World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:5, No:11, 2011

The Response Relation between Climate Change and NDVI over the Qinghai-Tibet plateau

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***Abstract*—**Based on a long-term vegetation index dataset of NDVI and meteorological data from 68 meteorological stations in the Qinghai-Tibet plateau and their relations with major climate factors were analyzed. The results show the following: 1) The linear trends of temperature in the Qinghai-Tibet plateau indicate that the temperature in the plateau generally increased, but it rose faster in the last 20 years. 2) The most significant NDVI increase occurred in the eastern and southern plateau. However, the western and northern plateau demonstrate a decreasing trend. 3) There is a significant positive linear correlation between NDVI and temperature and a negative correlation between NDVI and mean wind speed. However, no significant statistical relationship was found between NDVI and relative humidity, precipitation or sunshine duration.4) The changes in NDVI for the plateau are driven by temperature-precipitation, but for the desert and forest areas, the relation changes to precipitation-temperature-wind velocity and wind velocity-temperature-precipitation.

***Keywords*—**Qinghai-Tibet plateau; NDVI; climate warming

I. Introduction

THE Qinghai-Tibet Plateau is located in southwest China.The plateau is bounded by the Pamirs to the west, the Heng Duan mountains to the east, the Himalayas to the south and the Kunlun-Qilian Mountains to the north. Because of its special topography and the role of thermal power, the plateau hosts a variety of climate types, from the tropics to cold and from wet to dry climates [1]. This variability makes the causes of the plateau's climates and their changes a hot topic of research [2], [3]. Vegetation is the main terrestrial ecosystem, and it plays an irreplaceable role in regulating atmospheric, soil and water conservation, reducing greenhouse gas concentrations and increasing and maintaining climate stability. Consequently, any vegetation cover change will have an enormous impact on the physical environment [4], [5]. The normalized difference vegetation index (NDVI), as an important description of vegetation, is widely used in the state of plant growth and plant phenology studies and is recognized, at a large regional scale, as an important indicator of ecological conditions. In recent years, much research home and abroad has been conducted regarding the NDVI response relationships to vegetation and climate change, and the Qinghai-Tibet Plateau has attracted much attention [6]-[13]. Xu Duo et al. [14] utilized SPOT NDVI data to analyze the response relation between the northern Tibet plateau's typical vegetation and climate. Zhao Yuping et al. [15] analyzed the response relation between the northern Tibet plateau grassland ecosystem and climate. Ding Mingjun and Zhang Yili et al. [16] analyzed the response between the vegetation of the Qinghai-Tibet Plateau and hydrothermal condition changes. Mao Fei et al. [17] used AVHRR NDVI data to analyze the response between the northern Tibet plateau vegetation changes and climate.

This paper utilizes two kinds of long term vegetation index datasets, SPOT NDVI and AVHRR NDVI, to analyze the NDVI evolution trends in the Tibetan Plateau over a period of many years. Using data from the 68 meteorological stations in the Qinghai-Tibet plateau, the change of air temperature, relative humidity, precipitation, wind speed, and sunshine is analyzed in relation to the vegetation status response to climate change.

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II. Materials and Methods

A. NDVI data

Through Western Center for Pathfinder AVHRR NDVI data sets, and get SPOT VEGETATION NDVI data from Free VEGETATION Products. The Pathfinder AVHRR NDVI dataset covers July 1981 to December 2001 in 10-day periods based on the four bands of synthetic spectral reflectance and the synthesis of each 10-day period, of which the resolving power is 8 km (due to the NOAA-13 launch failure, the Pathfinder AVHRR NDVI 1994 data are not used). The SPOT VEGETATION NDVI vegetation index data set covers April 1998 to December 2007 in 10-day periods. This set has a synthesis of four bands of spectral reflectance and a 10-day maximum NDVI data set based on a 1 km resolution. To maintain the integrity of time series, for the period of 1982 to 1998, we used the Pathfinder AVHRR NDVI index data set, and for the period of 1999 to 2010, we used the SPOT VEGETATION NDVI vegetation index NDVI data sets. As the highest NDVI in the plateau is from July to August [19], the national average NDVI from July to August from 1982 to 2010 was calculated using remote sensing software (ENVI). The Tibetan border proposed by Zhang Yili, etc. [20] intercepts the regional NDVI values, which analyze the changes in vegetation in the Qinghai-Tibet Plateau.

