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Source characterization and temporal variation of methane seepage from thermokarst lakes on the Alaska North Slope in response to Arctic climate change

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QUARTERLY PROGRESS REPORT
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Summary

The goals of this research are to characterize the source, magnitude and temporal variability of methane seepage from two representative thermokarst lake areas within the Alaskan North Slope gas hydrate province, assess the vulnerability of these areas to ongoing and future Arctic climate change and determine if gas hydrate dissociation resulting from permafrost melting is contributing to the current lake emissions. Work during this quarter has focused on continuing laboratory analyses on samples and data collected from the Year 1 and 2 fieldwork. Analyses have focused on four main lake locations refered to in this report: Lake Qalluuraq (referred to as Lake Q) and Lake Teshekpuk (both on Alaska's North Slope) and Lake Killarney and Goldstream Bill Lake (both in Alaska's interior). Analyses of samples from Year 1 field work are nearing completion and data from this field work and sites are being included in a range of papers and presentations (see below). Analyses of samples collected from Year 2 field work at Lake Teshekpuk are currently ongoing.

Tasks 1 through 4: These tasks referred specifically to field activities and have earlier been completed.

Task 5.0 and 6.0 - Measuring methane flux on multiple temporal scales. Katey Walter Anthony (UAF): Long-term ebullition flux measurements conducted with support from this project in the interior Alaska thermokarst lake site were integral to the recent publication entitled 'Estimating methane emissions from northern lakes using ice-bubble surveys' (Walter Anthony et al. 2011, *Limnology and Oceanography: Methods*). The magnitude and variability in methane (CH_4) emissions from lakes is uncertain due to limitations in methods for quantifying the patchiness of ebullition (bubbling). We presented a new field method to estimate an important and highly uncertain source- ebullition from northern lakes. We defined four classes of CH_4 bubble clusters trapped in lake ice representing distinct types of biogenic ebullition seeps that varied by flux. Mean annual ebullition determined through long-term (up to 700 days) continuous flux measurements of 31 seeps in three Siberian and one Alaskan lake was (mean ± standard error of 4-10 seeps per class in units of $g\ CH_4\ seep^{-1}\ yr^{-1}$): A, 6 ± 4; B, 48 ± 7; C, 354 ± 52; Hotspot, 1,167 ± 126. Discrete-seep ebullition comprised up to 87% of total emissions from Siberian lakes when diffusive flux, background and seep ebullition were considered together. Including seep ebullition increased previous estimates of lake CH_4 emissions based on traditional methods 5-8 fold for Siberian and Alaskan lakes. We linked new ebullition estimates to an established biogeochemical model, the Terrestrial Ecosystem Model, for intercalibration of regional CH_4 emissions from northern wetland regions in Siberia, increasing previous estimates of regional terrestrial CH_4 emissions 3- to 7-fold. Assessment of the method revealed that ebullition seeps are an important component of the terrestrial CH_4 budget; identifiable by seep type among independent observers consistent in different regions by flux; and that the largest source of uncertainty in upscaling is ecological differences within and between lakes.

In related contributions, **Katey Walter Anthony** (UAF) and **Carolyn Ruppel** (USGS) were coauthors on a recently published, first-order climate modeling study that included a consideration of pan-Arctic methane emissions and their synergistic impact on warming climate: Isaksen et al., *Global Biogeochemical Cycles*, 2011.

