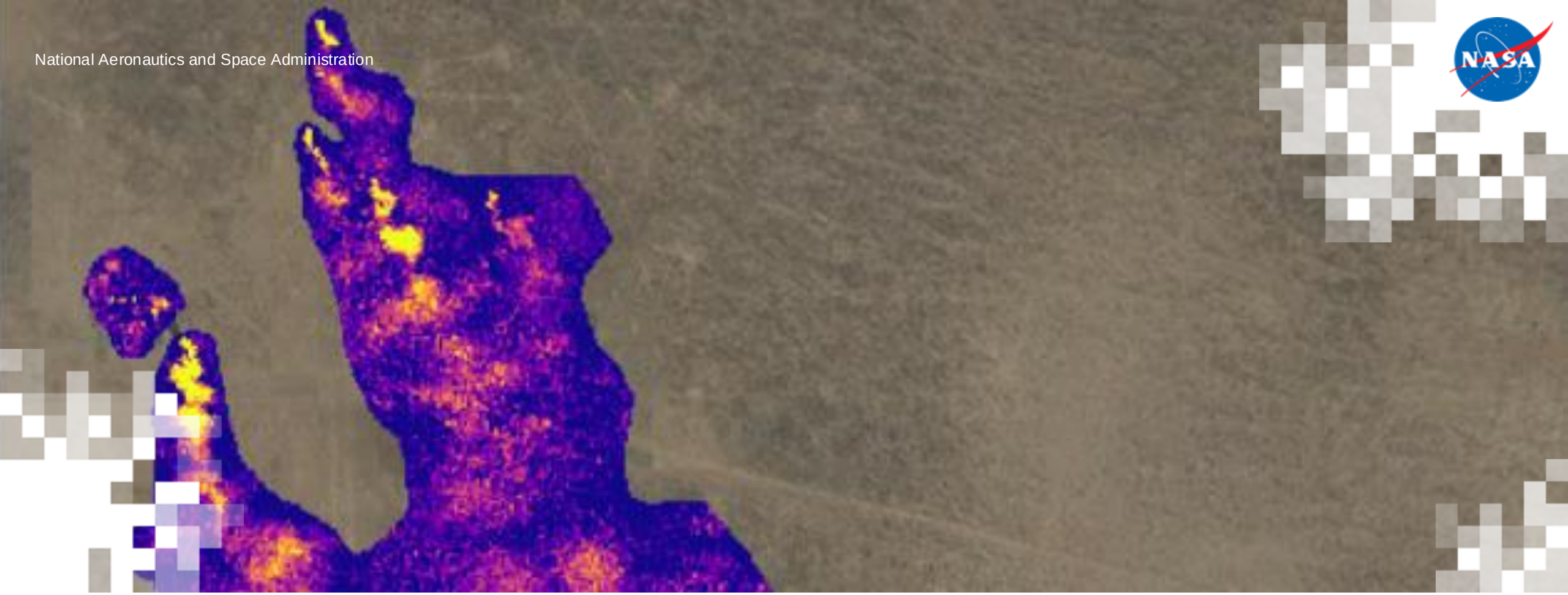
National Aeronautics and Space Administration

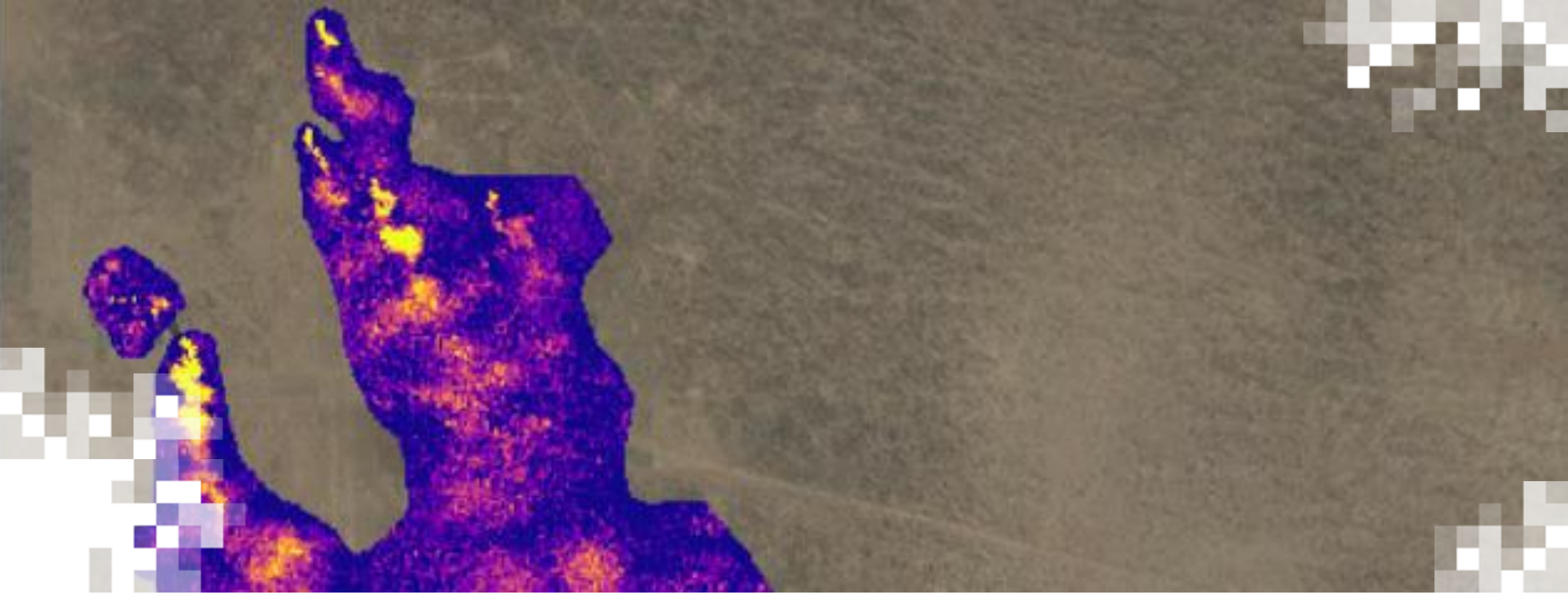


Methane Observations for Large Emission Event Detection and Monitoring

Part 1: United States Greenhouse Gas Center (US GHG) and Remote Detection of Large Methane Emissions

Lesley Ott (NASA Goddard Space Flight Center), Andrew Thorpe (Jet Propulsion Laboratory), Dana Chadwick (Jet Propulsion Laboratory), Melanie Follette-Cook (NASA Goddard Space Flight Center)

November 19, 2024



About ARSET

About ARSET

- **ARSET provides accessible, relevant, and cost-free training on remote sensing satellites, sensors, methods, and tools.**

- Trainings include a variety of applications of satellite data and are tailored to audiences with a variety of experience levels.

AGRICULTURE

CLIMATE & RESILIENCE

DISASTERS

ECOLOGICAL CONSERVATION

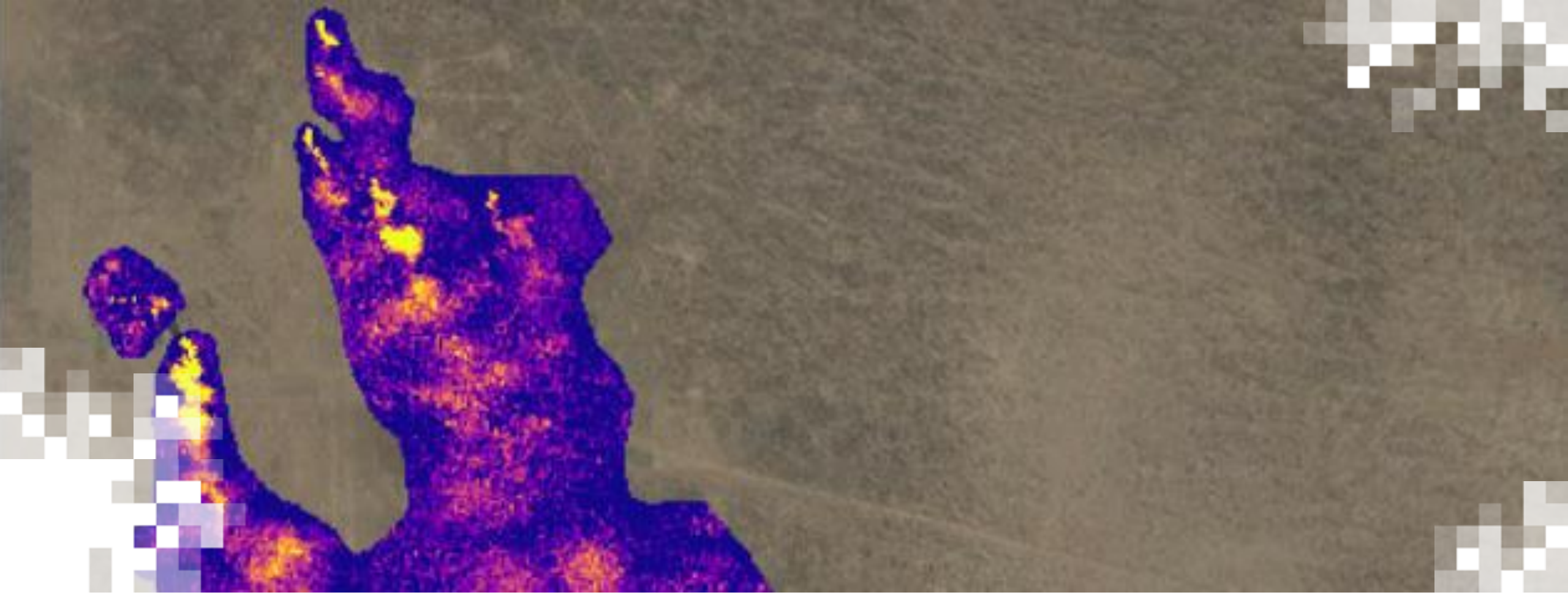
HEALTH & AIR QUALITY

WATER RESOURCES

About ARSET Trainings

- Online or in-person
- Live and instructor-led or asynchronous and self-paced
- Cost-free
- Bilingual and multilingual options
- Only use open-source software and data
- Accommodate differing levels of expertise

- Visit the ARSET website to learn more.



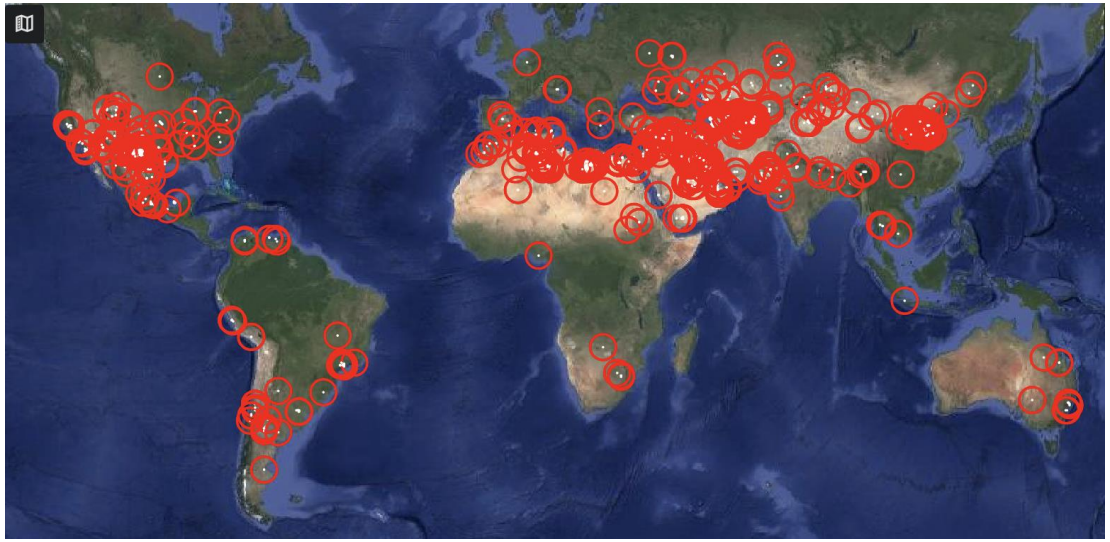
Methane Observations for Large Emission Event Detection and Monitoring

Overview

Background

- Methane (CH4) is estimated to be around 80 times more effective at trapping heat in the atmosphere than CO2.
- Methane is an attractive target for emission mitigation activities
  - Relatively short lifetime in the atmosphere (~decade)
  - Can be utilized as an energy source or combusted
  - Issues with safety associated with high concentrations of this flammable gas.
- Industrial activities or accidental releases can lead to the release of large concentrations of methane, these are often referred to as super emitter events, which can be identified using modern satellites.

The Earth Surface Mineral Dust Source Investigation (EMIT) sensor has identified >1,400 plumes.



Training Learning Objectives

By the end of this training, participants will be able to:

1. Identify the goals and objectives of the U.S. Greenhouse Gas Center
2. Define the roles of methane and large emission events in climate change
3. Identify the sensors used to measure methane
4. Recognize the strengths and limitations of satellite observations used to measure methane for large emission event tracking
5. Navigate the U.S. Greenhouse Gas Center Portal and the EMIT Open Data Portal to access and visualize data for large emission event tracking

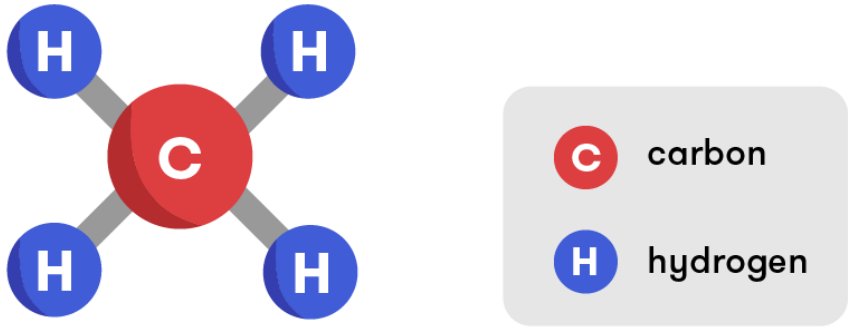


Image credit: pngegg.com

U.S. GHG CENTER

Prerequisites

- Fundamentals of Remote Sensing

Training Outline

Part 1

United States Greenhouse Gas Center (US GHG) and Remote Detection of Large Methane Emissions

November 19, 2024

11:00-12:30 EST

Part 2

EMIT Data Products and Visualization

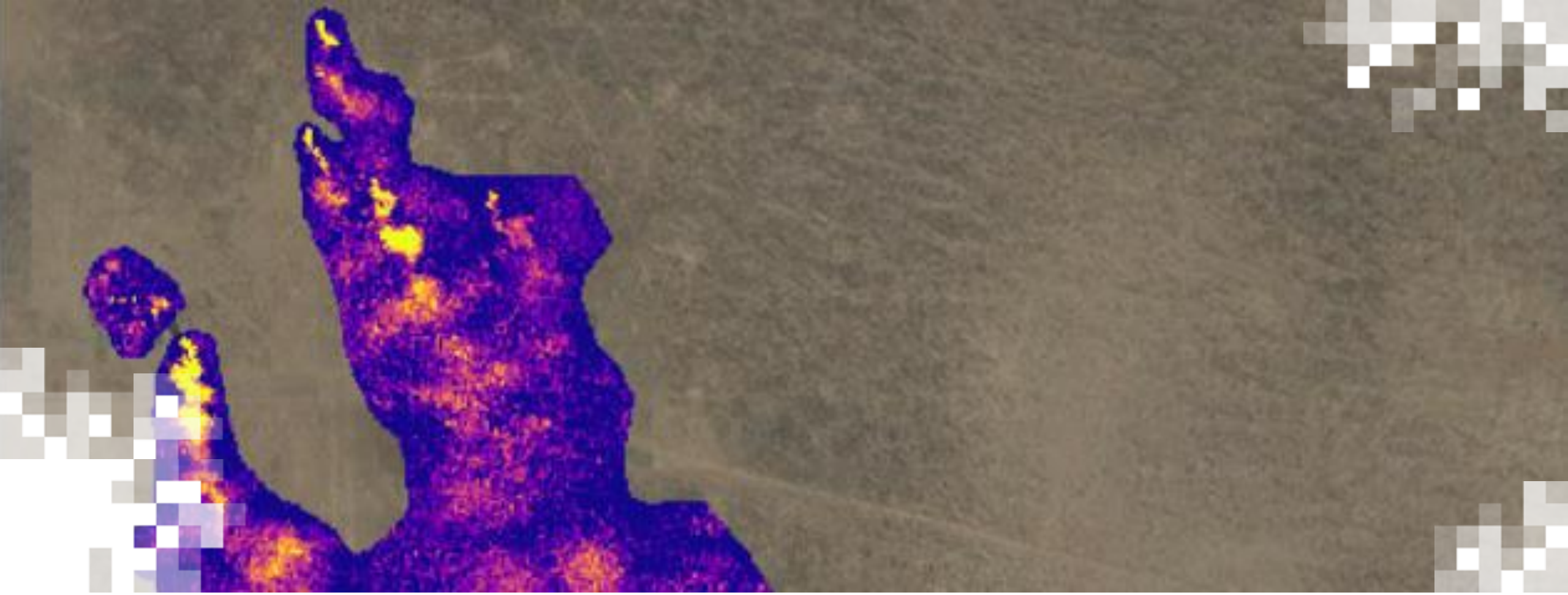
November 21, 2024

11:00-12:30 EST

Homework

Opens November 21 – Due December 05 – Posted on Training Webpage

A certificate of completion will be awarded to those who attend all live sessions and complete the homework assignment before the given due date.



