P2.1 VTMX: PROFILING THE STABLE NOCTURNAL BOUNDARY LAYER

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1. INTRODUCTION

The National Center for Atmospheric Research / Atmospheric Technology Division (NCAR/ATD) participated in the U.S. Dept of Energy's VTMX (Vertical Transport and MiXing, Doran et.al, 2002) October 2000 field campaign. The VTMX program is concerned with stable nighttime boundary layer conditions in urban basins. The field campaign was centered on the Salt Lake Valley and NCAR operated enhanced Integrated Sounding System (ISS, Parsons et.al. 1994) at a site near the Jordan Narrows, Bluffdale, at the extreme southern end of the valley. The instruments included a sodar, a backscatter lidar, an advanced wind profiler radar MAPR (Cohn et.al. 2001), a tethered blimp supporting in situ instruments, soundings, and two surface meteorological stations. Among the various phenomena being investigated with these instruments include the variability of airflow in and out of the valley and how the flow relates through the narrows is related to mixing and vertical transport processes.

The nocturnal stable boundary layer is a challenging region to probe. The subdued turbulence and cool, dry conditions (as was the case during VTMX) provide only weak reflecting structures for wind profiler radars. During VTMX these weak echoes were largely obscured by clutter from large numbers of migrating birds.

On the other hand, inversions provide strong reflective layers for sodars, however these layers can be confined to just a few heights, often near the surface. The stable layers also trap aerosols, which can be probed by lidar, however with common aerosol backscatter lidar (which give no Doppler information) there is a challenge in extracting quantitative dynamical information. Instrument performance and other aspects of these measurements will be discussed here and in the presentation.

2. LIDAR OBSERVATIONS

SABL (Scanning Aerosol Backscatter Lidar, Laursen et.al. 1995) was operated in vertically pointing and infrared (1 micron) only modes for the VTMX campaign. This instrument produced very detailed images showing interesting fine structure. An example is shown in Fig. 1. Note the sharp fall in reflectivity with altitude at around 400 meters. Such a sharp boundary was a persistent feature during the project, typically varying in altitude a hundred meters or so. These observations suggest a persistent near surface aerosol layer, however the relationship between backscatter intensity and aerosol concentration is a complicated one. In gross terms, increased backscatter can be expected to indicate increased aerosol concentration (ignoring variations in aerosol size and type, and ignoring humidity variations since generally dry condition prevailed). Another feature sometimes seen were small-scale fluctuations in reflectivity such as the feathery features most clearly seen here at around 500 meters. This behavior is suggestive of Kelvin-Helmholtz activity and sodar wind measurements did show a jet below these features that gradually weakened from about 8 UT (Fig 3).

The SABL images give lots of qualitative information, however it can be difficult to interpret such images quantitatively. Here two approaches are investigated; fits are made to the profile of reflectivity, and fluctuations in reflectivity are correlated to measurements from other systems.

