J 3.6 LIDAR MEASUREMENTS OF ATMOSPHERIC FLOW THROUGH A DOWNTOWN CLUSTER OF HIGH-RISE BUILDINGS

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1. ABSTRACT

The Joint Urban 2003 experiment was a field study of urban dispersion conducted in Oklahoma City during the summer of 2003. The experiment involved a wide range of instrumentation operating together for 10 Intensive Observation Periods during the month of July. Measurements were taken both for tracer gas and for the associated meteorological fields. The ASU lidar measured both aerosol backscatter and radial velocities fields upwind of the Central Buisiness District (CBD). The lidar was deployed approximately 4 kilometers south of the downtown area with a clear line of sight through downtown building clusters and over several other instrument sites. Joint Urban 2003 presented an opportunity to deploy two matched coherent Doppler lidar systems with close collaboration (between the Army Research Laboratory's and ASU's lidar teams) in operation of the instruments. Data was collected over 28 days in a variety of RHI, PPI, and VAD scan patterns providing inflow conditions and insight into the urban interaction with the mean atmospheric flow for the area south of the CBD. Two periods of mean flow reversal are of particular interest due to a southerly flow which made building wakes clearly observable. During these periods wake meandering and the downstream and cross-stream extents of the wakes are evident. Approximate velocity deficits measured were 2-8 m/s. Possible merging of wakes from separate buildings in the CBD were observed. Steering effects and re-direction of the mean flow vectors due to the urban core are also being studied.

2. INTRODUCTION

The ASU Lidar team was invited to participate in the Joint Urban 2003 experiment in Oklahoma City, Oklahoma during June/July 2003. We acquired data for 29 days between June 27th to July 30th. These data sets are stored in a proprietary data format and can be manipulated using a series of Matlab scripts that have been developed by the ASU team.

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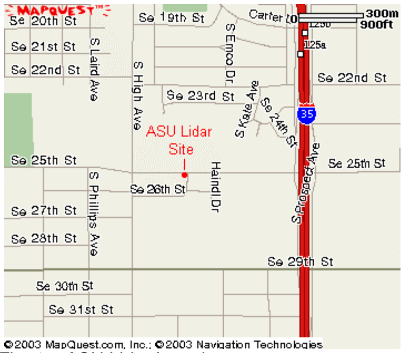

Fig. 1 – ASU Lidar Location

The ASU LIDAR was located approximately 3.8 kilometers to the southeast from the OKC downtown (Central Business District) on the southwest corner of 25th St. and Akin Drive. LIDAR coordinates were: N 35deg26.330' , W 97deg29.533' , 384m MSL. The LIDAR was operating during the last 9 IOPs as well as during non-IOP periods. Most of the scanning strategies used during the URBAN 2003 Experiment were coordinated with the ARL LIDAR group to capitalize on the opportunity for Dual Doppler scanning strategies.

Collaboration of two matched Coherent Doppler Lidar systems allowed for a detailed full-field, full-scale view of the interaction between a turbulent boundary layer flow and individual urban obstructions. The subject of building wakes has been theorized (Counihan 1973), modeled (Belcher 2003, Lien 2004), studied in wind tunnels (Raupach 1979), and observed with in-situ sensors (Hosker, 1981). However, data from the Joint Urban 2003 experiment presents some of the first observations of full-scale, large-area physical effects of this interaction.

All Lidar figures presented in this document contain a color scale at the bottom of the plot, which represents radial velocity (m/s) in the plot. The scale on all axes is in kilometers. The date, time, and angle information for the specific sweep is at the top of each plot. All times are in UTC (Oklahoma City local time +5 hours) unless stated otherwise.

3. DETAILED SURVEY

The ASU Lidar group recorded data on 29 days during the Joint Urban 2003 Experiment. Overall, the ASU Lidar data comprises over 2800 Base data files that require 33 GB of storage space. In addition, approximately 100 GB of the Lidar Spectral data were also recorded and will be available upon request. At this time, reprocessing of the spectral data requires a Lidar and the associated signal processing hardware.

Four different types of scans were run either individually or in various combinations over the 29 days ASU recorded data. The four scan types were the PPI, RHI, VAD, and a point-staring scan run on two occasions.

