NREL/CP-440-23157 • UC Category: 1212

The Integration of Climatic Data Sets for Wind Resource Assessment

Marc N. Schwartz
Dennis L. Elliott

Presented at
American Meteorological Society
10th Conference on Applied Climatology
Reno, Nevada
October 20–24, 1997

National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401-3393
A national laboratory of the U.S. Department of Energy
Managed by Midwest Research Institute
for the U.S. Department of Energy
under contract No. DE-AC36-83CH10093

Work performed under task number WE711020

September 1997

Available to DOE and DOE contractors from:
Office of Scientific and Technical Information (OSTI)
P.O. Box 62
Oak Ridge, TN 37831
Prices available by calling (423) 576-8401

Available to the public from:
National Technical Information Service (NTIS)
U.S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650

Printed on paper containing at least 50% wastepaper, including 20% postconsumer waste

12B.3 THE INTEGRATION OF CLIMATIC DATA SETS FOR WIND RESOURCE ASSESSMENT

Marc Schwartz* and Dennis Elliott
National Renewable Energy Laboratory, Golden, Colorado

1. INTRODUCTION

One barrier to wind energy development, in many regions of the world, is the lack of reliable information about the spacial distribution of the wind energy resource. The goal of the U.S. Department of Energy (DOE) Wind Energy Program's wind resource assessment group, located at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, is to improve the characterization of the wind resource in many of these regions in support of U.S. wind energy industry (Elliott and Schwartz, 1996). NREL provides wind resource assessments for our clients in the form of reports, atlases, and wind resource maps. The assessments estimate the level of the wind resource, at wind turbine hub heights (typically 30 m to 50 m above ground level), for locations exposed to the prevailing winds.

A combination of wind climatology elements help determine the level of the wind energy resource in a particular area. Factors such as the annual and monthly average wind speeds, the distribution of individual wind speed observations, and the seasonal and diurnal wind patterns affect the suitability of a region for wind energy project development. In general, locations with an annual average wind speed at least 7 m/s, at turbine hub height, are likely to be suitable for utility grid-connected wind energy applications. Rural power applications can be viable with lower wind energy resource (5.5 m/s to 6 m/s) than utility applications. However, the average wind speed is not the best indicator of the resource. Instead, the level of the wind energy resource is often defined by the wind power density value, expressed in units of Watts per square meter. This parameter incorporates the combined effect of the frequency distribution of wind speeds, and the dependence of the wind power on air density and on the cube of the wind speed. The wind energy resource level is frequently classified based on ranges of wind power density values, with the higher wind power classes (best suited to wind energy power development) assigned to areas with high values of wind power density. Details of the wind classification scheme used for the United States are presented in the *Wind Energy Resource Atlas of the United States* (Elliott et al. 1987).

The assessments, used by a variety of organizations (DOE, other U.S. government agencies, utilities, and the U.S. wind energy industry), need to be as accurate as possible in order to accelerate the development of wind energy. NREL has developed a wind assessment resource methodology to produce sophisticated wind resource assessments and maps that are useful for wind prospecting and wind energy project implementation. The use of global climatic data sets that have become available in the last few years has provided the capability to develop wind assessments and maps with much greater resolution and accuracy than was possible in previous surveys.

2. ASSESSMENT METHODOLOGY

This section describes the methodology used by NREL to perform wind resource assessments. A diagram of the structure of NREL's international wind assessment methodology is shown in Figure 1. This figure summarizes how the climatic and geographic data sets are combined to produce an assessment. The success of NREL's wind assessment methodology relies on two major activities. The first activity is the acquisition and development of updated comprehensive global climatic databases. Wind data are the most important element of climatic data sets, though temperature and pressure data can also be quite meaningful in certain circumstances. NREL seeks to obtain the broadest variety of wind data sets including surface observations, marine data, and upper-air data. This is because the quality of wind data can be quite variable in any one particular data set, and high quality data can be quite sparse in many regions of the world. Each type of wind data set fulfills a role in the wind resource assessment.

