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Marc Schwartz
Dennis Elliott

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Validation of Updated State Wind Resource Maps for the United States

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

Background

The National Renewable Energy Laboratory (NREL) has coordinated the validation of updated state wind resource maps for multiple regions of the United States. These maps were produced by a private USA company, TrueWind Solutions (now AWS Truewind [AWST]), using its proprietary MesoMap system. AWST's system uses a version of a numerical meso-scale weather prediction model as the basis for calculating the wind resource and important wind flow characteristics. The independent validation project was a cooperative activity among NREL, AWST, and private meteorological consultants. The validation concept originated at a May 2001 technical workshop held at NREL to discuss updating the *Wind Energy Resource Atlas of the United States* (Elliott et al., 1987). Part of the workshop, which included more than 20 attendees from the wind resource mapping and consulting community, was dedicated to reviewing the latest techniques for wind resource assessment and mapping. It became evident that using a numerical modeling approach was soon to be the preferred technique for wind resource mapping for several reasons. The numerical modeling technique is faster compared to older mapping methods and, in theory, should be quite accurate because it directly estimates the magnitude of boundary-layer processes that affect the wind resource at a particular location. Numerical modeling output combined with high-resolution terrain data can produce useful wind resource information at a horizontal resolution of 1 km or finer. At that time, the numerical modeling approach was new and relatively unproven, and experienced meteorological consultants questioned the accuracy of the approach. It was clear that updated state or regional wind maps produced by this method would have to undergo independent validation (i.e. a comparison between model estimates and measured data at specific locations) before the results would be accepted by the wind energy community and developers.

Concurrent with the workshop, the Wind Powering America initiative (Flowers and Dougherty, 2001) was actively supporting the acceleration of wind energy development in the Northwest region of the USA, and the production of updated wind resource maps for that region. Thus, the updated wind resource maps for the states of Washington, Oregon, Idaho, Montana, and Wyoming became the pilot validation effort. The lessons and experience gained from the ultimately successful Northwest validation effort (Elliott and Schwartz, 2002) led to similar validation projects for the Southwest and Mid-Atlantic regions of the USA plus California and several states in the Midwest. The purpose of the validation effort is to produce the best map possible within fairly stringent time constraints. Technical issues that arose during the process had to be resolved quickly and research on these issues, though important, would not be directly part of the validation process.

Mapping and Validation Approach and Results

The approach for developing the final wind resource maps consisted of three steps: 1) modeling and production of the preliminary maps by AWST; 2) review and validation of the preliminary maps by

NREL and meteorological consultants; and 3) revisions required to create the final maps. MesoMap, the modeling and mapping system employed by AWST, consists of three components: models, databases, and computer and storage systems (Brower et al., 2001). At the core of the MesoMap system is MASS (Mesoscale Atmospheric Simulation System), a numerical weather model used in commercial and research applications. MASS can be coupled to WindMap, a mass-consistent wind-flow model, to increase the spatial resolution of the MASS simulations. The main meteorological inputs for MASS are model-derived gridded historical weather data (the reanalysis database), weather balloon data, and land surface measurements. The main geophysical inputs are elevation, land cover, vegetation cover, soil moisture, and where applicable, sea-surface temperatures. The MesoMap system creates a wind resource map by simulating weather conditions from a large number of days (typically 365 days) selected from a historical period (typically 15 years). For each day in the sample, the wind speed and direction and other weather variables (including temperature, pressure, moisture, etc.) are simulated and stored at hourly intervals over the model domain. When the runs are finished, the data are compiled and summarized to produce maps of mean wind speed and power density (and other statistics) at various heights above ground. The final MASS simulation output for the maps ranged from 2.0 to 2.6 km resolution. These data were then used in WindMap to improve the final resolution to less than 1 km.

The validations were done on the preliminary maps produced by AWST of mean annual wind speed at heights of 30 meters and 50 meters above ground (agl), and mean annual wind power density at 50 meters agl. NREL and the meteorological consultants worked to identify and obtain available wind measurement data for use in the validation. The bulk of the wind data used in the validation were collected by the weather service, agricultural, transportation, and environmental agencies. Most of these data were collected at heights at or near 10 meters agl. The estimation of the wind shears (change of wind speed and power density with height) was a major issue in extrapolating data measured at lower heights to estimates at 30 meters and 50 meters. NREL generally used the standard 1/7 power law equation for the vertical adjustment, though for special circumstances (e.g. coastal locations and acceleration zones) other power law values were used. Decisions about the wind shear adjustments for the data provided by the meteorological consultants were left to their discretion. For some regions, there were also substantial wind measurement data from heights near 30 meters to 50 meters in some areas, particularly in areas where wind projects have been developed or are being considered. Measurement data from these heights were the most valuable, because these data are at or near the map heights for which the wind resource estimates were generated. Many of the taller tower wind measurement data sets are proprietary, but due to the efforts of the private consultants summaries of the proprietary data were used for the validation.

