Responses of NDVI to climate change in the Hai Basin

CHEN Fujun[1,2], **SHEN Yanjun**[2], **HU Qiaoli**[1,2], **QI Yongqing**[2], **ZHANG Yucui**[2,3]

1. *College of Resources and Environmental Sciences, Hebei Normal University, Hebei Shijiazhuang* 050016*, China;*
2. *Center for Agricultural Resources Research, Chinese Academy of Sciences, Hebei Shijiazhuang* 050021*, China;*
3. *University of Chinese Academy of Sciences, Beijing* 100049*, China*

Abstract: In this study, based on the RS and GIS systems, AVHRR/NDVI data of 8 km resolution and meteorological data were used to analyze NDVI, annual precipitation, and temperature change rates by pixel from 1981 to 2000. In addition, the correlation between NDVI, annual rainfall, and annual average air temperature were calculated. The results showed that annual precipitation increased in the northern and southern areas of the Hai Basin from 1981 to 2000 while declining in the central area, with a range of –80 to 80 mm/10 a (‘a’ represents a year). As basin-wide temperatures increased, the Wutai Mountains area had the most significant increase, up to about 2℃/10 a. The NDVI reduced significantly in Beijing, Tianjin and other large adjacent cities, with a change rate of about –0.8 NDVI/10 a while increasing in the southeast part of the plains of the Hai Basin and the Yanshan Mountains, at about 0.8 NDVI/10 a. The correlation between NDVI, precipitation, and air temperature had significant spatial variation. In the cold and wet areas of the Hai Basin, such as the grasslands in the upstream areas of the Luanhe River and the area of the Wutai Mountains, the vegetation index is not sensitive to precipitation while it is correlated positively with the air temperature. In the warm and wet climate areas, such as the south end of the Taihang Mountains, the precipitation affected vegetation growth when it increased. In dry conditions, such as the eastern coastal plain and north of the Yanshan Mountains of the Hai Basin, NDVI significantly was correlated positively with precipitation and negatively with air temperature. In the irrigated agriculture areas of the piedmont plain, crop growth was not sensitive to climate changes.

Key words: NDVI, climate changes, temperature, precipitation, Hai Basin

CLC number: TP79 **Document code:** A

Citation format: Chen F J, Shen Y J, Hu Q L, Qi Y Q and Zhang Y C. 2011. Responses of NDVI to climate change in the Hai Basin. *Journal of Remote Sensing*, **15**(2): 401–414

1 INTRODUCTION

Since industrialization, with the worldwide extensive use of fossil fuels, a large amount of CO_2 and other greenhouse gases are discharged into the atmosphere, which has led to environmental pollution, rising temperatures, and a series of serious problems (Solomon, *et al*., 2007). In recent years, global climate changes caused by human activities and their influence on ecological systems have caused widespread concerns (Guo & Wang, 2007). As the main body of terrestrial ecosystems, vegetation plays an important role in the biomass production, ecological functions of regulation, and maintenance of the global carbon balance. Climate changes in temperature, moisture, sunshine, and light intensity will lead to vegetation changes, which will affect regional biomass production and ecosystem composition. Therefore, research into the relationship between vegetation changes and climatic factors has great significance in understanding the response of regional vegetation production to climate changes.

Previous studies have confirmed that vegetation changes were related to climatic factor changes on a global or regional scale (Melillo, *et al*., 1993; Keeling, *et al*., 1996; Field, *et al*., 1998; Nemani, *et al*., 2003; Weltzin, *et al*., 2003). Temperature and precipitation are the most significant factors that affect the ecosystem characteristics and distribution in climatic factors (Liu & Fu, 2001). The normalized difference vegetation index (NDVI), calculated using remote sensing image data, currently is one of the most commonly used indicators to monitor regional or global vegetation and the ecosystem and is the best instruction factor to reflect vegetation growth conditions and coverage (Zhao, 2004; Zhang, *et al*., 2005).

Due to the continuity in time and space, as well as having a good linear relationship with photosynthetic active radiation, vegetation greenness, biological carbon sequestration, vegetation coverage, and other parameters, NDVI is used widely in the study of the relationship between vegetation cover and climate. Recently in a study of the relationship between NDVI and climatic factors, Piao and Fang, *et al.* (2001) analyzed the vegetation dynamics with NOAA-AVHRR/NDVI

Received: 2010-03-01; **Accepted:** 2010-08-01

Foundation: Innovation Program of Chinese Academy of Sciences (No. KZCX1-YW-08-03-07, KZCX2-YW-448); Project for Public Aelfare of Ministry of Water Resources (No. 200801012); National Key Project on R & D Program (No. 2008BAD95B12)

First author biography: CHEN Fujun (1983—), male, Master degree candidate. He majors in eco-environmental remote sensing and GIS. E-mail: cfjgis@126.com

Correspondent author: SHEN YanJun, E-mail: yjshen@sjziam.ac.cn

data in China for a period of 18 years (1982 to 1999). The results showed that NDVI declined significantly in the arid areas in northwest China. In addition, China's Pearl River Delta and Yangtze River Delta were the most significant areas where vegetation cover declined in the past 18 years, which indicated the impact of rapid urbanization. Chen, *et al*. (2002) studied the regional differentiation rule on NDVI change responses to climate factors in China and believed that NDVI in the northeast region of China, eastern Inner Mongolia, and the Qinghai-Tibet Plateau were more sensitive to average annual precipitation. However, South China, the Yellow River-Huai River Basin, and the western region of Xinjiang were more sensitive to average annual temperatures. Song and Ma, *et al*. (2008) found a positive correlation between vegetation, precipitation, and temperature in the cold and arid regions of China. Further research by Wang, *et al*. (2005) showed that the responses of different forest types to climate change factors were quite different in the northeast China forested areas. According to Zhang, *et al*. (2009), the NDVI of spring vegetation and temperature were closely related in Xinjiang, while vegetation had a significant positive correlation with precipitation in summer. The NDVI change in autumn showed the combined effect of temperature and precipitation.

The Hai Basin has some of the most intensive human activities and shows serious deterioration of the ecological environment in all of China's regions. As the political and economic center of China and the important breadbasket in northern China, vegetation changes have a significant impact on the ecosystem and agricultural production in this area. To carry out studies of the relationship between NDVI and climatic factor changes in the Hai Basin and to predict vegetation (NDVI) change is meaningful for estimation of regional vegetation productivity, biological carbon sequestration processes, and ecosystem structure and functions evaluation.

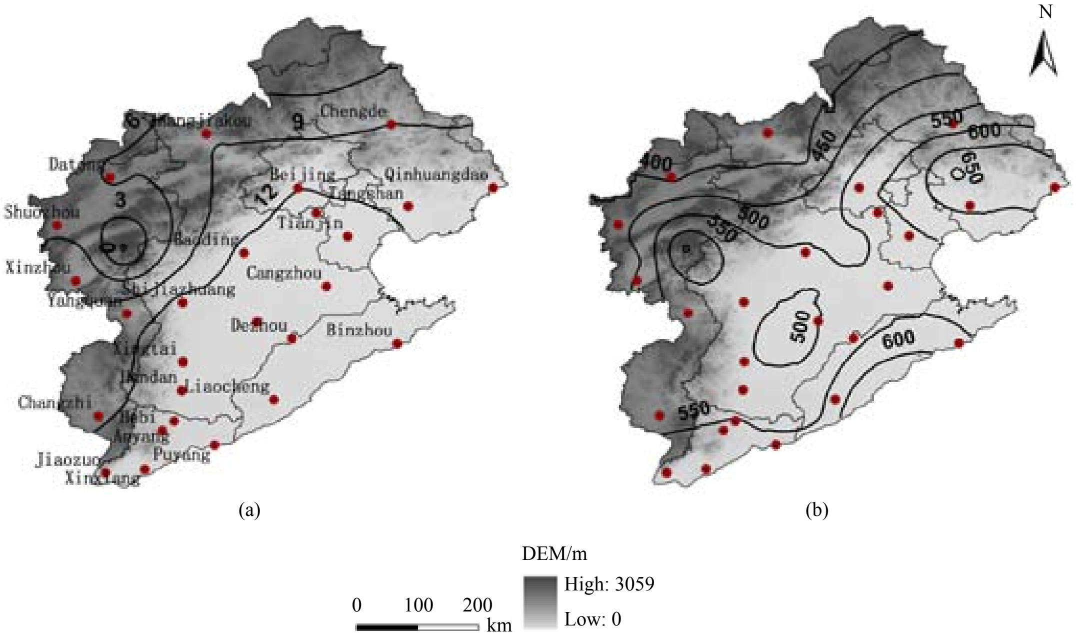
In this study, the NOAA/AVHRR NDVI data of the Hai Basin from 1981 to 2000 and the surrounding 67 meteorological stations' data were used to analyze the correlation between the vegetation index and the main climatic factors. The spatial pattern of the response of vegetation to climatic factor changes was studied, which can provide scientific support for ecological environmental building in the Hai Basin.

