Using the NORSEWInD lidar array for observing hub-height winds in the North Sea

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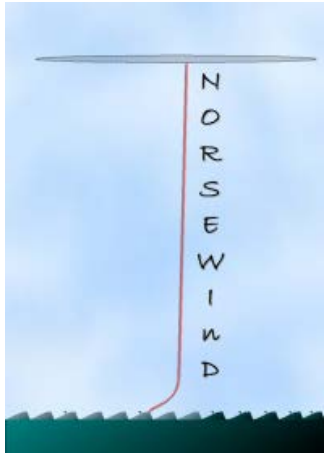


Trondheim, 22 - 24 January 2014

NORSEWInD in brief

Northern Seas Wind Index database project (2008-2012)

Coordination of Oldbaum Services for a consortium of 20 partners.

The budget of €7.9 million with €3.9million from EC FP7.

Offshore wind development is becoming increasingly expensive as developers move to deeper waters. Recent met masts have demanded prices upwards of €15million.

Motivation for alternatives: LIDARs on platforms.

LIDAR data has been acquired, collated, quality controlled and analysed.

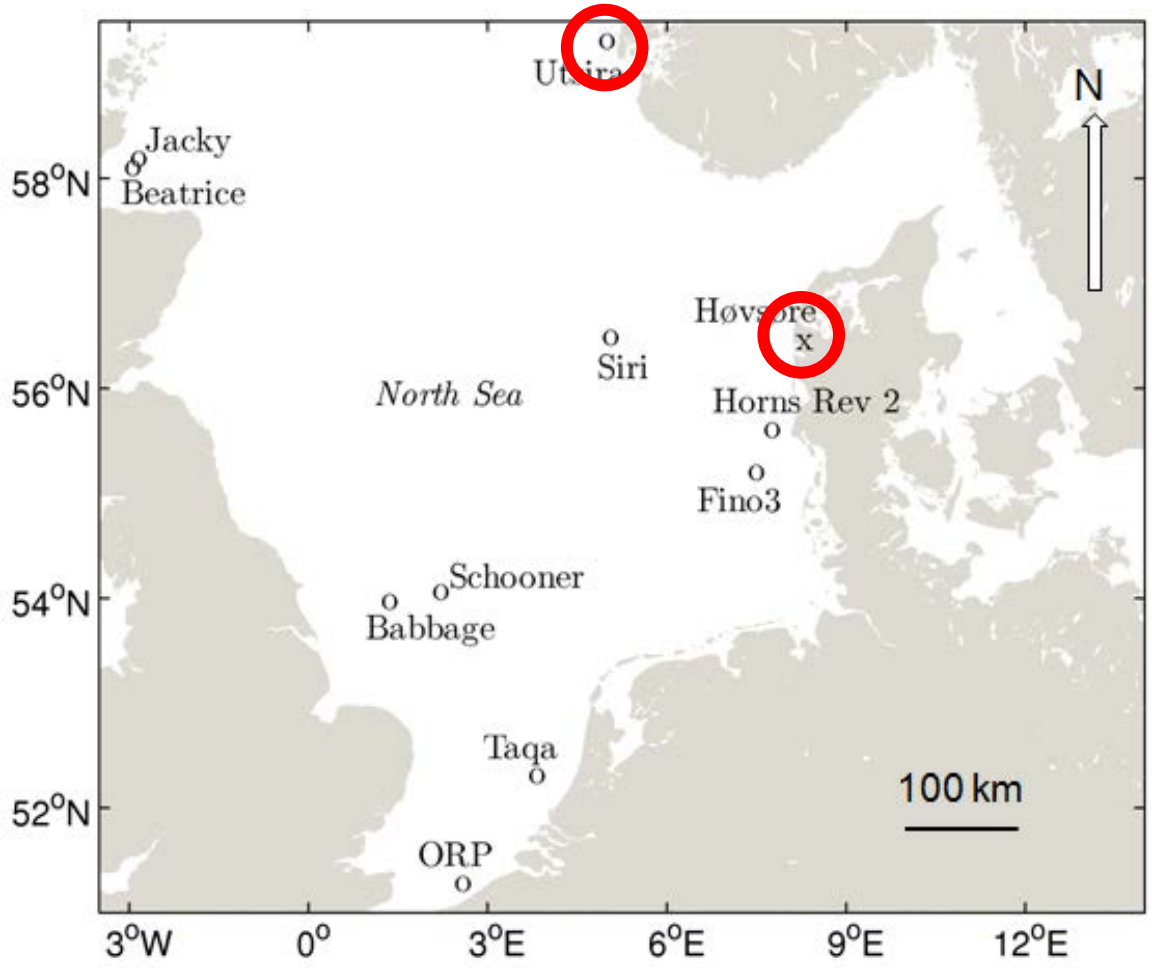
This represents the largest single purpose wind LIDAR dataset in the industry worldwide.

NORSEWInD provides offshore wind atlases of the North, Irish and Baltic Seas based on mesoscale modelling and satellite images.

Content

- Study area
- Pre deployment lidar tests
- Deployment of lidars at offshore platforms
- Post deployment lidar tests
- Flow distortion at platforms
- Selected results
- Summary