Methane Observations for Large Emission Event Detection and Monitoring

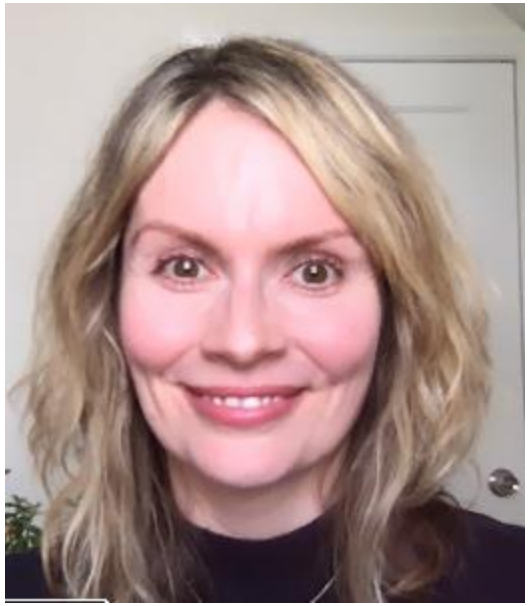
Part 1: United States Greenhouse Gas Center (US GHG) and Remote Detection of Large Methane Emissions

Part 1 – Trainers

Lesley Ott

Project Scientist, US Greenhouse Gas Center

NASA Goddard Space Flight Center



Andrew Thorpe

Research Technologist

Jet Propulsion Laboratory

Melanie Follette-Cook

Project Scientist, ARSET

NASA Goddard Space Flight Center

Part 1 Objectives

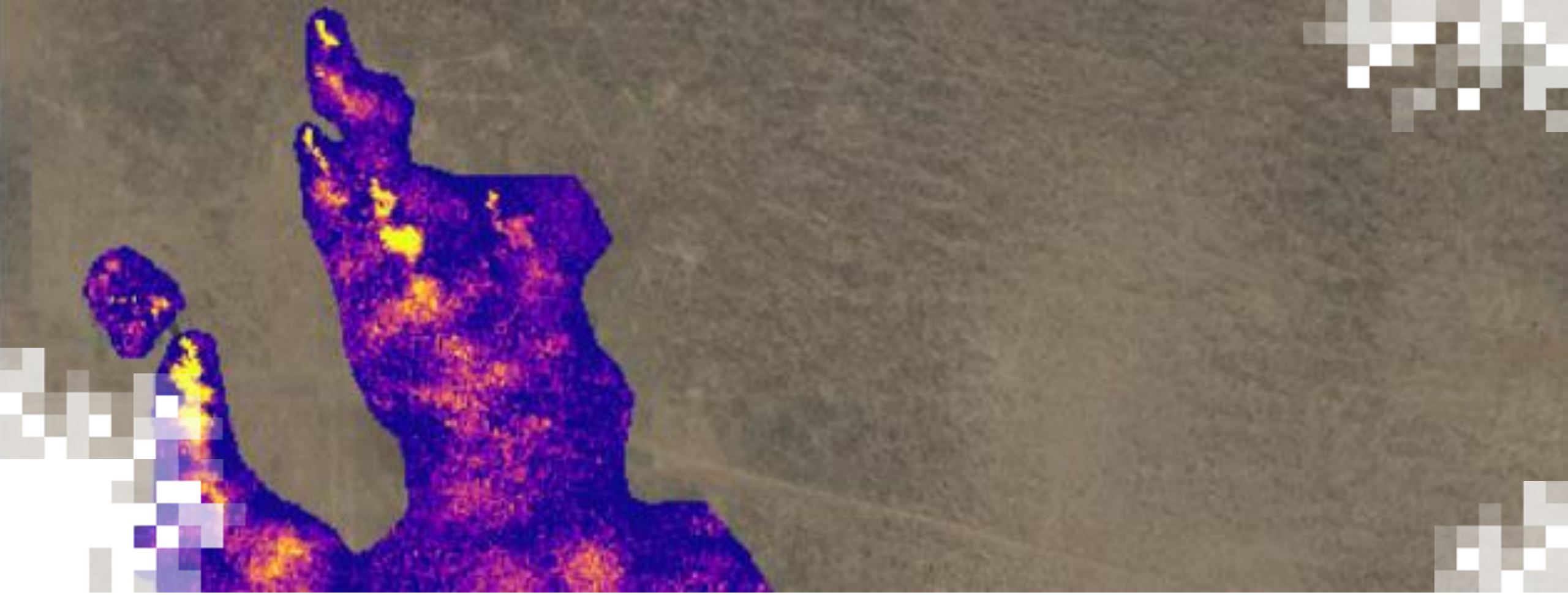
By the end of Part 1, participants will be able to:

- Identify the goals and objectives of the U.S. Greenhouse Gas Center
- Define the roles of methane and large emission events in climate change
- Identify what types of sensors can be used to measure methane

Image credit: Alan Levine

How to Ask Questions

- Please put your questions in the Questions box and we will address them at the end of the webinar.
- Feel free to enter your questions as we go. We will try to get to all of the questions during the Q&A session after the webinar.
- The remainder of the questions will be answered in the Q&A document, which will be posted to the training website about a week after the training.

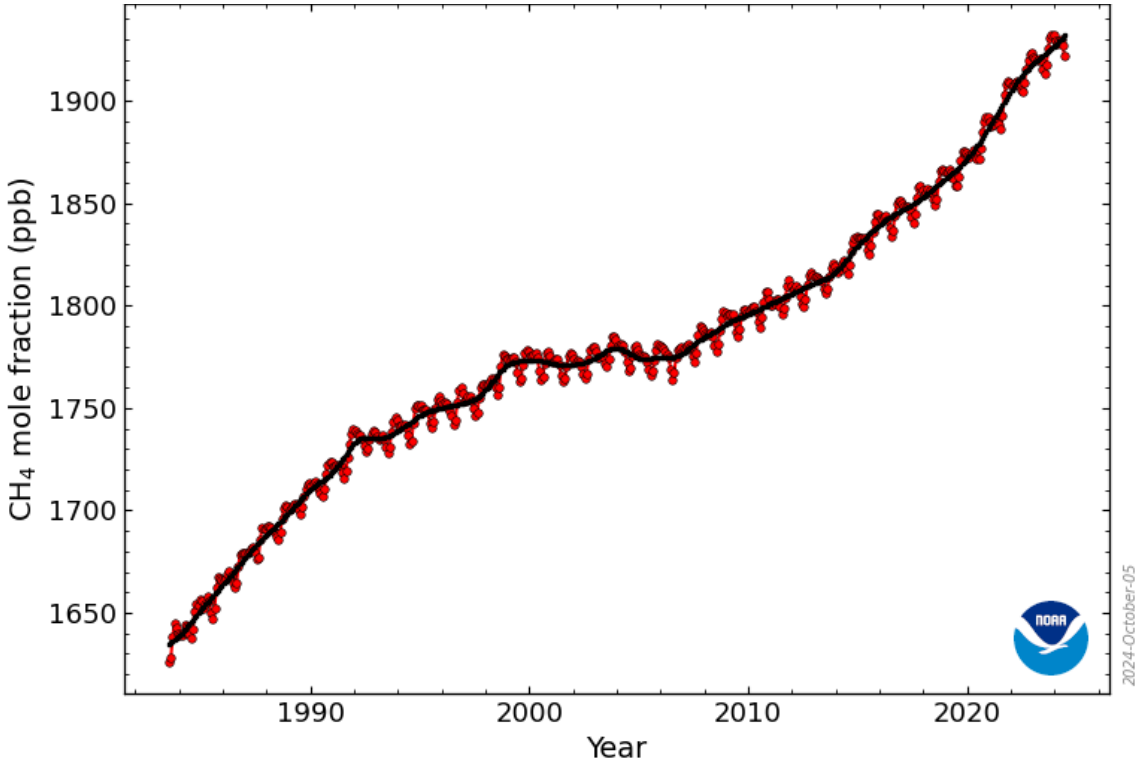


The Role of Methane in Greenhouse Gas Monitoring

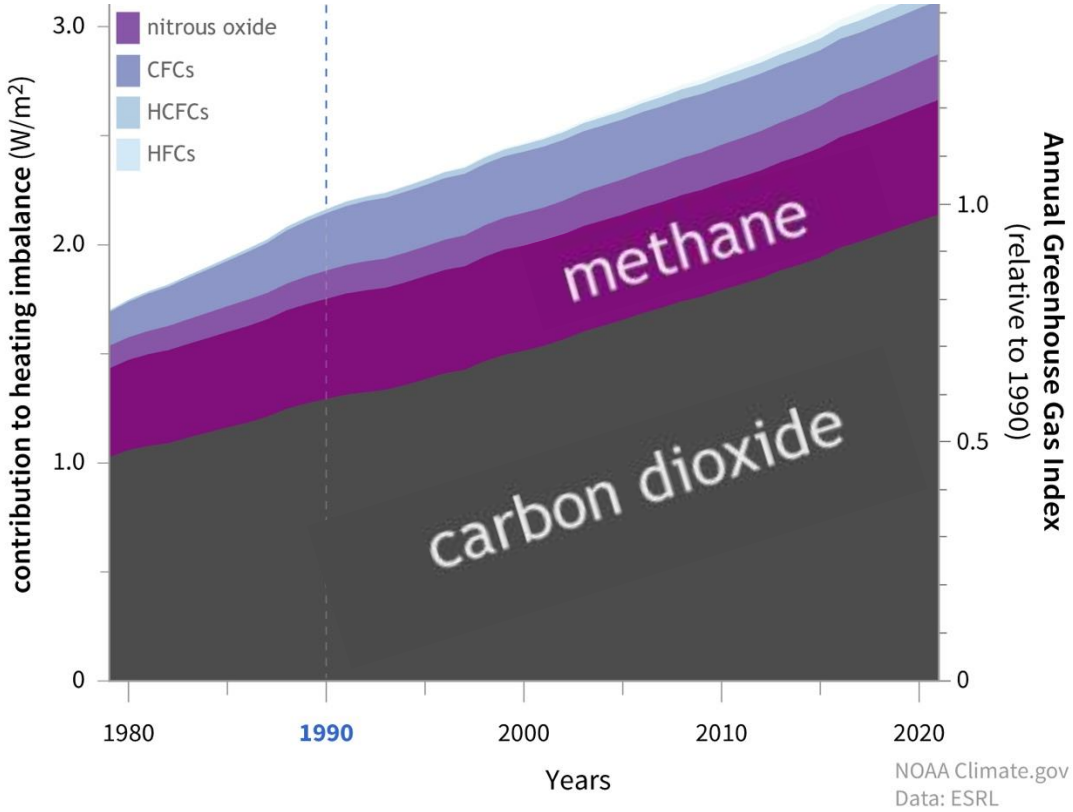
Why is methane important

Methane is a potent greenhouse gas and atmospheric concentrations continue to rise

Global average methane concentration – surface sites



Greenhouse gas combined contribution to warming



Why is methane important

Methane budgets have significant uncertainties and require more measurements

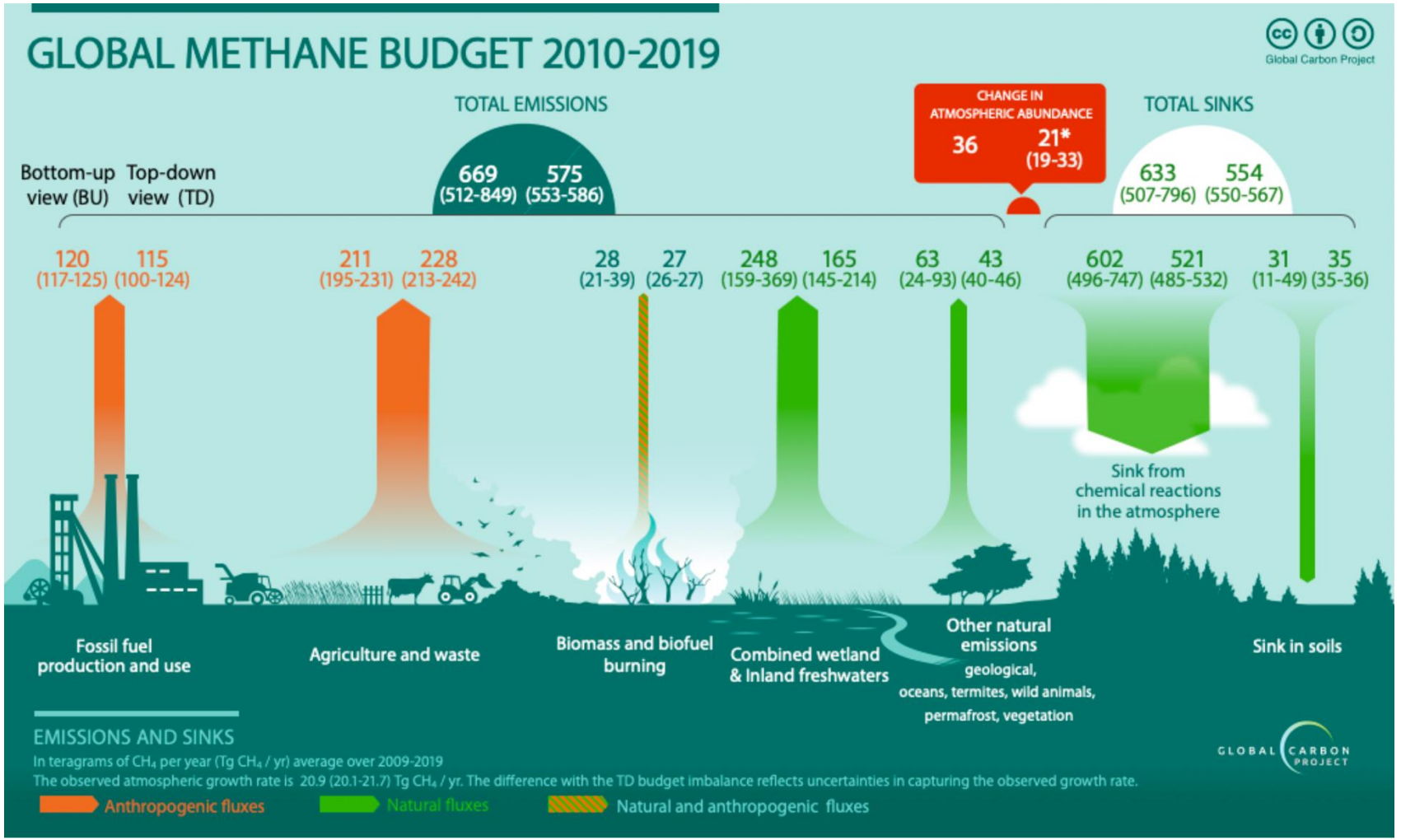


Image credit: Global Carbon Project

Why is methane important

Countries around the world are working to reduce methane emissions to limit warming.

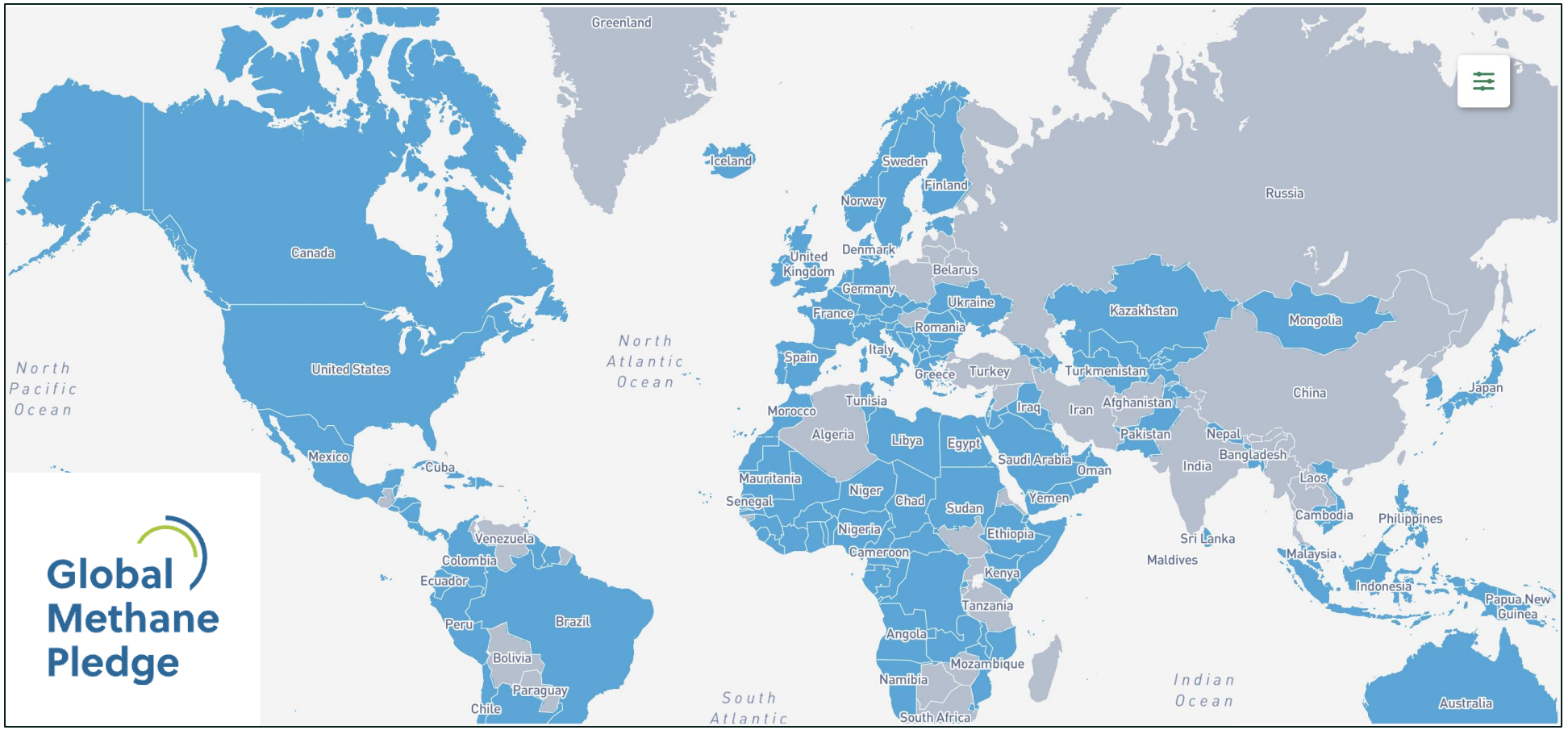
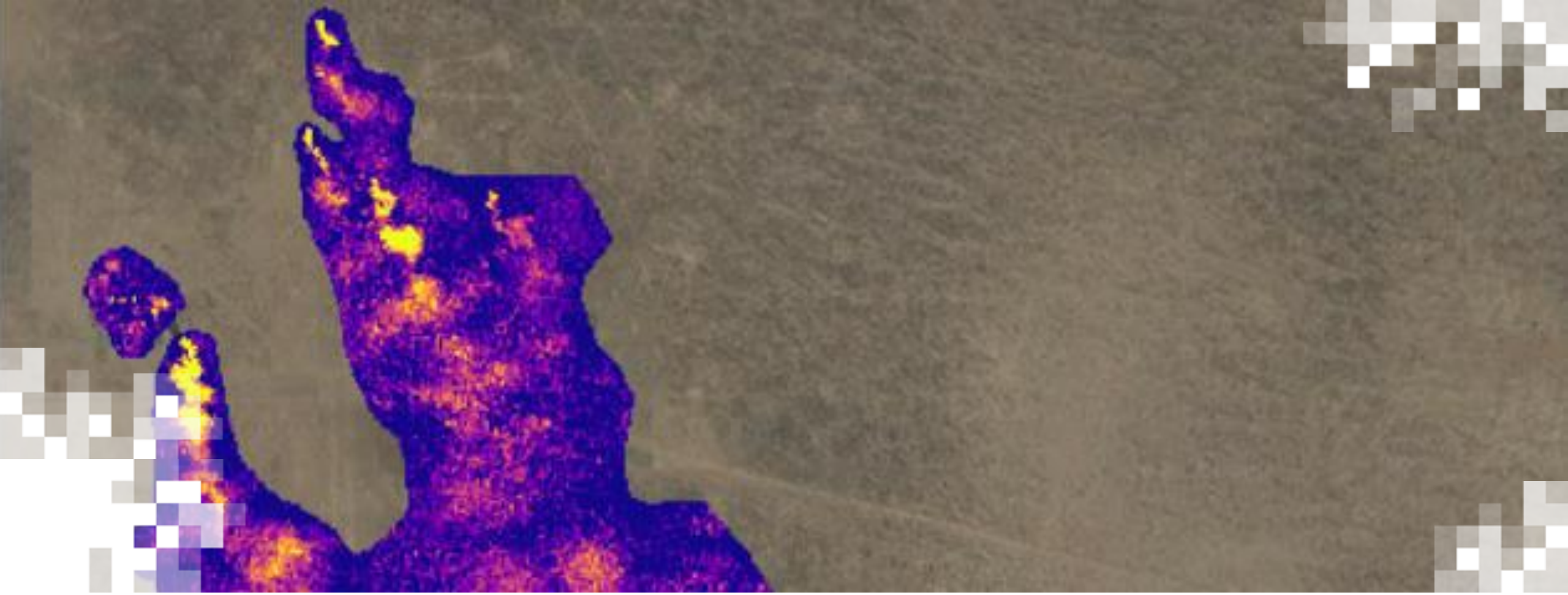


