Quantifying methane emissions and their trends using satellites: from the global scale down to point sources

Daniel Jacob

with Lucas Estrada, Megan He, James East, Daniel Varon, Xiaolin Wang

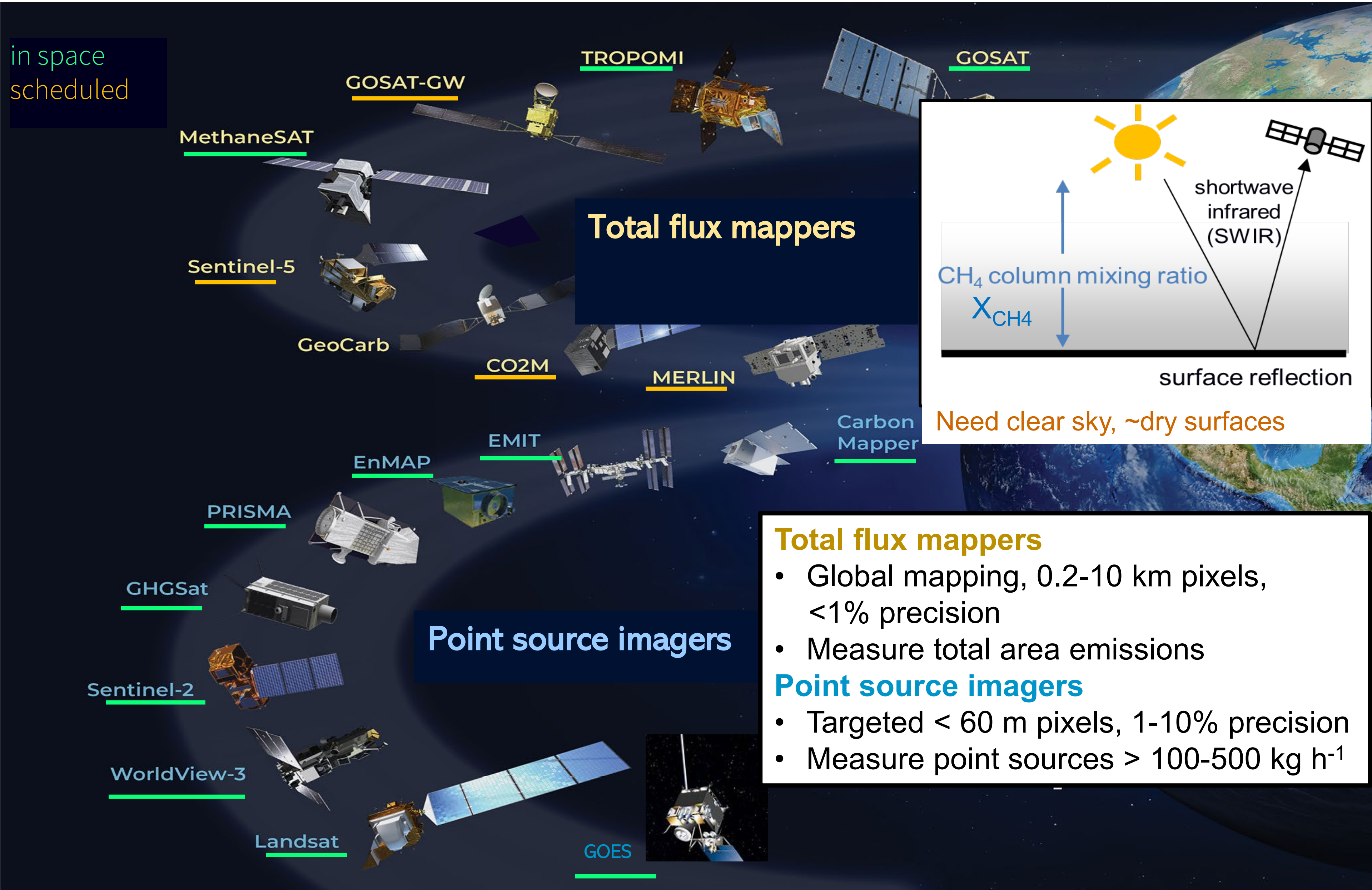
HARVARD UNIVERSITY

ATMOSPHERIC CHEMISTRY MODELING GROUP

and Carrie Jenks (Harvard Law School)

Satellite remote sensing of atmospheric methane

updated from Jacob et al., ACP2022



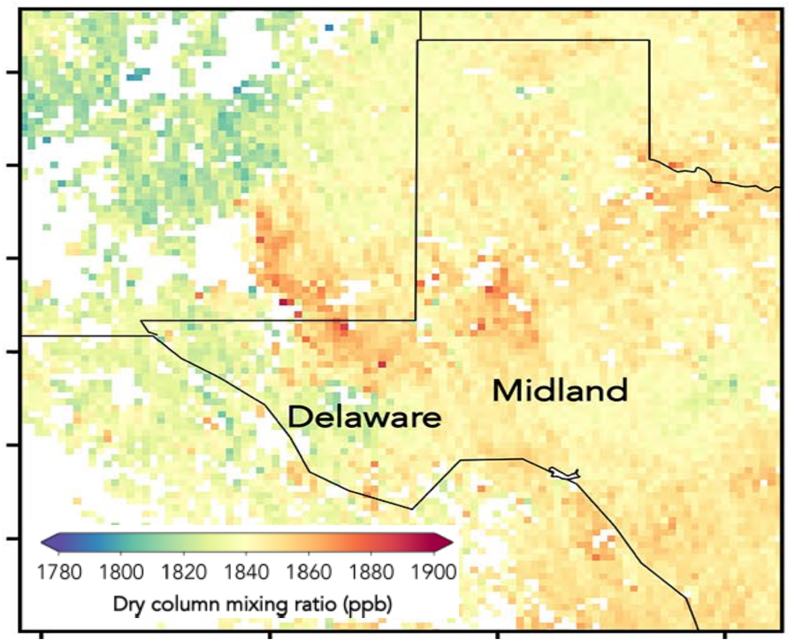
Total flux mappers
- Global mapping, 0.2-10 km pixels, <1% precision
- Measure total area emissions

Point source imagers
- Targeted < 60 m pixels, 1-10% precision
- Measure point sources > 100-500 kg h^{-1}

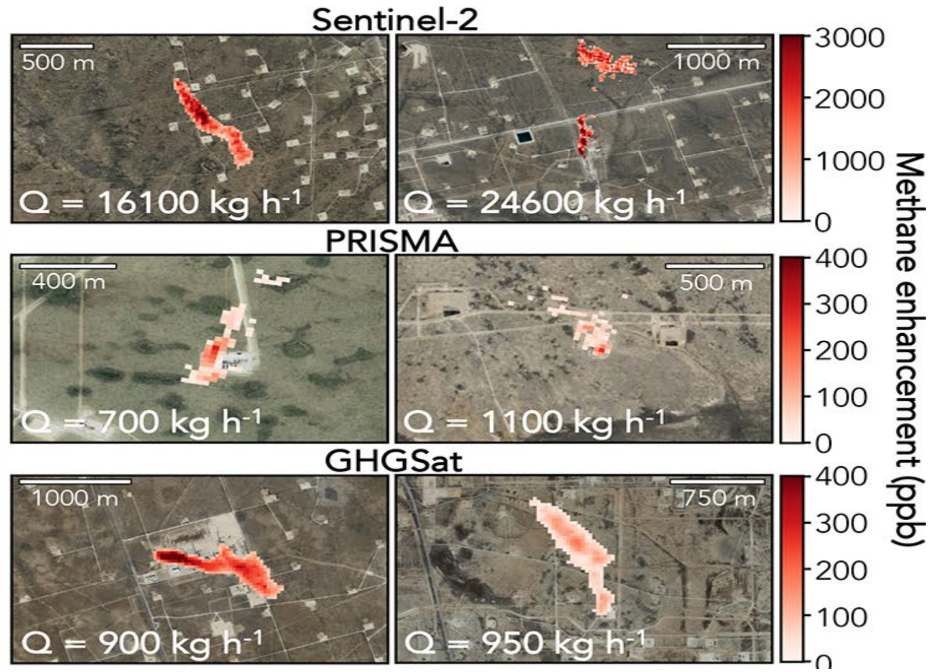
Complementary information from total flux mappers and point source imagers

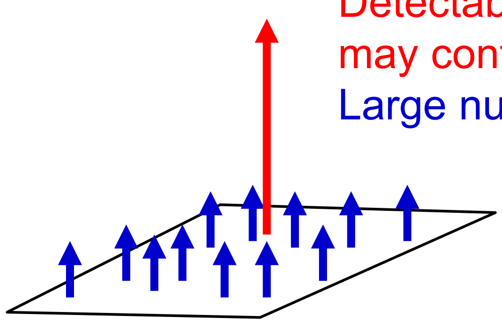
Methane observations over the US Permian Basin

