GTI ENERGY SAGE
STATISTICS, ANALYTICS, AND GIS IN ENERGY CONFERENCE

August 13-14, 2025 | Des Plaines, Illinois

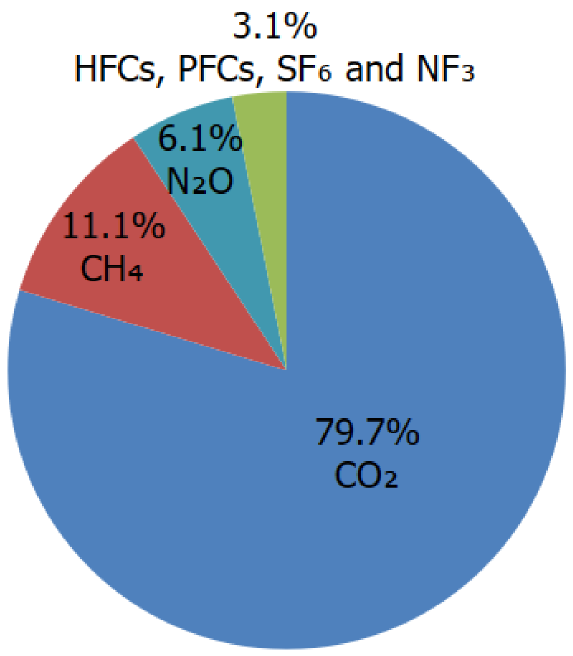
Visual Analytics for Methane Emissions Monitoring: Integrating Multi-Scale Data for Enhanced Detection and Mitigation

Parisa Masnadi[1], Wolfgang Jentner[2], Binbin Weng[1], Chenghao Wang[1], Xiao-Ming Hu[1], and David Ebert[1, 2]

University of Oklahoma[1], University of Arizona[2]

DATA INSTITUTE FOR SOCIETAL CHALLENGES
The UNIVERSITY of OKLAHOMA

Environmental Impact and Regulatory Landscape



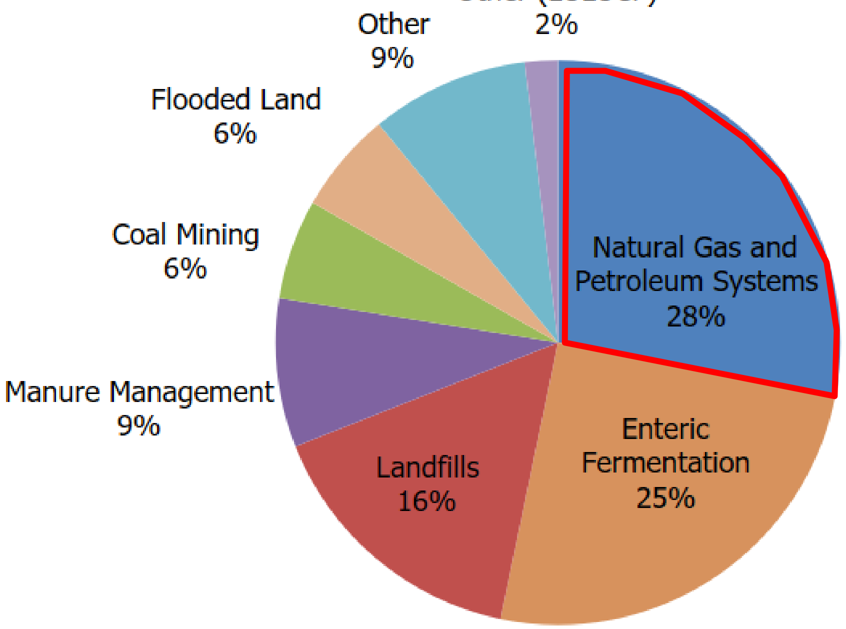
- Methane (**CH_4**)'s **lifetime** is much **shorter** than carbon dioxide (**CO_2**), but CH_4 is more efficient at trapping radiation than CO_2.
- The **impact** of **CH_4** is **28 times** greater than that of **CO_2** over **100 years.**

Reference: https://www.epa.gov/ghgemissions/overview-greenhouse-gases

Environmental Impact and Regulatory Landscape

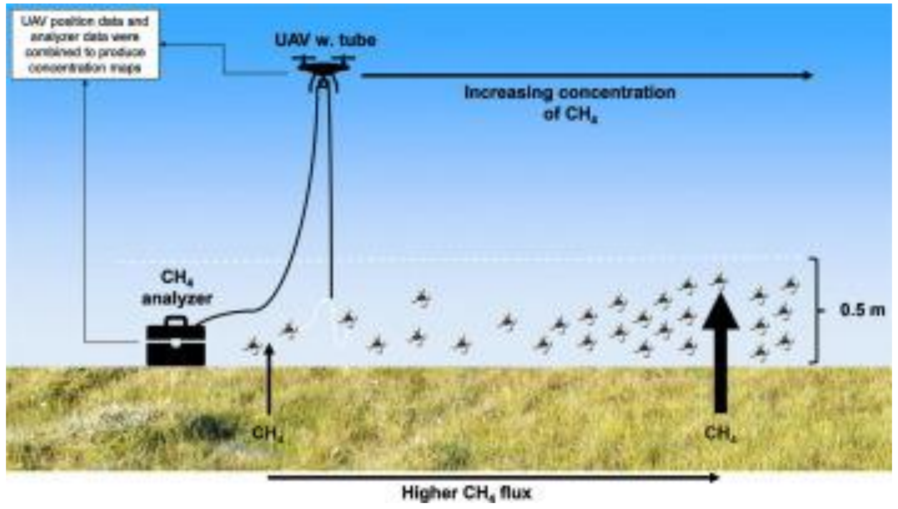
- Methane (CH_4)'s **lifetime** is much **shorter** than carbon dioxide (**CO_2**), but CH_4 is more efficient at trapping radiation than CO_2.
- The **impact** of **CH_4** is **28 times** greater than that of **CO_2** over **100 years.**

- **CH_4** Driven by both **human** activities and **natural** processes.



