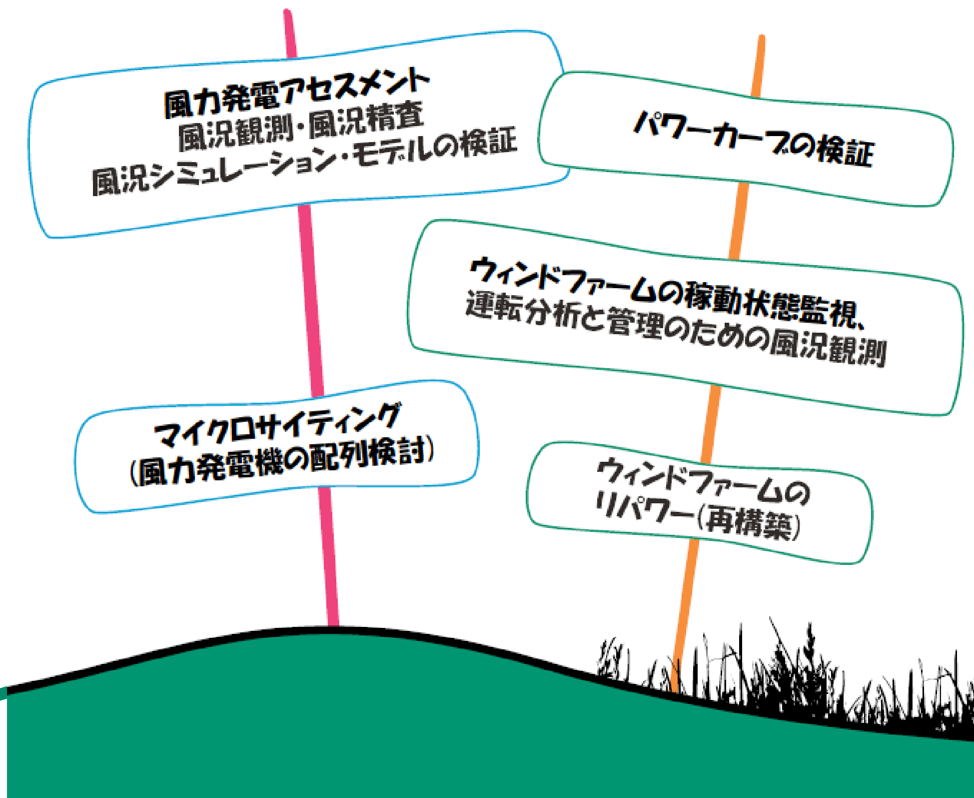
QinetiQ
ZephIR®
（キネティック　ゼフィア）



何がいいのかLIDAR

風力発電事業の計画に正確な発電電力予測が必要不可欠であることは言うに及びません。事業サイト全域にわたり風力発電機の最高高度まで、くまなく正確に計測できるほど、予測の精度は高くなります。このように観測密度を上げるためには、風況観測タワーの設置だけで済ますには限界があります。数多くの風況観測タワーの設置には時間も手間もかかり経済的ではありません。

ZephIR（ゼフィア）は地上に設置します。観測タワーは立てません。200mの観測高度まで、任意の高度の風速の水平及び垂直成分、風向および乱流強度を1秒間に50点のハイスピードで正確にレーザー光で観測します。

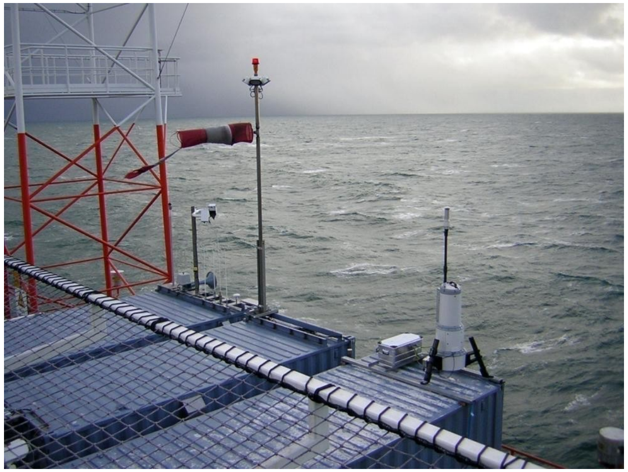
ZephIRは惑星探査機を思わせる全天候型の全自動ハイテク容器に納まっています。厳しい気象条件に晒される準備が最初から整っています。

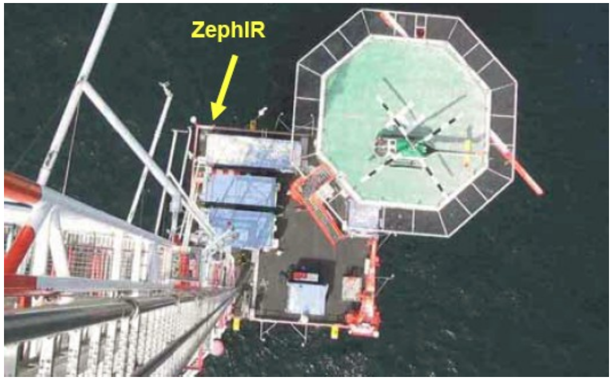
人力で持ち運びが可能な機動性と簡単な設置方そして高密度の観測によりサイトの精密な風況観測が可能となりました。

