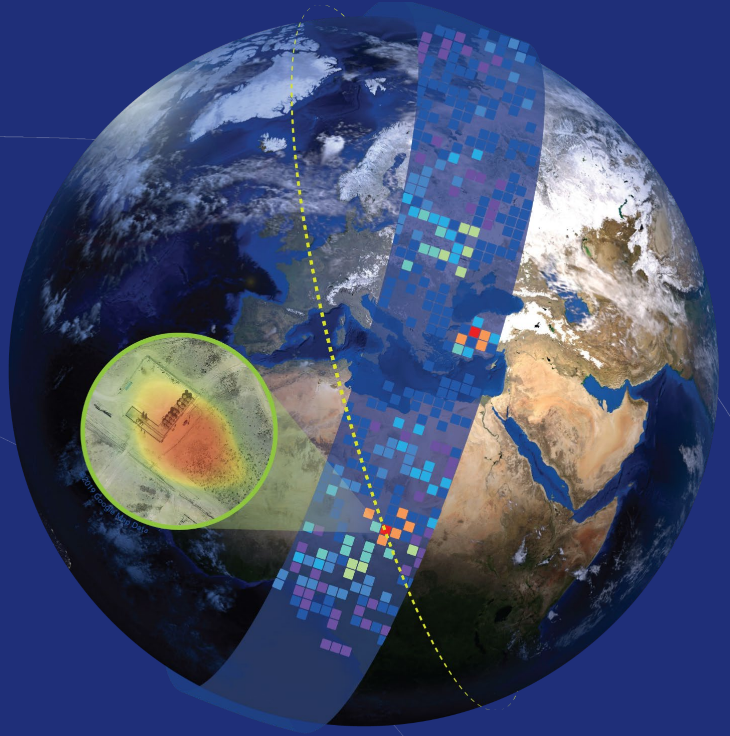


Technical Overview of GHGSAT Data Available through NASA CSDA

Tanya Harrison, Ph.D. | Senior Science Advisor

Dylan Jervis, Ph.D. | Senior Scientist

March 19, 2025

GHGSAT

AGENDA

- Introductions
  - GHGSat constellation and data overview
- GHGSat Data products available through CSDA
- GHGSat Methane Data Deep Dive
  - Methodology for methane emission monitoring
- How to apply for GHGSat data access through CSDA
- Q&A

INTRODUCTION TO GHGSAT

INTRODUCTION

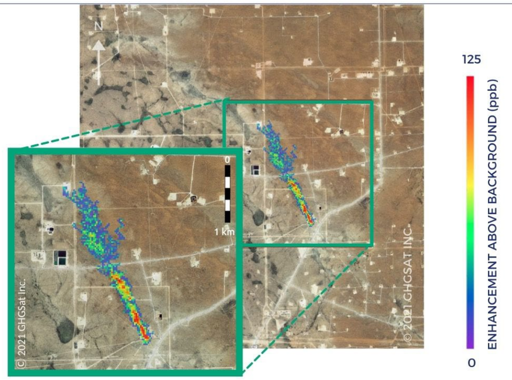
GHGSAT

- A leading-edge space and data technology company founded in 2011
- Provides actionable metrics and insights through advanced emission monitoring solutions and analytics tools
- A team of 160, including engineers, scientists, data analysts, and sector specialists with the goal of supporting emission reductions
- Launched first prototype satellite Claire in 2016, growing to a satellite constellation of 10 methane monitoring and 1 CO_2 monitoring satellites

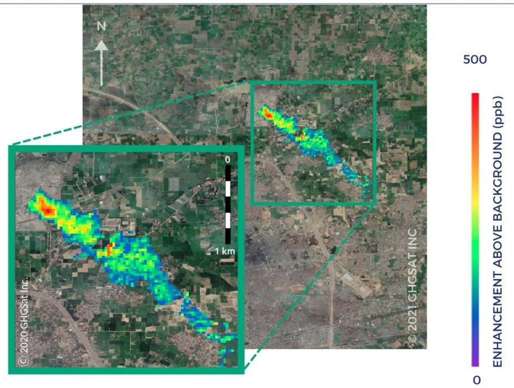
GLOBAL POINT SOURCE EMISSIONS MONITORING

GHGSat operates its own satellites and aircraft to detect and quantify methane emissions from facilities around the world

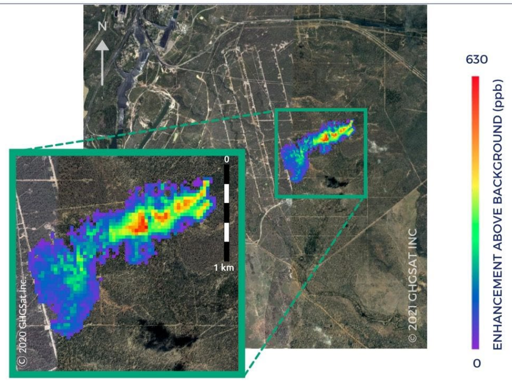
Oil & Gas - USA
CH_4 Measurement



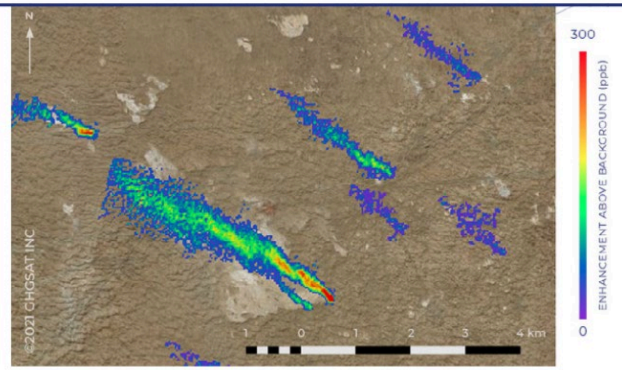
Landfill - Asia
CH_4 Measurement



Coal Mine - Australia
CH_4 Measurement



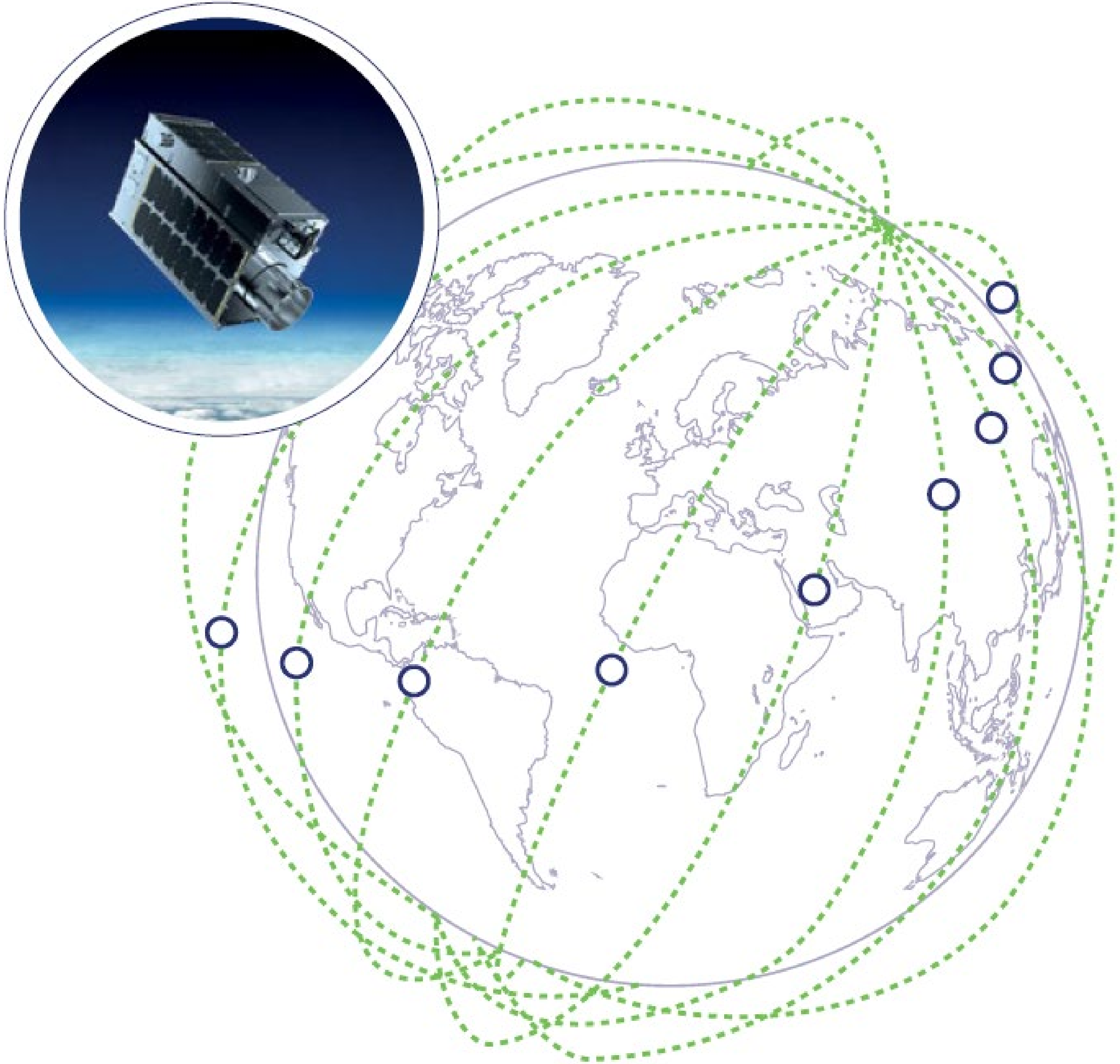
Oil & Gas – Central Asia
CH4 Measurement



OUR SATELLITES

10 methane detecting satellites in space

- **Spatial resolution:** 25 m
- **Spectral range:** 1630-1675 nm
- **Spectral resolution:** 0.3 nm
- **Detection threshold:** (50% PoD at 3 m/s)
    - **Onshore:** 100 kg/hr
    - **Offshore:** 150 – 1000 kg/hr (seasonally and latitude dependent)
- **Field of View:** 12 km x 12 km
- **Revisit Time:** 1-2 days with combined satellite revisit



FROM OBSERVATION TO METHANE QUANTIFICATION

Observation Planning
Intelligent pointing for satellites in target mode

→

Observation
Collect data

→

Data Processing & Validation
Process raw data to retrieve a map of methane concentration

→

Identify Emissions

→ Source Rate in kg/hr

→ Source Location

GHGSAT DATA PRODUCTS AVAILBLE THROUGH NASA CSDA

GHGSAT & NASA CSDA

- Data is available to researchers funded by any U.S. federal agency for non-commercial use through a USG EULA
  - Derived products can be shared and published
    - Please include an attribution to GHGSat (e.g., in figure captions)
  - Original data products cannot be shared with non-CSDA users
    - For publications, we suggest including a list of observation IDs for reproducibility
- Through CSDA, researchers can request:
  - New taskings over both single and complex sources onshore and offshore

GHGSAT DATA ACCESS

Data Products Details

- **What order types are available?**
  - **Catalogue**: Historical data that is contained in GHGSat's archive
  - **New Tasking**: Ability to request the collection of new observations of a specific site
    - **Single Source:** Analysis of the emissions in a specific location in the image (lat/lon required)
    - **Complex Source:** 3 or more individual sites to be analyzed in one image, or complex/diffused/offshore emissions

- **What frequency of monitoring is available through CSDA?**
  - **Monthly:** 12 observations of **a single site*** over a full year
  - **Single**: A single observation of a requested site as a specific time

DATA PRODUCTS

Single Source vs Complex Source

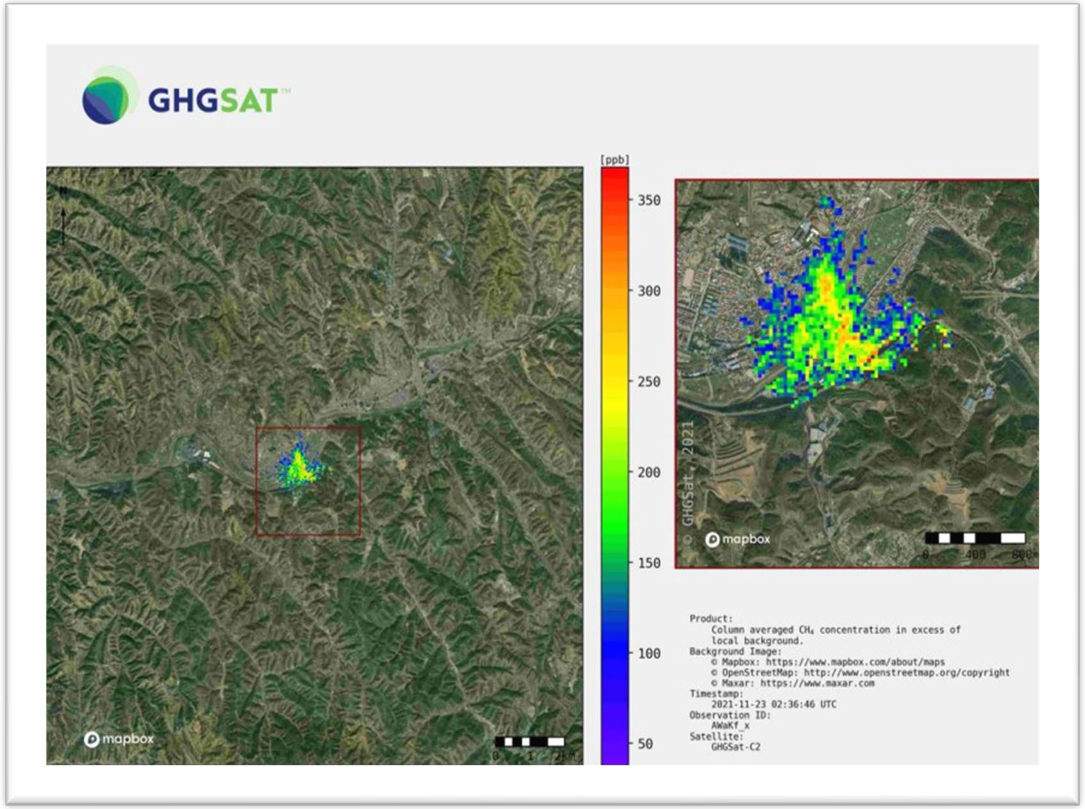
- **Single Source:** Analysis of the emissions in a specific location in the image (lat/lon required)
  - Examples: Underground coal mine shafts, O&G facilities, LNG storage tanks

- **Complex sources:** 3 or more individual sites to be analyzed in one image, or complex/diffused/offshore emissions
  - Examples: Landfills, offshore emissions, complex O&G sites, pipelines, open-pit coal mines

DATA PRODUCTS

What's in the ZIP file?

- **Data files:**
  - Per-pixel SWIR surface reflectance (GeoTIFF)
  - Per-pixel methane abundance and error in ppb (GeoTIFF)
  - Per-pixel quality designation flag (GeoTIFF)
  - Methane concentration map (PNG)
  - Metadata (JSON)
- **If there is an emission:**
  - Per-pixel methane abundance for isolated emission (GeoTIFF)
  - Site-attributed emission data (CSV)



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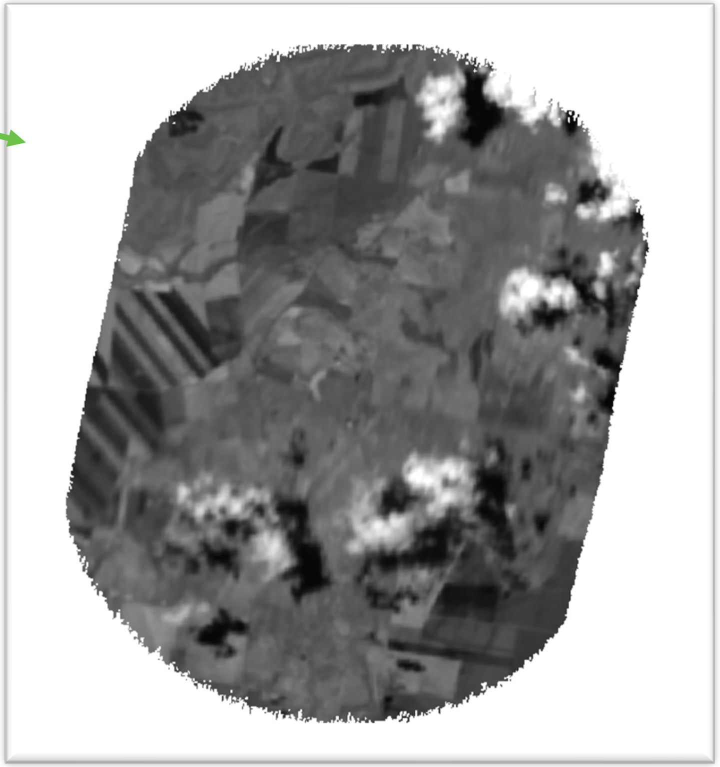

