Dynamic Changes of Net Primary Productivity and its Response to Temperature and Precipitation in China

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Abstract. River basins are important natural and geographical units on the land surface that witness intense human activities. This paper shows that: (1) the Net Primary Productivity (NPP) values in the Inland River and the Yellow River Basins were below the national average. (2) The NPP showed a general decreasing trend in all river basins, while the proportion of NPP increased in inland river area and the southwest river area; the NPP in the Yellow River Basin was slightly higher, which might be explained by the increasing amounts of glacial meltwater due global warming. This indicates lower impact of human activities and the possible implementation of ecological and protection projects. (3) The hydrothermal conditions in the Pearl River Basin and the Songliao River Basin were relatively abundant and balanced. Moreover, the hydrothermal conditions in the southeast river area were not balanced and vegetation showed a demand for heat. On the contrary, in the other six river basins, vegetation showed a demand for water.

1. Introduction

The Net Primary Productivity (NPP) is the net increase of energy by the primary natural producers (green plants) through photosynthesis of solar energy after subtracting the energy consumed by plant respiration [1]. The research on dynamic changes of NPP and its relationship with climatic factors is necessary to the scientific understanding and assessment of ecological (in terms of vegetation) changes on one hand, and provides support for the formulation of ecological and environmental protection policies on the other.

Global NPP had increased by 6% between 1982 and 1999 due to global warming [2], while it had decreased by 0.55PgC (1PgC=1×10^9tC) due to drought events in the Southern Hemisphere from 2000 to 2009 [3]; it is worth mentioning that there was a significant correlation between drought events and NPP [4-5]. Yuan et al. showed that the NPP in China generally increased from 1961 to 2005, nevertheless, the NPP in the eastern and Loess Plateau regions decreased [6]. The abovementioned research focused on the scope of administrative units; there were some differences in research results which can be related to the research period, NPP calculation methods, remote sensing data, and resolution. The MOD17A3 data is an NPP product based on MODIS data. It has been applied in different regions [7-8] and was proven as a reliable method for studying the dynamic changes of NPP.

China has a big landmass, diverse climate zones, and rich flora; consequently, the dynamic changes of NPP and its response to temperature and precipitation provide a way to understanding macro-ecological and environmental changes. Additionally, dynamic changes in NPP reflect global climate change [9-10]. The basin is an important natural and geographical unit. The change of NPP in river

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basins reflect changes in the environment in general, and in ecology in particular; this provides a basis for assessing hydrology and soil erosion in the basin [11].

2. Materials and methods

2.1. Materials

The data used include: (1) Annual 500m resolution MOD17A4H Terra MODIS NPP dataset that covered China from 2000 to 2014 (downloaded from http://lpdaac.usgs.gov). (2) China's yearly temperature and precipitation data with 1km resolution from 2000 to 2014. The dataset was provided by Data Center for Resources and Environmental Science, Chinese Academy of Sciences (RESDC, http://www.resdc.cn). For grids with non-real values that exist in the NPP data, 0 was used a value for substitution. The NPP data were resampled to 1km resolution, which was consistent with the resolution of temperature and precipitation data.

2.2. Methods

2.2.1. Coefficient of variation. The change of NPP was analysed during the study period using the coefficient of variation based on the following formula [12]:

$$C_v = \frac{1}{\bar{x}} \times \sqrt{\frac{1}{(n-1)} \sum_{i=1}^{n} (x_i - \bar{x})^2} \tag{1}$$

where: C_v is the coefficient of variation, $\bar{x}$ is the average value of the samples, and x_i is the sample value.

2.2.2. Linear trend and F-test. A linear regression model was used to analyse the linear variation trend of NPP. Furthermore, it was used to analyse the temporal and spatial changes of NPP and to indicate possible future changes. It also reflects the linear trend and spatial distribution of the NPP during the study period. The following formulas were used [12]:

$$Y = aX + b \tag{2}$$

$$a = \frac{\sum_{i=1}^{n} x_i y_i - n\bar{x}\bar{y}}{\sum_{i=1}^{n} x_i^2 - n\bar{x}^2} \tag{3}$$

$$b = \bar{y} - a\bar{x} \tag{4}$$

where: Y is the annual average value of NPP or NPP spatial distribution data of the research area from 2000 to 2014, X is the year (from 2000 to 2014), a is the coefficient, b is the constant, and $\bar{x}$ and $\bar{y}$ are the average values of X and Y. Positive and negative a values reflect the linear increase and decrease of NPP, respectively.

