771 A U.S. WIND CLIMATOLOGY: NEW TOOLS TO MONITOR WIND TRENDS ACROSS THE CONTIGUOUS UNITED STATES

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1. Introduction

NOAA's National Climatic Data Center has developed a new monthly and seasonal product to provide a spatially continuous wind climatology for the contiguous U.S. using gridded National Centers for Environmental Prediction (NCEP) reanalysis data. Surface wind observations are sparse over specific regions of the country, and are subject to local effects. By utilizing the sigma .995 level of the reanalysis data we can monitor wind conditions and trends of the lower troposphere across the entire United States. Data are analyzed from January 1950 to the most current month. Monthly averaged winds and wind anomalies are calculated with respect to the 1971-2000 base period, and time series for each grid point show how regional winds have changed over the 60 year period of record.

The main goal of this new climatology product is to provide regional decision support for the emerging wind energy sector, in addition to others who are interested in the current state of wind conditions. The U.S. Department of Energy has outlined a plan for 20 percent of U.S. electricity production to be from wind by 2030, and having a temporally and spatially continuous wind dataset, updated on a monthly basis, will be beneficial to understanding wind trends nationwide. The lack of a long-term, spatially complete, routinely updated, and publically available wind climatology prompted the development of this product. Using the publically available NCEP reanalysis wind dataset, we were able to create a wind product that meets the listed shortcomings of other wind climatologies. This climatology also serves as an addition to the other wind products that the NCDC currently produces, including a station wind observation climatology and a satellite derived sea surface wind product. The scientific objective is to provide information on the variability and trend of winds on a monthly basis and on a regional scale. It is not intended to assist in the diagnosis of the availability of wind resources at particular locations. These types of decisions are on finer scales and involve more detailed analysis than this product alone can provide.

2. Background

The NCEP reanalysis dataset was commissioned to provide a long-term record of global analyses of atmospheric fields in support of the needs of research and climate monitoring communities (Kalnay et al., 1996). Since the product has been in existence it has been used to initiate weather and climate forecast models and to monitor atmospheric phenomenon such as atmospheric winds, temperature, pressure, precipitation, surface fluxes, and many others (Kistler et al., 2001). In 2008, the BAMS State of the Climate publication was the first in the series of annual reports to include data from the NCEP reanalysis dataset, including atmospheric winds, and set a precedent for using the dataset in a climate monitoring setting (Peterson et al., 2009).

The NCEP reanalysis dataset uses weather observations taken from land surface measurement sites, ships, rawinsondes, pibals, aircraft, satellites, and other platforms. Data assimilation techniques and numerical models are used to extrapolate the data to regions

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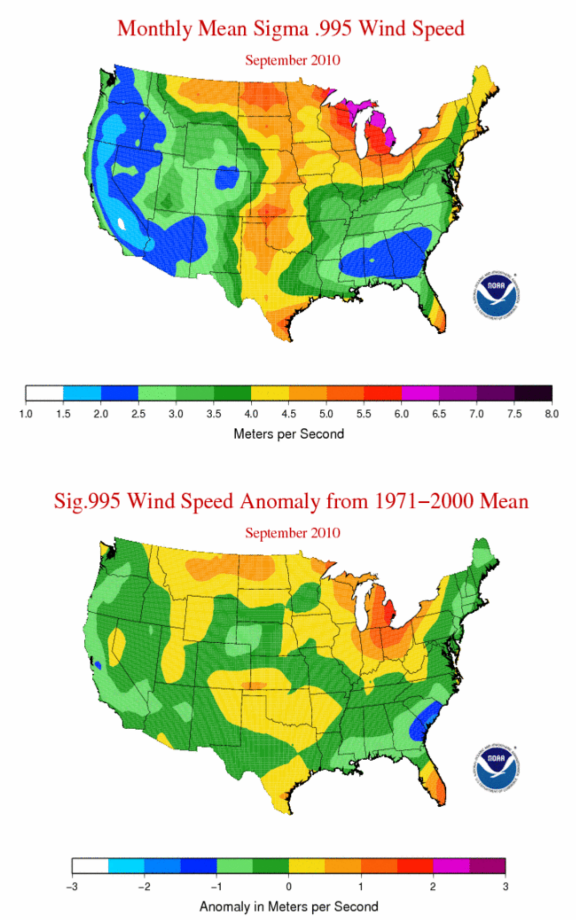

