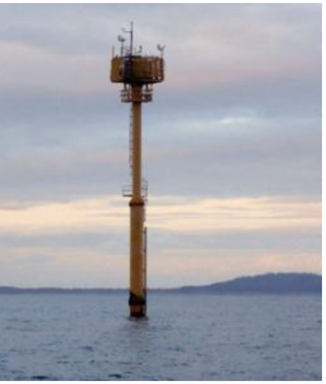
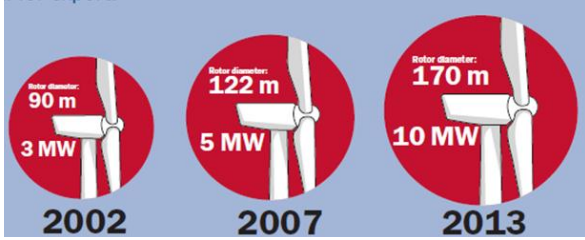
An insight into lidars for offshore wind measurements





Matt Smith
Wind Lidar Innovations

January 2012



CONTEXT – EUROPEAN OFFSHORE WIND

In Europe, as of 30 June 2011, there are 1,247 offshore wind turbines fully grid connected with a total capacity of 3,294 MW in 49 wind farms spread over 9 countries.

Over 100 GW of offshore wind projects are in various stages of planning and, if realised, would produce 10% of the EU's electricity

The offshore wind energy resource will never become a limiting factor. There is enough energy over the seas of Europe to meet total European electricity demand several times over. In a recent study, the European Environment Agency (EEA) estimates the technical potential of offshore wind energy in the EU to be 30,000 TWh annually. The European Commission estimates total EU electricity demand of between 4,279 TWh and 4,408 TWh in 2030.

It would require eight areas of 100 km times 100 km (10,000 km2.) to meet all of the EU’s electricity demand, or less than 2% of Europe’s sea area not including the Atlantic. The combined area of the North, Baltic and Irish Seas and the English Channel is more than 1,300,000 km2. The Mediterranean is an additional 2,500,000 km2

Mediterranean and Atlantic basins as well as Norway. Within these waters (over 50m in depth) it is likely that floating support structures will prove to be more economical.

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CONTENTS

Introduction to Lidar
Reasons for Lidar measurements offshore
Offshore lidar history, acceptance and best practice
Existing platforms, monopiles, tilt ups and other fixed solutions for lidar
Floating lidars - why the industry wants them
Floating lidars – two main product developments
Floating lidars - what is available today
Going forwards – power performance testing offshore turbines

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ZephIR 300 wind lidar

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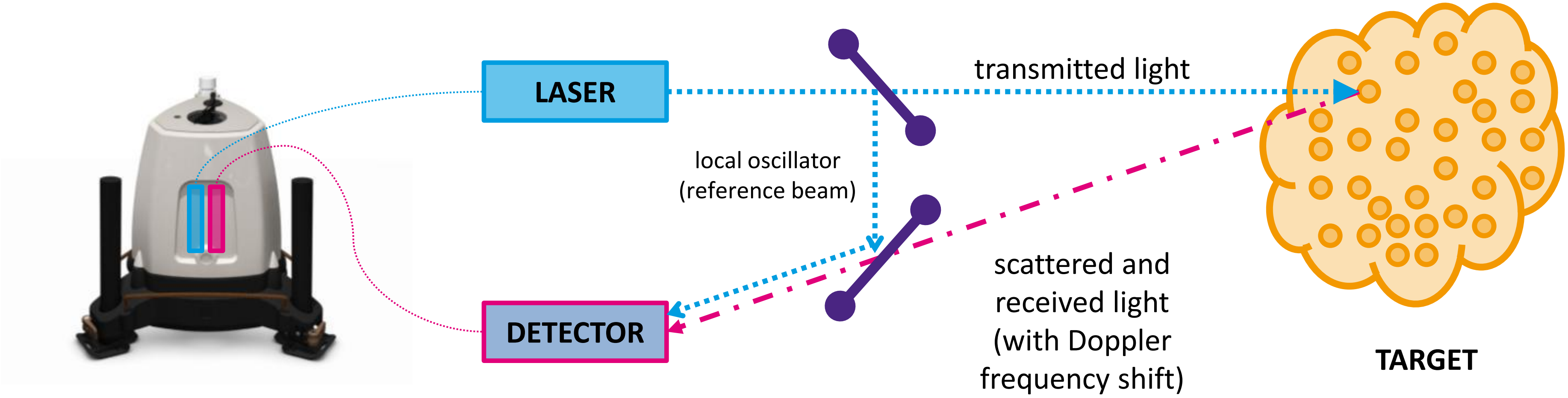
INTRODUCTION TO LIDAR



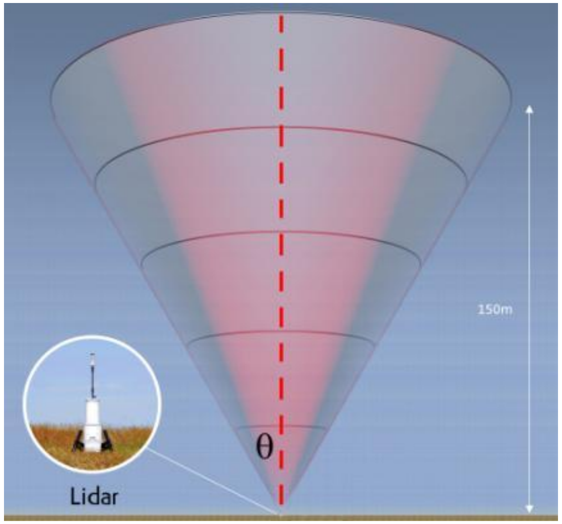
Principles of operation:

- Laser radiation scatters from atmospheric aerosols
- A laser is focussed at a point incident with the aerosols
- Aerosols movement follows the wind
- Scattered radiation is 'Doppler' shifted by the wind speed
- The 'in-line' component of wind speed is measured

INTRODUCTION TO LIDAR

Lidar can provide:

- remote wind profiling across heights from 10 metres to 200 metres
- hub height , tip height measurements and beyond
- wind speed measurements – both vertical and horizontal wind components
- turbulence intensity measurements
- minimised health and safety risks due to removal of working at height on mast structures
- rapid installation in hard to reach areas – forested sites, helicopter drop zones



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REQUIREMENTS FOR LIDAR MEASUREMENTS OFFSHORE

Reduce cost of offshore anemometry in comparison to fixed mast / platform configuration

