6.3 TURBULENCE CHARACTERISTICS OVER AN URBAN DOMAIN OBSERVED BY DOPPLER LIDARS

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1. INTRODUCTION

The Joint Urban 2003 (JU2003) project, a cooperative undertaking to study turbulent transport and diffusion in urban atmospheric boundary layers, was conducted in Oklahoma City (OKC) in June and July of 2003. Two Doppler lidars, operated by the Army Research Laboratory (ARL) and Arizona State University (ASU) respectively, and a number of sonic anemometers were deployed to monitor the wind field during the experiment. A large amount of lidar data has been collected for various wind conditions, and we will present some preliminary analysis and results related to the spatial structure of turbulence using the Doppler lidar data. The effect of both the roughness and the thermal properties in the urban setting on the length scale of large eddies and the turbulent intensity will be analyzed. Some of the particular characteristics of the urban environment, such as the turbulent wakes on the lee side of buildings will also be investigated.

2. INSTRUMENTATION

The Doppler lidars deployed in the project are WindTracer® Systems, products of the Coherent Technologies, Inc. in Lafayette, Colorado. The systems were designed specifically for atmospheric boundary layer observations and research (Grund et al., 2001). The laser system is operated at wavelength of 2025nm with 2.5 μJ laser pulse energy. The pulse repetition is 48Hz and the gate range varied from 66 to 71m depending upon the data set. The system measures range-gate resolved backscatter intensity and the Doppler radial velocity. The location of the ARL lidar is shown in Fig. 1, where the lidar is located at the top of a two story parking garage (Global Position System (GPS) coordinate: N35^0 28.385', W 97^0 30.266', 20m above ground). The ASU lidar is located southeast of OKC (GPS coordinate: N35^{0}26.330', W97^{0}29.553'), about 3.8km from the downtown Central Business District (CBD), out of the domain shown in Fig.1. Both systems functioned well during the JU2003 and a large amount data was collected.

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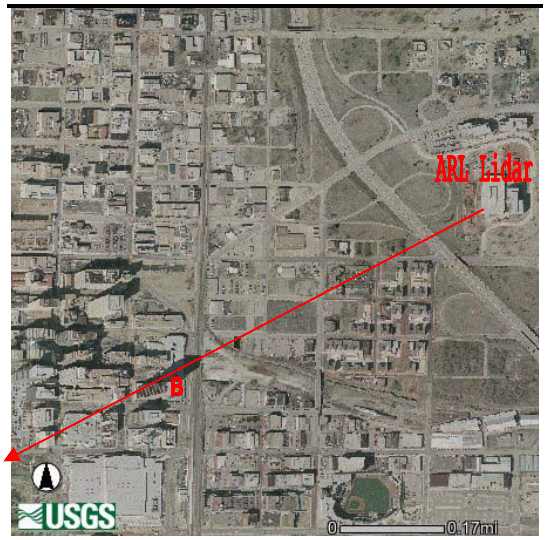

Fig.1 The Aerial photography shows the ARL lidar site and relative position to the CBD of the Oklahoma City. The tallest building is the Bank One tower (B). Red arrow line indicates the laser beam.

3. DATA AND ANALYSIS

The data presented in this paper were collected with the ARL Lidar during the Intensive Observation Period 2 (IOP2) on 2 July 2003. The data selected are the RHI (range-height-indicator) scans from 1346 to 1748 UTC. Each case contained 8 frames with a duration of 3 minutes (Table 1).

Table 1. list of lidar data used

Case	Date	Time (UTC)	
		Start (1st frame)	End (8th frame)
1	07/02/03	13:46:10	13:48:58
2	07/02/03	14:46:10	14:48:58
3	07/02/03	15:46:10	15:48:58
4	07/02/03	16:46:10	16:48:58
5	07/02/03	17:46:10	17:48:58

The other scans, such as PPI (plan-position-indicator), VAD (velocity-azimuth-display) are also scheduled with the same order at each hour. We choose the data from these RHI scans for the reason that mean wind direction is approximately parallel to the vertical scan slice. The RHI scan was from 0 to 45^0 elevation angel and a scan took 20 seconds to complete.

