



# Applying the WIND Toolkit and WTK-LED to Grid Integration

Luke Lavin  
Caroline Draxl  
Greg Brinkman


National Renewable Energy Laboratory (NREL)

June 11, 2024



With thanks to

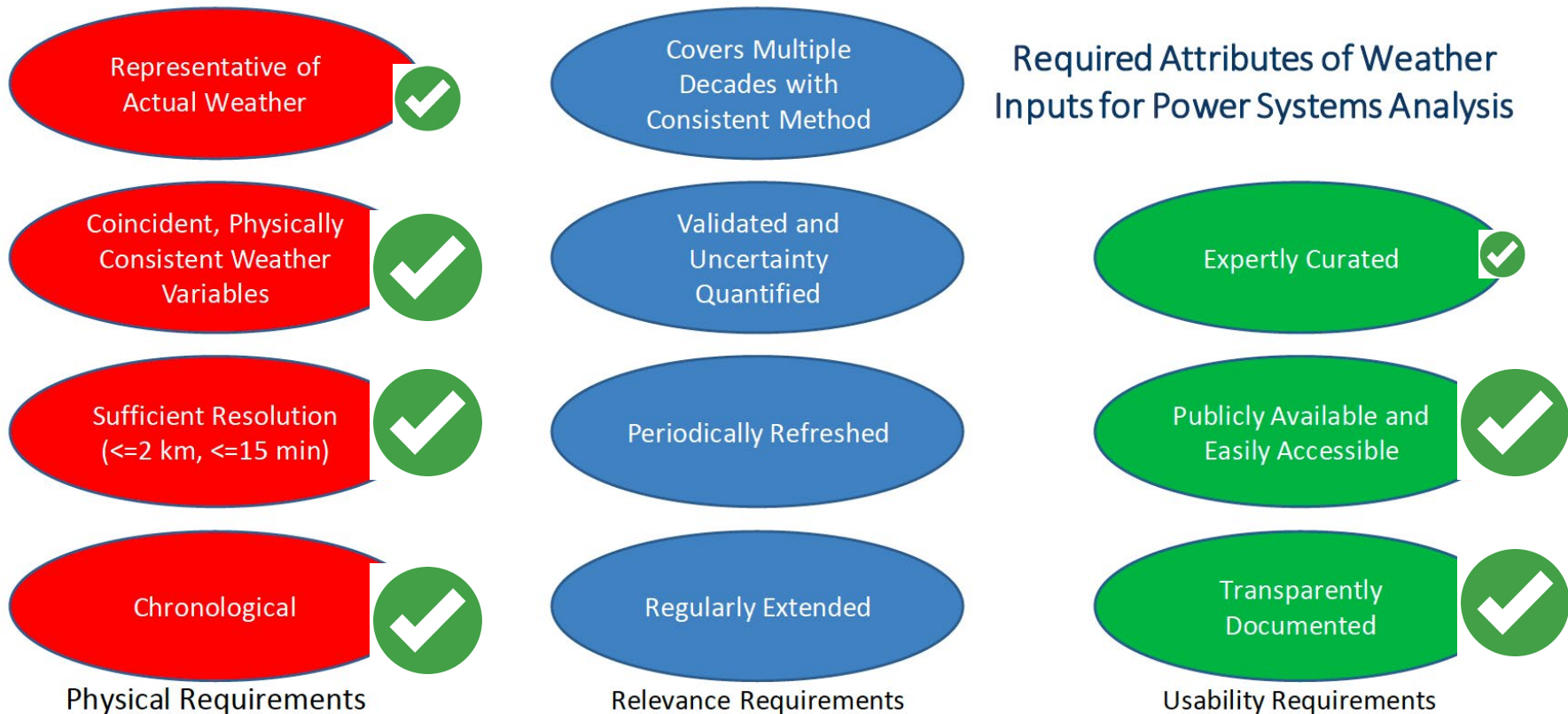
Trieu Mai  
Dave Corbus  
Grant Buster  
Becca Fuchs  
Victor Igwe  
And our March 2024 workshop participants!

A topographic map of the United States showing state boundaries and major water bodies. The map uses a color gradient from light yellow to dark blue to represent elevation. The Great Lakes region is highlighted in a darker blue. The text "Growing need for more high-quality resource data for power systems applications" is overlaid in white on a semi-transparent blue background across the center of the map.

