CAMPBELL SCIENTIFIC®

WHEN MEASUREMENTS MATTER

ZephIR 300 OFFSHORE CREDENTIALS

Accepted for wind resource assessment onshore and offshore by leading Banks Engineers, globally

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The Need for offshore wind measurements

- OFFSHORE WIND MEASUREMENTS

Site prospecting - Energy Yield Assessment

- Wind resource assessment
  - Wind speed and direction profile
  - Vertical wind shear profile

Project design

- Layout and wake considerations
  - Turbulence intensity

Foundation & Structural Design

- Turbine Loadings
  - Vertical wind shear profile

Hub height measurements are required to reduce uncertainty

Turbine full rotor measurements further reduce uncertainty

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OFFSHORE MET-Mast challenges

TURBINE HUB HEIGHTS ARE INCREASING,
CHALLENGES ARE INCREASING:

- Structure & Logistics
- Health & Safety
- Flow distortion
- COST

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OFFSHORE MET-Mast challenges

Structure & Logistics

- STRUCTURE
  - Massive foundations required to support the structure
  - More steel/structure required
  - Increased maintenance of the structure
  - Increased maintenance of the anemometry and support booms
  - Boom alignment and stability is critical

- DEPLOYMENT LOGISTICS
  - Large crane vessel required to install
    - More expensive vessel
    - Availability constrained
    - Increased risk of weather delay

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OFFSHORE MET-Mast challenges

H&S

- HEALTH & SAFETY

  – Working at height risks and large support teams required
  – Anemometry requires regular maintenance
  – Human free installations are being promoted in Europe
  – Large structure vulnerable to extreme wind events & fatigue

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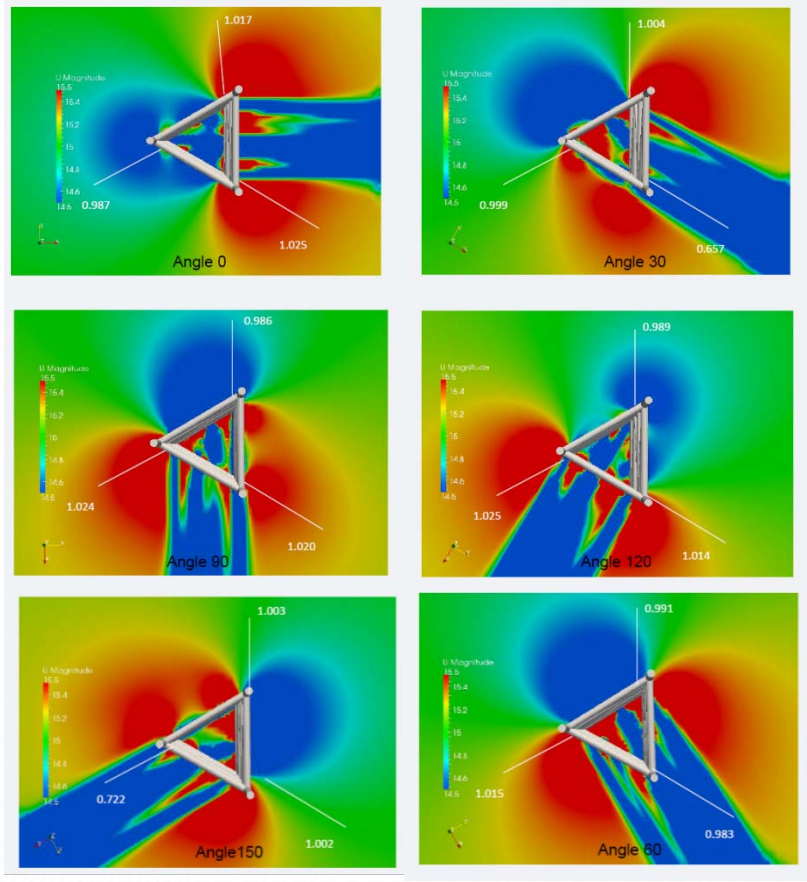
OFFSHORE MET-Mast challenges

