Memorandum

To: Owen Roberts, NREL

From: Michael C. Brower, CTO, and Mikel Shakarjian, Project Manager

Date: 10 September 2014

Re: U.S. Virgin Islands Wind Resource Maps and Data, Subcontract AFA-4-42036-01

We are pleased to report on the outcome of this project to map the wind resources of the U.S. Virgin Islands.

Mean annual, seasonal, monthly and diurnal wind maps of the onshore areas of the United States Virgin Islands have been completed and delivered for six heights above ground level (AGL): 30, 55, 70, 80, 100 and 120 m, on a 50 m horizontal grid. Map images (pdfs) and GIS shapefile data will be provided for the annual means at all heights. The wind resource grid data for each height include dry season (December – May) and wet season (April-Nov) (wet/dry), monthly, and diurnal gridded data sets. Hourly atmospheric datasets have been delivered for the two mast locations and include wind speed and direction for each height over a 15 year period. The datasets are for release to the public.

Method

Wind speeds over the US Virgin Islands were simulated with the Weather Research and Forecasting (WRF) model version 3.5. Initial and updated boundary conditions were provided by the ERA-Interim reanalysis dataset. The runs employed a nested grid configuration of 27-9-3-1 km with 40 vertical levels; the innermost grid covered the islands of St. Thomas, St. John, and St. Croix, with a sufficient buffer to provide valid data at all onshore points. The simulations were run for the year 2013, consistent with the period of measurements (January 1, 2013 to middle or late December 2013). The runs were re-initialized at the beginning of each calendar month, and the spectral nudging technique was used to maintain consistency between the simulations and reanalysis data. The simulations are intended to provide a reasonably accurate picture of the factors influencing wind conditions on the islands, including synoptic weather patterns, island topographic influences, and mesoscale circulations, at the 1 km resolution of the innermost WRF grid.

The WindMap software, a mass-conserving diagnostic wind flow model, was then used to downscale the 1 km simulations to a 50 m horizontal resolution. This stage is intended to capture localized terrain and surface roughness influences that cannot be seen by the WRF model. The topographic data came from the 90 m Shuttle Radar Topographic Mission (SRTM) dataset. (It should be noted that the use of 90 m topographic data resulted in some smoothing of the final maps compared to the target 50 m resolution.)

Diurnal and monthly ratios of 2013 mean wind conditions to the long term were then calculated from AWST's windTrends 20-km database (1997-2013). It was found that mean speeds in 2013 were approximately 10% higher than mean speeds over the 1997-2013 period. This would imply a downward adjustment to the 2013 maps of 10%. However, according to two leading global reanalysis data sets (ERA-Interim and MERRA), 2013 was very nearly an average year compared to 1997-2013 and 1989-2013. Therefore, after consultation with NREL, it was decided to assume the 2013 maps and data files are representative of long-term conditions, and to make no long-term adjustments to the maps

Validation and Uncertainty

The resulting maps representing 2013 conditions were compared with measurements from one Triton sodar and one tall tower on St. Thomas[1] and one Triton sodar and one tall tower on St. Croix, as well as to offshore wind speed estimates from satellite-based scatterometer data (QuikSCAT).

The following table summarizes the comparison of the tower and sodar measurements with the unadjusted wind resource map at 55 m height AGL. (This height was chosen as one typical of wind projects in tropical islands prone to hurricanes.) The observed and predicted (modeled) mean wind speeds are for 2013. The observed data have been annualized, meaning the values are the average of monthly averages weighted by the number of days; in addition, the December data for Langford have been estimated by comparison with the same month at Bovoni2. The data for all sites have been projected from the nearest measurement height to 55 m using the observed or estimated wind shear. The shear adjustments are small, however, and so not likely to contribute substantially to observed errors.

Table 1. Comparison of observed and predicted mean speeds for 2013 at 55 m height AGL at the four measurement locations with sufficient data. The observed speeds have been annualized to the full year.

