The simulation of land surface process with MODIS data in Haihe basin, China

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Abstract

By using MODIS data products, combined with DEM data, land use data, meteorological data, employed SEBAL model, light use efficiency model, PAR model and the algorithm of vegetation index , the parameters of ET (Evapotranspiration) , NPP (Net Primary Product) , PAR (Photosynthetic Active Radiation), NDVI (Normalized Difference Vegetation Index) and EVI (Enhance Vegetation Index) in Haihe River Basin were estimated. The impacts of elevation and land cover change on ET, NPP, PAR , NDVI and EVI are analyzed. We found that the impacts of elevation and land cover change on parameters are significant. The conclusions are as follows: 1) The ET in areas below 500m is the biggest, the ET in areas above 1500m is bigger and the ET in areas between 500-1500 is the smallest. 2) The impacts of location and elevation on PAR are significant, the PAR in areas with lower elevation is smaller; with the rising of elevation, the PAR has a increasing trend. The difference of PAR in different land cover is caused with location and elevation. 3) The NPP, NDVI and EVI in areas between 20-800m are bigger, and the values of these parameters in others areas is smaller. 4) The NDVI, EVI and NPP in areas covered with farmland, grassland and forest are bigger, and the values of these parameters in areas covered with unused land, water body and built-up land are smaller.

Keywords: Simulation, MODIS, Haihe Basin,China

1. INTRODUCTION

The natural ecosystems and the agro-ecological systems in northern China are generally subjected to water stress conditions. By remote sensing advantages of a quick means and macro-observation, the study of simulation and monitoring water/heat flux in regional scale is a theoretical significance and the scientific problems of practical value. The remote sensing is the only means to provide estimates of regional water/heat flux, so nearly 30 years, the method of estimate water/heat flux in regional scale with remote sensing data was pay widespread attention, many scientists at home and abroad have carried out extensively studies and achieved a series of results (Anderson,et al.,2005) 。

The ET (Evapotranspiration) as an important factor in the water cycle of land surface is both as a major component of water balance and an important component of energy balance, it is the largest and the most difficult to estimate in the water cycle of land surface which involved many complex processes of soil, vegetation and atmosphere. The ET of accurate measured and estimated not only is great significance in the study of the global climate evolution, ecological environmental problems and water resources evaluation, but also it is far-reaching significance in guiding agricultural drainage and irrigation, monitoring of agricultural drought, improving the utilization rate of agricultural water resources (Li, et al.,2005).

There are many research results on the surface ET and many scholars have put forward different

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estimation methods and models from a difference points(Jiang L, et al. 1999). According to energy balance and crop resistance principle, Seguin et al (1983)and Hatfield et al.(1983) attempt to calculate difference between surface radiation temperature and air temperature with satellite thermal infrared information to estimate the large-scale regional ET;

Bastiaanssen et al have systematically published a series of essays about estimate regional surface ET with SEBAL model based on surface energy balance equation using Landsat TM data,. The SEBAL model was widely used in the United States, Spain, Pakistan, Egypt, Sri Lanka, Turkey , China and other countries and areas under different weather conditions (Bastiaanssen et al. , 1998a, 1998b, Allen, et al.,2005); Kustas et al. (1999) estimated ET within a one and two layer model of heat transfer using remote sensing data.

The study of carbon cycle in terrestrial ecosystem is an important component in global change research. The model of light use efficiency (LUE) with the energy balance mechanism estimates NPP (Net Primary Product) using parameters of the Photosynthetic Active Radiation (PAR) absorbed by vegetation canopy ,LUE (ε) and others environmental control factors. Monteith et al.(1972) first proposed to estimate NPP with PAR and LUE (ε) （Ruimy et.al.,1994）. GLO-PEM (Global Production Efficiency Model) is light use efficiency model combined the ecological process of photosynthesis and autotrophic respiration mechanism mainly driven with the remote sensing data , this model has been used in estimation global NPP with long time and high-resolution (Prince,et.al., 2001). CASA (The Carnegie Ames Stanford Approach) model is the first model to use concept of LUE to apply to global-scale studies of vegetation productivity (Potter,et.al.,1993).

