TO BRING ABOUT BREAKTHROUGHS IN INTERNATIONAL SPACE RESEARCH

Impact of hydroxyl radical data on methane inversions

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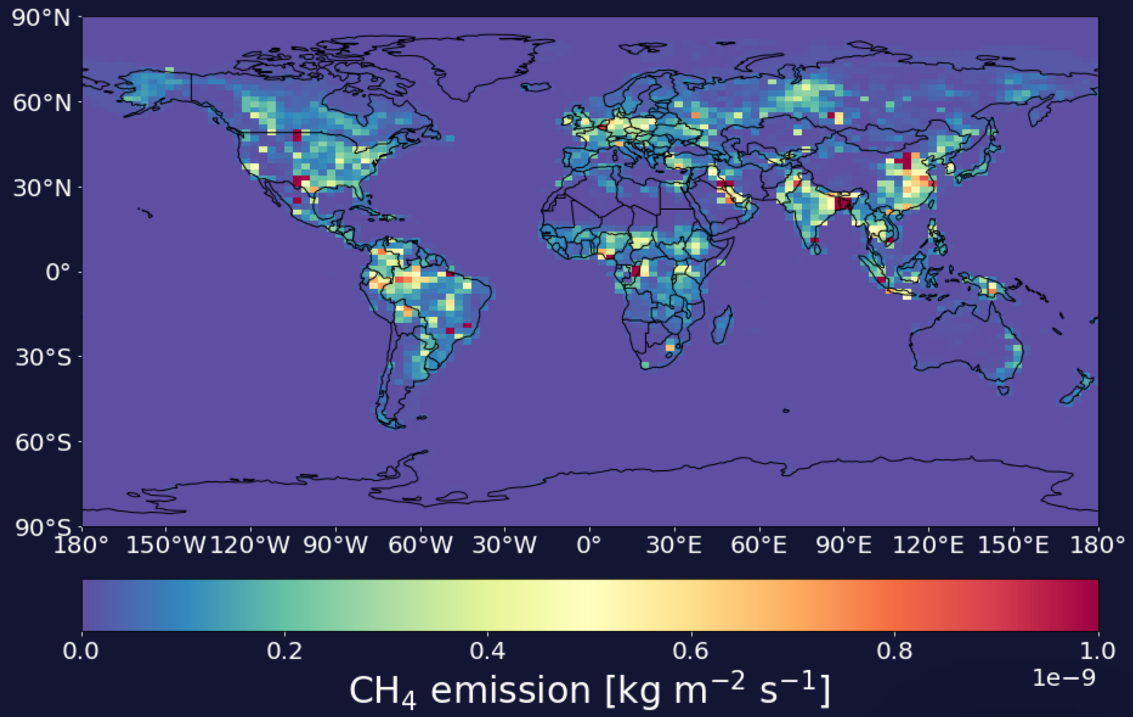
SRON SPACE RESEARCH ORGANISATION NETHERLANDS



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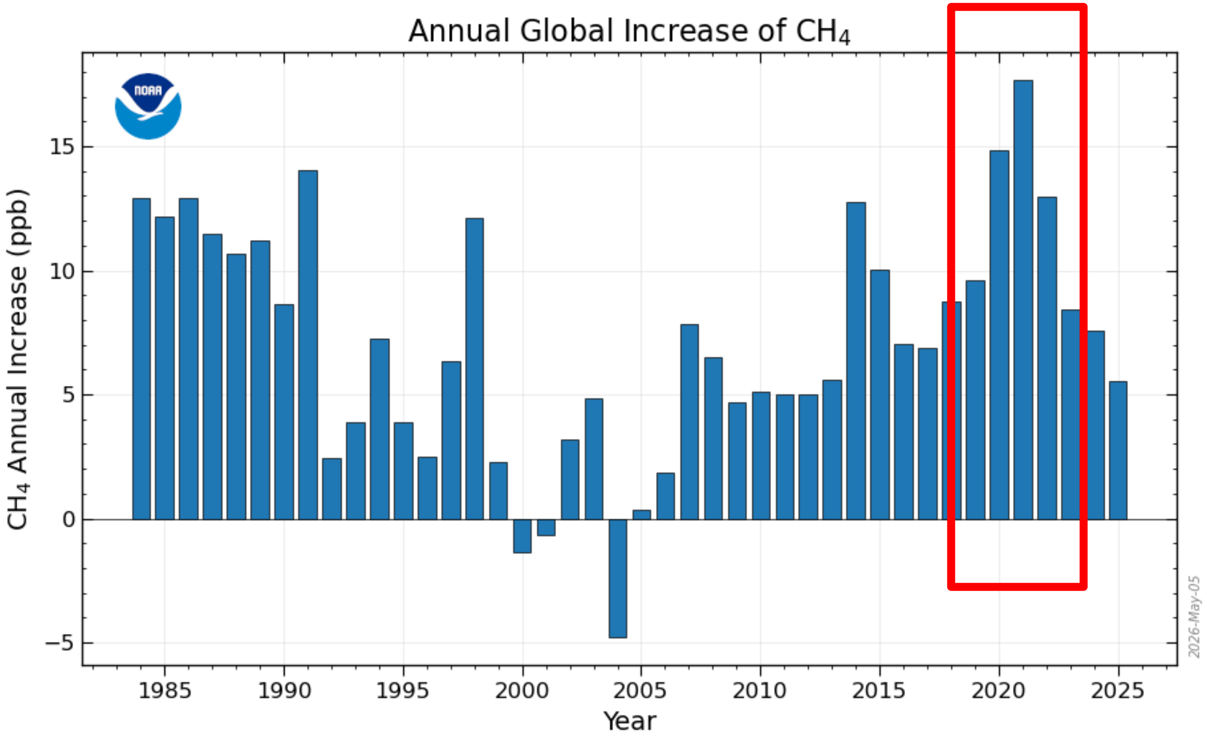
Methane Growth

- Explanations
  - Wetlands
    - Nisbet et al. (2023)
  - Microbial
    - Michel et al. (2024)
  - Loss (OH)
    - Stevenson et al. (2022)
  - Combinations
    - Ciais et al. (2026)
    - Peng et al. (2021)
- Emissions: explain 50%-130% of 2020/2021 methane growth



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TM5-4DVAR

- CAMS GHG surface inversion
  - ~30 long term stations
  - EDGAR, LPJ, GFAS
- 3x2 degrees
- 2019-2023

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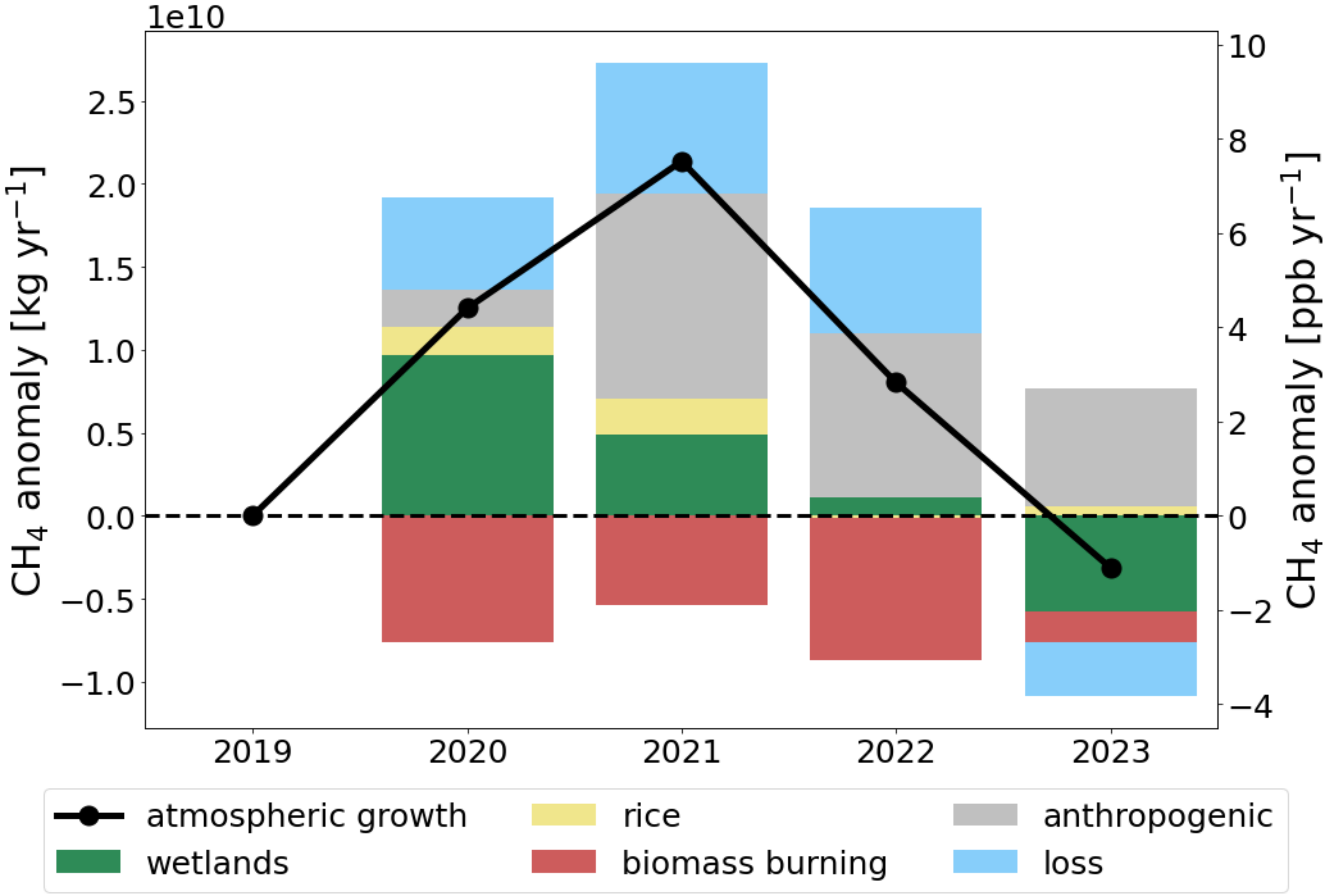
TM5 Methane inversion

- Emission 65% of 2021 growth
- Simlar to Ciais et al. (2026)
- Loss uncertain
    - Emission uncertain



