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Estimation of evapotranspiration in the Mu Us Sandland of China

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Abstract

Evapotranspiration (ET) in Wushen County, located in the Mu Us Sandland of China, was estimated by Advection-Aridity Model based on the complementary relationship hypothesis with reflectance data of NOAA/AVHRR and MODIS, meteorological data etc. from 1981 to 2003. The results have showed that the estimated monthly ET was about 18.9% lower than measurements of Eddy Covariance (EC) system after forcing energy balance closure over forest and grassland, and about 18.7% lower than measurements by microlysimeter over sand dune. From 1981 to 2003, annual ET in Wushen County was between 200 and 310 mm with an average of 252 mm, increasing from west to east spatially. The inter-annual relative variability of ET was between 10% and 24%, decreased from northwest to southeast spatially. Both the inter-annual and seasonal variations of ET were great. Maximum and minimum annual ET could reach 340 mm and 200 mm respectively. The seasonal pattern of ET showed a single peak normal distribution. The cumulative ET during the period (June, July, August and September) was 223 mm, which was 88% of the total annual ET. The relationships between annual ET, precipitation and Normalized Deviation of Vegetation Index (NDVI) showed positive correlations temporally and spatially.

1 Introduction

Evapotranspiration (ET) is an indispensable component of surface energy and water balance. Accurate estimation of ET plays a significant role in the study of global climate change, environmental evolution as well as rational utilization of water resources. The Mu Us Sandland is one of the four sandlands in China, located at the transition zone of several ecological regions, with greatly changed water and heat resources, little precipitation, and dry climate (Yao et al., 1992). In this region, drought and water shortage are the primary performances of the fragile ecosystem (grassland degradation and land desertification), and the key limited factors for local economy growth and social devel-

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opment. Therefore, both rational exploitation and optimal utilization of water resources are of great importance. So far, studies in the Mu Us Sandland have mainly focused on dynamic change of landscape and desertification (Wu and Ci, 2002; Runnström, 2003; Yang et al., 2005), physiological and ecological characteristics of plant (Jiang and He, 1999; He and Zhang, 2003; Huang et al., 2007), as well as dynamic monitoring of soil moisture (Lv et al., 2006). And change of groundwater has also been reported (Masakazu, 1992; Yu et al., 1998). However, there are still few studies on ET in the Mu Us Sandland (Li et al., 1989; Li and Li, 2000), especially for estimation of regional ET.

After the complementary relationship between actual and potential evapotranspiration presented by Bouchet (1963), several models to estimate regional evapotranspiration have been proposed by Morton (1975, 1983), Brutsaert and Stricker (1979), Granger and Gray (1989), Sugita (2001) and others. These models were compared and applied in different climate categories and land surfaces (Hobbins et al., 2001; Xu and Singh, 2004; Ramirez et al., 2005; Liu et al., 2006; Virginia et al., 2008). These complementary relationship approaches are attractive because of needing only routine meteorological data (without runoff and soil moisture information), and they are comparatively easier to use over a larger area.

The objective of this paper is: (1) to estimate regional ET by Advection-Aridity model, with remote sensing data (NOAA/AVHRR, MODIS) and meteorological data, taking the hinterland of the Mu Us Sandland – Wushen County in Inner Mongolia as a case, (2) to analyze the temporal and spatial distribution of the ET in Wushen county, (3) to analyze the relationships between ET, precipitation and NDVI.

2 Materials and methods

2.1 Study area and data

The Mu Us Sandland (37°27.5′ N–39°22.5′ N, 107°20′ E–110°30′ E) locates at the junction of Ningxia Hui Autonomous Region, Inner Mongolia Autonomous Region

and Shaanxi Province, including the south of Ih Ju League in Inner Mongolia, the north of Yulin in Shaanxi Province, and the northeast of Yanchi in Ningxia Hui Autonomous Region, with a total area of 4×10^4 km^2. It is at the transition zone of Ordos Plateau and Loess Plateau, and belongs to continental semiarid climate. As shown in Fig. 1, the shaded part stands for the Mu Us Sandland with Wushen County (37°38′54″ N–39°23′50″ N, 108°17′ E–109°40′22″ E, 1300 m above sea level, the total area is 11 645 km^2) lying in the centre. The mean annual temperature in Wushen County is 6.4°C with mean annual precipitation of 362 mm for the period from 1958 to 1990 (Wushenqi Chorography, 2001). Forestland mainly located in the northeastern and southeastern parts of Wushen County, accounting for 11% of the total area, sandland dominants most northwest and middle area, accounting for 23% of the total area, while the grassland mainly distributed in the middle and southwest, taking about 64%.

Meteorological data used in this paper was collected from 12 stations in and around Wushen County (Table 1) between 1981 and 2003, including monthly mean temperature, maximum and minimum temperature, sunshine percentage, wind speed, actual vapour pressure, and surface temperature etc. The meteorological data of 12 meteorological stations were interpolated spatially to 1 km×1 km grid data. For air temperature, it is firstly converted to corresponding 'sea-level' values according to the altitude of each station. Then the interpolated air temperature was further converted to the actual air temperature using DEM data. Kriging method was used in the interpolation of air temperature, wind speed, sunshine percentage, actual water vapour pressure and surface temperature, while GIDS (Gradient plus Inverse-Distance-Squared) method for precipitation.

