

LAND COVER TRANSFORMATION FEATURE UNDERSTANDING BY MODIS AND RESPONSE TO CLIMATE IN UPPER STREAM OF YELLOW RIVER

Wei Ouyang ^{a,b,c}, Andrew Skidmore ^{b,c}, FangHua Hao ^a, Chen Zhao ^a, Huaping Yao ^a, Xuan Zhang ^a

^a School of Environment, State Key Laboratory of Water Environment Simulation, Beijing Normal University, Beijing, 100875, China (Ouyang Wei, Hao FangHua, Zhao Chen, Yao Huaping, Zhang Xuan) wei@itc.nl,

^b International Institute for Geo-Information Science and Earth Observation (ITC), Hengelosestraat 99, P.O. Box 6, Enschede 7500 AA, The Netherlands (Ouyang Wei, Skidmore Andrew) Skidmore@itc.nl

^c Resource Ecology Group, Wageningen University, Bornsesteeg 69, 6708 PD Wageningen, The Netherlands (Ouyang Wei, Skidmore Andrew) Skidmore@itc.nl Corresponding Author: FangHua Hao fanghua@bnu.edu.cn

KEYWORDS: Vegetation transformation; Correlation analysis; MODIS; Climatic variation; Yellow River

ABSTRACT:

The vegetation quality in upper catchment of the Yellow River is critical for ecological stability in the whole watershed, which is also sensitive to climate change. The dominant land covers in this region are grassland and forest, which intensively affect water quality and quantity, soil erosion for whole watershed. With MODIS products on twelve dates in 2000, 2003, 2006, the normalized difference vegetation index (NDVI) for grassland and forest was calculated with the reference data and the daily vegetation NDVI variation regression models in three years were deduced. Then, three watershed annual climatic indicators (i.e. yearly accumulated precipitation, highest and lowest temperature) were averaged from nine weather stations. After that, the inter-annual grassland and forest NDVI variation principles with three indices were regressed. Except the lowest temperature, the yearly precipitation and highest temperature had strong correlation with two community vegetations NDVI. The correlation coefficients of four regression models ranged from 0.8690 to 0.9768. Furthermore, the NDVI responses to monthly precipitation, highest temperature and lowest temperature were analyzed. The vegetation NDVI and three climatic indices had strong positive correlations and the coefficient was larger than 0.7331. The monthly correlation also provides the threshold value of three climatic indicators, which is the starting point for vegetation growth. Consequently, the daily weather information may be used to predict regional vegetation NDVI. Meteorological indicator may simulate the regional grassland and forest NDVI simulated with climate change considerations, which is critical for vegetation quality assessment and regional environmental management.

1. INTRODUCTION

The Yellow River is the second longest river in China and dominates the ecological stability in whole north China. The eco-environmental quality, especially the vegetation coverage status in the upper catchment, is critical for the whole watershed (Alexander and Allan, 2006). The local ecosystem is fragile for the typical continental climate and far away from ocean. The dominant land covers are grassland and forest, which intensively affect water quality and quantity, sediment load (Wang et al., 2003). Despite the advance in the understanding of regional climate variation and its connection with land cover processes, the accurate description of local vegetation dynamic by NDVI and climate-vegetation interaction in China are still not be systematically studied.

The consequent impacts of climate variation on local ecosystem process can be demonstrated by the response of vegetation to climate change with the application of remote sensing technologies (RS). RS has the potential to monitor and detect land cover change at a variety of spatial and temporal scales, especially the satellite data with high temporal resolution (Carlson and Arthur, 2000; Wittenberg et al., 2007). The normalized difference vegetation index (NDVI) is the widely used in biophysical remote sensing studies. The NDVI is calculated by the amounts of reflectance in near infrared (NIR) and red (RED) portions of the electromagnetic spectrum and is an efficient indicator of photosynthesis for vegetation dynamics (Seaquist et al., 2003). The NDVI has been applied to biophysical variables research, such as leaf area, canopy coverage, land cover characteristics, chlorophyll density as well

as vegetation ecosystem dynamic (Fensholt et al., 2004; La et al., 2007).

