AI-relevant remote sensing work at UPV-LARS

Luis Guanter

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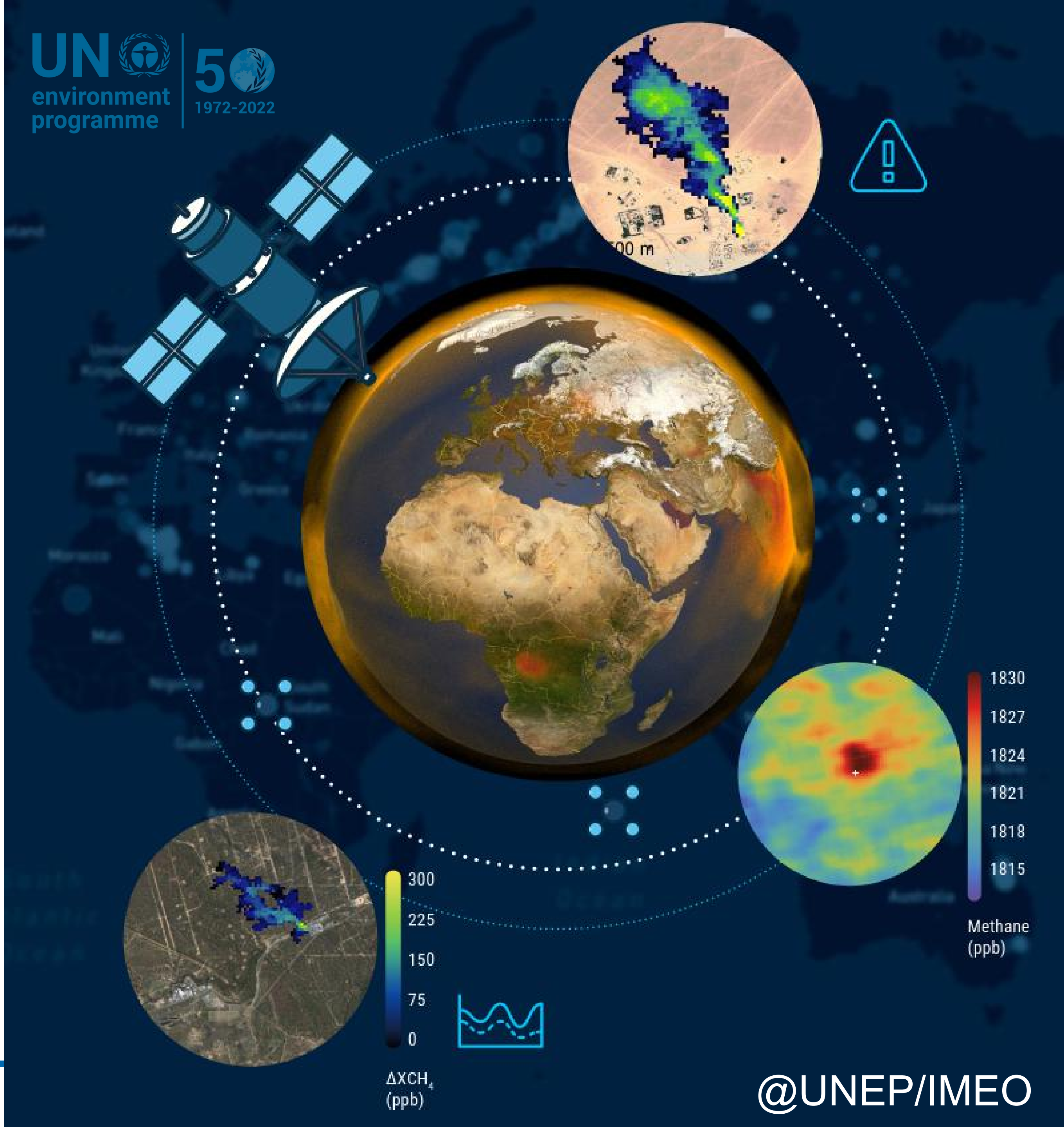
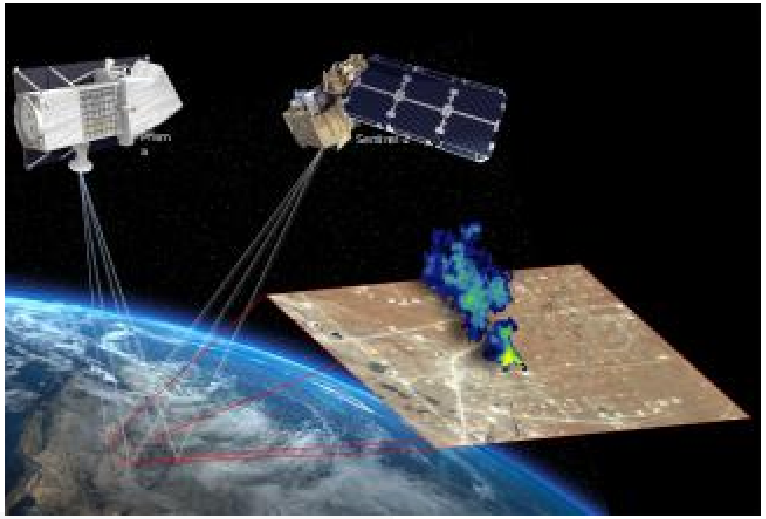
UNIVERSITAT POLITÈCNICA DE VALÈNCIA

EDF ENVIRONMENTAL DEFENSE FUND
Finding the ways that work



Land and Atmosphere Remote Sensing group (LARS)

- Active since 2020, young group (?) focused on satellite remote sensing methods
- Luis, also a part-time contract as Senior Scientist at the Environmental Defense Fund
- Main funding from ESA and UNEP, soon also Eumetsat



UN environment
United Nations Environment Programme

esa
European Space Agency

EDF
ENVIRONMENTAL DEFENSE FUND
Finding the ways that work

Luis Guanter

Professor of Applied Physics & Head of the LARS group

Remote sensing, Imaging spectroscopy, Radiative transfer modeling, Earth observation missions and instruments

Itziar Irakulis Loitxate

Doctoral researcher

Detection of greenhouse gas (GHG) emitters, Spatial data analysis and GIS, Climate change mitigation, Air quality monitoring

Javier Roger

Doctoral Researcher

Image processing, Detection and quantification of trace gases, EO analysis

Javier Gorroño

ESA Living Planet Postdoctoral Fellow

Calibration and validation of optical sensors, Uncertainty analysis of EO products, EO processing chain development

Adriana Valverde-Iglesias

Msc candidate, Geomatics

Cartography and GIS projects, Methane mapping with high-resolution satellite images.

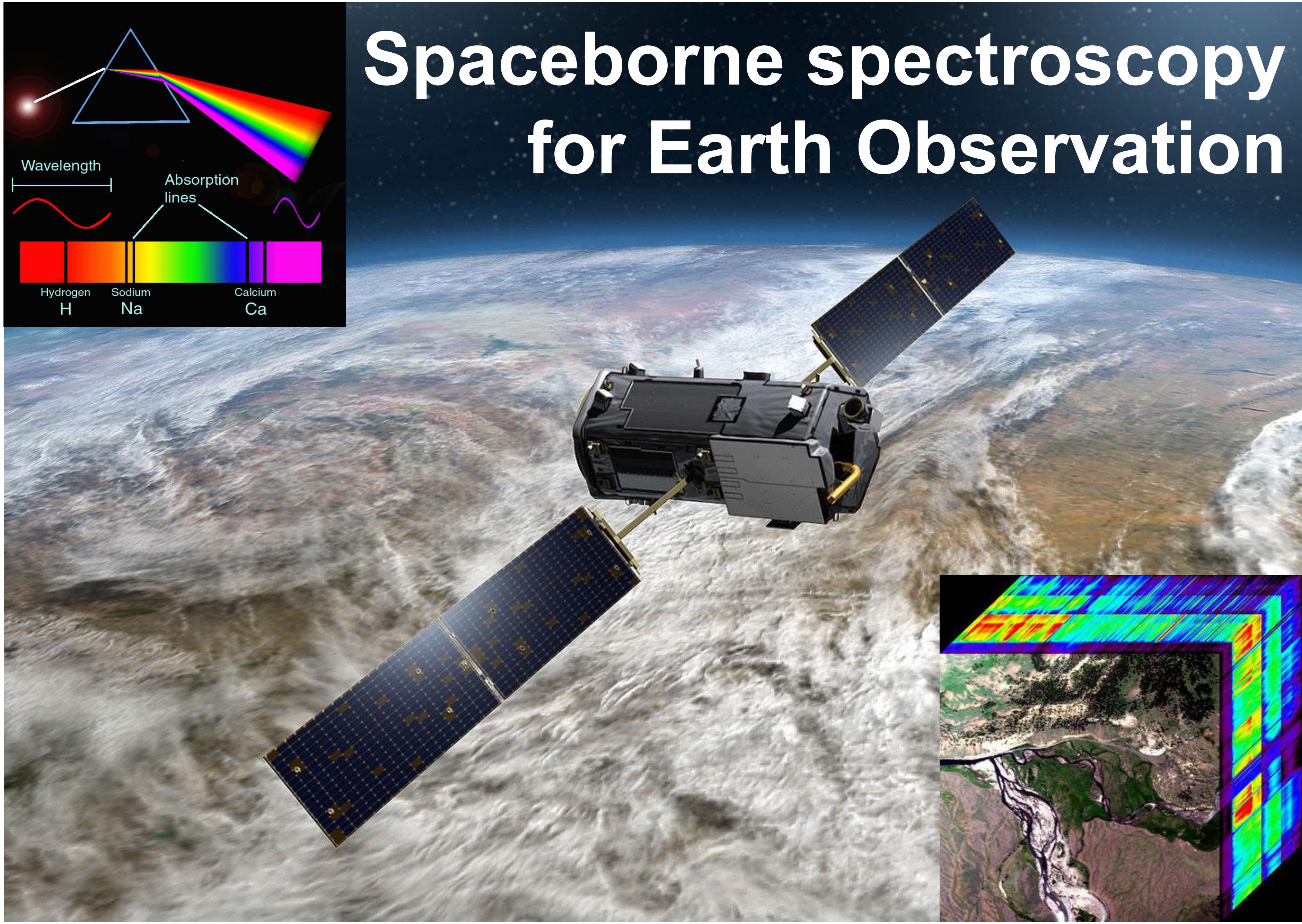
LARS’ background & main research interests

Overarching topics:

