Long-term, Global, and Space-Based Constraints on Methane's Emissions and the Factors that Control Them

A response to the Request for Information for the 2017-2027 NRC Decadal Survey on Earth Science and Applications from Space

Contact: Bryan N. Duncan, NASA (Bryan.N.Duncan@nasa.gov)

November 1, 2015

Co-Contributors (in alphabetical order): James B. Abshire (NASA), Abhishek Chatterjee (Universities Space Research Association), Yasin Elshorbany (University of Maryland), Arlene M. Fiore (Columbia University), Daniel J. Jacob (Harvard University), Stephan R. Kawa (NASA), Lesley E. Ott (NASA), Paul I. Palmer (University of Edinburgh), Haris Riris (NASA), Sarah A. Strode (Universities Space Research Association), James S. Wang (Universities Space Research Association)

Methane is the second most important anthropogenic greenhouse gas (GHG), influences the atmosphere's oxidizing capacity, and affects climate and air quality through its contribution to tropospheric ozone formation. Its 100-year and 20-year global warming potentials (GWP) are 28-32 times and 84-86 times, respectively, larger than those of CO_2 (Myhre et al., 2013; Holmes et al., 2013), making anthropogenic methane a critical target for mitigation (e.g., Kirschke et al., 2013). However, there are large uncertainties in methane's anthropogenic sources (Ciais et al., 2013) that must be reduced. There are also large uncertainties associated with natural sources and how they will respond to a warming climate. These potentially substantial feedbacks would accelerate climate change, including the possibility of the climate reaching a critical tipping point.

The existing methane observing network has proven inadequate to 1) constrain global, regional, and sectoral sources, and 2) explain observed trends and variations in atmospheric methane over the last few decades. These deficiencies limit confidence in modeling the future evolution of methane. Current surface measurement sites are mostly located far from methane's sources and continuity and/or expansion of the surface network alone would not be adequate to constrain emissions given the spatial heterogeneity of the fluxes. Existing large-footprint, passive satellite observations are hampered by aerosol scattering and clouds, including over tropical wetlands, and a lack of sunlight at higher latitudes, including the Arctic-Boreal Zone (ABZ).

This is a critical time to establish a coordinated and comprehensive methane observing network of passive and active instruments on both satellite and suborbital platforms for constraining the strength and distribution of methane's sources. The network would allow for (a) closure of the global methane budget, (b) better understanding of methane's sources, including regional and sectoral anthropogenic contributions, and (c) support new national and international agreements to reduce GHGs. Another critical part of this network is a suite of instruments to observe the biogeochemical processes and feedbacks that control emissions from global wetlands and permafrost thaw. Timely deployment of such a network would allow for a crucial baseline of current ABZ methane fluxes, against which to compare future releases. Design of the observing network would involve scientists from several communities, including atmosphere, climate, radiation, biosphere, hydrosphere, and cryosphere.

What are the key challenges or questions for Earth System Science across the spectrum of basic research, applied research, applications, and/or operations in the coming decade?

A key challenge is constraining methane fluxes as there are a number of source types, some of which have large discrepancies between bottom-up and top-down emission estimates (Ciais et al., 2013; Kirschke et al., 2013). Data from the existing observing network has not allowed for a clear determination of the causes of methane's observed trends and variations. Surface measurements from the Greenhouse Gas Reference Network (Dlugokencky et al., 2010) show that the global methane growth rate began to level off in the 1990s, but there is only limited understanding of the causes of the slowdown (e.g., Kirschke et al., 2013 and reference therein). A decrease in fossil fuel, rice agriculture and livestock emissions (e.g., Kirschke et al., 2013) and the trend toward more El Niño than La Niña events leading to lower wetland emissions (Hodson et al., 2011) may have contributed. Reaction with OH is the primary sink for methane, but inferred trends in global OH are generally too small (e.g., Montzka et al., 2011) to explain the slowdown. After 2006, the methane growth rate began to increase and continues to do so, but the causes are uncertain (e.g., Nisbet et al., 2014).

The processes that affect methane fluxes from wetlands and thawing permafrost are not well understood, which has seriously limited our ability to project future emissions in a warmer and wetter world. The factors that affect microbial methane production are not well constrained (e.g., Meng et al., 2012), and land cover, including wetlands, is not always well categorized (e.g., Frey and Smith, 2007). The current methane growth rate may be associated with wetland emissions (Dlugokencky et al., 2009; Bousquet et al., 2011) and many observed global anomalies are thought to be associated with fluctuations in wetland emissions (e.g., Wang et al., 2004; Kirschke et al., 2013). Current process-based models predict a wide range of emission estimates (e.g., ± 40% for annual global emissions) as shown in the recent Wetland and Wetland CH_4 Inter-comparison of Models Project (WETCHIMP; Melton et al., 2013) and confidence in these emissions is low (Ciais et al, 2013).

