UNCERTAINTY ANALYSIS ON THE EVAPORATION AT THE SEA SURFACE

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1. Introduction

Evaporation at the sea surface plays an important role in the budgets of energy and water. Thus, the water vapour flux at the sea surface has to be estimated with a sufficient accuracy. The most widely used method is the so-called bulk method, where bulk transfer coefficients are introduced to relate the mean values of humidity, wind speed, and temperature observed at a reference height z_R (usually z_R = 10 m) in conjunction with the measured sea surface temperature to the fluxes of water vapour, momentum, and heat (e.g., Kraus and Businger, 1994). These bulk transfer coefficients, however, are frequently taken from the literature so that the effects owing to thermal stratification, wind-wave interaction, gustiness, inappropriate fetch conditions close to the shore etc. cannot be addressed in a reliable manner. Moreover, the transfer of momentum, heat and water vapour across the thin molecular-turbulent sublayer adjacent to the sea surface is strongly controlled and limited by molecular transfer properties, no matter how irregular the sea surface may be, but the relative importance of this sublayer cannot be expressed by such bulk transfer coefficients. Therefore, to obtain bulk transfer coefficients and, hence, reliable results on evaporation at the sea surface from numerical atmospheric models not only the turbulent exchange, but also the transfer across the sublayer has to be parameterised in an adequate manner.

The purpose of our project is to quantify the uncertainty that parameterisation schemes, empirical quantities and the limited accuracy with which input data can be observed contribute to water vapour fluxes predicted with mathematical models. Here, the influence of different parameterisation schemes to describe the transfer across the interfacial sublayer over aerodynamically smooth sea surfaces on the evaporation as a whole is elucidated.

2. Theoretical Background

The vertical transfer of water vapour, Q, from the sea surface may be written as (see, e.g., Sheppard 1958)

$$Q = -\rho\left(D_q + K_q\right)\frac{\partial q}{\partial z} \quad , \tag{1}$$

where $\partial q/\partial z$ is the vertical gradient of the specific humidity, and where D_q and K_q are the molecular diffusivity and the vertical eddy diffusivity for water vapour, respectively. The latter is *customarily* approximated by K_h, the vertical eddy diffusivity of heat (see, e.g., Kraus and Businger, 1994). Considering Monin-Obukhov scaling and integrating this flux-gradient relationship over the constant flux layer, $0 \le z \le z_R$, provides

$$Q = -\,r_{a,q}^{\;-1}\,\rho\left(q_R - q_s\left(T_g\right)\right) = -\,\rho\, C_q\, U_R\left(q_R - q_s\left(T_g\right)\right) = -\,\rho\, u_*\, q_* = \text{const.} \tag{2}$$

Here, $q_s(T_g)$ is the saturated specific humidity at the sea surface, T_g is the absolute temperature at the surface, q_R is the specific humidity at reference height, z_R, U_R is the corresponding wind speed, C_q is the bulk transfer coefficient for water vapour (often called Dalton number), and $r_{a,q}$ is the total bulk resistance of the air against water vapour transfer. The latter quantity is defined by $r_{a,q} = r_{t,q} + r_{mt,q}$, where $r_{t,q}$ is the bulk resistance of the fully turbulent region of the surface layer given by (e.g., Kramm, 1989)

$$r_{t,q} = r_{t,h} = \int_{z_r}^{z_R} K_h^{-1}\, dz = \frac{1}{u_*\,\kappa}\left(\ln\frac{z_R}{z_r} - \Psi_h\left(\zeta_R, \zeta_r\right)\right) \quad , \tag{3}$$

and $r_{mt,q}$ is the resistance of the underlying interfacial sublayer expressed by (see, e.g., Kramm et al. 1996)

$$r_{mt,q} = \frac{1}{u_*\, B_q} \quad \text{with} \quad B_q^{-1} = Sc_q \int_0^{\eta_r} \frac{d\eta}{1 + Sc_q\, K_m/\nu} = \frac{q_r - q_s(T_g)}{q_*} \quad . \tag{4}$$

Here, z_r is the lower boundary of the fully turbulent region of the surface layer (i.e., the height of the molecular-turbulent sublayer), $\zeta = (z - d)/L$ is a non-dimensional height, L is the Monin-Obukhov stability length, u_* is the friction velocity, $\eta = u_*\, z/\nu$ is a normalised height, $\eta_r = u^*\, z_r/\nu$ is the roughness Reynolds number, K_m is the eddy diffusivity for momentum, B_q is the sublayer Stanton number of water vapour, and $\Psi_h(\zeta_R, \zeta_r)$ is the integral similarity functions of heat and water vapour for the interval $[\zeta_R, \zeta_r]$ within the surface layer (e.g., Kramm, 1989). Similar expressions can be derived for the sensible heat flux. The vertical wind profile is given by

$$U_R = U_r + \frac{u_*}{\kappa}\left(\ln\frac{z_R}{z_r} - \Psi_m(\zeta_R, \zeta_r)\right) \quad , \qquad (5)$$

where U_r can similarly be determined like B_q in Eq. (4) by arbitrarily setting $Sc_w = 1$ (see Fig. 1). The quantity $\Psi_m(\zeta_R, \zeta_r)$ is the integral similarity function of momentum for the interval $[\zeta_R, \zeta_r]$ within the surface layer (e.g., Kramm 1989).

