Chinese Geographical Science 2007 17(2) 151–159
DOI: 10.1007/s11769-007-0151-5
www.springerlink.com

Response of Vegetation in the Qinghai-Tibet Plateau to Global Warming

XU Weixin[1, 2, 3], LIU Xiaodong[1]
(*1. Institute of Earth Environment, Chinese Academy of Sciences, Xi'an 710075, China; 2. Meteorological Institute of Qinghai Province, Xining 810001, China; 3. Graduate University of Chinese Academy of Sciences, Beijing 100049, China*)

Abstract: Using satellite-observed Normalized Difference Vegetation Index (NDVI) dada and station-observed surface air temperature anomalies for the Northern Hemisphere (NH), we analyze the spatio-temporal characteristics of vegetation variations in the Qinghai-Tibet Plateau and their correlations with global warming from 1982 to 2002. It is found that the late spring and early summer (May−June) are the months with the strongest responses of vegetation to global warming. Based on the Rotated Empirical Orthogonal Function (REOF) method, the study shows that the first REOF spatial pattern of average NDVI for May−June reveals the northern and southern zones with great inter-annual variations of vegetation, the northern zone from the eastern Kunlun Mountains to the southwestern Qilian Mountain and southern zone from the northern edge of the Himalayas eastward to the Hengduan Mountains. The vegetation, especially grassland, in the two zones increases significantly with global warming, with a correlation coefficient of 0.71 between the first REOF of May–June vegetation and the April–May surface air temperature anomaly in the NH during 1982–2002. A long-term increasing trend in May–June vegetation for the plateau region as a whole is also attributed mainly to global warming although there are considerable regional differences. The areas with low NDVI (grassland and shrubland) usually respond more evidently to global warming, especially since the 1990s, than those with moderate or high NDVI values.

Keywords: NDVI; REOF; global warming; vegetation; Qinghai-Tibet Plateau

1 Introduction

The warming trend of the world's climate is the most remarkable climate change over the past one hundred years, especially during the last few decades (Houghton, 2005). Recent study showed that climate change has broad impacts on the biosphere (Walther et al., 2002). The pronounced surface warming may have promoted vegetation growth in the northern mid- and high-latitude regions in recent decades (Myneni et al., 1997; Zhou et al., 2001; Gong et al., 2002). The regional vegetation change in China was also found to be related with the climatic warming (Piao et al., 2004; Xiao and Melillo, 1998). The Qinghai-Tibet Plateau is usually regarded as an ideal area to study the response of natural ecosystems to global climate change (Sun and Zheng, 1998) because the mountainous region is one with the most fragile environment within the global ecosystem (Stone, 1992). Several studies (Liu and Chen, 2000; Lin and Zhao, 1996; Liu et al., 2006) found that the Qinghai-Tibet Plateau has experienced distinct warming in recent decades, especially for cold seasons, and the trend of warming over the plateau is usually larger than that of the surrounding areas. As a key factor controlling vegetation growth (Piao et al., 2006; Yang et al., 2005; Zhang and Gao, 2005), climatic warming may result in the movement of the vegetation community toward higher altitudes (Fan et al., 2005) and the southward outspreading of the alpine steppe on the plateau (Wang et al., 2005) according to some predictions. A simulation study (Ni, 2000) showed that the temperate climate induced by doubling atmospheric CO_2 would cause a large reduction in the temper-

---

Received date: 2006-09-06; accepted date: 2007-02-28
Foundation item: Under the auspices of the National Natural Science Foundation of China (No. 40599424, No. 40472086, No. 40121303), National Basic Research Program of China (No. 2004CB720208)
Corresponding author: XU Weixin. E-mail: Weixin.Xu@163.com

ate desert, alpine steppe, desert and ice/polar desert, a considerable increase in the cold-temperate deciduous conifer forest, temperate shrubland/meadow and temperate steppe, and a general northwestward shift of all vegetation zones in the plateau.

Previous researches have revealed recent vegetation changes potentially induced by climate change in the Qinghai-Tibet Plateau. Up to now, however, we still know little about the influence of recent global warming on the regional terrestrial ecosystem. In this study, we further explore the large-scale spatio-temporal patterns of vegetation changes in the Qinghai-Tibet Plateau and their relations to global warming.

2 Data and Methods

2.1 Data

2.1.1 NDVI

The 1982–2002 Pathfinder Normalized Difference Vegetation Index (NDVI) (available at http://daac.gsfc.nasa.gov/) derived from the Advanced Very High Resolution Radiometer (AVHRR) on the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting satellite was used as an indicator of the vegetation activity.

The NDVI value generally varies from 0 to 1 and a higher value indicates a stronger vegetation activity. Since the objective of this study is to examine the relationship between the regional NDVI and global air temperature, the monthly data with a resolution of 1°×1° were mainly used in the analyses. Further technical details for the dataset, which was produced by the Goddard Space Flight Center, can be found in Agbu and James (1994) and James and Kalluri (1994).

