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Introduction to special section on Synthesis of Recent Terrestrial Methane Emission Studies

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1. Introduction

[1] Methane (CH_4) is a potent greenhouse gas, second in importance to carbon dioxide (CO_2) [*Intergovernmental Panel on Climate Change* (*IPCC*), 2007]. Biogenic sources account for 70% of global emissions – wetlands, rice paddies, livestock, landfills, forests, oceans and termites. Natural wetlands and rice paddies are the largest CH_4 sources, and account for 20–60% of the total natural and anthropogenic emissions. While the existing estimates of emissions from these known sources still have great uncertainty, recent studies reveal a number of new sources contributing to the atmospheric CH_4 burden. For example, the bubble emissions due to thawing lake sediments from north Siberia alone were estimated to release 3.8 Tg CH_4 yr^{-1} [*Walter et al.*, 2006]. Permafrost thawing also increases the CH_4 emissions from wet soils [e.g., *Wickland et al.*, 2006]. To adequately quantify total CH_4 emissions and reconcile atmospheric CH_4 concentrations with the earth surface emissions, the mechanisms of and controls on these CH_4 sources need to be further understood.

[2] The last synthesis effort of studying CH_4 emissions focused on data compilation and data analysis at site-levels [*Ojima et al.*, 2000]. Our current synthesis continues the data compilation effort and incorporates new more sophisticated biogeochemistry and atmosphere transport models in quantifying regional and global CH_4 emissions. Specifically, recent CH_4 studies have focused on the following areas: (1) Understanding the processes and mechanisms of CH_4 production and consumption in different environments through field observations, environmental manipulations, and using isotopic analyses; (2) Measuring the emission fluxes from natural sources and observing atmospheric CH_4 concentrations and profiles using flask measurements and satellite instruments [e.g., *Dlugokencky et al.*, 2001; *Bergamaschi et al.*, 2007]; and (3) Refining the estimates of CH_4 emissions and their effect on the atmosphere with process-based biogeochemistry models and atmospheric transport and inversion models [e.g., *Zhuang et al.*, 2004, 2006, 2007; *Walter et al.*, 2001; *Chen and Prinn*, 2005, 2006]. This section resulted from a project supported by the National Center for Ecological Analysis and Synthesis (NCEAS) and presents results from new field studies, new instruments, and new approaches to the above areas. The section specifically addresses the issues of methane emissions in both natural and managed ecosystems, which are undergoing anthropogenic and natural perturbations of water table, permafrost thaw, volcanic deposition, sulfur deposition, and manure/fertilizer amendment. To better quantify the regional and global CH_4 emissions, these effects and controls need to be considered in biogeochemistry models. The continuous and long-term observations of CH_4 fluxes impacted by those factors and processes should still be a priority for the CH_4 research community.

2. Contents of This Special Section

[3] Wetland constitutes the largest single source of CH_4 emissions with emissions ranging from 100 to 231 Tg CH_4 yr^{-1} [*IPCC*, 2007]. The climate variability and change modify the wetland distribution, soil wetness, water table depth, and soil temperature, affecting CH_4 emissions. The first two papers in this section involve field manipulations of soil temperature and water table depth in northern peatlands [*Turetsky et al.*, 2008; *White et al.*, 2008]. The *Turetsky et al.* study involved an ecosystem-scale manipulation of water table and soil surface temperature in a moderate rich fen located in interior Alaska. Methanogen populations were found to respond rapidly to changes in soil moisture and temperature changes. *White et al.* studied the effects of water table, soil warming, and wetland type on production, oxidation, and emission of CH_4 in northern peatlands. Acetate fermentation was found to be the principal methanogenic pathway in these systems. The *White et al.* paper does not appear in the print version of this section, but will be electronically linked to the section in the online version.

[4] Arctic wetlands account for about half of the world's wetland area and store about one-third of earth's soil carbon [*Gorham*, 1995]. Thawing permafrost and fire disturbances change the conditions and transitions of wetlands and uplands, resulting in complex CH_4 emission patterns. In addition, the presence of permafrost promotes the formation and persistence of lakes in the Arctic [*Smith et al.*, 2007], and the CH_4 emissions from these lakes have not been well quantified. Using data from Siberia and Alaska, a recent study estimated that arctic lakes emit 15 – 35 Tg of

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methane per year, most of it through bubbling [*Walter et al.*, 2007]. To address some of these issues, the next three papers [*Walter et al.*, 2008; *Sachs et al.*, 2008; *Gauci et al.*, 2008b] focus on CH_4 emissions and their controls, including effects of permafrost thawing and bubble emissions from thawed lakes in northern high latitudes, ecosystem-scale field observations of CH_4 emission from polygonal tundra in the Lena River Delta, Siberia, and the possibility of a large Icelandic volcanic eruption resulting in a large decrease in CH_4 emission.

