

Inverse modelling of CH₄ emissions in permafrost regions

with

TM5-MP/4DVAR

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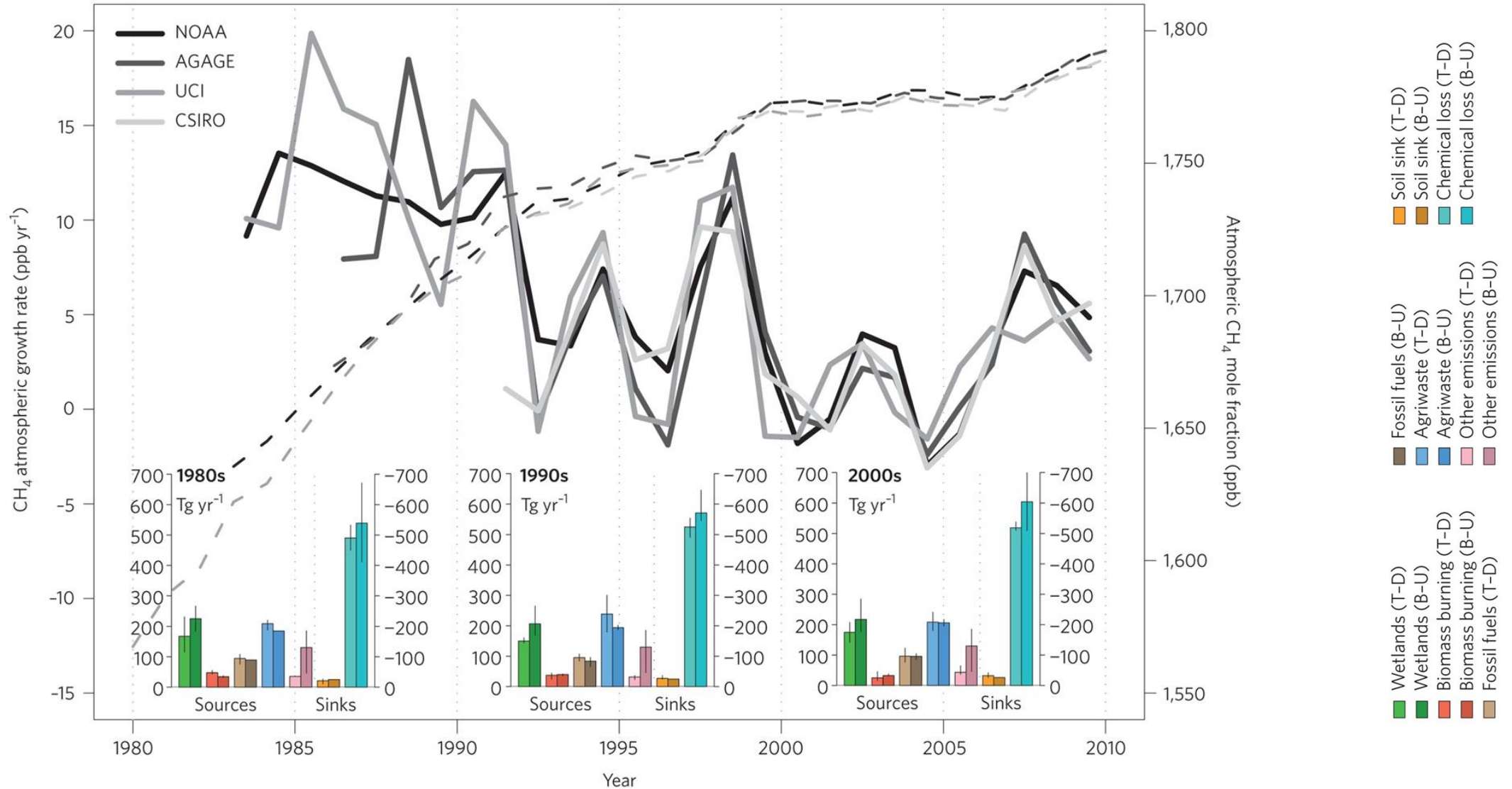
TM Meeting – 16 / 17 October 2023

Methane (CH₄)

Methane is a Greenhouse Gas (GHG) with a long lifetime (over a decade) and a Global Warming Potential (GWP) of 32 in the 100-year horizon ^[1]

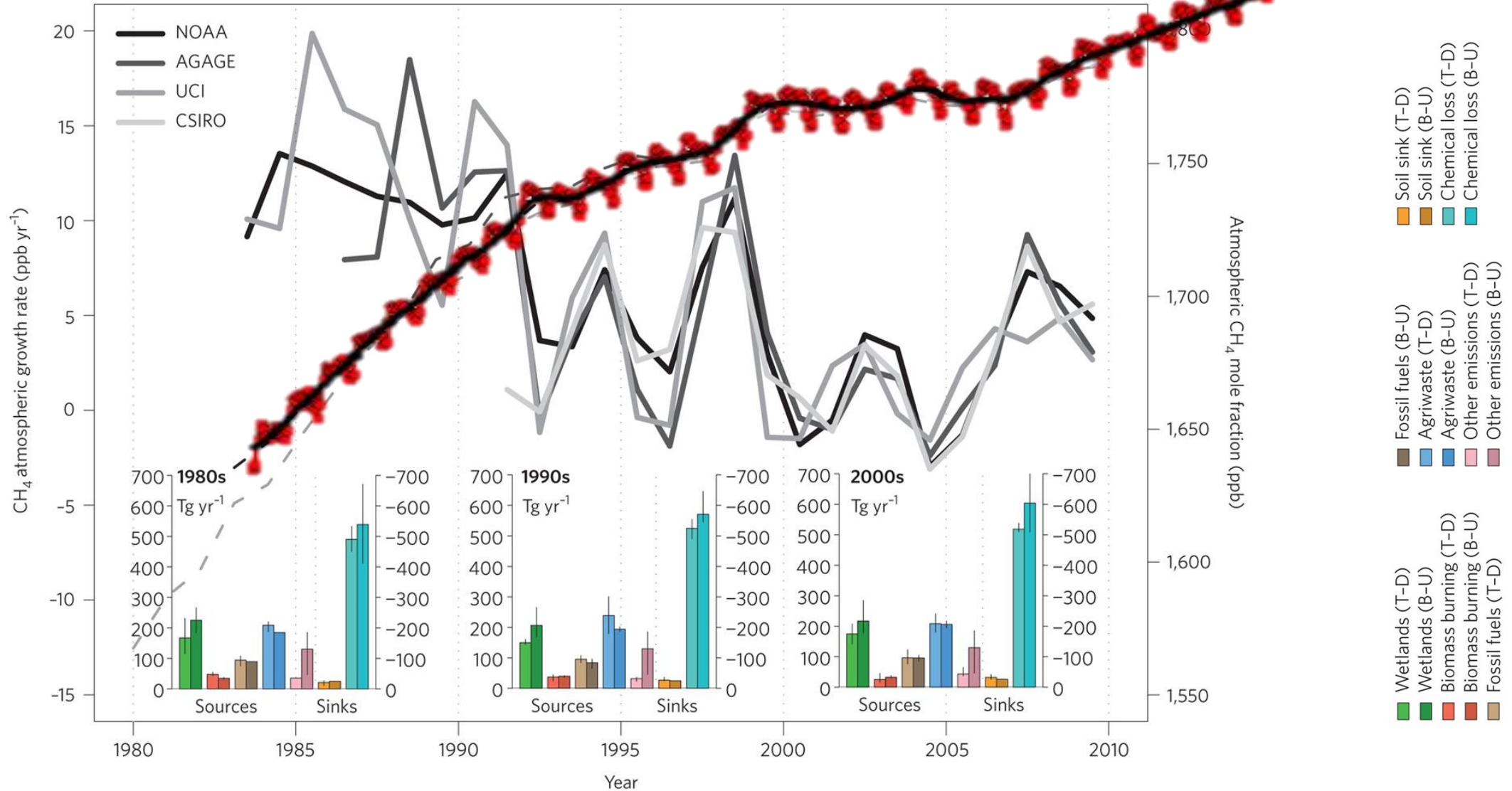
[1] Etminan et al. (2016). Radiative forcing of carbon dioxide, methane and nitrous oxide. In *Geophys. Res. Lett.*

Evolution of the atmosphere global mole fraction, growth rate and budget of methane for the past three decades



Source: Kirschke, S. et al. (2013) Three decades of global methane sources and sinks.

