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Dynamic change of net primary productivity and fractional vegetation cover in the Yellow River Basin using multi-temporal AVHRR NDVI Data

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An exponential relationship between net primary productivity (NPP) and integrated NDVI has been found in this paper. Based on the relationship and using multi-temporal 8 km resolution NOAA AVHRR-NDVI data, the spatial distribution an d dynamic change of NPP and fractional vegetation cover in the Yellow River Basin from 1982 to 1999 are analyzed. Fin ally, the effect of rainfall on NDVI is examined. Results show that mean NPP and fractional vegetation cover have an inclining trend for the whole basin, and rainfall in flood season influences vegetation cover most.

Dynamic change of net primary productivity and fractional vegetation cover in the Yellow River Basin using multi-temp oral AVHRR NDVI Data SUN Rui1, LIU Chang-ming2, ZHU Qi-jiang1 (1. Department of Geography, Beijing Normal Universit y, Beijing 100875, China; 2. Institute of Geographic Sciences and Natural Resources Research, CAS, Beijing 100101, Ch ina) 1 Introduction As a major part of terrestrial ecosystem, vegetation plays an important role in the energy, matte r and momentum exchange between land surface and atmosphere. The spatial distribution of vegetation and land cover ch ange can change surface roughness, surface temperature and evapotranspiration, which will affect latent and sensible heat exchange in vegetation-atmosphere system. Meanwhile, through the process of photosynthesis, land plants assimila te carbon in atmosphere and incorporate into dry matter while part of carbon is emitted into atmosphere again throug h plant respiration. The remainder of photosynthesis and respiration is called net primary productivity (NPP), which is important in the global carbon budget. As we know, change of vegetation is mainly caused by climate variation and human activities. The change of fractional vegetation cover and NPP can be a good indicator of climate variation to s ome extent. Therefore, it is necessary to study the relationship between climate factors and inter-annual change of v egetation, which will help us to understand global change. Recently, the availability of multi-temporal and multi-spe ctral remote sensing information has enabled measurement and monitoring of land cover condition, especially the AVHR R sensor on NOAA satellite to provide daily data for large area, which will help us to study the spatial distributio n, seasonal and inter-annual change of vegetation for large area. Many studies showed that NDVI, the normalized diffe rence vegetation index (NDVI=(NIR-VIS)/(NIR+VIS), NIR and VIS are the reflectance at near infrared band and visible b and respectively), is highly correlated to vegetation parameters like green biomass, leaf area index (LAI) and fracti on of absorbed photosynthetic active radiation by vegetation (FPAR) (Asrar et al., 1985; Nemani et al., 1989; Prince et al., 1995). There exists quasi-linear relationship between integrated NDVI and NPP (Asrar et al., 1985; Tucker et al., 1981). The relationship has been used for natural vegetation research in arid area. The limits of this method ar e essentially collected to the heterogeneity of natural vegetation; the relationship is only fit for homogeneous vege tation. So other researchers use exponential relationship between NPP and ?NDVI to estimate NPP (Lo Seen Chong D et a l., 1993). NDVI also represents the fractional vegetation cover to some extent; so many studies have analyzed the cha nge of vegetation cover or land cover with NDVI data directly; and some scientists study the effect of climate factor s on vegetation cover using multi-temporal NDVI data (Nicholson et al., 1990; Schmidt et al., 2000; Sun et al., 199 8). In semi-arid area, AVHRR NDVI have been found highly correlated to precipitation, and NDVI is a very sensitive in dicator for inter-annual change of rainfall. For example, Nicholson et al. analyzed time response of NDVI to rainfal l; their results showed that at seasonal and yearly time scale, there is good relationship between NDVI and rainfall (Nicholson et al., 1990). In 1998, Sun Hongyu et al. used monthly NOAA data from 1985 to 1990 to study the relationsh ip between seasonal land cover change and climate factors and the shift of green wave and brown wave (Sun et al., 199