Use of tried and tested solutions, with proven experience

Flexibility in anemometry location – roving anemometry across large sites

Long servicing intervals due to cost of access offshore

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OFFSHORE LIDAR HISTORY AND CURRENT ACCEPTANCE

The ZephIR lidar has been used in over 30 offshore campaigns around the world, including:

Beatrice platform, North Sea	2005
Horns Rev, North Sea	2006
Fino 1, North Sea	2006
NaiKun, Hecate Strait	2006
Cleveland Crib, Great Lakes	2009
Fino 3, North Sea	2010
Robin Rigg, Solway Firth	2010
Dogger Bank, North Sea	2011

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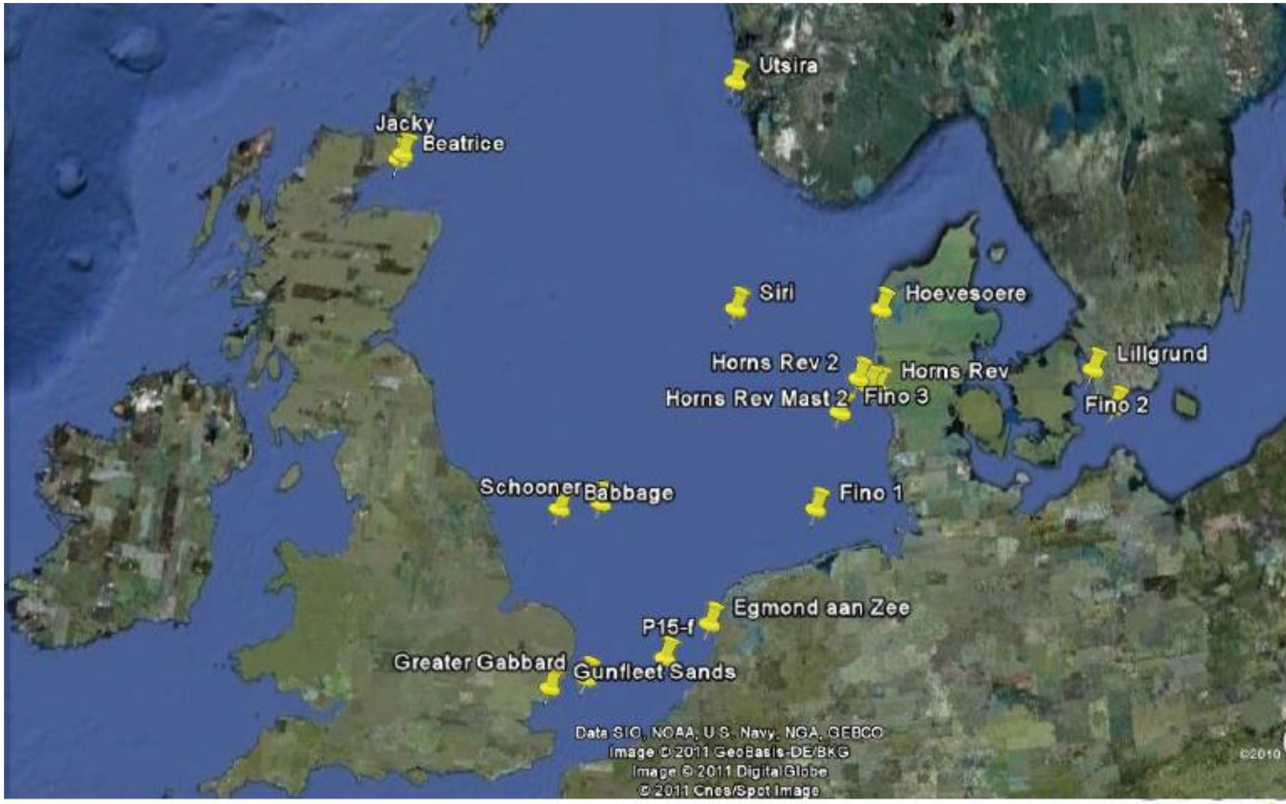
NORSEWIND – NORTHERN SEAS WIND INDEX DATABASE

GOALS:

- Offshore resource assessment
- Lidar utilisation in the wind industry
- Satellite based remote sensing
- Computational modelling
- Offshore wind shear profiling
- Wind power forecasting
- Offshore economics



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NORSEWIND – NORTHERN SEAS WIND INDEX DATABASE

REMOTE SENSING:

The project was the first systematic use of Lidar for large area mapping

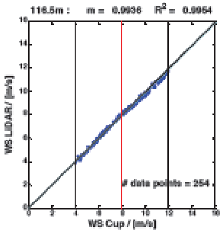
LiDAR Network maintained by: Oldbaum, GL Garrad Hassan Deutschland, Kjeller Vindteknikk

Developed its own testing and validation programme

Over 3000 operational days of data (to Nov 2011)

+ Level of system availability and reliability

- Getting a system offshore



SOME LESSONS:

Offshore Shear –Extremely important

Mast Flow Distortion – an issue even when looking at IEC "compliant" masts

Offshore Deployments – never easy

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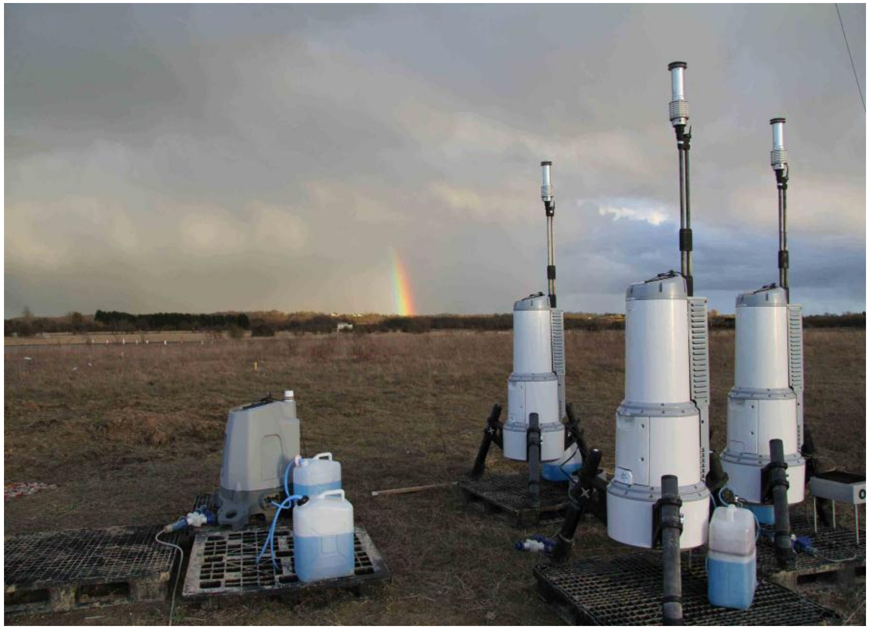
OFFSHORE LIDAR HISTORY AND CURRENT ACCEPTANCE