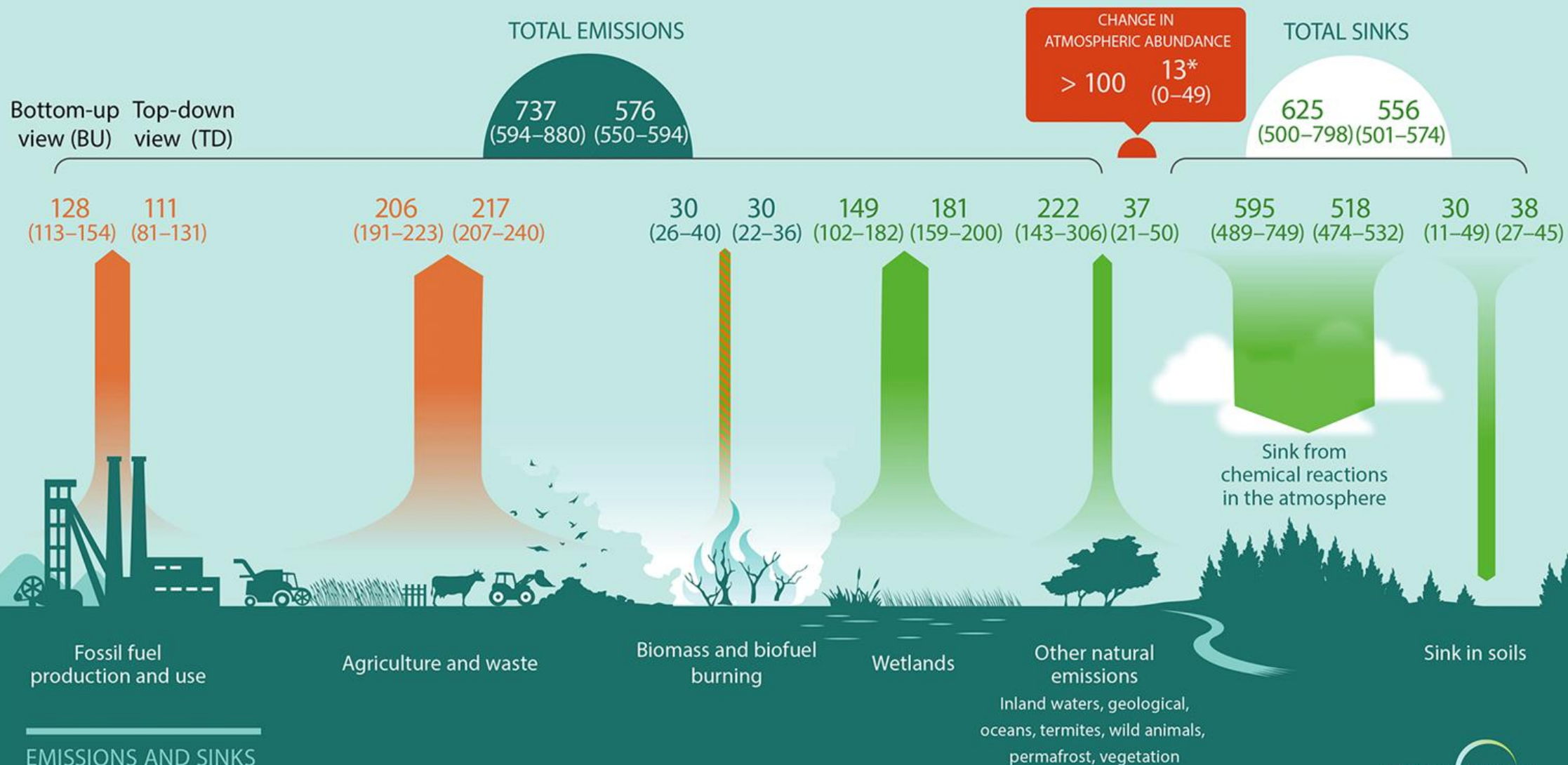
Evolution of the atmosphere global mole fraction, growth rate and budget of methane for the past three decades



1922,2 ppb in April 2023

Source: Kirschke, S. et al. (2013) Three decades of global methane sources and sinks.

GLOBAL METHANE BUDGET 2008–2017



Source: Saunio, M. et al. (2020) The global methane budget 2000–2017.

Permafrost

Permafrost is defined as frozen soil, sediment, or rock having temperatures at or below 0°C for at least 2 consecutive years [2]

[2] Harris and Pedersen (1998). Thermal regimes beneath coarse blocky materials. In *Permafrost and Periglacial Processes*.

Relevance of permafrost

Contains ~1,300 Pg of organic carbon. [3]

Thawing of permafrost releases carbon as CO₂ and CH₄



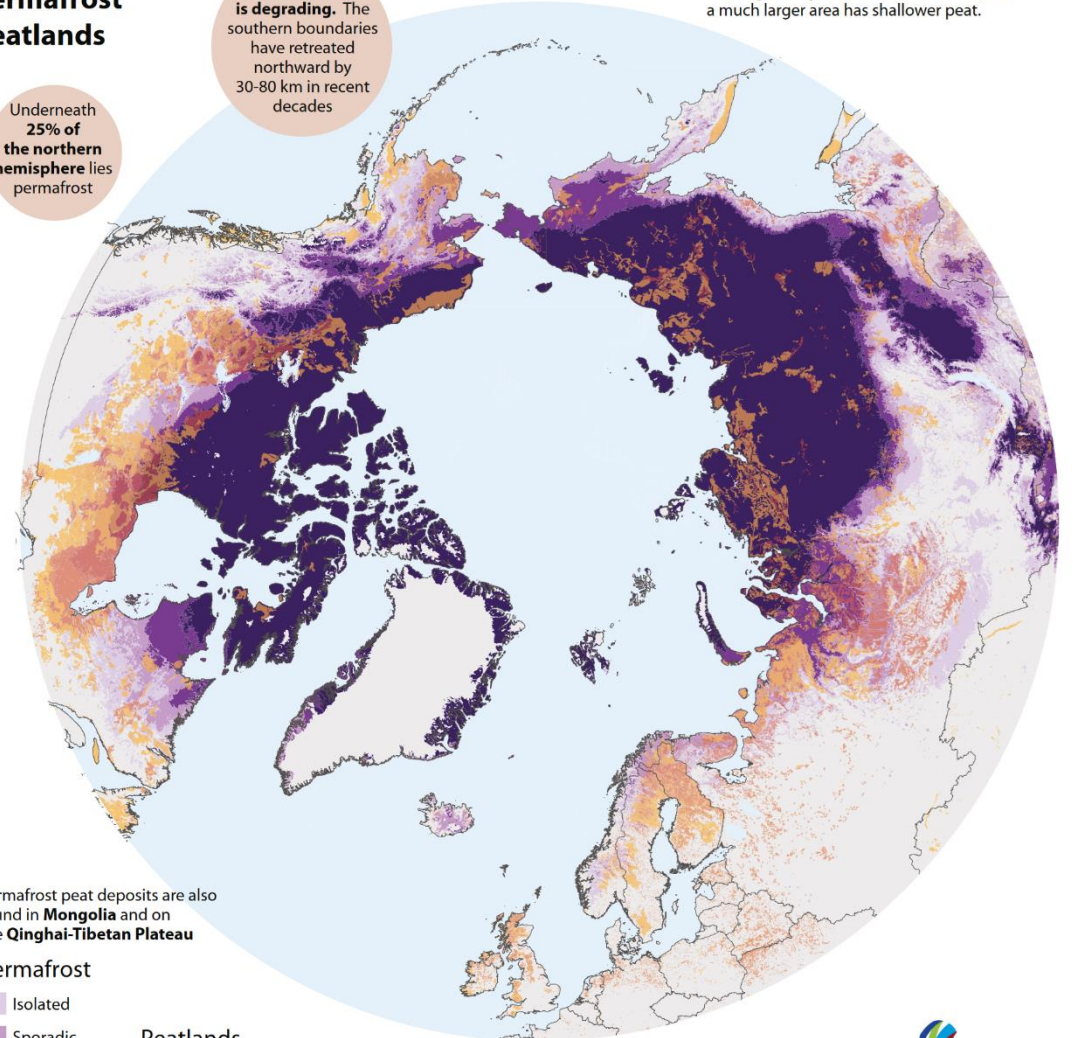
Drives a positive feedback on climate change

Distribution of Permafrost Peatlands

Underneath 25% of the northern hemisphere lies permafrost

Permafrost is degrading. The southern boundaries have retreated northward by 30-80 km in recent decades

Peatlands span vast areas in the permafrost zones. At least 1.4 million km² of permafrost peatlands have a peat layer thicker than 40 cm, and a much larger area has shallower peat.



