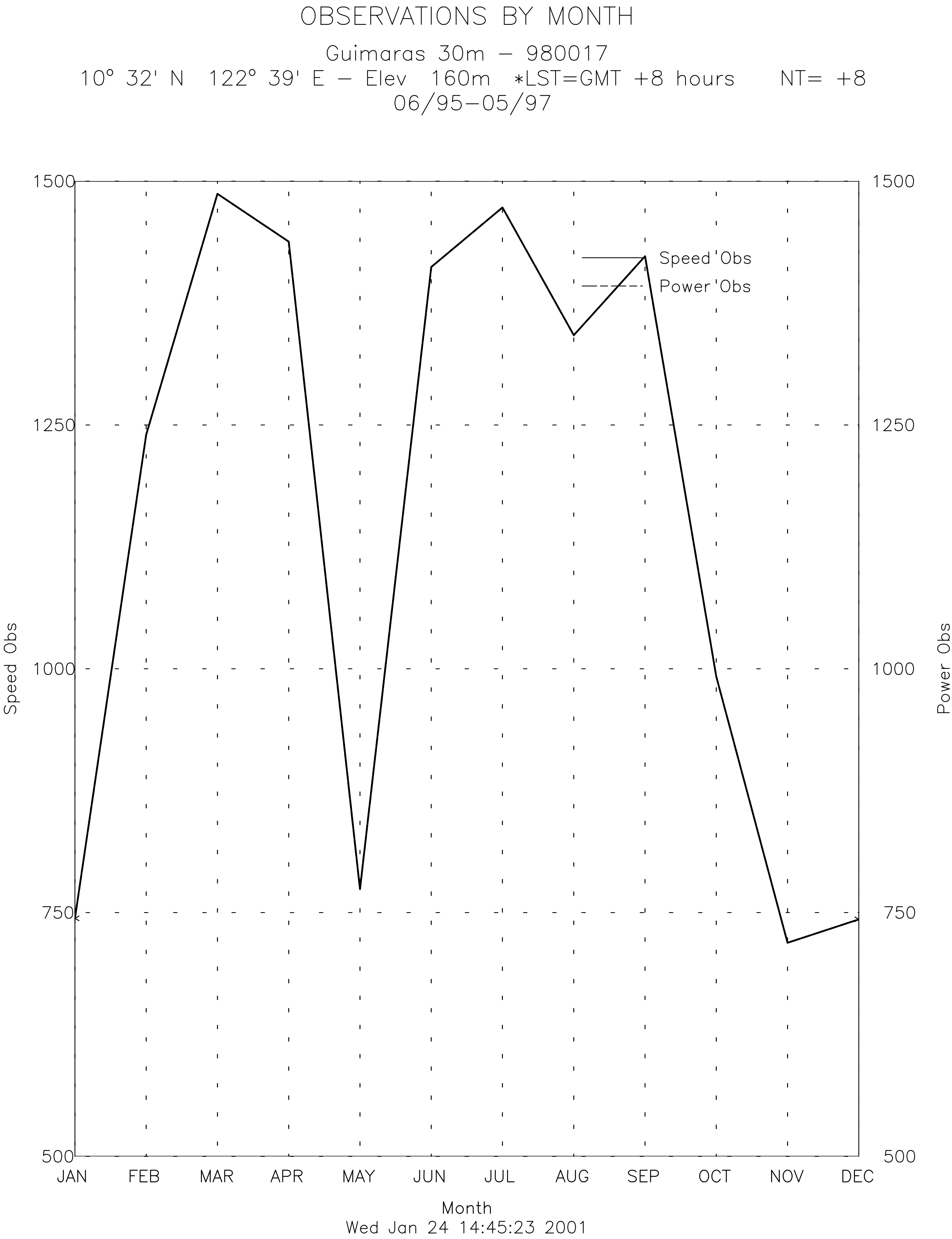
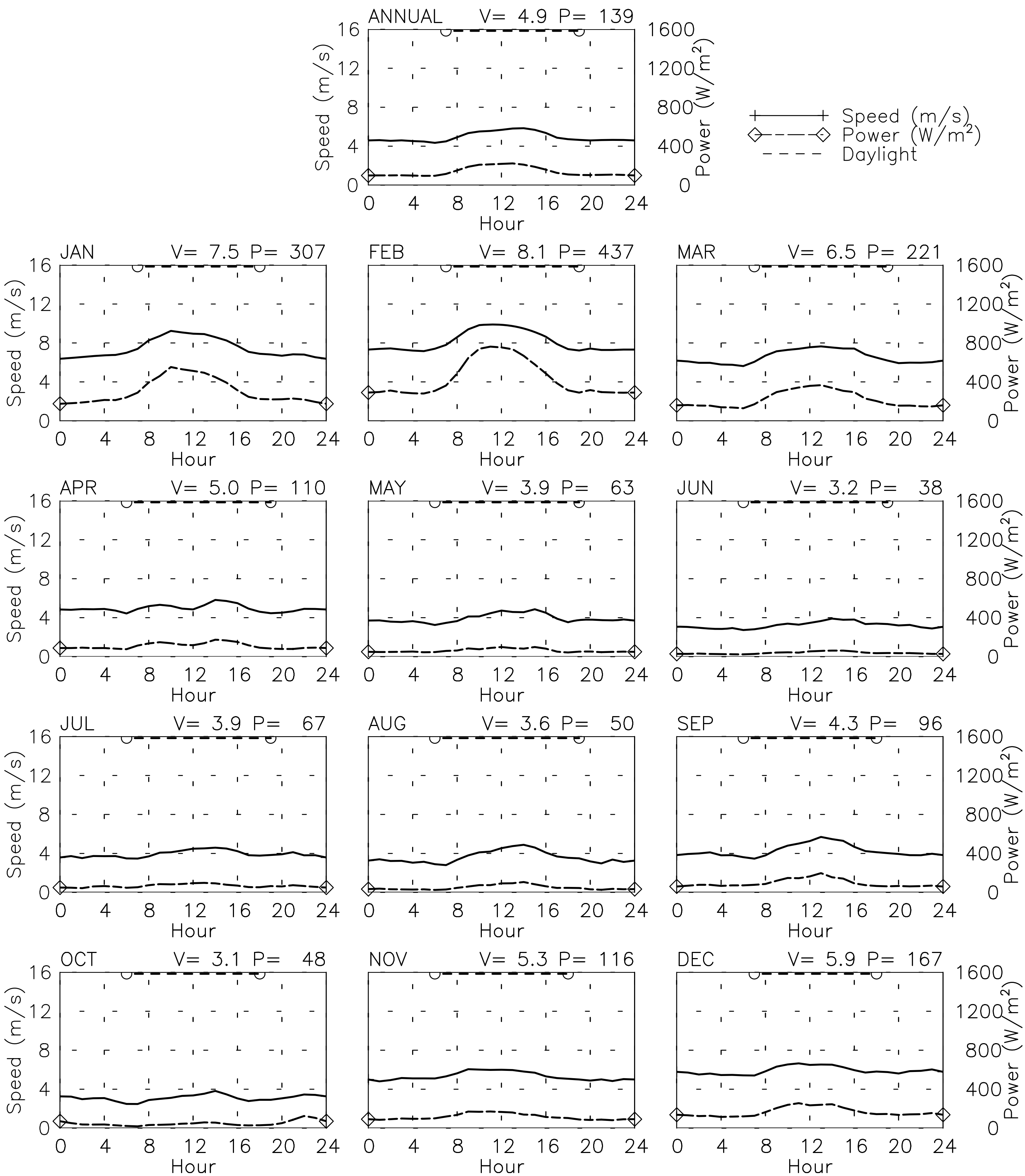

OBSERVATIONS BY MONTH
Guimaras 30m - 980017
10° 32' N 122° 39' E - Elev 160m *LST=GMT +8 hours NT= +8
06/95-05/97
Speed'Obs
Power'Obs
1500
1250
1000
750
500
Speed Obs
Power Obs
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:45:23 2001

SPEED AND POWER BY HOUR

Guimaras 30m – 980017

10° 32' N 122° 39' E – Elev 160m *LST=GMT +8 hours NT= +8

06/95–05/97



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FREQUENCY AND SPEED BY DIRECTION

Guimaras 30m – 980017
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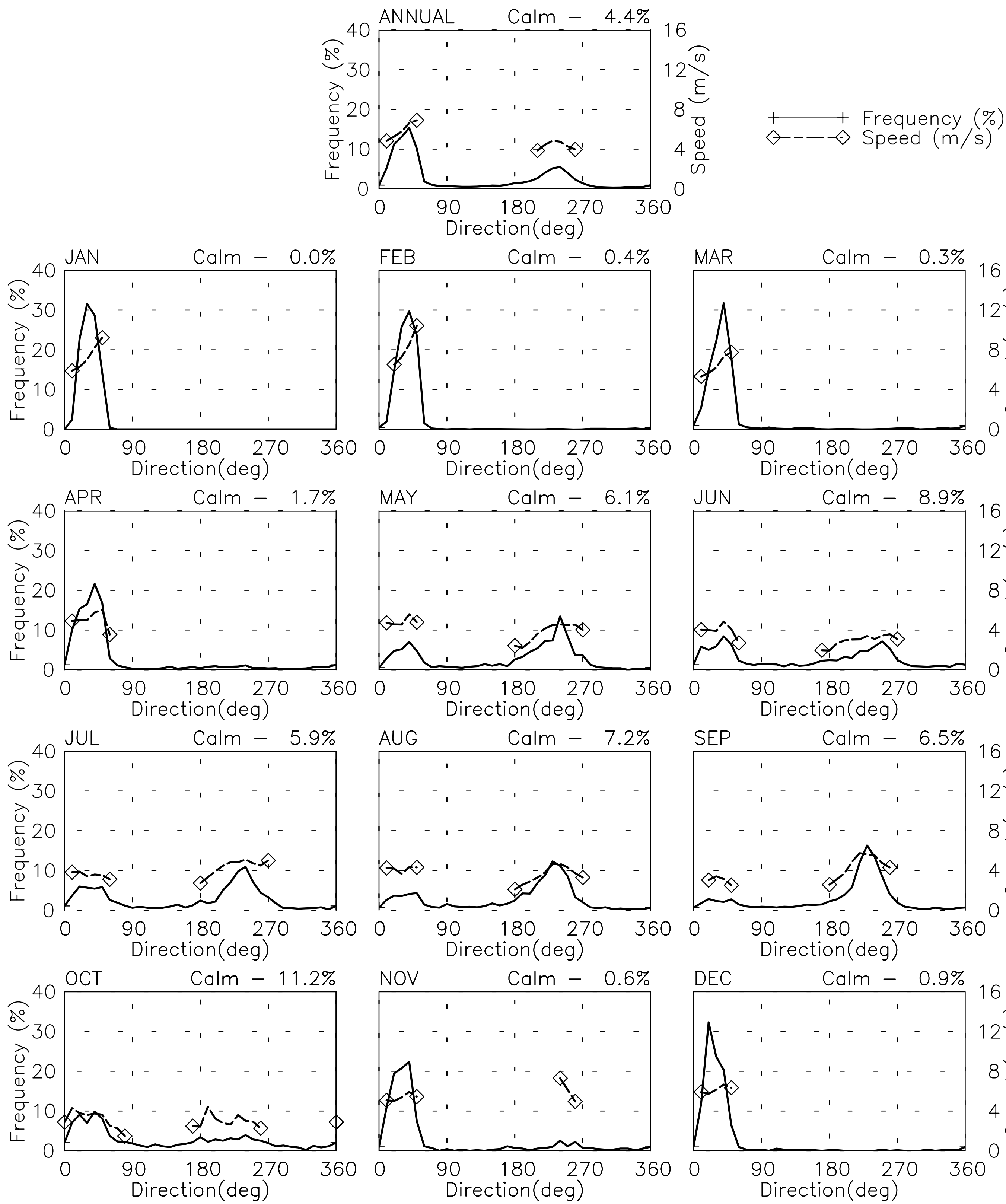
06/95–05/97



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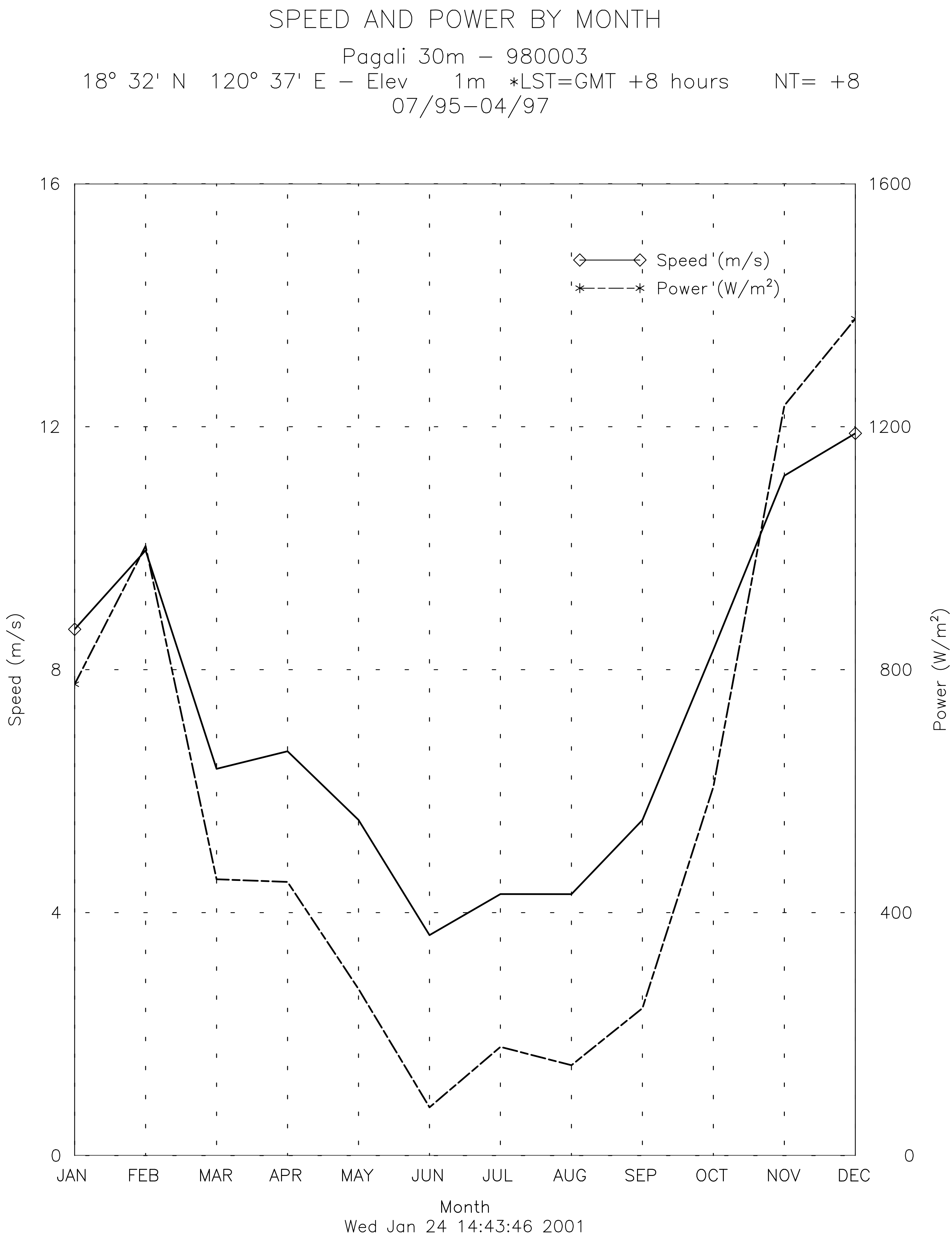
SPEED AND POWER BY MONTH
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07/95-04/97
Speed (m/s)
Power (W/m²)
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
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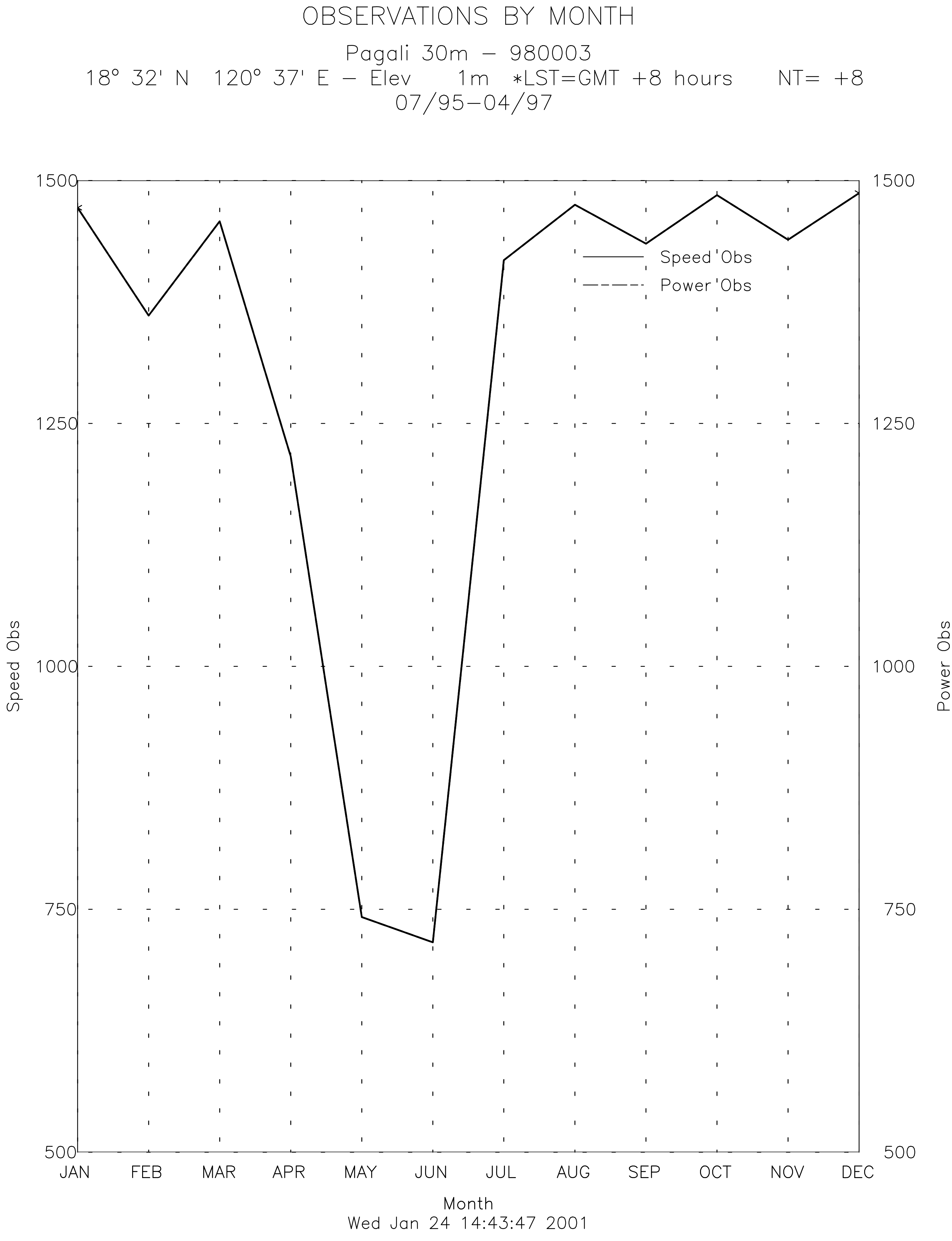
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:43:46 2001


OBSERVATIONS BY MONTH
Pagali 30m - 980003
18° 32' N 120° 37' E - Elev 1m *LST=GMT +8 hours NT= +8
07/95-04/97
Speed'Obs
Power'Obs
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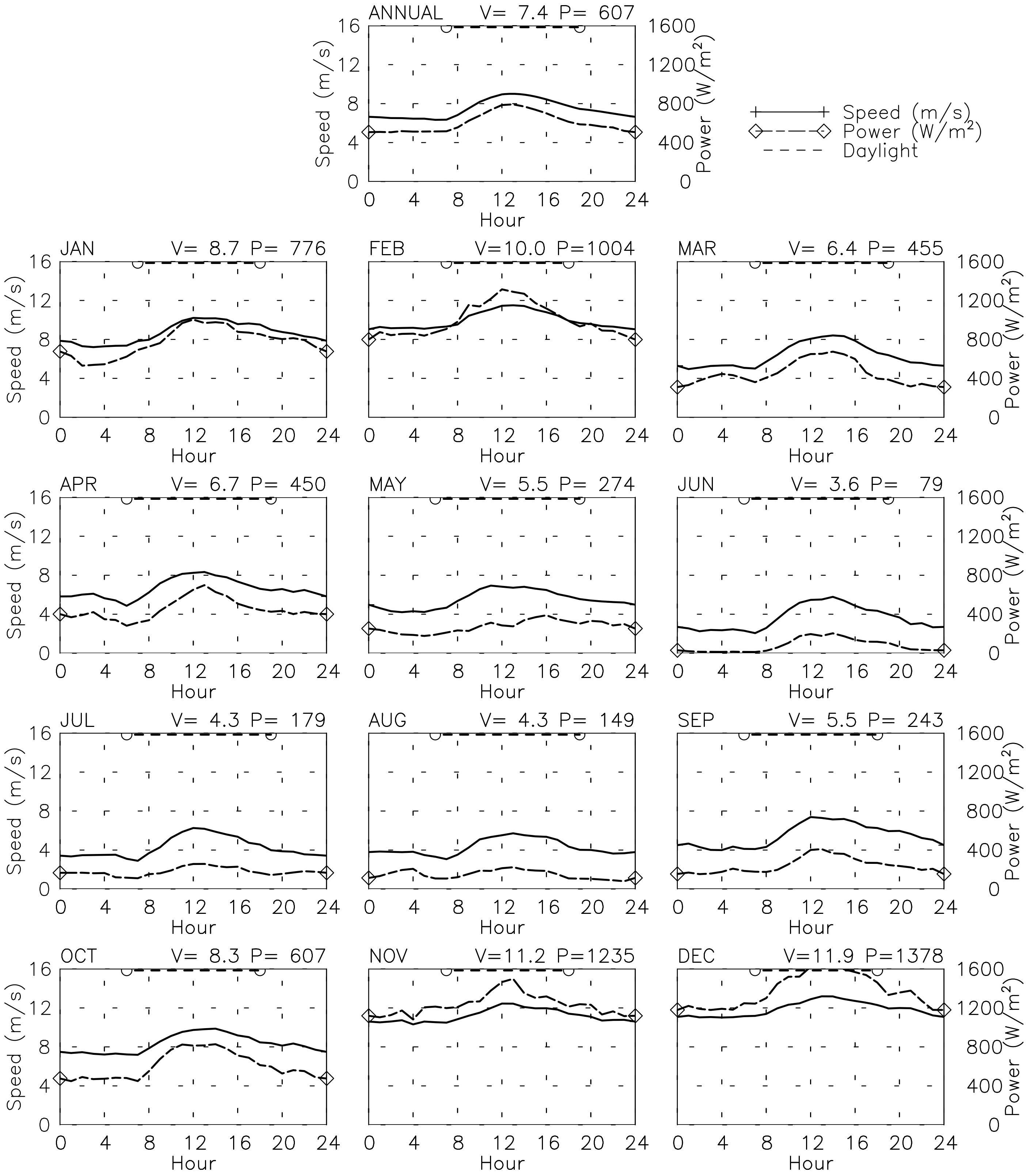
1250
1000
750
500
Speed Obs
Power Obs
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:43:47 2001

SPEED AND POWER BY HOUR

Pagali 30m – 980003
18° 32' N 120° 37' E – Elev 1m *LST=GMT +8 hours NT= +8
07/95–04/97



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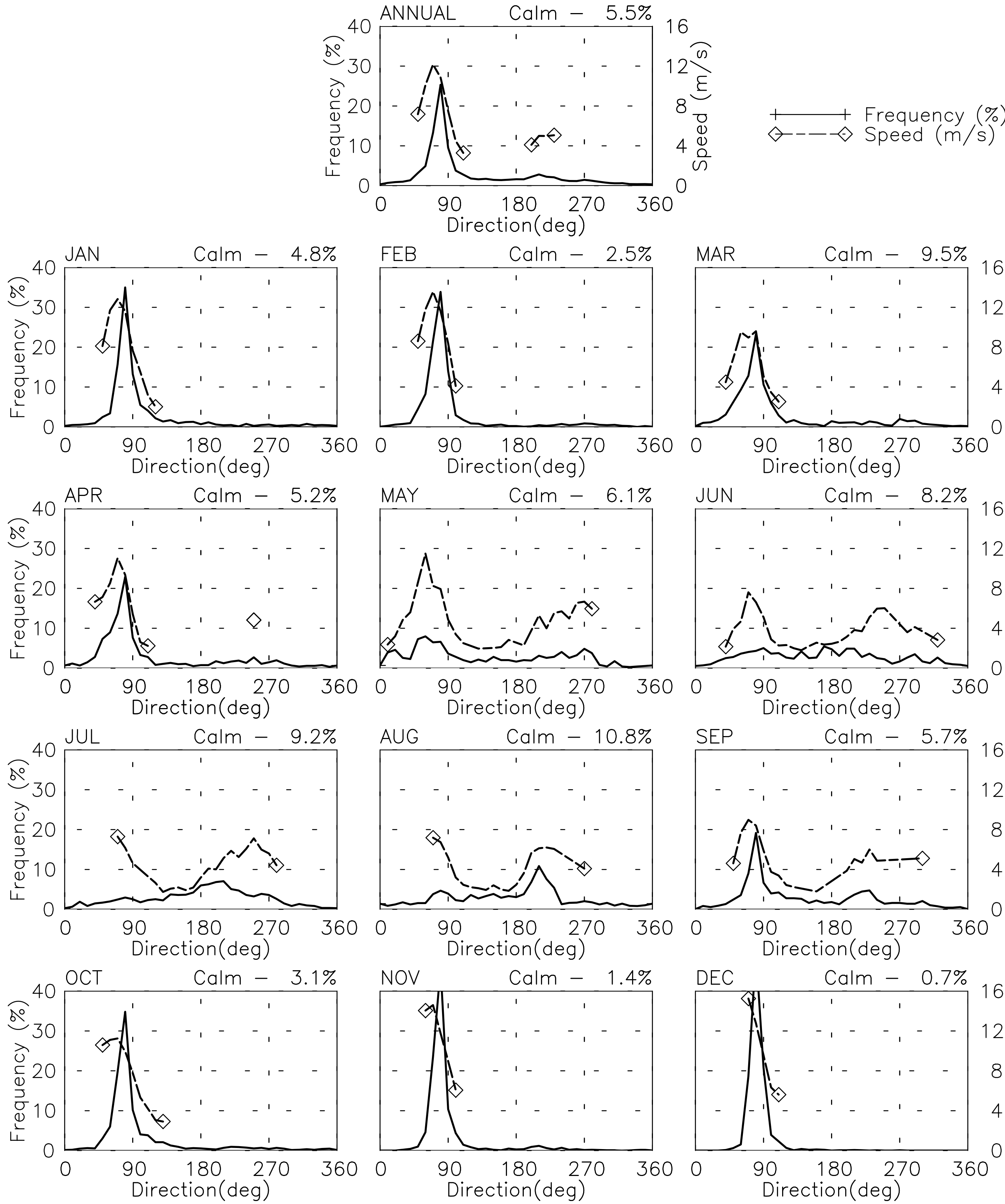
FREQUENCY AND SPEED BY DIRECTION

Pagali 30m – 980003

18° 32' N 120° 37' E – Elev 1m *LST=GMT +8 hours NT= +8

07/95–04/97



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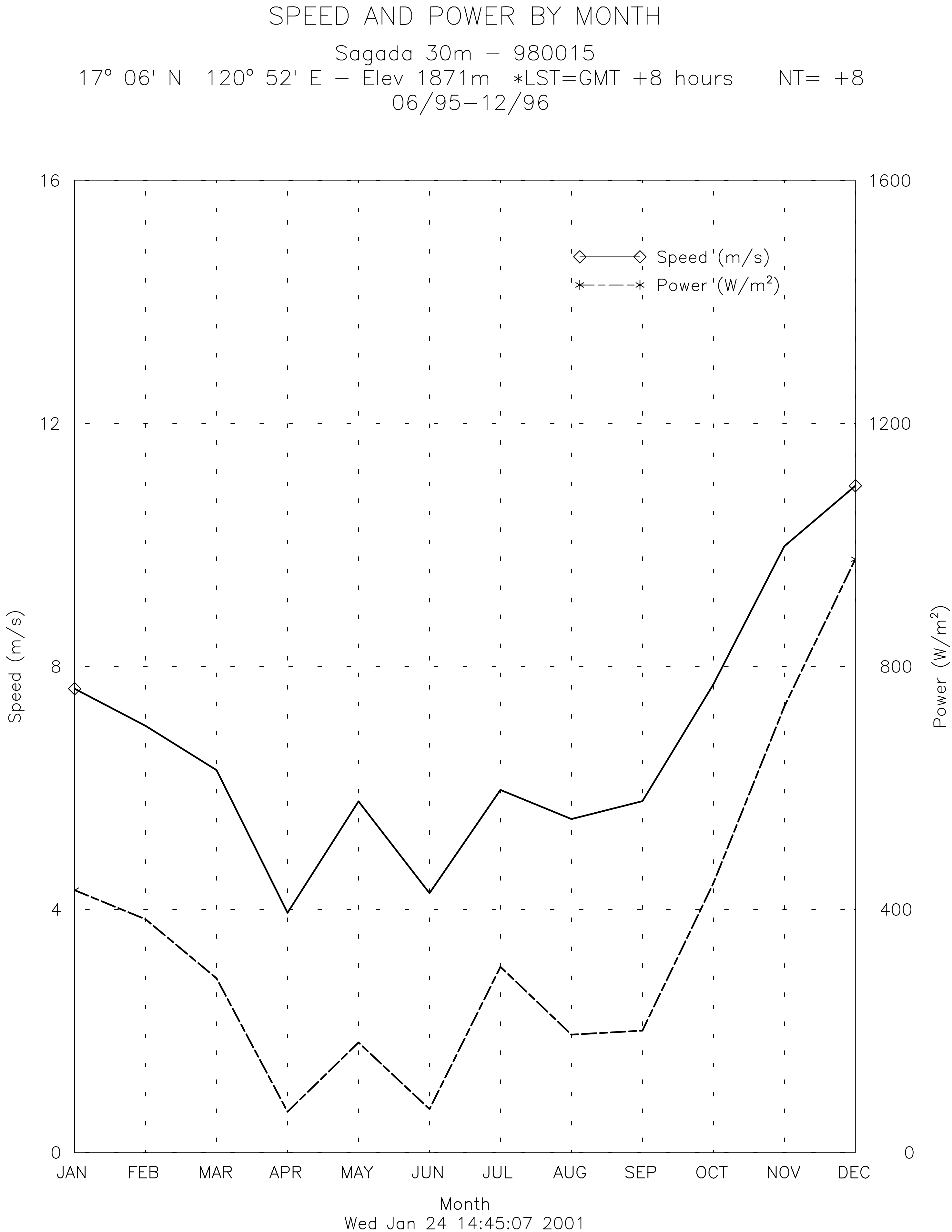

SPEED AND POWER BY MONTH
Sagada 30m - 980015
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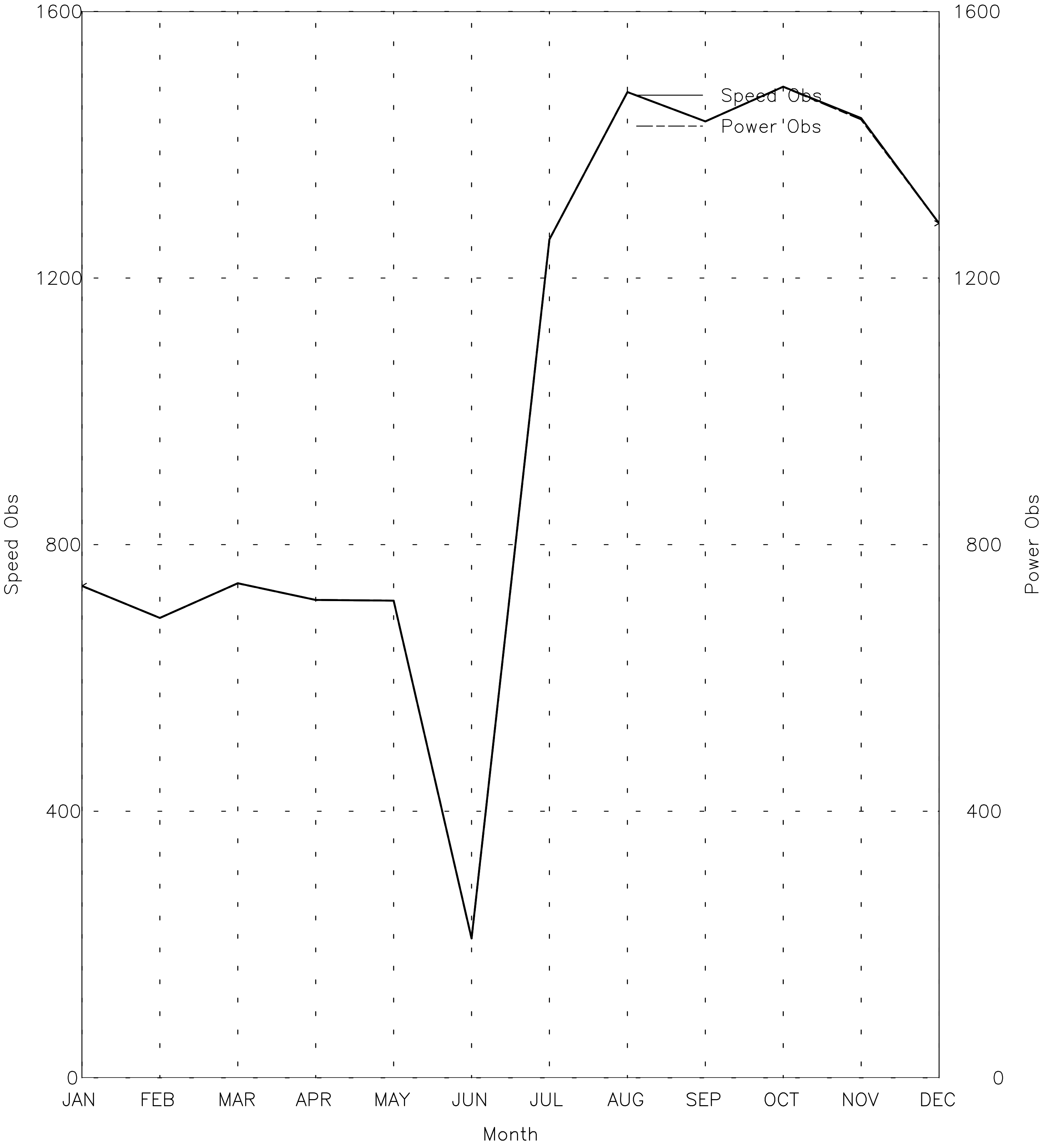
06/95-12/96
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:45:07 2001

OBSERVATIONS BY MONTH

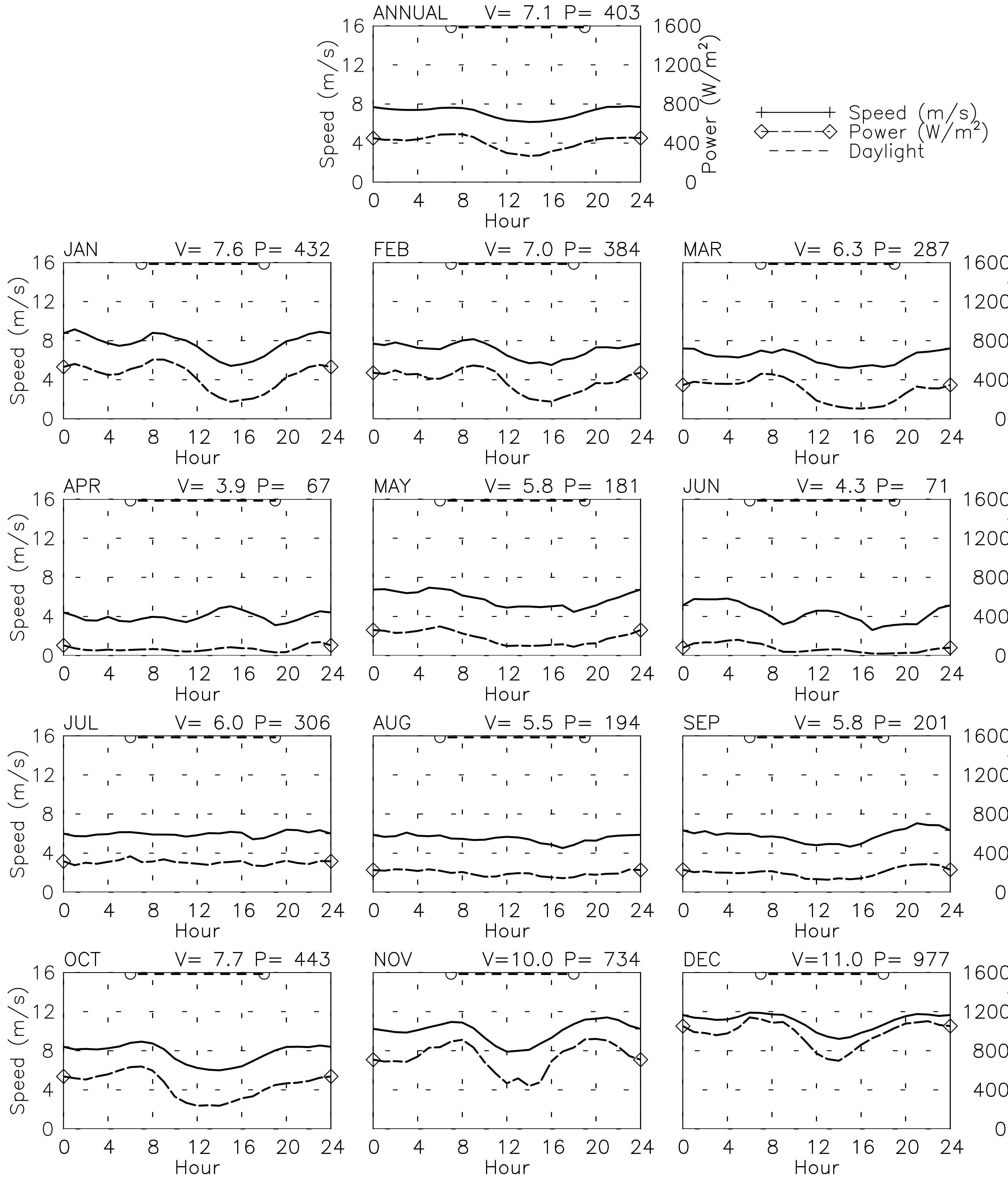
Sagada 30m – 980015
17° 06' N 120° 52' E – Elev 1871m *LST=GMT +8 hours NT= +8
06/95–12/96



Wed Jan 24 14:45:09 2001

SPEED AND POWER BY HOUR

Sagada 30m – 980015
17° 06' N 120° 52' E – Elev 1871m *LST=GMT +8 hours NT= +8
06/95–12/96



