ESTIMATING METEOROLOGICAL INPUTS FOR DISPERSION MODELING IN URBAN AREAS

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INTRODUCTION

Dispersion of releases in urban areas can be estimated with information on micrometeorological variables in the urban boundary layer (*Venkatram et al.,* 2005). However, this information is not generally available although meteorological measurements are routinely made in rural airports. The first part of the paper presents a method to estimate urban micrometeorology using measurements from rural sites, and describes its performance in explaining data from a field experiment. The second part of the paper examines the usefulness of measurements made in urban sites that are not ideal for the application of the Monin-Obukhov (MO) similarity. The research described in this paper is motivated by the need for methods to estimate meteorological inputs required to apply dispersion models such as AERMOD (*Cimorelli et al.*, 2005) in urban areas.

ESTIMATING URBAN DISPERSION METEOROLOGY FROM RURAL VALUES

An internal boundary layer (IBL) is formed when air flows over a change in surface conditions such as surface roughness, thermal and moisture properties. There are a number of formulae of varying complexity to estimate the growth of the IBL. One such formula based on Miyake's diffusion analogy and discussed by *Savelyev and Taylor* (2005) is

$$U(h)\frac{dh}{dx} = A\sigma_w , \qquad (1)$$

where h is the height of the IBL, x is the downwind distance from the roughness change, $U(h)$ is the wind speed at height h, and A is a constant (≈1). The values of $U(h)$ and σ_w are those of the modified flow over the urban surface.

The data (*Luhar et al.*, 2006) indicate that MO surface similarity theory is valid within the IBL over an urban area. Then, Equation (1) can be solved if L for the specified urban area. We assume that under daytime convective mixing conditions, L_U is the same as L_R. When the rural conditions are stable in the nighttime (*i.e.* $L_R > 0$), the heat flux comparison plot presented in *Luhar et al.* (2006) shows that it is reasonable to assume that the conditions over the urban area are largely neutral (see also *Britter and Hanna*, 2003). These assumptions about the MO length over the urban area allow us to estimate the internal boundary layer height h as a function of x from Equation (1). Once h is known, the micrometeorological variables over the urban area can be calculated using two assumptions: 1) the micrometeorological variables above h are the same over the urban and the rural areas, 2) the urban profiles below h follow MO similarity.

RESULTS FROM THE IBL MODEL

We compared estimates from the IBL model with data collected as part of the Intensive Observation Period (IOP) 10 June – 10 July 2002 of the Basel Urban Boundary Layer Experiment (BUBBLE) conducted in the city of Basel, Switzerland (*Rotach et al.*, 2005; http://pages.unibas.ch/geo/mcr/Projects/BUBBLE/). Here we use meteorological data from two towers. The main urban measurements tower, Basel-Sperrstrasse, was 32 m high and located inside a street canyon in an area with dense, fairly homogeneous, residential building blocks. The rural site, Village Neuf was located about 6.5 km NNW of the urban site, and measured flow and turbulence at 3.3 m AGL over bare soil in an agricultural area (z_0 = 0.07 m). 10-min averaged data on the mean temperature, mean wind components in the horizontal plane, standard deviations of the turbulent velocities in the three directions, cross-correlations of the turbulent velocities and sensible heat flux were available for both urban (at all heights) and rural areas, which were then averaged over hourly periods.

Figure 1a compares estimates of u_* at 22.4 m from the IBL model to observed values over the urban area. Although the scheme underestimates observations under daytime conditions, its overall performance is good: 85% of the model estimates lie within a factor of two of the observations, the correlation coefficient (*r*) is 0.62, and the slope and intercept of the linear regression line are 0.73 and 0.04 m/s, respectively. Figure 1b compares estimates of σ_w from MO similarity with corresponding observations. The comparison indicates that 93% of the model values are within a factor of two of the observations, *r* is 0.56, and the slope and intercept of the regression line are 0.79 and 0.15 m/s, respectively. Figure 1c compares wind speeds computed with observed wind speeds at 22.4 m. We find that 77% of the model values are within a factor of two of the observations, *r* is 0.49, and the slope and intercept of the regression line are 0.76 and 0.73 m/s, respectively.

(a) (b) (c)

