# Using satellites to support detection, quantification, and attribution of methane emissions

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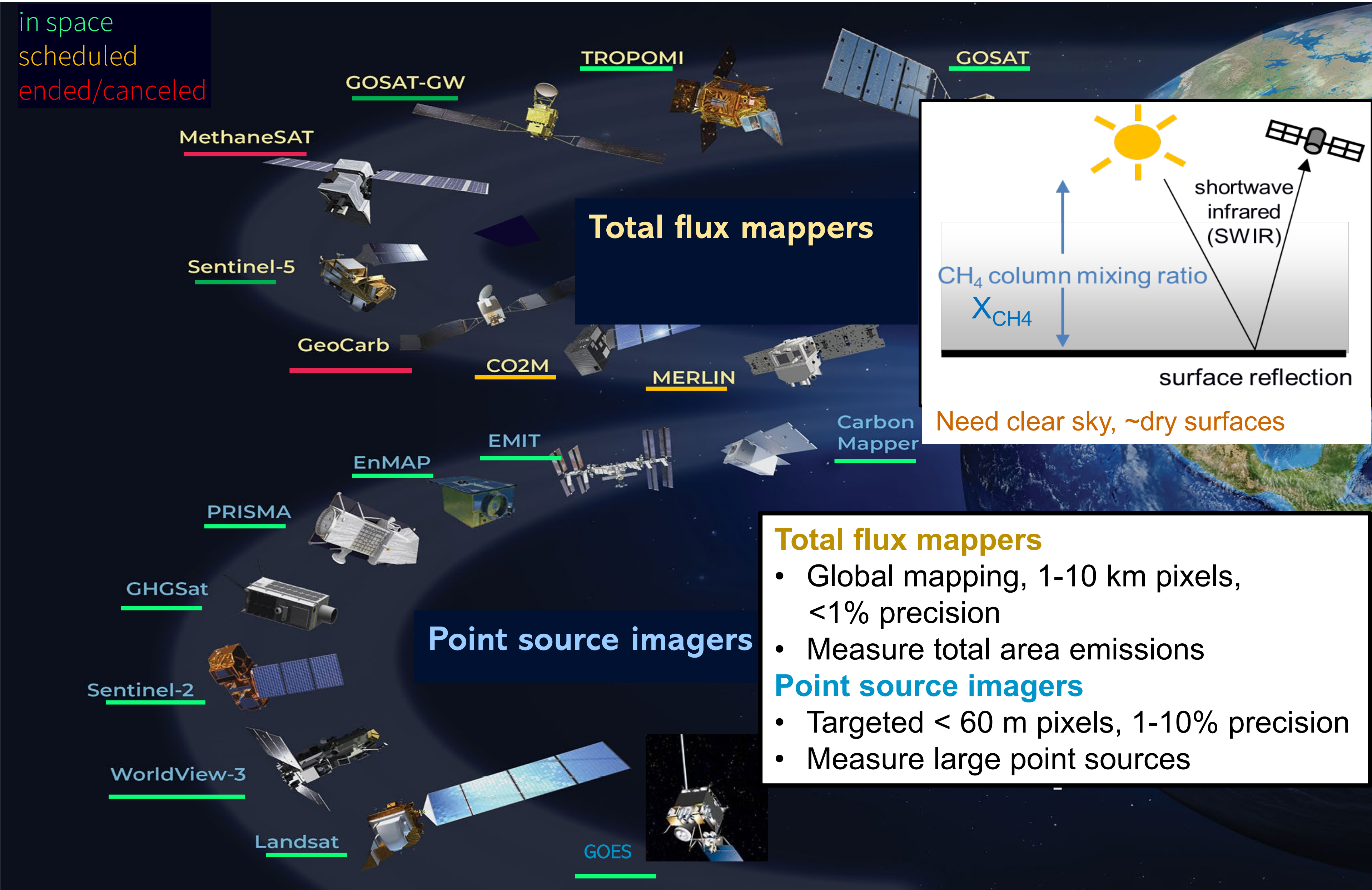
# Satellite observations of atmospheric methane

*updated from Jacob et al., ACP2022*




**Total flux mappers**

- Global mapping, 1-10 km pixels, <1% precision
- Measure total area emissions

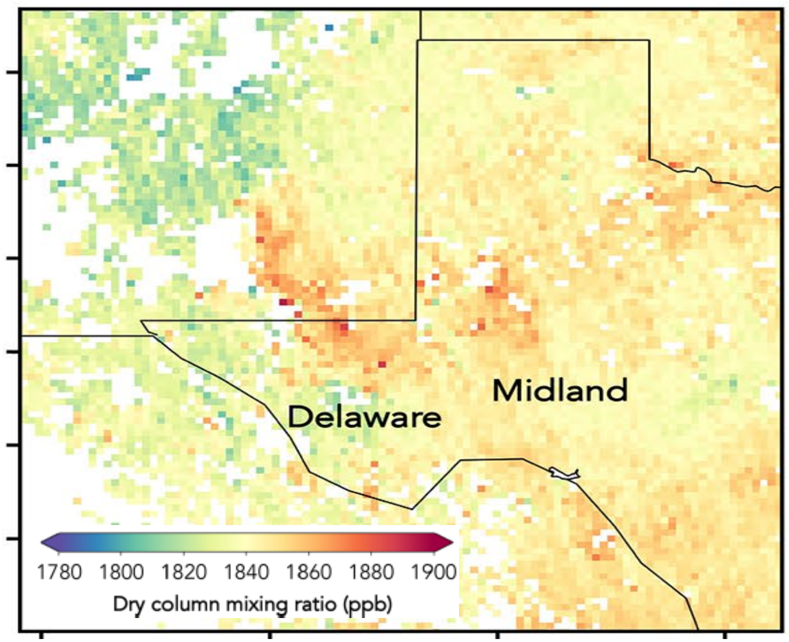
**Point source imagers**

- Targeted < 60 m pixels, 1-10% precision
- Measure large point sources

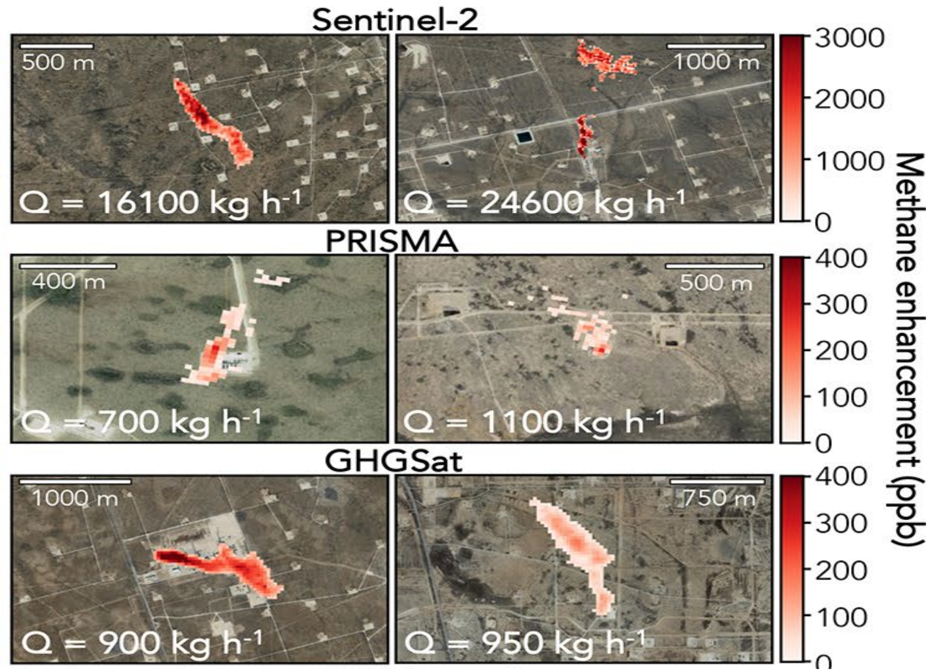
# Complementary information from total flux mappers and point source imagers

