Evapotranspiration estimation with remote sensing and surface energy balance algorithm

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Abstract: As a crucial component in the energy and water balance of the hydrological cycle at the land-air interface, evapotranspiration (ET) is crucial to provide insight into the surface energy balance of the earth. Based on the surface energy balance models, this study presents the incorporation between remote sensing and meteorological data for ET estimation. The proposed method applies Landsat satellite data for a location situated in the Tainan, Taiwan

Keywords: evapotranspiration, near surface air temperature, surface energy balance, Landsat.

1. Introduction

ET is one of the most important factors of the hydrological cycle. Traditional approaches for ET estimation have been proposed through estimating surface flux. However, they rely on point observations and have difficulties to give ET estimation over a regional or large scale. With the development of remote sensing technology, it provides a promising source of data for determining the ET over a large area with temporal efficiency, lower cost, and better accuracy.

The main objectives of this study are to use Landsat 8 images and meteorological data to produce the instantaneous value of ET for Tainan, Taiwan at 02.27 am (GMT time) on Jan 20, 2014. The results of this study have shown that there still remains room to improve the retrieval accuracy of some surface variables essential in ET remote sensing algorithms, such as near-surface air temperature (NSAT), which is one of the critical factors affecting the accuracy of the ET estimates and depends on the heating of the land surface.

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2. Study area

Tainan is located in southern Taiwan, facing the Taiwan Strait in the west and south with geographic coordinates of 22°99' N and 120°21' E and it is situated at elevation 26 meters above sea level (http://www.worldatlas.com). Tainan has a humid subtropical climate that borders on a tropical savanna climate. The annual rainfall is approximately 1,698.2 mm with average temperature 24.31^{0}C, and average relative humidity 77.2 % (Climate data for Tainan 1981–2010 – http://www.wikipedia.org)

3. Materials

The remote sensing data applied to this study is Landsat 8 OLI image, which was obtained from the United States Geological Survey - USGS with spatial resolution of 30 meter. The image acquisition time for Tainan is approximately at 10.27 a.m. (local time).

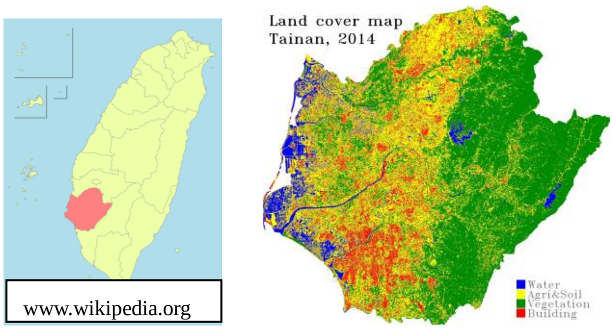

Figure 1 (Left) Location of Tainan, (right) Land cover map of Tainan Jan, 2014 by Landsat 8 OLI.

The visible and near-infrared bands of Landsat 8 were used to calculate the vegetation indexes and surface albedo, while thermal infrared bands for Land Surface Temperature retrieval. The digital elevation model (SRTM), 30 m spatial resolution, was used to perform terrain correction. In addition, meteorological data recorded close to the image acquisition time was used.

4. Methodology

The proposed methodology for ET estimation from remote sensing data and in situ measurement data is based on the theory of surface energy balance at the land - air interface. This model can be written as equation (1) below:

$$R_n = G + H + LE \qquad (1)$$

where R_n is net radiation, G is soil heat flux, H is sensible heat flux, and LE is latent heat flux where LE is associated with ET. Instantaneous ET estimation (mm/hour) is computed by equation below (Bastiaanssen, 2000).

$$ET = 3600 * (LE/\lambda); \qquad (2)$$

where λ is latent heat of Vaporization (kJ kg^{-1}).

Net radiation (Rn) flux represents the actual radiant at the surface. It can be calculate by the function of incoming and outgoing radiation. The equation can be expressed as the equation (2) below

$$R_n = R_s{\downarrow} (1-\alpha) + R_L{\downarrow} - R_L{\uparrow} - (1-\varepsilon_0) R_L{\downarrow} \qquad (3)$$

where $R_s{\downarrow}$ is incoming shortwave radiation (W/m^2), $R_L{\downarrow}$ is incoming longwave radiation, $R_L{\uparrow}$ is outgoing longwave radiation, ε_0 is surface thermal emissivity (dimensionless), and α is surface albedo (dimensionless), which is initially obtained as the ratio of the reflected radiation to the incident shortwave radiation and it was calculated using the following equation of Zhong & Li, 1988; (Bastiaanssen, 2000); (Silva et al., 2016).