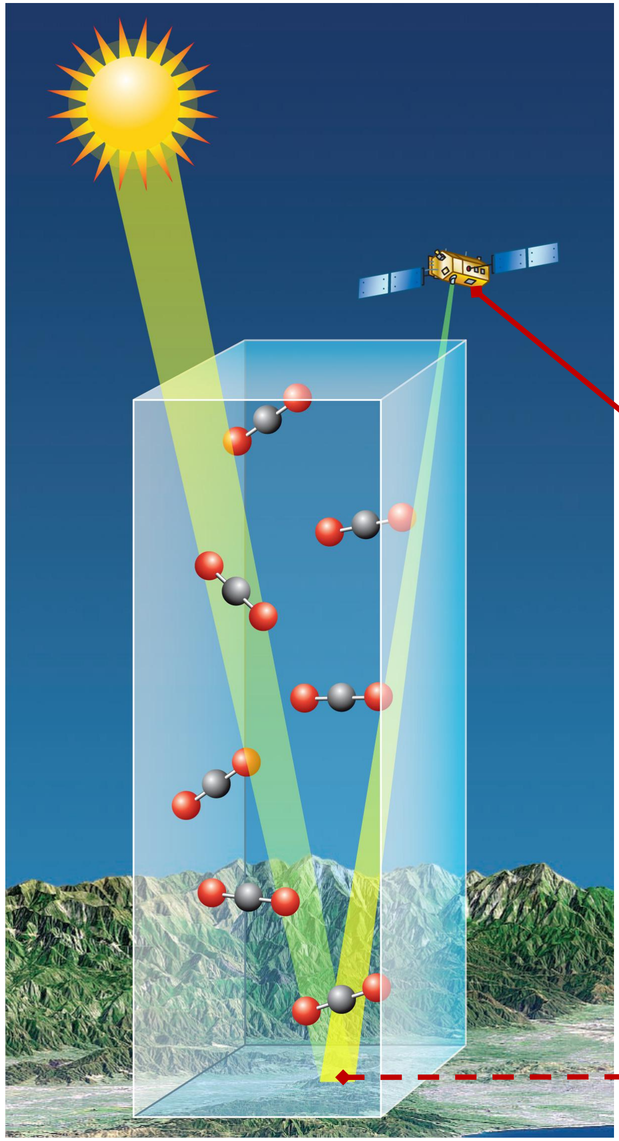
- Imaging spectroscopy
- Radiative transfer modeling
- Simulations and information retrieval

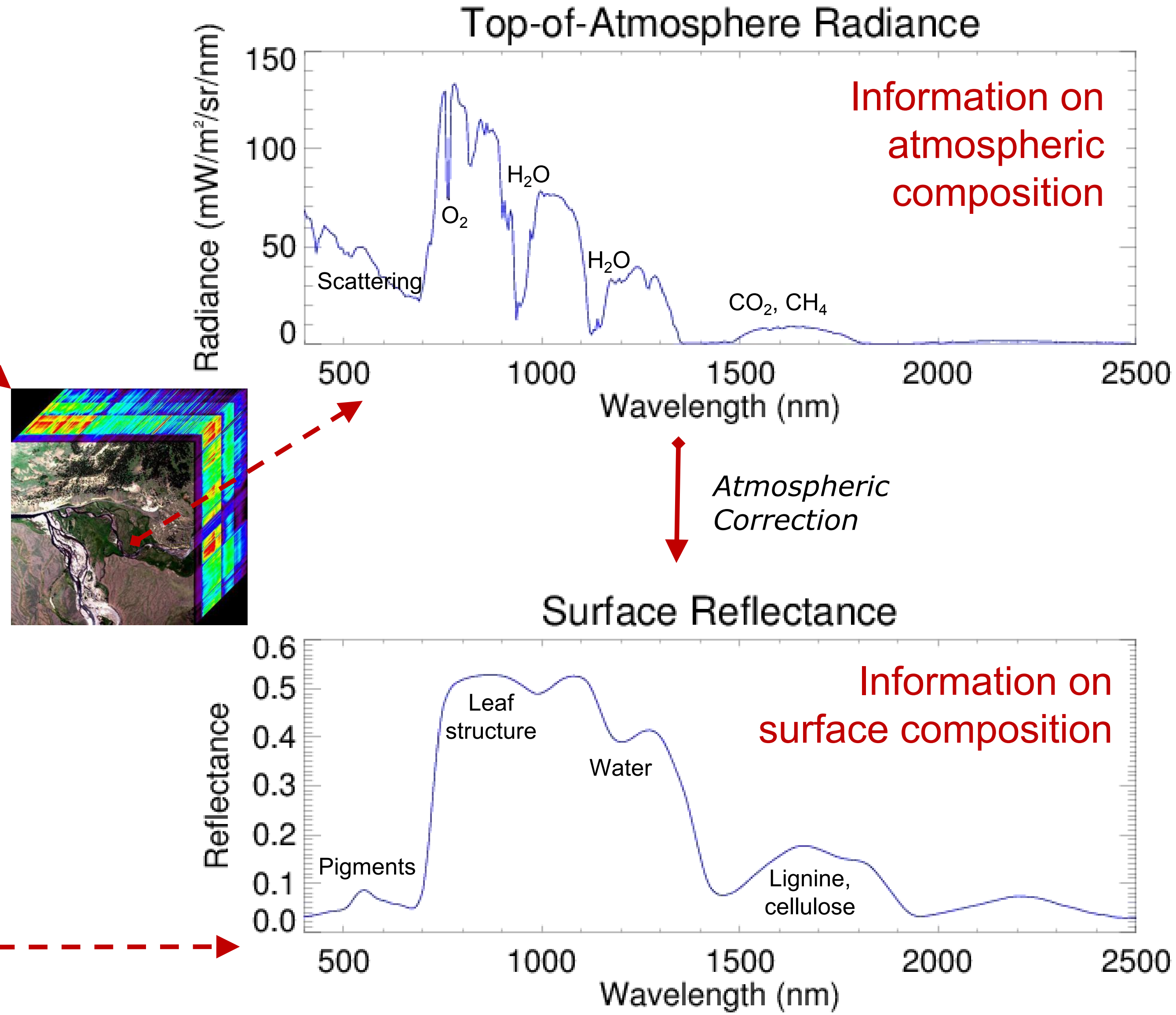
Specific interests:

- Detection and quantification of methane emissions
- Monitoring of sun-induced fluorescence
- Monitoring of air and water quality
- Uncertainty estimation and cal-val



Imaging spectroscopy (aka hyperspectral remote sensing)



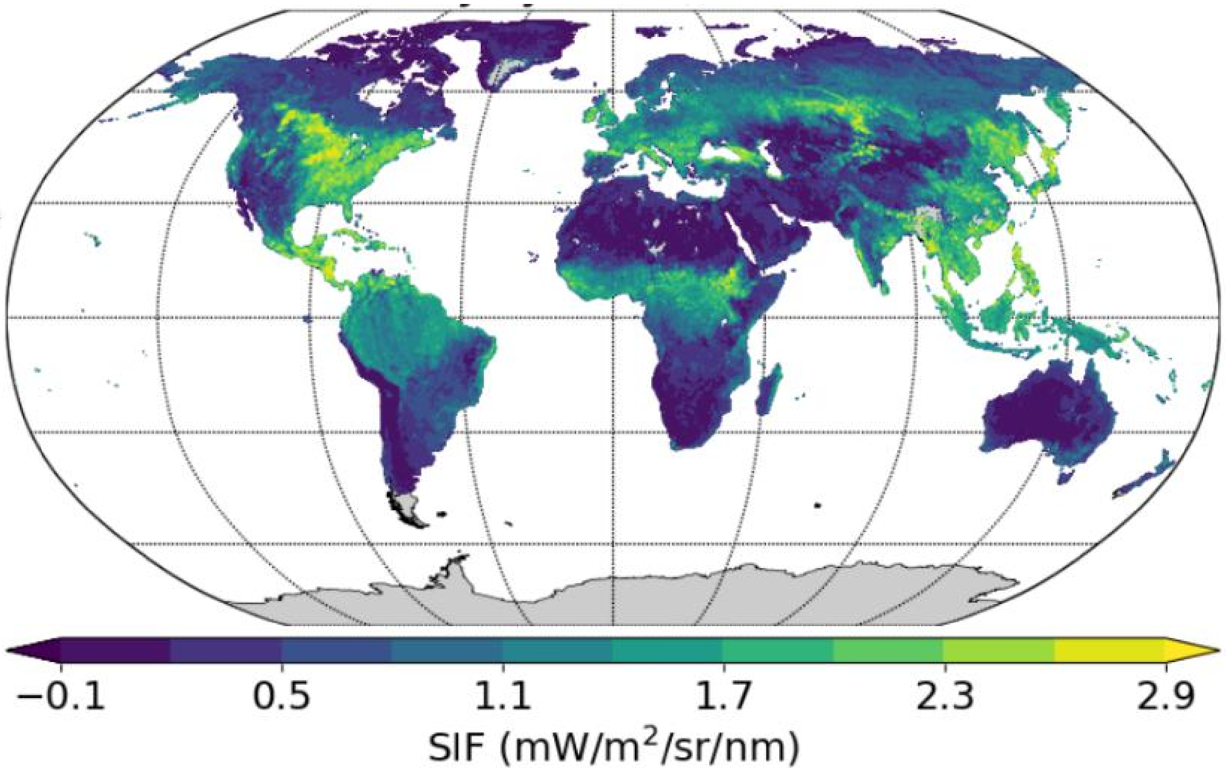


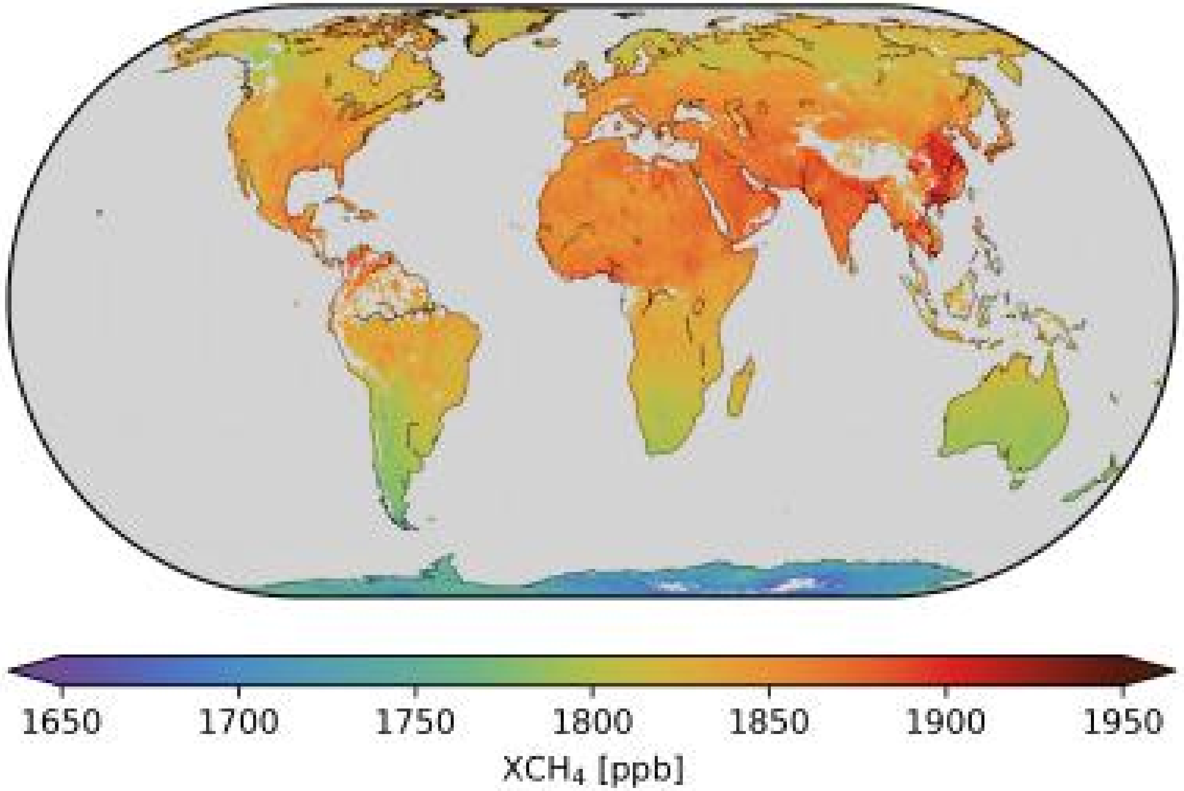
Monitoring of atmospheric and surface parameters with spaceborne spectrometers