Measurement locations in the North Sea

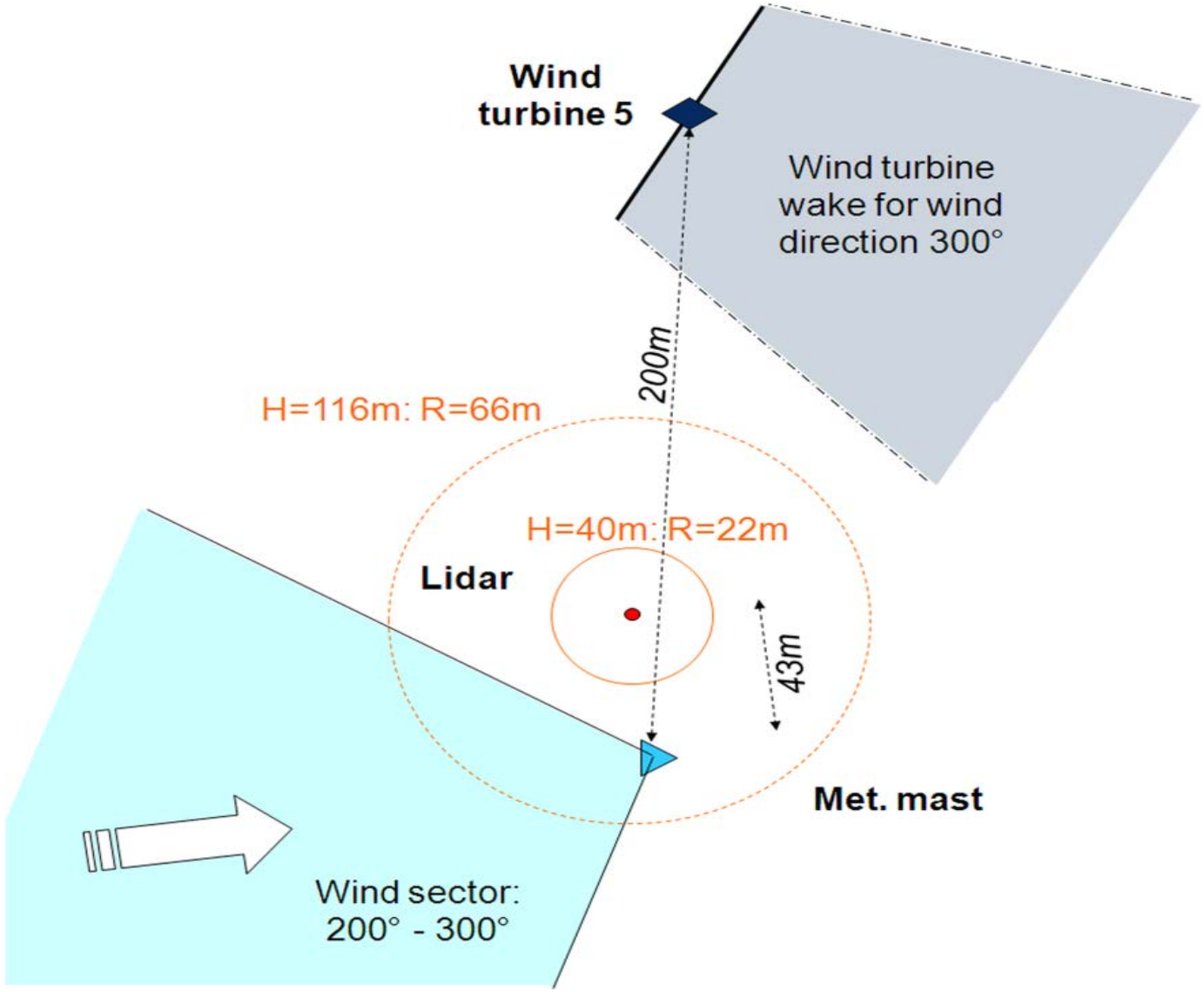


In collaboration with industries:

DONG energy
Statoil Hydro ASA
TAQA
Shell UK
Talisman Energy
Kinsale Energy
SSE
3E
Scottish Enterprise
Scottish and Southern Renewables

Pre and post deployment lidar tests at Høvsøre

Høvsøre illustration of set up



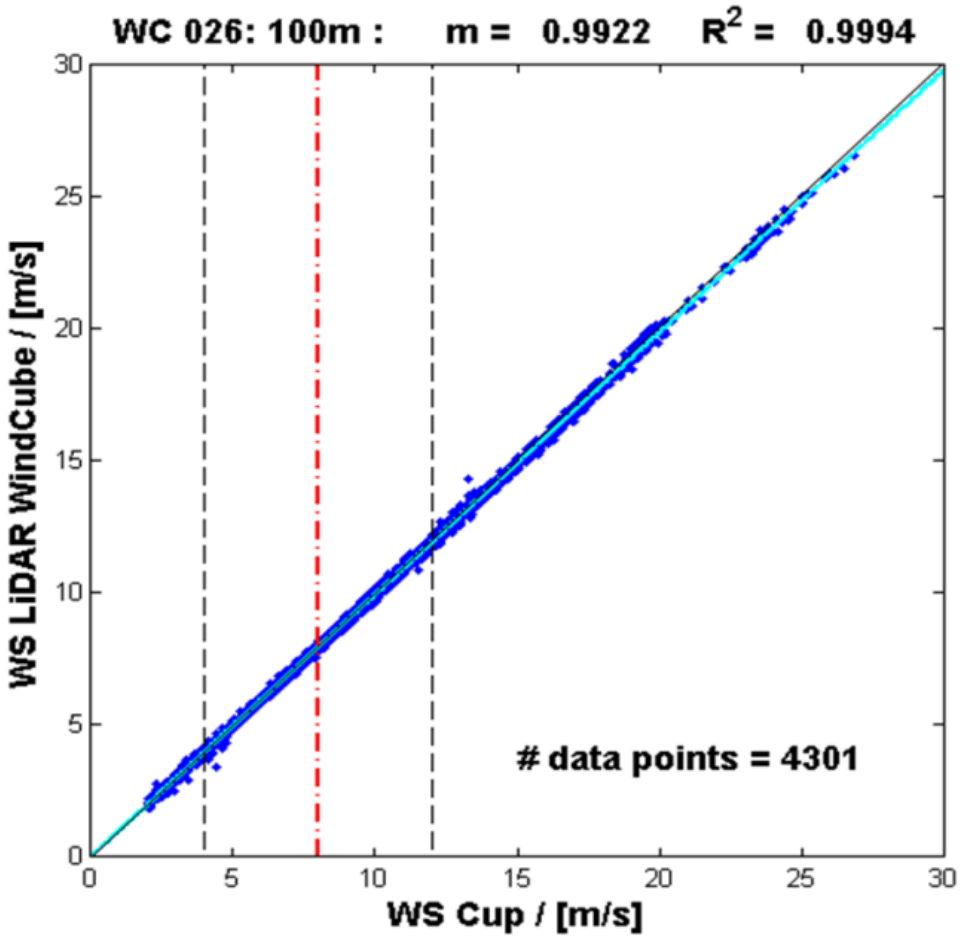
“NORSEWInD standard”

Data quality acceptance levels for NORSEWInD lidar systems. *u* stands for wind speed.

