UNIVERSIDADE FEDERAL
DE SANTA CATARINA

LEPTEN
Laboratórios de Engenharia de Processos
de Conversão e Tecnologia de Energia

Lidar measurements validation under coastal condition

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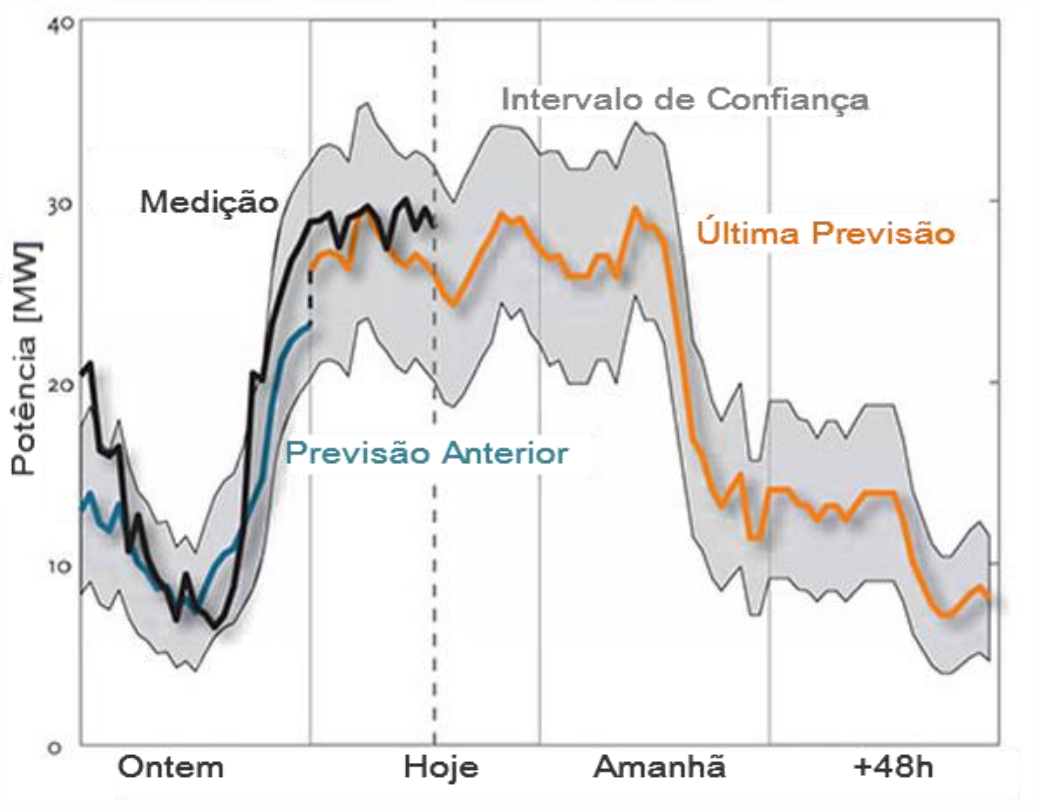
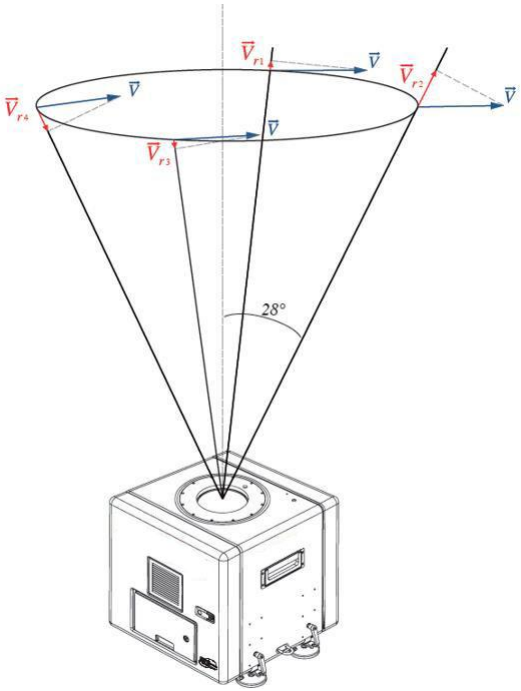
VIII WORKSHOP LIDAR MEASUREMENTS IN LATIN AMERICA

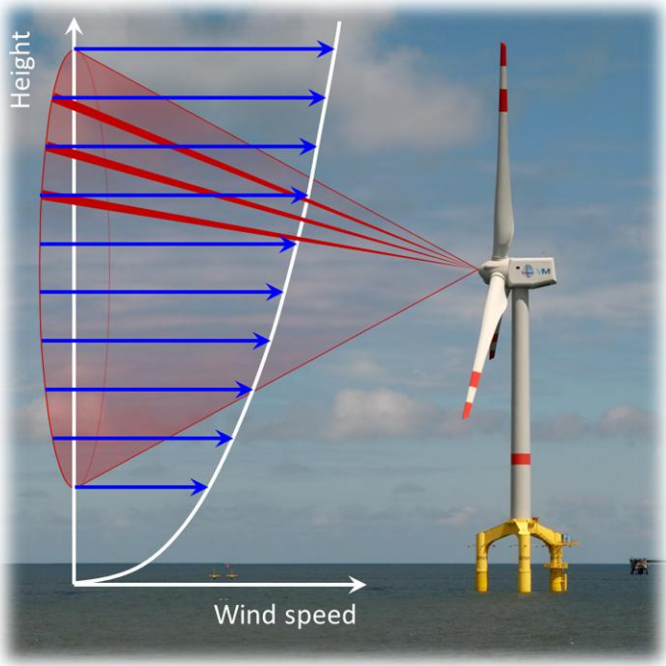
April 9th, 2014
Lidar applications for environmental sciences
VIII Workshop in Lidar Measurements
in Latin America
Cayo Coco, Cuba

