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Variation in vegetation greenness in spring across eastern China during 1982–2006

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Abstract: Vegetation greenness is a key indicator of terrestrial vegetation activity. To understand the variation in vegetation activity in spring across eastern China (EC), we analysed the variation in the Normalised Difference Vegetation Index (NDVI) from April to May during 1982–2006. The regional mean NDVI across EC increased at the rate of 0.02/10yr (r^2=0.28; p=0.024) prior to 1998; the increase ceased, and the NDVI dropped to a low level thereafter. However, the processes of variation in the NDVI were different from one region to another. In the North China Plain, a cultivated area, the NDVI increased (0.03/10yr; r^2=0.52; p<0.001) from 1982 to 2006. In contrast, the NDVI decreased (–0.02/10yr; r^2=0.24; p=0.014) consecutively from 1982 to 2006 in the Yangtze River and Pearl River deltas, two regions of rapid urbanisation. In the eastern region of the Inner Mongolian Plateau and the lower reaches of the Yangtze River in East China, the NDVI increased prior to 1998 and decreased thereafter. In the Hulun Buir area and the southern part of the Yangtze River Basin, the NDVI increased prior to 1998 and remained static thereafter. The NDVI in the grasslands and croplands in the semi-humid and semi-arid areas showed a significant positive correlation with precipitation, while the NDVI in the woodlands in the humid to semi-humid areas showed a significant positive correlation with temperature. As much as 60% of the variation in the NDVI was explained by either precipitation or temperature.

Keywords: eastern China; spring; vegetation activities; NDVI; spatial heterogeneity

1 Introduction

Terrestrial vegetation is an active component of the Earth system. It is not only sensitive to climate change (e.g., Fischlin *et al.*, 2007) but also regulates climate change through feedback via both geophysical mechanisms and biogeochemical mechanisms (e.g., Foley *et al.*, 2000; Denman *et al.*, 2007; Mahmood *et al.*, 2010). Therefore, knowledge concerning the variation in vegetation activity is valuable for understanding the interactions between vegetation and the atmosphere. In the studies examining large-scale variations in vegetation activity, the satellite-based Normalised Difference Vegetation Index (NDVI) has been widely

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used because of the NDVI’s clear physical implications and simple retrieval method. As a vegetation greenness index, the NDVI has shown significant correlation with indicators of vegetation activity, such as the leaf area index (LAI) (e.g., Baret and Guyot, 1991), the fraction of vegetation coverage (FVC) (e.g., Gutman and Ignatov, 1998) and photosynthetically absorbed active radiation (APAR) (e.g., Sellers, 1985; Myneni *et al.*, 1995). Generally, a higher NDVI indicates a greater LAI, a larger FVC, a greater APAR, and therefore, stronger vegetation activity.

Myneny *et al.* (1997) and Tucker *et al.* (2001) analysed the NDVI from 1981 to 1991 and from 1981 to 1999, respectively. Both of these studies reported that the vegetation activity across the Northern Hemisphere increased over time, with the greatest rates occurring in the mid-latitudes, and attributed the ascending trends primarily into climate warming. However, more recent studies indicated that the ascending trend in vegetation activity ceased after 2000 and was even replaced by a descending trend in some regions of the Northern Hemisphere. For instance, Park and Sohn (2010) found that vegetation activity during the growing season (April–October) exhibited an ascending trend prior to the mid-1990s but declined significantly thereafter in Northeast Asia. Similar temporal trends were also detected for the temperate and boreal regions of Eurasia (e.g., Piao *et al.*, 2011). Wang *et al.* (2011) reported that the spring vegetation activity of the northeast region of North America had increased until the early 1990s and declined thereafter, while such a change in the direction of the trend could not be detected in the northwest region of North America. These findings implied that the direction of the changes in vegetation activity might shift and suggested that variation in vegetation activity had a large spatial heterogeneity at the continent-to-hemisphere scale.

