RESPONSE CHARACTERISTIC ANALYSIS OF CLIMATE CHANGE OF VEGETATION ACTIVITY IN HUANGHE-HUAIHE-HAIHE ZONE BASED ON NOAA NDVI DATA SET

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KEY WORDS: NDVI; Climate Change; Green Wave; Brown Wave; Huanghe-Huaihe-Haihe (HHH) Zone

ABSTRACT:

The article, using the each ten day's data of NOAA/AVHRR from 1981 to 2000 and adopting the Maximum-Slope Method and Curve-Fitting Method, analyzes the beginning and ending of the growth season of the vegetations in the Huanghe-Huaihe-Haihe (HHH) zone. Meanwhile, the pixel by pixel NDVI map is worked out with typical bands as the sample. The article, through researching on the change of green wave and brown wave, reveals the changing rules of vegetation activities and its response to climate changes in the past 20a. According to the researches, the growth season in the HHH zone starts at the last 10 days of March and ends at the first 10 days of November on average. The average NDVI for the vegetations in the researched area in the past 20 years is generally increasing, especially in Spring. With the time passing by, the green wave of the critical value of the growth season in the area changes from south to north, while the emergence of brown wave prolongs from north to south. As the main response of the vegetation activities in the area to climate changes, the growth season of the vegetation happens ahead in the HHH zone.

1. FOREWORD

Vegetation, as the main composition of the land eco-system, is regarded as the most important parameter for environmental evaluation and monitoring because of its special role in the cross research of land circle-biological circle-air circle. Plants as well as its colony share the most sensitive response and the most complete expression to the effect of the nature, embodied not only in changes of vegetations and their species, coverage and biomass, but also in the annual and seasonal alternations which are unique for vegetations[1].

Many researchers, using the character of vegetations, adopt the macro remote sensing data to monitor the changes of vegetations to reflect climate changes and its effect. Meanwhile, due to the altitude difference of the global surface, the response of vegetations to the global changes are greatly characterized with the rule of territorial differentiation and different timing standards[2]. According to the researches, the growth season of plants is changing with the worsening of green effect. Many types of plants are changing their synchronous activities concerning with the coming of Spring and Autumn to adapt themselves to green effect, so their growth seasons are going to be prolonged. In the past over 20 years, the vegetation activities in the medium and high latitude regions of the Northern Hemisphere, especially the areas between 40°N~70°N in Asia and North America, are greatly increased, which is indicated by the fact that for the vegetations in the high latitude areas from 1981 to 1991, their growth season was 8d ahead and declining season was 4d behind. The increasing temperature in Spring is considered to the factor which brings longer growth season to the vegetations in the high latitude areas [2]. With the worsening of green effect, the growing activities of vegetations are strengthened and the beginning of their growth season is also much earlier than before[3]. The following reasons are considered to be the main factors deciding the changes: 1. Due to the increasing of CO_2 concentration and temperature as well as the sedimentation of N and P, the swing of vegetation activities is enlarged in season changes; 2. Due to the worsening green effect, the growth season of vegetations is brought forward or delayed[4-6], which means the response of vegetation activities differ from each season. The researches at present mainly focus on the averaged activities of the vegetations in the globe or some regions and the seasonal differences of annual changes of vegetation activities are in great shortage, so it is impossible to clearly state the detailed response expressions of vegetations in different regions to climate changes. The article, adopting the NDVI data of the NOAA/AVHRR Pathfinder Data Sets resulted from the 10d Maximum Value Composite Method in 1982~2000, researches on the changing rules of vegetation activities and its response to climate changes in Huanghe-Huaihe-Haihe (HHH) zone in the past 20a.

