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LES of thermally-stratified wind-turbine array boundary layers: Fringe region approach for stationary conditions and results

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In recent years, various large eddy simulation (LES) studies of interactions between the atmospheric boundary layer (ABL) and infinitely large arrays of wind turbines have been performed in neutral conditions, and new models for the effective roughness length have been developed. The analysis relied on observations of long-time averaged vertical profiles of mean flow and turbulent fluxes. The extension to thermally stratified ABL, which is the main objective of the present study, turns out to be challenging since the heat flux at the ground determines the vertical profiles of mean temperature to be time-dependent. To achieve a stationary temperature profile, an artificial source of heat, providing the amount of heat necessary to keep the overall temperature field stationary, is applied within a fringe region located above the ABL. A PI controller is used to update the appropriate amount of heat inside the source region. To keep the mean flow direction perpendicular to the wind turbine rotor, as required by the actuator disk model, another controller is used to drive the flow within ABL, causing the mean velocity to achieve a prescribed direction at a specified height. A suite of LES at various mesh resolutions and various levels of thermal stratification are carried out, and the profiles of horizontally averaged velocity, temperature and turbulent fluxes, with and without wind turbines, are compared with each other. In stable conditions, the trends of the turbulent heat flux are quite consistent with the neutral case, showing an increase when wind turbines are included, but in unstable conditions the turbulent heat flux decreases with increasing stratification. (Financial support provided by the National Science Foundation, NSF-AGS-109758.)