



# Multi-component Wind Measurements of Wind Turbine Wakes performed with three LiDARs

G.V. Iungo, Y-T. Wu, F. Porté-Agel

Wind Engineering and Renewable Energy (WIRE)  
Ecole Polytechnique Fédérale Lausanne (EPFL) Switzerland

- Motivations;
- Wind LiDAR description;
- Field measurements;
- Single-LiDAR measurements;
- Data retrieval from  
simultaneous measurements  
with three LiDARs;
- Conclusions.



- Field measurements of wind turbine wakes are necessary to overcome issues related to lower Reynolds numbers reproduced with wind tunnel tests and to assess numerical methods;
- Traditional met-mast data are difficult to retrieve due to the high non-stationarity of the wind turbine wakes;
- Remote sensing, in particular LiDARs, are considered a suitable measuring technique for wind energy.



**LiDAR** (LIght Detection And Ranging) is a remote sensing instrument, which enables to evaluate the velocity component along the direction of the emitted laser beam from the Doppler effect on the backscattered ray.

## Halo Photonics Wind LiDAR Characteristics:

- Wavelength: 1.5  $\mu\text{m}$ ;
- Repetition rate: 15 kHz;
- Maximum Sampling rate between two consecutive scans: 0.77 Hz;
- First point distance: 40 m;
- Maximum spatial resolution: 18 m;
- Maximum distance: 3 km;
- Telescope: 50 mm.



## Wind turbines

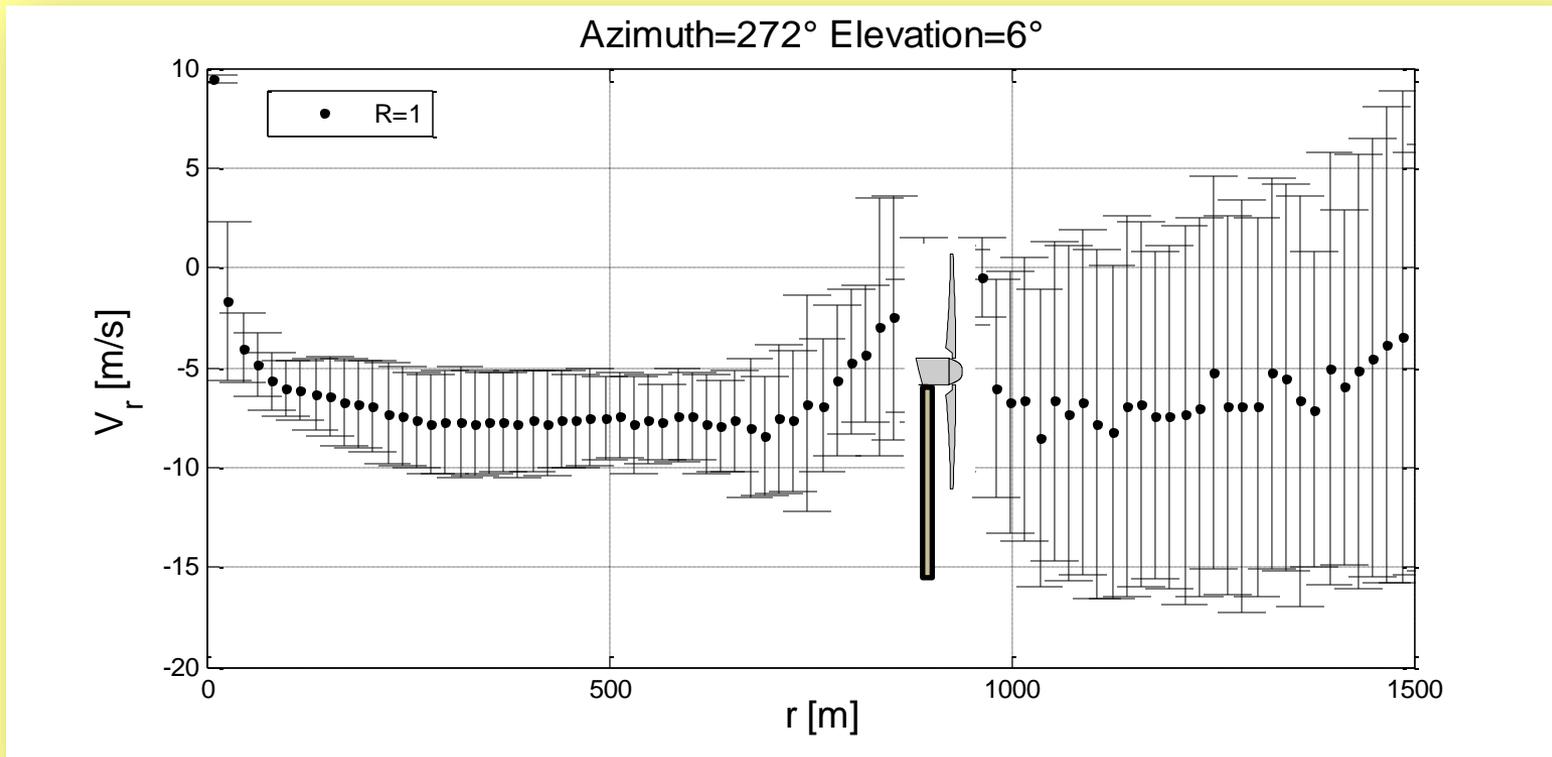
- @ Martigny: «Mont d'Ottant»; Enercon E-90, 2050 kW; rotor diameter 91 m; hub height 100 m;
- @ Collonges: «Cime de l'Est»; Enercon E-70, 2050 kW; rotor diameter 71 m; hub height 95 m.





The signal-to-noise ratio of the LiDAR could be enhanced by increasing the number of rays emitted for each measurement. It is strictly dependent of the aerosol conditions.