The temporal and spatial resolution is the basic factor for remote sensed data application. From 2000, the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument onboard NASA's Terra satellite can scan 36 spectral bands, which range from the visible to thermal infrared wavelengths. The first seven bands are designed primarily for remote sensing of land surface with spatial resolution of 250 m and other bands are commonly referred to as 250 and 500 m (Running et al., 1994). The MODIS can provide moderate spatial and high temporal resolution data, which give a good opportunity to monitor and analyze regional land surface processes. It has been popularly applied in diverse missions for its advantages of daily data and offered a new possibility for large area coverage (Loboda et al., 2007; Pflugmacher et al., 2007). In the upper stream of Yellow River, the vegetation are sensitive to seasonal changes, which is the advantage for this study (Piao et al., 2006).

The objectives of this paper are to synthesize results of multi-temporal remote sensing to monitor vegetation distribution characteristics and temporal dynamic in upper stream of the Yellow River. The emphasis is placed on daily NDVI variation rules from MODIS data and the response to climatic variances. The inter-annual and monthly principles with precipitation, highest temperature, and lowest temperature were analyzed.

2. METHODS

2.1 Study area

The study area is upper part of Yellow River basin and is the connection of Qinghai-Tibet Plateau and Loess Plateau. The research region locates in Qinghai Province of Northwest China. This region is the most important water holding area for whole Yellow River watershed and nearly 49.2% of flow comes from here. The typical continental climate in this area is cold, dry and with obvious seasonal variation for it is far away from the sea. The yearly average temperature is $-2.3\text{ }^{\circ}\text{C}$. Land desertification in one of the main aspects of regional environment changes and imposed a great threat to watershed environmental stability (Feng et al., 2005).

The vegetation is largely consisted of high-cold meadow and high-cold steppe, which are the typical pasturelands in southern Qinghai Plateau. The deciduous forests locate in mountain area and the villages mainly distribute near the river and reservoirs. Steppe locates in most part of watershed and the dominant species are *Stipa krylovii*, *Orinus thoroldii*, *Stipa breviflora*, and *Artemisia frigida*. Desert steppe appears in some west places of

the research area, and it is composed of *Stipa breviflora*, *Heterocappus altaicus*, *Poa annua*, *Carex duriuscula*, *Leymus secalinus* (Wang et al., 2006).

