Estimation of Large Scale Evaporation by a Complementary Relationship with a simple ABL Model

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1. Introduction

Estimation of evaporation from the land surface is still a difficult job, particularly in an area where soil moisture decreases frequently to a point to force the stomatal closure of vegetation and thus to reduce evaporation even when the atmospheric condition requires and allows more evaporation. Traditionally there have been two ways to incorporate this effect. The first approach uses some kind of soil moisture information and uses that information to reduce the potential evaporation calculated from commonly available meteorological data. The main difficulty of this approach is that it is not easy to obtain any soil moisture information to begin with, especially when one deals with the regional evaporation. Even when soil moisture data are available, they do not necessarily represent the whole region well since soil moisture is known to vary quite largely both vertically and horizontally. Another approach that avoids the use of soil moisture data is to treat the soil moisture as one of the variable to be predicted within a model; thus not only the atmosphere but also upper soil column are included within the model. This is becoming a common practice in some of the regional and global circulation models. Unfortunately, the accuracy of the predicted fluxes and soil moisture are still not satisfactory, even though a constant progress has been made to improve the products. Also, it is usually necessary to increase the complexity of a model to enhance the accuracy, while more complicated models tend to have a problem of "equifinality" in the calibration (Franks et al, 1997); because of the complex nature of these models, it is difficult to make a calibration of needed parameters and there are many possible combination of optimal parameters that produce an equally good result. Thus it may not always be clear if the calibrated parameters are universal and one can expect a reasonable result with them outside the area where the calibration took place.

Sugita et al. (2001) presented a simple model which has a potential to avoid the problems outlined above to estimate large scale evaporation even under drying surface conditions without the knowledge of soil moisture. In this paper, a brief outline of the model and the results of the model application will be presented together with possible usages of the method to derive a continental scale evaporation map.

2. Method

The idea of a simple procedure to estimate evaporation estimation without soil moisture data has been accomplished by employing the complementary relationship (Bouchet, 1963) as the main framework of the model. In essence, it can be expressed by.

$$E_p + E = \eta \times E_{po} \qquad (1)$$

where E_p is the potential evaporation which would take place under the prevailing atmospheric conditions with the available energy being the only limiting factor, E is the actual regional evaporation, and η=2.0. When E=E_p, it is denoted by E_{po} and this is the case when there is plenty of available water and there is no plant physiological control to the water transfer from the soil into the atmosphere. The main hypothesis of Bouchet (1963) was that when evaporation E decreases for some reason below E_{po} while the available energy remains the same, the potential evaporation E_p is increased by exactly that amount, which yields the complementary relation between E and E_p. The rationale behind this argument is that the energy that becomes available due to the decrease of E will be used to raise the air temperature through the sensible heat flux, and this should dry the air and result in the increase in E_p. Thus if the appropriate forms for E_p and E_{po} can be specified, E should be able to be evaluated without the knowledge of soil moisture and vegetation status.

However, recent studies have shown that the hypothesis is not strictly valid (e.g., McNaughton and Spriggs, 1989; Lhomme 1997, Sugita et al. 2001). Thus an alternative method was proposed in Sugita et al. (2001) in which the η value is treated as unknown variable and is determined thourgh iteration in (1). This "relaxed complementary relationship" can be applied to the data sets to estimate regional evaporation still without the knowledge of soil moisture condition.

For E_p and E_{po} evaluation, the Penman-type equation

$$E_{PE} = \frac{\Delta}{\Delta+\gamma}\frac{(Rn-G)}{\ell} + \frac{\gamma}{\Delta+\gamma}E_A \quad \textbf{(2)}$$

was used, in which Δ is the slope of the saturation water vapor pressure at temperature T_a and γ is the psychrometric constant defined as $\gamma = c_p p / (0.622 \times \ell)$ where c_p is the specific heat of air, p is the air pressure, and ℓ is the latent heat for vaporization. E_A is a drying power of the air and can be evaluated by (3).

$$E_A = ku_* \rho \, (q^* - q) \Big/ \left[\ln\left(\frac{z-d_0}{z_{0v}}\right) - \Psi v\left(\frac{z-d_0}{L}\right) \right]^{-1} \quad \textbf{(3)}$$

where u_* is the friction velocity, ρ is the air density, k is the von Karman's constant (=0.4), q^* is the saturation specific humidity and q is the specific humidity, z is the height above the ground, d_0 is the zero-plane displacement height, z_{0v} is the scalar roughness for water vapor, Ψ_v is the stability correction function for water vapor and L is the Obukhov length. Actual measurements of (q^*-q) is used to determine E_p while (q^*-q) values simulated by an ABL model with surface resistance r_{st}=0 are used to predict E_{po}. A modified ABL model (Sugita et al., 2001) of Lhome (1997) can be used for this purpose.