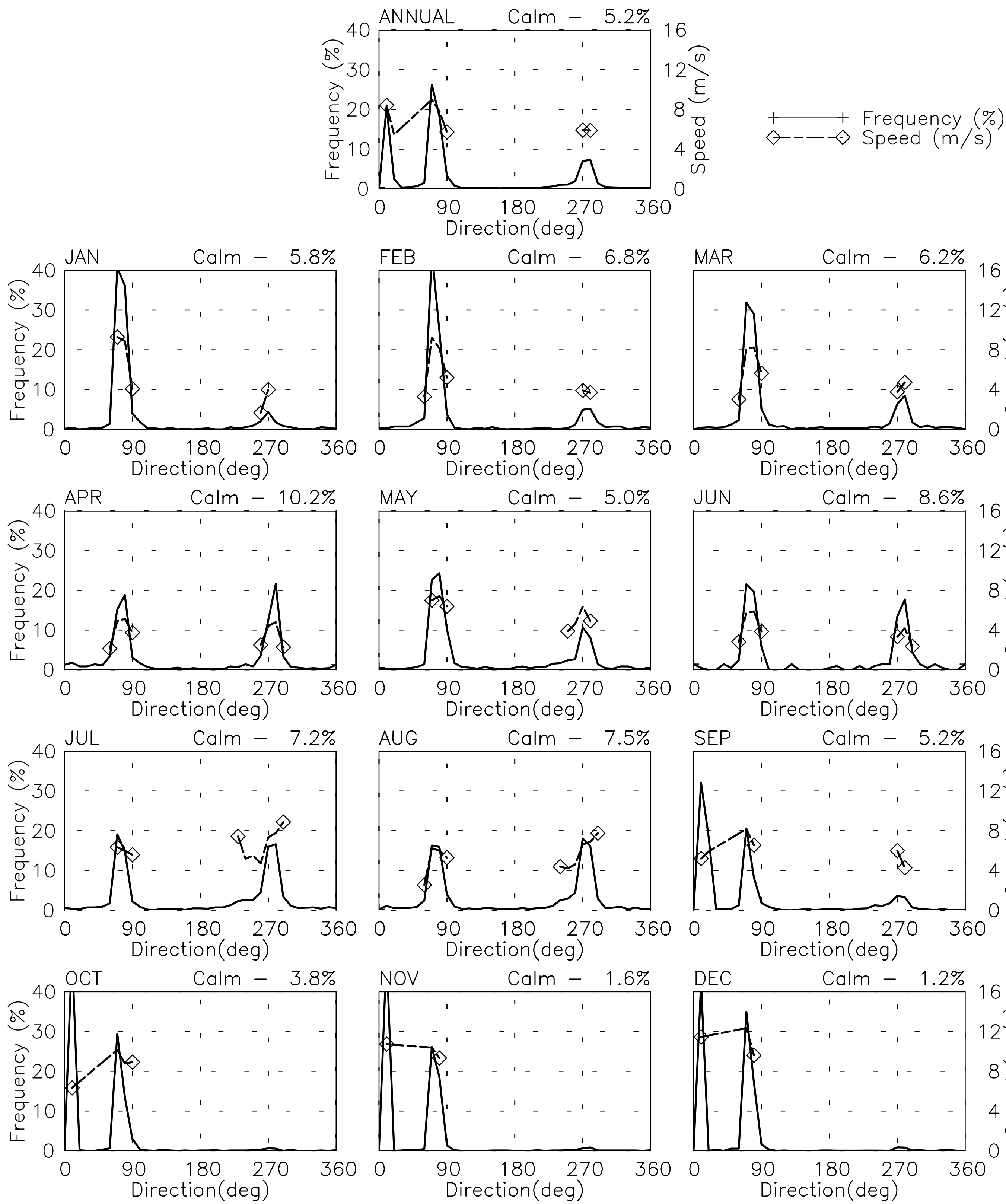
Wed Jan 24 14:45:11 2001

FREQUENCY AND SPEED BY DIRECTION

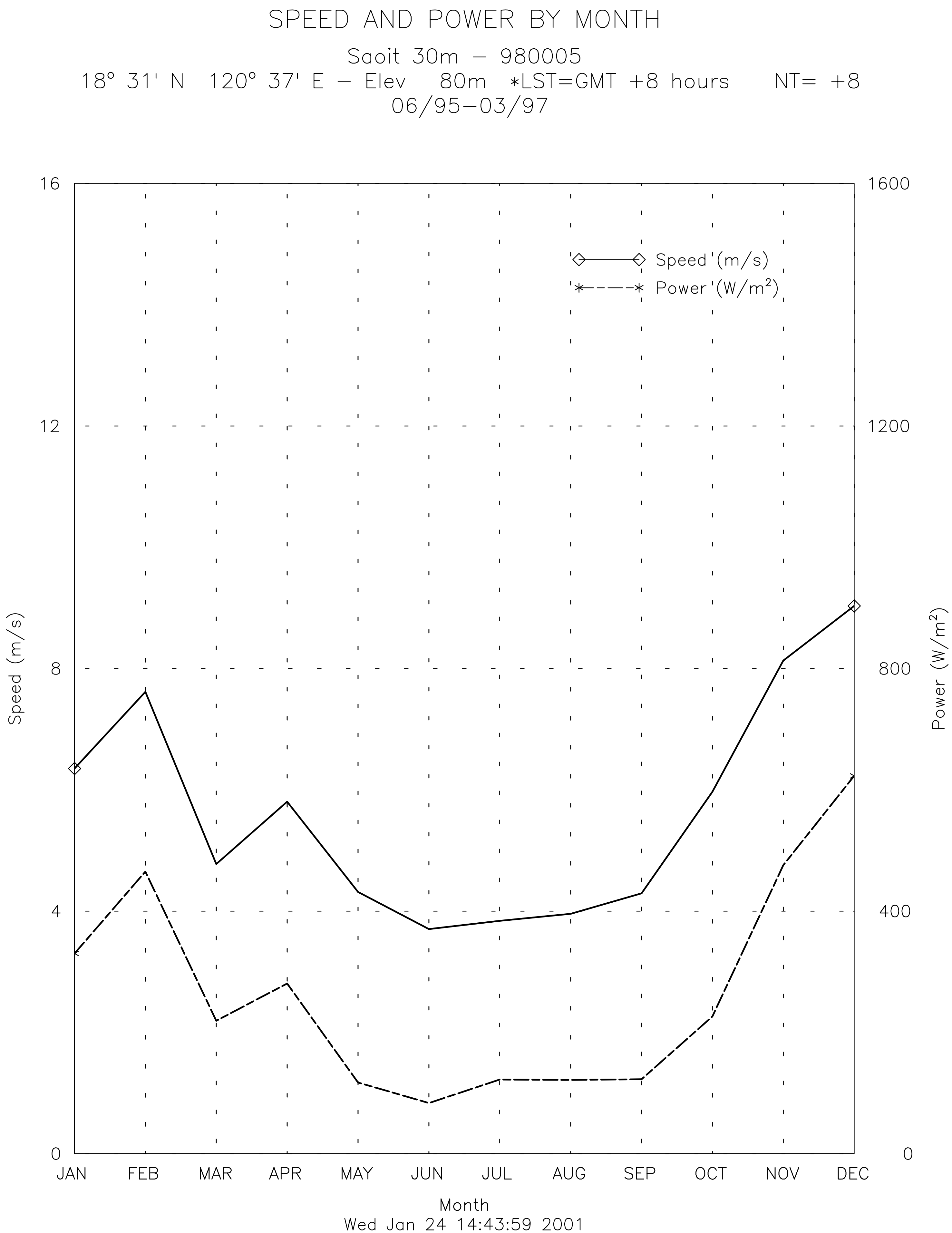
Sagada 30m – 980015

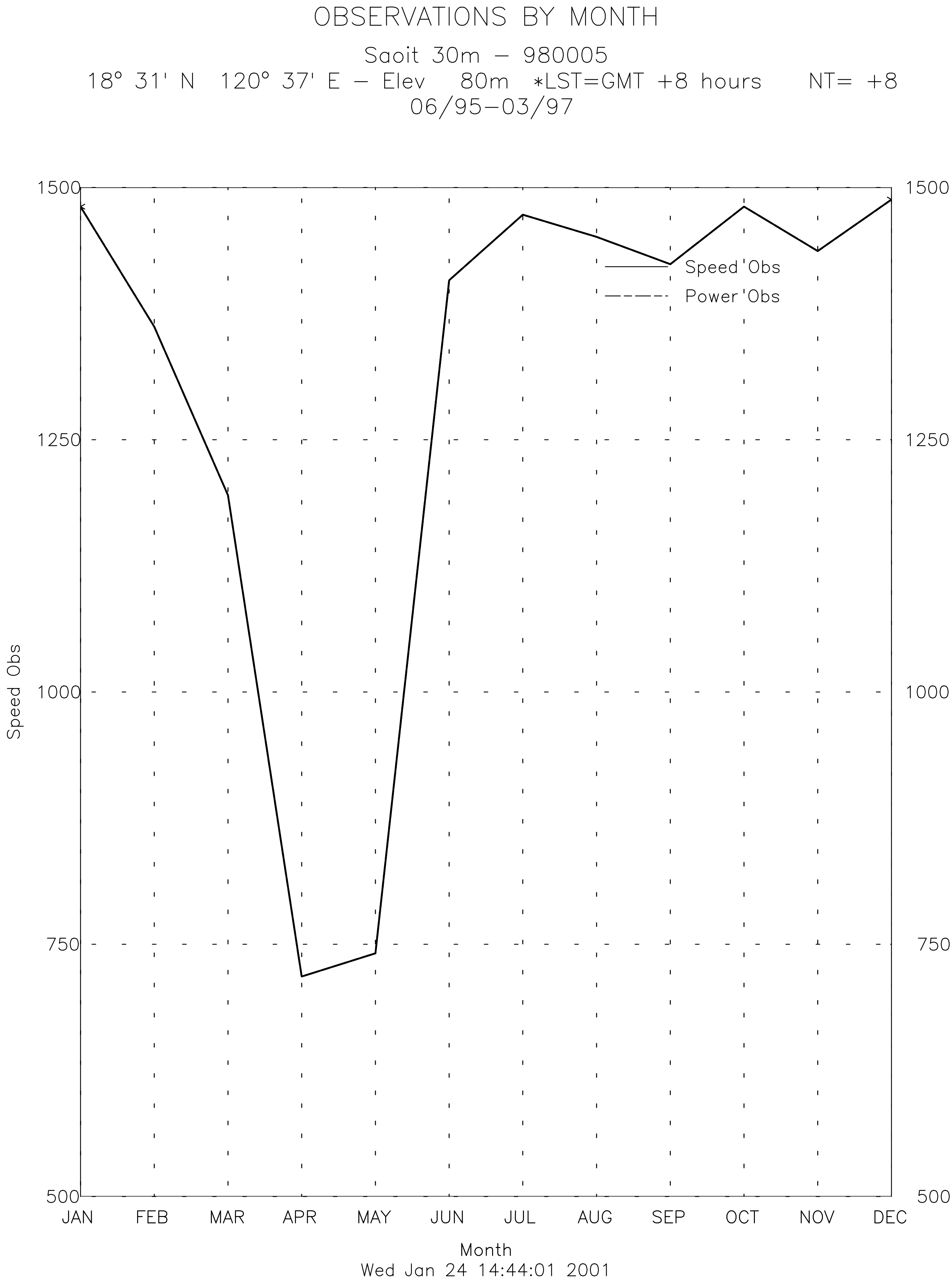
17° 06' N 120° 52' E – Elev 1871m *LST=GMT +8 hours   NT= +8

06/95–12/96



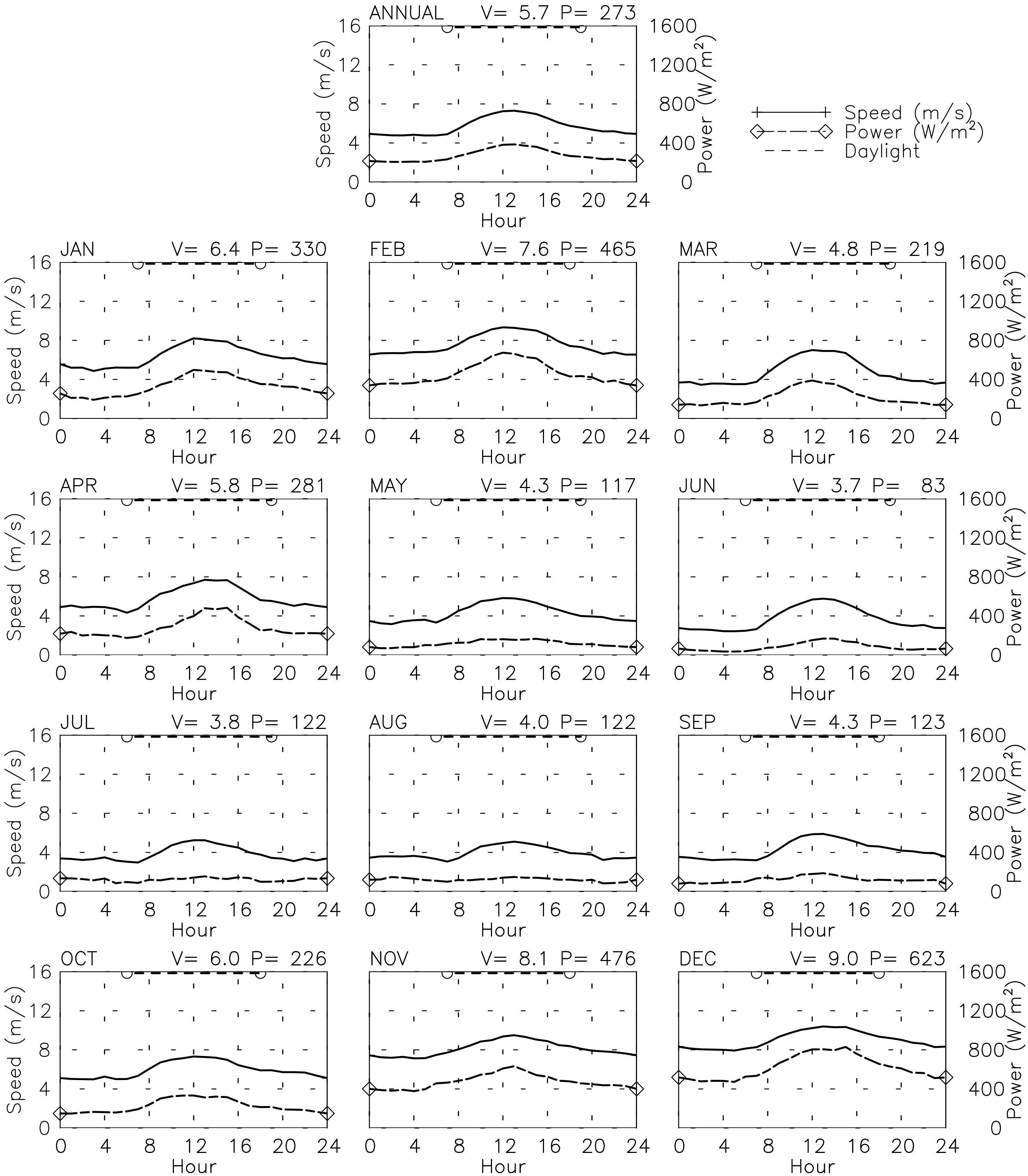
Wed Jan 24 14:45:14 2001


SPEED AND POWER BY MONTH
Saoit 30m - 980005
18° 31' N 120° 37' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97
Speed (m/s)
Power (W/m²)
16
12
8
4
0
1600
1200
800
400
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:43:59 2001


OBSERVATIONS BY MONTH
Saoit 30m - 980005
18° 31' N 120° 37' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97
Speed'Obs
Power'Obs
1500
1250
1000
750
500
Speed Obs
Power Obs
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:44:01 2001

SPEED AND POWER BY HOUR

Saoit 30m - 980005
18° 31' N 120° 37' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97



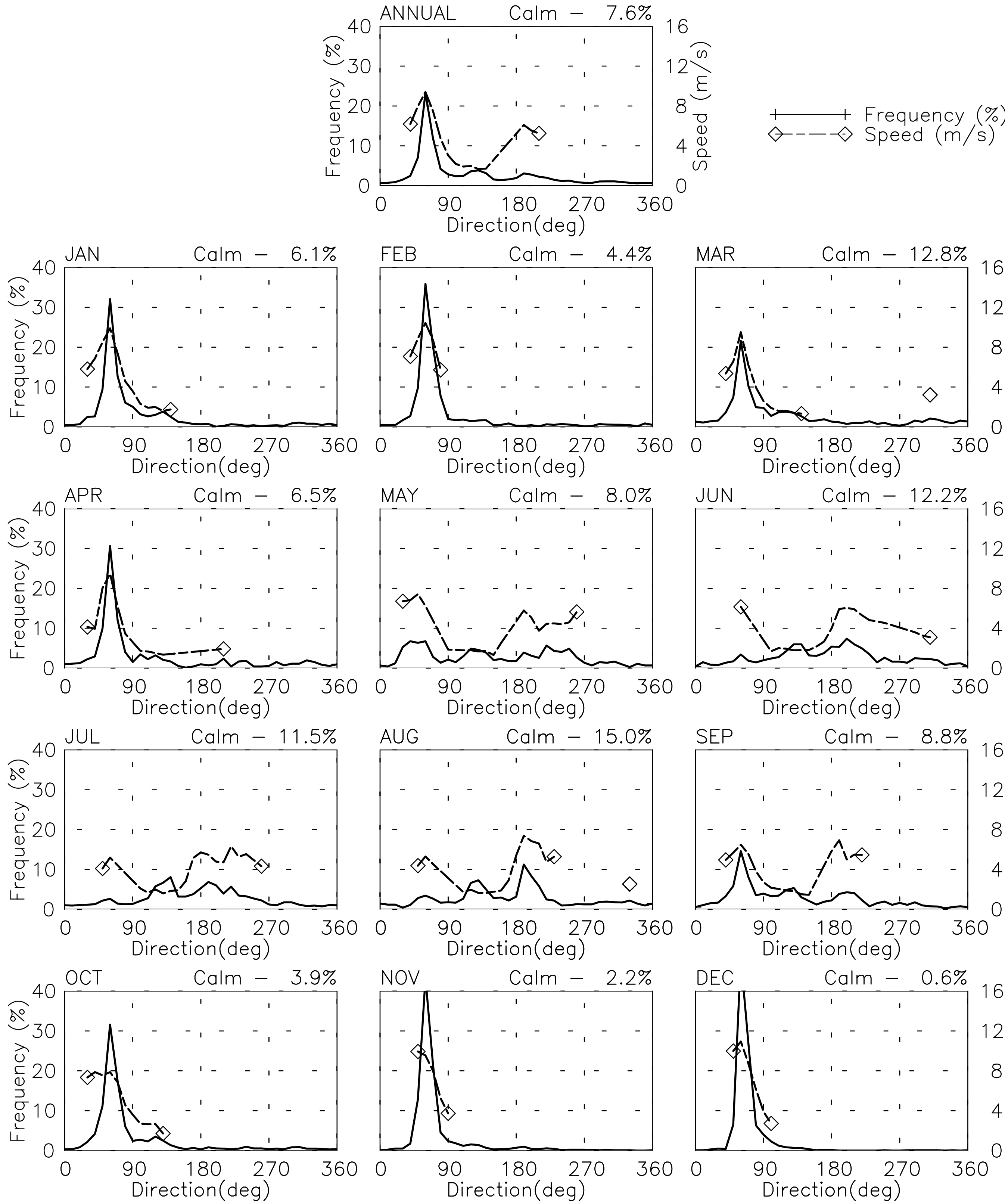
Wed Jan 24 14:44:03 2001

FREQUENCY AND SPEED BY DIRECTION

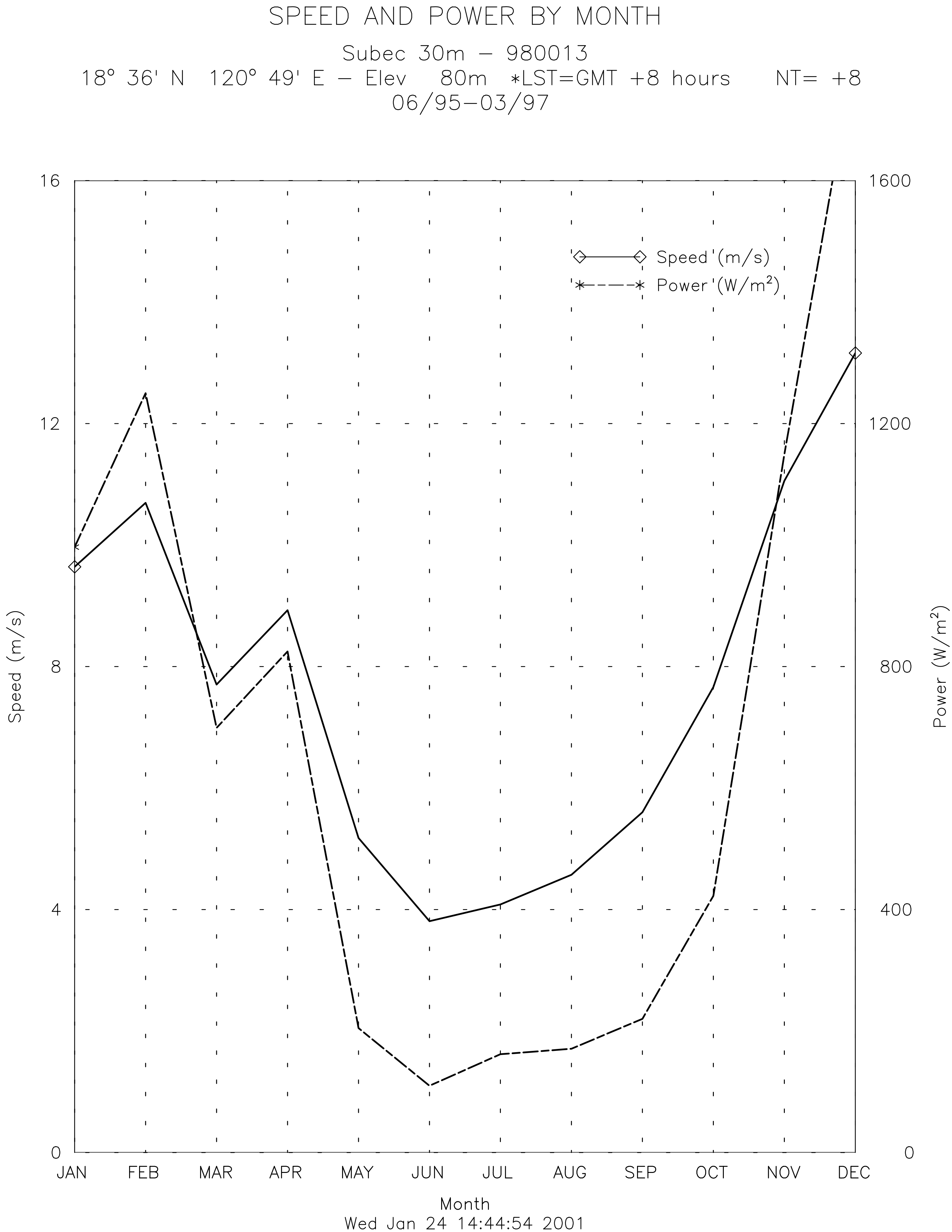
Saoit 30m - 980005

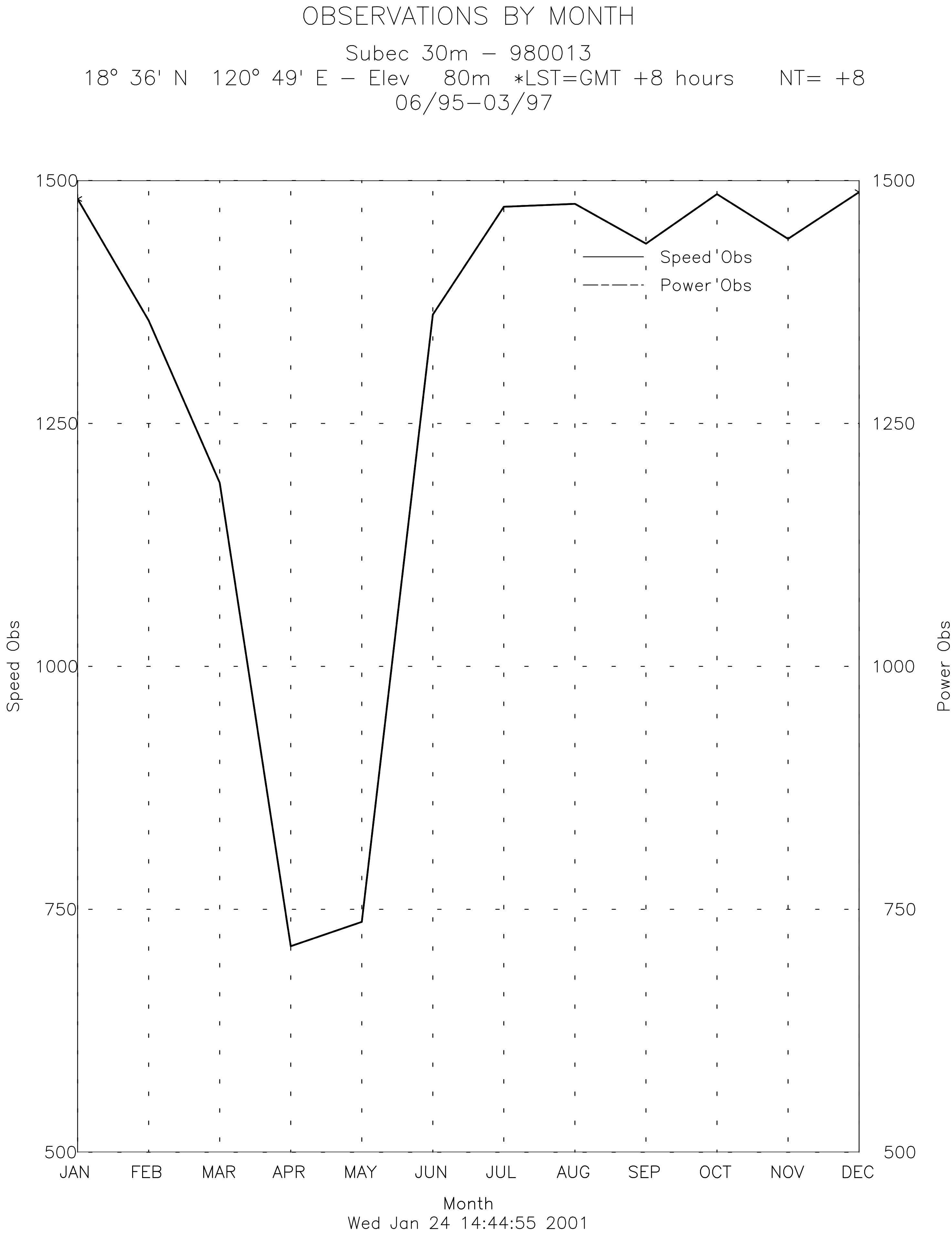
18° 31' N 120° 37' E - Elev 80m *LST=GMT +8 hours NT= +8

06/95-03/97



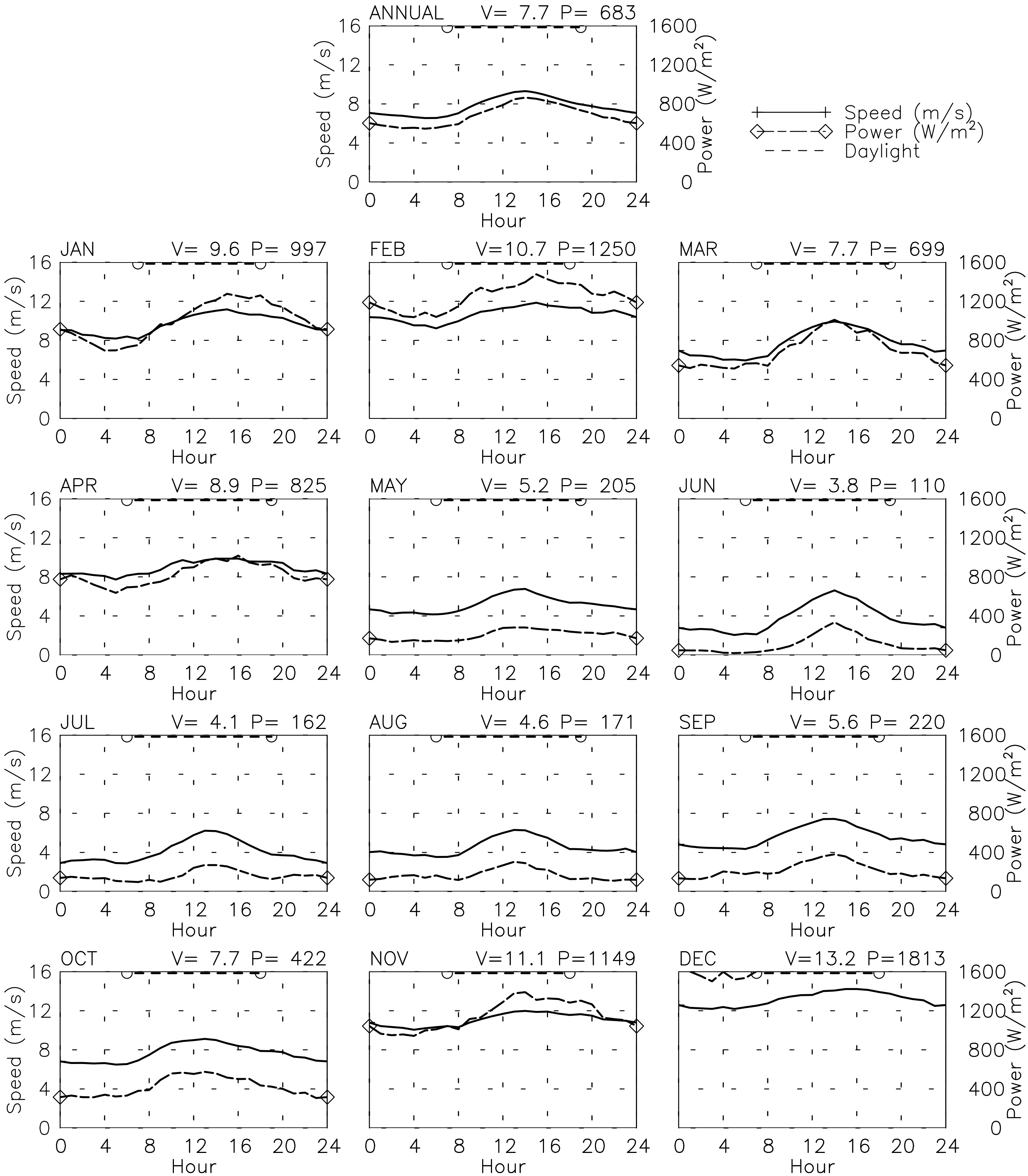
Wed Jan 24 14:44:07 2001


SPEED AND POWER BY MONTH
Subec 30m - 980013
18° 36' N 120° 49' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97
Speed (m/s)
Power (W/m²)
Month
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
0 4 8 12 16
0 400 800 1200 1600
Wed Jan 24 14:44:54 2001


OBSERVATIONS BY MONTH
Subec 30m - 980013
18° 36' N 120° 49' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97
Speed'Obs
Power'Obs
Speed Obs
Power Obs
1500
1250
1000
750
500
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Wed Jan 24 14:44:55 2001

SPEED AND POWER BY HOUR

Subec 30m - 980013
18° 36' N 120° 49' E - Elev 80m *LST=GMT +8 hours NT= +8
06/95-03/97



