8-1-2014

Separation Of Soil Evaporation And Vegetation Transpiration By MODIS Data For Central And Northern China

Tingting Li

Jinhui Jeanne Huang

11th International Conference on Hydroinformatics
HIC 2014, New York City, USA

ESTIMATION OF EVAPOTRANSPIRATION BY USING MODIS DATA FOR CENTRAL AND NORTHERN CHINA

JINHUI HUANG (1), TINGTING LI (1)
(1): State key laboratory of hydraulic engineering simulation and safety, Tianjin university, Tianjin 300072，China

ABSTRACT

Evapotranspiration(ET) plays a crucial role in the hydrologic system. To estimate evapotranspiration quantitatively in a large scale, remote sensing data has been used in a number of models and shows its applicability in the estimation of evapotranspiration. In this paper, evapotranspiration for central and northern China was derived from MODIS data. In arid and semi-arid regions, soil evaporation can be considered as the minimum water requirement for bare area, while evapotranspiration can be considered as the minimum water demand for the area covered by vegetation. Hence the separation of soil evaporation and vegetation transpiration is valuable for efficient water resources management. In this study, the land surface temperature-fractional vegetation coverage(Ts-f) trapezoid method was applied in conjunction with an operational two-layer model. A modified algorithm for the determination of actual dry/wet edges(MADE) of the Ts-f trapezoid was proposed, which is an improvement of the original method based on Ts-VI(vegetation index) triangle developed by Ronglin Tang(2010). The MADE was then integrated with the two-layer model to estimate the latent heat flux (evaporation and transpiration). It's showed that the retrieved latent heat flux is in good agreement with FLUXNET data obtained from Department of Biogeochemical Integration. The root mean square error of monthly ET is below 25 W/m2. The result demonstrated that the accuracy of the modified algorithm to determine dry/wet edges in the Ts-f trapezoid was satisfactory. Finally, the spatial and temporal distribution of soil evaporation and vegetation transpiration of central and northern China was further investigated in this study.

Keywords: remote sensing，evapotranspiration，two-layer model，latent heat, MODIS, Ts-f trapezoid

INTRODUCTION

Evapotranspiration(ET) has been long regarded as an very important component in energy and mass exchange between hydrosphere, atmosphere and biosphere (Sellers et.al., 1996) .Traditional method for calculating or measuring ET is limited to fixed time and space scale, Nowadays with the development of remote sensing technology, retrieving ET by utilizing the information obtained from remote sensing imagery had gained more and more attention (Kalma et. al., 2002; Stisen et.al., 2007; Carlson et al., 1995; Carlson 2007). In recent years, researchers started the efforts of separating evaporation(E) and transpiration(T) apart by two-layer model (Carlson et al., 1997, Zhang et al., 2003). In this study, a modified algorithm for two-layer model was introduced. This algorithm was applied to retrieve the evaporation and transpiration separately for the central and northern China as shown in Figure 1.

