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Wind-turbine wakes responding to diurnal cycle-driven boundary-layer flow over homogeneous and complex terrain: A numerical modelling study

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The wake characteristics of a wind turbine for different regimes occurring throughout the diurnal cycle are investigated systematically by means of large-eddy simulation for homogeneous and complex terrain.

An idealised diurnal cycle simulation of the atmospheric boundary layer is performed with the geophysical flow solver EULAG over homogeneous terrain. Under these conditions, the diurnal cycle significantly impacts on the low-level wind shear and the atmospheric turbulence. A strong vertical wind shear and a wind veer with height occur in the stable boundary layer and in the morning boundary layer, whereas the atmospheric turbulence is much larger in the convective boundary layer and in the evening boundary layer.

The convective, stable, evening, and morning regimes of the atmospheric boundary layer over homogeneous surface are used to study the flow in a wind-turbine wake under homogeneous surface conditions. Therefore, synchronized turbulent inflow data from the idealized atmospheric boundary-layer simulations with periodic horizontal boundary conditions are applied to the wind-turbine simulations with open streamwise boundary conditions. The resulting wake is strongly influenced by the stability of the atmosphere. The flow in the wake recovers more rapidly under convective conditions during the day, compared to the night. The wake characteristics of the transitional periods are influenced by the flow regime prior to the transition.

Further, the stable, evening, and morning regimes of the atmospheric boundary layer over homogeneous surface are used to study the response of the wind-turbine wake to stably stratified flow for a hill-top wind-turbine, with the same simulation strategy as in the homogeneous case. Here, the wind turbine with a hub height of 100 m is placed on the top of a 3 D hill with heights up to 50 m. The wake characteristics for different stably stratified regimes are compared with simulation results of the same flow field passing through the same wind turbine standing on a homogeneous surface.

An investigation of different stably stratified flow regimes over a 3 D hill without a wind turbine reveals that the occurrence of flow separation not only depends on hill properties but also on the atmospheric stratification. A comparison of the wind-turbine wake characteristics between homogeneous and complex terrain showed for the same atmospheric stratification only a near-wake region impact of the hill geometry, whereas the stratification impact on the hill-top wind-turbine wake is much more distinct, especially in the far wake.