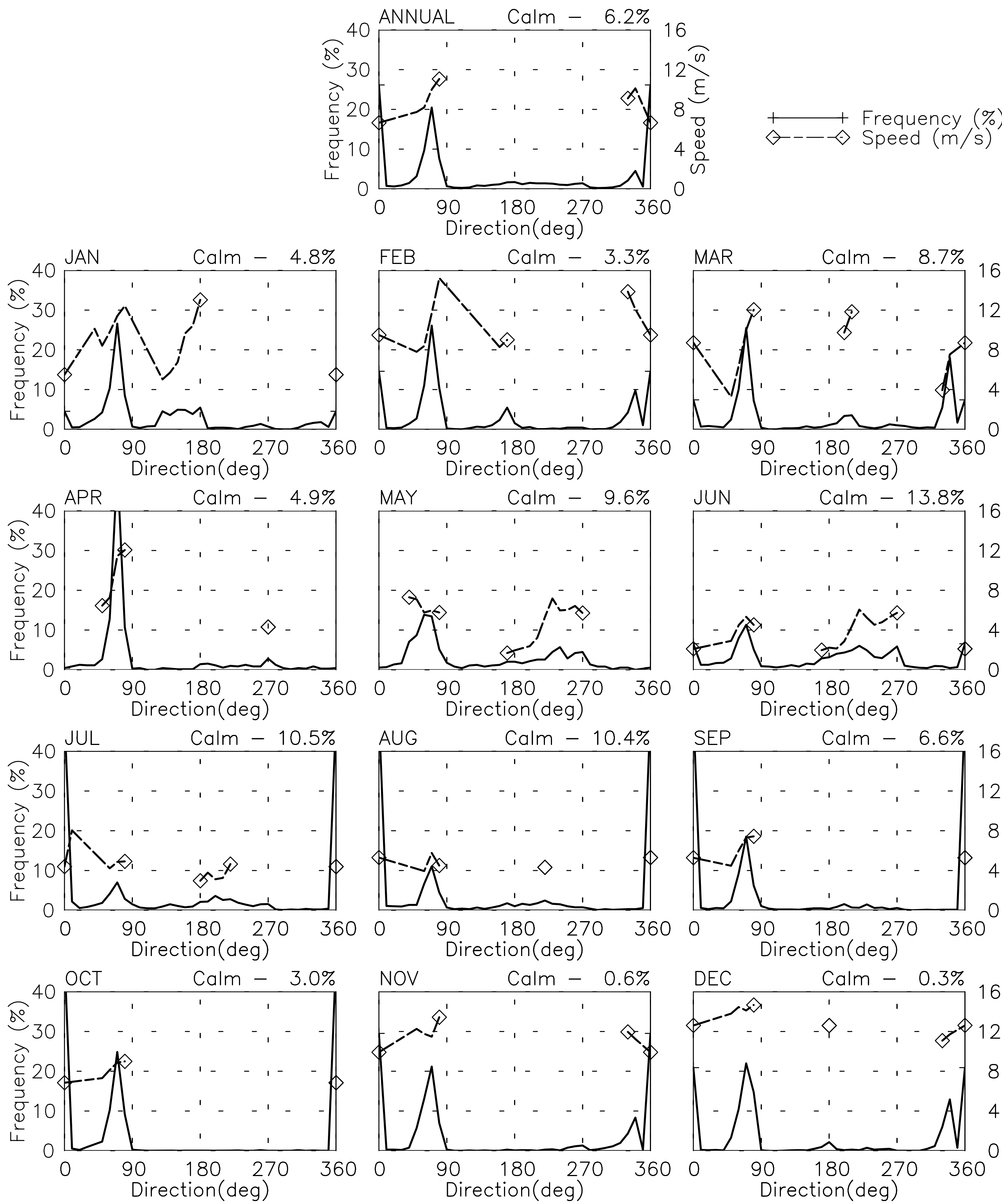
Wed Jan 24 14:44:57 2001

FREQUENCY AND SPEED BY DIRECTION

Subec 30m – 980013

18° 36' N 120° 49' E – Elev 80m *LST=GMT +8 hours NT= +8

06/95–03/97



Wed Jan 24 14:45:00 2001

Appendix B

Analysis Summaries—Selected Sites from DATSAV2 Data Files

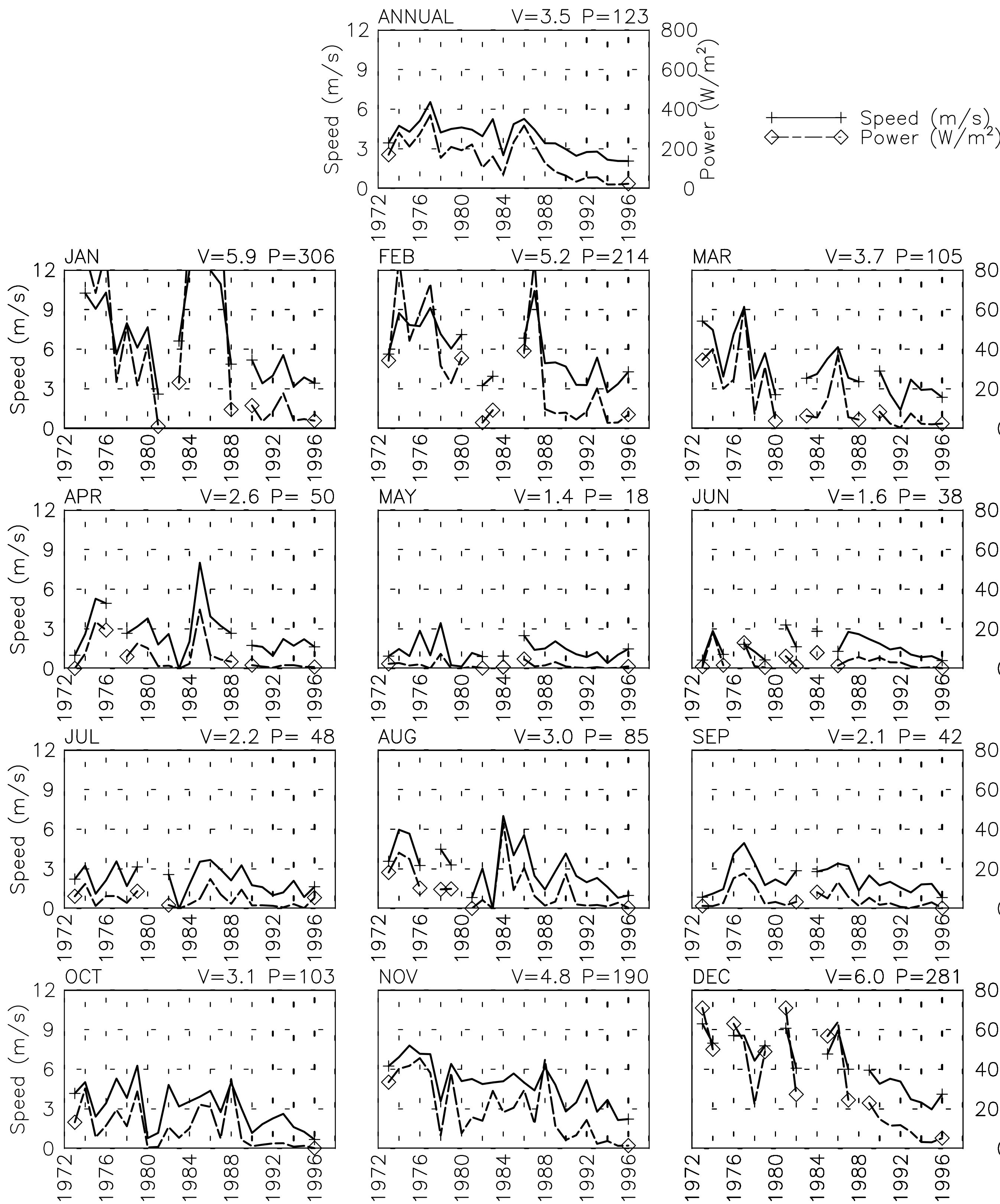
Cuyo
Daet
Guiuan

SPEED AND POWER BY YEAR

CUYO ISLANDS   PH - 986300

10° 51' N 121° 02' E - Elev   4m *LST=GMT +8 hours   NT= +8

02/73-12/96



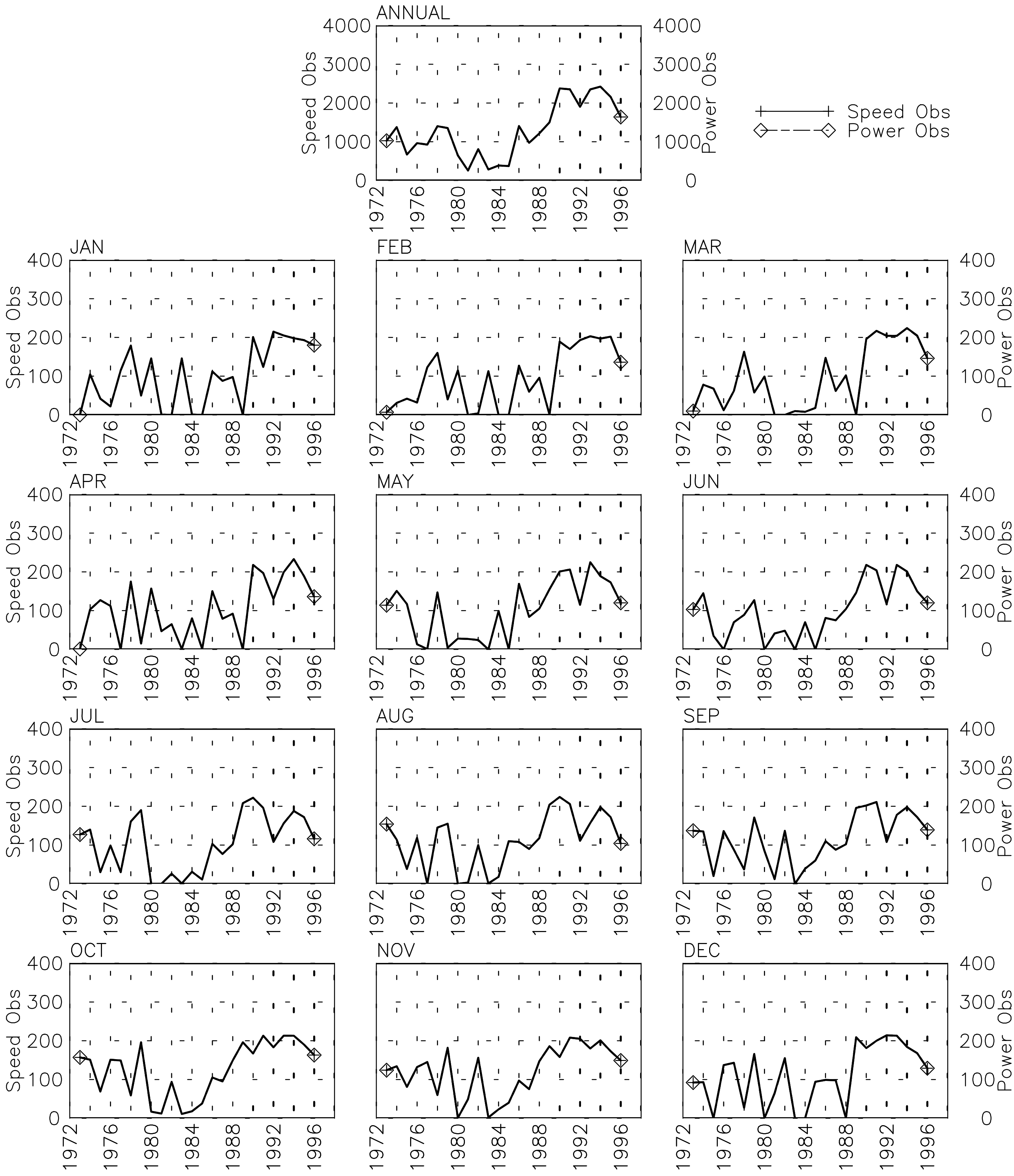
Fri Jul 9 12:07:18 1999

OBSERVATIONS BY YEAR

CUYO ISLANDS PH – 986300

10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8

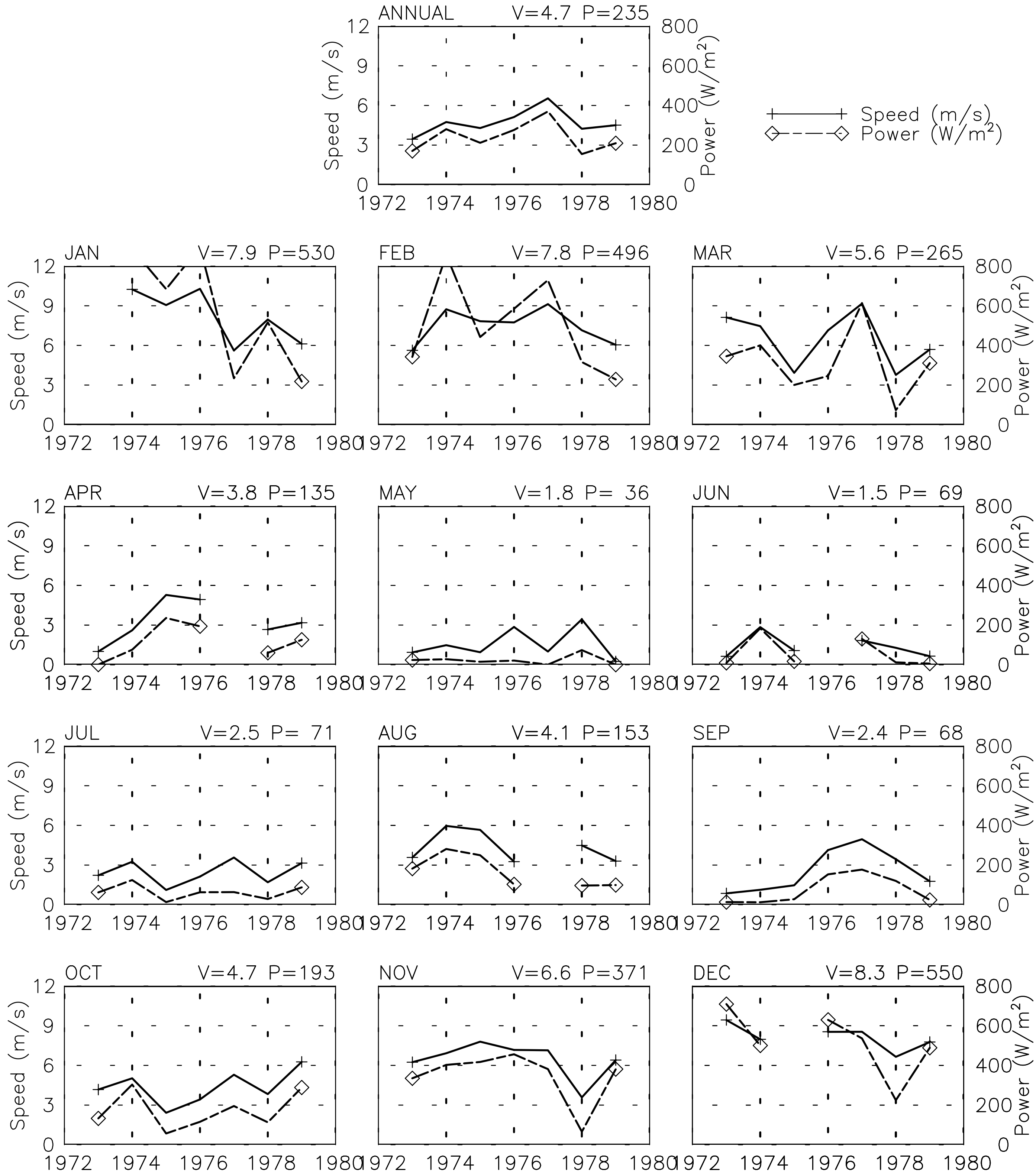
02/73–12/96



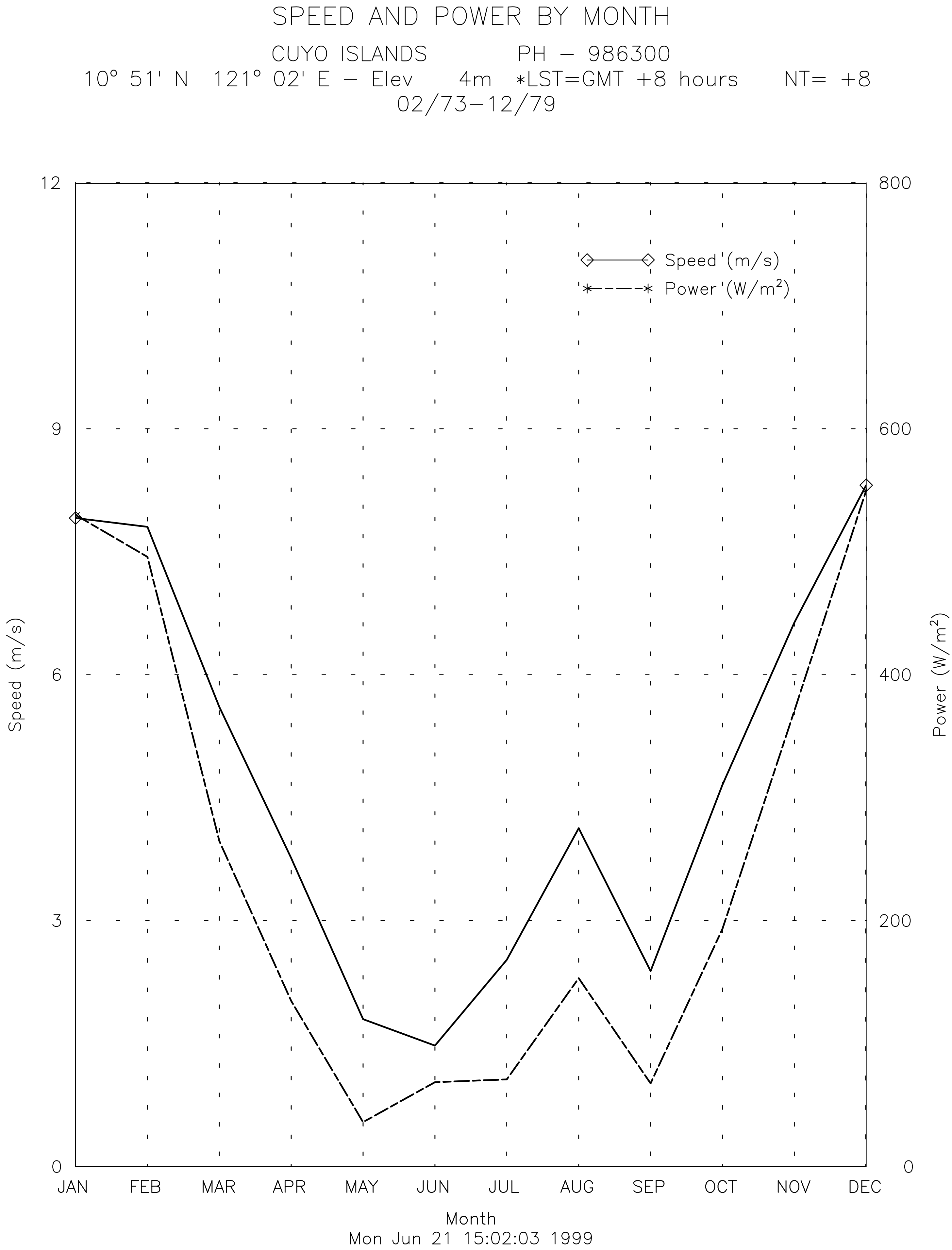
Fri Jul 9 12:07:25 1999

SPEED AND POWER BY YEAR

CUYO ISLANDS PH – 986300
10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8
02/73–12/79



Wed Jun 23 15:05:25 1999

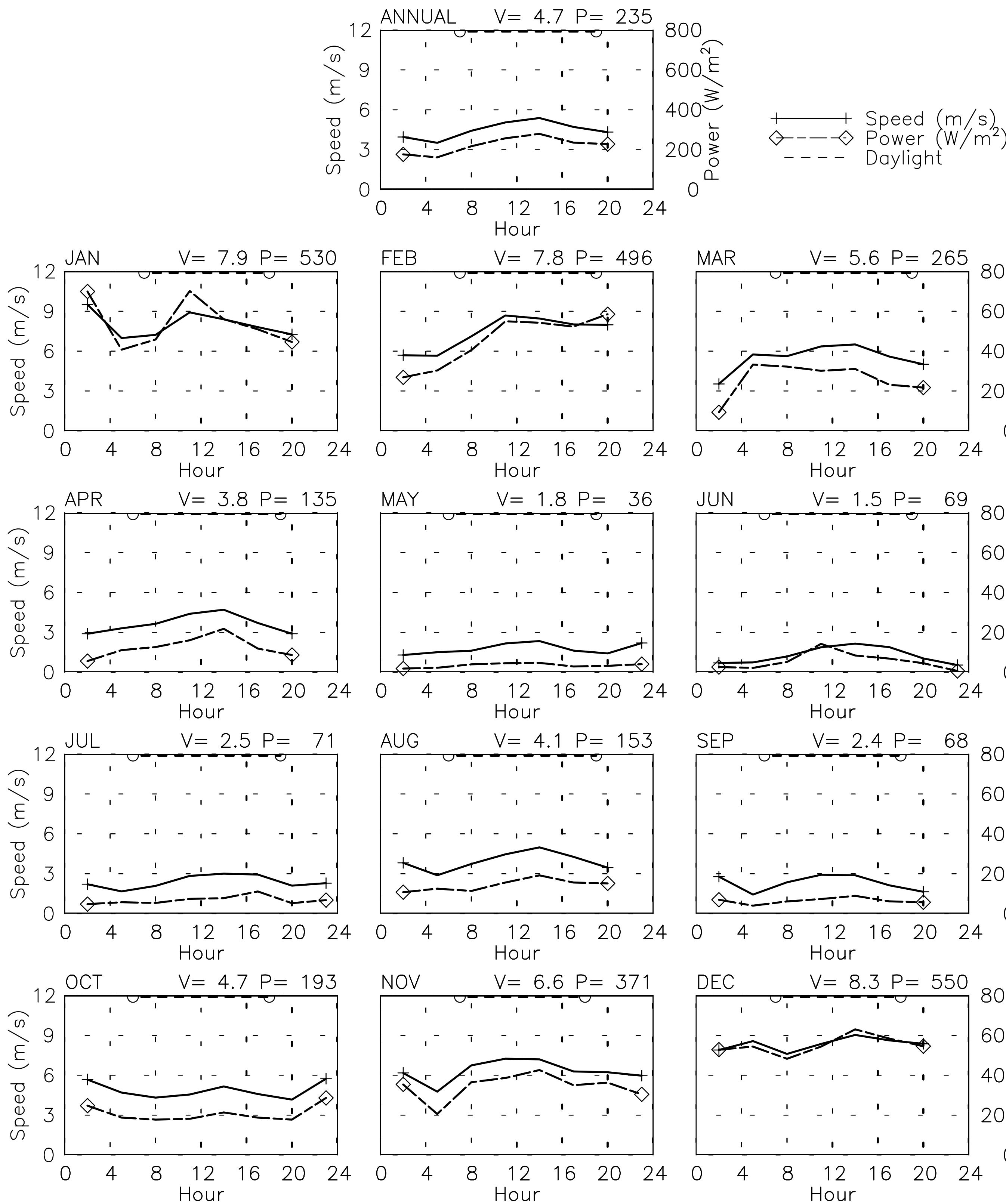

SPEED AND POWER BY MONTH
CUYO ISLANDS PH – 986300
10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8
02/73–12/79
Speed (m/s)
Power (W/m²)
Month
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
0
3
6
9
12
0
200
400
600
800
Mon Jun 21 15:02:03 1999

SPEED AND POWER BY HOUR

CUYO ISLANDS PH – 986300

10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8

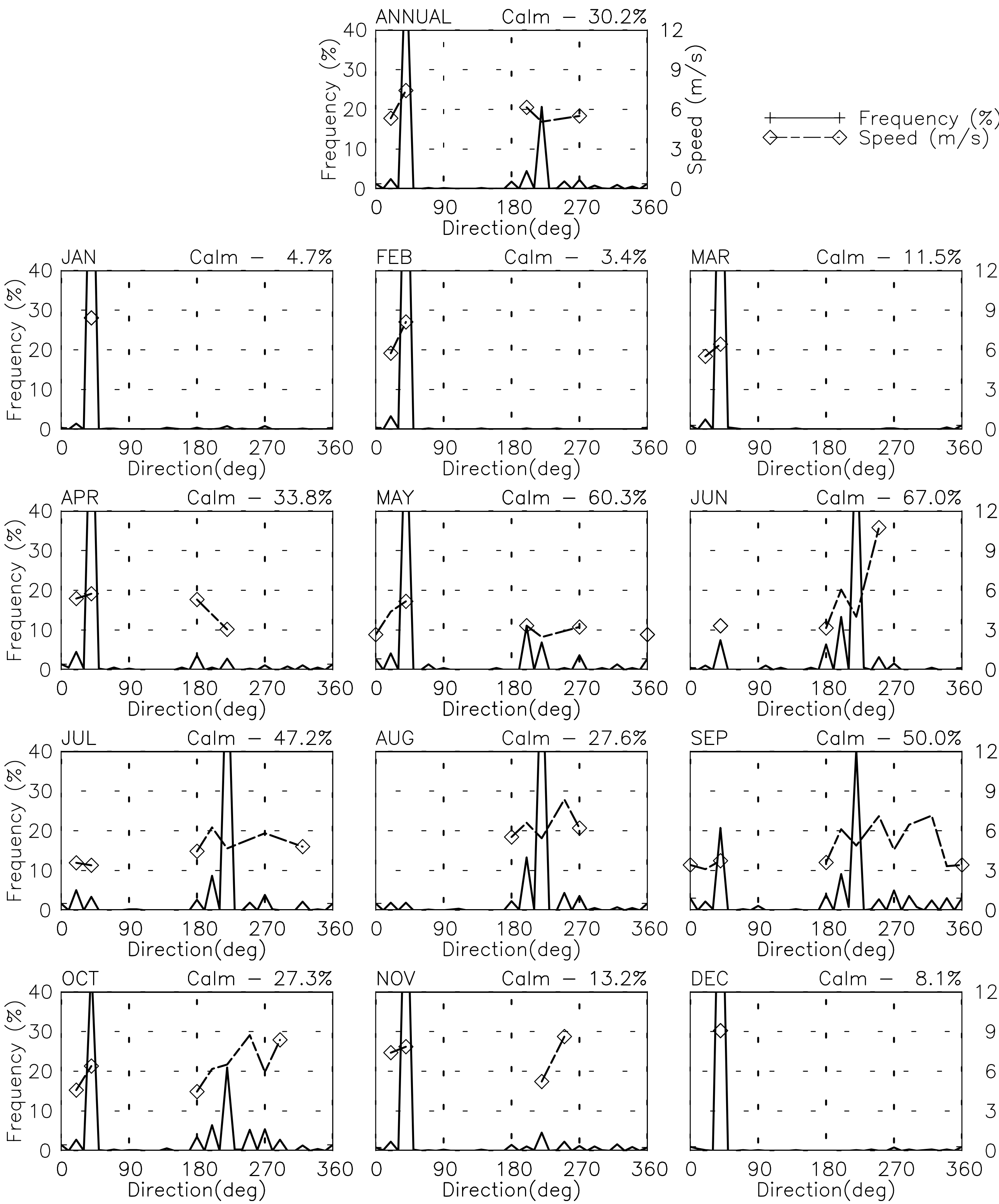
02/73–12/79



Mon Jun 21 15:02:05 1999

FREQUENCY AND SPEED BY DIRECTION

CUYO ISLANDS PH - 986300
10° 51' N 121° 02' E - Elev 4m *LST=GMT +8 hours NT= +8
02/73-12/79



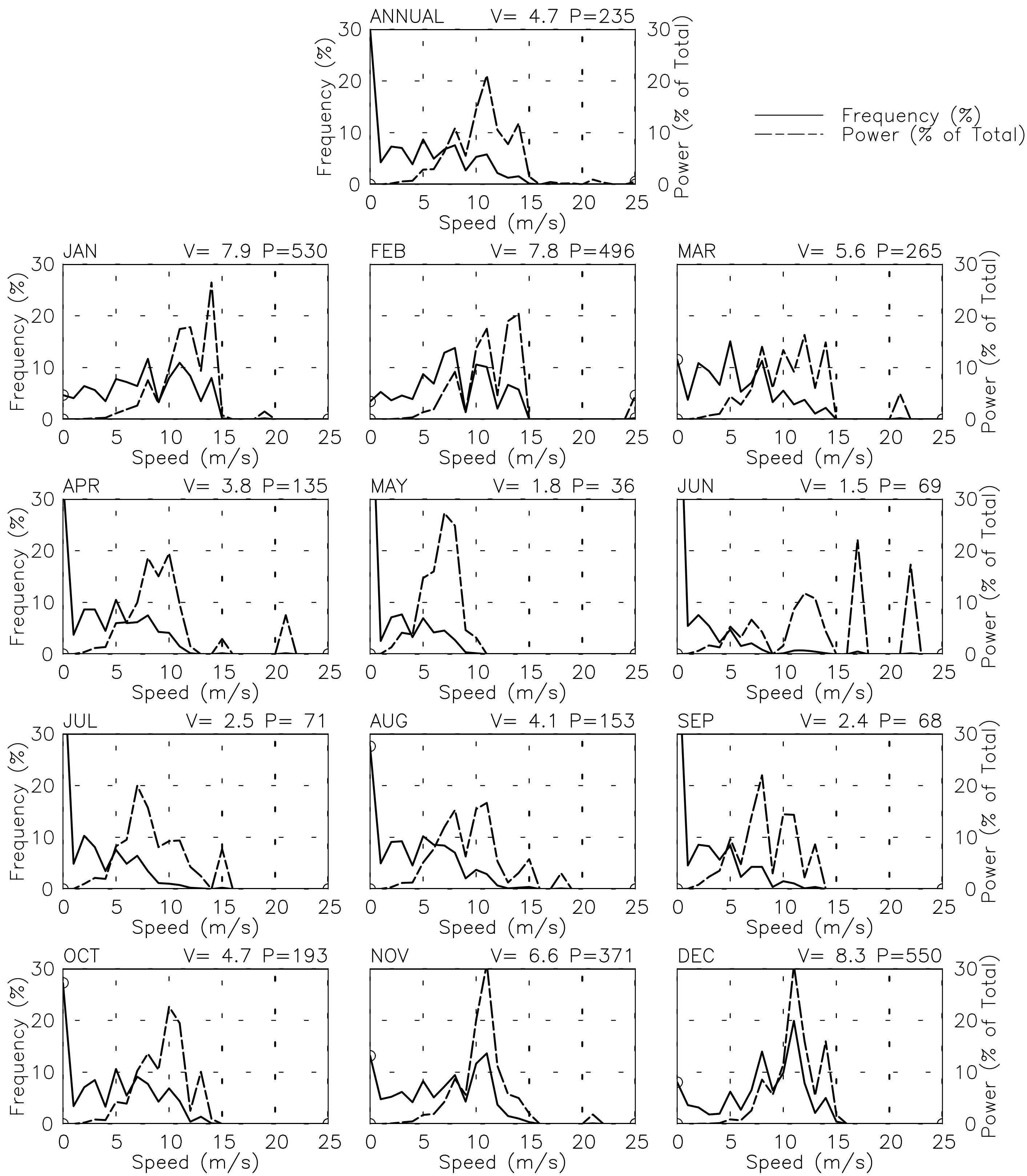
Mon Jun 21 15:02:10 1999

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

CUYO ISLANDS PH – 986300

10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8

02/73–12/79



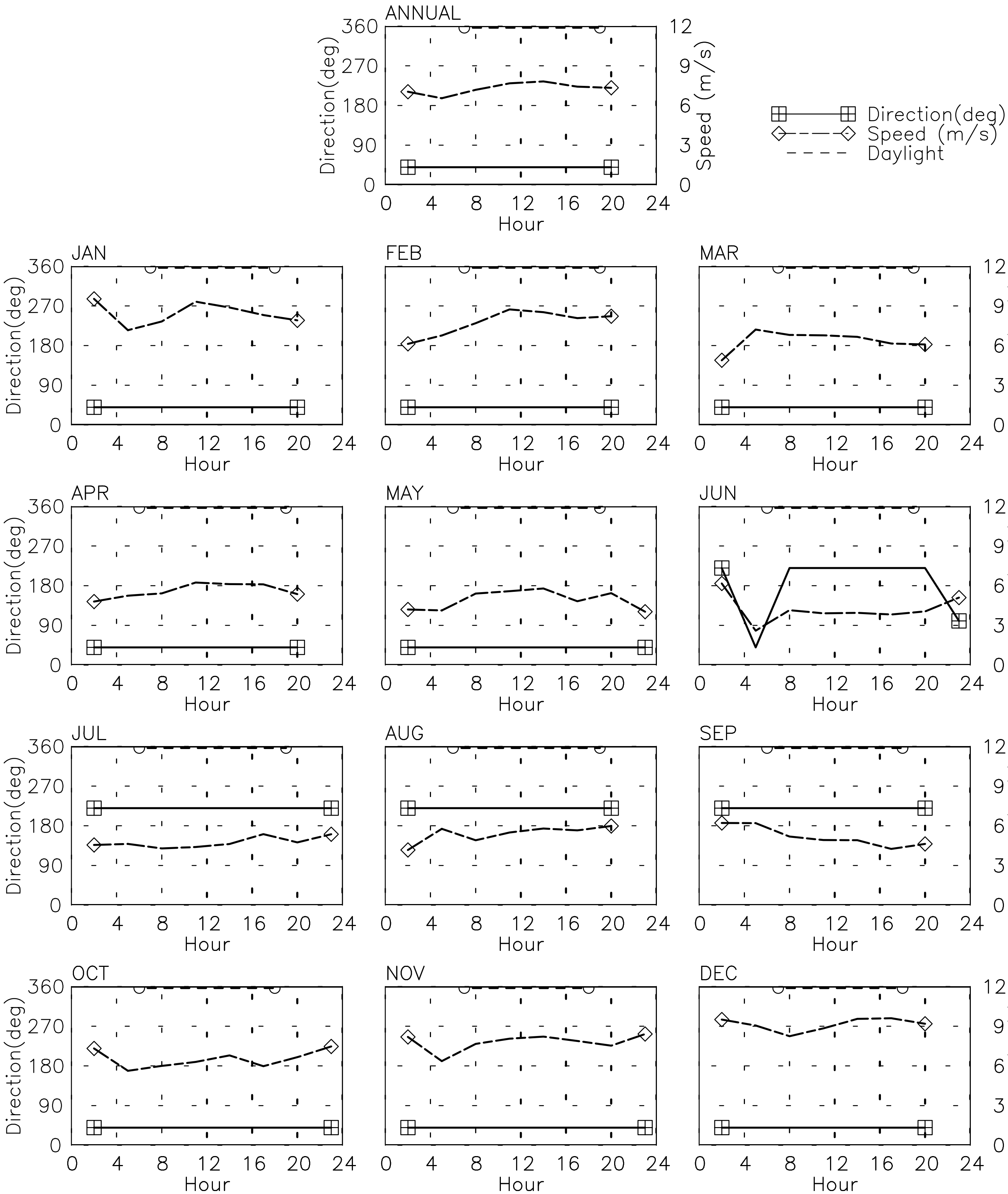
Mon Jun 21 15:02:15 1999

PREVAILING DIRECTION & SPEED BY HOUR

CUYO ISLANDS PH – 986300

10° 51' N 121° 02' E – Elev 4m *LST=GMT +8 hours NT= +8

02/73–12/79



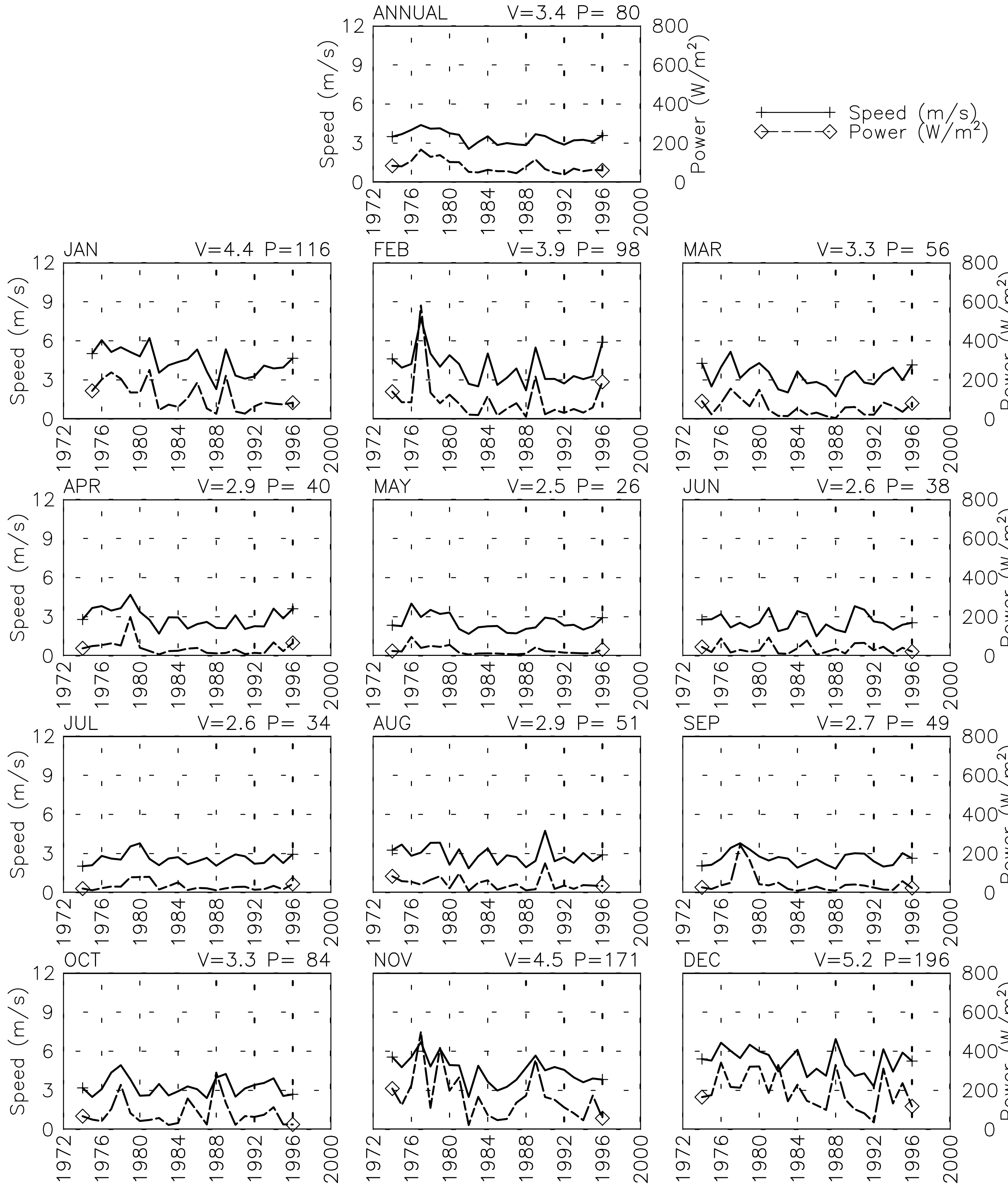
Mon Jun 21 15:02:19 1999

SPEED AND POWER BY YEAR

DAET/LUZON ISLAND PH – 984400

14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8

02/74–12/96



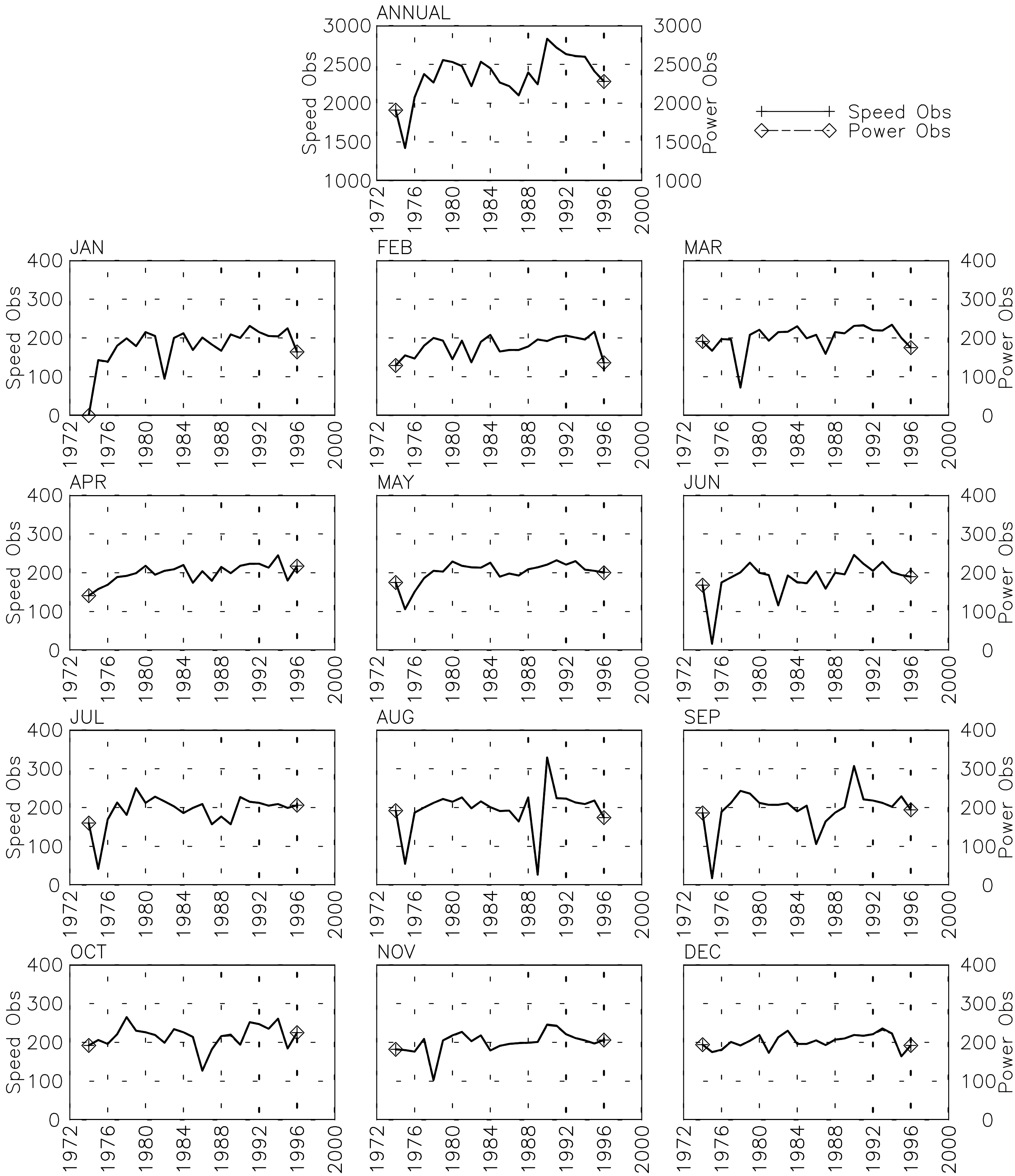
Wed Jun 23 14:53:54 1999

OBSERVATIONS BY YEAR

DAET/LUZON ISLAND PH – 984400

14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8

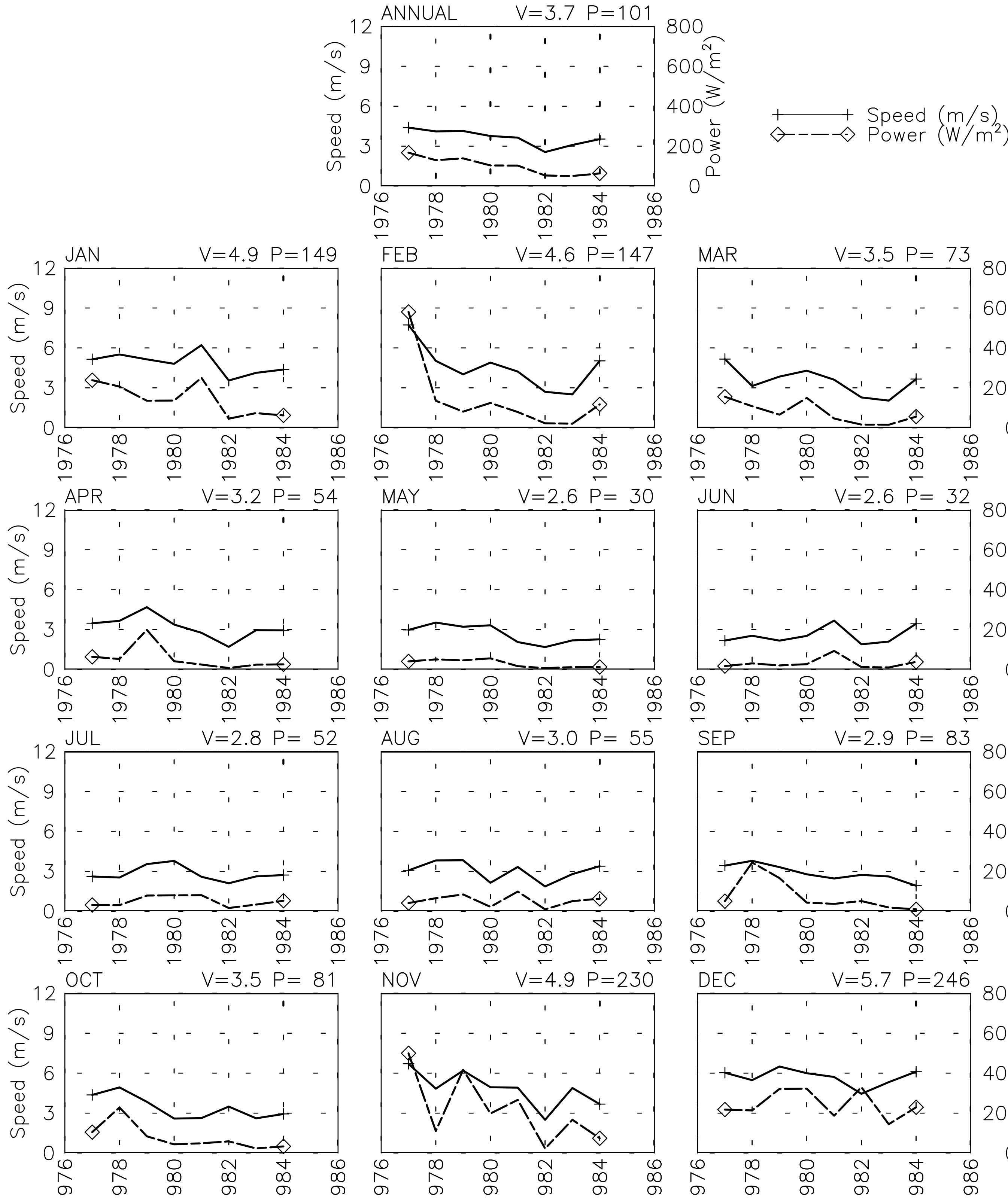
02/74–12/96



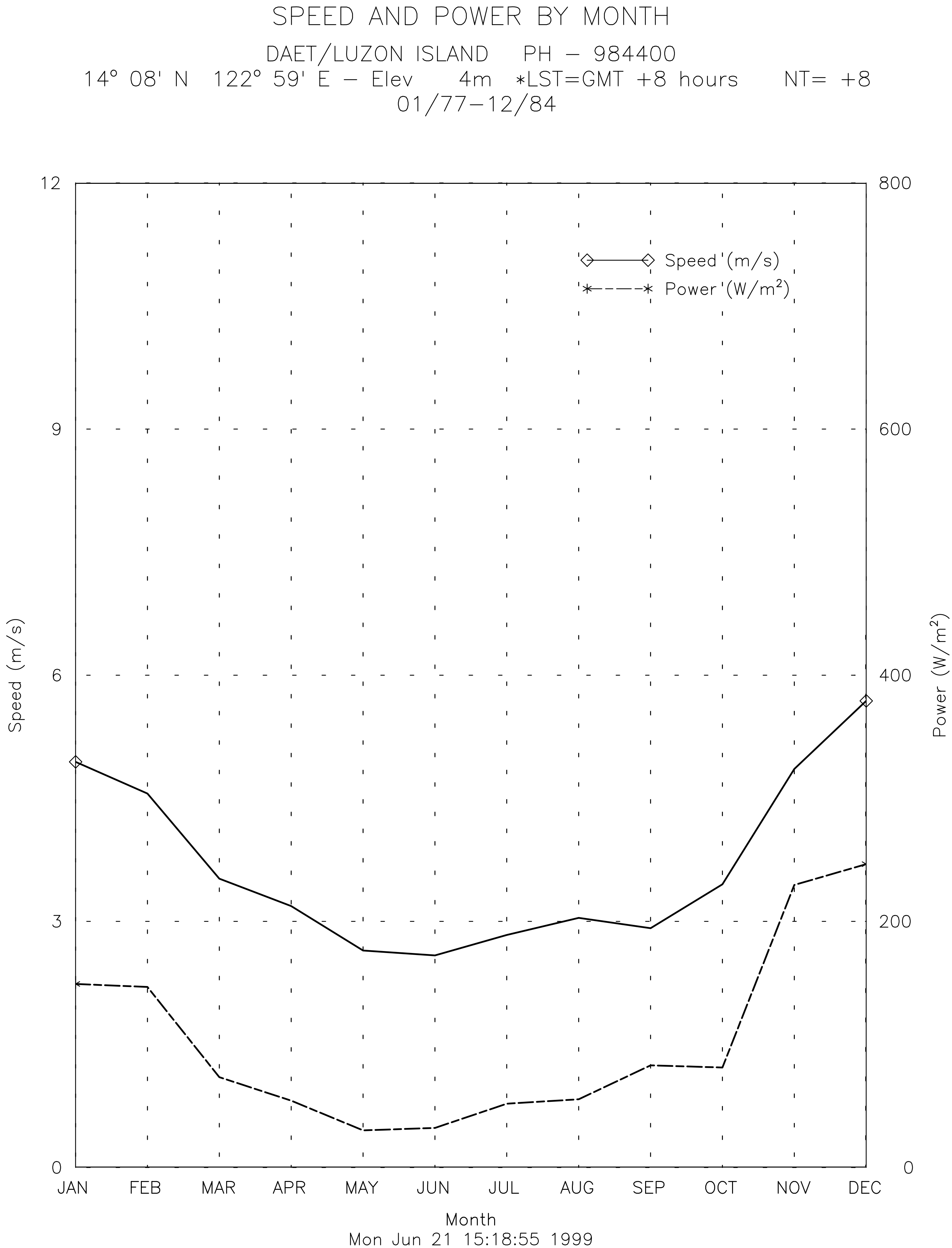
Wed Jun 23 14:53:58 1999

SPEED AND POWER BY YEAR

DAET/LUZON ISLAND PH – 984400
14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8
01/77–12/84



