Supplementary Materials: Variation of Net Primary Production and Its Correlation with Climate Change and Anthropogenic Activities over the Tibetan Plateau Remote Sensing 2018, 8, remotesensing-336096

Zhaohui Luo,1,2 Wenchen Wu1, Xijun Yu1,2, Qingmei Song1, Jian Yang1, Jiahui Wu1 and Hengjun Zhang1,*

2. Materials and Methods

2.1. Study Area

The Tibetan Plateau (26°00′12″–39°46′50″ N, 73°18′52″–104°46′592″ E), located in Western China (Figure S1) and covering an area of approximately 2.5 million km² is the highest and most extensive highland in the world, with an average elevation exceeding 4 km above sea level, and is called the “Third Pole” of the Earth.

Figure S1. Altitude map for the Tibetan Plateau and also field observation sites for NPP on the plateau.
2.2.3. Land Cover Data

The Global Land Cover 2000 (GLC-2000; Figure S2) dataset was applied to recognize land cover types in the Tibetan Plateau. This dataset, with a spatial resolution of 1 km, was generated by daily S1 data (from the SPOT-4 satellite) based on different classification methods, and local expert knowledge was considered to improve the data accuracy.

![Vegetation types across the Tibetan Plateau](image)

**Figure S2.** Vegetation types (DNF, deciduous needle-leaf forest; ENF, evergreen needle-leaf forest; EBF, evergreen broadleaf forest; DBF, deciduous broadleaf forest; SW, sparse woods; GM, grassland and meadow; and BR, bare rocks) across the Tibetan Plateau.

2.3.1. NPP Estimation and Validation

After NPP was estimated based on the original and modified CASA models, field-observed biomass data acquired from previously published studies encompassing the time range between 2001 and 2015 (Table S1) were used to evaluate the performance of the models. Similar to previous studies, the biomass was converted to NPP based on Equations (5)–(7).
3. Results

3.2. Spatial Patterns of NPP

Figure 2 illustrate the spatial pattern and standard deviation of NPP over 2001–2015 in the Tibetan Plateau. The mean annual NPP for these 15 years showed an increasing pattern from northwest to southeast (Figure 2a). The lowest values occurred in the west and north of the plateau, with values lower than 0.042 kg·C·m⁻². In contrast, the highest values (more than 0.700 kg·C·m⁻²) were found in the southeast of the plateau. NPP values ranging from 0.250 and 0.700 kg·C·m⁻² mostly occurred in the east of the plateau. For the remaining areas, NPP values mostly ranged from 0.042 to 0.250 kg·C·m⁻², and they were mainly distributed in the middle and southwest of the plateau. Additionally, the spatial pattern of annual NPP for each year (2001–2015) was similar to that of the mean annual NPP (Figure S3). The spatial pattern of the standard deviation (Figure 2b) was similar.
to that of the mean annual NPP. For most of the study area, the standard deviation was lower than 0.037 kg·C·m⁻², accounting for 75.70% (Figure S4). However, higher values were found in the east and southeast of the plateau, with values more than 0.037 kg·C·m⁻².

Figure S3. Spatial patterns of annual NPP between 2001 and 2015.

Figure S4. Frequency distributions of NPP standard deviation in the Tibetan Plateau.
3.3. Temporal Trend of NPP

The temporal trend of annual NPP across the Tibetan Plateau is displayed in Figure 3a. During the study period (2001–2015), pixels that displayed either a significant decrease or increase \((p < 0.05)\) accounted for 15.01\% (Figure 3b). Of the total pixels, 53.20\% displayed a decreasing trend, and 9.05\% of the total pixels displayed a significantly negative trend \((p < 0.05; \text{Figure S3})\). Overall NPP decreased with a mean value of \(-0.02 \times 10^{-2} \text{kg} \cdot \text{C} \cdot \text{m}^{-2} \cdot \text{a}^{-1}\), and the magnitudes of decreasing NPP mostly ranged from 0 to \(-0.15 \times 10^{-2} \text{kg} \cdot \text{C} \cdot \text{m}^{-2} \cdot \text{a}^{-1}\) (Figure S5), distributed in the south and southwest of the Tibetan Plateau. In contrast, 46.80\% of the total pixels exhibited an increasing trend, of which approximately 6\% showed a significantly positive trend \((p < 0.05; \text{Figure S5})\). The increasing trend of NPP was mostly distributed in the center of the plateau, with the magnitudes mainly ranging from 0 to \(0.13 \times 10^{-2} \text{kg} \cdot \text{C} \cdot \text{m}^{-2} \cdot \text{a}^{-1}\) (Figure S5).

