WIND POWER | WEATHER & CLIMATE | AVIATION WEATHER | AIR QUALITY & INDUSTRIAL RISK

# LIDAR TECHNOLOGY & APPLICATIONS in the WIND ENERGY

## (OFFSHORE FOCUS)

# Agenda

## 1. Corporate presentation

## 2. Product introduction

- WINDCUBE V2 onshore – Vertical profiler
- WINDCUBE V2 offshore – Vertical profiler
- AXYS/FLIDAR – Floating LIDAR
- WINDCUBE Scanning Lidar range
- WIND IRIS – Nacelle mounted LIDAR

## 3. LIDAR for Wind Resource Assessment

- Onshore WRA
  - flat terrain
  - complex terrain
- Offshore WRA

## 4. LIDAR for Power Performance

- Power curve measurement
- Power optimization

## 5. LIDAR for Other applications

# 1. Corporate presentation

# LIDAR technology is at the crossroads of atmospheric environmental applications

## Wind power


## Airport weather

## Air Quality

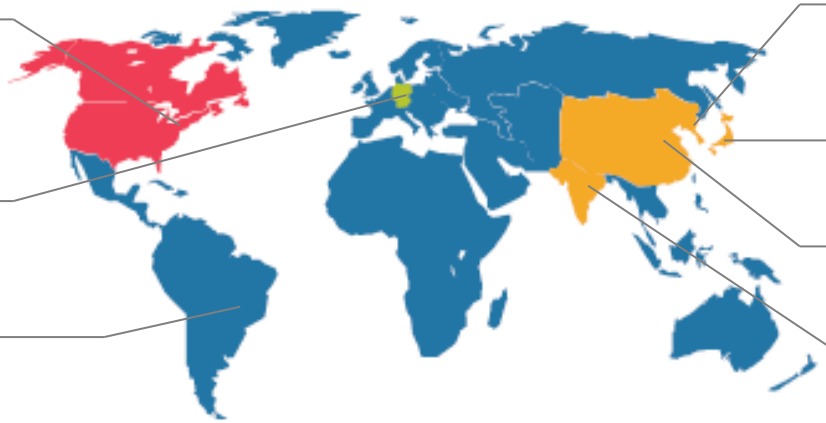
## Weather & Climate

# A world leadership in Lidar technologies driven by innovation

- 20M€ Revenue
- 75% in Wind Power
- 85% export
- 100 people
- 25% R&D Expenses
- Over 500 installations in 25 countries
- Corporate independency: owned by founders & managers
- ISO-9001 : 2008 certified

# Dedication : Anywhere, anytime

## More than 500 lidars in operation worldwide



# The only Lidar one-stop-shop to rely on at each stage of the wind farm life cycle

**Over 500 wind Lidars operating worldwide**

- Wind Ressource Assessment
- Power performance testing
- Performance monitoring and optimization
- Wind farm monitoring and forecast
- Wind assessment
- Performance verification

**ase**
**Scanning Lidar**
**Turb ounte**
**ing Lid**









DEVELOPMENT | COMMISSIONING | OPERATIONS & MAINTENANCE | REPOWERING / RESELL

# Manufacturing capacity : up to 100 LIDAR / year

# REFERENCES


MAINSTREAM
RENEWABLE
POWER


Vestas


IBERDROLA


edp
renewables
powered by nature


DEWI


oldbaum
REACHING
FOR THE WIND


DONG
energy


eDF
energies nouvelles


ENERCON
ENERGIE FÜR DIE WELT


res
power for good


REpower
Systems


e·on


AREVA


KEMA
DNV


SSE
Renewables


RWE
npower renewables


DTU Wind Energy
Department of Wind Energy


SIEMENS


GL
GL Garrad Hassan

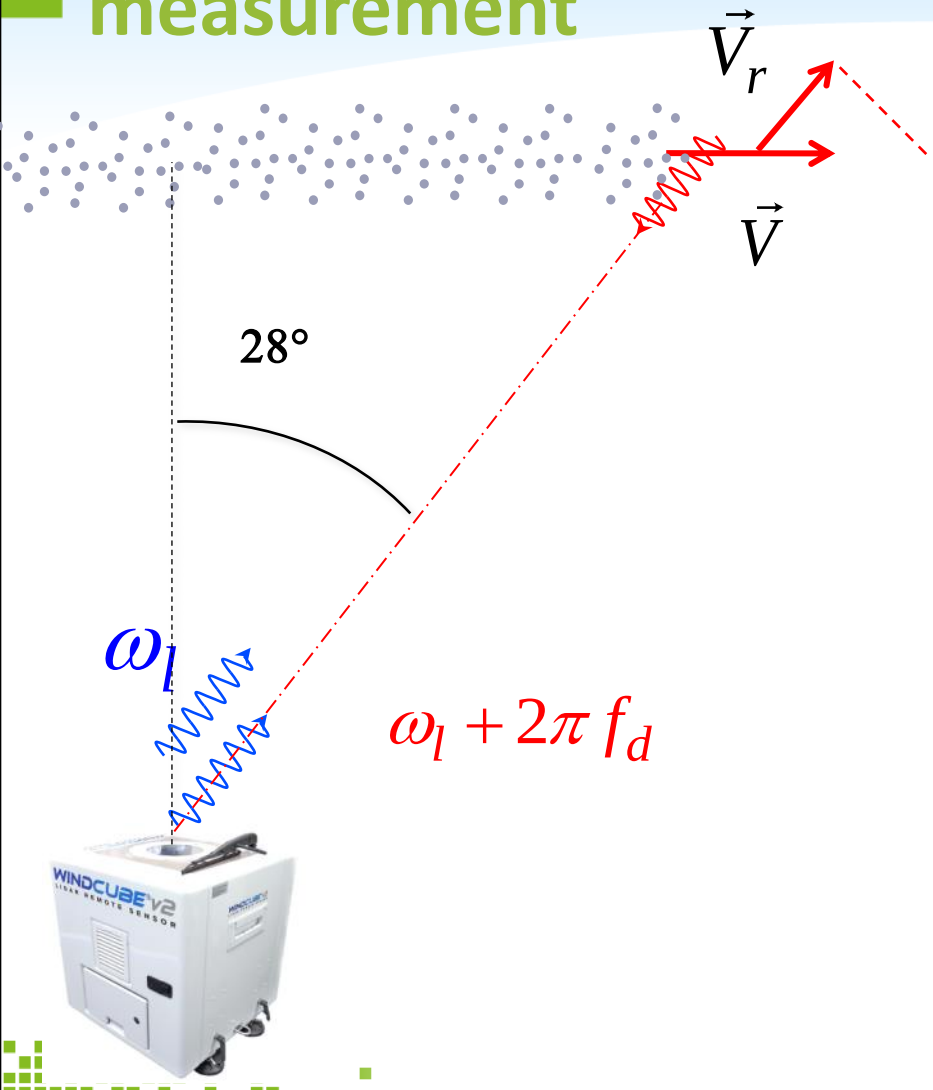

VATTENFALL


GOLDWIND

# 2. Product introduction

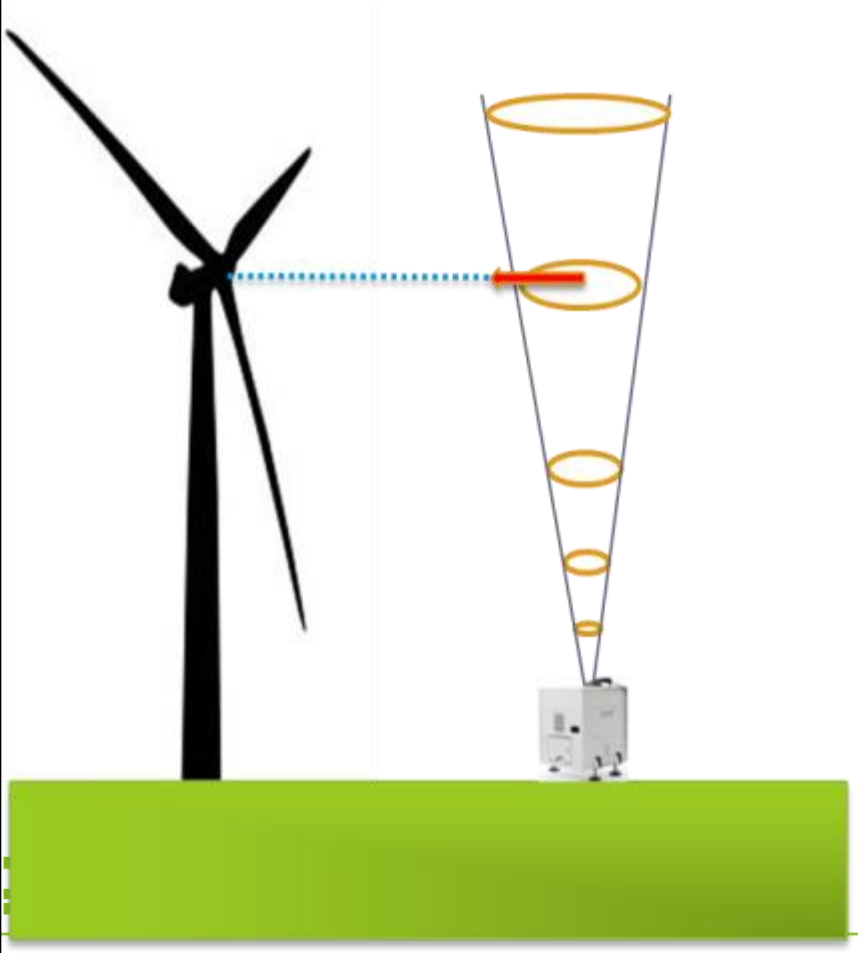
- WINDCUBEv2
- WINDCUBEv2 Offshore
- Floating LIDAR
- Scanning WINDCUBE
- WIND IRIS

# Doppler Effect – principle of measurement




- Light frequency is shifted by Doppler effect due to aerosols speed
- Aerosols speed = wind speed
- Only radial component is affected by Doppler shift
- Doppler shift is measured by heterodyne detection
- Multiple height measurements per line of sight

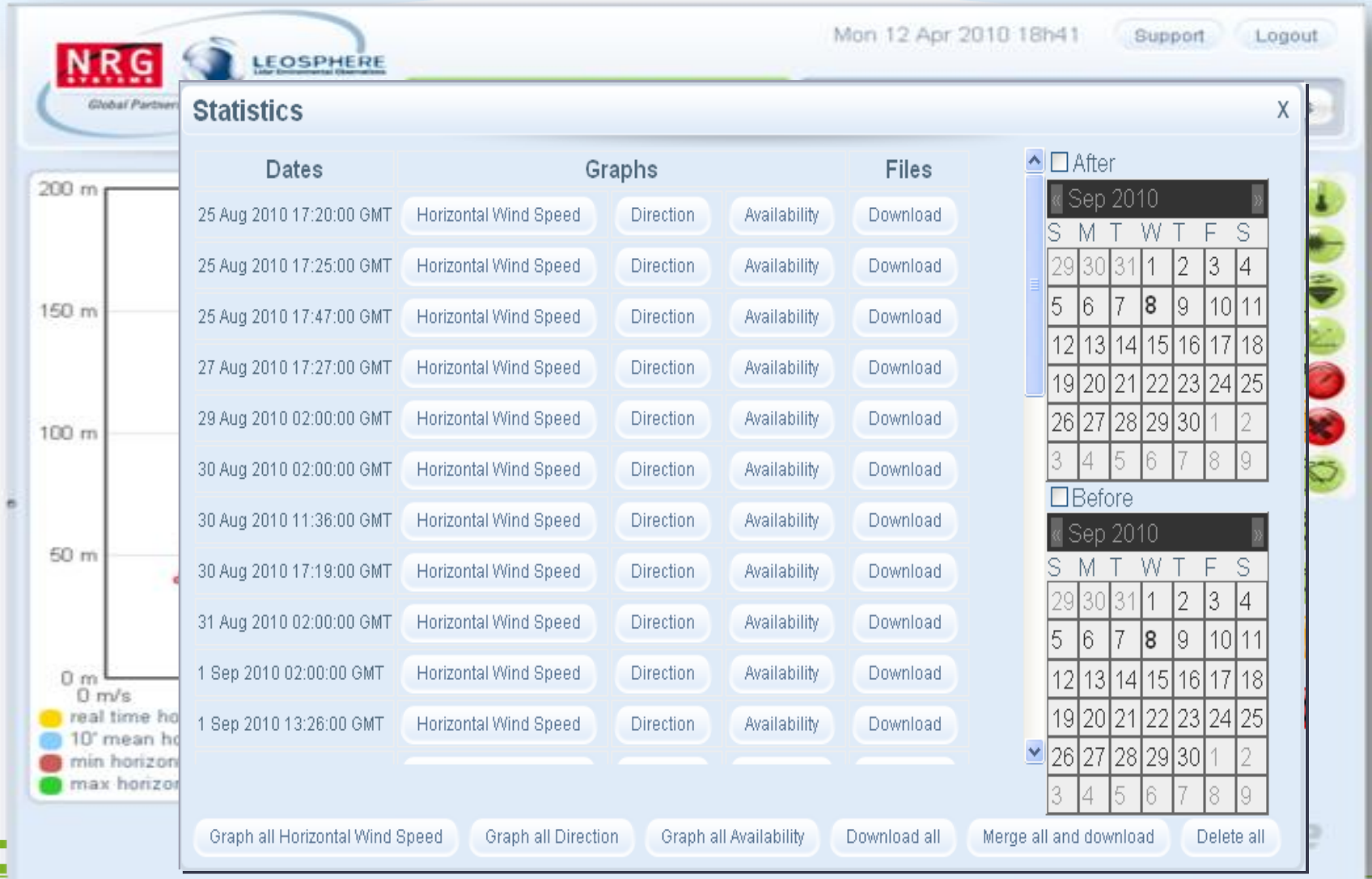
# Windcube v2 : the ground based vertical profiler



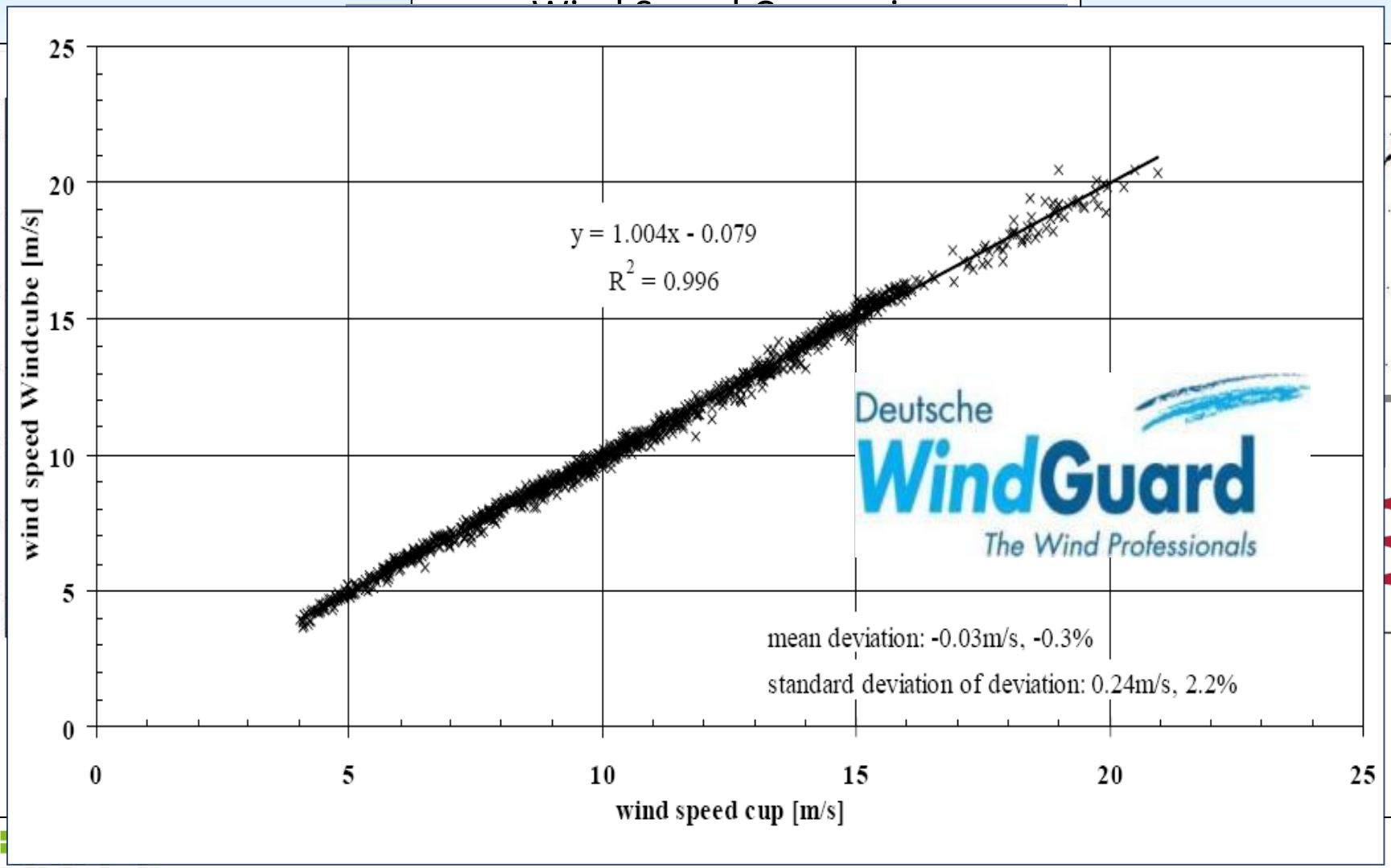
| | |
|---|---|
| Measurement range | 40 to 290m |
| Frequency | 1 Hz |
| Number of programmable heights | 12 simultaneously |
| Speed accuracy | 0.1m/s |
| Speed range | 0 to 60 m/s |
| Direction accuracy | 2° |
| Consumption | 45 W |
| Weight | 45 kg |