2 STUDY AREA AND METHOD

2.1 The Hai Basin

The Hai Basin is located in 112°E to 120°E, 35°N to 43 °N. The total area is 318,000 km^2, and it has a temperate semi-humid, semi-arid continental monsoon climate with average temperatures between 0℃ and 14.5℃, reducing from south to north and from the plains to the mountains. The coldest point is located in the north Bashang Plateau and the Wutai Mountain areas (Fig. 1(a)). Average precipitation over the years in this basin has been from 600 to 650 mm in the southeast, gradually reducing to 350 to 400 mm in the northwest, with a mean value of 535 mm, which is the lowest precipitation region of eastern coastal China. Affected by the mountainous terrain, two rainy areas are found, where the annual rainfall is greater than 600 mm, near the windward slope of Wutai Mountain and Zunhua of Tangshan City, and the rainfall reduce from the top to the sides along the mountains arc (Fig. 1(b)).

The Hai Basin, as the most important political, economic, and cultural center of China and with a total population of 126 million, accounts for 13% of the country's GDP, and grain production accounts for approximately 10% of all grain production in the country. Due to intense human activities, natural vegetation has been destroyed, and the main vegetation is crops in the plains areas. Only a small amount of natural vegetation can be found in the mountain areas, and natural secondary forest is distributed mainly at elevations above the 1000-meter range. Because of the wet zone where annual precipitation is more than 600 mm on the windward slope of the Taihang Mountains, vegetation grows well. Due to the Yanshan-Taihang Mountain barrier, at the leeward slope, annual precipitation is approximately 400 mm, and where the vegetation is sparse, and the ecosystem is fragile.



(a) (b)

Fig. 1 Twenty-year average precipitation and average temperature contour map of Hai Basin
(a) Average annual temperature 1981—2000 contour (℃); (b) Annual precipitation 1981 mm—2000 mm

2.2 Data and methods

2.2.1 NDVI and meteorological data

In this study, 8 km resolution by 10 days AVHRR/NDVI data from 1981 to 2000 (Ryutaro, 2001) was used. The monthly maximum NDVI was calculated using the Maximum Value Composite (MVC), which provided the annual average, and then we analyzed the correlation between climatic factors and NDVI.

Based on the meteorological data from 67 sites in and around the Hai Basin, from 1981 to 2000, spatial interpolation of the average annual temperature and the annual rainfall in the Hai Basin was carried out. Then we obtained the annual average temperature and precipitation distribution maps of the basin with a resolution of 8 km × 8 km from 1981 to 2000.

2.2.2 Methods

In this study, we analyzed the vegetation NDVI change, annual precipitation change, and annual temperature change in different regions of the Hai Basin from 1981 to 2000 by using linear regression method. The slope of the trend line of the regression equation in each single pixel was set as the inter-annual rate of change.

To study the correlation between the vegetation NDVI and annual precipitation, as well as mean annual temperature, we analyzed the relationship between NDVI and standardized precipitations and temperature data of each pixel, respectively, and then conducted a significance test for the results (Wang J, *et al*., 2001; Wang & Rich, 2003; Wang & Meng, 2008).

3 RESULTS AND ANALYSIS

3.1 NDVI, temperature and precipitation change trends on a basin-scale

To study the above-mentioned elements changes' spatial distribution, we used the least-squares method to calculate the linear change rate of annual precipitation, temperature, and NDVI by pixel and to analyze the significance of these changes. Annual precipitation increased, and the average inter-annual rate of the change was 30 mm/10 a to 80 mm/10 a in the southern and northern regions of the basin; in the eastern coast, the western mountain areas, and some areas of the central part, the annual precipitation was reduced to -30 mm/10 a in some regions (Fig. 2(a)).

The temperature throughout the entire Hai Basin increased, showing an upward trend (Fig. 2(b)) with small increases in the northeast and southwest regions of the basin, and the change rate was 0.6 ℃ per 10 a; the increases in the Wutai Mountain area were the most obvious, up to 2 ℃ per 10 a. Throughout most of the basin, NDVI showed an increasing trend (Fig. 2(c)). In the southeastern plains and the Yanshan Mountain, NDVI values increased significantly. As construction areas expanded in and around Beijing, Tianjin, Shijiazhuang, Tangshan, and other large cities, NDVI appeared to change negatively. The NDVI also showed a decreasing trend in the northern basin, the upper reaches of the Luanhe River grassland area, and individual areas of the leeward slope of the Taihang Mountains.

3.2 Spatial analysis for the correlation of NDVI with precipitation and temperature

To study the responses of NDVI to climate change, we calculate the linear correlation of NDVI with precipitation and temperature by pixel using the least-square method and evaluated its significance in the dominance level of 0.05. Fig. 3 shows the spatial distribution of the significantly related region of NDVI with precipitation and air temperature.

As shown in Fig. 3(a), the significant positive correlation region between precipitation and NDVI is distributed mainly in the eastern elevation <10 m of the low plains area of the Hai Basin. This region holds large tracts of saline because shallow underground water is salt water, which cannot be used for irrigation. It is rain-fed agriculture (He, *et al*., 2002) in most part of this area, and vegetation growth conditions are affected significantly by annual precipitation. Another region with a positive correlation with precipitation is distributed in the eastern part of the YanShan Mountain, where most vegetation types are natural woodland, with a dry climate and environment. Precipitation had a significant impact on vegetation growth in this area. A strong negative correlation was found between NDVI and annual precipitation in the Wutai Mountain area, and the average annual temperature and NDVI were related positively. This is because the Wutai Mountain area has large precipitation, so water is not a major limiting factor for vegetation growth. However, due to the high altitude and low temperatures, vegetation growth is more sensitive to temperature changes (Dai, *et al*., 2005). A significantly negative correlation between NDVI and annual rainfall was found in the southern Taihang Mountains region. As seen in Fig. 1 and 2, abundant precipitation falls in the region, with a significant increasing trend. As the environment is humid, NDVI and precipitation were

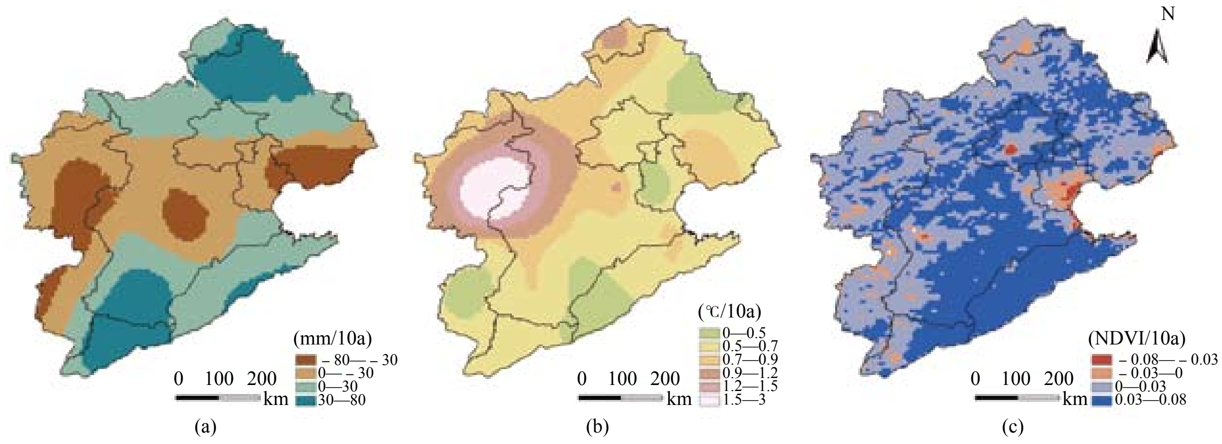


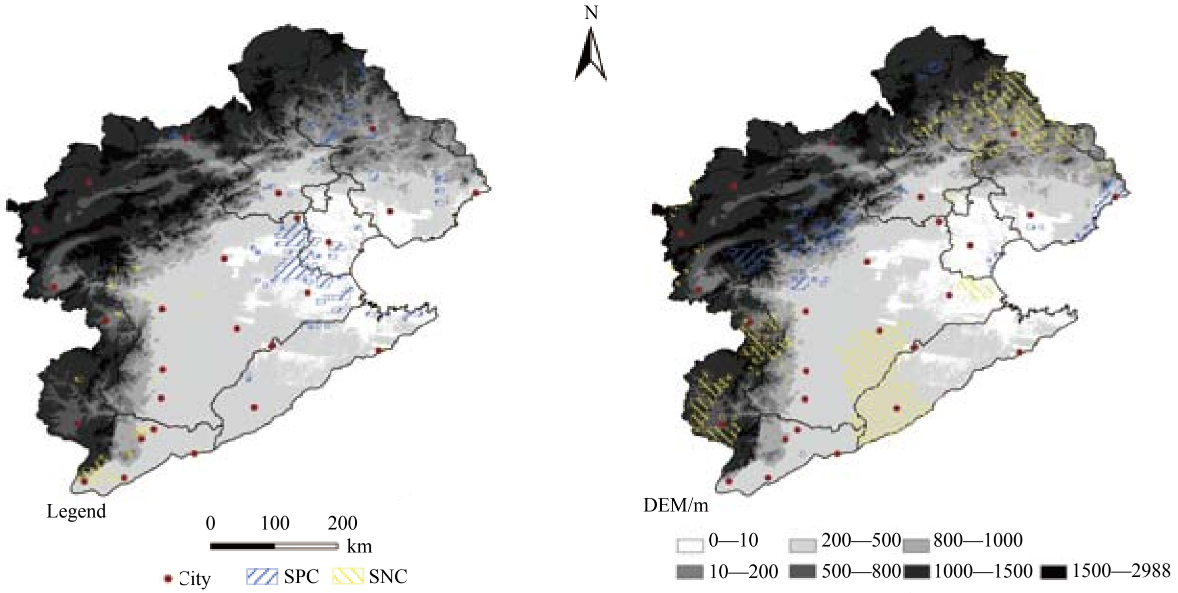
Fig. 2 The change rate of the climatic factors and NDVI in the Hai Basin

(a) The rate of annual precipitation change; (b) The rate of average temperature change; (c) The rate of annual NDVI change correlated negatively. The piedmont plain of the Taihang Mountain and irrigated areas of the southeast basin are the most important agricultural areas of the Hai Basin. With a high irrigation protection rate, crop production levels appeared to increase steadily (Li, *et al*., 2008), and therefore, the NDVI annual variation had little to do with precipitation.