ニュージーランド

【陸上設置例】

ボスニア（複雑地形でSODARとの比較実験）





Fino 1 – 北海沖 Offshore certification

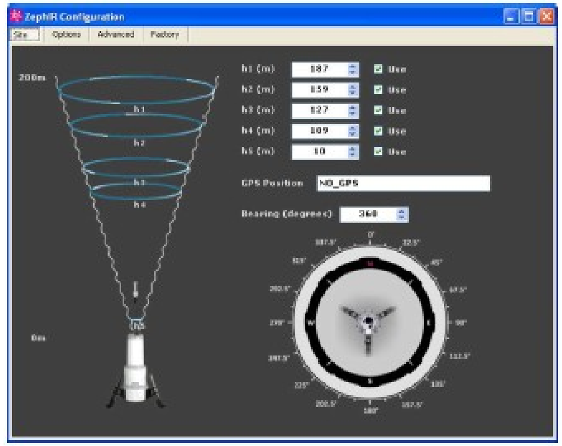
カナダ西海岸洋上ファームF/S

【洋上設置例】

【計測と記録】

水平風速Horizontal wind speed (m/s)
鉛直風速Vertical wind speed (m/s)
Spatial Variation(無次元)
風向Wind direction (degrees)
分散Variance((m/s)2)
気温Air temperature (C)
大気圧Air pressure (hPa)
湿度Humidity (%)
最小風速Minimum gust
最大風速Maximum gust

Points in fit
Height (m)
Status Flags
Packets in average



ユーザーインターフェース

2GBフラッシュメモリに記録
・各層3秒間の風況データ(テキスト形式)
・Spectraデータ(3日間分)

ダウンロードの方法
・LANケーブル直接接続
・GSMアナログ接続
・インターネットデジタル接続→取り組み中
・Iridium衛星回線

B	C	D	E	F	G	H	I	J	K	L	M	N
Time and Date	Height (m)	Horizontal Velocity (m/	Vertical Velocity (m/s)	Wind Direction (degre	Turbulence	Min Gust	Max Gust	Variance	Temperature (C)	Pressure (hPa)	Humidity	Status Flags
02/06/08 06:40:00	20	2.19812	-0.012433	50.754875	0.090321	1.5165	3.924836	0.103057	15.5625	1003.5	76.875	Green
02/06/08 06:40:00	100	2.445747	-0.009663	334.693512	0.134161	2.279595	2.597057	0.006989	15.5625	1003.5625	76.875	Green
02/06/08 06:40:00	150	2.534049	-0.017396	342.701843	0.102233	2.27686	2.713784	0.012095	15.5625	1003.5625	76.75	Green
02/06/08 06:50:00	20	2.373992	0.025782	95.010902	0.143388	2.122059	3.358332	0.060823	15.875	1003.8125	74.625	Green
02/06/08 06:50:00	100	2.49433	0.000501	146.141846	0.089624	2.368266	2.6677	0.008685	15.875	1003.8125	74.625	Green
02/06/08 06:50:00	150	2.64638	-0.000442	149.78862	0.107171	2.5216	2.815485	0.005819	15.875	1003.8125	74.75	Green
02/06/08 07:00:00	20	2.26575	-0.02452	3.381678	0.125547	0.136815	2.879259	0.110551	15.875	1003.8125	73.75	Green
02/06/08 07:00:00	100	2.63957	0.008862	313.563812	0.135788	2.43287	2.787472	0.007489	15.875	1003.875	73.75	Green
02/06/08 07:00:00	150	2.72606	0.007577	184.708633	0.123559	2.556745	2.906385	0.008029	15.875	1003.875	73.875	Green

