Observational constraints on the distribution, seasonality, and environmental predictors of North American boreal methane emissions

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Objectives:

- This study uses atmospheric methane observations and geostatistical inverse modeling to understand North American boreal methane fluxes and associated biogeochemical models.
- To achieve those goals, the authors combine *in situ* methane measurements across Canada and the United States from 2007-2008, a regional atmospheric transport model, and a geostatistical inverse modeling framework to estimate North American boreal methane fluxes and understand their spatial and seasonal distribution.
- The *in situ* measurements included hourly measurements from four Canadian observation towers and daily flask measurements from one U.S. tall tower: Chibougamau, Quebec; Fraserdale, Ontario; Park Falls, Wisconsin, East Trout Lake, Saskatchewan; and Candle Lake, Saskatchewan.
- The regional atmospheric model used to simulate *in situ* methane ratios was the Stochastic, Time-Inverted Lagrangian Transport model, in combination with an empirical boundary curtain.
- The existing flux models used in this study were the Kaplan Model, described in Kaplan (2002), and the Dynamic Land Ecosystem Model (DLEM).
- The flux estimate has two components: a deterministic model which utilizes environmental predictors (e.g. soil moisture and temperature) and is analogous to a weighted multivariate regression, and a stochastic component which measures spatial and/or temporal flux patterns lacking in the predictors.
- The geostatistical inverse model produces a final best estimate, termed the posterior fluxes, which is the sum of the deterministic and stochastic components.
- A number of auxiliary data sets were considered in the geostatistical model, including meteorological data from Weather Research and Forecasting (WRF) model, and North American Regional Reanalysis (NARR); solid carbon estimates from the Lund-Pottsdam-Jena(LPJ) model, and the Northern Circumpolar Soil Carbon Database (NCSCD); model outputs from LPJ and surface water data from the Global Inundation Extent from Multi-Satellites (GEIMS) database; and the EDGAR v4.2 for anthropogenic emissions estimates.
- To choose from the auxiliary data sets the Bayesian information criterion (BIC) was implemented.

New Science:

- A simple wetland flux model, when combined with WRF-STILT, provides as good agreement with atmospheric methane observations as a more complex flux process model.
- Reasons why more complex models are not always better than simpler models may be 1) simple models may adequately parameterize regional-scale flux patterns or 2) the spatiotemporal distribution of important but complex flux processes is difficult to accurately model with available data at this scale.
- Wetland methane fluxes have a broader spatial distribution across western Canada and into the northern U.S. than represented in existing flux models.
- Total methane budget for the Hudson Bay Lowlands (50-60 ^{o}N, 75-96°W) was found to be 1.8 $\pm$ 0.24 $TgCyr^{-1}$, a number which is midrange of previous estimates.

- The total Canadian methane budget was found to be 16.0 $\pm$ 1.2 Tg Cyr^{-1}, which is larger than existing inventories.
- The larger number for total Canadian methane budget was attributed to high anthropogenic emissions in Alberta.
- Methane observations were found to be sparse in western Canada.
- Model-data comparison implies that existing inventories underestimate both wetland and anthropogenic fluxes in western Canada.
- Model-data comparison also revealed that the estimation of wetland fluxes hinges on a reliable atmospheric emissions estimate.
- The deterministic model fits the atmospheric methane observations better than the model set up with Kaplan or DLEM.
- The deterministic model has two notable shortfalls: does not reproduce the summer maxima observed at western sites and it under estimates the summer maxima at two sites.
- The posterior flux estimate identified two major source regions in Canada: over Alberta and over the Hudson Bay Lowlands.

Significance:

- Atmospheric methane (CH_4) is the second most important long-lived greenhouse gas.
- Since the preindustrial era, its radiative forcing has increased to 0.5007W m^{-2}, approximately one-third that of CO_2.
- Wetlands comprise the single largest global source of atmospheric methane but current flux estimates disagree in both magnitude and distribution at the continental scale.
- Boreal and arctic regions are of particular concern because of their large carbon soil stocks; they may contain half of all wetlands and soil carbon in the world (~1700 PgC), which is twice the amount of carbon currently held within the atmosphere.
- Greenhouse gas reduction strategies and future climate predictions will require accurate estimates of methane emissions.
- The results of this study bridge an existing gap between traditional top-down inversion studies (typically emphasizing total emission budgets) and biogeochemical models, which usually emphasize environmental processes.
- The results raise the question of why a simple flux model fits the atmospheric methane data as well as sophisticated process models, and also suggests that models with many processes and parameters could run the risk of over-fitting limited available data.
- Because the fluxes are found to be more broadly distributed than in existing inventories, the study results imply that existing maps may under-represent the extent of soil moisture and/or distribution of wetlands.
- Because available atmospheric data are limited near Alberta, this work highlights a need for more intensive methane measurements over that region.

