Mesoscale to microscale wind farm flow modeling and evaluation

The increasing size of wind turbines, with rotors already spanning more than 150m diameter and hub heights above 100m, requires proper modeling of the atmospheric boundary layer (ABL) from the surface to the free atmosphere. Furthermore, large wind farm arrays create their own boundary layer structure with unique physics. This poses significant challenges to traditional wind engineering models that rely on surface-layer theories and engineering wind farm models to simulate the flow in and around wind farms. However, adopting an ABL approach offers the opportunity to better integrate wind farm design tools and meteorological models. The challenge is how to build the bridge between atmospheric and wind engineering model communities and how to establish a comprehensive evaluation process that identifies relevant physical phenomena for wind energy applications with modeling and experimental requirements. A framework for model verification, validation, and uncertainty quantification is established to guide this process by a systematic evaluation of the modeling system at increasing levels of complexity. In terms of atmospheric physics, 'building the bridge' means developing models for the so-called 'terra incognita,' a term used to designate the turbulent scales that transition from mesoscale to microscale. This range of scales within atmospheric research deals with the transition from parameterized to resolved turbulence and the improvement of surface boundary-layer parameterizations. The coupling of meteorological and wind engineering flow models and the definition of a formal model evaluation methodology, is a strong area of research for the next generation of wind conditions assessment and wind farm and wind turbine design tools. Some fundamental challenges are identified in order to guide future research in this area.

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