Ensuring Quality, Access, and Trust in Greenhouse Gas (GHG) Emissions Data

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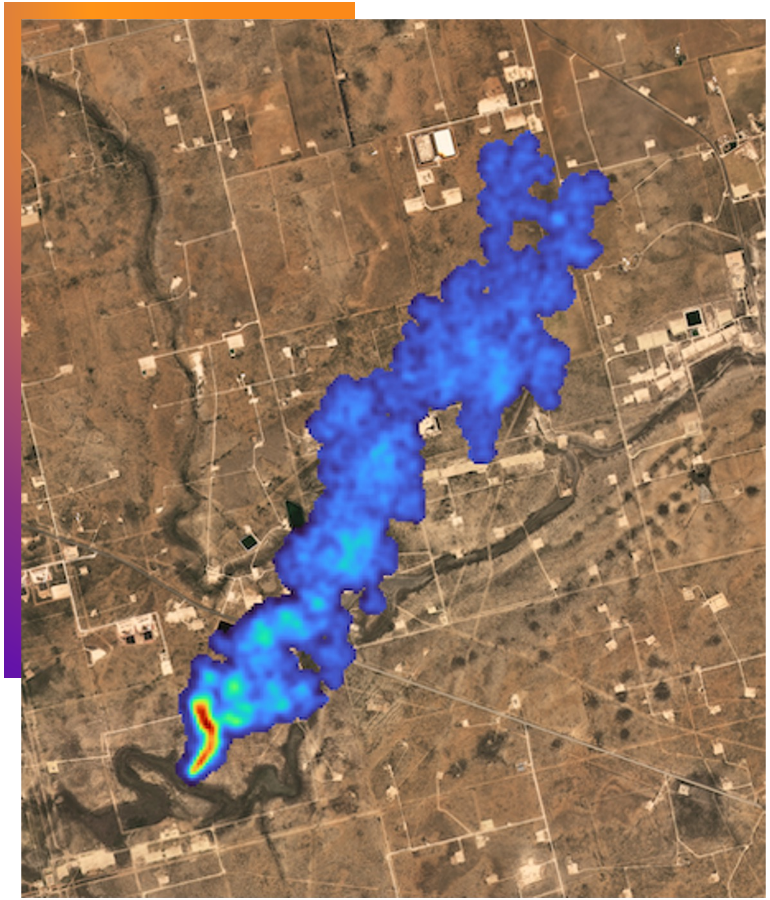
OUTLINE

- Background
- Use cases for GHG data
- Attributes of trusted and actionable data
- Traditional and evolving estimation methods
- Case studies: capabilities and limitations
- Some cautionary notes
- Looking ahead: challenges and opportunities

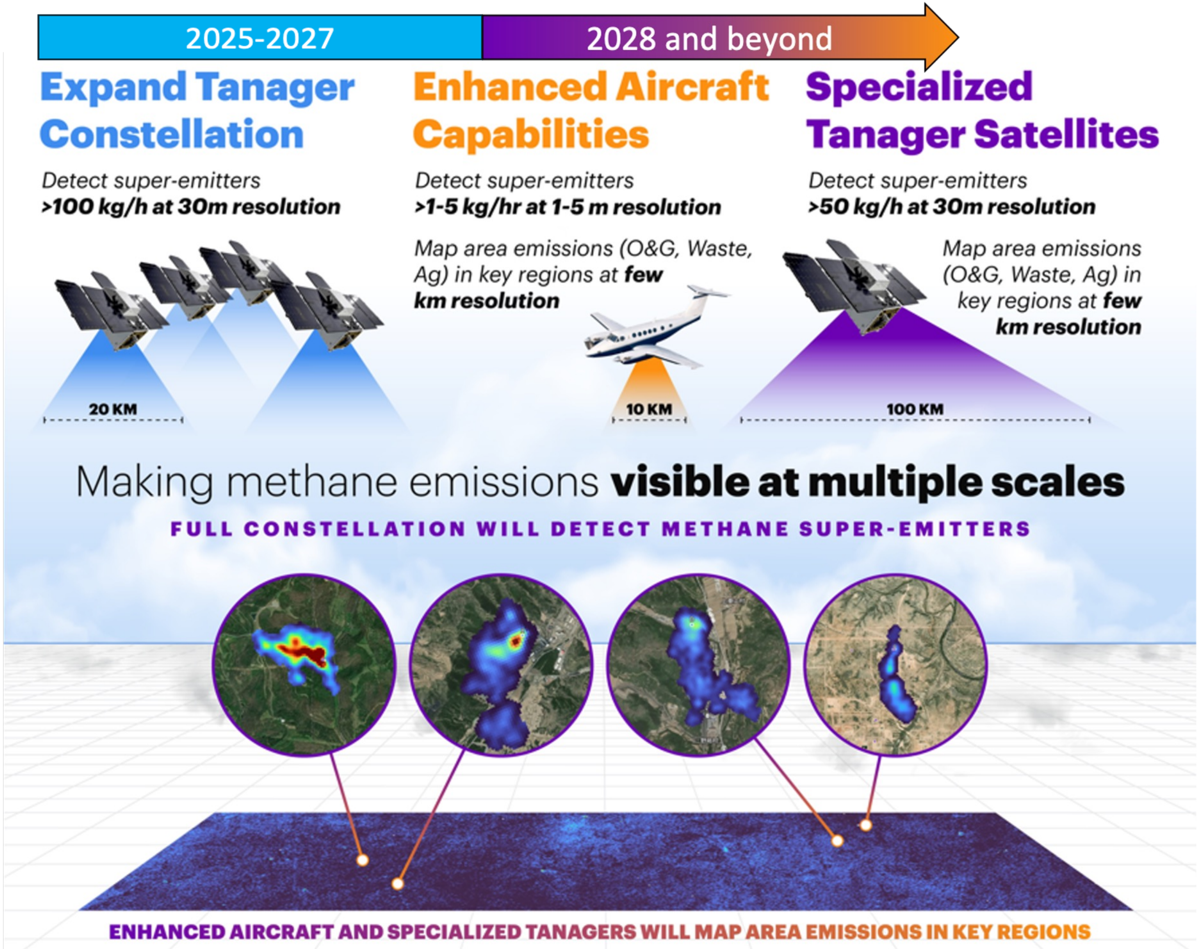


ABOUT CARBON MAPPER

A non-profit working to reduce emissions by delivering accessible, actionable methane and carbon dioxide data

