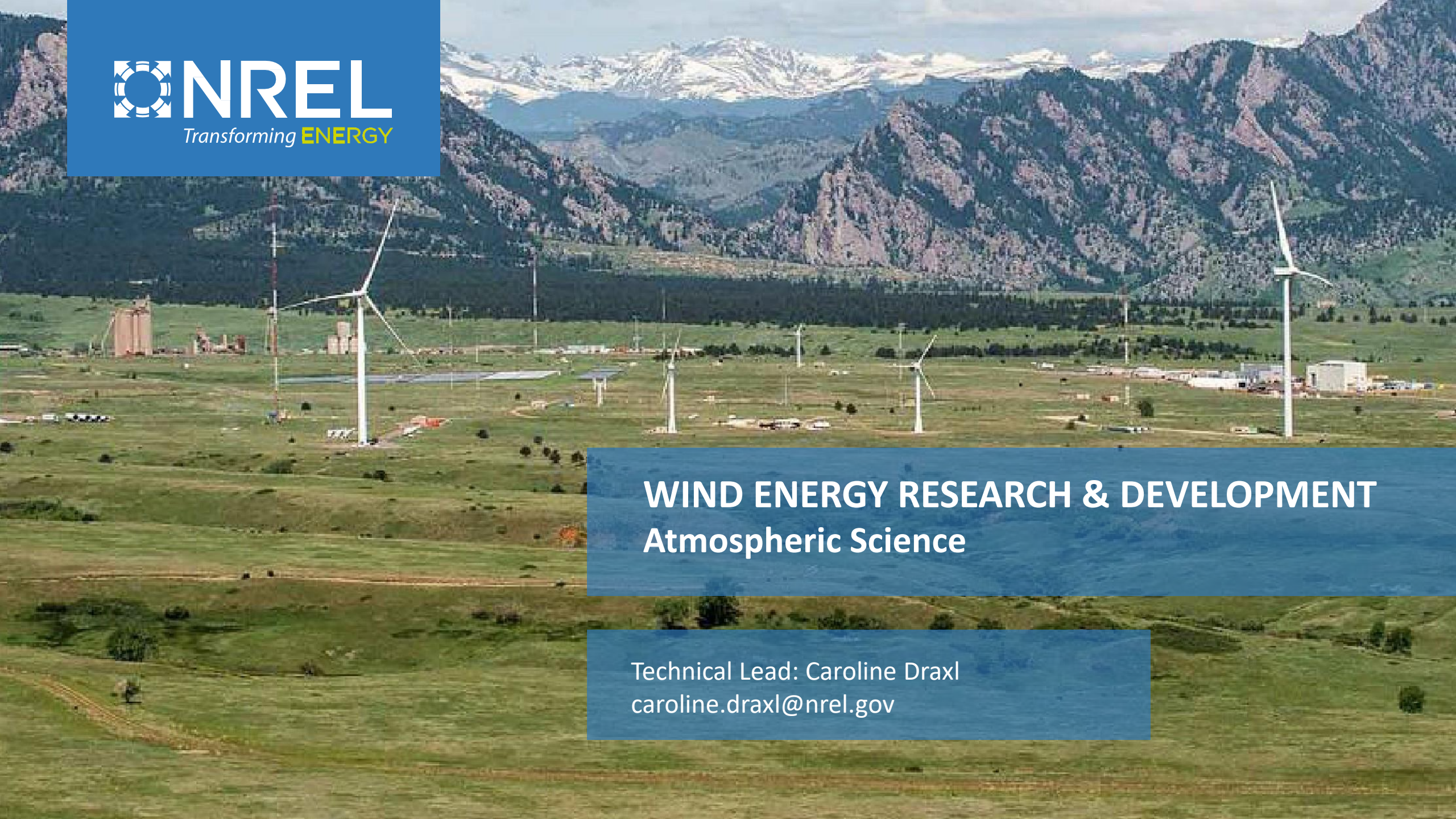

NREL
Transforming ENERGY

WIND ENERGY RESEARCH & DEVELOPMENT
Atmospheric Science

Technical Lead: Caroline Draxl
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Atmospheric Science

Leading renewable energy weather prediction efforts and improving understanding of the atmospheric forces that affect wind turbine performance to inform wind power plant development and increase energy capture.

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.

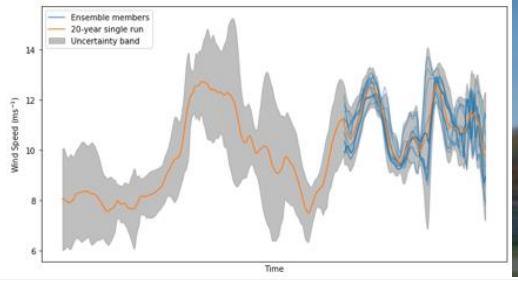
Areas of Expertise

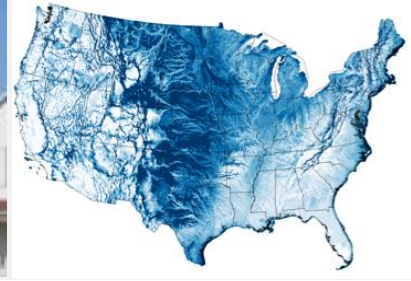
- Wind resource assessments
- Mesoscale numerical weather predictions
- Turbulence-resolving atmospheric simulations
- Remote-sensing technologies
- Machine learning.

