Mobile Wind Lidar measurements of the spatial variability of atmospheric boundary layer flows in complex terrain

Stephan F.J. De Wekker[(a)], S. Greco[(b)], G.D. Emmitt[(b)]
[(a)] *University of Virginia*
Charlottesville, VA, USA
[(b)] *Simpson Weather Associates*
Charlottesville, VA, USA
dewekker@virginia.edu

Abstract: Making observations of the spatial structure of atmospheric boundary layer flows is an ongoing challenge that we attempt to address with the development of the surface-based mobile observing platform UWOW (University of Virginia Wind Observatory on Wheels. UWOW uses a Doppler wind lidar, a GPS, and an inertial navigation system placed in a custom trailer to measure boundary layer winds while traveling on the road. UWOW can measure wind profiles from approximately 100 to 3000 m above ground with 30 m vertical spacing. We show some observations made during the Sundowner Wind Experiment (SWEX) in Santa Barbara, CA, where UWOW travelled about 7000 km on roads around the Santa Ynez Mountains to document the spatial wind variability during downslope windstorm events.

1. Introduction

Traditional ground-based boundary-layer profilers measure atmospheric variables as a function of height at a given time and at a given geographical location. When operated over a certain time period, these measurements provide important insights into the temporal evolution of the atmospheric boundary layer (ABL). However, in many situations, information about the spatial structure of the ABL is needed, especially in complex terrain such as mountainous, coastal, and urban areas. In these areas, vertical profiles are often not representative, and the installation of profilers at multiple locations and/or aircraft facilities would be desirable. This may not be feasible for various reasons, including costs, lack of personnel, and unavailability of multiple identical facilities. Furthermore, these ground-based facilities may not be easy to move around. Recent technological advancements have enabled ground-based remote sensors to become more compact and portable, but they are still expensive. In addition, unattended operation may not be feasible if, for example, environmental conditions are outside the operation range of sensors or if there is a chance that the sensor may get vandalized or stolen. These considerations motivated the development of the University of Virginia Wind Observatory on Wheels (UWOW) facility. The major component of the UWOW is a Doppler Wind Lidar (DWL). UWOW can take stationary fixed location measurements like other ground-based scanning Doppler wind lidars (stationary operation). However, since it is integrated in a customized cargo trailer, it can also sample wind profiles when towed by a small truck (mobile operation). In our presentation, we will describe UWOW and show some results made with the mobile facility during the recent Sundowner Wind Experiment (SWEX) in California, USA.

2. Lidar-trailer system

The major component of the UWOW is a Doppler Wind Lidar (DWL) integrated in a cargo trailer. The DWL is a HALO StreamLine XR. The instrument is a very compact DWL system conveniently housed in a box with dimensions of 63x53x40 cm3. The DWL's eye-safe class 1M laser emits short pulses of near-infrared radiation into the atmosphere. This radiation is scattered predominantly by suspended aerosols and cloud particles, whose movement confer a Doppler frequency shift to the backscattered radiation. The DWL's heterodyne detector measures this along-beam frequency shift and from it, calculates the Doppler velocity which equals the radial velocity. Assuming that the scattering particles are moving with the wind, measurements of radial velocity can be translated into an air volume's wind field (horizontal speed and direction, and vertical speed) using an appropriate scanning strategy.

The DWL is integrated in a 12 ft covered cargo trailer (Figure 1). This trailer was purchased with tandem axles and with Torflex suspension to make the motion of the trailer as smooth as possible. Additional features of the trailer include surge brakes for compatibility with different towing vehicles, a 1-foot tongue extension to accommodate a generator and an HVAC-unit, and scissor jacks on each corner to stabilize the trailer when stationary.

The trailer was modified to allow full-scanning operation of the lidar while being towed. Modifications included the replacement of part of the curved trailer roof with a flat roof section. This was done so that the lidar could be pushed upward and sit snug against the flat roof. Additionally, a hole was cut out in this roof section to accommodate the lidar scanner. A rubber gasket was installed along the edge of the hole in the roof to create a water-tight seal. The lidar's scanner clears the roof entirely so that the instrument can scan the full 360°azimuthal and 180° elevation range.

The lidar was installed in the trailer on a mechanically-operated lift table by bolting the DWL legs to the top surface of the table. The lift table allows the DWL to be raised to its measurement position in a controlled manner. The DWL is stabilized in its raised position using four ratchet straps. Each strap extends from an eyebolt in the ceiling of the trailer, and hooks underneath the lift table's surface. The DWL’s power transformer and power conditioner were installed on top of the lift table, below the DWL.

Figure 1. University of Virginia Wind Observatory on Wheels (UWOW). The Doppler Wind Lidar is installed on a mechanically-operated lift table in a cargo trailer.

Incorporating a DWL instrument into a mobile measurement platform introduces several challenges for the collection of accurate wind field data. The velocity of the platform (and thus the DWL) introduces a frequency shift to the lidar measurement in addition to the frequency shift from moving scatterers. In addition, changes to the attitude of the DWL between scans need to be taken into account when calculating the wind properties. To account for these effects, a GPS-INS was installed in the trailer to determine the DWL's attitude and velocity at all times. The selected GPS-INS was a VectorNAV VN-200.

