TURBULENCE CLOSE TO A ROUGH URBAN SURFACE
PART II: VARIANCES AND GRADIENTS

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Abstract. Measurements of the turbulent wind and temperature fluctuations were carried out in the vicinity of the roof level, over an urban surface at a site where mean gradients of wind speed and temperature were also available. The measurement heights were about 23 and 28 m above ground, the local roof level being 18 m. Measurements were taken on top of a building (at \( z = 23 \) and \( 28 \) m) and over a street canyon (at \( z = 23 \) m), i.e., fully within the urban roughness sublayer.

The scaled variances of temperature and wind velocity, as well as the non-dimensional gradients of wind speed and temperature, are presented and discussed in terms of departures from Monin–Obukhov similarity theory. Local scaling is found to be a useful concept for the description of turbulence within a roughness sublayer. Expressions for the scaled velocity variances are presented that are valid for all measurement positions; they compare well with results from other urban studies. The non-dimensional gradient of mean wind speed is found to be well represented by the semi-empirical functions for the inertial sublayer if locally scaled. At 5 m above roof level, however, the variability due to horizontal inhomogeneity becomes very large. The non-dimensional temperature gradient, on the other hand, is height dependent and not well defined over the present rough urban surface.

1. Introduction

The present paper describes the results concerning some general turbulence characteristics from an experimental study conducted in the city of Zürich, Switzerland. In a companion paper (Rotach, 1993a; henceforth referred to as I), the behaviour of Reynolds stress at the same site is described. The Reynolds stress is found to vary with height at the present site. Scaling considerations, taking this into account, will be discussed in some detail here.

The lowest part of the urban boundary layer, the surface layer, will be considered in two parts: the roughness sublayer (RS), where the flow is three-dimensional due to the influence of individual roughness elements, and the inertial sublayer (IS), where surface layer scaling (i.e., Monin–Obukhov similarity theory, MOST) may be expected to hold (see Figure 1 in I). The existence of a roughness sublayer is not specific to urban surfaces but, unlike the case of smoother terrain, it can have a substantial vertical extension of several tens of meters. Because sources of pollutants are often situated within or close to the RS in urban environments, knowledge of the structure of turbulence in the roughness sublayer is essential for improving urban dispersion models. Due to the lack of better knowledge, the semi-empirical relationships according to MOST are used in many urban diffusion (and/or flow) models even within the roughness sublayer (e.g., Beniston, 1987; Eichhorn et al., 1988; Gross, 1989). One approach to studying RS turbulence.
is thus to look at the departures from inertial sublayer predictions (knowing that the latter cannot be expected to hold in principle). It has been followed in much of the work on flow modification of rough vegetated surfaces, and will be adopted here.

If the turbulent fluxes are not constant with height, as observed at the present site and discussed in detail in I, we are left with the problem of how to scale flow variables in the RS. Two approaches have been followed: the first is to use the state of the inertial sublayer as a reference and thus to introduce the IS turbulent fluxes together with one (or more) length scale as scaling variables. This can be convenient if these length scales are available (from measurements or model predictions) and has often been used in wind tunnel experiments (e.g., Perry et al., 1969; Raupach et al., 1980; Raupach, 1981). On the other hand, Högström et al. (1982) have suggested that local scaling may be appropriate for the urban RS. Some support for this concept will be presented concerning various non-dimensional variables. In addition, possible modifications with respect to IS formulations are discussed in the case of the vertical velocity variance.