Analysis of China Vegetation Dynamics Using NOAA-AVHRR Data from 1982 to 2001

HABIB Aziz Salim  CHEN Xiaoling  Gong Jianya  WANG Haiyan  ZHANG Li

Abstract  The authors derived the normalized difference vegetation index (NDVI) from the NOAA/AVHRR Land dataset, at a spatial resolution of 8km and 15-day intervals, to investigate the vegetation variations in China during the period from 1982 to 2001. Then, GIS is used to examine the relationship between precipitation and the Normalized Difference Vegetation Index (NDVI) in China, and the value of NDVI is taken as a tool for drought monitoring. The results showed that in the study period, China’s vegetation cover had tended to increase, compared to the early 1980s; mean annual NDVI increased 3.8%. The agricultural regions (Henan, Hebei, Anhui and Shandong) and the west of China are marked by an increase, while the eastern coastal regions are marked by a decrease. The correlation between monthly NDVI and monthly precipitation/temperature in the period 1982 to 2001 is significantly positive ($R^2=0.80$, $R^2=0.84$); indicating the close coupling between climate conditions (precipitation and temperature) and land surface response patterns over China. Examination of NDVI time series reveals two periods: (1) 1982-1989, marked by low values below average NDVI and persistence of drought with a signature large-scale drought during the 1982 and 1989; and (2) 1990-2001, marked by a wetter trend with region-wide high values above average NDVI and a maximum level occurring in 1994 and 1998.

Keywords  NOAA-AVHRR; NDVI; temperature; precipitation; drought; China

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Introduction

The most exciting breakthrough in atmospheric and land-surface process modeling since the 1980s has come from the recent integration of biophysical and biogeochemical processes, plant physiology, and remote-sensing products. These researches are interdisciplinary in nature and help us to further understand the Earth’s system. Investigating the long-term variations in both vegetation condition and climate change is a good method for monitoring the changes of the global environment [1]. The spatial distribution of vegetation cover is strongly related to mean climatological conditions [2]. The growing season length, the total amount of biomass, and the ecosystem composition are strongly influenced by interannual climate variations [3]. At the same time, vegetation changes can feed back to the atmosphere by modifying the surface roughness, evapotranspiration, and...
albedo\(^4\). Recently, satellite observations have been used to quantitatively describe vegetation growth patterns \(^5\). The foundation for using NDVI data in monitoring arid and semi-arid lands is based on a large body of research in the 1980s in a wide range of arid land regions demonstrating the close relationship between NDVI and rainfall variations on seasonal to interannual time scales\(^6\). This relationship between NDVI and rainfall provided the basis for using time series NDVI data for drought monitoring and development of famine early warning systems in regions with sparse terrestrial rainfall networks\(^7\).

Advanced very high resolution radiometer (AVHRR) of the National Oceanic and Atmospheric Administration (NOAA) datasets have been widely used in studies of national, continental, and even global vegetation activities. As an indicator of vegetation cover and plant productivity, the NDVI has been used in analysis of vegetation activity in the past two decades\(^8,9\). A recent study in western China shows that rainy season NDVI (May to October) has increased in most areas of arid and semiarid regions over the past two decades\(^10\). Compared to the early 1980s, the area of arid and semiarid regions decreased by the end of the 20th century, implying a reversal of desertification processes in these two climate regions. The vegetation activity in China has increased through agricultural practices such as forestation, irrigation, and intensive agricultural management\(^11\). On the other hand, vegetation coverage has decreased due to rapid urbanization, industrialization, and overgrazing\(^12\), so we used a time series dataset of normalized difference vegetation index (NDVI) to analyze China’s vegetation dynamics during the period 1982-2001.

1 Data and method

Two kinds of data sets were used in this study.

(1) NDVI data. The NDVI data used in this analysis were produced by the Global Inventory Monitoring and Modeling Studies (GIMMS) group, and were derived from the NOAA/AVHRR Land dataset, at a spatial resolution (8 km) and at 15-day intervals, for the period January 1982 to December 2001 (480 images for the 20 years of our interest). The NDVI values were converted to digital number (DN) values between 0-255 (IDA 8-bit color) for graphic display purposes. We transformed the DN values to real NDVI values of the MVC images. The corrections of the NDVI data were performed using the Maximum Value Composite (MVC) method. This technique has the advantage of minimizing cloud contamination and off-nadir viewing effects since these factors tend to reduce the NDVI values over green surfaces\(^13,14\).

