TURBULENCE PARAMETERIZATION FOR DISPERSION IN URBAN AREAS

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INTRODUCTION

The urban boundary layer is one of the challenging areas of parameterization in meteorology, because of its spatial and time variability. Typical scale for the urban area is of the order of 20 km, but the urban area is not homogeneous on this scale. The different types of built-up areas are referred to as neighborhoods. It can be noted that the typical neighborhood scale for an urban area is rather similar to the typical landscape patches of agriculture and forest in Western and Northern Europe. When the urban area is characterized by narrow irregular streets and houses of varying height the momentum transport is controlled by the street configuration and the dissipative stress is expected to be important. When a rectangular street system of broader streets and high buildings is considered, momentum transport is dominated by the drag forces of the high buildings. An area with high buildings and vast space among them is a separate case. In different cities different combinations of these area types are present thus leading to use of combinations of different meteorological parameterizations. Recently micrometeorology studies addressing the meteorological processes (related with dispersion) in all these different types of urban areas are performed.

TURBULENCE CHARACTERISTICS

A general discussion of the flow and turbulence regimes of the urban atmosphere in the framework of neighborhoods is presented in Batchvarova and Gryning (2005a). On the level of street canyons each part of the city at each moment is characterized by different flow characteristics. This flow regime is called the roughness sublayer (Roth, 2000). It is highly inhomogeneous both in its vertical and horizontal structure. Turbulent fluxes and variances can be expected to be strong functions of height. The height of the roughness sublayer is of considerable practical importance. Above the roughness sublayer the the structure of the flow over a neighborhood becomes more uniform and is considered to be in equilibrium with the underlying surface area. This regime is known as the inertial sublayer, and the Monin-Obukhov similarity theory applies. This means that turbulent fluxes are near constant with height. During the last few years there has been an ongoing discussion on the height of the roughness sublayer. Consensus (Batchvarova and Gryning, 2005b; Feddersen, 2005) is slowly being reached that its height is about 3-5 times the average building height.

Understanding the behaviour of the crosswind and vertical fluctuations of the wind velocity, σ_v and σ_w is important because they are controlling parameters for the dispersion of plumes in the atmosphere. Here we compare commonly used parameterizations of σ_w and σ_v (Gryning et al., 1987) to observations from 3 urban experiments. In the report of the COST Action 710 (Cenedese et al., 1998), these parameterizations were validated on a large number of data sets and found to perform well. They are based on the Monin-Obukhoc similarity theory and developed for flat homogeneous terrain. Therefore they are expected to be valid in the inertial sublayer, but not in the roughness sublayer. These formulations read:

$$\sigma_w^2 = u_*^2\left[1.5\left(\frac{z}{z_i}\right)^{2/3}\left(\frac{w_*}{u_*}\right)^2\exp\left(-2\left(\frac{z}{z_i}\right)\right)+\left(1.7-\left(\frac{z}{z_i}\right)\right)\right] \qquad (1)$$

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where the convective velocity scale is $w_* = \left((g/T)\overline{w'T'}\, z_i\right)^{1/3}$, with g for the acceleration due to gravity, T for temperature and z_i for mixed layer height, and

$$\sigma_v^2 = 0.35\, w_*^2 + (2 - z/z_i)\, u_*^2 \;. \qquad (2)$$

The BUBBLE experiment

From the BUBBLE experiment (Rotach et al., 2004 and Gryning et al., 2005) we use the observations from Sperrstrasse meteorological mast. The local building height is 14.6 m. An aerosol Lidar located within Basel 5 km from the experimental area gave information on the height of the mixed layer, z_i .

Comparisons were performed between parameterizations and the measurements of σ_w and σ_v at 17.9 and 31.7 m height. At both heights the parameterization gave higher values than actually measured in such a way that the agreement between parameterised and measured values improved with height for σ_v and remained about the same for σ_w .