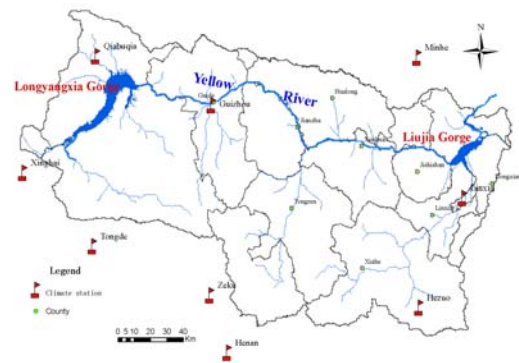


Figure. 1 Study area location and weather station distribution

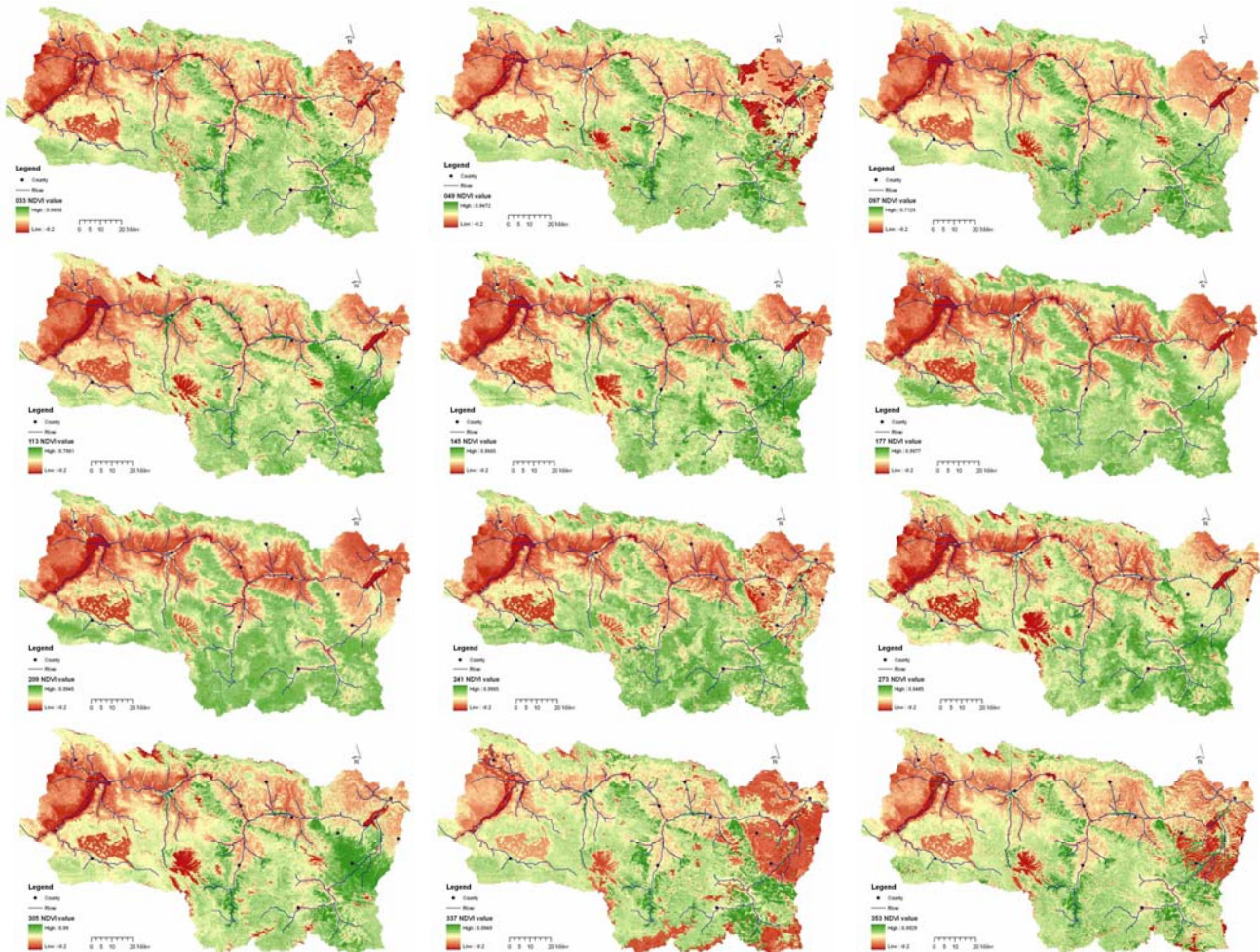


Figure.2 NDVI distribution based on MODIS data on twelve dates in 2006 of study area

2.2 MODIS image processing

In this paper, the raw NDVI data is extracted from the MODIS NDVI product (MOD13Q1), which comes from land processes distributed active archive center, NASA. The NDVI value is calculated from MODIS surface reflectance of the red band (610–680 nm) and near infrared band (780–890 nm), which has been corrected with molecular scattering, ozone absorption, and aerosols. This 250 m spatial resolution NDVI dataset repeats over period of 16 days (Pontus et al., 2007). According to local land cover and climatic characteristics, a 12-date time (every thirty-two days) series of MODIS NDVI data started from February 18 to December 18 in 2000, 2003 and 2006 were ordered from EOS data gateway website. Data were required from the MODIS tile (h26 v05) for statewide coverage. Then the NDVI data were mosaicked and georeferenced to the Universal Transverse Mercator (UTM) projection system by nearest-neighbor resampling method (William and Maik, 2005).

2.3 Regional meteorological collection

In general, precipitation is the most direct factor influencing vegetation primary productivity, especially in arid and semi-arid environments. The other weather variables, such as solar radiation, temperature and wind, have direct impacts on vegetation (Okin et al., 2001). In order to analyze the vegetation biomass response to local meteorological characteristic, the daily precipitation, highest temperature and lowest temperature are selected. The temperature index can present the solar energy over land cover. The daily monitoring weather information was collected from local nine weather stations (Fig.1). In this study, the yearly and monthly rainfall, highest temperature, lowest temperature in 2000, 2003 and 2006 were employed to explore the principle with vegetation NDVI. The climatic data of whole watershed were averaged with the monitoring data from all nine stations.

3. RESULTS AND DISCUSSION

3.1 Vegetation NDVI characteristic

Firstly, the regional land use characteristic was analyzed with national land use database in 2000 from Data Center for Resources & Environmental Sciences, Chinese Academy of Science (Fig.3). The dominant land cover is grassland, which occupy 59.57% of whole area. The forest and farmland are consisted of 15.49% and 12.82% of study area, respectively. Most of forests concentrate in mountain area and with latitude higher than 2800m. The construction land, water area and bare land occupy other 12.13%. In brief, the grassland and forest took nearly 75% of whole study region, which are critical for regional eco-environmental quality. The vegetation strongly influences the soil erosion and water holding. So, these two categories of vegetations are selected to study land cover variation characteristics in upper steam of Yellow River.

