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Large-eddy simulation of wind-turbine wakes: Evaluation of turbine parameterizations

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Large-eddy simulation (LES) offers a great potential to study the effects of turbulent atmospheric boundary layer flow on the performance of wind turbines and wind farms. The accuracy of the simulations, however, hinges on our ability to parameterize subgrid-scale (SGS) turbulent fluxes as well as turbine-induced forces. In this study, we investigate the performance of LES in simulations of wind-turbine wakes in neutrally stratified boundary layer flows. The subgrid-scale stress tensor is parameterized using the scale-dependent Lagrangian dynamic model (Stoll and Porte-Agel, 2006). This model optimizes the local value of the Smagorinsky coefficient based on the dynamics of the resolved scales. The turbine-induced lift and drag forces are parameterized using two types of models: an actuator disk model (ADM) that distributes the force loading uniformly on the rotor disk; and an actuator line model (ALM) that distributes the forces on lines that follow the position of the blades. Simulation results are compared to wind-tunnel measurements collected with hot-wire anemometry in the wake of a miniature 3-blade wind turbine at the St. Anthony Falls Laboratory atmospheric boundary layer wind tunnel. In general, the characteristics of the wakes simulated with the proposed LES framework are in good agreement with the measurements. The ALM is better able to capture vortical structures such as helicoidal tip vortices, which are induced by the blades in the near-wake region. Our results also show that accounting for rotation in the ADM leads to a more realistic turbine wake structure.