For eastern China (EC), a number of studies of the NDVI have reported that the vegetation activities have been mostly characterised by an ascending trend in the last two decades of the 20th century, and the fastest increase has occurred in spring. For instance, the NDVI increased significantly during 1982–1999. Moreover, the rates of increase were greater in spring and summer than in autumn and winter, and the increases were greater in cultivated areas than in other areas. Piao and Fang (2003) suggested that the dominant response of vegetation activity to climate change was the earlier beginning of growth in spring. Furthermore, the spring NDVI increased at the greatest rate when compared with the other seasons in EC. Chen *et al.* (2006) reported that the NDVI increased in spring, while it decreased in summer across the Huang-Huai-Hai Plain during 1982–2003. Zhang *et al.* (2011) found that the NDVI in the Hulun Buir Glassland increased in spring, summer, and autumn, and the greatest increasing rate occurred in spring, especially in April and May. However, it was also reported that the vegetation activity oscillated instead of continuously increasing since 1982. For instance, Xin *et al.* (2008) reported that variations in the NDVI over the Loess Plateau were characterised by an increasing trend from 1981 to 1990, no trend from 1990 to 1998, a sharp decrease from 1999 to 2001 and another increase from 2002 to 2006. Peng *et al*. (2011) detected a turning point in the mid-1990s. Before the turning point, increases in the NDVI prevailed, whereas decreases in the NDVI were dominant for most of EC after the turning point.

The existing studies have demonstrated that the spring generally had the most distinct variations in the NDVI, and the direction of the variation changed from an ascending trend to a descending trend across EC. This study aims to clarify the temporal variation in the NDVI among regions and the correlation between the variation in the NDVI and climatic changes among regions. It is expected to elucidate the variation in vegetation activity from 1982 to 2006 across EC.

2 Data and methods

2.1 Datasets

The NDVI dataset used in this study was obtained from the Global Inventory Monitoring and Modeling Studies (GIMMS) group. It was derived from the NOAA/AVHRR Land dataset (available at http://www.landcover.org/data/gimms/) at a spatial resolution of 8 km by 8 km and a 15-day temporal interval for the period from January 1982 to December 2006 (Tucker *et al.*, 2001; Zhou *et al.*, 2001). To minimise the non-vegetation effects on the data, such as those of cloud and smoke contamination, and to view the geometric effects, these data are available as maximum NDVI values for each 64-km^2 pixel from each 15-day composite period. These data are available globally and have been calibrated to correct for orbital drift and sensor degradation from a time series of five satellites (1982–1985, NOAA-7; 1986–1988, NOAA-9; 1989–1993, NOAA-11; 1995–2000, NOAA-14; 2001–2003, NOAA-16; 2004–2006, NOAA-17). The data were also processed to correct for the atmospheric effects resulting from two major volcanic eruptions, El Chichon in 1982 and Mount Pinatubo in 1991 (Tucker *et al.*, 2005). Fang *et al.* (2004) and Piao *et al.* (2011) reported that the GIMMS NDVI data are of sufficient quality to be used to study the vegetation dynamics of China. Zhou *et al.* (2003), Piao *et al.* (2011) and Wang *et al.* (2011) used the GIMMS NDVI dataset to investigate the responses of vegetation to climate change.

The monthly mean temperature data were derived from Xu *et al.* (2009) and had a spatial resolution of 0.5°×0.5°. This dataset was created by performing spatial interpolation using the site observations from 751 sites across China. It was reported that Xu’s dataset has a higher precision than the CRU dataset (Xu *et al.*, 2009). The monthly precipitation data were derived from Xie *et al.* (2007) and had a spatial resolution of 0.5°×0.5° as well. This dataset was created by compiling the rain gauge measurements from more than one thousand sites across China.

2.2 Methods

This study had three tasks: (1) to reveal the spatial pattern of the mean NDVI in spring (April to May) for the period 1982–2006 and the temporal variation of the regional mean NDVI from 1982 to 2006; (2) to extract representative models of the temporal variation of the NDVI by performing a cluster analysis of the spring NDVI during 1982–2006 across EC; and (3) to investigate the response of vegetation activity to temperature and precipitation by conducting a correlation analysis between the NDVI and the contemporary (April to May) and previous (March to May) temperature and precipitation.

