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Assessments Reduce Prediction Uncertainty

On-site data combined with advanced atmospheric models improve energy production predictions.

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Wind resource assessment methods continue to improve, primarily through the use of more sophisticated models and improved data sources, such as satellite-based sensors. However, on-site meteorological (met) measurement campaigns still serve as the cornerstone of wind resource assessment.

AWS Truewind has found that on-site data combined with advanced atmospheric models provides reductions in energy production uncertainty. Improved measurement practices and technologies have also reduced uncertainties. Examples include identification and reduction of error sources, use of sodar to measure conditions across the heights relevant to a turbine's rotor plane and the use of hub-height measurement towers.

This article provides an overview of the on-site resource assessment process and describes recent research demonstrating the sensitivity of energy uncertainty to the following four factors:

- long-term climate adjustment method;
- duration of on-site data collection;
- wind shear model; and
- tower effects, using standard tower offsets.

Typically, at least one tall tower is installed to assess the wind resource of a prospective wind plant location. The tower is equipped with two or more instrumentation levels and with redundant sensors, and data is collected for at least one year. Additional towers may be in order to minimize energy prediction uncertainty, which is a function of terrain complexity and the geographical size of the project.

Tower siting at representative locations, together with proper measurement system design, help reduce overall project performance uncertainties. Data should be collected and examined at least weekly to identify and correct failures with the communication, instrumentation, sensor or power systems. When problems are identified, they should be corrected quickly to minimize data loss.

Typical sources of error in energy production estimates include the sensors, shear model (used to extrapolate from sensor heights to hub-height), long-term climate adjustment (which adjusts the speeds recorded during the measurement period to the long-term climate), the spatial distribution model (used to model wind speeds throughout the project area) and plant losses (from turbine availability, icing, blade soiling, collector system resistance, etc.).

Assuming each source of uncertainty is statistically independent from the others – the total uncertainty – *total* is defined as follows:

$$\sigma_{Total} = \sqrt{\sum_{i=1}^{J} \sigma^2}$$

where, σ is the uncertainty of each error source.

Long-term climate adjustment method

Due to the natural year-to-year variation in wind speeds (67% of the cases with a variation of +/-6% or less), a long-term climate adjustment is made to better relate observed speed to the average speed during the plant operation. Three types of long-term climate adjustment methods were tested using the same high quality datasets used above: bulk regression, directional regression and directional ratios.

The first technique – called bulk regression – involved computing one regression equation between the concurrent daily mean wind speeds at both the monitoring site and each reference station for each data subperiod. Wind speed projections were

Table 1. **Data Sensitivity Related to Study Length**

Monitoring Period (months)	Standard Error
1	6.4 - 11.8
3	4.9 - 10.3
6	3.5 - 7.8
12	1.2 - 2.8
24	0.6 - 1.5

then calculated by substituting the appropriate reference station long-term mean wind speed into each equation. Meanwhile, directional regression and directional ratios compared hourly wind speeds at long-term reference stations with the on-site tower(s).

Since most sites are distant (more than 10 km) from reference stations, and weather events effecting one may not have reached the other, bulk regression proved to be the most appropriate method. Directional regressions and directional ratios are more valuable for intra-site correlations, between met towers or between a met tower and a sodar unit.

Duration of data collection

Prior industry research indicates that the length of data collection affects uncertainty. Without correlation to a regional reference station, the standard error for six months of data is 8.5% while dropping to 6% with a full year of data. However, as discussed above, correlating to one or more reference stations further reduces this uncertainty.

AWS Truewind conducted additional research, showing the error associated with different measurement periods when using reference data. Several tall tower (40 or 50 m) datasets obtained from the Northeast and Midwest U.S. were evaluated to test the sensitivity of the measured wind speed to the duration of the data collection period.

The full four-year periods were assumed to represent the long-term speed of each site (a valid assumption, since the standard error of the four-year periods in relation to projected speeds was 1%). To test the uncertainty for period of record, average speeds for one, three, six, 12 and 24 months were compared. The results are given in Table 1.

As shown, collecting at least 12 months of data significantly reduces wind resource uncertainty and, therefore, energy production uncertainty.

A wind shear model is used to estimate hub-height wind speeds from measurements taken below hub-height. Shear is calculated from the speed ratio of anemometers at different monitoring heights and then used to extrapolate the hub-height speed. Most met towers are 50 m tall, 15 m to 35 m below modern hub-heights. Our research shows that hub height measurement standard error is approximately 2.3% when extrapolated from 50 m up to 80 m using a 50 m / 30 m wind shear and anemometers with a 1% measurement uncertainty. If the lower anemometer was positioned at 40 m, the standard error would increase to greater than 4%. This substantial rise is due to the smaller vertical layer that would be sampled under this monitoring scenario.

Considering vertical anemometer spacing effects on wind shear uncertainty and the systematic errors caused by, among others, flow acceleration around the tower, the suggested practice is to mount the upper level anemometer on a side-oriented boom 1 m to 2 m below the tower top, and place the lower anemometer at a level that minimizes surface influences while maximizing the vertical layer being sampled.

