Wind Lidar Activities in the United States

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IEA Wind Task 32 General Meeting
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Contributions

- Jennifer Newman, National Renewable Energy Laboratory (NREL)
  Improving Lidar Turbulence
- Alexandra St. Pé, University of Maryland Baltimore County (UMBC)
  U-SPARC: UMBC- atmoSpheric Profiling for Advancing offshoRe wind researCh
- G. Valerio Iungo, University of Texas Dallas
  Proactive monitoring of an onshore windfarm
- Sonia Wharton, Lawrence Livermore National Laboratory (LLNL)
  Wind Forecasting Improvement Project (WFIP) 2
- Tommy Herges, Sandia National Laboratories
  Lidar measurements at SWIFT
- Matthew Filippelli, AWS Truepower
  2016 Lidar Applications Snapshot
- Philippe Pontbriand, Renewable Energy Systems (RES)
  C-FARS: Industry Consortium for Advancement of Remote Sensing
- Evan Osler, Renewable NRG Systems
  Wind Energy Lidar Trends in North America.

All nonattributed slides were prepared by Andrew Clifton, NREL

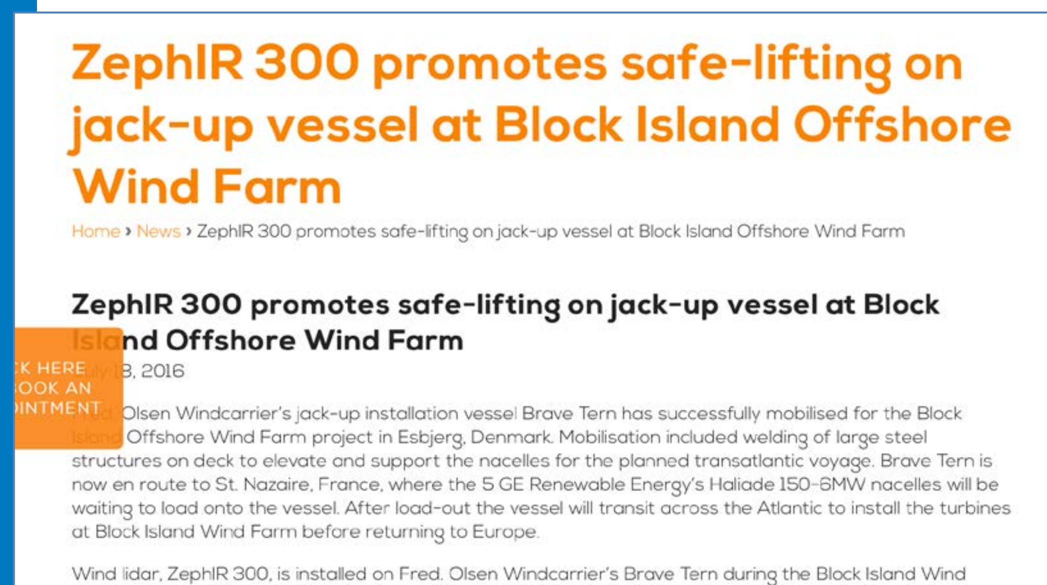
Contributions were requested from approximately 20 U.S.-based members of the International Energy Agency Wind Task 32 group and are presented as is, with modifications for different slide aspect ratios or to satisfy a two-slide limit. **Inclusion does not imply endorsement by NREL or the U.S. Department of Energy (DOE), or agreement with the content**. Questions about contributions should be directed to the slides' author(s).

Dec. 2016: First U.S. Offshore Wind Plant Begins Commercial Operations!

- Block Island Wind Plant, Rhode Island
- 5x Alstom Halide Turbines
- Resource assessment (2011) and turbine installation (2016) supported by wind lidar.

Provided by Andrew Clifton, NREL

Block Island Turbines. Photo by Dennis Schroeder, NREL



ZephIR 300 promotes safe-lifting on jack-up vessel at Block Island Offshore Wind Farm

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ZephIR 300 promotes safe-lifting on jack-up vessel at Block Island Offshore Wind Farm

