Spatio-temporal distribution of net primary productivity along the northeast China transect and its response to climatic change

ZHU Wen-quan, PAN Yao-zhong, LIU Xin, WANG Ai-ling
Key Laboratory of Environmental Change and Natural Disaster of Ministry of Education, College of Resources Science and Technology, Beijing Normal University, Beijing 100875, P. R. China

Abstract: An improved Carnegie Ames Stanford Approach model (CASA model) was used to estimate the net primary productivity (NPP) of the Northeast China Transect (NECT) every month from 1982 to 2000. The spatial-temporal distribution of NPP along NECT and its response to climatic change were also analyzed. Results showed that the change tendency of NPP spatial distribution in NECT is quite similar to that of precipitation and their spatial correlation coefficient is up to 0.84 ($P < 0.01$). The inter-annual variation of NPP in NECT is mainly affected by the change of the aestival NPP every year, which accounts for 67.6% of the inter-annual increase in NPP and their spatial correlation coefficient is 0.95 ($P < 0.01$). The NPP in NECT is mainly cumulated between May and September, which accounts for 89.8% of the annual NPP. The NPP in summer (June to August) accounts for 65.9% of the annual NPP and is the lowest in winter. Recent climate changes have enhanced plant growth in NECT. The mean NPP increased 14.3% from 1980s to 1990s. The inter-annual linear trend of NPP is 4.6 $gC·m^{-2}·a^{-1}$, and the relative trend is 1.17%, which owns mainly to the increasing temperature.
Keywords: China Transect; Remote sensing; Net primary productivity (NPP); Climatic change; Spatio-temporal distribution
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Introduction

Net primary productivity (NPP) is a key component of the terrestrial carbon cycle, and it is defined as the accumulative organic matters by green plants per unit in time and space. NPP, the direct reflection of plant community productivity for a certain natural environment, is the basis of matter and energy cycle of the terrestrial ecosystem (Field *et al.* 1998). International Geographical and Biological Plan (IGBP), Global Change and Terrestrial Ecosystems (GCTE) and Kyoto Protocol all take it as their key research field (Steffan *et al*. 1998).

Terrestrial transect has become an important and effective method for the study of global change (Zhang *et al*. 1995; Koch *et al*. 1995; Raich *et al*. 1997; Ni *et al*. 1999). The Northeast China Transect (NECT) is one of the fifteen global transects recognized by IGBP, which is mainly driven by precipitation, and has become an effective platform for the global change research in China (Zhang *et al*. 1997a).

Many studies aimed at estimating the terrestrial NPP (Zhu 1993; Zhou *et al*. 1995; Sun *et al*. 2000; Alexandrov *et a*. 2002). However, a comprehensive analysis on the impact of global climatic changes on the NECT vegetation productivity has not been expressed in the context of variable limiting factors to plant growth (Cao *et al*. 1998; Nemani *et al*. 2003; Tao *et al*. 2003). In this paper, an improved Carnegie Ames Stanford Approach (CASA) model was used to estimate the NPP of NECT from 1982 to 2000 based on geographic information system (GIS) and remote sensing (RS) technology. The spatial-temporal distribution of NPP along NECT and its response to climatic change was also analyzed.

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Biography: ZHU Wen-Quan (1975-), male, Ph.D. in College of Resources Science and Technology, Beijing Normal University, Beijing 100875, P. R. China. (Email: zhuwq75@163.com)
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*Corresponding author: PAN Yao-zhong (E-mail: pyz@ires.cn)

Data and method

Study site

The Northeast China Transect (NECT) identified as a mid-latitude semi-terrestrial transect by the global change and terrestrial ecosystems (GCTE), runs in parallel to 43º30′N, ranging from 42º to 46ºN and from 111º to 131ºE (Fig. 1). The range in altitude is from 117 m to 1700 m. The major global change gradient is precipitation decreasing gradually from the eastern mountainous region to the middle farmland and then to the western pastoral area (Zhou *et al*. 2002). Vegetation along the transect varies gradually from temperate evergreen conifer and deciduous broad leaf mixed forests, deciduous broad leaf forests, woodlands, and shrublands in the east to typical steppes and desert steppes in the west, with agricultural fields, temperate savannas and meadow steppes in the middle. It is basically a gradient driven by precipitation/moisture located in the Mid latitude of temperate zone. The vegetation zone, soil, land use and climate are characterized along an east westward continuously transitional spatial series (Zhang *et al*. 1997b).