- **3-years R&D Project UFSC-IFSC-Tractebel Energia S.A. (GDF Suez);**
- **EUR 800,000.00 (Hardware + Software + HR) from 2011 to 2014;**
- **Short-term (72h) wind power forecasting software;**



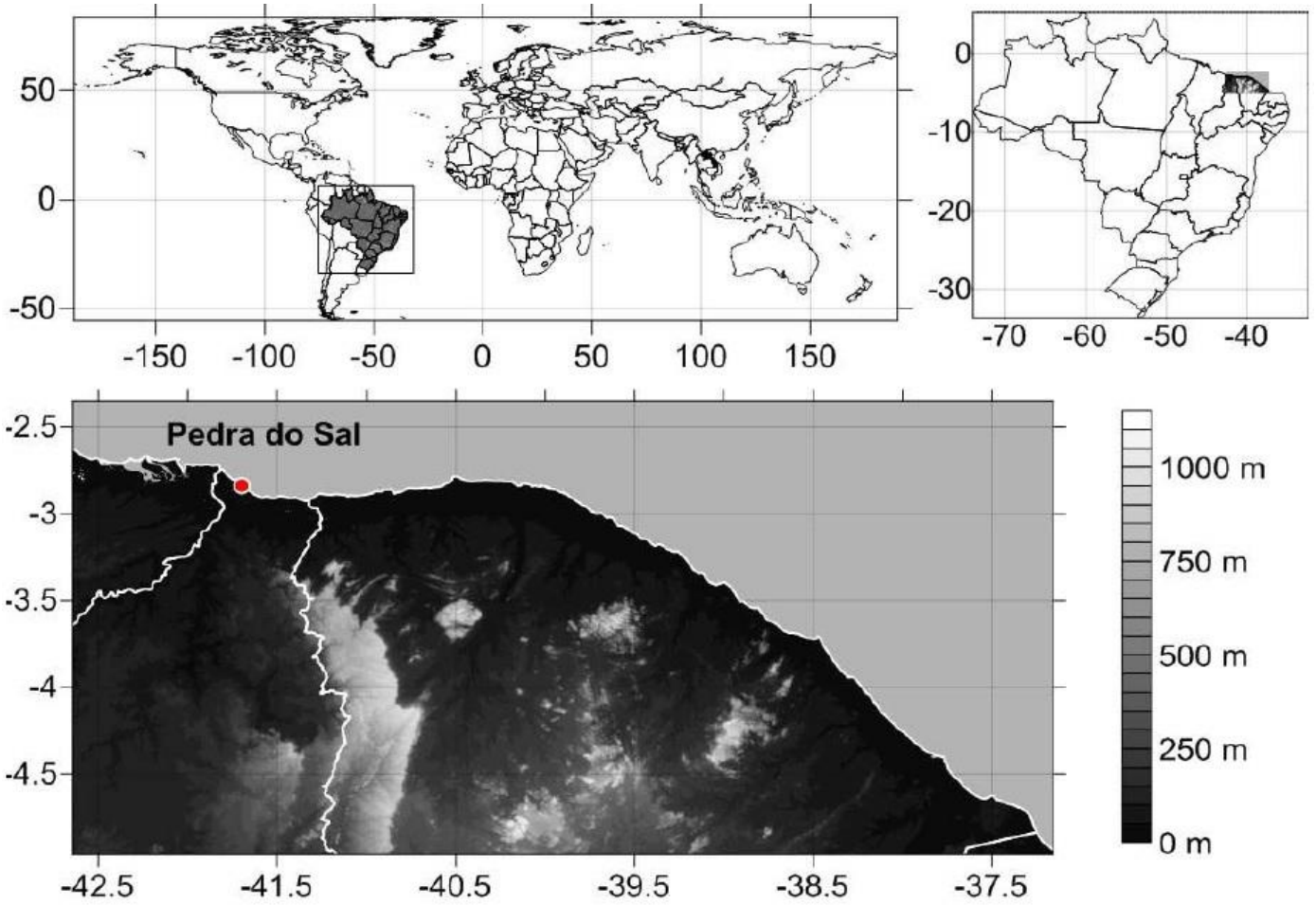
- **Lidar technology being used in wind energy applications;**
- **Data validation under distinct atmospheric conditions;**



