J. Geogr. Sci. 2010, 20(2): 163-176
DOI: 10.1007/s11442-010-0163-4

Temporal and spatial response of vegetation NDVI to temperature and precipitation in eastern China

CUI Linli[1], SHI Jun[2]

1. Shanghai Center for Satellite Remote Sensing and Application, Shanghai 201100, China;
2. Shanghai Climate Center, Shanghai 200030, China

Abstract: Temporal and spatial response characteristics of vegetation NDVI to the variation of temperature and precipitation in the whole year, spring, summer and autumn was analyzed from April 1998 to March 2008 based on the SPOT VGT–NDVI data and daily temperature and precipitation data from 205 meteorological stations in eastern China. The results indicate that as a whole, the response of vegetation NDVI to the variation of temperature is more pronounced than that of precipitation in eastern China. Vegetation NDVI maximally responds to the variation of temperature with a lag of about 10 days, and it maximally responds to the variation of precipitation with a lag of about 30 days. The response of vegetation NDVI to temperature and precipitation is most pronounced in autumn, and has the longest lag in summer. Spatially, the maximum response of vegetation NDVI to the variation of temperature is more pronounced in the northern and middle parts than in the southern part of eastern China. The maximum response of vegetation NDVI to the variation of precipitation is more pronounced in the northern part than in the middle and southern parts of eastern China. The response of vegetation NDVI to the variation of temperature has longer lag in the northern and southern parts than in the middle part of eastern China. The response of vegetation NDVI to the variation of precipitation has the longest lag in the southern part, and the shortest lag in the northern part of eastern China. The response of vegetation NDVI to the variation of temperature and precipitation in eastern China is mainly consistent with other results, but the lag time of vegetation NDVI to the variation of temperature and precipitation has some differences with those results of the monsoon region of eastern China.

Keywords: SPOT VGT–NDVI; temperature; precipitation; response characteristics; lag time; eastern China

1 Introduction

Vegetation is the natural link of soil, atmosphere and moisture on the earth (Chen *et al*., 1998) and acts as a sensitive indicator in the research of environment and global change (Habib *et al*., 2008). Climatic factors, land use change, the fertilization effect of CO_2, and so on could make different impacts on the terrestrial vegetation of different regions (Schimel *et*

Received: 2009-06-03 **Accepted:** 2009-07-10
Foundation: National Natural Science Foundation of China, No.40901031; Shanghai Natural Science Foundation, No.09ZR1428800; National Key Project of Scientific and Technical Supporting Programs, No.2007BAC29B05; Special Project of Research-style Operation in Shanghai Meteorological Bureau, No.YJ200803; No.YJ200805; National 863 Program, No.2006AA12Z104
Author: Cui Linli (1975–), Ph.D, specialized in remote sensing and climate change. E-mail: cllcontact@yahoo.com.cn

al., 2000; Marco *et al*., 2006). Among these factors, temperature and precipitation are the most direct and important for plant growth (Braswell *et al*., 1997; Nemani *et al*., 1999; Fang *et al*., 2004). As a sensitive parameter of surface vegetation coverage and vegetation growth status, the normalized difference vegetation index (NDVI) has been used widely in environmental, ecological and agricultural research (Fung *et al*., 2000; Nathalie *et al*., 2005; Brian *et al*., 2008). Many scholars have studied the response of vegetation NDVI to the variation of temperature and precipitation on the global and regional scales (Braswell *et al*., 1997; Ichii *et al*., 2002; Wang *et al*., 2003; Zhao *et al*., 2001; Li *et al*., 2000; Chen *et al*., 2001; Xu *et al*., 2003).

Eastern China is located in the East Asian monsoon climate zone, with diverse climate and vegetation types (Zhu, 1962; Wu, 1980). Since the reform and opening up, especially in recent 20 years, the impacts of human activity on natural vegetation have been more intense and severe than that in the western and northern parts of China. Several scholars have studied the relationship between NDVI and climatic factors in the monsoon region of eastern China during 1982–1993 (Wen *et al*., 2000; Fu *et al*., 2002), but few study has discussed the correlation between vegetation NDVI and temperature and precipitation in recent 10 years. Furthermore, compared with NOAA/AVHRR sensor, SPOT-4 VEGETATION sensor has many advantages, such as more sensitive to chlorophyll absorption in its red band, the elimination of strong water vapor absorption in its near infrared band, higher spatial resolution, and so on, so the SPOT-4 VEGETATION NDVI is more suitable for studying and monitoring the vegetation dynamics (Xia *et al*., 2008; Yan *et al*., 2008). Therefore, the spatial and temporal response characteristics of vegetation NDVI to the variation of temperature and precipitation in eastern China were analyzed based on the SPOT-4 VEGETATION NDVI dataset in this study.

2 Data and methods

2.1 Data

In this study, eastern China is defined as the areas to the east of longitude 111.2˚E, and to the south of latitude 40.2˚N, including most of the eastern mainland China, mainly Shanxi, Hebei, Tianjin, the southern part of Liaoning, Shandong, Jiangsu, Anhui, Henan, Hubei, Hunan, Jiangxi, Zhejiang, Fujian, Guangdong provinces and Shanghai Manicipality. Data used in this study are as follows: (1) ten-day composited (maximum-value) SPOT VGT-DN data from April 1998 to March 2008, with 1 km × 1 km spatial resolution and stretched value ranged from 0 to 255, which were downloaded from the internet database (http://free.vgt.vito.be/home.php) and the atmospheric, radiometric and geometric correction had been done; and (2) daily mean temperature and daily precipitation data in 205 typical meteorological stations of eastern China from January 1998 to March 2008, which were obtained from Climatic Data Center, National Meteorological Information Center, China Meteorological Administration.

2.2 Method

2.2.1 Spatial and temporal series of temperature, precipitation and NDVI

For the daily mean temperature and daily precipitation data from 205 meteorological stations, the average and addition per 10 days were done respectively to obtain the ten-day mean temperature and precipitation data for each station from January 1998 to March 2008. Kriging method was used to interpolate the ten-day mean temperature and precipitation grid from 205 stations with 1 km × 1 km spatial resolution in ArcGIS. True NDVI was restored with the formula NDVI=DN*0.004–0.1 in ArcGIS and the NDVI series with 1 km × 1 km spatial resolution were obtained from April 1998 to March 2008. The ten-day time series of temperature, precipitation and NDVI were also obtained in ArcGIS with eastern China as a whole.

