EGU2012-6622: Bracketing the Range of Lake and Wetland Methane Emissions Rates in West Siberia, using Models, In Situ Observations, and Remote Sensing

T. J. Bohn[1], S. Maksyutov[2], H.-S. Kim[2], M. Glagolev[3], R. Schroeder[4], K.C. McDonald[4,5], E. Podest[5], X. Chen[1], *B. Livneh*[1], and D. P. Lettenmaier[1]

[1]University of Washington, Seattle, Washington, USA; [2]National Institute for Environmental Studies, Tsukuba, Japan; [3]Moscow State University, Moscow, Russia; [4]City College of New York, New York, USA; [5]JPL-NASA, Pasadena, California, USA

EGU General Assembly, Vienna, Austria, April 24, 2012

Contact: Ted Bohn, tbohn@hydro.washington.edu

Abstract

Large uncertainties exist in estimates of global lake and wetland methane emission rates, due in part to their large spatial and temporal heterogeneity and also due to the sparseness of in situ observations. This is especially true of lakes and inundated wetlands, for which ebullition is a major methane pathway. Here we use a large-scale coupled land-atmosphere model and remote sensing observations to bracket the range of possible emissions rates from lakes and wetlands in West Siberia. Our modeling framework consists of a large-scale hydrology model (Variable Infiltration Capacity; VIC), extended to handle carbon cycling and methane emissions, coupled to an atmospheric tracer-transport model (NIES Chemical Tracer Model; CTM) driven by NCAR/NCEP reanalysis fields. In the model, "permanent" lake areas are prescribed by the Global Lake and Wetland Database, bias-corrected to account for small lakes. Seasonal inundation of wetlands is dynamic and has been calibrated to match an inundation dataset derived from remote sensing (AMSR-E and Qscat). We calibrated the model's wetland methane emissions to match in situ observations from a large dataset collected in West Siberia between 2006 and 2010. Lake emission rates are prescribed in several scenarios that span the range of observed rates reported in the literature. We explore the relative sizes of various sources of uncertainty in simulated methane emissions: uncertainty in inundated area, parameter uncertainty in the methane emissions model, and the range of possible lake emissions rates. Using values from different ends of the spectrum of these uncertainty sources leads to markedly different spatial patterns of methane emissions across West Siberia. These emissions are ingested by the atmospheric tracer model to produce maps of atmospheric methane concentrations. We compare the resulting spatial patterns of methane concentrations with remotely-sensed observations from the AIRS and GOSAT satellite sensors and explore the implied likelihoods of the different lake and wetland emissions rates.

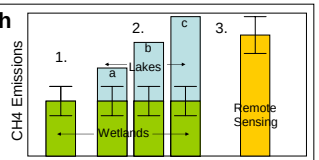
1. Uncertainties in Lake and Wetland Methane Emissions

Component	*Area*	*Emission Rate*
Lakes	Underestimated by GLWD[1]: factor of 2? (Walter et al 2007)	Poorly Constrained: 2 orders of magnitude (Walter et al 2007)[2]
Saturated / Inundated Wetlands	Poorly-Constrained	+/-10% in W. Siberia
Unsaturated Wetlands	Water table distribution poorly constrained	+/- 10% in W. Siberia

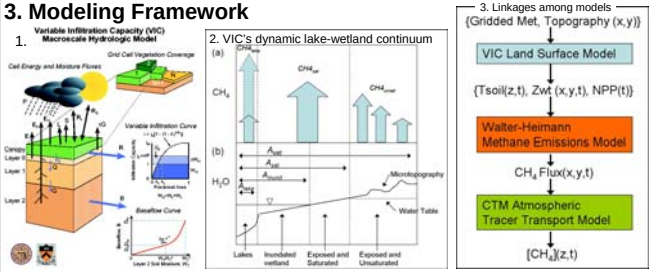
[1]GLWD = Global Lake and Wetlands Database, Lehner and Döll (2004)
[2]Main source of uncertainty is large spatial/temporal heterogeneity of methane bubbling

