Estimation of farmland evapotranspiration based on SEBAL model in Kai-Kong River Basin, Xinjiang

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Abstract: Evapotranspiration (ET) is an important reference for scientific management of farmland irrigation, accurate estimation of crop yields, and optimal allocation of water resources. The purpose of this paper is to estimate ET by taking the farmland of Kai-Kong River Basin in Xinjiang province as an example. The method was based on the SEBAL model and the Landsat data; it estimated the net radiation flux, soil heat flux using the land-surface parameters first, and the instantaneous evapotranspiration was then calculated using the energy residual method and the latent heat flux. The sinusoidal function method was used to extend the time scale of the instantaneous evapotranspiration to the daily evapotranspiration and the daily evapotranspiration were verified using the FAO56 Penman-Monteith formula. The compared results shown that the error of daily evapotranspiration between SEBAL and FAO56 Penman-Monteith is within 1mm, and except for the estimation accuracy of final growth stage is about 80%, the estimation accuracy of other growth stages are more than 80%. The SEBAL model, coupled with the Landsat remote sensing data, can offer an efficient and adequate alternative to estimate ET at catchment scale.

Keywords: crop; evapotranspiration; SEBAL; Penman-Monteith

1. Introduction

Water is transported from the earth surface (i.e., the plant-soil system) to the atmosphere by evaporation (E) from surfaces (soils and wet vegetation) and by transpiration (T) from plants through stomata present in the plant leaves is called evapotranspiration (ET) [1]. The ET is a vital component to describe the hydrological cycle in ecological systems, to estimate water balance and to schedule the irrigation [2]. SEBAL (Surface Energy Balance Algorithm over Land) model can be applied to different vegetation types and climatic characteristics with solid physical foundation and has been widely used in the estimation of regional ET [3][4][5]. Xinjiang is one of mostly water stressed region in China, but it is also an important crop-producing region. We applied SEBAL to estimate the ET for main crops in cropland of Kai-Kong River Basin and discussed the applicability of SEBAL model in ET estimation in this study area.

2. Study Area and Datasets

Cropland of Kai-Kong River Basin, Xinjiang is located between 40°48′ and 43°20′ N latitude and 82°56′ and 88°12′E longitudes (Figure 1). Various datasets used in this study were satellite data (Landsat 7 ETM+, Landsat 8 OLI and MODIS data), metrological data (wind speed (m·s⁻¹), air temperature (°C), average air pressure (kPa), precipitation (mm), relative humidity (%) and daily sunshine hours (h)), land use data, digital elevation model (DEM) and crop sample points.
3. Methods

SEBAL converts satellite radiances into land surface characteristics, such as surface albedo, vegetation index, and surface temperature. These are used in solving the instantaneous energy budget equation given by equation (1). Then the instantaneous evapotranspiration ($ET_{inst}$) of the satellite transit time is calculated in equation (2).

$$LE = R_n - G - H$$

$$ET_{inst} = 3600 \times \frac{LE}{\lambda}$$

Where $R_n$ is the net radiation at the surface (W/m$^2$), $G$ is the soil heat flux (W/m$^2$), $H$ is the sensible heat flux to the air (W/m$^2$), $LE$ is the latent heat flux for the time of satellite overpass (W/m$^2$). The sinusoidal function method was used to extend the time scale of the instantaneous ET ($ET_{inst}$) to obtain the daily ET ($ET_{daily}$).

$$ET_{daily} = \frac{2n}{\pi \sin(\pi t / n)}$$

$$ET_{daily} = LE \times \frac{2n}{\pi \sin(\pi t / n)} \times \frac{86400}{\lambda}$$

$$\lambda = (2.501 - 0.002361 \times (LST - 273.15)) \times 10^6$$

Where $ET_{daily}$ is the daily ET (W/m$^2$), $NE$ is the daily ET time (i.e., the time interval from the start of evapotranspiration to the evapotranspiration in the evening to near zero, generally 2 hours less than the sunshine hours).