Determination of wind profiles by DWL is done using VAD (Velocity Azimuth Display) scans with 6 (or more) equally-spaced angles along a full 360° range and 65 degree elevation angle.

A complete vertical wind profile can be retrieved at approximately 30 second intervals. When operating the DWL while the trailer is moving, attitude (pitch, roll, yaw) and navigational data are required to determine the wind field. The VN-200 GPS-INS collects these data at a frequency of 1 to 100 Hz (currently set at 10Hz) and sends these to a computer over a serial connection. The trailer was outfitted with a router and a laptop to receive the UDP-broadcasted lidar messages (wirelessly) and the serial GPS-INS data. A python script continuously collects the DWL and GPS-INS data, parses the data strings, and saves the data to a file containing the combined GPS-INS and lidar data, from which the two instruments can be time-synchronized. The GPS-INS data allows for the correction of radial velocities for changes in attitude and for ground speed of the DWL. The combined DWL and GPS/INS data are subsequently processed by software previously developed by Simpson Weather Associates (SWA, Charlottesville, VA, USA) for calculating the wind field parameters from aircraft-mounted Doppler lidar measurements.

3. Results

We show some results from UWOW measurements collected during the Sundowner Winds Experiment (SWEX, [1]). SWEX was a field campaign that took place in Santa Barbara, California, between 1 April and 15 May 2022. It was a collaborative effort of 10 institutions to advance understanding and predictability of Sundowners, while providing rich datasets for developing new theories of downslope windstorms in coastal environments. On a typical intensive observational period (IOP), UWOW traveled around a part of the east-west oriented Santa Ynez Mountains several times with each loop taking about 1.5 hours (Fig. 2)

Figure 2: typical UWOW road track during an intensive observational period. The yellow line indicates the location of the cross sections shown in Figs. 3 and 4.

Cross sections of wind speed and direction obtained from UWOW provide a detailed picture of the temporal evolution of the spatial variability of the ABL flows in the lee side (south) of the Santa Ynez Mountains (Fig. 3).

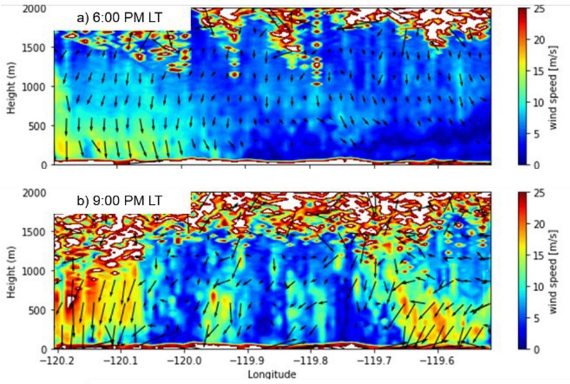

Figure 3: Cross sections of wind speed (color scale) and direction (arrows) obtained from UWOW on IOP 5, 23 April 2022, at (a) 6 PM and (b) 9 PM local time (LT) along the yellow line in Fig. 2

Winds first start increasing in the western part of the domain around sunset (Fig. 3a) with other smaller areas following at later times (Fig. 3b). These “Sundowner” winds are produced by multi-scale dynamical and thermal processes over mountainous terrain and are also affected by the presence of the marine boundary layer. The interplay between these processes results in complex wind patterns that are challenging to forecast. Preliminary WRF simulations at 1 km resolution valid for the same times as in Fig. 3 show some resemblance of the observed flow pattern at the larger scale but are clearly missing some of the intricacies of the Sundowner winds (Fig. 4). This example clearly demonstrates the effectiveness of UWOW in capturing the spatial variability of the winds in complex terrain.

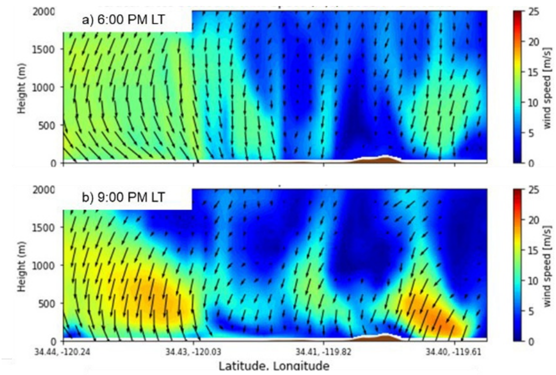

Figure 4: Cross sections of wind speed (color scale) and direction (arrows) obtained from 1-km WRF simulations for IOP 5, 23 April 2022, at (a) 6 PM and (b) 9 PM local time (LT) along the yellow line in Fig. 2

4. Summary

We have developed the mobile wind lidar facility UWOW, which is capable of measuring the spatial variability of ABL flows. UWOW was successfully deployed during a recent field campaign in complex terrain where it has documented large spatial and temporal wind variability in the leeside of a mountain range. UWOW measurements are important for atmospheric model evaluation and process studies, and we plan to deploy UWOW in more upcoming field experiments.

5. References

[1] L. M. V Carvalho, and Coauthors, 2024: “The Sundowner Winds Experiment (SWEX) in Santa Barbara, California: Advancing Understanding and Predictability of Downslope Windstorms in Coastal Environments”. Bull. Amer. Meteor. Soc., **105**, E532–E558, https://doi.org/10.1175/BAMS-D-22-0171.1.