A Whirlwind of Research

NCAR

The National Center for Atmospheric Research (NCAR) is working with a range of research partners to help put more scientific rigor into wind power prediction and resource assessment. This effort is building on longstanding NCAR research in areas ranging from statistics to artificial intelligence, turbulence theory, and model development. It also comes on the heels of a highly successful three-year project to develop an advanced wind forecasting system for Xcel Energy, which uses more wind power than any other U.S. investor-owned utility.

By collaborating with public and private sector partners, RAL is generating research results that can enhance the wind energy industry as a whole. At the January 2012 annual meeting of the American Meteorological Society (AMS), there were more than a dozen talks and posters by NCAR staff on wind energy research and development efforts, many of them part of the Third Conference on Weather, Climate, and the New Energy Economy.

Better wind power forecasts
NCAR’s most prominent success to date in wind energy prediction has been the forecasting system it developed for Minnesota-based Xcel Energy. The system saves ratepayers several million dollars yearly by enabling utility operators to anticipate the amount of wind energy produced at wind farms within Xcel’s service areas, which span much of the central United States. Thanks to forecasts that are updated every 15 minutes (see graphic), the utility can save money by powering down coal and natural gas plants when possible while maintaining a reliable power supply for its customers. The wind energy prediction system was formally handed over to Xcel Energy in October 2011. NCAR will continue to make refinements on request, and the system will continue to become more accurate on its own: its software automatically makes adjustments based on any differences between the energy forecasts and actual energy generation.

This graphic shows sample output from NCAR’s wind energy prediction system for Xcel Energy.

Where to put the turbines
A traditional approach to wind resource assessment is to gather data from an instrumented tower for one to two years then correlate the observations to randomly selected historical weather datasets initialized from larger scale (40-km or more) model reanalyses.

A new method developed at NCAR promises to help developers identify prime wind sites more quickly and accurately. Instead of randomly selecting a single 365-day set of wind data, the new method creates thousands of such sets. It then uses a statistical technique, a Monte Carlo method, to compare
each set to a high-quality reanalysis of observations of wind in the general vicinity. The set that aligns most closely with the observation-based reanalysis is selected as the basis for a detailed map of likely winds at the site.

Such a method, when combined with a year of actual observations, reduces the uncertainty in average wind speed by as much as 40% compared with the current approach. Moreover, it is so effective that an energy company can analyze just 180 days of data using this technique and obtain results as reliably as the current 365-day approach with far less cost and effort. NCAR scientist Luca Delle Monache is also developing a new approach that identifies analogs in the forecasts that can further streamline resource analysis and provide uncertainty information.

RAL is also using its state-of-the-science global reanalysis for wind resource assessment, one that provides global coverage for 1985–2005, using a 40-km (24-mi) horizontal grid. Created with NCAR’s WRF-based Climate Four-Dimensional Data Assimilation (CFDODA) system, this reanalysis provides hourly 3-D output, which permits the full diurnal cycle to be analyzed for any point on the globe. NCAR is working with the Renewable Energy Research Laboratory (NREL) to produce new maps of the wind and solar resource and their interannual variability.

Turbines and turbulence

The critical zone for wind energy is the atmospheric boundary layer. Stronger winds aloft often mix into the boundary layer during the day, when the zone typically expands to a depth in the range of 2–3 kilometers (1.2–1.9 miles).

As the sun goes down, the turbulence collapses, and the boundary layer may only be 100 meters deep or less. Especially at night, winds can be very strong just above the top of the boundary layer but much lighter just below that interface. If a turbine’s blades spin into and out of the boundary layer every few seconds, the resulting shear stress can be enough to damage a turbine’s blades and gearbox. Ned Patton of NCAR has studied how trees, hills, and other obstacles can affect the air flow in and near wind turbines. He’s simulated these events using NCAR’s large-eddy simulation (LES) model, an influential tool developed by Chin-Hoh Moeng over the last 20-plus years to analyze turbulent flow. The model illuminates processes that are sometimes overlooked by wind energy prospectors, such as the potential for the formation of breaking Kelvin-Helmholtz waves at the top of the boundary layer at night. These atmospheric waves are the same type that can produce clouds resembling a series of ocean waves. LES processes representing the behavior of wind turbines themselves have also been woven into the WRF model framework by RAL’s Branko Kosovic, in collaboration with Lawrence Livermore National Laboratory and industry.

A team that includes scientists from NCAR and private industry partners is now embarking on a project funded by the U.S. Department of Energy to examine how ocean waves can themselves influence the wind at turbine height. At NCAR, Peter Sullivan has spent more than a decade studying the many ways in which ocean waves and the lower atmosphere interact. The new DOE effort will examine how atmospheric impulses produced by large ocean waves, including swell, might propagate upward and affect turbines located offshore or near shore. The goal is to find ways to represent these processes within models.

Another research frontier is the effects of turbines within a wind farm on the atmosphere and on each other. As wind flows around a turbine and through its blades, its speed is reduced while turbulence increases. NCAR’s Jimy Dudhia is working on new techniques to represent such processes in modeling with WRF, which is widely used for wind energy research and prediction at NCAR and elsewhere. WRF’s first publicly available wind-farm parameterization was added to the model last spring.

And since wind farms often share the land with traditional farms, it’s important to know whether their turbines might have effects, good or bad, on crops beneath them. Over the summers of 2010 and 2011, Eugene Takle (Iowa State University) led the Crop/Wind-Energy Experiment. It drew on sensors from ISU, CU-Boulder, NCAR, the NREL, and the National Laboratory for Agriculture and the Environment that gathered data on turbulence, sensible and latent heat, and carbon dioxide fluxes upwind and downwind of wind turbines across a central Iowa corn field. So far, according to Takle and colleague Julie Lundquist (CU), it looks as if the turbines create modest but measureable changes in the microclimate for Midwestern crops. The pressure variations and turbulence produced downstream of turbines appears to help stir the air near the ground, which may affect surface fluxes. The mixing may result in slightly longer growing seasons for crops within wind farms and protect crops from damage when temperatures are hovering near freezing.

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