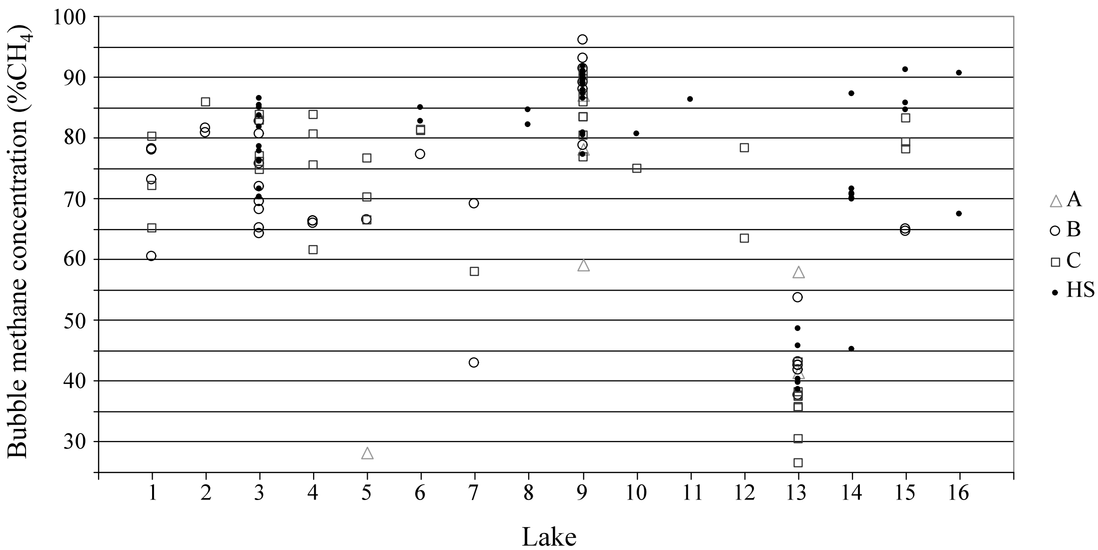


Figure 1. Methane concentration measured in type A, B, C and Hotspot seeps in different regions of Alaska and Siberia: Lakes 1-6 (Northern Seward Peninsula, Alaska); lakes 7-8 (North Slope of Alaska's Brooks Range); lakes 9-14 (Interior Alaska); lakes 15-16 (Kolyma Lowland, Siberia).

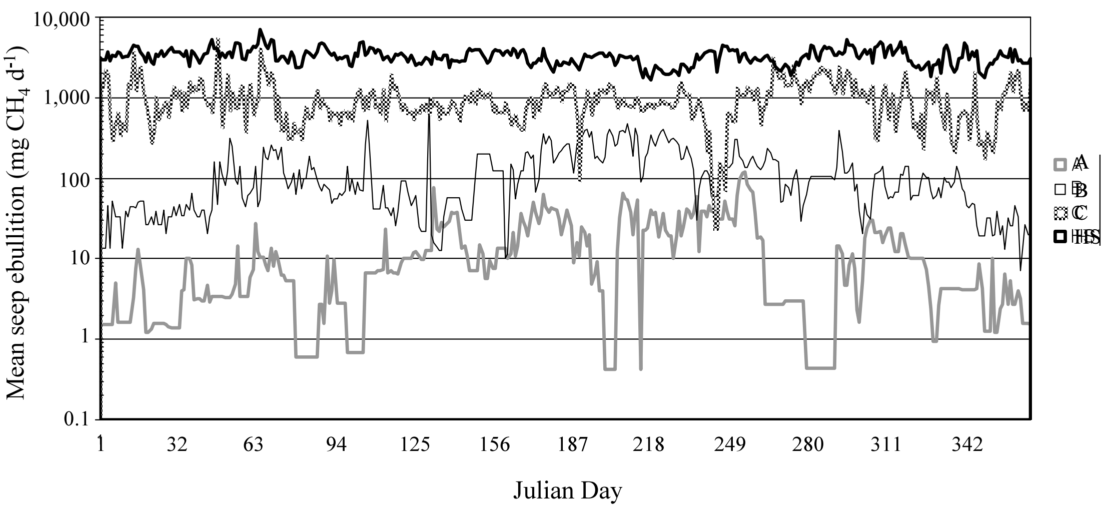


Figure 2. Mean daily ebullition of biogenic seeps types A, B, C, and Hotspot (HS) as the average of all long-term ebullition values (4-10 seeps per class) measured on each Julian Day in Siberia and Alaska. Data were interpolated across 2/29 on non-leap years. Ebullition data are presented on a log-scale on the Y-axis.

