P2.3 RE-EVALUATION OF INTEGRAL TURBULENCE CHARACTERISTICS AND THEIR PARAMETERISATIONS

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1. INTRODUCTION

Integral turbulence characteristics are statistical measures describing atmospheric turbulence in the surface layer. They are defined as the normalised standard deviations of fluctuating turbulent parameters (Tillmann, 1972). Integral turbulence characteristics have been widely used in a variety of applications, such as an instrument for quality assessment of turbulence data (Wichura and Foken, 1995), in accumulation methods assuming flux-variance similarity (e.g. Businger and Oncley, 1990), for the direct determination of turbulent fluxes (Foken, 1990; Wyngaard et al., 1971), in air pollution models (e.g. Blackadar, 1997), or in applications representing the influence of surface properties on turbulent fluxes as e.g. footprint models (Schmid, 1997).

A general form of integral turbulence characteristics represents Eq.1, where x is the fluctuating parameter, X_* its corresponding normalising factor derived from its characteristical turbulent flux, ϕ_x a function scaling with different parameters such as the aerodynamical height (z – d), the mixing layer height z_i, the Coriolis parameter f, the friction velocity u_* and the Obukhov-length L.

$$\frac{\sigma_x}{X_*} = \phi_x\left(\frac{z-d}{L}, \frac{z_i}{L}, \frac{(z-d)\cdot f}{u_*}, \ldots\right) \qquad (1)$$

Integral turbulence characteristics were observed to scale with local and non-local parameters. The locally influencing parameters include atmospheric stability and surface properties. Atmospheric stability, commonly expressed in terms of the dimensionless height (z-d)/L following from the Monin-Obukhov similarity theory (Monin and Obukhov, 1954), was used by many authors to formulate parameterisations for integral turbulence characteristics of wind components, the temperature and humidity (e.g. Foken et al., 1991; Panofsky et al., 1977; Tillmann, 1972; Wyngaard et al., 1971). Surface properties such as distribution of aerodynamical obstacles, roughness length, water saturation and canopy height were found to have a considerable effect on turbulent fluxes, and therefore on the general applicability of the concept of integral turbulence characteristics (DeBruin et al., 1991). The non-local influencing parameters, including geographical latitude and mixing layer height, were regarded as having no significant influence on integral turbulence characteristics by most authors. However, parameterisations scaling with $f\cdot(z\text{-}d)/u_*$, using the geographical latitude represented by the Coriolis parameter and derived from the underlying concept of the Rossby-number similarity, were found to be appropriate scaling factors for near neutral data in the surface layer (Högström, 1990; Smedman, 1991; Tennekes, 1982; Yaglom, 1979). The mixing layer height, represented by the term z_i/L, was observed to be a scaling parameter of the integral turbulence characteristic of wind velocities under unstable conditions (Johansson et al., 1999; Panofsky et al., 1977; Peltier et al., 1996).

The present study aims to re-evaluate previously published parameterisations of integral turbulence characteristics to find statistically robust parameterisations for a wide range of local and non-local influencing scaling parameters.

2. DATA

Data from five individual experiments have been used for this re-evaluation study, namely the EBEX 2000 experiment in California/ USA (Oncley et al., 2000), the 4th International Turbulence Comparison Expedition (ITCE) in Tsimlyansk/ former USSR (Tsvang et al., 1985), the FINTUREX experiment at the Neumayer-Station in Antarctica (Foken, 2002; Foken and Baum, 1994), and the LINEX 96/2 and LINEX 97/1 experiments carried out at the Meteorological Observatory Lindenberg/ Germany (Foken, 1998; Foken et al., 1997).

