A high-resolution ($0.1° \times 0.1°$) inventory of methane emissions from Canadian and Mexican oil and gas systems

Jian-Xiong Sheng[a,b,*], Daniel J. Jacob[a], Joannes D. Maasakkers[a], Melissa P. Sulprizio[a], Daniel Zavala-Araiza[b], Steven P. Hamburg[b]

[a]*School of Engineering and Applied Sciences, Harvard University, MA*
[b]*Environmental Defense Fund, Austin, TX*

Abstract

Canada and Mexico have large but uncertain methane emissions from the oil/gas industry. Inverse analyses of atmospheric methane observations can improve emission estimates but require accurate source patterns as prior information. In order to serve this need, we develop a $0.1° \times 0.1°$ gridded inventory of oil/gas emissions in Canada and Mexico by disaggregating national emission inventories using best available data for production, processing, transmission, and distribution. Results show large differences with the EDGAR v4.2 gridded global inventory used in past inverse analyses. Canadian emissions are concentrated in Alberta (gas production and processing) and Mexican emissions are concentrated along the east coast (oil production).

Keywords: methane, natural gas, oil, inverse modeling

*Corresponding author
Email address: jsheng@seas.harvarad.edu (Jian-Xiong Sheng)

1. Introduction

Methane is an important greenhouse gas (GHG). The oil and gas industry is a major global source but the related methane emissions are poorly quantified [1]. Inverse analyses of atmospheric methane observations can help to quantify methane emissions but require reliable gridded bottom-up inventories of source patterns to serve as prior knowledge [2]. National inventories reported to the United Nations Framework Convention on Climate Change (UNFCCC) often include detailed information on source sectors but no spatial information. Most inverse analyses have relied on the global Emission Database for Global Atmospheric Research (EDGAR) inventory with $0.1^\circ \times 0.1^\circ$ spatial resolution [3, 4], but this inventory has large errors in source patterns particularly for oil/gas sources [5]. More accurate spatial disaggregation of methane emissions starting from the national inventories has been done by Wang and Bentley [6] for Australia, Defra [7] for the United Kingdom, Hiller et al. [8] for Switzerland, and Maasakkers et al. [5] for the US. Here we present such a disaggregation for oil/gas emissions in Canada and Mexico, with the objective of enabling inverse analyses of atmospheric observations on the scale of North America and in particular from satellite.

Current national oil/gas emission inventories reported to the UNFCCC are 1.7 Tg a^{-1} for Canada [9], and 3.6 Tg a^{-1} for Mexico [10], as compared to 9.2 Tg a^{-1} for the US [11] and 67 Tg a^{-1} globally [12]. Canada and Mexico have joined the US in pledging to reduce methane emissions from the oil and gas sector by 40-45% by 2025 [13], but this requires better knowledge of the present-day baseline. Canadian oil/gas emissions estimated by ICF International [14] are 2.4 Tg a^{-1}, 30% higher than Environment Canada [9].

Mexican oil/gas emissions estimated by the Mexican Petroleum Institute[15] are 1.2 Tg a^{-1}, three times lower than Mexican Secretariat of Environment and Natural Resources (SEMARNAT)[10]. Inversions of atmospheric data may resolve this discrepancy between bottom-up inventories if accurate spatial patterns are available as prior information.

2. Methods and Data

2.1. National inventories

We start from national inventories of oil/gas emissions reported by ICF International (ICF) [14] for Canada in 2013 and the Mexican Petroleum Institute (IMP) [15] for Mexico in 2010. We chose these inventories because they include detailed sectoral breakdown of source contributions. Both use advanced IPCC (2006) Tier 2/3 methods, including country-specific emission factors. The IMP [15] inventory is incorporated in a broader Mexican national inventory of methane emissions by the National Institute of Ecology and Climate Change (INECC) [16].

Table 1 shows national emission totals by source category for natural gas (production, processing, transmission, distribution) and petroleum (i.e. oil). Other anthropogenic emissions in Canada and Mexico (taken from the EDGAR v4.2 inventory for 2008[17]) are included for comparison. US emissions are from the EPA inventory of US Greenhouse Gas Emissions and Sinks [11]. Oil/gas emissions from EDGAR v4.2 are 30% lower than ICF for Canada and 70% higher than IMP for Mexico. EDGAR uses cruder IPCC Tier 1 methods, and so does the older Mexican inventory from SEMARNAT [10].