Why are these challenges/questions timely to address now especially with respect to readiness?

Numerous Earth science datasets indicate that climate change is occurring rapidly (Walsh et al., 2014). As methanogenesis exhibits a strong temperature dependence (Yvon-Durocher et al., 2014), the primary scientific question for methane is how climate change will affect wetlands, permafrost and the stability of methane hydrates in a warmer, wetter world, including how potential feedbacks could accelerate climate change. There is a critical need for a baseline of current fluxes against which to compare possible future releases and feedbacks (e.g., O'Connor et al., 2010; Ciais et al., 2013). Additionally, knowledge of methane along with CO_2 is necessary to close the carbon budget. Effective national and international regulations to reduce GHGs require sound scientific knowledge of both natural and anthropogenic methane sources, which could be accomplished with data from a coordinated and comprehensive space-based observing system. Given the time required to design instruments and launch satellites, it is critical to begin establishing this observing system.

Why are space-based observations fundamental to addressing these challenges/questions?

The primary advantage of satellites is spatial coverage, including in areas that are difficult to collect in situ data (NRC, 2003). There is a critical need for long-term observations of methane and the processes that affect it, which would be best met from a suite of satellite sensors in combination with suborbital data, particularly in the ABZ. Given the importance of constraining methane fluxes for climate and the urgency of monitoring the potential climate feedbacks, redundancy in the satellite observing network is critical.

Our ability to estimate emission fluxes with inverse modeling studies (e.g., Bergamaschi et al., 2013) is limited because these estimates have depended on the sparse surface network of methane observations. Isotopic measurements provide information on methane's sources, however, routine observations are expensive and very limited (Dlugokencky et al., 2011). Therefore, quantification of methane's sources depends on high-resolution (in space and time) global observations provided by space-borne missions, as well as, credible and similarly resolved models of the processes that affect methane fluxes.

Satellite methane column data, which are retrieved from NIR/SWIR wavelengths, are used to infer methane fluxes (e.g., Zhang et al., 2013). The main products are 1) the now defunct SCIAMACHY (2002 – 2012), which had detector degradation beginning in 2005 resulting in lower quality data afterwards, and 2) the JAXA GOSAT (2009 – present), which has sparse coverage, particularly over major source regions in the tropics and high latitudes. ESA TROPOMI is expected to launch in 2016 and will have similar capabilities as SCIAMACHY, a 7-year design life, and better spatial coverage than GOSAT. TIR instruments, such as AIRS, TES and IASI, lack sensitivity near the surface and, therefore, are not useful for inferring surface fluxes though they may provide complementary information to column data. Other methane mission concepts are discussed in Moore et al. (2014).

Our ability to estimate fluxes from methane column data is limited by clouds and aerosol scattering, which lead to data gaps. However, satellite measurements of other quantities detect variability in some of the factors known to control wetland fluxes and, thus, are useful for quantifying the processes governing methane fluxes. Microwave instruments provide inundation depths and have the advantage of detecting through clouds. Bloom et al. (2010) used GRACE gravity anomalies as a proxy for water table depth. Suborbital observations in data sparse regions (tropics, high latitudes) could complement satellite data and improve understanding of flux processes.

Inferring ABZ methane fluxes is particularly difficult for sensors relying on reflected sunlight (e.g., GOSAT, TROPOMI) because of limited sun angles and atmospheric scatter. Highly-elliptical orbits, such as the Molniya orbit, are proposed to increase integration time over the ABZ (e.g., Nassar et al., 2014). The active sensor, MERLIN (expected launch in 2019; Ehret et al., 2010; Kiemle et al., 2014), will demonstrate the capability to constrain methane fluxes in cloudy and/or low-light environments, but its 3-year design lifetime will not address the critical need for long-term, continuous observations.

Summary: A space-based, long-term and comprehensive observing network for methane is necessary to close the budgets for atmospheric methane and carbon, which is essential for developing effective strategies to reduce GHGs. This network will aid process-based understanding of emissions from wetlands, the largest single methane source and primary cause of global interannual variations, and from permafrost thaw. It is critical to begin establishing this network as 1) the design and deployment of satellites takes time and 2) numerous datasets confirm the onset of human-induced climate change.

References

Bergamaschi, P., et al. (2013), Atmospheric CH_4 in the first decade of the 21st century: Inverse modeling analysis using SCIAMACHY satellite retrievals and NOAA surface measurements, J. Geophys. Res., 118, 7350-7369, doi:10.1002/jgrd.50480.

Bloom, A., et al. (2010), Large-scale controls of methanogenesis inferred from methane and gravity spaceborne data, Science, 327, January 15.

