lidarwind: A Python package for retrieving wind profiles from Doppler lidar observations

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Summary

Wind is one of the essential components of the atmospheric system, modulating precipitation on larger scales, transporting moisture and heat, and contributing to dispersing aerosols. Due to the urgent need to replace fossil fuel-based power plants with systems based on renewable energy sources, wind has become one of the primary energy sources. Understanding wind variability is imperative for improving numerical weather prediction models and for planning wind farms. However, the number of currently available wind observations is still limited, and most of the available observations are from radiosondes or meteorological towers (met-towers). Those observational systems are restricted to a particular time (radiosondes) or height (met-towers). Wind lidar has been used to minimise those limitations, allowing monitoring of wind constantly from near the surface up to, for example, 5 km.

Several wind lidar models are commercially available, but their operating software is often proprietary. Although different scanning strategies for retrieving wind exist, for example, the Doppler beam swing [DBS, (Van Zandt, 2000)], the velocity azimuth display [VAD, (Eberhard et al., 1989; Lhermitte, 1962)] and the 6-beam introduced by (Sathe et al., 2015) most of the lidar operating software provides horizontal wind speed and direction profile retrievals for the DBS and VAD scanning strategies. However, the retrievals of horizontal wind profiles are unavailable if the lidar is set to scan using the 6-beam strategy. In addition, in the case of the WindCube 200s, the different scanning strategies also generate NetCDF files with different structures.

Statement of need

lidarwind is a Python package for retrieving horizontal wind speed and direction profiles from the 6-beam scanning strategy but also includes routines for retrieving wind profiles from the DBS. This package was developed for retrieving wind profiles from WindCube's NetCDF output, but it can be extended to process NetCDF (Rew & Davis, 1990) output from other Doppler lidar systems. lidarwind reproduces the data filtering described in WindCube's manual (Leosphere, a Vaisala company, 2020) and allows the user to define the signal-to-noise ratio threshold for filtering noisy measurements or using the status variable. In addition, two experimental filters to minimise the presence of second trip echoes on the observations are included in the package.

lidarwind was developed to be easy to use and flexible, allowing it to be used operationally to retrieve wind profiles continuously. With this package, the user can read and merge a list of WindCube's files and choose to retrieve wind using the DBS or the 6-beam dedicated modules. In particular, for the 6-beam observations, the wind is retrieved using the Fast Fourier Wind Vector Algorithm (Ishwardat, 2017). Since the 6-beam strategy is idealised for studying turbulence, lidarwind also contains a module for calculating the Reynolds stress tensor according to the methodology introduced by Sathe et al. (2015). lidarwind also includes a basic visualisation module, allowing a quick inspection of the retrieved wind speed and direction

profiles. Thanks to its flexibility, this package was used to process WindCube's data from The Tracing Convective Momentum Transport in Complex Cloudy Atmospheres Experiment (José Dias Neto, 2022).

