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WIND TUNNEL INVESTIGATION OF THE SPATIAL VARIABILITY OF TURBULENCE CHARACTERISTICS IN THE URBAN AREA OF BASEL CITY, SWITZERLAND

B.Feddersen
Meteorological Institute, University of Hamburg
Bundesstraße 55, 20146 Hamburg, Germany
Email: feddersen@dkrz.de

B.Leitl
Meteorological Institute, University of Hamburg
Bundesstraße 55, 20146 Hamburg, Germany

M.W.Rotach
Institute for Atmospheric and Climate Science ETH
Winterthurerstr. 190, 8057 Zürich, Switzerland

M.Schatzmann
Meteorological Institute, University of Hamburg
Bundesstraße 55, 20146 Hamburg, Germany

ABSTRACT

Motivated by recent findings concerning the improvement of urban pollutant dispersion models by appropriate roughness sublayer (RSL) parameterisations the present wind tunnel study plans to investigate the turbulence structure within the surface layer over urban roughness. To this purpose a wind tunnel model representing Kleinbasel (part of Basel (CH), approx. 2.4km x 1.2km full scale, mean building height approx. 15.5m, mean plan area density approx. 49%, model scale 1:300) is constructed. The turbulence measurements in the wind tunnel (laser Doppler anemometry, LDA) will be conducted in summer 2003. First results will be presented in September 2003 concerning the approach flow characteristics (boundary layer flow) and the layered turbulence structure over the central urban area. Focus will be on the depth of the inertial sublayer (ISL), height and local variation of the RSL as well as horizontally averaged profiles of mean wind speeds and Reynolds stresses within the RSL.

The measurements will be compared to (a) parameterisations for vertical Reynolds stresses which have been suggested recently for the RSL and to (b) single location field measurements within the model area to assess the appropriateness of the wind tunnel model as well as the representativeness of the field measurements.

NOMENCLATURE

UBL – Urban boundary layer
ISL – Inertial sublayer
RSL – Roughness sublayer (including the UCL)
UCL – Urban canopy layer
z_h - height of roughness elements

INTRODUCTION

The existence of a roughness sublayer (RSL) within the surface layer over urban roughness is now well-established and documented by detailed field and wind tunnel measurements (e.g. Roth 2000, Rotach 1993a, 1993b, Cheng and Castro 2002). First attempts to include explicitly the RSL turbulence in numerical models for pollutant dispersion in urban environments have shown encouraging improvements in comparison to modelling approaches which include urban roughness solely by adjusting the roughness length z_0 (Rotach 1999, 2001). Within the RSL the vertical Reynolds stress u´w´ shows a characteristic increase with height. Parameterisations for this behaviour have been suggested (Kastner-Klein et al. 2001, Rotach 2001) which should be further augmented with detailed studies of the RSL. Up to now these studies are relatively rare, at least compared to extensive studies conducted, e.g., for rural environments and plant canopies.

The height of the RSL has been subject to discussion, estimations ranging e.g. from 2-5 z_h (Raupach et al. 1991), 2.5-3 z_h (Roth 200) and $\leq 3\,z_h$ (Rafailidis 1997). Since the height of the RSL determines (a) the range where RSL stress parameterisation is to be applied and (b) the interpretation of measurements from urban measurement towers, further investigations seem appropriate. From wind tunnel experiments it has even been speculated that the RSL over randomly varying roughness (as typical on house block scales in urban environments) might occupy most of the height range normally attributed to the ISL, therefore ‘squeezing’ the ISL resulting in a thin or not existing ISL (Cheng and Castro 2002, they define the ISL in terms of approximate constancy of spatially averaged shear stress).

Due to the important influence of pollutant dispersion on human health and comfort in urban areas further investigations of the UBL and, in particular, the RSL are under way within the BUBBLE project (Basel UrBan Boundary Layer Experiment within the European COST 715 action, *http://www.unibas.ch/geo/mcr/Projects/BUBBLE/*) which combines extensive field measurements in the greater area of Basel with numeric modelling and the present wind tunnel study (Rotach 2002). Besides modelling the urban turbulence structure, the aim of the wind tunnel study is to provide a model to study urban dispersion phenomena. The corresponding dispersion experiments are planned for 2004.

The wind tunnel turbulence study (planned for summer 2003) will be conducted under neutral conditions with the following (therefore referring to neutral stratification) to be investigated:

(i) What is the depth and height of the ISL over urban roughness? Two definitions of the ISL, as a (nearly) constant flux layer (Cheng and Castro 2002) as well as a logarithmic wind profile layer (Tennekes 1982), will be analysed.

(ii) What is the height of the RSL and how are its local variations correlated with the relevant (local) roughness elements?

(iii) How do representative horizontally averaged profiles of mean wind speed and Reynolds stresses appear in the RSL? What are appropriate scalings and parameterisations of these profiles?

(iv) What is the magnitude of the dispersive stress within the urban canopy layer (UCL)? Cheng and Castro (2002) found it to be negligible in the RSL above the UCL but there are indications (Böhm et al. 2000) that this might not be the case within the UCL.

Since the significance of the conclusions drawn from the wind tunnel model are crucially dependent on their applicability to full scale scenarios, the model measurements will be carefully compared to full scale measurements made in Kleinbasel within the BUBBLE project. To ensure appropriate boundary conditions the approach flow in the wind tunnel will be modelled according to the boundary layer flow characteristics found in Basel (e.g. mean wind profile, turbulence intensities, spectral densities). The comparison to full scale data is also intended to support the interpretation of these full scale measurements. This two-way-interaction is seen as the basic success factor of the above outlined wind tunnel study.