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

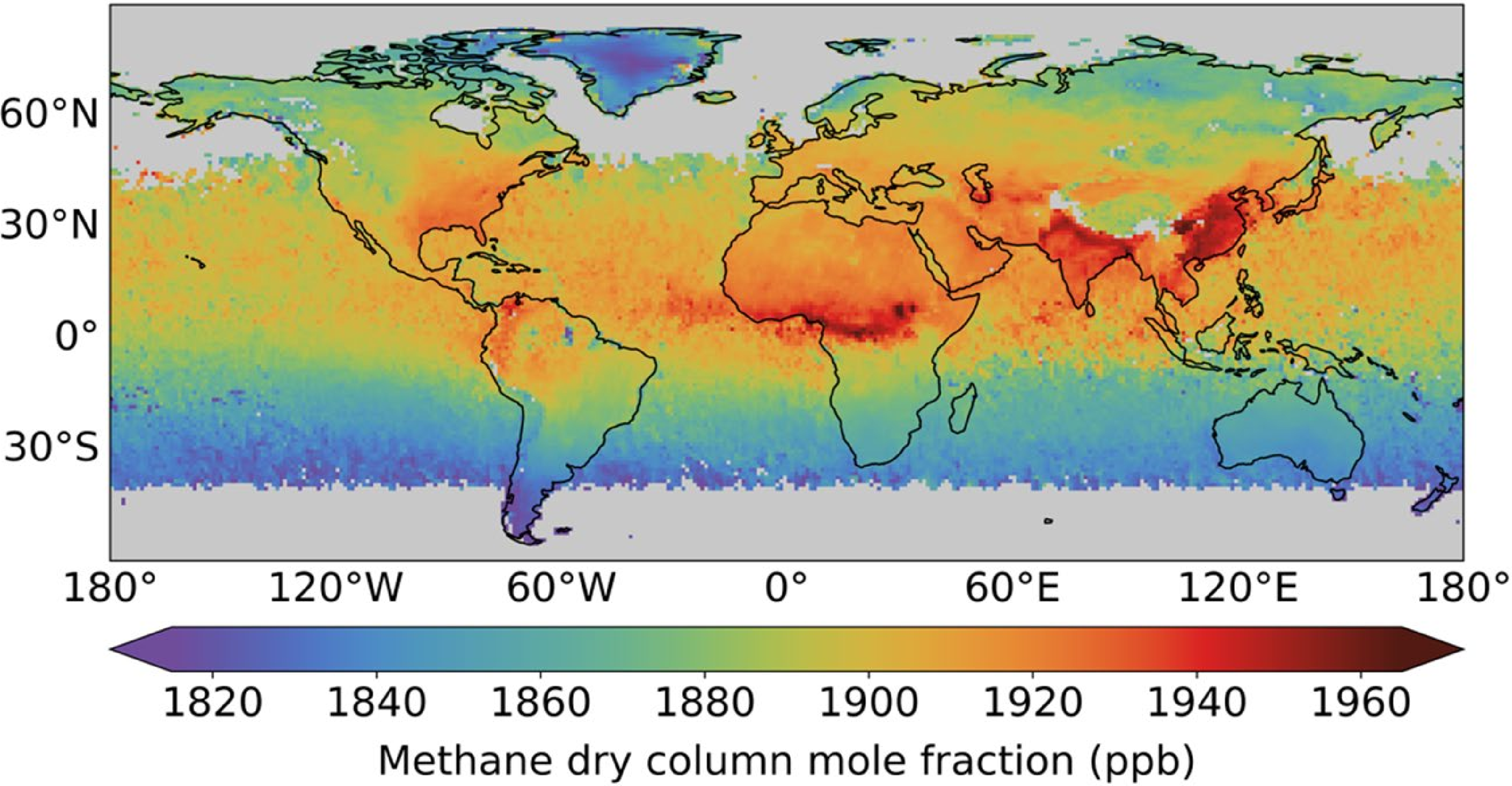
Large number of smaller sources contribute the rest

Jacob et al., ACP2022

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

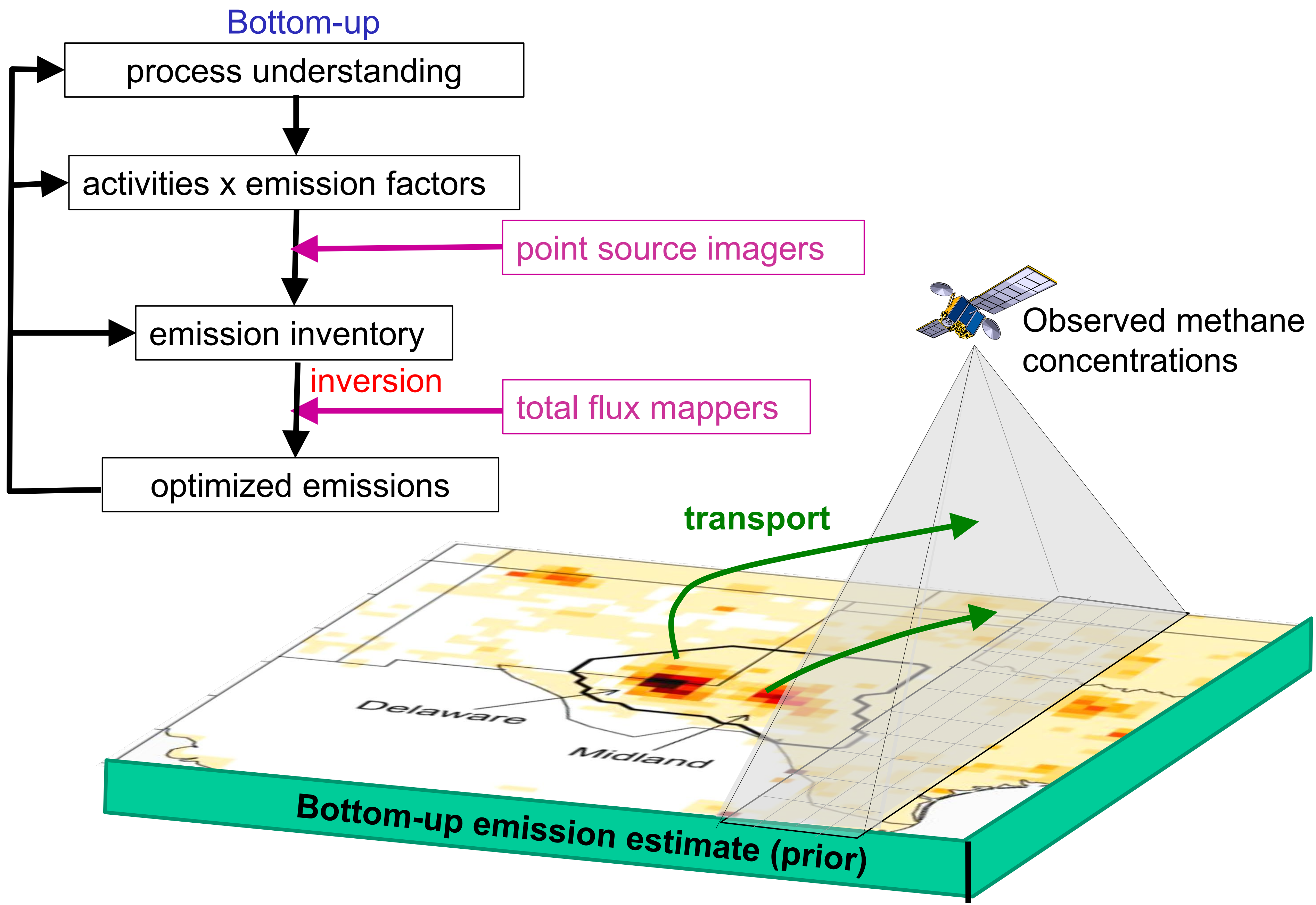
Over 100 million observations per year

Annual mean TROPOMI+GOSAT observations, 2024

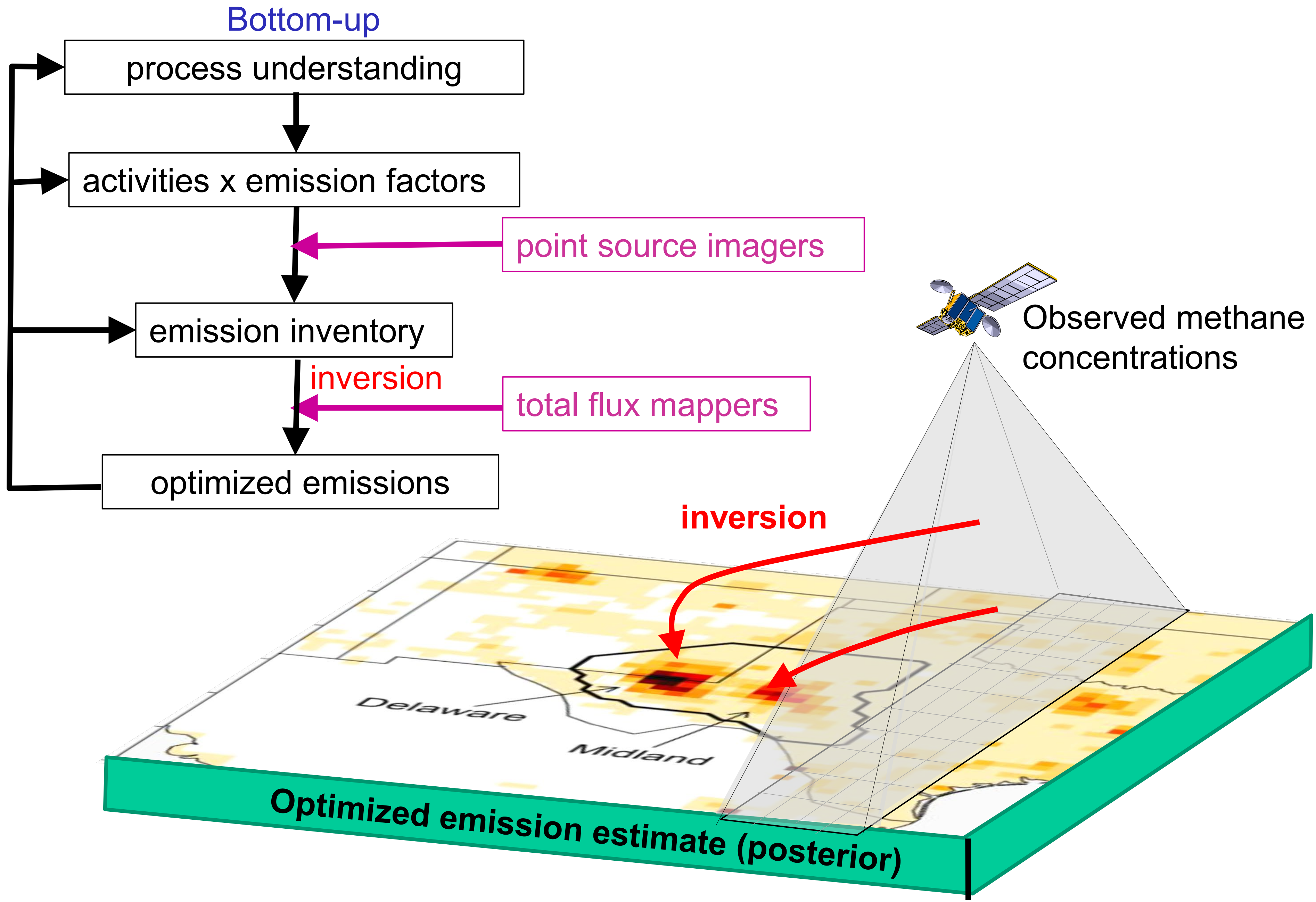


Updated from Balasus et al., AMT 2023

Using satellites to improve/update emission inventories through inverse analyses



Using satellites to improve/update emission inventories through inverse analyses



Cloud-based open-source Integrated Methane Inversion (IMI) puts cutting-edge inversion of satellite data in the hands of stakeholders