2. Two-Tiered Bayesian Approach

1. Constrain ***wetland*** emissions from intensive field measurements, remote sensing, and modeling
2. Choose ensemble of ***lake*** areas and emission rates from range of plausible values to produce ensemble of total emissions
3. Constrain ***lake*** emissions by comparing ensemble of total emissions to remote sensing observations ("poor-man's inversion")



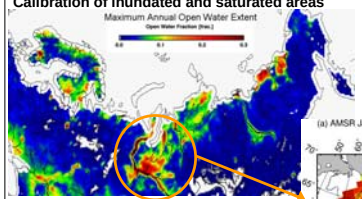
3. Modeling Framework



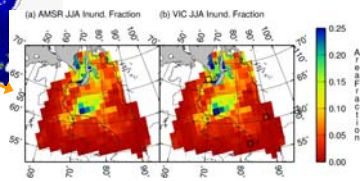
1. Simulate land surface hydrology and carbon cycle using Variable Infiltration Capacity (VIC) model
2. VIC's dynamic lake-wetland model impounds surface water, allowing lakes to expand and flood wetlands; within exposed wetlands, water table is distributed according to microtopography
3. Distributed water table is input to Walter-Heimann (2000) wetland methane emissions model; total grid cell methane fluxes are input to NIES Atmospheric Chemistry Tracer Transport Model (CTM)

4. Model Calibration

Calibration of inundated and saturated areas



Inundation = standing water above soil surface
A_{inund} = inundated extent
= lakes + flooded wetlands

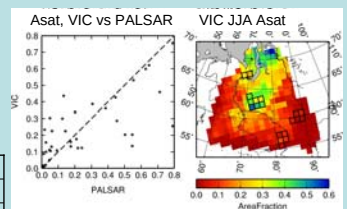


Use NASA/JPL global daily inundation product derived from AMSR-E/QSCAT (Schroeder et al., 2010)
- Daily
- 25km resolution

Saturation = soil completely full of water
A_{sat} = saturated extent
= A_inund + exposed but saturated wetlands

- CH4 emissions from exposed but saturated wetlands can be as high as those from inundated wetlands
- A_{sat} can be >> A_{inund}
- A_{sat} is not as well observed as A_{inund}
- Here, we use classifications of saturated soil derived from PALSAR images on select dates (courtesy E. Podest and N. Pinto, JPL/NASA)
- VIC's A_{sat} exhibits much scatter about observations
- Assumed CDF of A_{sat}:

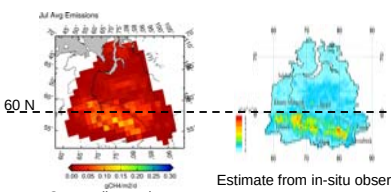
Percentile	*Value*
1st	A_{inund}
50th	1.06 * VIC A_{sat}
99th	Total wetland area



5. Wetland Methane Emissions over West Siberia

Bayesian calibration of wetland methane emissions model vs. extensive in situ observations of Glagolev et al. (2011) yields:

Percentile	*Formula*	*Saturated Area (km²)*	*Total Annual Emissions*
1st	1^{st} pctl A_{sat} * 1^{st} pctl $CH4_{sat}$ + ($A_{wetland}$-A_{sat}) * 1^{st} pctl $CH4_{unsat}$	0.13x10⁸	3.24 Tg CH4/year
50th	50^{th} pctl A_{sat} * 50^{th} pctl $CH4_{sat}$ + ($A_{wetland}$-A_{sat}) * 50^{th} pctl $CH4_{unsat}$	0.55x10⁸	4.17 Tg CH4/year
99th	99^{th} pctl A_{sat} * 99^{th} pctl $CH4_{sat}$ + ($A_{wetland}$-A_{sat}) * 99^{th} pctl $CH4_{unsat}$	1.07x10⁸	6.92 Tg CH4/year



