Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations

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Chen, Z., Jacob, D., Nesser, H., Sulprizio, M., Lorente, A., Varon, D., Lu, X., Shen, L., Qu, Z., Penn, E., and Yu, X.: Methane emissions from China: a high-resolution inversion of TROPOMI satellite observations, Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2022-303, 2022.

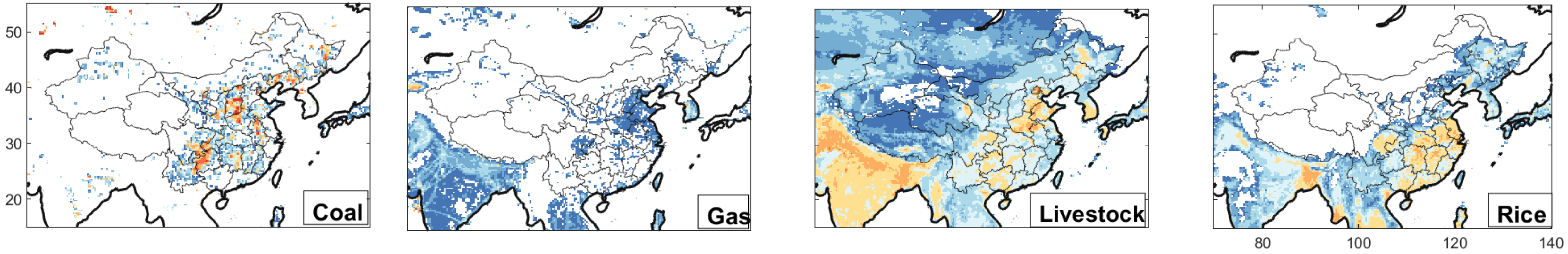
China plays a large but uncertain role in global methane emissions.
46-74 Tg a^{-1} out of a global anthropogenic source of 349-393 Tg a^{-1}

Largest coal producer

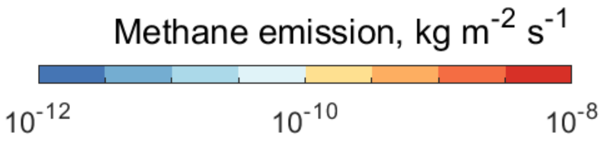
Coal-to-gas transition;
15% energy supply by 2030

Major livestock production

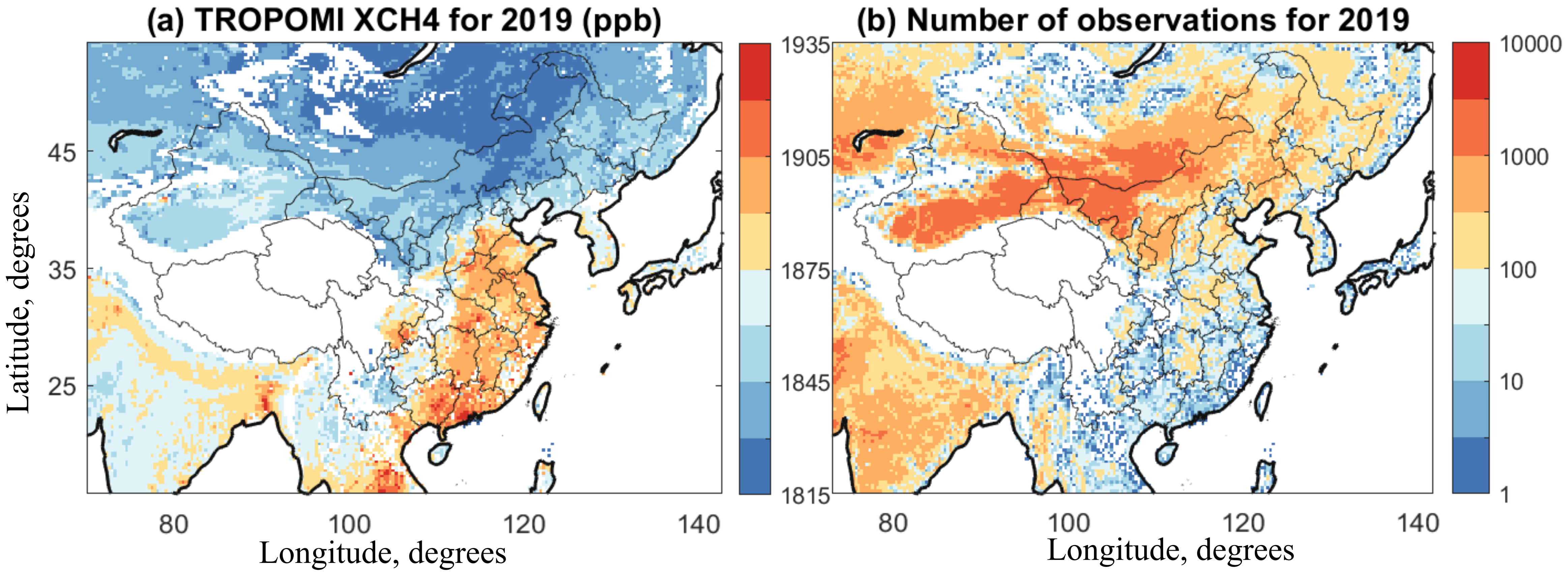
Rice paddies



UNFCCC-based GFEI v2 (*Scarpelli et al.*, 2022)



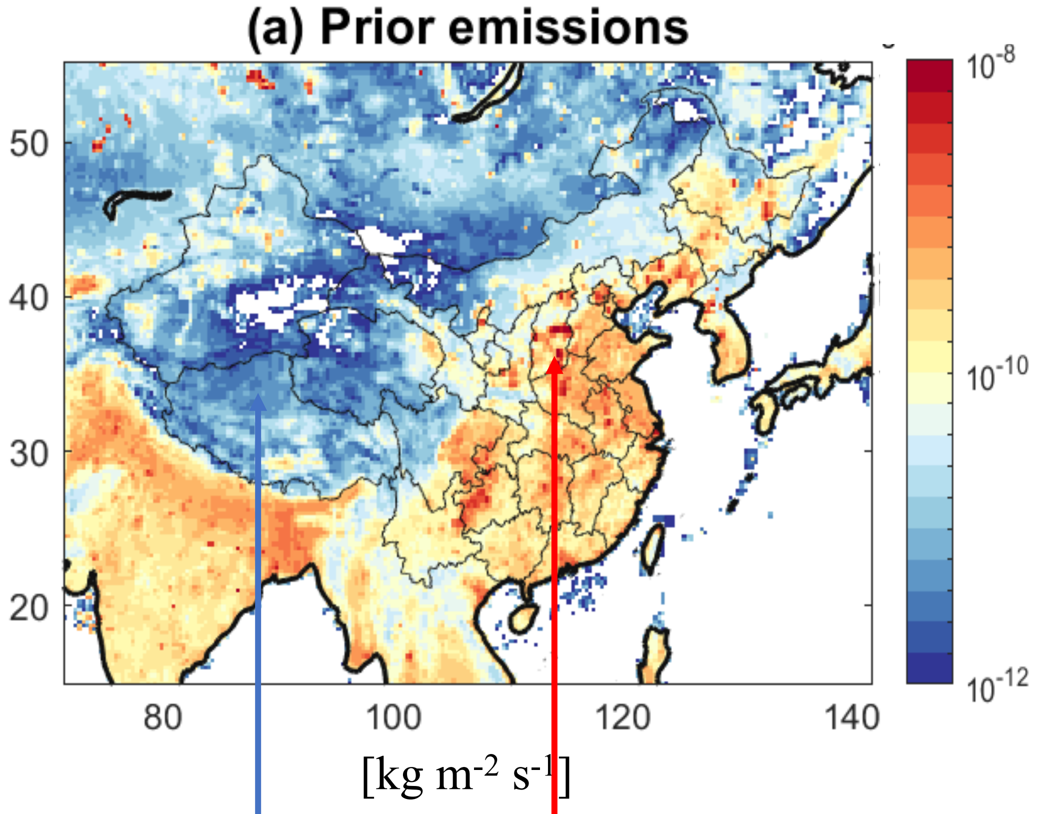
Using TROPOMI satellite data to infer emissions