8); however, their studies mainly focused on seasonal change. In order to understand the effects of rainfall on vegetation cover more clearly, we selected the Yellow River Basin in China as our study area to assess the inter-annual change of fractional vegetation cover and NPP in the Yellow River Basin, and analyze the relationship between rainfall and fractional vegetation cover using multi-temporal AVHRR NDVI data. 2 Study area and data 2.1 Study area description The Yellow River Basin, located in central-northern China (32?N-42?N, 96?E-119?E), covers an area of 794,712 km2 with most parts in the first and second topographic terrace of China, where the terrain undulates drastically and the relief types vary. In the basin, the elevation increases from east to west, the climate changes from humid to semi-arid and to arid from southeast to northwest. Because of the various living environments and condition, different types of vegetation are distributed in the basin where there are four vegetation zones spanned from east to west: broad-leaved deciduous forest, steppe and grassland, desert and Qinghai-Tibet Plateau vegetation (YRCC, 1989). Influenced by the distance to ocean, latitude and terrain, there are following characteristics of rainfall in the Yellow River Basin: it is rainy in southeast and dry in northwest, and precipitation in mountainous area is higher than that on plain, the annual precipitation decreased from above 800 mm to less than 200 mm from south to northwest; rainfall concentrates in summer with least in winter; inter-annual variation is very high, the ratio of maximum annual rainfall to minimum rainfall changes between 1.7-7.5, and it is higher than 3 in most areas. It is the reason mentioned above that leads to frequent drought in the Yellow River Basin. Figure 1 shows the dynamic change of annual average rainfall for the whole basin from 1961 to 1998. It can be seen that the fluctuation of annual rainfall is very large in the Yellow River Basin and it has a declining trend since the 1960s, annual rainfall decreased from about 460 mm in the early 1960s to 420 mm up to now. Drought becomes more and more serious. 2.2 Data In order to analyze changes of fractional vegetation cover and NPP in the Yellow River Basin since the 1980s, we use 8 km resolution NOAA AVHRR-NDVI data covering 1982 to 1999 (except 1994) from NASA Pathfinder AVHRR land data sets (Agbu et al., 1994). The NDVI image is composited from 10 days data using maximum value composite method to get cloud free data, and a correction for Rayleigh scattering is also applied. The original projection of image is Goode Interrupted Homolsine Projection. During processing, we reprojected the image to Albers equal area projection and cut out the Yellow River Basin. After examining the NDVI data, we find that some data are still contaminated by cloud, so we use maximum value composite method again to composite monthly NDVI image from three 10-day images in that month. For each pixel, we select maximum NDVI value among 3 images as final NDVI value. One year integration is done by summing up positive values of (NDVI(i)-0.05) for all months, where i represents month. The threshold NDVI of 0.05 is the accepted minimum value for the presence of vegetation (Lo Seen Chong D et al., 1993). Climate data are monthly precipitation observed by meteorological stations in or around the Yellow River Basin from 1982 to 1998. The data are gridded to 8 km resolution data using Kriging method. 3 Study method Because the fractional vegetation cover can be linear expressed by NDVI, so we use NDVI directly to analyze the inter-annual change of fractional vegetation cover and the effect of rainfall on it. Considering that NDVI is the highest when the way that vegetation is growing is best, we compute yearly maximum NDVI for every pixel to represent the fractional vegetation cover for that year based on monthly NDVI data. In the following text we call yearly maximum NDVI as yearly NDVI. The fraction of photosynthetically active radiation absorbed by vegetation can be estimated by NDVI, so if only we know absorbed PAR and light use efficiency, then we can estimate NPP. This kind of NPP model is called light use efficiency model (Pince et al., 1995; Sun