Flow distortion

- Offshore met-masts are large structures and produce significant flow distortion and consequently increased uncertainty. Error due to distortion on laminar flow up to 3%, even in optimised layouts. The graphs to the right show in each simulated wind direction the flow distortion as would be seen by the cup anemometers at the end of the booms
- Mast prone to motion; affects boom alignment and creates up to 1% additional error
- Boom lengths need to be long enough to allow for measurements outside of the flow distorted area, hence structure increases further
- Cup anemometers can in part be calibrated to reduce the effect of flow distortion but this is not ideal
- Based on clutter surrounding the top-mounted cup anemometers, which is the less distorted area, an additional 1% uncertainty is generally applied to the data



"Computational and Experimental Study on the effect of flow field distortion on the accuracy of the measurements made by anemometers on the Fino3 Meteorological mast": M Stickland, T Scanlon, S Fabre, A Oldroyd, T Mikkelsen, D Kindler, Poster 334, EWEA 2012

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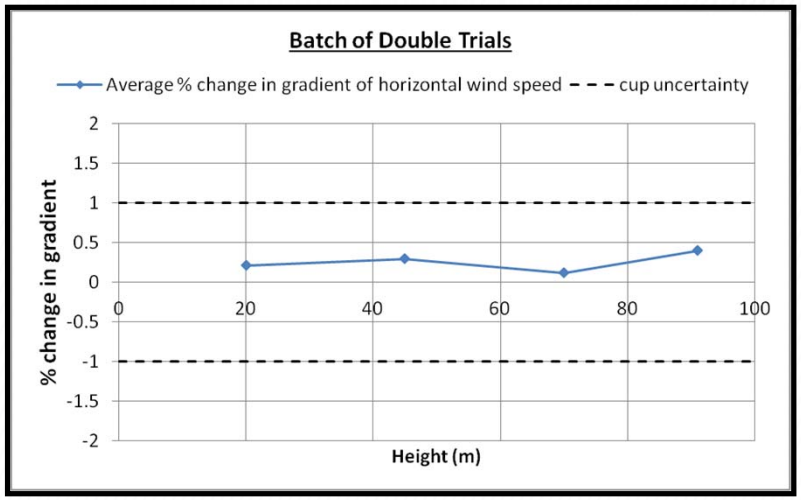
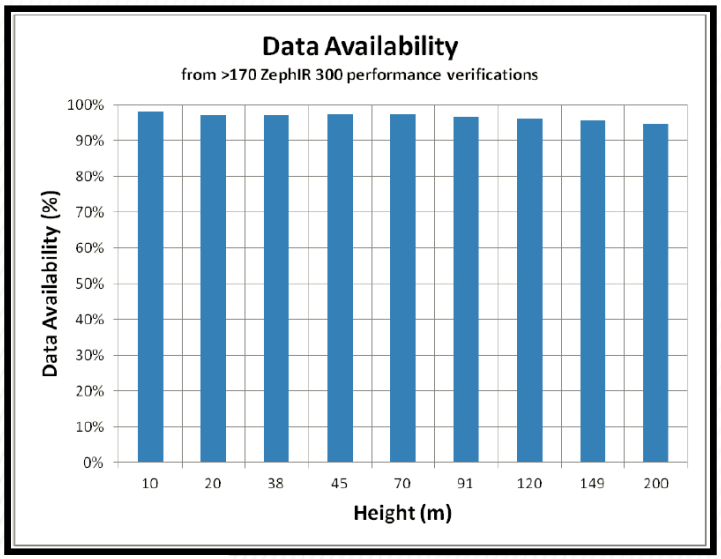
Data accuracy and availability

170+ ZephIRs verified – the single largest batch of lidars verified against an IEC mast, globally

Combined results from >170 ZephIR 300 performance verifications Horizontal Wind Speed						
Height (m)	Gradient		R^2		Avail (%)	
	Mean	Std	Mean	Std	Mean	Std
91	1.004	0.007	0.988	0.007	96.66	2.61
70	1.002	0.005	0.991	0.008	97.20	2.22
45	1.002	0.004	0.991	0.006	97.37	2.10
20	0.999	0.005	0.992	0.005	97.15	2.66





'Double trials' represent validations against the mast pre- and post-deployment.

