SATI: spectral averaging turbulence intensity. A cup-equivalent TI measure for nacelle-mounted CW lidar
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Abstract
A new method has been developed for measuring Turbulence Intensity (TI) from a nacelle mounted lidar. This is based on averaging of the lidar’s Doppler spectra directly (Spectral Averaging Turbulence Intensity - SATI) and results in lidar TI measured closely agreeing with cup anemometer measured TI. Moreover, SATI results are largely independent of measurement range. The required Doppler spectra are available from continuous wave (CW) lidars. This paper presents new results from analysis of data from a Zephir Dual Mode (ZDM) CW nacelle mounted lidar, including that from the NarreRærke Enge measurement campaign, part of the Danish UniTiTe lidar project [1]. The results confirm the utility of the SATI approach, with hub height TI correlation gradient difference of just 4%. This compares to a more usually experienced ~25% observed difference between lidar and cup TI measurements when calculated using conventional algorithms.

Objectives
Turbine-mounted lidars are a powerful tool for turbine performance measurement. Turbulence intensity (TI) measurement is relevant to both power curve and loads assessment, and can confirm site classification. Traditionally, cup-based TI measurements have been used. Despite the numerous advantages of turbine-mounted lidars over meteorological masts (met masts), and the high accuracy of their measurements, lidar measures of TI are generally lower than those from cup anemometers. The principle reason for this is that a lidar measures wind speed over a volume, whilst a cup measures the wind speed at a point. As the lidar volume (both in terms of the lateral distance between lidar probe sample points and lidar probe length) will increase with distance, the apparent under-read normally varies with the measurement range. The SATI approach is explained in detail in [2] and [3]. The objective of the work reported here is to show that this approach for calculating TI from a nacelle-mounted lidar results in much closer agreement with cup based TI measures.

Method
The principal source of data for this paper was the NKE UniTiTe measurement campaign, in which a ZDM was mounted on the nacelle of a 2.3 MW Siemens turbine between June and December 2016. The ZDM has a continuously scanning circular beam, with each circular scan taking 1 s. The full lidar Doppler spectrum is measured at 50 points around the scan i.e. at 50 Hz. The raw spectral lidar data was filtered to select normal turbine operation in an un-waked sector. Lidar signals from blades and foreign objects were removed. During each circular scan of the beam, the lidar makes two measurements at hub height (HH), one either side of scan centre. The normalised Doppler spectra from hub height at each side over a 10-minute period were summed separately and a standard deviation calculated for each spectral sum. The medians of the left and right spectra were used to calculate the left and right line-of-sight wind speeds. The left and right TIs were calculated as the ratio of the standard deviations to the wind speeds and the two TIs were averaged. Figure 1 illustrates the principle.

The SATI results were compared with TI derived from HH cups on a met mast at 2.5 rotor diameters (D) upstream of the turbine. SATI measurements were also made at various ranges within the turbine induction zone, both to explore any effects of lidar sampling volume changes and also to investigate TI changes through the induction zone (see Figure 2).

Conclusions
These results show a good level of agreement between SATI-derived turbulence statistics measured by nacelle-mounted circular-scan CW lidar and mast-mounted cup anemometers. This, and other studies, confirms that the spectral averaging approach to calculating turbulence intensity has significant merit. The Doppler spectra are recorded routinely with this type of lidar, so no major hardware changes are needed to implement the technique. Moreover, lidar data can be reprocessed to yield improved TI results from historical lidar campaigns. The results presented in this paper add further weight to the case for using nacelle-mounted CW lidars for lidar performance analysis and loads measurements.

References

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