Evaluation of Carbon Gas Emissions from the Zoige Peatlands: Overview of a Decade Study

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Peatlands are usually located between terrestrial upland and aquatic environments and play an important role in element cycling and energy exchange. Very few studies have been conducted to understand the ecological functions of peatlands in the Hindu Kush Himalayan (HKH) region, especially the emission of carbon in the form of carbon dioxide (CO_2) and methane (CH_4). A long-term study on the Zoige peatlands, China, the largest peatland area in the HKH region, was initiated in 2003. Research over the past decade has included spatial variations of emissions at microtopographic, community, and ecosystem scales and temporal variations of emissions at diurnal, seasonal, and interannual scales. Initial trends have been obtained for the factors influencing emissions at various spatio-temporal scales. However, there are still many knowledge gaps such as i) patterns of emission from drained, restored and pristine peatlands; ii) mechanisms of soil microbial processes relevant to carbon gas production, transformation, and transportation; and iii) emissions generated by waterborne carbon from peatland to aquatic ecosystems.

Keywords: CH_4; CO_2; spatio-temporal pattern; Zoige peatlands

Introduction

The Zoige peatlands on the eastern Tibetan Plateau is the largest alpine peatland worldwide, covering an area of approximately 7,000 km^2, and located at an average elevation of 3,500 masl (Fei 2006). As major interfaces between upland terrestrial ecosystems and a network of water bodies, the peatlands serve as a vital buffer zone for adjusting regional hydrology, and an important source of water for the world famous Yellow River (SAFS 2006). Moreover, the Zoige peatlands provide critical habitats for numerous endangered and endemic species (Tsuyuzaki 1990; Ekstam 1993; Schaller 1998). In terms of other environmental services, the Zoige peatlands store an estimated carbon stock of 750 megatonnes (Bjork 1993), which is a significant portion of China's peat carbon storage. Because of its immense conservation significance, the Zoige peatlands were included as a Ramsar site in 2008.

Peatlands started to sequestrate atmospheric CO_2 and play an important role in the earth's climate system after the end of the Last Glacial Maximum (LGM) (Yu et al. 2010). At present, the carbon pool in peatlands accounts for at least 12% of terrestrial carbon stocks (Gorham 1991). Naturally, peatlands are sensitive to environmental change and disturbance. Although peatlands are considered to be a sink of CO_2 and source of CH_4 to the atmosphere, the carbon stocks in peat are tending to become more and more unstable in recent decades under the changing climate and increased human activities (Page et al. 2002; Ward et al. 2007). Peat extraction, construction of drainage ditches, and overgrazing by domestic livestock, along with climate change, is leading to extensive degradation of peatlands. Previous studies have shown that drained peatlands in boreal and tropical zones have already shifted to become strong sources of CO_2, rather than sinks as they used to be (Limpens et al. 2008). CH_4 emissions from peatlands might be reduced as the water table is lowered, but the overall global warming potential (GWP) of drained peatland is much higher than that of pristine peatland. The potential result is a fatal positive feedback between carbon gas emissions from peatlands and climate warming, which would accelerate the degradation process of peatlands, exhaust the carbon pool of peatlands, and ultimately largely change the composition of the atmosphere.

During the last decades, the Zoige peatlands have suffered from both climate change and human activities (Xiang et al. 2009). Between the 1950s and 2000, the annual air temperature increased by 0.23°C per decade and the annual precipitation by 1.75 mm per decade (Wang et al. 2005). With the rising demand for food, fuel, and forage, degradation caused by overgrazing, peat extraction, and construction of drainage ditches increased dramatically. It is estimated that less than 20% of the remaining peatlands in Zoige are intact or pristine (Schumann et al. 2008). In recent years, various levels of government and NGOs have carried out different pilot projects aimed to protect and restore the Zoige peatlands, and several long-term observation sites/stations have been established by local government and research institutions for scientific monitoring and evaluation of typical ecosystems in the peatlands. Considering the ecological functions of peatlands, the Chinese Academy of Sciences initiated long-term studies on carbon gas dynamics and causative factors in the early 2000s. The major objectives were to quantify the spatial variation in emissions, including the role of microtopography, community composition, and ecosystem type, and to assess the temporal variation, including diurnal, seasonal, and interannual climatic pattern scales. This paper gives an overview of the research findings, knowledge gaps, and way forward in terms of peatland research and management.

Progress Achieved

CO_2 emissions

Spatial variation

A comparative study was conducted on the ecosystem respiration in peatlands and grasslands in 2003 during the growing season. The mean flux rates of CO_2 over the three years were

203 mg CO_2 $m^{-2}h^{-1}$ from peatlands and 323 mg CO_2 $m^{-2}h^{-1}$ from grassland. The perennial waterlogging of peatlands limited the decomposition of plant residues, roots, and organic substances, resulting in a lower CO_2 flux. The seasonal changes of CO_2 fluxes in peatlands and grasslands correlated positively with air temperature, with the peak value usually observed in July or August; the diurnal changes in CO_2 flux also correlated positively with air temperature with peak values observed between 11:00 and 17:00 hrs. The CO_2 fluxes had a higher correlation with soil temperature at a depth of 5 cm than at depths of 10 and 15 cm (Wang et al. 2008).