Referring to digital elevation model and land use data, the two greenness cover communities NDVI in three years were derived and averaged (Weiss et al. 2003). The mean NDVI of grassland and forest on twelve dates in 2000, 2003 and 2006 was calculated to present the monthly vegetation growth dynamics. The vegetation NDVI information in all thirty-six dates was statistically analyzed and the results are listed in Table 1 Grassland and forest NDVI statistical analysis. The grassland NDVI fluctuated from minimum 0.129988 on 49th day in 2000 to maximum 0.527692 on 225th day in 2003. The forest NDVI ranged from 0.1458008 to 0.7119630 in three years. The

grassland NDVI range in 2003 was 0.375212, which was bigger than the two years'. However, the forest NDVI range in 2003 was the lowest one. The minimum NDVI of two vegetations appeared on the same date. Despite different climatic condition, the minimum grassland and forest NDVI date in 2003 was on 353rd day in 2000 and on 49th day in 2006. But it was not same happened to maximum NDVI. The maximum NDVI data in 2003 and 2006 was on 255th day and on 177th day in 2000. Based on the mean NDVI, it can be concluded that grassland and forest NDVI both increased form 2000 to 2006.

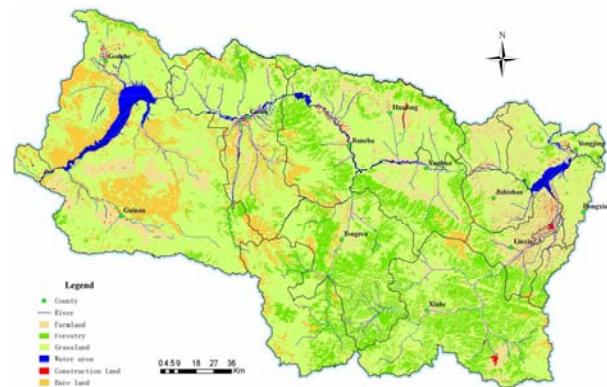


Figure.3 Land use distribution characteristics in upper Yellow River

Index	Yea	2000	2003	2006
Grass Land (G)	Range	0.355958	0.375212	0.31289
	Min	0.129988	0.15248	0.189733
	Min Date	49	353	49
	Max	0.485946	0.527692	0.502623
	Max Date	177	225	225
	Mean	0.306908	0.323433	0.3453
	Std. De	0.136795	0.142217	0.125629
	Range	0.566162	0.438742	0.566162
	Min	0.145801	0.25497	0.253898
	Min Date	49	353	49
Forest (F)	Max	0.711963	0.693712	0.676258
	Max Date	177	225	225
	Mean	0.433348	0.447745	0.462569
	Std. De	0.207575	0.1787876	0.168471

Table 1 Grassland and forest NDVI statistical analysis

From Fig.4, monthly NDVI variations of two vegetations can be understood more clearly. The vegetation NDVI began to drop from the middle of August. On most periods, the vegetation NDVI in 2003 and 2006 were overlaid. The vegetation did not grow obviously in first two months of 2003 and 2006, but had higher biomass in middle of the year. The vegetation NDVI in spring of 2000 was much lower than other two years and the summit value happened a month earlier than normal occasion. With the standard deviation (Std. De) analysis, the vegetation NDVI become more concentrated from 2000 to 2006.

