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TURBULENCE CHARACTERISTICS, SIMILARITY AND CO_2 (CO)SPECTRA OVER AN URBAN CANYON

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1. INTRODUCTION

Unlike in the homogeneous surface layer, the basis of traditional micrometeorological approaches such as the gradient method or Monin-Obukhov similarity (MOS) framework is in doubt at low heights over a city surface. Because of the absence of another suitable framework and several observational methods (*e.g.* scintillometry or remote sensing using sodar) use MOS, there is a need to investigate and evaluate the applicability of this framework for the measurement, analysis and presentation of turbulence in the urban environment, in particular in the roughness sub-layer.

The present paper is based on measurements undertaken in a densely urbanized part of Basel, Switzerland as part of the Basel Urban Boundary Layer Experiment (BUBBLE). The main site at Sperrstrasse provides the opportunity to study the exchange of heat, mass and momentum between the canyon volume and the above canyon flow in more detail than has been previously possible. The long-term array of turbulence sensors on the micrometeorological tower at 3 levels below and above roof level (z_H = 14.6 m), respectively is able to monitor the instantaneous fluctuations of all pertinent variables. For the duration of IOP (June 26 – July 12, 2002) two CO_2/H_2O flux sensors (Licor Model 7500) were added; one at the top of the mast (at 31.7 m) and another over the street near the top of the canyon (at 14.8 m). The main interest of the present contribution is on the vertical variation of the turbulence statistics presented within the Monin-Obukhov similarity (MOS) framework and the corresponding similarity functions. Also presented are *CO2* spectra and *CO2* flux co-spectra. The results from BUBBLE (denoted by B02 in the text and figures) are compared to observations taken at a micrometorological tower installed close to the current site in 1995 (B95; Feigenwinter *et al*., 1999), urban results reviewed in Roth (2000) and rural reference data from the homogeneous surface layer.

2. RESULTS

The results presented in the following are from 2 days (July 5 and July 8, 2002) during the IOP which were characterized by relatively clear skies. Data from 2 levels are included in this paper, z_s = 31.7 m and 14.8 m above ground, respectively. The former height at z_s/z_H = 2.2 should be above the roughness sub-layer. The runs analysed were selected on the basis of wind direction. Only those observations which had unobstructed approach flow, i.e. when the sensors were located upwind of the tower were selected. For the top (lower) level acceptable wind directions were from the east, north and west (east, south and west) quadrants. Flow during the present observations was generally from the north-west, which is perpendicular to the canyon. Variables were sampled at 20 Hz and averaged over 60 and 30 minutes at the 31.7 and 14.8 m levels, respectively. The longer averaging time at the top level guarantees that the large eddy sizes are adequately sampled by the eddy correlation sensors (e.g. Wyngaard, 1973). All fluxes are corrected for contributions due to a non-zero mean vertical velocity where appropriate (Webb *et al*., 1980). MOS theory relies on appropriate specification of the height of measurement above zero-plane displacement height z_d. Based on data from a digital city model the estimated mean building height in the 250 m region around the tower is 14.6 m. Based on a review of surface roughness parameters (Grimmond and Oke, 1999) z_d at the site is estimated as (z_H*0.7) or 10.2 m. Where appropriate the effective measurement height $z' = z_s - z_d$ is used and local scaling is applied, i.e. turbulence statistics are normalized by their local (i.e. measured at the same level) scaling parameters (e.g. Rotach, 1993).

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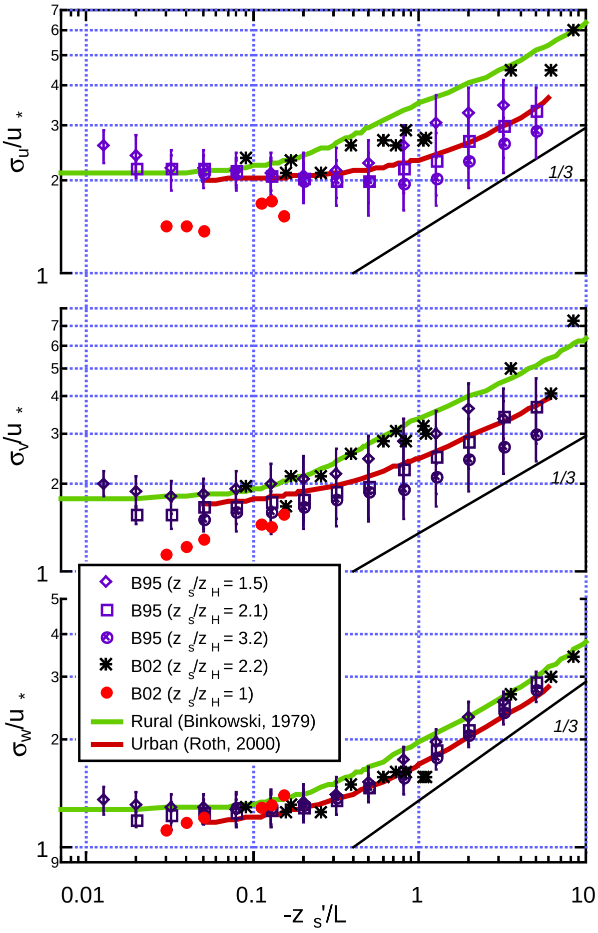
Figure 1 shows the normalized turbulence statistics of velocity. The *u* and *v* components at the upper level show slightly higher values compared to previous urban results but are significantly smaller at the lower level. Near the top of the canyon (z_s/z_H = 1) the turbulent transfer is strongly affected by the local roughness and probably not in equilibrium with the flow. A similar result is obtained for the normalized temperature statistics (Fig. 2).



