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GREENHOUSE GAS FLUXES AT BOREAL AND ARCTIC WETLAND IN ALASKA

Masahito Ueyama[1*], Hiroki Iwata[2], Hirohiko Nagano[3], Kazuhito Ichii[4] and Yoshinobu Harazono[1]

[1]*Graduate School Of Life And Environmental Sciences, Osaka Prefecture University, Japan*
[2] *Department Of Environmental Sciences, Faculty Of Science, Shinshu University, Matsumoto, Japan*
[3]*Graduate School Of Horticulture, Chiba University, Japan*
[4]*Japan Agency For Marine-Earth Science And Technology, Japan*

**Corresponding author: miyabi-flux@muh.biglobe.ne.jp*

SUMMARY

For evaluating long-term greenhouse gas budget, we have continuously measured CO_2 and CH_4 fluxes by the eddy covariance and gradient methods at boreal and Arctic wetlands in Alaska. In this study, we review our recent activities of the field measurements and synthesis based on multi-site eddy covariance measurements with satellite remote sensing. Based on a decade of measurements, an autumn warming shifted the annual CO_2 balance at a peatland forest on permafrost from sink to source. CH_4 fluxes at the forest played a minor role on the greenhouse gas budget. In contrast, CH_4 fluxes played a major role on greenhouse gas budget at Arctic wet sedge tundra. Synthesizing CO_2 fluxes from 21 eddy covariance towers in Alaska, most of ecosystems acted as growing-season CO_2 sink, and its spatial variability was explained by growing-degree days, satellite derived LAI, and growing-season length. Applying satellite data with a machine learning technique, upscaled CO_2 fluxes showed that GPP and RE were 369 ± 22 and 362 ± 12 Tg C yr^{-1} for Alaska, respectively, indicating an approximately neutral CO_2 budget from 2000 to 2011. Network of long-term eddy covariance measurements can be particularly useful for evaluating greenhouse gas fluxes at high-latitude ecosystems.

Keywords: *alaska, eddy covariance, greenhouse gas flux, synthesis*

INTRODUCTION

Northern high-latitudes contains substantial extent of wetland, most of which are on peat soils with permafrost. The high-latitude soils contained substantial amount of carbon (Ping *et al.*, 2008). These regions currently suffer rapid environmental change, including air and soil warming, permafrost thawing, and hydrological cycle (Chapin *et al.*, 2005; Hinzman *et al.*, 2005). Greenhouse gases (GHGs) budget of high latitude ecosystems are highly vulnerable to the current and predicted future changes associated with stimulated carbon, water, and nutrient cycles.

The eddy covariance method is a strong tool to evaluate GHG fluxes at terrestrial ecosystems (Baldocchi 2014). Currently, a number of eddy covariance sites were established in order to understand carbon and water budgets (Euskirchen *et al.*, 2012; Harazono *et al.*, 2003; Nakai *et al.*, 2013; Kwon *et al.*, 2006; Oechel *et al.*, 2000; Vourlitis *et al.*, 2000; Ueyama *et al.*, 2006, 2014b), role of understory vegetation (Ikawa *et al.*, 2015), methane dynamics (Euskirchen *et al.*, 2014; Harazono *et al.*, 2006; Iwata *et al.*, 2015; Sturtevant and Oechel, 2013), disturbance effects (Iwata *et al.*, 2011; Randerson *et al.*, 2006; Rocha and Shaver, 2011; Welp *et al.*, 2007), and effect of vegetation shift (Beringer *et al.*, 2005; McFadden *et al.*, 2003) in Alaska. Integrating those data and knowledge could provide insight into the current status and possible future state of high-latitude GHGs flux on different spatial and temporal scales.

Key restriction for understanding the high-latitude GHG balance is the limited availability of long-term data, especially of methane (CH_4) flux, and lack of appropriate methodology of spatio-temporal scaling GHG fluxes. Consequently, we have conducted long-term observations at ecosystems in the Arctic (*e.g.*, Harazono *et al.*, 2003, 2006) and boreal (*e.g.*, Iwata *et al.*, 2015; Ueyama *et al.*, 2014b) peat-dominated wetlands in Alaska, obtaining decade of GHG fluxes data. Then, we compared our flux data with those observed in Alaska by other groups (Ueyama *et al.*, 2013b); finally empirically upscaled the GHG fluxes using satellite remote sensing with a machine learning method (Ueyama *et al.*, 2013a, 2014a). In this study, we review our recent activities of the field measurements and synthesis based on multi-site eddy covariance measurements.