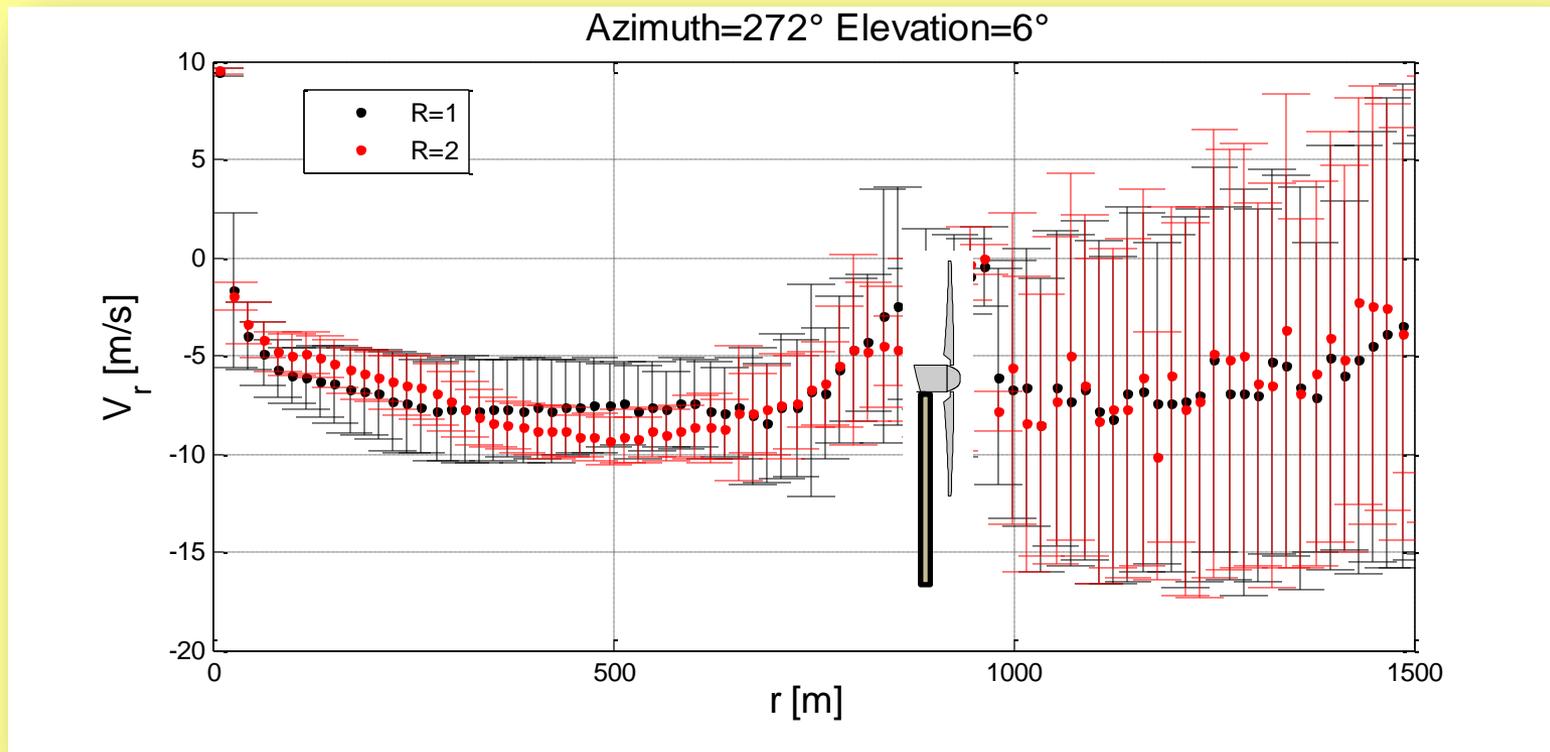
## Number of rays = 1





The signal-to-noise ratio of the LiDAR could be enhanced by increasing the number of rays emitted for each measurement. It is strictly dependent of the aerosol conditions.

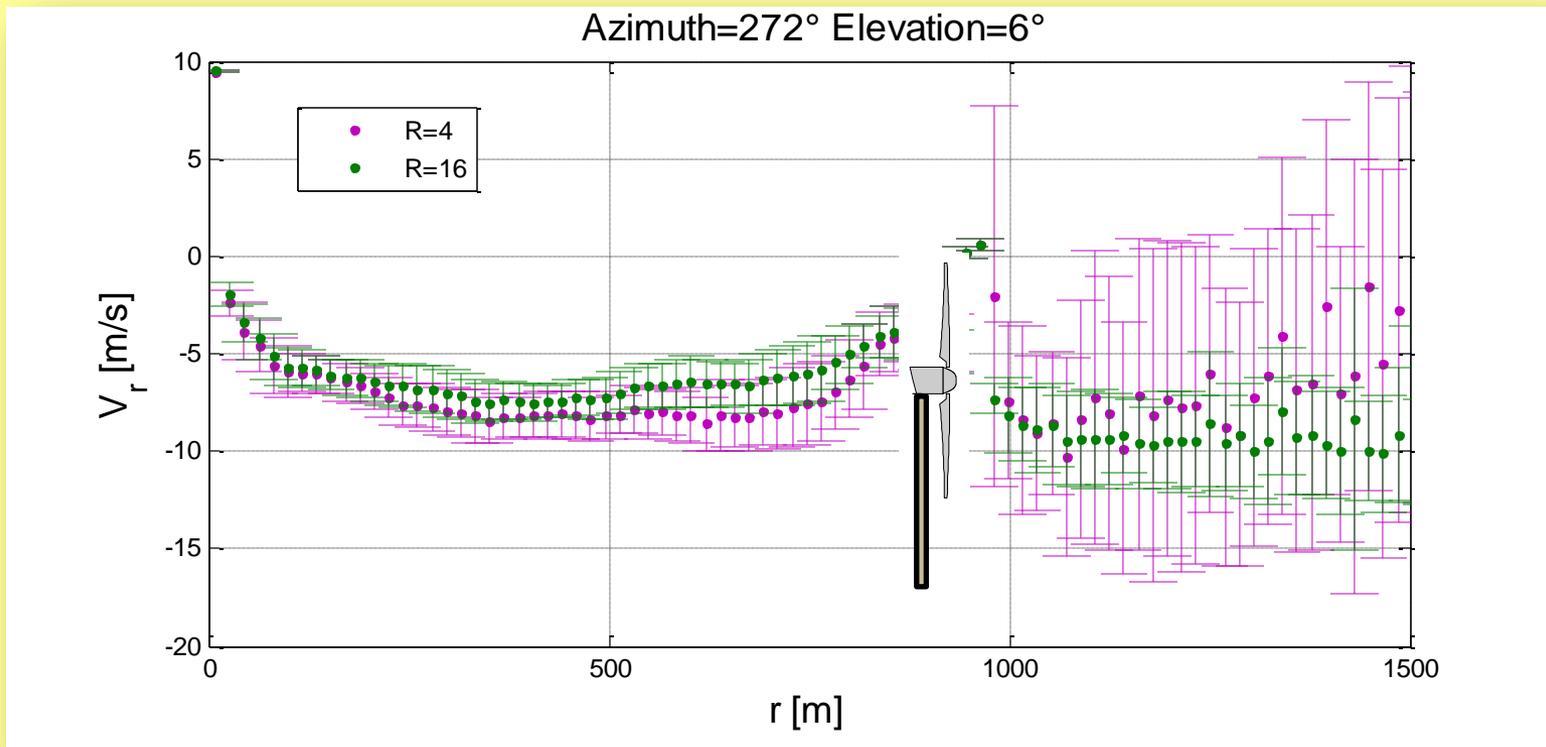
Number of rays = 2





The signal-to-noise ratio of the LiDAR could be enhanced by increasing the number of rays emitted for each measurement. It is strictly dependent of the aerosol conditions.