2. INTRODUCTION TO THE RESEARCH AREA AND THE SOURCE OF DATA

2.1 Introduction to the research area

The HHH Plain (110°E~123°E，32°N~42°N), located at eastern China, meets Bohai Sea and the Yellow Sea in the east, lies on the Taihang Mountain and the Tongbai Mountain in the west, and reaches the Great Wall in the north and the Huai River in the south. It covers the most territories of Beijing, Tianjin, Hebei, Shandong and Henan in the middle and lower reaches of the Yellow River, Huai River and Hai River, northern Jiangsu, northern Anhui and the Fenwei Basin on the branches on the Yellow River[7] (referring to the Figure 1). According to the China Climate Band Division Map worked out by Zhu Kezhen, Lu Xi, Tu Changwang and Zhang Baokun, the HHH zone belongs to the sub-humid region of the warm-temperature band in north China. According to the China Vegetation Coverage Map, the research area belongs to the defoliation-latifoliate forest area and the defoliation-shrubbery area in the warm-temperature band, with the defoliation-fruit trees which

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are featured with two cultivations in one year or three cultivations in two years as the main agricultural vegetations.

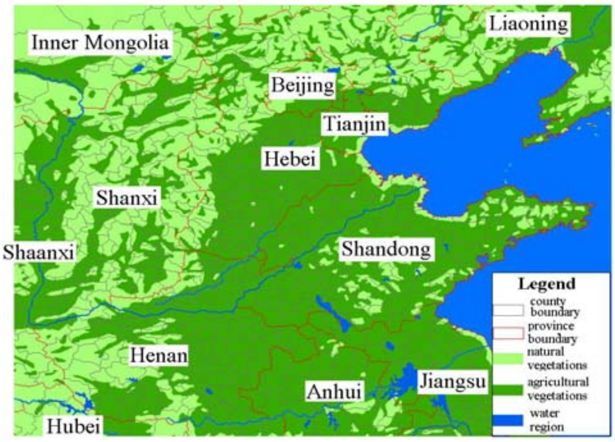


Figure 1 Location of the research area and the types of vegetation coverage

2.2 Source of data and its pre-processing

Vegetation index is one of the most clearly signified indexes in satellite remote sensing. Among various vegetation indexes, NDVI（Normalized Difference Vegetation Index）is able to accurately reflect the coverage, growth, biomass as well as photosynthesis of the vegetations. Therefore, it is always directly or indirectly applied into the researches on vegetation activities [8-10]. It is defined：

$$NDVI = \frac{R_{nir} - R_{vis}}{R_{nir} + R_{vis}} \qquad (1)$$

In the formula, R_{nir} refers to the reflection rate of a subject next to the near infrared waveband and R_{vis} refers to the reflection rate of a subject under visible light. The visible light and near infrared spectrum of the vegetations have totally different assimilation and reflection characters. The near infrared waveband is sensitive to the differences and growth of plants, indicating whether photosynthesis of the plant happens normally. The visible infrared waveband, which is absorbed fiercely by the chlorophyll of vegetations for photosynthesis, is the representative waveband of photosynthesis. NDVI composed of visible light and near infrared waveband has a good relativity with the growth, biomass, coverage and season changes of the vegetations.

The research adopts NOAA NDVI digital image as the remote sensing data, which is widely applied into surface researches due to the sensitivity of NOAA/AVHRR data to the red light and infrared waveband of spectrum. The figure of the first waveband depends on the sensitivity of red light waveband to the assimilation of chlorophyll and other pigments of vegetations, namely, the sensitivity of red light to the photosynthesis of plants. The figure of the second waveband depends on the sensitivity of infrared light to the leaf mesophyll of green leaves[11]. Since NDVI is closely related with the biomass of green plants and the NOAA data has high timing differentiating rate as well as most effective and uniform calibration which assure the accuracy of the data[12], NOAA/NDVI data is widely used not only in the initial calculation of crop planting area, the monitoring of crop growth and the initial calculation of unit productivity, but also in the monitoring of natural vegetations including forests and grasslands, such as the monitoring of the response of growth season to climate changes[13]. What's more, NOAA/NDVI data is irreplaceable in the researches on the activities of vegetations in the globe or some regions[14].