Different classess of spaceborne imaging spectrometers now operating:

- Sentinel-5P TROPOMI: global daily coverage, ~5x5 km² pixel, atmospheric chemistry (pollution and GHG)
- EnMAP, PRISMA and others: targeted acquisitions, 30-m pixel, land/water/GHG

→ TROPOMI-based sun-induce fluorescence (SIF) projects by LARS in the last years; current focus on methane





Detection of methane point sources

- Methane emissions from fossil fuel production (e.g. oil & gas extraction, coal mining) represent a major contribution to the methane budget
- Emitters are typically point sources: strong emissions as plumes from small surface elements
- Detection of super-emitters from space is key to guide mitigation efforts and inform inventories

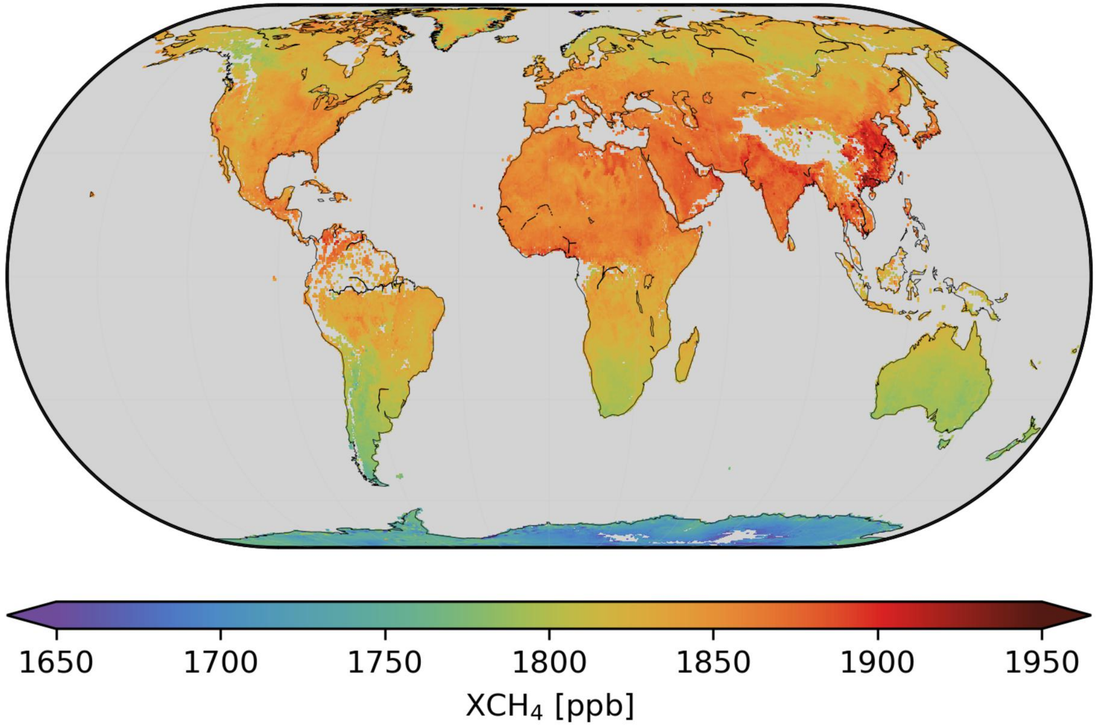
- **Current core research line at LARS:** development of methods for the detection, quantification and monitoring of methane emissions from point sources
- Funding from ESA and UNEP (IMEO)

Satellite-based detection of methane point sources

- Coordination of observations is required for the quick and accurate detection of emissions and the identification of sources

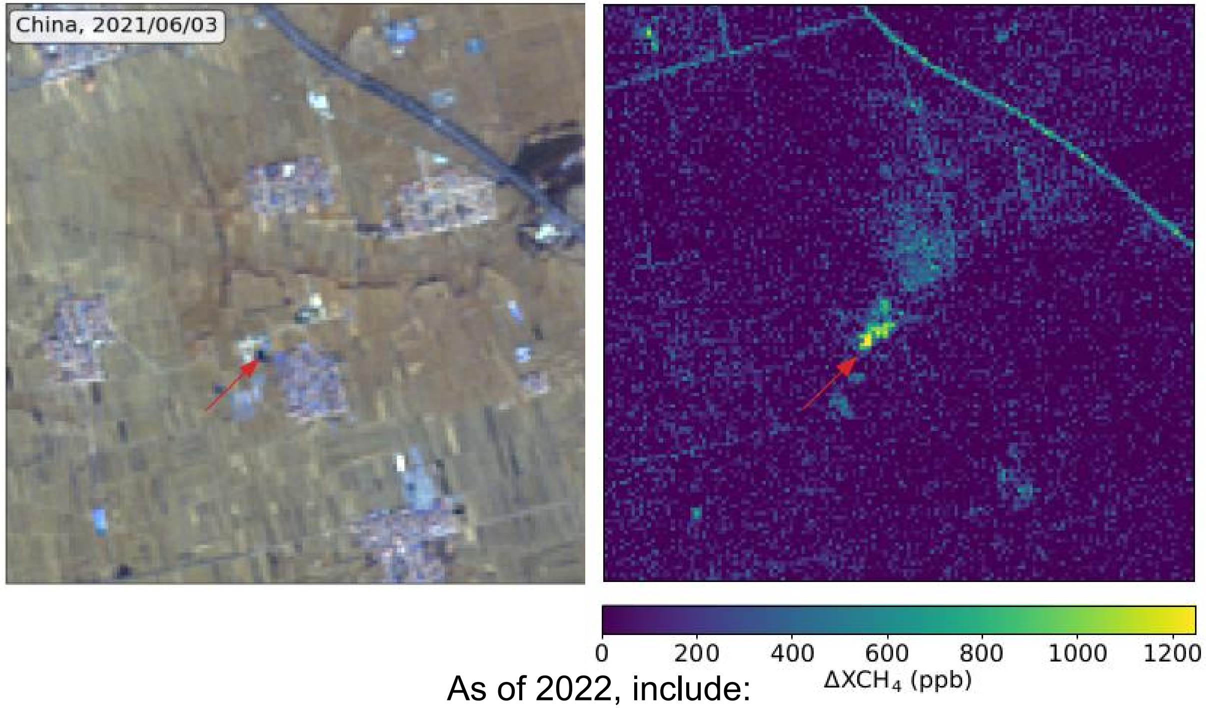
Area flux mappers (TROPOMI)

7 km/pixel, global daily coverage,
~10 t/h emissions, in general no attribution



Point-source imagers (PSIs)

~30 m/pixel, sparse acquisitions
0.1-1 t/h emissions, attribution to sources

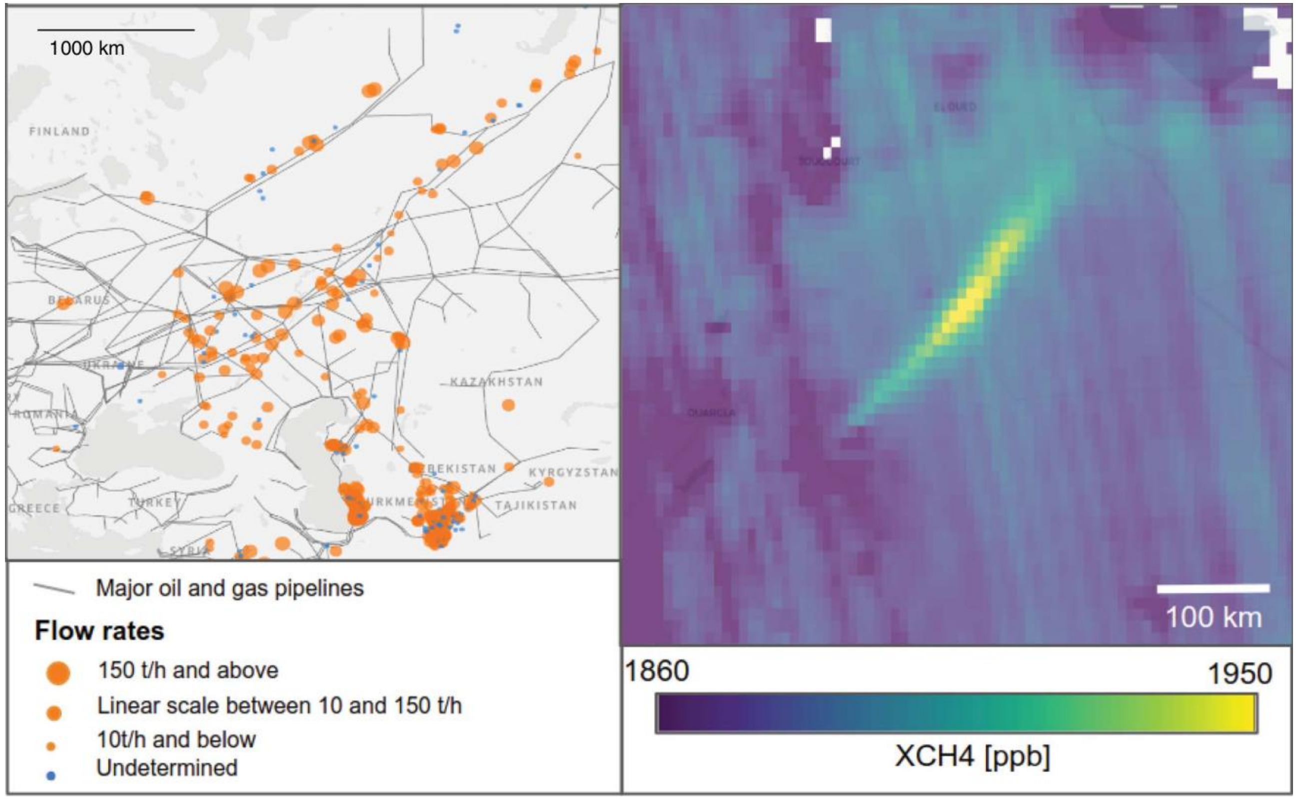


As of 2022, include:
GHGSat (Canada), PRISMA (Italy), EnMAP (Germany), EMIT (USA), GF5-02 (China), Sentinel-2 (EU), Landsat (USA)

ESA/EU Sentinel-5P/TROPOMI (area flux mapper)