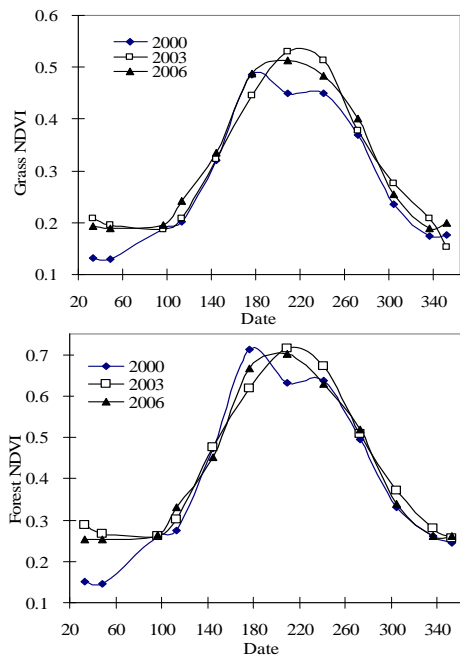


Figure.5 Grassland and forest NDVI temporal variation Regression model about grassland and forest daily NDVI variation in these three years is deduced (Table 2). All these order four polynomial models have strong coefficients of regression determination (R^2), which range from 0.9792 to 0.9899. The higher R^2 value means the achieved models can objectively describe daily vegetation NDVI variation. All the forest regression models have stronger significances than the grassland. By these models, the regional vegetation NDVI can be calculated and assessed daily. The vegetation NDVI value is an important index for environmental simulation and assessment. With simulated NDVI under similar climatic condition, the daily vegetation quality can be quantified conveniently, which can indicate regional eco-environmental quality. So that, the model can help regional environmental management.

Year	Regression model	R^2
2000	$NDVI_G=1*10^{-9}x^4-8*10^{-7}x^3+0.0002x^2-0.0189x+0.6342$	0.9792
	$NDVI_F=2*10^{-9}x^4-1*10^{-6}x^3+0.0003x^2-0.0266x+0.8316$	0.9836
2003	$NDVI_G=1*10^{-9}x^4-8*10^{-7}x^3+0.0002x^2-0.0199x+0.6553$	0.9661
	$NDVI_F=1*10^{-9}x^4-1*10^{-6}x^3+0.0003x^2-0.0261x+0.8689$	0.9797
2006	$NDVI_G=1*10^{-9}x^4-9*10^{-7}x^3+0.0002x^2-0.0223x+0.8047$	0.9866
	$NDVI_F=2*10^{-9}x^4-1*10^{-6}x^3+0.0003x^2-0.0296x+1.0598$	0.9899

Table 2 NDVI regression model of two vegetations

3.2 Yearly principle between NDVI with climate

It is hypothesized that significant positive relationships may appear between meteorological variables and vegetation NDVI. In order to explore inter-annual correlation between them, the annual mean NDVI in each year is selected to present the greenness growth. The precipitation, highest and lowest temperature are employed to describe meteorological feature. The correlation between vegetation NDVI and precipitation is demonstrated in Fig. 6A. The grassland and forest NDVI will rise with the increase of precipitation and the correlation coefficient (R^2) between them are 0.8690 and 0.9135, respectively. When annual precipitation climbed from 301.8mm in 2000 to 426.0 mm in 2006, the grassland NDVI value increased from 0.3069 to 0.3453 and the forest NDVI increased to 0.4626. The analysis proved that more precipitation would definitely cause higher vegetation NDVI.

The vegetation NDVI also has strong linkage with yearly highest temperature (Fig. 7B). The higher highest temperature leads to higher vegetation NDVI. With two correlated climatic indexes, the forest always has stronger relationship than grassland. However, the yearly lowest temperature does not have close correlation with grassland NDVI (Fig. 8C). The yearly total lowest temperature in 2003 was -678.348 degree, which was the lowest one in three years. However, the two vegetation NDVI are not the lowest one correspondingly. So, there is not simple and direct correlation about temperature

variations. The correlation models and the regression coefficients are listed in Table 3.

As the result, the grassland and forest NDVI could increase 0.003 and 0.002 respectively if there is more 10 mm precipitation. The sensitiveness of highest temperature is a little lower than the precipitation, but still has strong correlation factor. The increased vegetation NDVI can improve local ecosystem stability. The more intense vegetation cover can decrease the soil erosion, which will result in better water quality. The regional vegetation NDVI can be predicted with the consideration of climate change, which can improve environmental management efficiency.