First results from the turbulence measurements will be presented at the conference.

EXPERIMENTAL SETUP

The wind tunnel experiments will be done in the Large Boundary Layer Wind Tunnel 'WOTAN' of the Meteorological Institute at the University of Hamburg, Germany. This wind tunnel is designed for neutral stratification studies, its test section is 18m long, 4m wide with an adjustable ceiling between 2.75m to 3.25m in height. For precise probe positioning and automated measurements the tunnel has a computer controlled traverse system featuring a position accuracy of about 0.1mm on all three axes for all types of probes used in the wind tunnel. The typical geometrical resolution of the velocity measurements is expected to be at least 0.6mm in the wind tunnel. For each measurement point time series of turbulent velocity components will be recorded using a high resolution 2D laser Doppler anemometer (LDA) using LDA burst analyser technique (BSA F70, DANTEC).

The model area covers a large area of Kleinbasel (part of Basel (CH), approx. 2.4km x 1.2km full scale) with an approach flow from DD=330° (see Figure 1). The model itself (model scale 1:300) is based on a digital model (CAD) of Kleinbasel provided by the authorities of Basel and augmented by an extensive photo documentation. It includes an extended fetch (approx. 1km) in the direction of the approach flow to facilitate a suitable adjustment of the approach flow to urban roughness. The core model area (diameter approx. 1km) centres around the on-site measurement tower at Basel-Sperrstrasse (BSPR) where extensive turbulent measurements (November 2001 to July 2002) were made at six height levels (3.6m, 11.3m, 14.7m, 17.9m, 22.4m, 31.7m a.g.l.), all presumed to be within the RSL. These measurements are available for comparison with wind tunnel results (additionally wind profile data from a measurement station (RASS profiles) close to the inflow edge of the model is available to characterize the approach flow). The model also covers a large part of the area where four on-site tracer release experiments were performed in June/July 2002. The mean building height in the area is given by approx. 15.5m, the mean plan area density by approx. 49%.

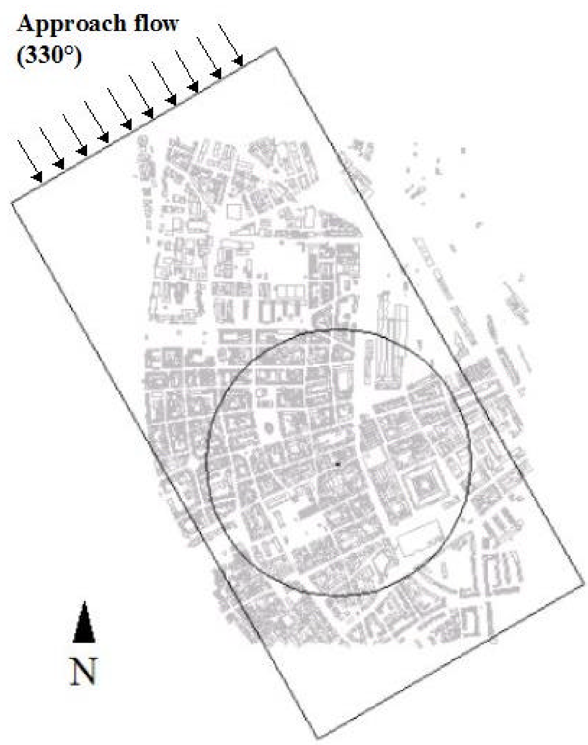

Figure 1: Model area in Kleinbasel. Rectangle indicates extended fetch, circle gives core model area with the measurement tower Basel-Sperrstrasse (BSPR) at the centre (model scale 1:300). The smoothly curved westerly border of the area is due to the river Rhein. (Ground plan provided by the authorities of Basel)

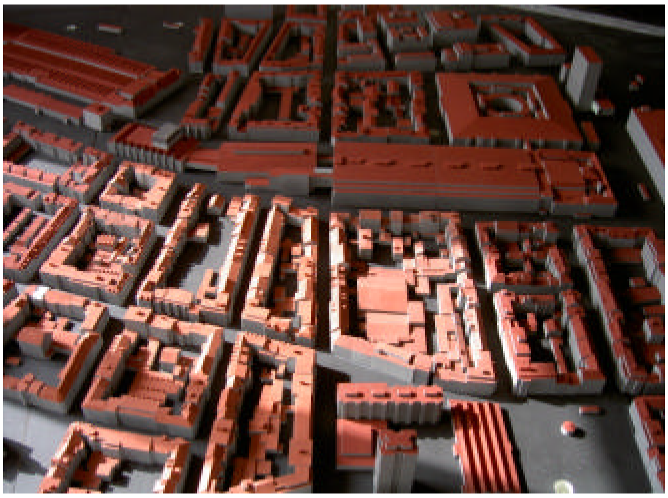

Figure 2: Snapshot of the wind tunnel model showing BSPR in the centre, looking in easterly direction.

The complete model compris es 3284 building structures each documented by shape and size. The buildings are made from Styrodur ® which has several advantageous properties: (i) stiff enough to form sharp edges at the corners important for eddy separation, (ii) easy to cut and work with, (iii) light enough to allow an extensive model area (see Figure 2). Additionally its surface shows an inherent roughness which helps to maintain the turbulence in the internal boundary layer.

EXPECTED RESULTS TO BE PRESENTED

Since the wind tunnel turbulence experiments are planned for summer 2003, the following comprises an overview of the first results expected to be obtained until September 2003:

(i) Documentation of the boundary layer characteristics of the approach flow.

(ii) Results for the layered turbulence structure above the core model area.

(iii) First comparison to field turbulence measurements at BSPR.

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