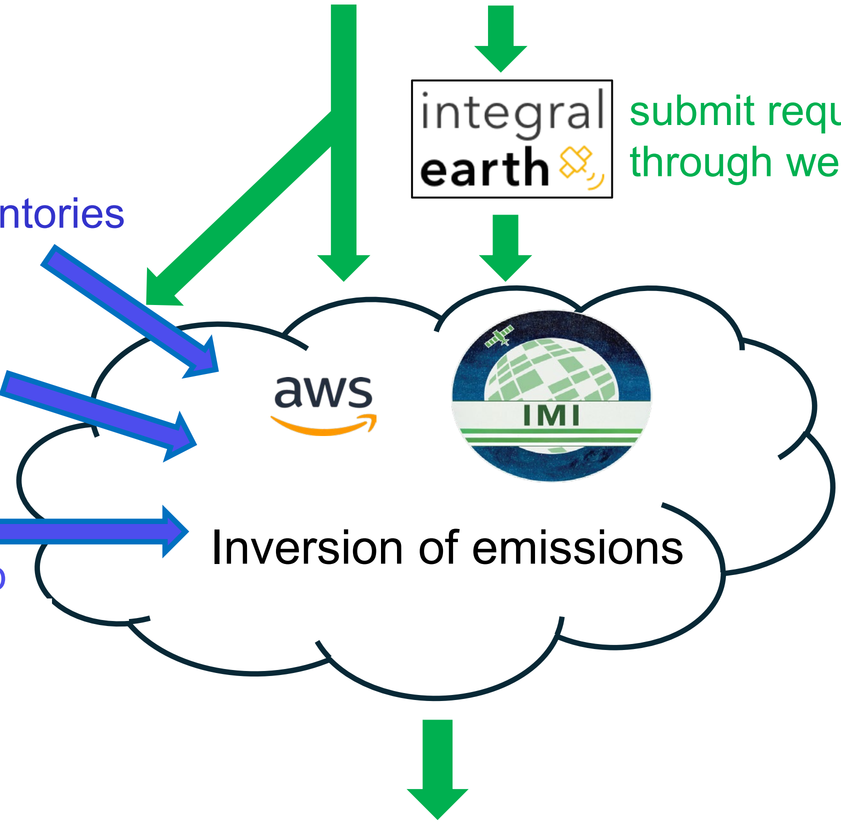
Stakeholders

integral earth — submit request for specific region/period through web user interface

Bottom-up emission inventories

TROPOMI, GOSAT, MethaneSAT data

Sustained R&D by Harvard group

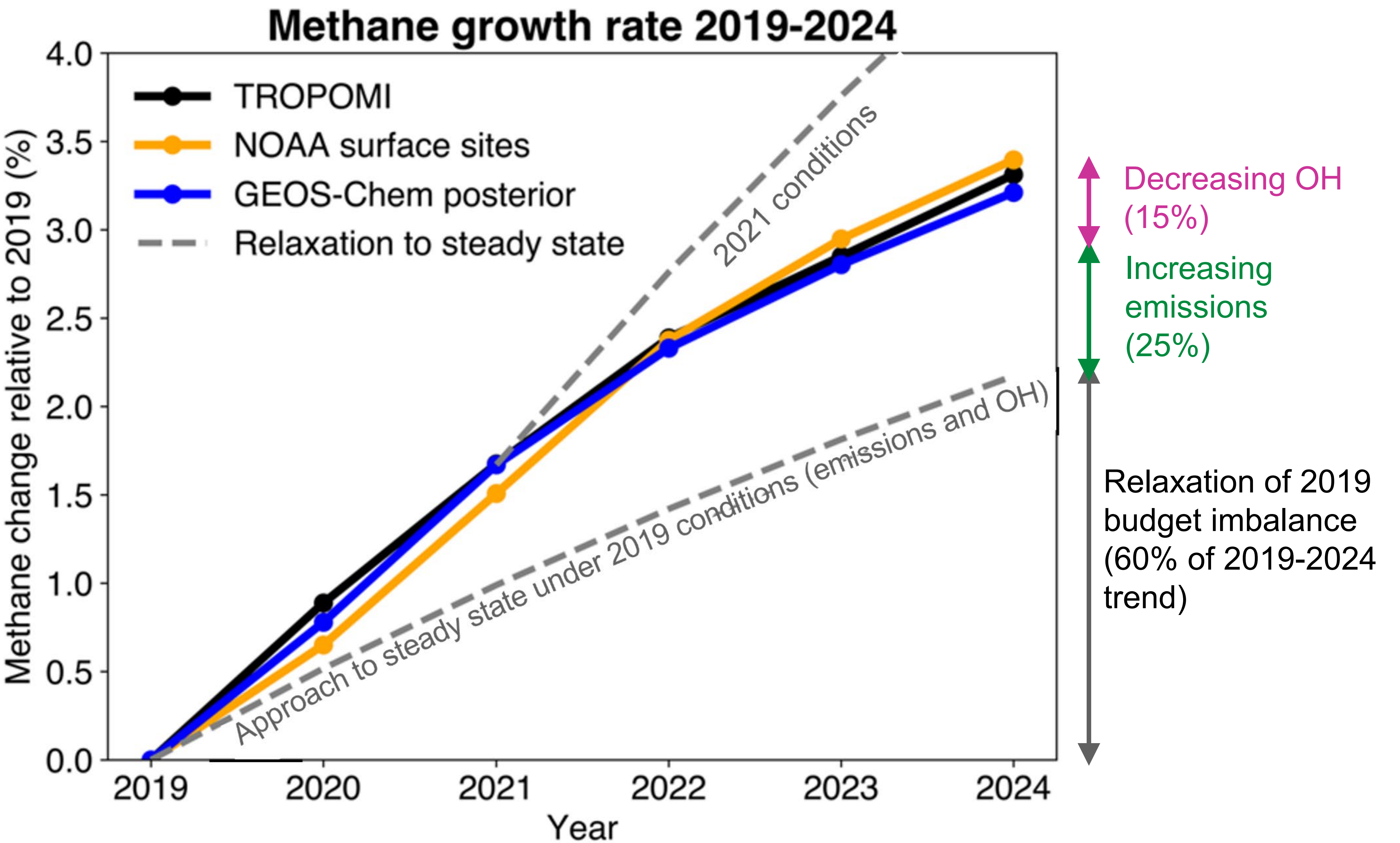


Open-source code ensures
- reproducibility
- transparency
- credibility
- traceability

- Optimized emissions with uncertainty estimates
- Supporting and additional data

Varon et al., GMD 2022
Estrada et al., GMD 2025

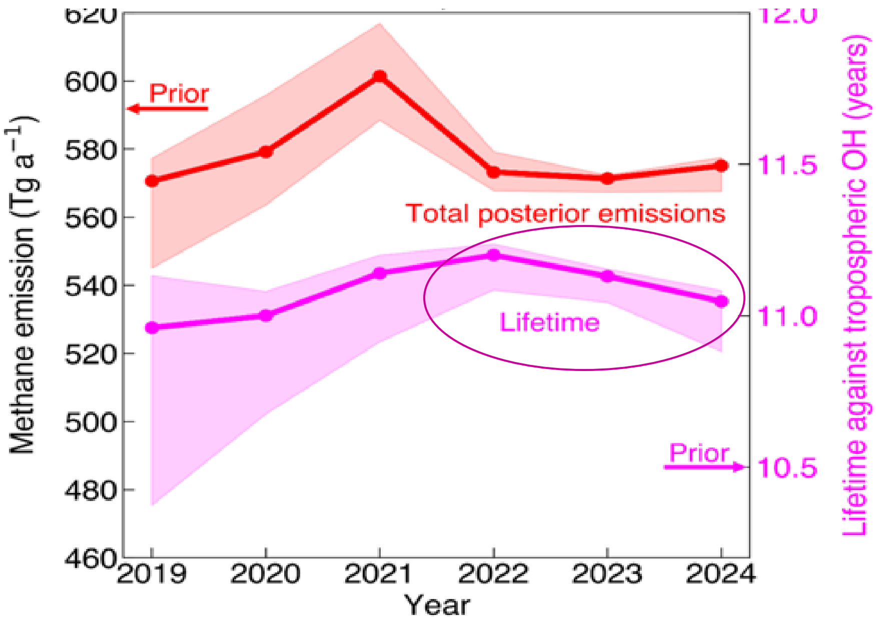
Attributing the 2019-2024 global trend of atmospheric methane



