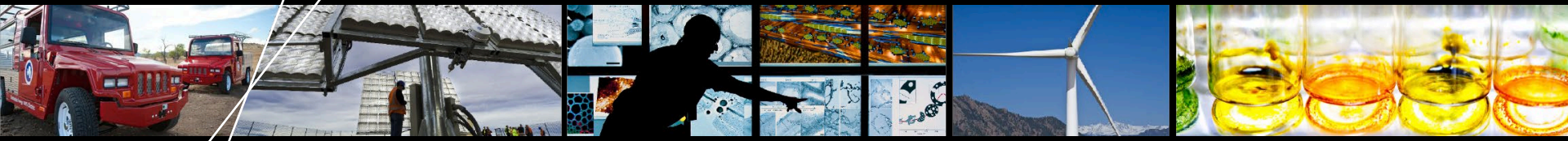
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Wind Integration National Dataset (WIND) Toolkit



Webinar

Caroline Draxl and Bri-Mathias Hodge

July 14, 2015

NREL/PR-5000-64691

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

Content

- **Motivation**
- **Creation of the WIND Toolkit**
  - Meteorological and power data
- **Data Access**
- **Validation**
  - Meteorological and power validation
- **Use of the WIND Toolkit**

Impact of High Wind Penetrations on Power Systems Operations?

Photo by Jamie Keller, NREL 19697

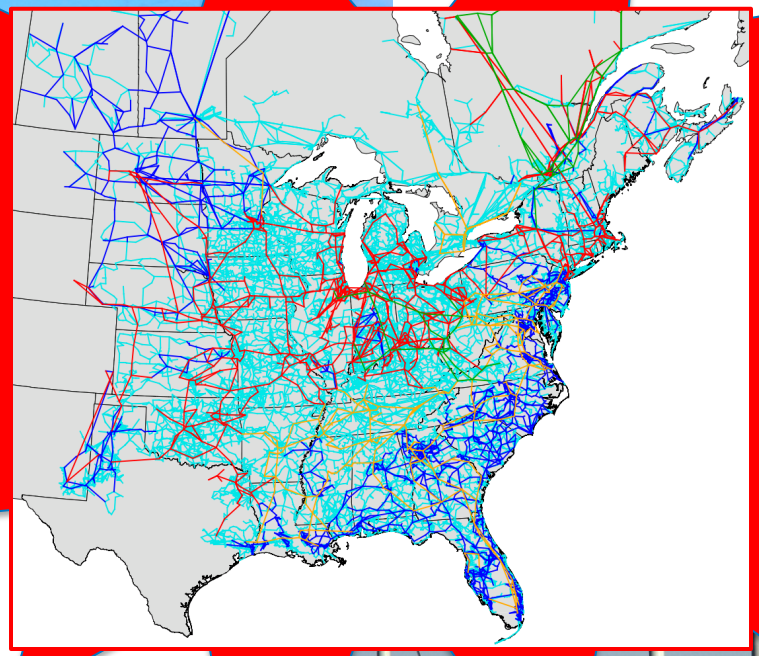
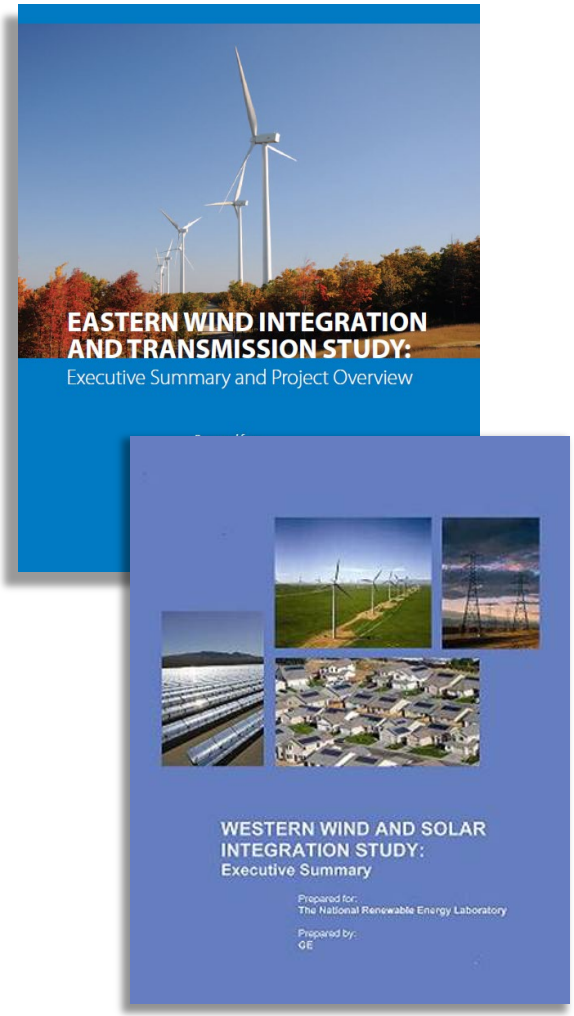
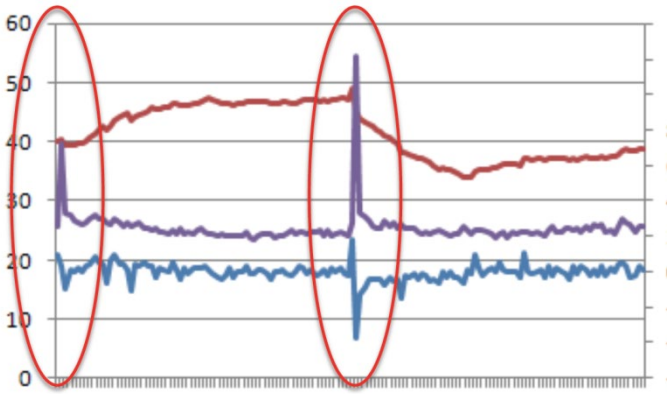


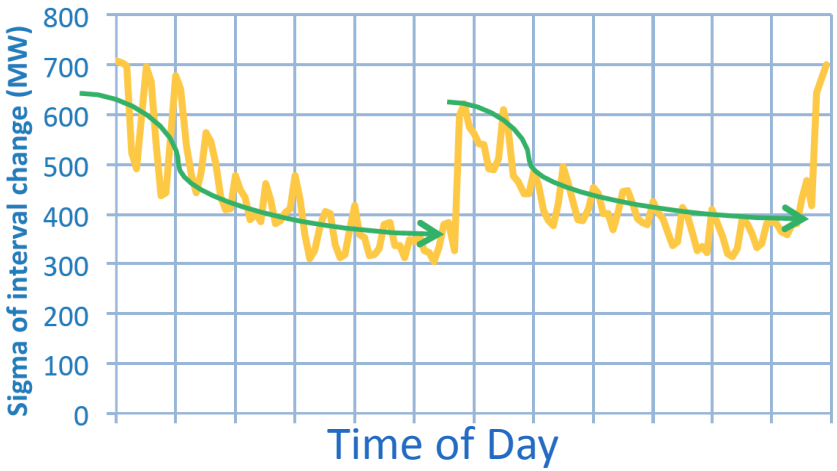
Photo by Energy Northwest, NREL 12307

Need for High-Resolution Wind Power Data





Artifacts remained after corrections



Need for High-Resolution Wind Power Data That…

- Realistically reflects ramp characteristics
- Is seamless in time and space
- Offers capacity factors of wind plant production
- Is time-synchronous with load profiles
- Includes recent years
- Takes several years to evaluate inter-annual variability
- Is easily accessible.

Wind Power Forecasts and Production Time Series for 2007–2013

Wind Integration National Dataset (WIND) Toolkit:

Re-analysis: Meteorological and power data set

Re-forecast: Power data set (1 hour (h), 4 h, 6 h, 24 h)

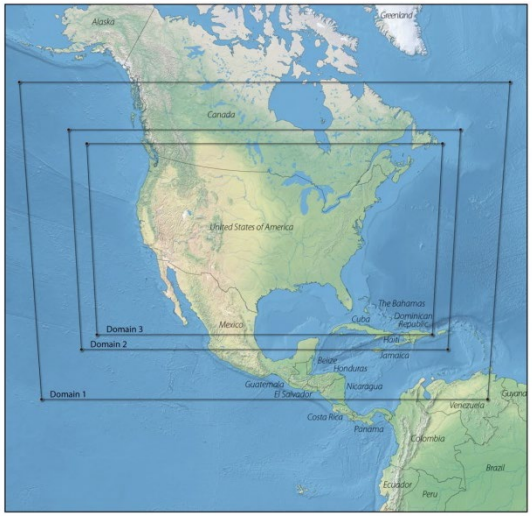
Freely available online data extraction tool

The WIND Toolkit is a collaboration between the National Renewable Energy Laboratory (NREL) and 3Tier by Vaisala, run on supercomputers at Sandia National Laboratories and NREL, with input from a board of subject matter experts.

Meteorological Data Set

The Weather Research and Forecasting (WRF) Model Setup

- WRF V3.4.1
- Yonsei University boundary layer scheme
- Topographic wind enhancement
- Output at 15, 47, 80, 112, 145, and 177 meters (m) interpolated to 10, 40, 60, 80, 100, 120, 140, 160, and 200 m.



WRF model domains

Re-Analysis

- Two-km nest
- Boundary conditions: ERA Interim
- Model output every 5 min
- Scale-selective grid-nudging
- One-month runs, 48-hour spin up, overlap of 3 days.