Dependent	Regression equation	R^2
Yearly precipitation	$NDVI_G=0.0003* X +0.2215$	0.8690
	$NDVI_F=0.0002* X +0.3672$	0.9135
Yearly highest temperature	$NDVI_G=0.0002* X - 0.4094$	0.9502
	$NDVI_F=0.0001* X - 0.1172$	0.9768

Table 3 Yearly correlation between climatic index and NDVI

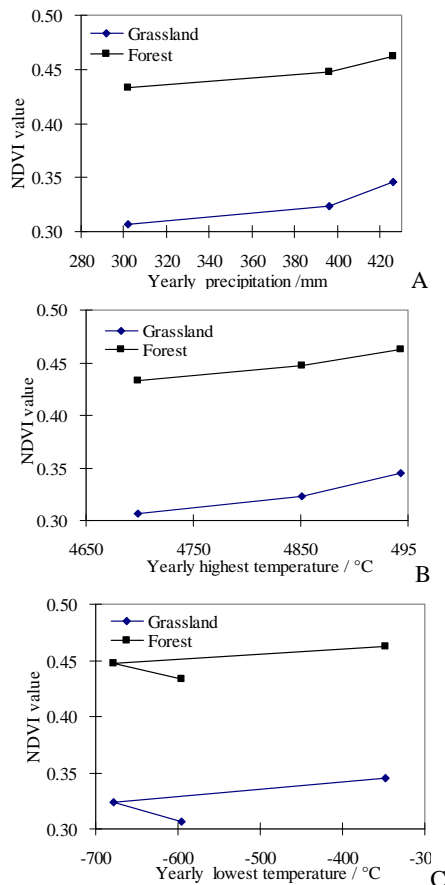


Figure. 9 Grassland and forest NDVI correlation with yearly meteorological index

3.3 Monthly principle between NDVI with climate

After test yearly principle between annual meteorological index and vegetation NDVI, the lowest temperature did not have strong impacts on greenness growth. In order to examine their correlation systematically, correlations were calculated between monthly meteorological variables and grassland, forest NDVI averages. The three meteorological variables were correlated and the analysis is summarized in Fig. 7. The expectation of positive correlation between meteorological data and vegetation NDVI values are definitely confirmed. The correlation coefficient of three climatic indices with NDVI are higher than 0.7331. The coefficient of lowest temperature, not precipitation, is most highly correlated with NDVI, as might have not been anticipated from previous studies (Lin et al., 1996). The grassland and forest NDVI have the strongest relationship with monthly lowest temperature, the coefficients of exponential regression model are 0.8623 and 0.8384. The monthly highest temperature has a lighter correlation relationship with vegetation NDVI. The exponential regression coefficients with grassland and forest are 0.8225 and 0.8155, respectively. The forest NDVI has the slightest correlation relationship with precipitation, but the R^2 value still is 0.7331. The widely distributed grassland has higher R^2 value with climatic indicators forest, which indicates grassland is more sensitive to the weather variation.

The Fig. 7 also demonstrates that the monthly climatic indicators concentrate in two groups. In the first group of two temperature indices, the vegetations NDVI fluctuate very slightly, but increase rapidly in the second group temperature condition. The conjunction point of two groups is the starting temperature that vegetations begin to grow. Furthermore, the threshold value of lowest and highest temperature for two vegetations is same and are 0, 13 °C, respectively. The vegetations NDVI increase in the first group precipitation condition. After the threshold point (14mm), both vegetations NDVI climb into higher step, but keep steady. In brief, the correlation analysis of monthly climatic variation and vegetation NDVI provide threshold data for vegetation growth.

The correlations between climatic indicators and vegetation NDVI have been observed for a long period, which demonstrated complex relationships between growth and climate variables (Fritts 1974). In same kind of arid region, Jeremy (2004) also tested that precipitation is not principally correlated with vegetation NDVI change. Climate change across Qinghai-Tibet Plateau had been modulated on decadal-century time-scales. The scientists have predicted that the temperature in whole Qinghai-Tibet Plateau will increase with 0.20°C every (Long et al., 2006). The regional severe drought periods have happened in recent past. Consequently, the correlation model between weather information and NDVI can be used to simulate regional vegetation NDVI variations.

4. CONCLUSION

By applying NDVI and meteorological data from 2000 through 2006, the daily grassland and forest communities NDVI simulation models were calculated for in upper stream of Yellow River. The results confirm the utility of NDVI as an index of integrated vegetation variability in a watershed with typical continent climate, high latitude, and little precipitation. Achievements of this study also added knowledge of complex understanding about climate and vegetation. The inter-annual and monthly relationships between grassland, forest NDVI with meteorological variables were calculated. The correlation coefficients confirm the strong relationships between vegetation NDVI and climate characteristics. The strongest inter-annual correlation between meteorological variables and vegetation NDVI are precipitation and highest temperature, which are completely different with monthly correlation pattern. Overall, the research results indicated that the monthly lowest temperature has the most pronounced impacts over land cover change. The monthly highest temperature and precipitation also affect vegetation NDVI value remarkable.