The NDVI index is calculated from AVHRR measurements in the visible and infrared bands as:

\[
NDVI = \frac{(\rho_{\text{vis}} - \rho_{\text{nir}})}{(\rho_{\text{vis}} + \rho_{\text{nir}})}
\]

where \(\rho_{\text{vis}}\) and \(\rho_{\text{nir}}\) are the surface reflectances in the 550-700 nm (red) and 730-1 000 nm (near-infrared) regions of the electromagnetic spectrum, respectively.

Then, a yearly NDVI anomaly during the growing season (April to October) was calculated as follows:

\[
NDVI_{\sigma} = \left[\frac{(NDVI_{\sigma})}{(NDVI_{\mu})} - 1\right] 100
\]

where \(NDVI_{\sigma}\) are the respective (April to October) percent anomalies, \(NDVI_{\sigma}\) are individual seasonal (April to October) means, and \(NDVI_{\mu}\) is the long-term (April to October) mean.

(2) Meteorological data. Monthly mean temperature (204 images for the 17 years in the time period of 1982-1998) and monthly precipitation (240 images for the 20 years in the time period of 1982-2001) of 680 weather stations across China were obtained from the Global Historical Climatology Network GHCN V2 data in National Climatic Data Center (NCDC).

2 Results and discussion

2.1 Interannual change in vegetation cover

The distribution of China’s annual NDVI in the early 1980s (3-year averaged NDVI value for 1982-1984) and the early 2000s (1999-2001) (Fig.1) reveals the following characteristics:

(1) In both periods, NDVI values exhibited an increasing trend from the northwest to the southeast of China, with a considerably greater NDVI in the east...
of the country than in the west. The NDVI in the northwestern desert areas was extremely low. The favorable precipitation and temperature conditions in the southeast of China corresponded with high NDVI values.

Fig.1 Spatial distribution of three years averaged NDVI at the early 1980s (1982-1984), and early 2000s (1999-2001)

(2) Compared to the early 1980s, the NDVI values in the early 2000s for the Northeast and North-central plains, agricultural areas showed a significant increase. However, urbanization clearly led to a decrease in NDVI along the eastern coast.

(3) Statistical analysis clearly showed an increasing NDVI trend in the past 20 years (1982-2001), with a coefficient of correlation of \( R^2 = 0.383 \) at a rate of 3.8% in (Fig.2).

2.2 Relationship between NDVI and meteorological factors

The correlation between monthly NDVI and monthly (precipitation and temperature) for the period 1982-2001 is significantly positive (\( R^2 = 0.80 \), \( R^2 = 0.84 \), respectively, indicating the close coupling between climate conditions and land surface response patterns over China. Fig.3 shows the results.

Fig.2 Mean NDVI changes in China during 1982-2001

Fig.3 Relationship between NDVI and precipitation/temperature in China (1982-2001)

Fig.4(a) shows the seasonal changes in the average of monthly NDVI for China’s vegetated areas from the early 1980s (1982-1984) and early 2000s (1999-2001). NDVI values in the early 2000s were generally higher than those in the early 1980s and the situation was more obvious in Spring and Winter, which might imply an impact of climate warming.

We also analyzed the monthly NDVI contribution to annual NDVI trends; Fig.4(b) shows seasonal changes of average monthly NDVI over the period of 1982-2001.

Fig.4 NDVI during the period 1982-2001

The values for every month tended to increase, representing an overall increase in NDVI. The largest
changes occurred in Spring, especially in April and May. NDVI values in June, August and October showed a decrease trend. The contribution from May was the largest (7.2%), followed by April (6.3%). Spring (March to May) accounted for 18.2%. It is evident that NDVI increase in China mainly occurred in Spring and Winter. This is consistent with the results, which concluded that the early advance of Spring was the major factor causing the increase in the northern hemisphere’s vegetation activity \cite{15,16}.