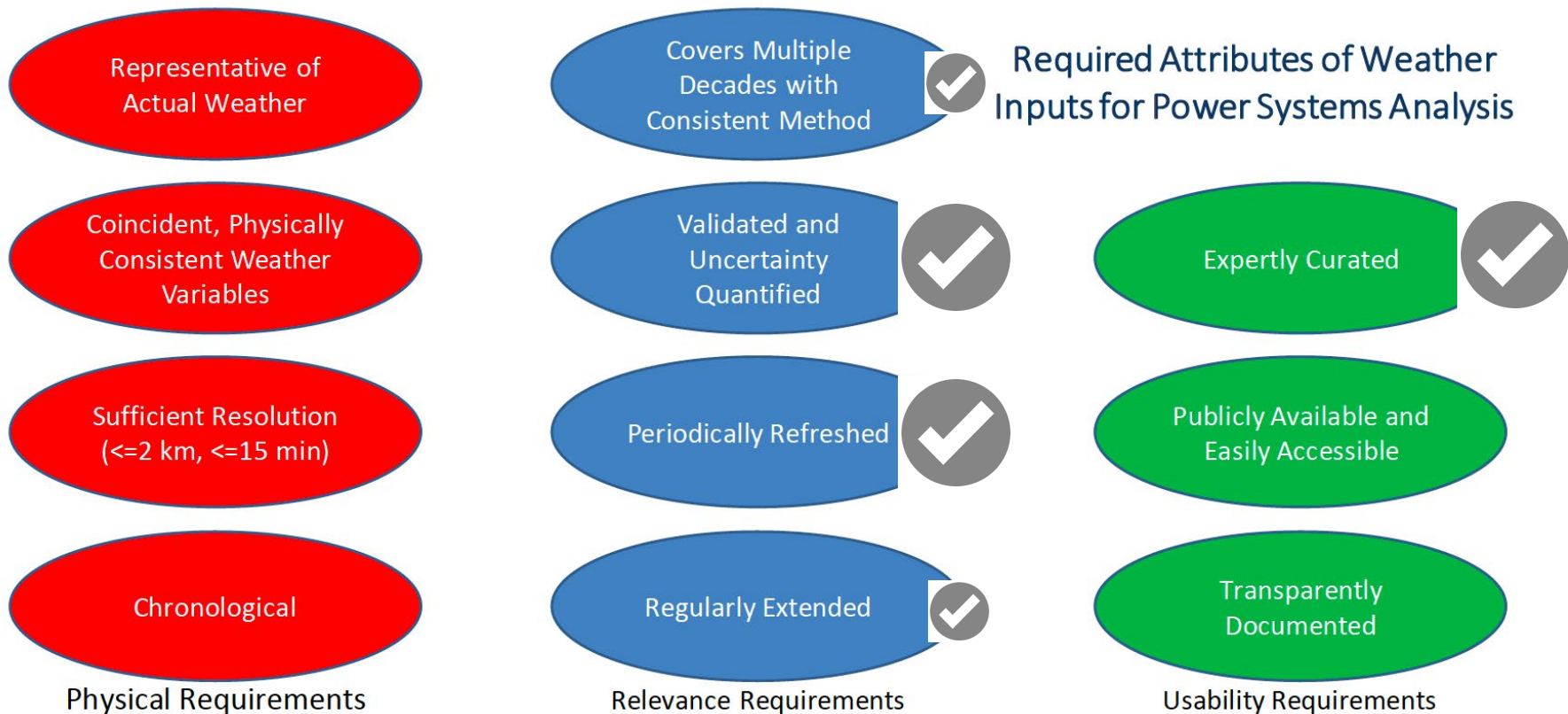
**Growing need for more high-quality resource data  
for power systems applications**



# New WIND Toolkit Long-Term Ensemble Dataset covers many physical and usability requirements for grid integration



# Ongoing NREL work will address curation and validation



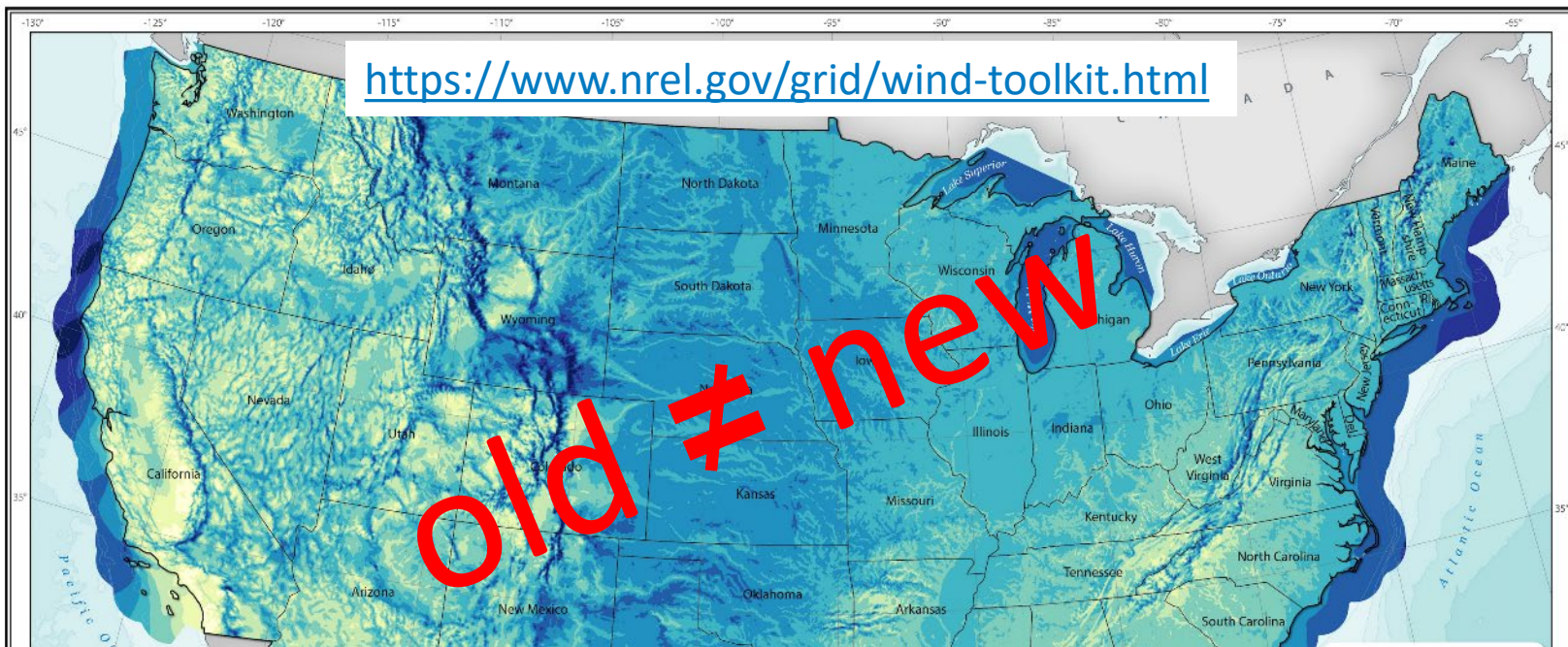
Gray checkmarks represent ongoing work with WTK-LED and NREL-adjusted HRRR data to be discussed

A topographic map of the United States, showing state boundaries and major geographical features. The map uses a color gradient from light yellow to dark blue to represent elevation. A semi-transparent grey rectangular box is overlaid on the map, containing white text. The text reads: "Release of the Wind Toolkit Long-term Ensemble (WTK-LED) dataset".