The original data is the projection of GOODE, the space differentiating rate is 8km and the data is the raster field data with equal longitude and latitude. The data mainly records the index information of the vegetations with the information value ranging from 0 to 255 and the size of the raster point 0.072º×0.072º. The data has no unit. The information value refers to the vegetation situation of the spot on the global surface. The data with the timing differentiating rate of ten days, is composed of the maximum vegetation index of each sport in each 10 days and goes through the filtering wave processing with the time order from July, 1981 to December, 2000. The data from Oct. to Dec., 1994 which is missed is replaced by the averages of the corresponseing months in 1993 and 1995 and revised with the figures in other months.
NDVI index is transferred into -1～1 according to the following formula:

$$NDVI=0.008*(nn-128) \qquad (2)$$

In the formula, nn refers to information value of the vegetation.
While pre-processing the data, the programs related will be written with C++ and the original data will be transferred into raster images. According to formula 2, the value of NDVI shall be expressed with the number between -1～1 and then the numbers of NDVI ten days, month and year which are needed by the researches shall be abstracted. Then, the pixel by pixel NDVI data as well as the data on the types of the vegetations in longitude and latitude bands in the research area shall be abstracted on the basis of ArcGIS. After arranging the bands in time sequence, the map will be finally finished.

3. GROWTH SEASON CHANGE OF VEGETATIONS IN HHH ZONE AND THE CHARACTERISTICS OF ITS RESPONSE TO CLIMATE CHANGES

3.1 Division of vegetation growth season

There are many methods for dividing the growth season on the basis of NOAA/AVHRR NDVI data, including the method of confirming the vegetation growth season by NDVI threshold value[15], moving average method[16], averaging method[17], maximum-slope method[18], principal component analysis method[19] and curve-fitting method, which all have their pros and cons[20]. The article, according to the area of the research area and the NDVI changing characteristics within the area, mainly adopts the maximum-slope method and curve-fitting method to confirm the vegetation growth season in HHH zone.
By averaging the NDVI ten day's data in the past 20 years from 1982 to 2000 of the research area, the multi year's and ten day's average changing curve on the growth of vegetation is worked out just as what is shown in figure 2. According to the map, there are 2 maximum values of average NDVI index which are in the 14th and 23rd ten days, namely, the middle ten days of May and August, when vegetations grow most prosperously. After undertaking phase-by-phase multi fittings to the curve, the

beginning and ending time of the growth season and their corresponseent NDVI critical values can be concluded.

The article, adopting the linear regression method to fit the multi years average NDVI ten day's changing curve, has linear regressions to the NDVI in the middle ten days from Jan. to May and Sep. to Dec. According to the fitting result (Figure 3), the relativity indexes of fitting value and actual value is R^2 = 0.9872, and R^2 = 0.9944 respectively, which all pass the prominence test of α=0.001. By undertaking speed changing analysis on the NDVI time changing curve, the 1 rank differential coefficient indicates the changing speed of the vegetation growth season and the 2 ranks differential coefficient shows the changing situation of the changing speed of vegetation growth season. According to the changes of the curve's slope as well as the turning point of the actual changing curve, it is confirmed that the growth season of the vegetation in the research area starts at the 9^{th} ten days (last 10 days of Mar.) and ends at the 31^{st} ten days (first 10 days of Nov.), which is consistent with the Wen Gang's research on the vegetation growth season on north China on the basis of EOF analysis with AVHRR NDVI data[19]. Therefore, the multi year's average NDVI critical values for the beginning and ending times of vegetation growth season in HHH zone are 0.19604 and 0.22899 respectively.