NDVI increase in China corresponds closely with climate changes\cite{17,18}. To analyze the relationship between NDVI and climate, Fig.5 presents the interannual variations of annual mean NDVI, temperature and precipitation over the period of 1982-2001. In this period, temperature increased markedly, at a rate of 0.056°C per year. Compared to other regions of the world, this increase is notable\cite{19}. NDVI also showed an increase trend in the study period, but rainfall had no obvious trend though there were relatively large fluctuations.

Compared with annual fluctuations in climate factors, seasonal climate variation had an even more direct influence on vegetation growth. As shown in Fig.6, meteorological characteristics in Spring contributed more to China’s NDVI increase than other seasons,

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig5.pdf}
\caption{Interannual variations in mean NDVI, mean precipitation (1982-2001) and mean temperature (1982-1998) in China.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{Fig6.pdf}
\caption{Interannual variations in China from 1982 to 2001.}
\end{figure}

\[
y = 0.800 \times -0.262 \times \frac{1}{2} R^2 = 0.3825
\]

\[
y = 0.251 \times 669.63 \times \frac{1}{2} R^2 = 0.0027
\]

\[
y = 0.0364 \times 669.01 \times \frac{1}{2} R^2 = 0.0168
\]

with a rate of increase (slope of regressed linear equation) of 0.001 ($R^2 = 0.31$), while the increases in Autumn and Winter were 0.000 4 ($R^2 = 0.16$), and 0.000 1 ($R^2 = 0.02$), respectively. There was no clear trend in Summer. However, the most evident increase in temperature occurred in Winter, rising by 0.075°C/a, followed by a 0.063°C/a increase in Spring. Temperature increases in Summer and Autumn occurred in a similar scope. Although there were no obvious trends in annual precipitation, seasonal precipitation exhibited clear patterns over the 20 years: the rainfall in Summer significantly increased ($R^2 = 0.12$), while the precipitation in Autumn clearly decreased ($R^2 = 0.14$). The precipitation has no distinct change in Spring. During the growing seasons, simultaneously increasing precipitation and temperature can undeniably enhance plant growth. This is a notable characteristic for the relationship
between climate and vegetation growth in China. In addition to the slight decrease in precipitation in Autumn, when vegetation ceases to grow, it is likely to exert a relatively small influence on overall vegetation growth.

2.3 Spatial variations in NDVI trends

Fig. 7 shows the spatial distribution of annual NDVI patterns. NDVI increases clearly occurred in the major agricultural areas of east China (Shandong, Henan and Anhui) provinces, western Xinjiang, eastern Qinghai and southwestern Yunnan. NDVI tended to fall in the Yangtze River and Pearl River deltas, and the Yunnan plateau. Since the 1980s, the climate of northwest China (including mountain areas of Xinjiang) has been shifting from warm-arid to warm-humid climate[20].

Table 1 shows mean annual NDVI, regression slope, and changing rate of NDVI for each province. In agreement with previous analyses, the NDVI values in the southeastern coastal regions were relatively large, while those in the western regions were relatively small. The mean NDVI in Xinjiang was only 0.10, lower than in all other regions. The largest mean annual NDVI values were measured in Taiwan, Hainan, and Fujian provinces at 0.59, 0.55 and 0.55, respectively. These provinces are situated in the tropical/subtropical zones, with a high level of vegetation coverage.

In addition, NDVI across the country generally decreased from southeast to northwest, with the exceptions of marked NDVI decrease due to urbanization around major metropolitan areas, such as Shanghai. The analysis of the changing rate of averaged annual NDVI for each province revealed the following characteristics:

(1) Lower NDVI level occurred in the urban areas of Shanghai, Fujian, Guangxi, Hainan, Zhejiang and Guangdong Provinces. In the majority of these regions, the urbanization has led to a reduction of NDVI values.

(2) Henan, Hebei, Anhui, Shandong, and other agricultural provinces had a relatively large NDVI increase. The economic reforms and “opening” in China in the last 20 years had without a doubt increased the national food production in the major agricultural areas. The pronounced NDVI increase in China’s north-central and northeast regions closely correlates with the increase in grain production in those regions[21].