Re-Forecast

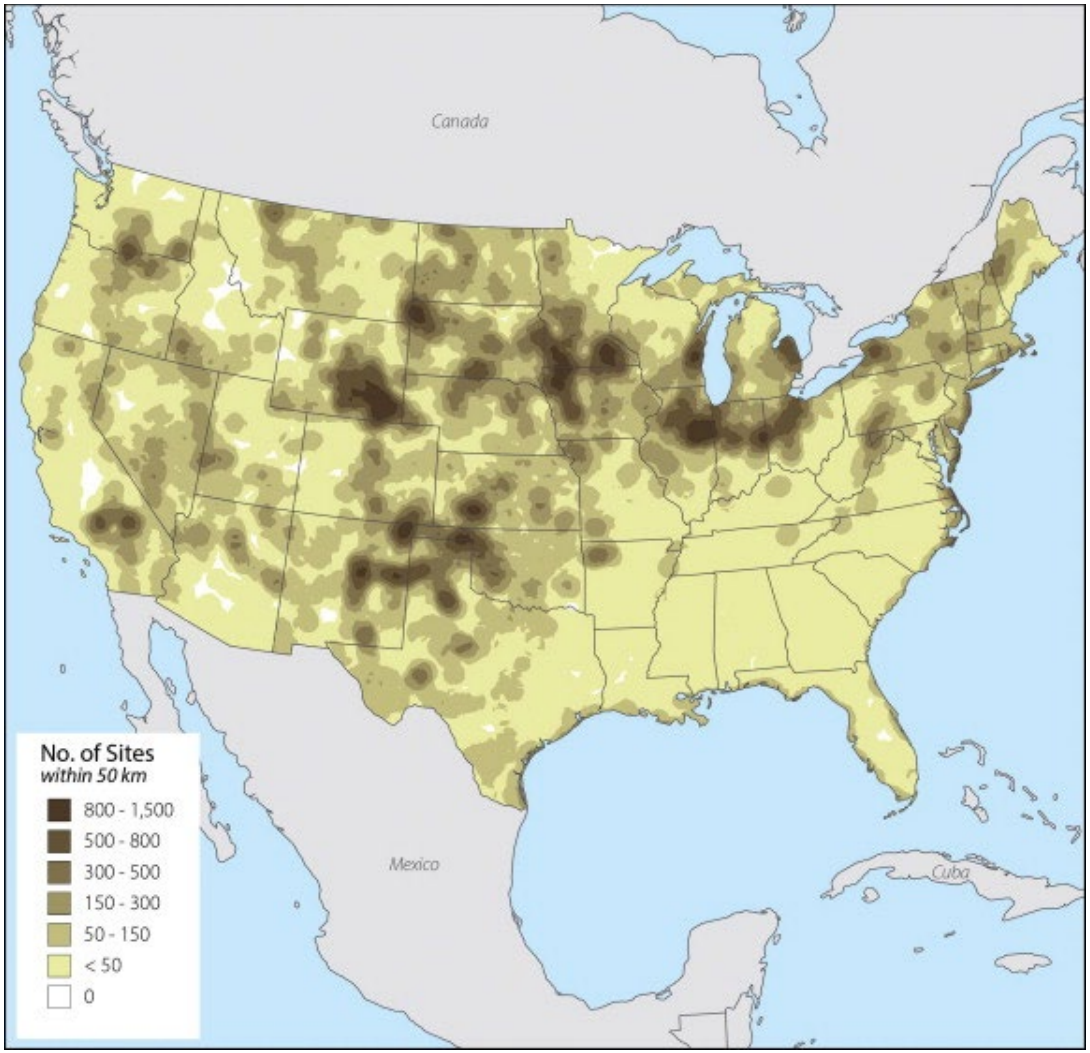
- Six-km nest
- Boundary conditions: NOAA Reforecast2 GEFS Control
- Model output every 1 h.

Innovative Solutions to Running High-Resolution WRF Runs

- **The WIND Toolkit model output:**
  - ~300 terabytes model output
  - 200 million grid points

- **We used parallel asynchronous input/output to improve output speed 50:1.**

More than 126,000 Land-Based and Offshore Existing and Potential Wind Facilities



Number of sites available in the WIND Toolkit.
Image by Billy Roberts, NREL

112,471 Land-Based and 14,221 Offshore Existing and Potential Wind Facilities

How did we choose the sites available in the WIND Toolkit?

- **Each site is a 2-by-2-km grid cell in the Numerical Weather Prediction (NWP) data set**
- **Site selection process**
  - Apply exclusion criteria:
    - Federal lands, national parks, open water areas
    - Areas with slopes greater than 20%
    - Within buffer area of developed land and airports
    - Offshore: wind resource, distance from shore at least 8 km
- **Select turbine model based on existing annual mean wind speed data at 100 m above ground**
- **Ranking based on computed potential annual megawatt-hours.**

Power Data Set

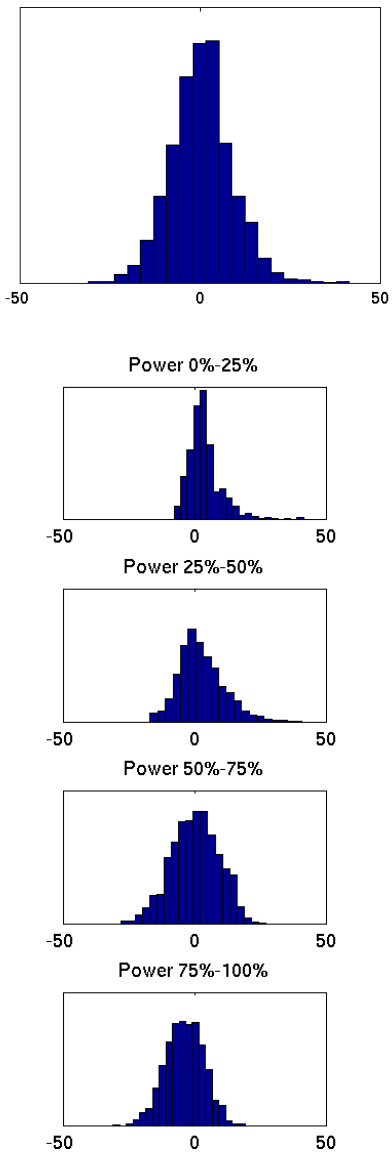
Create State-of-the-Art Forecasts Without "Cheating"…

…by mimicking "real" forecast errors.

- **NWP is the basis:**
  - Initialized daily at 00 UTC
  - Six-km grid
  - Hourly output
- **Respect the spatial-temporal correlation of typical forecast errors at forecast horizons**
- **For forecast horizons <= 6 h: statistical model for each site**
- **Each forecast: deterministic value + P10/P90 probability of exceedance values.**

Probabilistic Forecasts with Nonparametric Error Quantiles

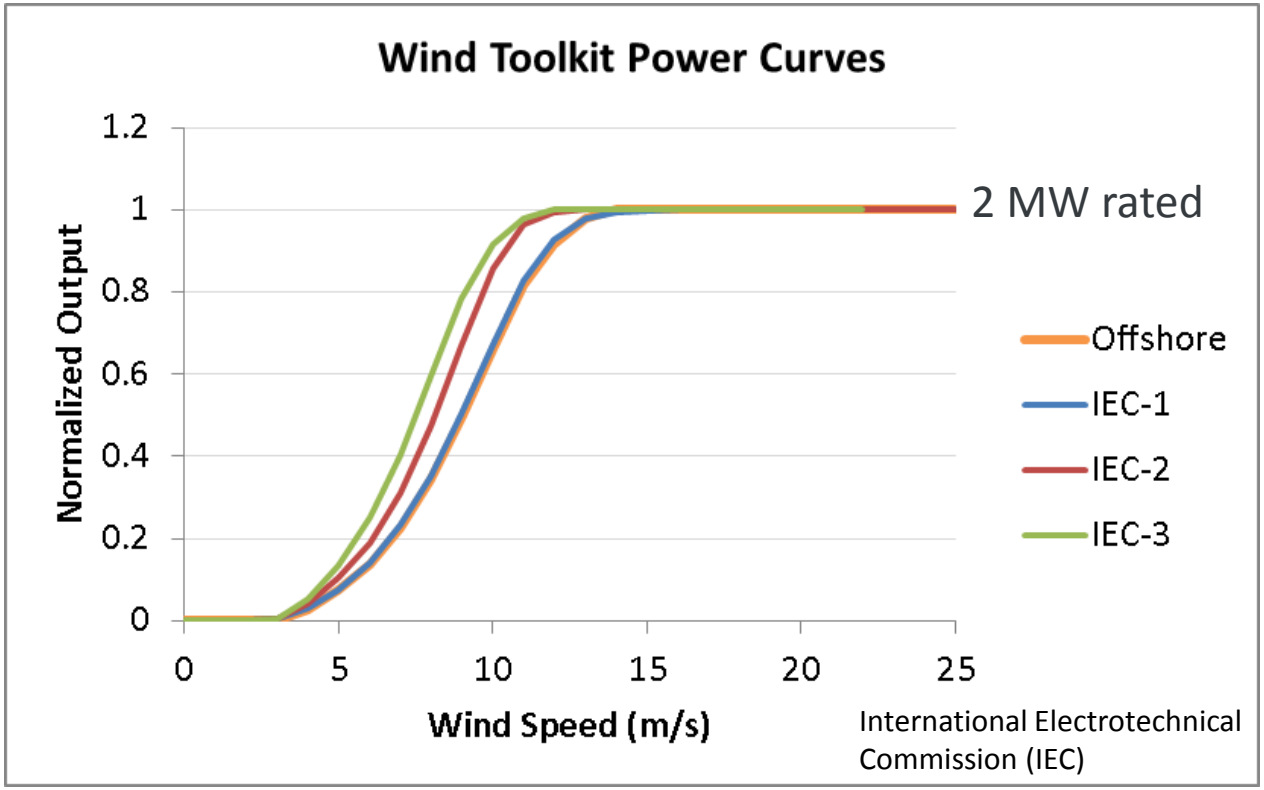
- **Empirical forecast error distributions differ based on power regime**
- **Conditional, nonparametric dressing approach**
- **Yields approximate calibration (reliability)**
- **Dynamic adjustment to weather regime changes and seasonal forecast skill.**



