Temporal and Spatial Dynamics of Normalized Difference Vegetation Index on the Southern Slope of Qilian Mountains from 2000 to 2015

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Abstract: MOD13A1 data of 500 m resolution of 2000-2015 years annual growth season (5-9 months) is utilized, and the cumulative average method, average method, trend line are put into use to analyze of the dynamic features of NDVI in southern slope Qilian Mountains, and the 16A maximum value and the growth rate of NDVI are simulated. The NDVI increases significantly in the southern slope of Qilian Mountains, the increased area was 3589 km², an increase of 14.95%. The growth rate is 0.018/10a. The area of NDVI reduction is 1131 km², which is reduced by 4.71%. The area of NDVI increased by more than 2458 km², accounting for 52.07%. The spatial variation of NDVI in the growing season showed a trend of increasing from northwest to Southeast; the annual changes of NDVI in the growing season showed a single peak, and the interannual variation showed a fluctuating trend.

1. Introduction
Vegetation is an important part of the global terrestrial ecosystem, and the relationship between vegetation and climate factors is a hot topic of global change research [1]. Remote sensing technology can be used for long-term continuous observation of the surface, which is an effective means of quantitative description of vegetation [2]. Normalized difference vegetation index (NDVI) is a numerical expression of surface vegetation growth information monitored by remote sensing and can effectively describe green plant growth and biomass information [3,4]. It provides a simple, fast and accurate means for the study of temporal and spatial dynamic changes of vegetation index and its influencing factors. Fensholt et al. [5] found that precipitation in arid and semi-arid regions around the world is the main factor limiting plant yield, while temperature is the main factor limiting vegetation
growth. Wang Zhipeng et al. [6] discussed that it is unreasonable to characterize the influence of the amount of precipitation change on vegetation solely by precipitation in Qinghai-Tibet Plateau. Du Jiaqiang et al. [7] found that vegetation responds differently to climate change under different climatic characteristics. Wang xizhi et al. [8] believed that spatial distribution characteristics of vegetation coverage in Huangshui watershed showed zonal differences in different topography. Qi shuhua et al. [9] analyzed that although there was a certain correlation between vegetation growth and precipitation and temperature, vegetation growth was the result of the joint action of multiple factors. To sum up, scholars have systematically studied the response of NDVI and climate factors from different perspectives, and achieved fruitful results.

Qilian Mountain, a mountain range on the northeastern edge of the Qinghai-Tibet Plateau, is the key area of ecological environmental protection and environmental governance that the state pays close attention to, and is also the most important ecological barrier of the northwest arid region. Its ecological environment is fragile and sensitive to climate change. It is also the priority area for biodiversity conservation in China. It plays an irreplaceable role in coping with climate change and mitigating CO2 emissions. [10] Located in the hinterland of the middle Qilian Mountain, the southern slope of Qilian Mountain is located in the northeastern edge of the Qinghai-Tibet Plateau and the western edge of the Loess Plateau, which is a transitional zone from the Loess Plateau to the Qinghai-Tibet Plateau and a complex of the characteristics of the Qinghai-Tibet Plateau and the Loess Plateau. [11] It is also the birthplace of several inland river systems, such as Heihe, Shiyang River, Shule River, Qinghai Lake, and outflow water systems, such as Huangshui River and Datong River. It has a very important water conservation function. Therefore, it is of great practical significance to study the dynamic changes of vegetation growth and its influencing factors in the ecosystem of this region.

Taking the southern slope of Qilian Mountain as the research object, this paper uses remote sensing technology to study the dynamic change characteristics of NDVI on the southern slope of Qilian Mountain and its response to temperature and precipitation, in order to grasp the dynamic change characteristics of NDVI on the southern slope of Qilian Mountain from 2000 to 2015, and to provide a basis for the protection and management of the ecological environment of the southern slope of Qilian Mountain.

2. General Situation of Research Area
The total area of the south slope of Qilian Mountain is about 2.4×10⁴ km². Geographical location is 98°08′13″-102°38′16″ for the east longitude and 37°03′17″-39°05′56″ for the north latitude (figure 1). The research area is located in the hinterland of the mainland in the alpine cold zone, belongs to the plateau continental climate, with the annual average temperature -5.9℃, extreme maximum temperature 30.5℃, and extreme minimum temperature of -37.1℃ [12]. Annual precipitation is mainly concentrated between May and September, with an average annual precipitation of about 400 mm. With the increase of elevation, all climatic elements change regularly from bottom to top, showing an obvious vertical climatic zone in mountainous areas. Major vegetation includes picea crassifolia, sabina przewalskii, populus davidiana, betula platyphylla, dasiphora fruticose, caragana jubata [13].
3. Data Processing and Method

3.1 NDVI data

The remote sensing data used in this paper are the standardized 500 m MOD13A1 vegetation index downloaded from the geospatial data cloud (https://ladsweb.nascom.nasa.gov/search/).