# Technical specifications

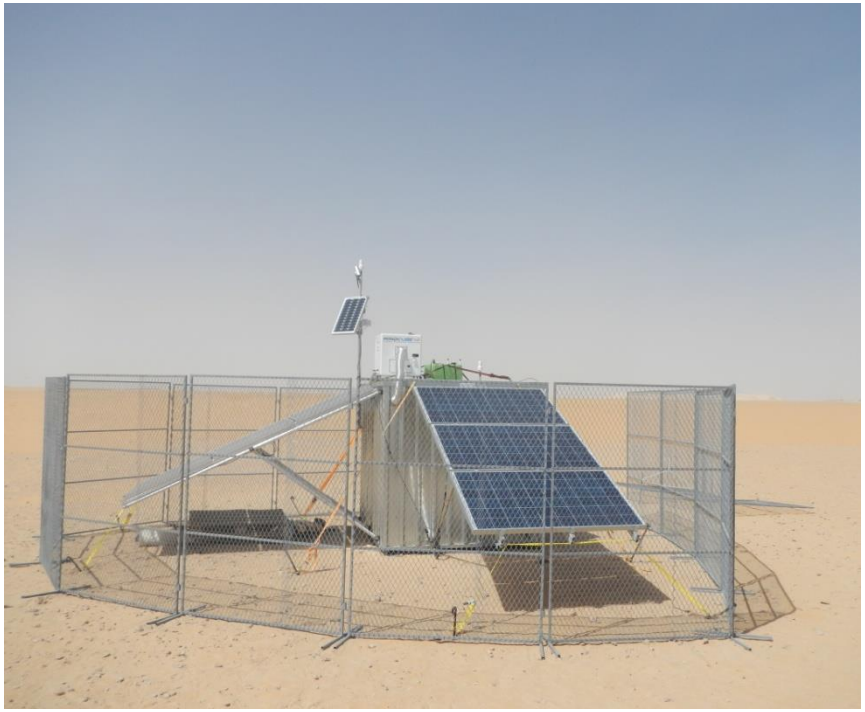
# Data specifications



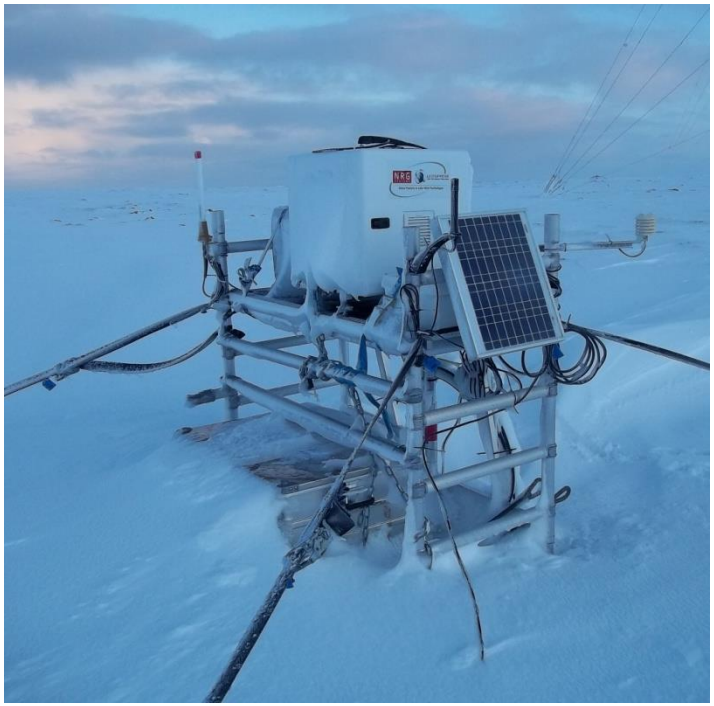
# Validation examples



# Installations
# 500 units operating worldide



Installation in hot desert
(Courtesy of Alpha Wind)



Installation in Cold climate
(Courtesy of RES)

# Installations
# 500 units operating worldide

Installation in Cold climate
( October in Northern Europe)


Installation in hot climate
(September in Southern Europe)

# Installations
# 500 units operating worldide

WINDCUBE v2 and POWER PACK in a trailer
(courtesy of WIND ENERGY HOLDING - THAILAND)

# Offshore WINDCUBEv2

- Based on the WINDCUBE V2 technology:
  - IP67 enclosures
  - Salt atmosphere compliant IEC 60068-2-52 (Zinc coating, protected wires, etc.)
- Services
  - Standard 1-year warranty and service
  - Dedicated staff for offshore services
  - Stand alone power pack
  - 3G Remote communication


# Floating LIDAR: FLiDAR and WINDSENTINEL

## COST-EFFECTIVE OFFSHORE WIND RESOURCE ASSESSMENT USING A FLOATING LIDAR


# AXYS Floating LiDAR Systems

*AXYS Floating LiDAR platforms accurately measure and reliably transmit wind speed and wind direction data offshore at turbine hub-height and across the blade span.*

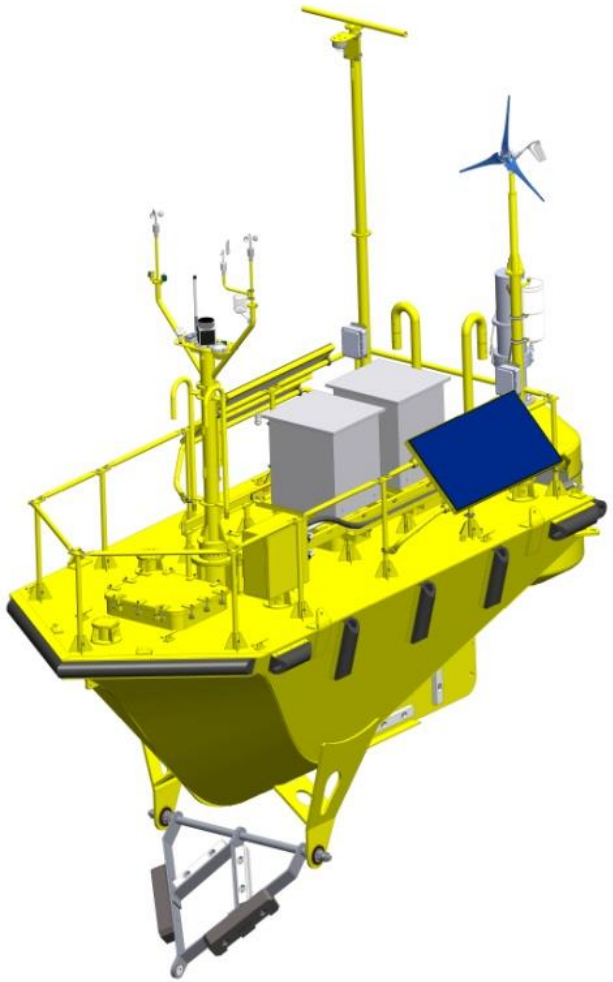
FLiDAR

AXYS WindSentinel

# Windsentinel track record

## Deployments

1. 2009 – Trial off Vancouver Island
2. 2011-2013 – GVSU (Michigan Univ)
3. 2013 – Fishermen's Energy, East US
4. **2013 – NCKU, Taiwan**
5. 2014 – EDPi Demowfloat, Portugal
6. 2014 – US Navy
7. 2014 – US Dept of Energy (x2)
8. 2015 – ORE Catapult validation (x2)
9. 2015 – GDF (Engie) France (x2)
10. 2015 – FINO1 NORCOWE Validation



# FLiDAR deployments

*Highly accurate with its combination of* ***mechanical stabilization and software-based measurement correction****, the FLiDAR has been validated at Stage 2 of the Carbon Trust Roadmap*

DONG energy

MAINSTREAM RENEWABLE POWER

IBERDROLA

EDF

FLiDAR 1 (V0.9)

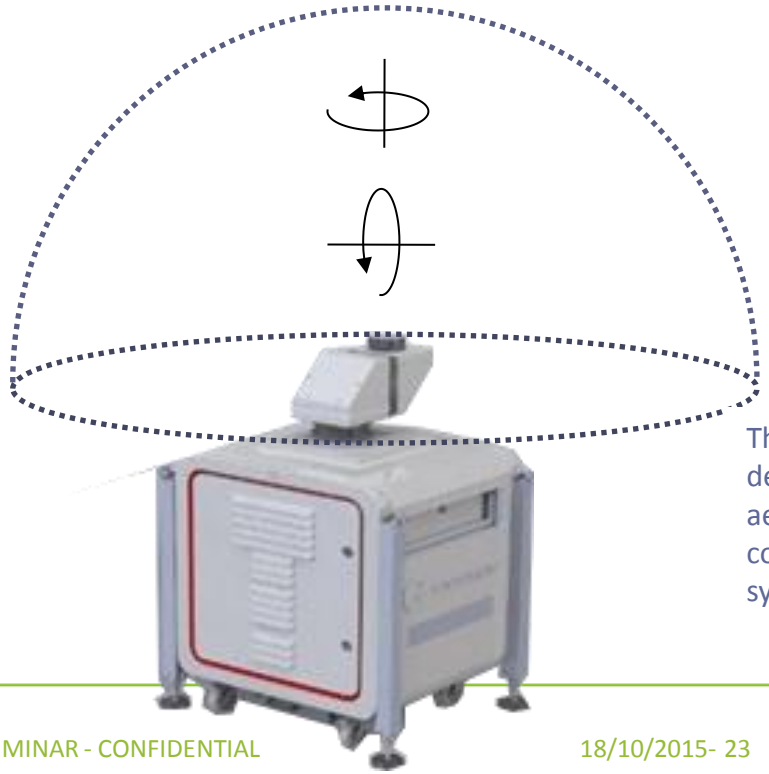
FLiDAR 2 & 3 (V1.0)

FLiDAR 4 (V1.1)

# WINDCUBE scanning LIDAR

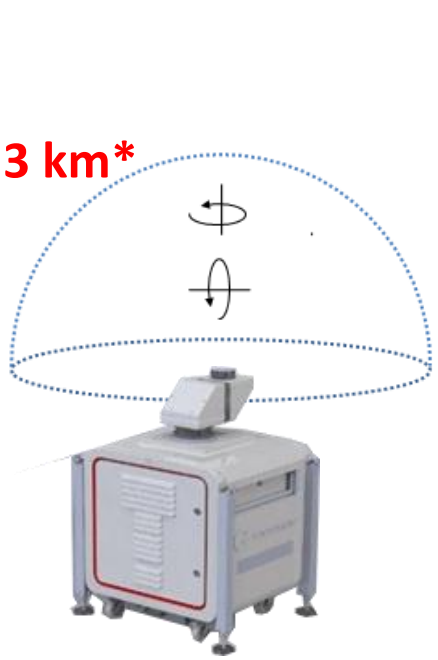
- Full **3-D hemispheric scan** capacity up to 10 km
- Scenarios **fully configurable** (PPI/RHI/DBS/LOS, spatial and temporal resolution, rotation speed)
- **Continuous measurement** (no time loss)
- Product output : Radial Wind Speed, CNR, Wind Speed, Direction, Availability

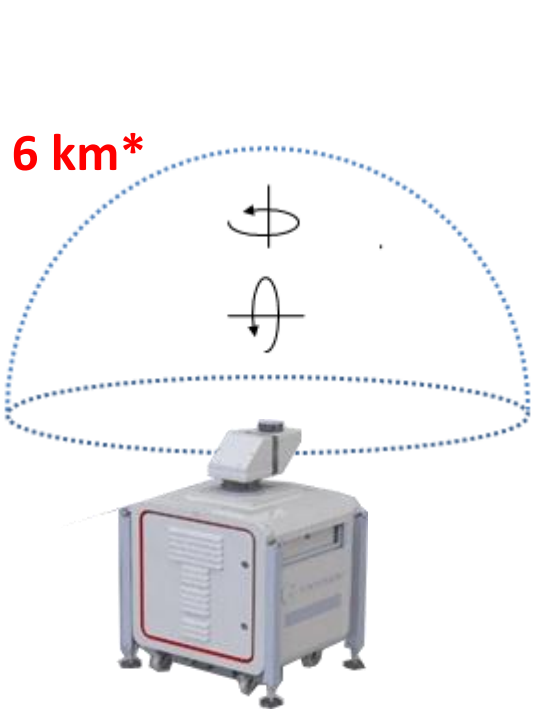

Based on the **WINDCUBE v2 technology**

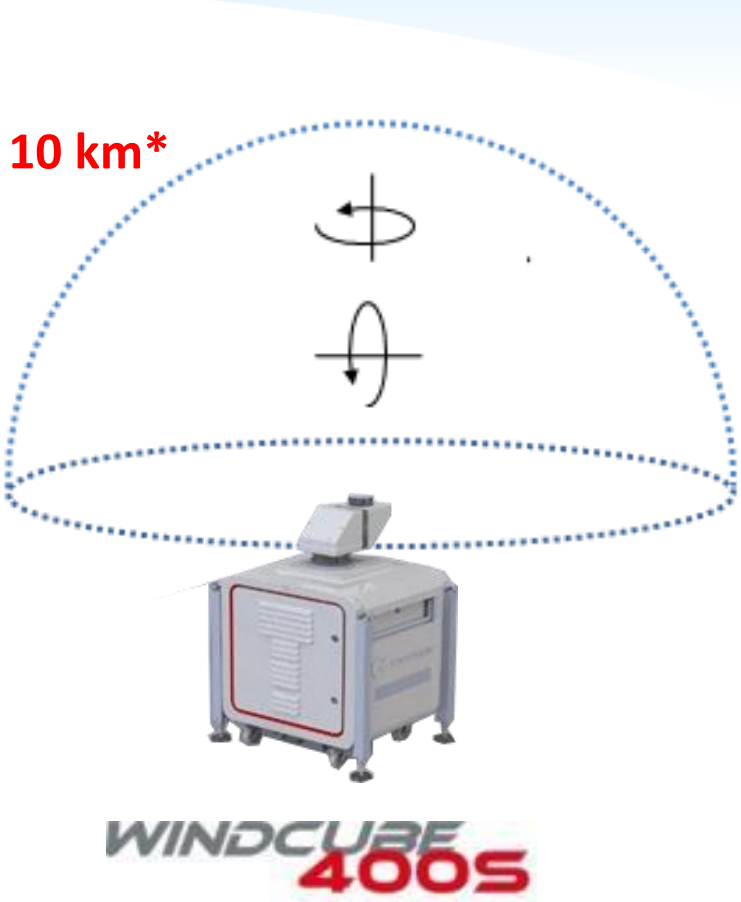


The measurement range depends on the presence of aerosols, the environmental conditions and how the system is parametered

