NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Ground-Based Remote or In Situ Measurement of Vertical Profiles of Wind in the Lower Troposphere

Andrew Clifton and Jennifer Newman

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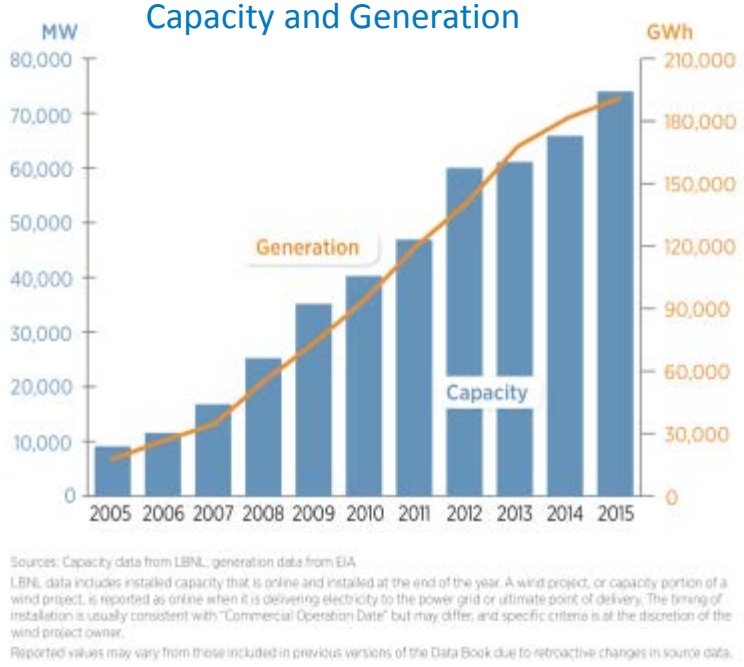
NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Let's Focus on Wind Energy

- Troposphere is 10 km deep
- Wind turbines are up to 200m tall
- There are around 49,000 wind turbines in 40 U.S. states[1]

US Total Installed Wind Electricity Capacity and Generation



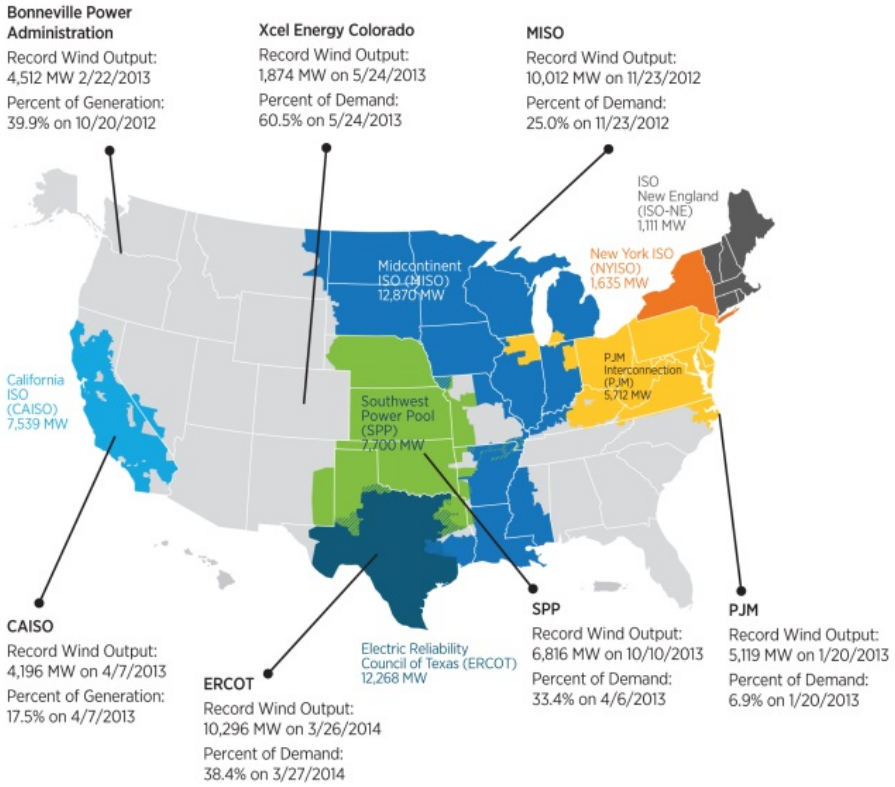
Sources: Capacity data from LBNL; generation data from EIA

LBNL data includes installed capacity that is online and installed at the end of the year. A wind project, or capacity portion of a wind project, is reported as online when it is delivering electricity to the power grid or ultimate point of delivery. The timing of installation is usually consistent with "Commercial Operation Date" but may differ, and specific criteria is at the discretion of the wind project owner.