Figure 1. The location of study area

The PAR is part of the solar radiation (400nm-700nm) to be used for photosynthesis, it is the source of energy to form dry matter of plant. Therefore, the studies of PAR have important meaning and value in fields of ecology, agriculture and climate (Reich, et al.1999). From the related reference literature, the approaches of estimating spatial PAR can be divided into two categories: The first, the regionally continuous PAR can be obtained with spatial interpolation by using ground field observation data. The second, the methods of estimation PAR adapting to a variety of sensors are proposed with satellite data based on the theoretical basis of radiation transfer model. (Carder, et al., 2003).

In this paper, using MODIS data products, combined with DEM data, land use data, meteorological data, employed SEBAL model, light use efficiency model, PAR model and the algorithm of vegetation index , the parameters of ET, NPP（Net Primary Product）, PAR, NDVI (Normalized Difference Vegetation Index) and EVI (Enhance Vegetation Index) in Haihe River Basin, China were calculated, the spatial patterns and characteristics of land cover and these parameters are analyzed, the impacts of land cover and elevation on these parameters are studied.

2. METHODOLOGY

2.1 The Study Area

The Haihe River Basin is located east longitude between 111°26'35" ~ 120°21'43" latitude between 34°53'24" ~ 43°5'17", it neighbors Shanxi Plateau in the west, Mongolian Plateau in the north, Yellow River in the south and Bohai Sea in the east, its area is of about 656,000km^2, including all of Hebei Province, Beijing City, Tianjin City, and parts of Liaoning, Inner Mongolia, Shanxi, Henan and Shandong Province (Figure 1). The general topography is high in the northwest and low in the southeast, the part of the west is the Taihang Mountains in Shanxi Plateau area, the part of northern is Mongolian Plateau and Yanshan mountains, the part of the east and southeast is vast plains. The Haihe River Basin belongs to continental monsoon climate zone of temperate semi-humid and semi-arid, the multi-year average rainfall is 535mm and the mean annual temperature is range of 1.5 ~ 14℃, the annual average relative humidity is range of 50 ~ 70%, the annual surface ET ranged between 850 ~ 1300mm. The resources of light and heat in the region are rich and suitable for crop growth. Haihe River Basin is one of China's three major grain production bases.

2.2 Retrieval ET with SEBAL model

The SEBAL(Bastiaanssen et al 1998a,1998b) that is designed based on the traditional surface heat balance equations can assimilate multisource and multi-sensor information to estimate land water/heat fluxes making use of the regional advantage of remote sensing technology. These equations involved in SEBAL are described below based on the theory that incoming net solar radiation drives all energy exchanges on the earth surface and can be expressed as a surface energy balance equation as follows:

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

where R_n is the net radiation flux; G is the soil heat flux; H is the sensible heat flux; LE is the latent heat flux. As long as the values of R_n, G and H are known, the LE value can be calculated. The calculation of R_n and G is relatively simple and H is the most critical one to calculate.

2.3 Light use efficiency model

The Light use efficiency model estimates NPP with solar radiation absorbed by vegetation and environmental control factors based on the solar energy utilization efficiency mechanism, the calculation of NPP can be expressed as:

$$NPP = \sum_t [FPAR_t \times PAR_t \times \varepsilon_g \times (1 - R)] \tag{2}$$

Where: $FPAR_t$ (Fraction of PAR) is PAR proportion absorbed by vegetation; PAR_t is Photosynthetically Active Radiation in t time; ε_g is rate of PAR absorbed by vegetation conversion into organic matter, or the use efficiency of PAR, ε_g is affected by temperature, moisture, and the seasons of leaves growing.

2.4 The model to estimate instantaneous PAR with MODIS data.

For plant growth, the solar radiation in the visible light band (0.4-0.7μm) can be absorbed by chlorophyll is the most important, so the solar radiation in visible light band often referred to as photosynthetic active radiation (PAR), the range of band is usually between 0.4-0.7μm. PAR is defined as the part of down solar radiation in the visible light , the formula can be express as follows (Ruimy, et al., 1999):

$$PAR(W \cdot m^{-2}) = \int_{0.4}^{0.7} I(\lambda) d\lambda \tag{3}$$

Where, I_λ is solar down monochromatic radiation, λ is wavelength in vacuum. The attenuating effects of atmosphere to the solar radiation in the visible light band mainly are divided in five areas: the effects of mixed gas scattering (Rayleigh scattering); effects of mixed gas absorption (mainly absorption of oxygen); the effects of absorption by ozone; the effects of scattering and absorption by aerosol; the effects of absorption by water vapor. In order to simplify the process of calculation, the hypothesis is set as mutually independent of effects by atmospheric composition on solar radiation.