Corresponding author address: Marc Schwartz, National Renewable Energy Laboratory, 1617 Cole Boulevard., NWTC, Golden, CO 80401;
e-mail:mschwart@nrel.gov

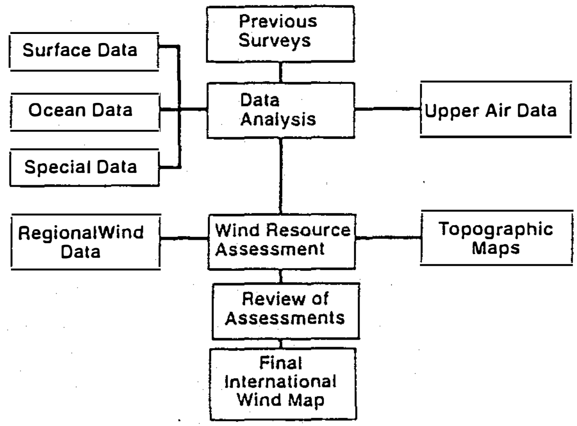

Figure 1. Summary diagram of NREL's international wind assessment methodology.

2.1 Data Sets

Surface wind data of high quality from exposed meteorological stations can give the best indication of the magnitude and distribution of the wind resource in a particular region. The major source of the surface wind data used in NREL's assessments is the DATSAV2 Surface Climatic Database obtained from the U.S. National Climatic Data Center (NCDC). DATSAV2 contains the actual hourly surface weather observations from first-order meteorological stations, and enables NREL to process and manipulate the raw data for wind energy purposes. Reliable and sophisticated wind resource assessments in many parts of the world could not be accomplished without the use of this data set. At present, NREL has at least 21 years of DATSAV2 data for all areas of the world . NREL also seeks to obtain historical summaries of surface wind data and previous wind resource assessments for the area under study. Sources of these data sets include published books and articles, and summaries compiled by foreign agencies and organizations such as national meteorological services and universities. These surface data are supplemented by surface wind data from new measurement programs undertaken specifically for wind energy purposes.

Upper-air data can be useful in estimating the wind resource at low levels just above the surface and in estimating vertical profiles of wind speed aloft for extrapolation of the wind energy resource to elevated terrain features. NREL acquired upper-air observational data from the National Center for Atmospheric Research (NCAR) archive of the National Centers for Environmental Prediction (NCEP, formerly the National Meteorological Center) ADP data set for use in the assessments. This data set includes upper-air observations from rawinsonde instruments and pilot balloons for approximately 1800 stations worldwide. NREL has nearly 25 years of upper-air ADP data in-house. The ADP data is supplemented in areas without adequate upper-air data by the "Global Gridded Upper Air Statistics" data set obtained from NCDC. This data set contains long-term monthly means and standard deviations of climatic elements for the 1980-1991 period of record for 15 atmospheric levels on a 2.5 degree global grid.

Marine wind data can be used to estimate the wind resource for offshore areas, and also can be used through extrapolation to estimate the wind resource at coastal and inland sites that are well exposed to the prevailing direction of the ocean winds. NREL uses two global marine wind data sets. The first is the *Marine Climatic Atlas of the World* derived from historical ship observations. The observations are summarized for quadrangles 1^{o} latitude by 1^{o} longitude. The summaries include monthly means and standard deviations of wind speed, pressure, temperature, and wind direction frequency and speed. The other data set that has proved to be quite valuable is the 10-meter ocean wind speeds derived from the special sensor microwave imager (SSMI) measurements taken as part of the Defense Meteorological Satellite Program. NREL currently has data from 1988 through 1994. These data were obtained from the Jet Propulsion Laboratory and Remote Sensing Systems, Inc. The satellite ocean wind data set's advantage over the ship data is the much more uniform coverage. The ship data is concentrated in the primary shipping lanes. Thus, ocean areas outside the shipping lanes frequently had a minimal amount of data, which increased the difficulty of accurately estimating the wind resource at offshore and coastal sites in those regions. Preliminary comparisons of satellite-derived winds to ship observations from data-rich regions show a good match in the wind speed patterns, with the satellite data providing more detailed resolution of these patterns.