[5] Rice paddies are another significant source of CH_4 emissions ranging 31 to 112 Tg CH_4 yr^{-1} [*IPCC*, 2007]. The large uncertainty of the emissions is due to incomplete understanding of mechanisms and controls of emissions and consumption affected by agricultural management, such as fertilization and irrigation. The next four papers [*Khalil and Butenhoff*, 2008; *Khalil et al.*, 2008a, 2008b; *Gauci et al.*, 2008a] investigated CH_4 emissions from rice paddies and controls on emission controls through field and laboratory experiments. *Khalil and Butenhoff* [2008] showed that there are large natural variations in CH_4 emission between rice plots, and that these variations must be considered in scaling-up plot measurements to larger areas. *Khalil et al.* [2008a] found that manure additions to two crops of rice in Qing Yuan, Guangdong, China, under hot weather conditions resulted in an increase in CH_4 emission. *Khalil et al.* [2008b] found that high organic fertilizer additions increased CH_4 production, but also decreased CH_4 oxidation. *Gauci et al.* [2008a] showed that sulfate deposition through simulated acid rain decreased CH_4 emission.

[6] The Atmospheric Infrared Sounder (AIRS) on EOS/Aqua platform launched on 4 May 2002 provides a good opportunity to monitor atmospheric CH_4. The paper of *Xiong et al.* [2008] presents their satellite retrieval methodology and the product of atmospheric CH_4 vertical profiles based on the instrumentation of the Atmospheric Infrared Sounder (AIRS).

3. Data Archives Associated With This Special Section

[7] Under the auspices of the NCEAS, we have assembled in situ measurements, flask measurements, and satellite data of methane concentrations and fluxes and process-based and atmospheric transport models in our Working Group. The flux and ancillary data for wetlands, rice paddies, and Siberia lakes are archived in NCEAS Data Repository website (http://data.nceas.ucsb.edu). These data include site descriptors (location, ecosystem type and description, fractional inundation, elevation), daily / monthly climate, soil characteristics, and methane fluxes, monthly net primary production and net ecosystem carbon exchange. The data archive effort is continuing and these data will facilitate synthesizing the global methane cycle with process-based and atmospheric transport chemistry modeling approaches.

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References

Bergamaschi, P., et al. (2007), Satellite cartography of atmospheric methane from SCIAMACHY on board ENVISAT: 2. Evaluation based on inverse model simulations, *J. Geophys. Res.*, *112*, D02304, doi:10.1029/2006JD007268.

Chen, Y.-H., and R. G. Prinn (2005), Atmospheric modeling of high- and low-frequency methane observations: Importance of inter-annually varying transport, *J. Geophys. Res.*, *110*, D10303, doi:10.1029/2004JD005542.

Chen, Y.-H., and R. G. Prinn (2006), Estimation of atmospheric methane emissions between 1996 and 2001 using a three-dimensional global chemical transport model, *J. Geophys. Res.*, *111*, D10307, doi:10.1029/2005JD006058.

Dlugokencky, E. J., B. P. Walter, K. A. Masarie, P. M. Lang, and E. S. Kasischke (2001), Measurements of an anomalous global methane increase during 1998, *Geophys. Res. Lett.*, *28*(3), 499–502.

Gauci, V., N. B. Dise, G. Howell, and M. E. Jenkins (2008a), Suppression of rice methane emission by sulfate deposition in simulated acid rain, *J. Geophys. Res.*, doi:10.1029/2007JG000501, in press.

Gauci, V., S. Blake, D. S. Stevenson, and E. Highwood (2008b), Halving of the northern wetland CH_4 source by a large Icelandic volcanic eruption, *J. Geophys. Res.*, doi:10.1029/2007JG000499, in press.

Gorham, E. (1995), The biogeochemistry of northern peatlands and its possible responses to global warming, in *Biotic Feedbacks in the Global Climatic System: Will the Warming Feed the Warming*? edited by G. M. Woodwell and F. T. Mackenzie, pp. 169–187, Oxford Univ. Press, New York.

Intergovernmental Panel on Climate Change (IPCC) (2007), *Climate Change 2007: The Physical Science basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, edited by S. Solomon et al., Cambridge Univ. Press, New York.

Khalil, M. A. K., and C. Butenhoff (2008), Spatial variability of methane emissions from rice fields and implications for experimental design, *J. Geophys. Res.*, doi:10.1029/2007JG000517, in press.

