COMPARING SITEWIND WITH STANDARD MODELS FOR ENERGY OUTPUT ESTIMATION

1. Introduction

Uncertainty in wind resource modeling is often a large component of the total uncertainty of energy output estimates for wind projects. This uncertainty can raise barriers to wind project financing and lower returns to investors. In addition, concern about modeling accuracy often drives developers to install many met masts, at considerable expense. Consequently, there is an urgent need for the industry to continually develop and evaluate new models that may offer improved accuracy.

In the past year, AWS Truewind has introduced a new micrositing tool called SiteWind. In a SiteWind analysis, a mesoscale numerical weather model (MASS) is coupled to a spectral fluid-dynamical model (MSFD) and on-site data to produce a detailed wind map and wind resource grid for a project area. The mesoscale model establishes the wind climate of the region, including such important features as katabatic (downslope) mountain winds, channeling through mountain passes, lake and sea breezes, low-level jets, and temperature inversions. The microscale model refines the mesoscale picture, accounting for the localized effects of terrain and surface roughness changes. Lastly, on-site data are used to adjust the wind resource map in both speed and direction, assuring that the model results remain closely tied to measurement.

AWS Truewind has conducted a number of real-world studies comparing the accuracy of SiteWind with that of standard micrositing models such as WAsP. Although performance varies, we have found improvements in the accuracy of speed predictions, as determined by independent tower data, of as much as 70%. The degree of improvement depends on several factors, including the topography, climate conditions, and project size (or distance from the reference mast).

In this paper we present the results of the case studies and discuss their implications for uncertainty analysis. We also show how the demonstrated accuracy improvements can translate into lower uncertainty of energy output estimates, and thus lower financing costs, or can reduce the number of met masts required to achieve a desired level of uncertainty.

2. The SiteWind Modeling Process

The SiteWind system has several major components. First, there are the models: a mesoscale atmospheric simulation model (MASS) and a microscale spectral fluid-dynamical model (MSFD). MASS is a non-hydrostatic weather model run in a series of nested grids. MASS is similar in many respects to the MM5 family of mesoscale models, but is a commercial program developed by MESO, Inc., a co-owner of AWS TrueWind. In mapping projects, the innermost MASS grid normally operates at a scale of 1-3 km. The microscale model, MSFD (Mixed Spectral Finite Difference), is a numerical model for atmospheric boundary-layer flow over complex terrain developed at York University in Canada. MSFD is a linear model with turbulence closure for neutrally stratified atmospheric surface flows. It normally operates at a final grid scale of 50 to 100 m.

The second major component is a distributed computer processing system consisting of 94 Pentium III and IV processors connected in a network. It is the parallelization of the mapping process that makes it possible to produce high-resolution maps using this technique in a reasonable amount of time. A typical SiteWind project requires two CPU-years of processing, but can be completed on this system in about a week.

Global meteorological data bases (reanalysis, surface, and rawinsonde) and geophysical data bases (topography, land cover, vegetation greenness, sea temperatures, snow cover, soil moisture) make up the third component. The reanalysis data, which are produced by the National Centers for Environmental Prediction (NCEP), provide a three-dimensional snapshot of global weather conditions every 6 hours over the past several decades on a 2.5 degree grid. Along with rawinsonde and surface data, they provide the initial conditions for the MASS simulations, and they provide updated lateral boundary conditions. The topographic and land cover data are essential, of course, to properly simulating interactions between the atmosphere and land or ocean surface.

The mapping process begins by defining several grids around the area to be mapped. The largest is typically more than 2000 km wide, with a mesoscale grid spacing of 30 km. Within that large grid there are usually two or three levels of nested grids, each covering a smaller area at higher resolution, with the last extending perhaps 200-400 km at a grid scale of 1-3 km. The mesoscale model then simulates weather and wind conditions throughout the area at all levels of the atmosphere for 366 days randomly sampled from a 15 year period. The three-dimensional output of the model (including wind, temperature, pressure, and other parameters) is stored every hour of simulated time, resulting in a total of 8784 samples at each grid point.