2.5 Calculation of NDVI and EVI

The algorithms for Normalized Difference Vegetation Index (NDVI) (Tucker , 1979), Enhance Vegetation Index (EVI) are following as:

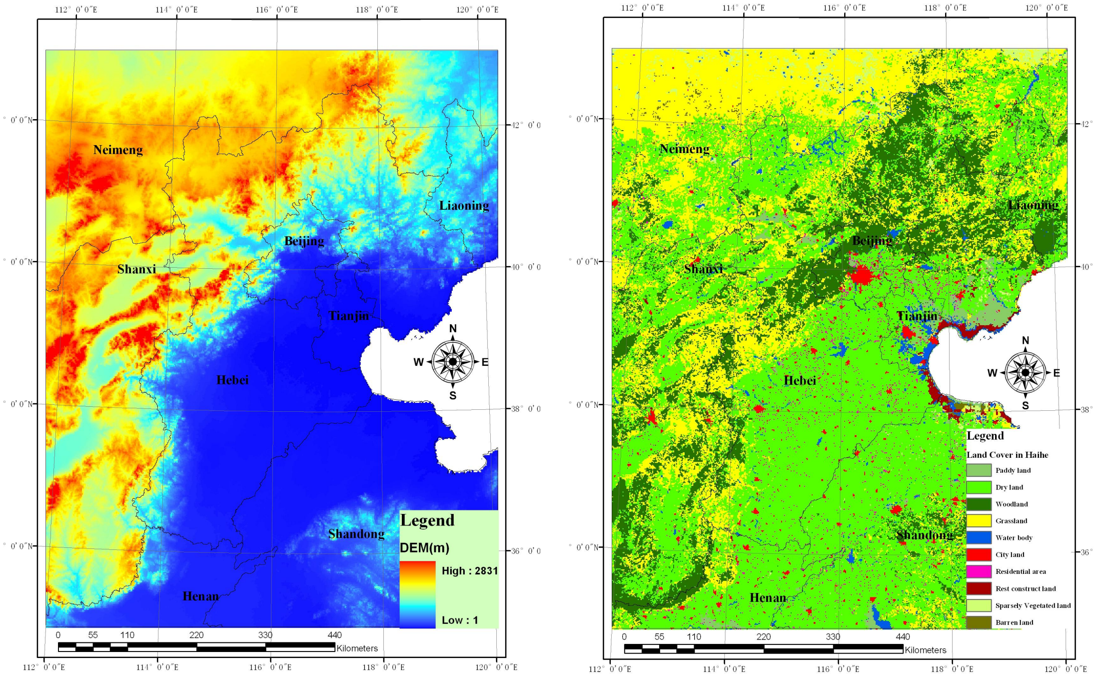
$$NDVI = \frac{\rho_{\mathrm{nir}} - \rho_{\mathrm{red}}}{\rho_{\mathrm{nir}} + \rho_{\mathrm{red}}} \qquad (4)$$

$$EVI = \frac{\rho_{\mathrm{nir}} - \rho_{\mathrm{red}}}{\rho_{\mathrm{nir}} + C_1\rho_{\mathrm{red}} - C_2\rho_{\mathrm{blue}} + L}(1+L)$$

Where: ρ_{red} is red band (0.63-0.69 μm) reflectance, ρ_{nir} is near red band (0.76-0.90 μm) reflectance, ρ_{blue} is blue band (0.45-0.52 μm) reflectance, L is adjustment factor, set to minimum background effects (L=0.5)。The C_1,C_2 are adjustment parameters, the values are 6.0 and 7.5,respectively.

3 RESULTS AND DISCUSSION

3.1 DEM and the spatial distribution of LUCC



(a) DEM of Haihe River Basin

(b) LUCC of Haihe River Basin

Figure 2. The maps of DEM and LUCC in Haihe River Basin

The study area locates north of the North China plain, south of Inner Mongolia plateau and east of Loess Plateau, it is adjacent to Bohai Bay. The study area is component of plains, plateaus and mountain, the plains and plateaus account for 72% of the total area, and mountains account for 28% of the total area.