The significance of the linear regression model uses the F-test, according to the following formulas [12]:

$$F = U/[Q/(n-2)] \tag{5}$$

$$Q = \sum_{i=1}^{n} (y_i - \hat{y}_i)^2 \tag{6}$$

$$U = \sum_{i=1}^{n} (\hat{y}_i - \bar{y})^2 \tag{7}$$

where: $\hat{y}$ is the fitting value of y calculated using a and b (the other parameters were indicated in the previous formulas). Concerning the F-test, and when α=0.05, the critical value is 4.67. When F>4.67, the finding is significant, otherwise, the finding is not significant.

2.2.3. Correlation coefficient. The correlation coefficient was used to identify the relationship between temperature and precipitation changes on one hand, and NPP changes on the other. The calculations were done according to the following formula [12]:

$$\mathrm{r} = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2} \sqrt{\sum_{i=1}^{n} (y_i - \bar{y})^2}} \tag{8}$$

where: x and y are NPP and temperature/precipitation, respectively. The r value is between [-1, 1]. r=0 indicates that the two variables are not related. The closer the r value is to -1, the stronger the negative

correlation; the closer the *r* value is to 1, the stronger the positive correlation. According to the critical table of correlation coefficient, when α=0.05, the critical value is 0.5139; that is when $|r|>0.5139$, the correlation is significant, otherwise, it is not significant.

3. Results

3.1. The overall characteristics of the NPP in the river basins

From 2000 to 2014, the average NPP in China was 358.7gC/m^2. The Pearl River Basin, the Southeast River Region, the Yangtze River Basin, the Songliao River Basin, the Huaihe River Basin, and the Haihe River Basin had NPP values higher than the average. The average NPP values of the Yellow River Basin and the Inland River Region were lower than China's overall average. The coefficient of variation of NPP was 0.40 during the study period; the Inland River Region, the Songliao River Basin, the Yellow River Basin, the Haihe River Basin, the Yangtze River Basin, and the Huaihe River Basin had higher coefficient of variation (i.e. >0.40).

3.2. Spatial change characteristics of the NPP in river basins

The NPP of the basins generally decreased from 2000 to 2014. The NPP reduction of the Songliao River Basin accounted for 99.4% of the total area, and the insignificant decreasing NPP accounted for 55.6% of the area. The significant increase was mainly distributed in the northern and the eastern regions. The NPP declining of the Haihe River Basin accounted for 99.8% of the total area, with a significant reduction for 28.6% of the area, mainly distributed from the northern to the southern region. The NPP reduction of the Huaihe River Basin accounted for 99.9% of the total area, with a significant reduction of 75.8% of the area mostly located in the central region.

