Comparison of methane emissions estimated with a high-resolution inverse model using GOSAT and ground-based observations with national inventories.

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Background

We used the national reports on methane emission to the United Nations Framework Convention on Climate Change (UNFCCC) as the base information on fluxes in a high-resolution methane inverse model using GOSAT and surface observations of methane concentrations. We relate the observed concentrations to the spatio-temporal variabilities in the methane emissions using a transport model. Corrections to the input fluxes are made iteratively to bring the misfit between the observed concentrations and the simulated concentrations to minimum so that we get optimized flux. Thus, the use of UNFCCC-reported values as input to the inverse model gives the valuable opportunity for a national level comparison between the UNFCCC reported emissions and the model optimized fluxes. This poster is based on a paper by Janardanan et al., (2020).

Data

CH_4 concentration observations used

1. Greenhouse Gas Observing Satellite (GOSAT) Observations (NIES Level 2 product, v.02.72)
2. Surface, Aircraft, and Ship Observations from Global Carbon Project
3. Aircraft Observations over India for Validation

Input fluxes

1. Annual anthropogenic emission was from the Emissions Database for Global Atmospheric Research (EDGAR v4.3.2, Janssens-Maenhout et al, 2019) at a spatial resolution of 0.1°×0.1° scaled to UNFCCC reports (Wang et al, 2019).
2. Emission from wetland and soil sink were estimated by Vegetation Integrative Simulator of Trace gases (VISIT, Ito and Inatomi, 2012) terrestrial ecosystem model simulation at 0.5°, remapped to 0.1°.
3. Emission from biomass burning was taken from Copernicus Atmosphere Monitoring Service (CAMS) Global Fire Assimilation System (GFASv1.2, Kaiser et al, 2012) daily data at 0.1° resolution
4. Annual oceanic, geological, and termite emissions. The emission from termites was from Fung et al. (1991). The emissions due to oceanic exchange were distributed over the coastal region (Lambert and Schmidt, 1993), and mud volcano emissions were based upon Etiope and Milkov (2004)

Meteorological data

The meteorological data used for the transport model, were obtained from the Japanese Meteorological Agency (JMA) Climate Data Assimilation System (JCDAS, Onogi et al., 2007) at 1.25°×1.25° spatial resolution, 40 vertical hybrid sigma-pressure levels, and a temporal resolution of 6 h.

NTFVAR Inverse Modeling System

- Global Eulerian–Lagrangian coupled model NIES-TM-FLEXPART-VAR (NTFVAR)
- Consists of the National Institute for Environmental Studies (NIES) model as a Eulerian three-dimensional transport model, and FLEXPART (FLEXible PARTicle dispersion model) as the Lagrangian particle dispersion model (LPDM).
- The model development were reported Belikov et al. (2016) and Maksyutov et al. (2021).
- The forward model simulates the observed concentrations using the input (initial) fluxes. Depending on the difference between the observations and the simulations (misfit), the input flux is corrected iteratively until the misfit between the observations and the simulation using adjusted fluxes becomes minimum. This optimized flux (output of inverse model), constrained by available observations are estimated on biweekly time step.
- The model uncertainty is calculated as the standard deviation of estimated flux due to perturbations in the input flux and observed concentrations.