【気象の影響】

雨と雪の影響

雨雪粒の鉛直運動は鉛直風速の観測に影響する
。

→鉛直風速の観測からは除外

同水平成分は水平風速の観測に使える。

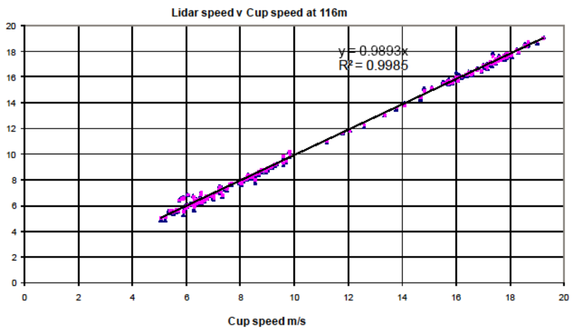
→水平風速の観測には算入

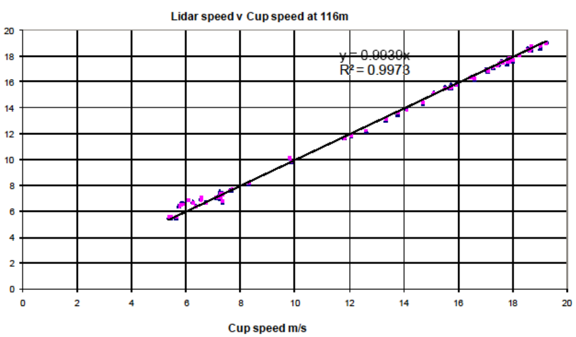
Risoe 116m観測タワーカップ風速計との比較検証

水平風速10分平均値

上　全データ

下　雨中のデータのみ抽出





雲の影響

雲からのレーザー反射が強いため、観測層の正確な風速を得るためには雲からの反射光を検出する必要あり。

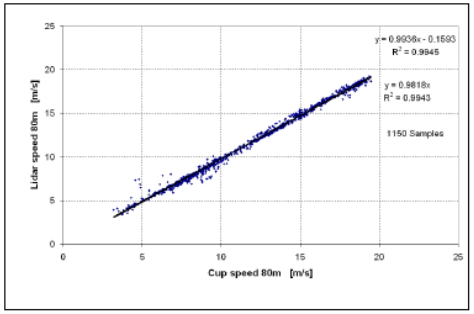
→Cloud detection アルゴリズムでフィルター

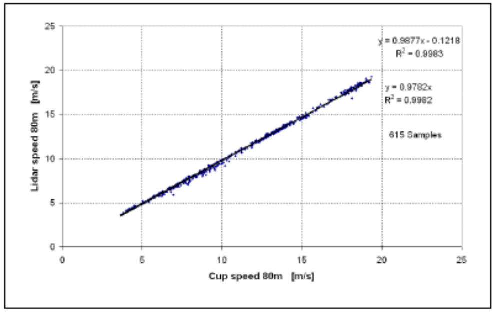
Risoe での80m高さでのフィルター検証

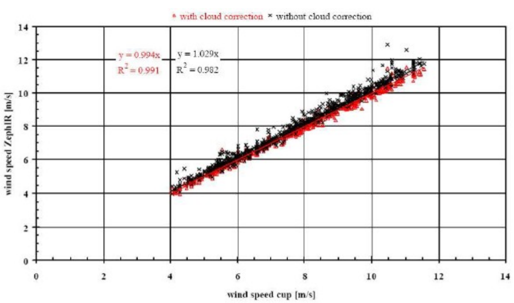
左　フィルターなし

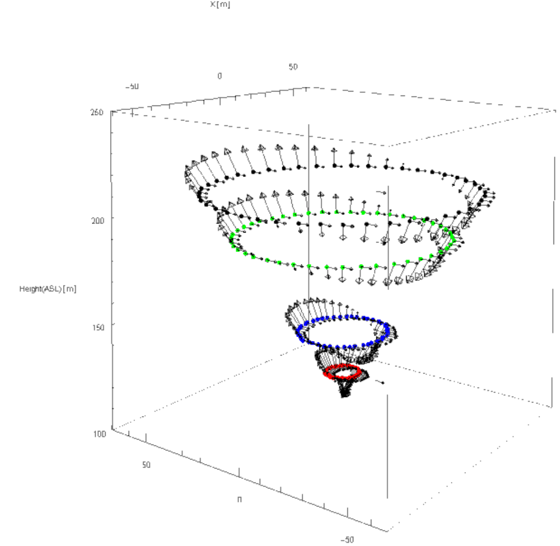
右　フィルターあり

傾きに0.3%の差が発生









【地形の影響】

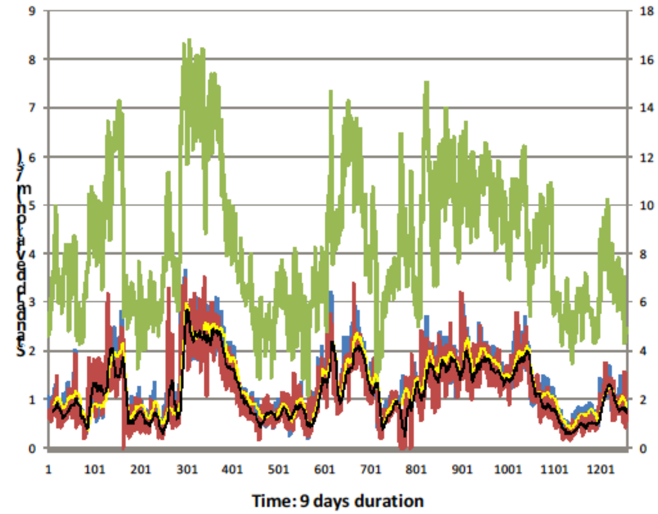
→乱流計測 複雑地形の影響評価

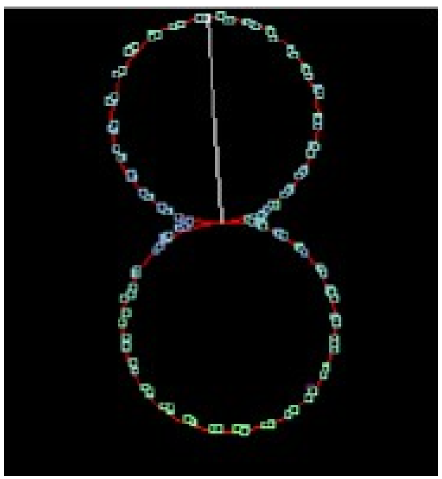
2つの乱流要素の記録

- **乱流強度TI**
  カップ式風速観測同様の乱流強度

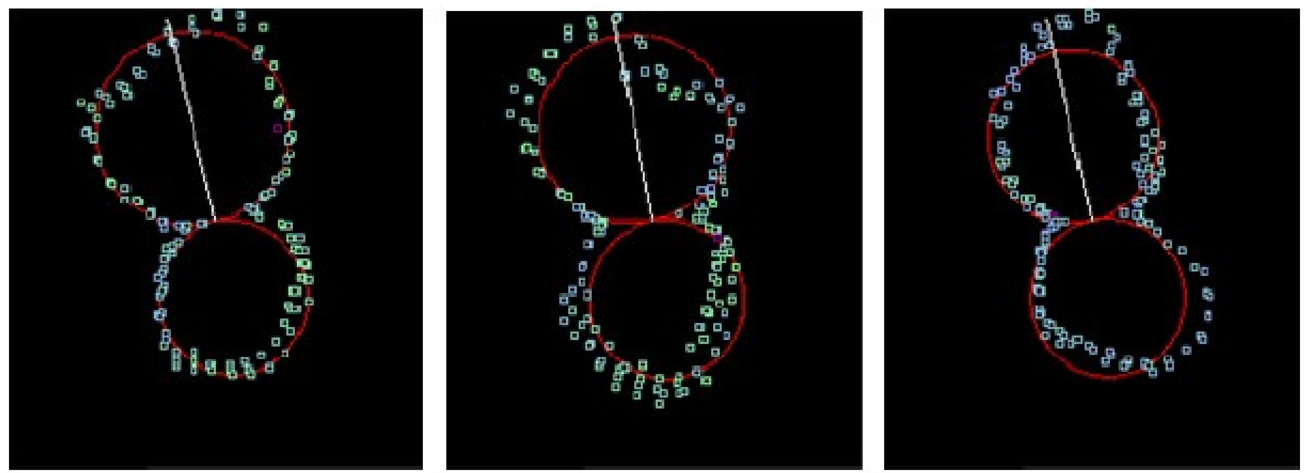
例）9日間のグラフ at 50m高
青cup／赤ZephIR　10分標準偏差
黄cup／黒ZephIR　2時間平均標準偏差
緑は水平風速ZephIR

② **Spatial Variation（カップにはできない）**
観測各層円周上のスキャン中の乱れ





均一流



地上100m高での乱流の例

turbulent kinetic energy (TKE)=乱流運動エネルギーとの関連

Turbulence Intensity = SQRT(TKE)/U
Where:　U is the mean wind speed (m/s)
　　　　TKE is the Total Kinetic Energy
So, in short: “Spatial Variation” ≈ 0.65 SQRT (TKE)/U

インター・ドメイン株式会社

2009/03/10

