NWP Wind Forecasting Benchmarks

Forecasting Session 3: IEA Wind Task 36 Joint Session

ESIG 2020 Meteorology and Market Design Online Workshop

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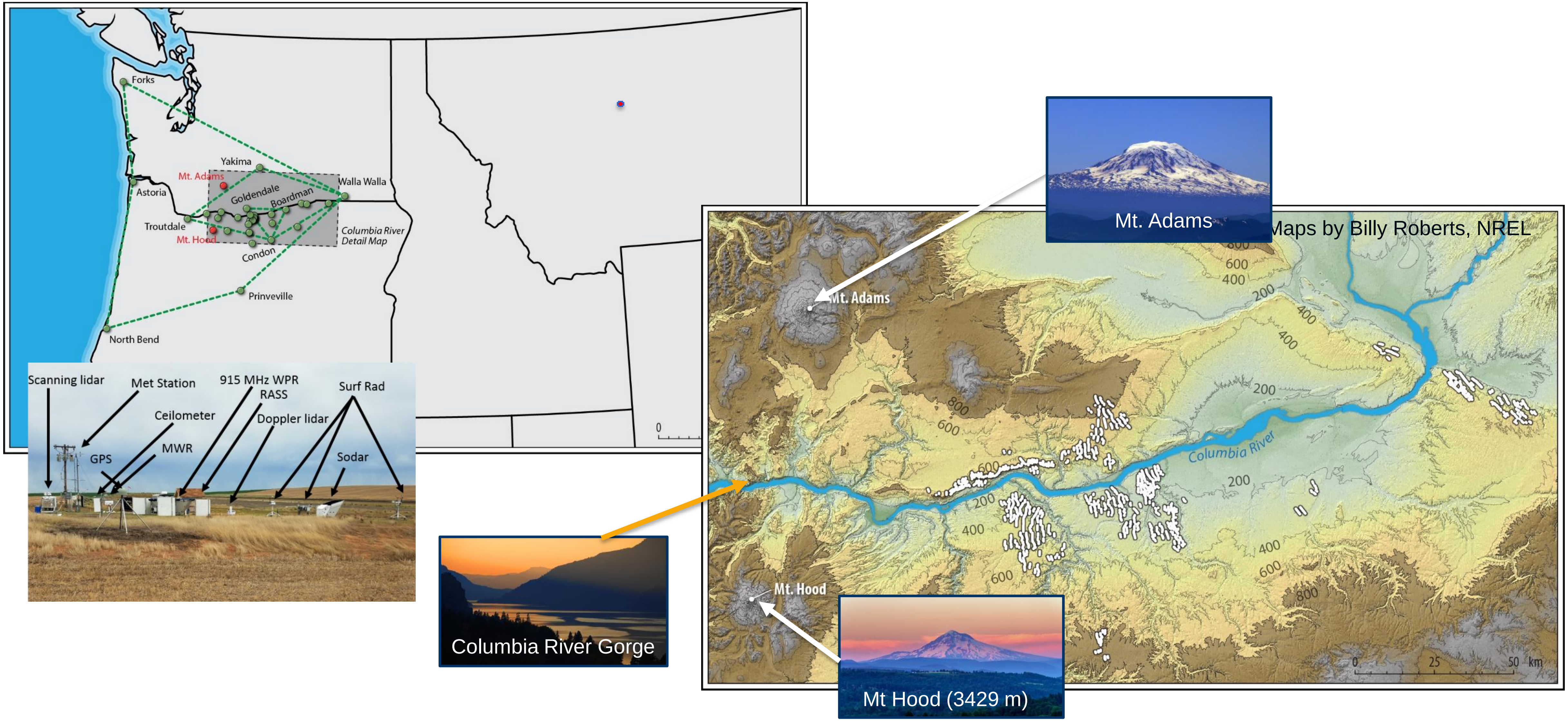
June 25, 2020

