Scaling from Instantaneous Remote-sensing-based Latent Heat Flux to Daytime Integrated Value with the Help of SiB2

Yi Song[a, b,] *, Mingguo Ma[a], Xin Li[a], Xufeng Wang[a, c]

[a]Cold and Arid Regions Environmental and Engineering Research Institute, Chinese Academy of Sciences, Lanzhou 730000, China;

[b]Institute of Earth Environment, Chinese Academy of Sciences

[c]Graduate University of Chinese Academy of Sciences, Beijing 100049, China

ABSTRACT

This research dealt with a daytime integration method with the help of Simple Biosphere Model, Version 2 (SiB2). The field observations employed in this study were obtained at the Yingke (YK) oasis super-station, which includes an Automatic Meteorological Station (AMS), an eddy covariance (EC) system and a Soil Moisture and Temperature Measuring System (SMTMS). This station is located in the Heihe River Basin, the second largest inland river basin in China. The remotely sensed data and field observations employed in this study were derived from Watershed Allied Telemetry Experimental Research (WATER). Daily variations of EF in temporal and spatial scale would be detected by using SiB2. An instantaneous midday EF was calculated based on a remote-sensing-based estimation of surface energy budget. The invariance of daytime EF was examined using the instantaneous midday EF calculated from a remote-sensing-based estimation. The integration was carried out using the constant EF method in the intervals with a steady EF. Intervals with an inconsistent EF were picked up and ET in these intervals was integrated separately. The truth validation of land Surface ET at satellite pixel scale was carried out using the measurement of eddy covariance (EC) system.

Keywords: Instantaneous latent heat flux; Daytime Integrated ET; evaporative fraction; SiB2

1. INTRODUCTION

Evapotranspiration (ET), which governs the water cycle and energy transport among the biosphere, atmosphere and hydrosphere as a controlling factor, plays an important role in hydrology, meteorology, and agriculture, such as in prediction and estimation of regional-scale surface runoff and underground water, in simulation of large-scale atmospheric circulation and global climate change, in the scheduling of field-scale field irrigations and tillage [1, 2, 3]. Remotely sensed data are acquired instantaneously and can only provide instantaneous two dimensional spatial information related to the properties of the land surfaces, such as surface albedo, surface vegetation fraction, surface temperature, and surface net radiation, etc., which are indispensable variables to know for remote sensing estimate of land surface ET [3,4,5,6].

However, temporally integrated daily, weekly and monthly ETs at regional and global scales are required for many ET-related disciplines. Therefore, temporal scaling, which is one of the weaknesses of remotely sensed data, is needed to convert the instantaneously spatial ET to a longer-time value. Nowadays, great progress has been made to convert the instantaneous ET to the daily value on clear-sky days. The sine function and the constant evaporative fraction (EF) method are commonly used in scaling from instantaneous Latent Heat Flux (LE) to Daytime Integrated Value. Jackson et al. related the ratio of instantaneous LE to daily value to the diurnal trend of solar irradiance with a sine equation [7]. The sine function gives a good approximate of the change of diurnal solar irradiance from near sunrise to sunset. The constant EF method assumed the EF to be constant during the daylight hours to determine regional daily evapotranspiration (ET) [8]. Knowing the daytime available energy (Rn-G)d, and assuming that EF is constant during the daytime, daily estimate of ETd can therefore be obtained. The variability or conservation of EF on individual day is affected by complicated combination factors, such as weather conditions, soil moisture, topography, biophysical conditions, cloudiness and the advections of moisture and temperature directly contributed to the amount of variability of EF on a given day [9]. Zhang and Lemeur compared the sine function with the constant EF method and concluded that both methods were accurate to estimate daily total ET for cloud-free days and recommended that the sine function was preferable for the purpose of estimating ET using remotely sensed data [10]. However, both these two methods do not

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work well in cloudy days, and ignore ET in night.

This research dealt with a daytime integration method with the help of Simple Biosphere Model, Version 2 (SiB2) [11, 12].

2. DATA

The remotely sensed data and field observations employed in this study were derived from Watershed Allied Telemetry Experimental Research (WATER). WATER is a simultaneous airborne, satellite-borne, and ground-based remote sensing experiment occurring in the Heihe River Basin, the second largest inland river basin in the arid regions of northwest China [13].

2.1 Satellite images

A Landsat TM image acquired at 11:42 am (Beijing time), July 7, 2008, was involved in the remote-sensing-based estimation of latent heat flux (λE). The TM image was pre-processed using radiative, atmospheric and geometric correlations. Atmospheric correlation was carried out using ENVI FLAASH. Initial visibility was 33.86 km obtained by a sun photometer (CE318).

