A SATELLITE-BASED DAILY ACTUAL EVAPOTRANSPERSION ESTIMATION OVER EAST ASIA

Soo-Jae Park¹, Jeong-Hyun Park², Mi-Lim Ou¹, Sang-Boom Ryoo¹ and Kyung-Soo Han³

¹Korea Meteorological Administration/National Institute of Meteorological Research, 45 Gisangcheong-gil, Dongjak-Gu, Seoul, Republic of Korea
²School of Earth and Environmental Sciences, Seoul National University, 1 Gwanak-ro, Gwanak-Gu, Seoul, Republic of Korea
³Department of Spatial Information Engineering, Pukyoung National University, Daeyeon Campus 45, Yongso-ro, Nam-Gu, Busan, Republic of Korea

ABSTRACT

National Institute of Meteorological Research at Korea Meteorological Administration (KMA/NIMR) has developed an algorithm of NIMR daily actual evapotranspiration (AET) estimation based on surface energy balance using remote sensing data and ground-based meteorological data. In the NIMR daily AET algorithm, the spatial resolution is 1km and the temporal resolution is 1-day composite and the mapping area is over East-Asia region. The developed algorithm is characterized by simplified aerodynamic resistance considering a variety of surface roughness length in the sensible heat flux. To evaluate the estimated NIMR daily actual evapotranspiration, we compared two methods; Indirect validation method and Direct validation method. The indirect validation compared to the potential evapotranspiration with Priestly-Taylor (1972) equation and the result is relatively reasonable agreements. The direct validation compared with the micrometeorological tower observation data that use eddy covariance methods.

INTRODUCTION

The evapotranspiration is the process of converting water into water vapor, which means the sum of evaporation from soil surface and transpiration from vegetation. It plays a key role in the hydrological cycle and the global water cycle between the land-surface and the atmosphere. Understanding spatial distribution and variation of actual evapotranspiration is one of most important things in hydrology and climatology, which contributes to various applications in agricultural meteorology, ecology studies and meteorological modeling. This product is useful indicator for drought monitoring and assessment and water stress status for land-surface. Estimation of NIMR daily actual evapotranspiration is based on surface energy balance that can be expressed by the following equation;

\[ R_n = LE + H + G \]  

Where, \( R_n \) is the net radiation flux (W·m\(^{-2}\)), LE is the latent heat flux (W·m\(^{-2}\)), a function of evapotranspiration rate, E (kg·s\(^{-1}\)·m\(^{-2}\)) and heat of vaporization, L (J·kg\(^{-1}\)), H is the sensible heat flux (W·m\(^{-2}\)), G is the soil heat flux (W·m\(^{-2}\)).

The energy arriving at the surface must be equal to the energy leaving the surface for the same time period. All fluxes of energy should be considered when deriving an energy balance equation. As magnitude of the day or ten-day soil heat flux the grass reference surface is relatively small. Therefore, soil heat flux is ignored in this study. Neglecting the intergrated ground heat flux, the surface energy balance can be written as;

\[ LE - R_n = -H \]
For this study, we have used the so-called simplified method for determining the accumulated daily actual evapotranspiration first proposed by Jackson et al (1977).

**DATA**

The NIMR daily actual evapotranspiration is based on the surface energy balance. The study area for the matchup dataset is over the Korean Peninsular between 124.49°E to 130.00°E in latitude and 32.51°N to 40.00°N in longitude and the period from 1 January to 31 December 2006 during one year. The study area consisted of cropland and forest, mostly. We used various input parameters by combined the remotely-sensed data and the ground-based meteorological data.

The remotely-sensed data is the estimated air temperature using satellite data, Aqua-Terra/MODIS land surface temperature, net radiation using MTSAT-1R, SPOT/VEGETATION NDVI (Normalized Difference Vegetation Index), surface roughness length in Ecoclimap parameter, digital elevation model in USGS (U.S. Geological Survey’s), MODIS land cover map, etc. The net radiation is defined as the difference between incoming and outgoing radiation of both short wavelengths from the sun and long wavelengths from the earth (Burman and Pochop, 1994). In this study, incoming shortwave radiation algorithm is based on the Kawamura et al (1998) and is optimized for East Asia and outgoing shortwave radiation estimates using incoming shortwave radiation and the reflectance of the surface, surface albedo. The surface albedo estimated using SPOT/VGT satellite. And net longwave radiation is computed by the Stefan-Boltzman equation.