3.1 Low-level jet and wave motion

Four frames of radial velocity, sampled for each of 4 hours, are shown in Fig. 2,. Several points can be made from the sequence of the RHI scans. In the earlier morning (1346 UTC, 8:46 local time), the flow is dominated by a very organized low-level jet (LLJ) at heights of 200 to 400m. The figure (Fig.2a) shows very organized gravity waves due to the strong shear in the LLJ. The boundary layer underneath the LLJ is very shallow and very much influenced by the wave. A hour later (Fig.2b), the LLJ and wave structures still dominated the flow but the LLJ is weakened and elevated somewhat to 300 to 600m . The next hour (Fig.2c) slice shows a much weaker LLJ at 500 to 700m. By 1646 UTC, the LLJ has completely disappeared and a fully convective boundary layer has developed. This is a typical morning boundary layer evolution process for clear skies and moderate southerly wind common in OKC during the JU2003.

The LLJ and associated wave motions have been observed in many other investigations in the Great Plains of the United States. The reason for the development of the nocturnal LLJ is the wind becomes decoupled from the surface due to the development of a stable surface layer and the acceleration of air above the stable layer along the pressure gradient (Blackadar, 1957). Using a similar Doppler lidar in CASES-99, Banta et al. (2002) and Newsom et al. (2003) recently showed that nocturnal LLJ were often at or below 100m above ground level. Indeed, the nighttime data (not shown) indicated that the nocturnal LLJs developed around midnight and gradually strengthened until sunrise. Obviously, the LLJ has a great influence on the underlying boundary layer development and shear generated turbulence. This topic will be investigated in future data analysis.

3.2 The building lee wake

The RHI scans were right out of the northeast edge of the Bank One (B) tower (see Fig. 1). This building is about 154m tall and located on the east side of the CBD. The distance between the lidar and

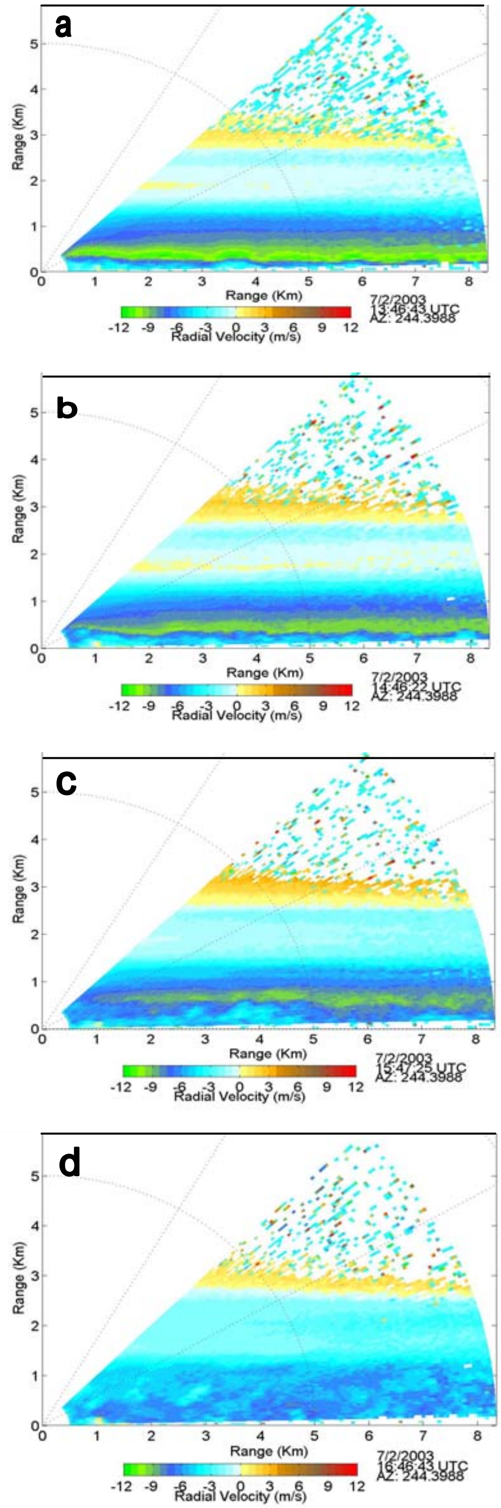

Fig. 2 Selected RHI slices from ARL Lidar. This sequence shows that LLJ and associated gravity waves in the morning and evolution of boundary layer.