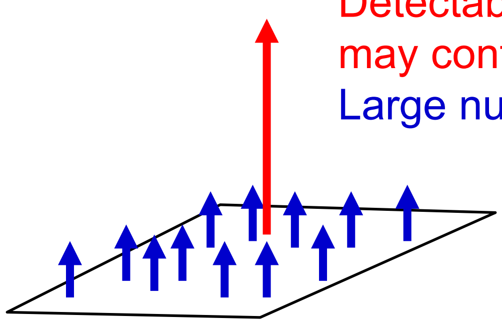
## Methane observations over the US Permian Basin

Total methane from TROPOMI
(July 2020 mean)




Point source observations



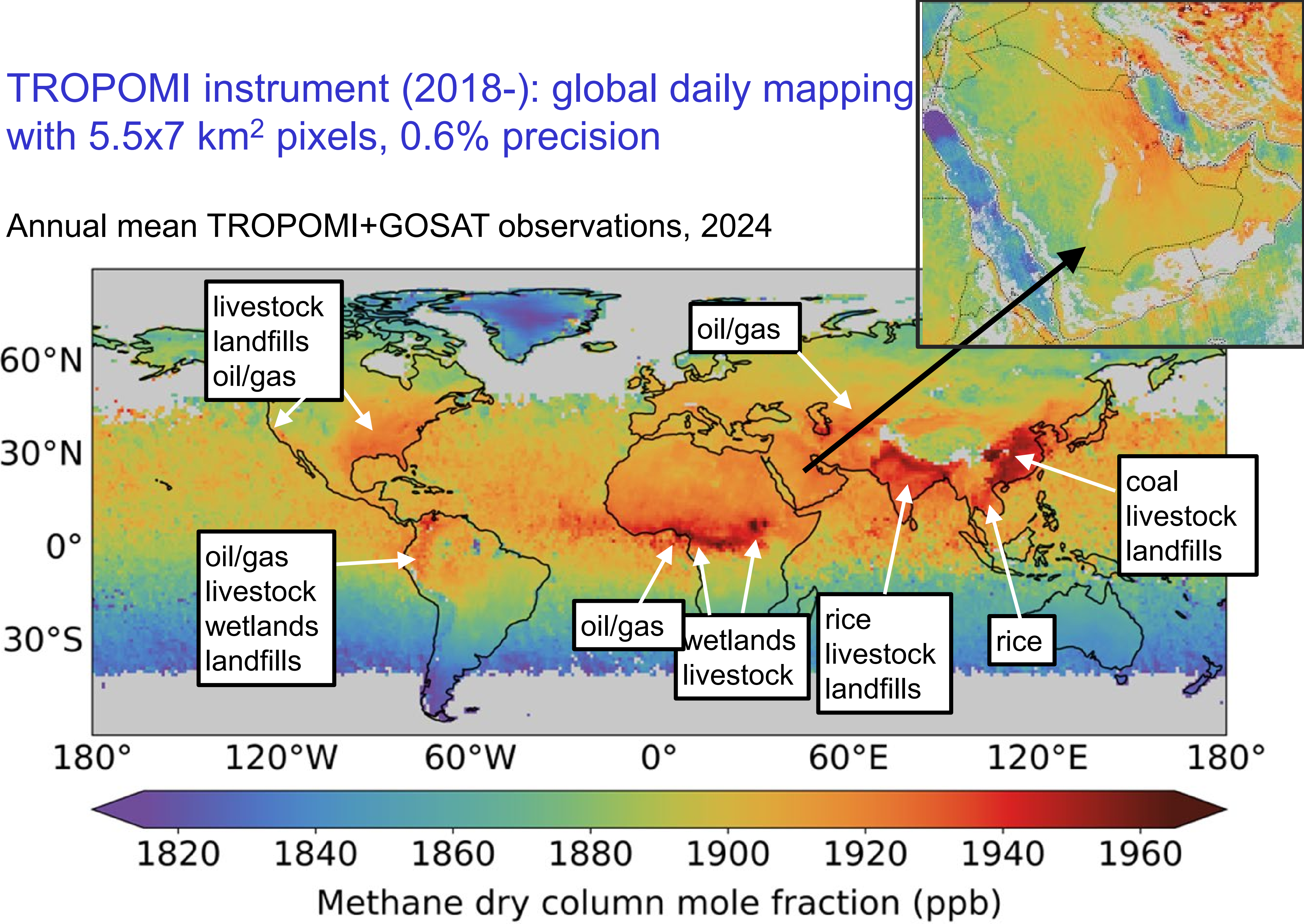
Detectable point sources ( >300 kg $h^{-1}$) tend to be highly intermittent, may contribute up to ~30% of total emissions

Large number of smaller sources contribute the rest

*Jacob et al., ACP2022*

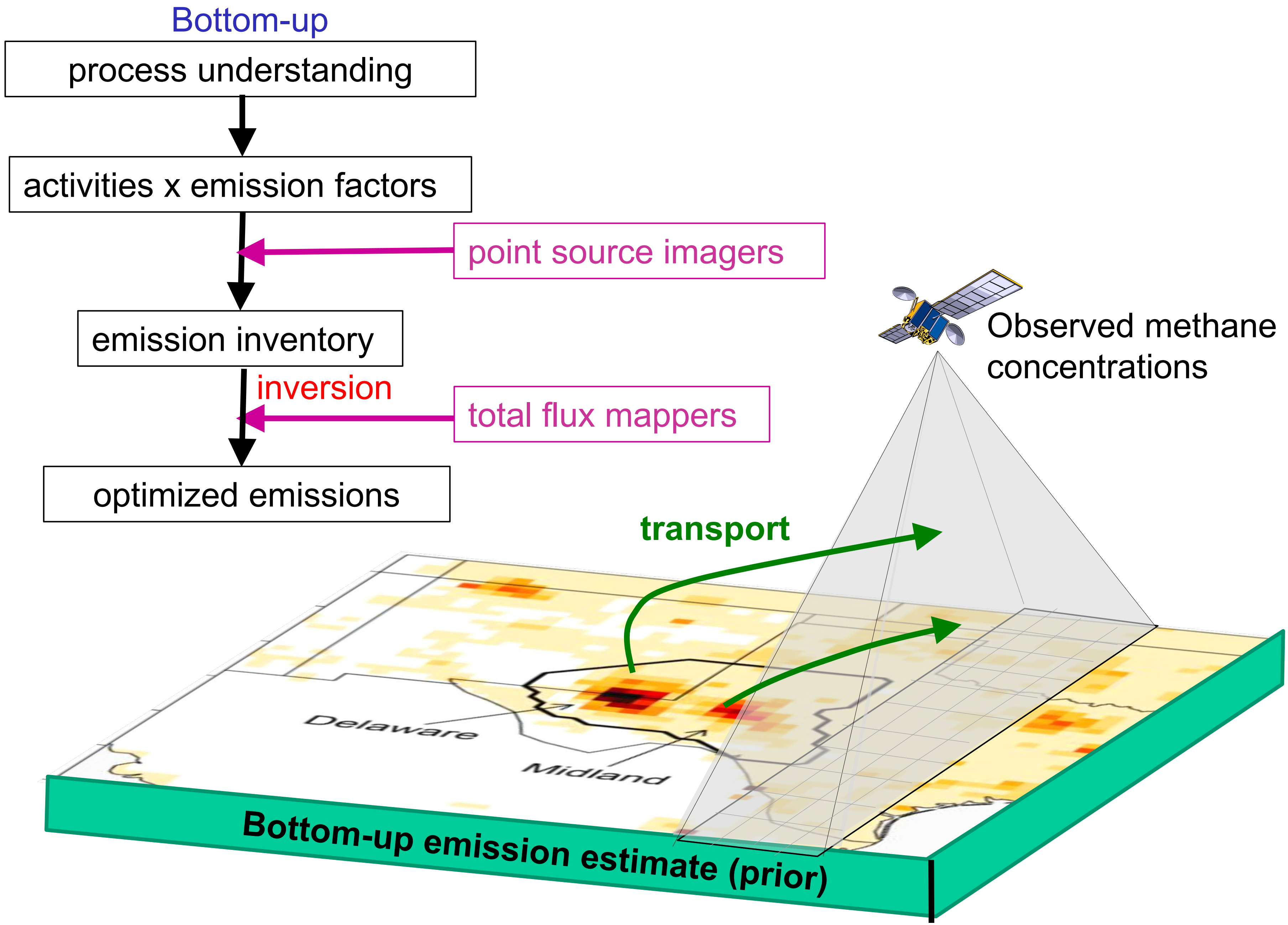
TROPOMI instrument (2018-): global daily mapping with 5.5x7 $km^2$ pixels, 0.6% precision