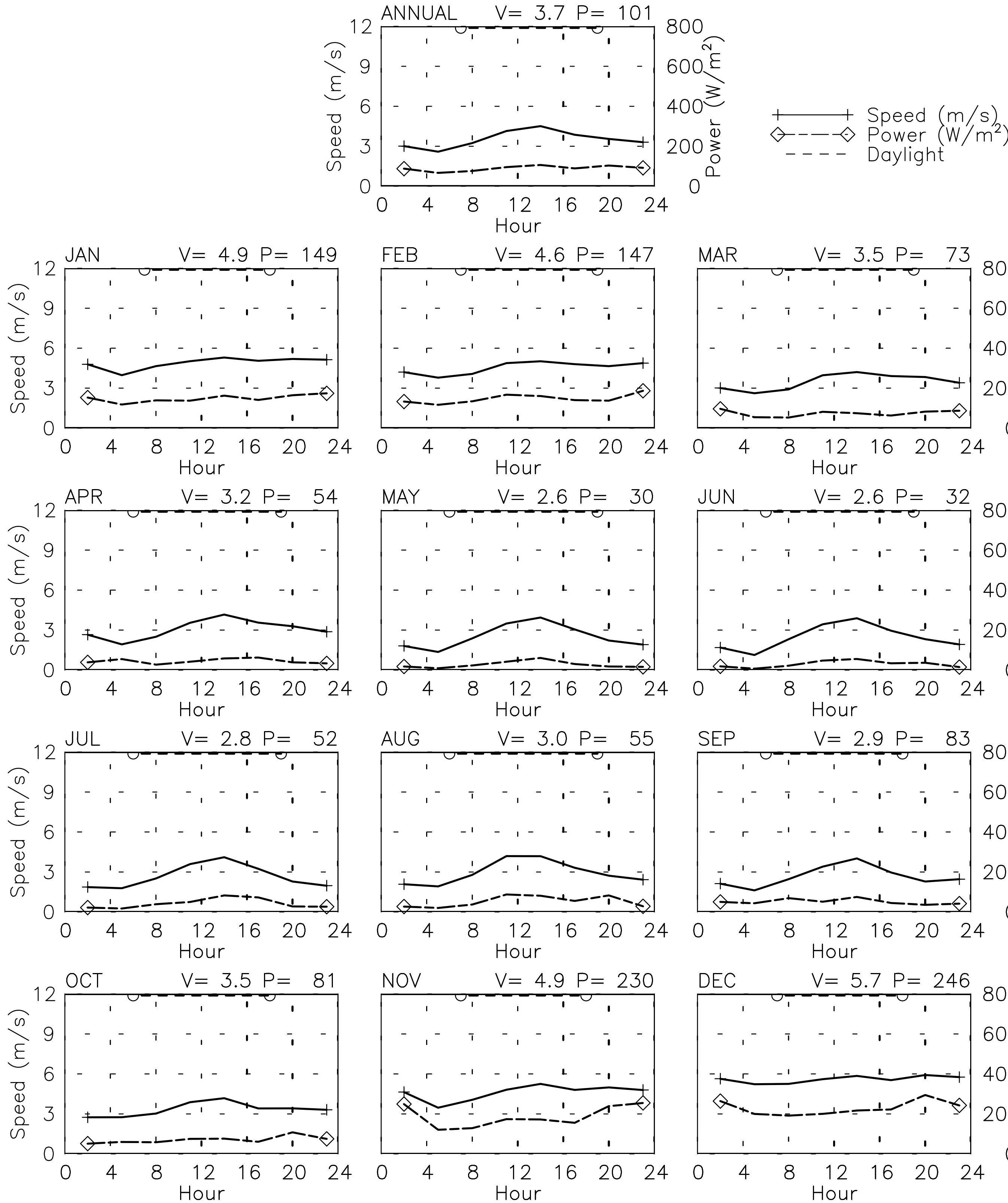
Wed Jun 23 14:56:05 1999



SPEED AND POWER BY MONTH
DAET/LUZON ISLAND PH – 984400
14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8
01/77–12/84
Speed (m/s)
Power (W/m²)
12
9
6
3
0
800
600
400
200
0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
Month
Mon Jun 21 15:18:55 1999

SPEED AND POWER BY HOUR

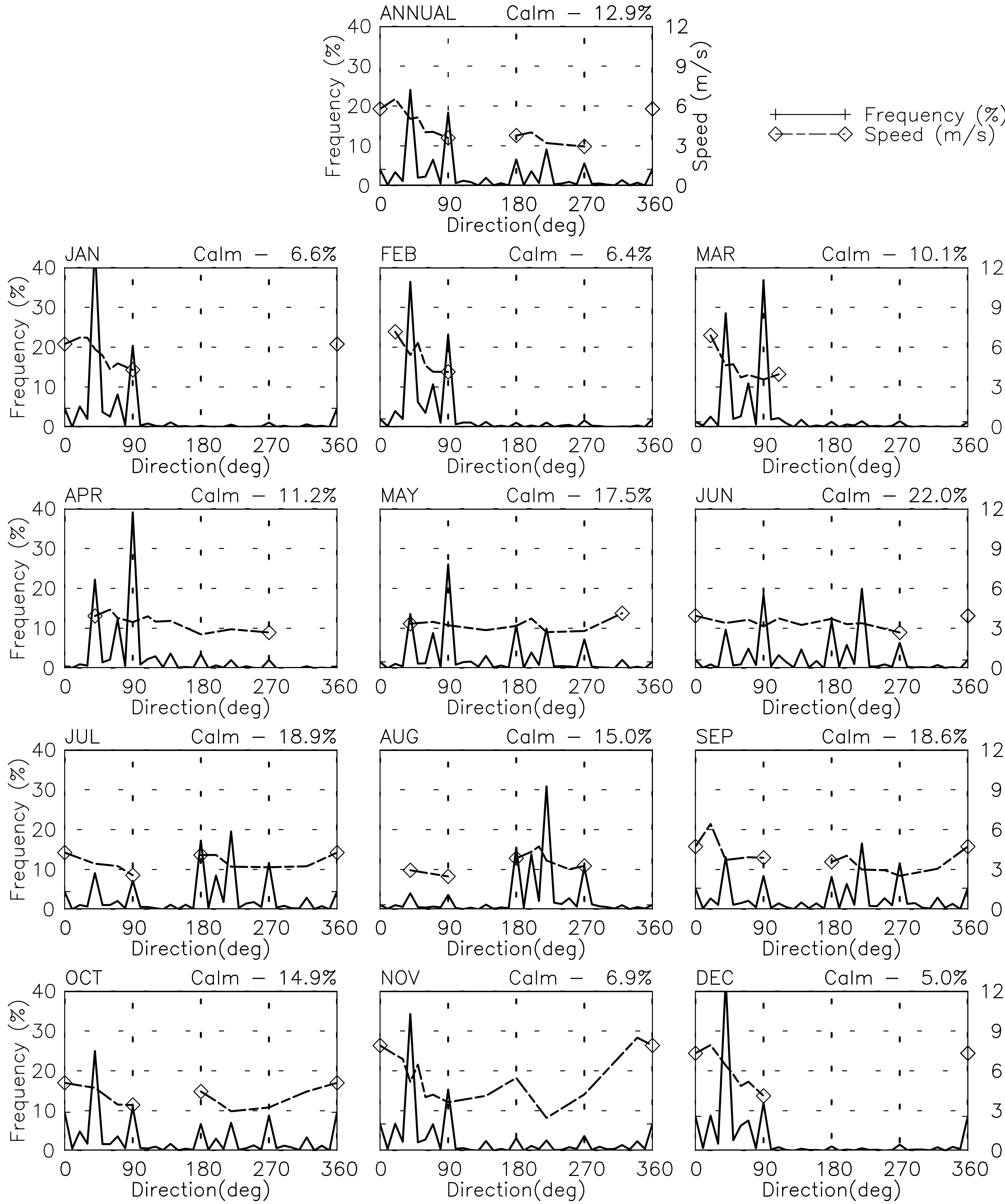
DAET/LUZON ISLAND   PH - 984400
14° 08' N 122° 59' E - Elev   4m *LST=GMT +8 hours   NT= +8
01/77-12/84



Mon Jun 21 15:18:57 1999

FREQUENCY AND SPEED BY DIRECTION

DAET/LUZON ISLAND PH – 984400
14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8
01/77–12/84