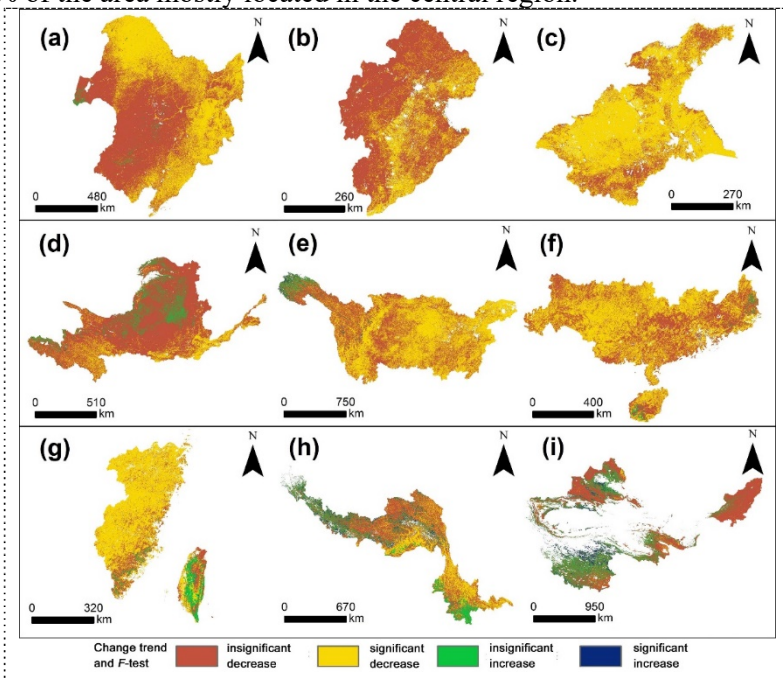

Figure 1. Spatial distribution of change trend and *F*-test of NPP between 2000 and 2014.
a-the Songliao River Basin, b-the Haihe River Basin, c-the Huaihe River Basin, d-the Yellow River Basin, e-the Yangtze River Basin, f-the Pearl River Basin, g-the Southeast River Region, h-the Southwest River Region, and i-the Inland River Region.

As for the Yellow River Basin, 91.6% of the total area witnessed a decrease in NPP, while the increasing NPP accounted for 8.4% of the area; 14.7% of the area showed a significant reduction and is mostly located in the eastern and western parts of the area. Moreover, the increasing NPP trend was mainly insignificant in the center of the region (the Loess Plateau Region). It indicated that the implementation of the Grain for Green Project in the Loess Plateau since 2000 had improved the local vegetation, and the NPP value had increased since then, which had achieved significant results [13]. The NPP decreasing trend of the Yangtze River Basin accounted for 97.3% of the total area. The proportion with significant change was 56.9% and mainly distributed in the central and eastern parts, while the increasing NPP trend was clearly distributed in the westernmost part. The decreasing NPP trend of the Pearl River Basin accounted for 99.2% of the area; furthermore, the significant decreasing NPP trend accounted for 55.0% of the area, mostly concentrated in the central and western regions.

Additionally, the decreasing NPP trend of the Southeast River Region accounted for 94.0%, and the significant reduction ratio accounted for 72.1% of the area mainly distributed in the northern and southern regions. In addition, Taiwan Island had a clear increasing trends in NPP. The NPP declining trend of the Southwest River Region accounted for 80.3% of the area, and the significant decreasing trend proportion was 28.6% and was distributed in the southern and central areas. As for the Southwest River Region, it has a complex landscape and is located between the southeastern edge of the Qinghai-Tibet Plateau western Sichuan and the west and south of the Yunnan-Guizhou Plateau. The impact of human activities in the western and southern regions was little, and showed a 19.7% increase in NPP. The Inland River Region had a 73.3% decrease in NPP, which is the lowest proportion among the 9 river basins. The significant reduction ratio accounted for 3.1% of the area, which had a smaller distribution range. The increase in NPP accounted for 26.7% of the area (Figure 1).

3.3. Response characteristics of NPP to temperature and precipitation

3.3.1. Response characteristics of NPP to temperature. From 2000 to 2014, 79.1% of the Songliao River Basin showed a positive correlation between NPP and temperature, while 19.3% of the area showed a negative correlation, with a 1.2% significant correlation for the latter, mainly concentrated in the northern region. Moreover, 83.2% of the Haihe River Basin showed a negative correlation between NPP and temperature, including a 1.2% significant correlation, mainly distributed in the southern region. As for the Huaihe River Basin, there was a negative correlation between NPP and temperature (for 92.4% of the area), including a 2.7% significant correlation mainly distributed in the northwestern area; the positive correlation was distributed in the northern part of the area and accounted for 4.9%.