The ground based meteorological data is wind speed (10m), air temperature (2m), relative humidity, precipitation from 76 meteorological network stations over Korean Peninsula.

The validation data used the micrometeorological tower observation data in Korea using eddy covariance methods. The eddy covariance method is widely used to monitoring the cycles of energy, water, and carbon dioxide. The KoFlux (http://koflux.yonsei.ac.kr) is a Korean network of micrometeorological tower sites in terrestrial ecosystems and is part of a “AsiaFlux” (http://asiaflux.yonsei.ac.kr) and “FLUXNET” (http://www.fluxnet.ornl.gov/fluxnet/).

Table 1 shows the validation data information located on Gwangnung coniferous forest in Korea. The period is from 1 January to 31 December 2009 during one year. The micrometeorological tower observation data consists of each 30-minute time period. For this study, we used daily maximum evapotranspiration in micrometeorological tower observation data.

<table>
<thead>
<tr>
<th>Site Name</th>
<th>Location Coordinates</th>
<th>Vegetation Type</th>
<th>Vegetation Age</th>
<th>Elevation</th>
<th>Yearly mean Temperature</th>
<th>Yearly mean Precipitation</th>
<th>Canopy Height</th>
<th>Tower Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gwangnung (Korea)</td>
<td>37°44′N 127°09′E</td>
<td>Coniferous Forest</td>
<td>80~100 years old</td>
<td>128 m</td>
<td>11.5 degree</td>
<td>1332 mm</td>
<td>23 m</td>
<td>40 m</td>
</tr>
</tbody>
</table>

Table 1: Flux-Tower observation information.

**METHODOLOGY**

To compute NIMR daily actual evapotranspiration, we have followed the simplified methodology, the B-method, proposed Jackson et al (1977). It is based on a linear relation between the differences \(ET_d-R_n\) and \(T_s-d-T_{a_d}\) measurements near midday, according to a statistically and theoretically justified (Sequin and Itier, 1983; Carlson and Buffum, 1989).

\[
ET_d-R_n = -B(T_s-d-T_{a_d})
\]  

(3)

Where,

- \(ET_d\): daily evapotranspiration, mm·day\(^{-1}\)
- \(R_n\): daily net radiation, mm·day\(^{-1}\)
- \(T_s\): daily surface temperature, K
- \(T_{a_d}\): daily air temperature, K
- \(B\): semi-empirical coefficient, mm·d\(^{-1}·K^{-1}\)
Firstly, the Match-up database (MDB) set up spatio-temporal collocation of the remotely sensed data and the ground-based meteorological data over the Korean peninsula. Secondly, B-coefficients model determine considering by relationship term ‘ET-Rn’ and ‘Ts-Ta’ dependent on surface roughness length. Finally, the estimated NIMR daily actual evapotranspiration is validated with the potential evapotranspiration with Priestley-Taylor equation and the micrometeorological tower observation data.

RESULT AND VALIDATION

The coefficient B values represent the slopes of the regressions between ‘ET-Rn’ and ‘Ts-Ta’. Figure 1 show a regression linear relationship ‘ET-Rn’ and ‘Ts-Ta’ that demonstrate their dependence on wind speed and surface roughness length in croplands. It is presents the variation of the slopes for wind speed values from 0.5 m/s to 2.5 m/s at intervals of 0.5 m/s over different surface roughness length from 0.025 to 0.925 m. The slopes decrease with increasing the surface roughness length and the wind speed.

