Final Report: International Workshop to Reconcile Methane Budgets in the Northern Permafrost Region

Organized by the Study of Environmental Arctic Change (SEARCH) and funded by the National Science Foundation, the National Aeronautics and Space Administration (NASA), the U.S. Geological Survey, and the U.S. Arctic Research Commission

A. David McGuire[1], Brendan P. Kelly[2], Lisa Sheffield Guy[3], Helen V. Wiggins[3], and other members of the organizing committee[4]

[1]U.S. Geological Survey, Alaska Cooperative Fish and Wildlife Research Unit, University of Alaska Fairbanks, Fairbanks, AK

[2]International Arctic Research Center, University of Alaska Fairbanks, Fairbanks, AK

[3]The Arctic Research Consortium of the United States (ARCUS), Fairbanks, AK

[4]Other members of the organizing committee include, in alphabetical order: Lori Bruhwiler, Jennifer Frederick, Henry Huntington, Rob Jackson, Robie Macdonald, Charles Miller, David Olefeldt, Edward Schuur, and Merritt Turetsky

Participants at the International Workshop to Reconcile Methane Budgets

in the Northern Permafrost Region held in Seattle, WA, USA on 7 – 9 March 2017

Summary

An International Workshop to Reconcile Methane Budgets in the Northern Permafrost Region, organized by the Study of Environmental Arctic Change (SEARCH), was held in Seattle on 7-9 March 2017. The workshop was funded by the National Science Foundation, the National Aeronautics and Space Administration, the U.S. Geological Survey, and the U.S. Arctic Research Commission. The primary goal was to produce a plan for reconciling methane budgets in the northern permafrost region. Forty-two scientists, including representatives of the atmospheric, inland (wetlands and lakes), marine (coastal and oceanic), and remote sensing communities studying methane dynamics participated in developing the research plan. Eleven of the participants were early career scientists, and nine of the scientists were from institutions outside the United States. The first day of the workshop included keynote presentations that provided atmospheric, inland, and marine perspectives on developing a plan to reconcile methane budgets. There were also keynote presentations on the role of remote sensing in reconciling methane budgets. The second day of the workshop was devoted to breakout groups that developed plans from disciplinary perspectives, followed by breakouts of mixed disciplinary groups that discussed all three plans. The breakout groups identified key uncertainties and near-term and longer-term priorities for addressing questions about methane dynamics in the northern permafrost region. Participants committed to completing a paper describing a roadmap for the synthesis plan by the end of 2017, and each of the groups developed plans to address, by the end of 2018, near-term priorities to reduce uncertainties in methane budgets. The longer-term priorities include addressing possible sensitivities of methane emissions to climate variability and change in the region and evaluating the degree to which changes in methane dynamics are detectable. To address these longer-term priorities, there is a need to organize extant methane data for the northern permafrost region so that studies using these data can evaluate how enhancements to the methane observation network would improve estimates of methane emissions and the detection of trends. The Permafrost Action Team of SEARCH will develop research summaries and briefs based on the follow-on activities from the workshop.

Scientific Justification and Background

Northern permafrost soils store carbon—more than twice as much as is currently in the atmosphere—in the form of accumulated organic matter. When frozen, permafrost organic matter is preserved, but after it thaws, microbes convert organic matter into carbon dioxide (CO_2) and methane (CH_4), greenhouse gases that have the potential to enhance climate warming if transferred to the atmosphere. Studies aimed at quantifying atmospheric CH_4 inputs from the northern permafrost region have focused on terrestrial contributions from wetlands and lakes, marine contributions from coastal shelves and the ocean, and inferred fluxes based on measurements of atmospheric CH_4. The 2009 Arctic Monitoring and Assessment Program (AMAP) Carbon Assessment identified a wide disparity between 'bottom-up' CH_4 emission estimates derived from aggregated wetland, lake, and coastal water contributions (32 to 112 Tg CH_4 yr^{-1}) and 'top-down' estimates determined from spatial and temporal variability of atmospheric CH_4 concentrations (15 to 50 Tg CH_4 yr^{-1}).