Parameter	Criteria	Ranges (Height and Speed)
Absolute error	<0.5 ms^{-1} for $2 < u < 16$ ms^{-1} Within 5% above 16 ms^{-1} Not more than 10% of data to exceed those values	All valid data
Data availability	Assessed case by case Environmental conditions dependency	All valid data
Linear regression Slope	Slope between 0.98 and 1.01 <0.015 variation in slope between u-ranges (b) and (c)	Heights from 60 to 116 m u-ranges: (a) 4–16 ms^{-1}, (b) 4–8 ms^{-1}, (c) 8–12 ms^{-1}
Linear regression Correlation coefficent (R^2)	>0.98	Heights from 60 to 116m u-ranges: (a) 4–16 ms^{-1}, (b) 4–8 ms^{-1}, (c) 8–12 ms^{-1}

Measurement wind speed at cup vs. lidar

The vertical lines indicate the 4, 8 and 12 ms^{-1} levels.



Pre-deployment test results

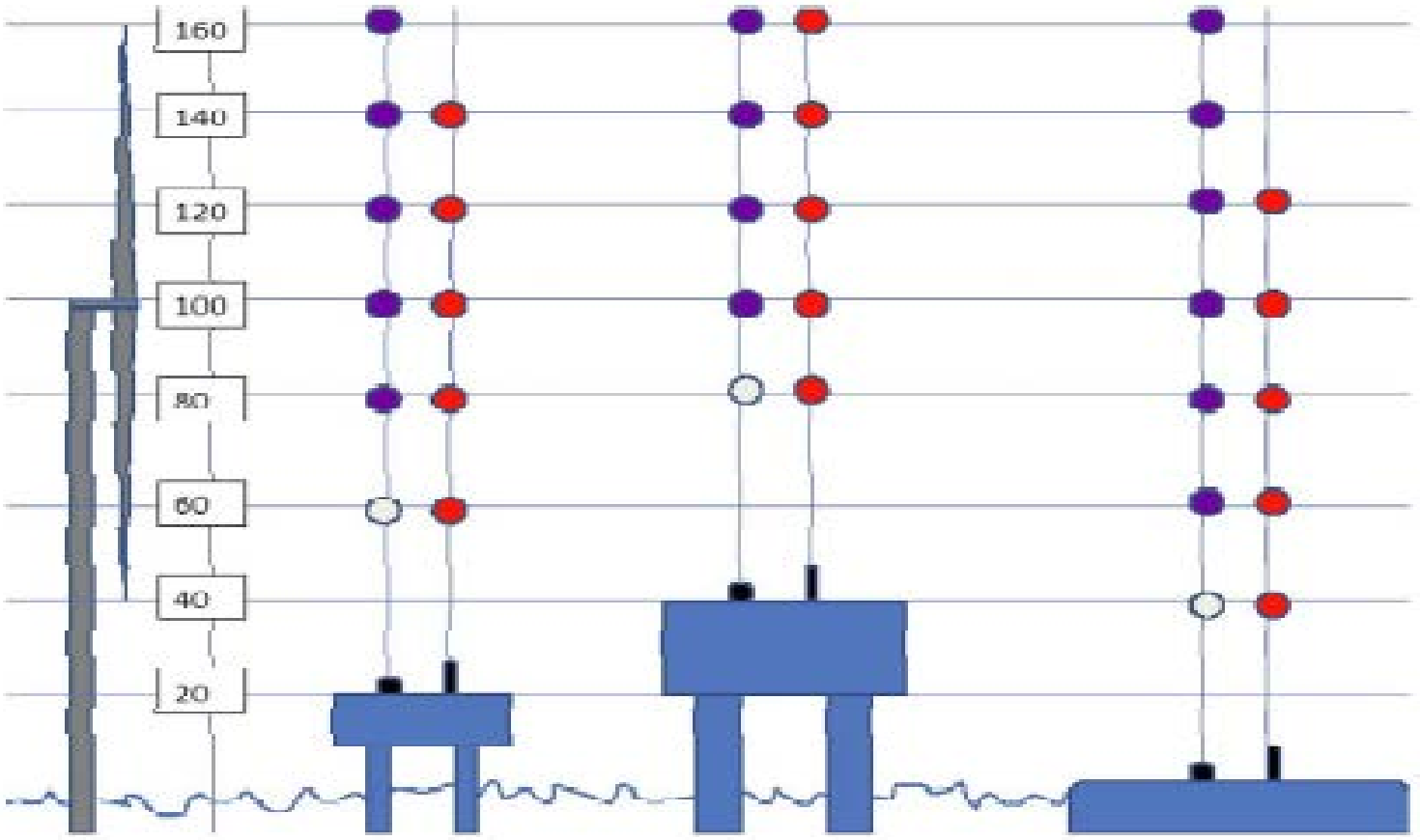
Linear correlation slope and R^2 for the wind speeds in the range from 4 to 16 ms^{-1} at four heights.

