Preparation of Meteorological Input Data for Urban Site Studies: Results from the COST 715 Programme

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Keywords: urban meteorology, air pollution, dispersion models

1 Introduction

The behaviour and spatial distribution of air pollution in urban areas depends on meteorological conditions, especially processes within the urban boundary layer (UBL). One issue of this paper deals with the alternative approaches proposed to describing urban meteorology. This was considered at a COST 715 Workshop on the Preparation of Meteorological Input for Urban Site Studies (Schatzmann, Brechler and Fisher, 2000). The most sophisticated approach can be characterised as one using some appropriate urban scale models nested within larger meso-scale models. This approach has been widely adopted in European countries to predict pollution episodes for which synoptic conditions is the main driver (see Section 2).

Another approach is based on the use of measured surface wind data or prescribed wind data and various techniques such as optimisation or on a utilisation of dynamic wind flow models to generate information on a wind field at a high resolution appropriate to the topography of the city. Several examples of these so-called dynamic ‘down-scaling’ methods were presented at the Workshop. These methods were discussed in several contributions (Kerschgens *et al*, 2000, Baumueller, 2000 or Brechler and Janousek, 2000).

A second issue is the current status of methods used to define the meteorological conditions under which dispersion within urban areas takes place. In most European countries the same approach as that adopted in rural areas is adopted using the meteorological conditions observed at the standard height at a nearby airport. The assumption is that these meteorological measurements are representative of the urban area. In cities associated with complex topography some form of 'downscaling' is used to define a more realistic wind field.

A third issue concerns new concepts regarding the structure of the UBL which are being developed based on the current approaches used in rural areas. These suggest ways of describing the UBL wind profile (Rotach et al., 2000) and the surface heat flux and thermal stability of the UBL (Grimmond and Oke, 2000) in terms of a few readily available parameters.

2 Meso-scale Models

A COST 715 report on Meteorology during Peak Pollution Episodes has been produced (Kukkonen, 2000), which surveys the national situation in each country (http://www.fmi.fi/eng/ila/cost715) and demonstrates that the approach to predicting peak pollution episodes in the main urban areas of European countries is broadly similar. The methods for dealing with episodes rely on numerical weather prediction models of various scales to predict weather conditions some days in advance and urban scale dispersion models to predict urban air quality one or two days in advance. Taking Norway as a specific example, the weather prediction modelling system is built on HIRLAM (High

Resolution Limited Area Model) run operationally at the Norwegian Meteorological Institute (DNMI http://www.dnmi.no/eng_index.html) and MM5 high-resolution model nested into it. The detailed meteorological information derived from the meso-scale model is then used in combination with an urban dispersion model and emissions inventory to calculate pollution levels (http://www.nilu.no/first-e.html).

3 Meteorological Input Data for Urban Dispersion Studies

The COST 715 Workshop reviewed ways in which the meteorological data are prepared and processed for application to dispersion models in urban areas. All operational methods are concerned with producing a climatology of stability categories/dispersion classes for urban areas follow approaches used in rural areas. Much of the theory is based on the same physical principles as used in the meso-scale models, adopting parameterisations but with some similar difficulties concerning latent heat and soil moisture. The advantage relative to meso-scale models is that they are tied firmly to meteorological measurements and can be tested. The disadvantage is that they may neglect spatial horizontal variations and temporal fluctuations, which a dynamical model can better allow for.

In routine urban dispersion calculations not much adjustment to urban meteorological conditions is usually made, apart from adopting an urban roughness length. Some correction to the surface sensible heat flux is made, for example by assuming that very extreme atmospheric stability does not occur in urban areas i.e. there is an upper bound on the rate of cooling. These methods are not adequate for calculating small scale variations in the concentrations near the surface, such as those within street canyons where some of the highest concentrations are expected to arise.

4 Street Canyon Models

Street Canyon Models strongly depend on local conditions. As examples of these models the Operational Street Pollution Model (OSPM) (Berkowicz et al, 1997, Sacre et al, 1995) and AEOLIUS model (Middleton, 2000) can be considered. The former takes the wind measured on a mast some height above roof level and extrapolates this to a roof level wind; the latter uses the standard 10m wind speed and direction at the nearest airport.

Both models make use of the greater roughness length in urban areas. The roughness length relates to turbulence in layers where the log profile is valid e.g. above the roughness elements. Both models use measured wind from masts located either near the centre of the city (OSPM) or at the nearby airport (AEOLIUS). Neutral vertical wind profiles are constructed using the measured data. The profiles are modified for urban and stability conditions via modification of friction velocity u_* (OSPM) to obtain an adequate wind at roof level and at the street level. If data from nearest airport are used some empirical rules (Manning *et al*, 2000) can be adopted.

5 Urban Wind Profile

A more advanced method for describing the UBL near the surface in terms of local scaling has been proposed by Rotach *et al* (2000) (http://www.geo.umnw.ethz.ch/research/ cost715/ cost715.html). A method for estimating the wind speed at an urban reference height is proposed using an observation at another height. Provisionally the reference height has been defined to be at the displacement height + 10m. This approach does not rely on applying a meso-scale model, but on an adjustment to conventional Monin-Obukhov similarity theory (MOST). MOST is assumed to still apply above the roughness elements, in the so-called inertial sub-layer. Typically the inertial sub-layer is taken to be between 0.1 × boundary layer height and 2 × height of the buildings (h). Below the inertial sub-layer is the roughness sub-layer typically 2h high, which incorporates the roughness elements and buildings. Within the inertial layer the friction velocity can be defined as a constant, with the Reynolds stress decreasing almost linearly with height above the inertial layer. Below 2h within the roughness sub-layer the friction velocity is found to decrease with height. Scaling similar to MOST can still be applied within the roughness sub-layer but with a height dependent friction velocity.