- Leveraging remote sensing technologies, to **detect, pinpoint, and quantify methane and other emissions** for effective action
- Launched **first satellite (Tanager-1) in August 2024;** more are being prepared for launch by Planet Labs
- Providing **operational monitoring** for regulatory & voluntary mitigation programs
- Working with industry, governments and civil society to **translate data into action**
- Making all methane and CO2 **data publicly available on our portal**

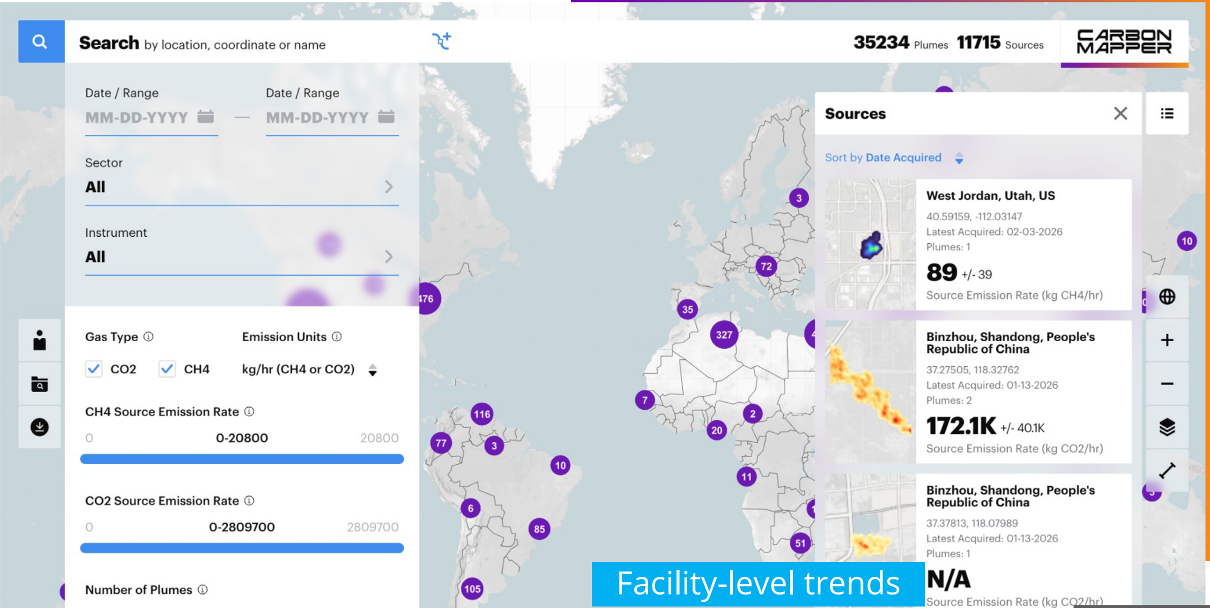
SCALING UP OBSERVING SYSTEMS



starting in 2028:
expanded trace-gas detection CH_4, CO_2, CO, C_2H_6, NH_3 for source apportionment and local health applications

Carbon Mapper contributes to a much larger ecosystem of observing systems

MAKING DATA AVAILABLE



data.carbonmapper.org

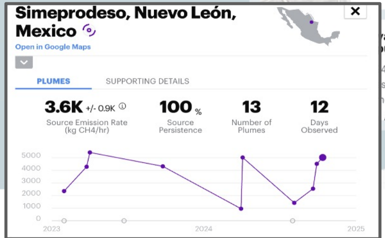
30 meter resolution

Quality-controlled data published 30-days after observation - free for non-commercial use

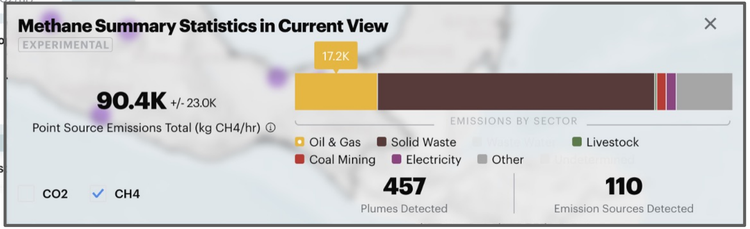
Low-latency data delivered to partner governments and Planet commercial subscribers

Alerts, filtering, APIs

Facility-level trends



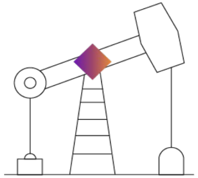
Summary statistics by region



USE-CASES: TRANSLATING DATA INTO ACTION*

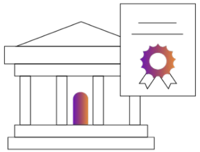
Emissions accounting, reporting, & auditing

National GHG inventories, GHG Reporting Program, EU methane supply index, CA Climate Corporate Accountability Act



Guiding leak detection/repair & management practices

National and state methane regulations, industry LDAR programs, IMEO, REDD



Informing Policy Development, Incentives, & Investments

Regulatory rule-making, industry initiatives (OGCI, OGDC)

Building User Capacity, Knowledge, & Tools

Regulatory implementation, international development and training programs, community resources

*overlapping but distinct use-case: carbon cycle science & understanding natural fluxes

