WINDTEST

Kaiser-Wilhelm-Koog GmbH

ZephIR LiDAR Assessment at the Offshore Met Mast on Platform FINO-1

– Offshore Certification Report –

Report No. WT 5256/06

August 2006

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Site of measurement:	Offshore Research Platform FINO-1, German North Sea
Customer:	TALISMAN ENERGY (UK) Limited Talisman House 163 Holburn Street Aberdeen AB10 6BZ Scotland UK
Contractor:	WINDTEST Kaiser-Wilhelm-Koog GmbH Sommerdeich 14b 25709 Kaiser-Wilhelm-Koog
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Prepared by	**Checked by**
Dipl.-Oz. D. Kindler	Dipl.-Ing. Chr. Thiel Energy Group, Head of Group

Kaiser-Wilhelm-Koog, 25th of August 2006

TABLE OF CONTENTS

1 Introduction

In February 2006 WINDTEST Kaiser-Wilhelm-Koog GmbH (WINDTEST) was ordered by TALISMAN ENERGY (Limited) UK to assess the offshore performance of a LiDAR system of type QinetiQ/ZephIR relative to classical measurements at an offshore meteorological mast on the German wind energy research platform FINO-1 located in the German North Sea sector.

The motivation of such performance test of the ZephIR LiDAR system was to investigate its comparability to classical measurements and hence to proof its suitability to deploy it on an offshore platform – mainly for wind resource measurements – as part of the Beatrice Offshore Demonstrator Project.

This report is based on the success criteria as formulated in the *Certification Programme Document* [Doc02] for the offshore campaign, and hence it is called the *Offshore Certification Report*. It exclusively compares the results gathered within the offshore measuring period from 2006-03-02 until 2006-07-13 to the formulated success criteria. Those criteria were the only certification guideline. **This report is not comparable to any certification as known for cup anemometers.**

The performance assessment was done by setting a focus on the data availability on one hand and on the wind speed data quality to be assessed relative to measurements of mast mounted cup anemometers using linear regression on the other hand. The success criteria to be applied were defined in terms of percentage of data availability, value of linear regression slope (constrained through the origin) and the R^2 value of the regression. The performance values to be achieved for a successful test were defined as [Doc02]:

- Data Availability equal to or larger than 95%
- Linear regression slope (m) through origin to be between 0.97 and 1
- Regression coefficient R^2 equal to or larger than 0.95

Any statement of fail and success according to data quality and availability of the ZephIR system that is made in this report is exclusively based on the data collected and on the site and weather conditions present during the prescribed offshore measuring period. WINDTEST does not guarantee the transferability of the results neither to other sites nor to other environmental conditions.

2 Setup of Offshore Campaign

A thorough description of the site and the measurement setup can be found in the 1st offshore status report [*SR03*].