- Data available since May 2018
- Footprint 7/5.5 km ×7km
- 4% retrieval success limited by clouds, surface heterogeneity, aerosols
- Quality flag >0.5
- Surface altitude<2000m
- Filtering for snow-covered scenes
- Comparing with GOSAT

Chen et al, ACPD, 2022

Analytical inversion setups



1. retaining native resolution for strong localized source

2. merging weak source regions

1. GEOS-Chem forward model (v13.0.0), GEOS-FP **0.25°×0.3125°** met field.

2. Oil, gas, and coal are from UNFCCC-based GFEIv2, Other anthropogenic emissions (livestock, landfills, wastewater, rice) are from UNFCCC with allocation from EDGARv432;
Wetland are from WetCHARTs (*Ma et al.*, 2021).

3. Gaussian mixture model (GMM) of *Turner* and *Jacob* (2015) with 600 state vector elements to find suitable dimension.

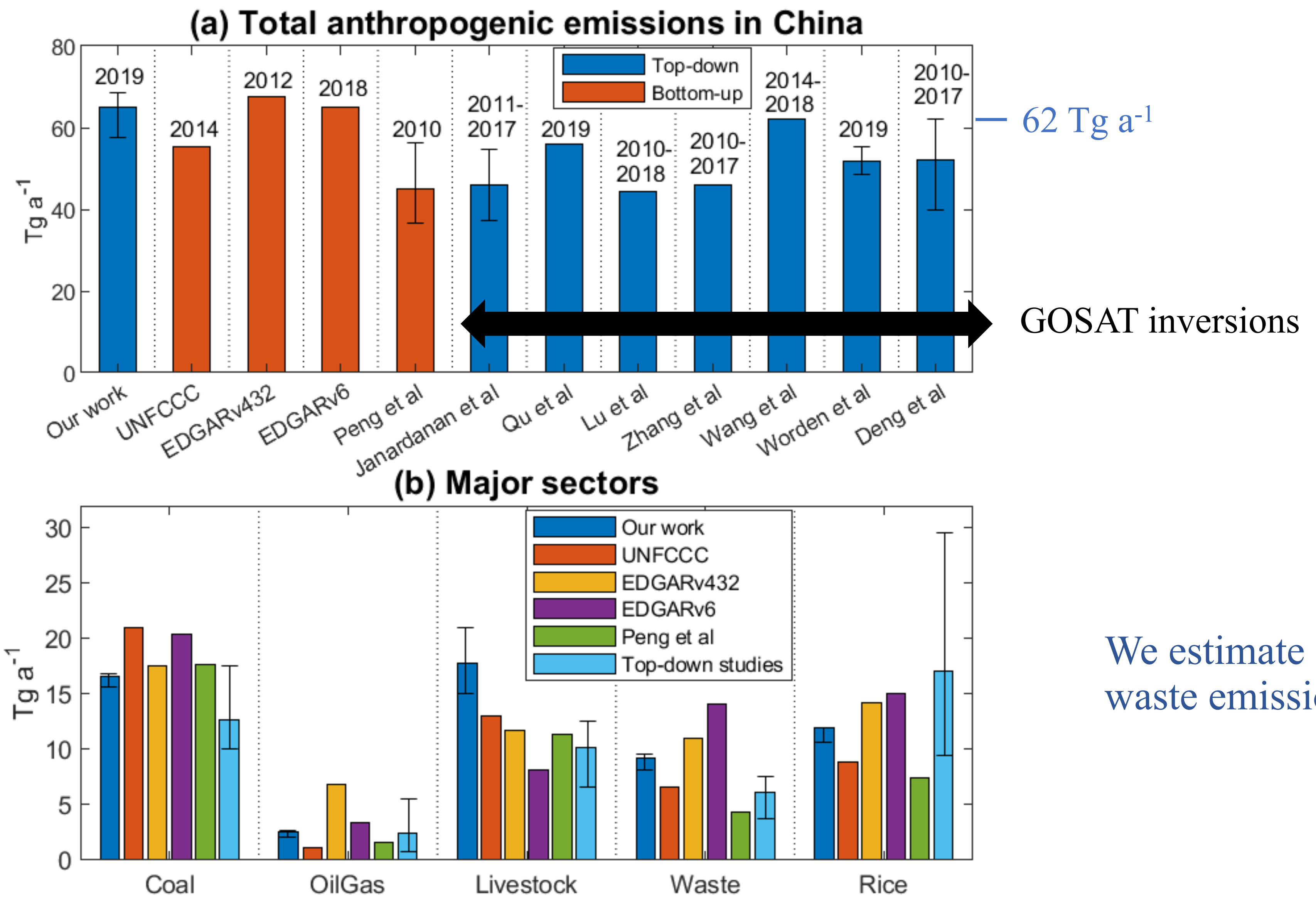
4. Log-normally distributed errors for high-tailed emission PDFs.

Underestimate of anthropogenic emissions in the national government report

	Prior estimate ($Tg\ a^{-1}$)	Posterior estimate ($Tg\ a^{-1}$)	Sensitivity to observations
Anthropogenic	**53.6**	**65.0 (57.7-68.4)**	0.91
Coal mining	**19.5**	**16.6 (15.6-17.6)**	0.91
Oil	**0.93**	**2.3 (1.8-2.5)**	0.76
Natural gas	**0.18**	**0.29 (0.23-0.32)**	0.30
Livestock	13.0	17.8 (15.1-21.0)	0.75
Waste	6.6	9.3 (8.2-9.9)	0.71
Rice paddies	8.9	11.9 (10.7-12.7)	0.86
Other	4.6	6.7 (5.8-7.1)	0.81

Downward correction in coal (-15%).
Upward correction in **oil (+147%), natural gas (+61%)**, livestock (+37%), waste (+41%), and rice (+34%).

Also higher than recent top-down studies



We estimate larger livestock, coal, and waste emissions.

We obtain a small loss rate, does that indicate net climate benefits from the coal-to-gas transition in China?

