Conference Paper

April 1999 • NREL/CP-500-26152

The Use of Reanalysis Data for Wind Resource Assessment at the National Renewable Energy Laboratory

M. Schwartz, R. George, and D. Elliott

Presented at the European Wind Energy Conference 1999
Nice, France
March 1-5, 1999

National Renewable Energy Laboratory

1617 Cole Boulevard
Golden, Colorado 80401-3393

NREL is a U.S. Department of Energy Laboratory
Operated by Midwest Research Institute • Battelle • Bechtel

Contract No. DE-AC36-98-GO10337

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
703-605-6000 or 800-553-6847
or
DOE Information Bridge
http://www.doe.gov/bridge/home.html

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

THE USE OF REANALYSIS DATA FOR WIND RESOURCE ASSESSMENT AT THE NATIONAL RENEWABLE ENERGY LABORATORY

M. Schwartz, R. George, D. Elliott
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO
USA

ABSTRACT: An important component of the National Renewable Energy Laboratory wind resource assessment methodology is the use of available upper-air data to construct detailed vertical profiles for a study region. Currently, the most useful upper-air data for this type of analysis are archived observations from approximately 1800 rawinsonde and pilot balloon stations worldwide. However, significant uncertainty exists in the accuracy of the constructed profiles for many regions. The United States Reanalysis Data Set, recently created by the National Center for Atmospheric Research and the National Centers for Environmental Prediction, has the potential to improve the quality of the vertical profiles. The initial evaluation of the usefulness of the Reanalysis data for wind resource assessment consisted of contrasting reanalysis-derived vertical profiles of the wind characteristics to those generated from upper-air observations for comparable locations. The results indicate that, while reanalysis data can be substituted for upper-air observation data in the assessment methodology for areas of the world where observation data are limited, enough discrepancies with observation data have been noticed to warrant further studies.
KEYWORDS: Wind assessment: data bases: meteorology: resources

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 [1]. 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 [2] 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 started 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 [3,4].

The mapping system uses computerized spatial analysis and 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 functions 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 identifying 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 the wind speed and wind speed distribution, are used as direct input into the mapping system. It is important to note that seemingly minor changes in wind speed can cause significant 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 balloon stations (pibal) 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 [5]. 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 pibal data, and 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 regardless of 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 the 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 or pibal 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 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. 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. The first area chosen for the comparison was the 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 tremendous potential for wind energy development, and the fact that NREL recently conducted a wind mapping validation study for a section of this region [4]. 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 1973 to 1994.

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.

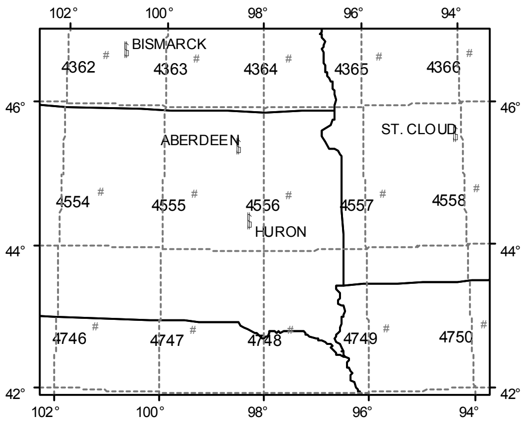

Figure 1. Locations of Reanalysis grid points (circles) and ADP upper-air stations (triangles) in the northern Great Plains.

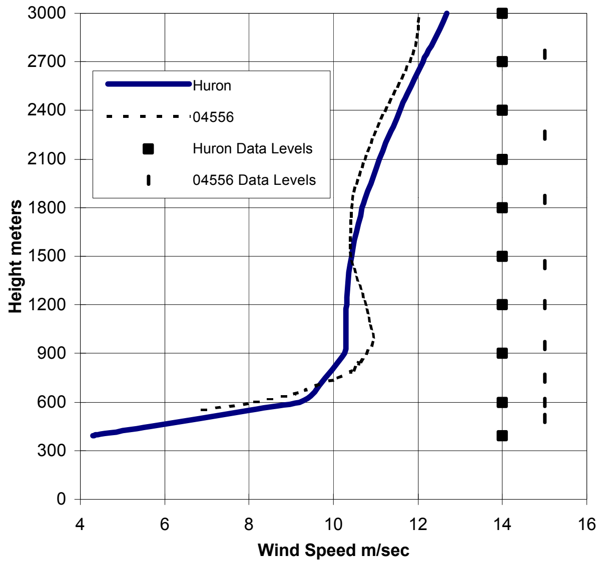

Figure 2. Vertical profiles of wind speed for Huron, South Dakota, and Reanalysis data point 4556 at 12 GMT.

The shape and the magnitude of the two profiles are for the most part similar but with a notable difference in the vicinity of the 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 m 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 km 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.

