Comparison of inversions of global CH_4 emissions using TM5-MP/4DVAR with TROPOMI and in situ measurements

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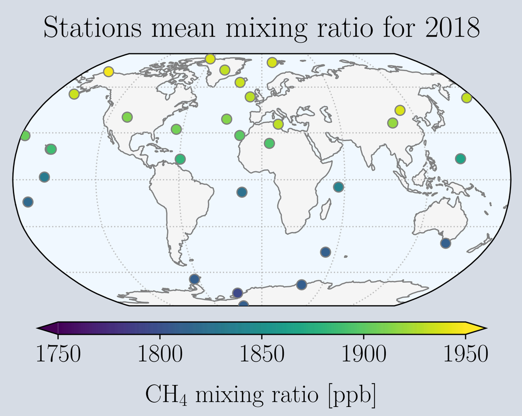
Motivation

Methane (CH_4) is a important greenhouse gas with an estimated global warming potential (GWP) of 32 over the 100-year horizon. Its concentration has increased more than 2.6 times since pre-industrial times [1], primarily due to anthropogenic activities, contributing significantly to global warming. Persistent uncertainties exist regarding CH_4 sources, leading to inconsistencies between top-down and bottom-up emission estimates. In this study, we undertake a comparative analysis of global inversions of methane emissions using TROPOMI satellite observations and data from NOAA surface stations.

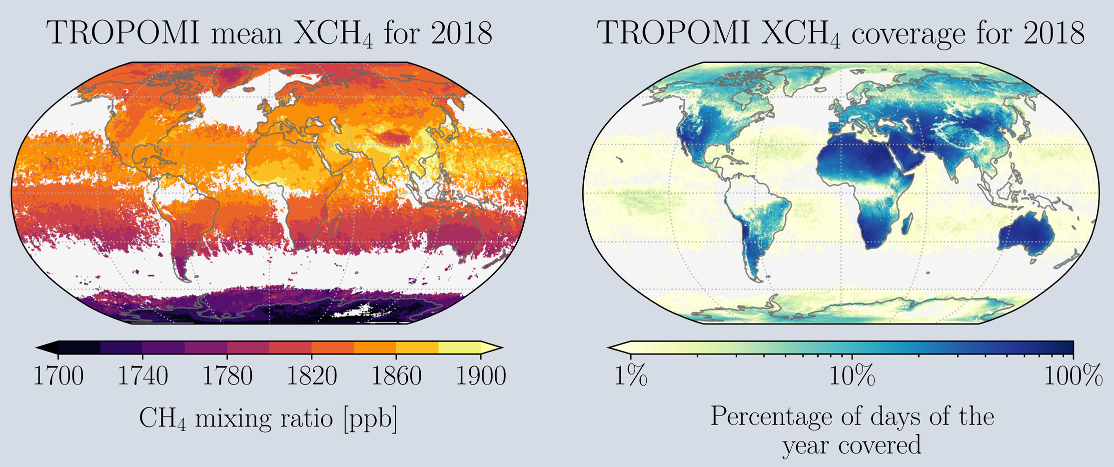
Measurements from NOAA stations

- In situ CH_4 surface concentrations (32 stations)
- Low spatial and temporal coverage, specially over land
- Low uncertainty at measurement point



Observations from TROPOMI instrument

- WFMD product v1.8 column-averaged mole fraction [2]
- High spatial resolution (7 km × 7 km at nadir) with global daily coverage (overpass around 13:30 local time) [3]
- Larger uncertainty over vertical distribution from single-value averaged column



