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SOME IMPROVEMENTS TO LOUIS SURFACE FLUX PARAMETERIZATION

Shouping Wang[1], Qing Wang[2] and James Doyle[1]

[1] Naval Research Laboratory, Monterey, California

[2] Naval Postgraduate School, Monterey, California

1. INTRODUCTION

Surface flux parameterization developed by Louis (1979) and Louis *et al*. (1982) [L82 hereafter] have been widely used in meteorological models due to its simplicity in formulation and non-iterative nature. This parameterization, however, has following weakness as discussed in many papers: weak dependence on bulk Richardson number over smooth surfaces in convective conditions and overall inability dealing with different roughness lengths for momentum and heat transfer.

We take following steps to address these weakness. For convective regimes, Louis scheme is tuned to match Monin-Obukhov Similarity (MOS) with gustiness effects: COARE2.6 parameterization developed by Fairall and Bradley group (Bradley et al., 2000) We then use an approach similar to that of Uno *et al*. (1996) to address different momentum and heat roughness length issue. Finally, an analytical method is developed to solve z/L in the Monin-Obukhov similarity formulation by Holtslag and DeBruin (1988) under stable conditions.

2. CONVECTIVE CONDITIONS WITH $z_0 = z_{0h}$

The original Louis scheme can be written as

$$u_* \theta_* = \frac{U \, \Delta\bar{\theta} \, k^2}{\ln(z/z_o)\ln(z/z_o)} F_H\left(z/z_0, R_{b0}\right) \qquad (1)$$

$$u_*^2 = \frac{U^2 \; k^2}{\ln(z/z_o)\ln(z/z_o)} F_M\left(z/z_{0h}, R_{b0}\right) \qquad (2)$$

where z_0 is the momentum roughness length, R_{b0} bulk Richardson number calculated between z_0 and the reference height z_a, Note that the heat transfer roughness length does not appear in (1) and (2), because they are assumed to be equal. We separate two regimes: "smooth" surface with $z_a/z_0 \geq 10^3$ and "rough" surface with $10 \leq z_a/z_0 \leq 10^3$ and then adjust the stability functions to fit COARE2.6.

3. CONVECTIVE CONDITIONS WITH $z_0 \neq z_{0h}$

Uno *et al*. (1996) (U96 hereafter) derived an approach to adjust z_0 to z_{0h} in L82, and found very consistent performance. Their idea is to use θ^* derived from (1) and (2) to adjust $\Delta\theta_0 = \theta(za) - \theta(z_0)$ to $\Delta\theta_T = \theta(za) - \theta(z_{0h})$. There are, however, two difficulties associated with their approach. One is θ^* derived from (1) and (2) is singular at U=0, which means that the corresponding z_{0h} correction must be infinitely large. This feature may cause problems at large Richardson number under unstable and light wind conditions, and is inconsistent with the convective limit originally designed in L82. Another minor complication is the iterative nature of the approach, although two iterations are usually sufficient for the desired accuracy.

Based on these considerations, we follow U96 idea but use the θ^* stability function from MOS function. We consider the stability parameter *z/L*

$$\frac{z}{L} = \frac{\left[\ln\left(z_a/z_0\right)\right]^2}{\ln\left(z_a/z_{0h}\right)} \bullet \frac{R_b}{1+\left(\beta w^*/U\right)^2} \bullet \frac{\left(1-\dfrac{\psi_m(z/L)}{\ln(z/z_0)}\right)^2}{\left(1-\dfrac{\psi_h(z/L)}{\ln(z/z_{0h})}\right)} \qquad (3)$$

where L is Monin-Obukhov length, ψ_m and ψ_h are stability functions for momentum and scalar transfer. Following Stull (1994), we use convective velocity definition to write

$$\left(\frac{\beta w^*}{U}\right)^2 = -\beta^2 C_g \frac{z_i}{z_a} R_b \,, \qquad (4)$$

where (β, C_g, z_i) are chosen to be (1.2, 0.006, 600.0). Note here that the *z/L* as defined by (3) and (4) is no longer singular at *U=0* under convective condition. The last factor in (3) is a complicated function of *z/L*. Consequently, a stability-like parameter is chosen and defined by

$$\zeta_t = b_b \frac{\left[\ln\left(z_a/z_0\right)\right]^2}{\ln\left(z_a/z_{0h}\right)} \bullet \frac{R_b}{1-R_b/b_b} \qquad (5)$$

Corresponding author Address: Shouping Wang, NRL, Monterey ,California 93943. wang@nrlmry.navy.mil

where b_b is defined in the Appendix.