2.2.2 The temporal response of vegetation NDVI to temperature and precipitation

Considering the lag response of NDVI to temperature and precipitation (Braswell *et al.*, 1997; Wen *et al.*, 2000; Wang *et al.*, 2003), the NDVI-temperature and NDVI-precipitation correlation analysis were carried out between each ten-day NDVI and the temperature and precipitation of previous 0–9 ten-days (previous 0–90 days) for the whole year(from December to November), spring (from March to May), summer (from June to August) and autumn (from September to November) respectively. For example, in order to analyze the response of spring NDVI to the variation of previous temperature, the annual NDVI data from the 7th to the 15th ten-day were selected and formed a NDVI time serial data (including 90 numbers of NDVI values), accordingly, the temperature from the 7^{th} to the 15^{th} ten-day, the 6^{th} to the 14th ten-day, ……, the 35th to the 7th ten-day, and the 34th to the 6th ten-day were annually selected and formed 10 numbers of temperature time serial data, each including 90 numbers of temperature values, and the time serial correlation between NDVI and temperature of previous 0-9 ten-days was analyzed respectively. The response of NDVI to previous temperature in the whole year was analyzed based on the NDVI data of 360 ten-days from April 1998 to March 2008 and temperate data of 369 ten-day from January 1998 to March 2008 in eastern China. In the northern part of eastern China, vegetation is deciduous in most places, so the response of NDVI to temperate and precipitation in winter was not analyzed specially.

2.2.3 The spatial response of vegetation NDVI to temperature and precipitation

Based on the location of 205 meteorological stations in eastern China, the average ten-day NDVI of each station and its surrounding 3 km × 3 km areas was calculated to form the time series ten-day NDVI of each station in ArcGIS from April 1998 to March 2008. With the above-mentioned method, the NDVI-temperature and NDVI-precipitation correlation coefficients of each station between ten-day NDVI and temperature and precipitation of previous 0–9 ten-days were calculated for the whole year, spring, summer and autumn respectively. The maximum correlation coefficients of NDVI-temperature and NDVI-precipitation were selected respectively and the spatial distribution of maximum correlation coefficient and its corresponding lag time were displayed with ArcGIS, and the regional difference of vegetation NDVI response to temperature and precipitation was analyzed.

3 Results and discussions

3.1 Temporal response characteristics of NDVI to temperature and precipitation

In the whole eastern China, vegetation NDVI had higher correlation with temperature of previous 0–20 days, and had higher correlation with precipitation of previous 20–40 days (Figure 1a). Vegetation NDVI had the highest correlation with temperature of previous 10 days, and had the highest correlation with precipitation of previous 30 days, with the correlation coefficient of 0.85 and 0.70 respectively. That is to say, the maximum response of vegetation NDVI to the variation of temperature on the whole had a lag of about 10 days, and the maximum response of vegetation NDVI to the variation of precipitation had a lag of about 30 days in eastern China.

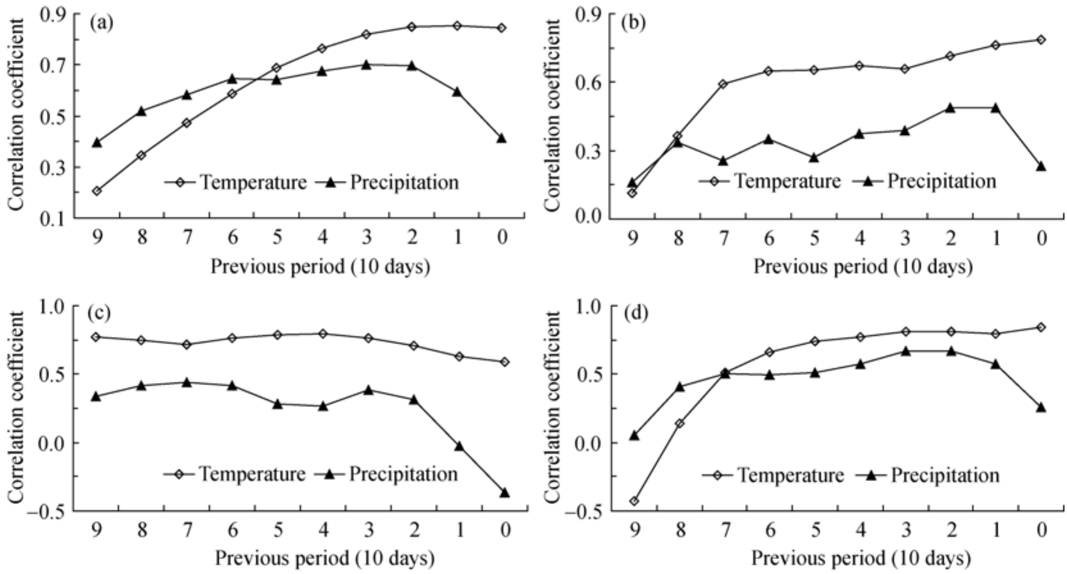

Figure 1 Correlation coefficient between NDVI and temperature and precipitation (a. the whole year; b. spring; c. summer; d. autumn)

The correlation coefficient between NDVI and previous temperature decreased gradually with the increase of previous days (Figure 1a). The correlation coefficient between NDVI and precipitation of previous 0–30 days increased gradually with the increase of previous days, but the correlation coefficient between NDVI and precipitation of previous 30–90 days decreased gradually with the increase of previous days. Vegetation NDVI had higher correlation with temperature of previous 0–50 days than that with precipitation of the corresponding periods, but the correlation between NDVI and temperature of previous 60–90 days was lower than that between NDVI and precipitation of the corresponding periods, i.e. for the whole eastern China, the response of NDVI to temperature was more pronounced but temporary than that of precipitation.

In eastern China, the NDVI-temperature and NDVI-precipitation correlation were the highest in autumn. In spring, summer and autumn, the response of vegetation NDVI to temperature was more pronounced than to precipitation (Figure 1). In spring and autumn, vegetation NDVI had the highest correlation with temperature of the same time and with precipitation of previous 20 days (Figures 1b and 1d). The NDVI-temperature and NDVI-precipitation correlation coefficient decreased quickly with the increase of previous days, i.e. vegetation NDVI responded to temperature and precipitation with shorter lag in spring and autumn. In summer, the correlation between NDVI and temperature of the previous 40 days was the highest, and the correlation between NDVI and precipitation of the previous 20–90 days was higher (Figure 1c), namely, the lag time of NDVI response to temperature and precipitation was longer.