ID	Name	Island	Lat	Lon	Elev (m)	Obs Mean Speed (m/s)	Map Mean Speed (m/s)	Bias (m/s)
1	Longford	St. Croix	17.708	-64.693	28	7.21	7.00	-0.20
525	Triton 525	St. Croix	17.743	-64.636	239	6.82	7.61	0.79
2	Bovoni2	St. Thomas	18.306	-64.876	49	7.41	6.66	-0.74
512	Triton 512	St. Thomas	18.305	-64.877	36	6.68	6.43	-0.25
Avg						**7.03**	**6.93**	**-0.10**
SD								**0.64**

The average bias is quite small, only -0.10 m/s. The standard deviation (SD) of the biases, 0.64 m/s, is comparatively large, however. This is likely due in part to the complex terrain in which the measurement systems are deployed, which results in large localized speed gradients that cannot be accurately captured by the model, particularly at the 1 km resolution of the WRF simulations. In addition, it is challenging to simulate winds on tropical islands like the US Virgin Islands that experience frequent, intense convective weather systems (e.g., tropical storms) with complex features below the grid resolution of the WRF model. Errors in the placement, intensity, and structure of such systems can result in significant errors in mean wind speed.

The comparison of the offshore maps with QuikSCAT data indicate a high bias of about 10% in the mean wind speed maps at 10 m across most of the region spanned by the islands. There is considerable uncertainty in the QuikSCAT data, however, especially when extrapolated to hub heights of wind turbines. Therefore we do not believe this necessarily indicates a general high bias across the region.

Given these findings, we conclude that no adjustment should be applied to the maps. We believe there is too much uncertainty in the biases and too few observations to justify making adjustments to specific areas or islands.

Our estimate of the overall uncertainty in the mean wind speed at any location is about 10%. This is somewhat larger than usual for AWS Truepower maps for the reasons outlined above. With additional data, it is likely the uncertainty could be reduced.

Validation Plots

The plots on the following pages compare the wind resource characteristics predicted by WRF at the two towers, Longford and Bovoni2. The height in each case is 50 m. The predicted values come directly from the WRF runs, with no downscaling with the microscale model. Thus the mean WRF speeds do not match

[1] Data from a second Triton sodar on St. Thomas could not be used as only 4 months were available for comparison.

the downscaled map values shown in the table above. However this does not affect the distribution patterns or scatter plots.

The scatter plots show a very good agreement (linear relationship with relatively high r^2) between the model and observations at both sites. The scatter in the daily averages is much smaller and the r^2 higher than for the hourly averages, as is to be expected given the greater noise from chaotic processes at finer time resolutions. The wind rose plots likewise show a very good agreement between the observations and WRF model. This is not surprising considering the dominant influence of easterly trade winds in this region, which are well simulated in numerical weather prediction models. A similar conclusion can be drawn from the comparison of the monthly and diurnal average speeds. The one exception to this is the larger midday peak in the observed diurnal pattern compared to the modeled data, especially at Longford. This may indicate that the model is underestimating the strength of the sea breeze. The same explanation could account for the slightly greater southerly tendency of the observed winds compared to the model at this location.

In summary, the WRF model appears to capture the essential characteristics of the wind resource these two locations. Results for the lidars are very similar.