3.1 *Scan Types*

PPI and RHI scans account for the majority of the data collected by the ASU Lidar during the campaign. VAD's were also performed, but proved problematic for the ASU Lidar system to process and record. On two occasions (6/7 July and 13/14 July), the ASU Lidar performed a point-staring scan designed to collect data for TKE turbulence measurements.

The selection of PPI and RHI measurements provide good data about Boundary Layer characteristics and patterns, as well as providing good information on the inflow patterns for the CBD. On two occasions for periods of several hours, the mean flow experienced a reversal and came from the north (14:19 to 16:49, July 10 and 12:03 to 16:33, July 12). These periods provide excellent data to observe and characterize the wake structure from the Urban Environment and the downstream effects of the CBD.

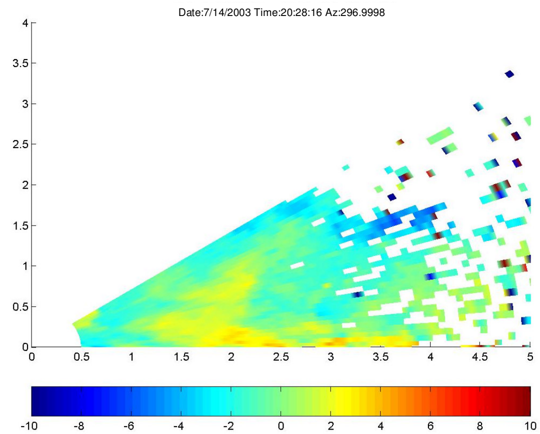

Fig 2a – BL Height RHI Comparisons (Convective)

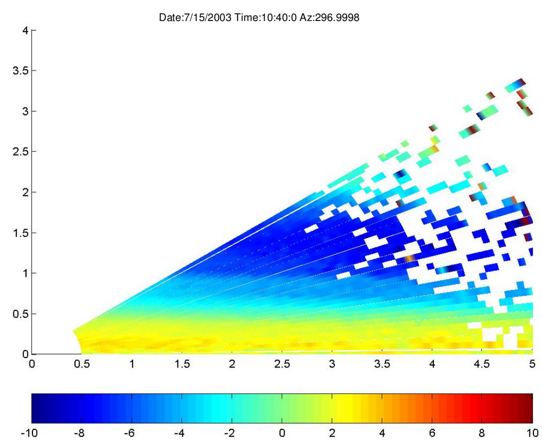

Fig 2b – BL Height RHI Comparisons (Nocturnal)

4. OBSERVED FEATURES

Several notable features have become apparent from the visual survey of the data. These are areas that we would like to pursue in more depth, and are characterized in the following figures.

4.1 *Boundary Layer Behavior*

The ASU scanning strategies almost always utilized a period long enough to note the change in Boundary Layer height and complexity through the convective-nocturnal or nocturnal-convective transition. The majority of the ASU data can be used to make these observations, and through post-processing physical heights and transition characteristics can be determined. Figures 2a and 2b show two identical RHI scans taken on July 14/15.

These changes in the boundary layer height and structure can also be seen in PPI scans. Figures 3a and 3b show two identical PPI scans taken from a raster scan pattern on July 20th. These scans are at 7 degrees above the horizon, an angle which corresponds to approximately 500m above street level at the CBD (3.8 km)