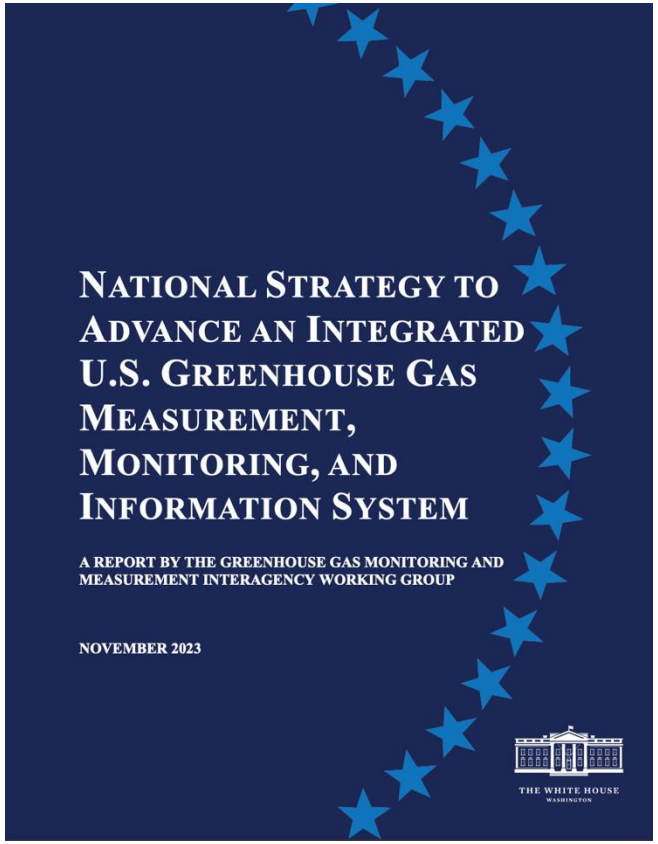
Image credit: Global Methane Pledge



Introduction to the US Greenhouse Gas Center

What is the U.S. Greenhouse Gas Center?

From the National Strategy to Advance an Integrated U.S. Greenhouse Gas Measurement, Monitoring, and Information System:



The U.S. GHG Center, initially led by NASA, EPA, NIST, and NOAA, will **facilitate coordination** across federal and non-federal, domestic, and international entities to **integrate and enhance GHG data and modeling capabilities** from the USG and non-USG sources for **scalable impact**.

What is the U.S. Greenhouse Gas Center?

Virtuous Cycle
- User needs inform refinement of tools, products

Public Understanding & Exchange
- Coordinated communications, outreach
- Workforce, educational initiatives
- Earth Information Center – interactive events

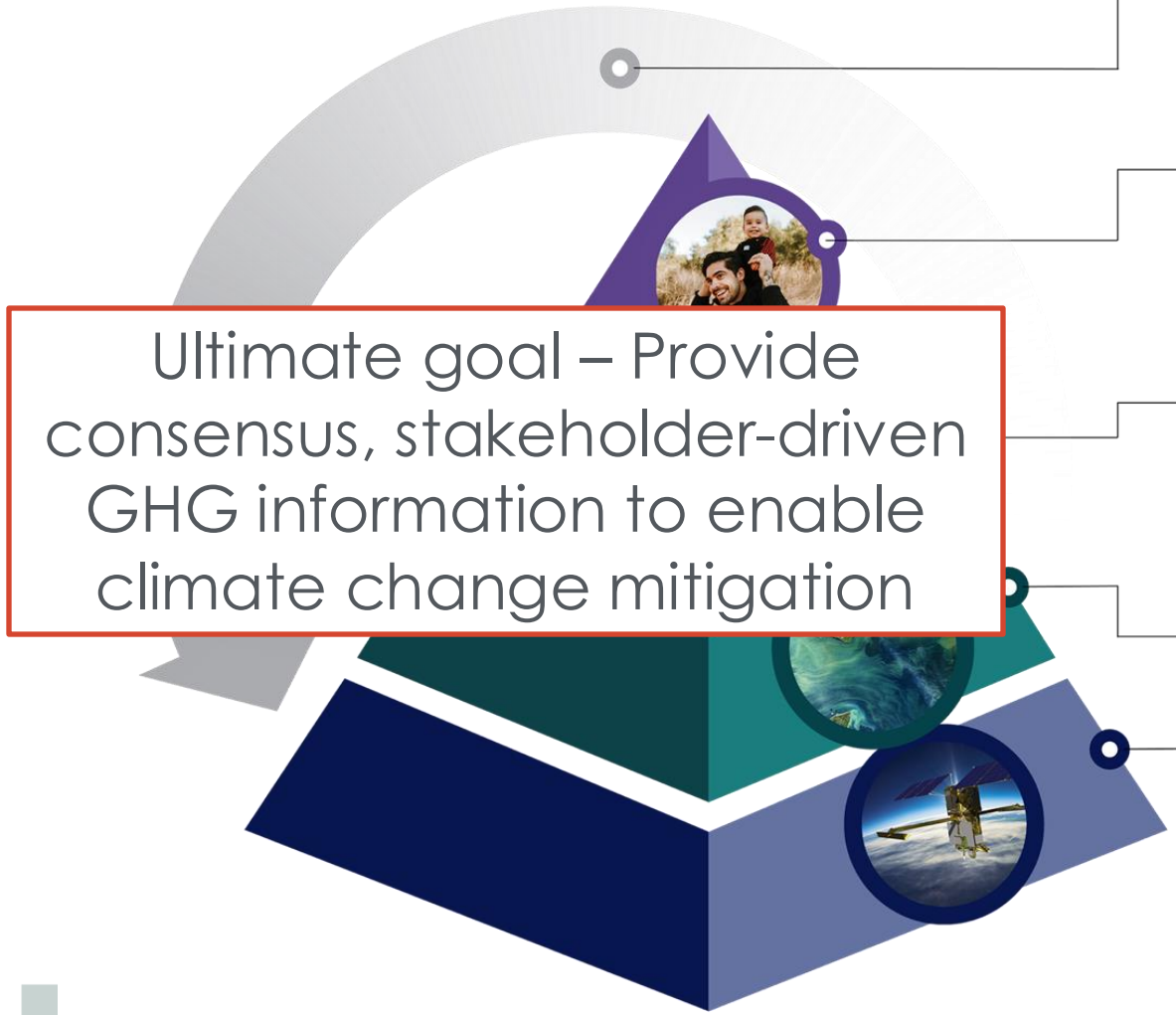
Solutions & Societal Value
- Stakeholder engagement
- Development of user-driven GHG tools/data portal
- Trust through open science principles

Earth System Science & Applied Research
- Quasi-operational GHG modeling
- Standardized model evaluation, methods for providing consensus estimates
- Interagency modeling strategy and coordination

Foundational Knowledge, Technology, Missions, & Data
- Coordination and evaluation of satellite data
- Ground network coordination and standards
- Expanded airborne measurements and coordination

Cross-cutting: Alignment with stakeholder needs, interagency coordination, open science, and inclusivity

What is the U.S. Greenhouse Gas Center?



Ultimate goal – Provide consensus, stakeholder-driven GHG information to enable climate change mitigation

Outreach	Outreach	Outreach	Outreach
Tools OCO portal EMIT portal GMAO site ...	**Tools** GHGRP (facility scale) GHGI data and	**Tools** GHG website Urban testbed website	**Tools** OCOMIP site CarbonTracker site ...
Models GMAO CMS-Flux GISS Model-E Land, ocean	**Models** CMAQ Activity models Exposure models	**Models** WRF-STILT inversions VPRM Hestia* (NALI)	**Models** CarbonTracker CT-Lagrange HYSPLIT Land, ocean
Observations OCO-2, 3 EMIT ... Ground-based remote sensing	**Observations** Stack monitoring Ground stations (AQ) Research	**Observations** Urban Testbeds Low cost sensors Airborne	**Observations** GGGRN Airborne (research) monitoring, CrIS

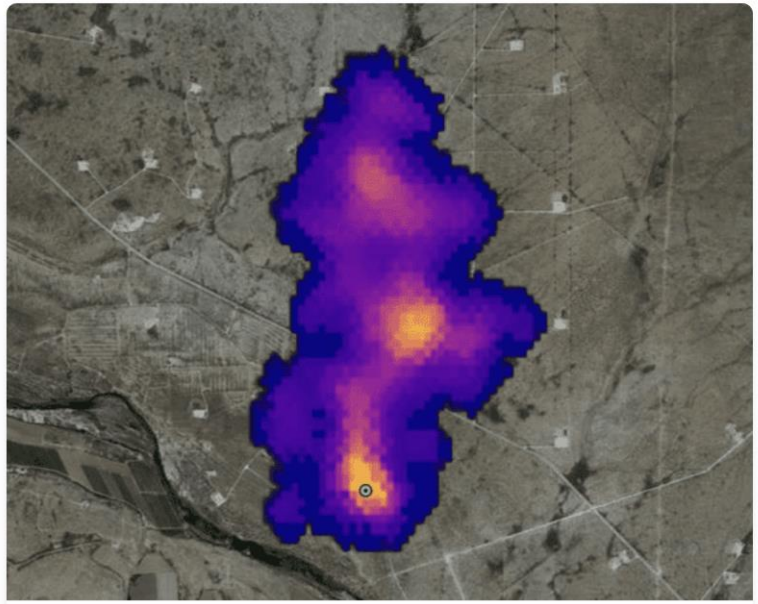
US GHG Center: Methane information across different scales

Gridded Anthropogenic Greenhouse Gas Emissions

Emission estimates from human activities including the energy, agriculture, waste and industry sectors.

Natural Greenhouse Gas Sources and Sinks

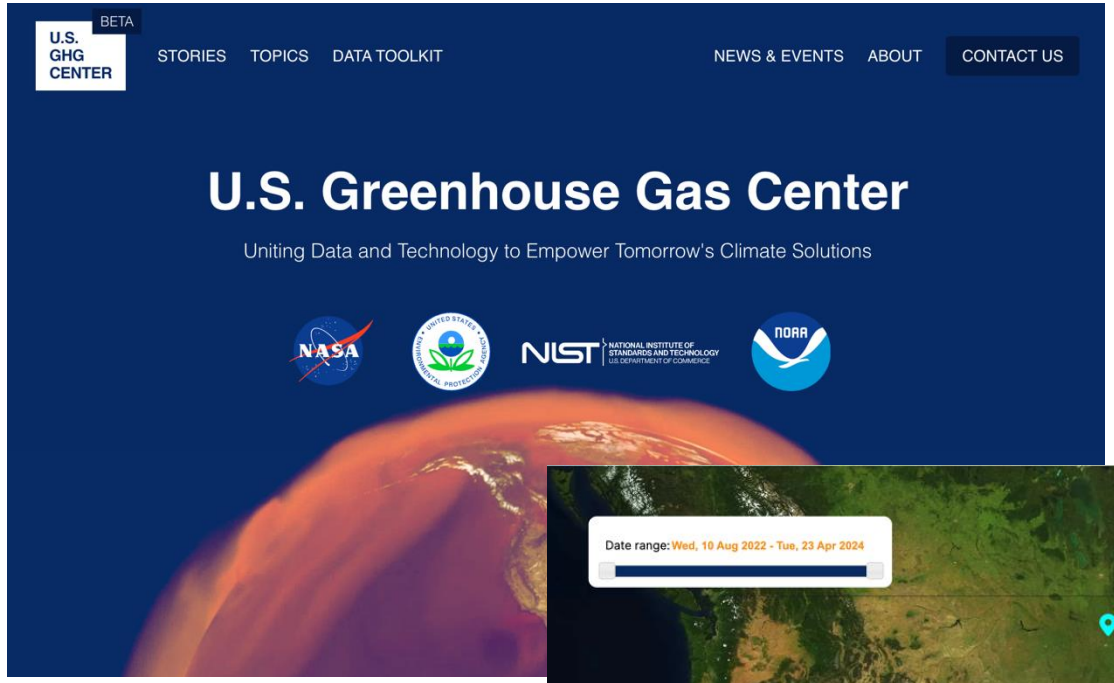
Naturally-occurring greenhouse gas fluxes from land, ocean, and atmosphere.

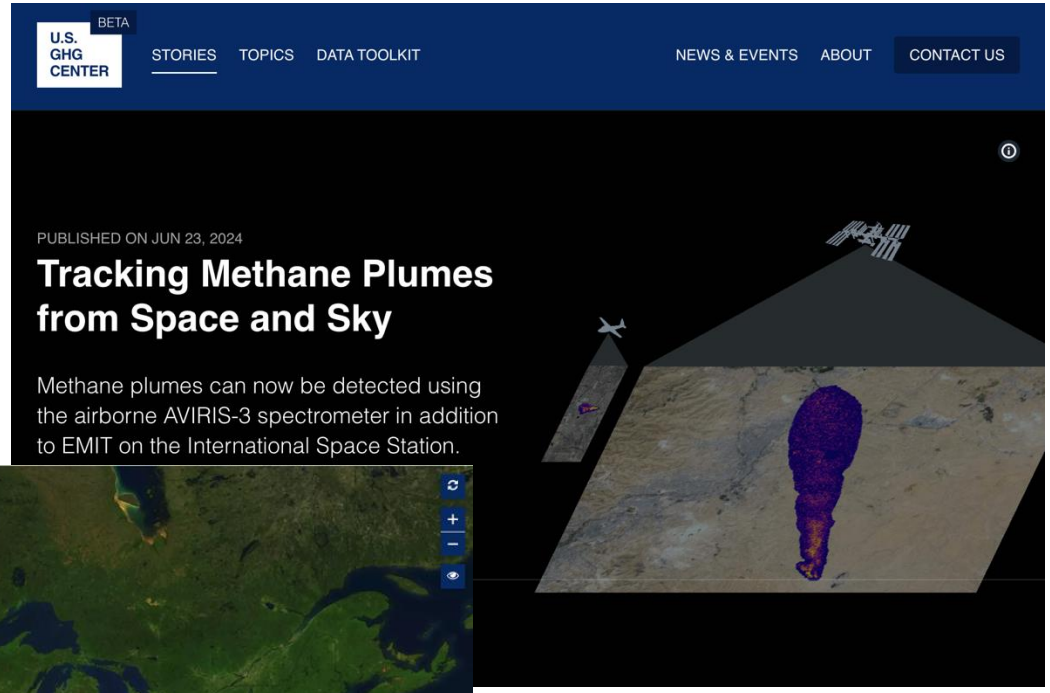


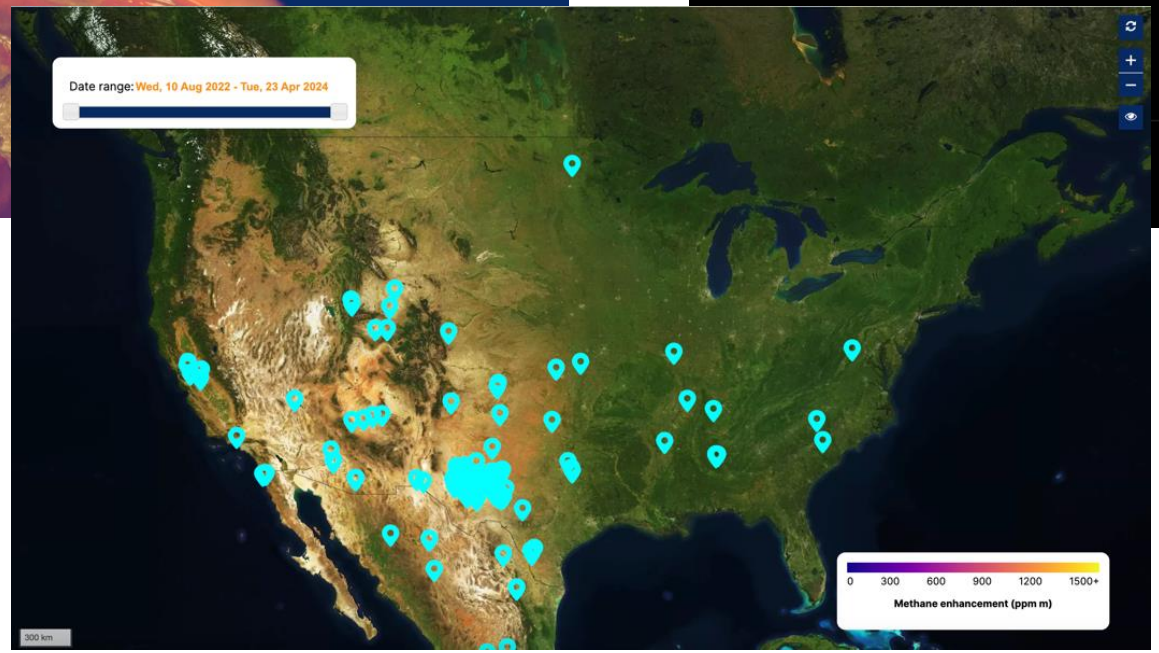
New Observations for Tracking Large Emission Events

Identify and quantify large methane leak events leveraging aircraft and space-based data.