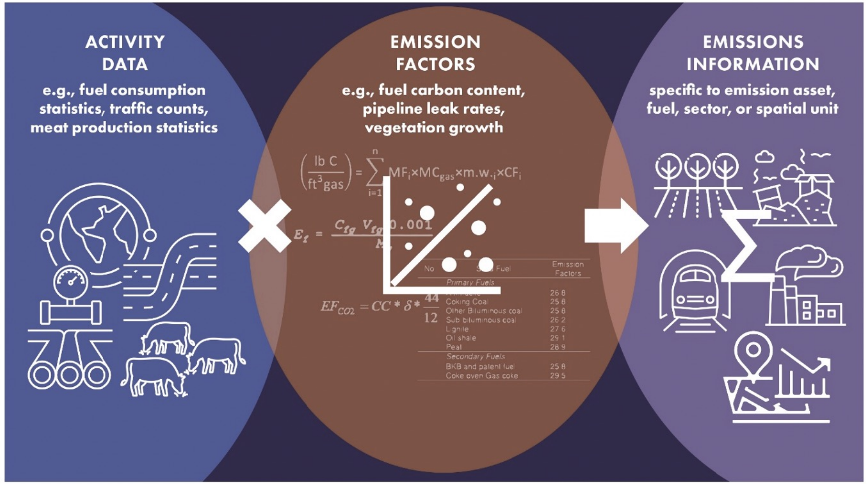
ATTRIBUTES OF TRUSTED & ACTIONABLE DATA

COMPLETENESS	Sensitivity, coverage, and frequency sufficient to detect most emissions
QUALITY	Precise, accurate, validated, with quantified uncertainties
ACCESSIBILITY	Equitable, transparent, timely, and in usable formats for diverse stakeholders
RESPONSIVENESS	Enables user incentives and capacity to care-about, understand and act
CONTINUITY	Sustained data delivery through reliable systems and stable funding

Challenge: implementation with an evolving ecosystem of data providers, analysts, & translators

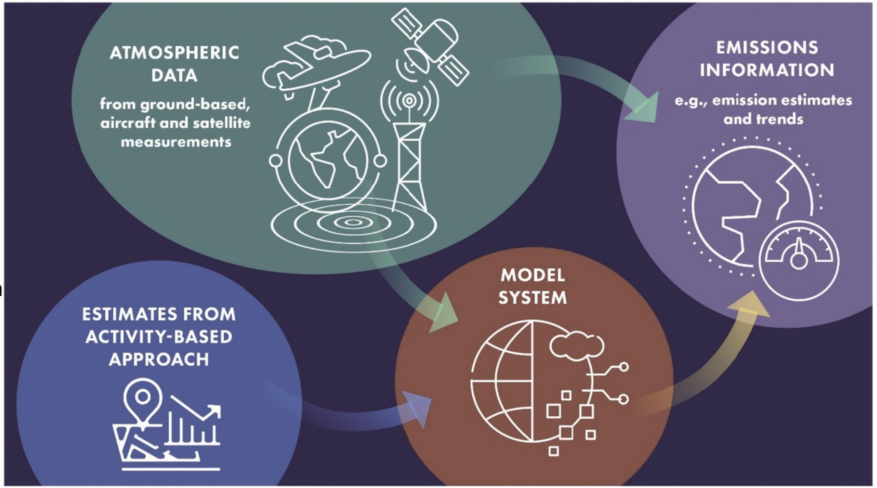
TRADITIONAL ESTIMATION METHODS

Activity-based (“bottom-up”)



intercomparison

Atmospheric-based (“top-down”)



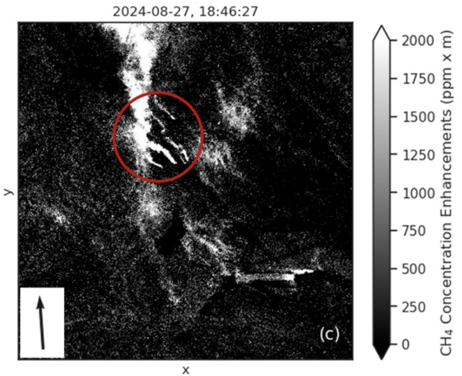
- Official inventories: state/national, annual, IPCC standard
- Experimental inventories: downscaled to few km, hourly-annual
- Attribution: sectors fully disaggregated in input data
- Emission factors: population-wide assumptions

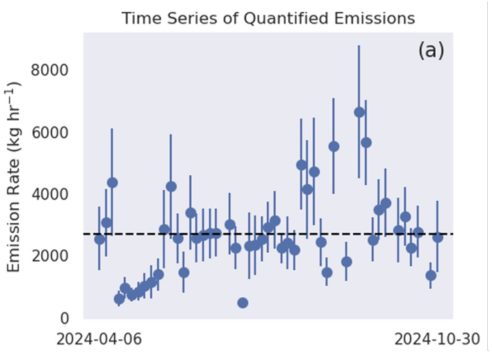
- Operational monitoring: daily or better, low latency, routine
- Experimental monitoring: wide-spread, high latency, inconsistent
- Attribution: atmosphere mixes everything
- Emission factors: directly testable within and across populations

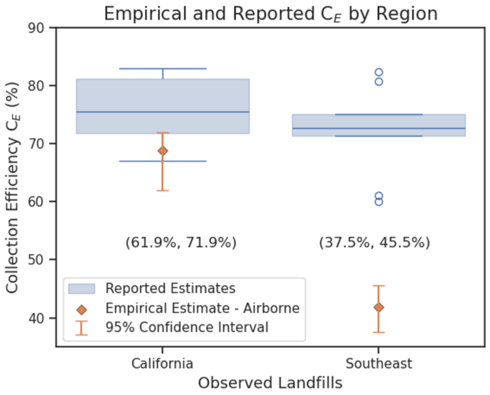
AI is beginning to contribute activity data and assist in data analysis – but requires careful supervision

Graphic courtesy National Academies 2022. Greenhouse Gas Emissions Information for Decision Making: A Framework Going Forward. https://doi.org/10.17226/26641

