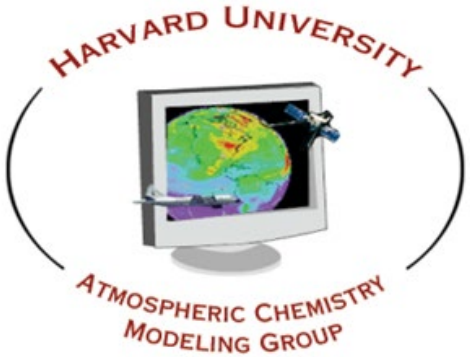
Welcome to the 1st Integrated Methane Inversion (IMI) and Integral Earth (IE) Workshop!

hosted by the Harvard Atmospheric Chemistry Modeling Group

November 4, 2024 11am-1pm eastern time

We will be starting soon!

11:00-11:05 Welcome and logistics (James East, IMI Developer)
11:05-11:15 Why the IMI (Daniel Jacob, IMI Principal Investigator)
11:15-11:25 IMI description and capabilities (Daniel Varon, IMI Co-Principal Investigator)
11:25-11:45 Running the IMI (Lucas Estrada, IMI Lead Developer, and Melissa Sulprizio, IMI Software Engineer)
11:45-12:00 Using IE for easy access to the IMI (John Thomas, IE Lead Developer)
12:00-13:00 Q&A (moderated by James East)



integral earth

The Integrated Methane Inversion (IMI):

a user-friendly cloud-based tool to quantify total methane emissions from satellite data