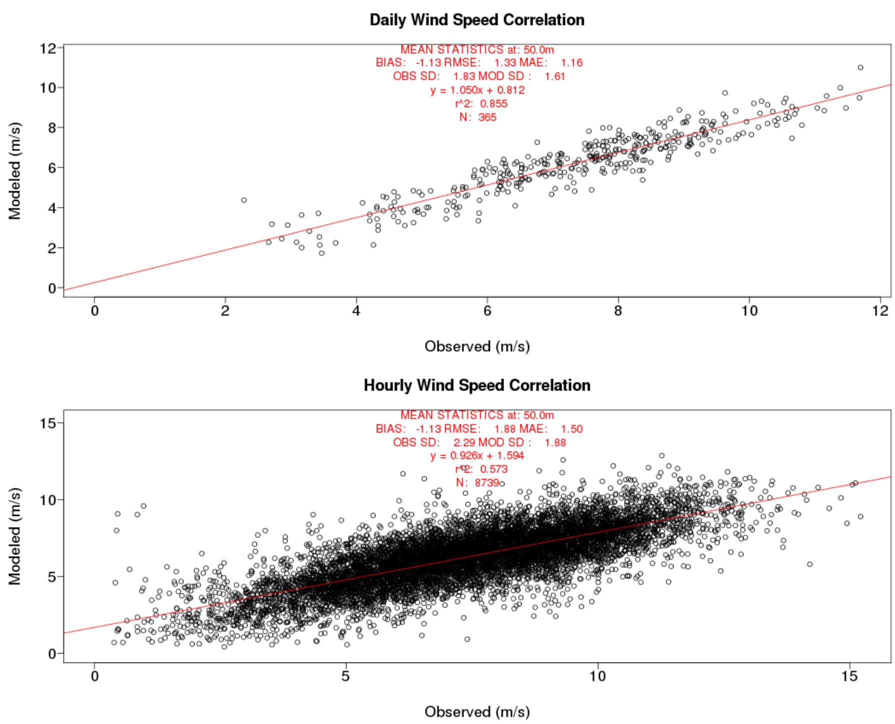

Figure 1a. Scatter plots of observed and WRF daily average (top) and hourly average (bottom) wind speeds at the Bovoni2 tower for 2013.

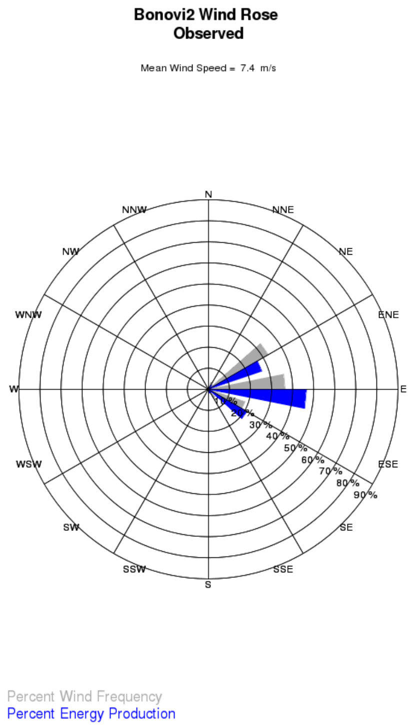

Figure 1b. Observed (left) and WRF (right) wind roses for the Bovoni2 tower, for 2013.

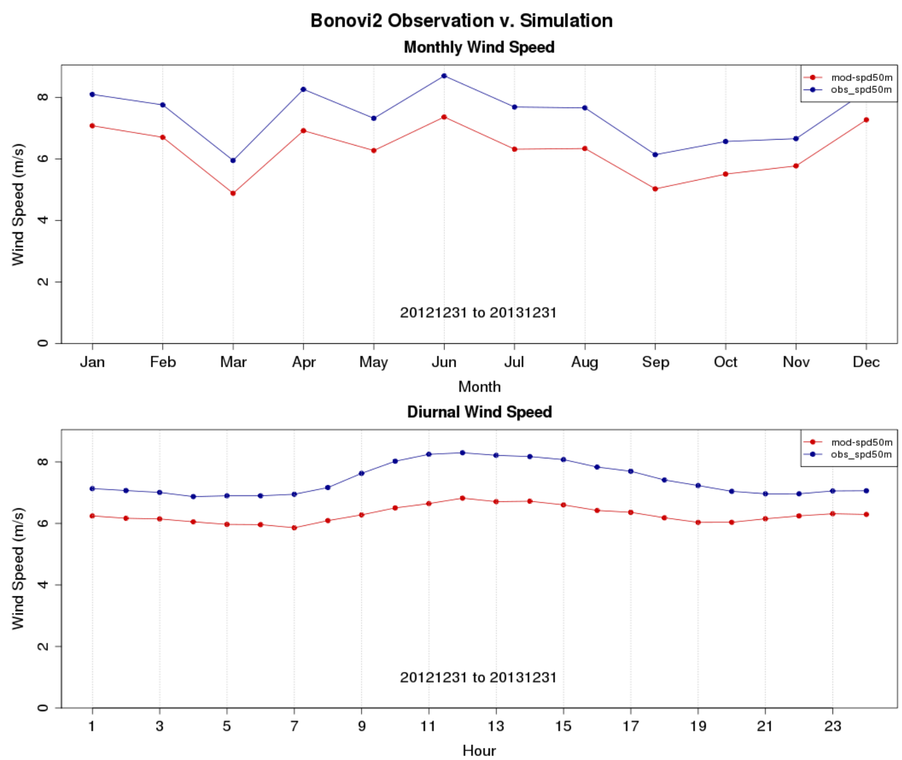

Figure 1c. Comparison of observed and WRF-generated monthly average (top) and diurnal average (bottom) wind speeds at Bovoni2.

