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Dennis L. Elliott
Marc N. Schwartz
*National Renewable Energy Laboratory*

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National Renewable Energy Laboratory
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# Update of Wind Resource Assessment Activities at NREL

Dennis L. Elliott and Marc N. Schwartz
National Renewable Energy Laboratory
1617 Cole Boulevard
Golden, Colorado 80401
United States

## ABSTRACT

The goal of the wind resource assessment activity at the National Renewable Energy Laboratory (NREL) is to improve the characterization of the wind resource for regions where there are market opportunities for U.S. wind energy technology. A variety of wind resource assessment activities have recently been undertaken at NREL in support of this effort.

The major tasks during the past year include aiding the establishment of new wind measurement programs in the United States, the development of updated comprehensive meteorological and geographical data bases to be used for resource assessments in the United States and abroad, and designing progressive wind resource mapping tools to facilitate products used in support of emerging markets.

## BACKGROUND

The wind resource assessment activity has been an integral part of the U.S. Department of Energy (DOE) Wind Energy Program for approximately twenty years. The activity was located at Pacific Northwest Laboratory in Richland, Washington until 1994 when it was transferred to NREL. The activity's location at the National Wind Technology Center promotes direct interactions between the resource assessment staff and personnel involved with wind energy projects such as wind-hybrid system design, wind turbine design, certification and standards, and utility integration.

The wind resource activity is led by key personnel who have extensive experience in wind resource assessment activities over the past 20 years. The staff also has conducted research in other aspects of wind characterization including wake characterization, array losses, turbulence characterization, and wind forecasting. At present, the expertise of the group is primarily in meteorology, wind climatology, computer mapping using Geographic Information System (GIS), software development using FORTRAN and C programming, and management of large data bases. The computer equipment used for wind resource assessment activities include personal computers and advanced UNIX- based operating systems on Sun Workstations.

NREL's wind resource assessment tasks are also ably supported by expert private consultants and subcontractors. Areas of support include wind monitoring station installation and operation, analysis of wind and other meteorological data, wind resource assessment training and presentation, and technical assistance in support of utility/industry requests.

## NEW MEASUREMENT PROGRAMS

During the past year, DOE, through NREL, initiated three new cost-shared U.S. wind measurement programs. These programs are the Utility Wind Resource Assessment Program (U*WRAP), the Sustainable Technology Energy Partnerships (STEP), and the Cooperative Networks for Renewable Resource Measurements (CONFRRM). The goal of these programs is to accelerate multi-regional U.S. market penetration of wind systems and to move the United States towards being the world leader in the development and use of advanced wind turbine technology. The programs are designed to form partnerships with diverse types of organizations including state and tribal energy offices, private and public utilities, universities, research institutions, the financial community, and private consultants that wish to help accelerate the commercial development of wind energy.

Most of the previous assessments of wind energy resources in the United States have been accomplished by the use of existing meteorological data from National Weather Service (NWS) stations located at airports. Though the data are useful in characterizing the wind resource over broad areas as illustrated in the *Wind Energy Resource Atlas of the United States* (Elliott et al. 1987), the wind energy community has special measurement needs that the NWS stations were not designed to meet. There have been special programs designed for wind energy resource evaluation in the past such as the DOE Candidate Wind Turbine Site program (Sandusky et al. 1983) but much more of that type of valuable data are needed. These programs are designed to provide long-term data bases that meet the needs of the wind energy community by providing minimum standards for equipment specifications and data quality control. In addition to contributing to wind resource assessment, these data bases will also be useful for wind characterization projects such as climatological adjustment and wind forecasting. A brief description of the three measurement programs and their progress follows.

U*WRAP is a program designed to technically and financially support private and public utilities conducting wind resource assessments. This program will increase the quantity of wind data available to utilities, and enlarge the qualified workforce that can conduct a skilled resource assessment program. The development of U*WRAP has been a collaborative process among several organizations: DOE, the Edison Electric Institute, the Electric Power Research Institute, and the American Public Power Association. U*WRAP is administered by The Utility Wind Interest Group, Incorporated (UWIG). UWIG is a non-profit corporation with a mission to accelerate the appropriate integration of wind power for utility applications through the coordinated efforts and actions of its member utilities in collaboration with wind industry stakeholders. The results from the U*WRAP program will give utilities the means to assess their wind resources and wind electric potential, identify candidate development areas, target the most compatible wind turbine designs, and assess the economics of wind-based generation. Six utilities were chosen in 1995 to participate in U*WRAP with a total of 34 new wind measurement stations to be established in 1995 and 1996. The data collected by the utilities under this program will be proprietary for 5 years after the start of the measurements because the utilities are cost-sharing one-half of the cost of U*WRAP.

