Estimating Methane Emissions Consistent with Both Satellite and Isotope Constraints

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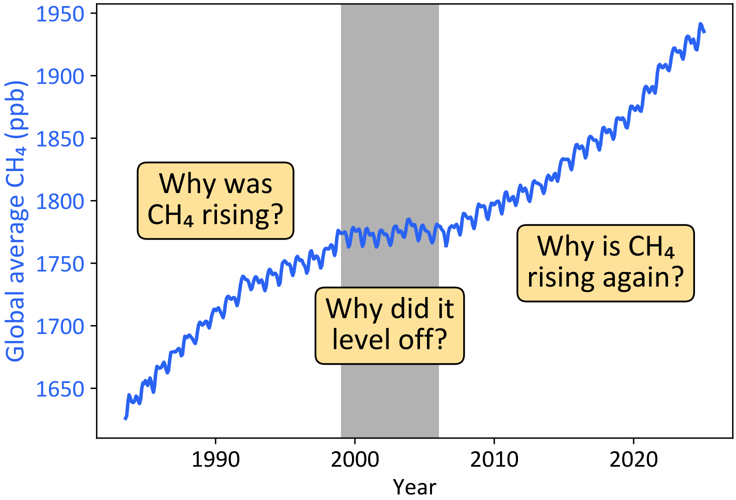
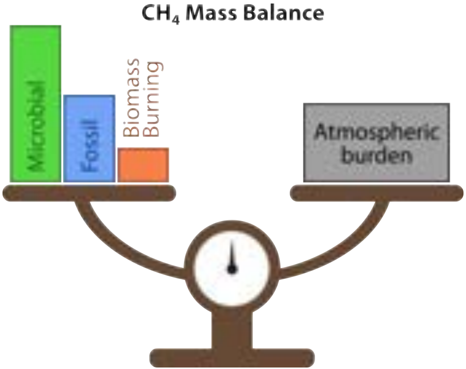
12th June 2025, Session 5, 12:00-12:15

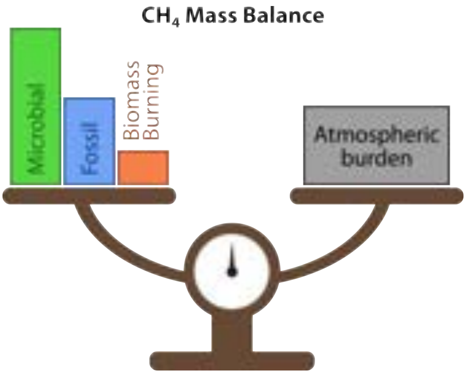


The leveling off of CH_4 in the early 2000's and its renewed growth after 2007 is a mystery with many possible explanations, but finding the right one is important for understanding current and future methane emissions and mitigation potential

What additional information can $\delta^{13}CH_4$ provide on top of CH_4 measurements?



Many combinations of sources can balance the atmospheric burden



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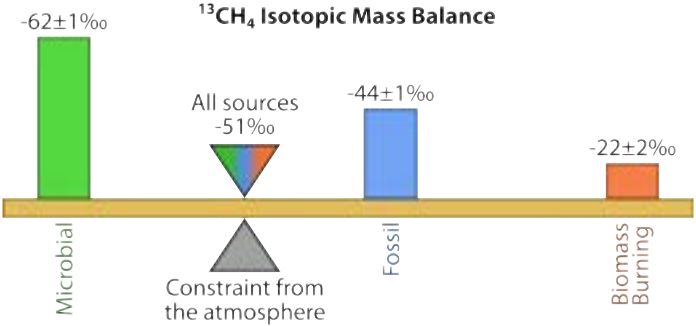
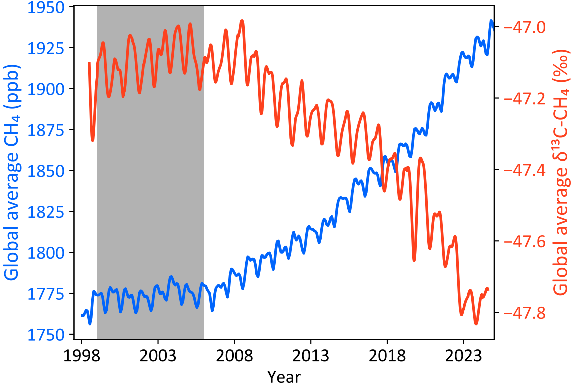
Different source types have different ^{13}C:^{12}C ratio, and the source distribution must match the ^{12}C and ^{13}C budgets

