

# On- and Offshore Assessment of the ZephIR Wind-LiDAR

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IEA R&D Task 11, Wind Energy

51<sup>st</sup> Topical Expert Meeting

on Remote Sensing

RISØ January 2007



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**Title**

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- Motivation of test programm, acceptance criteria
- Onshore campaign at 5M site, Brunsbüttel
- Offshore campaign on FINO-1:
- Summary of assessment campaign
  - o WS turbulence
  - o Met. conditions: precipitation and visibility
  - o WS profiles
  - o Twin experiment
- Further objectives
  - technical experiences
  - offshore challenges
  - future applications

## Outline



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- Remote Sensing (LiDAR) chosen as **the primary wind resource monitoring method** for the DOWNVinD / *Beatrice* Windfarm Demonstrator Project



- Assessment of the capabilities of the system in terms of availability and data quality
- Suitability for offshore challenges as of an installation on Beatrice



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## Motivation

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Acceptance criteria for the ZephIR being used  
**as the primary wind monitoring method**  
on the Beatrice Alpha platform:

→ Availability > 95 % (system & data)

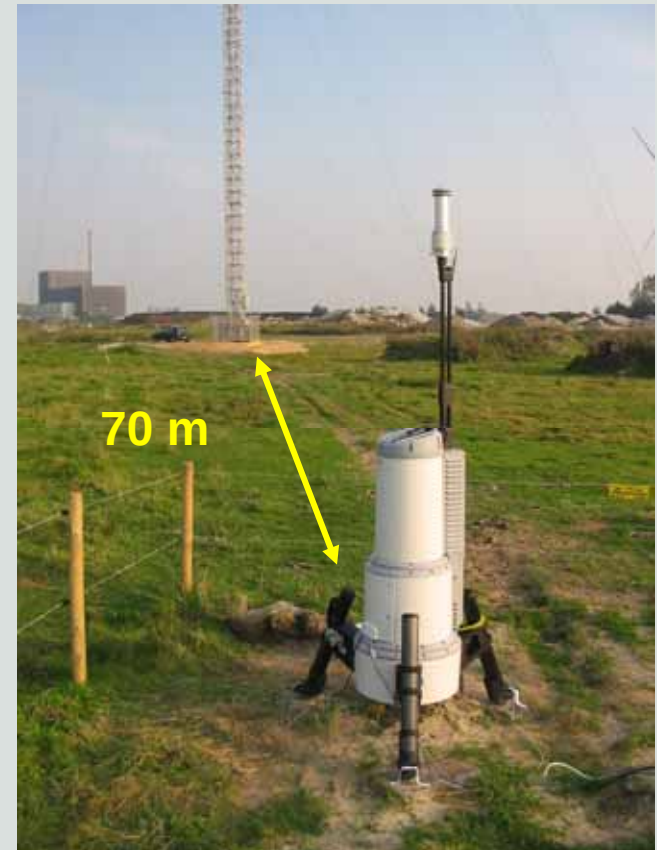
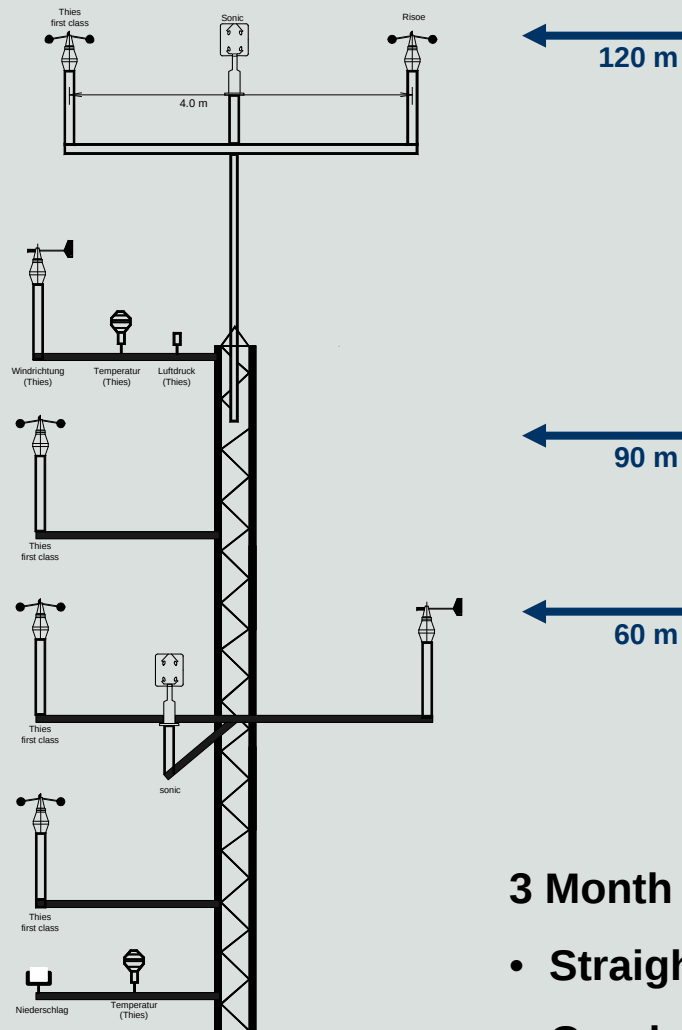
→ Data quality relative to cups  
linear regressions through origin

$$Y = mx + b \quad (\text{i.e. with } b=0)$$

$$0.97 < m < 1$$

$$R^2 > 97\%$$





### 3 Month campaign

- Straight forward setup procedures
- Good data access



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## Onshore Test Site

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| Data Storage Period No. | Start Date | End Date   | Height Settings        | Cloud Correction |
|-------------------------|------------|------------|------------------------|------------------|
| 1 to 6                  | 14.9.2005  | 30.9.2005  | 120 / 300              | off              |
| 7 to 16                 | 30.9.2005  | 8.11.2005  | 120 / 300              | off              |
| 17 to 24                | 8.11.2005  | 19.12.2005 | 60, 90, 120, 150 / 300 | off              |
| 24 twin                 | 15.12.2005 | 19.12.2005 | 60, 90, 120, 150 / 300 | off              |
| 25 to 27                | 19.12.2005 | 5.1.2006   | 60, 90, 120, 150 / 300 | on               |

**Overall System Availability:** **99.6 %**

**Overall Data Availability (10-Min.-Av.):** **95.2 %**



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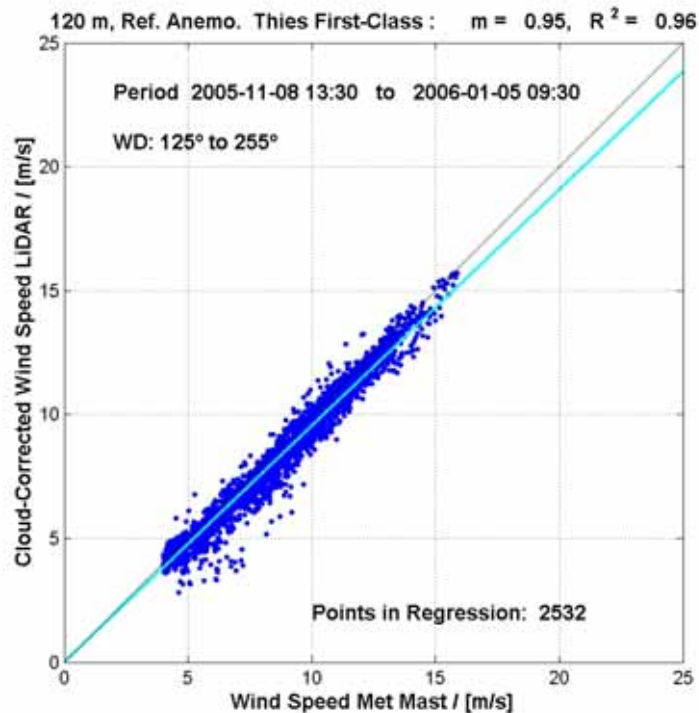
## Availability Onshore

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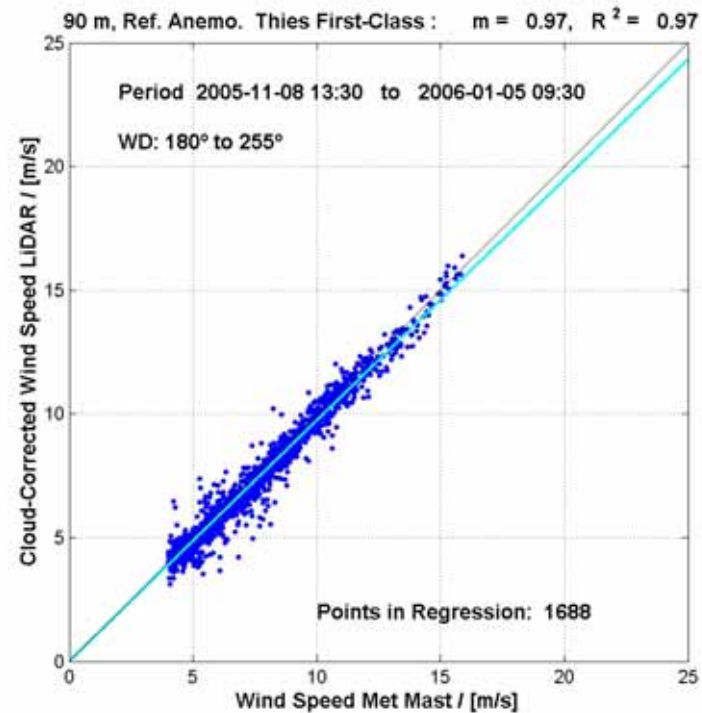