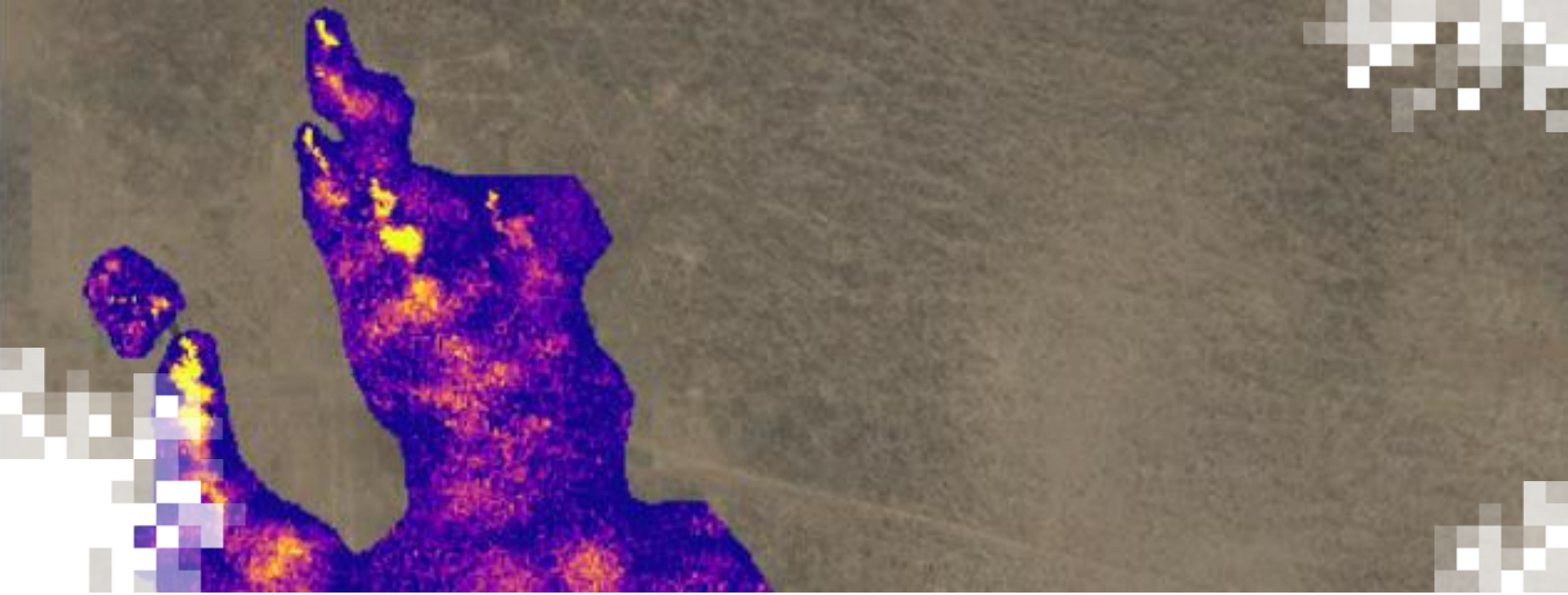
Tracking large emission events





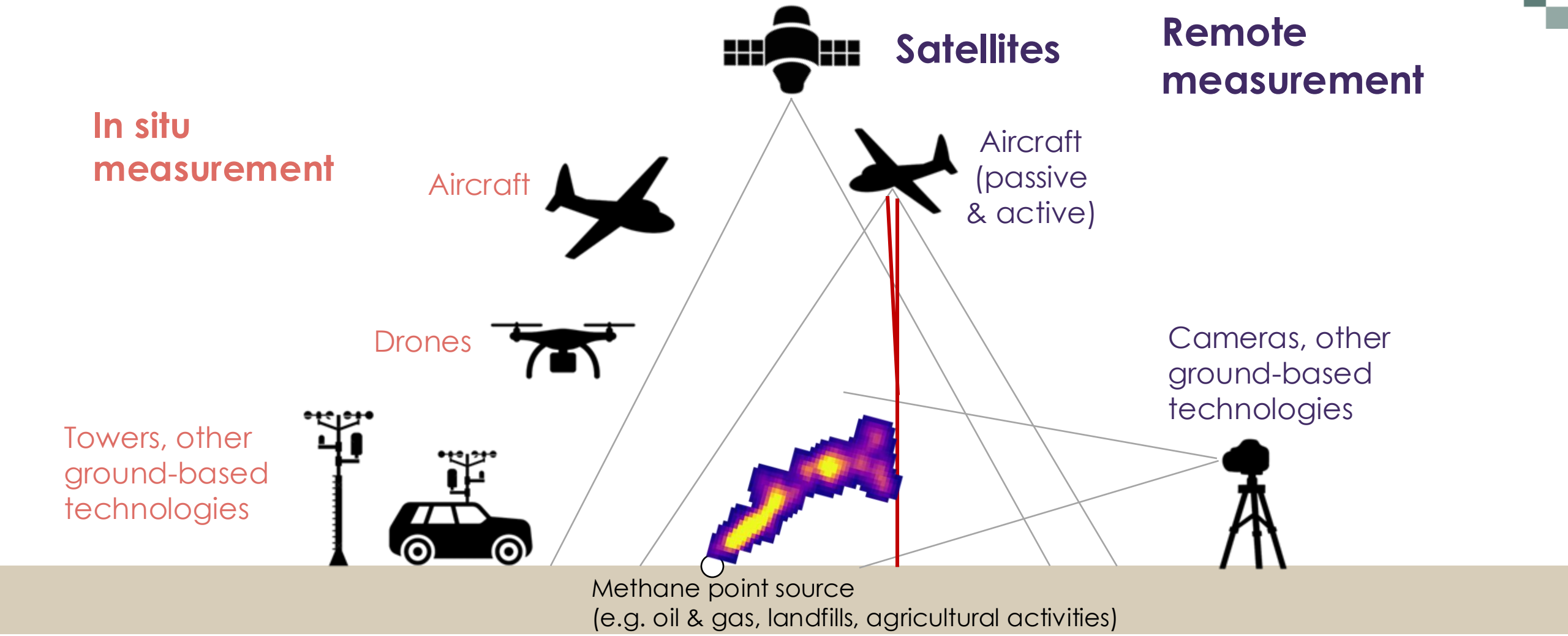


Currently visualizing EMIT methane plumes, will soon host airborne and other spaceborne datasets.

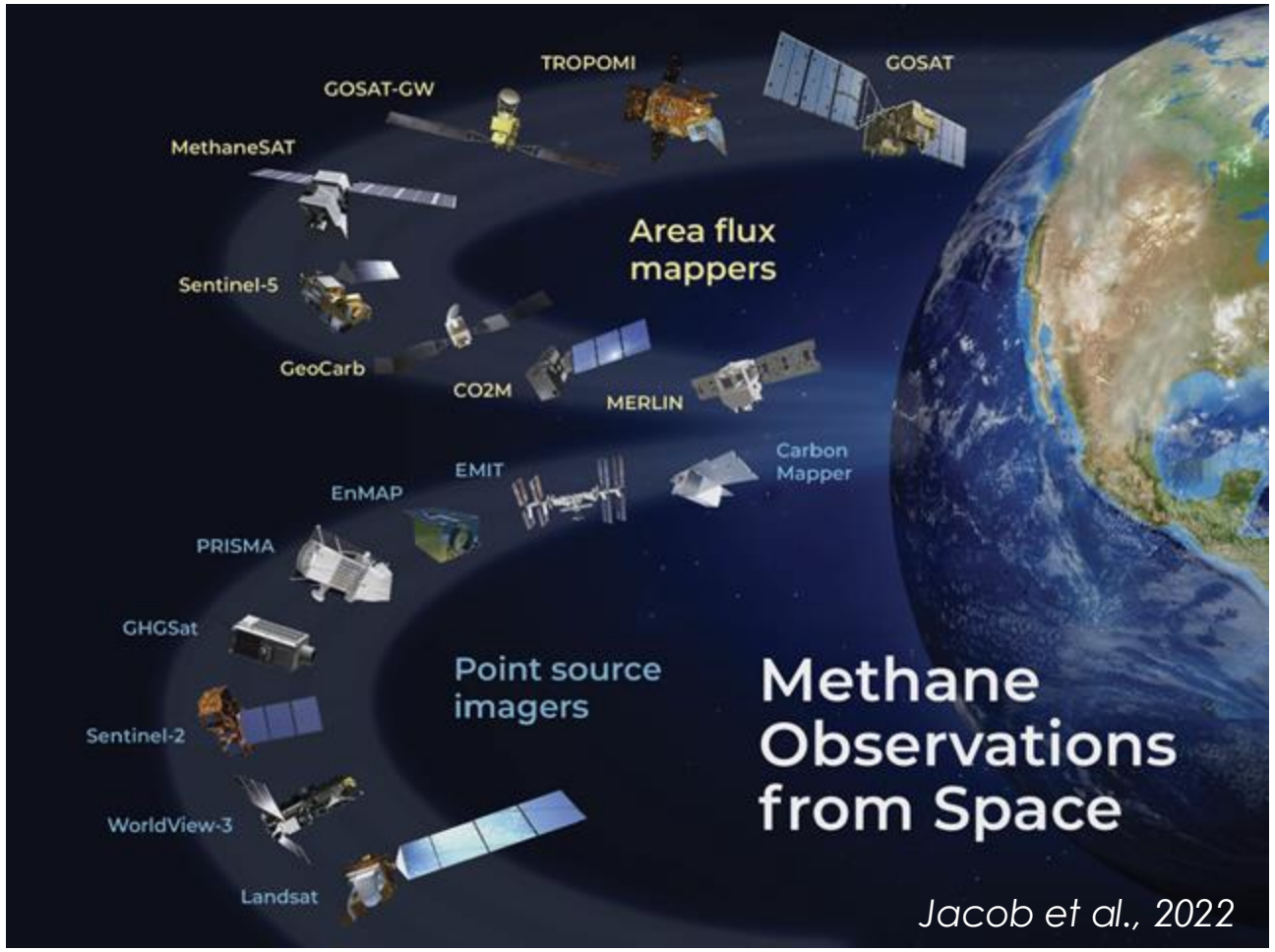


Satellite Observations of Methane

Technologies to Detect Point Sources



Satellite Measurements of Methane

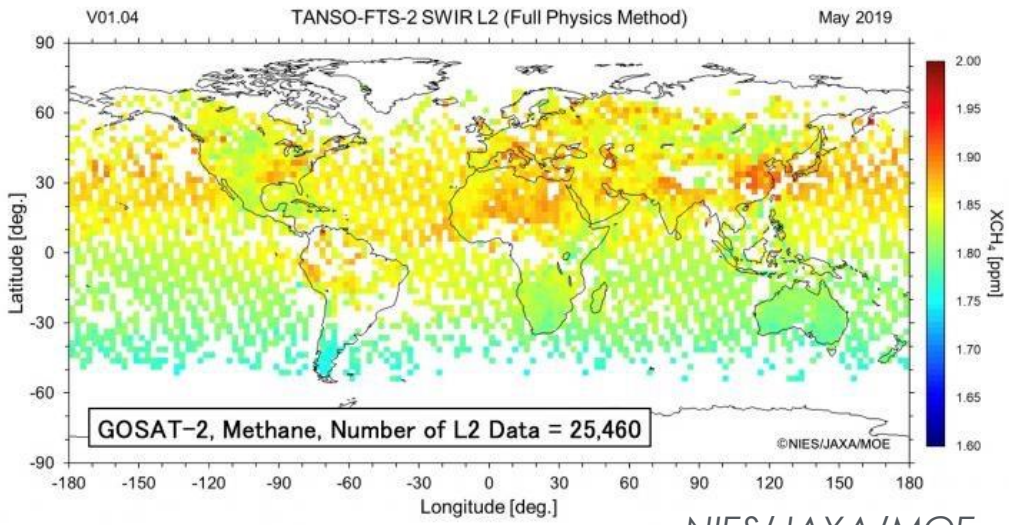


Area Flux Mappers

- Coarse spatial resolution (km scale image pixels)
- Best suited for mapping global methane gradients

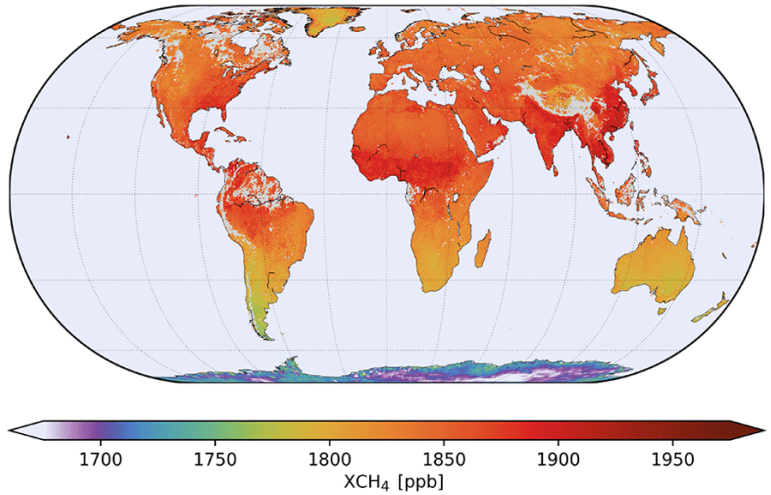
Jacob et al., 2022

GOSAT-2 (10.5 km diameter measurement)



NIES/JAXA/MOE

TROPOMI (5.5 km × 3.5 km image pixels with global mapping each day)

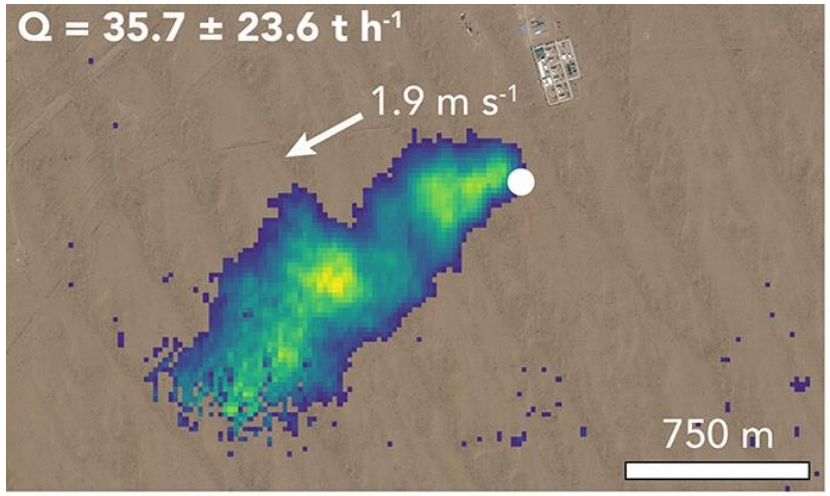


Lorente et al., 2021

Point Source Imagers

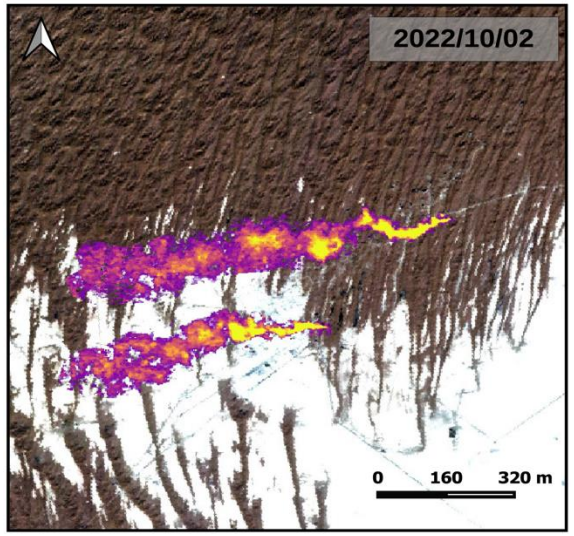
- Fine spatial resolution (m scale image pixels)
- Ideal for identifying distinct methane point sources

GHGSat (30 m × 30 m image pixels, 12 km x 12 km scenes)



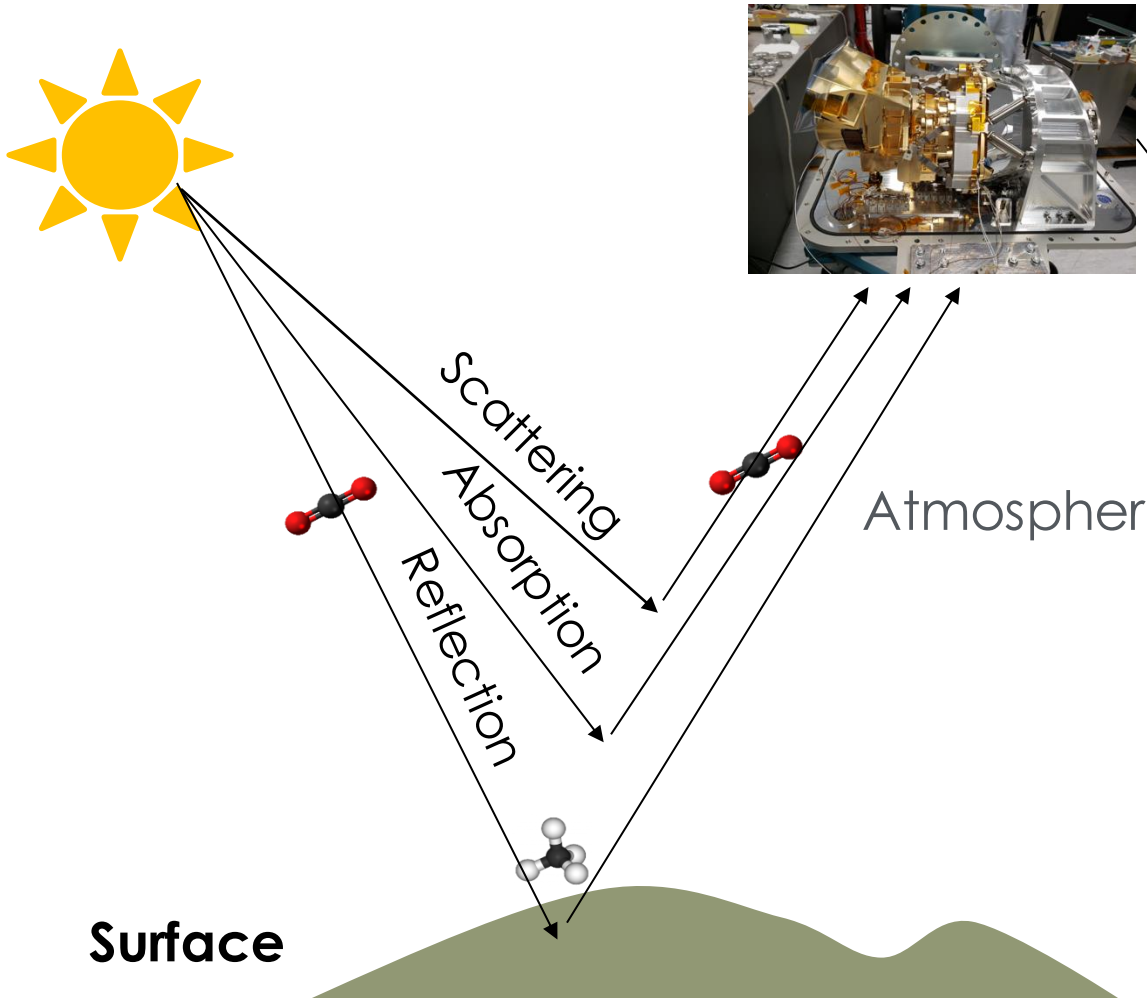
Varon et al., 2019

EnMAP (30 m × 30 m image pixels, 30 km image swath)



