ZephIR Lidar
wind speed at light speed

TURBINE MOUNTED LIDAR

Necessity is the mother of invention:
Nacelle mounted lidar for
measurement of turbine performance

Matt Smith – 22nd January 2014

ZephIR DM

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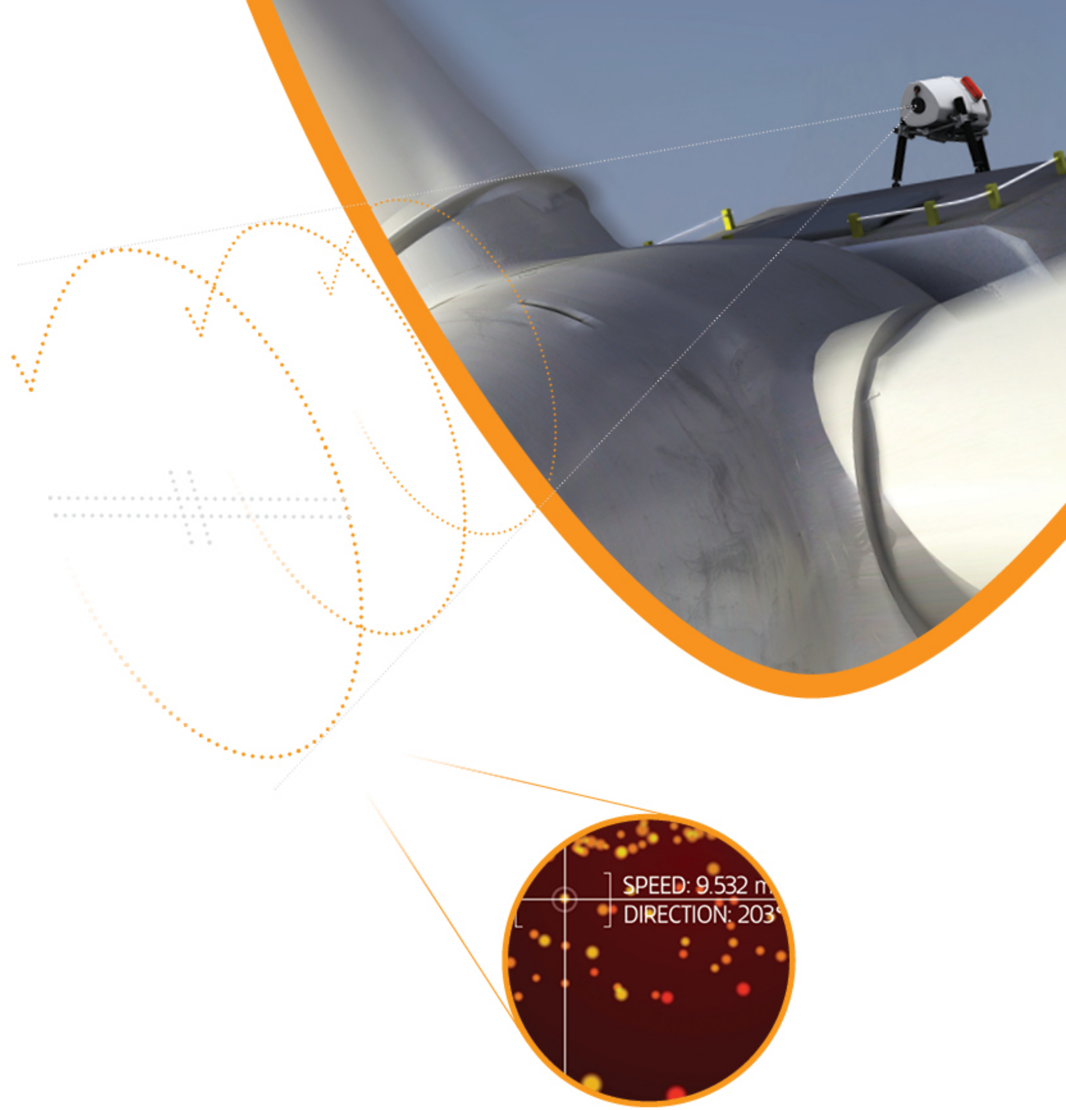
- Lidar principles
- History – World first, ground based
- Ground based on turbines
- Basic Accuracy and results
- Nacelle mounted lidar products
- Benefits of nacelle lidar offshore



