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Two-beam lidar measurements in a non-homogeneous wind field

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Abstract

Nacelle based wind lidars are designed to sit atop a wind turbine structure and make measurements at given distances from it. Most times the lidar faces the turbine's upstream direction to sense oncoming wind.

Two lidars were set up looking upstream on two adjacent offshore turbines in Denmark. The case considered was for when the turbines were oriented such that one lidar was looking into the free stream while the other lidar had one beam in the first turbine's wake and the other beam in near free stream conditions. This enabled the possibility to look at horizontal wind speeds reconstructed inside homogeneous and non-homogeneous wind fields.

Data for the two lidars were processed and averaged over different intervals. Correlations of radial and horizontal wind speeds in different wind fields were performed. Results in this case show horizontal wind speeds reconstructed in non-homogeneous field similar to those reconstructed in an (assumed) homogeneous one.

Objectives

The Wind Iris (two beam) lidar is capable of resolving a 2-D horizontal wind vector under the assumption that the wind field it measures in is homogeneous in the range measured by the two line of site beams. In non-homogeneous conditions velocity vectors, $v_{inc,1}$ and $v_{inc,2}$, incident along the lines of sight (los) will, very likely, be unequal (see Fig. 1).

The objective of the test discussed in this paper is to look at the effect of non-homogeneous flow on the horizontal wind field as reported by the system. In this case the non-homogeneous flow as seen offshore is generated by an upstream wind turbine.

The study looked at:

- Horizontal wind field output in wake induced flows
- Effect of averaging period on results

