WIND ENERGY RESEARCH & DEVELOPMENT
Atmospheric Science

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Resource, Site Characterization, and Forecasting
National Renewable Energy Laboratory (NREL) scientists are leading efforts in numerical weather prediction for renewable energy, resource assessments, remote sensing, and forecasting that are essential for the development of wind and solar energy.

Oceanographic and Meteorological Processes
We improve understanding of the physical meteorological and oceanographic processes that affect wind resource characterization offshore. We also characterize the marine energy resource.

Global Weather, Mesoscale, and Plant-Level Effects
NREL scientists study the impact of atmospheric flow on turbulence and power output of wind power plants by considering various scales of weather phenomena.

Maps and Visualizations
NREL’s maps and data visualizations illustrate large and complex data sets to communicate the technological capabilities of the laboratory.
Resource, Site Characterization, and Forecasting

- Our capabilities include mesoscale numerical weather prediction, impact of atmospheric flow on turbulence and power output of wind power plants, cutting-edge wind resource assessments, grid-integration studies, and conversion of wind and solar radiation to power.

- NREL has expertise in measurement and remote-sensing technologies that determine atmospheric quantities important for wind energy research.

Areas of Expertise
- Wind resource assessments
- Mesoscale numerical weather predictions
- Turbulence-resolving atmospheric simulations
- Remote-sensing technologies
CHALLENGE
Produce data sets that display the wind resource in an area while accounting for uncertainties.

APPROACH
Using machine learning, NREL is producing an uncertainty-based, 20-year, time-series data set covering land-based and offshore wind resources across the entire United States in an ensemble fashion.

IMPACT
This data set will be used by academia, industry, and national labs to inform future wind power plant development, thereby increasing deployment.
CHALLENGE
Improve capabilities of remote-sensing technologies and provide guidelines to industry.

APPROACH
Design field campaigns with an optimal use of different remote-sensing instruments to characterize:
- Atmospheric turbulence
- Turbine-level physics
- Wind power plant-level physics
- Wind power plant control.

IMPACT
Remote-sensing lowers the levelized cost of energy, provides high-fidelity observations of atmospheric flows and their interactions with wind power plants, and defines the limitations of numerical models.
**CHALLENGE**
Improve wind energy forecasts in complex terrain.

**APPROACH**
NREL participated in an 18-month field campaign in the Columbia River Basin. The observations from this campaign are used to evaluate wind energy forecast improvements in the National Oceanic and Atmospheric Administration's operational weather model and to provide further code enhancements.

**IMPACT**
These improvements will ultimately benefit the wind energy community and society through better weather forecasts.
**CHALLENGE**

Improve the value of wind energy forecasts to the wind industry.

**APPROACH**

- Improve the representation of physical processes in forecast models
- Review state-of-the-art tools for error and uncertainty quantification for wind and wind power forecasting models
- Develop best practices for evaluating forecast uncertainties
- Establish standards for data formats
- Representation, communication, and use of forecast uncertainties to support decision-making in plant operations and electricity markets.

**IMPACT**

Increased international collaboration regarding improvement of forecast models for the wind industry and guidelines for the evaluation of uncertainties will strengthen the wind energy community.
Oceanographic and Meteorological Processes

- NREL scientists help improve numerical weather prediction models in the marine environment to improve offshore wind energy forecasts.
- NREL will participate in an offshore field campaign off the U.S. East Coast to support offshore wind energy deployment.
- NREL offers the industry expertise in marine and atmospheric measurements, wind resource assessment, and extrapolation of low-level winds to hub height.

Areas of Expertise
- Numerical modeling
- Offshore measurements and remote sensing
- Wind resource assessments
- Marine and hydrokinetic atlas (wave and tidal data sets).
**CHALLENGE**

Improve the understanding of physical meteorological and oceanographic processes that affect wind resource characterization in the U.S. East Coast offshore environment and incorporate this understanding into foundational numerical weather forecast models and oceanographic models to improve wind energy forecasts.

**APPROACH**

NREL will support a multiseasonal offshore field measurement campaign and engage in associated data analysis and model development.

**IMPACT**

These improvements will ultimately benefit the wind energy community and society through better offshore forecasts.
Global Weather, Mesoscale, and Power Plant-Level Effects

- Improved understanding of wind turbine and wind power plant performance can lead to new designs and operation strategies that reduce the cost of wind energy.

- NREL simulates wind flow through a wind power plant across a wide range of atmospheric conditions that drive wind power plant performance.

- Because microscale models lack atmospheric physical processes, they are coupled with mesoscale models.

Areas of Expertise

- Numerical weather prediction modeling for global and mesoscales
- Large-eddy simulations for microscale effects
- Flow modeling for wind power plant performance and controls.
CHALLENGE
Perform accurate and versatile high-fidelity, turbulence-resolving flow simulations of winds in the atmospheric boundary layer.

APPROACH
Improve turbulence-resolving, atmospheric, large-eddy simulation codes while coupling those with regional-scale numerical weather prediction models or observations.

IMPACT
An improved understanding of complex wind characteristics and wind turbine and wind power plant performance in a wide range of atmospheric conditions can lead to new designs and operation strategies that could reduce the cost of wind energy.
Maps and Visualizations

- NREL’s maps and data visualizations illustrate large and complex data sets to communicate the technological capabilities of the laboratory.

- Our team specializes in turning data into stories through maps and data visualizations, which can help researchers determine the wind resource potential for a specific site, the best sites for wind power plants—and more.

Areas of Expertise
Developing maps, models, applications, and visualizations for wind energy planning and production.
CHALLENGE
Create a visual resource that accurately and attractively shows the offshore wind speed in the Gulf of Maine.

APPROACH
NREL is developing a static map that illustrates multiyear average wind speeds at various heights derived from NREL's Wind Integration National Dataset (WIND) Toolkit.

IMPACT
The map will be part of a series used as showpieces and educational materials to highlight the available wind resource, illustrate the WIND Toolkit data set, and demonstrate the technological and data visualization capabilities of the laboratory.
NREL’s technical experts are improving weather prediction forecasts that remove barriers to wind energy development, which:

- Allows wind power generating facilities to commit to power purchases in advance
- Helps operators make better day-ahead market, operation, and unit-commitment decisions
- Supports real-time wind power plant operations
- Lowers the cost of wind energy.