Coupled mesoscale and large-eddy simulations of a wind turbine wake over complex terrain

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Abstract
The Weather Research and Forecasting (WRF) model is used to generate coupled mesoscale to microscale (large-eddy) simulation results for the site of the 2017 Perdigão field campaign in Portugal. This site features a complex valley structure with a single wind turbine on one of the ridgelines. Modeling best practices are considered, and an analysis of the turbine wake is presented to provide insight into the interactions with the topography and the atmospheric boundary layer.

Keywords: *Large-Eddy Simulation, Mesoscale-Microscale Coupling, Complex Terrain, Wake Modeling*

Introduction
Wind turbine configurations are typically analyzed using engineering flow simulations, which use ideal conditions to analyze the details of turbine wake formation. In this work, we take advantage of coupled mesoscale to microscale modeling techniques to consider a wind turbine under real conditions. The site of the recent Perdigão field campaign in Portugal is considered, which offers a rich source of data to validate the model and inform the analysis [1]. The field site includes two parallel ridges surrounded by hilly terrain.

Model
The WRF model is set up using a nested grid to feed in large scale meteorological forcing from the NCEP GFS 0.25 dataset. Outer domains use a planetary boundary layer (PBL) closure scheme, while inner domains use a large-eddy simulation (LES) turbulence closure, with resolutions reaching as fine as 10-50 m in the horizontal. A variety of model configurations are considered, taking into account multiple strategies to span the 'grey zone' of grid resolutions where neither PBL nor LES closures prove effective. Additionally, an optimal vertical nesting strategy is proposed using the new vertical nesting features in WRF [2]. This allows selection of a vertical coordinate system to accommodate the steep terrain slopes which are resolvable at fine horizontal spacing. At the finest resolution, an actuator disk model is used within WRF to represent the effects of the wind turbine located on the southwest ridge of the valley.

Analysis
Analysis consists of comparisons of the model results with over 40 meteorological towers and multiple Lidar scans taken on site, among other observation data. A plan view of model and tower 10 m velocities is shown below for the 50 m LES domain. Tower data is used for validation of the model, with agreement between tower data and model values being used as a metric for measuring the relative performance of each model configuration. Cases are selected where the wind turbine wake is observed in field data. Simulation Lidar scans are generated from the WRF flow field for comparison with field Lidars. Lastly, the turbine wake is simulated in the model using the actuator disk model presented by [3]. Comparisons with the baseline simulation without the turbine are made to isolate the wake effects and determine the interactions of the turbine wake on the boundary layer flow field.

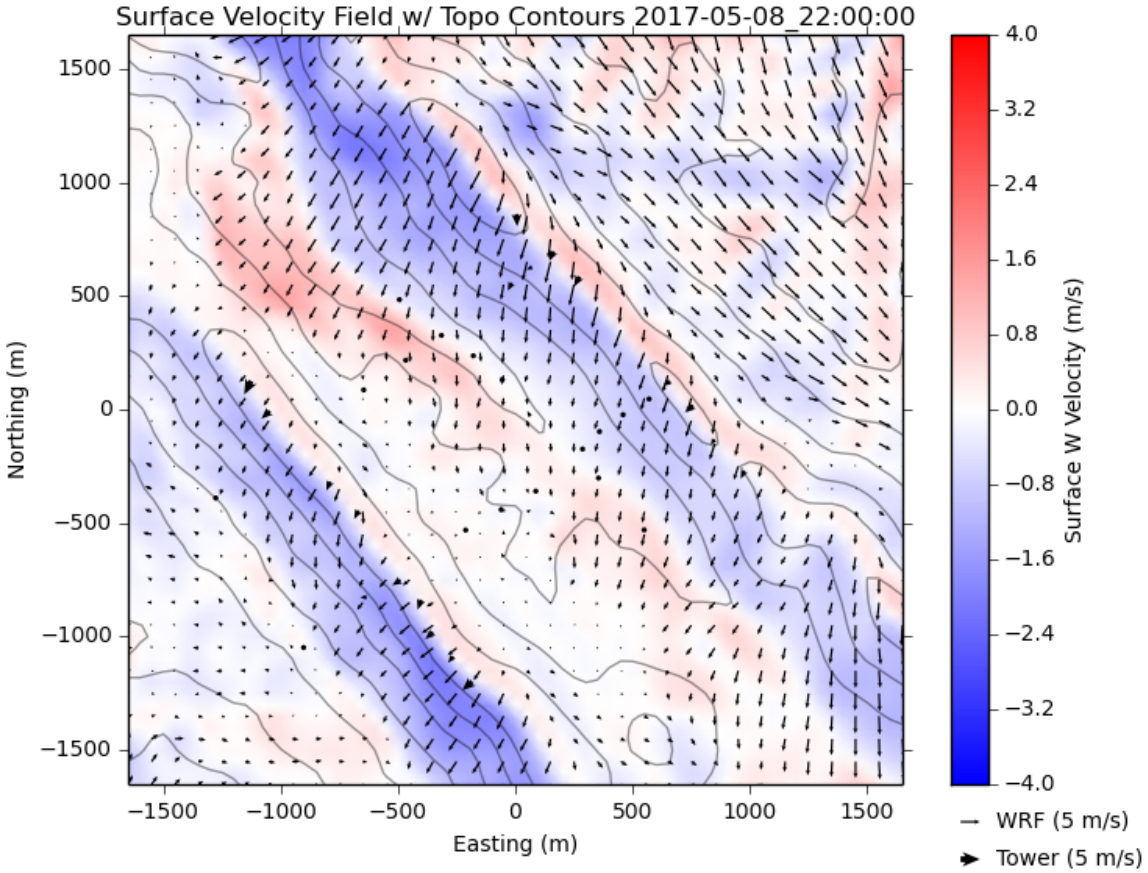

Figure 1. Surface w velocity contours and surface wind vectors from nested WRF simulations at 50 m resolution, with 10 m meteorological tower data and topography contours (black contours) for Vale do Cobrão, Portugal, the site of the Perdigão 2017 field campaign.

References

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