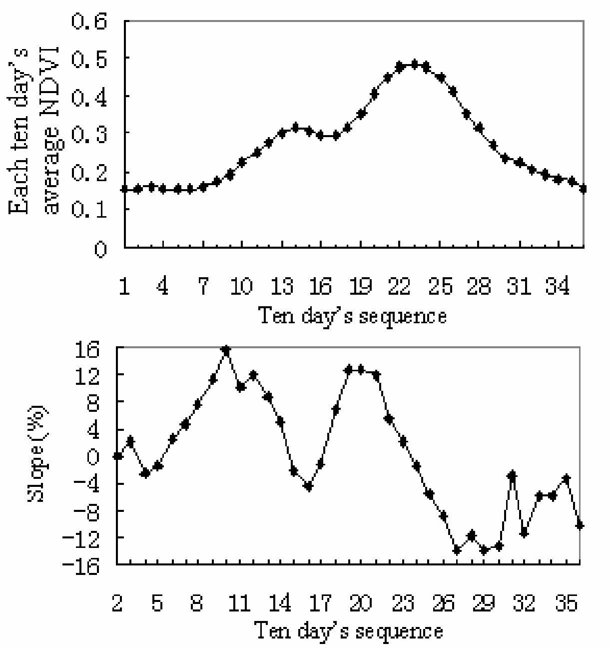


Figure 2 Multi years average NDVI ten day's changing curve (above) and changing slope curve (below)

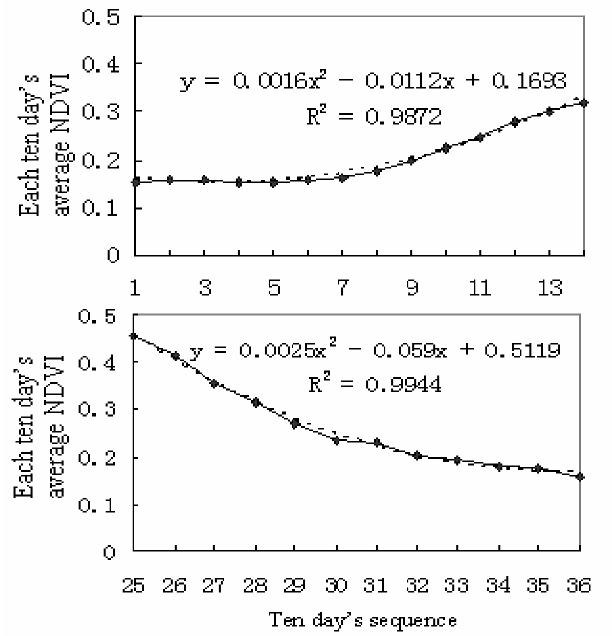


Figure 3 Multi fitting of multi years average NDVI ten day's changing curve

3.2 Annual change of vegetation growth season

With the times when the vegetation NDVI reaches the critical value of growth season in 1982-2000, the changing curve on the beginning and ending time of growth season is worked out just like figure 4 (The time sequence of the data is Jul., 1981-Sep., 2000. Since the annual NDVI in 1995 is higher than 0.2, so the year of 1995 is excluded.) and figure 5 (Since NDVI in the autumns and winters of 1990, 1995 and 1996 are higher than the critical value, the calculation is based on 36^{th} ten days when the critical value emerges.). According to figure 4, the decreasing ten day's value indicates that the growth season begins earlier. According to figure 5, the increasing ten day's value from 1982-2000 shows that the critical value of the growth season emerges later, which means the ending of growth season is also delayed. Therefore, from the aspect of multi year's average value, the growth season starts earlier and ends later in the past 20 years, which means the interval between the beginning and ending of growth season is prolonged. According to the linear changing analysis, the beginning of growth season is 0.23 ten day's (2.3d) ahead for per 10 years and the ending of growth season is 0.86 ten day's behind (8.6d) for per 10 years. In the past 20 years, the growth season is prolonged for nearly 10.9d for per 10 years.