4. STABLE CONDITIONS

For continuous turbulence under stable condition, the stability functions in MOS are essentially same for momentum and scalar transfer, i.e., $\psi_m = \psi_h$ for $z/L \leq 10$ (Holtslag and De Bruin, 1988), although $\psi_m > \psi_h$ for intermittence turbulence as discussed by Beljaars and Holtslag (1991). Because the stability functions of Holtslag and De Bruin (1988) can be readily simplified, their functions are used as basis for the parameterization and can be expressed as

$$\psi_m = \psi_h = -a\zeta - b(\zeta - \frac{c}{d})\exp(-d\zeta) - \frac{bc}{d} \qquad (6)$$

where a=0.7, b=0.75, c=5.0 and d=0.35. Because ζ can be analytically solved for linear functions of ψ, the idea is to use ζ_0 calculated from L82 scheme in the exponential factor only, then solve for ζ analytically from the general functional relationship between ζ and R_b. The new approach is summarized in Appendix. Note it maintains non-iterative nature of L82.

5. IDEALIZED CALCULATION

Given Richardson number, z_a/z_0 and z_0/z_{0h}, the stability functions can be calculated using the formula in Appendix. Some comparisons among different schemes are shown in Figs. 1 – 2. The COAMPS(OLD) scheme is the surface flux parameterization currently used in the NAVY's COAMPS and basically is the same as L82 except that the wind speed calculation includes the temperature difference between the surface and air to represent convective gustiness. Clearly, the modified (NEW) Louis scheme compares well with COARE2.6 for both smooth and roughness regimes for different z_0 and z_{0h}. COAMPS(OLD) and L82 significantly overestimates and underestimates the value of the functions respectively.

6. TOGA COARE DATA

TOGA COARE R/V *Moana Wave* turbulence data are used to evaluate the modified scheme. The results are shown in Fig 3-4. The modified Louis scheme (NEW) corrects the positive bias for the stress and reduces the scatter. The latent heat flux from the modified Louis (NEW) is also improved compared with that calculated using COAMPS(OLD) scheme.

Currently, we are refining the scheme particularly for stable regime and for the conditions where z_0 and z_{0h} are significantly different as discussed in Beljaars and Holtslag (1991).

