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Utilizing WRF data in CFD Models for Wind Energy Assessment

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Abstract

Wind fields data from high-resolution meteorological model runs are being used more frequently in wind resource assessment. However, limitations on the resolution of these models mean that they often cannot capture the micro scale terrain-induced effects that are so central to wind farm micro-siting.

There is thus a need to effectively integrate the time-varying data from the meteorological models with the high-resolution flow models used for micro-siting applications. One method for bringing the information from meteorological model into the microscale CFD model is to extract time series from the meteorological model and then to use them as 'virtual climatologies' with which to scale the microscale flow models.

In the present study a validation of this virtual climatology method is carried out over three different sites where observations could be obtained. The modelling approaches are compared to the observations and suggestions of general guidelines are made based upon the results from the three sites.

Objectives

The main objective of this study was to validate a 'virtual time series' approach to the use of data from mesoscale meteorological models in high-resolution CFD modelling for wind energy assessment and micrositing. A secondary objective was to use the results of the validation to provide guidelines for the use of this method at additional sites.

Methods

For each of the sites simulations were made in both WindSim and WRF.

The WRF simulations were run for one year at each site (in the past) during which simultaneous measurements were available from the ground for validation. Nesting was used to achieve a maximum horizontal resolution of 500m for two of the sites and 3km for the last site. Time series were then extracted at all of the vertical levels in the WRF model above the points of measurement masts. Time series at the exact x-, y-, and z-positions of the anemometers were extracted and their errors with respect to the measurements used to quantify the raw WRF error.

In the WindSim simulations wind fields were generated by running twelve direction sectors to steady state using the Reynolds Averaged Navier Stokes Equations (RANS) with two-equation turbulence closure. The simulations were run using high-resolution terrain and roughness data on horizontal resolutions of ca 25m to capture the local terrain effects on the flow within each site.

Once all simulations were finished the extracted time series from each level were used to scale the WindSim models and the resulting predictions at the mast locations were used to quantify the errors of a joint WRF-WindSim approach and compare them when using different WRF levels to scale the CFD.

General descriptions of the sites are given here:

Site 1: A large and only moderately complex site in the Western United States. This site contained eleven 60m met masts for validation.

Site 2: A smaller but very complex site in the mountainous Western United States for which four 50-60m measurement masts were available.

Site 3: A single10m mast from a weather station in an extremely rugged region of the Scottish Highlands called Bealach Na Ba.