![Fig. 7 Spatial distributions of the trends in annual NDVI over China during 1982-2001](image)

| Rank | Province | Mean NDVI | Regression slope | NDVI change(%) |
|------|----------|-----------|------------------|---------------|
| 1    | Heilongjiang | 0.36      | 0.000 3          | 1.7           |
| 2    | Inner Mongolia | 0.22     | 0.000 5          | 4.5           |
| 3    | Xinjiang   | 0.10      | 0.000 6          | 12.0          |
| 4    | Jilin      | 0.36      | 0.000 2          | 1.1           |
| 5    | Liaoning   | 0.36      | 0.000 7          | 3.9           |
| 6    | Gansu      | 0.19      | 0.000 5          | 5.3           |
| 7    | Hebei      | 0.35      | 0.001 2          | 6.9           |
| 8    | Beijing    | 0.39      | 0.000 8          | 4.1           |
| 9    | Shanxi     | 0.31      | 0.000 6          | 3.9           |
| 10   | Tianjin    | 0.27      | 0.000 4          | 3.0           |
| 11   | Shaanxi    | 0.36      | 0.000 6          | 3.3           |
| 12   | Ningxia    | 0.17      | 0.000 5          | 5.9           |
| 13   | Qinghai    | 0.15      | 0.000 6          | 8.0           |
| 14   | Shandong   | 0.37      | 0.001 2          | 6.5           |
| 15   | Xizang     | 0.15      | 0.000 5          | 6.7           |
| 16   | Henan      | 0.41      | 0.001 2          | 5.9           |
| 17   | Jiangsu    | 0.39      | 0.000 3          | 1.5           |
| 18   | Anhui      | 0.44      | 0.000 7          | 3.2           |
| 19   | Sichuan    | 0.38      | 0.000 3          | 1.8           |
| 20   | Hubei      | 0.45      | 0.000 4          | 1.8           |
| 21   | Chongqing  | 0.41      | 0.000 2          | 1.0           |
| 22   | Shanghai   | 0.33      | -0.001 1         | -6.7          |
| 23   | Zhejiang   | 0.51      | -0.000 5         | -2.0          |
| 24   | Hunan      | 0.46      | 0.000 4          | 1.7           |
| 25   | Jiangxi    | 0.50      | 0.000 1          | 0.4           |
| 26   | Yunnan     | 0.48      | 0.000 6          | 2.5           |
| 27   | Guizhou    | 0.40      | 0.000 3          | 1.5           |
| 28   | Fujian     | 0.55      | -0.000 2         | -0.7          |
| 29   | Guangxi    | 0.46      | -0.000 4         | -1.7          |
| 30   | Taiwan     | 0.59      | 0.000 3          | 3.1           |
| 31   | Hainan     | 0.55      | -0.000 2         | -0.7          |
| 32   | Guangdong  | 0.47      | -0.000 3         | -0.9          |
(3) The NDVI increase was evident in the (Inner Mongolia, Xinjiang, Ningxia, Qinghai, and Gansu) provinces. The largest rate of NDVI increase was in Xinjiang, reaching 12%. The climate change in these provinces, a rainfall increase especially occurring in Summer, is one of the most important factors to make this change. The synchronous change in precipitation and temperature conditions enhanced vegetation growth. In addition, artificial irrigation in parts of these regions had created artificial oases, further stimulating vegetation growth[22].

The majority of China’s western regions are used for grazing, so the fact of NDVI increase indicates that the positive effects of climate changes and agricultural engineering exceed the negative effects of grazing.

The analysis of climate changes in the northwest-ern regions (especially in Xinjiang), indicates that from the 1980s, the climate in northwest China has increasingly altered from warm-arid to warm-humid, with increasing rainfall. This alteration has led to greater glacial melting, runoff, and rising water bodies in the northwest region, all creating favorable conditions for vegetation growth[23]. A recent comprehensive review on the environmental developments in western China also confirmed that vegetation coverage has increased in a few recent decades[24].

2.4 Spatial NDVI anomaly patterns

The spatial NDVI anomaly patterns in China are shown in Fig.8. These series of images show the percent NDVI anomaly patterns for selected growing season (April to October) during the period 1982-2001.

