Meteorology Research in DOE's Atmosphere to Electrons (A2e) Program

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Abstract
DOE's Atmosphere to electrons (A2e) program is performing cutting edge research to advance modeling to allow optimization of wind plants. This talk will summarize the atmospheric science portion of the A2e project, with an overview of recent and planned observation and modeling projects designed to bridge the terra incognita between the mesoscale and the very fine scales that affect the operation of wind turbines within plants. This work is aimed at providing better models, modeling techniques, forecasts and tools for the wind industry.

Keywords: *wind plant optimization, atmospheric modeling, wind forecast improvement, mesoscale to microscale coupling*

Introduction
Atmosphere to Electrons (A2e) is a major focus of the Wind Energy Technologies Office (WETO) within the Office of Energy Efficiency & Renewable Energy (EERE) at the U.S. Department of Energy (DOE). The overall objective of A2e is to optimize wind power production at the plant level and integrates improved knowledge of atmospheric inflow (fuel), turbine and plant aerodynamics, and control systems. The atmospheric component of the work addresses both the need for improved forecasting of hub-height winds and the need for improved turbulence characterization for turbine inflows under realistic atmospheric conditions and in realistic terrain. Observations are key to the development of the models and the verification and validation of them. Several projects will be touched upon to address observations of meteorological and oceanographic variables in regions not typically observed. The modelling needs are addressed through major multi-institutional integrated studies comprising both theoretical and numerical advances to improve models and field observations for physical insight and model validation. Model improvements are subjected to formal verification and validation, and numerical and observational data are archived and disseminated to the public through the A2e Data Archive and Portal (DAP; http://a2e.energy.gov). The overall outcome of this work will be increased annual energy production from wind plants and improved turbine lifetimes through a better understanding of atmospheric loading. We will briefly describe major components of the atmospheric part of the A2e strategy and work being done and planned.

Experiments and Modeling for Wind Forecast Improvement
The second Wind Forecast Improvement Project (WFIP 2) is a four-year study focused on improving the physical parameterization of foundational weather forecast models to improve wind forecasts at hub height. This study focuses on the moderately complex terrain of the Columbia Basin of eastern Oregon and Washington, where more than 4 GW of wind turbine capacity is installed. The overall design for the WFIP 2 addresses a set of weather phenomena, determined by the wind industry, which poses particular challenges in this area for wind and wind power forecasting: frontal passages with stable mix-out; gap flows; convective outflows; mountain waves; topographic wakes; and marine pushes. In addition to these specific phenomena, the Columbia Basin area poses amplified challenges in general for numerical weather prediction models owing not only to the local terrain of the Columbia Basin but also to the highly complex terrain of the Cascade Mountains, and the associated the Columbia Gorge, just to the west. The improvement of our ability to characterize and forecast winds affected by these phenomena is expected to in turn improve the forecasts of wind energy and thus lower its overall cost.

DOE and its national laboratories, along with industry partner Vaisala and government partner NOAA, have conducted a comprehensive program of observations, model improvements, and decision support tool development anchored by a field campaign in the Columbia Gorge.

Work already in flat terrain has been conducted by DOE with the WFIP 1 project and planning for a future project that could benefit the offshore wind industry will be mentioned.

Coupling Mesoscale to Microscale Models

Microscale models are essential for representing the details of turbulent inflow into wind plants and of the wakes that the turbines generate. For these models to provide realistic solutions, they must be effectively coupled to mesoscale models of the atmosphere, which requires bridging atmospheric scales where key physical relationships are not well established. The purpose of the Mesoscale-Microscale Coupling (MMC) project is to develop, verify, and validate physical models and modeling techniques that bridge the most important atmospheric scales that determine wind plant performance and reliability. The MMC project seeks to create a new numerical simulation capability that is able to represent the full range of atmospheric flow conditions affecting wind plant performance. The first year of the project validated current modeling practices for the mesoscale and microscale at a flat site under canonical conditions. Validation focused on real cases at the Texas Tech/Sandia National Laboratory Scaled Wind Farm Technology (SWiFT) Facility. The team tested three different microscale models forced by the mesoscale model, Weather Research and Forecasting model (WRF) [1].

The recent focus of MMC has advanced to nonstationary conditions over flat terrain. These nonstationary conditions in many cases preclude periodic boundary conditions for microscale models and thus represent the next step toward realistic coupling of mesoscale meteorological forcing to the microscale. The MMC team modeled two types of non-stationary cases: 1) diurnal cycles in which the daytime convective turbulence rapidly decays with the setting of the sun setting up frequent formation of the nocturnal low-level jet (LLJ); and 2) frontal passage as an example of a synoptic weather event that may cause relatively rapid changes in wind speed and direction.

The team compared and contrasted two primary techniques for non-stationary forcing of the microscale by the mesoscale model. The first is to use the tendencies from the mesoscale model to directly force the microscale mode. The second method is to couple not only the microscale domain's internal forcing parameters, but also its lateral boundaries, to a mesoscale simulation. The boundary-coupled approach provides the greatest generality. However, the mesoscale flow information at the boundaries of the microscale domain contains no explicit turbulence information and thus requires explicit methods to accelerate turbulence production at the inflow boundaries. Various assessment strategies, including comparing spectra and cospectra, were used to assess the techniques. Testing methods to initialize turbulence at the microscale was also accomplished. Most recently, work has further advanced to nonstationary cases in complex terrain, utilizing the data collected from the WFIP2 experiment described above.

Expected Impact

Data generated through the WFIP 2 study will be delivered to the DAP for public use. WFIP 2 is yielding new knowledge and parameterizations to support improved better hub-height wind forecasts in numerical weather prediction models, some of which will be incorporated in the next-version operational models of NOAA's National Weather Service. Improved information generated by the MMC project will aid in the design, layout, site selection and optimal operations of wind plants both on and offshore.

References

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