Annual mean TROPOMI+GOSAT observations, 2024

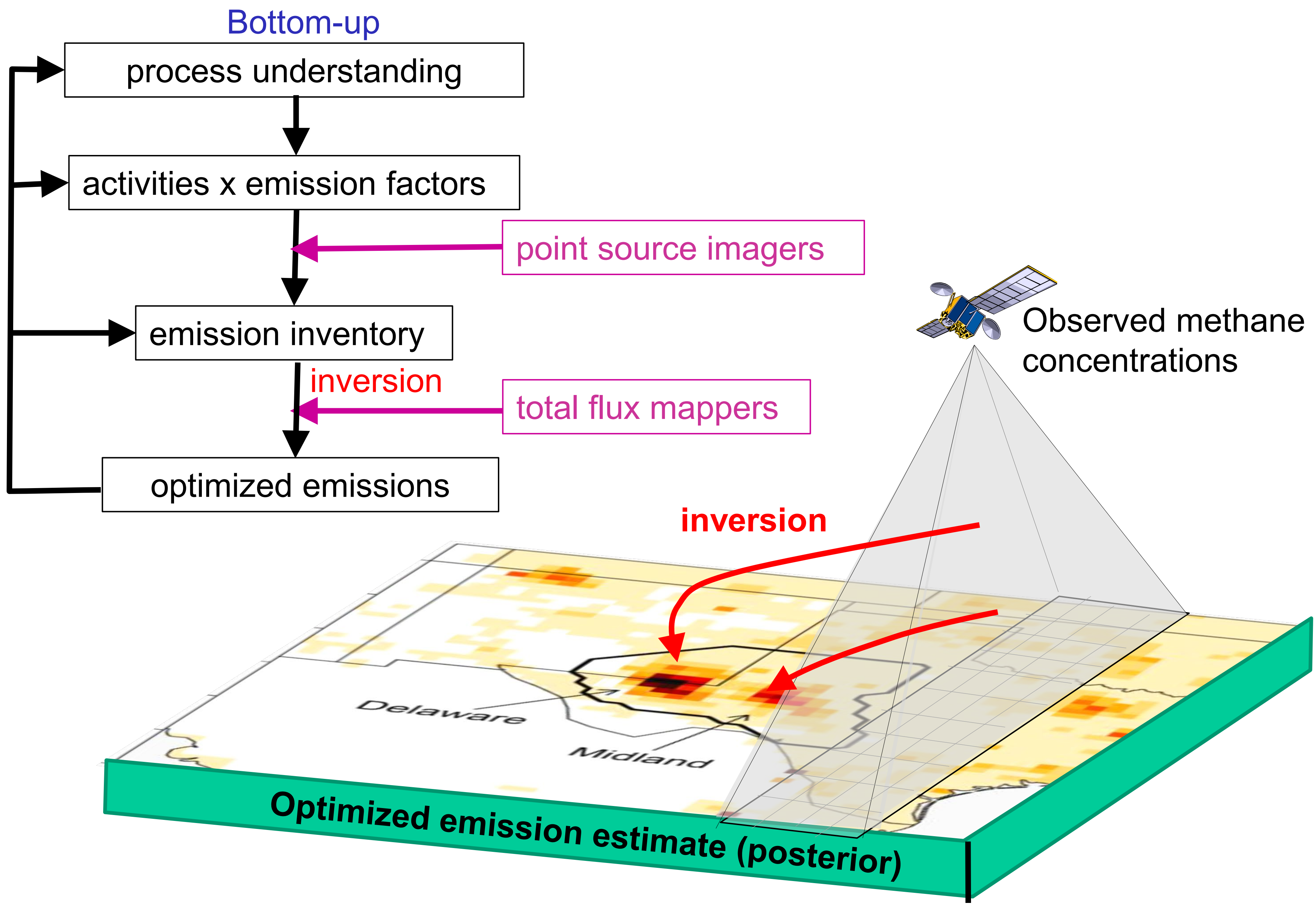



*Updated from Balasus et al., AMT 2023*

# Using satellites to improve/update emission inventories through inverse analyses



# Using satellites to improve/update emission inventories through inverse analyses



# Integrated Methane Inversion (IMI):
## A tool for stakeholders to infer total methane emissions from satellite data

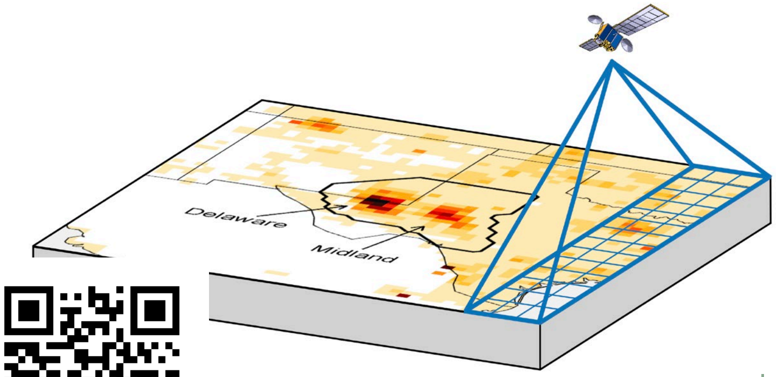
https://carboninversion.com

What IMI users can do:

- Use satellite observations to quantify methane emissions from any region at up to 12-km resolution with accounting of uncertainties
- Compare their results to bottom-up emission inventories
- Set up near-real-time continuous monitoring for their region
- Run the IMI freely on the AWS cloud or with the user-friendly Integral Earth dashboard