To evaluate the estimated NIMR daily actual evapotranspiration, we compared two methods; the indirect validation method and the direct validation method. Firstly, the indirect validation compared to the potential evapotranspiration with Priestly and Taylor (1972) equation. When interception evaporation (IET) (by T.Neff) can be well in excess of the potential evaporation (PET) during precipitation event (Stewart, 1977), actual evaporation (AET) is assumed to equal the potential evaporation (PET) from saturated surface (Kouwen et al, 2006). Figure 2 compared the estimated NIMR daily actual evapotranspiration with the potential evapotranspiration with Priestly-Taylor equation. The $R^2$ is 0.671, RMSE (Root Mean square Error) is 0.067 mm·d$^{-1}$, Bias is 0.009 mm·d$^{-1}$. The result is relatively reasonable agreements for surface roughness length.
Figure 2: The result of validation between the NIMR daily actual evapotranspiration with estimated algorithm and the daily potential evapotranspiration with Priestly-Taylor algorithm.

Secondly, Figure 3 shows the estimated NIMR daily evapotranspiration compared with the daily maximum micrometeorological tower observation data. The estimated NIMR daily evapotranspiration represent seasonal variation for vegetation from growing season to dyning season. As a preliminary result, compared with daily maximum micrometeorological tower observation data, the estimated NIMR daily actual evapotranspiration is higher during from January to June about 5 mm/day and is similar during from July to December.

**Figure 3:** Comparison Flux-Tower observation data (Gwangneung coniferous forest KoFlux site in Korea) with NIMR daily actual Evapotranspiration.

**COMPARISON OF TERRA/MODIS EVAPOTRANSPIRATION**

The NIMR daily actual evapotranspiration mapping area is the East Asia between 100.00°E to 145.00°E in latitude and 20.00°N to 50.00°N in longitude the period from 1 January to 31 December 2009 during one year. The MODIS global evapotranspiration (ET) products using Mu et al.'s improved evapotranspiration algorithm (2011) over previous Mu et al.'s paper Mu et al (2007a). The MODIS evapotranspiration algorithm is based on the potential evapotranspiration with Penman-Monteith (P-M) equation (Monteith, 1965) using MODIS data and global meteorology data. This product is 8-day composite data and spatial resolution is 1km.

The estimated NIMR daily actual evapotranspiration is obtained near midday by term 'Ts-Ta'. Ts is land surface temperature and Ta is estimated remotely-sensed air temperature and is characterized daily maximum temperature. For this study, compared seasonal mean NIMR daily actual
evapotranspiration with seasonal mean daily MODIS evapotranspiration. Overall, the estimated NIMR actual evapotranspiration is higher than daily MODIS evapotranspiration. The results showed the variation of the season dependent on growing vegetation.

(a) Seasonal mean daily actual evapotranspiration by NIMR

(b) Seasonal mean daily potential evapotranspiration by NASA

Figure 4: Spatial distribution of (a) seasonal mean daily actual evapotranspiration by NIMR (in Summer and in Winter) and (b) seasonal mean potential evapotranspiration (obtained by Penman-Monteith) (in Summer and in Winter) in 2009.

SUMMARY AND FUTURE PLAN

In this study, KMA/NIMR has developed NIMR daily actual evapotranspiration over East Asia based on surface energy budget equation using spatio-temporal collocated match-up database over Korean peninsula by combined remote sensing data and ground-based meteorological data. This algorithm is statistically determined by regression analysis between the ‘ET-Rn’ and ‘Ts-Ta’. Especially, aerodynamic resistance in the sensible heatflux correlated with surface roughness length. The estimated NIMR daily evapotranspiration shows relatively well agreement with validation data as $R^2$ is 0.671, RMSE is 0.067 mm·d$^{-1}$ and Bias is 0.09 mm·d$^{-1}$.

In the future, firstly, the developed NIMR daily actual evapotranspiration algorithm considering various land surface roughness length will improve to use spatio-temporal collocated match-up database from over Korean Peninsula to over East Asia. Secondly, daily net radiation and land surface temperature is one of the important parameter for actual daily evapotranspiration. Input parameters are will be improved to estimate using COMS satellite (Communication, Ocean and Meteorological Satellite, launched 27 June 2010). Thirdly, the relationship between NIMR daily actual evapotranspiration and several parameters such as Normalized difference vegetation Index, land cover type will be studied in more detail.
REFERENCES


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