There are several key factors contributing to uncertainties and differences between the bottom-up and top-down approaches. For example, CH_4 contributions from lakes are frequently also attributed to wetlands, which leads to double counting of that source. Also, the amount of CH_4 being emitted from submarine permafrost in the Arctic Ocean and its marginal seas is poorly constrained. Overall, we currently have a poor understanding of the relative contributions of CH_4 from microbes and petroleum systems, modern and ancient sources, in both the terrestrial and marine realms. A recent review suggests gas hydrates (an ice-like substance formed by CH_4 and water under pressure) are not presently contributing CH_4 to the atmosphere, but many issues regarding climate feedbacks and seafloor CH_4 emissions remain. Top-down estimates of CH_4 emitted from permafrost are also highly uncertain, but substantial progress quantifying the regional CH_4 budget for Alaska has recently been made by the NASA Carbon in Arctic Reservoirs Vulnerability Experiment (CARVE) campaign.

The Permafrost Action Team (PAT) of the interagency Study of Environmental Arctic Change (SEARCH) convened an international panel of experts for two hours at the December 2015 Permafrost Carbon Network (PCN) meeting to scope out activities that would synthesize data from terrestrial (primarily wetlands and lakes), marine, and atmospheric studies and work towards a reconciliation of the disparate bottom-up and top-down estimates of CH_4 emissions from northern permafrost region. Synthesis groups were organized around each theme and developed preliminary plans to synthesize extant data with the goal of reducing CH_4 budget uncertainties. The groups identified the need for a multi-day workshop to establish critical connections among the groups and other components of the broader Arctic System in order to refine and coordinate the preliminary plans that were developed.

Workshop Goal and Objectives

To address this need, we organized and convened a workshop. The workshop was held 7-9 March 2017 in Seattle at the Hyatt at Olive 8 Hotel, and was funded by the National Science Foundation, the National Aeronautics and Space Administration, the U.S. Geological Survey, and U.S. Arctic Research Commission. Logistical support in organizing and conducting the workshop was provided by the Arctic Research Consortium of the U.S. (ARCUS). Henry Huntington of the SEARCH Sea Ice Action Team was the outside facilitator of the workshop. The workshop was attended by 42 participants (Appendix A), including eleven early career scientists and nine scientists from institutions outside of the United States. The workshop website is https://www.arcus.org/search-program/permafrost/methane-workshop.

The primary goal of the workshop was to produce a plan for reconciling CH_4 budgets in the northern permafrost region. The specific objectives of the workshop were to:

(1) Communicate the state of the science among the three CH_4 synthesis groups;

(2) Communicate the synthesis plans of each group and progress made to date;

(3) Identify potential connections to sea ice and land ice;

(4) Refine synthesis plans based on workshop discussions; and

(5) Develop a plan for communicating subsequent progress to stakeholders.

The agenda was designed to address each of these objectives (Appendix B).

Research and Communication Plan

Overview

The research and communication plan that was developed has five parts: (1) development of a roadmap for making progress across the atmospheric, inland, and marine components, (2) issues and activities identified to reduce uncertainties in the atmospheric component, (3) issues and activities identified to reduce uncertainties in the inland component, (4) issues and activities identified to reduce uncertainties in the marine component, (5) a summary of synthesis activities, (6) the role of remote sensing in synthesis activities, and (6) the development of research summaries and expert briefs and the management and tracking of synthesis activities. Below we provide more details on each of these parts of the plan. It is important to note that there is some overlap in the activities of the three research groups, which we view as important to help promote synergy among them. The use of remote sensing as a tool to reduce uncertainties was extensively discussed and will be integrated into the follow-on activities, as described below.

Development of a Roadmap

The participants agreed that development of a manuscript providing a roadmap for unifying CH_4 emission estimates and evaluating the potential for strong climate feedbacks from future CH_4 emissions in the northern permafrost region would be of value to the scientific community. The roadmap document will be drafted over the next few months based on discussions during and after the workshop, and submitted before the end of 2017. The initial concept is to divide the roadmap into three parts. The first part is to identify issues of scale. For example, how does one compare ground-flux measurements at the meter scale to tall tower measurements at the kilometer scale? Also, does the relative lack of data on winter emissions and processes affect the ability to unify CH_4 emission estimates across the atmospheric, inland, and marine components? The second part is an attempt to resolve differences among the components. For example, how is the knowledge from field measurements transferred to process representation in models? Can wetlands be defined more realistically in process-based models? Are more sophisticated statistical approaches needed to reconcile CH_4 emission estimates across scales? The third part is to propose a campaign to achieve CH_4 budget closure across the northern permafrost region to resolve current data scarcity. The campaign would cover a broad range of scales, provide a benchmark for current emission rates, identify recent trends, and lead to a data-based projection of CH_4 emissions to support process-based models for the northern permafrost region.

