APPLICATION OF REMOTE SENSING IMAGERY ON THE ESTIMATE OF EVAPOTRANSPIRATION OVER PADDY FIELD

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Evaportranspiration is an important factor in hydrology cycle. Traditionally, it is measured by using basin or empirical formula with meteorology data, while it does not represent the evaportranspiration over a regional area. With the advent of improved remote sensing technology, it becomes a surface parameter of research interest in the field of remote sensing.

Airborne and satellite imagery are utilized in this study. The high resolution airborne images include visible, near infrared, and thermal infrared bands and the satellite images are acquired by MODIS. Surface heat fluxes such as latent heat flux and sensible heat flux are estimate by using airborne and satellite images with surface meteorological measurements. We develop a new method to estimate the evaportranspiration over the rice paddy. The surface heat fluxes are initialized with a surface energy balance concept and iterated for convergent solution with atmospheric correct functions associated with aerodynamic resistance of heat transport. Furthermore, we redistribute the total net energy into sensible heat and latent heat fluxes.

The result reveals that radiation and evaporation controlled extremes can be properly decided with both airborne and satellite images. The correlation coefficient of latent heat flux and sensible heat flux with corresponding *in situ* observations are 0.66 and 0.76, respectively. The relative root mean squared errors (RMSEs) for latent heat flux and sensible heat flux are 97.81 (W/m^2) and 124.33 (W/m^2), respectively. It is also shown that the newly developed retrieval scheme performs well when it is tested by using MODIS date.

KEY WORDS: Evapotranspiration, MODIS, Rice paddy, Remote sensing

1. INTRODUCTION

Evaportranspiration is an important factor in hydrology cycle. It also dominates the local and regional water balance. In the semi-arid region, the amount of evaportranspiration is almost equal to the precipitation and the regional evaportranspiration is more than half of the total precipitation (Engman and Gurney, 1991). However, it is difficult to measure the area evaportranspiration, which is often ignored. During the rice growing season, the irrigation water is mainly supplied for evaportranspiration and infiltration. According to the long time record, its amount must be at least 180-300 mm per month to get good quality of rice yields. Apparently, knowledge about the regional evaportranspiration over a rice paddy is useful for water resources management.

Liou et al. (2002) used the S-SEBI model (Rorink et al., 2000) to estimate the evaportranspiration over the rice paddy in Taiwan. Their results showed that the accuracy of retrieved evaportranspiration was not satisfactory. In this study, we use the airborne high-resolution data including green, red, NIR, and thermal bands to develop a retrieval model to obtain paddy's evaportranspiration effectively. The new model is then applied to derive the evaportranspiration from MODIS data and will be utilized to monitor long-term evaportranspiration over rice paddy.

2. PROCEDURE DESCRIPTION

1.1 Methodology

The methodology is based on the surface energy and radiation balance to retrieve the surface heat fluxes by using remote sensing data. Under atmospheric steady condition, the net radiation can be considered as a balance between incoming and outgoing radiation, i.e.,

$$R_n = K^{\downarrow} - K^{\uparrow} + L^{\downarrow} - L^{\uparrow} \qquad (1)$$

where $K^{\downarrow}$ = the incoming short-wave radiation (W/m^2)
$K^{\uparrow}$ = the outgoing short-wave radiation (W/m^2)
$L^{\downarrow}$ = the incoming long-wave radiation (W/m^2)
$L^{\uparrow}$ = the outgoing long-wave radiation (W/m^2)
R_n = the net radiation (W/m^2).

$$R = G + H + \lambda E \quad (2)$$

where R_n = the net radiation (W/m^2)
G_0 = the soil heat flux (W/m^2)
H = the sensible heat flux (W/m^2)
λE = the latent heat flux (W/m^2).

By Combining the surface radiation balance and surface energy balance, we can estimate latent heat flux (evapotranspiration) with remote sensing data, which depends on the evaluation of short- and long-wave radiations, soil heat flux, and sensible heat flux.

1.2 Algorithms

Our algorithm is developed based on the Liou et al. (2002) model by incorporating the concept of energy balance proposed by Rorink et al. (2000). We utilized the atmosphere correct function proposed by Paulson (1970) to correct the aerodynamic resistance of heat transport. The formulations are written as follow,

$$SH = \frac{\rho_{air} c_p (T_s - T_a)}{r_{ah}} \quad (3)$$

$$u_* = \frac{u_r \kappa}{\left\{ \left[\ln(\frac{z_r}{z_o}) \right] - \Psi_m \right\}} \quad (4)$$

$$L = \frac{-u_*^3 \rho_{air} C_p Ts}{\kappa g SH} \quad (5)$$

$$r_{ah} = \frac{\ln\left(\frac{z_2}{z_1}\right) - \Psi_{h(z2)} + \Psi_{h(z1)}}{\kappa u_r} \quad (6)$$

where κ= the von Karman's constant (=0.4)
u*= the friction velocity (m/s^2)
ρ_{air}= the density of air (kg/m^3)
C_p= the air specific heat (1004 J/(kg/K))
L= the Monin-Obukhov length
g= the gravitational constant (9.81 m/s^2)
z_0= the aerodynamic resistance (m).

The Monin-Obukhov length is used to define the stability condition of the atmosphere in an iterative process. After iterative process, the sensible heat flux pixel by pixel is initially determined. However, remote sensing data usually include a large number of pixels or area such as very dry or very humid regions, and heat fluxes at some regions are often underestimated or overestimated. Therefore, redistribution of these fluxes is required by inputting them to scattering plot (Fig.1).

