Wind profiling with LiDARs: detection of boundary layer inhomogeneity and uncertainty analysis

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Motivation of the study

• The accurate evaluation of wind speed using wind LiDARs is of utmost importance when it comes to evaluate the feasibility of a wind farm.

• Standard scanning strategies imply horizontal homogeneity of the ABL as a necessary condition for the correct reconstruction of the vertical profile of the wind velocity.

• Therefore, measurements where one could expect inhomogeneities, are to be treated very carefully, such as:
  ✓ Complex terrain  ✓ Wind turbine wakes  ✓ Roughness changes, etc.

The goal is: To study how circular scanning (or PPI) can be used to estimate the inhomogeneity of the boundary layer and relate uncertainty and inhomogeneity in the measurements.
LiDAR system

- **The LiDAR**
  - Company: Halo Photonics
  - Model: Stream Line
  - Type: all-sky scanner, pulsed Doppler LiDAR
  - Wavelength: 1.5μm
  - Spatial resolution: 18m
  - Maximum range: ~2km
  - Sampling rate: 0.77Hz

A Doppler LIDAR measures radial velocity in the direction of the laser beam!

![LiDAR system image]
Standard scanning strategies

- 3-beam method
- Trigonometric reconstruction

\[ u = \frac{v_E - w \sin(el)}{\cos(el)} \]

\[ v = \frac{v_N - w \sin(el)}{\cos(el)} \]

\[ v_H = \sqrt{u^2 + v^2} \]
Standard scanning strategies

- 4-beam method
- Trigonometric reconstruction

\[
u = \frac{v_E - v_W}{2 \cos(el)}
\]

\[
v = \frac{v_N - v_S}{2 \cos(el)}
\]

\[
v_H = \sqrt{u^2 + v^2}
\]
Circular scanning (PPI)

- 12-beams around the azimuth
Circular scanning (PPI)

- 12-beams around the azimuth
- Fit to cosine function

\[ v_r(az) = A \cos(az + B) + C \]

Fit standard error (RMS) or \( R^2 \) are an estimation of the homogeneity!
Multiple scanning modes

- One scan consists of 12-beams in the azimuth, repeated 15 times. It takes around 10 min to complete one scan. 2+ months of data.
- **Same dataset** for circular, 3-beam and 4-beam.
Multiple scanning modes

What is the influence of the inhomogeneity in the differences?

2+ months of data together look like…
Data analysis

- 2+ months of data together look like this: Same place, homogeneous and inhomogeneous!
Data analysis

- 2+ months of data together look like this
Data analysis

- The relationship between relative deviation and non-dimensional standard error is **linear**.
- Deviations are three times bigger for the 3-beam method than for the 4-beam method.
Example – wind turbine wake

- The wake region is highly inhomogeneous.

Can we predict the accuracy of the measurement?
Current state and outlook

3-beam, 4-beam scanning

✗ Not to be used if one expects inhomogeneity

• Where and when is the ABL inhomogeneous?

✗ Does not give an estimation of the homogeneity

✗ Blindly trust the results

Circular scanning

✓ No need to avoid complex terrain, wakes, etc.

✓ Can be used, in principle, under any conditions

✓ Gives an estimation of the homogeneity

• Possibility of quantifying the uncertainty by analyzing the fit?
Conclusions

• A circular scanning pattern allows the estimation of the inhomogeneity of the ABL.

• The inhomogeneity is a very important cause of disagreement between the different scanning patterns presented.

• A theoretical study of the error propagation is being carried out to relate the inhomogeneity to the uncertainty of each of the scanning patterns.

• The study needs to be completed with the reference of sonic anemometer measurements in complex terrain.
Thank you for your attention!

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