iea wind

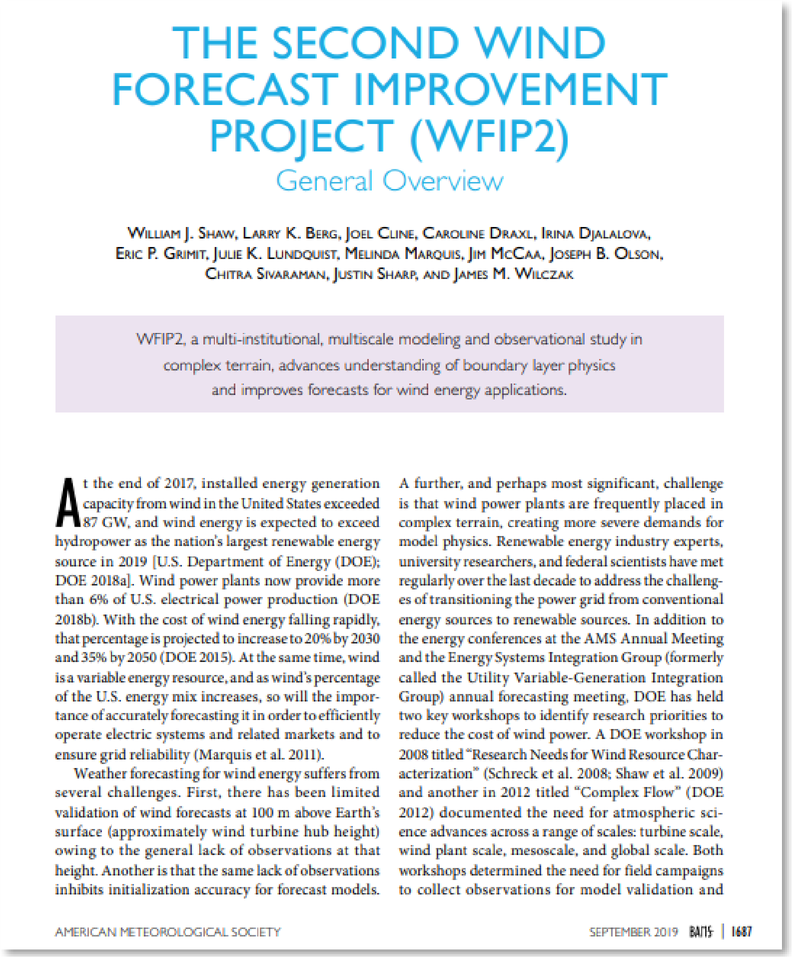
WP1: Global Coordination in Forecast Model Improvement

- Subtasks:
  - Subtask 1.1: Compile list of available wind data sets, especially from near the hub height of modern turbines (>100m a.g.l.).
  - Subtask 1.2: Annual reports documenting and announcing field measurement programs and availability of data. Ensure usable data description.
  - Subtask 1.3: Verify and Validate the improvements through one or more common data sets to test model results upon and discuss at IEA Task meetings
  - Subtask 1.4: Work closely together with the international modeling centers to include energy forecast metrics in NWP model upgrades.
- Deliverables
  - D 1.1: Annual summary of major field studies supportive of wind forecast improvement; list of available data
  - D 1.2: Common benchmark for V&V: definition, release and analysis of results as a paper
  - D 1.3: Report on future issues for research in wind power prediction

Second Wind Forecast Improvement Project (WFIP2)



Second Wind Forecast Improvement Project (WFIP2)



THE SECOND WIND FORECAST IMPROVEMENT PROJECT (WFIP2)

General Overview

William J. Shaw, Larry K. Berg, Joel Cline, Caroline Draxl, Irina Djalalova,
Eric P. Grimit, Julie K. Lundquist, Melinda Marquis, Jim McCaa, Joseph B. Olson,
Chitra Sivaraman, Justin Sharp, and James M. Wilczak

WFIP2, a multi-institutional, multiscale modeling and observational study in complex terrain, advances understanding of boundary layer physics and improves forecasts for wind energy applications.

At the end of 2017, installed energy generation capacity from wind in the United States exceeded 87 GW, and wind energy is expected to exceed hydropower as the nation's largest renewable energy source in 2019 [U.S. Department of Energy (DOE); DOE 2018a]. Wind power plants now provide more than 6% of U.S. electrical power production (DOE 2018b). With the cost of wind energy falling rapidly, that percentage is projected to increase to 20% by 2030 and 35% by 2050 (DOE 2015). At the same time, wind is a variable energy resource, and as wind's percentage of the U.S. energy mix increases, so will the importance of accurately forecasting it in order to efficiently operate electric systems and related markets and to ensure grid reliability (Marquis et al. 2011).

Weather forecasting for wind energy suffers from several challenges. First, there has been limited validation of wind forecasts at 100 m above Earth's surface (approximately wind turbine hub height) owing to the general lack of observations at that height. Another is that the same lack of observations inhibits initialization accuracy for forecast models. A further, and perhaps most significant, challenge is that wind power plants are frequently placed in complex terrain, creating more severe demands for model physics. Renewable energy industry experts, university researchers, and federal scientists have met regularly over the last decade to address the challenges of transitioning the power grid from conventional energy sources to renewable sources. In addition to the energy conferences at the AMS Annual Meeting and the Energy Systems Integration Group (formerly called the Utility Variable-Generation Integration Group) annual forecasting meeting, DOE has held two key workshops to identify research priorities to reduce the cost of wind power. A DOE workshop in 2008 titled "Research Needs for Wind Resource Characterization" (Schreck et al. 2008; Shaw et al. 2009) and another in 2012 titled "Complex Flow" (DOE 2012) documented the need for atmospheric science advances across a range of scales: turbine scale, wind plant scale, mesoscale, and global scale. Both workshops determined the need for field campaigns to collect observations for model validation and