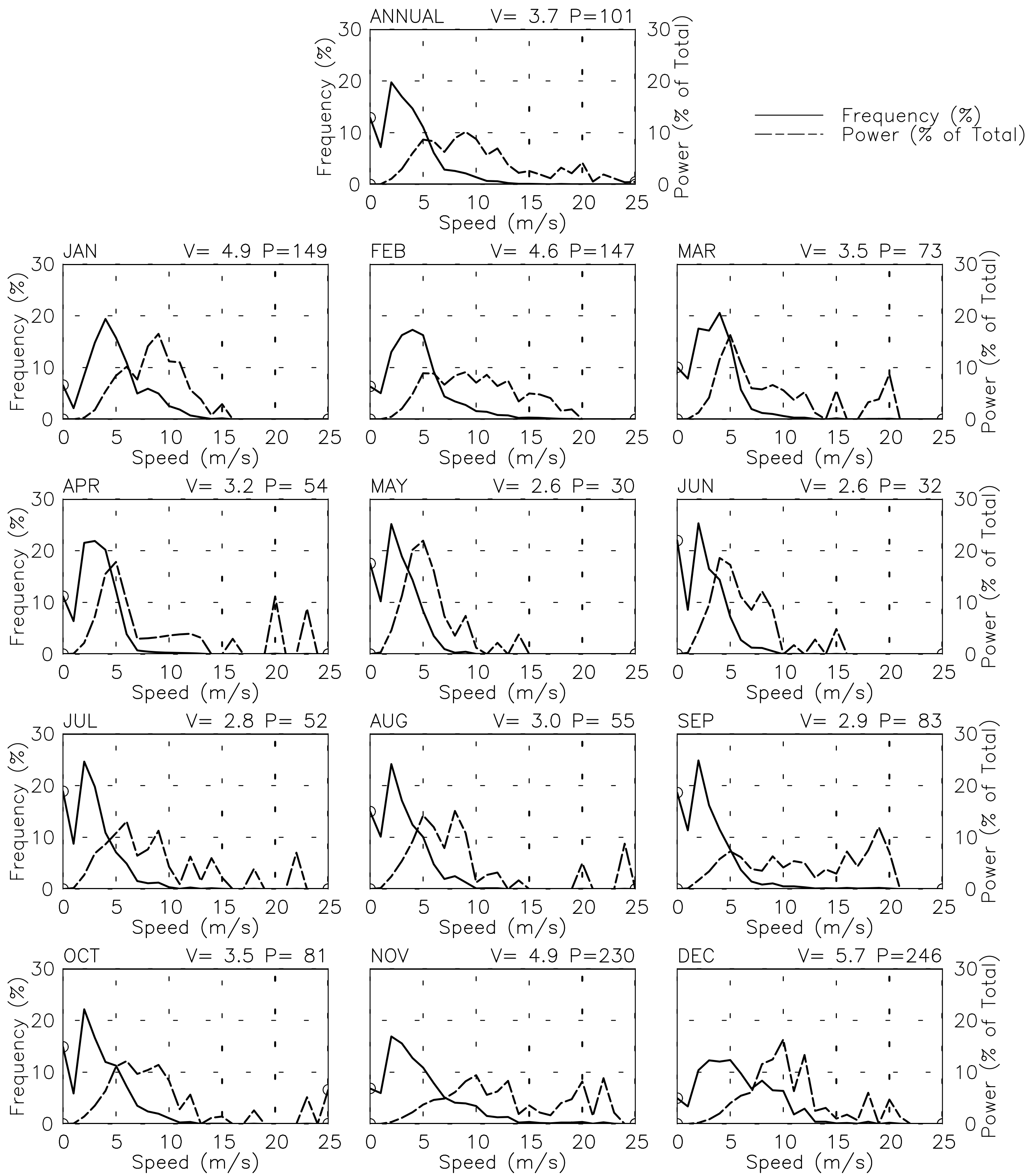
Mon Jun 21 15:19:01 1999

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

DAET/LUZON ISLAND PH – 984400

14° 08' N 122° 59' E – Elev 4m *LST=GMT +8 hours NT= +8

01/77–12/84



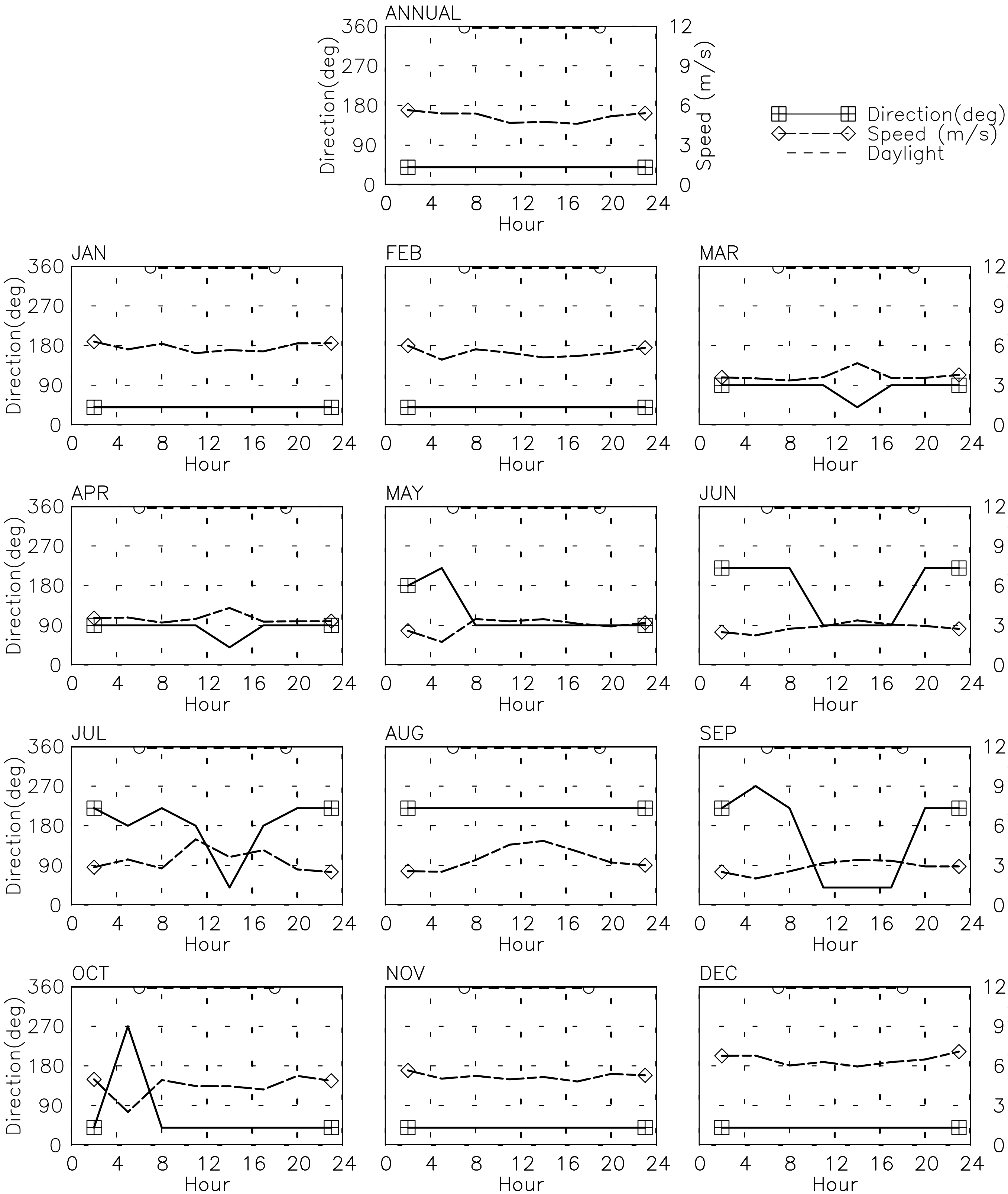
Mon Jun 21 15:19:06 1999

PREVAILING DIRECTION & SPEED BY HOUR

DAET/LUZON ISLAND PH - 984400

14° 08' N 122° 59' E - Elev 4m *LST=GMT +8 hours NT= +8

01/77-12/84



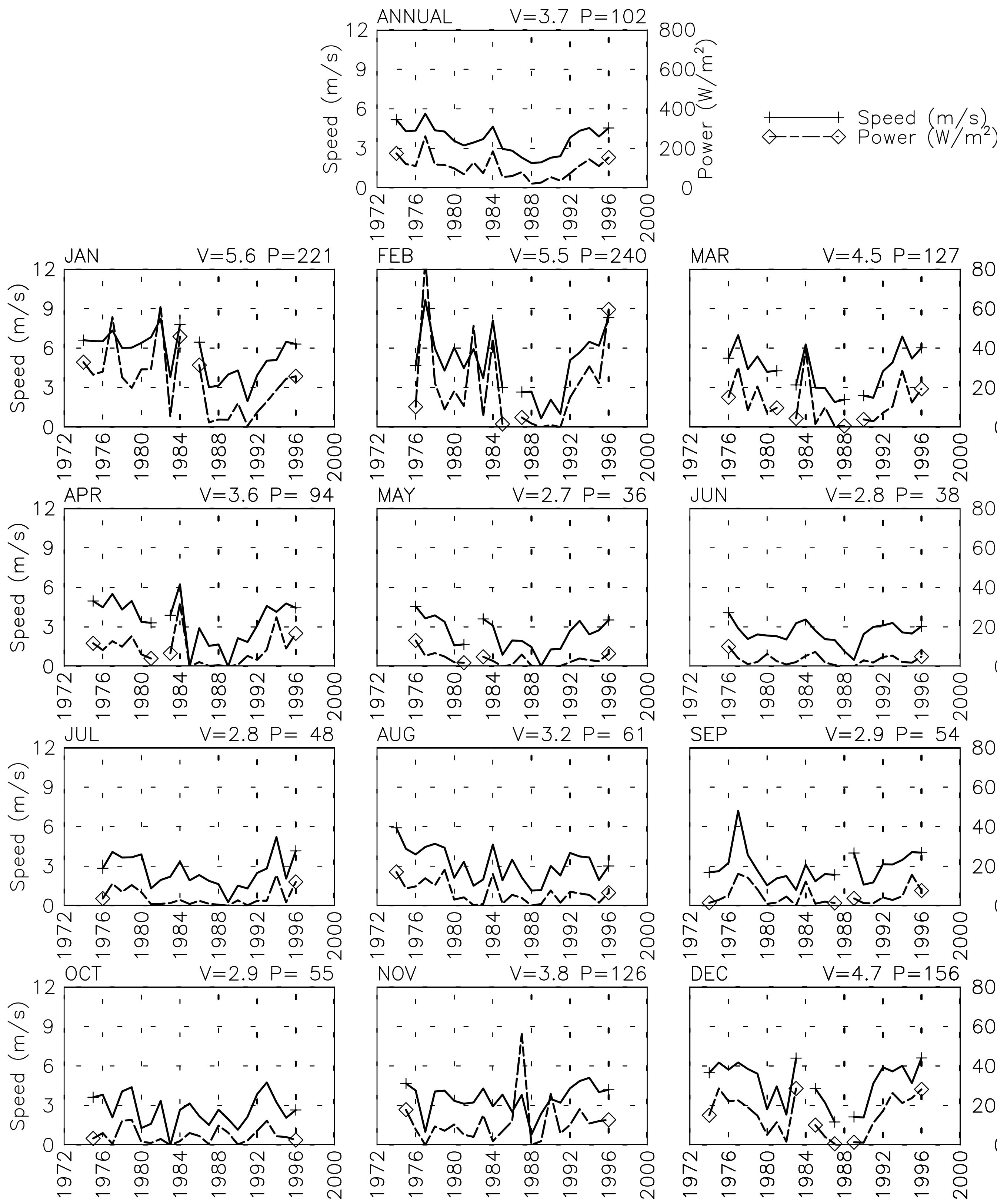
Mon Jun 21 15:19:10 1999

SPEED AND POWER BY YEAR

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

01/74–12/96



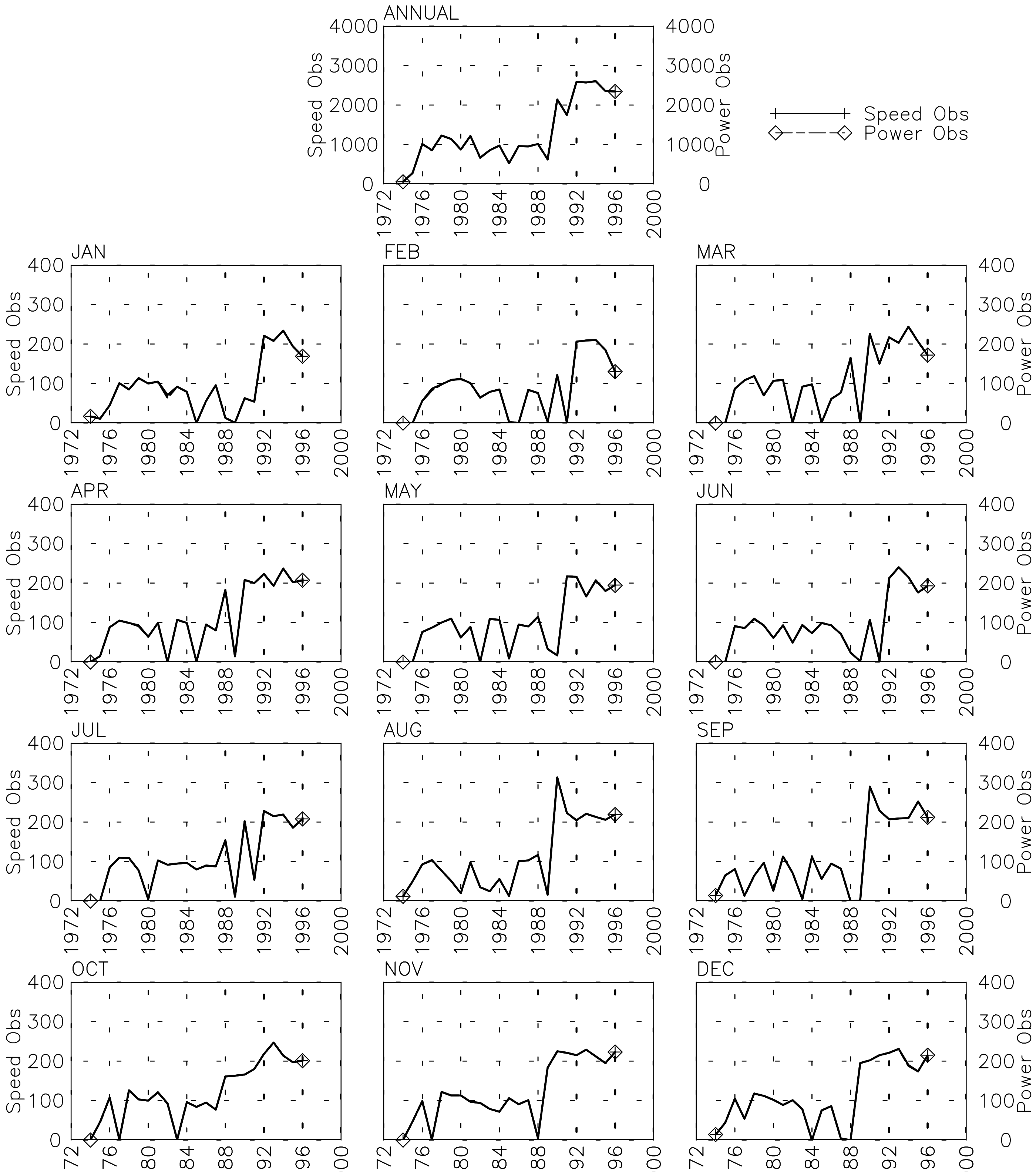
Wed Jun 23 14:54:09 1999

OBSERVATIONS BY YEAR

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

01/74–12/96



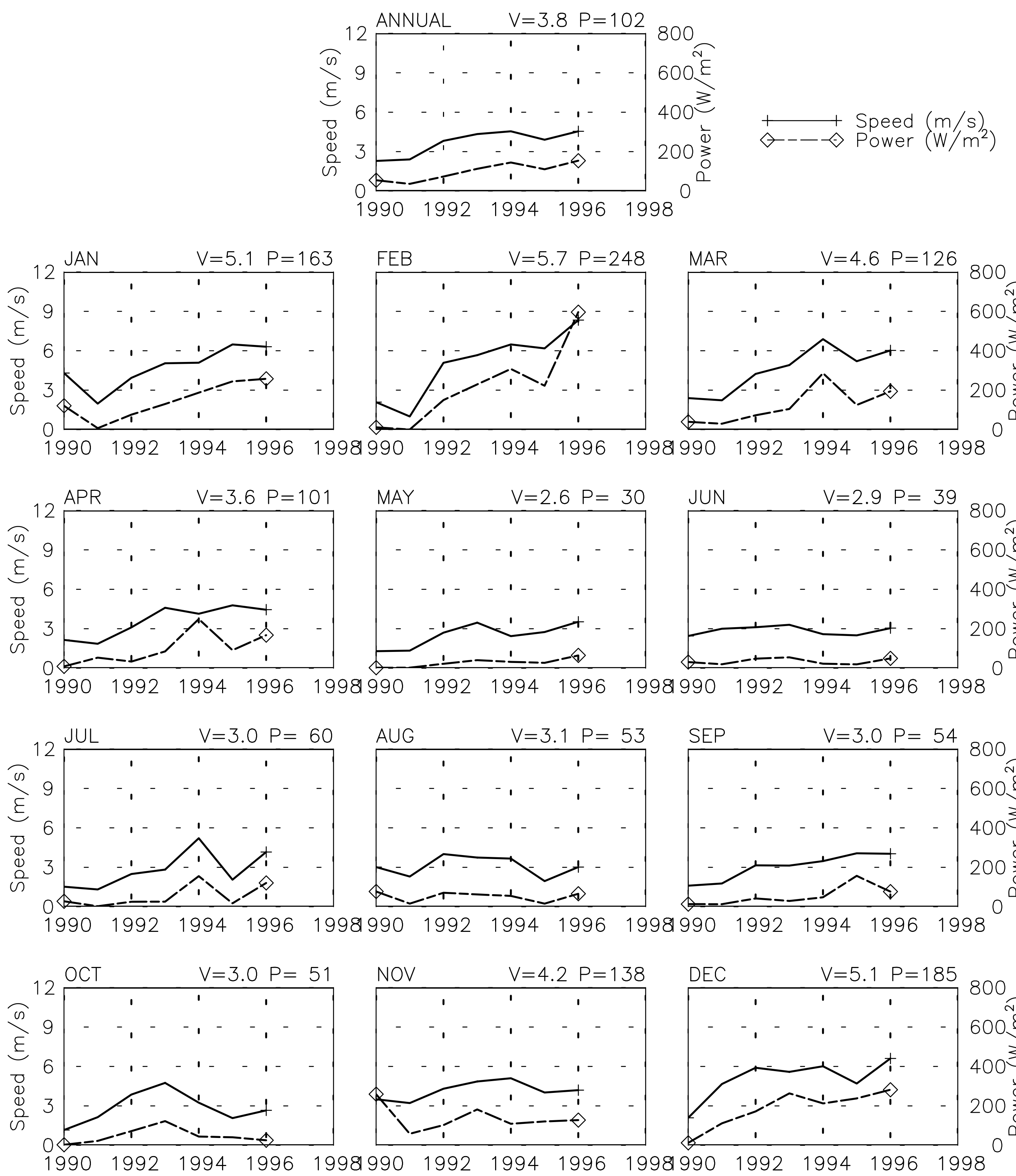
Wed Jun 23 14:54:15 1999

SPEED AND POWER BY YEAR

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

01/90–12/96



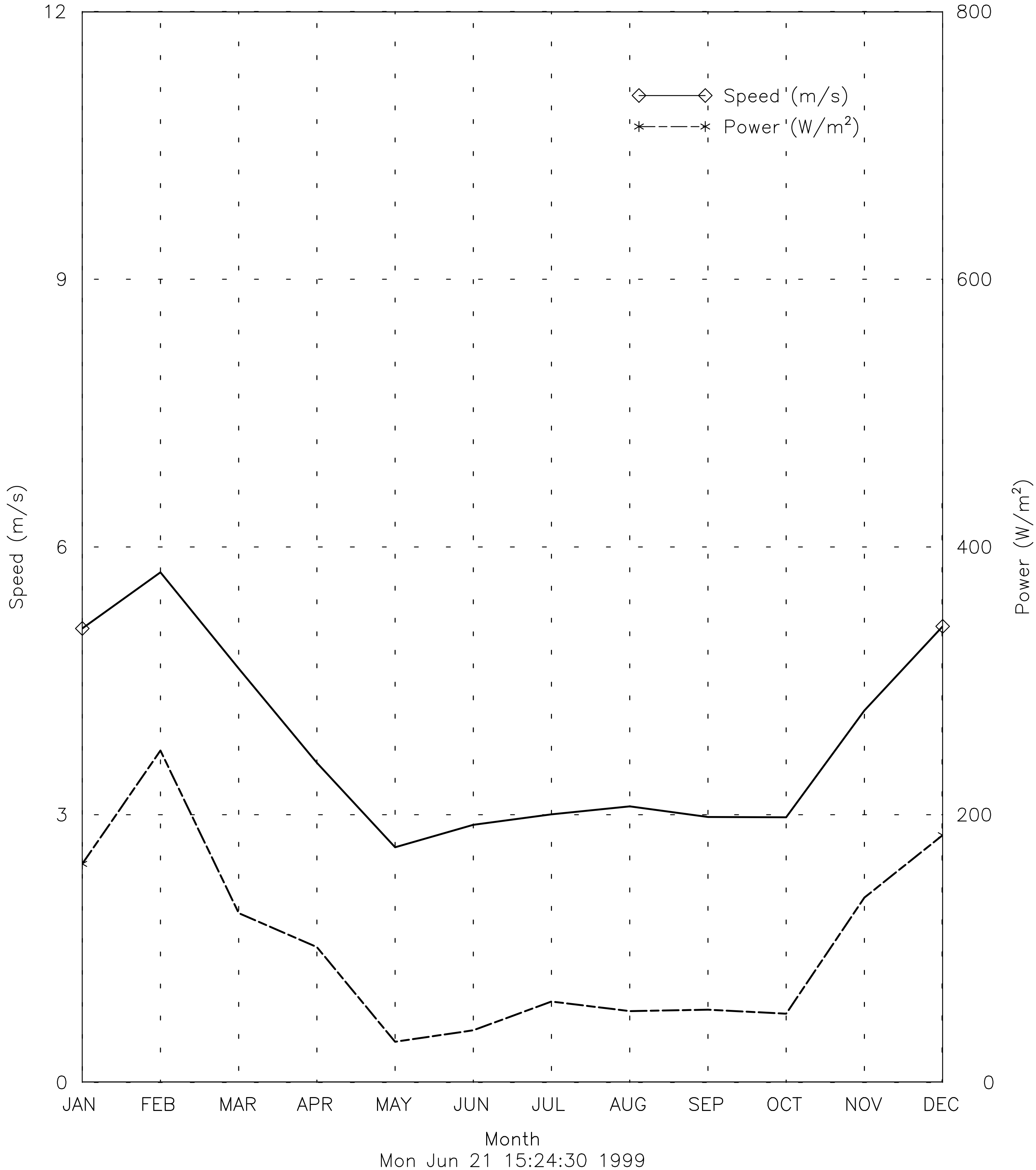
Wed Jun 23 14:57:08 1999

SPEED AND POWER BY MONTH

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

01/90–12/96

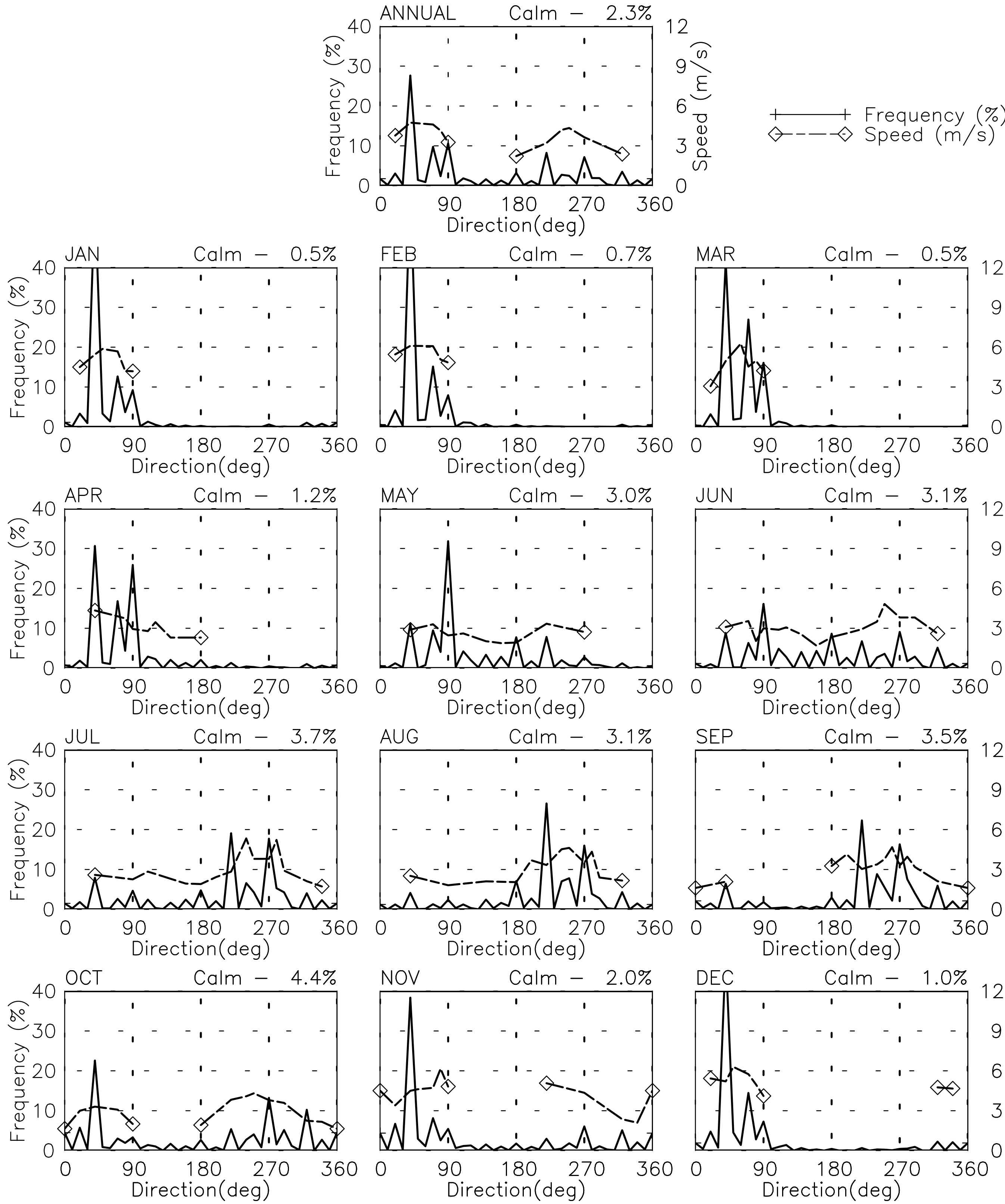


FREQUENCY AND SPEED BY DIRECTION

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

01/90–12/96



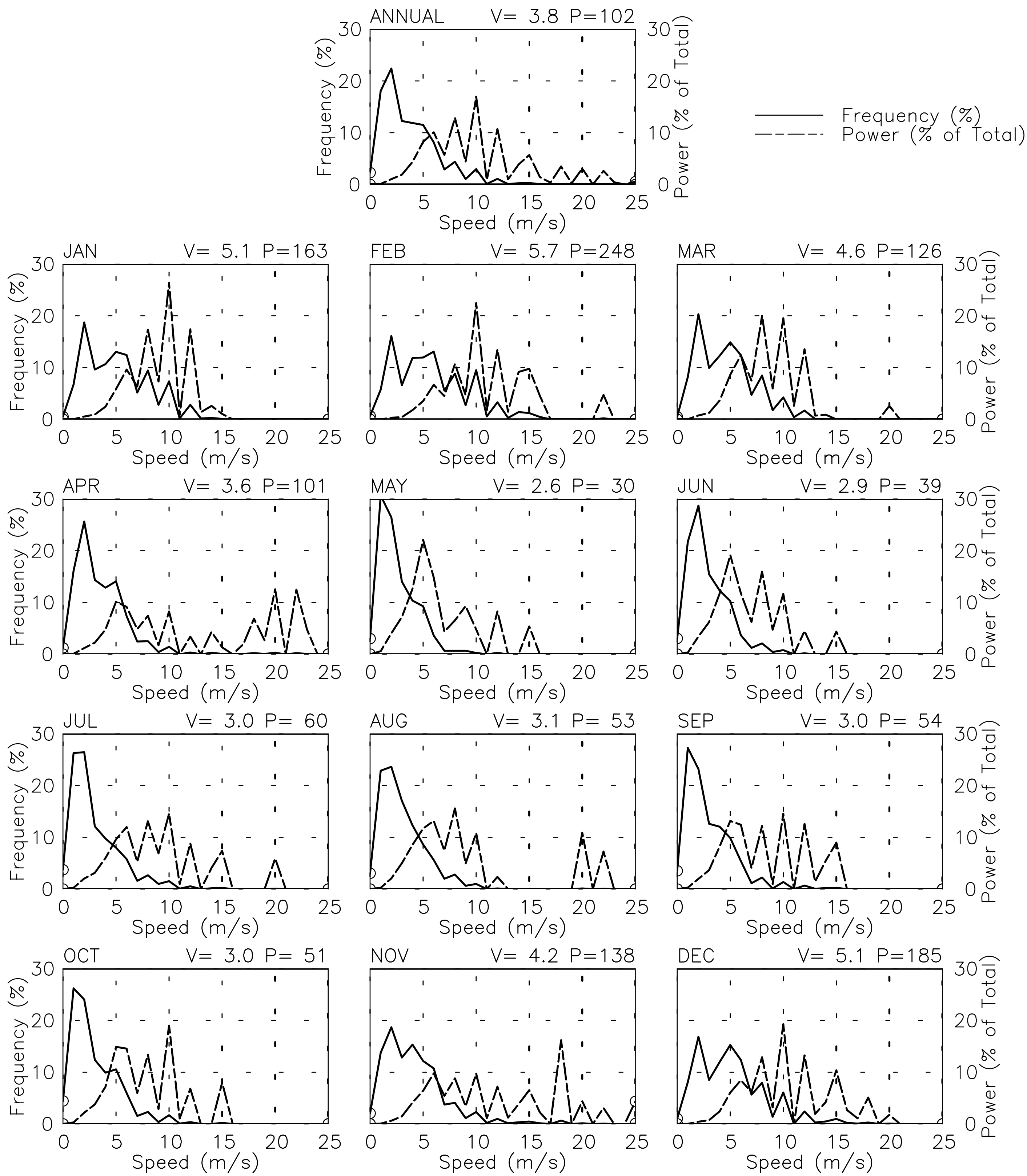
Mon Jun 21 15:24:37 1999

FREQUENCY OF SPEED & PERCENT OF POWER BY SPEED

GUIUAN/SAMAR ISLAND PH – 985580

11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8

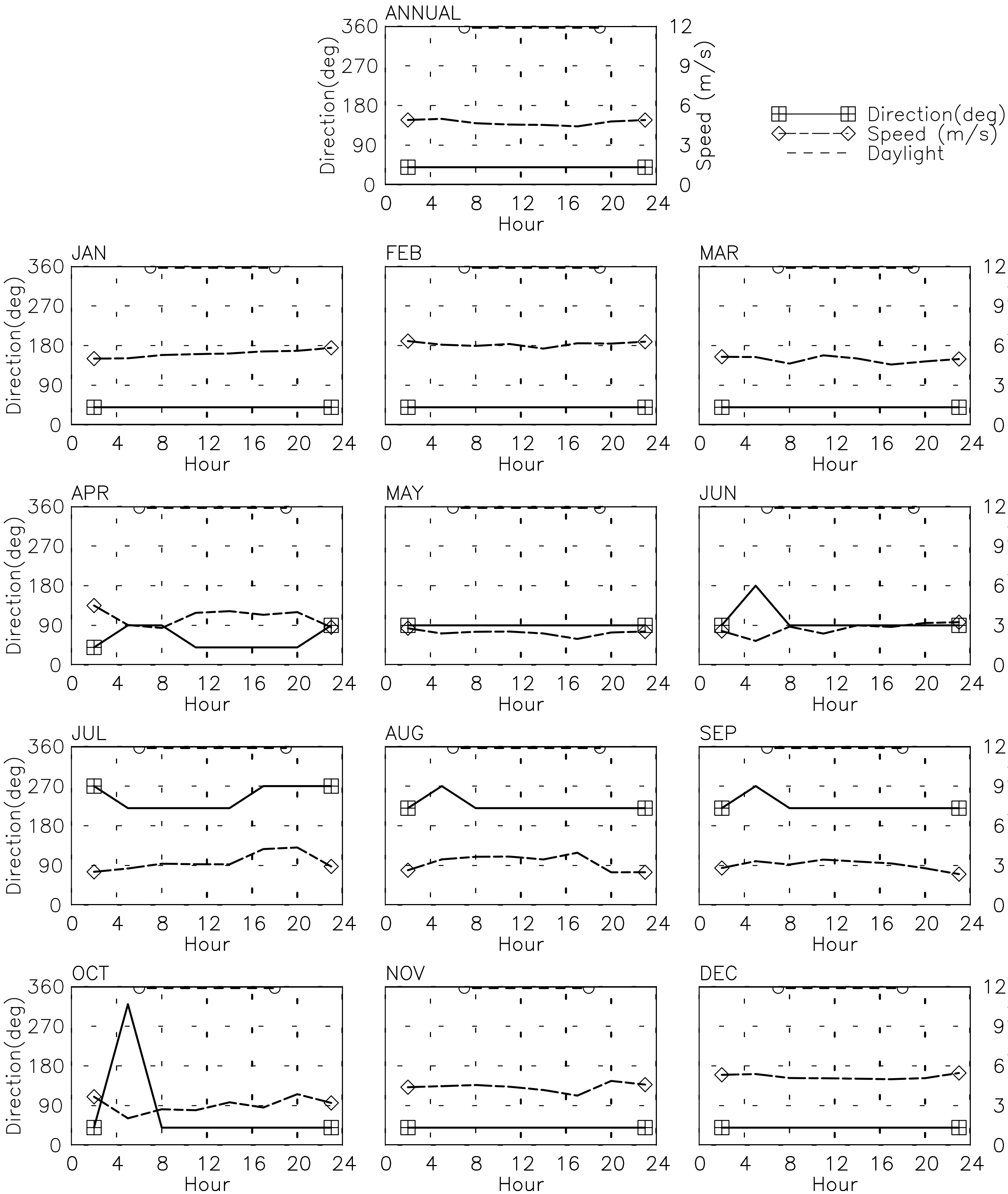
01/90–12/96



Mon Jun 21 15:24:41 1999

PREVAILING DIRECTION & SPEED BY HOUR

GUIUAN/SAMAR ISLAND PH – 985580
11° 02' N 125° 44' E – Elev 60m *LST=GMT +8 hours NT= +8
01/90–12/96



Mon Jun 21 15:24:44 1999

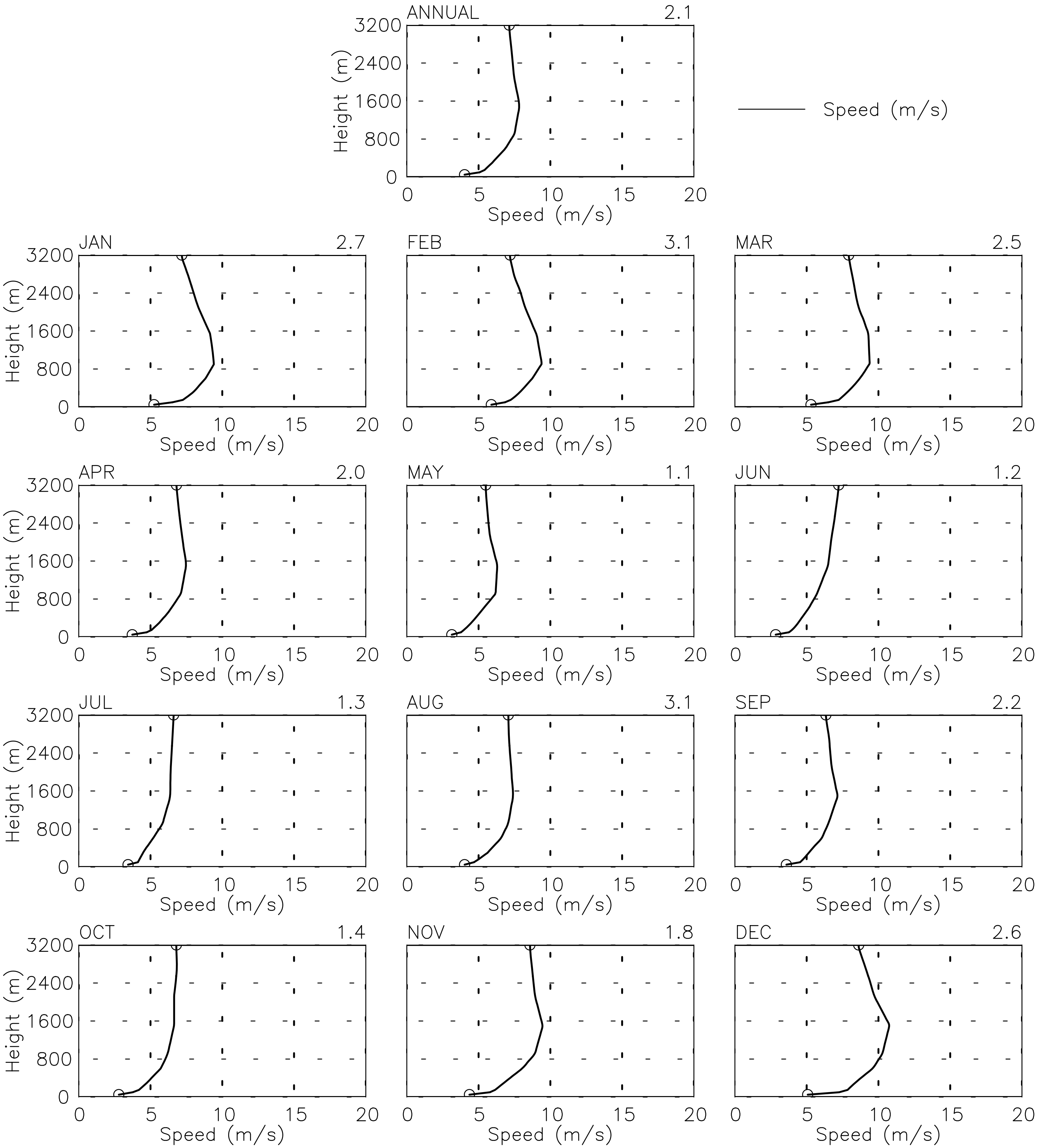
Appendix C

Analysis Summaries—Upper-Air Stations

Legaspi
Palau Island
Pratas Island

VERTICAL WIND SPEED PROFILE BY HEIGHT

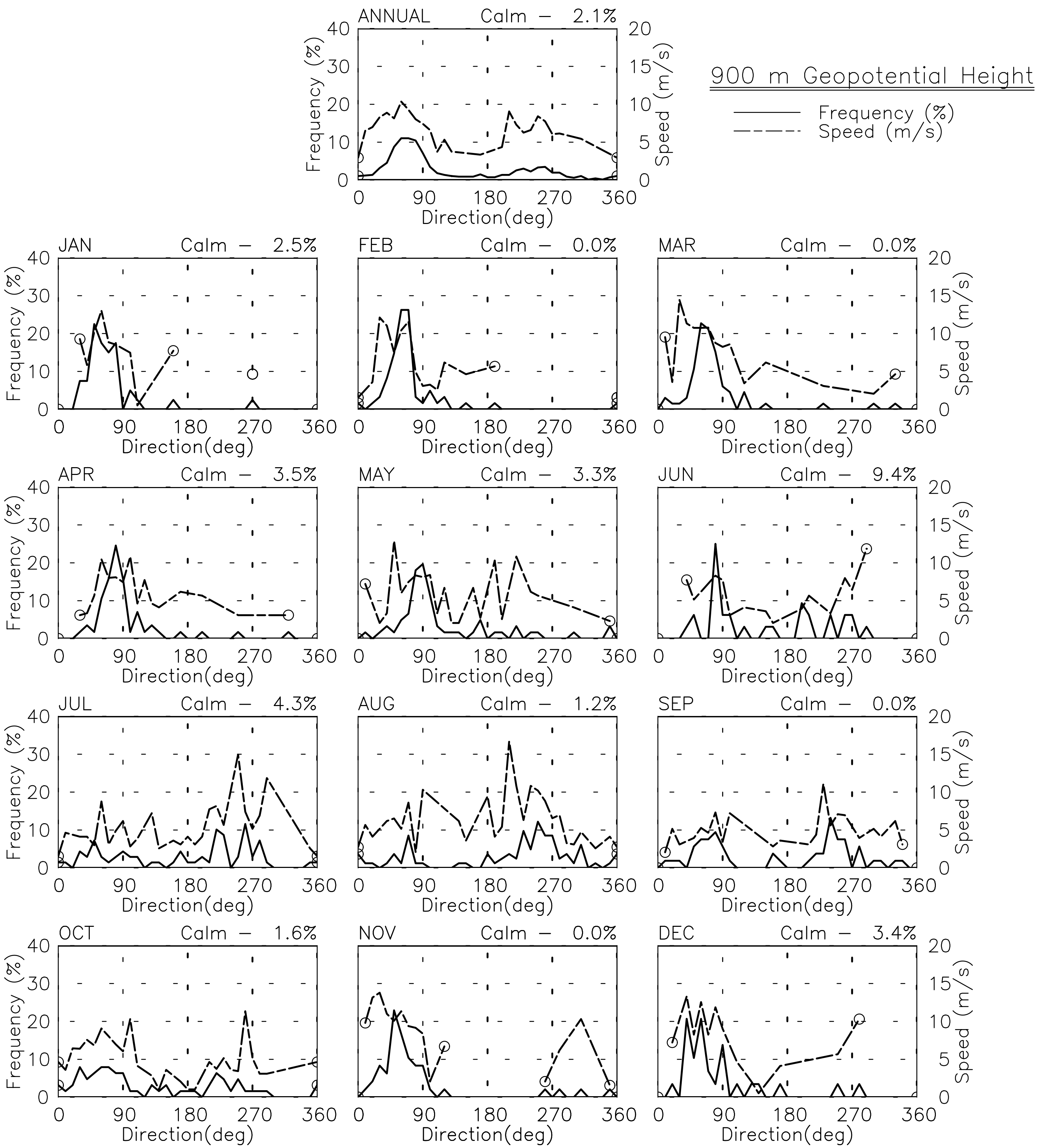
Legaspi – 98444 – 0800 LST
13° 08' N 123° 44' E – Elev 16m
01/73–10/84 08/90–02/97



Thu Mar 4 10:44:04 1999

FREQUENCY & SPEED BY DIRECTION

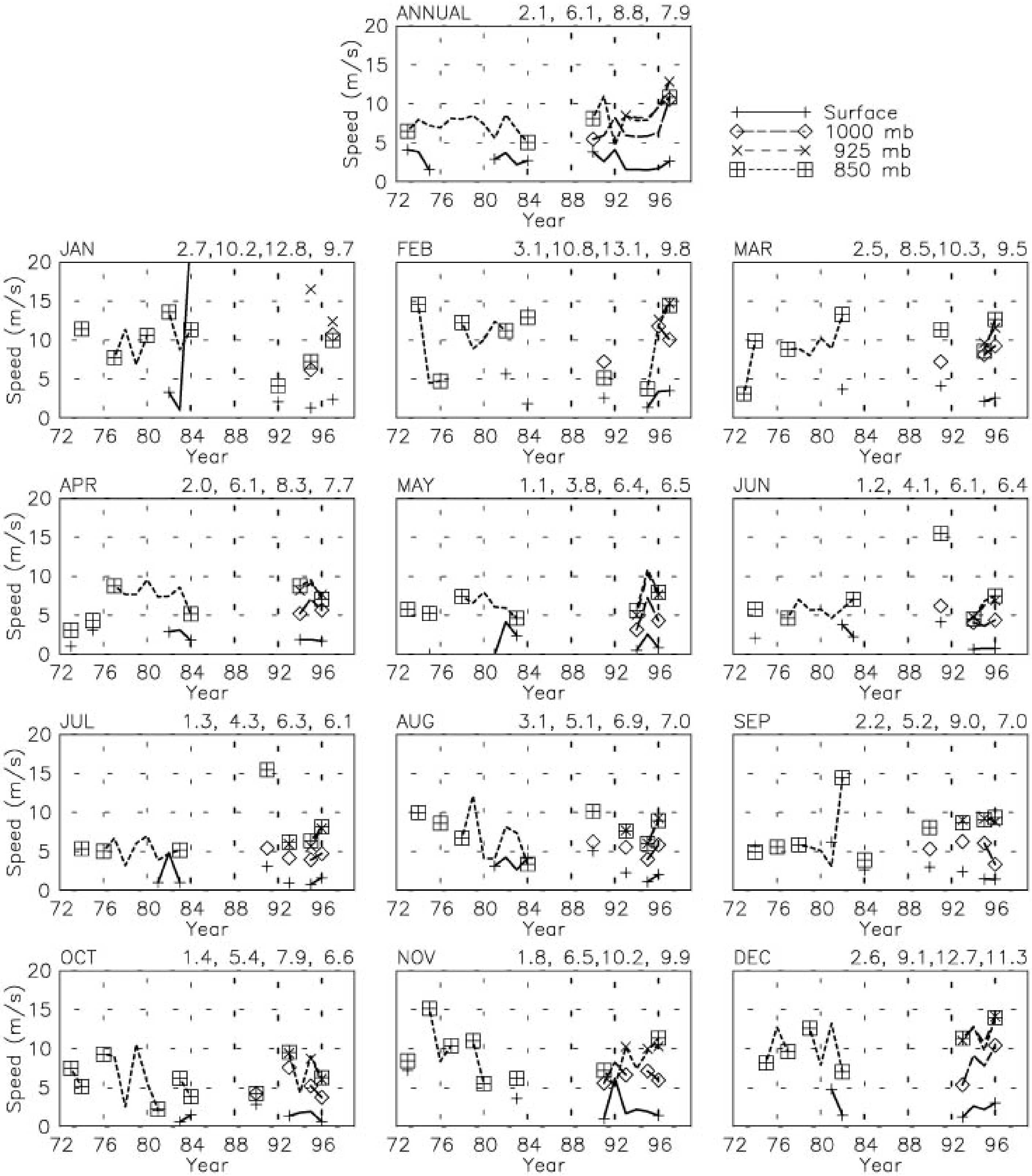
Legaspi – 98444 – 0800 LST
13° 08' N 123° 44' E – Elev 16m
01/73–10/84 08/90–02/97



Thu Mar 4 10:44:10 1999

SPEED BY PRESSURE LEVEL & YEAR

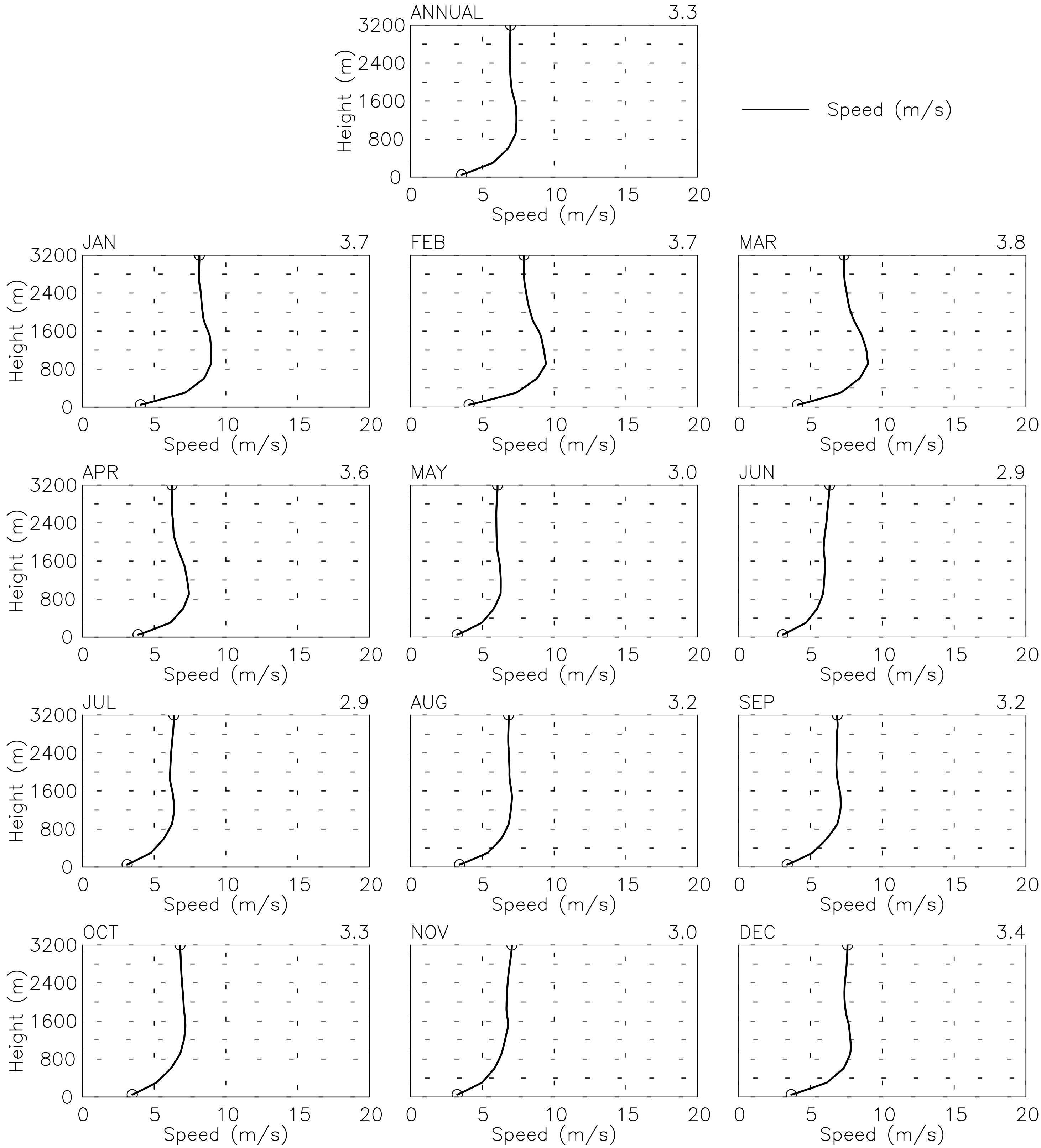
Legaspi - 98444 - 0800 LST
13° 08' N 123° 44' E - Elev 16m
01/73-10/84 08/90-02/97



Thu Mar 4 10:43:39 1999

VERTICAL WIND SPEED PROFILE BY HEIGHT

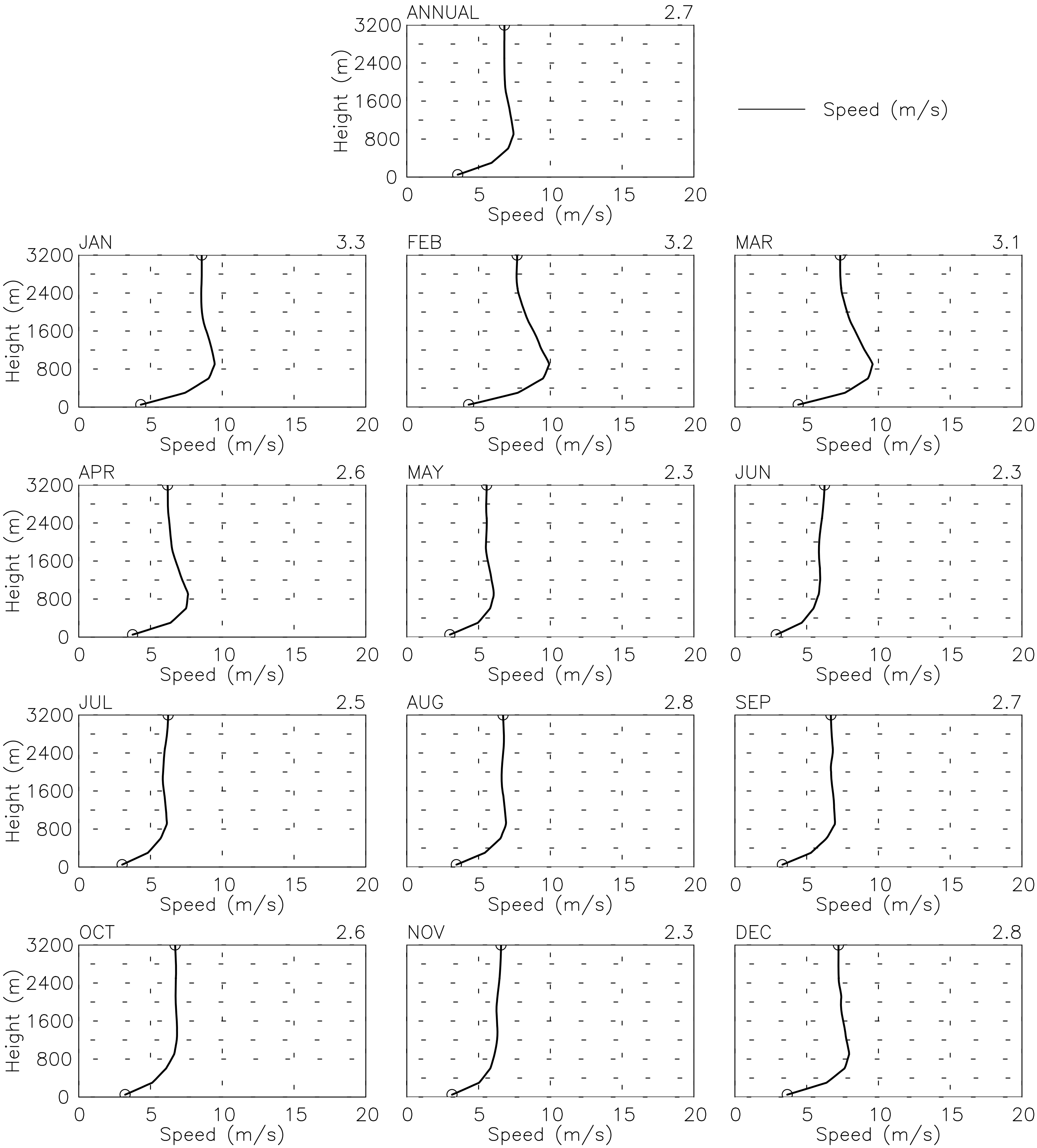
Palau Island – 91408 – 1000 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:49:42 1999

VERTICAL WIND SPEED PROFILE BY HEIGHT

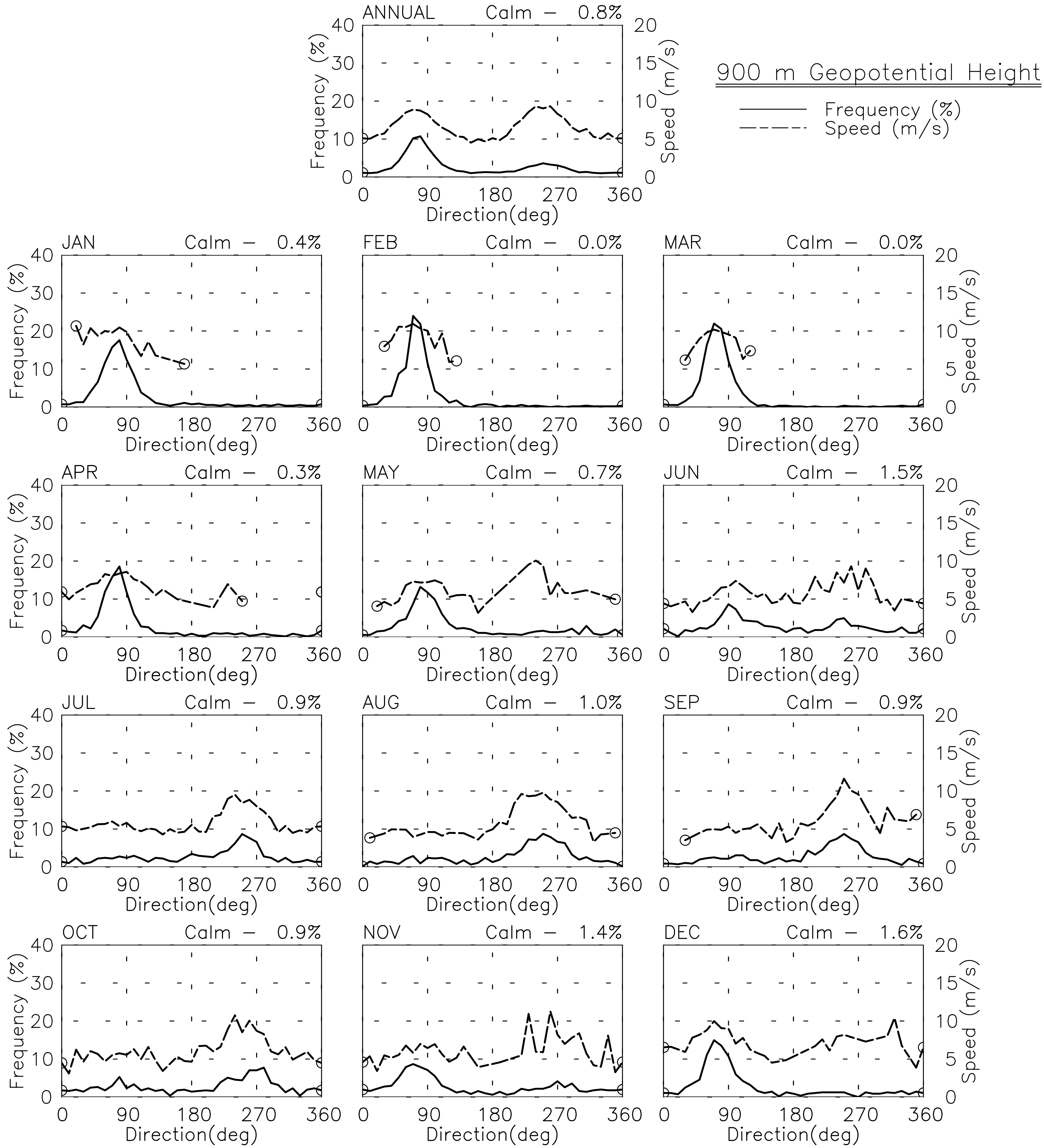
Palau Island – 91408 – 2200 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:49:45 1999

FREQUENCY & SPEED BY DIRECTION

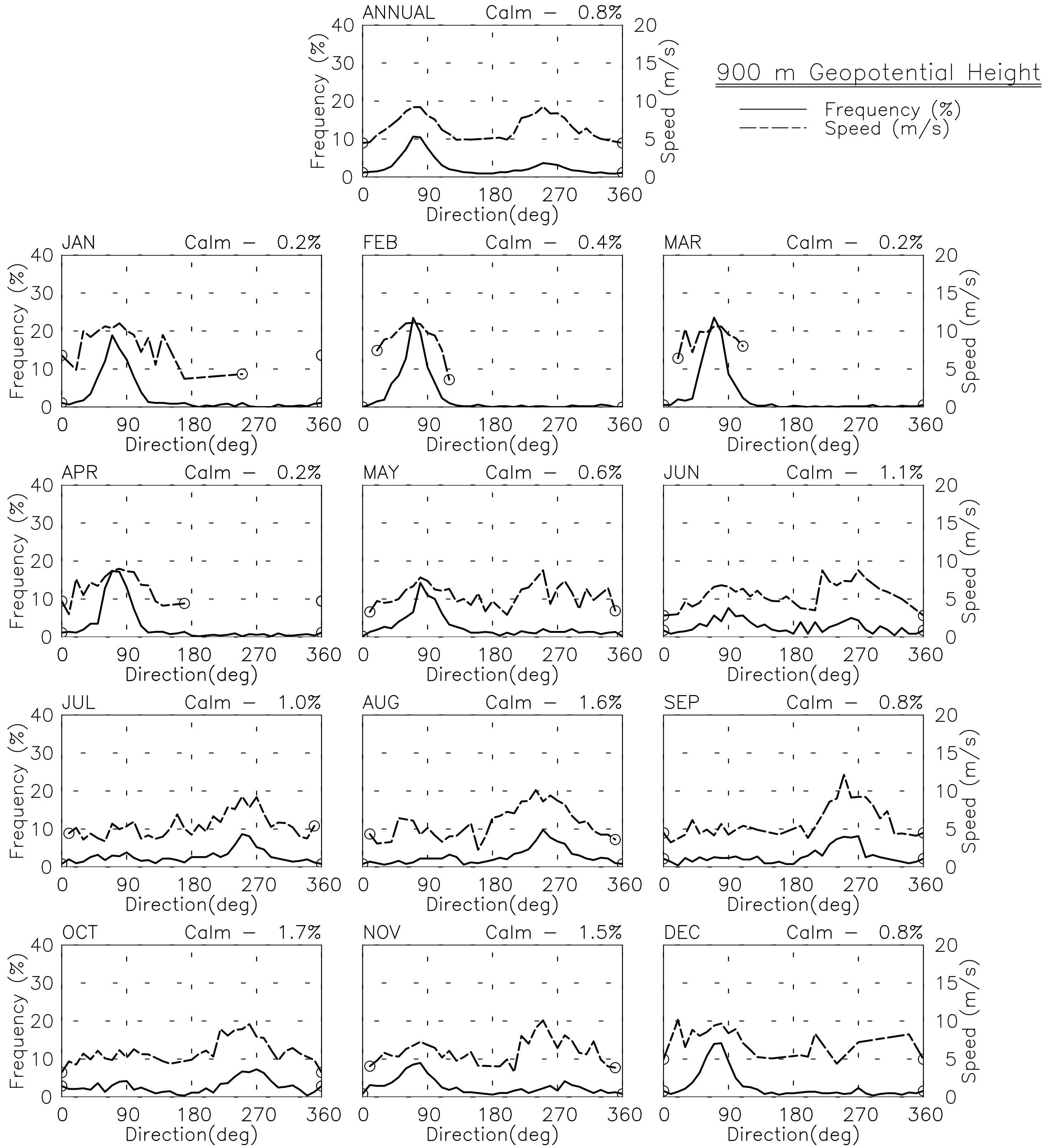
Palau Island – 91408 – 1000 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:49:53 1999

FREQUENCY & SPEED BY DIRECTION

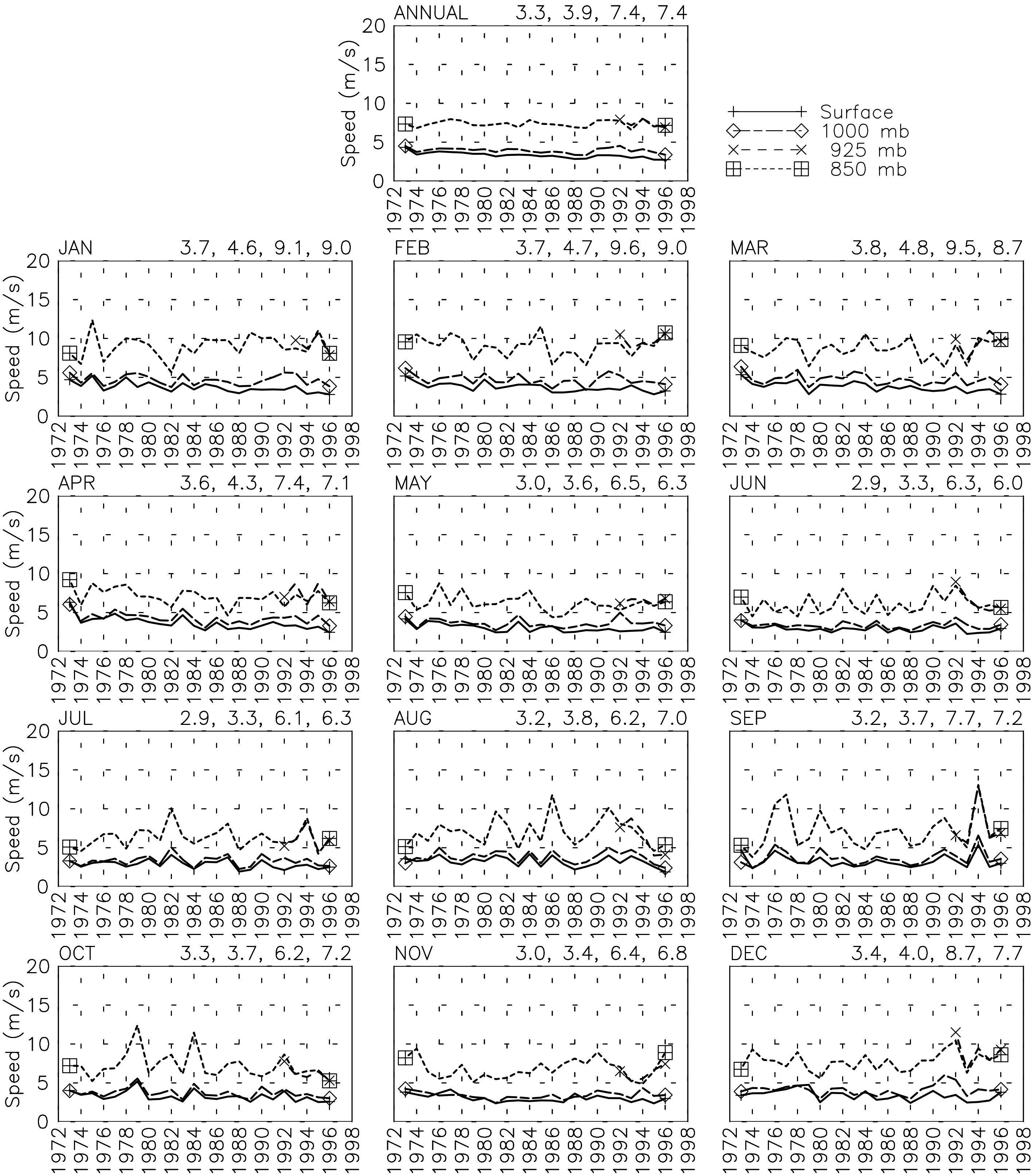
Palau Island – 91408 – 2200 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:49:58 1999