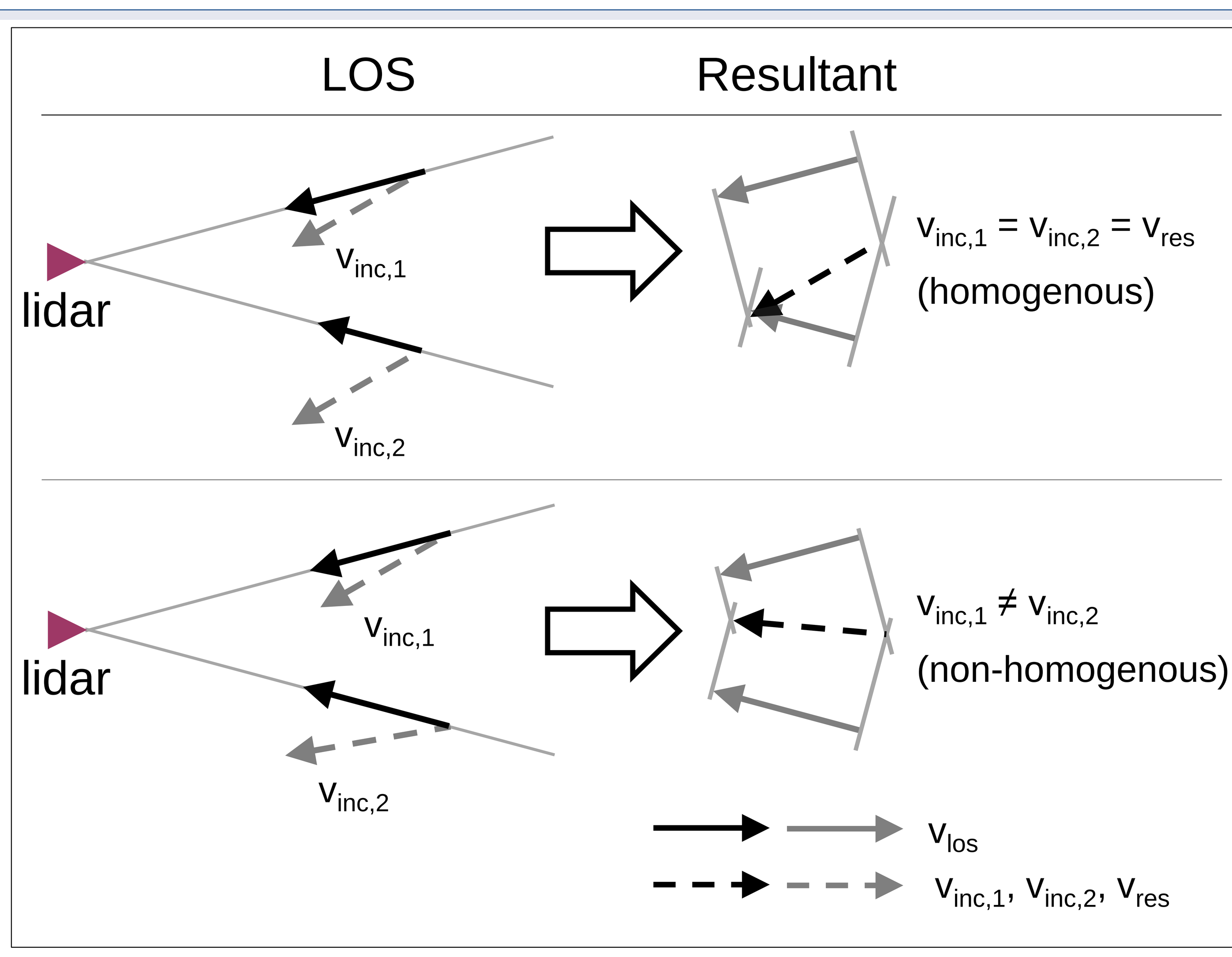

Fig. 1 – Representation of los measurements and wind vector reconstruction.

Method

Instances of data were looked at for when one lidar (atop turbine T1) looked at homogeneous free stream conditions while the adjacent turbine (T2) was oriented in such a way that the second lidar had its two beams in non-homogeneous wind conditions - one in wake conditions downstream from T1 and the other in near free stream (see Fig. 2). Turbine yaw angles were selected such that both turbines had more or less the same heading, with an orientation of +9° relative to when they were in a line with turbine T1 pointing in the free stream direction.

The yaw data was available as 10 minute averages whereas the lidar data had a temporal resolution of 1 second (1Hz radial wind speed, 2Hz resolved wind vector). Data from the lidars that fell within the periods that satisfied the yaw angle criteria were picked out from the complete dataset which covered 308 days. It was assumed that the turbines kept a constant heading for each 10 minute interval. The wind was then required to head directly onto T1, with a tolerance of ±5°.

Lidar data was processed and radial wind speeds from each lidar beam (los0 and los1) and horizontal wind speeds were averaged over periods of 1 minute, 5 minutes and 10 minutes, following some qualitative data filtering.

Method (cont'd)

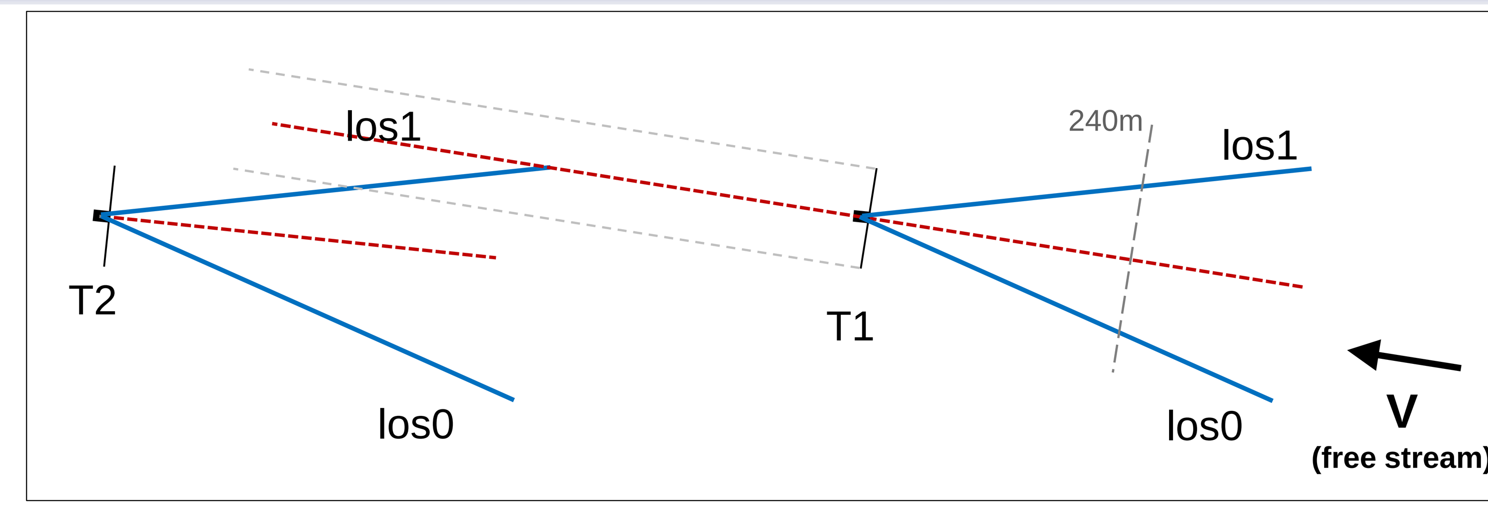

Fig. 2 – Lidar los oriented for the case when both turbines were each off alignment by +9°. Correlations were made using measurements taken at 240m upstream.

