

URBAN EFFECTS ON TRANSPORT AND DIFFUSION OF SMOKES AND TOXIC AGENTS

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ABSTRACT

With the recent emphasis on military operations in urban domains, the Army is concerned with the city environment and its effects on systems, sensors and personnel. The Joint Urban 2003 (JUT) project, a cooperative undertaking to study turbulent transport and diffusion in the atmospheric boundary layer conducted in Oklahoma City in the summer of 2003, afforded the Army Research Laboratory (ARL) the opportunity to leverage the capabilities of the Atmospheric Boundary Layer Exploitation (ABLE) suite of instruments to increase our understanding of this environment (Yee *et al.*, 2004). In this paper we focus on the near surface layer measurements of wind speed and air temperature fluctuations obtained from an array of twelve sonic anemometers on five towers set up outside the central business district (CBD) in surrounding industrial (urban) and semi-rural (suburban) areas. The anemometers sampled at a rate of 10 Hz. After quality control of these data, turbulent statistics of the three wind components and temperature were calculated using ten minute blocks of data (Garvey *et al.*, 2004).

1. INTRODUCTION

The effects of the urban environment on wind and turbulence fields affecting plume movement and spreading have the potential to be quite significant. Transport and diffusion models require the following kinds of information about atmospheric conditions and surface properties as input: the mean wind speed and direction, the temperature and stability characteristics of the atmosphere near the surface, and the turbulent velocity and time scales relevant to the location of interest. Turbulent transport over and around urban areas, as well as over flat terrain, has been studied. Transport and diffusion within the urban roughness layer and model performance in this area have not been well studied (Hanna and Britter, 2002). The ARL sonic anemometer network, as a part of the JUT study, gathered data about near-surface atmospheric properties within the urban roughness sublayer.

2. WIND SPEED AND DIRECTION

Wind speeds are on average smaller at the urban locations compared to the suburban sites (Table 1). For the most

part, wind directions were consistent throughout the area (Fig. 1). Occasionally wind directions were poorly correlated and varied considerably from one location to another. These are marked with stars in Figure 1. Not all of these poorly correlated winds correspond to weak wind conditions. Plume transport depends heavily on wind direction; so these times need closer examination to determine how to include this phenomenon correctly in the models.

Table 1. Wind Speeds and Turbulence Statistics Comparisons

Averages for July 2003, 10m elevation	Day urban	Day suburban	Night urban	Night suburban
Wind speed (m/s)	2.85	3.79	2.44	3.21
$-\overline{u'w'}$ (m^2/s^2)	0.367	0.327	0.243	0.202
$\overline{w'T'}$ (K m/s)	0.175	0.148	0.005	-0.023
TKE (m^2/s^2)	1.96	1.95	1.04	0.96

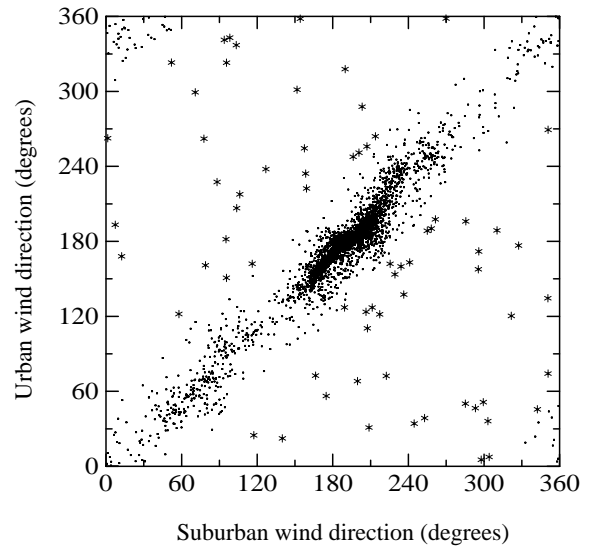


Fig. 1. Wind direction in an urban location compared to wind direction in a suburban location about 5 km WSW of the urban location. Points marked with a star (*) are poorly correlated between the two locations.

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3. MOMENTUM FLUXES

The loss of momentum from the atmosphere through frictional forces at solid surfaces is measured through the turbulent stress or momentum flux ($-\overline{u'w'}$). Values of momentum flux are higher on average at the urban sites than at the suburban sites (Table 1). Urban values can reach levels 35% higher than suburban values in late afternoon. The amount of momentum loss, which is related to the roughness elements of the surrounding surface, contributes significantly to the uncertainty associated with plume dispersion.

4. HEAT FLUXES

The amount of buoyancy-produced turbulence is proportional to the sensible heat flux ($\overline{w'T'}$) at any given location. Heat flux measurements are also useful for classifying the thermal stability at a location. From our data, the most notable differences in thermal stability from one location to another within the greater urban and suburban area arise at night. The suburban locations have downward nighttime heat fluxes consistent with theoretical expectations for nocturnal conditions. Downward heat flux allows a thermally stable layer to form, which suppresses turbulence. The urban locations however maintained upward heat flux throughout most nights (Table 1); the daytime heat fluxes were generally greater in the urban area than in the suburban area. Both day and night data are evidence of an urban heat island.

5. TURBULENT KINETIC ENERGY

Turbulent kinetic energy (TKE) is a measure of the turbulent velocity scales. Plume or puff spreading as a function of time is proportional to these turbulent velocity scales. Average turbulent kinetic energy values were found to be very similar from site to site (Table 1). The daytime average values were roughly twice the nighttime averages, implying that daytime dispersion will be greater than at night. Further study is needed to see how close proximity to buildings alters TKE components.

6. SPECTRAL ANALYSIS

Spectral analyses of the sonic anemometer data (Fig. 2) show a consistent shift in the temporal/spatial scales of the dominant turbulent eddies between the urban and suburban locations (Chang, *et al.* 2004). The shift is from larger spatial (lower frequency) scales at the suburban locations to smaller spatial (higher frequency) scales at the urban locations. This shift in scale is observed at all hours and for all variables (the three components of the velocity vector and temperature), indicating that the integral time scales within the city are smaller than in the suburban area.

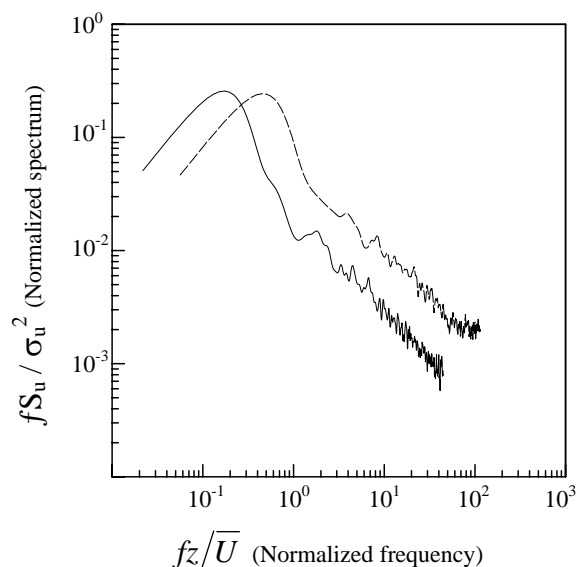


Fig. 2. Normalized Fourier spectra of wind speed fluctuation data at urban (---) and suburban (—) locations with frequency f (Hz), observation height z (m), mean wind speed \bar{U} (m/s), and variance of the wind speed fluctuations σ_u^2 (m^2/s^2) as the scaling factors. Data are for 1 July, 2003 at noon CDT.

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