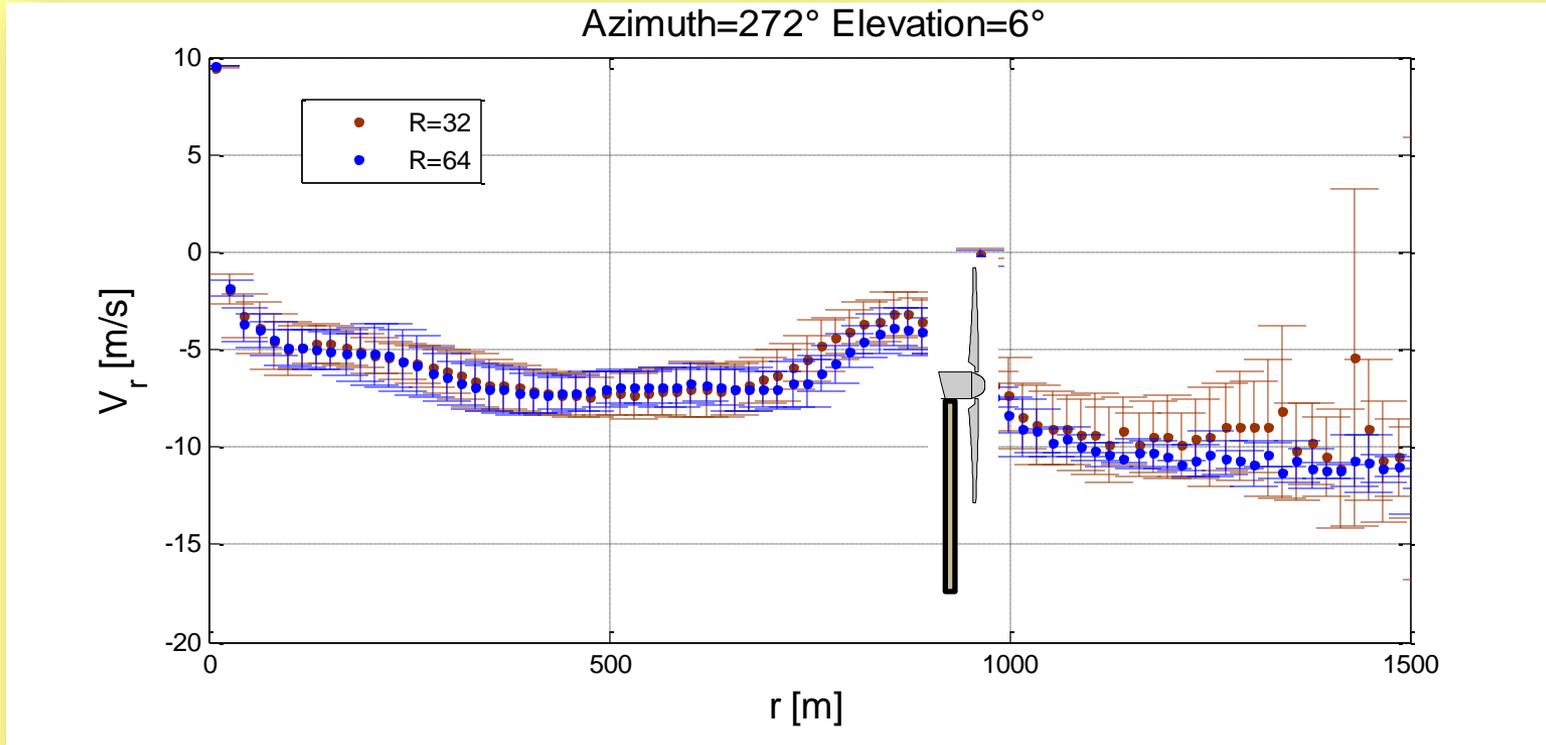
Number of rays = 16





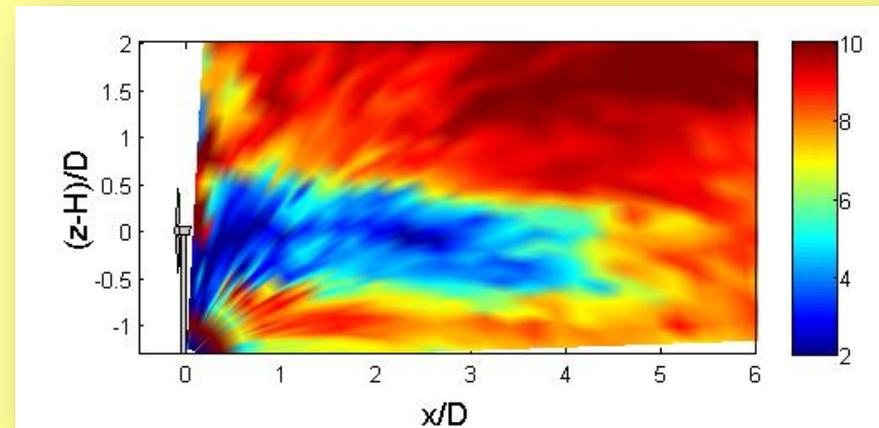
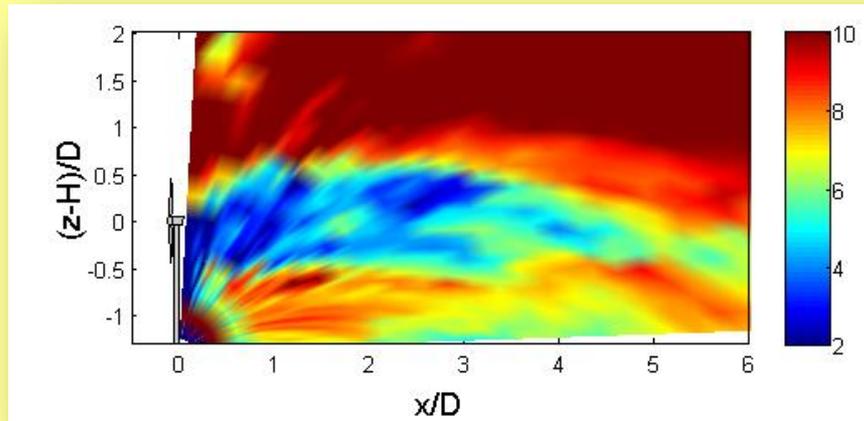
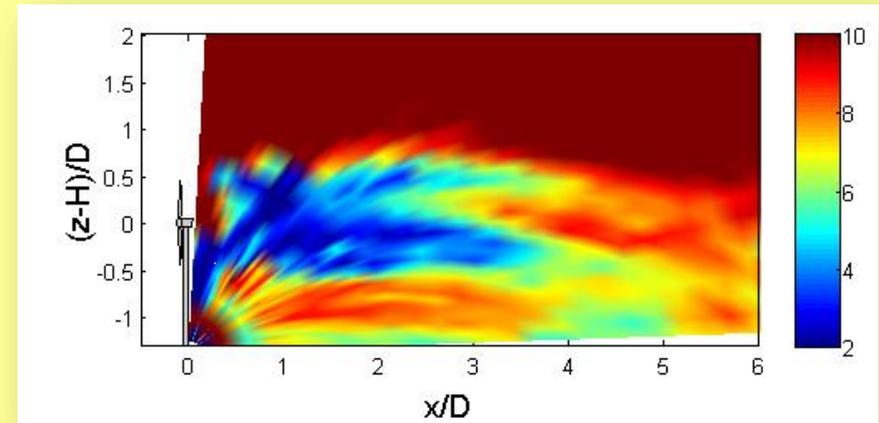
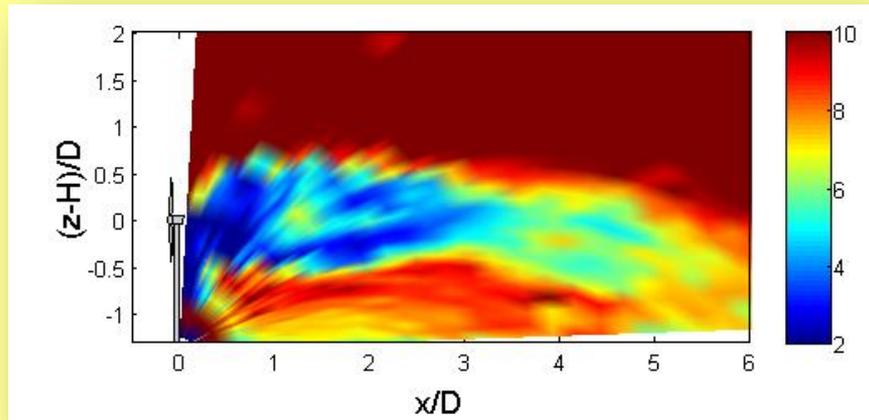
The signal-to-noise ratio of the LiDAR could be enhanced by increasing the number of rays emitted for each measurement. It is strictly dependent of the aerosol conditions.