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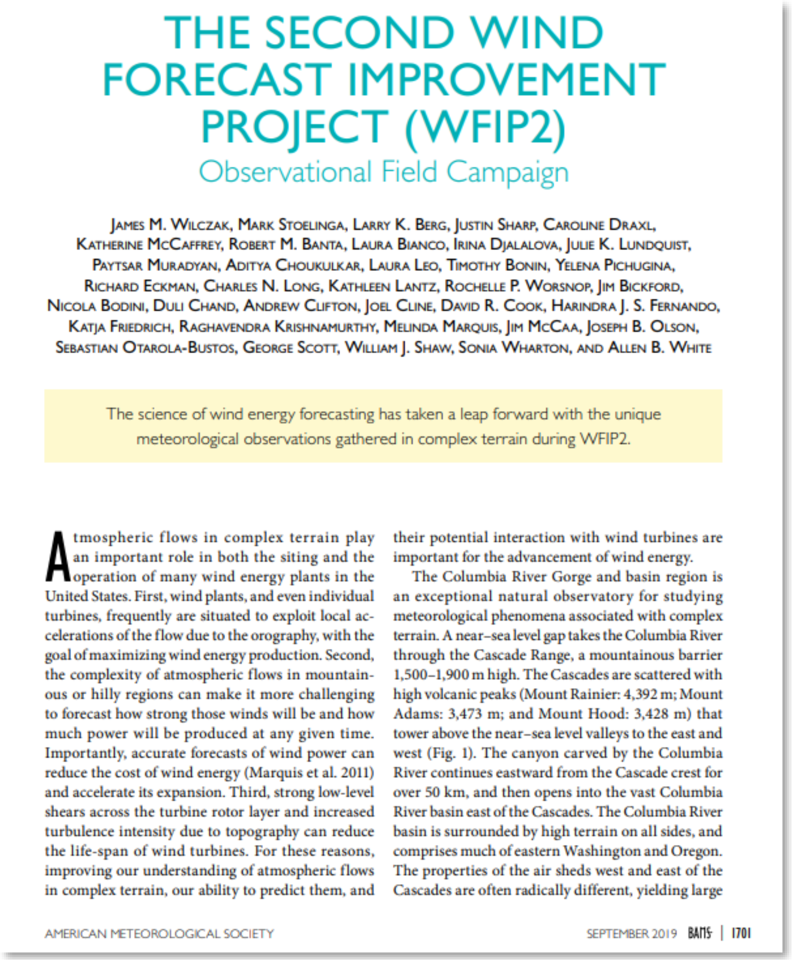

THE SECOND WIND FORECAST IMPROVEMENT PROJECT (WFIP2)

Observational Field Campaign

James M. Wilczak, Mark Stoelinga, Larry K. Berg, Justin Sharp, Caroline Draxl,
Katherine McCaffrey, Robert M. Banta, Laura Bianco, Irina Djalalova, Julie K. Lundquist,
Paytsar Muradyan, Aditya Choukulkar, Laura Leo, Timothy Bonin, Yelena Pichugina,
Richard Eckman, Charles N. Long, Kathleen Lantz, Rochelle P. Worsnop, Jim Bickford,
Nicola Bodini, Duli Chand, Andrew Clifton, Joel Cline, David R. Cook, Harindra J. S. Fernando,
Katja Friedrich, Raghavendra Krishnamurthy, Melinda Marquis, Jim McCaa, Joseph B. Olson,
Sebastian Otarola-Bustos, George Scott, William J. Shaw, Sonia Wharton, and Allen B. White

The science of wind energy forecasting has taken a leap forward with the unique meteorological observations gathered in complex terrain during WFIP2.

Atmospheric flows in complex terrain play an important role in both the siting and the operation of many wind energy plants in the United States. First, wind plants, and even individual turbines, frequently are situated to exploit local accelerations of the flow due to the orography, with the goal of maximizing wind energy production. Second, the complexity of atmospheric flows in mountainous or hilly regions can make it more challenging to forecast how strong those winds will be and how much power will be produced at any given time. Importantly, accurate forecasts of wind power can reduce the cost of wind energy (Marquis et al. 2011) and accelerate its expansion. Third, strong low-level shears across the turbine rotor layer and increased turbulence intensity due to topography can reduce the life-span of wind turbines. For these reasons, improving our understanding of atmospheric flows in complex terrain, our ability to predict them, and their potential interaction with wind turbines are important for the advancement of wind energy.