B. Meteorological Data

Monthly data for the Qinghai-Tibet Plateau from the China Meteorological Data Sharing Service network (http://cdc.cma.gov.cn/index.jsp) were obtained. The data include average temperature, maximum temperature, minimum temperature, precipitation, relative humidity, sunshine hours and wind speed. The data set adopts the Mann-Kendall (referred to as M-K) non-parametric trend analysis [21], [22] to deal with a variety of climatic factors. The M-K method is used to assess trends in time series of climatic factors, which does not require compliance with a certain distribution of the sample; thus, it has been widely used in the trend analysis [23], [24]. This paper calculates the M-K inclination of the various climatic factors to test its trends.

To reduce the one-sidedness of the individual station records, the Taylor polygons rule was used to calculate the average sequence of various climatic factors when analyzing the data of the Tibetan Plateau. In this article, the climatic factor data used are obtained by the average or cumulative, and ArcGIS9.3 is used to draw a variety of climatic factors on trend contours.

Statistical software SPSS13.0 is used for the Pearson-related correlation analysis, while partial correlation analysis was used to analyze NDVI climate-driven factors. The t test for the correlation coefficient significance test was used to acquire a better understanding of the response between the different nature of the Qinghai-Tibet Plateau vegetation and climate zones factors. To analyze the hysteretic effect of the impact of climate change on vegetation, the following formula is used: R '= max {R0, R1, R2, Rn}, where R ' is the hysteretic correlation coefficient and Rn is the correlation coefficient of the current month NDVI and climate factors before the push n months. If R '= Rn, the lag period is n months, n = 0,1,2,3.

III. Results and Analysis

A. Climate change of the Qinghai-Tibet Plateau in the past 40 years

1) The analysis of air temperature evolution trends during the past 40 years in the Qinghai-Tibet Plateau

According to the international Intergovernmental Panel on Climate Change (IPCC), the average air temperature of northern hemisphere was 0.4 higher in the 1980s than in the 1960s, and the warming range increased in the 1990s, reaching approximately 1[25]. The recent observations show that the global average air temperature rose 0.74 from 1906 to 2005 [26]; compared with the past 100 years, this trend has doubled in the past 50 years [27].

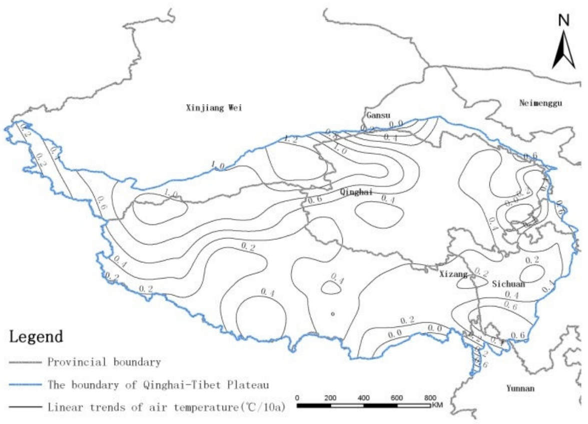

Fig. 1 Linear trends of air temperature in Qinghai-Tibet plateau from 1970 to 2010

It can be seen from the distribution of the linear trends of temperature in the past 40 years in the Qinghai-Tibet Plateau that the plateau's temperature is generally higher, presenting a warming trend from north to south. The temperature has increased $0.44 \cdot a^{-10}$in the past 40 years, and in the last 20 years, the Tibetan Plateau's warming rate has increased, reaching 0.64 ℃ $\cdot a^{-10}$. From Figure 1, the most obvious warming areas are mainly located in the desert in Qaidam, the Montane desert at the north side of Kunlun Mountain, the Alpine desert in Kunlun Mountain, the Montane semi-desert and the desert in Ali. The warming rate reached 0.5 $\cdot a^{-10}$ above, especially in Mangya, Xiao Zaohuo (located in the Qinghai Haixi Mongolian-Tibetan Autonomous Prefecture) and Shiquanhe (located in Tibet Ngari), and the increasing rate of air temperature is 0.6~1.2 $\cdot a^{-10}$. The growth rate of the average temperature in these regions is 3 to 6 times that in northern China (0.2~0.8^{-10} [28],[29]); the montane evergreen broad-leaved forest at the south side of eastern Himalayas (located in the southern Qinghai-Tibet Plateau) shows a lower increase rate of air temperature at 0~$0.4 \cdot a^{-10}$; this is especially pronounced in Gongshan (located in northern Yunnan), Chayu (located in Linzhi) and Malcolm (located in Sichuan), where the increase rate of air temperature is lower than $0.2 \cdot a^{-10}$.