In detail, we applied the hierarchical clustering method, which uses correlation coefficients to indicate the similarity/difference between samples and uses the nearest distance to represent the distance between two classes (Johnson and Wichern, 2002). To save computer resources, prior to the cluster analysis, we combined the 8-km resolution NDVI into a 24-km resolution NDVI by calculating the mean of 3 pixels by 3 pixels areas. We obtained 20 classes directly through the cluster analysis but only analysed the characteristics of 16 classes because the others occupied one cell each. Finally, we calculated the correlation coefficients between the regional mean NDVI and the temperature anomaly and the precipitation anomaly (as a percentage) for each class. It is worth noting that we calculated not only the correlation coefficients between the original time series but also the correlations between the first-order difference series of the original time series using Eq. (1)

$$d_i = v_{i+1} - v_i \tag{1}$$

where v_i denotes the original time series, and d_i is the first-order difference series; i=1, 2, …, 24 represents the year 1982, 1983, …, 2005.

3 Results

3.1 Spatial pattern of the mean spring NDVI during 1982–2006

Figure 1a illustrates the spatial pattern of the mean spring NDVI for 1982–2006. This spatial pattern was characterised by a high NDVI in the south and a low NDVI in the north. In addition, forested areas had a higher NDVI than did non-forested areas. Taiwan Province had the highest NDVI, which was greater than 0.6 in most areas. The Wudang Mountain—Wushan Mountain, Dabie Mountain, Jiuling Mountain and Tianmu Mountain—Wuyi

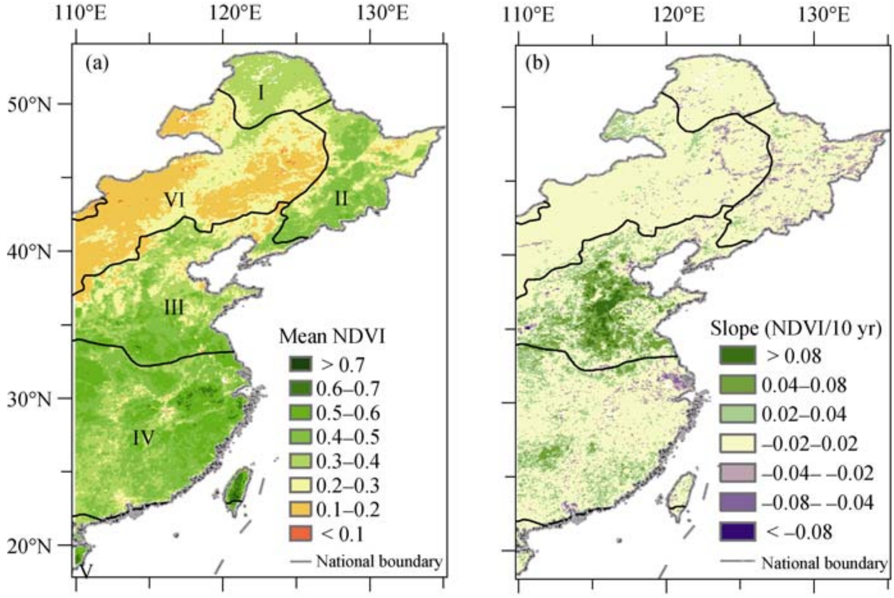

Figure 1 (a) Spatial distribution of the mean NDVI in spring (April–May) from 1982–2006 and (b) spatial distribution of the temporal trend of spring NDVI from 1982 to 2006 within eastern China (black solid curves denote the boundaries of vegetation regions as indicated by the editorial committee of the vegetation map of China (2007)). The Roman numerals indicate the following vegetation regions: I. cold-temperate needleleaf deciduous forest region; II. temperate mixed needleleaf and deciduous broadleaf forest region; III. warm temperate deciduous broadleaf forest region; IV. subtropical broadleaf evergreen forest region; V. tropical monsoon rainforest and rainforest region; VI. temperate grassland)

Mountain regions had the second highest NDVIs, which were mainly between 0.5 and 0.6. The cropland area in the plain area of the Huaihe River Basin and the forest area on the Changbai Mountains had the third highest NDVIs, which were mainly between 0.4 and 0.5. The croplands of the Northeast China Plain and the grasslands on the Inner Mongolian Plateau had the lowest NDVIs, which were between 0.15 and 0.2 and lower than 0.15, respectively. In total, grid cells having NDVIs of 0.4–0.5 accounted for the greatest area, 24.8% of the study area, and grid cells having NDVIs of 0.3–0.4 accounted for the second greatest area, 22.8% of the study area.