# Scanning WINDCUBE Range



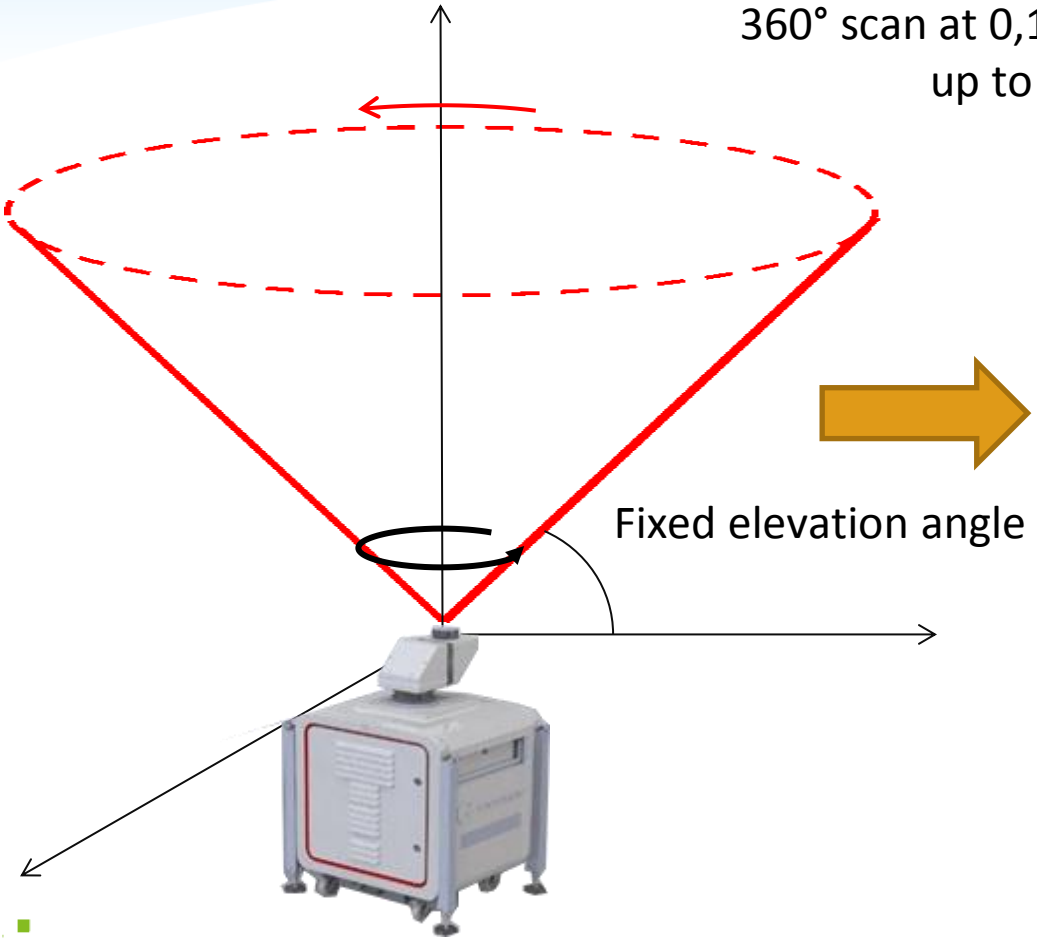



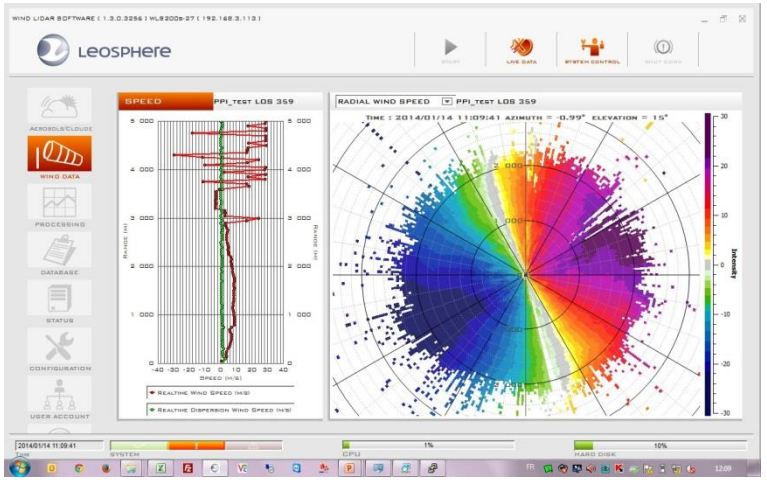



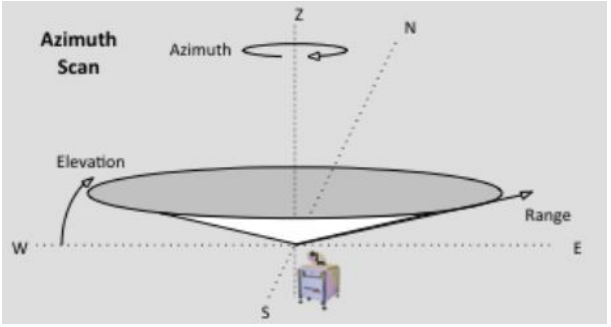

* The measurement range depends on the presence of aerosols, the environmental conditions and how the system is parametered

# Scanning Scenario - PPI scenario

360° scan at 0,1°/s resolution
up to 8°/s

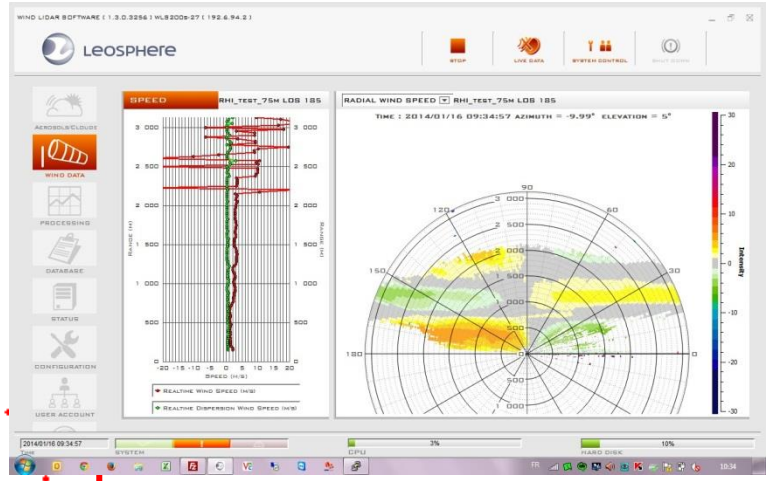


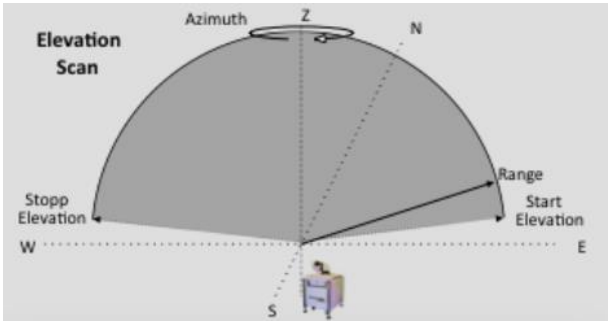



# Scanning Scenario - RHI scenario

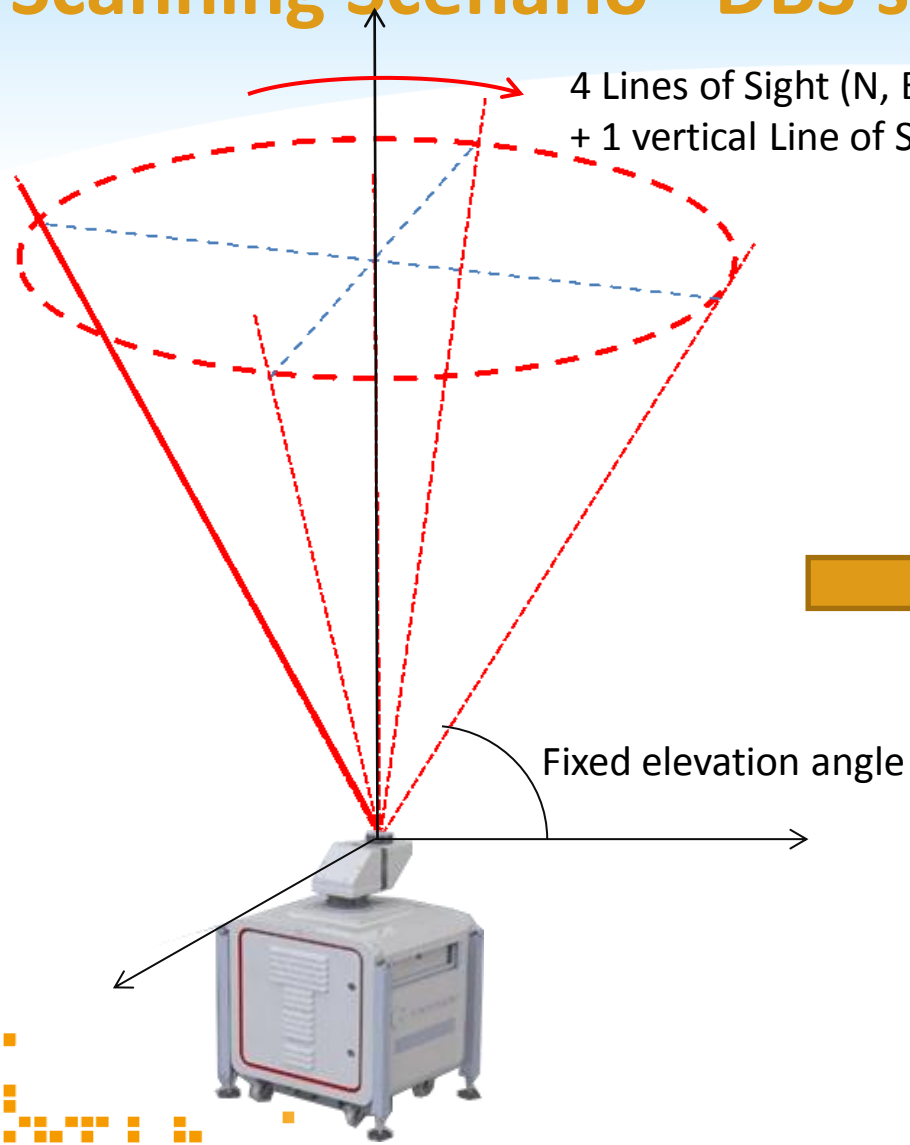
From -10° to 190° scan at 0,1° resolution
Up to 8°/second



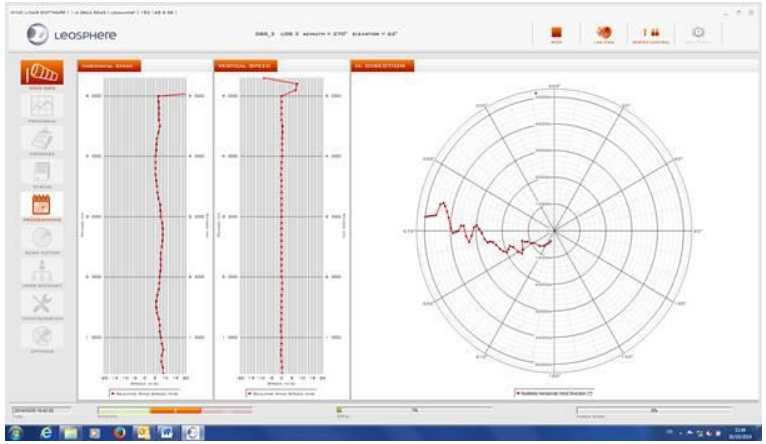

Fixed azimuth angle

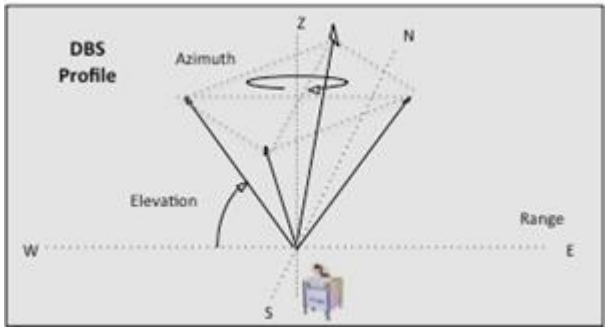


# Scanning Scenario - DBS scenario




➔ For wind reconstruction:
- 3 wind components (u,v,w)
- Mean horizontal wind speed and direction

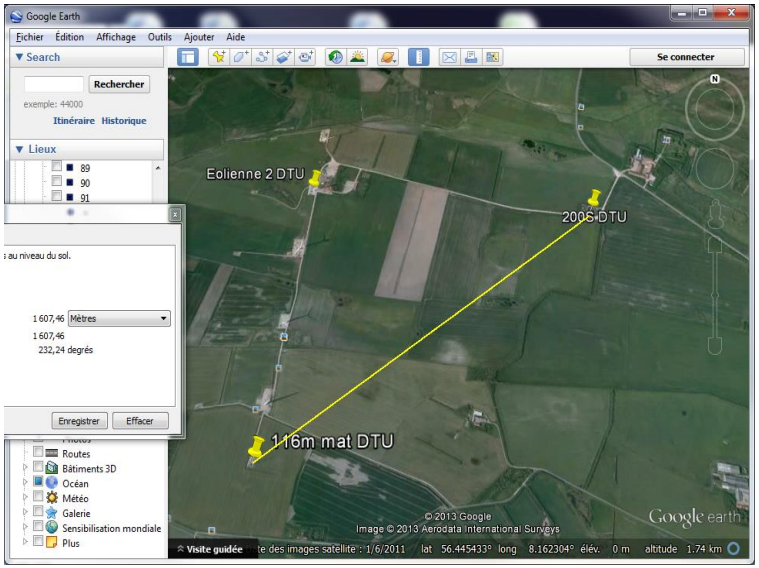


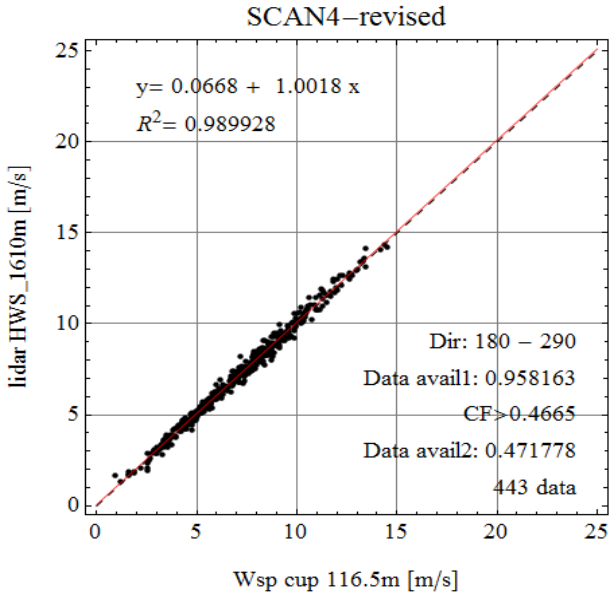



# Metrology validation at DTU Wind

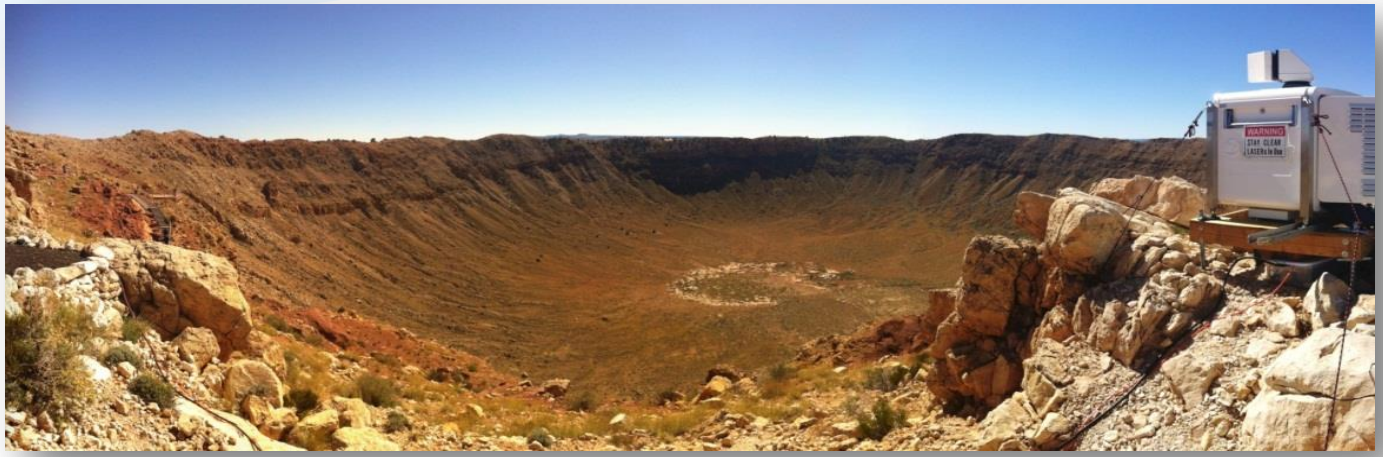
- WINDCUBE200S Lidar deployed at DTU, Hovsore test facility, 1.6 km away from a 116 m met mast, conducted from June

- The wind speed and direction were retrieved with high accuracy

# Installations
## 50 units operating worldwide



# Wind Iris, a field proven operational Lidar

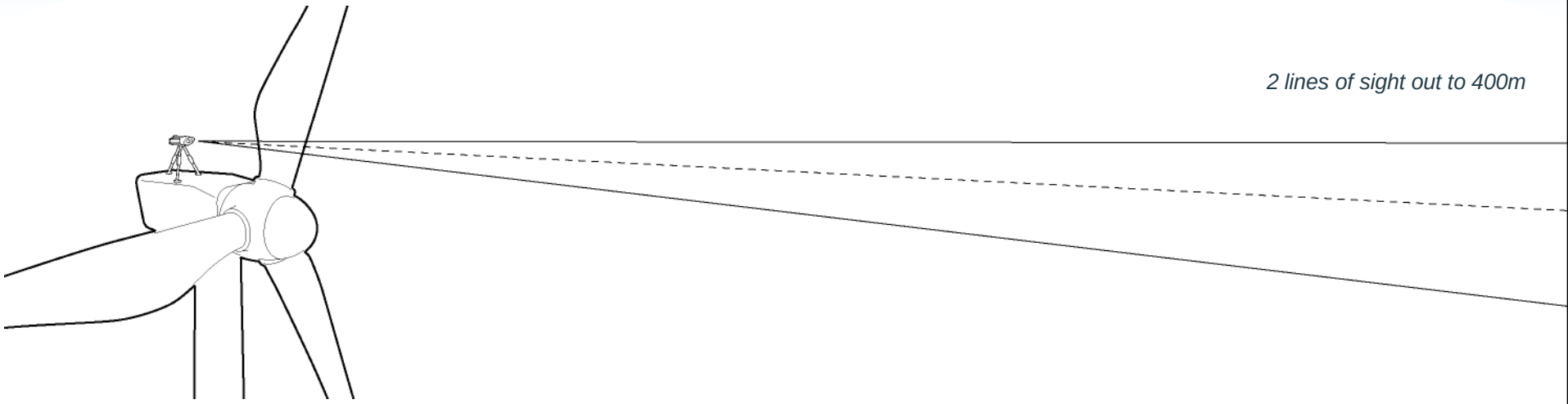
## for power performance optimization designed