Number of rays = 64



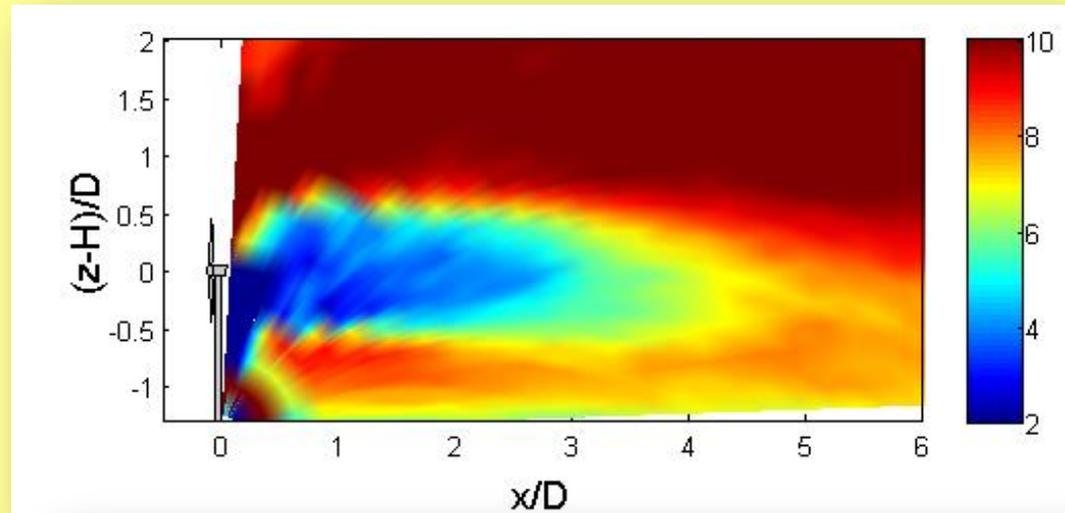
!!Signal-to-noise ratio vs Frequency resolution!!

**RII**, Range Height Indicator, i.e. maps of the streamwise velocity over the symmetry vertical plane of the wake. Each map made of 40 elevation angles; number of rays 1; sampling time 41 seconds.

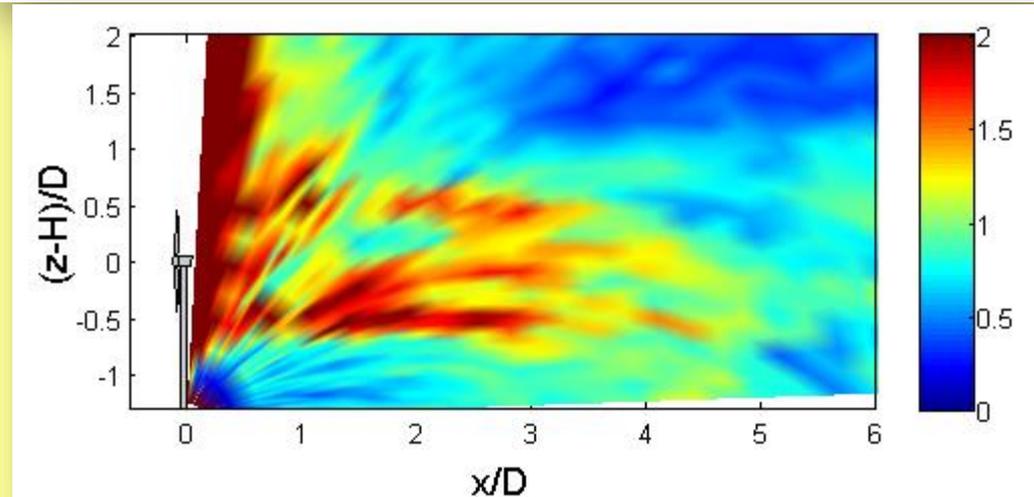


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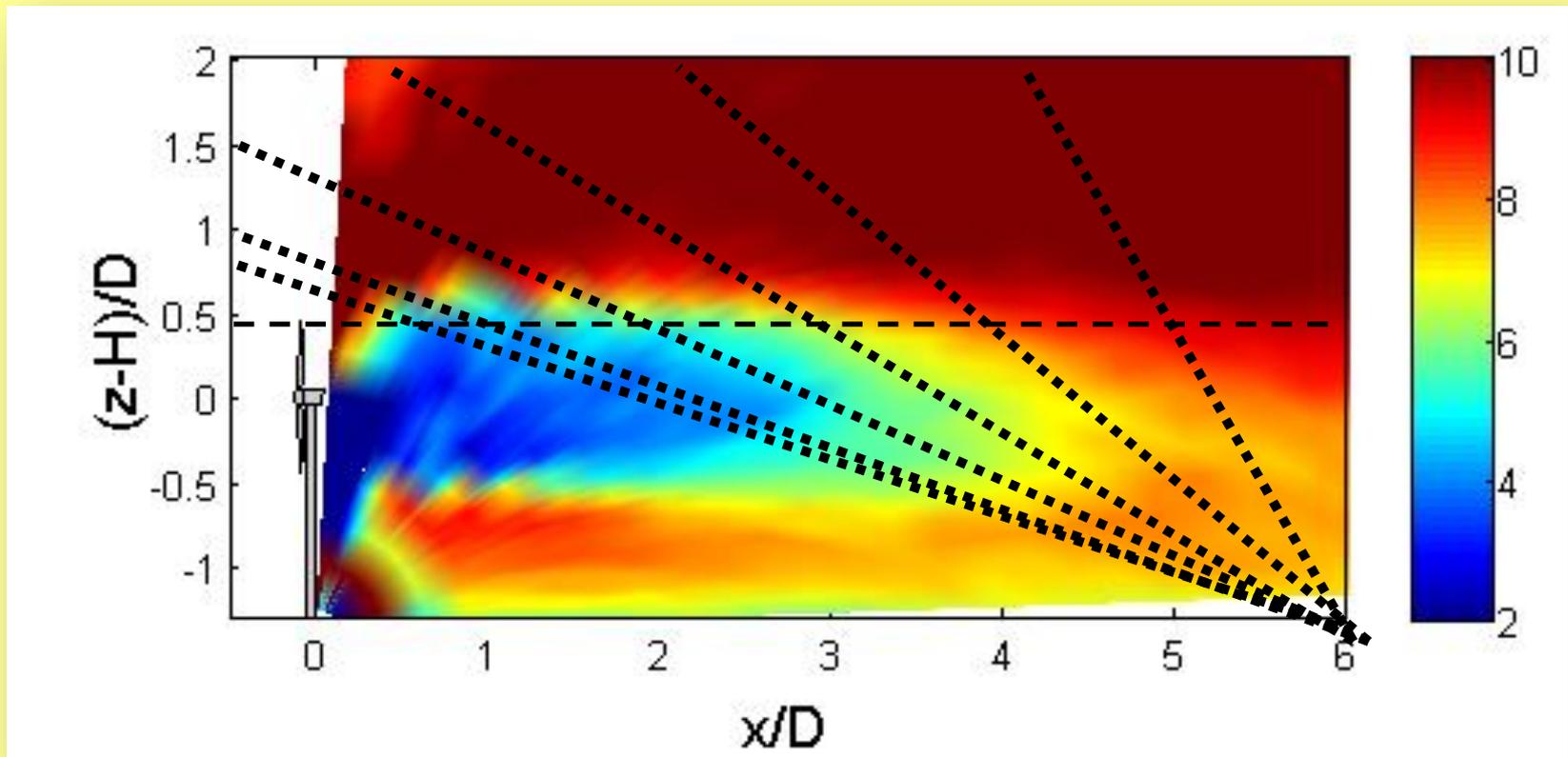
Mean value  
map



