

ATMOSPHERIC TURBULENT FLUXES OF HEAT AND MOMENTUM

Khaled S. M. Essa and M. Embaby

Mathematics and Theoretical Physics Department, Nuclear Research Center, Atomic Energy Authority, P. O. 13759, Cairo, Egypt

Rec. 20/7/2007

Accept. 13/11/2007

The standard deviations of both wind speed (σ_u) and temperature (σ_T) in different stabilities of the atmospheric surface layer are presented to determine the turbulent fluxes of momentum and heat respectively. Data has been obtained from North Carolina at 1996 for seven days in July. The dimensionless height η_e defined by the standard deviations σ_u and σ_T is strongly related to the dimensionless stability parameter $\eta=z/L$, Experimental relations for η_e are presented to calculate heat and momentum fluxes from σ_u and σ_T .

Keywords: *Turbulent Fluxes of Momentum and Heat/ Atmospheric Surface Layer/ Dimensionless Stability Parameter.*

INTRODUCTIONS

Tillman [15] proved that in the unstable surface layer the sensible heat and momentum fluxes can be obtained from the standard deviation σ_T and skewness of the temperature see also [1]. This method is called the variance method. [18, 10, 17, 4, 9], proved that the daytime heat and momentum fluxes can be derived from estimated σ_T and the horizontal wind speed. Although Monin-Obukhov[3] similarity theory is valid under special conditions, the variance method seems to be a good indicator [3, 4, 5]. It is to be noted that flux evaluation using variance method in stable surface layer is not so important because its value is small enough. Accordingly, the variance method will be used to evaluate the heat flux and the friction velocity for all stability conditions. Meteorologists dealing with the weather forecast and climate models need actual flux measurements for

legality of their models, so that the aptitude to determine surface fluxes from conventional weather station data would be of great importance [7].

STATISTICAL TECHNIQUES AND APPROACH

From Monin-Obukhov[3] similarity theory (MOST) we can write:

$$\sigma_T = \theta_* \Phi_T(\eta) \quad (1)$$

$$\sigma_u = u_* \Phi_u(\eta) \quad (2)$$

where σ_T is the standard deviation of temperature, (T), and σ_u is the standard deviation of the longitudinal wind speed, (u), θ_* is a temperature scale, u_* is the friction velocity and Φ_T , Φ_u are universal functions of the dimensionless height $\eta=z/L$ with z-is the height above a zero plane displacement and L-is the Monin-Obukhov scale length, where

$$\theta_* = \frac{-\overline{w'T'}}{u_*} \quad (3)$$

$$\overline{w'T'} = \frac{H}{\rho C_p} \quad (4)$$

H- is the sensible heat flux density, ρ - is the air density and C_p - is the specific heat of air at constant pressure.

From the definition of Monin-Obukhov[3] scale length, we can write:

$$\eta = -\left(\frac{kgz}{T}\right)\left(\frac{\overline{w'T'}}{u_*^3}\right) \quad (5)$$

Many authors reported the constancy of both Φ_T and Φ_u for a fairly wide stability of η [15, 4, 13] for Φ_T and [12, 14, 4, 2, 8] for Φ_u So let:

$$\phi_u = C_u \quad \text{and} \quad \phi_T = C_T \quad (6)$$

In this paper both ϕ_u and ϕ_T are not constant but varies relatively in all stability classes. As a consequence we shall consider C_u and C_T are the average value of ϕ_u and ϕ_T respectively. Hence the quantities C_T and C_u will vary according to different stability conditions. Now let u_{*e} and $\overline{w'T'_e}$ are the estimated friction velocity and the estimated heat flux defined as follows:

