Abstract of entire Ph. D Dissertation　全文の要約

Studies on vegetation mapping and methane emissions in a taiga-tundra boundary lowland, northeastern Siberia

北東シベリアのタイガ‐ツンドラ境界における植生マッピングとメタン放出に関する研究

北海道大学大学院環境科学院

Graduate school of Environmental Science,

Hokkaido University, Sapporo, Japan

両角友喜

Tomoki Morozumi

March 2019

1. Backgrounds

Circum-arctic terrestrial regions are highly vulnerable and affected by rapid temperature increasing in the surface air and the permafrost (e.g. Serreze and Barry 2011; Hartmann et al., IPCC, 2013; Vaugham et al., IPCC, 2013). Under changing climate in the arctic, a large amount of carbon (approximately 1672 Pg) in permafrost might become a source of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4) which have a potential of strong feedback to climate (Tarnocai et al., 2009). Especially, northern wetland and freshwater system are one of the largest natural sources of global CH_4 (Ciais et al., IPCC 2013). Therefore, the challenges on estimating CH_4 emissions in circum-arctic region is needed.

Taiga-tundra boundary ecosystems are surrounding terrestrial arctic as a complicated shape of treeline belt (Montesano et al., 2009). Taiga-tundra boundary (i.e. tundra taiga ecotone, or forest-tundra) is a region between continuous boreal forest and tree distribution limit. Successional changes from wetland to forest may occur over hundreds to thousands of years, although recent extreme climate events could affect to taiga ecosystems in shorter terms (e.g. Iwasaki et al., 2010, Tei et al., 2013, Ohta et al., 2014).

Methane (CH_4) is generally produced by methanogenic archaea under an environment of anoxic soils in wetlands (Bridgham et al., 2013). Anoxic conditions were maintained under high soil moisture and deeper soil isolated from atmospheric oxygen. Methanotroph could consume CH_4 in oxic soil in upland forest and in peatland, although the consumption rate is generally 10^{-1}- 10^{-2} times lower than production rate in wetland (e.g., Chen and Murrel 2010, Mander et al., 2016). In the freshwater system, CH_4 is generally produced in bottom sediments under anoxic condition, and from organic matter in a water column (Crawford et al., 2017, and Stanley, 2016).

Geographical information system (GIS) is strong tool to calculate the regional budget of methane cycles. Remote sensing techniques can provide suitable geographical information for GIS analysis. Satellite images, recording a visible-near infrared (NIR) band, are used for delineating land covers, vegetation, soils and water (Jones and Vaughan, 2010). In water surface reflectance, water quality indicators such as total suspended sediments are important characteristics to determine spectral properties

(Gholizadeh et al., 2016).

Heterogeneous landscapes of the taiga-tundra boundary have not been shown in previous geographic dataset. Vegetation and land cover are continuously changing from forests to fens or lakes. However, satellite data are stored in a pixel of a certain extent, and those features are discontinuous in an image. Spatial information in a satellite image are regulated by resolution of each pixel, therefore it is necessary to acquire high resolution data to observe small features such as vegetation patchesin an observation site.

2. Research aim and purposes

To clarify the local CH_4 emissions and the role of taiga-tundra boundary ecosystem among regional CH_4 budget in high latitude, we set four scientific questions: i) What are the environmental factors controlling vegetation distribution? ii) What is the factor limiting for local CH_4 emissions? iii) Whether hypothesized CH_4 absorption in forest floor could affect local CH_4 emissions? iv) Are there any effect on CH_4 emissions by flooding event? Approaches for answering those questions are below: The permafrost and locational factors were observed in the field. Vegetation coverage and contribution for CH_4 emissions were evaluated in the ecosystem using remote sensing and upscaling method. Local CH_4 emissions was compared to those in tundra site in previous studies and discussed for regional characteristics. Riverine dissolved CH_4 concentrations and fluxes were compared between flood year (2017) and normal year (2016). We expect to obtain field-based-knowledge for future change projection and adaptation under climate change.

