11.15 MOMENTUM AND SCALAR VARIANCE MEASUREMENTS IN THE ROUGHNESS SUBLAYER OF THE MUST ARRAY

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1. INTRODUCTION

Because the U.S. landscape is becoming increasingly urban, it is desirable to better understand the processes of turbulent momentum and scalar transport over urban terrain. In an attempt to better characterize the detailed physical mechanisms of momentum and scalar variance transport in an urban roughness sublayer (URSL), synchronized hot-wire and photo-ionization detector measurements were taken near the center of the grid of simulated buildings at the Mock Urban Setting Test (MUST) conducted at the Dugway Proving Ground, UT (September 2001), See Biltoft et al. (2002).

2. EXPERIMENTAL DETAILS

The test site consisted of an unstaggered 12 x 10 array of 12.2 m x 2.6 m x 2.6 m shipping containers (λ_p = 0.13, λ_{f1} = 0.11, λ_{f2} = 0.03). See Biltoft et al. (2002) for further details on the MUST experiment. The surrounding terrain consisted of a flat surface with a low, nearly uniform covering of sagebrush. The shipping containers were arranged such that an aligned wind angle produced an isolated roughness flow regime, while off-angle winds generated a wake interference regime. Spatially and temporally resolved turbulence measurements were taken near the center of the array at 0.5H above the building height, H, i.e., within a well-developed roughness sublayer. These measurements were acquired using the Scalar Transport Probe (STP) designed and built by Metzger and Klewicki (1999). The STP consists of a compact array of four hot-wire sensors surrounding two photo-ionization detectors as seen below in the diagram of the sensing tip, lengths are in mm. This arrangement allows high-resolution measurements of *u* (axial velocity), *w* (surface normal velocity), and *c* (concentration), as well as the gradients of these quantities in the *z* direction.

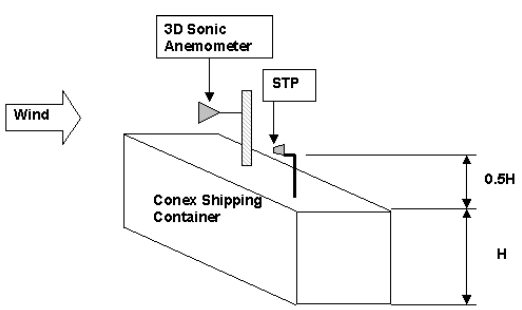

Figure 1. Experimental Setup.

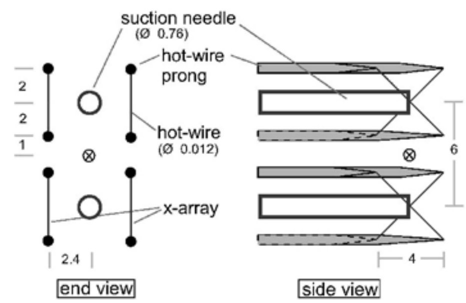

Figure 2. Diagram of STP sensor tip. Figure from Metzger and Klewicki (1999).

The 3D sonic anemometer was used to provide the flow direction relative to the array as well as local time-averaged flow characteristics. A mini-SODAR was used to measure mean upstream atmospheric surface layer (ASL) characteristics.

3. DATA PROCESSING

The present measurements make it possible to obtain time series data of several terms in the axial stress transport equation,

$$U\frac{\partial \overline{u^2}}{\partial x}+W\frac{\partial \overline{u^2}}{\partial z}=-2\left(\overline{u^2}\frac{dU}{dx}+\overline{uw}\frac{dU}{dz}\right)+2\overline{\frac{p}{\rho}\frac{\partial u}{\partial x}} -\left(\frac{\partial \overline{uu^2}}{\partial x}+\frac{\partial \overline{wu^2}}{\partial z}\right)+\nu\left(\frac{\partial^2 \overline{u^2}}{\partial x^2}+\frac{\partial^2 \overline{u^2}}{\partial z^2}\right)-2\nu\overline{\frac{\partial u}{\partial x_i}\frac{\partial u}{\partial x_i}} \quad (1)$$