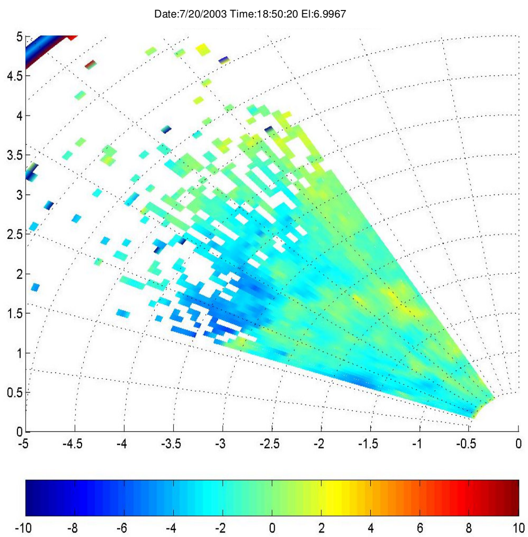

Fig. 3a – PPI Scan showing Afternoon Convective Boundary Layer Structure

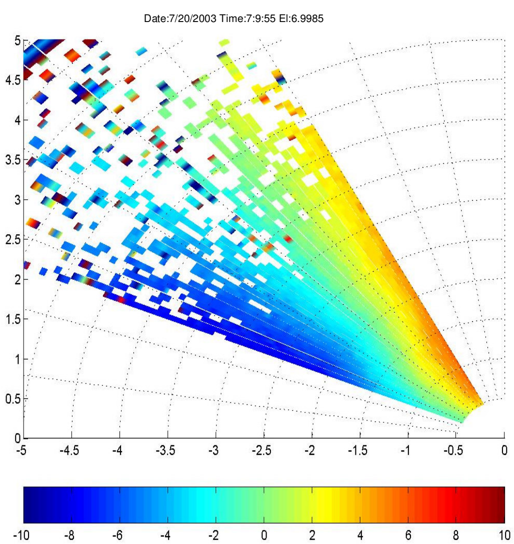

Fig. 3b – PPI Scan showing Nocturnal Boundary Layer structure.

4.2 *Shear Layers*

At several times shear layers become apparent in RHI scans. Figure 4 was taken during IOP 4 and shows a strong shear layer. Note the negative velocity above 500m, compared to the turbulent positive velocity field below 500m.

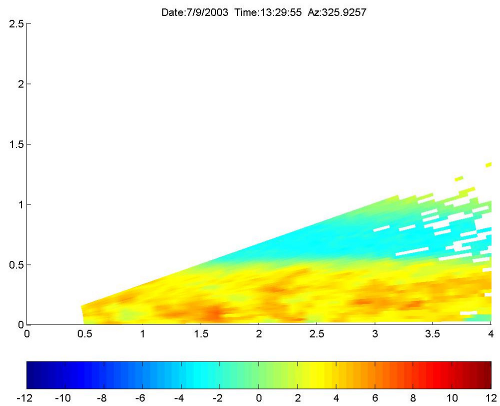

Fig. 4 – Shear Layer RHI (note the change from positive to negative velocity at approx. 0.5km height)

4.3 *Apparent Structure In PPI Scans*

In most of the low-angle PPI scans, streaky structures appear and propagate downwind. It is possible that these structures result from the underlying urban structure, as the PPI scans that display them most clearly are at very low elevation angles. Figure 5 shows streaky velocity deficit features in the scan area.

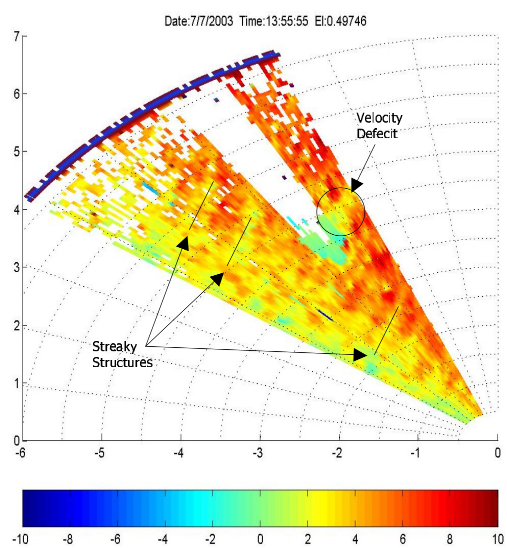

Fig. 5 – Streaky Structures

This plot also clearly shows the velocity deficit downwind of the CBD. All data files in which the ASU Lidar is able to gather data downwind of the CBD obstruction show this velocity deficit.

4.4 *Outflow studies*

During the two periods mentioned above, the mean flow direction turned dramatically and rapidly until the wind approached from the north. These periods are most likely tied to thunderstorm conditions that existed during the times the scans were being executed. The period from 12:03 to 16:33 on July 12th contains the most severe and significant turning, as the flow reverses directions and magnitudes in a period of minutes. Figures 6a and 6b show two PPI sweeps taken at 11:31 and 12:01 on July 12th, and clearly present the reversal in direction and magnitude.