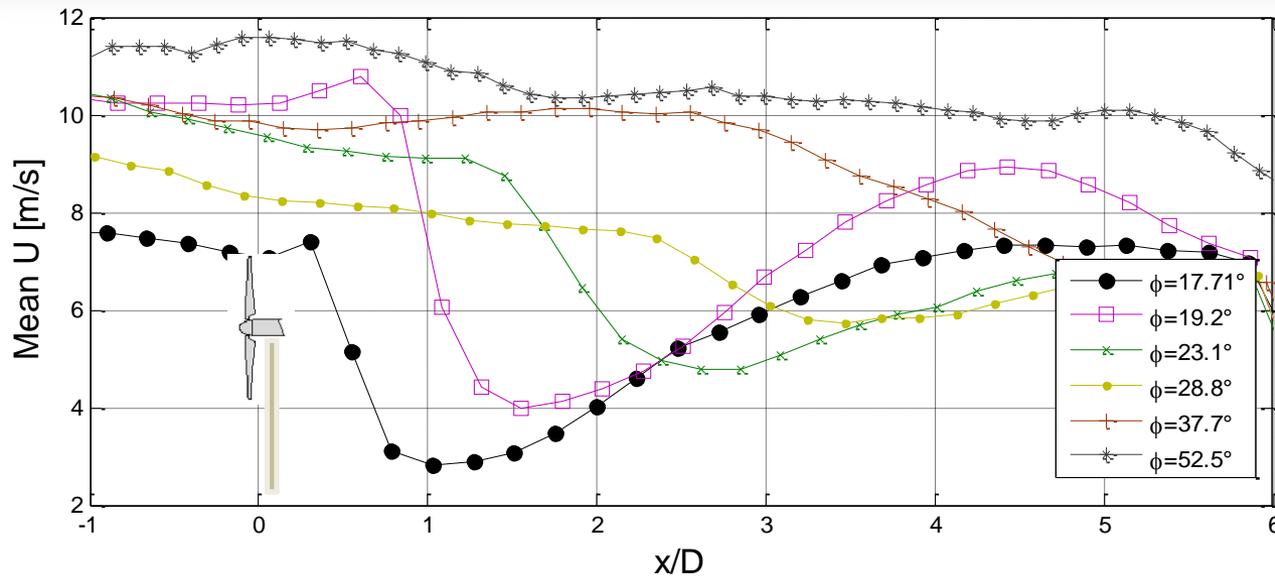
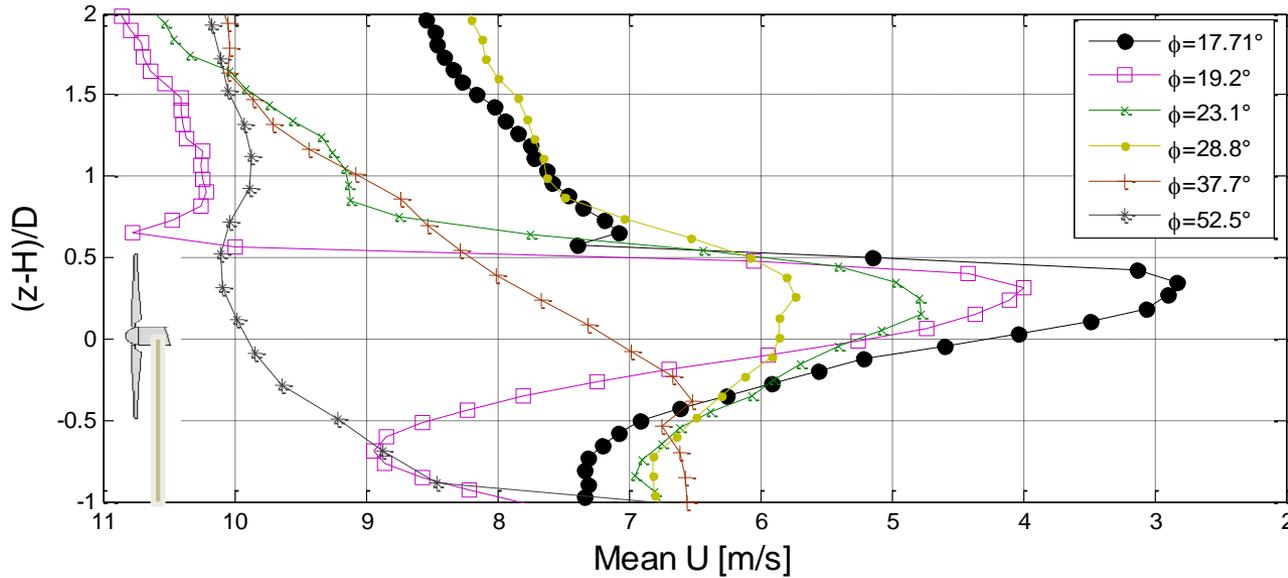
Standard  
deviation map

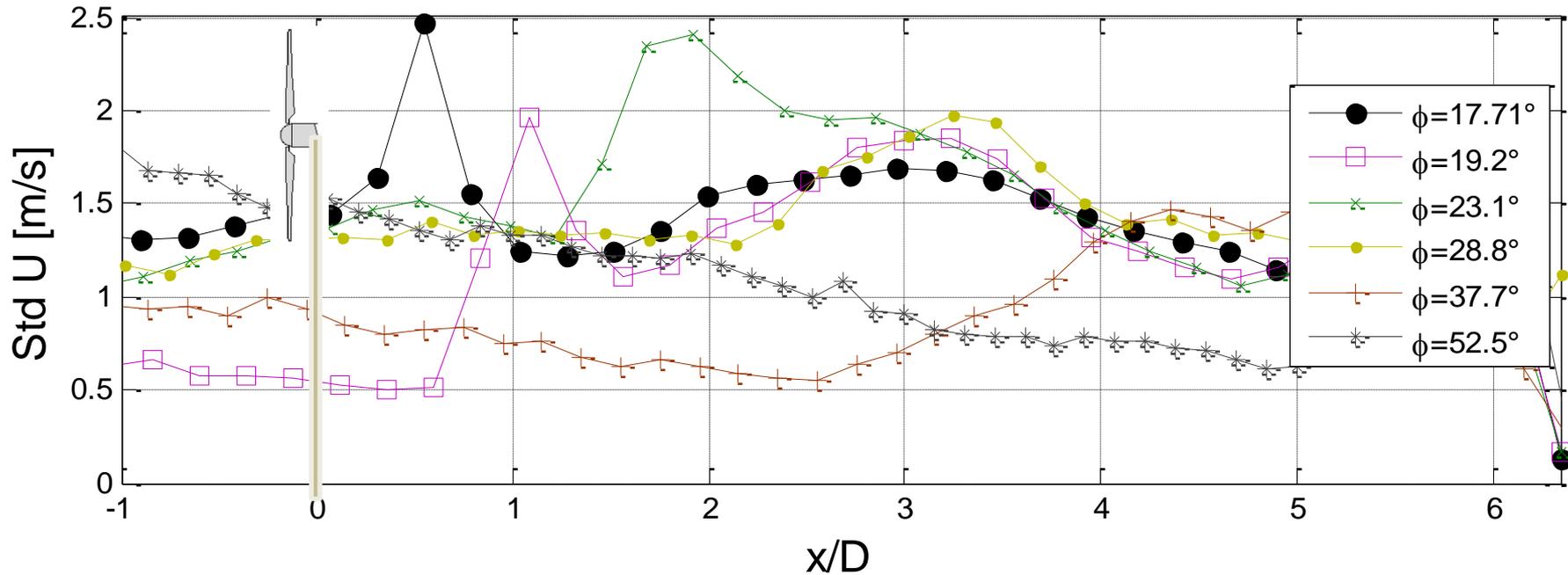


- Measurement performed with a fixed elevation angle;
- 1 Ray for each measurement;
- 512 Scans for each direction.