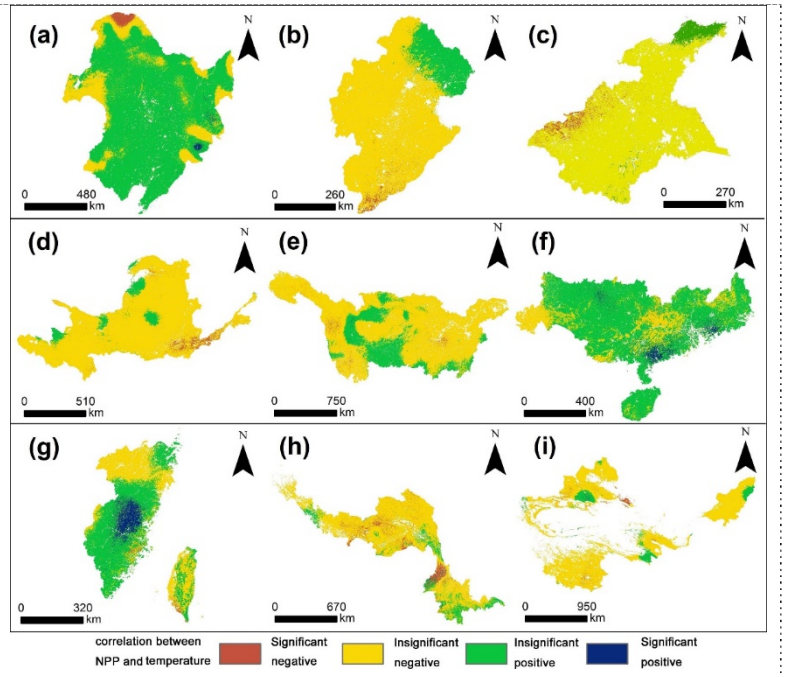

Figure 2. Spatial distribution of correlation between NPP and temperature between 2000 and 2014.
a-the Songliao River Basin, b-the Haihe River Basin, c-the Huaihe River Basin, d-the Yellow River Basin, e-the Yangtze River Basin, f-the Pearl River Basin, g-the Southeast River Region, h-the Southwest River Region, and i-the Inland River Region.

The relationship between NPP and temperature in the Yellow River Basin was mainly negative and accounted for 91.8% of the area, while 6.1% of the area showed a positive correlation for regions dispersed in the middle and western parts. As for the Yangtze River Basin, 78.9% of the area showed a negative correlation between NPP and temperature, including a 1.0% significant correlation scattered in the western, central and eastern parts of the basin. A positive correlation between NPP and temperature was recorded in the Pearl River Basin, and accounted for 74.8% of the area; 3.1% of the area showed a significant correlation and was mostly distributed in the southern and southeastern regions.

The correlation between NPP and temperature in the Southeast River Region was mainly positive, and accounted for 54.2% of the area, including a significant correlation for 8.1% of the area, which was concentrated in the middle of the region. The correlation between NPP and temperature in the Southwest River Region was negative for 80.3% of the area, including significant correlation for 7.0% of the area; it was mainly distributed in the central and southern parts, in addition to scattered areas in the central and western regions. Finally, 88.8% of the Inland River Region showed a negative correlation between NPP and temperature, including a significant correlation for 1.9% of the area concentrated in the northern part (Figure 2).

3.3.2. Response characteristics of NPP to precipitation. Hydrothermal conditions are the limiting factors for the growth and development of vegetation. From 2000 to 2014, the positive and negative correlations between NPP and precipitation in the Songliao River Basin were similar and accounted for 49.5% and 49.7% of the total area, respectively. The correlation between NPP and precipitation in the Haihe River Basin was mainly positive, and accounted for 55.1% of the area, with a significant correlation for 10.2% of the region, mainly distributed in the southern part, and to a lesser extent in the northwestern areas. In the Huaihe River Basin, 82.9% of the area showed a positive correlation

between NPP and precipitation; 9.9% of the area showed a significant correlation, mainly located in the northwestern area, and in the central and southern parts to a lesser extent.