**Processing unit**
Inside the nacelle


**Optical head**
On top of the nacelle

- **High reliability design** with no moving parts
- **Compact** and ergonomic for easy and safe installation in **½ a day**
- **Tripod** insures fast and accurate alignment

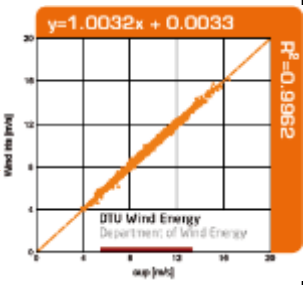
# Wind Iris, 400m range and the accuracy of a class 1 anemometer



*2 lines of sight out to 400m*

| | |
|---|---|
| **Range** | 40 to 400 meters |
| **Number of measurements distances** | 10 simultaneous points per line of sights |
| **Direction accuracy** | +/- 0.5° |
| **Proven speed accuracy** | **0.1 m/s** |

***Wind Iris against IEC met mast***



# Installations
# more than 100 installations on 25 different Turbine models


# Wind Resource Assessment Onshore

- Flat terrain
- Complex terrain

# WRA – Wind Resource Assessment

## Evaluation of the wind resource of a site before the construction of a wind farm

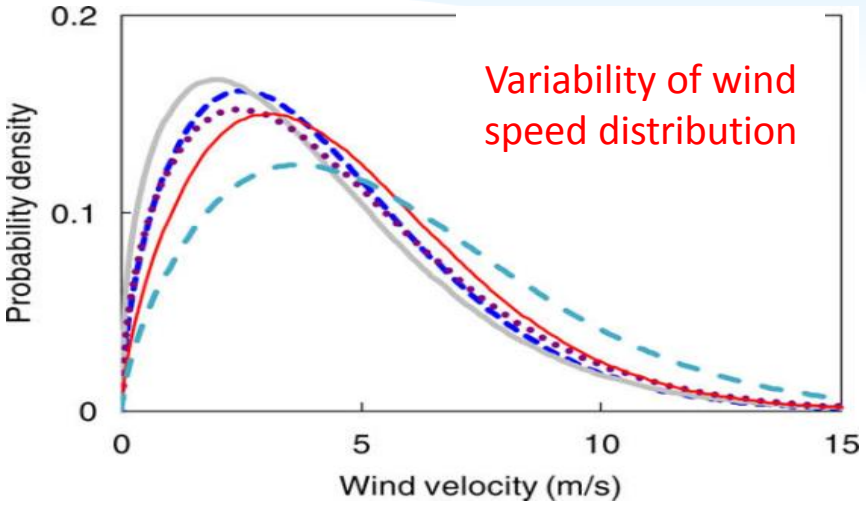
- Reduce the AEP uncertainty
- Optimize the cost of financing

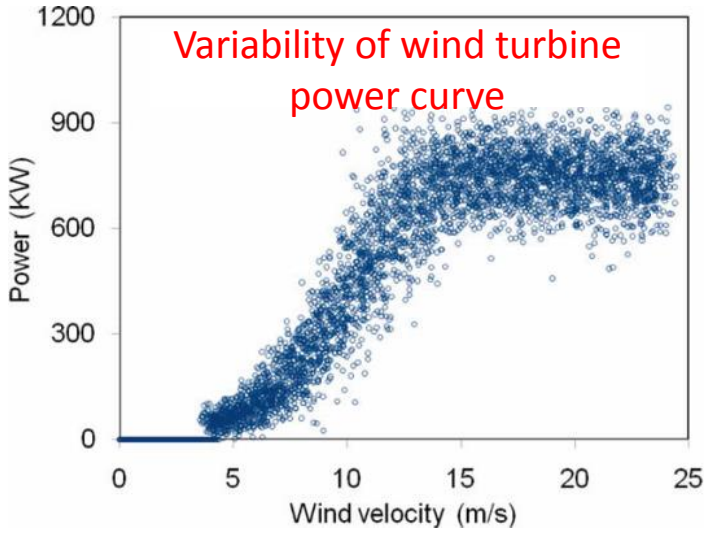
## Need

- Precise measurement of the wind
- Easy solution to deploy

## Existing solutions

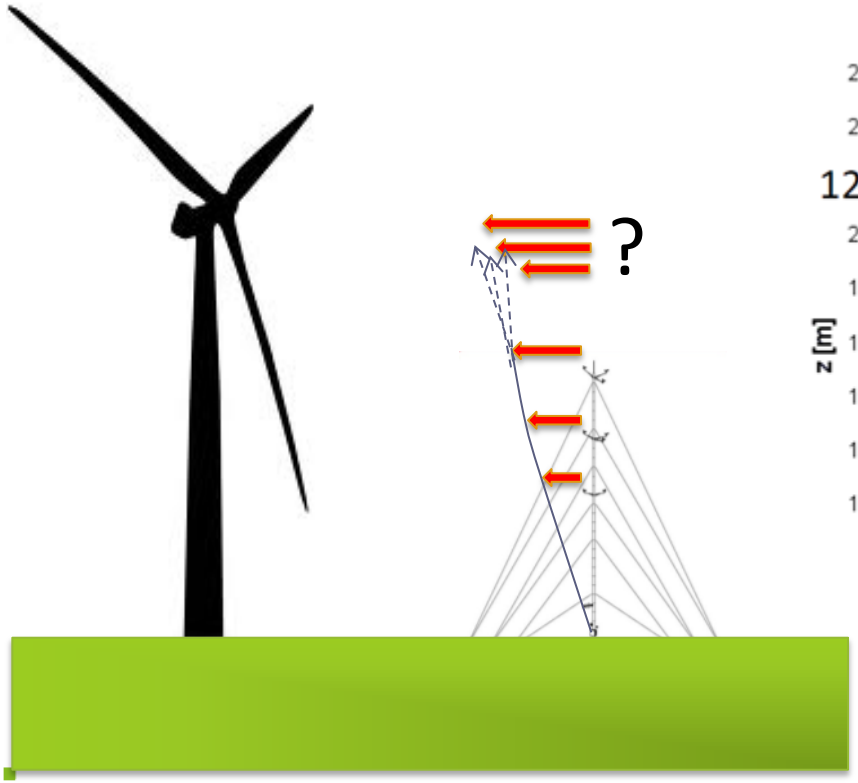
- Met models
- Met mast
- SODAR
- LIDAR

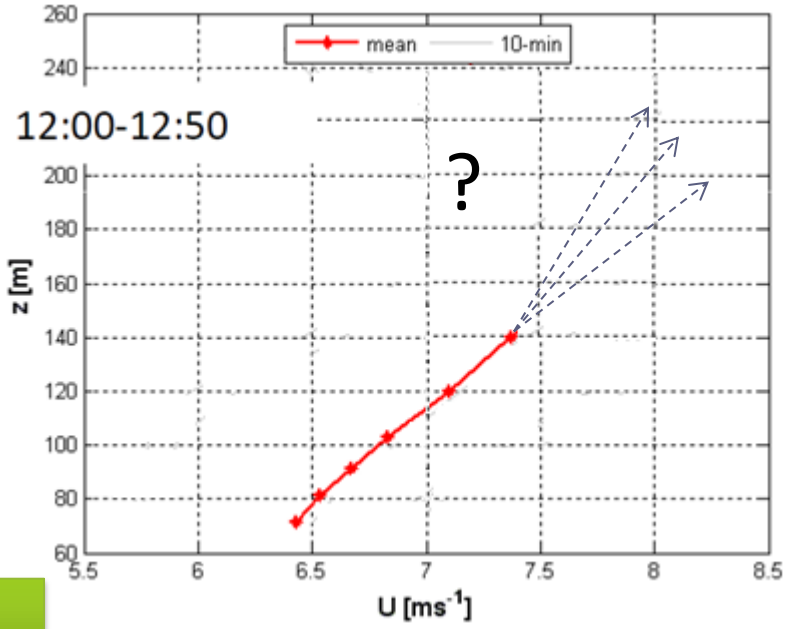


# A mast brings vertical uncertainty

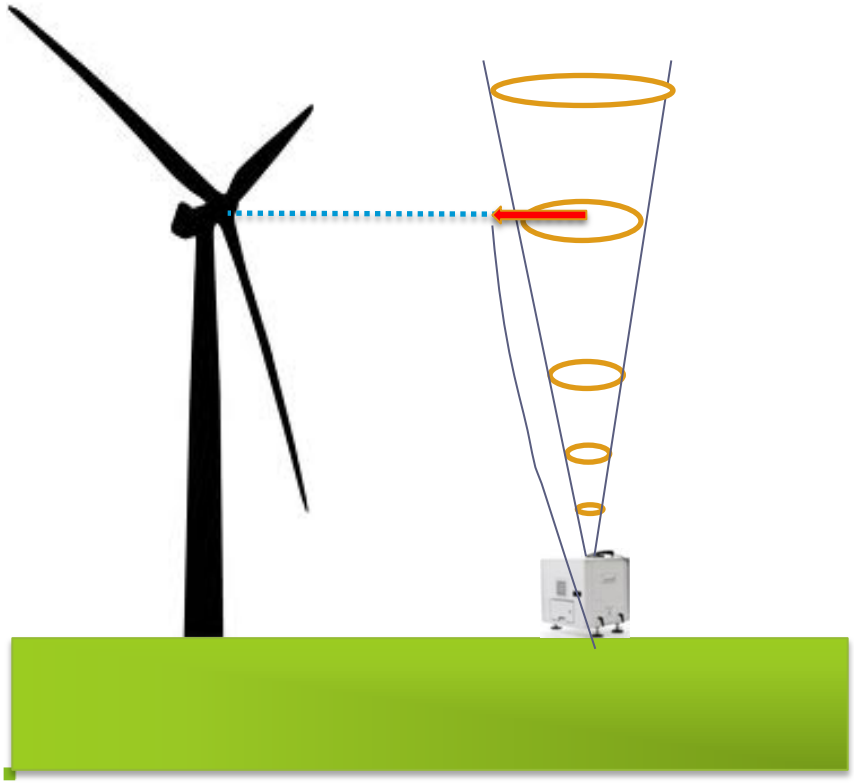
## Met. Mast cannot always measure at hub-height

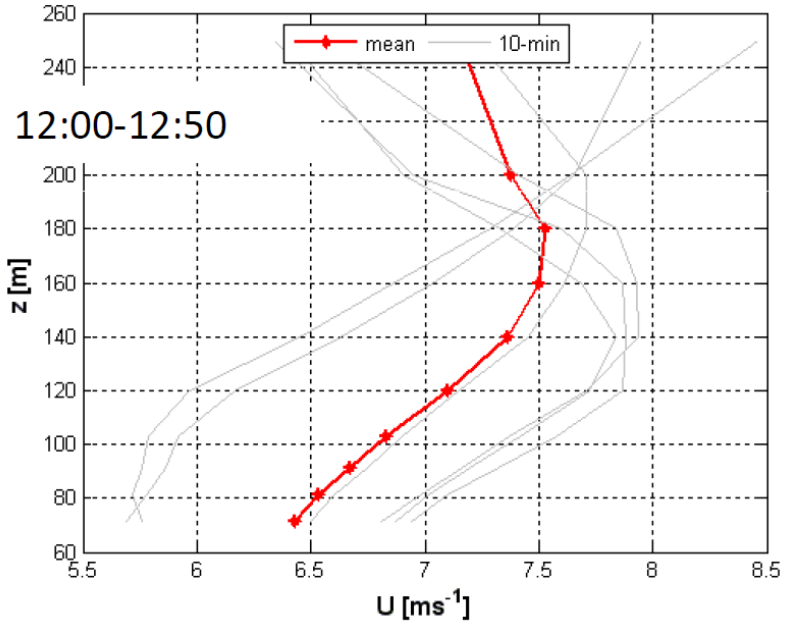


# WINDCUBEv2 reduces vertical uncertainty

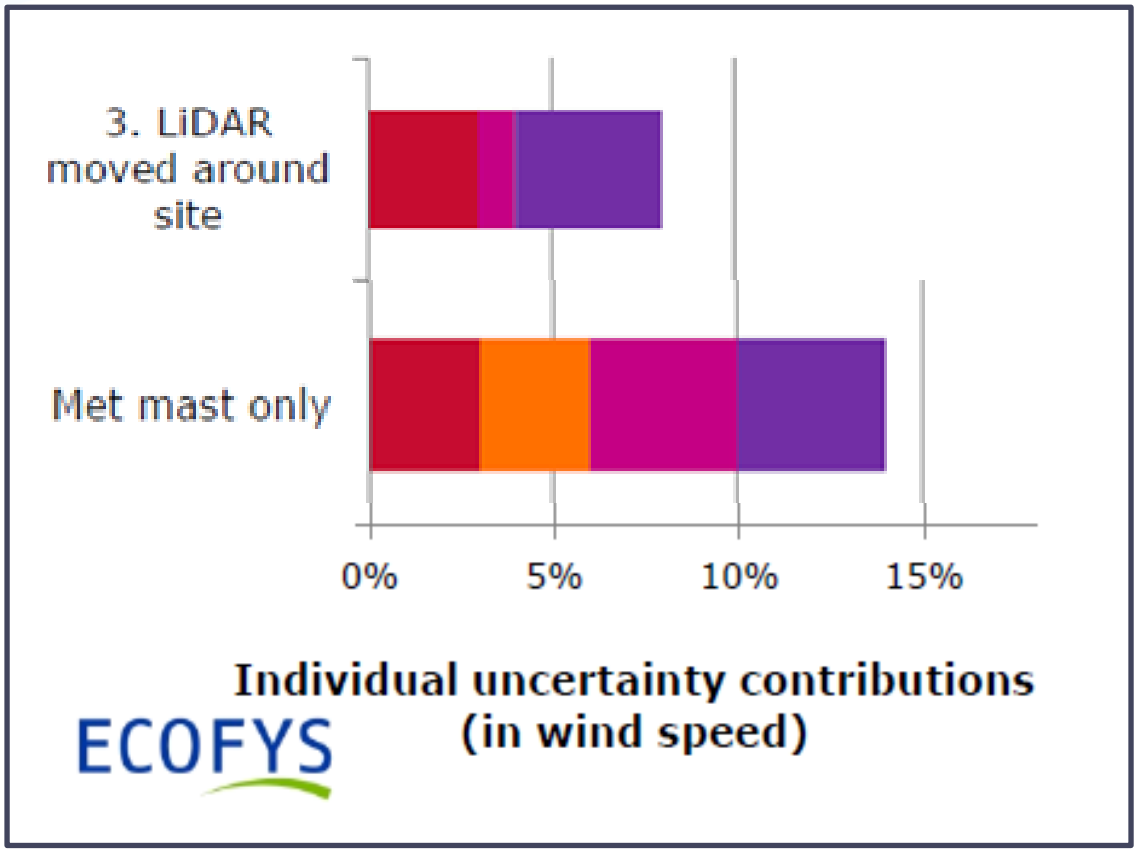
## WINDCUBE V2 measures the entire vertical profile