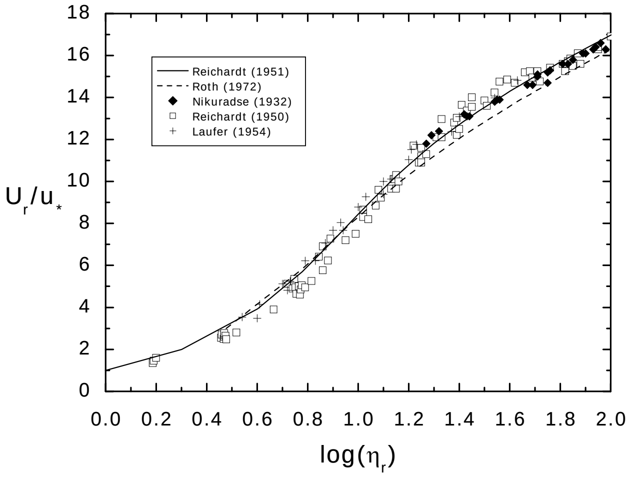

Fig. 1: Non-dimensional velocity profiles in the interfacial sublayer over aerodynamically smooth surfaces calculated on the basis of the integral expression in Eq. (4) with Sci = 1, where Roth's modified Heisenberg spectral model and Reichardt's (1951) K_m/ν-approach are considered, and compared with the laboratory measurements by Nikuradse, Reichardt, and Laufer (from Kramm et al., 1996).

3. Results

Typical results from the numerical investigation of the evaporation at the sea surface for different thermally stratified atmospheric flow are listed in Tab. 1. These results were derived with two different K_m/ν-approaches for the interfacial sublayer, namely Reichardt's (1951) semi-theoretical approach, $K_m/\nu = \kappa\ \{\eta - \eta_D \tanh(\eta/\eta_D)\}$ which well fits measured data (see Fig. 1), and Sheppard's (1958) simple approach $K_m/\nu = \kappa\ \eta$ which is unable to describe the transition range from a purely viscous to the fully turbulent transfer. The latter is applied, for instance, in the Penn State/NCAR mesoscale model MM5. Obviously, using Sheppard's approach provides nearly 50 per cent larger water vapour fluxes and, hence, latent heat fluxes compared to those derived with Reichardt's approach. The same is true for the amounts of sensible heat fluxes. These differences are mainly caused by the different values of the sublayer Stanton number. Based on these results we conclude that parameterisation schemes for the interfacial sublayer must be verified, not only on the basis of laboratory data as Reichardt's K_m/ν-approach, but also on the data from field experiments.

Tab. 1: Predicted values of sensible (H), and latent heat (E), total atmospheric ($r_{a,q}$), and turbulent resistances ($r_{t,q}$), the sublayer Stanton number (B_q), Monin-Obukhov stability length (L), friction velocity (u_*), and bulk transfer coefficient for water vapour (C_q). The predictions were performed for (a) stable case: $U_R = 6.0$ m s^{-1}, $\Theta_R = 287$ K, $q_R = 6.5$ g kg^{-1}, $T_g = 285$ K, and (b) unstable case: $U_R = 6.0$ m s^{-1}, $\Theta_R = 284$ K, $q_R = 6.0$ g kg^{-1}, $T_g = 285$ K.

H W m^{-2}	E W m^{-2}	$r_{a,q}$ s m^{-1}	$r_{t,q}$ s m^{-1}	B_q^{-1}	L m	u_* m s^{-1}	C_q	Remarks
-11.8	30.8	205.5	137.7	10.9	40.2	0.16	$8.1\cdot10^{-4}$	Reichardt's approach
-17.3	45.0	140.7	106.0	7.0	52.6	0.20	$1.2\cdot10^{-3}$	Sheppard's approach
7.5	50.4	155.9	93.6	11.2	-47.2	0.18	$1.1\cdot10^{-3}$	Reichardt's approach
11.2	72.3	108.5	76.3	7.3	-63.3	0.23	$1.5\cdot10^{-3}$	Sheppard's approach

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