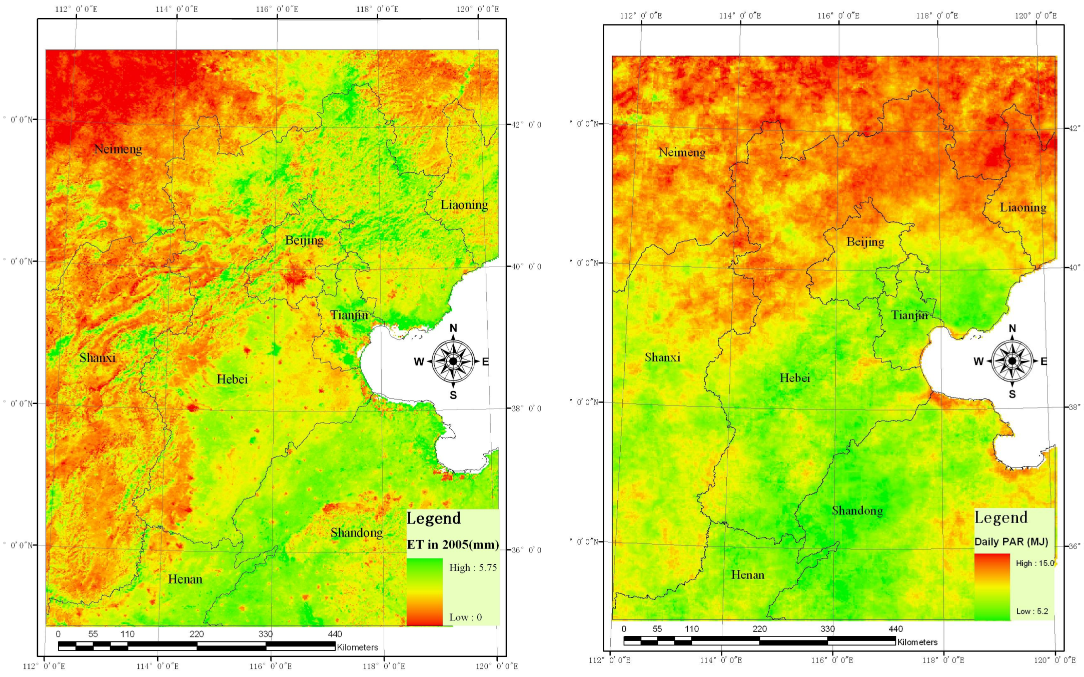
The land cover in study area mainly covered with dry land, grassland and woodland, account for 51.38% , 25.1% and 15.48% of total area, respectively, these three types of land cover account for 92% of total area. Others land cover types (paddy land, built-up land, water body and unused land) account for 8% of total area. The grasslands are mainly distributed in north-west of Inner Mongolia plateau and Taihang mountain. The woodlands are mainly distributed in the Mountains of Taihang , Yanshan and Shandong. The farmlands are mainly distributed in North China Plain and the east of Loess Plateau. The unused lands are mainly distributed in Inner Mongolia plateau and the surrounding area of Bohai Bay. The distribution of built-up lands and water body is sporadic, the distribution in plain areas is more dense (Figure 2b).

3.2 The impacts of Elevation and LUCC on ET and PAR

From figure (Figure 2a), the areas below 500m located in east of study area is north part of North China Plain, it is formed by the north part of Shandong , the east part of Hebei , Tianjin and Beijing accounting for 45% of total study area. The average daily ETs in 2005 for seasons(Spring, Summer, Autumn and Winter) are 1.09mm/day, 2.78mm/day, 3.40mm/day and 0.31mm/day, respectively. The areas between 500m-1500m located in the northwest of the study area (south of Inner Mongolia, north-west of Hebei province and east of Shanxi province) accounts for 47% of total study area, it is formed by the Inner Mongolia Plateau, Loess Plateau and the Taihang and Yanshan mountain ranges. The average daily ETs in 2005 for seasons(Spring, Summer, Autumn and Winter) are 0.98mm/day,1.61mm/day, 2.70mm/day and 0.27 mm / day, respectively. The areas above 1500m mainly locating in the northwest of Inner Mongolia Plateau, Loess Plateau and the Taihang Mountains accounts for 8% of total study area. The average daily ETs in 2005 for seasons(Spring, Summer, Autumn and Winter) are 1.43mm/day, 1.75mm/day, 3.10mm/day and 0.29mm/day, respectively.

By the above analysis shows that the ET in areas below 500m is biggest, the ET in areas above 1500m is bigger, the seasonal ET in areas between 500-1500m is smallest.

