Airborne Remote Sensing of Evapotranspiration over Rice Paddy

Y.Y. Chen
Institute of Hydrological Sciences, National Central University
No. 300, Jung-da Rd., Jung-li City, Taoyuan, 320 Taiwan
s1625001@cc.ncu.edu.tw

Yuei-An Liou
Center for Space and Remote Sensing Research, National Central University
No. 300, Jung-da Rd., Jung-li City, Taoyuan, 320 Taiwan
yueian@csrsr.ncu.edu.tw

Abstract: We present a retrieval scheme for the remote sensing of evapotranspiration (ET) over rice paddy. To perform the retrieval, high-resolution airborne imagery of multi-spectral visible and thermal infrared data, and ground-based meteorological measurements are utilized. Our ET retrieval scheme is based on the basic principal of surface energy budget, which is a result of balance in longwave and shortwave radiation, latent heat, sensible heat, and energy flux into the ground. To partition the latent and sensible heat fluxes of interest from the energy balance equation, three basic parameters are of most concern, including albedo, surface temperature, and normalized difference vegetation index (NDVI). The NDVI and albedo can be easily derived from the visible and near infrared spectral data, while the surface temperature can be determined through the analysis of the infrared data with the Stefan Boltzmann law. From the airborne imagery taken on 28 April 2003, we observe very good dry and wet pixels that can be easily corresponded to the radiation and evaporation controlled criteria, respectively, and, hence, for the further use in defining the evaporative fraction needed to partition sensible and latent heat fluxes from the net energy flux. The derived ET is compared with the *in situ* measurements.
Keywords: Evaportransipiration, Rice paddy, NDVI.

1. Introduction

During the recent decades, remote sensing data (METEOSAT、AVHRR、LandSat、SPOT) have been used to derive the surface ET (evaportranspiration) [1] [2] [4] [7] [9] [11]. However, the scale of agriculture field is on the order of hundred meters or less on Taiwan. Consequently, the spatial resolution of spaceborne remote sensing instrument that is generally too large should be used as a reference indicator. For example, Chung et al. [5] used the airborne instrument DMSV-1 (Digital Multi-spectral Video) to estimate ET over the rice paddy. In this paper, we utilize DUNCAN MS3100-CIR and TIR sensors onboard the helicopter to acquire images of radiance at green、red、NIR and thermal bands. Then, the radiance images are used to infer ET over the study field. The inferred ET is validated against the measurements from *in situ* porometer and eddy correlation instruments.

2. Procedure description

The estimate of evapotranspiration with remote sensing depends upon the evaluation of net radiation and soil heat flux; and a friction factor of evaporation that is defined by the spectral characteristic of scattering plot of the albedo versus surface temperature. The energy balance may be written as

$$\lambda E = \Lambda \times (R_n - G_0) \qquad (1)$$

where λE is the latent heat flux, Λ is friction factor of evapotranspiration, R_n is the net radiation, and G_0 is the soil heat flux, all in units of Wm^{-2}.

Net Radiation

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

$$R_n = (1-\alpha) \times K^{\downarrow} + L^{\uparrow} - L^{\downarrow} \qquad (2)$$

where the symbol K and L represent the short and long wave, respectively. The arrows indicate the flux direction. α is the surface albedo. $K^{\downarrow}$ is dependent on season, location and local time. $L^{\uparrow}=\sigma T_0^4$. T_0 is the surface temperature. $L^{\downarrow}$ is the long wave radiation coming from the contribution of the atmosphere [10].

Soil heat flux

We followed Kustas et al. [6] and Bastiaanssen et al. [1] to compute the soil heat flux that is a function of surface albedo, temperature and NDVI, i.e.,

$$G_0 = \Gamma \times R_n$$
$$\Gamma = T_0 (0.0032 + 0.0062\alpha)(1 - 0.987 NDVI^4) \qquad (3)$$

Friction factor

The friction factor of evportrnspiration can be derived form the scattering plot of surface albedo versus temperature. Roerink and Menenti [11] described the concept to derive the friction from the spectral 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.

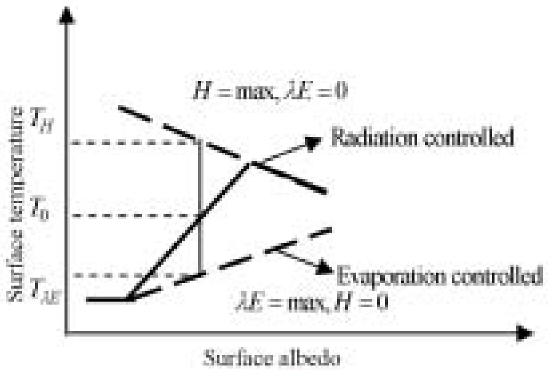

Fig. 1. The schematic represents the relation between surface albedo and temperature.

The friction factor can be defined as

$$\Lambda = \frac{T_H - T_0}{T_{\lambda E} - T_H} \tag{4}$$

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 $T_{\lambda E} = a_1 \cdot r_0 + b_1$.

3. Calculation of evapotransipiration

The meteorology data used to test the ET retrieval model come from the Wu-Fang weather station as shown in Table 1.

Table 1. The weather data at 13:00 p.m. on 28 April 2003.

Air temperature [˚C]	Short wave radiation [MJ/m2-hr]	Relative humidity [%]
31.8	2.24	62.7

To derive the surface albedo and temperature scattering plot, we choose some wet and dry pixels as shown in Fig. 2 into deriver linear regressions and the regression coefficients a and b as given in Table 2.

Table 2. Regression coefficients of a and b.