July 13, 2016

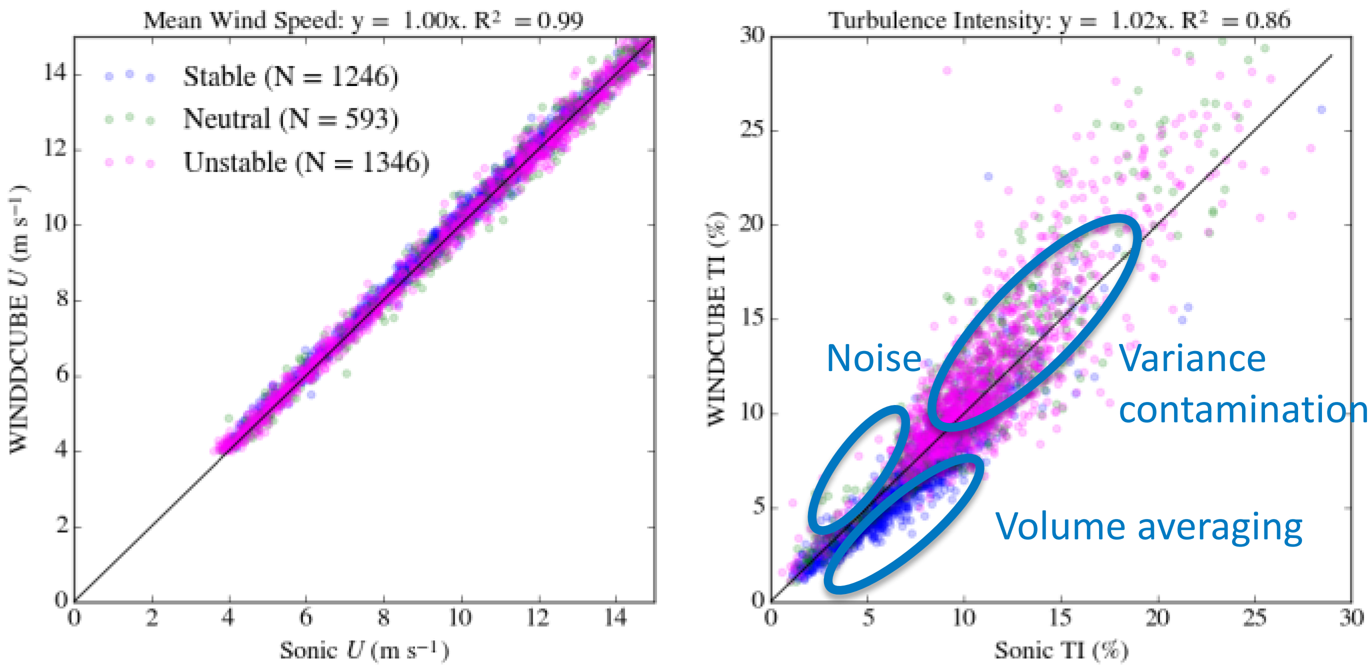
Fred. Olsen Windcarrier's jack-up installation vessel Brave Tern has successfully mobilised for the Block Island Offshore Wind Farm project in Esbjerg, Denmark. Mobilisation included welding of large steel structures on deck to elevate and support the nacelles for the planned transatlantic voyage. Brave Tern is now en route to St. Nazaire, France, where the 5 GE Renewable Energy's Haliade 150-6MW nacelles will be waiting to load onto the vessel. After load-out the vessel will transit across the Atlantic to install the turbines at Block Island Wind Farm before returning to Europe.

Wind lidar, ZephIR 300, is installed on Fred. Olsen Windcarrier's Brave Tern during the Block Island Wind

Text from zephirlidar.com

A Method To Improve Turbulence Measured By Lidar

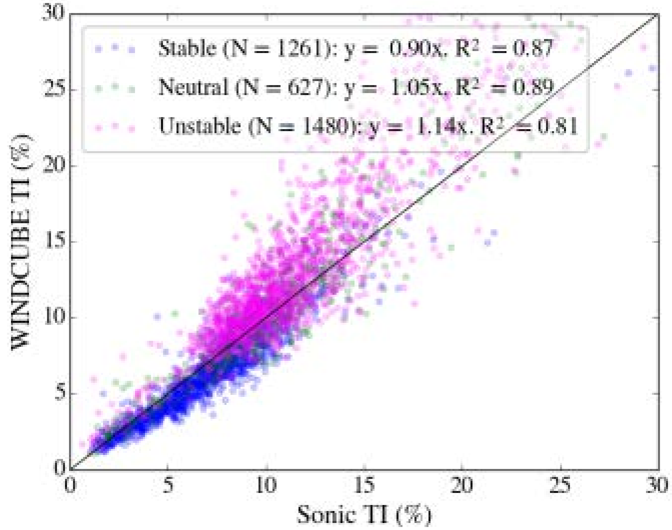
- **Motivation:** We have a good handle on mean wind speeds from lidar in flat terrain, but measurements of turbulence intensity (TI) are still a challenge
- **Current Work:** Lidar Turbulence Error Reduction Algorithm (L-TERRA)
  - Algorithm is dynamic – A new set of corrections is applied for every 10-minute period
- **The Big Question:** How good is good enough when it comes to lidar turbulence?
  - We will never get exactly the same values that we would get from a cup or sonic anemometer.



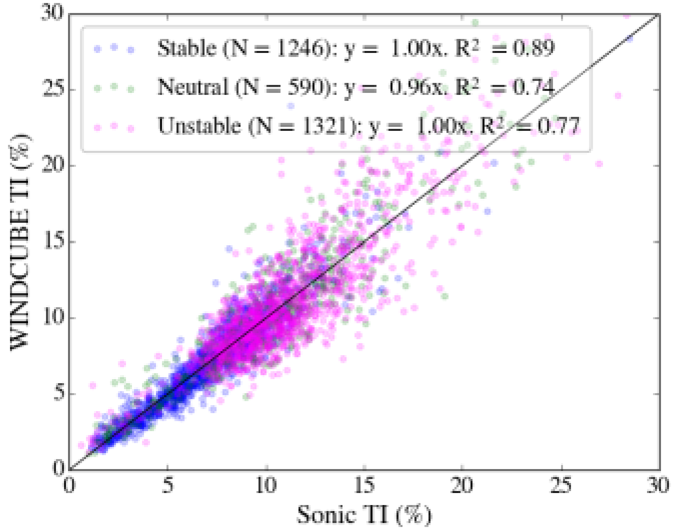
Slide and images provided by Jennifer Newman, NREL

A Method To Improve Turbulence Measured By Lidar

Before L-TERRA



After L-TERRA



Remaining Challenges

- Turbulence intensity accuracy improves on average, but still a large amount of scatter—L-TERRA is not currently capturing all the physics
- Currently using simulations to better understand how the three-dimensional flow field affects lidar turbulence intensity estimates.