![NDVI anomaly patterns](image)

These series of NDVI anomalies show the spatial coherence and temporal persistence of drought conditions during the 1980s.

In 1982, a patchy pattern of below normal NDVI showed the prevalence of drought conditions across the country, especially in the north, northeast and west of China (Inner Mongolia, Gansu, Ningxia, Hebei, Xizang and Xinjiang). From 1983 to 1987, it still showed negative departures in NDVI ranging between 10% and 60%. This pattern was enhanced in 1982, 1985 and 1989, and the whole region showed a low NDVI level of below normal conditions and the most extreme negative departures reached 80% lower than the normal conditions.

During the growing seasons in 1988, the whole area showed a high NDVI level of above normal
vegetation conditions (north and west of China), and had positive anomalies ranging between 20% and 80%. Region-wide drought conditions returned in the growing season in 1989, and the negative departures in NDVI were on the order of 10%-60%, which were concentrated in Inner Mongolia, Xinjiang Autonomous Regions and Qinghai province.

During the period 1990-2001, with the exception of 1995 and 1996, vegetation anomalies showed patterns largely opposite of the period 1982-1989. During the growing seasons in 1994, western and northern China showed above normal vegetation conditions and had the positive anomalies ranging between 20% and 80%, while in 1995 and 1996 China showed a low NDVI level of below normal conditions especially in the two provinces (Xinjiang and Qinghai).

During the growing seasons from 1997 to 2001, the whole area showed a high NDVI level of above normal vegetation conditions (north and west of China), and had positive anomalies ranging between 20% and 80%. Some results indicated that, since the late 1980s, the extreme desertification in Mu Us region in north China has been brought under control, with diminishing area undergoing desertification. According to the analysis on remote sensing data, the vegetation productivity in the Inner Mongolia region has been increasing. The persistence and spatial coherence of drought conditions during the 1980s is well represented by the NDVI anomaly patterns.

The time series was dominated by low NDVI values of below normal conditions, with 88% of the years showing below normal NDVI conditions and the severest departures in NDVI occurred in 1982 and 1989, and this situation persisted 7 years between 1982 and 1989, with the exception of the year 1988. While the period from 1990 to 2001 was dominated by above normal conditions with 83% of the years showing above normal NDVI conditions with severest departures in NDVI in 1994 and 1998 persisting 10 years between 1990 and 2001, with exceptions of 1995 and 1996. These patterns are summarized in Fig.9 and Table 2.

| Table 2 | NDVI anomaly scores (+/-) showing persistence patterns of above normal or below normal vegetation condition |
|---------|----------------------------------------------------------------------------------------------------------|
| Year    | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 89 | 90 | 91 |
| Anomaly | -  | -  | -  |    |    |    | -  |    |    |    |
| Year    | 92 | 93 | 94 | 95 | 96 | 97 | 98 | 99 | 00 | 01 |
| Anomaly | -  | -  | -  |    |    |    | +  |    |    | +  |

3 Conclusion

The NDVI time series data indicated that there was a gradual and slow but persistent recovery from the peak drought conditions that affected China in the 1980s, while it was the prevalence of conditions greener than normal during the 1990s to 2001.

During the growing season (April to October), simultaneously increasing rainfall and temperature can enhance plant growth. This is a notable characteristic for the relationship between climate and vegetation growth in China.

Most areas in China have experienced an increase in NDVI, demonstrating that vegetation activity in China is strengthening. It is true that the vegetation in some regions within China has deteriorated due to urbanization and excessive land use. However, the present condition of China’s vegetation cover has improved compared to the early 1980s; mean annual NDVI increased 3.8%. The NDVI change exhibits relatively large regional differences. NDVI in the eastern coastal regions has decreased, while it increased in western China and agricultural areas (Henan, Hebei, Anhui and Shandong). The prominent increase in NDVI in agricultural areas almost stems from the advance of agricultural technology. At the same time, the urbanization process is a critical factor in diminishing the increase of NDVI in the eastern
coastal areas. In China, the climate changes, especially the temperature and summer precipitation increase, are the most important factors driving NDVI increasing. All NDVI trends are related to climate changes or human impact. Recent researches from land surveys, remote sensing, and climate change, all support the conclusion that western China has an increasing NDVI.

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