Article ID: 1006-8775(2000) 01-0219-06

A METHOD FOR DETERMINING TURBULENT TRANSFER IN THE ATMOSPHERIC SURFACE LAYER

WAN Qi-lin (万齐林)

(*Guangzhou Institute of Tropical and Oceanic Meteorology*, *Guangzhou* 510080 *China*)

ABSTRACT: Derivation of bulk transport coefficients helps solving land surface processes. A similarity-based method for determining the turbulent transfer (including the flux exchange, the vertical distribution of wind and potential temperature) in the atmospheric surface layer is presented. Comparisons with iterative schemes (Businger, 1971) are given to demonstrate the advantages of the calculation methods.

Key words: turbulent transfer flux; vertical distribution; calculation methods

CLC number: P423.34 **Document code:** A

1 INTRODUCTION

The core question in the issue of land surface processes is the determination of the transfer and exchange of momentum, heat and matter between the underlying surface and the atmosphere. In real computation, parameterized overall transfer coefficients are usually used in which the solution of the coefficients is a key. Much work has been done in this regard and some schemes have been put forward for computation (Businger, Wyngaard and Izumi et al., 1971; Dyer, 1974; Panofsky, 1963; Rachele, Tunick and Hansen, 1995; Yaglom, 1977). A computation scheme, which determines turbulent transfer at the near-surface layers of the atmosphere through iteration-free methods, is put forward in the paper. It is characteristic of simple computation and easy derivation of the overall transfer coefficients and thus relatively more applicable in some aspects. In the meantime, the computed results are comparable to those obtained by some other schemes.

2 VERTICAL PROFILE OF METEOROLOGICAL ELEMENTS IN ATMOSPHERIC NEAR-SURFACE LAYERS AND FLUX EXCHANGE COEFFICIENTS OF UNDERLYING SURFACE

Based on the Monin-Obukhov similarity theory, we have in the near-surface layer that

$$\frac{kz}{u_*}\frac{\partial u}{\partial z} = f_M\left(\frac{z}{L}\right)$$

$$\frac{kz}{\theta_*}\frac{\partial \theta}{\partial z} = f_H\left(\frac{z}{L}\right) \tag{1}$$

Received date: 1999-08-30; **revised date:** 2000-08-25

Foundation item: Key National Scientific Project for the "9th-five year" economic plan (No.96-908-02-04-2)

Biography: WAN Qi-lin (1965 –), male, native from Ezhou City Hubei Province, senior researcher at Guangzhou Institute of Tropical and Oceanic Meteorology, studying numerical weather prediction.

where u_* is the velocity of friction and q_* the characteristic geopotential temperature. The Monin-Obukhov length is $L = u_*^2/(bkq_*)$ where $b = \frac{g}{q}$; k=0.35, a Von Karman constant. The f_M and f_H are two functions to be determined and vary according to computation schemes employed. Some schemes give explicit expressions (like Businger et al., 1971) and others give implicit ones. No explicit functions of any kind are presented here in our scheme.

Two heights, Z_1 and Z_2, are selected from the near-surface layer. Usually the former takes Z_0 (roughness) and Z_2 assumes the height of the top of the flux layer of conventional values.

By the definition of $h = \ln\left(\frac{Z_2}{Z_1}\right)$, $\Delta Z = Z_2 - Z_1$, with the overall Richardson number

$$\mathrm{Rib} = b(q_2 - q_1)(Z_2 - Z_1)/(U_2 - U_1)^2$$

and functions of

$$g_M(x) = \int \left(1 - f_M(x)\right) \,\mathrm{d}\ln x$$

$$g_H(x) = \int \left(1 - a f_H(x)\right) \,\mathrm{d}\ln x \quad , a = 1/0.74$$

we change Eq.(1) into

$$U_* = k\,(U_2 - U_1)/(h - y_M)$$

$$q* = k(q_2 - q_1)/[0.74(h - y_H)] \tag{2}$$

$$y_M = \int_{Z_1/L}^{Z_2/L} (1 - f_M)\,\mathrm{d}\ln(\frac{z}{L}) = g_M\left(\frac{Z_2}{L}\right) - g_M\left(\frac{Z_1}{L}\right)$$

$$y_H = \int_{Z_1/L}^{Z_2/L} (1 - a f_H)\,\mathrm{d}\ln(\frac{z}{L}) = g_H\left(\frac{Z_2}{L}\right) - g_H\left(\frac{Z_1}{L}\right) \tag{3}$$

