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USING SIMULATED WIND DATA FROM A MESOSCALE MODEL IN MCP

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ABSTRACT

Since field measurement campaigns for proposed wind projects typically last no more than a few years, the observed meteorological data collected on site often deviate from the long-term climatology. To reduce the uncertainty associated with climate variability, a statistical relationship is typically established between a monitoring site and one or more reference stations using a technique known as Measure-Correlate-Predict (MCP).

Proper use of MCP requires reference stations with long data records collected at the same location and height, with the same equipment, and in relatively unchanging surroundings. Identifying reference stations meeting these stringent criteria is becoming increasingly difficult, especially considering that the National Weather Service (NWS) is replacing cup anemometers with ice-free ultrasonic anemometers at its Automated Surface Observing System (ASOS) stations.

One approach that offers promise of mitigating these problems is to drive a mesoscale model with a consistent set of observational data. Though the concept is similar to reanalysis, the combination of higher model resolution and care in the selection of stations used in the simulations should improve on those data. Towards this end, we have created *windTrends*, a modeled dataset covering North America at 20-km resolution from 1997 to the present, and have conducted a thorough evaluation of its suitability for MCP and other applications. This study summarizes our findings.

INTRODUCTION

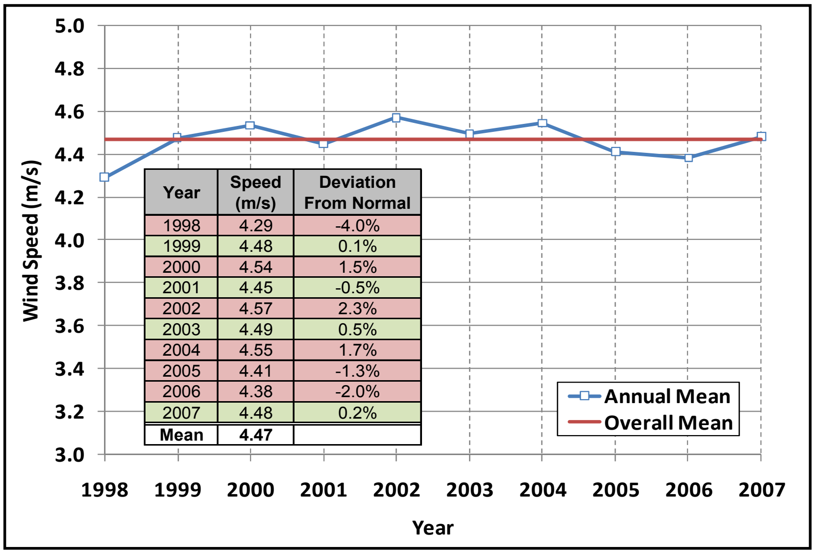
Predicting the future requires insight into the past. Until recently, most resource assessments for wind energy projects have relied on standard meteorological towers to establish historical climate conditions. But with intermittent changes in surroundings, locations, and equipment, the continuity and representativeness of these reference data is a growing concern. Other commonly-used reference sources include rawinsonde (instrumented balloon) and reanalysis data, but these sources also have potentially significant shortcomings as well. The relatively few rawinsonde stations often exhibit poor correlations with wind project sites, whereas reanalysis data are vulnerable to inconsistencies caused by changes in the observational data used to drive the models.

One approach that may overcome these problems is to drive a mesoscale model with a consistent set of observational data. We have created such a data series, known as *windTrends*. This report details our validation of *windTrends* against ASOS, rawinsonde, NCEP/NCAR Global Reanalysis (NNGR)[1] and North American Regional Reanalysis (NARR)[2] with respect to its consistency over time and its viability as a long-term reference for wind resource assessment.