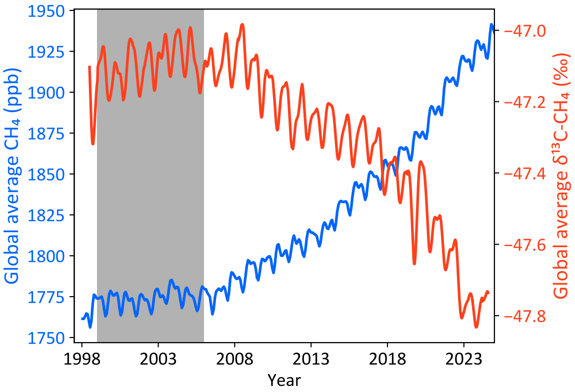


We have constructed an atmospheric inverse model with TM5 4DVAR to assimilate CH_4 and $\delta^{13}CH_4$ measurements and estimate source-specific emissions

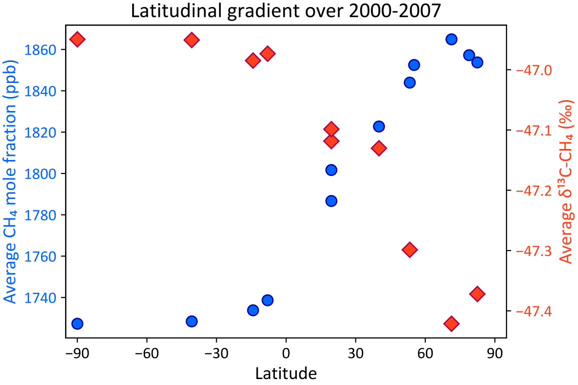


Through most of the 20th century, $\delta^{13}CH_4$ has been increasing due to increasing fossil emissions. After ~2007, the trend reversed, pointing to influence of lighter sources.

Some context for $\delta^{13}CH_4$ observations and modeling



$\delta^{13}CH_4$ is lower in the Northern Hemisphere because the average $\delta^{13}CH_4$ of all sources is lower than the atmosphere (CH_4 oxidation makes it heavier)