Release of the Wind Toolkit Long-term Ensemble  
(WTK-LED) dataset



<https://www.nrel.gov/grid/wind-toolkit.html>



### Original WIND Toolkit:

- 7 years (2007–2013) at 2 kilometers (km), 5 minutes (min)
- Deterministic dataset containing meteorological and power data
- Contiguous United States (CONUS)
- **Developed as a grid integration dataset to mimic forecast errors.**

### WIND Toolkit LED:

- Updated Weather Research and Forecasting version (4.1.3)
- CONUS, Alaska, and Hawaii for 2018, 2019, and 2020 at 2 km, 5 min
- North America Climate dataset covering 20 years (2001–2020) at 4 km, hourly
- Model uncertainty quantified (ensembles)
- *NO power forecasts.*

# WTK-LED comprised of three available datasets

**Recall:** No power forecasts this time!

**1**

CONUS

Alaska/Hawaii

**2**

North

America

**3**

NOW-23

*Offshore*

Time  
resolution

**5 minutes**

**1 hour**

**5 minutes**

Spatial  
Resolution

**2 kilometers**

**4 kilometers**

**2 kilometers**

Years  
covered

**2018-2020**

**2001-2020**

**20+ years**

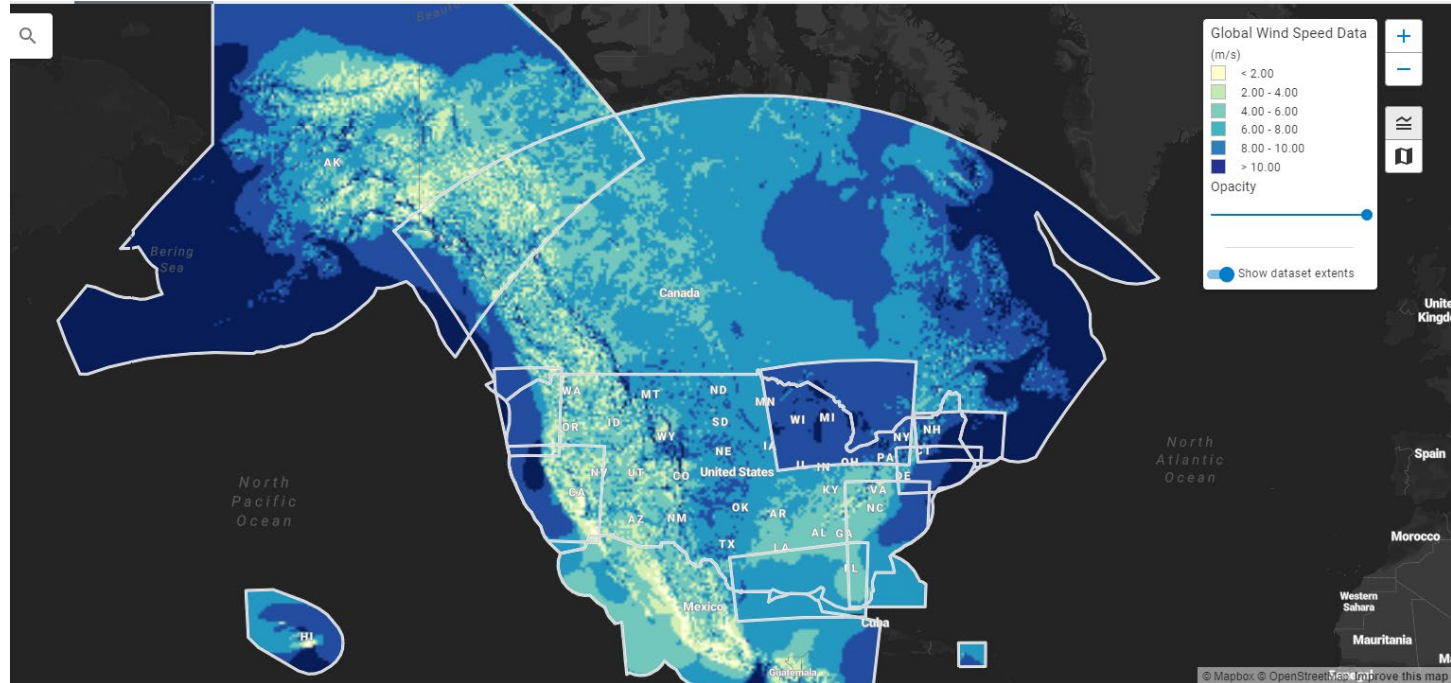
# Maps and data is available online

The screenshot displays the WINDExchange website interface. At the top, the logo for the Office of Energy Efficiency & Renewable Energy is visible, along with the WINDExchange name and a search bar. A navigation menu includes categories like Market Sectors, Project Development, Technical Assistance, Education & Workforce Development, Maps & Data, Policies & Incentives, Publications, and News & Events. The main content area features a 'Wind information by state' section with a dropdown menu to 'select a state' and a map of the United States. Below this, there are sections for 'Utility-Scale Wind' (Land-Based and Offshore) and 'Distributed Wind' (Community and Residential). A 'Maps & Data' section includes a tutorial on understanding wind resource maps and several map thumbnails for Land-Based Wind Resource Maps (80m), Installed Capacity Wind Maps, Wind Speed Maps (100m), and Offshore Wind Maps. A 'Project Development' section offers resources for Site Selection, Economic Costs & Incentives, Wildlife Impacts, and Community Impacts. A 'Technical Assistance' section provides access to models, data, tools, and guidebooks, along with frequently asked questions.

