Constraints on Canadian Methane Emissions Using the ECCC Surface Observation Network

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INTRODUCTION

Anthropogenic emissions of methane (CH_4) in Canada are estimated to be 4.3 Tg a^{-1} (Environment and Climate Change Canada, 2016), with sector contributions of 49% from energy, 28% agriculture and 23% waste (Fig 1). Top-down aircraft studies in the province of Alberta showed CH_4 emissions to be 48% higher in the Athabasca Oil Sands (Baray et al., 2018) and 25-50% higher from oil and gas activities in the rest of the province (Johnson et al., 2017). GOSAT satellite observations are relatively sparse over Canada, however inversions continue to show under-estimated emissions in western Canada and over-estimated emissions from Canadian wetlands (Maasakkers et al., 2019)

Canadian surface observations have moderate spatial coverage and the advantages of being high-precision measurements continuous in time. This study assimilates 2013-2015 measurements from the Environment and Climate Change Canada (ECCC) GHG monitoring network into the GEOS-Chem CH_4 simulation under a variety of model configurations to simultaneously constrain anthropogenic and biogenic fluxes within Canada.

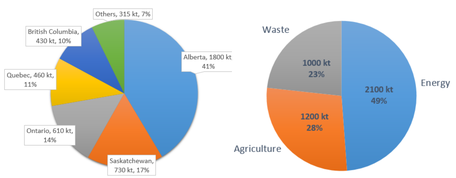

Figure 1: Total CH_4 emissions in Canada (4.3 Tg a^{-1} in 2013) from the National Inventory Report (Environment and Climate Change Canada, 2016)

METHODOLOGY

Observations: Surface measurements are from the Environment and Climate Change Canada GHG Monitoring Network which uses Picarro cavity ring-down spectrometers. Instrument precision for 0.2 Hz measurements is <0.6 ppb. Data is publicly available through the World Data Centre for Greenhouse Gases (gaw.kishou.go.jp).

Figure 2: Sites used in this study from the ECCC surface station network

Forward Model: The GEOS-Chem CTM (www.geos-chem.org) is used to simulate global atmospheric CH_4 at 4°x5° resolution using MERRA2 meteorology, with dynamic boundary conditions saved for a higher-resolution (0.5°x0.625°) nested North American simulation. Prior anthropogenic emissions use the EPA inventory for the United States (Maasakkers et al., 2016), the ICF inventory for Canadian oil/gas (Sheng et al., 2017) and EDGAR v4.3.2 for remaining non-wetlands emissions. Monthly wetlands emissions are from the extended ensemble of WetCHARTS v1.0 (Bloom et al., 2017).

Inversion: A custom tagged-CH_4 simulation is developed that defines species according to 15 source types separated by origins from Canada, the contiguous United States and Mexico (Table 2). Elements of the state vector, **x**, are a reduced set of 11 emissions categories within Canada and the Jacobian **K** is constructed from the tagged output (Heald et al., 2004). The inversion minimizes the Bayesian cost function $J(\mathbf{x})$ (Rogers, 2000):

$$J(\mathbf{x}) = (\mathbf{y} - \mathbf{K}\mathbf{x})^T \mathbf{S}_o^{-1} (\mathbf{y} - \mathbf{K}\mathbf{x}) + (\mathbf{x} - \mathbf{x}_a)^T \mathbf{S}_a^{-1} (\mathbf{x} - \mathbf{x}_a) \qquad (1)$$

