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On the Use of Reanalysis Data for Wind Resource Assessment

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9.6 ON THE USE OF REANALYSIS DATA FOR WIND RESOURCE ASSESSMENT

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1. INTRODUCTION

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 regions of the world in support of the U.S. wind energy industry (Elliott and Schwartz, 1996). NREL characterizes the level of the available wind resource at wind turbine hub heights (typically 30 m to 50 m above ground level) using wind power density, expressed in units of Watts per square meter. Wind power density values are frequently used to classify the wind resource level with the higher wind power classes assigned to areas with high power density values.

NREL's wind resource assessments result in the wind resource maps and atlases used by a variety of organizations (DOE, other U.S. government agencies, utilities, and the U.S. wind energy industry). The assessments need to be as accurate as possible in order to accelerate the development of wind energy. NREL has developed a wind assessment methodology to produce wind resource maps useful for wind prospecting and wind energy project implementation. The methodology integrates information from global climatic data sets (Schwartz and Elliott, 1997) and also involves a critical meteorological analysis of the climatic data. This critical analysis is a key component of an automated wind resource mapping system recently developed at NREL. It is in the context of the critical meteorological analysis and the automated mapping system that we plan to evaluate the usefulness of Reanalysis data for wind assessment purposes.

2. AUTOMATED MAPPING SYSTEM

NREL developed the automated technique for wind resource mapping with two primary goals in mind. The first goal is to produce more consistent and detailed analysis of the wind resource compared to the old style manual analysis that was subjective, time consuming, and prone to inconsistencies in the analysis. This goal is especially important for areas of complex terrain. The second, but no less important goal, is to generate high quality maps on a timely basis to ensure that wind energy projects are included in a renewable energy plan. Examples of the application of NREL's wind mapping system in developing regional-scale wind resource maps can be found in recent publications (Elliott and Schwartz 1997, 1998).

The mapping system uses computerized mapping software known as Geographical Information System (GIS). The main GIS software is ARC/INFO™, a powerful and complex package featuring a large number of routines for scientific analysis. None of the packaged software analysis routines is specifically designed for wind resource assessment work, therefore the mapping system requires extensive programming in order to create scientific routines that mimic direct wind resource assessment methods. The wind mapping system is regional (greater than 50,000 km^2) in scope. At present, the mapping system uses an empirical and analytical approach to determine the level of the wind resource for a particular location in a study region. The wind mapping system is organized into three main components. These are the input data, the wind power calculation, and the output section that produces the final wind map. The precision of the meteorological input data, derived from the critical analysis, is the most important factor in determining wind map accuracy.

A key element of the meteorological input for the mapping system is the use of available upper-air data to construct approximate vertical profiles of wind speed and wind power density by height that are representative of a study region. The vertical profiles are extremely useful in estimating the change of 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 poorly exposed surface meteorological stations. In addition, vertical profiles of the wind power density, derived from vertical profiles of wind speed, are used as direct input into the mapping system. It is important to note that seemingly minor changes in wind speed can cause significant

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differences in deriving the vertical profile of wind power density because wind power density is proportional to the cube of the wind speed. Currently, the most useful set of upper-air data for constructing vertical profiles are the Automated Data Processing (ADP) reports. These are archived observations from rawinsonde instruments and pilot balloons for approximately 1800 stations worldwide. However, significant uncertainty exists in the accuracy of the constructed profiles for many regions. This is due to the irregular horizontal and vertical spatial coverage of the upper-air stations, the limited data at many of these stations, and particular regional topography that may cause a peculiar vertical profile at a rawinsonde station that is not representative of the proximate study regions. NREL is currently evaluating whether the Reanalysis data set created by the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR) can improve the quality of vertical profiles in areas where ADP data are either limited or questionable due to terrain effects. There are two components to our evaluation. The first is to determine if Reanalysis data represent the real wind climatology based on understanding of the wind characteristics from many data sources. If the data are representative of the wind climatology, the second task is to decide how to integrate the Reanalysis data into the wind resource assessment methodology. The ultimate goal is to create comparable ADP and Reanalysis data sets that will enhance the accuracy of the meteorological input to the mapping system.