Power Conversion

- **Bias removal from wind speeds**
  - Time series smoothing
  - Blend in “truth” with a limited weight
  - Adjust until forecast time series and error histograms are reasonable and error metrics are similar to state of the art
- **Wind speed adjustment for wakes**
  - Maximum two turbines per km^2, each site maximum of eight 2-megawatt (MW) turbines
  - Apply wake losses to wind speed
  - Each 2-by-2-km site considered independently
- **Application of power curves**
- **Statistical adjustment to power using total variance, autocorrelation of sites, and spatial covariance.**

Site Power Time Series



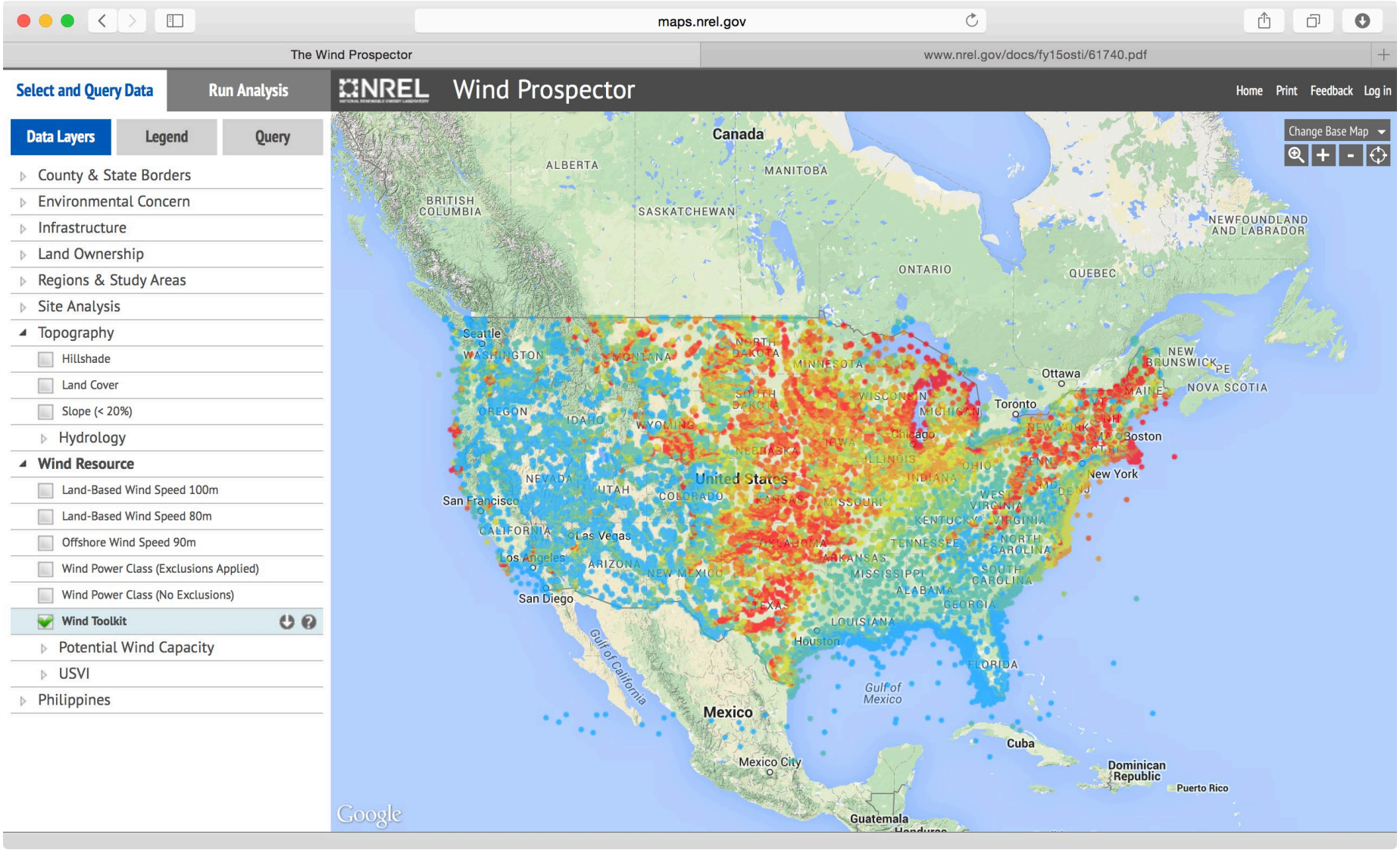
Class	V_{ave} (m/s)
I	10
II	8.5
III	7.5
Offshore	-

$$U_{\text{effective}} = U_{\text{WRF}} \cdot C_{\text{wake}}$$

where $$C_{\text{wake}} = 1 - \frac{1}{20}\left(\frac{n_{\text{turbines}} - 1}{7}\right)$$

Data Access

Data Access via https://maps.nrel.gov/wind-prospector/



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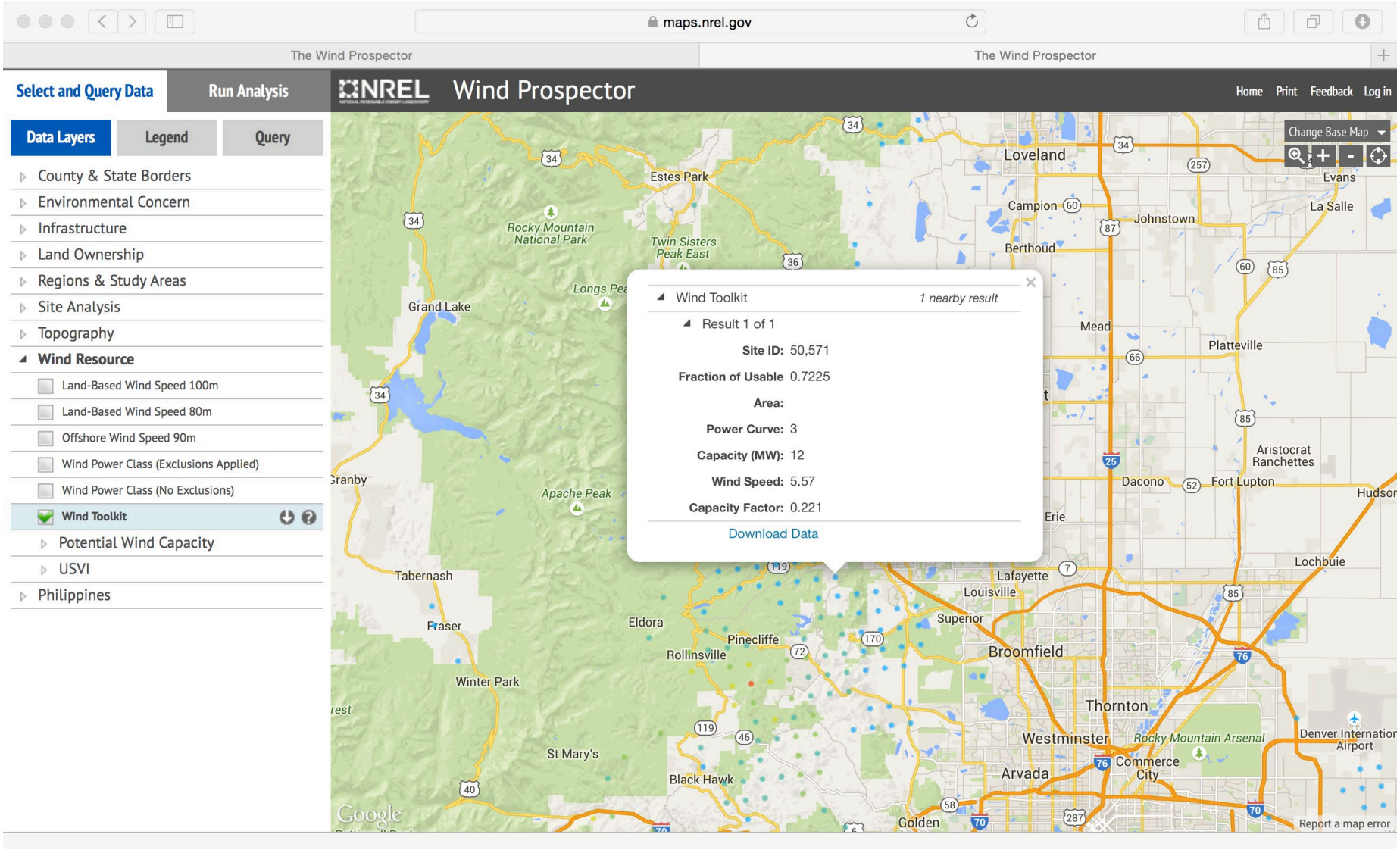

