Wind Energy Converter Wake Characterization by Means of Lidar Measurements in the Context of Perdigão 2017

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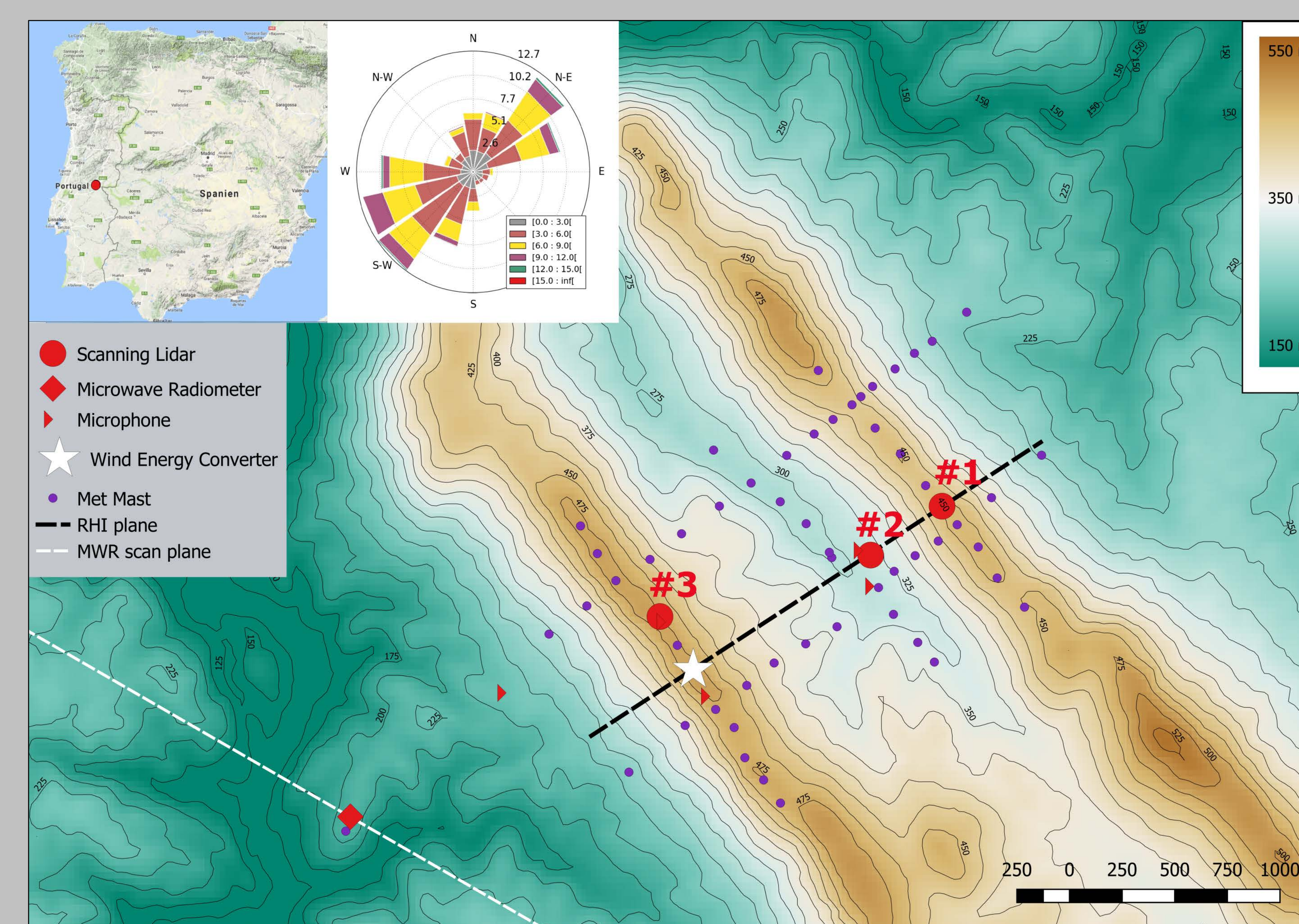
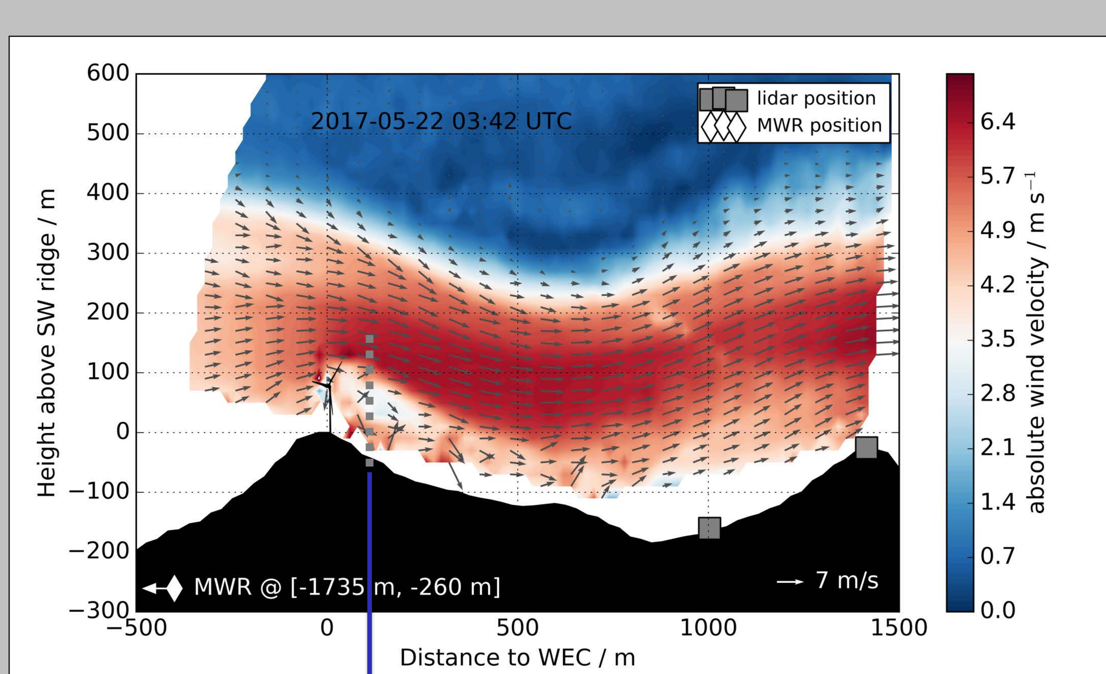
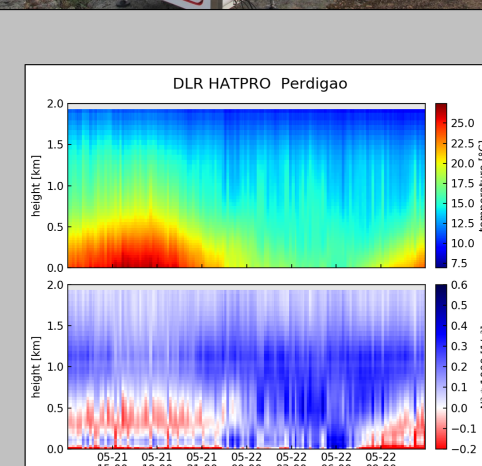
Introduction