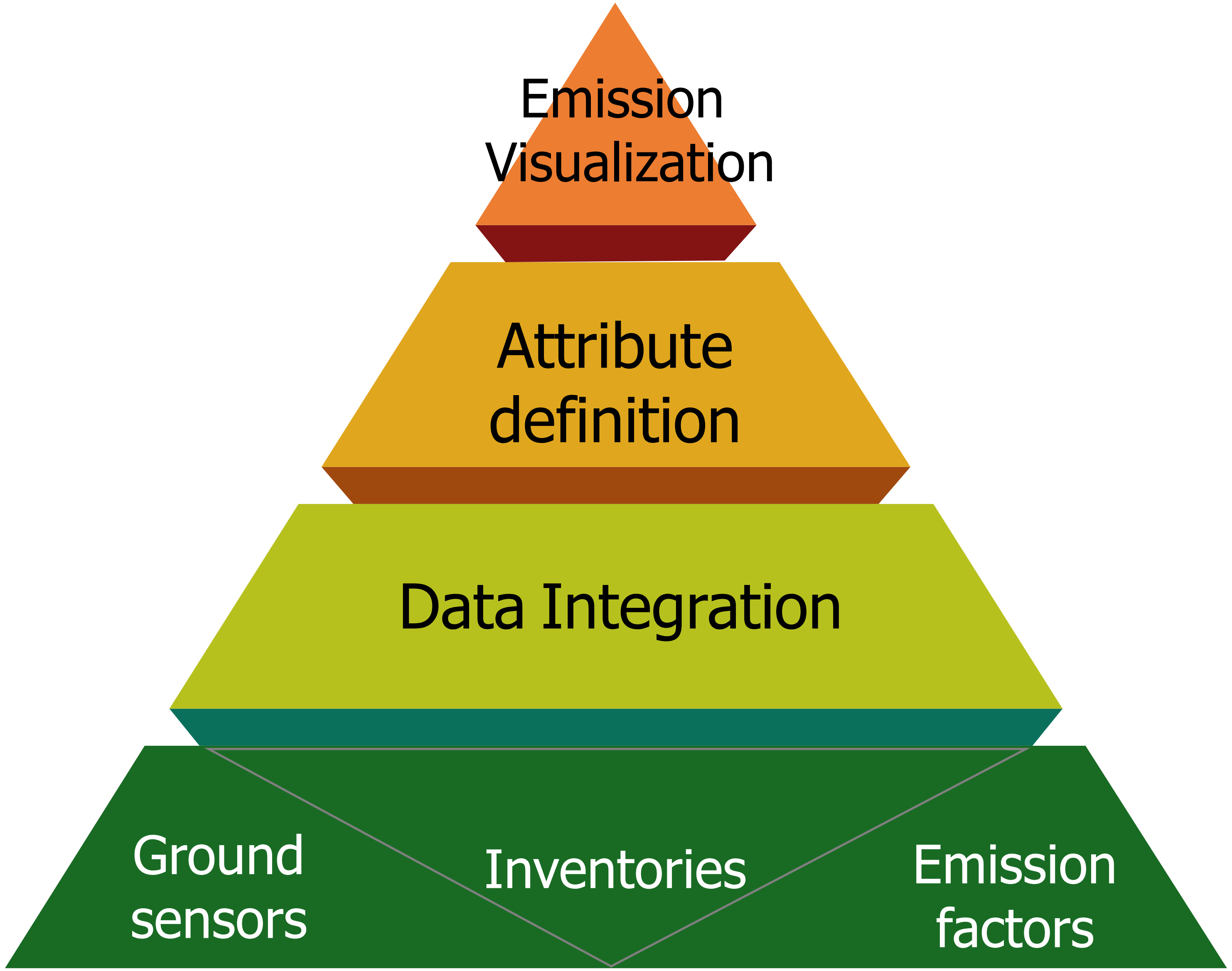
Current Monitoring Methods & Gaps

- Two main methods:
  - Bottom-Up
    - Ground sensors and inventory measurement
  - Top-Down
    - Atmospheric measurement and consideration



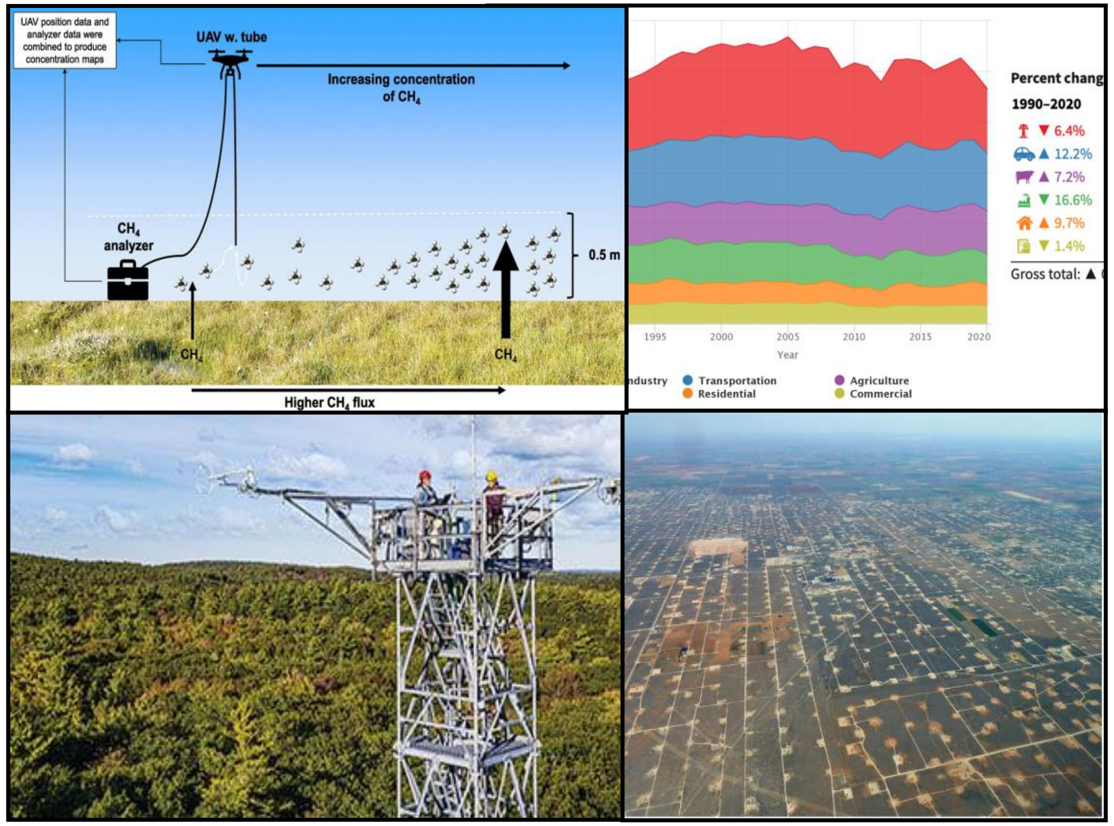
- Detailed explanation and challenges on the next slide.