Daniel Jacob
IMI Principal Investigator

Daniel Varon
IMI Co-Principal Investigator

Lucas Estrada
IMI Lead Developer

Melissa Sulprizio
IMI Software Engineer

John Thomas
IE Lead Developer

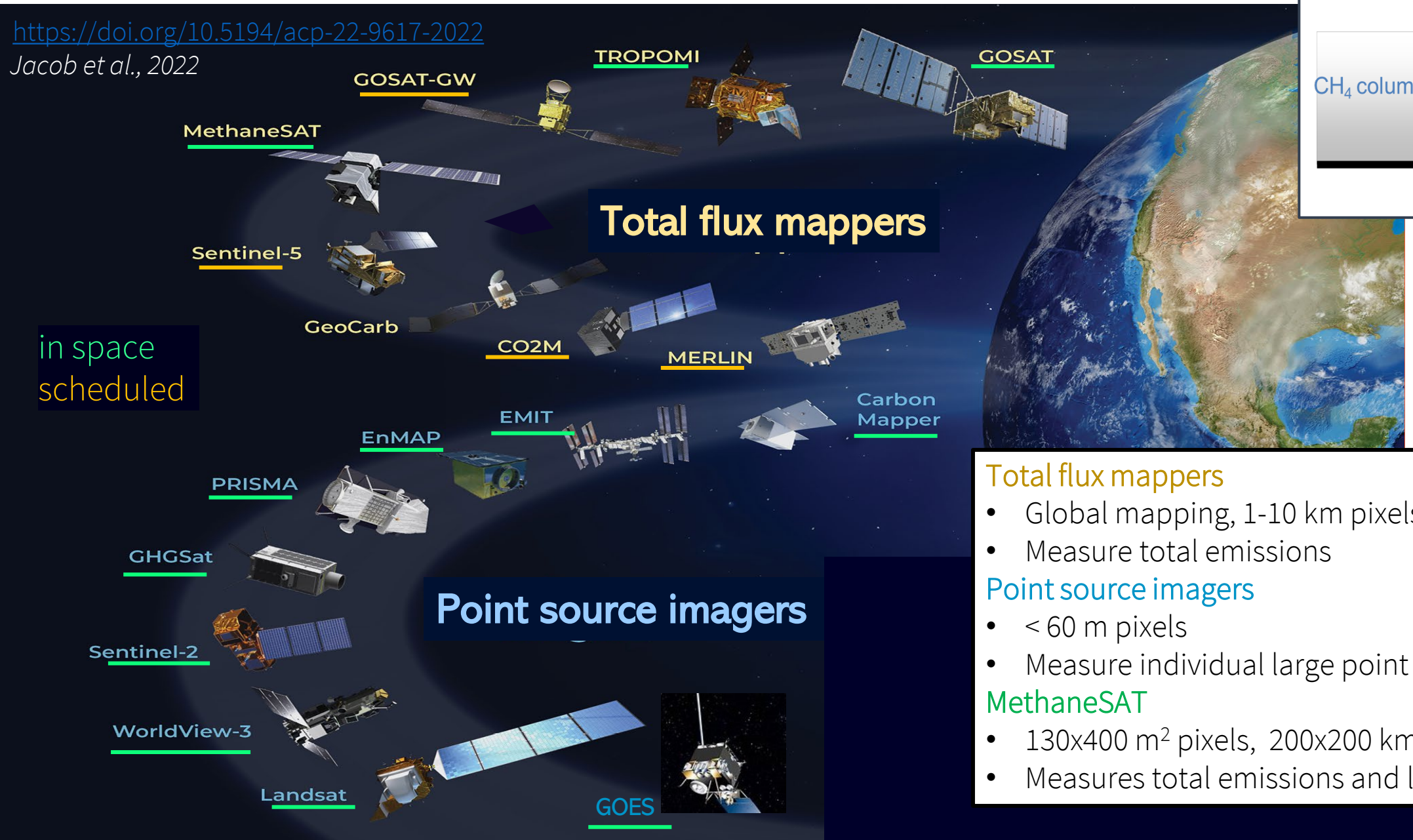
Mira Nagarajan
IE Business Lead

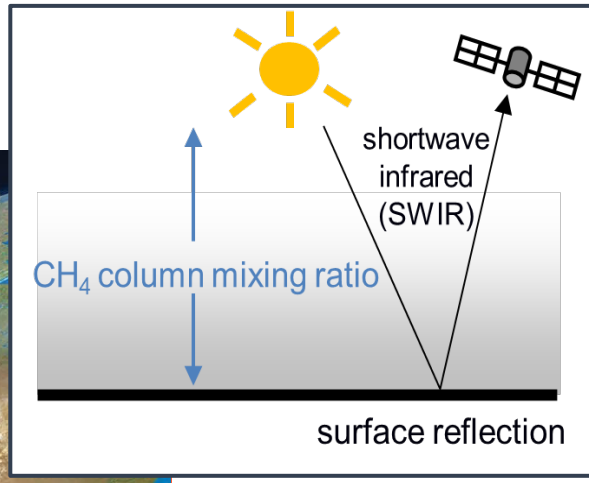
James East
IMI Developer
workshop moderator

Collaborators: JPL, SRON, ECCC
Funding: NASA, ExxonMobil, Harvard Salata Institute, Harvard Office of Technology Development, AWS
On the web: https://integratedmethaneinversion.github.io

Growing satellite constellation of methane observations

https://doi.org/10.5194/acp-22-9617-2022
Jacob et al., 2022





Total flux mappers
- Global mapping, 1-10 km pixels, high precision
- Measure total emissions