**120m Slope:**

$$m = 0.95$$

**Regr. coefficient:**

$$R^2 = 0.96$$



**90m Slope:**

$$m = 0.97$$

**Regr. coefficient:**

$$R^2 = 0.97$$



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## WS Regressions Onshore

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# Onshore

| Sector                        | 125° to 255° | 180° to 255° |  |             |              |
|-------------------------------|--------------|--------------|--|-------------|--------------|
|                               | <b>CUP</b>   | <b>CUP</b>   |  | <b>CUP</b>  |              |
| <b>1<sup>st</sup> Period</b>  | <b>120 m</b> | <b>90 m</b>  |  | <b>60 m</b> |              |
| 10-min-avg. values            | 3034         | /            |  | /           |              |
| Slope "m"                     | <b>0.94</b>  | /            |  | /           |              |
| Regr. Coeff "R <sup>2</sup> " | <b>0.95</b>  | /            |  | /           |              |
|                               | <b>CUP</b>   | <b>CUP</b>   |  | <b>CUP</b>  | <b>SONIC</b> |
| <b>2<sup>nd</sup> Period</b>  | <b>120 m</b> | <b>90 m</b>  |  | <b>60 m</b> |              |
| 10-min-avg. values            | 2532         | 1688         |  | 1577        | 1568         |
| Slope "m"                     | <b>0.95</b>  | <b>0.97</b>  |  | <b>0.99</b> | <b>1,00</b>  |
| Regr. Coeff "R <sup>2</sup> " | <b>0.96</b>  | <b>0.97</b>  |  | <b>0.95</b> | <b>0.93</b>  |



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## Onshore results

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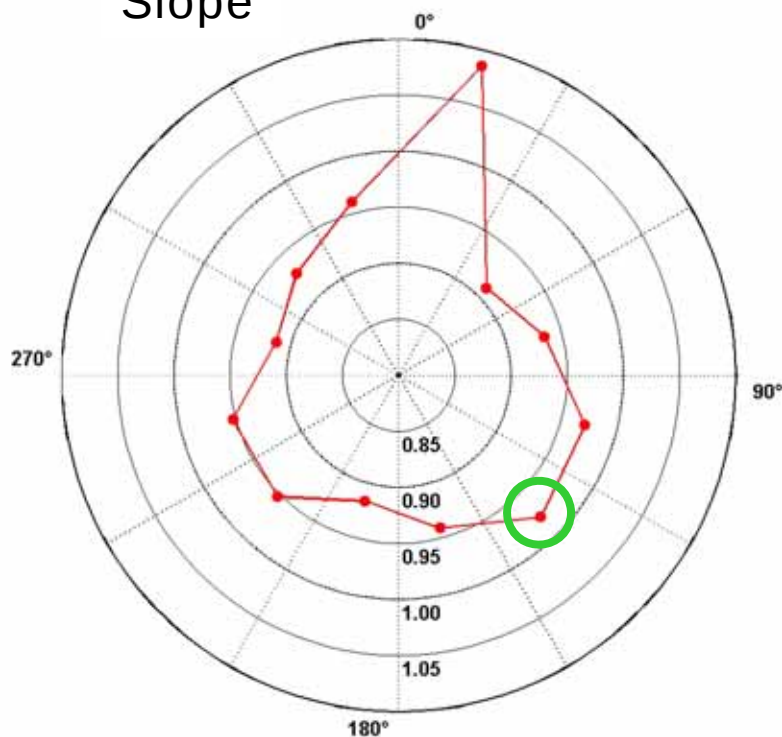
Slide No. 8

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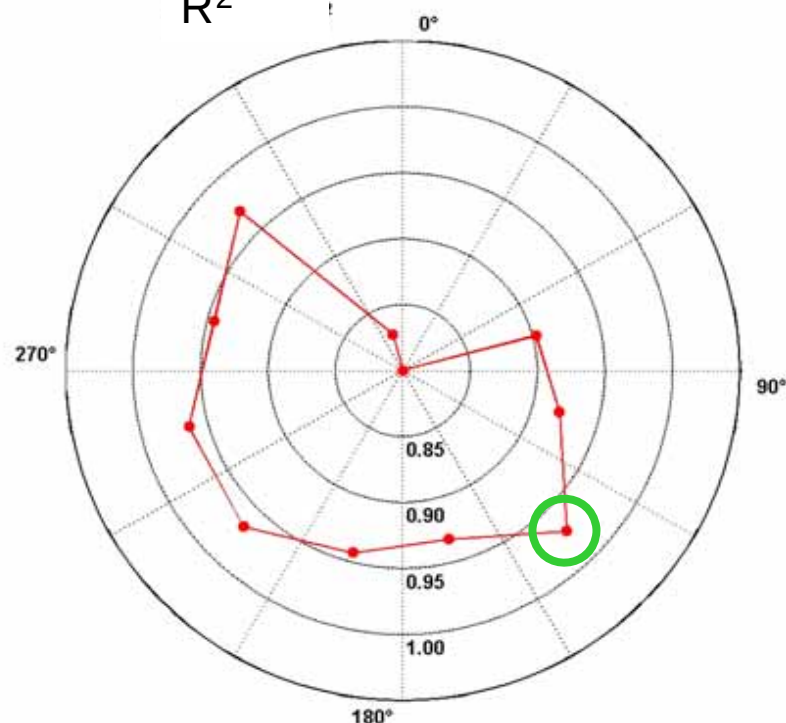


# Cup / LiDAR Sector Wise Comparison 120m

Slope



$R^2$



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**WS Regressions Onshore**

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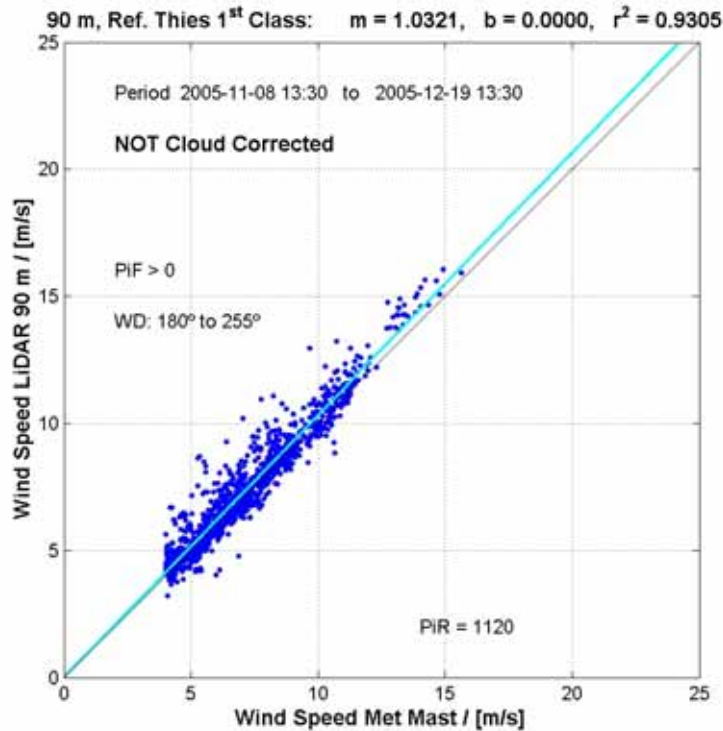
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No Correction

90 m AGL

Cloud Correction Applied

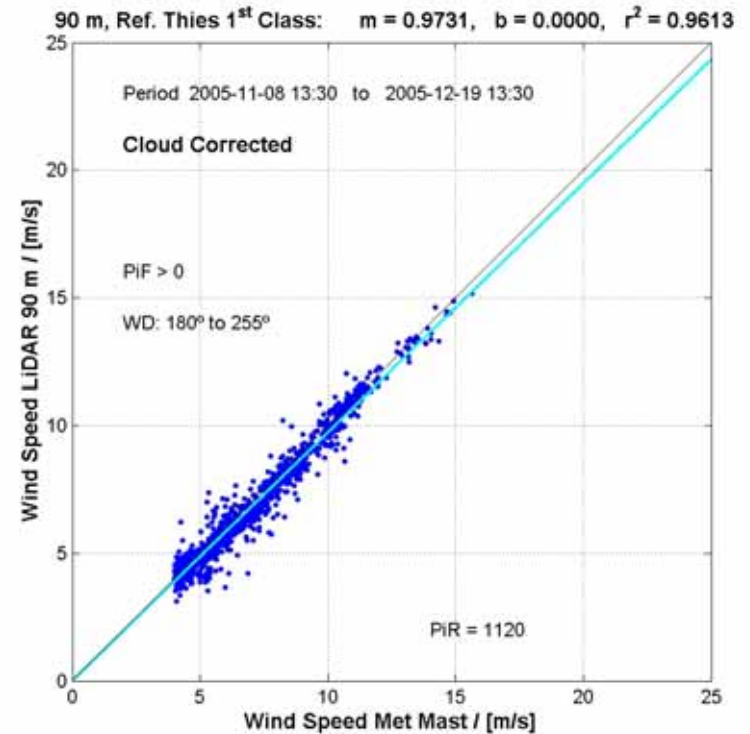


Slope:

$$m = 1.03$$

Regr. coefficient:

$$R^2 = 0.93$$



Slope:

$$m = 0.97$$

Regr. coefficient:

$$R^2 = 0.96$$

Cloud correction check



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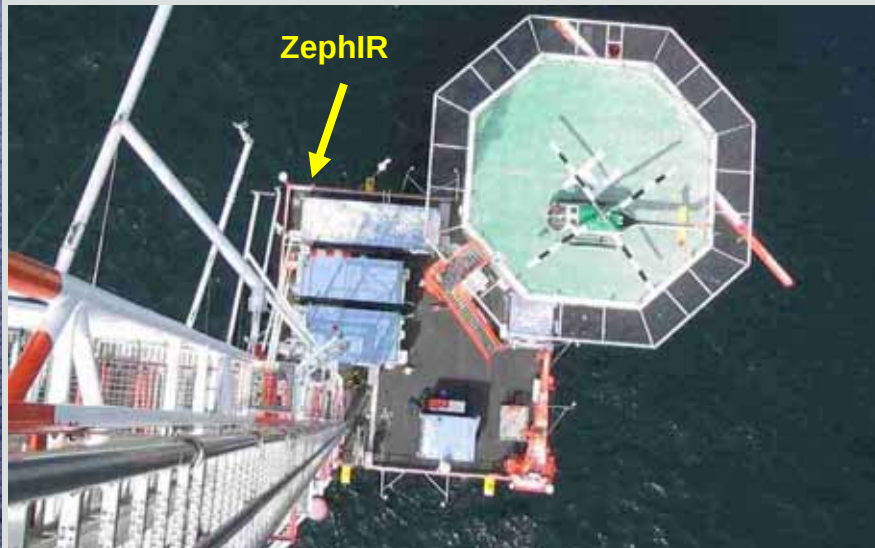
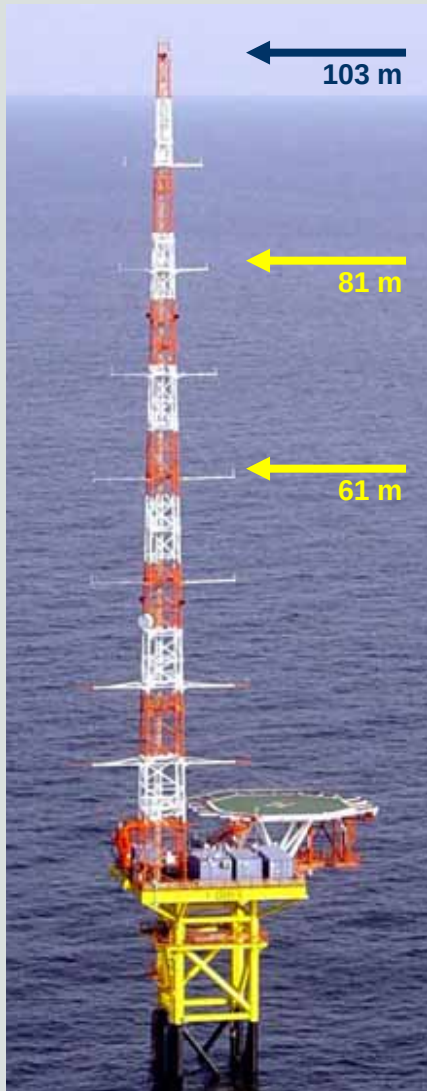
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- North Sea, 45 km North of Island Borkum (D)
  - Platform height: 20 m
  - Mast top height: 103 m
  - Annual mean wind speed on 100m app. 10 m/s
  - Prevailing wind dir. SW
- 
- 5 Month campaign March to July 2006
  - 3 Comparison levels cups, vanes, sonics



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## FINO-1 Offshore Test Site

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| Period No. | Data Storage<br>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              |

**Overall System Availability:** **100.0 %**

**Overall Data Availability (10-Min.-Av.):** **99.6 %**



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## Availability Offshore

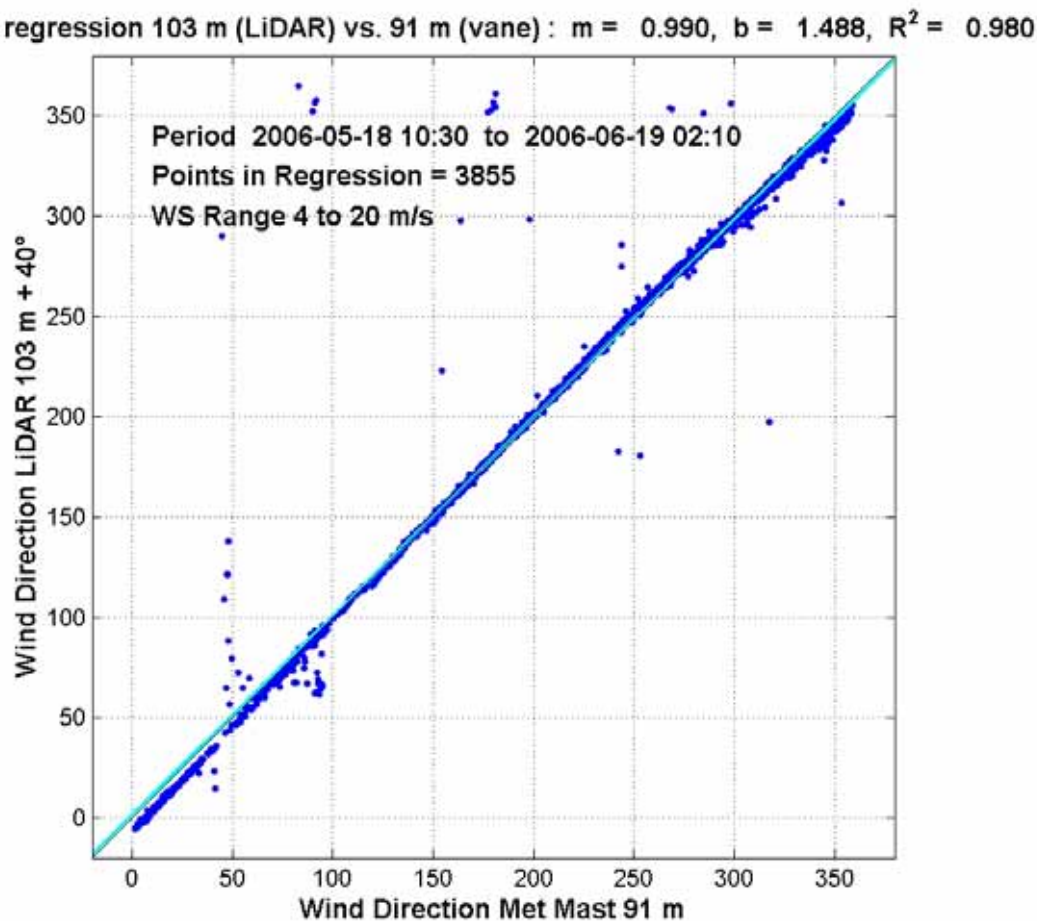
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LiDAR



Wind Vane

Height:  
103 (78) m

WS range:  
2 to 20 m/s

Slope:  
 $m = 0.99$   
 $b = 1.48$

Regr. coefficient:  
 $R^2 = 0.98$



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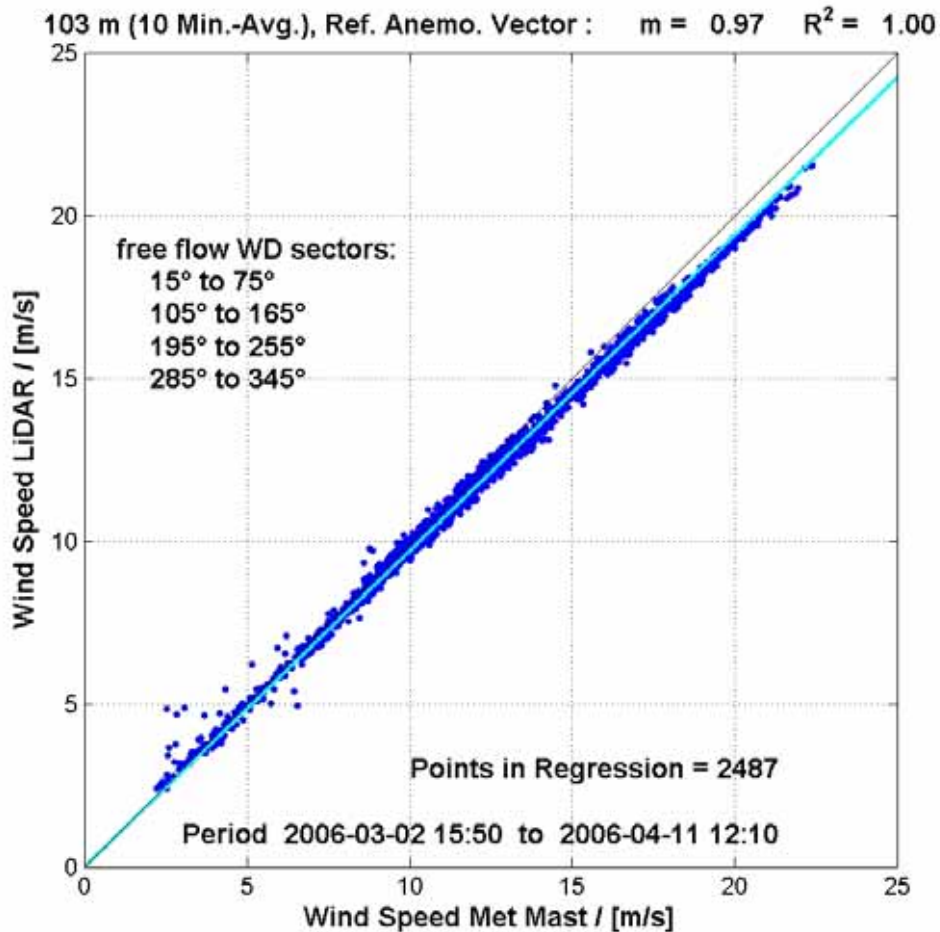
## Wind Direction Comparison