BACKGROUND AND METHODS

Interannual Variability and Measure-Correlate-Predict (MCP)

Most wind resource assessment programs span roughly one to two years. When examining the annual mean wind speeds from reference sites with long periods of record, we find that they vary considerably from year-to-year. Figure 1 shows a time series of the annual mean wind speeds at the Chicago – Midway (KMDW) Automated Surface Observing System (ASOS)[3] station between 1998 and 2007. The annual mean speed was within 1% of the ten-year average in only four of the ten years and deviated by as much as 4.0%. Given such variability, it is prudent to adjust observed data at a short-term resource assessment site to long-term conditions.



Year	Speed (m/s)	Deviation From Normal
1998	4.29	-4.0%
1999	4.48	0.1%
2000	4.54	1.5%
2001	4.45	-0.5%
2002	4.57	2.3%
2003	4.49	0.5%
2004	4.55	1.7%
2005	4.41	-1.3%
2006	4.38	-2.0%
2007	4.48	0.2%
Mean	4.47	

Figure 1. Annual Mean Wind Speeds at Chicago – Midway ASOS Station

The MCP method of estimating long-term wind speeds correlates short-term data from a site with concurrent data from a long-term reference station (Figure 2). A regression or other relationship between the two stations is derived, and the long-term mean speed or speed distribution at the reference station is applied to estimate the long-term speed or speed distribution at the site. The accuracy of the long-term projections is directly tied to the consistency of the reference data and the quality of the correlation between the target mast and reference site. Problems such as a limited period of reference data, poor correlation with on-site measurements, and changing observational methods and platforms can cause significant errors in energy production estimates.

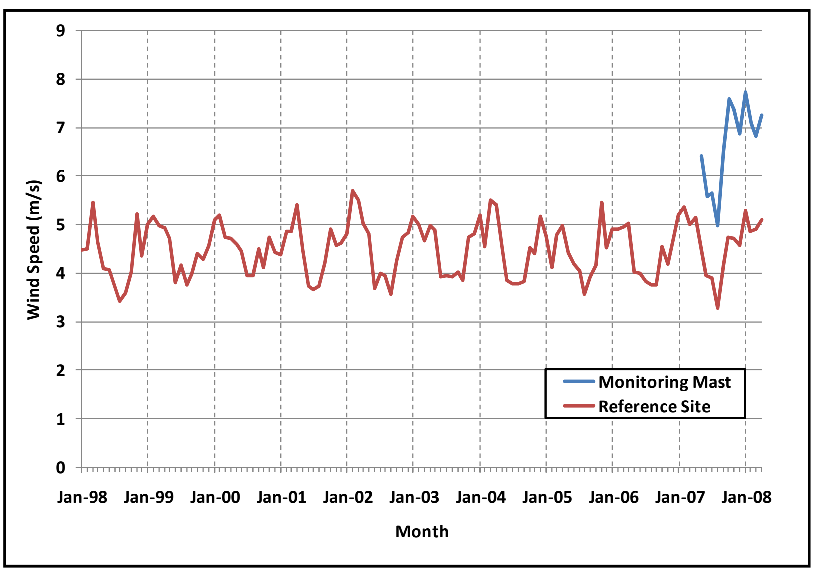


Figure 2. Comparison of Typical Monitoring Mast and Reference Site Periods of Record

Common Reference Data Sources

Surface Stations

The most widely used source of reference data is surface weather stations. They offer several advantages. Surface stations are relatively numerous and collect frequent (usually hourly) observations.

Additionally, in some countries, such as the United States, site histories, data collection protocols, and equipment maintenance records are well documented. Unfortunately, weather stations are often located far from wind project sites or in different wind regimes, and therefore can exhibit unsatisfactory correlations with onsite measurements. The wind monitoring heights at surface reference stations are also usually low (10 m is the ASOS and international standard); the result is that the measurements are very sensitive to changes in the surroundings, such as tree growth or building construction. Finally, as has been the case with the ASOS network, instrumentation and data collection protocols change occasionally, often introducing shifts in the observed wind speeds that may jeopardize the site's viability as a long-term reference. One such change occurred in the United States when the ASOS standard was implemented at weather stations starting in the mid-1990s and rendered prior measurements useless for MCP. Very recently, ASOS cup anemometers were replaced with ultrasonic ice-free wind (IFW) sensors. Test data indicate a small but measurable difference in wind speeds recorded by IFW, which adds uncertainty to the MCP process.[4]