Figure 1 shows the mean annual NDVI distribution in the Qinghai-Tibet Plateau above 2000m during 1982–2002. The vegetation biomass, overall, decreases from southeast to northwest, with the lowest NDVI in the western Kunlun Mountains above 4000m. The pattern of vegetation in this region is generally related to precipitation and temperature, with forests in the warm and humid southeastern parts and grasslands in the cold and dry central and northwestern parts. Cultivated crops are mainly located in lower altitudes with mild climatic conditions between grasslands and forests, while sparse shrubs or bare grounds with hostile climate mostly lie to the north of the grasslands.

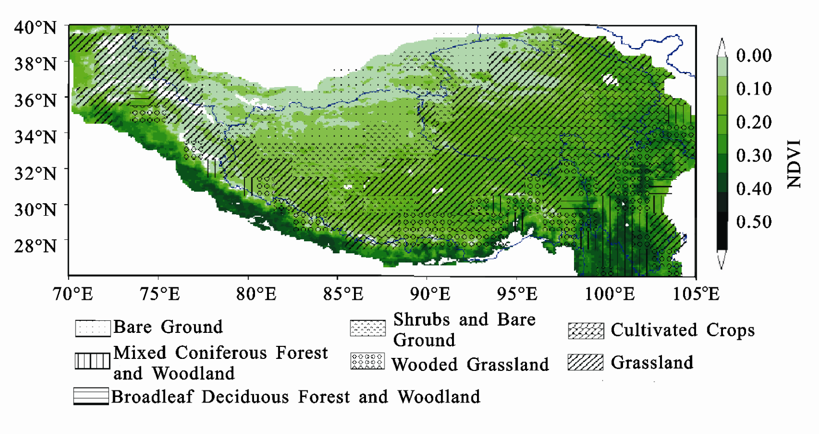

Fig. 1 Distribution of mean annual NDVI and vegetation classification in the Qinghai-Tibet Plateau in 1982–2002

2.1.2 Vegetation classification

Vegetation classification data in the study were derived from a global land cover classification product provided by the Institute for Advanced Computer Studies, University of Maryland (http://glcf.umiacs.umd.edu). The dataset describes the geographic distribution of land cover at regional and global scales by using multi-year (from 1981 to 1994) AVHRR Pathfinder Land (PAL) data with a spatial resolution of 1km×1km. Further details of the dataset can be found in Defries et al. (1998) and Hansen et al. (2000).

Although the dataset classifies Earth's vegetation into 10 types, only seven types of vegetation, including Mixed Coniferous Forest and Woodland, Broadleaf Deciduous Forest and Woodland, Wooded Grassland, Grassland, Shrubs and Bare Ground, Cultivated Crops, and Bare Ground exist in the Qinghai-Tibet Plateau (Fig. 1). For the sake of simplicity, we integrate Mixed Coniferous Forest and Woodland, Broadleaf Deciduous Forest and Woodland, and Wooded Grassland into one type and name it as Woodland in the following text. Thus, we can explore the responses of different vegetation to global warming according to three main types of natural vegetation, i.e., Woodland, Grassland, and Shrubs/bare (Shrubs and Bare Ground) in the plateau.

2.1.3 Temperature

Considering the similarity of surface temperature changes in the Qinghai-Tibet Plateau and at global scale (Liu and Chen, 2000; Lin and Zhao, 1996), and the main focus of this study, which is the potential response of the regional vegetation to global warming, we use a time series of 1982–2002 average monthly anomalies (relative to their 1951–1980 means) of surface air temperature in the Northern Hemisphere (NH), extracted from a global surface temperature dataset prepared by the National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies (GISS) (Hansen et al., 2006). It is clear that the annual-mean NH or global surface temperatures both have generally been increasing since the early 1980s (Fig. 2). This strong global warming trend provides us with a good opportunity to examine the regional responses of terrestrial ecosystems.

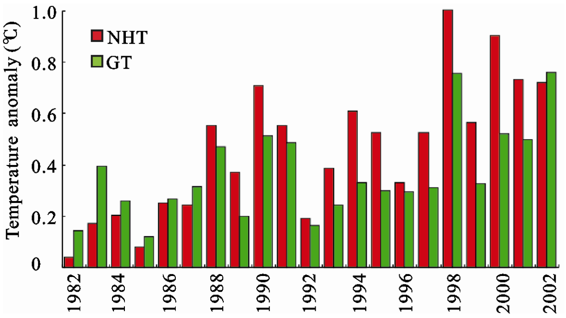

Fig. 2 Mean annual surface air temperature anomalies in NH (NHT) and the globe (GT) in 1982–2002

2.2 Methods

2.2.1 REOF

The analysis of empirical orthogonal function (EOF) or rotated empirical orthogonal function (REOF) is commonly used for the decomposition of a signal datum or a dataset in terms of orthogonal basis functions. The EOF or REOF analysis is a useful method for statistical analysis of large data sets and has been widely used in meteorology and climate research (Wei, 1999). Compared with EOF, REOF has obvious advantages, with more robust geographic characteristics and lower errors. In the process of computing REOF, the correlation matrix of original data serves as input and then the Varimax method of orthogonal rotation is applied. The number of eigenvectors for rotation is usually decided by the cumulative percentage greater than 85% of variance explained.