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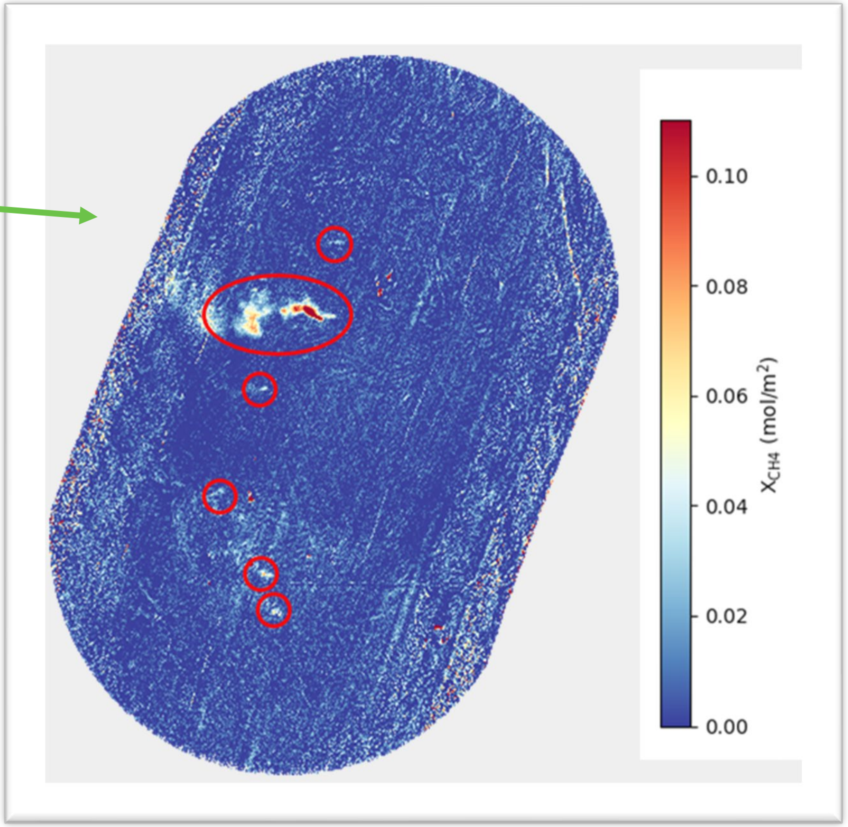

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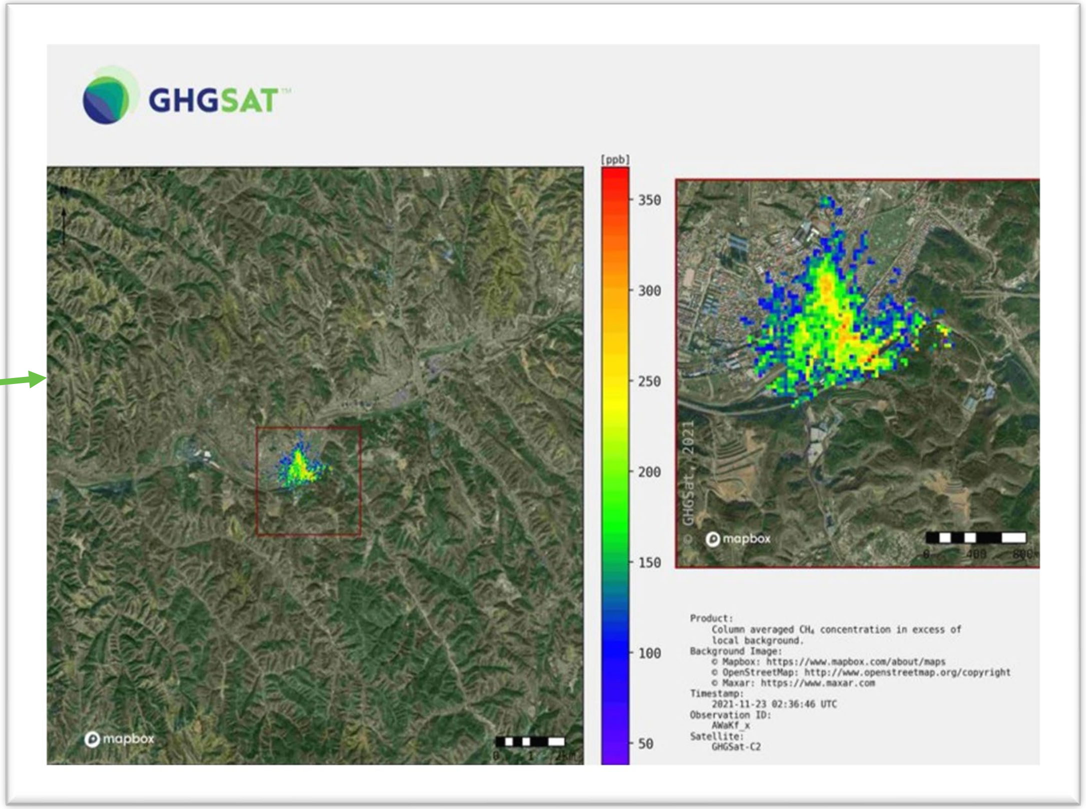


DATA PRODUCTS

Metadata

Data files:

- Per-pixel SWIR surface reflectance (GeoTIFF)
- Per-pixel methane abundance and error in ppb (GeoTIFF)
- Per-pixel quality designation flag (GeoTIFF)
- Methane concentration map (PNG)
- Metadata (JSON)

If there is an emission:

Per-pixel methane abundance for isolated emission (GeoTIFF)

Site-attributed emission data (CSV)

Data	Description
Position	The latitude and longitude of the source of the detected emission.
Zone	The region (typically country) in which the emission was detected.
Site Name	The name of the site that the emission source is attributed to. This only applies for asset monitoring in which the customer has provided a site list.
Observation Date (UTC)	The date of the observation in which the emission was detected.
Sensor	The sensor that collected the observation with the emission (e.g. GHGSAT satellites, aircraft, third-party).
Source Rate (kg/hr)	The source rate represents the mass of methane released in the atmosphere over time. If the emission is a "maybe" for DATA.SAT or < 1000 kg/hr for Sentinel-2, then no source rate is shared.
Source Rate Error (%)	The standard deviation of the source rate calculation resulting from uncertainties in the model, methane abundance, and wind speed.
Wind Speed (m/s)	The wind speed at the source of the emission as provided by GEOS-FP, which was used to calculate the source rate.

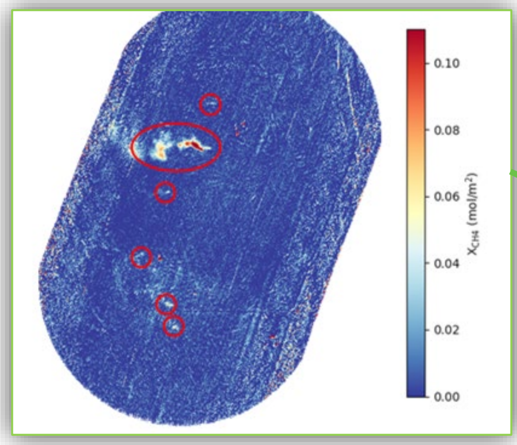
DATA PRODUCTS

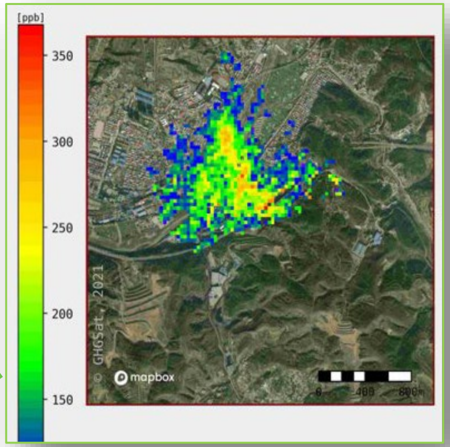
Processing levels and data formats

- **Abundance dataset (Level 2):** Set of per-pixel abundances of CH_4 in excess of the local background (ppb), and per-pixel measurement error expressed as a standard deviation for a single site on a single satellite pass. Data format is 16-bit GeoTIFF.

- **Concentration Maps (Level 2):** High readability pseudocolour map combining surface reflectance, and column density expressed in ppb for a single species in PNG format.

- **Emission Rates (Level 4):** Instantaneous rate for a detected emission from a targeted source applying dispersion modelling techniques, in kg/h. The delivered product includes the emission rate estimate with uncertainty and key dispersion parameters (in CSV format).

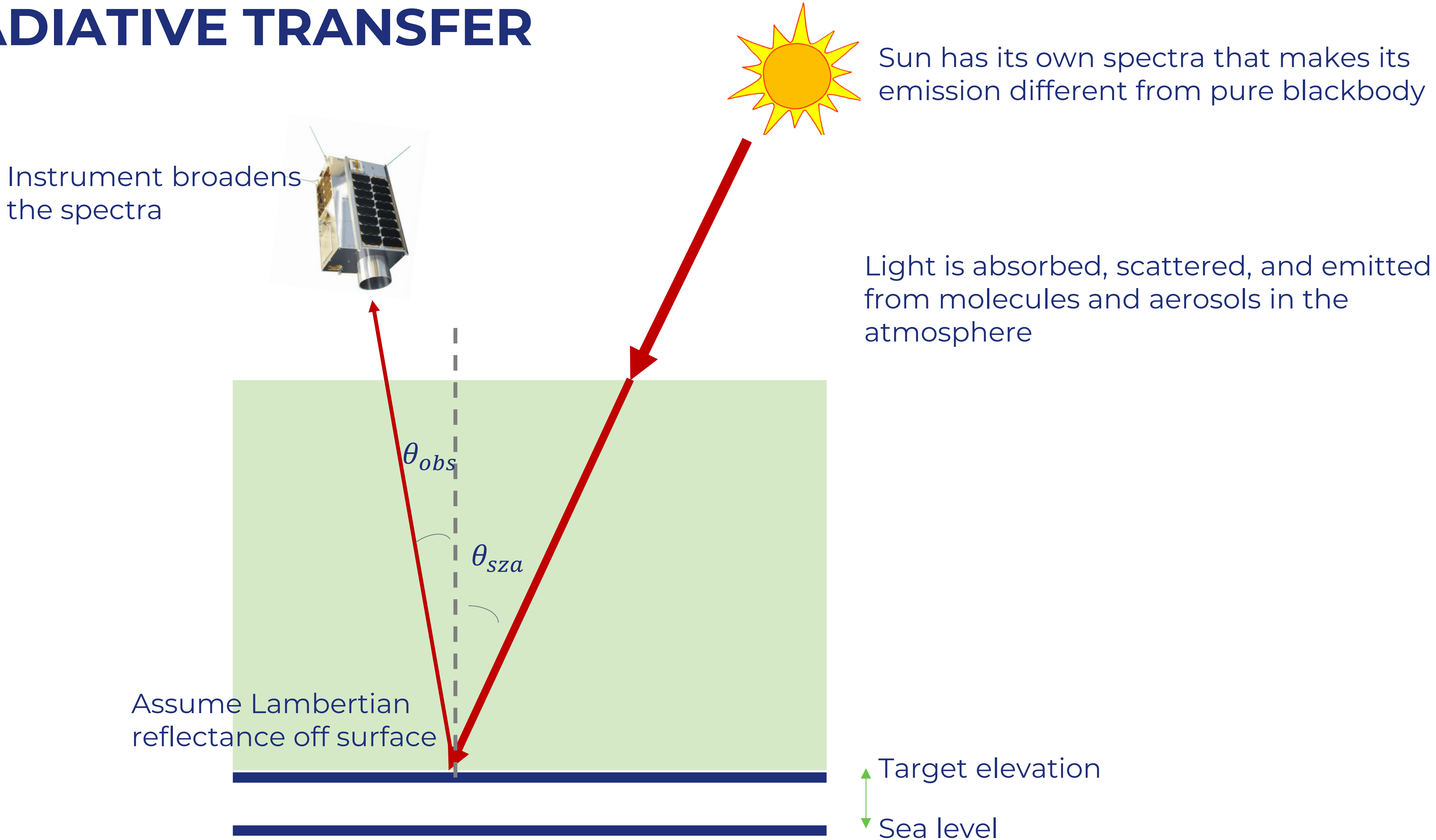




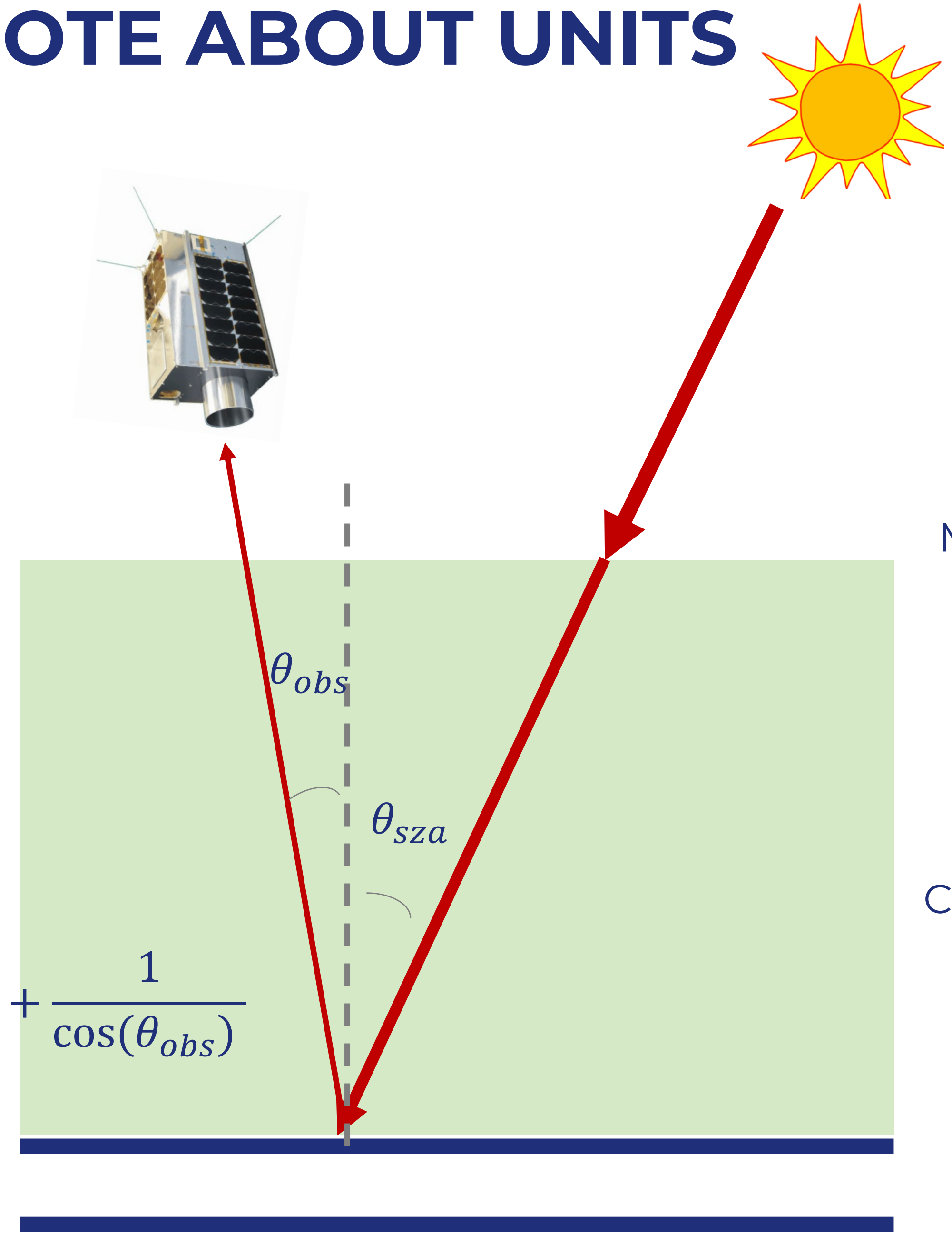
121 kg/hour ± 20%

METHANE DATA DEEP DIVE

RADIATIVE TRANSFER



A QUICK NOTE ABOUT UNITS



$$AMF = \frac{1}{\cos(\theta_{sza})} + \frac{1}{\cos(\theta_{obs})}$$

Density of methane:

n_{CH_4}

Units of [# molecules / m^3]