Rawinsonde Stations

Rawinsonde data are acquired using instrumented balloons to sample the vertical profile of the atmosphere.[5] Compared to surface stations, this measurement technique has changed relatively little in the past two or three decades, resulting in a long data record that is typically quite consistent and reliable as well as – for heights well above ground – free of impacts from changing surface conditions. However, rawinsonde stations are far less numerous than surface stations, and they generally collect soundings only once every 12 hours.[1] In addition, the lowest useful height of measurement (defined by standard pressure levels) is often above the planetary boundary layer. For these reasons, rawinsonde data often do not correlate as well as surface weather data with measurements taken at wind project sites.

Reanalysis Data

The term "reanalysis data" refers to a gridded data base of weather observations that have been assimilated at a later time into a global or regional weather model. NNGR and NARR, two publicly available reanalysis data sets, are the focus of our discussion; others include a global data set developed by the European Centre for Medium-Range Weather Forecasts[6]. Observational data sources assimilated into the reanalysis models include surface, rawinsonde, satellite and aircraft. The main advantage of reanalysis data is that they provide a convenient source of weather data extending back several decades (to 1948, in the case of NNGR). However, the quantity and sources of weather observations used to drive the reanalysis model have varied greatly over the past several decades, leading to false trends and variations in some regions.[7] In addition, due to the coarse model resolution (210 km for NNGR), there is often a poor correlation with wind monitoring sites.

windTrends: Controlled Regional Reanalysis

windTrends is a controlled regional reanalysis dataset developed by AWS Truewind. Though conceptually similar to reanalysis, the process differs in two key ways: the grid resolution is finer and the source of observational data - rawinsonde only - has been kept fixed throughout the simulation period. These modifications should allow for a more consistent data set that correlates better with onsite observations than standard reanalysis data.

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[1] According to the NWS rawinsonde fact sheet posted at http://www.ua.nws.noaa.gov/factsheet.htm, there are 69 operational rawinsonde stations in the conterminous United States. Observations are usually collected twice daily.

The *windTrends* data were produced from Mesoscale Atmospheric Simulation System (MASS)[8] model simulations on a grid covering the conterminous United States and southern Canada starting in January 1997. The simulations were made on a 60-km outer grid and a 20-km nested grid, with NNGR data supplying the initial and lateral boundary conditions. Rawinsonde data from the Integrated Global Rawinsonde Archive (IGRA) were also used in the objective analyses of the initial fields. For each month, two series of runs were made, beginning with a cold start 12 hours before the first of the month and 12 hours before either the 15th or 16th of the month, followed by two weeks of simulations with rawinsonde observations assimilated at 0000 and 1200 UTC. This simulation strategy was designed to minimize the influence of the initial conditions from NNGR.

Validation

Trend Verification

The selection of validation stations for this part of the analysis began with a list of 371 high-quality stations used by the Goddard Institute of Space Studies in their analysis of long-term surface temperature trends.[9] Stations outside the conterminous United States were eliminated. Next, the availability of surface data for each station was verified. Stations were retained if they had 95% availability for each of 10 years (1997 – 2006), resulting in a list of about 185 stations. Plotting those stations on a map, there were some areas with sparse station coverage: New York, Vermont, the Upper Peninsula of Michigan, coastal North and South Carolina, coastal Louisiana, and central and southern California. Fifteen stations in those areas with almost 95% coverage were selected and added to the list, resulting in 198 stations, of which 30 were rawinsonde stations. Using these sites, we compared the long-term wind speed trends and anomalies from the NNGR, NARR, and *windTrends* with concurrent observed data at each of the selected stations on hourly, monthly, and annual temporal periods.