Contact

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Slide and images provided by Jennifer Newman, NREL

U-SPARC:

UMBC- atmo**S**pheric **P**rofiling for **A**dvancing offsho**R**e wind resear**C**h

U-SPARC

Motivation

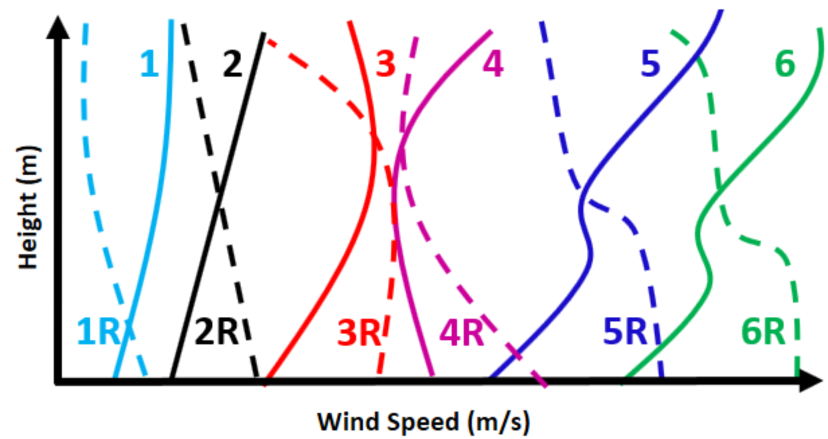
Demonstrate the advantages of Doppler wind lidar measurements for understanding the frequency of complex rotor-layer wind structures (i.e., vertical wind speed and direction and turbulence profiles) in the offshore Mid-Atlantic USA environment

- **Activity:** July-August 2013 collected offshore wind measurements (40–220 meters [m]) in Maryland's Wind Energy Area (Windcube V2 Offshore)

Method

Classified vertical wind speed profile 'shapes' using goodness of fit to mathematical expressions and other criteria

Schematic of Classified Rotor-Layer Wind 'Shapes'



- Once 'shapes' were classified, UMBC investigated relationships with meteorological drivers and turbine-available power estimates.

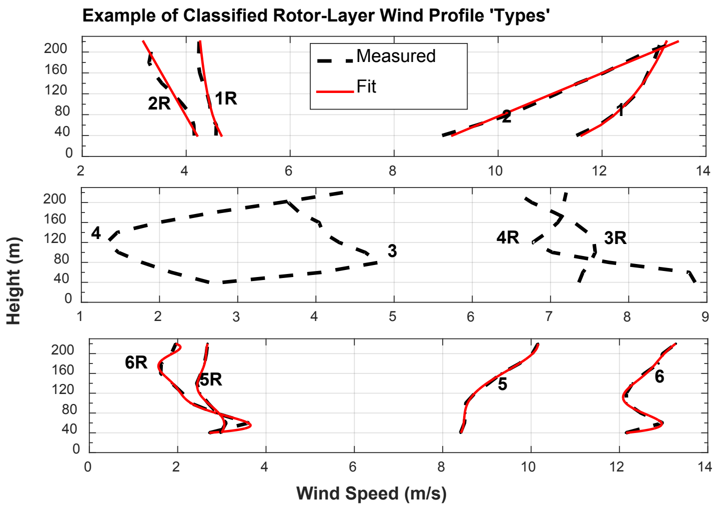
Slide provided by UMBC

U-SPARC:

UMBC- atmo**S**pheric **P**rofiling for **A**dvancing offsho**R**e wind resear**C**h

Lessons Learned

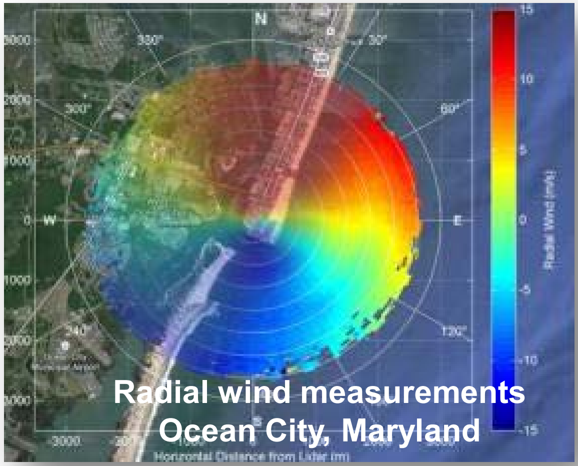
Only ~17% of data classified as Type 1, power-law fit; majority of data set 'unexpected' shapes (Types 3-6); ~18% of data 'reversed' wind profile shapes



Rotor equivalent wind speed (REWS) available power estimate = **5 to 11% less than hub-height estimate**, depending on wind profile shape

Take-Away/Next Steps

Offshore lidar measurements are extremely valuable for characterizing rotor-layer wind conditions that deviate from expected 'logarithmic-like' power law shapes



Collecting long-term scanning wind lidar measurements off Maryland's coast (Nov 2014-present)

Investigating impact of classified profile shapes on coastal turbine's performance and relationships with atmospheric stability

Contact: Ruben Delgado (delgado@umbc.edu)
Website: http://lidar.umbc.edu/wind-energy/

