3.8 MEASUREMENT OF WINDS FLOWING TOWARD AN URBAN AREA USING COHERENT DOPPLER LIDAR

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1. INTRODUCTION

It is likely that the successful incorporation of modern remote sensing data into dispersion modeling systems will yield improvements in the characterization and prediction of dispersion scenarios. Two forms of input that are crucial for accurate dispersion modeling are the specification of the wind fields and the estimation of eddy viscosities / diffusivities. In the following, we present initial efforts in two areas. The first is to retrieve vertical columns of velocity vectors from intersecting RHI scans from two coherent Doppler lidar – i.e., using the two lidars to act as reconfigurable "virtual towers". To our knowledge, this is a unique attempt to-date in a major urban dispersion experiment. The second is to explore the degree to which the lidar data can provide information concerning turbulence in the wind field approaching the downtown city area.

Data presented in this work were collected during the Joint Urban 2003 (JU2003) field campaign in Oklahoma City during the period from June 28 to July 31, 2003. This large effort was supported by the U.S. Defense Threat Reduction Agency (DTRA), Army Research Office (ARO), and the U.S. Department of Homeland Security (DHS) (see Allwine et.al., 2004). Our team from Arizona State University deployed a coherent Doppler lidar, a surface energy budget station, and sonic anemometers (see Princevac et al. 2004). We report on the coordinated ASU-ARL effort to obtain intersecting RHI data, our ongoing postprocessing developments, and acquisition / postprocessing for the ASU lidar stares on the upwind side of the central business district.

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2. EXPERIMENTAL SETUP

The purpose of JU2003 field campaign was to obtain knowledge to improve, refine and validate computer models that simulate flow and dispersion in urban areas. The JU2003 was conducted in Oklahoma City with experimental equipment placed throughout the urban area. The opportunity to closely collaborate and coordinate with another lidar team with a matched coherent Doppler lidar created valuable opportunities for novel data acquisition involving coordinated lidar scanning.

By design, the ASU lidar was placed south of the city with the goal of characterizing the inflow winds toward the city. The ARL lidar was placed north and east of the downtown area and was able to focus on the downwind area, although its position allowed it to view the inflow area as well. The GPS values for the locations used in the initial postprocessing described below were as follows.

arl_lat = 35 + (28.387/60)
arl_lon = 97 + (30.265/60)
arl_alt = 380 m

asu_lat = 35 + (26.330/60)
asu_lon = 97 + (29.533/60)
asu_alt = 380 m

On July 9, 2003, the two lidars executed coordinated RHI scans, where the ARL lidar performed a constant azimuthal RHI at 235.78 degrees clockwise from north with elevation angles in the range from 0 to approximately 45 degrees above the horizon. The ASU lidar performed an automated series of 10 RHI scans designed to intersect the ARL scan in vertical columns in front of the urban core area. Figure 1 shows the intersecting scans from the ARL and ASU lidars, where the intersecting points are labeled with red circles. Major buildings have been geo-located in the lidar domain so that the intersection points can be seen relative to the city layout. The ASU lidar's 10 repeating RHI's had azimuthal angles of approximately 312, 314, 316, 318, 320, 322, 324, 326, 328, and 330 degrees clockwise from the north.

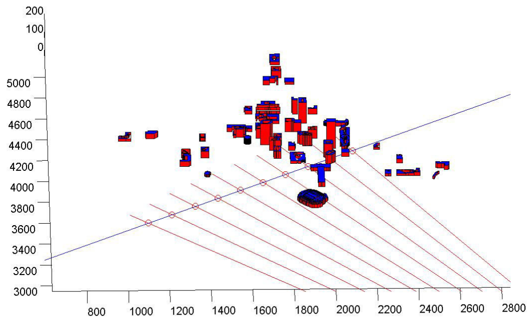

Figure 1. Oklahoma City downtown area with blue line indicating location of ARL lidar RHI and red lines indicating repeating ASU RHI scans. Their intersections were calculated and are designated with red circles.