Khalil, M. A. K., M. J. Shearer, R. A. Rasmussen, X. Li, and J.-L. Liu (2008a), Methane and nitrous oxide emissions from subtropical rice agriculture in China, *J. Geophys. Res.*, doi:10.1029/2007JG000462, in press.

Khalil, M. A. K., M. J. Shearer, R. A. Rasmussen, C. Duan, and L. Ren (2008b), Production, oxidation, and emissions of methane from rice fields in China, *J. Geophys. Res.*, doi:10.1029/2007JG000461, in press.

Ojima, D., A. Mosier, S. Del Grosso, and W. J. Parton (2000), TRAGNET analysis and synthesis of trace gas fluxes, *Global Biogeochem. Cycles*, *14*(4), 995–997.

Sachs, T., C. Wille, J. Boike, and L. Kutzbach (2008), Environmental controls on ecosystem-scale CH_4 emission from polygonal tundra in the Lena River Delta, Siberia, *J. Geophys. Res.*, doi:10.1029/2007JG000505, in press.

Smith, L. C., Y. Sheng, and G. M. MacDonald (2007), A first pan-arctic assessment of the influence of glaciation, permafrost, topography and peatlands on northern lake distribution, *Permafrost Periglac., Processes*, *18*, 201–208.

Turetsky, M. R., C. C. Treat, M. Waldrop, J. M. Waddington, J. W. Harden, and A. D. McGuire (2008), Short-term response of methane fluxes and methanogen activity to water table and soil warming manipulations in an Alaskan peatland, *J. Geophys. Res.*, doi:10.1029/2007JG000496, in press.

Walter, B. P., M. Heimann, and E. Matthews (2001), Modeling modern methane emissions from natural wetlands: 2. Interannual variations 1982–1993, *J. Geophys. Res.*, *106*(D24), 34,207–34,219.

Walter, K. M., et al. (2006), Methane bubbling from Siberian thaw lakes as a positive feedback to climate warming, *Nature*, *443*(7107), 71–75.

Walter, K. M., L. C. Smith, and F. S. Chapin III (2007), Methane bubbling from northern lakes: Present and future contributions to the global methane budget, *Philos. Trans. R. Soc. London, Ser. A*, *365*, 1657–1676.

Walter, K. W., J. P. Chanton, E. A. Schuur, S. A. Zimov, and F. S. Chapin III (2008), Methane production and bubble emissions from arctic lakes: Isotopic implications for source pathways and ages, *J. Geophys. Res.*, doi:10.1029/2007JG000569, in press.

White, J. R., R. D. Shannon, S. D. Bridgham, J. F. Weltzin, and J. Pastor (2008), Effects of soil warming and drying on methane cycling in a northern peatland mesocosm study, *J. Geophys. Res.*, doi:10.1029/2007JG000609, in press.

Wickland, K. P., R. G. Striegl, J. C. Neff, and T. Sachs (2006), Effects of permafrost melting on CO_2 and CH_4 exchange of a poorly drained black spruce lowland, *J. Geophys. Res.*, *111*, G02011, doi:10.1029/2005JG000099.

Xiong, X., C. Barnet, E. Maddy, C. Sweeney, X. Liu, L. Zhou, and M. Goldberg (2008), Characterization and validation of methane products from the Atmospheric Infrared Sounder (AIRS), *J. Geophys. Res.*, doi:10.1029/2007JG000500, in press.

Zhuang, Q., J. M. Melillo, D. W. Kicklighter, R. G. Prinn, D. A. McGuire, P. A. Steudler, B. S. Felzer, and S. Hu (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, *Global Biogeochem. Cycles*, *18*, GB3010, doi:10.1029/2004GB002239.

Zhuang, Q., J. M. Melillo, M. C. Sarofim, D. W. Kicklighter, A. D. McGuire, B. S. Felzer, A. Sokolov, R. G. Prinn, P. A. Steudler, and S. Hu (2006), CO_2 and CH_4 exchanges between land ecosystems and the atmosphere in northern high latitudes over the 21st century, *Geophys. Res. Lett.*, *33*, L17403, doi:10.1029/2006GL026972.

Zhuang, Q., J. M. Melillo, A. D. McGuire, D. W. Kicklighter, R. G. Prinn, P. A. Steudler, B. S. Felzer, and S. Hu (2007), Net emissions of CH_4 and CO_2 in Alaska: Implications for the region's greenhouse gas budget, *Ecol. Appl.*, *17*(1), 203–212.

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