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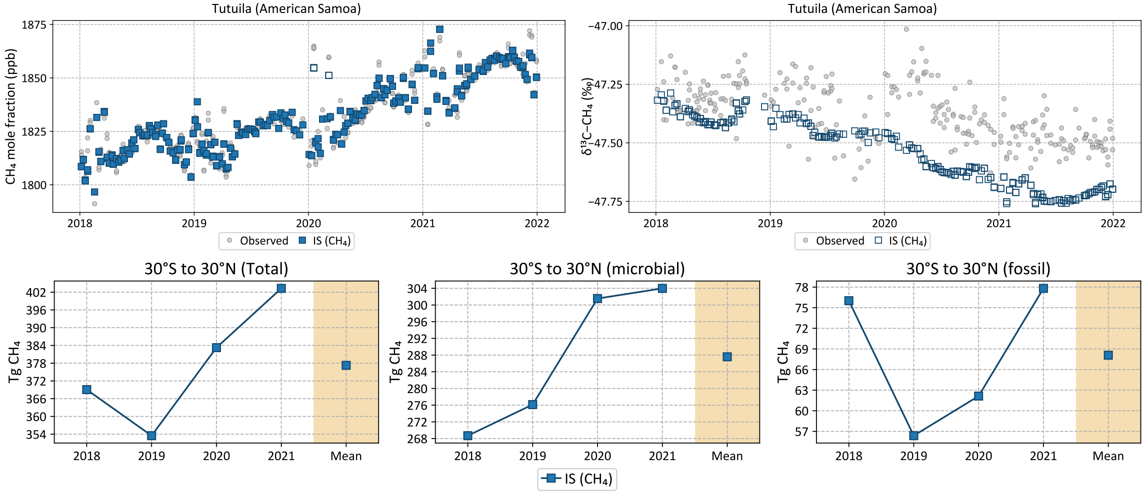
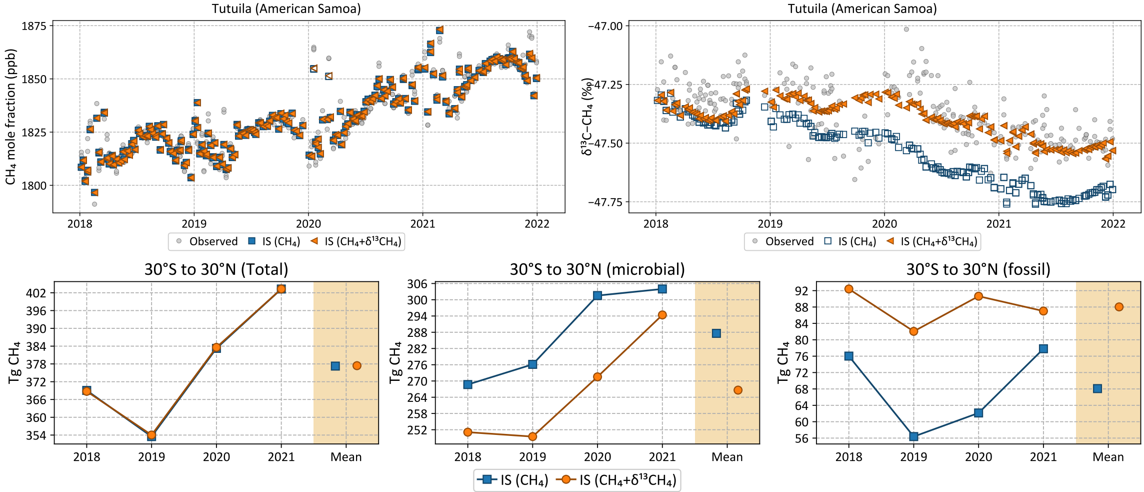
A CH_4-only inversion yields incorrect source partitioning



A CH_4-only inversion is not guaranteed to fit atmospheric $\delta^{13}CH_4$ measurements, so unlikely to have the right partitioning between different source types unless the priors are already correct



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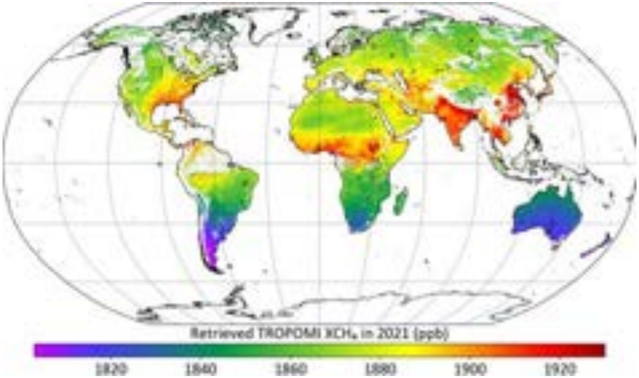
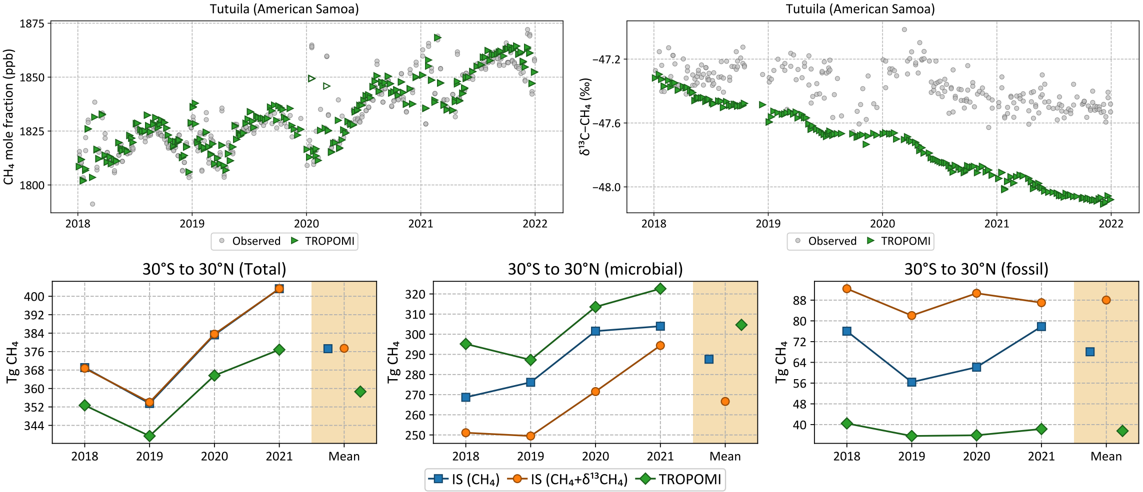
- SWIR XCH_4 retrievals starting 2018
- Current data selection:
  - Use only land data
  - Assimilate all retrievals with QA >= 0.5
  - Exclude snow & ice land retrievals (Lindqvist et al, 2024)
- High data density (~300,000/day) leads to highly correlated retrieval errors, so inflate XCH_4 error based on the number of neighbors within 100 km and 30 min
- Isn't source-specific except when different source types are spatially separated



