Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.12785/amis/072L21

Temporal and Spatial Variation of Surface Evapotranspiration Based on Remote Sensing in Golmud Region,China

Ai-Di Huo[1], Jian-Guo Li[2],Guang-Zhi Jiang[2], and Yun Yang[3]

[1]School of Environmental Science & Engineering, Chang'an University, Xi'an 710054,China
[2]Department of Physics, Zhengzhou Normal University, Zhengzhou 450044,China
[3]School of Geology Engineering & Geomatics, Chang'an University, Xi'an 710054,China

Received: 1 Oct. 2012, Revised: 21 Dec. 2012, Accepted: 23 Dec. 2012
Published online: 1 Jun. 2013

Abstract: Estimation of land surface evapotranspiration(ET) is one of the most difficult tasks in the field of hydrology and water resources. In this study, ET of the Golmud Region is estimated with an improved surface energy balance system model and the earth observation remote sensing data. The influence factors of the temporal and spatial distribution of the land surface evaporation quantity in the Golmud region were analyzed by combining with the real measured data in the geographic information system(GIS). The analysis result indicates that the annual ET has a single-peak distribution in monthly scale with a well seasonal variation, meanwhile the land surface ET increases as the groundwater depth decreased from south to north as well as the altitude from high to low in the spatial distribution.

Keywords: land surface ET, remote sensing, Golmud region

1 Introduction

ET plays an important role in the global hydrological cycle. Effectively estimate ET is an important research subject of hydrology, soil science, agriculture, meteorology due to its important applications in water resources management, regional planning and management of agricultural production in arid areas[1,2].

There are many traditional ET computation methods which generally include two calculation steps: firstly, calculate reference ET; secondly, ET equals to multiplied by crop coefficient which varied for different crops and their growth stages[3]. The traditional computation methods can be classified into three types: temperature methods, radiation methods and combination methods which are based on the original Penman combination equation that consists of two terms: the radiation term and the aerodynamic term[4]. Moreover, ET can be measured quite accurately using apparatus such as weighing hypsometers[5] and TDR(Time-Domain Reflect meter)[6]. All these ET computation and measurement methods are limited because they only provide point values of ET for a specific location while ET has an obvious spatial and temporal heterogeneity. Earth observation remote sensing provides an effective method to determine and mapping the spatial and temporal structure of ET as it can cover large areas and provide estimates at a very high resolution[7]. Several remote sensing methods were developed to compute ET, such as satellite-derived feedback mechanism, Choudhury developed a biophysical model which linked the water, energy and carbon processes by using satellite and ancillary data to quantify ET and biomass production, Bastiaanssen developed a model named SEBAL which is comprised of 25 submodels[7,8,9,10]. Among these methods, SEBAL was used by many researchers[1,11,12,13]. It consists of the following three parts: a set of tools for the determination of the land surface physical parameters from spectral reflectance and radiance, such as albedo, emissivity, temperature, vegetation coverage etc.[14]; an extended model for the determination of the roughness length for heat transfer[15]; a new formulation for the determination of the evaporative fraction on the basis of energy balance at limiting cases.

* Corresponding author e-mail: e-mail: huoaidi@163.com

Correspondingly, SEBAL model requires three sets of information as input. The first set consists of land surface albedo, emissivity, temperature, fractional vegetation coverage, leaf area index, and the height of the vegetation (or roughness height). The Normalized Difference Vegetation Index(NDVI) is used as a surrogate when vegetation information is not explicitly available. These parameters can be derived from remote sensing data in conjunction with other information about land surface. The second set includes air pressure, temperature, humidity, and wind speed at a reference height. The reference height is the measurement height for point application and is the height of the planetary boundary layer(PBL) for regional application. This data set can also be variables estimated by a large scale meteorological model. The third set includes downward solar radiation and downward long wave radiation which can either be get by measure directly, model output or parameterizations.

Remote sensing methods used for determination of land surface physical parameters can be found elsewhere[14, 15], the emphasis of this study lies in the formulation of SEBAL model and its improve and validation with different data sets.SEBAL model was used to compute ET of the Golmud region, and then the temporal and spatial distribution characteristics of ET was analyzed within GIS.