ZephIR DM

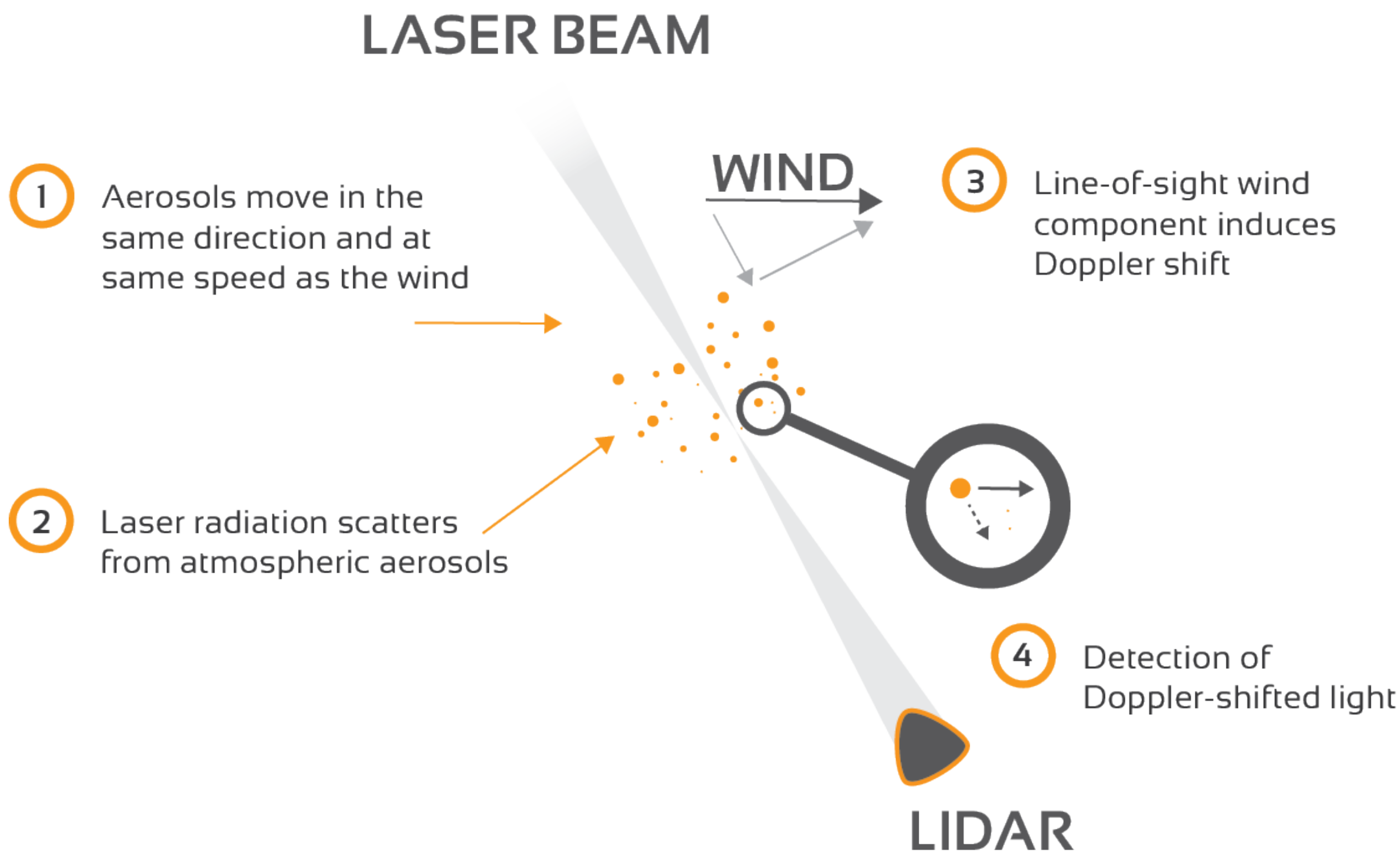
Apology

As much as possible I have tried to make this presentation about turbine mounted lidar in general.

