15.12 Turbulent Properties of Momentum Transfer Within The Urban Roughness Sublayer

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1 INTRODUCTION

Air flow in the urban roughness sublayer is much more complex than its counterpart in the atmospheric surface layer. This is due to the much larger size of the roughness elements and the unevenly distributed heat sources. Thus, the use of surface layer similarity theory (slst) for the parameterization of the mean flow is limited. Recent evidences from wind tunnel experiments indicate that the basic assumption of slst, e.g. the constancy of momentum fluxes,in the vicinity of the roughness elements, is not fulfilled, Kastner-Klein (2001), Ashie (2000). In both experiments a sharp maximum of the momentum flux was observed above the roughness elements. Kastner-Klein (2001) suggested that in spite of the inconstancy of the momentum flux, a logarithmic velocity law may be reproduced with u_* obtained from a single reference point. The aim of this work is to investigate the momentum flux and the wind profile above the roof level in a real urban site.

2 EXPERIMENTAL SETUP

The experimental setup is shown schematically in Fig. 1. The data, discussed in this paper, were collected above the roofs from poles T1, T2,T3,T4, and from two tethered balloons. Measurements on poles T1,T2 & T3 were taken from two heights, 2m & 6m above the roof, i.e. z/h=1.2, 1.6. On T4 measurements were taken only from 6m. The balloons height was 20 m above the roof level, i.e., at z/h=3.

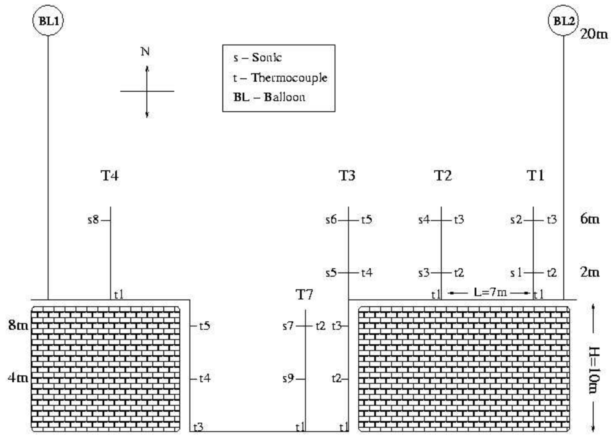

Figure 1: Experiment setup

3 RESULTS

The measurements were taken during four days in summer 2001. The numbering of the measuring stations, to which we refer in the following, corresponds to the numbering in Fig. 1. In Fig. 2 we present hourly averages of three days: 31/7 - 2/8/2001.

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3.1 wind field

During the day the wind regime was controlled by the sea breeze which came mainly from west, i.e. perpendicular to the street between the two buildings. At night the wind changed direction and came mainly from the south-east. Above the street, the wind direction is almost uniform, including the station outside the city, designated by 'Y20' in Fig. 1. The difference between the direction inside the street and above it may be as much as 90^0. Wind speed, on the other hand, may be divided into four groups, corresponding to the height of the measurements.

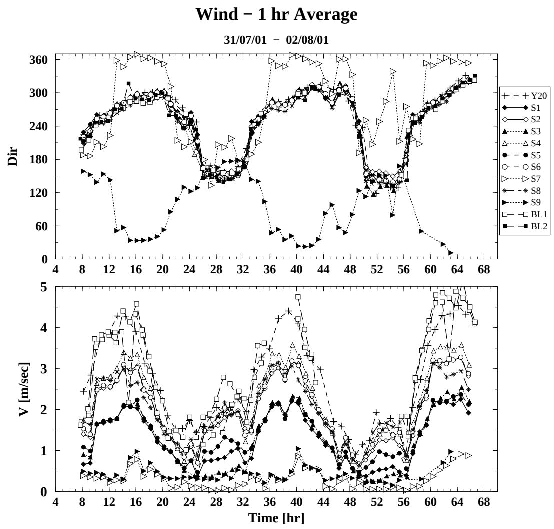

Figure 2: speed & direction

3.2 momentum fluxes

Fig. 3 presents hourly averages of the momentum fluxes parallel and perpendicular to the mean wind. During the day, the flux component, parallel to the mean flow, exhibits clear dependence on height. In fact, the fluxes at z/h=1.6 are 2-4 times larger than those at z/h=1.2. The horizontal pattern of the flux is more complex. At night, when the wind speed diminishes, all fluxes collapse to almost the same value, thus preserving similarity properties. The flux component perpendicular to the flow exhibits a more complex behavior. All upper stations, except station 6, which is located above the street, exhibit positive fluxes during the morning. In the afternoon the fluxes change to negative values. At night most of the stations show zero fluxes. One should note that in an open area the flux component perpendicular to the main flow vanishes.

