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Focus on the impact of climate change on wetland ecosystems and carbon dynamics

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Abstract

The renewed growth in atmospheric methane (CH_4) since 2007 after a decade of stabilization has drawn much attention to its causes and future trends. Wetlands are the single largest source of atmospheric CH_4. Understanding wetland ecosystems and carbon dynamics is critical to the estimation of global CH_4 and carbon budgets. After approximately 7 years of CH_4 related research following the renewed growth in atmospheric CH_4, *Environmental Research Letters* launched a special issue of research letters on wetland ecosystems and carbon dynamics in 2014. This special issue highlights recent developments in terrestrial ecosystem models and field measurements of carbon fluxes across different types of wetland ecosystems. The 14 research letters emphasize the importance of wetland ecosystems in the global CO_2 and CH_4 budget.

Introduction

Wetlands cover approximately 6% of the Earth's land surface and contain a large portion of the world's biodiversity (Junk *et al* 2013). Wetland ecosystems are an important component in the global carbon cycle and play an important role in terrestrial ecosystem and atmosphere interactions. On the one hand, wetland ecosystems are an ideal natural environment for the carbon sequestration and long-term storage of atmospheric CO_2 (Frolking *et al* 2011); on the other hand, wetlands are the largest single source of atmospheric methane (Meng *et al* 2012). Therefore, wetlands serve as both a carbon sink and source from global warming perspectives (Junk *et al* 2013). It is highly uncertain that whether wetlands act as a positive or negative feedback to the climate system.

Currently, carbon stored in wetlands is close to that stored in the atmosphere (Lenhart 2009). Understanding the impact of climate changes and human activities on carbon dynamics of wetland ecosystems is critical to climate predictability. The 14 letters included in this special issue 'focus on the impact of climate change on wetland ecosystem carbon dynamics' deal with carbon dynamics in different types of wetlands in high latitudes, altitudes (e.g., Tibetan plateau), and tropical regions through observational studies and modeling simulations. Thus, this special issue provides a set of valuable findings and data related to wetlands carbon cycling and its environmental controls.

Northern wetlands (45 °N north)

Northern wetlands store over 50% of the global soil organic carbon due to the slow organic carbon decomposition rate as a result of wet surface conditions and cold temperatures (Hugelius *et al* 2013). The IPCC (Intergovernmental Panel on Climate Change 2014) AR5 (the fifth assessment report) (IPCC 2014) predicts that increasing temperatures will affect high latitudes more than tropical and subtropical regions (Collins *et al* 2013). Therefore, northern wetlands might be more vulnerable to the changes in temperatures. A few letters from this special issue address the impact of environmental changes on wetland ecosystem carbon balance and methane emissions. Peichl *et al* (2014) used 12 years of Eddy covariance (EC) measurements to investigate the inter-annual variation in the long-term net ecosystem exchange (NEE) of carbon dioxide (CO_2) and its relationship to environmental factors such as water table level and pre-growing season air temperatures in an oligotrophic mire in northern Sweden. It was found that this boreal peatland serves as a persistent long-term sink of atmospheric CO_2 that is not subject to moderate inter-annual climate variations except under extreme low water table level conditions. Another study found that dry conditions have no persistent effects on the CO_2 exchange dynamics in the Andoya blanket bog in northern Norway on seasonal to annual time scales, and that growing season onset and amount of incoming light are more important controls of inter-annual variation of the CO_2 exchange in this blanket bog (Lund *et al* 2015). Similarly, Pelletier *et al* (2015) found boreal peatlands with pools in Quebec, Canada are net sinks of CO_2 at the ecosystem level during the growing season using one-season of EC measurement of NEE and CO_2 flux despite the pools themselves being persistent sources of CO_2.

In addition to the natural causes of carbon dynamics and changes on high latitude wetland ecosystems, agricultural activities such as grazing also affect vegetation structure and greenhouse gas emissions in a high arctic mire (Falk *et al* 2015). Falk *et al* (2015) conducted controlled grazed and ungrazed experiments to investigate the impact of muskox grazing on the vegetation composition and the carbon balance in a high arctic mire located in the Zachenberg valley, NE Greenland. It was found that net ecosystem uptake of CO_2 and CH_4 emissions have decreased by 47% and 44% in the ungrazed experiment plots respectively, suggesting the importance of grazing mammals in ecosystem greenhouse gas dynamics. Another study evaluated 5 years of EC measurement of CO_2 and 4 years of chamber measurements of CH_4 from a freshwater Marsh in Ottawa, Ontario, and found that the Marsh C budget as a sink was significantly reduced when combining CO_2 and CH_4 emissions (Strachan *et al* 2015) due to the substantial Marsh CH_4 emissions. Strachan *et al* (2015) also demonstrated that cold season ecosystem respiration, driven by temperature and snowfall, was an important component of the Marsh annual C budget and Marshes should be included in national and global estimates of wetland greenhouse gas contributions to the global carbon cycle.