2) Analysis of precipitation and sun duration trend in the Qinghai-Tibet Plateau during the past 40 years

In the vast Qinghai-Tibet Plateau, the terrain is very complex, leading to large differences in precipitation. The precipitation shows a general lowering trend from the southeast to the northwest plateau. There are few meteorological stations in the western region of the plateau; thus, the current studies on the precipitation trends of the Qinghai-Tibet Plateau are somewhat conflicting [30]-[34]. For rainfall in the Qinghai-Tibet Plateau from 1970 to 2010, the rate of increase is 6.65 mm $\cdot a^{-10}$, and the increase rate is more significant at 16.77 mm ℃ $\cdot a^{-10}$ in the last 20 years. Ma Xiao-bo [30], Yao Li [31] and Du et al. [32] also proposed a rising trend of precipitation in the Qinghai-Tibet Plateau. The precipitation in the alpine grassland in Qiangtang and the alpine meadow in southern Qinghai and Sichuan and eastern Tibet show the most significant increase of 15 ~ 28 mm $\cdot a^{-10}$, especially in the Xainza, Wudaoliang and Deqin, where the increase of precipitation is more than 25 mm $\cdot a^{-10}$. In the montane alpine shrub grassland in southern Tibet, the alpine shrub in Guoluo and Naqu and the montane evergreen broad-leaved forest at the south side of the eastern Himalayas, the precipitation shows a downward trend, at a rate of 1.2 ~ 25 mm $\cdot a^{-10}$; additionally, in Nie Lal, Jiu Zhi and Hong Yuan, the rate of decline is higher than 20 mm $\cdot a^{-10}$.

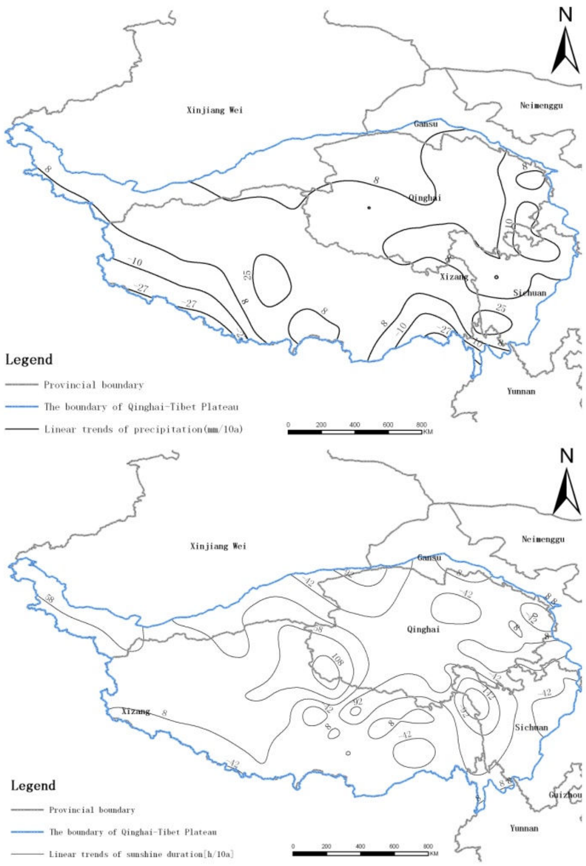

Fig. 2 Linear trends of precipitation and sunshine duration in Qinghai-Tibet plateau from 1970 to 2010