MCP Verification

In earlier work, Taylor et al.[10] developed a method whereby the accuracy of MCP was tested for wind resource assessment sites having periods of record spanning at least four years. The onsite (target) data were divided into a sequence of shorter periods typical of what would be available for MCP. A regression with a reference data set was performed for each sub-period and the mean speed for the entire period was predicted. The error margin of the procedure was derived from the biases between the predicted and actual mean speeds for all the sub-periods.

For this assessment, we selected the entire ASOS network as target sites and repeated the same MCP analysis using, as reference, the nearest ASOS site and nearest *windTrends* grid point with the strongest correlations. The ASOS network yielded 629 sites that, until the installation of the IFW sensors, operated using the same wind measurement system for several years. We focused on the results with a 12-month sub-period.

We also identified ten wind resource assessment sites that have high data recovery and fit the established criteria, and repeated the same analysis using direct observations (ASOS and rawinsonde) and modeled *windTrends* and NNGR data as references. For an additional 12 sites with less than four years of data, we compared only the coefficient of determination or square of the correlation coefficient (r^2) values of the regressions. For ASOS reference sites that were converted to IFW sensors, we used a preliminary correction to the data developed by AWS Truewind from side-by-side test data provided by the NWS.

RESULTS

Trend Verification

Figure 3 contains a time series comparing the annual mean wind speed anomalies (deviations from the average) for NNGR, NARR, and *windTrends* with the observed anomalies. *windTrends* and NNGR data both correlate well with the observations. However, the NNGR data exhibit a downward trend that deviates from *windTrends* and the observed data. The NARR data show a noticeable discontinuity starting in 2002, which may be related to a change in procedures for assimilating rawinsonde data.

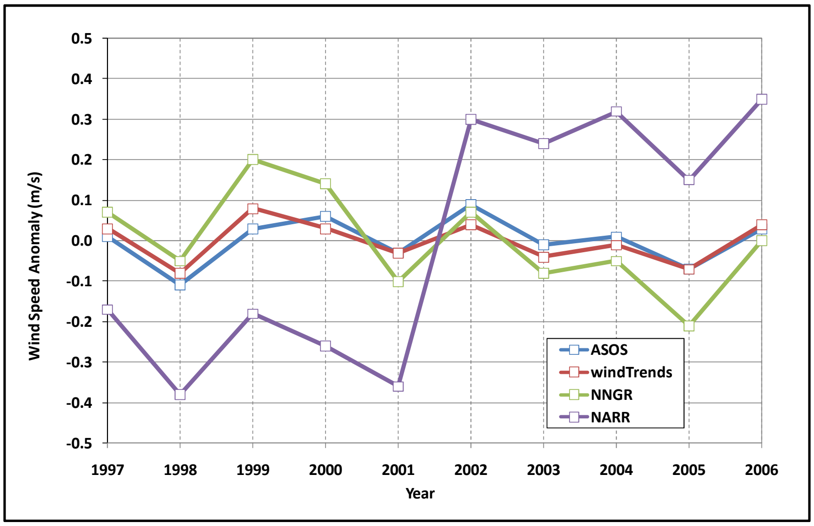

Figure 3. Comparison of Annual Mean Wind Speed Anomalies for 198 Surface-Based Monitoring Stations

Time series of the annual mean wind speeds from *windTrends* interpolated to several mast locations and compared with nearby ASOS or rawinsonde data suggest good agreement. Two examples of these comparisons are contained in Figure 4.