Johnston *et al* (2014) investigated the effects of lowland permafrost thaw over millennial timescales using a measurement of CO_2 and CH_4 from thermokarst collapse bogs and adjacent fen locations that contain a ~1000 yr thaw chronosequence in western Alaska. They found that CH_4 efflux has been enhanced during the growing season following lowland permafrost thaw over decadal time scales, suggesting that thaw features (such as thaw stages and cycles) should be included when evaluating high latitude CH_4 dynamics (Johnston *et al* 2014).

This special issue also includes a perspective by Stark and Ylanne (2015) on the importance of grazing in affecting ecosystem processes and C budgets in Arctic peatlands. They develop a conceptual model of possible pathways by which grazing and climate change may affect peatland C storage, CO_2 balance, and CH_4 release in the Arctic.

Tropical and subtropical wetlands

Tropical and subtropical wetlands contribute at least 50% of total wetland methane emissions, and over 80% of the natural sources, to the atmosphere partially due to large inundated areas and high temperatures (Riley *et al* 2011, Meng *et al* 2012, Meng *et al* 2015). Understanding the carbon dynamics and their influential factors will be critical to the estimation of global carbon budgets and its spatial distribution. Jauhiainen *et al* (2014) evaluated the heterotrophic CO_2, N_2O, and CH_4 fluxes in a drained tropical peatland under four shading conditions with different treatments in Central Kalimantan, Indonesia. They found that soil shading by vegetation decreases greater greenhouse gas (GHG) emissions to the atmosphere through reducing peat temperatures. Land management differences affect how greenhouse gas fluxes respond to peat temperature and fertilization, but increases in temperatures do not necessary translate into GHG emissions. The internal characteristics of peatlands (such as open degraded peatlands, intact peatland forests) may decrease the sensitivity of GHG emissions to temperature change (Jauhiainen *et al* 2014). A study by Oliveras *et al* (2014) assessed net primary productivity and carbon cycling in Andean tropical alpine grasslands based on direct measurements and found that Andean grasslands had similar NPP and soil carbon stocks to tropical montane cloud forests. Therefore, high elevation tropical grasslands are an important reservoir for soil carbon stocks and production (Oliveras *et al* 2014). A study of CO_2 budget dynamics in a subtropical estuarial Marsh wetland ecosystem in Taiwan shows that temperature and radiation have stronger influence on gross primary production of CO_2 than soil moisture content and vapor pressure deficit. Further, these environmental variables have strong but different impacts on the CO_2 budget in the two different low-latitude ecosystems (para grass and reed) (Lee *et al* 2015).

Wetland ecosystem modeling

Wetland ecosystem models have been used to estimate CH_4 and CO_2 fluxes at regional and global scales (Zhuang *et al* 2004, Wania *et al* 2010). Uncertainties associated with the environmental controls of methane biogeochemical processes prevent the accurate prediction of global and regional methane budgets (Riley *et al* 2011). One of the largest uncertainties is wetland extent or inundated area (Riley *et al* 2011, Meng *et al* 2012). Three letters from this special issue address the impact of changes in wetland inundation extents on regional CH_4 and CO_2 fluxes using two different models. Watts *et al* (2014) investigated the impact of surface warming and moisture availability on northern latitude CH_4 emissions using the Joint UK Land Environment Simulator (JULES) methane emission model driven by satellite-derived fractional inundation. The JULES methane model experiments produced mean summer contribution of 53 Tg $CH_4\ yr^{-1}$ from the boreal-arctic wetlands ($\geqslant$45 °N). The JULES model sensitivity analysis highlighted the importance of finer (or sub-monthly) temporal resolution of fractional inundation on annual CH_4 emission estimation. Zhuang *et al* (2015) used the terrestrial ecosystem model (TEM) to evaluate the influence of the inter-annual variability in wetland inundation extent from 1993–2004 on CO_2 and CH_4 emissions from the northern wetlands ($\geqslant$45 °N). The TEM model, driven by the same satellite-derived fractional inundation used in Watts *et al* (2014), estimated the annual methane emission to be 67.8 ± 6.2 Tg $CH_4\ yr^{-1}$ and regional CO_2 sink of -1.28 ± 0.03 Pg C yr^{-1}. Zhuang *et al* (2015) found northern wetlands to be a consistent greenhouse gas sink per global warming potential and that variability in wetland inundation plays a very important role in affecting regional greenhouse gas budgets. Jin *et al* (2015) applied the TEM to estimate net exchanges of methane and CO_2 fluxes on the Qinghai-Tibetan Plateau from 1979 to 2100 under different climate change scenarios. Their simulations, by considering both CO_2 and CH_4 fluxes, demonstrate that the Qinghai-Tibetan Plateau will serve as a carbon source from 1979–2030 and turn to a carbon sink from 2030 to 2100.