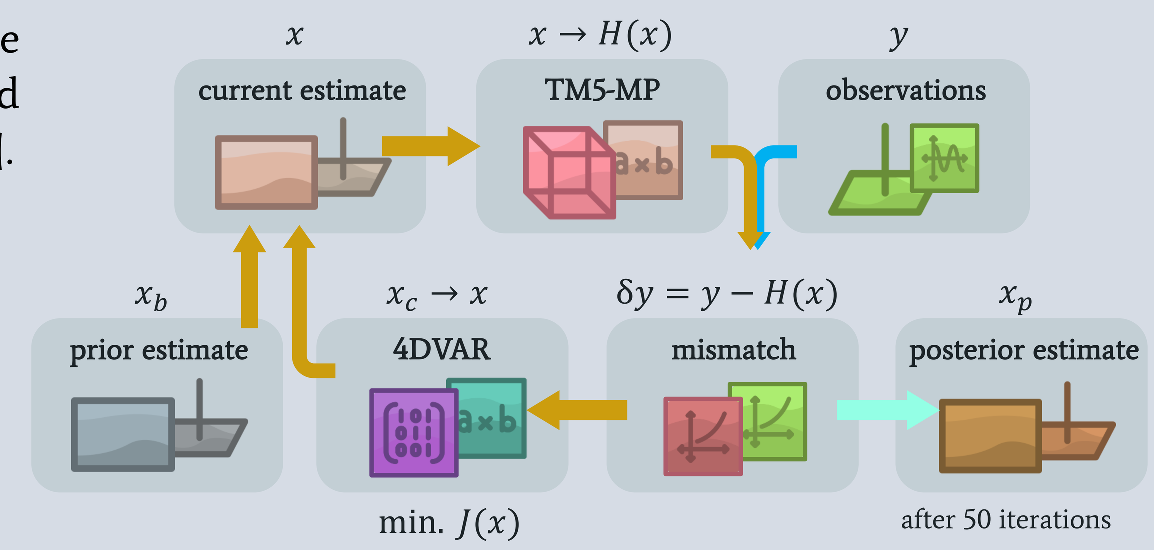
A priori emissions

- Anthropogenic: EDGAR v7.0 [4]
- Biomass burning: GFAS v1.2 [5]
- Wetlands: LPJ-wsl 2022 [6]
- Others (soil, wild animals, ocean, thermites): CAMS [7]

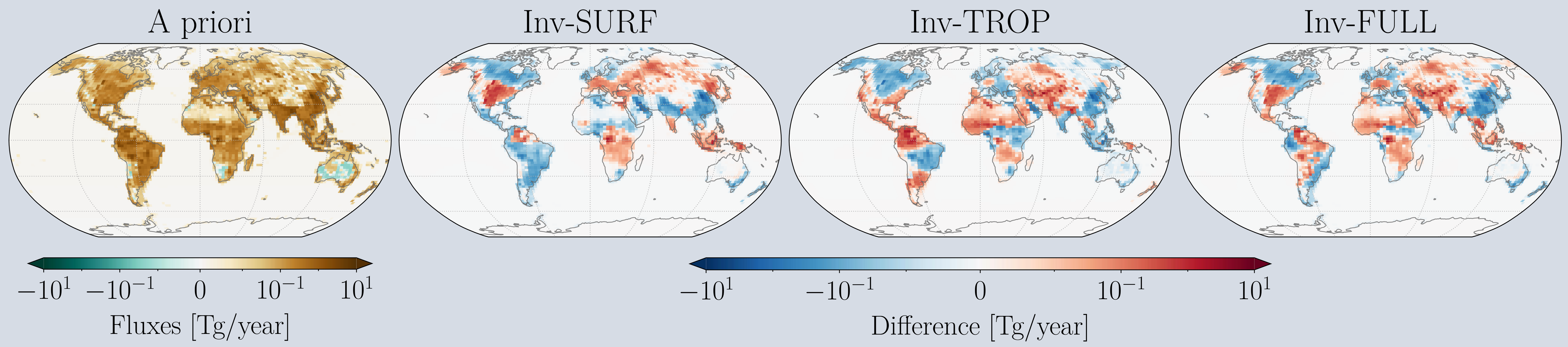
Model and experiment setup

We use the TM5-MP/4DVAR inversion system; which consists of the chemistry-transport model TM5, in its Massive Parallel version [8], and the data assimilation technique 4DVAR to optimize the emissions [9, 10].