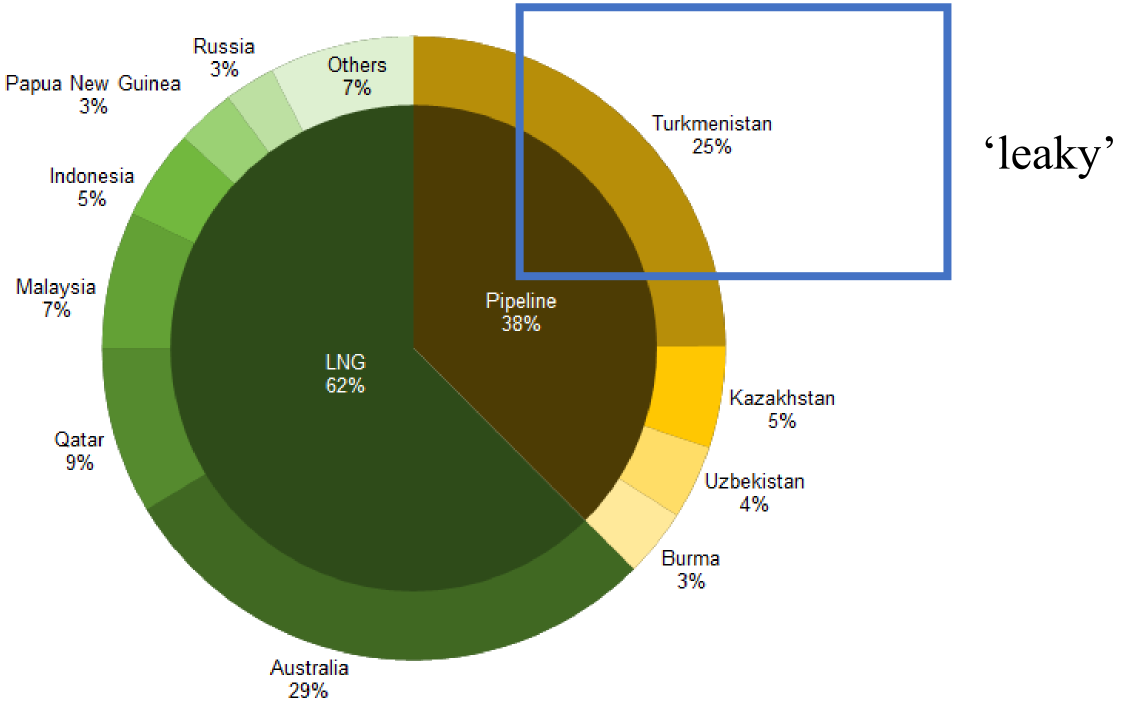
Loss rate: emissions per unit of domestic gas production

Supply chain break-even loss rate: **3.2%** (*Alvarez et al.*, 2012), beyond which climate damage of gas is worse than coal.

Our result for China: **1.7 (1.3-1.9) %**

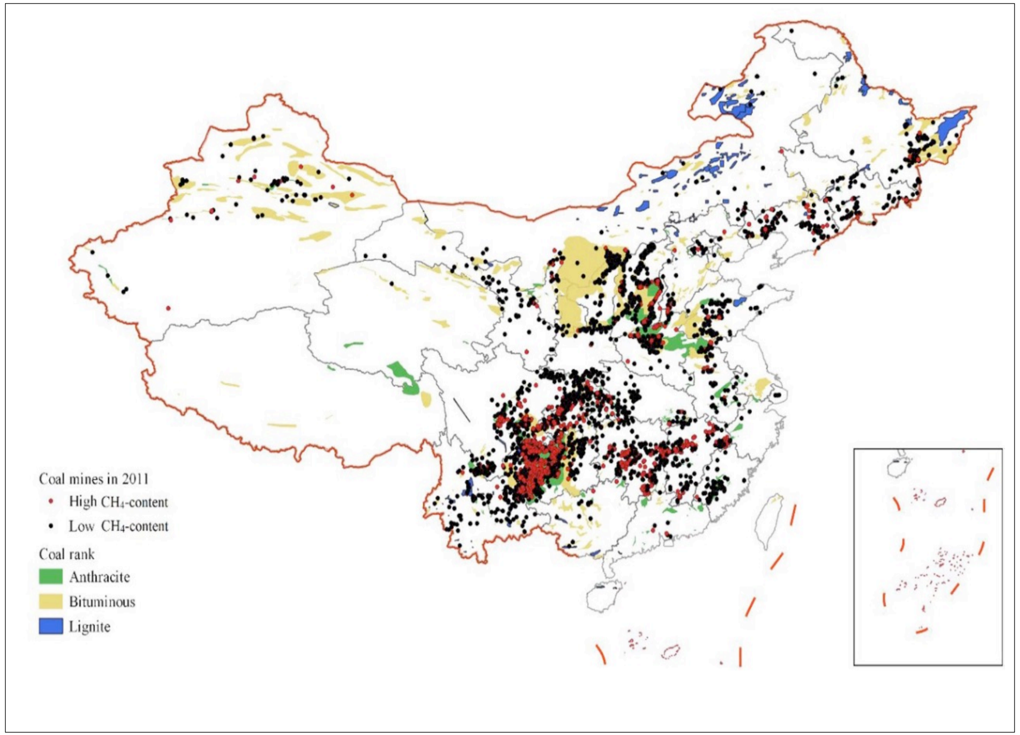
However, this low loss rate could be somewhat misleading.

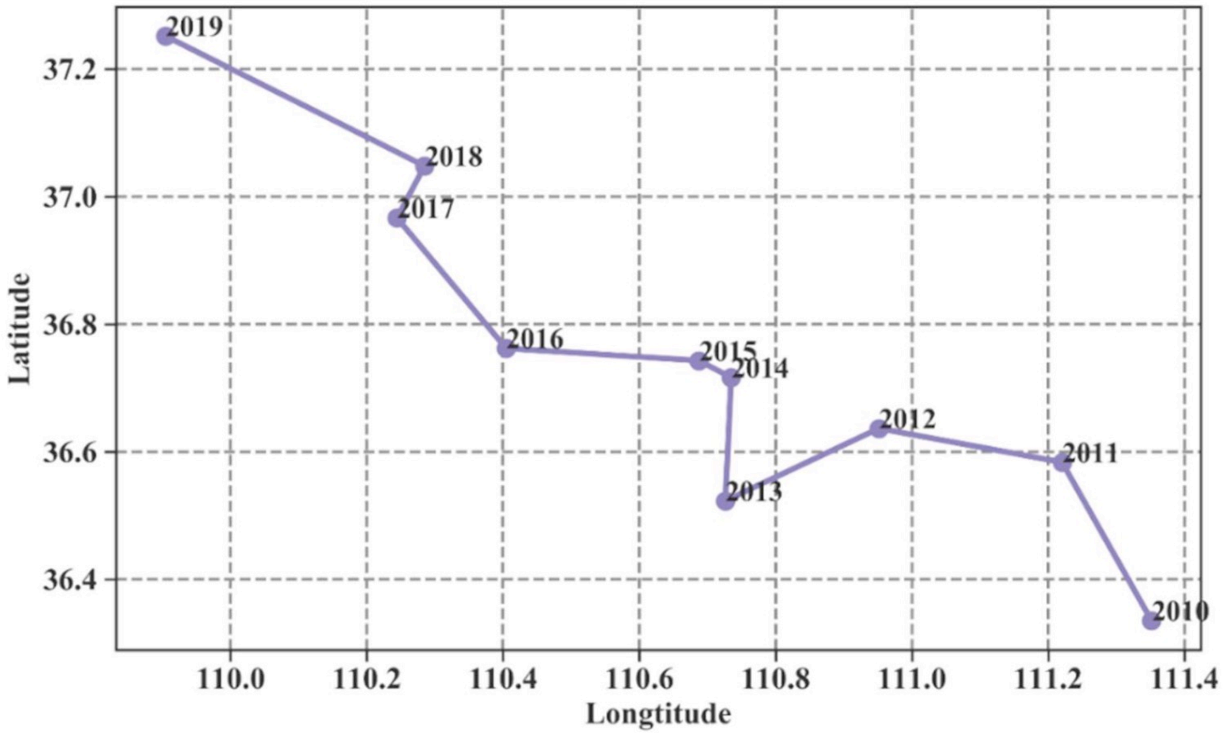
China imports 42% of its gas.