The results of the mesoscale simulations are then summarized in data files containing gridded wind rose and Weibull statistics at 11 levels above the surface. These files are input into the microscale model, which uses a spectral technique to solve the momentum and energy equations in the horizontal direction and a finite-difference technique in the vertical dimension. Essentially, MSFD perturbs the MASS wind field to account for differences in the topography and land cover as seen by MSFD and MASS. Lastly, on-site data from one or more meteorological masts are used to correct for any errors in the predicted speed and direction.

3. Case Study A: Altamont Pass, California, USA

We compared SiteWind with a conventional micrositing model and measurements in a case study in Altamont

Pass involving 132 met masts. Conventional micrositing models, such as WAsP, are equilibrium models which create a wind map and climatology of a region using data from a single reference mast. The models typically assume a constant, homogenous, neutrally stratified externally determined wind flow; the terrain acts as a perturbation on this flow. SiteWind, in contrast, resolves the dynamic forces within the region affecting the flow caused by temperature gradients, non-neutral stability, and other factors.

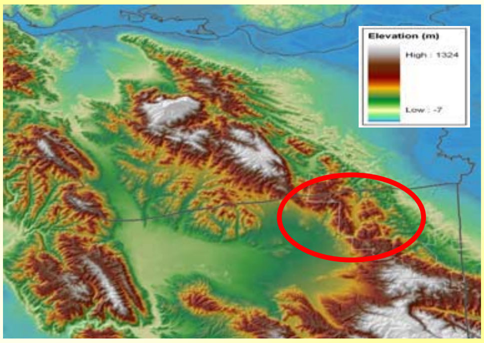


Figure 1: Altamont Pass terrain.

The Altamont Pass area (Figure 1) experiences strong downslope mountain winds driven by temperature differences between the land and ocean and channeled through a gap in the mountain range. While WAsP predicts the best winds to be at the top of the pass, SiteWind predicts – correctly – that they extend well down the eastern slope, as shown in Figure 2.

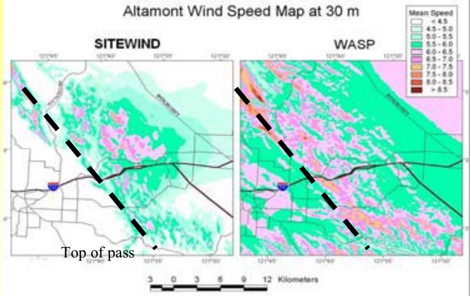


Figure 2: SiteWind and WAsP wind speed maps.

Figure 3 displays the discrepancies between model and data as a function of distance from any reference mast. The discrepancy associated with WAsP increases substantially with distance from a reference mast, whereas the discrepancy associated with SiteWind is virtually constant with distance. The estimated rms error for WAsP was 1.47 m/s, whereas that of SiteWind was 0.62 m/s, a 58% improvement.

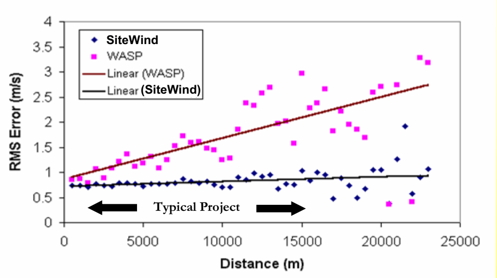


Figure 3: Growth of wind speed prediction errors with distance from a reference mast.

As this case study illustrates, SiteWind is highly advantageous where "mesoscale effects", induced for example by temperature differences, are significant. Even where such conditions do not apply, SiteWind can substantially improve accuracy over micrositing models alone, as demonstrated in Case Study B.

4. Case Study B: Gaspe Peninsula, Quebec, Canada

We compared SiteWind with a conventional micrositing model in a study in the Gaspe Peninsula of Quebec involving eight high quality meteorological masts sited along ridgelines within a 10 km radius.

The area of interest on the Gaspe Peninsula is located in complex, mountainous terrain with local elevations ranging from approximately 500 m on the valley floors to 850 m on the highest peaks. A topographic map of the entire peninsula is presented in Figure 4. The site is generally forested with tree heights ranging from 2 m to 10 m.