STEP seeks to meet the needs of states, industry, and localities in accelerating the commercialization of renewable energy technologies. DOE and NREL work directly with state, territorial, and tribal energy offices to foster research, boost economic development, create jobs, and advance working partnerships between the government and the private sector. One of the areas of interest of the STEP program is wind resource assessment. The STEP program actively supports the establishment of new measurement stations in areas being considered for wind plants and analysis of existing wind data using GIS techniques leading to detailed areal resource characterization. At present, six states are participating in Phase 1 of this program.

CONFRRM is designed to improve the assessment of solar and wind energy resources in the United States. CONFRRM supports the establishment of long-term wind benchmark stations at locations with high wind

energy potential. The benchmark stations are located at sites that are representative of areas where wind technology applications are feasible. There are no restrictions on the type of organizations that are responsible for the operation and maintenance of the benchmark stations. The data collected from the stations will be in the public domain and will be made available through NREL's Renewable Resource Data Center. Twelve wind benchmark stations will be established in 1996.

Figure 1 shows the distribution of the twelve individual states that presently have projects under these three programs. The states are concentrated in the Great Plains and Rocky Mountains, the region with the highest overall wind resource in the United States, but other sections of the country, such as the Northeast and the Great Lakes states, with promising wind resource are also represented. Additional states are likely to be funded in the near future. The three cost-shared programs should significantly increase detailed wind resource assessments and accelerate the commercialization of wind energy in the United States.

NREL also provides technical assistance to wind resource assessment programs run by non-federal agencies such as state and tribal offices and utilities. The assistance, based on past NREL experience, can include reviewing the station siting approach and procedures, offering historical perspectives on wind resource assessment activity in a region, and offering advise on enhancing wind measurement programs.