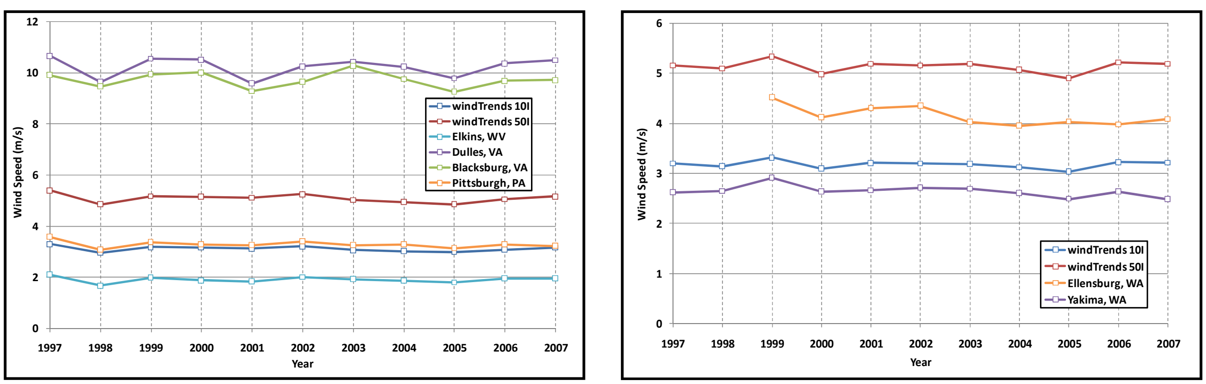

Figure 4. Annual Mean Wind Speeds from *windTrends* and Nearby Reference Stations for an Eastern Ridgetop (left) and Central Washington (right)

Figure 5 contains a time series comparing the monthly mean wind speed anomalies from NNGR and *windTrends* with the observed anomalies at the 198 surface and rawinsonde stations. *windTrends* correlates very well with the observed data; the NNGR anomalies also correlate well, but are systematically larger, likely because they were calculated at 25 m height above ground. Of importance is that a close examination of both datasets reveals periods in the NNGR dataset that deviate substantially from the observed values. Those discrepancies do not appear in *windTrends*, or are much smaller.

