Spatiotemporal Variation in Vegetation Net Primary Productivity on the Tibetan Plateau (2000-2014) and Its Response to Climate Change: Postprint

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Abstract

The Tibetan Plateau is one of the regions most sensitive to global climate change. Calculating the net primary productivity (NPP) of ecosystems on the Tibetan Plateau is of great significance for accurately estimating the global carbon cycle. Based on the CEVSA model and utilizing the M-K trend test method, Sen' s slope estimator, and Pearson correlation coefficient method, we analyzed the spatiotemporal variation characteristics of net primary productivity of ecosystems on the Tibetan Plateau from 2000 to 2014. The results show that: (1) The net primary productivity of alpine ecosystems on the Tibetan Plateau exhibits a decreasing trend from southeast to northwest in terms of spatial distribution. In the forest areas of the eastern and southeastern regions, 〔WTBX〕NPP 〔WTBZ〕ranges between 600~1,200 gC•m-2•a-1; in the central grassland and meadow areas, NPP ranges between 200~400 gC•m-2•a-1; and in the western and northern desert areas, NPP is very small due to limitations in water and heat conditions. This trend is basically consistent with the distribution trend of water and heat. (2) Interannual variation of NPP is positively correlated with multi-year average temperature and negatively correlated with precipitation. The area where NPP is positively correlated with temperature accounts for 82.24% of the total study area, while the area where NPP is negatively correlated with precipitation accounts for 49.31%, indicating that temperature is the main factor affecting the spatial distribution of vegetation NPP. (3) Over the past 15 years, NPP on the Tibetan Plateau has shown an overall increasing trend, consistent with the trend of temperature change, while precipitation has shown a slight decreasing trend. The increase in temperature accompanied by the decrease in precipitation is the main reason for the slow increase in NPP on the Tibetan Plateau. Therefore, the ability to accurately describe the response of NPP to climate change will enable us to deeply understand the response of

terrestrial ecosystems to global change.

Full Text

Preamble

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Abstract: As the "Third Pole" of the world, the Qinghai-Tibetan Plateau in China is located between 74-104°E and 25-40°N. Known for its high altitude, complex terrain, and harsh climate, the plateau represents one of the most sensitive regions to global climate change. Increases in temperature and changes in precipitation can significantly affect ecosystem productivity on the plateau. Calculating the net primary productivity (NPP) of the Qinghai-Tibetan Plateau ecosystem is crucial for accurately estimating the global carbon cycle. Since NEP cannot be measured directly at regional or global scales, model-based estimation is the only viable approach. In this study, we analyzed the spatiotemporal patterns and trends of NPP on the Tibetan Plateau between 2000 and 2014 using the process-based ecosystem model CEVSA (Carbon Exchange between Vegetation, Soil and Atmosphere), the M-K trend test method, Sen' s slope estimation method, and the Pearson correlation coefficient method. The model was based on a $0.1° \times 0.1°$ resolution map of vegetation types, soil texture data, and daily meteorological data. The results indicated: (1) NPP on the Qinghai-Tibetan Plateau decreased from southeast to northwest, consistent with the water-heat distribution gradient. These results align with those obtained by ZHOU Caiping et al., who applied a combination of terrestrial ecosystem models and MODIS data to estimate NPP for the plateau. Spatially, forest NPP in the east and southeast ranged between 600-1200 g $C \cdot m^{-2} \cdot a^{-1}$, central grassland and meadow NPP varied from 200-400 g $C \cdot m^{-2} \cdot a^{-1}$, while western and northern desert NPP was limited by moisture and temperature. (2) Increasing annual average temperature had a significant positive effect, whereas decreasing precipitation had a significant negative effect on plateau NPP. Annual NPP was positively correlated with mean annual temperature over 82.24% of the region, while negatively correlated with annual precipitation over 49.31% of the region. Therefore, temperature is considered the dominant factor determining spatial variations in NPP, a finding consistent with previous studies. For example, LIU Gang et al. analyzed spatiotemporal variation in NPP and climate controls across China from 2001-2014, finding positive correlations between NPP and temperature in the Changbai Mountains, Qinghai-Tibetan Plateau, and southern regions. (3) From 2000-2014, the increasing NPP trend was consistent with warming trends, while precipitation showed slight decreases. This period of warming accompanied by decreasing precipitation contributed to the grad-

ual NPP increase on the Qinghai-Tibetan Plateau. However, challenges remain, particularly regarding NPP prediction uncertainty, which primarily stems from driving variables and model parameters. To improve regional climate impact predictions on ecosystems, modeling uncertainty can be reduced by increasing the spatial resolution of driving variables and optimizing model parameters.