3.2 Spatial pattern of linear trend in spring NDVI during 1982–2006

Figure 2 illustrates the variation in the mean spring NDVI across EC during 1982–2006. The spring NDVI tended to increase with large inter-annual fluctuations. As in previous studies, the spring NDVI increased at a rate of 0.02/10yr (r^2=0.28; p=0.024) from 1982–1999. Although the increasing trend ceased after 1999, the entire period 1982–2006 had a positive slope of 0.007/10yr (r^2=0.09; p=0.15). Moreover, the ascending trend showed large spatial variability (Figure 1b). The NDVIs of the North China Plain, the Hulun Buir Glassland and the plains surrounding the Dongting Lake increased significantly. Among those areas, the North China Plain had the greatest increase, at a rate of approximately 0.03/10yr (r^2=0.52; p<0.001). The NDVIs of the Yangtze River Delta, the Pearl River Delta and some areas in the Northeast China Plain decreased significantly. Among those areas, the Yangtze River Delta had the greatest decrease, at a rate of approximately –0.016/10yr (r^2=0.24; p=0.014). In the other areas of EC, the variations in the spring NDVI exhibited no significant linear trend.

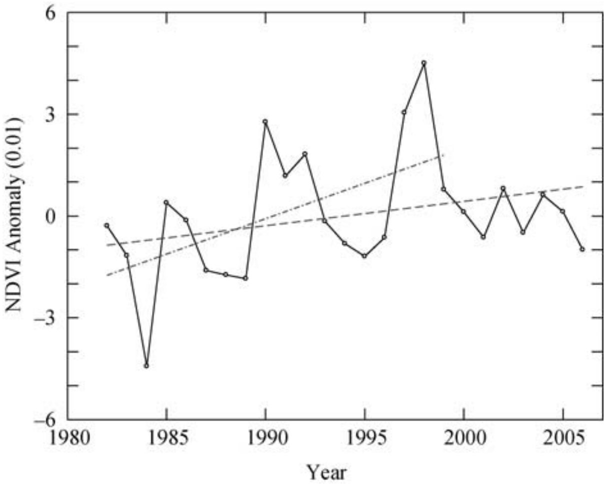

Figure 2 Variation in the mean spring NDVI across eastern China for 1982–2006 (refers to the mean of 1982–2006; the bold dashed line and thin dashed-dot line denote linear trends during 1982–2006 and 1982–1999, respectively

Fang *et al.* (2004) reported that the NDVI of North China increased significantly from 1982 to 1999 and that this increase was mainly caused by the increases in spring and summer, especially from April to May. Chen *et al.* (2010) reported that the spring (March to May) NDVI of North China increased significantly, at a rate of 0.02/10yr, from 1982 to 2003. Our findings, as described above, confirmed their conclusions and suggested that the spring NDVI of North China exhibited a significant increase from 1982 to 2006. Fang *et al.* (2004) attributed the significant increase in the spring NDVI of the North China Plain to the intensification of agricultural activities, such as the use of artificial fertiliser and irrigation. However, Xu (2009) attributed this increase to the replacement of spring wheat with winter wheat and an earlier start of spring because of the background climate warming. Fang *et al.* (2004) also reported that the NDVI of the Yangtze River Delta region decreased from 1982 to 1999 and attributed this decrease to urbanisation. Our findings illustrated that the NDVI of this region also decreased significantly during 1982–2006, and the rate of decrease for this period was larger than that during 1982–1999. This finding is consistent with the observation from Sun *et al.* (2011) that urbanisation accelerated after 1990. In addition, our findings that the spring NDVI of the Pearl River Delta decreased significantly were also consistent with the results of Sun *et al.* (2011).