Model description

The NPP estimated by the model can be expressed as the product of Absorbed Photosynthetically Active Radiation (APAR) and the actual radiation conversion efficiency (ε). The estimate formula is represented as:

$$\text{NPP}(x,t) = \text{APAR}(x,t) \times \varepsilon(x,t) \quad (1)$$

where, APAR(x, t) represents the absorbed photosynthetically active radiation at the t months for the x grids (unit: $MJ·m^{-2}·month^{-1}$) and $\varepsilon(x, t)$ represents the actual radiation conversion efficiency at the t months for the x grids (unit: $gC·MJ^{-1}$). Their computation functions can be found in the references (Zhu *et al*. 2004; Zhu *et al*. 2005).

Data acquisition and processing

Remote sensing data: The NOAA/AVHRR NDVI images came from the Pathfinder Data Set (PDS), which was sponsored by the Earth Resources Observation System (EROS). The spatial resolution is 8 km × 8 km. The monthly composite data were taken from January of 1989 to December of 1993. Atmosphere calibration was conducted, and cloud contamination was eliminated. The sensor degradation was revised with the assumption that the NDVI in deserts was zero (Los 1993; Tucker *et al*. 1994). These images were rectified to a reference topographic map, and then resampled to Albers conical equal area projection.

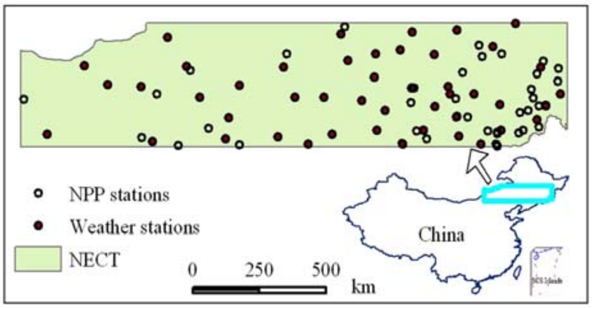

Fig. 1 Study area and the spatial distribution of meteorologic stations and NPP observation stations

Meteorological data: Monthly meteorological data in 46 meteorological stations (Fig. 1) in the same period as NDVI images included total monthly precipitation, mean monthly temperature, and total monthly solar radiation. All these data were validated with the missing and suspicious data eliminated. The data were then interpolated at the same scale with remote sensing data by using Kriging method and a new interpolation based on digital elevation model (DEM) (Pan *et al*. 2004).

Vegetation map: The vegetation map of China with a spatial resolution of one kilometer came from the Joint Research Centre (JRC), which was compiled by the Institute of Remote Sensing Application, Chinese Academy of Sciences. The original remote sensing data used in the classification came from SPOT-VGT in 2000.

NPP validation

The precision evaluation of NPP estimated in regional or global scale is always very difficult to be solved. Two methods are usually used to validate the estimated NPP: one is to compare with observation data, and the other to compare with the results estimated by other models.

Data on NPP of 33 stations were compiled based on the inventories of the Forestry Ministry of China between 1989 and 1993 (Ni *et al*. 2001). Other four observation stations of NPP were located at the middle west of NECT, which were mainly covered by cold desert grassland, with 41 samples from 1982 to 1995 (Yuan *et al*. 2005; Olson *et al*. 2001). For those sites lacking a value for total net primary productivity (TNPP), we estimated TNPP from aboveground NPP (ANPP) by using a ratio of 0.5 ANPP: TNPP for grasslands, deserts, and tundra and a ratio of 0.22 ANPP: TNPP for forests (Olson *et al*. 2001). The observed NPP was provided in units of dry biomass (organic matter). We converted these to carbon units (e.g., $gC·m^{-2}·a^{-1}$) using a mass fraction of 0.475 (Raich *et al*. 1991; Scurlock *et al*. 1999).