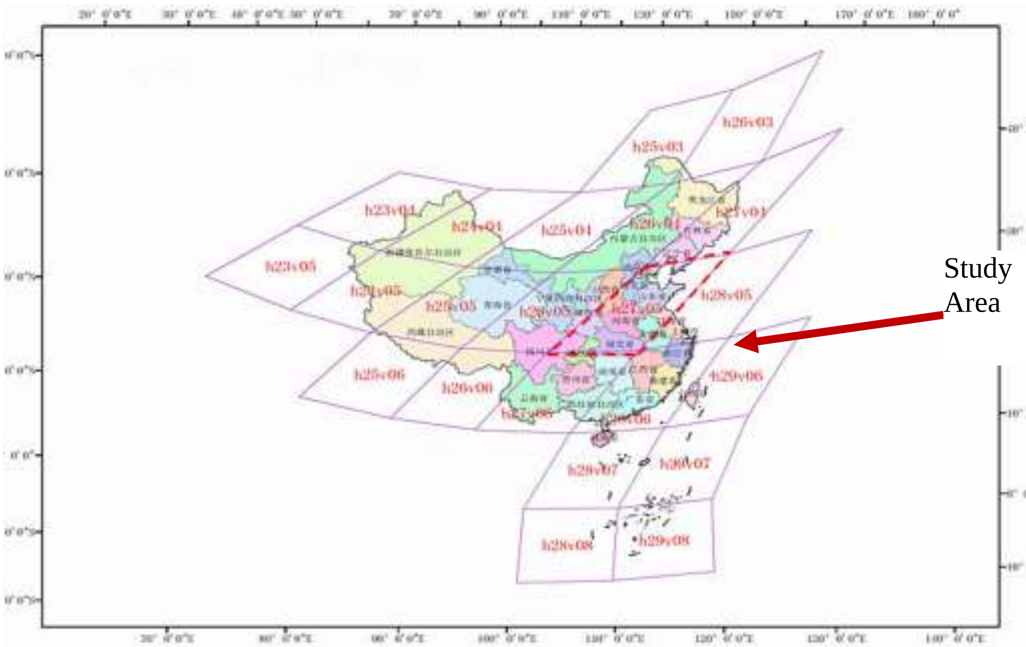


Figure 1: Study Area

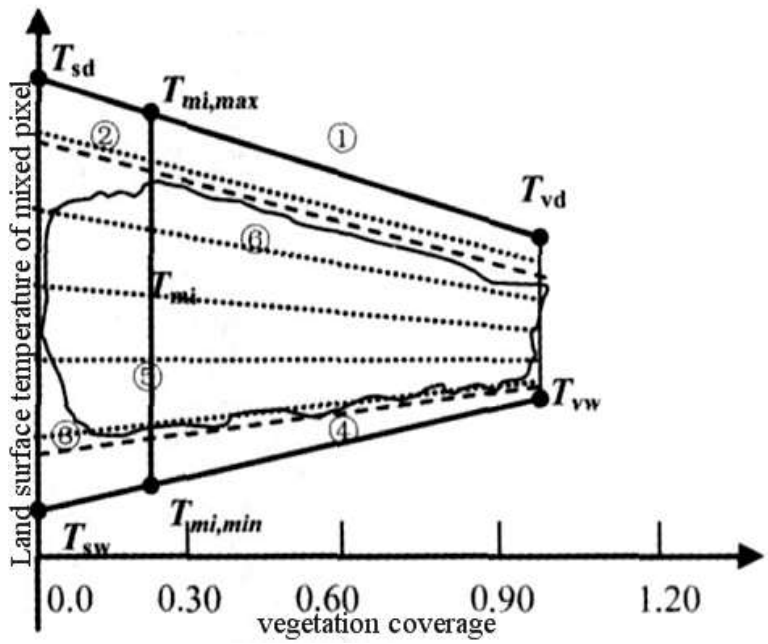
METHODOLOGY

In the operational two-layer model, the PCACA (pixel component arranging and comparing algorithm) and Layered Energy-Separating Algorithm are the two core algorithms. The former one is used for decomposing surface temperature of mixed pixel into soil temperature and vegetation temperature, and the latter one is used for calculating Bowen-ratio of soil and vegetation.

The combination of vegetation index and land surface temperature contains rich information. It was found that scatter plot of land surface temperature and vegetation coverage forms a shape of trapezoid (Figure 2). Based on this finding, Zhang et al., (2001, 2004) proposed an algorithm to separate the mixed pixel temperature. This algorithm is called PCACA (pixel component arranging and comparing algorithm). Its fundamental equation is as follow:

$$\sigma\varepsilon_m T_m^4 = \sigma\varepsilon_v f T_v^4 + \sigma\varepsilon_s (1-f) T_s^4 , \qquad (1)$$

where, T_m,T_v,T_s are respectively the temperature of mixed pixel, vegetation canopy and soil surface, ε_m, ε_V,ε_S are respectively the emissivity of mixed pixel, vegetation canopy and soil surface,σ_{is} Stefan-Boltzmann constant, f is the vegetation coverage of mixed pixel. In this method, the determination of actual dry boundary/edge and wet boundary/edge is the key step to separate the temperature and eventually separate the evaporation and transpiration.



①theoretical dry boundary②actual dry boundary③theoretical wet boundary④actual wet boundary⑤vegetation coverage contour⑥soil moisture contour

Figure 2 Trapezoid of mixed land surface temperature and vegetation coverage

A modified algorithm for the determination of actual dry/wet edges(MADE) of the Ts-f trapezoid was proposed. This method was based on $T_{s\text{-}VI}$(vegetation index) triangle developed by Ronglin Tang(2010). It was an improvement of the original method. To locate the wet boundary accurately, we come up with an effective way to divide the scatter zone in $T_M - f$ trapezoid into a number of intervals and locate the efficient frontier of wet boundary by judging the change of point density in contiguous horizontal intervals. This process can not only automatically filter out spurious wet points and outliers, also prevent the wet boundary to be located too low caused by abnormal pixels in study area with special geographical conditions or landforms. Blow is the detailed process of our proposed algorithm:

(i) Firstly, dividing the $T_M - f$ trapezoid space evenly into M vertical intervals and every interval into N subintervals (According to the actual points distribution of study area, we take 20 for M and 10 for N as initial 3umber), then dividing the range of T_M into horizontal intervals by a temperature step;

(ii) Finding and saving the minimum temperature of every vertical subintervals, taking their average (T_{AV}) and standard deviation (δ) as initial state. The standard deviation can be computed by

$$\delta = \sqrt{\frac{1}{N}\sum_{j=1}^{N}(T_j - T_{AV})^2},\ j = 1, 2, 3, \ldots, N \tag{2}$$

(iii) Judging whether the minimum temperature of each subinterval of this grid is greater than $T_{AV} - \delta$, if it is, this subinterval is discarded in the following steps;

(iv) Recalculating average minimum temperature and standard deviation of the remaining subintervals;

(v) Utilizing a linear regression between the minimum temperature of each f

interval(vertical interval) and f_i to finally obtain the actual wet boundary:

$$T_{MIN,i} = c + df_i \tag{3}$$

so, the two lower corner points of the trapezoid are located as pixels with

$$f = 0, T_M = c \text{ and } f = 1, T_M = c + d \tag{4}$$

A similar procedure was used to determine the actual dry boundary and the two higher corner points of the trapezoid.

The MADE was then integrated with the two-layer model to estimate the latent heat flux (evaporation and transpiration). To determine the outline of theoretical trapezoid is to determine the four corners' temperature value T_{SD},T_{VD},T_{SW} and T_{VW}(Figure 2). T_{SD} and T_{VD} are calculated by land surface energy balance equation:

$$R_n - G = H + LE\ , \tag{5}$$

Where Rn is the net solar radiation flux, G is the soil heat flux, H is the sensible heat flux and LE is the latent heat flux.

T_{SW} and T_{VW} are obtained through positioning method for wind range of water body.
For the points on "theoretical dry boundary", evaporation equals 0 in theory, that is LE=0. T_{SD} and T_{VD} can be obtained by following certain procedures as shown in Equation 6.

$$\left.\begin{aligned} &R_n - G = H \\ &G \approx 0.3(1 - 0.9f)R_n \\ &H = \frac{\rho Cp(T_{sd} - T_{sda})}{r_{sda}} \\ &R_n = S_0(1 - \alpha_{sd}) + \sigma\varepsilon_{sky}T_{sky}^4 - \sigma e_{sd}T_{sd}^4 \end{aligned}\right\} T_{sd} = \frac{0.7[S_0(1 - \alpha_{sd}) + \sigma\varepsilon_{sky}T_{sky}^4] + \frac{\rho Cp}{r_{sda}}T_{sda}}{\frac{\rho Cp}{r_{sda}} + 0.7\sigma\varepsilon_{sd}T_{sd}^3}$$

Similarly,

$$T_{VD} = \frac{0.97[S_0(1-\alpha_{VD}) + \sigma\varepsilon_a T_{sky}^4] + \frac{\rho C_p}{r_{VDa}}T_a}{\frac{\rho C_p}{r_{VD}} + 0.97\sigma\varepsilon T_{AVD}^3} \tag{6}$$

In which, T_{sda}, T_a represent the air temperature of the corresponding pixels of T_{VD} and T_{SD}, r_{sda} and r_{VD} represent aerodynamic resistance of the corresponding pixels of T_{VD} and T_{SD}, α_{sd} and α_{VD} are albedo, S_0 is total solar radiation, ρ、C_p are respectively the density of air and specific heat at constant pressure, ε_{sky} is emissivity of sky, T_{sky} is temperature of the sky.

After vegetation coverage of a pixel is confirmed, there exists countless combination of T_V and T_S, however pixels on one isocline in the trapezoid have the same soil moisture availability. So the value of T_S-T_V on one isocline is equivalent as well as T_V and T_S, vegetation coverage f is the only changing factor. According to the analysis above, the key in separating mixed pixel land surface temperature is to determine dT_m/df, which is the slope of the isocline in the trapezoid, indicated by letter *k*. *k* is obtained by following equation:

$$k_i = \frac{T_{mi} - T_{mi\_min}}{T_{mi,max} - T_{mi,min}}(k_u - k_L) + k_L \tag{4}$$

in which, k_U,k_L are the slope of "theoretical dry boundary" and " theoretical wet boundary" of the trapezoid. Thus, the separation of mixed land surface temperature is accomplished. With the similar process, mixed albedo can also be separated.

The second step is to use layered energy-separating algorithm in estimating Bowen ratio of soil(β_S) and vegetation(β_V). Then soil evaporation and vegetation transpiration can be determined based on the Bowen Ratio-equilibrium Energy Method.