![Figure S5. Frequency distributions of NPP trends in the Tibetan Plateau.](image)

3.4.2. Relative Effects of Climatic Factors on NPP

The relative impacts of climate factors on NPP are illustrated in Figure 5. Among the three climate factors, the impact of annual cumulative precipitation was the greatest; Mean annual cumulative precipitation contributed to over 58\% of the total pixels, mainly scattered in the middle of the Tibetan Plateau. Annual cumulative solar radiation contributed to approximately 29\% of the total pixels, mainly occurring in the eastern edge of the plateau. The extent of the impact of annual mean temperature seemed very limited when compared with the other two climatic factors (<13\%), and those pixels were mostly scattered in the southwestern area of the plateau. Furthermore, the annual cumulative precipitation contributed to 47.84\% of significantly increasing NPP, followed by the annual solar radiation—approximately 13.48\%—and the lowest was the annual mean temperature, only accounting for 13.48\%. The percentage of relative contributions of climatic factors to significantly decreasing NPP was similar to that of significantly increasing NPP, approximately
44.58%, 31.98%, and 23.44% for annual cumulative precipitation, annual cumulative solar radiation, and annual mean temperature, respectively (Figure S6).

**Figure S6.** Relative contributions of climate factors on significantly \((p < 0.05)\) decreasing NPP (a) and significantly increasing NPP (b). Only pixels with significantly increasing or decreasing NPP are displayed. Tem, temperature; Pre, precipitation; Rad, solar radiation.

4. Discussion

4.2. Spatiotemporal Variation of NPP

The temporal trend of NPP showed spatial heterogeneity in the Tibetan Plateau, and an overall decreasing trend with a mean value of \(-0.02 \times 10^{-2} \text{ kg C m}^{-2} \text{ a}^{-1}\) was found, which is similar to previous findings. The reasons for the decreasing NPP include harsh environmental conditions caused by both climate change and anthropogenic activities. For instance, an increasing trend in temperature and a decreasing trend in cumulative precipitation (Figure S7) result in warmer and drier environmental conditions for impending vegetation growth. Additionally, decreased cumulative solar radiation (Figure S7), which inhibits the photosynthesis of vegetation, also contributed to the decreasing NPP.
Figure S7. Climatic factors variation in the Tibetan Plateau from 2001 to 2015. Tem, mean annual temperature; Pre, annual cumulative precipitation; Rad, annual cumulative solar radiation.

4.4. Relative Contribution of Climatic Factors and Anthropogenic Activities to NPP

Climate change and anthropogenic activities are the two main factors that affect NPP variation. In terms of climatic factors, approximately 48.57% of the total pixels were regulated by annual cumulative precipitation, and they mainly occurred in the middle of the plateau. This is because precipitation is one of the most important factors affecting vegetation growth in arid and semi-arid areas, especially for grassland with a shallow root system. Additionally, the amount of precipitation in the plateau is usually small and varies extremely in time and space. Moreover, the overall trend of precipitation in the plateau displayed a decreasing trend during the study period (Figure S7 and S8). Both of these reasons make precipitation a dominant climatic factor that regulates vegetation growth in the plateau. The relative contribution of annual cumulative solar radiation accounted for approximately 29% over the study region, and they were mainly distributed in the eastern edge of the plateau. Although solar radiation in the Tibetan Plateau is usually abundant due to less water vapor content, high elevation, and thin clouds, an overall decreasing trend of cumulative solar radiation (Figure S7) may also have contributed to the decreasing trend of NPP in the plateau, as it impacts photosynthesis—such as the composition of chlorophyll and carbohydrate, as well as the decomposition of CO₂—and then impacts dry matter accumulation. The spatial distribution of annual mean temperature that contributed to NPP variation was lower than that of the other two factors, accounting for approximately 12.56% of the total number of pixels. Usually, temperature in the Tibetan Plateau is low due to the high elevation. However, an overall increasing trend of annual mean temperature (Figure S7 and S8) in the plateau may have mitigated the restriction of low temperatures on plant growth.
In terms of human intervention, the effects of ecological destruction on NPP trend changes were larger than that of ecological restoration. For instance, 12.18% of the grassland transformed into built-up areas (Figure S9) in the plateau during 2001–2015, which seems to indicate that ecological destruction is responsible for the decreasing trend of NPP. Therefore, compared with the ecological restoration, such as Natural Forest Conservation Program and Grazing Withdrawal Program, ecological destruction, such as urbanization, unsustainable logging practices, and overgrazing, should be paid more attention in the plateau. Furthermore, more efforts, such as the implementation of grassland protection policies, ecological restoration projects, and ecological compensation in the plateau, should be made in the future to compensate for the negative effects of ecological destruction on decreasing NPP.
References


© 2016 by the authors; licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons by Attribution (CC-BY) license (http://creativecommons.org/licenses/by/4.0/).