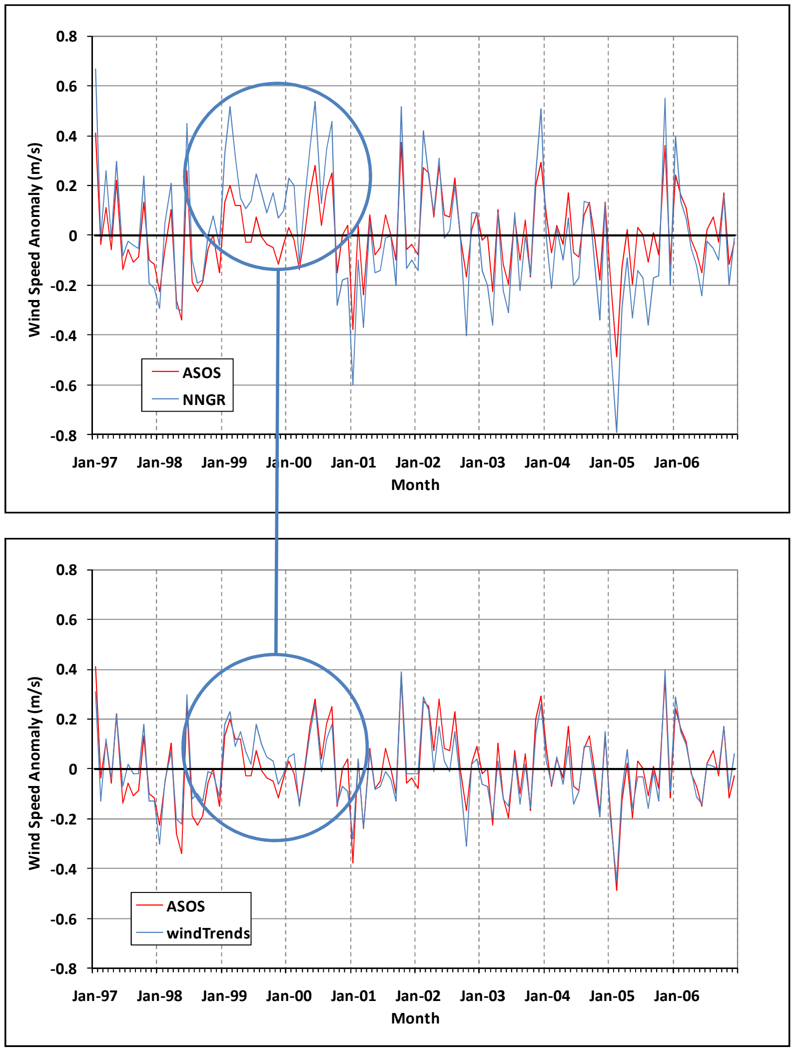

Figure 5. Comparison of Monthly Mean Wind Speed Anomalies for 198 Surface-Based Monitoring Stations

MCP Verification

For the 629 ASOS sites, the ASOS-to-ASOS regressions had a stronger correlation in about 80% of cases; the average r^2 value was 0.71 between ASOS sites, while it was 0.65 between the ASOS target site and the best *windTrends* grid point. Figure 6 shows the geographic distribution of the differences in r^2 between the ASOS-to-ASOS and ASOS-to-*windTrends* correlations. Green contours on this map indicate the *windTrends* grid point has the superior r^2, whereas red indicates the ASOS station does. *windTrends* generally does better in the complex terrain of the Appalachian and Rocky Mountains. Conversely, in coastal regions and the southeastern United States, ASOS data provide the stronger correlation. Throughout much of the Great Plains, the two are roughly equivalent.

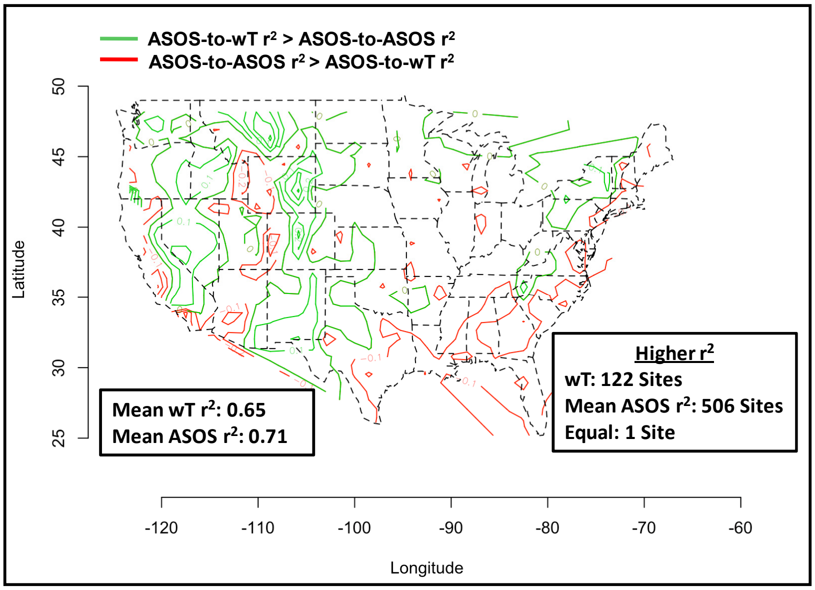

Figure 6. Geographic Distribution of Relative ASOS-to-ASOS and ASOS-to-*windTrends* Correlation

In contrast to the ASOS target sites, the wind resource assessment sites generally have stronger correlations with the *windTrends* data than with the ASOS reference data. Figure 7 contains a scatterplot of the r^2 values for 22 target sites and their correlations with ASOS and *windTrends* reference data. In 16 cases, the *windTrends* correlation is higher. This pattern may reflect the fact that most wind project sites are better exposed to synoptic-scale winds, which are captured well by the *windTrends* simulations, whereas ASOS stations are often in sheltered locations, such as valleys.

