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Full two-dimensional rotor plane inflow measurements by a spinner-integrated wind lidar

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Introduction

Wind turbine load reduction and power performance optimization via advanced control strategies are active areas in the wind energy community. In particular, feed-forward control using upwind inflow measurements by lidar (light detection and ranging) remote sensing instruments has attracted an increasing interest during the last couple of years[1]. So far, the reported inflow measurements have been along a few measurement directions or at most on a circle in front of the turbine, which is not optimal in a complex inflow such as in the wakes of other turbines. Here, however, we present novel full two-dimensional radial inflow remote measurements.

The field campaign 2012

During the summer of 2012, a proof-of-concept field campaign was conducted. A two-dimensional upwind scanning wind lidar was mounted in the rotating spinner of an operating Vestas NM80 turbine (59 m hub height and 80 m rotor diameter) located at Tjæreborg Enge in western Denmark. The new two-dimensional scanning device including two rotating prisms was integrated on top of a modified ZephIR 300 continuous-wave coherent Doppler lidar (ControlZephIR) operating at a wavelength of 1.565 µm. The lidar was modified to stream averaged Doppler spectra at a rate selectable up to about 500 measure-ments per second. This ensured short enough transversal sampling volumes when the prisms were rotating at maximum speed.

The scanning strategy

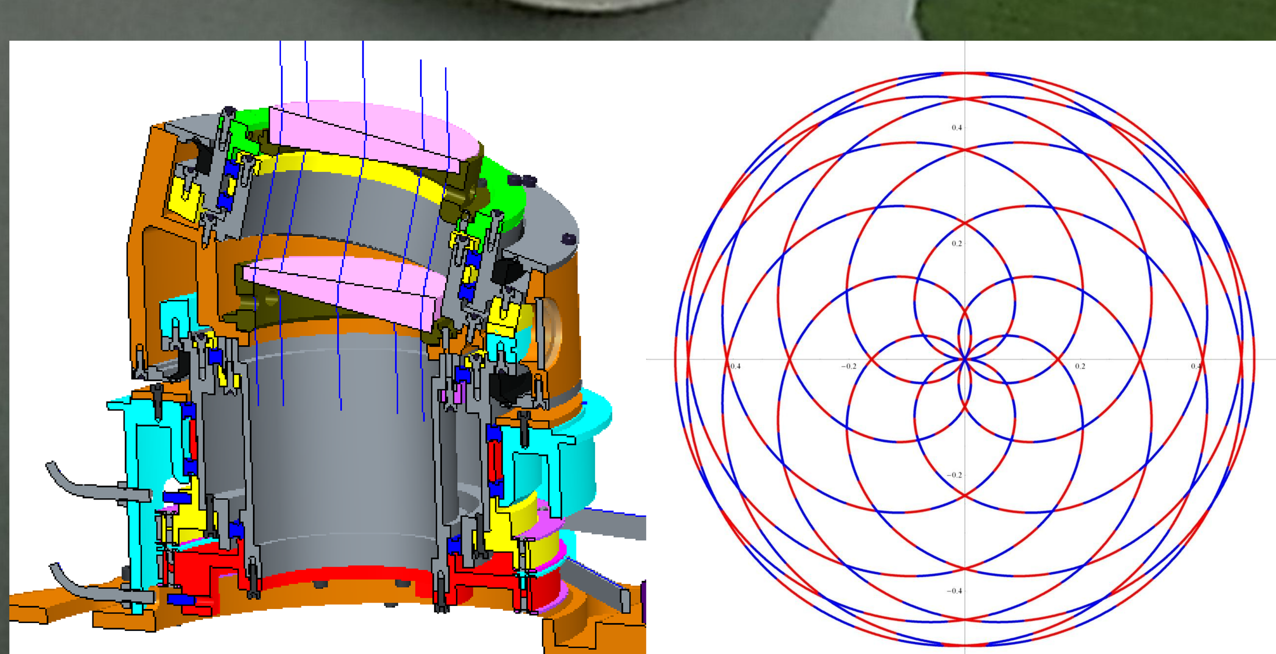
The scanning speed is adjustable and it is possible to complete within only one second a complete two-dimensional scan pattern covering an upwind spherical surface, in the rotating coordinate frame of the spinner, bounded by the perimeter of a cone with its apex in the spinner-mounted lidar and with a full opening angle of 60°.

