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Flow structure inside and above a variable wind farm: A wind tunnel study.

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Wind turbine wakes are known to have important effects on both power generation and fatigue loads in wind farms. Wake characteristics are expected to depend on the incoming atmospheric boundary layer flow statistics (e.g., mean velocity, turbulence intensity and turbulent fluxes), and vertical transport, which is affected by the relative position of the turbines in the wind farm.

In this study, wind-tunnel experiments were carried out at the St. Anthony Falls Laboratory atmospheric boundary layer wind tunnel using a 10 by 3 model wind turbine array placed inside a neutrally stratified boundary layer developed over a smooth surface. Different turbine layouts (aligned and staggered farm with different inter-turbine spacing) were considered. Cross-wire anemometry and Particle Image Velocimetry (PIV) were used to characterize the mean velocity, turbulence intensity and turbulent stress at different locations in the wind farm. Results suggest that the turbulent flow can be divided into two main regions. The first, located below the turbine top tip height, has a direct effect on the performance of the turbines. Here the mean flow statistics appear to reach equilibrium as close as 3-4 turbines downwind from the edge of the wind farm. In the second region, located immediately above the first region, the flow adjustment is slower. Here, two distinct layers were found: and internal boundary layer where the flow starts to adjust to the new farm conditions but is still affected by the upwind condition; and an equilibrium layer, where the flow statistics are fully adjusted to the wind farm conditions. The high-resolution spatial and temporal information obtained in the laboratory experiments is 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).