EIA, 2020

Downward correction of **coal** emissions





Gao et al., 2020

- Closure of mines with low coal production efficiency.
- Regional shift of coal productions, driven by de-capacity policies in China.

Overestimate of EFs

[*more than **6000** coal mines were closed over 2010–2019 due to the de-capacity policies*]

Under-accounting of surface mines and coal mine methane (CMM) utilization

Coal mining industry is shifting rapidly for economic, safety, and political reasons – a new coal inventory with up-to-date coal emission locations is essential for an effective inversion.

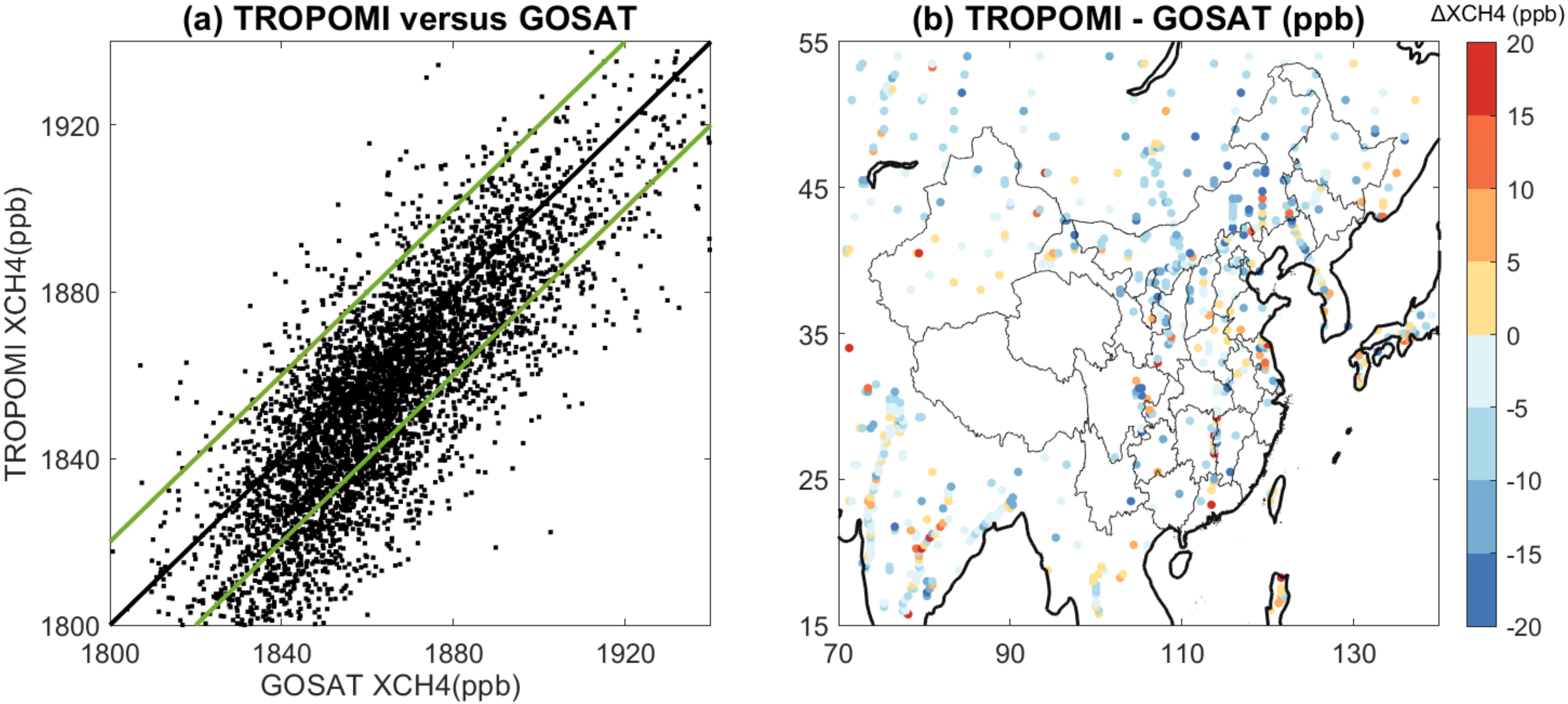
Conclusions

We quantify methane emissions in China and the contributions from different sectors by inverse analysis of 2019 TROPOMI satellite observations of atmospheric methane:

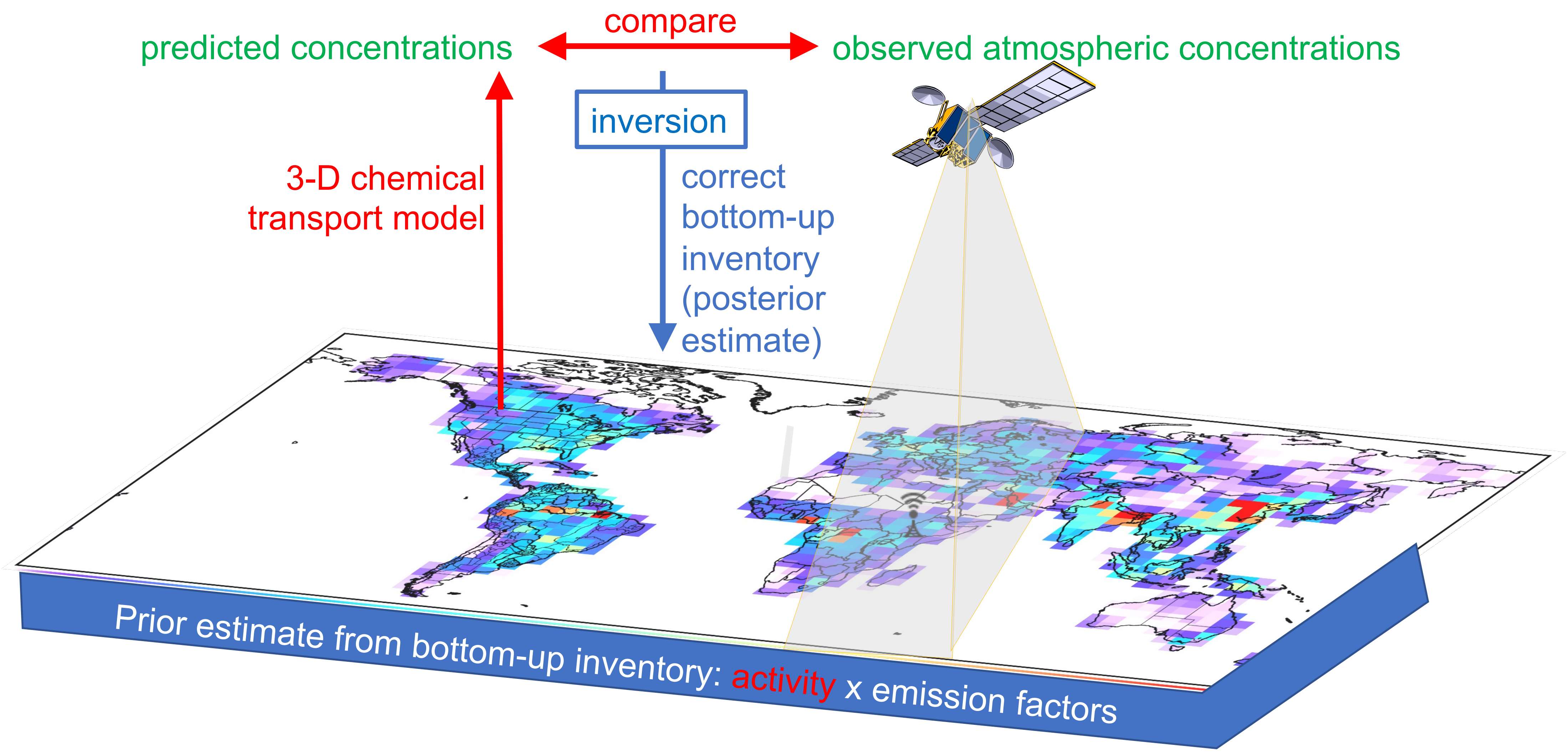
- Our estimate is 21% higher than the Chinese inventory reported to the UNFCCC (53.6 Tg a^{-1}), reflecting upward corrections to emissions from oil (+147%), gas (+61%), livestock (+37%), waste (+41%), and rice paddies (+34%), but downward correction for coal (-15%).
- We are better able to separate coal and rice emissions.
- Our higher livestock emissions are attributed largely to northern China where GOSAT has little sensitivity.
- Underestimate of oil emissions in the UNFCCC report appears to reflect unaccounted super-emitting facilities.
- Our estimate of emissions per unit of domestic gas production indicates a low life-cycle loss rate of 1.7 (1.3-1.9) %, which would imply net climate benefits from the current coal-to-gas energy transition in China. However, this small loss rate is somewhat misleading considering China's high gas imports.
- Coal mining industry is shifting rapidly in China, and therefore a new coal inventory with up-to-date coal emission locations is essential for inversion.