Slide provided by UMBC

Proactive Monitoring of a Land-Based Wind Farm

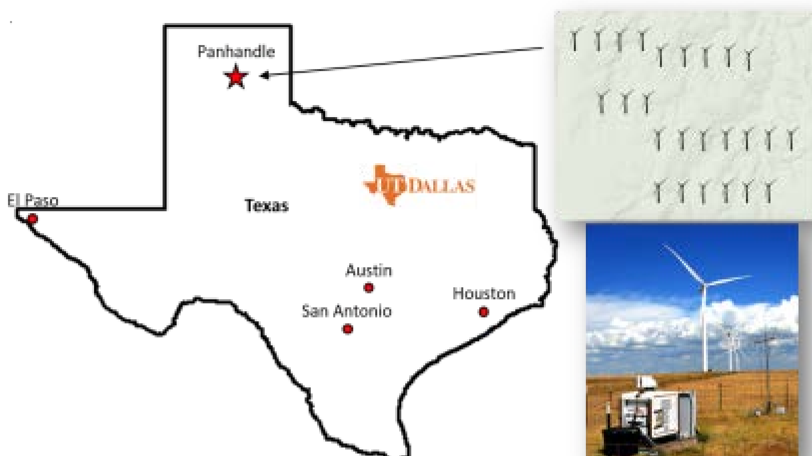
G. Valerio Iungo, email: *valerio.iungo@utdallas.edu* Web: *www.utdallas.edu/windflux*

Motivation:

- Evidence of power losses due to wake interactions
- Need for improved wake models for real-time coordinated wind farm control.

Site: Panhandle, Texas

Subarray of 25 turbines; 2.3 megawatts (MW)
Supervisory control and data acquisition and meteorological data available

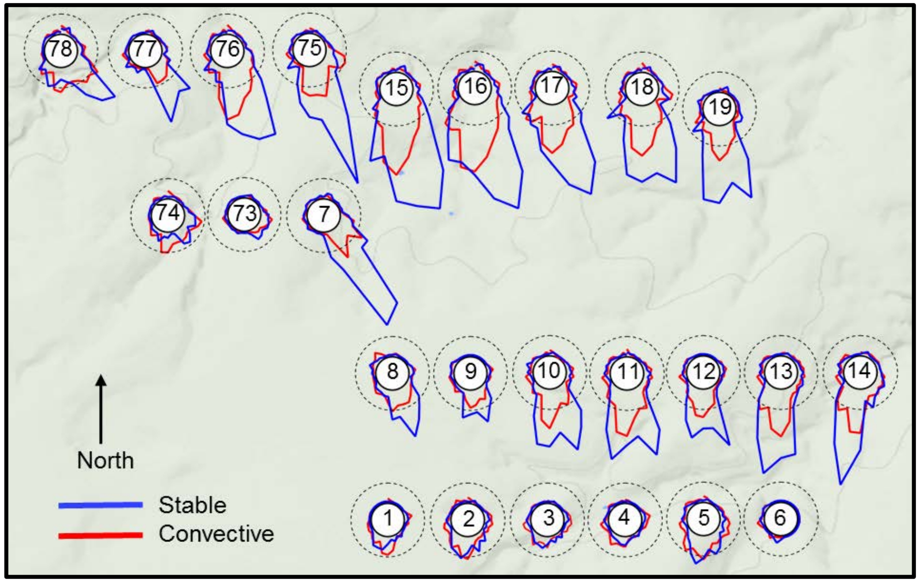


UTD Mobile Lidar Station

Two long-range scanning lidars
Arrays of sonic anemometers and licors

Slide provided by UT Dallas

Proactive Monitoring of a Land-Based Wind Farm

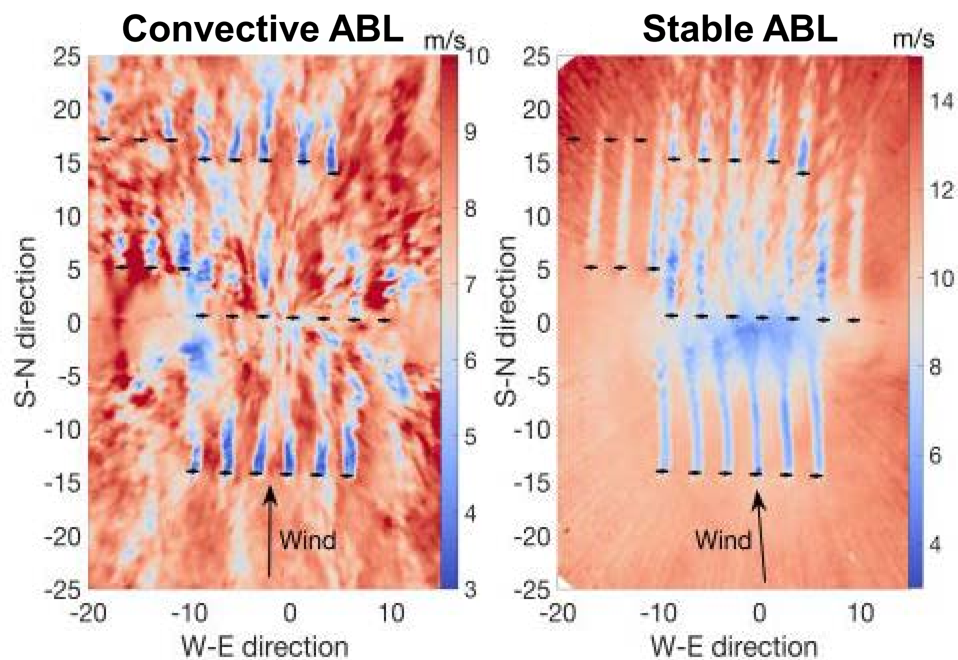


Effects of atmospheric stability on wind turbine wakes and wake interactions:

- Experimental power curves show generally larger power production under convective ABL conditions
- Wind turbine wakes recover faster under convective ABL conditions as a consequence of higher turbulence intensity and flow entrainment
- Reproducing effects on wakes due to atmospheric stability is essential for accurate power predictions and wind farm control.