Bousquet, P., et al. (2011), Source attribution of the changes in atmospheric methane for 2006–2008, Atmos. Chem. Phys., 11, 3689-3700, doi:10.5194/acp-11-3689-2011.

Ciais, P., et al. (2013): Carbon and Other Biogeochemical Cycles. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY.

Dlugokencky, E., et al. (2009), Observational constraints on recent increases in the atmospheric CH_4 burden, Geophys. Res. Lett., 36, L18803, doi:10.1029/2009GL039780.

Dlugokencky, E.J., et al. (2010), Atmospheric Methane Dry Air Mole Fractions from the NOAA ESRL Carbon Cycle Cooperative Global Air Sampling Network, 1983-2009, Version: 2010-08-12, Path: ftp://ftp.cmdl.noaa.gov/ccg/ch4/flask/event/.

Dlugokencky, E., et al. (2011), Global atmospheric methane: budget, changes and dangers, Phil. Trans. R. Soc. A, 369, 2058-2072, doi:10.1098/rsta.2010.0341.

Ehret, G., et al. (2010), The French-German Climate Monitoring Initiative on Global Observations of Atmospheric Methane, ILRC 25 (25th International Laser Radar Conference), St. Petersburg, Russia, July 5-9, 2010, p. 1348-1351.

Frey, K., and L. Smith (2007), How well do we know northern land cover? Comparison of four global vegetation and wetland products with a new ground-truth database for West Siberia, Global Biogeochem. Cycles, 21, GB1016, doi:10.1029/2006GB002706.

Hodson, E., et al. (2011), The El Niño-Southern Oscillation and wetland methane interannual variability, Geophys. Res. Lett., 38, L08810, doi:10.1029/2011GL046861.

Holmes, C., et al. (2013), Future methane, hydroxyl, and their uncertainties: key climate and emission parameters for future predictions, Atmos. Chem. Phys., 13, 285-302, doi:10.5194/acp-13-285-2013.

Kiemle, C., et al. (2014), Performance simulations for a spaceborne methane lidar mission, J. Geophys. Res. Atmos., 119, doi:10.1002/2013JD021253.

Kirschke, S., et al. (2013), Three decades of global methane sources and sinks, Nature Geoscience, 6, doi: 10.1038/NGEO1955.

Melton, J., et al. (2013), Present state of global wetland extent and wetland methane modeling: conclusions from a model inter-comparison project (WETCHIMP), Biogeosciences, 10, 753-788, doi:10.5194/bg-10-753-2013.

Meng, L., et al. (2012), Sensitivity of wetland methane emissions to model assumptions: application and model testing against site observations, Biogeosciences, 9, 2793-2819.

Montzka, S., et al. (2011), Small interannual variability of global atmospheric hydroxyl, Science, 331, doi:10.1126/science.1197640.

Moore, B., et al. (2014), CEOS Strategy for Carbon Observations from Space, Chap. 4: Atmosphere Domain, 2014.

Myhre, G., D., et al. (2013): Anthropogenic and Natural Radiative Forcing. In: Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Nassar, R., et al. (2014), Satellite observations of CO2 from a highly elliptical orbit for studies of the Arctic and boreal carbon cycle, J. Geophys. Res. Atmos., 119, 2654–2673, doi:10.1002/2013JD020337.

Nisbet, E., et al. (2014), Methane on the Rise-Again, Science, 343, doi:10.1126/science.1247828.

NRC, Satellite Observations of the Earth's Environment: Accelerating the Transition of Research to Operations, The National Academies Press, Washington, D.C., 2003.

O'Connor, F. M., et al. (2010), Possible role of wetlands, permafrost, and methane hydrates in the methane cycle under future climate change: A review, Rev. Geophys., 48, RG4005, doi:10.1029/2010RG000326.

Walsh, J., D., et al. (2014): Ch. 2: Our Changing Climate. Climate Change Impacts in the United States: The Third National Climate Assessment, J. M. Melillo, Terese (T.C.) Richmond, and G. W. Yohe, Eds., U.S. Global Change Research Program, 19-67. doi:10.7930/J0KW5CXT.

Wang, J., et al. (2004), A 3-D model analysis of the slowdown and interannual variability in the methane growth rate from 1988 to 1997, Global Biogeochemical Cycles, 18, GB3011, doi:10.1029/2003GB002180.

Yvon-Durocher, G., et al. (2014), Methane fluxes show consistent temperature dependence across microbial to ecosystem scales, Nature, 507, 488–491, doi:10.1038/nature13164.
Zhang, X., et al. (2013), Estimate of methane release from temperate natural wetlands using Envisat/SCIAMACHY data in China, Atmos. Environ., 69, 191-197.