<https://windexchange.energy.gov>



# Maps and **data** is available online



[wrdb.nrel.gov](http://wrdb.nrel.gov) (also on AWS)

# Uncertainty estimates included, but no full validation for grid integration

## Intended stakeholders:

- distributed and utility scale wind industry
- airborne wind energy
- grid integration
- power systems modeling
- environmental modeling

1

CONUS  
Alaska/Hawaii

2

North  
America

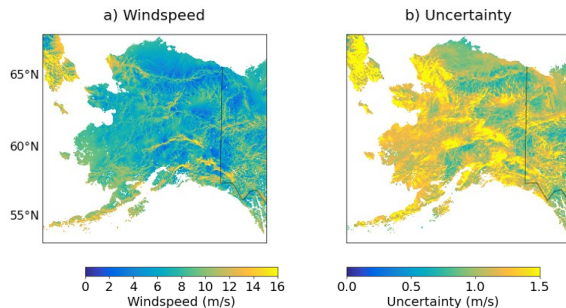
3

NOW-23  
*Offshore*

## Authors' intended use statements

grid integration studies ( <i>a priori validation required</i> )	wind resource estimates (interannual variability, seasonal variability); annual, monthly, diurnal signals	offshore grid integration studies ( <i>a priori validation required</i> )
------------------------------------------------------------------	-----------------------------------------------------------------------------------------------------------	---------------------------------------------------------------------------

## Uncertainty estimates



A topographic map of the United States, color-coded by elevation. The map shows state boundaries and labels for various states including Oregon, Nevada, California, Arizona, New Mexico, Utah, Idaho, Wyoming, Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Arkansas, Missouri, Iowa, Minnesota, Wisconsin, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, New Jersey, Connecticut, Massachusetts, Rhode Island, New Hampshire, Vermont, New Mexico, Virginia, West Virginia, Kentucky, Tennessee, North Carolina, South Carolina, and Maine. The Great Lakes (Superior, Michigan, Huron, Erie, Ontario) and the Mississippi River are also labeled. The map is framed by latitude lines at 35° and 45° North and longitude lines. A semi-transparent grey box is overlaid on the map, containing the text "Validation efforts and data used for grid integration studies at NREL".

# Validation efforts and data used for grid integration studies at NREL



# Datasets used at NREL



Validation focused  
on 2019-2020

2007-2013 // 2014 2015 2016 2017 2018 2019 2020 2021

High Resolution Rapid  
Refresh (HRRR) (NOAA)

*2 km over CONUS; hourly*

BCHRRR (bias-corrected  
HRRR) (NOAA/NREL)

*2 km over CONUS; hourly*

WIND Toolkit Long-  
Term Ensemble  
(WTK-LED) (NREL)

*2 km over  
CONUS+HI+AK; 5min*

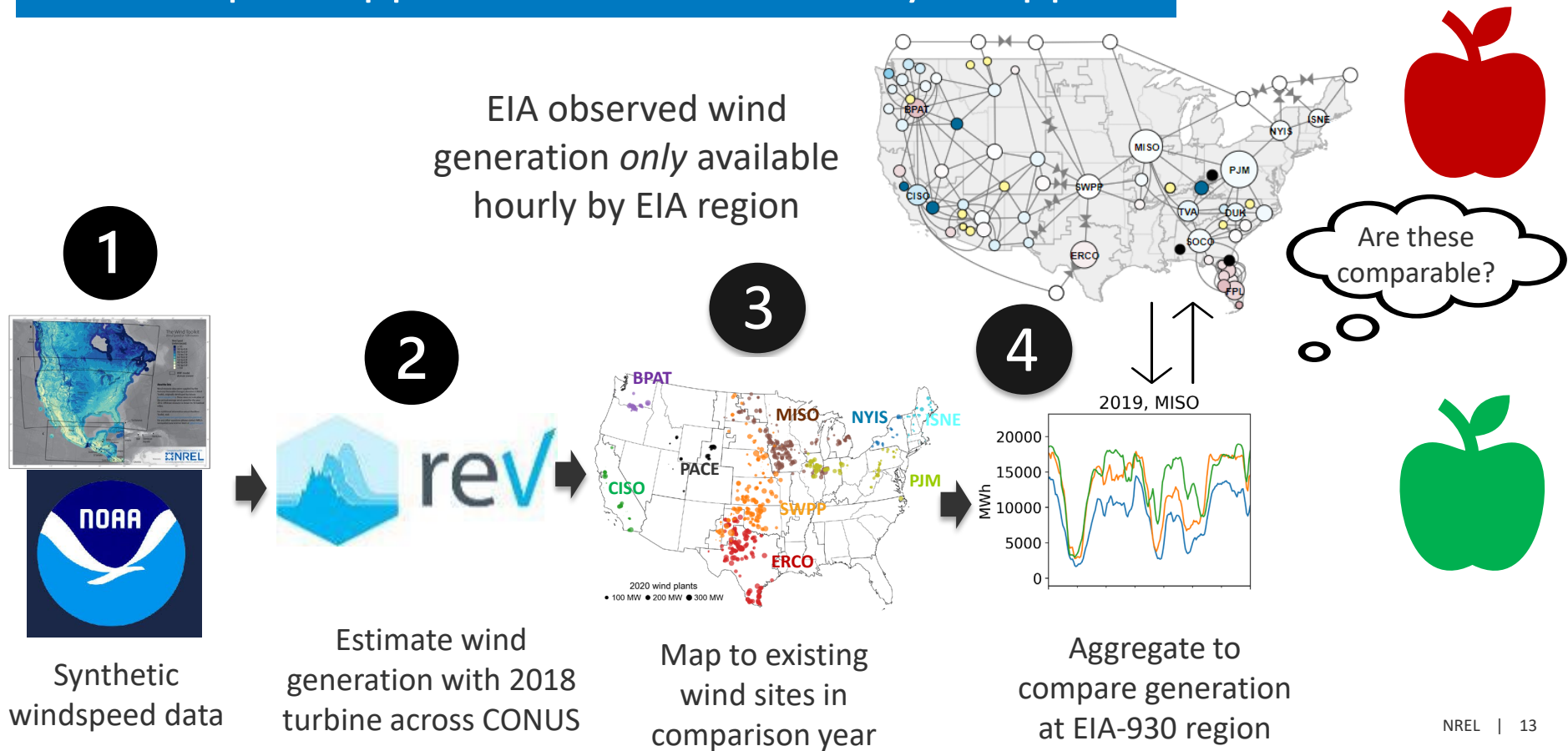
Historical WIND  
Toolkit (NREL)