Point source imagers
- < 60 m pixels
- Measure individual large point sources

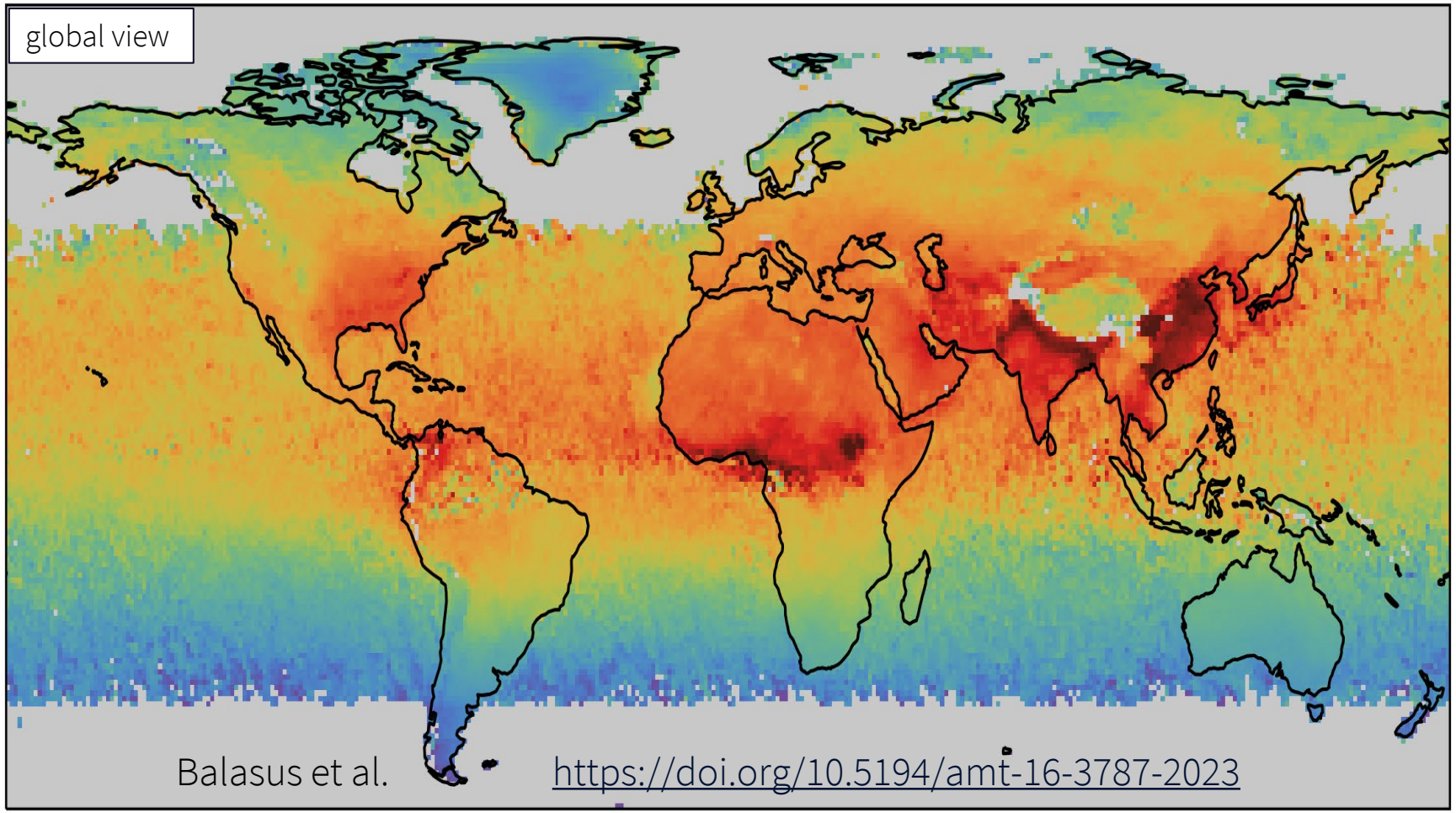
MethaneSAT
- 130x400 m^2 pixels, 200x200 km^2 targets
- Measures total emissions and large point sources

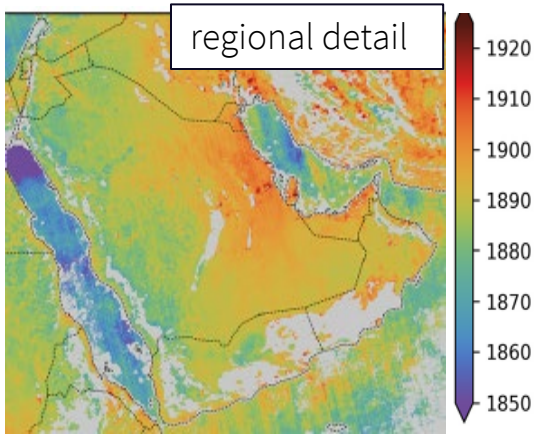
TROPOMI (2018-): global daily mapping
5.5x7 km^2 pixels, 0.6% precision

