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Simulating wind turbine interactions with low-level jet using a meso-to-micro downscaling approach

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This study presents a high-resolution simulation of a low-level jet (LLJ) with explicit representation of wind turbines using the Weather Research and Forecast (WRF) model and the newly-developed Simple Actuator Disk model for Large Eddy Simulation (SADLES). LLJs are low-level wind maxima that can impact the power output and structural loads of turbines. Therefore, accurate prediction of the LLJ is essential for wind energy planning and management. The meso-to-micro downscaling approach is used to capture the LLJ dynamics, which involves nested domains with increasing spatial resolution from the mesoscale to the microscale. The WRF model is configured with five nested domains: mesoscale domains with grid spacing of 9 km, 3 km, and 1 km to capture the general dynamics structure of the LLJ, and two micro domains with grid spacing of 200 m and 40 m with large eddy simulation (LES) configuration. The SADLES model is used in the 40-m domain to enable the interaction between the LLJ and the wind turbines of the Alpha Ventus wind farm located in the North Sea. The simulation results are verified against observations at the FINO1 mast stations, including cup anemometers at various heights and LiDAR wind profiles. The WRF-SADLES system captures the LLJ dynamics and the interactions of turbines on the LLJ. The LLJ is well-reproduced in terms of its intensity, depth, and spatial extent, and the wakes of individual turbines are explicitly captured, significantly impacting the LLJ. The study provides insights into the LLJ dynamics and turbine-wake interactions, which can inform wind energy planning and management.