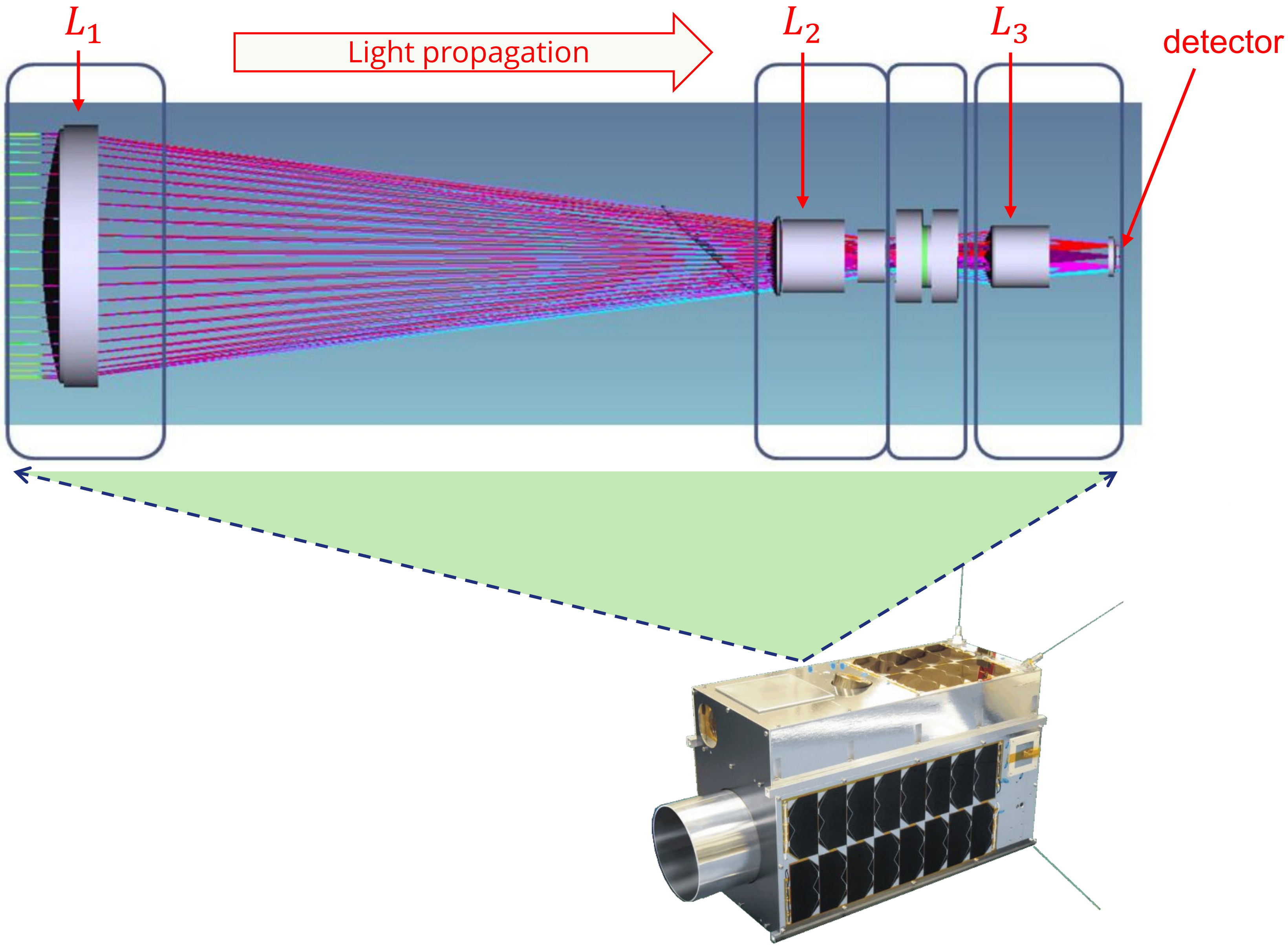
Measurement integrates the density along photon's path l:

$$\Omega_{CH_4}[\mathrm{mol/m^2}] = \frac{1}{AMF}\int n_{CH_4} dl$$

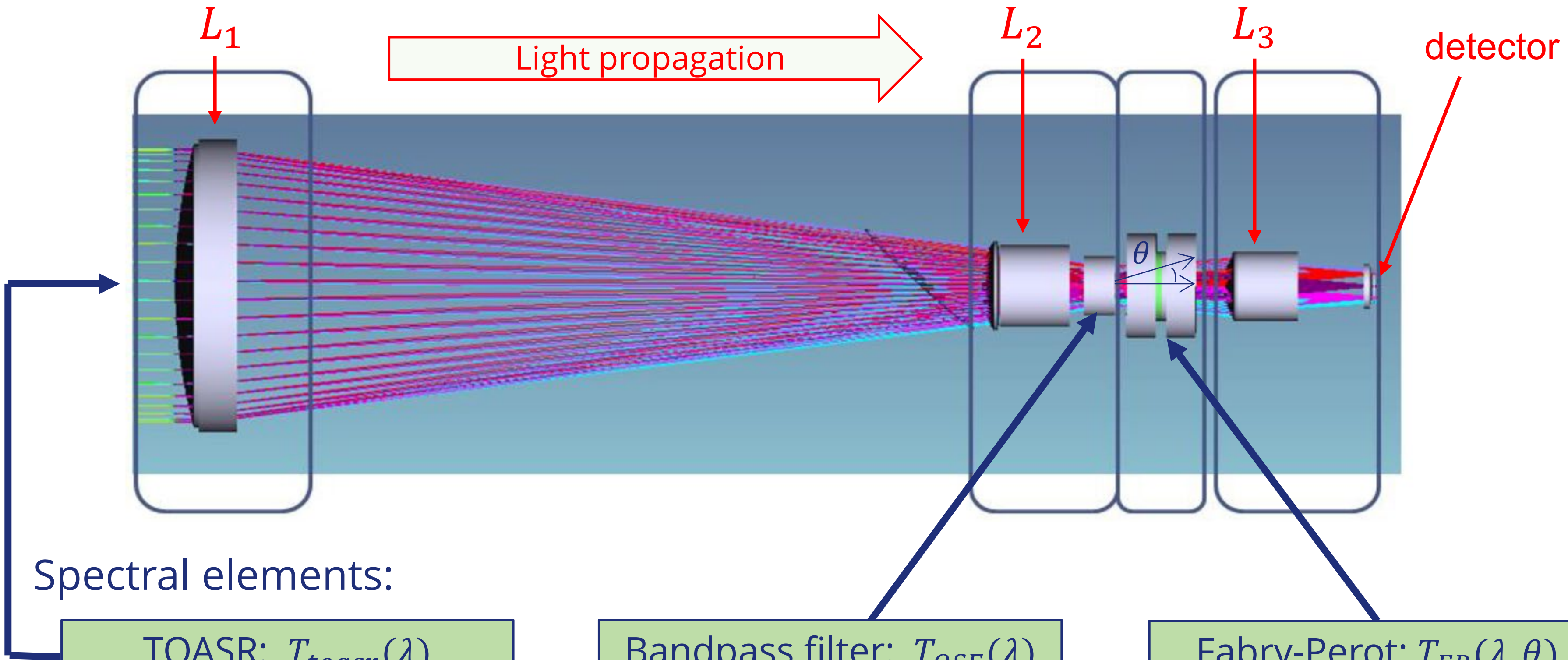
Can express this quantity equivalently as the column-averaged mixing ratio (or concentration)

$$\mathrm{C}_{CH_4}[\mathrm{ppb}] = \frac{\int n_{CH_4} dl}{\int n_{air} dl}$$

IMAGING FABRY-PEROT

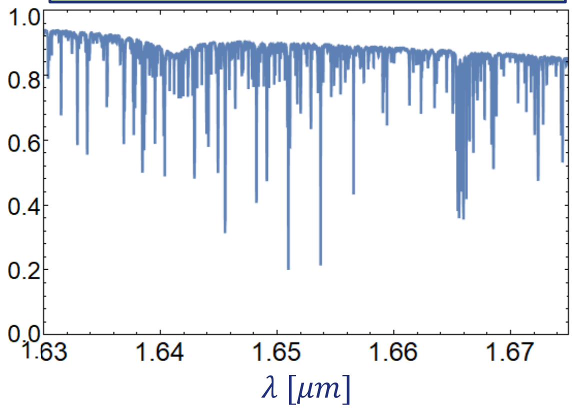


IMAGING FABRY-PEROT

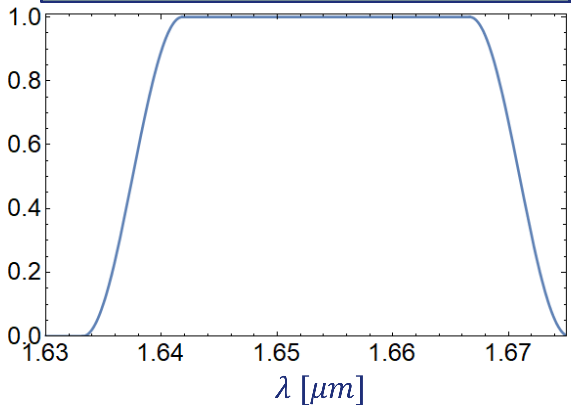


Spectral elements:

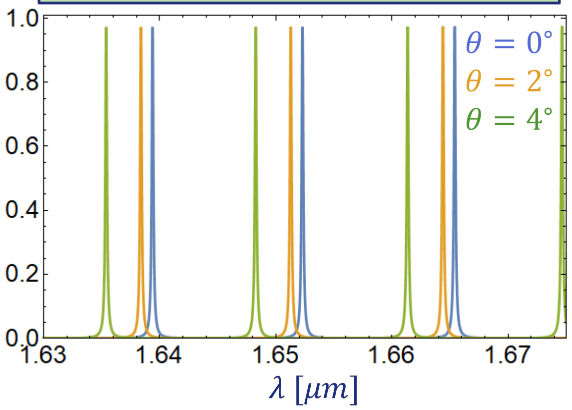
TOASR: $T_{toasr}(\lambda)$



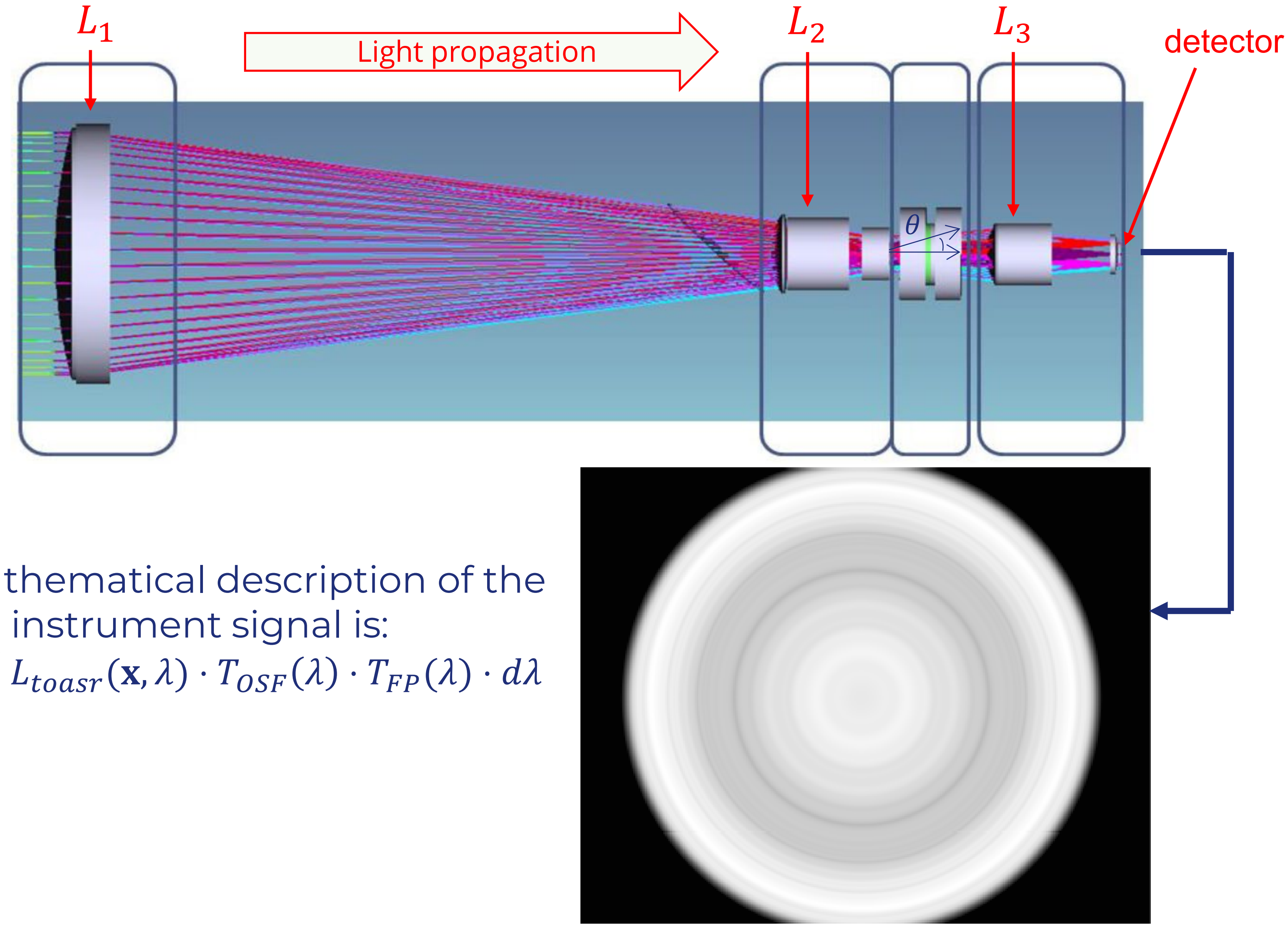
Bandpass filter: $T_{OSF}(\lambda)$



Fabry-Perot: $T_{FP}(\lambda, \theta)$



IMAGING FABRY-PEROT

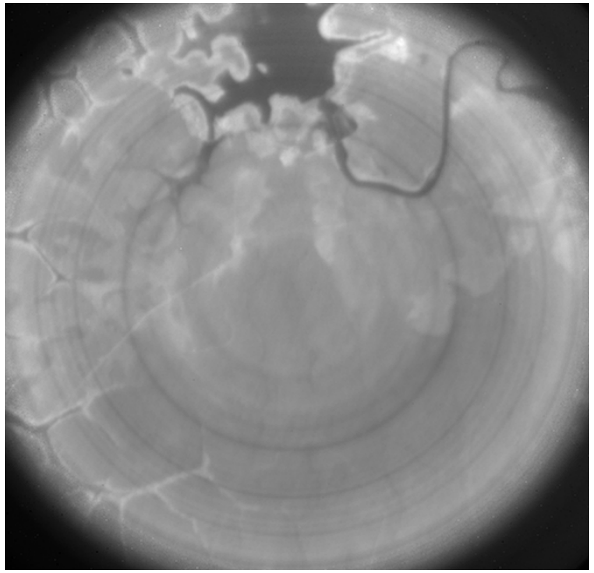


The mathematical description of the instrument signal is:

$$F(\mathbf{x}) = \int L_{toasr}(\mathbf{x}, \lambda) \cdot T_{OSF}(\lambda) \cdot T_{FP}(\lambda) \cdot d\lambda$$

MEASUREMENT CONCEPT

- Multiple overlapping images: "panning" sequence
- Image registration enables "tracking" each ground point through the frame sequence
- Retrievals match data traces to model for instrument + radiative transfer



Observation
Sequence of ~200 images
Spectral and spatial information mixed

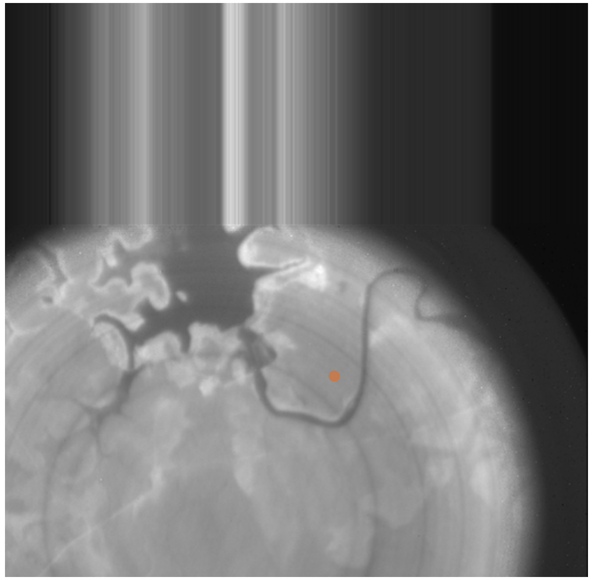
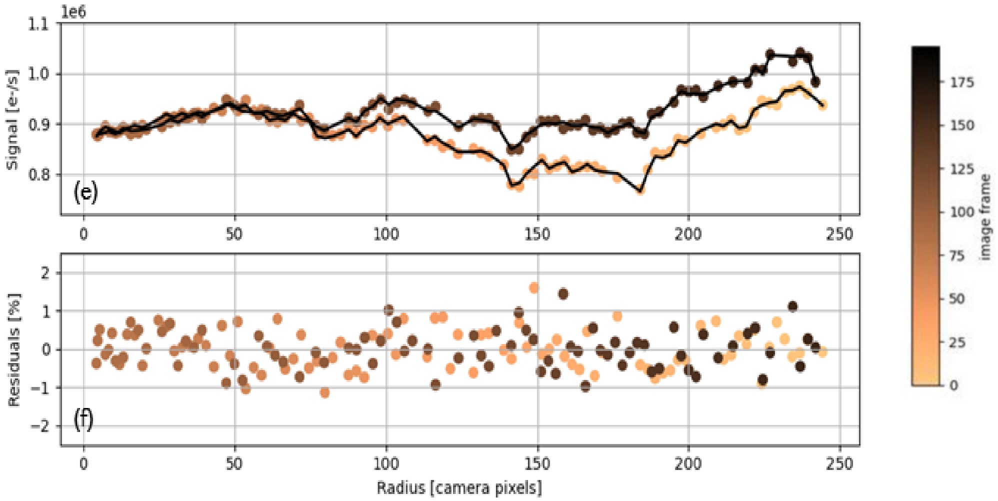


