Effects of Vegetation Cover on Summer Climate in China During 1982~2001

HABIB Aziz Salim  CHEN Xiaoling  GONG Jianya  ZHANG Li

Abstract  In this paper, we apply lagged correlation analysis to study the effects of vegetation cover on the summer climate in different zones of China, using NOAA/AVHRR normalized difference vegetation index (NDVI) data during the time period from 1982 to 2001 and climate data of 365 meteorological stations across China (precipitation from 1982 to 2001 and temperature from 1982 to 1998). The results show that there are positive correlations between spring NDVI and summer climate (temperature and precipitation) in most zones of China; these suggest that, when the vegetation cover increases, the summer precipitation will increase, and the lagged correlations show a significant difference between zones. The stronger correlations between NDVI in previous season and summer climate occur in three zones (Mid-temperate zone, Warm-temperate zone and Plateau climate zone), and this implies that vegetation changes have more sensitive feedback effects on climate in the three zones in China.

Keywords  NOAA-AVHRR; NDVI; vegetation cover; summer climate; China

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Introduction

Climate is the dominant factor in classifying and marking out vegetation cover; conversely, vegetation cover can affect the surface fluxes and consequently the climate at both regional and global scales as one of the important forces. The feedback of vegetation change could accelerate or restrain climate change, and the study of the effects of vegetation cover on the climate system will be helpful for understanding the mechanism of climate change and the summer climate prediction in China.

The effects of loss and increase of the vegetation cover on climate, at the regional scale, have been investigated by observation, dynamical and theoretical analyses, and model studies. However, the interactions between land and atmosphere in the dynamical and theoretical analyses have been simplified[1-2], so the regional differences in the responses of climate to vegetation cover are difficult to distinguish. Land use and land cover change and their feedback to the climate system form very substantial aspects, and the changing of land use and land cover patterns is considered as one of the driving forces of regional environment change superimposed on the natural changes.

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HABIB Aziz Salim, State Key Laboratory of Information Engineering in Surveying, Mapping and Remote Sensing, Wuhan University, 129 Luoyu Road, Wuhan, 430079, China.
E-mail: salimhabib73@yahoo.com
Over the past few decades, numerous reports of rapid loss of vegetation cover in many regions such as the deforestation and desertification in West Africa\cite{3-4} and aridification and desertification in the north of China have raised widespread concerns\cite{5-6}.

The observed data of land-surface climatology have been limited to a few points in space and time due to a few field experiments\cite{7}, and are hardly directly helpful for studying the response of regional climate to vegetation cover. Remote sensing data were often applied to investigate the responses of vegetation to climate change\cite{8-9}, yet were rarely used to study the impacts of vegetation cover on the climate system. These satellite data can be an attractive tool to assess the feedback effects of vegetation.

In this paper, the long-term and large-scale satellite data sets represented by the Pathfinder data sets developed by the Earth Observation System project of NASA and NOAA were integrated to study the relationship between summer climate and vegetation change in the time period of 1982~2001 in China.

1 Data and method

The AVHRR satellite, 15-day composites of surface reflectance with its 20 year data record (1982~2001) and reasonably spatial resolution (8km), provides an excellent tool for the analysis of regional vegetation. NDVI values were downloaded from the World Meteorological Organization (WMO) website. The NDVI values were converted to digital number (DN) values between 0~255 (IDA 8-bit color) for graphic display purposes. So 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\cite{10-11}. The NDVI is calculated from AVHRR measurements in the visible and infrared bands as:

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

where \(\rho_{\text{red}}\) and \(\rho_{\text{nir}}\) are the surface reflectances in the 550~700 nm (red) and 730~1000 nm (near-infrared) regions of the electromagnetic spectrum, respectively. The red spectral response is inversely related to absorption by plant chlorophyll while the near-infrared spectral response increases as leaf canopy layers increase. NDVI is therefore sensitive to vegetation density and photosynthetic capacity.

Monthly mean temperature (1982~1998) and monthly precipitation (1982~2001) of 365 weather stations across China were obtained from the Global Historical Climatology Network GHCN V2 data in the National Climatic Data Center (NCDC). Then, the correlation coefficients between monthly NDVI in the previous winter and in spring and precipitation in summer are calculated to investigate the lagged responses of climate to vegetation ecosystems.

2 Distributions of the climatic zones

According to the different climatic characteristics in different regions of China, the study area is divided into six climatic zones (http://www.huanggao.net), shown in Fig.1.

1) Plateau climate zone: Qinghai-Tibet Plateau.
2) Subtropical zone: south of isotherm of Qinling Mountain-Huaihe River, east of Qinghai-Tibet Plateau, Taiwan.
3) Warm-temperate zone: area of the middle and lower reaches of the Yellow River, Shandong, Shanxi, Shaanxi, and Hebei Provinces.
4) Tropical zone: Hainan province, and southern Guangdong, and Yunnan Province.
5) Cold-temperate zone: north part of Heilongjiang province and Inner Mongolia.
6) Mid-temperate zone: Jilin, northern Xinjiang, and most of Heilongjiang, Liaoning, and Inner Mongolia.

Monthly precipitation (1982~2001) of 365 weather
stations across China were obtained from the Global Historical Climatology Network GHCN V2 data at the National Climatic Data Center (NCDC).

3 Results and discussion

The correlation coefficients between NDVI in the previous winter, spring and summer (precipitation and temperature) in six climatic zones of China are displayed in (Fig.2). The relations between winter NDVI and summer temperature (Fig.3 and Table 1) are positive in four climatic zones of China and negative in the subtropical zone and the tropical zone, and the lagged correlations over the mid-temperate zone are at 94% confidence level.