Results demonstrate long-term calibration stability.

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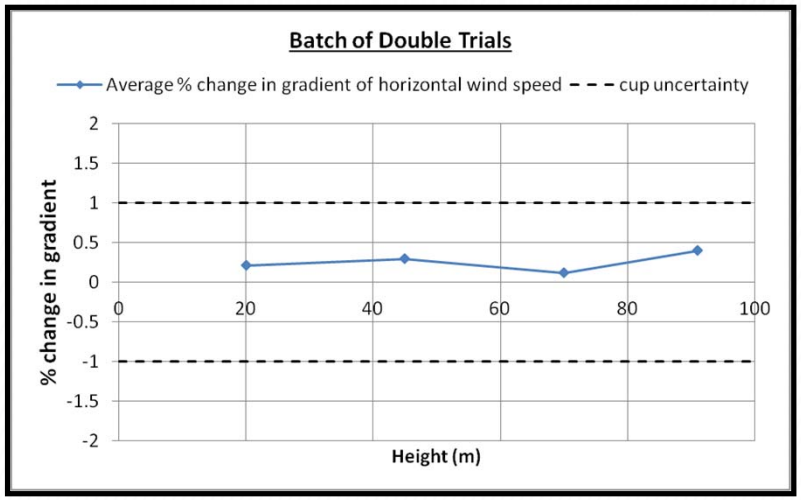

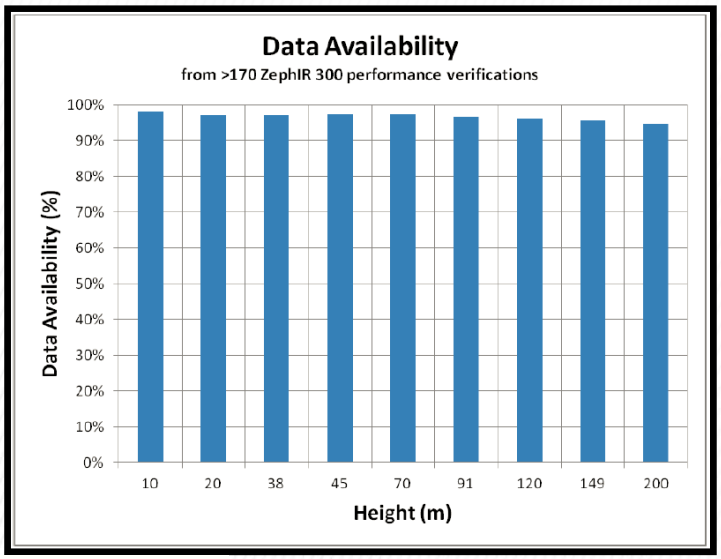

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ZephIR Lidar

Long term system availability

- 40 months continuous operation of a single zephir

- Operational evidence of long term system availability
- Drifts in performance would require recalibration which would be a disadvantage to the operator in terms of inconvenience, cost and time
- Evidence of a 40 month operational deployment, during which time no maintenance or servicing conducted on the ZephIR (due to operational constraints associated with the specific deployment, it was not possible to recover the device for inspection and service within the recommended service interval)

- **Changes in accuracy of the ZephIR over the period were insignificant and much less than 1% in wind speed**

- Accuracy remained well within the industry standard (IEC) requirement for accuracy which is of the order of 1.5% to 2.0% depending on wind speed for a first class, calibrated, well-mounted cup anemometer (this includes the possible contributions from differing atmospheric conditions during the two test periods, which took place at different times of the year. In addition, during this period, the mast was re-instrumented in accordance with IEC guidelines).