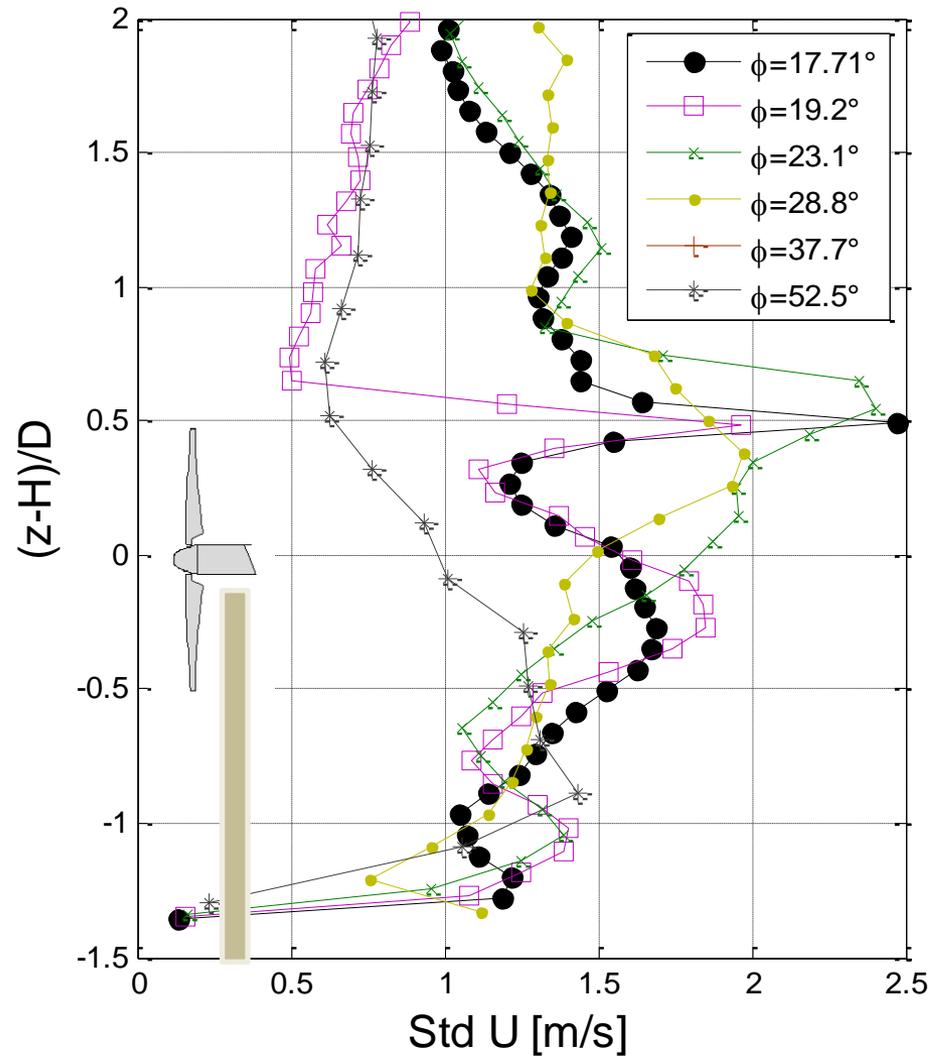


# Stares: mean velocity





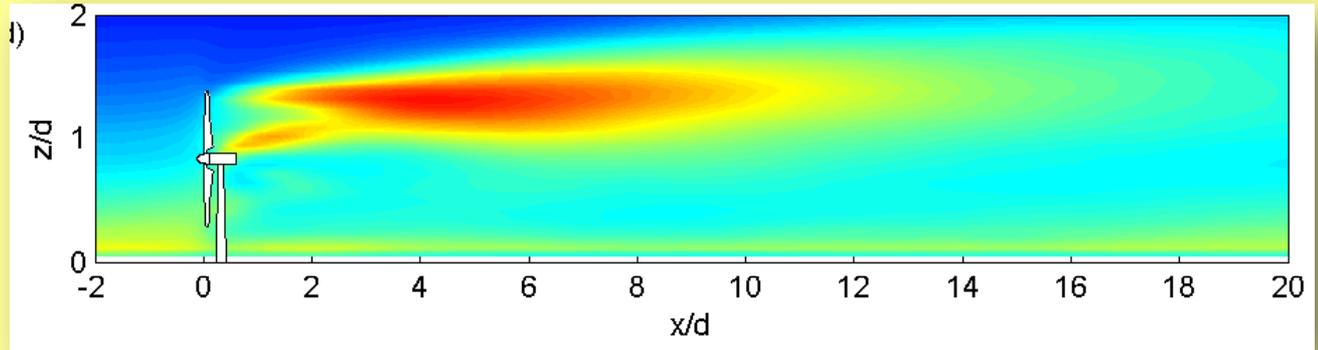
Detection of peaks of the fluctuating velocity...



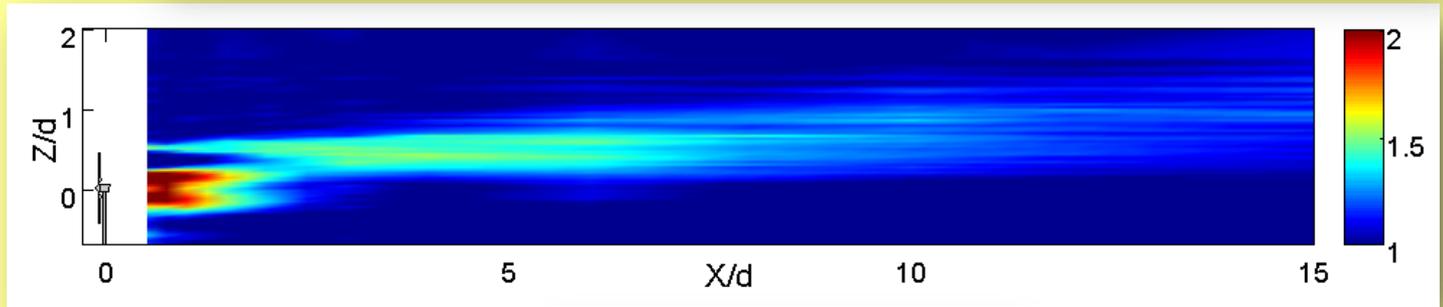
Detection of peaks of the fluctuating velocity in proximity of the top-tip of the blade.



