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Net primary production of major plant functional types in China: Vegetation classification and ecosystem simulation

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ABSTRACT

The characteristics and distribution of vegetation are essential information for understanding the structure and functioning of terrestrial ecosystems across a large region. In this study, we developed the contemporary and potential vegetation maps of China with a spatial resolution of 1 km × 1 km. The vegetation classification scheme includes 17 types of vegetation and 3 non-vegetated land cover types. For cropland, we further provide spatial information on three major cropping systems across China, i.e., single, double and triple cropping system. In addition, we further evaluate the accuracy of this classification against field survey. As a case study, we used this vegetation data set combined with other environmental factors (climate, atmospheric CO_2 and nitrogen deposition) to drive the Dynamic Land Ecosystem Model (DLEM) for estimating terrestrial net primary production at both plant functional type and national levels. DLEM simulations indicate that net primary productivity (NPP) in China's terrestrial ecosystem has substantially increased by 51%, from 2.50 Pg C y^{-1} in the 1900s to 3.79 Pg C y^{-1} during the first decade of the 21st century. Among major plant functional types across China, cropland shows the largest NPP increase by nearly 3–4 fold during 1901–2010 primarily due to cropland expansion as well as increased nitrogen fertilizer use and irrigation. The NPP increase is estimated to be 480 and 692 gC $m^{-2} y^{-1}$ for upland crops and rice fields, respectively. This vegetation distribution data set was originally developed for driving the Dynamic Land Ecosystem model (DLEM), but it can be used for other purposes such as driving hydrological and climate models.

1. Introduction

Vegetation plays an important role in ecosystem processes and shows complex interaction with temperature, precipitation, topography, and management strategies. In the past decades, China has experienced a rapid land use/land cover change, which is related to the unprecedented changes in socioeconomic structures across the nation [1–3]. Changes in carbon storage and fluxes in terrestrial ecosystems can be largely attributed to land use/land cover changes, such as urbanization, deforestation, and afforestation [4–7]. In order to explore the impacts of vegetation distribution on the major ecosystem processes and carbon stocks, and to better understand the responses of vegetation to anthropogenic disturbances over China, it is imperative to develop a spatial database of vegetation types with higher spatial resolution.

Mapping of vegetation distribution and dynamics at regional and global scales have attracted increasing attention [1,2,8–10]. Vegetation distribution and change have been simulated by using dynamic global vegetation model (DGVM) (e.g. Sitch et al. [11]), although DGVM application requires physiological parameters, and is partly limited by the knowledge of vegetation dynamics [12]. Many products derived from remote sensing and inventory data have been generated to characterize the spatial pattern of land use/land cover throughout China [1,3,8]. The satellite- and census-derived data sets can be used to validate the simulated vegetation patterns. However, these data sets are inadequate to meet the requirements of biogeochemical simulation due to inappropriate classification system [1].

To meet the needs of biogeochemical/ecosystem models, we developed a contemporary vegetation map based on Landsat TM/ETM+ data to describe the spatial vegetation patterns under the current climatic conditions and human activities. Potential vegetation map was generated to depict the quasi-equilibrium state of natural vegetation before alteration by humans. The difference between potential and contemporary vegetation is to introduce croplands into the former one. By overlaying these two data sets, we can determine where natural vegetation has been changed for cultivation.

The overall goal of this study is to estimate terrestrial net primary production (NPP) for major plant functional types and the nation

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of China through vegetation classification and ecosystem simulation. The specific objectives include the following: first, we present the potential and contemporary vegetation maps at a 1 km × 1 km spatial resolution. Second, we aggregate this vegetation data set into a spatial resolution of 10 km × 10 km in consistence with other environmental factors (climate, atmospheric CO_2 and nitrogen deposition). Finally, we use the Dynamic Land Ecosystem Model (DLEM) [6] to assess how multiple environmental changes in climate, atmospheric CO_2, ozone pollution, nitrogen deposition, land cover, nitrogen fertilizer use and irrigation have affected terrestrial NPP in major plant functional types and China as whole.

2. Methods

2.1. Vegetation classification

The spatial pattern of land use/land cover in China for the year of 2000, which was developed from Landsat TM/ETM+ data with a hierarchical classification system [1], was used as the primary data source for the contemporary vegetation map. This thematic map with 25 land-cover classes was validated against field survey across China and aggregated into 1 km × 1 km spatial resolution from spatial data set at 30 m × 30 m resolution. A maximum algorithm was used to determine the dominant vegetation type (e.g., forest, grassland, shrub, etc.) for each grid cell. A grid cell is assigned as cropland only when cropland occupies greater than 50% of total area in the cell. Cropland system was further classified into several main crop types (e.g. wheat, rice, corn, etc.) and a simplified crop rotation system was developed based on AVHRR/NDVI, the farming system map in China (1:18,000,000) and observation database in National Agrometeorological Stations.