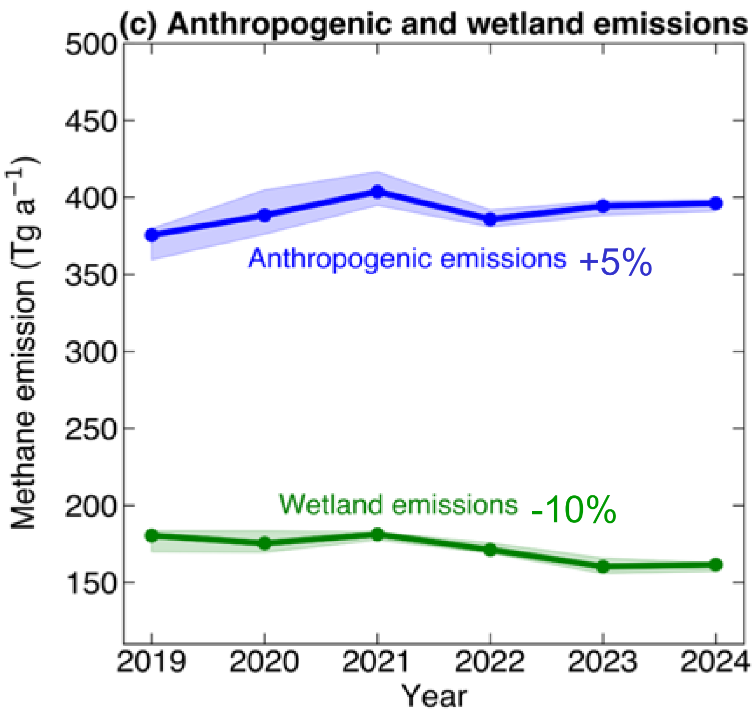
- 2019 budget was out of steady state (sources exceed sinks by 28 Tg/year or 5%)
- Increasing emissions have contributed 25% of increase, decreasing OH 15%
- Growth rate peaked in 2021, has decreased since then

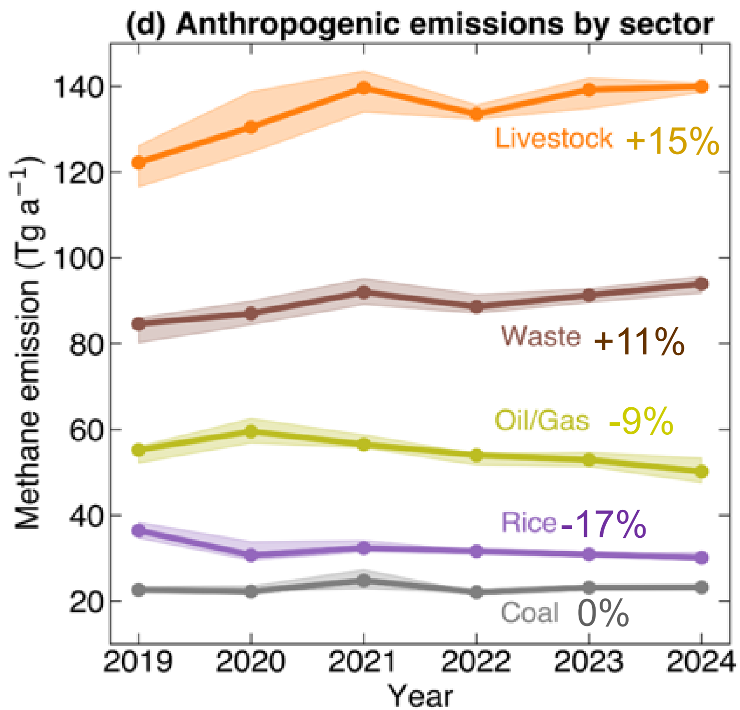
He et al., submitted

Year-by-year trend of emissions by sector, 2019-2024



- Anthropogenic emissions have continued to increase; decrease in oil/gas and rice emissions has been offset by increases in livestock and waste.
- The decrease in growth rate over 2022-2024 is driven by increasing OH

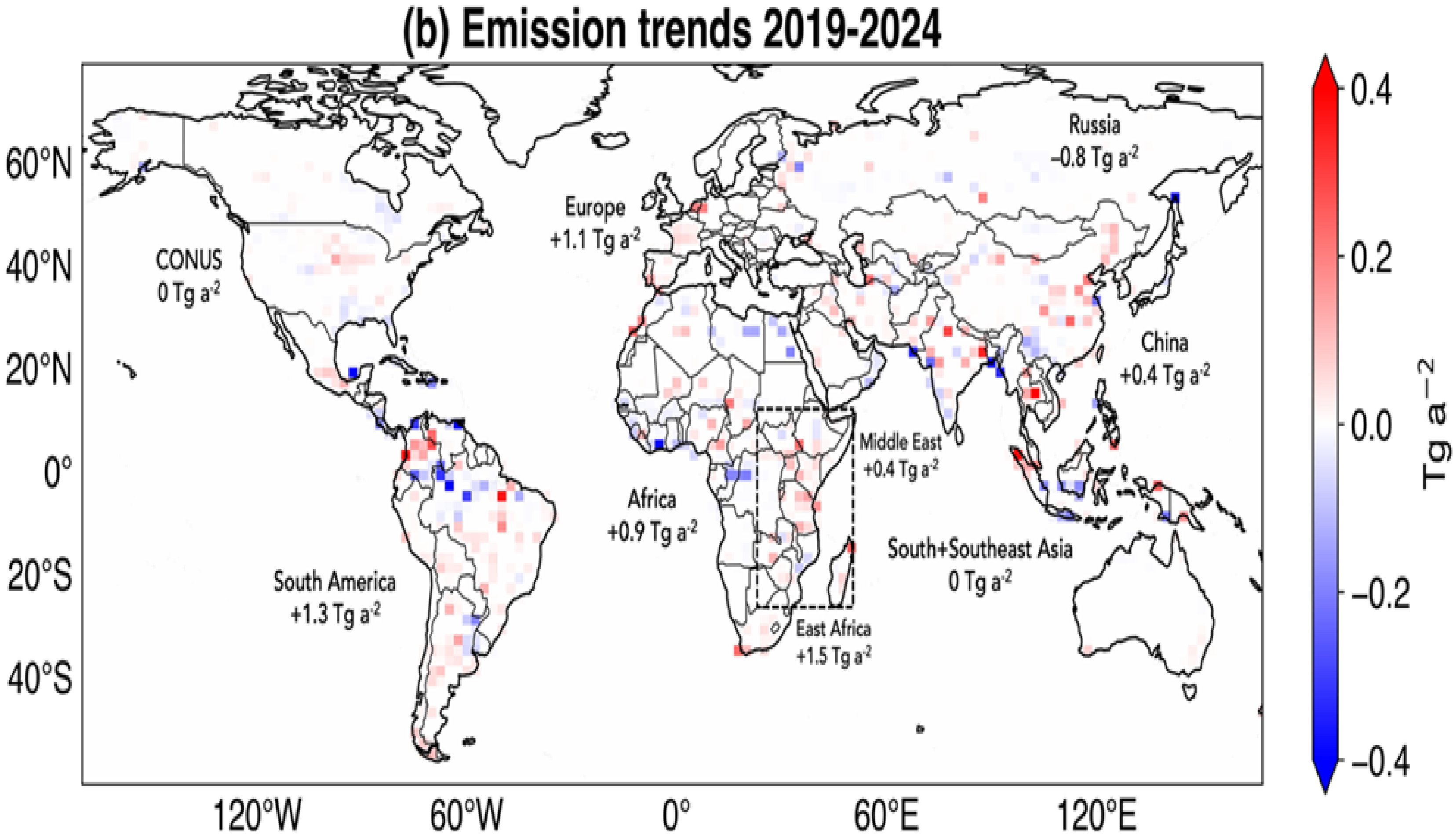




He et al., submitted

Regional attribution of 2019-2024 methane emission trends

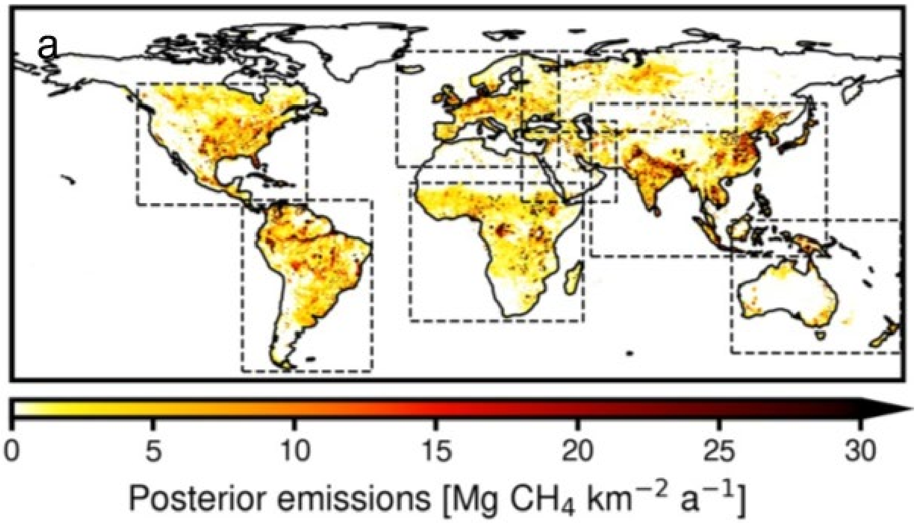
East Africa, South America, Europe account for most of the increase