- Wind-energy in complex terrain is of great importance for the energy transition towards renewable energies, because it enables energy harvesting **close to the consumer** in many regions.
- **Perdigão 2017** was a large field campaign jointly organized by international research groups to investigate the **flow over two parallel mountain ridges** and its interaction with a single Enercon E-82 wind energy converter (WEC) placed on one of the ridges (see map on the right).
- The DLR took part with three Leosphere Windcube 200S **long-range lidar** instruments, one RPG HATPRO-5G microwave radiometer (MWR) and acoustic sensors (microphones) to measure sound propagation of the WEC.

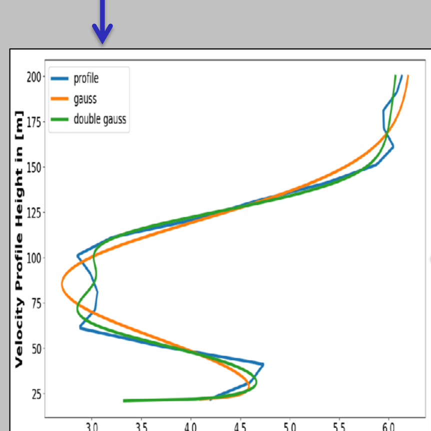


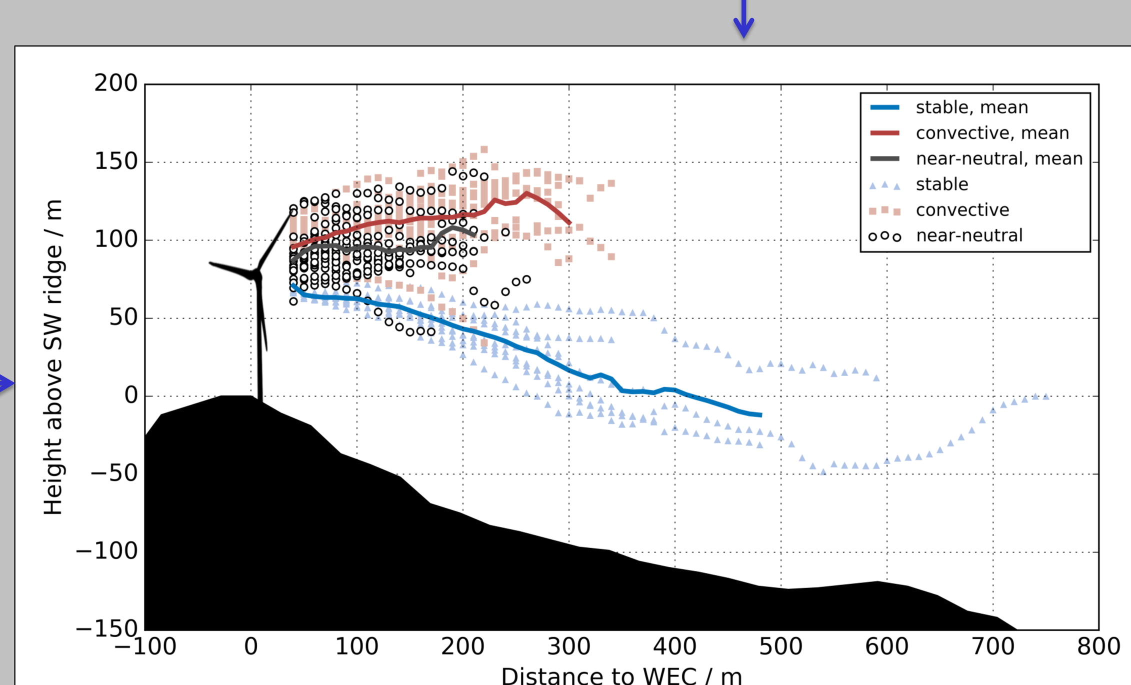




Temperature profiles from MWR for determination of static stability (e.g. Brunt-Väisälä frequency *N*).

Analysis of wake center propagation through fit of Gaussian function.





Coplanar RHI wake scans

- Lidar #1 and lidar #2 were both configured to measure **vertical (RHI) scans at 237°** azimuth, perpendicular to the ridge and towards the WEC.
- Typical RHI parameters for lidar #1 and #2 are:

Physical resolution	**25 m (100 ns pulse length, 64 point FFT)**
Range gate separation	**10 m**
Angular resolution	**0.5°**
Accumulation time	**500 ms**
Duration of one RHI	**1-2 minutes**

- Horizontal and vertical wind of the flow in and over the valley can be calculated from the **dual-Doppler** radial wind speed measurements v_{ri} by solving the geometric equation for the meteorological wind vector u and w, where u is the horizontal wind in the scanning plane, and cross-winds are assumed to be small.

