Evaluation of the Wind Farm Parameterization in the Weather Research and Forecasting Model with Meteorological and Turbine Power Data

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Abstract
Using wind turbine power production data for a 300-MW wind farm, we assess the skill of the wind farm parameterization (WFP) distributed with the Weather Research and Forecasting (WRF) model as well as its sensitivity to model configuration, via a case study of four diurnal cycles with significant power production. We quantify the improvement in wind power forecasts by the WFP as it accounts for wake impacts on power production of downwind turbines. We illustrate the importance of using a vertical grid with nominally 12-m vertical resolution in simulating accurate power production. Finally, we emphasize that the ability of the WFP to predict power production is fundamentally dependent on the skill of the WRF model in simulating the ambient wind speed.

Keywords: *Mesoscale modelling, Power production verification, Wind farm parameterization, Weather Research and Forecasting model*

Introduction
Numerical weather prediction models have become an important tool in the wind energy industry, from wind resource assessments to everyday production forecasts. Compare to large-eddy simulations, mesoscale modeling is relatively efficient in simulating regional-scale winds, wake effects, and turbine power generations. The Wind Farm Parameterization (WFP) scheme in the Weather Research and Forecasting (WRF) model [1] simulates wind turbines and their power production in each grid cell. However, the modelled power generation of the WFP has not yet been verified with actual power production. Hence, the goal of this study is to evaluate the WFP in the WRF model via comparison to observed turbine production data.

Data and Methods
The observed meteorological data and the 10-minute SCADA data are collected as part of the 2013 Crop Wind Energy eXperiment (CWEX-13), which took place in central Iowa at a 200-turbine wind farm [2,3]. Meteorological data recorded by the WINDCUBE v1 profiling lidars, the WINDCUBE 200S scanning lidar and surface flux stations are compared with the simulated ambient flows. We select a four-day period with nocturnal low-level jet occurrences that provides sufficient power generation for the model verification.

To assess the value of the WFP, we simulate winds with and without the WFP in the WRF model (version 3.8.1) using either the ERA-interim (ERA-I) [4] or the Global Forecast System reanalysis dataset as boundary conditions. We also employ two resolutions of vertical grids, 12 m and 22 m resolution below 400 m above the surface. In the simulations, we use the General Electric 1.5-MW super-long extended model [5], which constitutes half of the turbines in the wind farm.

Results
We first evaluate the skill of the WRF model in simulating the ambient flow. Among all simulations, the run using the ERA-I for boundary conditions and 12-m vertical resolution captures the general temporal and vertical fluctuations in wind speed and wind direction, compared to the lidar observations. Broadly speaking, simulations using finer vertical resolution have more skill in simulating winds than those with coarser resolution [6].

For power prediction, the simulations omitting the WFP ignore the wake effects on downwind turbine power production, and therefore overestimate total power production of the wind farm. The simulations with the WFP produce total power of the wind farm that generally agrees with observation. Results from statistical tests also demonstrate that the WFP power simulations improve when using 12-m rather than 22-m vertical resolution as well.

Furthermore, we find that assessing the interactions between atmospheric forcing and power is an important step to examine and improve the performance of the WFP. In particular, the WFP overestimates wake effects and hence underestimates downwind power production during high wind speed and low turbulence conditions.

When the WRF model simulates wind speed close to the observations, the WFP predicts power properly, making wind speed the critical factor in improving the WFP. We also find the WFP performance is independent of atmospheric stability, the number of wind turbines per model grid cell, and the upwind-downwind position of turbines. Rather, the ability of the WFP to predict power production is most dependent on the skill of the WRF model in simulating the ambient wind speed.

Conclusions

We conclude that the simulations using the WFP predict wind-farm power production have more skill than the simulations without the WFP. More importantly, choosing a fine vertical grid resolution drastically improves the accuracy of the WFP power performance, as the model results for these cases are relatively insensitive to the choice of reanalysis datasets.

Compared to wind direction, the role of wind speed is much more important in simulating power accurately. Hence, improving the skills of the WRF model in simulating wind speed can improve the WFP power performance.

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