2 Materials

A. Study area

Golmud region is located in the southern margin of the Qaidam Basin in Qinhai province, China, with an average altitude of 2800 meters(see Figure 2.1). The warm air come from southwest is difficult to enter this area due to the barrier layers caused by the Tibetan Plateau. This situation formed an extreme drought continental climatic characteristics with strong solar radiation, strong evaporation, low air pressure and windy. The annual average rainfall in this region is 40.6 mm but mean annual evaporation is 2709.7mm. The mean annual temperature is 4.2 Celsius degree and somewhere is even below zero. The geographical distribution of ET and precipitation are totally discord with each other. It is significant that the precipitation and evaporation subject to the geographical and altitude in Golmud River basin. When there are 100 meters increases in altitude and precipitation 12 mm increases, evaporation reduces 70 mm. Fig. 2 shows the distribution of Study area and water.

B. Datasets

This study used two data sets: MODIS satellite image dataset and ground measurement dataset. The MODIS dataset was downloaded from the U.S. National Oceanic and Atmospheric Agency's website. The MODIS reflectivity data used in this study is a 16 days synthesis data with 500 meters spatial resolution got in July, 2009.

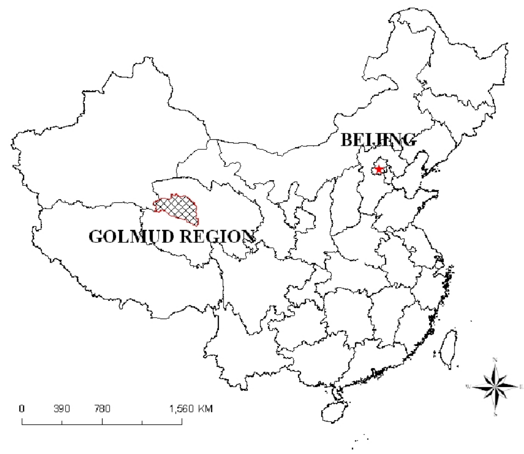

Fig. 2.1: Location of the Golmud region in China

This dataset has been widely used in eco-environmental change study. It was downloaded from the web site of Earth Observing System (EOS) of NASA. Images have preliminary been preprocessed and analyzed, improvement such as radiometric and atmospheric correction have been done. The quality of the available dataset was improved by removal of some noise influential points. Field investigations and ground measurement were carrying on in Golmud-Nanshankou region for the ET, vegetation, soil and groundwater data in July, 2009.

3 Methods

a)Regional ET of the two-resistance model

The surface energy balance is commonly written as[16]

$$LE = R_n - H - G \tag{1}$$

where R_n is the net radiation, G is the soil heat flux, H is the turbulent sensible heat flux, and LE is the turbulent latent heat flux (L is the latent heat of vaporization and E is the actual ET).

Non-uniform surface is formed by the vegetation and bare ground. Apparently, the corresponding water heat exchange process of the vegetation and the bare ground are different. Two-impedance model will fully take into account because the canopy microclimate has different effects on soil and vegetation thus the model parameterized respectively for the soil and vegetation. The energy balance equation in the vegetation coverage areas and bare soil area will be expressed by:

$$LE_v = R_{nv} - H_v - G_v \tag{2}$$

$$LE_g = R_{ng} - H_g - G_g \tag{3}$$

Therefore, the calculation of regional ET becomes the calculation of the R_{nv},R_{ng} ,H_v ,H_g , G_v and G_g . Where

LE_v is vegetation canopy latent heat flux, LE_g is the soil surface latent heat flux; R_{nv} and R_{ng} respectively are vegetation and soil surface net radiation; H_v and H_g , respectively is vegetation canopy and soil surface Sensible heat flux; G_v and G_g were that into the vegetation canopy and soil surface flux. The unit of all above parameters is W/m^2.

b) Obtain model parameters

1)Vegetation canopy and soil surface net radiation(R_{nv} ,R_{ns})

Vegetation canopy and soil surface net radiation can be expressed by Equation (4) and (5):

$$R_{nv} = f_v R_n \quad (4)$$

$$R_g = (1 - f_v) R_n \quad (5)$$

where f_v is the ratio of vegetation covered area in the unit area, there is following formula f_v and NDVI[17]:

$$f_v = \frac{NDVI - NDVI_{min}}{NDVI_{max} - NDVI_{min}} \quad (6)$$

where $NDVI_{max}$ and $NDVI_{min}$ are the maximum and minimum NDVI during the growing season , the value adopted in this study is 0.92 and 0.005 respectively.