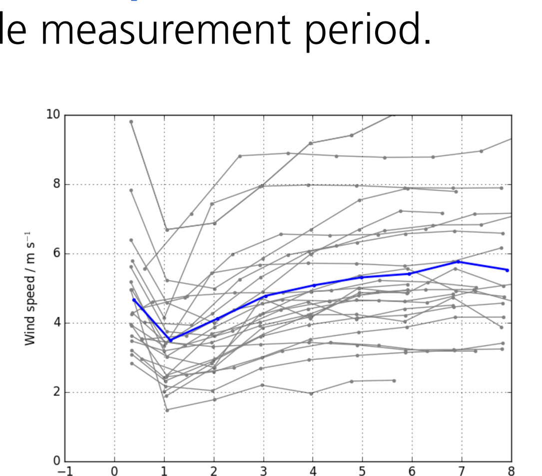
$$\begin{bmatrix} v_{r1} \\ v_{r2} \end{bmatrix} = \begin{bmatrix} \cos\varphi_1 & \sin\varphi_1 \\ \cos\varphi_2 & \sin\varphi_2 \end{bmatrix} \begin{bmatrix} u \\ w \end{bmatrix}$$

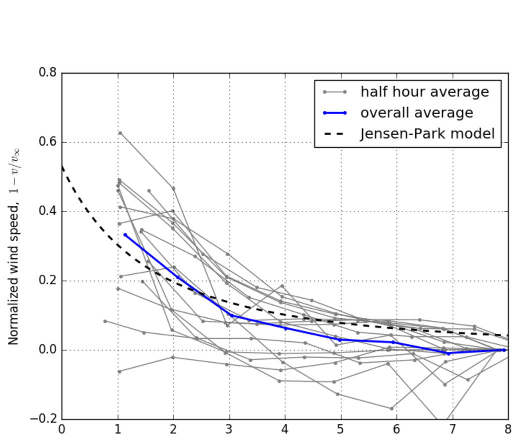
- From the coplanar scans of the wake, its **propagation path in different atmospheric conditions** can be studied (see Figures on the left).
- The wake center was tracked by fitting a superimposed **Gaussian and logarithmic function** to vertical profiles $v(z)$ of wind speed downstream the WEC.