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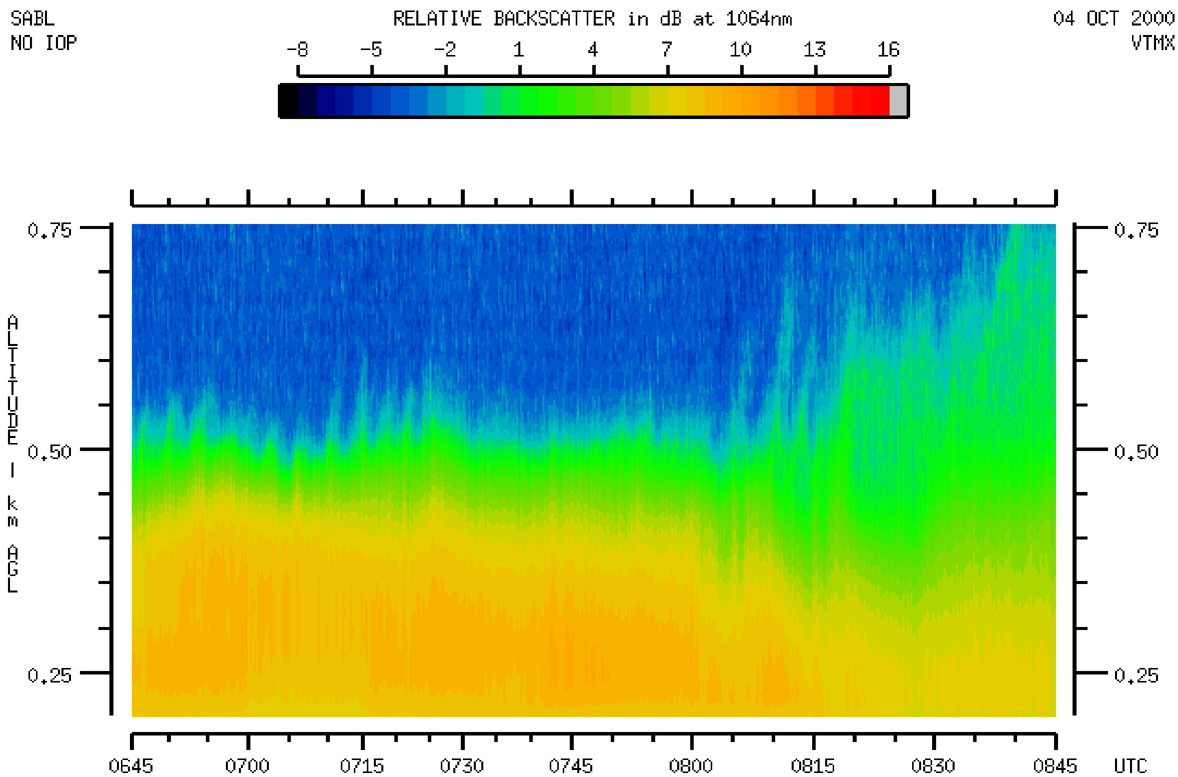

Figure 1. SABL Lidar observations of an apparent Kelvin-Helmholtz activity, Oct 4, 2000.

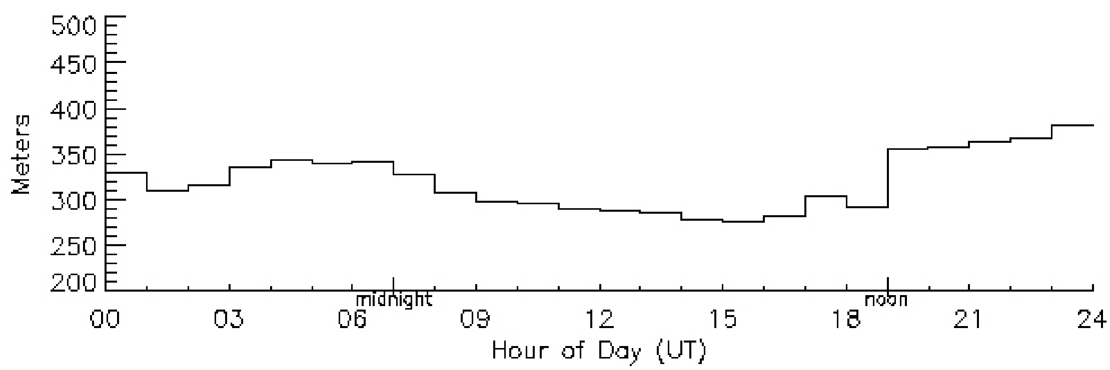

Figure 2. Diurnal variation of the altitude top of the surface reflectivity layer averaged over 11 clear days, 4 – 24 Oct 2000.

Fig 2. gives an example of analysis of profile fits. Here a simple polynomial fit was made to reflectivity profiles to find the average depth of the surface reflectivity layer. An hourly averaged composite from 11 clear days to show the mean diurnal variation is shown in Fig 2. On these days two flow regimes dominated; northerlies during the afternoon that appear to have originated as a lake breeze from the Great Salt Lake about 40 km to the northwest, and southerly down-valley flow from the nearby Utah Lake basin during the evening through early morning (Pinto et.al. 2004). The sudden jump in the depth of the surface reflectivity layer at noon appears to be related to the northerly flow regime rather than solely gradual convective boundary layer evolution.