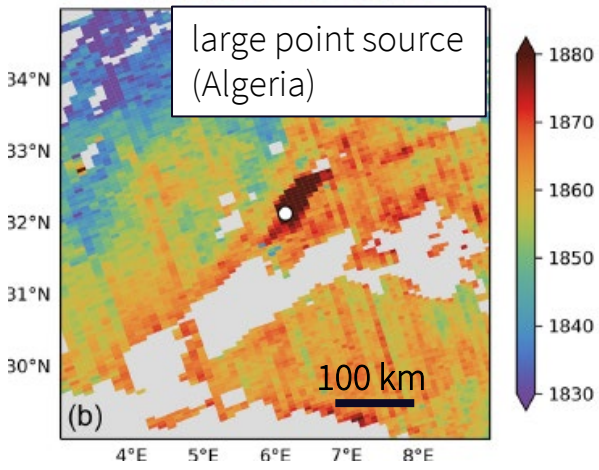
open-access operational methane data produced by SRON

over 100 million observations per year

Annual mean blended TROPOMI+GOSAT observations, 2021

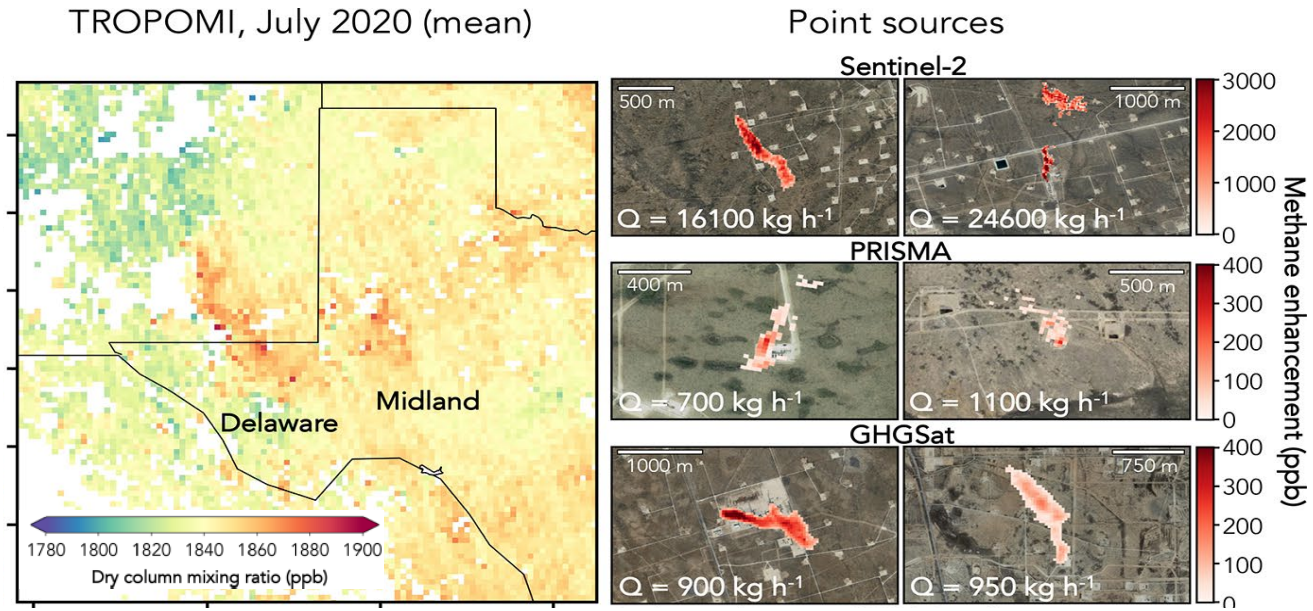






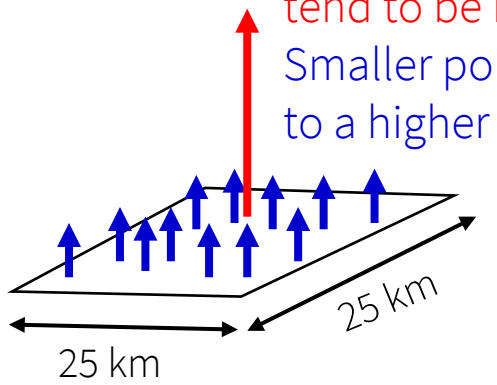
IMI quantifies <u>total</u> methane emissions using TROPOMI open-access data

