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Monitoring, modeling and mitigating impacts of wind farms on local meteorology

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Wind power is one of the fastest growing sources of energy. Most of the growth is in the industrial sector comprising of large utility-scale wind farms. Recent modeling studies have suggested that such wind farms can significantly affect local and regional weather and climate. In this work, we present observational evidence of the impact of wind farms on near-surface air temperatures. Data from perhaps the only meteorological field campaign in an operational wind farm shows that downwind temperatures are lower during the daytime and higher at night compared to the upwind environment. Corresponding radiosonde profiles at the nearby Edwards Air Force Base WMO meteorological station show that the diurnal environment is unstable while the nocturnal environment is stable during the field campaign. This behavior is consistent with the hypothesis proposed by Baidya Roy et al. (JGR 2004) that states that turbulence generated in the wake of rotors enhance vertical mixing leading to a warming/cooling under positive/negative potential temperature lapse rates.

We conducted a set of 306 simulations with the Regional Atmospheric Modeling System (RAMS) to test if regional climate models can capture the thermal effects of wind farms. We represented wind turbines with a sub-grid parameterization that assumes rotors to be sinks of momentum and sources of turbulence. The simulated wind farms consistently generated a localized warming/cooling under positive/negative lapse rates as hypothesized. We found that these impacts are inversely correlated with background atmospheric boundary layer turbulence. Thus, if the background turbulence is high due to natural processes, the effects of additional turbulence generated by wind turbine rotors are likely to be small.

We propose the following strategies to minimize impacts of wind farms:

• Engineering solution: design rotors that generate less turbulence in their wakes. Sensitivity simulations show that these turbines also increase the productivity of wind farms and reduce damages to downwind rotors.
• Siting solution: develop wind farms in regions where ABL turbulence is naturally high. Since, turbulence data is not widely recorded, we use surface KE dissipation rate as a proxy for ABL turbulence. Indeed, in our simulations, these 2 parameters are strongly positively correlated ($P<0.99$). Using the JRA25 dataset, comprising of 25-year long 6-hourly global meteorological data, we identify such regions in the world. These regions that include the Midwest and Great Plains as well as large parts of northern Europe and western China are appropriate sites for low-impact wind farms.