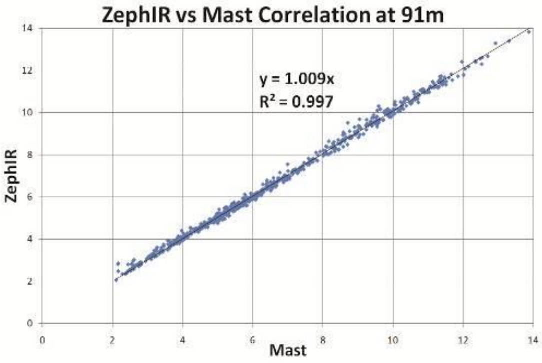
Offshore deployments are subject to three key performance criteria for wind data:

Lidar velocity calibration
Lidar performance verification
Lidar batch production results

These criteria form the basis for many of the Best Practice Guidelines in place today, including:

GL Garrad Hassan
Natural Power





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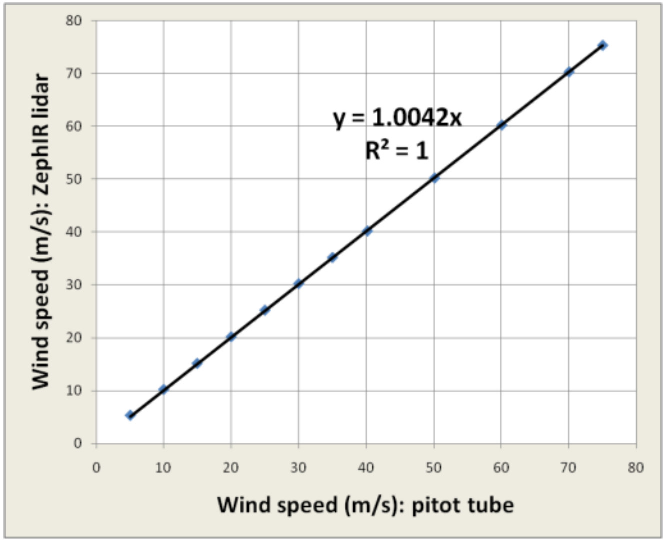
LIDAR VELOCITY CALIBRATION

Velocity calibration depends only on laser frequency and sampling rate of analogue-to-digital converter

Drift of these quantities over extended periods and temperature ranges is <0.1%

Recent measurements in a high-specification wind tunnel confirm very close agreement over a wide velocity range (up to 75m/s)

Lidar was operating at range 3.3m, beam aligned with flow, 50Hz data rate, integrated over 2 seconds; no seeding in tunnel



Acknowledgement: LM Windpower, Risø DTU and NKT Photonics

LIDAR PERFORMANCE VERIFICATION AT RS TEST SITE

Natural Power has established its remote sensing test site close to Pershore, UK

90m mast in flat terrain (disused airfield)

Speed data from paired cups at 4 heights; direction data from vanes at 2 levels

Lidar verification process devised in collaboration with GLGH

Instrumentation conforms with IEC recommendations

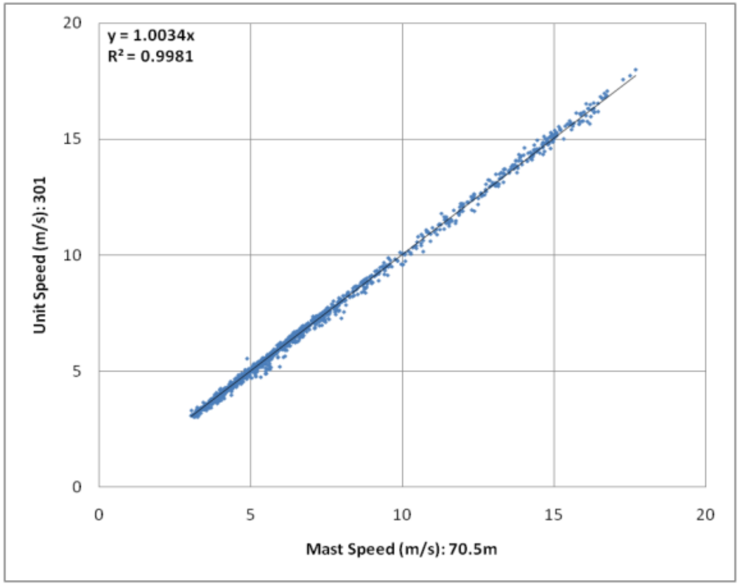
LIDAR BATCH PRODUCTION RESULTS

Standard performance verification example for ZephIR 300 unit

Calibration consistency has been analysed for new and returning units

Statistical analysis of regression slopes for 15 ZephIR 300 units shows standard deviation of <0.5% at all heights

Results provide confidence in ZephIR lidar for bankable offshore resource assessment



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BEST PRACTICE APPLICATIONS

The following table summarises Natural Power's present position on the acceptability of different ZephIR campaign configurations where ZephIR is being used as the primary measurement device for the purposes of finance level resource and energy yield analysis

	Offshore	Simple terrain	Complex/Forested
Single ZephIR, no co-located mast	YES	YES	NO
Single ZephIR with co-located mast	YES	YES	YES*

*Mast should be at least 15 m above the tree tops. Volume-to-point conversion calculations may be required (discussed later).

It is assumed in all cases that the ZephIR unit is subject to pre-and post campaign verification on a suitably-equipped calibration test site (see following slides).

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OFFSHORE BEST PRACTICE

ZephIR can be recommended as a primary wind measurement system for offshore wind farms.

There is a significant and consistent body of evidence to support the use of ZephIR in offshore conditions as the sole data capture system.

Consider the installation of two Lidar systems for redundancy and to enable continued data to be collected during service intervals.

Where redundant ZephIRs are not practical or possible, consideration should be given to the installation of a short mast (20m above platform height) in order that there is a second source of wind measurements.

This should be done in the interests of data coverage, and not for wind speed measurement validation.

OFFSHORE BEST PRACTICE

Power supplies and communication systems should be scoped to provide double redundancy and be remotely manageable.