and scalar variance transport equation,

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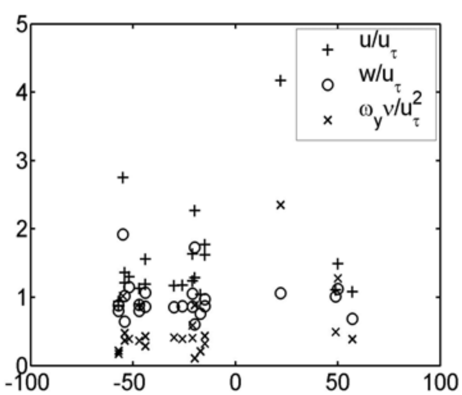
$$U\frac{\partial \overline{c^2}}{\partial x}+W\frac{\partial \overline{c^2}}{\partial z}=-2\left(\overline{u^2}\frac{dC}{dx}+\overline{wc}\frac{dC}{dz}\right) \quad (2)$$
$$-\left(\frac{\partial \overline{uc^2}}{\partial x}+\frac{\partial \overline{wc^2}}{\partial z}\right)+\alpha\left(\frac{\partial^2 \overline{c^2}}{\partial x^2}+\frac{\partial^2 \overline{c^2}}{\partial z^2}\right)$$
$$-2\alpha\overline{\frac{\partial c}{\partial x_i}\frac{\partial c}{\partial x_i}}$$

shown here for 2-D (in the mean), statistically stationary flow. In the present study special attention is paid to the turbulent transport terms $\partial wc^2/\partial z$ and $\partial wu^2/\partial z$.

Due to the meandering nature of ASL flows, the following procedures were performed during data analysis: 1) Time series are inspected for signal integrity and statistical stability. 2) The portion of the time series without a stationary mean is omitted.

4. PRELIMINARY RESULTS

Results are presented for a stably stratified surface layer over a range of incident flow angles. Turbulence results include long time statistics. Owing to the likely effect of the building wakes on the turbulent length scales within the URSL flow, particular attention is paid to the spectra of the vertical transport terms and their comparison to similar spectra taken in an undisturbed ASL over homogeneous terrain.



Relative wind angle (degrees)

Figure 3. Normalized turbulence statistics at various relative wind angles.

The concentration data is found to be sensitive to meander. Changes in flow conditions often caused intermittency in the concentration data possibly due to the propylene plume being channeled into different areas of the array than the test location. However, wind angle and thermal stability had little effect on the *u, w* and ω_y measured by the STP (see Figure 3).

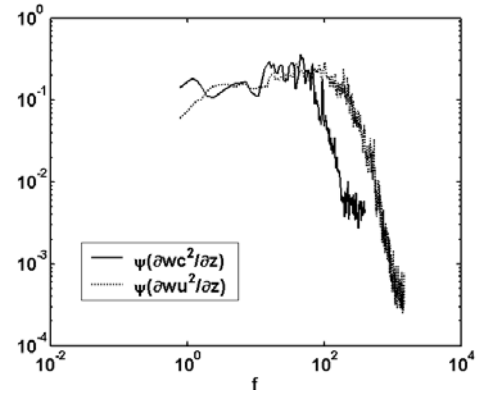


Figure 4. Plot of the spectral function of the vertical transport of scalar variance and axial stress normalized by the signal variance.

The spectral functions of Figure 4 (pre-multiplied spectra) indicate that the motions involved in transport occur at high frequencies (small scales). It can also be seen in Figure 4 that the peak in the spectral function of $\partial wc^2/\partial z$ occurs at a slightly lower frequency than does that of $\partial wu^2/\partial z$. Using a typical St for a bluff body of 0.2, an approximation of the characteristic vortex shedding frequency is found to be 0.06 Hz for the time period over which the data in Figure 4 was taken. This is orders of magnitude lower frequency than the spatial peaks shown in Figure 4. Thus the length and time scales due to the presence of the Conex containers may have an effect on but do not dominate the vertical transport of scalar variance and axial stress. This suggests that much of the vertical transport occurs at very small scales.

5. CONCLUSIONS

From the above results the following conclusions can be made: 1) The ratio of axial to vertical velocity fluctuations, *u/w*, is smaller in the URSL than in the undisturbed ASL, indicating enhanced vertical transport. 2) Turbulent transport is a small-scale phenomenon.

6. REFERENCES

Biltoft, C.A., Yee, E., and Jones, C.D., 2002: Overview of the Mock Urban Setting Test (MUST). *In Proceedings of the 4th Symposium on the Urban Environment,* Paper J1.1, Norfolk, VA, May 20-24, 2002.

Metzger, M.M. and Klewicki, J.C., 1999: Combined hot-wire anemometry and photo-ionization in the measurement of scalar variance transport. *ASME-FEDSM-7353*.