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Simulation and prediction of nitrous oxide emission by the water and nitrogen management model on the Tibetan plateau

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A B S T R A C T

Process-based simulation models have been used to assess the characteristics of N_2O emission and to examine the potential impacts of climate change in grassland ecosystems. Temporal N_2O fluxes from the soil–atmosphere interface were monitored in this study continuously for two years by using flux chamber measurements and were simulated by using the water and nitrogen management model (WNMM_NSWDPI version) on the Tibetan plateau. The model predictions of N_2O flux in an alpine meadow agreed well with the observed values in 2013 and 2014 at daily and monthly scales. Annual emissions of the model output and the measured data agreed closely with lower than 4% relative deviation. Therefore, we concluded that the model captured the key driving process of N_2O formulation in which nitrification was the predominant process, contributing to 72.8% and 64.8% in 2013 and 2014, respectively. The average annual N_2O emission flux from 1961 to 2014 was 2.02 ± 0.04 kg N_2O–N ha^{-1}. We further identified that future moderately increases in precipitation could partially reduce the positive response of N_2O flux to global warming on the Tibetan Plateau.

1. Introduction

Concerns in current ecological research about increases in global warming have resulted in strong emphasis on the study of terrestrial ecosystem gas emissions (Miles and Kapos, 2008; Baral et al., 2014). Among the greenhouse gases, N_2O is a long-lived (>120 years) substance in the atmosphere, with a potential radiation effect of about 310 times than CO_2 over one hundred years. It contributes to about 6% of the warming on a global scale, and it also depletes stratospheric ozone (IPCC, 2014; Jones et al., 2014; Shcherbak et al., 2014). Furthermore, the atmospheric concentration of N_2O has risen steadily by

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nearly 0.8 ppbv per year during the last century (Frame and Casciotti, 2010; Jones et al., 2014). Hence, research that quantifies its significant sources, sinks, and mitigation strategies in various ecosystems has increased gradually.

Terrestrial soils have been identified as a predominant source, contributing about 65–70% of the total N_2O atmospheric loading (Flückiger et al., 1999; Chianese et al., 2009; Baral et al., 2014). Grasslands are one of the most widespread vegetation types, accounting for nearly 20% of the global land surface (Adams et al., 1990; Wang et al., 2011), and numerous studies have shown that grasslands are a significant source of N_2O emission, with higher emission rates than some arable and forest soils (Du et al., 2008; Luo et al., 2013). Production and emission of N_2O occurs predominantly through microbial mediated nitrification and denitrification in soils (Li et al., 2005; Doltra et al., 2015) in extremely complicated processes linked to many factors such as soil organic carbon, available nitrogen, pH, soil moisture, temperature, bacterial activity, and grazing intensity (Wrage et al., 2001; Saggar et al., 2004; Chen et al., 2008). However, because N_2O emission from grassland soils has shown considerable spatiotemporal variability and therefore production rates from individual fields and regions remain highly uncertain (Chen et al., 2008; Baral et al., 2014; Kim et al., 2014). Consequently, the prediction of N_2O fluxes under various climatic and management strategies are difficult without improved understanding of the current flux patterns.

Robust process-based models such as the water and nitrogen management model (WNMM) have been developed to stimulate N_2O flux of biogeochemical cycles within agriculture systems, with particular focus on soil N transformation. Such models are highly useful for exploring the best management practices under different climates (Li et al., 2007; Chen et al., 2008). The denitrification decomposition model (DNDC) is another process-based model widely used for simulation of N_2O emissions. However, DNDC model was found inaccurate in simulating the seasonal variation of N_2O emission for degraded typical and meadow steppes (Xu et al., 2003). In addition, modeled N_2O fluxes by DNDC were found to be relatively high in meadow and swamp grasslands (Zhang et al., 2010). Moreover, DNDC and Daycent models were used to simulate the N_2O fluxes in alpine meadows and Kentucky bluegrass and found that the deviations of annual emission between measured and simulated flux were relative high (Du et al., 2011; Zhang et al., 2013). Compared with the DNDC and Daycent models, the WNMM has been found to perform consistently well in predicting daily N_2O emissions for a well-drained loam soil (Li et al., 2005). Based on a 37-year historic simulation, multivariate regression models for estimating annual N_2O emissions have explained about 50% of the variations in wheat cropping systems determined using the WNMM (Li et al., 2008). Currently, field quantification of N_2O emissions and more accurate model simulation for extrapolating the N_2O fluxes are urgently required for the alpine grasslands of the Tibetan Plateau (Hu et al., 2010; Zhang et al., 2010; Du et al., 2011).

Alpine grassland is the principal vegetation of the Tibetan Plateau, covering an area of 140×10^4 km^2 and constituting one of the most important grazing ecosystems in the world (Foggin, 2008). The entire plateau covers an area of 250×10^4 km^2, accounting for approximately 25% of China's total territory. Its average elevation is greater than 4000 m, ranked as the world's highest-elevation plateau (Du et al., 2011). The Tibetan Plateau is the source of many Asian's primary rivers, supplying water to 40% of the world's population (Foggin, 2008). Because of its high elevation, the ecosystems on the plateau are fragile and very sensitive to climatic warming and precipitation variation, which can lead to grassland degradation (Piao et al., 2010; Du et al., 2011). Continuous measurements since 1960 have revealed strong warming on the Tibetan Plateau (Piao et al., 2010). Serious impacts have been reported for future global mean temperature increases of 1–3 °C, and it was estimated that China' average temperature will increase by 1–5 °C by 2100 (Piao et al., 2010). Global warming has increased global precipitation and causes changes into its spatial distribution. It has been established that during 1960–2005 the glaciers on the Tibetan Plateau shrunk by 7% (3.79×10^3 km^2), and that precipitation has gradually increased during the peak growing seasons, even with a notable 14% increase in winter precipitation per decade recorded on the Tibetan Plateau (Piao et al., 2010). Instantaneous flux rates of N_2O are essential for assessing the contributions and feedbacks of alpine meadow to climate change (Zhang et al., 2010). However, the lack of field measurements and poor model simulation results for the Tibetan Plateau have limited adequate development of the global N_2O emission inventory, and prevented the assessment of the viability of mitigation strategies.

To contribute to the understanding of the role of alpine meadows in both global N_2O budgets and future climate change, this study adopted a number of objectives: (1) to observe the temporal variation of N_2O flux at different time scales (i.e., daily, monthly, annually); (2) to evaluate the output of WNMM regarding N_2O release and identify the contribution of nitrification and denitrification; and (3) to illuminate the potential implications of annual N_2O flux in future global climate change scenarios.

2. Methods and materials

2.1. Site description

The study site is located at Haibei Alpine Meadow Research Station of the Chinese Academy of Sciences, Menyuan County, Qinghai Province (37°32′ N, 101°15′ E, 3280 m elevation). It has a semi-arid continental climate with an annual average temperature of −1.7 °C and a mean annual precipitation of 560 mm, 85% of which falls in growing season (from May to late September). The soil is Mat-Gryic Cambisol with high organic matter content (Hu et al., 2010; Du et al., 2011).

The grassland community consists of two vertical layers and has nearly 40 species per m^2. *Kobresia humilis* meadow is one of dominant alpine grassland types on the plateau. The *Kobresia* meadow is dominated by *K. humilis* Serg. *Festuca ovina* Linn, *F. rubra* Linn., *Saussurea superba* Anth., *Stipa aliena* Keng., *Helictotrichon tibetica* Henr., *Poa crymophila* Keng., *Leontopodium*