Are TROPOMI retrievals consistent with in situ CH_4 and $\delta^{13}CH_4$ obs?



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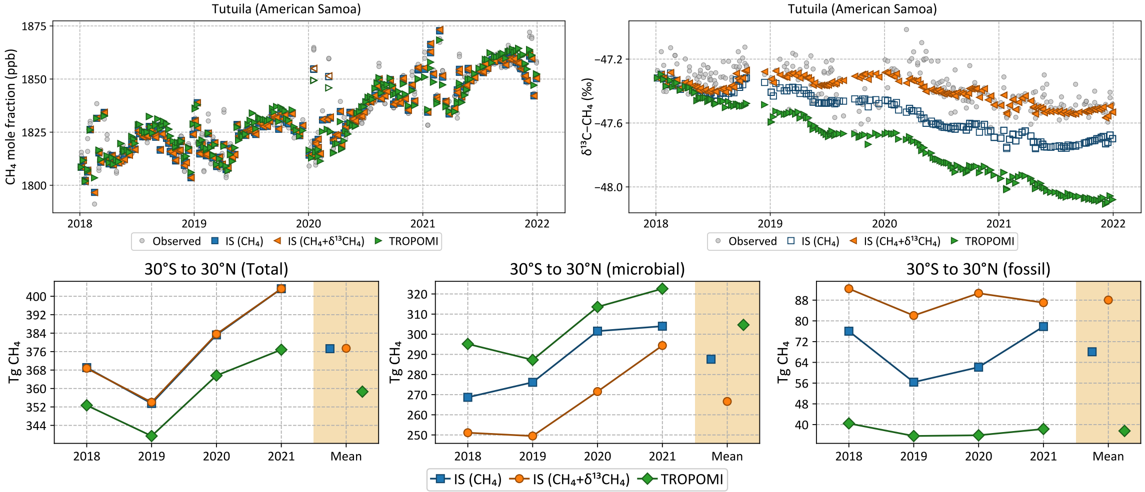
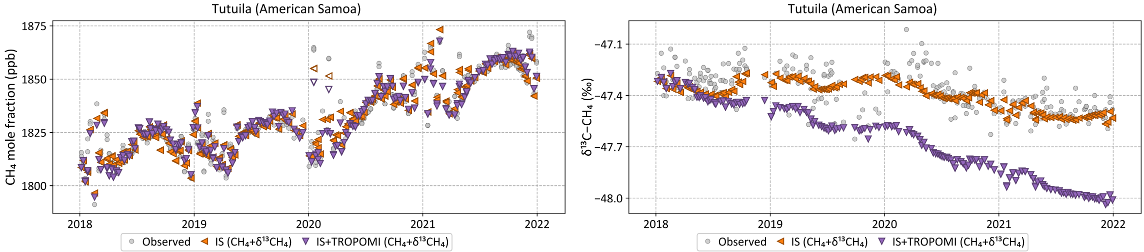