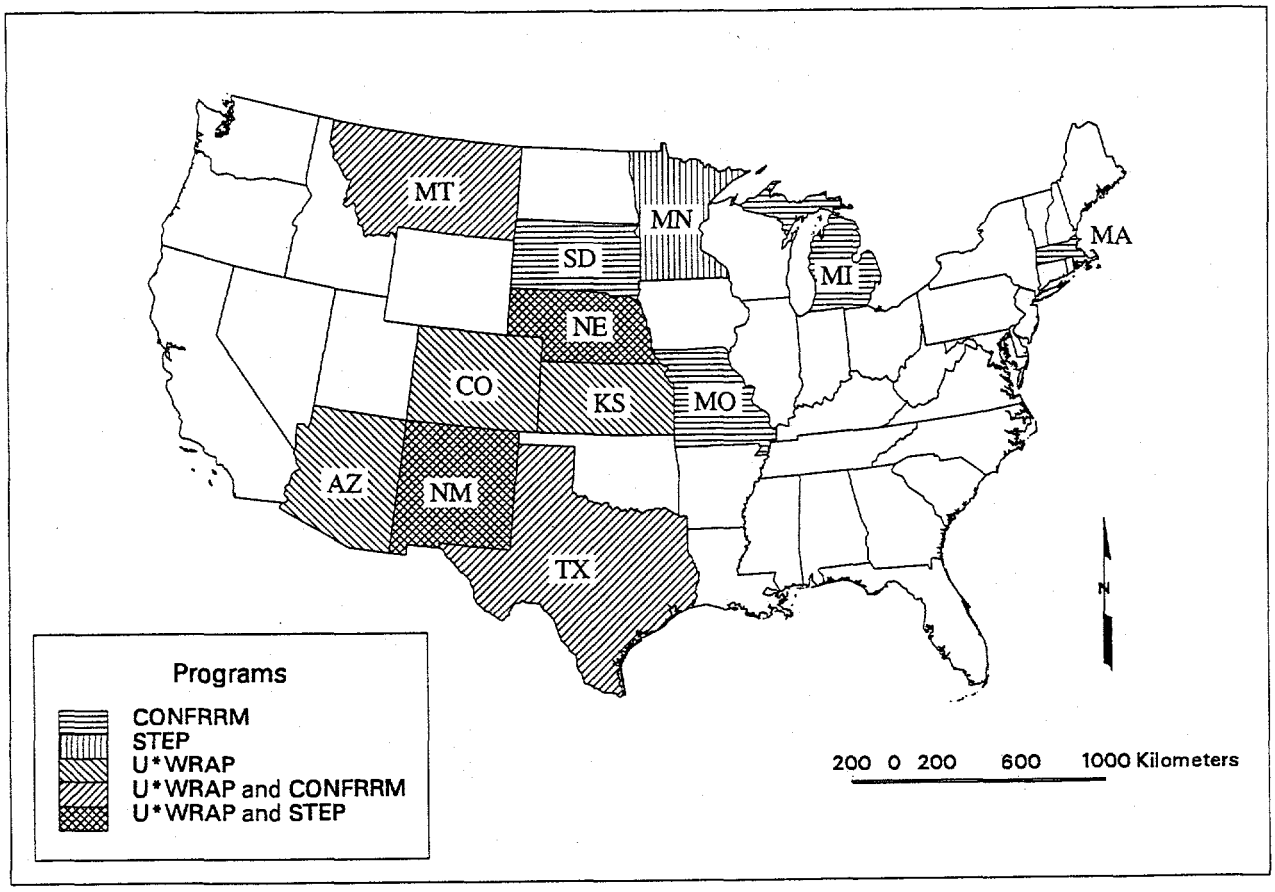


FIGURE 1: MAP OF STATES HAVING PROJECTS UNDER DOE WIND MEASUREMENT PROGRAMS

## METEOROLOGICAL and GEOGRAPHICAL DATA BASES

A key component of the wind resource activity at NREL is the development of updated comprehensive global data bases to be used in resource assessments in the United States and abroad. These data bases contain the meteorological and geographical information that are the building blocks for sophisticated wind resource mapping projects.

NREL has data from a variety of meteorological and topographical data sets. These data are necessary both to produce and use the most sophisticated techniques of estimating the wind resource. The principal meteorological data sets at NREL are a global surface Climatic Database, the global upper-air (weather balloon) wind data, and the marine wind data from ship observations. These data sets were used in the Mexico wind resource assessment project (Schwartz and Elliott, 1995). These data are supplemented by surface data from new measurement programs undertaken in areas shown by NREL's original wind maps to have good-to-excellent wind resource. The major type of geographical data used in our assessments are digital elevation data. For U.S. resource assessment activities, NREL has access to the data set produced by the U.S. Geological Survey. For international assessment efforts, the data set used most frequently is the Digital Chart of the World. The elevation data are especially important in the production of advanced wind mapping tools.

NREL has continued to seek and purchase the most useful new types of data sets to supplement and/or supplant existing ones. During the past year, NREL has purchased several data sets that promise to enhance future wind resource assessment work. The most promising of these is a data set of 10-meter ocean winds derived from polar orbiting satellite measurements. The data cover the period from 1987-1994. The ocean wind speeds are derived from the reflectivity of the ocean surface as measured by sensors on the satellite. The satellite ocean wind speed data set's advantage over the historical ship data is the much more even coverage. The historical ship data was 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. NREL is currently comparing satellite ocean wind data to ship data from data-rich regions. Preliminary results show a good match in the wind speed patterns between the ship and satellite data, with the satellite data proving more detailed resolution of these patterns. An example of satellite ocean wind data is shown in Figure 2. Other data sets recently obtained by NREL include global vegetation index data that can eventually be used for delineation of land cover, more detailed elevation data for several areas of the world, and pre-1970 surface observations for locations in the United States and regions abroad. NREL is also currently exploring whether it is possible to obtain gridded average surface temperature data.

The rapidly changing and expanding market opportunities demand that any quality wind resource mapping project be accomplished as quickly as possible. In-depth analyses of the meteorological data, necessary for the production of the wind map, require that raw data from the comprehensive data sets be transformed into a visual form that can be easily examined. Therefore, the development of an efficient method of processing and archiving the extensive data sets is one of the wind resource assessment group's major tasks. Several advanced processing and archiving tools have been developed in the past few months. Software was written to rapidly process twenty-plus years of raw weather balloon upper-air data into summarized graphical and tabular output. The time to process the raw data for a particular upper-air station or group of stations was previously measured in days. Now, data can be processed and usable output can be produced in a matter of minutes. The evolution of a similar type of tool for the global surface data is underway. This is a challenging venture because of the volume of raw data (250 GB) in the global data set and the need to address issues such as the changing locations and identification numbers of many surface stations. The completion of this task in the near future will improve the accessibility of the processed surface data and accelerate the process of producing the wind maps. The work to integrate the newer data sets into the NREL data base is on-going and will continue to be emphasized in the future.

## DEVELOPMENT OF WIND MAPPING TOOLS

One of the chief goals of the wind resource group at NREL is to help the U.S. wind energy industry accelerate the deployment of wind energy by producing the most progressive and sophisticated wind maps possible. A necessary component of the production of these maps is the development of progressive wind resource mapping tools.