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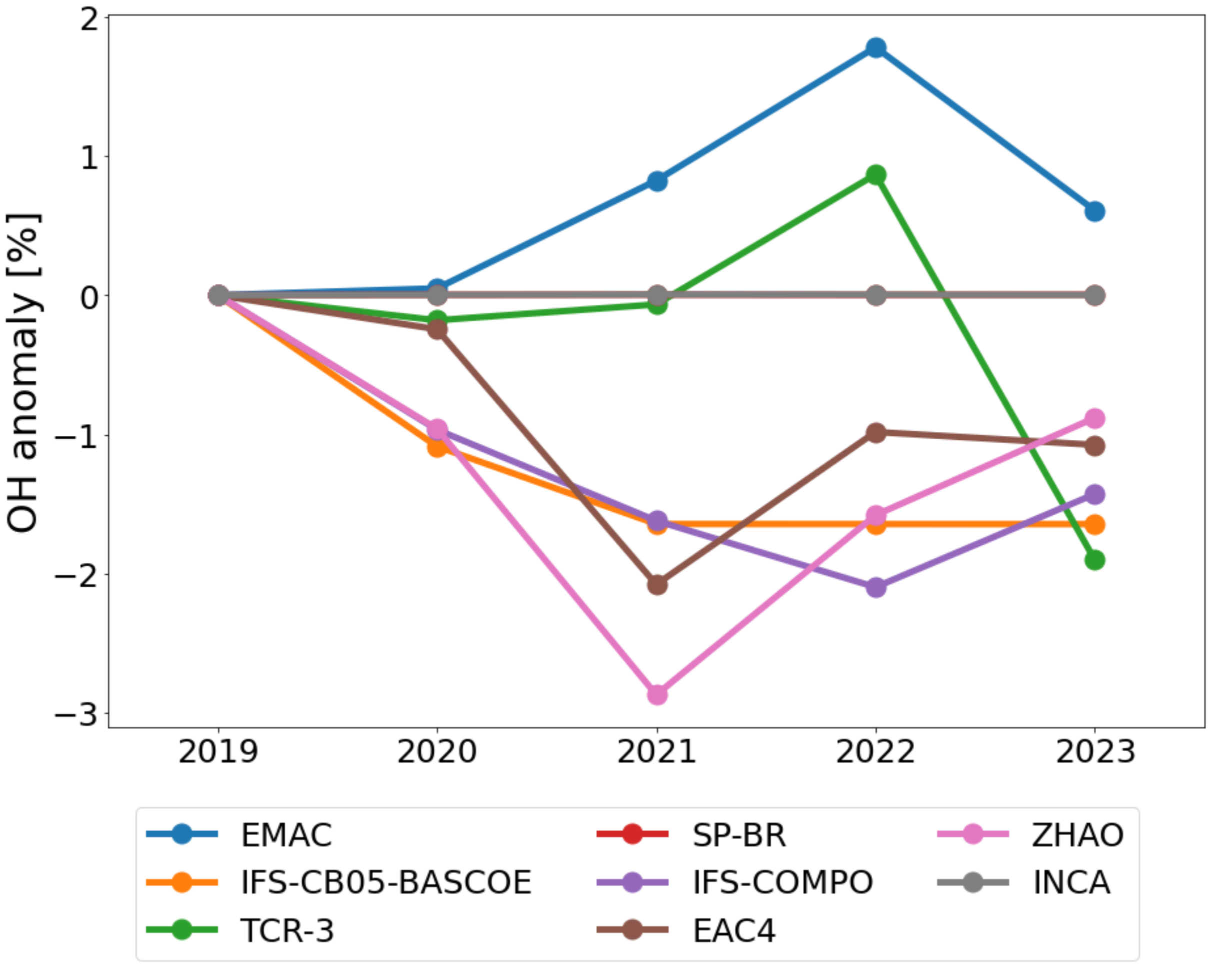
OH fields

- 8 OH fields
- Scale forward methane loss
- Lockdown effect?
- OH drivers
    - ENSO
    - Fires



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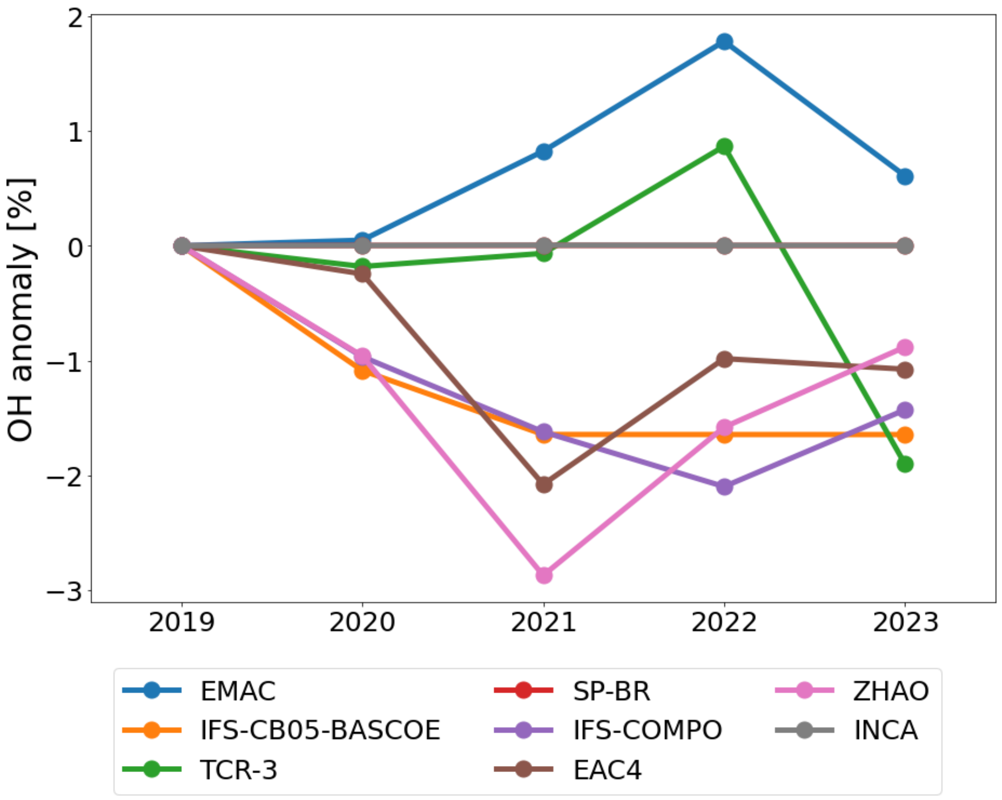
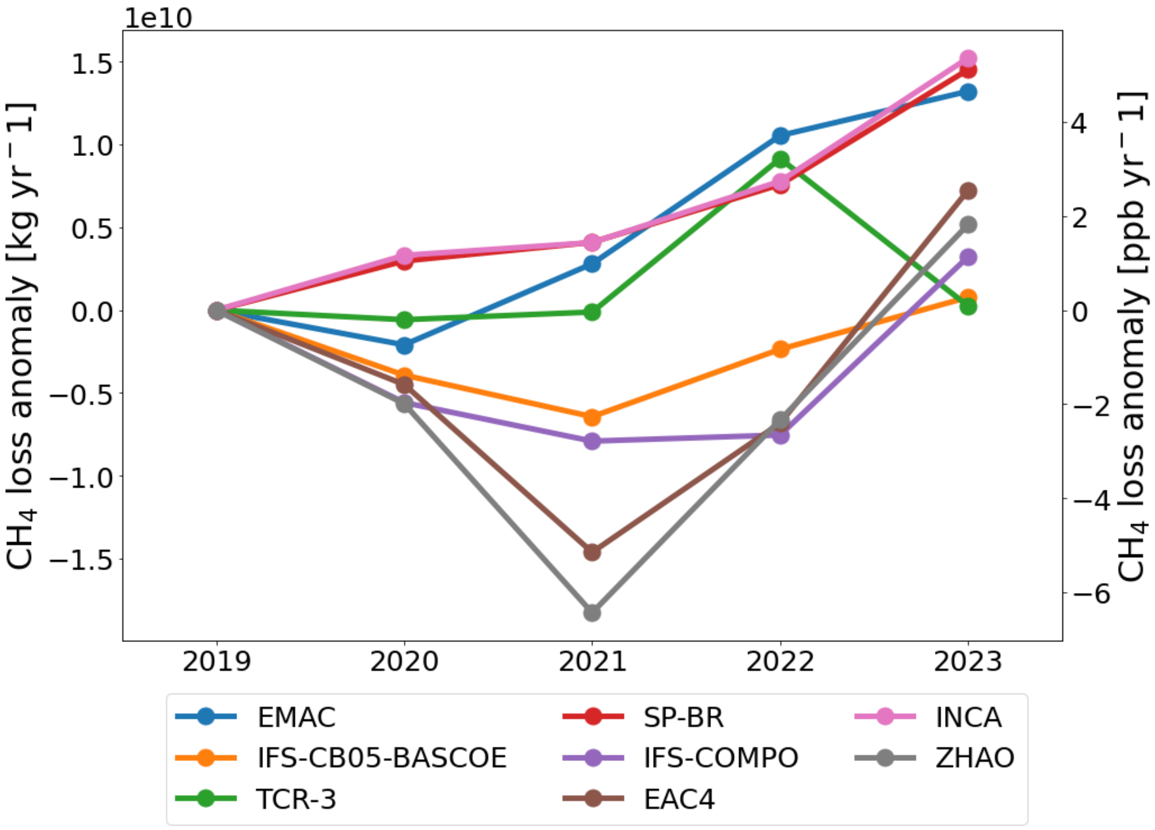
Loss rates