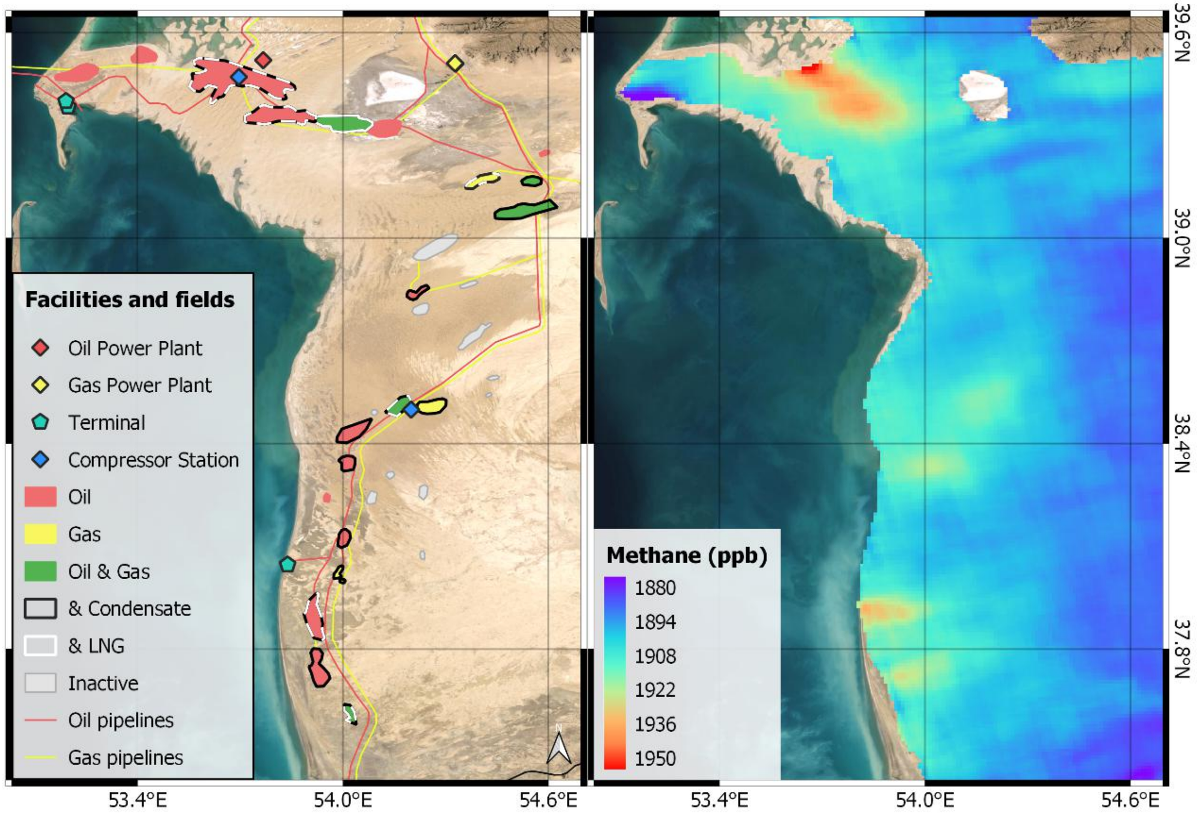
TROPOMI - operational, global and daily sampling, but coarse resolution

Application #1
Detection of individual ultra-emission events
(daily global surveillance, very large plumes)



Lavaux et al., Science, 2022

Application #2
Determination of “hotspot” regions
(average over time, persistent emissions)



Irakulis-Loitxate et al., ES&T, 2022

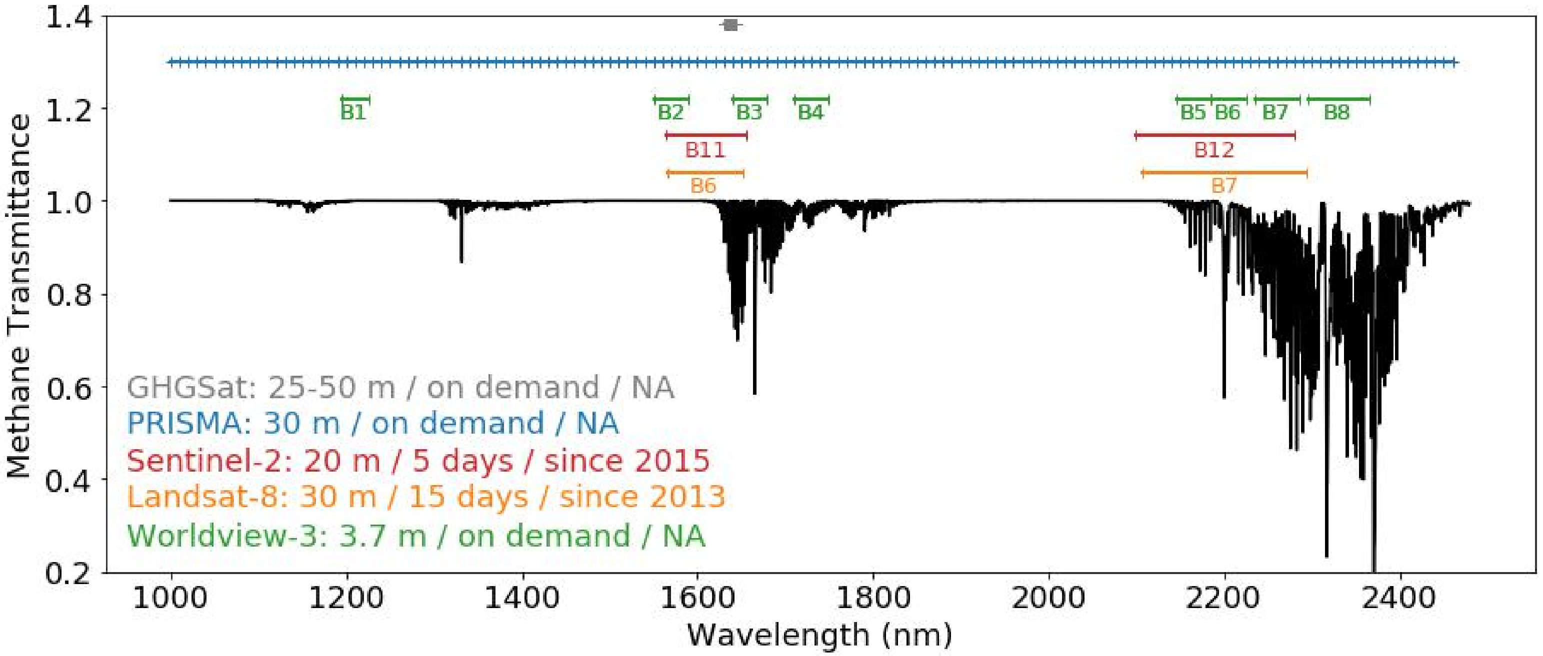
High-resolution satellites (point-source imagers)

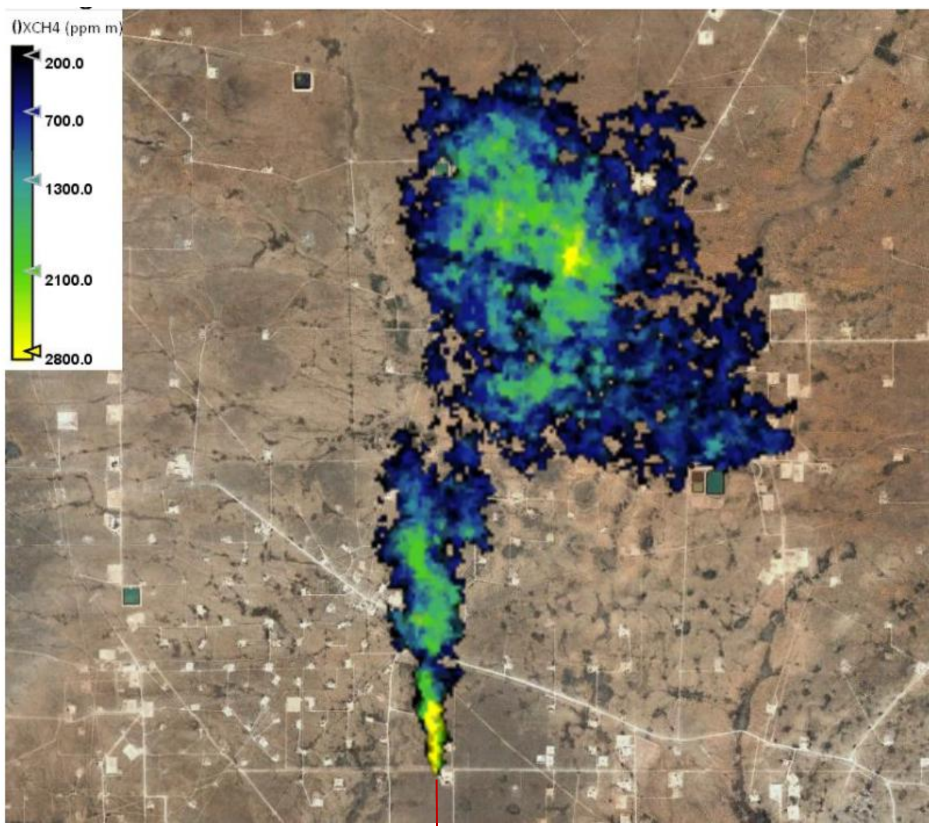
Instruments covering the methane absorptions in the SWIR

Allow attribution to sources and lower detection limits (>300 kg/h)

Two classes of missions

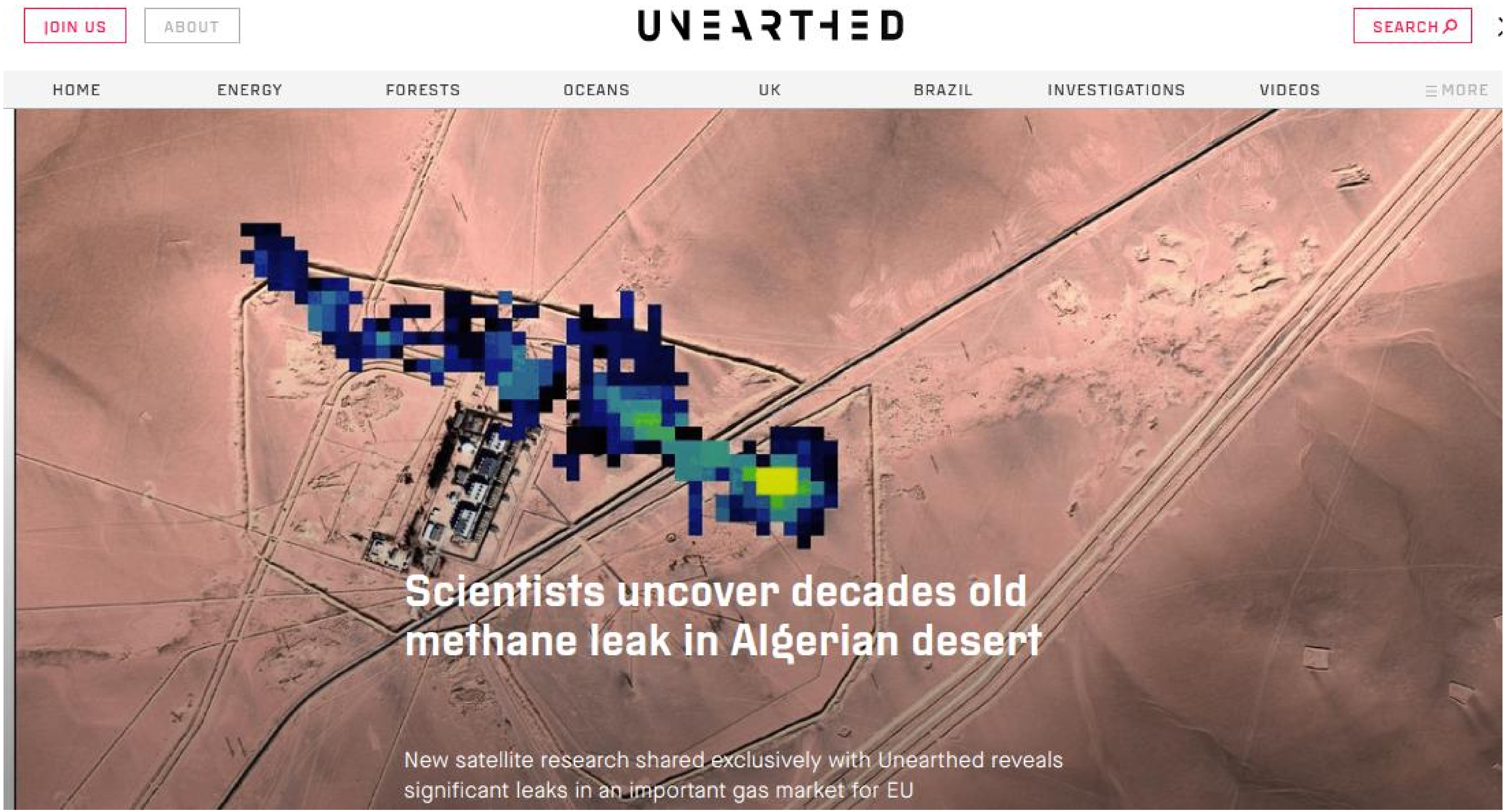
- Hyperspectral missions (GHGSat, PRISMA, ...): 30-m resolution, medium sensitivity, sporadic acquisitions but wide spatial coverage 30-60 km, require tasking
- Multispectral missions (S-2/Landsat): 20-30 m resolution, low sensitivity, but “monitoring” with frequent and global coverage





