PO.ID 160

Simulating wind farms in the Weather Research and Forecasting model, resolution sensitivities.

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1. Introduction

The numerical weather prediction model WRF has recently included a parameterization that accounts for wind farms (Fitch et al., 2012, 2013 [1][2]).

The WRF built-in wind farm parameterization can be a useful tool to study meso-scale effects of a wind farm, e.g. wake interactions between parks. Since the scheme runs online with the model, two-way interactions between the wake and the planetary boundary layer will be captured.

In this study we investigate the resolution dependency of the wind farm parameterization by conducting a number of simulations of the Lillgrund wind farm for a 9-day period that was characterized by prevailing strong southwesterly winds.

2. Model description

Version v3.5.0 of the mesoscale model WRF (Weather Research and Forecasting) is used in this study (described in Skamarock et al. 2008 [3]).

One simulation is setup without influence of wind turbines. A second simulation follows the exact same setup but with the addition of the 110 MW Lillgrund wind farm included in the setup, implemented trough the description by [1][2].

Three such pair of simulations have been carried out, a pair of Control simulation and two pairs of sensitivity simulations (HiVert and HiHor). The nest setup is shown in Figure 1 and an overview of the inner nest of the simulations is given in Table 1.

The model is run with data from ERA Interim reanalysis (Dee et al. 2011, [4]) as input on the boundaries.

Table 1: Overview of the simulations.

Name	Grid points inner domain	Horizontal resolution inner domain [km]	Vertical layers… … in rotor plane	Vertical layers… … below 400 m	Max WTGs in single grid point
Control	232 x 241	1	3	5	10
HiVert	232 x 241	1	5	15	10
HiHor	199 x 199	0.3333	3	5	2

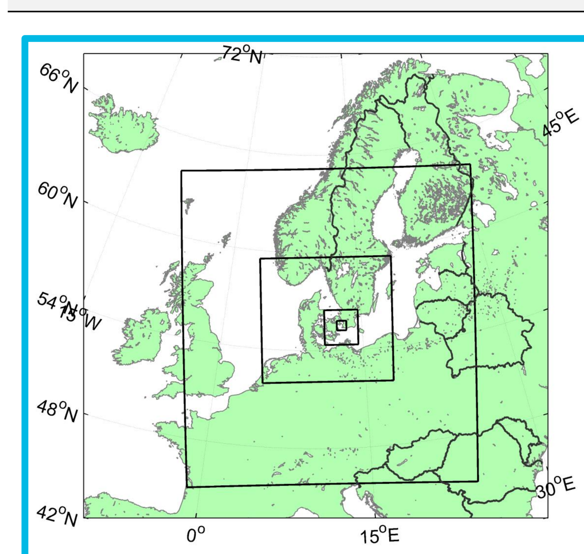

Figure 1: Domain setup in the simulation. The smallest domain is only present in the HiHor simulations.

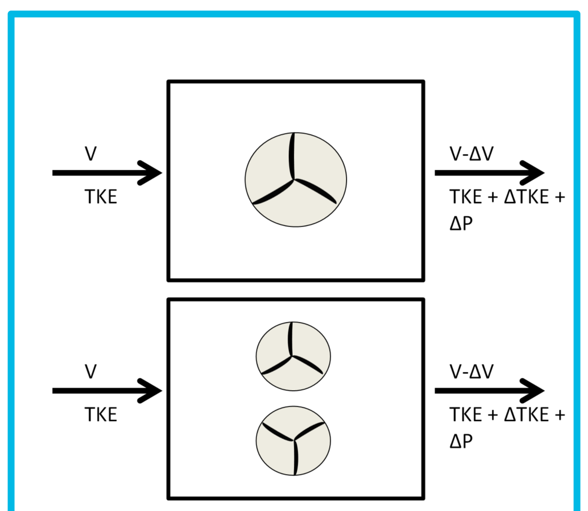

Figure 2: Schematic illustration of the Fitch wind farm parameterization

Employing the Fitch wind farm parameterization in the WRF model means that the wind farm is felt by the model as a sink of the resolved atmospheric momentum. The fraction of the resolved atmospheric momentum that is extracted is given by a specified thrust coefficients and the extracted energy is divided into electric energy and turbulent kinetic energy (TKE), following a specified power coefficient. The Fitch wind farm parameterization in schematically illustrated in Figure 2.