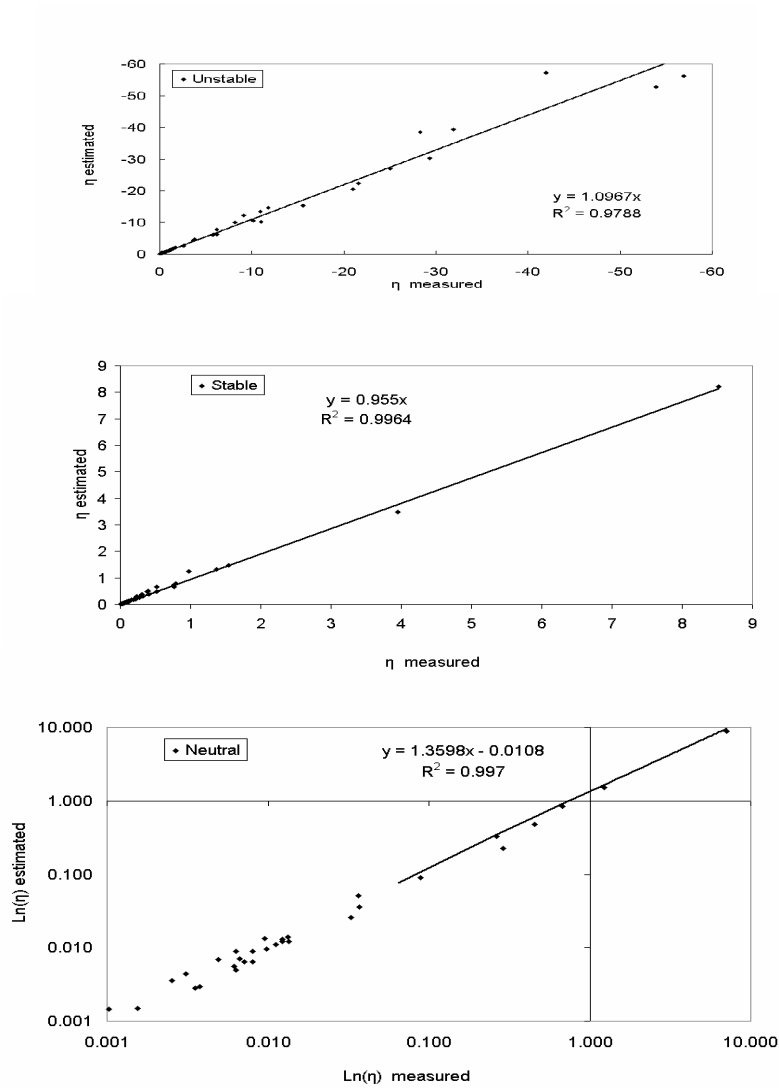


Figure 1. Dimensionless height, η_e , calculated from σ_u and σ_t versus the measured dimensionless height, η .

$$u_{*e} \equiv \frac{\sigma_u}{C_u} \quad \text{and} \quad \overline{w'T'_e} = -u_{*e} \frac{\sigma_T}{C_T} \quad (7)$$

These relations are expected to be closed to the measured values u_* and $\overline{w'T'}$. Hence the estimated dimensionless height η_e can be written as:

$$\eta_e = -\left(\frac{kgz}{T}\right)\left(\frac{\overline{w'T_e'}}{u_{*e}^3}\right) \quad (8)$$

It is expected that η_e will be close to η_z measured as shown in figure (1).

ALTERNATIVE VARIANCE APPROACH (CASE STUDY):

An alternative (Most) variance approach is suggested by defining a dimensionless friction velocity u_*/u_{*e} and a dimensionless heat flux $\overline{w'T'}/\overline{w'T_e'}$ which are both expected to be a function of η_e . Consequently,

$$\frac{u_*}{u_{*e}} = G_u(\eta_e) \quad (9)$$

$$\frac{\overline{w'T'}}{\overline{w'T_e'}} = G_{wT}(\eta_e) \quad (10)$$

Now, we shall compare this approach with experimental data of velocity and temperature that has been measured at North Carolina meteorological station, U.S.A. (see [12]). A three dimensional sonic anemometer was used at three meters height. Data were calculated every 30 minutes averages for seven days from 10 to 16 of July 1996.

A suitable fitting for the above functions to our data will give the following equalities in different stability conditions:

$$G_u(\eta_e) = G_{wT}(\eta_e) = \exp [10(2\eta_e + 1)] \quad \text{in unstable condition.} \quad (11a)$$

$$G_u(\eta_e) = G_{wT}(\eta_e) = \exp [40\eta_e - 5] \quad \text{in stable condition.} \quad (11b)$$

$$G_u(\eta_e) = G_{wT}(\eta_e) = \exp [100\eta_e + 1] \quad \text{in neutral condition.} \quad (11c)$$

We have excluded all irregular data points for which the spectrum did not show a clear inertial range. These data were used to evaluate $\sigma_u, \sigma_T, u_*, \overline{w'T'}, C_u$ and C_T using eddy correlation from which one can evaluate u_{*e} and $\overline{w'T_e'}$ using equations (9) -(11). Comparison between the measured and estimated values will give a very good agreement as shown in Figures 2. and 3.