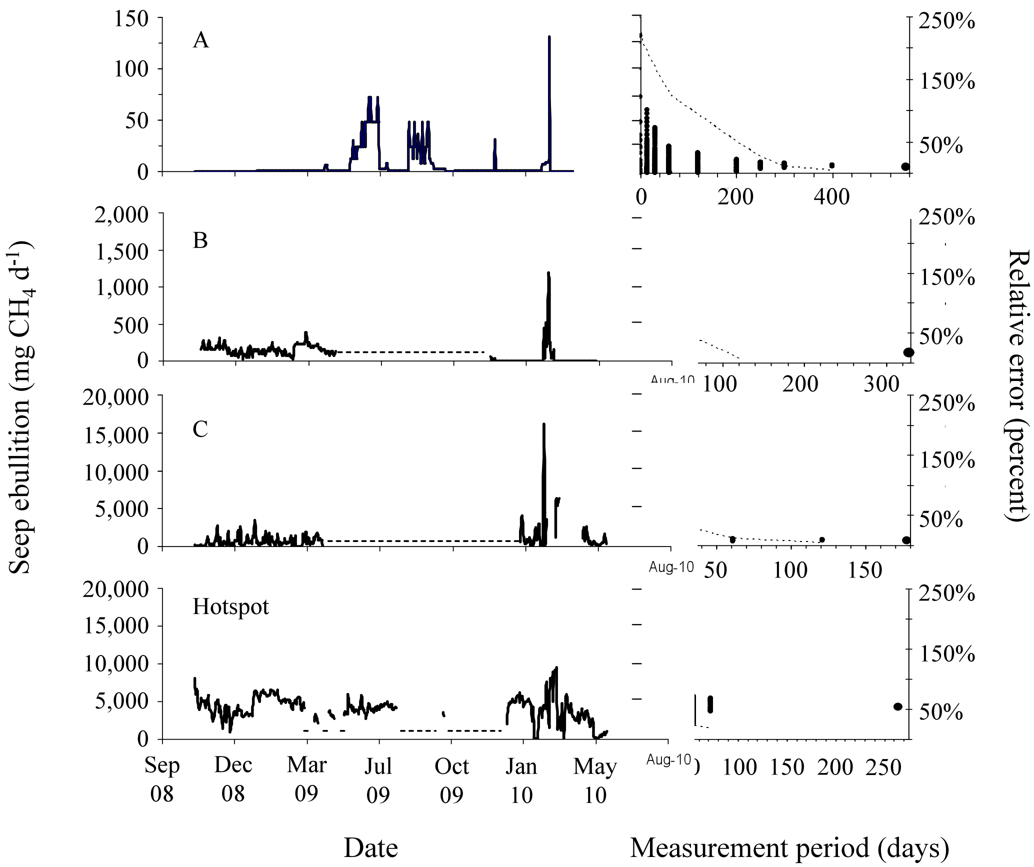


Figure 3. Mean daily ebullition measured from August 2008-May 2010 for individual A, B, C, and Hotspot seeps on an Alaskan lake (left), and the distribution of measured ebullition values as a function of measurement period (right). The scale of the Y_1-axis differs for A, B, C and Hotspot examples. Relative error of ebullition (standard deviation/ mean) was inversely related to period of measurement (dotted line; Y_2-axis). Over short periods of measurement, ebullition from individual seeps was highly variable suggesting that such that short-term flux measurements are unlikely to represent the long-term mean emission from seeps. Periods of no data are indicated by a dashed line on the left-side panels.

Task 7.0 - Methane oxidation in Alaskan thermokarst lakes. Mary Beth Leigh (UAF) and Ruo He (UAF): Stable isotope probing (SIP) microcosms have been conducted to identify and quantify active methane utilizing bacteria in sediments from a range of depths from several sampling sites from our study lakes. SIP sediment samples were harvested, a subsample was frozen immediately at -80ºC for molecular analysis and the remaining sediment was freeze-dried for phospholipid fatty acids (PLFA) analysis.

DNA was extracted from the sediment SIP samples and was subjected to isopycnic centrifugation and fractionation using established methods. ^{13}C-DNA-containing fractions were subjected to PCR to amplify bacterial 16S rRNA genes, as well as type I and type II methanotrophs and methane oxidation genes. Bacteria and functional genes were characterized and phylogenetically identified by terminal restriction fragment length polymorphism (T-RFLP), cloning, Sanger sequencing and high throughput pyrosequencing analysis. T-RFLP profiles of 16S rDNA gene amplicons from the sediment from our study sites showed that methane utilizing bacteria varied with depth (Figure 4). We sent 96 clones of type I, type II methanotrophs, 16S rRNA genes and functional genes, respectively, for sequencing. Raw clone sequences of Type I, Type II methanotrophs and 16S rRNA genes were processed by using pipeline quality filter tools on the Ribosomal Database project website (http://rdp.cme.msu.edu/pipeline) and tested for chimeric sequences using Mallard 1.02 software. Sequences were dereplicated with the CAP3 program with 97% sequence identity cutoff to separate the sequences into groups of related