the northwest edge of the building B is 1.018km. Since the wind was blowing into the lidar, a very clear view of the lee wake was captured in this data set. The reversed flow signal at a distance of 1.02km, can be identified in all frames of Fig 2. The preliminary analysis indicates that the wake existed over a large range of wind speeds (from 2 m/s and above) and stability conditions (from nocturnal to very convective boundary layers).

Fig.3 is a closer look at the same scan as Fig 2d. A detailed observation of the scan slices (Fig 2) shows the collected effect of the CBD area. When the jet flows over the CBD area, there is a slight lifting due to the thermal effect in the city. The data will be analyzed further to characterize the lee wakes for parameterization of the phenomena in a diagnostic wind model (Wang et al., 2004).

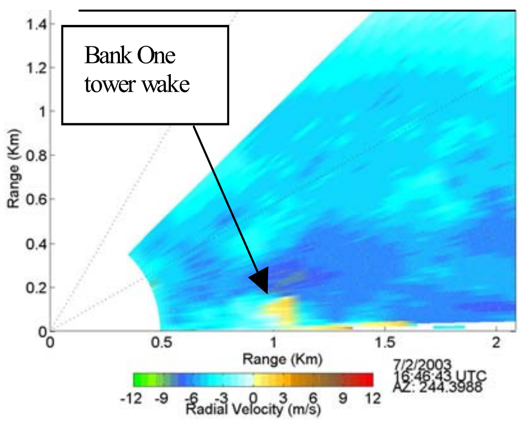

Fig.3 A zoom in view of the Fig.2d. A flag-shaped reversal flow area signal shows the Bank One tower wake.

3.3 Turbulence Characteristics

Since the Doppler lidar gate resolution is 70m for the selected data sets, it cannot resolve eddies smaller than that length scale. The statistics presented here only represent the contribution from the large turbulent eddies which contain most of the turbulent kinetic energy. Because the steady wind direction is approximately parallel to the lidar beam, the horizontal wind velocity can be computed by dividing the radial velocity by the cosine of the elevation angle. This approximation is valid for small elevation angles and much stronger horizontal wind components compared to the vertical component (Newsom and Banta 2003; Banta et al., 2002). The horizontal wind is first computed from the radial wind and then interpolated into regular Cartesian coordinate with dx=70m and dz=5m. The turbulence statistics are based on the interpolated data.

Fig. 4 (a, b) are the spatially averaged profiles of horizontal wind speed and standard deviation of the wind speed. The standard deviation divided by the mean represents the turbulent intensity of the horizontal wind component. The statistics are computed for the urban area (2.8 km from the lidar) and for the suburban area (distance from lidar greater than 2.8 km). Since the lidar data has a substantial amount of the ground clutter as the laser beam goes further away from the lidar, the near surface data below 80m about the lidar was filtered out in the