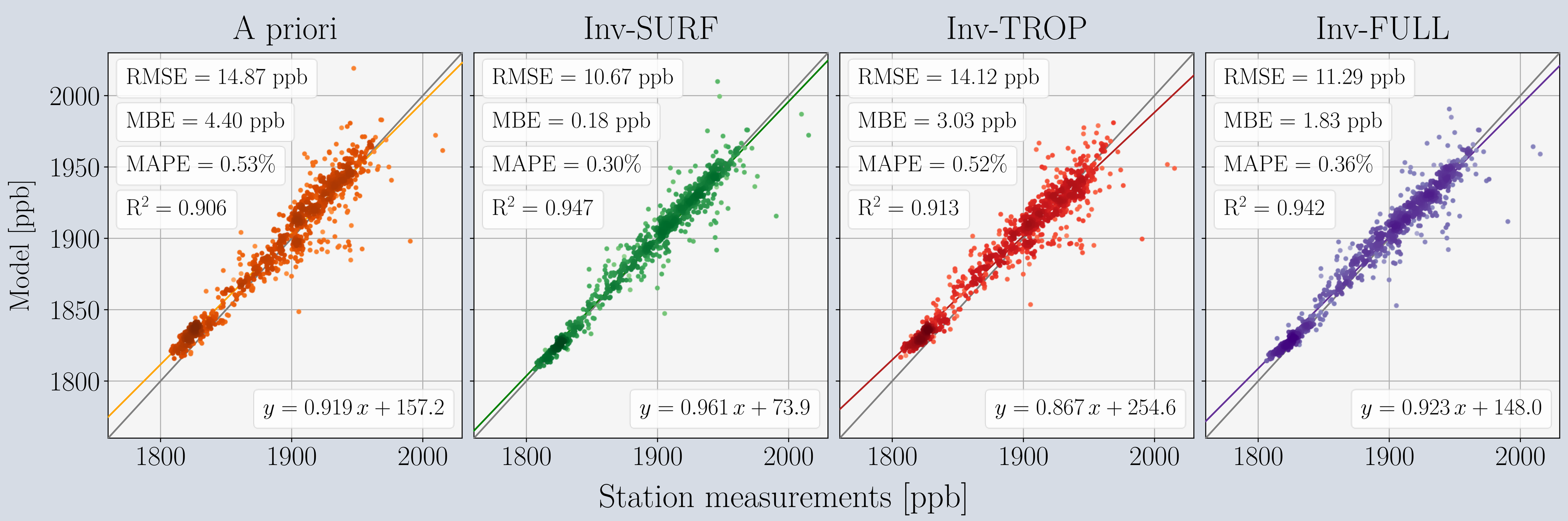
- Single year simulation for 2018 (6 months analysis)
- Global 3° × 2° (lon × lat) grid resolution
- ERA5 meteorology [11]
- Simplified chemistry based on CAMS OH climatology [7]
- Non-linear M1QN3 optimizer
- Three different inversions: only-stations, only-satellite, both