Reported values may vary from those included in previous versions of the Data Book due to retroactive changes in source data.

Chart from the 2015 Renewable Energy Data Book, USDOE Office of Energy Efficiency and Renewable Energy DOE/GO-102016-4904

Record Wind Output and Contribution to Supply



Note: Acronyms used in graphic: Midcontinent ISO (MISO); PJM Interconnection (PJM); Southwest Power Pool (SPP); Electric Reliability Council of Texas (ERCOT); California ISO (CAISO); Independent system operator (ISO) .

Source: AWEA [7]

Figure from U.S. Department of Energy (DOE) WindExchange. See http://apps2.eere.energy.gov/wind/windexchange/slideshows/index.asp.

[1] American Wind Energy Association, *U.S. Wind Industry Third Quarter 2016 Market Report*

Things We Need to Know for Wind Energy

Profiles:

- Wind speed and direction
- Temperature and humidity
- Pressure and precipitation.

Applications:

- Resource assessment
- Power curve testing
- Wind power plant control
- Research and development (R&D) model validation
- Forecasting.

For more information, see:
A. Clifton, A. Smith, and M. Fields, *Wind Plant Preconstruction Energy Estimates: Current Practice and Opportunities* (NREL/TP-5000-64735) (2016).

Aerial view of the National Wind Technology Center (NWTC).
Photo by Dennis Schroeder, NREL 30770

Why Do We Still Use Met Towers?

Met towers are great:

- Off-the-shelf up to 100 m
- Can measure almost anything
- Pretty rugged
- We know how to use them.

But:

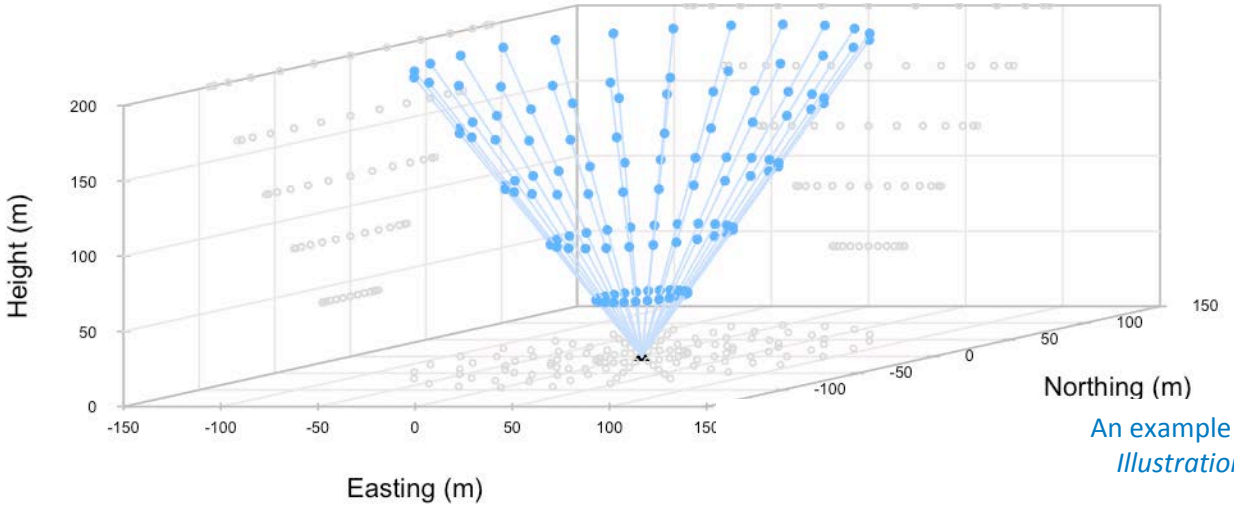
- A pain to permit
- Expensive
- Dangerous to climb
- On many operating wind power plants, they aren't even there.