2.2.2 Linear tendency analysis

The changing trend of NDVI during 1982–2002 was estimated by calculating linear regression coefficients with the least squares method. A non-parameter test method, Z-test (Wei, 1999), was used to check the statistical significance. The thresholds of 0.05 and 0.01 significant levels for the 21-year samples, denoted as $Z_{0.05}$ and $Z_{0.01}$, are equal to 0.31 and 0.41, respectively, according to Z-test.

3 Results

3.1 Sensitivity of vegetation responses to global warming

3.1.1 Sensitive months of vegetation responses

Vegetation grows most evidently in the Qinghai-Tibet Plateau in spring (Yang and Piao, 2006). It is in the late spring and early summer (May–June) when the alpine meadow develops fastest (Shi et al., 2001). Since alpine grassland covers about 60% of the area of the plateau, May−June is probably the most suitable period to study the vegetation responses to climate change. We computed the trends of May−June average NDVI (hereafter V56) during 1982–2002 for every grid cells and their statistical significance. It is found that the V56 shows an increasing trend in 39% of the total area of the plateau at a significant level of 0.05, and in 17% of the total area of the plateau at a significant level of 0.01. This means that May and June are important months in terms of vegetation activities in the study area.

Table 1 lists the correlation coefficients between mean monthly NDVI of the Qinghai-Tibet Plateau and mean air temperature anomalies of the NH in simultaneous or previous months. The vegetation varies closely with the preceding air temperature during March–June. The correlation coefficient of NDVI in May (June) with temperature in the previous month can reach 0.6109 (0.6778), which is statistically significant at 0.001 level. Moreover, the correlation between V56 and the mean air temperature anomaly of April–May (hereafter T45) in the Northern Hemisphere is higher, reaching 0.69. The rate of T45 increase has been 0.0339℃/a during 1982–2002. Therefore, late spring and early summer (May–June) may be the period during which vegetation has the most

Table 1 Correlation coefficients between mean monthly NDVI in the Qinghai-Tibet Plateau and mean air temperature anomalies in the NH in simultaneous and previous months

	NDVI											
	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
TA in month *i*	0.1683	0.3991	0.3963	**0.5912**	**0.7668**	**0.5710**	0.0522	−0.2956	−0.0272	0.2023	0.1481	0.1090
TA in month *i*–1	0.3181	0.3183	**0.5594**	0.5275	**0.6109**	**0.6778**	0.2810	−0.3630	0.0165	0.0916	0.1599	0.1824
TA in month *i*–2	0.2845	0.5116	0.4969	**0.5875**	**0.6219**	0.4959	0.3929	−0.2863	−0.0393	0.1776	0.1151	0.0776
TA in month *i*–3	0.1933	0.3298	**0.5685**	**0.6647**	0.5198	0.5083	0.3663	−0.2444	0.0047	0.1700	0.1969	0.0781

Notes: *TA* is mean air temperature anomaly; *i* is simultaneous month; bold numbers indicate that correlation coefficients are significant at 0.01 level

sensitive responses to global warming, especially to temperature change in the previous months. In the following analyses, if not otherwise noted, we mainly employ the May–June vegetation.

3.1.2 Sensitive areas of vegetation responses

In order to analyze the spatial pattern of the responses of regional vegetation to NH air temperature in previous months, we calculate the correlation coefficients of T45 with V56 at each grid cell in the plateau. The area with correlation coefficients greater than 0.5 (significant at 0.05 level) are mainly located in the northern and southern zones: the northern zone from the eastern Kunlun Mountains to the southwestern Qilian Mountain and the southern zone from the northern edge of the Himalayas eastward to the Hengduan Mountains (Fig. 3). The correlation coefficients are greater than 0.6 (significant at 0.001 level) in most portions of the two zones, with the highest correlation of 0.8. This indicates that the vegetation in the two specific zones responds sensitively to NH temperature, thus, these two zones can be regarded as sensitive areas in response to global warming. It is worthy to note that the sensitive zones generally occupy higher-elevation and lower-NDVI areas, where V56 is usually less than 0.12 (Fig. 1).