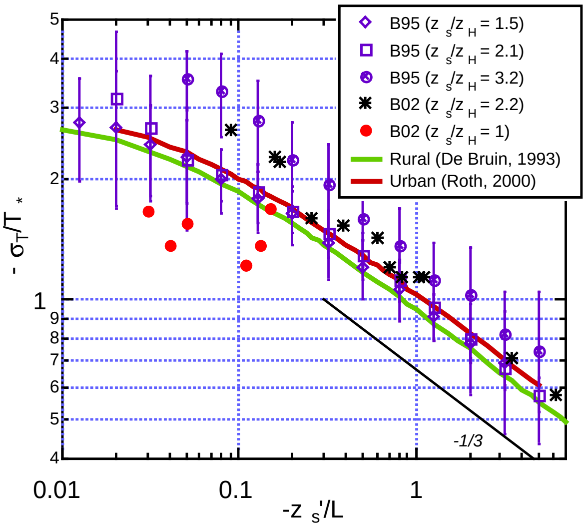


Figure 1: Normalized standard deviations of *u* (top), *v* (middle) and *w* (bottom plotted against z'_s/L. B95 – Feigenwinter *et al.* (1999); B02 – present study.

Figure 2: Same as Fig. 1 but for *T*.

Only very few urban observations of CO_2 fluxes are available. The results in Figs. 3 and 4 are among the first published (co)spectra. The overall shape of both the spectra and cospectra agree well with those from measurements in the homogeneous surface layer (e.g. over wheat: Ohtaki, 1985) in terms of the location of the peaks and the observance of the theoretically predicted –2/3 (spectra) and –4/3 (cospectra) slopes in the inertial subrange at the high frequency end. In particular Ohtaki's results which are from similar stability conditions also show a relatively broad peak region for CO_2 (similar to *T* spectra). Direct comparison with the only other published results of the CO_2 cospectra in Nemitz *et al.* (2002) is difficult because they apply a different normalization.

The good agreement between urban and rural data is surprising given the differences in the processes which govern the surface-atmosphere exchange of CO_2 between the two environments. Unlike for a vegetated surface where the exchange is dominated by photosynthetic activity, emissions from fixed (industrial, commercial or residential) and mobile (traffic) sources are of primary importance in a city center. It is possible that for large enough measurement heights (i.e. above the roughness sub-layer) the influence of individual CO2 sources and sinks is sensed as an integrated, spatially averaged flux. It is interesting to note that that (co)spectra from more unstable conditions did not show the same well-behaved shape. In many cases there was no or little drop-off at low frequencies and the slope at the high frequency end was less than –2/3. This is possibly because they are more strongly influenced by discrete sources or sinks closer to the measurement point because of the smaller footprint under more unstable stratification.

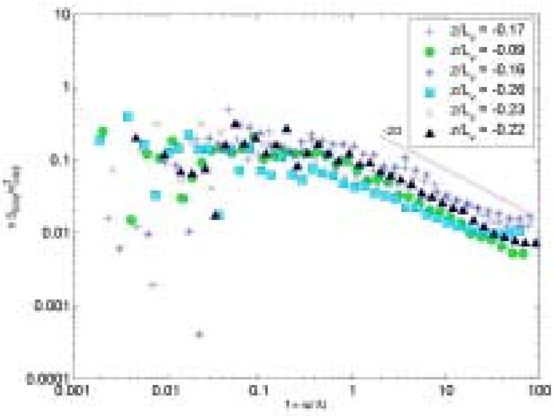


Figure 3: **Normalized spectra of CO_2 for near neutral conditions ($-0.26 < z'/L_v < -0.09$; 6 runs) measured at top level ($z_s/z_H = 2.2$).**

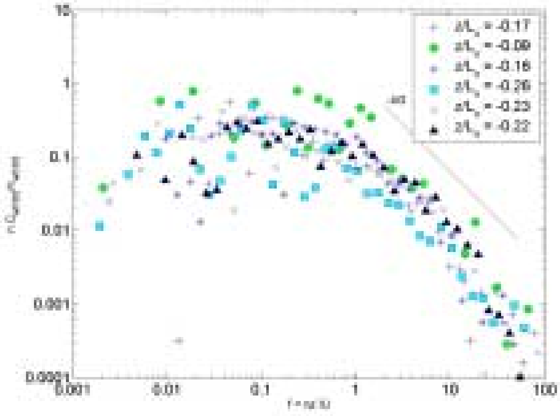


Figure 4: **Same as Fig. 4 but for cospectra of CO_2 flux.**

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