A New Method to Retrieve Sensible Heat and Latent Heat Fluxes from the Remote Sensing Data

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Abstract:

In order to retrieve the latent and sensible heat fluxes, high-resolution airborne imageries with visible, near infrared, and thermal infrared bands and ground-base meteorology measurements are utilized in this paper. The retrieval scheme is based on the balance of surface energy budget and momentum equations. There are three basic surface parameters including surface albedo (α), normalized difference vegetation index (NDVI) and surface kinetic temperature (T0). Lowtran 7 code is used to correct the atmosphere effect. The imageries were taken on 28 April and 5 May 2003. From the scattering plot of data set, we observed the extreme dry and wet pixels to derive the fitting of dry and wet controlled lines, respectively. Then the sensible heat and latent heat fluxes are derived from through a partitioning factor Λ. The retrieved latent and sensible heat fluxes are compared with in situ measurements, including eddy correlation and porometer measurements. It is shown that the retrieved fluxes from our scheme match with the measurements better than those derived from the S-SEBI model.

KEYWORDS: albedo, NDVI

1. Introduction

There are many methods to estimate evapotranspiration (ET) such as evaporating pans, widely used in the weather stations in Taiwan, or empirical methods like Penman-Monteith equation. With the development of remote sensing technology, high-resolution airborne imageries with visible, near infrared, and thermal infrared bands can be used to retrieve the latent and sensible heat fluxes.

In this paper, we study sensible heat flux and latent heat flux from remote sensing data. Some previous studies used energy balance method to estimate evapotranspiration, and neglected the influence on the energy reciprocation (Land Surface Atmospheric Interaction) between the earth's surface and atmosphere near the ground. In fact the evapotranspiration on the earth's surface is actually closely linked with the atmospheric state. That is, the atmospheric state need be considered when evapotranspiration is estimated.

Weather stations spread all over the whole Taiwan. Hence, micro-meteorological data in Taiwan are quite abundant. If the remote sensing imageries and meteorological data are acquired concurrently, evapotranspiration may be derived easily.

2. Procedure description

The estimate of evapotranspiration with remote sensing depends upon the balance of net radiation and soil heat flux; and sensible heat flux. The energy balance may be described by

$$LH_f = R_n - G_0 - SH_f \tag{1}$$

where LH_f is the latent heat flux, , R_n is the net radiation, G_0 is the soil heat flux, and SH_f is the sensible heat flux, all in units of Wm^{-2}.

2-1 Net Radiation

Under steady atmospheric condition, the net radiation can be considered as a balance between incoming and outgoing radiation, i.e.,

$$R_n = (1-\alpha)R_s^{\downarrow} + R_L^{\downarrow} + \varepsilon_0 R_L^{\uparrow} \quad (2)$$

where the symbols R_s and R_L represent the short and long wave radiation, respectively, the arrows indicate the flux direction, α is the surface albedo, and ε_0 is the surface emissivity of thermal infrared band.

2-2 Soil heat flux

We followed methodology proposed by Kustas et al. (1990) and Bastiaanssen et al. (1998) to compute the soil heat flux that is a function of surface albedo, temperature and NDVI, i.e.,

$$G_0 = \Gamma \times R_n$$

$$\Gamma = T_0(0.0032 + 0.0062\alpha)(1 - 0.987NDVI^4) \quad (3)$$

2-3 Sensible heat flux

We can derive sensible heat flux from unstable atmospheric correct function (Businger et al., 1971; Dyer, 1974).

$$SH = \frac{u_* \kappa \alpha_h \rho c_p (T_s - T_a)}{\left\{\left[\ln(\frac{z_2 - z_d}{z_1 - z_d})\right] - \left[\Psi_h(\frac{z_2 - z_d}{L})\right] + \left[\Psi_h(\frac{z_1 - z_d}{L})\right]\right\}} \quad (4)$$

$$u_* = \frac{u_r \kappa}{\left\{\left[\ln(\frac{z_r - z_d}{z_o})\right] - \left[\Psi_m(\frac{z_r - z_d}{L})\right]\right\}} \quad (5)$$

$$L = \frac{-u_*^3 \rho}{\kappa g\left[\frac{SH}{T_a c_p} + 0.61LH\right]} \quad (6)$$

There are two conditions to calculate ψ_h and ψ_m.

i: L>0 (stable):

$$\Psi_h = \Psi_m = \frac{-5(z_r - z_d)}{L} \quad (7)$$

ii: L<0 (unstable):

$$\begin{cases} \Psi_h = 2\ln\left[\frac{(1+x_h^2)}{2}\right] \\ \Psi_m = 2\ln\left[\frac{(1+x_m)}{2}\right] + \ln\left[\frac{(1+x_m^2)}{2}\right] + 2\arctan(x_m) + \frac{\pi}{2} \end{cases} \quad (8)$$

$$x_h = x_m = \left[1 - \frac{16(z_r - z_d)}{L}\right]^{\frac{1}{4}} \quad (9)$$

where

κ : von Karman's constant(κ=0.4) [-]

u* : friction velocity(u*=(τ/ρ)1/2) [ms^{-2}]

ρ : air density[kg/m^3]

α_h : ratio of eddy diffusivity and eddy viscosity [-]

c_p : air specific heat [J/(Kg K)]

L : Monin-Obukhov Length (Monin and Obukhov 1954) [-]

g : acceleration of gravity [m/s2]

z_0 : momentum roughness length [m]

u_r : wind velocity at reference height [m/s]

z_d : the displacement of zero wind velocity plane [m]

T : temperature [K], indices s and a represent the surface temperature and air temperature

z : reference height [m], indices r、1、2 represent the value at three different positions

ψ_s ψ_h :represent vapor and heat stable function[-].