- OH effect on posterior loss

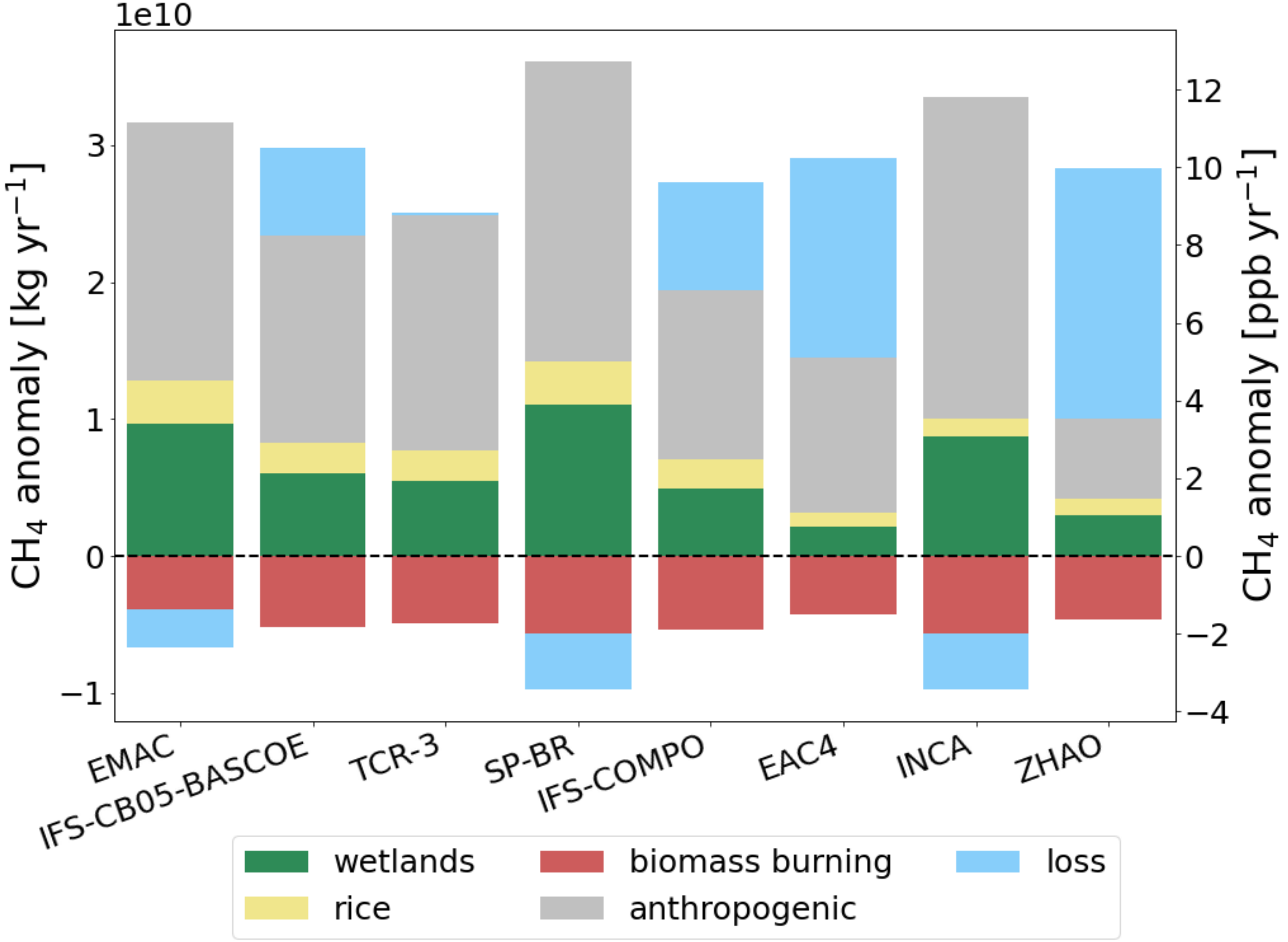


OH + CH4



2021 Methane Growth

- Emission & Loss anomaly (2021-2019)
- Emission:
  - 20% - 119%
- Loss:
  - -19% - 80%



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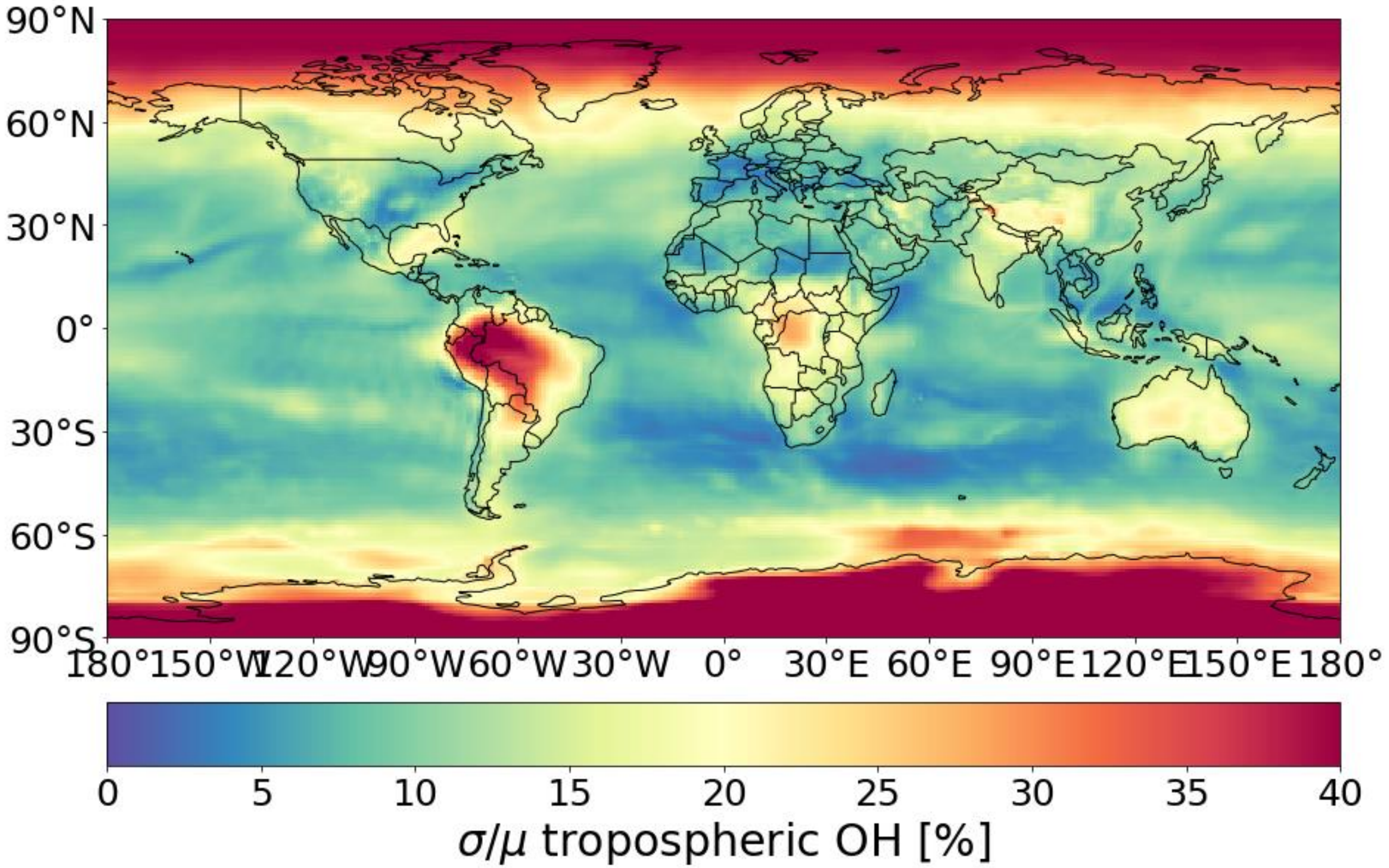
Spatial variation OH

- Relative variation over different oh fields
- Tropospheric mass-average
- 5-30% spatial variation



