The relationship analysis of vegetation cover, rainfall and land surface temperature based on remote sensing in Tibet, China

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Abstract: The analyses of vegetation influenced by meteorological factors contribute to research the relationships between terrestrial ecosystems and climate changes. Using the data of normalized difference vegetation index, land surface temperature from MODIS satellite products and rainfall from TRMM satellite products to build 16-day data sequence from 2000 to 2011 years, this paper analyzed the spatial-temporal distribution of vegetation cover, land surface temperature and rainfall, and also discussed the relationships among three factors in Tibet. The results indicated that the mean vegetation coverage in August varied in the range of 0% to 99% depending on location. The southeastern part of Tibet had annual rainfall of 600–800 mm, whereas the western part suffered from drought with a value below 200 mm. The mean annual land surface temperature varied between -8.9°C and 16.3°C. During the whole year, the correlation coefficient between vegetation index and land surface temperature was the smallest in July. The correlation coefficient between vegetation index and rainfall was the biggest in September. Vegetation was influenced greater by the rainfall than land surface temperature from April to October in Tibet.

1. Introduction
Vegetation, an important component of global ecosystem, modulates the ecosystem through water retention, atmosphere circulation and terrestrial soil stability, and helps to maintain a balance of ecosystem greatly. The Tibetan Plateau is a sensitive region in terms of ecosystem changes, where the manifestation of climate dynamics is particularly noticeable [1-2]. Climate variability affects local ecosystem strongly, produces notable local ecosystem changes [3]. Thus, a study focusing on vegetation, land surface temperature and rainfall in Tibetan region, the main part of the Tibetan Plateau, is of great significance to global ecological changes.

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With the superiorities of utilizing large-scale, repeated ground observation and acquiring multi-temporal, comprehensive images, remote sensing has been an indispensable approach to study ecosystem changes. In the past several years, massive meaningful achievements have been obtained in the research of the impact and feedback of climate variation on vegetation \(^{[4-5]}\). Rainfall and air temperature measurements from weather stations were conventionally considered the most accurate and reliable source of data in previous. However, surface data interpolated from points, with a coarse spatial resolution, were improper for resolving regional spatial dynamics and comparatively an error for the Tibet region which had sparse weather stations in total, sparser in the northwest. In this article, remote sensing data were considered to discuss the spatial-temporal variation of vegetation, land surface temperature and gridded satellite rainfall including their distribution characteristics and relationships in the past 12 years in Tibet area.

2. Data and Methods

2.1 Data source
In this paper, vegetation research was based on NDVI data widely used and directly obtained from MOD13A2 products, the 16-Day L3 Global 1km SIN Grid VI datasets, which were designed for vegetation. Since air temperature was unavailable, we characterized land surface temperature (LST) through MOD11A2 products available at a spatial resolution of 1\(\times\)1km and a temporal resolution of 8 days. The 3-hour merged 3B42 products from the Tropical Rainfall Measuring Mission (TRMM) archived on a 0.25\(^\circ\)\(\times\)0.25\(^\circ\) grid served as a source of precipitation data in Tibet region\(^{[6-7]}\). This study centralized in Tibet region between 72\(^\circ\)-100\(^\circ\)E in the east-west direction and 26\(^\circ\)-37\(^\circ\)N in the north-south direction. In addition, the long series of data downloaded from National Aeronautics and Space Administration (NASA) was from January 2000 to December 2011.

2.2 Data proceeding and methods
2.2.1. Time series. MODIS Resample Tool (MRT) software was used to transform MODIS products into WGS84 projection, make image format conversion and piece maps together. We converted data into appropriate units and extracted areal data in the ENVI software to provide a convenient presentation for the Tibet.

MOD11A2 products contain average values of 8-day composite LST images generated from band 31 and band 32 through the generalized split-window algorithm. In order to compose 16-day LST time series from 8-day MOD11A2 products, we selected the image with less cloud in our study area or averaged the two images when the qualities were both good.3-hour gridded satellite rainfall from TRMM 3B42 products were converted into series of 16-day rainfall totals for later analyses.

NDVI data from MOD13A2 images at the same time of each year were processed with the maximum-value compositing (MVC) method which had the advantages of minimizing cloud contamination, atmosphere and solar elevation angle interference\(^{[8]}\). For making further study at finer spatial resolution and correlation analyses with vegetation, 16-day composite TRMM 3B24 rainfall datasets were resampled to match the 1km spatial resolution NDVI datasets.

2.2.2. The calculation of correlation coefficient. Correlation coefficient is a statistical value used to
elucidate the degree that a variable is linearly related to another in the correlation analysis. In order to investigate the impact of land surface temperature and rainfall on NDVI, numerical values calculated through simple equation (1) were assigned to judge relative influence of each factor. A positive (negative) value indicated that an enhancement of land surface temperature or rainfall was beneficial (inhibitory) to vegetation.

$$r_{XY} = \frac{\sum_{i=1}^{N}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{N}(X_i - \bar{X})^2} \sqrt{\sum_{i=1}^{N}(Y_i - \bar{Y})^2}}$$

Where $X_i$ and $Y_i$ denote the independent variable and dependent variable; $\bar{X}$ and $\bar{Y}$ represent mean values of each sample, respectively.