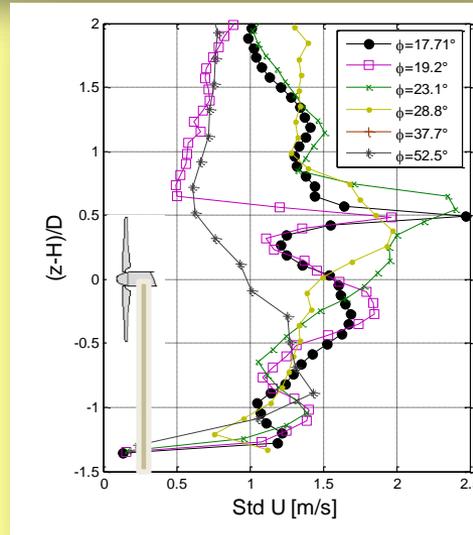
LES



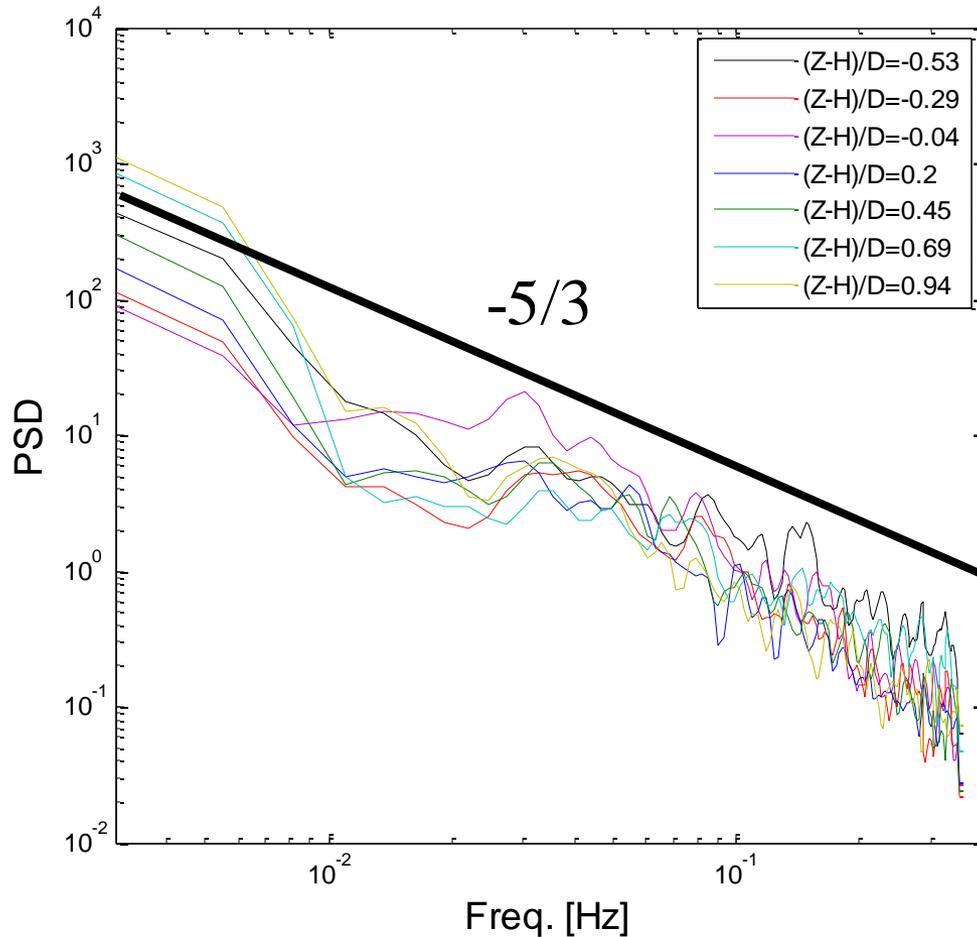
Wind tunnel



LiDAR Measurements

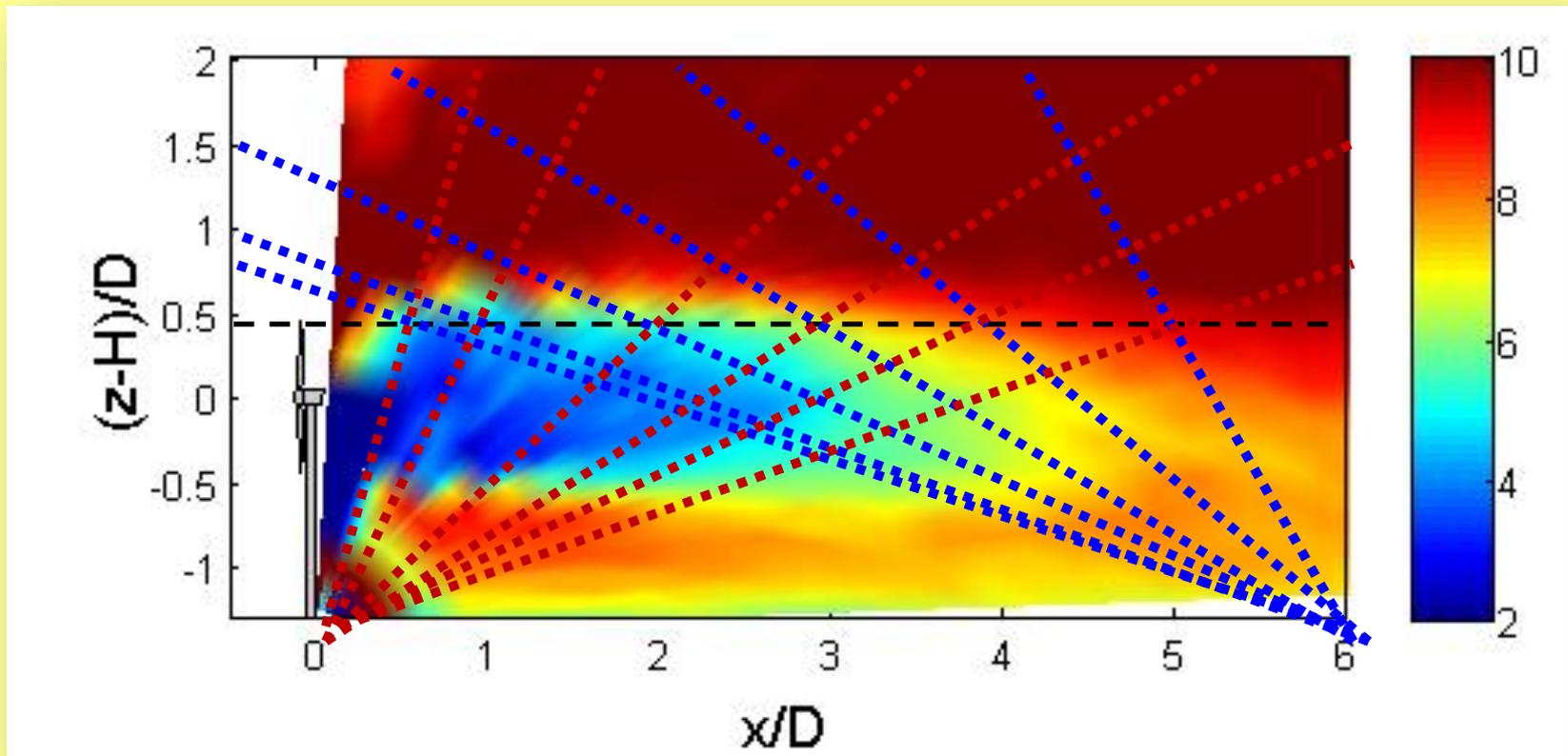


Stare at a fixed elevation angle  $17^\circ$ , 512 scans, sampling frequency 0.77 Hz