3. Production data

Measured production for the Lillgrund wind farm conditioned by wind speed, wind direction and thermal stability was provided by Vattenfall AB. The following filtering was applied; 207° < dir < 237°, 8.2 m/s< wind speed < 11.7 m/s and neutral conditions.

4. The case

A 9-day period in April 2005 (20050403 - 20050411) is simulated. The case was chosen due to prevailing, relatively strong, south-westerly winds (Figure 3).

Figure 3: Wind distribution at the location of the Lillgrund wind farm for the period 3-11 April 2005. Colour coding indicates wind speed level.

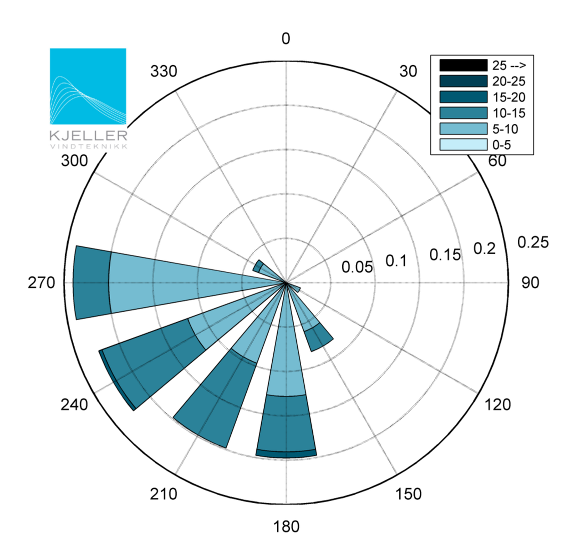

Figure 4 shows the average vertical profiles of the wind speed and the temperature in the three simulations without the wind farm parameterization employed. The free wind speed at hub height (65 m) is approximately 10 m/s. The thermal stratification varies considerably during the 9-day simulation, however, averaged over the full period, a temperature inversion characterizes the lowest 200 m. It is apparent that the higher vertical resolution in the HiVert simulation results in more detailed vertical profiles and somewhat stronger winds at hub height.

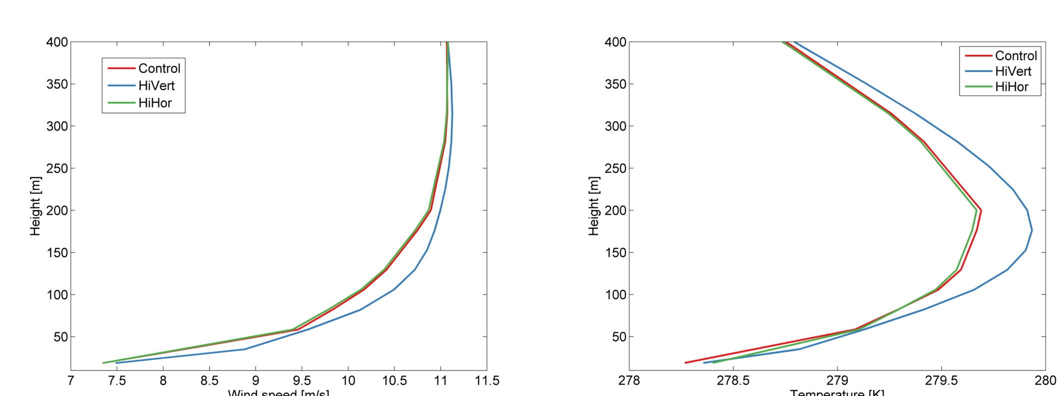

Figure 4: Mean vertical profile of wind speed (left) and temperature (right) in the undisturbed simulations (no wind farm parameterization employed).

5. Approach

To facilitate a fair comparison between the simulations only concurrent episodes longer or equal to 20 minutes during the 9-period simulations with wind directions between 207 and 237 degrees are considered.

Conclusions

This study highlights the sensitivity of the Fitch wind farm parameterization to resolution, both in the horizontal and vertical grid.

The results indicate that increasing the vertical resolution increases the rate of wake recovery due to better representation of vertical wind shear.