For eastern China, the response of vegetation NDVI to temperature was more pronounced than to precipitation, which was consistent with other results. For example, Chen *et al*. (2001) studied the driving effects of temperature and precipitation on the variation of NDVI across China and the results indicated in the humid plain of eastern China coastal area, the main driving factor for the variation of surface NDVI was temperature. Zhao *et al*. (2001) studied the relationship between different ecosystems and climate in China, and suggested that at an averaged year, temperature had more pronounced force to vegetation than precipitation. Liu *et al*. (2007) analyzed the relation of vegetation index and its driving factors in Hainan Island and the results indicated that the variation of temperature dominated the vegetation variation, and the changes of vegetation index was more highly affected by monthly mean temperature than monthly precipitation.

3.2 Spatial characteristics of maximum NDVI response to temperature and precipitation

3.2.1 Spatial distribution of maximum NDVI response to temperature

In the northern and middle parts of eastern China, the maximum response of vegetation NDVI to the variation of temperature was more pronounced than that in the southern part as a whole (Figure 2a). In Zhejiang, Jiangxi, Hunan and the areas to the north of these provinces, the maximum correlation coefficient between NDVI and temperature was more than 0.7 in most stations, but in Guangdong and Fujian, the maximum correlation coefficient was less than 0.7 basically. In some stations in the southern part of Liaoning, the eastern part of Shanxi, the southern part of Hebei, the middle and eastern parts of Shandong, the southwestern part of Anhui, the eastern part of Hubei, Jiangxi and Zhejiang, the maximum correlation coefficient was more than 0.8, but in some stations in Henan, Hubei, the northern part of Anhui and Jiangsu, the maximum correlation coefficient was less than 0.6.

The maximum correlation coefficient between vegetation NDVI and temperature was more in spring and autumn than that in summer as a whole. In spring, the spatial distribution of maximum correlation coefficient between NDVI and temperature was basically consistent with that in the whole year. In the northern part of eastern China, including Shanxi, Hebei, Shandong, the northern part of Henan and Jiangsu, and the southern part of Liaoning, the maximum correlation coefficient was more than 0.7 in most stations (Figure 2b). In the southern part of eastern China, including Guangdong and Fujian, the maximum correlation coefficient was basically less than 0.6. In some stations of Henan, Hubei, Anhui, Jiangsu, and Fujian, the correlation coefficient between NDVI and temperature was very little or was negative. In summer, the maximum correlation coefficient between vegetation NDVI and temperature had obvious difference in the northern and southern parts of eastern China. To the north of latitude 30°N, the maximum correlation coefficient was basically more than 0.5, but to the south of latitude 30°N, the maximum correlation coefficient was basically less than 0.5 (Figure 2c). In autumn, the maximum correlation coefficient between vegetation NDVI and temperature was basically more than 0.6 in Shanxi, Hebei, the southern part of Liaoning, Shandong, Anhui, Jiangsu and Jiangxi, but in other regions, the maximum cor-