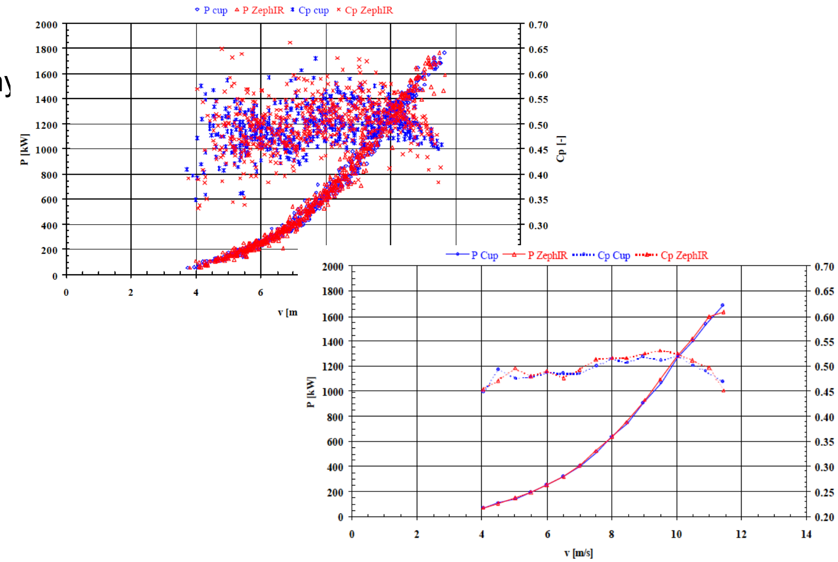
【評価報告】65mマストWestdorf & 124mマスト Emden, Germany

Evaluation of ZephIR

Report: PWG 06005, Evaluation of ZephIR

1 Introduction

ZephIR is a new laser based device for wind measurements in the lower atmosphere. The device has been developed by the British company QinetiQ with special intension to the wind energy industry [1]. Deutsche WindGuard is collaborating with QinetiQ in evaluating this new technology. In this frame the ZephIR system is tested by Deutsche WindGuard against conventional wind measurements with mast mounted cup anemometers. This report briefly summarises results of the comparison of ZephIR against measurements with a 65 m high mast and a 124 m high mast as well as Deutsche WindGuards' first practical experience with the system.



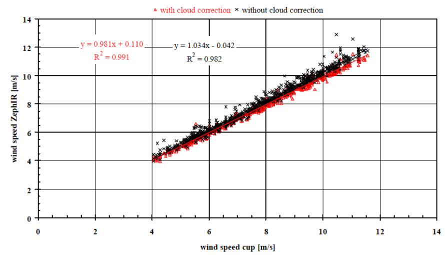
Report: PWG 06005, Evaluation of ZephIR

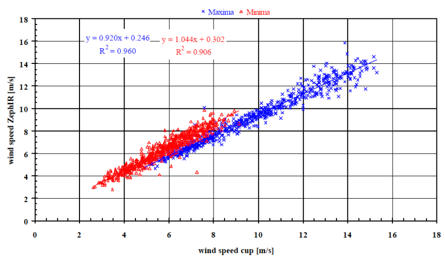
Westdorf 2005/12/20～2006/1/3

観測高度　300m-65m-65m-65m-65m

Figure 1: Photo of the 65 m high met mast and wind turbine of type Enercon E70 E4 in Westdorf. The photo has been taken near to the position of the ZephIR.