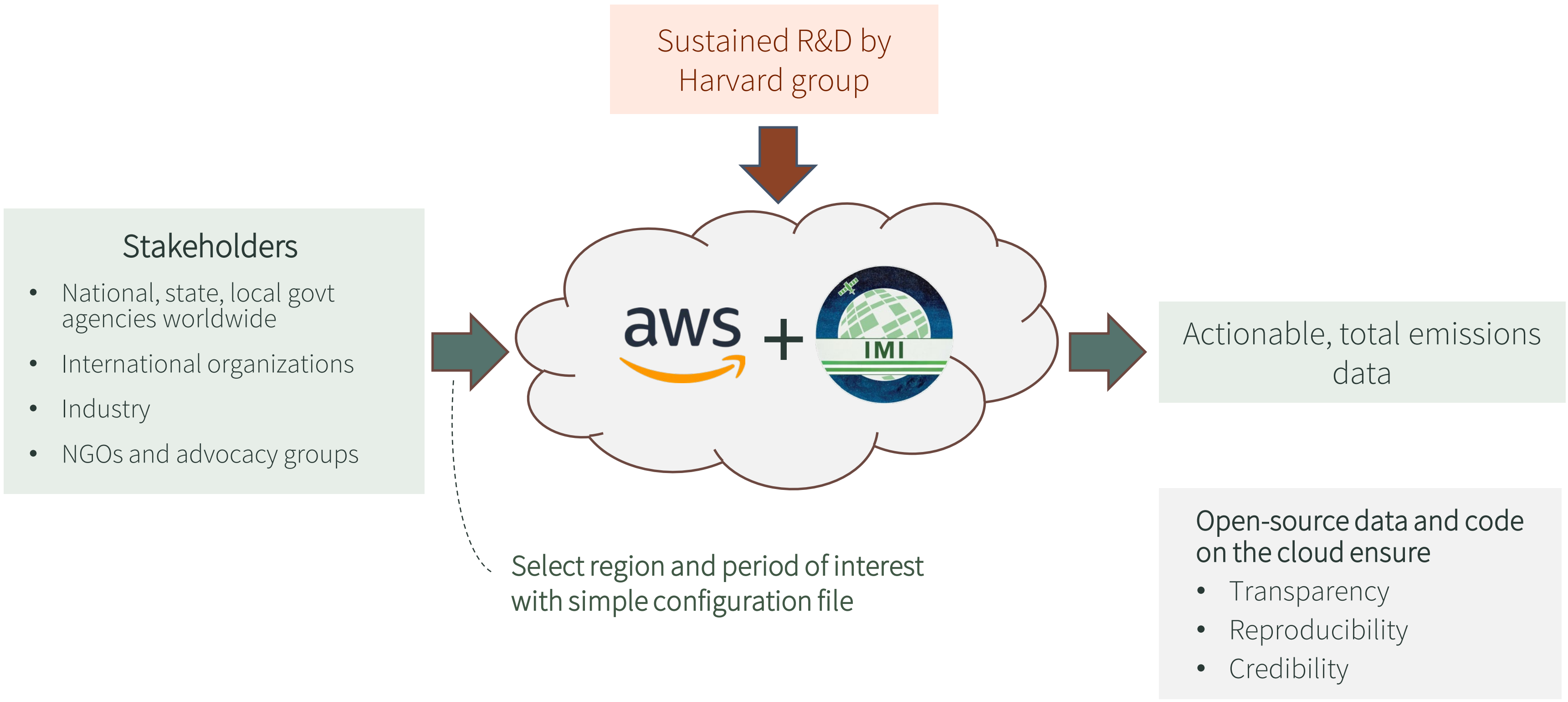
What is under the IMI hood:

- Advanced inverse methods documented in the scientific literature and made easy to use
- A team of Harvard developers supported by NASA, Exxon-Mobil, and the Harvard Methane Initiative
- An open-source code for transparency of results

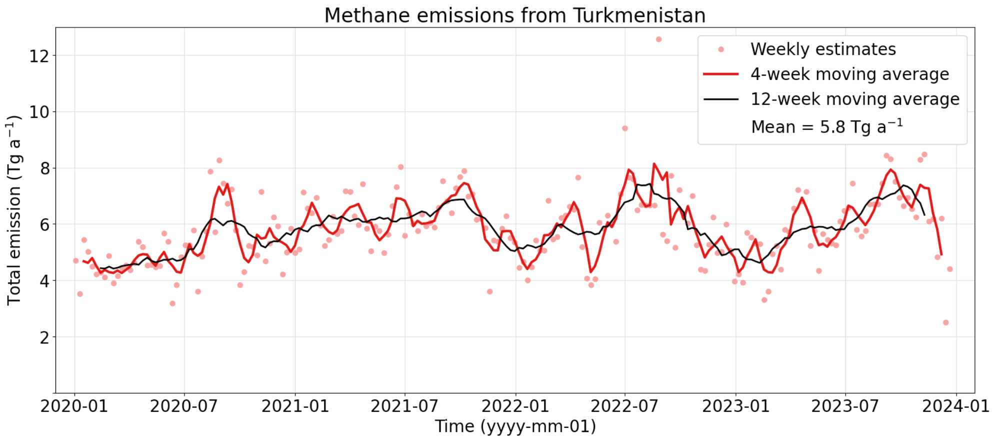


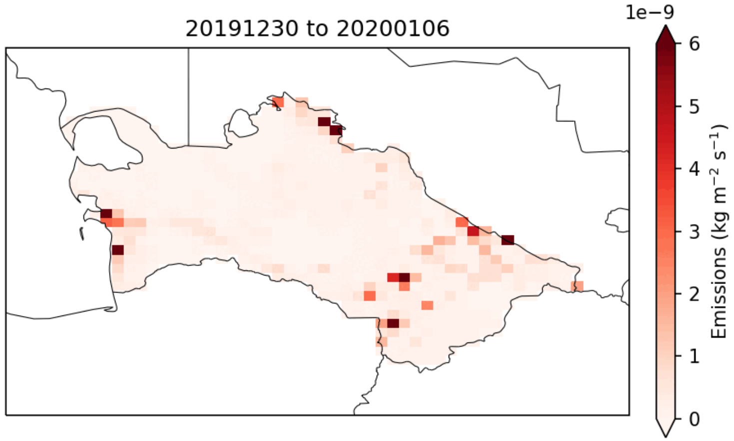

Estrada, L. A., Varon, D. J., Sulprizio, M., Nesser, H., Chen, Z., Balasus, N., Hancock, S. E., He, M., East, J. D., Mooring, T. A., Oort Alonso, A., Maasakkers, J. D., Aben, I., Baray, S., Bowman, K. W., Worden, J. R., Cardoso-Saldaña, F. J., Reidy, E., and Jacob, D. J.: Integrated Methane Inversion (IMI) 2.0: an improved research and stakeholder tool for monitoring total methane emissions with high resolution worldwide using TROPOMI satellite observations, Geoscientific Model Development, 18, 3311–3330, https://doi.org/10.5194/gmd-18-3311-2025, 2025.

# The IMI puts the power of satellite data in the hands of non-expert stakeholders

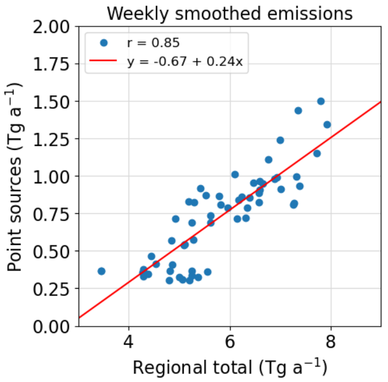


# Continuous weekly monitoring of Turkmenistan's methane emissions with IMI 2.0



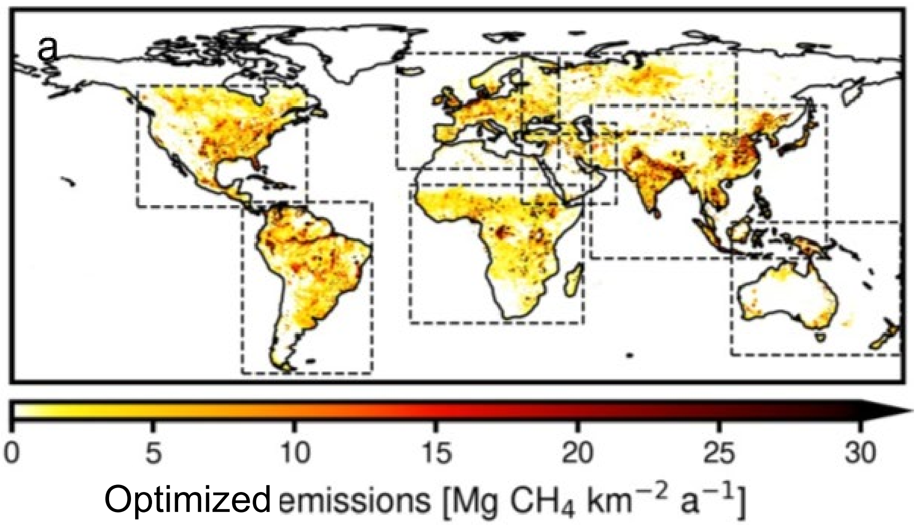




- IMI 2.0 enables continuous monitoring (e.g.,weekly, monthly) of methane emissions from any region of interest
- Example: Continuous weekly monitoring of Turkmenistan's methane emissions supports diplomatic activities of the UNEP International Methane Emissions Observatory (IMEO)
- National total methane emissions are highly correlated with sums of point source detections in Turkmenistan (bottom right figure)

