Downscaling MERRA Mesoscale Data for the Generation Microscale Wind Fields Using CFD

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Abstract

For many wind farm developers, obtaining meteorologically representative and accurate wind climatology data proves to be one of the most challenging aspects of their wind resource assessment campaign. As an alternative to the conventional technique of deploying multiple tall met masts and waiting several years for this data, we propose the use of mesoscale reanalysis model output statistically and dynamically downscaled using computational fluid dynamics (CFD).

Background & Method

In the proposed methodology, we use long term global mesoscale reanalysis data to scale CFD simulations, of varying complexity, in order to generate wind (speed and direction) time series comparable to those measured by met mast sensors. These 'synthetic' wind time series (referred to as virtual climatologies henceforth) primarily rely on (1) accurate CFD simulations and (2) properly defined forcing data from the mesoscale model. Despite the inherent challenges involved (i.e., coarse resolution, model sensitivities to physical parameterizations, etc.), incorporation of mesoscale reanalysis data into the wind resource assessment process offers a number of unique advantages and opportunities for application:

Advantages	Applications
➢ Provides decades worth of quality controlled, historical meteorological data (i.e. wind, temperature, moisture, etc.)	➢ Reference dataset for long term correction (MCP)
➢ Provides realistic wind speed and direction time series for any location on the globe and at any height if downscaled properly	➢ Identification of potential site for wind farm project
➢ Reduces dependency on expensive measurement campaigns	➢ Aide for measurement campaign design
	➢ Siting/energy assessment for small wind turbines
	➢ Other early phase wind farm planning in the absence of measurements

In this study, modeled meteorological data from NASA's "*Modern-Era Retrospective analysis for Research and Applications*" (MERRA) reanalysis dataset [*1*] was used to scale CFD simulations carried out by the WindSim model. The major components of the downscaling procedure are:

- ➢ Multiple MERRA grid points are utilized
- ➢ An in-house height correction is applied to each MERRA grid point to improve wind speed representativeness
- ➢ A horizontally stretched grid is required in the region close to each MERRA point to minimize erroneous terrain speed-up near climatology point

Sites and Accuracy

The validity of the downscaling methodology was verified against 7 sites of varying atmospheric stability and terrain characteristics. At each site, virtual climatologies were compared to measured wind climatologies with respect to vertical profile, speed and direction distribution, and time series. At sites where energy production data were available, AEP validations were carried out.

Table 1: *Description of cases and percent errors of virtual climatology versus met mast mean wind speed measurement.*

Case	Surface Characteristics	Stability % (Neutral/Stable/Unstable)			Mean Wind Speed % Error*
1	Complex-Coastal/Smooth	16	73	11	+2.51
2	Flat/Forested	8	59	33	+4.90
3	Very Rugged/Forested + Fields	21	51	26	+15.86
4	Small Hills/Smooth	28	36	36	+6.24
5	Small Hills/Forest + Grassland	21	50	29	-10.83
6	Small Trenches/Low vegetation	12	49	39	-6.72
7	Offshore	22	54	24	-1.33