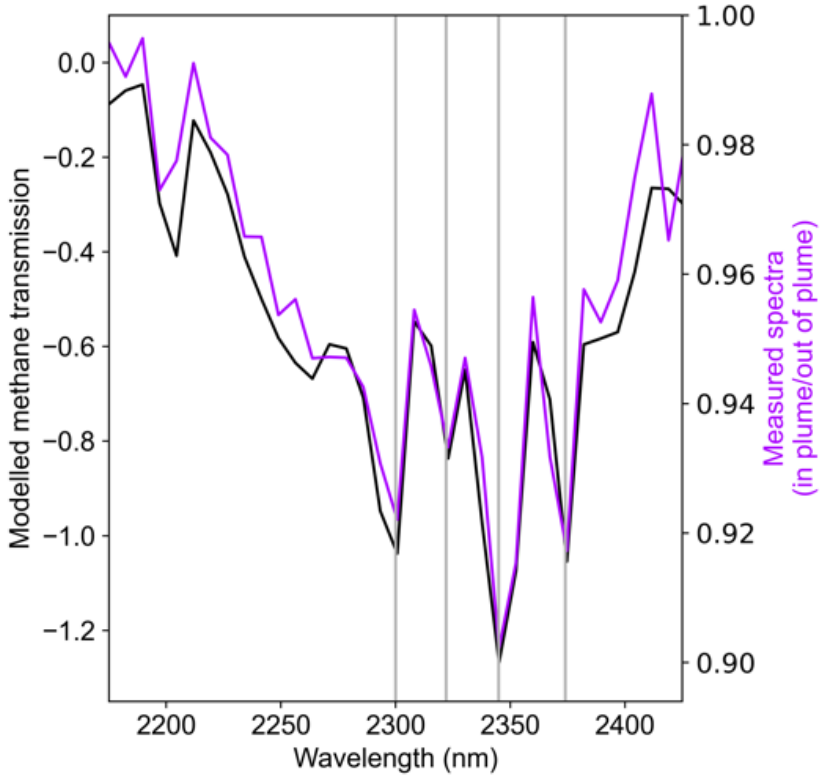
Roger et al., 2024

Mapping Methane Point Source Emissions



NASA/JPL imaging spectrometer

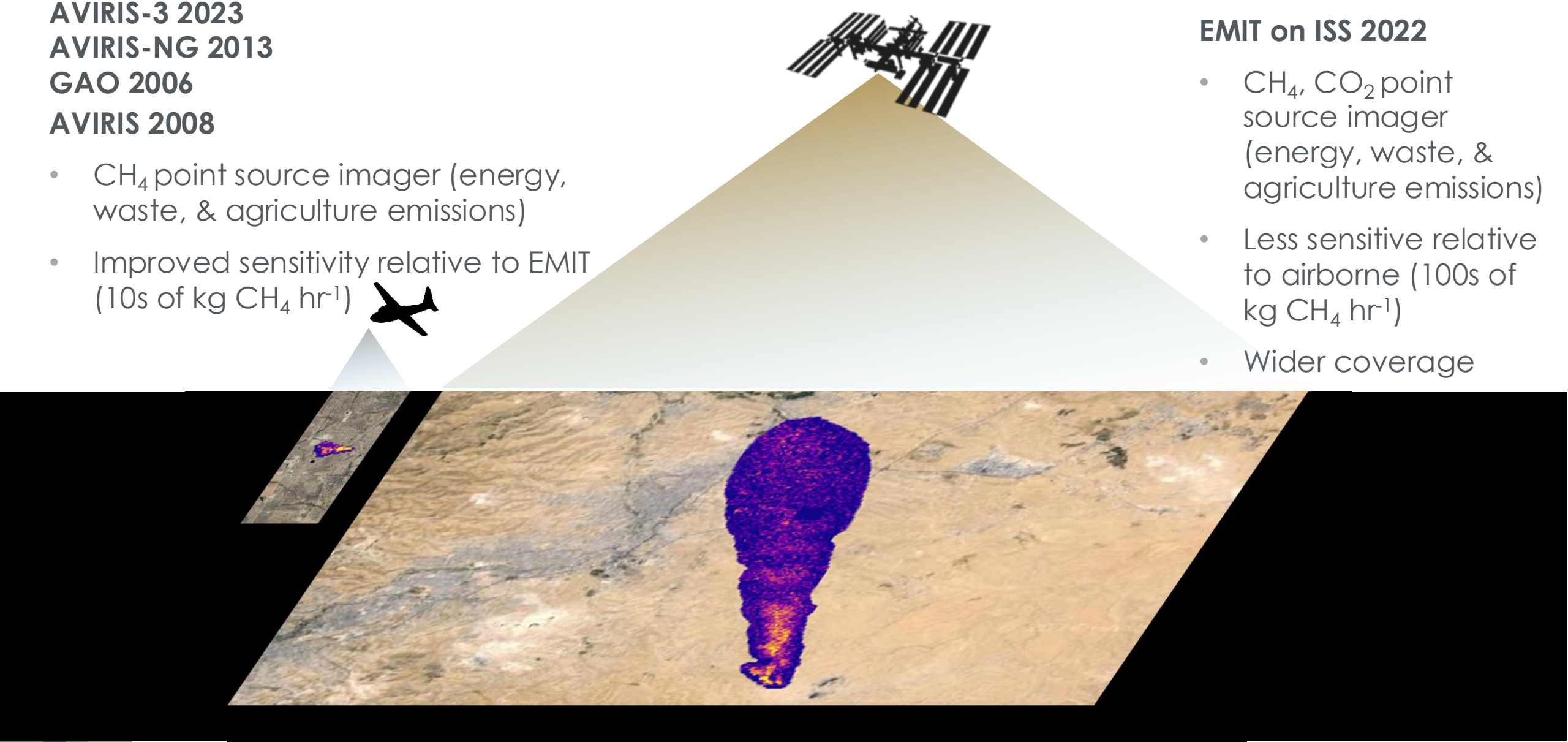
Methane spectral fingerprint



Airborne Imaging Spectrometers Enabled Future Observations from Space

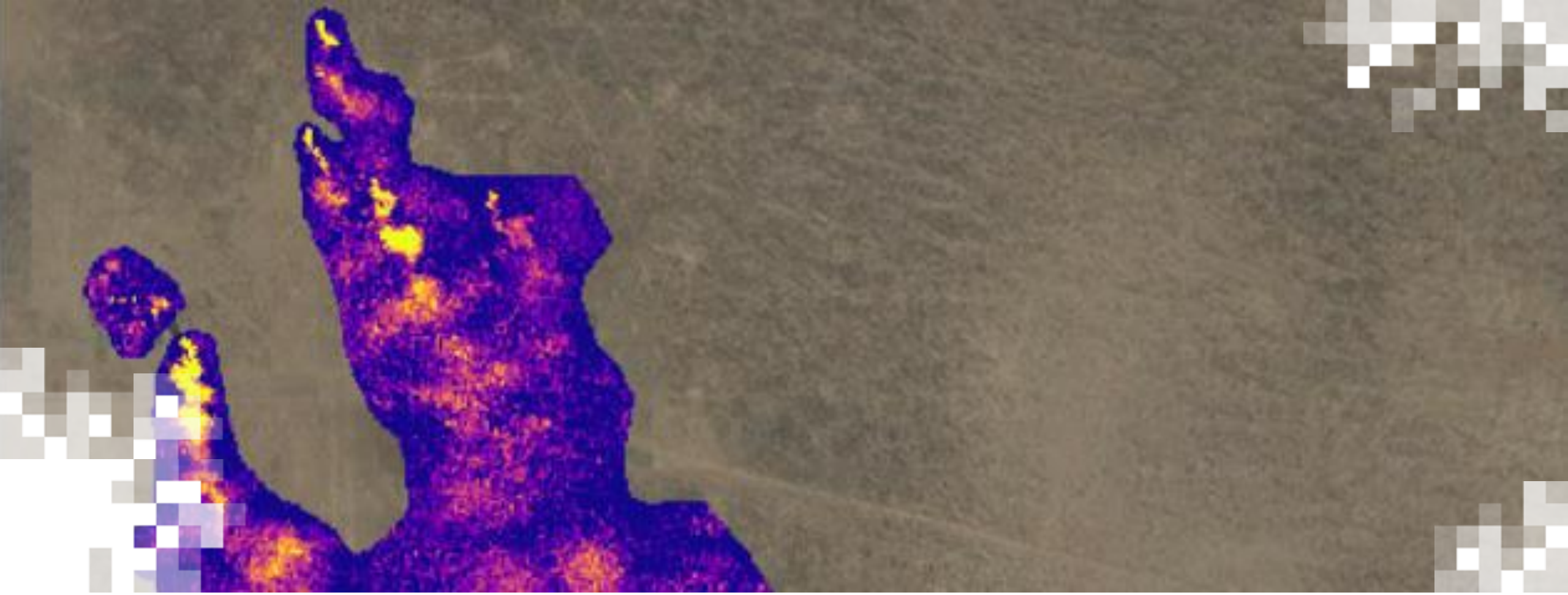
AVIRIS-3 2023
AVIRIS-NG 2013
GAO 2006
AVIRIS 2008

- CH_4 point source imager (energy, waste, & agriculture emissions)
- Improved sensitivity relative to EMIT (10s of kg CH_4 hr^{-1})



EMIT on ISS 2022

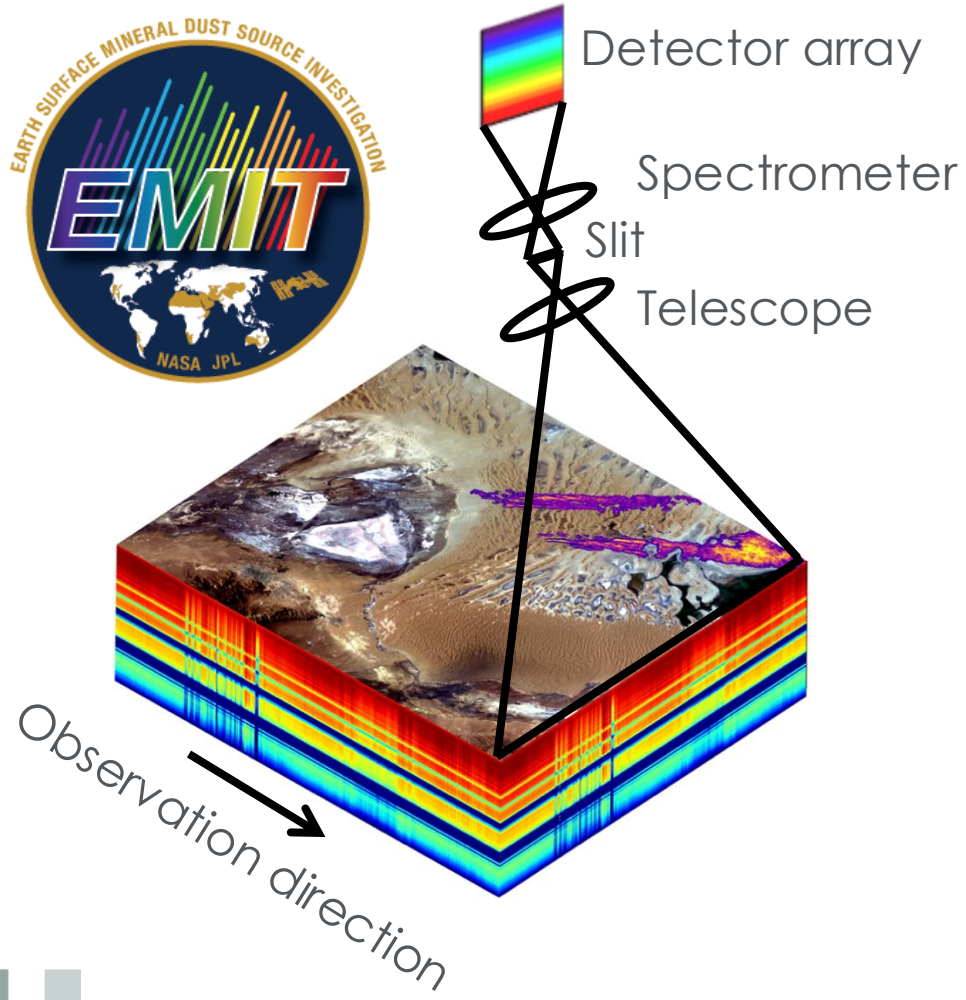
- CH_4, CO_2 point source imager (energy, waste, & agriculture emissions)
- Less sensitive relative to airborne (100s of kg CH_4 hr^{-1})
- Wider coverage



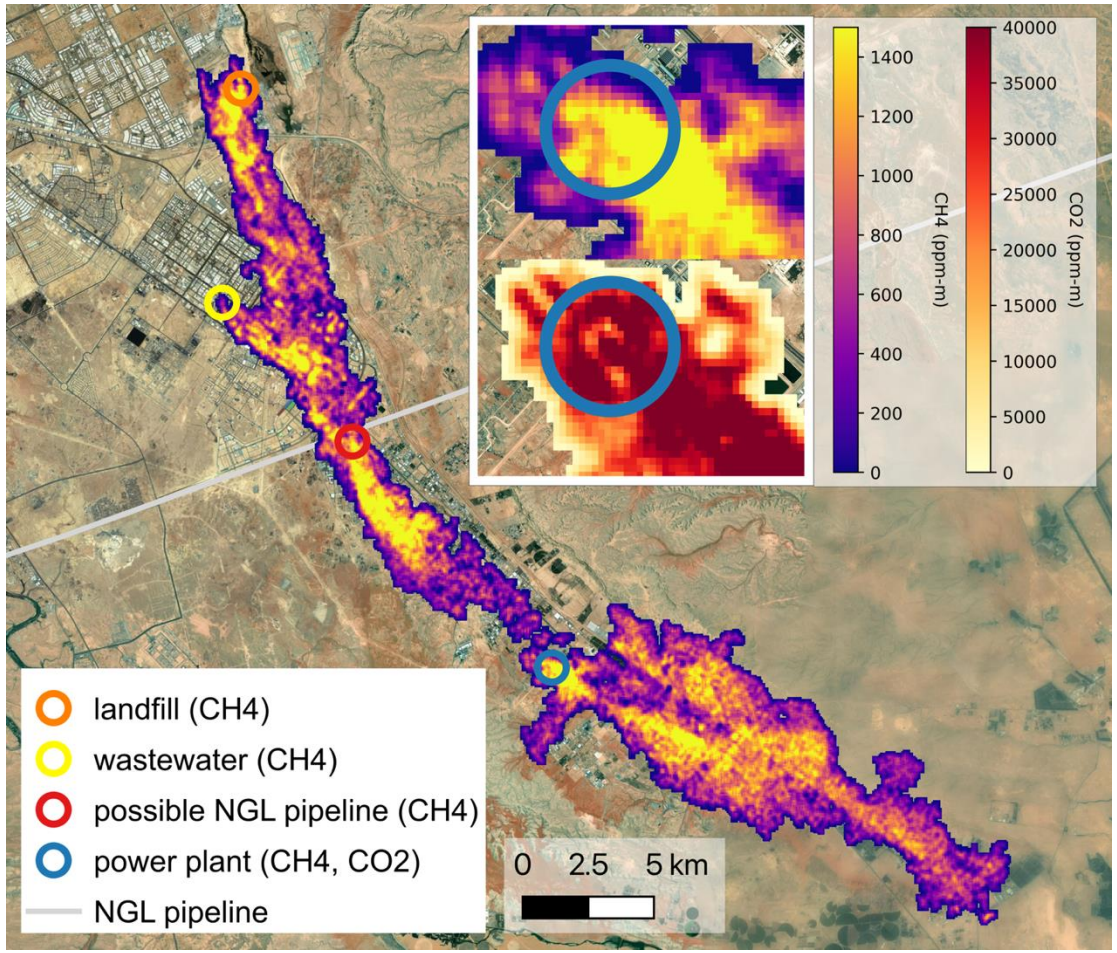
EMIT Observations for Methane Point Source Detection

