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Large Eddy Simulation study of fully developed thermal wind-turbine array boundary layers

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It is well known that when wind turbines are deployed in large arrays, their efficiency decreases due to complex interactions among themselves and with the atmospheric boundary layer (ABL). For wind farms whose length exceeds the height of the ABL by over an order of magnitude, a "fully developed" flow regime can be established. In this asymptotic regime, changes in the stream-wise direction can be neglected and the relevant exchanges occur in the vertical direction. Such a fully developed wind-turbine array boundary layer (WTABL) has recently been studied using Large Eddy Simulations (LES) under neutral stability conditions (Calaf et al. Physics of Fluids 22, 2010). Related wind-tunnel experiments on the WTABL are reported in Cal et al., J. Renewable and Sustainable Energy 2, 2010). The simulations showed the existence of two log-laws, one above and one below the wind turbine region. These results confirm basic assumptions made in prior work by Frandsen (J. Wind Eng. Ind. Aerodyn. 39, 1992) and Frandsen et al. (Wind Energy 9, 2006), and have enabled the development of more accurate parameterizations of the effective roughness scale for a wind farm. Now, a suite of Large Eddy Simulations, in which wind turbines are also modeled using the classical "drag disk" concept are performed but for non-neutral conditions. The aim is to study the effects of different thermal ABL stratifications, and thus to better understand the efficiency and characteristics of large wind farms and the associated land-atmosphere interactions for realistic atmospheric flow regimes. Such studies help to unravel the physics involved in extensive aggregations of wind turbines, allowing us to design better wind farm arrangements. By considering various turbine loading factors, surface roughness values and different atmospheric stratifications, it is possible to analyze the influence of these on the induced surface roughness, and the sensible heat roughness length. These last two can be used to model wind turbine arrays in simulations of atmospheric dynamics at larger (regional and global) scales, where the coarse meshes used do not allow to account for the specifics of each wind turbine. Results from different sets of large-eddy simulations under stable and unstable conditions will be presented, for which also the corresponding effective roughness length-scales are determined.

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