The Qinghai-Tibet Plateau has abundant solar energy resources and has the highest level of radiation in all of China's regions. Most areas in the Qinghai-Tibet Plateau have long hours of sunshine, except in southeast plateau, and the sunshine duration is higher in the west and lower in the east. By calculating the sunshine duration, an increasing trend is seen at first followed by a declining trend. The sunshine duration generally shows a downward trend in the Qinghai-Tibet Plateau, dropping by 15.54 h^{-10} over the 40-year period. However, the declining trend slowed down in the past 20 years, with a value of 9.93h^{-10}. The sunshine duration shows a significant decreasing trend in most parts of the Qinghai-Tibet Plateau, especially in Dege, Shiqu, Nagqu and Leng Hu, where the sunshine duration shows a significant decrease within the range of 100 ~ 190h/10a. However, in Amdo, Jiali and Shi Quanhe, the sunshine duration shows an increasing trend, within the range of 20 ~ 80h $\cdot$ a^{-10}.

3) Analysis of the relative humidity and wind speed trend in Qinghai-Tibet Plateau during the past 40 years

It can be seen from Figure 3 that the relative humidity shows a weak increasing trend in the Qinghai-Tibet Plateau in the past 40 years, with a range of 0.1% $\cdot$ a^{-10}, which is cattle Tao et al.'s [35] results by using REOF. The relative humidity in the Qinghai-Tibet Plateau shows an increasing trend at first and then a decreasing trend. The declining range in the last 10 years is as much as 5.76% $\cdot$ a^{-10}. The relative humidity increase was more significant in the alpine grassland in Qiangtang and the montane alpine shrub grassland in southern Tibet, where the increase rate reached 1 ~ 3% $\cdot$ a^{-10}. In Xainza and Nanduo, the increase rate of relative humidity was higher than 1.5%. The relative humidity decline is significant in the alpine shrub in Guoluo and Naqu, with a decrease range of 0.1 ~ 1.7% $\cdot$ a^{-10}, whereas Yushu, Maduo and Shiqu show the largest declining trend, with a rate higher than 1.5%.

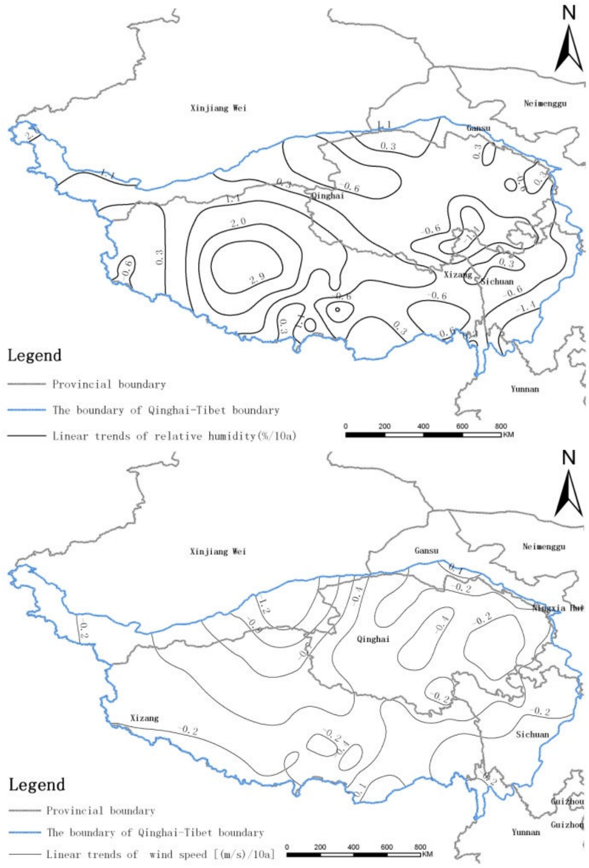

Fig. 3 Linear trends of relative humidity and mean wind speed in Qinghai-Tibet plateau from 1970 to 2010