The presentation template I have used is for ZephIR DM because certain images and diagrams are embedded within this

Certain benefits of turbine mounted lidar do relate specifically to using continuous wave lidar; ZephIR is the one that I know best

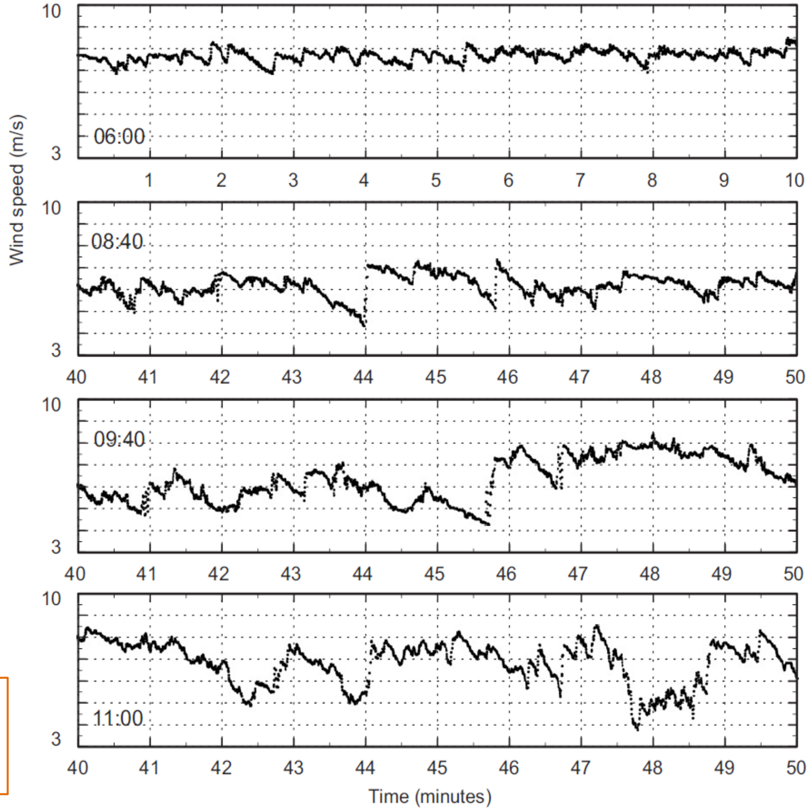
HOW DOES A LIDAR MEASURE WIND SPEED?



2003 - A WORLD FIRST

2003 - TRIAL

2.3 MW Nordex N90 turbine in Germany (90m hub height)
Single staring beam lidar system (CW) – Single Line of Sight (LoS) measurement
Turbine aligned it roughly into the wind
Single Beam - no measurements of wind yaw misalignment or wind shear or wind veer



- Good estimate of approaching wind speed
- Simple gust warning

NACELLE MOUNTED - SIDELINED

GROUND BASED LIDAR DEVELOPED

- The nacelle mounted application was interesting but the market was not there
- Ground based lidar started being developed and addressed accuracy and reliability for remote resource assessment
- Adoption increased , competition entered the market and lidar remote sensing begins
- Validations completed onshore and offshore and over time the confidence grows

NACELLE MOUNTED - RESTART

GROUND BASED LIDAR DEPLOYED ON TURBINES

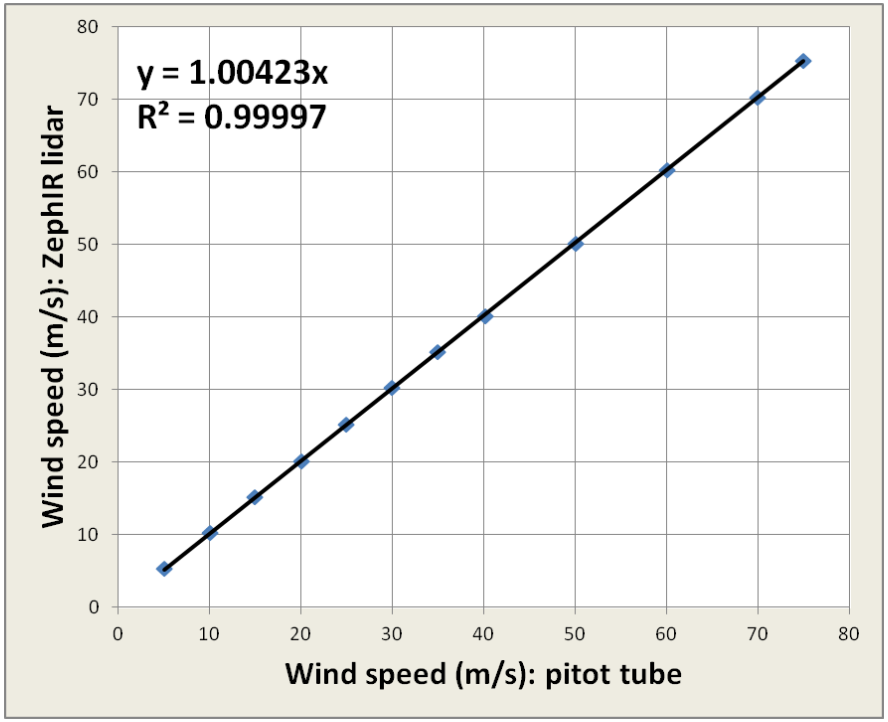
- Ground based production units, mounted on a frame to allow positioning and attachment of the lidar on a nacelle roof
- The mounting tended to be bespoke and difficult
- Much of this work was behind closed doors and explored the accuracy, benefit and reliability of the systems