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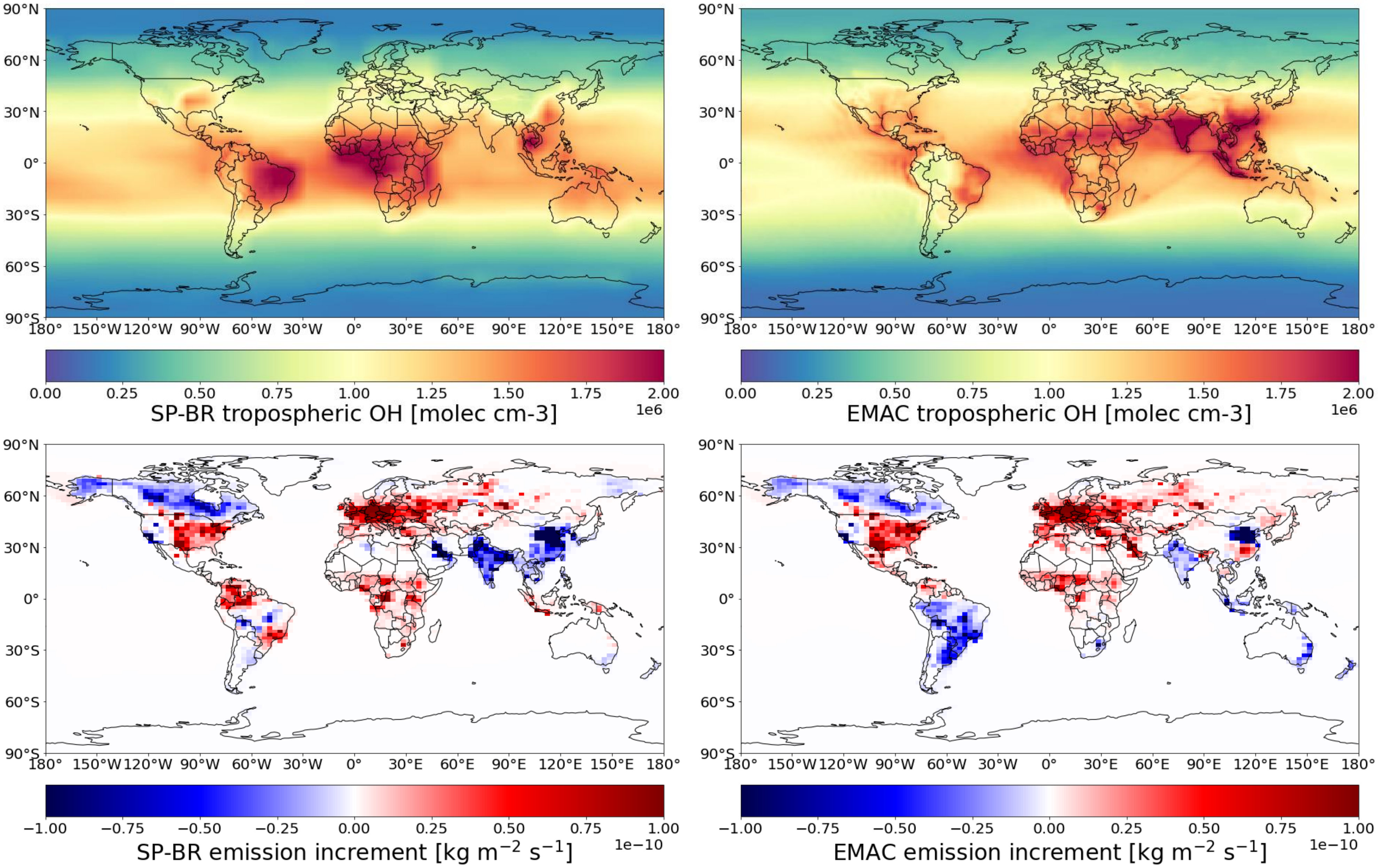
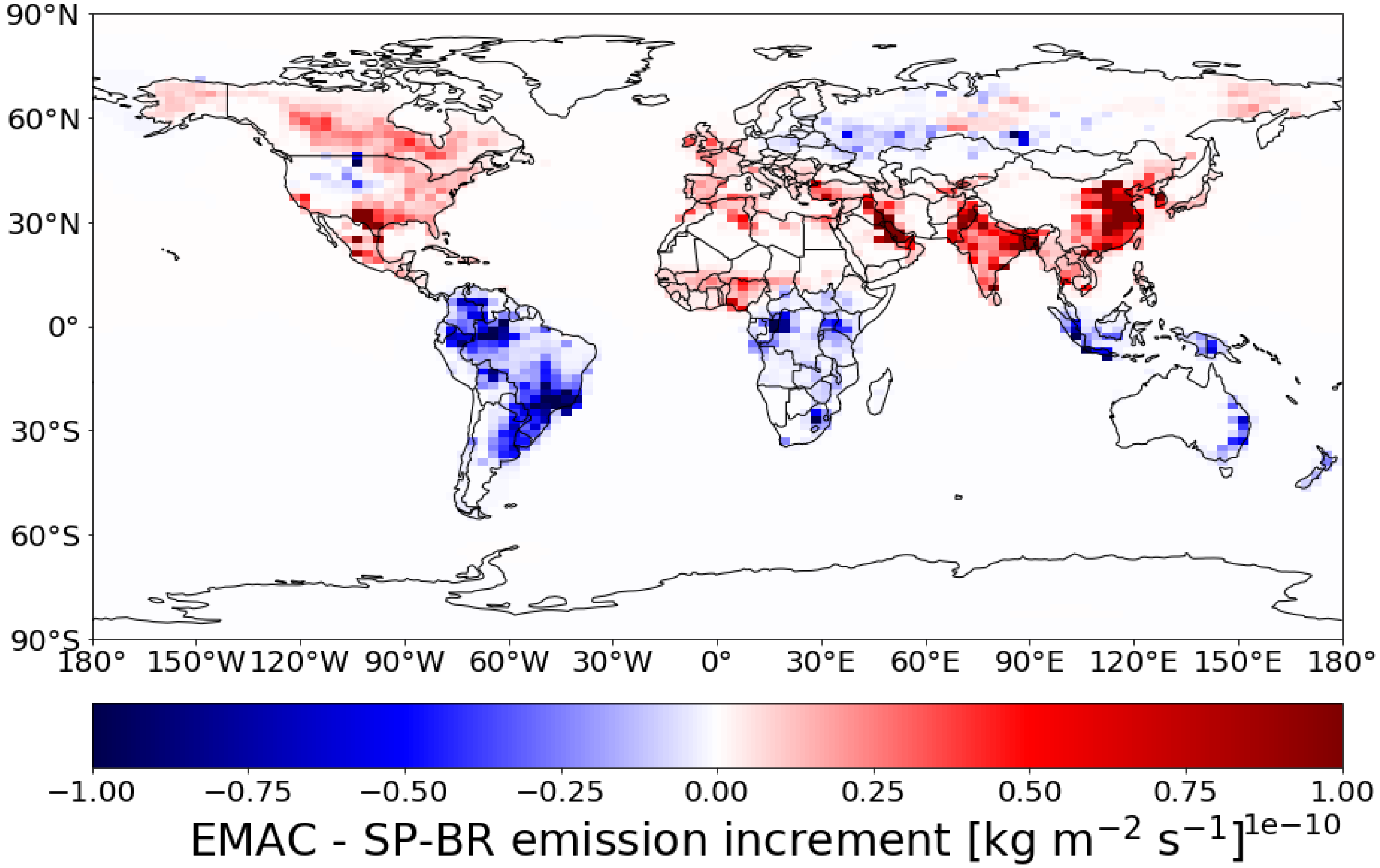
OH affects posterior Emissions

- 5 year Average OH & increment
  - SP-BR
  - EMAC
- South America
- South-East Asia



Interhemispheric OH ratio

- Difference posterior
  - EMAC – SP-BR
- Interhemispheric OH ratio
  - NH/SH
  - EMAC: ~ 1.4
  - SP-BR: ~ 1.0



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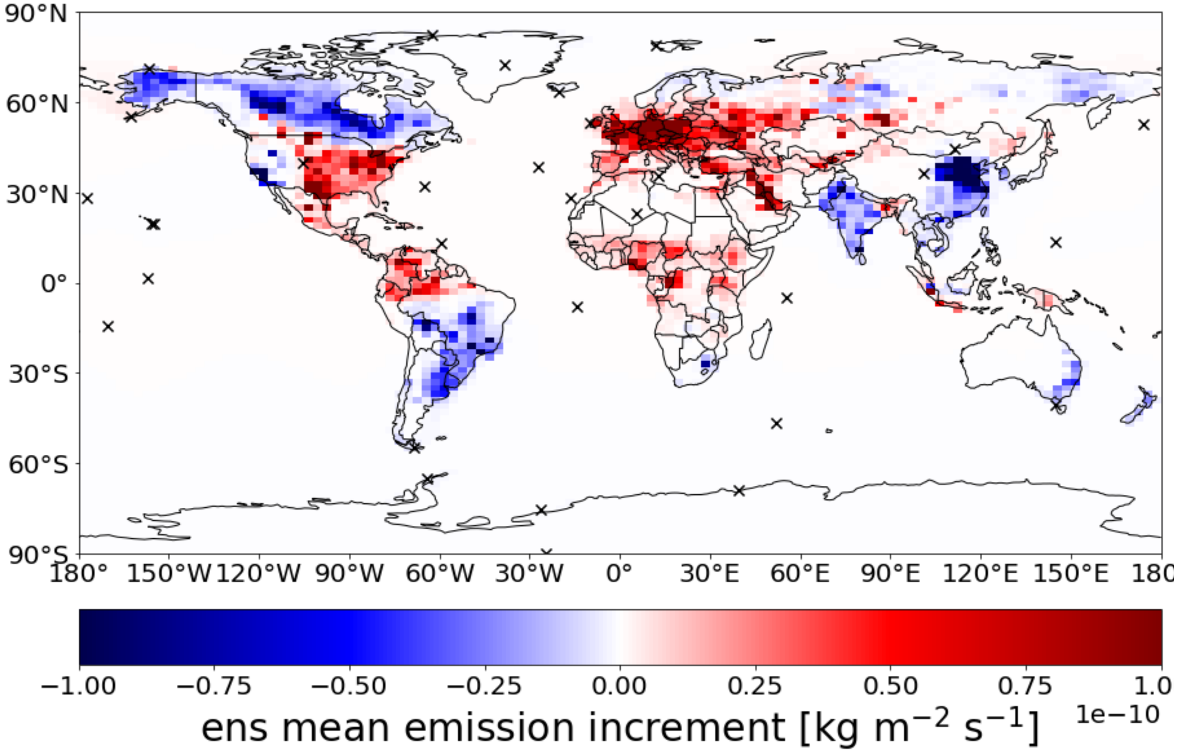
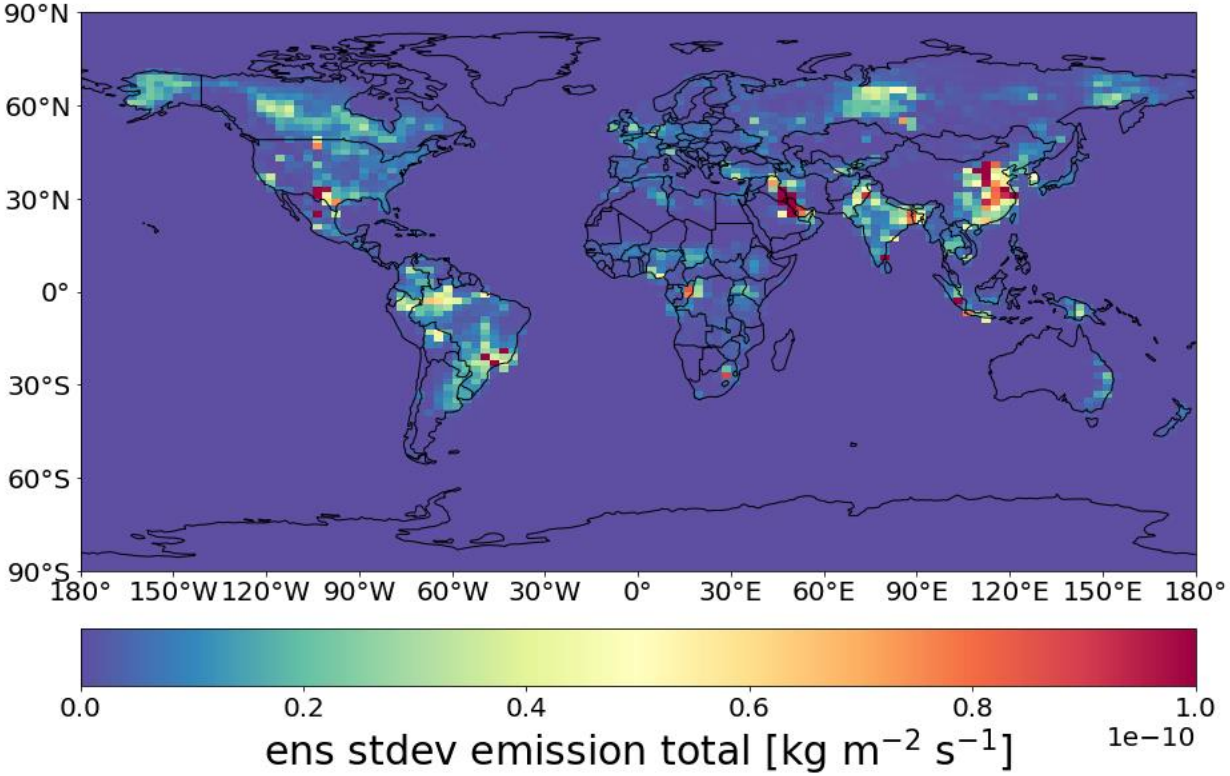
Spatial variation OH

