ESTIMATION OF EVAPOTRANSPIRATION OVER NORTHEAST ASIA USING MODIS PRODUCTS AND MM5 FDDA DATA

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1. INTRODUCTION

Evapotranspiration (ET), including transpiration from vegetation and evaporation from soil, is a key variable of hydrological cycle to understand the land-atmosphere interactions such as surface energy and water balances. ET also affects climate dynamics and terrestrial ecosystem productivity because it is closely associated with energy transfer processes (Nishida et al., 2003a; Mu et al., 2007; Jang et al., 2009). Among numerous methods for estimating ET, the satellite remote sensing such as the MODerate resolution Imaging Spectroradiometer (MODIS) sensor offers promising techniques to monitor regional or global ET patterns (Nishida et al., 2003b; Jang et al., 2009; Jang et al., 2010), but frequent clouds or missing data hamper the continuous monitoring of ET. The objectives of this study are 1) to apply and test a stand-alone ET algorithm during clear or partial cloudy sky conditions using MODIS land surface and atmospheric products, and 2) to use the Fifth Generation Meso-scale Meteorological Model (MM5) data in cloudy conditions to facilitate continuous daily ET estimates, and 3) to examine the spatial and temporal distributions of ET over Northeast Asia region.

2. MATERIAL AND METHOD

2.1 Evapotranspiration algorithm

The Penman-Monteith (PM) algorithm has been popularly used in hydrological and agricultural forest studies to calculate the potential ET in a variety of hydroclimatic regimes (Nishida et al., 2003b; Cleugh et al., 2007). In this study, the revised RS-PM (Mu et al., 2007) algorithm which is a modified version of the RS-PM algorithm proposed by Cleugh et al. (2007) is used. In this algorithm, latent heat flux (λE; Eq. 1) was divided into canopy ET (λE_{veg}; Eq. 2) and soil evaporation (λE_{soil}; Eq. 3) to estimate total ET.

$$\lambda E = \lambda E_{veg} + \lambda E_{soil} \quad (1)$$

$$\lambda E_{veg} = \frac{\Delta R_n + \rho c_p (e_s - e_a)/r_a}{\Delta + \gamma \times (1 + r_S/r_a)} \quad (2)$$

$$\lambda E_{soil} = \frac{\Delta R_{n,soil} + \rho c_p (e_s - e_a)/r_a}{\Delta + \gamma \times (r_{tot}/r_a)} \times \left(\frac{RH}{100}\right)^{\left(\frac{e_s - e_a}{100}\right)} \tag{3}$$

This algorithm considers the effects of surface energy partitioning processes (Bisht et al., 2005) and environmental constraints such as daily minimum air temperature and vapor pressure deficit on stomatal conductance and ET (Mu et al., 2007). In this study, the gap-filling techniques for MODIS aerosol and albedo products are devised to improve the retrieval rates of shortwave radiation and ET. The MODIS-based ET based on the PM equation (Cleugh et al., 2007; Mu et al., 2007; Jang et al., 2009; Jang et al., 2010) are validated through comparisons with the ground-based observations measured at nine flux sites in Northeast Asia (see Table 1).

2.2 MODIS-MM5 FDDA

The meteorological simulation is implemented via the Four Dimensional Data Assimilation (FDDA) between MODIS products and MM5, which is a suitable technique for incorporating ground observations or satellite data. For cloudy conditions or pixels, the MODIS-derived meteorological input data are not provided and hence, replaced with those from MODIS-MM5 FDDA predictions to estimate the daily ET in cloudy conditions.

3. RESULT AND DISCUSSION

3.1 Validation of ET inputs

The input variables derived from MODIS atmosphere and land products to estimate ET, including air temperature, actual vapor pressure, vapor pressure deficit, and radiation components (i.e., incoming and outgoing short- and long-wave radiation), showed a good agreement with those observed at nine eddy covariance flux towers in Northeast Asia. The error statistics of these variables are presented in Table 1.

Table 1. Error statistics of MODIS input variables calculated from comparisons with flux tower data