The Columbia River Gorge and basin region is an exceptional natural observatory for studying meteorological phenomena associated with complex terrain. A near–sea level gap takes the Columbia River through the Cascade Range, a mountainous barrier 1,500–1,900 m high. The Cascades are scattered with high volcanic peaks (Mount Rainier: 4,392 m; Mount Adams: 3,473 m; and Mount Hood: 3,428 m) that tower above the near–sea level valleys to the east and west (Fig. 1). The canyon carved by the Columbia River continues eastward from the Cascade crest for over 50 km, and then opens into the vast Columbia River basin east of the Cascades. The Columbia River basin is surrounded by high terrain on all sides, and comprises much of eastern Washington and Oregon. The properties of the air sheds west and east of the Cascades are often radically different, yielding large

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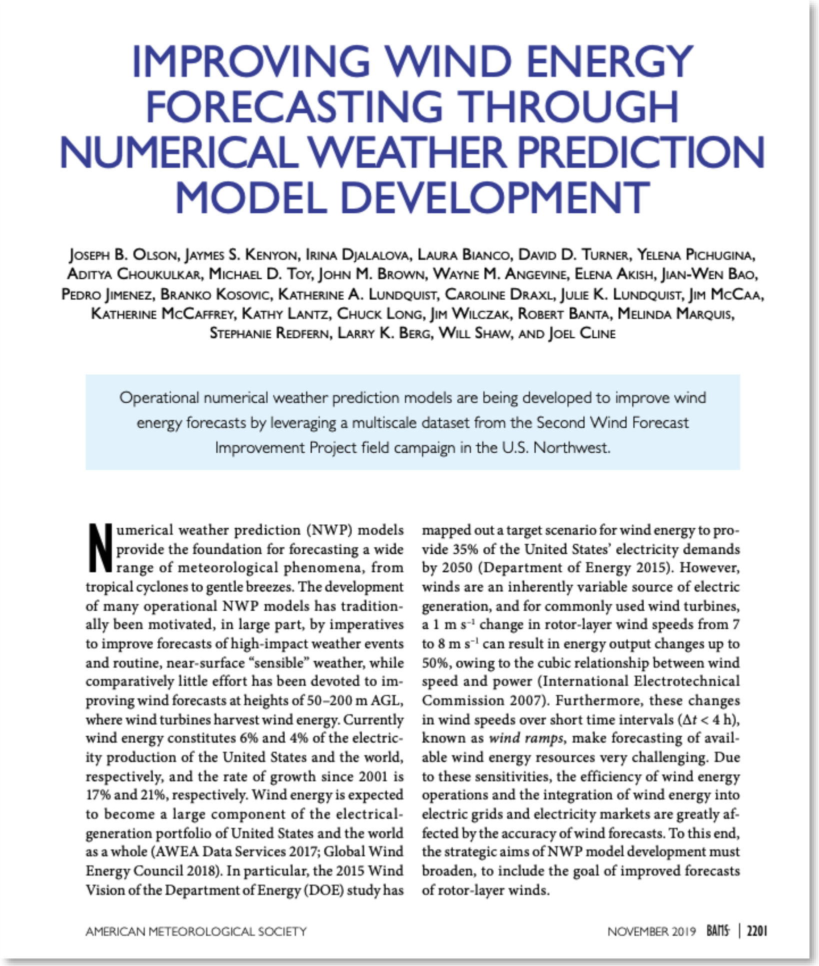