Total emissions from non oil/gas anthropogenic sources in EDGAR are 3.2 Tg a^{-1} for Canada as compared to 2.8 Tg a^{-1} in Environment Canada [9], and 3.8 Tg a^{-1} for Mexico as compared to 3.4 Tg a^{-1} in INECC [16]. These differences are smaller than for oil/gas, and previous work by Maasakkers et al. [5] for the US also found smaller differences in source patterns for these non oil/gas sources. We see from Table 1 that oil/gas is the largest anthropogenic sources of methane in Canada (40% of total), while it is the second in Mexico (25% of total) after agriculture.

2.2. Spatial Disaggregation

We disaggregate the national oil/gas emissions given by ICF [14] for Canada and IMP [15] for Mexico by using an ensemble of activity databases for different source sectors including gas production, gas processing, gas transmission, gas distribution, and petroleum.

Gas production.. We use the Drillinginfo [18] well data to allocate Canadian and Mexican emissions from gas production, similar to the approach used by Maasakkers et al. [5] for US emissions. The Drillinginfo dataset covers all active oil and gas wells in North America including Canada (onshore only), the US, and Mexico. It provides historical information on well type, location, production, completion date, and drilling type, e.g., conventional or unconventional (hydraulic fracturing). Emissions from different production activities resolved by ICF and IMP are mapped according to the Drillinginfo well map. ICF reports offshore gas production emissions (0.4 Gg a^{-1}) in the Nova Scotia that are not covered by Drillinginfo, and for those we use the well map from the Canada-Nova Scotia Offshore Petroleum Board [19].

Gas processing.. Gas processing in Canada is exclusively done in Alberta, British Columbia and Saskatchewan. The largest gas processing plants report their emissions individually to the national greenhouse gas reporting program [20] and we take those at face value. They account for 15% of the ICF national total for gas processing. Locations and capacities of non-reporting gas processing plants are provided by the Alberta Energy Regulator [21], British Columbia Oil and Gas Commission [22], and Natural Resources Canada [23]. We use these data to allocate the remaining 85% on the basis of gas processing capacity. Locations and capacities of Mexican gas processing plants are from the Mexican Secretariat of Energy (SENER) [24], and the IMP total emissions are distributed by capacity.

Gas transmission.. The gas transmission sector includes separately resolved emissions in the ICF and IMP inventories from transmission pipelines, compressor stations, liquid natural gas (LNG) import terminals, and storage facilities (Canada ICF only). Pipeline emissions for Canada and Mexico are mapped to the database of North American natural gas pipelines from Platts [25]. National totals for compressor stations are allocated to each station based on their compressor horsepower. Canadian compressor station data (including locations and compressor horsepower) are obtained from the North American Energy Industrial Complex [26]. Mexican compressor station data are from SENER [24]. There was only one active LNG import terminal Canada in 2013 at St. John, New Brunswick [27]. There were two operating LNG import terminals in Mexico in 2010 at Altamira and Energia Costa Azul[28], and emissions are distributed to each terminal according to its regasification capacity. Emissions from gas storage in Canada are distributed across Alberta, British Columbia, Saskatchewan, and southwestern Ontario on the basis of storage capacities. Storage facility data (including locations and capacities) are obtained from Alberta Energy Regulator [21], British Columbia Oil and Gas Commission [22], TransGas [29] (for Saskatchewan), and Union Gas Limited [30] and Enbridge Gas [31] (for Ontario).

Gas distribution.. National emissions from gas distribution are first segregated by province in Canada and by state in Mexico using residential gas consumption data [32, 33] and then mapped to a $0.1^\circ \times 0.1^\circ$ grid using 2010 population data from the Socioeconomic Data and Applications Center [34].

Petroleum.. Emissions from different oil production activities in ICF and IMP are mapped using the Drillinginfo [18] data for onshore and offshore (Mexico only) oil wells. Additional offshore emissions in Canada (Newfoundland and Labrador) are allocated using the offshore well information map from the Department of Natural Resources Newfoundland and Labrador [35]. IMP includes emissions from venting, flared gas, refining, and transport. Venting emissions are allocated to oil production, while flaring emissions are distributed according to associated gas production as given by Drillinginfo [18]. Oil refining and transport are small sources. Emissions from oil refining are allocated to refineries based on crude distillation capacity as shown in Mexico's petroleum infrastructure map from EIA [36]. Emissions from transport are uniformly distributed along crude oil pipelines.