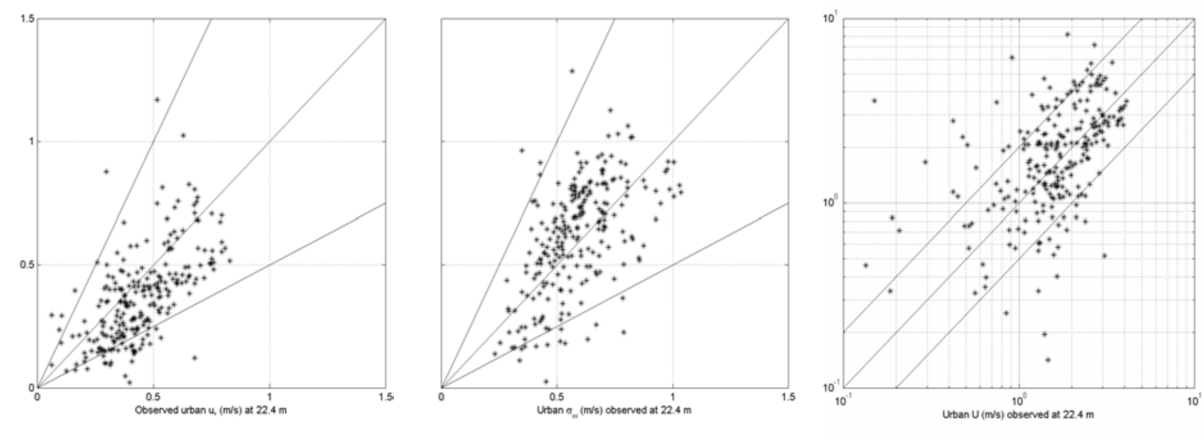

Fig. 1; Scatter plot of the data measured (horizontal axes) at 22.4 m over the urban area vs. the values computed (vertical axes) from the present analytical scheme for (a) friction velocity (u_*), (b) wind speed (U), and (c) standard deviation of the vertical turbulent velocity (σ_w).

USING MEASUREMENTS IN AN URBAN AREA

Venkatram (1980) and *Irwin and Binkowski* (1981) evaluated two methods to estimate u_* and L with data collected in flat rural sites with adequate homogeneous upwind fetches. These methods are based on fitting measurements of mean wind and temperature to profiles given by MO similarity theory (*Businger*, 1973). *Venkatram* (1980) proposed a simple method to solve for u_* and L using a single measurement of mean wind speed. The method is based on the empirical observation, derived from measurements made in Kansas (*Izumi*, 1971), Minnesota (*Caughey et al.*, 1979) and Prairie Grass (*Barad*, 1958), that $\theta_* = -\langle w'\theta' \rangle / u_*$

varies little across these experiments and for practical purposes, can be taken to be 0.08° C. We will refer to this method as SU to stand for single *U*.

Irwin and Binkowski (1981) proposed the Bulk Richardson method based on using additional information on the difference in potential temperatures between two levels, z_1 and z_2 (referred here as UDT to stand for single *U* and delta *T*). The UDT method, like the SU method, requires an estimate of the surface roughness z_0 and displacement height, *d*. The DUDT (delta *U*, delta *T*) method uses velocity measurements at two heights, z_1 and z_2, to eliminate surface roughness from the equations.

COMPARISON WITH FIELD OBSERVATIONS

Data from two field studies were used to evaluate the methods to estimate u_* and *L* described earlier. The studies are Wilmington 2005 (*Yuan et al.*, 2006), and VTMX 2000 (*Monti et al.*, 2002). The instruments in Wilmington were deployed at the Harbor Generating Station of the City of Los Angeles's Department of Water and Power (LADWP). The residential areas, consisting mostly of one storey buildings about 4 m high, are located upwind of the LADWP site during the dominant nighttime, stable, northwesterly flows. Data from the Vertical Transport and Mixing Experiment (VTMX), conducted in Salt Lake City (SLC), consisted of measurements from a tower located in the northeastern side of the valley, in a grassy open area (aerodynamic roughness length < 0.1 m), having a gentle slope (~0.07, *i.e.* 4°).

The analysis of the Wilmington data is based on 5 minute averaged data from a sonic anemometer. In the SU method, wind speed data from a height of 6 m were used to minimize local building effects. In the UDT method, temperatures at heights of 3.1 m and 6 m were used. The DUDT method used both temperatures and winds at these two heights.

Figure 2 compares the relative performance of the three methods in estimating the surface friction velocity. The top left panel indicates the performance of the neutral estimate. The top right panel of Figure 2 indicates that the SU method, based on a constant θ_*, yields an r^2=0.49 and 65% of the observations are within a factor of two of the model estimates. The simple correction for stability appears to be an improvement over the neutral estimate from. The UDT method or the bulk Richardson method does not perform as well as the SU method: r^2=0.3 and only 22% of the observations are within a factor of two of the model estimates. Using two levels of velocity leads to further deterioration in estimating u_*.

Estimates of *L* from the simplest SU method compare best with observations although the method has a tendency to underestimate at values of L > 100 m. About 26% of the observations are within a factor of two estimates from the UDT method, but there is little correlation between model estimates and observations. The DUDT method performs poorly presumably because the differences in temperatures and velocities between the two levels are comparable to the uncertainty in measuring the ensemble means at these levels.

At the VTMX site, the relative performance of the four methods to estimate u_* is similar to that observed from the Wilmington site, although the overall level of performance is higher. This could be related to the fact that the VTMX site is more rural and has a larger uniform upwind fetch.