The observation data includes ET measurements in the Mu Us Sandland Exploitation and Control Research Centre (38°59′ N, 109°09′ E) from 1st to 31st August 2004. Two sets of Eddy Covariance System (Campbell, CAST3; LI-7500; Instrumental height 155 cm and 140 cm) were installed in the *alfalfa* and *Artemisia ordosica* field respectively, combined with the measurements of net radiation (REBS, Q7; 100 cm and 150 cm) and soil heat flux (Campbell, HFT3, 2–3 cm below surface). The experi-

mental field was flat, and the distance between two observation points was about 500 m. EC data was collected at 10 Hz sampling rate with a data logger (CR5000, Campbell, the USA), while net radiation as well as soil heat flux were sampled every 30 s with a same data logger, which were averaged to 30 min at last. Higher quality data was obtained through rigorous data processing and quality control, which included spike detection, lag times correction, converting sonic virtual temperature into actual temperature, coordinating rotation using planar fit method, correction for air density fluctuations (WPL-correction), etc. An EdiRe (University of Edinburgh, http://www.geos.ed.ac.uk/abs/research/micromet/EdiRe) software package was used for this purpose. Besides, the half-hourly flux data was screened via two steps: firstly, measurements in the periods of precipitation (including 1 h before and after) were rejected. Secondly, measurements with the friction velocity u_*<0.1 m/s were rejected (Blanken et al., 1998). The gaps of missing data were filled by Nonlinear regression method (Alavi et al., 2006). A second power function between latent heat flux and net radiation was established according to the data in adjacent ±10 d of the missing value, then the missing value was calculated by the regression equation if the determination coefficient (R^2) was greater than 0.5. If R^2 is less than 0.5, more data should be chosen to form the regression equation.

The ground data used in this study also included ET measurements by using microlysimeters at the top, middle and bottom parts of sand dune in the East Experiment site (38°59′ N, 109°10′ E) of the Mu Us Sandland Exploitation and Control Research Centre in June and July of 1988. The microlysimeter was used every 1 h to measure the ET (Masakazu, 1992).

The remote sensing data used in this study included surface albedo and Normalized Different Vegetation Index (NDVI). The monthly surface albedo from 1981 to 2000 was calculated with the first and second band reflectance of NASA Pathfinder/AVHRR (8×8 km) land data sets (Valiente et al., 1995):

$$r = 0.545r_1 + 0.320r_2 + 0.035 \quad (1)$$

Where r is the broad band albedo, r_1, r_2 are the reflectance of NOAA/AVHRR in the

first and second band respectively. Judgement was carried out on remote sensing images, and high reflectance contaminated by clouds was rejected before calculation. The monthly mean reflectance data were obtained by averaging the three 10-d images in a month. Then, it was resampled to 1 km×1 km image.

The monthly surface albedo during 2001 and 2003 were calculated with the MODIS products of black-sky albedo r_{dir} and white-sky albedo r_{dif} per 16 d. The 16-d averaged surface albedo can be derived from the following equation, then the monthly mean albedo image is obtained by averaging the two 16-d images per month:

$$r = (1 - s) \times r_{dir} + s \times r_{dif} \quad (2)$$

where s is the ratio of diffuse radiation to the global radiation.

NDVI from 1981 to 2003 was collected from 8 km NDVI dataset of GIMMS (Global Inventory Modelling and Mapping Studies). Remote sensing data was processed by Empirical Mode Decomposition Methods to remove the effect of atmospheric and radiometric calibration on NDVI. The image was transformed from original isometric projection to Albers Equal area projection. Inter-annual variation of vegetation coverage condition was analyzed based on annual maximum NDVI ($NDVI_{max}$) from 1981 to 2003.

The DEM data was collected from HYDRO1K data sets supplied by US Geological Survey's (USGS) EROS Data Centre, which then transformed to the Albers Equal area projection.

2.2 Model and methodology

Bouchet (1963) proposed that, for a homogeneous surface on a regional scale (1–10 km), when the external available energy remains a constant and water supply is sufficient, the actual regional evapotranspiration ET_a equals to the potential evapotranspiration ET_P, which is referred to a humid environment evapotranspiration ET_w. When the water availability becomes limited, actual evapotranspiration is reduced. Energy at the surface that is not taken up in the process of evaporation increases the temperature and humidity gradients of the atmospheric surface layer and leads to an increase

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in ET_P. When there is no advection, an increase in ET_P would be equal in magnitude to the decrease in ET_a. The complementary relationship between ET_a and ET_P is expressed as (Liu et al., 2006):

$$ET_P + ET_a = 2ET_w \quad (3)$$

Brutsaert and Stricker (1979) put forward the Advection-Aridity Model based on the principle above, and the equation can be expressed as:

$$ET_a = 2\alpha \frac{\Delta}{\Delta + \gamma}(R_n - G) - \left[\frac{\Delta}{\Delta + \gamma}(R_n - G) + \frac{\gamma}{\Delta + \gamma}E_A\right] \quad (4)$$

Where α is the Priestley–Taylor coefficient, Δ (hPa/°C) is the slope of the saturation vapour pressure to air temperature, γ (hPa/°C) is the psychrometic constant, G ($W\,m^{-2}$) is the soil heat flux, E_A ($W\,m^{-2}$) is the 'drying power of the air'. R_n ($W\,m^{-2}$) is the monthly net radiation at the surface and is given by:

$$R_n = (1 - r)Q - R_{nl} \quad (5)$$

Where R_{nl} ($W\,m^{-2}$) is the net longwave radiation, monthly total radiation Q ($W\,m^{-2}$) is calculated from astronomical radiation Q_0 ($W\,m^{-2}$) and sunshine percentage S. Monthly astronomical radiation can be obtained by summing up daily astronomical radiation, thus the monthly total radiation Q is given by:

$$Q = Q_0(a + b \times S) \quad (6)$$

where a, b are empirical coefficients and fitted by least square method with radiation data at Dongsheng station and Ejinhollo station (Table 2), combined with astronomical radiation and sunshine percentage.

The net longwave radiation R_{nl} ($W\,m^{-2}$) is parameterized according to sunshine percentage-surface temperature model (Zeng, 2004):

$$R_{nl} = \varepsilon\sigma T_a^4 \left(a_0 + a_1\sqrt{e_d}\right)\left[b_0 + (1 - b_0)S\right] + \Delta R_{nl} \quad (7)$$

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where ε is surface emissivity and taken as 0.95 here, σ is the Stephan-Boltzman constant, T_a (K) is the air temperature, e_d (hPa) is the actual vapor pressure. a_0, a_1 and b_0 are the empirical coefficients, and obtained by fitting the monthly average data at 17 radiation stations in nationwide from 1993 to 2001 (Table 3). ΔR_{nl} ($W\,m^{-2}$) is the correction term of radiation, and expressed as $\Delta R_{nl} = \varepsilon\sigma T_0^4 - \varepsilon\sigma T_a^4$, where T_0 (K) is the surface temperature.