3. Methods

Plant species compositions and environmental factors (e.g. soil moisture, topographic level, thaw depth) were sampled, as an indicator of CH_4 emissions with step-by-step in multiscale from site (100 m) to local (10 km). Chamber measurements were conducted to detect spatial variation of fluxes from wide areas. High resolution (0.5 m per 1 pixel) satellite data were classified by supervised using in-field spectral measurements and training pixels based on field observations, and the vegetation map was obtained. A local CH_4 emission was estimated from fractional covers of vegetation classes and in-situ CH_4 flux values (Chapter 2).

Dissolved CH_4 was sampled from river water using head-space equilibrium method by calculating solubility of CH_4. Satellite surface reflectance data (30 m per 1 pixel) were used for water color detection, and modelling dissolved CH_4 concentration for water mixing between main flow and tributary on flooding in the region (~200 km). A riverine CH_4 emission was calculated by theoretical diffusivity from water (Chapter 3).

4. Summary of Chapter 2: *Local-scale vegetation mapping and estimation of methane emissions in taiga-tundra boundary lowland*

The heterogeneous vegetation distribution and coverages were provided by a microtopographic level vegetation map using high resolution satellite imagery and field survey for 10×10km local CH_4 upscaling. Vegetation and land cover types were classified into nine classes (Figure 1). Methane flux was observed at 37 locations (212 flux measurements in total), using the chamber method during the growing seasons (July) of 2009 to 2016 (Figure 2). The taiga–tundra boundary ecosystem of the Indigirka River lowland has a large coverage of wetlands (28% by cotton-sedge and 10% by emergent), leading to larger local CH_4 emissions (37 ± 10 mg CH_4 m^{-2} d^{-1}) than that in the tundra located in northeastern Siberia.

Results from site- and local-scale vegetation mapping, validated by field survey of apparent plant species, indicated that site-scale hydrological conditions and geomorphological structures with rivers and permafrost could explain vegetation distribution patterns. Highly heterogeneous vegetation and spatially varied CH_4 flux makes high-resolution satellite images essential for assessing local CH_4 emissions.

Our findings indicate that tree distribution was spatially limited (coverage of 4%) to small microtopographic elevations, and that forest CH_4 sink might not provide significant local balance in the taiga–tundra boundary lowland.

Accepted; Morozumi et al., TelllusB: Chemical and Physical Meteorology, 10.1080/16000889.2019.1581004.

5. Summary of Chapter 3: *Estimation of riverine dissolved methane using water surface reflectance remote sensing in extreme flood event*

An extreme flooding event influenced an extensive lowland and made to increase river CH_4 concentrations under recession phase in tributary in Indigirka watershed, eastern Siberia at the end of July 2017. We reported that the dissolved CH_4 concentrations using head-spase method along the Indigirka River and its tributaries (0.1–1.1 μM) were higher than those previously reported at Lena (0.01–0.7 μM), adjacent catchment from our study location in northeastern Siberia.

An empirical end-member model to estimate the dissolved CH_4 concentrations from red band (636–673 nm) satellite data, validated by *in situ* river CH_4 measurements and training pixels corresponding to sampling sites, revealed spatial patterns of river CH_4 concentrations in the study region (approx. 250 × 350 km) at flood recession of 2017 summer.

We further presented that the total river flux in 2017 (9.4±3.5 mg CH_4 m^{-2} d^{-1}), of which 60% was sourced from the tributaries, was higher than that in 2016 (2.6±1.1 mg CH_4 m^{-2} d^{-1}); daily emissions of river CH_4 were 3.6 times higher in 2017 than 2016. The methods applied to dissolved CH_4 with satellite observations has a benefit for efficient monitoring of an extreme event in remote areas such as Siberian lowlands in high latitude.