**Heights of wind speed validation are respective of sensor height*

Wind Validation

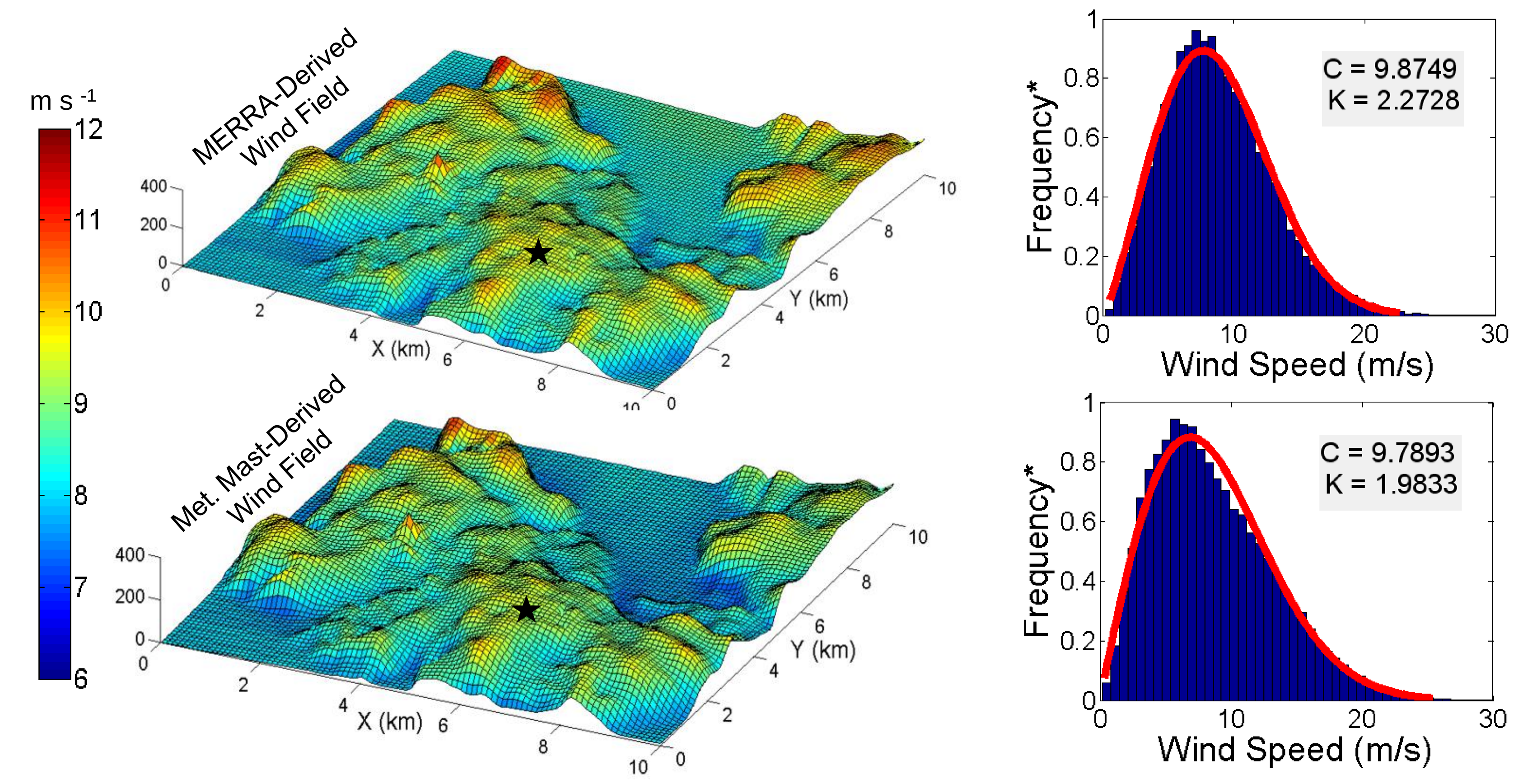

Fig. 1: *Simulated mean wind speed for Case 1 scaled by measured (bottom left) and virtual climatology (top left) time series. Also, corresponding wind speed frequency distribution for the measurement location, as denoted by the black star, extracted from the model solutions scaled by the measured (bottom right) and virtual (top right) climatology time series.*