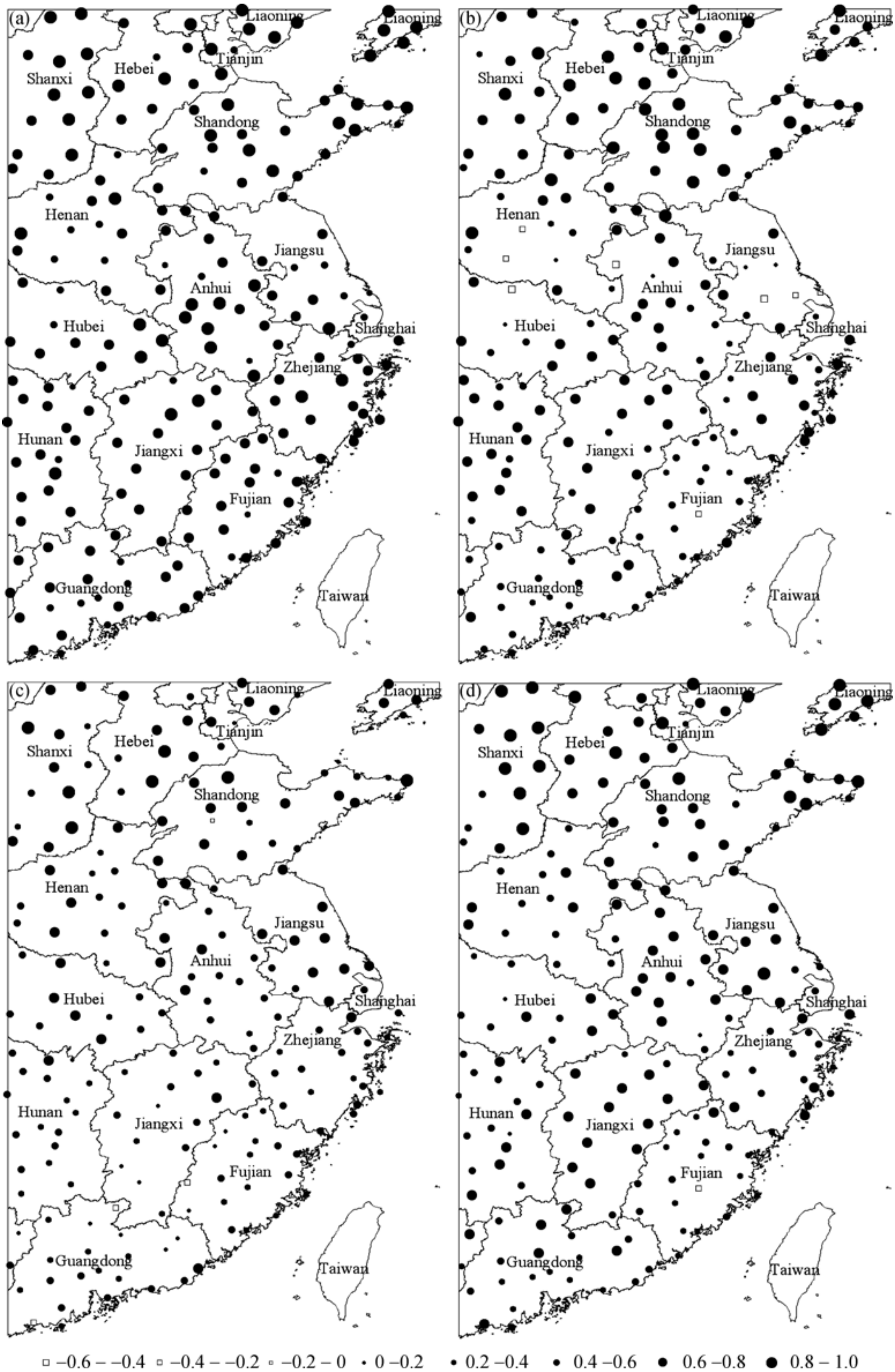

Figure 2 Spatial distribution of maximum correlation coefficient between NDVI and temperature (a. the whole year; b. spring; c. summer; d. autumn)

relation coefficient was more than 0.4 in most stations (Figure 2d).

3.2.2 Spatial distribution of maximum NDVI response to precipitation

Spatially, the maximum response of vegetation NDVI to precipitation in the northern part was more pronounced than that in the middle and southern parts of eastern China, and the difference of maximum response between the middle and southern parts was not obvious (Figure 3a). In the northern part of eastern China, including Shanxi, Hebei, Tianjin, Shandong and the southern part of Liaoning, the maximum correlation coefficient between NDVI and precipitation was basically about 0.5, but in the middle and southern parts of eastern China, the maximum correlation coefficient was mostly 0.2–0.4. Besides Baoding station in Hebei province, the maximum correlation coefficient between NDVI and precipitation in eastern China was less than that between NDVI and temperature. The maximum correlation coefficient between NDVI and precipitation was less than 0.6 except for very few stations. In Weixian station of Hebei province, the correlation between NDVI and precipitation was the highest.

In spring and autumn, the maximum correlation coefficient between NDVI and precipitation was basically positive, i.e. previous precipitation could help plant growth as a whole. In spring, the maximum correlation coefficient between NDVI and precipitation was about 0.3 in most regions of eastern China; moreover, the maximum correlation coefficient in the northern part was slightly more than that in the middle and southern parts of eastern China (Figure 3b). In the Yangtze River Delta, the maximum correlation coefficient was less than 0.2 in spring. In summer, the maximum correlation coefficient between NDVI and precipitation was positive to the north of latitude 31˚N, and negative to the south of latitude 31˚N (Figure 3c). The maximum correlation coefficient between NDVI and precipitation in the northern part was mostly about 0.4, and in the southern part of eastern China was mostly about –0.3. In some stations in the northern part of Jiangxi, the southwestern part of Zhejiang, Hunan, Fujian and Guangdong, the maximum correlation coefficient was less than –0.4 in summer. In autumn, the maximum correlation coefficient between NDVI and precipitation in the northern part of eastern China, mainly to the north of Jiangsu, Anhui and Henan, and in the southern part of eastern China, mainly in Guangdong, was more than 0.3 mostly, but in other regions, the maximum correlation coefficient was mostly less than 0.3 (Figure 3d). In several stations in Hubei, the northern part of Hunan, Jiangxi and Fujian, vegetation NDVI was negatively correlated with precipitation in autumn.

In eastern China, the maximum response of vegetation NDVI to temperature and precipitation decreased with the decrease of latitude, this is basically consistent with other results in China. For example, Li *et al*. (2000) shown that from the southeastern to the northwestern part of China, the correlation coefficient between NDVI and climatic conditions increased gradually. Lin *et al*. (2007) studied the temporal and spatial variation of MODIS vegetation indices in Hunan province and found the seasonal variation of vegetation indices were more influenced by temperature, moreover, the impact of temperature on vegetation indices decreased with the decrease of latitude. In eastern China, especially in its middle and southern parts, the response of vegetation NDVI on precipitation was less pronounced, relatively rich precipitation in these regions may be the main reason. Xu *et al*. (2003) concluded that with very sufficient precipitation, the precipitation could satisfy the need of plant growth, so the impact of precipitation on plant growth would weaken, and temperature would be the main

