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Review

Soil methane uptake by grasslands and forests in China

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ABSTRACT

Sinks of methane (CH_4) become highly variable due to both human activity and climate change. An urgent need therefore exists to budget key sinks of CH_4, such as forests and grasslands. In this study, CH_4 uptake of forests and grasslands in China was first reviewed and then estimated based upon the review itself. Total uptake from the two CH_4 sinks were 1.323 Tg CH_4 yr^{-1} in China (ranging from 0.567 to 2.078 Tg CH_4 yr^{-1}), lower than a previous estimate in China (2.56 Tg CH_4 yr^{-1}). Among the uptake, 0.650 Tg CH_4 yr^{-1} (ranging from 0.168 to 1.132 Tg CH_4 yr^{-1}) was consumed by grasslands and 0.675 Tg CH_4 yr^{-1} (ranging from 0.399 to 0.946 Tg CH_4 yr^{-1}) by forests. The largest CH_4 uptake of grasslands was found in the Qinghai-Tibetan Plateau High-Frigid Domain, which consumed 0.284 Tg CH_4 yr^{-1}, about 44% of the whole uptake of grasslands in China. The greatest CH_4 uptake (0.553 Tg CH_4 yr^{-1}) of forests took place in Eastern Humid and Semi-humid Domain of the country, which was about 82% of the total annual CH_4 uptake of forests in China. With forests and grasslands taken together, Eastern Humid and Semi-humid Domain was the largest CH_4 consumer, taking up about 0.715 Tg CH_4 yr^{-1}, accounting for 82% of the whole forest uptake and 25% of the whole grassland uptake in China. On the ecoregion scale, due to extensive forest distribution and longer growing season, Southern Asia monsoon broadleaf forest ecoregion was the greatest CH_4 uptake (0.320 Tg CH_4 yr^{-1}) of forests and grasslands in China, consuming more CH_4 than the Northeastern Arid and Semi-arid Domain combined. Our results indicated that forests and grasslands are not constant sinks of CH_4 but decreasing ones influenced by climate change and anthropogenic activity. More field data, mechanism understanding and process-based models could help better estimate and understand CH_4 uptakes of forests and grasslands in China.

1. Introduction

Methane (CH_4) is an important greenhouse gas, about 25 times more powerful in warming the atmosphere than carbon dioxide (CO_2) for the time horizon of 100 years (Denman et al., 2007). It is also involved in a number of chemical reactions which can exert strong influence over chemistry of the troposphere and the stratosphere (Cicerone and Oremland, 1988). Recently, a study reported that CH_4 emissions have larger overall impacts than current carbon-trading schemes, which modified its radiative forcing from $+0.48$ W m^{-2} to $+0.90$ W m^{-2} (Forster et al., 2007; Shindell et al., 2009). Therefore, CH_4 as an important greenhouse gas second only to CO_2, has a considerable impact on the earth's climate

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system. Since the preindustrial era, atmospheric CH_4 increased significantly and reached a new high of 1813 ppb in 2011, 159% higher than the pre-industrial level (WMO, 2013). Moreover, after a near zero-growth decade from 1997 to 2006, a renewed growth in atmospheric CH_4 occurred since 2007 (Rigby et al., 2008; Dlugokencky et al., 2009). The present global CH_4 budget must therefore be determined without delay (Heimann, 2010).

Biological CH_4 oxidation in drier soil is one of the major CH_4 sinks, absorbing 26 to 34 Tg CH_4 yr^{-1} (Denman et al., 2007), making it the second largest sink after CH_4 oxidation in the troposphere (Ueyama et al., 2012; Wang et al., 2012). With the uncertainty range about ±15 Tg (CH_4) (50%), soil CH_4 oxidation is also one of the most uncertain sinks (Denman et al., 2007). The uncertainties in the global CH_4 budget come mainly from the limited observational data coverage and the great variation in the factors influencing CH_4 fluxes (Heimann, 2011). Among all, forest and grasslands soils under well-aerated conditions are recognized as a major contributor to the global soil CH_4 uptake. The contribution of forest soils to the global soil CH_4 uptake was estimated as 11.6 Tg CH_4 yr^{-1} (52%) (Dutaur and Verchot, 2007). Based on direct extrapolation of multiyear measurements, CH_4 uptake by temperate grasslands was preliminarily estimated to be 4.3 Tg CH_4 yr^{-1} (Mosier et al., 1991) and then refined as 2.3 Tg CH_4 yr^{-1} based on a literature review (Mosier et al., 1997). Thus, it would be very helpful to estimate CH_4 uptake from forests and grasslands on national, regional, as well as global scales (Mosier et al., 1991; Dutaur and Verchot, 2007; Vuichard et al., 2007; Wang et al., 2009c).

