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Assessment of the global wind and the local wake direction at »alpha ventus« using long range scanning LiDAR

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Introduction

Wind turbine inflow conditions throughout a wind farm are commonly assumed homogeneous for simulations. In reality, different atmospheric effects and induced wake effects cause deviations of the flow. For the optimisation of wind farm layout and control strategies to improve energy yield, it is interesting to investigate the large-scale flow behaviour through and around wind farms. For this purpose, long range LiDAR measurements performed between June 2013 and March 2014 in the offshore wind farm »alpha ventus«, in scope of the project GW Wakes, subproject A (part of the RAVE initiative) are used. PPI scan data from two Leosphere WLS200S LiDAR units, both positioned on the FINO1 platform west of »alpha ventus«, are considered.

Methodology

Based on PPI scans with a sufficiently large azimuth range, a varying geometrical projection of the main wind vector (speed v and direction θ) is measured and a sinusoidal relationship is established between azimuth angle (χ) and measured radial wind speed (v_{LOS}), according to the well-known Velocity Azimuth Display (VAD) algorithm, see Courtney et al. [1]. Ten minute intervals are always used.

The global wind direction is assessed in two steps:

1. Ten-minute PPI scan data sets (Fig. 1) are used to fit the sinusoidal function according to the VAD algorithm (Fig. 2), yielding the global wind direction (θ_g)

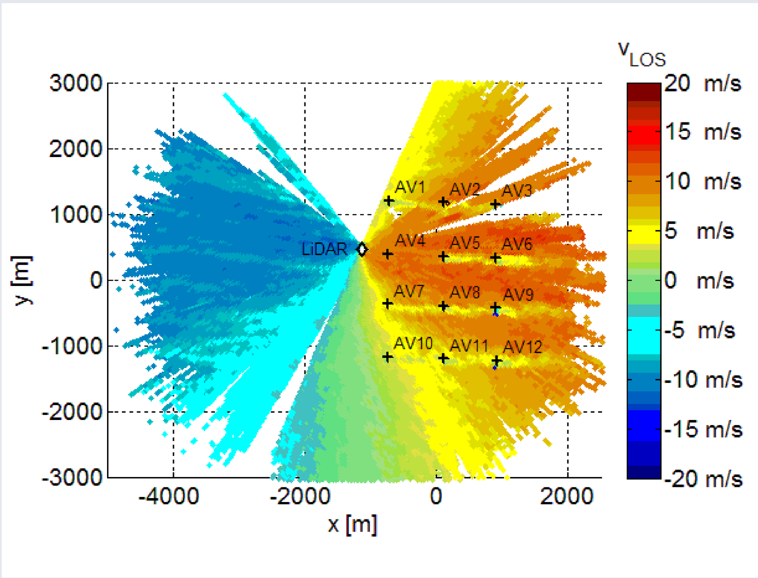

Figure 1: Radial speed from the PPI scan of one LiDAR unit at »alpha ventus«, for the time frame 1:50-2:00 AM on 8.12.2013