A collapsed met tower.
Photo by Owen Roberts, NREL

Remote Sensing Is a Potential Solution to Tower Problems

A SODAR at the NWTC.
Photo by Andy Clifton, NREL

A lidar at the NWTC.
Photo by Andy Clifton, NREL



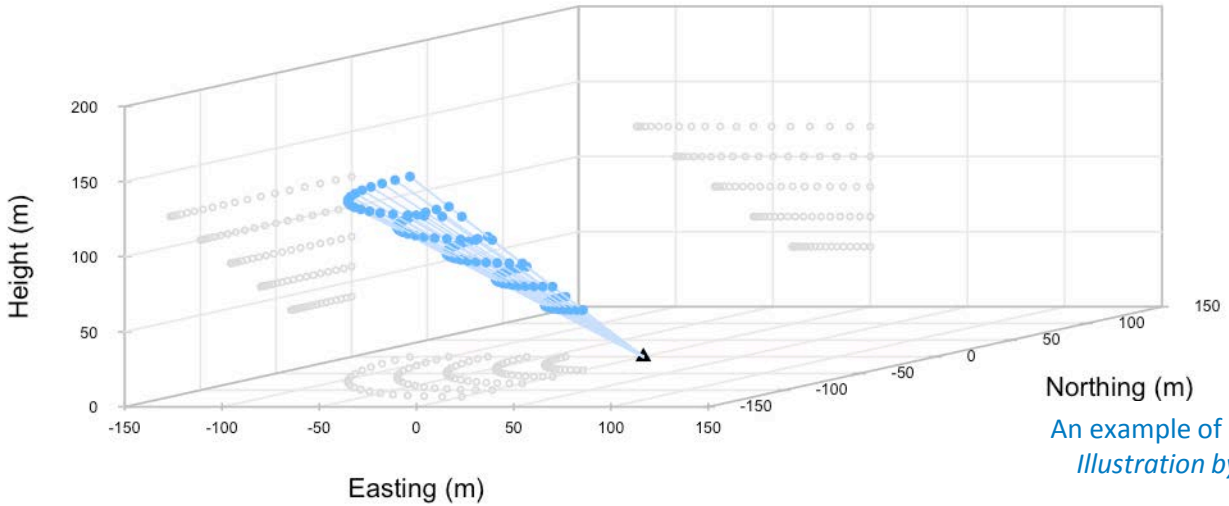
An example of a lidar scan pattern.
Illustration by Andy Clifton, NREL

Challenge: Ensuring repeatability and getting more than mean values

There Are Lots of Ways To Get Wind Data

A scanning lidar at the NWTC.
Photo by Andy Clifton, NREL

A radar at the NWTC.
Photo by Andy Clifton, NREL



An example of a lidar scan pattern.
Illustration by Andy Clifton, NREL

Challenges: Wind field reconstruction from line-of-sight wind speeds and quantifying uncertainty

Remote Sensing Opens Opportunities

Remote Locations

Long-lining a lidar into a remote deployment.

Photo by Andy Clifton, NREL

Offshore

A floating buoy equipped with a lidar.

Photo from Flickr, courtesy of Pacific Northwest National Laboratory

So what do you need to make a new technology acceptable?

- Develop a product.
- Make the thing reliable.
- Help users do things properly.
- Generate confidence in the data.
- Develop user communities.
- Enable research.

Deploying a lidar at a wind plant.
Photo by Jennifer Newman, NREL

Standards Help Users Do Things Properly

This is a preview - click here to buy the full publication

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PERT GROUP STUDY ON
COMMENDED PRACTICES

ND-BASED VERTICALLY-
G REMOTE SENSING FOR
ESOURCE ASSESSMENT

IRST EDITION, JANUARY 2013

Submitted to the Executive Committee
rnational Energy Agency Implementing Agreement
for
on in the Research, Development, and Deployment of
Wind Energy Systems

January 2013

There Is Confidence in the Data

"DNV GL considers ZephIR 300 to be at Stage 3 under "benign" conditions—accepted for use in bankable/finance-grade wind speed and energy assessments with either no or limited on-site met mast comparisons."