Bottom-Up Approach in a Glance

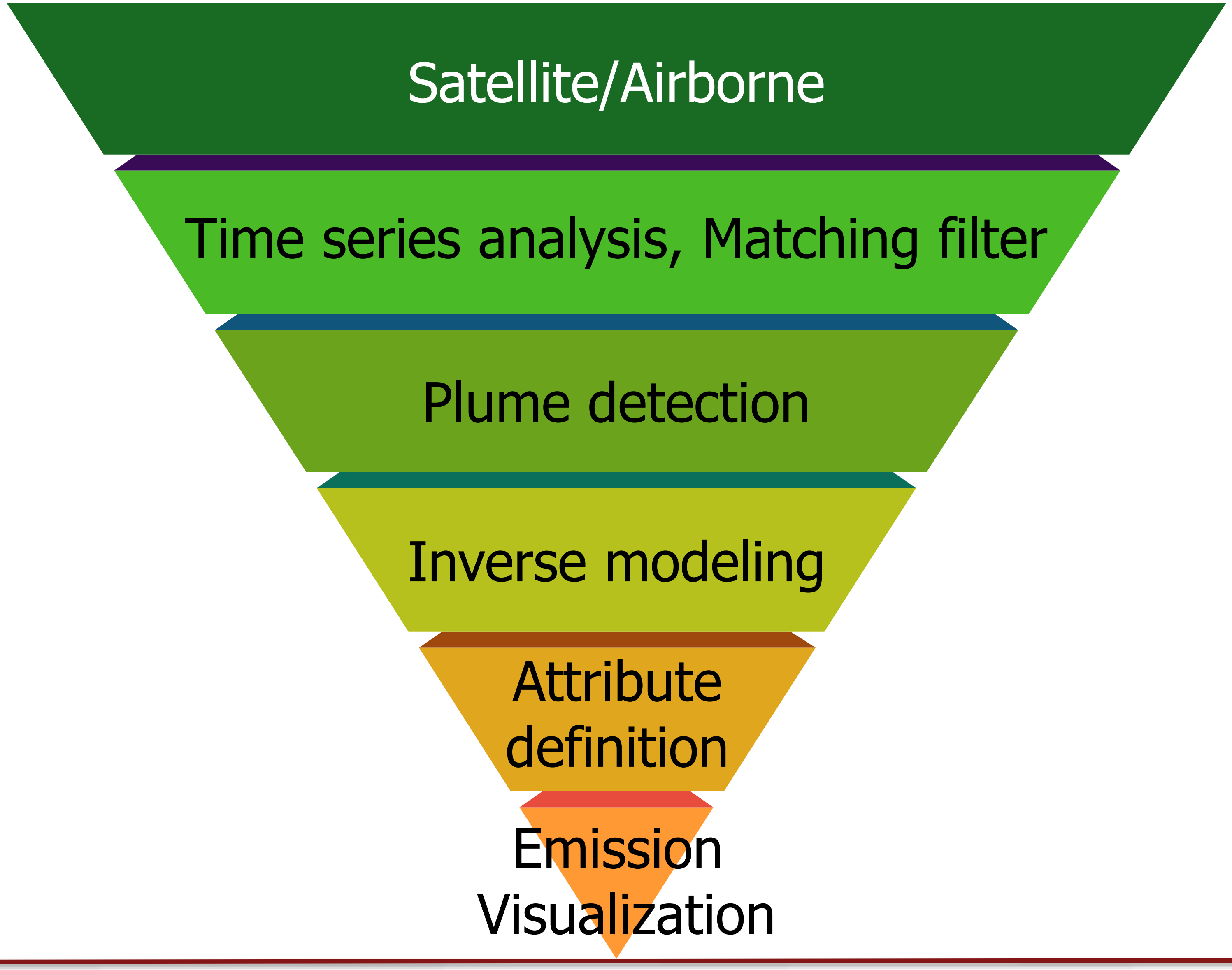


Bottom-Up Limitation

- **Infrastructure required for** high-resolution data
- **Infrequent** inventory updates
- **Challenging** data integration and validation
- **Uncertain** emission estimates
- **Lack** of accurate Infrastructure information

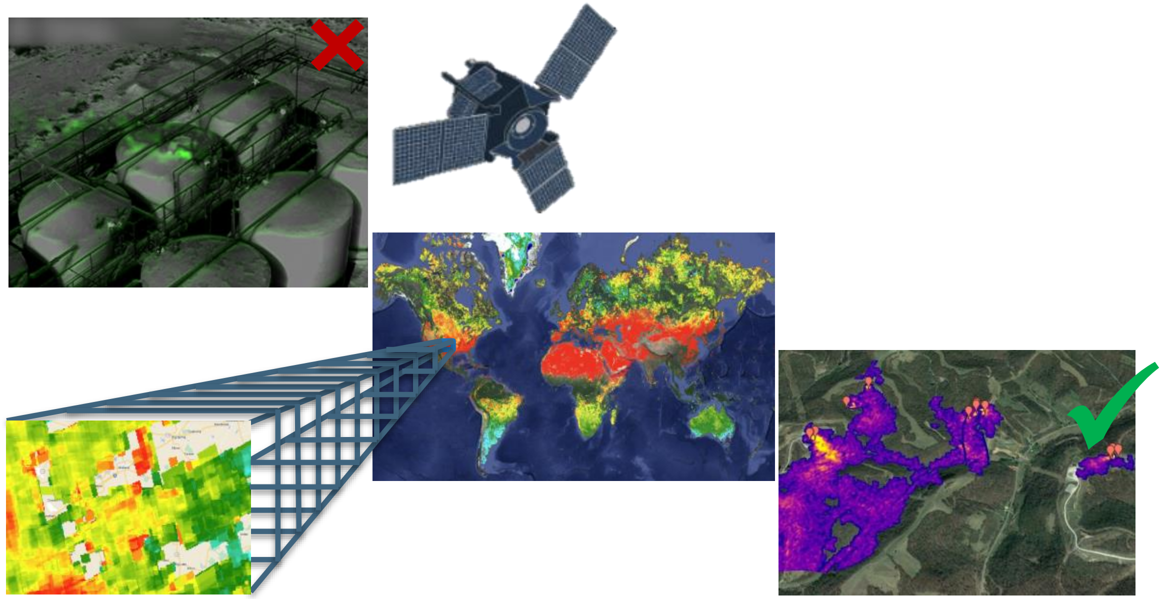


Top-Down Approach in a Glance

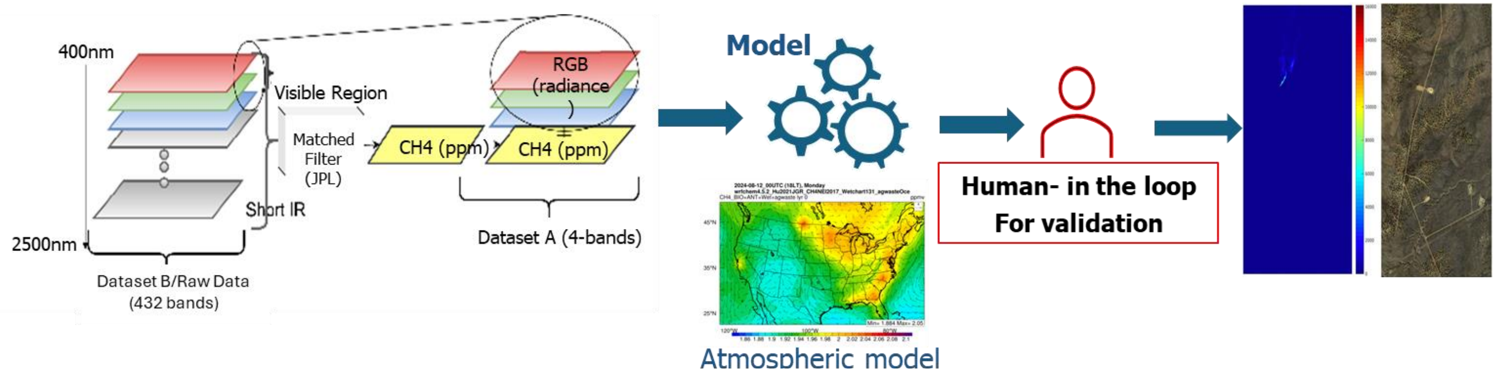


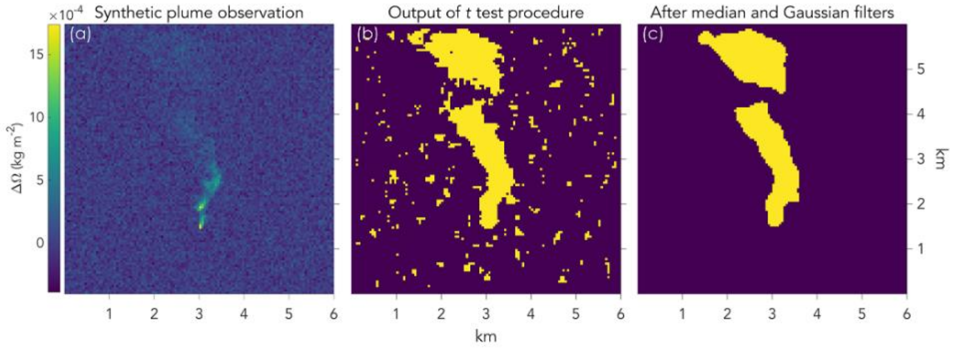
Top-Down Limitation

- **Challenges in Detecting** Low-Rate Emissions
- **Low** spatial **resolution** and **weather** sensitivity
- **Revisit limitations** for intermittent emission detection