The differences between the profiles leads to questions of how realistic we think the Reanalysis profile is and which profile is the most appropriate for assessment purposes. We have not yet reached definite conclusions in regards to these questions. It is interesting to note that 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) and this type of structure has also appeared on ADP-derived profiles in other regions of the world where NREL has performed wind resource assessments. These factors indicate the Reanalysis profile is physically reasonable and in the absence of ADP data, Reanalysis could be the source of the majority of the upper-air data in NREL's assessment methodology. However, the results from a comparison of two Reanalysis points recently made for southeastern Indonesia have significant implications for the uncritical use of Reanalysis for wind resource assessment.

The Reanalysis grid points are near the islands of Timor and Sumba. ADP data were available from Kupang, West Timor, and Waingapu, Sumba, from 1973 through 1997. The upper-air station at Kupang changed equipment from pibal observations to rawinsonde in December 1986 while Waingapu remained a pibal station. The equipment change at Kupang resulted in an increase of 3 m/s (towards what we believe is a more realistic value) of the average wind speed at the 850 mb (1500 m) level in the ADP data there, while the speed at Waingapu remained constant. We wanted to determine the effect of the observational speed increase on the regional Reanalysis data set. The two Reanalysis data points are grid point 10050 (10^0 $28'$ S, 123^0 $45'$ E) about 30 km south of Kupang, and grid point 10048 (10^0 $28'$ S, 120^0 $00'$ E) off the south coast of Sumba. The Reanalysis data were divided into periods 1973-1986 that corresponded to the Kupang pibal observations and 1987-1991, and 1994-1996 that corresponds with the rawinsonde observations. Figure 3 shows the vertical profile of wind speeds at these grid points for both periods. In the pibal period, 10048 had higher wind speeds than 10050 until 1100 m. Above that level, wind speeds at 10050 were higher than at 10048 by about 0.3 m/s. In contrast, during the rawinsonde period wind speeds at 10050 were higher than 10048 above 600 m with the difference reaching 1 m/s between 1500 m and 2000 m asl. Clearly, relying on Reanalysis data as the sole upper-air meteorological input for the automated mapping system would yield significantly different resource assessments for this region depending whether pibal or rawinsonde era data were used. This points out the need for a critical evaluation of the Reanalysis data set and to cross-reference it against other data sets to ensure accurate and consistent meteorological input for the mapping system.

5. CONCLUSIONS

NREL has performed an initial evaluation of the utility of including Reanalysis data in NREL's wind resource assessment methodology. The evaluation results were somewhat encouraging but there are still 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

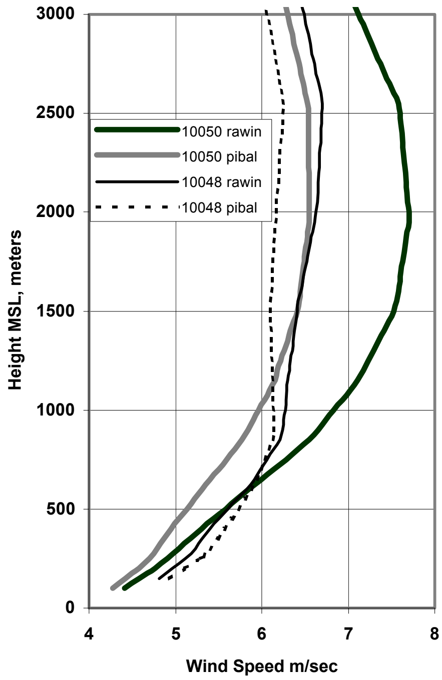

Figure 3. Vertical profiles of wind speed at Reanalysis point 10048 and 10050 for pibal and rawinsonde periods.

may be substituted for ADP data in the wind resource assessment methodology. However, like all of NREL's data sets, Reanalysis must be critically evaluated and cross-referenced in order to prepare the most accurate meteorological inputs for the mapping system. The example from Indonesia certainly emphasizes this point. We will continue to evaluate and compare the Reanalysis and ADP data for regions where ADP data are relatively plentiful.

6. ACKNOWLEDGEMENTS

We would like to thank the National Center for Atmospheric Research for providing the Reanalysis data and Donna Heimiller and Ray George for their work on preparing the figures and developing visual software tools. This paper was written at the National Renewable Energy Laboratory in support of U.S. Department of Energy under contract number DE-AC36-98GO10337.

7. REFERENCES

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

[2] Schwartz, M.N., and D.L. Elliott, 1997: The Integration of Climatic Data Sets for Wind Resource Assessment. *Preprints, 10th Conference on Applied Climatology,* Reno, NV, 368-372.

[3] Elliott, D.L., and M.N. Schwartz, 1997: Recent Wind Resource Characterization Activities at NREL. *Proc. Windpower '97,* Austin, TX, American Wind Energy Association, 417-423.

[4] Elliott, D.L., and M.N. Schwartz, 1998: *Validation of Regional Wind Resource Predictions in the Northern Great Plains*. Report No. NREL/CP-500-25069, National Renewable Energy Laboratory, Golden, CO.

[5] Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, A. Leetma, R. Reynolds, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-Year Reanalysis Project. *Bull. Am. Meteor. Soc.,* **77**, 437-471.