Lidar	Slope at 116 m 100 m 80 m 60 m	R^2 at 116 m 100 m 80 m 60 m
1	0,991 0,976 0,977 0,948	0,999 0,976 0,974 0,915
2	0,988 0,992 0,991 0,993	0,999 0,999 0,998 0,998
3	0,993 0,997 0,997 1,000	0,998 0,998 0,998 0,997
4	0,996 0,999 0,998 0,998	0,999 0,999 0,999 0,998
5	0,985 0,993 0,992 0,993	0,999 0,998 0,998 0,997
6	0,983 0,986 0,986 0,990	0,996 0,996 0,996 0,995
7	0,978 0,983 0,984 0,992	0,994 0,994 0,995 0,995
8	0,976 0,980 0,977 0,989	0,995 0,996 0,996 0,995

Lidars 1-5 are WindCube and 6-8 are ZephIR

Offshore platforms used for deployment

Offshore installation schematic rig / platform



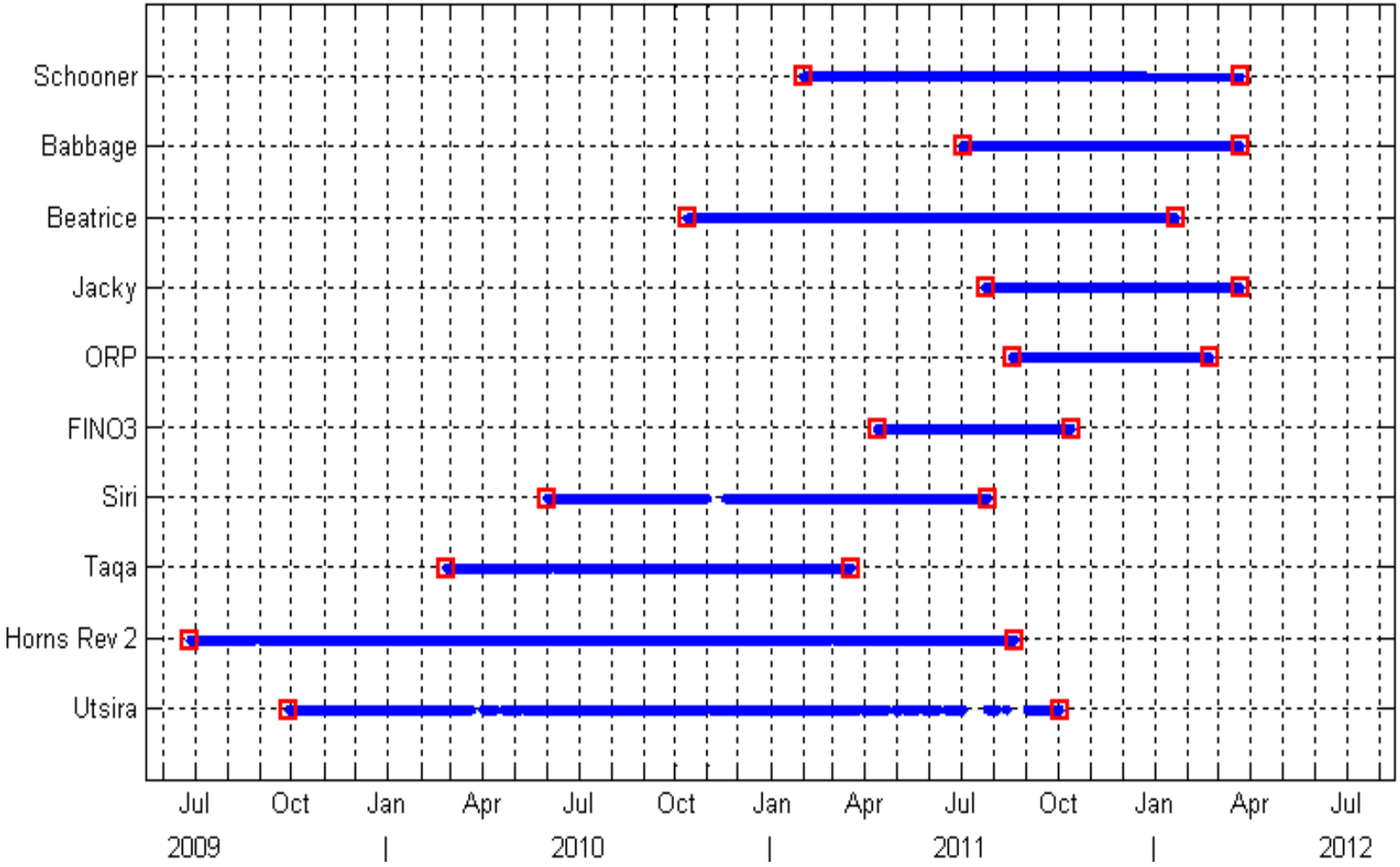
Red dots ZephIR, Blue dots WindCube

Offshore measurement heights

The lidar deployment height and observational heights are listed in meter above mean sea level. WC is WindCube, ZP is ZephIR.

