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The spatial and temporal dynamics of carbon budget in the alpine grasslands on the Qinghai-Tibetan Plateau using the Terrestrial Ecosystem Model

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ABSTRACT

Grasslands in Tibetan Plateau play an important role in carbon emission reduction. Accurately evaluating the carbon budget of alpine grassland ecosystems is of great importance. Based on the parameterization and validation of a process-based ecosystem model (Terrestrial Ecosystem Model, TEM5.0), we analyze temporal and spatial dynamics and patterns of grassland ecosystem carbon emission and sequestration of Tibetan Plateau in China from 1961 to 2010. Alpine grasslands act as a carbon sink with mean annual value of 10.12 Tg C yr^{-1} during the past 50 years. The alpine meadow contributes most to the sink at 9.04 Tg C yr^{-1}, while the alpine steppe only contributes 2.03 Tg C yr^{-1}. 83.7% of the total area trends to be carbon sink and only 0.2% of the region showed no significant trend. Furthermore, the annual net ecosystem productivity shows significantly positive relationship with increasing temperature and atmosphere CO_2 concentration, but it shows no significant relationship with precipitation. Alpine grasslands in Qinghai-Tibetan Plateau is a carbon sink and sequestrate totally 520 Tg C from 1961 to 2010. The carbon budget of alpine experienced dramatically spatial and temporal dynamics during past 50 years. Inter-annual variability of the net ecosystem productivity mainly depends on different sensitivities of net primary productivity and heterotrophic respiration to temperature and precipitation variability. Temperature and atmosphere CO_2 concentration are main driving forces of carbon budget dynamics of grassland ecosystems in Qinghai-Tibetan Plateau during 1961–2010.

1. Introduction

Human caused greenhouse gases emission has risen to unprecedented levels over the past eight hundred thousand years (IPCC, 2013). China has become the world's largest energy related CO_2 emitter since 2007 and is facing great pressure in carbon emission reduction (Tian et al., 2011; Zhang et al., 2013; Shao et al., 2014). As the biggest terrestrial ecosystem of the world, grassland ecosystem contributes a lot to carbon emission reduction (Petsri et al., 2013). In China, grasslands account for 40% of the national land area and mostly distributed in temperate regions and alpine regions. About 1.0×10^6 km^2 of the grasslands occur in the Qinghai-Tibetan Plateau (Ni, 2002; Sun, 2005).

Known as "The Third Pole" and "Roof of the World", Qinghai-Tibetan Plateau is the youngest and highest plateau of the world. Because of the high elevation, the Qinghai-Tibetan Plateau is one of the most critical and sensitive regions to climate change (Zhang et al., 2002; Zheng et al., 2002; Zheng and Yao, 2006). It has been shown that each warm and cold stage in China appears firstly on the plateau in the recent 600 years. The temperature starts to increase earlier and the increasing rate is faster than other regions of China (Feng et al., 1998; Piao et al., 2012). Due to low temperature, the decomposition rate is slow in Qinghai-Tibetan Plateau, thus the soil contains a large amount of soil organic carbon (Ni, 2002). The increasing of air temperature and CO_2 concentration will not only enhance the net primary production, but also cause permafrost

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areas to shrink and enhance soil respiration simultaneously (Yu et al., 2010; Piao et al., 2011; Jin et al., 2013). Hence, great uncertainty exists on carbon budget of Qinghai-Tibetan Plateau under global change (Ni, 2000; Zhang et al., 2004). Kato et al. (2004) estimated net ecosystem production of alpine meadow is 58.5–192.5 gC m^{-2} yr^{-1} by eddy covariance method. He et al.(2006, 2008) studied the stoichiometry and patterns of leaf carbon and nitrogen based on 82 sites in Qinghai-Tibetan Plateau. Ma et al. (2010) investigated the relationship between productivity and diversity based on transect survey, and Shi et al. (2013) further analyzed the production dynamic, given that aboveground net primary production of alpine meadow and alpine steppe is 120.13 g Cm^{-2} and 79.05 g Cm^{-2}, respectively. Yang et al.(2008, 2009) investigated the magnitude, spatial patterns and environmental controls of the soil and vegetation carbon storage based on transect survey. Great progress has been made in evaluating carbon storage and balance of this region, but most of the studies based on site or transect level (Baumann et al., 2009; Luo et al., 2002). Temporal and spatial of regional carbon budget in Qinghai-Tibetan Plateau grasslands and its driving factors are still not clear.

