Project: **1069**

Project title: **Boundary layer meteorology in complex terrain and for wind energy applications**

Principal investigator: **Gerard Kilroy**

Report period: **2022-11-01 to 2023-10-31**

1.1 Overview

In the previous application, we requested computer hours in order to produce numerical simulations using the Weather Research and Forecasting (WRF) model (Skamarock et al., 2019), with the aim of providing realistic high-resolution simulations at the new German Aerospace Centre (DLR) experimental wind park, which officially opened on 15.08.2023. High-resolution simulations of the wind park are necessary to accurately simulate boundary layer flows, which are of the utmost importance for calculating loads on turbines and subsequent energy output estimates.

The WRF model is a state-of-the-art mesoscale numerical weather prediction system designed for atmospheric research. WRF can be run in Large Eddy Simulation (LES) mode when there are sufficient nested domains, so that the horizontal grid spacing drops below values of roughly 200 m. Previously, our group showed that WRF in LES mode can reasonably well simulate the observed mesoscale wind field (Wagner et al., 2019a) over a long time period (1.5 months). In the current project, we have produced simulations of the DLR wind park with grid spacing down to 5 m. With high-resolution simulations in LES mode located over flat terrain, such as at the location of the DLR wind park, there are unfortunately issues in producing an accurate representation of turbulence.

In WRF, lateral boundary information is passed from outer domain to inner domain, a mesoscale-to-microscale coupling, with the outermost domain typically driven by global weather model analyses. For this project we use initial and outer boundary conditions provided by the European Centre for Medium-Range Weather Forecasts (ECMWF) operational analysis. In the transition from a mesoscale domain to a microscale domain, the boundary conditions supplied are often too smooth at the inflow edges (a result of transitioning from a 1D planetary boundary layer scheme to LES closures). To develop realistic fine-scale turbulent features in WRF at the location of interest, a relatively large fetch is required. Typically, turbulence in LES domains is generated through a combination of friction, momentum and heat mixing, heat fluxes from the surface, complex topographical features, or variable land cover including nearby urban structures or forests. The DLR wind park is topographically very simple, with flat low-lying terrain, and has little in terms of complex land-usage features. This means that if the inner LES domain is too small, and the wind speeds relatively large, it is possible that turbulence does not manifest and calculations of power generation and turbine-wake interactions would be inadequate.

To this extent, the so-called cell perturbation method (CPM) was developed over the last decade (Munoz-Esparza et al., 2014; 2018). This method helps develop realistic small-scale turbulence without the need for prohibitively long fetches by introducing stochastic temperature perturbations at the LES inflow boundaries. These perturbations trigger small-scale vertical motion that produce complex small-scale horizontal vortical motion. This method significantly accelerates the generation of realistic turbulence. During the past few months, this tool was successfully implemented in the WRF model (it is not included in the standard version).

Early results from simulations of the DLR wind park suggest that the CPM (Figure 1) leads to much more realistic simulations of the observed turbulent fields, and the turbulent intensity and energy spectra are much closer to observations (not shown). Currently, we are producing simulations of real weather phenomena using the CPM method, including test cases which represent quasi-neutral, -stable and -convective boundary layer stability profiles for internal DLR projects. At 5-m grid spacing, these simulations take from weeks to months of calculation time. These early results suggest that the proposal goal to develop improvements to the WRF model was successful. Results are to be presented at the TORQUE conference (https://www.torque2024.eu/) in May 2024.

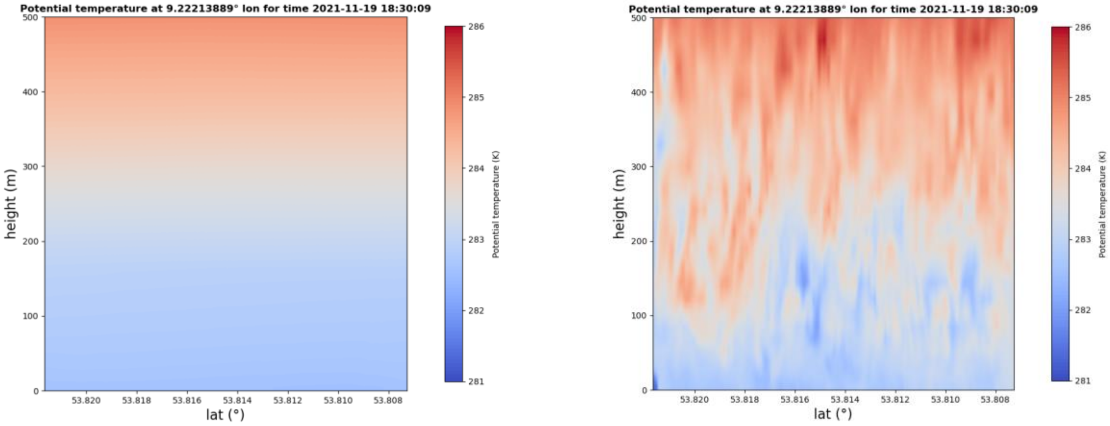

Fig. 1. Vertical profiles of potential temperature in the boundary layer for simulations without (left panel) and with (right panel) the cell perturbation method.

In addition, wind profiles from these WRF simulations were used recently by our team to generate realistic atmospheric inflow for wind turbines using the EULAG () model. A new data assimilation technique was tested, with the goal being to more accurately investigate wind turbine wakes. A publication is being prepared and will be submitted shortly to the Wind Energy Science Journal.

Computer hours were requested also to run WRF operationally over the previous year. Operational forecasts for the wind park have been successfully produced for the majority of the year (https://www.pa.op.dlr.de/DFWind_PA/model.html) which provides guidance to turbine operators. Additionally, the forecast data is saved and will be used in the coming year for identifying heavy load cases for wind turbines. In particular, it will be used to diagnose strong convective events involving cold pools and other high load/strong shear and veer events. These events will be studied in more detail by producing high-resolution simulations to study turbine loads in real case events.

Furthermore, resources were requested for the new project ESTABLIS-UAS, which is funded as an ERC Starting Grant by the European Union. In this project, a fleet of unmanned aerial vehicles are developed to measure wind characteristics, temperature and humidity with high resolution and are deployed within the international field experiment TEAMx. The field experiment will be accompanied by WRF simulations prior to the experiment in 2024 in order to plan and optimize the measurements. Simulations with WRF are currently ongoing, although significant issues have arisen when performing LES simulations over mountainous terrain. Collaborations are ongoing with TEAMx project partners to overcome these hurdles.

Further work and testing of WRF are currently underway, with the goal of implementing a Generalized Actuator Disk model (wind turbine parametrization) into WRF in order to validate its ability to produce realistic wind turbine wakes against observations from a LIDAR mounted on one of the turbines at the wind park. This is an ongoing area of work.

Literature cited in this report:

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