METHODS

6. Flux measurements

We have conducted micrometeorological flux measurements at a boreal peat-dominated forest and Arctic wet sedge tundra in Alaska, USA. The tower sites were located at an open black spruce forest at interior Alaska (FAI site; 62.87^{o}N, 147.86^{o}W, Iwata *et al.*, 2012; Ueyama *et al.*, 2006, 2009, 2014b) and a wet sedge tundra in the Arctic Coastal Plain (CMS site; 71.31^{o}N, 156.62^{o}W; Harazono *et al.*, 2003). Both sites were on peat soil over permafrost. Heat, water vapor, and CO_2 fluxes were measured by the eddy covariance method since October 2002 at FAI and from 1999 to 2005 at CMS. CH_4 flux was measured by the eddy covariance method at FAI (Iwata *et al.*, 2015), and by the gradient method (Harazono *et al.*, 2006).

7. Inter-site comparison

Growing-season CO_2 fluxes measured at various landscapes, including Arctic tundra, boreal forests, and fire scars, in Alaska, were synthesized in order to understand spatial and temporal dynamics of CO_2 exchange (Ueyama *et al.*, 2013b). We used flux data from 13 eddy covariance towers (Beringer *et al.*, 2005; Euskirchen *et al.*, 2012; Harazono et al., 2003; Ikawa *et al.*, 2015; Nakai *et al.*, 2013; Kwon *et al.*, 2006; Randerson *et al.*, 2006; Rocha and Shaver, 2011; Ueyama *et al.*, 2014b; Welp *et al.*, 2007), and compared NEE, GPP and RE among the sites. Consistent data processing, including gap-filling and flux partitioning, were applied based on a method proposed by Ueyama *et al.* (2012).

8. Upscaling CO_2 fluxes using satellite remote sensing

Regional CO_2 budget of Alaska was estimated based on upscaling eddy-covariance CO_2 fluxes from the 21 sites using satellite remote sensing and machine-learning techniques (Ueyama *et al.*, 2013a). Eight-day mean GPP and RE were upscaled by inputting green ratio (Harazono *et al.*, 2009) and land surface temperature from MODIS, solar radiation by JRA25 (Onogi *et al.*, 2007), landcover classification, and fire-scar information by Alaska Fire Service into support vector regression model (SVR; Yang *et al.*, 2006; Ichii *et al.*, 2009). Regional NEE was calculated at eight-day interval based on balance between upscaled GPP and RE, and then compared with those by a top-down approach (CarbonTracker; Peters *et al.*, 2007).

RESULTS AND DISCUSSION

9. CO_2 and CH_4 Fluxes at two selected wetlands

Based on the decade of the measurements at FAI, an autumn warming shifted annual CO_2 balance at the peatland forest (FAI) from sink to source (Fig. 1; after Ueyama *et al.*, 2014b). During the same period, GPP and RE increased significantly, indicating that the measured shift of annual CO_2 balance was mainly due to increase in RE. Separating contributions of spring, summer, and autumn months, the positive trends in CO_2 fluxes were mostly contributed by increases in autumn fluxes. This autumn fluxes was highly explained by autumn warming. During the study period from 2003 to 2014, the autumn warming (0.10 °C yr^{-1}; p = 0.13) was six times greater than the long-term warming trend between 1905 and 2014 (0.015 °C yr^{-1}; $p < 0.01$) due to decadal climate oscillation. This indicates that most of the shifts in observed CO_2 fluxes could be due to the decadal climate variability.

Both wetlands acted as net CH_4 source throughout the growing season (Fig. 2). The greater emission was observed in early growing season at the Arctic tundra (CMS; Harazono *et al.*, 2006), whereas in late growing season at FAI (Iwata *et al.*, 2015). CH_4 fluxes at CMS were approximately an order of magnitude higher than those by FAI. This could be due to larger oxidation in unsaturated surface soil at FAI than CMS. Consequently, CH_4 fluxes at the peatland forest played a minor role on the GHGs budget; however, CH_4 fluxes played a major role on GHGs budget in the Arctic tundra.

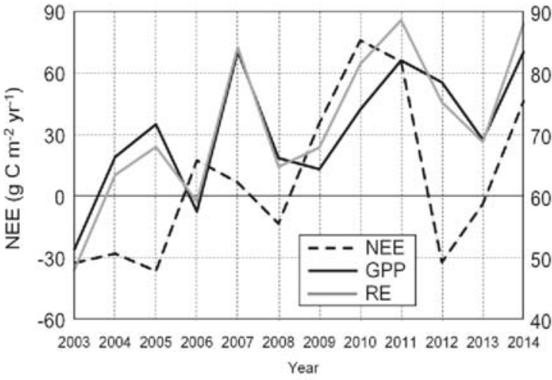

Fig.1 Annual NEE, GPP, and RE from 2003 to 2014 at the peatland forest in Fairbanks (After, Ueyama *et al.*, 2014b).

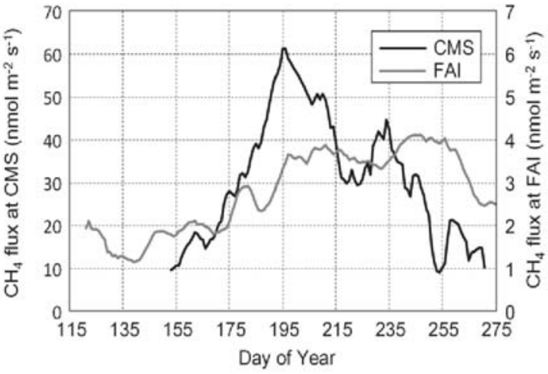

Fig.2 Mean seasonal variations of CH_4 fluxes at CMS (1999-2000) and FAI (2011-2013).