3.3 Models of temporal variation in spring NDVI and correlation between spring DNVI and climate change

Figure 3 illustrates the spatial distribution of the models of temporal variation in the spring NDVI during 1982–2006 across EC. Large differences in temporal variation in the NDVI occurred across EC. At the top-most level, differences were observed between the urbanised areas, such as the Yangtze River Delta (type 17) and the Pearl River Delta (type 9), and other non-urbanised areas. In the Yangtze River and the Pearl River deltas, the spring NDVI decreased during both the period 1982–1998 and the period 1982–2006. From 1982 to 2006, the NDVI decreased at rates of –0.016/10yr and –0.014/10yr in the Yangtze River Delta and the Pearl River Delta, respectively, while the spring NDVI more or less increased during these periods in the other areas. At the secondary level, the rest of EC excluding the Yangtze River and the Pearl River deltas could be divided into two categories. One category consisted of the Hulun Buir (type 13), North China (type 2 and type 4), Huaihe River Basin (type 11), areas south of the Yangtze River—South China (type 8) and mountains in Hainan and Taiwan (type 1 and type 19). In these areas, the spring NDVI increased continuously at mean rates of 0.02/10yr and 0.015/10yr from 1982 to 1998 and 1982 to 2006, respectively. The other category consisted of Northeast China (type 15 and type 18), the southeast Inner Mongolian Plateau (type 6, type 7, type 12 and type 14) and the lower reaches of the Yangtze River (type 10). In these areas, the spring NDVI increased from 1982 to 1998 and then decreased after 1998. As a result, the mean NDVI increased at a rate of 0.01/10yr for the period 1982–1998, but the mean rate was 0.00/10yr for the period 1982–2006 (Figure 3). At the third level, the spatial variability of the temporal trend in the NDVI was characterised by differences in the inter-annual variability among the various types. For instance, although the NDVIs in the Hulun Buir and the North China Plain increased significantly, the Hulun Buir area had a negative anomaly in the NDVI in 1997 and positive anomalies in 2001 and 2002, while the converse was true for North China. In addition, both the lower reaches of the Yangtze River and Northeast China were characterised by the cessation of the increase in NDVI after 1998. The Northeast China NDVI had extreme positive anomalies in 1985, 1990, 1992 and 1998, while the lower reaches of the Yangtze River did not experience these extreme anomalies.