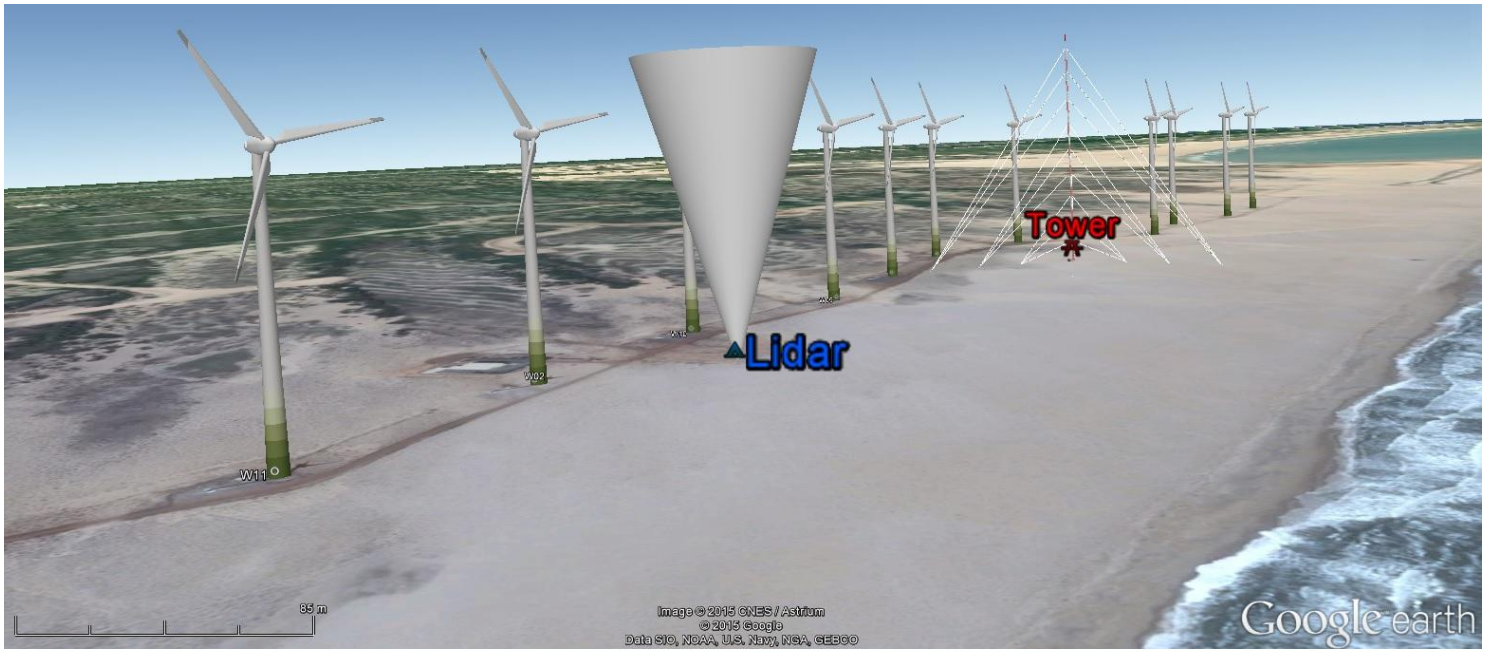


- Few studies with **long-term measurement campaign** (1 year or more);
- Validate seasonal effects and winds at coastal conditions;
- Minimize the drawbacks of being an **end-user**;

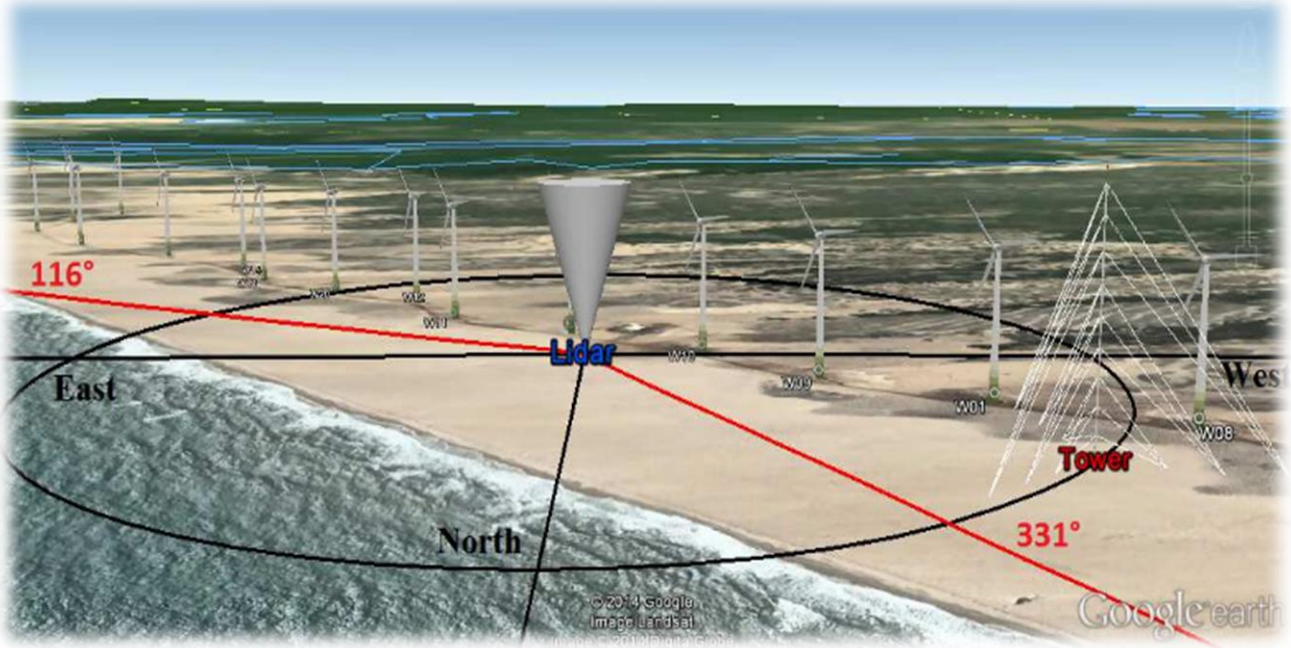
- **Experiment set at the Brazilian northeast coast;**

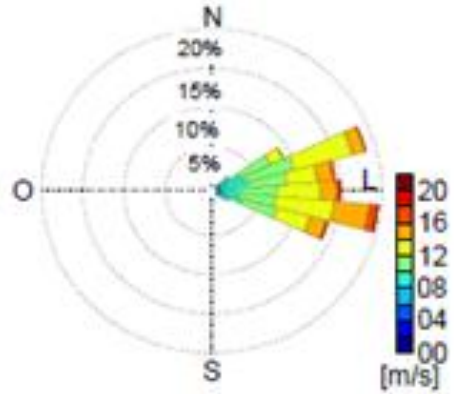


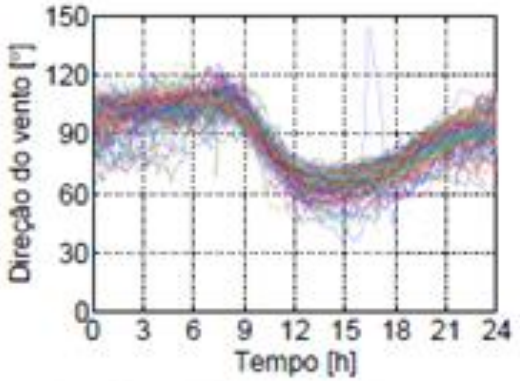
- Inside **Pedra do Sal Wind Farm**: 18MW of installed capacity;
- **Windcube® 8** lidar and a **100m** meteorological **mast**;



- **Lidar and tower: 150m upwind the turbines and 300m from the shoreline;**
- **The wind turbines array is aligned with the coast and with the prevaling wind;**
- **Measurement equipments are 565m apart each other;**







Sakagami, Y et al. Wind shear assessment using wind LIDAR profiler and sonic 3D for wind energy applications – Preliminary Results. In: **XIII World renewable Energy Congress**. London, 2014.