The actual absolute measurement positions were calculated from the instantaneous positions of the two wedge-shaped optical prisms and the instantaneous azimuth position of the spinner-mounted wind lidar measured by an integrated three-axis accelerometer.

Additional measurements

Turbine parameters such as yaw direction, yaw misalignment and wind speed on top of the nacelle were logged as well as wind at a nearby met mast. Root-bending moments in the blades were acquired by an optical fiber-based strain measurement system. This data will be used in a future analysis to study the correlation between the incoming wind field and the load on the turbine.

In addition, a proof-of-concept trial with a blade mounted lidar was performed during the measurement campaign. This is reported in a separate EWEA 2013 contribution (Abstract ID 460).



The Spinner Lidar approach

In order to achieve full two-dimensional line-of-sight inflow measurements, a special laser beam scanner has been developed at the DTU Wind Energy Department. It is based on two rotating prisms that each deflect the laser beam direction by 15°, resulting in a space filling scan pattern within a full opening angle of 60° on an upwind spherical surface. The scanner is similar to the short-range WindScanner[2] developed at the same department. However, the SpinnerLidar implementation is only using one motor with a fixed gear ratio (7/13) between the two prism axes in order to achieve a reliable implementation for turbine control applications.

References

1. Mikkelsen, T., Angelou, N., Hansen, K., Sjöholm, M., Harris, M., Slinger, C., Hadley, P., Scullion, R., Ellis, G. and Vives, G. (2012), *"A spinner-integrated wind lidar for enhanced wind turbine control"*, Wind Energy, doi: 10.1002/we.1564
2. Sjöholm, M., Angelou, N., Hansen, P., Hansen, K. H., Mikkelsen, T., Haga, S., Silgjerd, J. A., Starsmore N., (2013), *"Two-dimensional rotor-craft downwash flow field measure-ments by lidar-based windscanners with agile beam steering"*, Submitted to J. Atmos. Oceanic Technol.

Conclusion

The study presented here is the novel full two-dimensional continuation of the previous inflow measurements on a circle presented in Ref. 1. The new data set with two-dimensional upwind radial wind speeds poses interesting questions concerning which properties in the measured inflow to extract and how they can be used in wind turbine control algorithms. In summary, this two-dimensional lidar-based turbine inflow measurement technique provides new capabilities and prospects for advanced feed-forward control of turbines in complex inflows.

Acknowledgements

Steen Andreasen (IPU, Lyngby, Denmark) is gratefully acknowledged for the mechanical design of the 2D scan head / the blade lidar telescopes. Karen Enevoldsen, Per Hansen, Kasper Hjorth Hansen and Claus Brian Munk Pedersen (DTU Wind Energy) are gratefully acknowledged for their skilled assistance with electronics, communication software and remote control. Lars Christensen and Michael Rasmussen (DTU Wind Energy) are gratefully acknowledged for their skilled assistance with installation of the lidars. Jens Engholm Pedersen (NKT Photonics) is gratefully acknowledged for his skilled assistance with the optical switch and Dong Energy (Denmark) are gratefully acknowledged for providing access to the NM 80 test turbine at Tjæreborg Enge and the Vestas Service team is acknowledged for safe control and operation of the turbine during the measurement campaign.