The comparison between the estimated NPP and the observed NPP are listed in Table 1. The mean value of NPP estimated by remote sensing model is close to the observed mean value for some vegetation types (such as desert grassland, broadleaf deciduous forest and bush). The relative errors vary from –17.4% to 61.5% for different vegetation types, but the mean relative error is 4.7% for the total samples, which is much lower than the simulated results of BEPS (Boreal Ecosystem Productivity Simulator) in East Asia (-20%), (Matsushita *et al*. 2002). The estimated results of NPP with this improved CASA model excelled that of Miami model and Thorthwaite model (Leith *et al*. 1975; Uchijima *et al*. 1985). The distribution trend of NPP estimated by different models is the same: Forest has the highest NPP, then swamp, farmland, grassland, and desert has the lowest NPP (Table 1).

Table 1. Comparison between the estimated NPP and the observed NPP ($gC·m^{-2}·a^{-1}$)

Vegetation type	Samples	Observed NPP	Model in this paper		Miami model		Thornthwaite model	
			NPP	Relative errors (%)	NPP	Relative errors (%)	NPP	Relative errors (%)
Broadleaf deciduous forest	17	686.9	655.9	-4.5	430.8	-37.3	477.2	-30.5
Bush	3	459.0	454.1	-1.1	468.3	2.0	489.3	6.6
Desert grassland	42	326.6	327.7	0.3	324.1	-0.8	306.8	-6.1
Meadow	4	596.5	565.6	-5.2	444.0	-25.6	457.0	-23.4
Swamp	1	329.0	531.2	61.5	444.7	35.2	444.2	35.0
Farmland	7	579.0	478.2	-17.4	433.6	-25.1	427.6	-26.1
Total/Mean	74	501.5	525.0	4.7	440.8	-12.1	442.9	-11.7

The large difference in spatial scale between the observed data (about several hectares) and the remote sensing data (8 km for a pixel in this paper) largely debased their comparability. Such difference may be more enlarged if the observed NPP data is not representational. So it is impossible and unpractical to seek out their typical correlation (Fig. 2). In fact, the real NPP value is still unable to be accurately estimated in existing technique conditions. However, it is significant to compare their mean value with large samples and study the spatio-temporal dynamics of regional NPP at certain precision (Matsushita *et al*. 2002)