3.2 Spatio-temporal patterns of vegetation change

3.2.1 Spatial pattern

We conduct EOF and then REOF analyses of May–June NDVI. Considering V56 in each grid cell as a variable in the region of 26°–40°N and 70°–105°E, there is a total of 572 available variables with 21-year samples after removing 4 missing values. According to the percentage of variance explained by each eigenvector of EOF analysis and the threshold of the cumulative percentage of more than 85%, a total of 11 eigenvectors are selected for rotation. In the spatial pattern of the first rotated eigenvector (REOF1) as shown in Fig. 4, the largest REOF loading, with 18.1% of explained variance, lies in the main part of the plateau. The main centers of the fifth and seventh REOF eigenvectors (not shown) are also located in the plateau, but each of their variances explained is lower than 10%. Therefore, the interannual variations of vegetation are mostly reflected in REOF1. On the other hand, from Table 2, the correlation coefficient of the time coefficient of REOF1 with T45 can reach 0.71 (significant at 0.001 level), while the correlations of the remaining 10 eigenvectors are insignificant (less than 0.35). This indicates that the interannual variation and trend of the vegetation, especially its dominant spatial pattern,

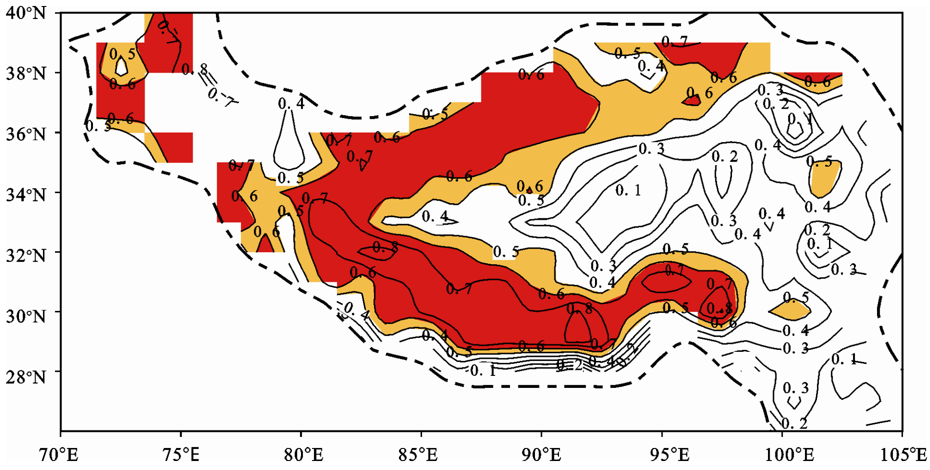

Fig. 3 Distribution of correlation coefficients between mean May–June NDVI (V56) in the Qinghai-Tibet Plateau and mean April–May surface air temperature anomaly in the NH (T45)

closely follow the NH air temperature in the last 21 years though there are considerable regional differences.

As shown in Fig. 4, the spatial pattern of V56 REOF1 reveals the northern and southern zones with great variability. It is easy to see that the areas with great variability are nearly consistent with sensitive zones as shown in Fig. 3. Therefore, the high sensitivity of vegetation increase to climatic warming may have resulted in the great vegetation change. In addition, areas with great variability of vegetation are generally located in areas with low NDVI values (Fig. 1), and areas with little variability and weak trends correspond to moderate or high NDVI values. As such, it seems that the impact of air temperature on vegetation is greater in the areas with low vegetation coverage.

3.2.2 Temporal pattern

The temporal patterns of vegetation and the relationship between the plateau vegetation change and NH air temperature can be demonstrated by comparing the time coefficients of V56 REOF1 and the time series of T45 (Fig. 5). There are nearly consistent ascending trends and interannual variations of V56 REOF1 and T45. That is, increased (decreased) May–June NDVI in the sensitive regions follows a rise (fall) of April–May temperature in the NH, especially in abnormally warm (e.g., 1998 and 1990) and cold (e.g., 1996 and 1992) years. The significant positive correlation (the correlation coefficient reaching 0.71, significant at 0.001 level) of V56 REOF1 with T45 suggests that previous air temperature is a dominant factor inducing the vegetation change. In other words, the responses of the vegetation in the plateau during the late spring and early summer to global warming are quite remarkable and rapid in the sensitive areas, as shown in Fig. 3 or Fig. 4.