Permafrost peat deposits are also found in **Mongolia** and on the **Qinghai-Tibetan Plateau**

Permafrost

- Isolated
- Sporadic
- Discontinuous
- Continuous

Peatlands

- > 50% cover
- 20-50% cover



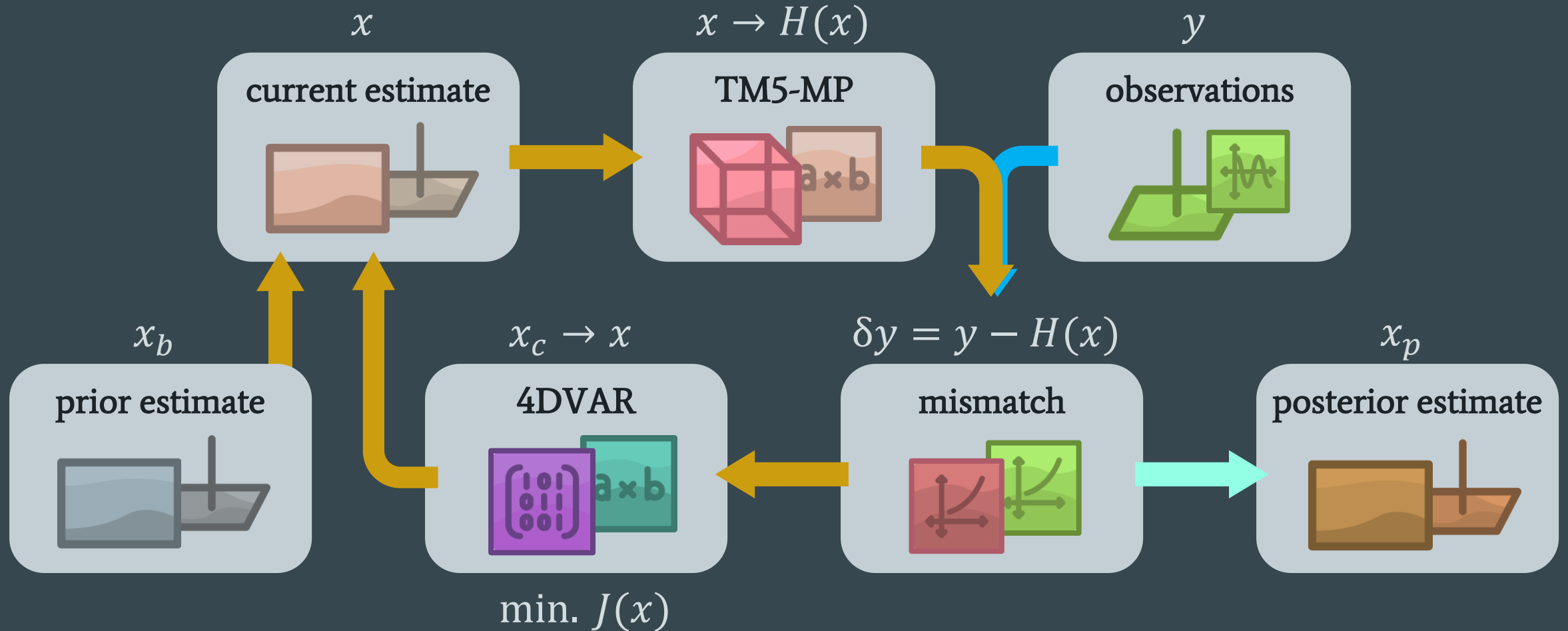
Geospatial data sources:
Peatlands data provided by Greifswald Mire Centre, Greifswald, Germany
Permafrost data provided by Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research (AWI), Bremerhaven, Germany²⁰

[3] Hugelius et al. (2014) Estimated Stocks of Circumpolar Permafrost Carbon with Quantified Uncertainty Ranges and Identified Data Gaps.