—From www.zephirlidar.com, December 2015

"Dong Energy's 258-MW Burbo Bank 2 in the UK is the first offshore project to proceed on the back of floating lidar wind data."

—From www.leosphere.com, April 2015

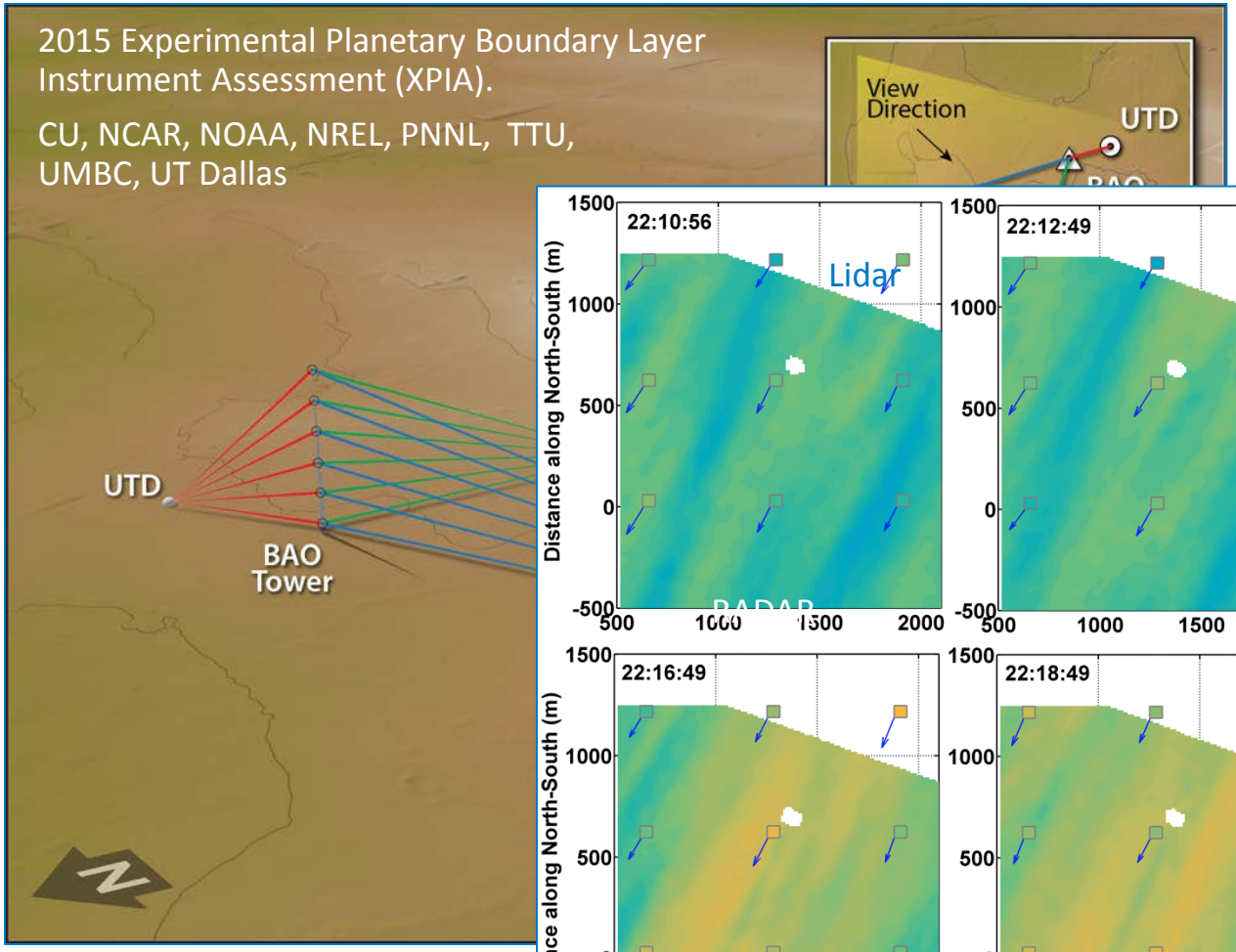
"[Fraunhofer IWES] states that Galion Lidar … 'may be recommended … for a power performance assessment offshore with the Galion Lidar installed on the transition piece of the test turbine.'"