Advanced analysis techniques using information from the updated NREL data sets are quite important in more accurately assessing the quantity of the wind resource in a particular area (whether it is for utility or rural power applications). A key task is to evolve a conceptual model that explains what causes the wind to blow in a certain region. The scale of the meteorological factors that cause the wind flow can vary from several hundred kilometers (storm-scale) to only a few kilometers when local circulations (eg. sea-land breeze, mountain-valley circulation) predominate. The availability of a variety of meteorological data sources at NREL makes the process of conceptualizing wind patterns in most regions of the world easier. Many regional wind patterns can now quickly undergo three dimensional analysis because of the wide variety of data sources. The diversity of the wind data sources also enables poor quality or suspect data from one data set to be checked and screened against data from other sources. A more rigorous and improved wind resource analysis is now applied as one of the major inputs to the wind resource maps.

The most ambitious plan at NREL for wind resource mapping is to eventually automate the entire wind mapping process. This will be accomplished using a GIS system to create computerized wind maps. The wind resource estimates from advanced analysis techniques will be combined with digital elevation models (DEM) created by GIS software to produce wind maps showing good-to-excellent resource areas as determined by the various algorithms in the software. The computer mapping system developed by NREL uses an analytic approach and is designed to portray the distribution of wind resource over a large area. The computerized mapping technique greatly reduces the effort needed to create a wind map as compared to the old style manual analysis that had characterized wind mapping in the 1980s and early 1990s. This is especially true in areas of complex terrain. Under the old style of manual analysis, the distribution of the wind resource had to be physically drawn in for topographic features such as ridge crests and elevated plateaus. Naturally, this process was time consuming, subjective, and prone to inconsistencies in the analysis. Utilizing computer mapping techniques considerably reduces the time it takes to produce a wind resource map in complex terrain. The analysis of the distribution of the wind resource is also treated consistently throughout the region of interest.

A prototype of NREL's computer generated wind resource maps is presented in Figure 3. Figure 3 is a resource map of Nan'ao Island, a small island a few kilometers off the southeast coast of China. This map was developed as part of a special wind resource assessment project that NREL participated in at the request of the World Bank. This island, for several reasons, proved to be the ideal subject for the first effort at producing computerized wind maps. First, NREL had access to detailed terrain data on the island, which made the production of an accurate DEM quite straightforward. Second, the small size of the island, plus access to sufficient meteorological data from the island and the nearby mainland, enabled the analysis of the wind resource to be integrated with the terrain data in a few steps. NREL has received favorable comments about the realism of the mapped distribution of the wind resource from people familiar with wind energy development on Nan'ao Island.

Another computer wind resource map has been produced for the island of Sumba in southeastern Indonesia. The process of producing a computerized wind resource map of Sumba was more complex than Nan'ao Island. This island is considerably larger with more varied terrain than Nan'ao Island, and there is not as much available wind data in the surrounding region. The time needed to produce the Sumba map was substantially longer than the Nan'ao map because of a more difficult analysis of the wind regime and additional steps in integrating the wind and terrain data in the computer model. The prototype Sumba map can be used to identify

