OBSERVATIONS OF DIURNAL MOUNTAIN VALLEY FLOW UTILIZING DUEL DOPPLER LIDAR VIRTUAL TOWER TECHNIQUE

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1. INTRODUCTION

The study of thermally driven diurnal flow phenomena in complex terrain is of both scientific and anthropologic interest. Flow phenomena observed in such locations can prove to be quite interesting and often unpredictable. Owens Valley, California was the site of the Terrain-Induced Rotor Experiment (TREX) carried out during the months of March and April 2006. The main objective of this experiment campaign was the observation of mountain wave and rotor activity in the lee of the Sierra Nevada Mountains. Secondary objectives which focused on the stable boundary layer included the study of thermally driven flow as well as the creation and depletion of cold air pools. The unique local topography, set between two large and nearly parallel mountain ranges, offered the opportunity to study diurnal flow phenomena in an idealized valley setting.

Arizona State University (ASU) participated in TREX for the duration of the campaign, utilizing both a sodar/RASS system as well as a scanning coherent Doppler lidar. The ASU Doppler lidar produces radial velocity data by first emitting laser pulses at 500Hz into the atmosphere. These laser pulses are scattered back to the lidar by aerosols within the boundary layer. Once the signal has returned to the lidar, its frequency shift from the original signal can be measured and used to determine the radial velocity within a given range gate. Similar Doppler lidar systems have been used in previous experiments to study flow in complex terrain. Banta (1999) used a Doppler lidar to observe several flow patterns in the Grand Canyon. As part of the VTMX campaign, Banta (2004) also used a Doppler lidar to study flow within the Great Salt Lake basin. One interesting result of this measurement campaign was the observation of nocturnal low-level jet using the Doppler lidar.

A large measurement campaign such as TREX affords added flexibility in experimental design. Due to the variety of measurement equipment present during the campaign, the ability to verify data and coordinate measurement strategies was readily available. One such cooperative opportunity was made possible by the presence of a second scanning coherent Doppler lidar situated near the ASU Doppler lidar. The second Doppler lidar, operated by Deutsches Zentrum fur Luft-und Raumfahrt (DLR), was a near identical system to that of ASU. Dual Doppler lidar coordinated scans were thus carried out on two occasions during the measurement campaign utilizing the ASU and DLR Doppler lidars.

Dual Doppler lidar coordinated scans have the potential to overcome the difficulties associated with resolving the radial wind velocity field data that a scanning coherent Doppler lidar retrieves. Overlapping data sets from multiple Doppler lidars can theoretically be unified to

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form a single data set that combines radial velocities from each instrument to form a more complete wind velocity vector at a given point in space. The coordinating of two coherent Doppler lidars to study atmospheric phenomena can be seen as far back as observations by Rothermel (1985) during the JAWS Project. More recently, dual Doppler lidar coordinated experiments have been carried out by Collier (2005), Davies (2005) and Newsome (2005). Of greatest relevance here are dual Doppler lidar observations made by Calhoun (2006) during the JU2003 campaign. A "virtual tower" dual Doppler lidar scanning technique was utilized during this experiment to observe wind velocity vertical profiles near an urban area. As one of the focuses of this paper, this technique will later be discussed in further detail.

2. METHODS

On the dates of April 7, April 18, and April 19 of 2006, the ASU and DLR Doppler lidars performed coordinated Range Height Indicator (RHI) scans for purposes of obtaining "virtual tower" profiles. The "virtual tower" dual Doppler lidar technique was developed by Calhoun (2006) to obtain vertical profiles of wind velocity at several locations along a horizontal line. A "virtual tower" is the vertical column that is created by the intersection of two Doppler lidar RHI scans as seen in figure 1. This column, shown in yellow, can be thought of as being rectangular, with horizontal lengths being determined by the size of the range gates of each Doppler lidar. Homogeneity of the wind velocity is assumed at a given elevation within the volume bounded by the column walls. Two dimensional horizontal wind velocities are resolved within this column using the algorithm developed by Calhoun (2006). The result is a vertical profile of the horizontal wind velocity similar to that of other instruments used to find such vertical profiles, e.g. sodars.