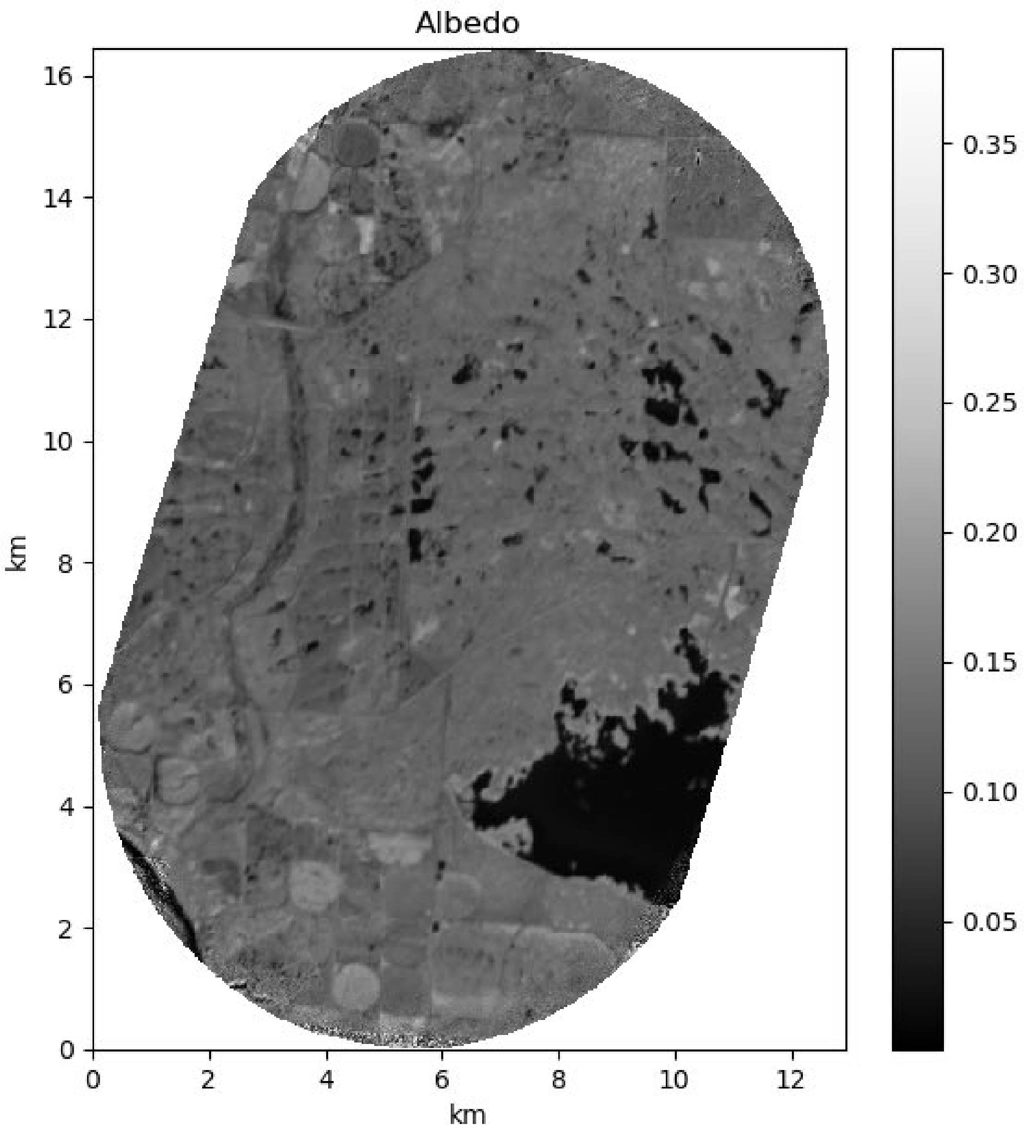
Image registration
Alignment to ground frame
Unmixing of spectral and spatial information

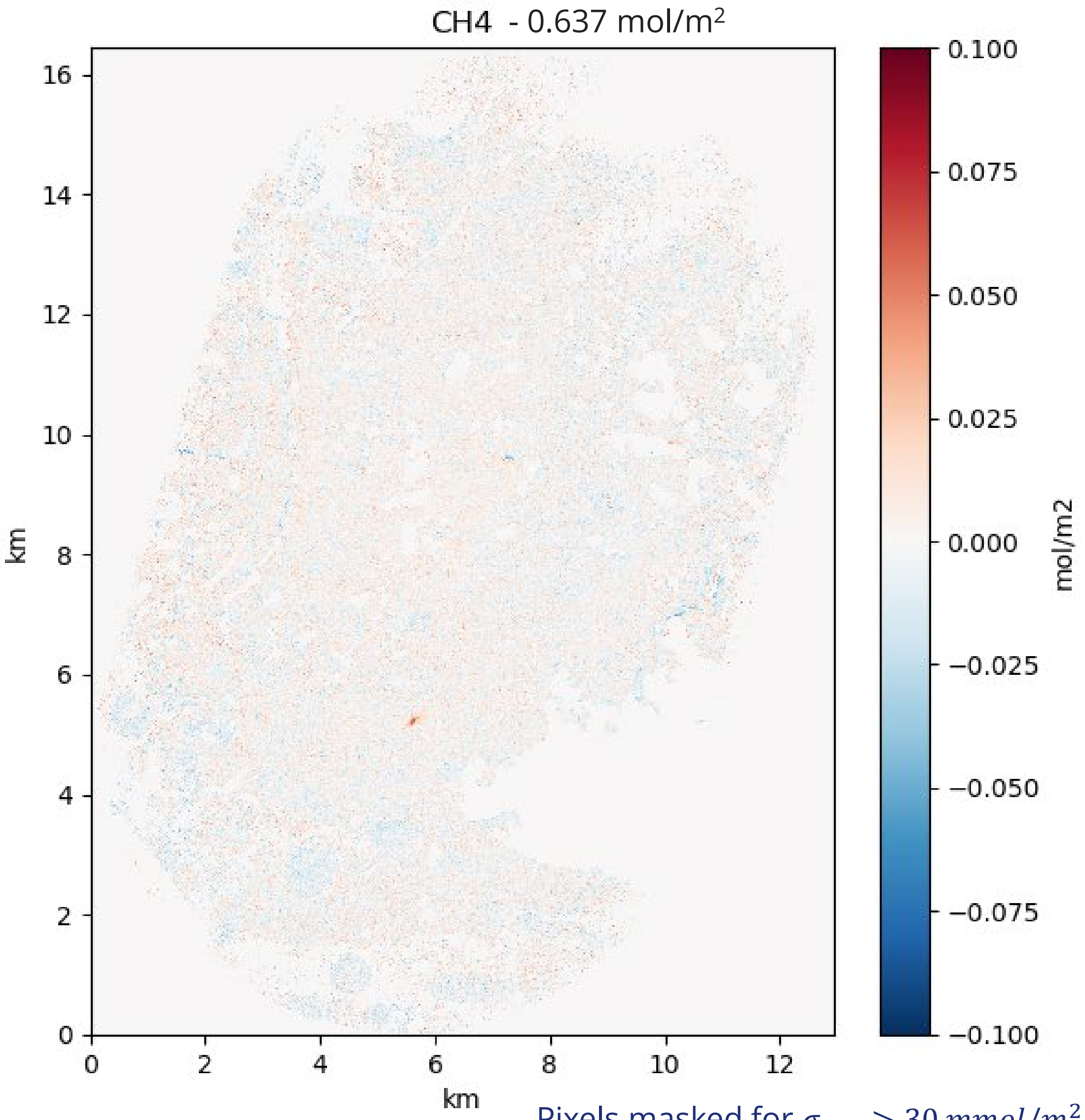


Jervis et al., AMT, 2021
https://doi.org/10.5194/amt-14-2127-2021

GHGSAT-C2 CONTROLLED RELEASE

ALBERTA, CANADA 2021-03-04



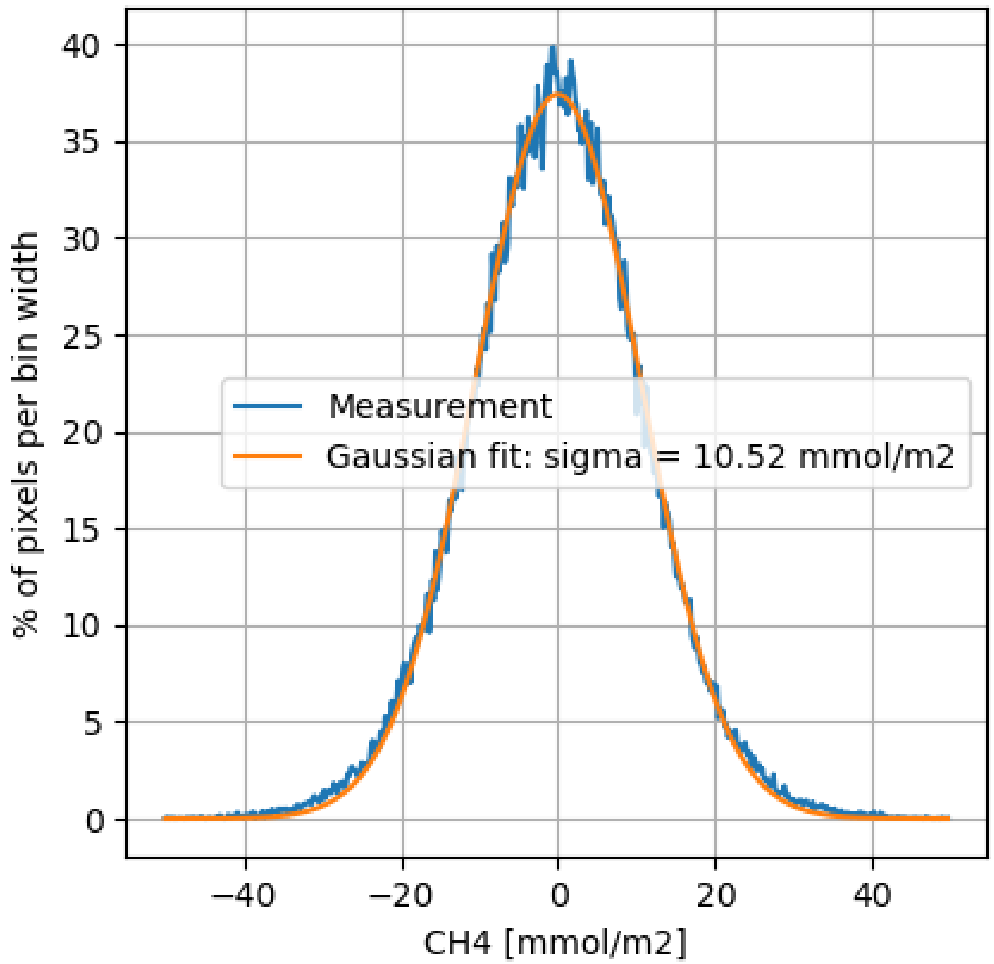


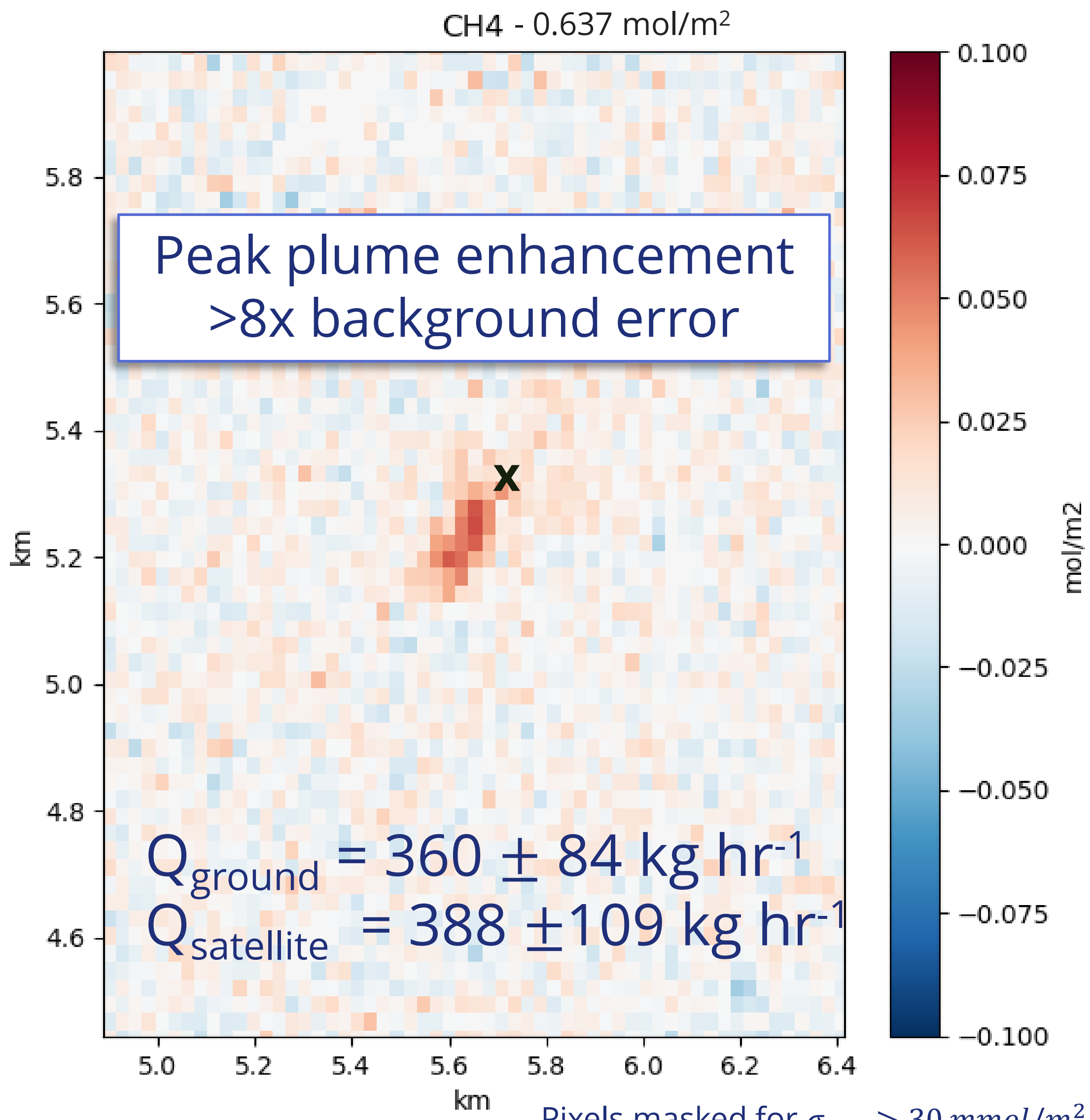
Pixels masked for $\sigma_{CH_4} > 30\ mmol/m^2$

GHGSAT-C2 CONTROLLED RELEASE

ALBERTA, CANADA 2021-03-04

RMS over whole domain:
1.6% of background

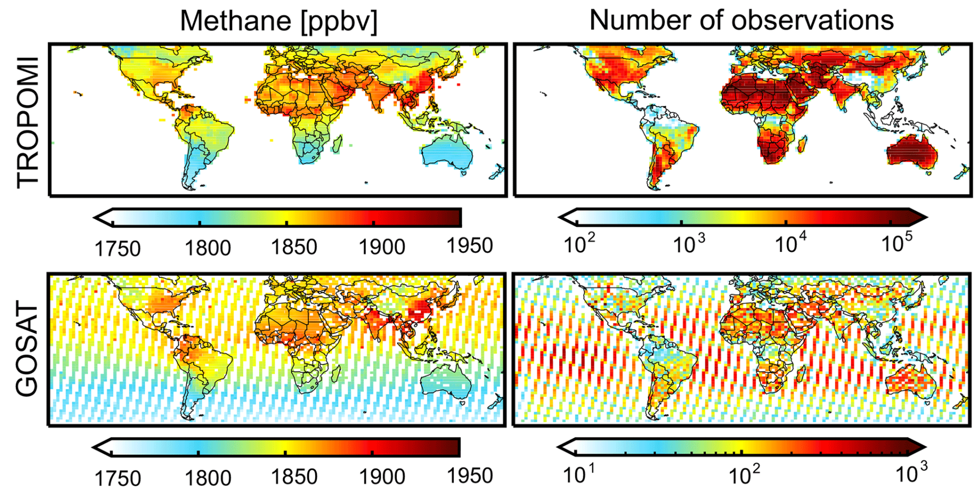




Pixels masked for $\sigma_{CH_4} > 30\ mmol/m^2$

CAL/VAL: DIFFERENT FOR POINT SOURCE IMAGERS

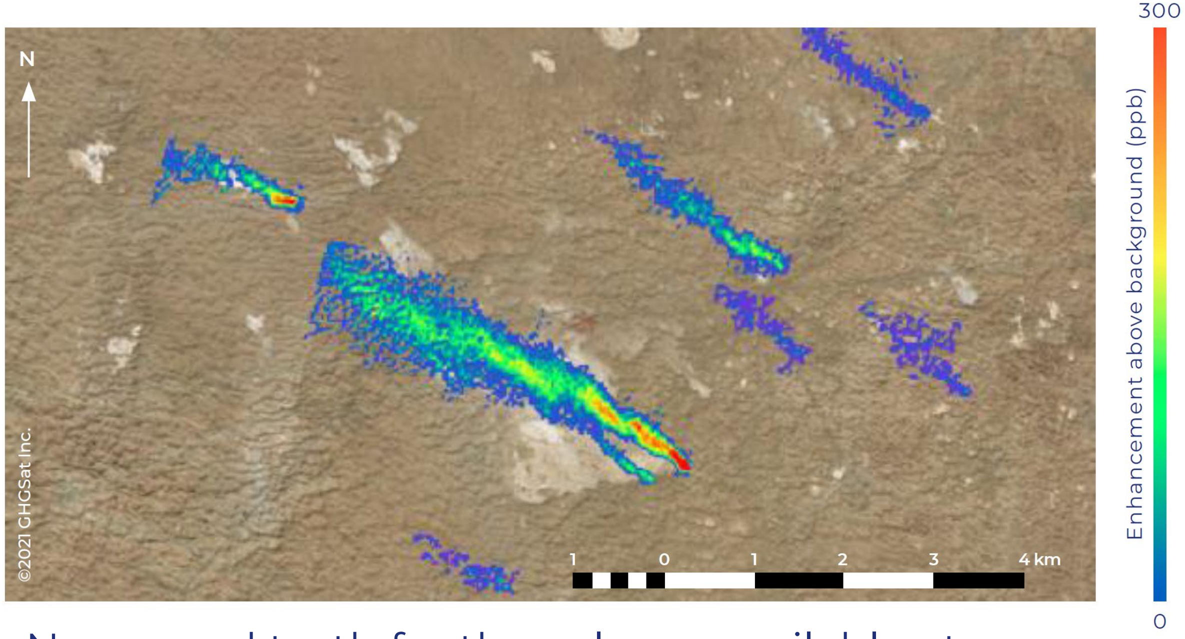
Area flux mappers



Z. Qu et al, ACP 2021

TCCON Site Map

Point source imagers



No ground truth for the column available at relevant scales (length and time)