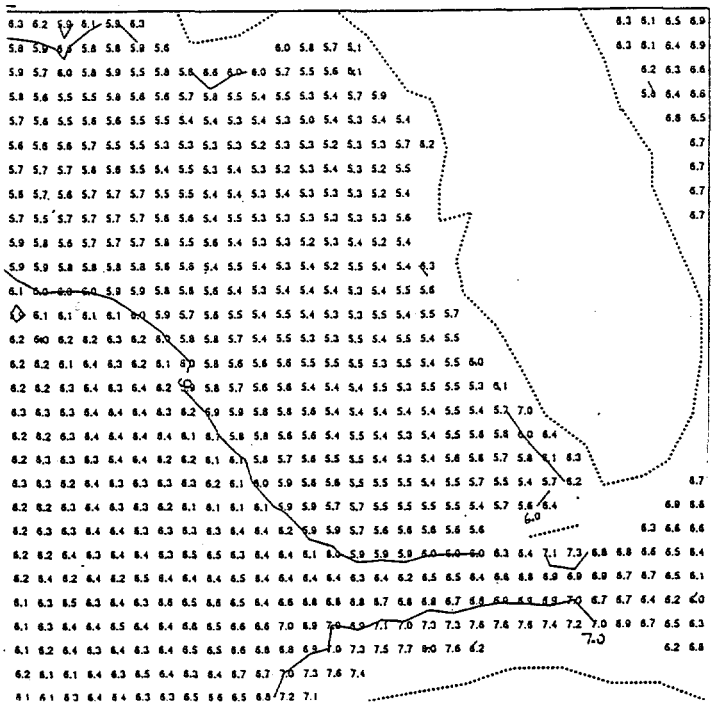

FIGURE 2: 1993 ANNUAL AVERAGE OF SATELLITE DERIVED 10 M WIND SPEEDS (M/S) FOR EASTERN GULF OF MEXICO

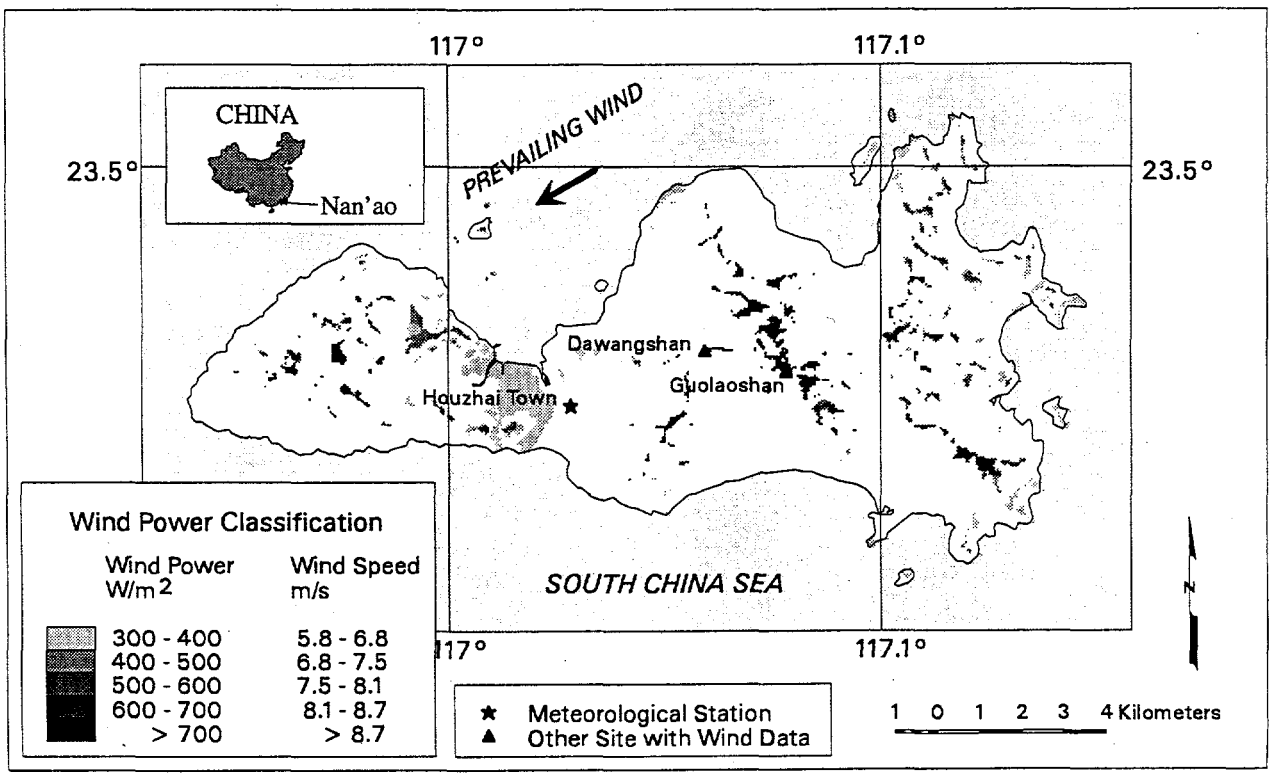


FIGURE 3: COMPUTERIZED WIND RESOURCE MAP OF NAN'AO ISLAND, CHINA

and target sites for wind measurements that ultimately will accelerate wind energy development on that island.

Nan'ao Island and Sumba represent, both from a meteorological and topographic point of view, relatively simple regions to map via computer techniques. Other regions in the United States and abroad present more complex wind flow regimes and topography. Additional routines to account for these complexities will be added to the computer mapping system in the future. Another activity that NREL plans on performing is verification and sensitivity research on the results of the computer mapping. This will enable the mapping system to be modified and result in more accurate wind resource maps. The advanced computerized technique will be applied as part of current or planned wind mapping projects in several areas of the world in support of U.S. wind energy interests. These include specific regions of Mexico, Chile, Argentina, China, and Indonesia.

## CONCLUSION

The wind resource assessment group at NREL is involved in a variety of activities designed to accelerate the deployment of wind energy by boosting knowledge of the wind resource. NREL will continue to work with the U.S. industry, and state and other governmental organizations to improve the wind characterization in the United States and develop the comprehensive data bases and advanced wind mapping techniques that will ensure NREL's standing as leader in wind resource assessment.

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