SPEED BY PRESSURE LEVEL & YEAR

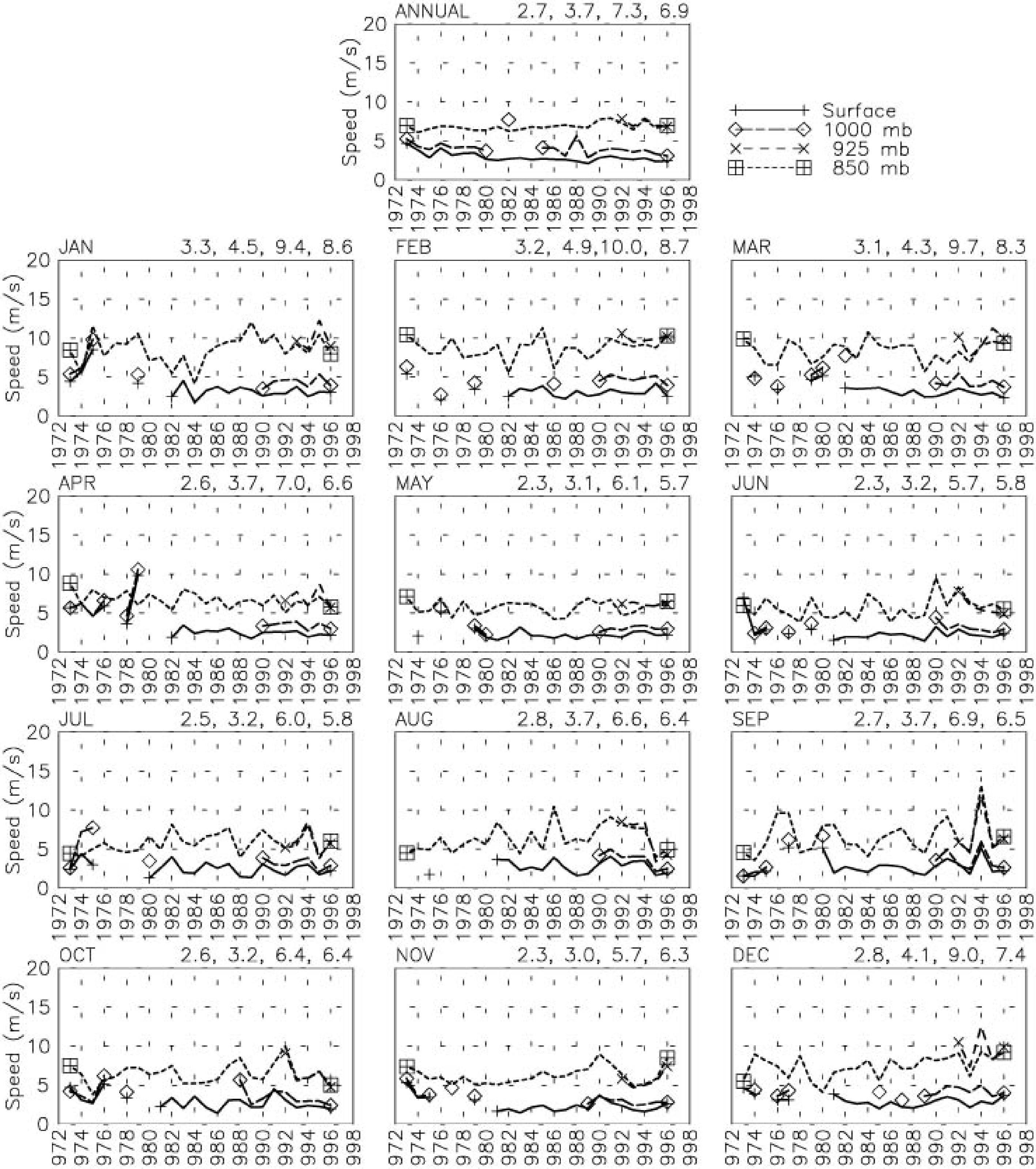
Palau Island – 91408 – 1000 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:48:47 1999

SPEED BY PRESSURE LEVEL & YEAR

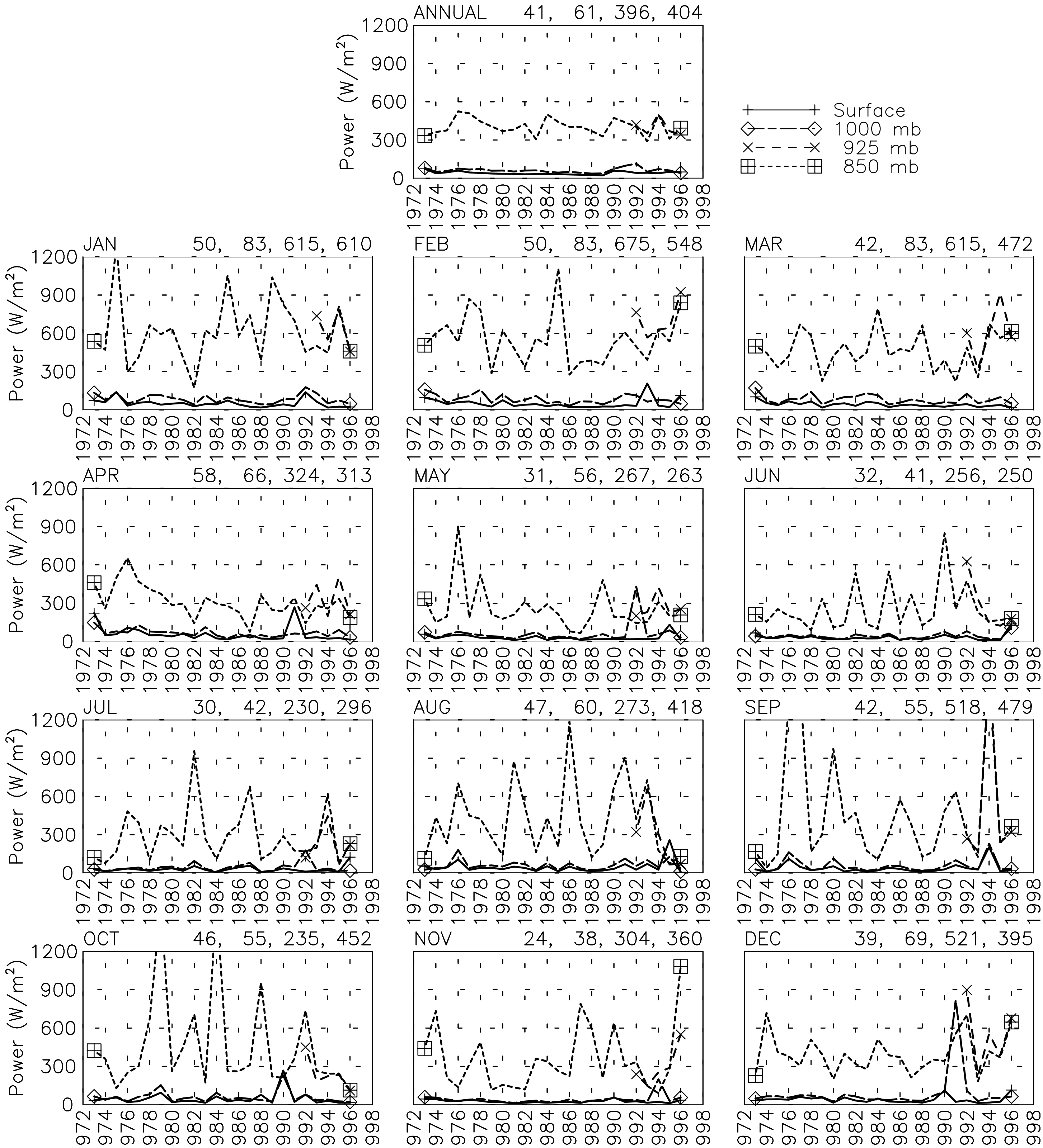
Palau Island – 91408 – 2200 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



Fri Jul 9 14:48:56 1999

POWER BY PRESSURE LEVEL & YEAR

Palau Island – 91408 – 1000 LST
7° 20' N 134° 29' E – Elev 2m
01/73–12/96



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POWER BY PRESSURE LEVEL & YEAR

Palau Island – 91408 – 2200 LST
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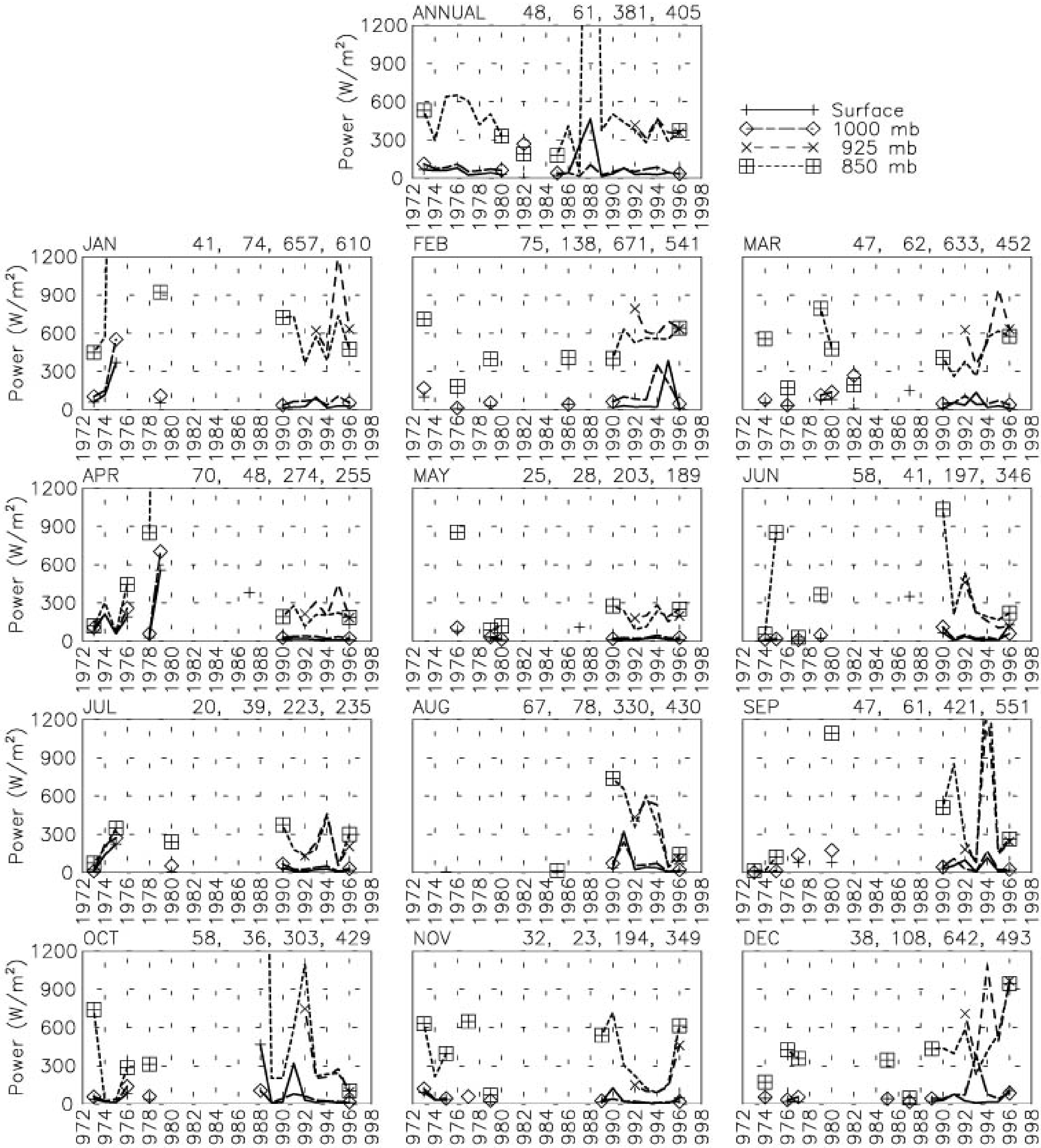
01/73–12/96



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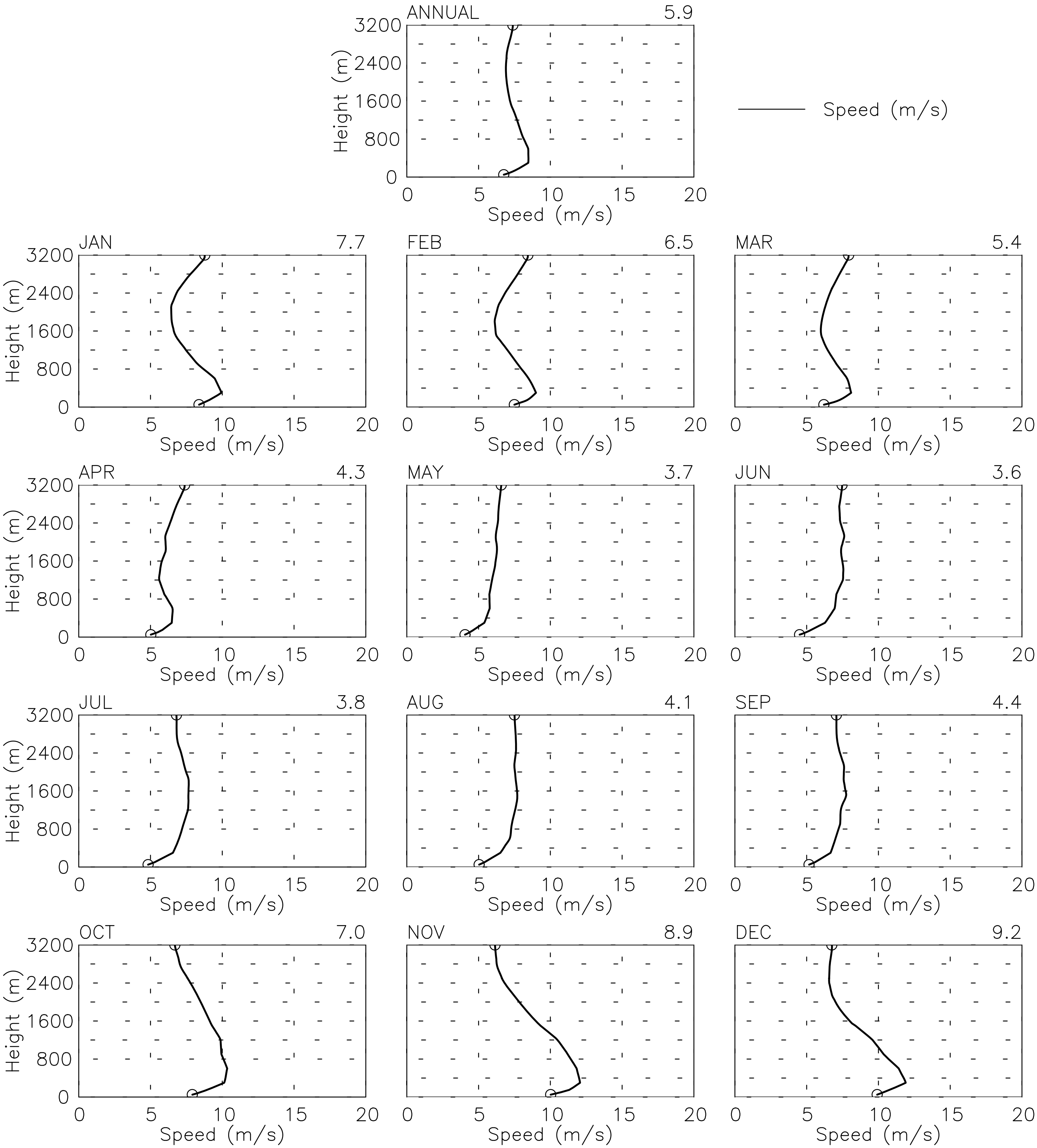
VERTICAL WIND SPEED PROFILE BY HEIGHT

Pratas Island – 46810 – 0800 LST
20° 43' N 116° 43' E – Elev 6m
02/73–03/94



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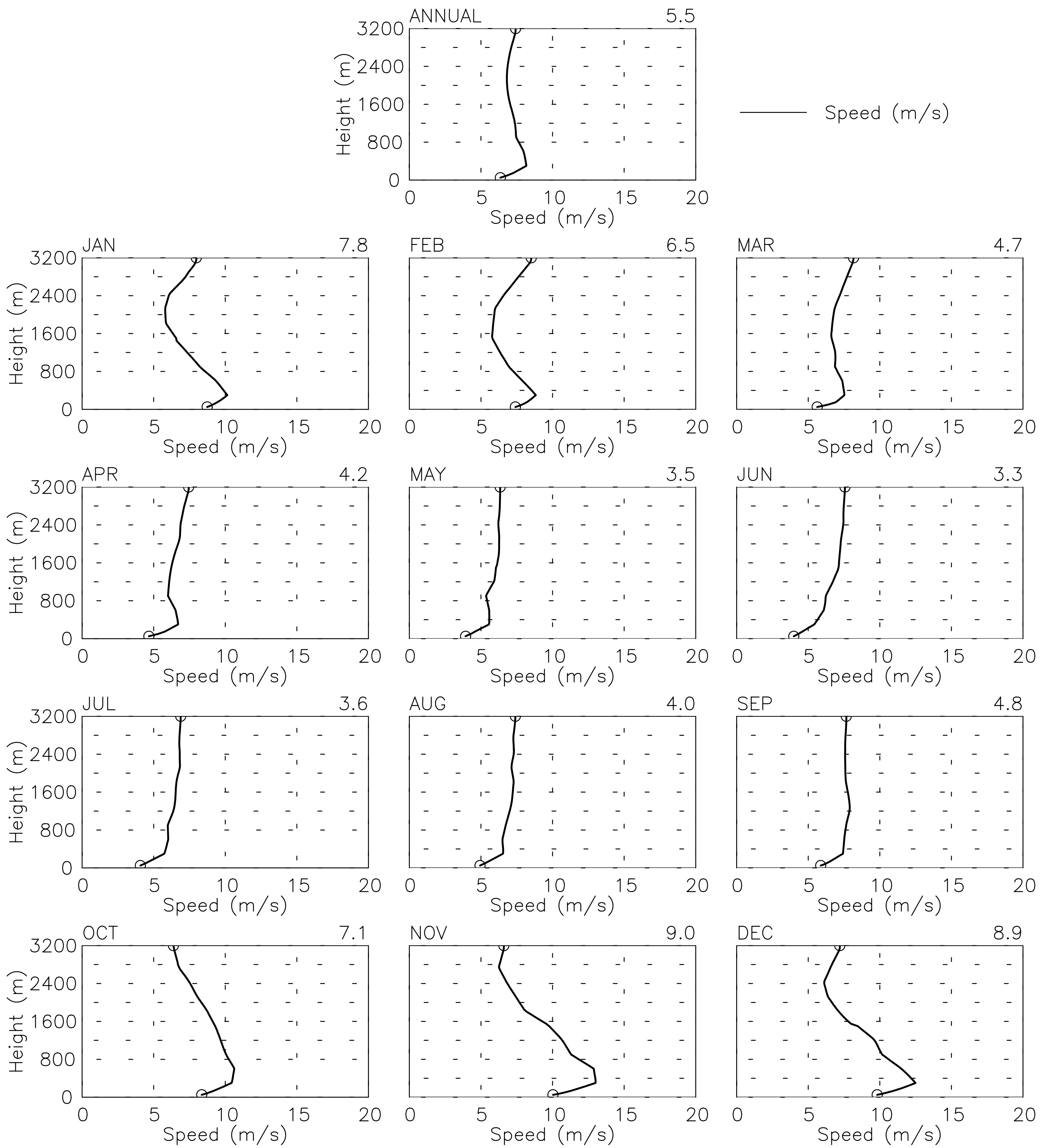
VERTICAL WIND SPEED PROFILE BY HEIGHT

Pratas Island – 46810 – 2000 LST
20° 43' N 116° 43' E – Elev 6m
02/73–03/94



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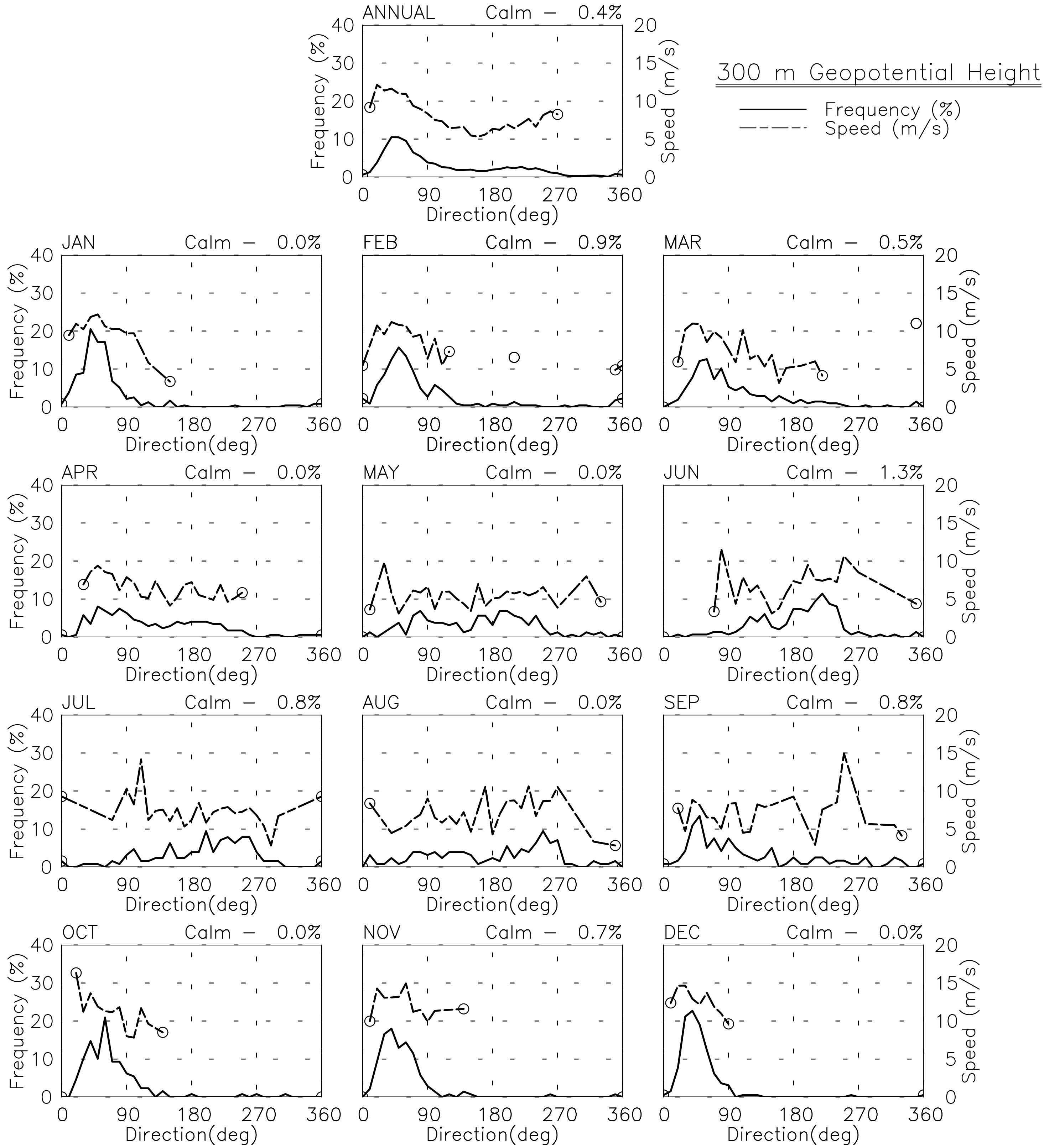
FREQUENCY & SPEED BY DIRECTION

Pratas Island – 46810 – 0800 LST
20° 43' N 116° 43' E – Elev 6m
02/73–03/94



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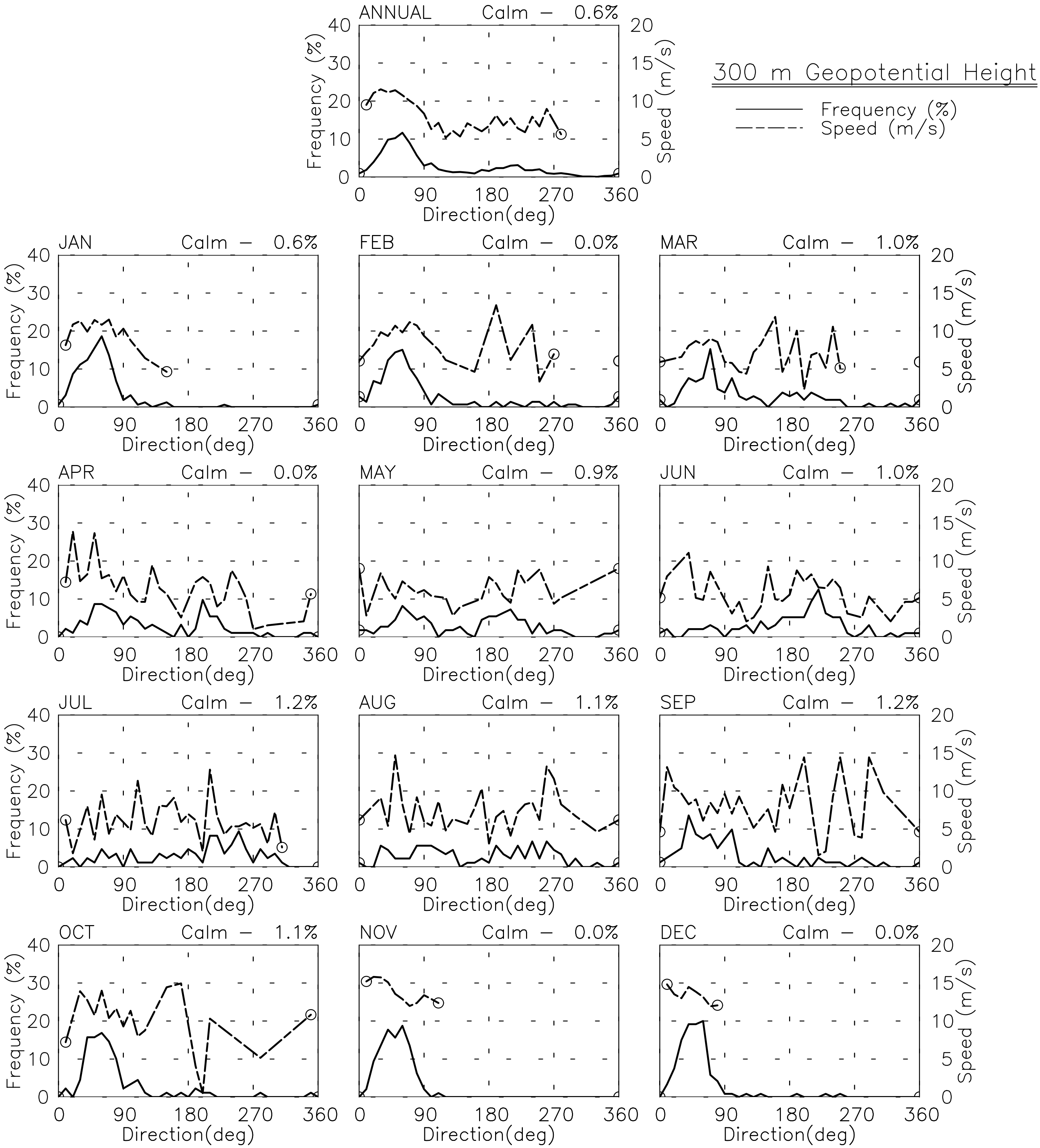
02/73–03/94



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SPEED BY PRESSURE LEVEL & YEAR

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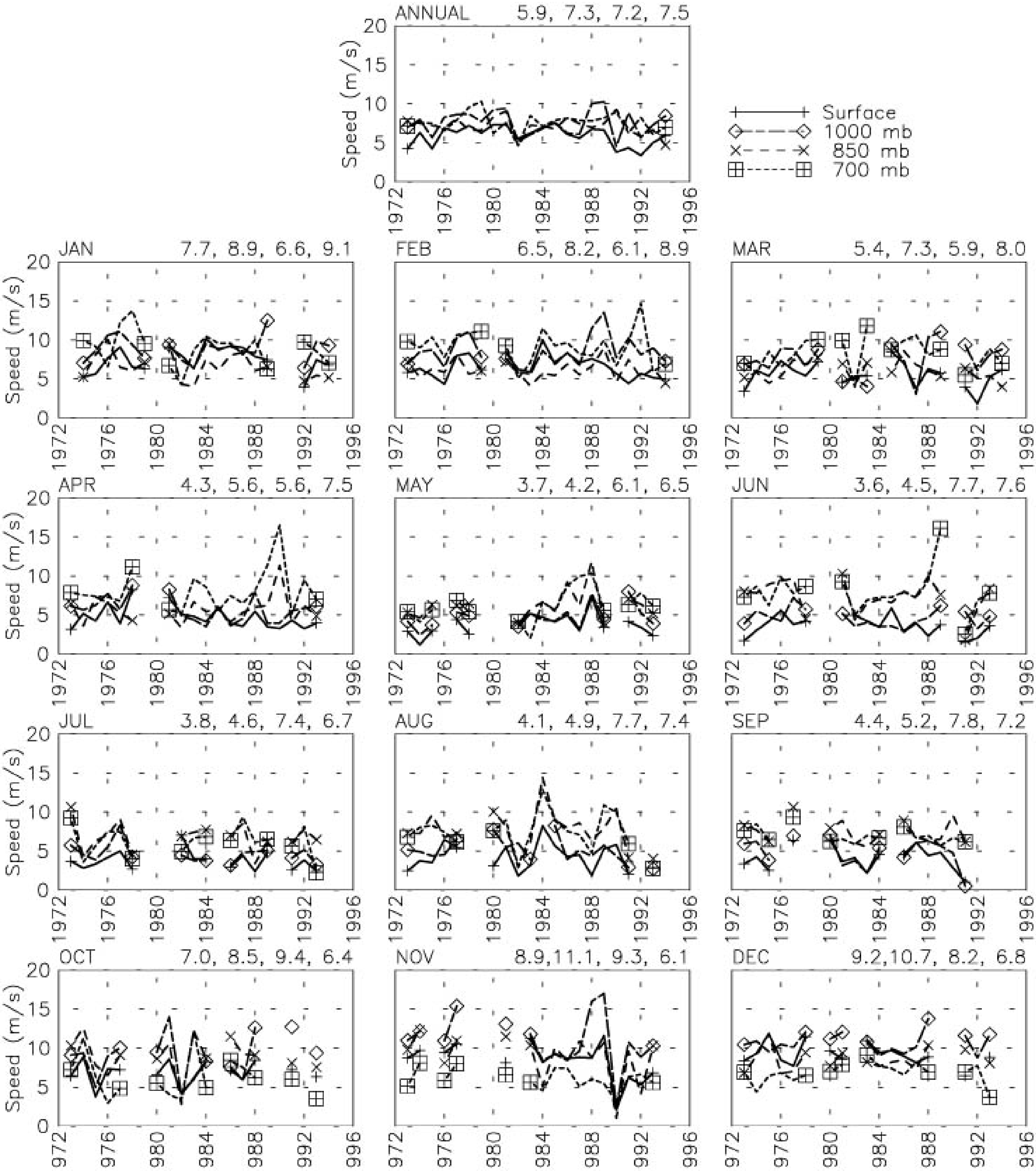
02/73–03/94



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SPEED BY PRESSURE LEVEL & YEAR

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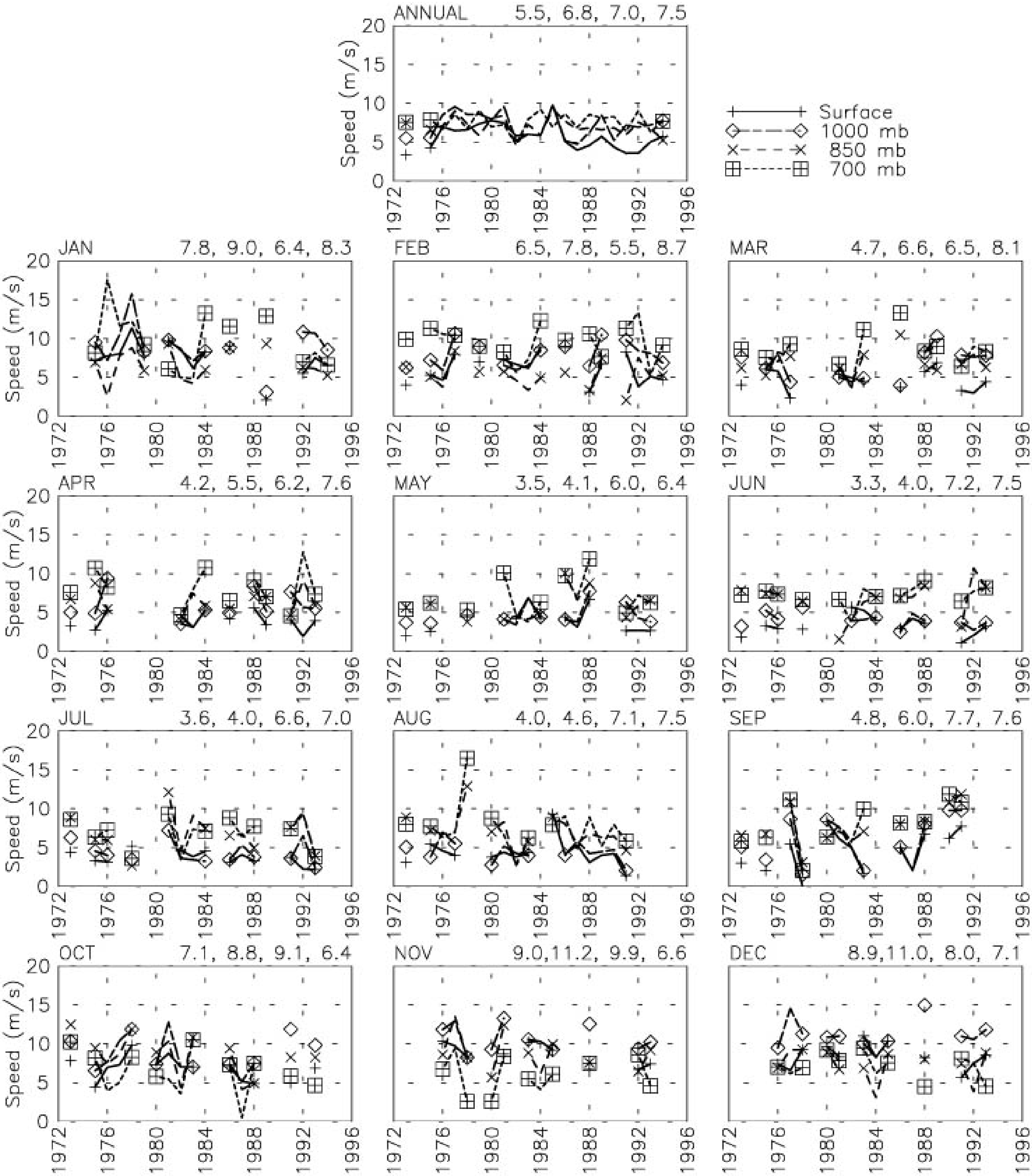
02/73–03/94



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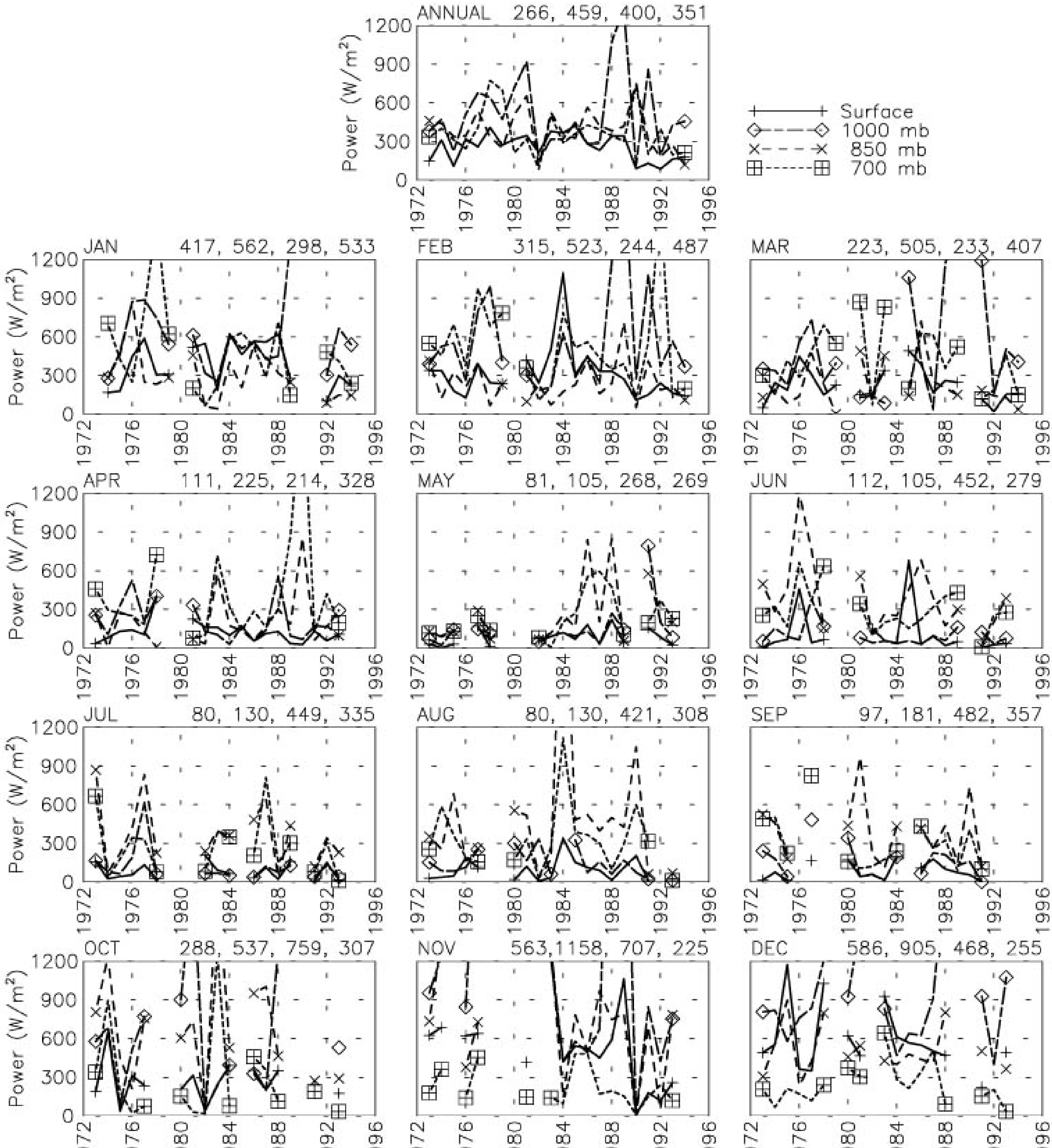
20° 43' N 116° 43' E – Elev 6m
02/73–03/94



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POWER BY PRESSURE LEVEL & YEAR

