Atmospheric simulations

The idealized simulations are conducted with the Weather Research and Forecasting (WRF) simulation tool [1], version 4.2.1 [2][3]. We use the native parametrization for the wind turbines, which represents them as sinks of momentum (the turbine drag proportional to the thrust coefficient data) and sources of turbulence kinetic energy (the fraction of kinetic energy not transferred into electricity) [4][5][6]. We use the default value for the correction factor (= 0.25) to the turbulent kinetic energy produced by the turbines. The WRF model domain has a horizontal size of 50 x 50 km^2 with a uniform grid resolution of 1 km. The vertical dimension is 10 km with a variable, stretching resolution, finer at the bottom (23 levels in the first 1 km) and coarser at the top (37 levels in the remaining 9 km). Here, we consider a wind farm with a set of Vestas V164-9.0MW, one of the largest wind turbines currently available, with a hub height of 130 m, arranged on a uniform grid with spacing of 1000 m. We populate this uniform grid to obtain and study two different installed capacity densities: 9 W/m^2, where all the grid cells contain a turbine resulting in an aligned layout with a turbine density of 1 km^{-2}, and 4.5 W/m^2, where the grid cells are populated alternatively resulting in a staggered layout with a turbine density of 0.5 km^{-2}. We parametrize this wind farm on the 8 layers intersecting the rotor area in a doubly periodic domain that we use to emulate an infinite wind farm. On this domain, we specify a set of vertically uniform geostrophic wind values and constant Coriolis parameters (f-plane approximation). The set of Coriolis parameters is 0.05, 0.55, 1.05, 1.35, and $1.45 \cdot 10^{-4}$ rad/s^{-1}, which corresponds to the set of latitudes 2.0, 22.2, 46.1, 67.8, and 83.8° N. These settings in the boundary conditions implicitly assume a driving constant pressure-gradient field for each of the considered combinations. The bottom boundary is defined as a sea surface with a roughness length of 10^{-4} m. We use a dry atmosphere with no surface heat, radiation and moisture fluxes.

The planetary boundary layer physics is parameterized using the Mellor–Yamada–Nakanishi–Niino (MYNN) Level-2.5 model [7][8]. Each simulation is run with a time step of 10 s and for a total of 7 days in order to reach stationary conditions. Resulting variables are then averaged horizontally and over the last 12 hours. The power produced by each turbine is calculated with the power curve provided by the manufacturer according to the wind speed at the turbine-containing levels where the turbine is located.

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