2.2 Field observations

WATER contains 6 key stations that include an Automatic Meteorological Station (AMS) and a Soil Moisture and Temperature Measuring System (SMTMS). There are an additional 6 super-stations that observe the same parameters as the key stations plus energy and CO_2 fluxes. The field observations in this study were obtained from the Yingke (YK) oasis super-station, which includes an AMS, an eddy covariance (EC) SMTMS [13]. The underlying surface around the YK oasis super-station is a typical irrigated farmland. The primary crop is seed corn. The observations included the following: wind speed (3 m and 10 m), air temperature (3 m and 10 m), humidity (3 m), air pressure, four components of radiation (3 m), soil temperature and moisture profiles (measured at depths of 10 cm, 20 cm, 40 cm, 80 cm, 120 cm, and 160 cm), and turbulent fluxes (measured at 2.81 m above the ground by the EC system). The four components of radiation indicate the total solar radiation, the reflective shortwave radiation, the land surface long wave radiation, and the atmospheric long wave radiation.

The raw high frequency (10 Hz) data from EC was processed to produce half-hourly fluxes of CO_2, water vapour and sensible heat above the canopy by using post-processing software EdiRe (developed by Edinburgh University, UK). The turbulent flux data were calculated from EC data after de-spiking [14], tilt correction [15], sonic virtual temperature correction [16], time-lag calculations, frequency response correction [17], and WPL correlation [18]. The energy balance closure over the entire experimental period (from 1st Jun to 9th Jul) at YK reached 89%. Those records with a friction velocity below 0.1 (m s^{-1}) were not involved in the energy balance closure calculation and validation.

2.3 Atmospheric forcing data

The 25km and 3 hourly atmospheric forcing data from GLDAS (Global Land Data Assimilation System) project [19] were interpolated to 1km and 1 hourly. The temporal interpolation algorithm of precipitation is a statistical method provided by Global Soil Wetness Project 2 (GSWP2). The temporal interpolations of incident solar radiation, incident longwave radiation, wind speed, relative humidity, air pressure and air temperature are based on the cubic spline method [20]. The high resolution meteorological interpolation model MicroMet [21] and 1km SRTM Digital Elevation Model [22] was used in the spatial interpolation of the forcing data. The atmospheric forcing data was prepared for the SiB2.

3. METHODS

Regional net radiation (R_n) is derived from the energy balance equation at the thermal infrared band. It is given by the following:

$$R_n = (1-\alpha)R_S^{\downarrow} + \varepsilon R_L^{\downarrow} - \varepsilon\sigma T_S^4, \tag{1}$$

where R_n is the net radiation (W m^{-2}); α is the surface albedo estimated using the reflectance of bands 1, 3, 4, 5 and 7 of the Landsat TM image [23]; $R_S^{\downarrow}$ and $R_L^{\downarrow}$ are the downward short-wave and long-wave radiation flux densities, respectively, measured by the four-component net radiation sensor at the YK oasis super-station; ε, is the land surface emissivity calculated using an NDVI threshold method [24]; σ is the Stefan-Boltzmann constant; and T_S is the land surface temperature (LST) calculated using the thermal band radiance values from the Landsat TM based on the mono-window algorithm developed by Qin *et al.* [25]. The LAI was calculated using the TM image based on the method introduced by Ross *et al.* [26].

G in our study region was calculated by the method presented by Su [2]:

$$G = R_n \times \left[\Gamma_c + (1 - f_c) \times (\Gamma_s - \Gamma_c)\right]. \quad (2)$$

The ratios between the soil heat flux and the net radiation for the full vegetation canopy (Γ_c) and bare soil (Γ_s) were 0.05 [27] and 0.315 [28], respectively. An interpolation was then performed between these extreme cases using the fractional canopy coverage, f_c. The λE was then estimated using R_n, G and the surface resistance. A revised surface resistance model [29] was used to obtain the parameters in the surface resistance.

Daily EF in temporal and spatial scale was obtained by using SiB2. The invariance of daytime EF values was examined using a detection algorithm. When the absolute value of the difference between three or more than three EF values was lower than a threshold, these EFs were considered to be relatively steady. The threshold was set as o.25. Figure 1 showed the logic behind the algorithm.