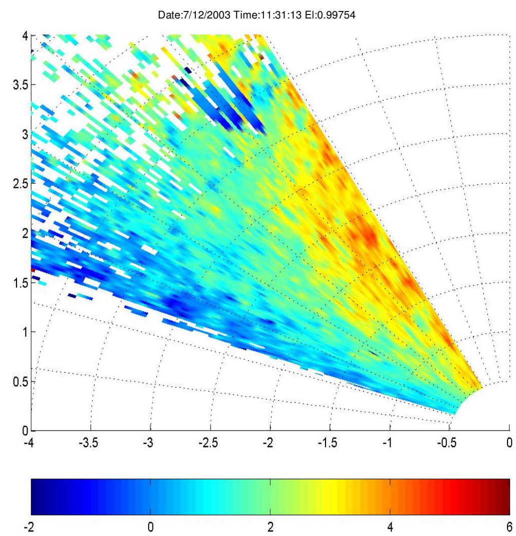

Fig. 6a – Flow Reversal

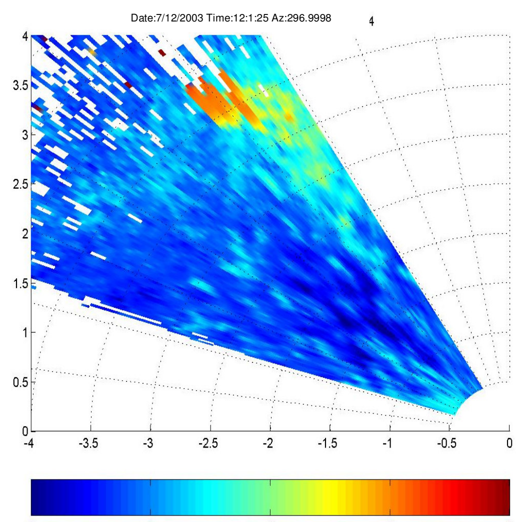

Fig. 6b – Flow Reversal

5. BUILDING WAKE OBSERVATIONS

During the two periods of flow reversal mentioned above, it is possible to use the ASU data for characterization of the downstream velocity disturbance of the CBD structure. Figure 6b also shows the visible downstream effects of the CBD.

On several occasions, the ASU Lidar performed RHI scans that intersected the buildings of the CBD. These scans clearly show a velocity disturbance above the buildings and may provide some data about the effect of the urban roughness on the Boundary Layer height and structure. Figures 7a and 7b show two of these RHI scans. Notice the change in velocity above the buildings at a range of 3.8km.

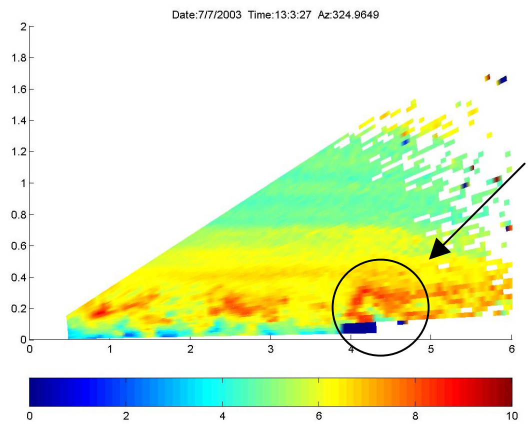

Fig 7a – Urban Disturbances

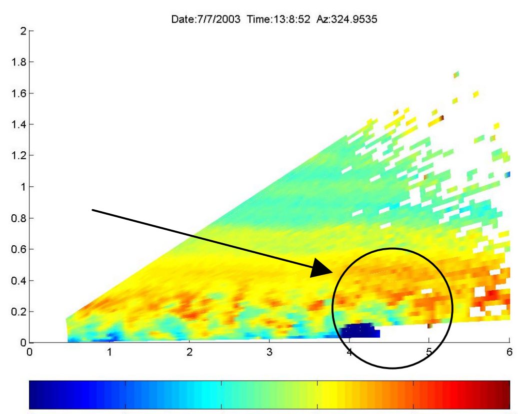

Fig 7b – Urban Disturbances

Figure 7a clearly shows the largest vertical velocity feature observed in the ASU data, extending to a height of 350 meters above the level of the ASU Lidar. The building causing the disturbance is the west-most building visible from the ASU Lidar Location and has a height of approximately 126m. The disturbance caused by the building extends to slightly more than 2 building heights.