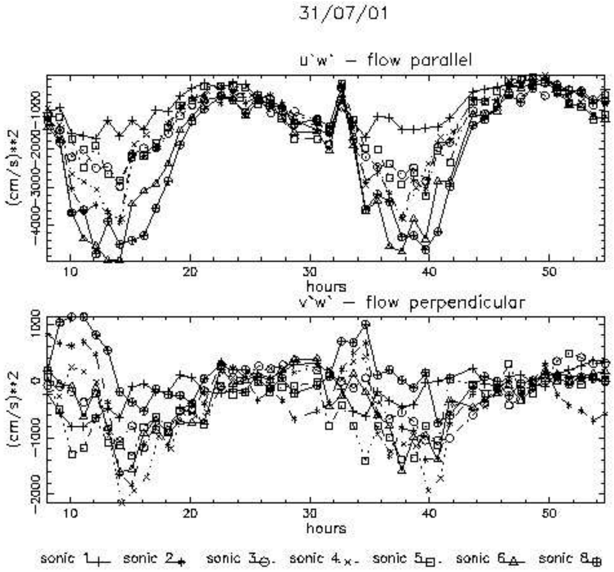

Figure 3: momentum fluxes

3.3 kinetic energy

Fig. 4 shows the horizontally averaged turbulent kinetic energy. Averaging is performed at two levels, 2m and 6m above roof level. These levels are 1.2h and 1.6h above street level (h is the roof height).The energy at 6m is always higher than at 2m except for the early morning hours. The largest differences between the two levels, approx. 40%, occur later in the morning when a sharp jump in the wind speed is observed and the difference between the two levels increases, see Fig 2. Fig. 5

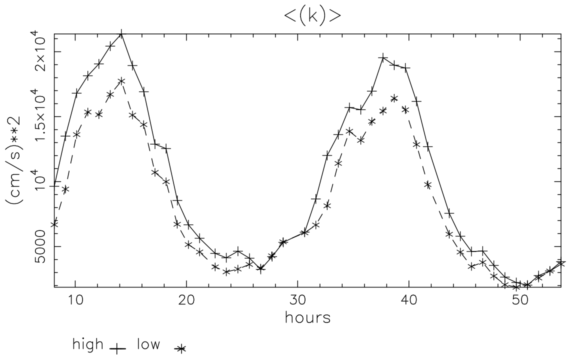

Figure 4: horizontally averaged kinetic energy

shows $\sigma u/u_*$ $and \sigma v/u_*$ in the different stations above the roof. There is little variability with height, except for station, 1 at 2m, which exhibits higher values. At night, the differences between the stations are even smaller and $\sigma u/u_*$ decreases. This decrease is accompanied by a 'relative' increase in u_* at the same time, see Fig. 6 in the following. $\sigma v/u_*$, on the other hand, hardly changes. Values shown here are close to the values shown in Roth (2000).

4 ANALYSIS

4.1 wind profile

In spite of the fluxes being height dependent, it is worthwhile determining whether the wind velocity obeys a logarithmic law, as in the wind tunnel experiment, Kastner-Klein (2001). To this end we define a height dependent 'effective' friction velocity:

$$u_*^{eff} = \kappa \tilde{u}(z) / \log\left(\frac{z - z_d}{z_0}\right)$$

where the following values were used: $z_d = 0.7h = 7m$, $z_0 = 0.1h = 1m$. $\tilde{u}(z)$ is the height