- Ensemble average emission increment
- Variation in increment related to OH
- ~15% uncertainty on emission





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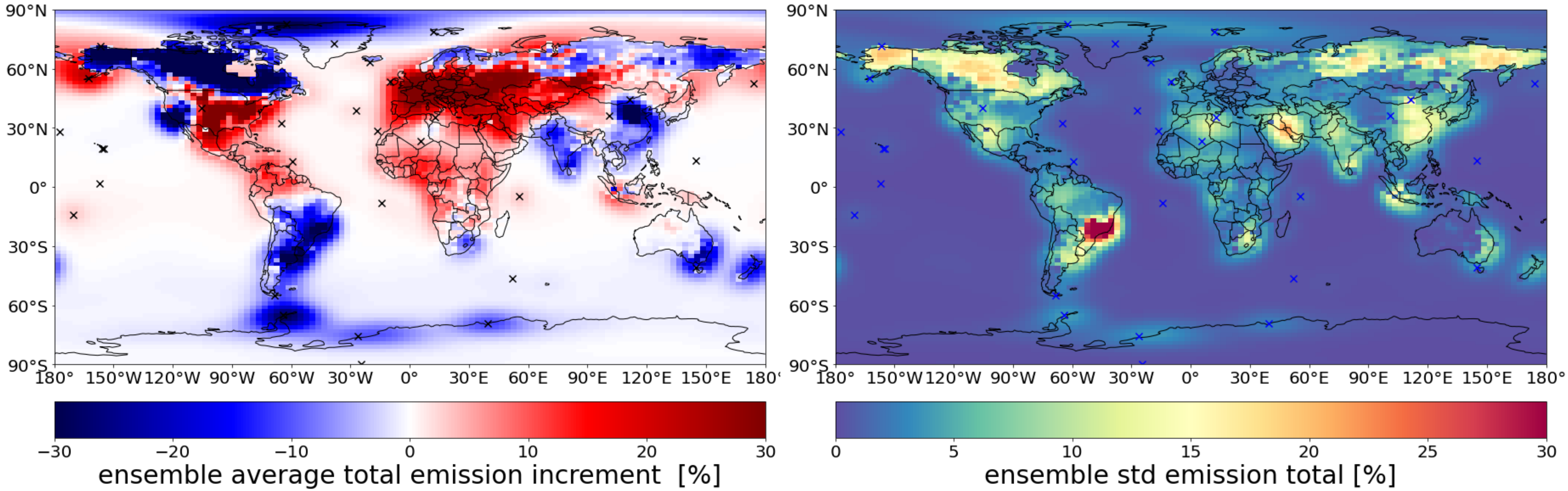

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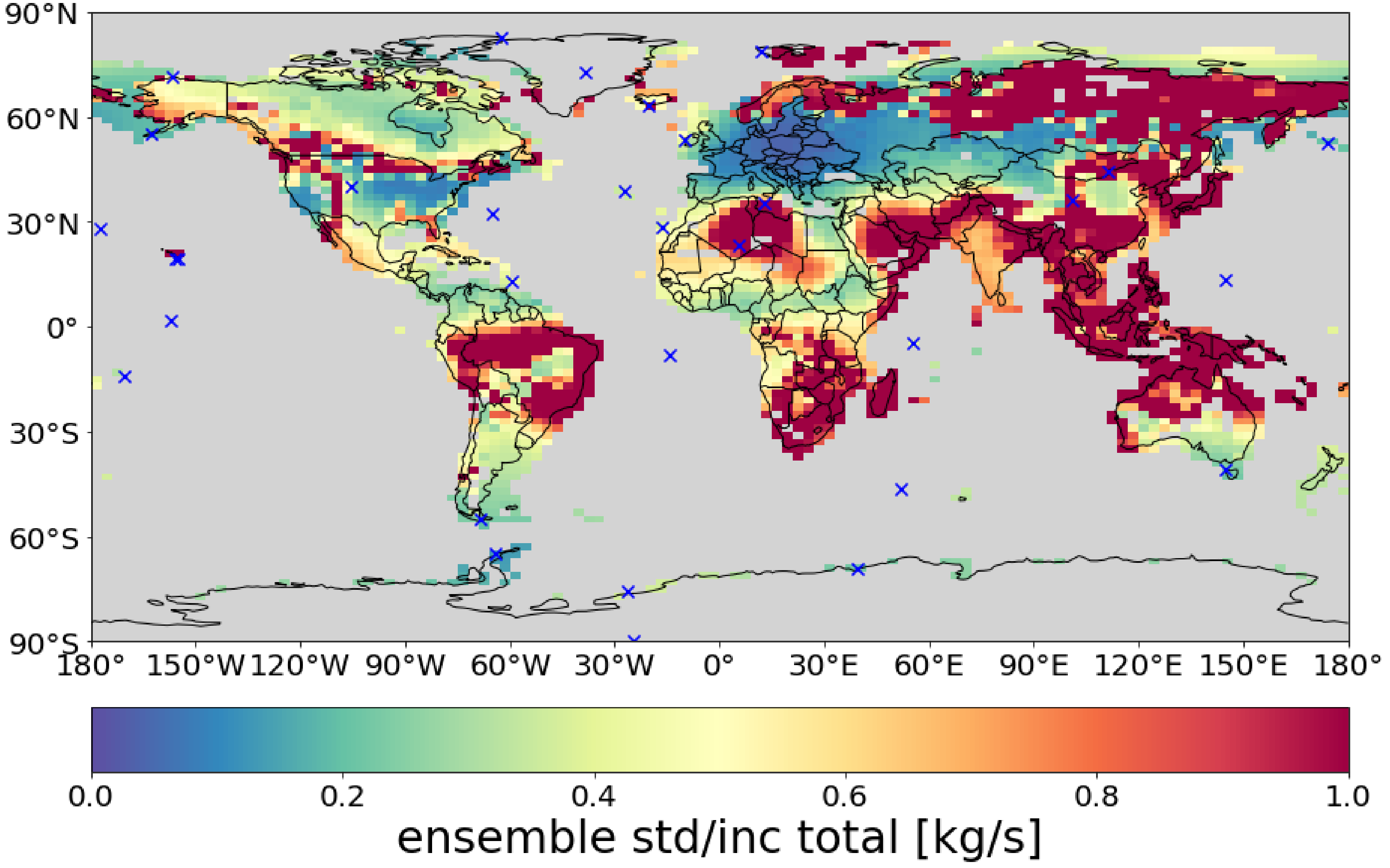
Ratio std/inc

- Ratio <1 : 1 sigma significance
- Ratio <0.5 : 2 sigma significance
- Red = no significant increment



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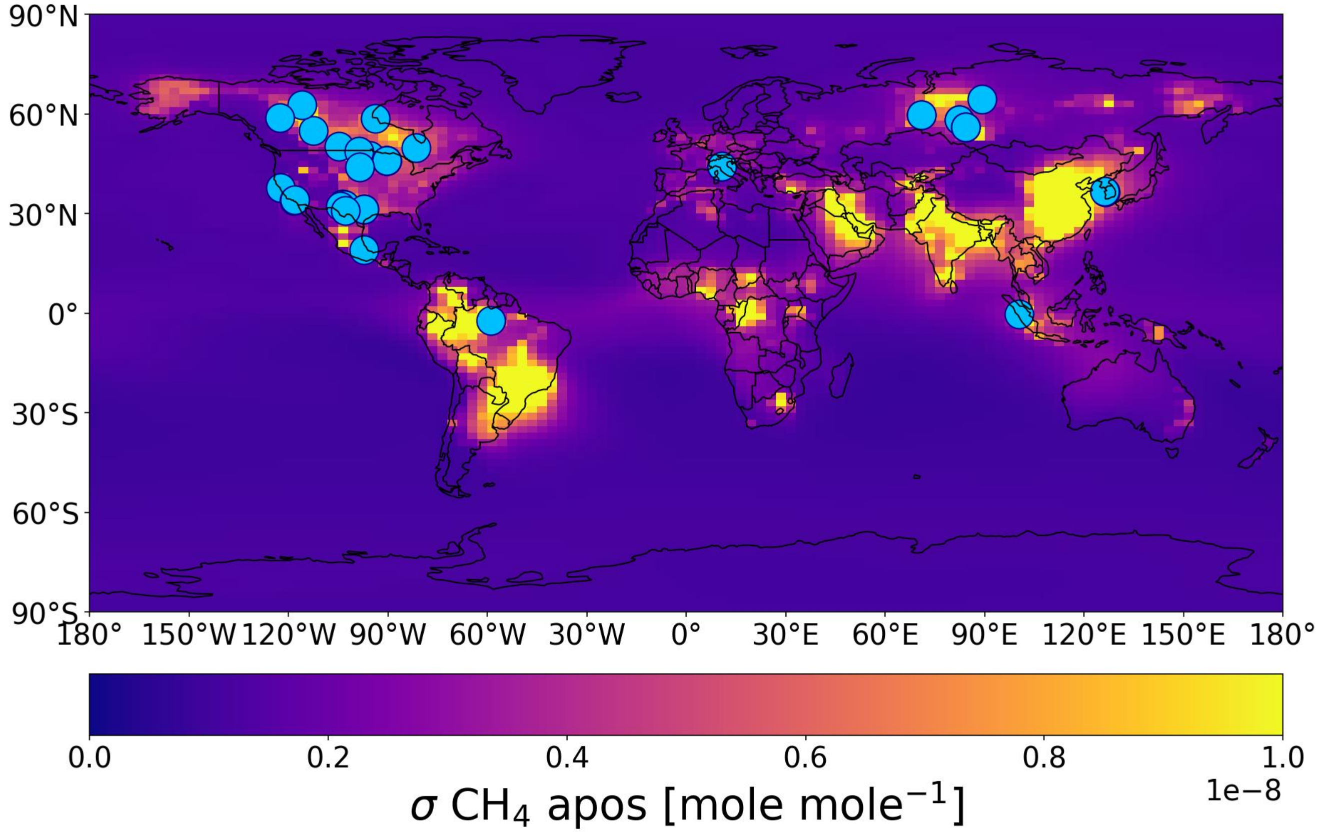
Validation

- Best OH field?
- $\sigma_{conc}(OH) = 2.27$ ppb
- $\varepsilon_{conc}(mod) >> \sigma_{conc}(OH)$

OH Field	RMSE validation [ppb]
EMAC	76.90
TCR-3	76.98
IFS-COMPO	77.13
IFC-CB05-BASCOE	76.91
SP-BR	77.61
EAC4	77.19



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Conclusion

- OH uncertainties
- 2021 methane growth
  - 41% - 119% emission based
- Regional budget
  - ~15% OH uncertainty
    - Overshadows local emission increment
    - South America
    - Southeast Asia

Questions?