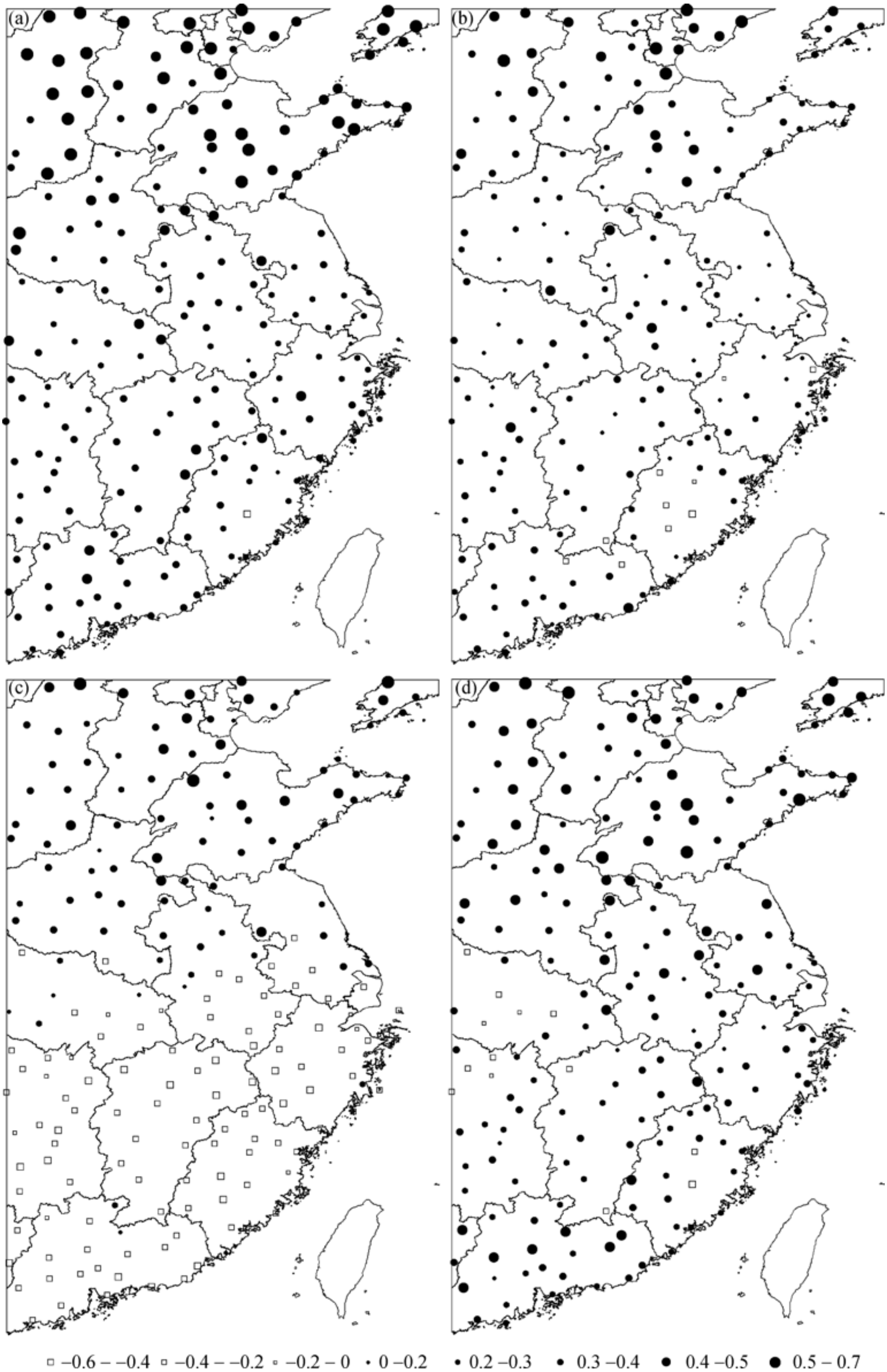

Figure 3 Spatial distribution of maximum correlation coefficient between NDVI and precipitation (a. the whole year; b. spring; c. summer; d. autumn)

factor influencing vegetation growth. Different regions have different climate, vegetation types, soil texture and so on, so the spatial distribution of NDVI-temperature and NDVI-precipitation correlation was uneven (Zhao *et al.*, 2001; Xu *et al.*, 2003).

In spring and autumn, the correlation between vegetation NDVI and temperature was basically positive, indicating that temperature is still a limiting factor for vegetation growth in eastern China. The correlation between NDVI and temperature was lower in the southern part of Henan, the northern part of Hubei and Anhui, and the middle and southern parts of Jiangsu. This probably has relationship with the growth laws of local crops. In May and June, the winter wheat in these regions is mature and harvested, and the NDVI begins to decrease (Xu *et al.*, 2003), so the impact of temperature on vegetation NDVI in the late spring and early summer is little, even in some places, the correlation between NDVI and temperature is negative. To certain extent, this also results in the lower correlation between NDVI and temperature in the whole year in these areas. In summer, the correlation between NDVI and temperature was higher in the northern part than that in the southern part of eastern China, which indicates that in the southern part, the impact of temperature on vegetation is less than that in the northern part. The maximum correlation coefficient between NDVI and precipitation was positive to the north of latitude 31˚N, and negative to the south of latitude 31˚N in summer (Figure 3c). The rich precipitation in the southern part of eastern China may be the probable reason. In summer, precipitation in the southern part is generally relative enough for plant growth, so excessive precipitation means the increase of cloud cover and the decrease of incident radiation, moreover, the increase of soil moisture may result in the increase of surface latent heat of evaporation and the decrease of temperature and the photosynthesis of plant, all these are unfavorable to plant growth (Zhao *et al.*, 2001).

3.3 Spatial characteristics of lag time for NDVI response to temperature and precipitation

3.3.1 Spatial distribution of lag time for maximum NDVI response to temperature

In eastern China, the lag time corresponding to vegetation NDVI maximum response to temperature was the longest in the southern part and the shortest in the middle part of eastern China (Figure 4a). In the northern part of eastern China, including Shanxi, Hebei, Tianjin, most places of Shandong, and the southern part of Liaoning, the maximum response of vegetation NDVI to temperature had a lag ranging from 10 to 40 days in most stations. In the middle part of eastern China, including Henan, the southwestern part of Shandong, Anhui, Jiangsu, Shanghai, Zhejiang, the northern part of Jiangxi, Hubei and Hunan, vegetation NDVI had the highest correlation with temperature of the same time, i.e. the response of vegetation NDVI to the variation of temperature was synchronous. In the southern part of eastern China, including Guangdong, Fujian and the southern part of Jiangxi, the maximum response of vegetation NDVI to temperature had a lag ranging from 20 to 60 days in most stations, especially in the middle and southern parts of Guangdong, the maximum response of vegetation NDVI to temperature had a lag ranging from 50 to 60 days.

In spring, the maximum response of vegetation NDVI to temperature was rapid, with a lag ranging from 0 to 20 days in most stations (Figure 4b). In the northern part of eastern China, including Shanxi, Hebei, the southern part of Liaoning, Shandong, the northeastern