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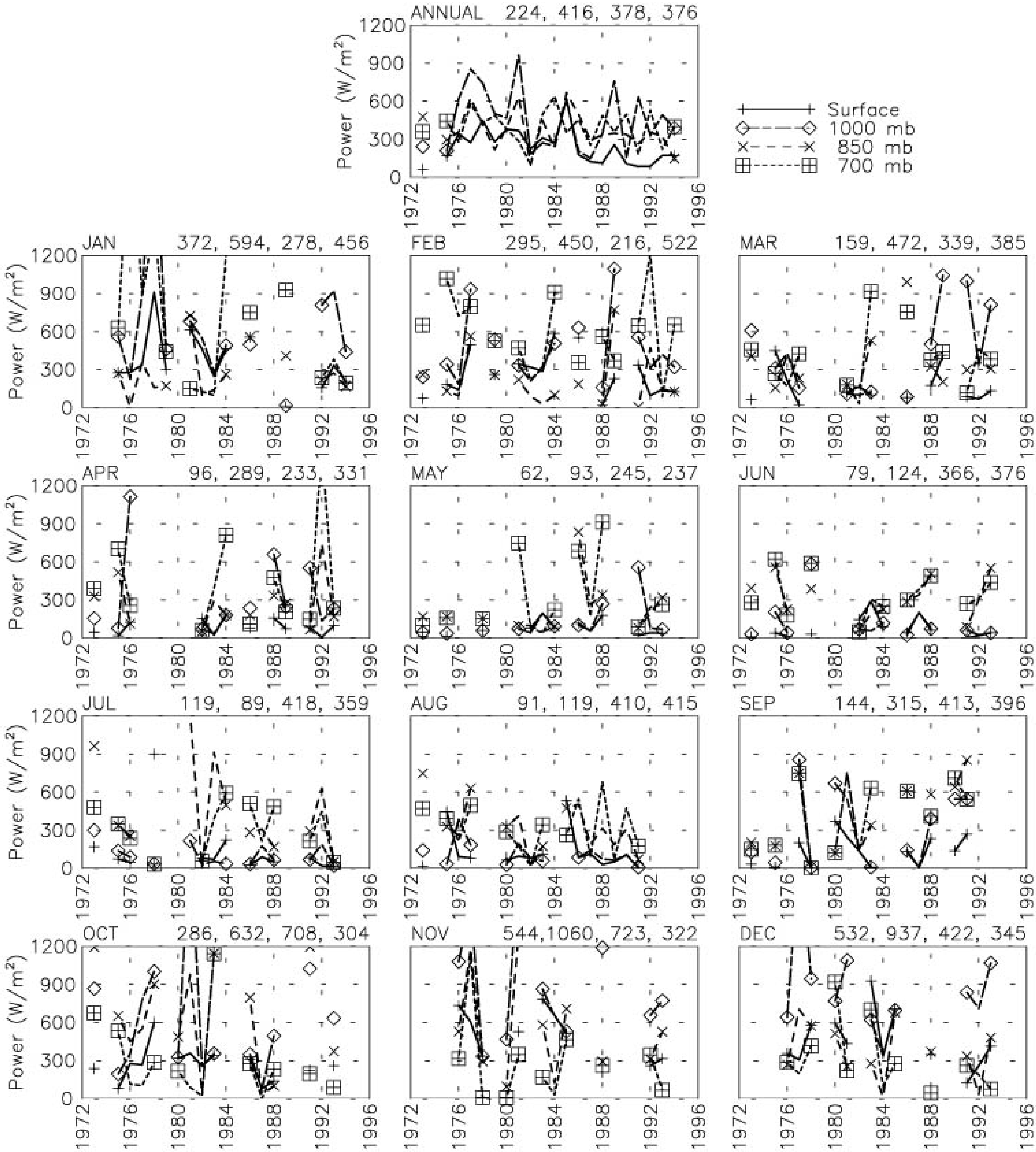
02/73–03/94



Thu Jun 17 14:43:58 1999

Appendix D

Wind Speed and Wind Power Density Computed from Satellite Ocean Wind Data

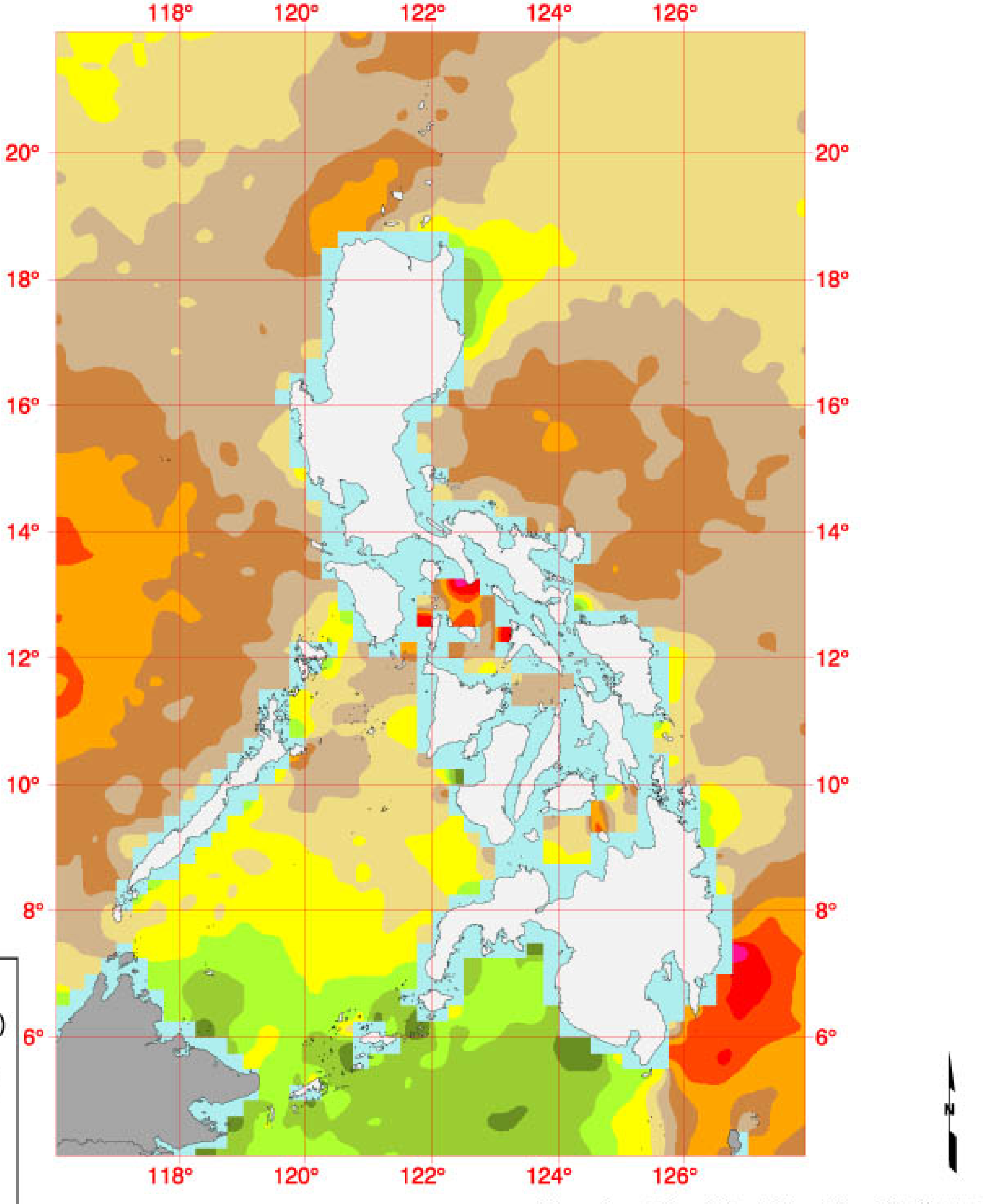
August and December
Wind Speed and Wind Power Density Maps
Computed from Satellite Ocean Wind Data

Region Location Map for the Satellite Ocean Wind Data

Satellite Ocean Wind Speeds at 10 m
Extreme North, East Coast, North Mindanao, East Mindanao,
Palawan-East Coast, Palawan-West Coast, and
West Coast Wind Corridors

Satellite Ocean Wind Power Densities at 10 m
Extreme North, East Coast, North Mindanao, East Mindanao,
Palawan–East Coast, Palawan–West Coast, and
West Coast Wind Corridors

Philippines
August, 1988 to 1994 - Wind Speed
Computed from Satellite-Based Ocean Wind Data



Legend

Wind Speed (m/s)

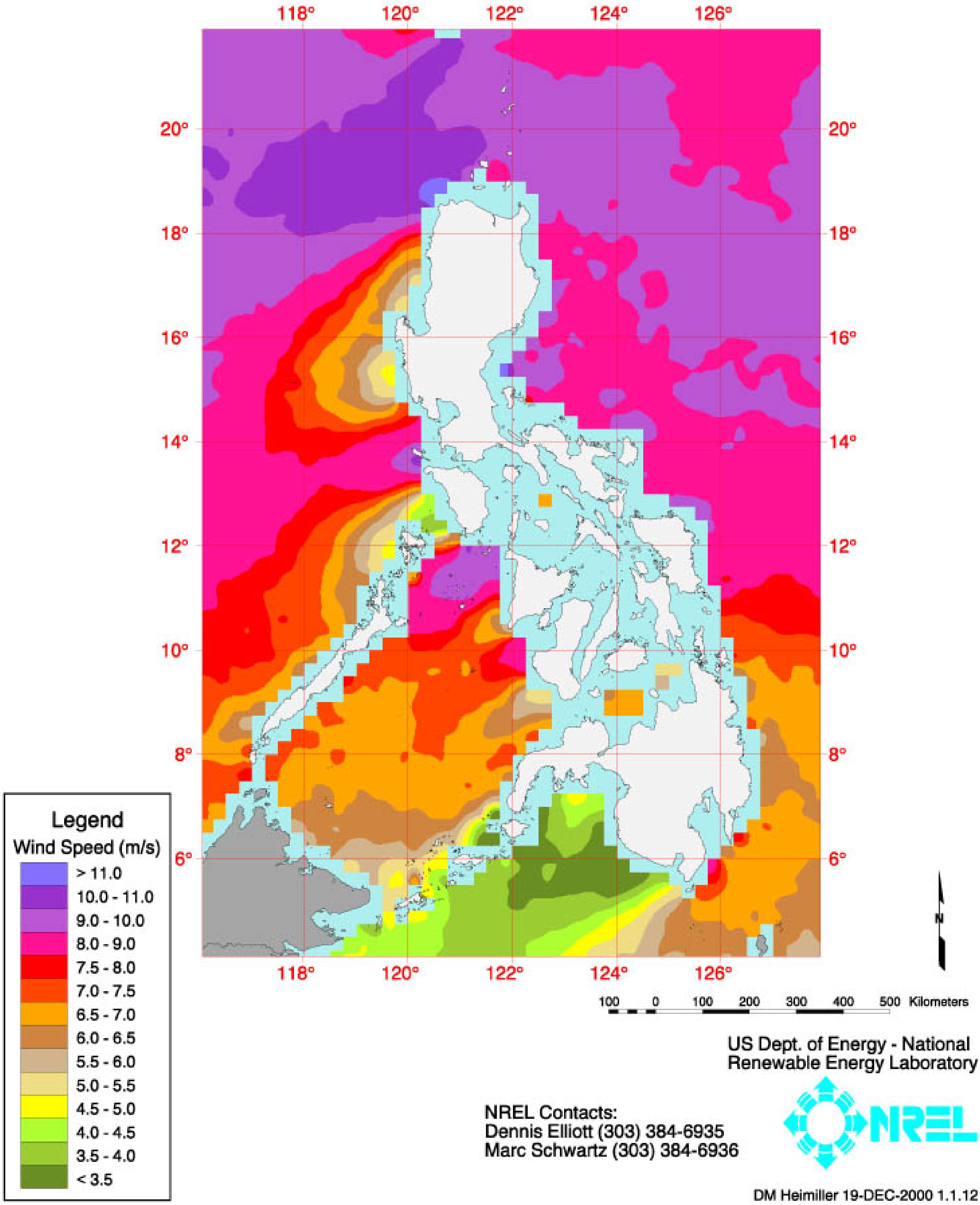
- > 11.0
- 10.0 - 11.0
- 9.0 - 10.0
- 8.0 - 9.0
- 7.5 - 8.0
- 7.0 - 7.5
- 6.5 - 7.0
- 6.0 - 6.5
- 5.5 - 6.0
- 5.0 - 5.5
- 4.5 - 5.0
- 4.0 - 4.5
- 3.5 - 4.0
- < 3.5

US Dept. of Energy - National Renewable Energy Laboratory

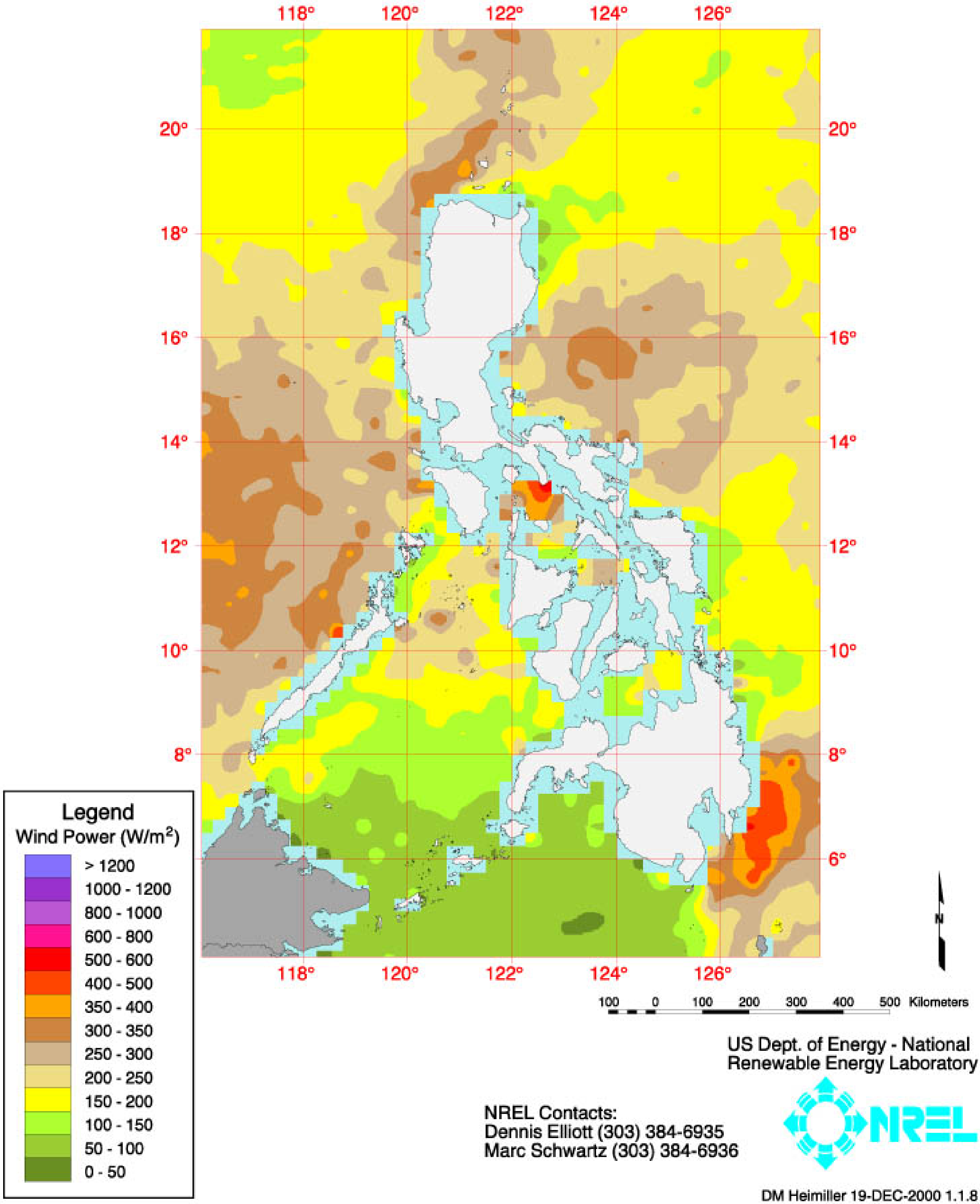
NREL Contacts:
Dennis Elliott (303) 384-6935
Marc Schwartz (303) 384-6936

DM Heimiller 20-DEC-2000 1.1.8

Philippines
December, 1988 to 1994 - Wind Speed
Computed from Satellite Ocean Wind Data



Philippines
August, 1988 to 1994 - Wind Power Density
Computed from Satellite Ocean Wind Data



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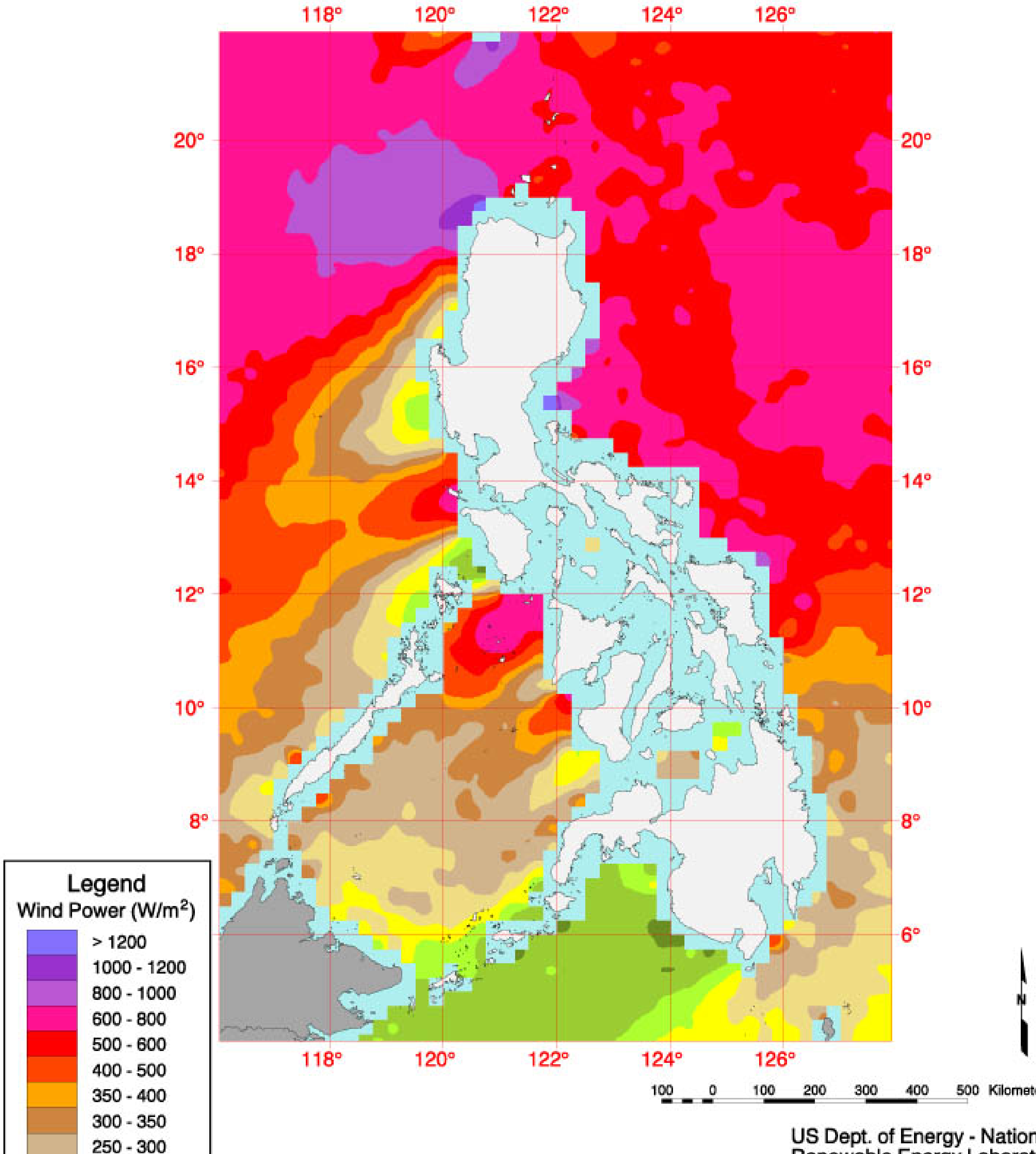
DM Heimiller 19-DEC-2000 1.1.8

Philippines
December, 1988 to 1994 - Wind Power Density
Computed from Satellite Ocean Wind Data



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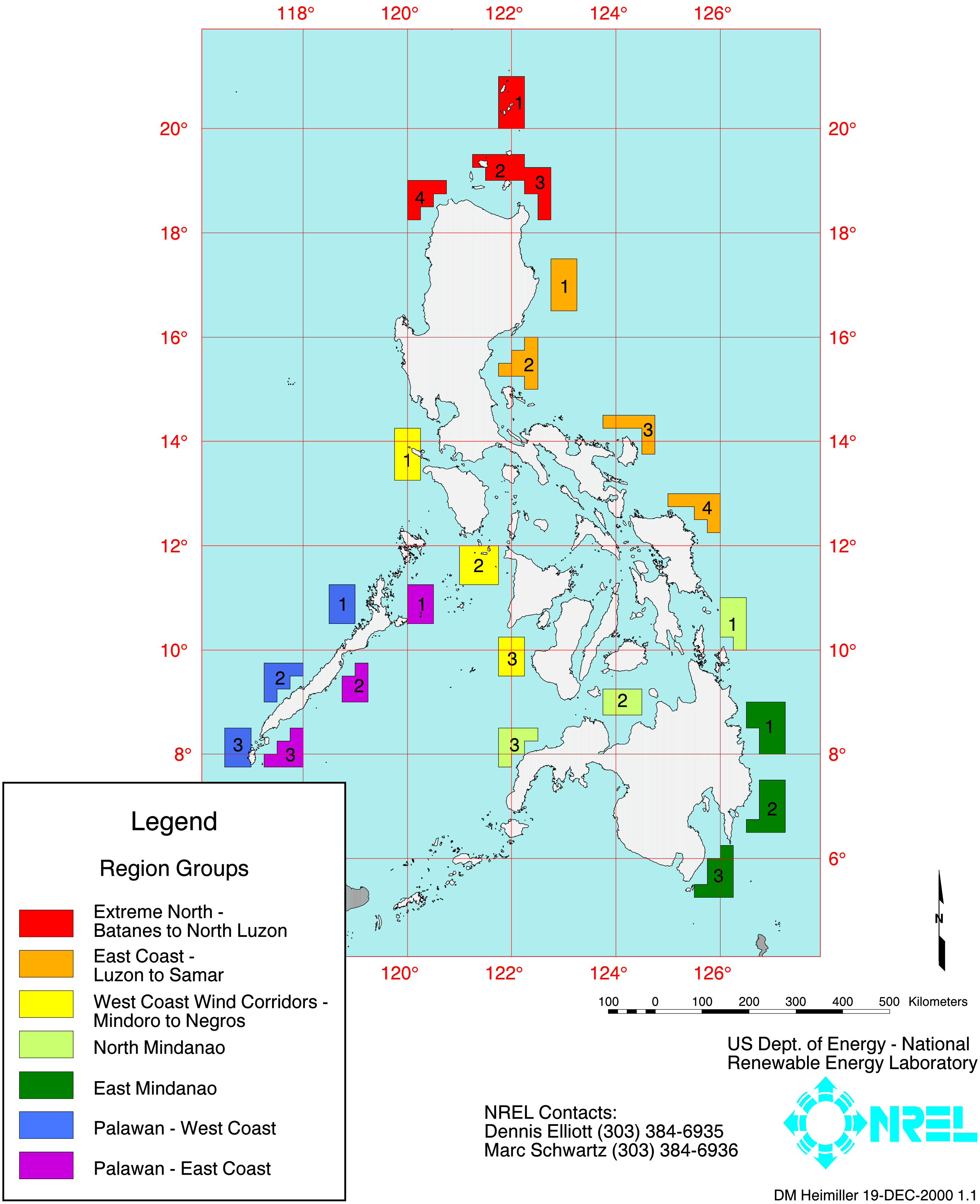
Philippines - Region Location Map
For Satellite Ocean Wind Data
Valid for 10 m Height



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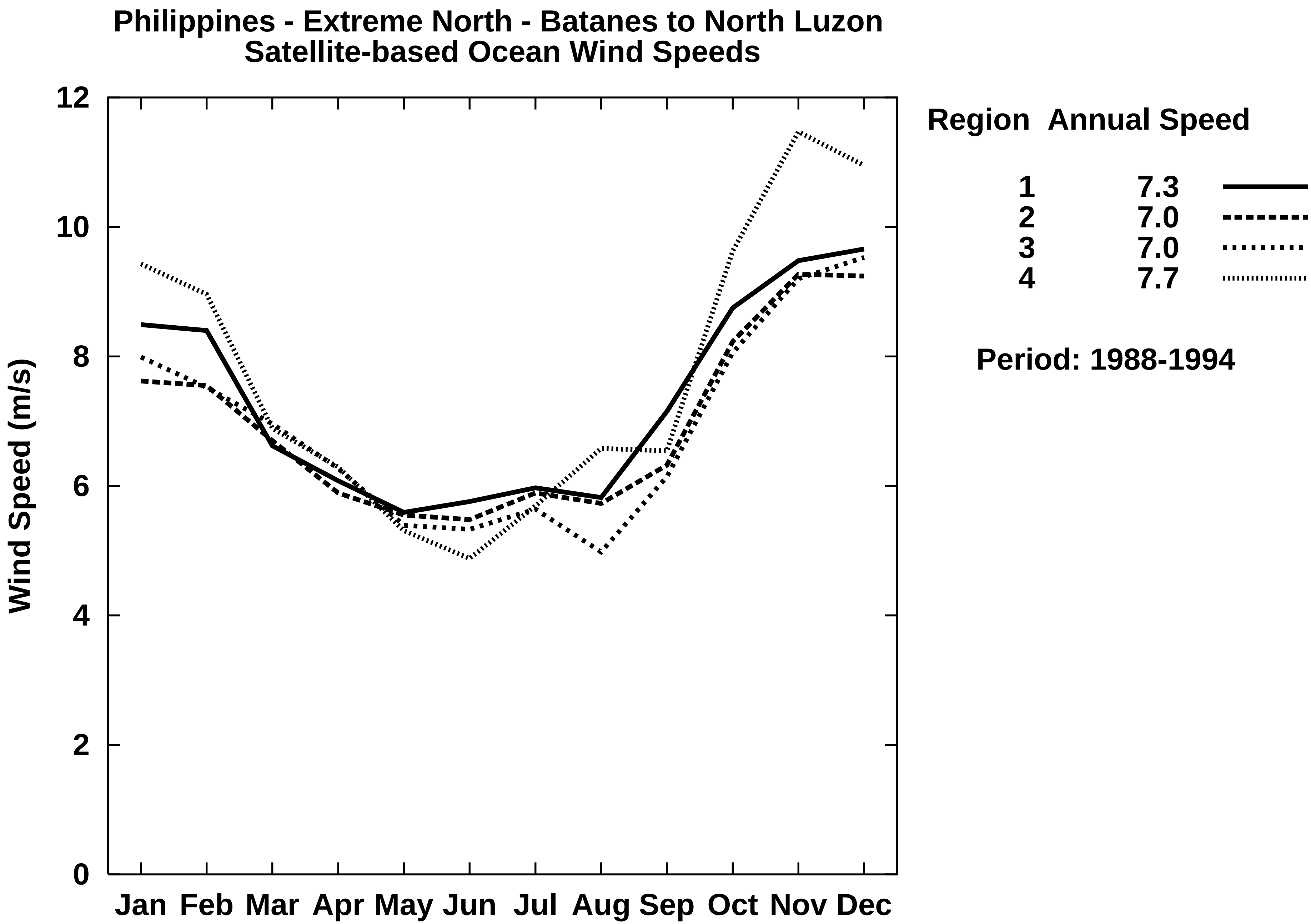
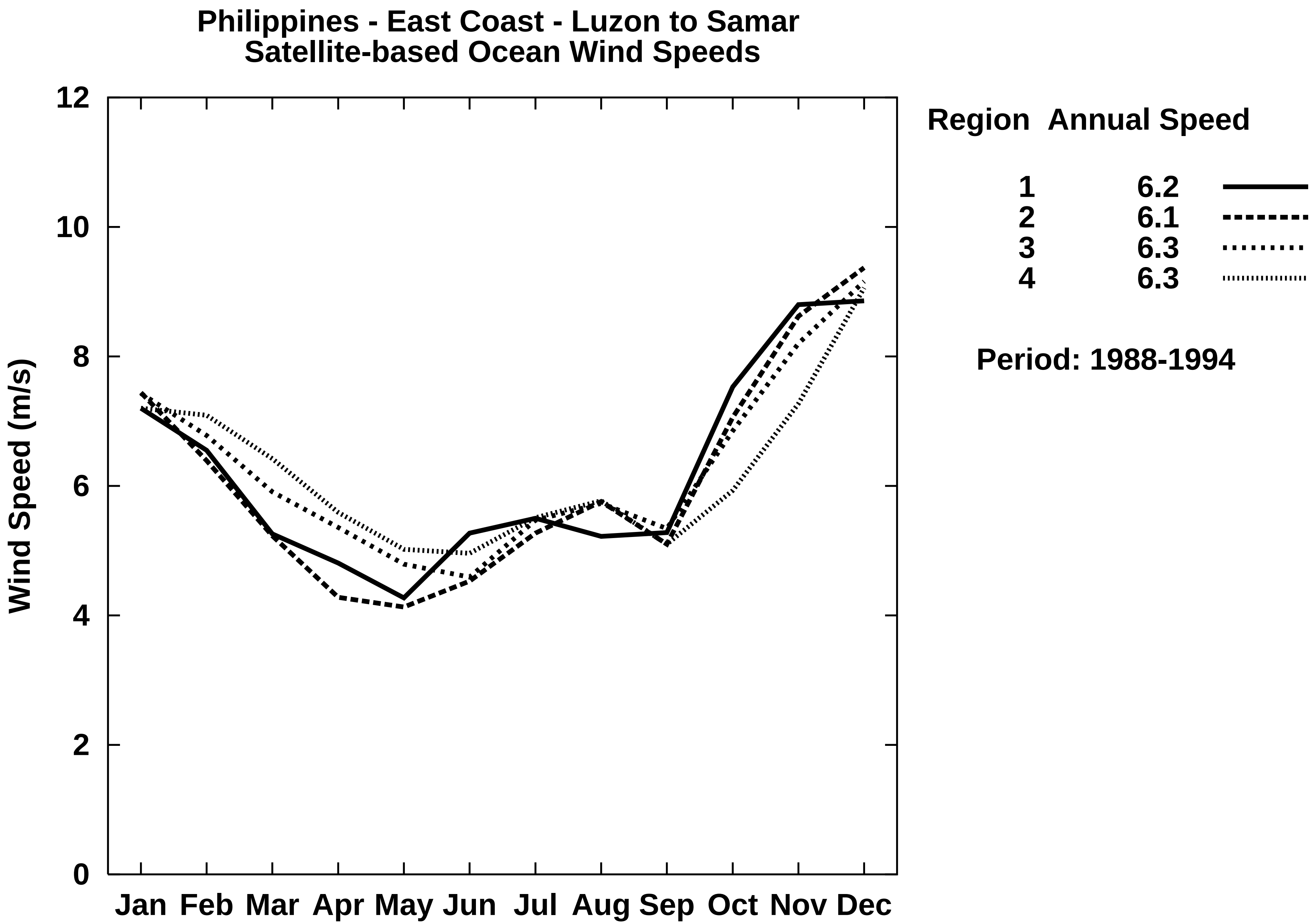
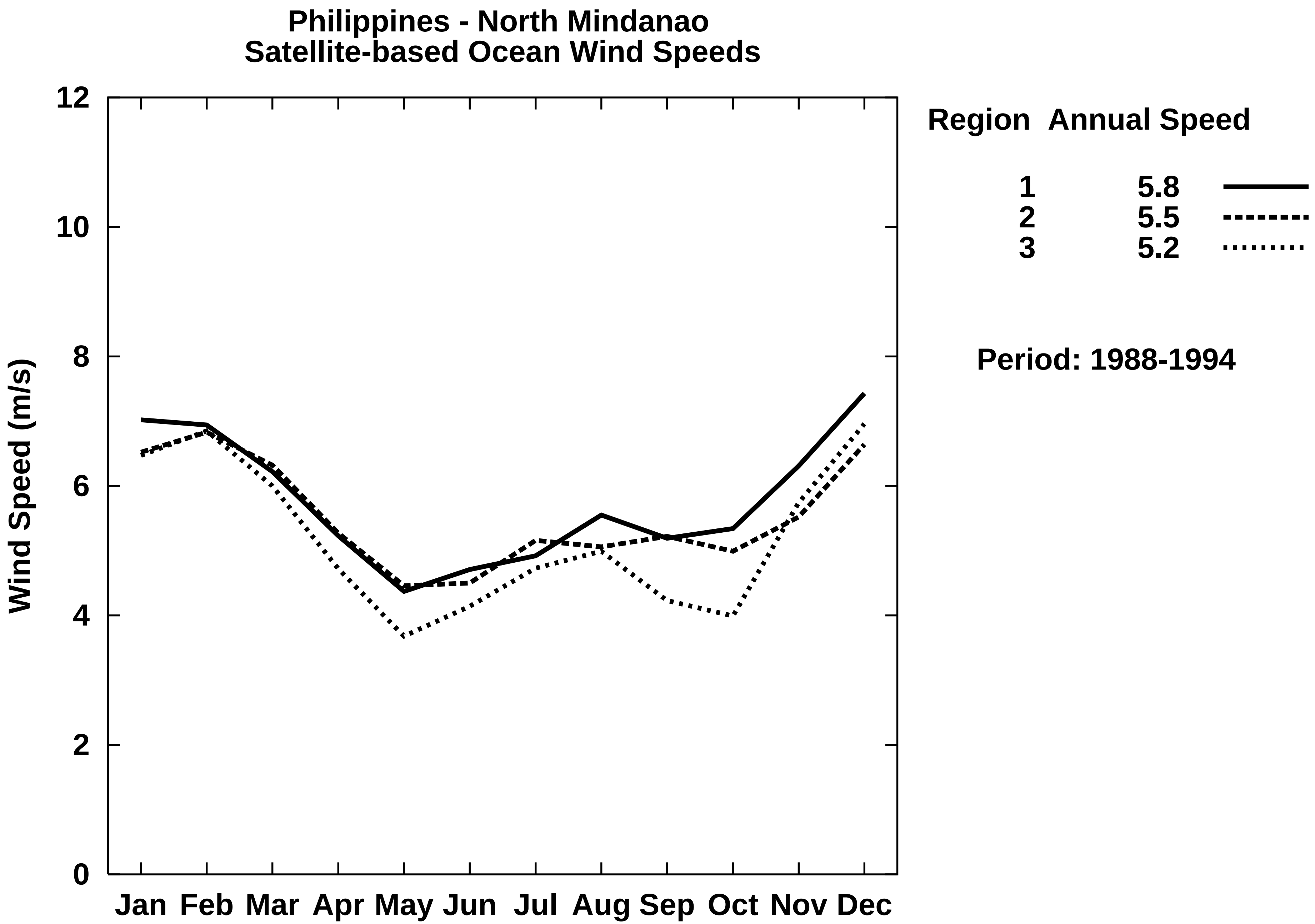
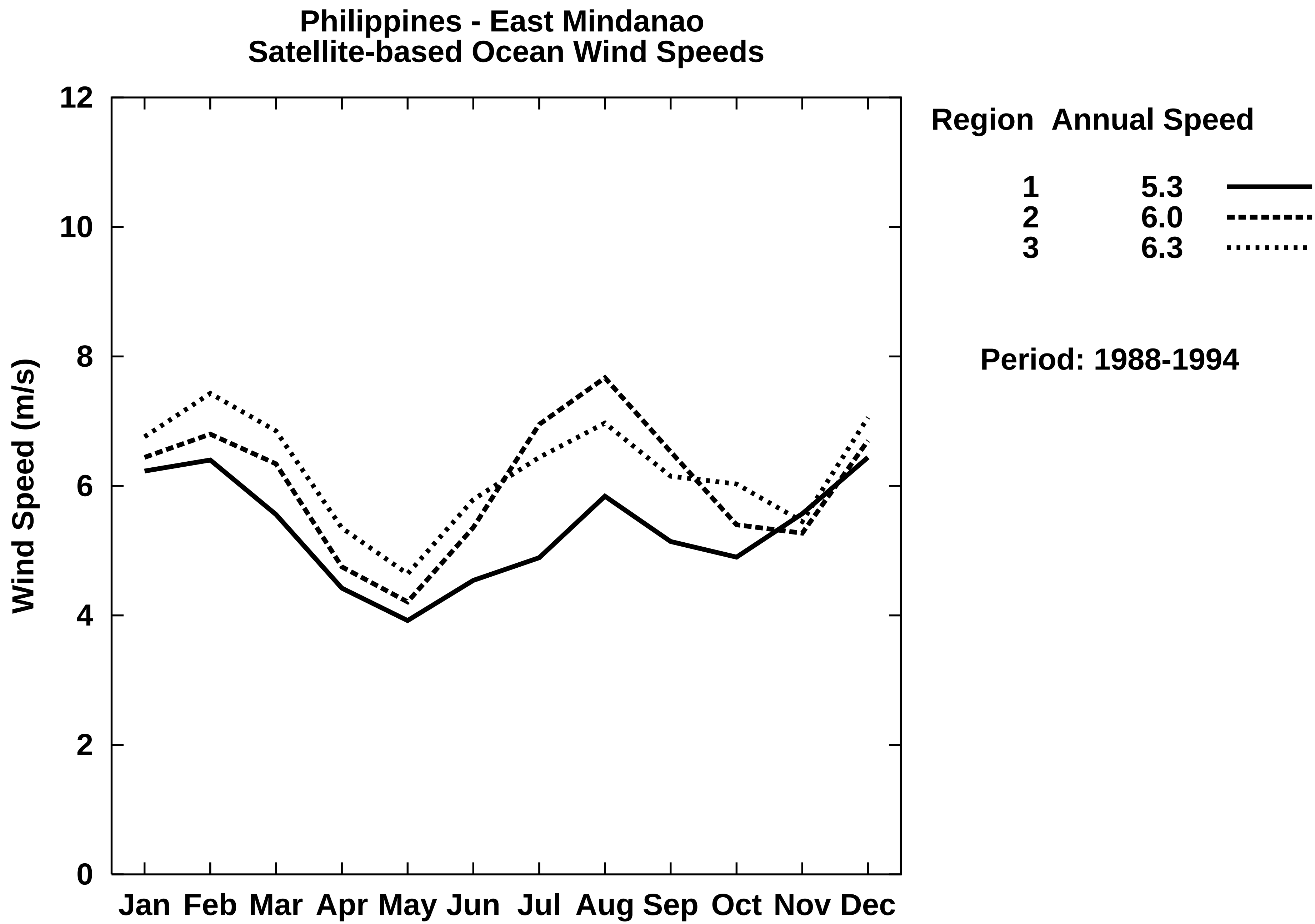
Marc Schwartz (303) 384-6936