The EBEX 2000 site was located at 36°N in an irrigated cotton plantation with about 1 m canopy height and can be classified as non-homogeneous terrain of type A (concept after DeBruin et al., 1991), but with homogeneous thermal conditions. Data were obtained using a tower at 4.7 m height above ground supplemented by continuous SODAR measurements. The data from the 4th ITCE experiment (47°N) were obtained over fairly homogeneous spatial distributed short grass steppe of about 0.4 m height on a tower at different measuring heights ranging from 4.5 to 2.2 m above ground. This site can be classified as type B with undistorted wind shear conditions. The FINTUREX site (70°S) represents a snow covered surface without vegetation and can be classified as type B with undistorted wind shear conditions. The dataset was obtained on a tower, measuring simultaneously at three different heights (2, 4 and 12 m above ground), supplemented by daily radiosonde data. The LINEX datasets were recorded at 52°N over long and short grass with a canopy height of 0.7 and 0.3 m, the terrain can be classified as type A. The tower measurements were operated at 2 m above ground; additionally, radiosondes were released daily.

Mixing layer heights were determined using the radiosonde or SODAR data.

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3. RESULTS

The nondimensional standard deviations of the vertical and horizontal wind velocities and temperature were directly measured, the corresponding parameterisations were determined according to various authors.

Fig.1 shows the nondimensional vertical velocity standard deviation of all experiments as a function of (z-d)/L. Most of the data lie in the stability interval $-0.3 \leq (z-d)/L \leq 0.3$, where the scatter of σ_w/u_* is large and no uniform behaviour can be derived. The parameterisations scaling with (z-d)/L yield correlation coefficients R of 0.26 maximum.

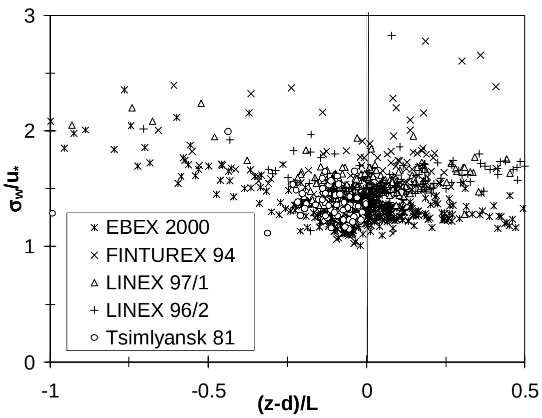

Fig.1: Measured σ_w/u_* data of all experiments as a function of (z-d)/L.

In Fig.2 the near neutral ($-0.2 \leq (z-d)/L \leq 0.1$) nondimensional vertical velocity standard deviation is plotted against $\ln[f \cdot (z-d)/u_*]$ as suggested by Högström (1990). Now the data follow a more uniform linear trend. However, his parameterisation $\sigma_w/u_* = 0.12\ln[f \cdot (z-d)/u_*]+2$ was found to systematically underestimate the observed data of this study, but match the overall shape of the data (R = 0.42).

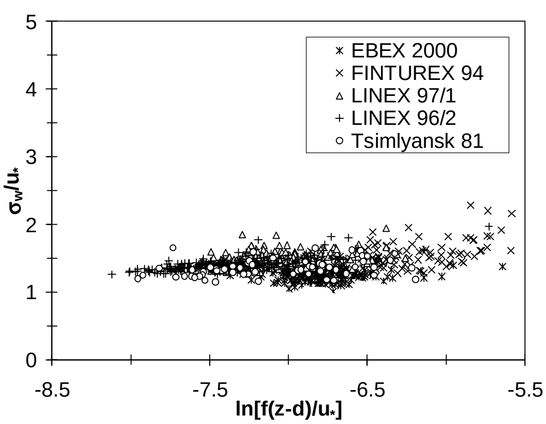

Fig.2: Measured near neutral σ_w/u_* data of all experiments as a function of $\ln[f \cdot (z-d)/u_*]$.