3. Results and Discussion

Figure 1 shows the $0.1° \times 0.1°$ gridded maps of Canadian oil/gas emissions. Emissions from gas production and processing are closely collocated and account for 61% of total oil/gas emissions, while oil production amounts to 22%. Alberta is the top emitter followed by British Columbia, Saskatchewan, and Manitoba. Emissions from gas transmission contribute 12% and are mainly in the west. Emissions in eastern Canada are very small and mostly from gas distribution (2% of total oil/gas source).

Figure 2 shows the $0.1° \times 0.1°$ gridded maps of Mexican oil/gas emissions. Mexico is mostly an oil-producing country. Emissions from onshore and offshore oil production account for 22% and 52%, respectively, of the national oil/gas total and are concentrated on the east coast (Tampico-Misantla and Southeastern basins, Bay of Campeche). Emissions from gas production/processing account for 18% of the national oil/gas total and are also located along the east coast. Emissions from gas transmission in Mexico are relatively small due to the small pipeline network. Emissions from gas distribution are also small. Despite relatively small total mileage, emissions from Mexican gas distribution are only 25% lower than Canada's, because of Mexican larger leak rates [15].

Figure 3 shows total gridded methane emissions from the oil/gas industry in North America, combining our data for Canada and Mexico with the gridded US EPA emissions from Maasakkers et al. [5]. Also shown is the EDGAR v4.2 inventory used in past inversions of atmospheric methane data to constrain emissions. There are large differences in spatial patterns between the two, as previously pointed out for the US by Maasakkers et al. [5]. EDGAR largely misses areas of production, and instead appears to allocates total oil/gas emissions mainly according to population. Use of EDGAR as prior inventory in inverse studies may thus incur large errors, both in optimizing emissions and in interpreting results.

Emissions in the US include a much larger contribution from gas transmission and distribution than either Canada or Mexico (Table 1) and are therefore more spread out across the country. The US has more extensive inter- and intra-state transmission pipelines with total length of nearly 500,000 km [37] that is five times Canada's [38] and 45 times Mexico's [15]. Longer transmission pipelines require more compressor stations. There are more than 1200 compressor stations in the US [39], compared to about 200 in Canada (North American Energy Industrial Complex, 2015) and 19 in Mexico [24]. The US also uses more natural gas, and has much larger distribution systems (about 2 million km) [40] than Canada's 450,000 km [38] and Mexico's 32,000 km [15]. Furthermore, the US distribution systems have much more high-emitting cast iron and bare steel pipes (9% of total distribution system) than Canada (0.2%) [40]. There is no such information on pipe materials in Mexico, but comparison of national emissions from gas distribution (Table 1) and lengths of distribution pipelines would imply a leak rate five times higher than the US.

ICF [14] does not provide error estimates on its oil/gas inventory, while IMP [15] provides national error estimates as given in Table 1. Errors are expected to be larger on the $0.1° \times 0.1°$ grid. Maasakkers et al. [5] derived scale-dependent error estimates for their gridded US inventory based on comparison with a detailed regional inventory for the Barnett Shale in Northeast

Texas [41, 42]. Error standard deviations for the gas sector increased from 24% on the national scale as given by EPA [11] to 52% on the $0.1° \times 0.1°$ grid, while error standard deviations for the oil sector were 86% at all scale. The same error estimates can be used for Canada since the emission inventories are constructed using similar methods and with datasets of comparable quality. The IMP Mexico inventory for Mexico reports high uncertainties on the national scale (+82%/-85% for the oil sector, and +136%/-80% for the gas sector); the results of Maasakkers et al. [5] suggest that such large errors may be applied to our grid-resolved inventory with no scale dependence.

In conclusion, we have disaggregated national inventories of methane emissions from the oil and gas sectors in Canada and Mexico to produce $0.1° \times 0.1°$ gridded estimates that can be used in inverse modeling of atmospheric methane observations. Our work corrects major spatial errors in the EDGAR v4.2 gridded inventory that would propagate to the inversion results and their interpretation. EDGAR error patterns for other anthropogenic sectors including livestock and waste are smaller [5]. An improved gridded anthropogenic emission inventory for North America including error estimates can thus be obtained by combining our inventory with (1) EDGAR emissions for other anthropogenic sectors in Canada and Mexico, (2) the disaggregated anthropogenic US EPA inventory from Maasakkers et al. [5]. In future work we will use this inventory for inversions of satellite observations over North America and for interpreting trends in the observations.