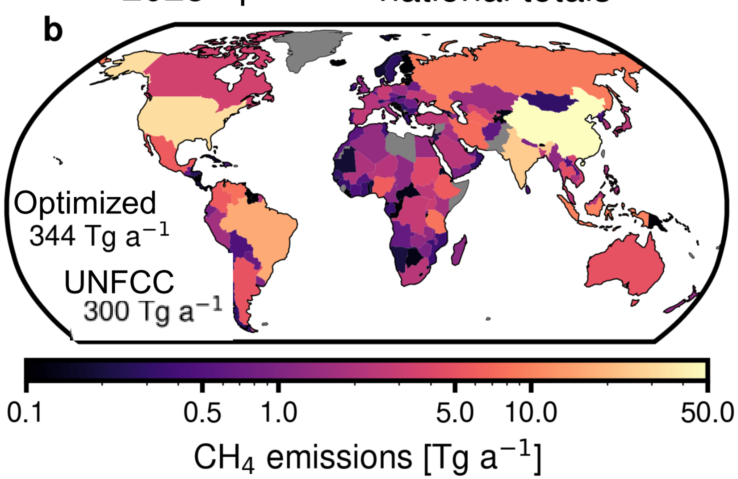


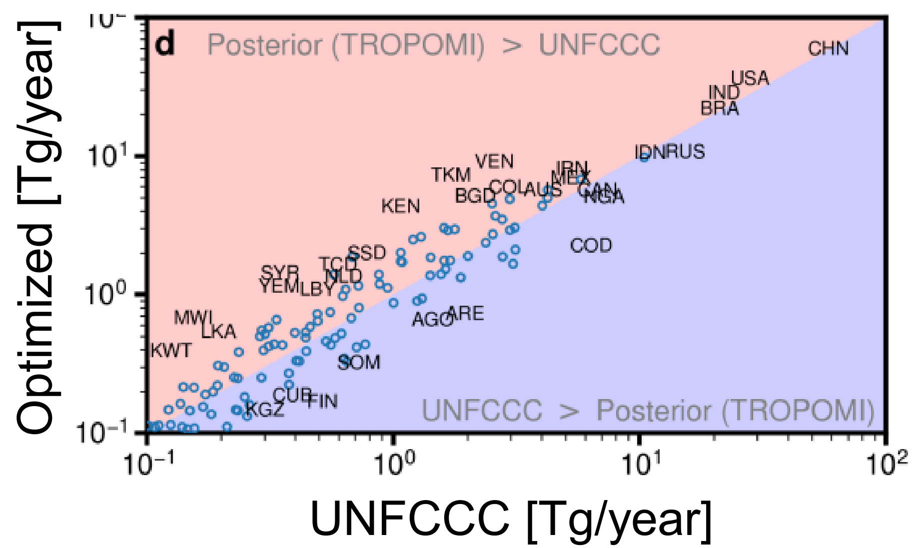
# Evaluating national emission reports to the UNFCCC with the IMI

Tile the world with regional inversions at 25x25 $km^2$ resolution,
using UNFCCC national inventories as prior estimates