Furthermore, both sensors should be oriented in the same direction. These guidelines attempt to equilibrate the simultaneous tower-induced flow acceleration experi-

Figure 1

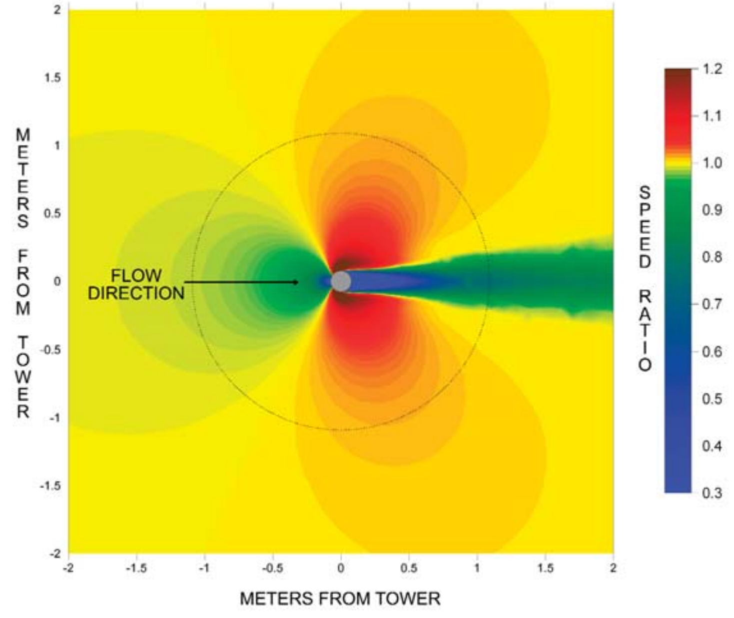
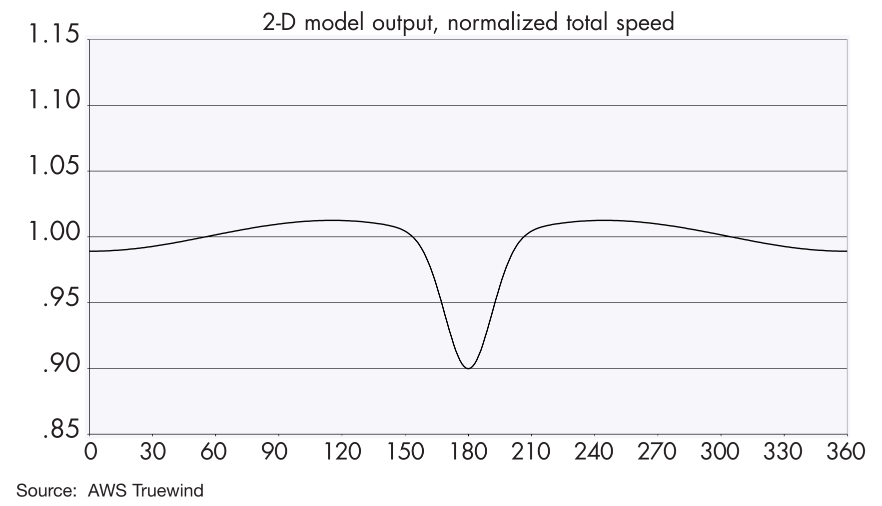


Figure 1. Two-dimensional computational fluid dynamics results show tower effects experienced in a given distance from a tubular tower.
Courtesy of AWS Truewind

enced by both anemometers, thereby canceling the tower effects on the measured shear. Collecting data at three levels is another advantageous practice that provides more information about the wind shear profile because it determines whether or not there is variability with respect to height. Mounting redundant anemometers at each level enables further validation of observed wind speeds and therefore easier identification of sensor damage or icing.

Figure 2



Source: AWS Truewind

Figure 2. Tower effects on an anemometer mounted at 7.5 tower-diameters from the tower, with a bearing of 0 degrees are shown.
Courtesy of AWS Truewind

CFD modeling of tower effects

AWS Truewind performed two-dimensional (2D) and three-dimensional (3D) computational fluid dynamics (CFD) modeling of the effects of standard 6-inch tubular towers on wind speed measurements. 2D modeling showed the speed deviation recorded by anemometers located well below the tower top (Figure 1). Even for anemometers offset by the industry standard of 7.5 tower diameters, speed measurements were deviant from free stream speed (Figure 2).

Outside the tower wake (in the vicinity of 180 degrees), the tower still impacts measurements by as much as 2%.

3D modeling was used to assess the effect of tower-top effects on anemometers mounted above and just below the tower-top. Not surprisingly, tower-top effects were a function of anemometer height above or below the tower. However, even four tower-diameters above the tower, the anemometers experience a 0.5% speed deviation. Deviations due to the tower-top were also experienced below the top.

Based on this work and field experience, it is recommended that side-mounted sensors be positioned at least 6 tower diameters below the tower-top and 7.5 tower-diameters radially away from the tower centerline. Tower-top sensors should be mounted at least six tower diameters above the tower.

Albany, N.Y.-based AWS Truewind provides wind assessment, mapping, engineering and forecasting services to the wind industry. Mark Taylor is a meteorologist with AWS Truewind and conducted the research on the uncertainties of the length of data collection, long-term climate adjustment method and wind shear model. He can be reached atmtaylor@awstruewind.com. Matt Filippelli is a project engineer and led the computational fluid dynamic studies. He can be reached at mfilippelli@awstruewind.com. Frank Kreikebaum is a project engineer at AWS Truewind and can be reached at fkreikebaum@awstruewind.com.