DATA AND MATERIALS

As introduced before, remote sensing data is substantial for this method. In our research, MODIS products: MOD02, Geolocation(MOD03), Land Surface Temeperature(MOD11), Vegetation Index(MOD13), Cloud Mask(MOD35), Albedo(MOD43) were used. MOD02 is used for geometric correction and MOD03 is for simplified method for the atmosphere correction. MOD13 is used to calculated vegetation coverage while MOD35 is used to remove the effects of cloud cover.

Besides, station meteorological data is very essential, such as wind speed which is for calculation of aerodynamic resistance[11], water vapour pressure and air temperature for calculation of T_{sky} and so on.

RESULTS

Figure 3 and 4 showed the separated latent heat for canopy (Transpiration of vegetation canopy, unit: w/m^2) and the latent heat for soil (evaporation of soil, w/m^2), respectively in the day of 290 Julian Day .

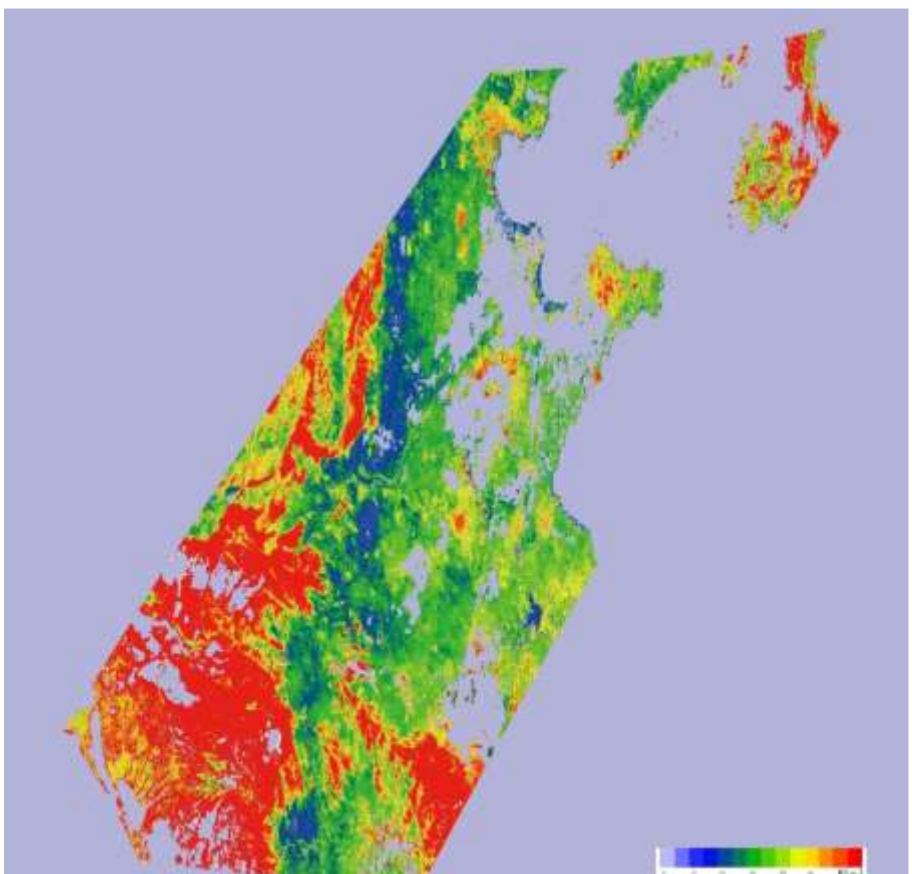


Figure 3. Latent Heat of vegetation canopy for Julia Day 290 (unit: w/m^2)