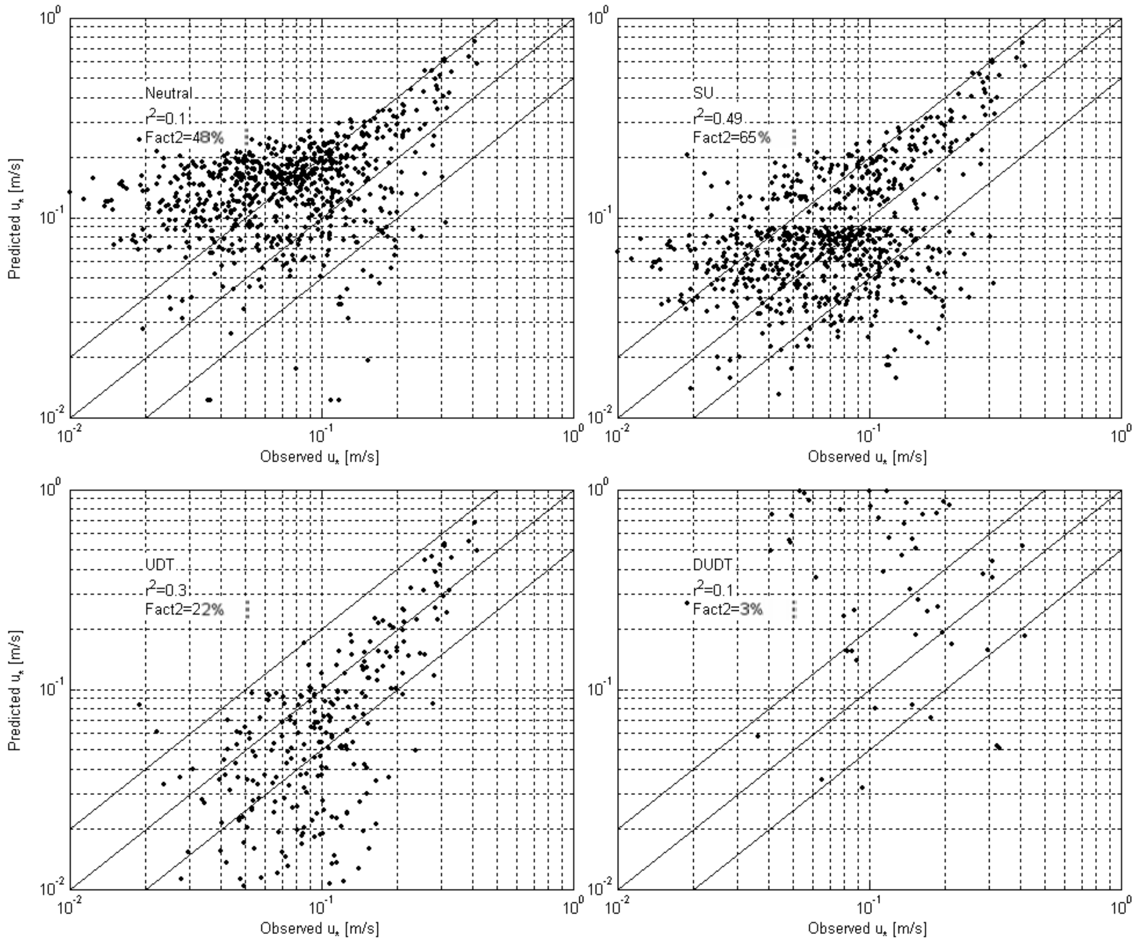

Fig. 2; Comparison of observed u from the Wilmington study with estimates from: Top left: formulation for neutral conditions (z/L = 0), Top right: SU method, Bottom left: UDT method, Bottom right: DUDT method. Here z_0 = 0.4 m and d/z_0 = 5 were used.*

CONCLUSIONS

We describe a method to estimate urban micrometeorology using a two-dimensional internal boundary layer model that uses Monin-Obukhov surface similarity theory and rural variables as upwind inputs. The model assumes that the urban Obukhov length is the same as that in the rural area under unstable conditions and is infinity (neutral) when rural conditions are stable. Estimates of friction velocity, winds, and turbulence estimated from the method compare well with observations made during the Basel Urban Boundary Layer Experiment (BUBBLE), conducted during June and July 2002 around Basel, Switzerland.

The second part of the part examines the use of M-O similarity to interpret near wind and temperature surface measurements in the stable boundary layer. The analysis of data from Wilmington and VTMX indicates that MO similarity provides an adequate description of velocity and temperature profiles in the near surface stable layer even when the measurements are made in an open area in the vicinity of buildings. The performance of the SU method based on a wind speed measurement at a single level (*Venkatram*, 1980) in estimating u_* and L is better or comparable to that of the UDT method (Bulk Richardson number method, *Irwin* *and Binkowski*, 1981) based on a single level wind speed and two levels of temperature. The DUDT method based on measurements of both wind speeds and temperatures at two levels (Gradient Richardson number method, *Irwin and Binkowski*, 1981) does not perform as well.

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