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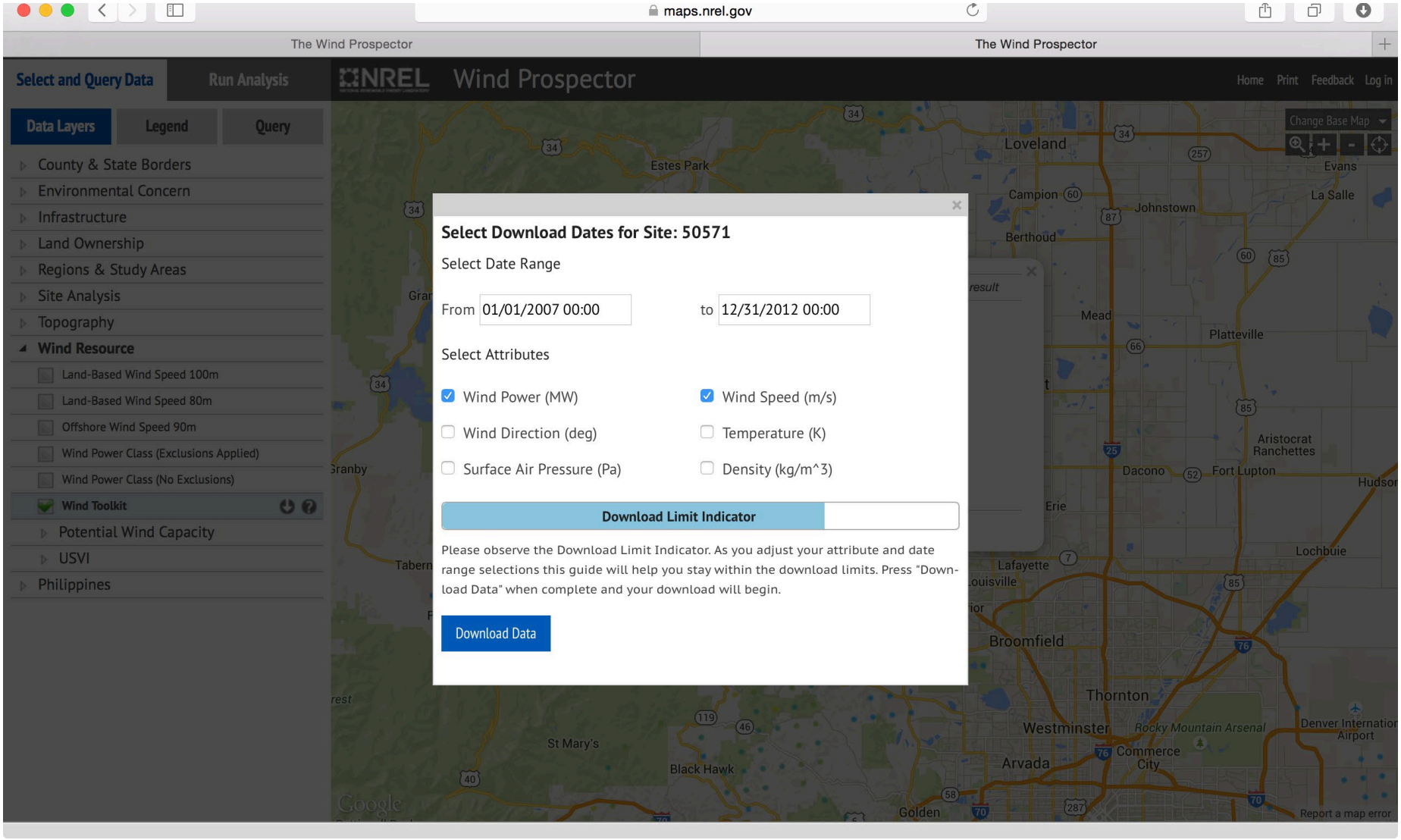
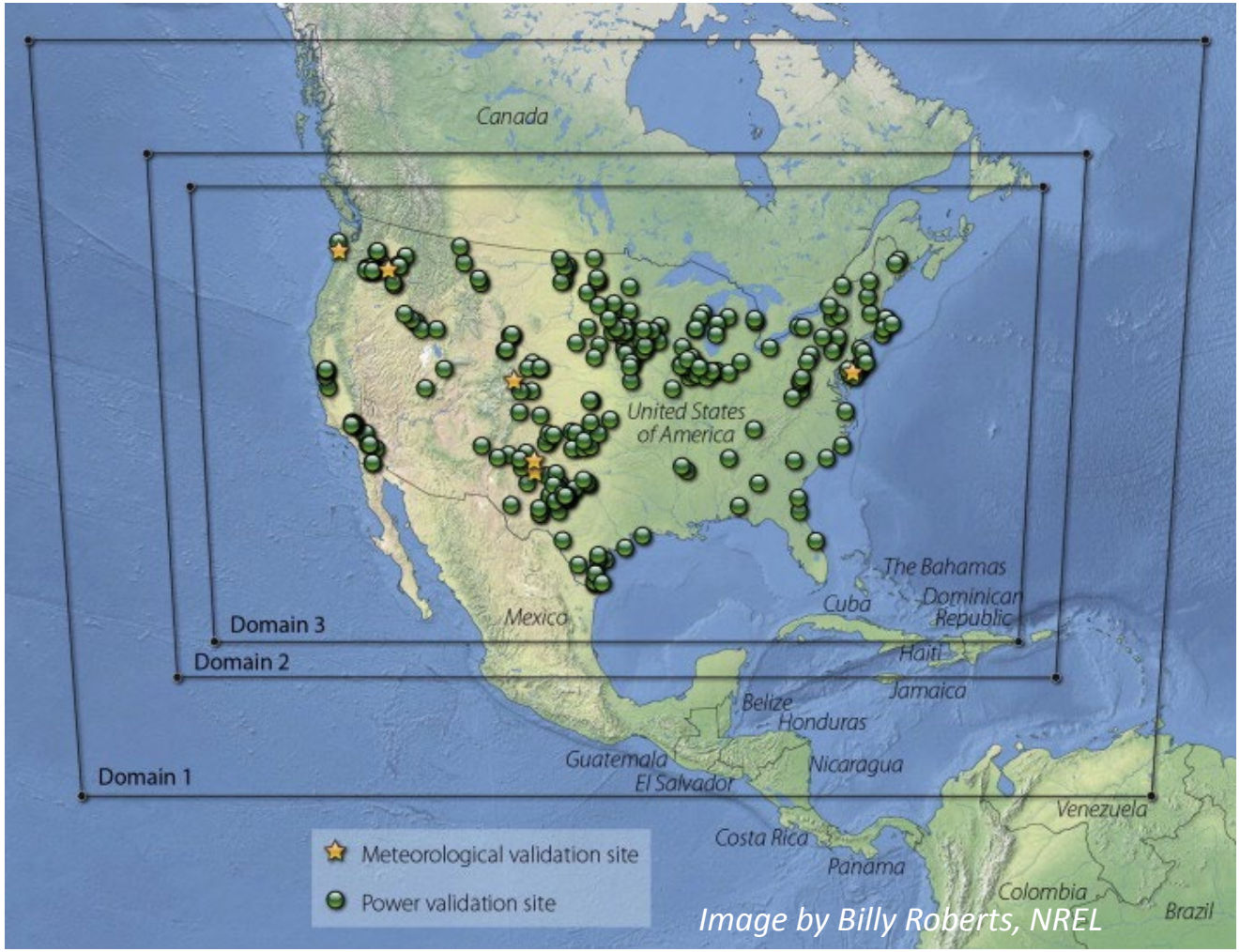


Validation

Slides courtesy Andrew Clifton

Validation



Sites used for power validation (green) and meteorological validation (yellow)