Cumulative power losses:

- Losses for 4% of the total power production under stable atmospheric boundary layer (ABL) conditions
- 2.4% loss under convective conditions
- Evidence of wake-related losses at the 2nd row (center) and 3rd row (top) for southerly wind directions
- Underperformance of turbine 7 for SE wind directions due to a spacing of 3.5 rotor diameters from turbine 8.



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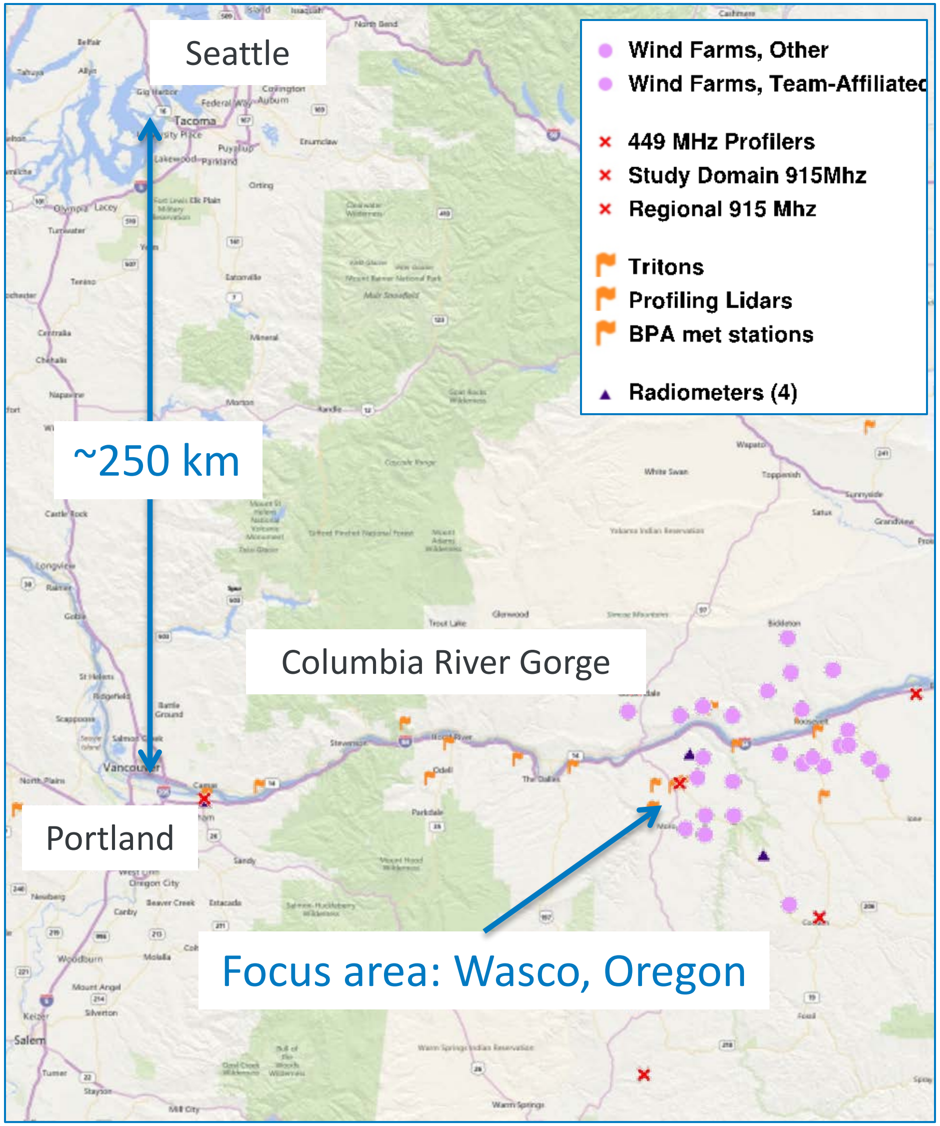
Wind Forecasting Improvement Project (WFIP2)

How good are wind forecasts in complex terrain? Can we improve them?

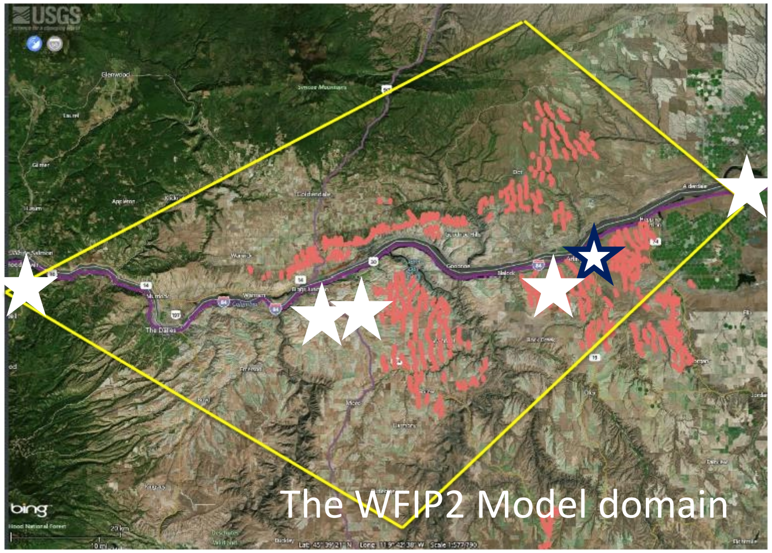
- Columbia River Gorge (Oregon/Washington border)
  - Area of complex flow
  - Four gigawatts installed capacity
- Competitive award in 2013
- Field campaign from summer 2015 to early 2017
- Comparing observations to WRF model improvements
- Validated improvements will flow into operational forecasts.