PRE-DEPLOYMENT

Height[m]	Gradient	R^2
91	1.0108	0.9918
70	1.0122	0.9917
45	1.0084	0.9877
20	1.0027	0.9768

POST-DEPLOYMENT
40 MONTHS LATER

Height	Gradient	R^2
91	1.0124	0.9943
70	1.0112	0.9956
45	1.0114	0.993
20	1.0079	0.9893

ZephIR Lidar

Acceptance offshore - bankability

DNV·GL

GL Garrad Hassan

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

Note - offshore is considered benign

natural power

"Natural Power considers that 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"

ECN
Your energy. Our passion.

"ZephIR is very capable of providing high quality, 10 minute average wind speed and direction data at all heights well above traditional tall mast heights. Correlation is excellent to our IEC compliant mast and site. ZephIR can therefore be considered, in our initial opinion, to be used in a stand-alone application for wind resource measurements."

ZEPHIR IS 'BANKABLE'

PRODUCING FINANCE GRADE DATA IN THE BENIGN ENVIRONMENT OF AN OFFSHORE FIXED PLATFORM

ZephIR Lidar

Offshore operations - examples

ZephIR lidar has been used in over 40 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
TME, Italy	2008
Cleveland Crib, Great Lakes	2009
DWW, US	2009
Fino 3, North Sea	2010
Robin Rigg, Solway Firth	2010
RWE (ECN/SSC), Germany	2010
EDF, Teeside	2010
Oriel, Ireland	2010
Saorgus, Dublin Array	2011
NaRec, UK	2011
CLP, Hong Kong	2011
Fugro, Norway	2011
BNET, China	2011
ECN Fixed Mast platform, North Sea	2011
Fugro Floating Buoy, Norway, North Sea	2011
RWE, NSO platform, North Sea	2011
Forewind Cavendish Platform, North Sea	2011
ECN Fixed Mast platform, North Sea	2012
Energia2020 Gas Platform, Med Sea	2012
BNET, China	2012
RWE, NSO platform, North Sea	2013
Babcock Spar Buoy, Gwynt y Mor, Irish Sea	2013
SSC Fixed Platform, North Sea	2013
Firth of Forth	2013
Fugro Floating Buoy, Norway, North Sea	2013
RWE Mast, Gwynt y Mor, Irish Sea	2014
NaRec Fixed Platform, North Sea	2014
Fugro Floating Buoy, Norway, North Sea	2014
SeaRoc Fixed Buoy, New Jersey	2014
Bell Rock Lighthouse, Dundee	2014

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Offshore operations - examples