RESULTS

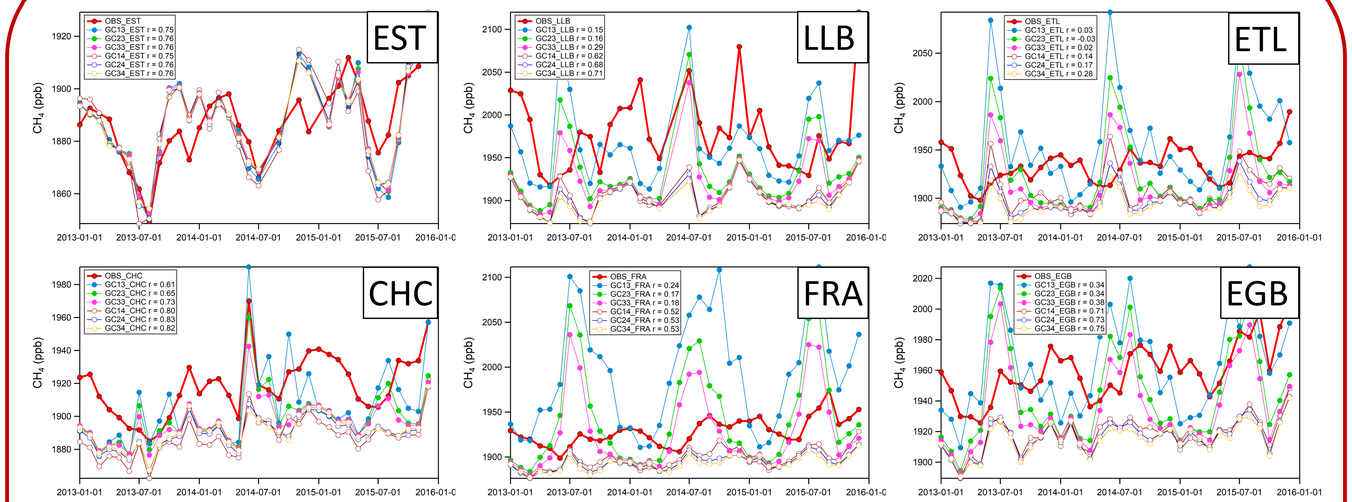

Figure 3: Comparison of GEOS-Chem forward modelling results from six WetCHARTS configurations to 2013-2015 observations from six select stations in Canada. Shown sites (top-left to bottom-right) are Estevans Point, British Columbia (EST), Lac La Biche, Alberta (LLB), East Trout Lake, Saskatchewan (ETL), Churchill, Manitoba (CHC), Fraserdale (FRA) and Egbert (EGB), both Ontario. Monthly-mean surface observations are shown in red and GEOS-Chem output from WetCHARTS configurations are colored and numbered.

Station Location

Model Configuration (Lower Emissions ↓)	EST	LLB	FMK	FMM	ANZ	ETL	CHC	FRA	EGB	SBL	MEAN
GC13	0.75	0.15	-0.14	0.16	-0.02	0.03	0.61	0.24	0.34	-0.19	0.19
GC23	0.76	0.16	-0.31	0.02	0.02	-0.03	0.65	0.17	0.34	-0.25	0.15
GC33	0.76	0.29	-0.21	0.09	0.08	0.02	0.73	0.18	0.38	-0.20	0.21
GC14	0.75	0.62	0.27	0.28	0.00	0.14	0.80	0.52	0.71	0.41	0.45
GC24	0.76	0.68	0.35	0.31	0.12	0.17	0.83	0.53	0.73	0.50	0.50
GC34	0.76	0.75	0.46	0.38	0.20	0.28	0.82	0.53	0.75	0.57	0.55

Table 1: Summary of correlation coefficients from the ensemble of forward model analyses against ECCC and WBEA ground stations in Canada. Lower rows correspond to decreasing wetlands emissions

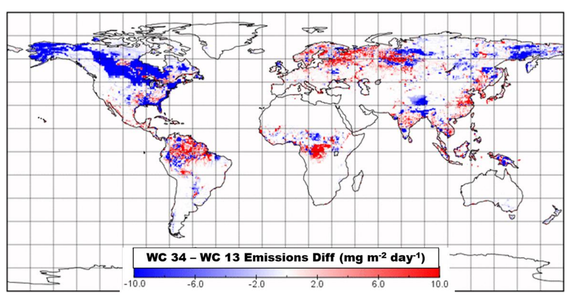

Figure 4: Differences in fluxes (mg m^{-2} day^{-1}) between the lowest (GC34) and highest (GC13) WetCHARTS configurations

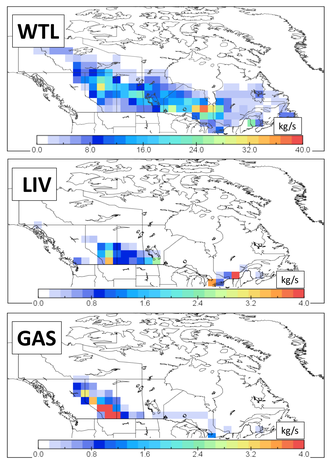

Figure 5: July 2013 HEMCO emissions (kg/s) for the customized CH_4 simulation tagging sources originating in Canada. Emissions shown are from the WetCHARTS ensemble mean (top), livestock (middle) and gas (bottom)