IMPROVING WIND ENERGY FORECASTING THROUGH NUMERICAL WEATHER PREDICTION MODEL DEVELOPMENT

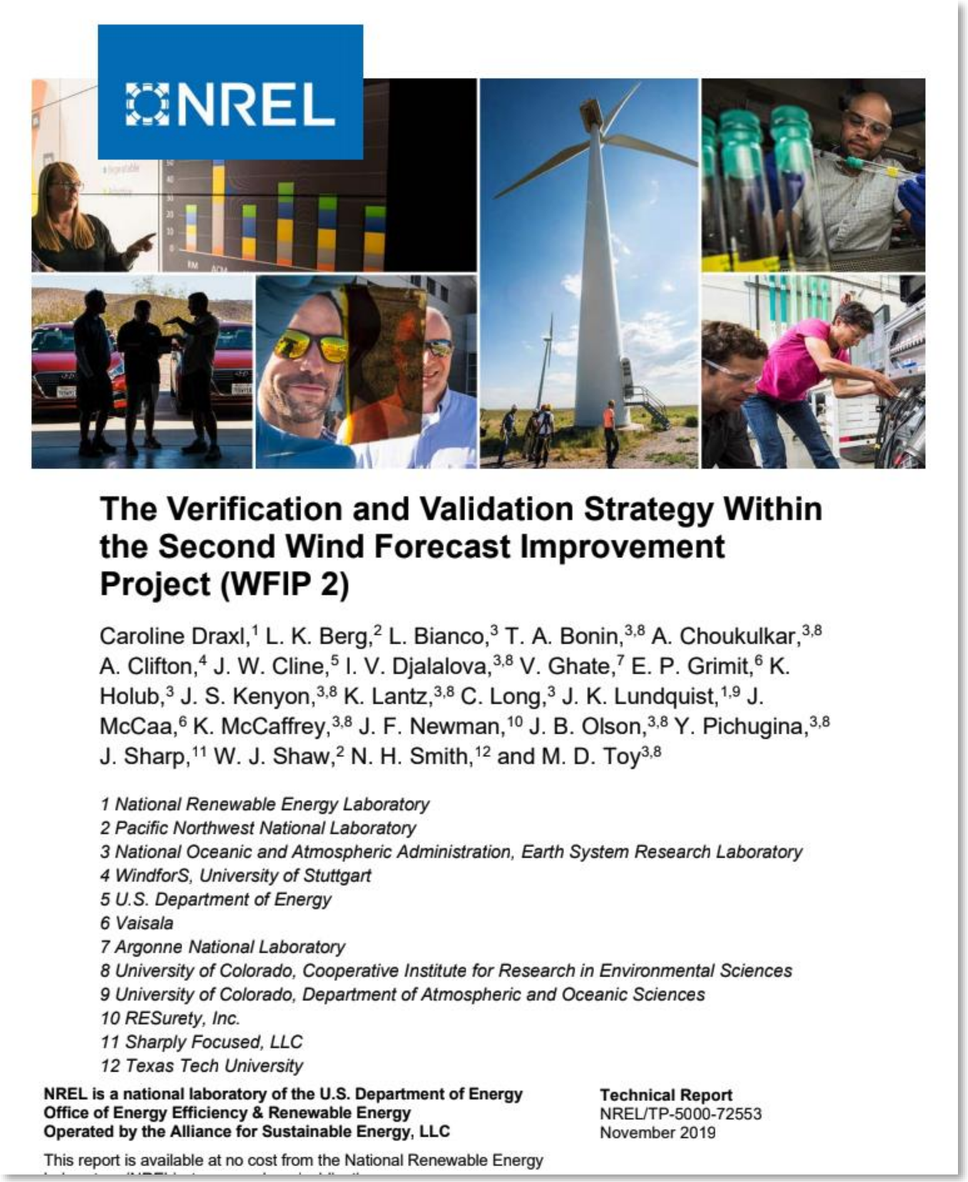
Joseph B. Olson, Jaymes S. Kenyon, Irina Djalalova, Laura Bianco, David D. Turner, Yelena Pichugina,
Aditya Choukulkar, Michael D. Toy, John M. Brown, Wayne M. Angevine, Elena Akish, Jian-Wen Bao,
Pedro Jimenez, Branko Kosovic, Katherine A. Lundquist, Caroline Draxl, Julie K. Lundquist, Jim McCaa,
Katherine McCaffrey, Kathy Lantz, Chuck Long, Jim Wilczak, Robert Banta, Melinda Marquis,
Stephanie Redfern, Larry K. Berg, Will Shaw, and Joel Cline

Operational numerical weather prediction models are being developed to improve wind energy forecasts by leveraging a multiscale dataset from the Second Wind Forecast Improvement Project field campaign in the U.S. Northwest.

Numerical weather prediction (NWP) models provide the foundation for forecasting a wide range of meteorological phenomena, from tropical cyclones to gentle breezes. The development of many operational NWP models has traditionally been motivated, in large part, by imperatives to improve forecasts of high-impact weather events and routine, near-surface "sensible" weather, while comparatively little effort has been devoted to improving wind forecasts at heights of 50–200 m AGL, where wind turbines harvest wind energy. Currently wind energy constitutes 6% and 4% of the electricity production of the United States and the world, respectively, and the rate of growth since 2001 is 17% and 21%, respectively. Wind energy is expected to become a large component of the electrical-generation portfolio of United States and the world as a whole (AWEA Data Services 2017; Global Wind Energy Council 2018). In particular, the 2015 Wind Vision of the Department of Energy (DOE) study has mapped out a target scenario for wind energy to provide 35% of the United States' electricity demands by 2050 (Department of Energy 2015). However, winds are an inherently variable source of electric generation, and for commonly used wind turbines, a 1 m s^{-1} change in rotor-layer wind speeds from 7 to 8 m s^{-1} can result in energy output changes up to 50%, owing to the cubic relationship between wind speed and power (International Electrotechnical Commission 2007). Furthermore, these changes in wind speeds over short time intervals ($\Delta t < 4$ h), known as *wind ramps*, make forecasting of available wind energy resources very challenging. Due to these sensitivities, the efficiency of wind energy operations and the integration of wind energy into electric grids and electricity markets are greatly affected by the accuracy of wind forecasts. To this end, the strategic aims of NWP model development must broaden, to include the goal of improved forecasts of rotor-layer winds.