2023 Optimized national totals

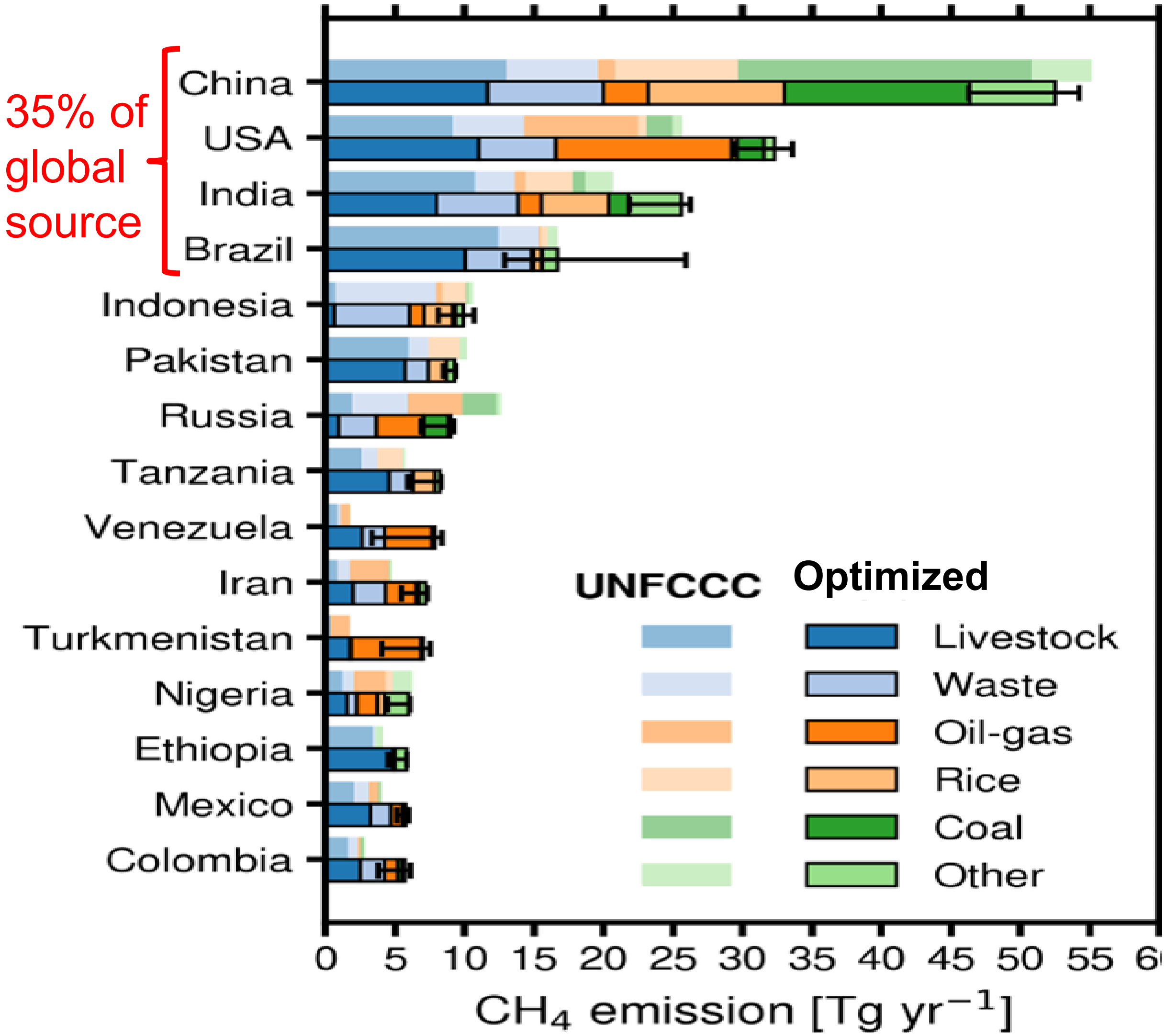



*East et al., NC2025*

# Top 15 emitting countries: comparison to UNFCCC reporting

Annual mean 2023 anthropogenic emissions




Corrections to UNFCCC emissions

**Oil & Gas: +10.1 Tg**

USA: +4.2 Tg
Venezuela: +2.8 Tg
China: +1.9 Tg

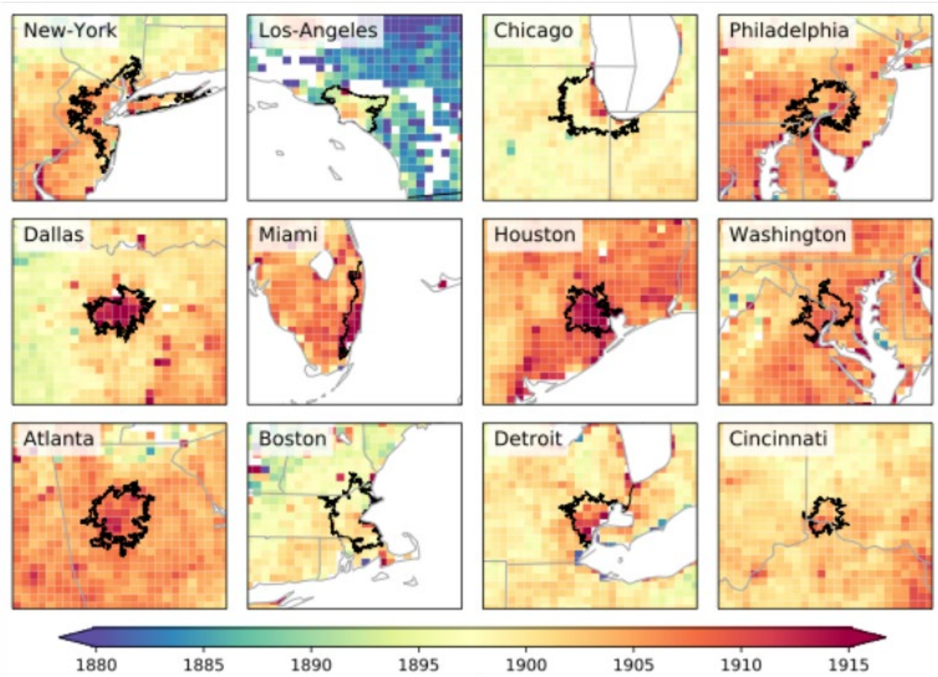
**Waste: +6.1 Tg**

India: +3.0 Tg
Brazil: +1.9 Tg
Venezuela: +1.3 Tg
China: +1.8 Tg

*East et al., NC2025*

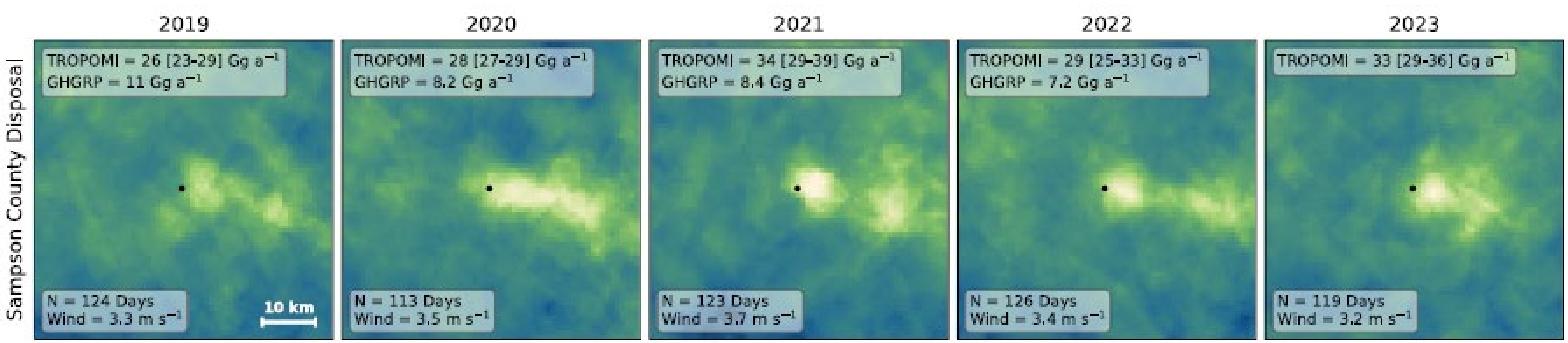
# Quantifying urban and landfill emissions using the IMI

TROPOMI observations in US cities, 2022




- Urban emissions are 80% higher than in EPA inventory, mostly because of landfills and with exception of Los Angeles;
- Landfills report decreasing emissions with time but satellite observations show an increase

Monitoring emission trends for individual landfills by oversampling of TROPOMI data:




*Wang et al., SciAdv 2025; Balasus et al., ERL 2025*

# Observing the Norte III landfill in Buenos Aires with TROPOMI and GHGSat

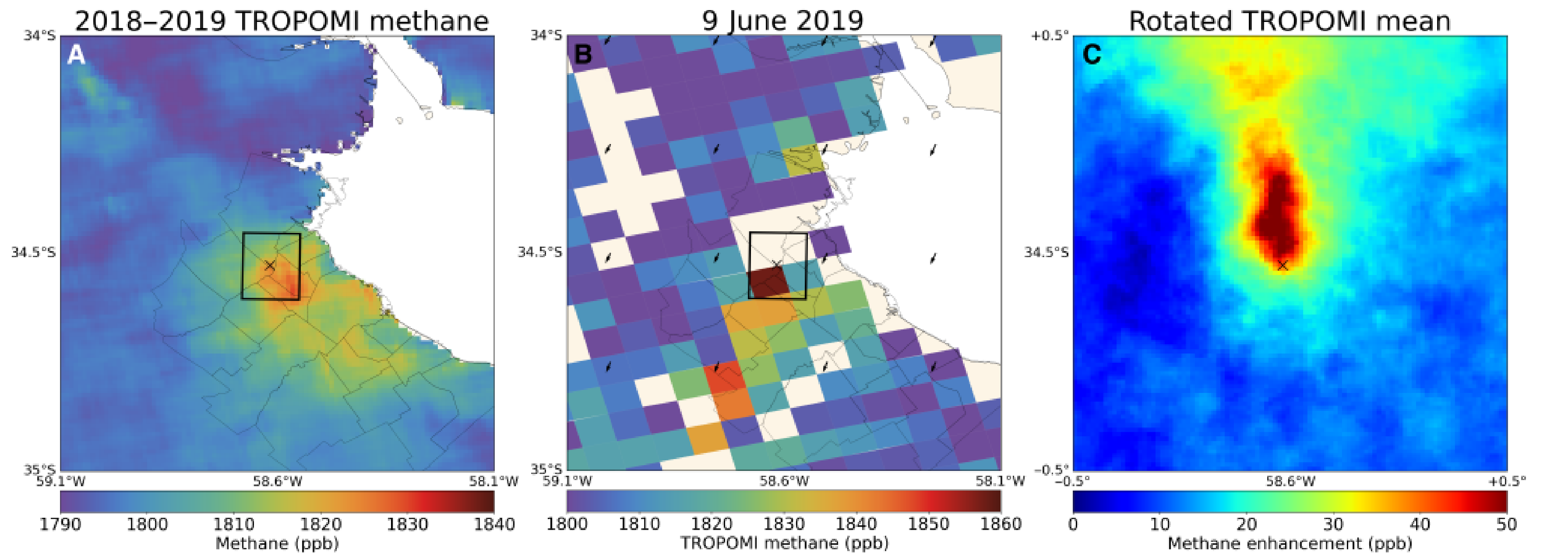
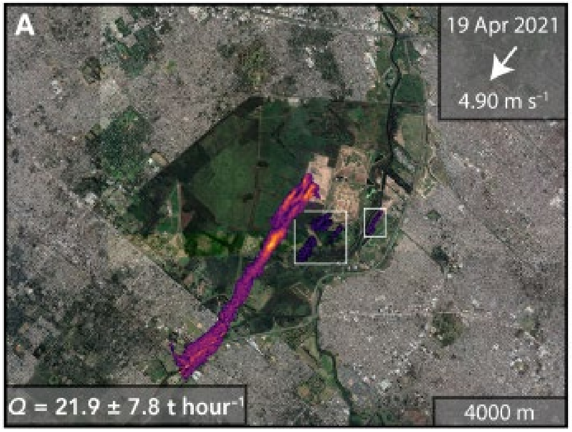


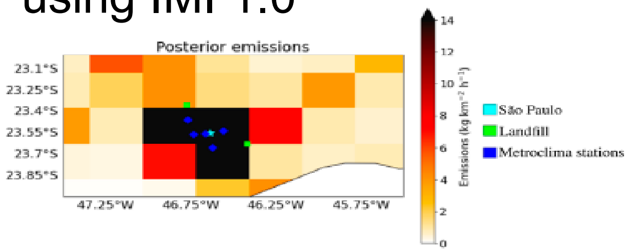

**Fig. 1. TROPOMI observations over Buenos Aires (Argentina).** (**A**) Mean 2018–2019 TROPOMI methane concentrations oversampled (i.e., accounting for the full footprint of the observation) on a 0.01° grid. The Norte III landfill is indicated by the black cross; also shown are a GHGSat window centered on the TROPOMI-derived target (thick lines) and the Greater Buenos Aires municipalities [thin lines (*60*)]. (**B**) A single TROPOMI overpass on 9 June 2019 exhibiting a methane plume downwind of Buenos Aires with wind arrows representing ERA5 10-m winds (*28*). (**C**) The 2018–2019 wind-rotated average giving a clear (north-oriented) plume signal indicating a concentrated source.