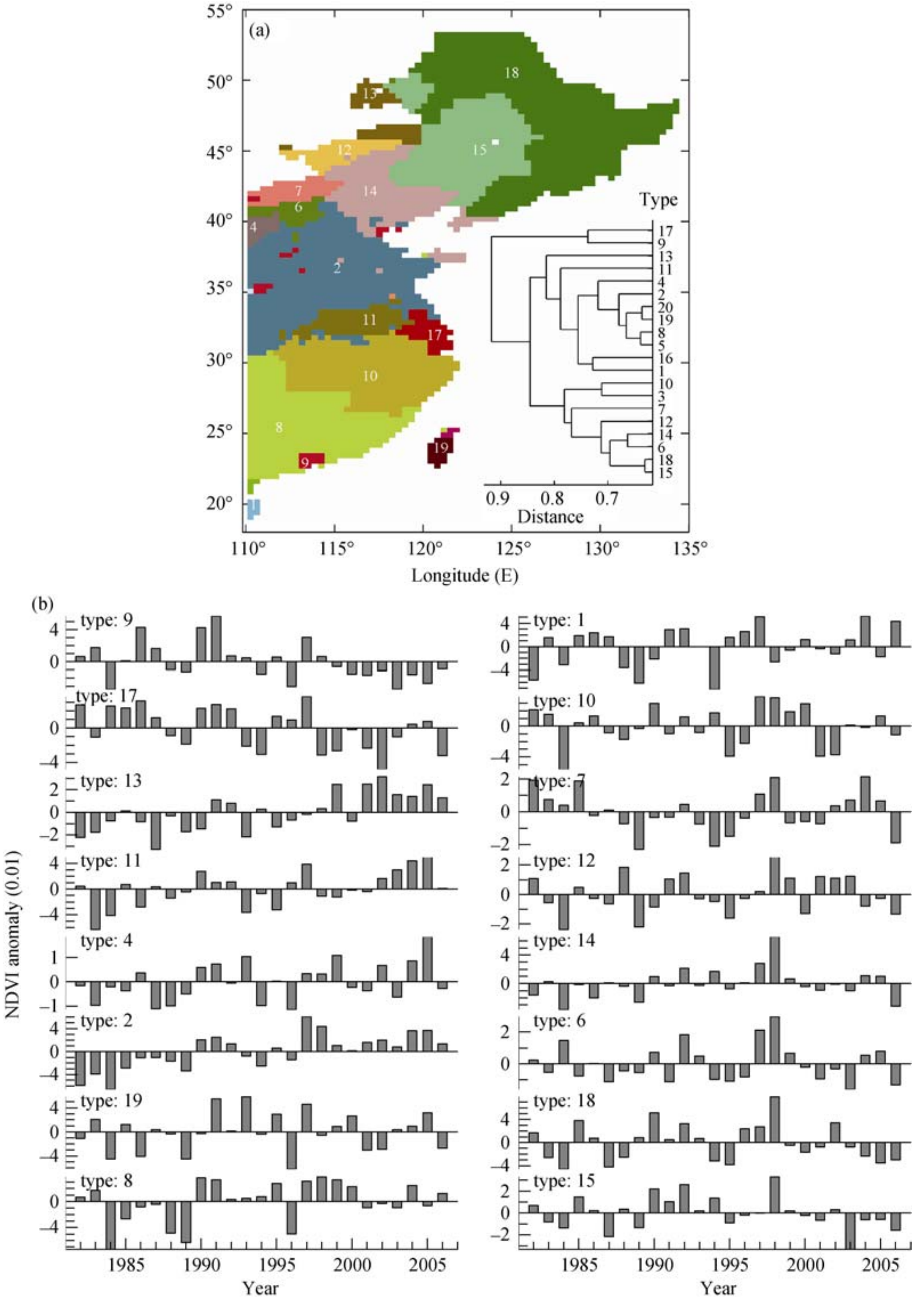

Figure 3 Models of temporal variation in the spring NDVI during 1982–2006: (a) spatial distribution of models of temporal variation and their hierarchical clustering dendrogram (bottom-right subfigure), and (b) characteristic temporal variations of the models

Table 1 lists the correlations between the temporal variations in the NDVI and those in temperature or precipitation. The spring NDVI showed the greatest positive correlation with temperature. The positive correlations between the inter-annual variations in the NDVI and those in temperature were statistically significant (p<0.01) in the mountainous areas in Northeast China (type 18), the hilly and mountainous areas in South China (type 8) and the lower reaches of the Yangtze River (type 10). These areas are all covered by woodlands. It is possible that the forest vegetation activity across EC is positively correlated with temperature variation. This finding is consistent with the results of Li *et al.* (2000). Furthermore, Table 1 shows that the intensity of these positive correlations varies from one region to another. The correlation coefficients were greater than 0.7 in Northeast China, while the correlation coefficients were mostly less than 0.6 in South China. Additionally, the strength of the correlation was partly dependent on the time scale. For instance, in Northeast China and South China, the correlation coefficients between the original time series of the NDVI and the temperature were close to the correlation coefficients between their first-order difference series. Thus, this correlation was detected at both the inter-annual time scale and the multi-year time scale. In the lower reaches of the Yangtze River, the correlation coefficients between the original time series of the NDVI and the temperature were lower than the correlation coefficients between their first-order difference series. Hence, this correlation was mainly detected at an inter-annual scale. The lower correlation at the longer time scale might

Table 1 Correlation coefficients between spring (April–May) NDVI and temperature or precipitation