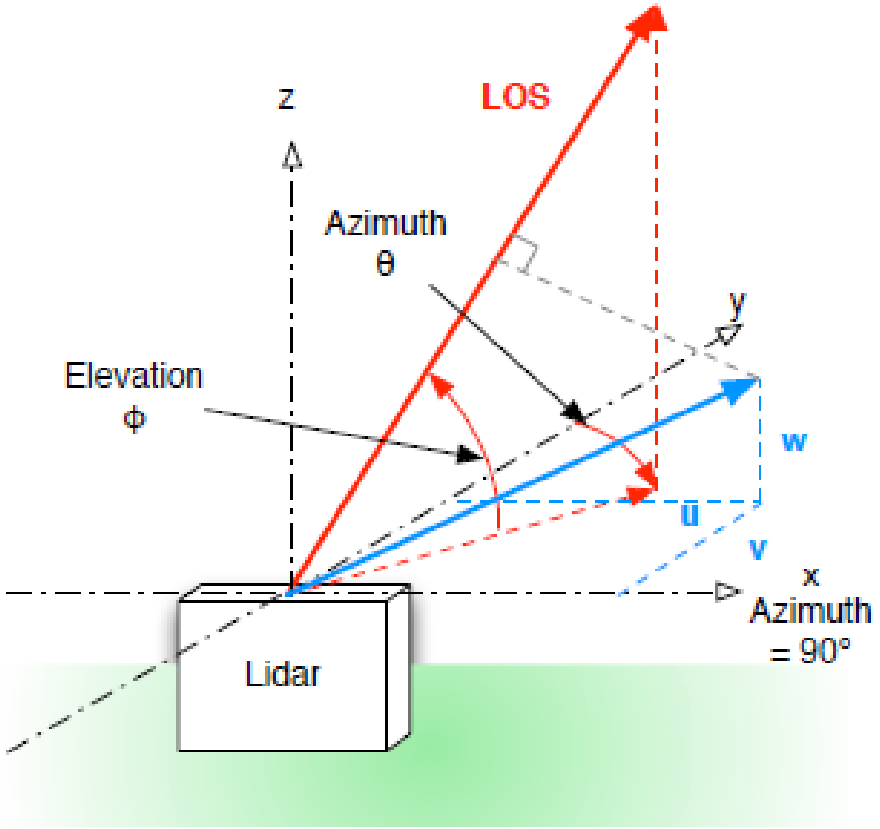
- **Manufacturer:** Leosphere (France)
- **Model:** Windcube® 8
- **Consumption:** 400W (LiDAR), 800W (A/C)
- **Weight:** ~100kg + 100kg (A/C)
- **Dimensions:** 950x650x550mm
- **Connection:** GSM and Ethernet
- **Final Cost:** ~EUR 170,000.00

- Vertical Range: 40m to 500m
- Vertical Resolution: 20m
- Time Resolution: ~6s (360º scan)
- Wind data: 10min average
- Wind speed range: 0 to 60 m/s
- Accuracy: < 0.3 m/s
- Prism angle: 14.8º
- Laser: 1.543µm
- Measurement: VAD

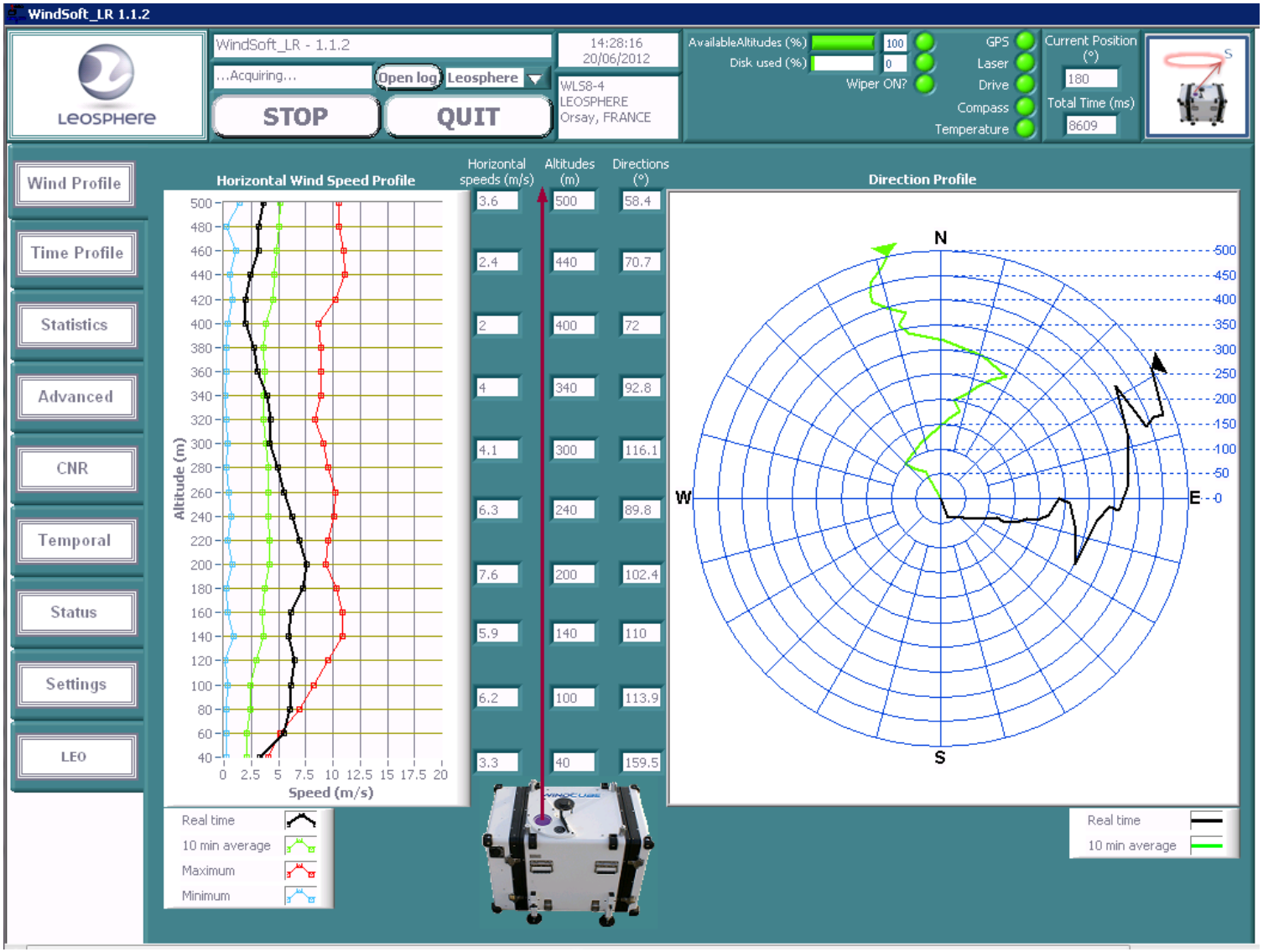
(velocity-azimuth display)