Increased horizontal resolution, improves the simulated internal wake effect of the wind farm. To describe the wake from each individual turbine, and to get a realistic wake influence on the park-wide production, it is important to chose a grid fine enough to resolve each individual turbine.

6. Results

Wake

The wind speed deficit is shown in Figure 5.

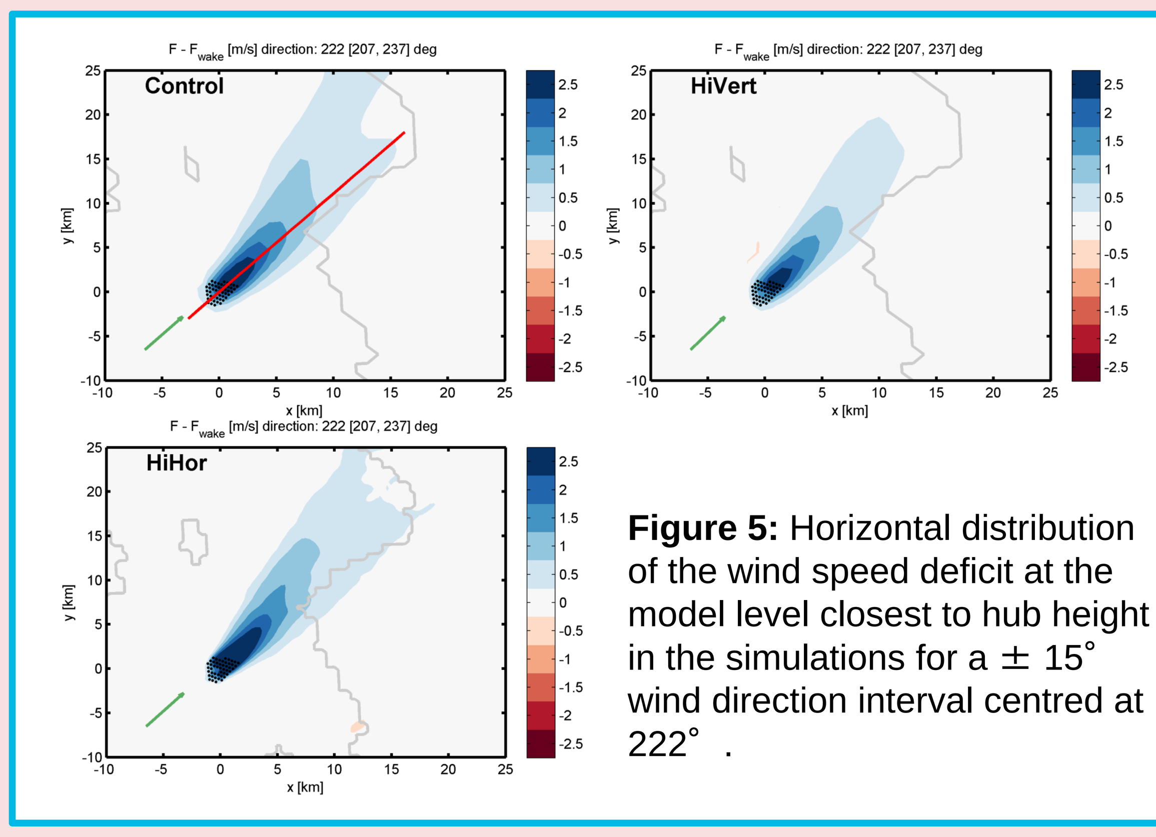

Figure 5: Horizontal distribution of the wind speed deficit at the model level closest to hub height in the simulations for a ± 15° wind direction interval centred at 222°.

Somewhat larger wind speed deficits over the wind farm are seen in the HiHor simulation. The wake recovery is fastest in the HiVert simulation . A better representation of the vertical wind shear emerging when resolved momentum is removed by the wind farm parameterization will result in increased shear production of the TKE, which in turn will lead to increased downward mixing of resolved momentum that will act to recover the wake.