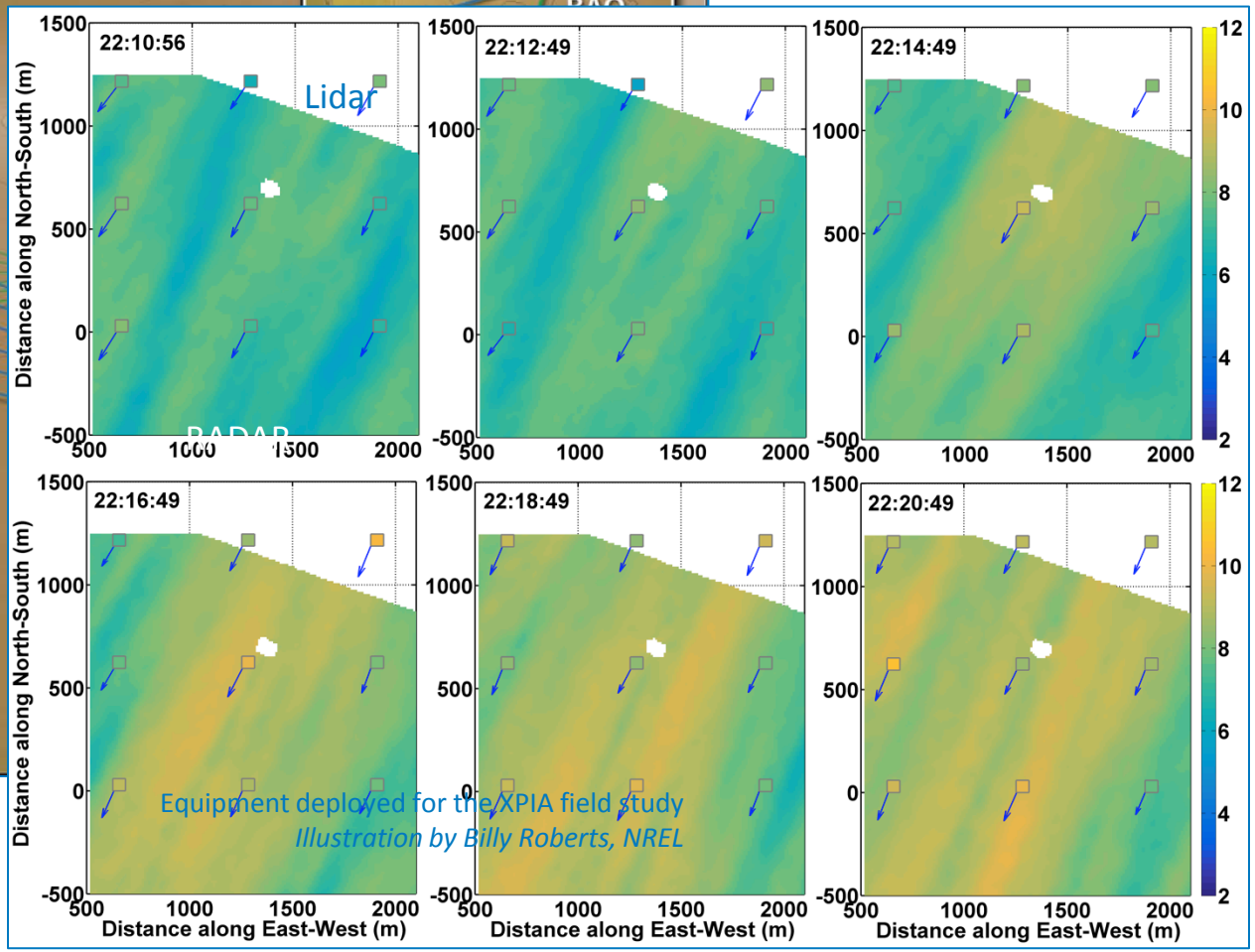
—From http://www.sgurrenergy.com, June 2013