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Table 1: Anthropogenic methane emissions in North America (Gg a^{-1}) [a]

Source type	Canada	Mexico	the US
Natural Gas	1900	$330^{+136\%}_{-80\%}$	6900
Production	1200	140	4400
Processing	280	81	890
Transmission [b]	380	73	1100
Distribution	48	36	460
Petroleum [c]	520	$890^{+82\%}_{-65\%}$	2300
Agriculture	1400	2600	9400
Waste	1600	980	6200
Coal Mines	94	45	4100
Other [d]	100	150	570

[a] Natural gas and petroleum emissions are from ICF [14] for Canada in 2013 and IMP [15] for Mexico in 2010. 95% confidence intervals in Mexican emission estimates are from IMP [15]. Other anthropogenic emissions in Canada and Mexico are from EDGAR v4.2 inventory (2008). All US emissions are from the EPA inventory of US Greenhouse Gas Emissions and Sinks for 2012 [11].

[b] Including transmission pipelines and compressor stations (280 Gg a^{-1} for Canada, 71 Gg a^{-1} for Mexico), LNG import (8 Gg a^{-1} for Canada, 2 Gg a^{-1} for Mexico), and gas storage facilities (88 Gg a^{-1}, Canada only).

[c] The petroleum source for Canada includes only oil production, while that for Mexico includes small additional contributions from refineries (19 Gg a^{-1}) and transportation (3 Gg a^{-1}).

[d] Including combustion, petrochemical production, ferroalloy production, and biomass burning.

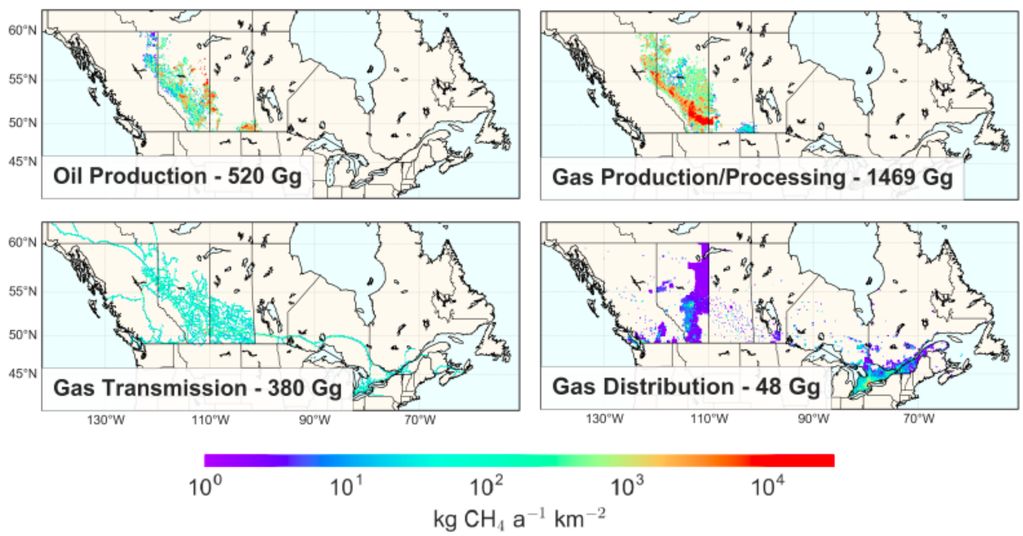

Figure 1: Spatial distribution of Canadian methane emissions from oil and gas activities in 2013. National totals are from ICF [14] and are disaggregated on a 0.1° × 0.1° grid. Emissions north of 60°N are negligible.