3. REANALYSIS DATA PROCESSING

The NCEP/NCAR Reanalysis project has produced a 40-year record of global analyses of atmospheric fields in support of the needs of the research and climate monitoring communities (Kalnay, et al., 1996). The project used a dynamic data assimilation model to create worldwide data sets of wind, temperature, and other variables on a 208 km resolution grid with over 18,000 points. This process incorporated all available rawinsonde and pilot balloon data, as well as observations from surface, ship, aircraft, satellites, and other data sources. The data assimilation model was the T62/28 level global spectral model with high resolution in the boundary layer (five levels in the lowest 1 km of the atmosphere and ten levels in the lowest 3 km). This model also used a terrain-following Sigma coordinate system that ensures that the same number of levels are present at each grid point no matter the surface elevation. The meteorological variables that are important for the calculation of the wind speed and wind power density profiles, the u and v components of the wind, the temperature and surface pressure (used with a hydrostatic approximation to determine observation pressure level) are classified as being "A" type variables. These variables are the most influenced by actual observations and are classified as the most reliable of the Reanalysis data. The output is available four times a day, each day, at 00, 06, 12, and 18 Greenwich Mean Time (GMT). The frequency of Reanalysis upper-air output is greater than most of the ADP data, which are generally limited to one or two rawinsonde launches per day.

The data processing software we use to create wind characteristic statistics requires a time series of all Reanalysis data "observations" for a particular grid point in one binary extract data file. However, the raw Reanalysis data are organized so that each file contains the data for the entire world for one particular date and time. This creates a significant data reordering problem to solve. We first create subset files, taking from the original Reanalysis data files only the variables and levels we need. This process reduces the data volume to 38% of the original files. We then place as many years of data as possible online and assign each grid point an identification from 0 to 18047. The identification number is the array index of the T62 Gaussian grid for all data from that point. We use the index number the same way we use the World Meteorological Organization (WMO) station numbers in the processing of ADP wind statistics, taking care to avoid conflicts with real WMO stations. We select the grid points for a region(s) of interest and then sequentially process the Reanalysis arrays for each of these grid points. We use a hydrostatic equation, integrating the surface and Sigma level information, to compute the vertical height above sea level for each "observation". The data processing steps result in a set of multiple year binary data files that can be converted to vertical profiles.

4. INITIAL EVALUATION OF REANALYSIS DATA

The initial evaluation of using Reanalysis data in NREL's wind resource assessment methodology involved creating vertical profiles of wind speed for a Reanalysis grid point and comparing these profiles to those created from ADP data at a nearby rawinsonde station for the same time period. The ADP data set covers the period 1973-1997 but, due to computer limitations, only four years of Reanalysis data could be accessed at the time of this study. Nevertheless, the four year comparison period was useful. In addition to the vertical profiles, we produced other graphs that described the salient wind characteristics at the Reanalysis grid point and the nearby upper-air station. One important difference between the ADP and Reanalysis data is the attributes of surface elevations reported by rawinsonde stations and Reanalysis grid points. Reanalysis has a characteristic scale of 208 km and its grid point surface elevation is representative of the average terrain elevation in the area. Surface elevations from upper-air stations are representative of the local terrain which may or may not reflect the average terrain in an area. This difference could cause problems with the interpretation of the profile comparisons in areas of complex terrain. Given this factor, it was logical to proceed with the initial evaluation of the Reanalysis data in an area with flat terrain. We decided to evaluate the Reanalysis data at locations in northern Great Plains of the United States. This area was chosen because of the flat terrain, fairly good coverage of upper-air stations in the region, interesting wind climatology, its extraordinary potential for wind energy development, and that NREL recently conducted a wind mapping validation study for a section of this region (Elliott and Schwartz, 1998). Figure 1 shows a map of the Reanalysis grid points and the ADP upper-air stations for part of the northern Great Plains. The rawinsonde station chosen was Huron, South Dakota, (WMO station number 72654) and the Reanalysis grid point was number 4556, located about 70 km northeast of Huron. The comparison period was four years, January 1990 through December 1993.

Figure 2 is the 12 GMT annual average vertical profiles of wind speed for Huron and Reanalysis grid point 4556 interpolated to every 100 meters. The surface elevation for Huron is 382 m above sea level (asl) while the surface elevation for point 4556 is 483 m asl. The figure also shows the differences in wind speed between the two profiles and the ADP and Reanalysis data observation levels used to derive the profiles. We have confidence that the two profiles are comparable because the ADP data for Huron contained 97% of the possible number of 12 GMT rawinsonde observations for this time frame.