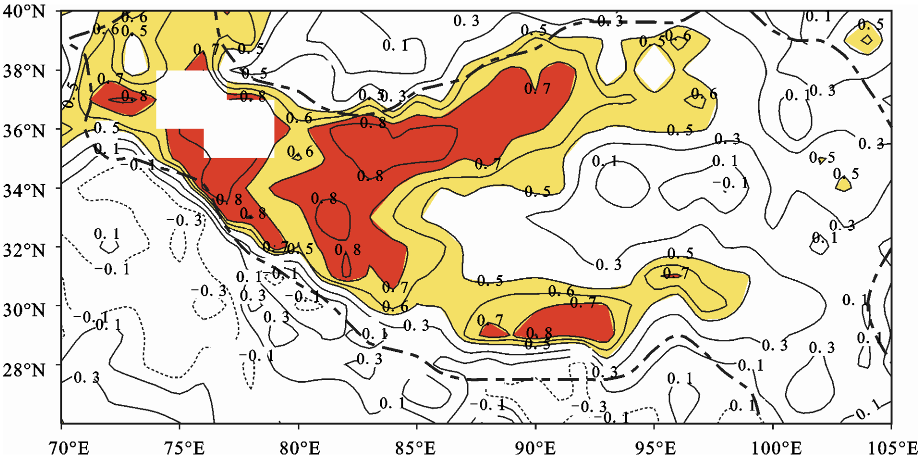

Fig. 4 The first eigenvector field of REOF of May–June NDVI (V56) in the Qinghai-Tibet Plateau

Table 2 Variances explained, their cumulative percentages and correlation coefficients (with T45) of first 11 REOFs of V56

	REOF1	REOF2	REOF3	REOF4	REOF5	REOF6	REOF7	REOF8	REOF9	REOF10	REOF11
Variance explained (%)	18.07	10.36	9.15	8.39	8.14	7.80	7.60	4.76	4.30	4.10	4.09
Cumulative percentage (%)	18.07	28.43	37.58	45.96	54.10	61.89	69.50	74.26	78.56	82.66	86.75
Correlation coefficient	0.71	0.07	0.03	–0.22	0.26	0.02	0.01	0.30	0.34	0.04	–0.06

3.3 Vegetation change in 1982–2002

3.3.1 Vegetation change dominated by air temperature

From the regression map of V56 by T45 (Fig. 6), we can estimate the regional vegetation changes induced by global warming. The strongly increasing trend in V56 occurs in two zones; the northern zone from the eastern Kunlun Mountains to Qilian Mountain and the southern zone from the northern edge of the Himalayas eastward to the Hengduan Mountains, which is consistent once again with the pattern of the above sensitive areas (Fig. 3). There exists more than 6% increment in most portions of the sensitive areas and over 10% increment in the Pamirs and the Hoh Xil Range in 1982–2002 (Fig. 6a). Actually, a large percentage increase in the vegetation usually appears in the low-vegetation-cover region; however, the absolute increment of vegetation is not great in these regions (Fig. 6b).

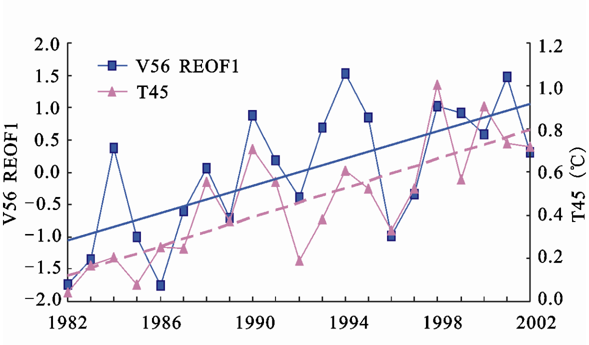

Fig. 5 Annual variations and linear trends of time coefficients of REOF1 of May–June NDVI (V56) in the Qinghai-Tibet Plateau and April–May surface air temperature anomaly in the NH (T45) from 1982 to 2002

Considering the limited duration of NDVI data available and the considerable rise in air temperature anomaly in the NH, which has increased from 0.24℃ in the 1980s (1982–1989) to 0.60℃ in the 1990s (1990–2002), we examine the actual change in vegetation by comparing the two decadal means (Fig. 7). The whole plateau areas, especially the above-mentioned sensitive zones, have become greener. For example, the vegetation in the 1990s has increased by up to 20% compared with that in the 1980s in the northern Hoh Xil Range and the western Kunlun Mountains. The greening process in the plateau, as what appeared in the northern high latitudes (Myneni et al., 1997), likely results from global warming.