Soil heat flux is the heat storage in the soil and vegetation due to conduction (Liaqat and Choi, 2015). General G is estimated as a fraction of Net

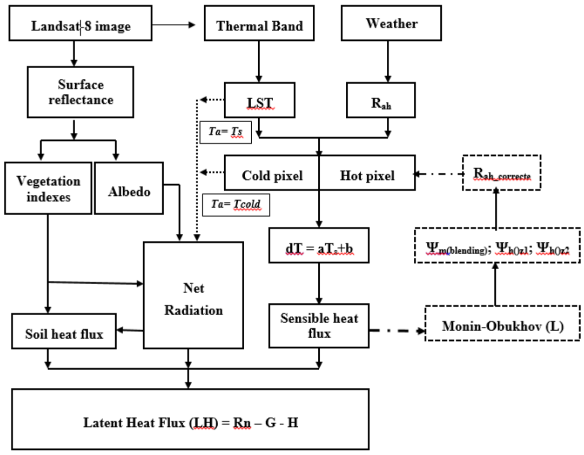

Figure 2. Flowchart

radiation using an empirical equation (4) by Bastiaanseen at el, (2000) as a function of NDVI, surface temperature (T_S) Celsius, and Albedo (α)

$$\frac{G}{Rn} = T_S\,(0.0038 + 0.0074\alpha)\,(1\text{-}0.98\,NDVI^4) \qquad (4)$$

Sensible heat flux (H) is the rate of heat loss to the air by convection and conduction due to a temperature difference (Liou and Kar, 2014). The bulk transfer of H is given by equation (4) below

$$H = \boldsymbol{\rho}_{air}\, C_p(dT/r_{ah}) \qquad (5)$$

where $\boldsymbol{\rho}_{air}$ is the density of the air and C_p is the specific heat of the air at constant pressure, dT is the near surface temperature different between two heights (z_1, z_2), and r_a is the aerodynamic temperature near the surface.

dT can be computed by the linear relationship between dT and surface temperature (T_S) (Bastiaanssen at el., 1998), which assumes that at “cold pixel”, H_{cold} = 0 and at “hot pixel”, LE = 0.

R_a can be computed using the Monin-Obukhov theory to reduce the effect of atmospheric conditions of stability (Chang et al., 2010)

$$r_a = \frac{\ln(\frac{z_2}{z_1}) - \psi_{h(z_2)} + \psi_{h_{(z_1)}}}{u * \times k} \qquad (5)$$

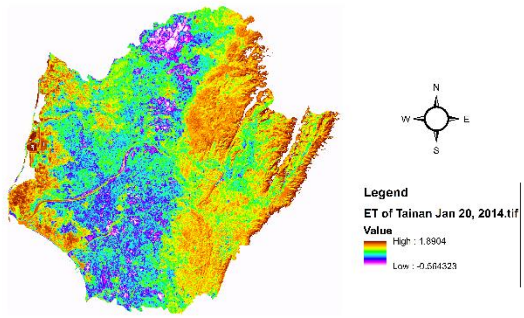

Figure 3. Distribution of ET using the Landsat 8 OLI image date Jan 20, 2014 for Tainan, Taiwan

where $\psi_{h(z_2)}$, $\psi_{h(z1)}$ can be computed using the function by Paulson (1970) and Webb (1970); z_1 = 0.1 m and z_2 = 2 m are acquired, respectively, from experienced analysis (Bastiaanssen, 2000); and friction velocity (u*) is computed for each pixel by function of wind speed and the momentum roughness length.

5. Results and Discussion

The ET of Tainan on Jan 20, 2014 were computed using Landsat 8 OLI image and meteorological data based on the surface energy balance equation. The spatial variation on instantaneous ET across the study area is shown in Fig. 3. It was observed that spatial variation of ET values ranged from -0.5 to 1.89 mm/hour with the average ET value about 0.5 mm/hour for the whole area. The highest value observed is the water body, while the urban and agriculture areas include bare lands showed a lower value of ET.

Figure 4 illustrates the instantaneous sensible heat fluxes, net radiation, soil heat flux, and latent heat flux, taken from Landsat 8 OLI image. The area has been divided into 4 main parts: agriculture, forest, water and urban. Sensible heat flux has been easily distinguished into the agriculture area, as shown in Figure 4. A higher latent heat flux and a lower