As the world's highest and largest terrain, the Qinghai-Tibet Plateau is impacted by the high-altitude westerly jet. This jet causes the perennial gale day frequency in the Qinghai-Tibet Plateau, and there are lots of mobile sand dunes in Qiangtang, which is in the northwestern Qinghai-Tibet Plateau and the Yarlung Zangbo basin. The ecological environment is extremely fragile, which makes the Qinghai-Tibet Plateau vulnerable to dust storms in multiple regions of China's lowest latitude [36]. The research shows that the average wind speed exhibited a significant plateau and downward trend in the past 40 years, dropping by 0.29 (m / s) $\cdot$ a^{-10}; however, the decline rate shows a slow trend over the last 20 years, as 0.11 (m / s) $\cdot$ a^{-10}. This conclusion agrees with Jiang Ying et al. [37], who used global climate models to assess future changes in China's wind. The Desert in Qaidam and the alpine grassland in Qiangtang show the most significant decreasing trend, at 0.4 ~ 1.0 (m / s) · a^{-10}. Mangya, Nuomuhong and Amdo have a declining rate of wind speed greater than 0.5 (m / s) · a^{-10}. The wind speed shows an increasing trend in the montane grasslands in the Qilian mountain in eastern Qinghai, Sichuan and eastern Tibet and in the montane evergreen broad-leaved forest at the south side of eastern Himalayas as 0.05 ~ -0.18 (m / s) · a^{-10}. In Hongyuan, the increase rate reaches 0.05 (m / s) · a^{-10}.

B. Change trends of NDVI during 1982-2010

A regression trend line method could predict change trends, which were used to analyze the change trends of NDVI during 1982-2010 based on the mean values of NDVI in July and August [25]. The trend line is calculated as follows:

$$S_{LOPE} = \frac{n \times \sum_{k=1}^{n} k \times Y_{NDVIk} - \sum_{k=1}^{n} k \sum_{k=1}^{n} Y_{NDVIk}}{n \times \sum_{k=1}^{n} k^2 - \left(\sum_{k=1}^{n} k \right)^2} \tag{1}$$

There is an increasing trend in NDVI during 1982-2010 when $S_{LOPE} > 0$ and a decreasing trend when $S_{LOPE} < 0$. The change trends of NDVI with reference to a classification method [25] based on natural areas [18] is shown in Fig. 4.

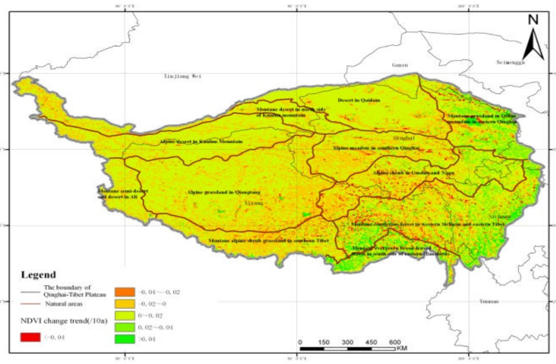

Fig. 4 Classification image of NDVI change trend simulated in Qinghai-Tibet plateau from 1982 to 2010

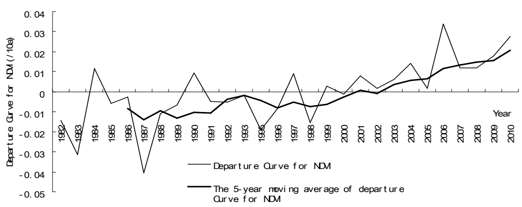

Fig. 5 Departure Curve for NDVI in Qinghai-Tibet plateau from 1982 to 2010

Most regions of the QTP exhibited increasing trends of NDVI (Fig 4). The rate of change of NDVI and the mean change rate during 1982-2010 was -0.05 ~ 0.08/10a and 0.013/10a. Vegetation coverage on the QTP increased mainly because climate changes boost plant growth. Meanwhile, human activity, mainly in the city and county, did not cause significant damage to the vegetation [19].

The montane evergreen broad-leaved forest at the south side of the eastern Himalayas and the eastern Sichuan province had a marked increasing trend with an increase rate of 0.03 ~ 0.08/10a. The NDVI increase rate in Jiulong and Muli in Sichuan province, Rikeze and Chayu in the Tibet autonomous region and the Gongga mountain region in Yunnan province was greater than 0.042/10a. The alpine meadow in southern Qinghai province and the alpine desert and mountainous semi-desert in Ali had very slow increasing trends that were nearly 0. The mountainous desert in the north part of the Qaidam Basin, the montane coniferous forest in Cangdu in the Tibet autonomous region and the alpine grassland at the south side of Naqu had decreasing NDIV trends. Jiali and Dingqing in the Tibet autonomous region and Ganzi in Sichuan province had the greatest decrease rate, at more than 0.035/10a. Overall, the increased trend of NDVI on the QTP decreased from the southeastern to northwestern QTP.