WFIP2 Verification and Validation (V&V)

- WFIP2 V&V Goals
  - Provide tools, methods, and guidance to enable repeatable, metrics-based assessment of WRF and HRRR for analysis and forecasting of mesoscale weather phenomena that are important for wind energy in the Columbia River Gorge and CONUS.
- Verification
  - Verification is concerned with checking the mechanics of the software code rather than checking that the model's physics are correct.
- Validation
  - Validation is determining the degree to which the model represents the real world for a particular application.



NREL

The Verification and Validation Strategy Within the Second Wind Forecast Improvement Project (WFIP 2)

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2 Pacific Northwest National Laboratory
3 National Oceanic and Atmospheric Administration, Earth System Research Laboratory
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5 U.S. Department of Energy
6 Vaisala
7 Argonne National Laboratory
8 University of Colorado, Cooperative Institute for Research in Environmental Sciences
9 University of Colorado, Department of Atmospheric and Oceanic Sciences
10 RESurety, Inc.
11 Sharply Focused, LLC
12 Texas Tech University

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

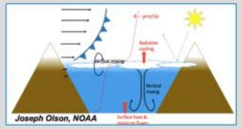
Technical Report
NREL/TP-5000-72553
November 2019

WFIP2 Approach to V&V

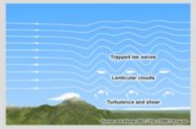
WFIP 2 Weather Taxonomy

Gap Flows

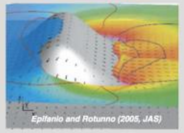
Cold Pool Mix-Outs



Mountain Waves



Orographic Wakes


Epifanio and Rotunno (2005, JAS)

Marine Pushes/Thermal Troughs


http://www.wikiwand.com/en/June_Gloom

Common case study data set to test validation code

EVS validation tool and data base

● TimeSeries ○ Profile ○ Scatter2d

LABEL Curve0
DATA-SOURCE a2e LIDAR
DISCRIMINATOR Surface Bulk Richardson Number
UPPER 2
LOWER -5
STATISTIC mean
REGION WFIP2 whole domain
VALID UTC HOUR All
SITES Troutdale, OR
SITESMAP 0
SITE-COMPLETENESS 0
VARIABLE Wind Speed
FORECAST LEAD TIME unused
TOP 200
BOTTOM 40
LEVEL-COMPLETENESS 0
DATES 3/25/2018 00:00 - 4/24/2018 00:00

Key variables and metrics:

- 80 m wind speed
- wind power
- Bulk rotor layer statistics (RMSE, bias, MAE, % improvement)
- wind ramp metric

Experiment to Model Analysis Table (EMAT):

- What, where, when?
- What are the dominant physics?
- How do we see this in measurements?
- What are the metrics we should use?