Extra slides

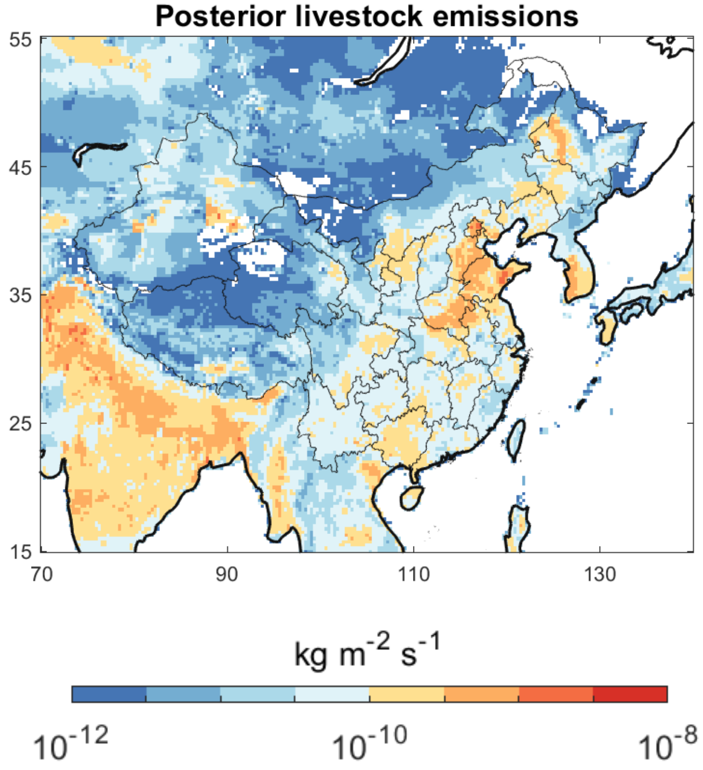
TROPOMI-GOSAT comparison

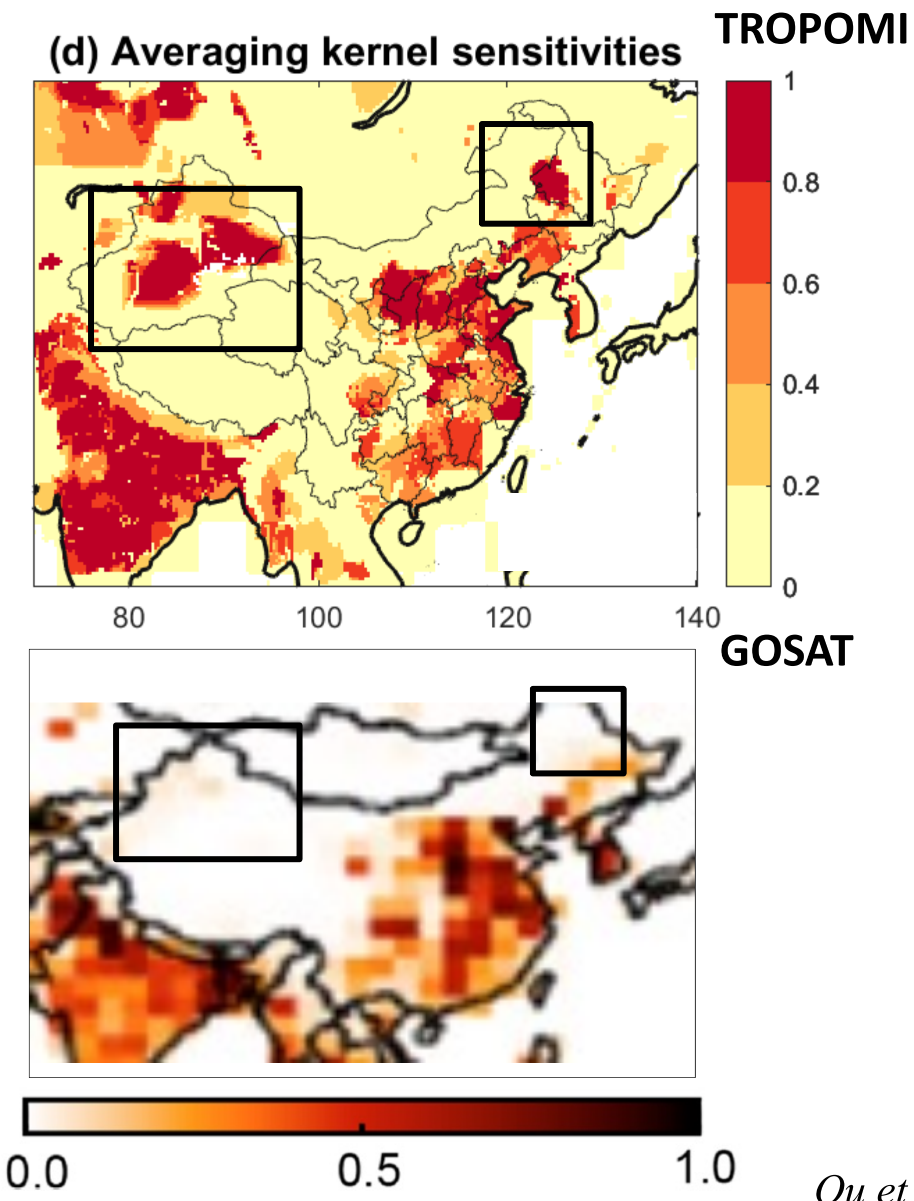


Using satellite observations to correct bottom-up emission inventories



We have higher **livestock** emissions in northern China, where GOSAT has little sensitivity

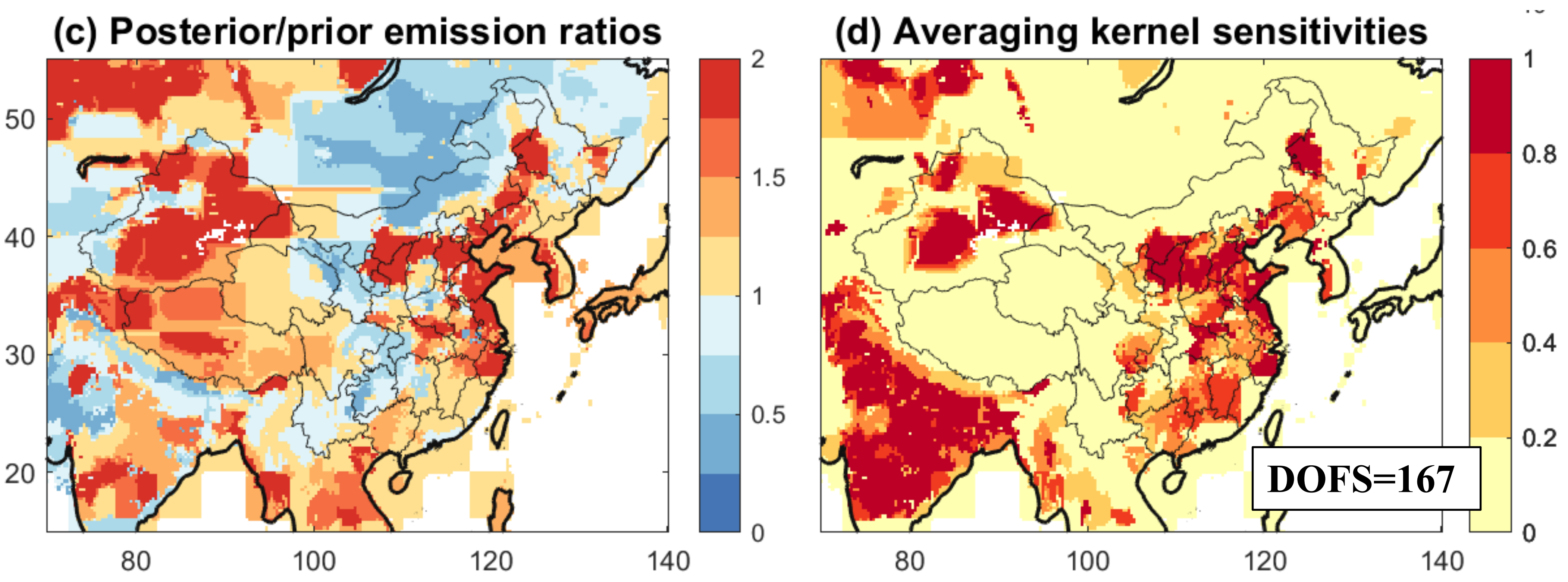




- Dense TROPOMI over **northwestern and northeastern** China enables more effective corrections than previous GOSAT inversions.
- Two regions account for **63%** of the upward adjustment for livestock.

Qu et al., 2021

Strong ability of TROPOM in determining the posterior emissions in major source regions



Upward

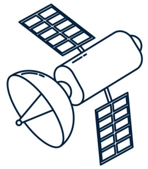
Downward

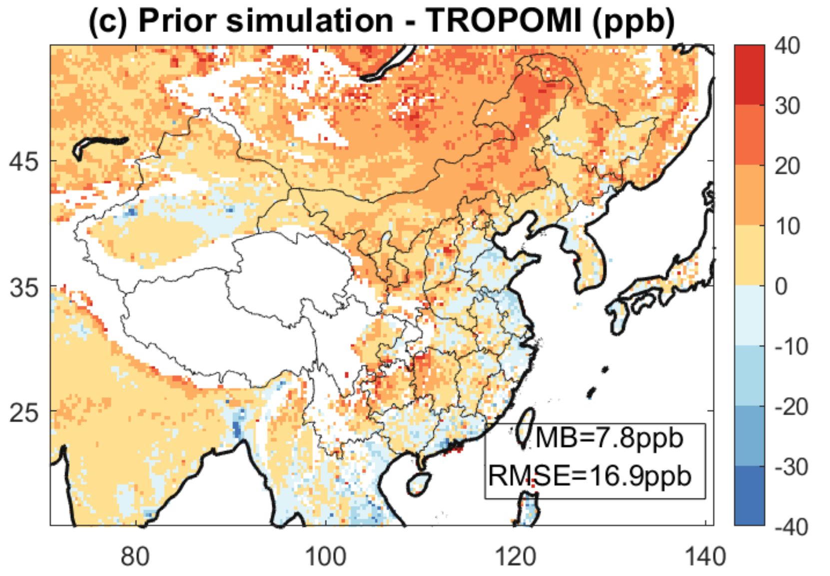
1: fully determined by observations
0: fully determined by prior information