Coastal wetlands and methane measurement techniques

The flux chamber technique has been one of the widely used methods to measure methane fluxes. Luan and Wu (2014) assessed how chamber characteristics affect artificial biases in methane fluxes measured using static chambers and found that opaque chambers tended to measure a significantly higher methane emission from hummocks than transparent chambers, but not at the hollows in a boreal peatland. It was concluded that both microtopography (hummocks versus hollows) and chamber characteristics can have large influence on the accuracy of methane flux measurements (Luan and Wu 2014). This information will be very valuable to field measurements to get more accurate measurement of CH_4 fluxes.

Caplan *et al* (2015) studied the primary production of *Phragmites* in response to increased CO_2 level and N enrichments in a North American mid-Atlantic Coast wetland using observations and model simulations. It was found that N enrichment increased carbon assimilation in the early and late growing season and CO_2 elevation enhanced assimilation more moderately in the early and mid-growing season. This suggests that carbon sequestration could be enhanced through the increase in *Phragmites* productivity if *Phragmites* were allowed to invade into the coastal wetland. Further research is needed to address the impact of *Phragmites* on coastal wetland ecosystems and carbon budgets.

Concluding remarks and future research

Wetland ecosystems are one primary component of the global carbon budget. The collection of 14 letters and one perspective in this special issue provides an excellent starting point for researchers who are interested in wetland ecosystem and carbon dynamics. Both field measurements and modeling studies are included to address different aspects of carbon cycling at local and regional scales. Environmental variables that affect CO_2 and CH_4 fluxes at local and regional scales are investigated, including temperature, radiation, agricultural treatments and land management, soil moisture content, and vapor pressure deficit. With the current global warming trend, it is expected that both tropical and northern wetland ecosystems will experience large changes in temperature and wetting and drying cycles. Future research should continue focusing on the influential factors that affect carbon dynamics across different wetland ecosystems. A few variables that were not addressed in this special issue are soil pH and redox potentials, soil moisture dynamics, and vegetation types and their impacts on CH_4 and CO_2 emissions. More field measurements of carbon budget and fluxes are required to further understand the dominant environmental variables that impact wetland carbon dynamics.

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References

Caplan J S, Hager R N, Megonigal J P and Mozdzer T J 2015 Global change accelerates carbon assimilation by a wetland ecosystem engineer *Environ. Res. Lett.* **10** 115006

Collins M *et al* 2013 Long-term climate change: projections, commitments and irreversibility *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ed T F Stocker *et al* (Cambridge: Cambridge University Press)

Falk J M, Schmidt N M, Christensen T R and Strom L 2015 Large herbivore grazing affects the vegetation structure and greenhouse gas balance in a high arctic mire *Environ. Res. Lett.* **10** 045001

Frolking S, Talbot J, Jones M C, Treat C C, Kauffman J B, Tuittila E S and Roulet N 2011 Peatlands in the Earth's 21st century climate system *Environ. Rev.* **19** 371–96

Hugelius G, Tarnocai C, Broll G, Canadell J G, Kuhry P and Swanson D K 2013 The Northern circumpolar soil carbon database: spatially distributed datasets of soil coverage and soil carbon storage in the northern permafrost regions *Earth Syst. Sci. Data* **5** 3–13

IPCC 2014 Climate Change 2014: Synthesis Report *Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* ed R K Pachauri and L A Meyer (Geneva, Switzerland: IPCC) 151 pp

Jauhiainen J, Kerojoki O, Silvennoinen H, Limin S and Vasander H 2014 Heterotrophic respiration in drained tropical peat is greatly affected by temperature-a passive ecosystem cooling experiment *Environ. Res. Lett.* **9** 105013