![Fig. 2: Correlation coefficients between NDVI in winter, spring, and summer climate (precipitation, temperature) in the six climatic zones of China](chart)

### Table 1 Correlation coefficients between winter NDVI and summer precipitation, temperature

|                     | Plateau climate zone | Subtropical zone | Warm-temperate zone | Tropical zone | Cold-temperate zone | Mid-temperate zone |
|---------------------|----------------------|------------------|---------------------|---------------|---------------------|-------------------|
| Summer precipitation| -0.377               | -0.081           | -0.127              | -0.256        | -0.266              | 0.340             |
| Summer temperature  | 0.241                | -0.397           | 0.145               | -0.200        | 0.293               | 0.459*            |

*Significant at 94% confidence level.

![Fig. 3: Interannual variations in Winter-NDVI and summer temperature in the six climatic zones in China](chart)

The NDVI in the previous winter and precipitation have more complex correlations, with negative correlation coefficients in most of the climatic zones of China, and positive correlations in the mid-temperate zone. There is a transitional zone of climate and ecosystem over the northern part of China (mid-temperate zone), and the climate can be more sensitive to vegetation changes in that region. The transitional zone is sensitive to natural variations and anthropogenic changes based on the analysis of satellite data and historical records. This is because the boundary regions of climate and ecosystems have strong gradients in climate and ecological variables and dynamic stability, and therefore are more sensitive in response to the natural and anthropogenic factors.

The relations between spring NDVI and summer temperature (Fig.4 and Table 2) are positive in most climatic zones of China. Among the six zones, the strongest correlation appears in the Plateau climate zone (significant at 99% confidence level), and the correlation coefficient in the warm-temperate zone is significant at 99% confidence level. These show that the stronger responses of summer temperature to spring NDVI occur in the two zones. The strong correlation in the Tibetan Plateau is possibly related to the...
feedback mechanism of vegetation snow-albedo because NDVI indirectly reflects the snow change in winter and spring to some extent. If the impact of snow is not considered, among the six climatic zones in China, the most sensitive response of climate occurs in arid/semi-arid region (the mid-temperate zone), and this implies that the destruction of vegetation cover in the region will lead to stronger response of climate.

The lagged correlation coefficients are a little weak over the mid-temperate zone and the cold-temperate zone and weaker over the subtropical zone and the tropical zone. There are positive correlations between spring NDVI and summer precipitation in most climatic zones of China. The strongest correlation appears in the tropical zone (significant at 95% confidence level) and the subtropical zone, and negative over the warm-temperate zone (Fig.4 and Table 2). This shows that the stronger responses of summer precipitation to spring NDVI occur in the tropical zone. Deforestation played an important role in the decreased precipitation from the 1950s to the 1980s over Southwest China[13].

### Table 2  Correlation coefficients between spring NDVI and summer precipitation, temperature

|                              | Plateau climate zone | Subtropical zone | Warm-temperate zone | Tropical zone | Cold-temperate zone | Mid-temperate zone |
|------------------------------|----------------------|------------------|---------------------|---------------|---------------------|-------------------|
| Summer precipitation         | 0.181                | 0.340            | -0.134              | 0.446*        | 0.223               | 0.248             |
| Summer temperature           | 0.703**              | 0.200            | 0.646**             | 0.293         | 0.343               | 0.311             |

* Significant at 95% confidence level, ** Significant at 99% confidence level.

The feedback effects of vegetation on climate are further proved by analyzing the lagged correlations between NDVI in the previous season and summer climate. There are positive correlations between spring NDVI and summer climate (temperature and precipitation), which suggests that, when the vegetation cover increases, the summer precipitation will increase. At the same time, the feedback effects have obvious regional character.

Fig.4  Interannual variations in spring-NDVI and summer (temperature, precipitation) in the six climatic zones in China
Any zone in which the correlation coefficient between NDVI in the previous season and climate (temperature, precipitation) is significant at 90% confidence level is defined as a sensitive zone. Therefore, there are three sensitive zones (Plateau climate zone, Warm-temperate zone and Mid-temperate zone) in China. Our study verifies further the sensitive feedback effect of vegetation cover on summer climate (temperature and precipitation) in China. However, the dynamical mechanisms responsible for the feedback of vegetation cover changes need further research\[15-16\].

4 Conclusion

The responses of climate to vegetation cover shows significant differences in different climate zones in China, which can be related to different spatial patterns for seasonal climate variation. By analyzing the relation between the vegetation cover in the six climate zones in China and the responses of summer climate (temperature, precipitation) during 1982-2001 using NDVI and climate data, we note that when NDVI in spring increases, temperature and precipitation in summer will increase in most climate zones.

The response of precipitation to NDVI is weaker than that of the temperature and there are three sensitive zones with (Plateau climate zone, Warm-temperate zone and Mid-temperate zone) the feedback effects of vegetation on climate especially temperature, which suggests more sensitive roles of vegetation changes in the summer climate in the three zones.

The NDVI cannot completely represent vegetation changes though it is a very efficacious method, so the lagged correlations between the natural variations of vegetation and climate should be further studied, and the impact of human activities on vegetation, climate and their relation should be further understood. These results are helpful for improving vegetation conditions in China and orderly converting agricultural land for forest and pasture in light of local natural conditions and realizing ecological and environmental benefits.

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