As stated in this study, correlations between vegetation NDVI with meteorological variables have implications for climate and vegetation in upper stream of Yellow River. With these conclusions in the present study, the regional vegetation daily variation features can be predicted under similar climatic characteristic. By meteorological indicator, the regional vegetation NDVI variance for climate change can be assessed much more convenient and accurate, which is critical for vegetation quality assessments. From vegetation quality simulation and prediction, the other eco-environmental factors can be calculated further.

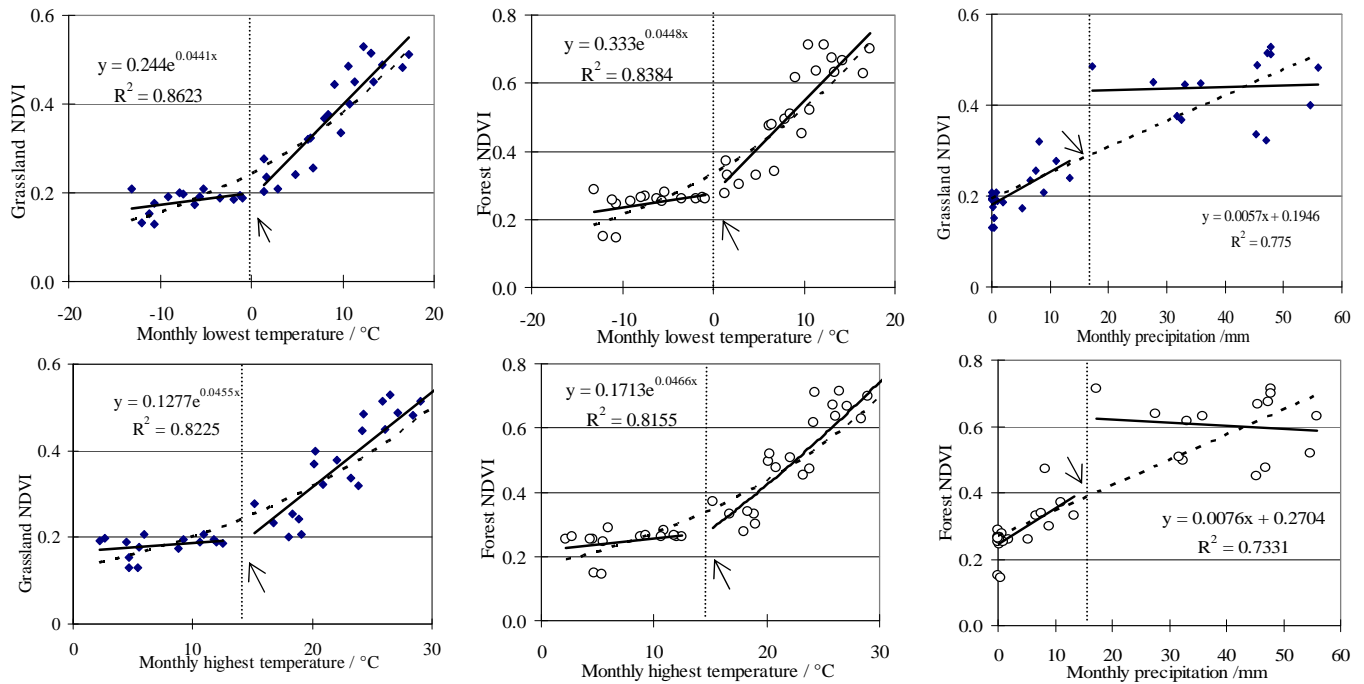


Fig.10 Correlation model between grassland, forest NDVI and monthly meteorological variation (general regression trend line---, group regression trend line-, threshold point →)