Generally speaking, the spatial pattern of correlation between NDVI and temperature shows an opposite trend with NDVI and precipitation (Fig. 3(b)). Areas where NDVI and temperature are related positively are located in the Wutai Mountain and the Luan River upper reaches grassland areas, as well as the eastern coastal areas of Qinhuangdao and Tangshan cities. The average annual temperature of the mountain areas is lower, where temperature promotes vegetation growth. In the coastal areas such as Tangshan and Qinhuangdao that are dominated by rice crops, rising temperature is also beneficial to the growth of the rice. In the northern end of Yanshan and the southern end of the Taihang Mountains areas, the vegetation relies mainly on rain. Higher temperatures could increase evaporation of land surface water and affect vegetation growth; therefore, a significant negative correlation was found between NDVI and air temperature. A significant negative correlation between NDVI and temperature also was found from the Yellow River irrigation area in northwest Shandong Province to the Hengshui area, Hebei Province. This may be related to the improvement of conditions for agricultural production from 1981 to 2000 (including irrigation, salinity control, and breed improvement), so that NDVI increased significantly. However, no significant temperature rise occurred over the same period (Fig. 2). In the Nandagang Wetland areas and in eastern Cangzhou of Hebei Province, higher temperatures accelerate the surface soil moisture evaporation and influence vegetation growth; therefore, NDVI and the annual average temperature in the region showed a significant negative correlation.

3.3 Samples analysis

In order to better explain the responses of NDVI to the climate change spatial distribution rule in the study area, we selected seven typical sample points, A through G, in the Hai Basin (Fig. 4) to analyze further. The climate, vegetation, elevation, and other natural elements of the sample points are shown in Table 1.



(a)

(b)

Fig. 3 Pixel-based spatial distribution map of the correlation between annual precipitation, annual mean temperature, and NDVI (SNC is significant negative correlation area, SPC is significant positive correlation area)

(a) The correlation between NDVI and annual precipitation; (b) The correlation between NDVI and annual mean temperature

Table 1 Climate, vegetation, DEM, and other elements' situations of the sample points, 1981—2000

Sampling point	A	B	C	D	E	F	G
Location	Duolun	Luanping	Huanghua	Wutai Mountain	Luancheng	Zaoqiang	Yuntai Mountain
NDVI associated with annual precipitation	0.14	0.44	0.41	–0.3	–0.23	0.01	–0.48
NDVI associated with average annual temperature	0.46	–0.13	–0.42	0.5	–0.21	–0.62	0.08
Terrain	Grassland	Mountains	Plain	Mountains	Plain	Plain	Mountains
Underlying conditions	Meadow	Forest	Alkaline land	Forest	Irrigated land	Irrigated land	Forest
Elevation(m)	1258	726	13	1145	53	27	175
Annual precipitation(mm)	400.8	500.7	526.1	584.6	508.7	503.7	569.9
Average annual temperature(℃)	3.5	8.1	12.7	1.2	13.3	13.2	13.4
Average NDVI	0.28	0.37	0.23	0.40	0.43	0.30	0.41
The rate of annual precipitation change(mm/a)	3.29	3.42	1.45	–4.87	1.09	0.09	2.97
The rate of average annual temperature change(℃/a)	0.085*	0.05	0.07	0.22	0.08**	0.05*	0.06
The rate of NDVI change(NDVI/a)	–0.017**	0.045*	0.049	0.030	0.024	0.067	0.012
Aridity index	29.7	27.7	23.2	52.2	21.8	21.7	24.3

* Significance level $P < 0.05$

** Significance level $P < 0.01$

The aridity index was calculated using a simple method proposed by de Martonne (1926), using temperature and precipitation as the two climate factors (Meng, *et al*., 2004):

$$I_{\mathrm{dM}} = \frac{p}{t+10} \tag{1}$$

where I_{dM} is De Martonne's aridity index; p is the average precipitation (mm), and t is average temperature (℃). An aridity index is less than 10 mean severe drought, flow-break, and artificial irrigation. An index between 10 and 30 indicates moderate drought and flow, transient flow for the river, and the areas are covered with prairie. When the index is larger than 30, it indicates that the weather will be warm and wet in this area, and the river will have enough water all year round, and the area covered by forest. I_{dM}, in its simple calculation and with clear indicators and strong correspondence to vegetation moisture, commonly was used in large-scale climate division.

The sample point A is located in the upper reaches of the Luanhe River; it is high altitude, low annual precipitation, and low temperature, and most vegetation is alpine meadows throughout the region. When analyzed by combining the aridity index and point A in Fig. 5, point A is found to locate in a cold and wet climate, where vegetation is not sensitive to precipitation changes. However, a significant positive correlation was found between NDVI and temperature changes. With the natural forest underlying the Yanshan Mountain of point B, the environment is drier than at point A. Precipitation was conducive to vegetation growth (point B in Fig. 5). Point C is located in Huanghua, Hebei Province. The saline environment has a serious impact on crop growth. In addition, the climate is dry, and groundwater cannot be used for irrigation, so vegetation significantly was positively correlated with precipitation and negatively with temperature (point C in Fig. 5). In the forest underlying the Taihang Mountains, points D and G are precipitation-rich and moist. The average temperature of point D was low. The vegetation index changed significantly with the average annual temperature (point D in Fig. 5). Because of the rich precipitation and high temperatures, the vegetation in point G was not sensitive to temperature changes, while excessive precipitation was not good for the vegetation growth in the wet conditions (point D in Fig. 5 and point G in Fig. 5). In points E and F, as the main food production area with dry climate (Table 1), a decline in precipitation or increased temperatures will lead to serious drought and reduction of food production. Points E and F are both irrigated land. However, because of the deep water table and sandy loam, surface soil water loss quickly in point F, Therefore, crops was negatively correlated to the temperature change in point F. And E points is located in the agricultural irrigation area, the crop is not response to climate change (point E in Fig. 5 and point F in Fig. 5).

As related in this study, in the cold, wet areas of the Hai Basin, such as the upstream grasslands of the Luanhe River and the area of the Wutai Mountains, the vegetation index was not sensitive to precipitation, while it was correlated positively with air temperature. In the warm, wet climate areas, such as the south end of the Taihang Mountains, precipitation affected vegetation growth when it increased. In dry conditions, such as the eastern coastal plain and the northern Yanshan Mountains of the Hai Basin, NDVI significantly was correlated positively with precipitation and negatively with air temperature. In the irrigated agriculture areas of the piedmont plain, crop growth was not sensitive to climate changes.

4 CONCLUSIONS

From 1981 to 2000, the annual precipitation increased in the northern and southern areas of the Hai Basin while it declined in the central areas, with a range of –80 to 80 mm/10 a. As basin-wide temperatures increased, the Wutai Mountains area had the most significant increase, up to about 2 ℃ per 10a. The NDVI reduced significantly in Beijing and Tianjin and around other large cities, with a change rate of approximately –0.8 NDVI /10 a, while it increased in the southeastern part of the Hai Basin plain and that Yanshan Mountains, at a rate of approximately 0.8 NDVI /10 a.