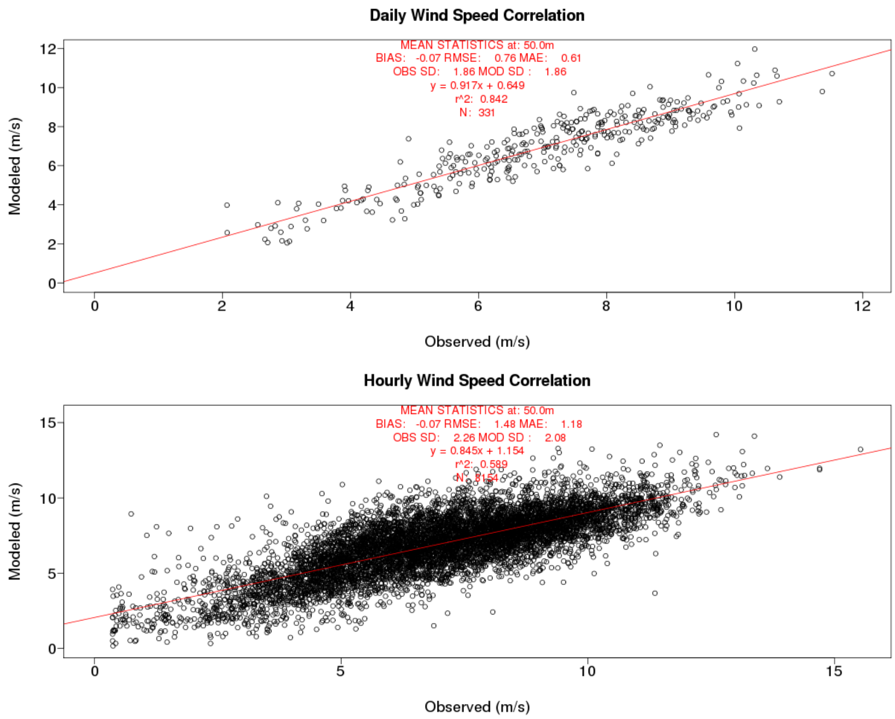

Figure 2a. Scatter plots of observed and WRF-generated daily average (top) and hourly average (bottom) wind speeds at the Longford tower for 2013.

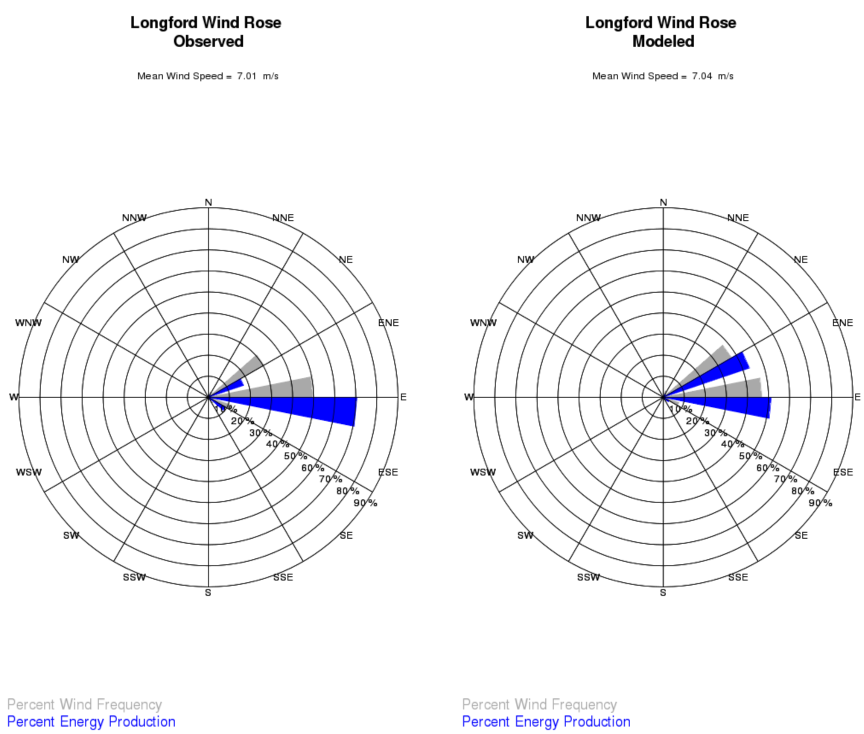

Figure 2b. Observed (left) and WRF (right) wind roses for the Longford tower for 2013.

