Developing a framework for integrating atmospheric boundary layer turbulence measurements and modeling for onshore and offshore wind energy

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With increasing demand for clean energy and development of wind farms over large areas, accurate prediction of atmospheric boundary layer (ABL) flow and its interactions with wind turbines is of great importance for optimizing design and improving efficiency at the individual turbine and wind farm scale. Once they are developed, wind power plant operators must ensure energy generation meets regulations and minimizes environmental impacts. This requires quantification of impacts to endangered species as well as effects on land-atmosphere exchanges. The Environmental Fluid Mechanics and Renewable Energy (EFRE) Laboratory at IIHR – Hydroscience & Engineering utilizes a synergistic approach conducting novel experiments to understand interactions between the ABL and wind farms to develop new technologies for sustainable energy development. Two large-scale experimental facilities have recently been developed to help achieve this goal, the Kirkwood Utility-Scale Wind Turbine Experimental Facility, and the IIHR Boundary Layer Wind-Wave Tunnel.

A 2.5 MW utility-scale wind turbine in Cedar Rapids, Iowa has been instrumented along with a nearby 350-foot tall-tower. Turbulence sensor and other environmental instruments installed at multiple heights are used to characterize the vertical structure and evolution of the ABL under variable weather conditions. Nacelle-mounted wind LiDARs, and SCADA data are used to improve turbine control strategies and models of the wake. We have found that turbulence and mean wind shear affect wind turbine performance and the evolution of the wake.

A new boundary layer wind-wave tunnel has been designed to model the ABL coupled with wind-generated waves. Unique to this facility, a deep air boundary layer is developed that scales similarly compared to the mean wave height to that in the field. Using time-resolved particle image velocimetry, we are studying the coupling between the wind and water currents within the two-sided boundary layer, and to understand the dynamics associated with waves and spray.

The data from the field and laboratory are used to advance and validate numerical models, such as large-eddy simulation (LES). The models can be used to improve turbine operation, optimize wind turbine arrays, and investigate the environmental effects such as changes in turbulent transport, the surface energy balance, and impacts of wind project on wildlife. For example, recent simulations have revealed that birds and bats struck by turbines fall in specific patterns around wind turbines. This knowledge can be used to improve survey strategies for quantifying mortality of protected species, as well as development and evaluation of deterrent technologies.