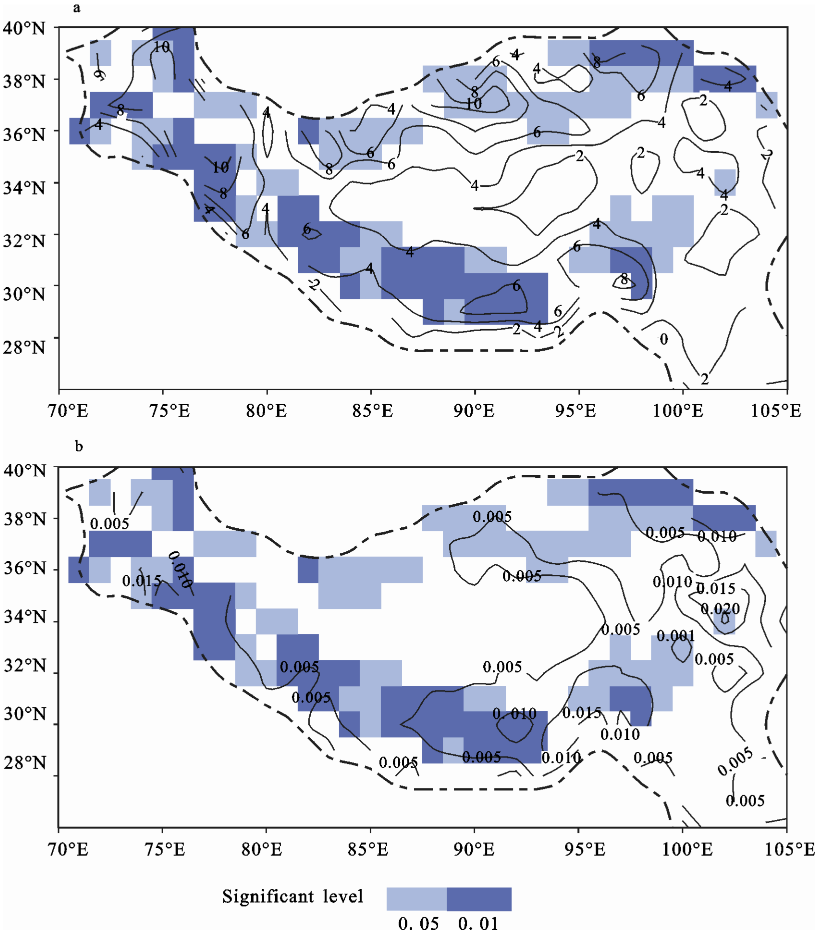

Fig. 6 Percentage increment (a) and absolute increment (b) of mean May–June NDVI (V56) in the Qinghai-Tibet Plateau based on mean April–May surface temperature in the NH (T45) during 1982–2002

3.3.2 Responses of different types of vegetation to air temperature

As mentioned above, the vegetation change may be associated with the original vegetation cover, therefore, it can be expected that the vegetation responses to climatic warming vary with different types of vegetation. Here, the climatic sensitivity of the above-mentioned three vegetation types in the Qinghai-Tibet Plateau is examined. The NDVIs of shrubs/bare, grassland and woodland in the plateau are found to have increased by 0.012

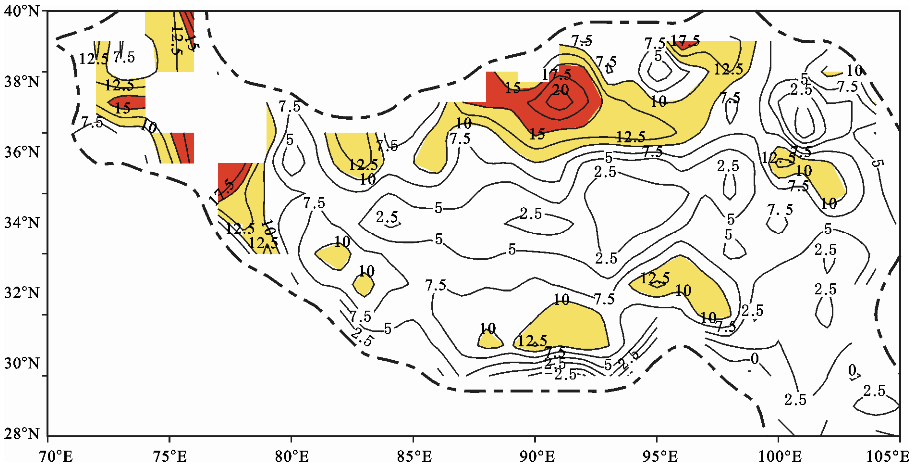

Fig. 7 Difference in percentage change of mean May–June NDVI (V56) between 1990s and 1980s

(~14%), 0.015 (~10%) and 0.20 (~5%), respectively, during 1982–2002. As shown in Fig. 8, there are clear ascending trends in the average May–June NDVIs of shrubs/bare, grassland and woodland along with the temperature rising in the NH. The correlation coefficients of May–June NDVI for shrubs/bare, grassland-only and woodland-only with T45 reach 0.82, 0.73 and 0.43, respectively. It seems that all other conditions being equal, the shrubs/bare and alpine grassland with a low coverage more sensitively respond to global warming than the woodland with a high coverage. Therefore, the alpine grassland covering an area of about 60% of the total plateau dominates the trend of vegetation change in the plateau.