Figure 1. a) Mean monthly wind speed for September 2010. b) Wind speed anomaly from 1971-2000 mean.

without direct observations in an attempt to yield an estimate with less uncertainty than either the model prediction or observations alone (Fitzmaurice and Bras, 2008; Kalnay et al., 1996). The numerous variables included in the reanalysis are divided into three categories depending upon their basis on direct observations or model output. The class 'A' variables rely mostly on observations and include wind and pressure measurements. According to Kistler et al. 2001, this makes the analyzed tropospheric wind field the most accurate variable included in the entire reanalysis dataset because it is less impacted by model parameterizations. Also, the consistency in the wind measurement technique over time makes the fields less susceptible to changes in observation systems (Trenberth et al. 2001; Kistler et al. 2001).

Several validation studies have been conducted on the accuracy of the wind reanalysis. The studies highlight both the weaknesses and strengths of the dataset. The majority of these studies were conducted in oceanic or polar regions, where atmospheric observations are sparse (Bromwich and Wang, 2005; Putman et al. 2000; Schafer et al. 2003; Smith et al. 2001; Swail and Cox 2000; Wu and Xie, 2003). In these locations, there is more of a reliance on the model for spatial completeness resulting in a higher probability of error due to the model parameterizations (Bromwich and Wang, 2005; Goswami and Sengupta, 2003; Schafer et al. 2003; Wu and Xie, 2003).

Swail and Cox, 2000 found issues within the wind dataset when there were extratropical storms present. Peak winds were systematically underestimated in major jet-streak features propagating about intense extratropical cyclones. Winds within tropical cyclones were also poorly resolved due to the coarse grid scale. In situ marine observations assimilated into the reanalysis have inherent issues including the height of ship observations not being taken into account as well as averaging intervals not being reported with the observation (Cardone et al., 1990). These marine issues would not directly impact the wind reanalysis over the U.S., and the winds within large cyclones, both tropical and extratropical, would likely be averaged out over the longer timescales (months and seasons) this product examines.

Kumar and Anandan, 2009 found that areas with significant terrain also pose a problem in the reanalysis of wind. Terrain affects the low level flow through the development of gravity waves, blocking, and thermal forcing. Data taken at several locations in the U.S. Mountain West are typically under the influence of these topographic effects. The reanalysis relies heavily on direct observations of the wind, so the reanalysis in the boundary layer tends to be more accurate than wind measurements aloft across complex terrain (Kumar and Anandan, 2009). The handling of the winds further from observations can be problematic, due to the data assimilation and models not being able to accurately represent complex terrain flows. It is important to take these factors into account when examining the wind reanalysis in mountains regions. It should also be noted that if an observation in a data sparse region is significantly different than the model data, it will be rejected from the reanalysis (Kalnay et al. 1996; Schafer et al. 2003).

3. Data and Methodology

The NCEP dataset was chosen over other reanalysis datasets because of its long period of record (1950-present) and its availability only a few days after the end of a month. This allows us to have an updated product online by the tenth day of each month. The sigma .995 level of the reanalysis data is analyzed because it is shown that the wind reanalysis performs best at lower levels in the atmosphere, and by using the .995 sigma height level we are minimizing the affects of the surface and avoiding the problematic upper levels of the atmosphere (Bromwich and Wang, 2005; Smith et al. 2001). The reanalysis wind data is comprised of the U component (east-west) and the V component (north-south) at each grid point. The wind components are used to determine the vector wind speed:

$$WindSpeed = \sqrt{U^2 + V^2} \qquad (1)$$

The monthly mean wind speed for each point is then calculated using the 6-hourly data files, and the monthly wind speed anomaly is calculated with respect to the 1971-2000 base period. The monthly mean and anomaly are also calculated for the U and V wind components. The U and V values can be used to study trends in wind direction over time. The inherent resolution of the NCEP data is 2.5 degrees x 2.5 degrees. We use a linear technique to interpolate the mean and anomaly data down to a 0.25 X 0.25 degree resolution. This provides finer detail in our final mapped product.

The raw binary data of the U and V components are available through ftp at ftp://ftp.cdc.noaa.gov/Datasets/ncep.reanalysis.dailyavgs/surface.