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Height:

103 (78) m

WS range:

2 to 23 m/s

Slope:

$m = 0.97$

Regr. coefficient:

$R^2 = 0.99$



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## WS Comparison Offshore

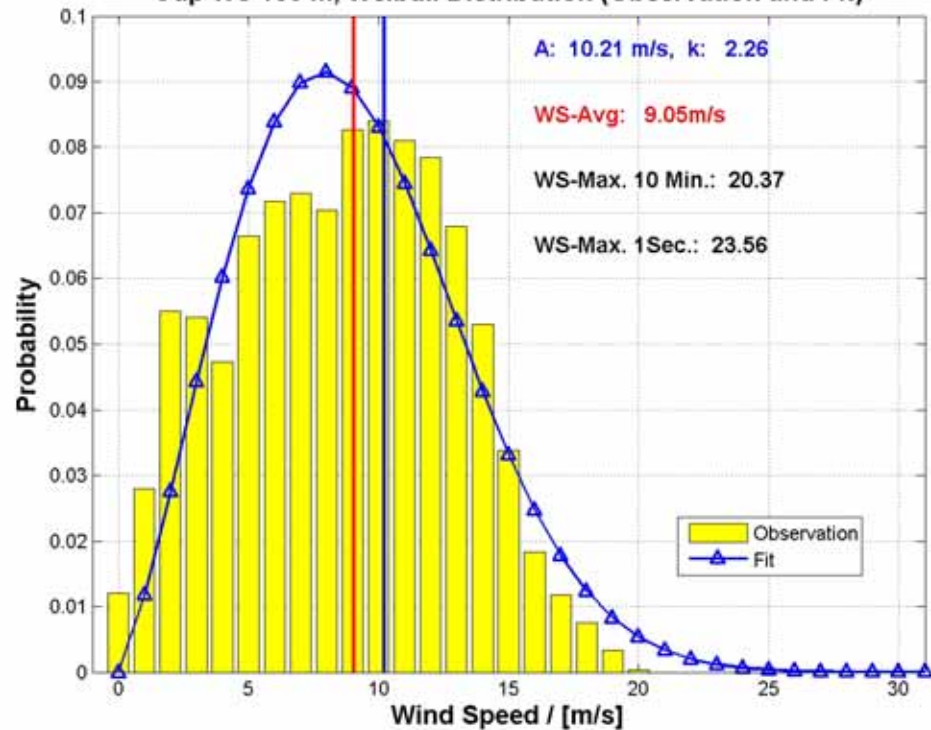
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Slide No. 14

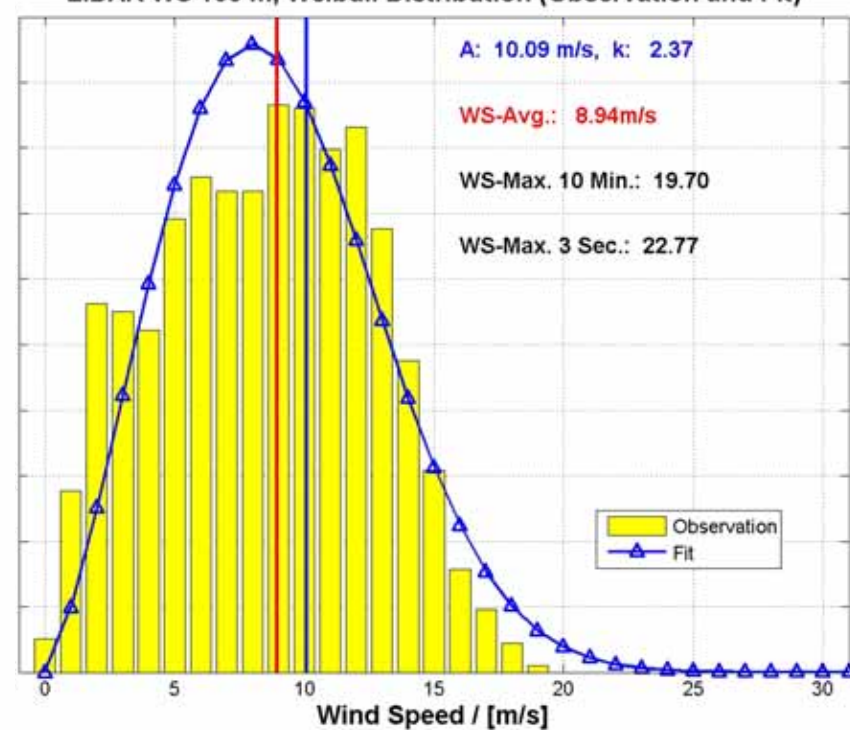
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Cup WS 103 m, Weibull Distribution (Observation and Fit)



LiDAR WS 103 m, Weibull Distribution (Observation and Fit)



## WS Weibull Distribution



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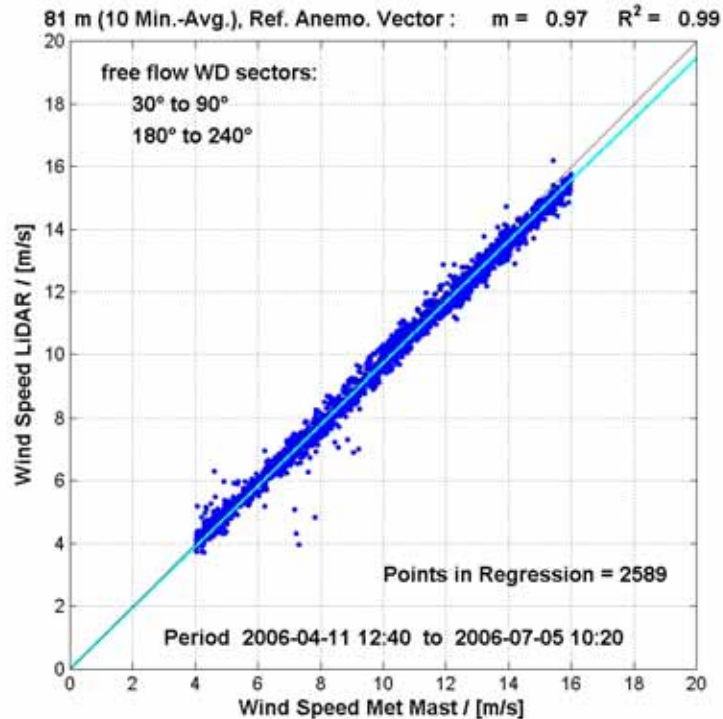
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81 (56) m



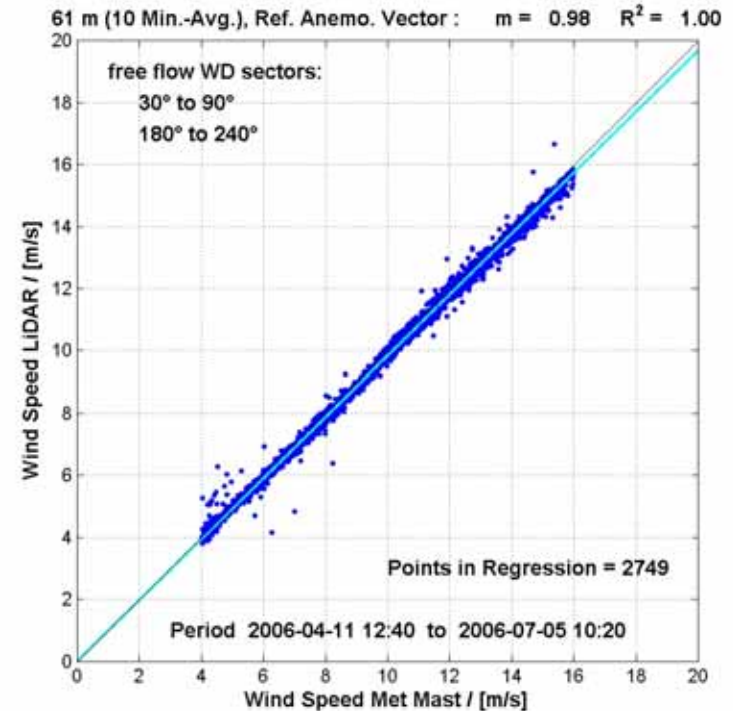
Slope:

$$m = 0.97$$

Regr. coefficient:

$$R^2 = 0.99$$

61 (36) m



Slope:

$$m = 0.98$$

Regr. coefficient:

$$R^2 = 1.00$$



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**WS Regressions Offshore**

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# Offshore

| Analysis Sector               | 15°-75°, 105°-165°, 195°-255°, 295°-345° | 30° to 90° and 180° to 240° |           | 0° to 60° and 210° to 270° |           |
|-------------------------------|------------------------------------------|-----------------------------|-----------|----------------------------|-----------|
|                               | CUP                                      |                             |           |                            |           |
| 1 <sup>st</sup> Period        | 103 (78) m                               | 81 (56) m                   | 61 (36) m |                            |           |
| 10-min-avg. values            | 1965                                     | /                           | /         |                            |           |
| Slope "m"                     | 0.97                                     | /                           | /         |                            |           |
| Regr. Coeff "R <sup>2</sup> " | 0.99                                     | /                           | /         |                            |           |
|                               | CUP                                      |                             |           | SONIC                      |           |
| 2 <sup>nd</sup> Period        | 103 (78) m                               | 81 (56) m                   | 61 (36) m | 81 (56) m                  | 61 (36) m |
| 10-min-avg. values            | 6005                                     | 2589                        | 2749      | 3228                       | 3245      |
| Slope "m"                     | 0.98                                     | 0,97                        | 0,98      | 1,01                       | 1,01      |
| Regr. Coeff "R <sup>2</sup> " | 0.99                                     | 0.99                        | 1,00      | 0.99                       | 1,000     |