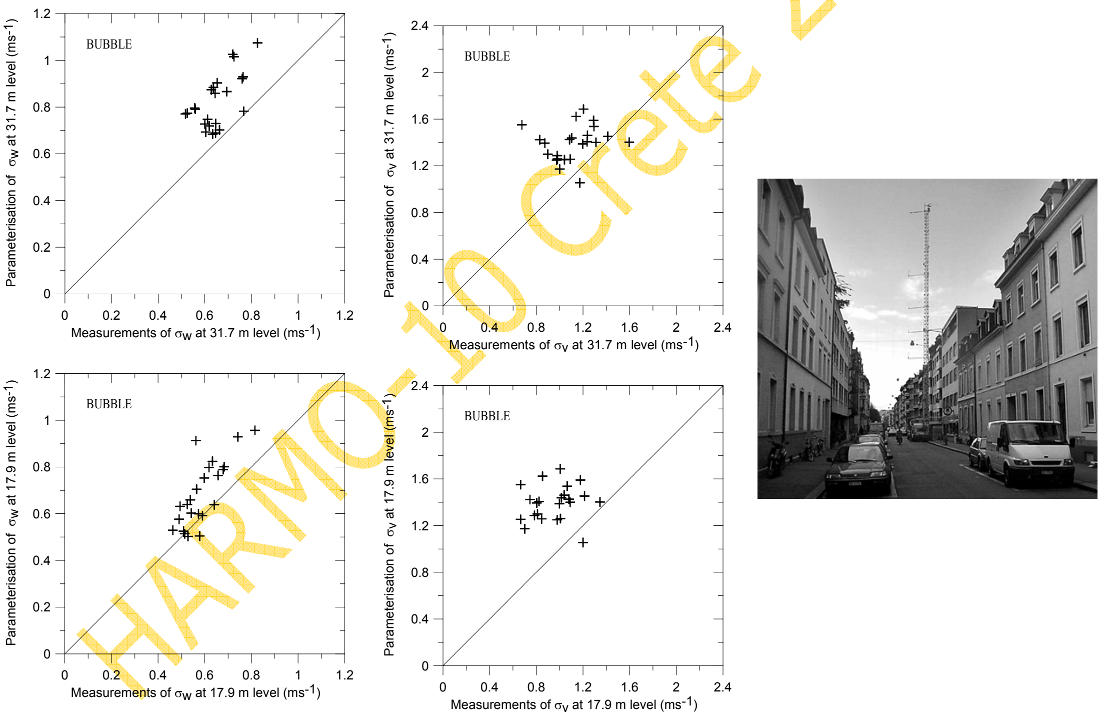

Figure 1: *Observed half-hourly averaged values versus parameterizations of σ_w (left panels) and σ_v (central panels) at a height of 31.7 m (upper panels) and 17.9 m (lower panels) at the Sperrstrasse tower (right panel), Basel. (BUBBLE experiment, June-July 2002).*

At the level of 17.9 m the parameterised values σ_v and σ_w were 40% and 18% larger than the measured ones. At 31.7 m the difference was reduced to 20% for σ_v and was 25% for σ_w, see **Figure 1**.

The strong vertical variability of σ_v in combination with the quite different behaviour of σ_w indicates that this layer is not part of the inertial sublayer, where σ_v should be bear constant

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and σ_w slightly increasing as function of height. It rather suggests that the layer belongs to the roughness sublayer, where the flow has a considerable spatial and vertical variability. The good performance of the parameterizations for σ_w and σ_v when compared to the measurements at the highest level of observation (31.7 m) is a result, indicating that the upper level is close to the transition to the inertial sublayer. This is in agreement with Feddersen (2005) based on laboratory simulation of the BUBBLE experiment.

Sofia 2003 experiment

The parameterizations were further tested on data from the Sofia 2003 experiment (Batchvarova et al., 2004) at 20 and 40 m above ground on the meteorological tower of the National Institute of Meteorology and Hydrology. The site is typical for an Eastern European suburban area. The parameterization of both the vertical and lateral variances, σ_w and σ_v is compared to measurements at a height of 40 m in **Figure 2**. The agreement suggests that at 40 m the transition between the roughness sublayer and the inertial sublayer has occurred. The mixed layer height was provided by high resolution (2 hours in time and about 10 m in height) radiosoundings performed at the same site.