Correlations were made between v_{los} values at 240m along los0 from T1 and v_{los} values at all range gates along los0 from T2. The same was done for beams los1. This was done since both beams los0 had roughly the same orientation, as did both beams los1. Horizontal wind speed values from the lidar at T2 were compared to those at 240m upstream from T1.

Regression coefficients (slope) and R^2 values for correlations between T1 and T2 against distance from T2 are presented in the results for each of the averaging periods.

Results

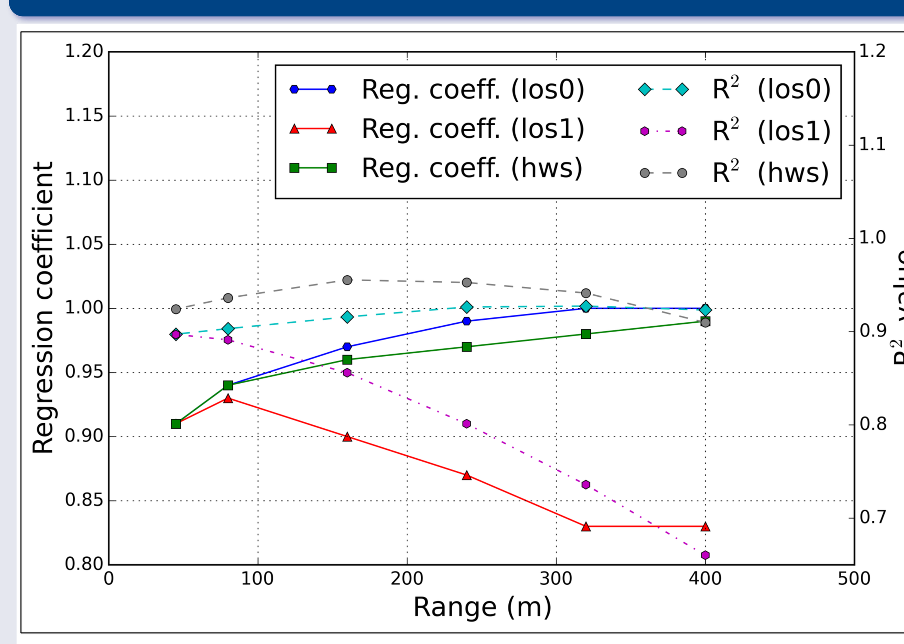

Fig. 3 – Statistics from correlations for data averaged over 1 minute intervals.