The average PAR in study area (Figure 3b) is 10MJ/ m^2, the PAR changes significantly with difference of elevation. The PAR in areas below 150m located the North China Plain and Shandong Jiaolai plain is 8-9MJ/ m^2 around; The PAR in areas between 150-450m mainly distributed in the hills of Shandong and the Loess Plateau is 10MJ/ m^2 around ; The PAR in areas above 450m mainly distributed in north part of study area (Inner Mongolia plateau and the Yanshan Mountains) is 11MJ/ m^2 around. This shows that the value of PAR is different in areas with different elevation, the elevation has significant effect on regional PAR.



(a) The mean ET in 2005

(b) The PAR in June,2005（MJ/M2）

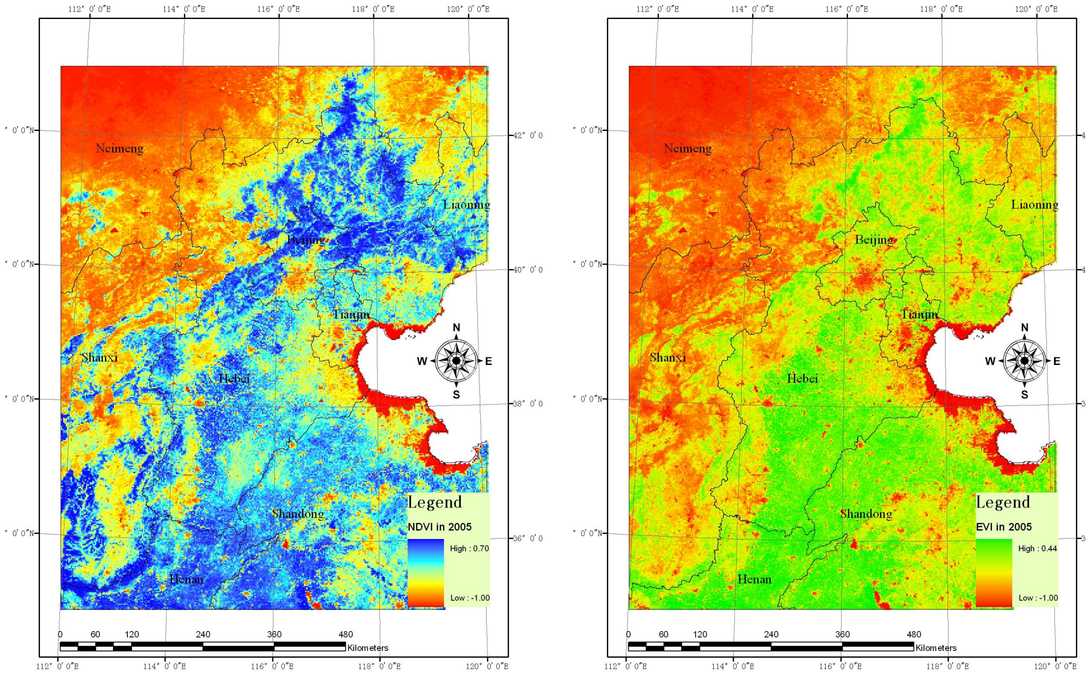
Figure 3. The maps of ET(2005) and PAR(Jun.2005) in Haihe River Basin

Because different types of land cover locate in different terrain and elevation areas, the PAR in different land covers also is difference (Figure 3b). The study found that the PAR in paddy land and dry land mainly distributed in the plain areas with lower elevation is 9.0MJ/M^2 around, the PAR in woodland and grassland mainly distributed in the highlands and mountainous areas with higher elevations is 10.5MJ/M^2 around, The PAR in water body , City , village and Rest built-up land mainly distributed in coastal , low plains and alluvial fan areas with lower elevations is 9.0MJ/M^2 around, The PAR in sparsely land and barren land mainly distributed in the plateau and mountain areas with higher elevations is 11.5MJ/M^2 around.