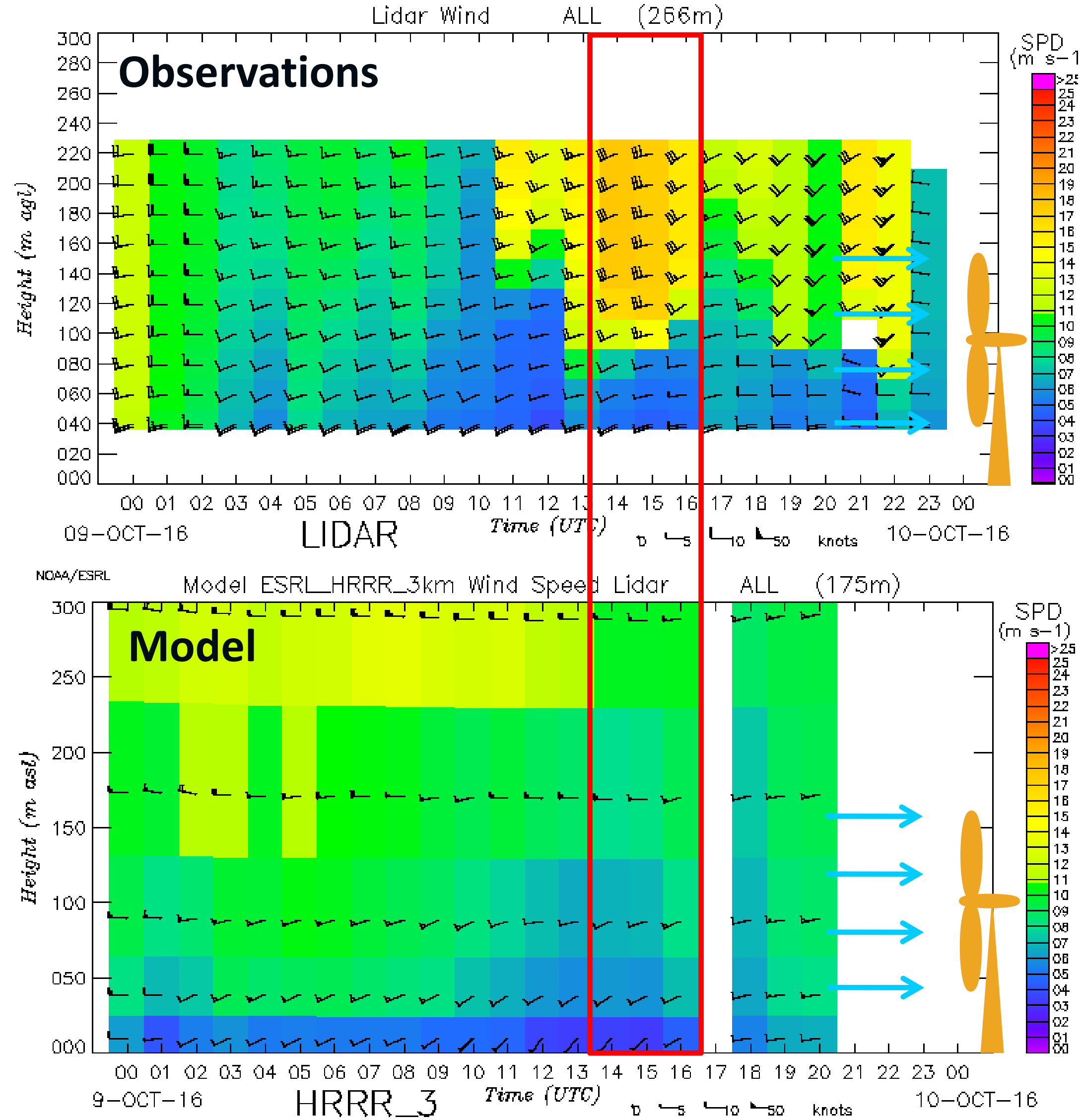


The Team:

- Vaisala (DOE Funding Opportunity Announcement awardee) leads a team including individuals from University of Colorado, Boulder, National Center for Atmospheric Research, Sharply Focused, Lockheed Martin, Texas Tech University, the University of Notre Dame, Iberdrola Renewables, Southern California Edison, Cowlitz County Public Utility District, Eurus Energy, Bonneville Power Administration, and Portland General Electric.
- DOE National Labs: NREL, Pacific Northwest National Laboratory, LLNL, Argonne National Laboratory
- National Oceanic and Atmospheric Administration

Results from Lidar – Model Comparison

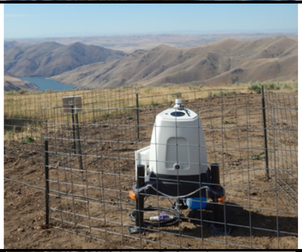




Slide provided by Sonia Wharton, wharton4@llnl.gov. All images used with permission.