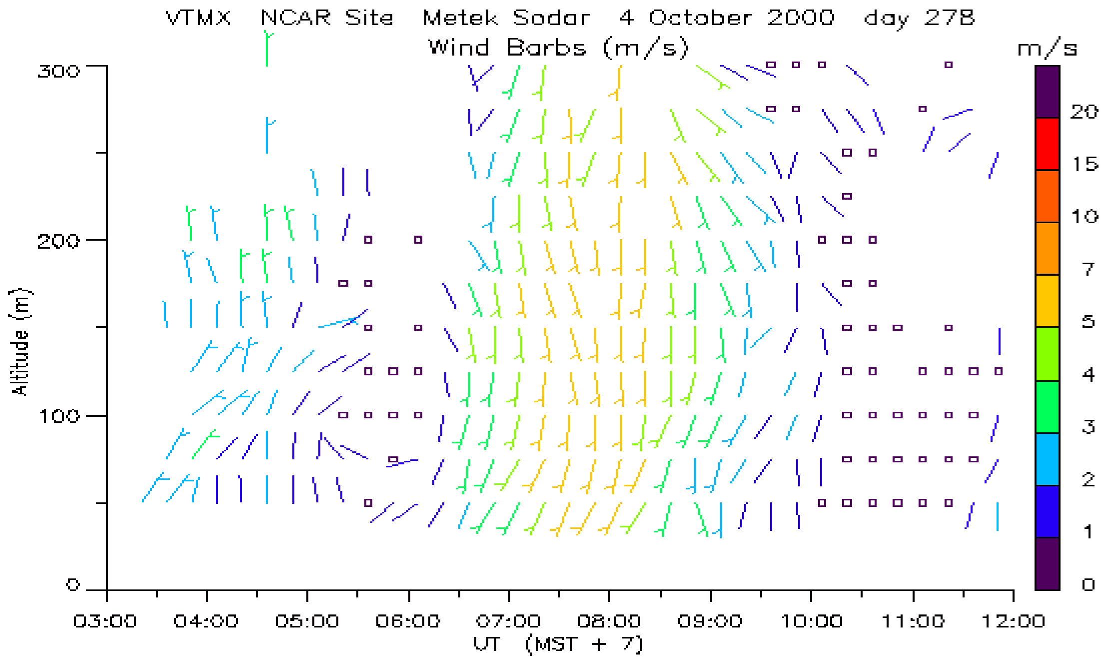

Figure 3: An example of sodar wind measurements for the same day as Fig 1.

3. SODAR

The sodar at the NCAR site (a Metek DSDPA.90-24 mini-sodar, Engelbart et.al. 1999) was another very effective profiling instrument during VTMX. An example of wind measurements made by the sodar is given in Fig 3. The northerlies followed by an evening change to southerlies discussed above can be seen. The sodar winds at the lowest range gates agreed well with surface anemometers and also produced winds up to the 250-meter level about 75% of the time. A diurnal variation in sodar performance was observed. Generally the best performance (in terms of reflectivity, number of acceptable wind measurements, and maximum height of winds) was around local mid-night to around dawn. As might be expected, a comparison of sodar performance and temperature lapse rates from soundings indicate that nocturnal inversions produce increased reflectivity and thus improved performance. There was also good performance during late morning to early afternoon when strong reflectivity appears to be related to convective boundary layer activity, as evidenced by a positive correlation between sensible heat flux as measured by a PNL sonic anemometer at the site and number of sodar winds. The worse performance was during the evening transition (late afternoon and early evening) as convective dies and before inversions develop and thus there are a lack of thermal gradients to provide scattering targets for the acoustic signal.

4. COMBINED SODAR & LIDAR OBS

The sodar sometimes observed strong variability in vertical velocity. These appeared to be correlated with fluctuations in backscatter as seen by SABL, particularly during the day. Similar, though weaker, events were occasionally seen at night and an example is given in Fig. 4, a subset of the data shown in Fig. 1.

The upper two panels show range-time contour plots of SABL backscatter and vertical velocity from the sodar (yellow/red is upward motion, blue is down) for the overlapping range bins of the instruments (200-300 meters). The profiles in the lowest panel show backscatter flux, which might be taken as some indication of vertical transport of aerosols (recalling however the uncertain link between backscatter and aerosol concentration).