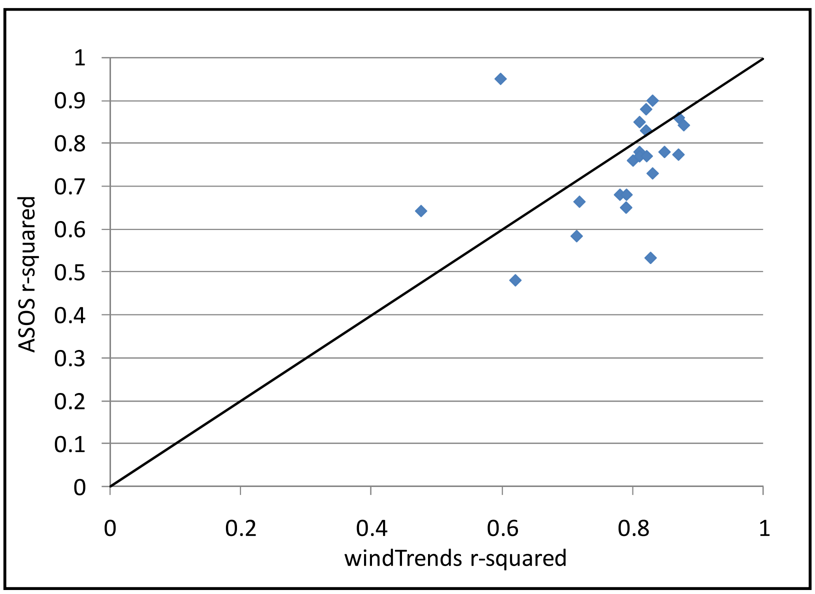

Figure 7. Scatterplot of Mast-to-ASOS and Mast-to-*windTrends* r^2 values for 22 Sites

As shown in Figure 8, the distributions of MCP standard errors for ASOS and *windTrends* are virtually identical. For ASOS-to-*windTrends* regressions, the mean standard error is 0.096 m/s; for ASOS-to-ASOS regressions, it is 0.095 m/s.

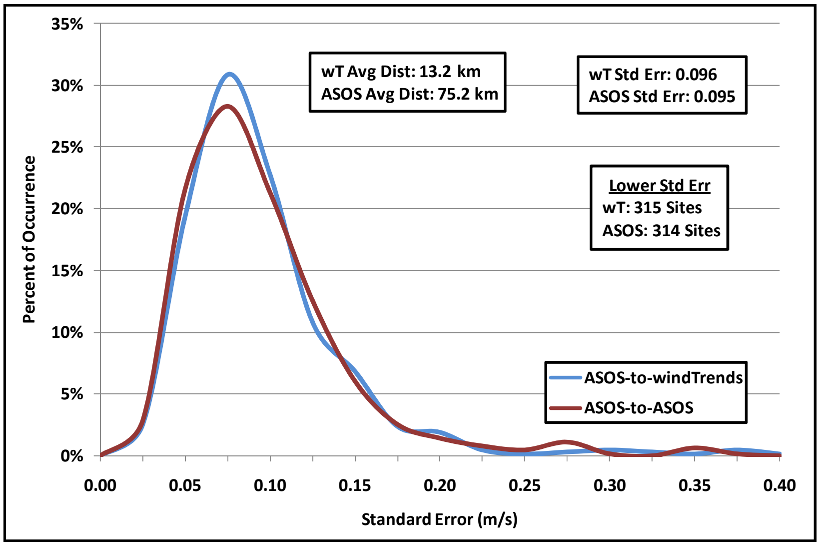

Figure 8. Frequency Distributions of ASOS-to-ASOS and ASOS-to-*windTrends* Standard Errors

For the ten wind resource assessment masts with periods of record of at least four years, *windTrends* performed slightly better than ASOS and significantly better than NNGR for MCP. The respective average r^2 values were 0.75 (mast-to-*windTrends*), 0.72 (mast-to-ASOS), and 0.55 (mast-to-NNGR), while the standard errors were 0.12 (*windTrends*), 0.13 (ASOS), and 0.16 (NNGR). The results are summarized in Figure 9.