Furthermore, the expression for the length L can be written as: $\frac{\Delta Z}{L} = \frac{(h - y_M)^2}{0.74(h - y_H)}\mathrm{Rib}$ and wind, temperature and humidity between the heights Z_1 and Z_2 are distributed in a vertical profile of

$$U(z) = U_1 + (U_2 - U_1)\left(\ln\left(\frac{Z}{Z_1}\right) - g_M\left(\frac{Z}{L}\right) + g_M\left(\frac{Z_1}{L}\right)\right)\Big/\left(h - g_M\left(\frac{Z_2}{L}\right) + g_M\left(\frac{Z_1}{L}\right)\right)$$

$$q(z) = q_1 + (q_2 - q_1)\left(\ln\left(\frac{Z}{Z_1}\right) - g_H\left(\frac{Z}{L}\right) + g_H\left(\frac{Z_1}{L}\right)\right)\Big/\left(h - g_H\left(\frac{Z_1}{L}\right) + g_H\left(\frac{Z_1}{L}\right)\right) \tag{4}$$

and the flux can be expressed as:

$$r\,u_*^2 = flx_M = r\,C_D(u_2 - u_1)^2$$

$$\boldsymbol{r} C_p u_* \boldsymbol{q}_* = flx_H = \boldsymbol{r} C_P C_H (U_2 - U_1)(\boldsymbol{q}_2 - \boldsymbol{q}_1)$$

and the coefficients for fluxes exchanged between the atmosphere and the underlying surface are written as:

$$C_D = u_*^2 \Big/ (U_2 - U_1)^2 = \left[k \Big/ (h - y_M) \right]^2$$
$$C_H = U_* q_* \Big/ [(U_2 - U_1)(q_2 - q_1)] = k^2 \Big/ [0.74(h - y_M)(h - y_H)] \tag{5}$$
$$C_q = C_H$$

Provided that functions g_M , g_H and L are given, the vertical profiles of flux exchange coefficients and meteorological elements at the near-surface layer are derived, based on the assumptions below.

Under the stable conditions, we have

$$g_M(x) = -4.7x$$
$$g_H(x) = -6.35x \tag{6}$$

$\frac{1}{L} \approx \frac{\Delta \ln Z}{\Delta Z} \frac{\text{Rib}}{1.0 - 4.7\text{Rib}}$, when Rib $>$0.2, Rib takes 0.2.

Under the unstable conditions, the writer gives that

$$g_M(x) = -2.05x - 1.20x^2 - 0.27x^3 \text{, when } -2.0 \le x \le 0$$
$$g_M(x) = -1.35x - 0.398x^2 - 0.045x^3 \text{, when } -4.0 \le x \le -2.0$$
$$\tag{7}$$
$$g_H(x) = -3.2x - 1.99x^2 - 0.47x^3 \text{, when } -2.0 \le x \le 0$$
$$g_H(x) = -2.15x - 0.665x^2 - 0.075x^3 \text{, when } -4.0 \le x \le -2.0$$

When $x <$ –4.0, x takes –4.0. $\frac{1}{L} \approx \frac{\Delta \ln Z}{\Delta Z} \text{Ri}$.

For signs that have not been specified, they carry the conventional meaning in meteorology.

It is seen from the scheme described above that given Rib, we know the functions L and g on basis of Eqs.(6) and (7) and further obtain the values of u_*, q_*, and vertical profile and flux exchange coefficients. The scheme is free of any iterative steps and leads to simple computation. It is so useful in operation that it gives easy expressions for deriving flux exchange coefficients.

3 EXPERIMENT IN COMPARISON

For explanation of how the computation is performing in the scheme, comparisons are made here with the iterative scheme by Businger (1971). For the experiment, it is assumed that the roughness is Z_0 =0.25 m for land surface and Z_0 =0.0025 m for water surface, Z_1 equals to Z_0 and Z_2 takes 30 m.

For convenience, the Businger scheme is called Scheme I and the scheme introduced here Scheme II.