4. Results

4.1 Estimation of $ET_{inst}$ based on SEBAL

The spatial distribution of $ET_{inst}$ in the study area were calculated based on SEBAL model and shown in Figure 2.
Figure 2. The spatial distribution of $ET_{\text{inst}}$ based on SEBAL.

The $ET_{\text{inst}}$ is in the range of 0.01-0.60 $\text{mm} \cdot \text{h}^{-1}$ in the early stage of crop growth according to the change of $ET_{\text{inst}}$ in Figure 2. The low value is mainly concentrated in the cotton area, because the cotton just started to grow and is similar to the bare soil in remote sensing image. The high value is mainly concentrated in the pear and reed area, because the high NDVI value of pear and the growth environment of the reed is water. In the middle of crop growth, with the growth of cotton, corn and other crops, the overall NDVI in the agricultural area is higher. At this time, the $ET_{\text{inst}}$ in the study area is concentrated at 0.40-0.80 $\text{mm} \cdot \text{h}^{-1}$. At the end of crop growth, the crop begins to mature and harvest, and the bare soil area increases, resulting in a gradual decrease in $ET_{\text{inst}}$.

4.2 Estimation of $ET_{\text{inst}}$ based on SEBAL

The spatial distribution of $ET_{\text{inst}}$ in the study area were calculated based on SEBAL model and shown in Figure 3.

Figure 3. The spatial distribution of $ET_{\text{daily}}$ based on SEBAL.

From the variation of the spatial distribution of $ET_{\text{daily}}$ in Figure 3, it is known that the variation of $ET_{\text{daily}}$ and $ET_{\text{inst}}$ is consistent. The high value of $ET_{\text{daily}}$ in the study area is also concentrated in the
4.3 Validation of the SEBAL performance

The ET was calculated using FAO56 Penman-Monteith formula to verify the performance of SEBAL model. Then the crop actual ET can be expressed as follows:

\[ ET_c = K_c \times ET_0 \]  

(6)

Where \( ET_c \) is the crop actual ET (mm·day\(^{-1}\)) that is calculated by multiplying the \( K_c \) and \( ET_0 \), \( K_c \) is the crop coefficient and the \( ET_0 \) is the reference ET (mm·day\(^{-1}\)). Accuracy verification result of SEBAL model is as follows:

| Growth stage     | Date(DOY)  | \( ET_{C_{SEBAL}} \) | \( ET_0 \) | \( K_c \) | \( ET_{C_{FAO}} \) | Difference | Accuracy |
|------------------|------------|----------------------|-------------|---------|-----------------|------------|----------|
| Initial          | 22 Apr(113)| 1.28                 | 4.38        | 0.35    | 1.53            | 0.25       | 0.84     |
| Rapid growth     | 25 June(177)| 4.75                | 6.06        | 0.76    | 4.61            | -0.14      | 0.97     |
| Middle           | 27 Jul(209)| 5.14                 | 5.01        | 1.18    | 5.91            | 0.77       | 0.87     |
| Final            | 21 Sep(265)| 3.45                 | 4.53        | 0.60    | 2.72            | -0.73      | 0.79     |

The ET estimation error between SEBAL and Penman-Monteith is within 1mm, and except for the estimation accuracy of final growth stage is about 80%, the estimation accuracy of other growth stages are more than 80%. The estimation of ET are close to the actual ET that calculated by FAO Penman-Monteith. It can be considered that the ET results of SEBAL model can accurately reflect the ET in the study area.

5. Conclusion

This paper estimated the evapotranspiration of crops at different growth stages in agricultural region of Kai-Kong River Basin in Xinjiang based on the SEBAL, and compared with the evapotranspiration calculated by Penman-Monteith. The spatial distribution of instant evapotranspiration and daily evapotranspiration at different growth stages of the crops is relatively consistent. Low-value is concentrated in cotton area, and high-value areas are concentrated in reed and pear areas. Results shown that the calculation results of SEBAL model are accurate and the method is relatively fast and efficient.

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