The correlation between NDVI, precipitation, and air temperature showed significant spatial variations. The NDVI was correlated negatively with precipitation in the south end of the Taihang Mountains and positively in the eastern coastal plain and northern Yanshan Mountains. Meanwhile, NDVI was correlated positively and significantly with temperatures in the area of the Wutai Mountains, the grassland in the Luanhe River upstream, and the eastern coastal areas such as Tangshan and Qinhuangdao. Conversely, a negative relationship between NDVI and temperature was found in Nandagang, in Cangzhou, in parts of the Yanshan Mountains, northwest of Shandong, and in Hengshui in Hebei. In addition, no clear correlation was noted between NDVI and climate factors in

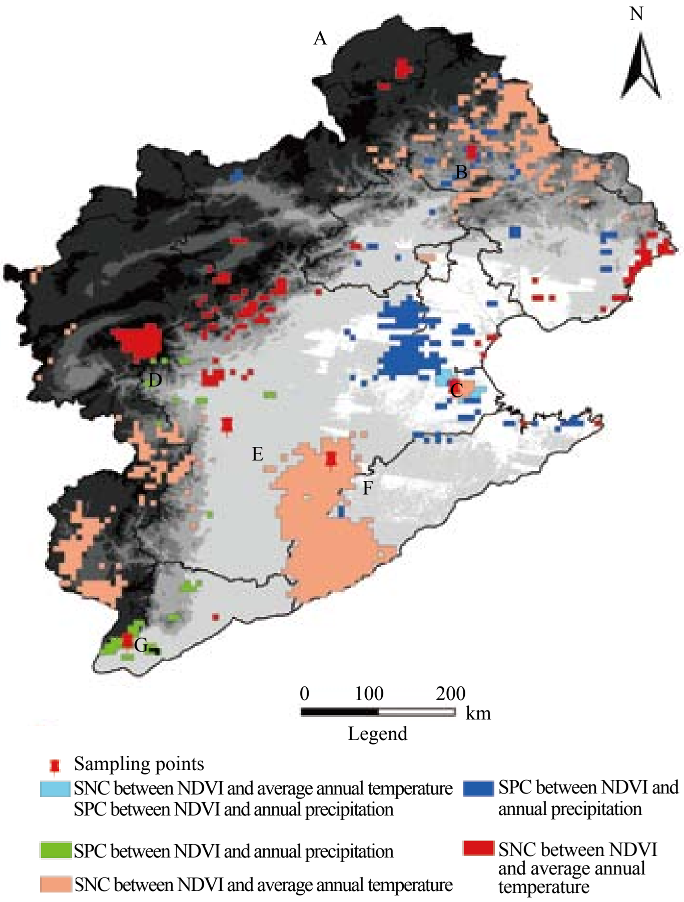


Fig. 4 Location of the sample points
(SNC is significant negative correlation area, SPC is significant positive correlation area, and NSC is the weak correlation areas)

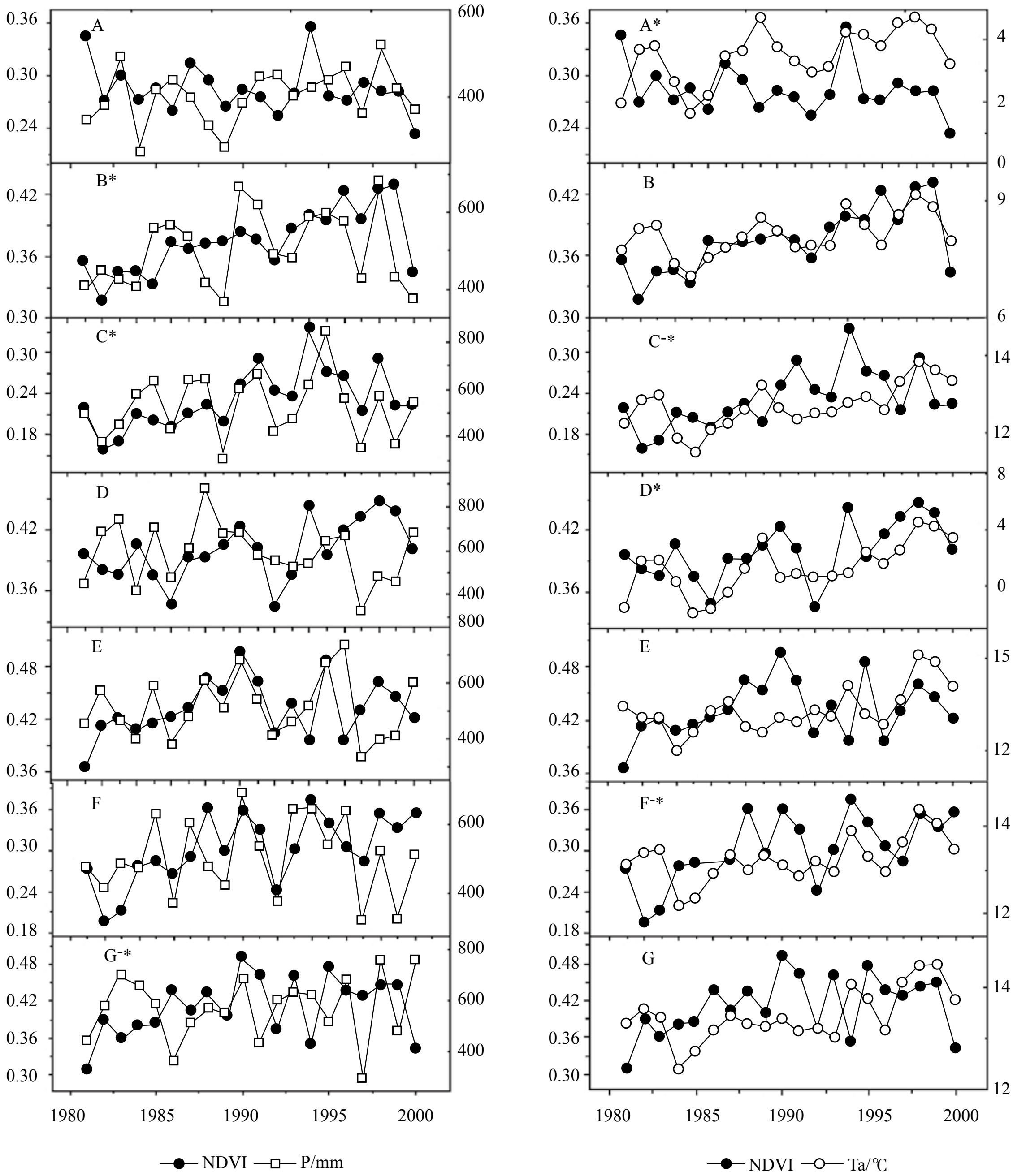


Fig. 5 NDVI of the sample points and the change trend of the climatic factors in Hai Basin
(* Significant positive correlation, -* Significant negative correlation, $N = 20$, $P < 0.05$)

some areas of this basin, such as the negative relationship of NDVI and precipitation in the southern end of the Taihang Mountains, which needs further research.

REFERENCES

Chen Y H, Li X B and Shi P J. 2002. The image forms of correlation between NDVI change and climate factors in China using remotely sensed data. *Journal of Image and Graphics*, **7**(4): 332–335

Dai J H, Pan Y, Cui H T, Tang Z Y, Liu H Y and Cao Y L. 2005. Impacts of climate change on alpine vegetation on Wutai mountains. *Quaternary Sciences*, **25**(2): 216–223

Field R R, Behrenfeld M J and Randerson J T. 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. *Science*, **281**(5374): 237–240

Gómez-Mendoza L, Galicia L and Cuevas-Fernández M L. 2007. Assessing onset and length of greening period in six vegetation types in Oaxaca, Mexico, using NDVI-precipitation relationships. *Biometeorol*, **52**(6): 511–520

Guo Z X, Wang Z M and Song K S. 2007. Correlations between forest vegetation NDVI and water/thermal condition in Northeast China forest regions in 1982—2003. *Chinese Journal of Ecology*, **26**(12): 1930–1936

He S J, Li X B and Liu S H. 2002. Beach resource characteristics and development model in Bohai Rim. *Progress in Geography*, **21**(1): 25–34

Keeling C D, Chin J F S and Whorf T P. 1996. Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. *Nature*, **382**: 146–149

Li H J, Zheng L, Lei Y P, Li C Q, Liu Z J and Zhang S W. 2008. Estimation of water consumption and crop water productivity of winter wheat in North China Plain using remote sensing technology. *Agricultural Water Management*, **95**(11): 1271–1278

Liu G H and Fu B J. 2001. Effects of global climate change on forest ecosystems. *Journal of Natural Resources*, **16**(1): 71–78

Melillo J M, Mcguire A D and Kicklighter D W. 1993. Global climate change and terrestrial net primary production. *Nature*, **363**: 234–240

Meng M, Ni J and Zhang Z G. 2004. Aridity index and its Applications in GEO-ECOLOGICAL study. *Chinese Journal of Plant Ecology*, **28**(6): 853–861

Nemani R R, Keeling C D and Hashimoto H. 2003. Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, **300**(5625): 1560–1563

Piao S L and Fang J Y. 2001. Dynamic vegetation cover change over the last 18 years in China. *Quaternary Research*, **21**(4): 294–302

Ryutaro Tateishi. 2001. Twenty-year Global 4-minute AVHRR NDVI Dataset of Chiba University. Center for Environmental Remote Sensing (CEReS) Chiba University

Solomon S, Qin D and Manning M. 2007. Climate Change 2007: The Physical Science Basis. New York: Cambridge University Press

Song Y and Ma M G. 2008. Variation of AVHRR/NDVI and its relationship with climate in Chinese arid and cold regions. *Journal of Remote Sensing*, **12**(3): 500–505

Wang H, Li X, Li X B, Yu F, Yu H J and Yang H. 2005. Torrelation between meteorological factors and NDVI in Northeastern China. *Journal of Beijing Normal University* (*Natural Science*), **41**(4): 425–430

Wang J, Meng J J and Cai Y L. 2008. Assessing vegetation dynamics impacted by climate change in the southwestern karst region of China with AVHRR NDVI and AVHRR NPP time-series. *Environ Geol*, **54**(6): 1185–1195