2.1 Location

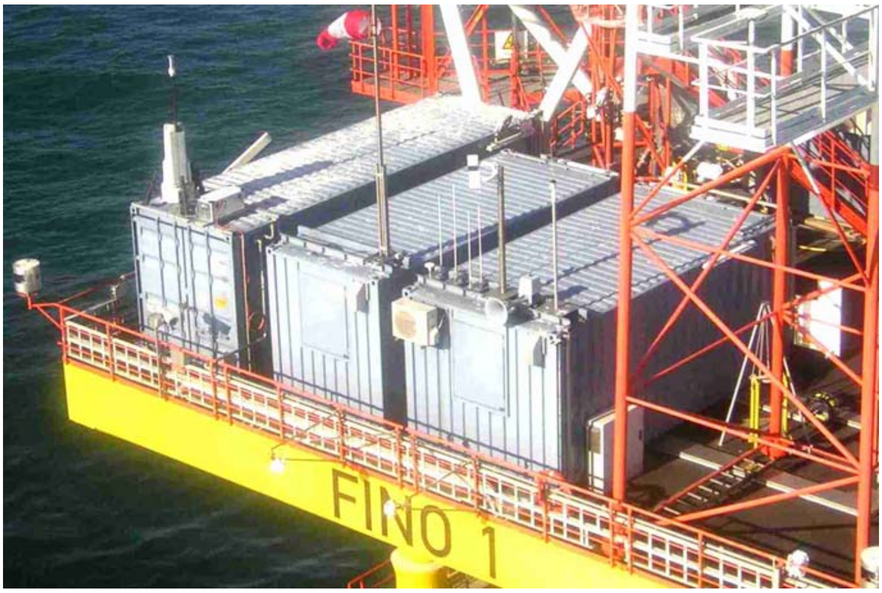

Figure 1: ZephIR on FINO-1 as mounted on the platform's Western most corner.

An overview of the offshore test site is given in figure 1, showing a photo taken from the Southwest during helicopter start. The LiDAR was placed on the western most corner of the platform, that was on the roof of the diesel generator container. Its distance to the 80 m tall met mast – as indicated by the orange coloured lattice structure to the right in figure1 – was about 11 m.

Since the mast mounted anemometers suffered from flow distortion induced by lightning rods of a cage shielding the top cup anemometer and by the mast's lattice structure, certain wind directions needed to be clipped to allow only free flow wind conditions to be used for comparisons. Figure 2 shows the respective wind direction sectors that were clipped to avoid data corruption by flow distortion, (A) towards the top cup anemometer (shaded) and (B) towards the lower anemometers mounted on 61 and 81m (hatched). The larger North-westerly sector accounts for the fact that the booms of those two lower anemometers were directed to the South-east and hence suffered complex flow distortions from the shadowing and edge effects of the met mast structure.

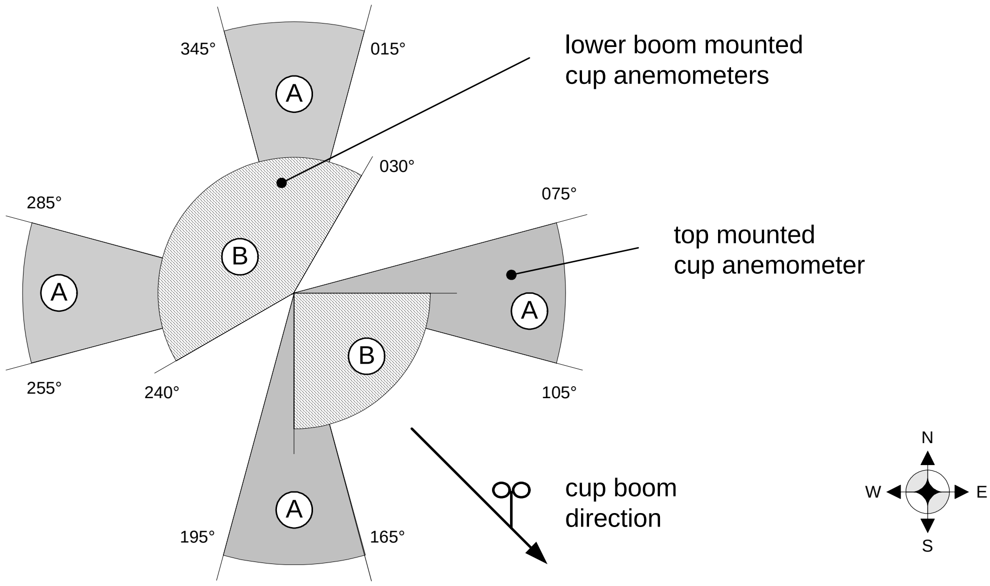

Figure 2: Wind direction sectors to be clipped due to flow distortion from lightning rods for top anemometer (A, shaded) and from mast structure for lower boom mounted cup anemometers (B, hatched). Note the direction of cup booms for 61 and 81 m level towards 135° (SE).