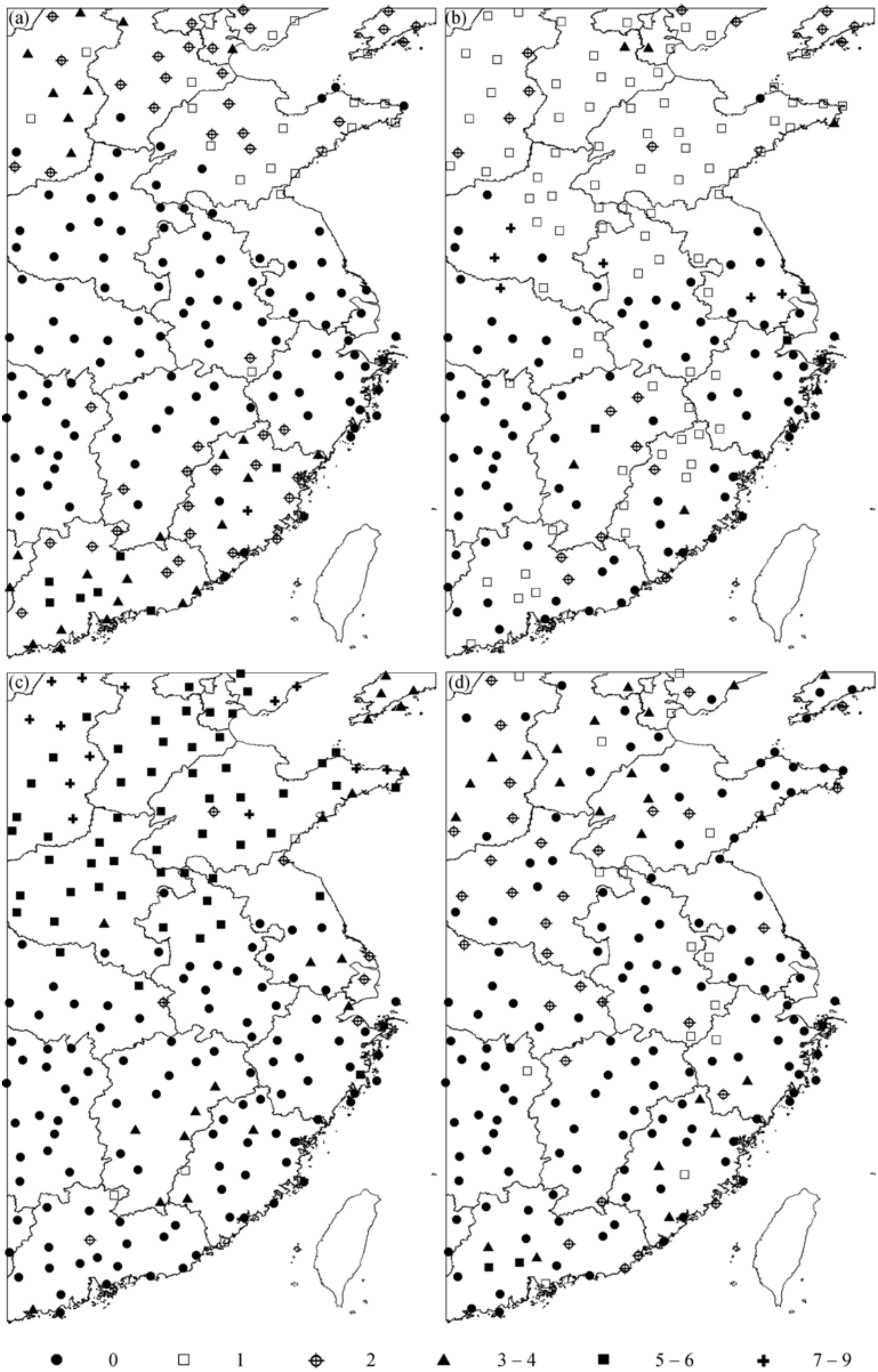

Figure 4 Spatial distribution of lag time for maximum NDVI response to temperature (units: 10 days; a. the whole year; b. spring; c. summer; d. autumn)

part of Henan, the northern part of Anhui and Jiangsu, the maximum response of vegetation NDVI to temperature had a lag ranging from 10 to 20 days in most stations. In the southern part of eastern China, the maximum response of vegetation NDVI to temperature also had a lag ranging from 10 to 20 days in the eastern part of Jiangxi, the western part of Fujian and some places of Guangdong, but in other places of the southern part of eastern China, vegetation NDVI responded to the temperature synchronously in most stations. In summer, the maximum response of vegetation NDVI to temperature had a lag ranging from 50 to 60 days to the north of latitude 32˚N, but to the south of latitude 32˚N, vegetation NDVI responded to temperature synchronously in most stations (Figure 4c). In autumn, the maximum response of vegetation NDVI to temperature had a lag ranging from 0 to 40 days mostly, and stations with vegetation NDVI synchronously responding to temperature were the most, but the spatial distribution had no obvious difference (Figure 4d).

3.3.2 Spatial distribution of lag time for maximum NDVI response to precipitation

The lag time corresponding to maximum NDVI response to precipitation in eastern China increased gradually from the northern to the southern part, i.e. the lag time was the longest in the southern part (Figure 5a). In the northern part of eastern China, including Shanxi, Hebei, Tianjin, the southern part of Liaoning, Shandong, the northern part of Jiangsu and Anhui, Henan and the middle and western parts of Hubei, the maximum response of vegetation NDVI to precipitation had a lag basically ranging from 10 to 20 days, of which the lag time in Shanxi, Shandong and the northern part of Henan was mostly 10 days, and in the southern part of Hebei and Henan was mostly 20 days. In the southern part of eastern China, the maximum response of vegetation NDVI to precipitation had a lag mostly ranging from 20 to 60 days. In the eastern and southern parts of Jiangxi, the western part of Fujian and the middle and northeastern parts of Guangdong, the maximum response of vegetation NDVI to precipitation had a lag ranging from 70 to 90 days in most stations.

In spring, vegetation NDVI maximally responded to precipitation with a lag ranging from 0 to 20 days in the most of eastern China. In Hebei and Shandong, spring NDVI maximally responded to precipitation synchronously (Figure 5b). In summer, the maximum response of vegetation NDVI to precipitation had a lag ranging from10 to 40 days to the north of latitude 31˚N, but to the south of latitude 31˚N, vegetation NDVI negatively responded to precipitation synchronously, i.e. within 10 days more precipitation could restrain vegetation growth in the southern part (Figure 5c). In autumn, vegetation NDVI mostly responded to precipitation with a lag ranging from 10 to 20 days in Shanxi, the western and southern parts of Hebei, the middle and southern parts of Shandong, the northern part of Jiangsu, the eastern and northern parts of Anhui and the northern and middle parts of Henan, but in the southern part of Liaoning, Tianjin, the eastern part of Hebei and the northern part of Shandong, the maximum response of vegetation NDVI to precipitation mostly had a lag ranging from 30 to 60 days. In the southern part of eastern China, the maximum response of vegetation NDVI to precipitation had a lag ranging from 30 to 40 days in most stations (Figure 5d). In the southern part of Jiangsu, Shanghai, and the eastern part of Zhejiang, vegetation NDVI responded to precipitation with a lag of about 20 days.