3. Results and Analyses

3.1 The spatial-temporal distribution pattern of vegetation, rainfall and temperature.

3.1.1 The temporal characteristics. 16-day composite land surface temperature data at the same time of each year were averaged. As was shown in figure 1, the maximum value appeared in January while the lowest occurred in July. 16-day composite rainfall images at the same time of each year were averaged for the period 2000-2011 to describe the variation of rainfall. 80%~90% of rainfall occurred between May and October with the highest in August (figure 2).

Figure 1. Seasonal LST variation
Figure 2. Seasonal rainfall variation

The maximum of NDVI indicated that plants grow best during this period. Seasonal variation of the maximum NDVI in Tibet presented a single-peak curve (figure 3). Vegetation coverage was low in spring and winter, but increased significantly in summer, with the highest appearing in July (figure 4).

Figure 3. Seasonal NDVI variation
Figure 4. Seasonal vegetation cover variation
From January to February, NDVI resulted from low land surface temperature and withered plants. A vast majority of plants grew luxuriantly and NDVI appeared an ascending tendency depending on the rapid increase of land surface temperature and rainfall from March to early July. Due to large-area mature crops and abloom grassland plants, NDVI had a downtrend from late July to the end of August. With the arrival of withering stage, NDVI continued to decline from September to December.

3.1.2 The spatial characteristics. Despite of partial differences, vegetation cover had distinct geographical regularities in spatial distribution with the characteristic of approximately 99% in the southeast and a steady decline to 7% toward the northwest. The spatial distribution of land surface temperature gradually decreased from the southeast to the northwest (figure 5). The annual average land surface temperature in the daytime was -1.6~23.7°C with -15.8~10.4°C at night. Alike vegetation, annual rainfall displayed a tendency of decreasing from the southeast with a maximum of 3232mm to the northwest with a minimum of 76mm.

Tibet region was characterized by abundant rainfall, appropriate land surface temperature in the southeast and little rainfall, low land surface temperature in the northwest. Corresponding to land surface temperature and rainfall greatly in spatial, the characteristics of vegetation were highly determined by the essential ecological factors. Through comparing mutually, summer rainfall with a maximum of above 2000mm, had a strong spatial consistency with annual rainfall.

Annual average land surface temperature was mainly in the range of 14°C~17°C in the southern Tibet, -6°C~5°C in most areas of Linz, 3°C~8°C in the central part and -3°C~3°C in the northwest.

3.2 The correlation analysis of vegetation with land surface temperature and rainfall

3.2.1 The temporal characteristics. Vegetation growth was tightly associated with fundamental environmental factors such as precipitation, air temperature, illumination intensity, soil type, etc. On account of the significant response of vegetation to rainfall and temperature variation, NDVI, land surface temperature and rainfall data of the same period were selected for correlation analyses at an interval of 16 days.

Seasonal relationships among the three factors were illustrated in figure 6. Vegetation was under
greater impact of rainfall with a correlation coefficient about 0.6 than land surface temperature from mid-April to October. Conversely, land surface temperature had greater influence on NDVI for the rest of year. Ranging from -0.16 to 0.69, correlation coefficients of NDVI with land surface temperature dropped to its minimum in July. Correspondence between NDVI and rainfall was high, with correlation coefficients ranging from 0.1 to 0.7 and reaching the peak in September.

![Figure 6. Correlation coefficients of NDVI with rainfall and land surface temperature at an interval of 16 days.](image)

3.2.2 The spatial characteristics. The variation of NDVI was primarily concentrated in March to November. Hence, it was appropriate to describe seasonal impact of the two factors on NDVI basing on correlation analyses to each pixel of same seasonal images in the MATLAB software.

Most districts presented a significant positive correlation between NDVI and rainfall in spring with the exception of Ngari and the northern Nagq (figure 7). Nyingchi and the southern Shannan took on a negative relationship in the rainy summer. This spatial distribution oppositely confirmed that vegetation grew better accordingly with a continuous increase of rainfall in rainless areas. As a result of consistent declines in autumn, NDVI and rainfall showed detectable positive correlation.

The relationship of NDVI with land surface temperature was basically positive in spring, especially to Lhasa. Xigaze, Qamdo, Shannan and Lhasa displayed a negative correlativity in summer. Due to the withering of plants and fall of land surface temperature in autumn, it was positive except the southeast.
4. Conclusions

The results indicated that seasonal changes of NDVI, land surface temperature and rainfall were all single-peak curves with the peak values ranging from July to August. NDVI, land surface temperature and rainfall all roughly had a downtrend from the southeast to the northwest.

NDVI was more susceptible to the variations of rainfall than land surface temperature on the whole. The relationships had strong seasonal dynamics and distinct regional characteristics that were related to snow melting, soil condition, climate change and vegetation types, etc.

The article discussed the spatial-temporal patterns and relationships of NDVI with land surface temperature and gridded satellite rainfall throughout the study period. The above analyses were basically consistent with actual situations in Tibet, which demonstrated the potential of using those data for regional research.

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