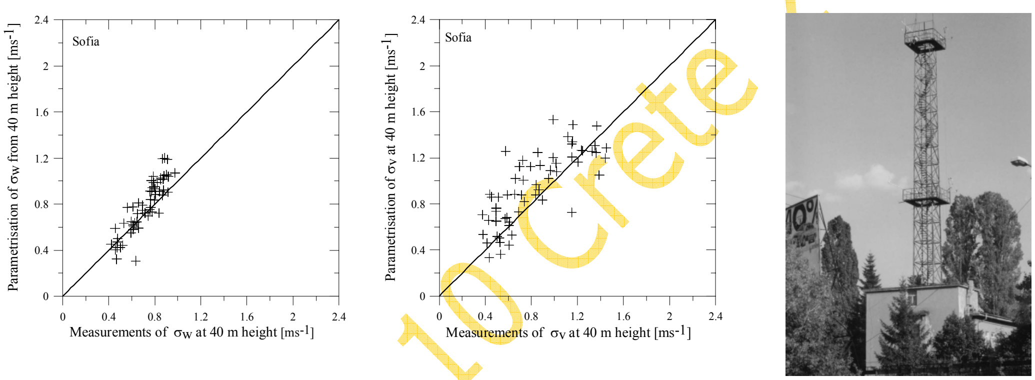

Figure 2: *Observed half-hourly averaged values versus parameterizations of σ_w (left panel) and σ_v (central panel) at 40 m at Sofia tower (right panel), NIMH (Sofia experiment, Sept. – Oct. 2003).*

The direct comparison between 20 m and 40 m measured variances (only convective conditions for the 5 days with high resolution radiosoundings) shows that the depth of the roughness sublayer is more that 20 m at this neighborhood, **Figure 3**.

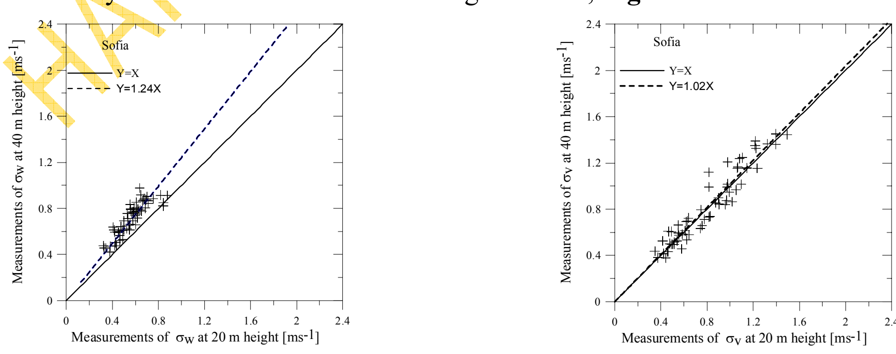

Figure 3: *Observed half-hourly averaged values at the 20 m and 40 m levels of σ_w (left panel) and σ_v (right panel) at Sofia tower, NIMH for days with mixed-layer measurements only.*

Copenhagen experiment

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The Copenhagen experiment (Gryning and Lyck, 1984) was performed mainly under near neutral to unstable meteorological conditions in a residential/urban area. Measurements of turbulence variances, σ_w and σ_v, were carried out at a height of 115 m, and the atmospheric stability was determined from temperature and wind profile measurements along the mast. Parameterised and measured values for σ_w and σ_v at 115 m are compared in **Figure 4**. The mixing height was determined from the standard routine radiosoundings that were launched 4 km northeast of the mast.

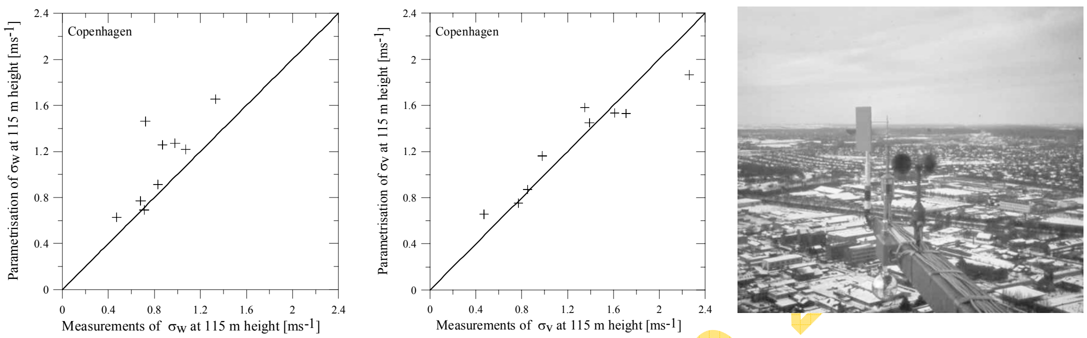

Figure 4: *Observed half-hourly averaged values versus parameterizations of σ_w (central panel) and σ_v (right panel) at 115 m at the Gladsaxe tower (right panel), Copenhagen.*

Results and discussion

The ability to predict the variances, σ_w and σ_v has been investigated for three urban experiments.