Observations over the Permian Basin



Jacob et al., 2022 https://doi.org/10.5194/acp-22-9617-2022

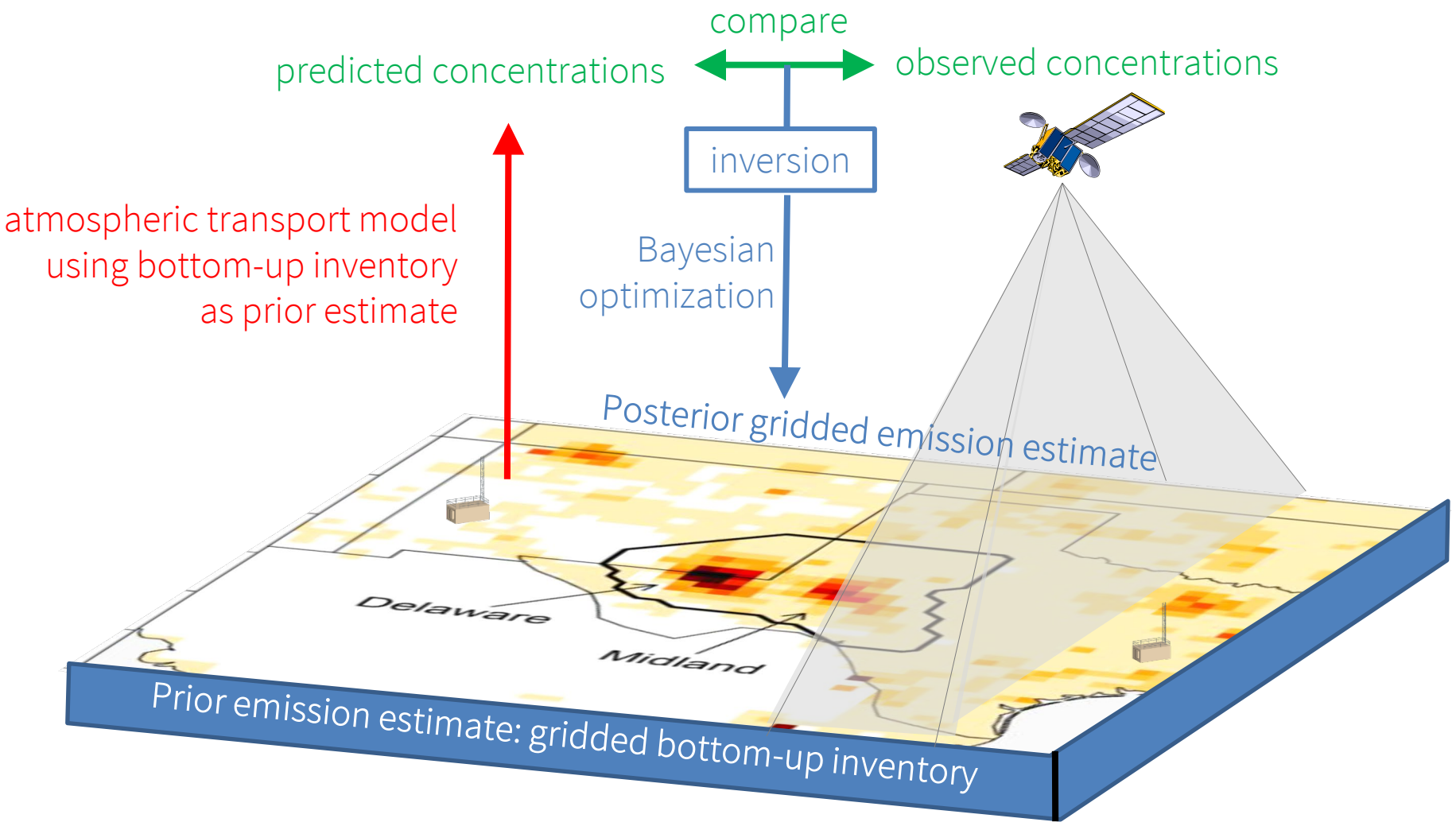
Detectable point sources (> 100 kg h^{-1})
tend to be intermittent
Smaller point sources add up
to a higher total