Source Type	Canada	CONUS	Mexico
Oil	0.5	2.2	0.9
Gas	1.8	6.8	0.3
Coal	0.1	2.9	0.0
Livestock	1.0	9.2	2.2
Landfills	0.7	5.5	0.3
Wastewater	0.2	0.6	0.6
Rice	0.0	0.5	0.0
Other Anthropogenic	0.1	0.4	0.2
Biomass Burning	0.3	0.3	0.3
Wetlands	14.6	13.7	0.8
Seeps	0.3	0.5	0.1
Termites	0.3	0.6	0.1
Soil Absorption	-2.0	-1.1	-0.1
Total Anthropogenic	4.3	28.1	4.4
Total Natural	13.4	14.0	1.2
Total	17.8	42.1	5.6

Table 2: Summary of North American prior emissions (in Tg a^{-1}) for the custom tagged-CH_4 simulation. Total anthropogenic is the sum of the first 8 categories, total natural is the sum of last 5

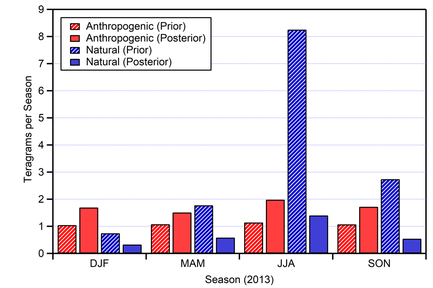

Figure 6: Initial results from an inversion assimilating 2013 ECCC surface observations organized by season. Anthropogenic emissions are shown in red-dash (prior) and red-fill (posterior), natural emissions are shown in blue

DISCUSSION

- Comparison of GEOS-Chem results to 2013-2015 ECCC surface observations using an ensemble of wetlands emissions inputs (Fig. 3) shows a high seasonal bias, peaking in July, at all locations spatially influenced by wetlands (Fig. 5). This summertime bias suggests over-estimated temperature dependencies in the model inputs.
- WetCHARTS configuration GC34, which has the lowest of 3 CH_4:C temperature dependencies and the lowest of 2 wetlands extent scenarios best reproduces surface observations (Table 1). This scenario lowers emissions across North America (Fig. 4), in particular Canada and the southeast United States.
- Usage of the lowest wetlands emissions does not correct a secondary, year-long low bias against surface observations (Fig. 3). This suggests the presence of under-estimated year-round emissions of another category.
- Development of a custom CH_4 simulation to tag Canadian emissions, which uses the ICF oil/gas inventory (Sheng et al., 2017) and EDGAR v4.3.2 for anthropogenic input, results in Canada-wide anthropogenic emissions of 4.3 Tg a^{-1} (Table 2) – consistent with the National Inventory (Fig. 1).
- Initial results from an inversion using 2013 ECCC surface observations (Fig. 6) show higher anthropogenic emissions (6.9 Tg a^{-1} posterior vs 4.3 Tg a^{-1} prior) offset by lower natural emissions (2.9 Tg a^{-1} posterior vs 13.5 Tg a^{-1} prior). Results are consistent with studies showing underestimated anthropogenic emissions in Alberta (Baray et al., 2018 and Johnson et al., 2017) and studies showing overestimated wetlands emissions in North America (Maasakkers et al., 2019; Miller et al., 2016; Sheng et al., 2018; Turner et al., 2015)

CONCLUSIONS

- Surface observations from the ECCC GHG Network are sufficiently sensitive to regional emissions to provide constraints on superimposed signals from anthropogenic and natural sources in Canada.
- Forward-model comparisons using GEOS-Chem and 6 members from the WetCHARTS extended ensemble show a minimum of bottom-up CH_4:C temperature dependencies and extent scenarios remove a high seasonal bias and best reproduce observations, however minimizing wetlands does not correct a secondary year-long low bias.
- Initial results from an inversion assimilating 2013 ECCC surface observations show anthropogenic emissions are 60% higher than the National Inventory which are offset by natural emissions that are 79% lower than the mean prior configuration.

ACKNOWLEDGEMENTS

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