2) Vegetation canopy and soil surface heat flux(G_v G_g)

In the double model, the net heat flux into the vegetation coverage area can be expressed as a function of radiation[18]:

$$G_v = \frac{T_v}{\alpha}(0.0032\alpha + \alpha^2)(1 - 0.978NDVI^4)/R_n \quad (7)$$

where T_v is vegetation canopy temperature; α is surface albedo.In the bare land, there is a linear relationship between soil heat flux and net radiation[19]:

$$G_g = 0.40 \times R_v \quad (8)$$

3) Surface net radiation(R_n)

Radiation energy is the main energy drives the land surface ET. The equation to calculate the net radiation is given by

$$R_n = Q(1 - \alpha) + \varepsilon_\alpha \sigma T_\alpha^4 - \varepsilon_s \sigma T_s^4 \quad (9)$$

where Q is the sun radiance on the land surface, α is the surface albedo, σ is Stefan-Boltzman constant($\sigma = 5.6696 \times 10^{-8} Wm^{-2}K^{-4}$), $\varepsilon_\alpha \sigma T_\alpha^4$ is atmospheric long-wave radiation, ε_α and ι_s is the emissivity of the atmosphere and land surface, T_α is atmosphere temperature, T_s is land surface temperature. Among them, the parameters can be estimated through following formula[20]:

$$\varepsilon_\alpha = 0.92 \times 10^{-5} T_\alpha^2 \quad (10)$$

Because of the soil emissivity (ε_s) is generally between 0.90 to 0.95[21], so the average value of 0.925 be used to calculate the net long wave radiation; According to local meteorological stations of surface temperature and temperature relations,

$$T_\alpha = 0.0473 \times T_s^2 + 2.8111 \times T_s - 18.459 \quad (11)$$

4) Surface albedo parameters(α)

The albedo α is obtained through compositing the seven reflection band(α_{1-7}) of MODIS images[22,23] (see Equation (12)); and the land surface temperature can be retrieved by using thermal infrared remote sensing data.

$$\alpha = 0.39\alpha_1 + 0.23\alpha_2 + 0.34\alpha_3 - 0.26\alpha_4 + 0.16\alpha_5 - 0.01\alpha_6 + 0.0682\alpha_7 + 0.0036 \quad (12)$$

5) Sensible heat flux(H)

Sensible heat flux is heat per unit area of surface transfer by release and absorption. The change of sensible heat flux has the relationship with characteristics of atmospheric boundary layer turbulence and expressed by:

$$H = \rho C_p (T_s - T_\alpha)/r_\alpha \quad (13)$$

where H is the sensible heat flux; ρ is the density of air (kg/m^3), dry air at standard atmospheric pressure and 20 °C, the density $\rho = 1.2Kg/m^3$; C_p is the air specific heat ($= 1004J/kg/K$); T_s is the surface or canopy temperature (K); T_α is the reference height air temperature (K); r_α is the aerodynamic resistance. Aerodynamic impedance is $r_{\alpha 0}$ under the neutral stratification condition.

4 Results and Analysis

a) Temporal distribution of ET

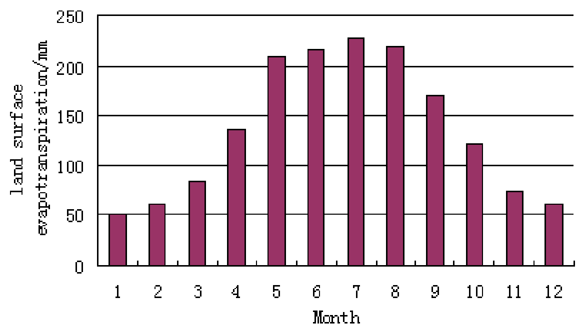

Fig. 4.1: Average monthly land surface ET in Golmud region in 2009

Figure 4.1 shows the simulated result of the land surface ET of Golmud region in 2009. The distribution of

Table 3.1: comparison of remote sensing retrieval and ground validation

Measured points	Groundwater depth(m)	NDVI	Instantaneous ET(mm)	Diurnal ET(mm)	Measured value	Error
TJ1	0.21	0.471	0.77	8.31	8.11	0.20
TJ2	0.23	0.573	0.79	8.60	7.98	0.62
TJ3	0.80	0.380	0.90	9.72	10.12	0.40
TJ3	0.80	0.380	0.90	9.72	10.12	0.40
TJ4-6	2.20	0.378	0.88	9.55	9.77	0.22
TJ7	1.70	0.406	0.84	9.12	8.96	0.16
TJ8-13	0.20	0.571	0.76	8.18	7.54	0.64

the surface ET in Golmud region showed a single peak pattern. The minimum ET, 50.51 mm, appears with the coldest month and the snow-covered surface is not conducive to the land surface ET in January. The maximum ET value is 250.33 mm, appears with the rainy season of this region and coupled with abundant sunshine, windy that help to evaporation in July.

b) Spatial distribution of ET

Plant transpiration and surface evaporation is the mainly discharge channel of groundwater in Golmud region. The maximum value synthesis for each pixel was used to pretreat the MODIS images in ENVI software platform. Then programming and calculate the improved SEBAL model for mapping the ET in Golmud region. Figure 4.2 is the spatial distribution of the ET. It shows that the diurnal ET near Golmud city is greater than other areas. Dabuxun Lake, Charles Lake and the surrounding areas near water bodies also have a larger diurnal ET. Statistical analysis showed that the minimum instantaneous value of ET is 0.02mm, the maximum is 2.66mm; the minimum diurnal ET is 0.201mm and the maximum is 17.404mm, average value is 7.677 mm in Golmud region.