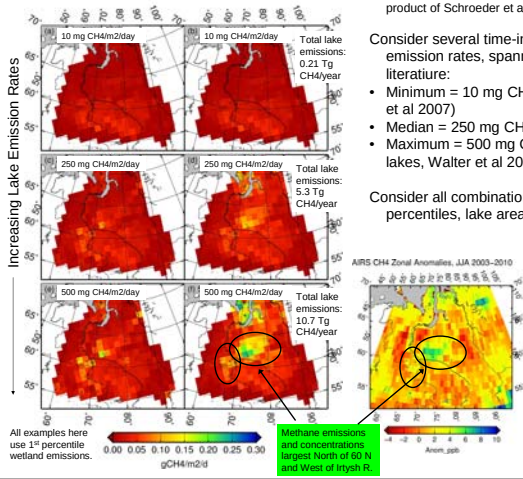
Our median estimate: 4.17 TgCH4/year

Estimate from in-situ observations: 3.96 +/- 1.4 TgCH4/year (Glagolev et al., 2011)

Our simulated wetland emissions have similar geographic pattern to those estimated from observations by Glagolev et al. (2011)

Wetland emissions are largest *south* of 60 N

6. Lake Areas and Emission Rates



Consider 2 estimates of lake areas:
1. Take directly from GLWD (Lehner and Döll, 2004)
2. Take minimum seasonal value of A_{inund} given by AMSR product of Schroeder et al (2010)

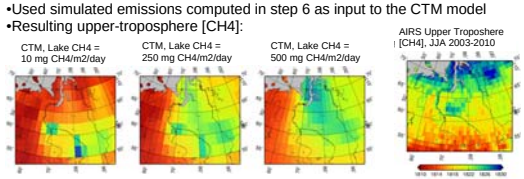
Consider several time-invariant values of lake emission rates, spanning ranges reported in literature:
- Minimum = 10 mg CH4/m2/day (bog pools, Repo et al 2007)
- Median = 250 mg CH4/m2/day
- Maximum = 500 mg CH4/m2/day (thermokarst lakes, Walter et al 2007)

Consider all combinations of wetland emissions percentiles, lake areas, and lake emissions rates

We can only match the AIRS observed spatial pattern of [CH4] by using AMSR lake areas and high lake emissions rates (250-500 mg CH4/m2/day)

7. Simulated Atmospheric Concentrations

- Used simulated emissions computed in step 6 as input to the CTM model
- Resulting upper-troposphere [CH4]:



- Unfortunately, AIRS is primarily sensitive to upper-troposphere [CH4]
- It is difficult for us to reproduce the AIRS spatial pattern in upper troposphere with the CTM simulations
- We are now using SCIAMACHY data

8. Conclusions

- Our median estimate of total emissions in W. Siberia is similar to that of an inverse study by J. Winderlich (Thesis, 2012) of 11.2 +/- 1.4 Tg CH4/yr

Total emissions from lakes and wetlands in W. Siberia:

Pctl	*Wetlands*		*Lakes (using AMSR area)*		*Total (Tg CH4/year)*
	Saturated Area (km²)	Total CH4 (Tg CH4/year)	CH4 per unit area (mg CH4/m²/day)	Total CH4 (Tg CH4/yr)	
1st	0.13x10⁸	3.4	250	5.3	8.7
50th	0.55x10⁸	4.2	375	8.0	12.2
99th	1.07x10⁸	6.9	500	10.7	17.6

- The largest sources of uncertainty here are:
  1. Lake CH4 emissions per unit area (likely values span a factor of 2)
  2. Extent of saturated wetlands (spans 1 order of magnitude, effect on totals is less)
  3. Lake areas (somewhere between GLWD and AMSR, up to factor of 2)
- More observations from ***active*** microwave sensors would help constrain saturated area
- Boreal and Arctic lake areas are likely underestimated by GLWD
- Lakes in West Siberia may be emitting CH4 at rates of 250-500 mgCH4/m2/day, similar to thermokarst lakes

Portions of this work were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract to the National Aeronautics and Space Administration.