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References (1/2)

- P. Ciais *et al*. Why methane surged in the atmosphere during the early 2020s. *Science* **391**, eadx8262 (2026). DOI: 10.1126/science.adx8262
- Nisbet et al. (2023). Atmospheric methane: Comparison between methane's record in 2006–2022 and during glacial terminations. Global Biogeochemical Cycles, 37, e2023GB007875. https://doi.org/10.1029/2023GB007875
- S.E. Michel et al., Rapid shift in methane carbon isotopes suggests microbial emissions drove record high atmospheric methane growth in 2020–2022, Proc. Natl. Acad. Sci. U.S.A. 121 (44) e2411212121, https://doi.org/10.1073/pnas.2411212121 (2024).
- Stevenson et al : COVID-19 lockdown emission reductions have the potential to explain over half of the coincident increase in global atmospheric methane, Atmos. Chem. Phys., 22, 14243–14252, https://doi.org/10.5194/acp-22-14243-2022, 2022.

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References (2/2)

- Peng, S., *et al*. Wetland emission and atmospheric sink changes explain methane growth in 2020. *Nature* **612**, 477–482 (2022). https://doi.org/10.1038/s41586-022-05447-w
- Pendergrass, D. C., et al: Trends and seasonality of 2019–2023 global methane emissions inferred from a localized ensemble transform Kalman filter (CHEEREIO v1.3.1) applied to TROPOMI satellite observations, Atmos. Chem. Phys., 25, 14353–14369, https://doi.org/10.5194/acp-25-14353-2025, 2025.
- Z. Qu, et al. Inverse modeling of 2010–2022 satellite observations shows that inundation of the wet tropics drove the 2020–2022 methane surge, *Proc. Natl. Acad. Sci. U.S.A.* 121 (40) e2402730121, https://doi.org/10.1073/pnas.2402730121 (2024).

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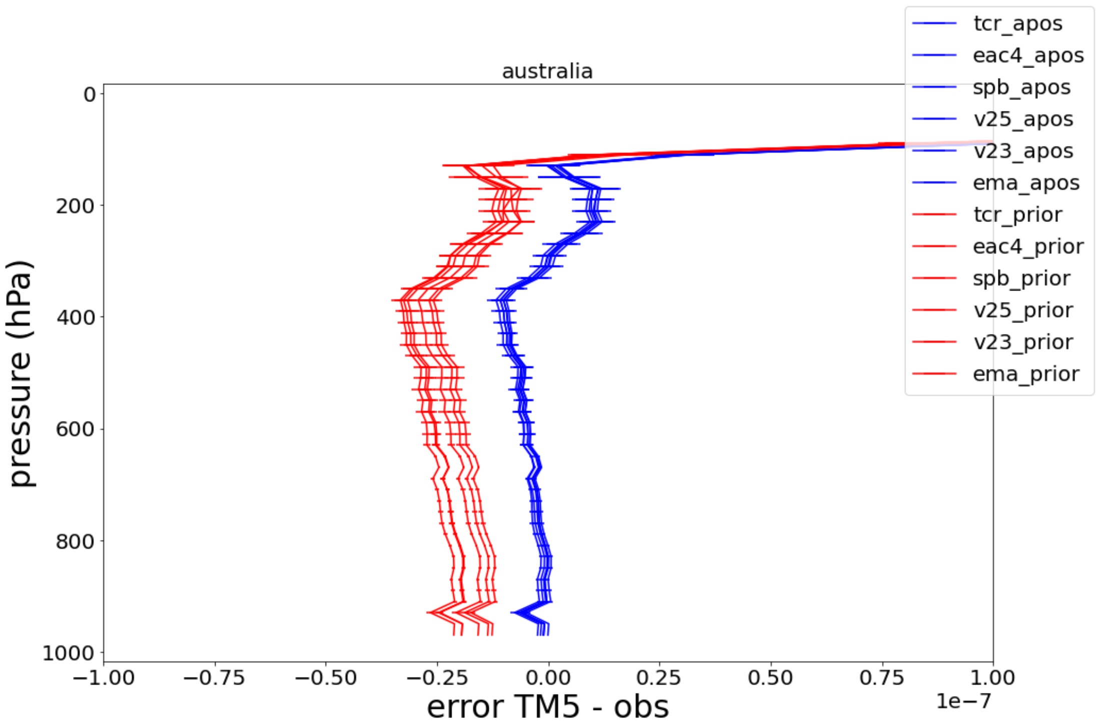
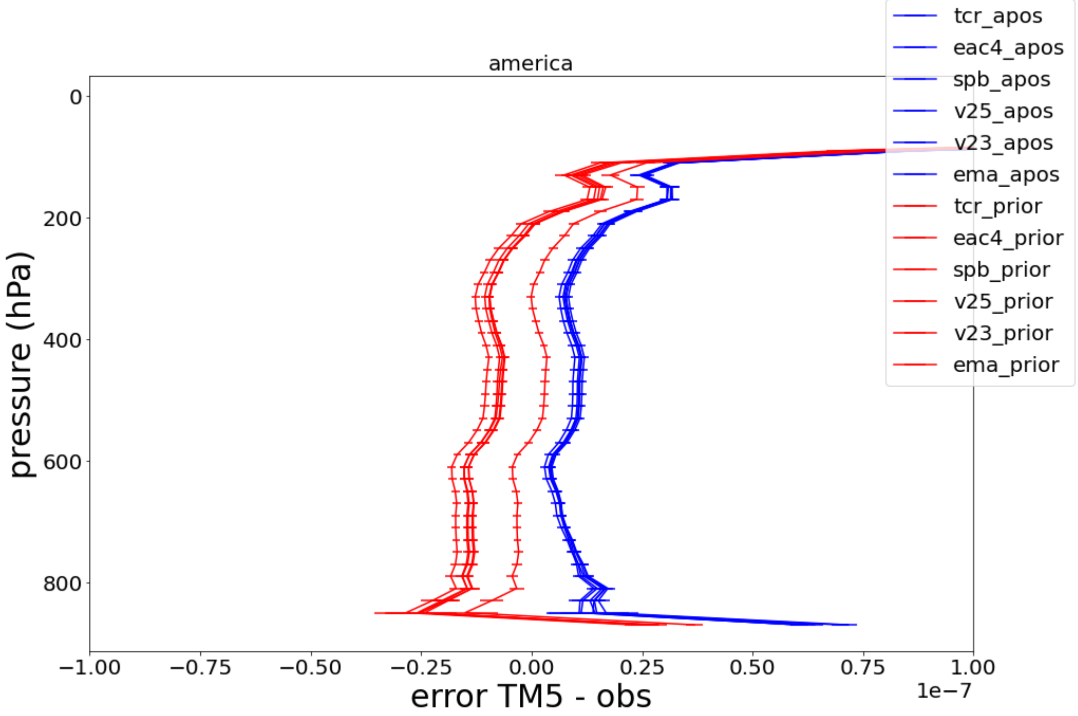

australia
pressure (hPa)
error TM5 - obs
1e−7
tcr_apos
eac4_apos
spb_apos
v25_apos
v23_apos
ema_apos
tcr_prior
eac4_prior
spb_prior
v25_prior
v23_prior
ema_prior


america
pressure (hPa)
error TM5 - obs
1e−7
tcr_apos
eac4_apos
spb_apos
v25_apos
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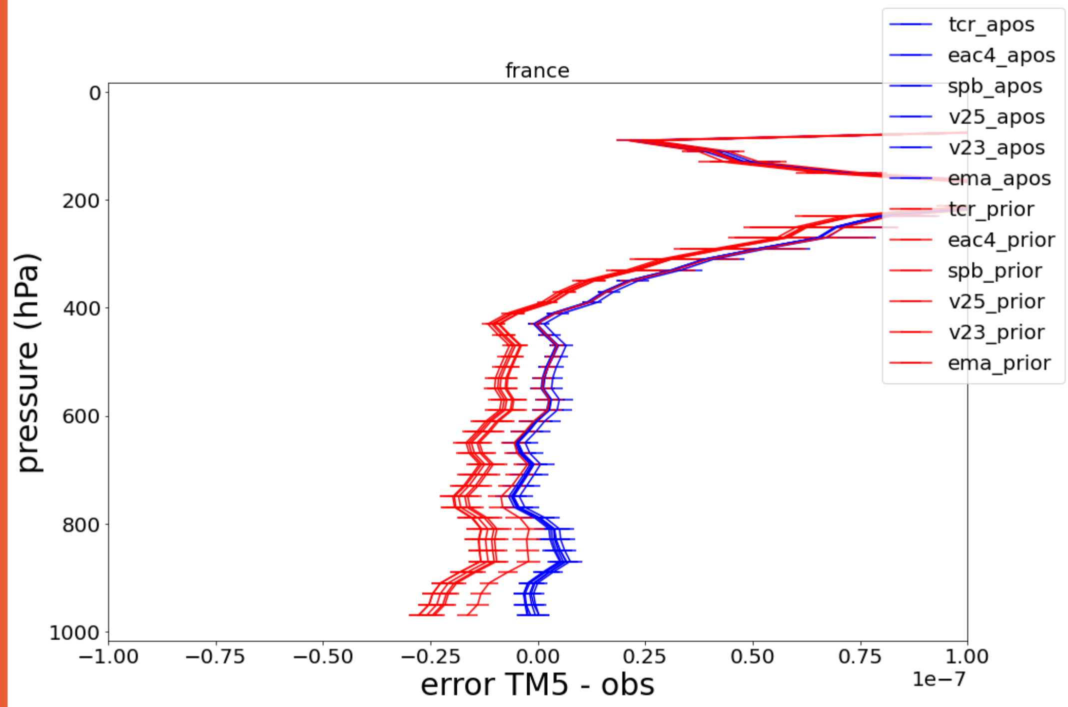
v25_prior
v23_prior
ema_prior