A pre-campaign test of ZephIR against a tall reference mast is required. A post-campaign test is also recommended.

As a minimum, offshore measurements should be conducted at the base of the planned rotor height, hub height and rotor top.

Post-processing and filtering of measurements should be carried out in accordance with best-practice for mast-based campaigns, in addition to any guidelines provided by the OEM.

Installation of a ZephIR on a sub-station platform can provide a permanent wind data solution on offshore projects. (see opposite which shows a ZephIR installed on the sub-station platform of E.ON's Robin Rigg 180MW offshore wind farm in the Solway Firth, SW Scotland)

METHODOLOGY FOR INITIAL FEASIBILITY STUDIES

Based on the use of an initial onshore ZephIR deployment

- Ideally at nearest point of coast to project location
- Quick and low cost installation, compared to a platform in early stages
- Ideally mains powered and secure

Derive offshore data point from validated meso-scale wind climate model (i.e. Vortex)

- Provides long-term (10-yr.) wind resource statistics and time series data

Correlation of onshore ZephIR data with meso-scale model data

- Perform correlation every 3 months (if required)
- Allows meso-scale model to be tuned to real data and prediction uncertainty reduced
- Derived site wind resource statistics can be used to perform an energy yield analysis

This method permits early, low-cost resource analysis, and delivers energy yield reports with lower uncertainty than can be otherwise achieved (without an offshore platform)

Offshore on-site data collection will still typically be required to provide full and final finance-grade analysis (see narec Case Study)...

NAREC: CASE STUDY IN THE NORTH SEA

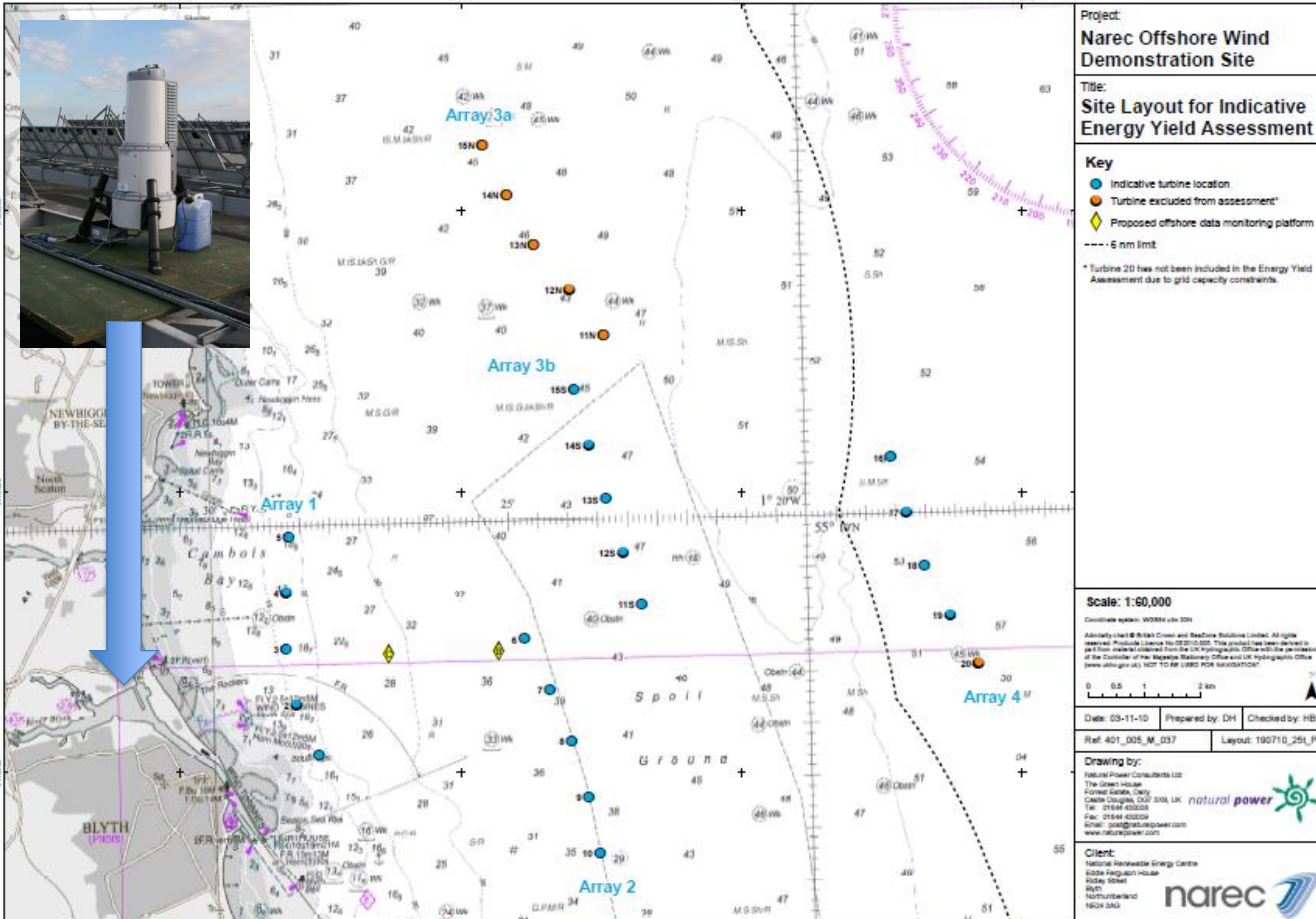
narec offshore wind demonstrator project (Northumberland, UK)

Phase 1: Onshore building mounted ZephIR, <5km from project location
Onshore ZephIR data correlated with long-term offshore Vortex meso-scale model data, as per methodology described above
Data and results used to underpin ongoing resource analysis, energy yield prediction and site classification reports for the site owner and prospective site tenants (turbine OEMs)