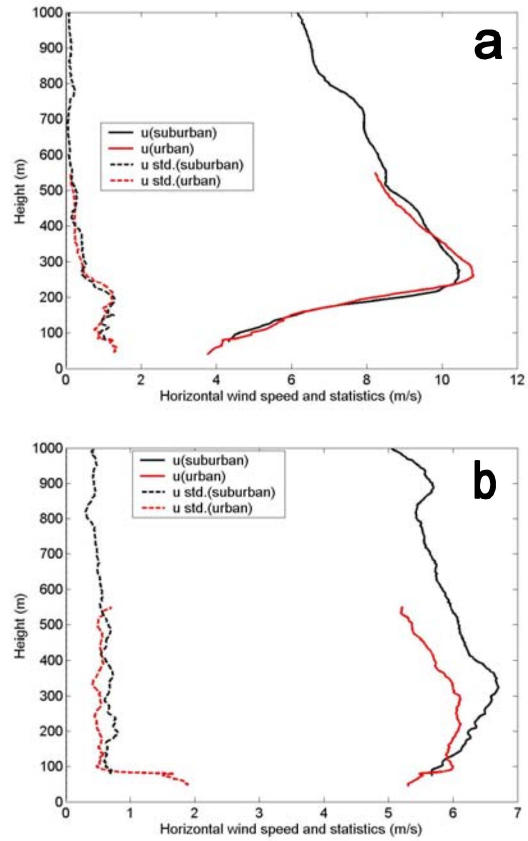

Fig. 4 Average horizontal wind profiles and standard deviations over urban and suburban areas. (a) at 1347 UTC when the LLJ and KH waves are dominated flow; (b) at 1648 UTC when the convective boundary layer was fully developed.

analysis. Fig. 4a shows the averaged horizontal wind profiles and standard deviation at 1347 UTC, when the LLJ and gravity waves dominate the flow. The LLJ is stronger and higher over the urban area than that over the suburban area. The standard deviation is slightly larger near the surface. After a convective boundary layer has fully developed (Fig. 4b), the wind profiles over urban and suburban areas are quite different. The average wind is stronger over the suburban area than that over the urban area. The standard deviations in the lower levels differ greatly. The urban area has more than double the standard deviation below 100 meters.

An integral turbulence spatial length scale can be computed by integrating the autocorrelation function of the spatial series. The turbulence signals of horizontal wind at each height were derived by subtracting the mean of the spatial series. The length scale, which represents the average spatial length in the horizontal direction, is a useful parameter for numerical modeling of the turbulence and associated trace gas transport. Unfortunately, our set-up (range gate length resolution) at this experiment was not fine enough to resolve the neutral boundary layers which have smaller length scales. The lidar data does offer a good estimate of the integral spatial length scale in more convective boundary layer turbulence. Fig. 5 shows an example of the integral spatial length scale corresponding to data set 5 (Table 1). The figure neglects the length scale less than 120m, about twice the lidar's range gate resolution. The length scales at lower levels are much greater than the upper levels over the urban domain. This is due to the convective plumes being rooted in the surface layer and spatial length gradually decreases as the height increases. The suburban domain appeared to have much smaller scales than those over the urban domain. This is probably due to the urban heat island effects and more convective conditions in the urban boundary layer.

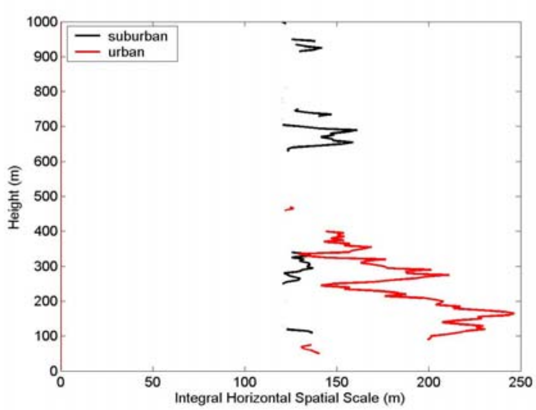

Fig. 5 Integral spatial length scales over the urban and suburban domains. The length scale less than 120m is not plotted due to the lidar gate resolution is about 70m resolution.

4. SUMMARY

A sequence of Doppler lidar RHI scans is displayed to show typical clear day boundary layer development from LLJ and gravity wave dominated flow to the fully developed boundary layer in OKC. The building wake at lee side of the Bank One tower is clearly shown in the image. The wave-turbulence interaction and the building lee wakes will be analyzed further in future studies. Some preliminary analysis on the mean horizontal wind profiles and standard deviation is presented. The results indicate that there are significant differences in the mean, turbulence intensity, and spatial integral length scale over urban and suburban domains. Obviously, the data set needs to be systematically analyzed to get more general statistics and to cover a larger dynamical range of turbulent flow conditions.

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