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# Effect of Gravity Waves on Numerical Solutions of Large Wind Farms

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## Abstract

In recent years, much attention, simulation, and modeling efforts have been posed on the upstream region of large wind farms, especially on the local deceleration that wind turbines impose on the atmospheric boundary layer. This phenomenon, also known as wind farm blockage, is the result of pressure perturbations triggered by atmospheric gravity waves living above the boundary layer, generated by its interaction with the wind farm. Blockage is currently neglected in reduced-order wind farm models, which assume that first-row turbines behave as isolated turbines. Besides, accurately capturing gravity waves using high-fidelity tools—which are in turn used to develop those reduced models—is not straightforward, as gravity waves physics involves spatial scales much greater than the size of the wind farm. As a result, the vast majority of wind farm simulations do not incorporate blockage arising from gravity waves, and this omission may severely over-estimate the wind farm power under certain atmospheric conditions. In the present study, we present a numerical framework for including gravity waves into large-eddy simulations of large wind farms. A 100-turbine wind farm is simulated for different heights and free atmosphere stratification lapse rates of the boundary layer. Periodic boundary conditions are applied in the spanwise direction to yield the asymptotic limit of 'infinite' wind farm. Results with and without atmospheric gravity waves are compared in terms of upstream velocity reduction, wind farm wake recovery, pressure gradient throughout the wind farm and spanwise-averaged kinetic energy budgets along the streamwise direction. The importance of damped boundary conditions to avoid gravity-wave reflections from the boundaries is also described, and a proportional-integral controller for dynamically tuning the damping intensity of such regions is presented. Parameters of interest in determining the extent of gravity-wave-driven blockage are described, and a reduced order model of the atmospheric boundary layer is used to predict the values of these parameters for which gravity waves become non-negligible.