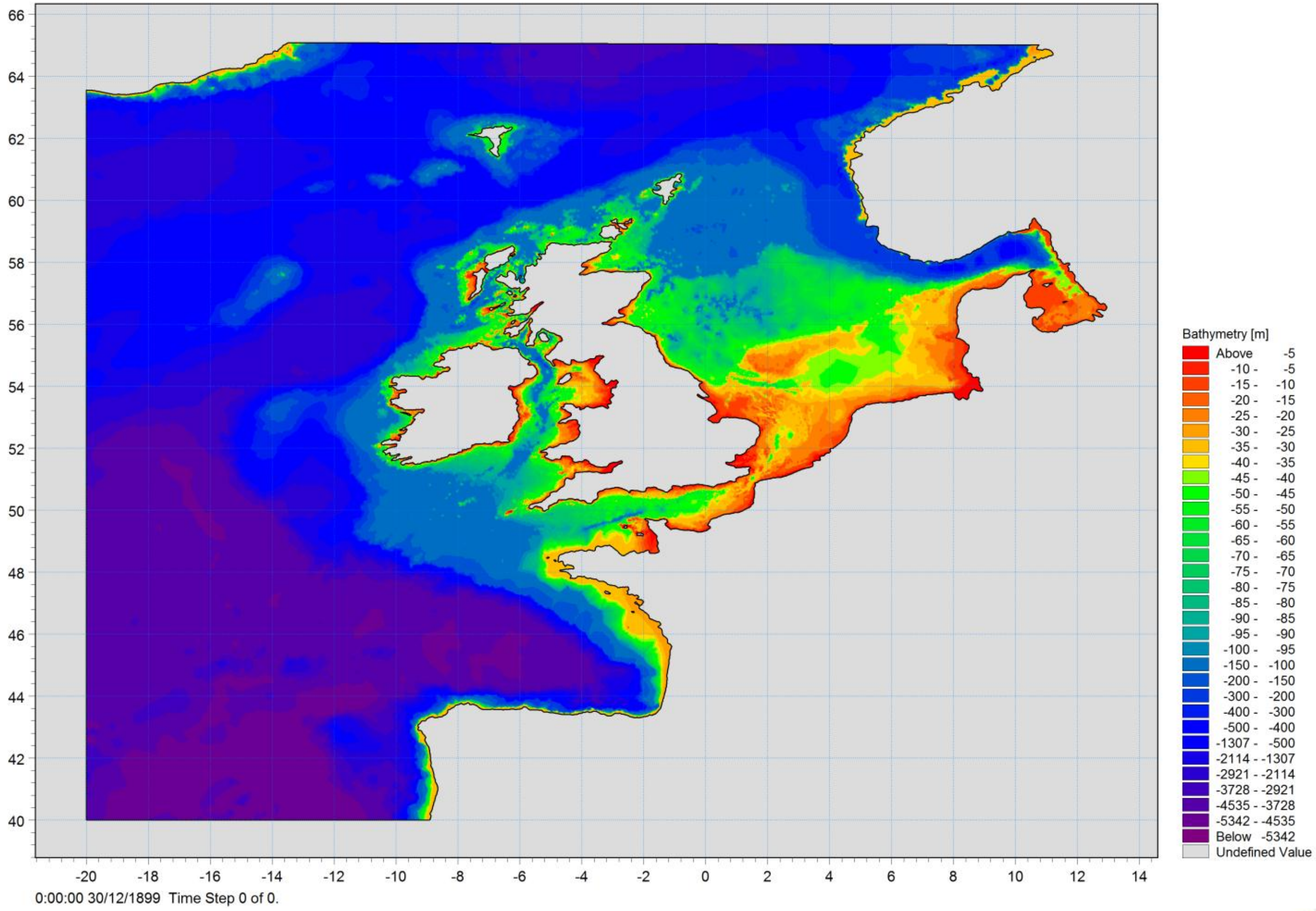
Phase 2: A second ZephIR and a tall met. mast are to be platform-mounted offshore
Onshore ZephIR to remain in-situ to provide consistency and allow extension of data period
All data will be utilised to produce finance-grade energy yield prediction and site classification reports, with minimised prediction uncertainty

Public domain reports by Natural Power (publicly funded project):
http://www.narec.co.uk/testing_development/offshore_demonstration_site/report_downloads/

narec: Onshore ZephIR location and proposed platform location(s)



EUROPEAN WATER DEPTHS



USE OF EXISTING PLATFORMS

The use of existing platforms offers a "quick" way to get offshore:

- Research Stations
- Light houses
- Sub stations
- Oil and gas platforms

In the Offshore Wind Industry there has been an increase in size of Meteorological Mast platforms to allow for fitting or retro fit of Lidar. The design is not only relevant to the structure but has an impact on power budget and control systems.

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TRADITIONAL PLATFORM SOLUTIONS

In the Offshore Wind Industry we have seen an increase in size of Meteorological Mast platforms to allow for fitting or retro fit of Lidar.

The design is not only relevant to the structure but has an impact on power budget (navigation aids) and control systems.

The costs associated with steel, power, installation and maintenance are all affected by the mix of mast and lidar. These round of installations will further boost the confidence in lidar only measurement campaigns.

This is especially relevant when you consider the development of deep water turbines.

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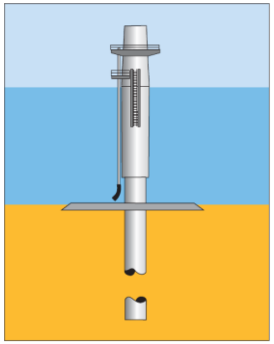
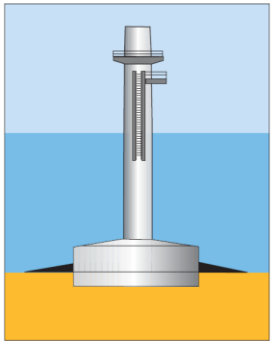
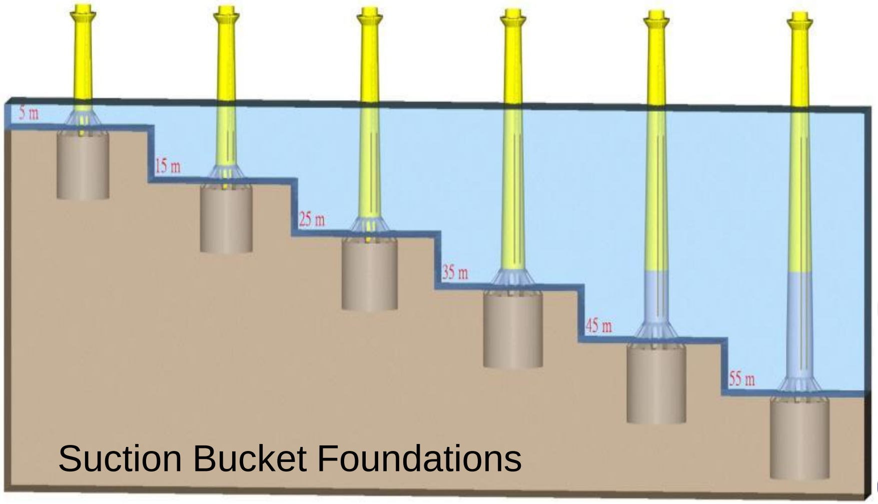
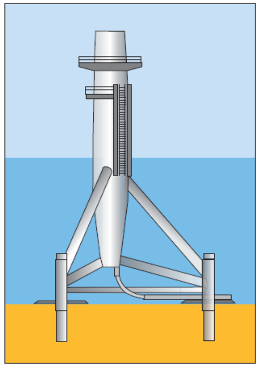
TRADITIONAL PLATFORM SOLUTIONS