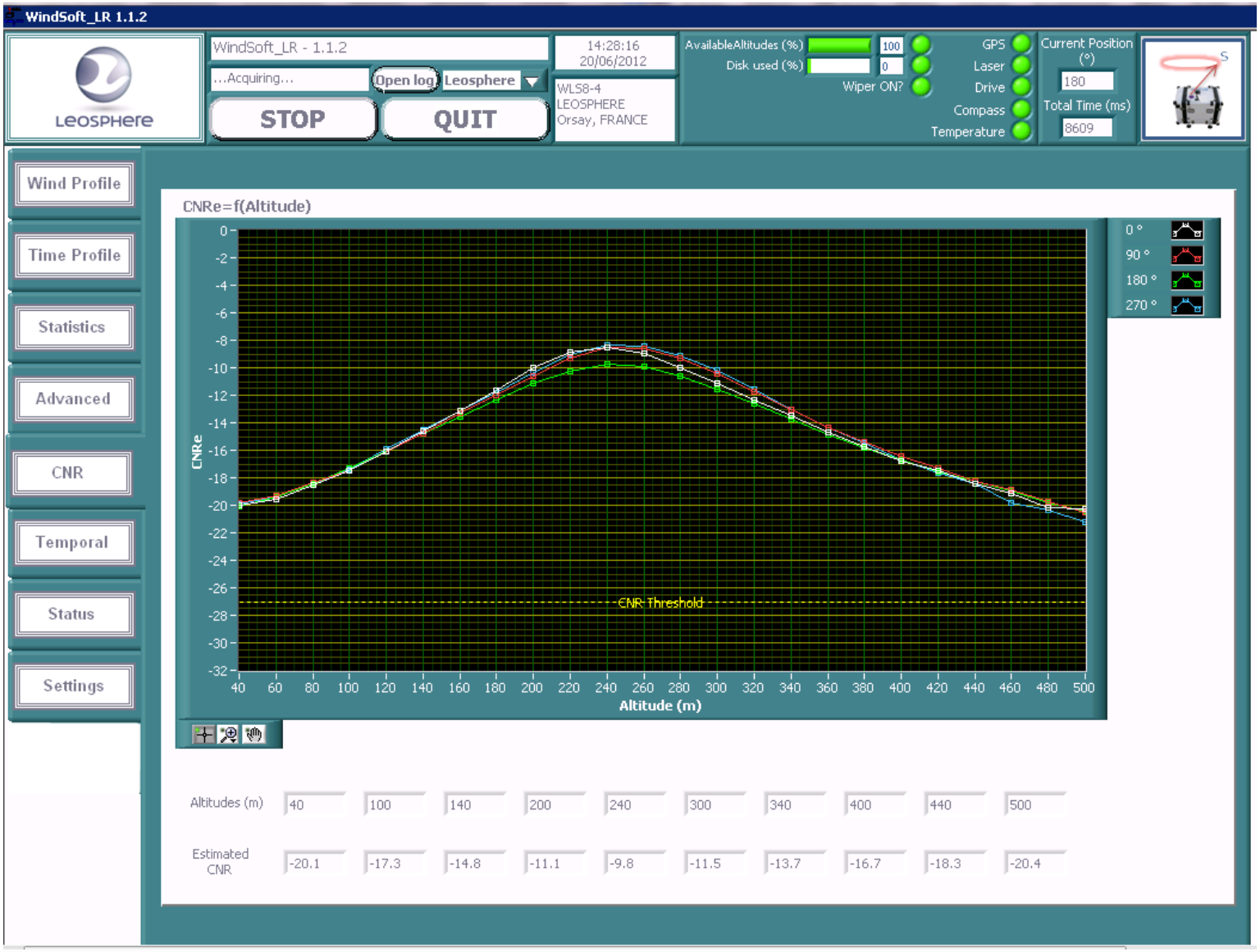
Velocity-azimuth display (VAD):