- **Matched filter** techniques require **humans** to filter out false detections.
- **Inversion methods** depend on **local wind**

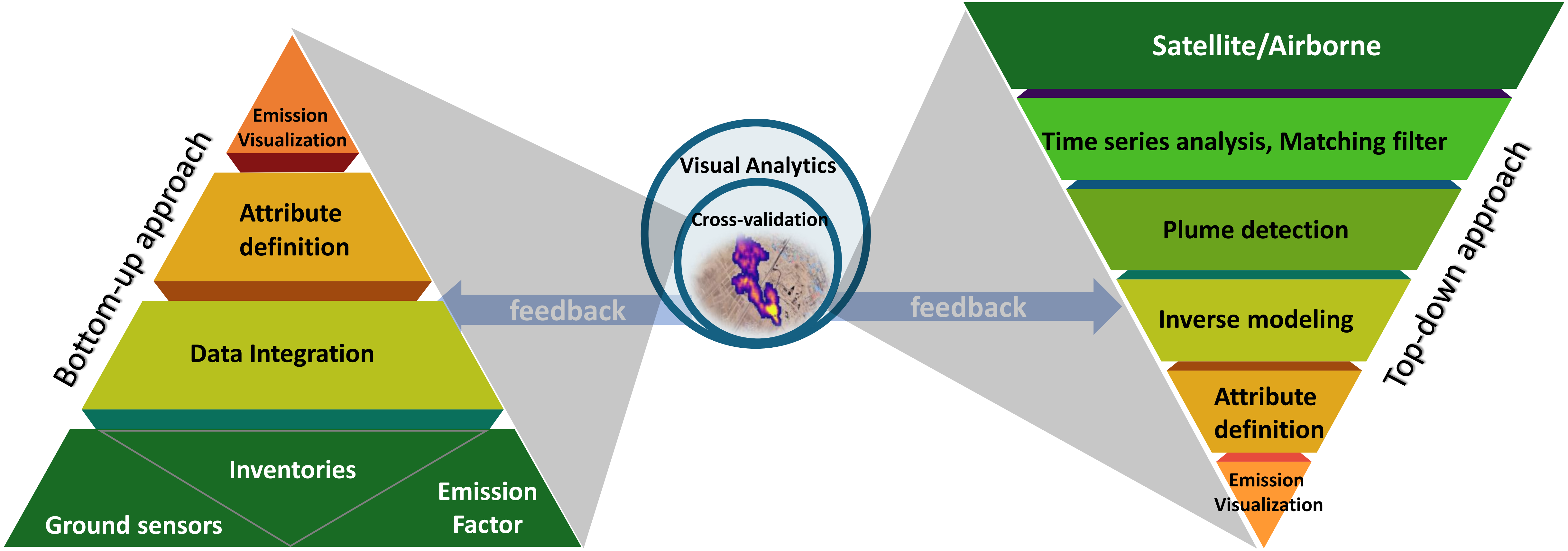




References: Varon, Daniel J., et al. "Quantifying methane point sources from fine-scale satellite observations of atmospheric methane plumes." Atmospheric Measurement Techniques 11.10 (2018): 5673-5686.
https://daac-news.ornl.gov/content/aviris-ng-spectra-above, https://sierraolympia.com/sierra-olympias-ogi-camera-featured-on-national-tv/

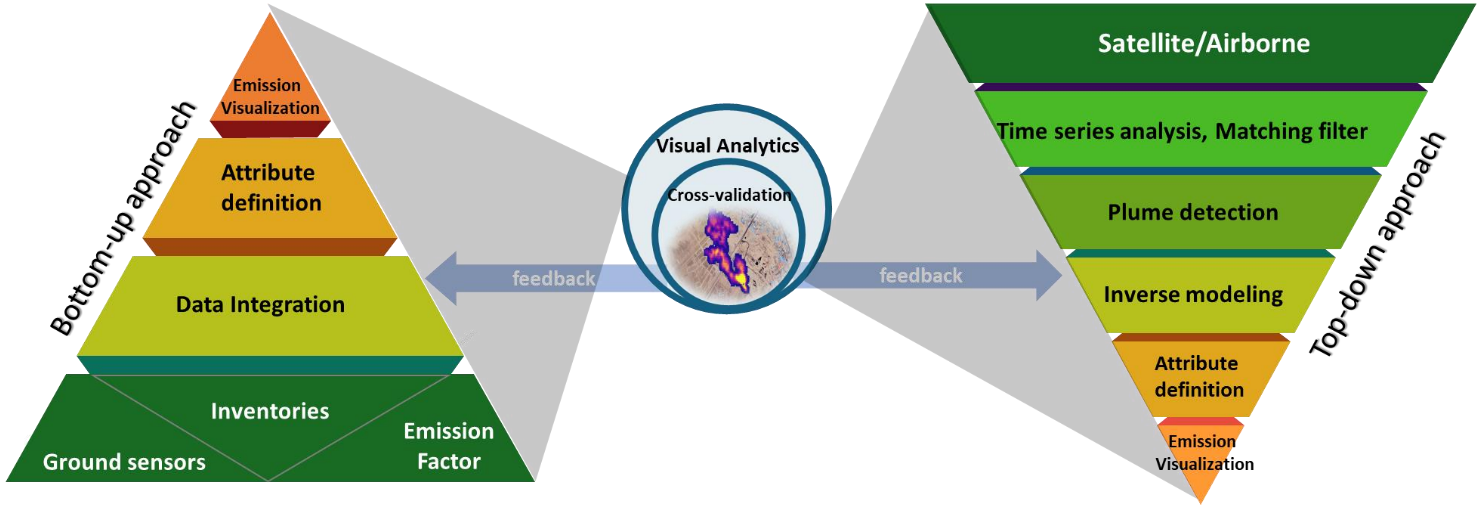
Integration approach and visual analytics solution

Integrated Monitoring System (IMS)



How can IMS Help?

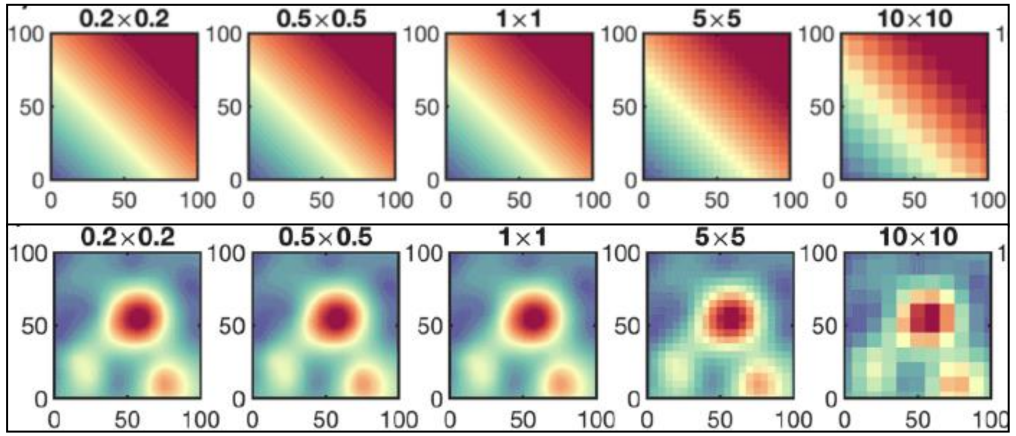
- Enable data comparison and **cross-validation**
- Identify data **discrepancies**, anomalies, and measurement **errors**
- **Improve** the accuracy of **emission volume** and **source identification**
- Enhance the process with:
  - Human-in-the-loop interactions
  - ML in VA combination
  - Data exploration techniques