Model of temporal variation in NDVI	Mean temperature of April to May		Mean temperature of March to May		Mean precipitation of April to May		Mean precipitation of March to May	
	r	r′	r	r′	r	r′	r	r′
type 9	–0.33	0.04	–0.18	**0.41****	0.00	–0.17	0.24	0.02
type 17	–0.33	–0.01	**–0.43****	0.03	**–0.41****	**–0.50****	–0.17	**–0.42****
type 13	**0.41****	0.10	0.20	–0.26	**0.37***	**0.34***	**0.41****	**0.36***
type 11	0.22	0.29	0.25	0.09	0.05	–0.08	0.17	0.03
type 4	0.06	–0.29	**0.38***	0.06	0.26	0.02	0.27	0.05
type 2	0.17	–0.03	**0.39***	0.19	0.18	0.26	0.24	**0.36***
type 19	——	——	——	——	**–0.56*****	**–0.69******	**–0.45****	**–0.54*****
type 8	**0.48****	**0.44****	**0.58*****	**0.58*****	**–0.40****	**–0.50****	–0.22	–0.27
type 1	–0.05	–0.28	0.13	–0.05	0.16	0.16	0.09	0.11
type 10	**0.51*****	**0.70******	**0.34***	**0.53*****	–0.29	–0.29	–0.21	–0.3
type 7	0.14	–0.06	0.13	–0.01	**0.59*****	**0.55*****	**0.56*****	**0.53*****
type 12	0.19	–0.04	0.18	–0.18	**0.69******	**0.52*****	**0.7******	**0.55*****
type 14	0.26	0.21	**0.35***	0.25	**0.66******	**0.77******	**0.64******	**0.75******
type 6	0.19	0.11	0.31	0.32	0.15	–0.03	0.16	–0.01
type 18	**0.67******	**0.67******	**0.73******	**0.78******	–0.21	–0.04	–0.24	–0.06
type 15	0.18	0.32	0.27	**0.42****	0.32	**0.44****	**0.38***	**0.49****

Note: See Figure 3 for the model types and distribution of models of temporal variation in NDVI; r and r′ represent the correlations of the original time series and first-order differences series, respectively; the statistically significant correlation coefficients are represented by black bold figures, and *, **, *** and **** designate the confidence levels of 90%, 95%, 99% and 99.9%, respectively.

be associated with the large area of cropland that was highly influenced by human activities and thus the temporal trend in the NDVI at the longer time scale was modified by human activities.

The signs of the correlation between the NDVI and precipitation varied with region as well. Five models of the temporal variation in the NDVI had significant positive correlations with precipitation. These models were in Northeast China (type 15) and the east to southeast of the Inner Mongolian Plateau (type 12, type 14, type 7 and type 13). These areas are predominantly covered by grassland. These negative correlations indicated that the vegetation in the semi-arid and arid areas were expected to have a stronger activity under wetter conditions. The highest correlation coefficient was greater than 0.7 and occurred in the southeast of the Inner Mongolian Plateau, while the lowest correlation coefficient was less than 0.3 and occurred in the Hulun Buir Glassland. The findings are consistent with results from Li *et al.* (2000). It is worth noting that in the type 15 and type 14 areas, the correlation coefficients between the original time series of the NDVI and precipitation were lower than the correlation coefficients between their first-order difference series. This difference suggested that the effects of variation in precipitation on vegetation activity were stronger on the inter-annual scale than at a longer time scale in these areas. This difference might also be associated with the presence of large areas of cropland for which the variations in the NDVI over longer time scales were deeply affected by human activities, such as the use of agricultural technology, artificial fertilisers and irrigation.

Additionally, three models of the temporal variation in the NDVI had significant negative correlations with precipitation. These models occupied the reaches of the Yangtze River (type 17), the areas from the south of the Yangtze River to South China (type 8) and Taiwan Province (type 19), all of which are predominantly covered by woodlands. The highest correlation coefficient was –0.69, which occurred in Taiwan (type 19). As we know, more precipitation indicated more cloud cover and thus less solar radiation; less solar radiation limited vegetation activity. The findings from He *et al.* (2007) also indicated that solar radiation is the limiting factor for forest growth in South China. Therefore, the linkage between the precipitation and vegetation activity might be cloud cover. However, the confidence levels of these negative correlations were mostly lower than 90%. This low confidence might be associated with the presence of extensive cropland areas that were heavily influenced by human activities.