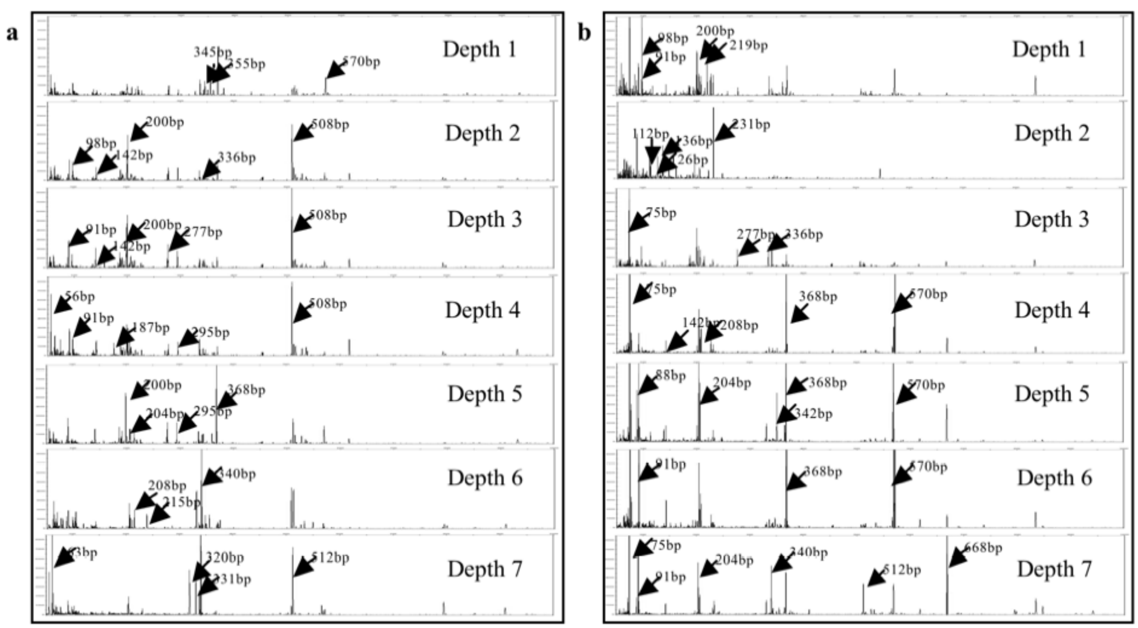


Figure 4: Terminal restriction fragment length polymorphism (T-RFLP) profiles of 16S rDNA gene amplicons from the sediment from our study sites (a) LQ at seep site and (b) LQ away from site.

sequences known as operational taxonomic units (OTUs). Phylogenetic trees have been constructed with one representative sequence from each OTU cluster along with reference sequences of the nearest matching sequences from GenBank. Pyrosequencing was performed using Roche 454 GS FLX Titanium sequencing (454 Life Sciences, Branford, CT, USA) at the Research Technology Support Facility, Michigan State University (East Lansing, MI USA). Sequences were first trimmed of the primer region and low-quality sequences were removed. Average of more than 2000 pyrosequencing reads was obtained for our samples. The sequences that passed this filter were taxonomically assigned by the Ribosomal Database Project's (http://rdp.cme.msu.edu) Naïve Bayesian Classifier (80% confidence threshold).

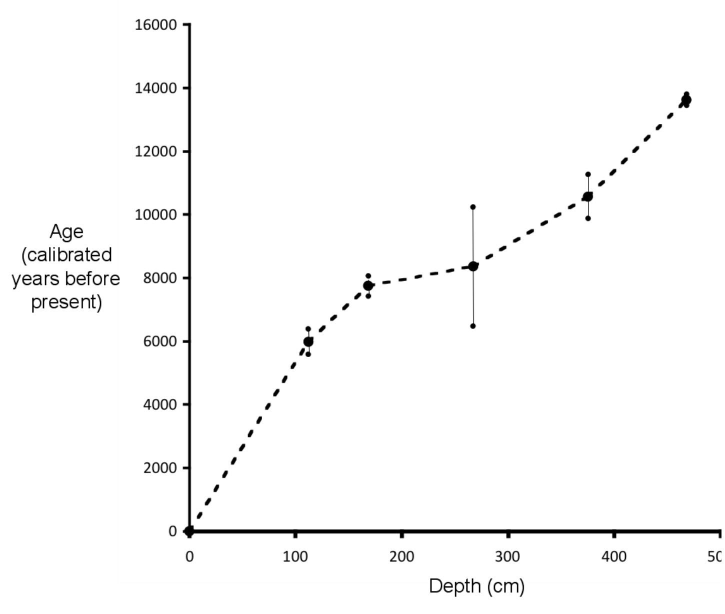
PLFA have been extracted from freeze-dried sediment sample using a modified Bligh-Dyer method. The phospholipid ester-linked fatty acid methyl esters were dissolved in hexane for analysis by GC-FID and gas chromatography-combustion-isotope ratio mass spectrometry (GC-C-IRMS). The analysis of total PLFA composition has been done, while the analysis of ^{13}C labeled PLFA is processing now. Many organisms that were previously known and others not known to be methane oxidizers were found to derive carbon from methane.