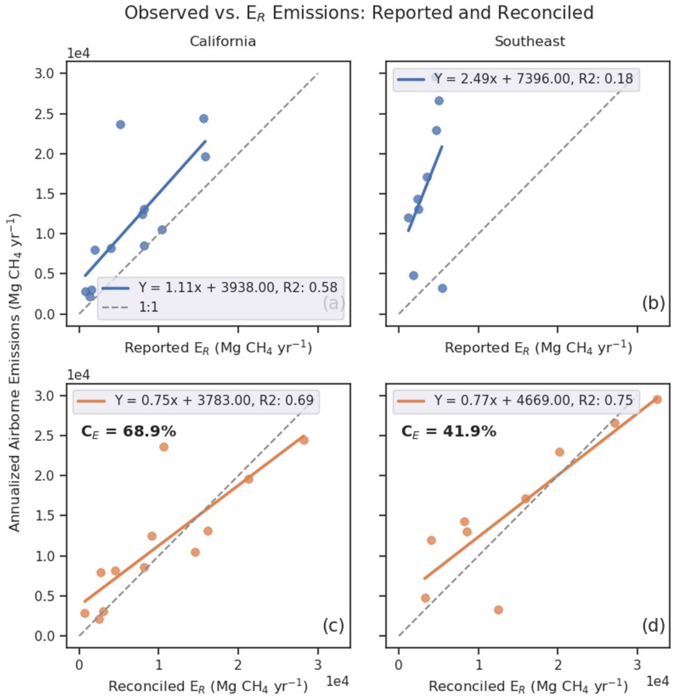
EMERGING: RECONCILING ACTIVITY-BASED & ATMOSPHERIC-BASED EMISSION ESTIMATES





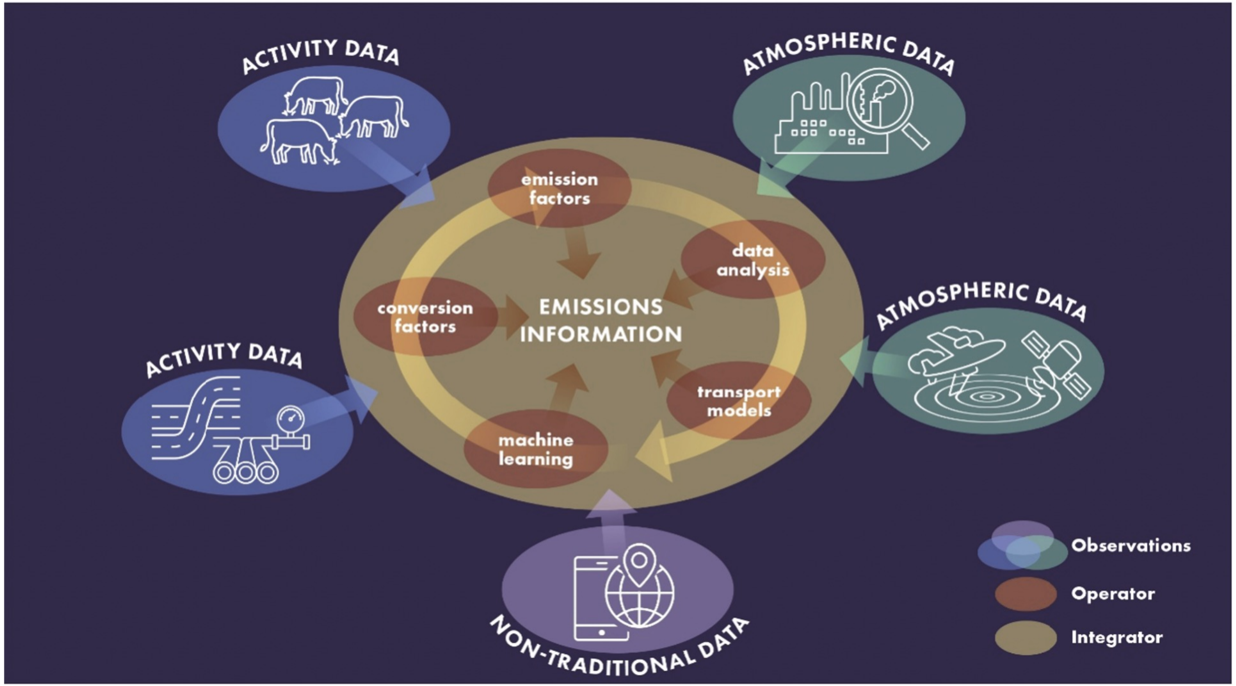


Howell et al., in review



High frequency, high resolution, independently validated atmospheric measurements can help identify and correct errors in emission factors (in this case, assumed landfill gas collection efficiency)

TOWARDS AN INTEGRATED FRAMEWORK?



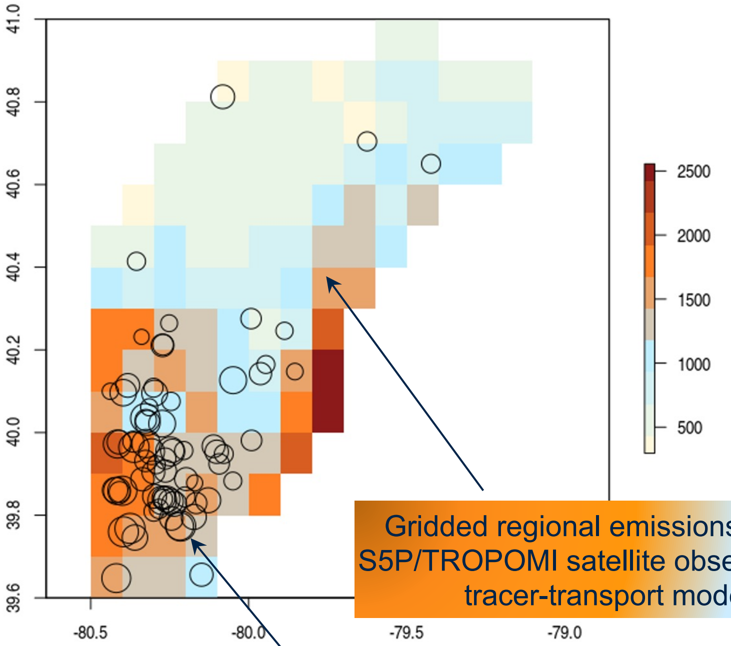
<u>Key questions to address</u>

- Are detected emission sources **real and properly geo-located**?
- Are they **properly attributed** to sector, equipment type, & responsible entity?
- Are **emission estimates accurate**?
- Are **uncertainties quantified**?
- Are data sets and methods sufficiently **transparent, accessible, and repeatable**?
- Are the data sets **fit for purpose**?
- How address **governance** with diverse contributors/operators (govt, commercial, non-profit, academia, AI)?