The Doppler lidars participating in this experiment are both Wind Tracer models manufactured by CLR photonics. Each employs a 2 mJ laser pulse with a wavelength of 2μm. The ASU Doppler lidar was located at 36.79771° N, 118.175640° W. The DLR Doppler lidar was located at 36.79537° N, 118.207983° W. The location of each Doppler lidar as well as the azimuthal location of each RHI scan can be seen in figure 2. This was the scan orientation for April 18 and 19. A mirror image of this configuration about the line of sight between the two Doppler lidars was used on April 7. For the orientation shown in figure 2, the DLR Doppler lidar performed repeating RHI scans at an azimuth of 98 degrees clockwise from north. The ASU Doppler lidar performed five separate RHI scans, cycling sequentially, at azimuths of 125.1, 134.0, 147.4, 172.5 and 197.2 degrees clockwise from north. The range gate sizes for the ASU Doppler lidar and DLR Doppler lidar where 86.97 and 105.09 meters respectively. Pulse averaging was set to 100 yielding 5Hz date. Because the beams are not synchronized with respect to sweeping elevation angle, an inherent lag exists between the times that data are acquired by each instrument for a given point in space. This difference is never greater than 32.5 seconds and, due to averaging times during post processing, this difference can be ignored.

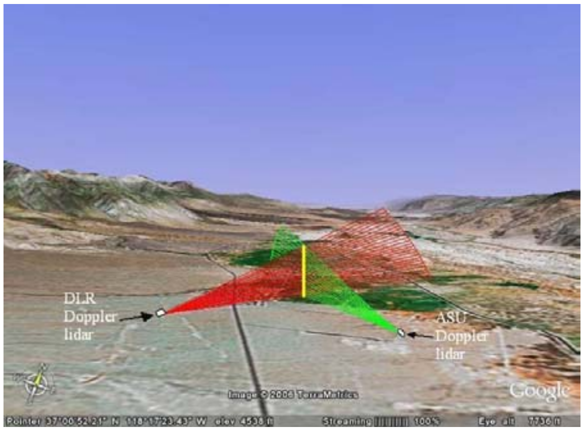

Figure 1. Owens Valley, CA "virtual tower"

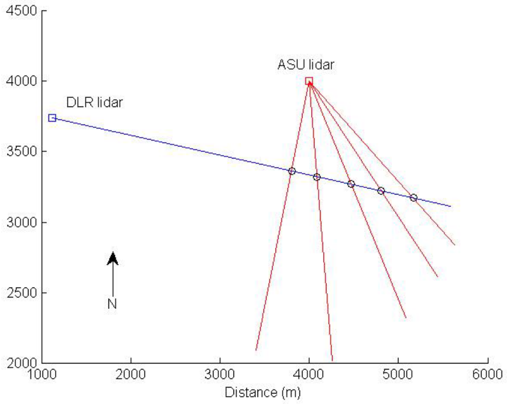

Figure 2. "virtual tower" schematic

3. RESULTS

Vertical profiles were retrieved up to 1.5km above ground level with data points at 50m intervals. The profiles are ten minute averages taken about the specified time. Figure 3 shows the “virtual tower” profiles for 18:25 UTC on April 7, 2006. The location of the ASU Doppler lidar is at x,y coordinate 4000,4000 and is not plotted here due to scaling considerations. This plot shows the five “virtual towers” in the mirrored orientation discussed previously. The wind direction here is from the south in a predominantly up-valley direction as would be expected during the late morning due to thermal forcing. As figure 3 shows, the wind velocity is of greatest magnitude for the “virtual tower” profile nearest the valley center. Toward the west, the magnitude of the wind velocity begins to decrease.

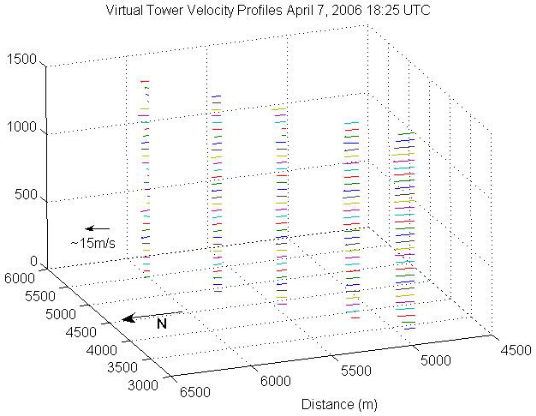

Figure 3. Daytime “virtual tower” profiles

Figure 4 displays the “virtual tower” data for 12:20 UTC on April 19, 2006. This set of virtual towers is oriented as shown in figure 2. Again, the ASU Doppler lidar is located at x,y coordinate 4000,4000. The wind direction in this case is to the south in the down-valley direction. There is a significant night time drainage flow taking place with wind velocity magnitudes of greater than 10m/s at each “virtual tower”. The velocity profile also changes shape gradually from a relatively smooth vertical velocity profile to a vertical velocity profile characterized by several local maxima. One more note on figure 4 is the existence of the low-level jet that can be seen below 500m above ground level.