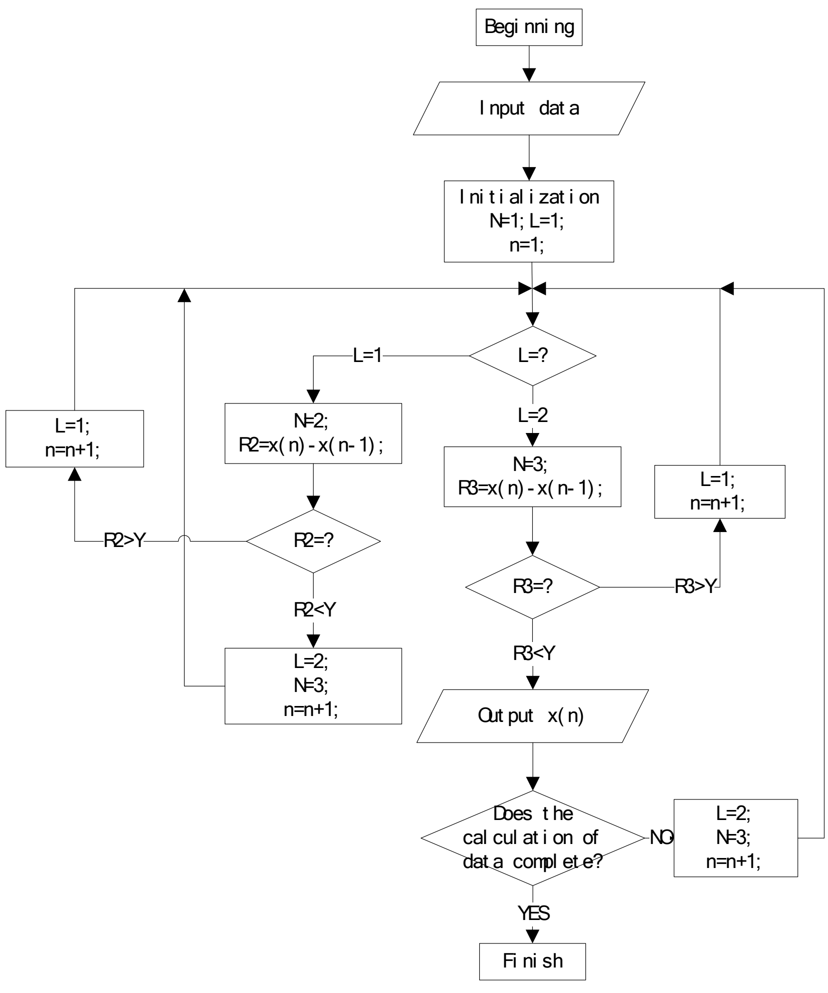

Figure 1. Flowchart of the detection algorithm

The integration was carried out using the constant EF method in the interval with a steady EF. An instantaneous midday EF was used for the intervals with a steady EF which was calculated based on a remote-sensing-based estimation of surface energy budget. Intervals with an inconsistent EF were picked up and ET in these intervals was integrated separately. Therefore the daily EF could be expressed as follows:

$$E_{24} = \sum_{i=0}^{M}\left(\frac{A_i \cdot ef_i \cdot T}{L \cdot \rho_w} \times 10^3\right) + \sum_{i=M}^{N}\left(\frac{A_i \cdot T}{L \cdot \rho_w} \times 10^3\right) \times ef_s + \sum_{i=N}^{24}\left(\frac{A_i \cdot ef_i \cdot T}{L \cdot \rho_w} \times 10^3\right), \quad (3)$$

where M and N are the beginning and terminal points of the interval with a steady EF in one day; ef_s is the steady EF value; A_i and ef_i are the available energy (equal to the net absorbed radiation) and the EF value for the i^{th} hour; L is the Latent heat of vaporization (2.45×10^6 Jkg^{-1}); ρ_w is the density of water (1000 kgm^{-3}).

4. RESULTS AND VALIDATION

Daily EF was not a constant value and varied in both temporal and spatial scale (see Figure 2). From the result of SiB2, it was concluded that EF kept steady in a certain interval of daytime. At sunrise and sunset, however, EF had a large fluctuation.

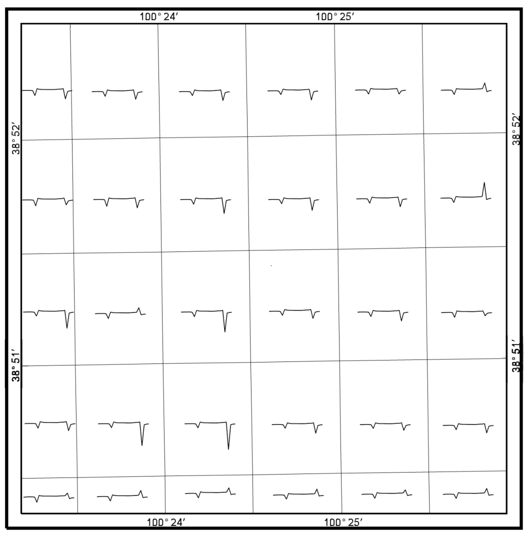

Figure 2. The spatial and temporal distribution of EF in July 7, 2008.

The beginning and terminal points of the interval with a steady EF was obtained with the help of the detection algorithm. In July 7, 2008, most area around YK station (white regions) had an interval with a steady EF from 9:00 to 19:00 (see Figure 3). Some area had the interval from 9:00 to 17:00 (gray regions).