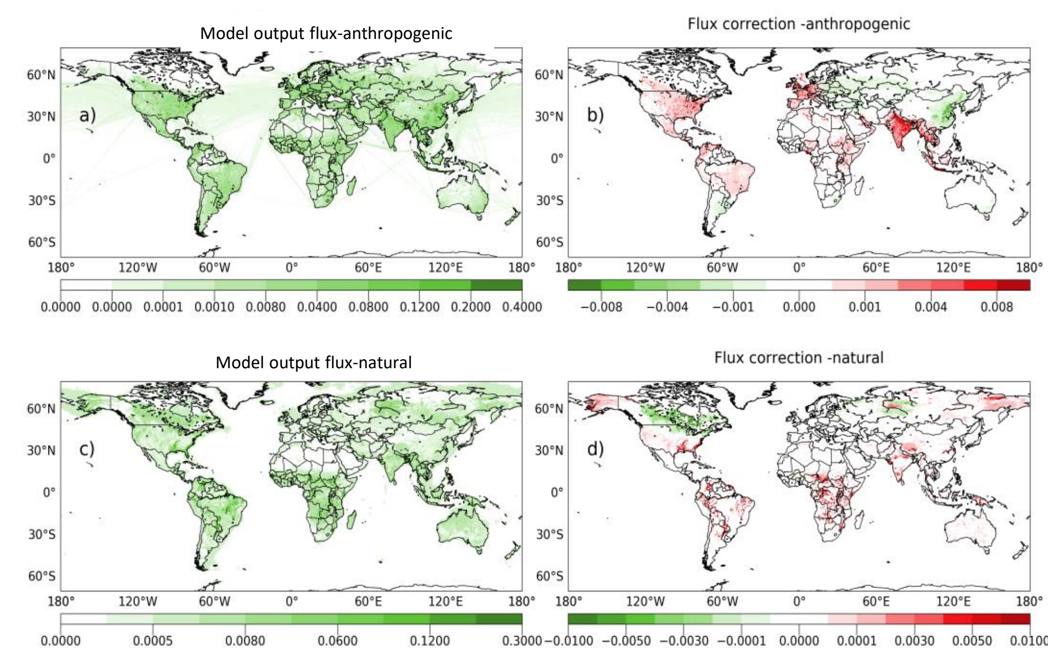

Figure 1. Estimated (posterior) fluxes (a and c) and the corresponding flux corrections (b and d) by inverse model, averaged for 2011–2017, for natural (bottom panel) and anthropogenic (upper panel) categories. The units are in g CH_4 m^{-2} d^{-1}.

Optimization of anthropogenic and natural emissions

- Our model makes flux adjustments for the natural (wetlands) and anthropogenic emissions (Fig.1)
- This allows for estimation of adjusted fluxes on country-scale and compare it with national reported emission inventories
- The model performance was evaluated using a direct comparison between the observations, model simulations with initial unadjusted fluxes and, model adjusted fluxes (Fig. 2) where Root Mean Squared Error (RMSE) was reduced for most of the stations.
- An independent check was carried out by aircraft observations over India as seen in Fig. 3. Model corrected fluxes gives better match with observations, especially in the well mixed boundary layer.

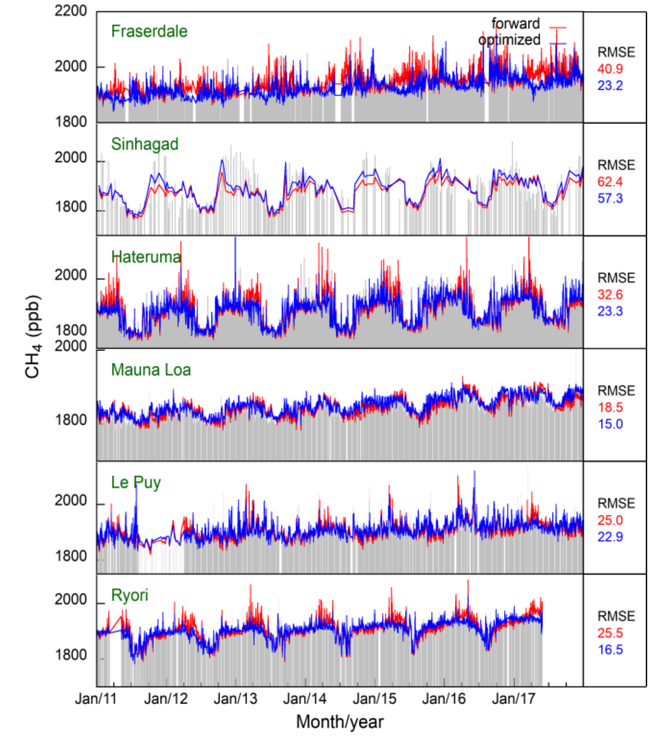

Figure 2. The observed CH_4 concentrations (grey impulses), forward simulation using initial fluxes(red), and forward simulation using model corrected fluxes (blue) at six sites, a) Fraserdale, b) Sinhagad, c) Hateruma, d) Maunaloa, e) Le Puy, and f) Ryori. The root mean squared error (RMSE, in ppb) for the prior and posterior are shown (red and blue, respectively).

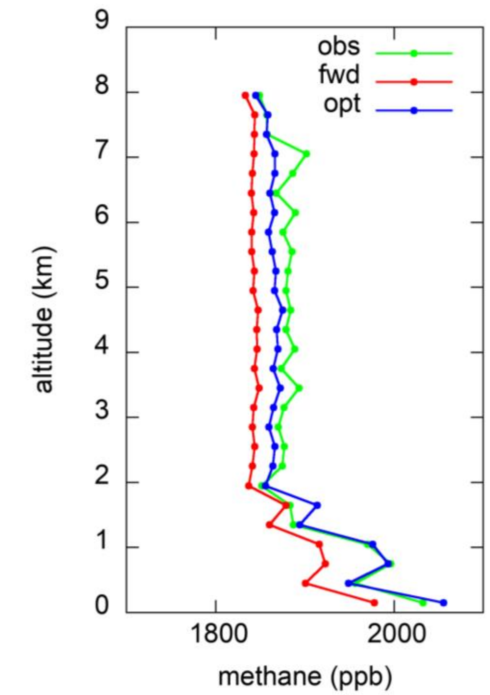

Figure 3. A comparison between averaged aircraft observations (green), model simulations using initial unadjusted fluxes (red) and with model adjusted fluxes (blue)