2.2 Met mast specifics

The offshore met mast is an 80 m high lattice tower mounted on top of the 20 m high research platform, i.e. reaching a height above mean sea level (AMSL) of 103 m. It is equipped according to the following table.

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 1: 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.

2.3 ZephIR settings

The main settings of the ZephIR-LiDAR were

- The device was installed at a height of about 25 m above mean sea level.
- The scanning heights of the LiDAR were chosen to be 78 m (103 m AMSL) and 300 m for cloud correction purposes [CC]) during the first period.
- During the second “profiling” period scanning heights were 36 m, 56 m , 78 m , 100 m (and 300 m), where the three lower heights served as comparison heights with the respective anemometers.
- For most of the campaign the cloud correction was enabled during operation.

Generally good experiences were made with a straight forward installation procedure of the ZephIR system on the offshore platform. After the preparations for energy supply and data transfer infrastructure had been finished the ZephIR system could be deployed and put into operation by three technicians during a single 6 hours visit on FINO-1.

3 Data Base

Table 1 represents the different main data periods (marked by different colours) during the onshore campaign, summarizing individual data storage periods (from 1 to 10) by their running order. Each data storage period denotes the duration between the two exchanges of data storage cards, i.e. the downloading of data.

In the first period (yellow, storage periods 1 & 2) the ZephIR’s scan heights were chosen to be 78 m for 4 out of the 5 possible scan slots and 300 m for the 5th slot; the latter being used to collect higher altitude wind speed data to allow for the cloud correction.

Period No.	Data Storage Period No.	Start Date	End Date	Heigth Settings	Cloud Correction
1	1 & 2	2.3.2006	11.4.2006	78 / 300	on
2	3 - 6	11.4.2006	26.6.2006	36, 56, 78, 100 / 300	on
2a	7 & 8	26.6.2006	1.7.2006	36, 56, 78, 100 / 300	off
2b	9	3.7.2006	5.7.2006	36, 56, 78, 100 / 300	on
2c	10	5.7.2006	13.7.2006	36, 56, 78, 100 / 300	off

Table 2: Listing of data storage periods 1 to 10 separated according to successive system parameter setting changes. Grey shading denotes periods with cloud correction switched off.

During the 2nd period (storage periods 3 to 6, cyan) the ZephIR was set to run at 4 scan height levels 36, 56, 78 and 100 m (plus 300 m). Such selection of settings with 4 different scan heights will be used offshore on Beatrice for standard operation of the ZephIR.

During data storage period 7, 8 and 10 the cloud correction was switched off in order to verify the effect of the cloud corrections by reprocessing the raw data with cloud correction in a later post processing step. In data periods 7 and 8 the system reset itself for a couple of times for unknown reasons. The reset automatically stopped the laser transmissions and hence the data recording. However, the transmission could be re-activated through a remote control access. It is speculated that a wrong choice of settings with respect to the order of scan heights may have caused such reset.

The data of period 1, 2 and 2b (omitting the cloud correction “off” periods) served as the data base for the wind speed and direction comparisons and hence for this certification report. The wind direction filtering as described in section 2.1 was the only filtering applied. No quality filtering was carried out.

4 Data availability and system availability

Figure 3 gives an overview of the system and data availability for each data storage period (as listed in table 2).

The system availability – denoted by green bars – was calculated based on periods of 10 minutes (each starting 0, 10 , 20 , 30 , 40 or 50 minutes after the full hour) from start to end of each individual data storage period. If time stamped data were written to the flash card within such 10 minutes periods (regardless of their contents) the system was treated as being available within this period.

The data availability as calculated for each data storage period (red bars) is based on available 10-minute averages (compare system availability). It represents an overall average for all scan heights. Such a 10-minute period was regarded as available if any number >0 of useful 3-second data values was available to form the average. This relative data availability was then multiplied by the respective system availability resulting in the absolute data availability (fig. 3 red bars).