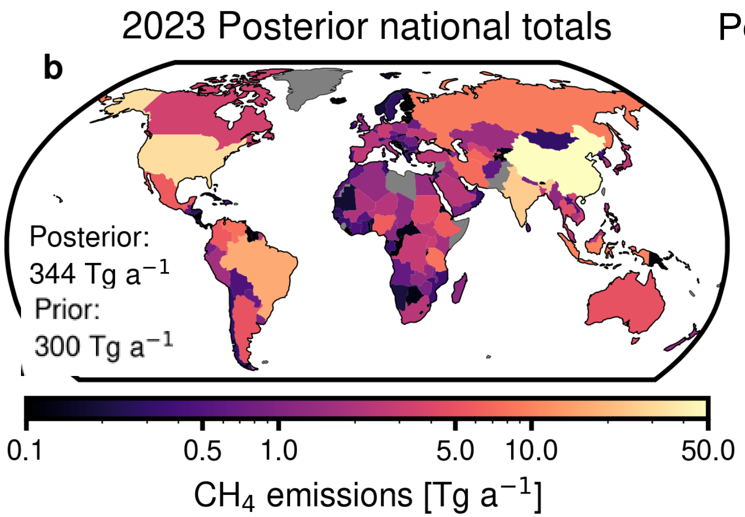


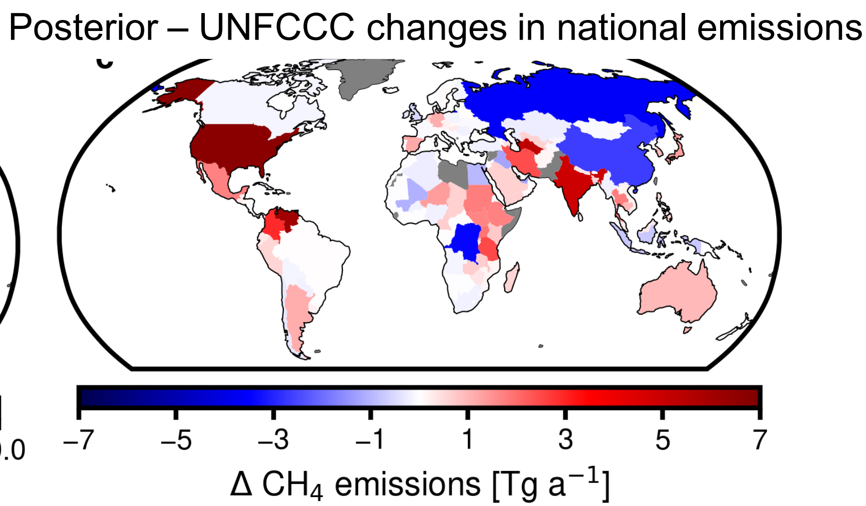
He et al., submitted

Quantifying national emissions by inversion of TROPOMI data

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



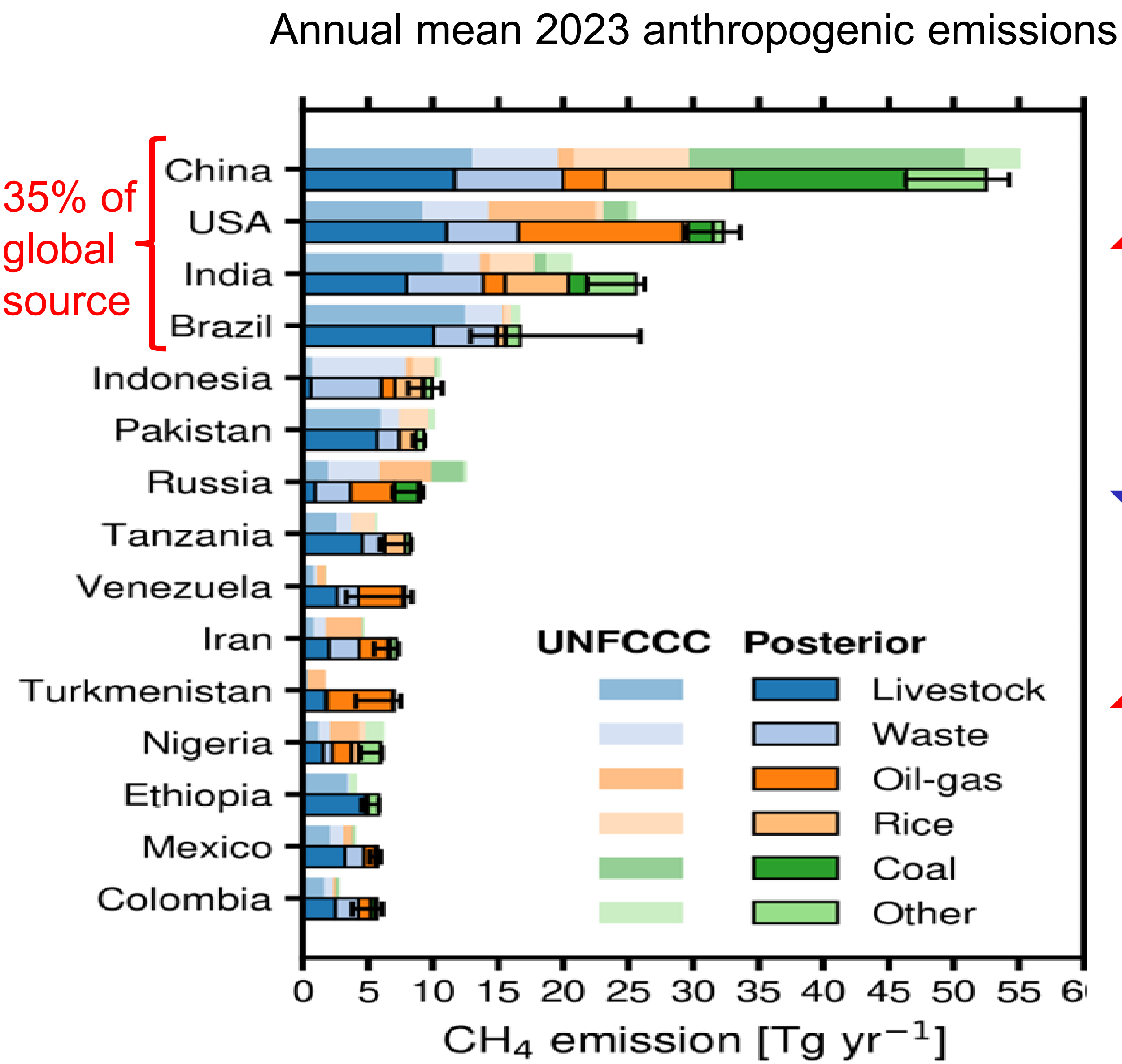




East et al., in prep.