Inverse modeling of emissions

TM5-MP / 4DVAR

Inverse modeling of emissions

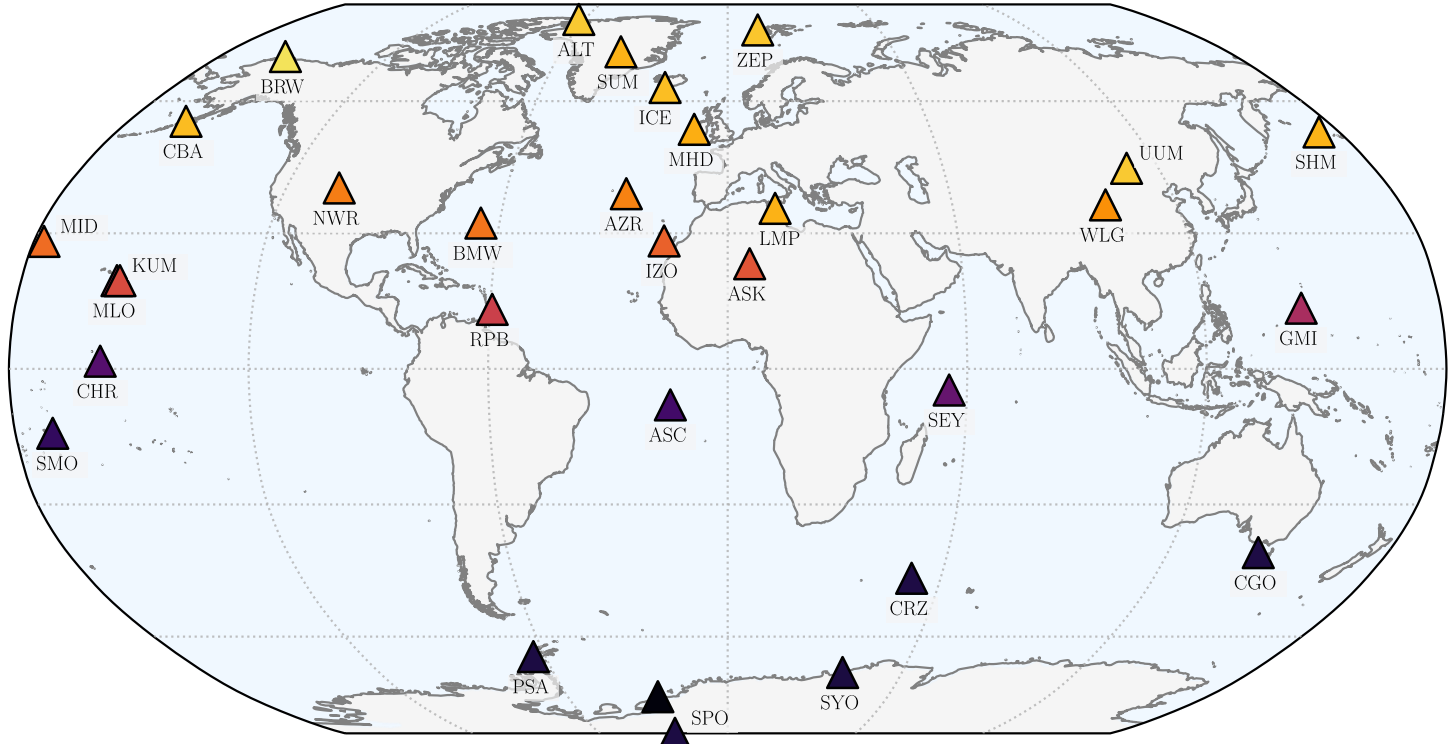


Measurements and remote observations

- Stations flask measurements
- Satellite instrument observations

Stations flask measurements

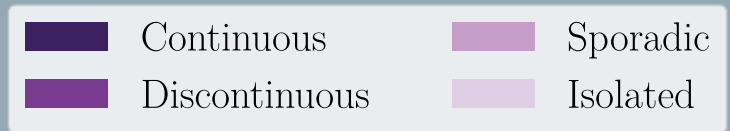
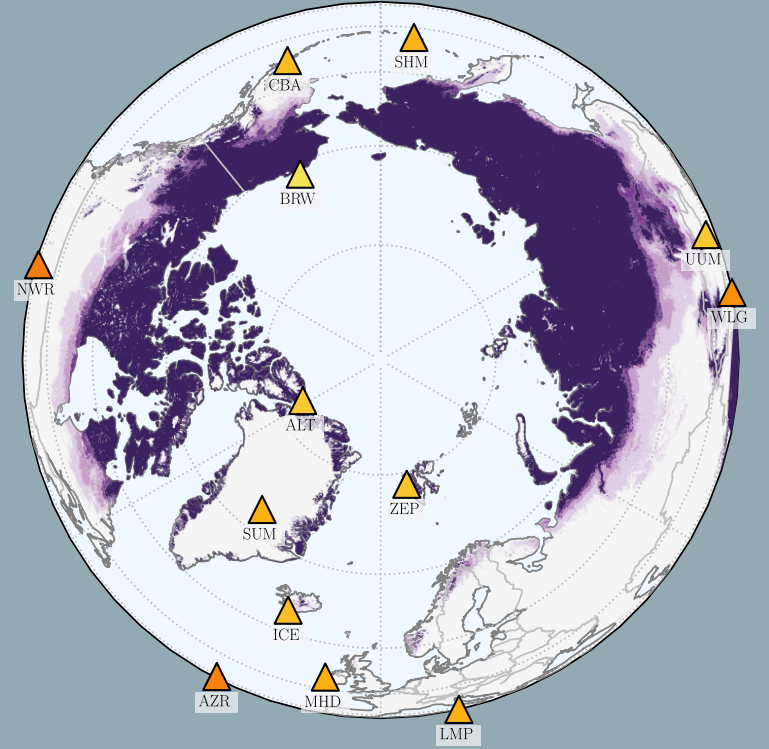
Station locations from NOAA network



1800 1825 1850 1875 1900 1925 1950

CH₄ annual mean concentration [ppb]

Permafrost region



Remote observations: TROPOMI

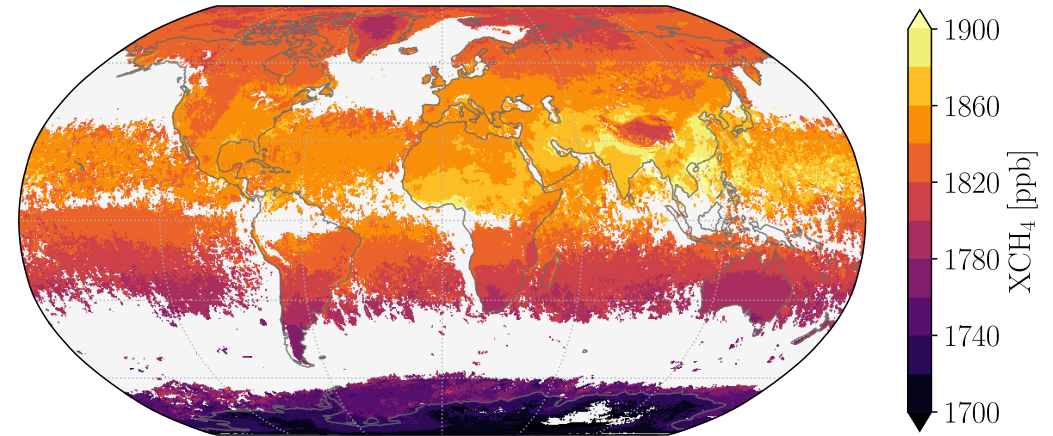
High resolution ($7.0 \times 3.6 \text{ km}^2$)

Global daily coverage

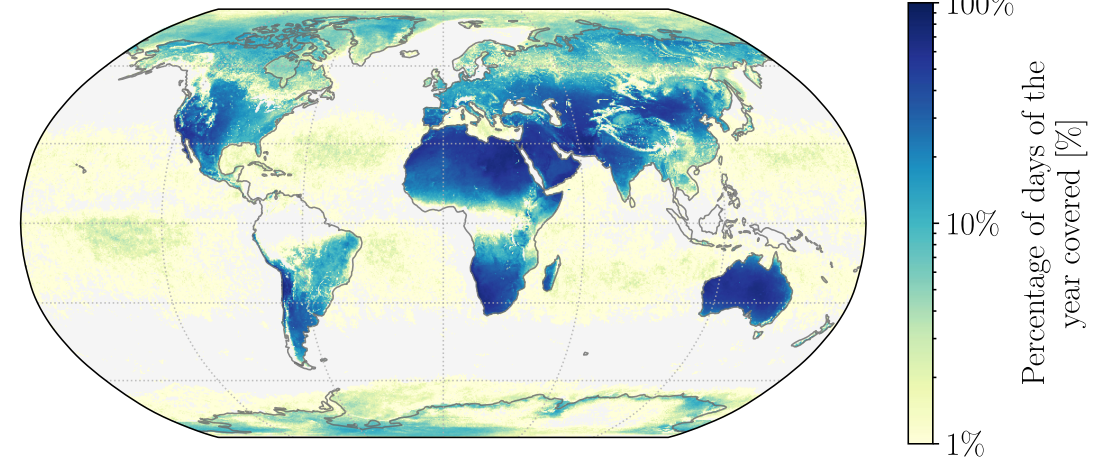
Continuous data since November 2017

Improved retrieval (WFMD CH_4 product)
covers high latitudes ^[4]

TROPOMI mean XCH_4 for 2018



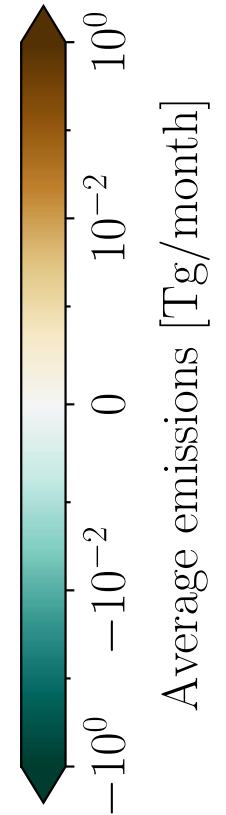
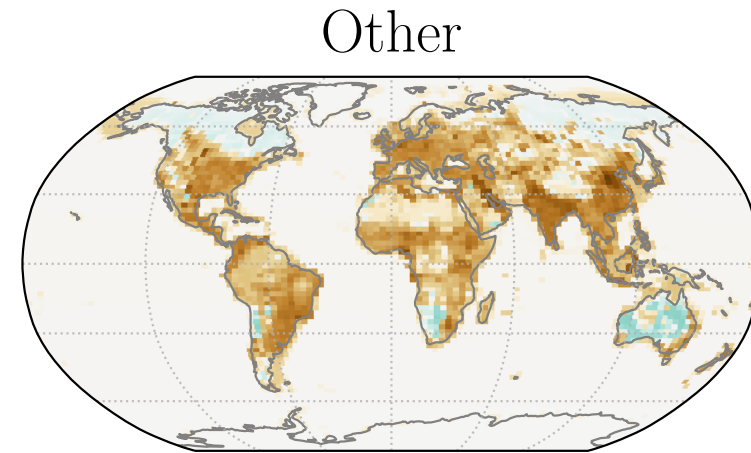
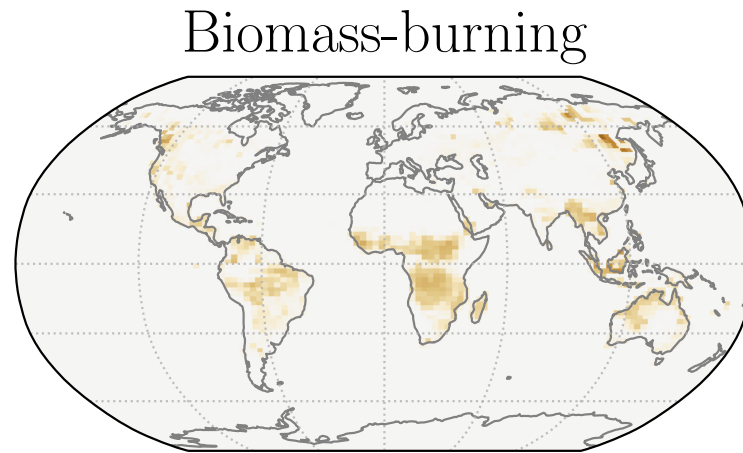
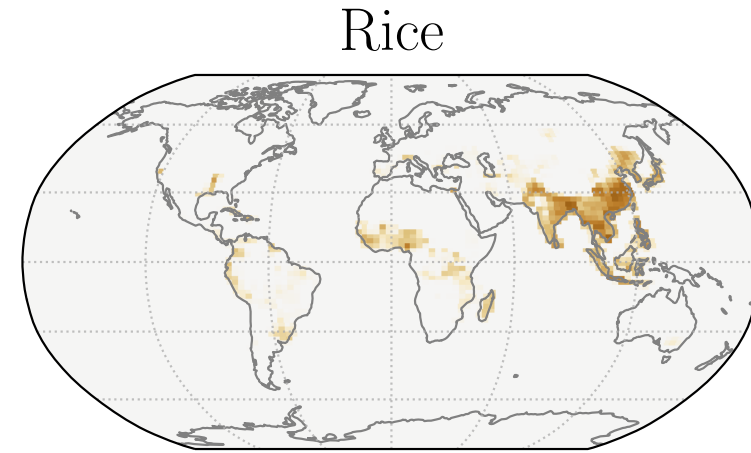
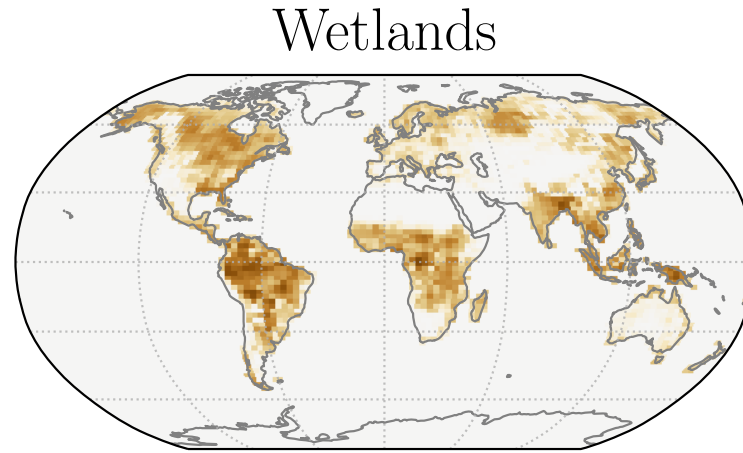
TROPOMI year XCH_4 coverage for 2018