Wang J, Price K P and Rich P M. 2001. Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains. *Remote sensing*, **22**(18): 3827–3844

Wang J, Rich P M and Price K P. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing*, **24**(11): 2345–2364

Weltzin J F, Loik M E and Schwinning S. 2003. Assessing the response of terrestrial ecosystems to potential changes in precipitation. *Bioscience*, **53**(10): 941–952

Zhang S J, Wang T, Wang T M, Lu A G and Ge J P. 2009. The variations in NDVI of different vegetation types in Xinjiang and its relation to climate factors. *Pratacultural Science*, **26**(5): 26–31

Zhang X X, Ge Q S and Zheng J Y. 2005. Impacts and lags of global warming on vegetation in Beijing for the last 50 years based on remotely sensed data and phonological information. *Chinese Journal of Ecology*. **24**(2): 123–130

Zhao Y S. 2004. The Principle and Method of Analysis of Remote Sensing Application. Science Press

海河流域NDVI对气候变化的响应研究

陈福军[1, 2]，沈彦俊[2]，胡乔利[1, 2]，齐永青[2]，张玉翠[2, 3]

1. 河北师范大学 资源与环境科学学院，河北 石家庄 050016；
2. 中国科学院 遗传与发育生物学研究所农业资源研究中心，河北 石家庄 050021；
3. 中国科学院 研究生院，北京 100049

摘　要：以海河流域为研究区，利用8 km分辨率AVHRR/NDVI数据和气象资料，逐像元对1981—2000年时段的流域NDVI值、年降水量和年均气温的变化率进行分析，计算了NDVI和年降水量、年均气温的相关关系。结果表明，1981—2000年时段内，海河流域年降水量变化总体呈现北部和南部增加，中部减少的趋势，其变化范围在-80 mm/10a—80 mm/10a之间。全流域气温均呈上升趋势，其中五台山地区上升最显著，达2 ℃/10 a左右。NDVI在京、津等大城市周围显著减小，变化率达-0.8/10 a，在流域东南部平原及燕山部分山区增加趋势明显，达到0.8/10 a左右。NDVI与降水、气温的相关关系空间差异明显。在海河流域冷湿区，如滦河上游草原区和五台山地区，植被指数对降水变化不敏感，与气温呈显著正相关关系。太行山南端暖湿气候环境中，降水增多影响植被生长。海河流域东部沿海平原及燕山北部等干燥环境下，NDVI与降水呈正相关关系，与气温呈显著负相关性，而在山前平原农灌区，作物对气候因子变化响应不敏感。

关键词：NDVI，气候变化，气温，降水，海河流域

中图分类号：TP79　　　**文献标志码：**A

引用格式：陈福军，沈彦俊，胡乔利，齐永青，张玉翠．2011．海河流域NDVI对气候变化的响应研究．遥感学报，**15**(2): 401–414
Chen F J, Shen Y J, Hu Q L, Qi Y Q and Zhang Y C. 2011. Responses of NDVI to climate change in the Hai Basin. *Journal of Remote Sensing*, **15**(2): 401–414

1　引　言

工业化以来，随着全球范围内化石燃料的广泛利用，大量CO_2等温室气体排入大气，导致了气温上升、环境污染等一系列严重问题（Solomon 等，2007）。近年来，人类活动所引起的全球气候变化及其对生态系统的影响，越来越受到广泛关注（国志兴 等，2007）。地表植被是陆地生态系统的主体，它对于生物量生产、生态功能调节、全球碳平衡维护等具有重要作用。气候变化会从温度、水分、日照和光强等方面引起地表植被的变化，进而影响区域生物量生产和生态系统构成等。因此，对地表植被变化与气候要素的关系进行研究，对于认识区域植被生产对气候变化的响应具有重要意义。

以往的研究证实全球尺度或区域尺度植被变化与气候因子变化存在相关关系（Melillo 等，1993；Keeling 等，1996；Field 等，1998；Nemani 等，2003；Weltzin 等，2003），在气候因子中气温和降水是影响生态系统的特点及其分布的最显著因素（刘国华 等，2001）。由遥感影像数据计算获得的NDVI（归一化植被指数）是目前监测区域或全球植被及生态系统的常用指标之一，是反映植被生长状况和覆盖度的最佳指示因子（张学霞 等，2005；赵英时，2004）。因其在时间和空间上的连续性，与植被吸收的光合有效辐射、植被绿度、生物固碳量和植被覆盖度等参数有很好线性关系，因而被广泛应用于植被覆盖特征与气候关系的研究中。近年来，在中国有关NDVI变化和气候因子相关性的研究中，朴世龙和方

收稿日期：2010-03-01；**修订日期：**2010-08-01

基金项目：中国科学院创新项目（编号：KZCX1-YW-08-03-07，KZCX2-YW-448）；水利部公益项目（编号：200801012）；国家科技支撑重点项目（编号：2008BAD95B12）。

第一作者简介：陈福军（1983—　），男，硕士研究生，研究方向为生态环境遥感与GIS，E-mail:cfjgis@126.com。

通信作者：沈彦俊，E-mail:yjshen@sjziam.ac.cn。

精云（2001）利用NOAA-AVHRR/NDVI数据分析了中国18年（1982年—1999年）植被覆盖动态变化，结果表明，西北干旱地区NDVI的下降趋势明显，中国珠江三角洲和长江三角洲地区是18年间植被覆盖下降趋势最明显的地区，这表明了快速城市化的影响。陈云浩等人（2002）研究了中国NDVI变化对气候因子响应的区域分异规律，认为东北地区、内蒙古东部以及青藏高原对年均降水的敏感度较高，而华南、黄淮地区和新疆西部对年均气温的敏感度较高。宋怡、马明国（2008）则发现中国寒区、旱区植被变化与降水、气温呈现正相关关系。王宏等人（2005）的研究进一步发现：在中国东北森林地区，不同森林类型对气候因子变化的响应有较大差异。而张生军人等（2009）的研究结果表明：新疆地区春季植被NDVI与温度关系密切，夏季植被NDVI与降水呈显著正相关关系，秋季NDVI的变化是温度和降水量共同作用的结果。

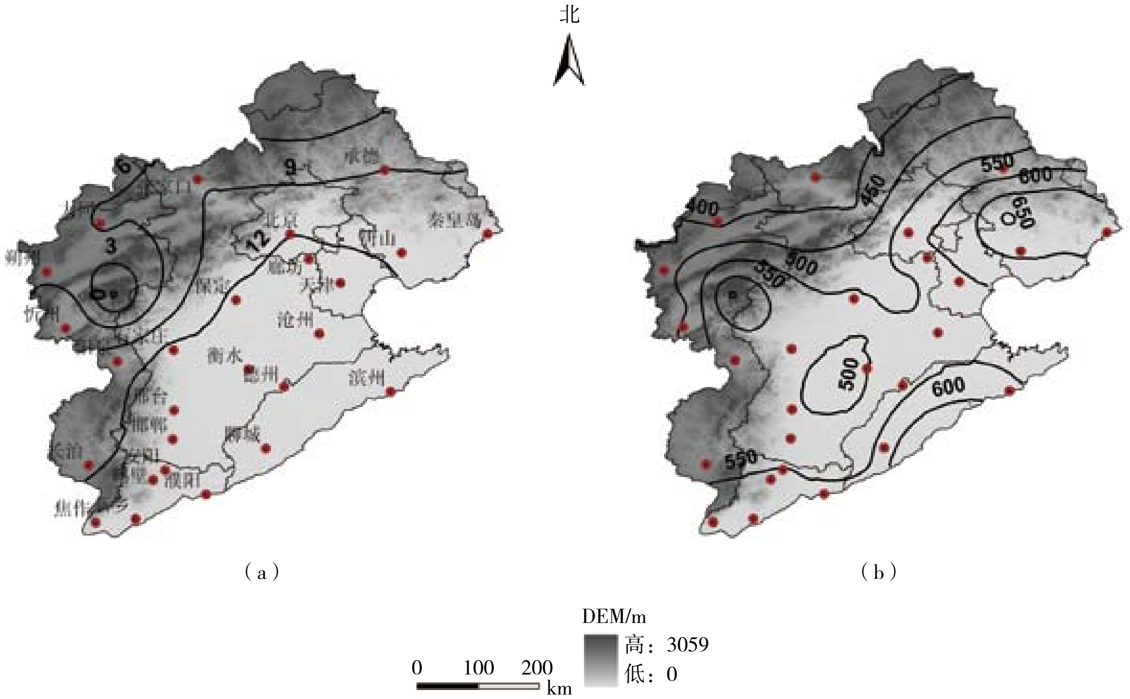
海河流域是中国人类活动最剧烈、生态环境严重恶化的地区之一，是中国的政治经济中心，也是华北地区的重要粮食产地。流域植被变化会对本区生态系统及农业生产带来重大影响，开展海河流域气候因子变化与NDVI变化关系研究，预测地表植被（NDVI）变化，对于区域植被生产力估测、生物固碳过程、生态系统结构和功能评价等研究工作具有参考价值。

利用1981年—2000年间的NOAA/AVHRR的NDVI数据和海河流域及周边67个台站的气象观测资料，分析了流域植被指数和主要气候因子的相关关系，研究了流域内植被对气候因子变化响应的空间格局，可为海河流域生态环境建设提供科学支撑。