- **Three measurements needed for distinct Line of Sight (LOS);**
- **4th LOS is the averaged of last three;**
- **Fixed elevation (Φ=75.2°): function of prism angle;**
- **No measurement of real vertical velocity (complex terrain);**
- **Azimuth (θ): North (0°), East (90°), South (180°), West (270°).**



$$\begin{bmatrix} V_{LoS,1} \\ V_{LoS,2} \\ V_{LoS,3} \end{bmatrix} = \begin{bmatrix} \sin\theta_1\cos\phi_1 & \cos\theta_1\cos\phi_1 & \sin\phi_1 \\ \sin\theta_2\cos\phi_2 & \cos\theta_2\cos\phi_2 & \sin\phi_2 \\ \sin\theta_3\cos\phi_3 & \cos\theta_3\cos\phi_3 & \sin\phi_3 \end{bmatrix} \cdot \begin{bmatrix} u \\ v \\ w \end{bmatrix}$$


WindSoft_LR 1.1.2
WindSoft_LR - 1.1.2
...Acquiring...
Open log
Leosphere
STOP
QUIT
14:28:16
20/06/2012
WLS8-4
LEOSPHERE
Orsay, FRANCE
AvailableAltitudes (%)
Disk used (%)
Wiper ON?
GPS
Laser
Drive
Compass
Temperature
Current Position (°)
Total Time (ms)
Wind Profile
Time Profile
Statistics
Advanced
CNR
Temporal
Status
Settings
LEO
Horizontal Wind Speed Profile
Altitude (m)
Speed (m/s)
Horizontal speeds (m/s)
Altitudes (m)
Directions (°)
Direction Profile
Real time
10 min average
Maximum
Minimum


WindSoft_LR 1.1.2
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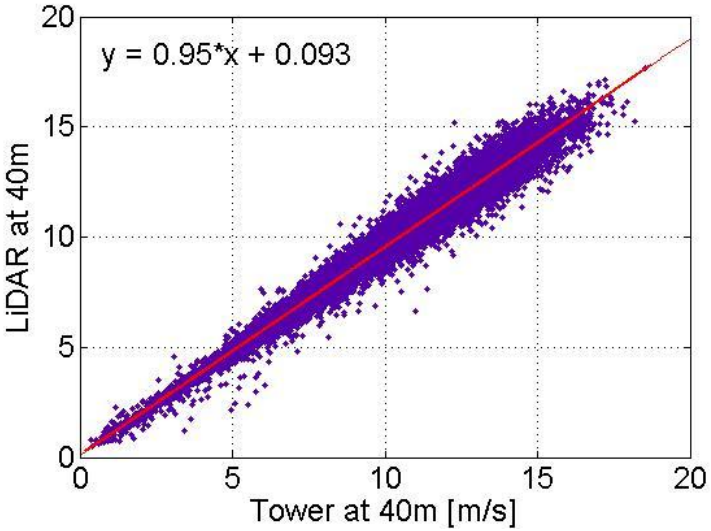
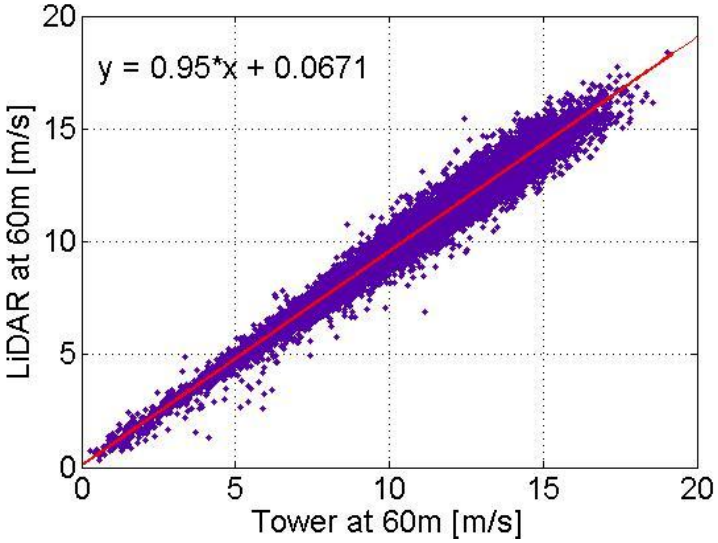
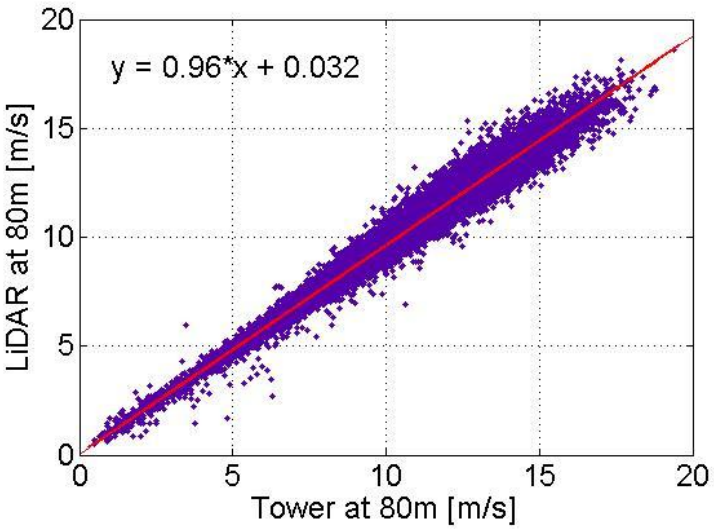
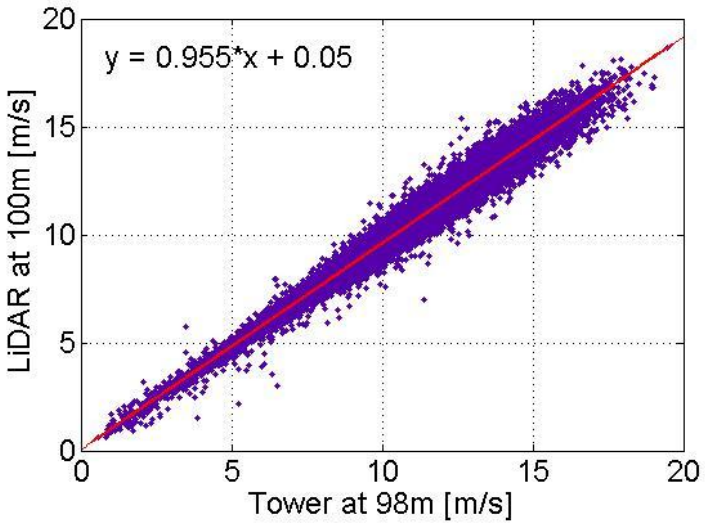
Temperature
Current Position (°)
Total Time (ms)
Wind Profile
Time Profile
Statistics
Advanced
CNR
Temporal
Status
Settings
CNRe=f(Altitude)
CNRe
Altitude (m)
CNR Threshold
0 °
90 °
180 °
270 °
Altitudes (m)
Estimated CNR