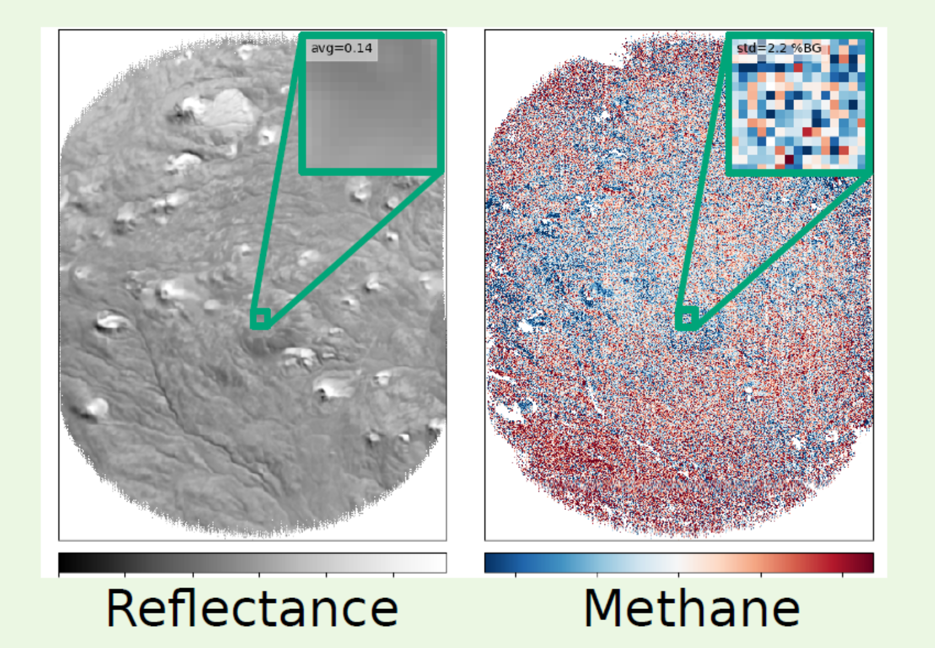
Instead:

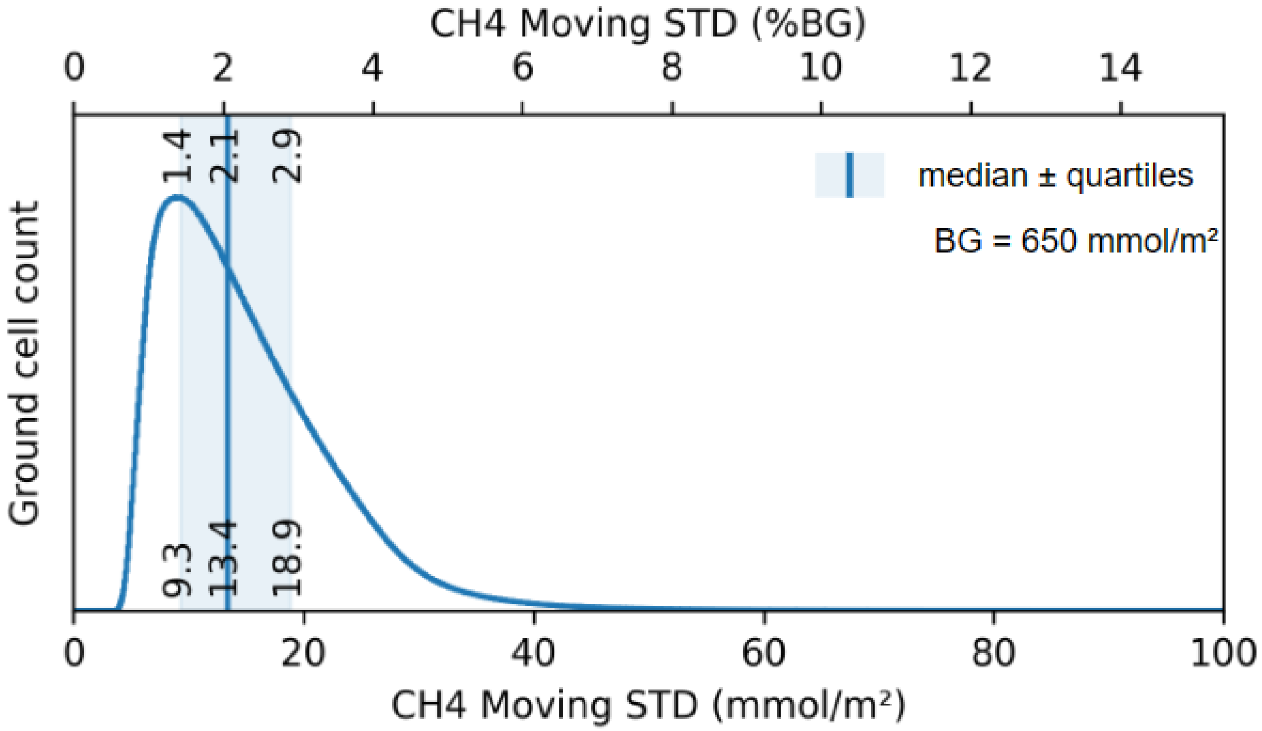
- **L2:** Empirically characterize column precision
- **L4:** Rely on **controlled releases** for detection limit and quantification accuracy

Approved for public release

CAL/VAL: L2 COLUMN PRECISION

Empirical noise analysis

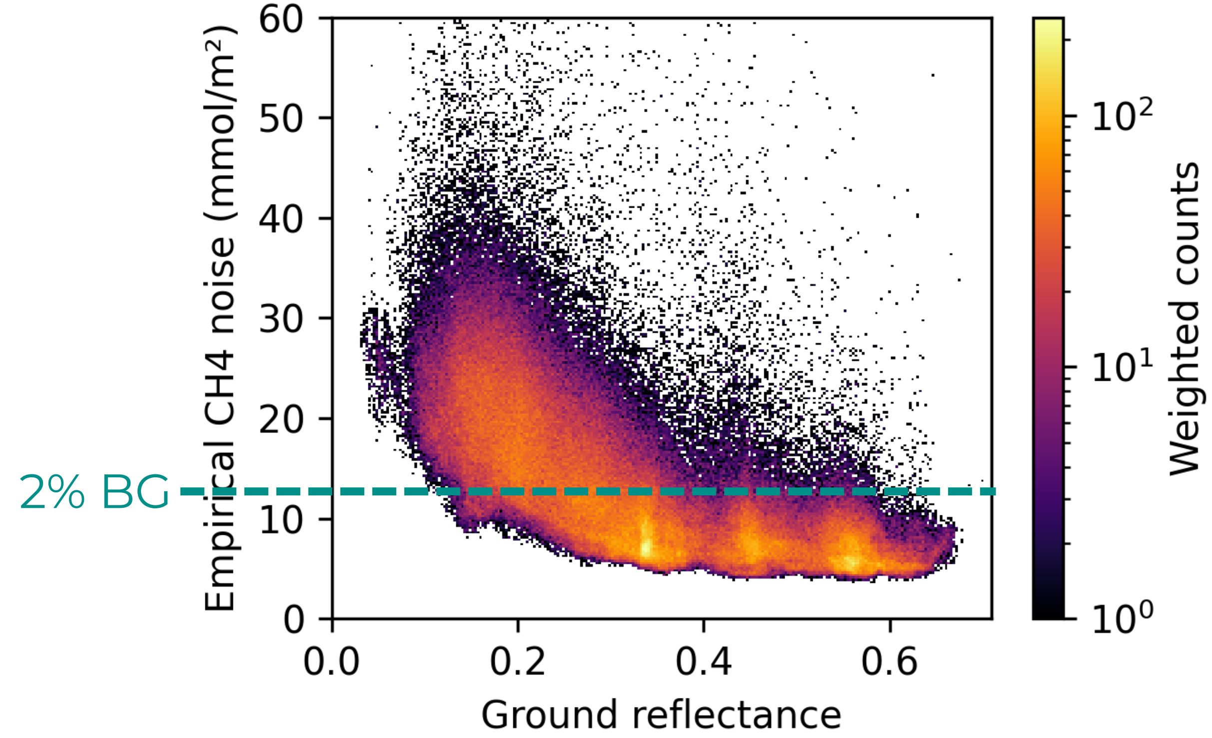




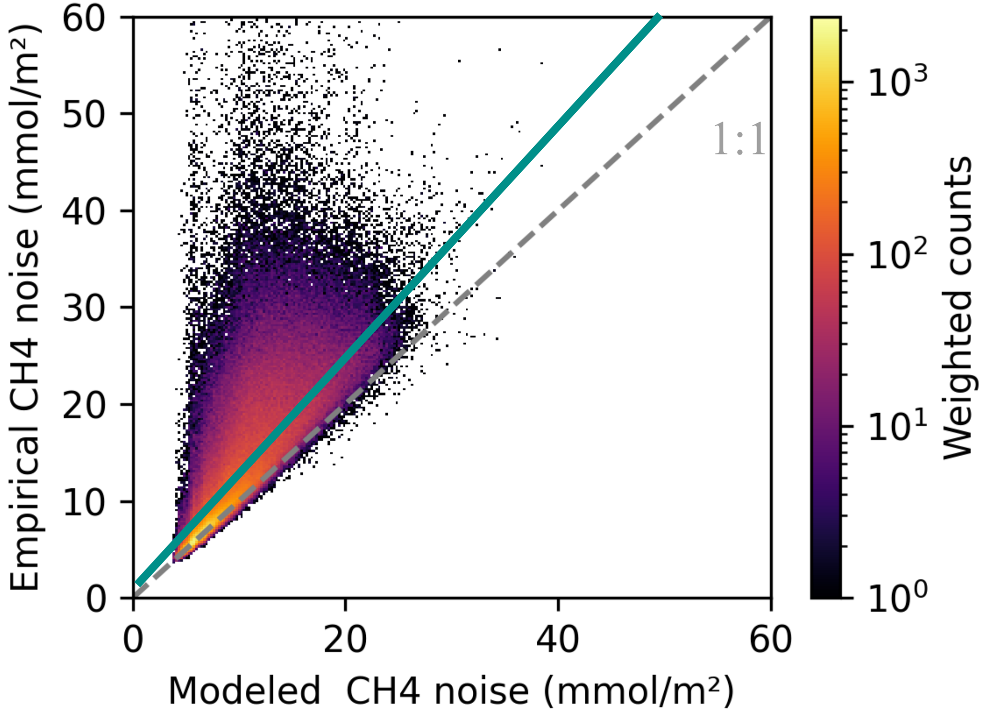
- "Scan" moving 500m x 500m ROI across all retrieval domains
- **Compute spatial standard deviation of retrieved CH4 column in each ROI**

- Nov 2021 – Aug 2023 - ~**19000 observations**
- **All seasons** and **all terrain classes**
- ~ 15% of histogram is below 1%BG (bright, quasi-uniform scenes)

PRECISION DEPENDS ON SIGNAL INTENSITY



50% of samples within
17% of shot noise limit



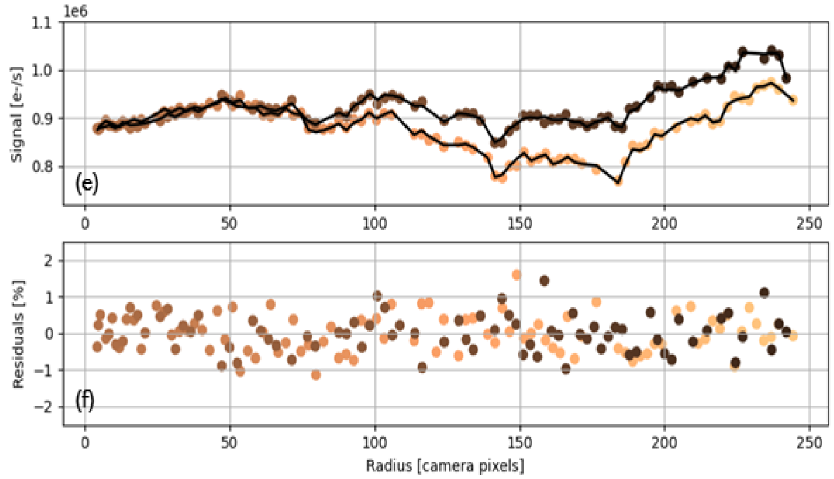
Most data is nearly shot noise limited
Main excess noise is found on albedo gradients

HOW ACCURATE IS OUR ERROR ESTIMATE?

We need an accurate error estimate to “flag” CH4 artefacts (i.e. to “flag” false positives)

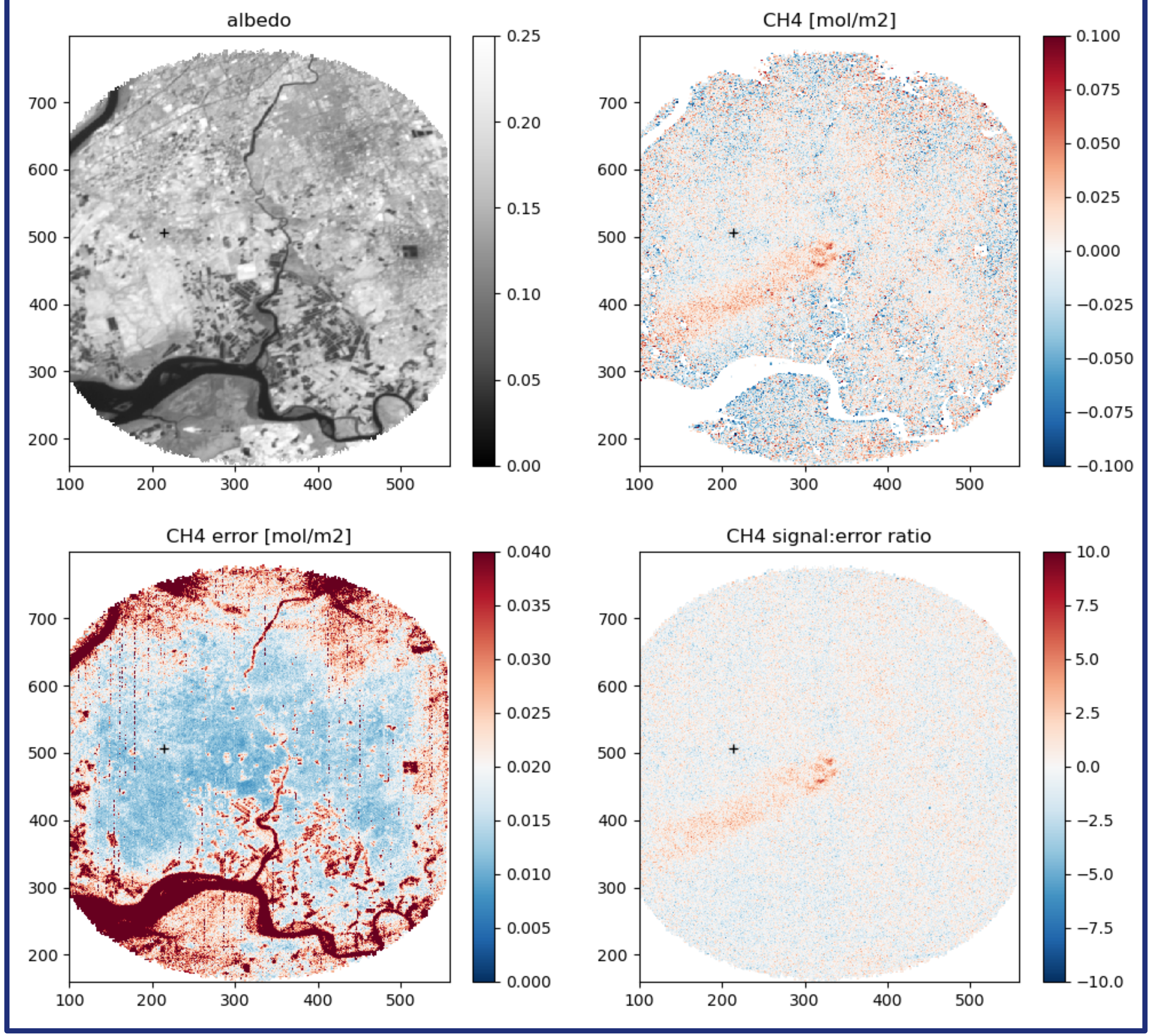
Our posterior error estimate $\hat{\mathbf{S}}$ is calculated from the RMS of the residuals of the spectral fit and therefore includes contributions from both shot-noise and systematic error sources

$$\hat{\mathbf{S}} = \left(\mathbf{J}^T(\bar{\mathbf{x}})\mathbf{S}_o^{-1}\mathbf{J}(\bar{\mathbf{x}}) + \mathbf{S}_p^{-1}\right)^{-1}$$



