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Microscale simulations of extreme events in wind farms over complex terrain driven by mesoscalar flows

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The increasing size of wind turbines, with rotor diameter already spanning more than 150m, requires proper modelling of the atmospheric boundary layer (ABL) from the surface to the free atmosphere. Local processes in the ABL are affected by mesoscalar (large-scale) circulations which are not captured using a microscalar model. An efficient way to obtain a high fidelity local-flow structure while incorporating large-scale variability is to couple a microscale with a numerical weather prediction code.

In this work, we apply a downscaling strategy to analize extreme wind speed events that occurred in wind farms. The mesoscalar to microscalar coupling methodology applies mesoscale momentum budget components (tendencies [1]) obtained with the Weather Research and Forecasting (WRF) model as forcing terms to the governing microscale equations. Our study focuses on flow over complex terrain during specific days to reproduce extreme weather events. The simulation results are compared with observations from meteorological towers and instrumentation.

We test the ability of the meso- to microscale coupling model to reproduce extreme events with regard to quantities of interest in wind energy. Details of the the coupling schemme formulation will be discussed, and its validity for complex terrain will be shown. An important objective is to understand which configurations of WRF and the microscale model are more appropriate for simulating complex terrain in the selected area.

The microscalar flow is solved with the finite element code Alya [2], developed at the Barcelona Supercomputing Center (BSC). The mass, momentum and energy equations are solved to simulate the wind flow during several days. The used turbulence closure models are the Unsteady RANS (URANS) and also Large Eddy Simulation(LES). Regardless of the turbulence closure, the same coupling methodology is applied to meso-scale flow. The URANS model is the k- epsilon model modified for atmospheric flows [6]; while the LES model uses Deardoff [3] and Vreman subgrid scale closures.

We present a comparison of the accuracy and the spent (CPU-time) of both URANS and LES approaches. The Navier Stokes equations are discretized using a very low dissipation schemme when using LES model[4] with a 3rd order Runge Kutta scheme for time discretization. The URANS model uses an implicit Backward Euler schemme for time discretization.

The microscale domains are periodic and have the same extension for both URANS and LES simulations. The tangential resolution of the mesh is around 40m for both URANS and LES models. When solving with URANS, the vertical resolution of the first element cell is close to 1.5m, while it is around 7m when solving with the LES model.

Recently, the Alaiz benchmark [5] presented results of different mesoscale to microscale coupling methodologies in complex terrain. Alya model coupled to WRF obtained a mean normalized BIAS vs the observations of 3.76% and 4.23% using LES and URANS closures The industrial validation of URANS and LES with mesoscale couplings is developed using Iberdrola data measurements at wind turbine locations in two different wind farms placed over very complex orography. The data comes from either meteorological masts or measurement at wind turbine locations. We have defined two cases for validation, with a direct impact and application in the wind energy industry: Use of URANS and LES microscale models coupled to WRF for the simulation of extreme weather events, as a tool to complement and extend the forensic analysis in cases of accidents (like turbine collapse).

While microscale simulations driven by mesoscale tendencies is still a relatively new approach, we show that it has great potential for understanding transient events under extreme weather conditions. The wind industry can use such simulations as a tool to enhance forensic analysis in cases of accidents. Simulation results using URANS and LES closures agree reasonably well with observations. However, we observe that the dynamics of the LES simulation agree better with measurements at almost all wind turbine positions.

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