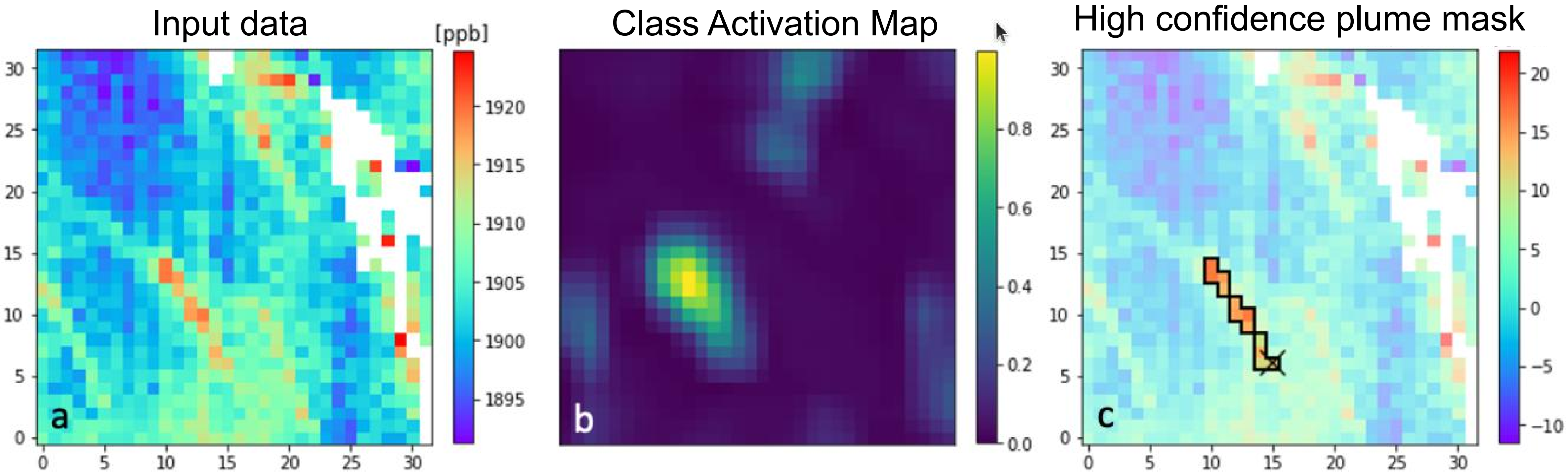
Malfunctioning flare, Permian Basin, NM, USA 9 Feb 2022

High-resolution satellites (point-source imagers)



Schuit et al. (2023), Automated detection and monitoring of methane super-emitters using satellite data, ACPD

- Goal: aumatic detection of methane plumes in TROPOMI's global & daily data
- Two-step machine learning approach:
  - CNN to detect plume like structures ("two convolutional blocks followed by two fully-connected layers and an output node")
  - Support Vector Classifier to distinguish emission plumes from retrieval artefacts
- Trained with pre-2021 manual plume detections --> 2974 plumes detected in 2021



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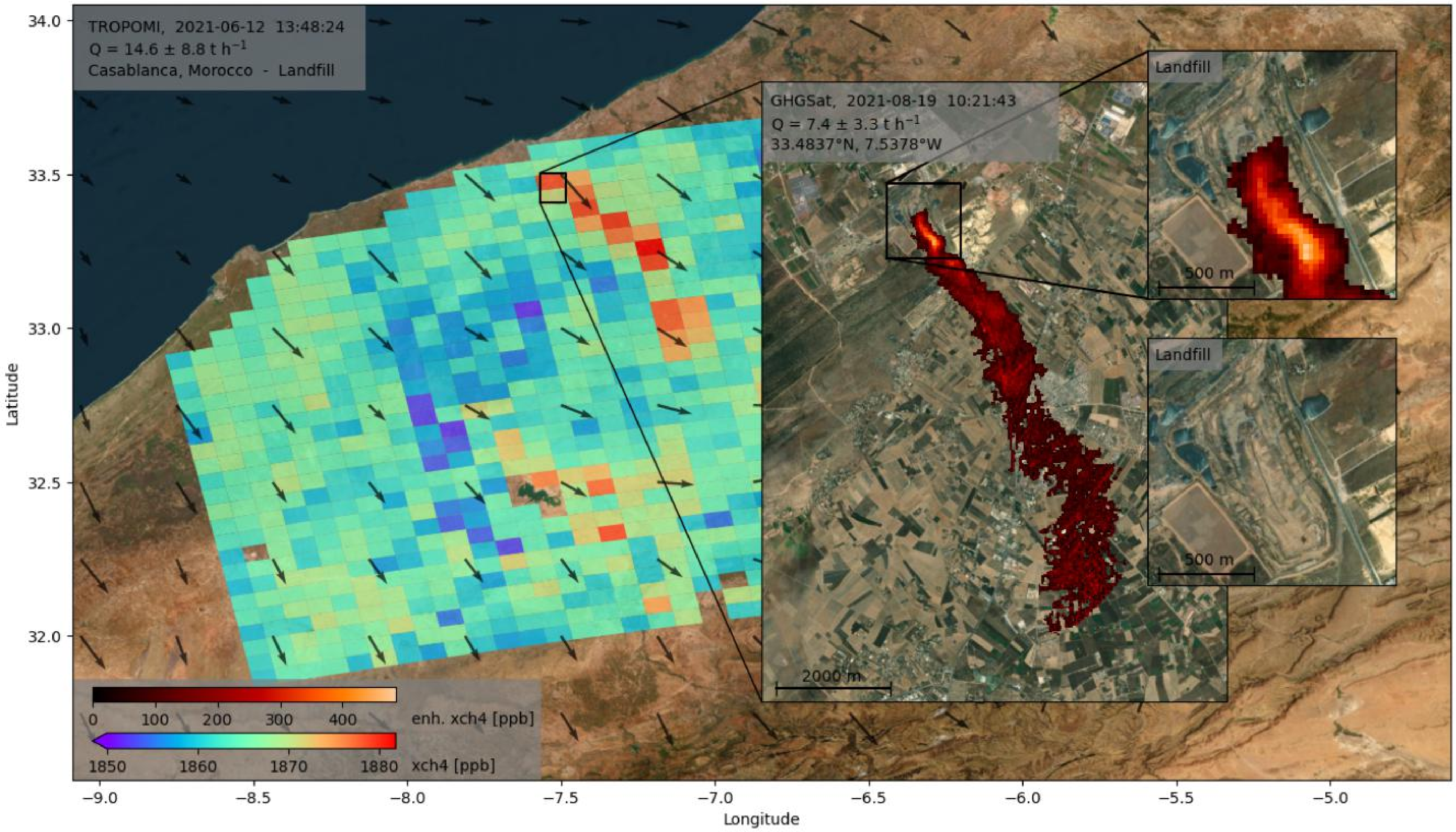
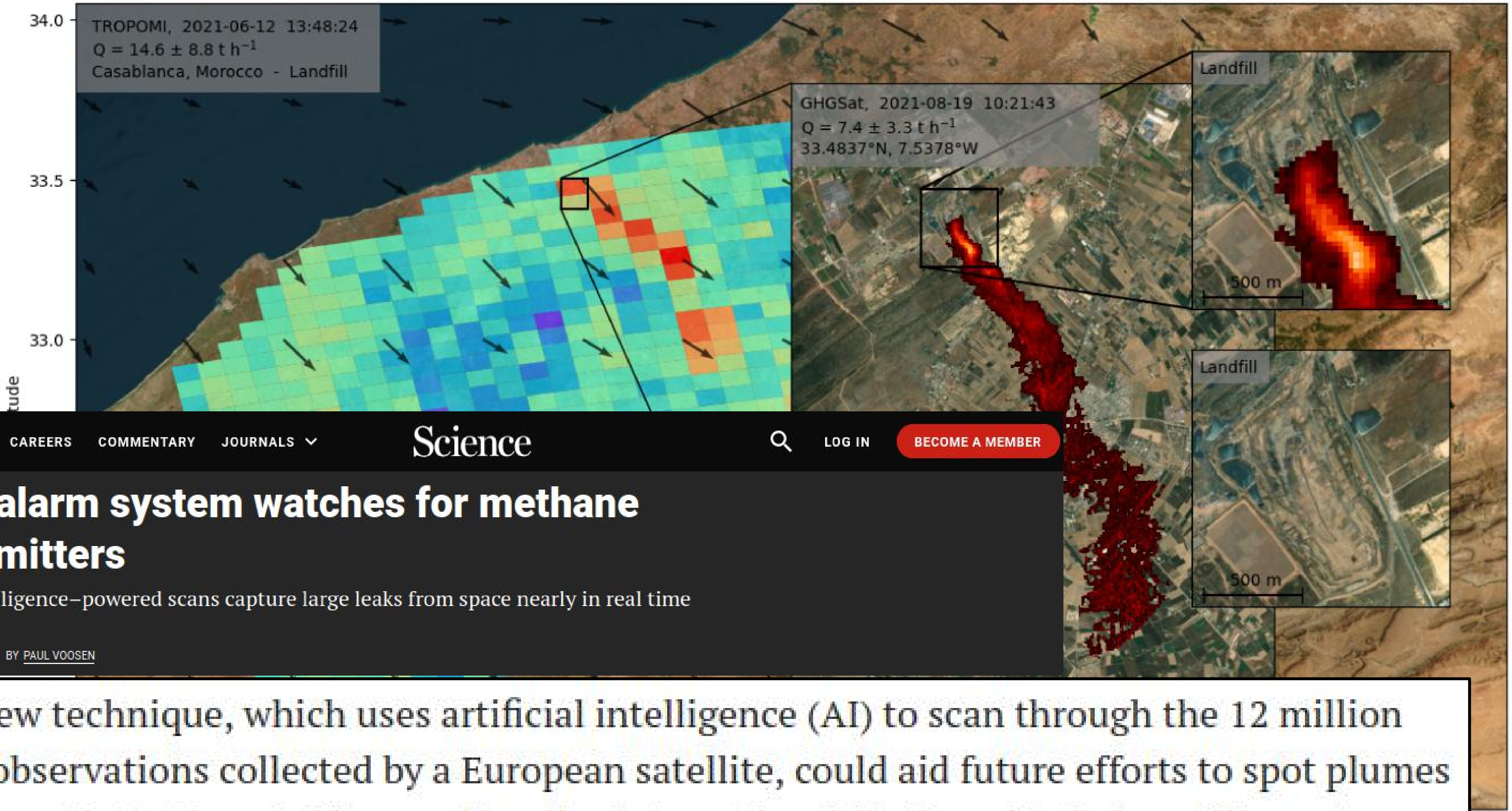