There's Healthy R&D Activity

2015 Experimental Planetary Boundary Layer Instrument Assessment (XPIA).

CU, NCAR, NOAA, NREL, PNNL, TTU, UMBC, UT Dallas





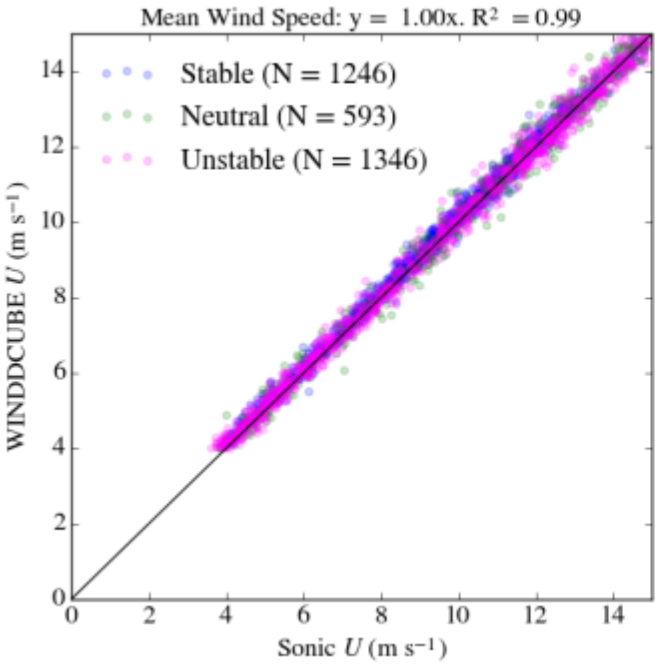
Equipment deployed for the XPIA field study

