The Structure of Turbulent Flows in Wind Farms

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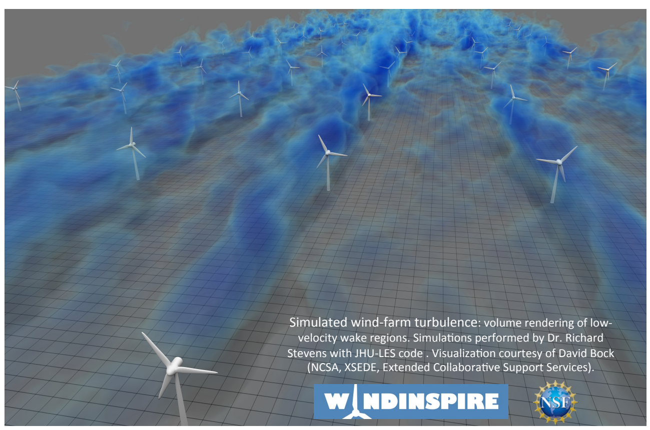
In this presentation we provide an overview of our current understanding of the flow structure and turbulence in the wind turbine array boundary layer (WTABL). This particular type of shear flow develops when the atmospheric boundary layer interacts with an array of large wind turbines (Calaf et al. 2010, Cal et al. 2010, Stevens & Meneveau 2017). We distinguish between developing and fully developed WTABL and perform a series of Large Eddy Simulations that represent the turbines as actuator disks (see Figure 1 below). Salient LES results are synthesized in order to develop simplified analytical models needed for wind farm design and optimization. There one encounters the dichotomy of modeling individual turbine wakes or to model the wind farm flow as a boundary layer over a roughened surface whose properties depend upon the wind farm array. The coupled wake boundary layer model (Stevens et al. 2016a) attempts to match these two approaches iteratively. Ultimately, such models can lead to improved estimation of optimal wind turbine spacing including costs associated with covered surface, cabling and operation & maintenance (Stevens et al. 2016b). We also present new results on the temporal variability of wind power as measured in a wind tunnel experiment (Bossuyt et al. 2017) and its relationship to the spatio-temporal properties of turbulent boundary layers (Wilzcek et al. 2015). It turns out that as a first approximation, for situations without thermal stratification effects, one may consider the sum of turbine power to be a discrete sampling of the wavenumber-frequency spectrum of turbulent boundary layers. This model thus enables us to connect wind farm design parameters (turbine spacing, positioning, etc.) to fundamental properties of turbulent boundary layers.



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