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Application of a large-eddy simulation model to the analysis of flow conditions in offshore wind farms

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Flows in the atmospheric boundary layer over a sea surface are characterised by a lower ambient turbulence intensity than boundary layer flows over land surfaces. Thus, offshore the wake turbulence behind a wind turbine might have a stronger impact on subsequent wind turbines than onshore. Due to the lower ambient turbulence intensity and therefore reduced turbulent diffusion, offshore the velocity minimum behind a wind turbine can probably be detected over a longer distance than onshore. Moreover, as the meandering of the wake flow might be due to the ambient atmospheric turbulence, also the meandering of the wake flow offshore might be different.

Maps, showing projected wind farms in the North Sea, reveal that also rather small distances between two adjacent wind farms will occur. Therefore, not only single wind turbines within a wind farm but also complete wind farms will affect each other.

Up to now all these potential impacts are not taken into account satisfactory when wind farms are planned. Most of the models applied today for estmating the yield of offshore wind farms have been derived about twenty years ago based on measurements at comparatively small onshore, sometimes near-coast, but never offshore sites. Moreover, the models are based on measurements at much smaller wind turbines as those used today. Due to the monotone increase of the wind velocity with height observed in the atmosphere, today's wind turbines experience a much larger variation of the mean wind velocity than their predecessors twenty years ago – increasing the potential for a vertical asymmetry of the wake flow.

The measurements carried out by the RAVE initiative at the German offshore test site „alpha ventus“ will allow a validation and further development of models that estimate the flow conditions within a wind farm consisting of multi-MW wind turbines under the special conditions of the marine atmospheric boundary layer.

ForWind at the University of Oldenburg supplements the data obtained at the offshore test site by data that is obtained from large-eddy simulations (LES) using the LES model PALM with actuator disk and actuator line approaches. The LES approach that shall be validated against the results of the measurements allows us to obtain flow data with a spatial and temporal resolution that cannot be reached in field experiments. Moreover, comprehensive parameter studies can easily be carried out with the LES model just by changing its initial and boundary conditions, such as thermal stratification or large-scale pressure gradient. PALM allows the application of turbulent inflow as well as cyclic lateral boundary conditions. Thus, it can be used to study the flow behind a single wind turbine, the flow within and behind a wind farm that has a limited horizontal extension as well as the flow within a wind farm of unlimited extension. Carrying out the simulations on the HLRN (North German Alliance for Supercomputing) supercomputer with about 25000 CPUs allows us to use a very high resolution of 1 m, while the horizontal extension of the model domain reaches several square kilometres. Thus, PALM seems to be a promising tool to study the turbulent flow in offshore wind farms with their giant numbers and dimensions of wind turbines.

The goal of this conference contribution is to point out the great potential of the LES method for the systematic analysis of wind turbine and wind farm wake flows. Results of the wake flow behind a single wind turbine validated with prior numerical results and measurements as well as behind a scale model of the “alpha ventus” test site will be shown.