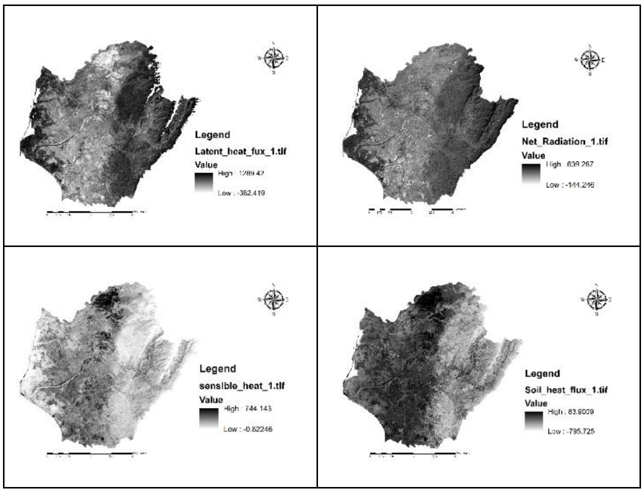

Figure 4. Instantaneous distributions of (1) Latent heat flux (LE); (2) Net radiation (Rn); (3) Sensible heat flux (H); and Soil heat flux (G) estimated for Tainan at 10.27 a.m. (local time), Jan 20, 2014.

sensible heat flux were reported in water bodies and vegetation areas than other areas. The net radiation of vegetation area was reportedly higher than that of developed areas, while the soil heat flux of vegetation was lower than that of developed areas. It can be said that these characteristics were due to different environmental path radiances and plant structures.

- **Comparison of LE estimations**

The T_a parameter presents near-surface air temperature (NSAT) is one of the critical factors affecting the accuracy of the ET estimation. This study has used two different T_a assumptions: (1) the land surface temperature (LST) obtained from the thermal band of Landsat 8 image is used as a T_a at each image pixel; and (2) temperature at the "cold pixel" is used as a single value for T_a in all of calculations.

In comparison based on figure 5, it could be shown that there was a deviation between 2 assumptions in terms of latent heat flux radiation. In assumption 1, the LE, which indicates the difference between the lowest and highest values, is larger than LE, which was obtained by assumption two. The difference is most clearly expressed in the urban and agriculture areas, including bare soil. Meanwhile, the LE was retrieved quite similar in the water body and dense vegetation areas.

6. Conclusions and Future Works

The methodology used in this study based on the incorporation of remote sensing and surface meteorological data to estimate the ET in Tainan, Taiwan at 10.27 a.m. (local time) on Jan 20, 2014. The considerable progress has been made in the quantitative retrieval of the land surface variables from remote sensing data. The spatial distribution of ET was analyzed in combination with the land cover

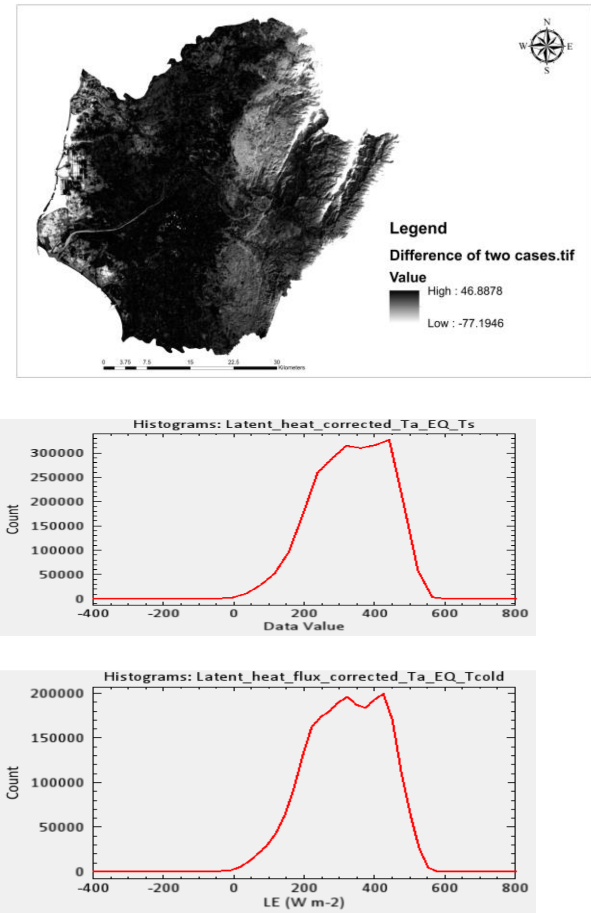

Figure 5. (1) Difference of LE between the two approaches, (2) Histograms of LE of assumption one, and (3) Histograms of LE of assumption two.

map. The variation of estimated ET over different kinds of land use closely matches with the evapotranspiration and surface energy balance theory.

There still remains room to improve the retrieval accuracy of some surface variables that are essential in ET remote sensing algorithms, such as near-surface air temperature (NSAT). Results from this study revealed that NSAT is one of the critical factors affecting the accuracy of the ET estimation. In the future, the possible sources of errors and limitations of the approach are discussed in detail in order to improve the retrieval accuracy of NSAT based on the nexus between vegetation indexes and LST to improve the accuracy of ET estimation

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