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Spatiotemporal structure of wind farm-atmospheric boundary layer interactions

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Wind power is currently one of the fastest growing energy sources in the world. Most of the growth is in the utility sector consisting of large wind farms with numerous industrial-scale wind turbines. Wind turbines act as a sink of mean kinetic energy and a source of turbulent kinetic energy in the atmospheric boundary layer (ABL). In doing so, they modify the ABL profiles and land-atmosphere exchanges of energy, momentum, mass and moisture. This project explores theses interactions using remote sensing data and numerical model simulations. The domain is central Texas where 4 of the world's largest wind farms are located. A companion study of seasonally-averaged Land Surface Temperature data from the Moderate Resolution Imaging Spectroradiometer (MODIS) on TERRA and AQUA satellites shows a warming signal at night and a mixed cooling/warming signal during the daytime within the wind farms. In the present study, wind farm-ABL interactions are simulated with the Weather Research and Forecasting (WRF) model. The simulations show that the model is capable of replicating the observed signal in land surface temperature. Moreover, similar warming/cooling effect, up to 1C, was observed in seasonal mean 2m air temperature as well. Further analysis show that enhanced turbulent mixing in the rotor wakes is responsible for the impacts on 2m and surface air temperatures. The mixing is due to 2 reasons: (i) turbulent momentum transport to compensate the momentum deficit in the wakes of the turbines and (ii) turbulence generated due to motion of turbine rotors. Turbulent mixing also alters vertical profiles of moisture. Changes in land-atmosphere temperature and moisture gradient and increase in turbulent mixing leads to more than 10% change in seasonal mean surface sensible and latent heat flux. Given the current installed capacity and the projected installation across the world, wind farms are likely becoming a major driver of anthropogenic land use change on Earth. Hence, understanding WF-ABL interactions and its effects is of significant scientific and societal importance.