*2 km over  
CONUS; 5min*

EIA-930 Generation  
Observations

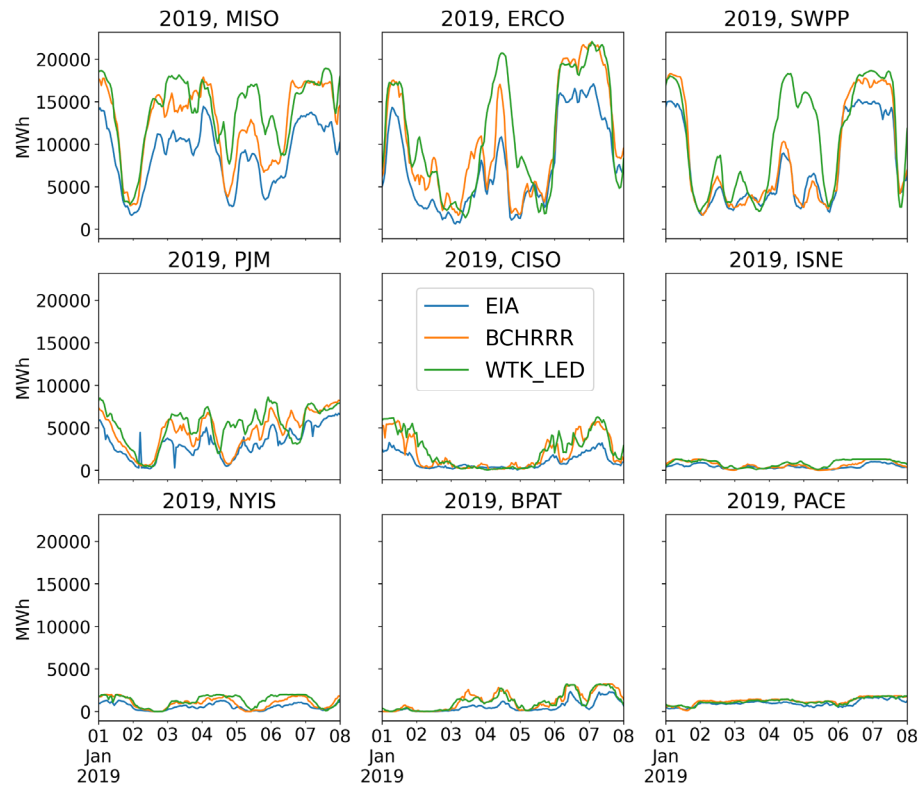
*EIA Regions, hourly*

# However, validating against EIA-930 requires trying to compare apples to a... similar variety of apple



# Adjacent NREL validation effort shows both new WTK-LED and bias-corrected HRRR correlate with regional generation observations

- WTK-LED and BCHRRR generation estimates higher than EIA-930
- Non-harmonized assumptions could drive overestimation, including:
  - High wind resource
  - Curtailment not included in reV
  - Wake losses (internal)
  - Installed capacity differences
  - Technology vintage inconsistencies between model and EIA
  - Inconsistent boundaries



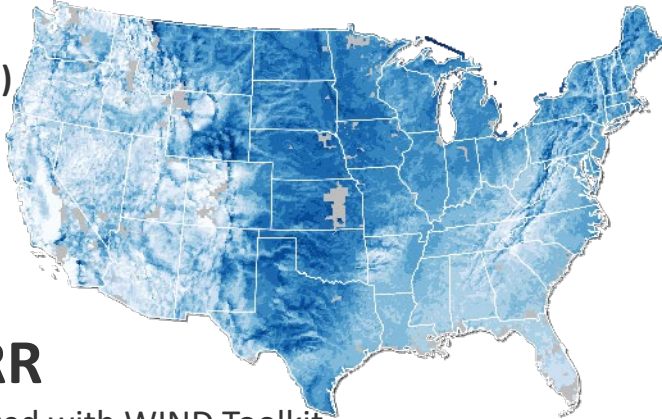
\*All timestamps Coordinated Universal Time (UTC)