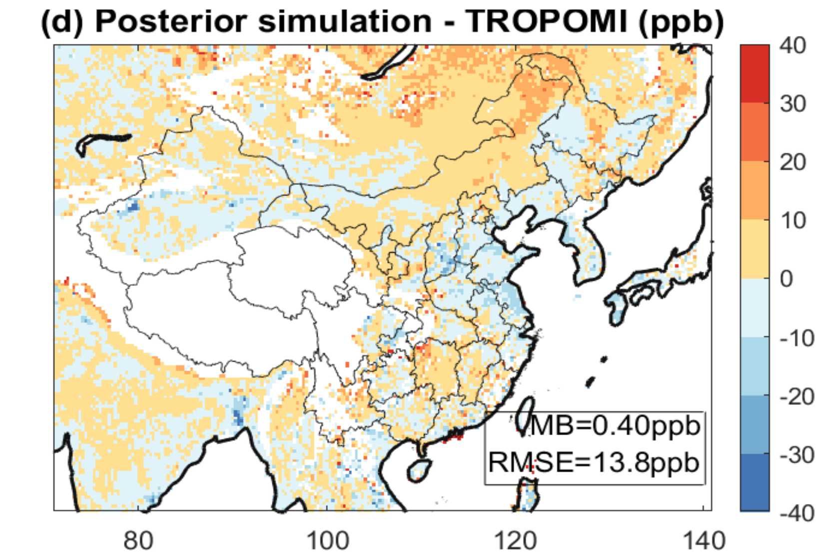
DOFS: degrees of freedom for signal
DOFS=600 if fully constrained

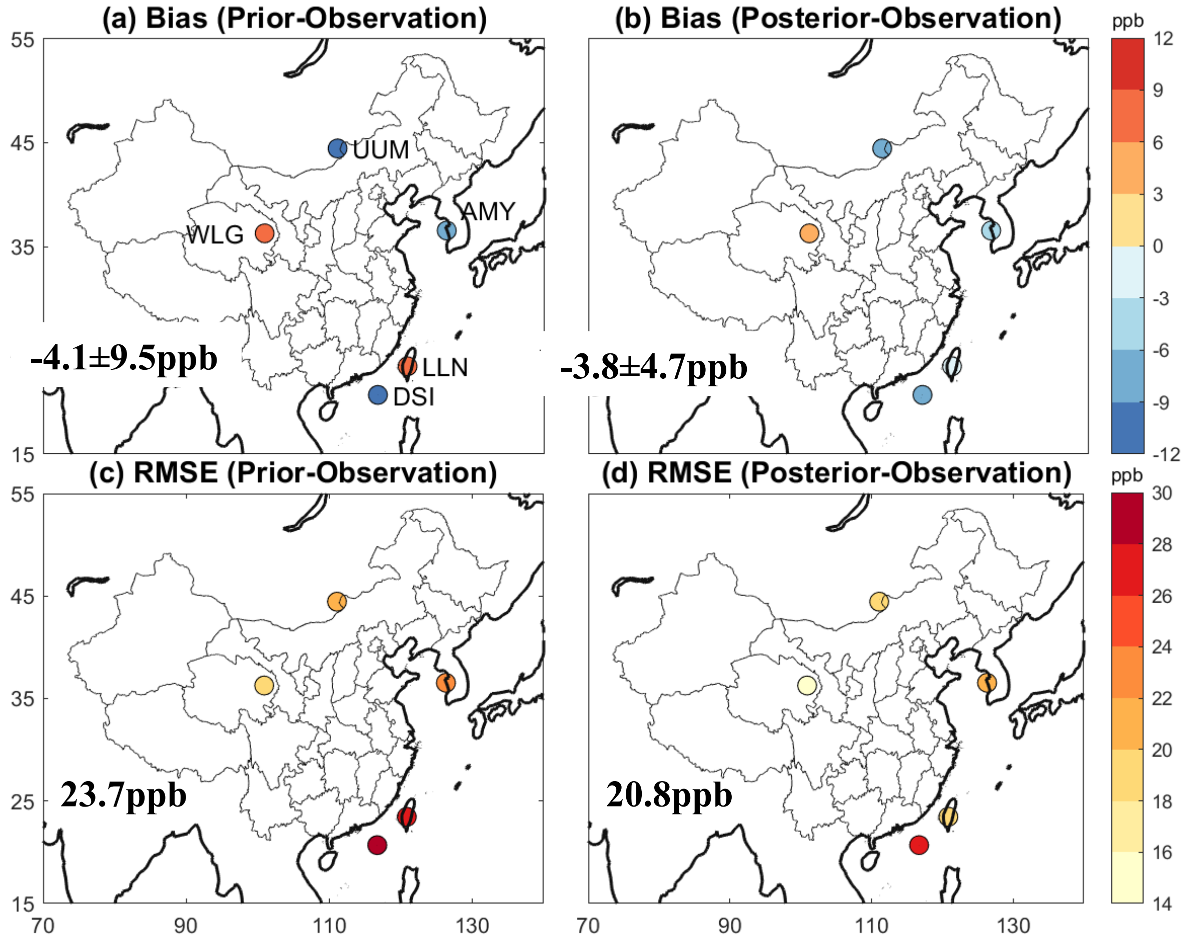
Number of independent pieces of information obtained from the observations