[4] Schneising et al. (2023). Advances in retrieving XCH_4 and XCO from Sentinel-5 Precursor: improvements in the scientific TROPOMI/WFMD algorithm. In *Atmos. Meas. Tech.*

Emission categories for inversion, yearly mean

Category	[Tg/year]
Wetlands	188,3
Rice	36,3
B. burning	14,4
Other	338,0
Total	577,3

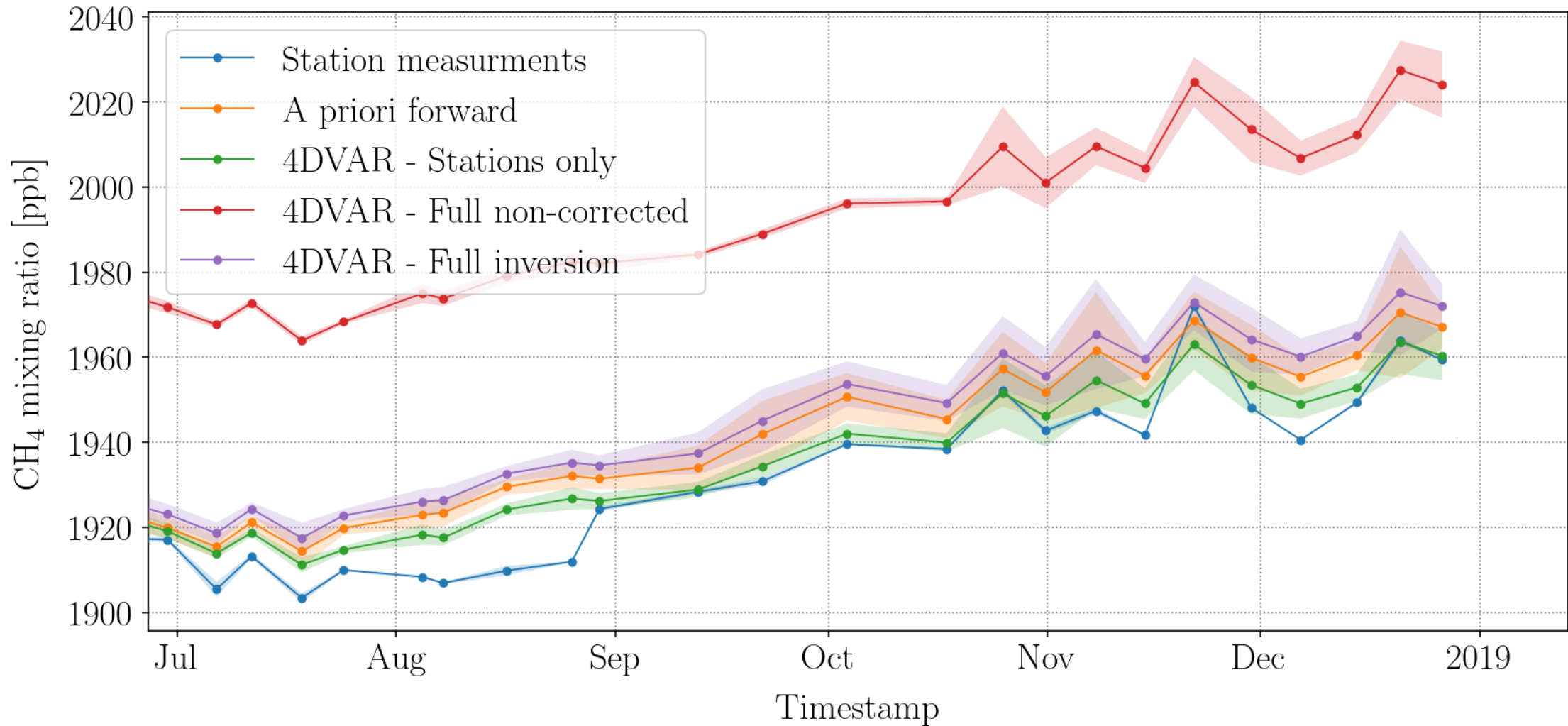


Inversion preliminary results

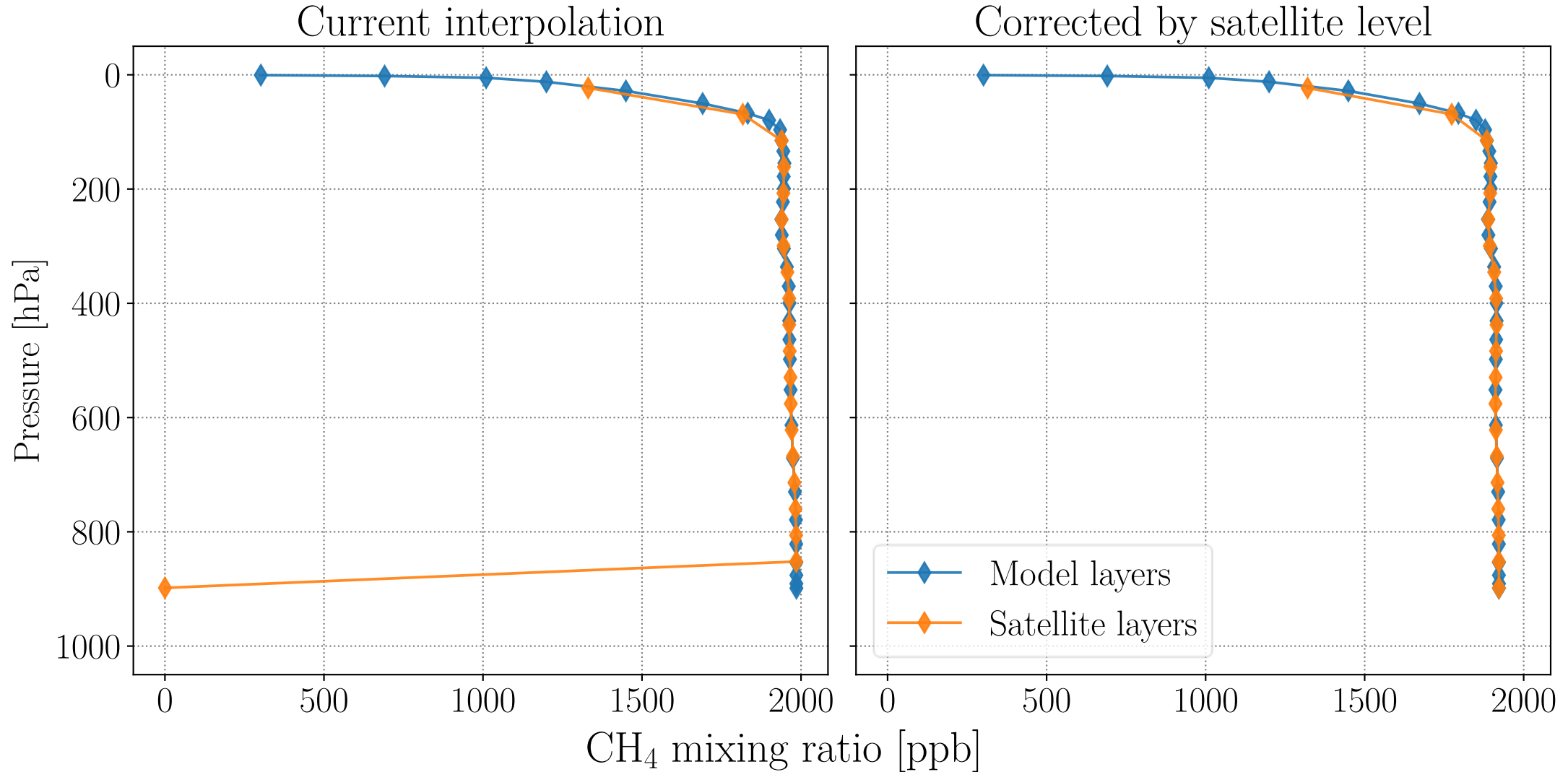
- Single year simulation (6 months of spin-up) for 2018
- Inversion with only stations and with both stations and satellite

