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Large-eddy simulation of atmospheric boundary layer flow through wind farms

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A new large-eddy simulation (LES) framework is introduced and used to study atmospheric boundary layer flow and its interactions with wind turbines and wind farms. It uses tuning-free Lagrangian scale-dependent dynamic models for the subgrid-scale momentum and heat fluxes, together with an actuator disk model with rotation (ADM-R) to parameterize the turbine-induced forces. The LES code is validated against high-resolution wind-tunnel measurements collected with hot-wire anemometry inside and above a model 10x3 array wind farm under neutral conditions. Different wind farm layouts are considered. In general, the characteristics of the wind farm wakes simulated with the proposed LES framework are in good agreement with the wind-tunnel measurements. Specifically, LES is able to predict the spatial distribution of turbulent wake characteristics such as velocity deficit and turbulence intensity enhancement, and their adjustment with distance downwind from the wind farm edge. The simulations show the development of an internal boundary layer within which the flow is affected by the wind turbines, and an equilibrium sub-layer, where the flow statistics are fully adjusted to the wind farm conditions. Finally, LES is used to study the effect of the wind farm layout (turbine siting) on the turbulent flow structure as well as the performance of the wind turbines.