Identifying, Quantifying, and Attributing Methane Point Source Emissions

Imaging spectrometer



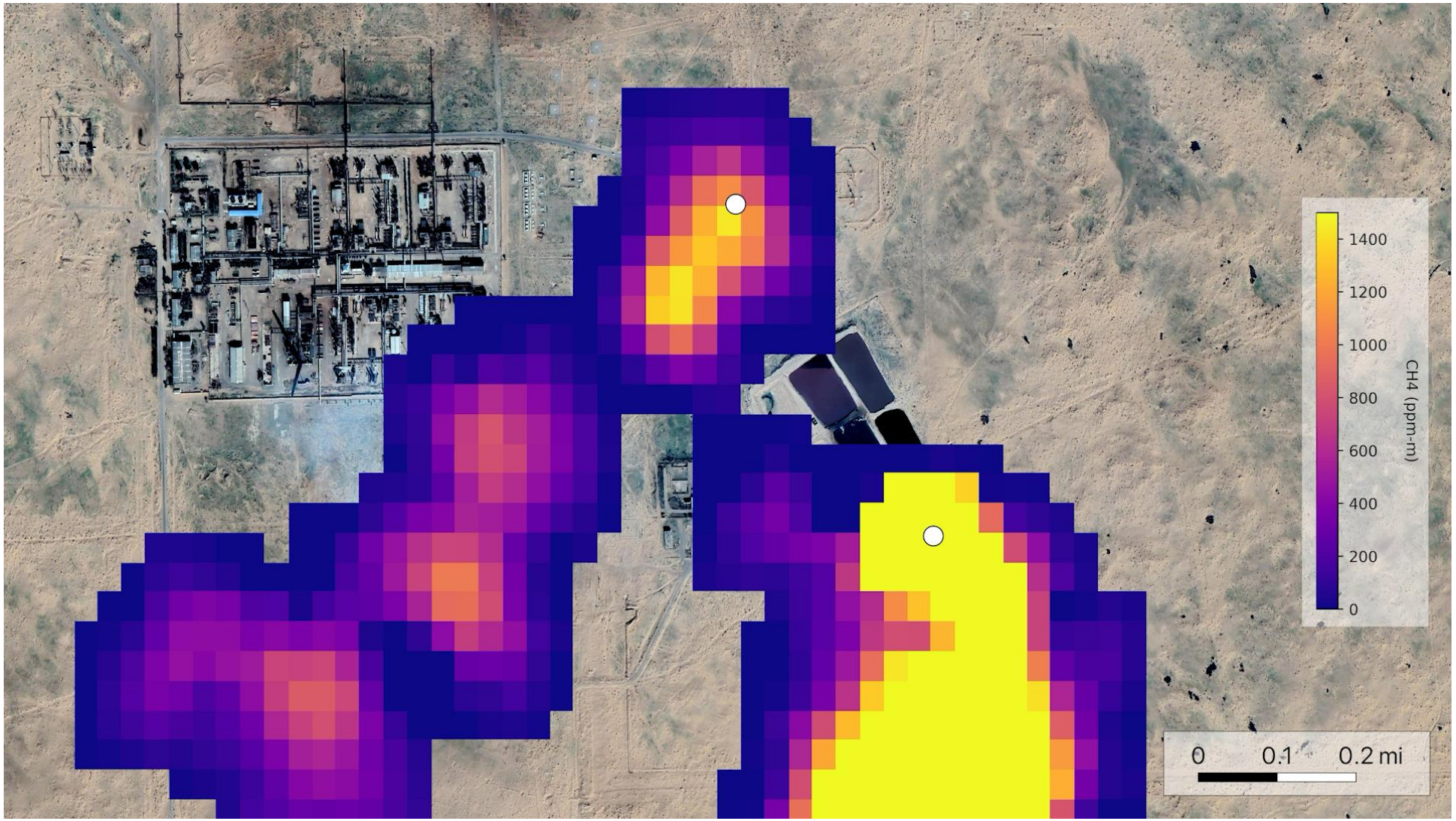
Attribution of emissions by sector



Thorpe et al., 2023

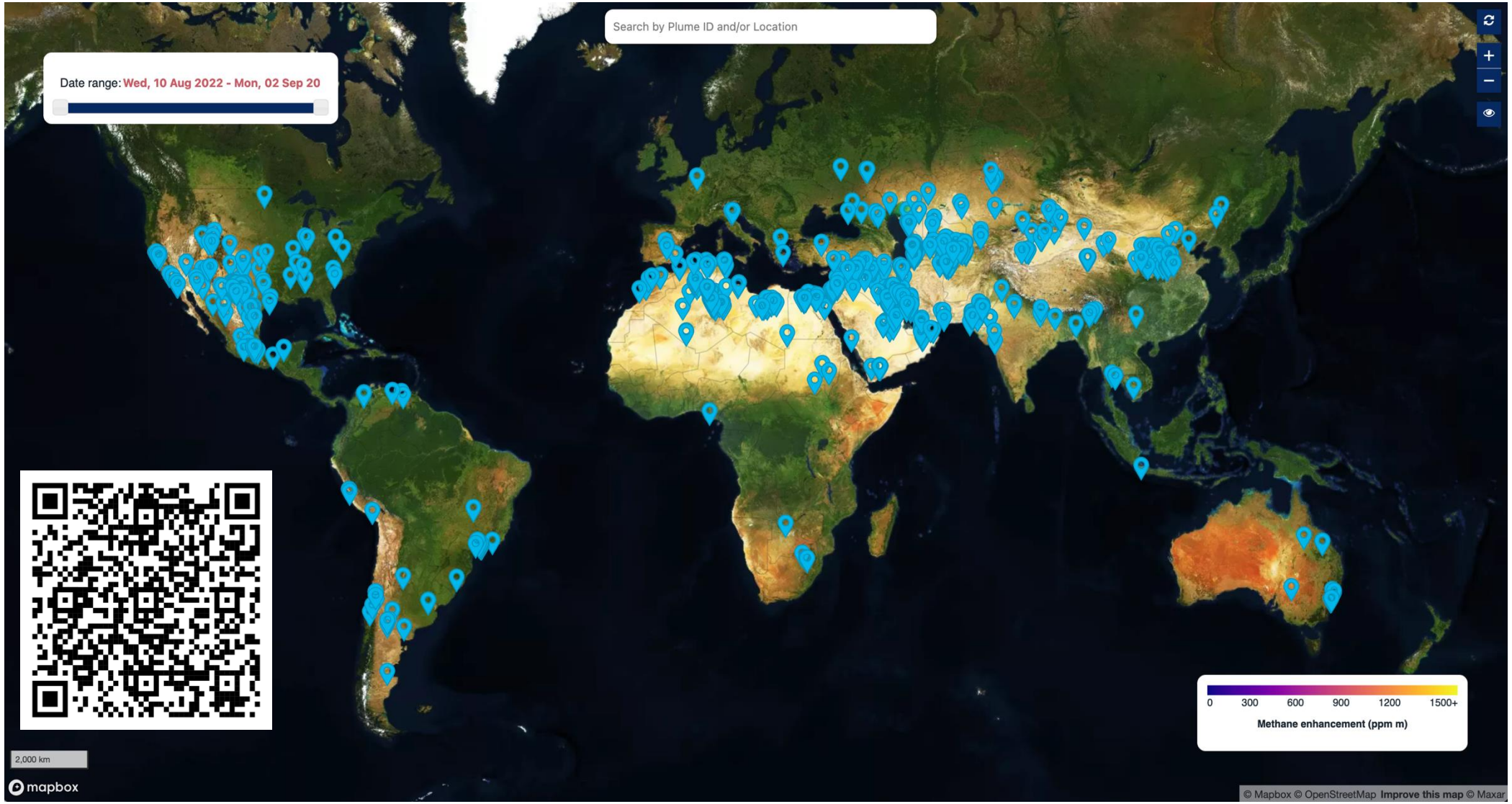
EMIT Methane Observations Provide Key Information

Locate methane sources

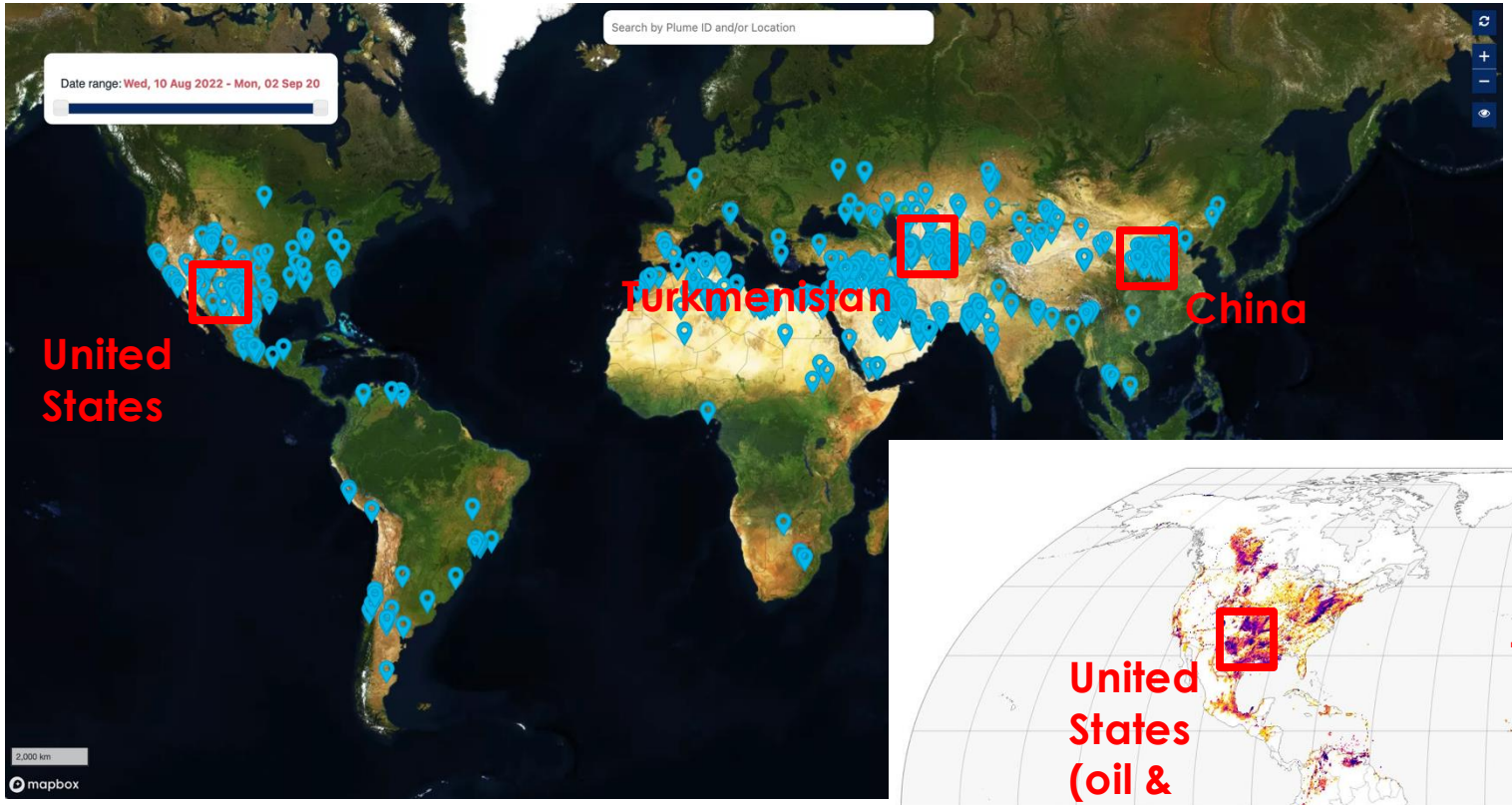


Sharing results can lead to emission mitigation

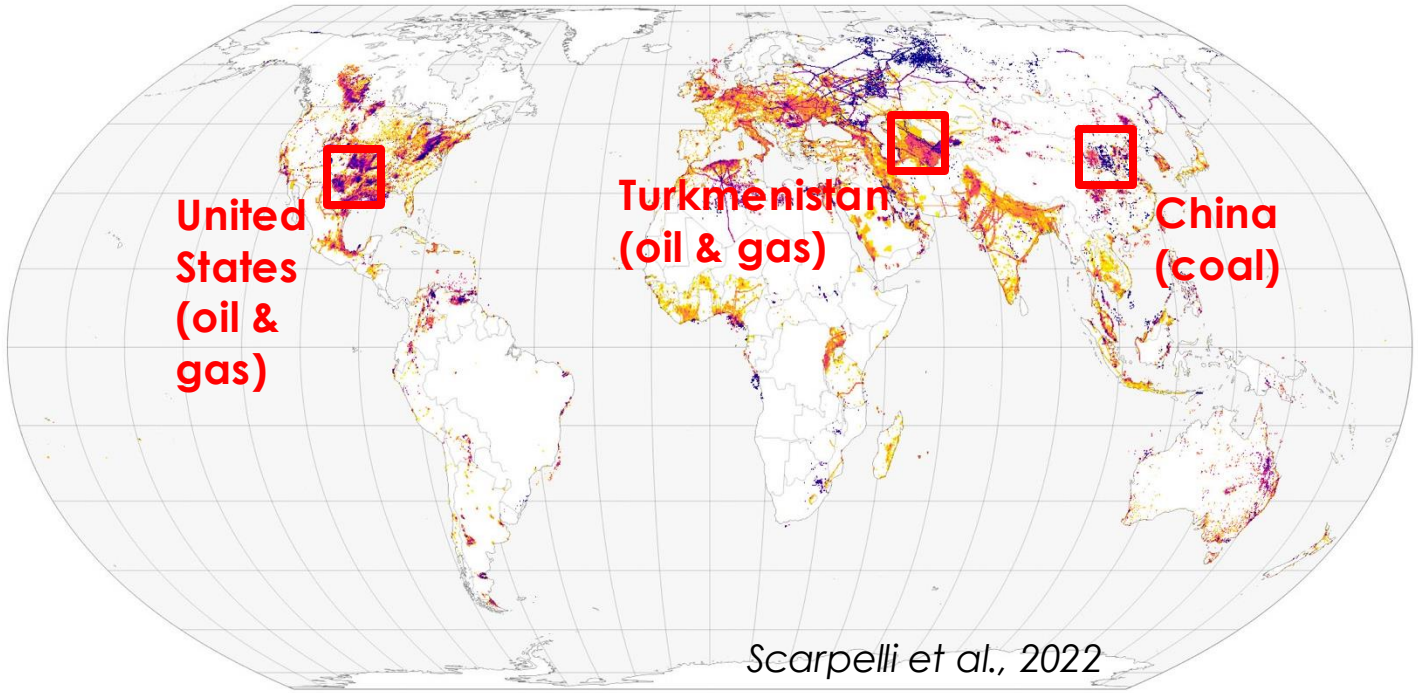
Methane Plumes Observed with EMIT



Distribution of Observed EMIT Methane Plumes (top down)



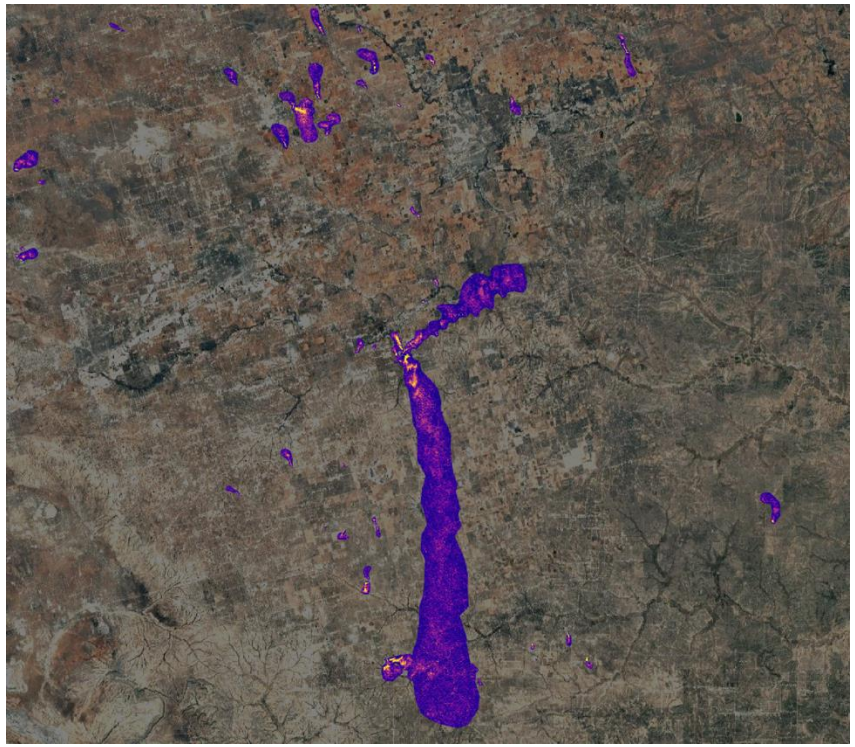
Correlated with estimated methane emissions from fossil fuel exploitation (bottom up)



Scarpelli et al., 2022

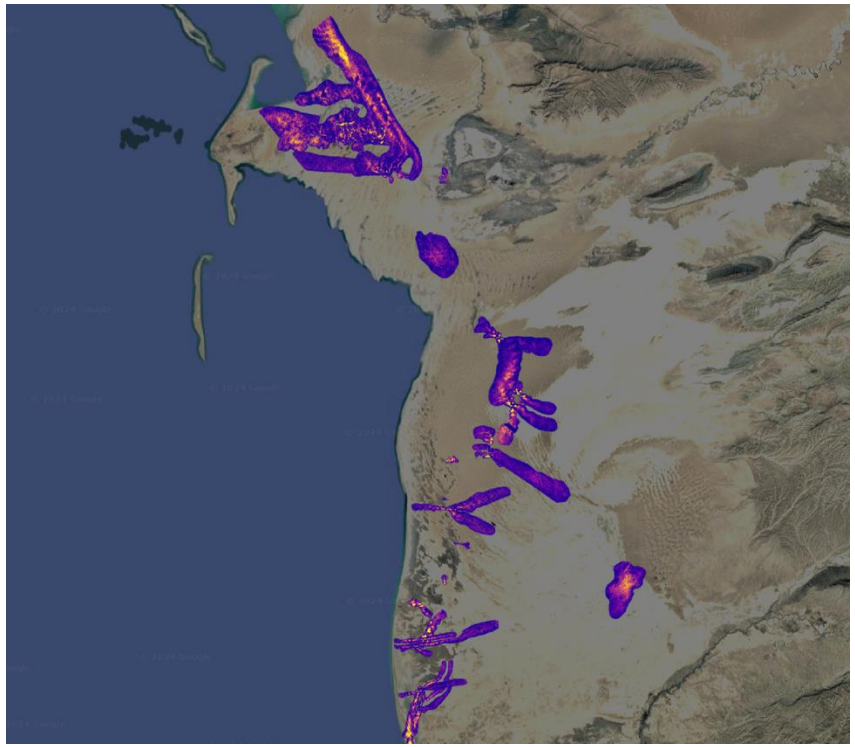
EMIT Methane Emissions from Fossil Fuel Sector

United States (oil & gas)



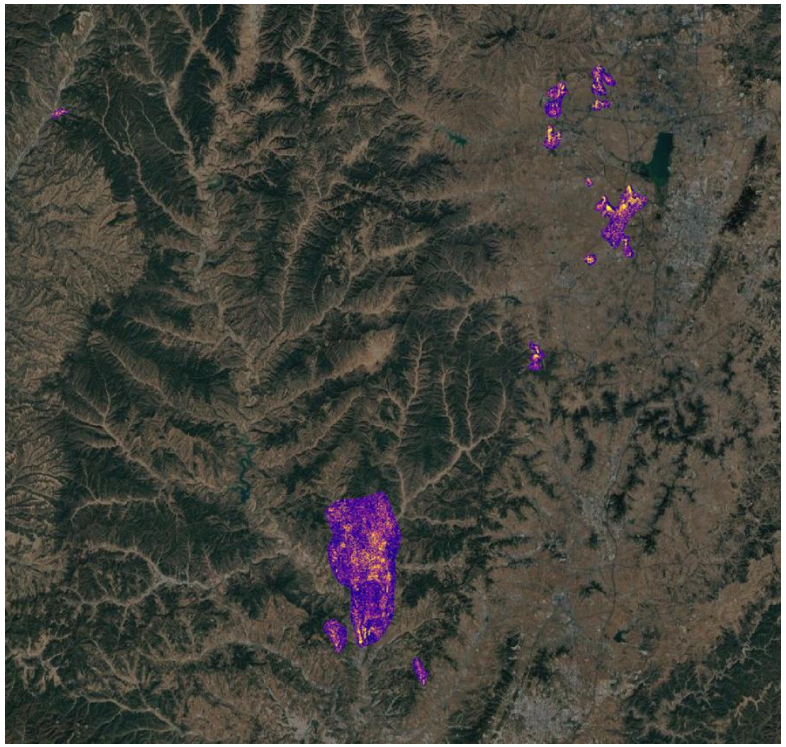
~100 km x ~100 km

Turkmenistan (oil & gas)



~200 km x ~200 km

China (coal)

