innovation

The Spectrum of
Clean Energy Innovation

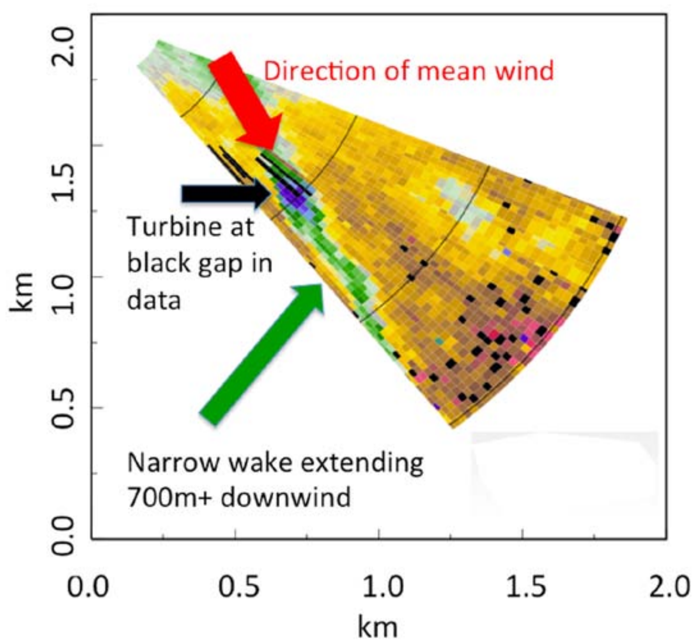
Fundamental Science
Market-Relevant Research
Systems Integration
Testing and Validation
Commercialization
Deployment

NREL Studies Wind Farm Aerodynamics to Improve Siting

NREL researchers have used high-tech instruments and high-performance computing to understand atmospheric turbulence and turbine wake behavior in order to improve wind turbine design and siting within wind farms.

The knowledge gained from this research could lead to improved turbine design standards, increased productivity in large wind farms, and a lower cost of energy from wind power. This is key, because as turbines grow in size—approximately doubling in height over the past five years—they present more complex challenges to wind turbine designers and operators. To gain new insights into turbine wind wakes, NREL and the Renewable and Sustainable Energy Institute (RASEI) joined together with the National Oceanic and Atmospheric Administration (NOAA), the University of Colorado at Boulder, and Lawrence Livermore National Laboratory to fund a high-tech study beginning in 2011.

A multi-organizational team of experts used precise instruments to create a detailed picture of the atmosphere surrounding large turbines. Among these instruments was the high-resolution Doppler LIDAR—a laser-based system that stands for "light detection and ranging"—used for the first time to produce a three-dimensional portrait of atmospheric activity in the wake of a multi-megawatt wind turbine. The scanning LIDAR can measure the wind speeds in a slice of air up to 999.7 meters (3,280 feet) from the ground and 6920 meters (4.3 miles) long (see illustration below); in other scanning modes, it can focus just on a turbine and 10 km (6.2 miles) beyond to observe its wake near the surface. Researchers focused on a 2.3-megawatt turbine that rises 80 meters (328 feet) from its base to its hub.



This high-resolution Doppler LIDAR scan shows radial wind velocities in the vicinity of a wind turbine, with cooler colors indicating lower velocities in the wind turbine wake.
Illustration from Yelena Pichugina, NOAA

Through deep technical expertise and an unmatched breadth of capabilities, NREL leads an integrated approach across the spectrum of renewable energy innovation. From scientific discovery to accelerating market deployment, NREL works in partnership with private industry to drive the transformation of our nation's energy systems.

This case study illustrates NREL's innovations in Fundamental Science through Market-Relevant Research.