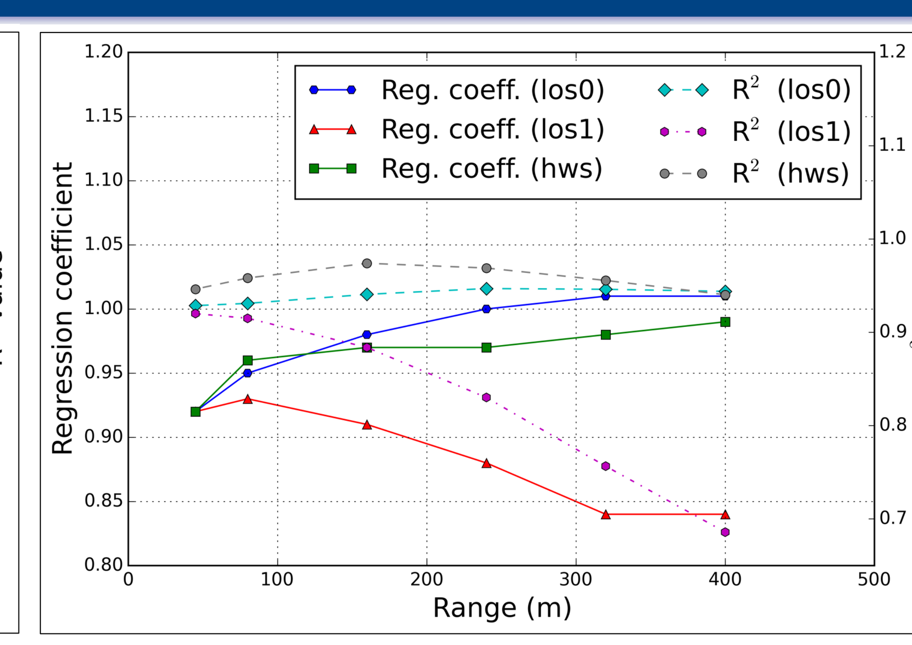

Fig. 4 – Statistics from correlations for data averaged over 5 minute intervals.

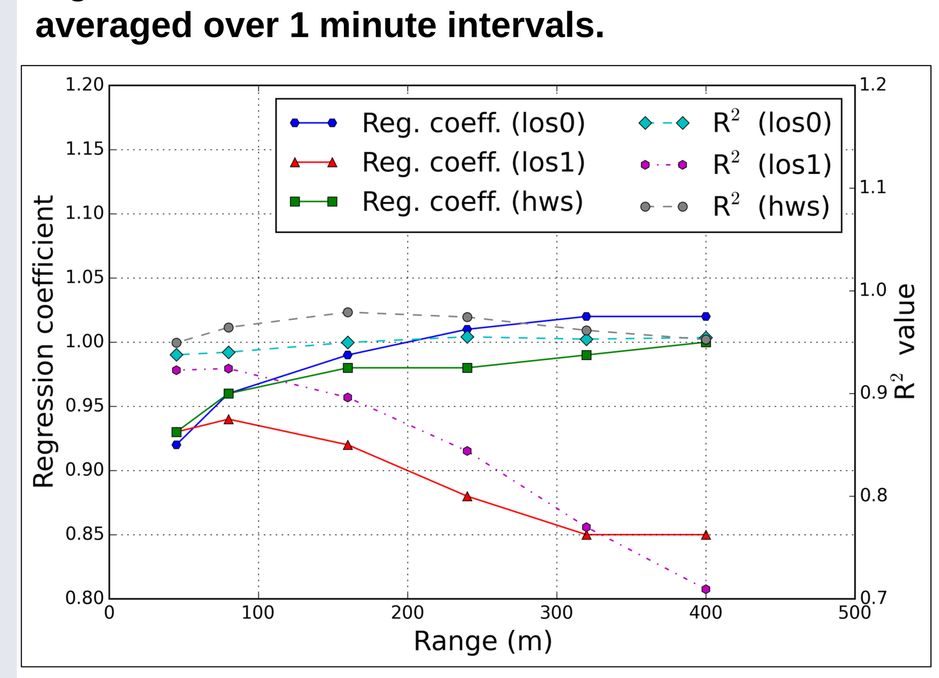

Fig. 5 – Statistics from correlations for data averaged over 10 minute intervals.

Correlations for v_{res} from the lidar on T2 (in partial wake) with v_{res} at 240m upstream of T1 gave relatively high reg. coeffs. even with most of los1 from T2 inside wake conditions. All R^2 values less than 0.98.

Average v_{los} values along los0 from T2 (beyond 200m) compared well to v_{los} along los0 from T2 (@ 240m) for all averaging periods. Reg. coeffs. and R^2 values for los1 were lower at ranges in wake conditions downstream of T1.

Reg. coeffs. for los0 and hws were lower at ranges close to turbine T2 due to the localised blockage effect in the induction zone.

Conclusions

The purpose of the study was to see what relationship v_{los} values along corresponding beams from nearby lidars had and then check that for v_{res} magnitudes. v_{los} values along beams los0 compared well and those along beams los1 did not. The relationship for values along beams los0 got worse for readings close to T2 inside the induction zone. For v_{los} along los1 the relationship improved nearer to T2 because the beam was in T1's wake at range gates further away.
Averaged v_{res} magnitudes from the lidars (T2 @ all ranges vs T1 @ 240m) varied. Correlations for v_{res} degraded with distance towards T2. Correlations for 1 second values (not shown) were poor and these improved with increasing averaging periods. Vector directions were not looked into.
It might not be possible to quantify the absolute effect of the non-homogeneous flow on v_{res} just by knowing the relationships between the two los signals, not without the help of some flow model, but one could get an idea of it.
When using a wind lidar it is imperative to know where, when and what it measures.

References

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