Former DOE-NETL Fellow **Monica Heintz** (UCSB) has also been working on studies related to methane oxidation in support of this project. Her research focuses on spatial and seasonal variations in methane oxidation rates in Lake Q and nearby lakes. Her results are mentioned in UCSB's DOE report, have been described in several presentations, are included in her now-completed PhD dissertation, and are described in detail in a manuscript in preparation by her and several other investigators on this project.

Task 8.0 - Establishing a long-term record of the variability in methane emissions in relation arctic climate change. Matthew Wooller (UAF) and Pohlman (USGS): The analyses of Lake Q are complete and a manuscript describing the results is being prepared.

The technologies developed and applied to analyze the Lake Q west core (i.e., stable carbon isotope analyses of biological fractions preserved in lake sediments to infer past changes in methane emissions) has also been applied to two other long cores accessed by Wooller et al. (one from the Brooks range [Burial Lake] and covering the period ~25,000 years to present) and one from the discontinuous permafrost region in the interior of Alaska (Quartz lake). Manuscripts describing findings from both of these additional sites are in production. Gaglioti and Wooller continue to prepare samples from the year 2 field work conducted at Teshekpuk. Results from a suite of AMS radiocarbon dates have been

Figure 5: Provisional age depth relationship for sediment core taken from Teshekpuk as part of year 2 field work.

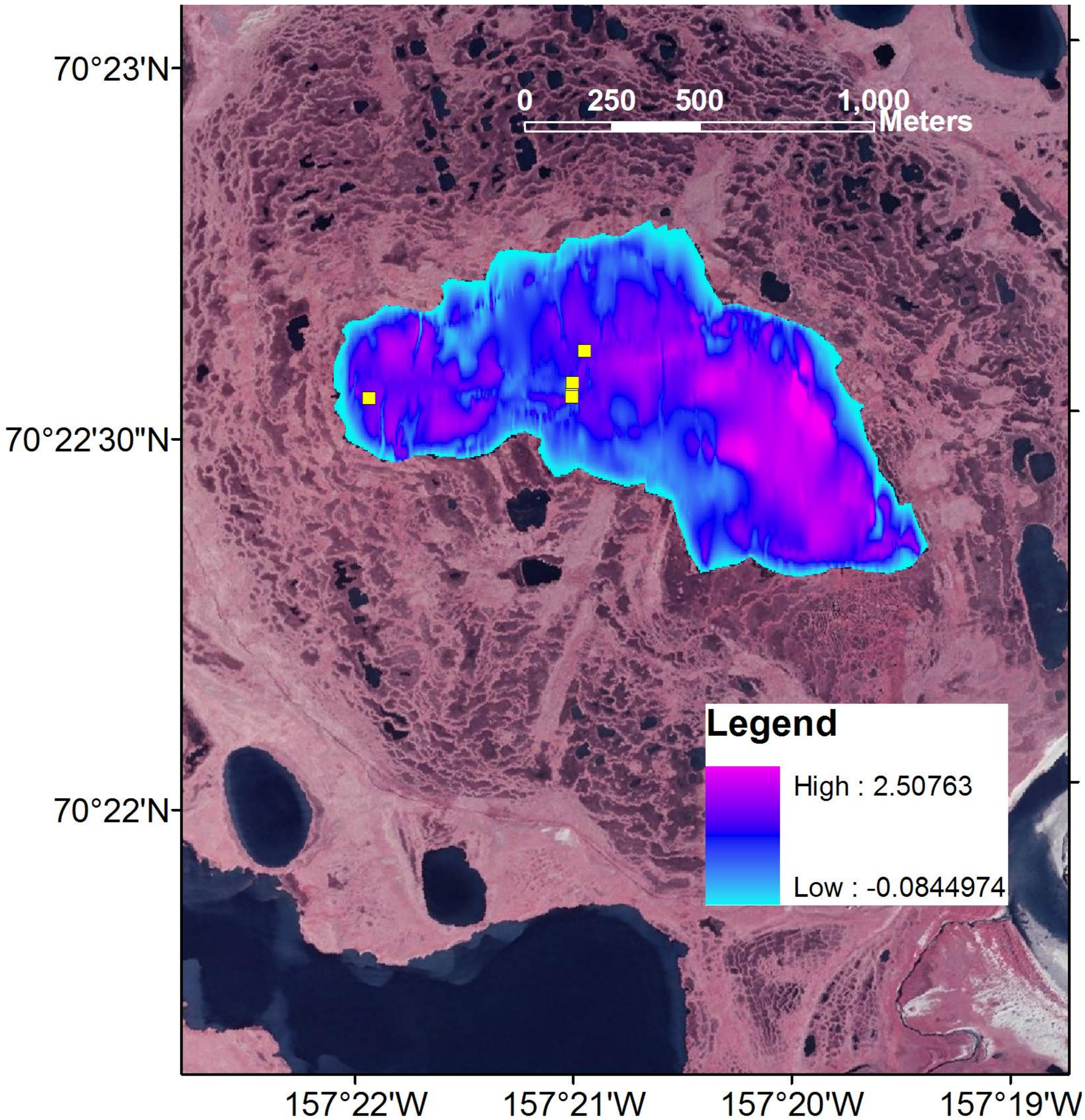


generated and a preliminary age vs. depth model for the core from Teshekpuk has been produced (Figure 5). To the best of our knowledge, this is the first record of sedimentation rates produced for Lake Teshekpuk.