From 2000 to 2015, MOD13A1 data products in the research area [14] used ENVI software for radiation correction, and the projection coordinate affected by NDVI was matched with the projection coordinate system in the research area.

The pre-processed remote sensing image was stretched by 2% to enhance the display effect of the image. Generate 16d maximum synthetic NDVI data, projected as Albers (equal area cut conical projection), WGS84 as the geodetic reference. NDVI data of the southern slope of Qilian Mountain were obtained by cutting the vector boundary of the southern slope of Qilian Mountain.

Meteorological data were obtained from China Meteorological Data Network (http://cdc.cma.gov.cn), including daily temperature, precipitation, accumulated temperature, average humidity and other meteorological data of nearly 16a at 16 meteorological stations in the surrounding areas of the study area. The basic overview of weather stations is shown in table 1 below.

| Weather station name | Latitude (* N) | Longitude (* E) | Altitude (m) | Year of observation (year) |
|----------------------|----------------|-----------------|--------------|---------------------------|
| Jiuquan              | 39°46’         | 98°28’          | 1477.2       | 2000–2015                 |
| Gaotai               | 39°22’         | 99°49’          | 1332.2       | 2000–2015                 |
| Tuole                | 38°47’         | 98°25’          | 3367.0       | 2000–2015                 |
| Yeniugou             | 38°25’         | 99°34’          | 3320.0       | 2000–2015                 |
| Zhangye              | 38°55’         | 100°25’         | 1482.7       | 2000–2015                 |
| Qilian               | 38°10’         | 100°15’         | 2787.4       | 2000–2015                 |
| Shandan              | 38°47’         | 101°4’          | 1764.6       | 2000–2015                 |
| Yongchang            | 38°13’         | 101°58’         | 1976.1       | 2000–2015                 |
| Wuwei                | 37°55’         | 102°40’         | 1530.9       | 2000–2015                 |
| Delingha             | 37°22’         | 97°22’          | 2981.5       | 2000–2015                 |
| Gangcha              | 37°19’         | 100°07’         | 3302.4       | 2000–2015                 |
3.2 Spatial Interpolation of Temperature and Precipitation

In order to obtain the temperature and precipitation of the whole study area on the southern slope of Qilian Mountain, a spatial interpolation algorithm was used. Firstly, mean temperature and precipitation of each month in the growth season (from May to September) of 16 meteorological stations in the surrounding areas of the research area from 2000 to 2015 were calculated, and the default and abnormal values were interpolated. Secondly, with the support of ArcGIS 10.0 software, combined with the longitude and latitude information of each station, the monthly mean temperature and monthly precipitation data were interpolated by inverse distance weighting method (IDW) to obtain the spatial distribution grid data of monthly mean temperature and monthly precipitation on the southern slope of Qilian Mountain. Thirdly, mean temperature and precipitation in the growth season of Qilian Mountain south slope were calculated by ArcGIS 10.0 spatial analysis function to obtain the temperature and precipitation in the growth season of 16a in the south slope of Qilian Mountain.

3.3 Land Use Classification

According to the "second-class resource survey" and combining with the characteristics of the study area, the land use types in this area can be summarized into 10 types. The main types of land use are: arable land, grassland, meadow, forest land, glacier, bare rock/bare soil, swamp, shrub, artificial land and water area.

3.4 Analysis of NDVI Variation Trend Line

With the help of θslope (unitary linear trend line) simulation, the variation trend of NDVI is obtained. The maximum value of 16a NDVI in each grid can be used to simulate the variation trend of NDVI value in the grid during the 16 years, and the variation range can be estimated. The calculation formula is as follows [15].

$$
\theta_{\text{slope}} = \frac{16 \times \sum_{i=1}^{16} i \times \text{NDVI}_i - (\sum_{i=1}^{16} i)(\sum_{i=1}^{16} \text{NDVI}_i)}{16 \times \sum_{i=1}^{16} i^2 - (\sum_{i=1}^{16} i)^2} \quad (1)
$$

Where, 16 is the number of monitoring years; when i=1, it is 2000; when i=2, it is 2001 and so on to 2015. θslope is the slope of the trend line. When θslope<0, it indicates that the change trend of NDVI during n years is decreasing, and on the contrary, it is increasing [15,16]. In layer properties of ArcGIS 10.0 software, according to the classification method of standard deviation [17,18], changes of θslope in the southern slope of Qilian Mountain are divided into: (-0.0455<θslope<0.0039) decreased significantly, (-0.0039<θslope<0.0023) decreased moderately, (-0.0023<θslope<0.0006) decreased slightly, (-0.0006<θslope<0.001) remained roughly the same, (0.001<θslope<0.0026) increased slightly, (0.0026<θslope<0.0042) increased moderately, and (0.0042<θslope<0.0186) increased significantly over seven intervals, and the area of each change interval and its percentage are calculated.