4 Conclusions

The surface vegetation of the Qinghai-Tibet Plateau is found to respond markedly to global warming with distinct differences in spatial and temporal patterns. May–June is the most sensitive period for the plateau vegetation to respond to the air temperature change. The correlation coefficient of mean May-June NDVI in the plateau with April–May NH air temperature during 1982–2002 reached 0.69, significant at 0.001 level. May–June vegetation responds most sensitively to the air temperature in the northern and southern zones, the northern zone from the east of the Kunlun Mountains to Qilian Mountain and the southern zone from the northern edge of the Himalayas eastward to Hengduan Mountains.

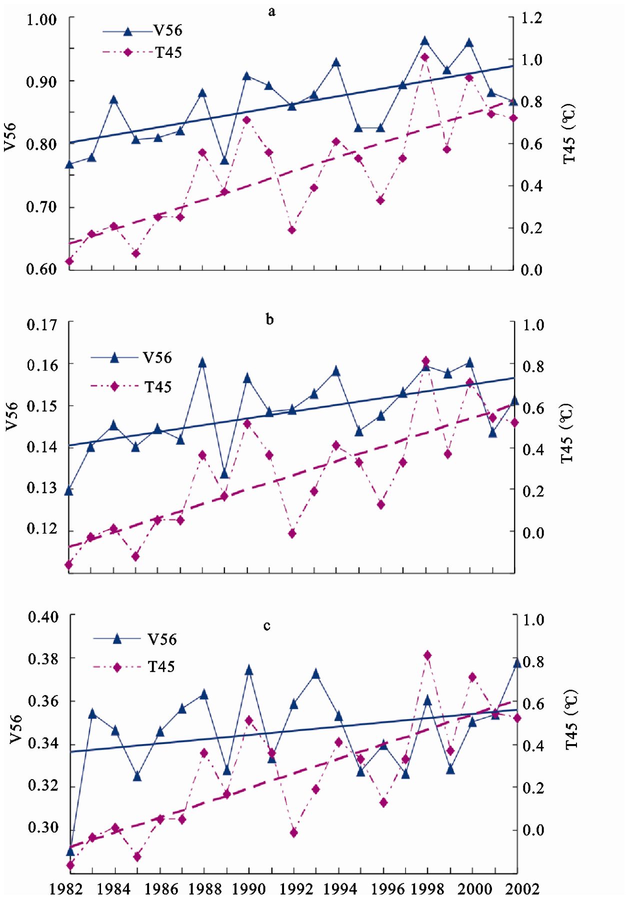

Fig. 8 Annual variations and linear trends of mean May–June NDVI (V56) for shrubs/bare (a), grassland (b) and woodland (c) in the Qinghai-Tibet Plateau and April–May surface air temperature in the NH (T45) during 1982–2002

A long-term increasing trend in May–June vegetation is observed for the plateau region as a whole along with an evident global-scale climatic warming during 1982–

2002. The increasing trend is more significant during the 1990s, especially in northern Hoh Xil Range and the western Kunlun Mountains. The 21-year correlation coefficient of the first REOF of May–June NDVI with April–May NH temperature reaches 0.71 (significant at 0.001 level). The first spatial pattern of V56 REOF also reveals the northern and southern zones with great variations, consistent with the sensitive areas of the vegetation responses to T45.

The May–June vegetation covering an area of 39% of the plateau total showed evident increases in 1982–2002. The remarkable increasing areas of vegetation in the northern and southern zones are consistent with the zones whose vegetation is sensitive to temperature. The Pamirs and Hoh Xil Range where the vegetation increases by 10% are the two areas with the greatest changes. The shrubs/bare and alpine grassland with a low vegetation coverage show more sensitive responses to global warming than other types of vegetation. The May–June shrubs/bare and grassland-only increases by 14% and 10%, with high correlations of 0.82 and 0.73 with April–May NH air temperature during 1982–2002, respectively.

It should be pointed out that there is usually a higher error in the data of NDVI with low values than those with high values, which may impact the results in low-biomass regions in the Qinghai-Tibet Plateau. However, the error is usually lower in the grassland and woodland (Kogan and Zhu, 2001). This study only focuses on the responses of the plateau vegetation to global warming. Actually, other factors such as precipitation cannot be ignored in modulating regional vegetation activities. Therefore, in-depth investigations are necessary in the future to further explore the relationship between the regional vegetation of the plateau and large-scale climate change.

References

Agbu P A, James M E, 1994. *The NOAA/NASA Pathfinder AVHRR Land Data Set User's Manual*. Goddard Distributed Active Archive Center, NASA, Goddard Space Flight Center, Greenbelt.

Defries R, Hansen M, Townshend J R G et al., 1998. Global land cover classifications at 8km spatial resolution: The use of training data derived from Landsat imagery in decision tree classifiers. *International Journal of Remote Sensing*, 19: 3141–3168.