I'd like to personally offer my thanks to Riso/DTU during this time for publicly exploring and publishing results of nacelle based applications of lidar

NACELLE MOUNTED – BASIC ACCURACY

THE WIND IS NO LONGER PERPENDICULAR (GROUND BASED) AND IS BLOWING TOWARDS THE LIDAR

- Measurements in a high-specification wind tunnel confirm very close agreement over a wide velocity range
- This is the accuracy of a single Line of Sight measurement

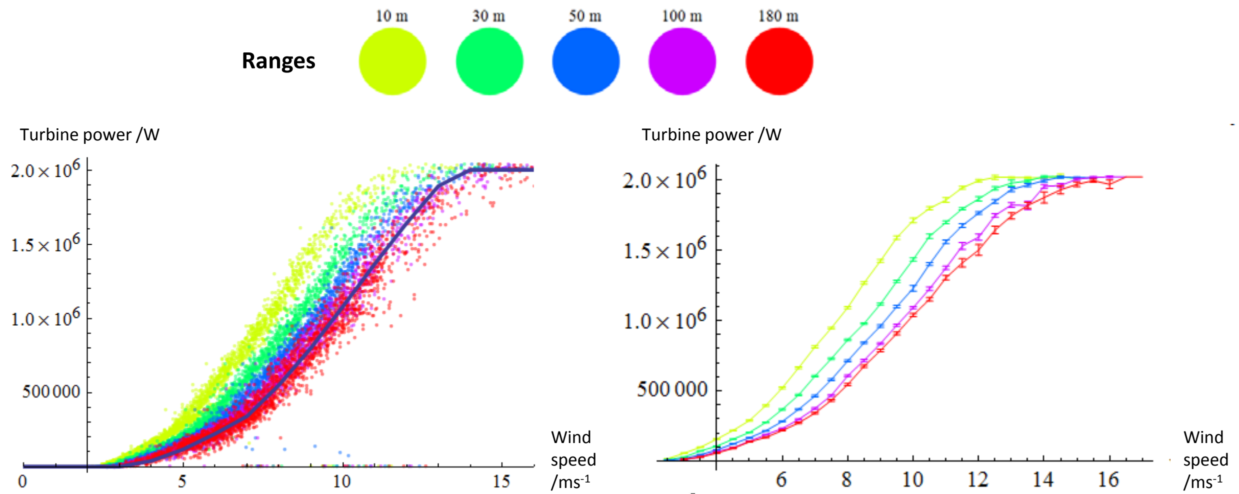


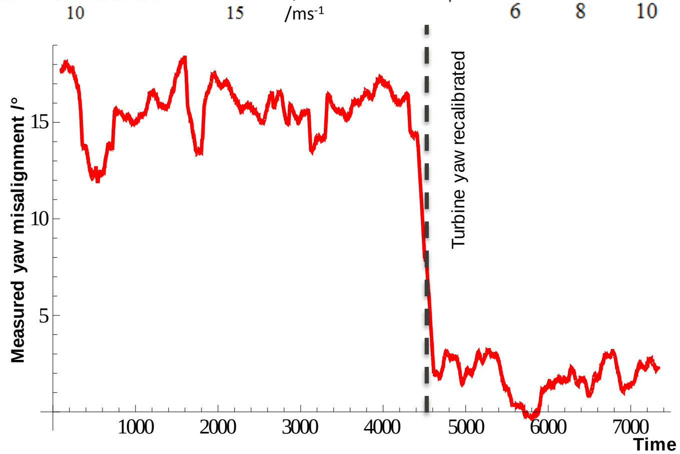
Credit:
"HTF number 049-2009-3 - Integration of wind LIDAR's in wind turbines for improved productivity and control",
a Danish National Advanced Technology Foundation's (DNATF) Project.