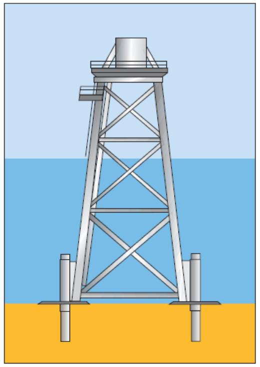
Type of substructure	Brief physical description	Suitable water depths	Advantages	Limitations
Monopile steel	One supporting pillar	10 – 30m	Easy to manufacture, experience gained on previous projects	Piling noise, and competitiveness depending on seabed conditions and turbine weight
Monopile concrete, installed by drilling	One supporting pillar	10 – 40m	Combination of proven methods, Cost effective, less environmental (noise) impact. Industrialisation possible	Heavy to transport
Gravity base	Concrete structure, used at´ Thornton bank	Up to 40m and more	No piling noise, inexpensive	Transportation can be problematic for heavy turbines. It requires a preparation of the seabed. Need heavy equipment to remove it
Suction bucket	Steel cylinder with sealed top pressed into the ocean floor	n.a.	No piling, relatively easy to install, easy to remove	Very sensitive to seabed conditions
Tripod / quadropod	3/4-legged structure	Up to 30m and more	High strength. Adequate for heavy large-scale turbines	Complex to manufacture, heavy to transport
Jacket	Lattice structure	> 40m	Less noise. Adequate for heavy large-scale turbines	Expensive so far. Subject to wave loading and fatigue failure. Large offshore installation period (first piles, later on placing of structure and grouting) therefor sensitive for weather impact

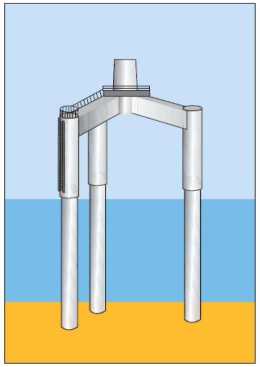

Monopile


Gravity-based Structure (GBS)




Space Frame (Tripod)


Space Frame (Jacket)


Space Frame (Tri-pile)

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DEEP WATER TURBINES

Country	Project name	Principal partner	Description
Norway	Hywind	Statoil	Hywind is the first full scale grid-connected floating prototype (using spar class technology). It was installed off Karmøy island on the south-west coast of Norway in 2009 with a Siemens 2.3 MW machine.
Norway	Karmøy	Sway	Sway is building a prototype spar class floating design with the ambition of deploying a 5 MW turbine in 2013.
France	Vertiwind	Technip	In association with Nénuphar, Converteam and EDF Energies, Technip have launched a project to test a pre-industrial prototype of a vertical-axis floating wind turbine.
France	Winflo	Nass & Wind	In partnership with Saipem, DCNS and InVivo. Windflo is a 2.5 MW moored floating jacket class prototype to be installed off the coast of Brittany. Currently under development.
Spain	Zèfir Test Station	Catalonia Institute for Energy Research	In collaboration with a number of major industry players the Zèfir Test Station programme is intended to further deep water developments around Spain in two phases, the second of which involves installing eight turbines on floating structures at water depths of over 100 m.
Europe	HiPRwind	EU project consortium	Five-year programme with a total budget of €19.8 million to develop a new floating platform for "very large" offshore turbines.
Spain	Azimut Project	Gamesa	In partnership with Alstom Wind, Acciona and Iberdrola, the Azimut Project has the objective of providing the groundwork for the development in around 2020 of a 15 MW offshore turbine.
Portugal	Windfloat	Principle Power	In partnership with EDP and InovCapital, the Windfloat Project intends to install a full-scale Vestas V80 2 MW turbine for 12 months of testing in 2011. The Windfloat is a floating jacket design with novel features.
Italy	-	BlueH	A multi-national group of companies based in the Netherlands have developed a TLP concept consisting of a larger structure with several piles implanted in the surface. An off-grid prototype with an inactive turbine for visualisation purposes was installed 21 km off Brindisi, Italy in 100 m deep waters during 2007/8.

TWO MAIN FLOATING LIDAR PRODUCT DEVELOPMENTS

Free floating lidar - free-motion platforms with motion compensation
Device floats on the water surface and compensate the motion of the buoy either:

- physically (using devices such as gimbals) or;
- in the processing of data (through algorithms)

"Free floating" lidars are useful tools for the industry but can have higher uncertainty attached to their data; particularly in more extreme offshore wave conditions.

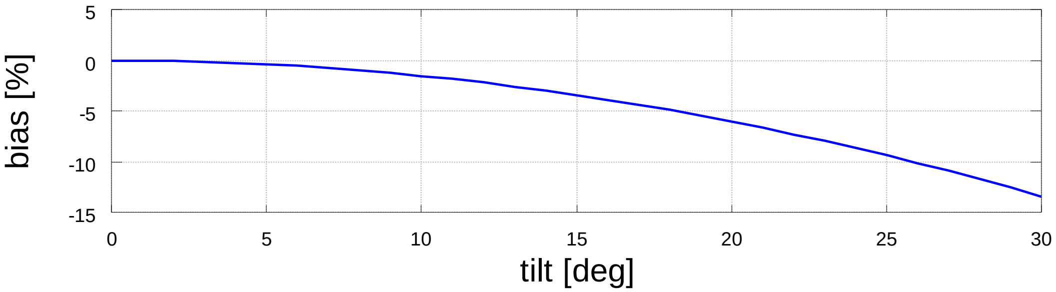
It is difficult to validate these compensations without experiencing all of the possible waves but they still offer a valuable insight into offshore wind conditions.

Motion-restricted floating lidar
Motion of the floating platform is minimised as much as possible removing the need for motion compensation, aiming to spend as much time as possible with the device within 5 degrees of vertical without there being large vertical or horizontal movements.