The shape and the magnitude of the two profiles are for the most part similar but with a notable difference in the vicinity of low-level jet, a well known feature of this area. Both of the profiles show the highest wind speed associated with the jet near the 900 m to 1000 m geopotential height level, about 500 meters above the surface. However, speed differences appear in the lowest levels of the profiles and in the structure and wind speed value of the jet "nose." The Huron ADP profile shows higher wind speeds than Reanalysis from the surface to about the 700 m level. Above that level, the Reanalysis profile has a more pronounced wind speed maximum that is close to 1 m/s higher than what is shown on the Huron ADP profile. The differences between the profiles in this section could be, in part, a reflection of the increased vertical resolution of the Reanalysis data in the lowest one-half kilometer above the surface. The ADP wind speed data for Huron have a 300 m vertical resolution above the surface, with wind speed data available near the 600 m and 900 m geopotential height levels. In contrast, Reanalysis contains wind speed data at four levels in the lowest 500 m above the surface. However, the evidence indicates that not all of the differences in wind speed from 800 m to 1200 m can be explained by resolution factors. We compared graphs of the 12 GMT mean wind speed and frequency by direction for Huron and Reanalysis grid point 4556 at the 1200 m height (not shown) to see what these data could tell us about the speed differences of the profiles. While the frequency of wind direction data with the prevailing directions of southwest and northwest was quite similar in both data sets, there are interesting differences in the average speed by direction between the two locations. The average speed of the southwest winds in the Reanalysis data was about 2 m/s higher than the observed data from Huron. The average speed of the northwest winds in the Reanalysis data was about 1 m/s lower than those observed at Huron. The difference between the two profiles is primarily caused by differences in the average speeds of the prevailing wind directions. Because this difference in wind speed has large implications for the amount of available wind energy, this characteristic will certainly be the subject of future evaluation studies.

The Reanalysis low-level jet structure with a pronounced "nose" also appears on the 12 GMT profiles for nearby grid points (4555, 4747, and 4748). Moreover, this type of structure has appeared on ADP-derived profiles in other regions of the world where NREL has performed wind resource assessments. Thus, the Reanalysis profile does seem to be reasonable. We have also briefly reviewed and compared Reanalysis data to ADP data in other parts of the world such as the Caribbean and Mongolia where wind resource assessments are under way. The Reanalysis profiles do clearly indicate the presence of low-level jets in these areas. This is especially important in the case of Mongolia because the ADP data from the rawinsonde stations only contain wind speed and direction from the mandatory pressure levels. For many locations in Mongolia, this degree of vertical resolution of the atmosphere is totally inadequate to produce a truly high quality wind resource assessment of the country. We anticipate that Reanalysis will be a great assistance in this work.

5. CONCLUSIONS AND FUTURE WORK

NREL has performed an initial evaluation of the utility of including Reanalysis data in NREL's wind resource assessment methodology. The evaluation consisted of comparing vertical profiles of wind speed during the period 1990 to 1993 from Huron, South Dakota, and Reanalysis grid point 4556, located 70 km to the northeast. The evaluation results were encouraging but there were enough questions raised to warrant further studies. For areas of the world where the ADP data are limited either in spatial or vertical resolution, our initial impression is that the Reanalysis data can be substituted for ADP data in the wind resource assessment methodology. We will continue to evaluate and compare the Reanalysis and ADP data for regions where ADP data are relatively plentiful. The types of future evaluations will include a comparison of horizontal gradients of wind between Reanalysis and ADP, profile comparisons in other mid-latitude areas, and profile comparisons for tropical and polar wind climatologies. We have noticed that wind speed disagreements between "Global Gridded Upper Air Statistics," the data set NREL currently uses to supplement the ADP data, and rawinsonde observation data increase dramatically in tropical wind regimes. It will be interesting to see if the Reanalysis data exhibits similar trends. Another valuable test will be to compare Reanalysis and ADP data in southeast Indonesia in the vicinity of Kupang, West Timor. There, the upper-air station changed from pilot balloon observations to rawinsonde in December, 1986. The equipment change resulted in an increase of 3 m/s in the average wind speed at the 850 mb (1500 m) level in the ADP data. It will benefit our evaluation to see the Reanalysis wind data characteristics in this region before and after the equipment change.