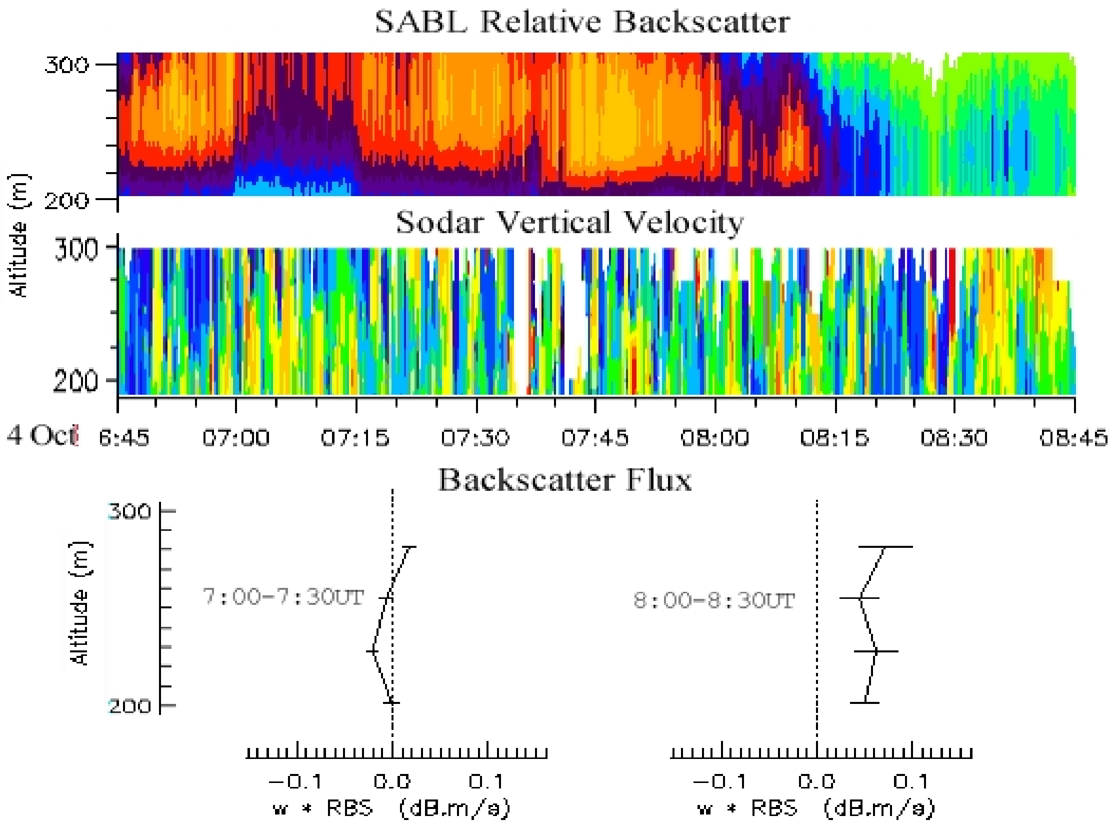

Figure 4. SABL and sodar. The top panel shows lidar backscatter (red/orange is stronger backscatter) and the middle panel shows corresponding sodar vertical velocity (orange/red is upwards, green/blue is down). The lower panel shows profiles of backscatter flux (the product of backscatter and vertical velocity perturbations) averaged over the time periods indicated.

For the first hour, the sodar vertical velocity and lidar backscatter fluctuations were positively correlated indicating upward transport of aerosols. For the second hour, there was a negative correlation suggesting either downward transport of aerosols, or rather, upward transport of cleaner air. The southerly winds were gradually decreasing during the second hour, and clean air appears to have been mixed in. The correlation coefficients were low (around 0.2 to 0.3), however student-t tests indicate there is statistically significant correlation to about the 90% confidence level or better.

5. MAPR

The wind profiler operated at the NCAR site was MAPR (Multiple Antenna Profiler Radar, Cohn et.al. 2001), an advanced UHF boundary layer profiler capable (at least during the day) of measuring horizontal winds every 1 - 5 minutes and vertical winds on even shorter time scales. Unfortunately the VTMX environment was challenging to all boundary layer wind profilers. The stable (and dry) conditions of interest to VTMX produce weak atmospheric scatter in the UHF band, and thus weak signals for wind profilers. Like many other wind profilers, MAPR was also very seriously affected by large numbers of migrating song-birds (and possibly bats) during the night-time hours of the VTMX project, probably exacerbated at the NCAR site by funneling through the Jordan Narrows.