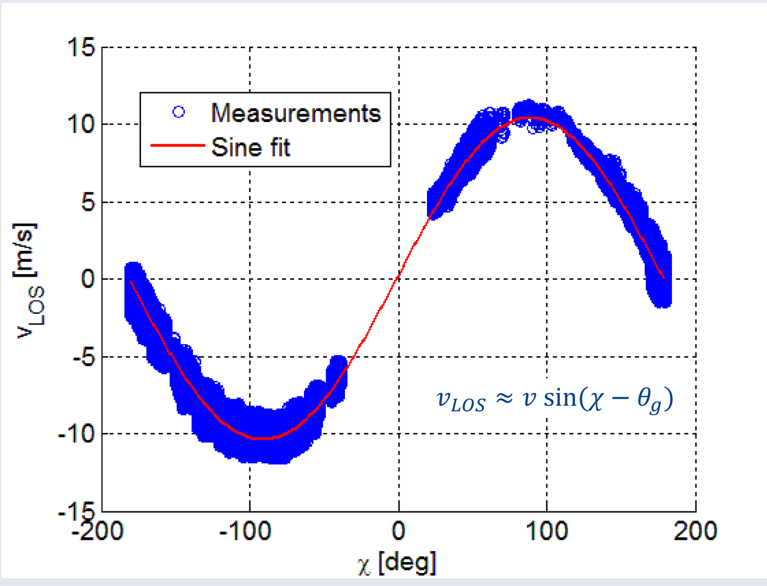

Figure 2: Fit of the sinusoid according to the VAD algorithm, based on measurements between 30 and 90 m height for the time frame 1:50-2:00 AM on 8.12.2013

2. All measurement data upstream of the first turbines in free flow are filtered out, such that the VAD can be repeated with exclusively the wind farm inflow as to evaluate the inflow wind direction (θ_i), see Fig. 3. Also the complementary sector containing the wakes is used for a fit to yield θ_w.

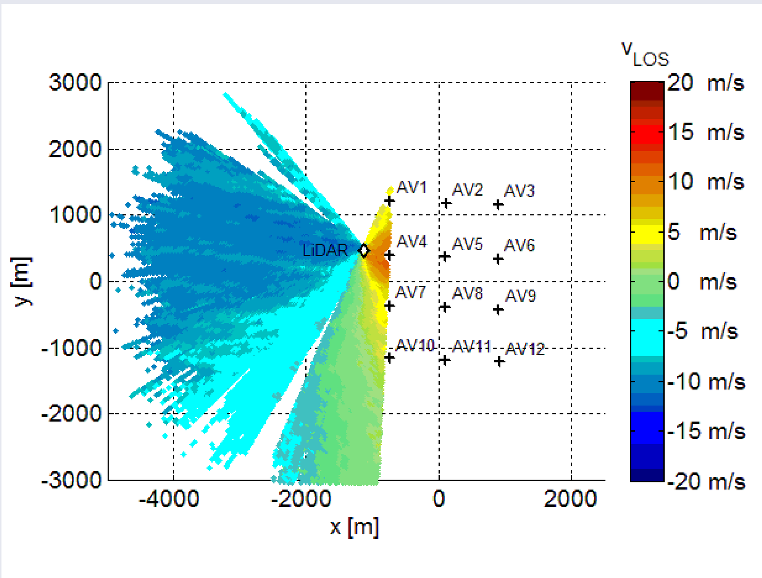

Figure 3: Radial speed from the inflow sector PPI scan of one LiDAR unit at »alpha ventus«, for the time frame 1:50-2:00 AM on 8.12.2013

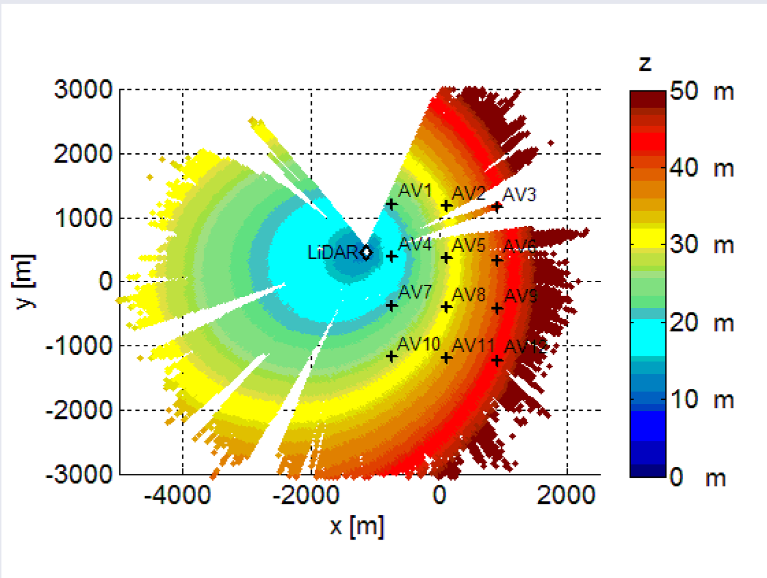

Figure 4: Heights at which the measurements of one LiDAR are taken on the PPI scan, for the time frame 1:50-2:00 AM on 8.12.2013

Note that the measurements on a PPI scan have the height distribution as shown in Fig. 4 due to the non-zero elevation angle.