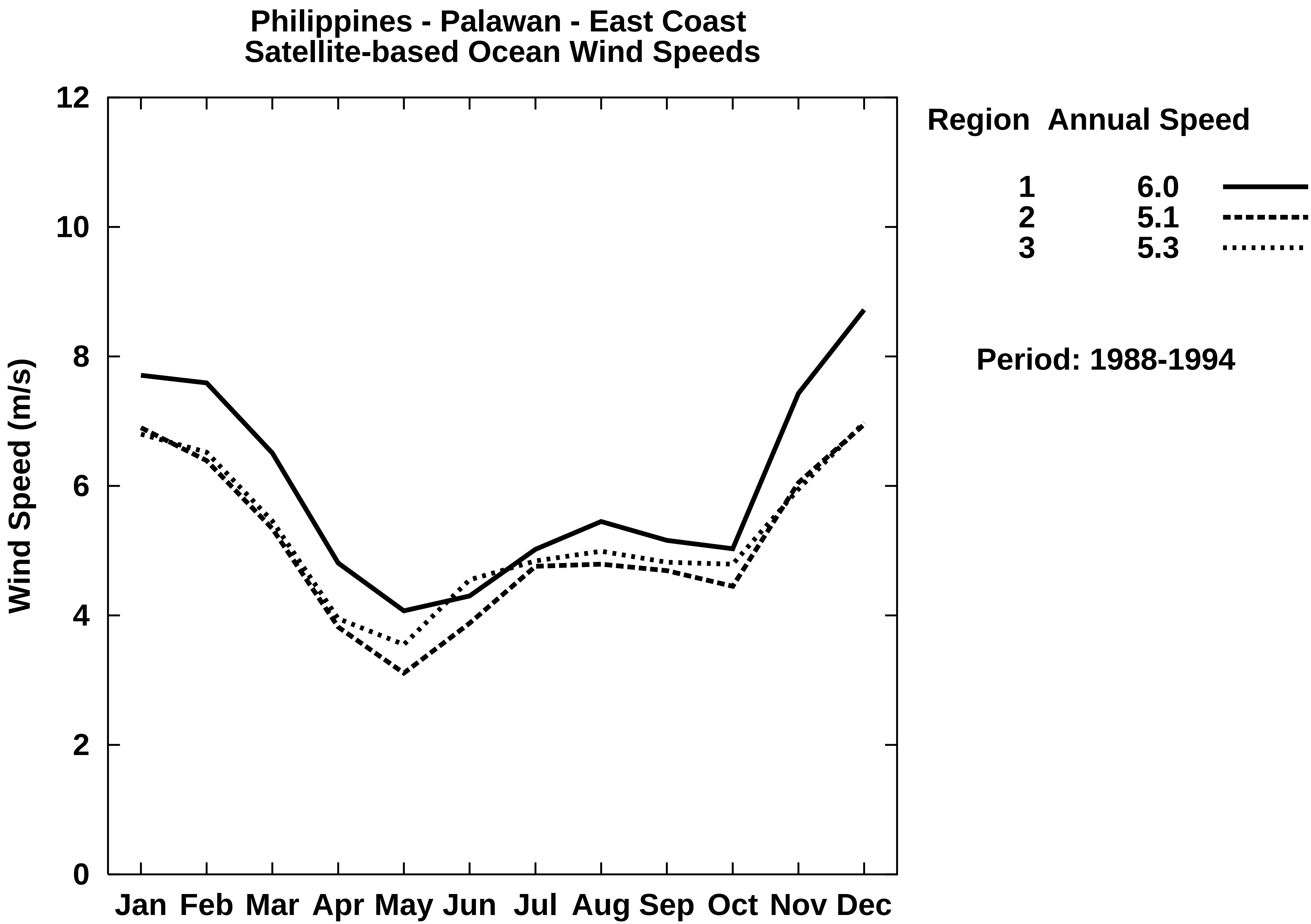
DM Heimiller 19-DEC-2000 1.1

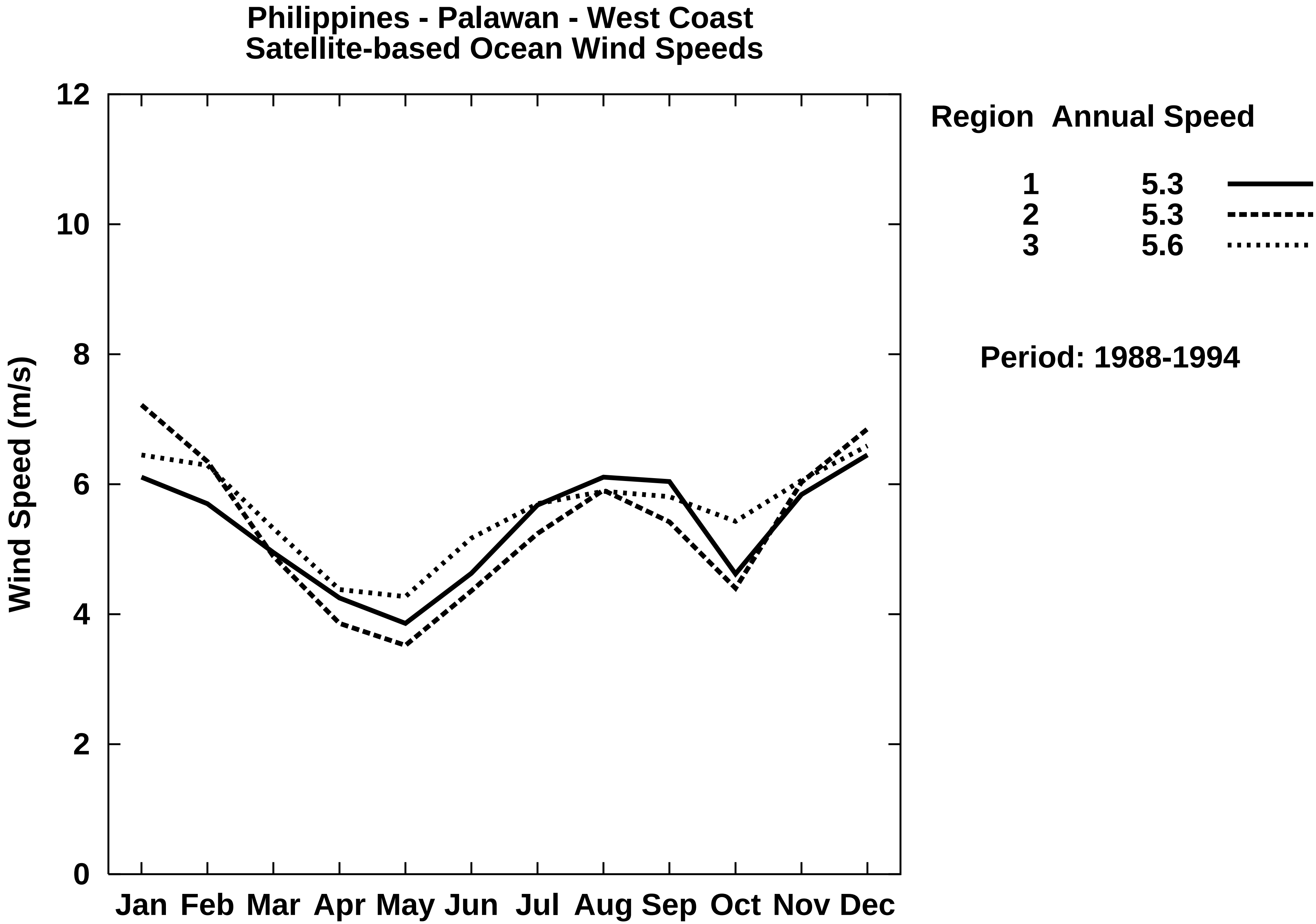

Philippines - Extreme North - Batanes to North Luzon
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 7.3
2 7.0
3 7.0
4 7.7
Period: 1988-1994

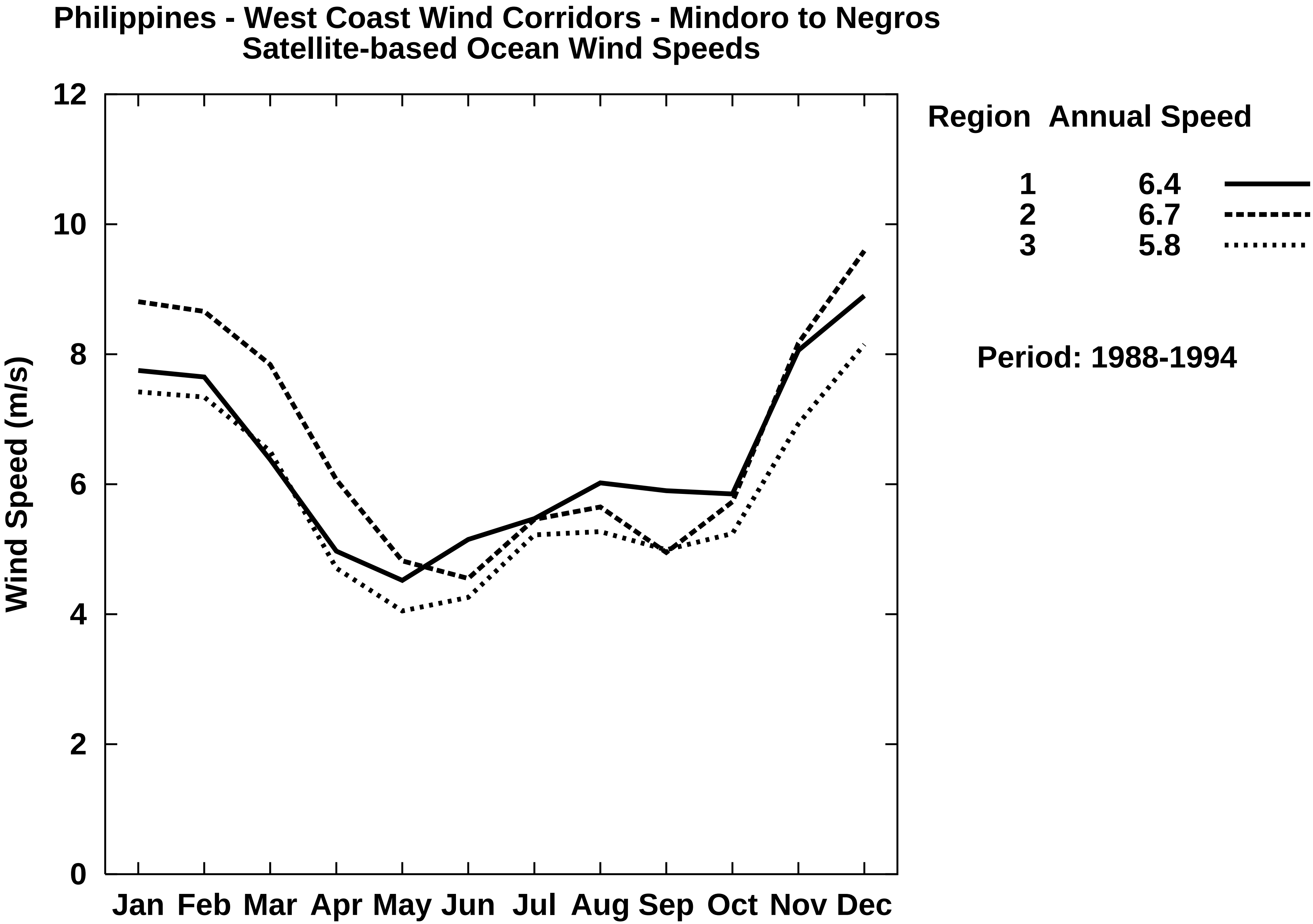

Philippines - East Coast - Luzon to Samar
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 6.2
2 6.1
3 6.3
4 6.3
Period: 1988-1994


Philippines - North Mindanao
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 5.8
2 5.5
3 5.2
Period: 1988-1994

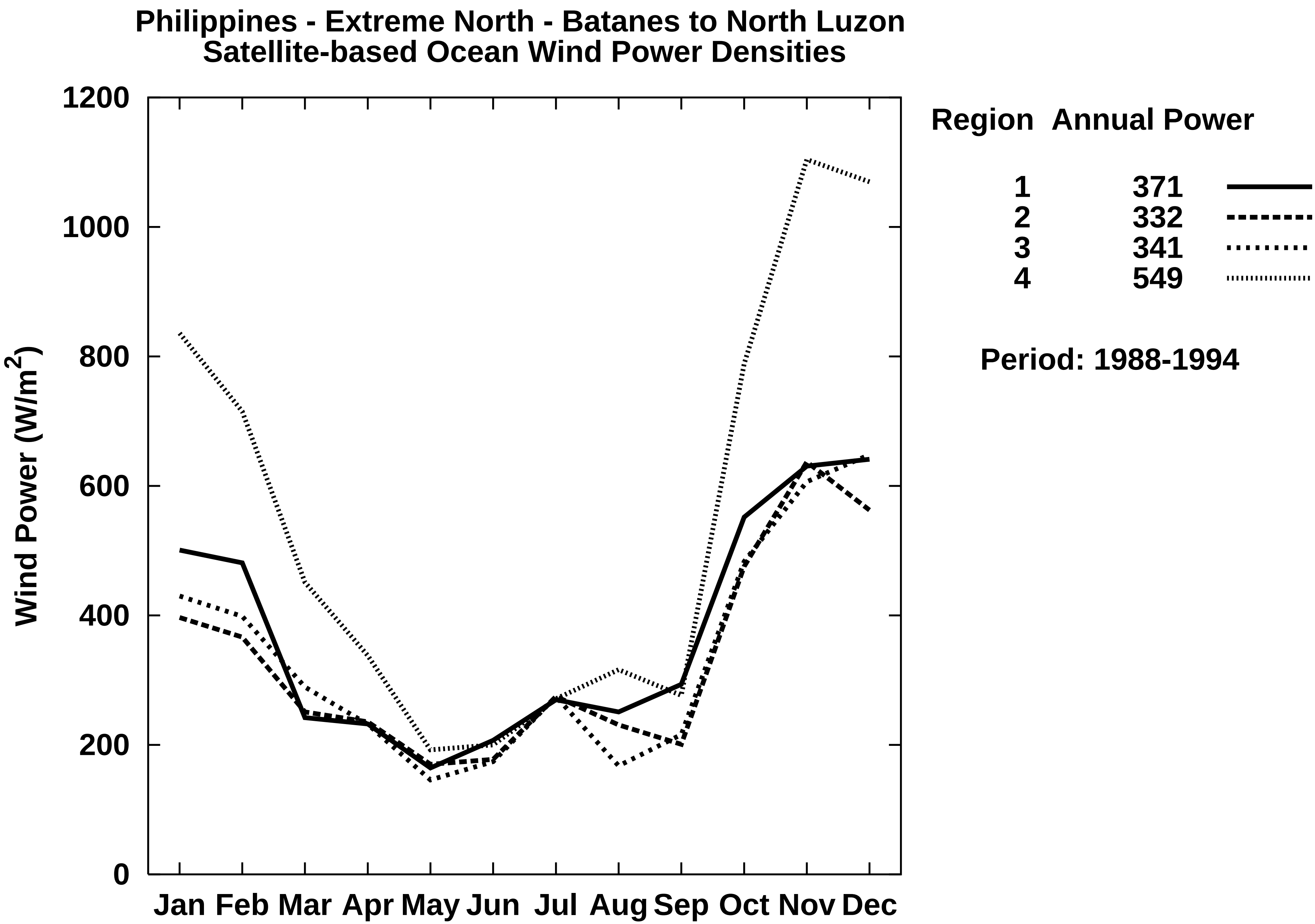

Philippines - East Mindanao
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 5.3
2 6.0
3 6.3
Period: 1988-1994

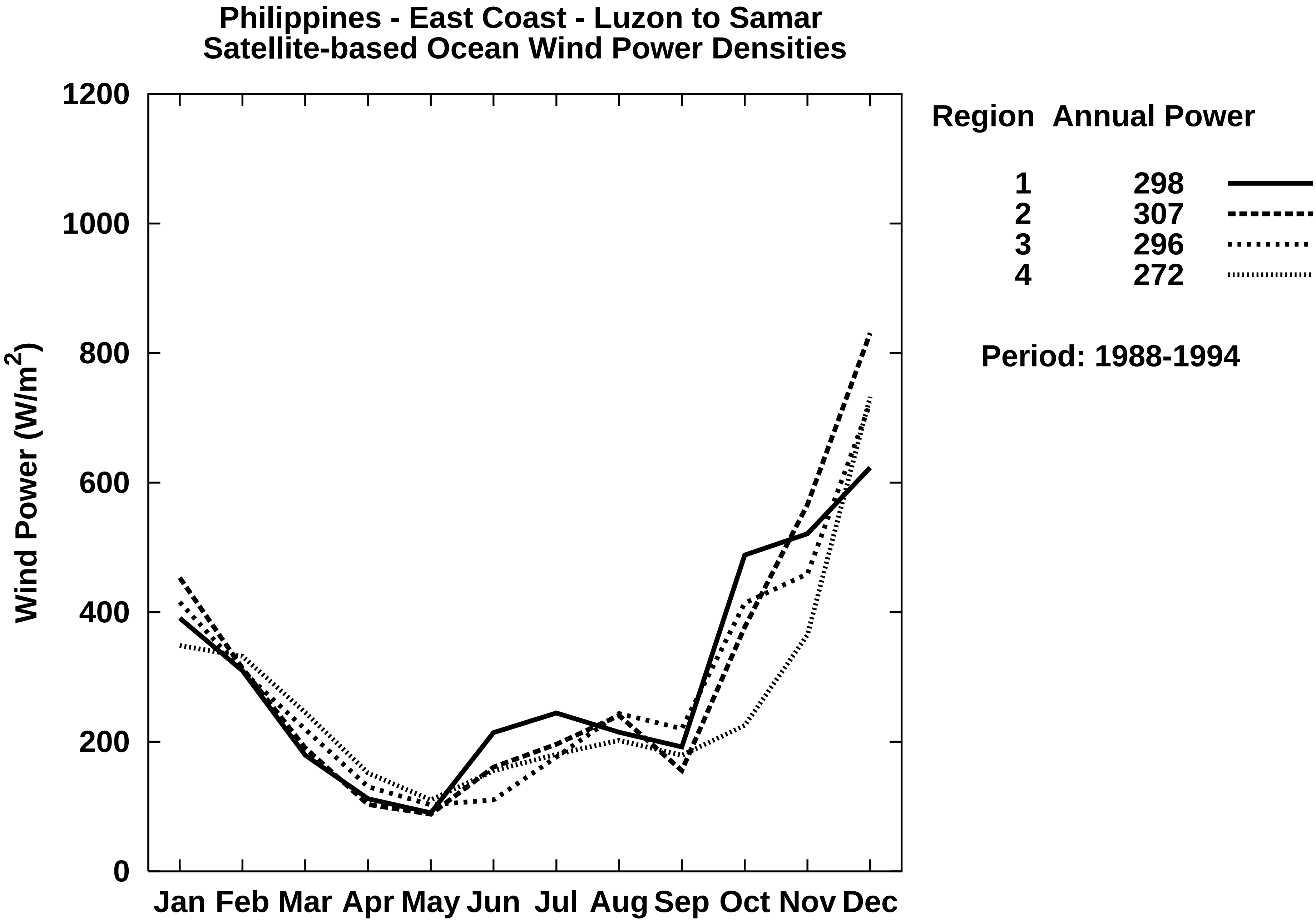

Philippines - Palawan - East Coast
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Region
Annual Speed
1
6.0
2
5.1
3
5.3
Period: 1988-1994


Philippines - Palawan - West Coast
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 5.3
2 5.3
3 5.6
Period: 1988-1994

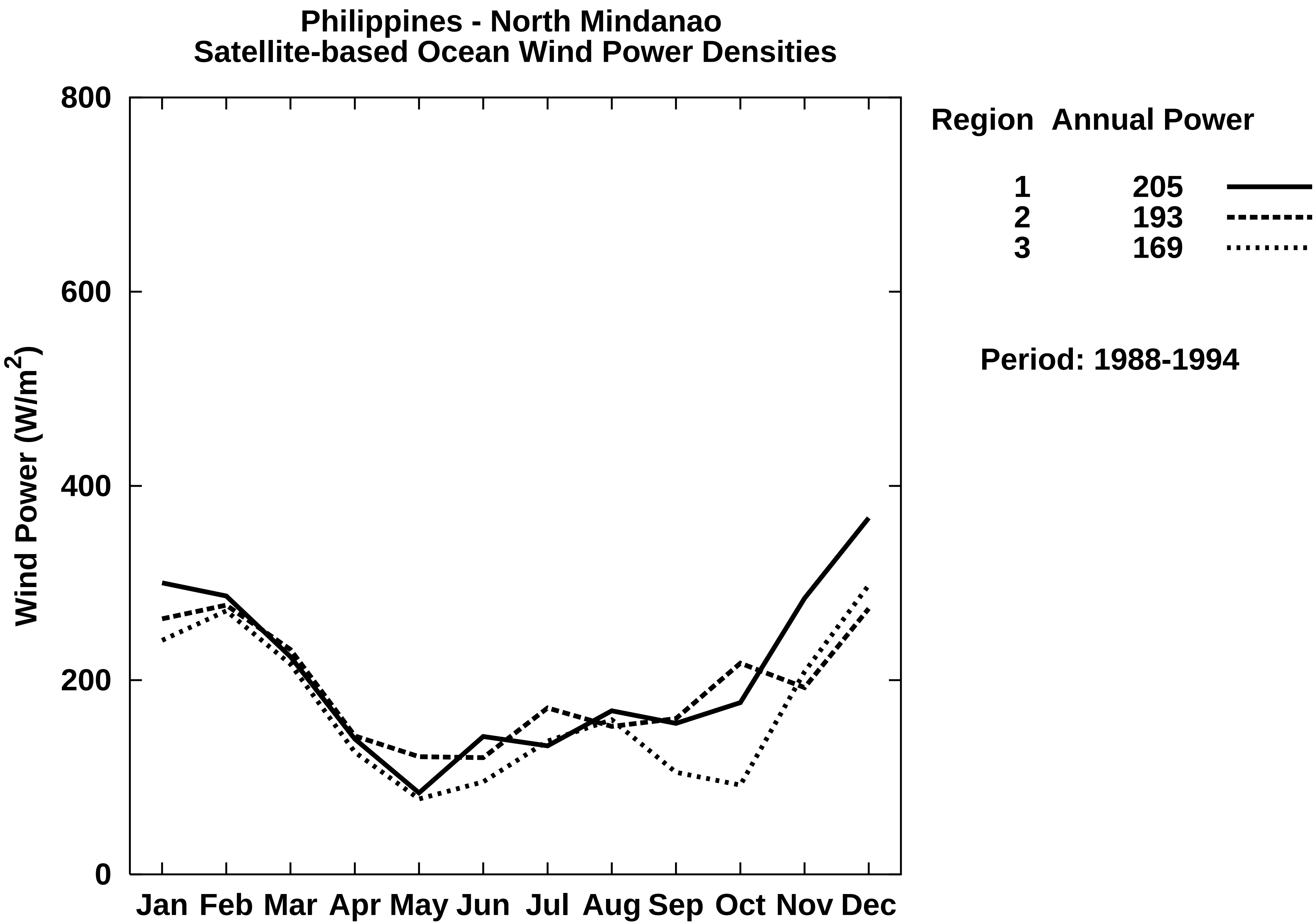


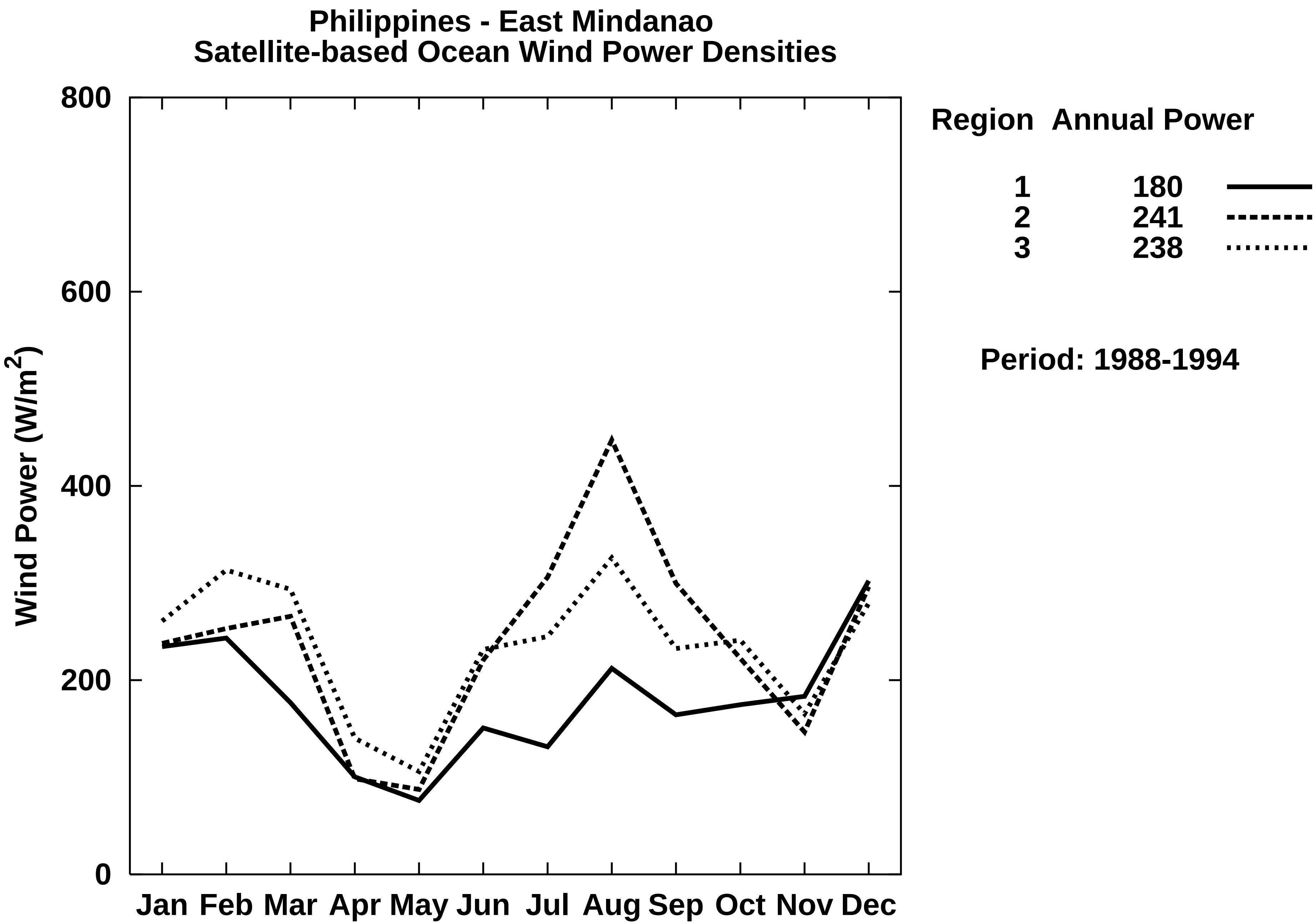
Philippines - West Coast Wind Corridors - Mindoro to Negros
Satellite-based Ocean Wind Speeds
Wind Speed (m/s)
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Speed
1 6.4
2 6.7
3 5.8
Period: 1988-1994


Philippines - Extreme North - Batanes to North Luzon
Satellite-based Ocean Wind Power Densities
Wind Power (W/m2)
1200
1000
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 371
2 332
3 341
4 549
Period: 1988-1994

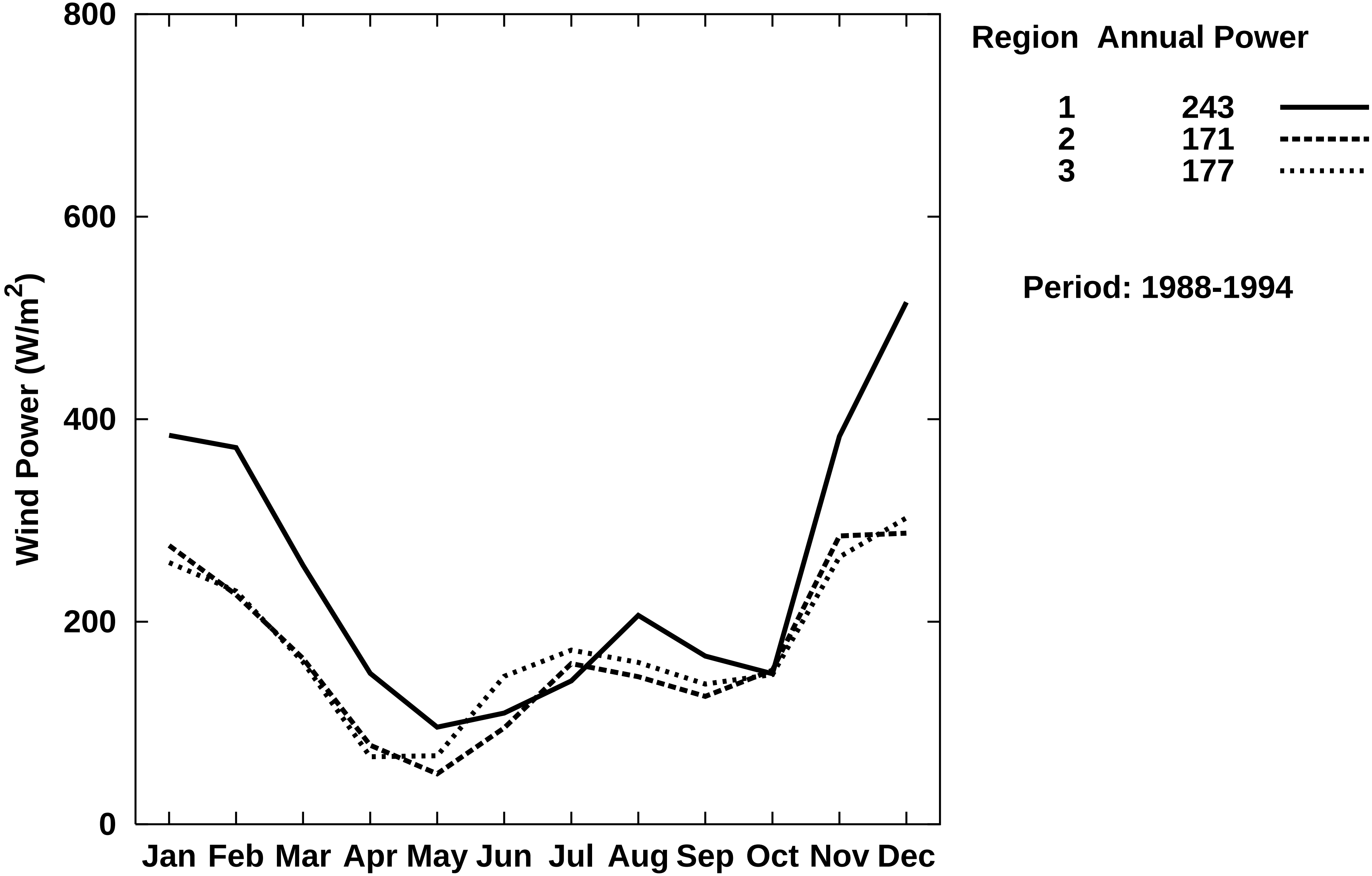


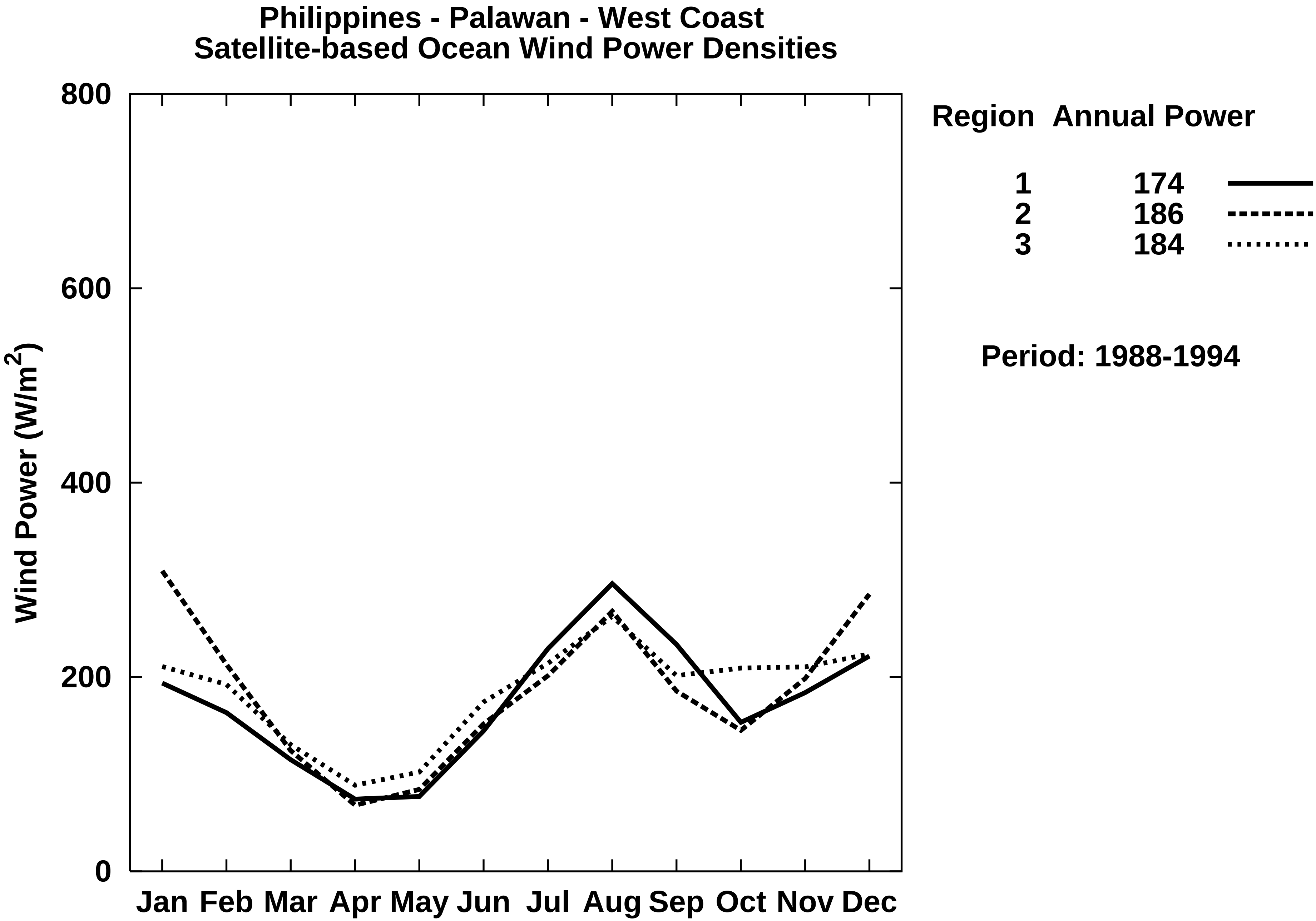
Philippines - East Coast - Luzon to Samar
Satellite-based Ocean Wind Power Densities
Wind Power (W/m^2)
1200
1000
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 298
2 307
3 296
4 272
Period: 1988-1994


Philippines - North Mindanao
Satellite-based Ocean Wind Power Densities
Wind Power (W/m2)
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 205
2 193
3 169
Period: 1988-1994

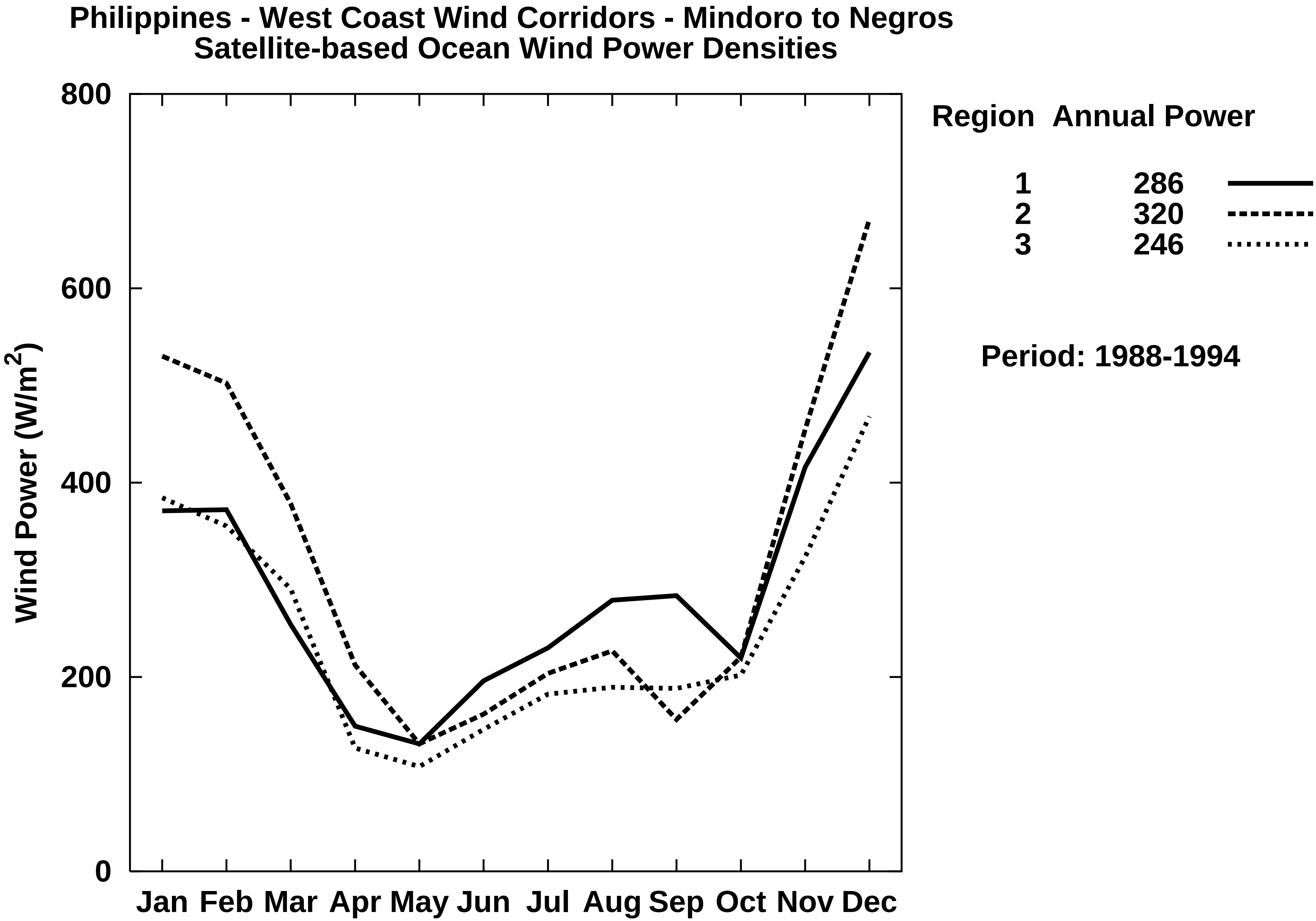

Philippines - East Mindanao
Satellite-based Ocean Wind Power Densities
Wind Power (W/m2)
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 180
2 241
3 238
Period: 1988-1994

Philippines - Palawan - East Coast
Satellite-based Ocean Wind Power Densities





Philippines - Palawan - West Coast
Satellite-based Ocean Wind Power Densities
Wind Power (W/m2)
800
600
400
200
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 174
2 186
3 184
Period: 1988-1994


Philippines - West Coast Wind Corridors - Mindoro to Negros
Satellite-based Ocean Wind Power Densities
Wind Power (W/m2)
0
200
400
600
800
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Region Annual Power
1 286
2 320
3 246
Period: 1988-1994

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This report contains the results of a wind resource analysis and mapping study for the Philippine archipelago. The study's objective was to identify potential wind resource areas and quantify the value of those resources within those areas. The wind resource maps and other wind resource characteristic information will be used to identify prospective areas for wind-energy applications.

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Philippines; wind resource; maps; Geographic Information System

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