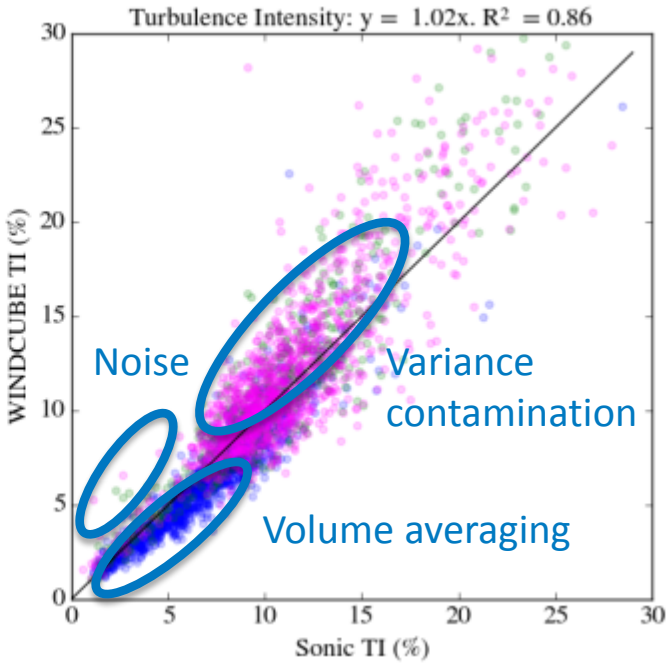
Illustration by Billy Roberts, NREL

Preliminary results courtesy of A. Choukulkar, NOAA CSD

We Need to Improve Turbulence Retrievals

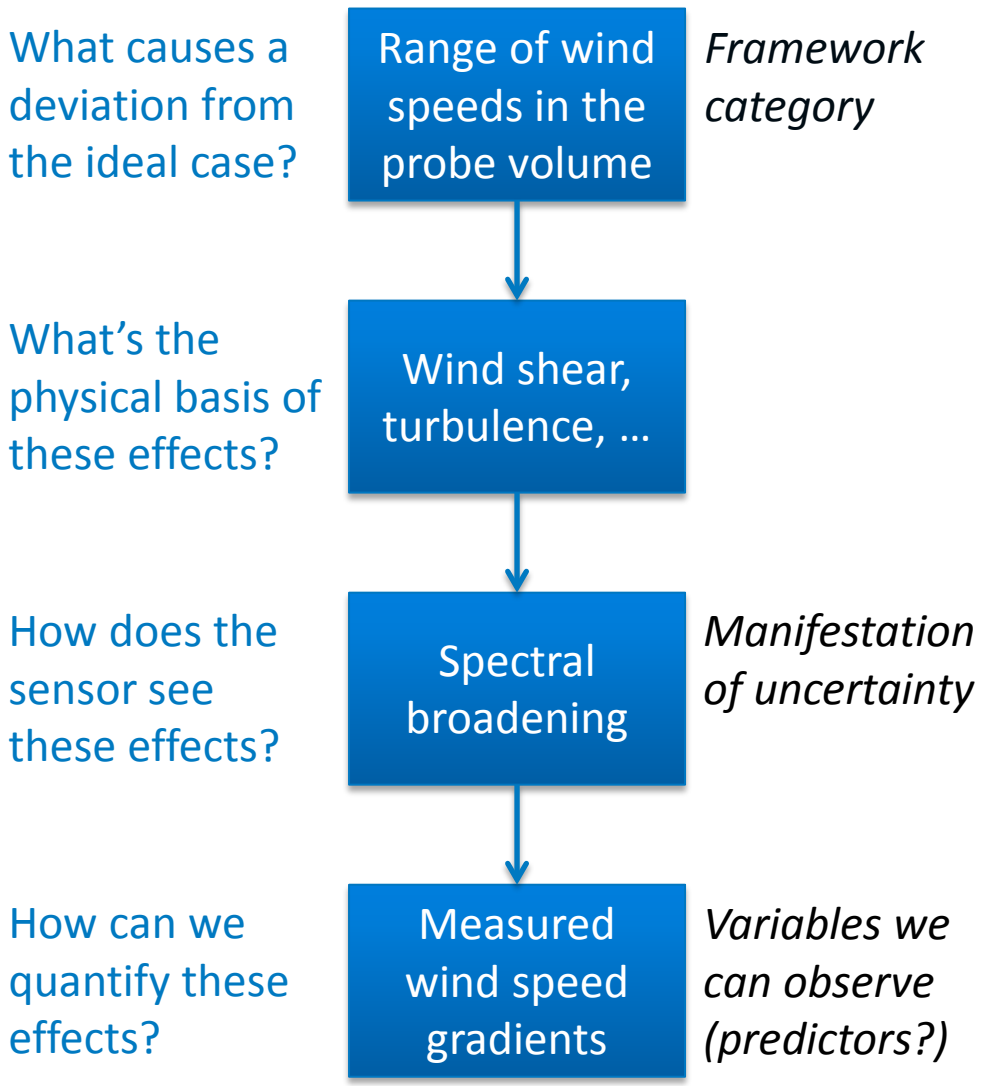
- **Motivation:** We have a good handle on mean wind speeds from lidar in flat terrain, but turbulence is still a challenge.
- **What's being done?** Lidar Turbulence Error Reduction Algorithm (L-TERRA) at NREL, some commercial tools
- **The big question:** How good is good enough?





We Need to Move Beyond Climatic Uncertainty Values

- **Motivation:** We need more granular uncertainty estimates.
- **What's being done?** Uncertainty frameworks being developed at NREL, U. Stuttgart, and the Technical University of Denmark based on measurement physics
- **The big question:** How do we calculate uncertainty without having an independent reference device on-site?



