Evaluation of a Mesoscale Wind Farm Parameterization by Aircraft Measurements

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Abstract

This study presents real case simulations of an observed offshore wake (over 10 km long), that was generated by a cluster of offshore wind farms. We evaluate the ambient upstream flow and the wake simulations by aircraft measurements. The observations were conducted in the framework of the German Research Project WIPAFF [1] at the 10. September 2016 under stable atmospheric conditions at the North Sea. The simulations were performed with the Weather Research and Forecasting model (WRF) in combination with a wind farm parameterization (WPF). Our results indicate, that the deviations between observed and simulated are not only rooted in WPF itself, but also in the upstream conditions.

Keywords: *Offshore Wake, Mesoscale Wind Farm Parameterization, Marine Boundary Layer*

Introduction

Large offshore wind farms generate wakes that are longer than 40 km when the marine atmosphere is stably stratified [2]. These long wakes are crucial, especially in the North Sea where offshore wind farms are clustered along electrical power lines with distances below 10 km. Consequently, offshore wakes can imply an economical loss for wind farms located within a wake [3]. Therefore, energy site assessment techniques that are able to simulate the wakes of already existing and planned wind farms are becoming more important. One way to investigate possible wake losses is to apply a mesoscale model. Mesoscale simulations are computational cheap compared to Large Eddy Simulations (LES) and can cover large areas, like the German Bight [4]. However, due to their coarse grid size (~1 km) the effect of wind farms on the atmosphere has to be parameterized in mesoscale simulations [5].

These wind farm parameterizations (WFPs) were so far mostly evaluated under idealized conditions [e.g. 6]. However, [7] showed that offshore wind farms in the Baltic Sea are exposed to stable stratifications. Therefore, there is the need to evaluate WFPs under real atmospheric stratifications.

Motivated by this question, this work presents a real case simulation of an observed offshore wake that was measured by a research aircraft on the 10. September 2016 under stable atmospheric conditions. We use the Weather, Research and Forecasting model (WRF 3.8.1) [8] in combination with the WFP introduced by [5] to model these wakes. This work only presents a cross section taken 5 km downstream of a wind farm cluster, a complete description of the measurement campaign of the 10. September 2016 can be found in [9].

Data and Method

The numerical simulations are conducted with WRF 3.8.1 with a grid size of 1.6 km in the innermost domain. The effect of the wind farms on the atmosphere is captured by the wind farm parameterization of [5]. This parameterization represents a turbine as an evaluated sink for the mean flow and as a source of turbulent kinetic energy (TKE). A more comprehensive description can be found in [5].

The aircraft measurements were conducted 5 km downstream of a wind farm cluster at 5 different heights (Fig. 1). In addition to that, the aircraft took a vertical profile upstream of the wind farms. Consequently, we were able to disentangle the two sources that cause the deviation between observation and simulation -x the upstream flow and the WFP.

The wind speed deficit for the observations was obtained by normalizing the wind speed with 8.0 m/s. This value was measured at the western flank outside of the wake.

Results

The simulation at 1000 UTC and 1100 UTC (i.e., start and end of measurements) show a wind speed deficit of the same magnitude as the observations (Fig. 1). However, the measurements indicate a maximal wind speed reduction of up to 30 % compared to 25 % in the model. The wind speed deficit in vertical direction is more pronounced in the simulation than in the observations. That corresponds to a more stable stratified atmosphere in the observations compared to the simulations (not shown).

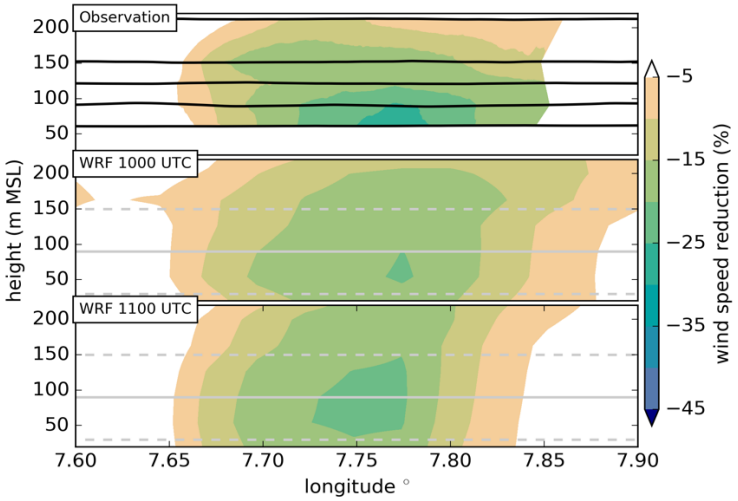

Figure 1: A comparison of observed and simulated wind speed reduction (colored contours) in a cross section perpendicular to the main flow, 5 km downstream of the wind farm clusters. The track of the air plane is indicated by black solid lines in the top panel. In the simulation panels the rotor area is indicated by a grey dashed line and the hub height by a solid grey line.

Conclusion

The used mesoscale WFP simulates the horizontal dimensions of the observed offshore wake. The deviation of the vertical extension of the simulated wake is partly rooted in the upwind conditions. Therefore, boundary layer parameterizations that represent the complex interactions between open sea and coastal regions are necessary for realistic wake assessments.

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