The NDVI had an increasing trend in the 1980s at a rate of 0.02/10a and a decreasing trend in the 1990s at a rate of 0.003/10a. The NDVI increased significantly from 2000 to 2010, with an increase rate 0.02/10a. The montane evergreen broad-leaved forest distributed on the south side of the eastern Himalayas had the largest increased extent, which was 0.13/10a. The montane grassland in the Qilian mountains in eastern Qinghai province and the alpine shrub in Guoluo and Naqu had the second largest increased extent, with an increase rate of 0.03 ~ 0.045/10a. The increase rate in the remaining area of the QTP was approximately 0.001/10a.

C. Response of NDVI to climate factors

1) Correlation analysis between NDVI and climate factors

The Pearson's correlation coefficient was used to assess the response of NDVI to different climate factors, and the t-test was used for the significance test on correlation coefficient. In this study, the lag characteristics of NDVI to climate factors in different natural areas was studied to determine the potential affect of climate change on vegetation growth because temperature, humidity and precipitation have different lag effects on vegetation growth [15],[16].

There was marked and significant relationship between NDVI annual change and the temperature and correlation coefficient between the annual change and mean temperature, with the largest and lowest temperatures of 0.5(P < 0.01), 0.51(P < 0.01), 0.49(P < 0.01).

The NDVI of the montane desert at the north side of Kunlun Mountain, the alpine desert at Kunlun Mountain, the montane grassland of Qilian mountain in eastern Qinghai, the alpine shrub in Guoluo and Naqu and montane alpine shrub grassland in southern Tibet all had a significant correlation with mean temperature, highest temperature and lowest temperature, with a correlation coefficient of 0.4-0.67, most of which reached marked significance (P < 0.01).

The NDVI of the montane evergreen broad-leaved forest at the south side of the eastern Himalayas, the montane coniferous forest in western Sichuan and eastern Tibet and the alpine meadow in southern Qinghai had a low correlation with temperature. The correlation extent between the montane evergreen broad-leaved forest at the south side of the eastern Himalayas and the mean temperature was lowest, and the correlation coefficient was 0.18 (P > 0.05). The correlation extent between NDVI in the eastern Himalayas and eastern Tibet and largest temperature was high (P < 0.01). The NDVI in southern Qinghai had a significant correlation between the lowest temperature (P < 0.05).

The NDVI in Qinghai-Tibet had a significant correlation with precipitation, and the correlation coefficient was 0.44 (P < 0.05). The largest correlation between NDVI and precipitation was in the montane coniferous forest in western Sichuan and eastern Tibet, with a correlation coefficient of -0.63 (P < 0.01). The second largest was in the montane semi-desert and desert in Ali, with a correlation coefficient of -0.47 (P < 0.05).

The NDVI in the montane grassland in the Qilian mountains in eastern Qinghai, the desert in Qaidam and the montane alpine shrub grassland in southern Tibet had no significant relationship with precipitation, and the correlation coefficient was (P > 0.05).

The NDVI in the Qinghai-Tibet plateau had no significant negative correlation with humidity, and the correlation coefficient was 0.44 (P < 0.05).

The NDVI in Qinghai-Tibet had significant negative correlation with wind velocity, and the correlation coefficient was -0.44 (P < 0.05). The largest correlation between NDVI and wind velocity was in the montane desert at the north side of Kunlun Mountain, with a correlation coefficient of -0.53 (P < 0.01); the second largest was in the alpine grassland in Qiangtang, with correlation coefficient -0.47 (P < 0.05). Wind velocity decrease was one of the driving factors for NDIV increase because wind effects evaporation [38]-[40]. There is a significant decreasing trend in wind velocity, which conserved soil moisture in the Qinghai-Tibet plateau and increased the NDVI. The sunshine hours and NDVI showed no significant correlation, and the correlation coefficient was -0.11 (P > 0.05).