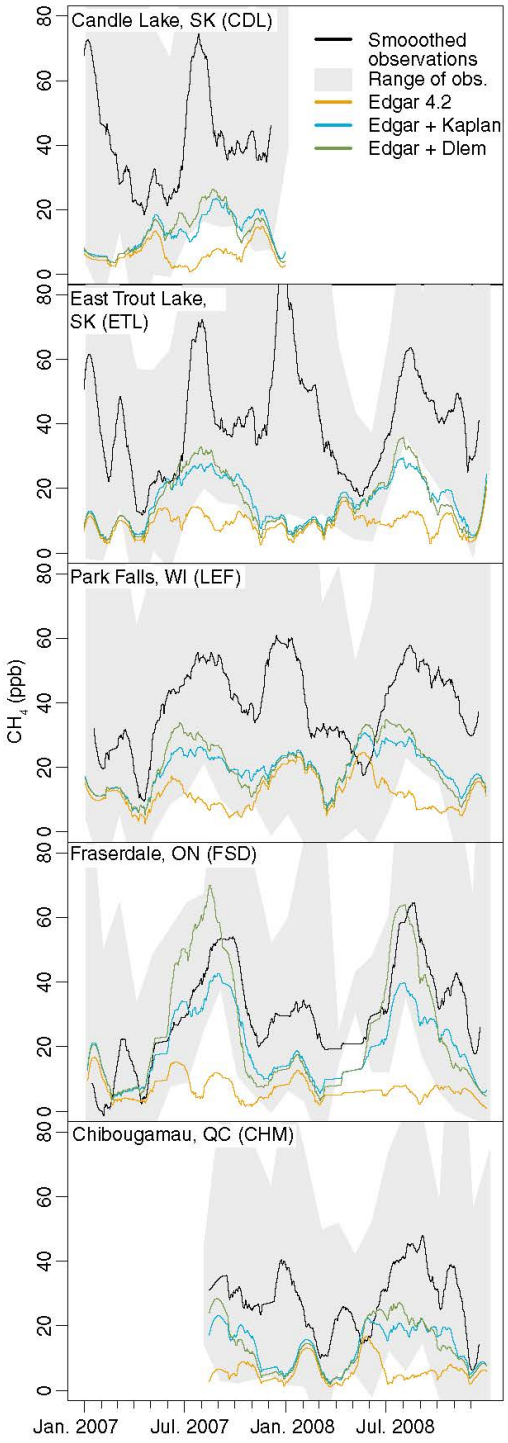

Figure 2 - A comparison of modeled mixing ratios against measurements at the observation sites. The estimated boundary condition values have been subtracted from the observations; the difference indicates the effect of North American methane sources on the measurements sites. EDGAR v4.2 is an anthropogenic emissions inventory, while Kaplan and DLEM model wetlands. The model and observations are smoothed using a third-order Savitzy-Golay filter with a 61-point window.

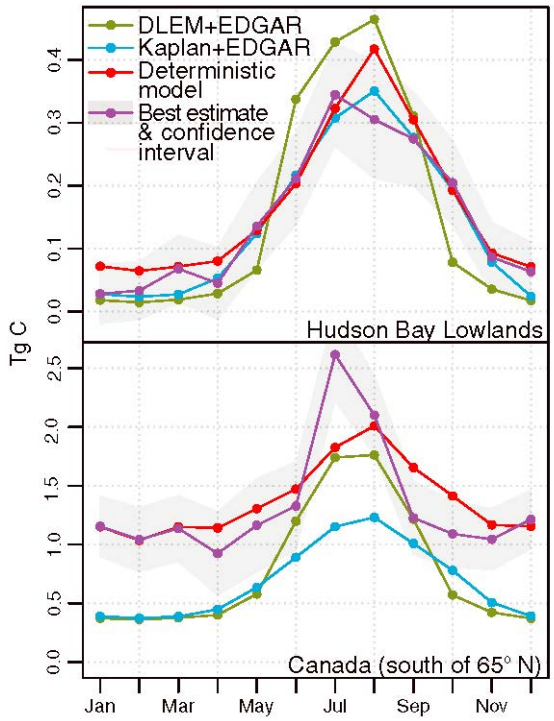

Figure 5 - The monthly average methane budget estimated for the HBL and Canada in 2007-2008. Existing models under-estimate wetland fluxes in western Canada. This regional shortfall explains much of the summertime discrepancy between the flux models and the posterior estimate in the lower panel.