Atmospheric Component Issues and Activities Identified

Discussion of the atmospheric component identified two priorities for understanding the CH_4 budget of the northern permafrost region. First, we need to develop a comprehensive view of what existing observations tell us about the present Arctic budget and its evolution over the past several decades. The question is then whether the top-down atmospheric analyses can be reconciled with bottom-up analyses that are based on process-level observations and models. We identified several impediments to reconciliation of CH_4 budgets. For example, both forward and inverse models fail to simulate cold season emissions that have been observed to be a potentially important contribution to annual total emissions. Another crucial issue to reconcile is why CH_4 emissions in this region have been stable over recent decades, while many process-based models indicate that increasing temperatures should have led to a detectable increase in emissions.

The atmospheric component identified several approaches to addressing these issues. First, there is a need for a compilation of existing atmospheric observations of CH_4 in the Arctic. This database would be made available to the Arctic CH_4 research community, would span several decades, and include *in situ* surface, tower, and airborne measurements as well as remotely sensed data. Based on this data compilation, the atmosphere component would summarize what existing atmospheric records say about the dynamics of CH_4 in the northern permafrost region during the past several decades. That synthesis is aimed at addressing the issue of whether bottom-up information about changing emissions agrees with the top-down atmospheric analyses.

Another follow-on activity involves the question of whether the atmospheric network is sensitive enough to detect what may possibly be small changes in CH_4 emissions. This question arises because of the large influence of lower latitude emissions on top-down analyses for the northern permafrost region. The atmospheric component will address the issue of trend detectability by generating synthetic time series at existing and hypothetical measurement sites, and then statistically analyzing the results to determine what trends are recoverable for particular observation strategies.

Finally, the atmospheric component identified the importance of better constraining estimates of cold season emissions. Current forward and inverse models do not capture cold season emissions, most likely because observations that have been used in analyses are characterized by low cold season emissions. Cold season emissions may also be difficult to model because many models have difficulty accurately simulating the cold wintertime lower atmosphere. The atmospheric component plans to use multiple transport models to examine this issue, along with estimates of cold season emissions obtained from observations.

Inland Component Issues and Activities Identified

The inland component focused on current key uncertainties for estimating on-shore CH_4 emissions of the northern permafrost region based on field measurements (chambers, eddy co-variance, airborne measurements) as well as uncertainties for projecting future changes. A quick survey of recently published field-measured CH_4 emission estimates confirmed that bottom-up estimates of high latitude fluxes remain significantly greater than estimates based on atmospheric inversions (top-down). The inland component identified several potential sources for this discrepancy:

1. *Spatial domain of comparison*. The same spatial domains are not always used in comparisons of bottom-up and top-down estimates of fluxes. Spatial domains can include permafrost zones,

biome extents, latitudinal cut-offs (>50˚N or >60˚N), or other reporting regions (e.g., the Arctic region in the Regional Carbon Cycle and Processes (RECCAP) Assessment. Contributions from anthropogenic emissions were deemed to be particularly sensitive to spatial domain definitions.