IMI quantifies total time-integrated emissions
at 25-km resolution

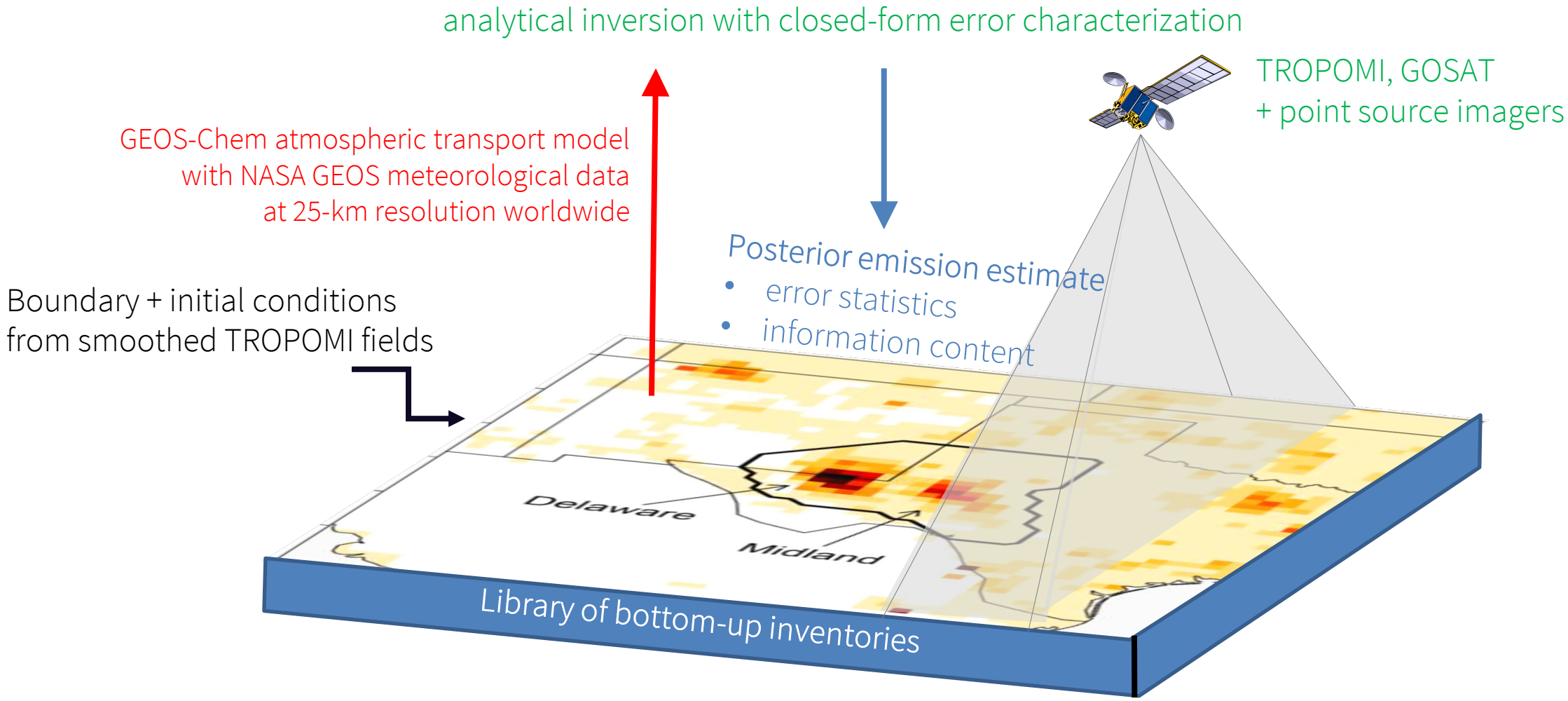
- IMI provides a unique capability for quantifying total methane emissions at up to 25-km and weekly resolution anchored by open-access TROPOMI satellite observations. This enables
  - basin/regional/state/national emission reporting
  - averaging over intermittent point source observations
  - monitoring emission trends
  - attributing emissions to different sectors (using prior information)

