3.5 Observational Study of Turbulence Spectra for Joint Urban 2003

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1. Introduction

The Joint Urban 2003 was a cooperative undertaking to study turbulent transport and dispersion in the atmospheric boundary layer in an urban environment. It was conducted in Oklahoma City in the summer of 2003. The Army Research Laboratory deployed a number of measurement facilities, including an array of sonic anemometers mounted on five meteorological towers in Oklahoma City. A large amount of sonic data has been collected. The sonic data have been processed for tilt correction and then computed for turbulence statistics.

This presentation focuses on the turbulence spectra characteristics in the urban roughness sub-layer. Comparison of the u, v, w and T spectra from urban and suburban locations are demonstrated. Significant building effects on the spectral peak frequencies of the spectral maxima are discussed.

2. Measurements and Data Processing

Sonic anemometers (R. M. Young Company, Model 81000) were mounted either at three levels (10 m, 5 m, and 2.5 m above the ground) or at two levels (10 m, and 5 m) on five micrometeorological towers of ten meters height during the Joint Urban 2003 field campaign. The locations for the five towers are provided in Yee et al. (2004). Data from two towers (Tower #1 in a suburban area and Tower #2 in an urban area) were selected for the current spectral analysis. Figure 1 and Figure 2 show the locations and immediate surroundings of these towers. As indicated in Figure 1, the area around Tower #1 is relatively open, there are no houses or trees within a distance of 50 m from Tower #1, except a small portable trailer of 3.5 m height to the south-southwest. On the other hand, Tower #2 is surrounded by buildings with an average height of 10 m within a distance of 30-50 m, as indicated by Figure 2. Lundquist et al(2004) have estimated the mean building height for the urban area of Oklahoma City as 5-15m, which varies slightly with wind direction.

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Figure 1 Location (X) and surroundings of a suburban meteorological tower (Tower #1) sited south-southwest of Oklahoma City, Oklahoma.

Figure 2 Location (X) and surroundings of an urban meteorological tower (Tower #2) sited in an industrial area, East of the Central Business District of Oklahoma City, Oklahoma.

Consequently the measurements by our sonic anemometers were conducted in the urban roughness sub-layer (Roth, 2000).

Sonic anemometer data consist of three wind components and sonic temperature (T). In this study, we use the sonic data from the 10 m sonic anemometers because both the 10 m sonic anemometers were mounted on the top of the two towers and therefore should have no "tower shadow " effects for any wind direction. The sampling rate of the sonic anemometers is 10 Hz. For sonic anemometer tilt correction, the traditional two angle rotation method (Kaimal and Finnigan, (1994) is used for each time series of 30 minutes (18000 data points). After the tilt correction, the three components of the wind vector are u (streamline), v (transverse), and w (normal) with $\overline{v} = \overline{w} = 0$, where the over-bar indicates the 30-minute average. For our analysis we adopted The Analysis Package for Time Series (APAK) developed at Oregon State University by Vickers and Mahrt. Each 30-minute time series is split into multiple sub-series. The length of the sub-series was chosen as a time series of 4096 (2^{12}) data points (409.6 seconds) for the spectra of u, v, w, and T, and the average of the four sub-series is taken as the spectrum for the 30-minute time series. We exploited APAK's capability for applying a modified Daniell smoothing (Bloomfield, 2000) to each of these sub-series to better determine the spectral peak.

3. Results

Figure 3 shows the energy spectra for the streamline (u, first row), transverse (v, second row), and normal (w, third row) wind components and the virtual (sonic) temperature (T, last row) from the suburban (Tower #1) and urban (Tower #2) locations. The first and second columns of Figure 3 are for 2300, 30 June and 0100, 1 July CDT (Central Daylight time, plus 5 hours in order to covert into UTC), respectively. The urban boundary layer was near neutral (very small heat fluxes) for these two night times. The third and fourth columns of Figure 3 are for 1000 and 1200, CDT, 1 July 2003, respectively. The boundary layer was unstable (large upward heat fluxes) for these two times. All of the spectra in Figure 3 are normalized by their respective variances. The non-dimensional normalized frequency, fz/U, is used for the abscissa, where f is the natural frequency (Hz), z is the measurement height (10 m) and U is the 30-minute average of horizontal wind speed.

As seen from Figure 3, all the spectra show a similar overall shape which includes the energy-containing sub-range and the inertial sub-range with a –2/3 slope. The large spectral values at high frequency (fz/U > 3) for the T spectra at night are probably not real, but reflect aliasing of turbulence energy above the Nyquist frequency. Comparing the spectra from the suburban and urban locations (solid lines versus dash lines) in the plots of Figure 3, the most significant feature is the shift of the peak frequency from a lower value for the suburban location (Tower #1) to a higher value for the urban location (Tower #2). This shift is consistent with the concept that, in the wake of upstream buildings, energy producing eddies shift toward smaller scales (higher frequencies). Recall that Tower #2 is surrounded by buildings as indicated in Figure 2, this shift of peak frequencies provides evidence for the strong effect of building wakes.

The non-dimensional peak frequencies for the u, v, w, and T spectra of Figure 3 are listed in Table 1. As shown in Table 1 the peak frequencies for the w-spectra, PF(w), are usually higher than those for the u-, v-, or T-spectra. Also the PF(w) are higher at night (near neutral stratification) than in the day (unstable stratification) which is consistent with rural observations from the Kansas experiment (Kaimal and Finnigan, 1994). The shift of the peak frequencies due to building wake effects is most pronounced in the w-spectra, as shown in Table 1.