Based on these results, a detailed discussion of $\ln[f \cdot (z-d)/u_*]$ was performed for the near neutral range, decomposing it and analysing the contribution of each term. The best correlation (R = 0.69) to all 946 individual data points was derived using the expression given in Eq. 2, using the newly derived scaling factor $\ln[z_+ \cdot f/u_*]$.

$$\frac{\sigma_w}{u_*} = 0.21\ln\left[\frac{z_+ \cdot f}{u_*}\right] + 3.1 \qquad (2)$$

The validity interval could be extended to $-0.2 \leq (z-d)/L \leq 0.4$. As the ratio f/u_* has the dimension m^{-1}, a new constant z_+ was introduced for mathematical convention, setting $z_+ = 1$ m. The resulting expression $z_+ \cdot f/u_*$ thus is dimensionless. Fig.3 plots the near neutral LINEX 96/2 data as a function of $\ln[z_+ \cdot f/u_*]$.

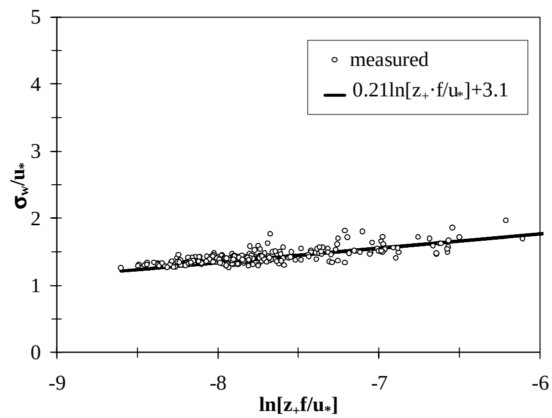

Fig.3: The near neutral nondimensional vertical velocity standard deviation observed during the LINEX 96/2 experiment and the new parameterisation (solid line).

The independence of σ_w/u_* on height as suggested by $\ln[z_+ \cdot f/u_*]$ contradicts the findings of Högström (1990), who found increasing nondimensional vertical velocity standard deviations with increasing height.

The unstable nondimensional vertical velocity standard deviation with $-3 \leq (z-d)/L \leq -0.2$ was found to be predicted best by the parameterisation after Panofsky et al. (1977) (see Tab.1), yielding a correlation coefficient of 0.84. The parameterisations of σ_w/u_* by Johansson et al. (1999), Peltier et al. (1996) including (z-d)/L and $|z_i/L|$ terms were not found to show better correlation (R = 0.79) to the data of all five experiments in this stability range.

The nondimensional standard deviation of the horizontal wind velocity was observed to show the same behaviour as the vertical wind velocity with generally higher scatter and lower correlation coefficients to the tested parameterisations. For the near neutral range ($-0.2 \leq (z-d)/L \leq 0.4$), the best results yields the parameterisation scaling with the new scaling factor $\ln[z_+ \cdot f/u_*]$ (see Tab.1). For the unstable data with $-3 \le (z-d)/L \le -0.2$, the best prediction (R = 0.35) was derived using the parameterisation by (Foken et al., 1991) (see Tab.1) scaling with (z-d)/L. The parameterisation $\sigma_u/u_* = 0.77|z_i/L|^{1/3}+2$ by Panofsky et al. (1977) shows significant correlation to the observed data with $(z-d)/L \le -1$, yielding a correlation coefficient of 0.30.

The nondimensional standard deviation of the acoustic temperature was found to scale with the atmospheric stability over the entire stability range. The best correlation to the observed data of all five experiments is given by a modified parameterisation after Foken et al. (1991) (Fig.4).

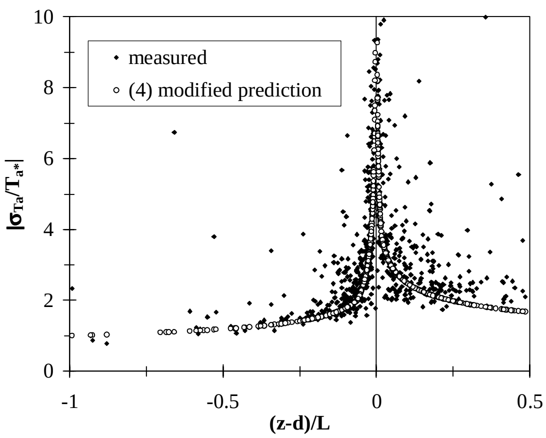

Fig. 4: The observed nondimensional temperature standard deviation of all experiments as a function of (z-d)/L and the modified prediction after Foken et al. (1991).