2. *Double accounting of CH_4 emissions from wetlands and lakes.* Definitions of wetlands and lakes vary among research approaches (scaling of wetland emissions, lake emissions, and for process-based models) and likely have led to double accounting when summing up bottom-up fluxes by counting some perennially or seasonally inundated areas as both wetlands and lakes. For example, shallow water bodies may be counted as wetlands in some estimates and as lakes in others.
3. *Inappropriate spatial data to scale field-measured CH_4 fluxes*. Inventories of CH_4 fluxes have shown distinct CH_4 emissions from specific wetland types and lake types, but spatial information on the spatial extents of these ecosystems is not available. Instead, available data for scaling CH_4 fluxes uses inundation data, modeled wetland extents, and other databases that do not indicate lake type or size distribution. This has consequences not only for total emission estimates, but also for their spatial distribution.
4. *Bias in field site selections for flux measurements.* There is a clear bias in the choices of field sites, chamber and eddy co-variance studies in particular, towards ecosystems where high CH_4 fluxes are expected. Often these ecosystems with high CH_4 emissions represent minor landscape components, e.g. small lakes or transitional wetlands at the interface to larger aquatic ecosystems. Thus, there is a risk that unrepresentative high fluxes are used to scale emissions to larger regions.
5. *Representativeness of field data*. Particularly for chamber-based studies, both in wetlands and for lakes, choices for sampling design may affect how representative field data are for estimating ecosystem-scale emissions. Choice of sampling frequency, timing, and spatial coverage can lead to bias or high uncertainty.
6. *Non-growing season fluxes*. Cold season emissions from wetlands and emissions during ice-out from lakes have been shown to potentially represent a significant fraction of the annual emissions but are still poorly constrained.
7. *CH_4 uptake*. While rates of CH_4 uptake in upland soils are low, they may occur over very large areas. The precision in measuring low levels of CH_4 uptake is relatively poor compared to the magnitude of the flux. Only a few studies have reported CH_4 uptake in the northern permafrost region, hence the uncertainty in the magnitude of CH_4 uptake across the region is large.
8. *Non-biogenic fluxes*. CH_4 emissions from geological seeps and anthropogenic sources are poorly quantified in the northern permafrost region.
9. *Scaling of hot-spots*. Both geological seeps and ebullition of biogenic CH_4 represent hotspots of CH_4 emissions that are challenging to quantify at the regional scale.

Furthermore, a few key uncertainties for making projections of future CH_4 fluxes were identified:

1. *Thermokarst.* Thermokarst disturbance will influence future CH_4 emissions from both lakes and wetlands. Significant research efforts have been aimed at understanding the role of thermokarst on CH_4 emissions, and although our understanding has improved much in the last decade, projections of how much thermokarst will affect CH_4 emissions of the northern permafrost region are characterized by large uncertainties.
2. *Wetting or drying of the landscape*. Projections of future landscape wetness is a key uncertainty for understanding impacts on CH_4 emissions. While increased precipitation is anticipated at high

latitudes, particularly as sea ice is retreating, warming temperatures will also affect evapotranspiration. The water balance will further be affected by altered permafrost conditions, which will influence infiltration and groundwater recharge and, thus, redistribute liquid water at the landscape scale.

3. *CO_2 fertilization*. CH_4 emissions from many wetland ecosystems are strongly linked to plant productivity. Therefore, CH_4 emissions may respond to CO_2 fertilization of plant productivity, the magnitude of which is very uncertain in the northern permafrost region.
4. *Soil temperatures*. Warming soil should increase both CH_4 production and oxidation rates. Estimates of temperature sensitivity of total emissions, thus, depend on the temperature sensitivity of both CH_4 production and oxidation. Furthermore, soil temperatures may not change in tandem with air temperature, as deep soil temperatures are strongly controlled by moisture conditions, shading and other factors that also may change.
5. *Ice-free periods of lakes*. The length of the ice-free season is an important factor in both the magnitude and timing of lake CH_4 emissions.

We need to better understand which of the factors above have a greater influence on the large uncertainty associated with bottom-up estimates. It is important to identify the major uncertainties to improve observation networks, scaling approaches, and forecasting capabilities. The inland component discussed several opportunities for using available data to understand which factors are responsible for the major uncertainties. Much of the discussion was focused on the need to create a land cover model that assesses spatial extents of land cover classes defined based on characteristic ecosystem CH_4 emission magnitudes and controls. The inclusion of both wetlands and lakes in the same land surface model framework will be a major step to reduce double accounting of emissions in bottom-up scaling approaches. The choice of specific land cover classes will be informed both by databases of observed CH_4 emissions and associated ecosystem descriptions, as well as by the availability of spatial data that can be used to discern among land cover classes. There currently is no single spatial data set that adequately represents the spatial extents of land cover classes needed to scale CH_4 emissions to the northern permafrost region. Therefore, we need to combine information from several spatial data sources and use expert assessment to translate the available spatial information into regional estimates of land cover distributions. Once developed, we can then use this land cover model to assess magnitude and spatial distribution of CH_4 emissions through assimilation of information on characteristic CH_4 flux magnitudes and controls for each land cover class. A key outcome of this activity would be to identify uncertainties for bottom-up scaling approaches to estimate CH_4 emissions for the northern permafrost region.