$$\mathbf{S_0} = \langle \text{Residuals} \rangle^2{}_{RMS}$$

Example of complex scene



PRIMARY VALIDATION METHOD: CONTROLLED RELEASES

Facility used by GHGSat in Southern Alberta, Canada

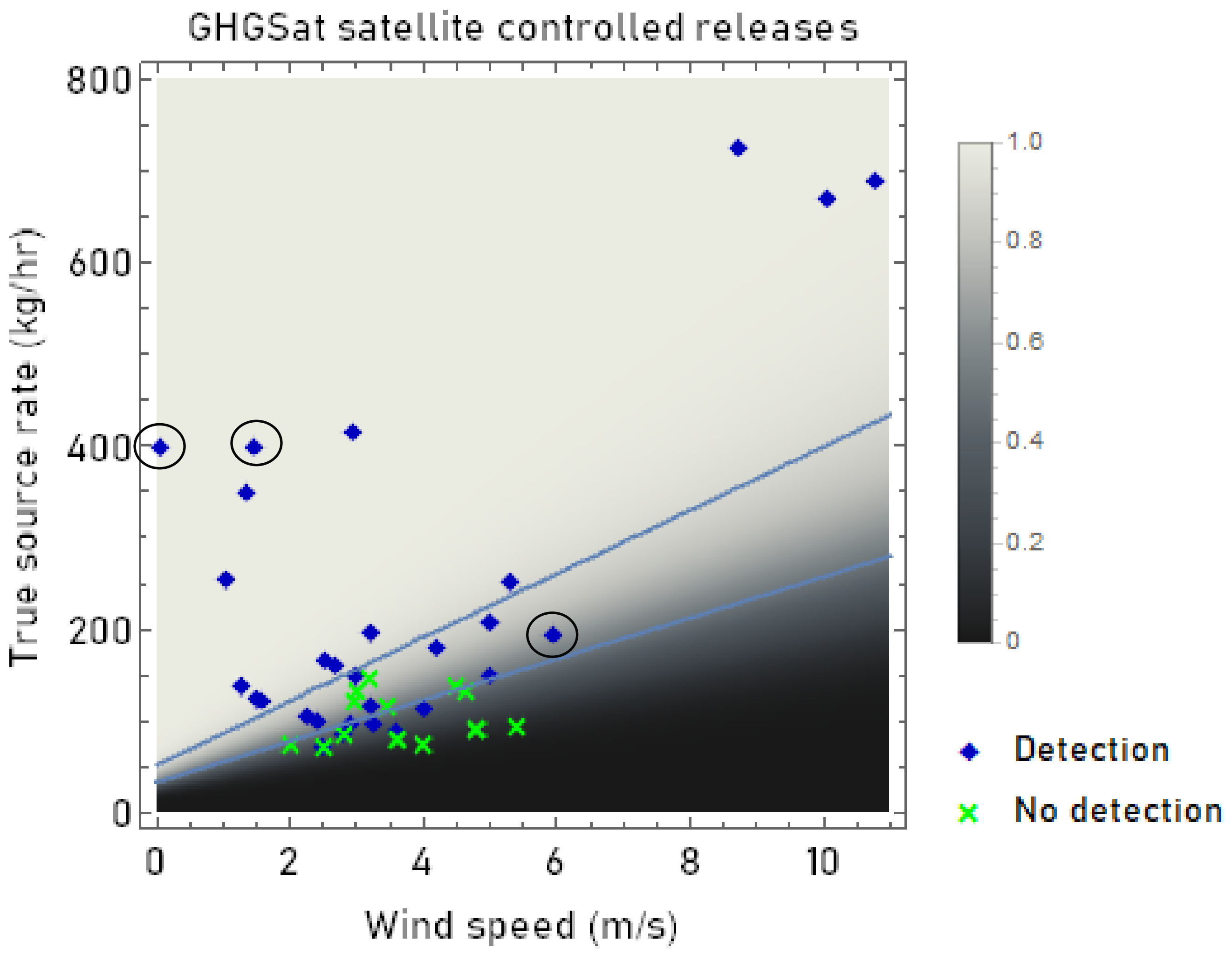
Used to validate both detection limit and quantification accuracy

Both for satellite and aircraft instruments

Most of our effort in 2022-2023 has been toward probing detection limit

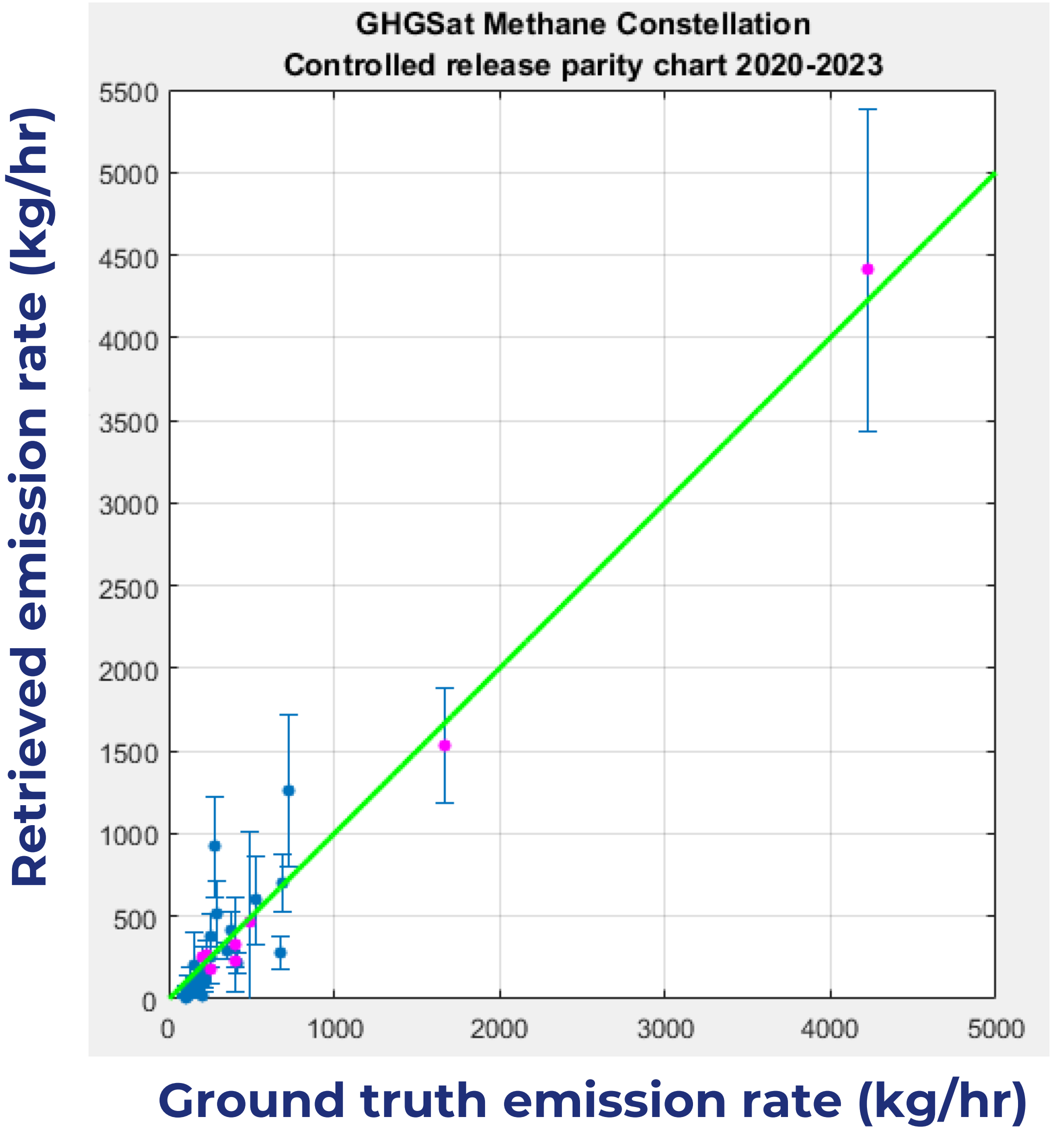
Organized by GHGSat airborne ops team, Calgary

VALIDATION AND PERFORMANCE METRICS : DETECTION LIMIT



- Binary regression analysis
- Data from 2021-2023, including C6-C8
- Internal and independently organized releases
- Average albedo very close to global average from our standard operations
- Fit model for probability of detection:
  - Lognormal CDF
  - Simple predictor function: Q/u
  - Conrad *et al*, RSE 288 (2023) 113499
- Accounts for wind-speed dependence
- **Implies detection limit of**
  100.4 kg/hr (50% PoD, 3 m/s)
  155.6 kg/hr (90% PoD, 3 m/s)

CONSTELLATION PERFORMANCE: QUANTIFICATION ACCURACY



- Emission rate estimate: $Q = \frac{IME \cdot u}{\sqrt{A}}$
  (Varon *et al.*, AMT, 2018)
- GHGSat facility in Southern Alberta
- Also includes some ***single-blind*** releases with customers and collaborators (**magenta points**)
- Participated in 2021 and 2022 single-blind studies with group of A. Brandt (Stanford)
  - Sherwin et al, Sci Rep **13**, 3836 (2023)
  - Sherwin et at, AMT **17**, 765 (2024)
  - all points included in plot
- Error typically dominated by wind-related uncertainty (even when using local measured wind)

OTHER CAL/VAL ACTIVITIES AND COLLABORATIONS

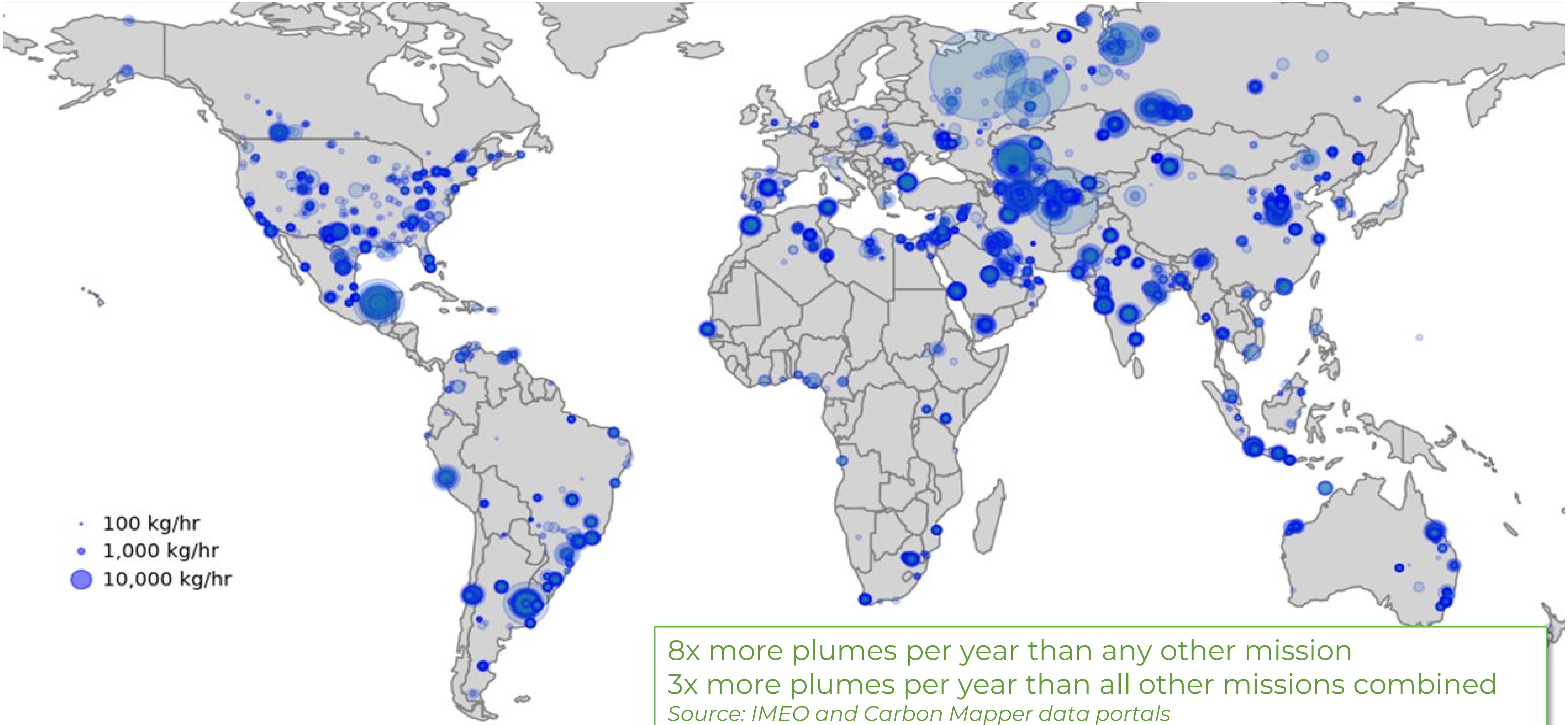
- **NIST** Facility-scale intercomparison efforts - ongoing
- **UNEP-IMEO** Workshop (June 2023)
- **NPL** UK Workshop February 2024
- ESA-funded **MEDUSA** project led by SRON
- Stanford controlled release studies (**single-blind**)
  - Satellite and aircraft (two published studies for each)
  - Releases underway in 2024 – cooperative phase for now
- **Landfill** releases with David Risk group

- Coincident measurements with **EMIT** (part of CSDA evaluation)

- Interested in **common controlled release facilities**
  - Diverse locations, different terrain classes
  - Have discussed with Stanford, CSU, IMEO
  - Off-shore of particular interest

2023 METHANE DETECTIONS

~16,000 detected plumes
~32,000 clear-sky observations



8x more plumes per year than any other mission
3x more plumes per year than all other missions combined
Source: IMEO and Carbon Mapper data portals

Approved for public release

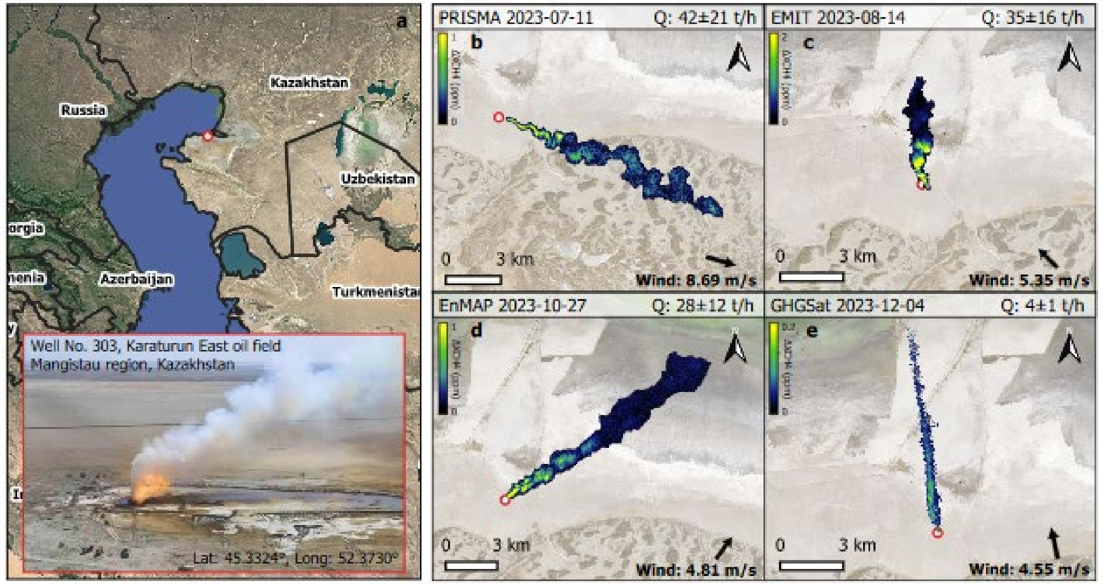
GHGSAT WELL-BLOWOUT STUDY IN KAZAKHSTAN

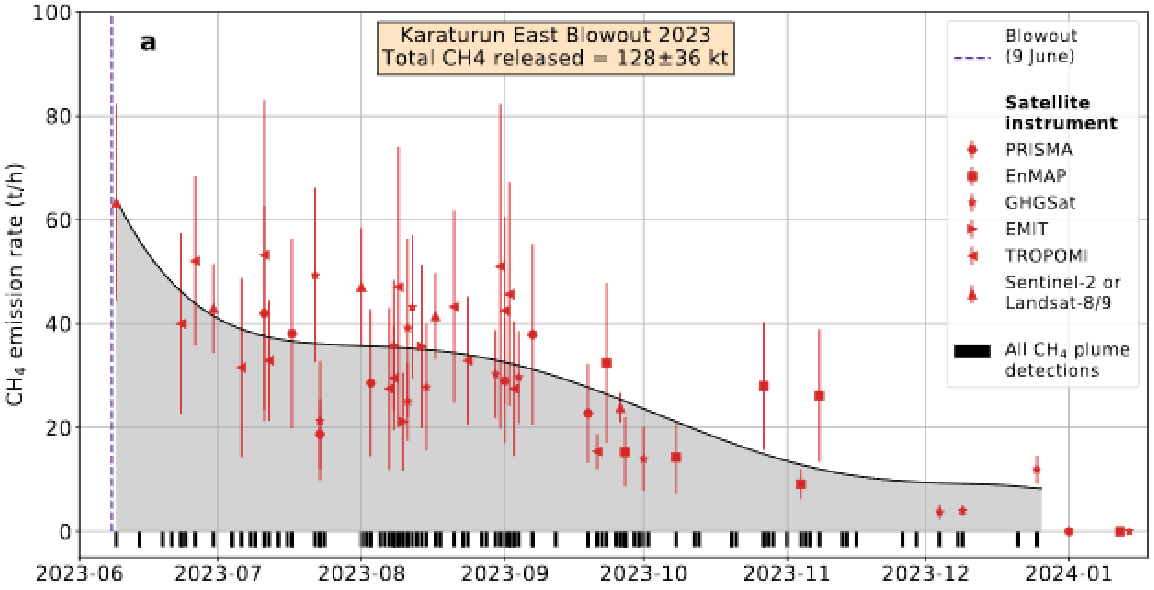
Multi-satellite data depicts record-breaking methane leak from a well blowout

Luis Guanter[1,2*], Javier Roger[1], Shubham Sharma[3], Adriana Valverde[1], Itziar Irakulis-Loitxate[4,1], Javier Gorroño[1], Xin Zhang[3], Berend J. Schuit[3,5], Joannes D. Maasakkers[3], Ilse Aben[3], Alexis Groshenry[6], Antoine Benoit[6], Quentin Peyle[6], Daniel Zavala-Araiza[2]