Meteorological Data Validation

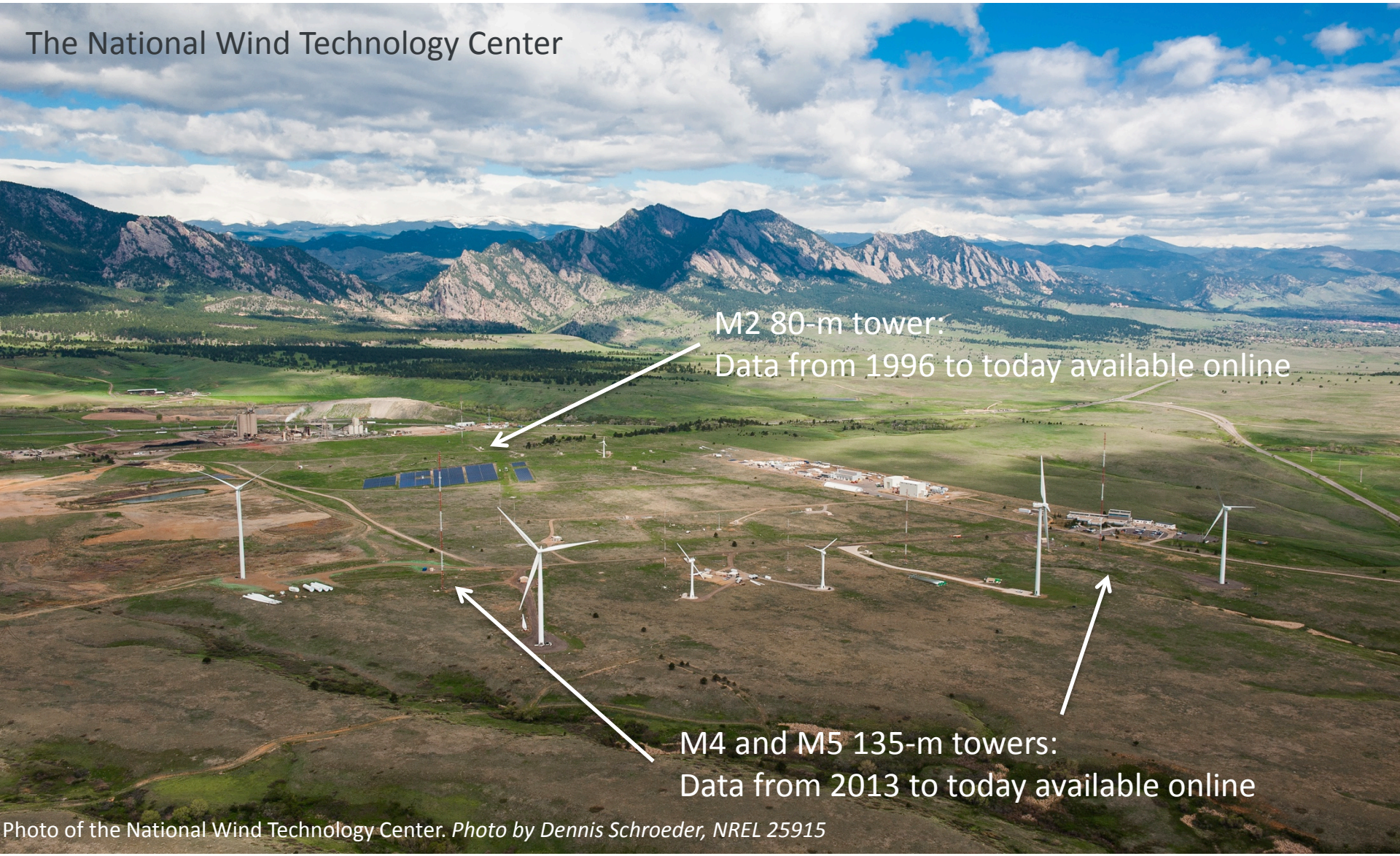


Photo of the National Wind Technology Center. *Photo by Dennis Schroeder, NREL 25915*

Meteorological Data Validation (continued)

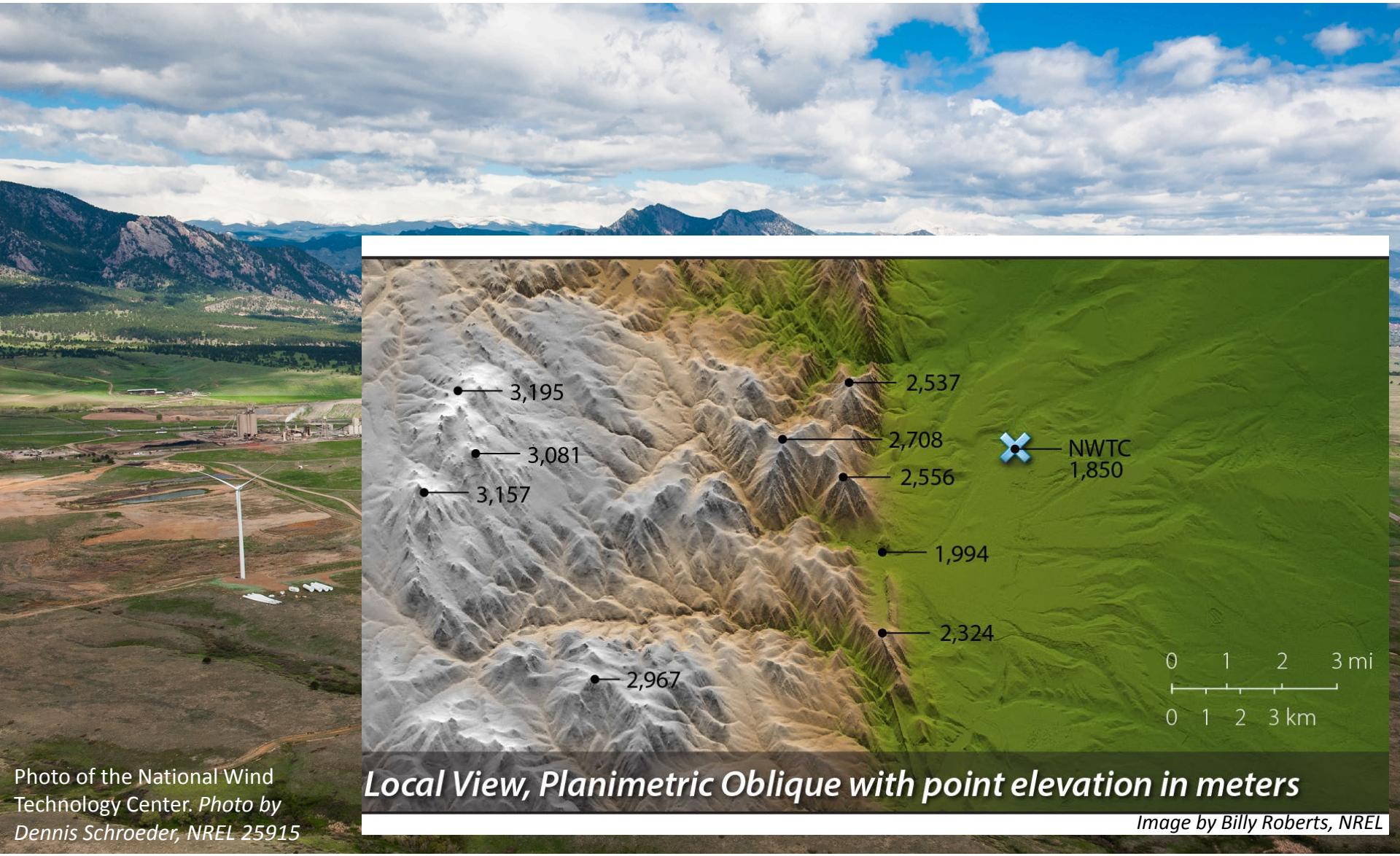
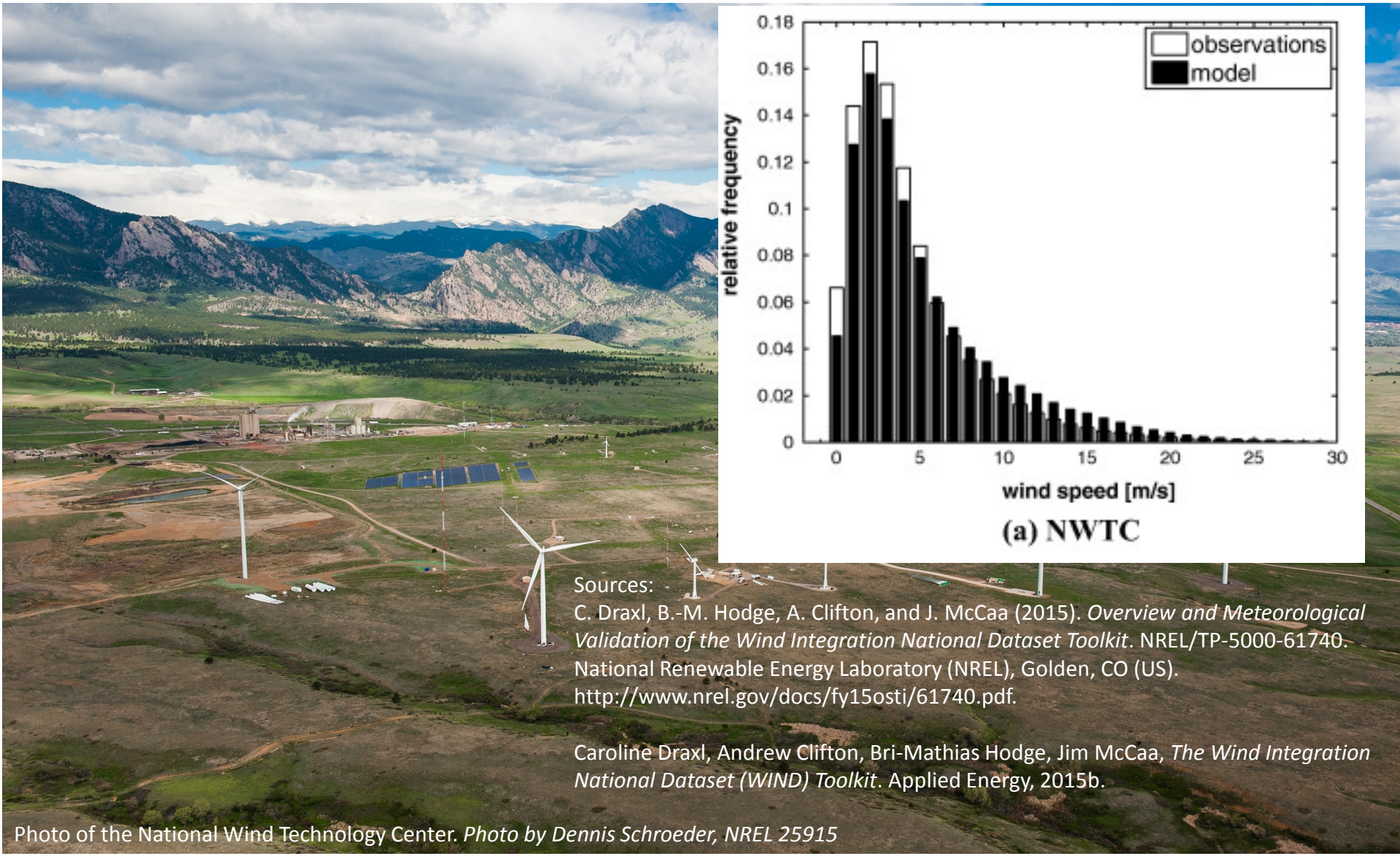