4. Result

4.1 Characteristics of NDVI Time Variation on the Southern Slope of Qilian Mountain

For analysis of annual variation, from 2000 to 2015, NDVI on the southern slope of Qilian Mountain showed a single-peak variation in the average value of NDVI in each annual growth season (from May to September), and the variation trend was obvious. Among them, NDVI began to increase from May
to June, peaked in July, and gradually decreased from August to September.

For analysis of interannual variation, from 2000 to 2015, the average annual NDVI of the southern slope of Qilian Mountain showed a fluctuating and rising trend (as shown in figure 2a-2f). The average annual maximum value of NDVI was 0.42 in 2010, and the lowest value was 0.39 in 2001. From the monthly variation trend, the average value of NDVI in May was 0.24, the minimum value of NDVI was 0.20 in 2001, and the maximum value of NDVI was 0.27 in 2007. In June, the average value of NDVI was 0.43, and the minimum and maximum values of NDVI were 0.38 and 0.46 respectively in 2001 and 2002. The average value of NDVI in July was 0.54, reaching the maximum value in a year. The minimum value of NDVI in that month was 0.51 in 2001, and the maximum value was 0.57 in 2010. The average value of NDVI in August was 0.5, and the minimum value and maximum value were 0.479 and 0.53 respectively in 2008 and 2006. The average value of NDVI in September was 0.33, and the minimum value and the maximum value were 0.28 and 0.36 respectively in 2007 and 2010.

Fig.2 Interannual variation of NDVI during the growing season on the southern slope of Qilian Mountains from 2000 to 2015
4.2 Characteristics of NDVI Spatial Variation on the Southern Slope of 16a Qilian Mountain

4.2.1 Spatial Variation of NDVI on the Southern Slope of 16a Qilian Mountain

During 2000-2015, the space distribution of NDVI on the southern slope of Qilian Mountain showed features of increasing gradually from northwest to southeast (as shown in figure 3 and figure 4), with increasing area mainly in the east of east longitude 101 °, growth of 0.018/10a, which is the Xianmi township, the eastern part of Dongchuan town, the near Menyuan county, the Sujitan township, the northwest part of Ebao town, the near Qilian county, the Zhamashi township and the western region of Yanglong township, with bigger increase of NDVI, and the increasing value of NDVI is between 0.3 to 0.46. The decreasing area of NDVI is mainly in the west of east longitude 101 °, distributed in the southwest and northeast region of Yanglong township, the southwest part of Kekeli township and the eastern part of Muli township, and the decreasing value of NDVI is between 0.67-0.40.

4.2.2 Characteristics of NDVI Spatial Distribution on the Southern Slope of 16a Qilian Mountain

From 2000 to 2015, NDVI on growth season in the south slope of Qilian Mountain showed a trend of increasing from northwest to southeast (as shown in figure 5 and table 2). In the range of $2.4\times10^4$ km$^2$ in the south slope of Qilian Mountain, the area increased by NDVI was 3589 km$^2$, an increase of 14.96%. The area decreased by NDVI was 1131 km$^2$, a decrease of 4.71%. The area increased by NDVI was 2,458 km$^2$ more than the area decreased, accounting for 52.07%. Among them, the significantly increased area is 791 km$^2$, accounting for 3.30%. The moderately increased area was 1086 km$^2$, accounting for 4.52%. The slightly increased area was 1714 km$^2$, accounting for 7.14%. The basically unchanged area was 19279 km$^2$, accounting for the largest proportion of 80.33%. The slightly decreased area was 747 km$^2$, accounting for 3.11%. The moderately decreased area was 238 km$^2$, accounting for 0.99%. The significantly decreased area was 147 km$^2$, accounting for 0.61%.