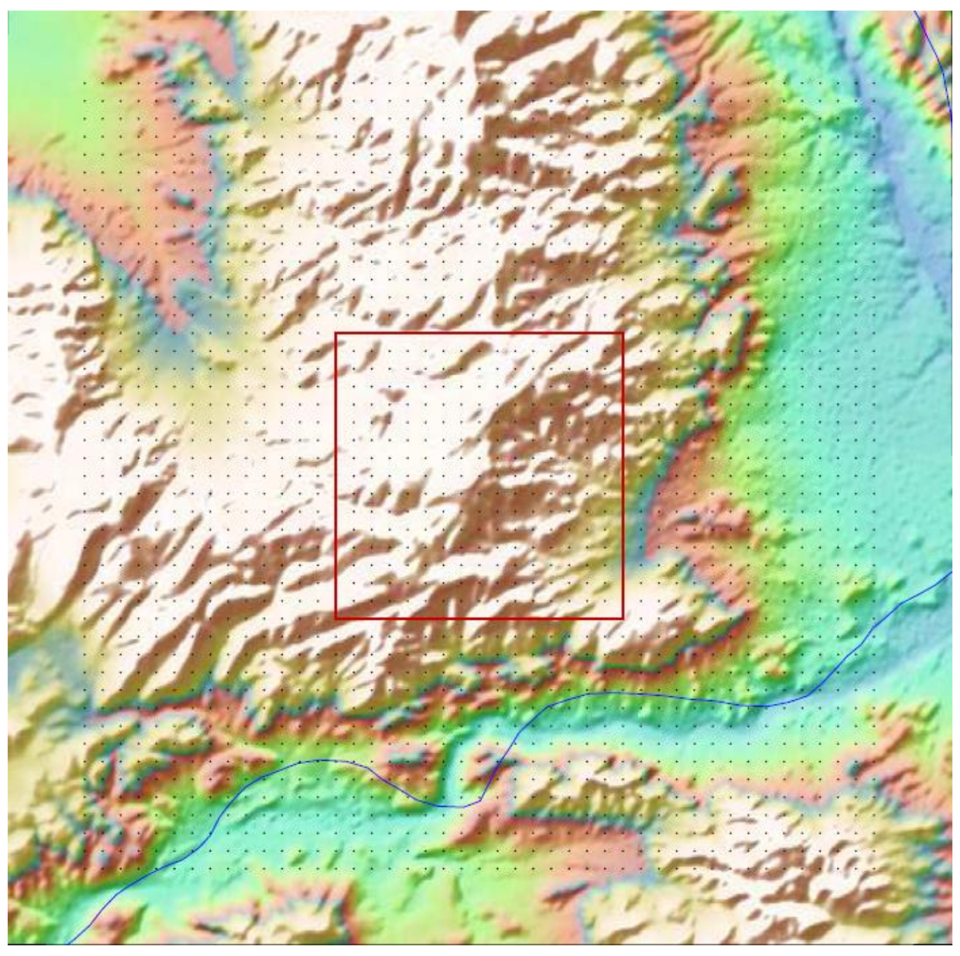

Figure 1: The innermost WRF domain for Site 2. The dots show the 500m resolution gridpoints and the red box shows the site area which is taken to be within a buffer zone so that results are not affected by the nesting procedure.

Results

-The results for sites 2 and 3 showed profound reduction (50% or more) of the errors in modelled annual average wind speed when using a joint WRF and WindSim approach vs. using raw WRF data.

-The results at Site 1 showed only modest reductions in the WRF error but at this site the errors in WRF were very low (on the order 3%) whereas the errors in the raw WRF at the other two sites were much higher.

-The errors in the raw WRF and also the ability of WindSim to correct the annual average wind speeds scaled with site complexity for these three sites. The more complex sites had higher raw errors in the WRF wind speeds and greater improvement when using WindSim to correct for local terrain-effects.

-The lowest errors for all sites were found when using WRF data away from the ground but still within the average height of the Atmospheric Boundary Layer. For these three sites extraction of the WRF data between 3-400m above ground level yielded the best results.