Wang *et al*. (2003) studied the temporal response of NDVI to precipitation and temperature in the Central Great Plains, USA and the results indicated that vegetation NDVI was

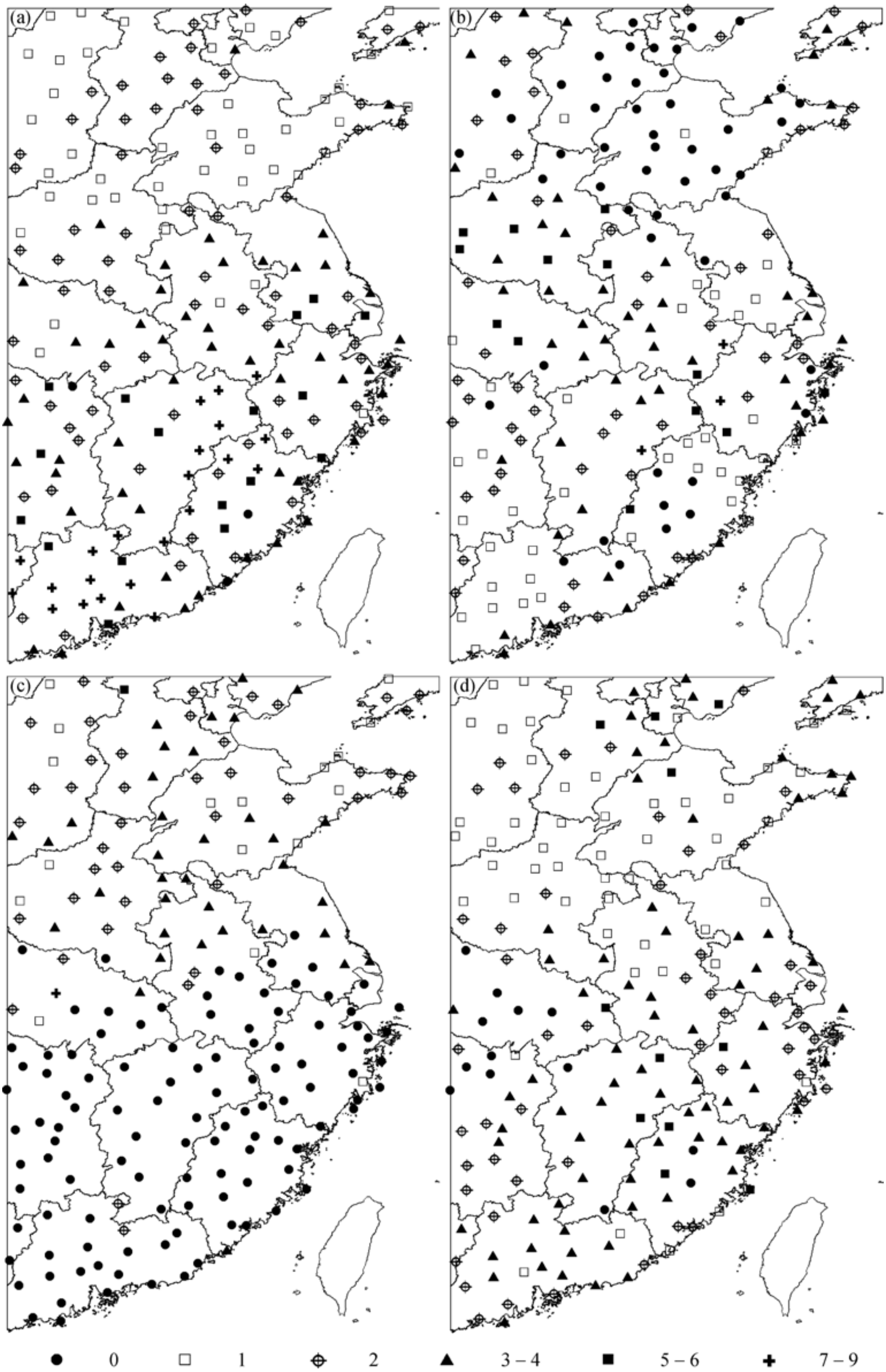

Figure 5 Spatial distribution of lag time for maximum NDVI response to precipitation (units: 10 days; a. the whole year; b. spring; c. summer; d. autumn)

significantly influenced by temperature of the concurrent and previous one month. In the northern part of eastern China, the maximum response of vegetation NDVI to temperature was longer in summer, with a lag ranging from 50 to 60 days. The possible reason may be in summer, temperature is no longer the main limiting factor for vegetation growth, and vegetation growth limits are imposed by other factors such as soil moisture or nutrient availability rather than temperature, so the response of vegetation to temperature is slower. Chen *et al*. (2007) studied the vegetation coverage and its relationships with temperature and precipitation in Ningxia and found the higher temperature in the late winter and the early spring, the higher vegetation coverage in summer in Qinghai lake area.

Based on the NDVI data and temperature and precipitation data from 152 meteorological stations, Wen *et al*. (2000) analyzed the large scale features of seasonal phenological responses to the monsoon climate in eastern China, and the results indicated that in multi-year average, the seasonal phenology kept significant synchronous correlation with temperature variation in all phases including the whole year, growing season, the increasing and declining parts of growing season, and in most phases, the seasonal phenology and the precipitation variation had their significant correlation with the time lag from 20 to 30 days. This has some difference with our results. The difference in studied temporal and spatial scale, the change of vegetation types, and so on may result in the difference of vegetation VDVI response to temperature and precipitation.

4 Conclusions

The temporal and spatial response of ten-day SPOT VGT-DNVI to temperature and precipitation of previous 0–9 ten-days was analyzed from April 1998 to March 2008 in this study and the main results were as follows:

(1) The response of vegetation NDVI to the variation of temperature was as a whole more pronounced than that of precipitation in eastern China. The maximum response of NDVI to temperature had a lag of about 10 days, and the maximum response of NDVI to precipitation had a lag of about 30 days. In autumn, the response of NDVI to temperature and precipitation was the most pronounced, and in summer, NDVI responded to temperature and precipitation with longer lag. The response characteristics of NDVI to temperature and precipitation in eastern China were basically consistent with other results.

