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On relationships between urban and rural near-surface meteorology for diffusion applications

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Abstract

Dispersion of releases in urban areas can be estimated with information on micrometeorological variables in the urban boundary layer. However, this information is not generally available. On the other hand, meteorological measurements are routinely made in rural surroundings (e.g. airports). We examine empirical relationships between urban and rural meteorological variables using data from the Basel UrBan Boundary Layer Experiment (BUBBLE), conducted during June and July 2002 around Basel, Switzerland, and present two methods to estimate urban micrometeorology using measurements from rural sites. The first method is based on a two-dimensional internal boundary-layer model that uses rural variables as upwind inputs. It assumes that the urban Obukhov length is the same as that in the rural area in unstable conditions and that it is very large (neutral) in stable rural conditions. The second method uses a three-dimensional prognostic model called TAPM in which upwind rural observations are assimilated. Urban variables estimated from TAPM compare well with observations. This performance is slightly better than that of the internal boundary-layer model.

Keywords: Urban meteorology; Internal boundary layer; Urban–rural differences; TAPM; Urban dispersion; BUBBLE experiment

1. Introduction

Recent studies (Venkatram et al, 2005) indicate that simple dispersion models can be used to estimate ground-level concentrations in an urban area if meteorological information at the site is used to construct model inputs. Because such information is usually not available, there is a need for methods that can estimate urban meteorological variables from more routinely available rural measurements. This paper examines two such methods, one based on an analytical scheme for the height of the mechanical internal boundary layer coupled with Monin–Obukhov (M–O) surface similarity theory, and the other using a three-dimensional (3D) prognostic meteorological model. The performance of these two methods is evaluated with data from a boundary-layer field study conducted in the city of Basel, Switzerland, in 2002.

The urban boundary layer can generally be divided into four layers (e.g. Rotach et al., 2005): (1) the urban canopy layer that extends from the ground to about the average height of roughness elements (or buildings); (2) the roughness sublayer, displaying complex flows and extending to the height where the influence of the individual roughness elements

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vanishes (roughly 2–5 times the height of typical roughness elements); (3) the inertial sublayer, equivalent to the surface layer over large, flat surfaces, where small-scale turbulence dominates transfer; and (4) the outer layer with mixing dominated by large-scale thermal effects. This paper focuses only on flow variables above the urban canopy layer. These variables govern the dispersion of releases at source–receptor distances at which the plume vertical extent is larger than the urban canopy height.

Before describing the models used to infer urban micrometeorology from rural inputs, we present analysis of the data used to evaluate these models.

2. Experimental data

The data analysed in this paper were 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/). The BUBBLE measurements, both surface and upper air, were made using a number of instruments with the objective of studying boundary-layer and surface-exchange processes over different types of surfaces (i.e. urban, sub-urban and rural) and their role in the transport and diffusion of air pollution. This paper uses meteorological data from two towers.

The main urban measurements tower, Basel-Sperrstrasse (or U1), was 32 m high and located inside a street canyon in an area with dense, fairly homogeneous, residential building blocks, and a mean building height of 14.6 m AGL (above the ground level). In the vicinity of the measurement tower, the building height was 14 m AGL and the street canyon aspect ratio (i.e. height-to-width ratio) was about unity. The surface roughness length (z_0) was 2.1 m, and the zero-plane displacement height (d) was 9.5 m (Christen and Rotach, 2004). The tower measured the three wind components and temperature using sonic anemometers at six levels, viz. 3.6, 11.3, 14.7, 17.9, 22.4 and 31.7 m AGL, to characterise the vertical structure of the mean flow and turbulence within the urban roughness sub-layer (i.e. the layer directly influenced by individual roughness elements).

The rural site, Village Neuf (or R2), was located about 6.5 km NNW of the U1 site, and measured flow and turbulence at 3.3 m AGL over bare soil in an agricultural area ($z_0 = 0.07$ m). There are hills located south-east and north-east of the U1 (urban) site, generating drainage flow in the nighttime, but there is a relatively flat fetch to the north-west of the U1 site, within which the R2 (rural) site is located. 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.

The BUBBLE data reveal the distinct influence of the urban surface on flow properties. This is examined next.

2.1. Observed winds

Fig. 1 shows wind roses at the six levels at U1, the urban tower. At the 31.7-m level (Fig. 1(a)), the wind is primarily from two sectors: 250°–360°, which mostly corresponds to daytime observations, and 90°–150°, which is dominated by nighttime and early morning hours (flows during these hours are influenced by drainage from the hills situated in the east, south-east of the monitoring site). The winds during the nocturnal hours are weaker than those in the daytime.

Fig. 1(b) for the 22.4-m level is similar to that for the 31.7-m level, with the main difference being an overall weakening of the winds at the lower height. In Fig. 1(c) for the 17.9-m level, the wind speeds decrease further, and the flow from the south-east quadrant has a larger easterly component. At 14.7 m (Fig. 1(d)), which is almost the local roof-top level, the winds become even lighter, with the dominant wind direction being east–north–east, which is also the direction of the local street. This behaviour suggests that the flow is now substantially influenced by the confining local street canyon. The dominant flow direction at the 11.3-m level (Fig. 1(e)), which lies within the street canyon, is along the direction of the street, with a small percentage of winds from the *northern* side of the street canyon.

In Fig. 1(e) for the 3.6-m level, the dominant flow is again along the direction of the street canyon; however, a small percentage of winds is from the *southern* side of the street canyon, which perhaps is in coherence with the flow from the *northern* side of the street canyon at 11.3 m but is in the opposite direction, possibly due to the formation of a cross-street vortex (e.g. Baik et al., 2000). The above wind roses suggest that the levels below 22.4 m are directly influenced by the local roughness elements.