TABLE I
CORRELATION COEFFICIENTS BETWEEN NDVI AND CLIMATE FACTORS IN QINGHAI-TIBET PLATEAU

Natural areas	Mean air temper-ature	Highest air temper-ature	Lowest air temper-ature	Precipi-tation	Relative humidity	Wind velocity	Sunshine hours
Alpine shrub in Guoluo and Naqu	0.67**	0.56**	0.49**	0.32(3)	-0.23(3)	-0.36	-0.12
Alpine meadow in southern Qinghai	0.21	0.03(1)	0.40*(1)	0.29(1)	0.26	-0.06	-0.43*
Alpine grassland in Qiangtang	0.44*(3)	0.4*(3)	0.53**(1)	0.38(2)	0.46*(1)	-0.47*	-0.37
Alpine desert in Kunlun Mountain	0.54**(3)	0.55**(3)	0.50**(2)	0.21	0.18(1)	-0.38	-0.35
Montane coniferous forest in western Sichuan and eastern Tibet	0.36	0.71**	-0.30	-0.63**	-0.74**	-0.05	0.74**
Montane alpine shrub grassland in southern Tibet	0.50**(1)	0.39*(1)	0.51**(1)	0.15(2)	0.18(1)	-0.07	0.00
Montane grassland in Qilian mountain in eastern Qinghai	0.52**	0.44*	0.52**	0.10	-0.40*(3)	-0.23	-0.17
Montane semi-desert and desert in Ali	0.47*	0.45*	0.41*(1)	-0.47*	-0.53**(3)	-0.09	0.47*
Desert in Qaidam	0.26(1)	0.24(1)	0.32(1)	0.18(2)	0.09(2)	-0.29	-0.21
Montane desert in north side of Kunlun mountain	0.61**(2)	0.59**(2)	0.61**(2)	-0.37(1)	-0.43*(3)	-0.53**	-0.26
Montane evergreen broad-leaved forest in s outh side of eastern Himalayas	0.18	0.55**	-0.33	-0.34	-0.64**	-0.03	0.63**
Qinghai-Tibet plateau	0.50**	0.51**	0.49**(2)	0.44*(3)、	-0.38(2)	-0.44*	-0.11

* Single asterisk in the same column indicated significant difference at p=0.05; ** Double asterisk in the same column indicated significant difference at p=0.01; numbers inside brackets indicated lag month.

The NDVI in the montane evergreen broad-leaved forest on the south side of the eastern Himalayas, the montane coniferous forest in western Sichuan and eastern Tibet and the montane semi-desert and desert in Ali had a significant positive correlation with sunshine hours, with correlation coefficients of 0.63 ($P < 0.05$), 0.74($P < 0.01$) and 0.47($P < 0.05$), respectively. The NDVI in the alpine meadow in southern Qinghai had a significant negative correlation with sunshine hours, and the correlation coefficient was -0.43 ($P < 0.05$).

2) Partial correlation analysis between NDVI and climate factors

There is a significant correlation between the NDVI in the Qinghai-Tibet plateau and temperature and precipitation. Temperature was dominant, with partial correlation coefficients of 0.40 ($P < 0.05$). The correlation between NDVI in the different natural areas and the climate show a regional difference. Accordingly, we can obtain the following results by partial correlation:

(1) The NDVI in the montane grassland in the Qilian Mountains in eastern Qinghai, the desert in Qaidam, the alpine desert in Kunlun Mountain, the montane desert on the north side of Kunlun Mountain, the alpine shrub in Guoluo and Naqu and the alpine grassland in Qiangtang were mainly influenced by temperature-precipitation, and temperature was dominant driving factor. The largest correlation coefficients between the NDVI and temperature-precipitation in Guoluo and Naqu, the north side of Kunlun Mountain and eastern Qilian in Qinghai and the partial correlation coefficients was 0.65 ($P < 0.01$), 0.59 ($P < 0.01$) and 0.51 ($P < 0.01$), respectively.

(2) The NDVI in the alpine meadow in southern Qinghai had a significant correlation with precipitation and temperature, and the precipitation was dominant, with a partial correlation coefficient of 0.40 ($P < 0.05$). In this region, the NDVI was mainly influenced by precipitation-temperature.

(3) The NDVI in the montane evergreen broad-leaved forest at the south side of the eastern Himalayas, the montane coniferous forest in western Sichuan and eastern Tibet and the montane semi-desert and desert in Ali were mainly influenced by temperature, precipitation and wind velocity. Precipitation was the dominant driving factor, followed by temperature and, finally, wind velocity. The NDVI in western Sichuan and eastern Tibet was influenced mostly by precipitation-temperature-wind velocity, and the partial correlation coefficient was -0.63 ($P < 0.01$).