AWS Truepower – 2016 Lidar Application Snapshot

Preconstruction Lidar Activities

Application	Description	Photo
Dedicated offshore measurements	On behalf of MassCEC, AWST is supporting the monitoring, operations and analysis of a Windcube V2 offshore of Martha's Vineyard, MA. Data is planned for public use.	
Floating lidar validation	AWST validated UMaine's prototype DeepCLidar floating lidar system (Windcube V2 offshore) against Carbon Trust framework; the system passed all KPIs	
Stand-alone wind map validation	Design, implementation, and analysis of campaigns employing stand-alone lidar data sets for wind model validation / adjustment (after verification with a tower)	
Mobile shear verification	Supported legacy approach of using lidar as a mobile, short-term measurement tool for shear (and veer) characterization	

Slide and all images provided by AWS Truepower

AWS Truepower – 2016 Lidar Application Snapshot

Postconstruction Lidar Activities

Application	Description	Photo
Permanent met mast replacement	Supported siting, installation, SCADA integration and operation of a profiling lidar in lieu of a permanent met mast on an operating project; data accepted by utility	
Forecasting support	On behalf of HECO, AWST is supporting operations and analysis of Windcube 100S as part of an integrated solar and wind forecasting system. Arc scans also set up to support potential wake analyses of adjacent farm.	
Power performance measurement methods development	Participate in IEA Task 32 round robin for Uncertainties in Power Performance measurements; Develop Power curve test methods to accommodate lidar use in IEC 61400-12-1 ed. 2	IEC
	Initiate multi-lidar power curve test – one two-beam nacelle lidar, one four-beam nacelle lidar, one ground-based profiling lidar, one IEC hub height mast all evaluating the same turbine; to be deployed Q1 2017	

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AWS Truepower – 2016 Lidar Application Snapshot

Needs and Activities for 2017

- **Design Inputs:** Expand lidar use in suitability assessments and offshore design basis development
- **Complex Terrain:** Encourage better mast, lidar, and flow model configurations to enhance analyses at complex sites
- **Broaden Overall Usage:** Encourage more frequent and longer duration lidar deployments for terrestrial and offshore projects (pre and postconstruction)
- **Power Performance Tests:** Conduct lidar-based power performance tests; experimentally and commercially.

Thanks!

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Industry Consortium for Advancement of Remote Sensing (C-FARS)

Who

- **2016 Founding Members:**

Five major North American wind <u>project owners, developers, and operators</u>

- **Industry Remote Sensing Facilitator**

Federated private industry consortium enabling collaboration on projects promoting the acceptance of remote sensing

- **Private Industry Players**

Private industrial players supporting the different working groups

Why

- **Create Consensus**

Seek private industry consensus around the use of remote sensing; speak with a common voice

- **Build Bridges**

Build bridges between industry players, research centers, normalization body, and tasks

- **Rapidly Address Private Industry Remote Sensing Needs:**

Steer short-term projects aimed at supporting private industry needs

How

- **Access to Information**

Give access to a large pool of industry remote sensing data from private sector

- **Support Remote Sensing Validation Projects**

Join members' resources to support short-term practical projects validating use of remote sensing

- **Jointly Present Results**

Present compelling results to banks, third parties, and other stakeholders

Slide provided by RES

Slide provided by RES

C-FARS: Progress and Projects Proposal

September 2016	November 2016	Jan-Feb 2017	March 2017	April 2017 …
Members expression of interest	**First grant application (Canada)**	**Governance definition**	**Official launch**	**Projects kickoff**

• Projects Proposal	• Project Outcome
• Remote sensing – performance validation	• Evaluation of performance indicators for the main remote sensing technologies commercially available • Demonstration of their respective ability to reduce project uncertainty • Demonstration of level of consistency across the various technologies (lidar, sodar) • Evaluation of their performance in various climatic conditions
• Filling the gap to achieve bankability of standalone remote sensing in noncomplex terrain	• Develop the largest industry data set of remote sensing collocation with International Electrotechnical Commission (IEC)-compliant masts in noncomplex terrain • Evaluate average performance parameters for the entire data set (sodar and lidar) in comparison to IEC compliance mast

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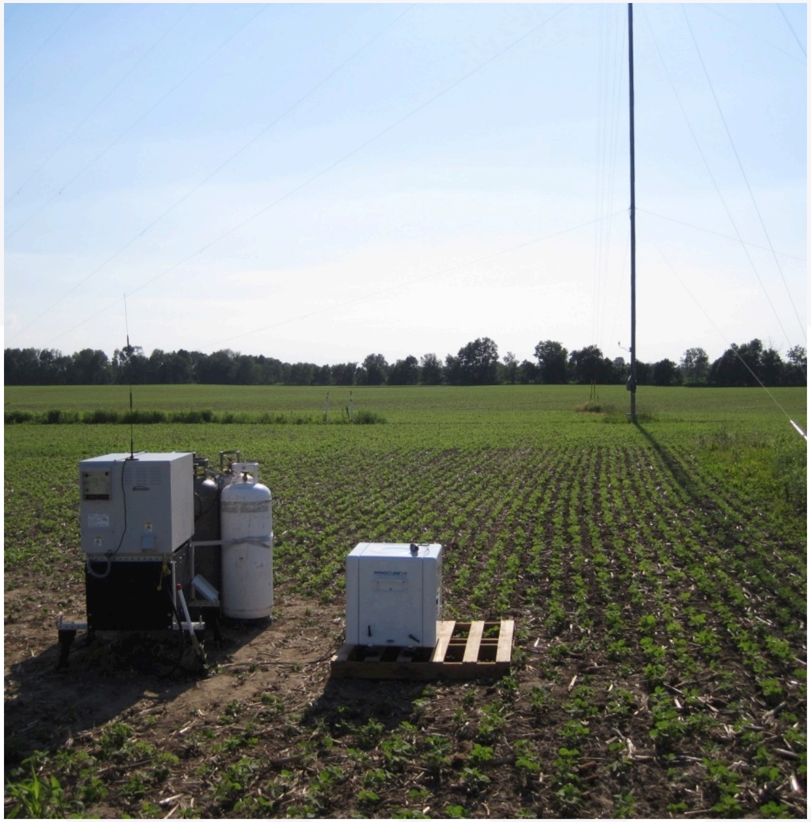
Wind Energy Lidar Trends in North America: Preconstruction