Graphic courtesy National Academies 2022. Greenhouse Gas Emissions Information for Decision Making: A Framework Going Forward. https://doi.org/10.17226/26641

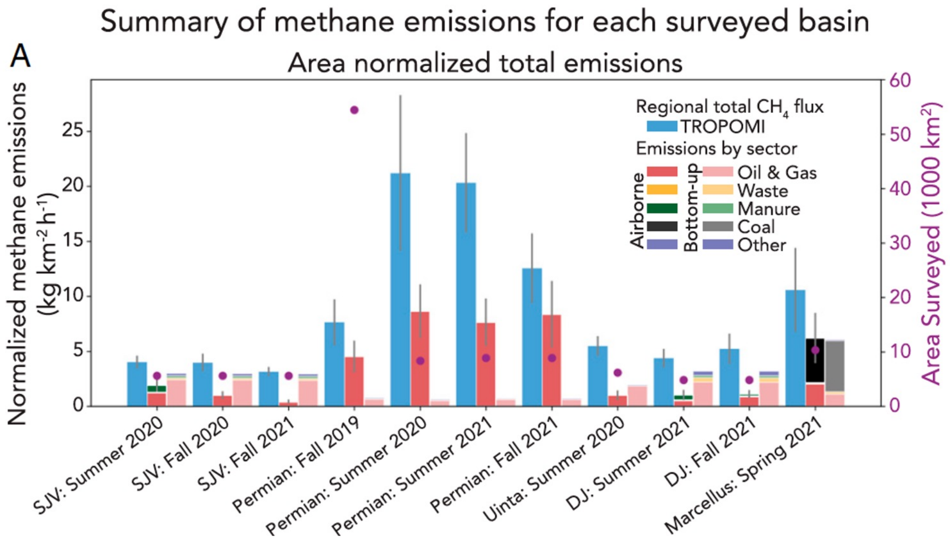
EXAMPLE: MULTI-SCALE CH4 QUANTIFICATION WITH AIRCRAFT & SATELLITE

Marcellus Shale (Pennsylvania)



Gridded regional emissions map from S5P/TROPOMI satellite observations and tracer-transport modeling

Individual point sources detected by Global Airborne Observatory aircraft

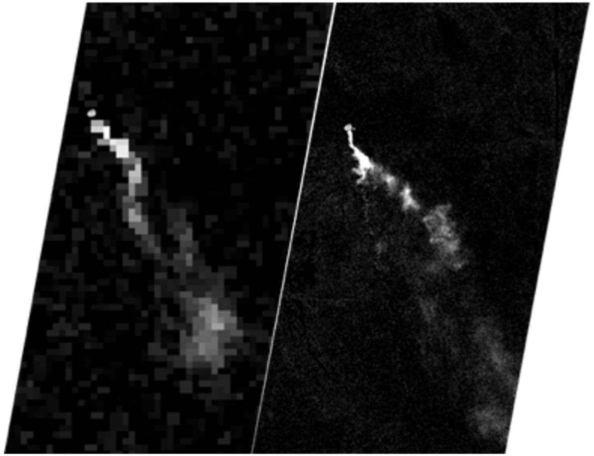


Cusworth *et al.*, *PNAS*, 2022, https://www.pnas.org/doi/10.1073/pnas.2202338119

Traditional physics-based methods are rapidly improving with expanding ecosystem of remote sensing observations – but gaps remain (sensitivity, resolution, frequency)

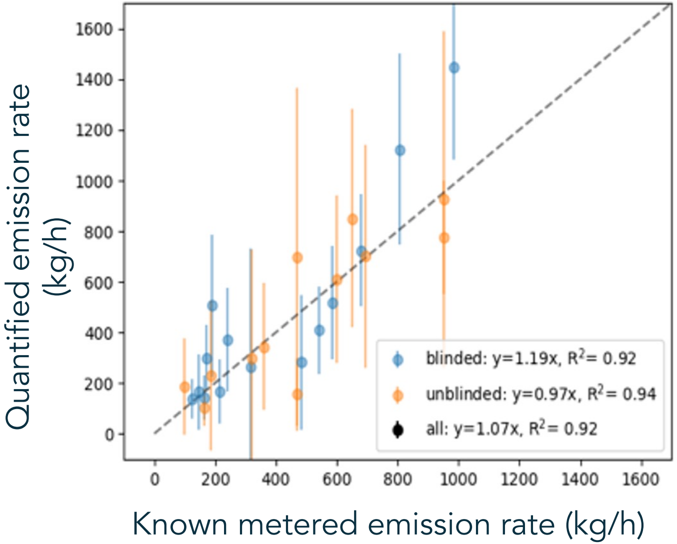
EXAMPLE: VALIDATION AND STANDARDS TO IMPROVE TRUST IN DATA

Intercomparison



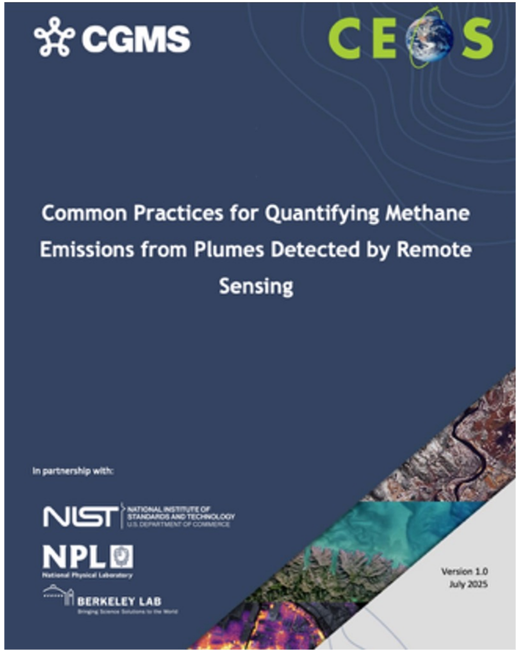
Simultaneous observation of controlled release test by satellite and aircraft