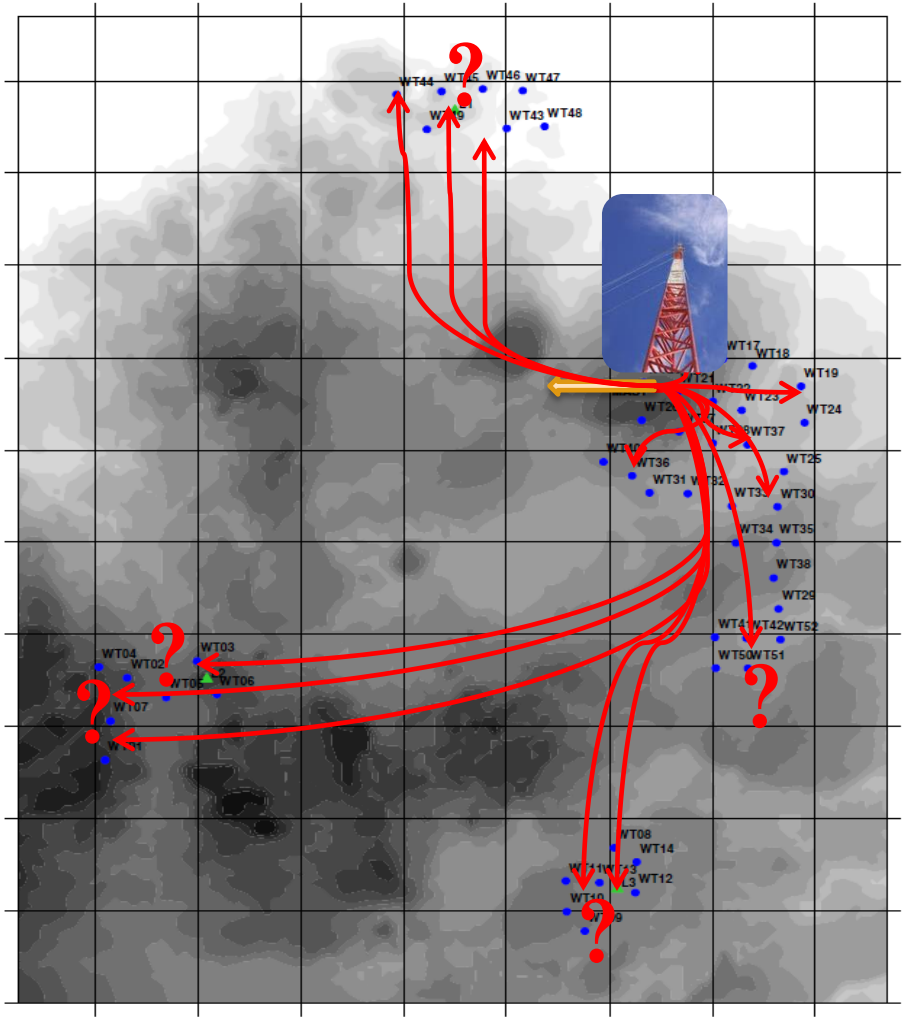

DEWI

# WINDCUBE provides lower AEP uncertainty

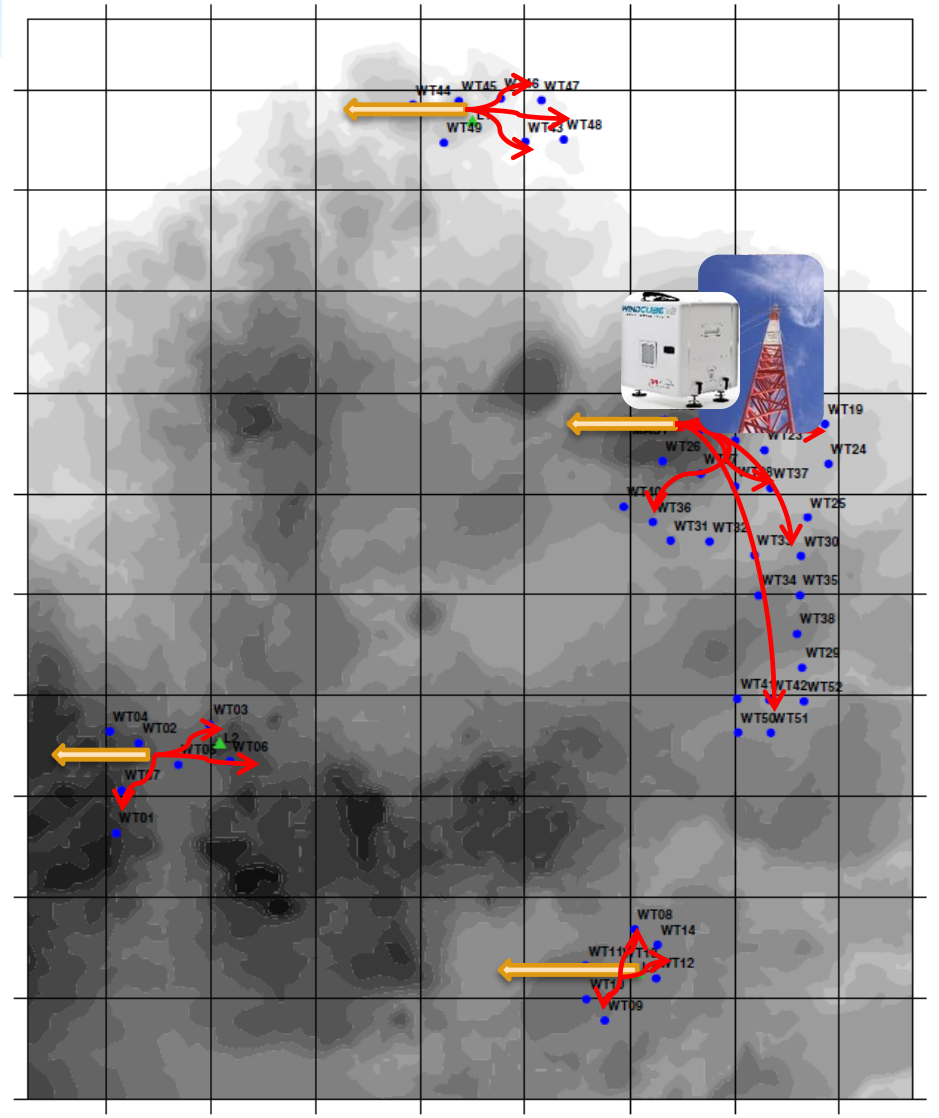



- Wind statistics
- Vertical extrapolation
- Horizontal extrapolation
- Long term representation

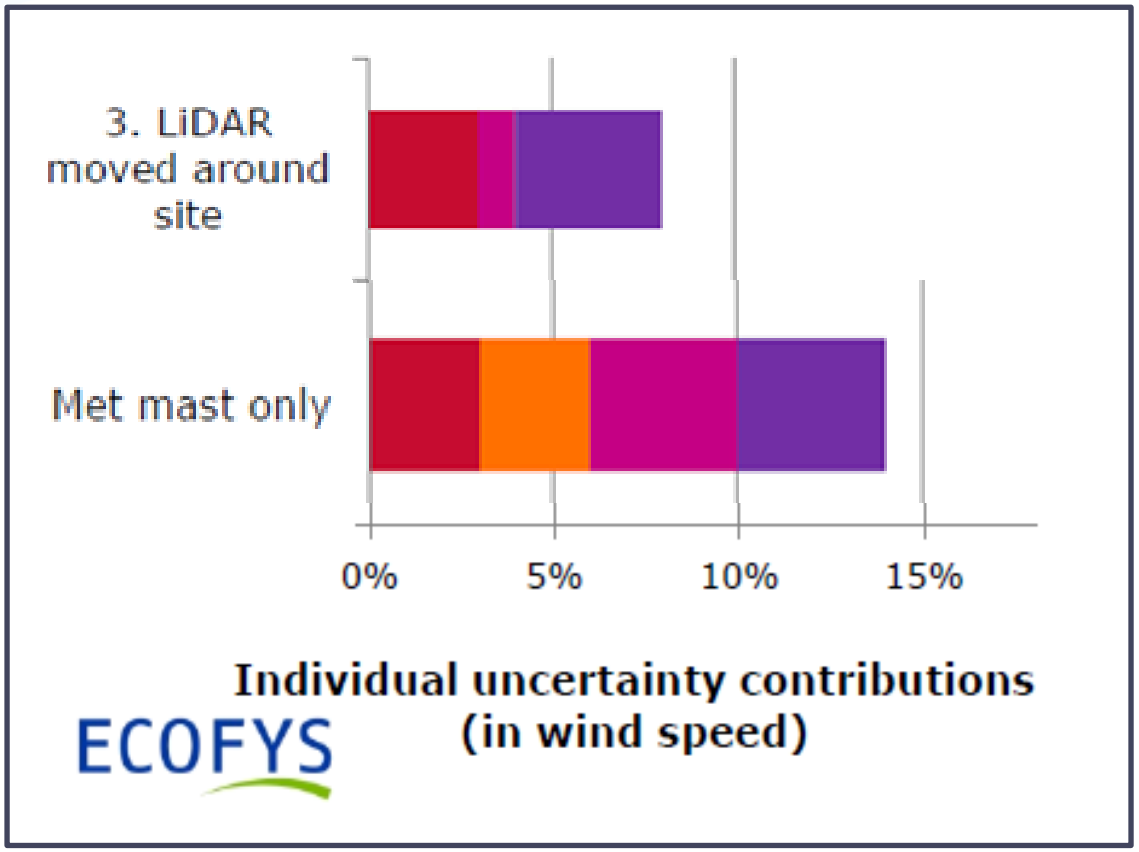
# Only 1 mast on site brings horizontal uncertainty



# A mast + Moving LIDAR reduce horizontal uncertainty

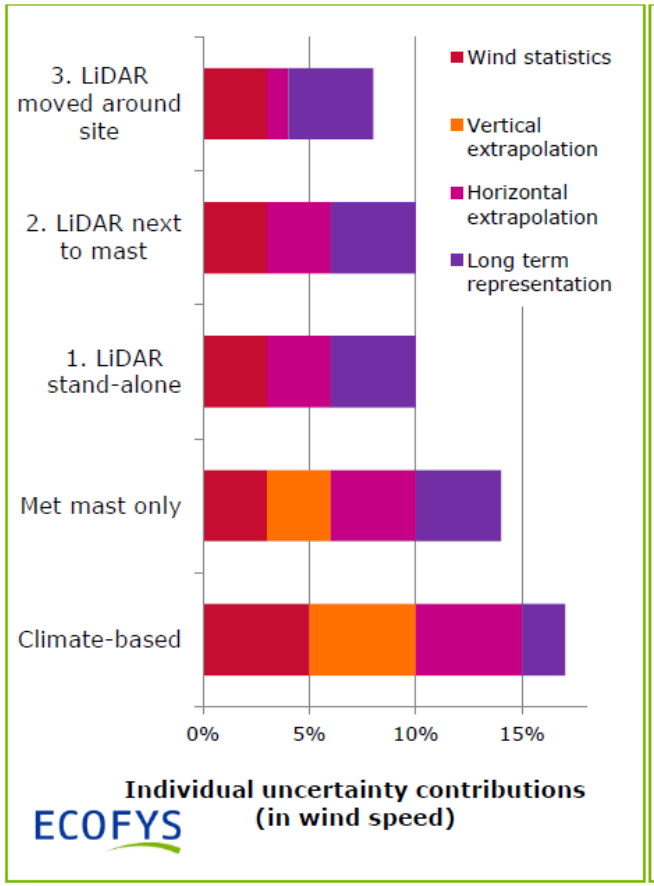


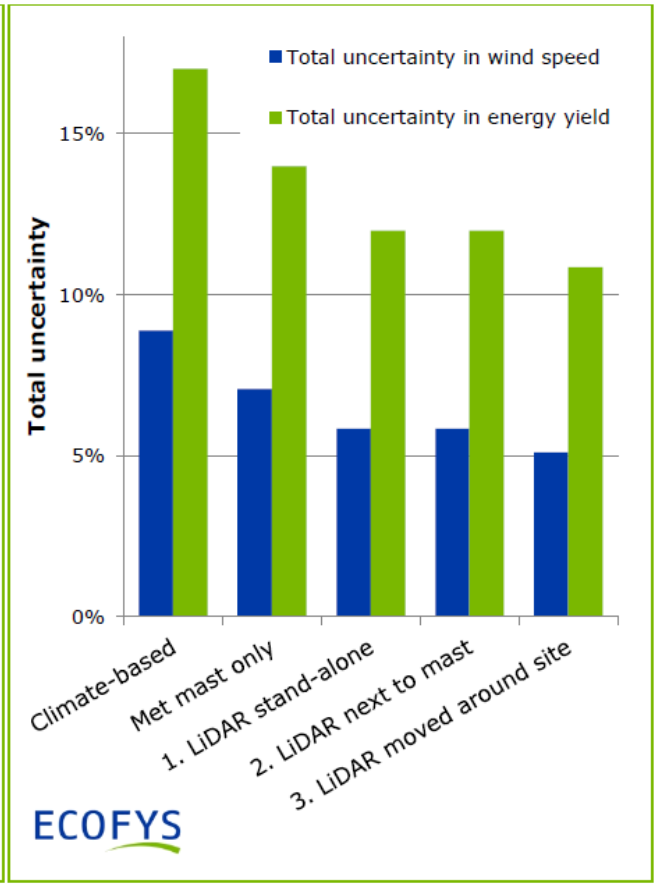
# WINDCUBE provides lower AEP uncertainty




- Wind statistics
- Vertical extrapolation
- Horizontal extrapolation
- Long term representation

# Uncertainty reduction with the WINDCUBE




Extract from “Improved Bankability: The Ecofys position on LiDAR use”

# The WINDCUBE V2 is bankable

- The acceptance of the WINDCUBE V2 is increasing
  - Stage 3 status  DNV GL in flat terrain (instrumentation specific)
  - The ECOFYS position on lidar use
  - TRL 6 German standard (remote sensors)
  - IEC 61400-12-1 Power curve
  - IEC 61400-15 Site assessment  (remote sensors) – starts en 2014
- Used in numerous bankable WRA projects
- These standards require external validation for each instrument (accuracy class verification)

**WINDCUBE V2 independant certificators body**

DEWI

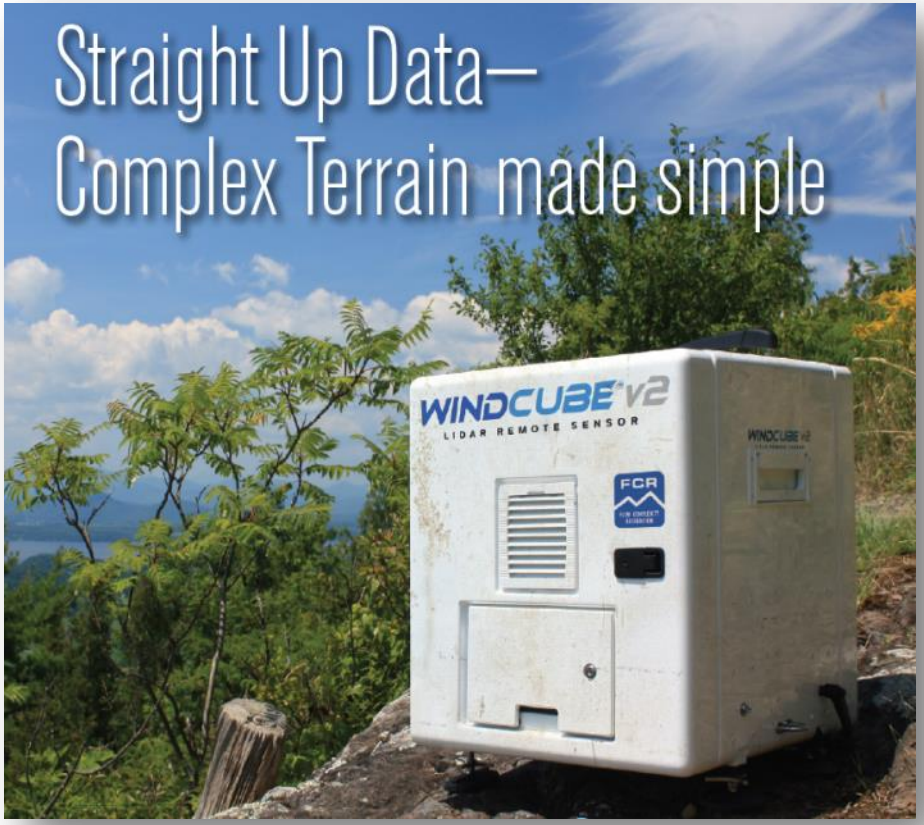
Deutsche WindGuard The Wind Professionals

METEOTEST

DNV·GL

DTU Wind Energy Department of Wind Energy

# WRA in complex terrain : FCR™ (Flow Complexity Recognition)




**Instant, bankable data**

- Significant improvement of complex terrain LIDAR data accuracy
- Measurements equivalent to Class One anemometry

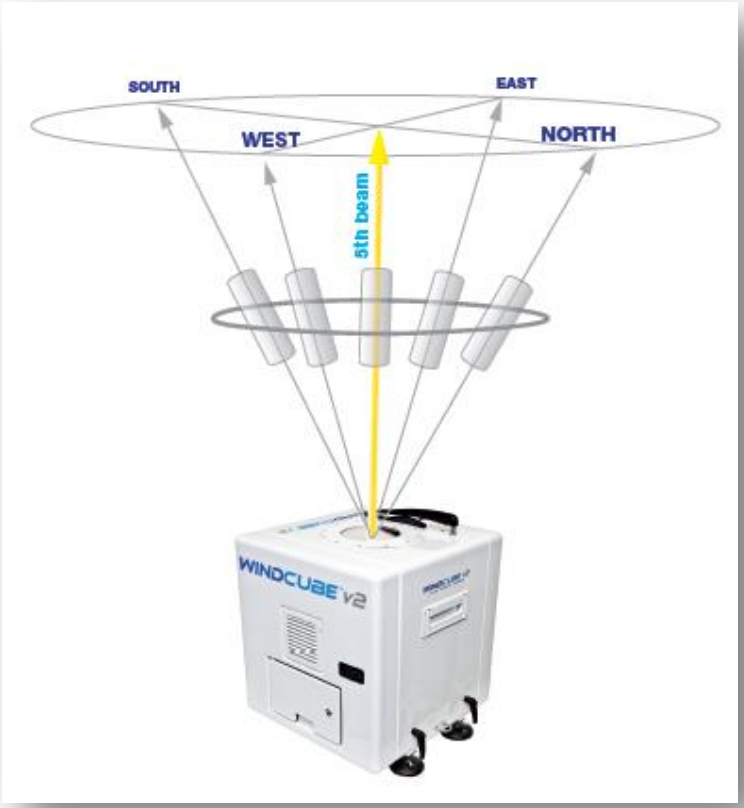
**Instant activation**

- No CFD post-processing burden
- No staff required for data post-correction

**Direct, accurate wind measurements in complex terrain**

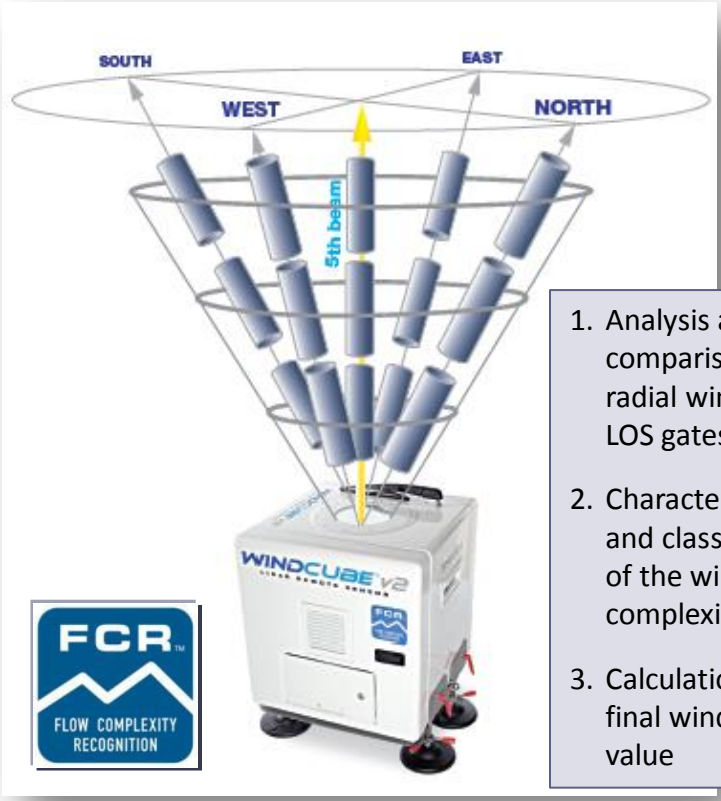
# Standard and FCR calculation: differences