While the development and application of the CH_4 land cover model is the flagship activity of the inland component, several other important synthesis activities were identified: (1) synthesis of lake ebullition data for the northern permafrost region, (2) synthesis of cold season CH_4 emissions from lakes and wetlands, (3) creation of a CH_4-centric land cover database using geotagged field photos; (4) an analysis of the sensitivity of different scaling approaches used for estimating wetland CH_4 emissions in the northern permafrost region, and (5) comparison of CH_4 scaling methodologies for the north slope of Alaska.

Marine Component Issues and Activities

The marine component discussed how it could most effectively contribute towards reducing uncertainties in CH_4 estimates in the northern permafrost region. In comparison to other components, there is a large range in the reported annual CH_4 emissions among the different marginal seas and shelves of the Arctic Ocean. Unpublished estimates from the Beaufort Sea and Svalbard margins indicate sub-teragram (Tg) sea-air sources to the atmosphere, which contrasts with an estimate that the East Siberian Arctic Shelf (ESAS) contributes ~17 Tg/yr to the atmosphere. More recent unpublished field work suggests the CH_4 emission estimate for the ESAS may be substantially higher, perhaps up to ~80 Tg/yr, which would further widen the bottom-up vs. top-down discrepancy. In contrast, a recent study along the western Svalbard margin demonstrates that enhanced CO_2 uptake within an area of shallow-water CH_4 seepage overwhelms the positive warming potential of emitted CH_4. The possibility that areas of CH_4 seepage are net greenhouse gas sinks suggests a broader range of greenhouse gases (e.g., CH_4, CO_2 and N_2O) flux studies should be evaluated to determine the net radiative forcing effect for northern permafrost regions.

The marine component decided that there would be value in trying to better understand if the large range in CH_4 emission estimates can be attributed to different fundamental processes operating along the pan-Arctic shelves. The scaling issue was discussed, and it was agreed that the difficulty in scaling of ebullition measurements vs. diffusive measurements is a large source of uncertainty. Because there are many misconceptions on marine processes that affect the CH_4 budget in shelves of Arctic Ocean, a logical place to start was to review the current literature and state of knowledge on these processes. The framework would be centered on an info-graphic that would be very general (e.g., a description of all possible processes on any shelf) and serve as a vehicle to explore in more depth the processes that occur on specific shelves. The literature synthesis for each specific shelf may allow the development of updated estimates on the annual CH_4 budgets for specific locations and would allow the comparison of processes among shelves to better understand uncertainties.

The marine component will develop a paper based on the comparison of processes affecting CH_4 dynamics among the shelves. The main question of the paper would be, “What is the CH_4 budget of the shelves of the Arctic Ocean?” The paper would review spatial and temporal variations of CH_4 emissions among the shelves and uncertainties associated with the extrapolation of sparse observations across the shelves. A key sub-question would be, “How much CH_4 from the seabed reaches the atmosphere?” To address this question, the paper will evaluate the state of subsea permafrost and ebullition vs. diffusive processes. The role of riverine inputs of carbon, sea ice processes, ocean processes, and oil and gas drilling in the Arctic Ocean will be reviewed and evaluated.

Summary of Synthesis Activities

Below we provide a summary of the near-term synthesis activities. The order of the list reflects the near-term priority to develop a roadmap (activity 1), near-term priority activities substantially based on data synthesis and analysis (activities 2 through 6), and longer-term priority activities that are primarily focused on evaluation of uncertainties in spatial and temporal scaling approaches (activities 7 through 9).

(1) Development of a paper that provides a roadmap for unifying CH_4 emission estimates in the northern permafrost region.
(2) Compile existing atmospheric observations of CH_4 in the northern permafrost region and summarize what this compilation says about the dynamics of CH_4 in this region during the past several decades.