Inferring total methane emissions by inversion of satellite data



Posterior estimate improves on prior bottom-up estimate by adding information from the atmospheric observations

How this is done in the IMI

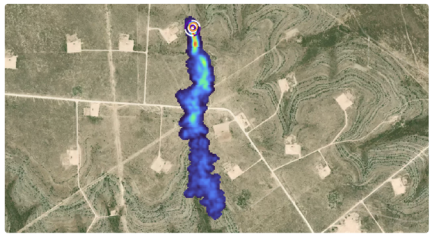


- Brasseur, G.P. and D.J. Jacob, *Modeling of Atmospheric Chemistry*, Cambridge University Press, 2017
- Varon, D. J., et al., Integrated Methane Inversion (IMI 1.0): a user-friendly, cloud-based facility for inferring high-resolution methane emissions from TROPOMI satellite observations, *Geosci. Model Dev.*, 2022
- IMI method is backed up by over 30 peer-reviewed publications from Harvard group

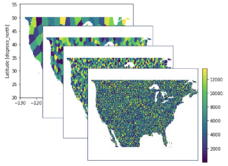
Newly released IMI 2.0

Expanded Input Options

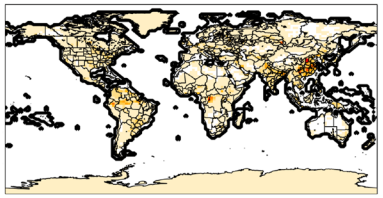
2. Incorporation of point source observations



5. Adaptive resolution state vector

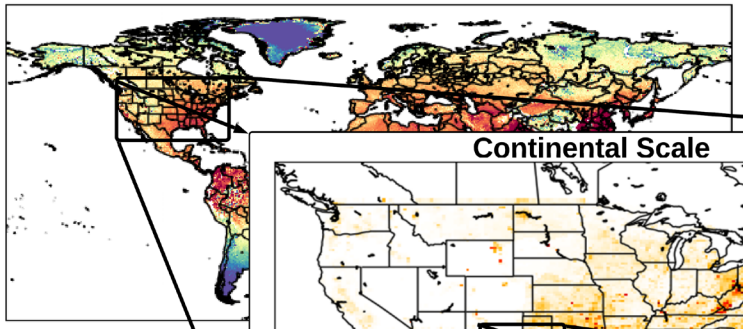


8. New bottom-up emission inventories



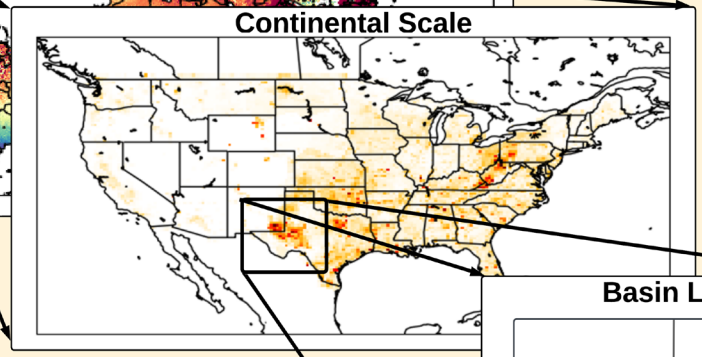
Multiscale Inversion Capabilities

6. Global Inversion Capability

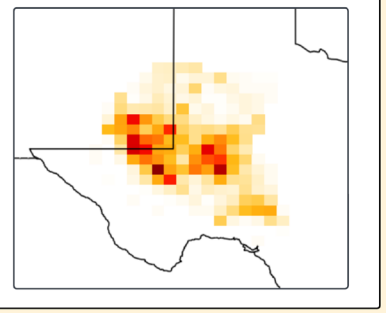


1. Blended TROPOMI+GOSAT observations

Continental Scale



Basin Level



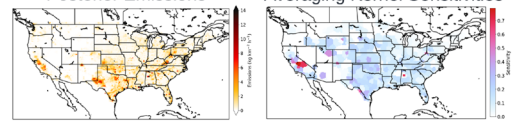
Updated Inversion Methods

3. Fast Jacobian computation
4. Application of super-observations
7. Kalman filter for temporal emission updates
9. Improved boundary/ inital conditions
10. Lognormal error PDFs