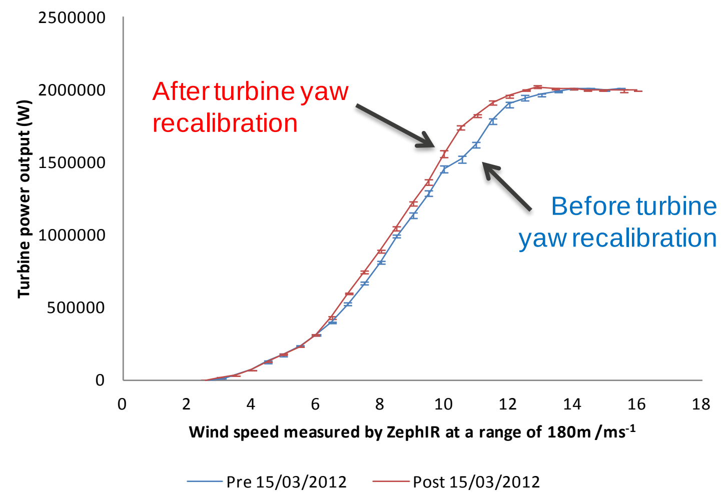
Reference:
A T Pedersen, B F Montes, J E Pedersen, M Harris, and T Mikkelsen,
"Demonstration of short-range wind lidar in a high-performance wind tunnel",
EWEA conf. PO78, Copenhagen (2012).

NACELLE MOUNTED – SOME RESULTS

THE BENEFITS OF LIDAR ON TURBINES:





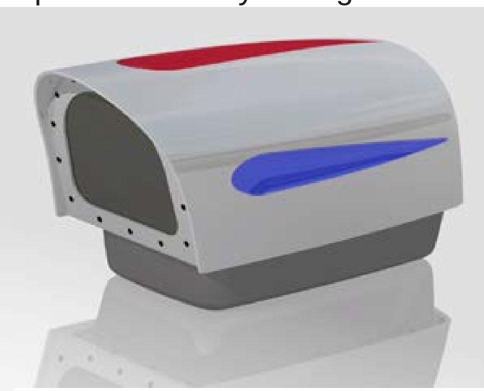


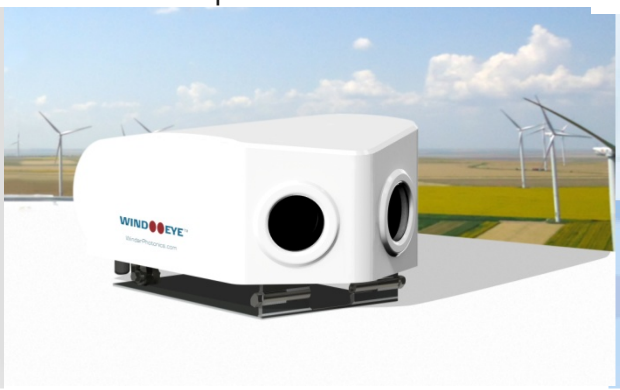
Thanks to ROMO Wind for these results

NACELLE MOUNTED – SPECIFIC PRODUCTS

LIDAR DEPLOYED ON TURBINES

- **Low System Mass.** the lidars must be light enough to allow, ideally, 2 man installation.
- **Small size.** small enough to allow it to be maneuvered through internal turbine spaces and hatches. Meeting this requirement typically allows the turbine's internal crane to be used for deployment, ideally designed to allow passage through hatches of aperture 0.55 x 0.55 m2.
- **Easy handling** and protection during installation. Adequate handles, padding, connections and rugged construction are needed.
- **Adaptable and flexible mounting arrangements.** This allows mounting on a variety of turbine roof shapes and at various heights. Often tripod arrangements, with independently adjustable legs, are a good solution. The ZephIR DM has carbon fibre tripod legs, and can be mounted at heights up to 1.5 m from the roof.
- **Adequate alignment procedures.** The ability to align the centreline of the lidar with the turbine axis is important where yaw alignment checks are to be performed.