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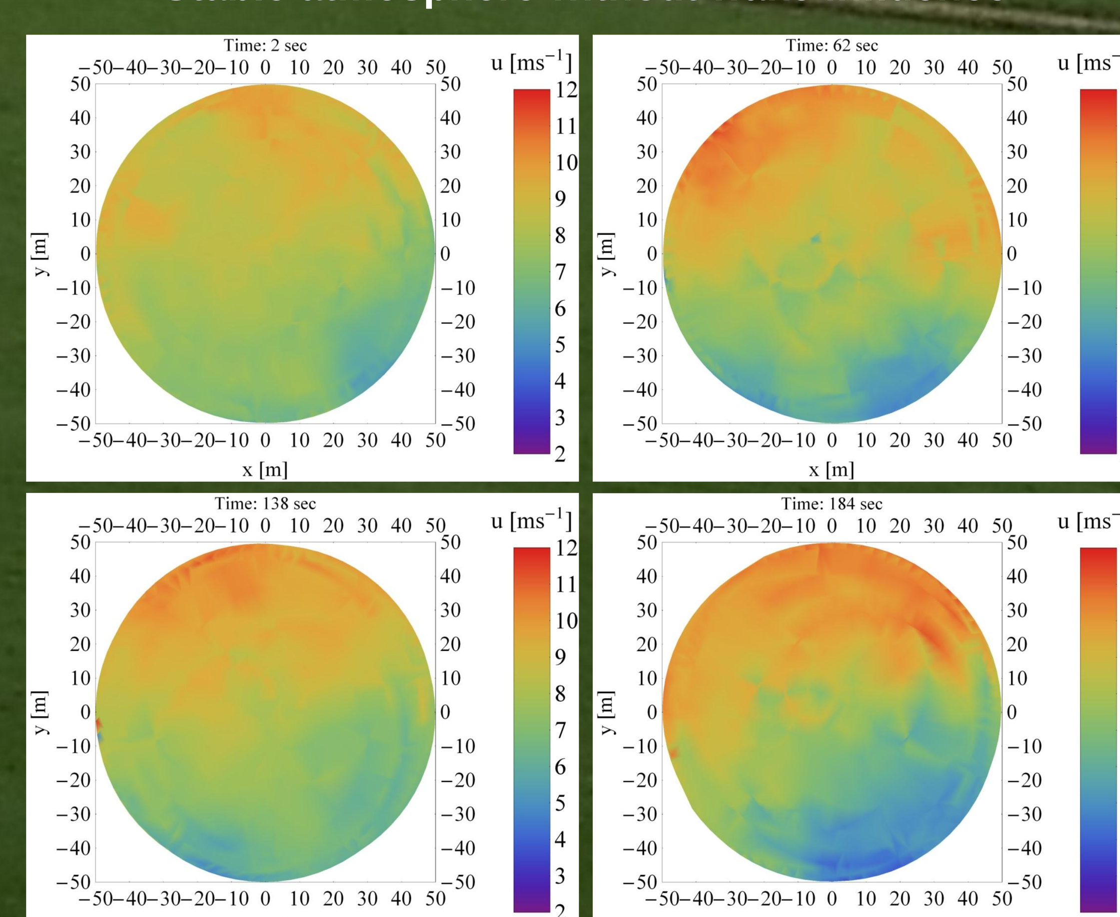
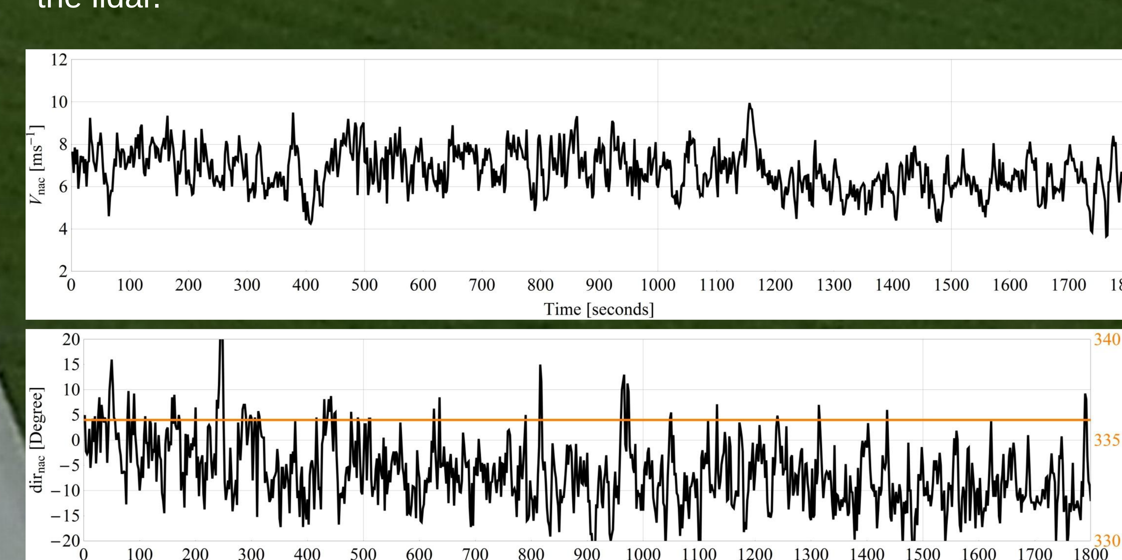
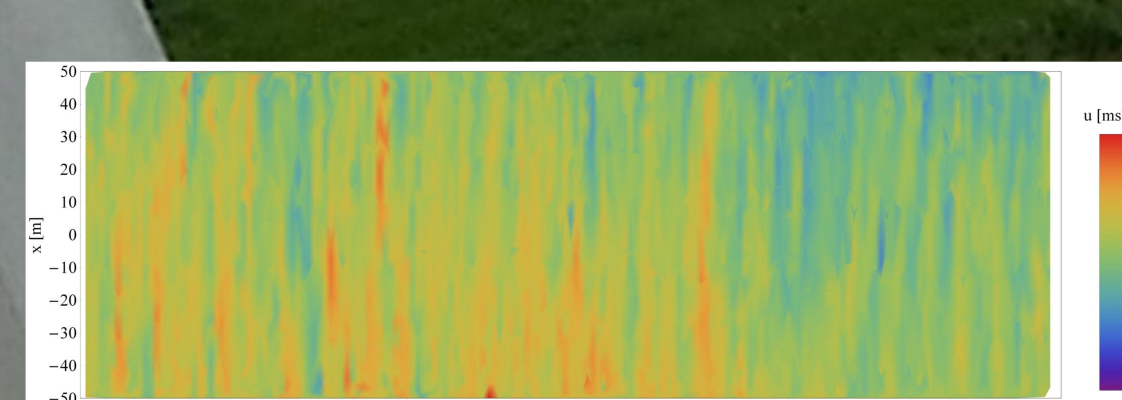
Stable atmosphere without wake influence