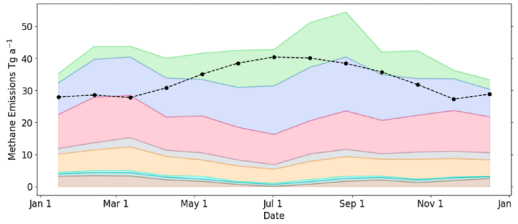
12. Containerized for easy install

11. Enriched Output

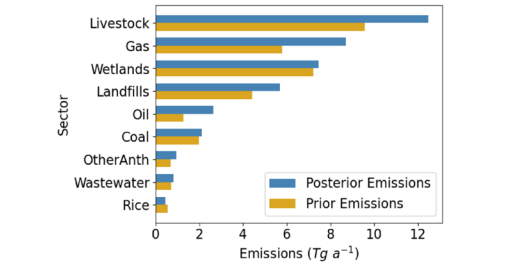
IMI 1.0 Standard Output



Continuous Emission Monitoring



National / Sectoral Output



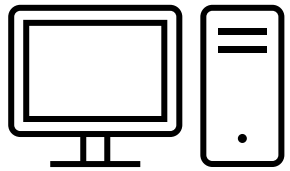
Estrada, L.A., et al., Integrated Methane Inversion (IMI) 2.0: an improved research and stakeholder tool for monitoring total methane emissions with high resolution worldwide using TROPOMI satellite observations, EGUsphere [preprint],, 2024.

Developments on the way (IMI 3.0):

- Integrate new satellite datasets (MethaneSAT, GHGSat, …)
- Include surface and aircraft observations
- Increase resolution to 12 km
- Extend capability to CO_2 (led by JPL)

How can I use satellite observations to better quantify emissions from my region of interest?

Delivering the IMI to users (simple slide)



aws

integral earth

On your own cluster

- Download IMI from the cloud using Docker container
- Run complete IMI workflow from simple configuration file
- Requires technical ability and computing resources

On the cloud

- Login to AWS
- Run complete IMI workflow from simple configuration file
- Use notebook to analyze output
- Requires some technical ability

Integral Earth

- Access IMI through web user interface
- Receive advice and QC from IMI team
- Use web-based output analysis tools
- Requires no technical ability

Delivering the IMI to users (detailed slide)

What are the methane emissions from my region of interest?

- Login to the cloud
- access the IMI on the cloud or download it
- edit configuration file
- preview and submit job

Remove need for
- scientific/technical know-how
- computational resources
- TB-scale data management

satellite data

submit request through web user interface

analyze output

integral earth

automated submission

aws cloud

IMI

IMI team can review request, give feedback, submit job

GEOS-Chem

bottom-up

Emission output: data and imagery
- gridded emissions at up to 25-km and weekly resolution with error statistics
- sectoral attribution
- point source information
- Independent evaluation

IMI is open-access, open-code: results are
- transparent
- referenceable
- reproducible

https://integratedmethaneinversion.github.io

IE is a service for accessing and using the IMI:
- all you need is an internet connection
- automated or personal service, interactive output
- currently in beta testing

https://integralearth.github.io/

Our vision for the IMI and Integral Earth

- We are committed to supporting and developing the IMI as open-source user-friendly cloud-based tool
  - We are building a grass-roots research and applications community using and developing the IMI
  - Users can run the IMI on the cloud or download it to their local systems

- We are developing Integral Earth as Software as a Service (SaaS) for accessing the IMI
  - Users submit job through web user interface, can interact with IMI staff
  - Free while in beta testing: contact us to be a beta tester
  - Public-release version by end of 2024

- We are still trying to figure out the best business model for Integral Earth
  - Private start-up company (for profit or non-profit)
  - Transfer to an existing company
  - Customer pay-for-service through Harvard
  - Embed into a larger operation such as NASA Greenhouse Gas Center

If you are interested in supporting the IMI or IE, we would love to hear from you