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Large-eddy simulations of the internal boundary layer and wake flow within very large wind farms

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Wind turbines extract momentum from the mean flow and generate additional turbulence. In wind farms this leads to a reduced power output and increased loads for downstream turbines. An internal boundary layer is developing within the wind farm comparable to the internal boundary layer above rough surfaces such as forests or cities.
In the near future, numerous and increasingly larger offshore wind farms will be installed, particularly in the North Sea. The power output of wind turbines in the center of very large wind farms is almost independent of wind direction. Both the power output and the flow characteristics converge towards the conditions within an infinite wind farm.
Measurements have shown that the atmospheric stability affects the wake flow significantly. A stable boundary layer with less turbulence leads to stronger and more persistent wakes compared to a convective boundary layer. Thus, atmospheric stability will affect the flow within large wind farms as well. The atmospheric stability is however neglected in most analytical wind farm models.

In this study, we perform turbulence resolving large-eddy simulations (LES) with the LES model PALM. The wind turbines are parameterized with an enhanced actuator disk approach including effects of blade rotation. Simulations of very large wind farms are performed and compared to the simulation of an infinite wind farm realized by periodic boundary conditions. The sensitivity of the results to wind farm layout parameters such as the distance between the turbines is investigated as well as the sensitivity to meteorological parameters such as wind speed and atmospheric stability.
With the results of this study it is possible to determine the number of turbines required to achieve an asymptotic wake deficit and the same flow characteristics as in an infinite wind farm depending on layout and meteorological parameters. The results can be used to develop and validate wind farm parameterizations in mesoscale weather models and analytical wind farm models.