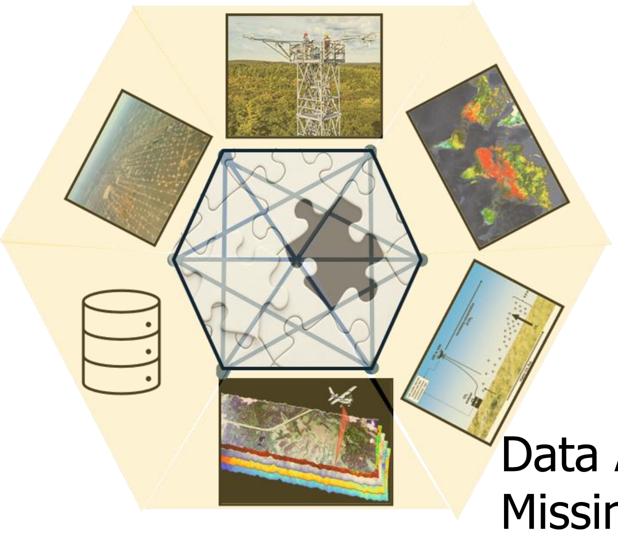
- Detect specific areas for **target mitigation**

IMS Challenges

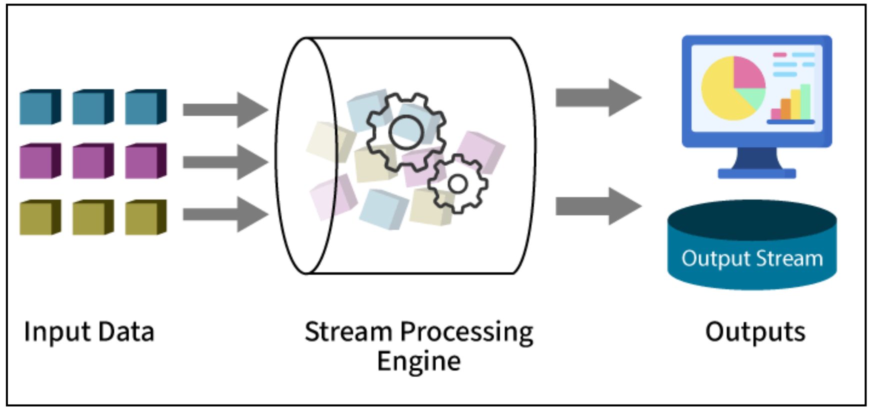
- **Data integration:** Heterogeneous, multi-dimensional data with semantic differences
- **Quality: Alignment** issues and **missing values** from environmental conditions and equipment failures
- With all these conditions, the whole procedure should be processed in **real-time**



Resolution differences



Data Alignment
Missing value



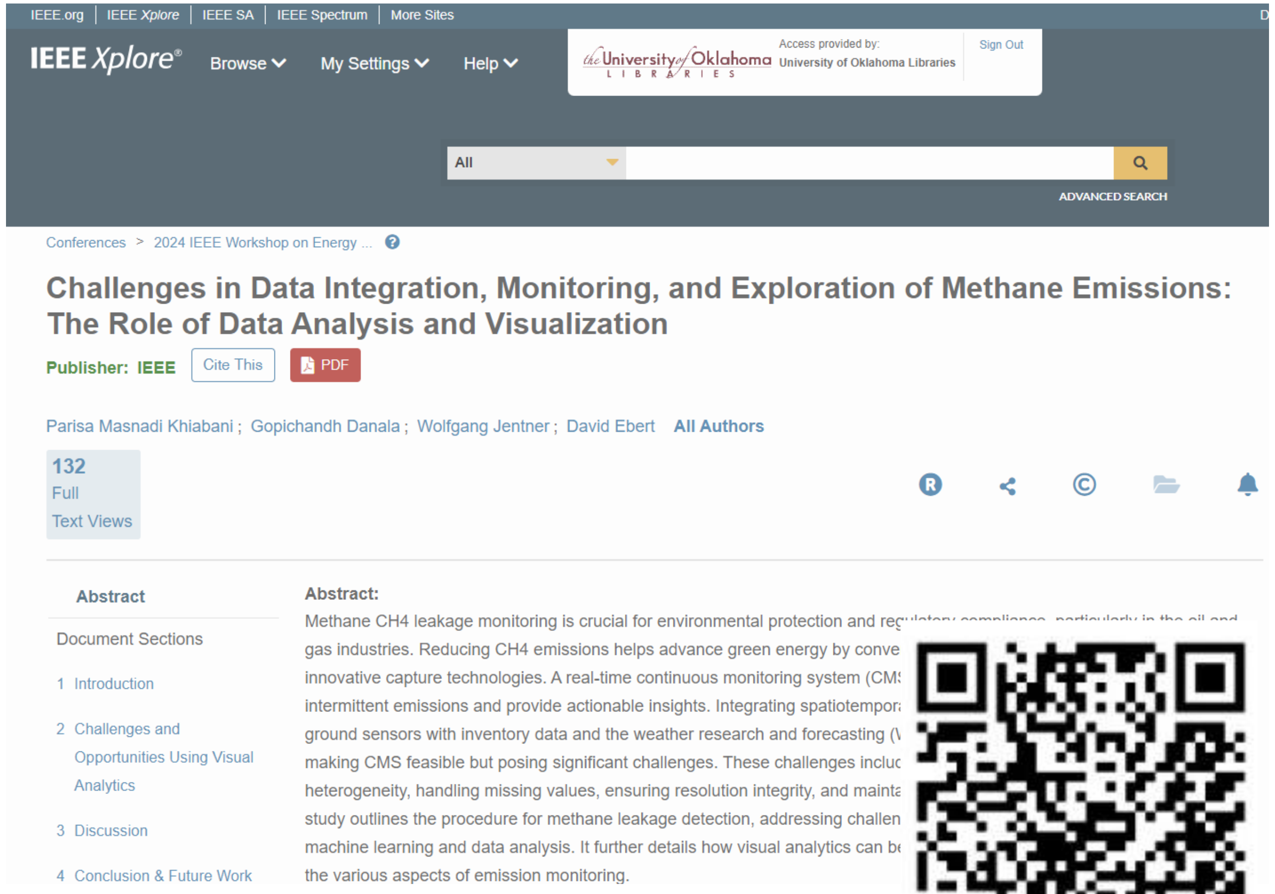
Data surge real-time processing

References: Souri, Amir H., et al. "Dealing with Spatial Heterogeneity in Pointwise to Gridded Data Comparisons." Atmospheric Measurement Techniques Discussions 2021 (2021): 1-33.