2 研究区与研究方法

2.1 海河流域

海河流域位于112° E—120° E，35° N —43° N之间，总面积31.8万 km^2，属温带半湿润、半干旱大陆性季风气候，多年平均气温0℃—14.5℃之间，由南向北、由平原向山地降低，最冷点出现在北部坝上高原和五台山地区（图1(a)）。流域多年平均降水量从东南部的600—650 mm向西北逐渐减少到350—400 mm，多年平均降水量535 mm，是中国东部沿海降水量最少的地区，受山地地形影响，在五台山和唐山遵化附近迎风坡形成两个年降水量大于600 mm的多雨区域，沿弧形山脉向两侧减少（图1(b)）。海河流域作为中国重要政治经济和文化中心，总人口达到1.26亿，GDP占中国的13%，粮食产量约占全国的



（a） （b）

图1 海河流域20年平均降水量及平均气温等值线图

（a）1981年—2000年均温（等值线——（℃））；（b）1981年—2000年降水（等值线——（mm））

10%；流域内人类活动强烈，天然植被大都遭人为破坏，平原区植被以农作物为主，仅山区有少量自然植被，天然次生林主要分布在海拔1000 m以上范围。太行山迎风坡由于存在年降水量600 mm以上的弧形多雨带，植被生长良好。燕山、太行山背风坡由于山脉阻隔，年降水量400 mm左右，植被稀疏，生态系统脆弱。

2.2 数据与方法

2.2.1 NDVI和气象数据

本研究采用1981年至2000年8 km分辨率的逐旬AVHRR/NDVI数据（Ryutaro，2001），使用最大值合成法（MVC）求出逐月最大NDVI，然后计算年平均值，与气候因子之间进行相关性分析。基于1981年—2000年海河流域及周边67个站点的气象数据，对海河流域进行年均气温和年降水量的空间插值，得到分辨率为8 km × 8 km的流域1981年—2000年逐年平均气温和降水量分布。

2.2.2 研究方法

应用一元线性回归分析法分析海河流域不同地区1981年—2000年植被NDVI、年降水量和年均温的变化，单个像元的回归方程中趋势线斜率即为年际变化率。为研究植被NDVI与年降水量和年均温的相关关系，逐像元分别对NDVI与标准化的降水、气温数据作相关分析，并对结果进行显著性检验（Wang和Meng 等，2008；Wang和Rich 等，2003；Mendoza 等，2008；Wang 等，2001）。

3 结果与分析

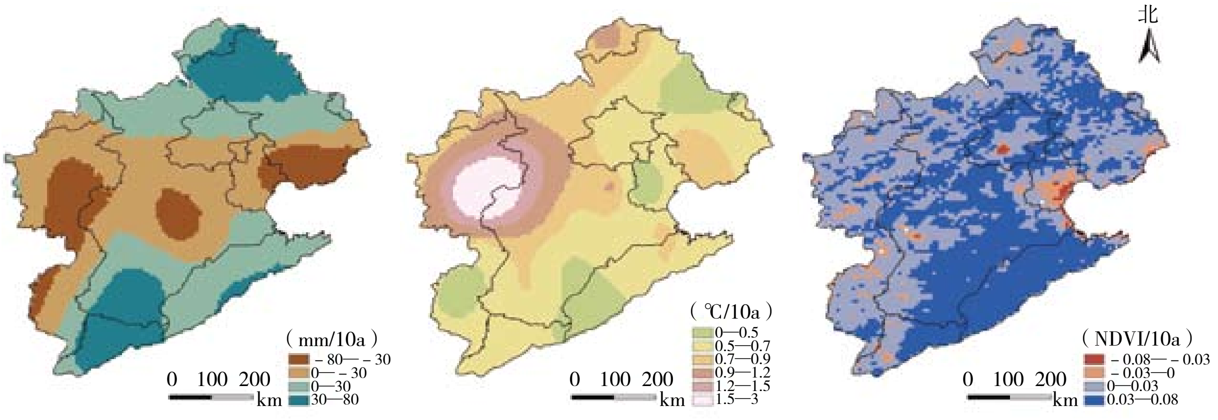
3.1 流域尺度NDVI、气温和降水的变化趋势

为研究上述各要素变化的空间分异特征，采用最小二乘法逐像元计算了流域内年降水量、气温和NDVI的线性变化率并分析其显著性。流域南部和北部地区年降水量增加，年际变化率平均可达到30—80 mm/10 a；在东部沿海、西部山区和中部一些地区年降水量减少，某些地区达–30 mm/10 a（图2(a)）。海河全流域气温呈上升趋势（图2(b)），流域东北和西南地区升幅小，变化率为0.6℃/10 a左右；五台山地区升幅最大，达2℃/10 a左右。流域大部分区域，NDVI值呈增加趋势（图2(c)），东南部平原和燕山山区NDVI值增幅明显；北京、天津、石家庄和唐山等大城市及周边由于建设面积扩大，NDVI出现负变化；流域北部滦河上游草原区和太行山背风坡个别地区也呈现了NDVI减少趋势。

3.2 NDVI与降水、气温间相关性的空间分析

为研究NDVI对降水、气温变化的响应，采用最小二乘法逐象元计算了NDVI与降水、气温的线性相关，并在优势度0.05水平上评价其显著性。图3为NDVI与降水、气温显著相关区域的空间分布。

如图3a所示，海河流域降水与NDVI显著正相关的区域主要分布在东部海拔<10 m的低平原区，该地区分布大片盐碱地，地下浅层为咸水，无法用于灌溉，大多属于雨养农业（何书金 等，2002），植被



(a) (b) (c)

图2 海河流域气候因子及NDVI变化率图

（a）年降水量变化率；（b）年均温变化率；（c）NDVI变化率

生长状况受年降水量影响明显。另一与降水正相关的区域分布在燕山东部山地，该地区多为自然林地，气候环境干燥，植被生长与降水关系密切。五台山地区年降水量与NDVI出现较强负相关，但年均温与NDVI呈显著正相关。这是因为五台山地区降水量大，水分不是植被生长的主要限制因子，但海拔高、气温低，植被生长对温度变化更为敏感（戴君虎 等，2005）。太行山南端区域NDVI与年降水量呈显著负相关，从图1和2可知，该区域降水丰富且增加趋势显著，为温湿环境，NDVI与降水呈负相关。太行山山前平原及流域东南部引黄灌区，是海河流域最主要的农作区，灌溉保障率较高，农作物生产水平稳定提高（Li 等，2008），因此，其NDVI年际变化与降水量关系不大。

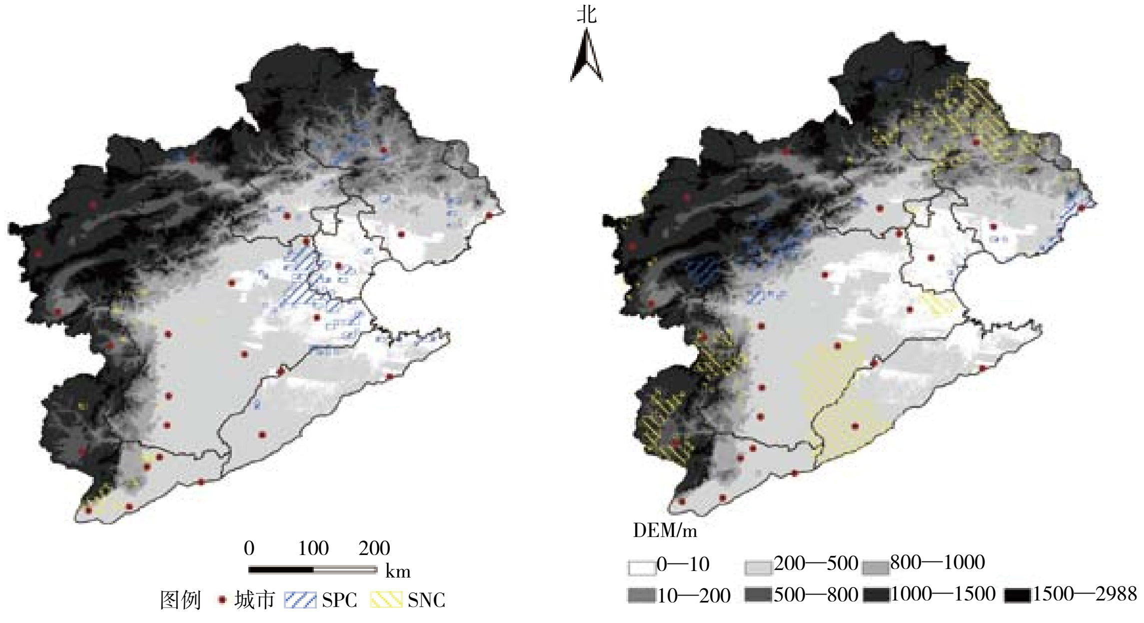
从总体来看，NDVI和气温相关性的空间分布格局与降水大致呈相反趋势（图3b）。NDVI和气温呈显著正相关的地区主要分布在五台山和滦河上游草原区，以及秦皇岛、唐山东部沿海地区。这些山区年均气温较低，气温升高可促进植被生长；唐山、秦皇岛沿海地区以稻作为主，气温升高对水稻生长也有利。燕山北部和太行山南段中低山区的植被主要依靠雨养，气温升高加剧地表水分蒸发，而影响植被生长。因此，NDVI与气温呈显著负相关关系。从鲁西北的引黄灌区到河北衡水地区NDVI和气温也存在着显著负相关性，可能与该地区1981年—2000年的20年内农业生产条件改善（包括灌溉、盐碱治理和品种改良等）使NDVI上升明显，但同期气温上升不显著（见图2）有关。河北省沧州东部的南大港湿地区，气温升高会加速表层土壤失水，影响植被生长，因此，该地区NDVI与年均温呈显著负相关。