3. Model Validation

3.1 HEIFE data set

The idea to estimate E with (1)-(3) with the inputs from the CBL model was explored with the data set obtained during the Heife River Field Experiment (HEIFE) (Mitsuta, 1988) whose major observations took place in 1990-1992 in the Hexi Corridor area between the Qilian Mountains and the Longshou Mountains in Gansu Province of China. A typical annual rainfall is as small as 100 mm and the land surfaces are covered primarily with sand and stony deserts with some dotted oases and irrigated farm lands. In the present study, the data set of surface fluxes and related variables produced from measurements at a desert station located at 100°10' E and 39°23' N with altitude of 1400 m above a surface of fine sand was mainly used. The data set of Mitsuta et al. (1995) were mainly used in the analysis.

Figures 1 and 2 give the comparison between measured daytime evaporation and corresponding estimated values. Figure 1 is the result of assumed value of η=2.0 while Figure 2 came from the procedure outlined above without the assumption. Clearly, the procedure gave better agreement of the evaporation.

3.2 GAME/AAN data sets

Similar analysis can be made with the data set obtaind from GAME/AAN project. In view of the experimental area of HEIFE, priorities should be placed to those data sets taken in vastly different regions. The candidate should include several data sets in Thailand which give opportunity to test the usefulness of the method in a very contrasting conditions of dry/wet season encountered in the same areas. Also data sets from cold regions should give important insights into not only the model applicability over these areas but also the land-atmosphere interaction problems in general.

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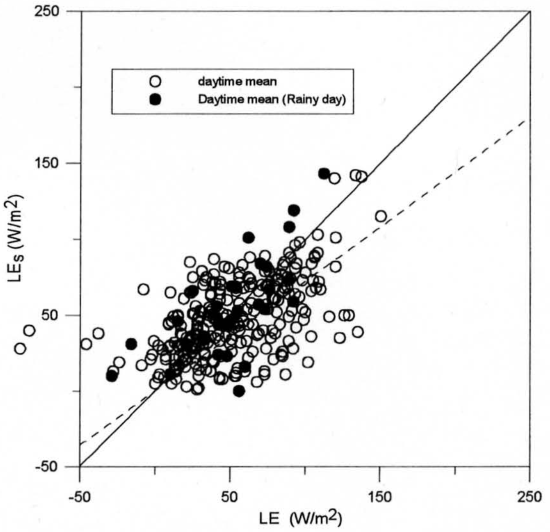

Fig. 1 Comparison between observed latent heat flux LE_s and model predicted values LE with η=2.0. The straight line indicates 1 to 1 agreement while the dotted line gives the slope of the regression equation of the form y=ax.

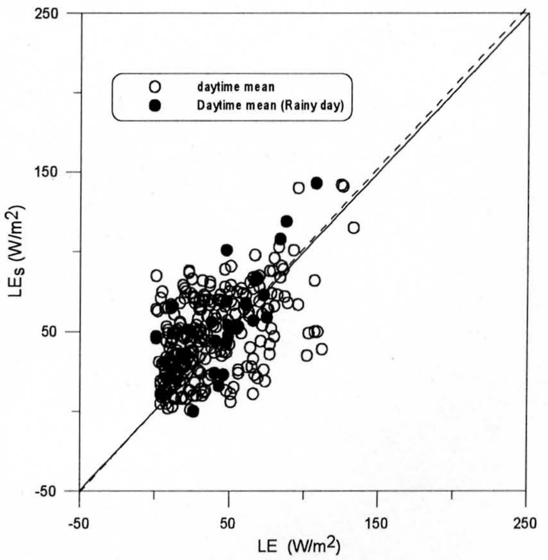

Fig. 2 Same as Fig.1 but model predication was carried out without the assumption of η=2.0