The ASU lidar scanned with elevation angles ranging from .5 degrees to ~19 degrees above the horizon. The initial data analyzed utilizes time values from both the lidars (in UTC) from approximately 14:30 on July 9, 2003, to 17:30. In particular, plots shown here were taken from the files covering from 14:29 to 14:52. An effort was made to match the lidar control parameters such as range gate size, and pulse averaging.

The lidar setup for the stares through the CBD area utilized 50 pulse averaging and the location of the stare can be seen in Figure 5.

3. ALGORITHM

The first task was to merge and rectify the lidar and city architecture data within one 7000m x 7000m coordinate system. It remains to perform careful cross-checking of major building locations with data taken by the lidar teams recording laser beam angles upon impact of corners of the buildings. Look directions for each lidar for each RHI scan were calculated. RHI intersection locations were calculated from simultaneous solution of the equations for two lines. A vertical column was defined over each intersection point broken into a defined number of levels, for example, 100 or 50m vertical levels. A space-time window was defined and all the beams were looped over, searching for range gates from both lidars which were inside the specified window. Radial velocities from both lidars were binned, separately, and a two dimensional linear system of equations was solved (Lu = r, where L is a matrix of look directions from the lidar, u is the vector to solve for, and r is a vector of radial velocities, where components are from each lidar.)

4. RESULTS

Two examples from the data of RHI sweeps are plotted in Figures 2 and 3. Notice that in the ASU lidar RHI, the data is moving mostly away from the lidar as indicated by the largely positive radial velocities. Higher up between 800m and 1.2 km, negative radial velocities are seen. In the ARL RHI, the velocities are large and negative indicating possibly either strong or winds aligned with and moving toward the ARL lidar site. This would suggest winds from the west direction.

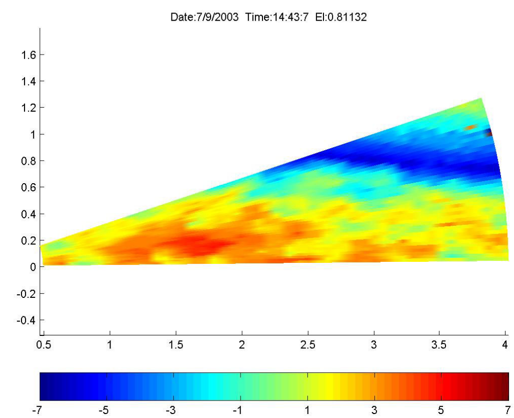

Figure 2. Example of intersecting ASU lidar RHI sweep.

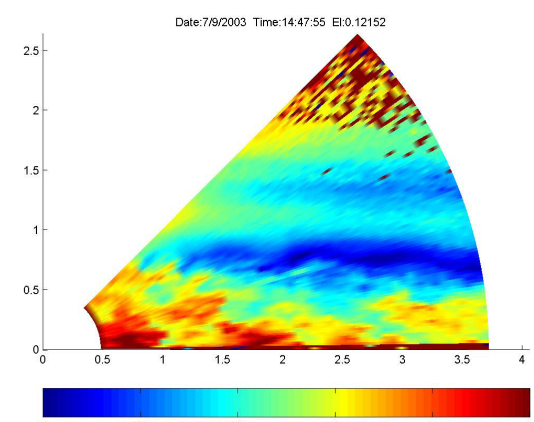

Figure 3. Example of intersecting ARL lidar RHI sweep.