The potential vegetation map (Fig. 1) is developed through a combination of contemporary vegetation map and the data set of permanent croplands from Ramankutty and Foley [9]. The cropland data set was created through incorporating national and subnational agricultural inventory data during the early 1990s into satellite-derived land cover data set (Fig. 2). It is assumed that the potential vegetation types are the same as the contemporary ones when the area is covered by natural vegetation. On the contrary, if the contemporary vegetation/land use in a certain grid cell is human-dominated (i.e., cropland, urban), the corresponding vegetation type from Ramankutty and Foley [9] is used to substitute the grid cell in the potential vegetation map.

The 1st-level classification system used in Liu et al. [1] was modified as Table 1. Collatz et al. [13] used global climatological data sets to identify the C4 plant areas where monthly average temperature is greater than 22 °C for at least 1 month within the year. This selected area was further screened by excluding the area where precipitation per month is less than 25 mm during the warm season, and was assigned as grasslands according to Matthews' [14] global vegetation map. Based on the percentage of global C4 grass in a grid cell with 1° × 1° (latitude × longitude) spatial resolution [13], grasslands in our data set was divided into C3 and C4 grass classes. We used the subdivision of shrublands presented in Chinese vegetation map at a scale of 1:4 million [15] to divide shrub into deciduous and evergreen shrubs. Combined with MODIS derived vegetation map and the Eurasia land cover database (version 2.0) from USGS (http://edc2.usgs.gov/glcc/eadoc2_0.php), forest was divided into 9 functional types according to climate zone and life forms. Comparing with the classification system from Liu et al. [1], we separate two subclasses for croplands (i.e., upland crops and rice fields) and further develop a set of crop farming system including several main crop types. We also have a specific urban module in DLEM for simulating urban ecosystem dynamics [16].

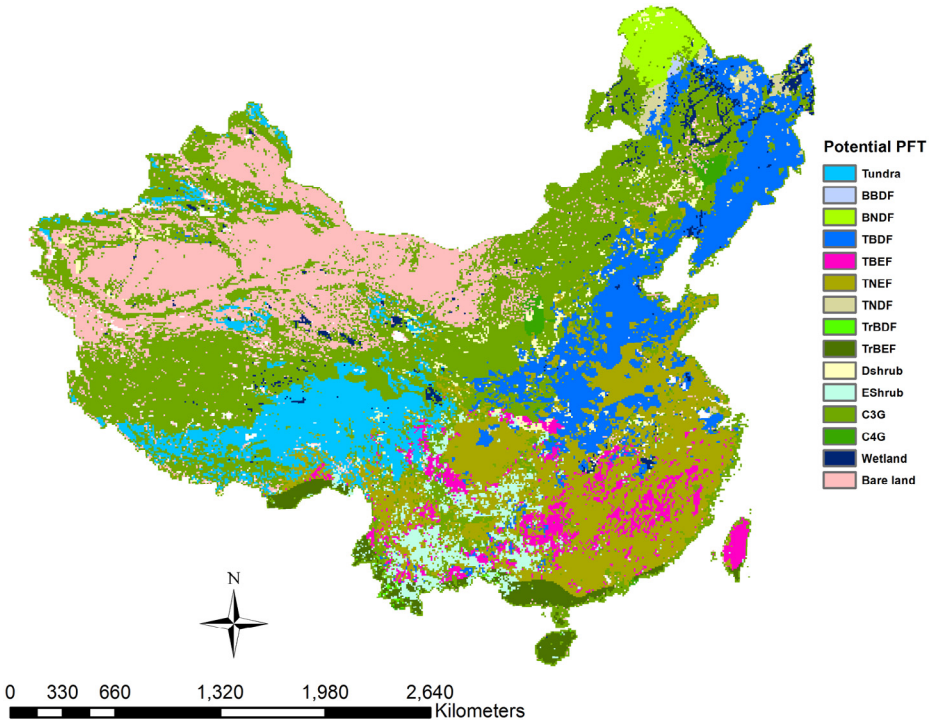

Fig. 1. Distribution of potential plant functional types in China. BBDF: Boreal Broadleaf Deciduous Forest; BNDF: Boreal Needleleaf Deciduous Forest; TBDF: Temperate Broadleaf Deciduous Forest; TBEF: Temperate Broadleaf Evergreen Forest; TNEF: Temperate Needleleaf Evergreen Forest; TNDF: Temperate Needleleaf Deciduous Forest; TrBDF: Tropical Broadleaf Deciduous Forest; TrBEF: Tropical Broadleaf Evergreen Forest; DShrub: Deciduous Shrub; EShrub: Evergreen Shrub; C3G: C3 Grassland; C4G: C4 Grassland.