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## Offshore results

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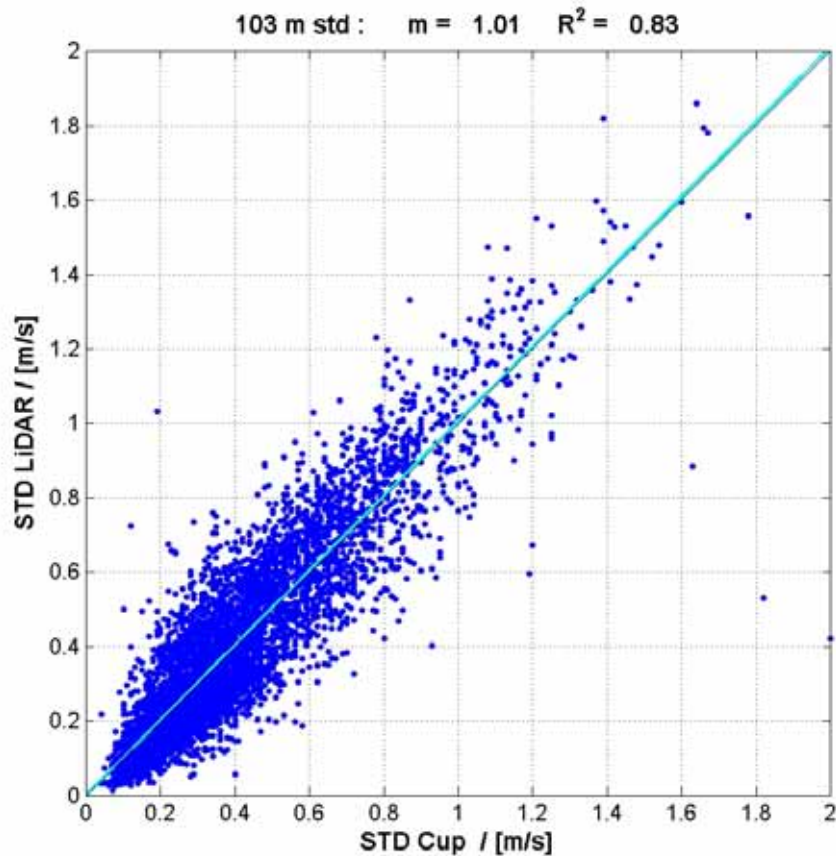
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- The QinetiQ ZephIR system has been subject to a stringent test campaign to test the quality of data output;
- The system has performed well onshore despite the complexity of the terrain surrounding the test site and passed acceptance;
- System has been tested offshore in similar conditions to the final deployment location on Beatrice, results offshore show better correlation than that returned onshore;
- Most promising results are
  - WS deviation from Cups < 3%
  - Availability close to 100% (NO weather dependence seen)
  - good handling, easy to install
- System has passed acceptance onshore and offshore;
- ZephIR has returned quality results in both on- and offshore environments indicating its potential for deployment in the wind industry in both on- and offshore environments.





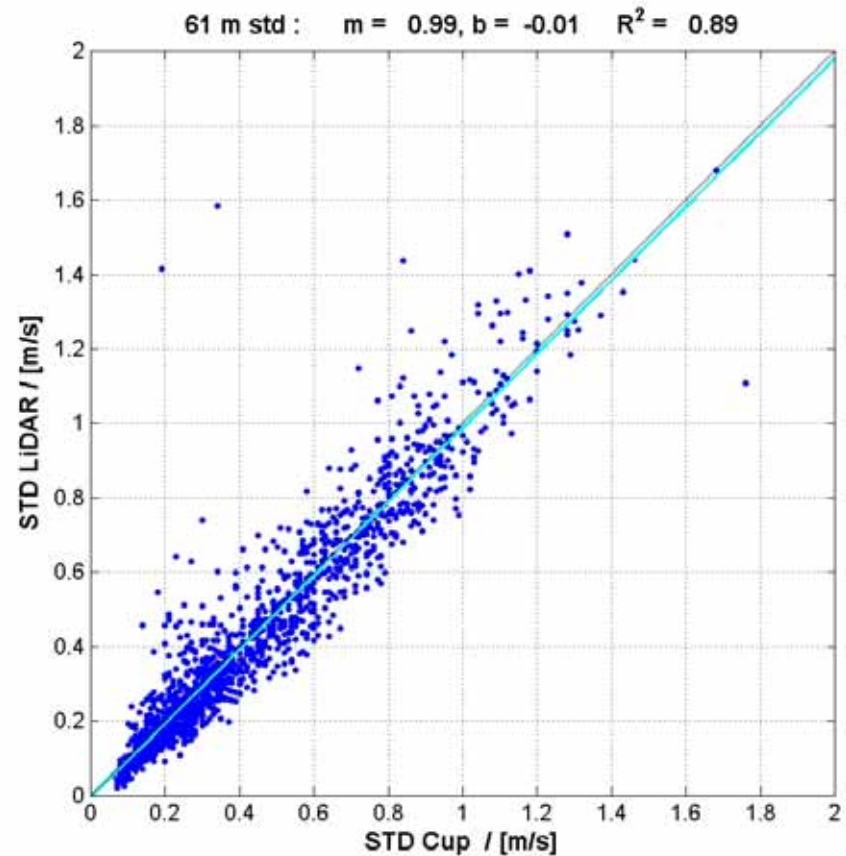
103m

Slope:

$$m = 1.01$$

Regr. coefficient:

$$R^2 = 0.83$$



61m

Slope:

$$m = 0.99$$

Regr. coefficient:

$$R^2 = 0.89$$

## Turbulence Offshore (%)



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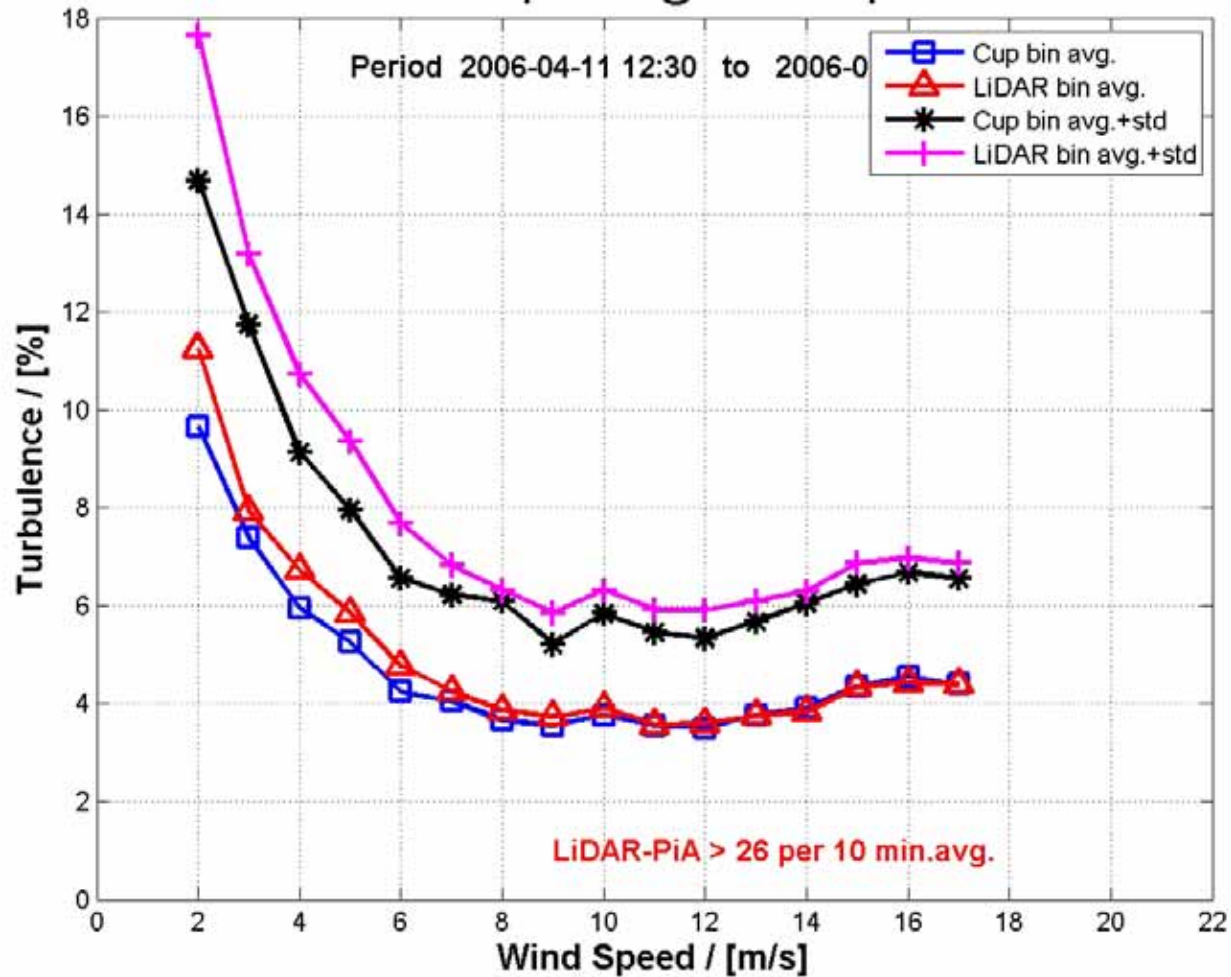
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## Turbulence Comparison @ 103 m: Cup vs. LiDAR