Schuit et al. (2023), Automated detection and monitoring of methane super-emitters using satellite data, ACPD



NEWS CAREERS COMMENTARY JOURNALS Science LOG IN BECOME A MEMBER

Global alarm system watches for methane superemitters

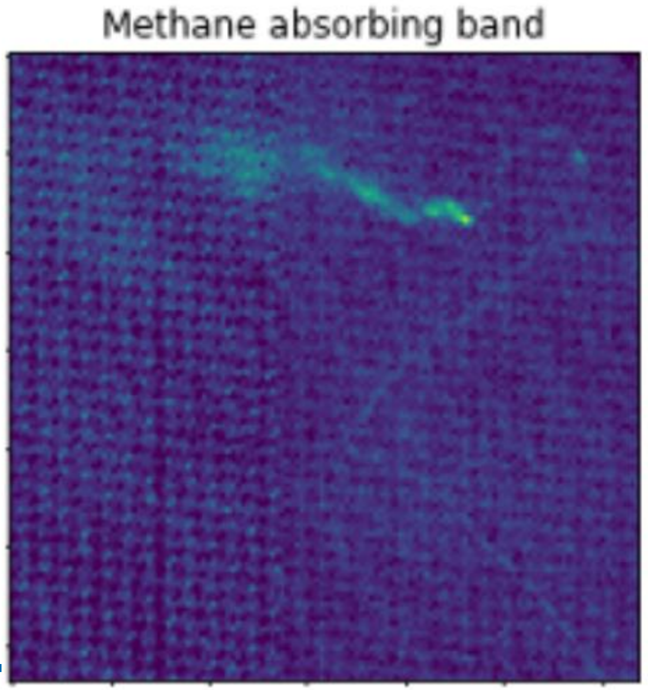
Artificial intelligence–powered scans capture large leaks from space nearly in real time

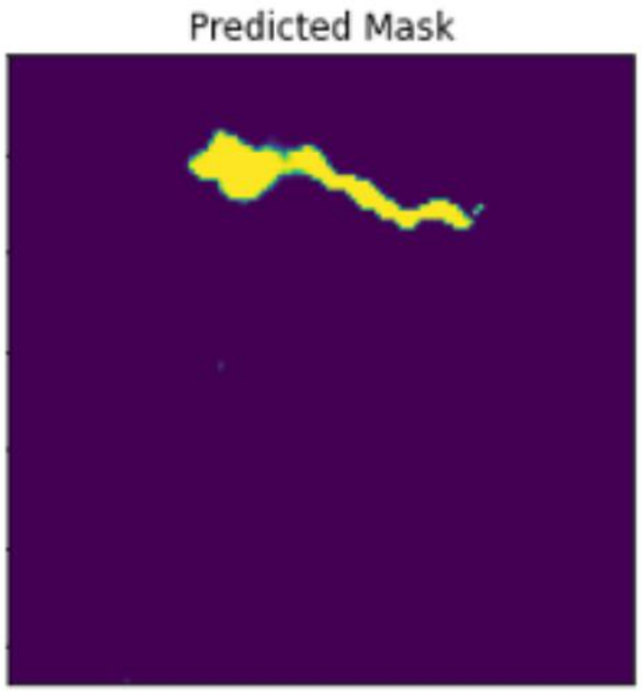
3 FEB 2023 · 12:25 PM · BY PAUL VOOSEN

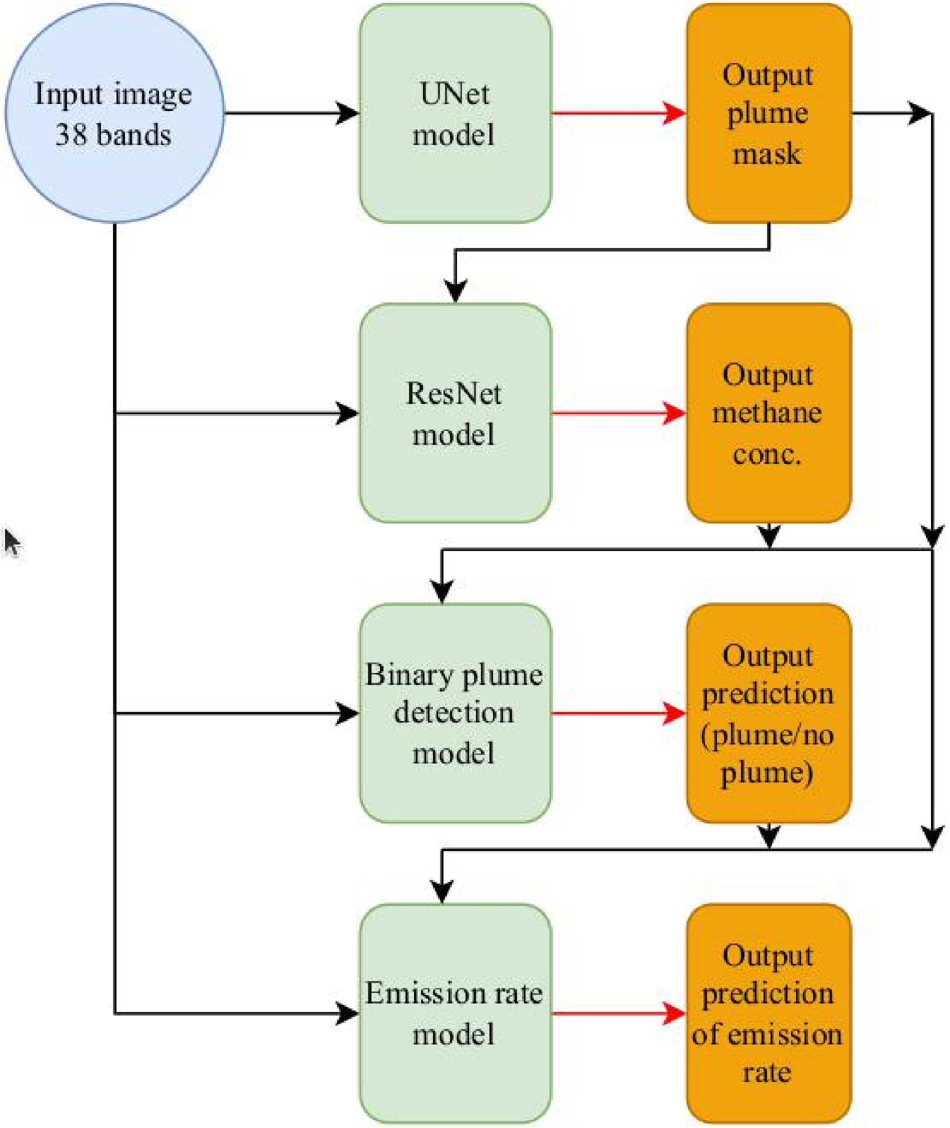
> The new technique, which uses artificial intelligence (AI) to scan through the 12 million daily observations collected by a European satellite, could aid future efforts to spot plumes in data collected by satellites, such as the International Methane Emissions Observatory

Joyce et al. (2023), Using a deep neural network to detect methane point sources and quantify emissions from PRISMA hyperspectral satellite images, AMTD

- Goal: aumatic detection and quantification of methane plumes in PRISMA hyperspectral data
- NN split into 4 stages, training set based on simulations
- Key points:
  - Plume detection (classification) + quantification (regression)
  - Reduces need for human intervation in the plume detection and quantificationprocesses







Wrap-up LARS

- Research topics:
  - Optical remote sensing, satellite spectroscopy, methane, data pre-processing and simulation
  - Lately, strong focus on methane remote sensing

- Link to the PROMETEO project:
  - No AI experience at all, despite dealing with classification and regression problems (methane plume detection and quantification)
  - Can support groups dealing with remote sensing data

Schuit et al. (2023), ACPD,

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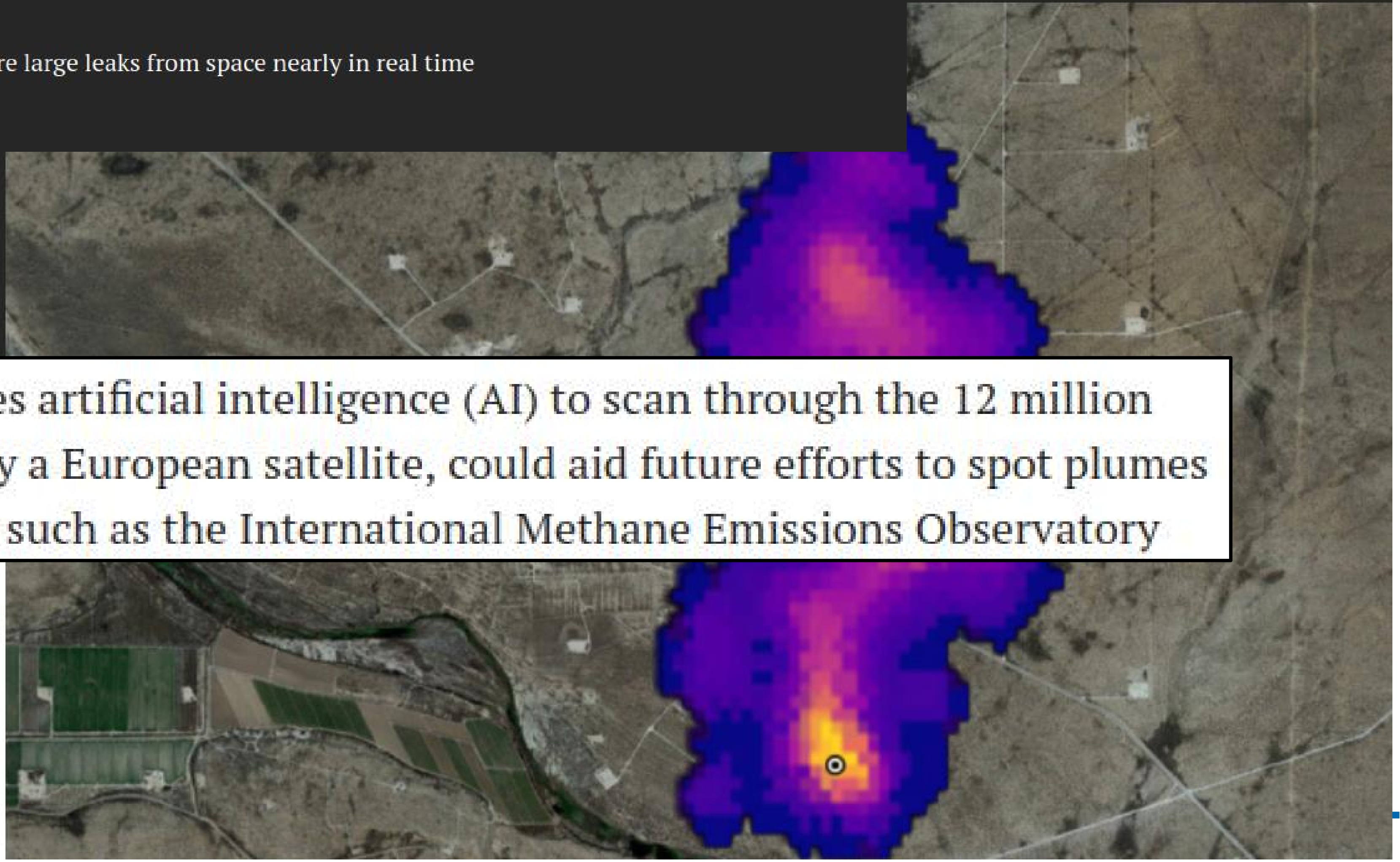
time