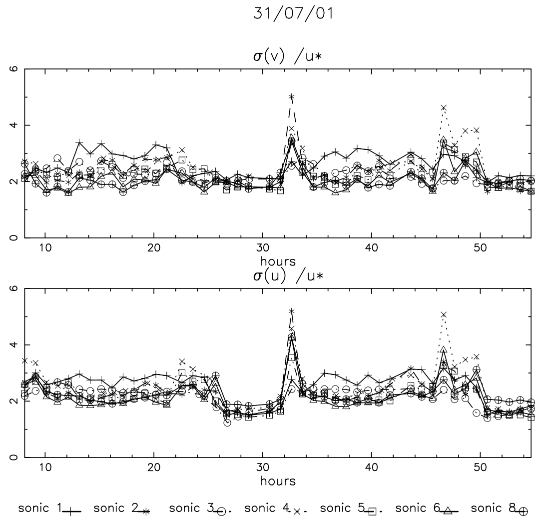

Figure 5: $\sigma u/u_*$ and $\sigma v/u_*$

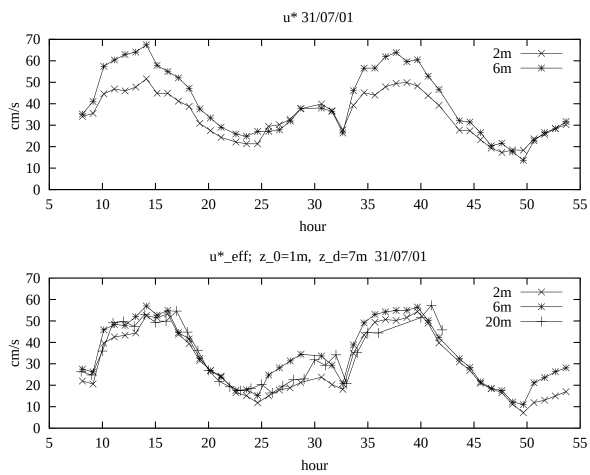

Figure 6: friction and 'effective' friction velocities

average of the measured velocity. As mentioned above, measurements were conducted at z=2m, 6m and 20m above roof level. Fig. 6 shows the effective friction velocity and the measured horizontal average of u_*. During daytime u_* at z/h=1.6 is about 30% larger than at z/h=1.2. The deviations of u_*^{eff} , on the other hand, amount to about 10 % - 15% during the first day. The larger deviations observed at 20m in the second day may be attributed to the lack of data. At night the tendency is reversed. We may, therefore, speculate that a logarithmic profile serves as a fairly good approximation during day time, at least up to z/h=3. We should mention that no stability corrections were taken into account. This point is discussed in the next section.

4.2 kinetic energy balance

The turbulent kinetic energy equation, in steady state, after division by $\kappa(z-d)/u_*^3$ assumes the form:

$$\Phi_m - \frac{z-d}{L} - \frac{z-d}{\Lambda} - \Phi_\epsilon + \tilde{I} = 0$$

Here Φ_m and Φ_ϵ are the stability functions for momentum and energy dissipation, see Kaimal & Finnigan (1994), $\tilde{I}$ is the pressure term and L is the M.O. length, κ is the Von Karman constant, d is the zero plane displacement. Λ is a height scale, emerging from the kinetic energy transport term:

$$\Lambda = \frac{u_*^3}{\kappa \frac{\partial \overline{w'k'}}{\partial z}}$$

In open area, in unstable conditions $\Lambda = -L$ so that the buoyant production and the energy transport terms balance each other.

In the urban roughness sublayer, both L and Λ are height dependent, and, as we now show, the above balance does not exist close to the roof level. Fig. 7 shows the horizontally averaged kinetic energy fluxes at 2m and 6m. At daytime the fluxes at 6m are directed up wards whereas those at 2m are directed down wards. At night, fluxes at both levels almost vanish. Typical daytime values of Λ and L, derived from these fluxes and from the heat fluxes (not shown) are:

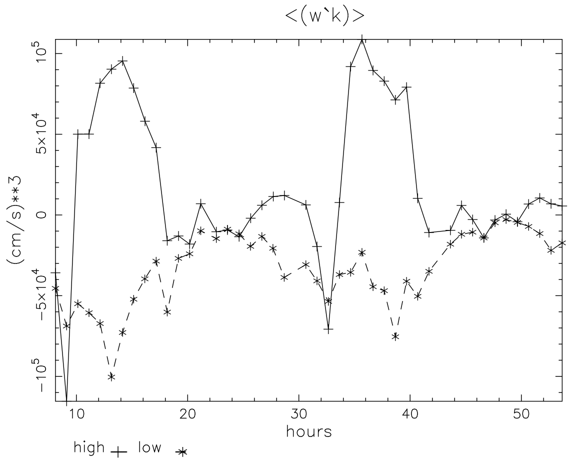

Figure 7: horizontally averaged kinetic energy fluxes

$\Lambda = 16m$ and $L = 72m$. This values suggest that close to the roof level buoyancy has a lesser effect than in comparable heights above an open area. We note that, Raupach (1991) found a similar value for Λ above a plant canopy (if the same normalization is used).

5 REFERENCES

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