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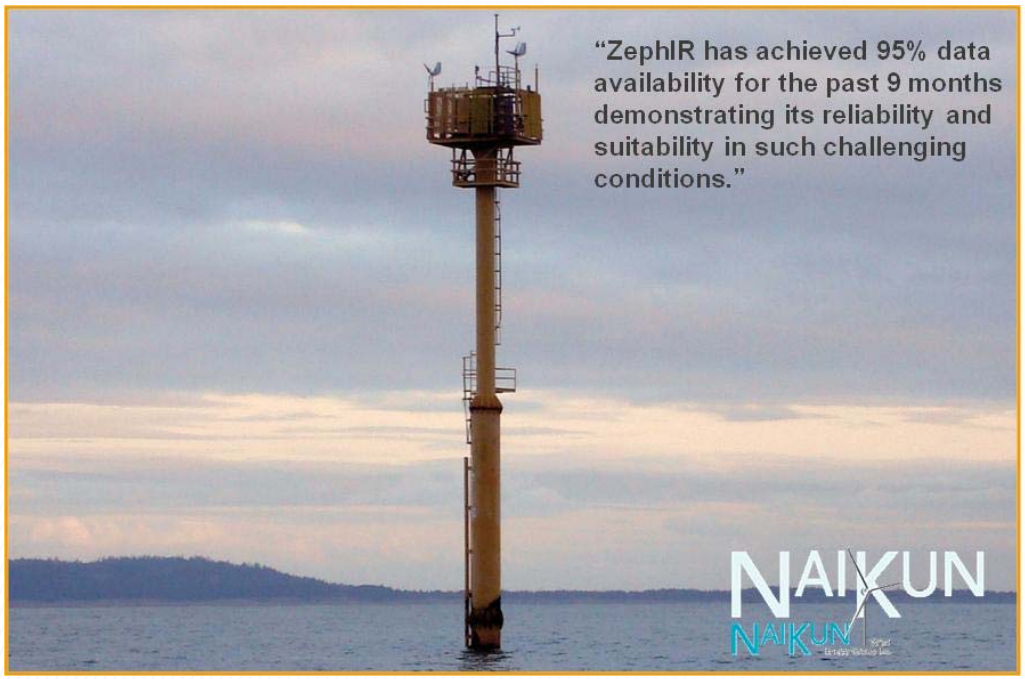
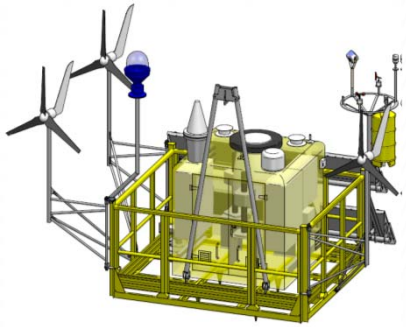
Offshore operations - examples





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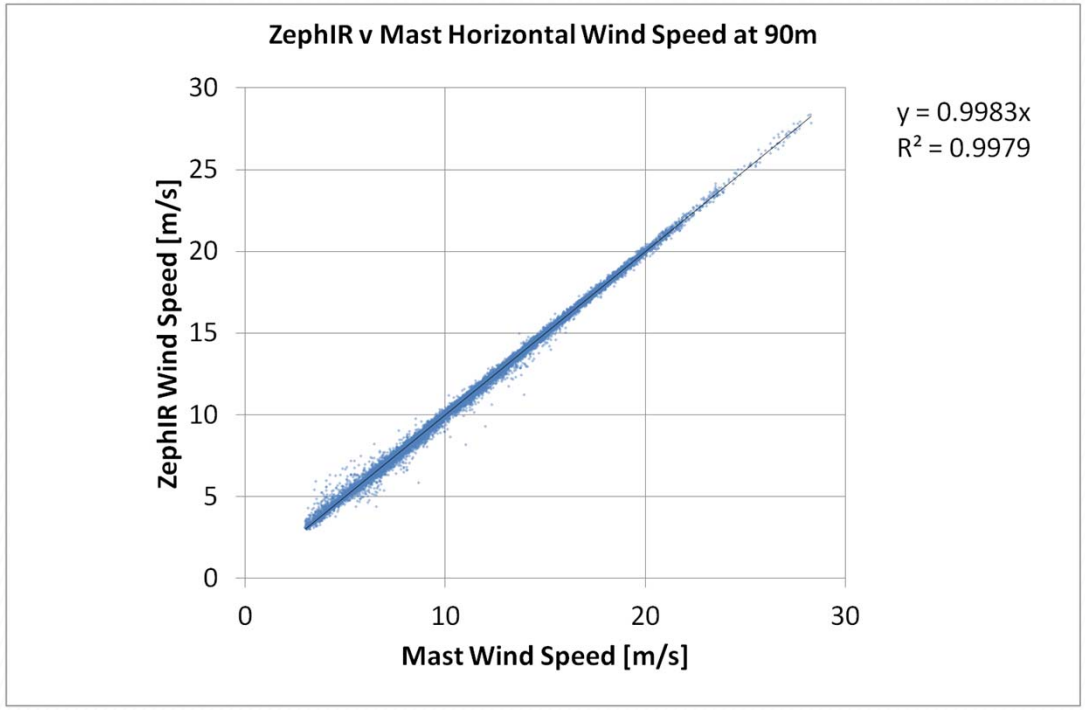
Offshore data availability and accuracy