Photo of the National Wind Technology Center. *Photo by Dennis Schroeder, NREL 25915*

Image by Billy Roberts, NREL

Meteorological Data Validation (continued)



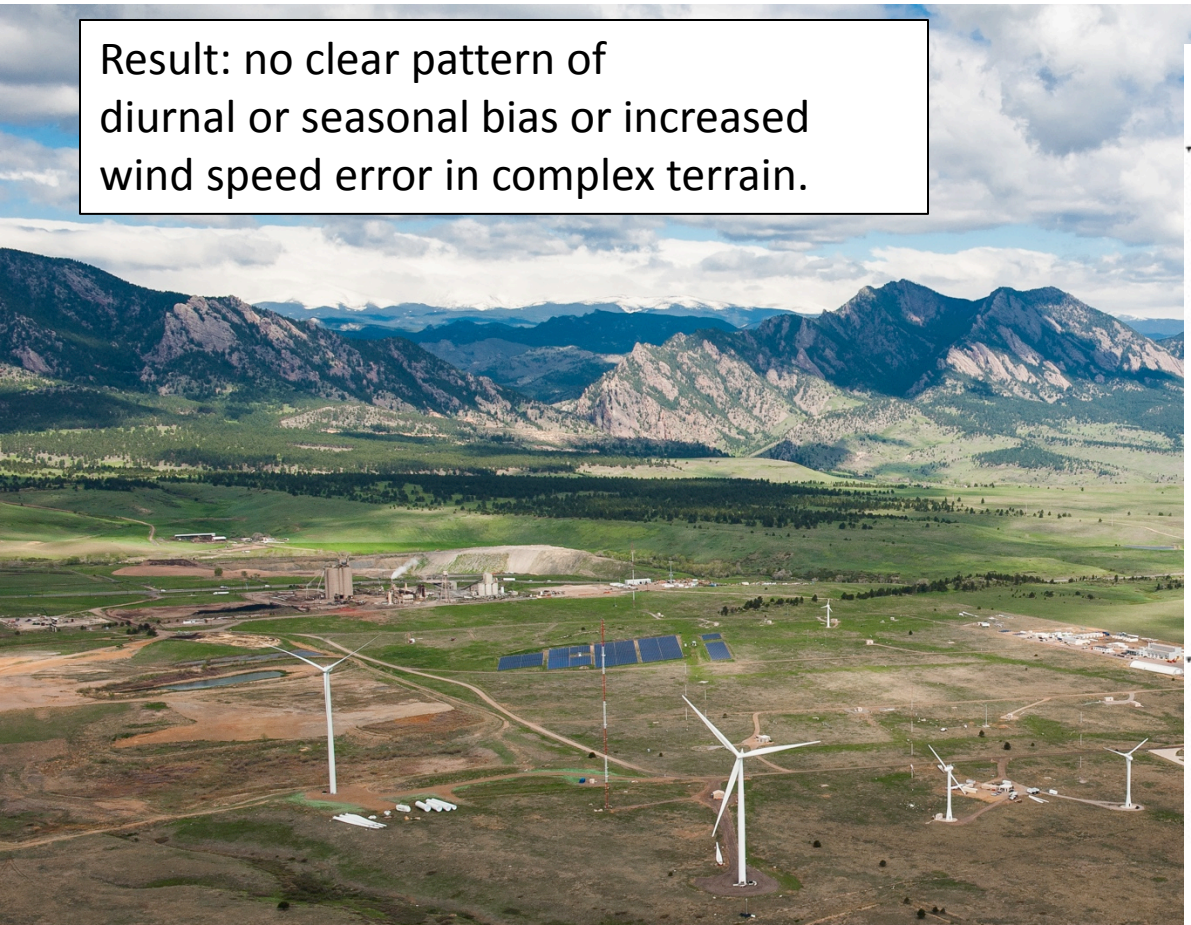
Sources:
C. Draxl, B.-M. Hodge, A. Clifton, and J. McCaa (2015). *Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit*. NREL/TP-5000-61740. National Renewable Energy Laboratory (NREL), Golden, CO (US). http://www.nrel.gov/docs/fy15osti/61740.pdf.

Caroline Draxl, Andrew Clifton, Bri-Mathias Hodge, Jim McCaa, *The Wind Integration National Dataset (WIND) Toolkit*. Applied Energy, 2015b.

Photo of the National Wind Technology Center. *Photo by Dennis Schroeder, NREL 25915*

Meteorological Data Validation (continued)

Result: no clear pattern of diurnal or seasonal bias or increased wind speed error in complex terrain.



The National Wind Technology Center. *Photo by Dennis Schroeder, NREL 25915*

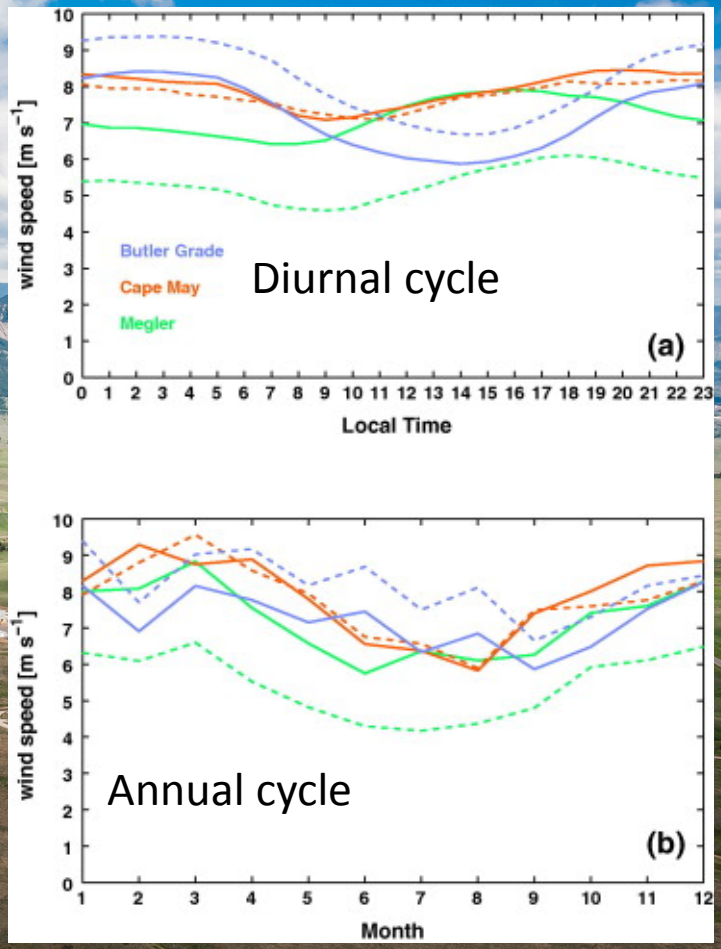


Figure sources: C. Draxl, B.-M. Hodge, A. Clifton, and J. McCaa (2015). *Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit*. NREL/TP-5000-61740. National Renewable Energy Laboratory (NREL), Golden, CO (US). http://www.nrel.gov/docs/fy15osti/61740.pdf.