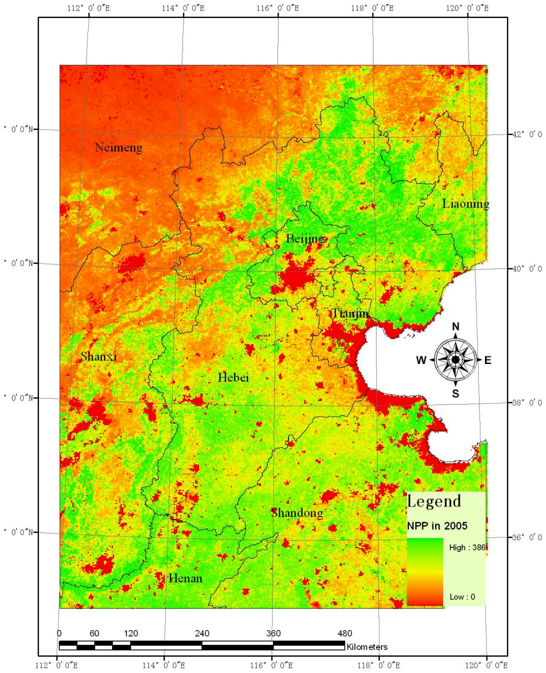
By the above analysis shows that the PAR in different land cover is different caused by different geographical location and elevation of land cover.

3.3 The impact of LUCC and Elevation on NPP,NDVI and EVI

The analysis impact of elevation on NDVI,EVI and NPP shows that the NPP , EVI and NDVI in these areas below 20m mainly covered with beach land located in surrounding of Bohai Bay are smaller, the NPP is 94.69gC/m2.year, NDVI is 0.34 and EVI is 0.21. The density of vegetation in these areas between 20m-800m mainly covered with farmland, woodland, grassland located in Haihe Basin is higher, the NPP is between 100-120gC/m2.year, the NDVI is between 0.39-0.45 and EVI is between 0.22-0.28. The density of vegetation in these areas between 800m-1500m mainly covered with grassland and unused land located in east and north-east of study area is lower and the vegetation productivity is not high, the NPP is 80 gC/m2.year around, the NDVI is 0.31 around and EVI is 0.18 around. The density of vegetation in these areas above 1500m mainly covered with woodland located in Yanshan Mountains is higher, the NPP is 95.56 gC/m2.year around, the NDVI is 0.37 around and EVI is 0.20 around. The average NPP, NDVI and EVI in whole study area are 96.58gC/m2.year, 0.37 and 0.21, respectively(Figure 4).



(a) The NDVI in 2005 **(b) The EVI in 2005**



(c)The NPP in 2005

Figure 4. The maps of NDVI,EVI and NPP in Haihe River Basin

From the analysis of above, we can find the NPP, NDVI and EVI in these areas between 20-800m are greater than average values of study area, respectively. The density of vegetation in these areas below 20 and above 1500m is more sparse and vegetation productivity is lower. The impact of land cover on NPP ,NDVI and EVI is obvious. The NPP, NDVI and EVI in areas covered with farmland are 100gC/m2.year around, 0.35 around and 0.20 around, respectively; The NPP, NDVI and EVI in areas covered with woodland are 130gC/m2.year around, 0.38 around and 0.23 around, respectively; The NPP, NDVI and EVI in areas covered with grassland are 79gC/m2.year around, 0.31 around and 0.18 around, respectively; The NPP, NDVI and EVI in areas covered with unused land are 34gC/m2.year around, 0.14 around and 0.08 around, respectively(Figure 4);

This shows that the NPP, NDVI and EVI in areas covered with farmland, grassland and woodland are greater, they are smaller in areas covered others land cover.

4 CONCLUSION

Using MODIS data products, employed SEBAL model, light use efficiency model, PAR model and the algorithm of vegetation index , the parameters of ET, NPP, PAR, NDVI and EVI in Haihe River Basin were calculated , and the changes and features of water and heat flux under different elevations and under different land coverage are analyzed.

The conclusions are as follows:

1) The ET in areas below 500m is the biggest, the ET in areas above 1500m is bigger and the ET in areas between 500-1500 is the smallest.

2) From the distribution of PAR in Haihe River Basin can be seen, the effect of geographical location and elevation on PAR is significant. The PAR in areas with lower elevation is smaller, the PAR has trend of increase with elevation rising. The PAR under different land cover in different location and elevation is different. The difference of PAR under different land cover caused with location and altitude.

3) The NPP, NDVI and EVI only in areas between 20-800 are bigger than average values of study area, the NPP , NDVI and EVI in areas below 20 m and above 800m are smaller than average values of study area. The impact of elevation on density of vegetation is obvious.

4) The NPP, NDVI and EVI in areas covered farmland, grassland and woodland are bigger, the NPP, NDVI and EVI in areas covered unused land, water body and built-up land are smaller. The difference of land cover result in the significant difference of NPP , NDVI and EVI.

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