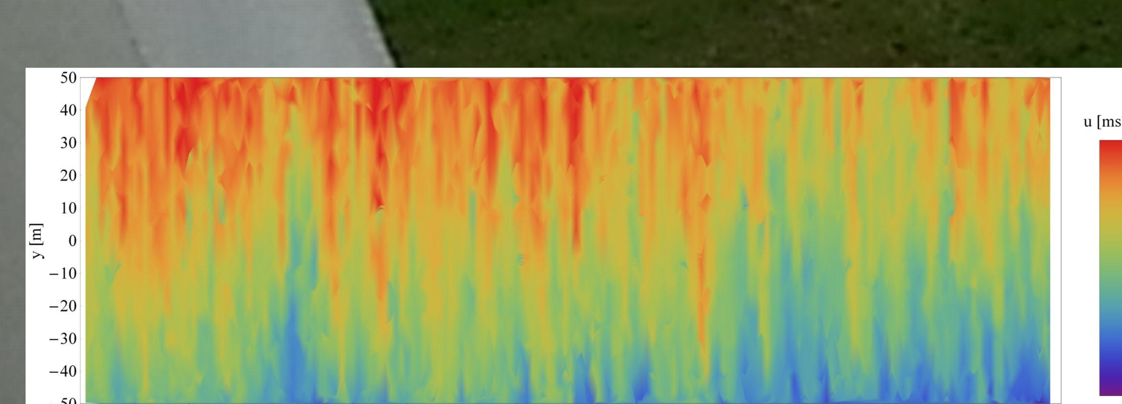
The inflow scanned at night on a spherical surface at a measurement distance of 100 m during periods of 10 seconds without any influence from wakes from nearby turbines. The line-of-sight speeds measured have been converted to axial (along the rotation axis of the wind turbine rotor) wind speeds corresponding to the measured projection along the line-of-sight of the lidar.



The yaw direction of the turbine, yaw misalignment and wind speed measured on top of the nacelle during a period without wakes. The signals are down-sampled to 0.5 Hz.