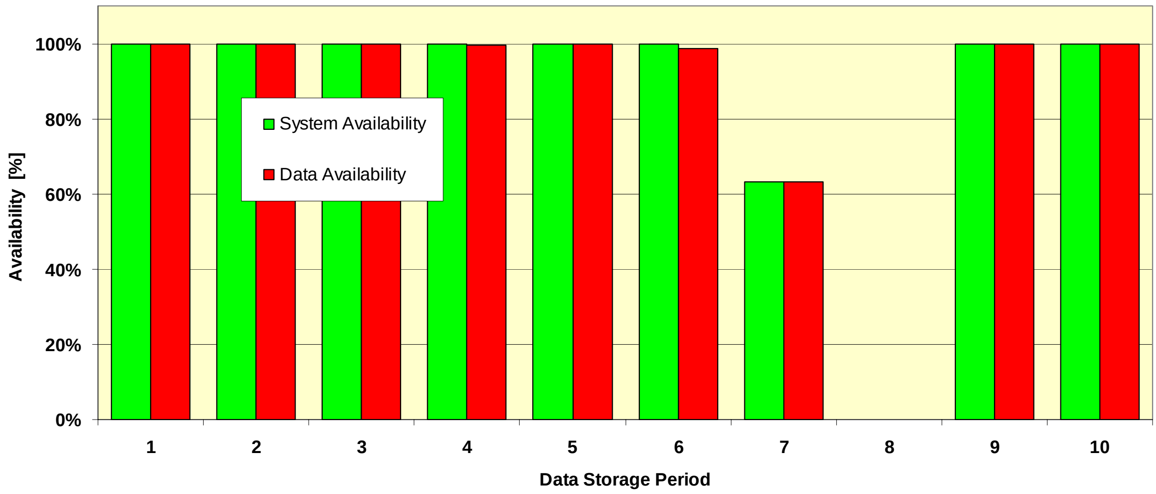

Figure 3: Overview of system (green bars) and data availability (red bars) of the ZephIR during the course of the offshore assessment campaign.

The resulting overall availabilities were averaged over the availabilities of all data storage periods, weighted by their individual duration. Data storage periods 7 and 8 were omitted from the overall availability calculations due to a mistake made in choosing the ZephIR settings for the cloud correction off mode (as described above).

From this the availability calculations resulted in the following values.

- **100% for the overall system availability and**
- **99.6% for the overall data availability.**

Taking into account the periods of failure (7 and 8, though pretty short) would reduce the system and data availability to values of 98.1 and 97.7 %.

With the achieved overall data availability of above 99% (or even 97 %) the success criterion – as demanded by the certification programme document [Doc02] – was fully met.

5 Data Comparison for Wind Speed

5.1 Linear Regression for wind speeds between LiDAR and cup

The data comparison between LiDAR wind speeds and cup wind speeds were realised by the application of a linear regression using the following relation:

*Y = m*X + b,* where

- Y is the wind speed from the LiDAR measurement
- X is the wind speed from cup, mounted to the met mast
- m is the slope of the resulting regression line
- b is the offset which is kept 0 by definition, i.e. linear regression line crosses the origin.

The parameter R^2 denotes the regression coefficient, being a measure for the quality of the regression.

5.2 Regression results

Table 3 presents a summary of regression values, which are relevant to the prescribed success criteria for the wind speed correlation [Doc02]. The graphs that belong to the individual regressions as listed in table 3 can be found in the appendix in figures 4 to 7.

Processing the first period, when the LiDAR's laser was set to focus on 78 m only (and hence samples on a higher frequency compared to the profiling mode chosen for the 2nd period) resulted in a slope of 0.97, i.e. a value at the prescribed success criterion. With the R^2 value of 0.99 the respective criterion could be met as well, clearly.