When the S-SEBI model was modified, there were four different ground control points chosen to determine the hot pixels and cold pixels in order to obtain the regress between the radiation and evaporation controlled lines.

Finally, the fraction factor of evportranspiration (Λ) was derived from the scattering plot (Roerink et al., 2000) (Fig.1) of surface albedo versus temperature and consequently obtained the final sensible heat and latent heat fluxes from the imagery. The inferred fluxes were validated against the measurements from *in situ* eddy covariance instruments.

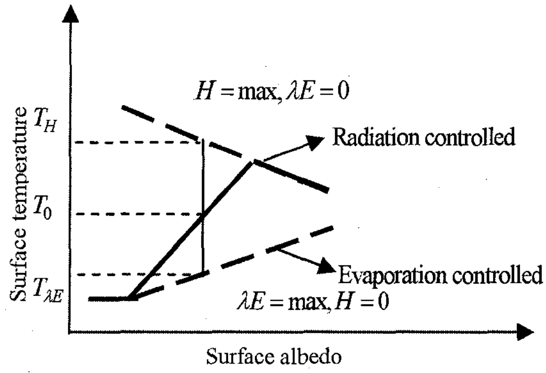

Fig. 1. The schematic representation of the relation between surface albedo and temperature.

1.3 Instrumentation

We used DUNCAN MS3100-CIR and TIR sensors onboard the helicopter to acquire images of radiance at green, red, NIR, and thermal infrared bands on April 28, 2003. Tables 1 and 2 show the spectrum of our instruments.

Table 1. MS3100CIR spectrum and its FWHM

Band	Center Wavelength	FWHM
Green	550 nm	40 nm
Red	660 nm	40 nm
IR	800 nm	65 nm

Table 2. Information of TIR instrument

Spectral Band	8 μm-12μm
Lens/f	10.5 mm /0.8 Germanium
Field of View	32.4 °

3. RESULTS

We chose four kinds of surface covers as ground control points including auto selected ground control points, building, asphalt, and the ridge in the rice fields to determine the hot and cold pixels, which were in turn used to obtain regressions for the radiation- and evaporation-controlled lines. *In situ* data and the derived surface energy fluxes over the four different surface covers as ground control points are compared. Table 3 shows that the lowest bias of evaporation fraction is obtained for the auto selected ground control points. The result is very useful because it indicates that our model may perform automatically and quickly.

Table 3. Comparison of *in situ* and four different covers as ground control points to estimate the surface energy fluxes

GCPs	Auto selected	building	asphalt	ridge	In situ
LH	389.6	87.67	84.994	28.84	393.4
SH	44.79	346.75	349.4	405.58	203.3
G_0	139.03	139.03	139.03	139.03	103.4
R_n	573.45	573.45	573.45	573.45	598.7
Λ	0.8968	0.2018	0.1956	0.0663	0.794

We decide the auto selected ground control point method as our method and compared with other algorithms such as SABLE (Bastiaanssen et al., 1998) and Chen et al. (2004). Table 4 shows that our method has the lowest error in evaporation fraction of all, and it was just 6.8%.

Table 4.Compared with in situ, our method, SABLE and Chen (2004)

	SABLE	Chen (2003)	Our method	In situ
LH(W/ m^2)	389.6	417.5	368.61	393.4
SH(W/ m^2)	44.79	192.3	65.8	203.3
G_0(W/ m^2)	139.03	39.1	139.03	103.4
R_n(W/ m^2)	573.45	648.9	573.45	598.7
Λ	0.8968	0.6847	0.8484	0.7943
Λ error	12.9%	13.7%	6.8%	

4. VALIDATION

We use satellite images acquired by MODIS from 1 January to 1 March, 2006 to validate our new model, but compared with *in situ* data, we find that the correlation coefficient is not as high as expected when using our model.

Therefore, we choose other atmosphere correct functions such as Dyer (1974) and Brustaert (1992) to redo the retrieval of surface heat fluxes. However, the correlation coefficients are not high either. (See, Table 5.)

We propose a new atmosphere correct function, which combines Paulson's and Dyer's unstable atmosphere correction functions in order to get batter results from MODIS data. Table 5 shows that the new Method indeed has better correlation coefficient of surface heat fluxes than the others.

Table 5. Correlation coefficients of surface heat fluxes for four different atmosphere correct functions.

	Paulson (1970)	Dyer (1974)	Brustaert (1992)	New Method
LH	0.50	0.54	0.02	0.66
SH	0.018	0.1	0.84	0.76
G_0	0.439	0.439	0.439	0.54
R_n	0.57	0.57	0.57	0.75

The new atmosphere correct method is proceeded as follows,

(1) Using Paulson's method to calculate the dT in whole image
(2) To estimate the new net radiation (R_n) again.
(3) Using new R_n to input Dyer's method
(4) To assume the Ta is the lowest Ts in the image.

5. CONCLUSIONS

In this paper, we develop a new model to obtain evaportranspiration over rice paddies by remote sensing data. Both airborne and satellite imagery were utilized, and the results reveal that we have a good result with airborne image by our proposed retrieval model. Compared with in situ data, the bias of evaporation fraction is only 6.8%, while it may be improved by combining Paulson's and Dyer's unstable atmosphere correct functions. The correlation coefficient of latent heat flux and sensible heat flux with corresponding in-situ observations are increased to 0.66 and 0.76, respectively. The relative root mean squared error for latent heat flux and sensible heat flux are 97.81(W/m^2) and 124.33(W/m^2), respectively.

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