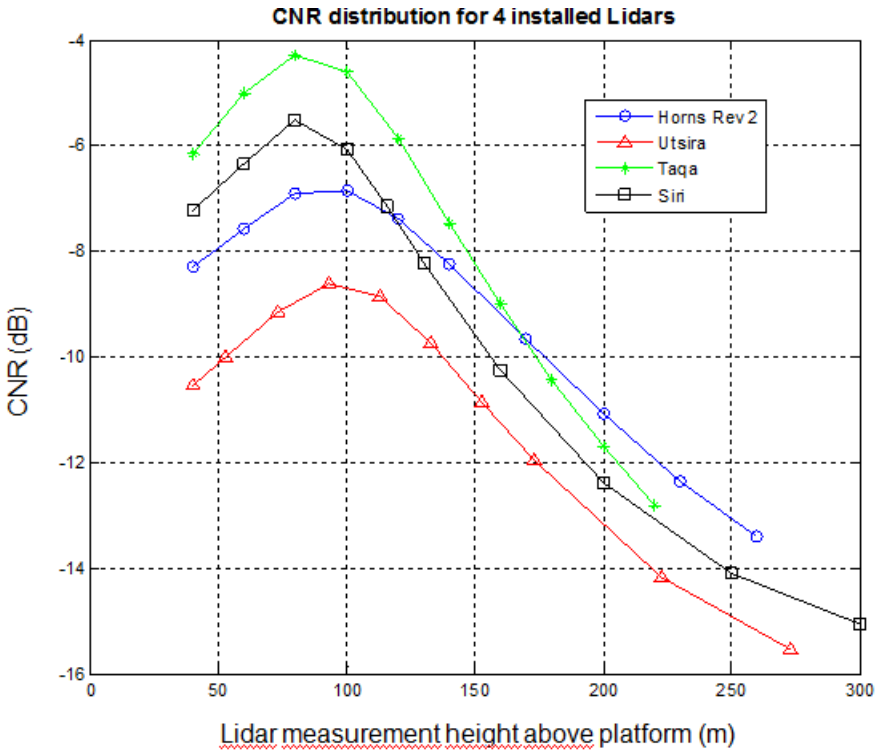
Platform	Babbage	Beatrice	Fino3	HornsRev2	Jacky	ORP	Schooner	Siri	Taqa	Utsira
Lidar type	ZP	ZP	ZP	WC	WC	WC	WC	WC	WC	WC
Height	42	42.5	26	26	28	30	36	45	30	26
1	60	52.5	51	66	60	70	76	85	70	67
2	80	75.5	71	86	80	90	92	*105*	90	80
3	*100*	90.5	91	*106*	*100*	*110*	*99*	125	*110*	*100*
4	130	*105.5*	*101*	126	116	130	102	145	130	120
5	160		130	146	130	150	107	161	150	140
6			160	166	160	170	116	175	170	160
7				196	200	190	126	205	190	180
8				226	250	210	152	245	210	200
9				256	300	230	182	295	230	250
10				286			216	345	250	300

Offshore measurement periods

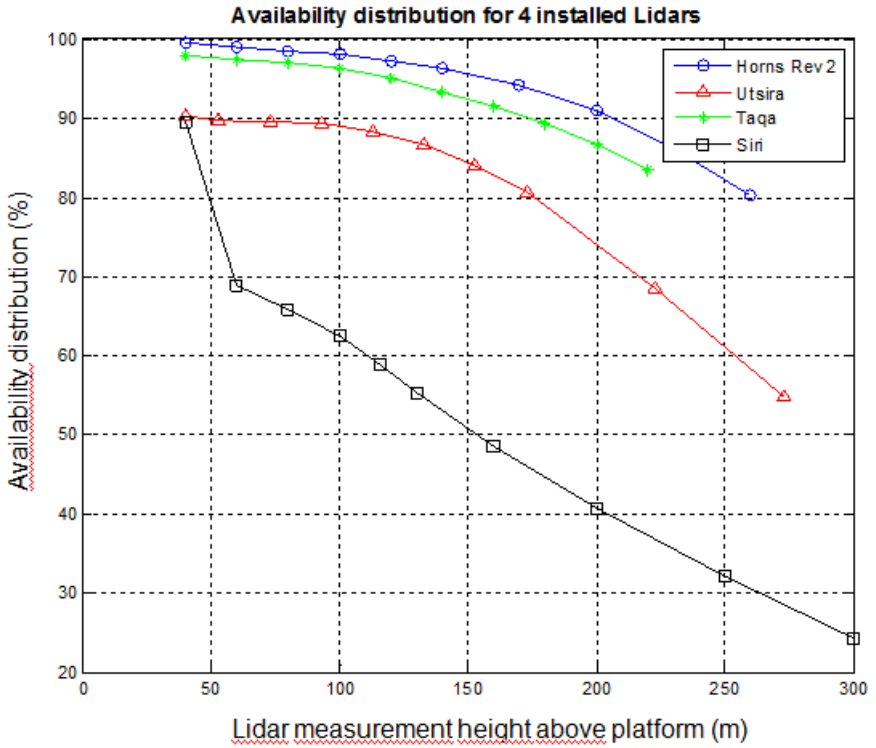


CNR and data availability offshore

The carrier-to-noise ratio (CNR) as a function of observations height above installation.



The average data availability as a function of observations height above installation.



Data availability

System and data availability in % and hours are listed during the offshore deployment. The values are for observations at around 100 m AMSL.

Lidar	System Availability in %	Operational Hours	Data Availability in %	Data Hours
Utsira	85	14,995	81	12,075
Horns Rev 2	98	18,433	98	18,019
Taqa	99	9120	97	8870
Siri	95	9585	85	8178
Fino3	98	4304	88	3778
ORP	100	792	73	581
Jacky	97	5622	93	5228
Beatrice	86	9597	85	8154
Babbage	99	6255	97	6070
Schooner	86	8583	76	6538
Total		87,286		77,491