Linear Wind Speed Correlation Results: Cup vs. ZephIR LiDAR			
Analysis Sector	15°-75°, 105°-165°, 195°-255°, 295°-345°	30° to 90° and 180° to 240°	
	CUP	**CUP**	**CUP**
1st Period	**103 (78) m**	**81 (56) m**	**61 (36) m**
10-Min-avg. values	1965	/	/
Slope "m"	**0.97**	/	/
Regr. Coeff "R^2"	**0.99**	/	/
	CUP	**CUP**	**CUP**
2nd Period	**103 (78) m**	**81 (56) m**	**61 (36) m**
10-Min-avg. values	6005	2589	2749
Slope "m"	**0.98**	**0,97**	**0.98**
Regr. Coeff "R^2"	**0.99**	**0.99**	**1,00**

Table 3: Summary of wind speed regression results for period 1 (single scan height 78 m) and period 2 (multi scan height, comparisons on 36 m, 56 m and 78 m). Regression values meeting the success criteria are highlighted in bold.

During the second period – when the LiDAR was working in the profiling mode – both the slope and the R^2 criteria were met on all levels, which were 36 (61) m, 56 (81) m, and 78 (103) m.

6 Summary

During the offshore assessment campaign the ZephIR came up with a remarkable data availability of clearly being better than the demanded value of 95%, so this criterion was fully met.

The wind speed correlations for both periods – the first one employing only a single comparison height as well as the second one with 3 comparison heights – yielded results in terms of slope and R^2 values which were well above the demanded acceptance criteria. In other words, offshore the deviations between LiDAR wind speeds and cup wind speeds were less then 3 %.

The offshore regressions results were remarkably higher or better than those achieved onshore (compare [*Cert01*]). The reasons for that may be

- a better proximity or overlap between the point probed by the cup anemometers and the volume in focus of the ZephIR LiDAR
- a clear definition of undisturbed and hence free flow wind direction sectors
- a possibly more homogeneous air flow offshore, in general

In addition to those very encouraging results the system proved its reliability offshore in terms of system availability and easy handling even in harsh weather conditions as present during the offshore installation in March 2006.

The results returned from this offshore study (as well as those form the onshore campaign) have shown that the QinetiQ LiDAR system is very capable of returning good quality results in both an offshore and onshore environment. The level of the results returned shows that the system under test should now be thought of as a powerful tool to aid in the understanding of flow conditions on sites being investigated.

7 References

Doc01 *LiDAR Met Mast campaign – Programme Overview,* by Andy Oldroyd, Oldbaum Services Ltd., July 2005.

Doc02 *LiDAR Met Mast campaign – Certification Programme,* by Andy Oldroyd, Oldbaum Services Ltd., July 2005.

Doc03 *LiDAR Met Mast campaign – Scientific Programme,* by Andy Oldroyd, Oldbaum Services Ltd., July 2005.

SR01 *1st Status Report: LiDAR Performance Test at the 5M Met Mast, in Brunsbüttel, WT 4588/05*, by Detlef Kindler, WINDTEST Kaiser-Wilhelm-Koog GmbH, October 2005.

SR02 *2nd Status Report: LiDAR Performance Test at the 5M Met Mast, in Brunsbüttel, WT 4678/05*, by Detlef Kindler, WINDTEST Kaiser-Wilhelm-Koog GmbH, December 2005.

Proc5M *Proceedings of the End Onshore test Phase Meeting, Malvern, 2006-01-18, Rev:1.1*, by Andy Oldroyd, Oldbaum Services Ltd., March 2006

Cert01 *LiDAR Assessment at the 5M Met Mast, in Brunsbüttel, Onshore Certification Report, WT 5035/06*, by Detlef Kindler, WINDTEST Kaiser-Wilhelm-Koog GmbH, May 2006.

SR03 *ZephIR-LiDAR Offshore Performance Test on FINO-1, Setup and 1st Status Report, WT 5053/06*, by Detlef Kindler, WINDTEST Kaiser-Wilhelm-Koog GmbH, May 2006.