Independent evaluation



Duren et al, 2025 https://doi.org/10.5194/amt-18-6933-2025

Consensus Standards



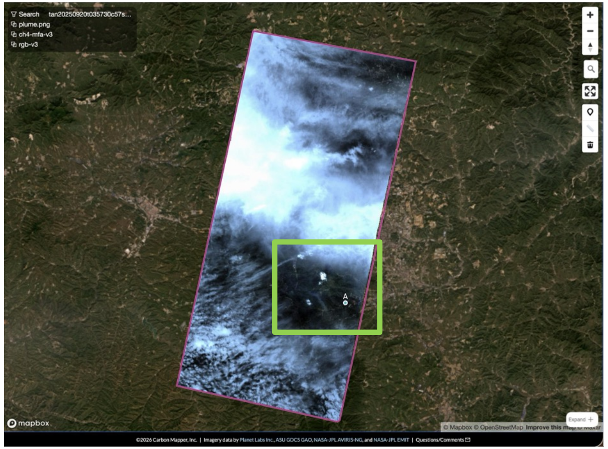
10.5281/zenodo.17047788

Independent evaluation frameworks exist for some gases and source types but need expansion/funding to cover range of environmental factors; emerging standards can promote methodological consistency in detection, quantification, and reporting

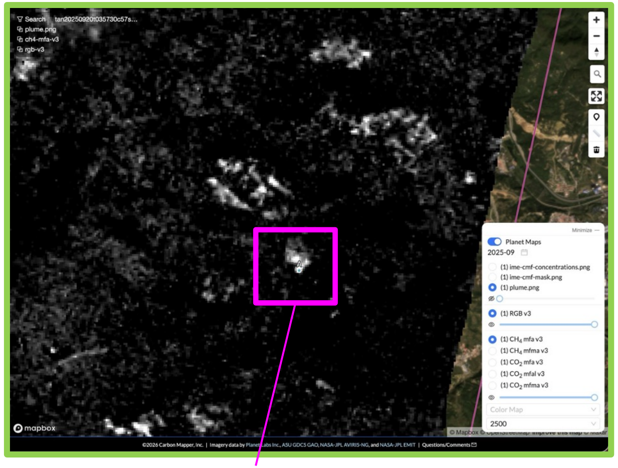
EXAMPLE: AUTOMATED PLUME DETECTION WITH AI & SPECTROSCOPY

Messy, real-world example of false positive rejection with Tanager-1 satellite

Visible bands (mostly cloudy scene)

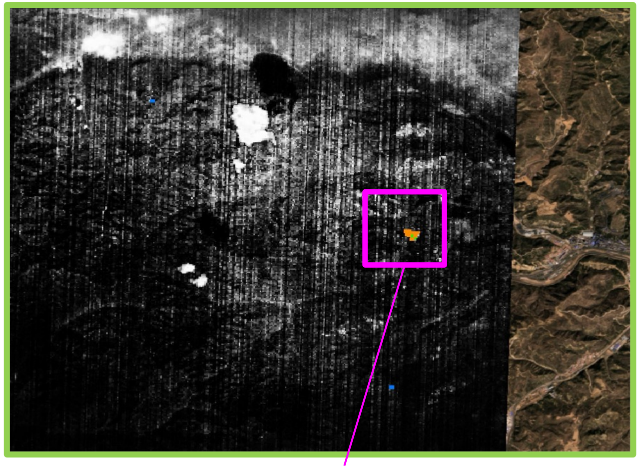


CH4 band with real plume + artifacts



Human analyst detected real plume

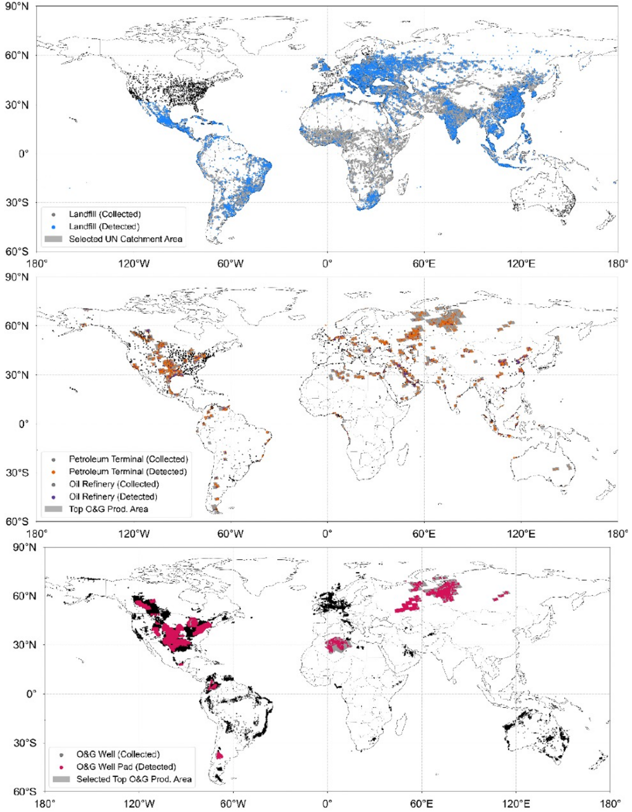
AI analysis of spectral features



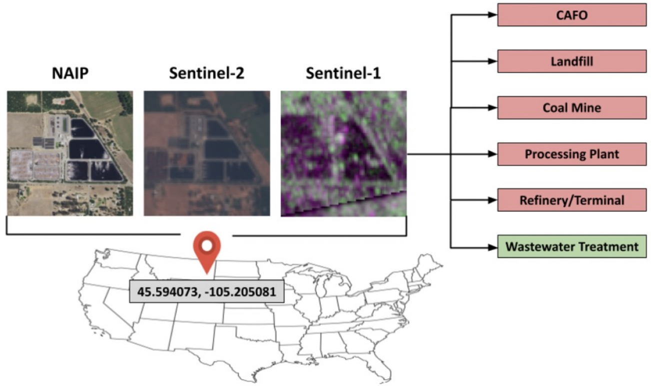
AI spectral classification of atmospheric absorption features verifies human detection

Conventional computer vision (trained on plume shapes) can detect large, clean sources under optimal conditions but true operational monitoring must function reliably under worst-case conditions…
also, every team using ML in production-mode include skilled humans in the loop.