et al., 2000). We have used 1 km resolution monthly AVHRR NDVI data and light use efficiency model to estimate NPP in China (Sun et al., 2000). After resampling the NPP image to 8 km resolution, the NPP computed by light use efficiency model is compared with yearly-integrated NDVI data produced from 8 km resolution Pathfinder NDVI land data (Figure 2), we find that their relationship can be fitted by the following exponential relationship. NPP = 218.2139 (exp0.2687SNDVI-1) (1) where NPP is net primary productivity estimated by light use efficiency model (gCm-2yr-1). Using equation (1) and yearly-integrated NDVI from 1982 to 1999, NPP in the Yellow River Basin is computed. Figure 2 Relationship between annually integrated NDVI and NPP calculated by energy use efficiency model Figure 3 Spatial distribution of the yearly maximum NDVI in the Yellow River Basin (1982-1999) 4 Results and discussion 4.1 Spatial distribution and inter-annual change of yearly NDVI Figure 3 shows the spatial distribution of the yearly average NDVI from 1982 to 1999. We can see that NDVI is higher in the upper reaches of the Yellow River where the vegetation belongs to alpine swampy meadow and in mountainous region, such as Anyemaqen Mountains, Liupan Mountains, Ziwuling Mountains, Luliang Mountains and northern slope of the Qinling Mountains, where the natural vegetation is forest or shrub, NDVI value is between 0.6-0.8. In Yinchuan Plain, Hetao Plain and Fenhe-Weihe Basin, the cropland can be irrigated, so the vegetation cover is better, and NDVI is 0.4-0.6, while on Ordos Plateau, where the vegetation belongs to semi-arid desert and semi-arid steppe, fractional vegetation cover is very low, NDVI is less than 0.3. The dynamic change of mean yearly NDVI for whole basin is drawn in Figure 4. I t shows the yearly maximum NDVI change of 0.42 to 0.49 in recent 20 years, mean NDVI is lowest in 1982 and highest in 1993. Different from the trend of annual rainfall, NDVI has incline trend, early NDVI value has increased from about 0.44 to 0.465 from the early 1980s to the end of the 1990s. The phenomena may be resulted from human activities such as farming, afforestation, etc., which led to the increase in fractional vegetation cover in some areas. Besides the inclined trend, there also exists fluctuation of NDVI, which may be caused by variation of climate especially the interannual change of rainfall. Because the fractional vegetation cover may be increased in one place and decreased in another for a whole basin, it is necessary to make clear the spatial distribution of fractional vegetation cover change. So we do 5-year average of yearly NDVI for 1982-1986 and 1995-1999 to represent the fractional vegetation cover at the beginning of the 1980s and the end of the 1990s, and then subtract the former image from the latter. The newly obtained image reflects the fractional vegetation cover change in recent 20 years (Figure 5). From the figure we can see that the fractional vegetation cover has decreased and the difference of NDVI is below zero at the headstreams of the Yellow River, while on Ordos Plateau, it has increased with a rise of NDVI being about 0.1. The maximum increase is in Daheihe and Hunhe river basins, being 0.1-0.2. Figure 5 Spatial distribution of the yearly max NDVI changes between the late 1990s and the early 1980s Figure 6 Mean NPP in the Yellow River Basin from 1982 to 1999 4.2 Spatial distribution and inter-annual change of NPP The spatial distribution of NPP (Figure 6) is similar to yearly NDVI. NPP is highest in forest and shrub by region, it is more than 500 gCm-2yr-1 in Liupan Mountains, Ziwuling Mountains, Luliang Mountains, Zhongtiaoshan Mountains and northern slope of Qinling Mountains. NPP is 200-500 gCm-2yr-1 in most parts of the Qinghai-Tibet Plateau and irrigated farmland, while it is below 100 gCm-2yr-1 in steppe and desert zone to the north of the Yellow River Basin. The change of average NPP for the whole basin is drawn in Figure 4. NPP has increased from about 240 gCm-2yr-1 to 280 gCm-2yr-1 in recent 20 years. The inter-annual change of NPP is very great, for example, the mean NPP is 220 gCm-2yr-1 in 1982 while it is close to 300 gCm-2yr-1 in 1998, the difference is about 80 gCm-2yr-1, which also indicates that the climate change and human activities influence vegetation very much.