Fan Qishun, Sha Zhanjiang, Cao Guangchao et al., 2005. Assessment of ecology and environments on climate changing of Qinghai-Tibetan Plateau. *Journal of Salt Lake Research*, 13(1): 12–18. (in Chinese)

Gong Daoyi, Shi Peijun, He Xuezhao, 2002. Spatial features of the coupling between spring NDVI and temperature over Northern Hemisphere. *Acta Geographica Sinica*, 57(5): 505–514. (in Chinese)

Hansen J E, Ruedy R, Sato M et al., 2006. NASA GISS surface temperature (GISTEMP) analysis. In trends: A compendium of data on global change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. Department of Energy, Oak Ridge, Tenn., U.S.A.

Hansen M, Defries R, Townshend J R G et al., 2000. Global land covers classification at 1km resolution using a decision tree classifier. *International Journal of Remote Sensing*, 21: 1331–1365.

Houghton J, 2005. Global warming. *Reports on Progress in Physics*, 68(6): 1343–1403.

James M E, Kalluri S N V, 1994. The Pathfinder AVHRR land data set: An improved coarse-resolution data set for terrestrial monitoring. *International Journal of Remote Sensing*, 15(17): 3347–3364.

Kogan F N, Zhu X, 2001. Evolution of long-term errors in NDVI time series: 1985-1999. *Advances in Space Research*, 28(1): 149–153.

Lin Zhenyao, Zhao Xinyi, 1996. Spatial characteristics of changes in temperature and precipitation of the Qinghai-Xizang (Tibet) Plateau. *Science in China* (*Series D*), 26(4): 254–258.

Liu Xiaodong, Chen Baode, 2000. Climatic warming in the Tibetan Plateau during recent decades. *International Journal of Climatology*, 20(14): 1729–1742.

Liu Xiaodong, Yin Zhiyong, Shao Xuemei et al., 2006. Temporal trends and variability of daily maximum and minimum, extreme temperature events, and growing season length over the eastern and central Tibetan Plateau during 1961–2003. *Journal of Geophysical Research*, 111(D19): 10901–10919. DOI: 10.1029/2005JD006915.

Myneni R B, Keeling C D, Tucker C J et al., 1997. Increased plant growth in the northern high latitudes from 1981–1991. *Nature*, 386: 698–702.

Ni Jian, 2000. A simulation of biomes on the Tibetan Plateau and their responses to global climate change. *Mountain Research and Development*, 20(1): 80–89.

Piao Shilong, Fang Jinyun, He Jinsheng, 2006. Variations in vegetation net primary production in the Qinghai-Xizang Plateau, China, from 1982 to 1999. *Climatic Change*, 74(1): 253–267.

Piao Shilong, Fang Jinyun, Ji Wei et al., 2004. Variation in a satellite-based vegetation index in relation to climate in China. *Journal of Vegetation Science*, 15(2): 219–226.

Shi Shengbo, Ben Guiying, Han Fa et al., 2001. Plant growth analysis of Kobresia humilis meadow community in the Tibetan

Plateau regions. *Acta Ecologica Sinica*, 21(6): 871–876. (in Chinese)

Stone P B, 1992. *The State of the World's Mountains: A Global Report*. London and New Jersey: Zed Books.

Sun Honglie, Zheng Du, 1998. *Formation, Evolution and Development to Tibetan Plateau*. Guangzhou: Guangdong Science & Technology Press. (in Chinese)

Walther G, Post E, Convey P et al., 2002. Ecological responses to recent climate change. *Nature*, 416: 389–395.

Wang Mou, Li Yong, Huang Runqiu et al., 2005. The effects of climate warming on the alpine vegetation of the Qinghai-Tibetan Plateau hinterland. *Acta Ecologica Sinica*, 25(6): 1275–1281. (in Chinese)

Wei Fengying, 1999. *Modern Methods of Climatological Statistic, Diagnosis and Forecast.* Beijing: Meteorological Press. (in Chinese)

Xiao X M, Melillo J M , 1998. Net primary production of terrestrial ecosystems in China and its equilibrium responses to changes in climate and atmospheric CO_2 concentration. *Acta Phytoecologica Sinica*, 22(2): 97–118. (in Chinese)

Yang Yuanhe, Piao Shilong, 2006. Variations in grassland vegetation cover in relation to climatic factors on the Tibetan Plateau. *Acta Phytoecologica Sinica*, 30(1): 1–8. (in Chinese)

Yang Jianping, Ding Yongjian, Chen Rensheng, 2005. NDVI reflection of alpine vegetation in the source regions of the Yangtze and Yellow Rivers. *Acta Geographica Sinica*, 60(3): 467–478. (in Chinese)

Zhang Wenjiang, Gao Zhiqiang, 2005. Study on the response of vegetation cover to precipitation and temperature in central/east Tibetan Plateau. *Progress in Geography*, 24(5): 13–22. (in Chinese)

Zhou Liming, Tucker C J, Kaufmann R K et al., 2001. Variation in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical Research*, 106(D17): 20069–20083.