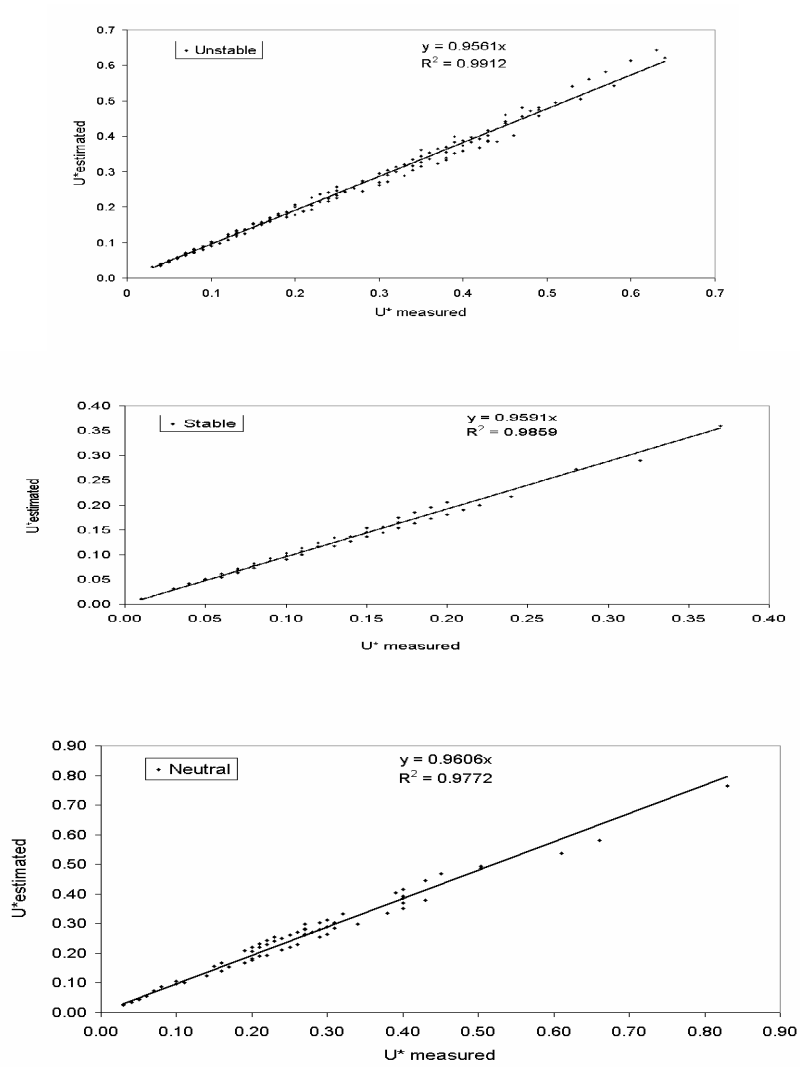


Figure 2. Friction velocity, u_* , estimated with the alternative variance method defined in equations (9) and (11) versus the measured, u_* , using eddy correlation.