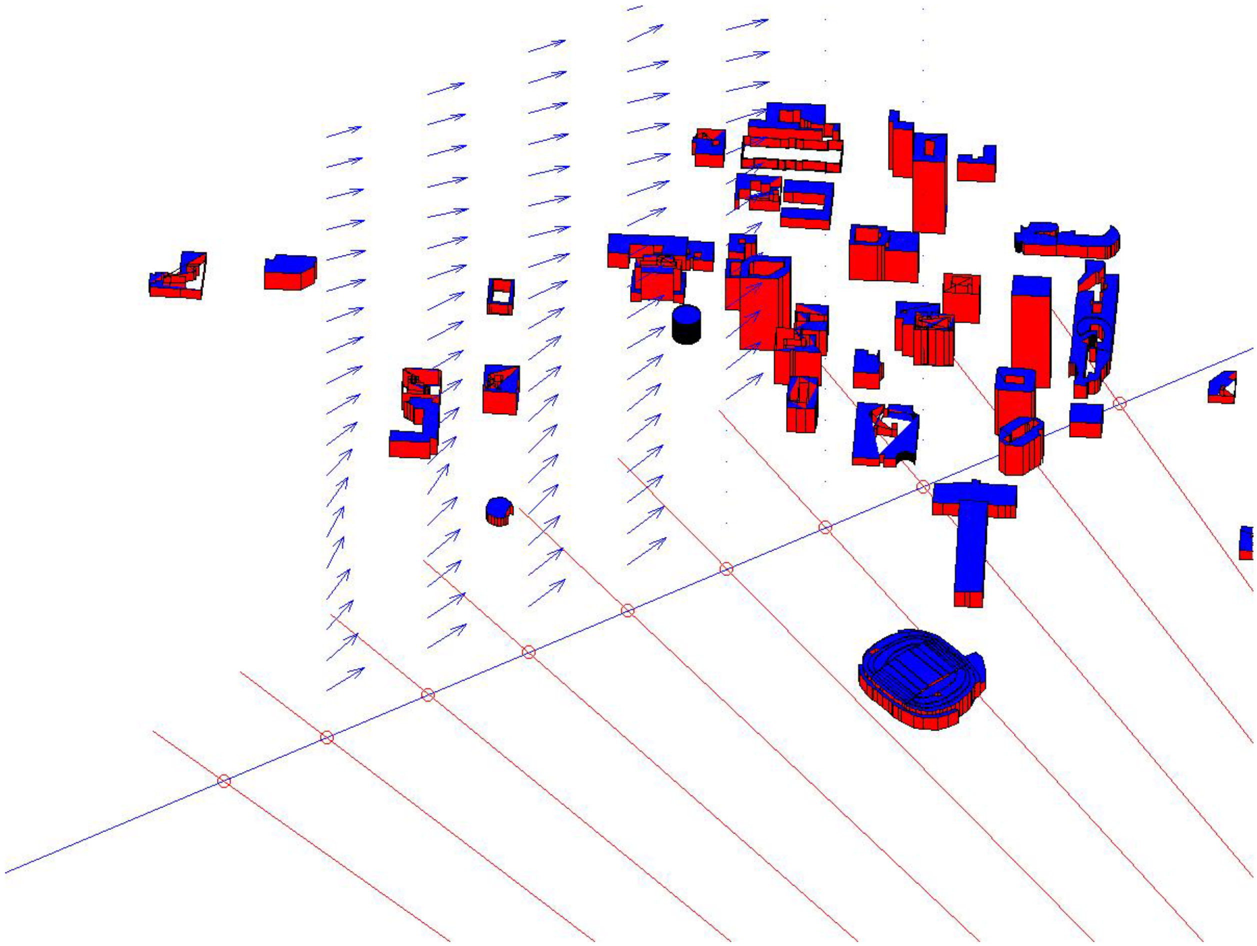

Figure 4. Vertical profiles of horizontal (u,v) velocity vectors as retrieved from intersecting RHI scans. The time window was 30 seconds in duration. The spatial window was 50 meters. 20 vertical levels were used with a top height of 1000 meters above the city.

Figure 4 above shows the results of applying the retrieval algorithm with 30s, 50m, 20 levels, and 1000m, respectively, for the time window, the spatial window, the vertical levels, and the defined top of the intersecting column. Note that the vectors shown are horizontal with u and v components, but not w. These early results show, for the columns on the left, a small northerly turning of the vectors in the 250m to 450 m middle heights. The algorithm needs to be tested further and data compared with other instruments when appropriate. Different sampling windows need to be defined and tested. "Intersection" of two lidar beams naturally does not imply a literal meeting of photons, rather, a double sampling from different directions of a similar volume within a time window. It should also be realized that lidar pulses sample a volume across, in our case, roughly orthogonal directions. Homogeneity of the winds across the sample volume is then implied.