The soil heat flux G ($W\,m^{-2}$) is estimated as (Allen et al., 1998):

$$G = 0.07\frac{10^6}{24 \times 60 \times 60}(T_{i+1} - T_{i-1}) \quad (8)$$

where T_{i-1} and T_{i+1} (°C) are the monthly mean air temperature of the preceding month and the next month respectively.

The drying power of air E_A ($W\,m^{-2}$) can be written as (Prere and Popov, 1979):

$$E_A = 0.26 \times 2.4702\frac{10^6}{24 \times 60 \times 60}(e_s - e_d)(1 + cu_2) \quad (9)$$

Where e_s and e_d (hPa) are the saturated and the actual vapour pressure of the air respectively, u_2 (m/s) is the wind speed at 2 m above the ground, c is the calibrated wind coefficient:

$$c = \begin{cases} 0.54 & T_{max} - T_{min} \le 12^\circ C \quad \text{or} \quad T_{min} \le 5^\circ C \\ 0.07(T_{max} - T_{min}) - 0.265 & T_{min} > 5^\circ C, \quad 12^\circ C < T_{max} - T_{min} \le 16^\circ C \\ 0.89 & T_{min} > 5^\circ C, 16^\circ C < T_{max} - T_{min} \end{cases}. \quad (10)$$

Where T_{max} and T_{min} (°C) are the monthly maximum and minimum temperatures respectively.

The Priestley-Taylor coefficient α has been determined by many authors. Priestley and Taylor (1972) chose α=1.26 as the optimum value based on the analysis of data observed at sea surface and large scale saturated land surfaces. Davies and Allen (1973) used a value of 1.26 for well-watered grass. Zhang et al. (2004) found that α

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varied quickly in growing season, and assigned 1.17 and 1.26 for winter wheat, 1.06 and 1.09 for maize as the seasonal average in the North China Plain for the year 1999 and 2000. Liu et al. (2006) set it as 1.26 to calculate the ET over the Yellow River basin based on the complementary relationship approach. In this paper, α=1.26 was adopted.

3 Results and discussion

3.1 Validation of ET estimation

The precision of ET estimated by Advection-Aridity Model was validated by comparing with the measurements over *alfalfa* and *A. ordosica* field in August 2004, as well as over sand dune in June 1988 in the Mu Us Sandland Exploitation and Control Research Centre.

Since the two observation points in *alfalfa* and *A. ordosica* field were at a distance of 500 m in the experiment of August 2004, the average ET of the two fields could be seen as the measured value of the corresponding pixel (1 km×1 km). The ET derived from the measurements in August 2004 was 77.7 mm, while the estimated ET of corresponding pixel was 80.8 mm, with an overestimation of about 3.84% compared to EC measurement. However, as the Energy Closure Raito of EC measurement was 0.78 in this study (an average of the two EC measurements), the ET after forcing closure using "Bowen-ratio Closure" method (Twine et al., 2000) reached 99.7 mm, which was about 18.9% higher than the estimated ET.

Meanwhile, the ET measured by microlysimeter over sand dune in June 1988 was 1 mm/d (Masakazu, 1992), which was agreed with the result of the simple method for estimating the rate of evaporation from a dry sand surface (Li and Li, 2000). Consequently, the averaged ET was about 30 mm in June. And the estimated ET of the corresponding pixel was 24.4 mm, which is about 18.7% lower than the ET measured by microlysimeter. Generally speaking, the results of two different validation

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approaches above are consistent, which indicates that the model performance in estimating monthly ET is acceptable.

3.2 Spatial pattern of ET in Wushen County

The spatial pattern of mean annual ET generated from Advection-Aridity Model in Wushen County during 1981–2003 is presented in Fig. 2. The ET in Wushen County increased from northwest to southeast spatially. Annual average ET in this region was 252 mm during the period of 1981 to 2003, varying between 200 mm and 310 mm. In the northwestern part, including the west of Wushen Zhao and Galutu, the ET was within 200 to 240 mm. While in the northeastern part (Wulanshibatai, Hujierte, Huangtaolegai) and southeastern part (Nalinhe and Henan), ET was from 280 mm to 310 mm. Then, in other areas, the ET was between 240 mm and 280 mm. The Wuding River basin and the Nalin river basin located in the southeastern part and the Hekou Reservoir in the east made the ET in this area much higher than other parts. The ET in the northeastern part was relatively higher because most areas of this part were covered with forestland, as well as the Bage Nur Lake and the Wulan Nur Lake located here. While in the northwestern part, the lower ET could be attributed to fixed or mobile sand dune distributed in most of this part.

Figure 3 shows the spatial distribution of relative variability of mean annual ET in Wushen County. The formula used can be expressed as following:

$$\mathrm{var}_{\mathrm{avg}} = \sum_{i=1}^{n} \left| \frac{\mathrm{ET}_{ai} - \mathrm{ET}_{\mathrm{avg}}}{\mathrm{ET}_{\mathrm{avg}}} \right| \tag{11}$$

where $\mathrm{var}_{\mathrm{avg}}$ is the relative variability, ET_{ai} is the annual ET of each year, $\mathrm{ET}_{\mathrm{avg}}$ is the mean annual ET during the period of 1981–2003.

The relative variability of annual ET in Wushen County was between 10% and 24%. While the relative variability in the northwestern part (the west of Wushen Zhao and Galutu) was between 20% and 24%, relatively higher than other areas. In the east part

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(Wulanshibatai, Hujierte, Huangtaolegai, Dabuchake, Nalinhe and Henan), since large areas are covered with forestland and rivers, the relative variability was between 10% and 14%. In other area, it was between 14% and 20%. In a word, the relative variability of annual ET in Wushen County was decreasing from northwest to southeast spatially.

The spatial patterns of annual ET in Wushen County from 1981 to 2003 are displayed in Fig. 4. Though the annual ET varied greatly year by year, the spatial distributing trend of ET was almost consistent as increasing from west to east. This was mainly resulted from more sand dunes distributed in the west while more forestlands and rivers in the east part of Wushen County. The region of higher ET extended to the west part and the lower ET regions shrank in wet years, while in dry years, the region of lower ET extended to the east part and the higher ET region shrank.

