**Title:** CU Profiling lidar data

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**1.0 Data Set Overview:**

These Windcube v1 doppler profiling lidars were deployed within the valley (at the lower "Orange" site) and east of the valley (at the "Beehive" site) during the IOP period (1 May – 15 June 2017).

The two v1 lidar sites were located at:

| Site | PT-TM06/ETRS89 x (more accurate) | PT-TM06/ETRS89 y (more accurate) | Latitude (less accurate) | Longitude (less accurate) | Elevation (msl) |
|---|---|---|---|---|---|
| Beehive | 34910.565 | 5638.862 | 39.718331° | -7.726405° | 259.672 |
| Lower Orange | 33954.637 | 5002.003 | 39.71245° | -7.737386° | 295.848 |

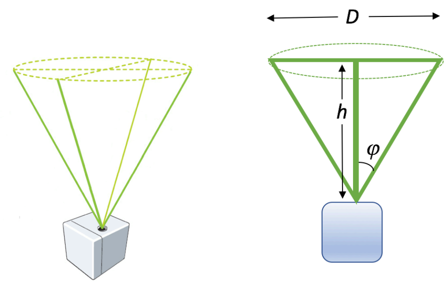
Daily plots of the output from these lidars are available at http://breeze.colorado.edu/Perdigao/ . Note that the plots located at that website include latitude and longitude measured with our GPS, which is accurate only to 10-20m. The more accurate PT-TM06 and elevation readings listed in the table above should be considered authoritative.

**2.0 Instrument Description:**

Doppler lidars sample the flow over a volume extending along the laser beam, by exploiting the Doppler shift of laser light backscattered by particulates carried by the wind. A known frequency of light is emitted from the laser, and the backscattered radiation will have a shift in frequency related to how rapidly particulates are moving toward or away from the laser source along the line of the beam or the line of sight (LOS) (Cariou 2011). To provide profiles of wind speed and wind direction, these systems use the Doppler beam swinging (DBS) technique. By shifting the beam between a series of four radial wind directions at approximately 60◦ elevation and perpendicular to each other, the Doppler shift (and therefore the LOS velocity) can be calculated. For pulsed lidars, all altitudes are measured based on the same pulse. Measurements at different heights are identified based on the arrival time of the backscatter compared to the initiation of the pulse. Typically, the assumption of horizontal homogeneity over a horizontal area is invoked to interpret DBS measurements to calculate horizontal and vertical wind speeds rather than LOS velocities.  The error introduced by this assumption has been assessed (Bingöl et al. 2009; Rhodes and Lundquist 2013; Lundquist et al. 2015).

A schematic of the scanning pattern (courtesy Leosphere) appears at right.

Specifications of the Windcube v1, according to Leosphere, are in the Table below.




View from NW    Side view

| | |
|---|---|
| Range | 40m to 220m in 20-m increments |
| Accumulation Time | 0.5 s |
| Data output frequency | Nominally 1 Hz, data stored in *.rtd files.<br>Two-minute averages are stored in *.sta files. |
| Probe length | 20m |
| Speed accuracy | 0.2 m s-1 |
| Direction accuracy | 1.5 degrees |
| Laser Wavelength | 1.54 micron |
| Pulse Energy | 10 microJoule |

**3.0 Data Collection and Processing:**

At the Lower Orange site, the WC49 lidar was co-located with the OU Halo lidar and a radiometer, and installed on April 28 (see Figures 1-3). At the Beehive site, the WC68 lidar was operated via a solar panel/diesel generator system as seen in Figures 4-5.

Line-of-sight (LOS) velocities $V_r$ of the flow along each beam denoted by subscripts $V_{rN}, V_{rE}, V_{rS}, V_{rW}$ were collected nominally every 1 second (rotating through the four beams: north, east, south, west). These LOS velocities are given in the *rtd files, and are converted to horizontal winds.

