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Wind-tunnel experiments of scalar transport in aligned and staggered wind farms

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Wind energy is the fastest growing renewable energy worldwide, and it is expected that many more large-scale wind farms will be built and will cover a significant portion of land and ocean surfaces. By extracting kinetic energy from the atmospheric boundary layer, wind farms may affect the exchange/transport of momentum, heat and moisture between the atmosphere and land surface. To ensure the long-term sustainability of wind energy, it is important to understand the influence of large-scale wind farms on land-atmosphere interaction. Knowledge of this impact will also be useful to improve parameterizations of wind farms in numerical prediction tools, such as large-scale weather models and large-eddy simulation.

Here, we present wind-tunnel measurements of the surface scalar (heat) flux from model wind farms, consisting of more than 10 rows of wind turbines, in a turbulent boundary layer with a surface heat source. Spatially distributed surface heat flux was obtained in idealized aligned and staggered wind farm layouts, having the same turbine distribution density. Measurements, using surface-mounted heat flux sensors, were taken at the 11th out of 12 rows of wind turbines, where the mean flow achieves a quasi-equilibrium state. In the aligned farm, there exist two distinct regions of increased and decreased surface heat flux on either side of turbine columns. The regions are correlated with coherent wake rotation in the turbine-array. On the upwelling side there is decreased flux, while on the downwelling side cool air moves towards the surface causing increased flux. For the staggered farm, the surface heat flux exhibits a relatively uniform distribution and an overall reduction with respect to the boundary layer flow, except in the vicinity of the turbine tower. This observation is also supported by near-surface temperature and turbulent heat flux measured using a customized x-wire/cold-wire. The overall surface heat flux, relative to that of the boundary layer flow without wind turbines, is reduced by approximately 4% in the staggered wind farm and remains nearly the same in the aligned wind farm.