## Normal mode




**Independent Heights Measurement**
**<u>Assumption</u>: Homogenous wind flow**

## FCR™ mode

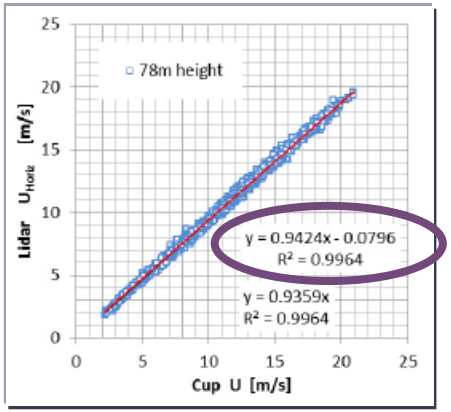


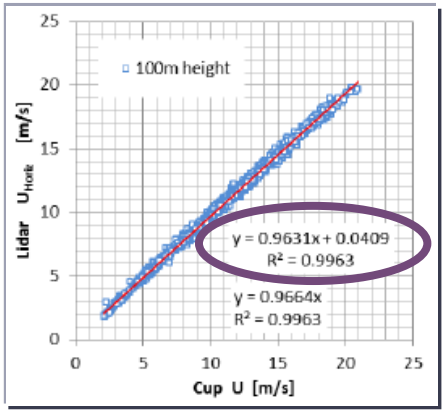

1. Analysis and comparison of radial wind of all LOS gates
2. Characterization and classification of the wind complexity
3. Calculation of the final wind speed value

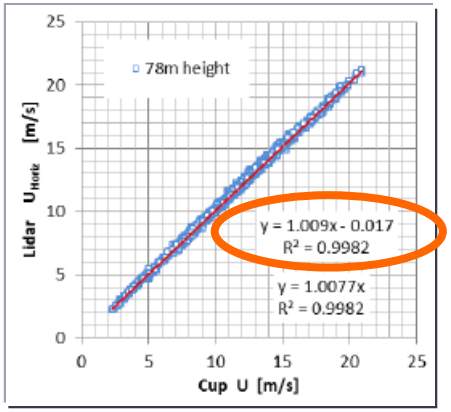
**Entire Profile Direct Measurement**
**<u>No wind flow homogeneity assumption</u>**

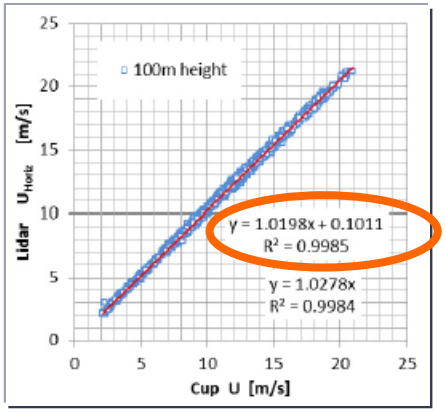
# FCR results

**Normal mode**




***Dimitri Foussekis (CRES):*** *"At 78m height, wind speed deviations are kept below 0.1%, with a coefficient of determination $R^2$>0.998. This is an outstanding value approaching results obtained before only in flat terrains."*

# FCR Validations

- **FCR™ has been tested and validated by independent industry experts in various locations around the globe.**

- **Among others:**
  - **CRES** validation campaign, moderately complex site, Greece, 2010: full report available
  - **GL-Garrad Hassan** validation campaign, *moderately complex site* Canada, 2011
  - **JUWI** validation campaign, *moderately complex site*, Germany, 2012
  - **Cowi / DTU** validation campaign, *moderately complex site*, Bosnia, 2013-2014
  - **Acciona Energia / Barlovento** validation campaign, *moderately complex site*, Spain, 2011

# 3. Wind Resource Assessment - Offshore

# Offshore WRA – Scanning Lidar

- With the current **highest capacity factors**, offshore wind power development has some good potential for the coming years

- The challenges are **cost driven**
  - Distance from the coast of wind farms
  - Installation cost of wind farm (cable, turbine, O & M, etc.)
- LEOSPHERE proposes **cost effective solutions:**
  - WINDCUBEv2 offshore
  - Scanning LIDAR
  - Floating LIDAR

# Offshore WINDCUBEv2


- Based on the WINDCUBE V2 technology:
  - IP67 enclosures
  - Salt atmosphere compliant IEC 60068-2-52 (Zinc coating, protected wires, etc.)
- Services
  - Standard 1-year warranty and service
  - Dedicated staff for offshore services
  - Stand alone power pack
  - 3G Remote communication

# Possible installations for WINDCUBEv2 Offshore

- To operate a WINDCUBEv2 OFFSHORE, you need:
  - a fixed ground
  - a power supply for WINDCUBE (power pack, solar panels)
  - a communication system (3G/GSM or Satellite)
  - adequate services (visits, maintenance)

| Configurations | |
|---|---|
| CONFIGURATION 1 | On an island |
| CONFIGURATION 2 | On a lighthouse |
| CONFIGURATION 3 | On a large platform with a met mast |
| CONFIGURATION 4 | On a small platform stand-alone |

# 1- On a small island

## Alphawind – Norway - 2007

Wind ressource assessment for
Havsul wind farm.
700MW

# 2- On a lighthouse

## Nass&Wind – France - 2010

St Brieuc, French channel.
200MW wind farm.

# 3- On a large platform

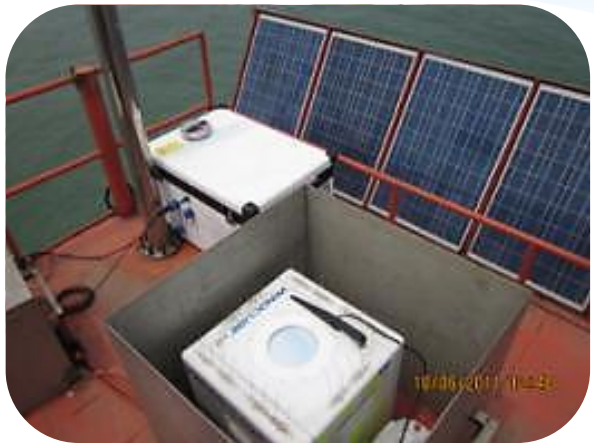
## RES – UK platform (Race bank round 2)

Race bank wind farm.
3GW

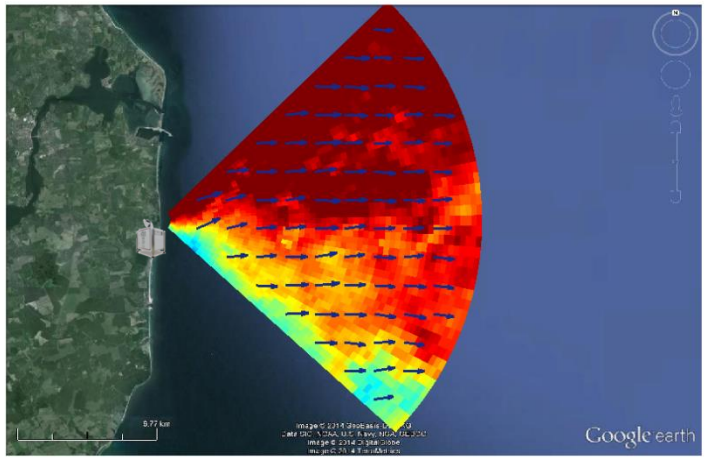

*(Photos courtesy of RES Ltd)*

# 4- On a small platform stand-alone

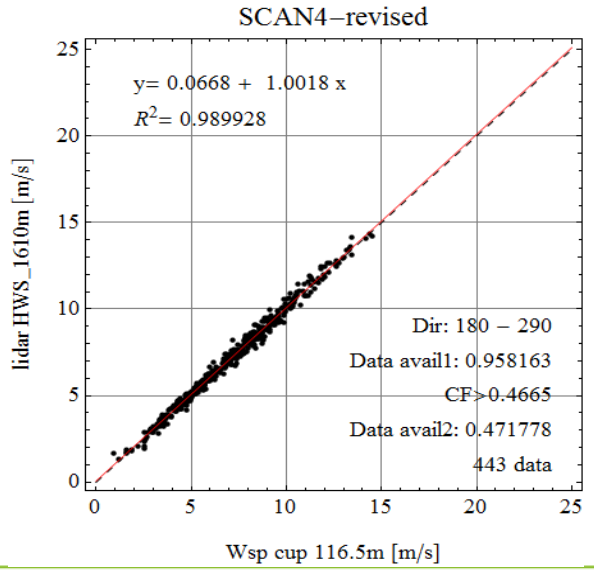
## Guodian project – China - 2011



# Scanning Lidar
# Offshore wind mapping from the shore


- Allows a **10 min average wind** mapping for site assessment and farm layout
- Multiple PPI scanning will allow to **reduce horizontal and vertical uncertainty**



# Offshore Wind Resource Assessment - France

## WINDCUBE V2 Offshore

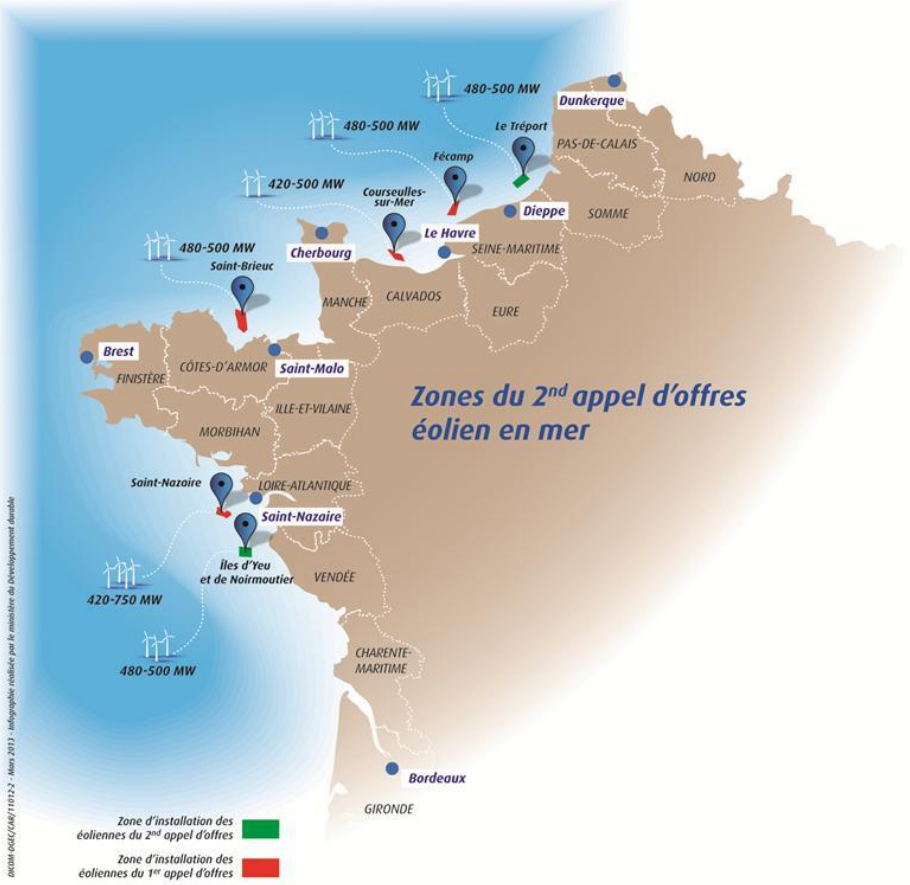
- 8 currently operating

## WINDCUBE Scanning Lidar

- Two 400S systems measur

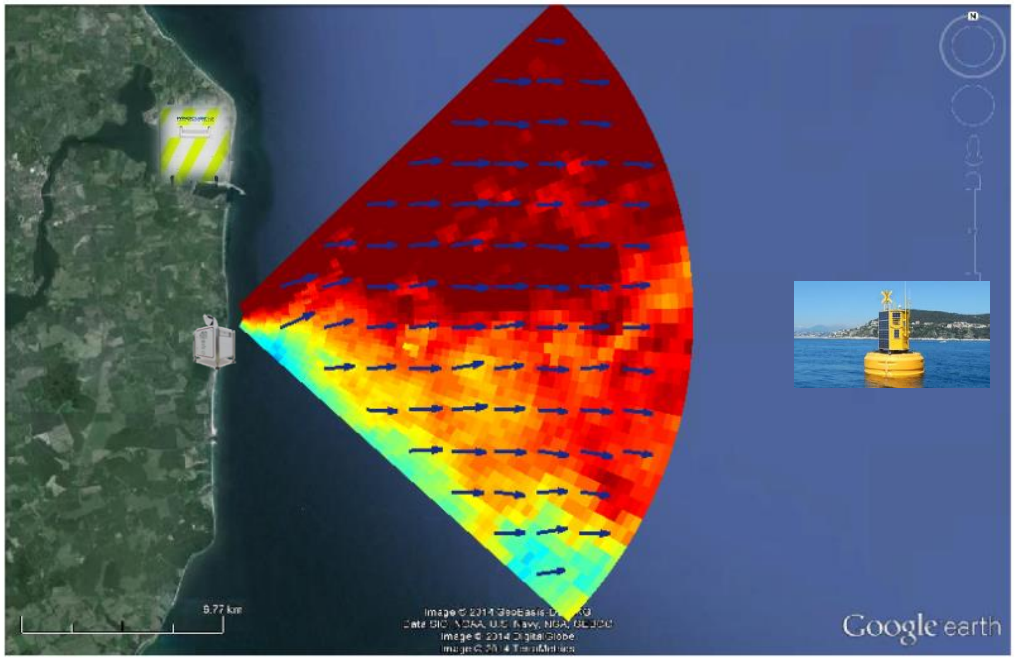
## Floating Lidar

- Currently 4 measuring and potentially 3 more in the next 2 years



# Typical strategy

- A cost effective solution to **reduce horizontal and vertical uncertainty**
  - Une vertical profiler on the shore
  - One scanning Lidar
  - One floating Lidar



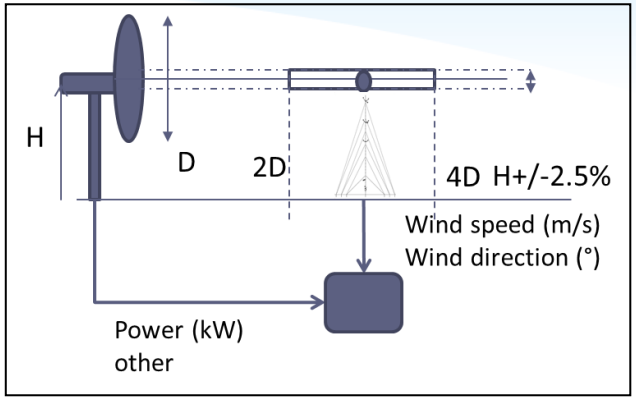
# OFFSHORE REFERENCES

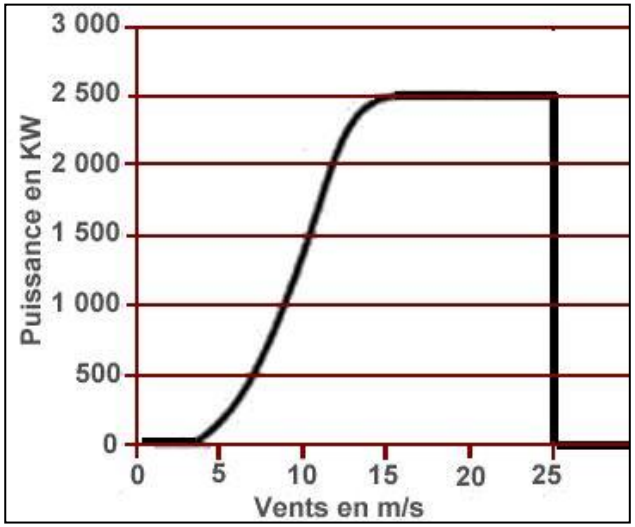
- 50 WINDCUBE Offshore systems deployed
- 5 Scanning WINDCUBE offshore deployed
- 5 Floating LIDARs deployed