During the flow reversal periods mentioned above, wake region characterized by a radial velocity deficit can be clearly seen by the ASU Lidar. Observation of these wake regions reveals the feature meandering over 6°-7° and a clearly observable feature at times up to 1.5km downwind of the buildings. Figures 8a and 8b show these features.

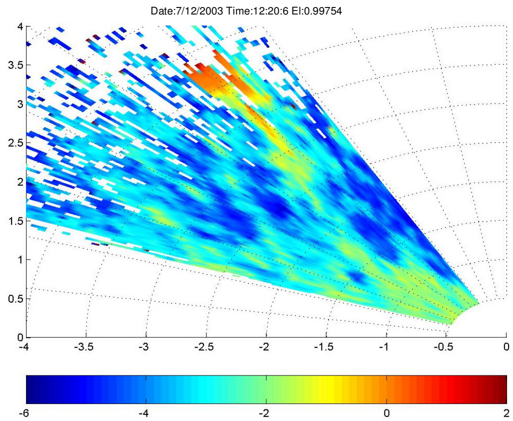

Fig 8a – Urban Wake regions (Note the change in location of the velocity feature between the two features. Each tick on the axes, and the corresponding arcs through the plot, is spaced 0.5km apart. The lines extending from the bottom right corner represent equal angular divisions of the Lidar's field of view, and are 9° apart.)

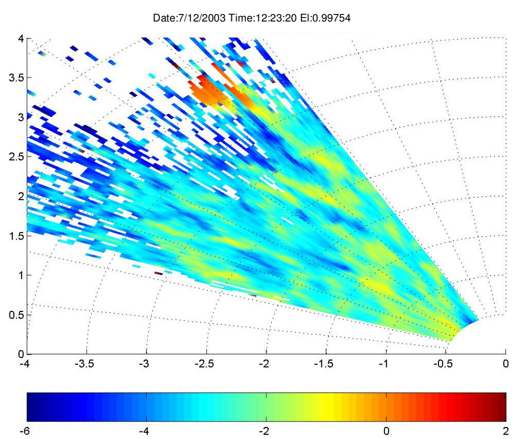

Fig 8b – Urban Wake regions

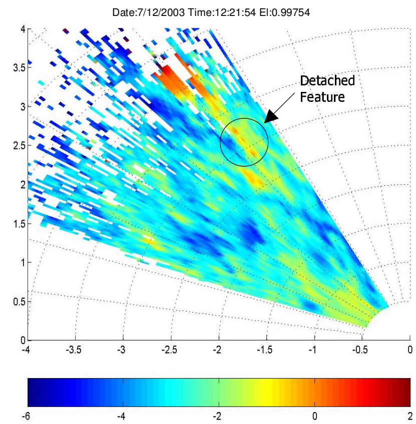

Fig 9 – Urban Wake region (Note the detached velocity feature)

The crosswind extents of the velocity features vary, but remain less than 140m across. Most of the observable features extend between 0.8 and 1.5 building heights across the flow. The cross-stream velocity profile appears to have the expected bell-distribution as described by Hosker (1981), but a spatially detailed profile cannot be extracted from the resolution of the lidar data. The observed wake is between 3 and 5 range gates across, providing only 3 to 5 points of data about the cross-stream velocity profile.

Radial velocity deficits inside the downwind feature range from 2m/s to 8 m/s less than the mean flow. There are several features apparent in the 90 minutes of outflow data recorded by ASU. These features, similar to the one highlighted in Fig. 9, appear as larger radial velocity deficits and advect downstream with the mean flow. The nature of these features, as well as information about turbulence, building vortices, and vortex shedding is not readily available through pure radial velocity data.

6. CONCLUSION

The data collected by the Arizona State Lidar team provides much useful information about velocity fields and possible structures in the inflow to the Oklahoma City Urban Core. Both Convective and Nocturnal Boundary Layer conditions are readily available in the data, as well as information about the interaction of building clusters with the mean flow through the Urban Core.

Current processing techniques allow the observation of the interaction of the buildings with the radial component of the flow. More advanced post-processing techniques are currently under development at ASU and may shed some light on turbulence, vortex presence, transport, and shedding, as well as large-scale turning of the mean flow.

7. REFERENCES

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