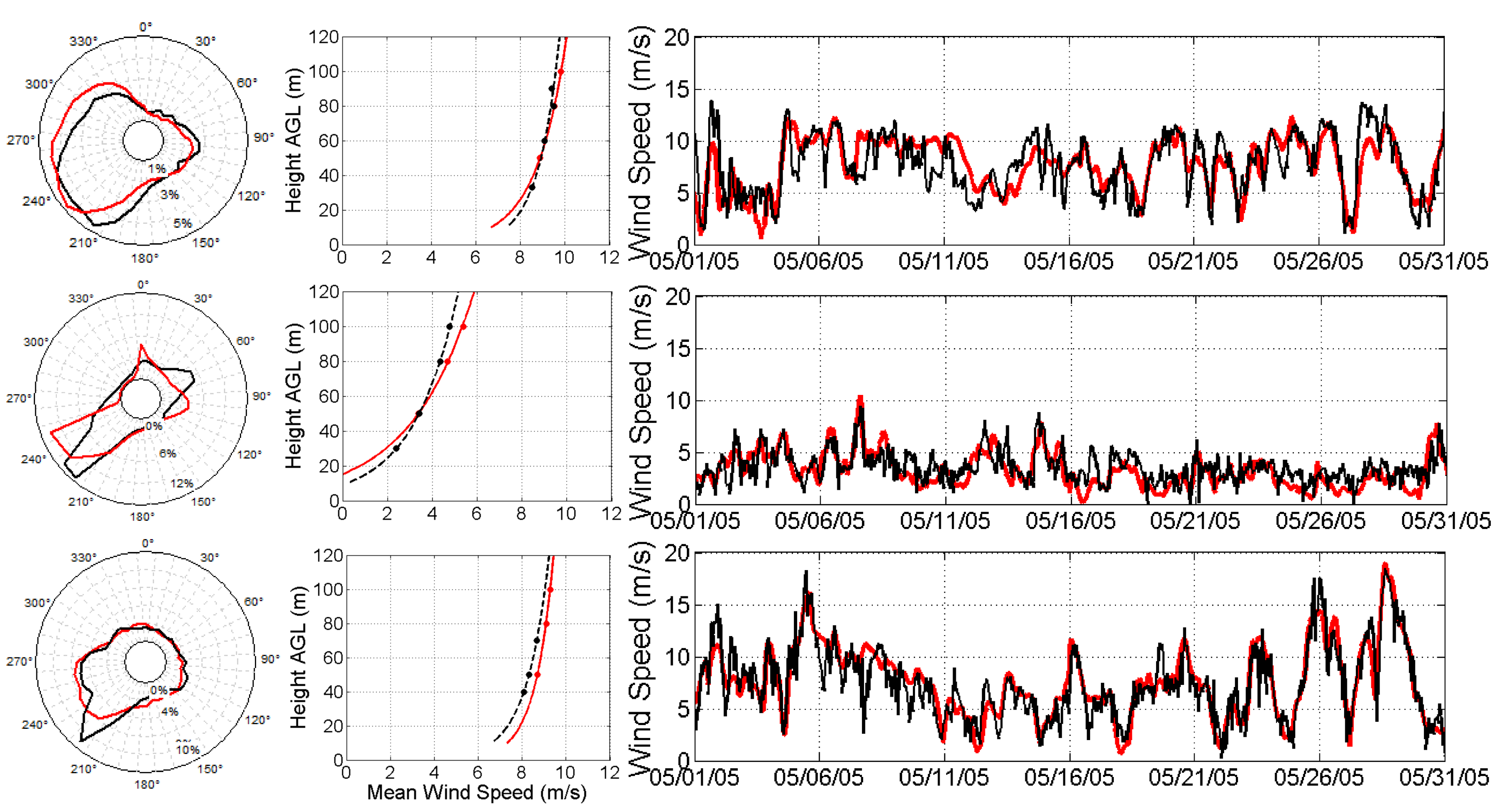

Fig. 2: *Comparison of wind rose (left column), mean wind speed profile (middle column), and sample 50m wind speed time series (right column) for met mast location. Red represents virtual climatology and black represents measurements. The three rows correspond to cases 7, 2, and 4 (in order from top to bottom).*

Table 2: *Root mean squared error (RMSE) of virtual climatology wind speed time series compared to measurements (50-70m AGL).*

	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
RMSE (m/s)	2.6685	1.4273	2.3486	1.8080	2.5908	3.2792	1.7676

Energy Validation

Table 3.1: *AEP estimates for Case 1 with respect to Wake Model (WM). Observed AEP was approx. 150 GWh/y.*

Total Farm Avg. AEP for Case 1	Met. Mast-Derived AEP (GWh/y)	Virtual-Climo-Derived AEP (GWh/y)
WM 1	165	171
WM 2	170	177
WM 3	165	170

Table 3.2: *Same as Table 3.1 but for Case 4. Observed AEP was approx. 82 GWh/y.*

Total Farm Avg. AEP for Case 4	Met. Mast-Derived AEP (GWh/y)	Virtual-Climo-Derived AEP (GWh/y)
WM 1	84	95
WM 2	88	100
WM 3	85	96

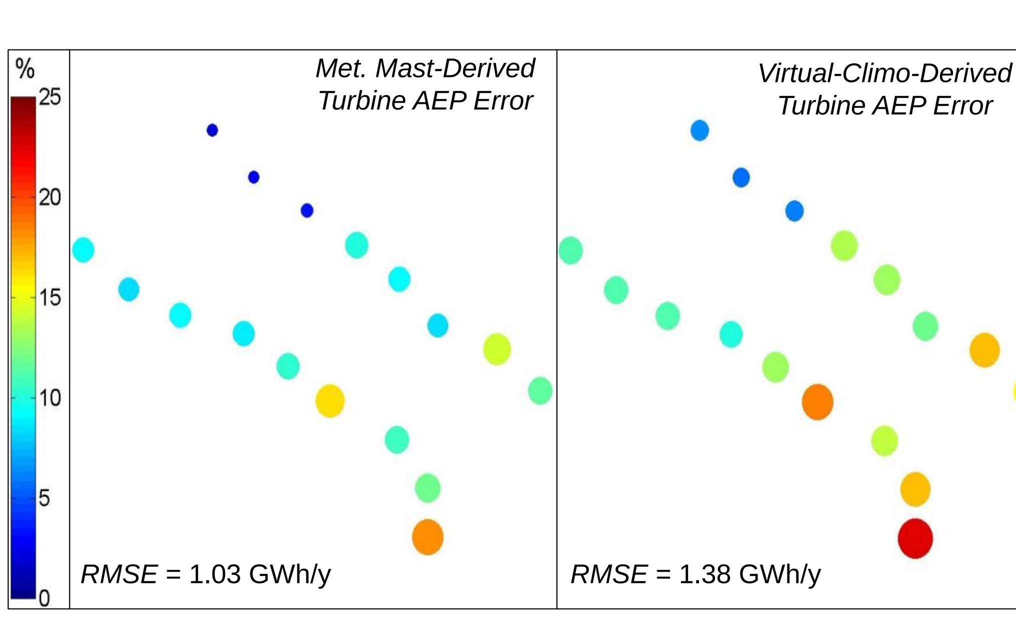

Fig. 3: *Turbine specific, AEP error of Case 1 when CFD simulation is scaled by 50m met mast measurements (left) and virtual climatology (right). RMSE is computed using historical power production data as truth.*

Conclusions

We have developed a methodology for generating high-resolution, virtual wind climatologies (i.e., speed and direction time series) for any location around the world and for any height within the surface layer. The accuracy of this technique is largely sensitive to terrain complexity but wind speed errors of less than approximately ±15% are easily achievable. Based on limited power production data availability, AEP errors of ±15% were observed.

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[1] "MERRA: NASA's Modern-Era Retrospective Analysis for Research and Applications" *M.* Rienecker and Coauthors, 2011, *J. Climate*, **24**, 3624–3648.