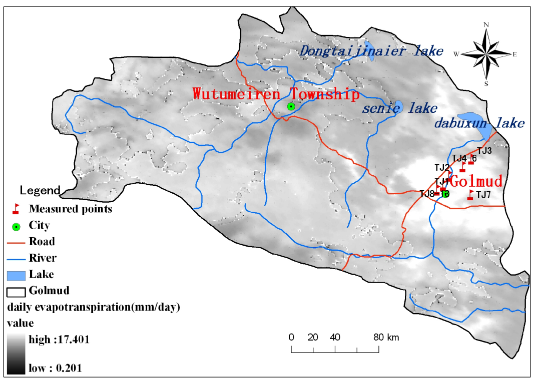

Fig. 4.2: Spatial distribution of evapotranspiration

Groundwater level is an important factor that affecting the ET in arid areas such as Golmud. It plays a key role in the discharge of ground water when comes with shallow groundwater depth. Comparison analysis (see Table 3.1) on the relations of ET, groundwater depth and vegetation reveals that along with the groundwater table rise gradually, the ET increase accordingly from the southern part to the northern part of Golmud region, salinity fields and lake have the maximum ET value.

c) Validation

Validation works on surface ET were conducted in GolmudCNanshankou region, July 2009. Model results based on remote sensing inversion and ground truth verification results are compared in Table 3.1.

Further analysis was conducted for the purpose of comparing the model calculated ET and the real pan evaporation under monthly scale and diurnal scale respectively. The analysis shows that the actual monthly ET is significantly less than the pan evaporation and the monthly ET at maximum frequencies is in agreement with other relevant researches, the typical diurnal ET is similar to the relevant researches.

5 Conclusions and Discussion

Based on the remote sensing data and model inversion, the value of ET and its temporal and spatial distribution can be obtained relatively easy and effective in desolate and expanse region like Golmud. However, there are still problems such as the model is not mature when it be used in steep mountain, it uses a large number of empirical field data needed to verify and the results need to be based on the actual situation of human amendments, etc., These deficiencies also have to be improved in the future work.

The depth of groundwater level is an important even key factor that affecting the ET in arid areas. It influences not only the evaporation constantly but also the change of surface vegetation distribution. This subject will be discussed in another article separately.

Acknowledgement

We are grateful to professor Xun-hong Chen for his insightful remarks and comments that improved the manuscript. The work was sponsored by the Special Fund for Basic Scientific Research of Central Colleges and for Fundamental Research Planning, Chang'an University(No.CHD2009JC090,CHD2010JC041), Henan Province the basis of cutting-edge technology research projects(No.122300410180) and China Postdoctoral Science Foundation Grant(2012M511961).We acknowledge the Program for Changjiang Scholars and Innovative Research Team in University of Ministry of Education of China(IRT0811)-PCSIRT and National Natural Science Foundation of China(No.41072183).

References

[1] Price, J., Land surface temperature measurements from the split window channels of the NOAA 7 Advanced Very High Resolution Radiometer. Journal of Geophysical research **89(D5)**, 7231-7237 (1984).

[2] Bastiaanssen, W., SEBAL-based sensible and latent heat fluxes in the irrigated Gediz Basin, Turkey. Journal of Hydrology **229(1-2)**, 87-100 (2000).

[3] Ray, S. and V. Dadhwal, Estimation of crop evapotranspiration of irrigation command area using remote sensing and GIS. Agricultural water management **49(3)**, 239-249 (2001).

[4] Jacobs, J., et al., Evaluation of reference evapotranspiration methodologies and AFSIRS crop water use simulation model. Publ. SJ2001-SP8(2001), http://www.sjrwmd.com/programs/outreach/pubs/techpubs/sj2001-sp8.pdf (Verified 20 October, 2003).

[5] Liu, C., X. Zhang, and Y. Zhang, Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. Agricultural and Forest Meteorology **111(2)**, 109-120 (2002).