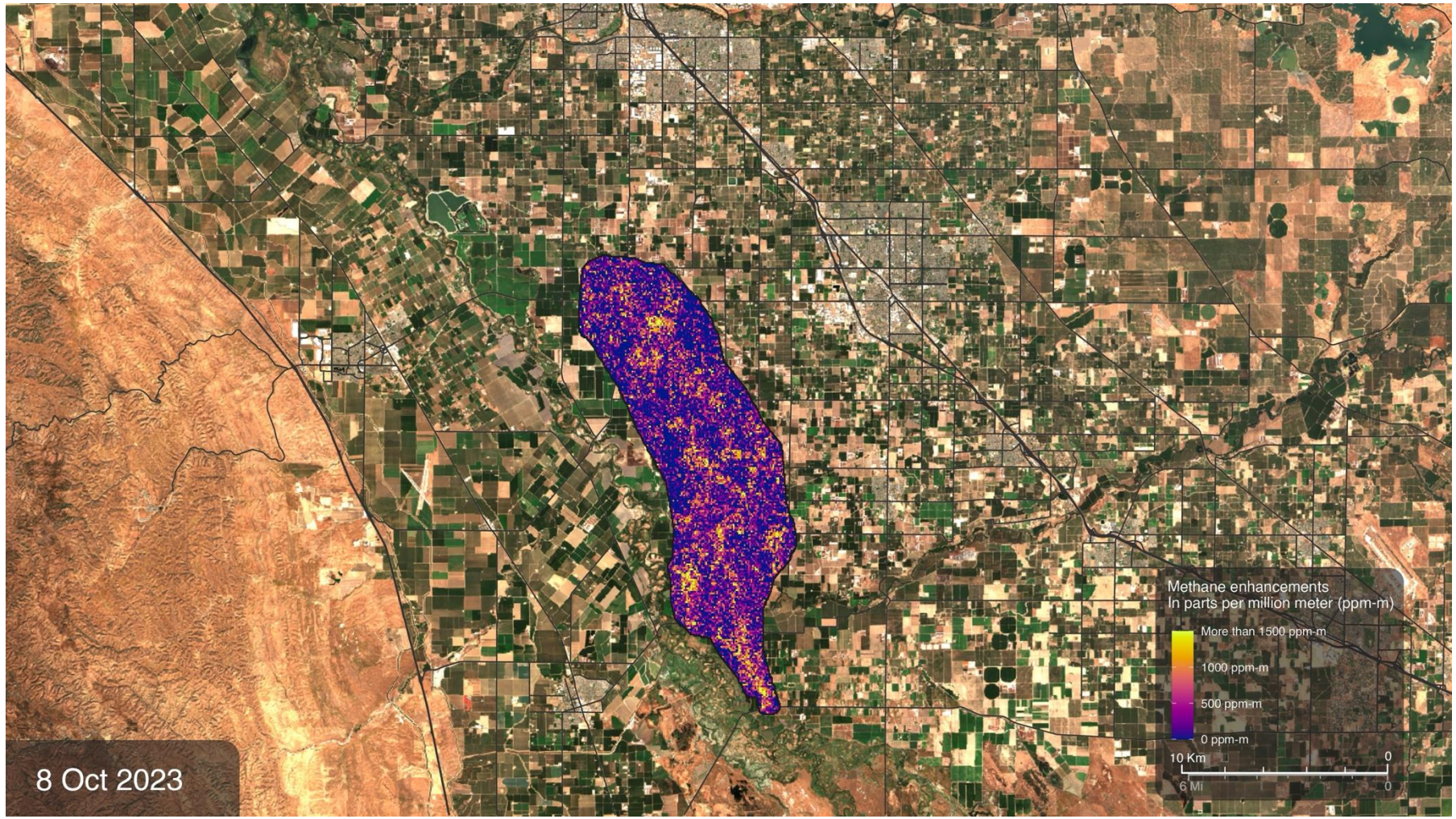


~80 km x ~80 km

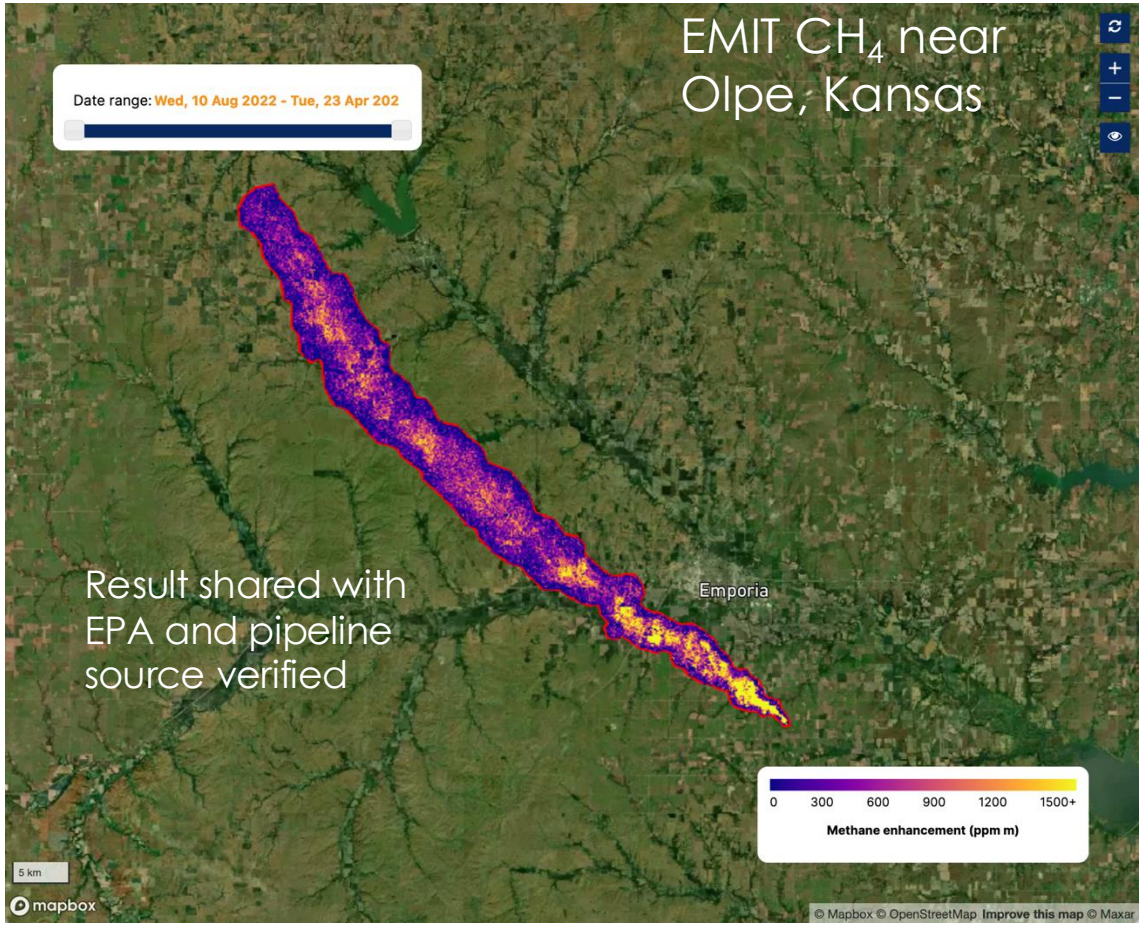
EMIT Methane Emissions from Landfill Sector

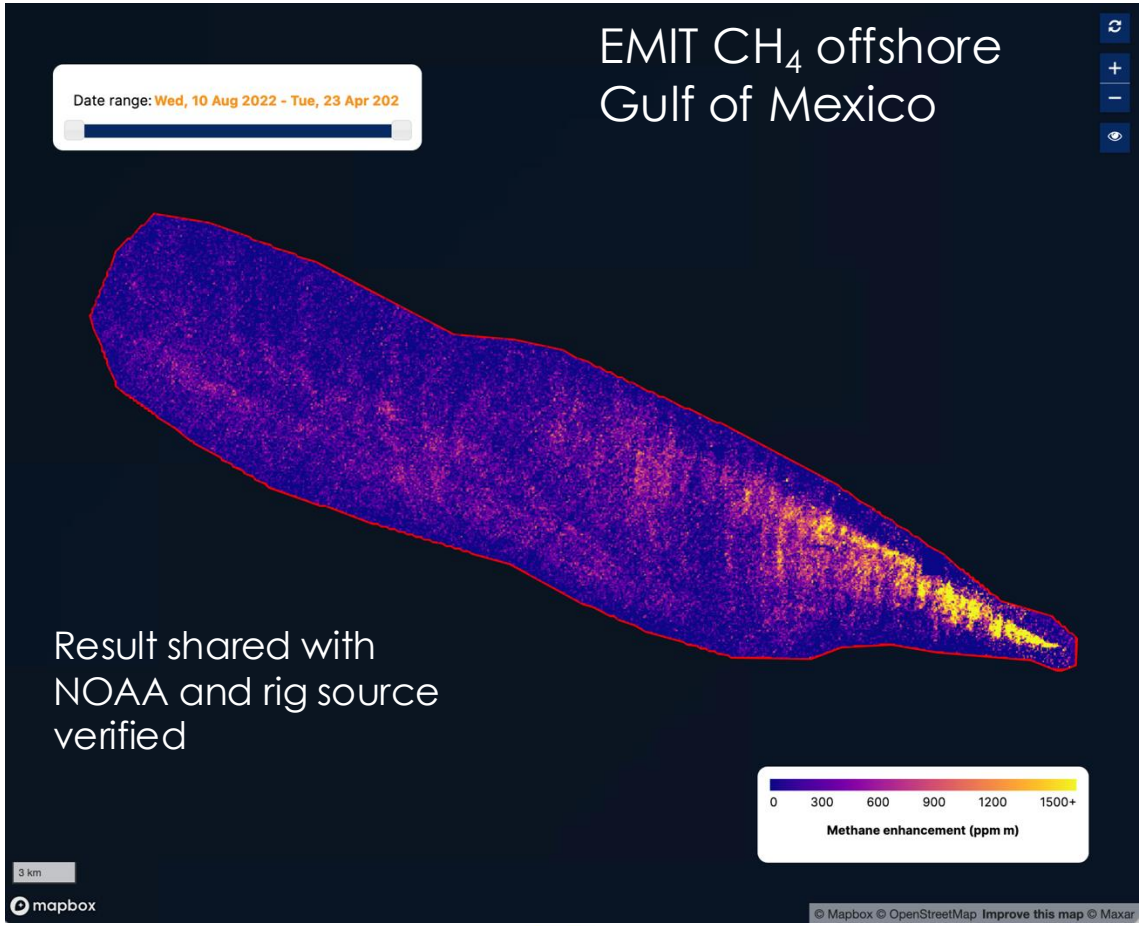
EMIT Methane Emissions from Agriculture

San Joaquin Valley, California



EMIT can Discover Unexpected Emissions and Provide Actionable Information



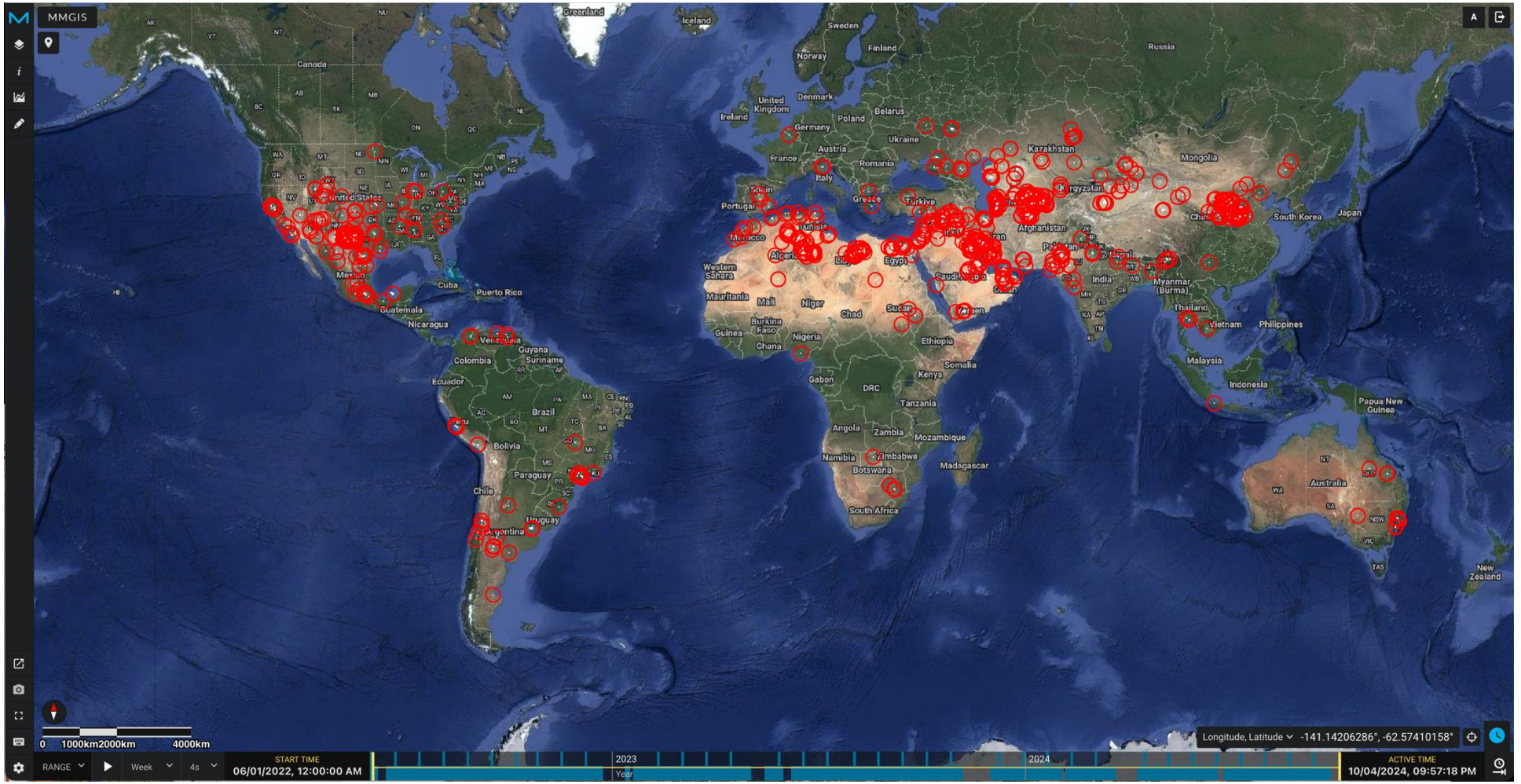


Sources verified by:

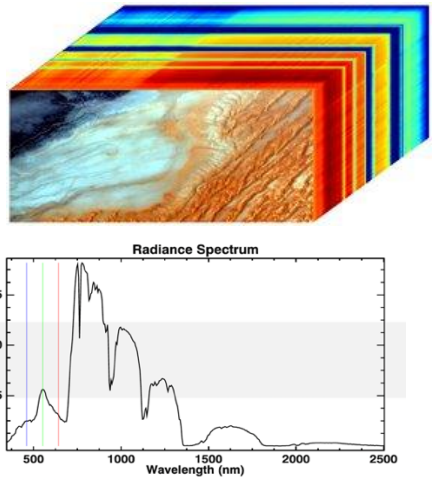
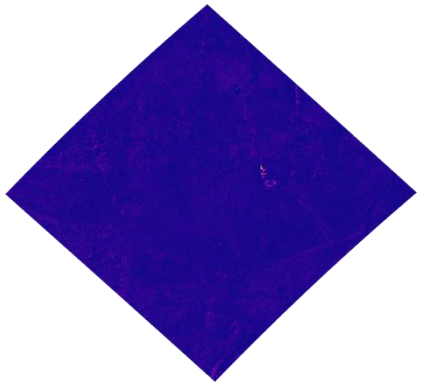
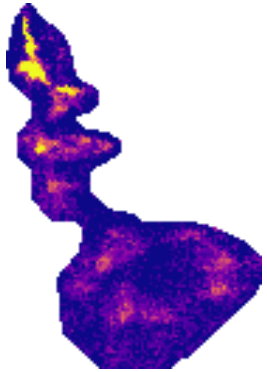
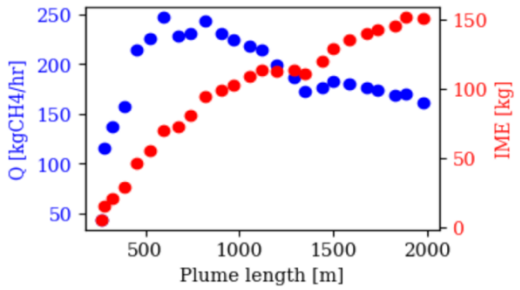
Understanding Satellite Coverage is Critical

Blue: EMIT coverage

Red: EMIT methane plumes



Current and Future Datasets

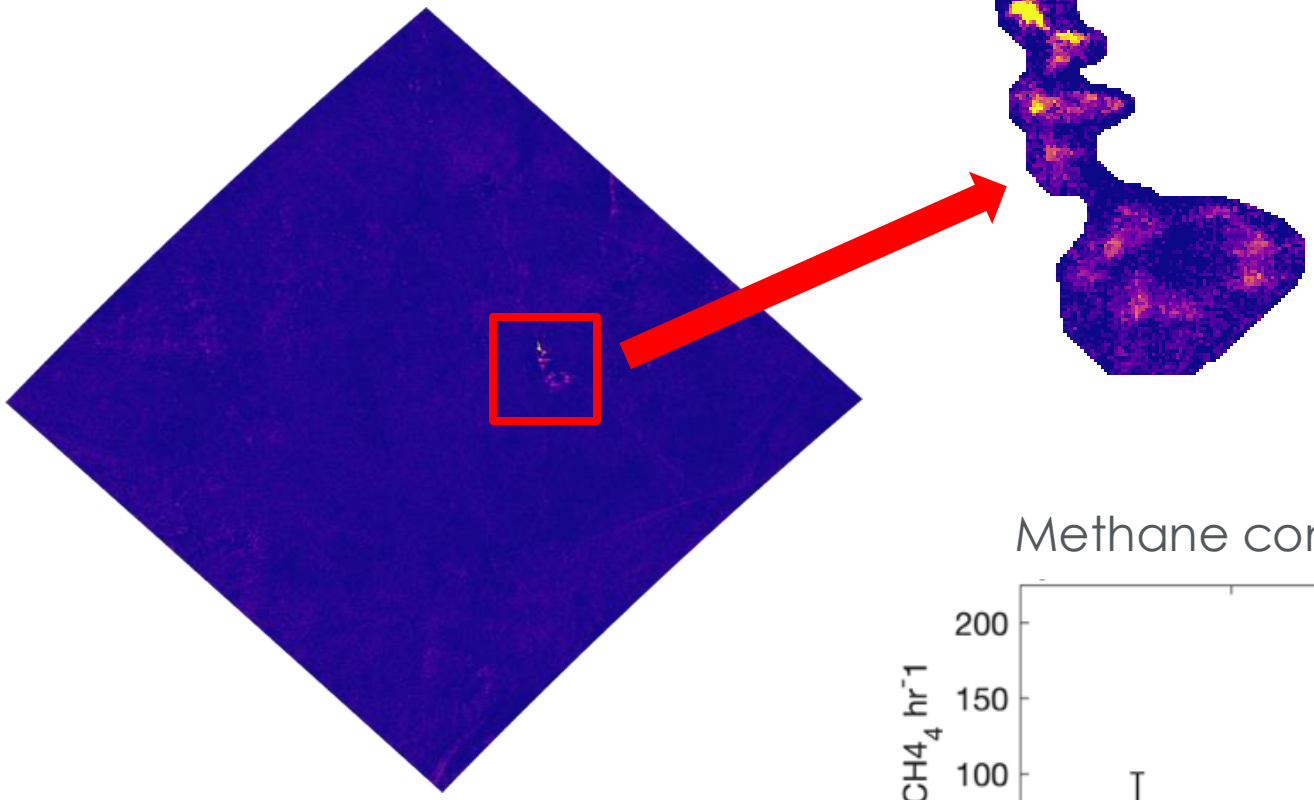
EMIT Level 1B: Calibrated radiance & geolocation LP DAAC 	Level 2B: Methane enhancement maps 	Level 2B: Methane plumes 	**Level 3: Methane emission rates with uncertainties (planned)** 
	Level 2B: CO2 enhancement maps	Level 2B: CO2 plumes	**Level 3: CO2 emission rates with uncertainties (planned)**