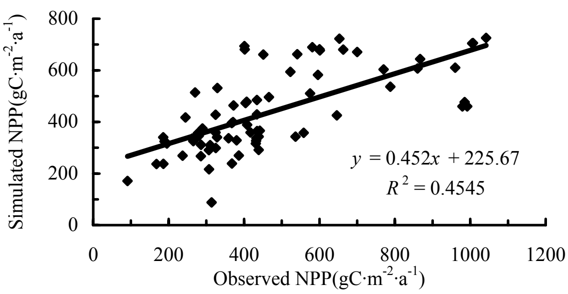

Fig. 2 Comparison of simulated NPP and observed NPP

Results

Spatial change

The spatial distribution trend of NPP is quite similar to that of precipitation, which decreased from east to west (in NECT). The annual precipitation of the eastern mountainous area is about 700–800 mm and the NPP is about 500–800 gC·m^{-2}·a^{-1}, which is 127%–204% of the mean NPP of the whole transect (392.4 gC·m^{-2}·a^{-1}). In the middle plains and valleys (main farm belt), the annual precipitation is about 450–550 mm and the NPP is about 350—500 gC·m^{-2}·a^{-1} (89%–127%). The annual precipitation in some parts in Daxing'an Mountains is also about 500 mm, but the NPP is about 250—450 gC·m^{-2}·a^{-1} (64%–115%). The annual precipitation of the southern edge in Daxing'an Mountains and the grass area of Inner Mongolia is about 250–450 mm and the NPP is about 200–300 gC·m^{-2}·a^{-1} (50%–75%). The annual precipitation of the desert grassland in the west of transect is below 200 mm and the NPP is also below 200 gC·m^{-2}·a^{-1}. The spatial correlation coefficient between NPP and precipitation is up to 0.84 ($P < 0.01$) (Fig. 3, 4). However, the spatial correlation coefficient between NPP and temperature is merely 0.02 ($P < 0.01$) (Fig. 4) and the coefficient between NPP and altitude is –0.52 ($P < 0.01$). These results indicated that the spatial distribution of NPP in NECT was mainly affected by the precipitation. The terrain may indirectly affect the spatial distribution of NPP by influence of the intensity of East Asia monsoon.