3.3 样点分析

为了更好地解释研究区内NDVI对气候因子变化不同响应的空间分布规律，在海河流域选取了A—G 7个典型样点（图4）深入分析。各样点气候、植被、高程等自然要素如表1所示。其中，干燥度指数采用De Martonne （1926）提出的一种利用温度与降水这两个气候因子计算气候干燥度的简单方法（孟猛 等，2004）：

$$I_{\mathrm{dM}} = \frac{p}{t+10} \qquad (1)$$

式中，I_{dM}即为De Martonne干燥度，p为平均降水量，t为平均温度值。干燥度小于10，表明严重干旱，河流断流，农作物需要强制人工灌溉；干燥度值在10—30之间，表明中等干旱，河流暂时性有水，流量中等，植被类型为草原；干燥度大于30，表明气候润，河流常年有水，不断流，并水量充足，植被类型为森林。I_{dM}因为计算简单，指标明确，与植被水分对应性强，常用于大尺度气候区划。



(a) (b)

图3 基于像元的年降水量、年均气温与NDVI相关关系空间分布图

（SNC为显著负相关区，SPC为显著正相关区，NSC为弱相关区）

（a）NDVI与年降水量相关性；（b）NDVI与年均温相关性

表 1　各样点气候、植被、DEM等要素状况

样点	A	B	C	D	E	F	G
所在地	多伦	滦平	黄骅	五台山	栾城	枣强	云台山
NDVI与降水量相关性	0.14	0.44	0.41	–0.3	–0.23	0.01	–0.48
NDVI与年均温相关性	0.46	–0.13	–0.42	0.5	–0.21	–0.62	0.08
地形	草原	山地	平原	山地	平原	平原	山地
下垫面状况	草地	林地	盐碱地	林地	水浇地	水浇地	林地
高程/m	1258	726	13	1145	53	27	175
年降水量/mm	400.8	500.7	526.1	584.6	508.7	503.7	569.9
年均温/℃	3.5	8.1	12.7	1.2	13.3	13.2	13.4
NDVI均值	0.28	0.37	0.23	0.40	0.43	0.30	0.41
年降水变化率/(mm/a)	3.29	3.42	1.45	–4.87	1.09	0.09	2.97
年均温变化率/(℃/a)	0.085*	0.05	0.07	0.22	0.08**	0.05*	0.06
NDVI变化率/(NDVI/a)	–0.017**	0.045*	0.049	0.030	0.024	0.067	0.012
干燥度指数	29.7	27.7	23.2	52.2	21.8	21.7	24.3

注：时间1981年—2000年，*显著性水平$P<0.05$，**显著性水平$P<0.01$

其中样点A位于滦河上游，该区域海拔高，年降水量少，气温低，植被多为高原草地。结合干燥度指数和图5中点A分析，该点处于冷湿气候环境，植被对降水变化不敏感，但和气温变化呈显著正相关关系。B点下垫面为燕山自然林地，环境较A点干燥，降水有利于植被生长（图5中点B）。C点位于河北省黄骅市，盐碱地环境对农作物生长影响严重，加之该地区气候干燥，地下水无法用于灌溉，植被与降水呈显著正相关与气温为显著负相关关系（图5中点C）。D、G点下垫面均为太行山林地，降水丰富，环境湿润。D点年均温低，植被指数随年均温变化明显（图5中点D），G点降水量大，气温较高，植被对气温变化不敏感，但过多降水对于湿润环境下植被生长有不利影响（图5中点D和G）。E、F点位于太行山山前平原区，为华北主要粮食产地，该区域气候干燥（表1），降水减少或气温上升会加重旱情，粮食减产。E、F点均为水浇地，但F点地下水水位深，沙质土壤，表土层水分散失迅速，所以F点作物对于气温变化呈显著负相关关系，而处于农灌区的E点作物对气候因子变化响应不大（图5中点E和F）。

综上所述，在海河流域冷湿区，如滦河上游草原区、五台山地区，植被指数对降水变化不敏感，与气温呈显著正相关关系。太行山南端暖湿气候环境中，降水增多影响植被生长。海河流域东部沿海平原及燕山北部等干燥环境下，NDVI与降水呈正相关关系或与气温呈显著负相关性。而在山前平原农灌区，作物对气候因子变化响应不敏感。

4　结　论

1981年—2000年时段内，海河流域年降水量变化总体呈现北部和南部增加，中部减少的趋势，其变化范围在–80 mm/10 a–80 mm/10 a之间。全流域气温均呈上升趋势，其中五台山地区上升最显著，达2℃/10 a左右。NDVI在京、津等大城市周围显著减小，变化率达–0.8/10 a，在流域东南部平原及燕山部分山区增加趋势明显，达到0.8/10 a左右。

NDVI与降水、气温的相关关系空间差异明显。NDVI与降水在太行山南段部分地区呈显著负相关，东部沿海地区和燕山部分山地等环境暖干区呈显著正相关。而NDVI与气温在五台山、滦河上游草原区和唐