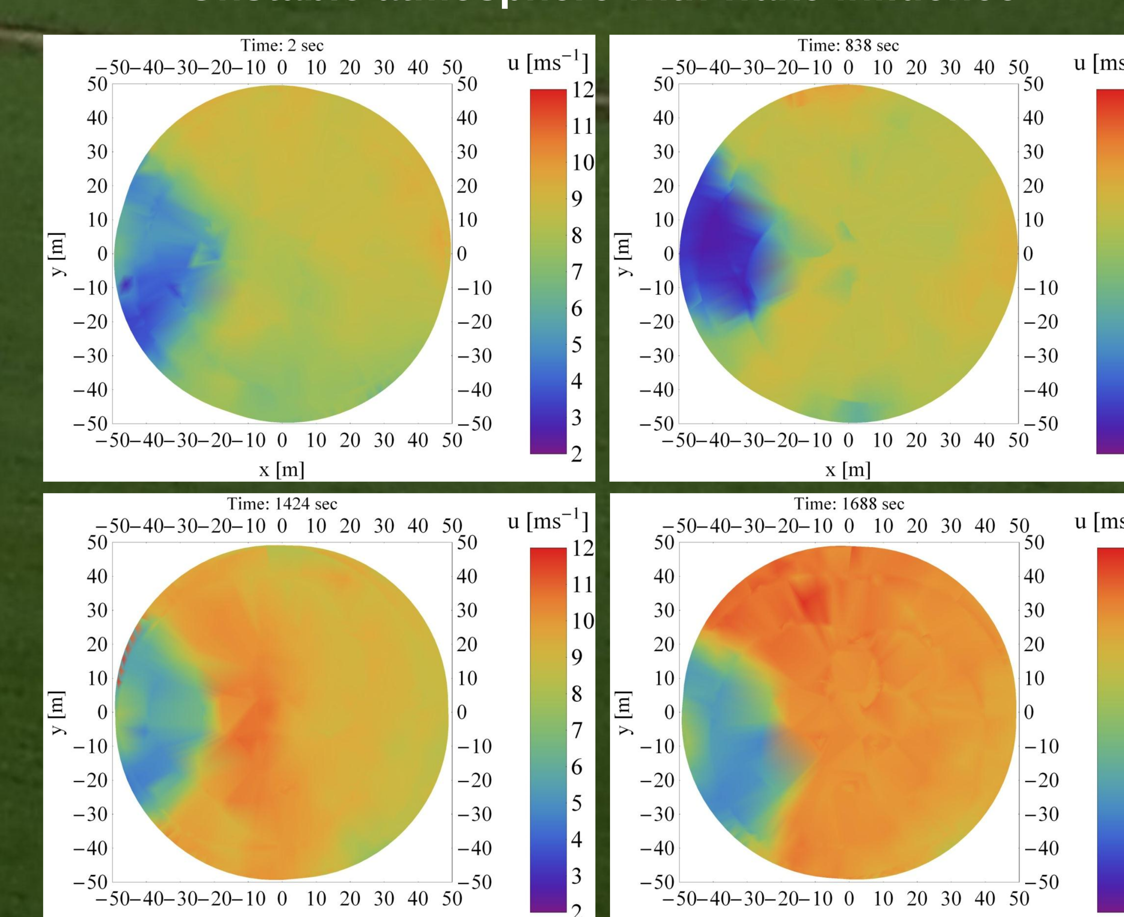


The time evolution of the axial wind speeds along a horizontal curve at hub height during a wake-free period in a stable atmosphere with vertical shear.

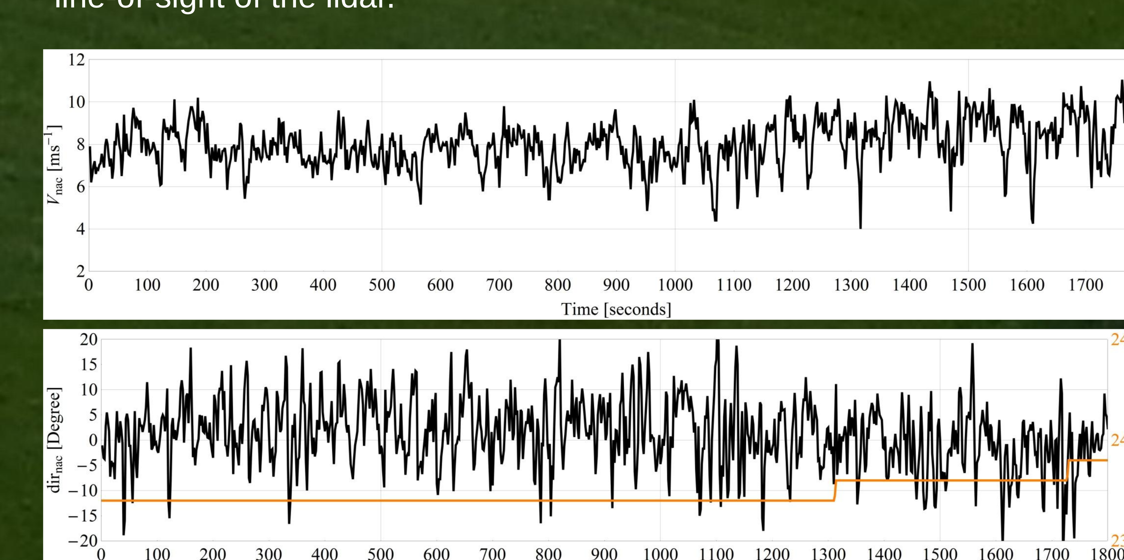


The time evolution of the axial wind speeds along a vertical curve at the center of the turbine during a wake-free period in a stable atmosphere with vertical shear.