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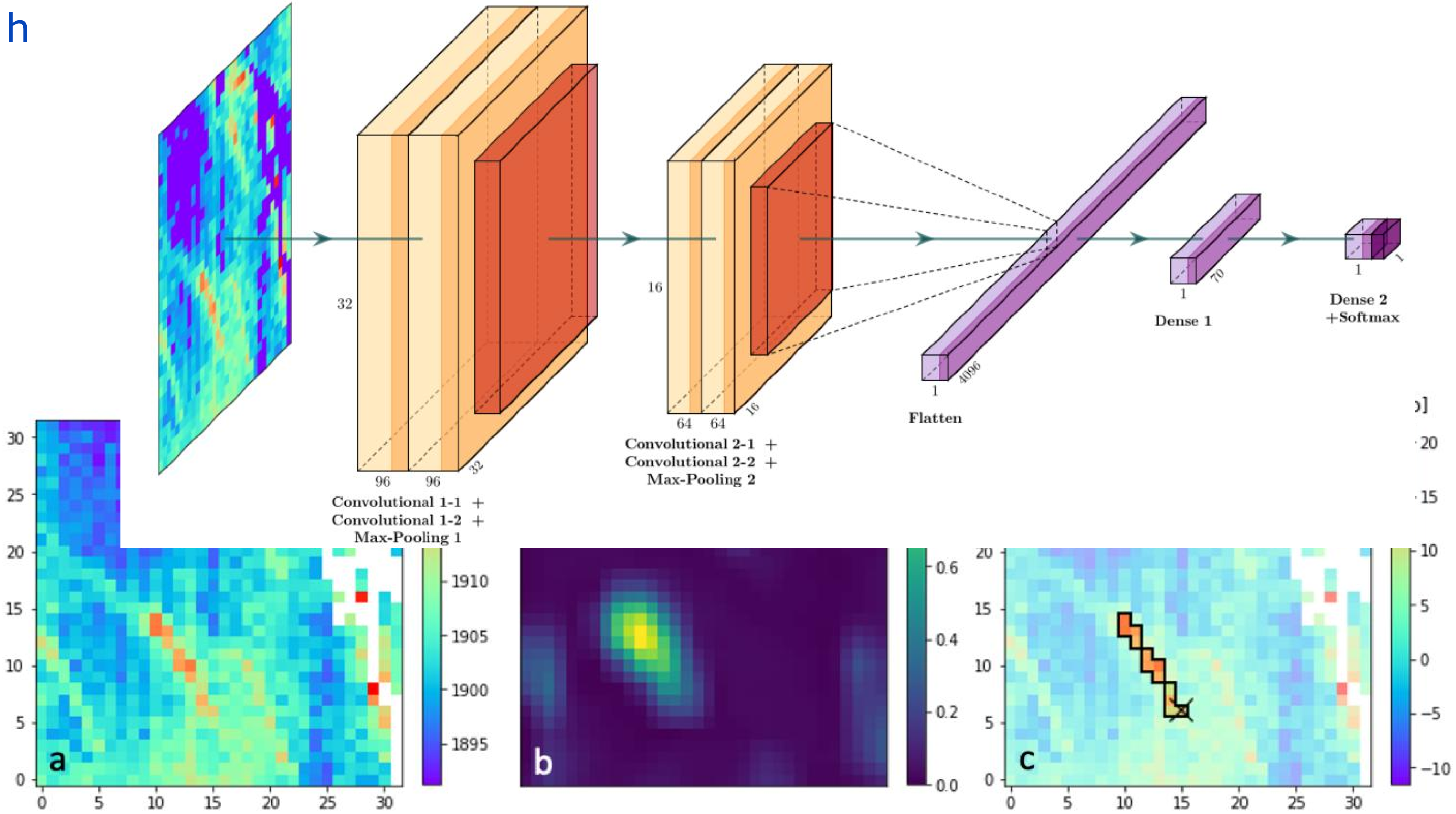
32
96 96
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Convolutional 1-1 +
Convolutional 1-2 +
Max-Pooling 1
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64 64
16
Convolutional 2-1 +
Convolutional 2-2 +
Max-Pooling 2
1
4096
Flatten
1
70
Dense 1
1
1
Dense 2
+Softmax
a
b
c

Methodology: methane retrieval & plume identification

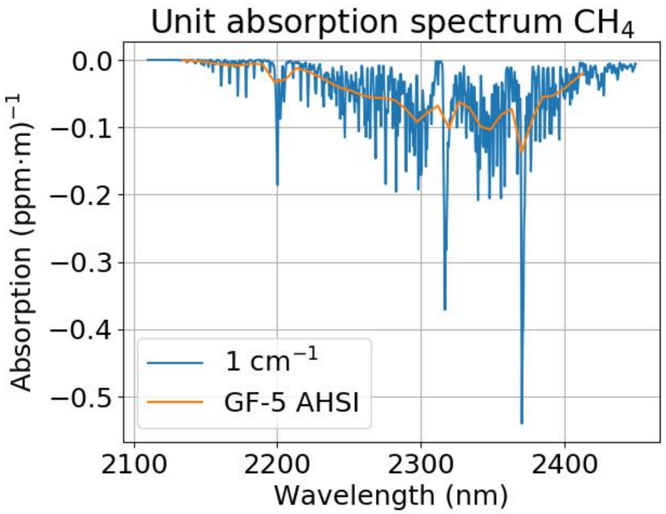
- XCH4 enhacements quantified through our own implementation of a simple matched-filter (MF) scheme (e.g. Thompson et al.)
- Markus Foote's MAG1C code also tested:
  - MF + sparsity + albedo correction
  - Results relatively similar. MAG1C higher SNR, but at the same time lower sensitivity to the edges of the plume and perhaps more false positives
- Issue: high number of false positives

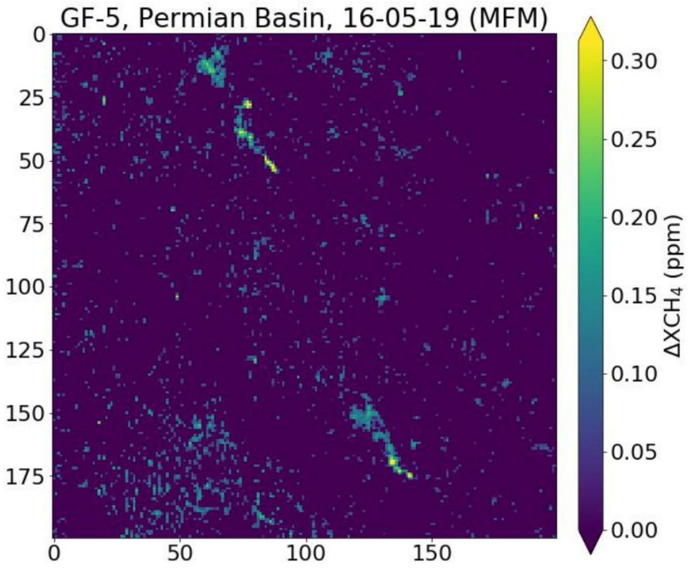
$$L_0 e^{-\alpha s} \approx L_0 - \alpha t_s(L_0)$$

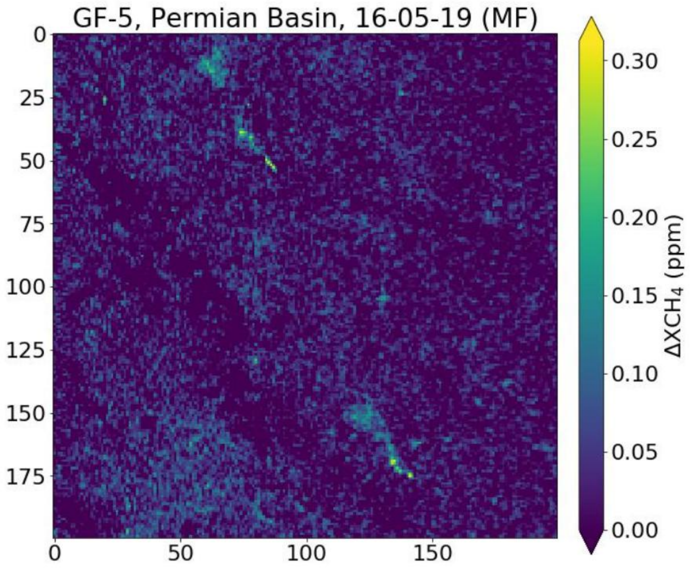
$$\hat{\alpha}_i = \underset{\alpha_i}{\operatorname{argmin}} \sum_i^N [d_2^T C^{-1} d_2]$$

$$d_2 = L_i - (\mu + \alpha_i t(\mu))$$

$$\hat{\alpha}_i = \frac{(L_i - \mu)^T C^{-1} (t(\mu))}{(t(\mu))^T C^{-1} (t(\mu))}$$



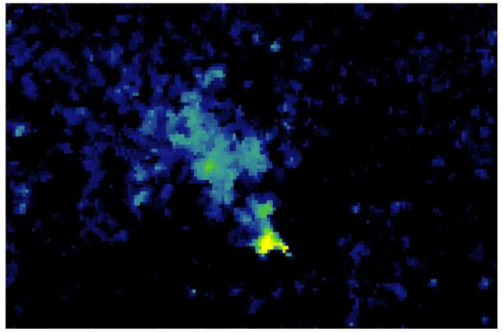




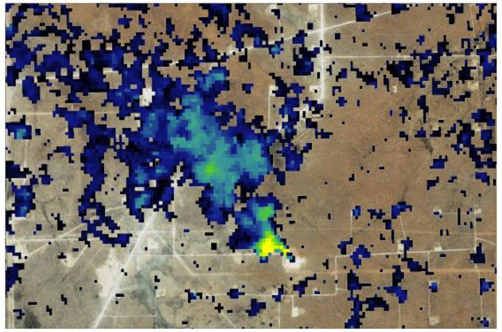
Methodology: methane retrieval & plume identification

- XCH4 concentration enhancements quantified through either full-physics or data driven methods (e.g. matched-filter retrieval by Thompson et al.)
- Plume identification with a supervised approach. Main criteria: consistency with winds and no correlation with surface structures.
- Flux rates (Q, in kg-CH4/hr) estimated using the Integrated Methane Enhancement method
- Sensitivity ~500 kg/h, depending on surface type and wind speed

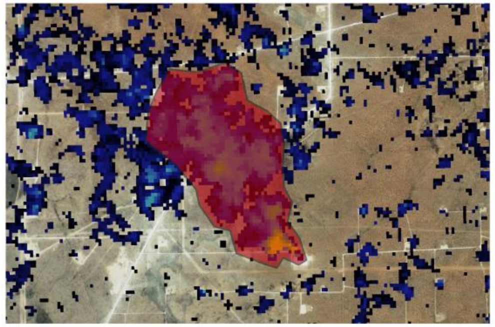
Processing →



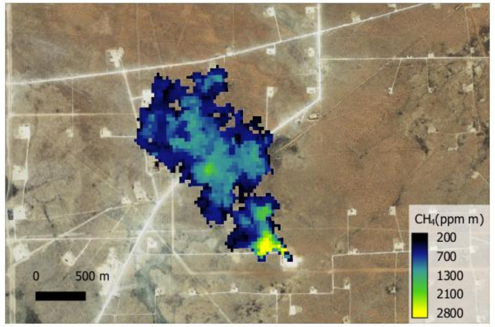
Methane concentration enhancement map



Methane map
+ 200 ppm·m threshold



Manual plume mask



Final plume

Introduction: high resolution methane mapping from space

- Methane emissions from fossil fuel production (e.g. oil & gas extraction, coal mining) represent a major contribution to the methane budget
- Emitters are typically point sources: strong emissions as plumes from small surface elements
- Detection of super-emitters from space is key to guide mitigation efforts and inform inventories