Country total anthropogenic emissions

- Anthropogenic emission totals calculated from EDGAR data were highest for China (54.3 Tg yr^{-1}), Russia (34.2 Tg yr^{-1}), United States (27.8 Tg yr^{-1}), India (20.1 Tg yr^{-1}), Brazil (16.4 Tg yr^{-1}) and Indonesia (11.2 Tg yr^{-1}) to list countries emitting more than 10 Tg yr^{-1}(Fig. 4, Table 1).
- The anthropogenic flux estimated by the inverse model were for China 45.7±8.6 Tg yr^{-1} (difference from inventory: 8.6 Tg; 15.8%), Russia 31.9±7.8 Tg yr^{-1} (2.25 Tg; 6.6%), United States 29.8±7.8 Tg yr^{-1} (2 Tg; 7.2%), India 24.2±5.3 Tg yr^{-1} (4.1 Tg; 20.4%) and Indonesia 11.8±2.5 Tg yr^{-1} (0.65 Tg; 5.8%).
- Among Asian countries emitting 2 Tg yr^{-1} or more besides listed above, Bangladesh and Myanmar showed largest upward revision by 13.7 and 10% respectively.
- Considering the posterior uncertainty for each country, most of the large emitting countries (greater than 2 Tg yr^{-1}) were found to have the inverse model corrections within the model uncertainty range (Table 1).

Table 1. List of countries with largest emissions and Asian countries (green cells) with anthropogenic annual emissions greater than 2 Tg.

Country	Total flux (input)	Total flux (output)	Difference (%)	Natural flux (input)	Natural flux (output)	Difference (%)	Anthropogenic flux (input)	Anthropogenic flux (output)	output-input (anthropogenic)	Difference (%)	Uncertainty (Tg)	Uncertainty (%)
China	60.1	52.0	-13.5	5.8	6.3	7.7	54.3	45.7	-8.6	-15.8	8.6	15.9
Russia	47.8	45.2	-5.5	13.6	13.2	-2.7	34.2	31.9	-2.3	-6.6	7.8	22.9
USA	51.6	55.7	7.9	23.8	25.9	8.8	27.8	29.8	2.0	7.2	7.8	28.1
India	29.9	36.5	21.9	9.9	12.3	25.2	20.1	24.2	4.1	20.4	5.3	26.5
Brazil	45.6	56.2	23.3	29.2	39.8	36.1	16.4	16.5	0.1	0.6	10.0	60.9
Indonesia	19.5	20.6	5.5	8.3	8.7	5.1	11.2	11.8	0.7	5.8	2.5	22.5
Pakistan	7.7	8.0	3.0	0.6	0.6	3.6	7.2	7.4	0.2	2.9	1.0	14.5
Iran	6.4	6.3	-1.6	0.8	0.8	0.0	5.6	5.5	-0.1	-1.8	0.8	15.0
Bangladesh	8.6	11.1	29.1	4.0	5.9	46.9	4.6	5.2	0.6	13.7	1.7	36.7
Thailand	5.8	6.4	10.0	1.2	1.4	17.1	4.6	5.0	0.4	8.1	1.0	21.8
Vietnam	6.2	6.7	8.2	2.1	2.4	14.0	4.1	4.3	0.2	5.2	1.1	26.5
Myanmar	5.4	6.1	13.3	2.0	2.3	19.5	3.4	3.8	0.3	10.0	0.8	24.6
Turkey	3.8	3.6	-4.8	0.1	0.1	0.0	3.6	3.4	-0.2	-5.0	0.5	14.4
Kazakhstan	3.8	3.6	-6.3	0.5	0.5	0.0	3.3	3.1	-0.2	-7.2	0.6	18.7
Saudi	2.8	2.9	1.8	0.0	0.0	0.0	2.8	2.8	0.1	1.8	0.4	14.7
Iraq	2.9	2.9	-1.4	0.1	0.1	0.0	2.9	2.8	0.0	-1.4	0.4	14.3
Uzbekistan	2.2	2.1	-3.7	0.0	0.0	0.0	2.1	2.0	-0.1	-3.3	0.3	14.2