3.3 Temporal variation of ET in Wushen County

The variation of annual ET and departure in Wushen County during 1981–2003 is shown in Fig. 5. In 1996, 1998, 2002 and 2003, the annual ET in Wushen County was larger than 300 mm. The annual ET even exceeded 340 mm in 2002 and 2003, much higher than those of other years. The annual ET was lower in 1982, 1983 and 1987, about 200 mm. Figure 5 also indicated that the annual ET departure in 1982, 1987, 1998, 2002 and 2003 were above 70 mm, and negative ones were in 1982 and 1987. It was between 30 and 70 mm in 1983, 1989, 1993 and 1996, with negative departure in 1983, 1989 and 1993, respectively. For other years, the annual ET departure was low, less than 30 mm. In general, the inter-annual variation of ET in Wushen County was significant.

Figure 6 depicts the variation of mean monthly ET and precipitation in Wushen County during 1981–2003. The variation trend of mean monthly ET and precipitation was similar, following a single peak normal distribution. Most of ET in Wushen County concentrated in June, July, August and September, which was 223 mm in total, accounting for 88% of the whole year amount. In the corresponding period, the precipitation was 245 mm, which was 74% of the whole year amount. In Fig. 6, it shows

that in April and May, when vegetation was at the early growth stage, ET increased slowly with the increasing of precipitation. In June, because of the rapidly rising of air temperature and sunshine hours, vegetation grew vigorously. The ET in this period increased much faster than precipitation. In Wushen County, most of the precipitation arrived in July and August. Plenty of precipitation dissipated in the form of evapotranspiration except for a small amount permeating into the sandland. The precipitation in September and October reduced obviously along with decreasing of air temperature. A large amount of water was still needed for grass and crops at the maturity stage, thus the ET during this period maintained a certain amount. During winter and spring (November, December, January, February, and March), the ET was extremely small due to withered vegetation, low air temperature and seasonal freezing of soil water.

3.4 The relationship between ET and precipitation, $NDVI_{max}$ in Wushen County

ET is mainly determined by local meteorological and vegetation conditions, soil water content. Since Wushen County locates in arid/semi-arid area, the main influence factors of ET are water condition (e.g. precipitation and soil moisture), vegetation coverage and growth status (e.g. NDVI and LAI). So the relationship between ET and precipitation, as well as $NDVI_{max}$ was analyzed as follows.

In Fig. 7, the spatial pattern of mean annual precipitation during 1981–2003 is shown. The mean annual precipitation in Wushen County increased from northwest to southeast spatially, with an average of 340 mm. For the northwestern part in Wushen County, the minimum precipitation was observed, which was below 310 mm. While in the northeastern and southeastern parts, the maximum precipitation (above 370 mm) occurred. The precipitation in other regions changed between 310 and 370 mm. The spatial pattern of mean annual ET was the same as the precipitation in Wushen County. Fig. 8 is the scatter plot of annual ET versus precipitation in Wushen County during 1981–2003. The result shows a positive relationship between annual ET and precipitation in Wushen County (r=0.572, n=23, passed 0.01 significance level test). In general, ET was higher in wet year, while lower in dry year in Wushen County.

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Figure 9 shows the spatial pattern of mean annual $NDVI_{max}$ in Wushen County from 1981 to 2003. It presents a positive correlation between the spatial distribution of ET (Fig. 2) and $NDVI_{max}$, in which higher ET was found in the region with higher $NDVI_{max}$ and vice versa. An increasing trend from west to east spatially was clearly seen in the distribution of $NDVI_{max}$. From the statistical analysis between $NDVI_{max}$ and ET in Wushen county during 1981–2003 (Fig. 10), a positive correlation between ET and $NDVI_{max}$ could be concluded (r=0.512, n=23, passed 0.01 significance level test). In general, ET in the year with well-developed vegetation and high coverage was higher, while lower in the year of poor growth conditions and low vegetation coverage.

4 Conclusions

With remotely sensed data and meteorological data, the ET in Wushen County, located in the Mu Us Sandland of China, was estimated by Advection-Aridity model based on the complementary relationship hypothesis. And the spatial and temporal distribution of ET were analysed. The following conclusions were drawn from this study:

1. The estimated monthly ET over forest and grassland was about 3.84% higher than measurements by EC, while 18.9% lower than the measured ET after forcing closure using "Bowen-ratio Closure" method, 18.7% lower than the measured ET by microlysimeter over sandland.

2. Mean annual ET in Wushen County was between 200 and 310 mm during 1981–2003, with an average of 252 mm increasing from west to east spatially. Multi-year relative variability of annual ET in Wushen County varied between 10% and 24%, decreasing from northwestern to southeastern region spatially. From 1981 and 2003, the region of higher ET extended to the west part and the lower ET regions shrank in wet years, while in dry years, the region of lower ET extended to the east part and the higher ET region shrank.

3. Both inter-annual and seasonal variations of the ET in Wushen County were great. The maximum annual ET was larger than 340 mm, while the minimum value was around 200 mm. Seasonal variation of ET followed a single peak normal distribution. A large amount of ET appeared in June, July, August and September, which is 223 mm in average, accounting for 88% of the whole year amount.

4. Positive correlation was obtained between annual ET and precipitation, annual ET and $NDVI_{max}$ respectively in their temporal and spatial distribution in Wushen County. Generally speaking, as the groundwater level was relatively stable (Masakazu, 1992), and mean annual precipitation during 1981–2003 was a little higher than ET, the revenue and expenditure of water resources were in a low level balance, which could satisfy the growth of vegetation basically. But the non-uniformity in temporal and spatial distribution of precipitation limited the growth of vegetation severely. As a result, improving water use efficiency is the key to accelerate vegetation recovery in Wushen County as well as Mu Us Sandland.

In our study, some parameters in Advection-Aridity Model such as the Priestley-Taylor coefficient are taken as constants and need further improvement combined with land cover/land use map. In addition, since the spatial resolution of remote sensing data is course (1 km×1 km or 8 km×8 km), the pixel mixture problem is popular, which brings certain errors, thus remote sensing images with higher spatial resolution should be used in future.