- Dataset covers a **continuous 1-year period** from August 2013 to September 2014;
- **Five** wind speed lidar levels are compared with met mast: 40m, 60m, 80m, 100m and 100m from a 3D sonic anemometer;
- **10min average** data is used only with **100% data availability** from the LiDAR;
- The behavior of the **wind speed bias** is analyzed (skewness and kurtosis);
- **Recovery rate** for Lidar data reached **66% up to 400m** for the 1-year period;
- **Met mast data** presented na average **recovery rate of 99,97%**.

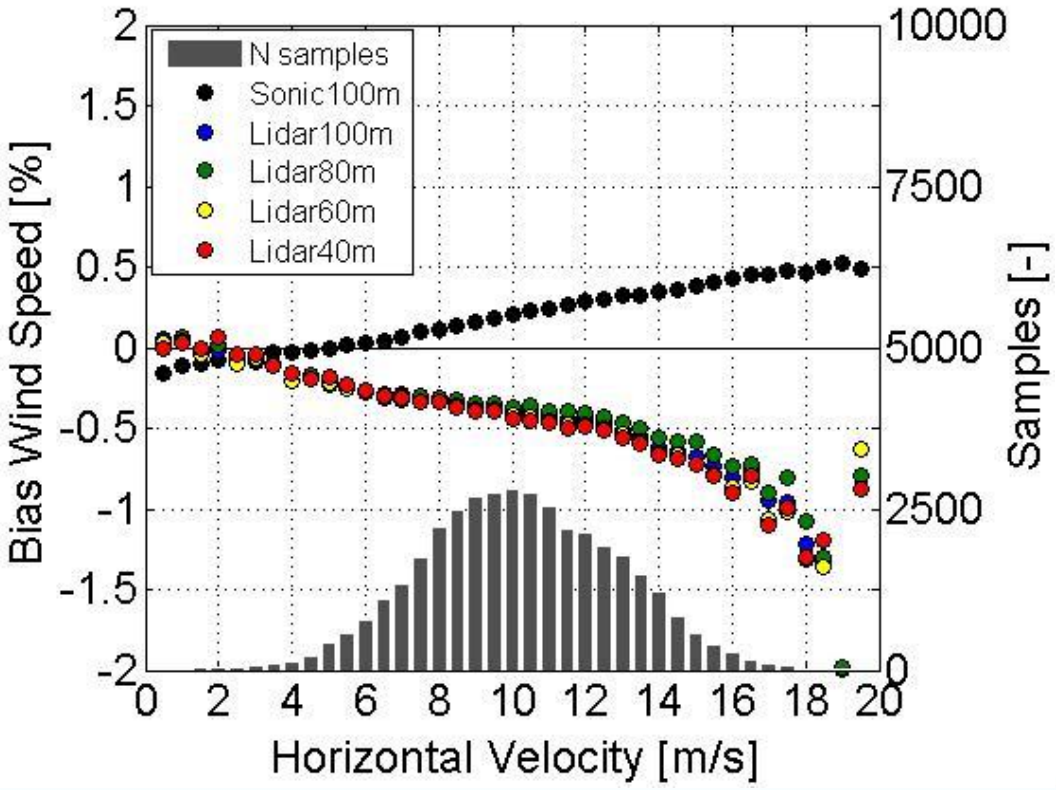

y = 0.95*x + 0.093
LiDAR at 40m
Tower at 40m [m/s]
0
5
10
15
20


y = 0.95*x + 0.0671
LiDAR at 60m [m/s]
Tower at 60m [m/s]
0
5
10
15
20


y = 0.96*x + 0.032
LiDAR at 80m [m/s]
Tower at 80m [m/s]
0
5
10
15
20


y = 0.955*x + 0.05
LiDAR at 100m [m/s]
Tower at 98m [m/s]
0
5
10
15
20

- Lidar presented a **systematic underestimation** (bias) of tower wind speed;
- **Increasing bias** for **high wind speed values**, see also Risø (2010) and CRES (2011);
- **Non-linear behavior** of bias with wind speed values.