Inversion for Jul-Dec 2018 NOAA sample and TROPOMI

Station ALT (82.45° N, 62.52° W, 210 m)



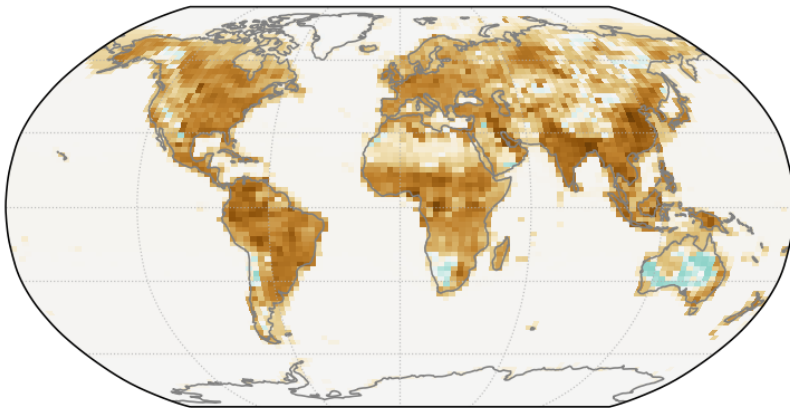
Model concentration interpolation to satellite layers



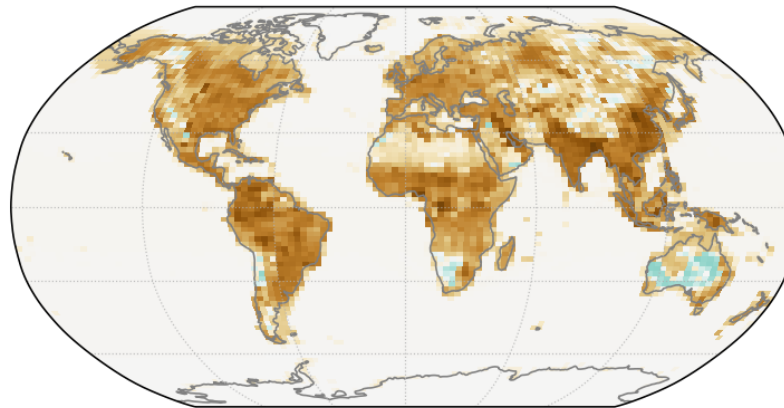
Inversion for Jul-Dec 2018, global view

NOAA sample and TROPOMI

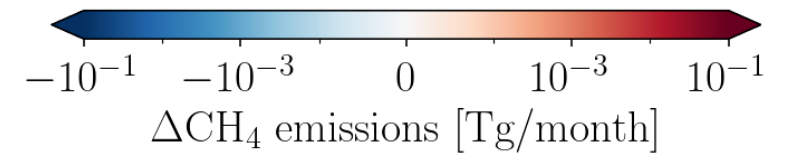
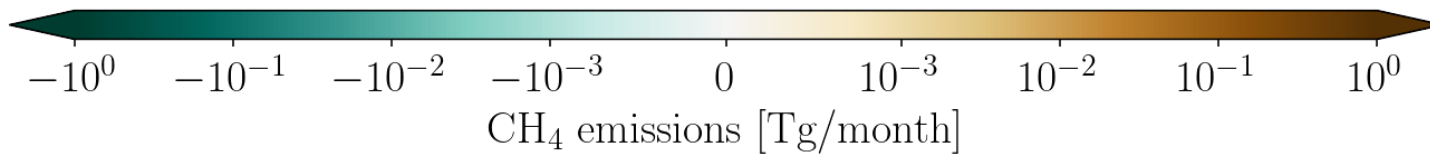
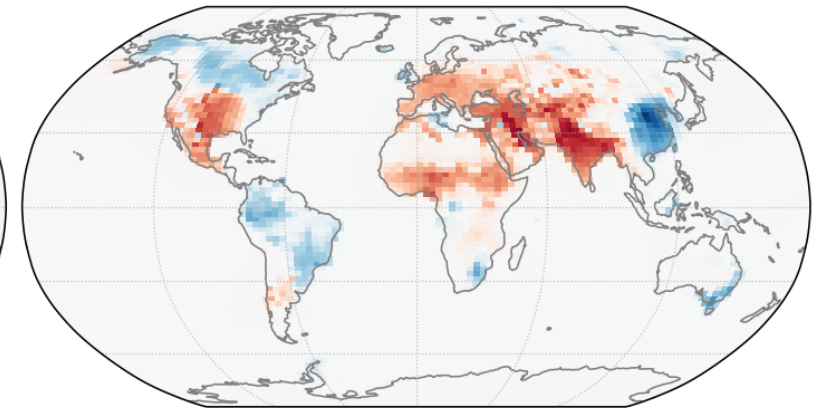
Mean a priori CH_4 emissions