Fig.1 compares the two schemes in terms of flux exchange coefficients. The figure shows that the momentum and flux exchange coefficients are, no matter with which scheme, consistent for both land and water surface. It is an indication that the computation in our scheme gives

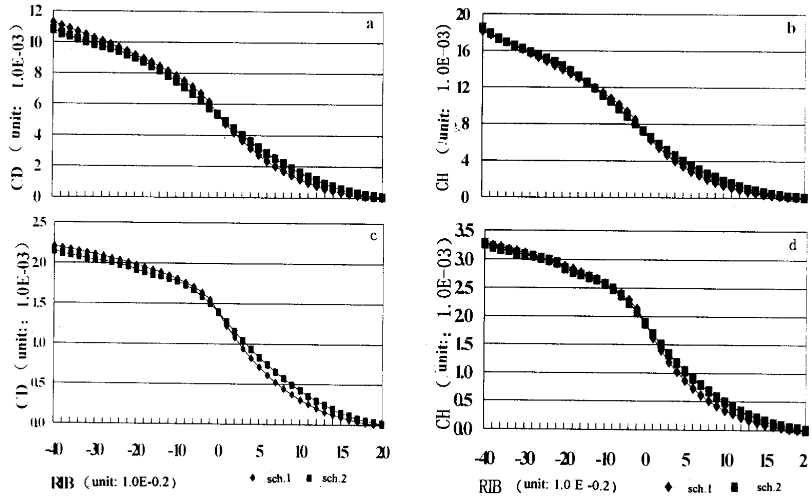

Fig.1 The coefficient of surface flux exchange (a) momentum flux on land; (b) thermal flux on land; (c) momentum flux on sea; (d) thermal flux on sea

workable and reliable computation of the flux exchange coefficients between the atmosphere and the surface underlying it.

Fig.2 compares the Monin-Obukhov length in the schemes. It shows that the length is also consistent in both schemes for either the land surface or water surface. Under the condition of strong stability, Scheme II performs better than Scheme I, which further indicates that our procedure is reliable.

Next, comparisons are to be made regarding the vertical profiles of wind and temperature. During the experiment, the roughness takes Z_0 =0.25 m for land surface and Z_0 =0.0025 m;

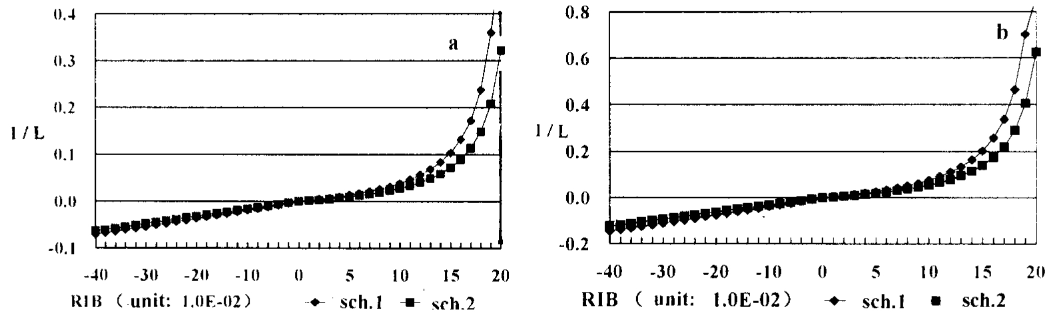

Fig.2 The Monin-Obukhov scaling length L for land (a) and sea (b)

Z_1 equals Z_0 and Z_2 takes 30 m; under the unstable condition, Ri takes –0.2 and u_2 takes 6 m/s, q_1 takes 300 K and q_2 is derived from the definition of Ri; under the stable condition, Ri takes 0.1, u_2 takes 6 m/s, q_2 takes 300 K and q_1 is derived from the definition of Ri.

Fig.3 compares the vertical profiles of wind speed and geopotential temperature in the two schemes. We can have consistent vertical profiles with both schemes regardless of land or water surface (Note that corresponding curves overlap each other in Fig.3a and Fig.3c). The only difference in the vertical profile, if any, is found in the case of stable condition. It shows that the scheme proposed in the paper is workable for the computation of vertical profiles.

The writer compares the proposed scheme with six other algorithms (referring to the reference) widely used for determination of flux exchange coefficients between the atmosphere and underlying surface. The current scheme is competitively better in terms of comprehensive performance, such as accuracy and speed of computation.