Figure 2: Photo of the mast top in Westdorf.





Report: PWG 06005, Evaluation of ZephIR

Emden 2006/1/10～1/28

観測高度

Figure 5: Photo of the 124 m high met mast and wind turbine of type Enercon E112 in Emden. The ZephIR is marked by a blue cross.

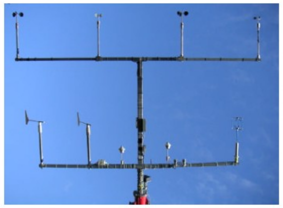
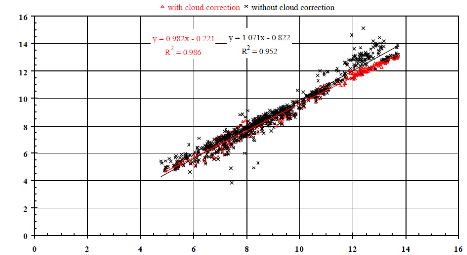
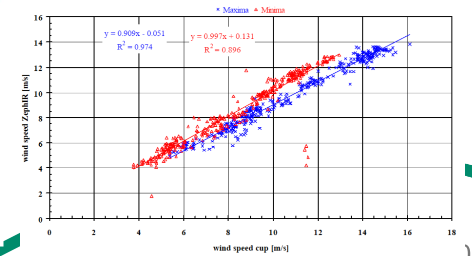


Figure 6: Photo of the mast top in Emden.





【洋上観測】 洋上5ヶ月 German Research Platform FINO-1 located in the German Bight area of the North Sea about 45 kilometres to the North of the German Island Borkum

An 8 month test campaign of the QinetiQ ZephIR system: Preliminary Results

Kindler, Detlef [1], Oldroyd, Andrew [2]*, MacAskill, Allan [3], Finch, Danny [4]
[1] WINDTESTKaiser-Wilhelm-Koog GmBH, Germany, [2] Oldbaum Services , UK, [3] Talisman Energy (UK) Ltd, [4] Scottish & Southern Energy, UK
Email:andy@oldbaumservices.co.uk
*corresponding author

3 The Offshore Test Site

The offshore component was undertaken on the German Research Platform FINO-1 (see figure 2) located in the German Bight area of the North Sea about 45 kilometres to the North of the German Island Borkum (see figure 3). Comparison results are presented as compared to a 80m meteorological mast on the 20m platform, for the top height (103m) and for two lower heights, i.e. 81m and 61m.

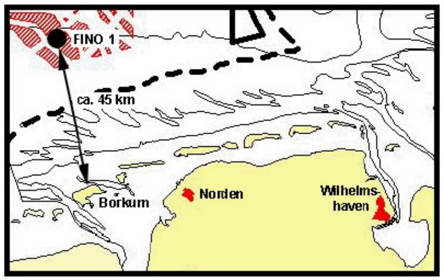


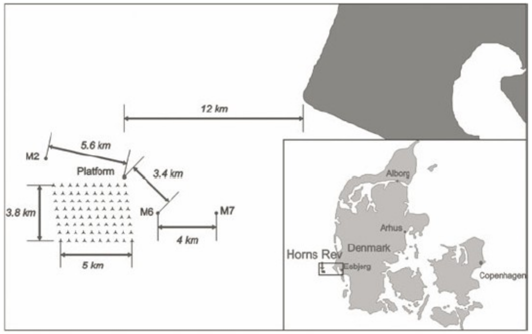
Figure 2: Left, postion of FINO-1 platform in the North Sea. Right, view on the platform during helicopter approach from the North-East.

Meas. Height / [m] AMSL	Sensor				
103 (78)	WS-Cup-1				
91	WS-Cup-2	WD-1	Hum-1	Pres	Rain
81 (56)	WS-Cup-3	WS/WD-USA-1			
71	WS-Cup-4	WD-2	Temp-1		
61 (36)	WS-Cup-5	WS/WD-USA-2			
51	WS-Cup-6	WD-3	Temp-2		
41	WS-Cup-7	WS/WD-USA-3	Temp-3		
33	WS-Cup-8	WD-4	Hum-2		
23	Visibilty				
20	Temp	Rain	Sol.Rad.		

Legend	
AMSL	Above mean sea level
WS-Cup	Wind speed cup anemometer
WS/WD-USA	Wind speed / direction Ultra sonic, 3D
WD	Wind direction, vane
Temp	Temperature
Pres	Air Pressure
Hum	Humidity
Sol.Rad.	Solar Radiation
Visibilty	Visibilty Sensor: range 0 to 16 km
Rain	Precipitation watch

Table 2: Sensor distribution at the FINO-1 meteorological mast. Bold printed heights indicate the comparison levels between anemometers and the ZephIR. Values in parentheses describe the corresponding scan height of the ZephIR.