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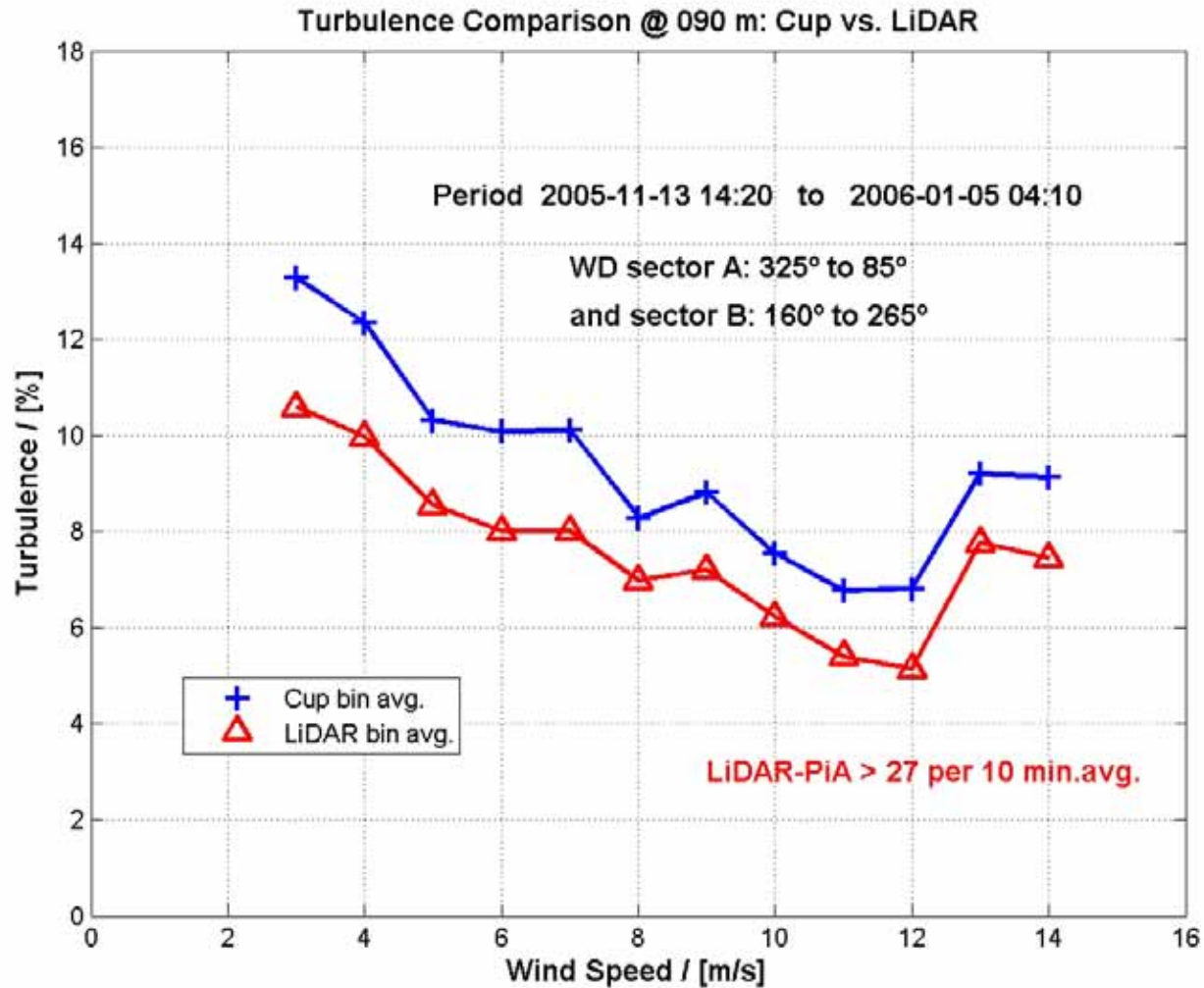
## Turbulence Offshore (%)

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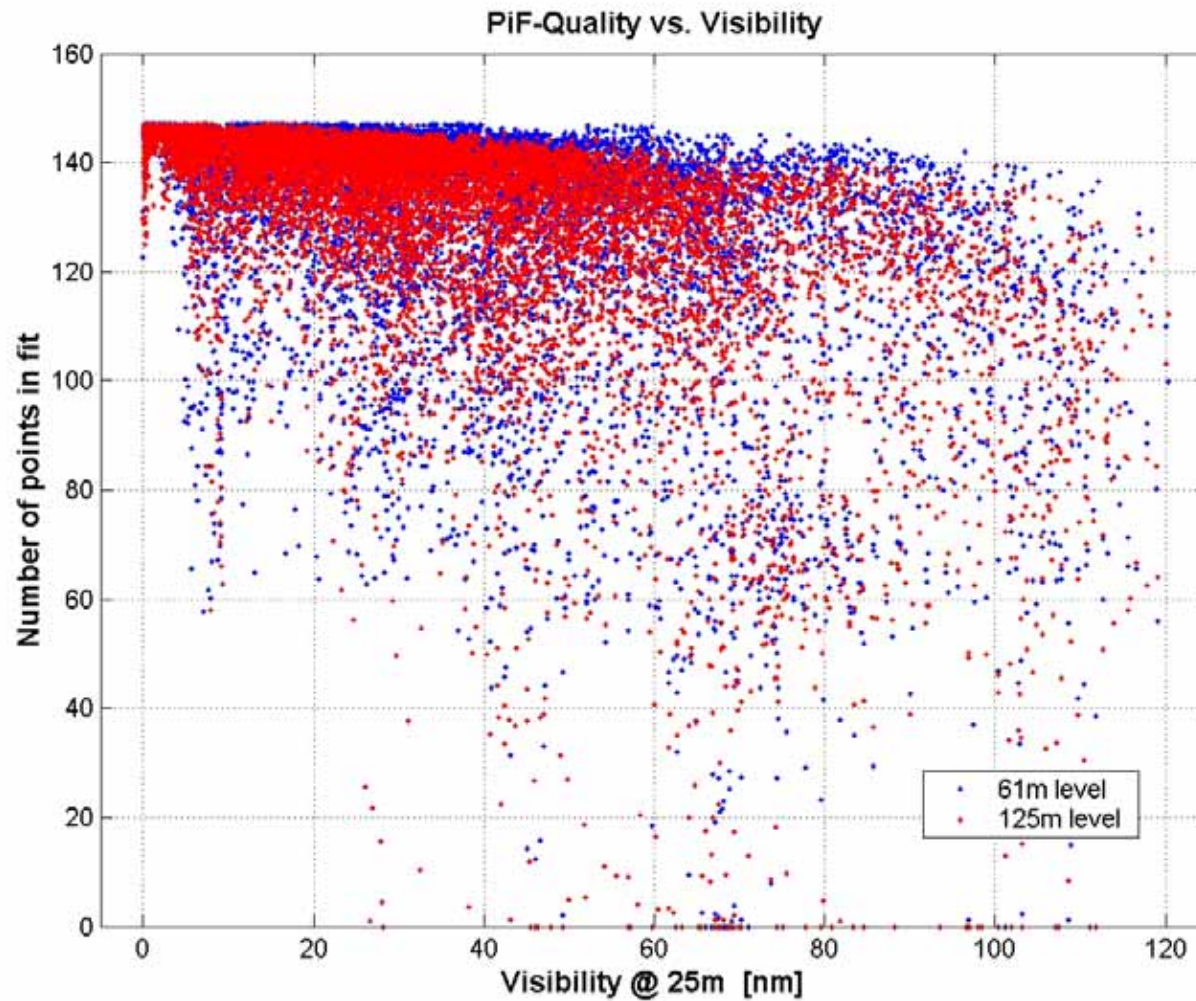
## Turbulence Onshore (%)