Results

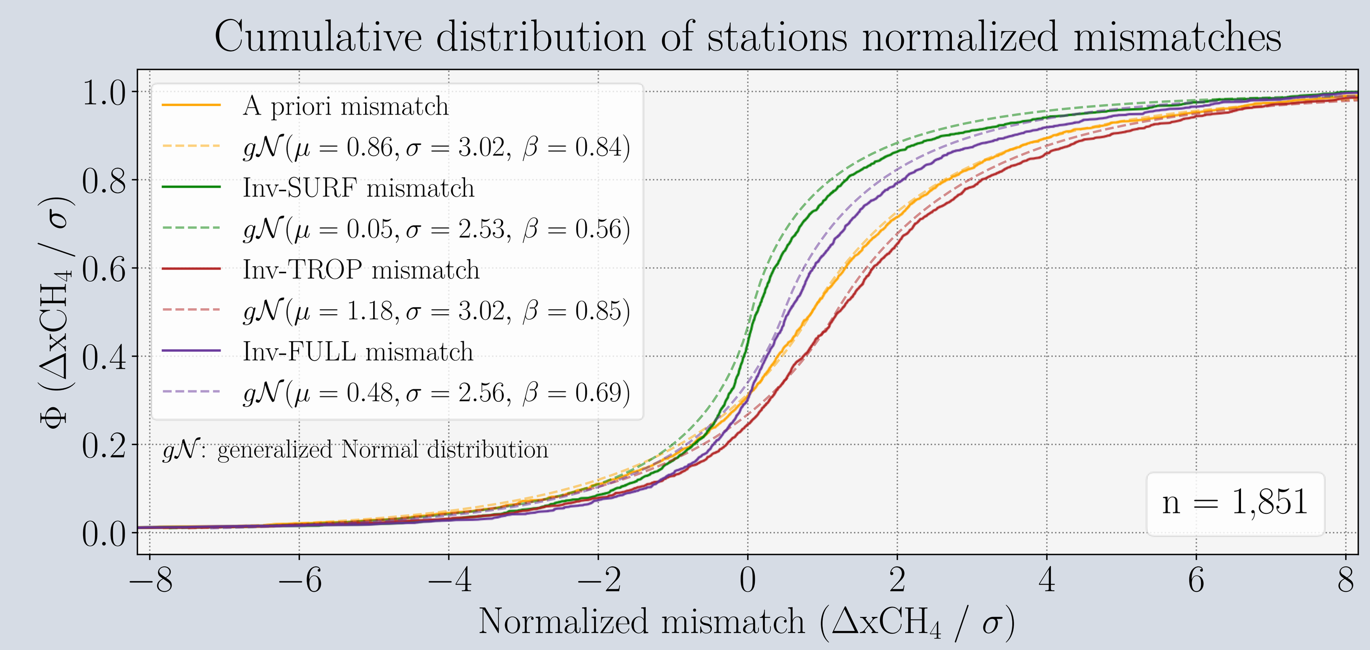


Simulation	Data assimilated
A priori	Non optimized
Inv-SURFace	Only stations
Inv-TROPOMI	Only satellite
Inv-FULL	Both stations and satellite



- All posterior modelled results successfully adjust to NOAA measurements, with the Inv-SURF run exhibiting the best fit, as expected. Inv-FULL run keeps adjustment, likely coming from the stations.
- All inversions result in a reduction in total yearly emissions, with the highest reduction observed in the Inv-SURF run. The lack of information in the upper troposphere and near big emission sources could explain this.

- Inv-SURF and Inv-TROP posterior fluxes have different spatial distributions, showing importance of different measurements.
- Inv-TROP increases normalized mismatches compared to a priori simulation, reducing confidence near stations.



Generalized normal distribution fits with mean μ, standard deviation σ and shape parameter β.

Total global emissions of CH_4	
	Emissions for 2018 [Tg/year]
A priori	585.61
Inv-SURFace	558.87
Inv-TROPOMI	584.55
Inv-FULL	576.37

Conclusions and outlook

- Optimized global methane emissions are within the range of reported values by Saunois *et al.* for period 2008-2017: 576 (550-594) Tg/year [1]
- Inversion Full corrects for differences near stations and adds information from satellite observations in a mayor scale.
- There is a considerable imbalance between the cost contributions of observations due to the large amount of data from TROPOMI, partially handled by inflation factors applied to satellite observations.
- Further trend analysis requires longer inversion periods

Acknowledgments

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References

[1] Saunois, M. *et al.* (2020). *Earth Syst. Sci. Data.* [doi]
[2] Schneising, O. *et al.* (2023). Atmospheric Measurement Techniques. [doi]
[3] Veefkind, J. P. *at al.* (2012). *Remote Sensing of Environment.* [doi]
[4] Crippa, M. *et al.* (2023). *Publications Office of the European Union.* [doi]
[5] Di Giuseppe, F. (2018). *Atmos. Chem. Phys.* [doi]
[6] Zhang, Z. *et al.* (2023). *Nat. Clim. Chang.* [doi]
[7] Inness, A. *et al.* (2019). Copernicus Atmosphere Monitoring Service (CAMS). [doi]
[8] Williams, J. E. *et al.* (2017). *Geosci. Model Dev.* [doi]
[9] Meirink, J. F. *et al.* (2008). *Atmos. Chem. Phys.* [doi]
[10] Bergamaschi, P. *et al.* (2013). *J. Geophys. Res. Atmos.* [doi]
[11] Hersbach, H. *et al.* (2020). *Quarterly Journal of the Royal Meteorological Society.* [doi]

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