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Table 1. Meteorological stations in and around Wushen County.

Station name (Province)	Latitude	Longitude	Elevation	Start Date	End Date
EtuokeBanner (Inner Mongolia)	39°06′ N	107°59′ E	1380.3	Jan 1981	Dec 2003
Dongsheng (Inner Mongolia)	39°50′ N	109°59′ E	1460.4	Jan 1981	Dec 2003
Ejinhollo Banner (Inner Monglia)	39°34′ N	109°44′ E	1329.3	Jan 1981	Feb 1995
Hequ (Shanxi)	39°23′ N	111°09′ E	861.5	Jan 1981	Dec 2003
Yulin (Shaanxi)	38°14′ N	109°42′ E	1057.5	Jan 1981	Dec 2003
Yanchi (Ningxia Hui Autonomous Region)	37°47′ N	107°24′ E	1347.8	Jan 1981	Dec 2003
Dingbian (Shaanxi)	37°35′ N	107°35′ E	1360.3	Jan 1989	Dec 2003
Wuqi (Shaanxi)	36°50′ N	108°11′ E	1272.6	Jan 1981	Dec 2003
Hengshan (Shaanxi)	37°56′ N	109°14′ E	1111	Jan 1981	Dec 2003
Wushenzhao (Inner Mongolia)	39°06′ N	109°02′ E	1312.2	Jan 1990	Dec 2003
Wushen County (Inner Mongolia)	38°36′ N	108°51′ E	1302	Jan 1999	Dec 2003
Research Center (Inner Mongolia)	38°59′ N	109°09′ E	1320	Jan 1987	Dec 1991

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Table 2. Empirical coefficient *a*, *b* in different seasons in Wushen County.

Season	*a*	*b*	Samples	Relative coefficient (r^2)
Spring (3–5)	0.156	0.598	91	0.676
Summer (6–8)	0.181	0.505	93	0.643
Autumn (9–11)	0.096	0.645	93	0.640
Winter (12, 1, 2)	0.138	0.639	92	0.729

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Table 3. Experiential coefficient a_0, a_1, b_0 of different seasons in Wushen County.

Month	a_0	a_1	b_0
1	0.495	−0.071	0.250
2	0.508	−0.070	0.196
3	0.514	−0.068	0.204
4	0.509	−0.072	0.269
5	0.515	−0.069	0.192
6	0.499	−0.068	0.276
7	0.500	−0.068	0.214
8	0.515	−0.072	0.247
9	0.492	−0.069	0.275
10	0.495	−0.070	0.247
11	0.500	−0.071	0.216
12	0.504	−0.075	0.239

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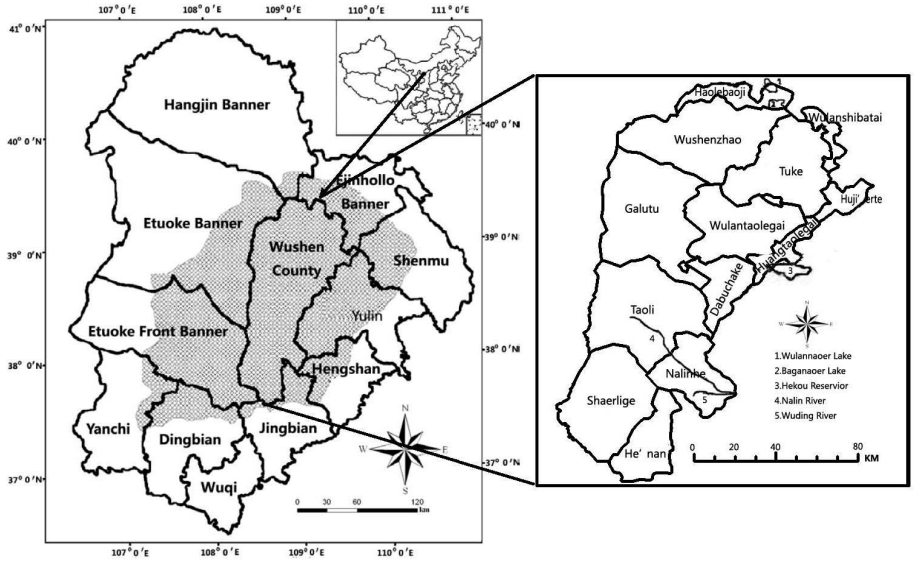

Fig. 1. Location of the Mu Su Sandland and Wushen County.

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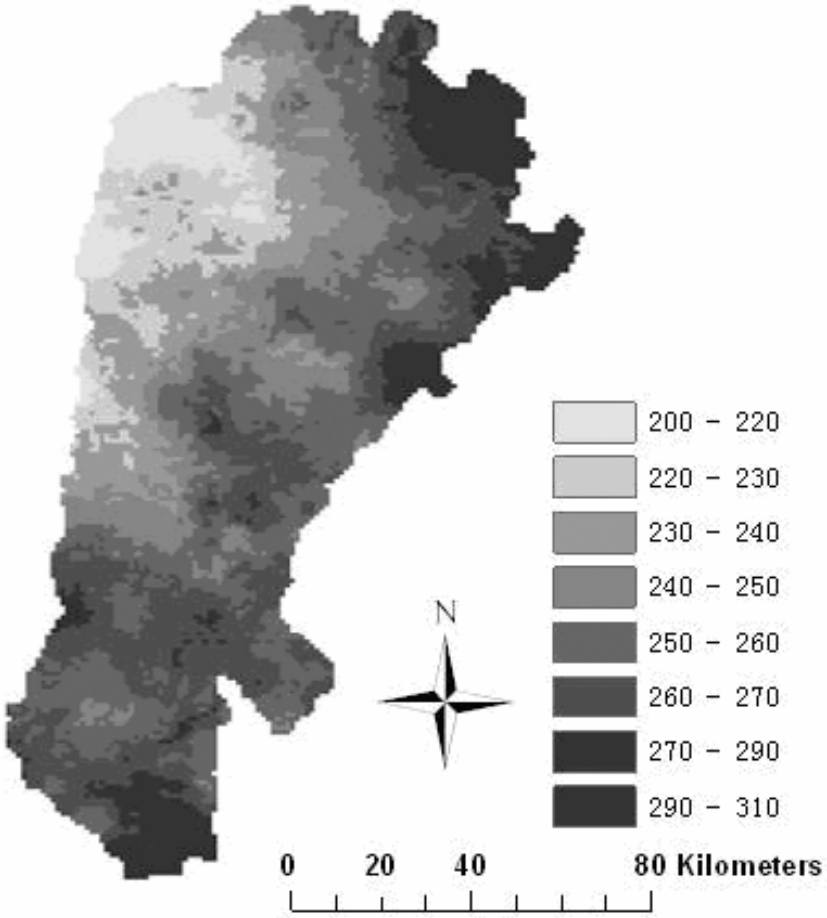

Fig. 2. The spatial pattern of mean annual ET (mm) in Wushen County during 1981–2003.