(2) Spatially, the maximum response of vegetation NDVI to temperature in the northern and middle parts was more pronounced than that in the southern part, and the maximum response of NDVI to precipitation in the northern part was more pronounced than that in the middle and southern parts of eastern China. The response of NDVI to temperature in spring and autumn was more pronounced than that in summer, and the response of NDVI to precipitation in spring and autumn was positive in most stations. In summer, the response of NDVI to precipitation was positive to the north of latitude 31˚N and negative to the south of latitude 31˚N.

(3) The maximum response of vegetation NDVI to temperature had the longest lag in the southern part and the shortest lag in the middle part of eastern China spatially. The lag time of maximum NDVI response to precipitation increased with the decrease of latitude. The maximum response of NDVI to temperature had longer lag in spring than that in autumn as a whole. In summer, NDVI synchronously responded to temperature to the south of latitude 32˚N in most regions, and synchronously responded to precipitation to the south of latitude 31˚N basically. The temporal and spatial difference of study scale, the change of vegetation types, and so on, could result in the difference between our and other results.

References

Braswell B H, Schimel D S, Linder E *et al*., 1997. The response of global terrestrial ecosystems to interannual temperature variability. *Science*, 278: 870–873.

Brian D. Wardlow, Stephen L. Egbert, 2008. Large-area crop mapping using time-series MODIS 250m NDVI data: An assessment for the U.S. Central Great Plains. *Remote Sensing of Environment*, 112(3): 1096–1116.

Chen Shupeng, Tong Qingxi, Guo Huadong, 1998. Research on mechanism of remote sensing information. Beijing: Science Press. (in Chinese)

Chen Xiaoguang, Li Jianping, Li Zhijun *et al*., 2007. Vegetation coverage and its relation with climate change in Qinghai Lake area. *Journal of Desert Research*, 27(5): 797–804. (in Chinese)

Chen Yunhao, Li Xiaobing, Shi Peijun, 2001. Variation in NDVI driven by climate factors across China, 1983–1992. *Acta Phytoecologica Sinica*, 25(6): 716–720. (in Chinese)

Fang Jingyun, Piao Shilong, He Jinsheng *et al*., 2004. Increasing terrestrial vegetation activity in China, 1982–1999. *Science in China* (Series C), 47: 229–240.

Fu Congbin, Wen Gang, Xie Li *et al*., 2002. The diagnosis and simulation studies on climate and ecosystem interactions in East Asia monsoon region. *Journal of Nanjing University* (Natural Sciences), 38(3): 281–294. (in Chinese)

Fung T, Siu W, 2000. Environmental quality and its changes, an analysis using NDVI. *International Journal of Remote Sensing*, 21(5): 1011–1024.

Habib Aziz Salim, Chen Xiaoling, Gong Jianya, 2008. Analysis of Sudan vegetation dynamics using NOAA–AVHRR NDVI data from 1982–1993. *Asian Journal of Earth Sciences*, 1(1): 1–15.

Ichii K, Kawabata A, Yamaguchi Y, 2002. Global correlation analysis for NDVI and climatic variables and NDVI trends: 1982–1990. *International Journal of Remote Sensing*, 23: 3873–3878.

Li Xiaobing, Shi Peijun, 2000. Sensitivity analysis of variation in NDVI, temperature and precipitation in typical vegetation types across China. *Journal of Plant Ecology*, 24(3): 379–382. (in Chinese)

Lin Hui, Xiong Yujiu, Wan Lingfeng *et al*., 2007. Temporal and spatial variation of MODIS vegetation indices in Hunan province. *Chinese Journal of Applied Ecology*, 18(3): 581–585. (in Chinese)

Liu Shaojun, Huang Yanbin, Li Tianfu *et al*., 2007. Study on driver factors of vegetation index based on MODIS in Hainan Island. *Yunnan Geographic Environment Research*, 19(1): 56–59. (in Chinese)

Marco Albani, David Medvigy, George C Hurtt *et al*., 2006. The contributions of land-use change, CO_2 fertilization, and climate variability to the Eastern US carbon sink. *Global Change Biology*, 12(12): 2370–2390.

Nathalie Pettorelli, Jon Olav Vik, Atle Mysterud *et al*., 2005. Using the satellite-derived NDVI to assess ecological responses to environmental change. *Trends in Ecology & Evolution*, 20(9): 503–510.

Nemani R, Keeling C, Hashimoto H *et al*., 2003. Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, 300: 1560–1563.

Schimel D, Melillo J, Tian H *et al*., 2000. Contribution of increasing CO_2 and climate to carbon storage by ecosystems of the United States. *Science*, 287: 2004–2006.

Wang J, Rich P M, Price K P, 2003. Temporal response of NDVI to precipitation and temperature in the Central Great Plains, USA. *International Journal of Remote Sensing*, 24: 2345–2364.

Wang Ling, Liu Hailong, 2007. Impacts of climate change on vegetation in Chongqing karst region. *Journal of Meteorology and Environment*, 23(1): 6–11. (in Chinese)

Wen Gang, Fu Congbin, 2000. The large scale features of the seasonal phenological response to the monsoon climate in East China: Multi-year average results. *Chinese Journal of Atmospheric Sciences*, 24(5): 676–682. (in Chinese)

Wu Zhengyi, 1980. The Vegetation of China. Beijing: Science Press. (in Chinese)

Xia Lu, Liu Yongmei, Ke Changqing, 2008. Study on the dynamic changes of vegetation in the Loess Plateau based on data from SPOT4. *Remote Sensing Technology and Application*, 23(1): 67–71. (in Chinese)

Xu Xingkui, Lin Zhaohui, Xue Feng *et al*., 2003. Correlation analysis between meteorological factors and the ratio of vegetation cover. *Acta Ecologica Sinica*, 23(2): 221–230. (in Chinese)

Yan Xiaoyu, Dong Wenjie, He Yong, 2008. Analysis of the suitability from different remote sensing data on the monitoring of vegetation change in Ruoergai marsh. *Remote Sensing Technology and Application*, 23(3): 300–304. (in Chinese)

Zhao Maosheng, Fu Congbin, Yan Xiaodong *et al*., 2001. Study on the relationship between different ecosystems and climate in China using NOAA/AVHRR data. *Acta Geographica Sinica*, 56(3): 287–296. (in Chinese)

Zhu Binghai, 1962. The Climate of China. Beijing: Science Press. (in Chinese)