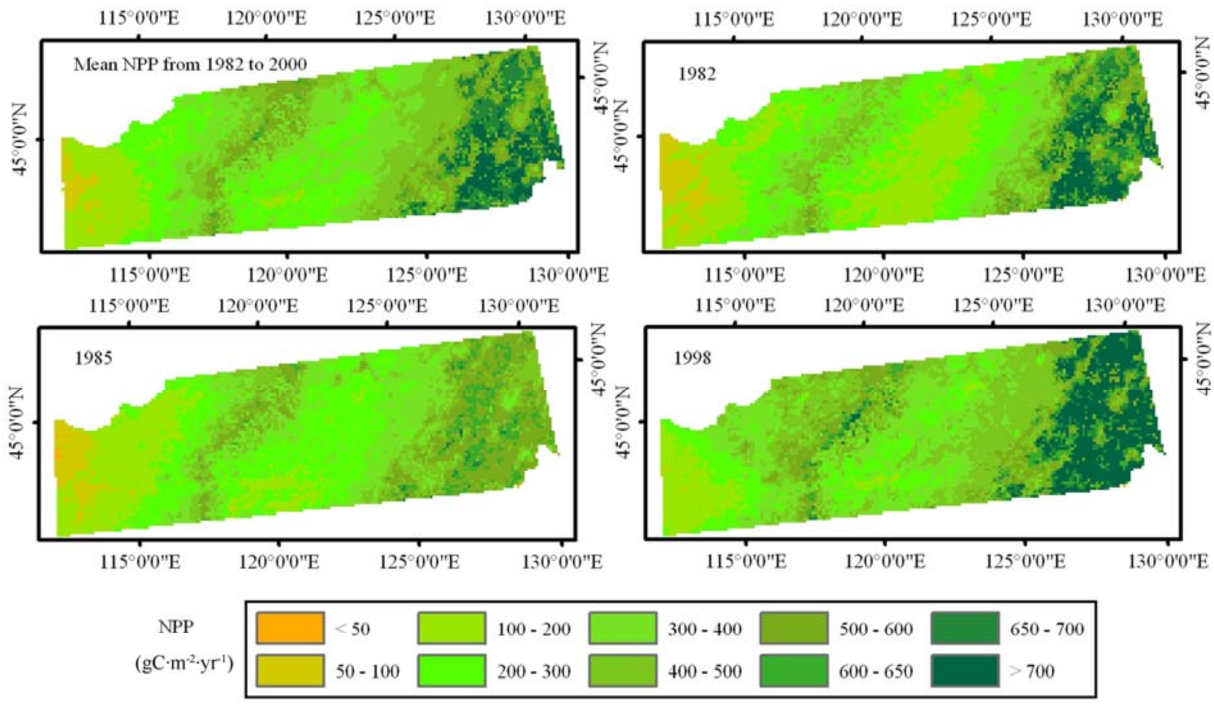

Fig. 3 The spatial distribution of NPP in NECT

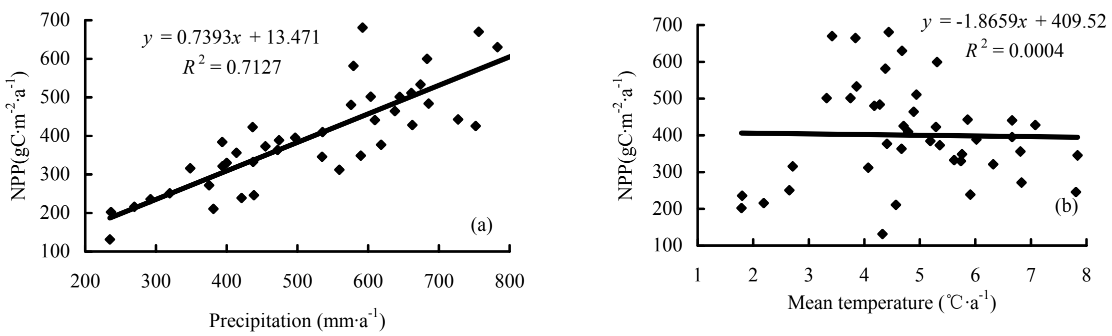

Fig. 4 The relationship between NPP and precipitation (a), NPP and temperature (b)

Temporal change

The total NPP in the NECT ranges from 204.1–274.1 Tg C (1Tg=10^{12}g) from 1982 to 2000 with a mean value 239.9 Tg C. The average unit value of NPP is 392.4 g C·m^{-2}·a^{-1}. NPP had an obviously increasing trend with a lower increase in 1980s and a notable increase in 1990s (Fig. 5(a)). The relative increase is 14.3% from 1980s to 1990s. The highest NPP value appears in 1994 and 1998 with the largest precipitation and the lowest in 1982 with the least precipitation (Fig. 5(b)). The value of NPP in 1985 is also very low, which may be relative to the low temperature of the year (Fig. 5(c)).

The inter-annual variations of NECT NPP in season showed that the annual NPP growth in spring, summer, autumn and winter is 0.136 gC·m^{-2} (R^2 = 0.01, P < 0.01), 3.089 gC·m^{-2} (R^2 = 0.38, P < 0.01), 1.239 gC·m^{-2} (R^2 = 0.44, P<0.01) and 0.105 gC·m^{-2} (R^2 = 0.19, P < 0.01), respectively. By analyzing the correlation between the annual NPP and the corresponding seasonal NPP, we found that the inter-annual variations of annual NPP was closely consistent with the inter-annual variations of summer NPP and their correlation coefficient was 0.95 (P < 0.01). These analyses indicate that the inter-annual variations of summer NPP mainly contributes to the inter-annual variations of annual NPP, which may be closely consistent with the inter-annual dynamic of East Asia monsoon.

The seasonal variation of NPP is significant (Fig. 5(d)). The NPP accumulative period is mainly between May and September when the combination of water and heat is in a good condition for vegetation growth. The quantity of NPP in these five months is about 89.8% of the total in a year. Vegetation growth peak appears in July and August and the corresponding monthly NPP is 90 gC·m^{-2}. The quantity of NPP in the whole summer (June to August) is about 65.9% of the total in a year and is nearly zero in winter (December to February).

Generally, plants in NECT have stopped to grow in winter, but there are still some low NPP values as the result of the model (Fig. 5(d)). The NPP value is 0.14 gC·m^{-2} in January, 1.36 gC·m^{-2} in February, 8.45 gC·m^{-2} in March, 5.84 gC·m^{-2} in November and 0.58 gC·m^{-2} in December. This little overestimate may be resulted from the NDVI data which is not sensitive to lower or higher vegetation coverage.