$$v(z) = A_l \ln(b_l z + c) - A_g e^{-\frac{(z-b_g)^2}{2\sigma^2}} + d$$

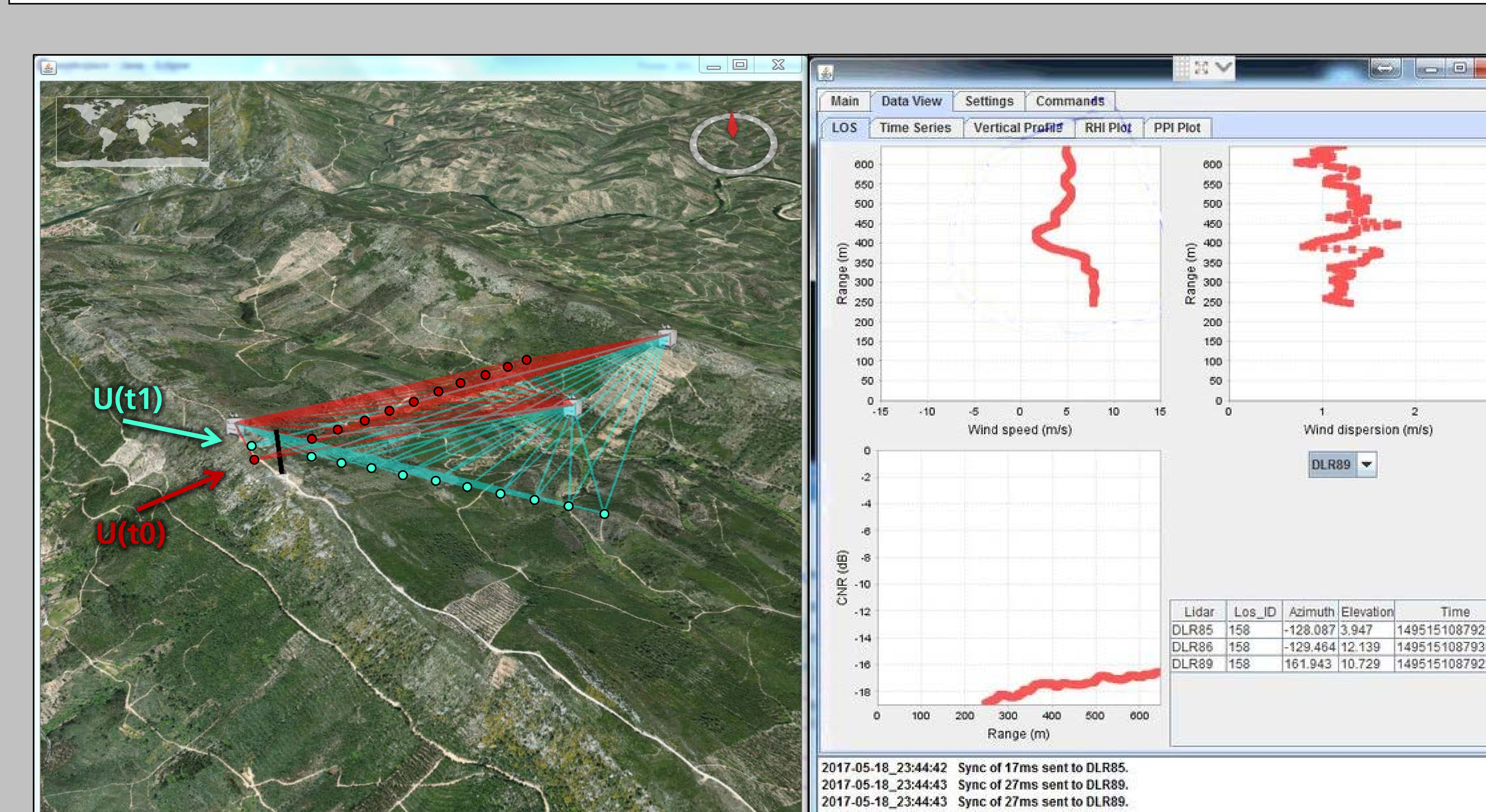
Adaptive multi-Doppler measurement

- Coplanar scans are only useful if the wind direction is aligned with the scanning plane.
- Placing multi-Doppler **measurement points in the wake** (see Figure on the right) is always possible, if the wind direction is known and scanning scenarios are adapted accordingly.
- In Perdigão 2017, case studies have been done with wind direction measurements by **VAD scans** of lidar #3 and real-time data of a **sonic anemometer** on a meteorological mast close to the turbine.
- **Adaptation** of scanning scenario was done **every 30 minutes**.
- The **wind speed deficit** downstream the WEC can be monitored over the whole measurement period.





- Rapid decay of wind speed deficit probably due to misalignment of the measurement points with the wake.
- Improvements could be achieved by using wind turbine yaw, or a real-time wake center estimation for scanning point control.



3D-visualization of scanning scenarios on a virtual globe, automatic calculation of lidar parameters and real-time data display.

Conclusion

- Multiple long-range lidar systems are a powerful tool to measure wake dynamics.
- Adaptive scenarios can increase the availability of ground-based wake measurements significantly, but need good input data.
- Best scanning strategies depend on the scientific goal, the site and the experimental setup. Multi-Doppler measurements with the WindScanner software add significant benefit and a multitude of possibilities to full-scale field experiments in wind-energy research.

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The work presented here is part of the projects LIPS and DFWind which are funded by the Federal Ministry of Economy and Energy on the basis of a resolution of the German Bundestag under the contract numbers 0325518 and 0325936A.

Federal Ministry for Economic Affairs and Energy

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12.03.2018