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

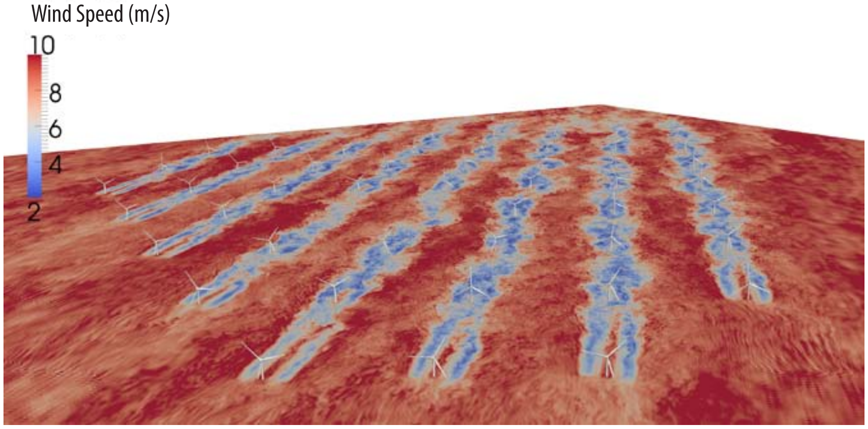
The interagency team also deployed other high-resolution atmospheric instrumentation. NREL scientists gathered wind and turbulence data using commercial platforms, including a specialized laser called a Windcube LIDAR and a sonic detection and ranging (SODAR) system, the Second Wind Triton. LIDAR looks at light bouncing off of particles in the atmosphere to measure wind speed, and SODAR measures sound waves bouncing off of density fluctuations in the atmosphere. One beam of light or sound measures one direction, so three beams are needed to measure all three directions.

These data were supplemented by the high-frequency sonic anemometers installed on two new 135-meter (440-foot) meteorological towers. Each of these instruments contributed a unique perspective on the dynamic inflow and turbine wake system.

Fluctuations in air temperature throughout the day can affect wind turbine wakes, according to Julie Lundquist, professor of atmospheric and oceanic sciences at the University of Colorado and a joint appointee at NREL. Lundquist noted that the resulting changes in wake behavior can impact the productivity of wind farms with their many rows of turbines, so it's important to observe them in detail and understand how to minimize their impacts.

The data are being used to validate advanced computer models. New questions are being explored, such as how wakes in wind farms lower the velocities at downwind turbines; how wake turbulence impacts turbine loading and reliability; and how wake behavior is controlled by the interactions among the turbine, the wind farm, and the atmosphere. The answers to these questions, along with a new computational capability (see sidebar), will lead to improved wind farm performance and a lower cost of energy.

Findings will be reported in upcoming journal publications and shared with the international wake modeling community. NREL researchers have discovered that the influence of the atmosphere and wakes is more complex than the way this influence is represented in computer models used by the industry today. NREL's work has shown that the atmosphere contains large-scale turbulence structures that propagate through the wind turbines and wind farms and influence wake motion. The wind plant performance and turbine fatigue loading changes dramatically over a 24-hour time period as the atmosphere goes through its diurnal cycle. Results from these studies will soon result in improved design practices for the industry.



In this top view of a simulated instantaneous wind field passing through the Lillgrund wind farm, the blue colors indicate lower wind speeds in the turbine wakes.
Illustration by Matt Churchfield, NREL

Supercomputing Helps Refine Wind Farms

To further wind farm research, NREL researchers are using RedMesa, currently NREL's most powerful high-performance computing system, located at Sandia National Laboratories and part of an NREL and Sandia collaboration. It has a peak computational capability of about 180 teraFLOPS, which means it can perform 180 trillion "FLOPS," or floating point operations per second. In comparison, a simple calculator needs only about 10 FLOPS to function. Drawing on this resource, NREL scientists and engineers are developing innovative software tools to simulate the behavior of both individual wind turbines and multi-turbine configurations in a variety of atmospheric environments, including hurricanes.

This kind of advanced software models the effects of turbulent inflow, including unsteady aerodynamic forces, and the inflow's effect on structural dynamics and drive-train response. Recently, NREL researchers completed the first-ever high-fidelity simulations of a fully operational wind farm, Lillgrund, off the coast of southern Sweden. They have also successfully calculated the relative impact of wake and atmospheric turbulence on wind turbine loading.

To improve these models, their results must be compared with actual observations. To carry that out, NREL and the Centro Nacional de Energías Renovables (CENER) in Spain are leading an international collaboration through the International Energy Agency to gather data from operating wind farms and benchmark existing simulation tools. The interagency study's data will provide valuable insights into the operation and optimization of these large wind turbines.

Wind plant developers could use this analysis to create improved layouts and controls for wind farms, thus enhancing wind farm efficiency and helping to extend the life of wind turbines. The research could also help the development of offshore wind farms. All of these applications will help to reduce the levelized cost of wind energy, making wind power more competitive with other sources of electricity.

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

NREL/FS-6A42-53609 • April 2012

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