世界最大の洋上ファームHorns Rev (デンマーク西岸12km沖合・Vestas V80 × 80基)での6ヶ月間観測



WIND ENERGY
Wind Energ. (2008)
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Research Article

Offshore Wind Profiling Using Light Detection and Ranging Measurements

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Charlotte Bay Hasager, Sven-Erik Gryning, Michael Courtney, Ioannis Antoniou and Torben Mikkelsen, Wind Energy Department, Risø National Laboratory for Sustainable Energy, Technical University of Denmark, Frederiksborgvej 399, 4000 Roskilde, Denmark

Key words:
LiDAR; offshore; surface layer; wake; wind profiles

The advantages and limitations of the ZephIR®, a continuous-wave, focused light detection and ranging (LiDAR) wind profiler, to observe offshore winds and turbulence characteristics were tested during a 6 month campaign at the transformer/platform of Horns Rev, the world's largest wind farm. The LiDAR system is a ground-based sensing technique which avoids the use of high and costly meteorological masts. Three different inflow conditions

【比較検証】複雑地形 LIDAR vs SODAR ボスニアにおける中程度の複雑地形で、ボーラと呼ばれる北～北東から吹く強風の季節風地帯での風況を観測した。期間：3週間

ANALYSIS OF THE VERTICAL WIND PROFILE AT A BURA-DOMINATED SITE IN BOSNIA BASED ON SODAR AND ZEPHIR LIDAR MEASUREMENTS

Saskia Bourgeois[1], René Cattin[1], Ian Locker[2], Hans Winkelmeier[3]

(1) bourgeois@meteotest.ch, Meteotest, Fabrikstrasse 14, 3012 Bern, Switzerland, Tel. +41 31 307 26 26
(2) The Natural Power Consultants Ltd., Malvern Technology Centre E708, St Andrews Road, Malvern, WR14, U.K.
(3) Verein Energiewerkstatt, Heiligenstatt 24, 5211 Friedburg, Austria

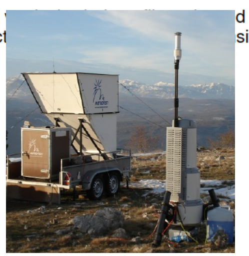
ABSTRACT

Knowledge of the shape of the vertical wind profile is an important issue particularly for site assessments and energy yield calculations. Strong efforts in the remote sensing technology yielded to state of the art wind measuring instruments like SODARs (SOund Detecting And Ranging) and LIDARs (LIght Detecting And Ranging).

This study presents a wind measurement campaign carried out in Bosnia near Mostar where the terrain was medium complex and the winds were known to be some times very strong and turbulent. A special attention was given to the so called Bora wind, a gusty wind from the north north-east. One goal of the study was to examine the performance of an Aerovironment SODAR and a ZephIR LIDAR under these harsh meteorological conditions in complex terrain. A 30 m mast provided cup anemometer data.

Both, the SODAR and the LIDAR showed a very good performance with high data availability up to 100 m above ground. Measured wind speeds and wind directions agreed well with the 30 m mast data. While the deployment and the data processing of the SODAR was more demanding the LIDAR proved to be more user friendly.

The ... d a ...
direct ... sity



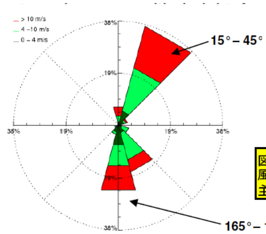


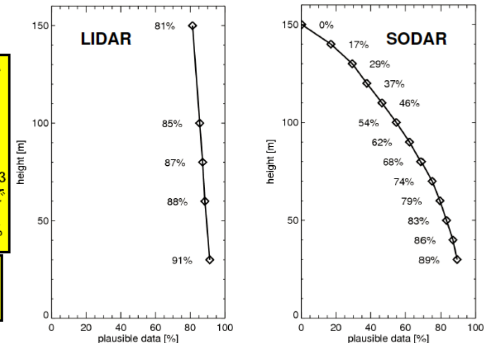
図２
風況マストの高さ30mでの風配図。
主風向は15°-45°と165°-195°

	measurement height of wind speed	measurement height of wind direction	measurement period
30 m mast, cup anemometers: Thies Classic (uncalibrated)	12 m; 30 m	30 m	May 2005 – in course
SODAR (Aerovironment 4000 miniSODAR, ASC)	30 m to 150 m with 10 m resolution	30 m to 150 m with 10 m resolution	30 Oct '07 – 4 Feb '08
LIDAR (ZephIR, Natural Power)	30 m; 60 m; 80 m; 100 m; 150 m	30 m; 60 m; 80 m; 100 m; 150 m	21 Nov '07 – 10 Dec '07

データ回収率の比較

SODARの観測データに入っていた明らかに異常なデータは比較材料から除外したが、LIDARの観測データはすべてこの比較材料に加えられた。LIDARの観測は5層に限られる。高度100mでデータ回収率は85%であった(図3左)。SODARは10m間隔で観測できるが、高度とともに回収率は著しく低下し、高度100mで54%