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 in a particular region. The recently developed Reanalysis data set shows promise for our analyses as a supplement to and, in some regions, a substitute for our ADP upper-air data. Future evaluations will determine the exact way Reanalysis will be integrated into wind resource assessments.

6. ACKNOWLEDGEMENTS

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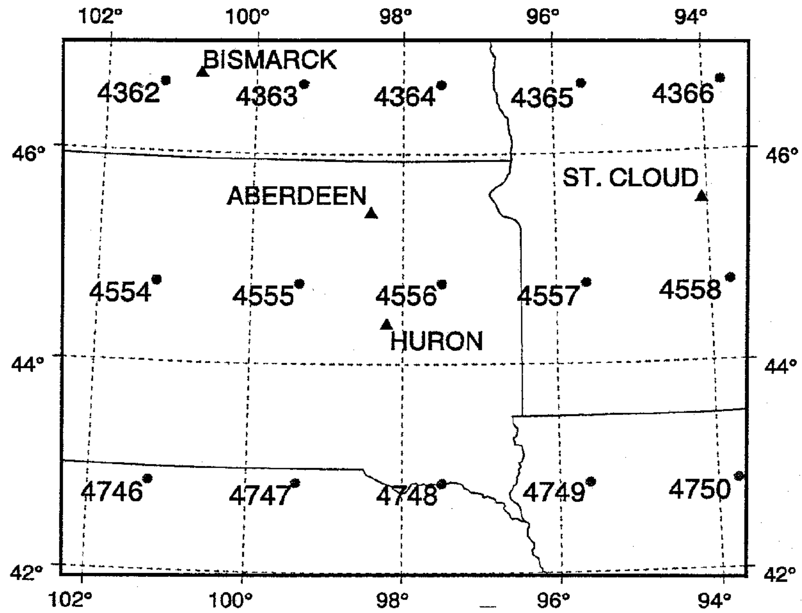

Figure 1. Locations of Reanalysis grid points (circles) and ADP upper-air stations (triangles) in the northern Great Plains.

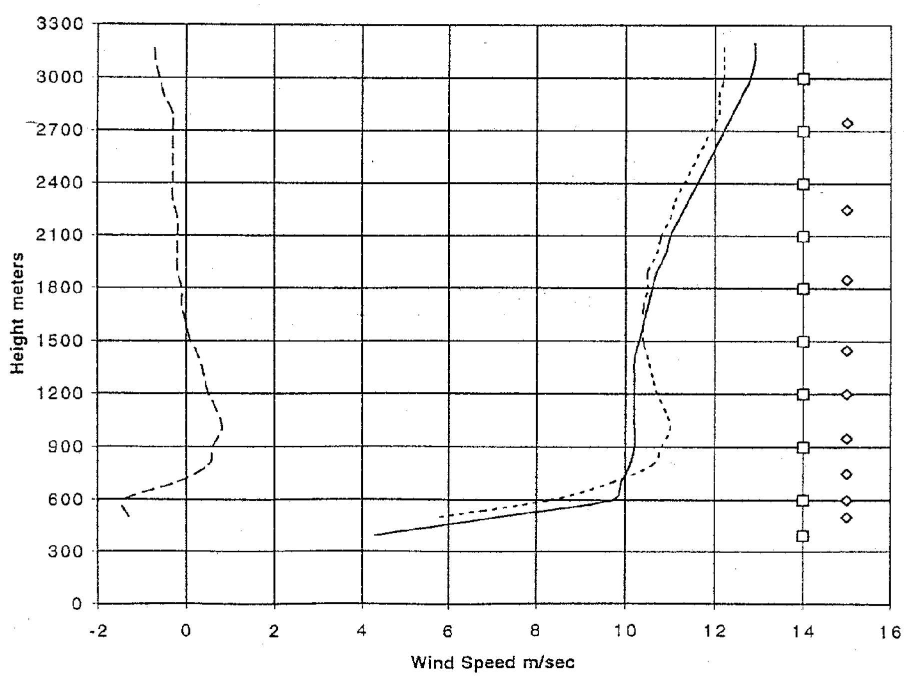

Figure 2. Vertical profiles of wind speed for Huron, South Dakota, (solid line), and Reanalysis data point 4556 (small dashed line) at 12 GMT. The large dashed line is the difference of the Huron wind speed from the Reanalysis wind speed. The squares represent the levels of wind speed data for Huron, and the diamonds represent the levels with Reanalysis wind speed data.