2.2 Meteorological Analysis

The second important activity in the methodology is to conduct a critical meteorological analysis of the climatic data. This is accomplished by first processing the raw data from the data sets and generating graphs and tables that highlight important regional wind characteristics. A few of the notable products are now described. A comprehensive processing package has been written to convert DATSAV2 data to statistical summaries of the salient wind characteristics. These statistical summaries include the interannual variability of the wind speed and power, the average wind speed and power on an annual and monthly basis, and the mean wind speed by direction. The upper-air ADP data is used to construct an approximate vertical profile of wind speeds by geopotential height. The vertical profiles are extremely useful in estimating the change in wind resource potential by elevation, and in depicting regions where a low-level wind maximum might enhance the available wind power (more than is evident at non-exposed surface stations). The ADP data can also be useful in estimating the wind speed shear in the planetary boundary layer just above the surface. The SSMI satellite ocean wind data has been processed and gridded by 25-km by 25-km cells. The high resolution of these data has proved useful in delineating zones of wind speed acceleration or deceleration in the vicinity of islands and coastal areas in regions where NREL has conducted wind assessments.

The critical meteorological analysis of the data includes an evaluation of the quality of the data and a resolution of the most representative data for a particular location. The data analysis employs techniques that have been developed through years of experience in wind resource characterization. The products generated for the analysis are cross-referenced against each other in order to form an understanding of the prevalent wind characteristics in the study area. This step is quite important due to the variable quality of the data and, in most cases, the lack of documentation of the anemometer height, exposure, and maintenance history at meteorological surface stations. For assessment purposes, NREL assumes an anemometer height of about 10 meters (the World Meteorological Organization standard height) unless we have specific measurement height information. Where there is a conflict among the information from the data sets as to certain wind characteristics in a region, the preponderance of meteorological evidence from that region serves as basis of the assessment. The ultimate goal of the analysis is to enable investigators to gain a conceptual model of the physical mechanism(s), whether produced by synoptic and/or local circumstances, that causes the wind to blow in a particular region. A conceptual model of the wind climatology becomes extremely important for assessments in regions where reliable climatic data is either sparse or deficient. The final product produced by NREL in an assessment is a wind resource map that shows the distribution of the estimated level of wind resource for locations with low surface roughness that are exposed to the prevailing winds.

3. CASE STUDY

Recently, as part of the DOE/United States Agency for International Development sponsored Mexico-U.S. Renewable Cooperation Program, NREL's wind resource methodology was used to identify regions in Mexico with sufficient wind resource for wind energy development (Schwartz and Elliott, 1995). A previous survey by the Organizacion Latinoamerica De Energia (OLADE) (Aiello et al. 1983) indicated low wind resource throughout the entire country. However, most of the wind data used in the OLADE survey were from anemometers in cities where the instruments are probably poorly exposed to the prevailing winds. The DATSAV2 data set includes data from better exposed airport locations as well as the city stations. To the best of our knowledge, the wind data from the Mexican airports had never been analyzed. Once we converted the raw data into statistical summaries, reviewed trends and other attributes of the data, and determined periods with representative data, the airport data indicated much higher levels of wind resource than previously had been estimated. The Yucatan Peninsula was one of the regions where this was true. For example, NREL's analysis of the data from the Merida airport, in northwestern Yucatan about 30 km from the Gulf of Mexico, showed the average annual wind speed was about 5.2 m/s and the annual wind power density around 160 W/m^2. This is a "good-to-excellent" wind resource for rural power applications. In contrast, the OLADE study showed the average wind speed and wind power from the Merida station being only 1.6 m/s and 22 W/m^2 respectively. Products from other climatic data sets were then generated and analyzed to confirm that the level of wind resource indicated by the airport data was reasonable. The ADP upper-air data from the Merida rawinsonde station was converted into an estimated profile of the wind speed by height. The profile from the 0600 Local Standard Time data (Figure 2) shows high wind speeds (8 m/s to 9 m/s) several hundred meters above the surface. Daytime heating at Merida is likely to mix this high speed air down to the surface through most of the year. Finally, both the 10 meter SSMI ocean wind data set and the historical ship observation data showed annual average wind speeds of 6 m/s to 6.5 m/s for the areas north and west of Merida, indicating significant low-level wind speeds in this region. The climatological evidence from the various data sets supported the conclusion that exposed locations in that area of the Yucatan Peninsula could be candidates for rural wind energy development. Similar analysis techniques were used for assessments for the remainder of the Yucatan Peninsula and the rest of Mexico. The result was a preliminary wind resource map for rural power applications (Figure 3) that showed the distribution of the wind resource for most areas of Mexico.