Temporal variation

CO_2 fluxes across the air-water interface were monitored at Lake Medo, a typical, shallow peatland lake, during the summer of 2009. The mean CO_2 flux was 489 ± 1,036 mg CO_2 m^{-2} h^{-1}. The flux rate was high compared to those of lakes in other regions, and represented a 'hotspot' of CO_2 evasion. The temporal variation in the CO_2 flux was significant, with the peak value at the start of the warm season, and lowest value at the end. The concentration of dissolved organic carbon (DOC) in lake water (WDOC) was high and found to be highly correlated with the CO_2 flux. The fluorescence index of WDOC showed its terrestrial origin. It seems likely that the large area of peatlands in the catchment support the high concentration of DOC in this lake, and the consequent high level of CO_2 evasion (Zhu et al. 2012) (Figure 19).

Net ecosystem CO_2 exchange (NEE) was measured at a long-term peatland observation site using the eddy covariance technique. Analysis of NEE over two years showed that the peatland was a net CO_2 sink with values of −47 and −79 g C m^{-2} a^{-1} in 2008 and 2009, respectively. The peak NEE value was −540 μg CO_2 m^{-2} s^{-1} (the negative value signifies net ecosystem carbon gain from air). The maximal daily integrated NEE was −4 g C m^{-2} d^{-1} during the peak growth season (from July to August). Gross ecosystem photosynthesis appeared to be more variable than ecosystem respiration at both seasonal and interannual timescales at this site. The data suggested strongly that the combination of precipitation and temperature, together with the phenological stage of vegetation, controlled the dynamics of ecosystem carbon gain, even in drought years (Hao et al. 2011).

CH_4 emissions

Most of the work on CH_4 emissions was done at the long-term observation site in the Zoige peatlands (Figure 20).

Spatial variation

Thirty plots were set to measure CH_4 emissions in order to understand the spatial variation of CH_4 emissions at the field scale in two phenological seasons – the peak growing season and the quickly thawing season (frozen soil melts dramatically during this period). The plots included three environmental types: dry hummock (DH), *Carex muliensis* (CM), and

Figure 19: **Sampling in the Lake Medo, the Zoige Peatlands, China**

Figure 20: **A long-term observation site on the Zoige Plateau, China**

Elaeocharis valleculosa (EV). There was a very high spatial variation in the rate of CH_4 emissions within and across the different environmental types in both the growing and the thawing seasons. Mean CH_4 emission rates ranged from 1,100 to 37,000 μg CH_4 $m^{-2}h^{-1}$ in the peak growing season, and from 4 to 691 μg CH_4 $m^{-2}h^{-1}$ in the quickly thawing season. Coefficients of variation (CV) averaged 38% among environmental types and 64% within environmental types in the peak growing season; and 61% among environmental types and 96% within environmental types in the quickly thawing season. The key influencing factors in the peak growing season were the standing water table and the plant community height; no significant correlations were found between factors and CH_4 emissions in the quickly thawing season. For extrapolation of CH_4 emissions to larger areas, best results will be obtained by using factors that are easy to determine, like vegetation, the standing water table, and environmental types (Chen et al. 2009).

Temporal variation

An apparent diurnal variation pattern in CH_4 emission was observed with one minor peak at 06:00 and a major one at 15:00. The sunrise peak was consistent with a two-way transport mechanism for alpine peatland plants (convective in daytime and diffusive at night). CH_4 emission correlated significantly with soil temperature. The afternoon peak could not be completely explained by diurnal variation in soil temperature, and may be attributable to changes in CH_4 oxidation and production driven by the plant gas transport mechanism. Diurnal variation in CH_4 emission from peatland is important, especially when the plants are capable of exploiting more than one transport mechanism. Accordingly, sampling strategies for estimating the amount of CH_4 emitted from wetlands have to be carefully designed in order to include this variation (Chen et al. 2009).

The 30 plots were also used to investigate the seasonality of the CH_4 flux in terms of the whole growing and non-growing seasons. Clear seasonal patterns were observed in the different environmental types. The mean CH_4 emission rate was 14,450 μg CH_4 $m^{-2}h^{-1}$ (170 to 86,780 μg CH_4 $m^{-2}h^{-1}$) in the growing season, and 556 μg CH_4 $m^{-2}h^{-1}$ (2 to 6,722 μg CH_4 $m^{-2}h^{-1}$) in the non-growing season. In the growing season, the main maximum values of CH_4 flux were found in July and August, except for a peak value in September in CM sites. In the non-growing season, all the three environmental types showed a similar seasonal variation pattern, in which the CH_4 emissions increased from February to April. The determining factors in the growing season were surface temperature (r^2=0.55, $P<0.05$), standing water depth (r^2=0.32, $P<0.01$), and plant community height (r^2=0.61, $P<0.01$); while in the non-growing season ice thickness (r^2=0.27, $P<0.05$; in CM and EV sites) was most related to flux. The study suggests that the seasonality of CH_4 emissions is temperature and plant growth dependent, and that the water table position is very important in shaping the temperature and plant growth dependent seasonal variation and its marked variation in alpine peatland ecosystems (Chen et al. 2008).