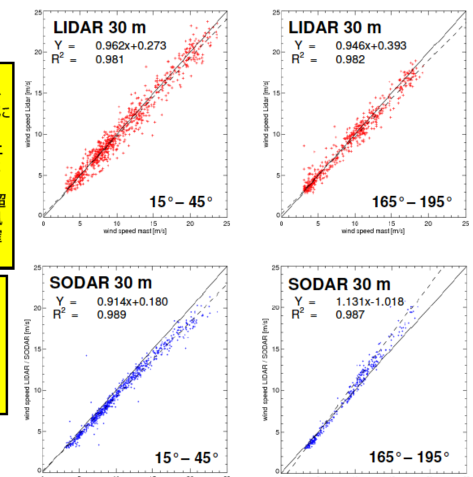
図3
観測高度とデータ回収率の関係
左がLIDAR、右がSODAR

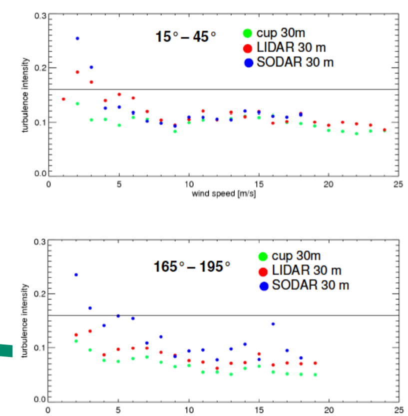


観測風速の比較

図4に高度30mでの観測風速の比較をプロットし、回帰相関係数を示した。データは2つの主風向別に表示した。
LIDARのデータは高度30mから上でよく回収でき、カップ風速計と良好な相関が認められた(図4上)。
SODARのデータは風速15m/sを超えると急激に精度を失い、また風向によってカップ風速計との明確な差異が現れた(図4下)。

図4
高度30mでの風速データ(10分平均)比較プロット
上：LIDARとカップ風速計
下：SODARとカップ風速計
左：風向セクタ15-45°
右：風向セクタ165-195°





乱流強度の比較

図6に示すとおり15°- 45°の風向セクタではカップ風速計とLIDAR、SODARのデータはよく一致する(図6上)。165°-195°では3者ともに乖離が見られ、カップ風速計に対しSODARの方がLIDARより乖離していた。

緑：カップ風速計
赤：LIDAR
青：SODAR

上：風向15°- 45°
下：風向165°-195°

【複雑地形】複雑地形での LIDAR 誤差(bias)を計算で予想し、ギリシャ2つの複雑サイトでのデータと比較。それぞれ100mマスト比較で07.9.19～10.11と54mマスト07.12.1～08.1.15。

Risø DTU
National Laboratory for Sustainable Energy

Modeling conically scanning lidar error in complex terrain with WAsP Engineering

1 Introduction

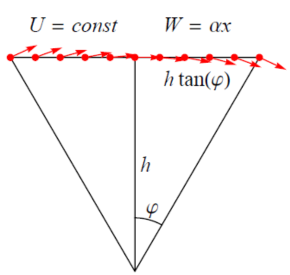
Lidars (light detection and ranging) are becoming an alternative to meteorological masts for vertical profile measurements for the assessment of wind energy potential. They have several advantages over traditional anemometry such as ease of deployment and that large heights can be reached without excessive costs (Emeis, Harris and Banta 2007). They have shown encouraging results reproducing cup anemometer wind speeds within a few percents both on- and off-shore, and several different types of lidars have been investigated thoroughly (Kindler, Oldroyd, Macaskill and Finch 2007, Courtney, Wagner and Lindelöw 2008a).

This success has been limited to flat terrain and it is the purpose of this paper to investigate the performance in mountainous terrain, occasionally called *complex terrain*. Here the the flow is no longer homogenous and that can give a large bias on the horizontal wind speed estimated from the lidar. To illustrate this very simply Figure 1 shows a lidar shooting at an angle φ from vertical upwind and downwind, situated in flow where the horizontal wind speed U is constant, but where the vertical wind speed W changes linearly with the downwind position x. This could crudely mimic the flow over a hill where (in case of $\alpha \equiv dW/dx$ negative) the upstream is tilting upwards and downstream downwards. The projected wind speed on the upwind beam is $v_{up} = -(U + h\alpha)\sin\varphi$ while it is $v_{down} = (U + h\alpha)\sin\varphi$ for the downwind beam. Assuming wrongly horizontal homogeneity, we can calculate the horizontal velocity as estimated from the lidar

$$U_{lidar} = \frac{v_{down} - v_{up}}{2\sin\varphi} = U + h\alpha \qquad (1)$$

and we see in the case of negative α that the horizontal wind is *underestimated*.

One remarkable fact seen from (1) is that the underestimation is not diminished as φ tends to zero. In other words, reducing φ will not reduce the bias on the horizontal velocity. It is a simple exercise (see section 2), to show that the same is true for a more realistic setting, where the horizontal wind is obtained from a conical scan in an arbitrary linear flow: $U_i(\mathbf{x}) = U_i(\mathbf{0}) + x_j \partial U_i/\partial x_j$.