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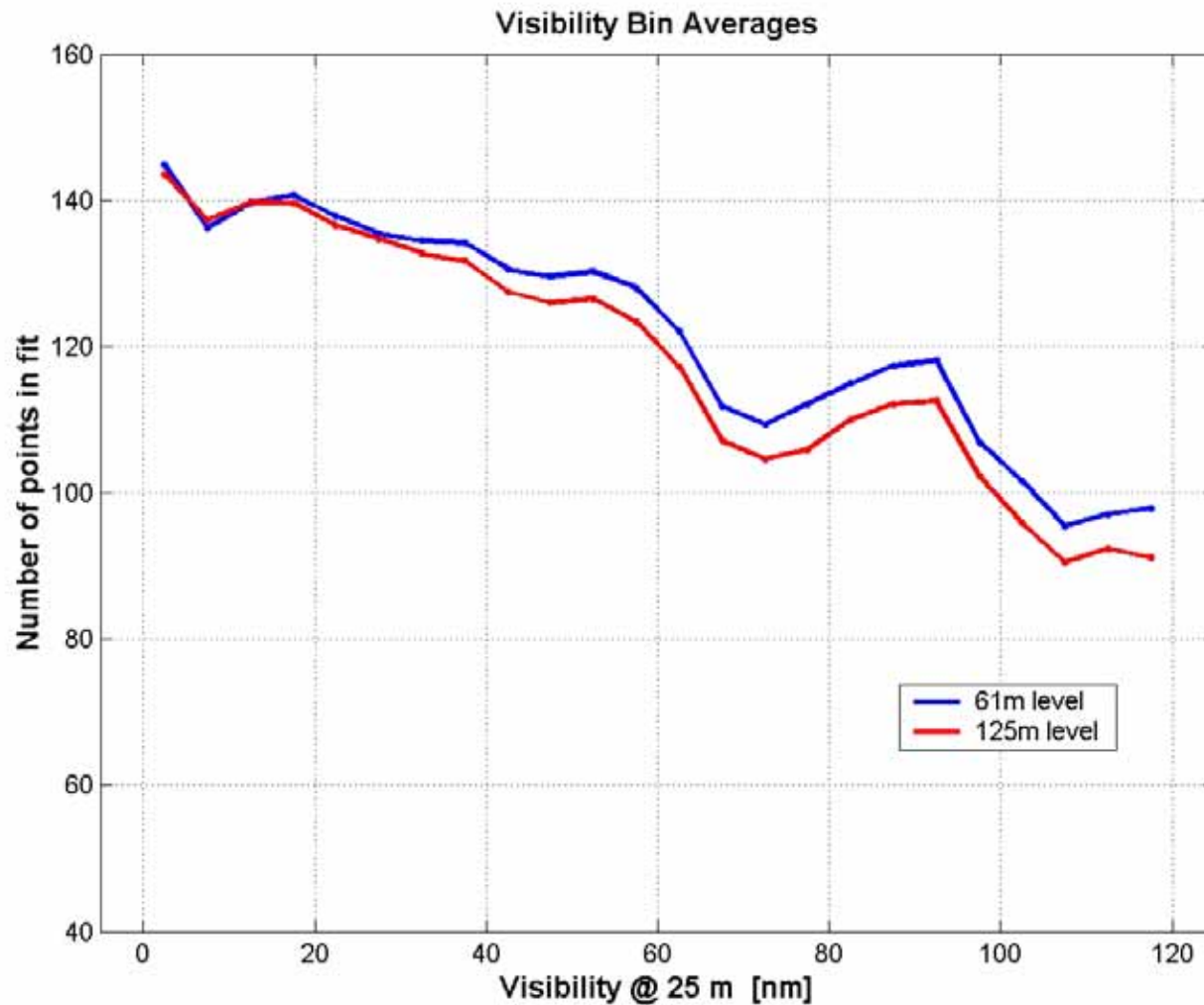
## Quality (PiF) vs. Visibility

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## Quality (PiF) vs. Visibility

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| Case |              | 2nd Period                                        |                             |     |       |       |
|------|--------------|---------------------------------------------------|-----------------------------|-----|-------|-------|
|      | WD Sector    | 15°-75°,<br>105°-165°,<br>195°-255°,<br>295°-345° | 30° to 90° and 180° to 240° |     |       |       |
|      | Meas. Height | 103 m                                             | 81                          | 61  | 81    | 61    |
|      | Anemometer   | CUP                                               | CUP                         | CUP | SONIC | SONIC |
|      |              | WS range: 4 to 16 m/s                             |                             |     |       |       |

| I. Without Filtering          |      |      |      |      |      |  |
|-------------------------------|------|------|------|------|------|--|
| 10-min-avg. values            | 6005 | 2589 | 2749 | 3228 | 3245 |  |
| Slope "m"                     | 0,98 | 0,97 | 0,98 | 1,01 | 1,01 |  |
| Regr. Coeff "R <sup>2</sup> " | 0,99 | 0,99 | 1,00 | 0,99 | 1,00 |  |

| II. Precipitation NO          |      |      |      |      |      |  |
|-------------------------------|------|------|------|------|------|--|
| 10-min-avg. values            | 5460 | 2234 | 2370 | 2876 | 2881 |  |
| Slope "m"                     | 0,98 | 0,97 | 0,98 | 1,01 | 1,01 |  |
| Regr. Coeff "R <sup>2</sup> " | 0,99 | 0,99 | 1,00 | 1,00 | 1,00 |  |

| III. Precipitation YES        |      |      |      |      |      |  |
|-------------------------------|------|------|------|------|------|--|
| 10-min-avg. values            | 545  | 355  | 379  | 352  | 364  |  |
| Slope "m"                     | 0,98 | 0,97 | 0,98 | 1,00 | 1,00 |  |
| Regr. Coeff "R <sup>2</sup> " | 0,99 | 0,99 | 0,99 | 0,99 | 0,99 |  |

→ No precipitation influence



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## Precipitation Offshore

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|        |              |              |  |  |
|--------|--------------|--------------|--|--|
| Sector | 125° to 255° | 180° to 255° |  |  |
|--------|--------------|--------------|--|--|

| No Filtering [a]              | CUP   | CUP  | CUP  | SONIC |
|-------------------------------|-------|------|------|-------|
| 2 <sup>nd</sup> Period        | 120 m | 90 m | 60 m |       |
| 10-min-avg. values            | 2532  | 1688 | 1577 | 1568  |
| Slope "m"                     | 0.95  | 0.97 | 0.99 | 1.00  |
| Regr. Coeff "R <sup>2</sup> " | 0.96  | 0.97 | 0.95 | 0.93  |

| Precipitation NO [b]          | CUP   | CUP  | CUP  | SONIC |
|-------------------------------|-------|------|------|-------|
| 2 <sup>nd</sup> Period        | 120 m | 90 m | 60 m |       |
| 10-min-avg. values            | 1787  | 1209 | 1146 | 1133  |
| Slope "m"                     | 0.95  | 0.97 | 0.98 | 0.99  |
| Regr. Coeff "R <sup>2</sup> " | 0.96  | 0.97 | 0.95 | 0.95  |

| Precipitation YES [c]         | CUP   | CUP  | CUP  | SONIC |
|-------------------------------|-------|------|------|-------|
| 2 <sup>nd</sup> Period        | 120 m | 90 m | 60 m |       |
| 10-min-avg. values            | 745   | 479  | 431  | 435   |
| Slope "m"                     | 0.96  | 0.98 | 1.00 | 1.01  |
| Regr. Coeff "R <sup>2</sup> " | 0.96  | 0.97 | 0.93 | 0.89  |

→ No significant precipitation influence



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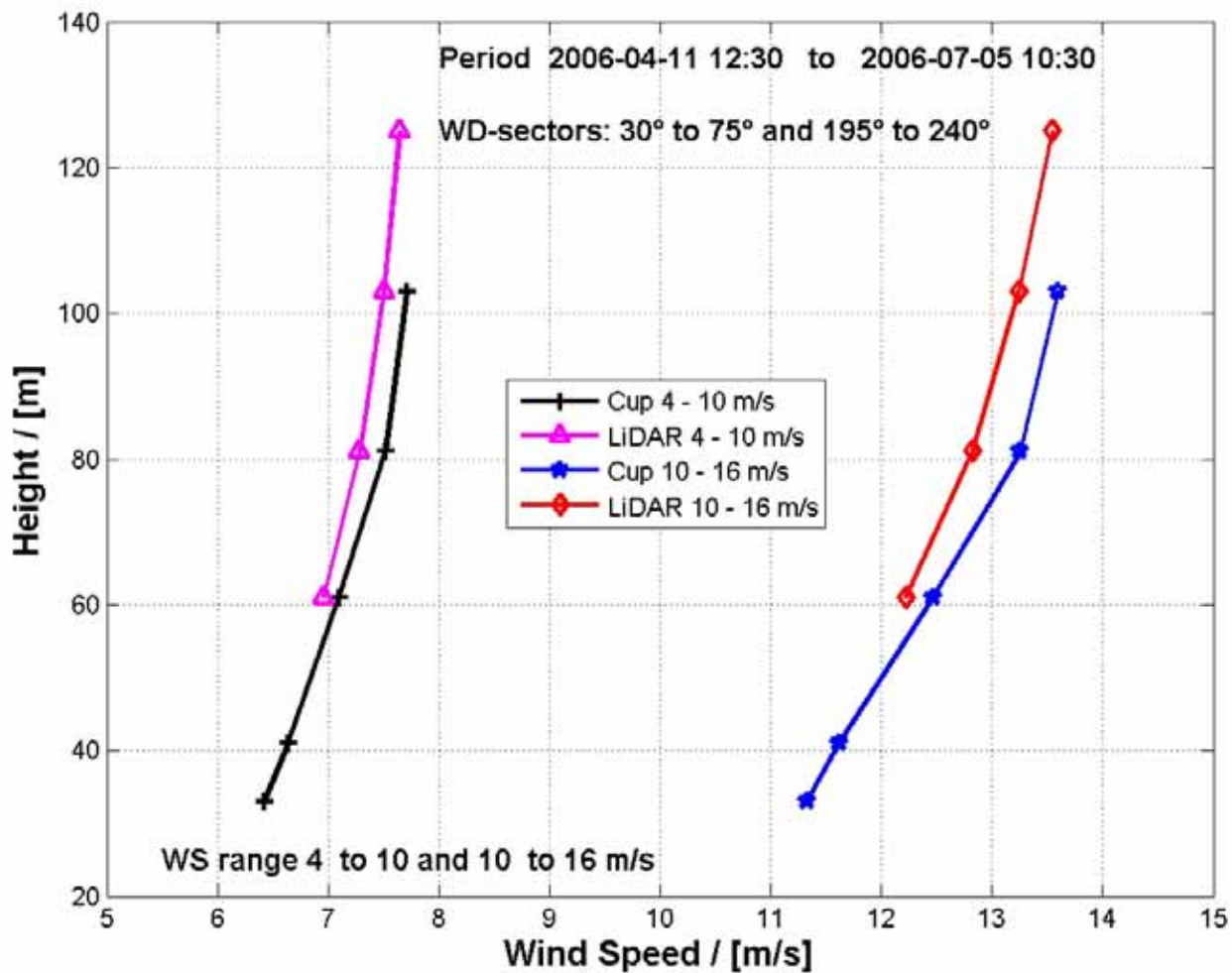
## Precipitation Onshore