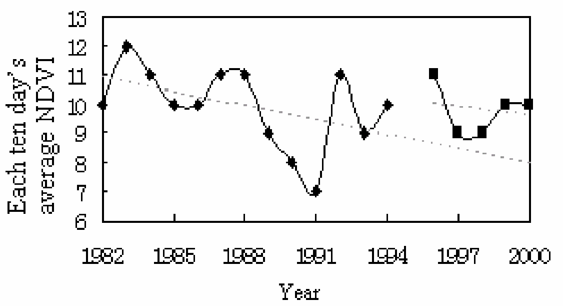


Figure 4 Changing curve on the beginning time of growth season from 1982 to 2000

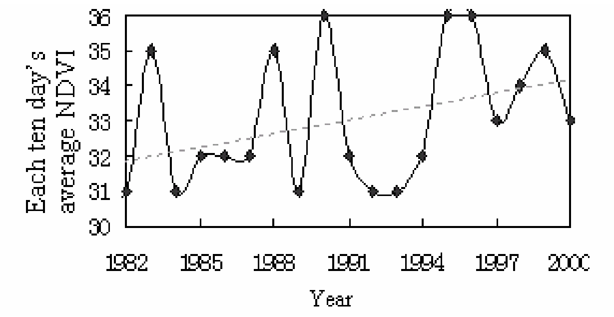


Figure 5 Changing curve on the ending time of growth season from 1982 to 2000

3.3 Space changes of vegetation's green wave and brown wave changing

The vegetation type of China, due to the effect of solar energy, is distributed from south to north like a band. Meanwhile, due to the effect of monsoon in East Asia which brings different precipitations in the same latitude area, the vegetation type of China also expands along the longitude. Therefore, China's vegetation type is distributed from east to west along the longitude. In addition, in the mountainous areas, the type of vegetation is distributed in line with vertical geomorphologic zonation with the increasing of latitude. Therefore, as far as the HHH zone is concerned, while the growth season begins, the greenness index changes from southeast to northwest, which is called green wave. While the growth season ends, the greenness index changes from north to south, which is called brown wave. In order to research on the changes of green wave and brown wave of the vegetations in HHH zone, the area between 116°E and 36°N in the central research area is selected as the sample for test. By adopting the monthly average NDVI data from 1982 to 2000, the cross section of pixel by pixel vegetation index (figure 6) is worked out to analyze the monthly average changing situation. According to the map, in the longitude-directed band, the green wave changes from south to north gradually from Jan. to Jul. and the vegetation indexes of the southern and northern regions decrease from Sep. after reaching the highest level in Aug. In the latitude-directed band, most vegetation types in the east of 114°E are the agricultural vegetations with two cultivations in 1 year, so the vegetation NDVI in this region, which has two maximum values in Apr. and Aug., is completely different from the other regions. The regions around 110°E and 112°E are latifoliate forests with the highest vegetation index from May to Sep. In the taiga area, the highest NDVI value happens from Jul. to Aug. However, the changing of NDVI in the latitude-directed regions is not that clear with that of the longitude-directed regions.

According to figure 6, the vegetation in the region changes clearly season by season, with the highest vegetation index happening in summer. In order to reflect the season changing characters of vegetations as well as their geological distribution difference, the analysis will be undertaken from the space aspect with the 116°E longitude-directed band（32°～42°N）from Jan., 1982 to Dec., 2000 and the 36°N latitude-directed band（110°～120°E） as two samples for test with the ArcGIS space analysis function. On the basis of vegetation coverage types, the monthly maximum index cross section worked out pixel by pixel is worked out to analyze the changing of vegetation index in HHH zone in the past 20 years