Event Log

PI Interviews

Case Study Report Template

Workshops to compare validation results and test EVS tool

Regular V&V meetings to discuss and coordinate results

Model Testing Framework

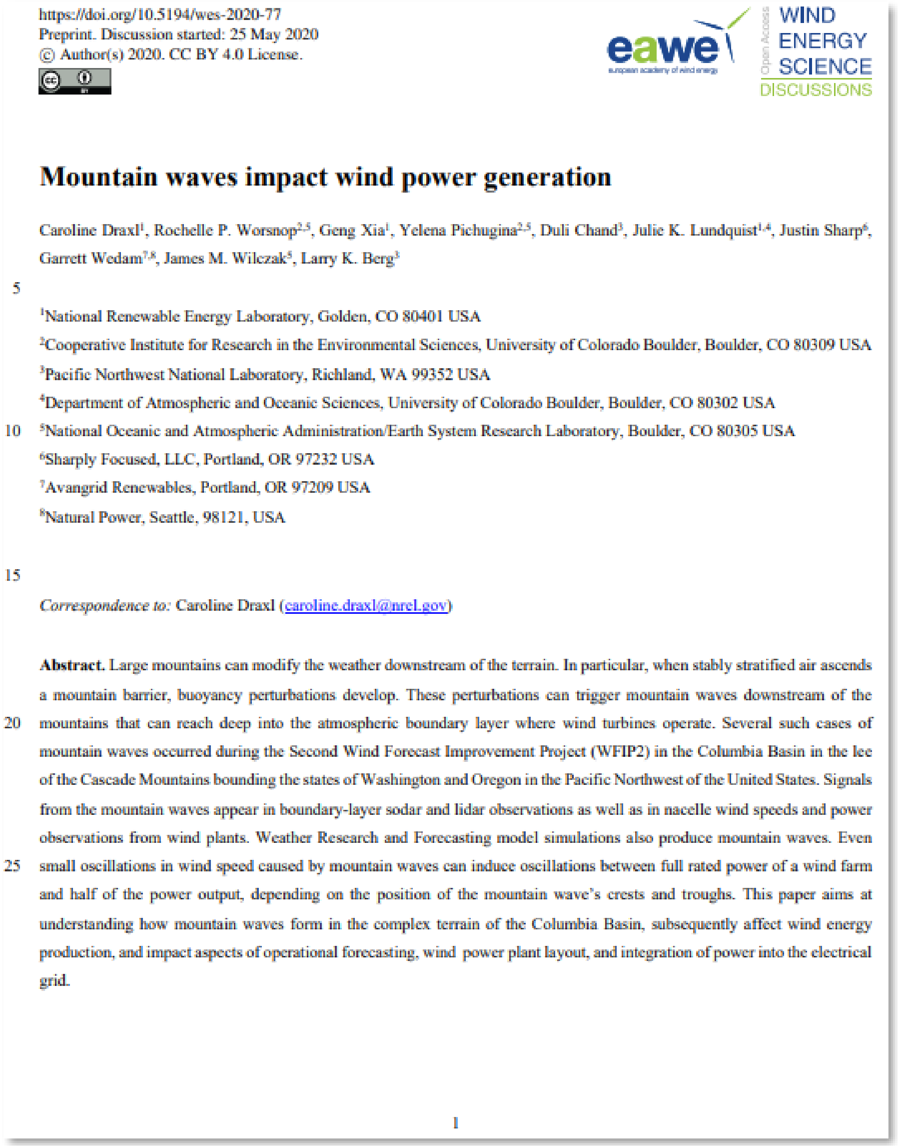
Plans for IEA Wind Task 36 Benchmark

- Experience from WFIP2
  - Tested a case study
    - Provided a time series with hourly time stamps
    - Everyone used their own scripts to calculate RMSE and bias
    - Provided results
  - Outcome: Different results
    - Different results due to wrong interpretations of time stamp
    - Different averaging techniques in horizontal and vertical
  - Motivation for Task 36

- Work for Task 36
  - Focus is on methodology
  - Select case study from WFIP2
    - Data are freely available
    - Observations *already* available
  - Reproducible by participants
    - WRF model
    - Benchmark output provided
      - Control and experimental (improved) runs
      - Observations provided
    - Validation framework provided

Case Selection

- Mountain Gravity Waves
  - WFIP2 cases analyzed
  - Challenging due to multiple time and spatial scales
- Team to Provide
  - WRF setup files/output
  - Observations
  - Defined 24-hr period
  - Documentation
- Task 36 Engagement
  - Concept discussion
  - Case reproduction/extension



https://doi.org/10.5194/wes-2020-77
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WIND ENERGY SCIENCE DISCUSSIONS

Mountain waves impact wind power generation

Caroline Draxl[1], Rochelle P. Worsnop[2,5], Geng Xia[1], Yelena Pichugina[2,5], Duli Chand[3], Julie K. Lundquist[1,4], Justin Sharp[6], Garrett Wedam[7,8], James M. Wilczak[5], Larry K. Berg[3]