Jin Z N, Zhuang Q L, He J S, Zhu X D and Song W M 2015 Net exchanges of methane and carbon dioxide on the Qinghai-Tibetan plateau from 1979 to 2100 *Environ. Res. Lett.* **10** 095009

Johnston C E, Ewing S A, Harden J W, Varner R K, Wickland K P, Koch J C, Fuller C C, Manies K and Jorgenson M T 2014 Effect of permafrost thaw on CO_2 and CH_4 exchange in a western Alaska peatland chronosequence *Environ. Res. Lett.* **9** 085004

Junk W J, An S Q, Finlayson C M, Gopal B, Kvet J, Mitchell S A, Mitsch W J and Robarts R D 2013 Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis *Aquatic Sci.* **75** 151–67

Lee S C, Fan C J, Wu Z Y and Juang J Y 2015 Investigating effect of environmental controls on dynamics of CO_2 budget in a subtropical estuarial Marsh wetland ecosystem *Environ. Res. Lett.* **10** 025005

Lenhart M 2009 An unseen carbon sink *Nat. Rep. Clim. Change* **3** 137–8

Luan J W and Wu J H 2014 Gross photosynthesis explains the 'artificial bias' of methane fluxes by static chamber (opaque versus transparent) at the hummocks in a boreal peatland *Environ. Res. Lett.* **9** 105005

Lund M *et al* 2015 Low impact of dry conditions on the CO_2 exchange of a Northern-Norwegian blanket bog *Environ. Res. Lett.* **10** 025004

Meng L, Hess P G, Mahowald N M, Yavitt J B, Riley W J, Subin Z M, Lawrence D M, Swenson S C, Jauhiainen J and Fuka D R 2012 Sensitivity of wetland methane emissions to model assumptions: application and model testing against site observations *Biogeosciences* **9** 2793–819

Meng L, Paudel R, Hess P G M and Mahowald N M 2015 Seasonal and interannual variability in wetland methane emissions simulated by CLM4Me' and CAM-chem and comparisons to observations of concentrations *Biogeosciences* **12** 4029–49

Oliveras I, Girardin C, Doughty C E, Cahuana N, Arenas C E, Oliver V, Huasco W H and Malhi Y 2014 Andean grasslands are as productive as tropical cloud forests *Environ. Res. Lett.* **9** 025004

Peichl M, Oquist M, Lofvenius M O, Ilstedt U, Sagerfors J, Grelle A, Lindroth A and Nilsson M B 2014 A 12 year record reveals pre-growing season temperature and water table level threshold effects on the net carbon dioxide exchange in a boreal fen *Environ. Res. Lett.* **9** 055006

Pelletier L, Strachan I B, Roulet N T and Garneau M 2015 Can boreal peatlands with pools be net sinks for CO_2? *Environ. Res. Lett.* **10** 035002

Riley W J, Subin Z M, Lawrence D M, Swenson S C, Torn M S, Meng L, Mahowald N M and Hess P G 2011 Barries to predicting changes in global terrestrial methane fluxes: analysis using CLM4ME, a methane biogeochemistry model integrated in CESM *Biogeosciences* **8** 1925–53

Stark S and Ylanne H 2015 Grazing in Arctic peatlands-an unknown agent in the global carbon budget *Environ. Res. Lett.* **10** 051002

Strachan I B, Nugent K A, Crombie S and Bonneville M C 2015 Carbon dioxide and methane exchange at a cool- temperate freshwater Marsh *Environ. Res. Lett.* **10** 065006

Wania R, Ross I and Prentice I C 2010 Implementation and evaluation of a new methane model within a dynamic global vegetation model: LPJ-WHyMe v1.3 *Geosci. Model Dev.* **3** 565–84

Watts J D, Kimball J S, Bartsch A and McDonald K C 2014 Surface water inundation in the boreal-Arctic: potential impacts on regional methane emissions *Environ. Res. Lett.* **9** 075001

Zhuang Q, Melillo J M, Kicklighter D W, Prinn R G, McGuire A D, Steudler P A, Felzer B S and Hu S 2004 Methane fluxes between terrestrial ecosystems and the atmosphere at northern high latitudes during the past century: a retrospective analysis with a process-based biogeochemistry model *Glob. Biogeochem. Cycles* **18** GB3010

Zhuang Q L, Zhu X D, He Y J, Prigent C, Melillo J M, McGuire A D, Prinn R G and Kicklighter D W 2015 Influence of changes in wetland inundation extent on net fluxes of carbon dioxide and methane in northern high latitudes from 1993 to 2004 *Environ. Res. Lett.* **10** 095009