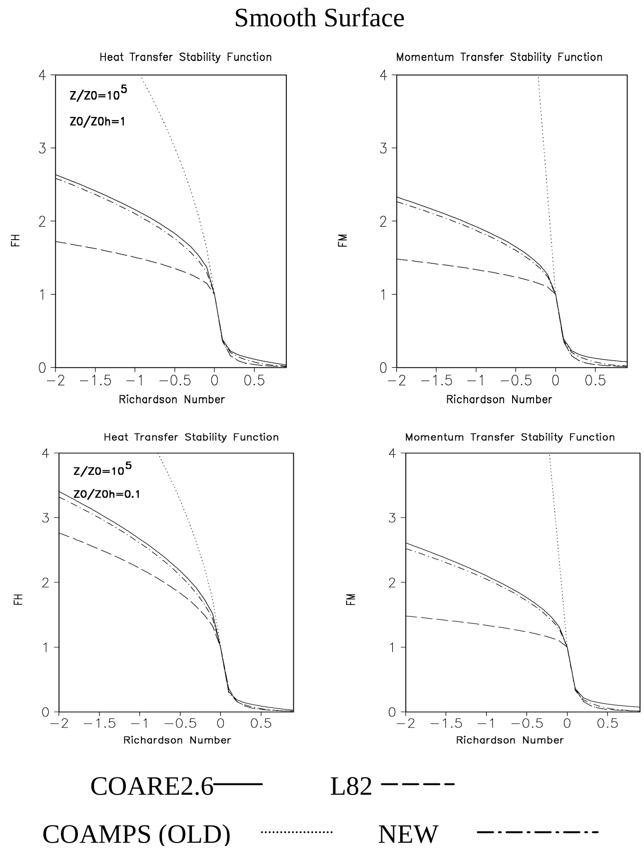

Figure 1 Stability functions over smooth surface

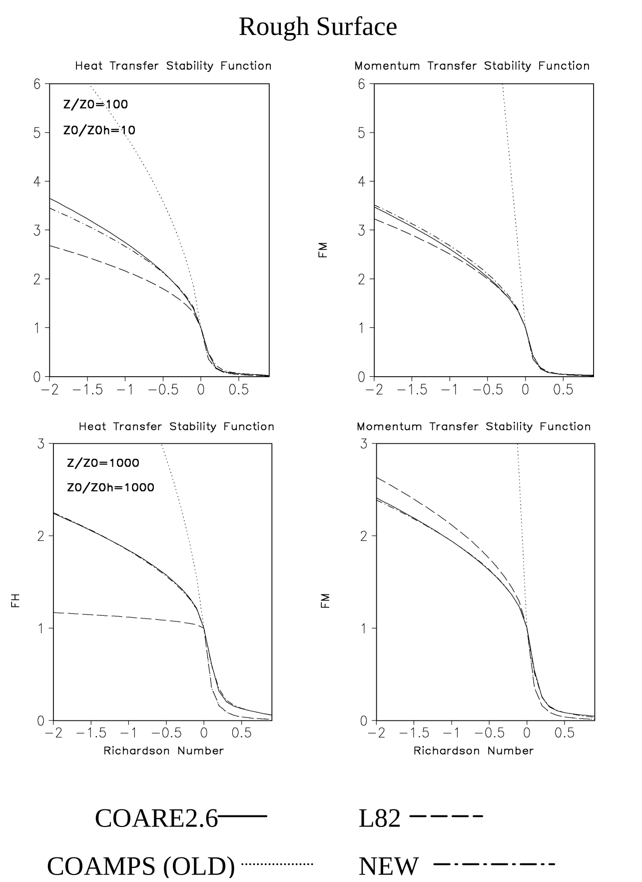

Figure 2 Stability functions over rough surface

STRESS (MODEL vs. OBS)

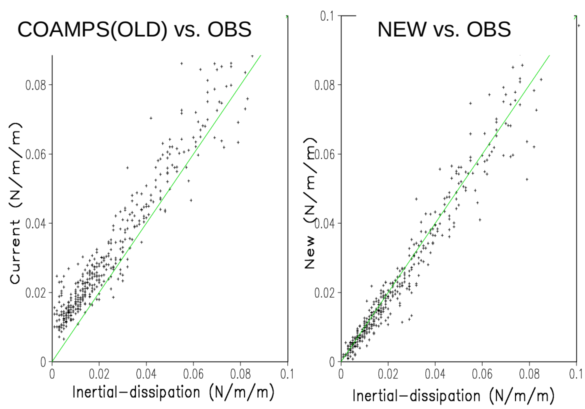

Figure 3 Stress: Model vs. COARE R/V *Moana Wave*

LATENT HEAT FLUX (MODEL vs. OBS)

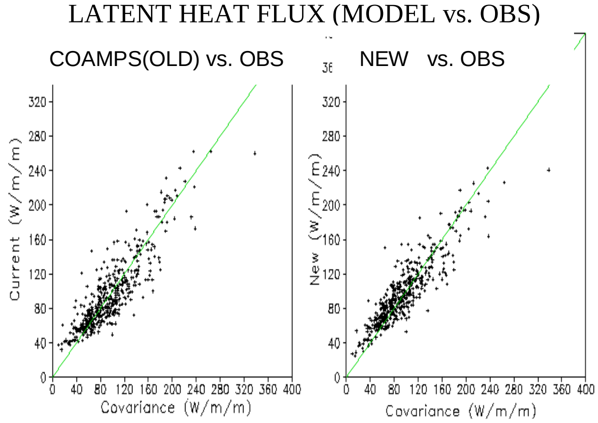

Figure 3 Latent heat flux: Model vs. *Moana Wave*

ACKNOWLEDGMENTS

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Appendix

1. Unstable Conditions

For $\frac{z_a}{z_0} \geq 1000$,

$$C_h = -1.675\times10^{-2}\left[\ln\left(1+\frac{z_a}{z_0}\right)\right]^2 - 8.716\times10^{-2}\ln\left(1+\frac{z_a}{z_0}\right) + 5.902;$$

$C_h \geq 1$

$$C_m = -3.116\times10^{-2}\left[\ln\left(1+\frac{z_a}{z_0}\right)\right]^2 - 2.7825\times10^{-2}\ln\left(1+\frac{z_a}{z_0}\right) + 7.7794$$

$C_m \geq 1.8$

$b_b = 1.0$.