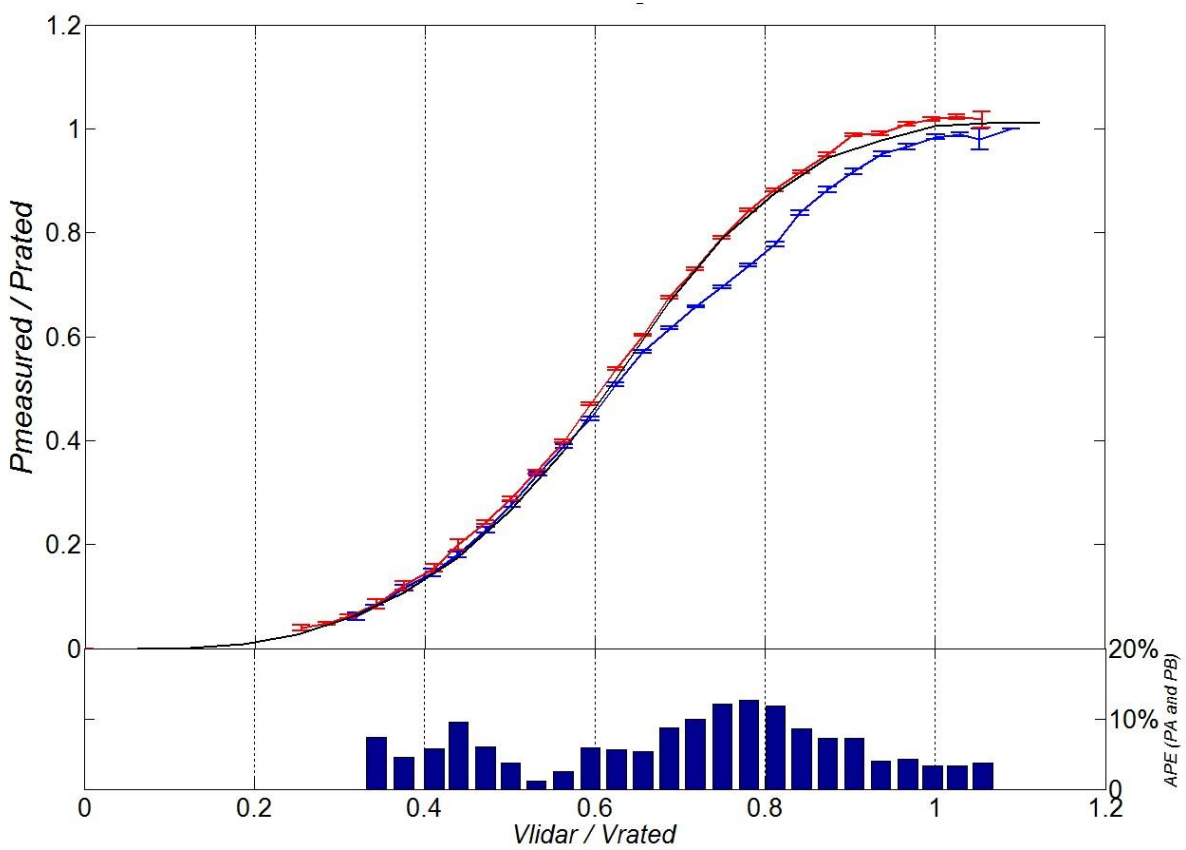
- The bias is higher than the manufacturer threshold (< 0.3 m/s) for all evaluated lidar heights. Confirmed by a high kurtosis and negative skewness (see table);
- Good correlation between lidar and tower for all heights;
- 3D sonic anemometer used as reference with cup anemometry at met mast;

Height	40m	60m	80m	100m	Sonic
Bias	-0.44	-0.43	-0.38	-0.41	0.21
Skewness	-0.49	-0.44	-0.18	-0.43	0.00
Kurtosis	5.77	5.50	5.45	6.04	2.93
RMSE	0.62	0.61	0.57	0.57	0.25
Slope	0.94	0.95	0.96	0.95	1.04
R^2	0.97	0.97	0.97	0.98	1.00

- Wind lidar presented a **fair correlation** with reference met mast during a **continuos 1-year** measurement campaign;
- The significant bias identified can be related with **atmospheric conditions** (next presentation);
- **Reprocessment of raw spectra** can be helpfull (*.dsp files);
- Source of such deviations are **open for discussion**;

Appendix A

- **Power output 3% difference spotted in operational power curve with lidar wind speed;**



Santos, P. A. A. et al. Monitoring power performance of operational wind farms using LiDAR wind profiler. In: **AWEA Windpower 2015,** Orlando, 2015 (*accepted*).

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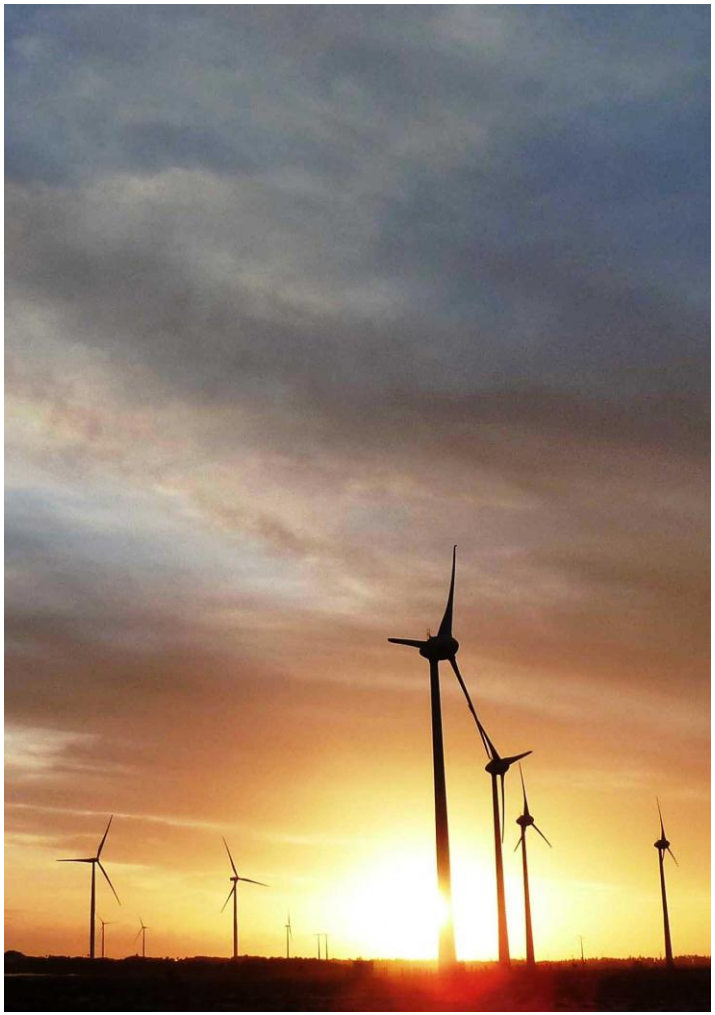

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Acknowledgments:

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