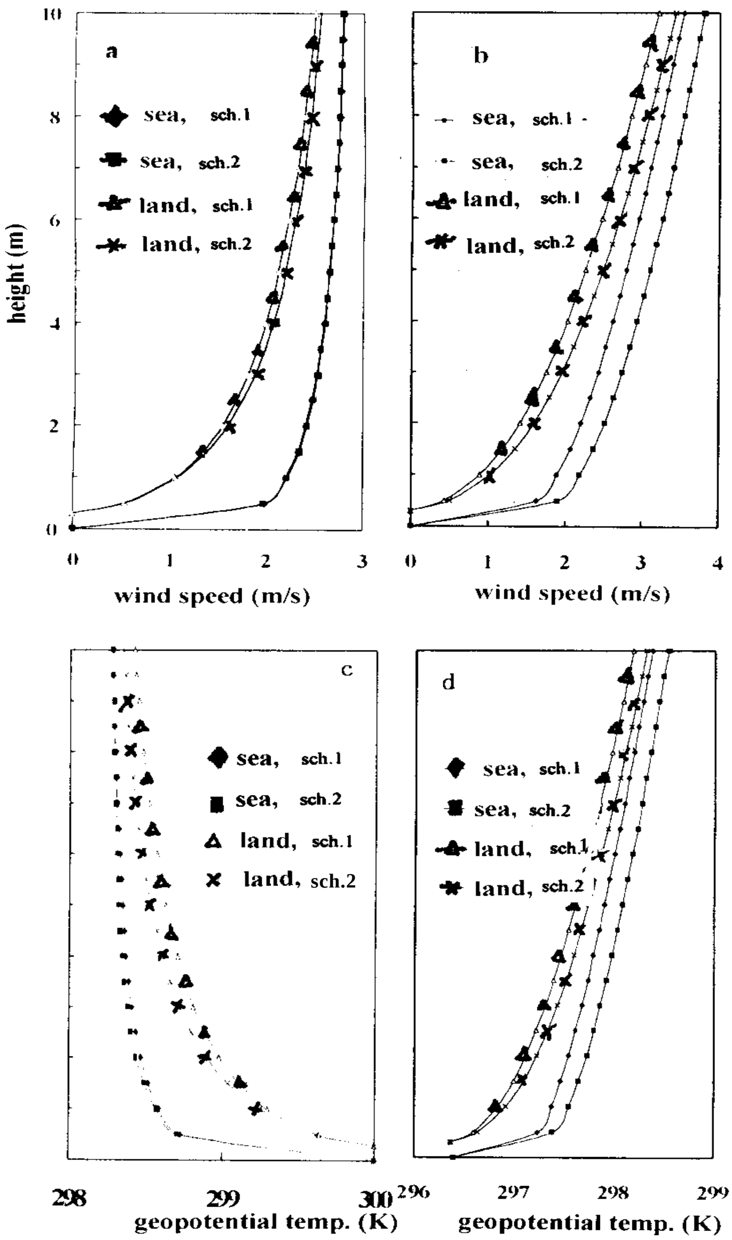

Fig.3 Distribution of wind for unstable conditions (a) and stable conditions (b) and potential temperature for unstable conditions (c) and stable conditions (d) in the vertical.

4 CONCLUDING REMARKS

Compared with the Businger scheme, which is widely used and with good results, the scheme, proposed here for determination of turbulent transfer at the near-surface layer of the atmosphere, is applicable and yielding satisfactory computations. Moreover, the scheme is featured by non-iteration, simple and rapid computation and easy derivation of flux exchange coefficients, and thus useful in operation. The scheme will be introduced in detail in another paper addressing a regional numerical climate model, RegCM2.

Acknowledgements: It is much appreciated that Mr. CAO Chao-xiong, who works at the Guangzhou Institute of Tropical and Oceanic Meteorology, has translated our paper into English.

REFERENCES:

BUSINGER J A, WYNGAARD J C, IZUMI Y, BRADLEY E F, 1971. Flux-profile relationships in the atmospheric surface layer [J]. *J. Atmos. Sci.*, **28**: 181-189.

DYER A J, 1974. A review of flux-profile relationships [J]. *Boundary Layer Meteorology*, **7**: 363-372.

PANOFSKY H A, 1963. Determination of stress from wind and temperature measurements [J]. *Quart. J. Roy. Meteor. Soc.*, **89**:85-94.

RACHELE H, TUNICK A, HANSEN F V, 1995. MARIAH-A similarity-based method for determining wind temperature, and humidity profile structure in the atmospheric surface layer [J]. *J. Appl., Meteor.*, **34**: 1000-1005.

YAGLOM A M, 1977. Comments on wind and temperature flux profile relationships [M]. *Boundary Layer Meteorology*, **11**: 89-102.

CORRIGENDUM

Due to negligence in proof checking, there is a mistake concerning Jiang Xun's biography on page 65 of Volume 6 Number 1, *Journal of Tropical Meteorology*. It should have appeared as:

Biography: JIANG Xun (1978-), female, native from Dangtu County Anhui Province, Master at Geophysics Department Peking University, undertaking the study of atmospheric dynamics.