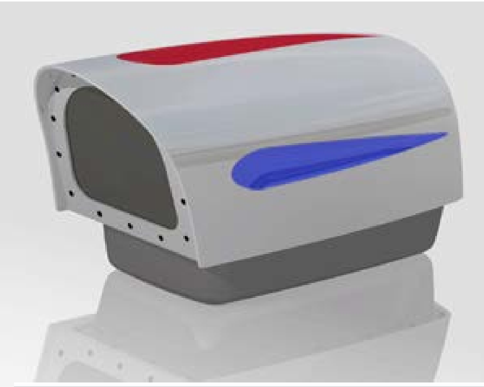


NACELLE MOUNTED – SPECIFIC PRODUCTS

LIDAR DEPLOYED ON TURBINES

- ZephIR DM Offers:
  - Hub height and rotor equivalent horizontal wind speeds
  - Wind yaw alignment relative to turbine
  - Vertical wind shear
  - Wind veer (variation of wind direction with height)
  - TI and other turbulence measures
  - Wind field complexity
  - Turbine wakes and effects of complex terrain

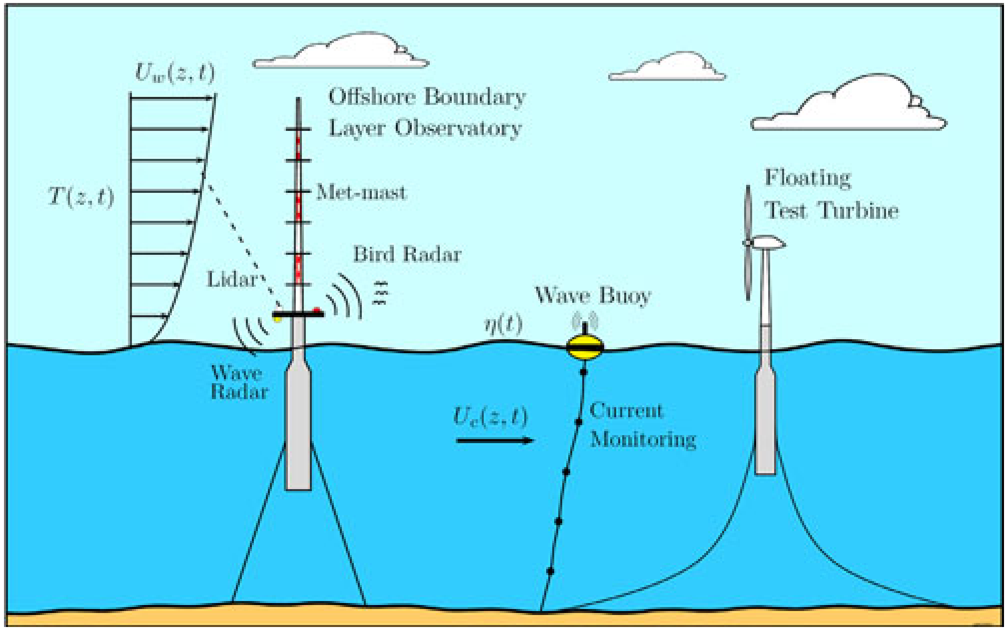



BENEFITS OFFSHORE

ASSESSING/OPTIMISING TURBINE PERFORMANCE

- Traditional and IEC accepted methodologies can be expensive offshore
- Deeper water with floating wind turbines could see this further complicated
- What will warranties be based on?



ZephIR Lidar

ZEPHIR DM– OFFSHORE?

THE FOLLOWING FEATURES ARE IMPLEMENTED FOR ONSHORE TURBINES:

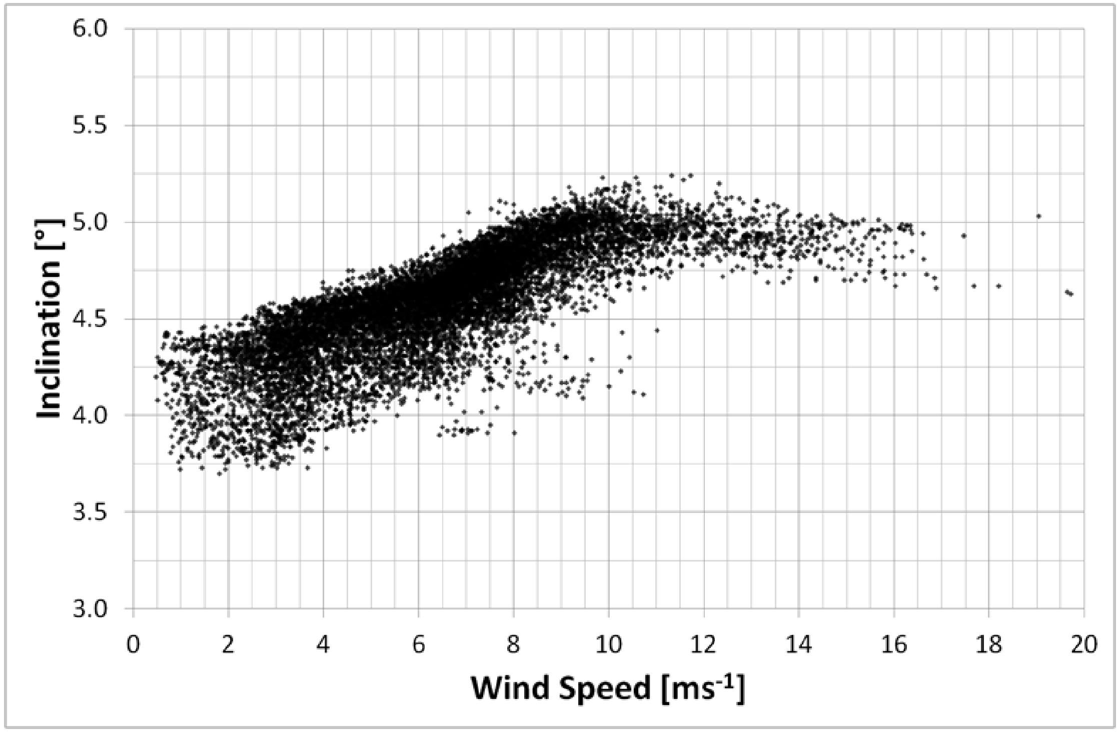
- **Real-time inclination and roll.** The nacelle roof rolls and tilts due to inherent machine resonances as well as wind flow variations. The lidar itself is also subjected to wind loading, and the roof can flex accordingly. These influences cause the lidar beam to move in space. The coordinates of the lidar probe positions change, so different parts of the incoming wind field are probed. this can introduce additional measurement uncertainties, especially at longer ranges, where a small angular change in inclination can translate into significant changes in height.
- The ZephIR DM uses real-time inclination and roll measurement, accurate to 0.1°, and incorporates these measurements in the calculation of the derived wind field quantities accordingly. Such a capability will be particularly important on floating turbines.

- **Motion compensation.** In a similar way that nacelle angle changes can impact measurement uncertainty, nacelle motion, especially fore-aft velocity, can have an impact on lidar measurements. Without measurement of such motion, the lidar will be measuring the wind speed relative to the (moving) lidar, not the wind speed relative to the ground. The ZephIR DM has an inbuilt accelerometer that measures its motion in real-time and optionally corrects the measured LOS speeds

WOULD THIS HAVE FURTHER BENEFIT FOR FLOATING TURBINES?

MOVEMENT OF TURBINE NACELLES

RECORDED FROM ZEPHIR DM DEPLOYMENT ONSHORE



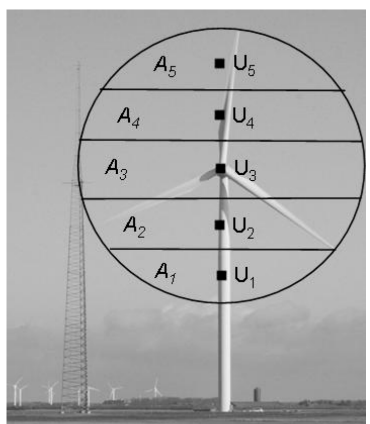
NACELLE MOUNTED – ROTOR EQUIVALENT

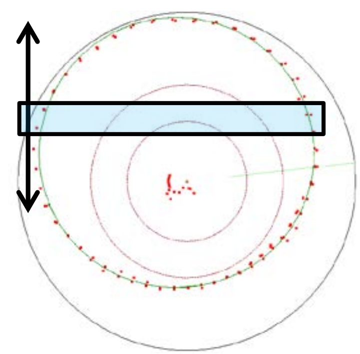
ROTOR EQUIVALENT WIND SPEEDS

The RE wind speed (u_{RE}) [6] concept was formalized in IEC 21400-12-1 CD. It aims for a more accurate measurement of the amount of energy in the wind, especially for larger rotor area (A) wind turbines. With these rotors sampling greater cross sections of wind flow, the effects of wind speed variation with height, and wind speed direction variation with height, become more significant. The RE formula in the standard incorporates these effects, but requires a knowledge of the horizontal wind speed u_i and direction θ_{wi} relative to the direction at hub height, at multiple (≥3) heights over the rotor disk.

$$u_{\mathrm{RE}} = \sqrt[3]{\frac{1}{A}\sum_{i=1}^{N}(u_i \cos\theta_{\mathrm{wi}})^3 \Delta \mathrm{A}_i}$$