Questions and comments to Jennifer Newman: jennifer.newman@nrel.gov

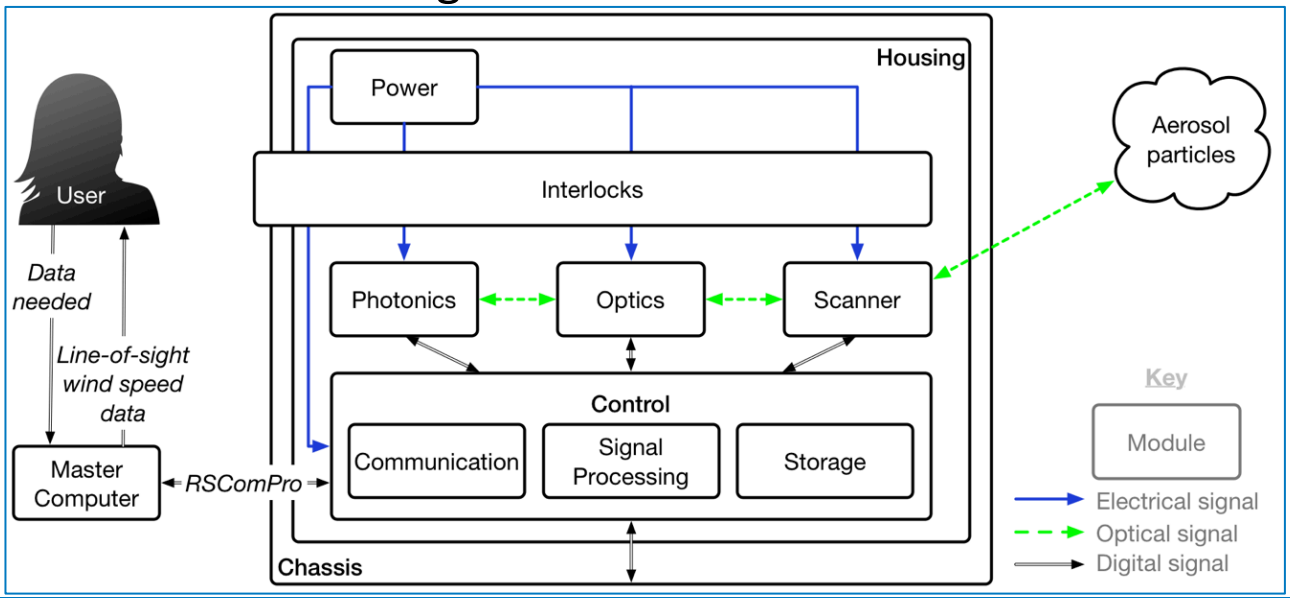
We Need Tools to Make Deployments Better

- **Motivation:** How do I set up a campaign to get the best data?
- **What's being done:** We need geographic information system tools to place and operate remote sensing devices given constraints such as wind roses, terrain, measurement needs, and device capabilities.
- **The big question:** Who pays for this?

A lidar deployed in a California wind plant.
Photo by Sonia Wharton, Lawrence Livermore National Laboratory

We Need Other Collaboration Tools

- **Motivation:** International collaboration always helps!
- **What's being done?**
  - **IEA Wind Task 32, "Wind Lidar":** identifying and mitigating barriers to the adoption of lidar for wind energy. See www.ieawindtask32.org.
  - **The OpenLidar initiative:** modular lidar architecture, wiki, software repository, and hardware. See www.openlidar.net.
  - **RSComPro:** communications protocol for remote sensing devices.
- **The big question:** How do we introduce enough commonality to collaborate but avoid stifling ideas?



The OpenLidar modular Architecture.
Illustration by Andy Clifton, NREL

Remote Sensing Use Is Increasing in the Wind Industry

- Strong push to use remote sensing for wind industry measurements
- Lots of benefits
- Challenges using devices in unusual circumstances
- Lots of collaboration and increasing coordination
- But will remote sensing ever *replace* met towers?

Deploying a sodar at the NWTC.
Photo by Andy Clifton, NREL

task 32 lidar

www.IEAwindtask32.org

OpenLidar

www.openlidar.net

Let's talk!

andrew.clifton@nrel.gov

The National Wind Technology Center, Boulder, Colorado.
Photo by Dennis Schroeder, NREL 21905

Things We Keep Learning The Hard Way

- Know what your ultimate customers need.
- Make a deployment and operations plan.
- Stuff breaks in odd ways.
  - Real-time monitoring is essential.
  - Look at high-frequency data as well as summaries.
  - Lightning loves expensive gear.
- Have a strategy for data management.
- Have a service contract.

Deploying a lidar by helicopter.
Photo by Andy Clifton, NREL

Lightning strike at the NWTC
Photo by Lee Jay Fingersh, NREL