Preprint led by Valencia group, published Feb 13, 2024

Estimated total emissions 128 ± 36 kt



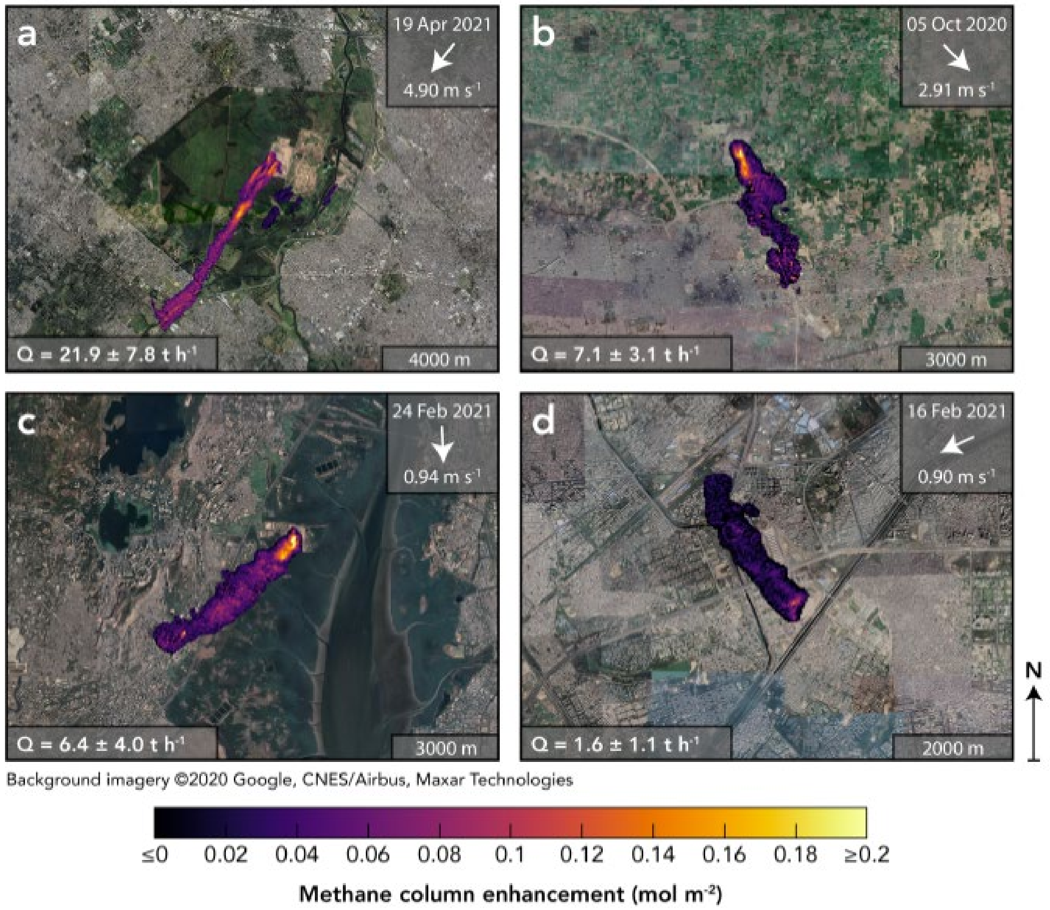


Approved for public release

GHGSAT GLOBAL LANDFILL STUDIES

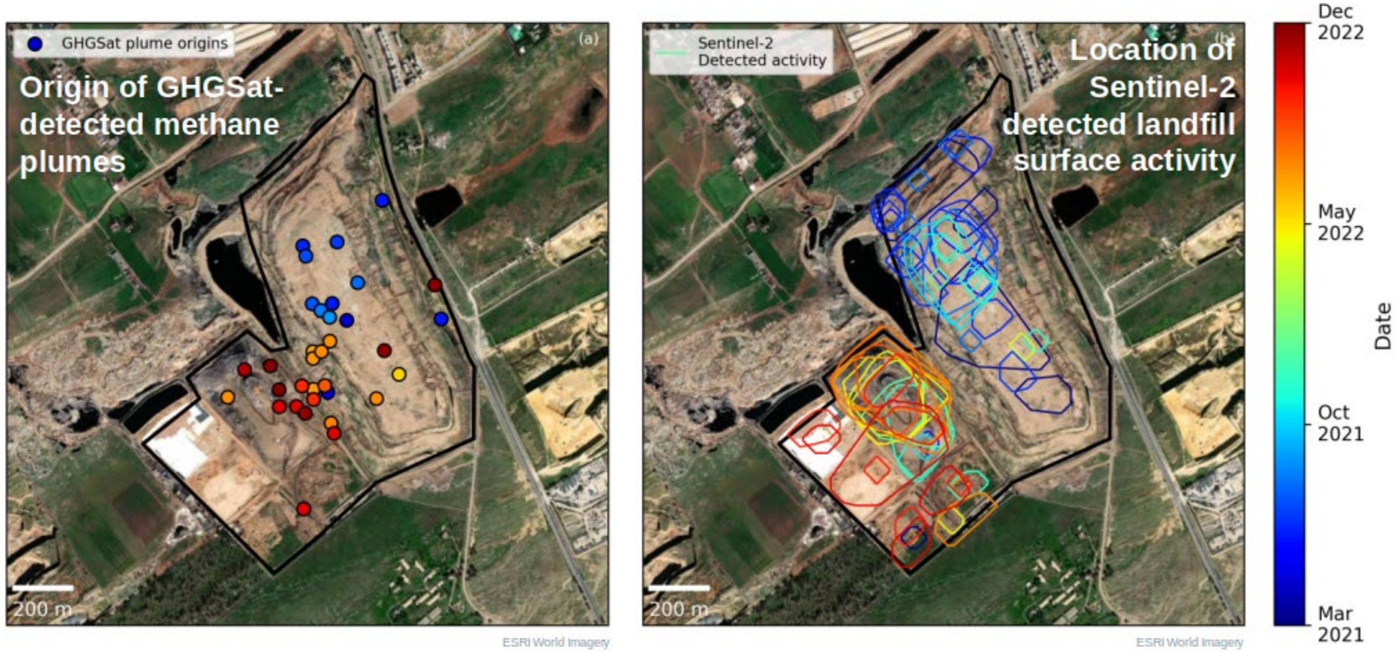
Landfill emissions constitute sizeable fraction (5-46%) of total urban emissions

Maasakkers et al., Science Advances, 2022



Emission locations correlated with surface activity

Dogniaux et al. preprint (2024)



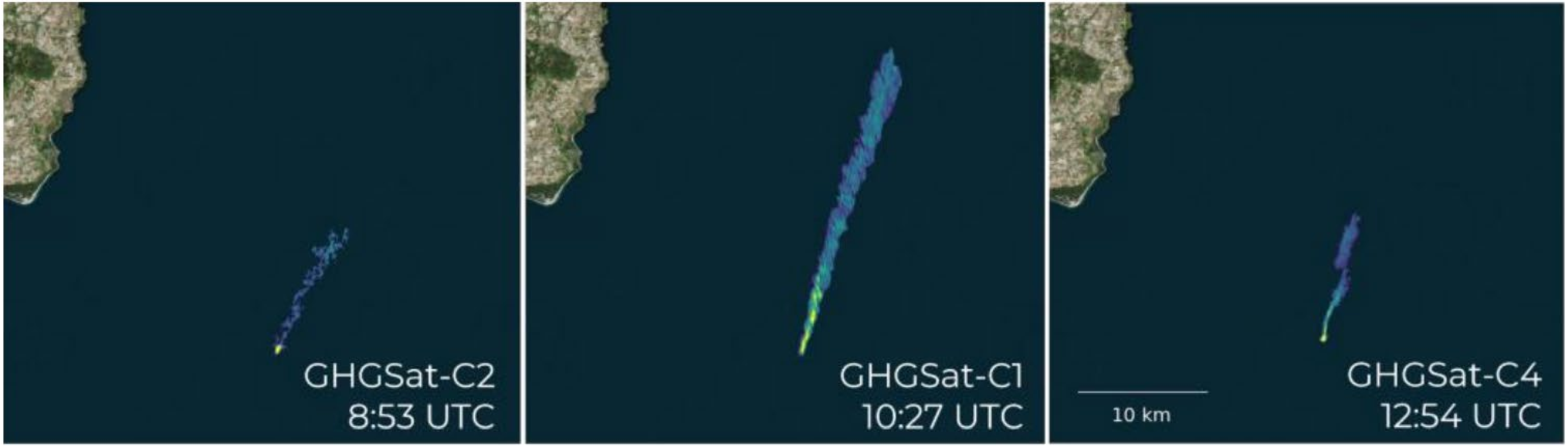
GHGSAT HARVARD UNIVERSITY SRON Netherlands Institute for Space Research

OFFSHORE EMISSION STUDY (NORDSTREAM-2 Leak)

Article

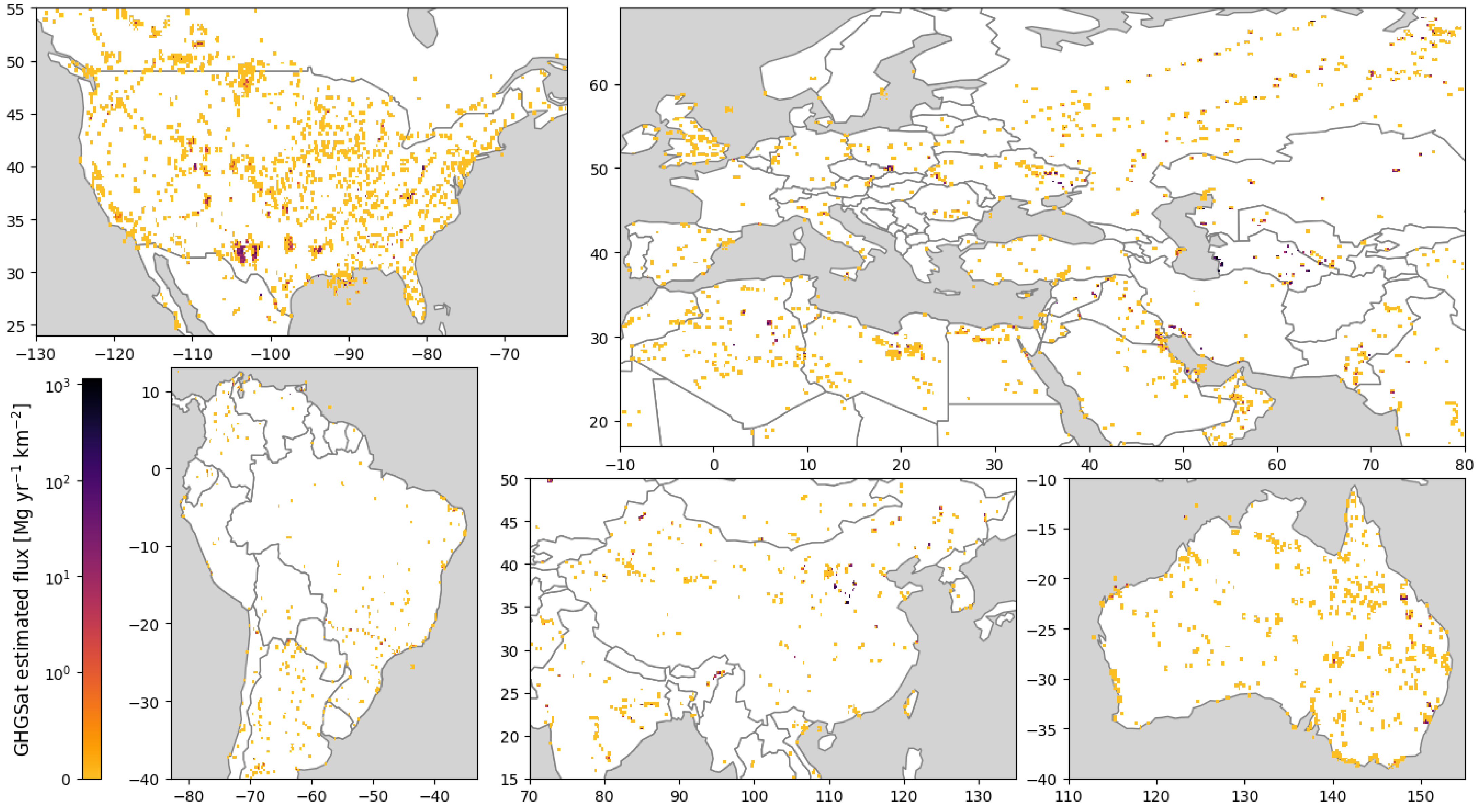
Methane emissions from the Nord Stream subsea pipeline leaks

Harris et al., Nature (2025)



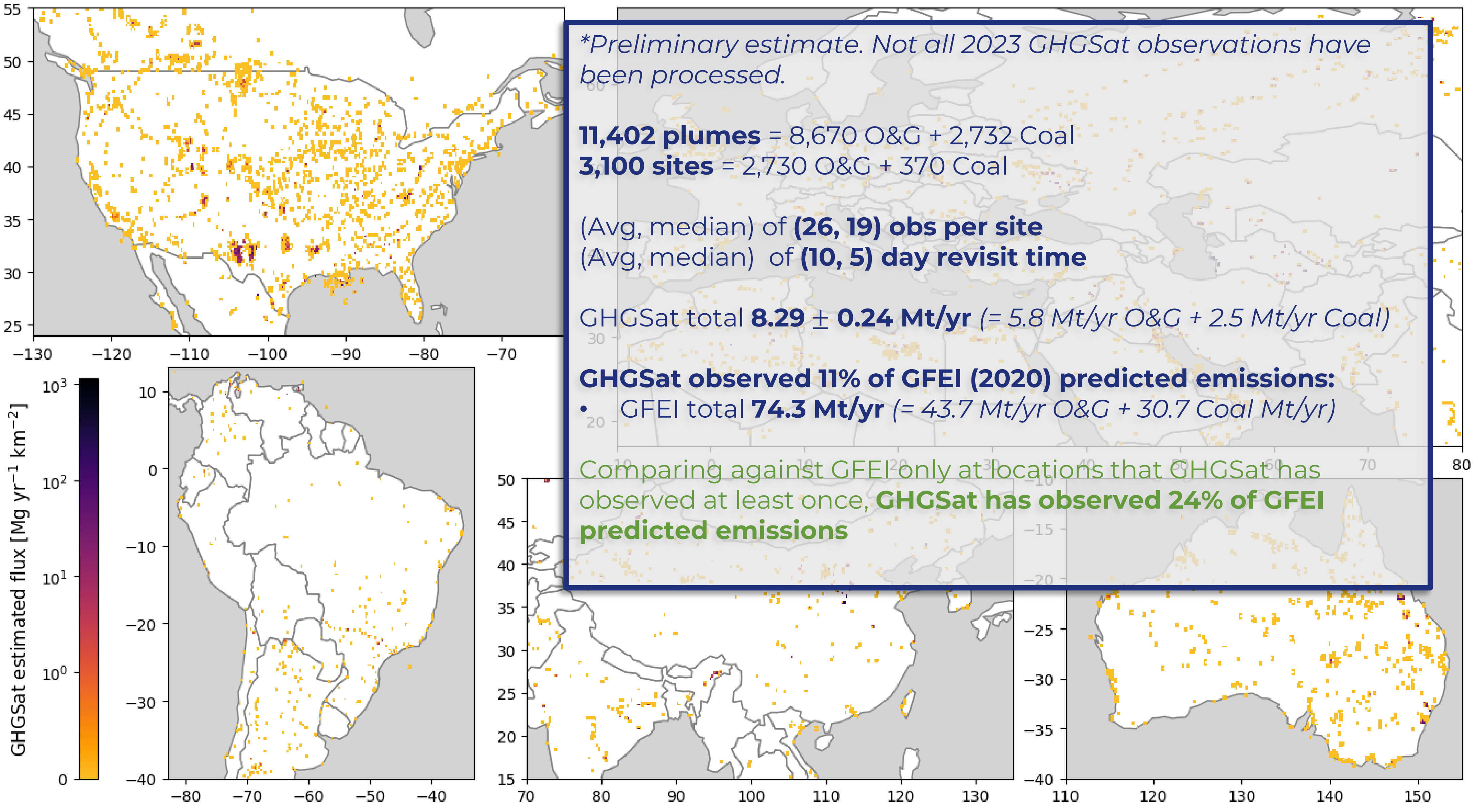
Plumes detected by GHGSat satellites from the Nord Stream 2 leak on Sep 30th, 2022. Colour scale is 0-700 ppb for all three images, which also have identical spatial scales.