Bird reduction algorithms based on time and frequency domain filtering are being investigated. An example is the Merritt (1995) method, which selectively averages components of the Doppler spectrum based on statistics that indicate the presence of bird echoes. Fig. 5 gives an example of MAPR data treated with this algorithm. Many measurements due to birds have been removed, however little background atmospheric signal survived. A further development of this technique being investigated adds spatial domain interferometry, whereby Doppler and phase differences between receivers can be used to estimate all scales of motion (atmosphere and birds), and then statistical filtering is used to attempt to filter out bird winds. An alternate technique that shows promise is based on RIM-FCA (Yu and Brown, 2003), whereby the range resolution of the radar is greatly enhanced allowing spatial filtering of bird echoes; literally the atmospheric echoes between bird echoes can be resolved.

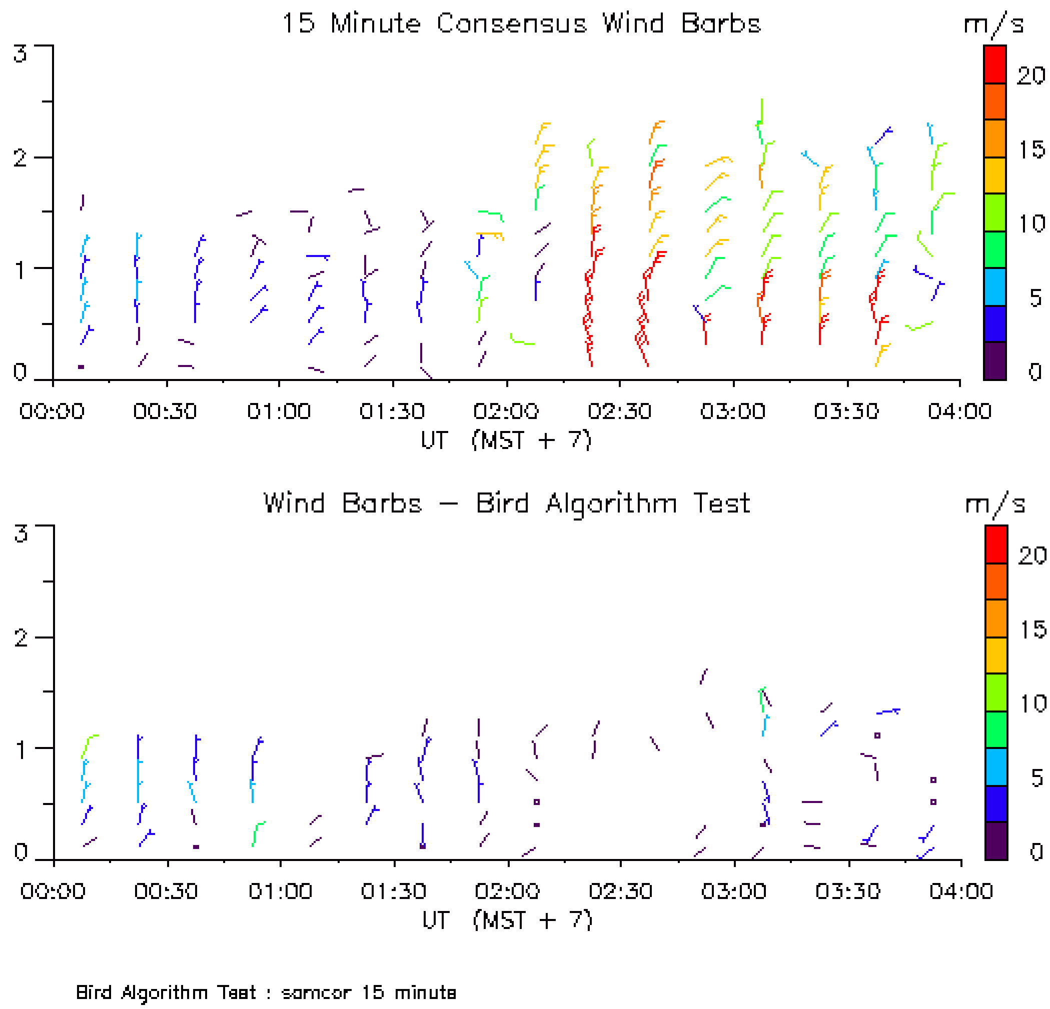

Figure 5: MAPR wind measurements. An example of spectral filtering to remove the effect of bird clutter (before top panel and after bottom panel).

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