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Effects of atmospheric stability on the evolution of wind turbine wakes: Volumetric LiDAR scans

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Aerodynamic optimization of wind farm layout is a fundamental task to reduce wake effects on downstream wind turbines, thus to maximize wind power harvesting. However, downstream evolution and recovery of wind turbine wakes are strongly affected by the characteristics of the incoming atmospheric boundary layer (ABL) flow, like the vertical profiles of the mean wind velocity and the turbulence intensity, which are in turn affected by the ABL stability regime. Therefore, the characterization of the variability of wind turbine wakes under different ABL stability regimes becomes fundamental to better predict wind power harvesting and improve wind farm efficiency. To this aim, wind velocity measurements of the wake produced by a 2 MW Enercon E-70 wind turbine were performed with three scanning Doppler wind Light Detection and Ranging (LiDAR) instruments. One LiDAR was typically devoted to the characterization of the incoming wind, in particular wind velocity, shear and turbulence intensity at the height of the rotor disc. The other two LiDARs performed scans in order to characterize the wake velocity field produced by the tested wind turbine. The main challenge in performing field measurements of wind turbine wakes is represented by the varying wind conditions, and by the consequent adjustments of the turbine yaw angle needed to maximize power production. Consequently, taking into account possible variations of the relative position between LiDAR measurement volume and wake location, different LiDAR measurement procedures were carried out in order to perform 2-D and 3-D characterizations of the mean wake velocity field. However, larger measurement volumes and higher spatial resolution require longer sampling periods; thus, to investigate wake turbulence tests were also performed by staring the LiDAR laser beam over fixed directions and with the maximum sampling frequency. Furthermore, volumetric scans of the wind turbine wake were performed under different wind conditions via two simultaneous LiDARs. Through the evaluation of the minimum wake velocity deficit as a function of the downstream distance, it is shown that the stability regime of the ABL has a significant effect on the wake evolution; specifically the wake recovers faster under convective conditions. This result suggests that atmospheric inflow conditions, and particularly thermal stability, should be considered for improved wake models and predictions of wind power harvesting.