STABILITY DEPENDENCE OF THE TEMPERATURE STRUCTURE PARAMETER

(Research Note)

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Abstract. Experimental data of C_T^2, determined during various experiments in the surface layer, are compared with several functions giving the stability dependence of the temperature structure parameter. The universal function of the dimensionless temperature gradient by Skeib (1980) follows very well the experimental data and the empirical function by Wyngaard *et al.* (1971). This function can be used in an inertial-dissipation method.

1. Introduction

The determination of the vertical distribution of the temperature structure function is of particular importance for use in models of the atmospheric boundary layer and for determination of the refraction structure parameter and its relation to the propagation of light and astronomical seeing. The vertical distribution of the temperature structure function depends mainly on the stratification:

$$C_T^2 = z^{4/3} \cdot (\partial\theta/\partial z)^2 \cdot f_T(\mathrm{Ri}) \tag{1}$$

(Wyngaard *et al.*, 1971) where C_T^2 = temperature structure parameter, z = height, θ = potential temperature, Ri = Richardson number. Using the vertical temperature profile,

$$\frac{\partial\theta}{\partial z} \sim \frac{\partial T}{\partial z} = \frac{T_*}{\lambda \cdot z} \cdot \phi_h(z/L)\,, \tag{2}$$

with T = temperature, $\phi_h(z/L)$ = universal function of the sensible heat flux, T_* = dynamic temperature scale ($T_* = -\overline{w'T'}/u_*$), u_* = friction velocity, L = Obukhov length, $\overline{w'T'}$ = temperature flux, λ = 0.5 for α_0 = 1.25 = ratio of the exchange coefficients of sensible heat and momentum, we obtain the well-known equation

$$C_T^2 = T_*^2 \cdot \lambda^{-2} \cdot \phi_h(z/L)^2 \cdot f_T(z/L) \cdot z^{-2/3}\,, \tag{3}$$

where $f_T(z/L)$ = empirical function given by Wyngaard *et al.* (1971). On the other hand, Wyngaard *et al.* (1971) determined

$$C_T^2 = T_*^2 \cdot \lambda^{-2} \cdot z^{-2/3} \cdot g_T(z/L) \tag{4}$$

with

$$g_T(z/L) = \begin{cases} 1.225[1 - 7(z/L)]^{-2/3}, & z/L < 0 \\ 1.225[1 + 2.75(z/L)^{2/3}], & z/L > 0 \end{cases} \tag{5}$$

for measurements over land. This function was confirmed by Davidson *et al.* (1978) over water.

The purpose of the present paper is to determine the stability functions $f_T(z/L)$ and $g_T(z/L)$ and to demonstrate that they can be used to compute the heat exchange. This will be proved by comparing fluxes estimated with an inertial-dissipation method with fluxes directly measured by the eddy correlation approach.

2. Description of the Measuring Site

During the international experiment KUREX-88 in Kursk/USSR (Foken, 1989), some special measurements were made with the turbulence measuring system of the Main Meteorological Observatory in Potsdam/GDR (among other devices sonic anemometer Kaijo Denki DAT-300 and highly sensitive platinum-wire temperature sensor) and a method of determination of the temperature structure parameter (Gerstmann, 1989; see also Moulsley *et al.*, 1982). Therefore, a narrow band-pass filtering of the temperature signal was performed to determine the spectral density at three frequencies within the inertial subrange of the temperature spectrum. The sensor signals are, via multiplexer and A/D converter, transmitted to a micro-computer to determine mean values, standard deviation and turbulent fluxes within the frequency range of 0.001 to 20 Hz. About 100 series of 35 min length each were made above a buckwheat field at a height of 2 m above the zero-plane displacement. The data were collected under several weather conditions.

3. Determination of the Empirical Function

The factor

$$A = \frac{z^{2/3} \cdot \lambda^2 \cdot C_t^2}{T_*^2} = \begin{cases} g_T, & \text{according (4)} \\ \phi_h^2 \cdot f_T, & \text{according (3)}\ , \\ \phi_h \end{cases} \tag{6}$$

was determined from all measuring series. In Figure 1 the relation to the stability parameter z/l is illustrated. Figure 1 also shows the universal function of the sensible heat flux given by Skeib (1980) (see also Foken and Skeib, 1983) in an updated form,

$$\phi_h(z/L) = \begin{cases} [(z/L)/0.125]^2 & 0.125 \leq z/L \\ 1 & -0.0625 < z/L < 0.125 \\ [(z/L)/-0.0625]^{-1/2} & z/L \leq -0.0625 \end{cases} \tag{7}$$