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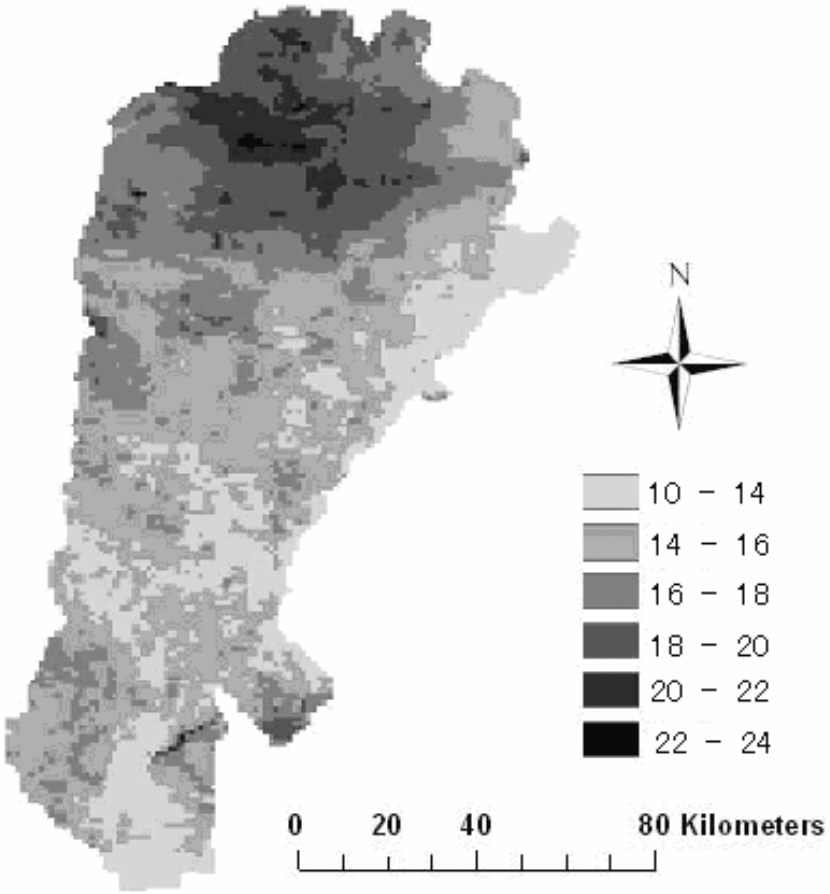

Fig. 3. The spatial pattern of relative variability (%) of mean annual ET in Wushen County during 1981–2003.

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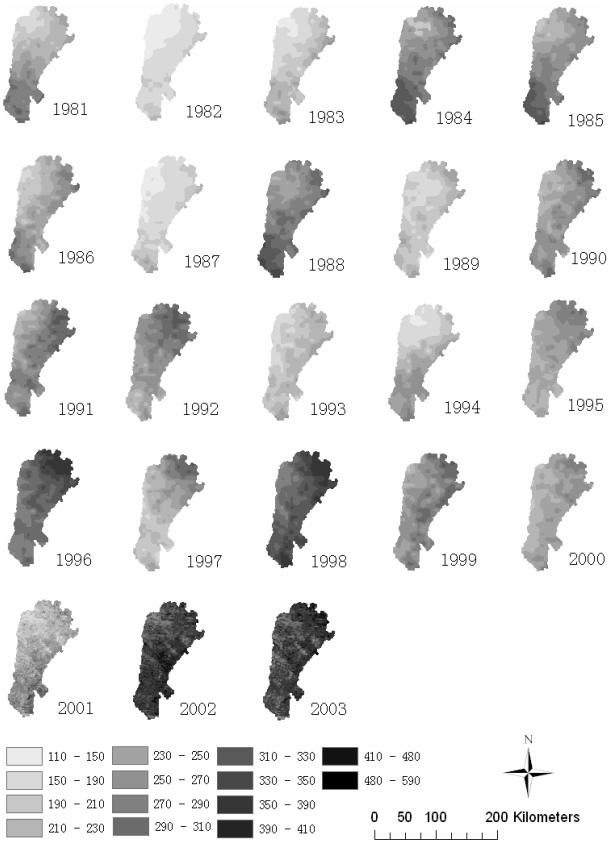

Fig. 4. The spatial patterns of annual ET (mm) during Wushen County in 1981–2003.

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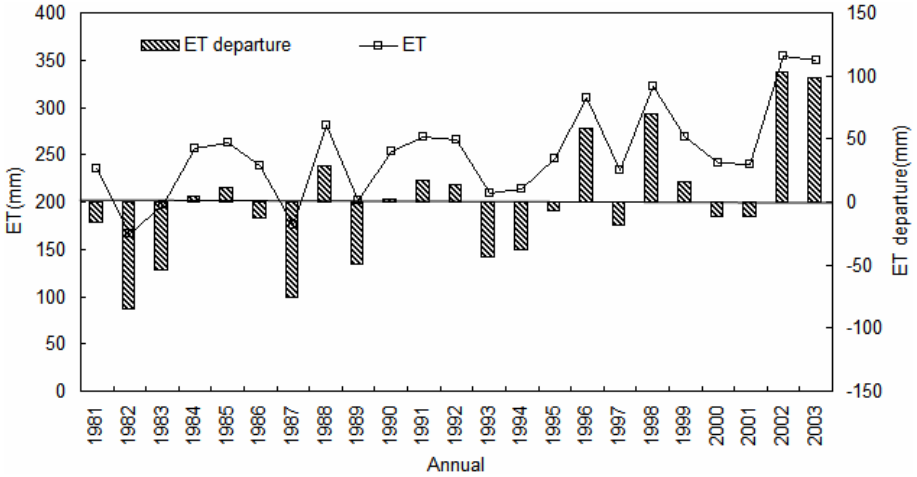

Fig. 5. The variation of annual ET and departure in Wushen County during 1981–2003.