The ET around the YK station at midday reached approximately 5.6 (mmd^{-1}) (see Figure 4). The maximal and minimal values of the ET was 11.7 (mmd^{-1}) and 0.9 (mmd^{-1}), respectively. A large, triangular bare soil with a ET lower than 1.5 (mmd^{-1}) was in the western area of the Yingke station. Areas with a regular shape, which also had low ET, were villages. Additionally, roads (straight lines in the figure) also had low ET. Farmlands covered by more crops had higher ET.

The truth validation of land Surface ET at satellite pixel scale was carried out using the measurement of eddy covariance (EC) system. The result indicated that the integration method proposed in this paper is reliable and can be used to estimate daily ET over cropland in arid regions. The validation strategy considering the footprint of EC is reasonable at satellite pixel scale. Figure 5 showed the source area of the EC measurements in July 7, 2008. The measurements of EC were 6.48(mmd^{-1}). After considering the footprint of the EC, the weighted averages of the ET within the source area were 6.93 (mmd^{-1}). This result indicated that our scheme for scaling from instantaneous λE to daytime ET could provide reliable estimation.

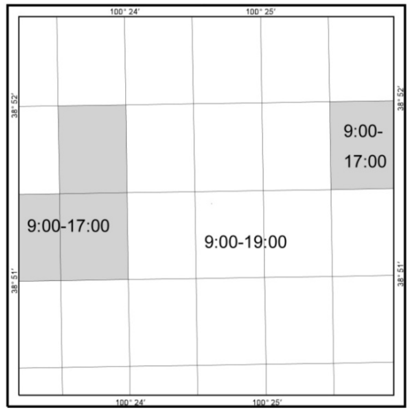

Figure 3. The interval with a steady EF in July 7, 2008.

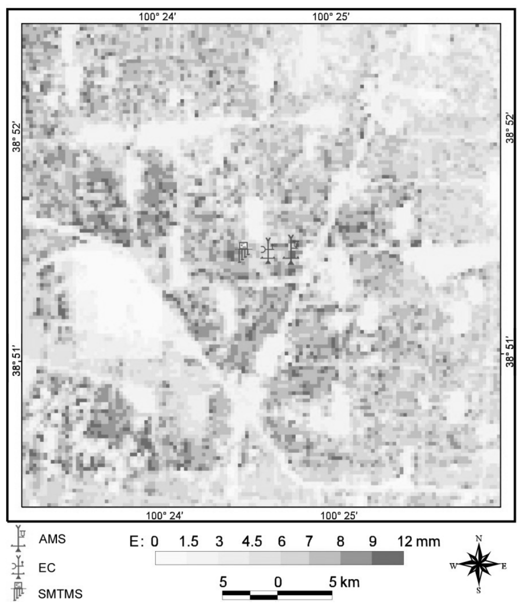

Figure 4 Map of the daily ET in July 7, 2008.

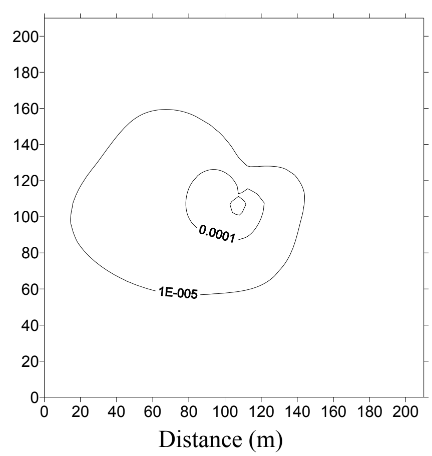

Figure 5. The source area of the EC measurements in July 7, 2008.

5. CONCLUSIONS

Daily EF varied in both temporal and spatial scale. Especially, EF had a large fluctuation at sunrise and sunset. In most regions, EF could keep steady in a certain interval of daytime. However, the length of the interval in different regions was diverse. The constant EF method ignored the variability of EF in temporal and spatial scale. Our revised method put up with this disadvantage in a certain degree.

The truth validation of land Surface ET at satellite pixel scale was carried out using the measurement of eddy covariance (EC) system. The result indicated that the integration method proposed in this paper is reliable and can be used to estimate daily ET over cropland in arid regions. The validation strategy considering the footprint of EC is reasonable at satellite pixel scale.

However, temporal scaling, which is one of the weaknesses of remotely sensed data, is needed to convert the instantaneously spatial ET to a longer-time value [3]. Moreover, due to the effect of cloud coverage, it is impossible to provide the spatial patterns of land surface variables under the clouds by the optical remote sensing and consequently impossible to estimate the surface instantaneous ET over the areas covered by clouds with optical remote sensing data [3]. Our revised method for temporally integrating daily ET at regional scales is still required for many ET-related disciplines. Most important progress in ET estimation will be in combination with improvements in assimilation into land surface models that have improved boundary-layer physics. This progress could be a primary focus of the community over the next decade.

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