SR04 *ZephIR-LiDAR Offshore Performance Test on FINO-1, 2nd Status Report, WT 5150/06*, by Detlef Kindler, WINDTEST Kaiser-Wilhelm-Koog GmbH, June 2006.

8 Appendix

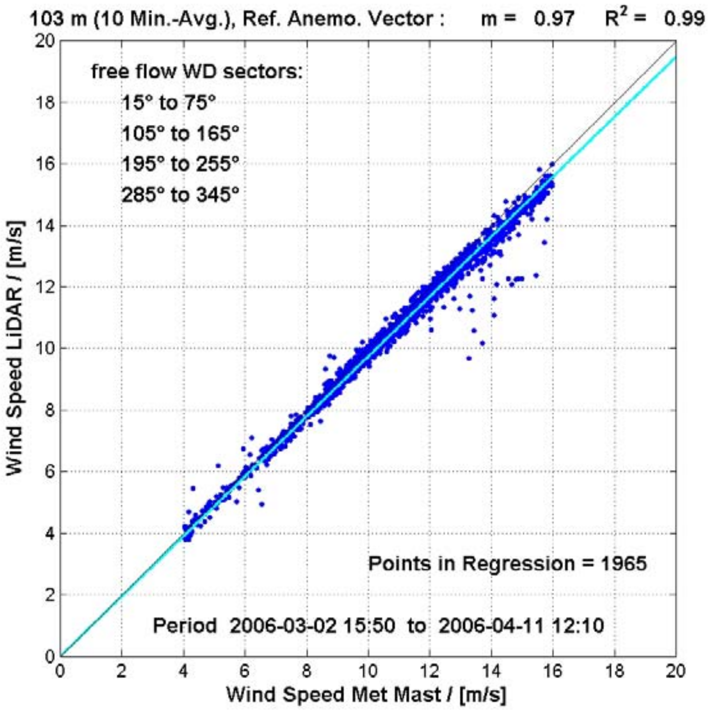

Figure 4: Wind speed regression for 103 m AMSL as derived from 10-minute averages of the cup anemometer (type Vector) on top of the met mast and of the respective ZephIR scan height of 78 m. Values were taken from the first test period for a wind speed range of 4 to 16 m/s and out of the prescribed free flow wind direction sectors. The grey coloured line represents linear fit through the origin.

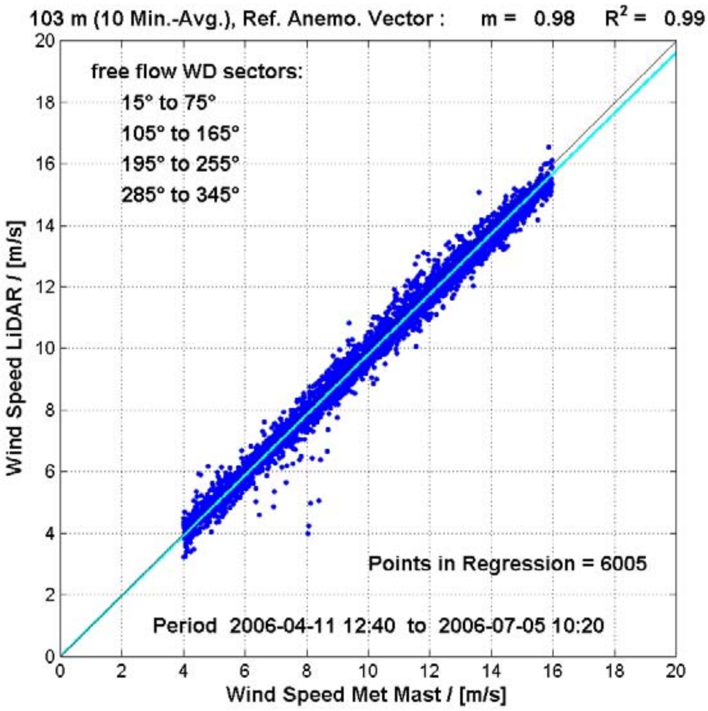

Figure 5: Same as figure 4, but for the second data period (profiling mode).

