Estimating Gross Primary Productivity in the Heihe River Basin Using Multi-Source Data (Postprint)

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Abstract

Gross Primary Productivity (GPP) determines the initial input of materials and energy into terrestrial ecosystems; however, the GPP derived from MODIS GPP products fails to accurately reflect the distribution of ecosystem material and energy in the Heihe River Basin, which is characterized by complex land surface cover. Therefore, this study utilized MODIS image data, ASTER GDEM data, 30 m resolution land use/cover data, and the China regional surface meteorological elements driving dataset to drive the VPM model, simulating gross primary productivity in the Heihe River Basin from May to October 2015, and thereby revealing the spatiotemporal patterns of GPP during the growing season at a temporal resolution of 8 days and a spatial resolution of 500 m. Results demonstrate that the VPM model estimation exhibits higher accuracy than the MODIS GPP product, with the coefficient of determination increasing by 45.5% and the total root mean square error decreasing by 57.0%. The accumulated GPP during the growing season demonstrates a pronounced spatial gradient pattern across the Heihe River Basin, with the highest values in the middle reaches, intermediate values in the upper reaches, and the lowest values in the lower reaches. Daily GPP in both the entire region and locally vegetated areas follows an inverted U-shaped temporal pattern, initially increasing and subsequently decreasing, with the former peaking in late July. In surface areas with extremely low vegetation coverage, daily GPP fluctuates around a relatively stable baseline throughout the growing season, with a stable value near 1 gC · m ^{2} · d ^{1}.

Full Text

Estimating Gross Primary Production in the Heihe River Basin from Multiple Data Sources

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Abstract

The initial matter and energy entering terrestrial ecosystems are determined by gross primary productivity (GPP). However, the GPP measurements acquired from MODIS GPP products are not sufficient to accurately reflect the distribution of ecosystem matter and energy in the Heihe River Basin (spanning Qinghai Province, Gansu Province, and Inner Mongolia, China) with its complex surface coverage. Therefore, based on MODIS image data, ASTER GDEM data, land cover data with a spatial resolution of 30 m, and the China Meteorological Forcing Dataset, the VPM model was applied to simulate the gross primary productivity of the Heihe River Basin from May to October 2015 with a spatial resolution of 500 m and a temporal resolution of 8 days. Based on simulations using the VPM model, the spatial and temporal patterns of GPP in the Heihe River Basin during the growing season were determined. The results indicate that the accuracy of estimates using the VPM model was higher than that of the MODIS GPP products, with the judgment coefficient increasing by 45.5% and the total root mean square error reducing by 57.0%. The study results also demonstrate that GPP accumulation during the growing season in the Heihe River Basin exhibited a significant spatial distribution gradient pattern, described as highest in the middle reaches, followed by the upper reaches, and lowest in the lower reaches. In addition, the daily GPP of the whole and partial vegetation-covered areas in the Heihe River Basin first increased and then decreased in an inverted U-shape. The daily GPP values of all vegetation-covered areas reached their maximum in late July. The daily GPP values of ground areas with very low vegetation coverage fluctuated around a basically stable value of approximately 1 g C · m ^{1} · d ^{1}.

Keywords: VPM model; multi-source data; gross primary productivity; spatial and temporal patterns; Heihe River Basin

3. VPM Model

3.1 Model Input The VPM model was driven using MODIS image data, ASTER GDEM data, and 30 m resolution land cover data. The meteorological forcing dataset used was the China Meteorological Forcing Dataset. The temporal resolution of the input data was 3 hours and 1 day, while the spatial resolution was 0.1°. The study period covered May to October 2015. The model calculates GPP using the light use efficiency (LUE) approach, where the actual light use efficiency (g) is modulated by temperature and water scalars from the maximum light use efficiency (max). The core equations are:

$$GPP = \varepsilon_g \times APAR_{chl}$$

where $APAR_{chl}$ is the photosynthetically active radiation absorbed by chlorophyll, calculated as:

$$APAR_{chl} = FPAR_{chl} \times PAR$$

with $FPAR_{chl}$ representing the fraction of photosynthetically active radiation absorbed by chlorophyll, derived from the Enhanced Vegetation Index (EVI):

$$FPAR = \alpha \times EVI$$

where is set to 1.0. The actual light use efficiency is calculated as:

$$\varepsilon_g = \varepsilon_{max} \times T_{scalar} \times W_{scalar}$$

The ε_{max} parameter was optimized using the Land Surface Water Index (LSWI) based on MODIS data from 2011-2015.

3.2 Model Validation The VPM model was validated by comparing its GPP estimates against MODIS GPP products (MOD17A2H). The validation was performed at both 8-day and 500 m resolutions. The coefficient of determination (R^2) and root mean square error (RMSE) were used as evaluation metrics to assess model performance.

4. Results and Analysis

4.1 Model Accuracy Accuracy assessment revealed that the VPM model significantly outperformed the MODIS GPP products. The judgment coefficient (R^2) increased by 45.5%, while the total root mean square error was reduced by 57.0%. The improved accuracy demonstrates that integrating multi-source data at finer resolutions better captures the spatial heterogeneity of GPP in the Heihe River Basin.

4.2 Spatial Distribution Characteristics The spatial distribution of GPP in the Heihe River Basin showed clear patterns related to vegetation cover and environmental conditions. The middle reaches exhibited the highest GPP values, followed by the upper reaches, with the lower reaches showing the lowest productivity. This gradient pattern reflects the influence of water availability, temperature, and land cover type on vegetation productivity. Areas with dense vegetation cover, such as irrigated croplands and riparian zones, showed consistently high GPP values, while sparsely vegetated areas maintained low but stable productivity.

5. Temporal Dynamics of GPP and LAI

The temporal dynamics of daily GPP across the Heihe River Basin followed a distinct inverted U-shaped pattern during the growing season. GPP values began increasing in early May, reached their peak in late July, and then gradually declined through August and September. This pattern aligns with the phenological development of vegetation and seasonal changes in climatic conditions. For areas with very low vegetation coverage, daily GPP remained relatively stable throughout the season, fluctuating around a baseline value of approximately 1 g C • m ¹ • d ¹. The consistency between GPP and leaf area index (LAI) temporal dynamics further validates the model' s ability to capture vegetation growth processes.

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