Top 15 emitting countries: comparison to UNFCCC reporting

35% of global source



Oil & Gas: +10.1 Tg

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

Coal: -7.8 Tg

China: -7.8 Tg

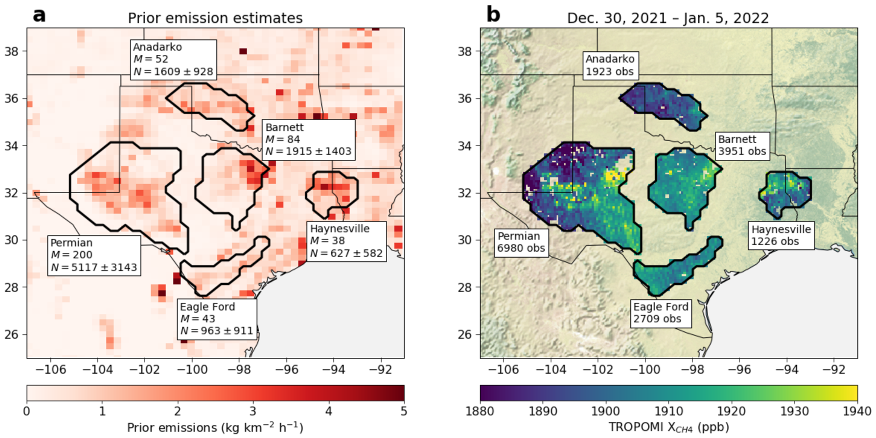
Waste: +6.1 Tg

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

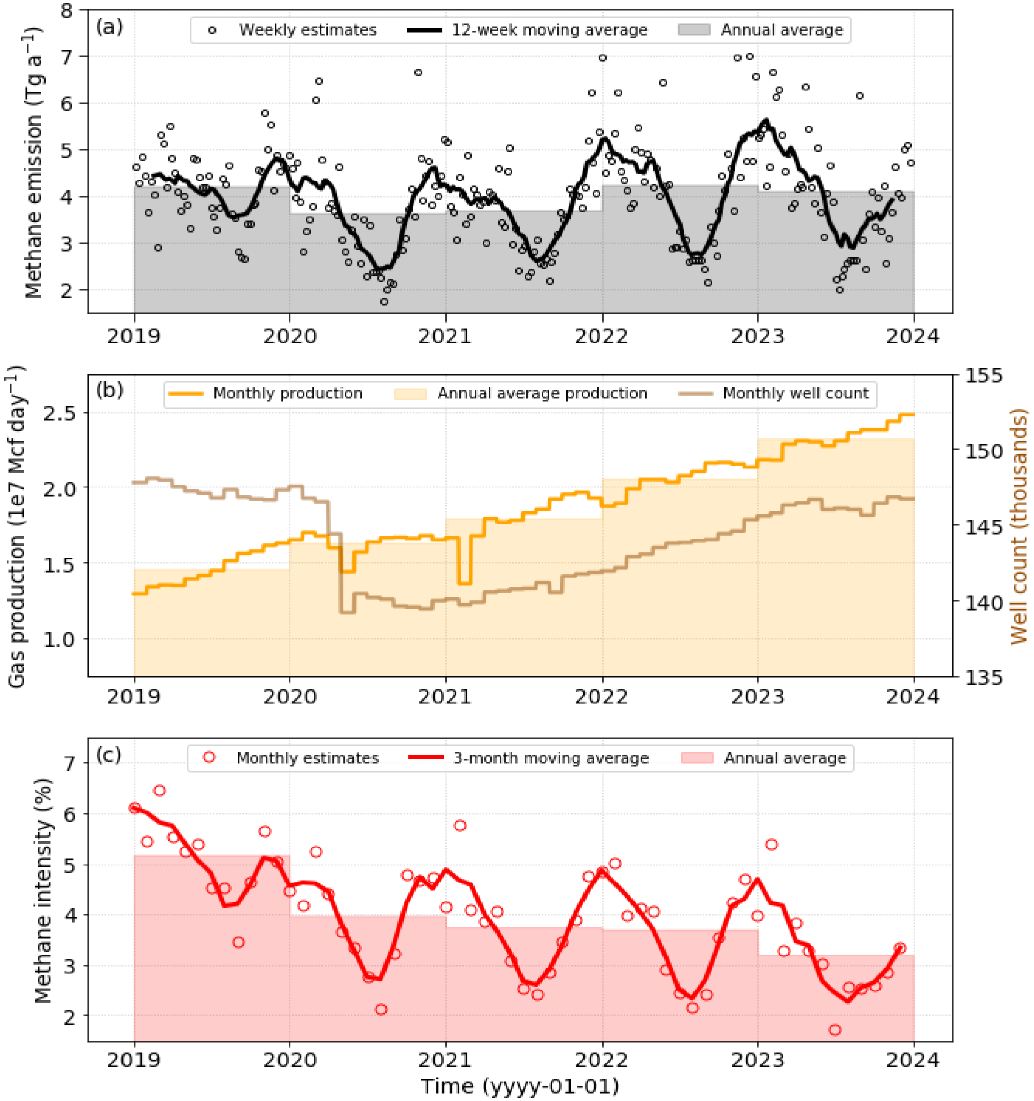
East et al., in prep

Seasonality and declining intensity of US oil/gas emissions

Weekly inversions for O/G basins, 2019-2024



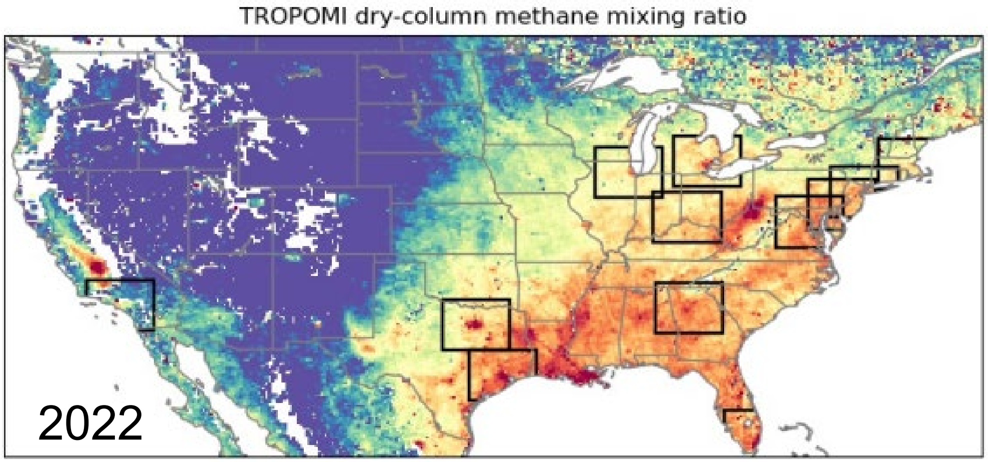
Permian weekly trends

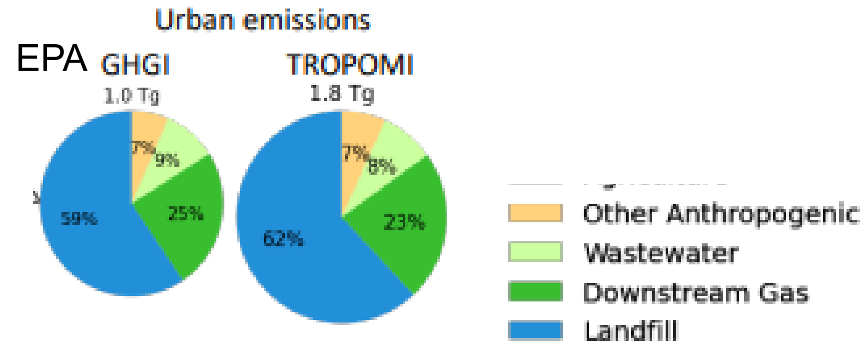


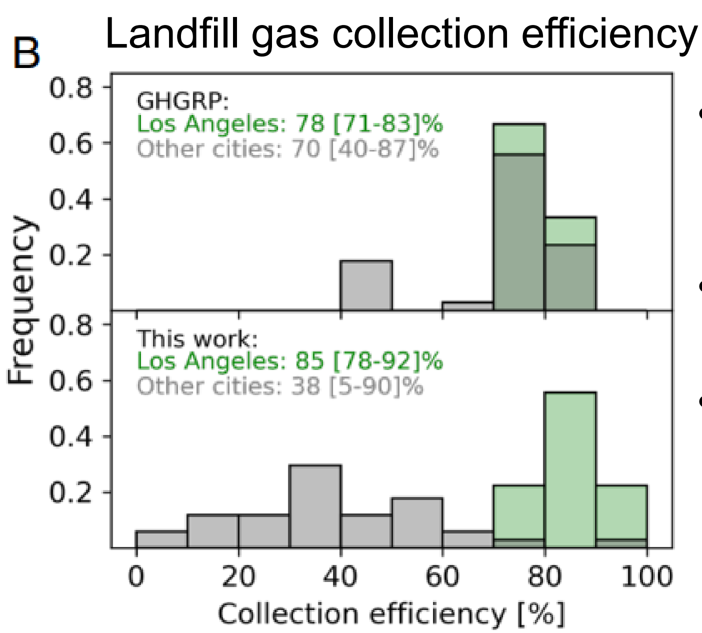
- O/G emissions have remained constant despite increased production: intensity has decreased by 50% over 2019-2024
- Emissions are 60% higher in winter than summer due to poor weatherization of equipment

Varon et al., in prep.

US urban emissions at 12km resolution: underestimation of landfills





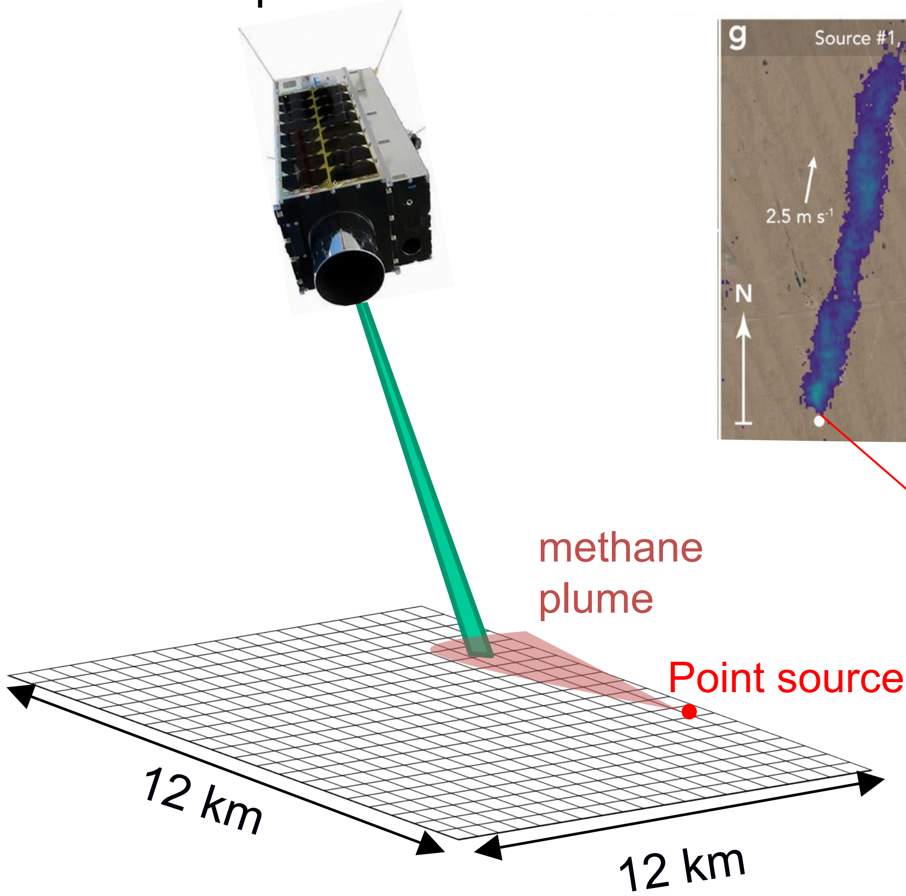


- EPA inventory underestimates urban emissions by 80% on average but overestimates by 40% for Los Angeles
- Landfills are largest contributors to urban emissions except in New York City (downstream gas)
- Landfill gas collection efficiencies (averaging 38%) are much lower than reported to EPA GHGRP (70%) except for Los Angeles (78%)