New wind measurement programs, designed for wind energy assessment purposes, are being carried out in several areas of Mexico and the data from these stations are being integrated with our other climatic data sets. The new data will help NREL to produce modified wind resource assessment maps of several regions of Mexico, including the Yucatan Peninsula and the state of Baja California Sur.

4. FUTURE PLANS AND CONCLUSIONS

NREL will continue to seek and purchase the most useful type of data sets to supplement and/or supplant existing ones. Data sets that have been recently obtained include global vegetation index data that can be used for delineation of land cover and cloud cover data that can be used to infer wind patterns in certain situations. The NCEP/NCAR Reanalysis Project data set could also prove to be quite useful in our assessment activities. We are also exploring whether it is possible to obtain gridded average surface temperature data that would be useful in assessments. NREL is currently developing a procedure to automate the entire wind mapping process. This will be accomplished using Geographic Information System software to create computerized wind maps. Utilizing computer mapping techniques reduces the time to produce a wind resource map in complex terrain and the analysis of the distribution of the wind resource is treated consistently throughout the region of interest. Several preliminary automated wind resource maps have been produced and the process is continually being tested and modified.

The integration of comprehensive climatic data sets as part of NREL's wind resource assessment methodology has allowed NREL to perform detailed evaluations of the wind resource characteristics and to develop conceptual models of the mechanisms for the wind climatology in a particular region. The use of the data sets provide the capability to produce wind assessments and maps with much greater resolution and accuracy than was possible in previous surveys. As a result, many areas of good wind potential have been identified in NREL's assessments that were previously estimated to have inadequate potential. These assessments have helped to accelerate and will continue to aid the development of wind energy projects around the world.

5. ACKNOWLEDGEMENTS

We would like to thank Steve Haymes, George Scott, and Ray George of the software development and data processing staff for their help in the assessment activity. This paper was written at the National Renewable Energy Laboratory in support of the U.S. Department of Energy under contract number DE-AC36-83CH10093.

6. REFERENCES

Aiello, J.L., J.I. Valencia, E.C. Munoz, and V.L. Gomez, 1983: *Atlas Eolico Preliminar De America Latina Y el Caribe*, Vol 1. Organizacion Latinoamerica De Energia, 44 pp.

Elliott, D.L., C.G.Holliday, W.R. Barchet, H.P. Foote, and W.F. Sandusky, 1987: *Wind Energy Resource Atlas of the United States*. DOE/CH 10093-4, Solar Energy Research Institute, 210 pp.

_____, and M.N. Schwartz, 1996: Update of Wind Resource Assessment Activities at NREL. *Proc. Windpower '96*, Denver,CO, American Wind Energy Association, 439-445.

Schwartz, M.N., and D.L. Elliott, 1995: Mexico Wind Resource Assessment Project. *Proc. Windpower '95*, Washington, DC, American Wind Energy Association, 57-66.

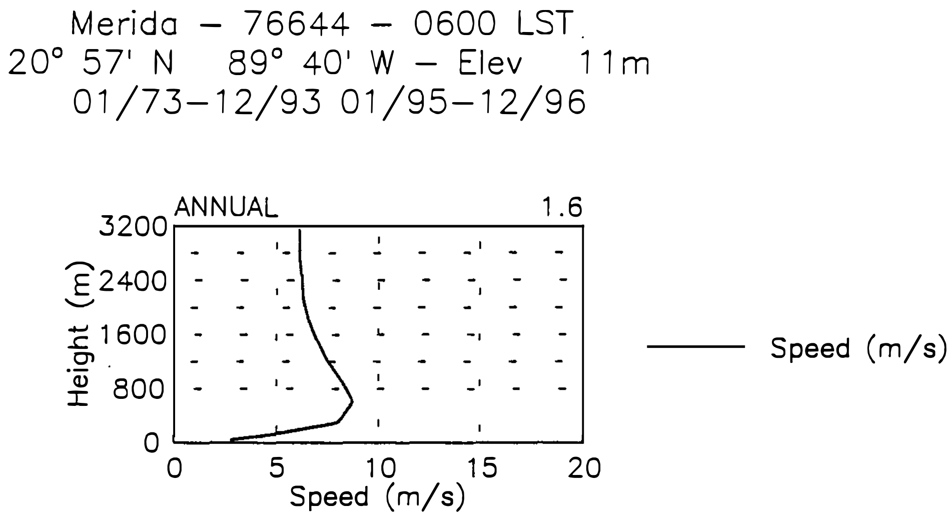

Figure 2. Annual average vertical profile of wind speed by geopotential height for Merida, Mexico, at 0600 Local Standard Time. The number at the top right of the graph is surface wind speed.