Mean a posteriori CH_4 emissions



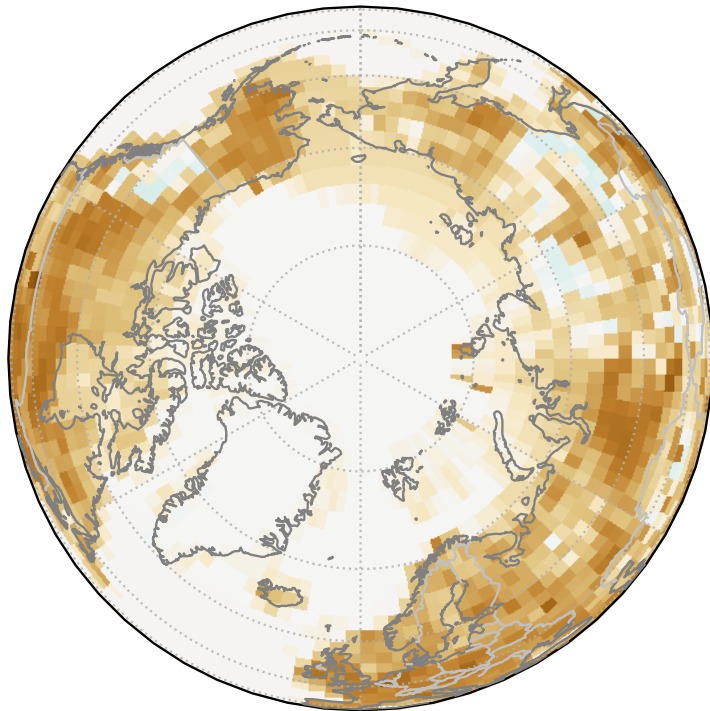
Difference



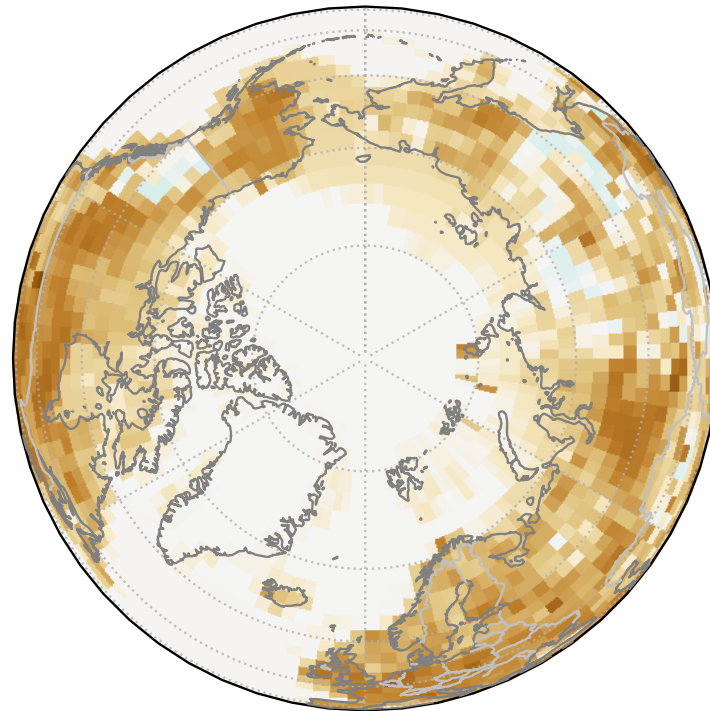
Inversion for Jul-Dec 2018, northern region view

NOAA sample and TROPOMI

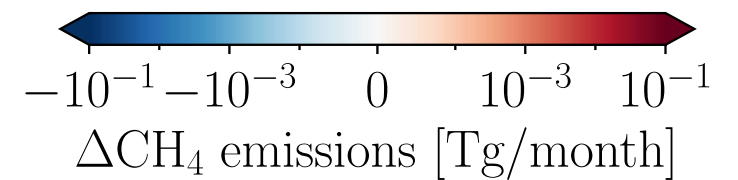
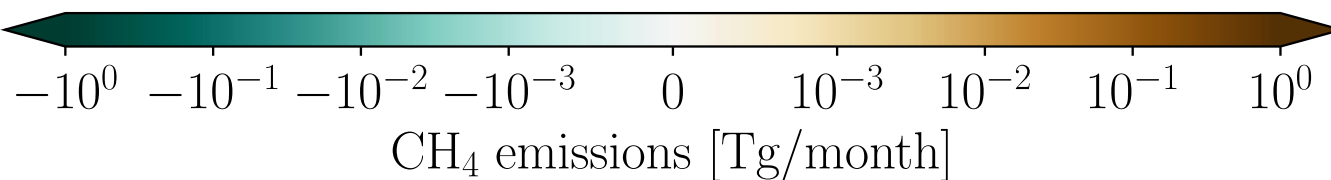
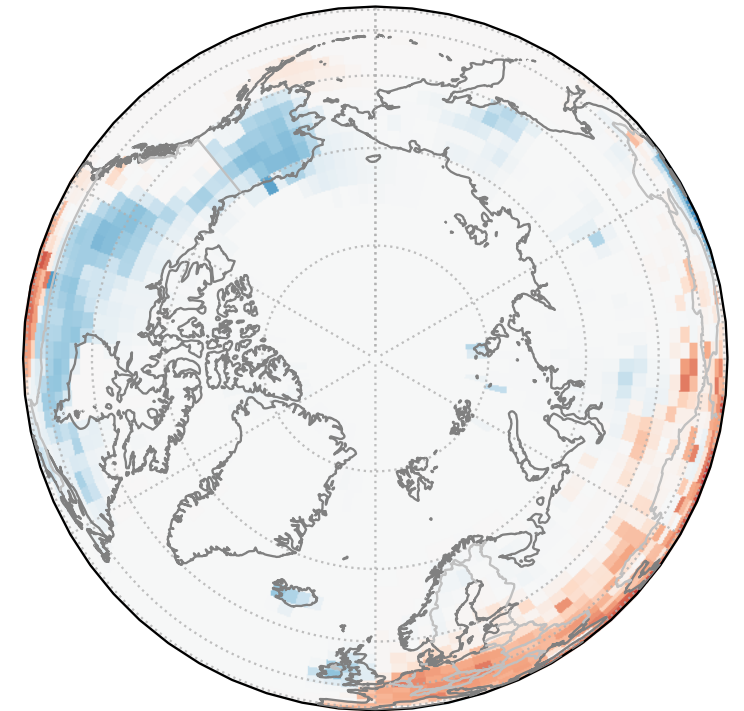
Mean a priori emissions



Mean a posteriori emissions



Difference



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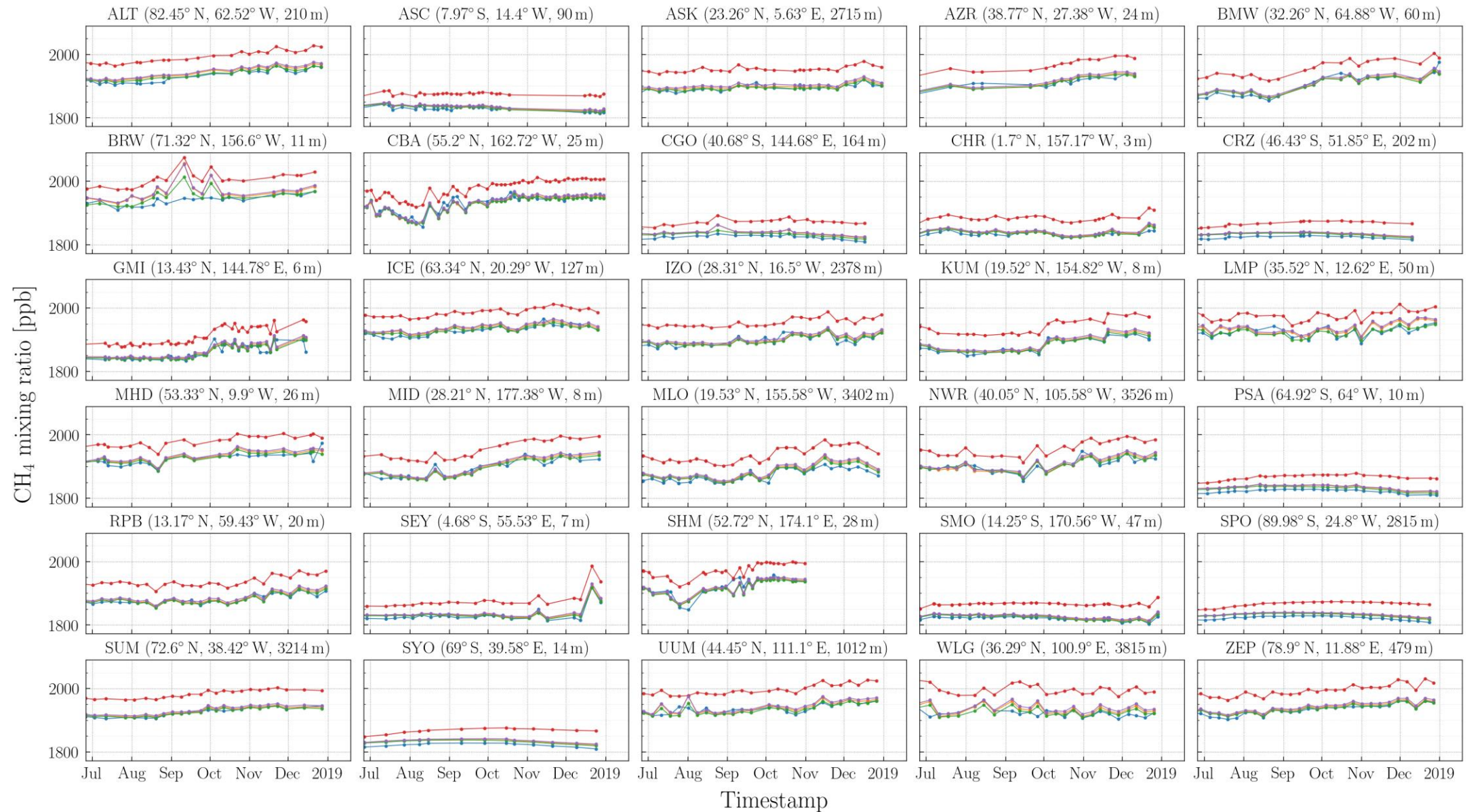
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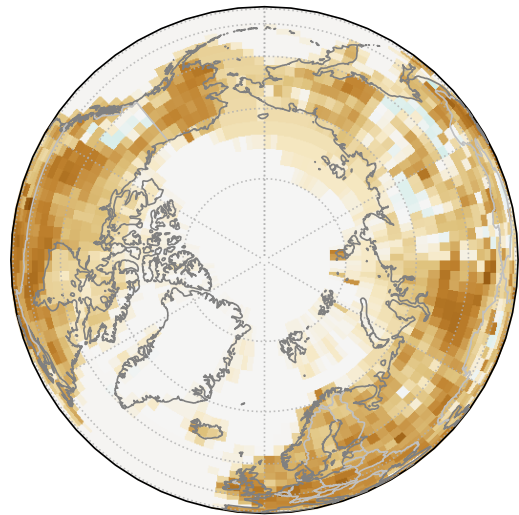
Inversion for Jul-Dec 2018 NOAA sample and TROPOMI