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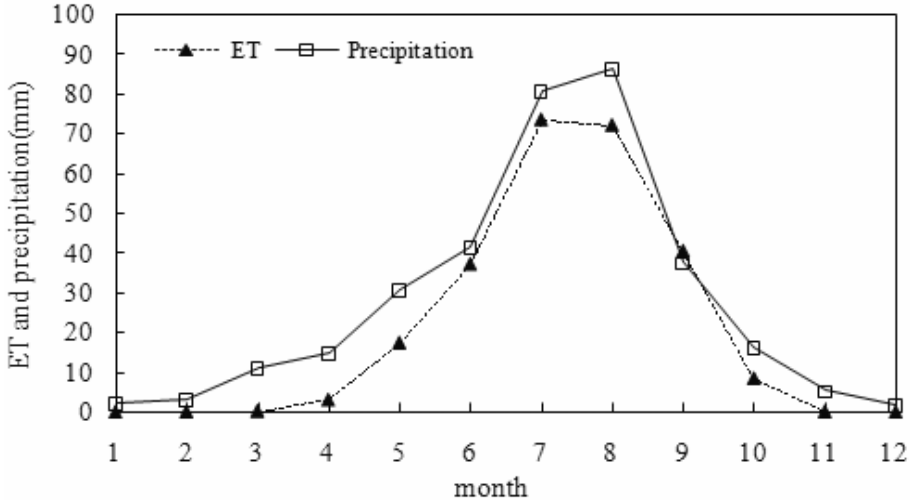

Fig. 6. The variation of monthly ET and precipitation in Wushen County during 1981–2003.

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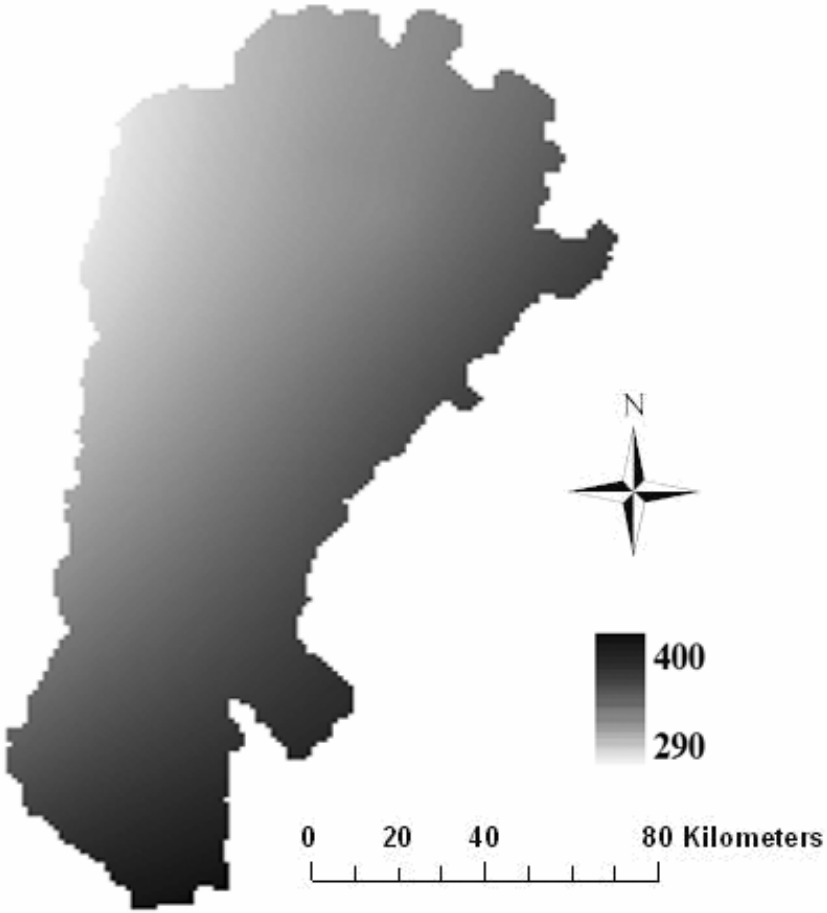

Fig. 7. The spatial distribution of mean annual precipitation (mm) in Wushen County during 1981–2003.

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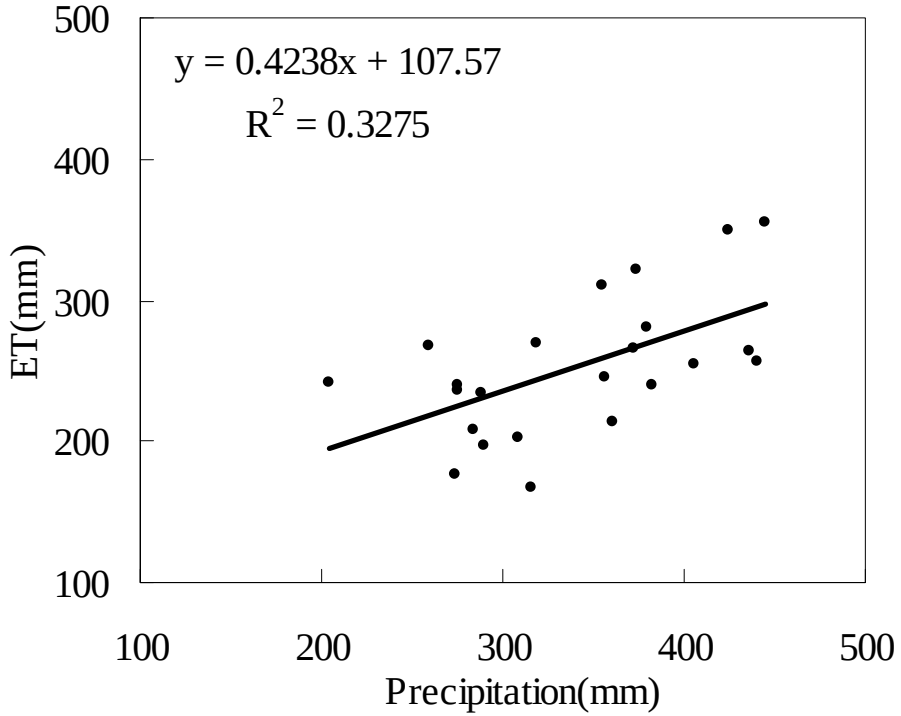

Fig. 8. The scatter plot of ET versus precipitation in Wushen County during 1981–2003.