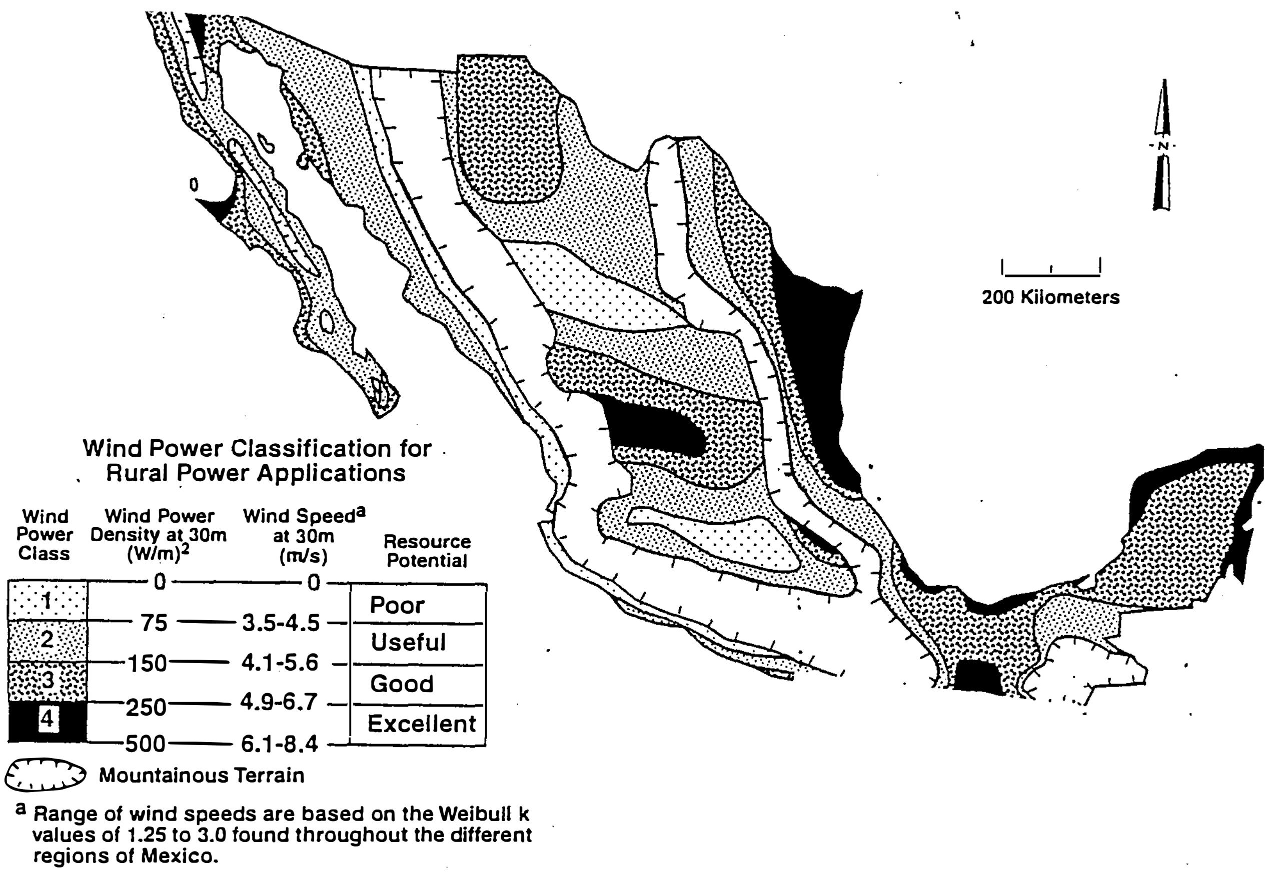

Figure 3. Annual average wind resource map of Mexico. The wind power classifications are for rural power applications.