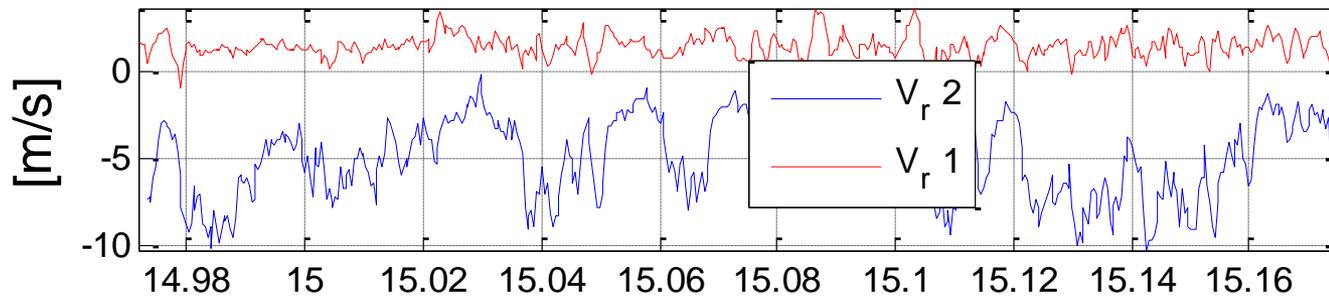
Characterization  
of the inertial  
subrange with  
LiDAR  
measurements

- LiDAR 1 placed at the wind turbine location and pointing downstream;
- LiDAR 2 placed  $x/d=6$  and pointing upstream;
- Measurements performed with 1 ray; 256 scans.

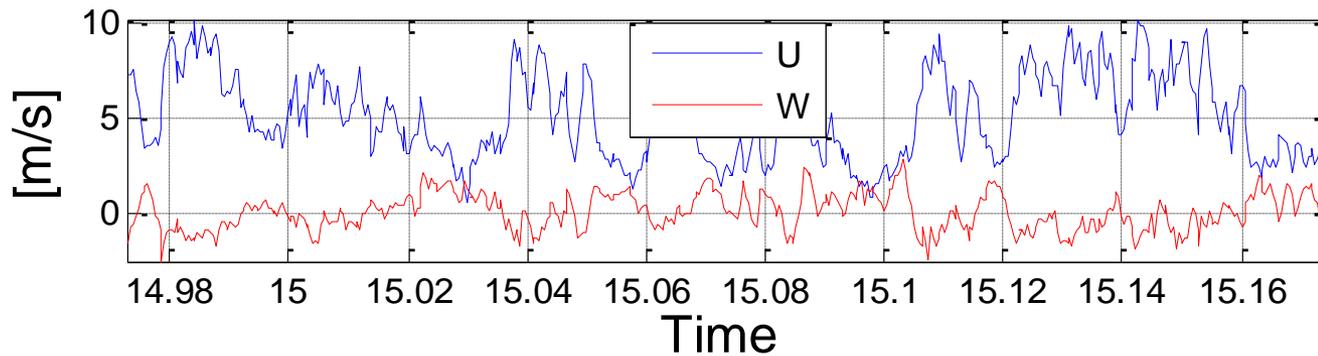


$$x/d=0.5, (z-h)/d=0.5$$

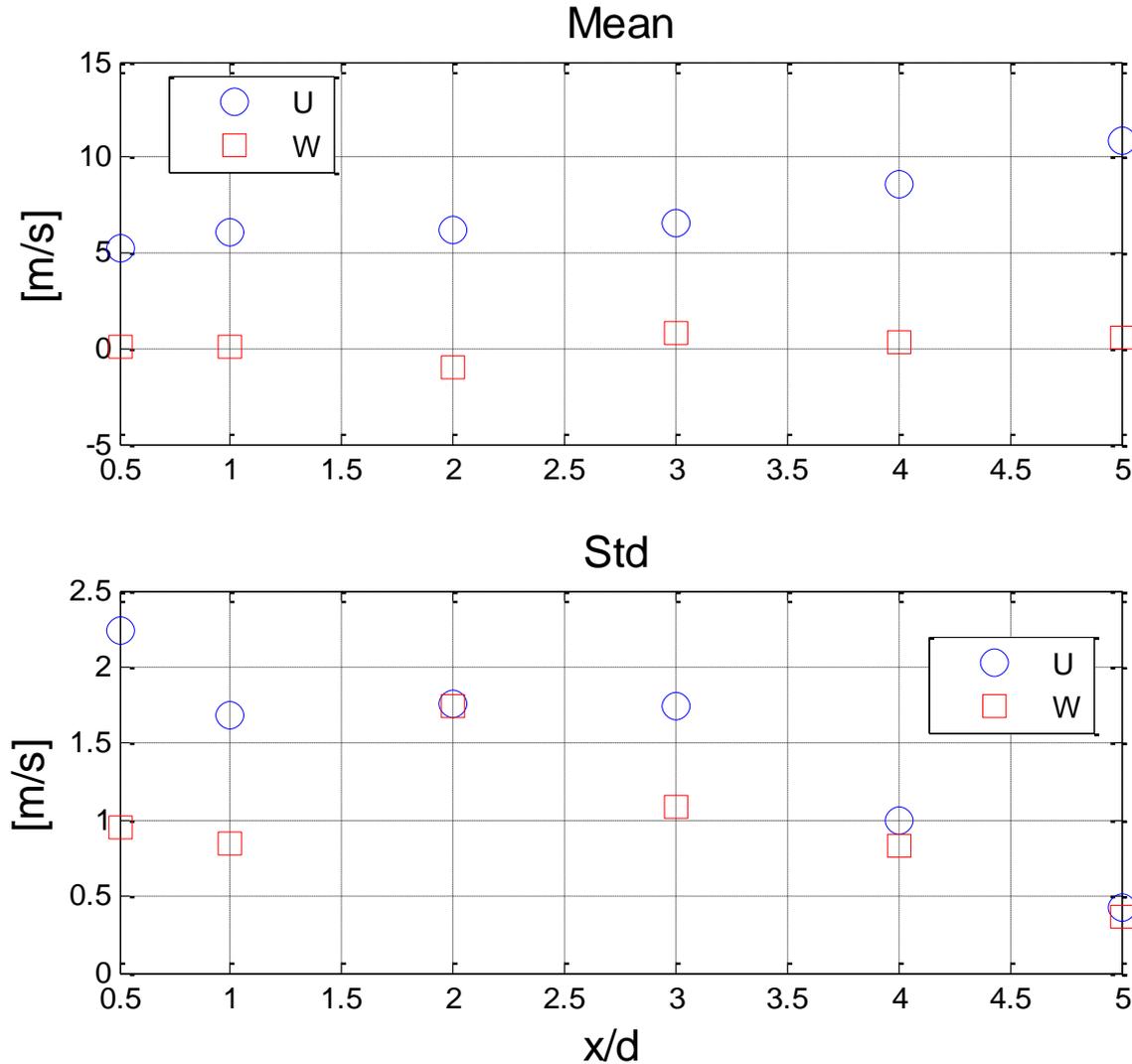
## Radial Velocities



## Horizontal and Vertical Velocities



## Statistics



- LiDAR measurements enable to characterize the mean flow downstream of a wind turbine;
- Detection of a wake region at the top-tip blade height with an increased turbulence, which represents a source of additional fatigue loads;
- Characterization of the inertial subrange with LiDAR measurements;
- Retrieval of 2D velocity field from data obtained with simultaneous measurements from 2 LiDARs.

## Outlook:

- Improvement of the LiDAR set-up and data retrieval from three simultaneous LiDAR measurements;
- Measurements of cumulative wakes produced by wind farms;
- Interference of wind turbine wakes with surrounding topographies.

Thanks for your attention!



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*email: [valerio.iungo@epfl.ch](mailto:valerio.iungo@epfl.ch)*