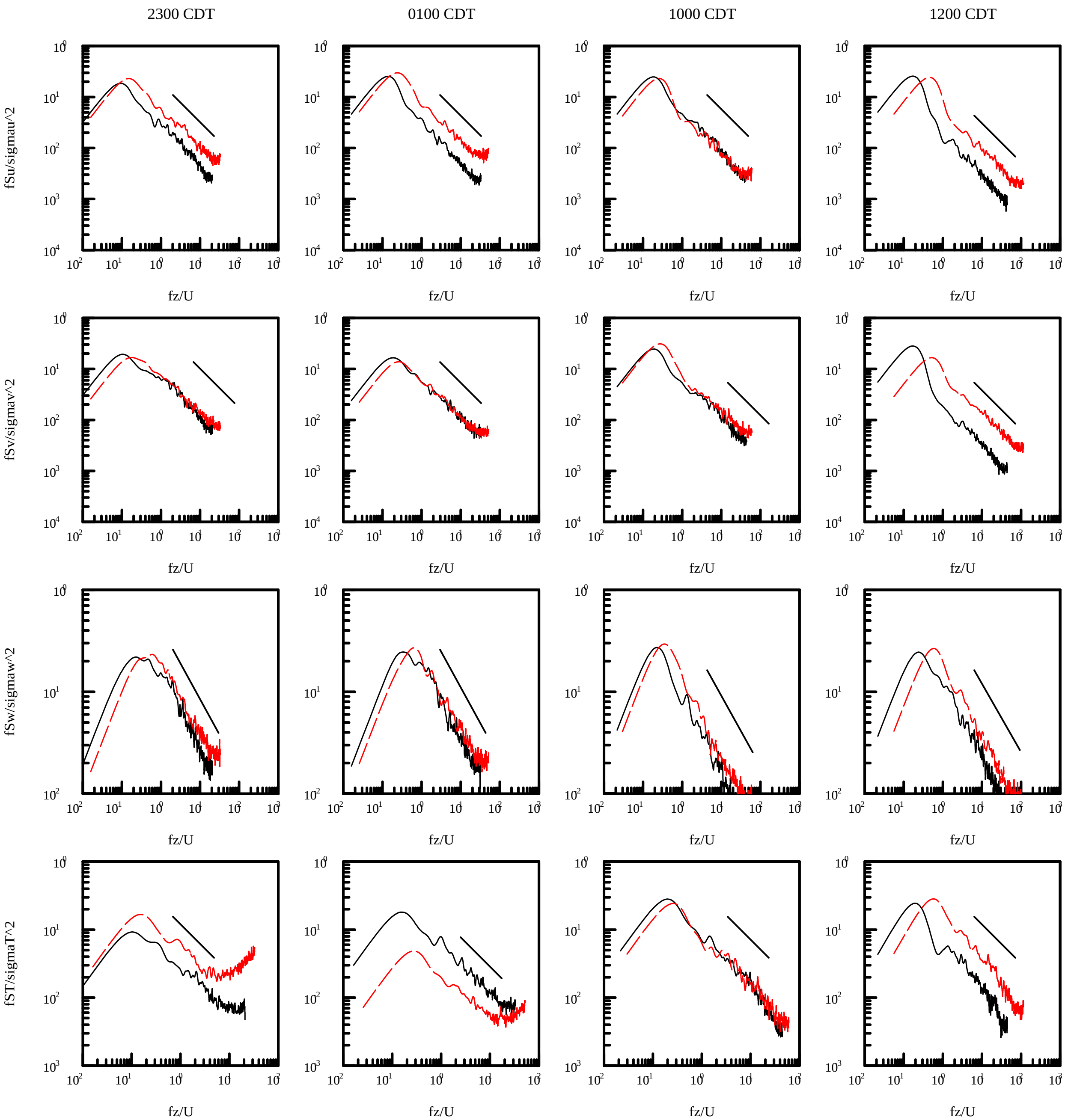

Figure 3 Normalized spectra for u, v, w, and T at 10m on suburban Tower #1 (solid) and urban Tower #2 (dashed) at four CDT times on Jun 30 and Jul 01,2003 versus fz/U on a log-log plot where f is the natural frequency (Hz), z is the measurement height (10m), and U is the 30 minute average wind speed (m/s). The straight lines indicate a -2/3 slope.

Table 1 Values of the non-dimensional peak frequency at spectra maxima, PF(u), PF(v), PF(w), and PF(T) corresponding to the u, v, w, and T spectra in Figure 3.

		CDT		Night Time	CDT		Day Time
		2300	0100	Mean	1000	1200	Mean
PF(u)	Suburban	0.0921	0.1451	0.1186	0.1736	0.1740	0.1738
	Urban	0.1450	0.2286	0.1868	0.2645	0.4495	0.3570
PF(v)	Suburban	0.1023	0.1934	0.1479	0.1953	0.1740	0.1847
	Urban	0.1772	0.2540	0.2156	0.2645	0.5057	0.3851
PF(w)	Suburban	0.2251	0.3385	0.2818	0.2387	0.2392	0.2390
	Urban	0.5960	0.6349	0.6155	0.3552	0.5618	0.4585
PF(T)	Suburban	0.1023	0.1612	0.1318	0.1953	0.1957	0.1955
	Urban	0.1611	0.2794	0.2203	0.2664	0.5618	0.4141

4. Summary

A large amount of sonic anemometer data from the Army Research Laboratory's five meteorological towers during Joint Urban 2003 (Oklahoma City Field Experiment) has been collected and processed. Preliminary spectral analyses show a significant shift of the normalized peak frequency from a suburban area to an urban area, as shown in Figure 3 and Table 1 above. Further analyses of the spectral characteristics in the urban boundary layer for the Joint Urban 2003 are still in progress and will be reported elsewhere.

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