(4) The NDVI in the montane alpine shrub grassland in southern Tibet was mostly influenced by temperature, followed by precipitation and, finally, wind velocity, which belonged to the temperature-precipitation-wind velocity driving type. The NDVI in this region had a significant correlation with the precipitation-temperature-wind velocity, and the partial correlation coefficients reached 0.56 ($P < 0.01$).

TABLE II
PARTIAL CORRELATION COEFFICIENTS BETWEEN NDVI AND CLIMATE FACTORS IN THE QINGHAI-TIBET PLATEAU

Natural areas	T NDVI-P	P NDVI-T	P NDVI-V&T	T NDVI-V&P	V NDVI-T&P
Alpine shrub in Guoluo and Naqu	**0.65****	0.33	0.33	0.62**	0.05
Alpine meadow in southern Qinghai	0.30	**0.40***	0.38	0.23	0.00
Alpine grassland in Qiangtang	**0.42***	0.27	0.23	0.24	-0.18
Alpine desert in Kunlun Mountain	**0.45***	-0.04	-0.03	0.32	-0.06
Montane coniferous forest in western Sichuan and eastern Tibet	0.33	-0.62**	**-0.63****	0.27	-0.18
Montane alpine shrub grassland in southern Tibet	0.55**	-0.09	-0.06	**0 . 56****	0.07
Montane grassland in Qilian mountain in eastern Qinghai	**0.51****	0.01	0	0.48*	-0.07
Montane s emi-desert and desert in Ali	0.37	-0.37	**-0.39***	0.3	-0.13
Desert in Qaidam	**0.38**	0.32	0.37	0.09	-0.22
Montane desert in north side of Kunlun mountain	**0.59****	-0.41*	-0.46*	0.29	-0.32
Montane evergreen broad-leaved forest in south side of eastern Himalayas	0.40*	-0.29	**-0.41***	-0.14	-0.3
Qinghai-Tibet plateau	**0.40***	0.30	0.28	0.25	-0.07

* Single asterisk in the same column indicated significant difference at p=0.05; ** Double asterisk in the same column indicated significant difference at p=0.01; TNDVI-P indicated partial correlation coefficients between temperature and NDVI when precipitation P fixed; P NDVI-V&T indicated partial correlation coefficients between precipitation and NDVI when precipitation P and temperature T fixed; so did P NDVI-T, TNDVI-V&P and VNDVI-T&P

D.Conclusions

(1) There was significant increasing trend in temperature in the past 40 years over the Qinghai-Tibet plateau influenced by climate warming. In the most recent 20 years, the increasing extent of temperature was aggravated, and the increasing rate decreased from south to north. There was no significant increasing trend in the past 40 years, but the precipitation increasing extent increased in the past 20 years, while relative humidity had a decreasing trend. There was a significant decreasing trend in wind velocity and sunshine hours in the last 40 years. In general, the climate of the Qinghai-Tibet plateau changed regarding the warm-humid trend, which was good for plant growth.

(2) The NDVI in the Qinghai-Tibet plateau increased in the past 30 years. The largest increase was at the south side of the eastern Himalayas, with a rate of 0.02 ~ 0.08/10a. Small regions distributed throughout the desert in Qaidam, the montane coniferous forest in Cangdu in eastern Tibet and the alpine shrub in Naqu had a decreasing trend with a change rate of 0 ~ 0.04/10a. In all, the NDVI in the Qinghai-Tibet plateau

had an increasing trend decreased from southeast to northwest.

(3) Climate change influenced the NDVI in the Qinghai-Tibet plateau mainly through temperature, precipitation and wind velocity. The changes in temperature, precipitation and wind velocity mostly influenced NDVI, and the relative humidity and sunshine hours exerted less influence on NDVI. In all, the changes in NDVI in the Qinghai-Tibet plateau belong to the temperature-precipitation driving type, of which temperature was the dominant driving factor. At the same time, the relationship between NDVI and climate factors shows a regional difference. Precipitation was the main reason for the NDVI change in south Qinghai, west Sichuan and east Tibet, Ali and the south side of the eastern Himalayas. The remnant parts were mainly influenced by temperature-precipitation.

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