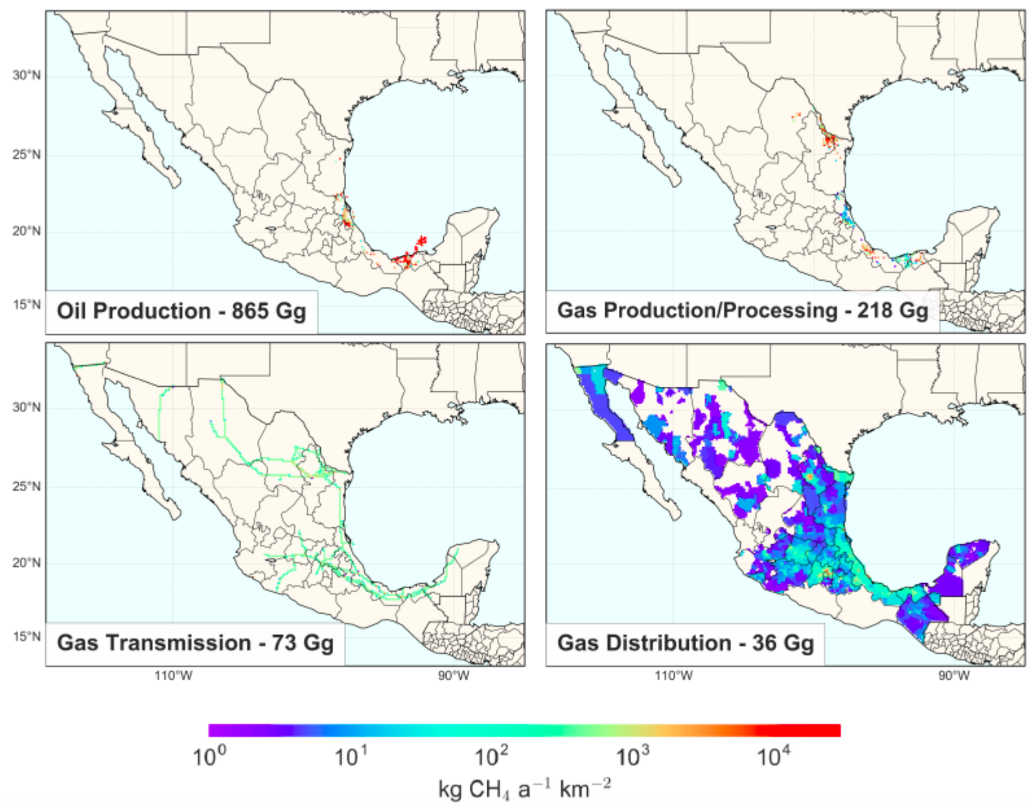

Figure 2: Spatial distribution of Mexican methane emissions from oil and gas activities in 2010. National totals are from IMP [15] and are disaggregated on a $0.1^\circ \times 0.1^\circ$ grid.

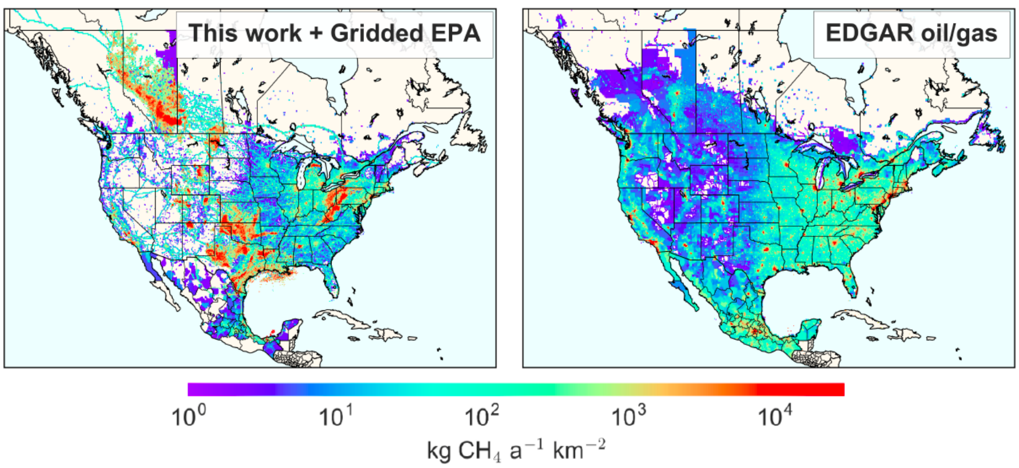

Figure 3: Total oil and gas methane emissions for North America including Canada, the US, and Mexico. Left panel: this work for Canada and Mexico combined with the gridded US EPA inventory (2012) described by Maasakkers et al. [5]. Right panel: EDGAR v4.2 inventory (2008). All inventories have $0.1° \times 0.1°$ spatial resolution.