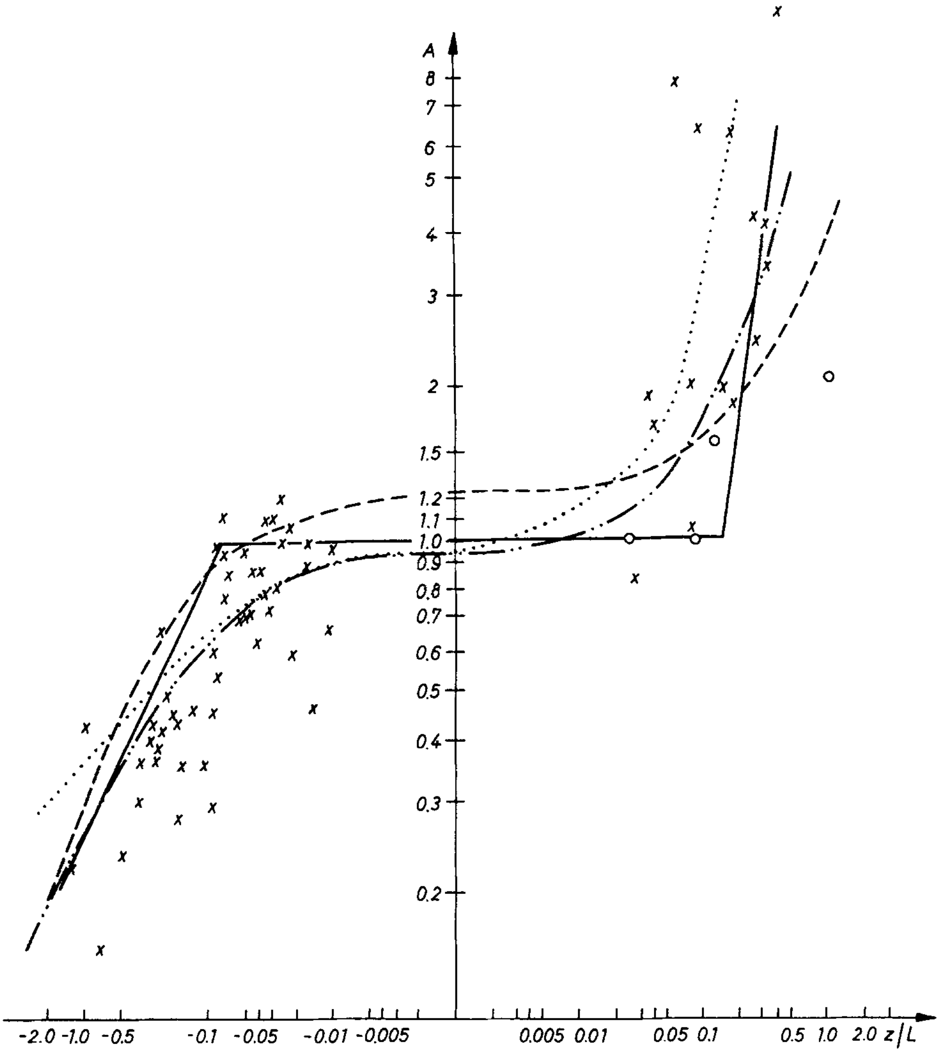

Fig. 1. Comparison of the stability dependence of experimental data of the factor A (see eq. 6) with several functions. ×: KUREX-88, 2 m, Foken (1989); ○: Karl Schwarzschild Observatory in Tautenburg 1987, 8 m, Foken *et al.* (1990). ······· empirical function $1/f_T$ by Wyngaard *et al.* (1971); ---- empirical function g_T by Wyngaard *et al.* (1971); ------ universal function by Skeib (1980); -·-·- universal function by Businger *et al.* (1971).

The comparison of the experimental data with this universal function shows

$$\phi_h(z/L) \sim \begin{cases} g_T(z/L) \\ 1/f_T(z/L) \end{cases}, \tag{8}$$

i.e., the use of the usual universal functions is possible.