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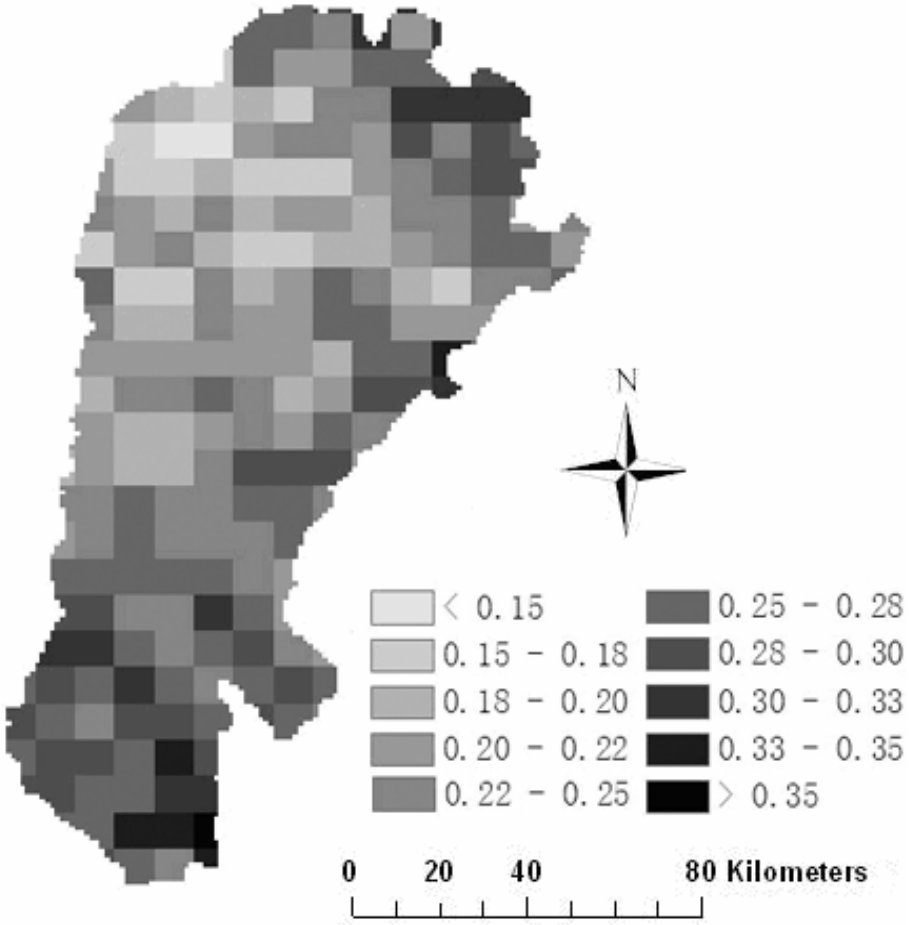

Fig. 9. The spatial distribution of $NDVI_{max}$ in Wushen County during 1981–2003.

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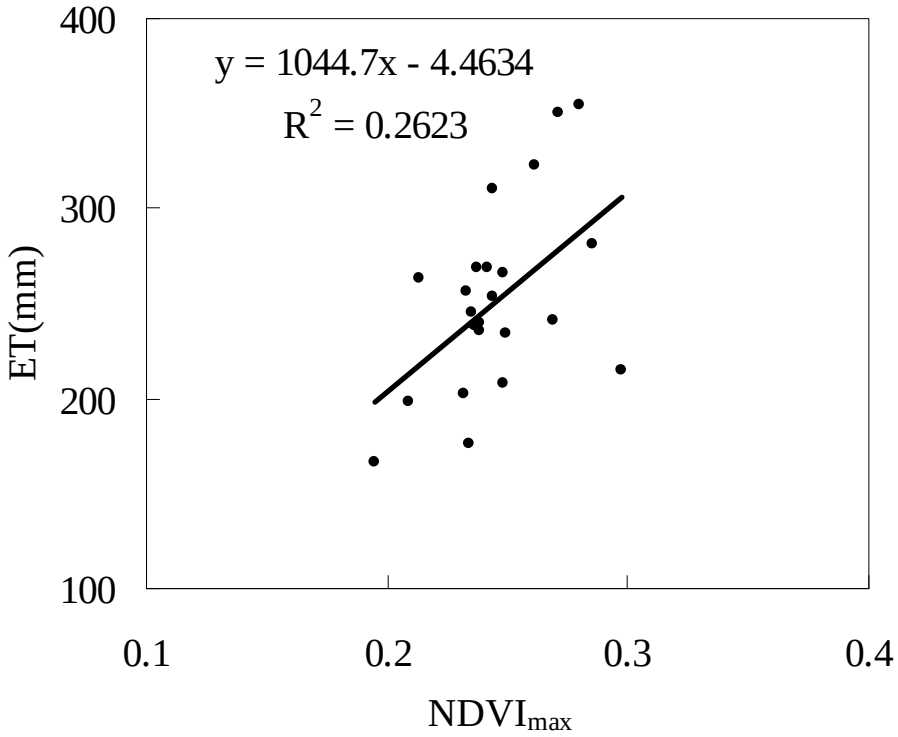

Fig. 10. The scatter plot of ET versus $NDVI_{max}$ in Wushen County during 1981–2003.

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