In press; Morozumi et al., Polar Science, 10.1016/j.polar.2019.01.005.

6. Figures

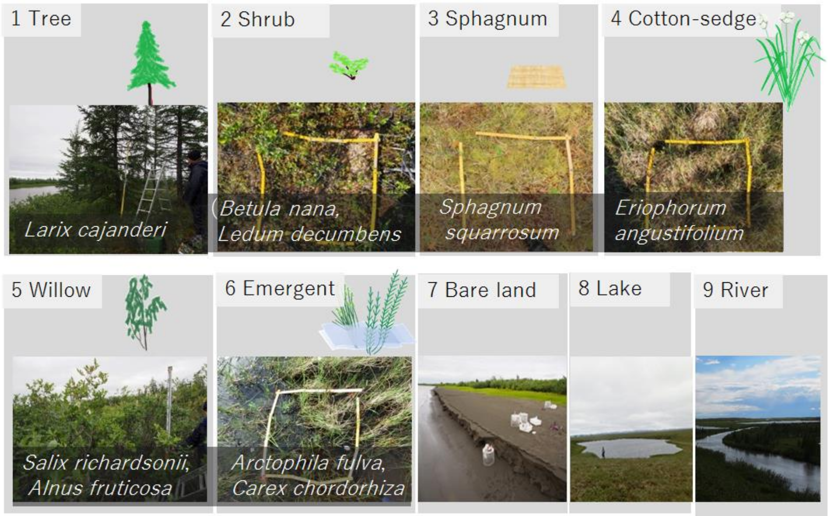

Figure 1. Photographs of nine vegetation classes with typical plant species. A leveling rod indicates 2 m height in tree and willow stands, and a yellow-color ruler frame indicates 0.5 m square block in shrub, *Sphagnum*, cotton-sedge and emergent vegetation cover.

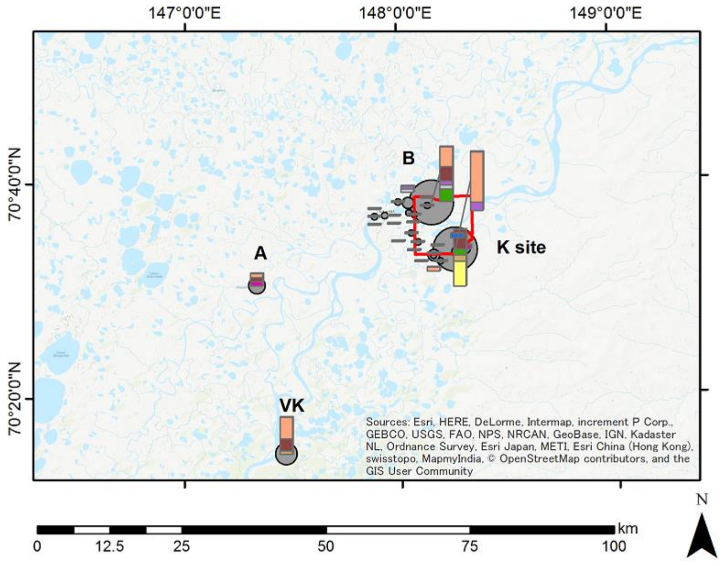

Figure 2. Location of chamber measurements in a local-scale map with bubble (indicating number of samplings) and bar (indicating vegetation classes in each color). Methane flux was observed at 37 locations (212 flux measurements in total), using the chamber method during the growing seasons (July) of 2009 to 2016. The flux measurements were conducted in each vegetation type: i) around site K (70.56 ° N, 148.26 °E), ii) around site B, which was located near the main flow of the Indigirka River (70.64 °N, 148.15 °E), and iii) at additional points in the Indigirka lowland (including the lake, river, and bare-land). (Generated by ArcGIS software, ESRI, Redlands, CA, USA)

7. References

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The Original Thesis submitted in February 2019. Hokkaido University, Sapporo, Japan.