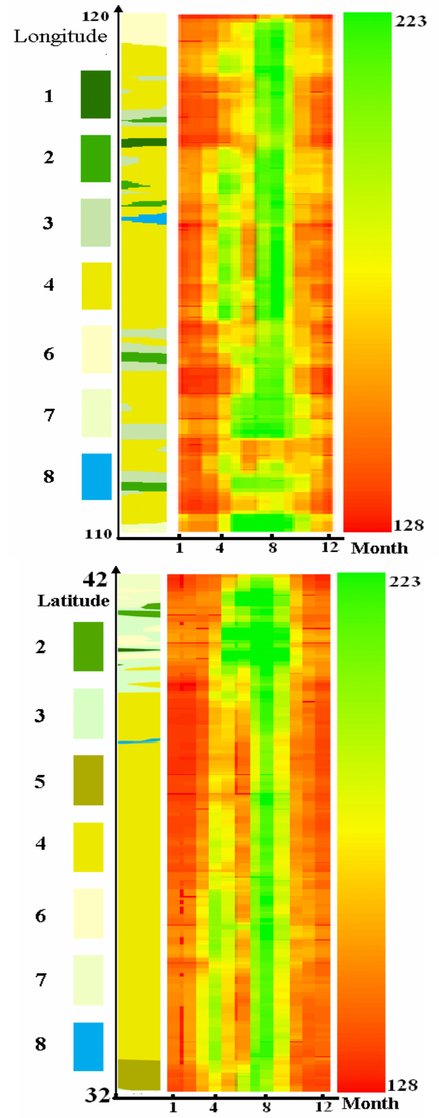
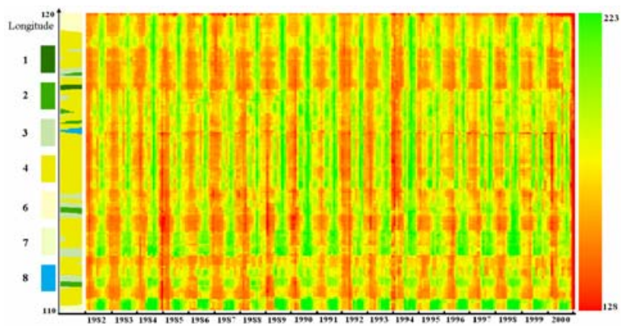


Figure 6 Cross section of vegetation index changing in 116°E longitude-directed band (above) and 36°N latitude-directed band (below) in 1982~2000



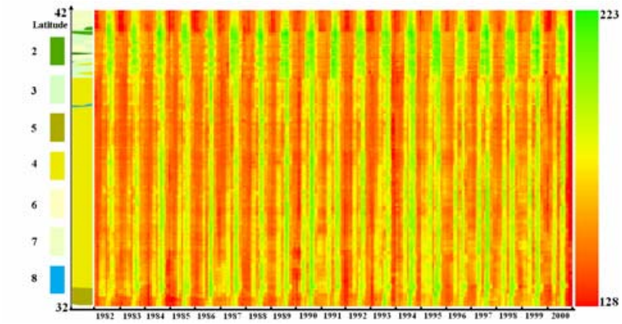


Figure 7 Cross section of vegetation index changing in 116°E longitude-directed band (above) and 36°N latitude-directed band (below) in 1982~2000

(In Figure 6-7,The vegetation includes vegetation type 1 for Taiga, 2 for Latifoliate forest,3 for Shrubbery,4 for Agriculture vegetations with 2 cultivations in 1 year,5 for Agriculture vegetations with 2 cultivations in 1 year (dry and humid regions),6 for Agriculture vegetations with 1 cultivations in 1 year,7 for Grassland,8 for Lake.)

According to figure 7, the minimum average NDVI emerges in winter and the highest average NDVI happens in summer. The NDVI in autumn and spring is between that in winter and summer. From spring to summer, the vegetation index increases gradually while from summer to autumn, the index decrease until winter. From winter to spring, the index begins to grow gradually. The higher the latitude is, the clearer the cross changing phenomenon is. Meanwhile, the non-growth period of vegetations prolongs while the corresponseing growth period shortens. As far as the types of land coverage, the seasonal changes in grassland, shrubbery-grassland area, agricultural and pasturing area and defoliation-latifoliate forest are much clearer, while the irrigation agricultural and pasturing area almost has no obvious season change. It is because that the vegetation coverage types with obvious season changes like grassland mainly change with natural environment and the response of vegetation index to climate changes are also obvious. However, the irrigation agricultural area is affected by human factors and the vegetation can be easily changed by human agricultural productions, so that the response of vegetation index to climate changes are relatively unobvious[21].