Internal production pattern

Figure 6 shows the normalized energy production in the simulations and according to production data for the whole wind farm. Figure 7 shows the same but only for the row of turbines indicated in lower panel of Figure 6 . It is obvious from the figures that HiHor shows better resemblance with the observed data compared to Control and HiVert. However, also for HiHor, the discrepancy with observed data is large, where the simulations show considerably smaller wake losses than observed. The reason why the simulations underestimate the wake is at least partly related to large differences in the generic C_T-curve implemented in the WRF model and the actual C_T-curve of the Siemens SWT-2.3-93 turbine.

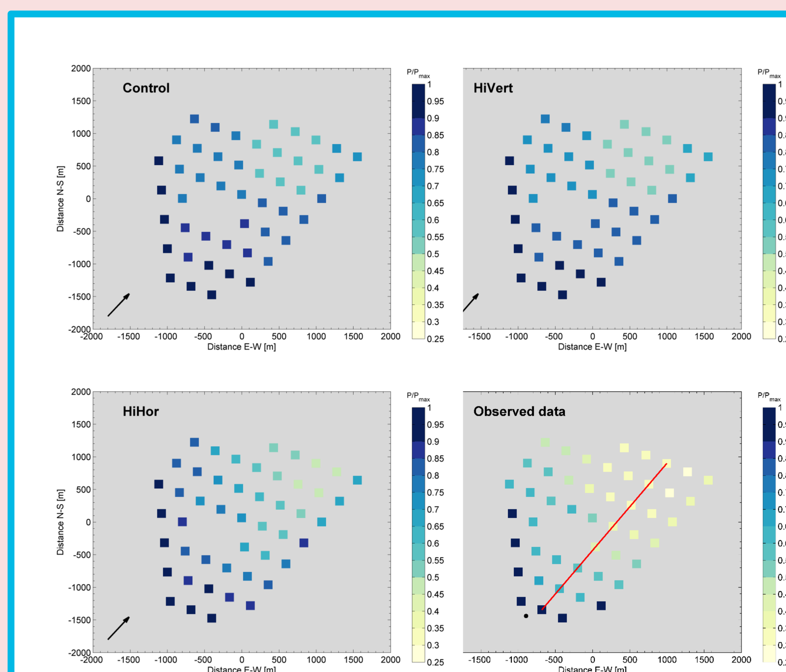

Figure 6: Fractional production with respect to the WTG with largest production. Arrow indicates mean wind direction and the black dot in the lower right panel shows the location of the met mast used in conditioning the observed data.

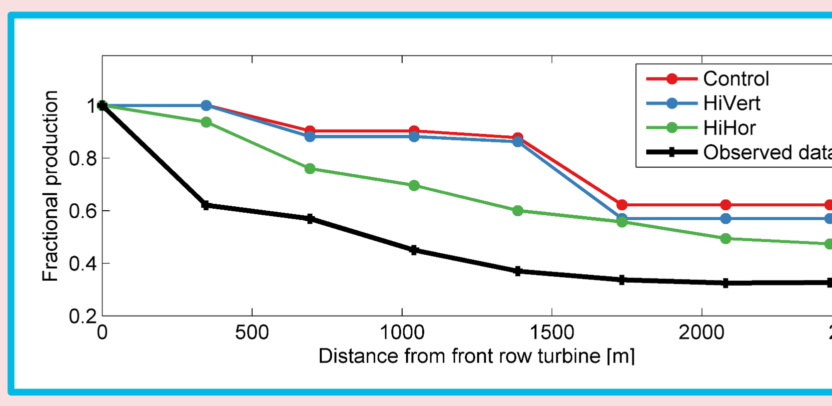

Figure 7: Fractional production along the row of turbines indicated by a red line in the lower right panel of Figure 6

References & Acknowledgements

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Acknowledgements: This work was supported financially by the Top-Level Research Initiative (TFI) project, Improved Forecast of Wind, Waves and Icing (IceWind). Jan-Åke Dahlberg at Vattenfall AB is acknowledged for providing measurement data from the Lillgrund wind farm and Kurt Hansen at DTU Wind is acknowledged for the post processing of these data. The simulations were performed on the Abel Cluster, owned by the University of Oslo and the Norwegian meta center for High Performance Computing (NOTUR), and operated by the Department for Research Computing at USIT, the University of Oslo IT-department. http://www.hpc.uio.no/.