Assuming horizontal homogeneity in the altitudes sampled, the system of wind equations becomes

$$u_L = \frac{V_{rE} - V_{rW}}{2\sin\theta}, \quad (1)$$

$$v_L = \frac{V_{rN} - V_{rS}}{2\sin\theta}, \text{ and} \quad (2)$$

$$w_L = \frac{V_{rN} + V_{rS} + V_{rE} + V_{rW}}{4\cos\theta}, \quad (3)$$

where $u_L$, $v_L$, and $w_L$ describe the estimates of flow in the zonal (west to east), meridional (south to north), and vertical directions where $w$ is positive for upward motion. *****Please note that the u, v, and w components of the flow given in the rtd and sta files use a different coordinate system ***.**

Basic quality control, requiring that an individual line-of-sight (LOS) velocity be measured with a carrier-to-noise ratio greater than -22 dB, has already been applied to these data. The two-minute averages are based only on the 1-Hz LOS with CNR exceeding -22 dB. However, two-minute averages with “Avail” less than 90% should be considered suspicious. Lidars require a sufficient number of scatterers for a return signal, so clean air conditions have lower availability (Aitken et al. 2012).

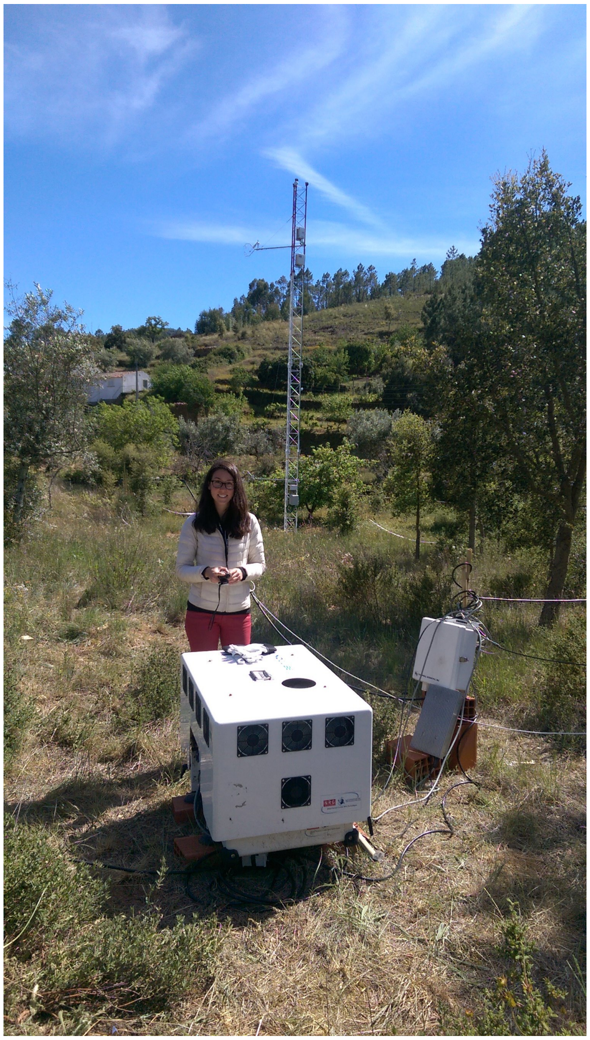


*Figure 1: WC49 at Lower Orange near the beginning of the IOP. Tower vall_04 is to the SW in the background, as is Vale do Cobrão*


*Figure 2: WC49 (Lower Orange) with view to the northwest, including OU radiometer and OU trailer.*

*Figure 3: WC49 (lower Orange) with lid removed, view to south-southwest with other instrumentation (left to right): OU Halo, tower vall_04, and OU radiometer*


*Figure 4: WC 68 at the beehive site east of the valley. This unit was operated by solar panels and a backup diesel generator provided by INEGI.*