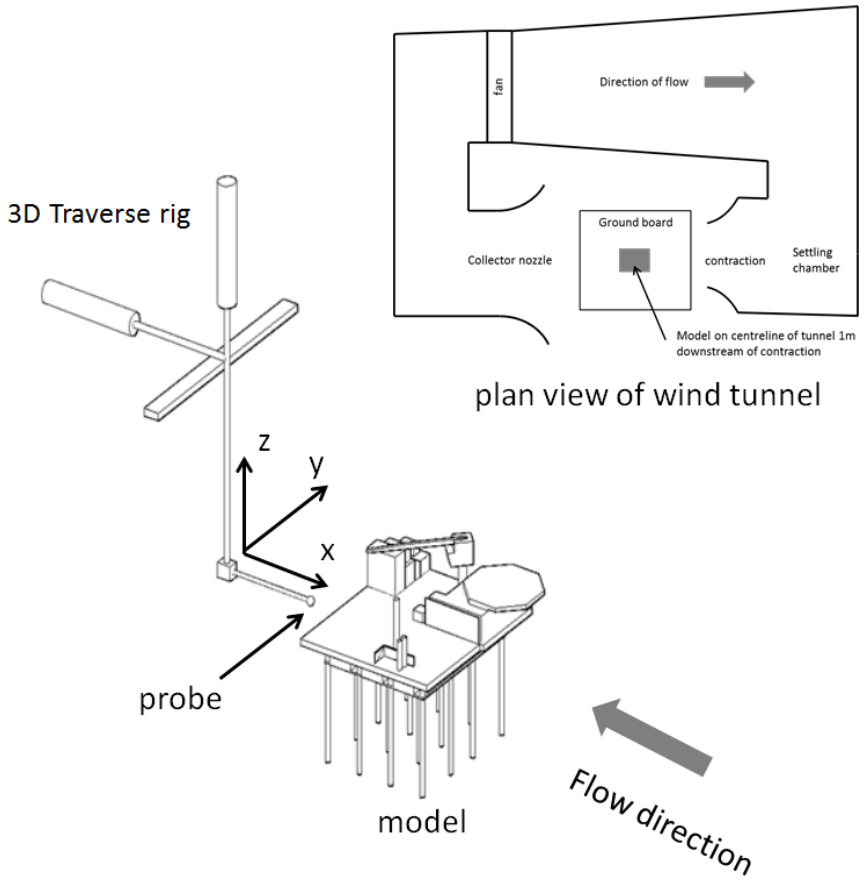
Around 12 years data in total

Post deployment test results

Linear correlation slope and R^2 for the wind speeds in the range from 4 to 16 ms^{-1} at four heights.

Lidar	Time	Slope at 116 m 100 m 80 m 60 m	R^2 at 116 m 100 m 80 m 60 m	N
	Pre	0,988 0,992 0,991 0,993	0,999 0,999 0,998 0,998	3,606
2	Post	0,991 0,997 0,993 0,992	0,999 0,998 0,998 0,997	3,659
	Diff.	0,003 0,005 0,002 −0,001	0,000 −0,001 0,000 −0,001	-
	Pre	0,996 0,999 0,998 0,998	0,999 0,999 0,999 0,998	5,065
4	Post	0,989 0,994 0,989 0,999	0,998 0,998 0,998 0,997	3,510
	Diff.	−0,007 −0,005 −0,009 0,001	−0,001 −0,001 −0,001 −0,001	-
	Pre	0,985 0,993 0,992 0,993	0,999 0,998 0,998 0,997	991
5	Post	0,983 0,987 0,984 0,992	0,999 0,999 0,998 0,998	2,791
	Diff.	−0,002 −0,005 −0,008 −0,001	0,000 0,000 0,001 0,001	-
	Pre	0,976 0,980 0,977 0,989	0,995 0,996 0,996 0,995	1,547
8	Post	0,960 0,971 0,970 0,979	0,993 0,994 0,995 0,995	1,206
	Diff.	−0,016 −0,009 −0,007 −0,010	−0,002 −0,002 −0,001 0,000	-

Flow distortion analysis for rigs / platforms



Wind tunnel experiments

CFD modelling

Wind tunnel and CFD results

Platform	Rign Height (m)	Lidarm Height (m)	Height above Lidar in m (Height Normalized by Rig Height)					Height AMSL for 2.5% Free-Stream	
			Wind Tunnel	CFD Results				CFD Results	
			Point	Point		Lidar		Lidar	
			u	u	θ	u	θ	u	θ
Babbage	42	42	33 (0.8)					75	
Beatrice	62	42.5	64 (1.0)	30 (0.5)	>64 (1.0)	34 (0.5)	59.5(1.0)	76.5	102
HornRev 2	26	26	30 (1.2)	44 (1.7)	57 (2.2)	25 (1.0)	55 (2.1)	50	80
Jacky	28	28		20 (0.7)	19 (0.7)	10 (0.4)	18 (0.6)	38	46
Schooner	38	36.25	24 (0.6)	24 (0.6)	35 (0.9)	9 (0.2)	24 (0.6)	39	54
Taqa	31.4	30	37 (1.2)	30 (1.0)	36 (1.1)	33 (1.1)	27 (0.9)	63	57
Utsira	26	26		108 (4.2)	192 (7.4)	150 (5.8)	300 (11.5)	176	326

Selected results from lidar observations

All NORSEWInD wind lidars were able to observe winds at 100 m and higher. Most of them were pulsed lidars (WindCubes). For those the availability of data decreases with height.

In order to maximize the amount of data we decided to estimate the wind shear from the two closest wind speed observations to the 100 m height.