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## Profiles Offshore

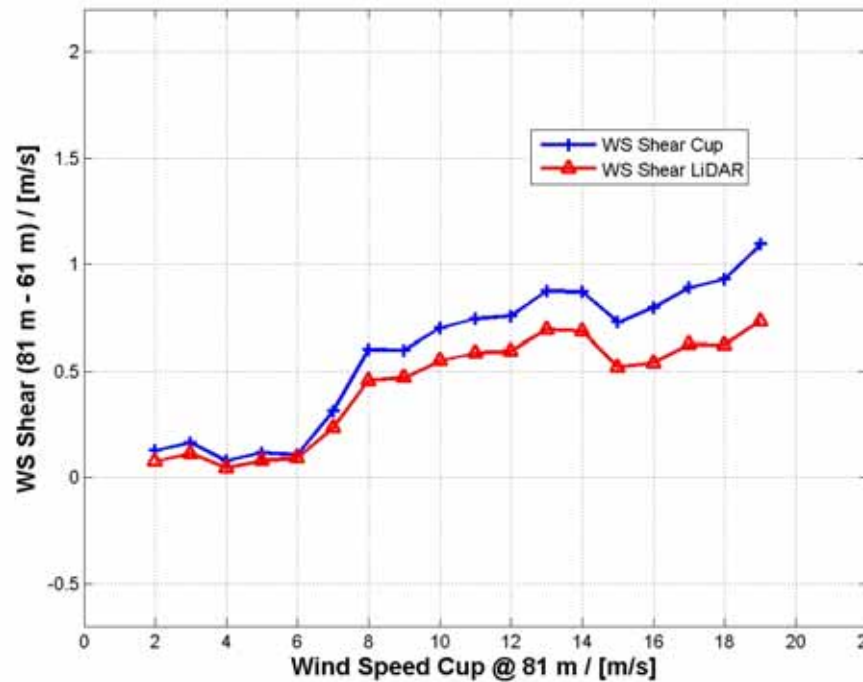
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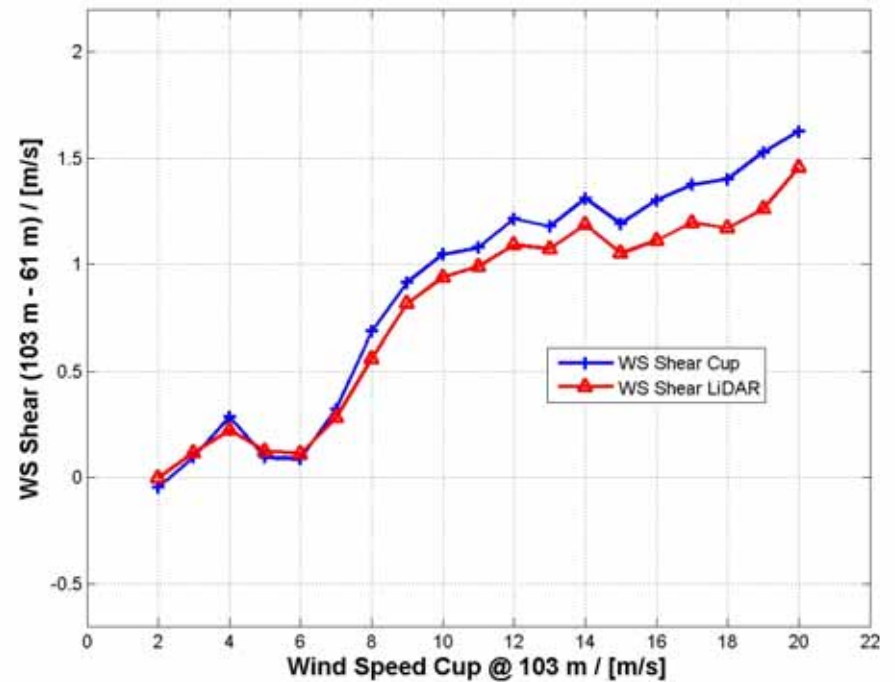
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Vertical Shear ( $WS_{81} - WS_{61}$ ), WS-Bin Averages



Vertical Shear ( $WS_{103} - WS_{61}$ ), WS-Bin Averages



## WS Shear Offshore (%)



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## Twin Experiment

### Device to Device



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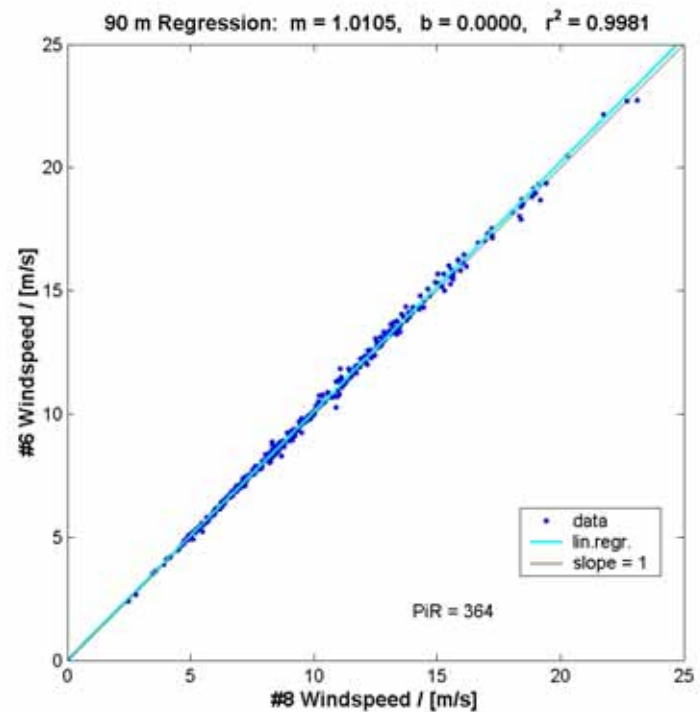
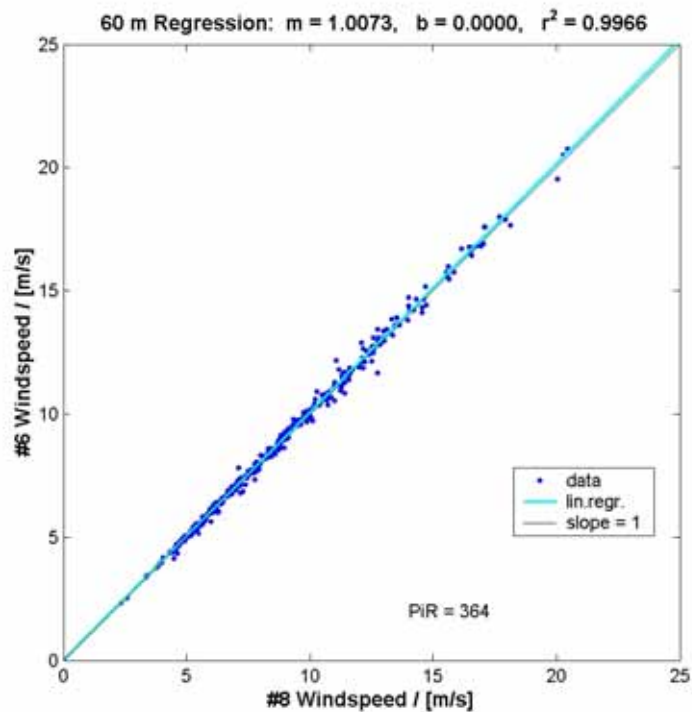
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## Device to Device

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# Technical Experiences

- handling, general
- setup on site
- theft pre-cautions
- data retrieval
- wind data acquisition
- turbulence measures



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## Technical Experiences

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# Challenges Offshore

- accessibility
- structural stability
- weather during erection
- proximity to mast / available space
- power supply
- screen clearance, salt & spray
- debris from birds
- corrosion: joints and aluminium parts
- remote control & data retrieval



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## Challenges Offshore

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# Acceptance and Standardized Application

- perform a number of real applications to increase experiences and knowledge of the system
- share experiences within the user community
  - scientific
  - best practice application
- create reproducible calibration procedures
  - focal length
  - absolute wind speed accuracy
- assure device to device reproducibility
- test site and position independent behaviour of system
- test each device individually against same standard prior to (and after?) actual deployment



# Applications & Options

- wind resource studies
- power performance tests
  - profiles over rotor plane
- site assessments
  - Turbulence
  - WS WD shear
  - Max. WS
- gust forecasting
- wind turbine wake studies