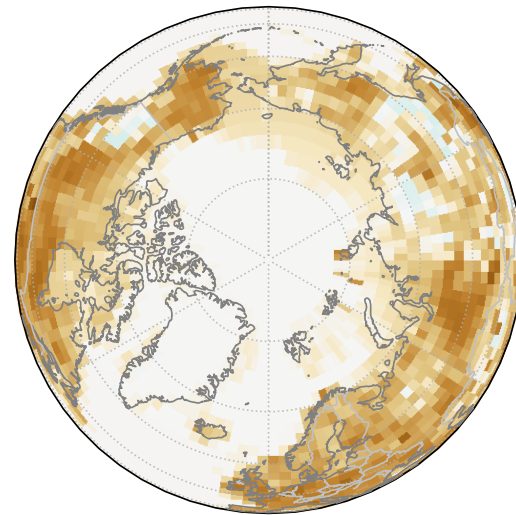
Inversion for Jul-Dec 2018, northern region view

NOAA sample and TROPOMI

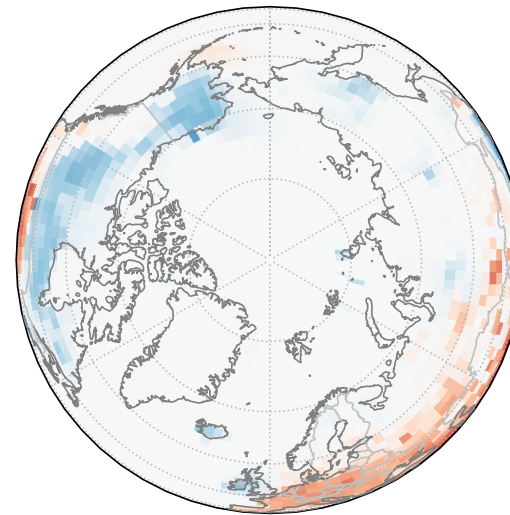
Mean a priori emissions



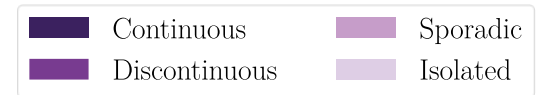
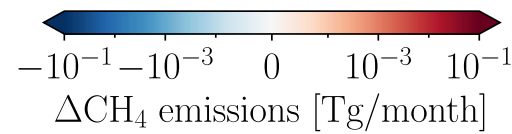
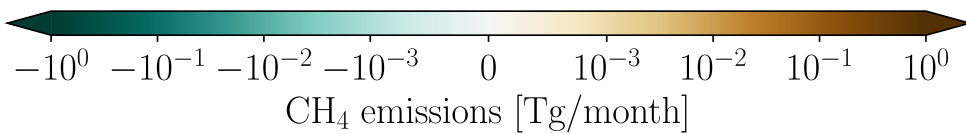
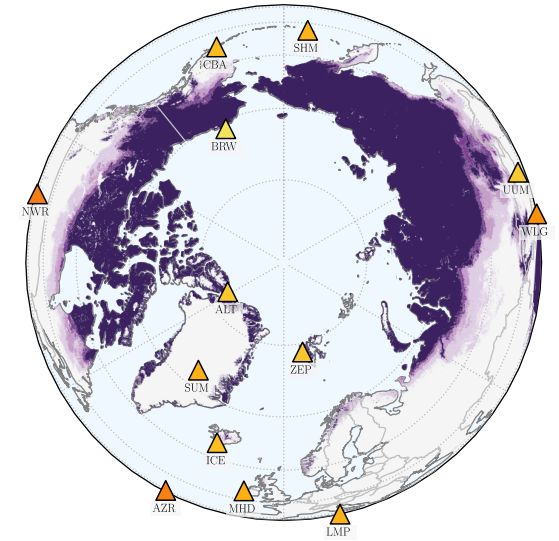
Mean a posteriori emissions



Difference

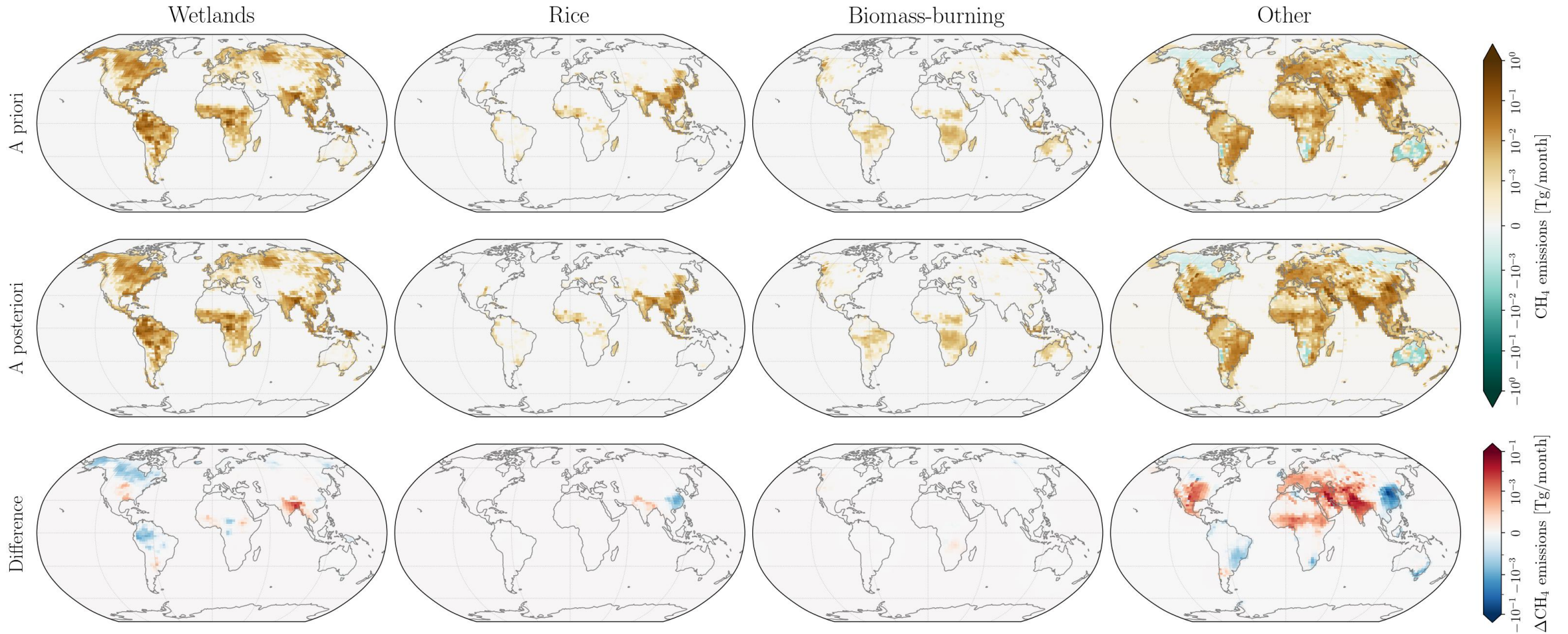


Permafrost region



Inversion for Jul-Dec 2018, mean emissions by category

NOAA sample and TROPOMI



Year emissions comparison by category

Category	A priori [Tg/year]	A posteriori [Tg/year]	Difference [Tg/year]	Relative difference [%]
Wetlands	188,3	188,0	-0,23	-0,12
Rice	36,3	36,6	-0,05	-0,14
B. burning	14,4	14,3	-0,13	-0,94
Other	338,0	345,8	7,84	2,32
Total	577,3	584,7	7,42	1,29

Inversion for Jul-Dec 2018, monthly total emissions

NOAA sample and TROPOMI