Relationship	a	B
T_H	-4.98	50.71
$T_{\lambda E}$	4.00	41.57

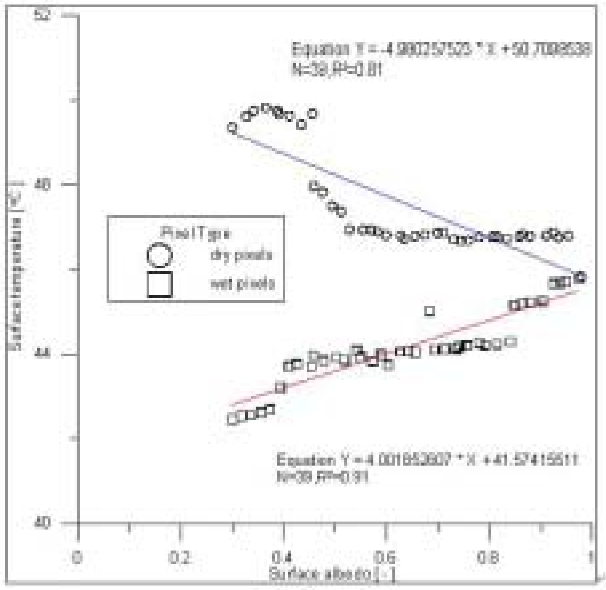

Fig. 2. The surface temperature and albedo scattering plot with the dry and wet pixels.

Through the regression process the friction factor (Λ) can be derived pixel by pixel. Then, the evapotranspiraion of rice paddy can be calculated. Fig. 3 shows the net available energy (R_n-G_0) 、sensible heat and latent heat fluxes of rice paddy at 12:45 p.m. on 28 April 2003.

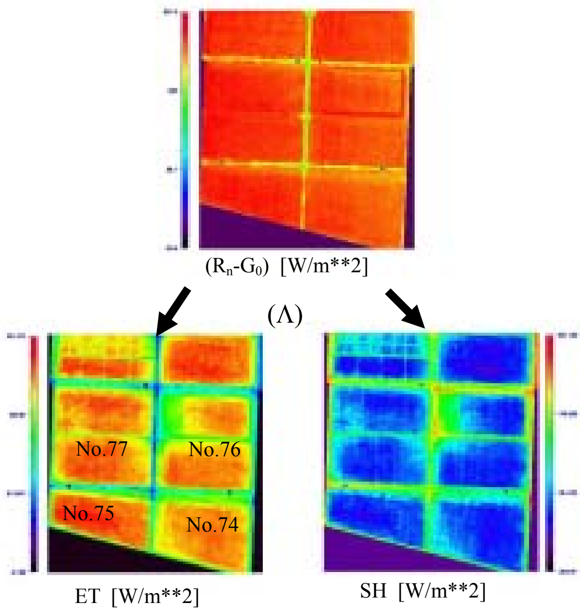

Fig. 3. The net available energy (Rn-G0) 、sensible heat and latent heat fluxes of rice paddy at 12:45 p.m. on 28 April 2003.

4. The Experiment

Eddy correlation

The eddy correlation measurement is set up on the center of field No. 77 as shown in Fig. 3; and takes measurements every 30 min as shown in Table 3.

Table 3. Eddy correlation measurements in No.77 on 28 April 2003. (All units in Wm^{-2})

Time	Latent heat	Sensible heat	Net radiation
12:00	417.54	205.74	578.54
12:30	393.36	203.30	598.70
13:00	405.82	185.81	580.08

Porometer

LI-1600 Steady State Porometer [8] is used to measure the tranaspiration in unit area of the foliage. It should be multiply the LAI (Leaf Area Index) for converting to the crop transpiration. The LAI of of the field is set to be 3.12 [3] [12] in the milk-ripe stage. The crop transpiration of the fields No. 74 and No. 75 are shown in Fig. 4 and Fig. 5, respectively.

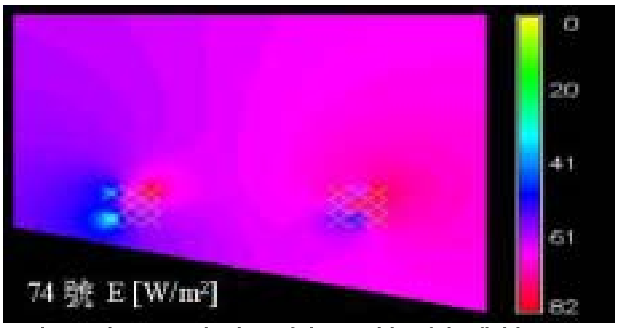

Fig. 4. The transpiration of rice paddy of the field No.74.

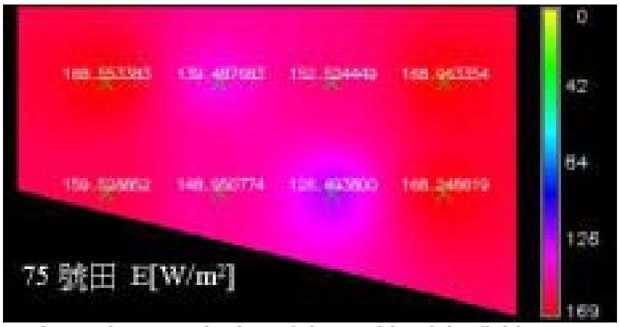

Fig. 5. The transpiration of rice paddy of the field No.75.

5. Conclusions

Two major findings are obtained.

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. The spatial information of evaportanspiration derived from the multi-spectral and in situ data indicate that the spatial ET distribution is more uniform for the field No. 75, but the ET distribution for the field No. 74 appears to be higher on the left than the right regions.

Acknowledgement

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