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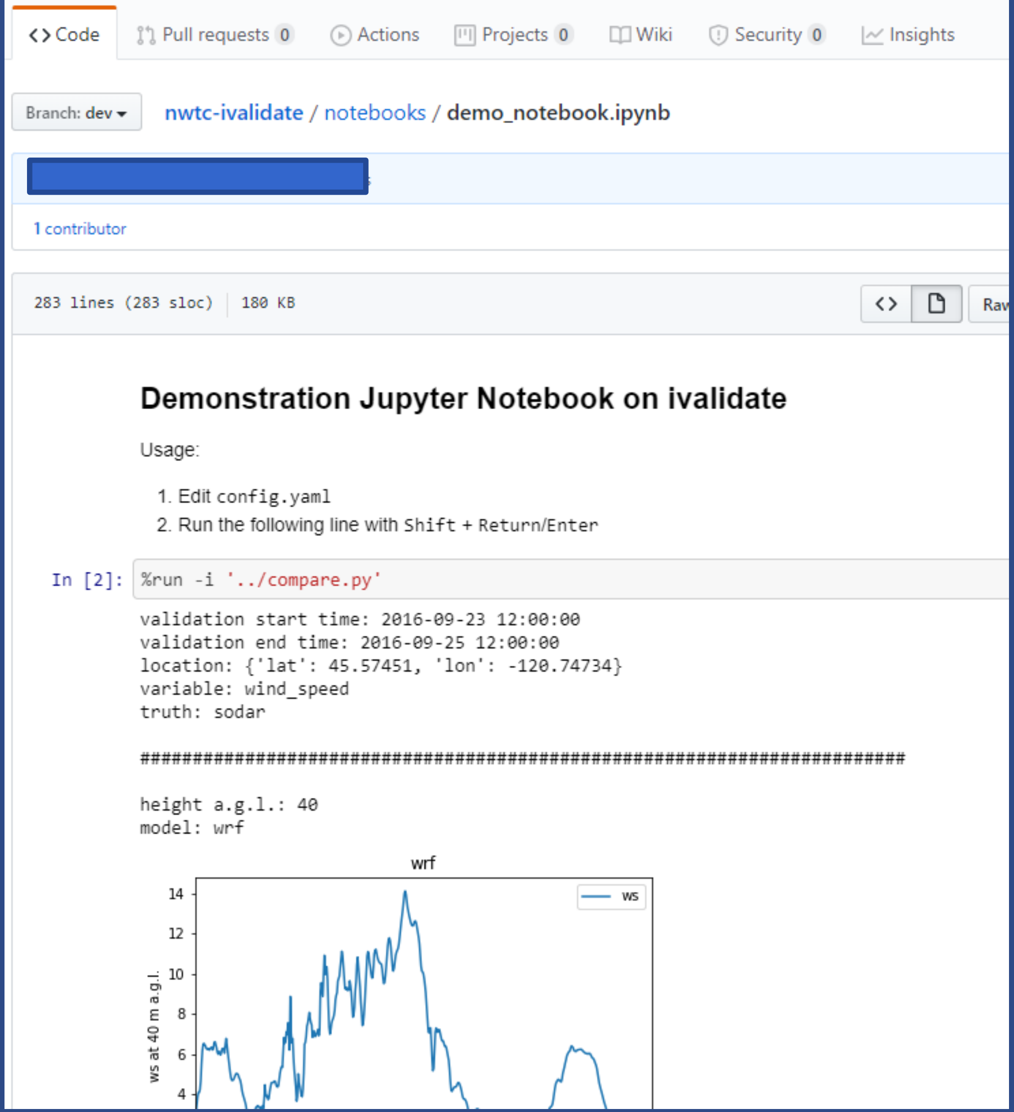
Abstract. Large mountains can modify the weather downstream of the terrain. In particular, when stably stratified air ascends a mountain barrier, buoyancy perturbations develop. These perturbations can trigger mountain waves downstream of the mountains that can reach deep into the atmospheric boundary layer where wind turbines operate. Several such cases of mountain waves occurred during the Second Wind Forecast Improvement Project (WFIP2) in the Columbia Basin in the lee of the Cascade Mountains bounding the states of Washington and Oregon in the Pacific Northwest of the United States. Signals from the mountain waves appear in boundary-layer sodar and lidar observations as well as in nacelle wind speeds and power observations from wind plants. Weather Research and Forecasting model simulations also produce mountain waves. Even small oscillations in wind speed caused by mountain waves can induce oscillations between full rated power of a wind farm and half of the power output, depending on the position of the mountain wave's crests and troughs. This paper aims at understanding how mountain waves form in the complex terrain of the Columbia Basin, subsequently affect wind energy production, and impact aspects of operational forecasting, wind power plant layout, and integration of power into the electrical grid.

Dissemination

- A2e Data Archive and Portal
  - WRF setup files/output
  - Observations
- Validation Framework
  - Bulk rotor layer statistics (RMSE, bias, MAE), NOAA wind ramp metric
- Framework Communication
  - Via GitHub
  - Jupyter notebook
  - R code as second option
- Documentation
  - Report/journal article
  - Perhaps recommended practice
- Invitation to collaborate
  - To provide feedback
  - To extend cases



nwtc-ivalidate / notebooks / demo_notebook.ipynb

[redacted]

1 contributor

283 lines (283 sloc) | 180 KB

Demonstration Jupyter Notebook on ivalidate

Usage:

1. Edit `config.yaml`
2. Run the following line with `Shift + Return/Enter`

```
In [2]: %run -i '../compare.py'
```

```
validation start time: 2016-09-23 12:00:00
validation end time: 2016-09-25 12:00:00
location: {'lat': 45.57451, 'lon': -120.74734}
variable: wind_speed
truth: sodar

##########################################################################

height a.g.l.: 40
model: wrf
```