In this study, we use the data of carbon and nitrogen pools and fluxes obtained from literatures to parameterize and verify a process-based biogeochemical ecosystem model, the Terrestrial Ecosystem Model (5.0), which is widely used to estimate carbon and nitrogen dynamics in various ecosystems at global or regional scale, including alpine region (McGuire et al., 1992, 1993, 1997; Tian et al., 1999, 2011; Zhuang et al., 2010). Then we extrapolate the model to the whole plateau at a 10 km × 10 km spatial resolution to reveal temporal and spatial dynamics and patterns of Qinghai-Tibetan Plateau grassland carbon budget during 1961–2010 and the driving factors of carbon dynamic.

2. Data and methods

2.1. Study area

Grasslands in Qinghai-Tibetan Plateau cover 1.0 × 10^6 km^2, dominated by two major types: alpine meadow and alpine steppe (Fig. 1). The alpine meadow mainly occurs in eastern and south-eastern Qinghai-Tibetan Plateau with annual mean temperature ranges from −3 to 4 °C and annual average precipitation ranges from 350 to 700 mm. The dominant species include *Kobresia humilis*, *Kobresia pygmaea*, *Kobresia tibetica* and *Kobresia capillifolia*. The alpine steppe spreads from Kunlun Mountains through Nyainqentanglha to Gangdise. The mean annual temperature ranges from −5 to 3 °C, annual precipitation is approximately 100–350 mm. The dominant species include *Stipa purpurea*, *Orinus thoroldii*, *Stipa basiplumosa*, *Carex moorcroftii* and *Deyeuxia arundinacea* (Zhang, 2008).

2.2. Data description

To extrapolate to region, the model needs spatially explicit data of climate, soil texture, elevation and vegetation. Daily climate data sets including radiation, temperature and precipitation are collected from 752 national standard weather stations from National Meteorological Information Center of China Meteorological Administration (CMA) during 1961–2010. First we interpolate the data to the region of Qinghai-Tibetan Plateau at 10 km × 10 km resolution by ANUSPLIN 4.3(Hutchinson, 2004). Then we aggregate the data to monthly step to drive TEM model. The atmospheric CO_2 concentration data is obtained from National Oceanic and Atmospheric Administration, United States Department of Commerce. Soil texture data sets are organized from the database of Nanjing Institute of Soil, the Chinese Academy of Sciences (CAS) with the resolution of 10 km × 10 km and elevation data sets are derived from 1:1 million Topographic Database of the National Fundamental Geographic Information System of China. The vegetation data are derived from "Vegetation Map of China" (1:1 million) compiled by the Editorial Board of Vegetation Map of China (Zhang, 2008). The land use data set is provided by "Environmental & Ecological Science Data Center for West China, National Natural Science Foundation of China" and Data sharing Network of Earth System Science. It's descripted by percentage of grassland in each grid cell with the resolution of 1 km × 1 km. All the spatially explicit data are reorganized at 10 km × 10 km resolution.

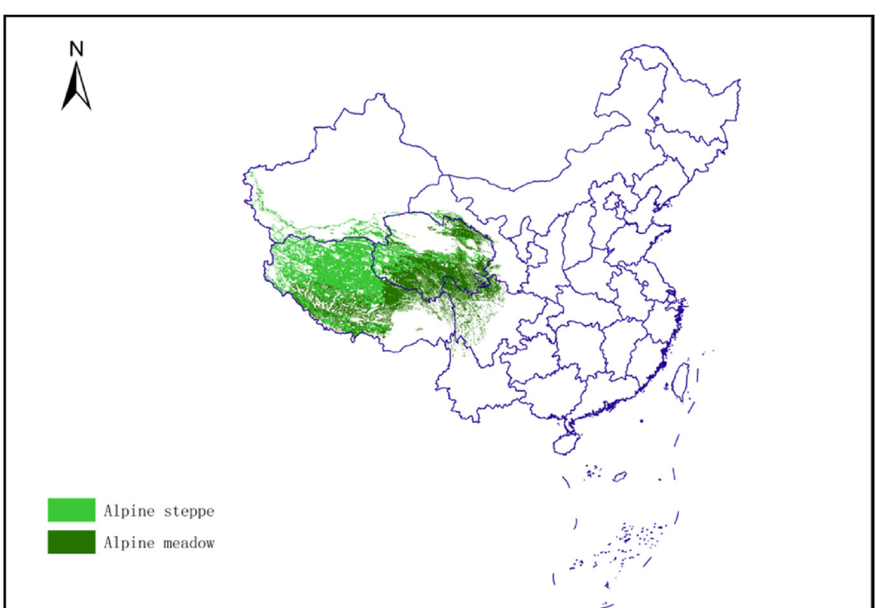

Fig. 1. Alpine steppe and alpine meadow in Tibetan Plateau from "Vegetation Map of China" (1:1 million) compiled by the Editorial Board of Vegetation Map of China (Zhang, 2008).