	ME / RMSE (r^2)						
Site	Ta(℃)	VPD(Pa)	Rs↓(Wm^{-2})	Rs↑(Wm^{-2})	Rl↓(Wm^{-2})	Rl↑(Wm^{-2})	Rn(Wm^{-2})
GDK	-0.3 / 3.5 (**0.94**)	-190.8 / 338.4 (**0.90**)	-33.0 / 69.1 (**0.88**)	-	-	-	-43.8 / 67.1 (**0.94**)
HFK	-0.4 /2.5 (**0.93**)	-231.6 / 410.1 (**0.71**)	-38.0 / 53.7 (**0.94**)	-	-	-	+35.9 / 46.2 (**0.95**)
TKY	-0.7 / 2.4 (**0.91**)	+95.7 / 342.5 (**0.53**)	-38.3 / 94.2 (**0.90**)	-29.4 / 35.5 (**0.85**)	-36.1 / 44.0 (**0.67**)	-26.2 / 30.9 (**0.89**)	-25.2 / 56.5 (**0.90**)
TMK	-2.5 /3.2 (**0.91**)	-134.0 / 275.9 (**0.45**)	-14.2 / 83.8 (**0.85**)	-7.7 / 16.3 (**0.81**)	-24.7 / 27.1 (**0.92**)	-7.6 / 13.7 (**0.93**)	-19.1 / 75.2 (**0.84**)
CBS	-5.6 / 6.2 (**0.88**)	-530.9 / 668.6 (**0.49**)	-43.7 / 81.5 (**0.83**)	+2.0 / 12.9 (**0.79**)	-4.8 / 56.0 (**0.47**)	+12.2 / 57.2 (**0.44**)	-51.2 / 103.2 (**0.60**)
HBG	+1.1 / 9.8 (**0.77**)	+393.0 / 807.5 (**0.20**)	-11.5 / 292.3 (**0.05**)	+74.3 / 118.8 (**0.05**)	+12.9 / 47.1 (**0.54**)	+19.7 / 92.4 (**0.54**)	-92.7 / 236.6 (**0.13**)
QYZ	+1.1 / 3.5 (**0.84**)	-8.7 / 471.2 (**0.62**)	-4.1 / 52.4 (**0.84**)	+33.4 / 36.9 (**0.20**)	+17.1 / 45.0 (**0.77**)	+5.1 / 34.1 (**0.96**)	-26.0 / 54.2 (**0.86**)
SKT	-1.2 / 4.2 (**0.89**)	-47.1 / 471.2 (**0.81**)	-40.0 / 97.1 (**0.83**)	+46.7 / 62.3 (**0.25**)	+32.5 / 36.6 (**0.92**)	+45.4 / 52.7 (**0.95**)	-90.1 / 117.5 (**0.82**)
MKL	-5.5 / 5.9 (**0.36**)	-1015.4 / 1177.1 (**0.34**)	-13.1 / 58.0 (**0.62**)	-4.3 / 9.5 (**0.47**)	-49.0 / 51.4 (**0.40**)	-18.5 / 21.4 (**0.80**)	-39.4 / 65.9 (**0.57**)

3.2 Evapotranspiration

Validation tests using flux observation data demonstrate that the ET estimated from the MODIS algorithm show meaningful errors (ME= -0.65 to -0.59 mm day^{-1}, RMSE= 0.50 to 1.10 mm day^{-1}) at nine flux measurement sites in spite of the high accuracy of MODIS-derived input variables. Detailed evaluations of input variables indicate that these errors are primarily associated with errors in the estimated canopy conductance. Figure 1 shows spatial distributions of partially gap-filled daily average ET (mm day^{-1}) and retrieval rate (%) in 2006 across Northeast Asia.

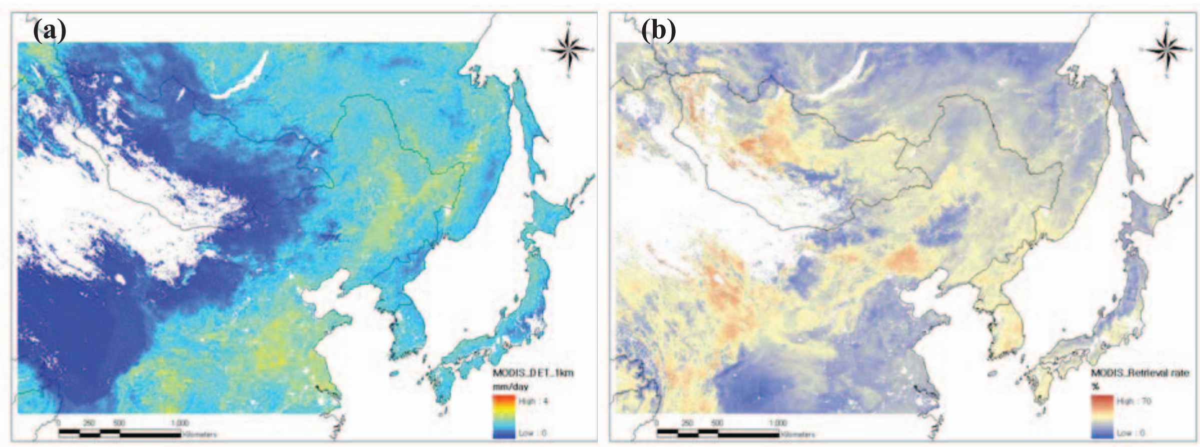

Fig. 1. Partially gap-filled daily average ET (a) and its retrieval rate (b) in 2006 using MODIS atmosphere and land products across Northeast Asia

3.2 MODIS-MM5 ET

The meteorological data improved by MODIS-MM5 FDDA technique are combined with the MODIS land products (i.e., vegetation indices and albedo) to produce the MODIS-MM5 daily ET. MODIS products are used to calculate ET in the pixels under clear sky conditions, while the MODIS-MM5 FDDA data are used as input variables to calculate ET in the pixels under cloudy sky conditions. The ET produced by incorporating with the MM5 was evaluated by comparing ET based on MODIS, which showed a good agreement with the MODIS ET. It is indicates that blending of two products are acceptable.

4. CONCLUDING REMARK

Our preliminary results indicate that MODIS can be applied to monitor the land surface energy budget and ET with reasonable accuracy and that MODIS incorporated with meteorological model has the potential to provide reasonable input data of ET estimation under cloudy conditions. However, the issues of spatial scale mismatch (resolution) between flux footprints, MODIS, and MM5, as well as the temporal scale mismatch (time lag) still remain and should be the focus of future research.

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