# Wind capacity factors higher in WTK-LED

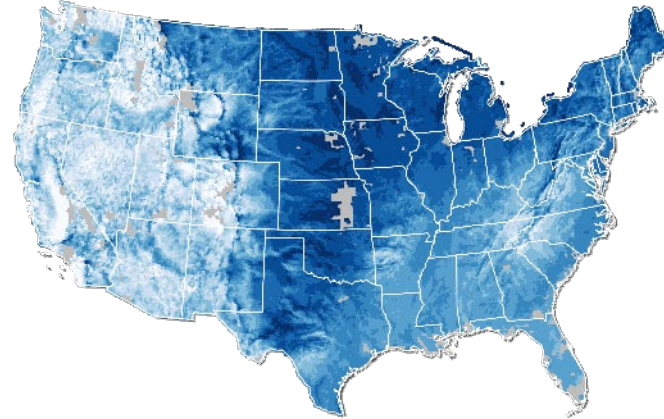
**WTK**

(2007-2013)



**WTK-LED**

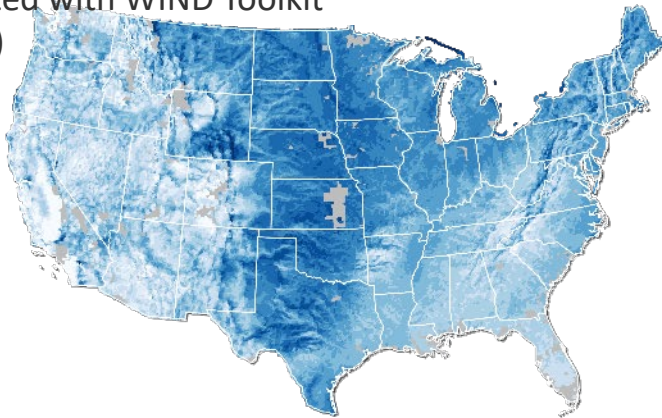
(2018-2019)



**BCHRRR**

Bias corrected with WIND Toolkit

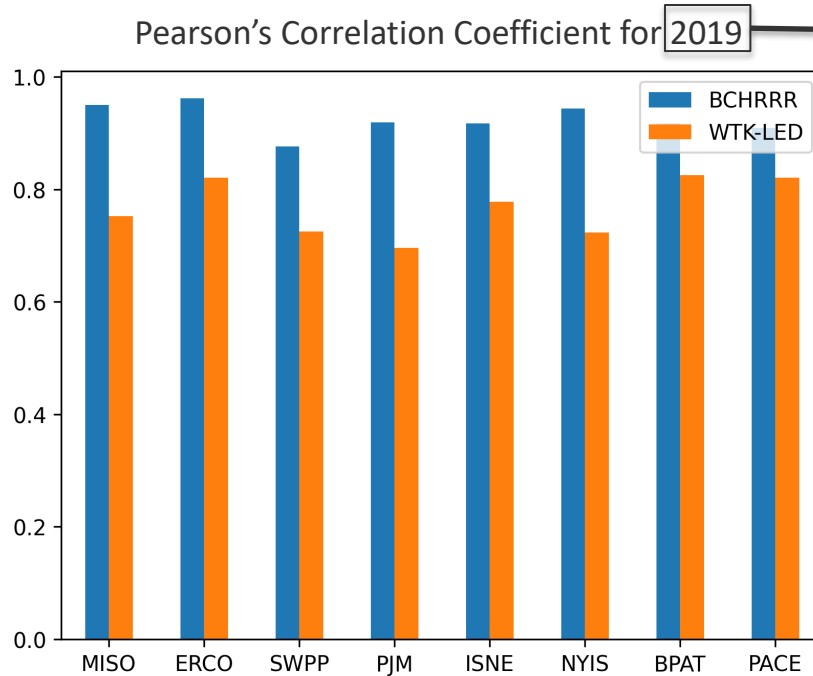
(2015-2021)



**Capacity Factor**



# Correlation shown in timeseries is present across full year of hourly wind data



Shows correlation over a longer time period than previous plots (Year vs Week)

Higher correlation of BCHRRR with EIA-930

HRRR data are taken from the analyses, not the forecasts.

# Conclusion of validation efforts and appropriate use of WTK-LED

Without a clearly defined end-use standard for grid integration studies it is challenging to say what “appropriate use” is, or what improvements would bridge a gap to making a specific atmospheric dataset the **gold standard**.



Recent workshop and survey to better align on what's most useful

**YOU CAN WEIGH IN SOON!**



# Recent workshop highlights further gaps ... and, you can also take a survey!

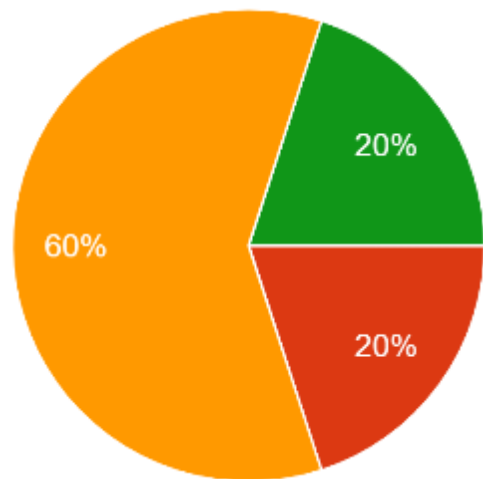


*Workshop participants touring the Flatirons Campus  
Photo from Justin Sharp*

# Grid integration practitioners use many atmospheric datasets

Which sector are you in?