According to the cross section of longitude-directed and latitude-directed bands, the following features are also discovered: the two maximum values within a year become clearer from 1982 to 2000, especially in the agricultural area in plain regions. However, there is no sign of the two values in the urban and mountainous areas of Beijing and Tianjin in the north to 38.5°N. Meanwhile, the maximum value in early summer is lower than that in autumn. In summer, the maximum value expands to the south. The growth season of vegetation of Beijing prolongs with the time passing by. Within the area, the maximum value of greenness in agricultural area widens from south to north with time passing by.

3.4 Average NDVI changes in different seasons

During the past 19 years from 1982 to 2000, the average NDVI index in 4 seasons of the vegetations in HHH zone is increasing (figure 8), especially in spring, followed by winter, summer and autumn.

Spring is not only the season sharing the most prominent increasing of average NDVI index in the four seasons (P<0.1), but also the season enjoying the fastest increasing speed at 0.022/10a. It indicates that the vegetation growth season in HHH zone is ahead from 1982 to 2000[22], which is consistent with the growth season changes analyzed before. The average NDVI index increases frustratedly in summer and autumn. However, it is not that prominent.

As we can see in the average NDVI changing curve in summer, there are 4 prominent wave crests (1984, 1990, 1994 and 1998) and 1 prominent trough (1992). The year of 1984 shares the highest precipitation in the middle 1980's, the year of 1989 has a lot of precipitation in summer and autumn and the year of 1998 witnesses the highest precipitation in HHH zone in the middle 1990's. The year of 1994 shares the highest average temperature in the past nearly 20 years. It is possible that these factors cause the prominent maximum average NDVI index in the 4 years. Comparatively speaking, the national average temperature and precipitation in 1992 are all lower than that of the other years, which may lead to the fact that the average NDVI index of vegetations in the summer of 1992 (spring and autumn) lower than that of the other years.

According to the data, the average temperature in winter in the past nearly 20 years increases relatively greatly [8]. Since the temperature in winter is the main factor limiting the growth of vegetations and higher temperature is beneficial to the growth of vegetations, the average NDVI index in HHH zone in the past nearly 20 years is increasing.

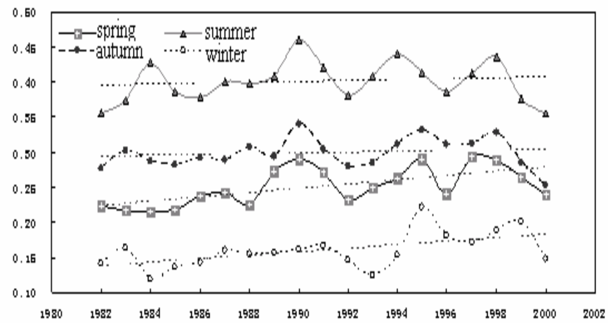


Figure 8 Average NDVI changes of vegetations in different seasons from 1982~2000

3.5 Selection of vegetation type and area for test

In order to better research on the growth season changing rules of the vegetations in HHH zone and its response to climate changes, according to China Meteorological Region Division and the Map of China Vegetation Coverage Types, select farm lands and the defoliation-latifoliate forest in the warm-temperature region in southern research area as the research targets. Each vegetation type has 5 areas for test, which have 3×3 pixel and take pixel average as the value of each area, so that the feature of each area can be maintained.

By averaging each ten day's NDVI index of two vegetation types from 1982 to 2000, the annual changing curve for the vegetation in the area for test is worked out just like figure 9. According to the map, agricultural vegetations share fluctuated NDVI index, which has two periods with each maximum index appearing in the 12th ten days (late Apr.) and the 22nd ten days (mid Aug.). It is closely related with the types of crops. The growth season begins earlier (late Feb.) if the crops of the area for test are mainly 2 cultivations in 1 year like winter wheat (cole) and summer rice. Crops grow fastest at the end of Apr. and mid Aug., so NDVI index in this time is the highest. As far as the defoliation-latifoliate forest is concerned, the trees enter growth season at the last 10 days of Mar. and reach the maximum index at the last 10 days of May. After the end of May, the trees enter slow growth period from fast grow period until the first 10 days of Aug. when they grow most prosperously. The annual changes of annual average NDVI index of the two vegetation types are consistent with the annual changes of NDVI index of the vegetations in HHH zone.