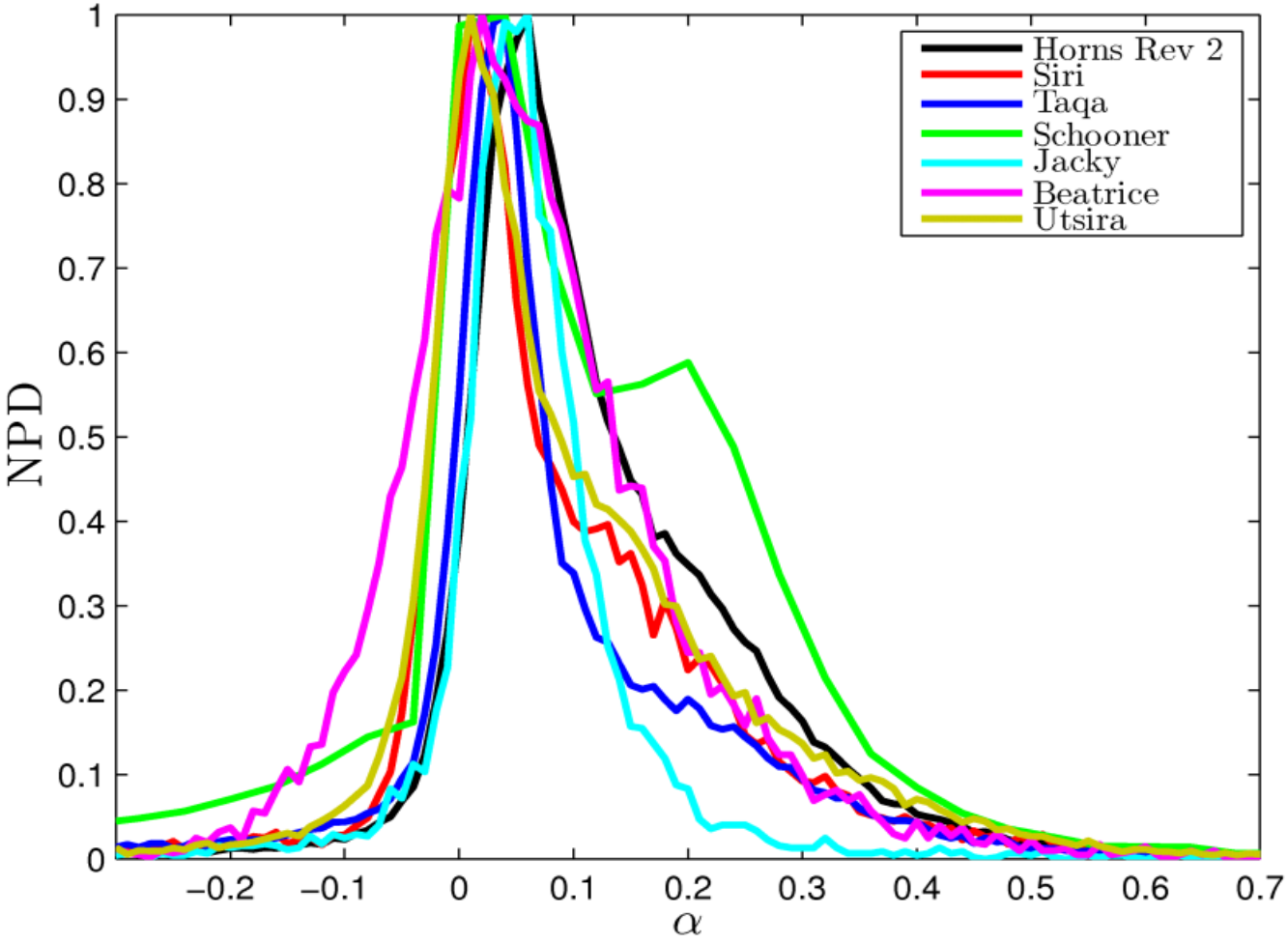
Wind shear (shear exponent α of the power law)

$$\frac{u_1}{u_2} = \left(\frac{z_1}{z_2}\right)^{\alpha}$$

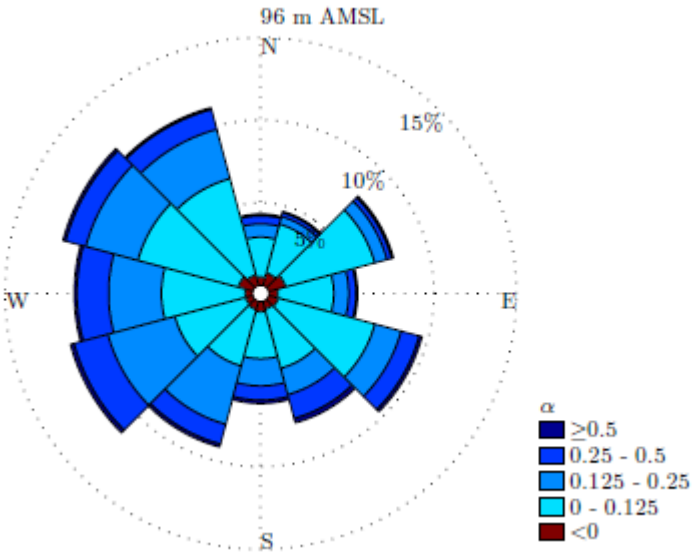
$$\alpha = \frac{z}{u}\left(\frac{du}{dz}\right) \approx \frac{z}{u}\left(\frac{\Delta u}{\Delta z}\right)$$

$$\alpha = \frac{\Phi_m}{\ln\left(\frac{z}{z_0}\right) - \psi_m}$$

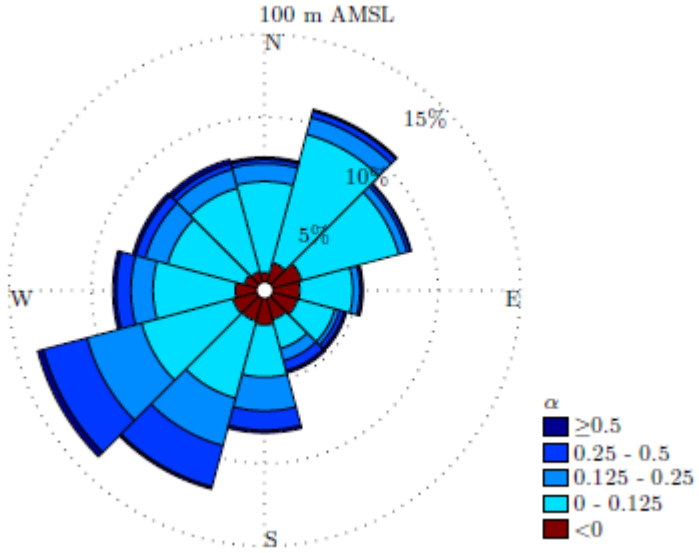
Normalized distribution of α-values around 100m