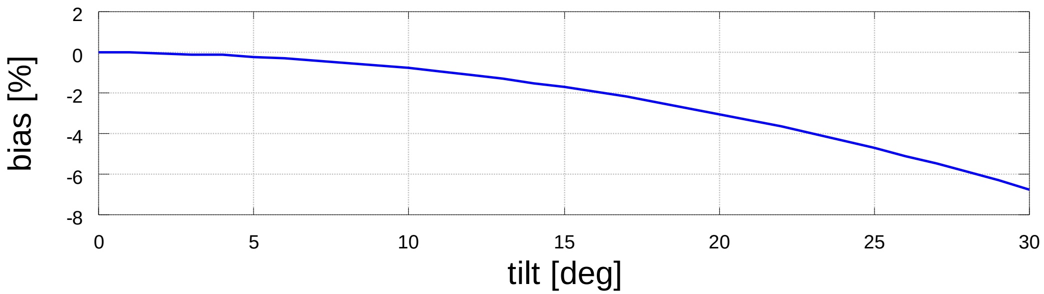
Easier to validate wind data as scenario is more representative of a lidar based on a fixed platform offshore or based at ground level onshore.

EFFECT OF TILT ON DATA – MOTION STABLE PLATFORM

Static tilt
This may occur due to tides or steady currents. It should be possible to correct for steady state tilt using the ZephIR's inbuilt tilt sensor. For tilt less than 5°, bias is seen as 1% or less.



Low frequency periodic tilt (0.01 Hz)
The averaging effect of a periodic (sinusoidal) tilt motion reduces the error by a factor of approximately 2, relative to the static case. For the cases of static and low frequency periodic tilt, vertical wind speed has no effect except at very high tilt angles. For tilt less than 5°, bias is seen as 0.25% or less.



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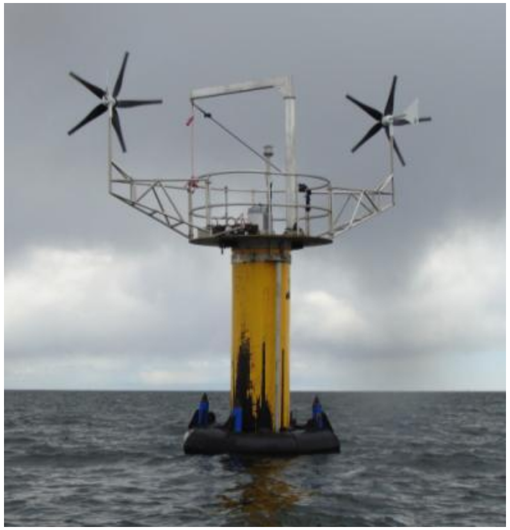
FLOATING PLATFORM LIDAR CASE STUDIES



"SeaZephIR" – production lidar mounted on spar buoy for platform stability

Concept trialled in 2009: two ZephIR units deployed off coast of Norway, LandZephIR on small island, SeaZephIR buoy anchored out to sea

Separation of units 800m: excellent correlation obtained

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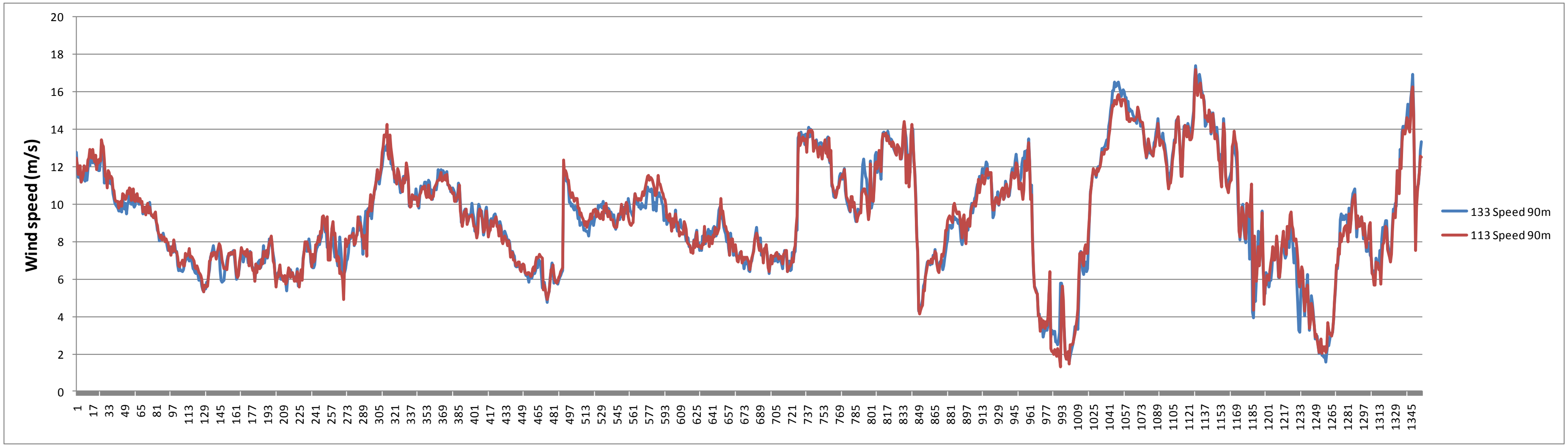
COMPARISON BETWEEN SEA- AND LAND-BASED LIDARS



Wind speed time series data from height 90m above sea level:

SeaZephIR data in red

LandZephIR data in blue

Data plotted here from 5-23 November 2009

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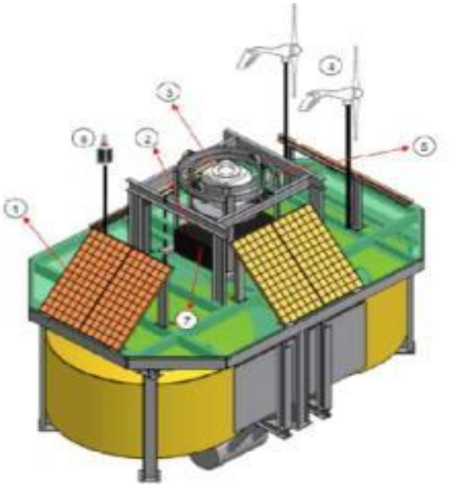
AVAILABLE PRODUCTS TODAY - FLIDAR

Industry standard buoy structure and anchoring adapted to most marine regulations

Rugged marine design by experienced marine engineers (GeoSea)