2-4. Friction factor

The friction factor of evportranspiration can be derived form the scattering plot of surface albedo versus temperature. Roerink and Menenti (2000) described the concept to derive the friction from the spectrum characteristic pixel by pixel. If the area reflects sufficient variations in hydrological conditions, the critical control lines can be easily defined. A schematic representation of S-SEBI is given in "Fig. 1".

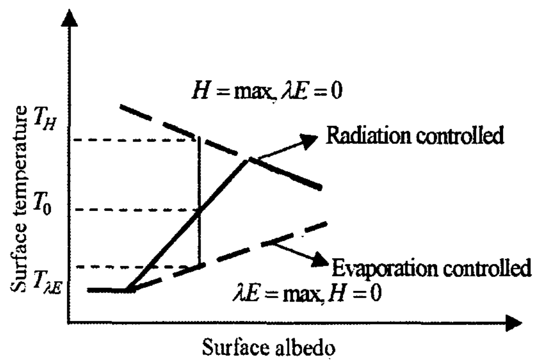

Fig. 1. Relation between surface albedo and temperature.

The friction factor can be defined as

$$\Lambda = \frac{T_H - T_0}{T_H - T_{\lambda E}} \quad (10)$$

where the T_H and $T_{\lambda E}$ are determined by the dry and wet pixels, respectively, through linear regressions $T_H = a_0 \cdot r_0 + b_0$ and $T_{\lambda E} = a_1 \cdot r_0 + b_1$.

2-5. The retrieval method

A numerical iterative method is used to estimate sensible heat flux. The flowchart is shown in Figure 2.

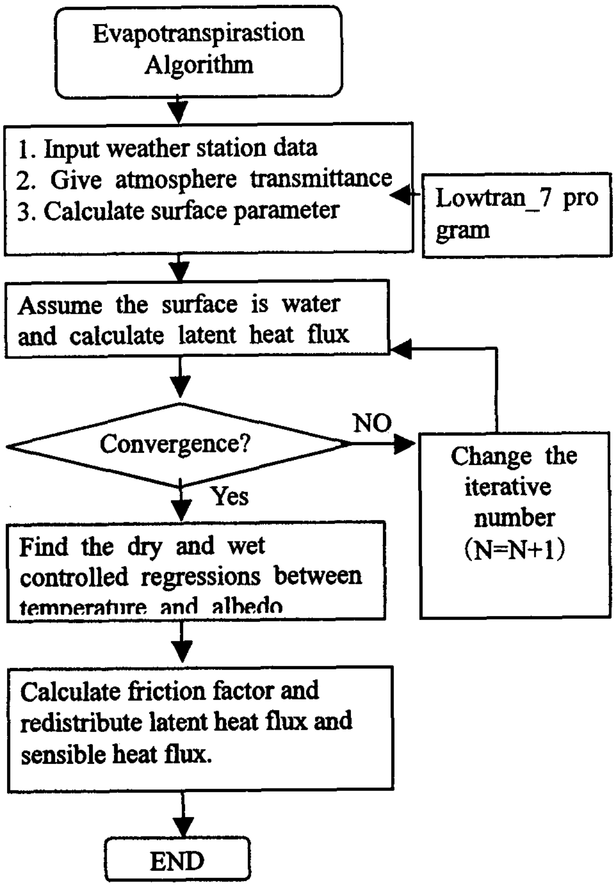

Fig. 2. Relation between surface albedo and temperature.

The sensible heat flux is obtained by the following equation:

$$SH_f = \Lambda \times SH \quad (11)$$

Then, we can find the true latent heat flux through Eq. (1).

3. Compared with other methods

Here we compare with Eddy correlation measurement and S-SEBI Model. The result is shown in "Table 1".

Table 1.New method compared with Eddy correlation and S-SEBI method

Unit in W/m^2	Eddy correlation	S-SEBI model	New algorithm	error SSEBI/NEW
Latent Heat Flux	393.4	487.2	417.5	+24/+6
Sensible Heat Flux	203.3	122.6	192.3	-40/-5
Soil Heat Flux	103.4	39.1	39.1	-61/-61
Net Radiation Flux	598.7	648.9	648.9	+8/+8

Eddy correlation measurement is in situ date. The above results show data retrieved by the new method are better than those derived by the S-SEBI method.

4. Conclusions

1. It is feasible to derive field ET from multi-spectral remote sensing data over the rice paddy in steady atmospheric conditions. Accurate partitioning of the available energy into sensible and latent heat must be carefully treated to separate dry and wet pixels.
2. Our new method assumes momentum roughness length as a constant. In fact, momentum roughness length will change with different surfaces. In future, we will study the effect of momentum rough coefficient.

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