# 4. Power Performance
# - Power Curve Measurement

# Power Curve measurement

- **Evaluation of the performance of a Wind turbine in agreement with a standard**
  - During commissioning: reduce the risks of under-performance
- **Need**
  - Precise measurement of the wind speed, direction and turbulence on the rotor
  - The instrument should be accepted by a standard and by the industry
- **The current IEC 61400-12-1 standard is commonly used in a contractual framework**
  - Written in 2005 the standard only accepts the mast
  - The wind should be measured at hub height
  - The future revision of the standard will include ground based remote sensors



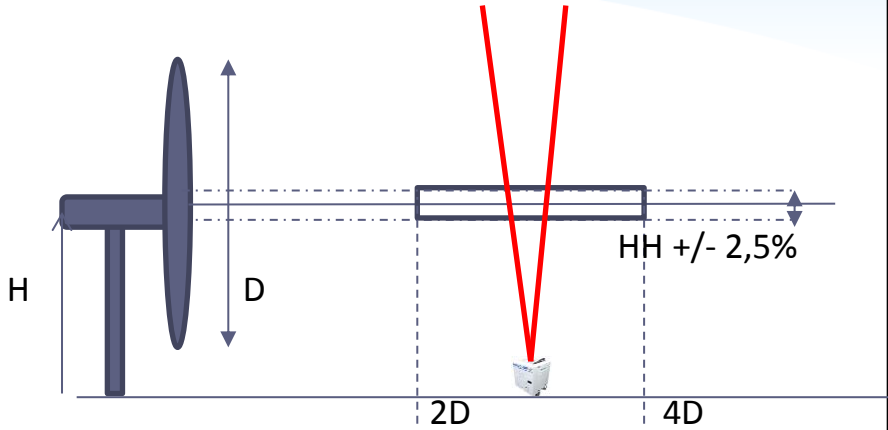



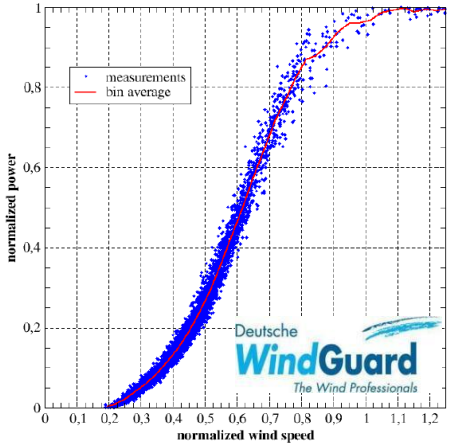
# Lidars are already used for operational power curves

- **Windcube v2, with or without mast**

- **Measurement advantages**
  - Proven accuracy up to 12 heights
  - Full wind field profile (wind shear)

- **Operational advantages**
  - No permit required
  - Ease of deployment and plug and play solution



# Lidars are already used for operational power curves

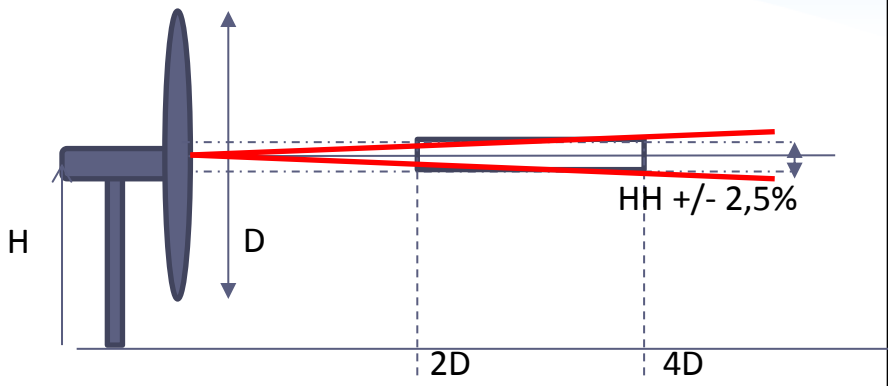
## Wind Iris based on a nacelle

## Measurement advantages

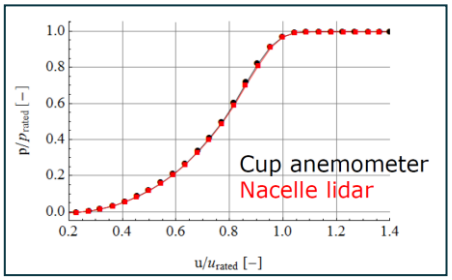
- Proven accuracy at 10 range gates, with industrial procedure
- Reduction of the bias

## Operational advantages

- Reducing campaign duration
- Operational flexibility (no permit required, all types of terrain)




IEC met-mast vs. Wind Iris power curve

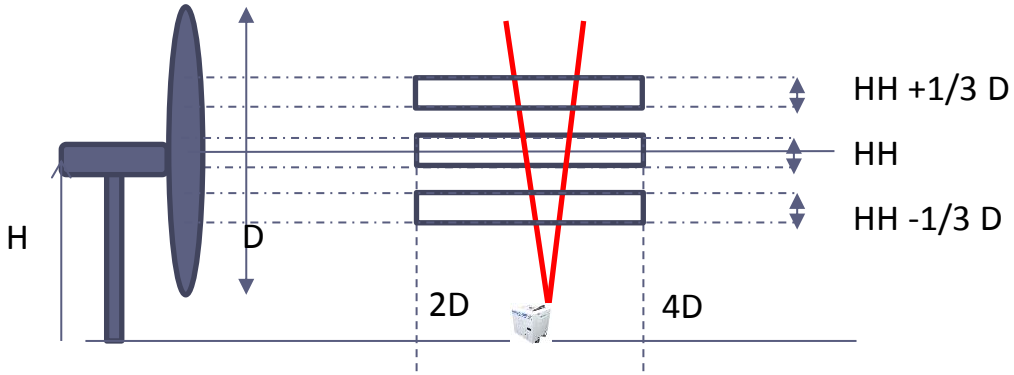


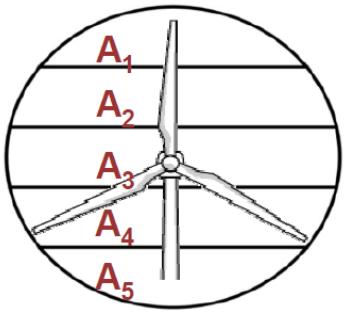

DONG energy SIEMENS

DTU Wind Energy
Department of Wind Energy

# The revision of the IEC standard includes the ground based Lidar

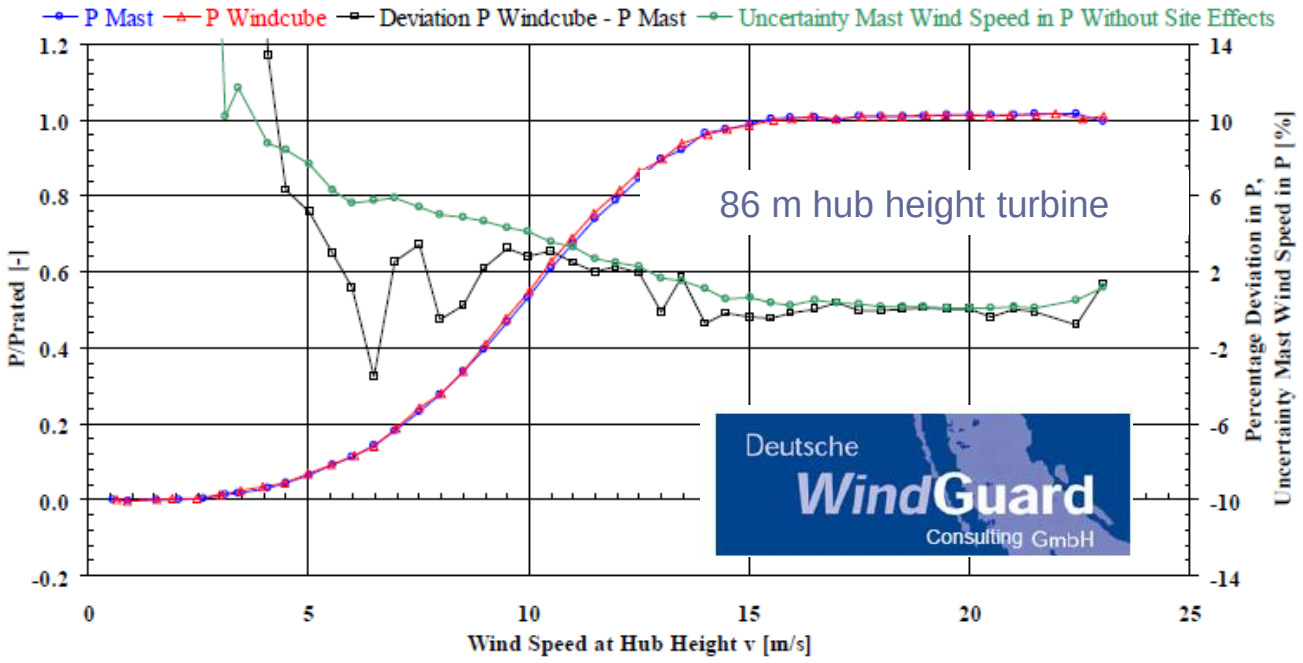
- In addition to hub-height measurement (HH), the full wind speed profile (shear) is taken into account: Rotor Equivalent Wind Speed (REWS)
  - 3 heights included : HH + 1/3D ; HH – 1/3D ; HH
  - This change reduces the uncertainty
- The WINDCUBE, in addition to a small mast of 40 m, is accepted to measure the REWS, to decrease the operational cost
- The WINDCUBE V2 has been used as reference for this revision



# WINDCUBE v2 validated for power curve

"The bin-averaged power curves evaluated from the WINDCUBE and the met mast agree very well."




# They selected LEOSPHERE for Power curve

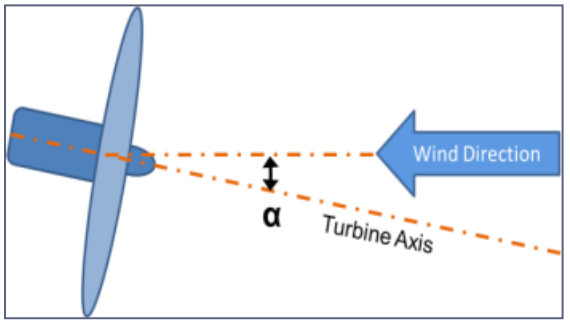
DONG Energy, EDF EN, E.ON, IBERDROLA, GDF Suez, JUWI, WPD, SSE, Mainstream, ENBW, RES ltd, Vattenfall, Edison, RWE, EDPr, USA : Gilead power, Enel America, Genivar, Element power, Iberdrola, Pattern energy…

| Company | Number of owned systems |
|---|---|
| ENERCON | 14 |
| REPOWER | 5 |
| SIEMENS | 6 |
| GOLDWIND | 5 |
| ENVISION | 2 |

# 4. Power Performance
# - Power Optimization

# Performance verification and optimization

- **Diagnose and improve the wind farm performances**
  - AEP gain
  - Lower O&M cost
- **Need**
  - Accurate wind measurement in all turbine model & all terrain
  - Quick and easy to deploy solutions for O&M staff
- **Growing offers in this market**
  - New O&M practices
  - SCADA analysis
  - Wind turbine manufacturers new O&M offers
  - Nacelle mounted LIDAR

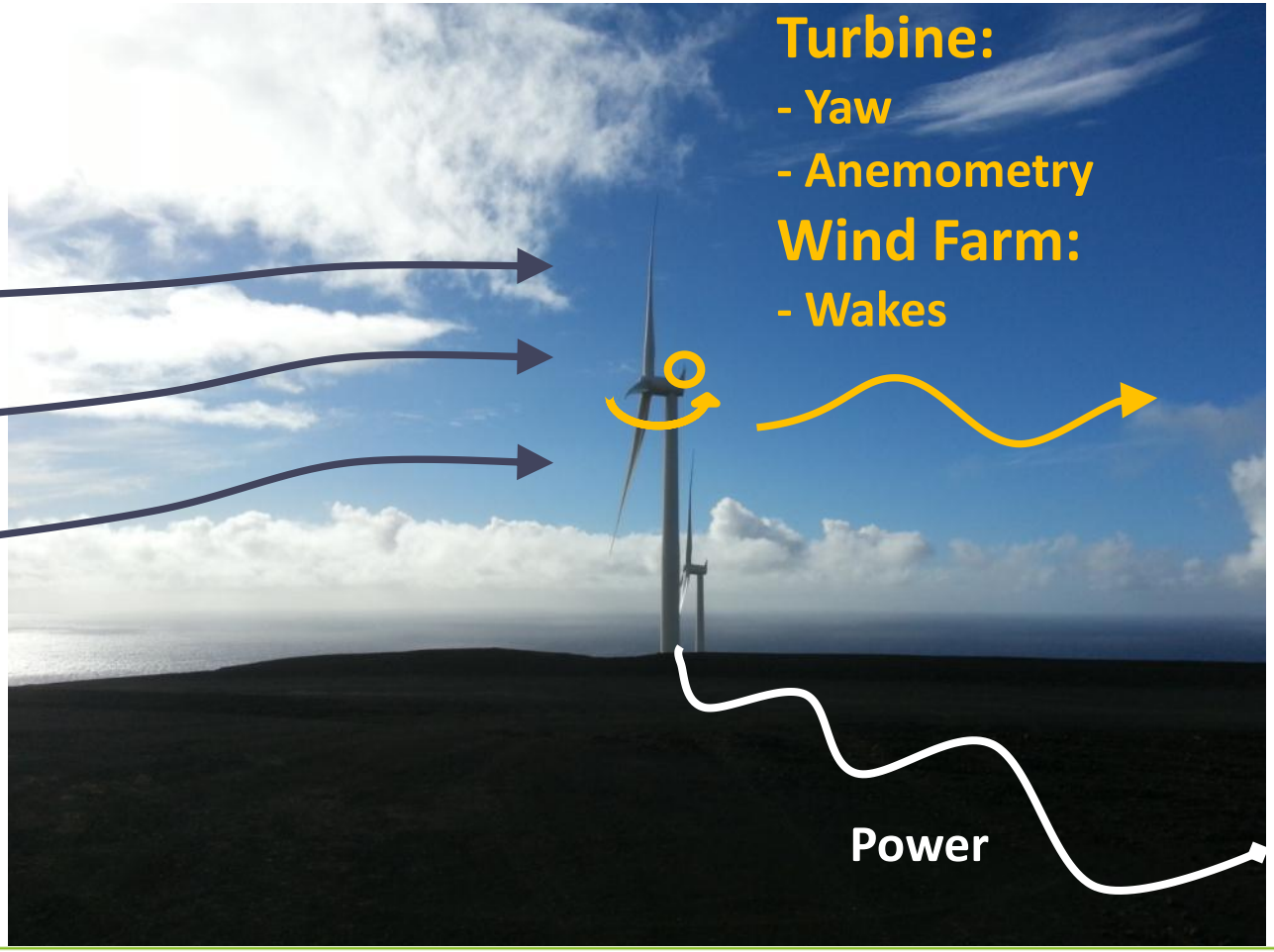



# Wind is the key information that allow evaluating the wind turbine performance

**Wind:**
- Speed
- Direction
- Turbulence
- Shear
- etc

# It is possible to adjust several parameters accorfind to the wind measured

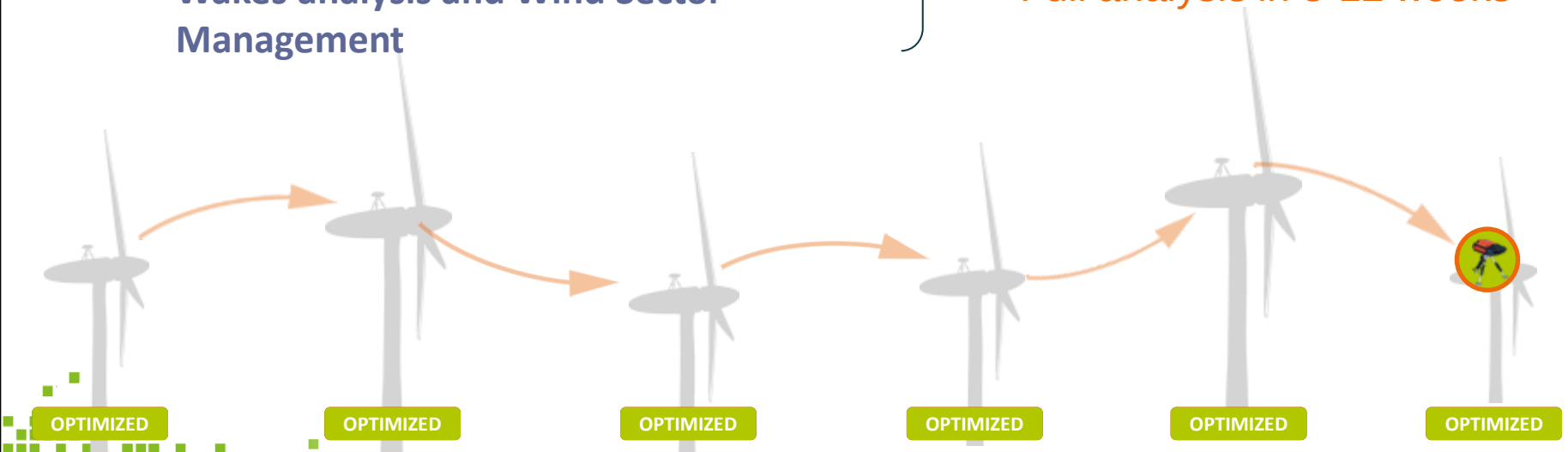
**Wind:**
- Speed
- Direction
- Turbulence
- Shear
- etc