NREL and the consultants validated the wind speed maps. NREL also validated the wind power density maps, except for a few locations where hourly or adequate time series data were not available to estimate the wind power density. NREL developed spreadsheets to score the validations for each state. Each spreadsheet contained entries for wind monitoring station locations and elevation, anemometer measuring heights, period of record, measured wind speed and power density, wind speed and power adjusted to map height, the map estimates of speed and power, and any qualitative comments the validators wished to make. Qualitative comments included any special circumstances about a particular monitoring station or special wind resource knowledge about a certain area. NREL requested that the spreadsheet be filled out as completely as possible, including essential monitoring station metadata and the adjusted measured and mapped wind speeds. The validators also had the option to include a general geographic description of the station location rather than a specific latitude and longitude for proprietary data. The consultants then sent the spreadsheets to NREL and AWST for review. The results formed the basis for adjusting the preliminary wind maps. The validation was an iterative process among NREL, AWST, and the consultants. Comprehensive discussions between NREL and AWST resolved outstanding technical issues and defined the adjustments to be made to the preliminary maps in order to produce the final wind resource maps.

Figure 1 shows the final wind power density and wind speed maps (50 m) for the state of New Mexico, plus some other useful information such as major transmission lines and county boundaries. The wind power classifications on the wind power map corresponds to the same seven power classes used for the 1987 U.S. wind atlas and updated state maps. Areas with Class 4 and higher wind resource are generally considered to have good potential for utility-scale wind energy applications. The large contiguous area of Class 4 and higher resource in central New Mexico between Albuquerque and Clovis is an area of potential wind energy development that was not identified on previous resource maps. It should be noted that the maps are not intended for micrositing because the numerical model resolution does not capture all of the smaller terrain features.

The links to all of the updated state maps (NREL has not been involved in all of the mapping projects) can be found at http://www.eere.energy.gov/windpoweringamerica/wind_resources.html.

Technical Modeling Issues

The typical root-mean-square model error is around 5%-7% of the mean speed at 50 m and about 10%-15% in wind turbine output. This is a useful level of accuracy but improvements are desirable because of the cubic relationship between the energy available in the wind and its speed. The intensive validation effort has identified several technical sources of model error (Brower, et al., 2004). Two of the most important are surface roughness parameterization, and atmospheric stability in the lower boundary layer. Though it was beyond the scope of the mapping and validation projects to study these in detail, identification of the sources of error has enabled AWST to make improvements to the MesoMap system. Here is a brief description of these issues.

Land cover data (directly related to surface roughness parameterization) obtained via remote sensing techniques must be properly interpreted to obtain realistic roughness values. Public global data sets have errors because of their relative coarse resolution and do not explicitly present information on vegetation height and density. Using higher-quality data sets such as the 1 km or better resolution Moderate Resolution Imaging Spectroradiometer data in the model is mitigating these problems.

The thermal stability of the atmosphere has an important effect on the vertical wind profile and on estimates of the wind resource at a particular height. The model accounts for different stability conditions by changing the mixing parameterization. Although these equations work well most of the time, highly stable and unstable atmospheric conditions pose particular challenges. AWST has recently adapted a method to determine the depth of the stable boundary layer based on turbulent kinetic energy to improve this aspect of model performance.