IMS Requirements

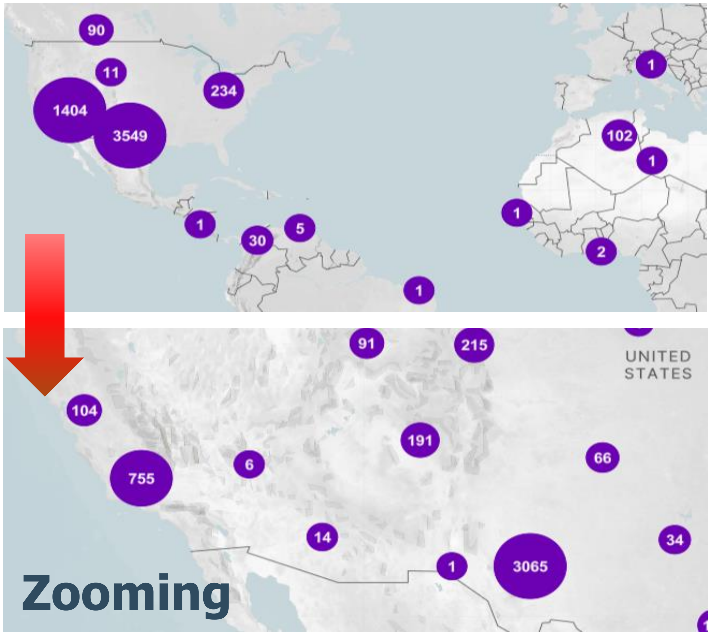
- **Robust Framework:**
  - Data **credibility**, **validation**, and **regulatory compliance**
- **Data Fusion**
  - **integrating** different data sources with varying quality, timing, and resolution
  - Critical for **creating** a **unified**, **reliable dataset** from **heterogeneous inputs**
- **Visual Analytics**
  - Essential for **stakeholder engagement** and **evidence-based decision processes**
  - Enables **anomaly detection**, result verification, and **multi-dimensional data exploration**

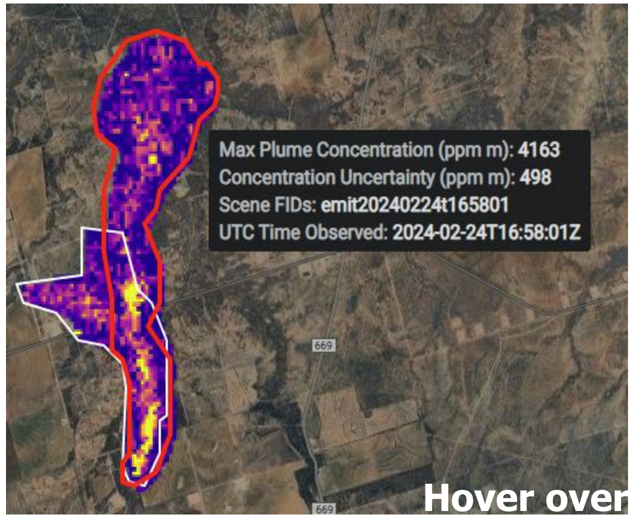
Challenges in Data Integration, Monitoring, and Exploration of Methane Emissions: The Role of Data Analysis and Visualization

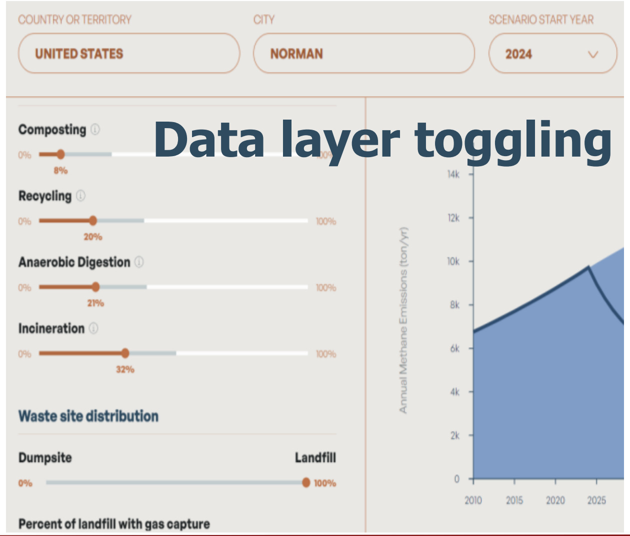


IMS - Interactive Dashboard Requirements

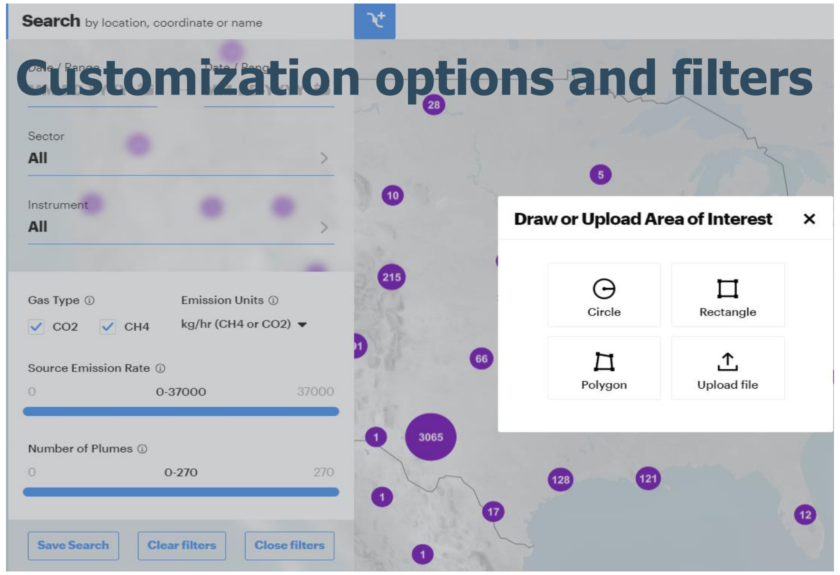
Data Interaction

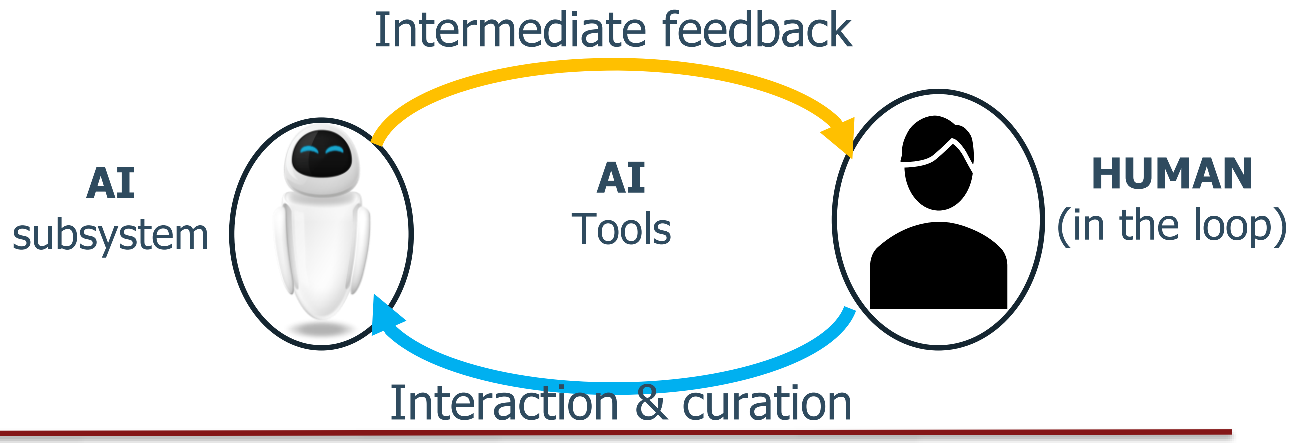






Customization & Filtering





References: https://data.carbonmapper.org/#1.73/30.8/50.5
https://earth.jpl.nasa.gov/emit/data/data-portal/Greenhouse-Gases/
https://wastemap.earth/map?mode=country&country=USA&city=&site=

How Modeling Enhances Methane Detection & Quantification

Forward Modeling (Bottom-Up Enhancement)

WRF-GHG Model — Regional /Facility
Regional atmospheric transport simulation

Large Eddy Simulation (LES) — Facility
High-resolution turbulence modeling

Predicted Concentrations
Spatial & temporal concentration patterns

Inverse Modeling (Top-Down Applications)