CH_4 emissions were also measured at the same site during the winters of 2006 and 2007. Winter CH_4 emissions were roughly estimated to be 94 μg CH_4 m^{-2} h^{-1}. The emissions showed high spatial-temporal variations (with a sequence of CM> EV> KT; and average values of 630 and 1,240 μg CH_4 m^{-2} h^{-1} for 2006 and 2007, respectively). The factors involved in the spatial-temporal variation were 1) water table in summer determining the winter amount of 'old' CH_4 stored in peat; 2) ice layer determining the release of CH_4; and 3) plant growth determining both the quantity of CH_4 stored in peat and available substrates for CH_4 production in winter. However, due to the homogeneity of freezing in winter, predictive factors such as plant growth and water table in summer can contribute more to winter CH_4 emissions than in situ freezing conditions. As plant growth and water table are also the key factors controlling the spatial-temporal variation of CH_4 emissions in summer, it seems likely that winter CH_4 emissions represents the 'inertia' of summer CH_4 emissions (Zhu et al. 2011).

Interannual variations in CH_4 emissions were also studied at this site from 2005 to 2007. The weighted mean CH_4 emission rate in summer from 2005 to 2007 was 8,370±11,320 μg CH_4 m^{-2} h^{-1}, which is within the range of CH_4 fluxes reported by other studies, with significant interannual and spatial variation. The CH_4 emissions in 2006 (2,110±3,480 μg CH_4 m^{-2} h^{-1}) were 82% lower than the mean values in 2005 and 2007 (13,910±17,800 μg CH_4 m^{-2} h^{-1} and 9,440±14,320 μg CH_4 m^{-2} h^{-1}, respectively), which corresponded with interannual differences in standing water depth during the growing season in the three years. Significant drawdown of standing water depth is believed to have caused the significant reduction in CH_4 emissions from the peatlands in 2006, probably through changing the methanogen composition and decreasing its community size, as well as activating methanotrophs to enhance CH_4 oxidation (Chen et al. 2013).

Knowledge Gaps and Perspectives

Network of a series sites for peatlands

Most of the studies focused on carbon gas emissions were carried out intensively at sites located in the heart of the Zoige peatlands. This area is a fen in low-lying position with seasonal surface water. The site had nearly 23% of intact peatland. There are no data with high spatiotemporal resolution for drained or degraded peatland. In recent years, the management authorities of Zoige have imposed a ban on draining of peatlands and started to fill the drainage ditches (Figure 21). The rewetting of large expanses of peatland has already resulted in a substantial improvement in the water table, restoration of plant communities, and improvement of soil properties (Zhang et al. 2012). However, the effect of restoration on carbon gas emissions has not yet been studied. A comparison of carbon gas emissions among pristine, drained, and restored peatland would provide a basis to protect the carbon storage of peatlands.

Figure 21: **Typical drain-blocking site in the Zoige Peatlands, China**

Soil process associated with carbon gas emission

Carbon gases, both CO_2 and CH_4, released from peatlands are the ultimate products of biogeochemical processes in peat. Physical and chemical parameters such as the water table, soil temperature, redox potential, and substrate content in peat were found to have a significant correlation with gas emission, even though the coefficients of correlation were relatively low. In boreal and northern regions, microbial processes, including aerobic and anaerobic process, are thought to be another key factor controlling carbon gas emission (Fenner et al. 2005). There are some studies on the community structure of methanogen (Tian et al. 2012) and relationship between methanogenic archaea and CH_4 production potential (Liu et al. 2011) in pristine peatlands from the Zoige peatlands. More incubation experiments, together with field sampling and microbe examination, are needed in order to explore the mechanisms underlying the production and transport of carbon gases.

Linkage of carbon exchange between terrestrial and aquatic ecosystems

Peatlands are considerable sources of waterborne carbon (including DOC, POC, DIC) added to aquatic ecosystems as well as a source of carbon gas emission into the atmosphere. CO_2 emissions from lakes in boreal regions are extensively fueled by terrestrial origin carbon (Lennon 2004), especially the carbon from peatlands. Furthermore, drained peatlands tend to have a higher export rate of waterborne carbon, and a large portion of that carbon will be decomposed by bacteria in aquatic ecosystems (Pastor et al. 2003; Dawson et al. 2004). In Lake Medo, a typical peatland lake in the Zoige peatland, the comparative high CO_2 emission rate was found to be supported by terrestrial DOC, mainly peatland origin DOC. Similarly, the CO_2 emissions from rivers and streams in this region might also be controlled by waterborne carbon from peatland. The production, export, and transportation of waterborne carbon in the Zoige peatlands should be examined.

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