Visualizing the 6-beam retrieved wind

As an example of the usage of this package, the vertical wind speed measured by the WindCube and the horizontal wind speed and direction retrieved using the Fast Fourier Wind Vector Algorithm are shown in panels a, b, and c from Figure 1.
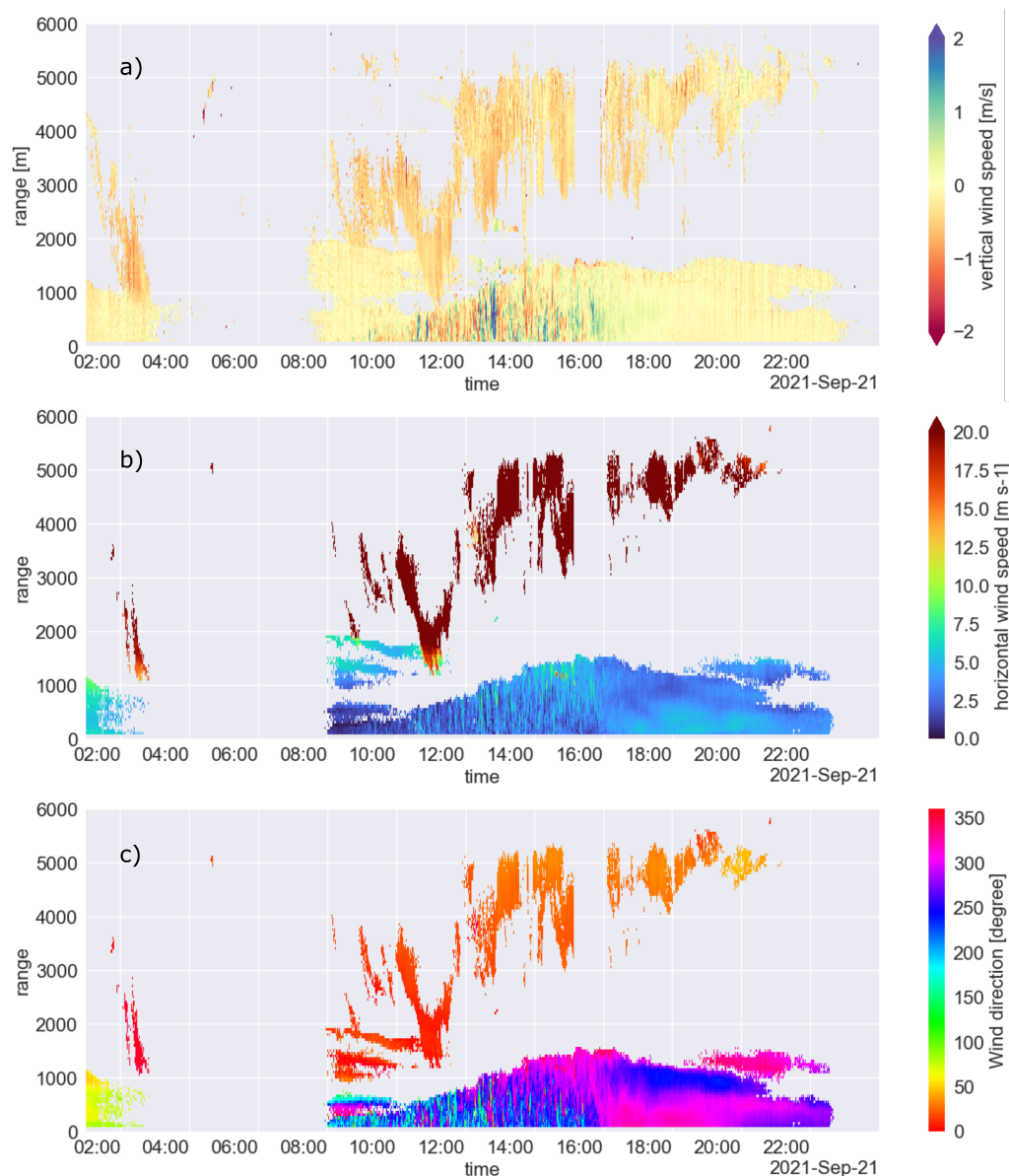
Figure 1: Time-height plots of the vertical wind speed (a), horizontal wind speed (b), and horizontal wind direction (c) derived from the 6-beam observations.

Panel a, in the lowest 2 km, reveals the daily evolution of the vertical wind. Before 9:00 UTC and after 17:00 UTC, the measured vertical wind is mainly 0 m/s, indicating the stable

Neto, & Castelao. (2023). lidarwind: A Python package for retrieving wind profiles from Doppler lidar observations. *Journal of Open Source Software*, *8*(82), 4852. https://doi.org/10.21105/joss.04852

period of the atmospheric boundary layer. Between 9:00 UTC and 17:00 UTC, the range of the vertical velocities increases, spaning values between -1 and 1 m/s, which indicates the formation of the turbulent layer, also known as the mixing layer (Stull, 2003). Panel a also shows a measurement gap between 3 UTC and 8 UTC. This gap is due to the absence of a backscattered signal caused by the extremely low amount of lidar scatterers in the atmosphere [aerosol]. Panel b, in the lowest 2 km, shows that for the whole day, the magnitude of the horizontal wind is mainly distributed between 0 and 10 m/s. This panel also reveals variabilities in the magnitude of the horizontal wind related to the presence of different temporal scales. During the stable period, the scales of the horizontal wind variability seem to be in the order of hours, while during the turbulent period, the temporal scales are in the order of minutes. In the lowest 2 km from panel c, the wind direction indicates a wind rotation along the day. Before 2 UTC, the wind is from the southeast; around 12:00 UTC, the wind is from the southwest; later, after 20:00 UTC, the wind is from the northwest. Similar to that noticed for the two previous variables, the wind direction indicates the presence of small-scale variabilities during the turbulent period. In contrast, during the stable period, the change in direction is only apparent between different heights (e.g. near the surface and around 1000 m).

Above 2000 m, all three variables suggest that the lidar was able to obtain observations from within the clouds. Even though the observations are from clouds, their heights are wrong. This mispositioning of those clouds is related to the WindCube operating settings used during the measurements. A methodology for removing those wrong clouds, introduced in (J. Dias Neto et al., 2022), is also available in this package, but ceilometer observations are required for applying it.

Acknowledgements

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