(3) Synthesis of cold season CH_4 emissions from lakes and wetlands and use of multiple transport models to better constrain estimates of cold season CH4 emissions.
(4) Synthesis of lake ebullition data for the northern permafrost region.
(5) Creation of a CH_4 centric land cover database and development of a state-of-the-art land cover model to assess the magnitude and spatial distribution of CH_4 emissions through assimilation of information on characteristic CH_4 flux magnitudes and controls for each land cover class.
(6) Development of a paper that reviews the spatial and temporal variations of CH_4 emissions among the shelves of the Arctic Ocean and its marginal seas to identify the uncertainties associated with the extrapolation of sparse observations across the shelves.
(7) An analysis of the sensitivity of different scaling approaches for estimating wetland CH_4 emissions in the northern permafrost region.
(8) Comparison of CH_4 scaling methodologies for the north slope of Alaska.
(9) Generate synthetic time series at existing and hypothetical measurement sites to determine what trends are recoverable for particular observation strategies.

Contribution of Remote Sensing to Synthesis Activities

Remote sensing will play a pivotal role in improving estimates of the CH_4 budget in the northern permafrost region given the challenges of logistics, environmental conditions, and the vastness of the region. The near-term synthesis activities in this plan will integrate existing ground, airborne, and space-based (primarily SCIAMACHY and GOSAT) information with advanced modeling techniques. New sensors may also be able to contribute to the longer-term synthesis efforts. For example, the TropOMI instrument on the European Space Agency's Sentinel 5P mission will be launched late this year and deliver observations of CH_4. The MERLIN instrument will be launched in 2021 and provide information in the cold/dark season, although it will only have a narrow sampling swath in comparison to TropOMI, which will acquire full surface coverage. The information from these new instruments will complement the existing data record from near infrared sensors on SCIAMACHY and GOSAT. The longer-term synthesis activities will also make use of expanded year-round atmospheric vertical profiling that are designed to cover gaps in the remote sensing surveys due to low light conditions and cloud cover.

Development of Research Summaries and Briefs and Management of Synthesis Activities

The initial outreach product from this workshop is a meeting report that has been submitted to *Eos* for publication. We also recognize the need to inform policy, and we will construct knowledge pyramids to convey the state of our science to policy makers (e.g., https://www.arcus.org/search-program/arctic-answers). Each knowledge pyramid will have four tiers. At the bottom of the pyramid are the scientific building blocks, which encompass the technical studies that offer in-depth and foundational information about individual concepts. The next tier are the syntheses produced from these technical studies that represent resources for a comprehensive understanding of the issue and how different concepts interrelate. Above that tier are accessible research summaries of science's main findings, critical questions, and societal importance. Finally, at the top tier are concise briefs that provide non-technical answers to specific questions based on rigorous science. These top two tiers are most useful to decision makers who make management and policy decisions. SEARCH has the infrastructure to develop and disseminate research summaries and briefs. The Permafrost Action Team of SEARCH, which will manage and track the progress of the synthesis activities identified in this plan, will take the lead in developing research summaries and briefs based on the follow-on activities from the workshop.