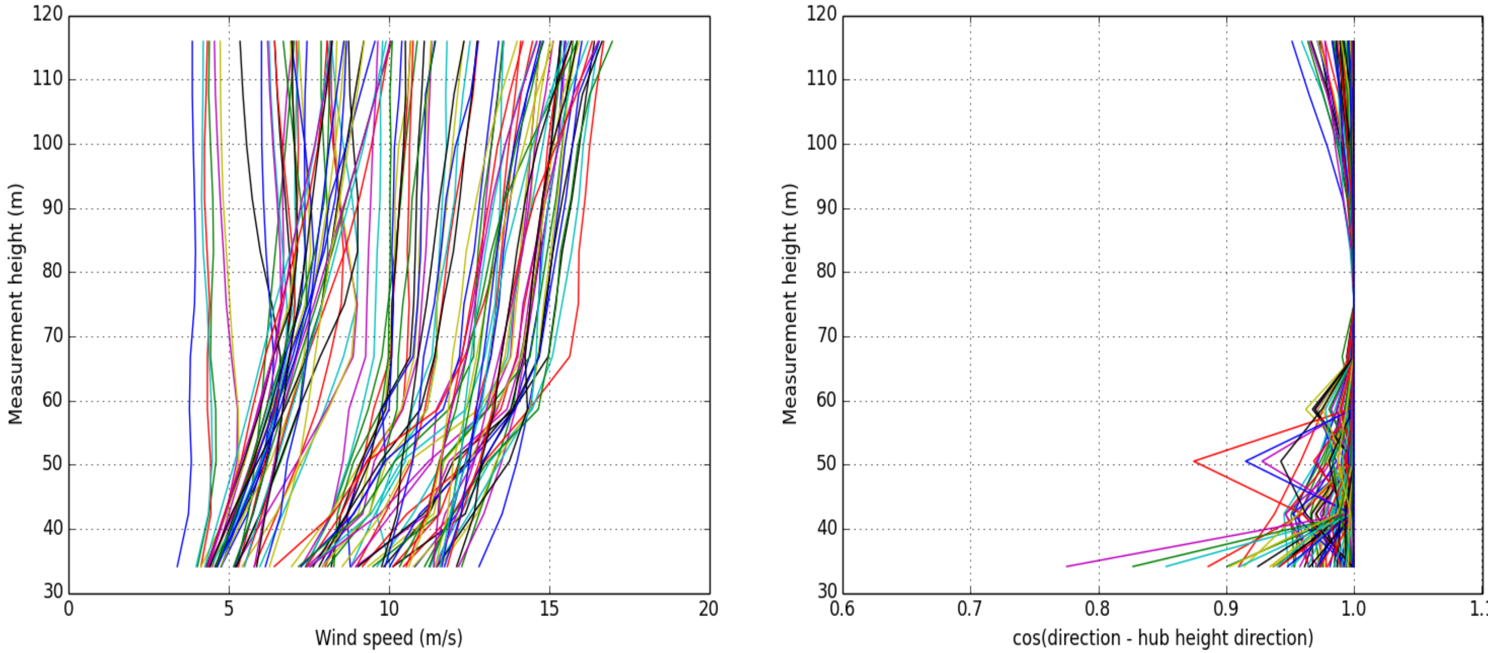
- where ΔA_i is the area of the *i*th slice of the rotor, and *N* is the number of slices over the rotor disk.





NACELLE MOUNTED – ROTOR EQUIVALENT

Nacelle-mounted ZephIR DM vertical wind profile (left) and vertical wind veer (θwi) from a single 24 hour period on a non-complex site in the UK. Each coloured line represents a 10 minute-averaged measurement. 2 MW turbine, rotor diameter 90 m, hub height 75 m



Vertical wind shear and TI. Both these quantities are influenced by atmospheric stability, and can have a significant effect on turbine performance. This is reflected in power curve measurements. Unless account of these effects is included, power curves will have larger uncertainties

DEEP AND DEEPER WATER

WHAT DOES NACELLE MOUNTED LIDAR OFFER?

- Onshore: We are seeing nacelle mounted lidar being used for optimisation and performance measurements.
- Offshore: There is no realistic turbine performance measurement option.
- Deeper water: Nacelle mounted lidar offers
  - turbine manufacturers the ability to articulate products performance
  - operators the ability to measure individual turbine performance. There is no alternative...

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