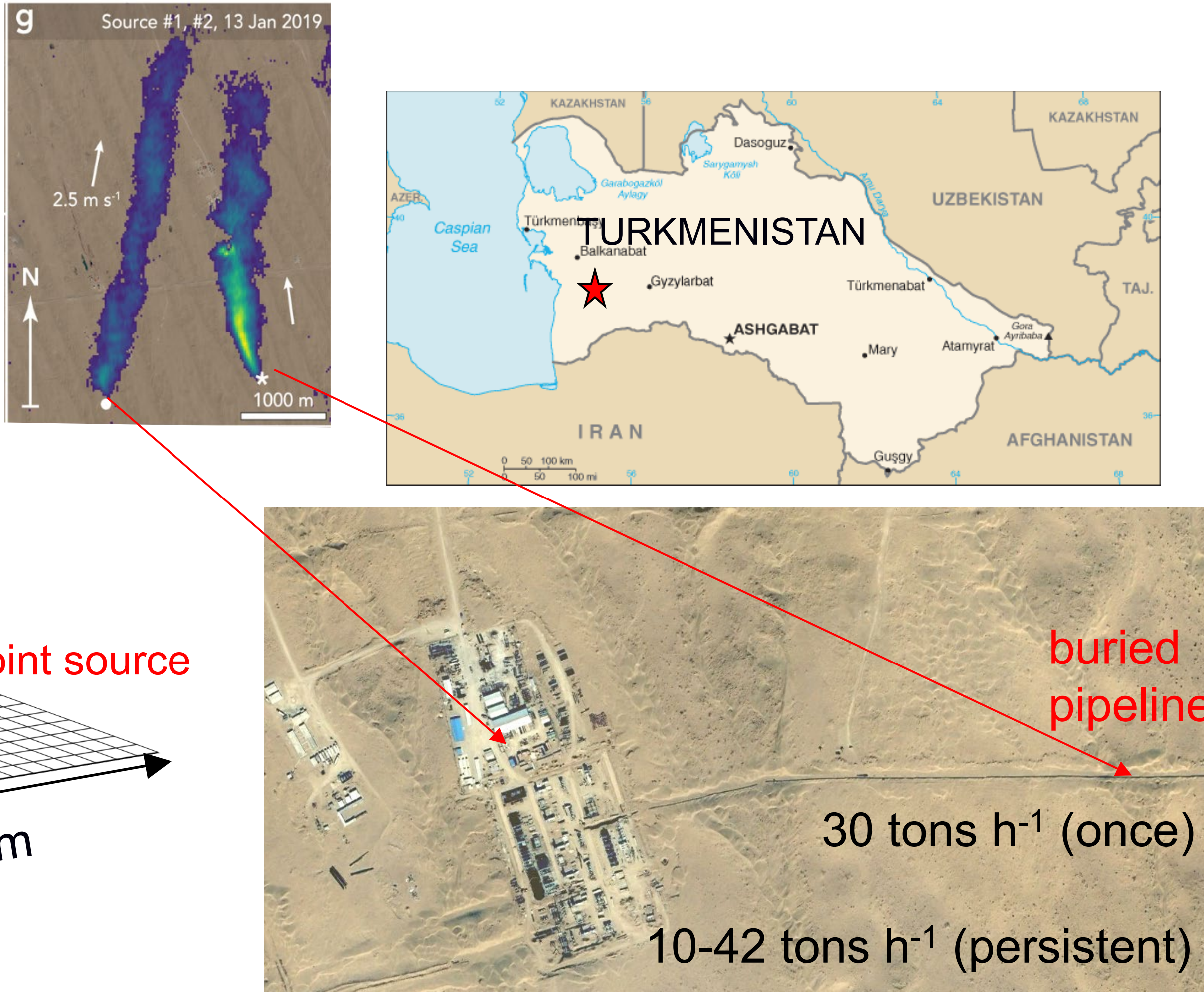
Wang et al., submitted

Observation of methane point sources from space

GHGSat microsatellite fleet
25x25 m^2 pixels



13 Jan 2019

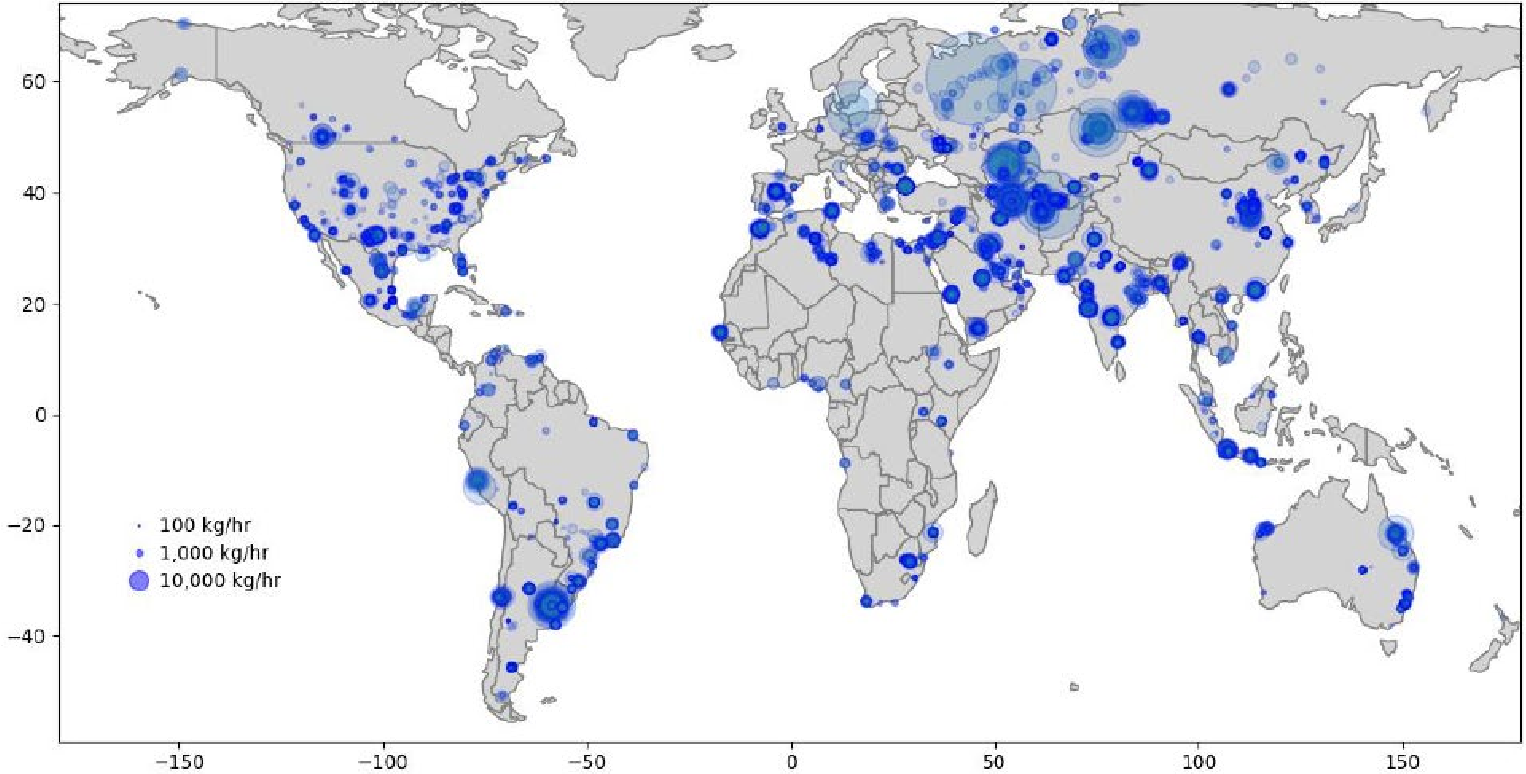


Korpezhe gas compressor station

Varon et al., GRL 2019

Detection of point sources as targets for climate action

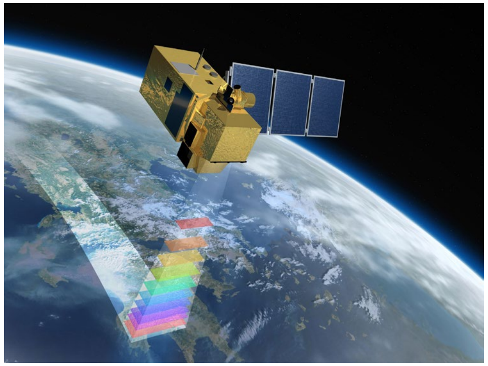
GHGSAT EMISSIONS: JUNE '22 – SEPT '23

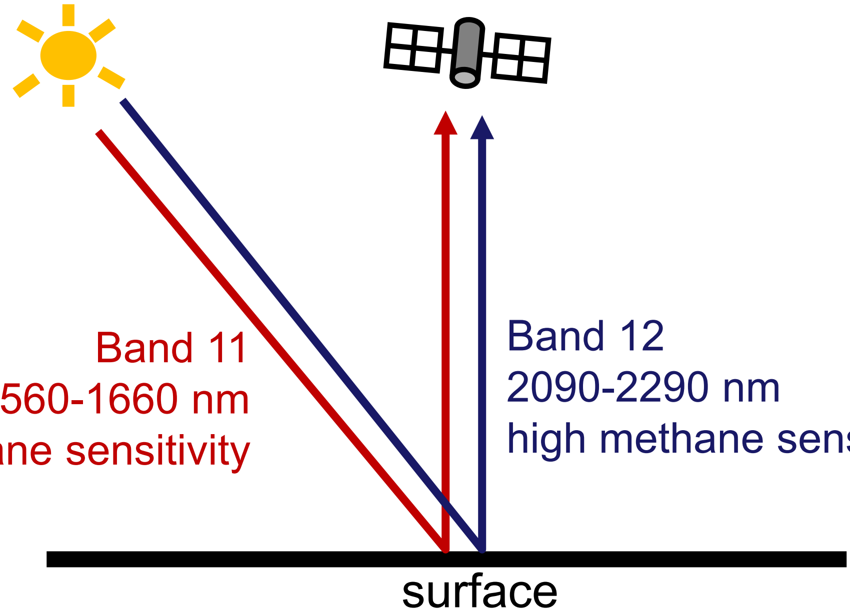


- Observed **> 15,000** plumes in 16 months

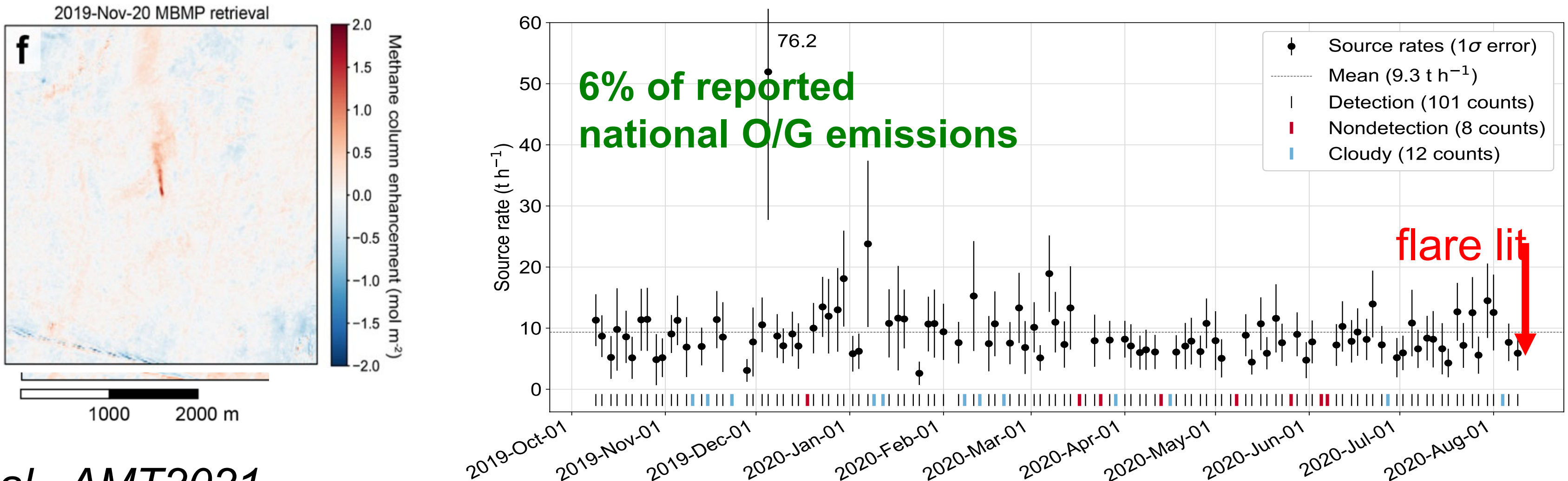
Large methane point sources can be observed with land-imaging spectrometers