Task: 9 - Geophysical analyses Carolyn Ruppel (USGS).

- Analysis of Lake Q geophysical data from Year 1 and full integration of SAR data into Heintz et al in prep manuscript is nearly complete. SAR data analysis for grounded and non-grounded ice was completed by the USGS using data obtained by **Mat Wooller** under agreement with the UAF's Geophysical Institute for the period of Winter 2009 to 2010. The analysis confirmed other inferences about possible isolation of water bodies beneath the ice and resulting changes in biogeochemistry (Figure 6). The results have been included in numerous talks given by/lead authored by **Monica Heintz** (e.g., Fall AGU meeting, 2010; USGS-DOE Climate-Hydrates Workshop in Boston, March 2011).
- Analysis of Chirp seismic data and other data were undertaken at the USGS to produce a GIS-based gridded bathymetric map for Lake Q. These results have been shown by project personnel in several presentations. There is good correlation between the SAR-based inferences about grounded ice and the location of shoals determined through analysis of the bathymetric data.
- Analysis of preliminary Year 1 data from Lake Teshekpuk to inform coring in Year 2 was not necessary since a 2^{nd} year of coring is not being carried out at Lake Teshekpuk. The geophysical survey lines have already been built into a GIS by the USGS. Sonar data clearly reveal changes in lake bottom sediments related to different sediments sources and drainage of adjacent lakes. These data and complementary water column imaging also provide information about the location and character of some of the methane-related features. Chirp seismic data show the distribution of shallow gas in the northern part of Lake Teshekpuk, and the preliminary results from these surveys correlate well with the lithologies and boundaries detected during the May 2010 coring operation. Low-frequency (boomer) data will require extensive swell filtering that has not yet been completed. The USGS does have the capacity to complete this analysis, as indeed it has done for shallow Beaufort Sea work.
- Analysis of the Teshekpuk geophysical data from Year 2 and integration with the geochemistry results from coring are underway. This will involve closer correlation of the swell-filtered Chirp seismic data with the sediment descriptions from the northern Teshekpuk cores. No geophysical data could be obtained over the coring site located in the middle of Lake Teshekpuk, as this location was still ice-covered when the USGS geophysics group was at the lake in July 2010. Some of the combined GIS and geochemistry results were reported by J **Pohlman** at the USGS-DOE Climate-Hydrates workshop convened by C **Ruppel** in March 2011 in Boston (Ruppel, *Fire in the Ice*, May 2011 edition).
- Continued development of Lake Teshekpuk project GIS by incorporating other non-physics data sets is underway. Currently, the USGS Gas Hydrates Project Lake Teshekpuk GIS includes limited remote sensing data, the geophysical data from Summer 2010, the coring locations, and other data that the USGS has available in permafrost, seismic, well log, sedimentary, and related databases for the area near Lake Teshekpuk.

Figure 6. Provisional bathymetry of Lake Q extracted through analysis of USGS geophysical data acquired in July 2009, superposed on regional, high-resolution remote sensing imagery. Yellow symbols denote locations of cores collected in 2009.



Publications: (DOE project participants in bold):

G. Grosse, V. Romanovsky, T. Jorgenson, **K. Walter Anthony**, J. Brown, P. P, Overduin. 2011. Vulnerability and feedbacks of arctic permafrost to climate change. EOS Transactions, American Geophysical Union. In press.

Isaksen, I. S. A., M. Gauss, G. Myhre, **K. M. Walter Anthony, and C. Ruppel**. 2011. Strong atmospheric chemistry feedback to climate warming from Arctic methane emissions, Global Biogeochem. Cycles, 25, GB2002, doi:10.1029/2010GB003845.