There are some estimates of national CH_4 budget in China. Anthropogenic CH_4 emission was about 34.29 Tg CH_4 yr^{-1} as presented by the People's Republic of China Initial National Communication on Climate Change (2004), which was submitted to the UNFCCC (http://unfccc.int/resource/docs/natc/chnnc1exsum.pdf). Several studies have made efforts to estimate the national emission of rice paddies (Cao et al., 1995; Kern et al., 1997; Huang et al., 1998; Khalil et al., 1998; Wang and Li, 2002; Huang et al., 2006; Cai, 2012; Chen et al., 2013), natural wetlands (Ding et al., 2004; Cai, 2012; Chen et al., 2013), and lakes (Chen et al., 2013). Based on limited measurement, aerobic soils was estimated to take up atmospheric CH_4 at a rate of 2.56 Tg CH_4 yr^{-1} (Cai, 2012). So far to the best of our knowledge, there is no synthesis study on a comprehensive CH_4 budget for either grasslands or forests in China, which is indispensable for a general CH_4 uptake estimate for this country.

Multiple studies on CH_4 fluxes of grasslands in China have already been carried out (Du and Chen, 1997; Wang et al., 1998, 2000, 2005, 2007, 2009b; Dong et al., 2000, 2005; Ma et al., 2006; Li et al., 2007; Liu et al., 2007, 2011, 2012a; Holst et al., 2008; Sun, 2008; Chen et al., 2010; Geng et al., 2010; Zhou et al., 2011; Luo and Jiao, 2012; Wei et al., 2012; Zhang et al., 2012), some even making efforts to estimate the total emission for specific regions (Du et al., 2005; Liu et al., 2009a; Wang et al., 2009c). Relatively fewer studies on CH_4 fluxes of forests in China have been published (Xu et al., 1995; Sun, 2000; Dong et al., 2003; Du et al., 2004; Mo et al., 2005; Yang et al., 2010; Liu et al., 2010b, 2012b; Guan et al., 2012; Yang, 2012). Increased knowledge concerning CH_4 uptake from forests and grasslands in China is important to understand the CH_4 budget of China as well as that of the world.

In light of such a rationale, this study had three primary objectives: 1) to review and analyze the existing studies on CH_4 uptake from grasslands and forests in China; 2) to provide estimates of the total CH_4 uptake from these two sinks; and 3) examine the existing knowledge gap and attempt to propose the future study direction to address the gaps.

2. Methods and materials

2.1. Data source and analyses

The latest information available of individual sites served as the original data sources for the map of dataset for CH_4 uptake of forests and grasslands in China (Fig. 1). We obtained the corresponding data from available published papers and dissertations including mean CH_4 uptake rates and their ranges, location site, latitude and longitude by using the "*GetData*" software (Version 2.24) and collected the available data in text format (Table S1 and Table S2). According to ecological zonation of China (Fu et al., 2001), there are three domains (Eastern Humid and Semi-humid Domain (EHSD)), Northeastern Arid and Semi-arid Domain (NASD) and Qinghai-Tibetan Plateau High-Frigid Domain (QPHD) and thirteen ecoregions in China (Fig. S1). In this study, we calculated the mean CH_4 uptake rates of forests and grasslands and their standard errors based on the data we collected, which clustered in the three domains (Fig. 1 and Fig. S1). Analysis of variance (ANOVA) was used to compare averages of CH_4 uptake rates in each domain for both forests and grasslands.

2.2. CH_4 emission estimation from grasslands and forests in China

2.2.1. CH_4 uptake calculation

The following formula was used to calculate the CH_4 uptake (MU) rate of grasslands and forests in each ecoregion of China:

$$\mathrm{MU} = \sum_i \sum_j \sum_k SR_{ijk} {}^* A_{ijk} {}^* D_{ijk}$$

Where i is the ecological domain (ESHD, NASD and QPHD); j is the growing season and non-growing season (in each domain); and k is the ecoregion. SR_{ijk} is the seasonal mean uptake rate under conditions of i, j and k. A_{ijk} is the grassland or forest area, and D_{ijk} is the duration of the growing and non-growing season. The range is calculated as from mean minus SD to mean plus SD in each ecoregion.

2.2.2. Grassland and forest area

Grassland (not including shrublands) in China is manly distributed in the NASD and QPHD. The area of grasslands in China in this study was obtained from one of the three grassland resource inventories since 1979, the one from 1981 to 1988 which covered more than 2000 counties in China (Department of Animal Husbandry and Veterinary et al., 1996). The forest inventory database was based on the Forest Resource Inventory of China since 1973, which spanned six periods: 1973–1976, 1977–1981, 1984–1988, 1989–1993, 1994–1998 and 1999–2003 (Xu et al., 2007). We used the latest inventory in this study. All area data was at the provincial scale, we added up provincial data for the total area of each ecoregion (Fig. S1). For cross-ecoregion provinces, the area of each ecoregion was calculated according to the ratio of specific ecoregions.

2.2.3. Duration of growing seasons

This study assumed that the growing season duration of grasslands is approximately 300 days for southern China and about 165 days (from early May to late October) for the arid, semi-arid northern China and the Qinghai-Tibetan Plateau, respectively. Chen et al. (2010) reported that the contribution of the non-growing season (October–April) to the cumulative annual CH_4 uptake is approximately 30% (25%–36%), so in this study we assumed that the contribution of the nongrowing uptake was about