Remote sensing in urban areas – recent advances

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1. Introduction

The requirements of the European Union Framework Directive on air quality assessment and management, already adopted by the Council of Ministers of the European Union in September 1996, present real practical problems for the meteorological community. Assessments of air quality will be required in certain areas for up to 13 air pollutants, mainly in large urban areas with high populations. Remedial plans may need to be drawn up in areas of poor air quality. Reliable air pollution models are to be developed to supplement or replace measurements and to investigate future emission scenarios. These models will need accurate meteorological input variables consistently applied within EU member states. Surface fluxes and some of the meteorological variables, such as the mixing layer depth, needed in urban air pollution assessments are not routinely measured, and the number of meteorological stations in urban areas is commonly limited to a few sites, often just at airports.

Considerable efforts have been undertaken recently to improve our knowledge on urban-related modifications of the atmospheric boundary layer. The following overview will start with the long-time experience of ZAMG in vertical sounding and remote sensing of urban boundary layers. ZAMG's research fits well into the aims of an ongoing COST Action on 'Meteorology applied to urban pollution problems' which initiated three urban field experiments. This paper ends with recommendations for future work.

2. Recent urban experiments

The potential of Sodars and tethersondes supplementing an existing dense array of conventional meteorological stations was studied explicitely with field experiments in Graz and Vienna, Austria. The scope of the Graz experiment conducted between 10 and 13 January 1998 (Piringer and Baumann, 1999) was to investigate the dispersion and conversion of air pollutants in a poor-ventilated urban area under predominantly anticyclonic conditions. The vertical soundings were used to investigate the most important flow regime, the valley wind circulation along the Mur river crossing the city from North to South. Therefore, two Sodars and five tethersondes had been placed along this North-South – transect through the city enabling to study the modifications of the along-valley flow as it crossed the city. The most striking findings are the regular development of a low-level jet with the

night-time down-valley flow, the increase of windspeeds and the height of the maximum speed as the down-valley flow crosses the city, and a near-surface inflow of cold air from the southern flatlands to the city, leading to strong vertical wind shear south of the city and especially in the area of the Graz airport.

Several field experiments in the Vienna area, where routine radiosoundings are undertaken, have been conducted to determine the summertime mixing height by Sodar (Piringer, 1988) and radio- and tethersonde (Piringer et al., 1998), to study the local circulation during photochemically active periods (Piringer et al., 1997) as well as interactions of flows of different scales with the underlying topography (Piringer et al., 2000). During the field experiments in Vienna, up to four Sodars installed on rooftop level and up to two tethersonde systems have been used. Although Vienna is a well-ventilated city, occasional stagnations are possible due to the topographic situation with mountains to the north and west of the city. In these situations, a near-surface cold air pool feeded by north-westerly down-slope and down-valley winds develops in the north-western parts of the city, with south-easterly currents aloft. Such a situation causes strong vertical wind shear. Although polluted air from industrial areas is transported to the city with south-easterly flow and affects parts of the city in the south and east, the down-valley flow simultaneously brings fresh air from the Vienna woods to built-up areas in the north and west f the city.

Within COST, a framework for scientific and technical co-operation, Action 715 "*Meteorology applied to urban pollution problems"* has been set up. The framework, objectives and work plan of this Action, which will end in September 2003, are discussed in Fisher *et al.* (2001). The Action conducted several workshops, e.g. on meteorological input data for urban site studies, on the surface energy balance in urban areas, and on mixing heights and inversions.. It furthermore initiated urban-scale experiments, in Basle, Marseilles and Birmingham, to more explicitly study processes in European cities.

BUBBLE, the **B**asle **U**r**b**an **B**oundary **L**ayer **E**xperiment, is an initiative of six Swiss research institutes (Rotach et al., 2001). It is supported by a large number of groups from all over the world. The objective of BUBBLE is to study the UBL in the city of Basle for a one-year period, monitoring near-surface turbulence characteristics as well as the vertical structure of the entire UBL. Near-surface observations are undertaken at two urban, one suburban and a rural reference sites up to a height greater than twice the mean roughness element height; these comprise conventional meteorological observations, turbulence measurements by sonic anemometers, full radiation balance, and, at the urban sites, detailed measurements of the canyon thermal and radiative properties. A 1290 MHz wind profiler is operated at one urban site. The aerosol distribution within the urban boundary layer and aloft is determined with an aerosol backscatter Lidar. The data set will be used to evaluate and improve the surface exchange parameterisation of Martilli et al. (2002).

Another experiment on the urban boundary layer was undertaken during the large French photochemistry experimental campaign ESCOMPTE in Provence, June-July 2001. The urban meteorological (UBL/CLU-Escompte) campaign took advantage of the project's dense network of meteorological and remote sensing observations both on the ground and from airplanes. Surface energy balance fluxes were measured at five stations within Marseilles, with three above the urban canopy of different parts of the city. A central site was also equipped with an array of infrared thermoradiometers with a thermal scanner monitoring street sections and individual building elements. These data are to be integrated with those from a small aircraft equipped with a scanning thermal infrared camera, NOAA/AVHRR satellite observations, and a network of 20 T-RH sensors 6 m above ground. The 4D structure of the UBL was documented with two mini-Sodars, one RASS sounder, one UHF radar, and two 3D-scanning O_3 and Doppler Lidars. The data are to be used to test urban energy budget models, improve remote sensing methods to determine the effective urban surface temperature to predict heat fluxes, and to test high resolution meteorological and chemistry-transport models.

A field program to measure surface fluxes at an industrial site at Birmingham, UK, has been set up to better forecast urban air quality and understand past pollution episodes (Ellis and Middleton, 2000). Three data sets (1998, 1999 and 2000) each of about four weeks collected data from ultrasonic anemometers and resistance thermometers on masts at 15, 30 and 45 m as well as radiation, humidity and pressure sensors.

3. Recommendations for future work

In the light of the world-wide increasing urban population as well as past and ongoing field experiments in urban areas recommendations are necessary to improve our knowledge of the urban atmosphere and urban exchange processes. Based on a European-wide survey on meteorological stations in urban areas, a survey on available meteorological and concentration data as well as models in European countries (COST-Action 715, 2000) and as a result of international workshops, these will comprise, among others:

Siting criteria for representative urban stations; use of meteorological masts extending 2 – 5 times the mean building height; harmonisation of measurement procedures;
Regular measurements of surface fluxes; studies of turbulent flux profiles;
Further development of models of fluxes for urban areas;
Improvement of the measurement of the urban surface energy balance by satellites;
Better use of available urban meteorological data and new meteorological measurement campaigns;
Optimum methods for measuring the urban mixing height; improve night-time mixing height determination;
European classification of air pollution episodes; meteorological criteria for the formation and

occurrence of air pollution episodes;
Practical measures for air quality protection; co-operation with local authorities.

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