Atmospheric Transport Models — Regional
WRF-GHG + optimization algorithms

Optimization Process
Work backward from measurements

Estimated Emission Rates
Unknown source identification & quantification

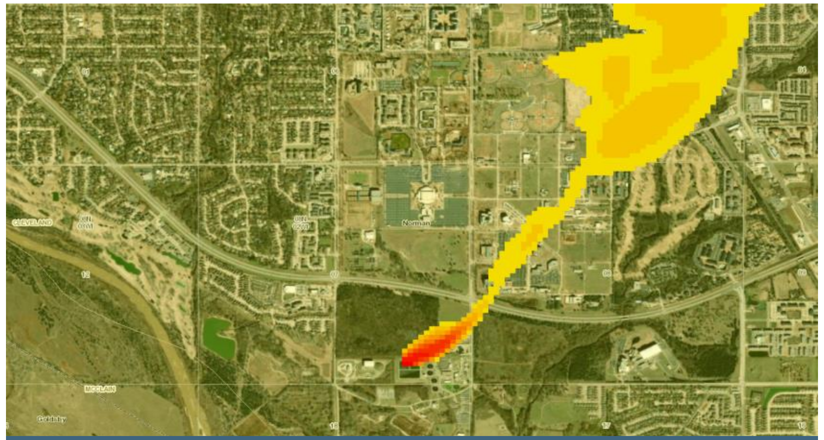
WRF-GHG Model: Weather Research and Forecasting model with greenhouse gas transport capabilities
• **Simulate** methane dispersal and regional methane transport • **Predict** concentration patterns

Large Eddy Simulation (LES): High-resolution turbulence modeling approach
• **Capture** detailed turbulent mixing around sources • **Enable** precise facility-scale emission quantification

Case Study – Mobile Sensor & WRF (Weather Research and Forecasting) Model Output Cross-Validation

LI-COR 7700

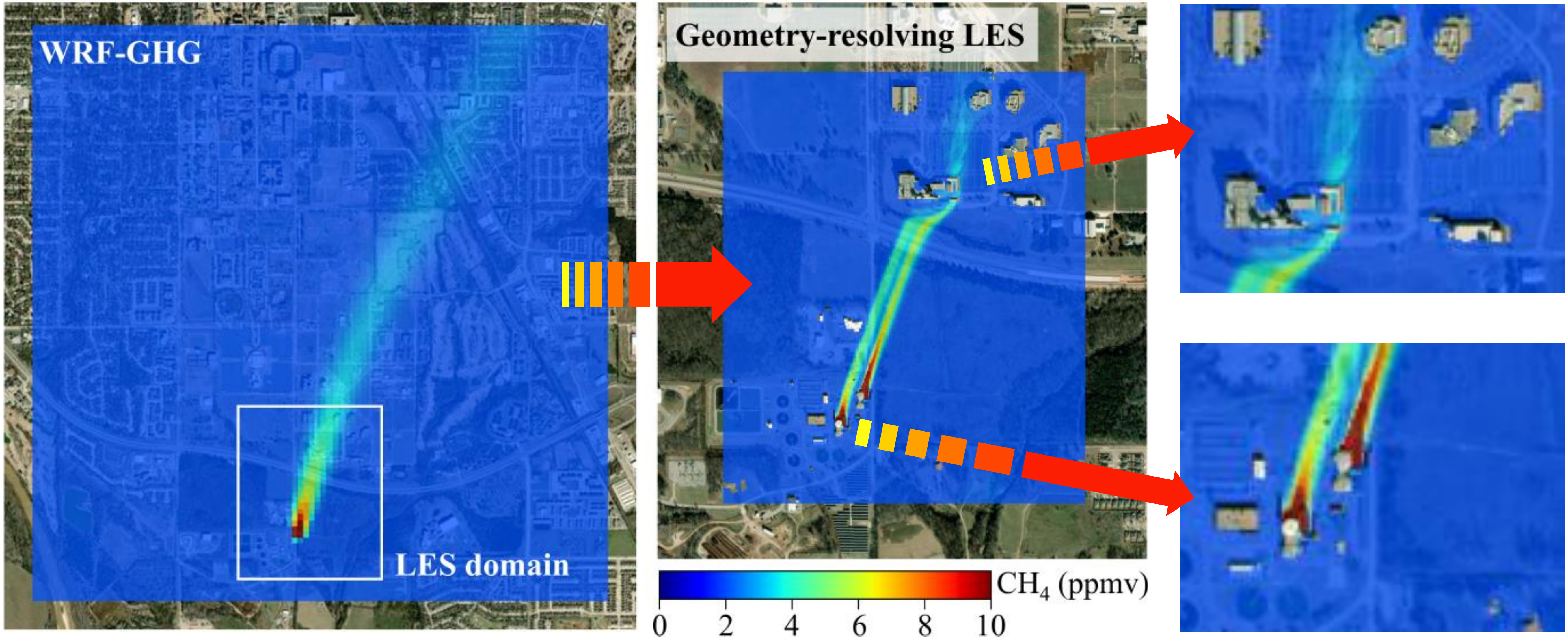
Mobile sensor measurement



WRF model output

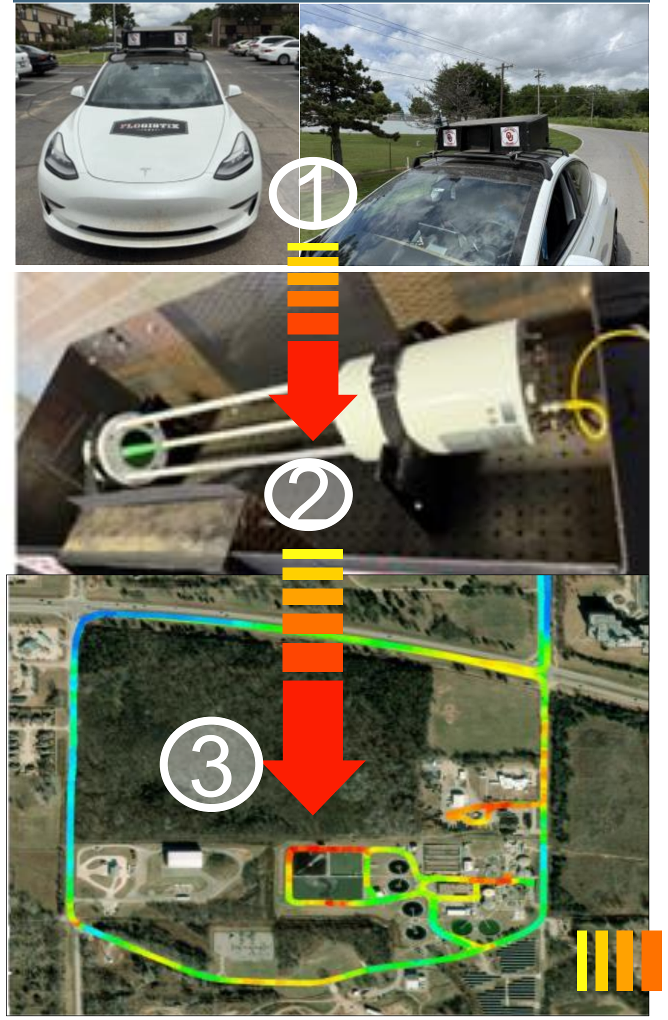
References: Dr. Xiao-Ming Hu: xhu@ou.edu