Keywords: CEVSA model; net primary productivity; climate change; Tibetan Plateau

1. Model Framework and Data

1.1 CEVSA Model Framework

The CEVSA model is a process-based terrestrial ecosystem model that simulates carbon, water, and nitrogen cycles. The model framework includes several key components:

Biochemical Processes: The model incorporates CO_2 assimilation, Rubisco enzyme kinetics, and photosynthetic pathways. The light extinction coefficient follows Beer' s Law:

$$I = I_0 e^{-kLAI}$$

where I_0 represents incident radiation, k is the extinction coefficient (typically 0.5), and LAI is leaf area index. The model calculates photosynthetically active radiation (PAR) interception and subsequent gross primary production (GPP) based on temperature, moisture, and nutrient constraints.

Temperature Response Functions: Maximum photosynthetic rate (A_{max}) is calculated as:

$$A_{max} = 306 + Ne^{(u_1 - 0.00831T_k)} \frac{u_{1T}k - 205.9}{0.00831T_k} k_T(T)$$

where N represents nitrogen content, T_k is temperature in Kelvin, and u_1, u_2, u_3, and $k_T(T)$ are temperature response parameters.

Soil Nitrogen Factor: The soil nitrogen factor ($SNFC$) is parameterized as:

$$SNFC = \begin{cases} 0 & \text{if } TEM \geq 2^\circ C \\ \frac{TEM-2.0}{2} & \text{if } -5^\circ C < TEM < 2^\circ C \\ 1 & \text{if } TEM \leq -5^\circ C \end{cases}$$

where TEM represents soil temperature.

Soil Moisture Dynamics: Soil moisture storage ($SMOS$) is calculated using a water balance approach:

$$SMOS_m = \min\{[SMOS_{m-1} + WATI - AET], SMOS_{sat}\}$$

where m denotes the current month, $WATI$ is water input, AET is actual evapotranspiration, and $SMOS_{sat}$ is saturated soil moisture content.

1.2 Data Sources and Model Parameterization

Meteorological Data: Daily meteorological data from 2000–2014 including temperature, precipitation, radiation, and humidity were used as model drivers. The data were interpolated to 0.1° spatial resolution.

Vegetation and Soil Data: Vegetation type maps and soil texture data from the Harmonized World Soil Database (HWSD) were used to parameterize plant functional types and soil hydraulic properties. Soil moisture saturation values were derived from soil texture classifications.

Model Validation: The model was validated against three FLUXNET sites: site u (2004–2005), site vw (2002–2004), and site ^ (2003–2005). Correlation coefficients between simulated and observed NPP were 0.77–0.82, 0.87–0.94, and 0.83–0.87, respectively, indicating good model performance.

2. Results

2.1 Model Validation and NPP Trends

Validation results showed strong agreement between CEVSA-simulated NPP and FLUXNET observations. The M-K trend test and Sen' s slope estimation revealed significant increasing trends in NPP across the plateau from 2000–2014. The Pearson correlation analysis demonstrated that temperature was the primary climatic driver, with positive correlations dominating 82.24% of the region. Precipitation effects were more complex, showing negative correlations in 49.31% of areas, particularly in water-limited regions.

The spatial pattern of NPP showed clear southeast-northwest gradients, with forests in the humid southeast exhibiting the highest productivity (600–1200 g $C \cdot m^{-2} \cdot a^{-1}$), followed by alpine meadows and grasslands in the central plateau (200–400 g $C \cdot m^{-2} \cdot a^{-1}$), and deserts in the northwest showing the lowest values. This pattern aligns with previous studies using MODIS data and ecosystem models.

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Note: Figure translations are in progress. See original paper for figures.