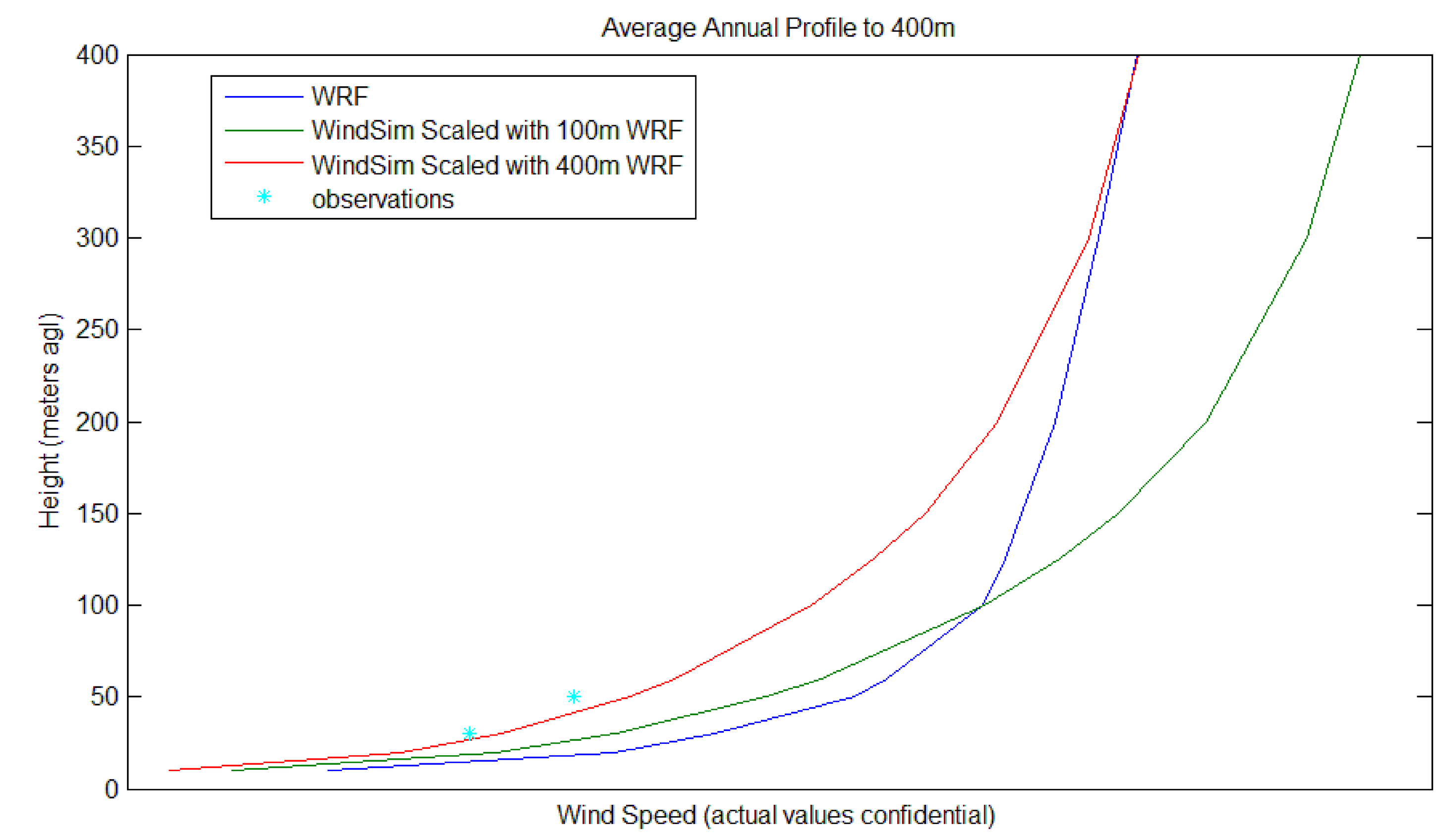

Figure 2: Profiles of average annual wind speed at a mast location in Site 2. The observations are plotted for comparison to three different modelling approaches. In blue is the raw WRF profile, in green the profile in WindSim when scaling from the 100m WRF wind speeds and in red the profile in WindSim when scaling from the 400m wind speeds, this being the modelling approach with the lowest errors.

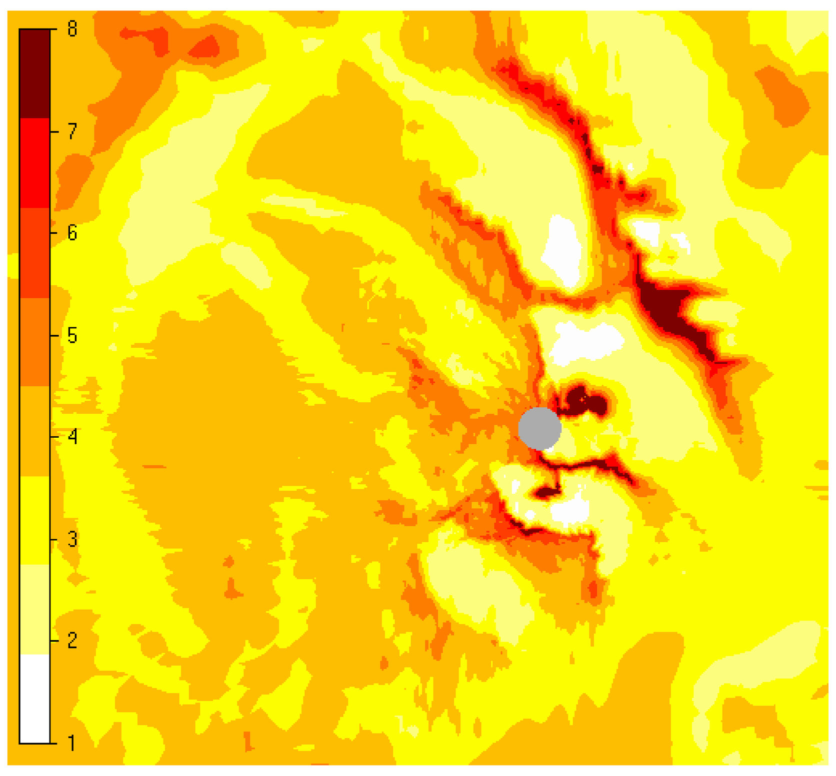

Figure 3: A map of mean wind speed at measurement height 10m created using WindSim simulations scaled by virtual time series from WRF at Site 3. Note the large spatial variation in mean wind speed which is induced by the complexity of the terrain. The grey dot shows the position of the Bealach Na Ba weather station.

Conclusions

-A validation of a virtual timeseries approach to using WRF data in WindSim's CFD modelling was carried out. Results of using the joint WRF-WindSim approach to modelling the mean wind speeds reduced errors by more than 50% for two complex sites, when compared to actual measurements from the sites.

-WRF errors, and subsequent improvements in the errors through using WindSim were highest for the sites with the most complex terrain. This emphasizes the importance of using CFD to define the local wind fields where they cannot be properly resolved using the coarse terrain and roughness descriptions in mesoscale meteorological models.

References

Brower, M. , J. W. Zack, B. Bailey, M. N. Schwartz, and D. L. Elliott, 2004: Mesoscale Modelling as a Tool for Wind Resource Assessment and Mapping, *American Meteorological Society's 14th Conference on Applied Climatology*