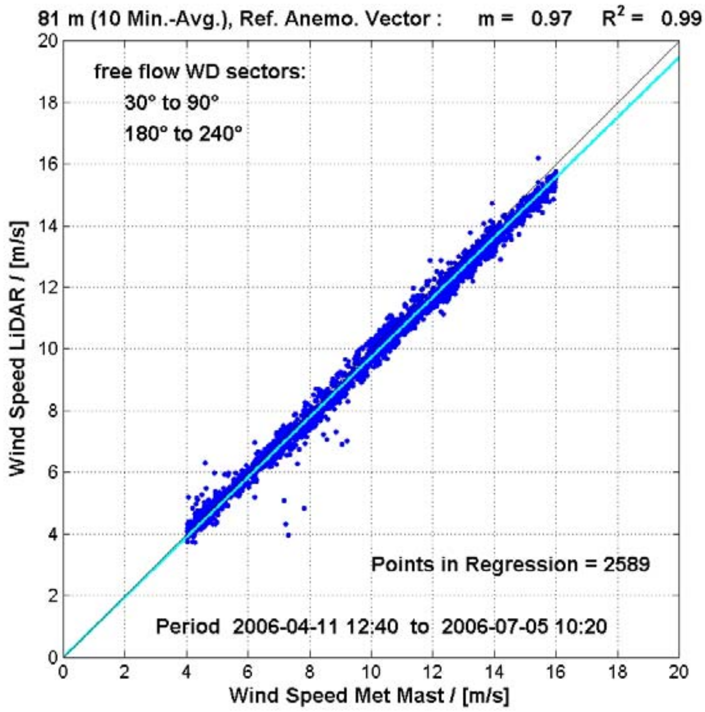

Figure 6: Wind speed regression for 81 m AMSL as derived from 10-minute averages of the cup anemometer (type Vector) on top of the met mast and of the respective ZephIR scan height of 56 m. Values are taken from the 2nd (profiling) test period for a wind speed range of 4 to 16 m/s and out of the prescribed free flow wind direction sectors.

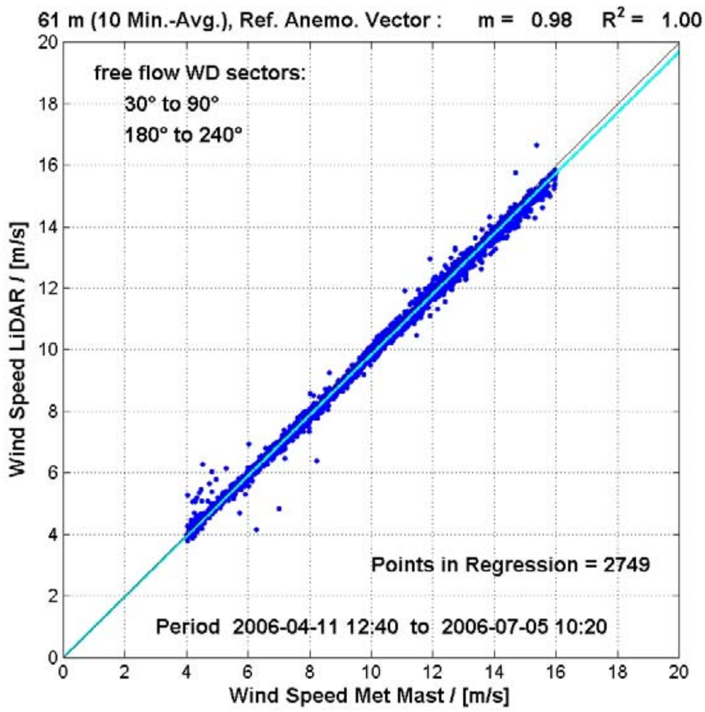

Figure 7: Same as figure 6 but for 61 (36) m height AMSL.