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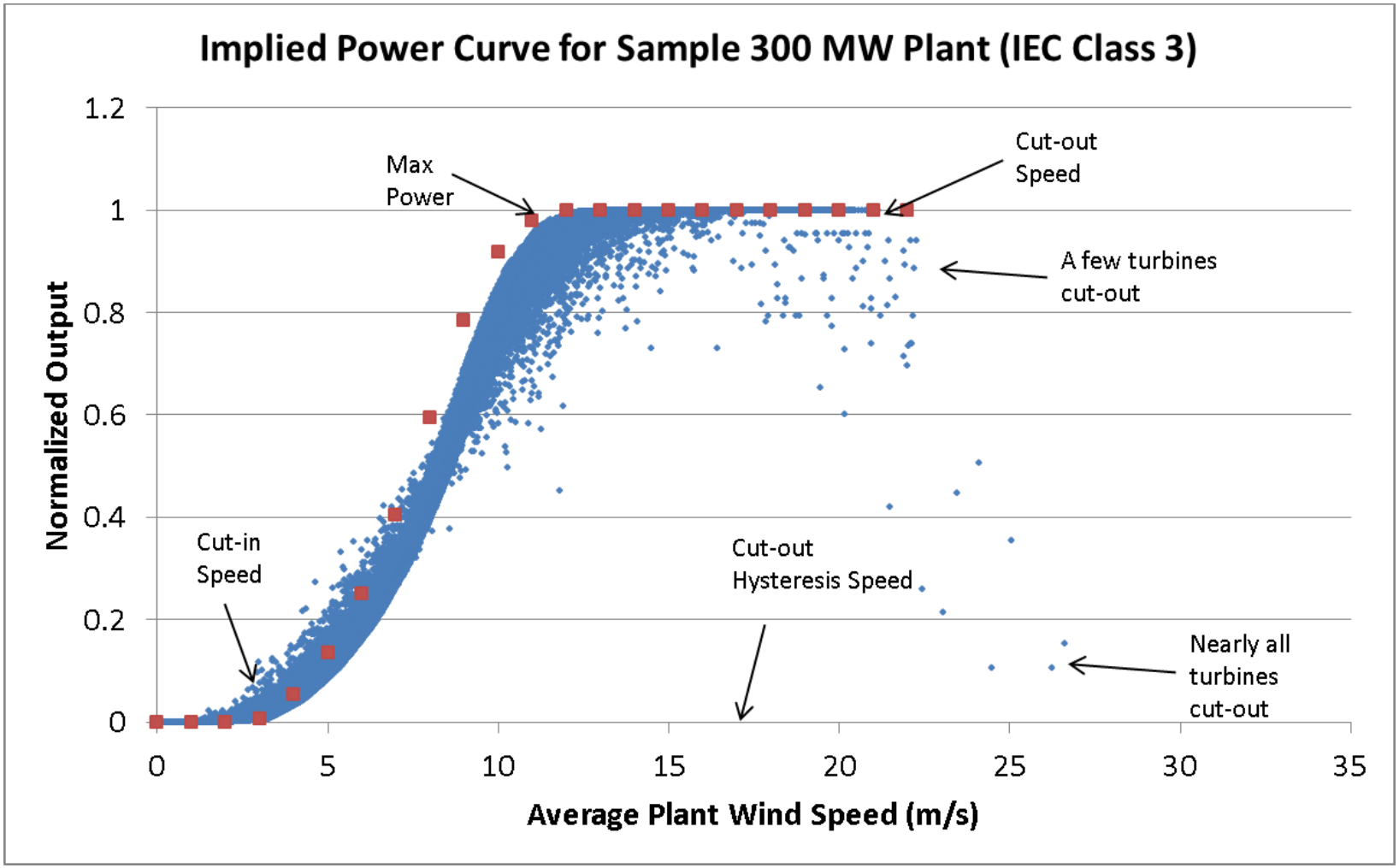
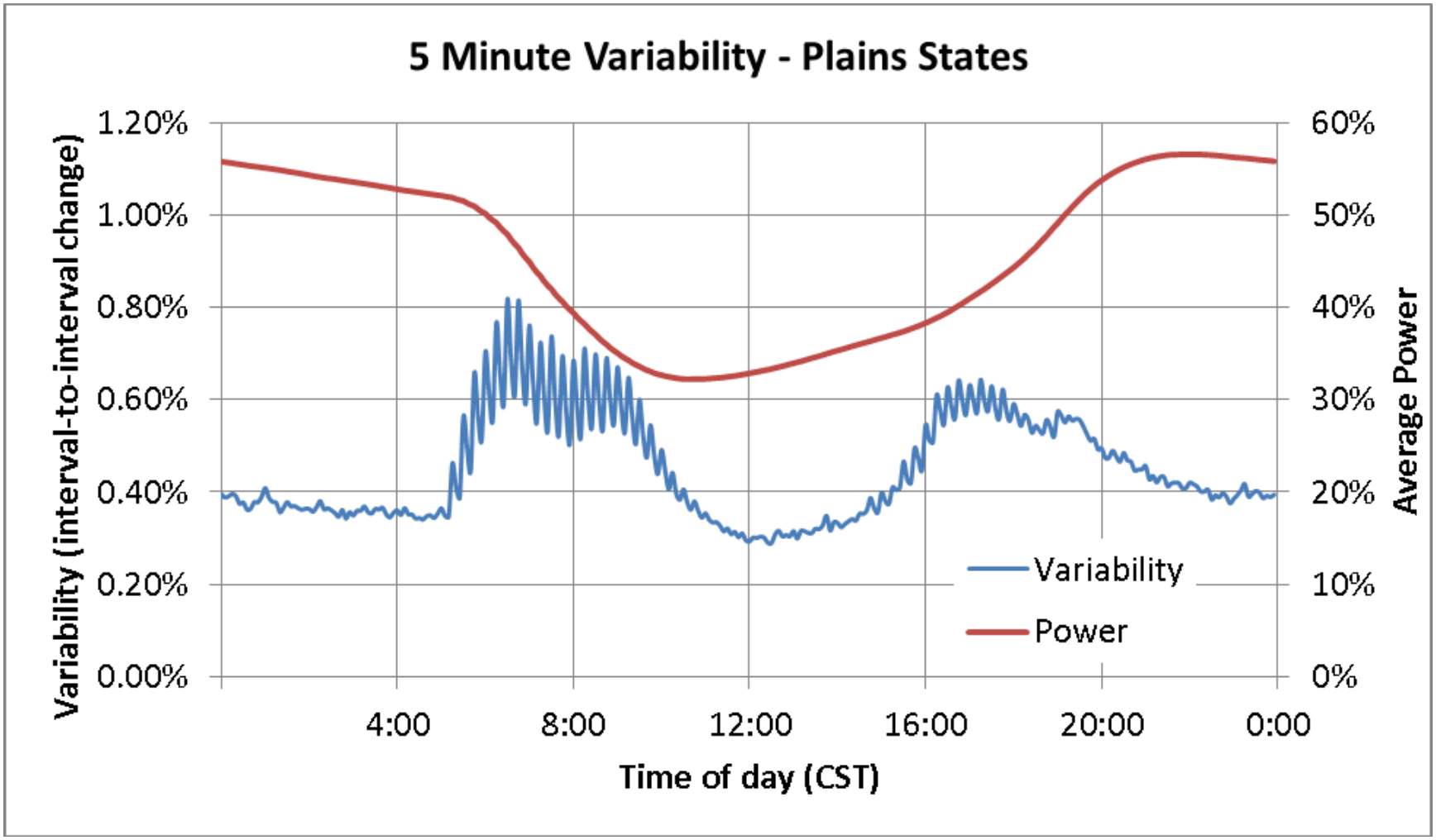
Power Data Validation



Source: J. King, Clifton, A., Hodge, B.M. 2014. Validation of Power Output for the WIND Toolkit. NREL/TP-5D00-61714. National Renewable Energy Laboratory (NREL), Golden, CO (US). http://www.nrel.gov/docs/fy14osti/61714.pdf.