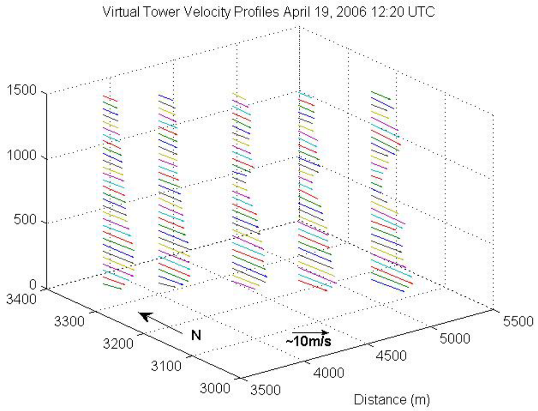

Figure 4. Night time “virtual tower” profiles

For purposes of comparison, data acquired by the ASU sodar/RASS system was plotted with data from the nearest “virtual tower”. The ASU sodar is an MFAS model manufactured by Scintec. The system was approximately 450m south of the closest “virtual tower”. During this period, the ASU sodar was producing vertical profiles of wind velocity up to a 500m ceiling with data at 10m intervals. Data is given for a 20 minute temporal averaging about the specified time. Figure 5 shows a plot of the magnitude of the wind velocity with height above ground level. The profiles were taken at 12:20 UTC on April 19, 2006. The plot shows good agreement between the “virtual tower” and the ASU sodar vertical profiles. Both profiles show the presence of the low-level jet seen also in figure 4. The profiles also both display the existence of two local maximum velocity points. The error in magnitude between the two profiles is approximately 11.4% on average.

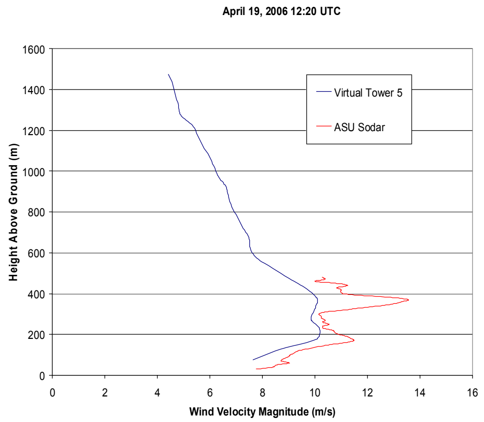

Figure 5. Sodar to “virtual tower” comparison

4. Discussion

The data presented displays the potential of the dual Doppler lidar “virtual tower” technique as a tool for studying diurnal thermally driven flow in complex terrains. The variance in wind velocity magnitude between each “virtual tower” shows the need for such techniques, in order to be able to fully characterize these flows. The gradual decrease in wind velocity magnitude displayed in figure 3 is one example of the type of complexities that are added to the flow by the presence of terrain features. The existence of bounding slopes can add both secondary thermal flow forcing as well as contributing to flow obstruction and channeling. Figure 4 displays another example of the need for a widely spread spatial sampling. The “virtual tower” plots in figure 4 show an obvious change in the shape of the vertical profile of the wind velocity with change in horizontal position. Had a wind velocity vertical profiler been at one of these locations, it would give a narrow and possibly misleading view of the actual larger scale vertical wind profile. The vertical profile in figure 4 between 5000m and 5500m on the east-west horizontal axis shows an acceleration of the low-level jet is perhaps taking place. A mere two kilometers away, the situation is quite different.

The comparison in figure 5 between the “virtual tower” vertical profile and the ASU sodar vertical profile reveals good agreement. The profiles have the same general shape showing the low-level jet in detail. It should be noted that even though the error in magnitude between the two profiles is on average 11.4%, the actual difference in magnitude is less than 1.4m/s in all but one of the data points. This difference could be due to the distance between the two instruments allowing for a slight change in the magnitude of the wind velocity. Another interesting result that was noted earlier was the shape of the low-level jet in the profile plot in figure 5. A similar low-level jet profile characteristic was observed by Banta (2004) where it was described as a “dual maximum”. In our case this “dual maximum” exhibiting low-level jet takes place at a lower altitude then that observed by Banta (2005).

Findings in this study show that dual Doppler lidar analysis improves the potential of an already powerful atmospheric research instrument. The opportunity to coordinate two scanning coherent Doppler lidars is not one that presents itself often, leaving room for future advancement of its development. The “virtual tower” technique allows for the use of two instruments to perform a task that in this case would have required five separate wind velocity vertical profilers. This technique is highly adaptable as the location and number of “virtual towers” can be changed to suit the prevailing atmospheric conditions. In the future, as more coherent Doppler lidar systems make their way into the research community, these types of analysis will become more refined and also perhaps commonplace.

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