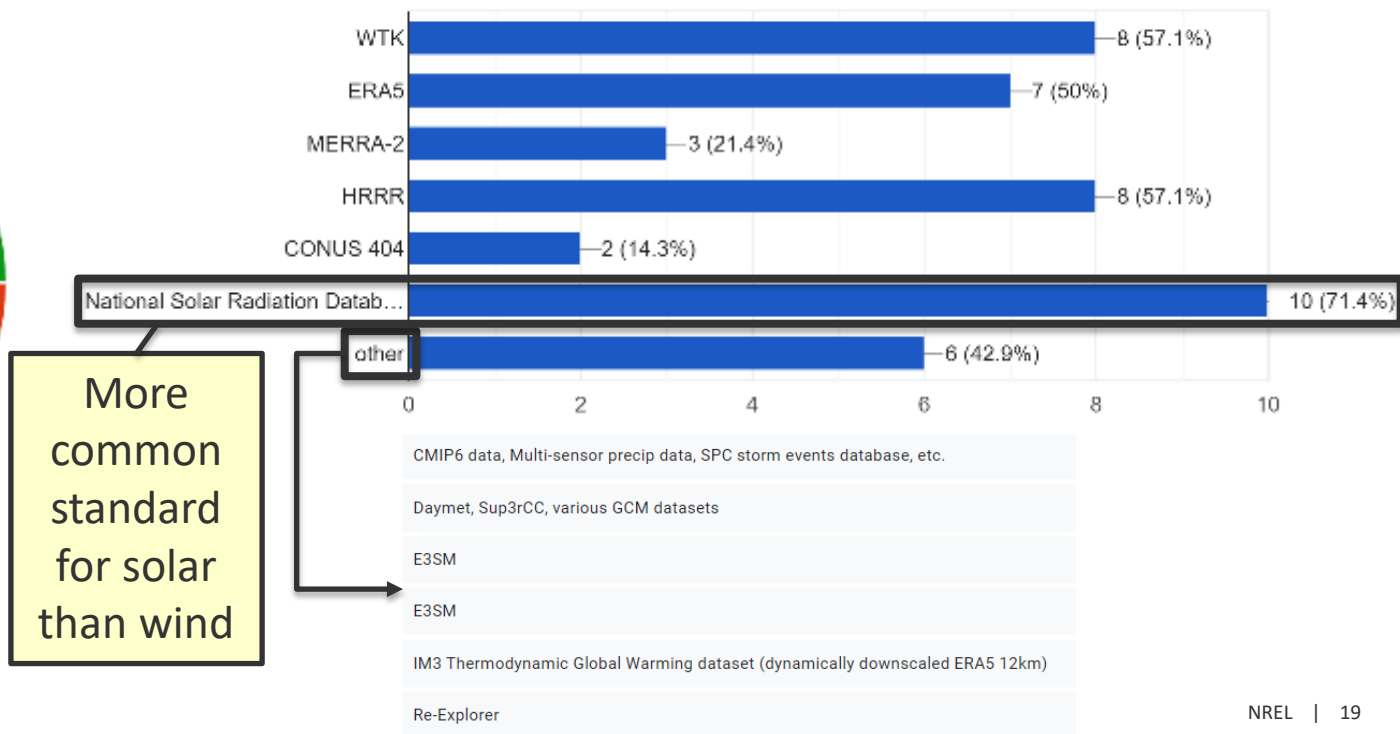
15 responses



- Industry
- National Lab
- Other

What atmospheric data set are you using for your grid integration studies?

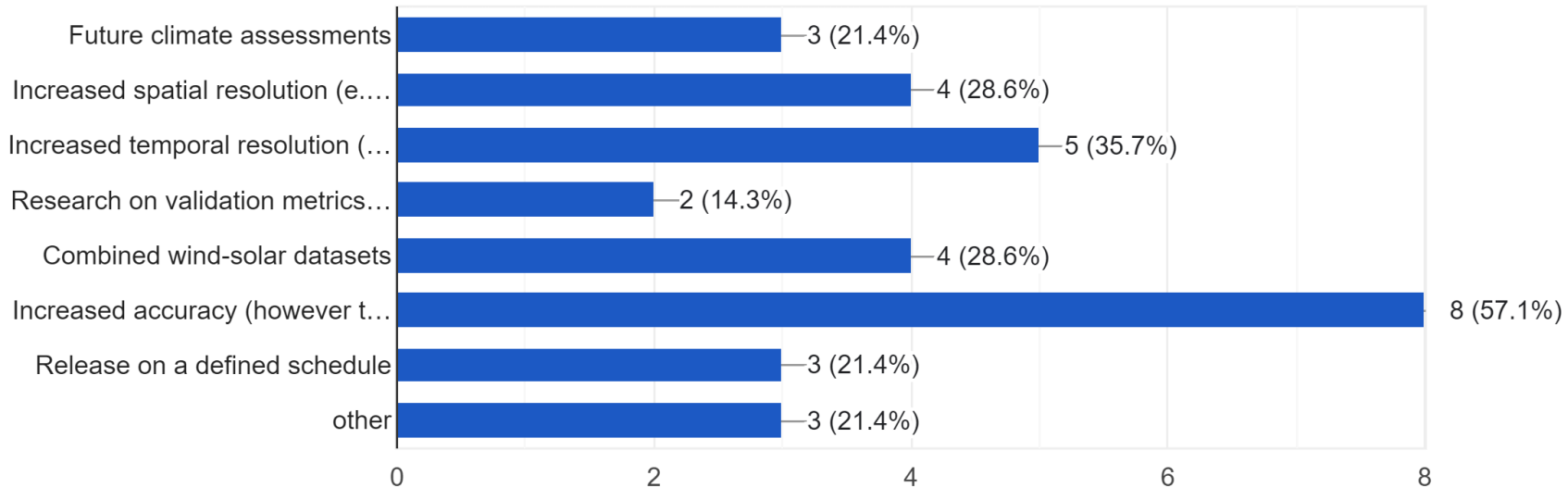
14 responses



# Accuracy stands out among high-priority needs for future datasets

Which of these should have the highest priority for future atmospheric datasets for grid integration studies? (Choose one)