Pulsed LIDAR technology (Leosphere) – from 40m to 200m

Mechanical stabilisation and software correction algorithms



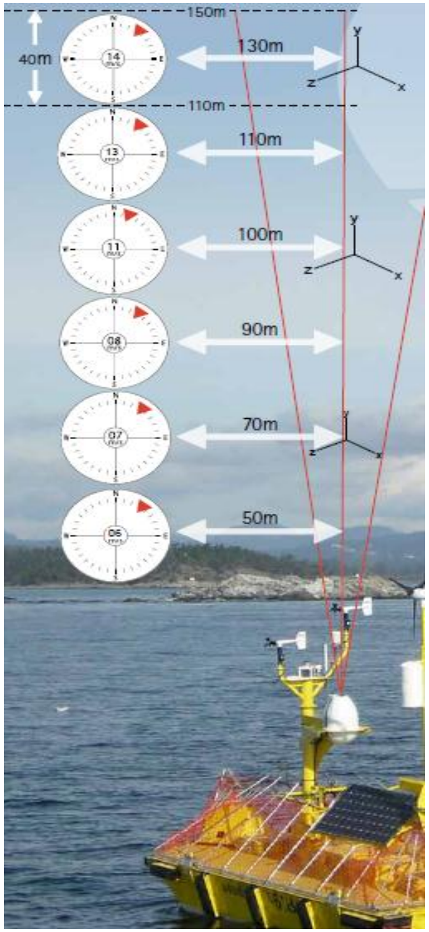
AVAILABLE PRODUCTS TODAY – WIND SENTINEL

Industry standard buoy structure and anchoring adapted to most marine regulations

Rugged marine design by experienced marine engineers (AXYS NOMAD buoy)

Pulsed LIDAR technology (Catch The Wind) – from 30m – 150m (extendable)

Motion compensated data



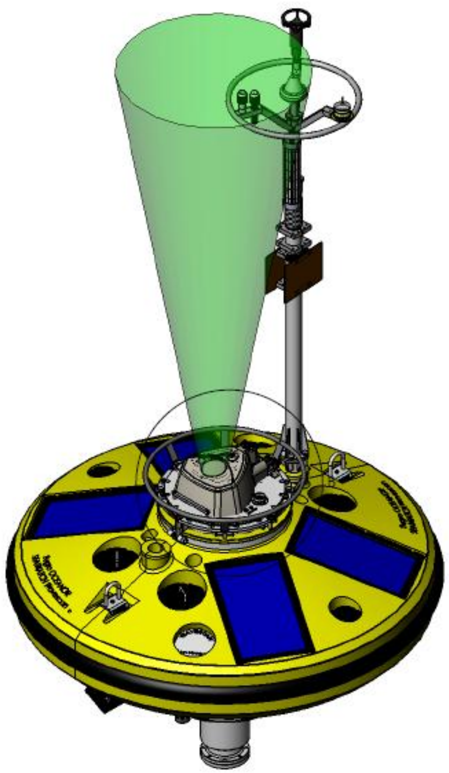
AVAILABLE PRODUCTS TODAY – WAVESCAN ZEPHIR

Marine designed by experts at Fugro Oceanor

Mounted on the existing successful Fugro Wavescan buoy

Continuous Wave ZephIR lidar measuring from 10m-200m

Currently at pre-production prototype, testing being conducted Sletringen light house, Frøya.



AVAILABLE PRODUCTS TODAY – SEA ZEPHIR

Industry standard stable tension leg buoy structure and anchoring adapted to most marine regulations

Rugged marine design by experienced marine engineers (SeaRoc)

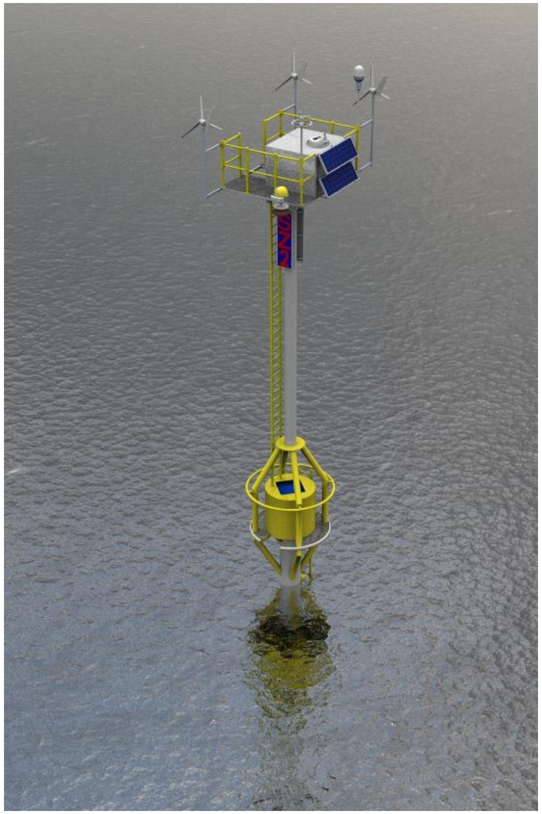
Continuous Wave LIDAR technology (ZephIR) – from 10m to 200m

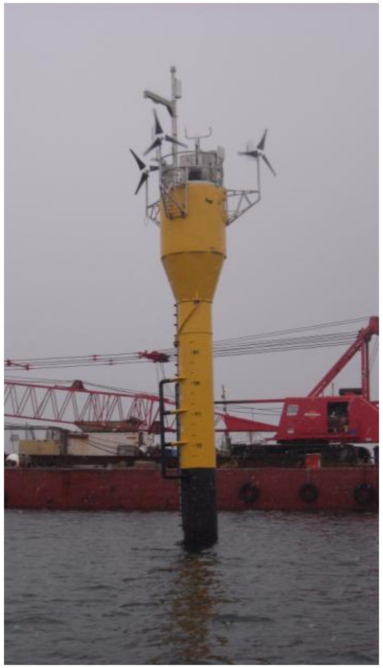
Inherently stable platform, no motion compensation

Energy autonomous

Satellite communication

Data retrieval and analysis via web interfaces (vuWind)





POWER PERFORMANCE TESTING OFFSHORE WIND TURBINES

To date this has not really been possible in accordance with IEC guidance, the placement of a mast in the prevailing wind direction being quite difficult and very expensive offshore.

These floating lidars offer the ability to get measurements from upwind and therefore to assess the turbine performance.

The use of lidars is being considered by the IEC steering group and guidance is expected in the near future. The question will remain whether these floating lidars can be compliant.

The floating lidars will offer a better understanding of the situation than the tools we have today.

But then there is always.....

.... but that's a different story!