α-’roses’ at Horns Rev 2 and Taqa around 100m

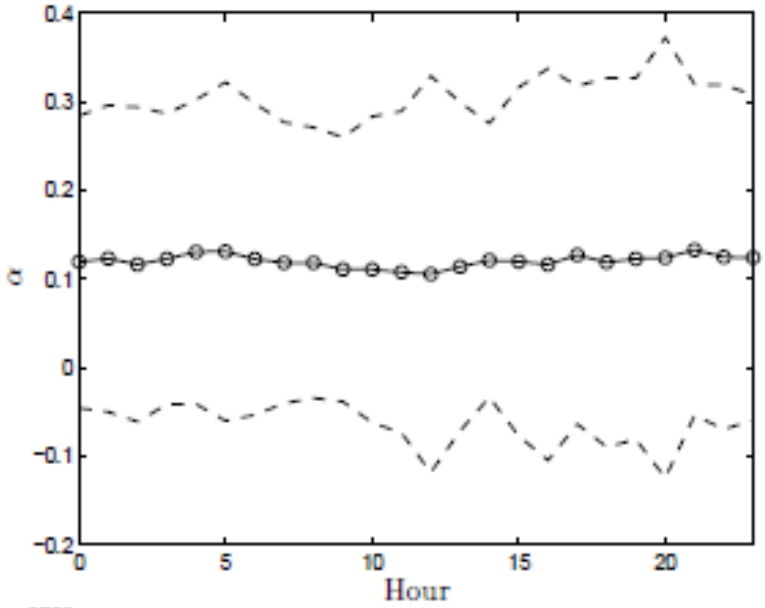


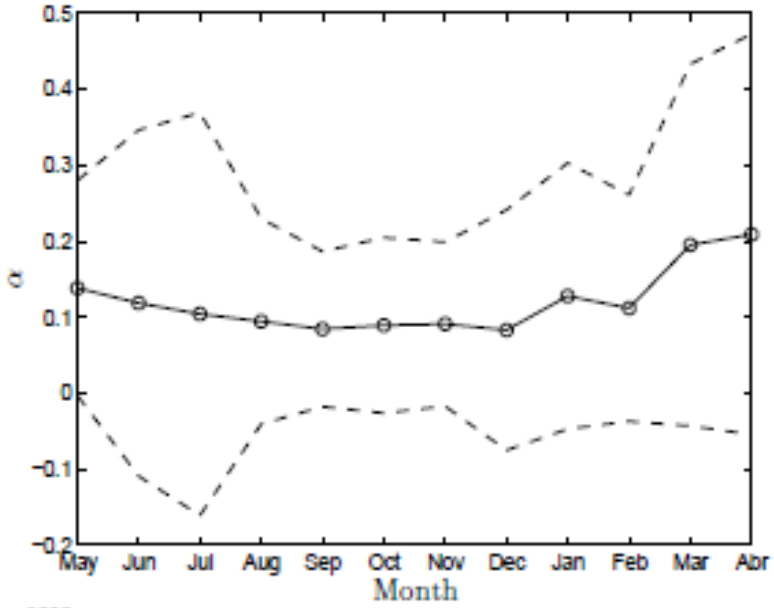
Horns Rev 2

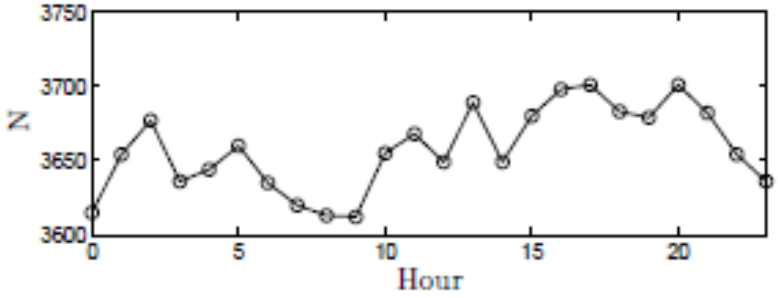


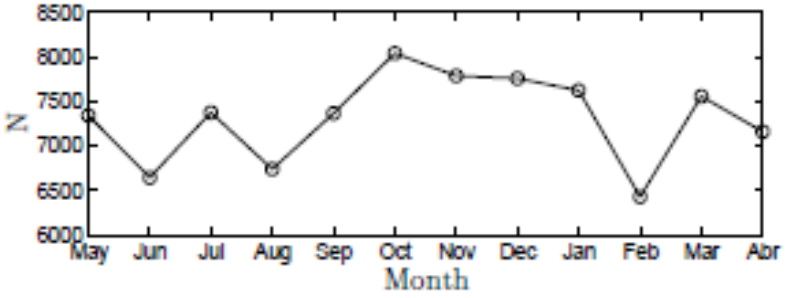
Taqa

α-variation diurnal and seasonal at Horns Rev 2









Summary

- ✓ First comprehensive project to demonstrate use of lidars offshore
- ✓ Pre and post deployment results were relatively good

--- notice this was for more than two years of observations offshore

- ✓ System availability was acceptable
- ✓ Further development in lidars since 2008 – this improve data availability and increase system reliability
- ✓ Wind shear data observed near hub-height at several nodes in the North Sea (also analysed from several met masts)
- ✓ Lidar wind data in database are now available for further research
- ✓ Bankable?

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Article

Hub Height Ocean Winds over the North Sea Observed by the NORSEWInD Lidar Array: Measuring Techniques, Quality Control and Data Management

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Abstract: In the North Sea, an array of wind profiling wind lidars were deployed mainly on offshore platforms. The purpose was t
hub height. Eight lidars were validated prior to offshore deployment with observations from cup anemometers at 60, 80, 100 a
mast situated in flat terrain. The so-called "NORSEWInD standard" for comparing lidar and mast wind data includes the crite
regression should lie within 0.98 and 1.01 and the linear correlation coefficient higher than 0.98 for the wind speed range 4–1

Hasager *et al.* 2013, Remote Sensing, open access journal, online

Peña *et al.* 2012, Offshore vertical wind shear, DTU Wind Energy report, online

Database available for research

Contact Andy Oldroyd at Oldbaum Services

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