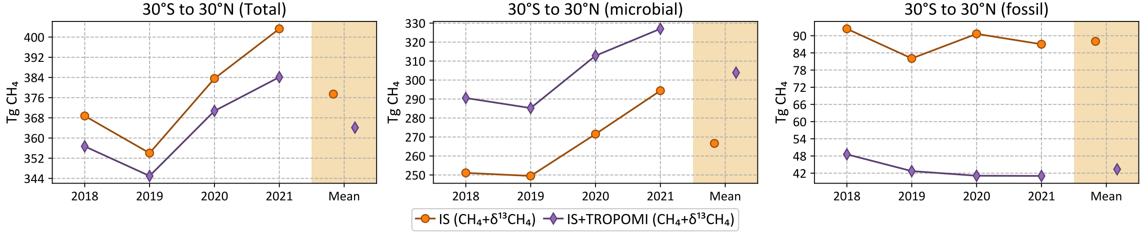
TROPOMI and $\delta^{13}CH_4$ pull the source mixture in opposite directions, at least in the Tropics

Can we just combine TROPOMI XCH_4 and in situ $\delta^{13}CH_4$?

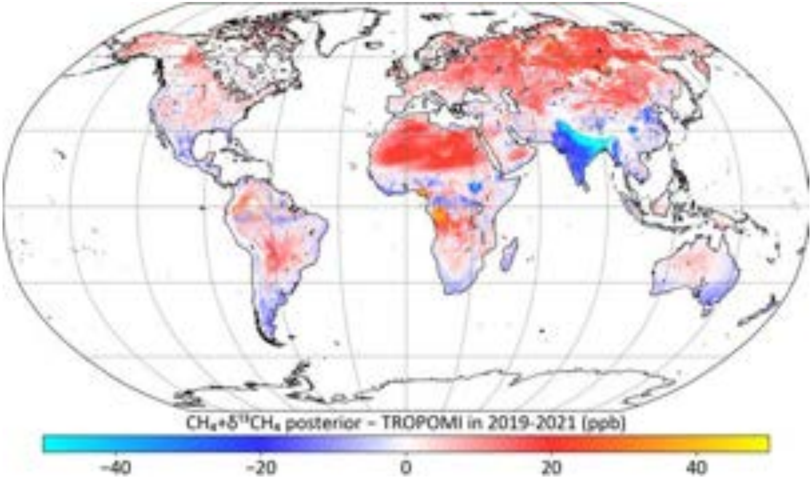
In a 1-box model of the atmosphere, this would be no problem. TROPOMI would provide a very strong constraint on the total CH_4 emissions, while $\delta^{13}CH_4$ would provide information to split that into different source types.

What happens when we try with the real atmosphere?



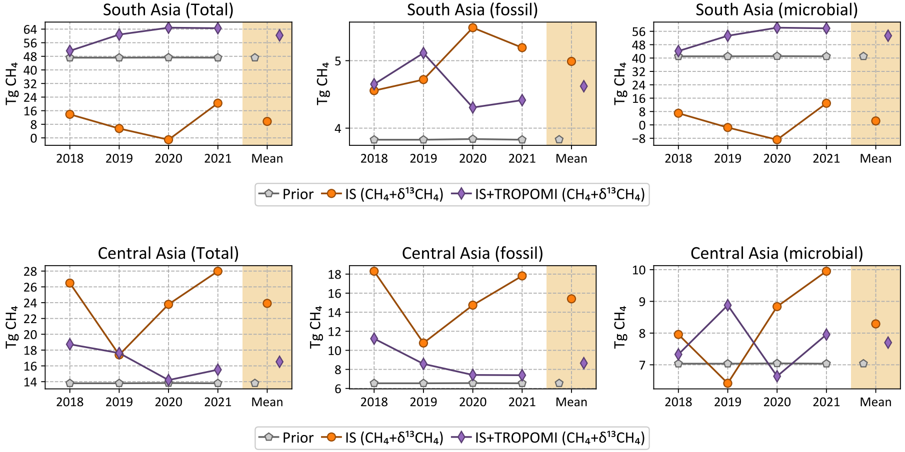


The partitioning is "wrong enough" with TROPOMI data that in situ $\delta^{13}CH_4$ can't fix it