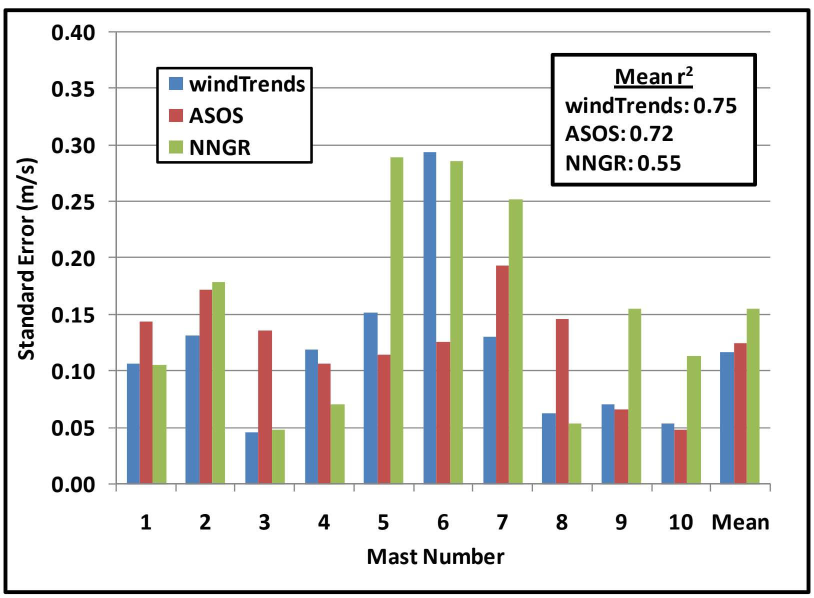

Figure 9. Standard Errors of MCP Analyses for 10 Monitoring Mast Using *windTrends*, ASOS, and NNGR Data as References

In most individual cases, the *windTrends* standard errors are comparable to or lower than those derived using the ASOS or NNGR reference data. The only location where *windTrends* performs substantially worse than ASOS is at Mast 6, which is located in a California mountain pass where the wind climate is highly localized and therefore not resolved by the 20-km *windTrends* simulations.

SUMMARY AND CONCLUSIONS

AWS Truewind developed *windTrends* in hopes of providing a consistent set of reference data for performing MCP studies that are well correlated to wind project sites in the conterminous United States and southern Canada. The validation work reported here shows that *windTrends* is generally superior to global reanalysis (NNGR) and comparable to ASOS stations for this purpose.

Whether ASOS or *windTrends* should be used in a particular MCP analysis can be decided on a case-by-case basis. Where the correlations are similar and there are no evident consistency problems in the ASOS data, either data set (or both) can be used. Where one exhibits a much stronger correlation than the other, that data set is likely to be the better choice. The consistency problems we have observed in both NNGR and its regional counterpart, NARR, suggest that they are not suitable in most situations for MCP.

ONGOING AND FUTURE WORK

Validation work continues. One goal is to identify and assess additional wind resource assessment masts with sufficiently long periods of record to provide a more extensive test of *windTrends* in MCP. The present sample of 10 such masts is fairly small. Another goal is to gauge the impact of the IFW correction on the accuracy of MCP using ASOS stations.

We are also working to improve the *windTrends* data set. Since the current 20-km resolution is insufficient to resolve highly localized wind climates such as mountain passes, we are planning to increase the grid resolution to 5 km. This should increase the quality of the correlations and decrease the standard errors in the long-term predictions.

The *windTrends* approach is also being extended to the rest of Canada, India, and other countries.

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