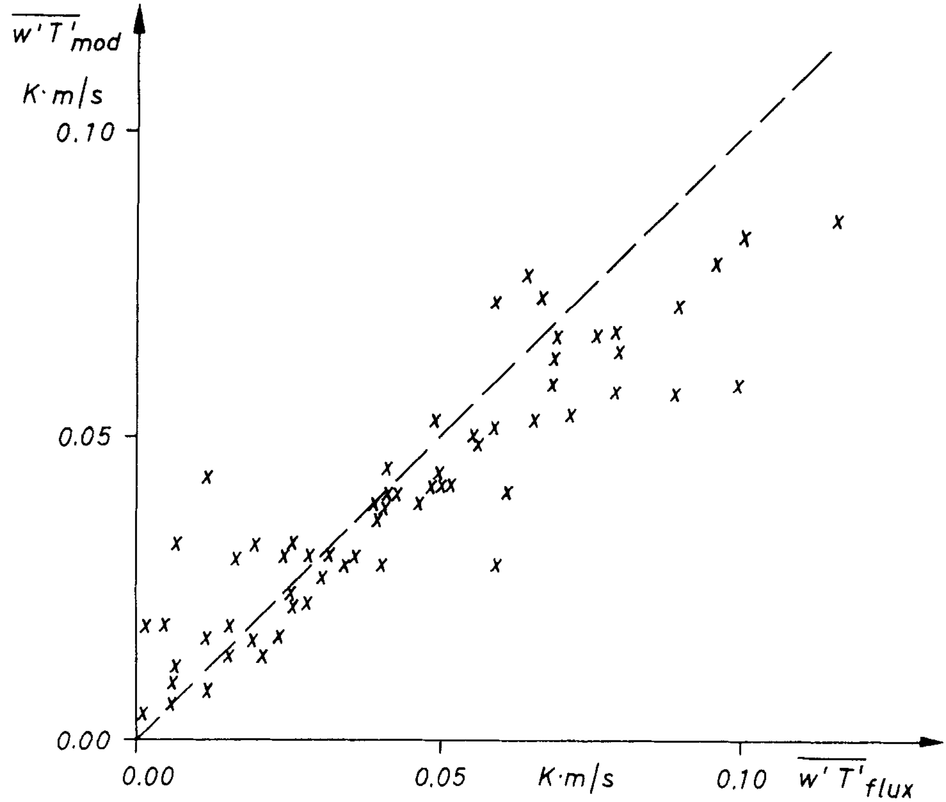

Fig. 2. Comparison of sensible heat fluxes determined by the inertial-dissipation method after eq. (9) and direct turbulence measurements (corelation coefficient 0.94, 92 measurements).

4. Comparison of the Model with Experimental Data

From equations (6) and (8) follows

$$C_T^2 = T_*^2 \cdot \lambda^{-2} \cdot \phi_h(z/L) \cdot z^{-2/3} . \tag{9}$$

This result was tested using the data of the KUREX-88 experiment (Figure 2). For this test the friction velocity was determined by flux measurements. For more practical use, the friction velocity can be determined by profile measurements or above the sea by the bulk method. An iterative scheme was used to determine z/L.

In a recent paper, Fairall and Larsen (1986) showed some ways to use the energy dissipation method for the determination of turbulent fluxes, especially over the ocean. The starting point is equation (9) with the empirical function by Wyngaard *et al.* (1971) according to (5). Obviously the function given by Skeib (1980) and the experimental data are in better agreement with the empirical function $1/f_T$ given by Wyngaard *et al.* (1971). In spite of some reservations concerning the dissipation method, the results speak in their favour.

Because it is easy to determine the structure parameter by the spectral method with highly selective filters, this technique may be used also for more practical problems.

References

Businger, J. A., Wyngaard, J. C., Izumi, Y., and Bradley, E. F.: 1971, 'Flux-Profile Relationships in the Atmospheric Surface Layer', *J. Atm. Sci.* **28**, 181–189.

Davidson, K. L., Houlihan, T., Fairall, C. W., and Schacher, G. E.: 1987, 'Observation of C_T^2 over the Ocean', *Boundary-Layer Meteorol.* **15**, 507–523.

Fairall, C. W. and Larsen, S. E.: 1986, 'Inertial-Dissipation Methods and Turbulent Fluxes at the Air-Ocean Interface', *Boundary-Layer Meteorol.* **34**, 287–301.

Foken, Th.: 1989, 'Information über die Turbulenzmessungen im Rahmen des internationalen Experimentes KUREX-88, Kursk/UdSSr, 13.6–22.7.1988', *Z. Meteorol.* **39**, 237–238.

Foken, Th. and Skeib, G.: 1983, 'Profile Measurements in the Atmospheric Near-Surface Layer and the Use of Suitable Universal Functions of the Turbulent Energy Exchange', *Boundary-Layer Meteorol.* **25**, 55–62.

Foken, Th., Woche, M., Richter, S. H. Kretschmer, D., Baum, W., and Schindler, V.: 1990, 'Astro-climatological Investigations at the Karl Schwarzschild Observatory in Tautenburg', *Z. Meteorol.* **40**, 310–315.

Gerstmann, W.: 1989, 'Determination of C_T^2 in the Lower Boundary Layer of the Atmosphere Using Different Spectral Methods', *Z. Meteorol.* **39**, 248–253.

Mousley, J. T., Asimakopoulos, D. N., Cole, R. S., Caughey, S. I., and Crease, B. A.: 1982, 'Temperature Structure Parameter Measurements Using Differential Temperature Sensors', *Boundary Layer Meteorol.* **23**, 307–315.

Skeib, G.: 1980, 'Zur Definition universeller Funktionen für das turbulente Stromfeld in der bodennahen Luftschicht', *Z. Meteorol.* **30**, 23–32.

Wyngaard, J. C., Izumi, Y., and Collins, S. A.: 1971, 'Behavior of the Refractive Index Structure Parameter Near the Ground', *J. Opt. Soc. Amer.* **61**, 1646–1650.