LIDARはスキャンする範囲が均一なフローであるとして風速を出している。従い均一ではない場合はbias誤差が発生する。図のような山頂付近のうえに湾曲するモデルでは水平風速の過小評価となる。注意すべきは、単純なモデルで表わせる不均一フローで水平風速はスキャンの角度に関係ないということ。鉛直風速の誤差は角度が狭まるとゼロに近づく。

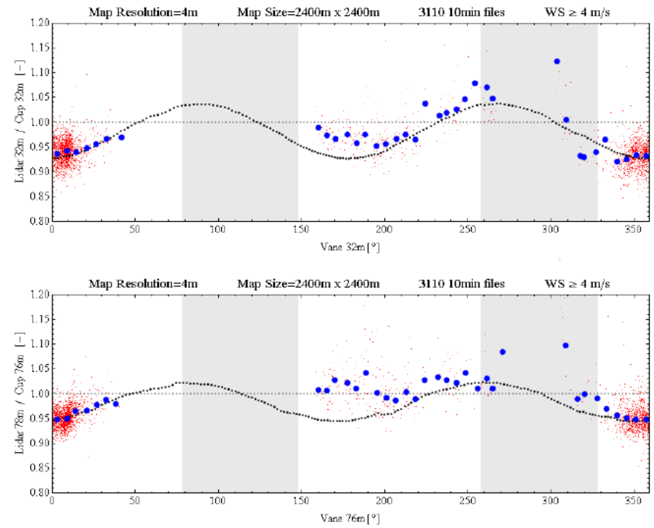
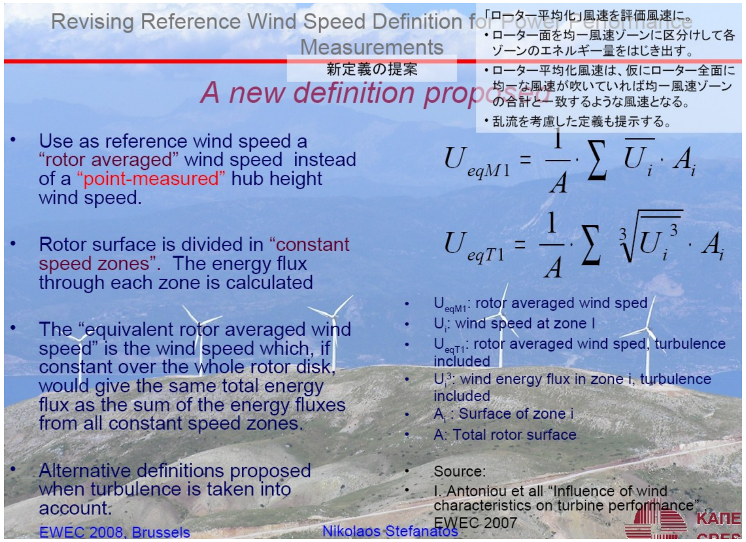


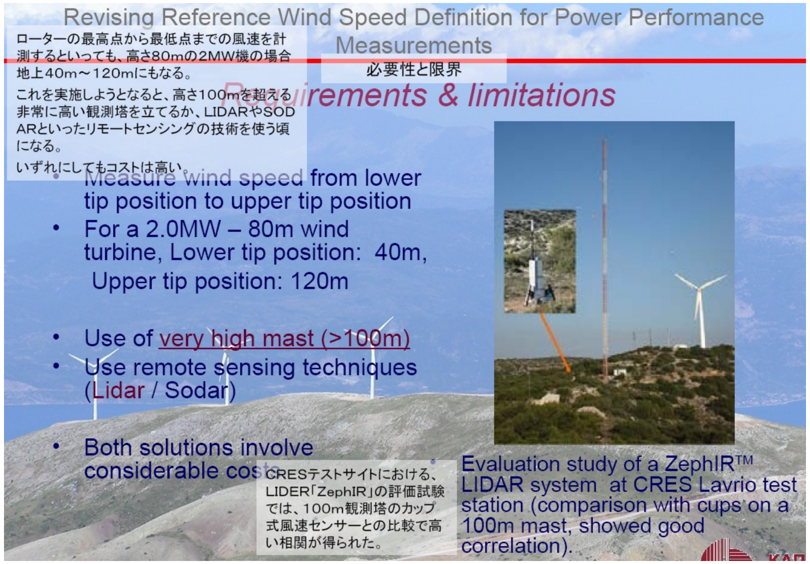
Figure 4. Lavrio: The scatter plots show generally 4% to 6% errors in wind speed measurements (top). Lower two plots are the comparison between the model and the measurement data for two different heights. Small red dots are the error ratio for each 10 minutes measurement, big red dots are the averaged 6° bins according to the wind direction and medium black dots are the model results. The mast shadow is marked with grey rectangles. The ideal ratio line of one, dashed blue, is also shown and it represents the cases where there is no difference between the lidar and the mast measurements. Especially for northerly directions the model predicts the lidar error well for both heights, while for the southerly directions the prediction is not so good.

WAsP Engineering計算でビーム方向の風速を割り出し、ZephIRが内部で行なっている計算で水平風速を出す。

グラフは異なる高さでの結果。細かい点は10分平均値のLIDAR/マスト比率。点は6°のビンの平均。黒い線(点)はモデル計算値。帯はブームのシャドーそれぞれ±30°。北方向は計算値と合っているが南は合っていない。南側の急な坂の影響が大きく、WAsP Engineering の限界を超えていると判断する。

【風力発電機設計基準への応用】現代の直径80m以上もある機種でのパワーカーブ評価にハブ高風速1点での代表風速を用いることはもはや現実的ではない





- パワーカーブ評価のための風速基準は見直しの時期に来ている。
- その風速基準には風速の鉛直シアが反映される必要がある。
- 将来技術としてはリモートセンシングが期待される。
- 経済的なアプローチ（従来式のハブ高より下の風速シアを使う方法）も単独もしくはリモートセンシングと合わせて利用はできる。ただし乱流要素は除外して。
- MEASNETでも取り組まれている。