10. Inter-site comparison

Spatial variations of growing-season GPP, RE, and NEE among 13 sites in Alaska were explained by multiple linear regressions using growing degree days, growing season length, and leaf area index by MODIS (Fig. 3; Ueyama *et al.*, 2013b). The regression models were not different among wetland and upland ecosystems, indicating scaling CO_2 fluxes of both wetland and upland was possible using same environmental variables. Except one burned forest and one Arctic tundra, terrestrial ecosystems in Alaska acted as net growing-season CO_2 sink (Fig. 3b).

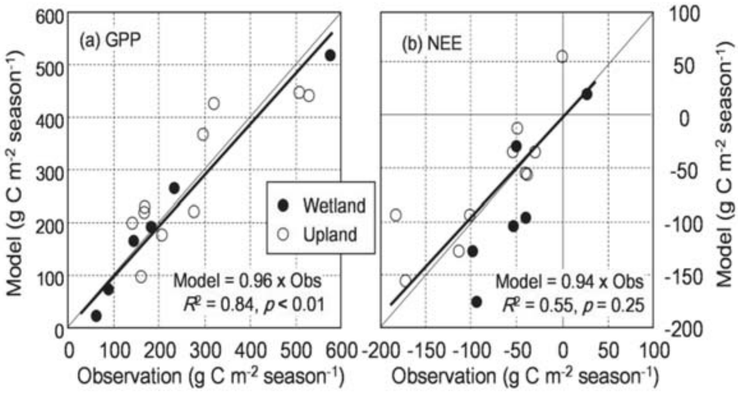

Fig.3 Comparison of growing season GPP (a) and NEE (b) among observations and a multiple liner regression model based on growing degree days, growing season length,

11. Regional fluxes based on upscaling

Applying satellite data with the SVR method, upscaled CO_2 fluxes showed that GPP and RE were 369 ± 22 and 362 ± 12 Tg C yr^{-1} for Alaska (Ueyama et al., 2013a), respectively, indicating an approximately neutral CO_2 budget for the decade. Upscaled fluxes suggested that boreal regions acted as a net annual CO_2 sink, but the arctic tundra acted as a source (Fig. 4). Magnitude and interannual variations in growing-season regional NEE were highly consistent with those estimated by the top-down approach, CarbonTracker. Interannual variability in the regional fluxes positively correlated with air temperature from June to August, indicating Alaska acted as a greater CO_2 sink in warmer years.

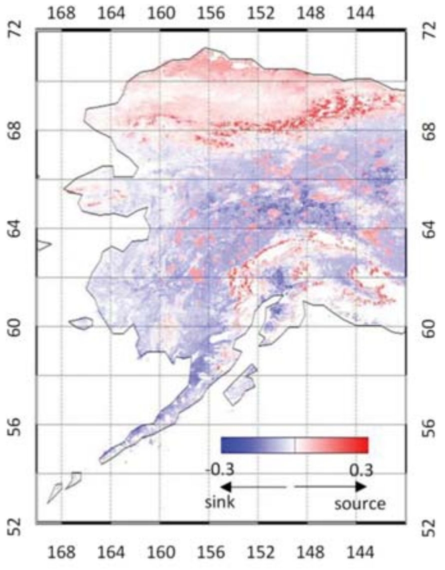

Fig.4 Spatial distribution of upscaled NEE for 2004 (g C m^{-2} yr^{-1}).

FUTURE DIRECTIONS

Based on the decade of the studies, seasonal, inter-annual, decadal, and spatial variabilities in CO_2 fluxes and physical controlling factors are beginning to be clarified; however, biological, ecological and physiological processes behind and further long-term changes are yet to be studies. Decade of the CO_2 fluxes indicate that carbon balance of the high-latitude wetland is highly vulnerable to ongoing warming; thus, continuous monitoring are particularly important at high-latitude wetland. Model-data synthesis could improve our understanding and expand our knowledge into further long and wide spatiotemporal scales (Ueyama *et al.*, 2013a, 2014b, 2016). Continuous monitoring CH_4 fluxes started in recent years at various landscapes in Alaska (Euskirchen *et al.*, 2014; Iwata *et al.*, 2015; Sturtevant and Oechel, 2013). Such measurements will clarify detailed picture of interannual and decadal variations of CH_4 flux at various landscapes. Linking and modelling CH_4 fluxes from towers with other dataset, such as satellite remote sensing, are challenge to estimate regional CH_4 fluxes in future. From 2015, Arctic Challenge for Sustainability (ArCS) project are initiated in Japan, and will facilitate challenging these issues.

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