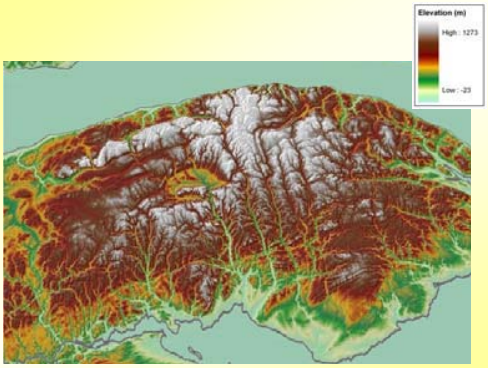


Figure 4: Gaspe Peninsula terrain.

The meteorological equipment consists of tilt-up tubular Tall Towers, Symphonie data loggers, Maximum Type 40 anemometers, and Maximum Type 200P wind vanes. The tall towers are manufactured locally while the dataloggers and sensors are supplied by NRG Systems. The data parameters have been sampled every second and averaged over ten-minute intervals since December 2000. All data were subjected to an AWS Truewind data validation process that included consistency checks and relational tests. All suspect values were examined and either accepted or rejected from the dataset. In cases of rejection, all reasonable attempts were made to replace the rejected values with ones available from a redundant sensor located at the same level or from a similar sensor located at another level (after height adjustment using the site's observed wind shear).

The mesoscale model was first run over a larger domain at a resolution of 3 km. The MASS model wind statistics were then input into MSFD, which produced wind speed forecasts over the area of interest at a final resolution of 50 m (see Figure 5). Finally, the wind resource grid was adjusted to on-site data from Met Tower A.

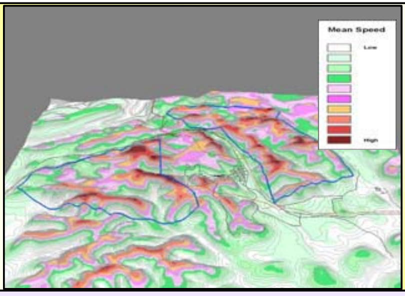


Figure 5: SiteWind relative wind speeds for an area of the Gaspe Peninsula of Quebec.

A wind resource grid driven by Met Tower A was also produced using WAsP. The WAsP bias was 0.29 m/s whereas SiteWind had a bias of only -0.09 m/s. In addition, WAsP had a standard deviation of 0.52 m/s and a rms error of 6.1%, while SiteWind had a standard deviation of 0.33 and an error of only 3.7% (see Figure 6). Compared to WAsP, the mean annual wind resource grid produced by SiteWind was 40% more accurate.

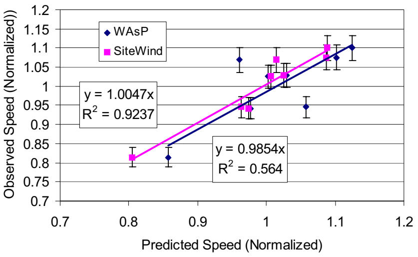
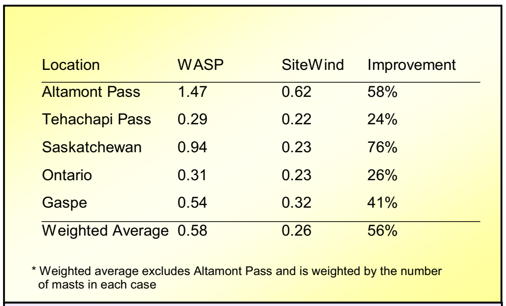


Figure 6: Measured wind speeds vs. predicted wind speeds from eight towers in Gaspe Peninsula.

5. Results and Implications

Through the aforementioned case studies, in addition to a number of other studies, SiteWind has shown improvements in wind speed predictions of up to 76% compared to WAsP. The average improvement, weighted by the number of masts and excluding Altamont Pass (to avoid skewing the results heavily to that case study) was 56%.



Location	WASP	SiteWind	Improvement
Altamont Pass	1.47	0.62	58%
Tehachapi Pass	0.29	0.22	24%
Saskatchewan	0.94	0.23	76%
Ontario	0.31	0.23	26%
Gaspe	0.54	0.32	41%
Weighted Average	0.58	0.26	56%

* Weighted average excludes Altamont Pass and is weighted by the number of masts in each case

Figure 7: Improvement in wind speed prediction accuracy with SiteWind.

A key factor determining the degree of improvement of SiteWind over WAsP is the total distance spanned by the met masts. This is illustrated in Figure 8, which plots the relative improvement as a function of distance scale.