ESA Sentinel-2
- 30-m resolution
- global coverage in 2-5 days





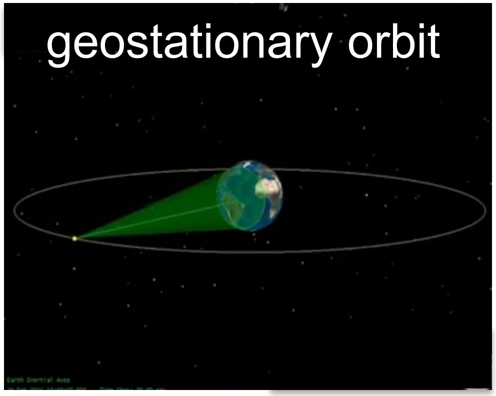
Single oil well plume in Algeria, observed by Sentinel-2 for almost a year

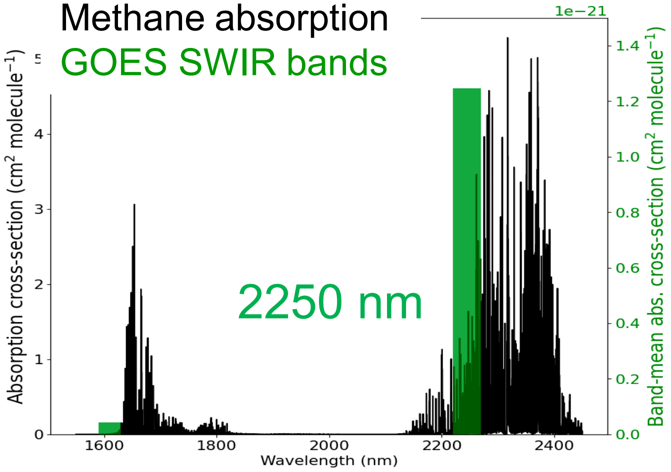


Varon et al., AMT2021

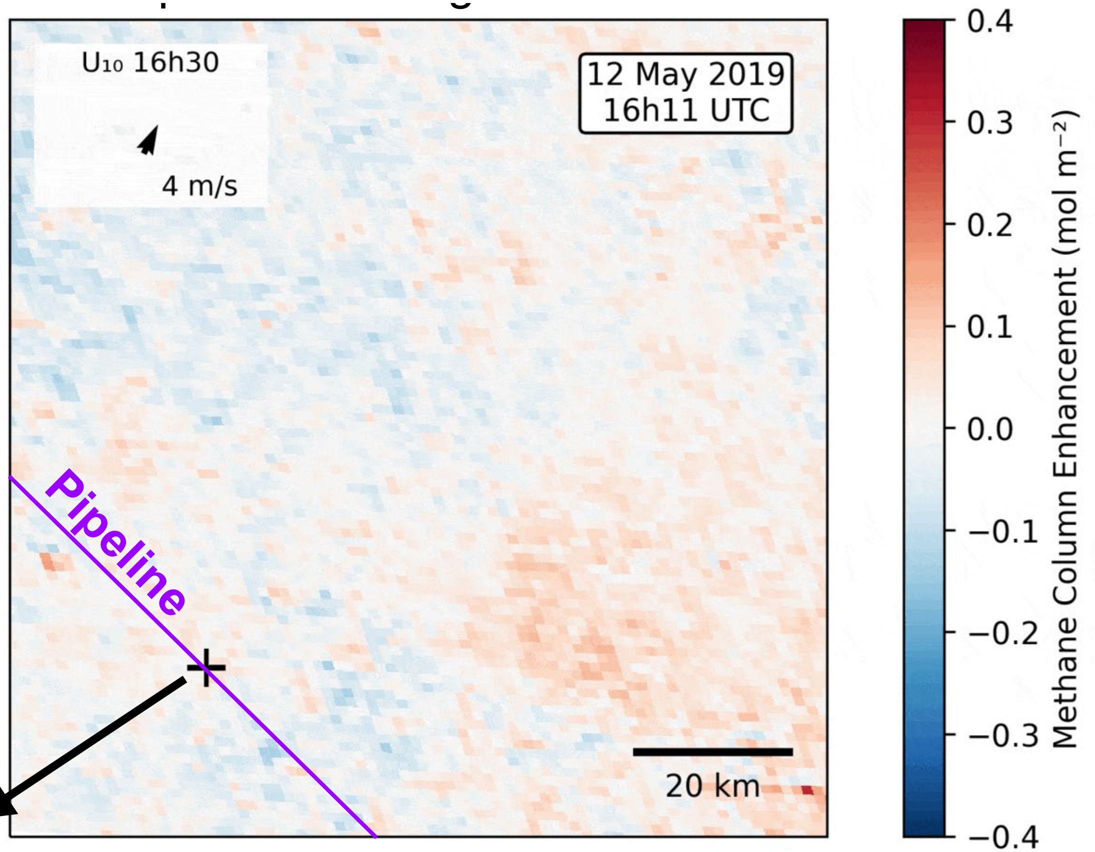
Geostationary observation of methane plumes from NOAA GOES

Observations every 5-10 minutes, 1-2 km pixels





EELL pipeline from Chihuaha to Durango supplying Permian gas to Mexico



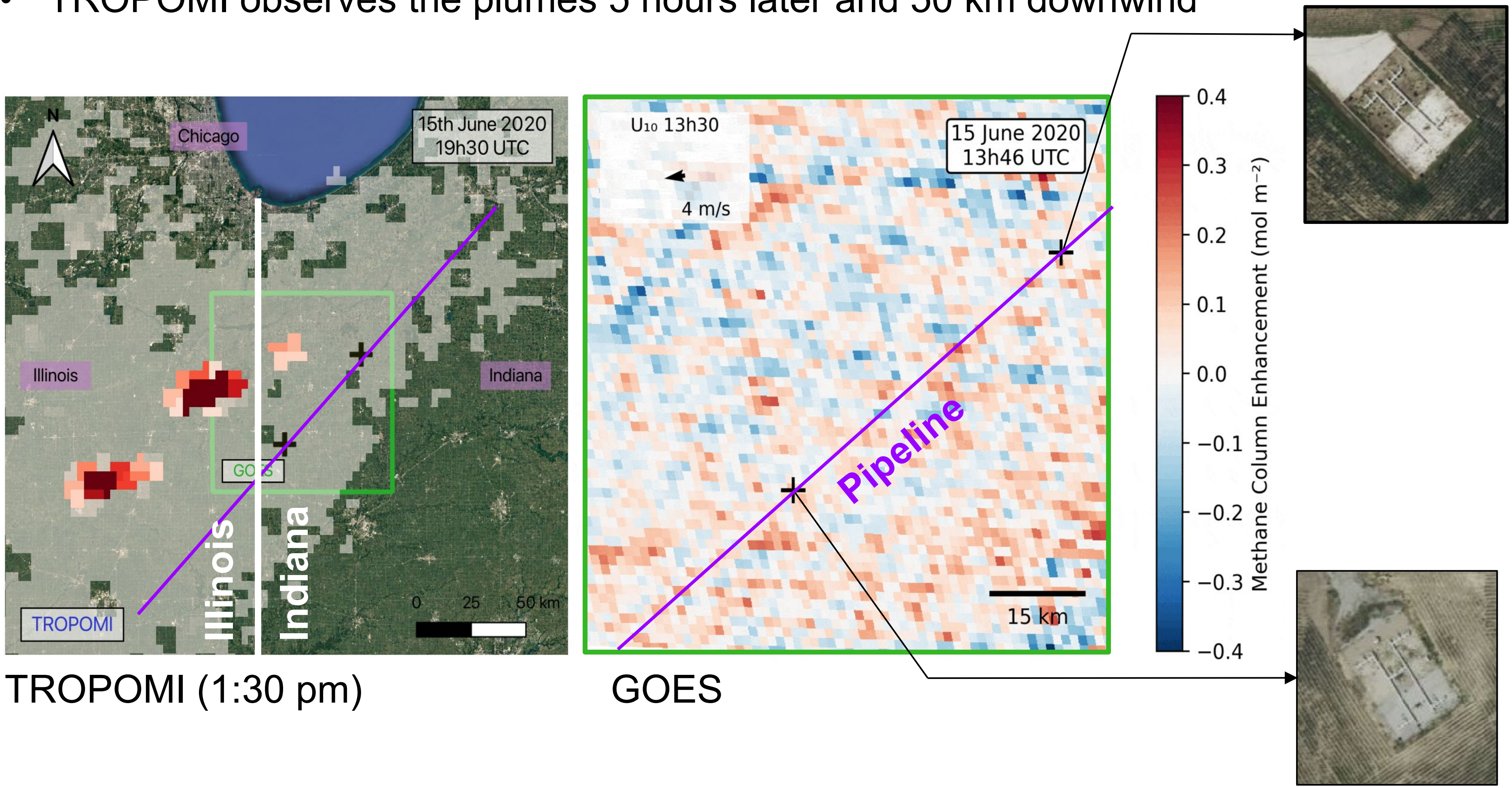
pipeline blocking valve

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

Watine-Guiu, Varon, et al., PNAS 2023

Simultaneous releases from an Indiana gas pipeline

- Releases are very brief (puffs) and synchronized, suggesting an automated venting operation for pipeline repair
- TROPOMI observes the plumes 5 hours later and 50 km downwind



TROPOMI (1:30 pm)

GOES

Watine-Guiu, Varon, et al., PNAS 2023