4. CONCLUSIONS AND RECOMMENDATIONS

From the present re-evaluation of integral turbulence characteristics and their parameterisation, the following conclusions and recommendations (Tab.1) can be drawn: For the nondimensional vertical and horizontal velocity standard deviations the present study supports the significant dependency on the geographical latitude as suggested by (Högström, 1990; Smedman, 1991) under near neutral conditions. The best overall fit to the data of five individual experiments is given by parameterisations using the newly derived scaling factor $\ln[z_+ \cdot f/u_*]$ as presented in Tab.1 for a stability range of $-0.2 \le (z-d)/L \le 0.4$. The integral turbulence characteristics of the wind components show a clear dependency on the atmospheric stability as found by various authors for unstable stratification with $(z-d)/L \le -0.2$. The parameterisations for σ_w/u_* by Panofsky et al. (1977) and σ_u/u_* by Foken et al. (1997) were supported. The parameterisations including terms with the mixing layer height z_i involved as given by Johansson et al. (1999), Panofsky et al. (1977), Peltier et al. (1996) were found to show significant, but not improved correlation to the data of the five experiments under increasing unstable conditions. The nondimensional temperature standard deviation was found to scale with the atmospheric stability over the entire stability range. The modified parameterisation after Foken et al. (1997) can be supported by the results of the present re-evaluation.

Thus, local and non-local parameters were found to significantly influence atmospheric turbulence and therefore its integral characteristics in the surface layer.

Tab.1: Recommendations for parameterisations of the integral turbulence characteristics of wind components and temperature

<table>
<tr><td rowspan="2">integral turbulence characteristic</td><td colspan="4">stability range</td></tr>
<tr><td colspan="2">$-3<(z-d)/L<-0.2$</td><td colspan="2">$-0.2<(z-d)/L<0.4$</td></tr>
<tr><td>σ_w/u_*</td><td colspan="2">$1.3\left(1-2\frac{(z-d)}{L}\right)^{1/3}$ (1)
by Panofsky et al. (1977)</td><td colspan="2">$0.21\ln\left[\frac{z_+\cdot f}{u_*}\right]+3.1$ (2)</td></tr>
<tr><td>σ_u/u_*</td><td colspan="2">$4.15\left(\left|\frac{(z-d)}{L}\right|\right)^{1/8}$
by Foken et al. (1991),
Foken et al. (1997)</td><td colspan="2">$0.44\ln\left[\frac{z_+\cdot f}{u_*}\right]+6.3$ (2)</td></tr>
<tr><td rowspan="2">integral turbulence characteristic</td><td colspan="4">stability range</td></tr>
<tr><td>$(z-d)/L<-1$</td><td>$-1<(z-d)/L<-0.0625$</td><td>$-0.0625<(z-d)/L<0.02$</td><td>$0.02<(z-d)/L$</td></tr>
<tr><td>$|\sigma_T/T_*|$</td><td>$\left(\left|\frac{(z-d)}{L}\right|\right)^{-1/3}$</td><td>$\left(\left|\frac{(z-d)}{L}\right|\right)^{-1/4}$</td><td>$0.5\left(\left|\frac{(z-d)}{L}\right|\right)^{-1/2}$</td><td rowspan="2">$1.4\left(\left|\frac{(z-d)}{L}\right|\right)^{-1/4}$</td></tr>
<tr><td></td><td colspan="3">by Foken et al. (1991)</td></tr>
</table>

(1) Other parameterisations tested were not found to yield significantly different results
(2) $z_+ = 1$ m

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