Power Variability is High in Shoulder Hours



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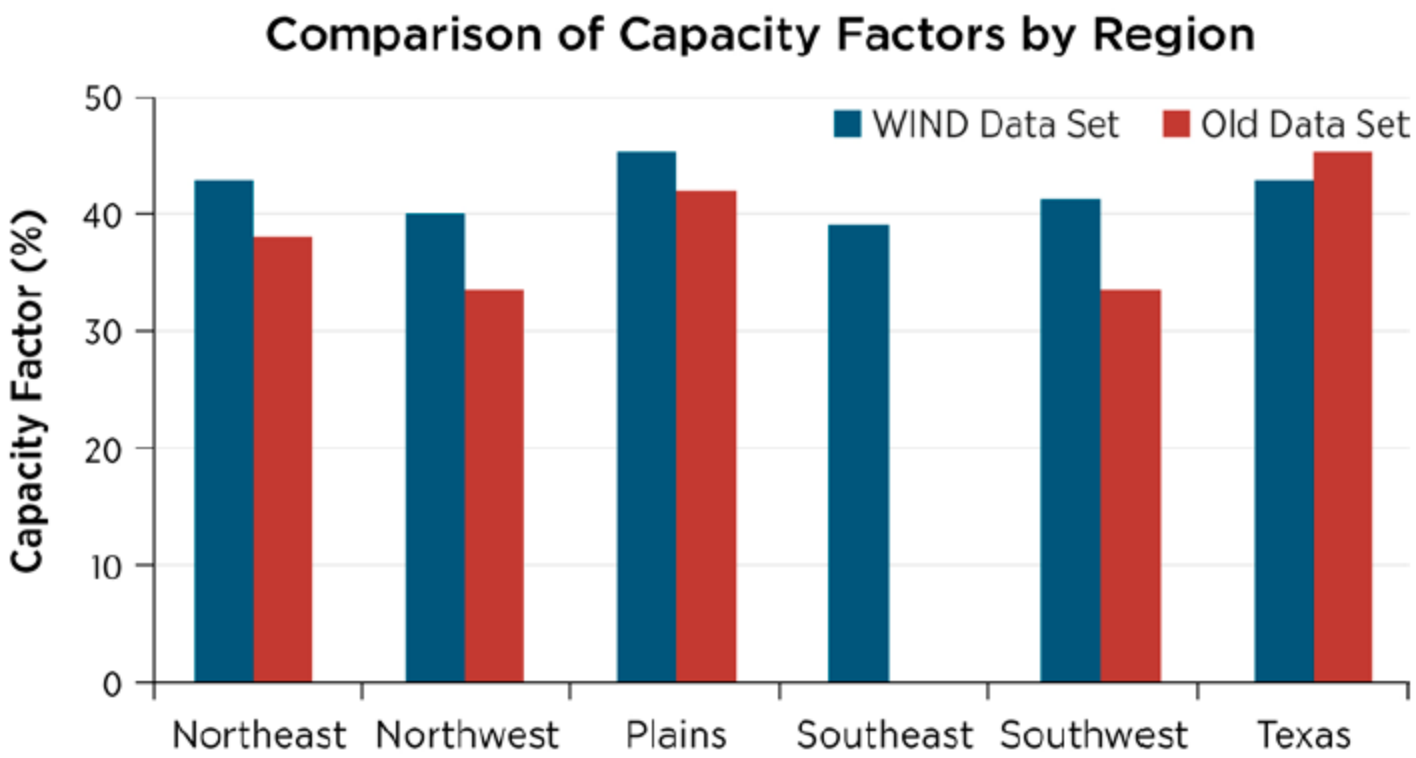
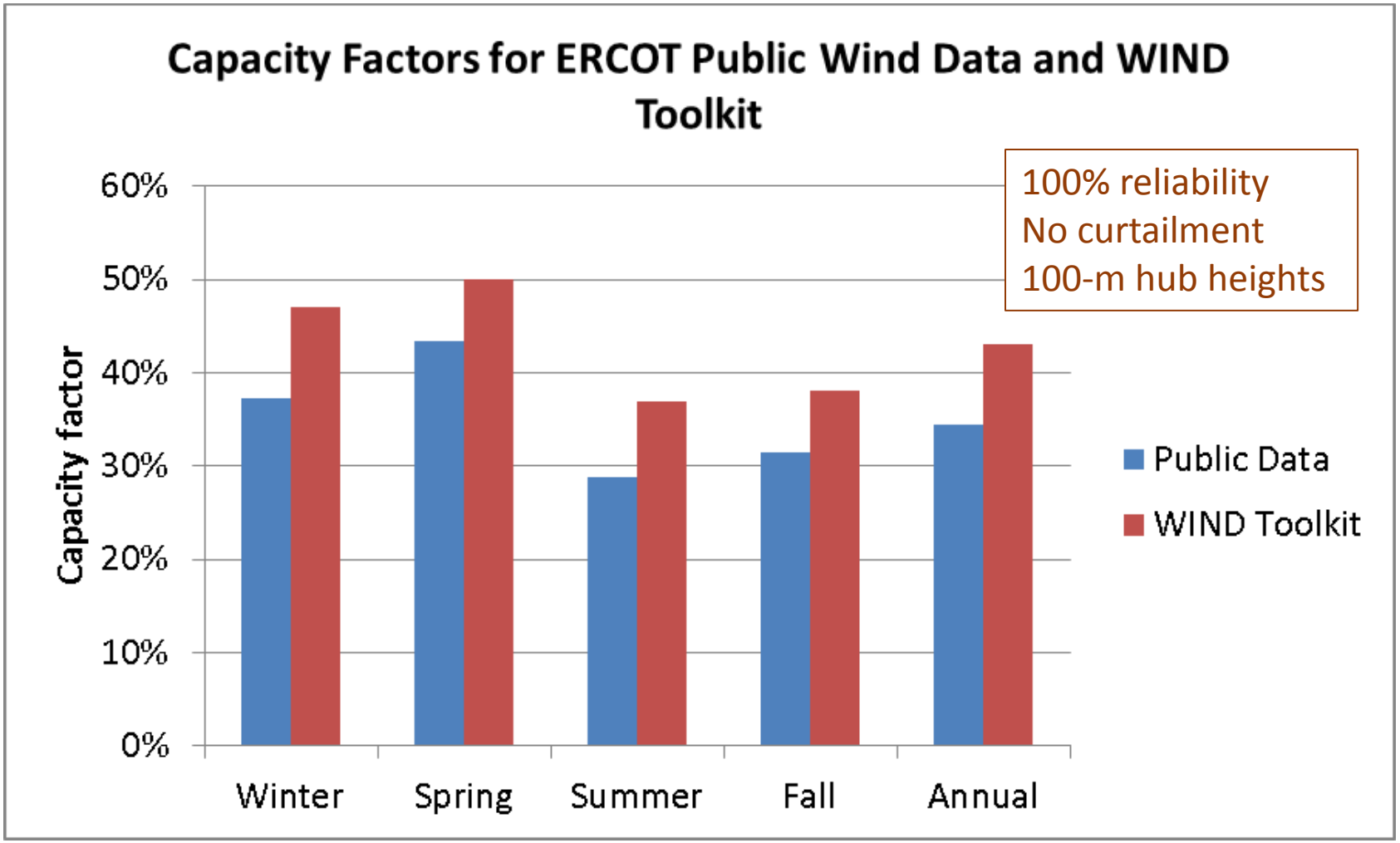
Capacity Factor Comparison

Season	Northeast	Northwest	Plains	Southeast	Southwest	Texas
Winter	54%	39%	50%	49%	38%	47%
Spring	47%	44%	48%	45%	47%	50%
Summer	27%	42%	33%	26%	43%	37%
Fall	43%	34%	47%	38%	36%	38%
Annual	43%	40%	45%	39%	41%	43%



Capacity Factor Comparison (continued)



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Summary

WIND Toolkit Components

Wind plant locations

- Turbine class
- Number of turbines
- Capacity factors

Power time series

- Site-optimized turbine choice
- Power at 5-m time steps

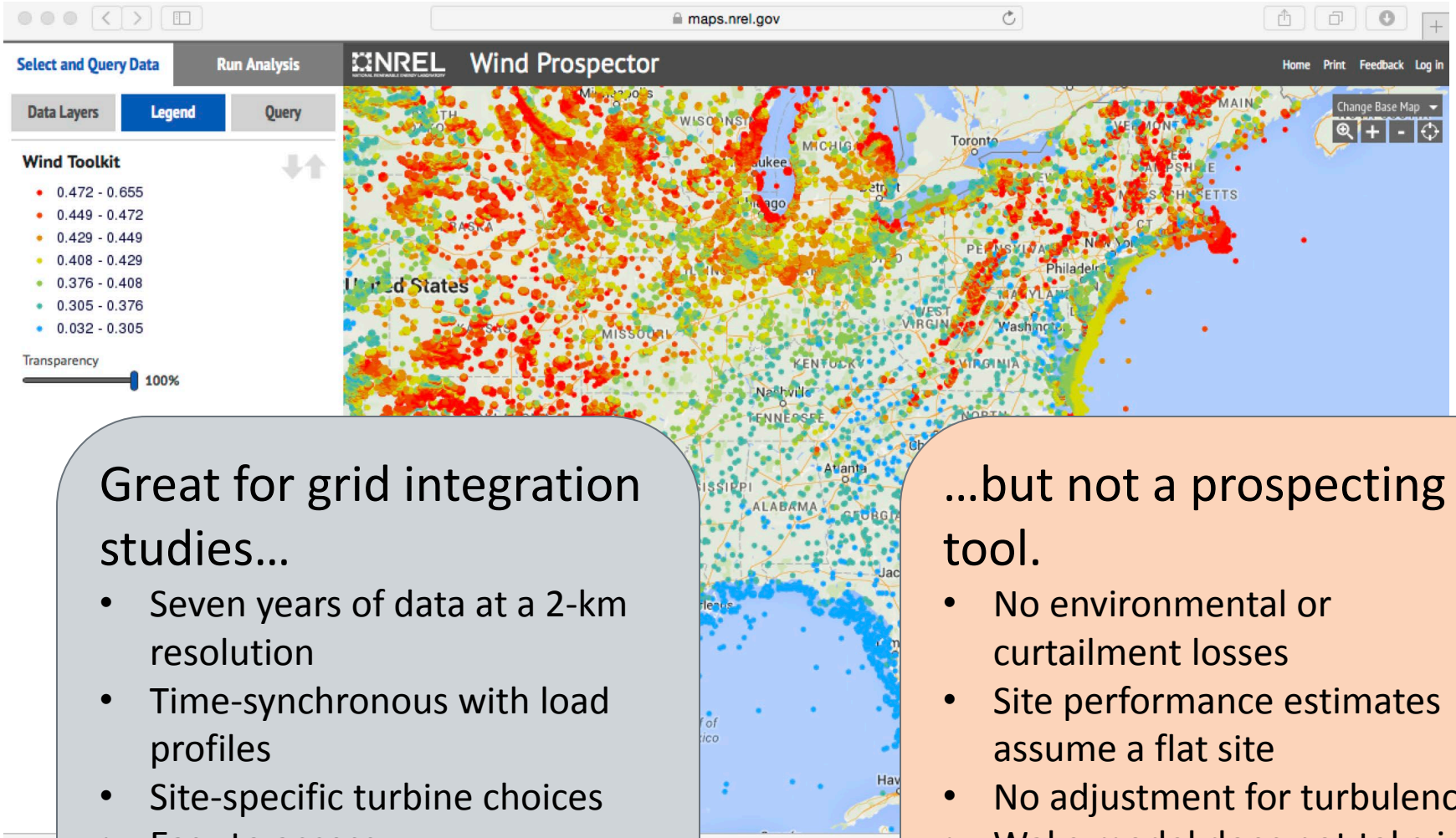
Forecasts

- Power [MW] at 1, 4, 6, and 24-h horizons

Meteorological time series

- Wind speed and direction
- Temperature
- Relative humidity
- Pressure (surface, 100 m, 200 m)
- Air density at 100 m
- Precipitation rate
- Solar radiation (shortwave downward, diffuse irradiance, direct normal irradiance, and global horizontal shortwave irradiance)
- Atmospheric stability
- Upward heat flux
- Boundary layer height
- U_* in similarity theory

Ways to Use the WIND Toolkit Data



Great for grid integration studies…

- Seven years of data at a 2-km resolution
- Time-synchronous with load profiles
- Site-specific turbine choices
- Easy to access
- Can be duplicated and refined.

…but not a prospecting tool.

- No environmental or curtailment losses
- Site performance estimates assume a flat site
- No adjustment for turbulence
- Wake model does not take into account turbine layout.

Questions?

- **Homepage:** http://www.nrel.gov/electricity/transmission/wind_toolkit.html

- **Applications:** Bri-Mathias.Hodge@nrel.gov
- **WRF Modeling:** Caroline.Draxl@nrel.gov

Photo by Dennis Schroeder, NREL 25896