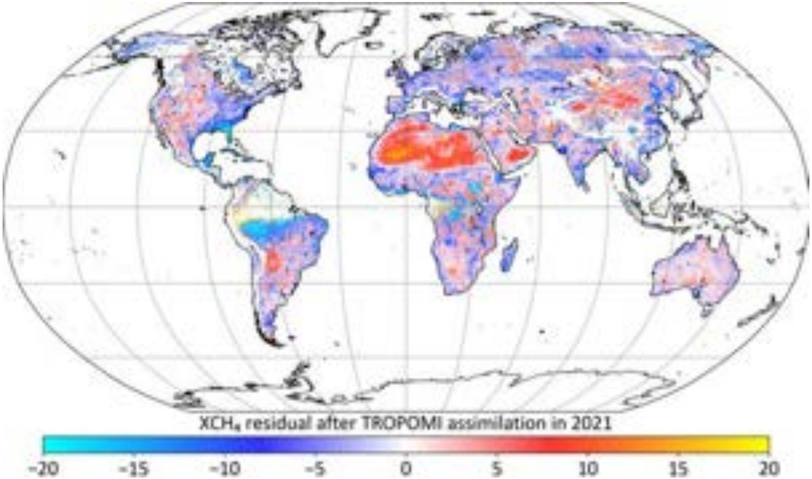
Adding TROPOMI XCH_4 will increase emissions over the blue regions and decrease them over the red regions, compared to an insitu-only $CH_4+\delta^{13}CH_4$ inversion

Why does this happen? Possibility 1



The total CH_4 estimates from TROPOMI are probably more accurate, but the source-specific adjustments are restricted by the priors

Why does this happen? Possibility 2



TROPOMI XCH_4 seems to have a low bias over high-albedo high-aerosol scenes,

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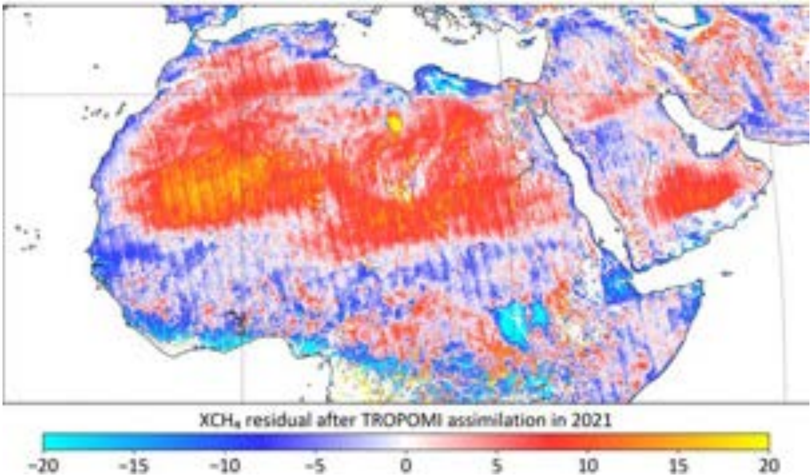

TROPOMI XCH_4 seems to have a low bias over high-albedo high-aerosol scenes, and a weird striping pattern that cannot exist in column CH_4

- Mathematically, the join assimilation of TROPOMI XCH_4 and in situ $\delta^{13}CH_4$ is feasible. In theory, XCH_4 should provide a tight constraint on total CH_4 emissions, while $\delta^{13}CH_4$ should split it among source types.
- In practice, TROPOMI assimilation is consistent with in situ CH_4 but not $\delta^{13}CH_4$
- We should be checking satellite-derived CH_4 fluxes, especially their sectoral attributions, against data such as $\delta^{13}CH_4$ that provide independent sectoral information

Take home points

- Mathematically, the join assimilation of TROPOMI XCH_4 and in situ $\delta^{13}CH_4$ is feasible. In theory, XCH_4 should provide a tight constraint on total CH_4 emissions, while $\delta^{13}CH_4$ should split it among source types.
- In practice, TROPOMI assimilation is consistent with in situ CH_4 but not $\delta^{13}CH_4$
- We should be checking satellite-derived CH_4 fluxes, especially their sectoral attributions, against data such as $\delta^{13}CH_4$ that provide independent sectoral information
- Part of the problem is that the relative magnitude of priors in some parts of the world are not consistent with atmospheric $\delta^{13}CH_4$
- TROPOMI XCH_4 retrievals also seem to have albedo dependent artifacts and some sort of across-orbit bias pattern (striping), working on better data selection