Appendix A – Workshop Participant List

International Workshop to Reconcile Northern Permafrost Region Methane Budgets

7-9 March 2017

Hyatt at Olive 8, 1635 8th Avenue, Seattle, WA 98101

Workshop Participants

Name	Email	Institutional Affiliation
Bastviken, David	david.bastviken@liu.se	Linköping University
Bloom, Anthony	abloom@jpl.nasa.gov	NASA Jet Propulsion Lab
Bruhwiler, Lori	lori.bruhwiler@noaa.gov	NOAA ESRL
Commane, Róisín*	rcommane@g.harvard.edu	Harvard University
Damm, Ellen	Ellen.Damm@awi.de	Alfred Wegener Institute
Dean, Joshua*	j.f.dean@vu.nl	Vrije Universiteit Amsterdam
Farrell, John	jfarrell@arctic.gov	U.S. Arctic Research Commission
Frederick, Jennifer	jenn@eps.berkeley.edu	Sandia National Labs
Gleason, Colin*	cjgleason@umass.edu	UMass Amherst
Guy, Lisa Sheffield	lisa@arcus.org	ARCUS
Hibbard, Kathleen	kathleen.a.hibbard@nasa.gov	NASA
Huntington, Henry	hph@alaska.net	Huntington Consulting/PEW
Ivakin, Anatoliy	aniv@uw.edu	University of Washington
Jackson, Rob	Rob.Jackson@stanford.edu	Stanford University
Kelly, Brendan	bpkelly@alaska.edu	University of Alaska Fairbanks
Malhotra, Avni*	malhotraa@ornl.gov	Oak Ridge National Laboratory
Matthews, Elaine	elaine.matthews@nasa.gov	NASA GISS
McGuire, David	admcguire@alaska.edu	USGS/University of Alaska Fairbanks
Melton, Joe	joe.melton@canada.ca	Environment and Climate Change Canada
Miller, Charles	charles.e.miller@jpl.nasa.gov	NASA Jet Propulsion Lab
Miller, Scot*	scot.m.miller@gmail.com	Stanford University
Olefeldt, David	olefeldt@ualberta.ca	University of Alberta
Ott, Lesley*	lesley.e.ott@nasa.gov	NASA GSFC
Parmentier, Frans-Jan	frans-jan@thissideofthearctic.org	The Arctic University of Norway
Pohlman, John	jpohlman@usgs.gov	U.S. Geological Survey / Woods Hole
Poulter, Benjamin*	benjamin.poulter@nasa.gov	NASA GSFC
Sachs, Torsten	torsten.sachs@gfz-potsdam.de	GFZ Potsdam
Schuur, Ted	ted.schuur@nau.edu	Northern Arizona University
Semiletov, Igor	igorsm@iarc.uaf.edu	University of Alaska Fairbanks
Steele, Michael	mas@apl.washington.edu	University of Washington
Striegl, Rob	rstriegl@usgs.gov	U.S. Geological Survey
Sweeney, Colm	colm.sweeney@noaa.gov	NOAA ESRL
Taylor, Meghan*	Meghan.Taylor@nau.edu	Northern Arizona University
Thonat, Thibaud	thibaud.thonat@lsce.ipsl.fr	Laboratoire des Sciences du Climat et de l'Environnement
Thornton, Brett	brett.thornton@geo.su.se	Stockholm University
Treat, Claire*	cctreat@gmail.com	University of Eastern Finland
Varner, Ruth	ruth.varner@unh.edu	University of New Hampshire
Voigt, Carolina*	carolina.voigt@uef.fi	University of Eastern Finland
Walter-Anthony, Katey	kmwalteranthony@alaska.edu	University of Alaska Fairbanks
Watts, Jennifer*	jennifer.watts@ntsg.umt.edu	University of Montana
Zhuang, Qianlai	qzhuang@purdue.edu	Purdue University
Zhu, Zhiliang	zzhu@usgs.gov	U.S. Geological Survey

* Early-career researcher

Appendix B – Workshop Agenda

Final Agenda for the International Workshop to Reconcile Northern Permafrost Region Methane Budgets