To determine the single wake directions, the following process is used:

1. Establishing a quasi-2D wind field from a PPI scan by projecting all radial speed measurements from a LiDAR onto the estimated global wind direction
2. Extraction of wake profiles along the wind direction downstream of the wind turbines and defining the wake center by fitting Gaussian profiles
3. Update of the local wake direction by evaluating the wake centerline based on the Gaussian fits
4. Iteration by repeating the previous steps 2. and 3. several times

Results

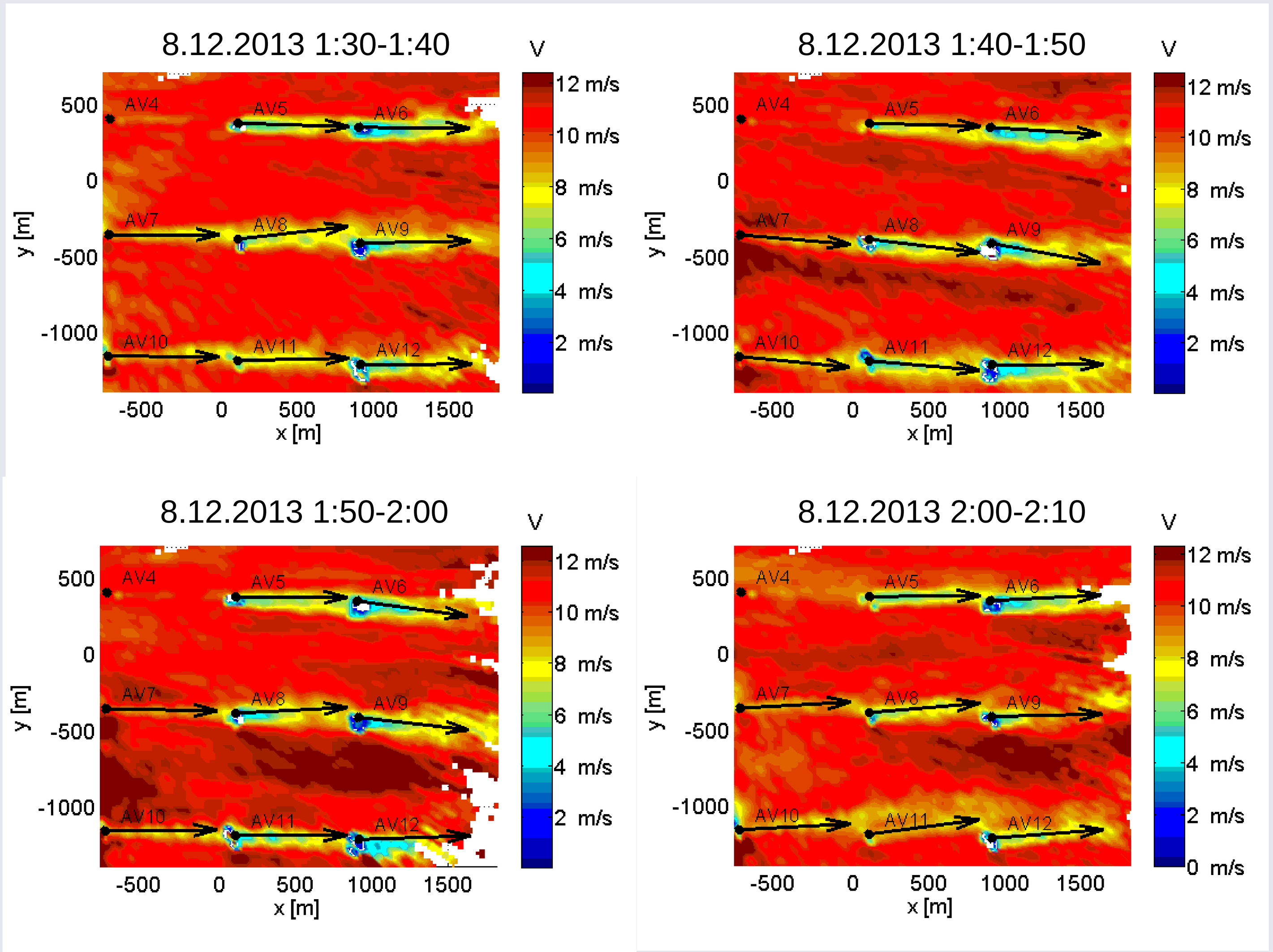

Figure 5: Evaluated quasi-2D wind fields of the largest part of »alpha ventus« (AV5-AV12) with wakes visible, for the time frame 1:30-2:10 AM on 8.12.2013

Figure 5 shows the aforementioned quasi-2D wind field with the direction of the wakes indicated for four time intervals. Table 1 lists the three different estimated wind directions and the inflow wind speed. In Table 2, the inflow wind direction (θ_i) is compared with the single wake direction differences ($\Delta\theta$). The observed wake direction deviations do not seem to follow a clear pattern and they cannot be related exclusively to deterministic large-scale wind farm flow effects.

Table 1: Evaluated inflow, wake and global wind directions and the inflow wind speed for the time frame 1:30-2:10 AM on 8.12.2013

	1:30-1:40	1:40-1:50	1:50-2:00	2:00-2:10
θ_i **Inflow [°]**	**269.3**	**273.5**	**268.9**	**264.3**
θ_w **Wake [°]**	**268.0**	**270.3**	**270.1**	**265.2**