Current Projects

Wind Resource Assessments

RESOURCE, SITE CHARACTERIZATION, AND FORECASTING





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.

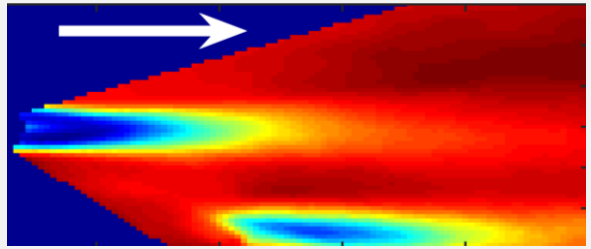
IMPACT

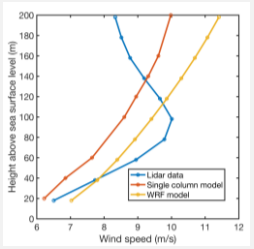
This data set will be used by academia, industry, and national labs to inform future wind power plant development, thereby increasing deployment.

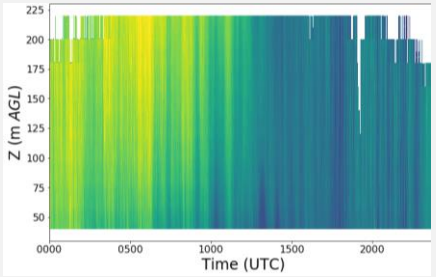
Current Projects

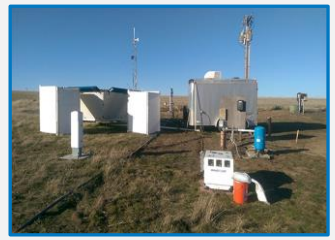
Measurements

RESOURCE, SITE CHARACTERIZATION, AND FORECASTING









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.

Current Projects

Second Wind Forecast Improvement Project (WFIP2)

RESOURCE, SITE CHARACTERIZATION, AND FORECASTING

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.

Current Projects

International Energy Agency (IEA) Wind Task 36 - Forecasting for Wind Energy

RESOURCE, SITE CHARACTERIZATION, AND FORECASTING

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).

Current Projects

Offshore Wind Resource Science

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.

Oceanographic and Meteorological Processes

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.

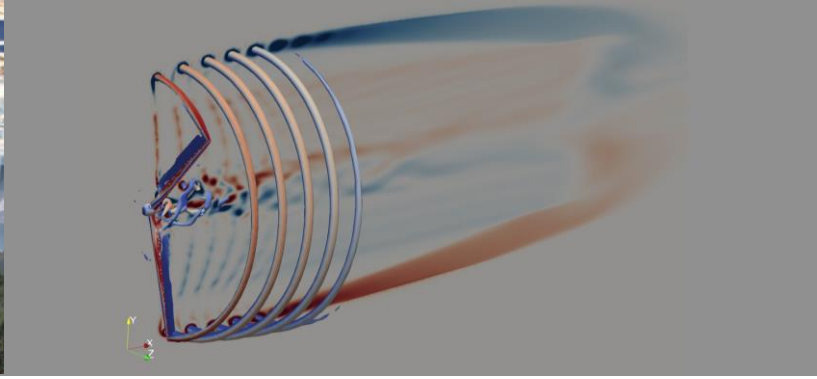
Areas of Expertise

- Numerical weather prediction modeling for global and mesoscales
- Large-eddy simulations for microscale effects
- Flow modeling for wind power plant performance and controls.

Current Projects

Mesoscale-to-Microscale Coupling Project

GLOBAL WEATHER, MESOSCALE, AND PLANT-LEVEL EFFECTS



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

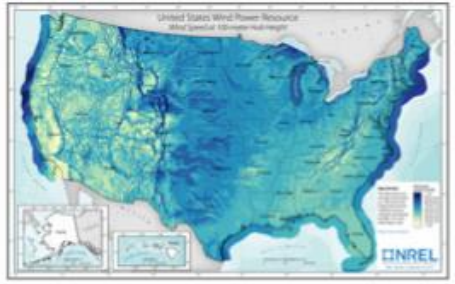
- NREL's maps and data visualizations illustrate large and complex data sets to communicate the technological capabilities of the laboratory.
- Our team specializes in turning data into stories through maps and data visualizations, which can help researchers determine the wind resource potential for a specific site, the best sites for wind power plants—and more.