Ruppel, C., J. **Pohlman**, and C. Worley, 2009, Studying the link between Arctic methane seeps and degassing methane hydrates, *Soundwaves* USGS national newsletter, October edition, cover article (http://soundwaves.usgs.gov/2009/10/)

Scandella*,* B.P., C. Varadharajan, H. F. Hemond, C. **Ruppel** and R. Juanes, 2011, *Geophysical Research Letters*, 38, L06408, doi:10.1029/2011GL046768

Walter Anthony, K. Vas, D., Brosius, L., Chapin, F. S. III, Zimov, S.A., and Zhuang, Q. 2010. Estimating methane emissions from northern lakes using ice bubble surveys. Limnol. Oceanogr.: Methods 8, 2010, 592–609.

Wooller, M.J., Ruppel, C., Pohlman, J.W., Leigh, M.B., Heintz, M., and Walter Anthony, K., Permafrost gas hydrates and climate change; lake-based seep studies on the Alaskan North Slope: Fire in the Ice (U.S. Department of Energy, National Energy Technology Laboratory Methane Hydrate Newsletter), summer 2009, p. 6-9 [http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/newsletter/newsletter.htm].

Publications in preparation:

Brosius, L.E., **K. M. Walter Anthony**, G. Grossee, J. Chanton, L. Farqharson, P. Overduin. Implications of δDCH4 from Alaskan thermokarst lakes for past and present atmospheric CH4 budgets. JGR Biogeoscience.

Ruo He, Matthew J. Wooller, John W. Pohlman, Catharine Catranis, John Quensen, James M. Tiedje, **Mary Beth Leigh**. Identification of functionally active aerobic methanotrophs in sediments from an arctic lake using stable isotope probing. Environmental Microbiology

Ruo He, Matthew J. Wooller, John W. Pohlman, John Quensen, James M. Tiedje, **Mary Beth Leigh**. Aerobic methanotrophs along depth profiles of arctic lake water column and sediments. The ISME Journal.

Ruo He, Matthew J. Wooller, John Pohlman, John Quensen, James M Tiedje, **Mary Beth Leigh**. Shifts in identity and activity of methanotrophs in arctic lake sediments in response to temperature changes. Environmental Microbiology.

Strohm, A., **K. M. Walter Anthony, F. Thalasso**. Seasonal methane emissions from an interior Alaska thermokarst lake. JGR Biogeoscience.

Vas, D.A., **K. M. Walter Anthony,** R. Barry, P. Anthony. Understanding the plumbing of methane ebullition seeps in interior Alaska thermokarst-lake sediments from high temporal resolution seep monitoring, Limnol. Oceanogr.

Matthew J. Wooller, et al. A ~12,000 year record of the variability in methane emissions from an arctic wetland related to climate change. Quaternary Research.

Matthew J. Wooller et al. A record of Late Quaternary climate change in the northwestern Brooks Range, Alaska derived from stable isotopic analyses of chironomids. Quaternary Research.

Matthew J. Wooller et al. 11,000 years of climate and limnological change from Quartz Lake, Alaska. Journal of Paleolimnology.

Presentations:

Brosius, L., **Walter Anthony, K.M.,** Chanton, J. (2009): Determining Organic Matter Sources to CH4 Production and Bubbling from Alaskan Lakes using Stable Isotopes and Radiocarbon Ages. *Eos Trans. AGU, 90(52),* Fall Meet. Suppl., Abstract B41C-0327.

Chanton, J., **Walter Anthony, K.M.,** Prater, J, Whiting, G. (2009): Contrasting natural abundance radiocarbon signatures of methane released upon permafrost decomposition. *Eos Trans. AGU, 90(52),* Fall Meet. Suppl., Abstract B44B-04.

Elvert, M, Hinrichs, K-U, **Wooller, M.**, **Gaglioti, B**., Becker, K., **Pohlman, J.W**. 2011. Carbon and hydrogen isotope biomarker records of methane release and hydroclimatic variability from a thermokarst lake in the Alaskan Arctic. International Meeting on Organic Geochemistry. Interlaken, Switzerland.

Geai M-L, **Walter Anthony KM**, Grosse G (2010): Climate Change and Methane Emissions: Pan Arctic Lake Ice Methane Monitoring Network (PALIMMN). International Polar Year Conference, Oslo, Norway, 8-12 June, 2010.

Grosse G, Jones B, **Walter Anthony K**, Romanovsky V, Marchenko S (2010): Classification of Lakes in Pan-Arctic Permafrost Regions. Third European Conference on Permafrost, Longyearbyen, Svalbard, Norway, June 13-17, 2010.

Grosse G, K. **Walter Anthony,** B. Jones, L. Plug, V. Romanovsky (2010): Thermokarst lake drainage in the continuous permafrost zone of NW Alaska and climate feedbacks. EGU General Assembly, 2-7 May 2010, Vienna, Austria.