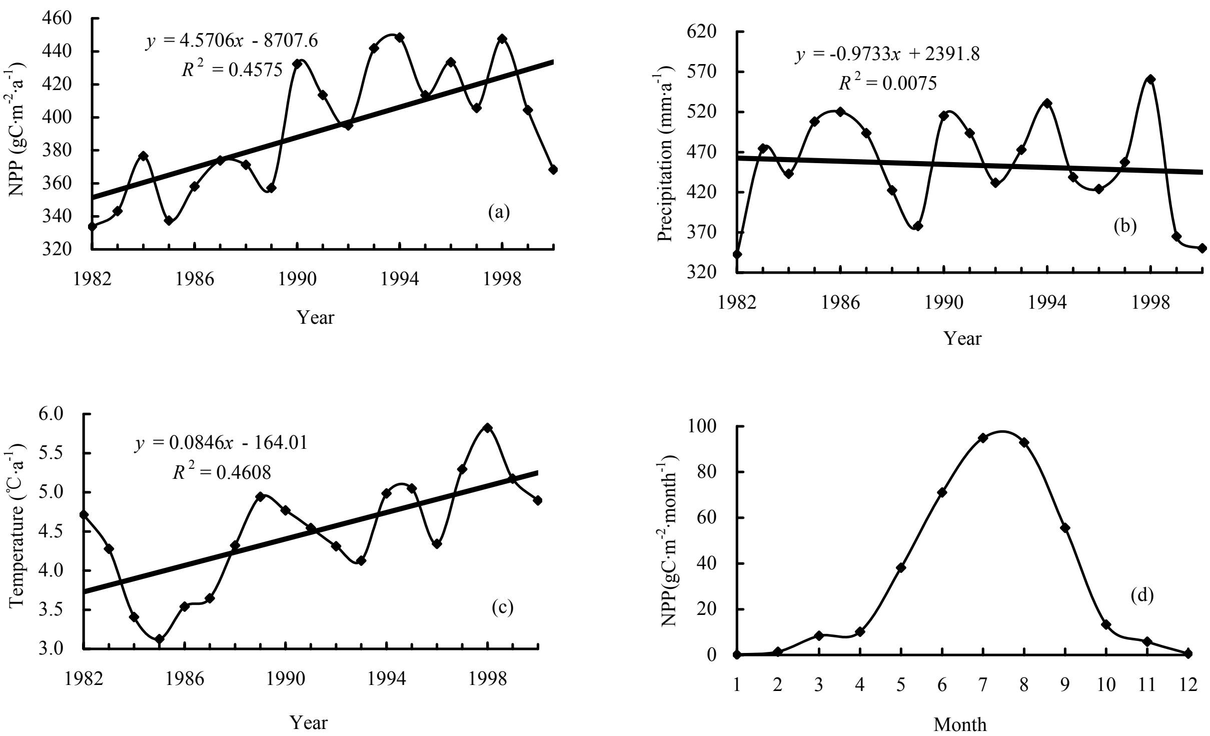

Fig. 5 Inter-annual variation of NPP (a), precipitation (b) and tempreture (c) and seasonal variation (d) of NPP in NECT from 1982 to 2000

Spatio-temporal change

The NPP in NECT has an increasing trend in the recent 19 years in Fig. 6. The NPP annual absolutely increasing trend is 4.6 gC·m^{-2}·a^{-1} and the annual relative increasing trend is 1.17%. The inter-annual absolute variation trend of NPP is significant. The maximum increasing trend of NPP appears in Changbai Mountain and farm belt in the middle plain, which is above 8 gC·m^{-2}·a^{-1}. The absolutely increasing value of the valley in the eastern area and the southern edge in Daxing'an Mountains is 4–8 gC·m^{-2}·a^{-1}. The inter-annual increasing trend of NPP in most parts of NECT is about 2 gC·m^{-2}·a^{-1} and (mostly in Horqin Sang Land) appears zero value in a few areas. The inter-annual relative variation trend of NPP is also significant. The high variation appears in Liaohe plain, which is above 2%, and even exceeds by 3% in a few areas. The variation of the southern edge of Greater Xing'an Mountains is also high (about 1.5%). The relative variations trend of other most part is all about 1%.

