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Wind tunnel study of multiple wake interactions in wind farms with different layouts

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The interaction between atmospheric boundary layer and wind farms leads to flow modifications, which have a strong effect on wind farm performance. The flow produced from a wind farm is the result of a strong interaction between multiple turbine wakes. Therefore, optimizing the wind farm layout is of key importance for the maximization of power production. In this study, a wind tunnel investigation was carried out, using hot-wire anemometry and multi-hole pressure probes, in order to study turbulence statistics of the atmospheric boundary layer inside and above wind farms. The tested wind farms consist of miniature wind turbine models with three blades. First, the wake flow generated from a single wind turbine is surveyed. It is characterized by a strong velocity defect in the proximity of the rotor. The magnitude of this velocity defect and the cross-dimensions of the wake are found to be related to the wind turbine performance and strongly affect the efficiency of the wind turbines placed downstream. The distance of recovery of the wakes, and thus the performance of downstream turbines, is found to depend on the characteristics of the incoming atmospheric boundary layer (mean velocity and turbulence intensity profiles). An increased turbulence level is typically detected downstream of each wind turbine for heights comparable to the top-tip of the blades. This flow feature produces increased fatigue loads on the wind turbines, which could represent a significant hazard for real wind turbines. The effect of the wind farm layout on power production was also investigated. Particular emphasis is placed on studying how the flow adjusts as it moves inside the wind farm and can affect the power production. Aligned and staggered wind farm layouts were analysed, also with varying separation distances between different rows in the streamwise direction. The results obtained from the present experimental campaign shed light on how wind farm performance could be affected by different flow features like, e.g., the atmospheric boundary layer characteristics, the flow turbulence and the wind farm configuration. The measurements are also being used to test and guide the development of improved parameterizations of wind turbines in high-resolution numerical models, such as large-eddy simulations (LES).