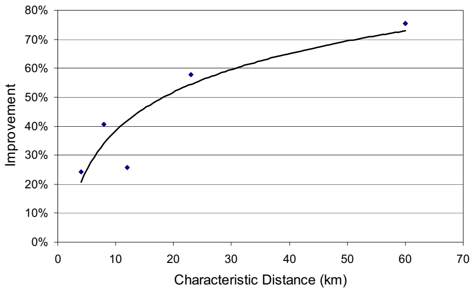


Figure 8: Improvement in accuracy of SiteWind v. WAsP as a function of the total distance spanned by the met masts.

This leads to an estimate of the typical improvement over wind project scales of about 30%.

Developers are often faced with the challenge of obtaining an accurate estimate of the potential energy production of a project while keeping costs low. The traditional approach has been to take measurements and then feed the data into simplified micrositing models, such as WAsP. These types of models extrapolate the wind resource from a single point, and thus their accuracy can decline dramatically with distance away from the mast, as demonstrated here, especially in complex wind climates. In response to this problem, some developers have taken to erecting a large number of masts to constrain the models. This solution, however, can be time-consuming and expensive.

SiteWind can be an advantageous tool for developers since it requires fewer masts to achieve the same level of accuracy as other models. This can result in substantial cost savings for each unneeded mast. Figure 9 illustrates this point. To achieve a 6% level of uncertainty, for example, WAsP would require eight monitoring sites while SiteWind would only require four.

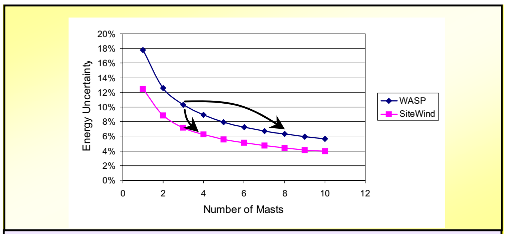


Figure 9: Alternative paths to reducing wind resource uncertainty in energy production estimates assuming 30% accuracy improvement of SiteWind over WAsP.

Figure 10 shows the impact on overall energy production uncertainty assuming SiteWind yields a 30% improvement in accuracy. This improvement raises the P90 energy predictions approximately 2.5%.

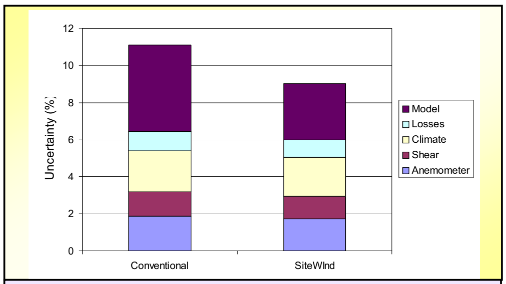


Figure 10: Impact on the total energy uncertainty of a typical project assuming 30% accuracy improvement. The total uncertainty is the square root of the sum of the squares of each individual uncertainty. The sections of each bar represent shares of the total uncertainty, which therefore change as the total changes.

6. Conclusion

A large component of the total uncertainty of energy output estimates is often due to the wind resource modeling. This uncertainty raises barriers to wind project financing, drives developers to install many met masts, and ultimately lowers returns to investors. Consequently, there is an urgent need for new models that offer improved accuracy with fewer met towers.

SiteWind is a new micrositing tool introduced by AWS Truewind that combines a mesoscale numerical weather model with a spectral fluid-dynamic microscale model and on-site data to produce a detailed wind map and wind resource grid for a project area. Conventional micrositing models such as WAsP (Wind Atlas Analysis and Application Program) are equilibrium models which create a wind map and climatology of a region using data from a single reference mast. The models typically assume a constant, homogenous, neutrally stratified, externally determined wind flow; the terrain acts as a perturbation on this flow. SiteWind, in contrast, resolves the dynamic forces within the region affecting the flow caused by temperature gradients, non-neutral stability, etc.

Through a number of real-world case studies, SiteWind has proven more accurate than WAsP. Although performance varies, we have found improvements in the accuracy of speed predictions, as determined by independent tower data, of as much as 76%, depending on topography, climate conditions and distance between masts. Over typical project scales, the improvement is around 30%.