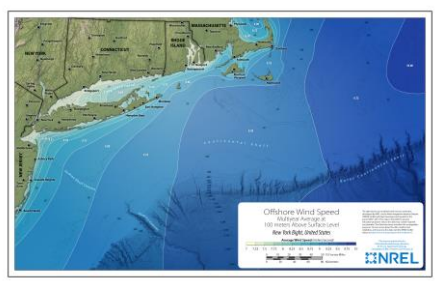
Areas of Expertise

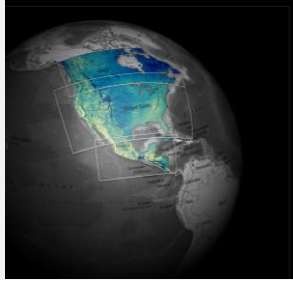
Developing maps, models, applications, and visualizations for wind energy planning and production.

Current Projects

Offshore Wind Speed in the Gulf of Maine







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

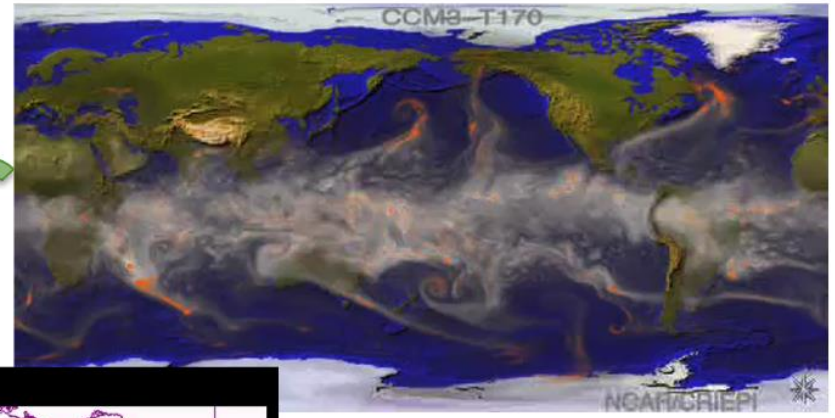
The map will be part of a series used as showpieces and educational materials to highlight the available wind resource, illustrate the WIND Toolkit data set, and demonstrate the technological and data visualization capabilities of the laboratory.

MAPS AND VISUALIZATION

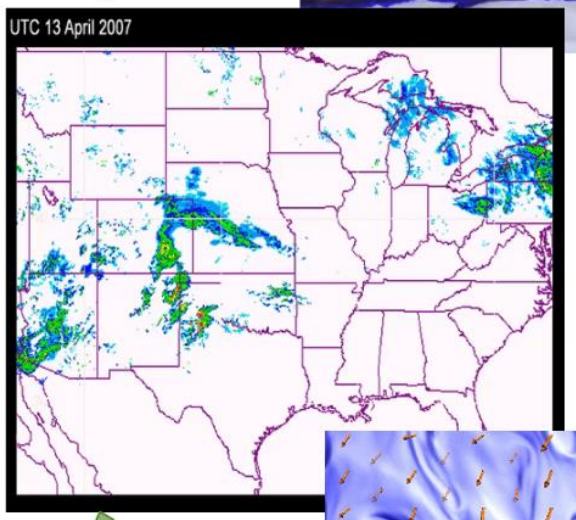
Accomplishments & Impacts

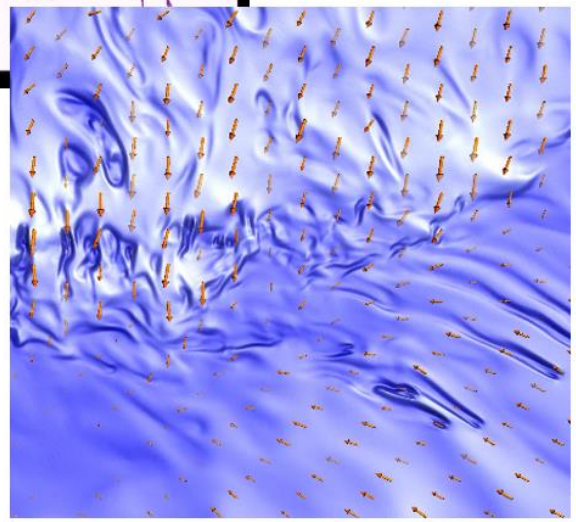
NREL's technical experts are improving weather prediction forecasts that remove barriers to wind energy development, which:

- 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.



Courtesy of Sue Haupt and colleagues at the National Center for Atmospheric Research





Courtesy of Jeff Mirocha, Lawrence Livermore National Laboratory

NREL experts worked with partners NCAR (top) and LLNL (bottom) to develop numerical simulations encompassing large-scale (top) and mesoscale (middle) flow to accurately describe wind and turbulence within wind power plants (bottom). These simulations help reduce the cost of wind energy through an improved understanding of the physics that govern electricity generation, inform wind plant operations, and new designs.