Although the NCEP wind reanalysis has some documented issues, we are confident that the low-level reanalysis wind data over the contiguous U.S. is more than adequate to study long term regional trends. Studies have shown that the dataset performs best over regions with a dense observational network (Betts et al. 1996), and that is the case for the United States. Surface wind observations are widespread, while upper-air observations are taken from a systematic balloon network across the country. Schafer et al., 2003 found that by looking at longer averaging periods the variances of the reanalysis winds approach the variances in actual wind observations. This is promising given the scope of this wind climatology. However, this suggests that the reanalysis is most likely missing local processes such as sea breezes and other diurnal scale phenomenon (Schafer et al., 2003). The aim of this climatology is not to study these wind features on small time or spatial scales, but to study longer term regional trends.

4. The Final Product and Future Analysis

The final wind climatology product consists of an interactive web interface where users can select a year and month back to January 1950 to display the monthly mean wind, the wind anomaly, and the 1971-2000 base period wind speeds. The user has the choice to view the wind components or the vector wind. Maps are contoured using a step interval of 0.5 m/s. Figure 1 shows example maps from September 2010. Figure 1a shows the map of the monthly mean wind speed and 1b illustrates the monthly wind anomaly. The maps indicate that during September 2010 winds were anomalously strong across the Great Lakes, northern Plains, and southern Florida. Conversely, winds were anomalously weak for parts of the southeastern coast.

Future analysis of the wind product will be conducted to determine ways to better calculate the wind climatology, including a follow-up comparison with in situ observations, particularly in known trouble spots, determine how to accommodate bi-modal distributions, and refine current in situ wind climatologies to be a regularly updated companion to this product. Additional functionality will also be added to the product in the future. Currently the programming which creates the current maps also creates monthly, seasonal, and annual time series for each grid point. The version 2 web interface will allow users to dig deeper into the data by clicking on areas to generate these time series on the fly. Figure 2 illustrates example time series which will be made available. Figure 2a shows the seasonal mean wind for the grid point 35.5 degrees north, 82.5 degrees west from 1950 through 2010. There is evidence of decreasing wind speeds during the winter and spring for the location. The chart also shows that winds for the location are consistently stronger during the winter than for the summer. Figure 2b graphs the seasonal wind anomaly for the same location in 2a. The anomaly graph shows a similar trend in the winter and spring wind trends. It is also noteworthy that the past several years have generally been associated with below average wind at this specific location according to this dataset.

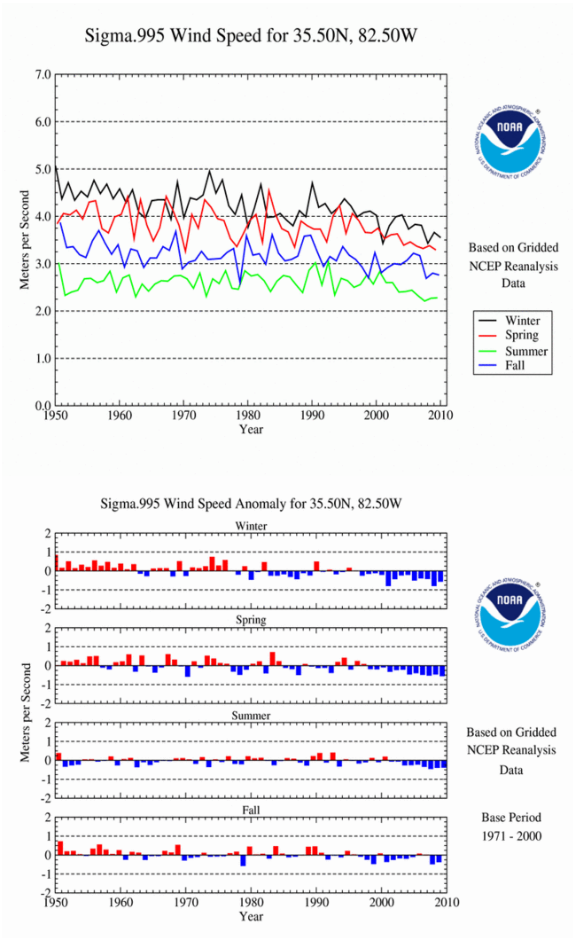

Figure 2. a) Seasonal wind speed time series for 35.5°N 82.5°W. b) Seasonal wind speed anomaly from 1971-2000 for 35.5°N 82.5°W

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