7-9 March 2017, Seattle, WA

Day 1 Agenda

Tuesday, 7 March 2017

Location: Hyatt at Olive 8, Azure room

AM	Breakfast on your own
8:30-9:00	Welcome, Introductions, Logistics, Objectives, Products: Dave McGuire/Brendan Kelly/Henry Huntington/Lisa Sheffield Guy
9:00-9:10	Brett Thornton: Top-down vs. Bottom-up Discrepancies
9:10-9:30	Discussion of Workshop Objectives and Products: Dave McGuire/Brendan Kelly
9:30-9:40	Overview of the Atmospheric Component: Lori Bruhwiler and Chip Miller, Moderators
9:40-9:50	Scot Miller: Inversions for the North America Arctic-Boreal Region
9:50-10:00	Colm Sweeney: Airborne and Tower Measurement Perspectives
10:00-10:10	Thibaud Thonat: LSCE Research on CH_4 Dynamics in the Arctic
10:10-10:30	Discussion: Henry Huntington, Chip Miller, and Lori Bruhwiler
10:30-11:00	Coffee Break (Azure foyer)
11:00-11:10	Overview of the Marine Component: Jennifer Frederick, Moderator
11:10-11:20	Igor Semiletov: Coastal Siberia Perspectives
11:20-11:30	John Pohlman: Beaufort Sea Perspectives
11:30-11:40	Ellen Damm: Sea Ice Perspectives
11:40-12:00	Discussion: Henry Huntington and Jennifer Frederick
PM	
12:00-1:30	Lunch on your own
1:30-1:40	Overview of the Inand Component: David Olefeldt, Moderator
1:40-1:50	Jennifer Watts: Dynamic Ecosystem Regulation of Northern Wetland CH_4 Flux
1:50-2:00	Torsten Sachs: Scaling Challenges in Heterogeneous Landscapes
2:00-2:10	David Bastviken: Lake/Wetland Scaling Challenges
2:10-2:30	Discussion: Henry Huntington and David Olefeldt
2:30-2:40	Role of Remote Sensing in Reconciling Methane Budgets: Chip Miller, Moderator
2:40-2:50	Colin Gleason: Overview of Surface Water Ocean Tomography (SWOT) Mission
2:50-3:00	Lesley Ott: Pan-Arctic Inversions Using Satellite Data
3:00-3:10	Anthony Bloom: Remote Sensing Constraints on North Wetland CH_4 Process Uncertainty
3:10-3:30	Discussion of the Role of Remote Sensing: Henry Huntington and Chip Miller
3:30-4:00	Coffee Break (Azure foyer)
4:00-4:10	Strategy Towards an Overall Synthesis: Dave McGuire
4:10-4:20	Initial Plans for Synthesis: Atmospheric Component: Chip Miller and Lori Bruhwiler
4:20-4:30	Initial Plans for Synthesis: Inland Component: David Olefeldt
4:30-4:40	Initial Plans for Synthesis: Marine Component: Jennifer Frederick
4:40-5:00	General Discussion of Strategy Towards and Overall Synthesis: Henry Huntington
5:00-5:30	General Discussion of Day 2 Agenda: Dave McGuire and Henry Huntington
5:30-7:00	Session for other attendees to briefly present their research (light snacks and cash bar)
7:00	Adjourn (dinner on your own)

Day 2 Agenda: **<u>Wednesday, 8 March 2017</u>**
Location: Hyatt at Olive 8, Azure room

AM	Breakfast on your own
8:30-9:00	Day 2 Organization (Refining Plans for Synthesis): Dave McGuire and Henry Huntington
9:00-11:30	Breakout Discussions (separate groups for Atmospheric, Inland, and Marine Components; to address individual and overall syntheses): Chip Miller/Lori Bruhwiler, David Olefeldt, and Jennifer Frederick
Whenever	Coffee Break (Azure foyer)
11:30-11:40	Atmospheric Group Report
11:40-11:50	Inland Group Report
11:50-12:00	Coastal Group Report
PM	
12:00-1:30	Lunch on your own
1:30-2:00	Discussion of Charge for Afternoon Breakouts: Dave McGuire and Henry Huntington
2:00- 4:00	Breakout Sessions
Whenever	Coffee Break (Azure foyer)
4:00-4:10	Summary Report from Group 1
4:10-4:20	Summary Report from Group 2
4:20-4:30	Summary Report from Group 3
4:30-5:00	General Discussion and Day 3 Agenda: Dave McGuire and Henry Huntington
5:00	Adjourn
7:00	Group Dinner at the Wild Ginger (maps available)

Day 3 Agenda: Thursday, 9 March 2017
Location: Hyatt at Olive 8, Azure room

AM

	Breakfast on your own
8:30-9:00	Potential Ties to the Global Carbon Project Methane Budget Analysis: Rob Jackson
9:00-9:30	General Discussion of Connections to Sea and Inland Ice: Brendan Kelly
9:30-10:30	Planning the Development of the Overall Synthesis:Dave McGuire and Henry Huntington
10:30-11:00	Coffee Break (Azure foyer)
11:00-12:00	Discussion of Next Steps, Timelines, and Deliverables: Dave McGuire
12:00	Adjourn (lunch on your own)

PM

12:00-1:00	Lunch for Organizing Committee at Urbane Restaurant
1:00-3:00	Debriefing and Discussion among Organizing Committee