*Figure 5: WC68 (beehive) with view looking northeast*

## 4.0 Data Format:

The *sta files and the *rtd files are both ASCII files. Missing data are denoted as NaN in both files. This is the first version of the data, March 14, 2018. Filenames indicate the starting time of data collection. Because the lidars tended to overheat in the mid-afternoon, especially near the end of the campaign, some days have multiple datafiles. For example, while the 8th and 9th of June each have one datafile, the 10th, 11th, 12th, 13th, and 14th all have two files.

```
-rw-rw-r-- 1 ftp jklgroup 787234 Jun  9  2017 WLS7-0068_2017_06_08__00_00_00.sta
-rw-rw-r-- 1 ftp jklgroup 770675 Jun 12  2017 WLS7-0068_2017_06_09__00_00_00.sta
-rw-rw-r-- 1 ftp jklgroup 457042 Jun 12  2017 WLS7-0068_2017_06_10__00_00_06.sta
-rw-rw-r-- 1 ftp jklgroup 191892 Jun 12  2017 WLS7-0068_2017_06_10__18_19_45.sta
-rw-rw-r-- 1 ftp jklgroup 450169 Jun 12  2017 WLS7-0068_2017_06_11__00_00_05.sta
-rw-rw-r-- 1 ftp jklgroup 185323 Jun 12  2017 WLS7-0068_2017_06_11__18_33_00.sta
-rw-rw-r-- 1 ftp jklgroup 409288 Jun 12  2017 WLS7-0068_2017_06_12__00_00_05.sta
-rw-rw-r-- 1 ftp jklgroup 154281 Jun 13  2017 WLS7-0068_2017_06_12__19_25_58.sta
-rw-rw-r-- 1 ftp jklgroup 483871 Jun 13  2017 WLS7-0068_2017_06_13__00_00_00.sta
-rw-rw-r-- 1 ftp jklgroup 171063 Jun 14  2017 WLS7-0068_2017_06_13__18_57_58.sta
-rw-rw-r-- 1 ftp jklgroup 506931 Jun 14  2017 WLS7-0068_2017_06_14__00_00_00.sta
-rw-rw-r-- 1 ftp jklgroup 190510 Jun 15  2017 WLS7-0068_2017_06_14__18_23_04.sta
-rw-rw-r-- 1 ftp jklgroup 369206 Jun 15  2017 WLS7-0068_2017_06_15__00_00_00.sta
```

### 4.1 *STA FILES

Within the *sta files, the first 56 lines are header information, providing the height settings (line 14) and other lidar operating parameters. Line 57 gives header information for the rows of data that follow, with each row a new 2-min average of the returned variables. Note that the "u" and "v" as defined in these files are NOT in meteorological coordinates, but rather in engineering coordinates:

U positive from north -> south
V positive from east -> west
W positive from up -> down

Therefore,
u_meteorological = -v_native
v_meteorological = -u_native
w_meteorological = -w_native

The useful header starts on line 57 and the data start on line 58.
Date/Time: DD/MM/YYYY HH:MM:SS UTC
Wiper Count: ignore unless suspect precipitation (but often poor metric for precip)
Tm: internal temperature (deg Celsius) of the laser unit
****** begin series of quantities that will repeat for each of ten heights **********

The available variables are:

- Vhm: mean **scalar-averaged** horizontal wind speed (m $s^{-1}$) for the 2-min period
- dVh: standard deviation of **scalar-averaged** horizontal wind speed (m $s^{-1}$)
- VhMax: maximum 1-sec wind speed measurement during the 2-minute period (m $s^{-1}$)
- VhMin: minimum 1-sec wind speed measurement during the 2-minute period (m $s^{-1}$)
- Azim: vector-averaged wind direction (meteorological coordinates)
- um1: average u-component (m $s^{-1}$)