france
pressure (hPa)
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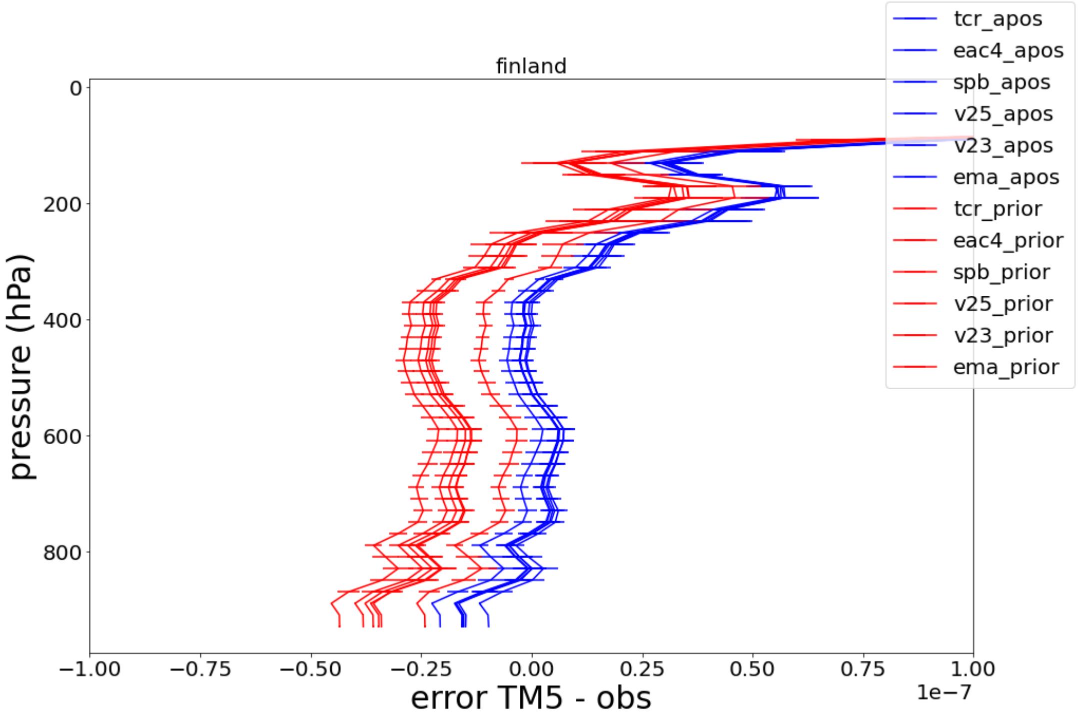
v25_prior
v23_prior
ema_prior


finland
pressure (hPa)
error TM5 - obs
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spb_apos
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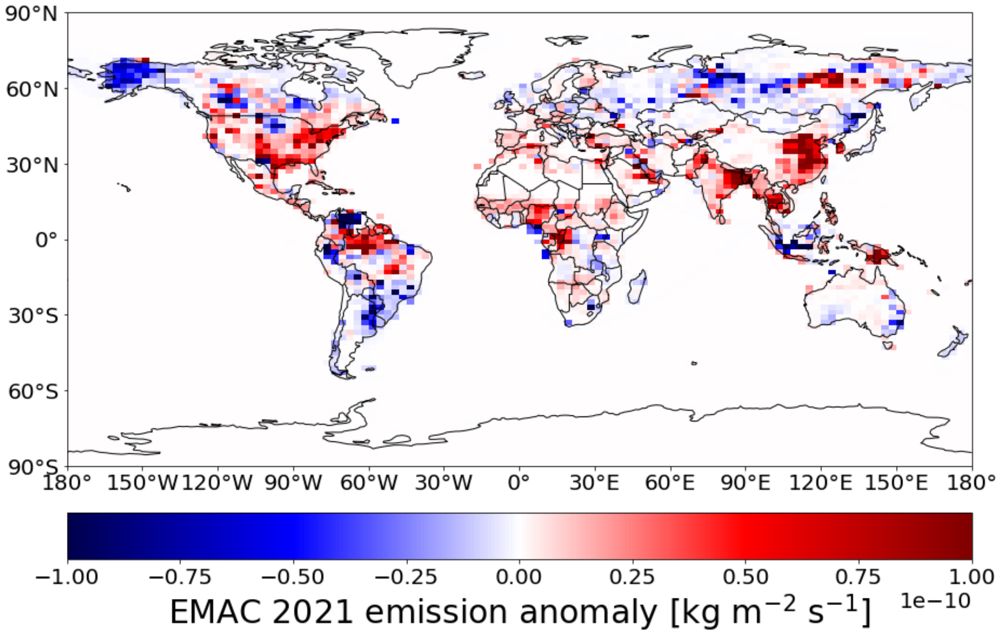
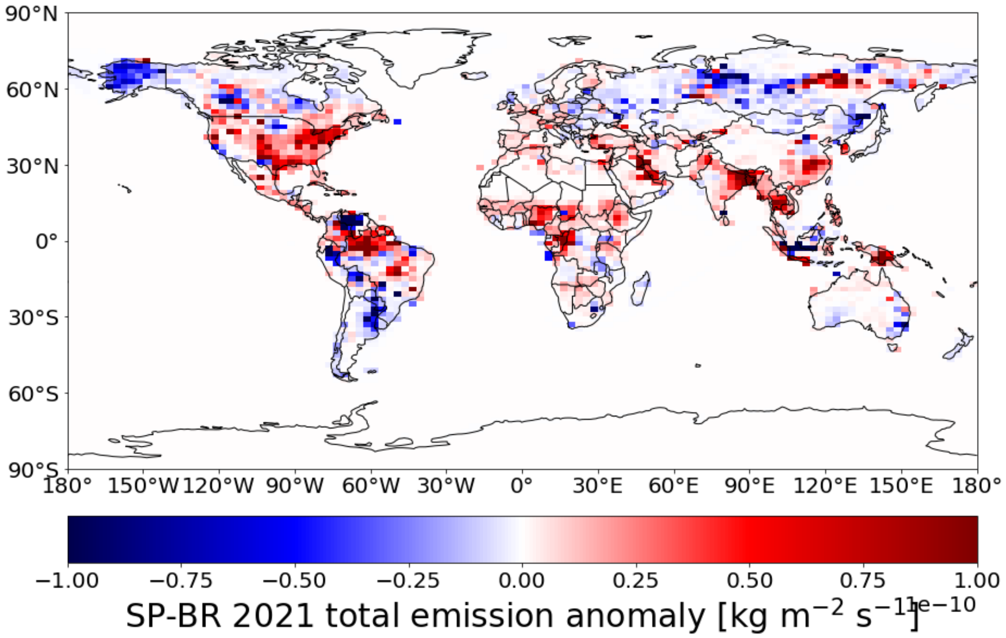
v25_prior
v23_prior
ema_prior


90°N
60°N
30°N
0°
30°S
60°S
90°S
180° 150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E 180°
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
1e−10
EMAC 2021 emission anomaly [kg m^{-2} s^{-1}]