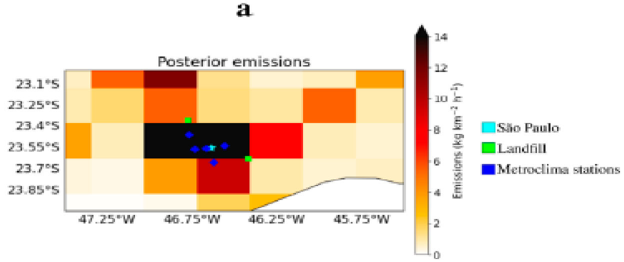

*Maasakkers et al., SciAdv 2022*

# Observing the Caleiras landfill in Sao Paulo with TROPOMI and EMIT

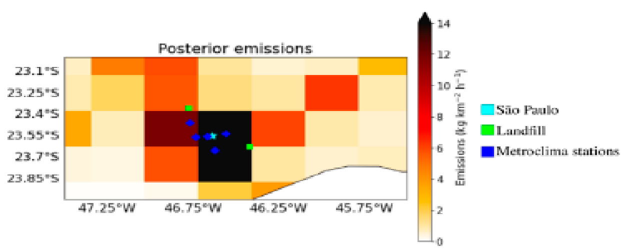
2019-2022 emissions using IMI 1.0



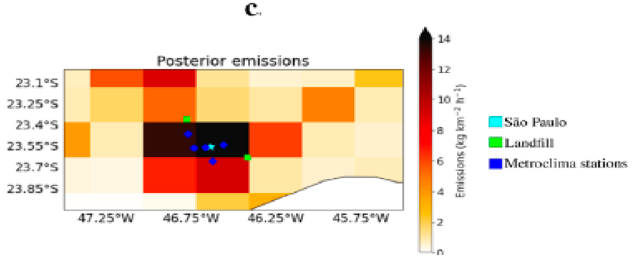

a



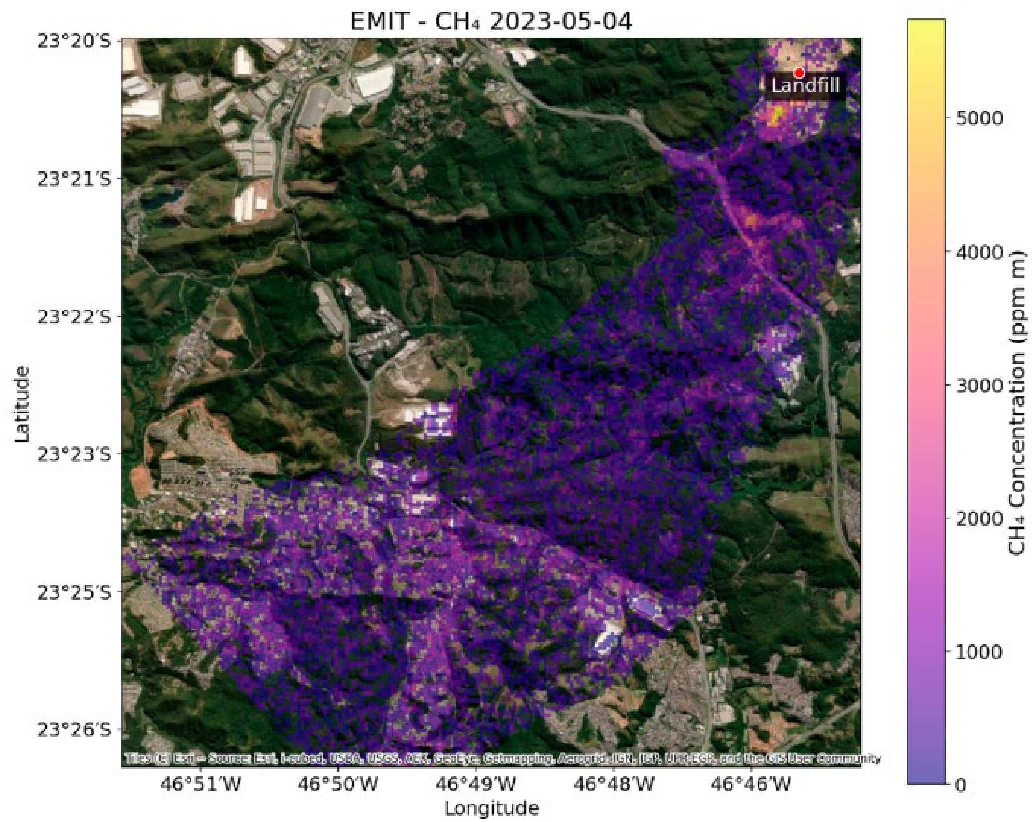

b




c



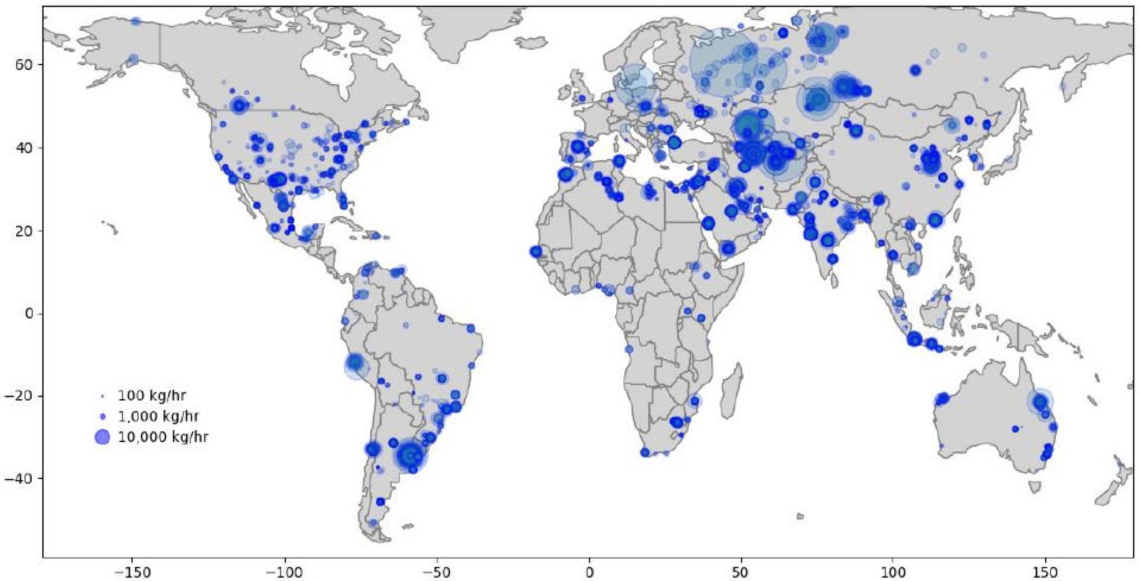

Landfill plume observed by EMIT

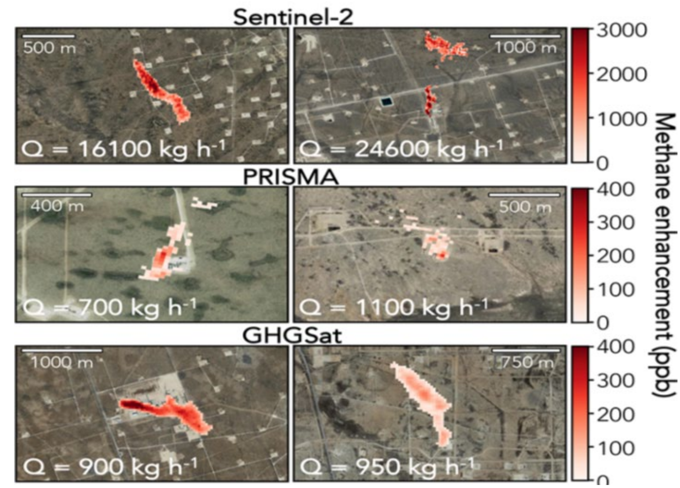



*Da Silva et al. Frontiers Earth Sci., 2025*

# Detection of point sources as targets for climate action

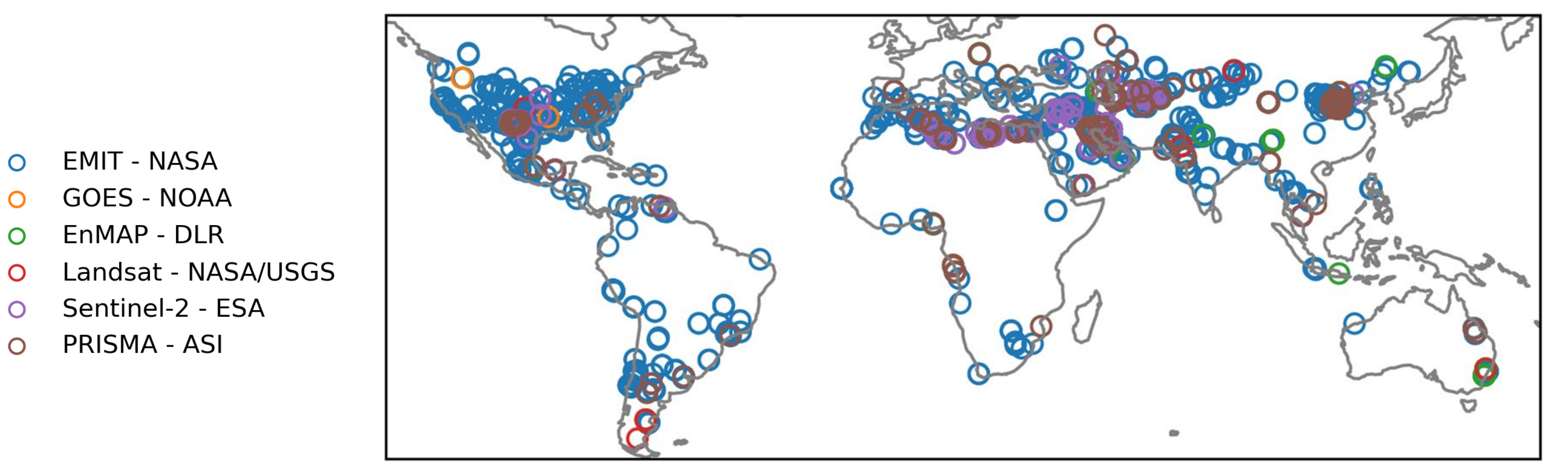
## GHGSat detections, June 2022-Sept 2023



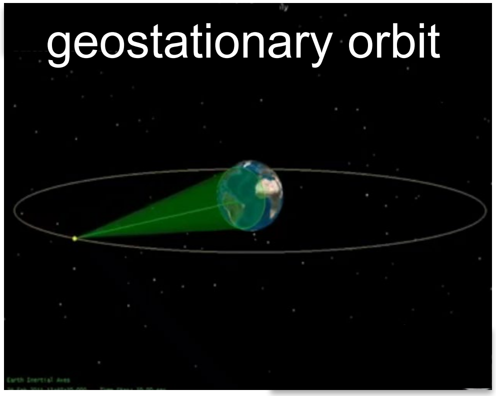




- Observed **> 15,000** plumes in 16 months

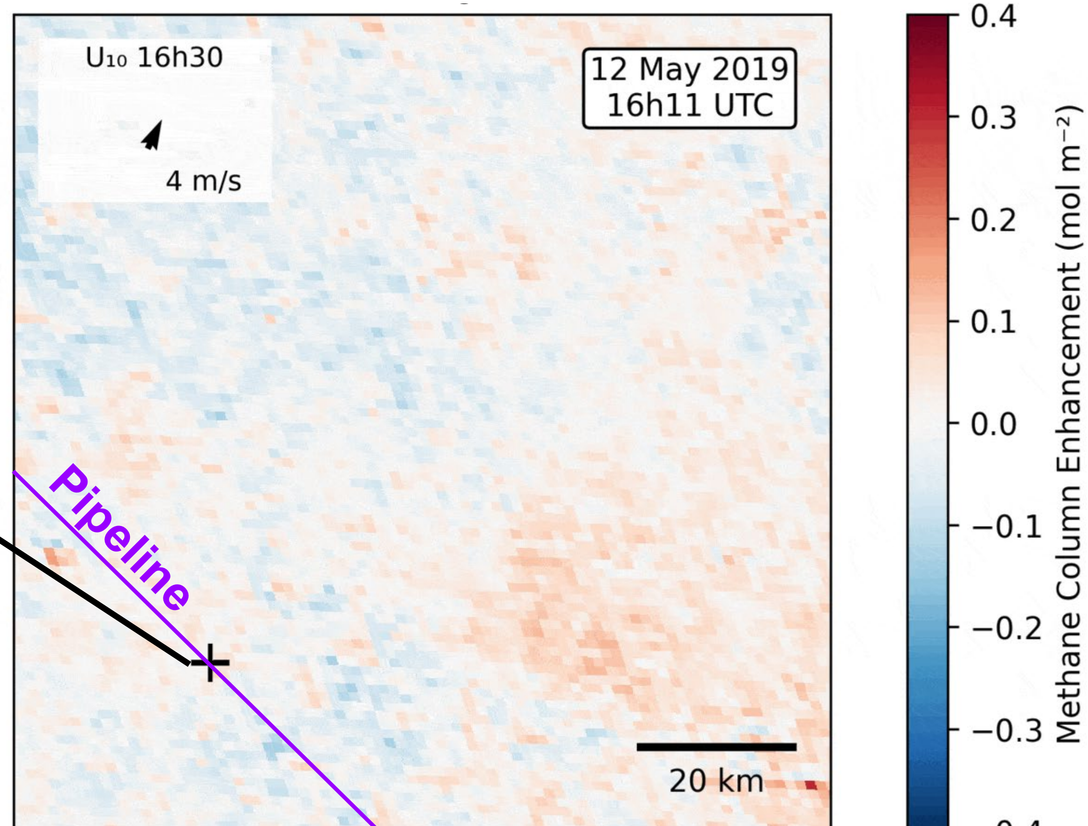
## IMEO-MARS detections



# Observation from geostationary orbit would enable continuous monitoring of N and S America




EELL pipeline from Chihuaha to Durango supplying Permian gas to Mexico


$Q$ = 300 tons $h^{-1}$, 3-h duration

*Watine-Guiu et al. [2024]*

# Takeaways

- **Satellites provide a unique resource for observing methane emissions and trends from the global scale down to point sources.** Recent launches (Sentinel-5, GOSAT-GW, Carbon Mapper) are improving coverage and resolution.

- **They can support national emission estimates and monitor progress on national emission goals.** They can evaluate and guide improvement in bottom-up emission inventory methods and track emission trends in near real-time.

- **They can detect large point sources worldwide to enable immediate action.** IMEO and CarbonMapper provide continuous near-real-time reporting.

- **We can’t do it all from space.** Satellites are just one piece of a comprehensive observation system for quantifying emissions to include surface sites and aircraft, supported by bottom-up models and inventories.