AVIRIS data can be found at the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC)

Open science repositories: https://github.co/emit-sds
https://github.com/emit-sds/emit-ghg

Emission Estimates

Level 2B: Methane enhancement maps



Level 2B: Methane plumes

Level 2B: Methane emission rates with uncertainties (planned)

$$Q = \frac{IME * U}{L}$$

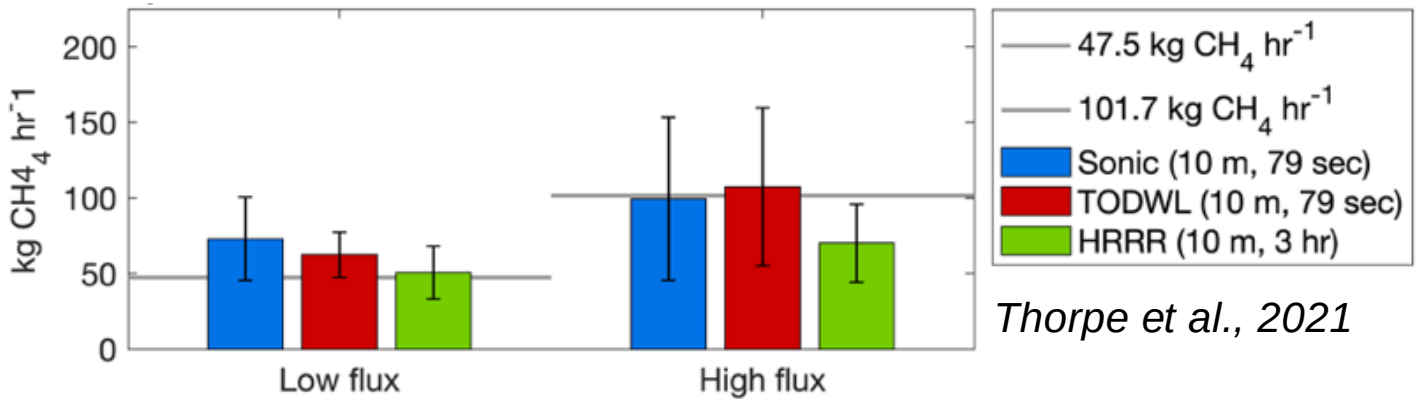
Emission rate: Q (kg/hr)

Integrated Mass Enhancement: IME (kg)

Wind speed: U (m/sec)

Plume length: L (m)

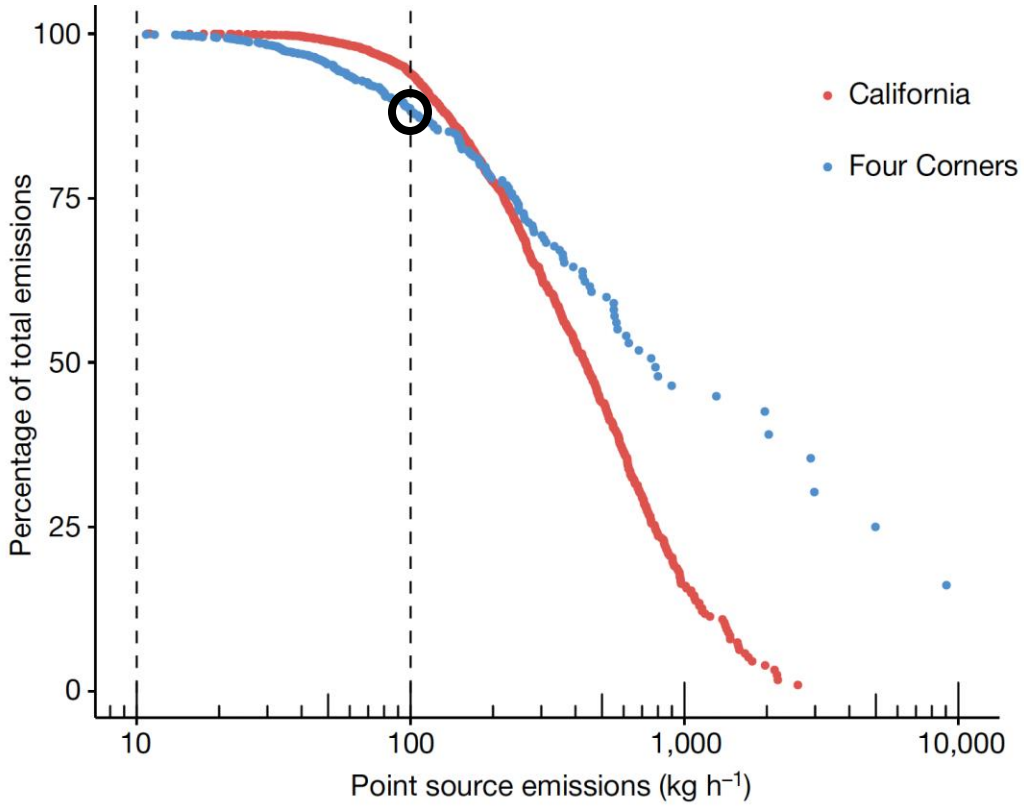
Methane controlled release



Thorpe et al., 2021

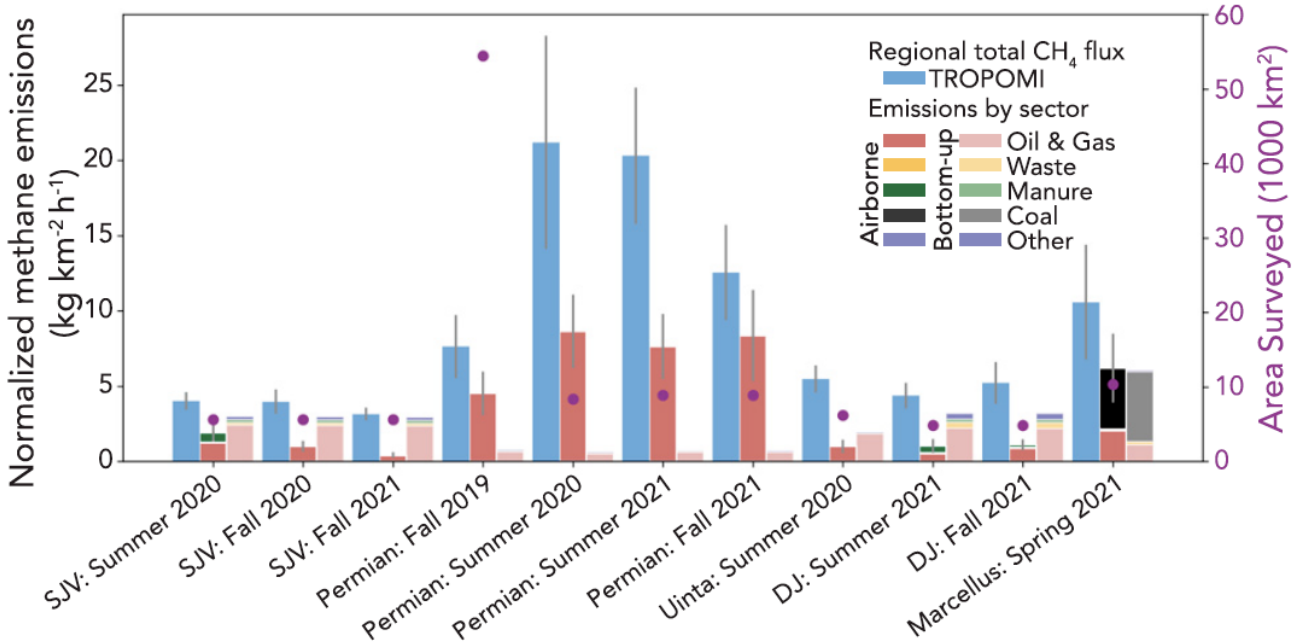
Importance of Large Methane Emission Events

Large point sources responsible for majority of observed airborne (AVIRIS-NG) emissions



Duren et al., 2019

AVIRIS-NG & GAO measurements indicate point source emissions represent a significant contribution of total regional flux (on average 40%)



Cusworth et al., 2022

NASA's Open Source Science Initiative expands use of EMIT data

Stakeholders who are, have indicated intent to, or are exploring, incorporating EMIT radiance or methane observations into their platforms or operations:

UN environment programme

EPA

Methane Alert and Response System (MARS)

KAYRROS

CARBON MAPPER

DEPARTMENT OF STATE · UNITED STATES OF AMERICA

NEW MEXICO ENVIRONMENT DEPARTMENT

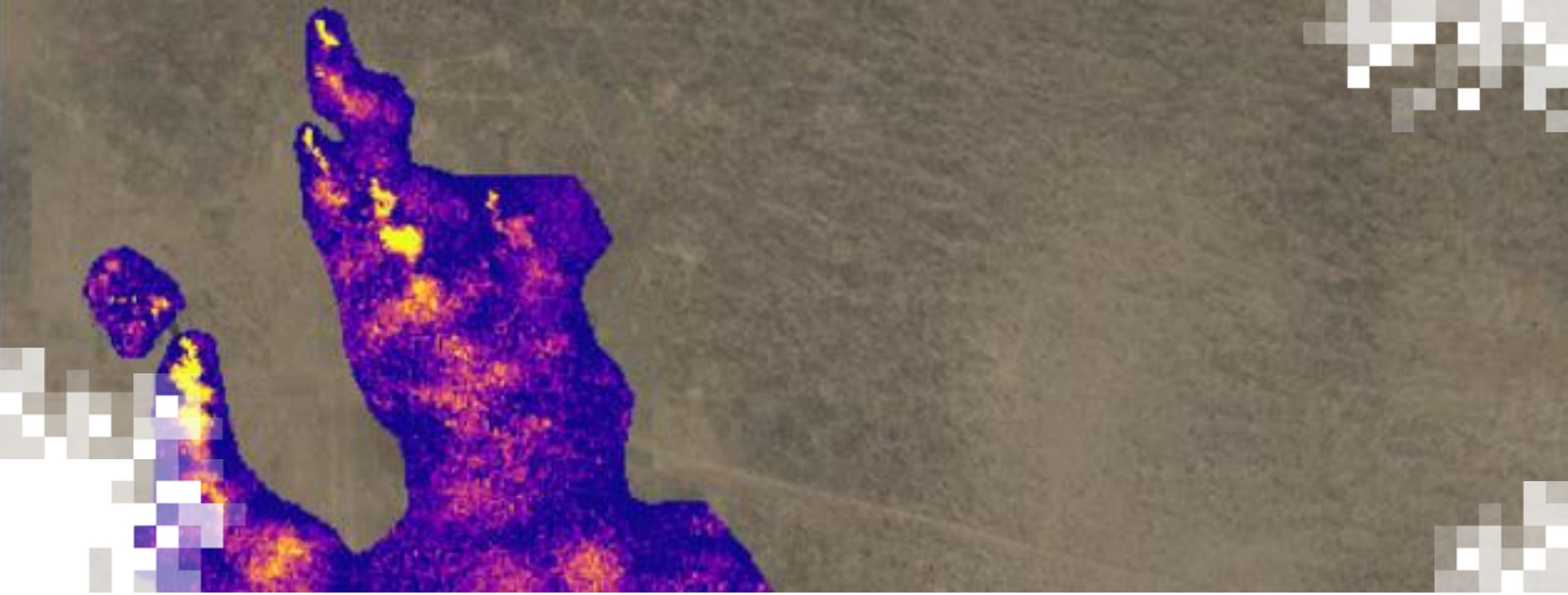
NEW MEXICO emnrd

Energy, Minerals and Natural Resources Department

CALIFORNIA AIR RESOURCES BOARD

Satellite Observations of Large Emission Events have Pros and Cons

- Strengths:
  - Observed point source emissions can be located, quantified, and attributed to emission sector.
  - Mapping capability leads to improved understanding of anthropogenic emissions.
  - Making these results publicly available can inform mitigation strategies.
- Limitations:
  - Current technology is limited to only large methane points source.
  - Individual instruments have limited spatial coverage and temporal revisits.
  - An observation reflects only a snapshot in time and repeat observations are required to assess if emissions are intermittent or persistence.



Part 1:
Summary

Summary

- Methane is a potent greenhouse gas and scientists have observed its growth in the atmosphere over recent decades
- Methane contributes ~16% of warming relative to the pre-industrial era
- Even though we can clearly see increases in methane, more measurements are needed to understand the sources and sinks of methane to understand how effective mitigation strategies will be
- Satellite observations are important for showing the effectiveness of policy changes
- The US GHG Center is initially led by NASA, EPA, NIST, and NOAA and is part of a national strategy to advance and integrated US GHG measurement, monitoring, and information system
- The goals of the US GHG Center involve making data that supports decision making, improving the quality and reliability of information, and ultimately providing users with consensus information to enable climate change mitigation.
- The US GHG Center Data Portal contains data stories, explanations of available data, alongside visualization tools

Summary

- Several satellite missions measure methane and there are two main types:
  - **Area flux mappers** have coarser spatial resolution (~3.5 – 10.5 km) and are best suited for mapping global methane gradients
  - **Point source imagers** have finer spatial resolution (~30 m) and are best suited to identifying distinct methane point sources
- Point sources are emissions of methane from a distinct location on the ground and can come from different emissions sectors such as oil and gas, landfills, and agricultural activities
- The EMIT sensor onboard the International Space Station is a point source imager with 60 m spatial resolution. EMIT cannot observe methane plume at high latitudes because of the ISS orbit.
- EMIT methane observations can be used to:
  - locate methane sources associated with known pieces of infrastructure, which can lead attribution to a given emission sector, and inform mitigation activities
  - discover unexpected emission not in inventories such as pipeline leaks or new sources
  - track methane point source emissions over time
- EMIT data products include methane enhancement maps and methane plumes
  - Methane enhancements are enhancements of methane above the background of their scene
  - Future products will include methane emission rates

Looking Ahead to Part 2

- Demonstrations of several platforms that can be used to access or visualize EMIT observations
  - US GHG Center Portal
  - EMIT VISIONS Portal
  - Earthdata Search

Homework and Certificates

- **Homework:**
  - One homework assignment
  - Opens on 21/11/2024
  - Access from the training webpage
  - Answers must be submitted via Google Forms
  - **Due by 05/12/2024**

- **Certificate of Completion:**
  - Attend both live webinars (attendance is recorded automatically)
  - Complete the homework assignment by the deadline
  - You will receive a certificate via email approximately two months after completion of the course.

Contact Information

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- ARSET Website
- Follow us on Twitter!
  - @NASAARSET
- ARSET YouTube

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- SERVIR

Resources

- U.S. GHG Center, https://earth.gov/ghgcenter/
- U.S. GHG Center, Large Methane Emission Events, https://earth.gov/ghgcenter/stories/discovering-large-methane-emissions
- EMIT Open Data Portal, https://earth.jpl.nasa.gov/emit/data/data-portal/Greenhouse-Gases/
- CEOS Greenhouse Gas Satellite Missions Portal, https://database.eohandbook.com/ghg/
- EMIT Open Science Repositories, https://github.co/emit-sds, https://github.com/emit-sds/emit-ghg
- Land Processes Distributed Active Archive Center (LP DAAC), EMIT data, https://lpdaac.usgs.gov/data/get-started-data/collection-overview/missions/emit-overview/#nav-heading
- Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC), AVIRIS-3 data, https://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=47

Publications

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- Varon, D.J., McKeever, J., Jervis, D., Maasakkers, J.D., Pandey, S., Houweling, S., Aben, I., Scarpelli, T. and Jacob, D.J., 2019. Satellite discovery of anomalously large methane point sources from oil/gas production. *Geophysical Research Letters*, *46*(22), pp.13507-13516.
- Roger, J., Irakulis-Loitxate, I., Valverde, A., Gorroño, J., Chabrillat, S., Brell, M. and Guanter, L., 2024. High-resolution methane mapping with the EnMAP satellite imaging spectroscopy mission. *IEEE Transactions on Geoscience and Remote Sensing*.
- Thorpe, A.K., Green, R.O., Thompson, D.R., Brodrick, P.G., Chapman, J.W., Elder, C.D., Irakulis-Loitxate, I., Cusworth, D.H., Ayasse, A.K., Duren, R.M. and Frankenberg, C., 2023. Attribution of individual methane and carbon dioxide emission sources using EMIT observations from space. *Science advances*, *9*(46), p.eadh2391.
- Scarpelli, T.R., Jacob, D.J., Grossman, S., Lu, X., Qu, Z., Sulprizio, M.P., Zhang, Y., Reuland, F., Gordon, D. and Worden, J.R., 2022. Updated Global Fuel Exploitation Inventory (GFEI) for methane emissions from the oil, gas, and coal sectors: evaluation with inversions of atmospheric methane observations. *Atmospheric Chemistry and Physics*, *22*(5), pp.3235-3249.
- Duren, R.M., Thorpe, A.K., Foster, K.T., Rafiq, T., Hopkins, F.M., Yadav, V., Bue, B.D., Thompson, D.R., Conley, S., Colombi, N.K. and Frankenberg, C., 2019. California's methane super-emitters. *Nature*, *575*(7781), pp.180-184.
- Cusworth, D.H., Thorpe, A.K., Ayasse, A.K., Stepp, D., Heckler, J., Asner, G.P., Miller, C.E., Yadav, V., Chapman, J.W., Eastwood, M.L. and Green, R.O., 2022. Strong methane point sources contribute a disproportionate fraction of total emissions across multiple basins in the United States. *Proceedings of the National Academy of Sciences*, *119*(38), p.e2202338119.


APPLIED REMOTE SENSING TRAINING PROGRAM
TRAIN - EMPOWER - ADVANCE

Thank You!