Observations from the BUBBLE experiment show a marked increase especially in σ_v between the 17.9 m and 31.7 m levels. It is also noted that the performance of the parameterization of σ_v increases with height, being a 25% overestimate for σ_w and 20% for σ_v at 31.7 m. It can be noted that even the 31.7 meter level might still not be within the inertial sub-layer.

Observations from Sofia (20 and 40 m levels) indicate a somewhat different structure. As for BUBBLE, an increase in σ_w and σ_v is observed between the lower level (20 metres) and upper level (40 metres). For σ_w the change is similar to the observed for BUBBLE, but for σ_v it is smaller. Furthermore, the parameterizations of σ_w and σ_v performs rather well at the upper level. The neighborhood in Sofia is characterized by vast open spaces and blocks of apartments of different size, quite different from central Basel.

Copenhagen measurements are available only at one height (115 m). There are rather few observations and the parameterizations are found to perform fairly well, especially for σ_v. But the limited number of measurements precludes any conclusions.

The result of the analysis suggests that the use of parameterizations for σ_w and σ_v is feasible within the urban inertial sublayer. This is of considerable interest for dispersion modelling in the urban boundary layer, because σ_w and σ_v are controlling parameters for spreading of plumes in vertical and lateral directions, respectively. Gryning and Batchvarova (2005) applied simple models for the lateral and vertical atmospheric dispersion for the BUBBLE

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and Copenhagen experiments and found an agreement of about a factor of two between model results and measurements. Similarly, the maximum observed half-hourly tracer concentration during the BUBBLE tracer experiment on 26 June compared with the maximum of the ground level concentration at the centreline from the Gaussian plume formula within a factor of 2.

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References

Batchvarova, E., Gryning, S.-E., 2005a, Progress in Urban Dispersion Studies. Theoretical and Applied Climatology. *In print.*

Batchvarova, E., Gryning, S.-E., 2005b, Advances in urban meteorology modeling. In Farago et al (eds), Advances in air pollution modelling for environmental security, Springer, 23-32.

Batchvarova E., Gryning, S.-E., Rotach, M. W., Christen, A., 2004, Modelled aggregated heat fluxes compared to turbulence measurements at different heights. Proc. 9th Int. Conference on Harmonisation within atmospheric dispersion modeling for regulatory purposes, 1-4 June 2004, Garmisch Partenkirchen, Germany, vol 2, 7-12.

Cenedese, A., Cosemans, G., Erbrink, H., Stubi, R., 1998, Vertical profiles of wind, temperature and turbulence. In: Harmonisation of the pre-processing of meteorological data for atmospheric dispersion models. COST action 710 Final report, EUR 18195 EN, 431 p.

Feddersen B. 2005, Wind tunnel modelling of turbulence and dispersion above tall and highly dense urban roughness. Dissertation ETH No 15934. 238 pp.

Gryning, S.-E. and Batchvarova, E., 2005, Advances in urban dispersion modeling. In Farago et al (eds), Advances in air pollution modelling for environmental security, Springer, 243-252.

Gryning, S.-E.; Lyck, E., 1984, Atmospheric Dispersion from Elevated Sources in an Urban Area: Comparison between Tracer Experiments and Model Calculations. J. Climate Appl. Meteorol. *23, 651-660.*

Gryning, S.-E., Holtslag, A. A. M., Irwin, J.S., Sivertsen, B., 1987, Applied Dispersion Modelling Based on Meteorological Scaling Parameters. Atmos. Environ*., 21, 79-89.*

Gryning S, Batchvarova E, Rotach M, Christen A and Vogt R, 2005: Roof-level SF_6 tracer experiments in the city of Basel, Zürcher Klima-Schriften*, **83**, 83p.*

Rotach, M. W., Gryning S.-E., Batchvarova, E., Christen, A., Vogt, R., 2004, Pollutant dispersion close to an urban surface - BUBBLE Tracer experiment, Meteorol. Atmos. Phys*., 87, 39–56*

Roth, M., 2000, Review of atmospheric turbulence over cities. Quart. J. R. Meteorol. Soc*., 26, 941-990.*

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