Improved ability of posterior emissions to fit observations

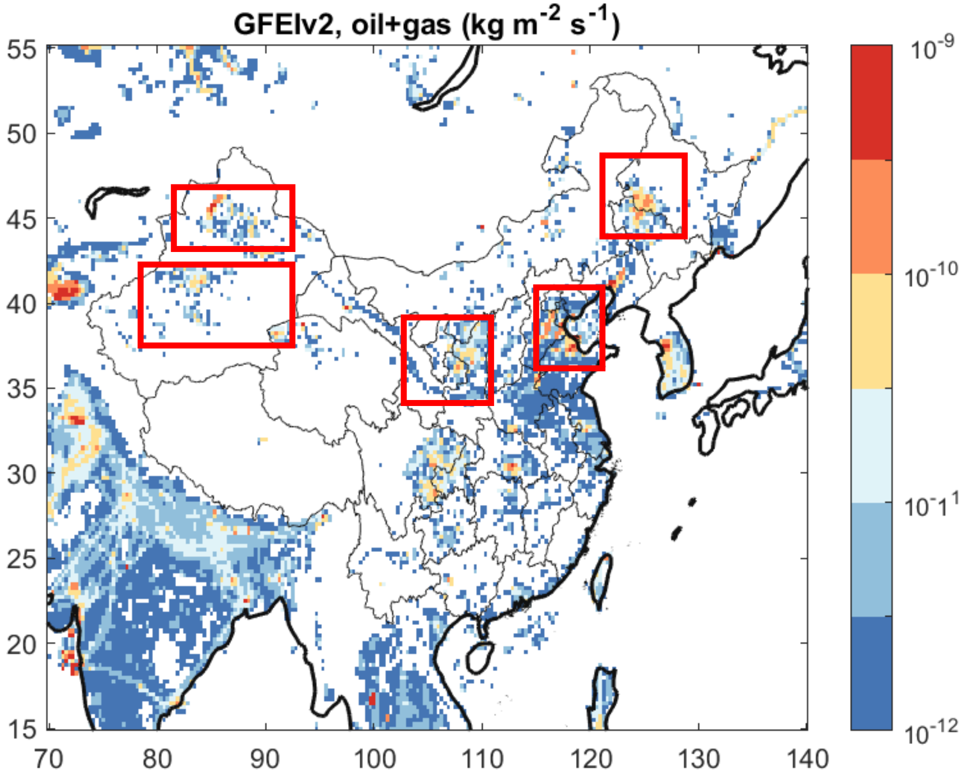


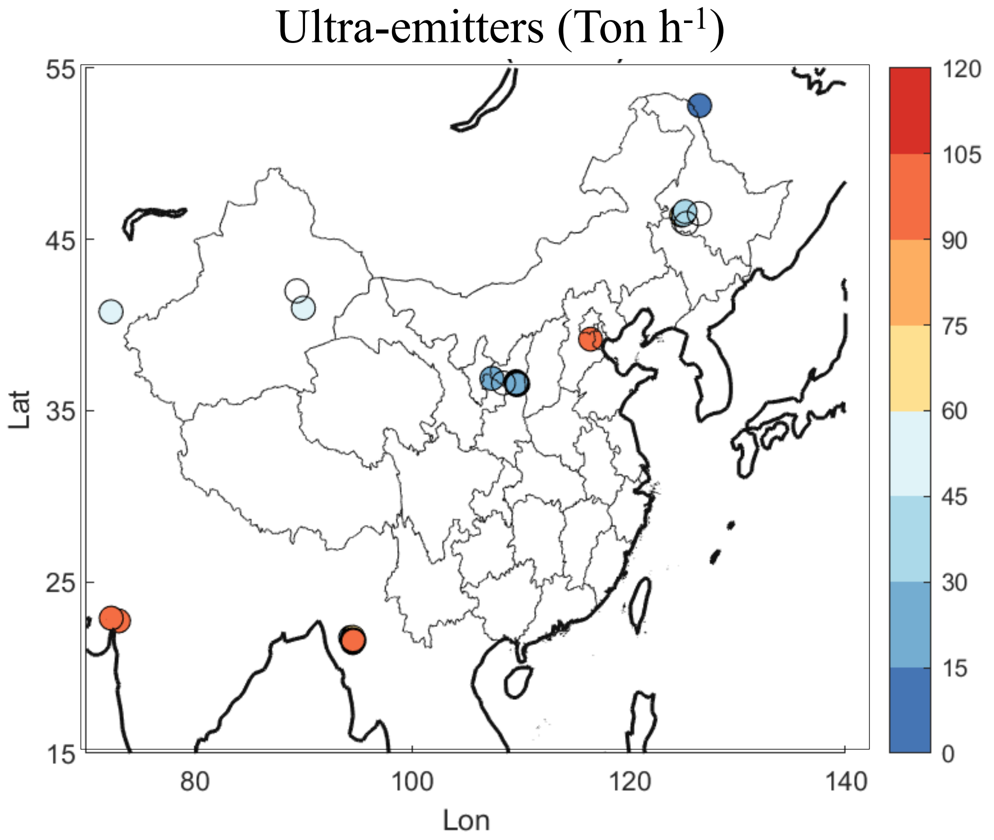






Large upward correction in **oil and gas** system



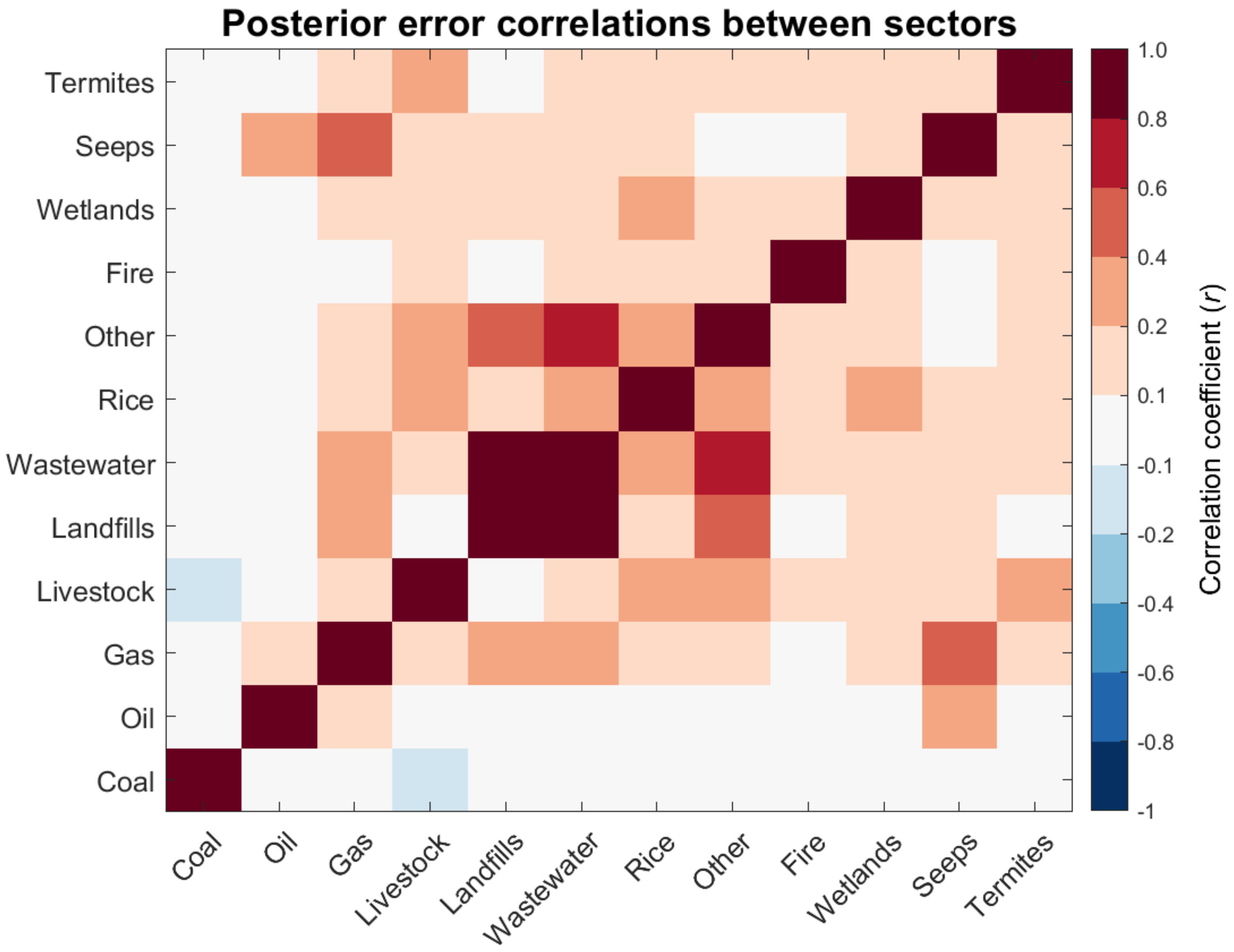


Where we find large upward adjustment of oil/gas.

Oil/gas, Data from *Lauvaux et al.*, 2022

Ultra-emitters are not fully included in inventories.

How well are posterior emissions between sectors separated?



- Landfills and wastewater are highly correlated, associated with urban areas; we then combine them.
- Other sectors are successfully separated (<0.2).

0: success
±1: fail

Prior emissions by sector