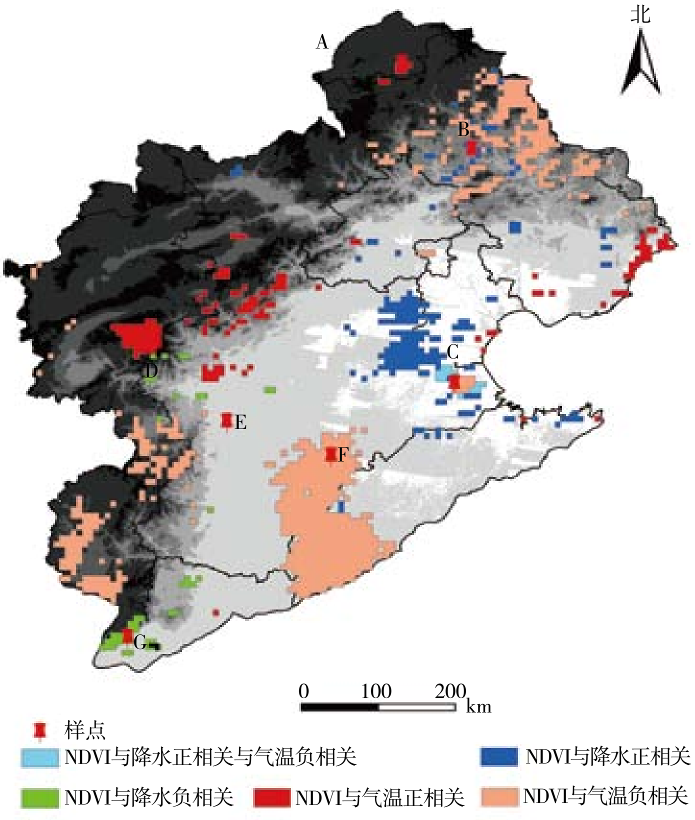


图4　样点位置

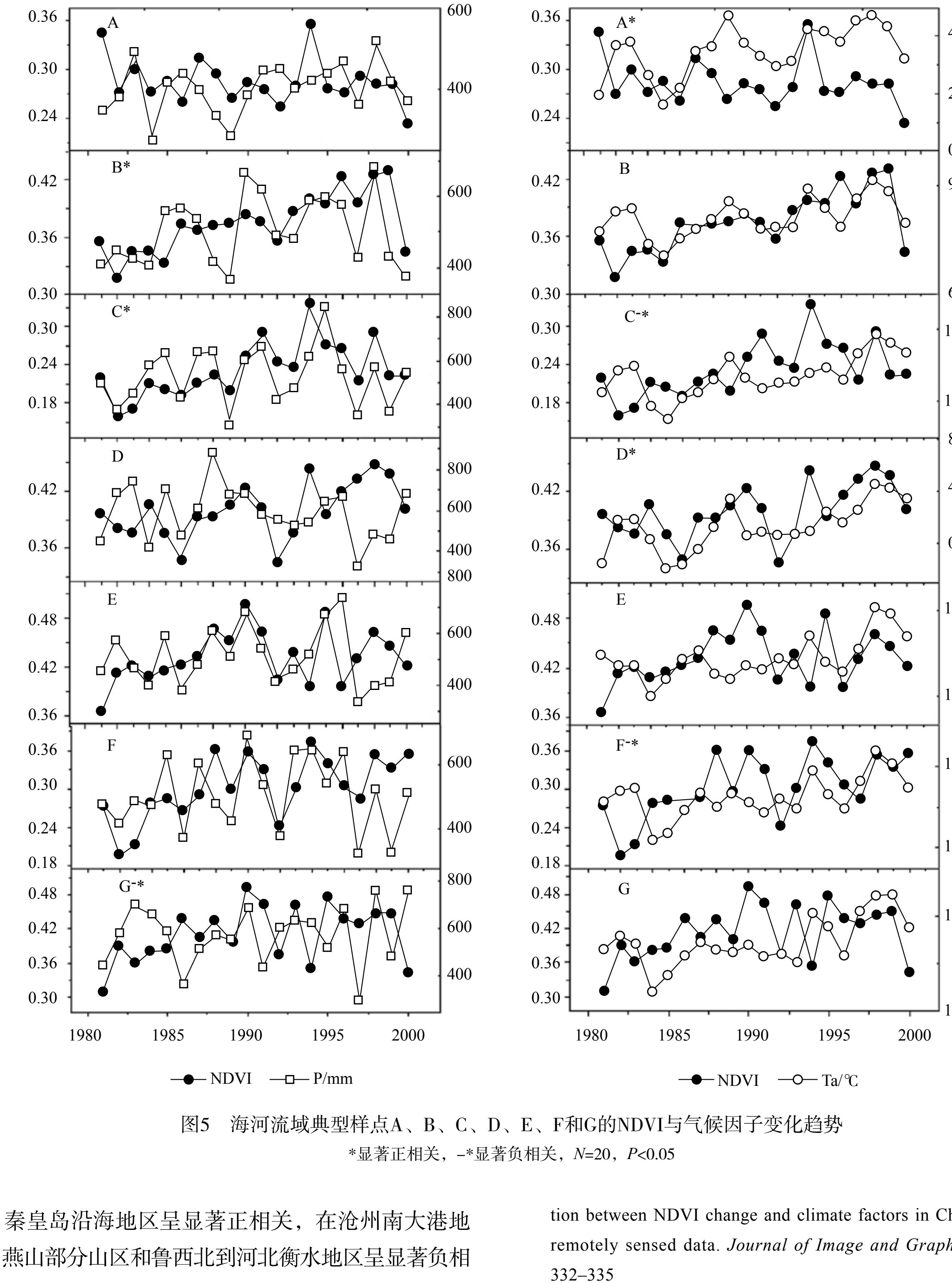


图5 海河流域典型样点A、B、C、D、E、F和G的NDVI与气候因子变化趋势

*显著正相关，-*显著负相关，N=20，P<0.05

山、秦皇岛沿海地区呈显著正相关，在沧州南大港地区、燕山部分山区和鲁西北到河北衡水地区呈显著负相关。另外，本研究对海河流域内某些地区NDVI与气候因子的相关关系尚无法做出明确解释，比如太行山南段NDVI与降水显著负相关等，有待于今后进一步研究。

REFERENCES

Chen Y H, Li X B and Shi P J. 2002. The image forms of correlation between NDVI change and climate factors in China using remotely sensed data. *Journal of Image and Graphics*, **7**(4): 332–335

Dai J H, Pan Y, Cui H T, Tang Z Y, Liu H Y and Cao Y L. 2005. Impacts of climate change on alpine vegetation on Wutai mountains. *Quaternary Sciences*, **25**(2): 216–223

Field R R, Behrenfeld M J and Randerson J T. 1998. Primary production of the biosphere: integrating terrestrial and oceanic components. *Science*, **281**(5374): 237–240

Gómez-Mendoza L, Galicia L and Cuevas-Fernández M L. 2007. Assessing onset and length of greening period in six vegetation types in Oaxaca, Mexico, using NDVI-precipitation relationships. *Biometeorol*, **52**(6): 511–520

Guo Z X, Wang Z M and Song K S. 2007. Correlations between forest vegetation NDVI and water/thermal condition in Northeast China forest regions in 1982–2003. *Chinese Journal of Ecology*, **26**(12): 1930–1936

He S J, Li X B and Liu S H. 2002. Beach resource characteristics and development model in Bohai Rim. *Progress in Geography*, **21**(1): 25–34

Keeling C D, Chin J F S and Whorf T P. 1996. Increased activity of northern vegetation inferred from atmospheric CO_2 measure–ments. *Nature*, **382**: 146–149

Li H J, Zheng L, Lei Y P, Li C Q, Liu Z J and Zhang S W. 2008. Estimation of water consumption and crop water productivity of winter wheat in North China Plain using remote sensing technology. *Agricultural Water Management*, **95**(11): 1271–1278

Liu G H and Fu B J. 2001. Effects of global climate change on forest ecosystems. *Journal of Natural Resources*, **16**(1): 71–78

Melillo J M, Mcguire A D and Kicklighter D W. 1993. Global climate change and terrestrial net primary production. *Nature*, **363**: 234–240

Meng M, Ni J and Zhang Z G. 2004. Aridity index and its Applications in GEO-ECOLOGICAL study. *Chinese Journal of Plant Ecology*, **28**(6): 853–861

Nemani R R, Keeling C D and Hashimoto H. 2003. Climate-driven increases in global terrestrial net primary production from 1982 to 1999. *Science*, **300**(5625): 1560–1563

Piao S L and Fang J Y. 2001. Dynamic vegetation cover change over the last 18 years in China. *Quaternary Research*, **21**(4): 294–302

Ryutaro Tateishi. 2001. Twenty-year Global 4-minute AVHRR NDVI Dataset of Chiba University. Center for Environmental Remote Sensing (CEReS) Chiba University

Solomon S, Qin D and Manning M. 2007. Climate Change 2007: The Physical Science Basis. New York: Cambridge University Press

Song Y and Ma M G. 2008. Variation of AVHRR/NDVI and its relationship with climate in Chinese arid and cold regions. *Journal of Remote Sensing*, **12**(3): 500–505

Wang H, Li X, Li X B, Yu F, Yu H J and Yang H. 2005. Torrelation between meteorological factors and NDVI in Northeastern China. *Journal of Beijing Normal University* (*Natural Science*), **41**(4): 425–430

Wang J, Meng J J and Cai Y L. 2008. Assessing vegetation dynamics impacted by climate change in the southwestern karst region of China with AVHRR NDVI and AVHRR NPP time-series. *Environmental Geology*, **54**(6): 1185–1195

Wang J, Price K P and Rich P M. 2001. Spatial patterns of NDVI in response to precipitation and temperature in the central Great Plains. *Remote sensing*, **22**(18): 3827–3844

Wang J, Rich P M and Price K P. 2003. Temporal responses of NDVI to precipitation and temperature in the central Great Plains, USA. *International Journal of Remote Sensing*, **24**(11): 2345–2364

Weltzin J F, Loik M E and Schwinning S. 2003. Assessing the response of terrestrial ecosystems to potential changes in precipitation. *Bioscience*, **53**(10): 941–952

Zhang S J, Wang T, Wang T M, Lu A G and Ge J P. 2009. The variations in NDVI of different vegetation types in Xinjiang and its relation to climate factors. *Pratacultural Science*, **26**(5): 26–31

Zhang X X, Ge Q S and Zheng J Y. 2005. Impacts and lags of global warming on vegetation in Beijing for the last 50 years based on remotely sensed data and phonological information. *Chinese Journal of Ecology*. **24**(2): 123–130

Zhao Y S. 2004. The Principle and Method of Analysis of Remote Sensing Application. Science Press

附中文参考文献

陈云浩，李晓兵，史培军. 2002. 基于遥感的NDVI与气候关系图式研究. 中国图象图形学报，**7**(4): 332–335

戴君虎，潘嫄，崔海亭，唐志尧，刘鸿雁，曹燕丽. 五台山高山带植被对气候变化的响应. 第四纪研究，**20**(2): 216–223

国志兴，王宗明，宋开山. 2007. 1982—2003年东北林区森林植被NDVI与水热条件的相关分析. 生态学杂志，**26**(12): 1930–1936

何书金，李秀彬，刘盛和. 2002. 环渤海地区滩涂资源特点与开发利用模式. 地理科学进展，**21**(1): 25–34

刘国华，傅伯杰. 2001. 全球气候变化对森林生态系统的影响. 自然资源学报，**16**(1): 71–78

孟猛，倪健，张治国. 2004. 地理生态学的干燥度指数及其应用评述. 植物生态学报，**28**(6): 853–861

朴世龙，方精云. 2001. 最近18年来中国植被覆盖的动态变化. 第四纪研究，**21**(4): 294–302

宋怡，马明国. 2008. 基于GIMMS AVHRR NDVI数据的中国寒旱区植被动态及其与气候因子的关系. 遥感学报，**12**(3): 500–505

王宏，李霞，李晓兵，喻锋，余弘婧，杨华. 2005. 中国东北森林气象因子与NDVI的相关关系. 北京师范大学学报(自然科学版），**41**(4): 425–430

张生军，王涛，王天明，卢爱刚，葛剑平. 2009. 新疆不同植被NDVI的变化及其与气候因子的关系. 草业科学，**26**(5): 26–31

张学霞，葛全胜，郑景云. 2005. 近50年北京植被对全球变暖的响应及其时效：基于遥感数据和物候资料的分析. 生态学杂志，**24** (2): 123–130

赵英时. 2004. 遥感应用分析原理与方法. 北京：科学出版社