In the North China Plain, where cropland was the dominant landscape, the inter-annual vegetation activity was significantly correlated with the variation in precipitation ($r=0.36$; $p<0.1$). In contrast, the spring NDVI was not significantly correlated with the variation in temperature at the inter-annual scale. Thus, the inter-annual variation in the NDVI exhibited a sensitive response to precipitation, while it was insensitive to temperature. Such findings could be explained by the climatology of the North China Plain, which is characterised as warmer and drier in spring. As a result, there was sufficient heat but the amount of moisture was the limiting factor. At the longer time scale, the vegetation activity was not significantly correlated with precipitation but was significantly correlated with temperature. This suggested that the vegetation activity would not be sensitive to variations in precipitation at longer time scales. Such an insensitive response might be attributed to the influence of the intensification of human activities, such as irrigation, the use of artificial fertiliser and the creation of new seeds, which could cause an increase in the NDVI over time. On the other hand, the significant correlation between the NDVI and temperature did not necessarily suggest that the increasing trend in the NDVI mainly resulted from the warming climate. One reason is that the amount of heat was sufficient for vegetation activities and, consequently, the warmer climate could cause an increase in transpiration and thus intensify drier conditions. The other reason is that human activity could produce strong vegetation activity, as mentioned previously.

4 Conclusions and discussion

The described findings confirmed that the spring NDVI generally increased before the mid-1990s and the increase ceased thereafter (e.g., Park and Sohn, 2010; Peng *et al.*, 2011). More importantly, our findings demonstrated that the variation in the NDVI during 1982–2006 was different from one region to another. There was a distinct increase (0.03/10yr) in the Huang-Huai-Hai Plain, a cultivated area; however, there were distinct decreases (–0.02/10yr) in the Yangtze River and the Pearl River deltas, two regions of rapid urbanisation. In the other areas, the NDVI increased until 1998, and thereafter, the trends in the NDVI differed among regions. After 1998, the NDVI decreased in Northeast China, the eastern region of the Inner Mongolian Plateau and the lower reaches of the Yangtze River. The NDVI stopped increasing in the Hulun Buir Glassland and the area from south of the Yangtze River to South China. These findings illustrated that it was difficult to identify a simple general model to represent the variation in the NDVI across EC.

The variation in the NDVI was more or less correlated with climatic changes; however, the correlations varied with region. In the semi-arid to semi-humid areas, which were predominantly covered by grassland and cropland, the NDVI showed a significant correlation only with precipitation. In the semi-humid to humid areas, which were predominantly covered by woodland, the NDVI showed a significant correlation only with temperature. In these areas, temperature or precipitation could explain up to 60% of the variation in the NDVI. In the intensely cultivated areas, the inter-annual variability in the NDVI was significantly impacted by climatic changes. However, additional efforts would be needed to separate the contribution of climatic change from that of human cultivation on the temporal variation in NDVI during 1982–2006. The correlation between the NDVI and climate change in the urban areas differed from those in the rural areas. Thus, human perturbations modify the responses of vegetation to climatic changes.

This study provided a scientific basis for understanding the variation in vegetation activity caused by climate change and human perturbations. These results are uncertain partially because of the limitations of analysing the NDVI. It is well known that the NDVI can become saturated once the LAI exceeds 2–3 and that the NDVI is easily impacted by soil radiance, which is related to soil moisture, when the vegetation is sparse (e.g., Xu, 2005). Additionally, this study only focused on large scale spatial patterns of variation in the vegetation activity over time. Our findings may differ from the knowledge gained from local analysis. These differences may be caused by many factors. For example, local climate variations might differ from large-scale climate variations, the local dominant vegetation type might differ from the regional dominant vegetation type, and local conditions might be impacted by fire, flood and pest insects as well as other factors. Finally, this study only analysed the correlations between the spring NDVI and the mean temperature and precipitation. However, vegetation activity could be affected by many environmental factors. Thus, the variations in the vegetation activity of some areas, such as the NDVI in the Huaihe River Basin, were poorly correlated with temperature and precipitation. A potential future direction would be to analyse the impact of other environmental factors on vegetation activity, such as the daily maximum temperature, the daily minimum temperature, the distribution of precipitation and solar radiation.

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