Conclusions

In this paper, an improved remote sensing model was used to estimate the NPP in NECT from 1982 to 2000 with remote sensing data, meteorological data and vegetation map. After a comprehensive analysis of the spatial-temporal distribution of NPP along the NECT and its response to climatic change, some results were acquired as follows:

1) The spatial distribution trend of NPP in NECT is closely consistent with that of precipitation, which both gradually decrease from the east to west. Their spatial correlation coefficient is 0.93 ($P < 0.01$). This can conclude that the distribution of NPP in NECT is mainly affected by the precipitation.

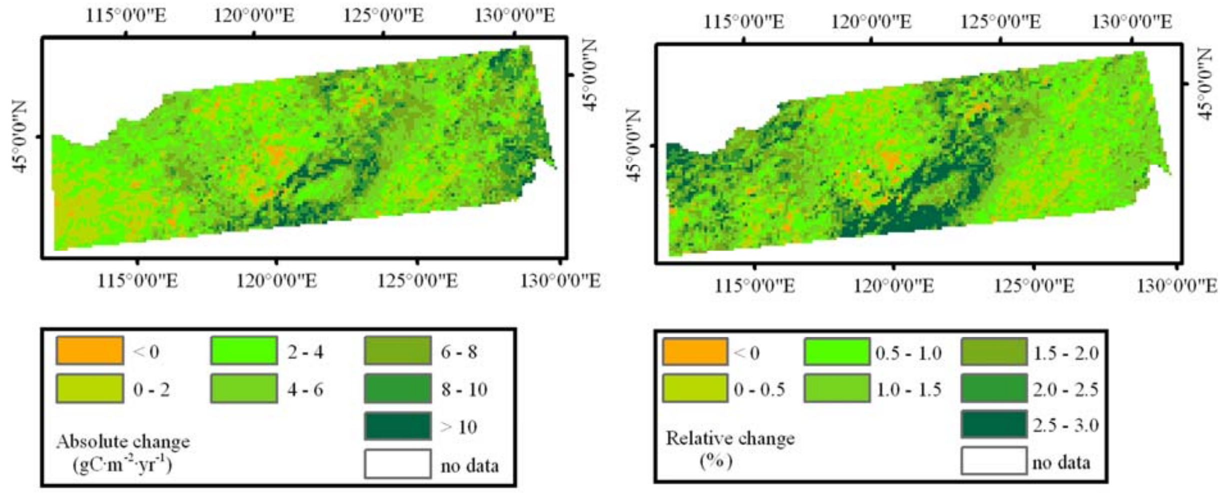

Fig. 6 Inter-annual linear variation trend of NPP in NECT

2) The mean NPP is 392.4 gC·m^{-2}·a^{-1} in NECT in 19 years (1982－2000). The inter-annual variations of NPP in summer mainly contribute to the inter-annual variations of annual NPP, which is 67.6%.

3) The NPP accumulative period in NECT is mainly between May and September. The quantity of NPP in these five months is about 89.8% of the total in a year. The quantity of NPP in the whole summer (June to August) is about 65.9% of the total in a year and is nearly zero in winter (December to February).

4) The climatic change in 19 years accelerated the vegetation growth in NECT. The NPP increased remarkably from 1980s to 1990s. The mean value of NPP had increased 114.6 gC·m^{-2} and the decade relative increasing trend is 14.3%. The NPP in NECT had an increasing trend in the 19 years except for in a few areas in Horqin Sang Land. The NPP annual absolutely increasing trend is 4.6 gC·m^{-2}·a^{-1} and the annual relative increasing trend is 1.17%. The high value of inter-annual absolute increasing trend of NPP appears in Changbai Mountain and farm belt in the middle plain, which is above 8 gC·m^{-2}·a^{-1}. The high value of inter-annual relative increasing trend of NPP appears in Liaohe plain and the value in most parts of area is above 2%, in a few areas even exceeds by 4%.

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