4.3 Effect of rainfall on fractional vegetation cover change Change of fractional vegetation cover mainly caused by climate fluctuation and human activities. Most areas of the Yellow River Basin are located in arid and semi-arid region. Rainfall is one of the most important factors that limit the growth of natural vegetation; the amount of annual rainfall and intra-annual distribution will affect fractional vegetation cover. As mentioned in section one, rainfall in the Yellow River Basin is very unevenly distributed, which mainly concentrates in flood season from June to September. In order to analyze the effect of rainfall on inter-annual change of fractional vegetation cover, we compute correlation coefficients between NDVI and annual rainfall, flood and non-flood season rainfall for every pixel from 1982 to 1998. Considering that rainfall from October to December in non-flood season does not influence fractional vegetation cover the same year very much, we only compute correlation coefficients between yearly NDVI and rainfall from January to May. The correlation coefficient images are shown in Figure 7. From correlation coefficient image between annual rainfall and yearly NDVI (Figure 7a) we can see that in most areas of the Loess Plateau, Ordos Plateau, Hetao Plain and part of the Qinghai-Tibet Plateau, NDVI is positively correlated with annual rainfall. As a matter of fact, the natural vegetation is steppe or grassland and rainfall is scarcy in these places, vegetation growth depends on rainfall largely. Correlation coefficient in forest vegetation area (such as Liupan Mountains, Ziwuling Mountains) and part of irrigated cropland is low because irrigation is feasible in these places, soil moisture can satisfy vegetation growth, and inter-annual rainfall does not influence fractional vegetation cover much. Figure 7b is correlation coefficient image between yearly NDVI and rainfall in flood season. The spatial distribution of correlation coefficient is similar to that in Figure 7a, which demonstrates that in the Yellow River Basin, the vegetation growth pattern is mainly affected by rainfall in flood season. The correlation coefficient between yearly NDVI and rainfall in non-flood season (Figure 7c) is small in most places, which indicates that rainfall in non-flood season does not influence yearly maximum fractional vegetation cover strongly. However, rainfall in winter and spring can affect germination and revival In order to assess the effect of rainfall in non-flood season on vegetation cover more clearly, we also compute correlation coefficient between rainfall from January to May and the maximum NDVI from January to May (Figure 7d). The distribution differs slightly from Figure 7c. NDVI and rainfall are positively correlated in Anyemaqen Mountains and southern Loess Plateau, while NDVI is negatively correlated to rainfall in headstream region of the Yellow River. The vegetation in headstream region is alpine steppe or swampy meadow, it is very cold in winter and spring there. If it rains or snows too much during that period, snow, ice and soil will thaw later, which will postpone the vegetation growth and the fractional vegetation cover will decrease correspondingly. 5 Conclusions Using 8 km resolution AVHRR NDVI data, we have analyzed the spatial distribution and dynamic change of NPP and fractional vegetation cover in the Yellow River Basin, and studied the effect of rainfall on fractional vegetation cover in recent 20 years. The

results show that: 1) NPP and fractional vegetation cover are the highest in forest and mountain shrub by areas and lowest in desert area, NPP changes from above 800 gCm-2yr-1 to below 50 gCm-2yr-1. 2) There exists an inclining trend of mean NPP and fractional vegetation cover for the whole basin, but for the Qinghai-Tibet Plateau, NDVI has declined. 3) There is good relationship between NDVI and rainfall in the Yellow River Basin, especially in arid and semi-arid steppe zones, and inter-annual change of fractional vegetation cover is mainly affected by flood season rainfall. However, human activities can reduce the effect, for example, the effect of rainfall on NDVI is small in irrigated cropland. References

关键词： net primary productivity; fractional vegetation cover; rainfall; remote sensing