The method assumes that the roughness length and displacement height (Davenport et al, 2000), can be defined in terms of properties of the urban area, such as the average building height and fractional surface area covered by buildings. Provided the number of buildings is sufficiently dense, changing the number of obstacles does not change the roughness illustrating that detailed surface characteristics are unimportant to the flow above the surface. Other assumptions such as assuming a relationship between the friction velocity inside and outside the city have also to be made. The overall effect is to reduce turbulence levels and the mean wind speed above and between the roughness elements. The method only enables a mean wind speed at a specified height to be derived. It does not give the wind speed variation on either side of the street. Hanna and Britter (2000) cite a simple relationship between the average wind speed below building height and the friction velocity within the inertial layer. Experimental data on the relationship between the wind speed at a standard 10m height outside a city to the wind speed on a mast within the city have been reported e.g.

Roof-top wind (Leek U.K.) =0.63 (airport wind at 10m)
Urban wind at 32m (Lisbon)=0.65 (rural wind at 10m) + 1.24
Urban wind at 30m (Copenhagen)=0.51 (airport wind at 10m).

These results cannot be directly compared unless a standard height for defining urban winds is selected.

6 LUMPS

The generalisation of UBL scaling has been proposed for deriving urban surface heat fluxes requiring only standard meteorological data routinely observed at synoptic stations and basic knowledge of the surface character of the urban area. This methodology is known under the acronym LUMPS - a Local-scale Urban Meteorological Pre-processing Scheme. At the present time this scheme has only been developed for and applied in North America and it needs to be tested in different European conditions i.e. cities with different building densities, shapes and structure (slanted roofs, different building material used, for example). The LUMPS scheme is based on a surface radiation budget to estimate the net all-wave radiation. It differs from conventional approaches for rural areas in incorporating a storage heat flux in the building fabric. The partitioning between the turbulent sensible and latent heat fluxes depends on a parameterisation which involves the surface moisture status. That depends on the fraction of the vegetated city surface which may range from 5% in a city centre to more than 50% in the residential suburbs.

There are plans to test the LUMPS scheme on European cities with different surface characteristics for which the net radiation and sensible surface heat flux have been measured. Such a comparison is to be made for Birmingham(UK), Basle(CH) and Graz(A) (Piringer, Baklanov, De Ridder, Ferreira, Joffre, Karppinen, Mestayer, Middleton, Tombrou and Vogt, 2001). Given the important links between the surface and the developing UBL, it also necessary to investigate urban boundary layer as a whole. Two such experiments are planned (http://cost.fmi.fi/wg2/furtherwork .html).

In one such experiment given the name BUBBLE (the Basle Urban Boundary Layer Experiment) the urban boundary layer over Basle will be investigated for one year by monitoring near-surface turbulence characteristics, as well as the UBL's vertical structure. The experiment includes rural reference station measurements, tracer experiments in and above streets and remote sensing equipment (http://www.mcrlab.unibas.ch/projects/ BUBBLE/). A meso-scale numerical model will be used to validate and improve urban surface parameterisations.

In the other experiment an intensive measurement campaign will be conducted over the Berre-Marseille region during June and July 2001. The experiment involves wind profilers, sodars and lidars, a ground network of pollution and meteorological measuring equipment and aircraft measurements (http://medias.obs-mip.fr:8000/escompte/maquette/mesures.php3). The project involves a meso-scale model (Bouzom, 2000) to describe the chemical transport and specifically will concern the analysis of the momentum flux, and the energy budget at the city surface.

7 Siting of Meteorological Instruments in Urban Areas

As a consequence of European Directives and UNECE Protocols there are mandatory requirements for monitoring air pollutants at fixed site. The purpose of the monitoring is to assess the air pollution climate of member states. Apart from differences in emissions influencing the site the next major factor is the meteorology. It therefore seems sensible to require local meteorological measurements to be co-located with air pollution monitors.

Problems exist as how to define objectively a position where the meteorological instruments should be placed, at what height the parameters like radiation fluxes or wind speed and direction, for example, would be measured and how to deal with the low wind speed situations. There are no national or international guidelines as to how these corrections may be applied. The problem is especially important in cities with few urban observations (or no observations) located in complex terrain. Urban dispersion calculations, which are performed in all countries, are often undertaken under probably totally inappropriate conditions

8 Conclusions

Numerical weather forecast models do not really see cities. Routine dispersion calculations apply basic corrections to obtain urban meteorological data sets and sometimes no correction at all. It is proposed that a survey is undertaken of national weather services as well as national and local environmental authorities to find out the number and type of instrumentation and location of urban meteorological observing stations and of stations close enough to urban areas, either to be influenced by the urban 'plume' or to provide information on the incident air flowing over the urban area. The COST 715 Management Committee approved this as an activity to be undertaken under this action. Testing of the two proposed improved methods for parameterising the urban wind profile and the surface heat flux was considered essential.

9 References

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