REFERENCES

- Alexander G.G., Allan J.D., 2006. Stream restoration in the Upper Midwest, USA. *Restoration ecology*, 14 (4): 595-604.
- Carlson T.N., Arthur S.T., 2000. The impact of land use - land cover changes due to urbanization on surface microclimate and hydrology: a satellite perspective. *Global and planetary change*, 25 (1-2): 49-65.
- Feng J.M., Wang T., Qi S.Z., et al., 2005. Land degradation in the source region of the Yellow River, northeast Qinghai-Xizang Plateau: classification and evaluation. *Environmental geology*, 47 (4):459-466.
- Fensholt R., Sandholt I., Rasmussen M.S., 2004. Evaluation of MODIS LAI, fAPAR and the relation between fAPAR and NDVI in a semi-arid environment using in situ measurements. *Remote Sensing of Environment*, 91 (3-4): 490-507.
- Fritts H.C., 1974. Relationships of ring widths in arid-site conifers to variations in monthly temperature and precipitation. *Ecological Monographs*, 44, 411-440.
- Jeremy L. Weissa, David S. Gutzler, Julia E. Allred Coonrod, et al., 2004. Seasonal and inter-annual relationships between vegetation and climate in central NewMexico, USA. *Journal of Arid Environments*, 57, 507-534.
- La Puma I.P., Philippi T.E., Oberbauer S.F., 2007. Relating NDVI to ecosystem CO₂ exchange patterns in response to season length and soil warming manipulations in arctic Alaska. *Remote Sensing of Environment*, 109 (2): 225-236.
- Lin G., Phillips S.L., Ehleringer J.R., 1996. Monsoonal precipitation responses of shrubs in a cold desert community on the Colorado Plateau. *Oecologia*, 106, 8-17.
- Loboda T.V., Csizsar I.A., 2007. Reconstruction of fire spread within wildland fire events in Northern Eurasia from the MODIS active fire product. *Global and planetary change*, 56 (3-4): 258-273.
- Long hu, Mao liqiang, Che Zhengxue, et al., 2006. Impact on water resources in Yellow River with climatic change. *Journal of Water Resources and Water Engineering*, 17(4), 74~77.
- Okin, G.S., Murray, B., Schlesinger, W.H., 2001. Degradation of sandy arid shrubland environments: observations, process modeling, and management implications. *Journal of Arid Environments*, 47, 123-144.
- Pflugmacher D., Krankina O.N., Cohen W.B., 2007. Satellite-based peatland mapping: Potential of the MODIS sensor. *Global and planetary change*, 56 (3-4): 248-257.
- Piao S.L., Fang J.Y., He J.S., 2006. Variations in vegetation net primary production in the Qinghai-Xizang Plateau, China, from 1982 to 1999. *Climatic change*, 74 (1-3): 253-267.
- Pontus Olofsson, Lars Eklundh, Fredrik Lagergren, et al., 2007. Estimating net primary production for Scandinavian forests using data from Terra/MODIS. *Advances in Space Research*, 39(1), 125-130.
- Running S.W., Justice C.O., Salomonson V.V., et al., 1994. Terrestrial remote sensing science and algorithms planned for EOS/MODIS. *International Journal of Remote Sensing*, 15 (17), 3587-3620.
- Seaquist J.W., Olsson L., Ardö J., 2003. A remote sensing-based primary production model for grassland biomes. *Ecological Modelling*, 169, (1): 131-155.

Wang G.X., Cheng G.D., Shen Y.P., et al., 2003. Influence of land cover changes on the physical and chemical properties of alpine meadow soil. *Chinese science bulletin*, 48 (2): 118-124.

Wang Xiaodan, Li MaiHe, Liu Shuzhen, et al., 2006. Fractal characteristics of soils under different land-use patterns in the arid and semiarid regions of the Tibetan Plateau, China. *Geoderma*, 134(1-2), 56-61.

Weiss, J.L., Gutzler, D.S., Allred Coonrod, et al., 2004. Long-term vegetation monitoring with NDVI in a diverse semiarid setting, central New Mexico, USA. *Journal of Arid Environments*, 58(2): 249-272.

William L. Stefanov, Maik Netzband, 2005. Assessment of ASTER land cover and MODIS NDVI data at multiple scales

for ecological characterization of an arid urban center. *Remote Sensing of Environment*, 99(1-2), 31-43.

Wittenberg L., Malkinson D., Beerli O., et al., 2007. Spatial and temporal patterns of vegetation recovery following sequences of forest fires in a Mediterranean landscape, Mt. Carmel Israel. *Catena*, 71 (1): 76-83.

ACKNOWLEDGEMENTS

The authors wish to thank Engineer Dong Dehong and Zhang Fugui from the Forestry Academic, Qinghai Province. This research was supported by the National Natural Science Foundation of China (Grant No. 40771192) and International Institute for Geo-Information Science and Earth Observation (ITC) in the Netherlands.