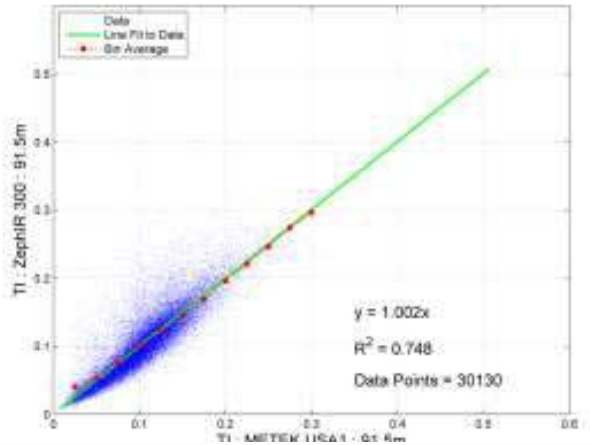
- **Ijmuiden – ECN – NORTH SEA**
- > 6 months continuous data
- ZephIR System Availability = 99.2%
- ZephIR Data Availability = 96%
- Mast data Availability = 91%
- Accuracy: y = 0.9983x
- Correlation: R^2 = 0.998

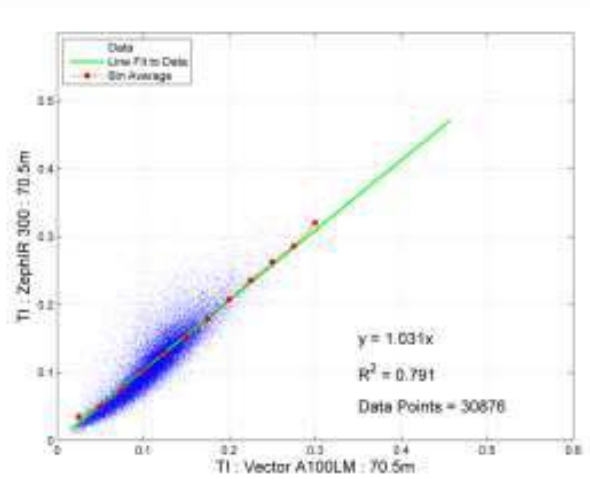


ZephIR Turbulence Measurements

Benign Terrain

- ZephIR 300 TI measurements at the Pershore test site. Over 5,000 hours of data presented at 91.5m and 70.5m.
- ZephIR TI measurements near typical hub height are shown to be in good agreement with traditional anemometry, with regression slopes less than 5% from unity and relatively high R^2 (near 0.75).
- Results in the order of reported accuracy for industry-standard cup anemometry
- Demonstrates the ability of ZephIR to measure TI to an accuracy suitable for use in wind energy applications:
  - Wind farm design
  - Turbine selection





Reference : Barker et al. *Lidar measurements for wind turbine selection studies: design turbulence,* EWEA, 2014

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Summary of ZephIR Benefits Offshore

OFFSHORE:

- ZephIR delivers ‘finance grade/bankable’ wind data offshore
- ZephIR offers a reduced cost solution for offshore wind data
- ZephIR is flexible; deployable on fixed or floating platforms
- ZephIR reduces risks – financial, data uncertainty and H&S
- ZephIR increases the return on investment

- ZephIR induces zero ‘flow distortion’ due to there being no infrastructure at or near measurement height
- ZephIR enables accurate measurement of wind resource and shear profiles across ranges between 10m and 200m above platform height
- Extensive proven accuracy and confidence of ZephIR onshore measured wind resource is maintained offshore due to the benign wind flow conditions

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