Early postprocessing of stares of the ASU lidar through the CBD also shows interesting results suggesting further analysis. Statistics were calculated for each range gate along the beam. Figure 5 shows the location of the stare from the ASU lidar site. Interestingly, in Figure 6 and 7, a –5/3 slope can be seen. The ASU team is currently studying the effect of lidar sampling on measurements of turbulence in the atmosphere (see also, Frehlich et al. 1998). Note Figure 7 shows that the increasing noise with increasing distance from the lidar site affects the measurement of smaller scales.

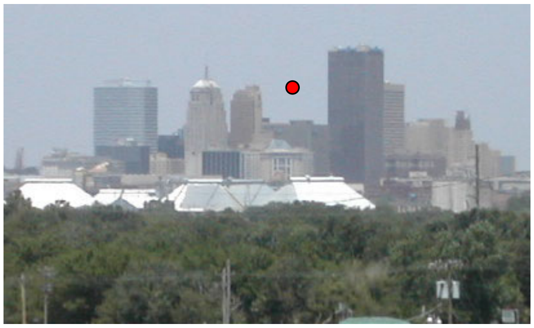

Figure 5. ASU lidar stare through the Central Business District as seen from the main ASU lidar site south of the city.

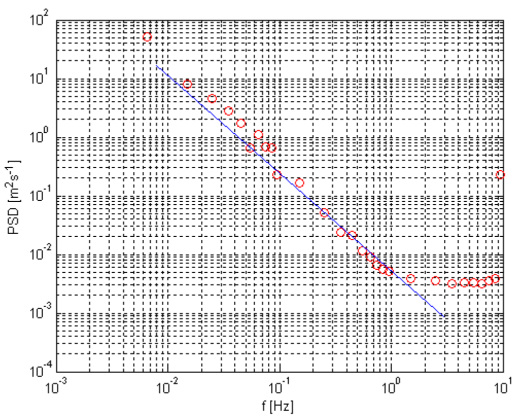

Figure 6. Bin-averaged spectra calculated from range-gate 1 of the stare, averaged for the whole scan duration. Blue line is -5/3 slope. Note that existing data (larger than zero) for the frequency larger than the Nyquist (5 Hz) is pure noise.

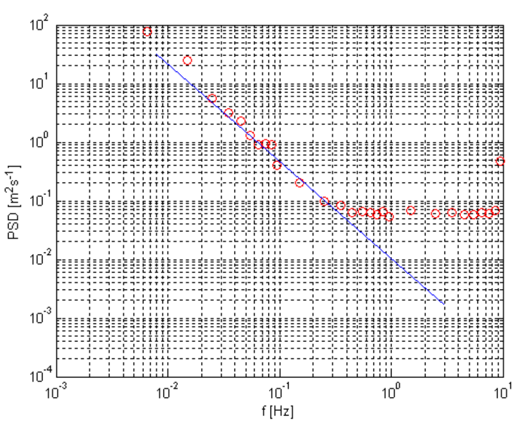

Figure 7. Bin-averaged spectra calculated for range gate 40. Notice much higher noise level. It contaminates even much lower frequencies.

4. CONCLUSIONS

The JU2003 field campaign provided a unique opportunity to acquire coordinated lidar data between two matched, coherent Doppler lidars. This has allowed, through postprocessing still under development, the retrieval of velocity vectors in some cases. If these techniques can be verified it would show that two Doppler lidars can act as re-configurable “virtual towers”, potentially obtaining vertical profiles of vectors in locations otherwise prohibitive. Preliminary analyses show that the retrieval algorithms appear to function well without numerical instability at least for the case where the two lidars have roughly orthogonal look-directions.

Analysis of stare lidar data appear to yield information about turbulence along a lidar beam. Further study is required to understand sampling and error analysis.

5. REFERENCES

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