[6] Mastrorilli, M., et al., Daily actual evapotranspiration measured with TDR technique in Mediterranean conditions. Agricultural and Forest Meteorology **90(1-2)**, 81-89 (1998).

[7] MKite, G. and P. Droogers, Comparing evapotranspiration estimates from satellites, hydrological models and field data. Journal of Hydrology **229(1-2)**, 3-18 (2000).

[8] Choudhury, B., Seasonal and interannual variations of total evaporation and their relations with precipitation, net radiation, and net carbon accumulation for the Gediz basin area. Journal of Hydrology **229(1-2)**, 77-86 (2000).

[9] Bastiaanssen, W., et al., A remote sensing surface energy balance algorithm for land (SEBAL). 1. Formulation. Journal of Hydrology **212**, 198-212 (1998).

[10] chunsu, S. and L. dinggui, hydrological forecast of Fengle River Based on AVSWAT. Chinese Agricultural Science Bulletin **22(009)**, 493-496 (2006).

[11] Caselles, V., et al., Mapping actual evapotranspiration by combining Landsat TM and NOAA-AVHRR images: application to the Barrax area, Albacete, Spain. Remote Sensing of Environment **63(1)**, 1-10 (1998).

[12] Chemin, Y., Alexandridis, T. and Sensing, R., Improving spatial resolution of ET seasonal for irrigated rice in Zhanghe, China(1998).

[13] Timmermans, W. and A. Meijerink, Remotely sensed actual evapotranspiration: implications for groundwater management in Botswana. International Journal of Applied Earth Observation and Geoinformation **1(3-4)**, 222-233 (1999).

[14] Su, Z., Remote sensing of land use and vegetation for mesoscale hydrological studies. International Journal of Remote Sensing **21(2)**, 213-233 (2000).

[15] Su, Z., The Surface Energy Balance System(SEBS) for estimation of turbulent heat fluxes. Hydrology and Earth System Sciences **6(1)**, 85-99 (2002).

[16] Yunhao, C., et al., A Simple Two-component Structure Model for Daily Evapotranspiration. Geomatics and Information Science of Wuhan University **30(012)**, 1075-1079 (2005).

[17] Gutman, G. and A. Ignatov, The derivation of the green vegetation fraction from NOAA/AVHRR data for use in numerical weather prediction models. International Journal of Remote Sensing **19(8)**, 1533-1543 (1998).

[18] Yaoming, M. and w. Jiemin, Estimation of flux densities over the heterogeneous land surface with the aid of satellite remote sensing and field observation. ACTA METEOROLOGICA SINICA **57(002)**, 180-189 (1999).

[19] Renhua, Z., et al., To differential thermal inertia-based remote sensing information model of surface evaporation and the whole desert region in Gansu authenticatio. Science in China: D Series **32(012)**, 1041-1050 (2002).

[20] Hatfield, J., R. Reginato, and S. Idso, Comparison of long-wave radiation calculation methods over the United States. Water Resour. Res **19(1)**, 285-288 (1983).

[21] GuoYu, Q., W. Shuai, and W. Xiao, Three temperature(3t) model-a method to estimate evapotranspiration and evaluate environmental quality. Journal of Plant Ecology **30(002)**, 231-238 (2006).

[22] Aidi, H., et al., Research in retrieval of land surface temperature in Aeolian desertification areas from MODIS image data. Chinese high technology letters **18(005)**, 511-518 (2008).

[23] Tang, Q.Y. and Zhang, C.X., Data Processing System (DPS) software with experimental design, statistical analysis and data mining developed for use in entomological research. Insect Science. doi: 10.1111/j.1744-7917.2012.01519.x(2012)

Aidi Huo received the Ph.D. degree in geographic information system from the College of Resource and Environment, Northwest A&F University in 2008. He is currently an Associate Professor in the School of Environmental Science & Engineering, Chang'an University. His research interests are in the areas of Remote Sensing, Geographic Information System and distributed systems.

Jianguo Li received Bachelor degree in physics from College of Physics and Information Engineering, Henan Normal University in 1996. He is currently an Associate Professor in the School of Department of Physics, Zhengzhou Normal University. His research interests are in the areas of Remote Sensing and Geographic Information System.

Guangzhi Jiang received the Master degree in physics from the College of Physics and Information Science, Shanxi Normal University in 2000. He is currently a Professor in the School of Department of Physics, Zhengzhou Normal University. His research interests are in the areas of Remote Sensing and Geographic Information System.

Yun Yang received Masters degree in 2005 and Doctors degree in 2008 from Wuhan University, China. She is now working in Chang'an University, China. Her research interests are in the areas of pattern recognition and their applications in remote sensing field.