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# A numerical study of wind turbine-boundary layer interactions in a large offshore wind farm

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Large offshore wind farm installations are rapidly increasing all over the world driven by the availability of strong, consistent winds and the unavailability of appropriate land sites. This study quantitatively explores the interaction between wind turbines and the marine atmospheric boundary layer and its impacts on power generation in a hypothetical large offshore wind farm off the western coast of India in the Arabian Sea. The simulations are conducted using the mesoscale model WRF equipped with a wind turbine parameterization, which approximates a wind turbine as a sink of resolved kinetic energy and a source of turbulent kinetic energy. In this study, the WRF parameterization is modified to include the effects of density variations. The simulations are conducted over a 300 km x 300 km domain discretised with an 1 km grid with 10000 turbines placed in the centre.

Wind turbines extract atmospheric kinetic energy and convert it into electricity. The extraction of kinetic energy from the atmospheric flow leads to two major phenomena: (1) momentum deficit in the wakes that reduce energy availability for downwind turbines and (2) enhanced vertical convergence to partly replenish the momentum deficit. Results show a 200% increase in vertical momentum convergence, with 95% of that coming from sub-grid turbulent eddies. However, the enhanced momentum convergence offsets only a small part of the momentum deficit. Consequently, there is a net reduction of almost 60% in power production for turbines in the interior of the farm compared to the turbines at the leading edge.

These results suggest that a numerical model like WRF that accounts for both the momentum deficit and enhanced momentum convergence effects may provide better estimates of wind power generation than traditional wind speed density or wake model approaches.