- Satellite missions for the detection of methane point sources:
  - Sentinel-5P/TROPOMI: ~5 km / pixel, daily global revisit --> detection of regional enhancements
  - Imaging spectrometers (e.g. PRISMA): detection of single plumes and attribution to sources

Satellites relevant to MARS – A diverse ecosystem of methane–sensitive missions

Area flux mappers:

- **TROPOMI**: 7 km/pixel, global daily coverage, >10 t/h emissions, no attribution to sources
- A number of other missions coming up in the next 2-3 years

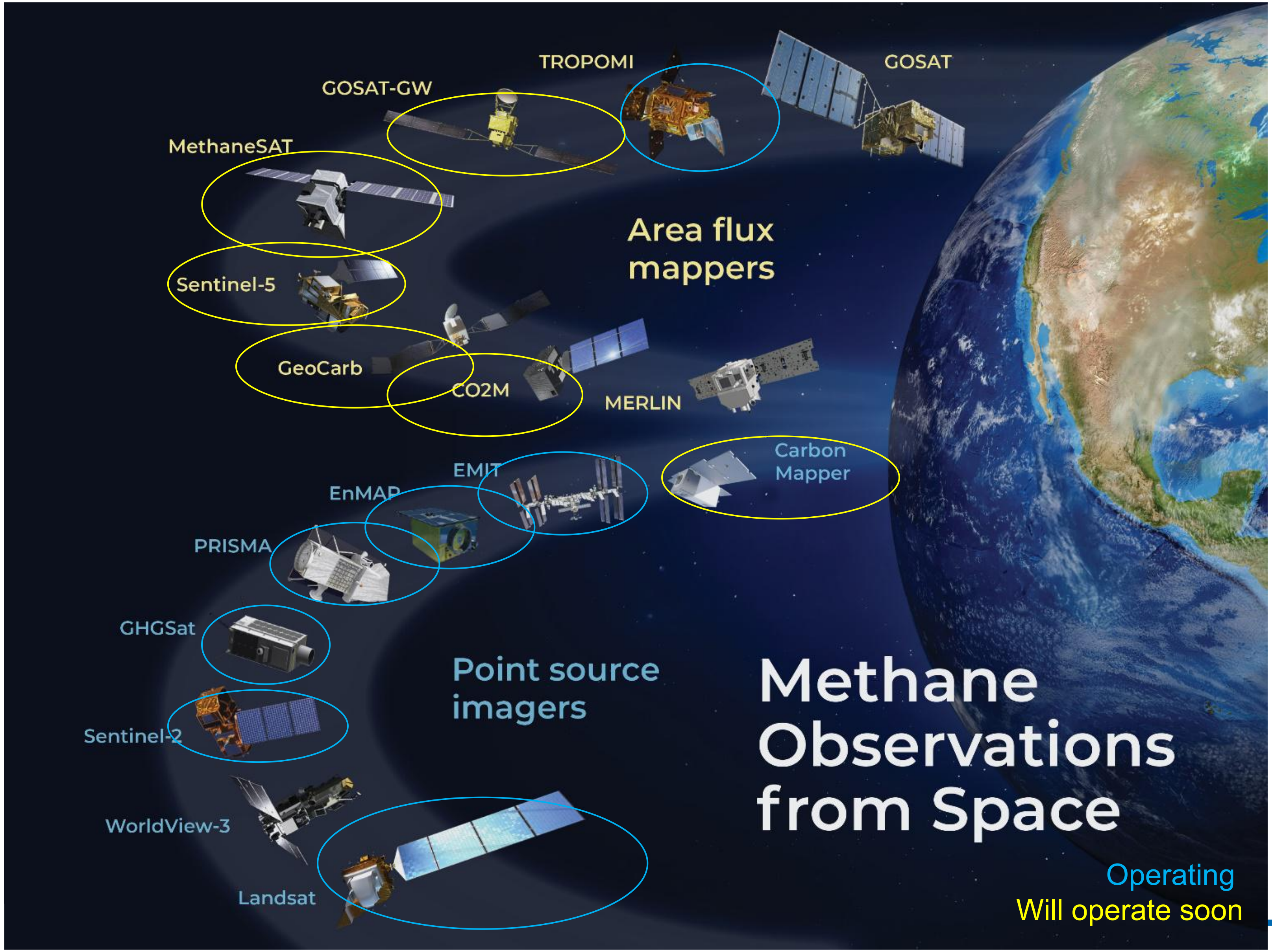
Point source imagers:

Hyperspectral missions

- **GHGSat** (private): 25/50 m resolution, high sensitivity, sporadic acquisitions, 12 km coverage
- Imaging spectrometers (**PRISMA, EnMAP, EMIT, AHSI**): 30 m resolution, medium sensitivity, 30-60 km coverage, require tasking

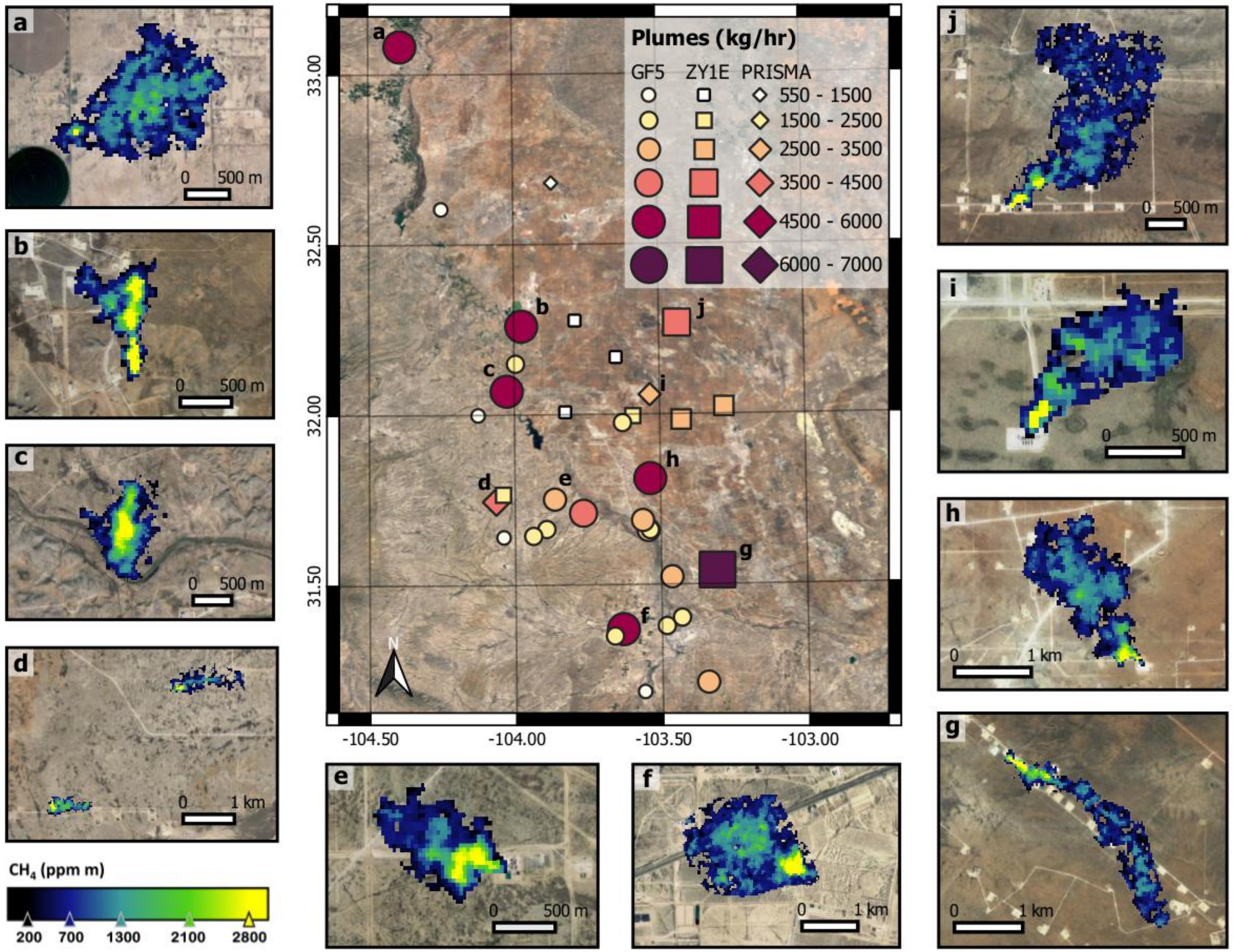
Multispectral missions

- **S-2/Landsat**: 20-30 m resolution, low sensitivity, but "monitoring" with frequent and global coverage



Jacob et al., ACP, 2022

Identificación de fuentes puntuales de emisión de GHGs

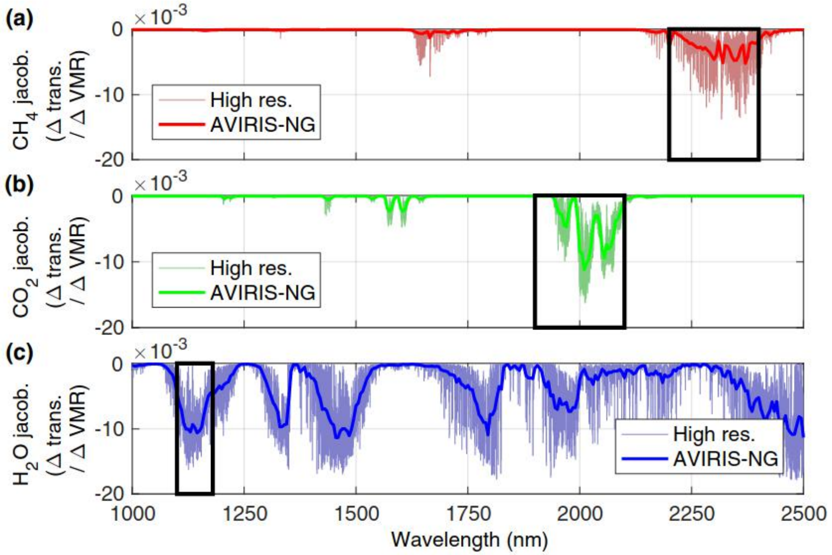


Irakulis, Guanter, et al. in preparation

- ❖ Espectrómetros de imagen en el SWIR operando desde satélite, avión o UAV pueden aplicarse al estudio de emisiones de GHGs (CH4, CO2)
- ❖ Permite identificar “super-emitters” como la zona del Permian Basin en los EEUU para CH4

Imaging spectroscopy (aka hyperspectral remote sensing)

- Capability of imaging spectroscopy for methane mapping demonstrated in ~2010 with JPL's AVIRIS airborne spectrometer
- Strong potential to detect and quantify methane point sources (most common in oil/gas or coal mine regions); diffuse sources (e.g. wetlands) more challenging
- Large-scale surveys of methane super-emitters in the USA with AVIRIS (e.g. Four Corners, California) and first demonstration at satellite scale with Hyperion during the Aliso Canyon gas leak (Thompson et al., 2015)



Thorpe et al. AMT 2017