# Nacelle mounted LIDAR detect and correct underperformances linked to wind

- Power curve measurement
- Yaw misalignment correction
- Nacelle Anemometer Calibration
- Wakes analysis and Wind Sector Management

- ✓ Same data for all applications
- ✓ Yaw misalignment detection in a few days
- ✓ Full analysis in 3-12 weeks



# Nacelle mounted LIDAR detect and correct underperformances linked to wind

- **Power curve measurement**
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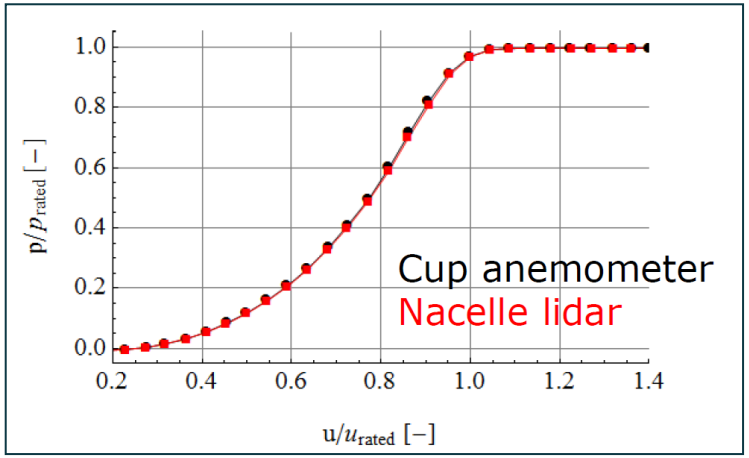
**IEC met-mast vs. Wind Iris power curve**



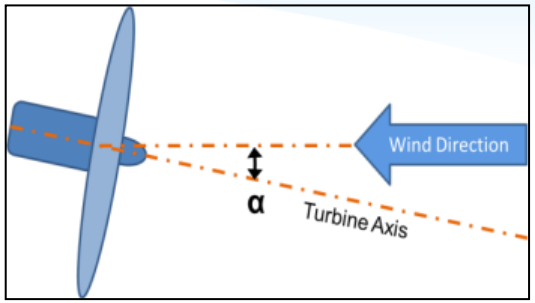

DONG energy SIEMENS DTU Wind Energy Department of Wind Energy

## Key benefits

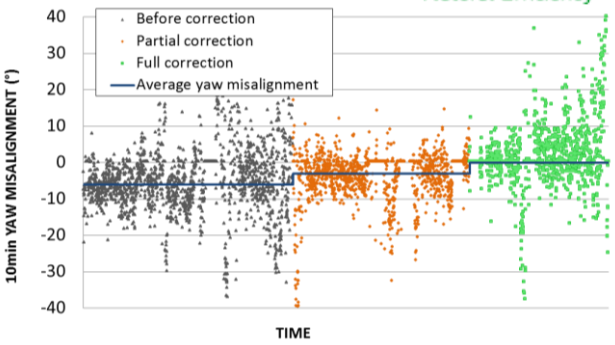
- Measure an IEC equivalent power curve in 6-12 weeks, with proven procedure
- Establish an accurate on-site production referential in 3-6 weeks

# Nacelle mounted LIDAR detect and correct underperformances linked to wind

- Power curve measurement
- **Yaw misalignment correction**
- Nacelle Anemometer Calibration
- Wakes analysis and Wind Sector Management




Iberwind
Natural Efficiency




4 weeks campaign Before/after correction

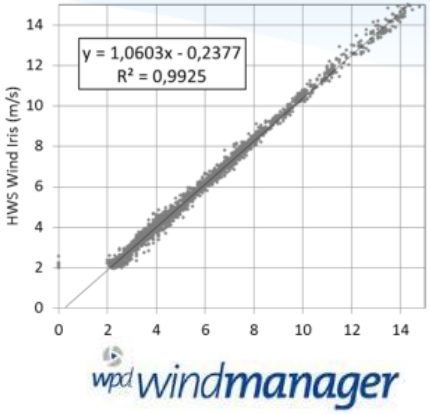
## Key benefits

- Direct and independent measure of the yaw misalignment in a few days
- Correction of yaw error results in a gain of AEP (~ +2% AEP for 7°)

# Nacelle mounted LIDAR detect and correct underperformances linked to wind

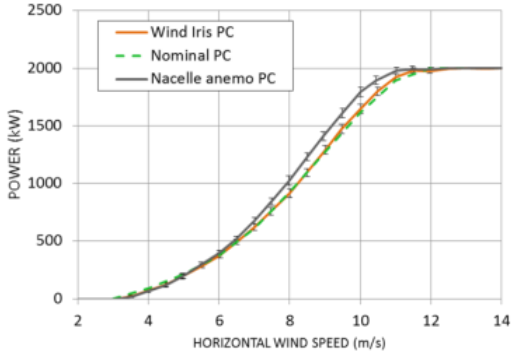
- Power curve measurement
- Yaw misalignment correction
- **Nacelle Anemometer Calibration**
- Wakes analysis and Wind Sector Management

6% under estimation of the nacelle Anemometer




wpd windmanager

Lead to an perfomance overestimation



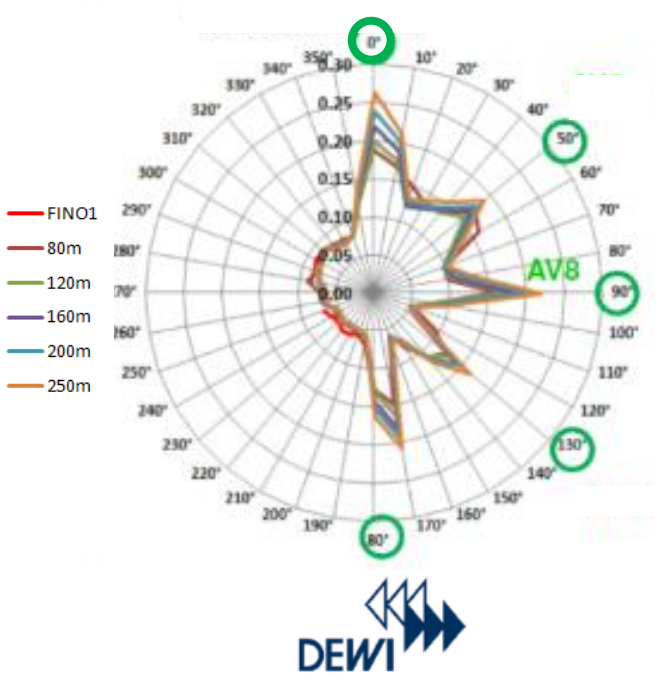

## Key benefits

- Get the right wind speed from your anemometer and improve your O&M
- Obtain accurate site specific calibration, without a mast

# Nacelle mounted LIDAR detect and correct underperformances linked to wind

- Power curve measurement
- Yaw misalignment correction
- Nacelle Anemometer Calibration
- **Wakes analysis and Wind Sector Management**

**Analyse de la TI à 360°**

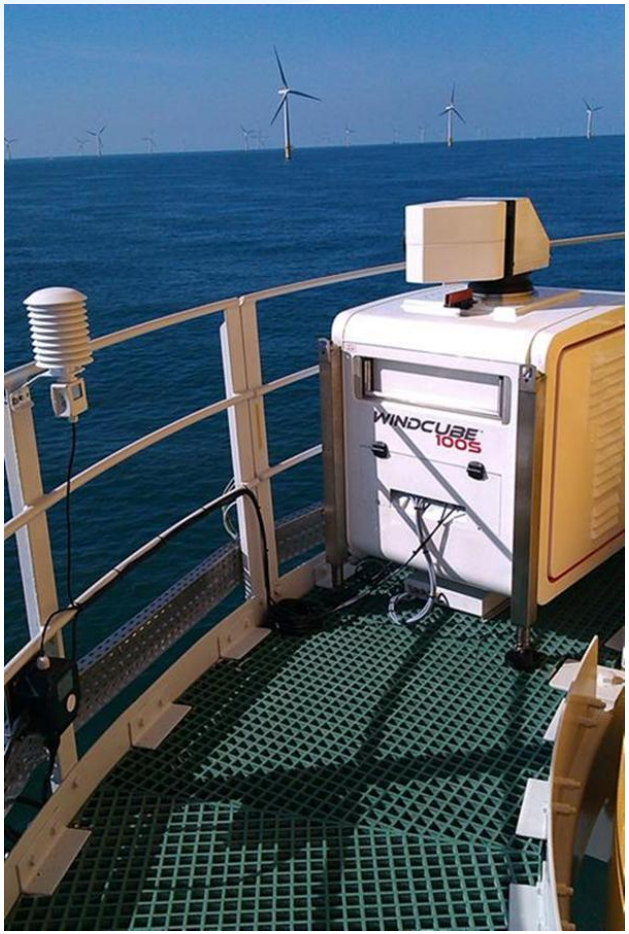



## Key benefits

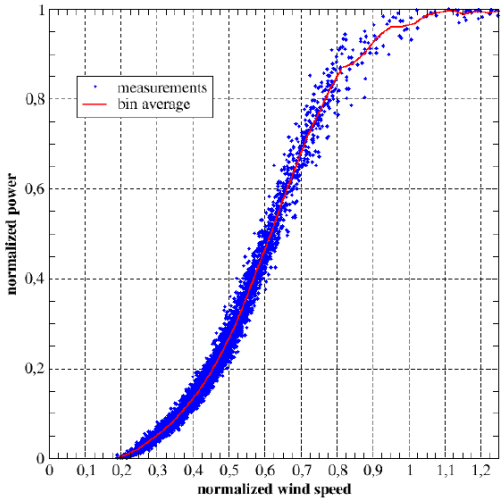
- Maximize AEP with increase energy capture
- Minimize O&M costs with reduced loads

# Other applications using the Scanning Lidar

# Offshore power curve



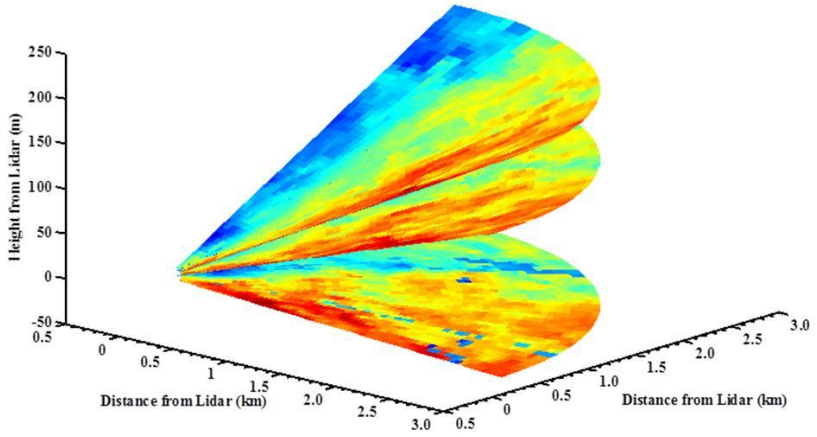

- Offshore power curve from the turbine basement
- Validation of the WINDCUBE Scanning Lidar with a nacelle mounted Lidar, the Wind Iris, for power curve verification.



# Campaign in North America

- Objectives : repowering of a large 25 years old wind farm


- Wind measurement in complex terrain
  - Multiple PPI scans at various elevation angles **to analyze flow features** over the terrain and **validate wind flow models**.
  - 10 min average shear evaluation for **optimization of the repowering**



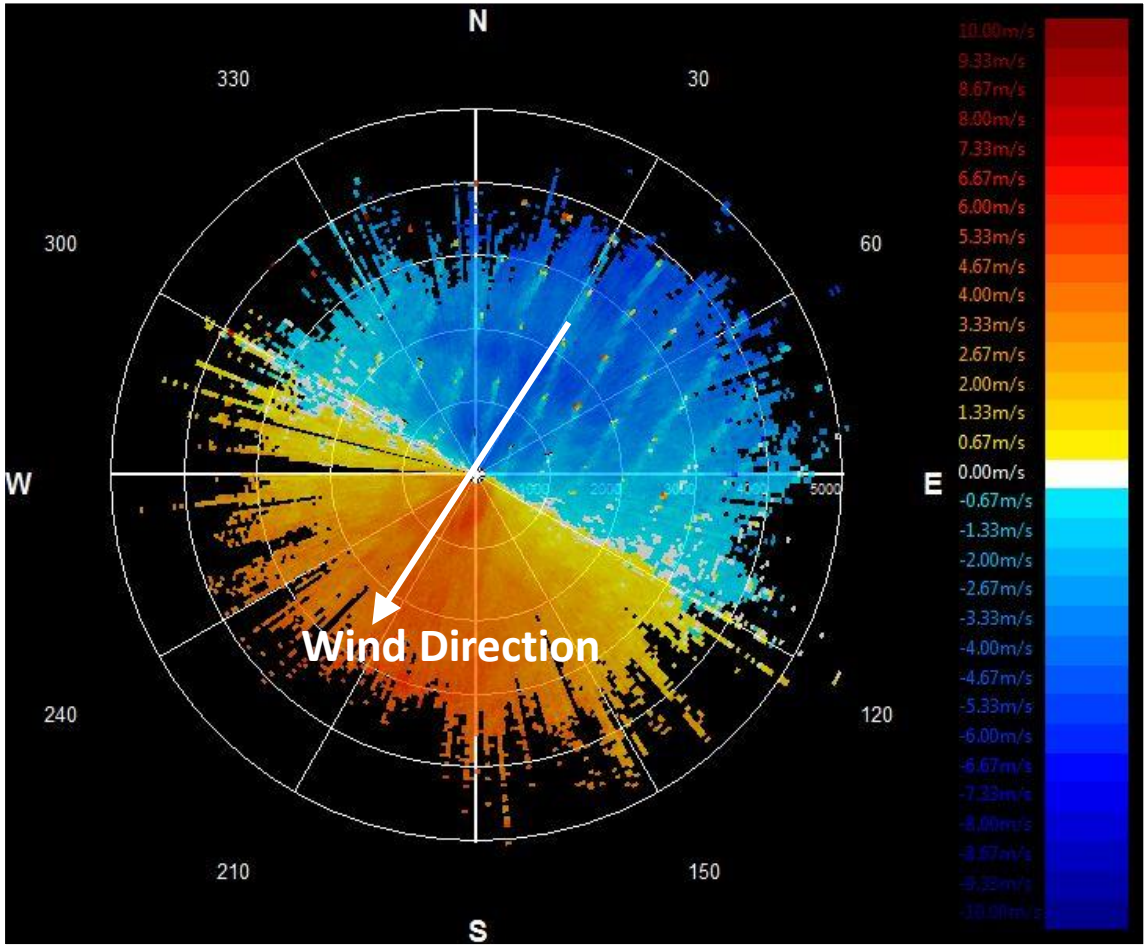
# Wind farm wake analysis campaign

**Goals**:

- Measure Inflow and outflow Parameters
- Validating advanced wake models
- Single Turbine Wake
- Wind farm Wake

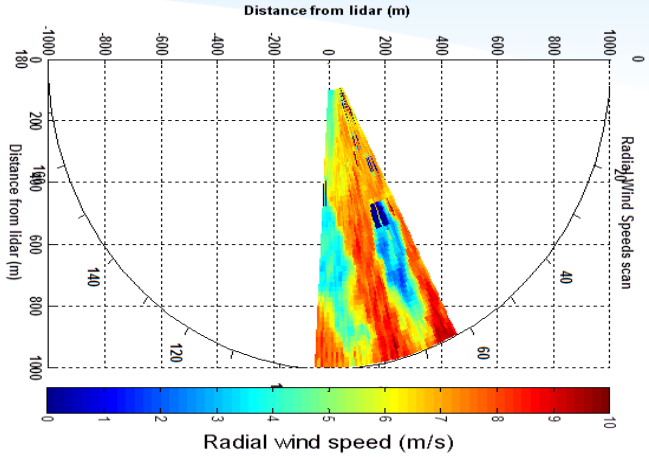
**What benefit from scanning Lidar**:

- Reducing the uncertainty in the AEP by a better measurment of the wake deficit



# Wake measurement

- OWA (Offshore Wind Accelerator)
- CWEX (Lundquist, CU)
  - Explore the propagation of the individual turbine wake and the interaction of multiple wakes in a range of atmospheric stability conditions.
- ECN-LAWINE / Norcowe
  - Multi-instrument campaign to measure the wake and the local turbulence
- Other ongoing projects




# Short term forecasting

- Capability to measure the wind 10km above the measurement point:

  15 min ahead forecast for a 10m.s$^{-1}$ wind

  30 min ahead forecast for a 5 m.s$^{-1}$ wind

- Electric networks are complicated to manage and for more reliability, grid operators need to know in advance how many power the wind farm will provide.
- Wind farm operators are charged for over and under scheduling.
- Ramp forecasting for turbine control and preventive shut-down

Scanning lidar deployed at Hawaii

# Thank you

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