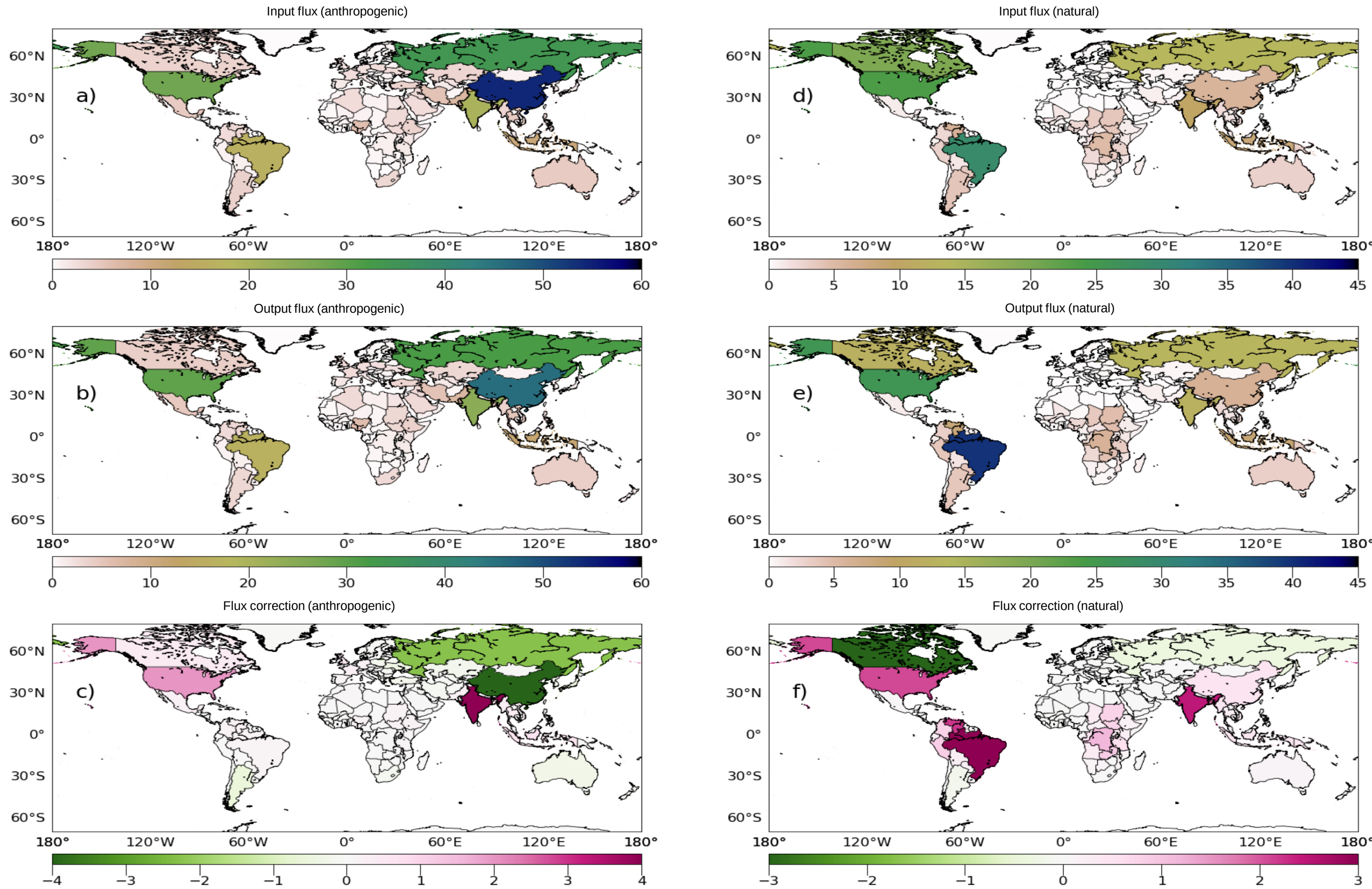

Figure 4. The mean annual total emissions averaged over 2011–2017 for each country for anthropogenic (left panels) and natural (right panels) categories. a) and d) (upper panel) input fluxes, b) and e) (middle panel) flux estimated by the model, and c) and f) (bottom panel) flux correction by the model in Tg yr^{-1}.

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Summary

- We carried out inverse estimation of methane fluxes for seven years using GOSAT satellite and surface observations using a high-resolution inverse model NIES-TM-FLEXPART-VAR (NTFVAR).
- Optimization was applied to natural (wetland only) and anthropogenic emissions on a bi-weekly time step, and the results were analyzed on a country scale globally.
- We used EDGAR anthropogenic methane emission inventory scaled to match the national emission reports to the UNFCCC as the initial approximation.
- Anthropogenic emission was found to differ from national reports for the United States by 2 Tg yr^{-1} (7.2%), China (8.6 Tg yr^{-1}; 15.8%), India (4.1 Tg yr^{-1}; 20.4%), Russia (2.3 Tg yr^{-1}; 6.6%), Bangladesh (0.6 Tg yr^{-1}; 13.7%), with all differences being within model uncertainty.
- Besides the world's major emitters, Asian countries ranged from Pakistan (7.4±1.0 Tg) to Uzbekistan (2.0±0.3 Tg).
- Bangladesh had the largest upward revision of 13.7% in anthropogenic emissions in the Asian countries.
- The inversion results for India were validated against aircraft data over two north Indian urban regions, and the posterior fit to the observations showed a clear improvement, especially in the boundary layer.