- du1: standard deviation of u-component (m $s^{-1}$)
- vm1: average v-component (m $s^{-1}$)
- dv1: standard deviation of v-component (m $s^{-1}$)
- wm1: average w-component (m $s^{-1}$)
- dw1: standard deviation of w-component (m $s^{-1}$)
- CNRm: average CNR for the two-minute period (dB);
- dCNR: standard deviation of CNR (dB)
- CNRmax: maximum CNR (dB)
- CNRmin: minimum CNR (dB)
- spectral_broadening: 2-minute-averaged spectral broadening (converted to m $s^{-1}$)
- dspectral_broadening: standard deviation of spectral broadening (m $s^{-1}$)
- Avail: percentage of data available at this altitude (assuming CNR threshold of -22 dB)

**4.2 *RTD FILES**
Within the *rtd files, the first 56 lines are header information, providing the height settings (line 14) and other lidar operating parameters. Line 57 gives header information for the rows of data that follow, with each row a new 2-min average of the returned variables. Note that the "u" and "v" as defined in these files are NOT in meteorological coordinates, but rather in engineering coordinates:

U positive from north -> south
V positive from east -> west
W positive from up -> down

Therefore,
u_meteorological = -v_native
v_meteorological = -u_native
w_meteorological = -w_native

The useful header starts on line 57 and the data start on line 58.
Date: DD/MM/YYYY HH:MM:SS UTC
Position: which beam (of 0, 90, 180, 270, or N, E, S, W) is reporting data
Temperature (deg C): internal temperature of the laser unit
Wiper count:
****** begin series of quantities that will repeat for each of ten heights **********

The available variables are:

- CNR: carrier-to-noise ratio for this beam (dB);
- RWS: the line-of-sight (radial) velocity for this beam (m s-1);
- RSWD: the Averaged Doppler Spectrum width converted into m s-1;
- Vh: the horizontal wind speed considering this beam and the three previous beams (m s-1);
- Azi: the horizontal wind direction considering this beam and the three previous beams (deg);
- u: the u-component considering this beam and the three previous beams (m $s^{-1}$);

- v: the v-component considering this beam and the three previous beams (m $s^{-1}$);
- w: the w-component considering this beam and the three previous beams (m $s^{-1}$);

**5.0 Data Remarks:**

At the lower orange site, there were frequent periods of very quiescent air, especially at night. These quiescent periods, coupled with lower quantities of scatterers, resulted in several data gaps. At both the lower orange and the beehive site, frequent overheaing of the lidars in the mid-afternoon near the end of the experiment also resulted in missing data. Several days have multiple files as the lidar would shut down (and close a datafile) when it overheated. When temperatures were cool enough for operations, a new file would be opened and data would be collected again.

**6.0 References:**

Aitken, M. L., M. E. Rhodes, and J. K. Lundquist, 2012: Performance of a Wind-Profiling Lidar in the Region of Wind Turbine Rotor Disks. *J. Atmospheric Ocean. Technol.*, **29**, 347–355, doi:10.1175/JTECH-D-11-00033.1.

Bingöl, F., J. Mann, and D. Foussekis, 2009: Conically scanning lidar error in complex terrain. *Meteorol. Z.*, **18**, 189–195, doi:10.1127/0941-2948/2009/0368.

Cariou, J.-P., 2011: 4 Pulsed lidars. http://rasei.colorado.edu/wind-research-internal1/Jean_Pierre_Cariou.pdf (Accessed September 26, 2015).

Lundquist, J. K., M. J. Churchfield, S. Lee, and A. Clifton, 2015: Quantifying error of lidar and sodar Doppler beam swinging measurements of wind turbine wakes using computational fluid dynamics. *Atmos Meas Tech*, **8**, 907–920, doi:10.5194/amt-8-907-2015.

Rhodes, M. E., and J. K. Lundquist, 2013: The Effect of Wind-Turbine Wakes on Summertime US Midwest Atmospheric Wind Profiles as Observed with Ground-Based Doppler Lidar. *Bound.-Layer Meteorol.*, **149**, 85–103, doi:10.1007/s10546-013-9834-x.