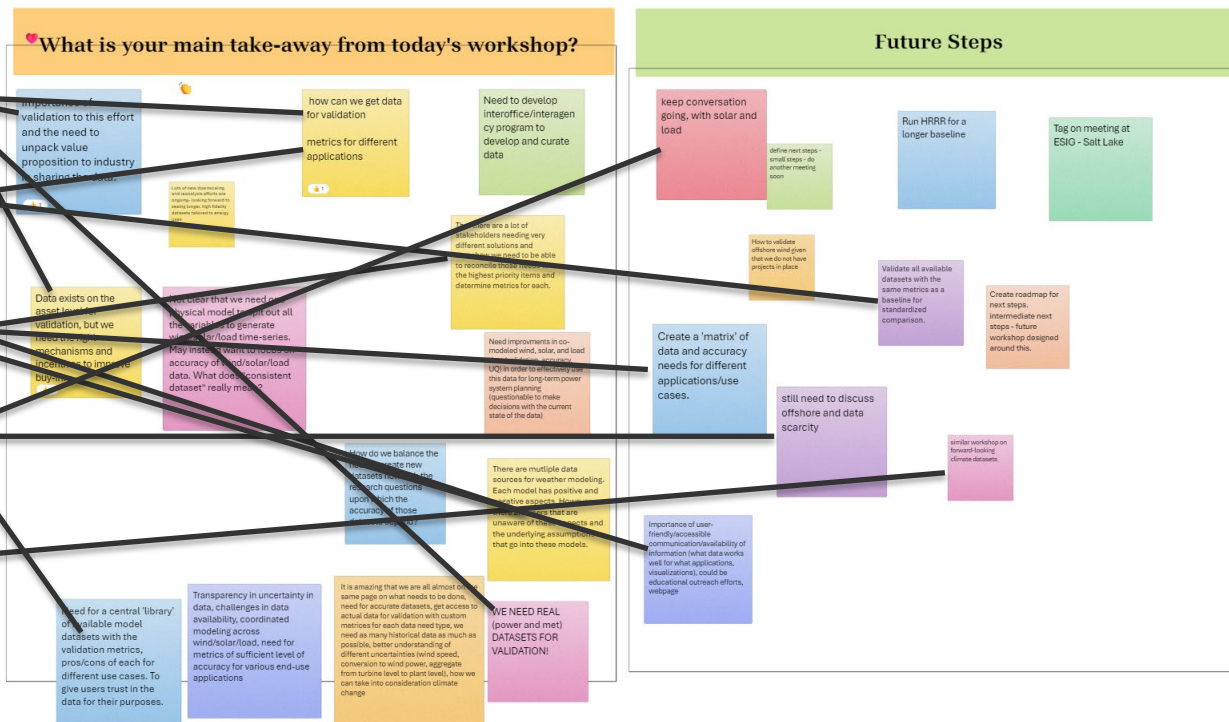
14 responses



Increased accuracy could be achieved with better validation and combined wind/solar/load/hydropower data.

# Workshop whiteboard identifies five key focus areas

1. Validation is missing
2. No common set of metrics for usability
3. Clear definition of use cases needed
4. Relevant datasets not linked
5. What about the future?



*These five key areas will inform next steps*



Add your thoughts to help inform next steps!

[National Scale Wind Data for  
Grid Integration - Survey  
\(google.com\)](#)

<https://bit.ly/3Xel2PC>

A topographic map of the United States, color-coded by elevation. The map shows state boundaries and labels for various states including Oregon, Nevada, California, Arizona, New Mexico, Utah, Idaho, Wyoming, Montana, North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, Arkansas, Missouri, Iowa, Illinois, Indiana, Michigan, Ohio, Pennsylvania, New York, New Jersey, Connecticut, Massachusetts, Rhode Island, New Hampshire, Vermont, New Mexico, and Maine. The Great Lakes region is highlighted in a darker blue. The text "Next steps from NREL" is overlaid in a semi-transparent blue box in the center of the map.

# Next steps from NREL

# NREL team continues to validate and release data; open to feedback!



Wind validation according to the use case, distributions, and tails



Release validation metrics and code from earlier analysis



Combined wind/solar/load datasets



Release of more historical years of datasets alongside NREL's power system planning tools



Address climate variability and quantify uncertainty of climate change models



Stay for Grant Buster's talk on SuperCC?!



Comprehensive, industrywide data transparency and sharing of meteorological measurements, and generation and availability data



How to make operational data more widely available?

# Thank You!

[luke.lavin@nrel.gov](mailto:luke.lavin@nrel.gov) or [gregory.brinkman@nrel.gov](mailto:gregory.brinkman@nrel.gov)

WTK-LED: [caroline.draxl@nrel.gov](mailto:caroline.draxl@nrel.gov)

Wind lead: [dave.corbus@nrel.gov](mailto:dave.corbus@nrel.gov)

---

[www.nrel.gov](http://www.nrel.gov)

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Wind Energy Technologies Office. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government. The U.S. Government retains and the publisher, by accepting the article for publication, acknowledges that the U.S. Government retains a nonexclusive, paid-up, irrevocable, worldwide license to publish or reproduce the published form of this work, or allow others to do so, for U.S. Government purposes.