![Figure 3 The variation of NDVI on the southern slope of Qilian Mountain from 2000 to 2015](image1)

![Figure 4 NDVI accumulation during the rowing season on the southern slope of Qilian Mountains from 2000 to 2015](image2)
Table 2 Trends of NDVI during the growing season on the southern slope of Qilian Mountains from 2000 to 2015

| Variation trend         | Area (km²) | Proportion (%) |
|-------------------------|------------|----------------|
| Significant reduction   | 147        | 0.61%          |
| Moderate reduction      | 238        | 0.99%          |
| Slightly reduction      | 747        | 3.11%          |
| Essentially unchanged   | 19279      | 80.33%         |
| Slightly increase       | 1714       | 7.14%          |
| Moderate increase       | 1085       | 4.52%          |
| Significant increase    | 791        | 3.30%          |

5. Discussion

5.1 Analysis of Characteristics of NDVI Time Variation on the Southern Slope of Qilian Mountain

From the perspective of annual variation, NDVI in the southern slope of Qilian Mountain presents single-peak changes in each annual growth season, which is in line with the plateau continental climate characteristics of the study area [12]. During the growth season, rain-heat is the same period from May to September, and the rain-heat reaches the best in July [20-22]. From the aspects of interannual variation, temperature of the southern slope of Qilian Mountain and its surrounding areas increased in recent years, and the amount of snowmelt and precipitation increased, so that the climate changes [23] from dry and warm to warm and wet, and NDVI changes with the temperature and precipitation collectively and has a trend of fluctuations rise (as shown in figure 6a, 6b), which is consistent with the conclusions made by Cheng Ying, Wu Zhengli and Dai Shengpei [21,24,25]. Due to the unique geographical location and climatic conditions of the southern slope of Qilian Mountain, NDVI basically does not change from January to April and October to December every year [19], so it is not considered in this paper.
5.2 Analysis of Characteristics of NDVI Spatial Variation on the Southern Slope of 16a Qilian Mountain

The reason to form the spatial distribution characteristics that increase gradually from northwest to southeast of NDVI on the southern slope of 16a Qilian Mountain from 2000 to 2015 is: on the one hand, the eastern Qilian Mountain is influenced by the central Asian monsoon all the year round, while the western is affected by prevailing westerlies, which means that the source of the water vapor is different, precipitation increasing from west to east [19, 26]; on the other hand, from the perspective of land use types (as shown in figure 7) on the southern slope of Qilian Mountains, the study area in northwest high altitude has large bare soil, glaciers and bare rock distribution area, while the southeast at relatively low altitude is mainly composed of forest land, shrub, grassland and farmland. Influenced by precipitation, temperature, altitude, terrain and other factors, the distribution pattern of NDVI on the southern slope of Qilian Mountain is more in the southeast and less in the northwest [21,27,28].

Fig.6 Interannual NDVI and monthly mean temperature (a) and precipitation (b) changes during the growing season on the southern slope of Qilian Mountains from 2000 to 2015

6. Conclusion

Based on the difference calculation of NDVI data of the southern slope of Qilian Mountain from 2000 to 2015, combined with the observation data of monthly mean temperature and precipitation of 16 meteorological stations in and around the study area, this study analyzed the NDVI change rule of the
southern slope of Qilian Mountain and its response to temperature and precipitation changes, and drew the following conclusions:

(1) The increase area of NDVI on the southern slope of Qilian Mountain was larger than the decrease area in 16a, and the ecological environment was significantly improved. On the whole, NDVI presents a gradually increasing spatial distribution characteristic from west to east, in which the NDVI increases significantly in the Xianmi township of Menyuan county, the eastern part of Dongchuan town, the near Menyuan county, the Sujitan township, the northwest part of Ebao town of Qilian county, the near Qilian county, the Zhamashi township and the western region of Yanglong township. The area where NDVI decreases significantly is in the southwest and northeast region of Yanglong township, the southwest part of Kekei township and the eastern part of Muli township.

(2) NDVI in the southern slope of Qilian Mountain during the growth season (from May to September) showed obvious changes in 16a, all of which presented the characteristics of single-peak variation. NDVI value began to increase from May to June, reached its maximum value in July, and gradually decreased from August to September.

(3) The annual variation of NDVI in the growth season was similar to that of the monthly average temperature in 16a, showing a single-peak variation trend, and the interannual variation trend of NDVI, temperature and monthly average precipitation fluctuated and increased.

Acknowledgment
Funding projects: National key research and development program (2017YFC0404304); The National Natural Science Foundation of China (41361005); "High-end innovative talents thousand talents plan" of qinghai province (youth talents no. 11 [2016]); "The 135 high-level personnel training project" of qinghai province; Special project grant of Qinghai Province Key Laboratory of Physical Geography and Environmental.

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