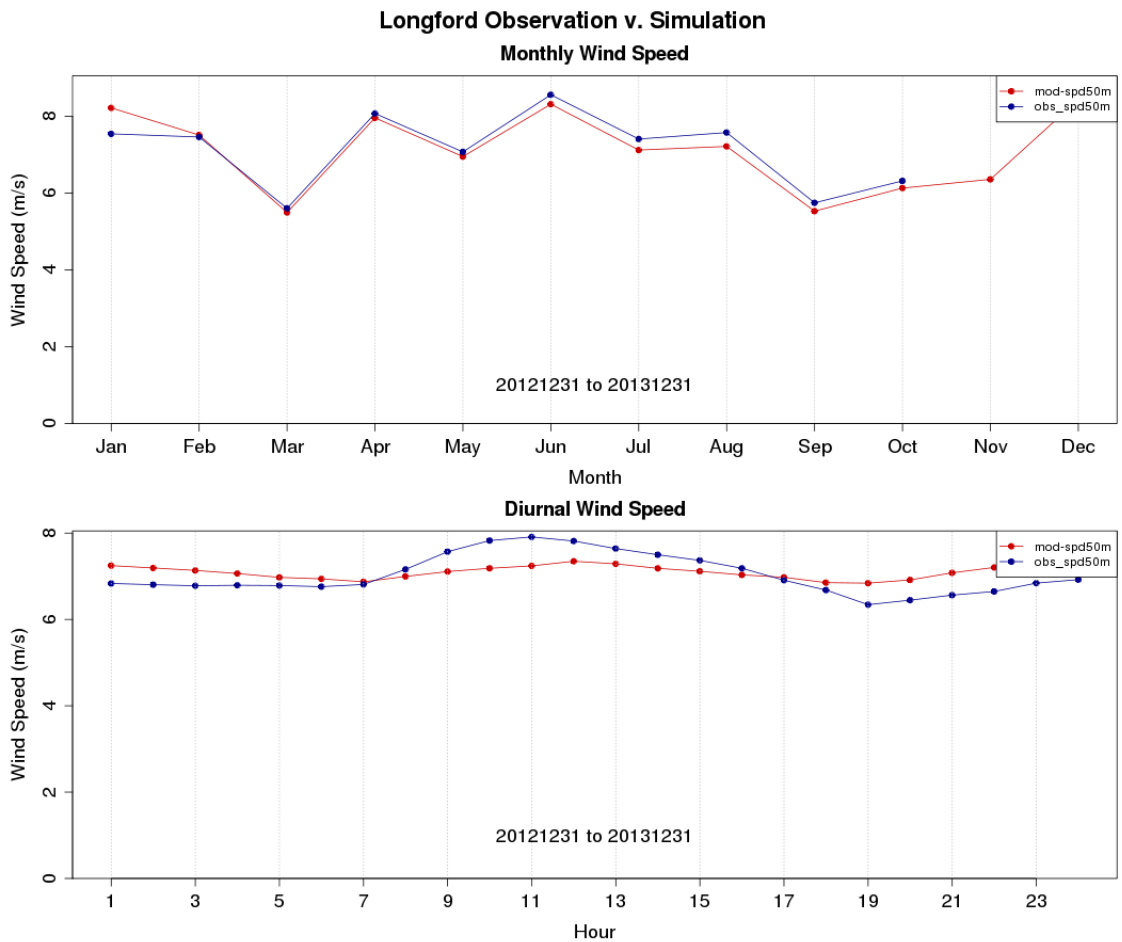

Figure 2c. Comparison of observed and WRF-generated monthly average (top) and diurnal average (bottom) wind speeds at Longford.