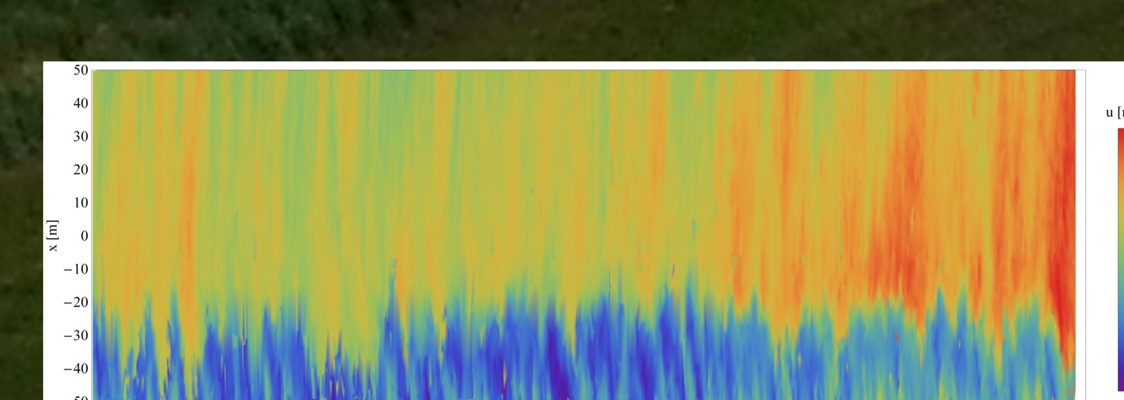
Unstable atmosphere with wake influence



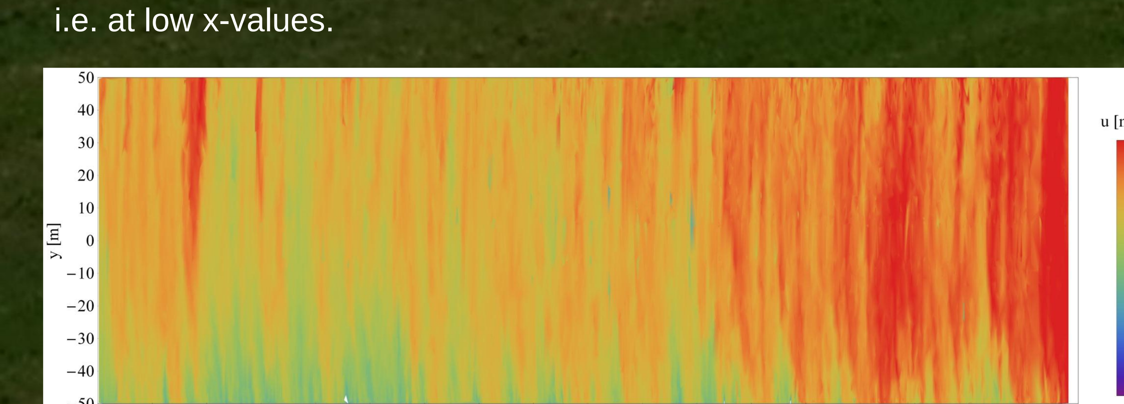
The inflow scanned in the afternoon on a spherical surface at a measurement distance of 100 m during periods of 2 seconds with influence from a wake from a turbine nearby. The line-of-sight speeds measured have been converted to axial (along the rotation axis of the wind turbine rotor) wind speeds corresponding to the measured projection along the line-of-sight of the lidar.



The yaw direction of the turbine, yaw misalignment and wind speed measured on top of the nacelle during a period with wake influence. The signals are down-sampled to 0.5 Hz.



The time evolution of the axial wind speeds along a horizontal curve at hub height during a period when a wake is influencing the left part of the rotor, i.e. at low x-values.



The time evolution of the axial wind speeds along a vertical curve at the center of the turbine during a period with wake interaction. However, the wake is not present in this particular vertical intersection.