EXAMPLE: CLASSIFY EMITTING INFRASTRUCTURE WITH AI & SATELLITE IMAGERY



Informs satellite observations and attribution analysis



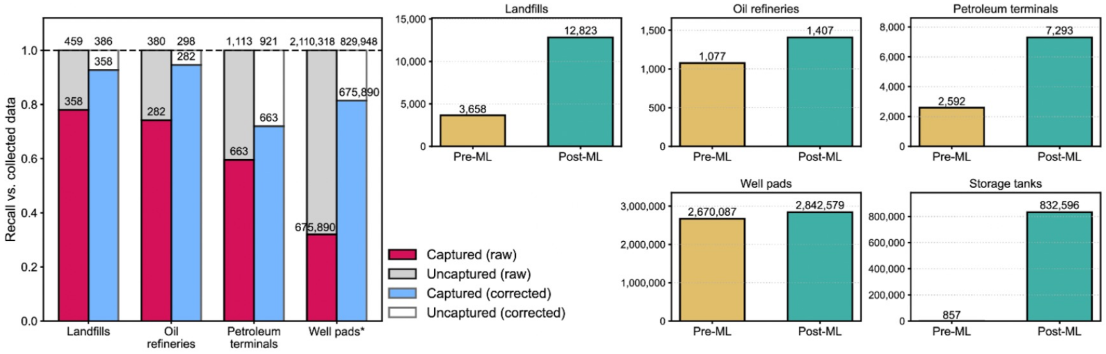
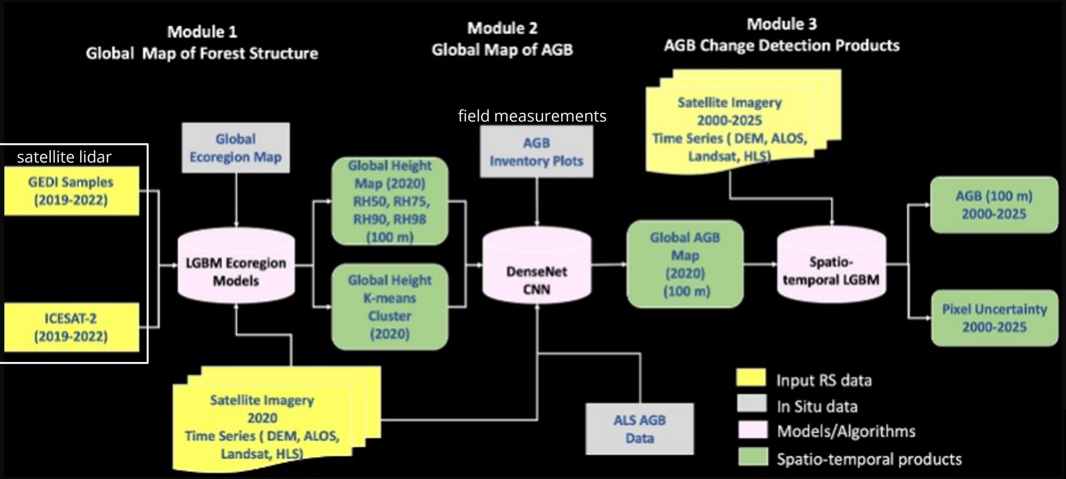


Figure 6: Comparison of ML detections with collected data in METER. The left plot shows the per-facility proportions of collected data in the target areas that the ML models captured, defined as an ML detection within d_f of the collected location (see Sects. 2.3.2 and 2.3.4). We plot both the raw proportions of collected facilities and corrected proportions, where we manually review and remove erroneous locations.

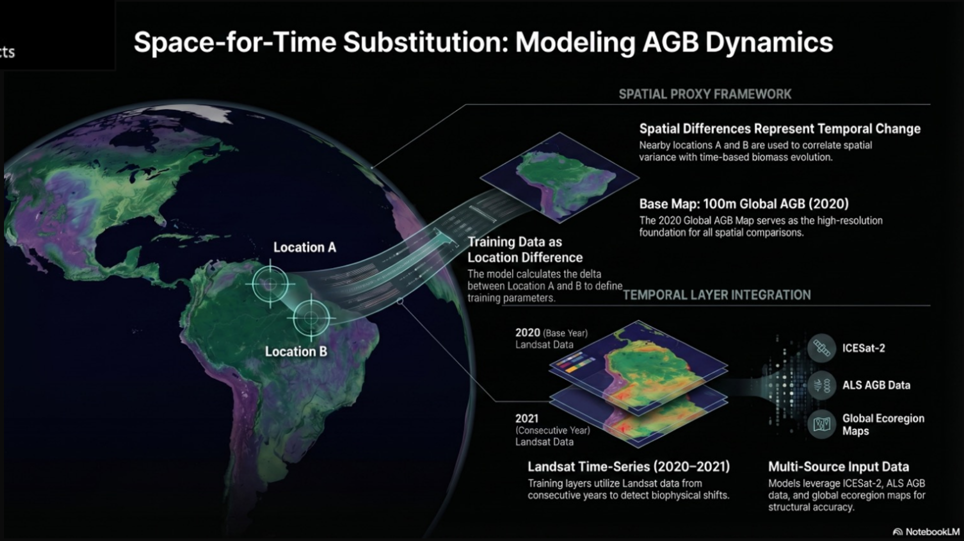
Jackson et al 2026 https://doi.org/10.5194/essd-2026-124