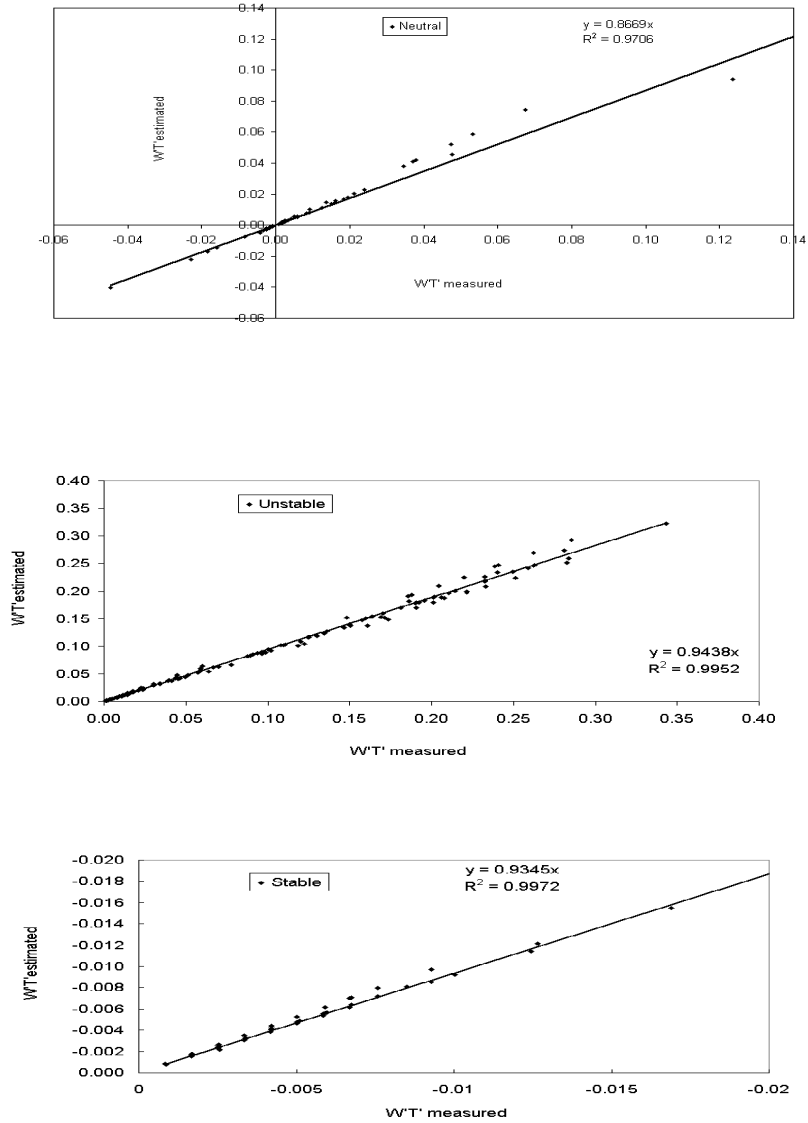


Figure 3. Heat flux, $W'T'$, estimated with the alternative variance method defined in equations (9)-(11) versus the measured, $W'T'$, using eddy correlation.

To demonstrate the presentation of our approach under conditions where turbulence is not continuously present, we show figures (4) and (5), where the estimated and measured values of u_* and \overline{wT} were compared over 2- days (192-193) in three stability conditions, (see [6, 16]). It is evident that the results are acceptable.

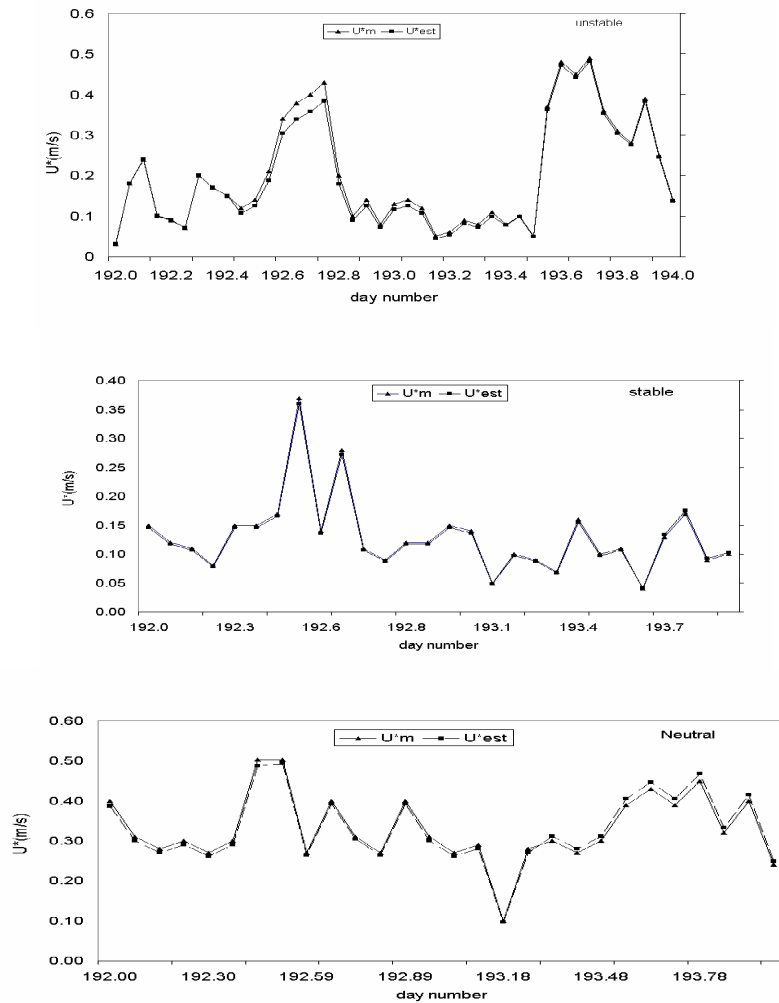


Figure 4. Estimated and measured friction velocity, u_* , as a function of time from 10-11 July.

