Turbulence measurement with a two-beam nacelle lidar

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Abstract
The analysis of the turbulence intensity measurement is performed for a lidar measuring horizontally with two beams. First the turbulence intensity measured by such a system was evaluated theoretically. The Mann model of turbulence was used to evaluate the true value of the turbulence intensity of the wind speed and the main effects of the lidar measurement principles on turbulence intensity measurement were modeled:
- A lidar senses the wind speed over the probe volume acting as a low pass-filter and thus cannot resolve high frequency turbulence;
- The horizontal wind speed is retrieved from the combination of the radial speeds measured along two line-of-sights with different orientations; this results in the contamination of the lidar turbulence intensity measurement from the transverse component of the wind field.

Secondly, the theoretical results were compared to experimental measurements. A two-beam nacelle lidar was placed on a platform at 60m height inside a lattice meteorological mast. The lidar was measuring forward at a range of 80m. The turbulence intensity measured by the lidar was compared to that measured by the cup anemometer placed on a boom at the same height as the lidar and on the same met mast.

Objectives
The objectives of this project were:
1) to evaluate how well a two-beam nacelle lidar could measure the turbulence intensity;
2) to investigate the main reasons for the systematic deviation observed from the comparison to cup anemometer measurements.

Method
The model:
A theoretical model was developed to estimate the wind speed variances measured by a ground-based lidar in [2]. This model was adapted to the case of a pulsed lidar with two horizontal beam separated by an angle of 30°. The true variance of wind speed were given by the Mann model [3]. The backscatter intensity along each lidar beam was modeled by a triangular weighting function, with its maximum at the center of the range gate.

The measurements:
A Wind Iris lidar was installed on a platform at 60m above the ground inside a lattice mast, with the two lidar beams oriented towards West and North-West. The lidar was measuring at a range of 80m. The 10 minute wind speed variance measured by the lidar was compared to that measured by the cup anemometer mounted on a boom on that South side of the mast.

Results
The following graphs display the experimental measurement together with the results from the model. The dots represent 10 minute experimental data whereas the plain lines represent the analytical results. The various colors represent the different atmospheric stability classes as follow:
- The systematic error in the standard deviation measured by the nacelle lidar depends strongly on the wind direction relative to the lidar axis. For a nacelle mounted lidar on a well-aligned wind turbine (small yaw error) this angle would typically be close to 0°. Thus a nacelle mounted lidar will normally underestimate the standard deviation of the wind speed.

Conclusions
- The lidar tends to underestimate the wind speed variance because of two effects:
  - The lidar senses the wind speed over a volume (defined by the probe volume and the space between the two beams), which prevents the lidar from resolving the small turbulence structures.
  - The horizontal wind speed is retrieved by combining the radial speeds measured in two different directions, separated by an angle of 30°. The lidar variance measure is contaminated by the transverse component of the wind field.
- The theoretical analysis showed that the ratio of turbulence intensity given by the lidar with respect to the true turbulence intensity is expected to vary with:
  - the direction of the wind relative to the lidar axis orientation;
  - the atmospheric stability;
  - the wind speed (only under stable conditions).
- The experimental data confirm the variation of the turbulence intensity reported by the lidar relative to the turbulence intensity measured by the cup anemometer with the relative wind direction. However the influence of the atmospheric stability and wind speed are not particularly evident, because of the poor distribution of the data.

References

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