EXAMPLE: QUANTIFY ABOVE GROUND BIOMASS (AGB) WITH SATELLITE & FIELD OBSERVATIONS AND PHYSICS-BASED AI



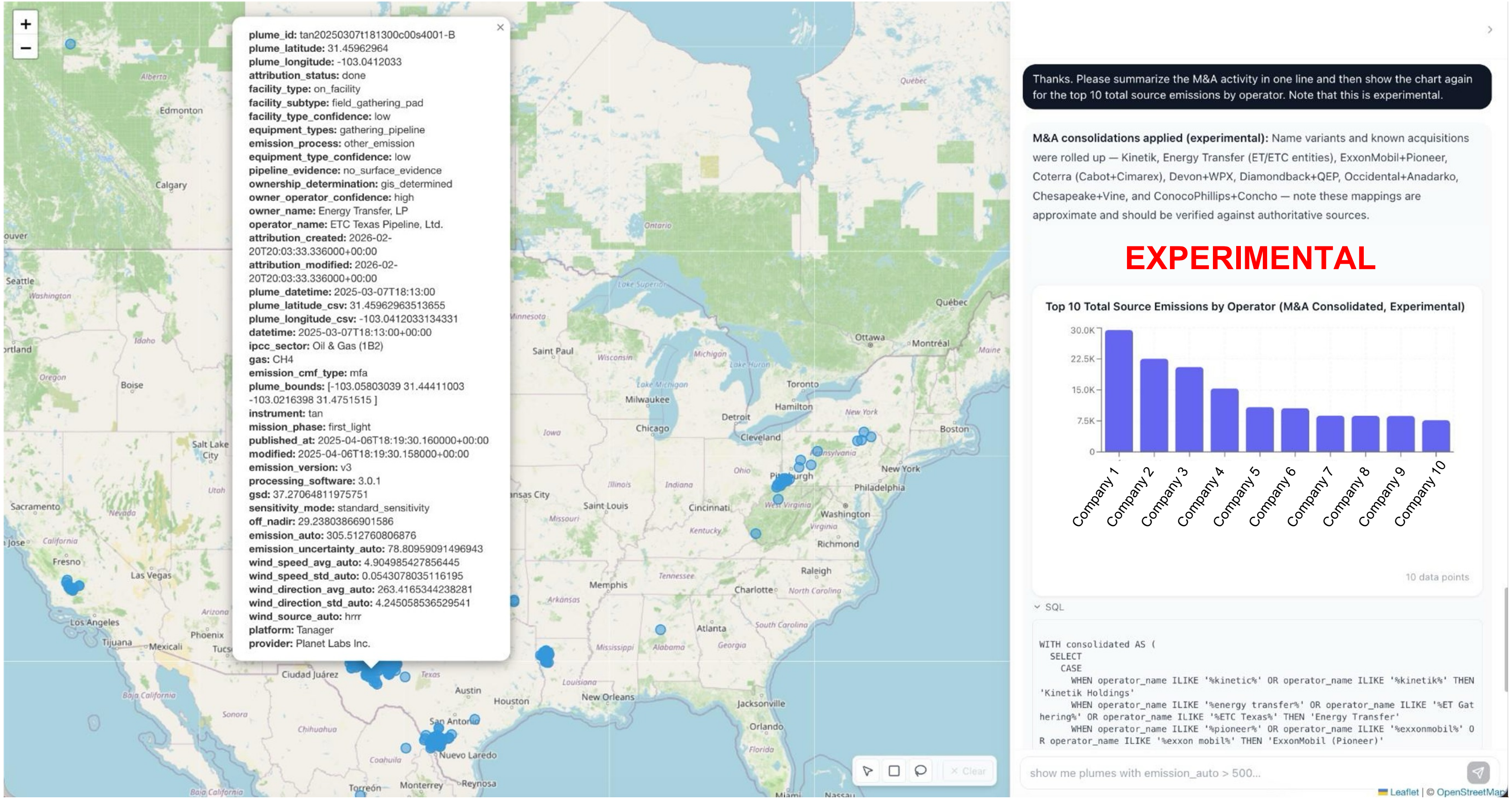
Physics-Informed Neural Networks for Building a Global Aboveground Biomass Monitoring Framework

Sassan Saatchi (CEO, CTrees.org)



EXAMPLE: INTERPRETING CH4 AND ASSET DATA WITH AI

Applied Claude Sonnet to Carbon Mapper data plus oil & gas mergers & acquisition info to rank prevalence of super-emitters



SOME CAUTIONARY NOTES

- Misperception #1: "AI is less uncertain/subjective than natural intelligence"
- Misperception #2: "We can have faster, better and cheaper"
- AI (when properly validated) can help fill gaps in activity data; physics-based methods are generally better suited at resolving errors in emission factors
- AI can amplify the black-box nature of complex data production
- What is truth? Training on data sets produced without standards
- Stakeholders may not appreciate data limitations, nuances, and uncertainties
- Can benefits of AI offset environmental impacts and QC overhead?

We're in the "messy middle" with rapidly evolving capabilities and actors; communication is key to managing risks

LOOKING AHEAD

- Roles for artificial intelligence (AI)
  - Improving efficiency for big data workflows
  - Filling gaps in activity data
  - Support for translating geophysical data and interpretation
- Roles for natural intelligence (NI)
  - Grounding AI and emission factors with empirical, physics-based methods
  - Validation, verification and quality control
  - Reconciliation, synthesis, interpretation, and translation
  - User engagement and co-development of knowledge (and policy)
- Specific challenges and opportunities
  - Establishing standards for methods, validation, and reconciliation
  - Data policy: balancing accessibility & trust with diversified funding & continuity
  - Governance: evolving landscape of data/analysis providers (govt, private sector, NGOs, AI)
  - Improving incentives and capacity for end-users to act on data
  - Communicating risk, nuance and uncertainty to stakeholders

CARBON MAPPER

Thank You

Nominations open for next Decadal Survey on Earth Science & Applications from Space:
https://survey.alchemer.com/s3/8833493/Call-for-Experts-Decadal-Survey-for-Earth-Science-and-Applications-from-Space-2028-2037

Forthcoming: Governance and Coordination Systems for Resilient Earth Observations – Issue Paper
https://www.nationalacademies.org/projects/CHPP-ESR-26-02