2023 GHGSAT ENERGY EMISSIONS STUDY



Jervis et al., in review (2025)

2023 GHGSAT ENERGY EMISSIONS STUDY



**Preliminary estimate. Not all 2023 GHGSat observations have been processed.*

11,402 plumes = 8,670 O&G + 2,732 Coal
3,100 sites = 2,730 O&G + 370 Coal

(Avg, median) of **(26, 19) obs per site**
(Avg, median) of **(10, 5) day revisit time**

GHGSat total **8.29 ± 0.24 Mt/yr** *(= 5.8 Mt/yr O&G + 2.5 Mt/yr Coal)*

GHGSat observed 11% of GFEI (2020) predicted emissions:

- GFEI total **74.3 Mt/yr** *(= 43.7 Mt/yr O&G + 30.7 Coal Mt/yr)*

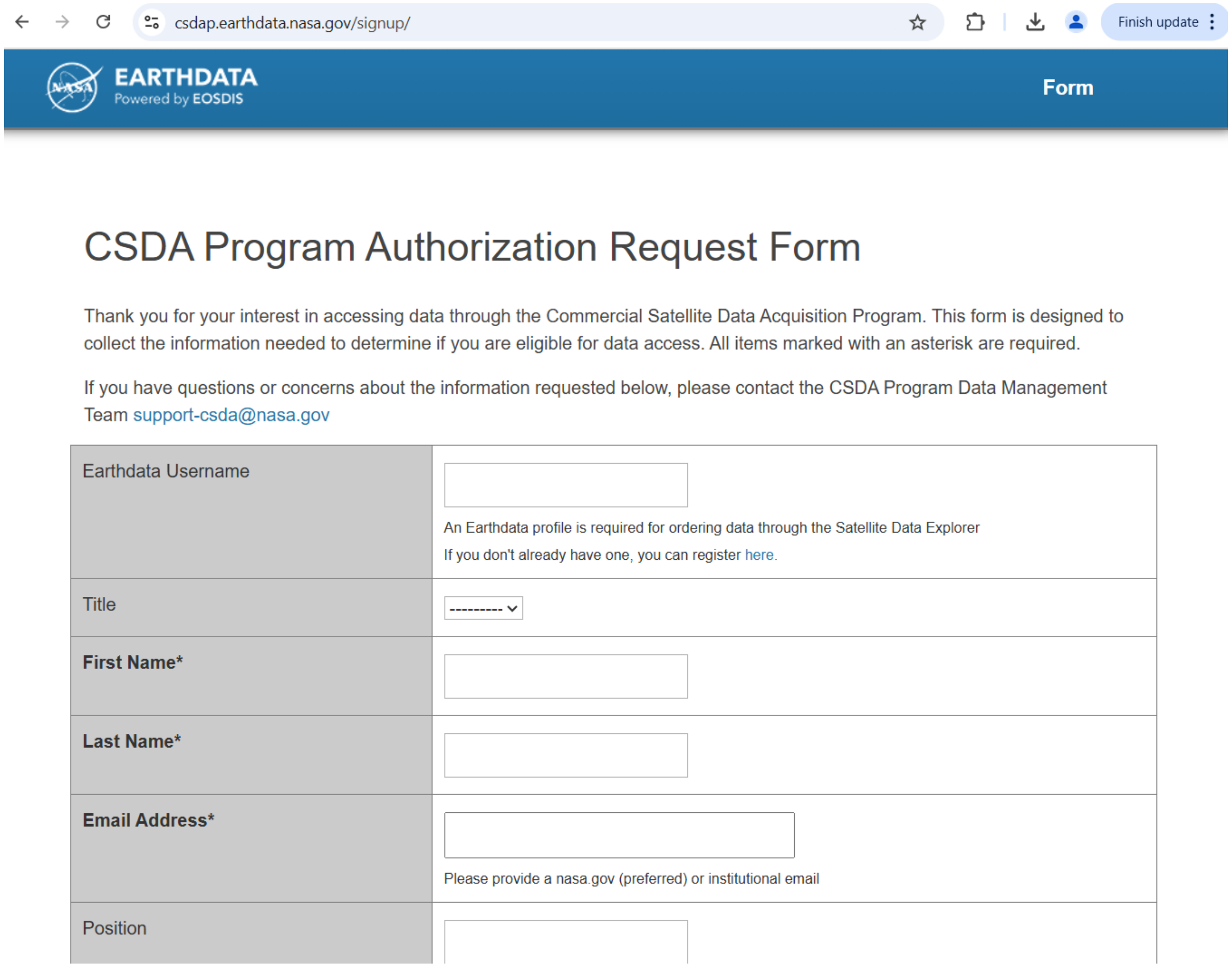
Comparing against GFEI only at locations that GHGSat has observed at least once, **GHGSat has observed 24% of GFEI predicted emissions**

Jervis et al., in review (2025)

HOW TO APPLY FOR DATA ACCESS

HOW TO APPLY FOR GHGSAT DATA

- Create a NASA Earthdata profile (if you don't already have one)
- Fill out the NASA CSDA authorization form


csdap.earthdata.nasa.gov/signup/

Finish update

EARTHDATA
Powered by EOSDIS

Form

CSDA Program Authorization Request Form

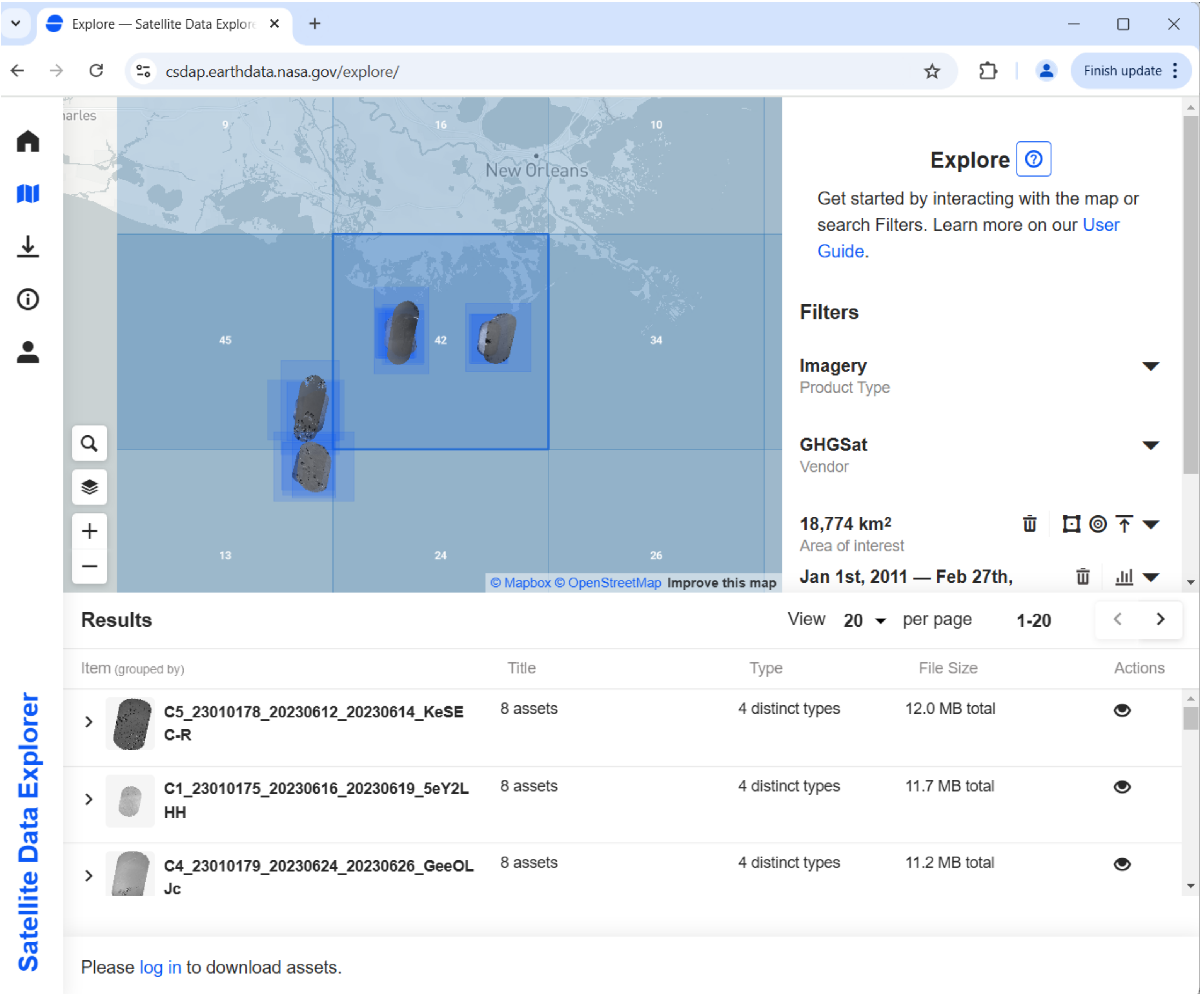
Thank you for your interest in accessing data through the Commercial Satellite Data Acquisition Program. This form is designed to collect the information needed to determine if you are eligible for data access. All items marked with an asterisk are required.

If you have questions or concerns about the information requested below, please contact the CSDA Program Data Management Team support-csda@nasa.gov

Earthdata Username	An Earthdata profile is required for ordering data through the Satellite Data Explorer If you don't already have one, you can register here.
Title	---------
First Name*	
Last Name*	
Email Address*	Please provide a nasa.gov (preferred) or institutional email
Position	

HOW TO ACCESS GHGSAT DATA

- Once NASA has approved your application, you can submit tasking requests through CSDA, and/or search the archive previously ordered by NASA through the Satellite Data Explorer (SDX)



GHGSAT SCIENCE NEWSLETTER

Questions?

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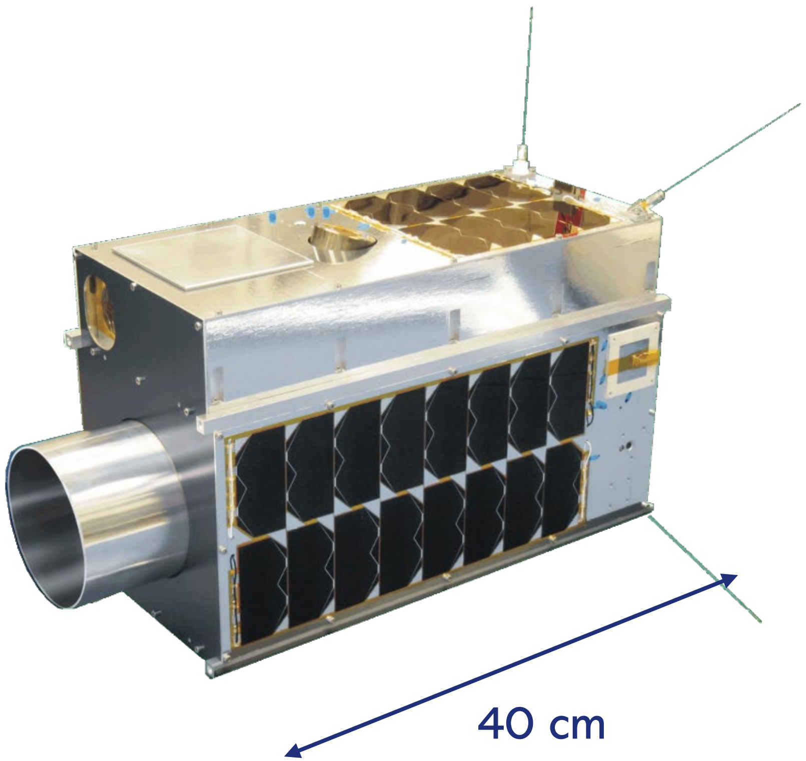
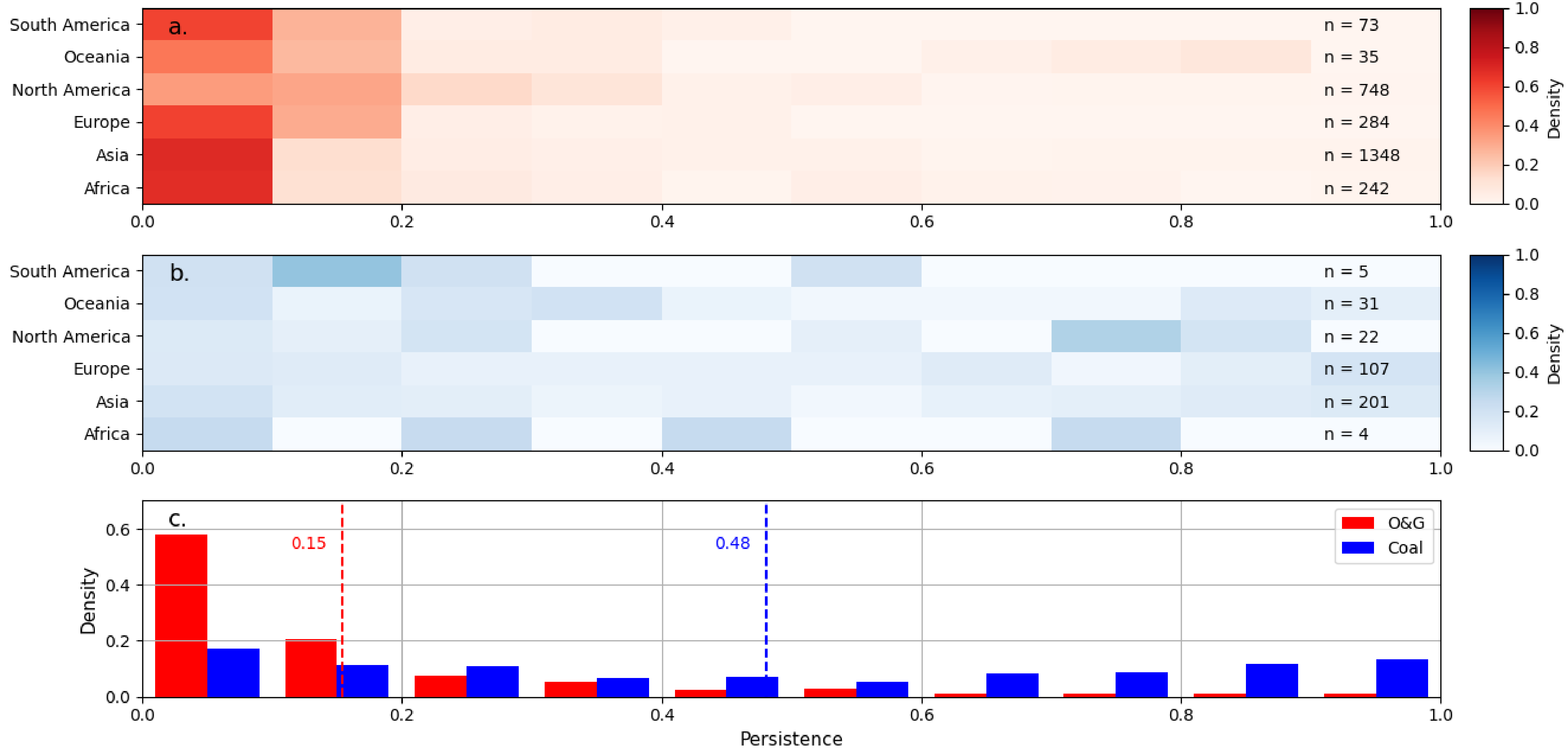
SATELLITE SENSOR DETAILS

- Commercial constellation since 2020 – 10 CH4 satellites today
  - Ongoing expansion includes 4 more in 2025
- 15 kg nanosatellites
- *Sun-synchronous orbit :* ~500 km altitude
- *Payload:*
  - Imaging Fabry-Perot spectrometer
  - Spectral region : 1.6 μm
  - **High spatial resolution (~25 m)**
  - Measurement domain: ~12 km width x 15-35 km length
  - Always operate in **target mode**
  - Onshore and offshore capabilities
- Measurement precision ~**2%** of background column density
- Emission rate detection threshold: ~**100 kg/hr**
- Number of observations per day (per satellite): up to **60**



10 CH_4 satellites in orbit → ~Daily revisits

2023 GHGSAT ENERGY EMISSIONS STUDY

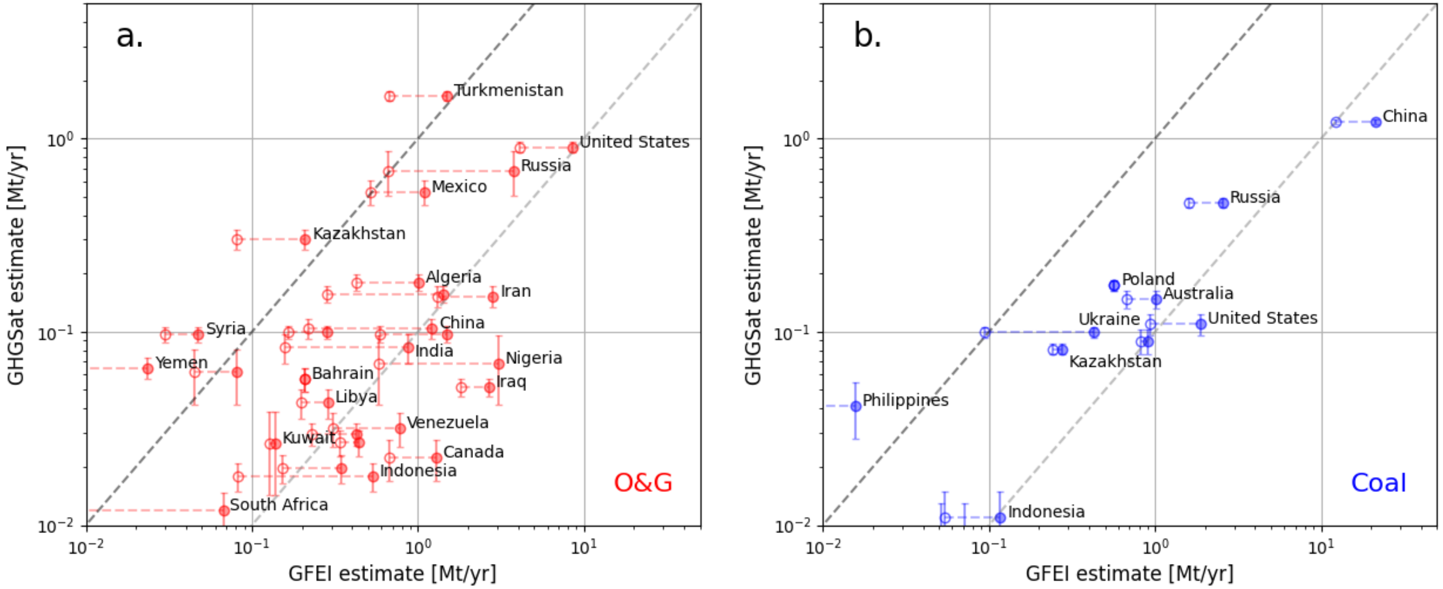


O&G emission sources much more intermittent than Coal sources, with minimal continental variation

Jervis et al., in review (2025)

2023 GHGSAT ENERGY EMISSIONS STUDY

Moderate agreement with inventory estimates at national scale



Poor agreement with inventory estimates at 0.2 deg scale