90°N
60°N
30°N
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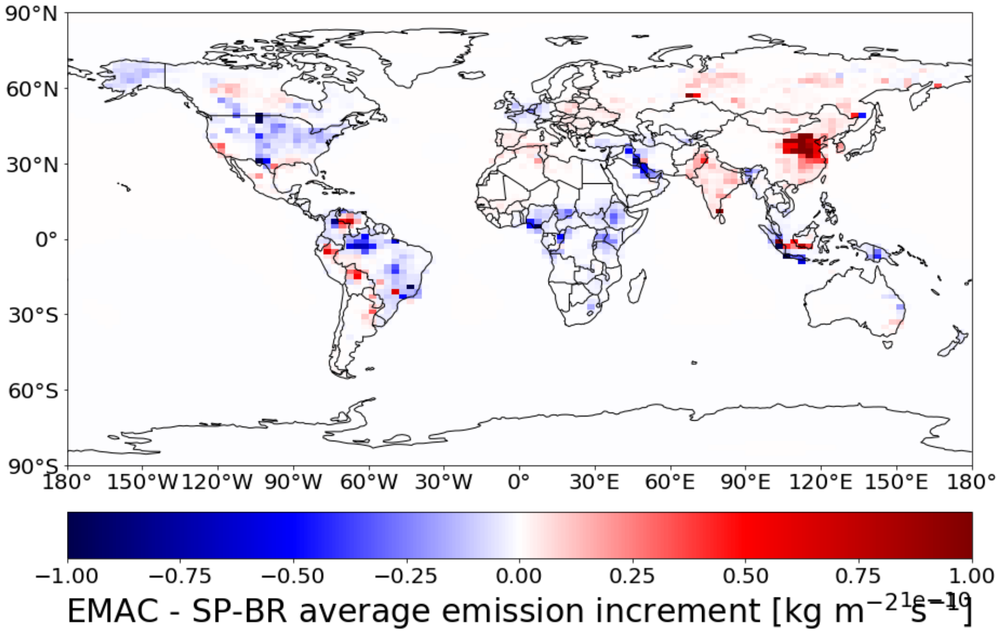
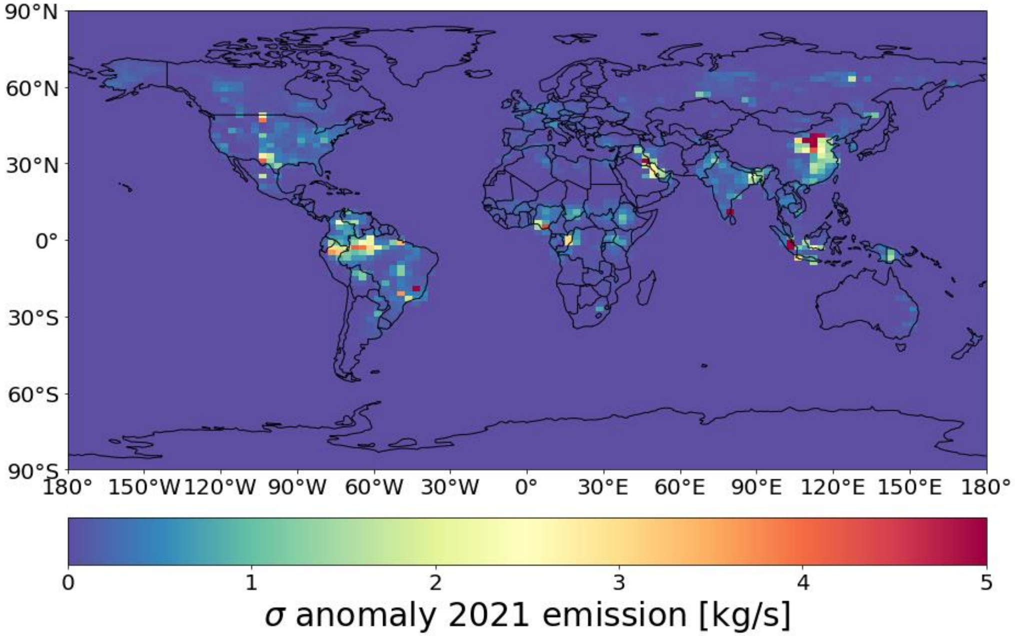
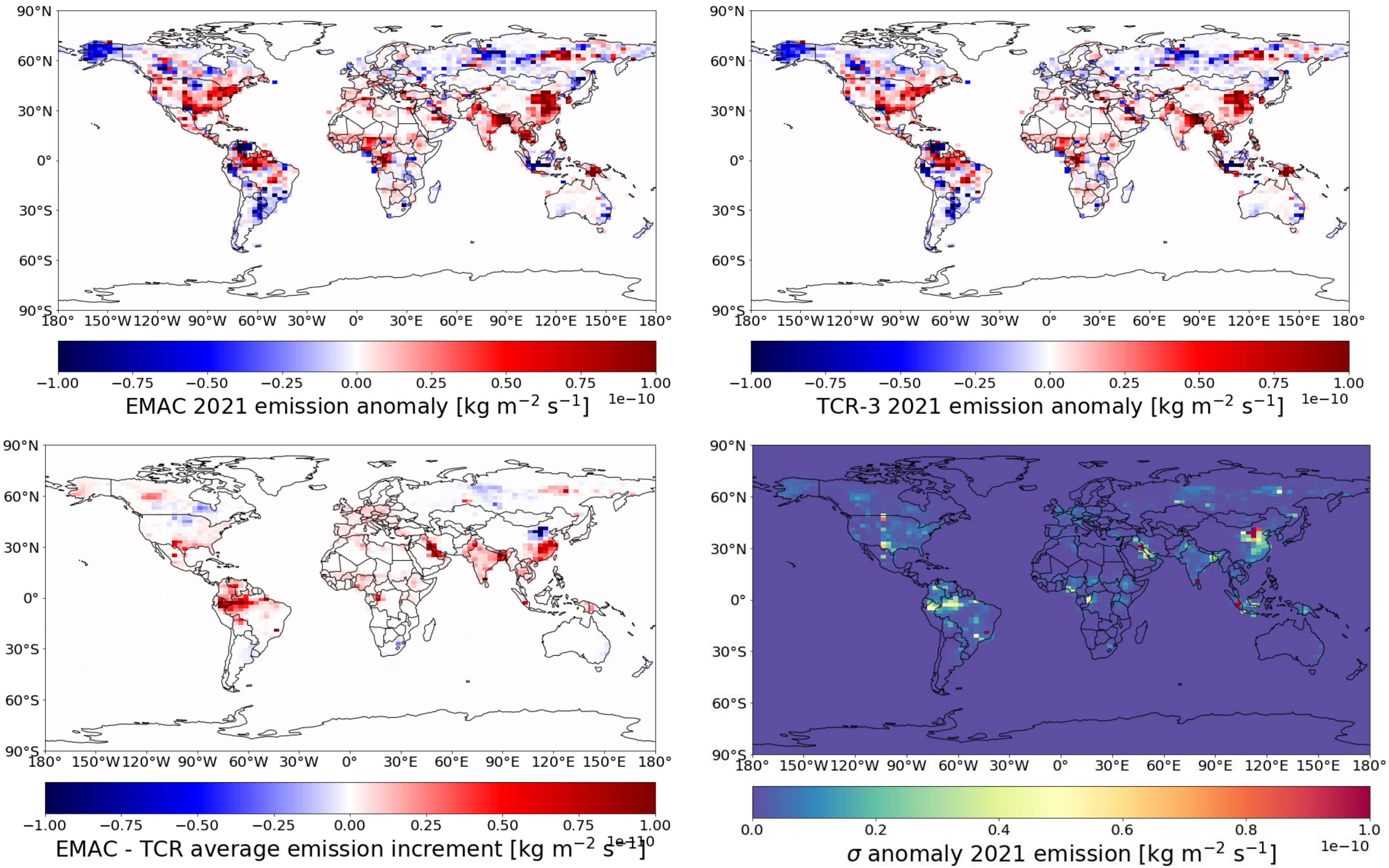
60°S
90°S
180° 150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E 180°
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
1e−10
SP-BR 2021 total emission anomaly [kg m^{-2} s^{-1}]

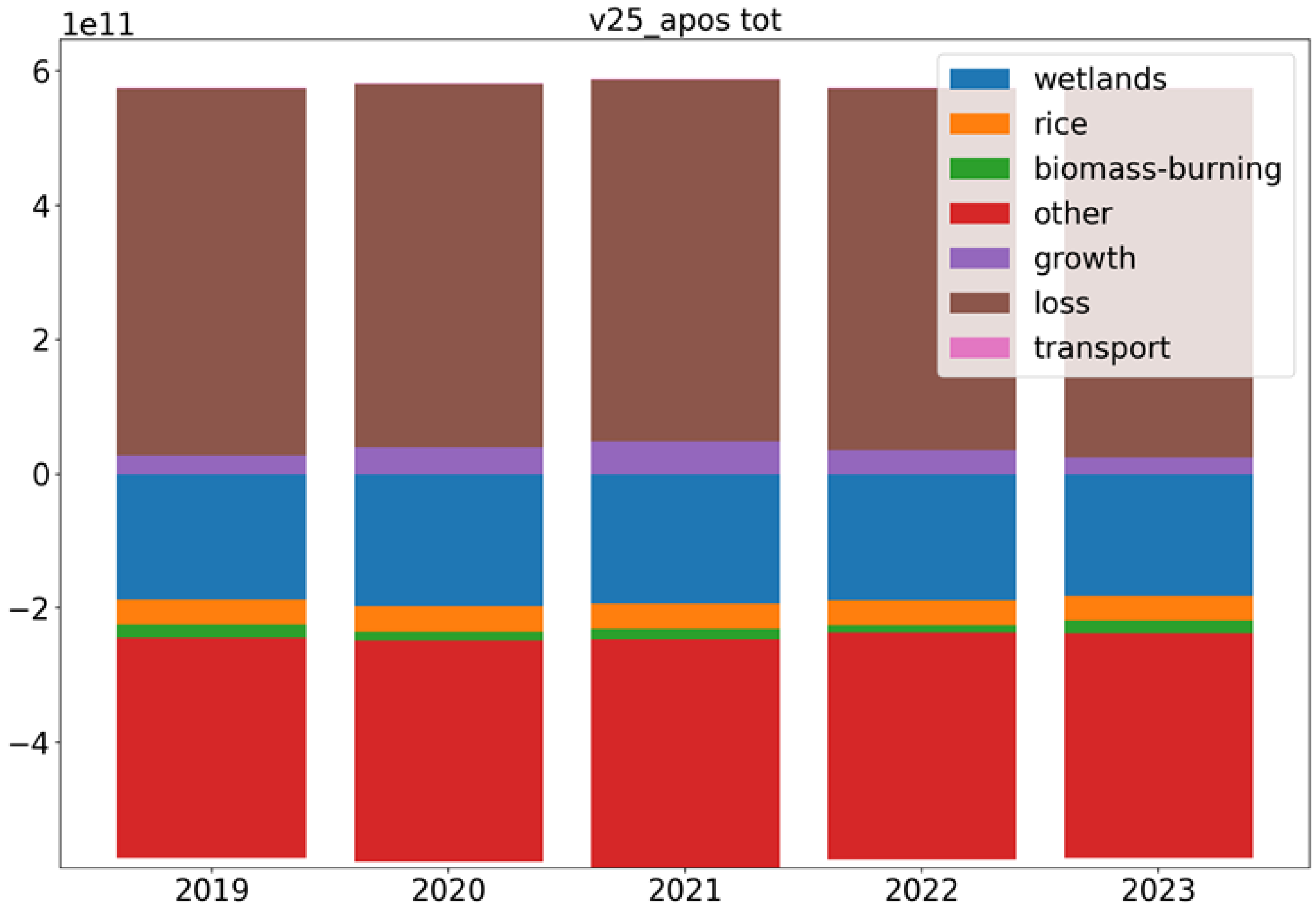

90°N
60°N
30°N
0°
30°S
60°S
90°S
180° 150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E 180°
−1.00 −0.75 −0.50 −0.25 0.00 0.25 0.50 0.75 1.00
1e−10
EMAC - SP-BR average emission increment [kg m^{-2} s^{-1}]


90°N
60°N
30°N
0°
30°S
60°S
90°S
180° 150°W 120°W 90°W 60°W 30°W 0° 30°E 60°E 90°E 120°E 150°E 180°
0 1 2 3 4 5
σ anomaly 2021 emission [kg/s]


EMAC 2021 emission anomaly [kg m^{-2} s^{-1}] 1e−10
TCR-3 2021 emission anomaly [kg m^{-2} s^{-1}] 1e−10
EMAC - TCR average emission increment [kg m^{-2} s^{-1}] 1e−10
σ anomaly 2021 emission [kg m^{-2} s^{-1}] 1e−10

Methane budget

- Growth = Emission – Loss
- Atmospheric growth small part of budget



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