Slides authored by Evan Osler
Renewable NRG Systems

- Most projects now utilize remote sensing in the wind resource assessment (WRA) phase
- 60-m met towers are still the standard despite hub heights in the 80–100 m range, leaving an important height gap for RSDs to fill for shear uncertainty reduction
- Sodars still outnumber Doppler lidars in terms of field use, but lidars have gained significant ground in last 2–3 years
- Lidars *tend* to be used in conservative (i.e., less mobile) ways, and with greater value placed on on-site verification vs. predeployment third-party validation, compared to European norms
- Project developers and WRA analysts are especially busy with production-tax-credit-related deadlines; anecdotally, there is less time and room for innovation in WRA techniques than there would be in times of lesser development pressures.



WINDCUBE + propane fuel cell adjacent to 60-m XHD mast in southern Ontario, Canada

Slide and photo provided by Renewable NRG Systems

Contact: Evan Osler at evan@rnrgsystems.com or 802/482-2255 x545

Wind Energy Lidar Trends in North America: Postconstruction

- Lidar use for operational power performance testing (PPT) has increased dramatically in popularity (hub-height method in spirit of IEC -12-1:2005)
- All else equal, general preference for ground-based lidar compared to nacelle lidar in simple terrain operational PPT
- Unlike majority of preconstruction projects, majority of wind farms do not use RSDs actively; this is slowly changing
- Impact of four-beam Wind Iris on ability to perform operational PPT in complex terrain is potentially significant
- With many projects underperforming, there is both a need for operational wind measurements and, in many cases, budget challenges to doing so
- A broad portion of the industry on the operational side is unfamiliar or only vaguely familiar with IEC -12-1 rev 2 and the rotor-equivalent wind speed (REWS) concept.

contact Evan Osler at
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Slides authored by Evan Osler
Renewable NRG Systems

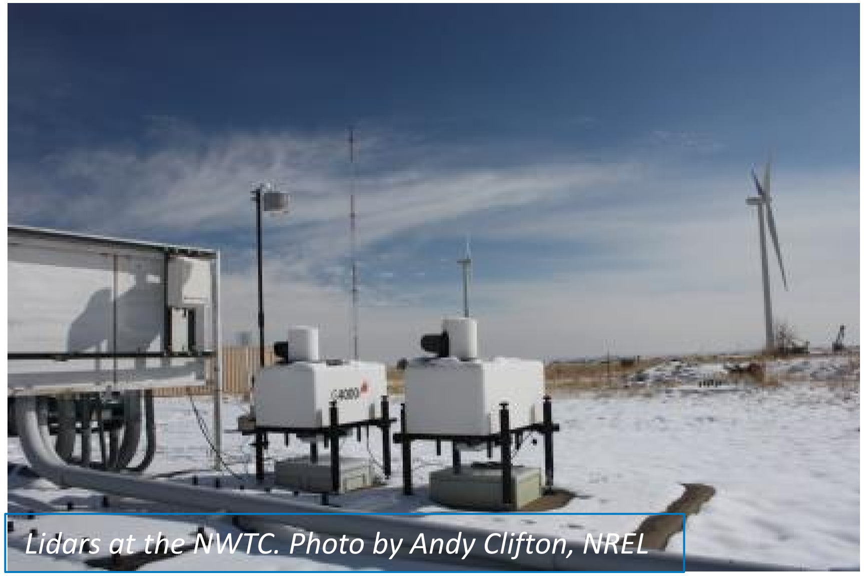
Wind Iris (two-beam) temporarily installed for calibration of upgraded turbine control sensor hardware in California

Slide and photo provided by Renewable NRG Systems

Summary of U.S. Activities in 2016

Themes

- Lidar supports resource assessment
- Used increasingly to monitor and improve plant performance
- Activities mirror U.S. commercial pressure to “get steel in the ground” and then maximize return on investment



Lidars at the NWTC. Photo by Andy Clifton, NREL

Needs

- Cheaper, more reliable, lower power systems for preconstruction
- Explore and document links to new standards (e.g., IEC 61400-12-1)
- Address practical challenges to using lidar pre and postconstruction

What Actions are Required?

- Workshops from Task 32
- Collaboration with PCWG and IEC
- Clear worked examples or flowcharts for resource assessment, operational analysis, and so on.

All nonattributed slides prepared by Andrew Clifton, NREL

Let’s talk!

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  Wind Energy Lidar Trends in North America

A multimegawatt wind turbine and 1-MW photovoltaic field at the National Wind Technology Center at the National Renewable Energy Laboratory. *Photo by Dennis Schroeder, NREL*