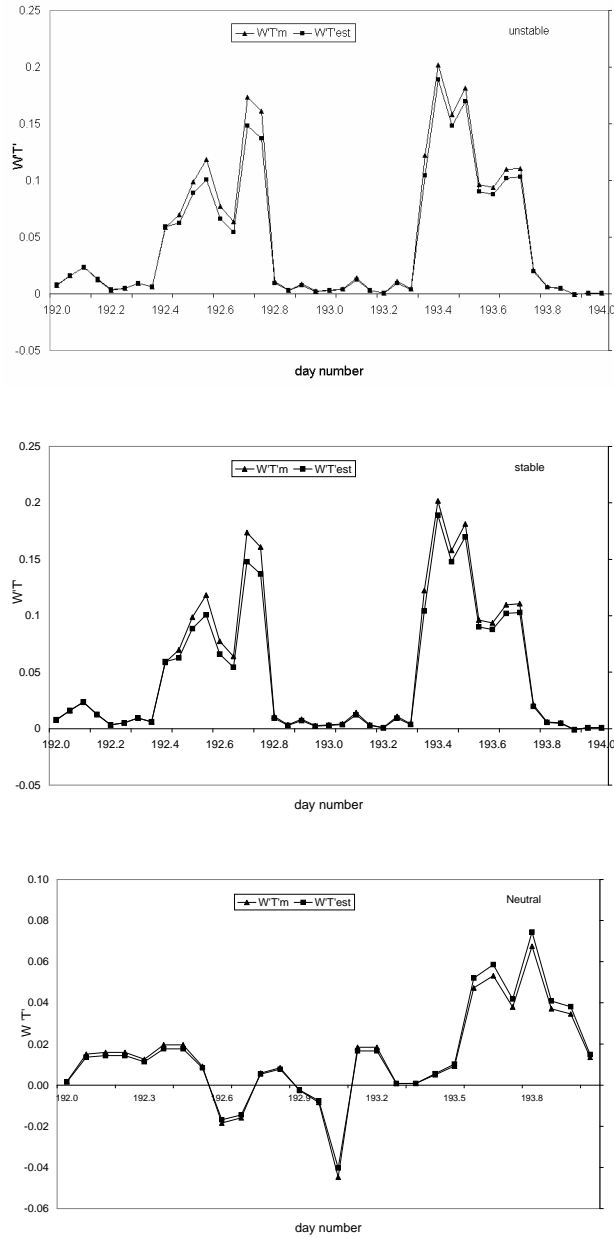


Figure 5. Estimated and measured heat flux, $W'T'$, as a function of time from 10-11 July.

DISCUSSION AND CONCLUSION

In different stability conditions the values of u_* and $\overline{w'T}$ can be obtained accurately from the standard deviations of longitudinal wind velocity and temperature over the range of η [as shown in figures (1)]. When we compare this method with eddy correlation fluxes it gives less scatter. Moreover, it is established that the presentation of the variance method is good enough in the different stability conditions. Experimental expressions has been used for the functions $G_u(\eta_e)$ and $G_{wT}(\eta_e)$ that need to be re-standardized for different stabilities and surface types, as was found by Weaver [18] and Katul et al. [9] for the temperature variance method under unstable conditions.

The data we used has been classified into three groups, according to the three stability conditions, unstable, stable, and neutral. We find that estimated η_e will be close to η measured. When we compare between the measured values u_* and $\overline{w'T}$ and estimated values u_{*e} and $\overline{w'T_e}$, we will get a very good agreement. Also the estimated and measured values of u_* and $\overline{w'T}$ over 2- days in three stability conditions are closing to each other.

REFERENCES

- [1] Businger, J.A., (Haugen, D.A. (ed.)) “*Turbulent Transfer in the Atmospheric Surface Layer*”, Workshop on Micrometeorology, Amer. Meteorol. Soc., Vol. 45, Boston, MA., 67-100(1973).
- [2] Chu, C.R., Parlange, M.B., Katul, G.G. and Albertson, J.D., *Water Resour. Res.* **32**, 1681-1688(1996).
- [3] De Bruin, H.A.R., Bink, N.J., and Kroon L.J.M., (Schmugge, T.J. and Andr, J.C. (eds.)) “*Fluxes in the surface layer under advective conditions*”, Land Surface Evaporation, Springer Verlag, New York, 157-171(1991).
- [4] De Bruin, H.A.R., Kohsiek, W., and Van Den Hurk B.J.M., *Boundary -Layer Meteorol.* **63**, 231-257(1993).
- [5] De Bruin, H.A.R., Van Den Hurk, B.J.J.M., and Kroon, L.J.M., *Boundary -Layer Meteorology.* **93**, 453-468(1999).
- [6] Hartogensis, O.K., De Bruin, H.A.R., and Van De Wiel, B.J.H., *Boundary-Layer Meteorology.* **105**, 148-176(2002).
- [7] Holtslag, A.A.M. and Van Ulden, A.P., *J. Climat. Appl. Meteorol.* **22**, 517-529(1983).
- [8] Hsieh, C.I. And Katul, G.G., *J. Geophys. Res.* **102**, 16391-16405(1997).