For $10 \leq \frac{z}{z_0} \leq 1000$,

$$C_h = -9.698\times10^{-2}\left[\ln\left(1+\frac{z_a}{z_0}\right)\right]^2 + 1.3792\ \ln\left(1+\frac{z_a}{z_0}\right) - 0.3996;$$

$$C_m = -0.125\left[\ln\left(1+\frac{z_a}{z_0}\right)\right]^2 + 1.854\ \ln\left(1+\frac{z_a}{z_0}\right) - 0.725$$

$$b_b = -1.541\times10^{-2}\left[\ln\left(1+\frac{z_a}{z_0}\right)\right]^2 + 0.2764\times\ln\left(1+\frac{z_a}{z_0}\right) - 0.1724;$$

$b_b \geq 0.01$

$$\zeta_t = b_b \frac{[\ln(1+z_a/z_0)]^2}{\ln(1+z_a/z_{0h})} \bullet \frac{R_b}{1-R_b/b_b} \quad \text{and}$$

$$\psi = 2\ln\left[\frac{1}{2}\left(1+\sqrt{1-16\zeta_t}\right)\right],$$

$$f_t = \frac{1}{1+\dfrac{\ln(z_0/z_{0h})}{\ln(1+z_a/z_{0h})} \bullet \dfrac{\psi}{\ln((z_a+z_{0h})/z_0)-\psi}} \quad \text{and}$$

$$f_c = \frac{\ln((z_a+z_{0h})/z_0)}{\ln(1+z_a/z_{0h})} f_t$$

$$u_* \theta_* = \frac{U\,\Delta\bar{\theta}\, f_t\, k^2}{\ln(1+z/z_o)\ln(1+z/z_{oh})}\left(1-\frac{3.6\,b\,R_b\, f_c}{1+\dfrac{3bC_h k^2}{[\ln(1+z_a/z_o)]^2}\sqrt{|R_b|\, f_c \dfrac{z_a}{z_o}}}\right)$$

$$u_*^2 = \frac{U^2\ k^2}{(\ln(1+z_a/z_o))^2}\left(1-\frac{2.4\ b\,R_b\ f_c}{1+\dfrac{2\,b\,C_m\ k^2}{[\ln(1+z_a/z_o)]^2}\sqrt{|R_b|\, f_c \dfrac{z_a}{z_o}}}\right)$$

2. Stable Conditions:

Louis scheme is used to calculate an initial guess of ζ, that is

$$\zeta_0 = \frac{[\ln(z/z_0)]^2}{\ln(z/z_{0h})} R_b \sqrt{1+10\, R_b\, (1+8R_b)}\ .$$

We then solve for ζ from the following simple quadratic equation

$$\zeta = \frac{[\ln(z/z_0)-\psi_0]^2}{(\ln(z/z_{0h})-\psi_0)} R_b, \quad \text{where}$$

$$\psi_0 = -a\zeta - b(\zeta - \frac{c}{d})\exp(-d\zeta_0) - \frac{bc}{d}$$

to give

$$\zeta = \frac{-B + \sqrt{B^2 - 4AC}}{2A} \quad , \text{ where}$$

$$p = (-a - b)e^{-d\zeta_0}, \quad q = \frac{b\,c}{d}\left(-1 + e^{-d\zeta_0}\right)$$

$$A = -p - R_b\, p^2 \quad ,$$

$$B = \ln(z/z_{0h}) - q + 2R_b\, p\ln(z/z_0) - 2R_b\, p\,q \quad \text{and}$$

$$C = -R_b\left[\ln(z/z_0)\right]^2 + 2\,q\,R_b\, \ln(z/z_0) - R_b\, q^2$$

We then have the transfer coefficients from (6)

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