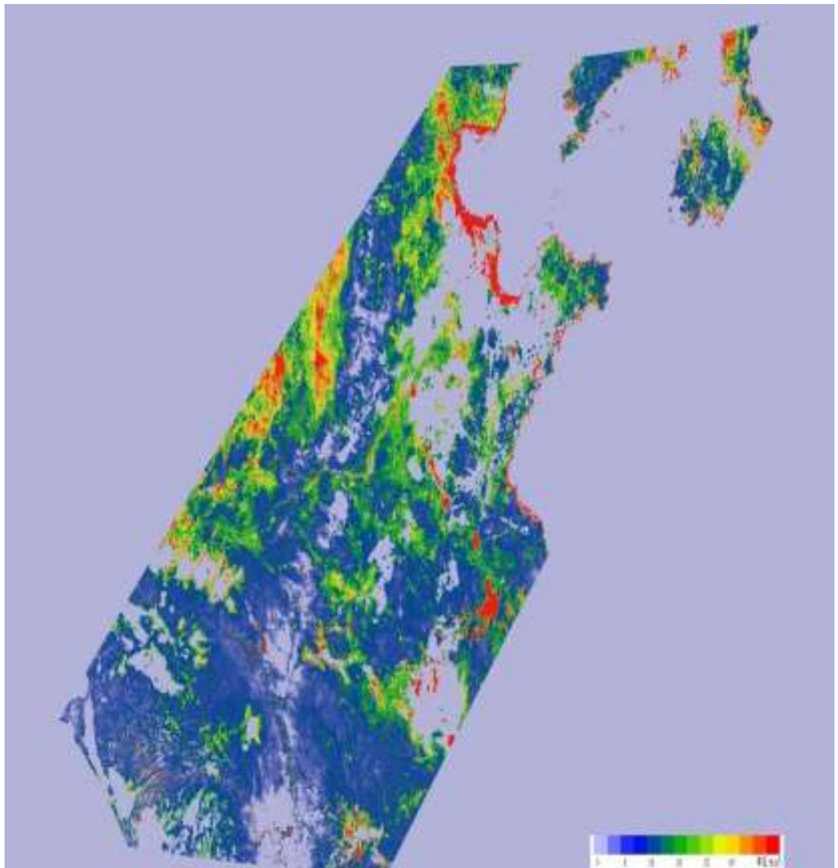


Figure 4. Latent Heat of soil for Julia Day 290 (unit: w/m^2)

The comparison of the estimated result with the field data at Yucheng shows that the the goodness of fit R^2 is 0.87 and the RMSE is about 23.8 w/m^2. This result was reasonably good.

SUMMARY AND CONCLUSIONS

From the above results, the proposed MADE method could model evaporation and transpiration fitted with the field measurement at Yucheng station very well. It demonstrated the applicability of the proposed method.

REFERENCES

[1] Sellers, P. J., D. A. Randall, G. J. Collatz, J. A. Berry, C. B. Field, D.A. Dazlich, C. Zhang, G. D. Collelo, and L. Nounoua. 1996. A revised land surface parameterization (SiB2) for atmospheric GCMS: Part 1. Model formulation. J. Climate9(4): 676- 705.
[2] Kalma J D, Jupp DLB. Estimating evaporation from pasture using infrared thermometry: evaluation of a one-Layer resistance model. Agricultural and Forest Meteorology, 1990, 51: 223~246
Sand holt I , Rasmussen K , et al . A simple interpretation of t he surf ace temperature/ vegetation index space for assessment of surface moisture status . Remote Sensing of Environment ,2002 ,79 : 13～224 .
[3] Stisen S, Sandholt I , Norgaard A , et al . Combining the triangle method with thermal inertia to estimate regional evapotranspiration - Applied to MS G - SEVIRI data in the Senegal River basin .Remote Sensing of Environment ,2007 , 112 : 1242～1255 .

[4] Carlson T N , Gillie s R R , Schmugge T J . An interpretation of methodologies for indirect measurement of soil water content . Agricultural and Forest Meteorology , 1995 , 77 : 191～205.
[5] Carlson T. An over view of t he "Triangle Method" for estimating surface evapotranspiration and soil moisture from satellite imagery. Sensors , 2007 , 7 : 1612～1629 .
[6] Carlson T N, William C, Rjobert J G. A New Look at the Simplified Method for Remote Sensing of Daily Evapotranspiration. Remote Sens Environ, 1995, 54: 161~167
[7] Zhang Wan-chang, Gao Yong-nian. Estimation of evapotraspiration of regional soil-vegetation system through two-source remote sensing. Geographic Science,2003,04:523-528
[8]Moran M S, Clarke T R, Inoue Y, et al. Estimating crop water deficit using the relation between surface -air temperature and spectral vegetation index. Remote Sens Environ, 1994, 49: 246~263
[9] Moran M S, Humes K S, Pinter Jr P J. The scaling characteristics of remotely-sensed variables for sparsely-vegetated heterogeneous landscapes. J of Hydrology, 1997, 190: 337~362
[10] Zhang Ren-hua, Sun Xiao-min, Liu Ji-yuan, et,al. Retrieval of the regional differentiation ofcrop transpiration and soil water utilization by remote sensing. Science China, 2001, 31(11): 959~968
[11] Zhang Ren-hua, Sun Xiao-min, Wang Wei-min,et al. The physical basement of an operational two-layer remote sensing for land surface flux in regional scale. Science China,Earth Science,2004,34:200-216.