Grosse G, **Walter Anthony K,** Romanovsky V, Marchenko S, Jones B, Plug L, Edwards M (2010): Pan-Arctic thermokarst lakes, methane emissions, and future permafrost thaw. International Polar Year Conference, Oslo, Norway, 8-12 June, 2010.

Leigh, MB. (2011). Into the black box: Carbon and contaminant cycling in Alaskan ecosystems. Institute of Arctic Biology Life Sciences Seminar. University of Alaska Fairbanks.

Nolan J, Parsekian A, Slater L, Plug L, **Walter Anthony K**, Grosse G (2010): Thaw Bulb Dimension Imaging Using Continuous Resistivity Soundings, Seward Peninsula, Alaska. State of the Arctic Conference, Miami, Florida.

Pohlman, J.W., Elvert, M, Hinrichs, K-U., **Gaglioti, B.**, **Wooller, M**. 2011. Holocene methane emissions from an Alaskan thermokarst lake: A multiproxy reconstruction. USGS-DOE Climate-Hydrates workshop. Boston MA.

Ruo He, M. Wooller and MB Leigh. (2011). Methane oxidizing microbes in Alaskan lakes. Platform presentation. American Society for Microbiology Alaska Branch Meeting, Anchorage, AK.

Ruo He, Matthew Wooller and Mary Beth Leigh. (2011). Methane oxidizing microbes in Alaskan lakes. Oral presentation. ASM Alaska branch meeting, April 22-23,

Ruo He, Matthew J. Wooller, Mary Beth Leigh. (2010). Community structure and activity of methanotrophs in arctic lakes. Poster 13th International symposium on Microbial Ecology.

Ruo He, Wooller MJ, Leigh MB (2010). Stable isotope probing analysis of methane oxidation activity and community structure in arctic lakes. Poster 7th Isotopes In Ecology Conference.

Ruo He, Matthew J. Wooller, Mary Beth Leigh. Chacterization of Methane Oxidation and Methanotrophic Community Structure in a lake on the North Slope of Alaska. Poster. ASM Alaska branch meeting, February 26-27, 2010

Ruppel, C., Climate change and methane hydrates onshore and offshore Northern Alaska, Alaska Environmental Forum (outreach), Anchorage, AK, February 2010.

Ruppel, C., Climate change and methane in the Arctic, WHOI Summer Student Fellow seminar series (outreach), Woods Hole Oceanographic Institution, June 2010. [talk also given to public as part of USGS Earth Day celebration, April 2010]

Ruppel, C., Global warming on the North Slope: a tale of permafrost and methane ice (hydrate), Schoolyard lecture series (outreach) hosted by Barrow Arctic Science Center, July 2010. [same talk also given to MIT's Dept of Earth, Atmospheric, and Planetary Sciences undergraduate seminar series, November 2010].

Ruppel, C., Methane hydrate degassing and global climate change—past, present, and future, Lawrence Livermore National Laboratory, April 2010.

Ruppel, C., USGS Gas Hydrates Project: Arctic methane-climate research, EU COST PERGAMON Arctic Methane meeting, Brussels, Belgium, February 2011.

Ruppel, C., Overview of USGS climate-methane hydrates research, USGS-DOE Climate-Hydrates workshop, Boston, MA, March 2011.

Walter Anthony, K.W. (2010): Methane emissions from thermokarst lakes, ABISKO Scientific Research Station Invited Speaker, December 17, 2010.

Walter Anthony, K. W. 2011, Methane ebullition from thermokarst lakes in the Arctic, Invited Talk, Physics of Sustainable Energy II: Using Energy Efficiently and Producing It Renewably; The American Physical Society's Forum on Physics and Society Topical Group on Energy Research and Application & The American Association of Physics Teachers, University of California, Berkeley, March 5, 2011.

Walter Anthony, K.M., Grosse, G., Jones, B.M. (2009): Positive and negative feedbacks to climate change associated with methane emissions from arctic permafrost systems. *Eos Trans. AGU, 90(52),* Fall Meet. Suppl., Abstract B43F-06.

Walter Anthony, K.M., Zimov, S.A. (2009): Greenhouse gas release from arctic permafrost: positive feedback to climate warming. *Eos Trans. AGU, 90(52),* Fall Meet. Suppl., Abstract U44A-02.

Walter KM, Grosse G, Finlay J, Chandra S, Michelle MC (2009): Disappearing permafrost and the response of Arctic lakes. Advancing the Science of Limnology and Oceanography Meeting, 25-30 January, 2009, Nice, France.

Wooller, M.J. 2011. Stable Isotopes role in addressing oil spills in ice covered water. ASF workshop, University of Alaska Fairbanks.

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