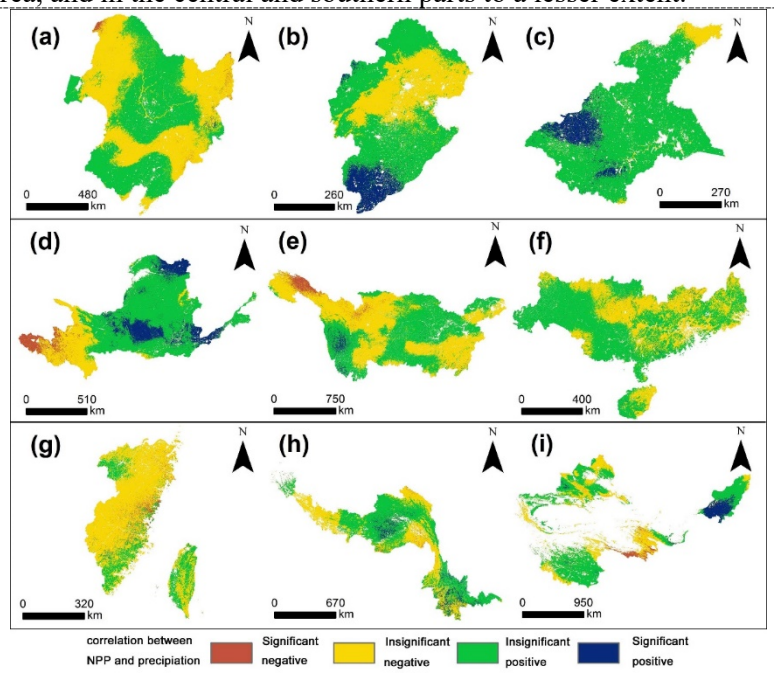

Figure 3. Spatial distribution of correlation between NPP and precipitation between 2000 and 2014.
a-the Songliao River Basin, b-the Haihe River Basin, c-the Huaihe River Basin, d-the Yellow River Basin, e-the Yangtze River Basin, f-the Pearl River Basin, g-the Southeast River Region, h-the Southwest River Region, and i-the Inland River Region.

The correlation between NPP and precipitation in the Yellow River Basin accounted for 60.4% of the area, including a significant one for 15.3% of the area mainly distributed in the southeastern, central-southern and northern parts. The positive and negative correlations between NPP and precipitation in the Yangtze River Basin were rather similar and accounted for 45.8% and 49.4% of the area, respectively. The correlation between NPP and precipitation in the Pearl River Basin was mainly positive and accounted for 61.1% of the area, mainly distributed in the western and southern regions, and west of the Hainan Island. The significant positive correlation accounted for only 0.6% of that area.

75.6% of the Southeast River Region evidenced a negative correlation between NPP and precipitation; 2.9% of that area showed a significant correlation. Those areas were scattered over the eastern edge of the region. Moreover, the correlation between NPP and precipitation in the Southwest River Region was mainly positive and accounted for 55.9% of the area; 5.5% of the area showed a significant correlation and were mainly distributed in the river valleys of the eastern Tibetan Plateau and southern Yunnan, which showed a clear band distribution. Finally, in the Inland River Region, 55.6% of the area showed a positive correlation between NPP and precipitation, with a significant positive correlation for 8.7% of the area; those areas were concentrated in the northeastern region and the southwestern Tibetan Plateau, and scattered in the river valley of northwest Xinjiang (Figure 3).

4. Conclusions

(1) The average NPP in the Inland River Region and the Yellow River Basin between 2000 and 2014 was lower than the national average. However, the inter-annual coefficient of variation of the

Southwest River Region, the Southeast River Region, and the Pearl River Basin were lower than the national average.

(2) From 2000 to 2014, the NPP of all basins and regions showed a general decreasing trend, while the proportion of NPP slightly increased in the Inland River Region, the Southwest River Region, and the Yellow River Basin.

(3) The basins where the NPP and temperature were positively and significant correlated include the Songliao River Basin, the Pearl River Basin, and the Southeast River Region, while the other basins generally showed a negative correlation.

(4) To conclude, the area where NPP was mainly negatively correlated to precipitation was only the Southeast River Region. The precipitation in this region was abundant, and the limiting effect of water conditions was small; heat had become the main limiting factor for vegetation growth and development. Finally, the precipitation in the Songliao River Region was relatively abundant, and the heat conditions had a relatively high impact on the growth and development of the vegetation.

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