θ_g **Global [°]**	**268.8**	**272.6**	**269.5**	**264.7**
v_i **Inflow [m/s]**	**10.4**	**10.2**	**10.4**	**10.3**

Table 2: Evaluated inflow wind direction and wake deviations of turbines AV5-AV12 for the time frame 1:30-2:10 AM on 8.12.2013

	1:30-1:40	1:40-1:50	1:50-2:00	2:00-2:10
θ_i **Inflow [°]**	**269.3**	**273.5**	**268.9**	**264.3**
$\Delta\theta$ AV5 [°]	2.5	-2.0	1.4	5.2
$\Delta\theta$ AV6 [°]	1.2	0.2	8.8	2.8
$\Delta\theta$ AV7 [°]	0.7	1.4	2.2	2.5
$\Delta\theta$ AV8 [°]	-5.8	3.3	-1.9	0.9
$\Delta\theta$ AV9 [°]	-0.4	6.8	7.6	4.3
$\Delta\theta$ AV10 [°]	1.1	2.2	0.6	2.7
$\Delta\theta$ AV11 [°]	-0.5	1.4	1.0	-1.7
$\Delta\theta$ AV12 [°]	0.4	-3.8	-0.8	1.3

Discussion

Methods are provided for comparison of the global wind direction with single wake directions in a wind farm, but in order to draw firm conclusions on the large-scale flow behaviour from this analysis, the following effects have to be accounted for:

- Yaw misalignment of turbines
- Natural wind direction heterogeneity over the large area
- Wind veer, i.e. the variation of wind direction with height
- Wake interaction, e.g. merging

Further research should therefore consider a wide selection of SCADA data from the wind turbines. Also, horizontal PPI scans at hub height would be preferred, although this is not always practically feasible.

Acknowledgments

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References

[1] Courtney, M. et al., Work Package 4: Research - D4.06 Data Reports and Databases: Data on coastal and offshore wind measurements, Tech. Rep., Feb. 2014, Marinet