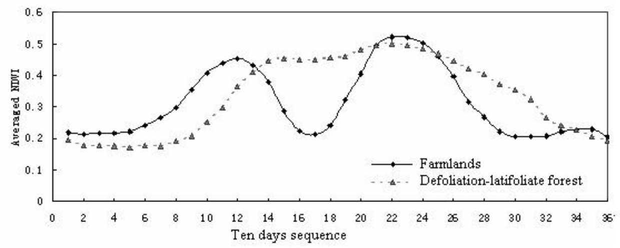


Figure 9 Annual NDVI index changing curve of vegetations in areas for test

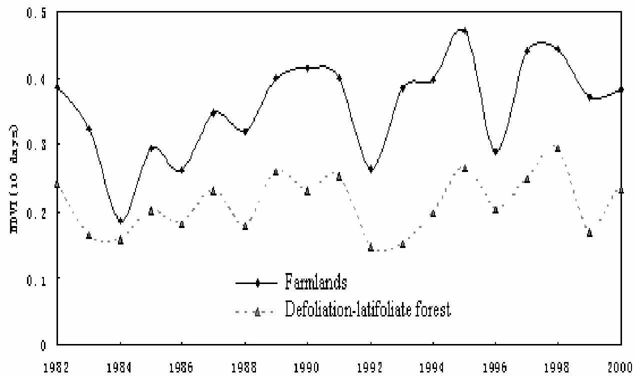


Figure 10 Annual NDVI index changing curve of vegetations in the last 10 days of Mar. in areas for test

Figure 10 is the annual NDVI index changing curve of vegetations in the last 10 days of Mar. in areas for test. Generally speaking, at the beginning of vegetation growth season of farmlands, the NDVI index is higher than that of the defoliation-latifoliate forest. With time passing by, the vegetation NDVI grows gradually, with the vegetation NDVI index of farmlands and most forests higher than the critical index while the growth season starts in HHH zone. It indicates that growth season in the areas for test begins earlier than the other areas in the research region. According to the increasing trend of the curve, the growth season is ahead, especially in the years between 1984 and 1990.

Vegetations in land ecosystem are most sensitive to the effect cast by other elements and their response to climate changes are mainly reflected on the changes of vegetation growth season. According to the researches above, the response of vegetations in HHH zone to climate changes are mainly embodied in the forwardness of growth season. In order to further research on the relations between vegetations and climate changes, the article selects the each ten day's meteorological data of the meteorological stations in (or near) the areas for test from 1982 to 2000 and undertakes related analysis (Sheet 1). According to the results, vegetation NDVI is closely related with temperature and precipitation and the relativity, which is especially sensitive to temperature, passes the test with the reliability of 0.01.

Vegetation type	Temperature	Precipitation
Farmland	0.538**	0.304**
Defoliation-latifoliate forest	0.894**	0.435**

Note： ** refers to passing the prominence test with a＝0.01.

Table 1 Relativity index of each ten day's average NDVI of vegetations in areas for test and the ten day's climate factors

4. CONCLUSION

Through the analysis on the response of vegetation NDVI in HHH zone to climate changes with the NOAA NDVI data from 1982 to 2000, the following conclusions are brought forward：

4.1 The vegetation growth season in HHH zone ranges from the last 10 days of Mar. to the last 10 days of Nov. In the past nearly 20 years, with the climate changing, the growth season begins to happen ahead and end later. The growth season is prolonged by 10.9d/10 years.

4.2 With time passing by, the region with critical index green wave of the beginning of vegetation growth season also changes from south to north, with the brown wave expands from north to south.

4.3 The average NDVI index of vegetations in HHH zone in 4 seasons is increasing. In spring, the average NDVI index grows greatly with the increasing speed higher than that of other seasons. Vegetation NDVI is closely related with temperature and precipitation, which indicates the forwardness of growth season is the mainly response of vegetations in HHH zone to climate changes.

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