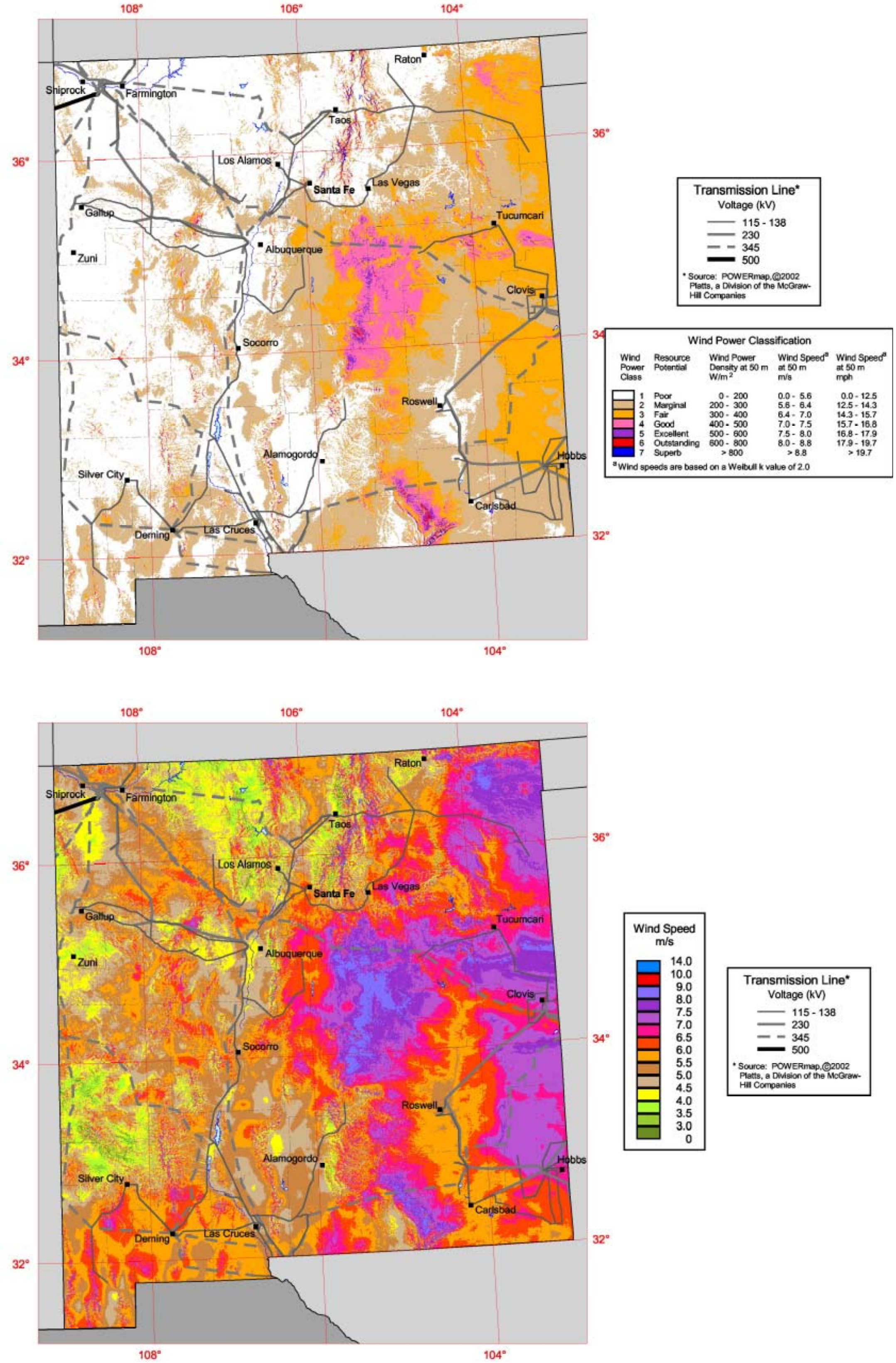

Figure 1. Final 50 m wind power (top) and wind speed (bottom) for New Mexico.

Conclusion

The validation process produced updated wind resource maps that have proved to be quite useful for developers and state planners, among others. The validation was successful because of the iterative process among NREL, AWST, and the consultant team. Success can be attributed in part to the considerable high-quality data from the region and the validators' knowledge of the wind resource in the mapped regions. Lessons learned from previous efforts continue to be applied for validations of updated state maps including Hawaii and parts of Alaska.

Important technical modeling and mapping issues have become better defined because of the validation project, and AWST is incorporating changes into the MesoMap system to produce improved model results.

NREL has also produced and validated new wind resource maps and atlases for several countries around the world. These efforts have been financially supported by the United States Agency for International Development and other organizations. The links to these maps and atlases can be found at http://www.rsvp.nrel.gov/wind_resources.html. In addition, NREL is currently working on new wind resource maps for the United Nations Environment Programme.

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