Case Study – WRF-GHG and LES (Large Eddy Simulation) Integration

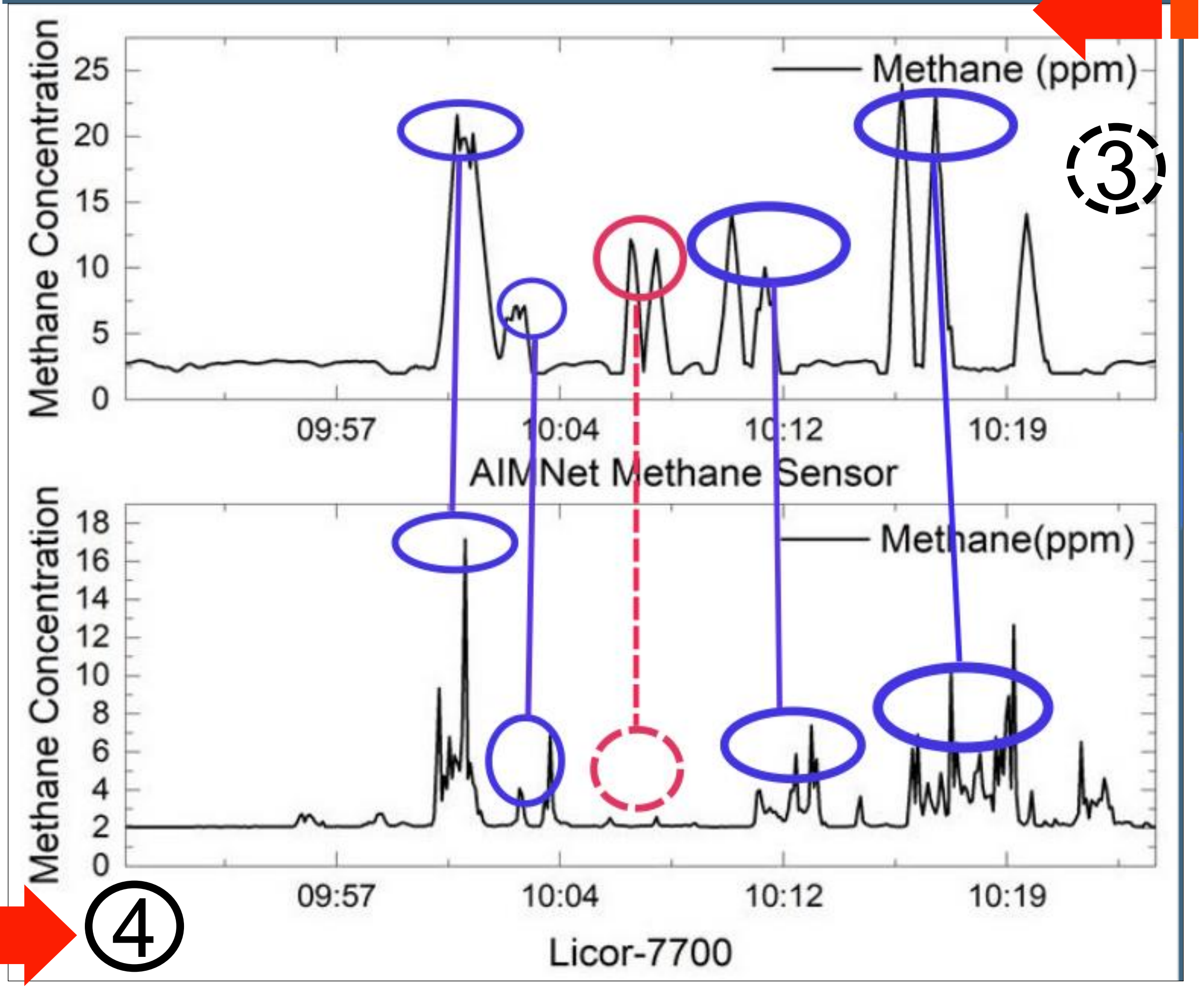


Case Study – Mobile Sensor & Static Sensor

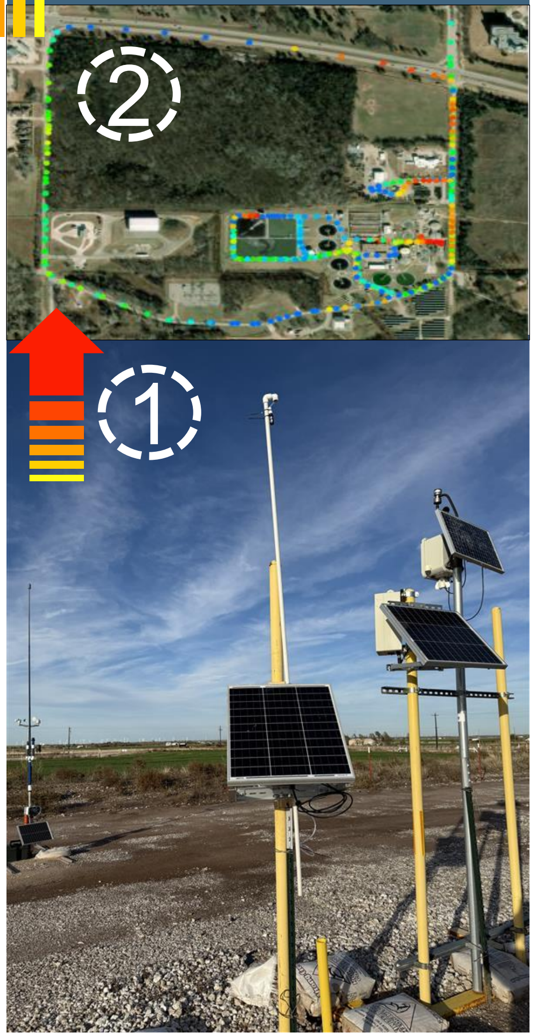
Reference measurement LI-COR 7700



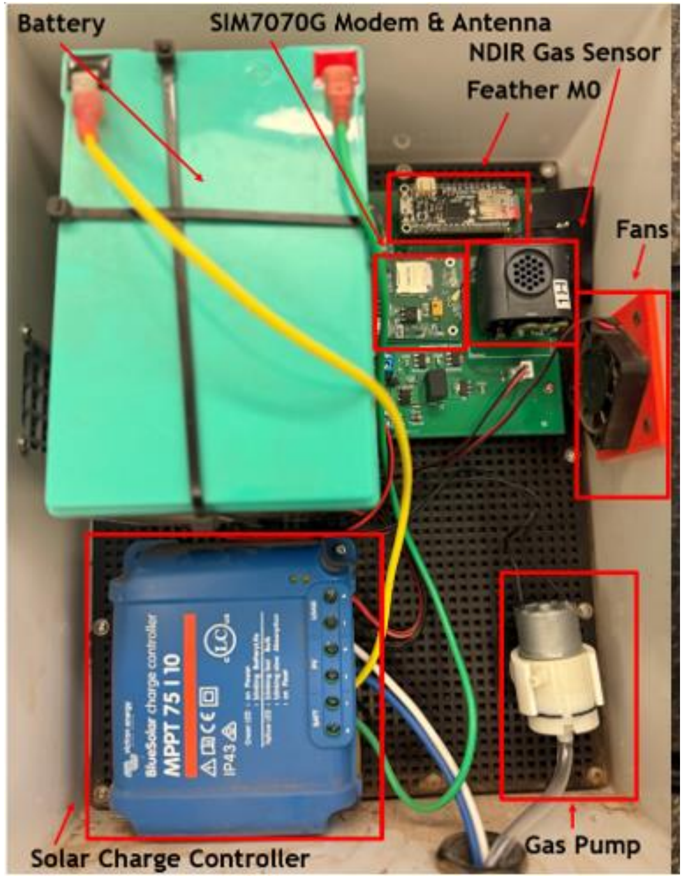
Methane Concentration



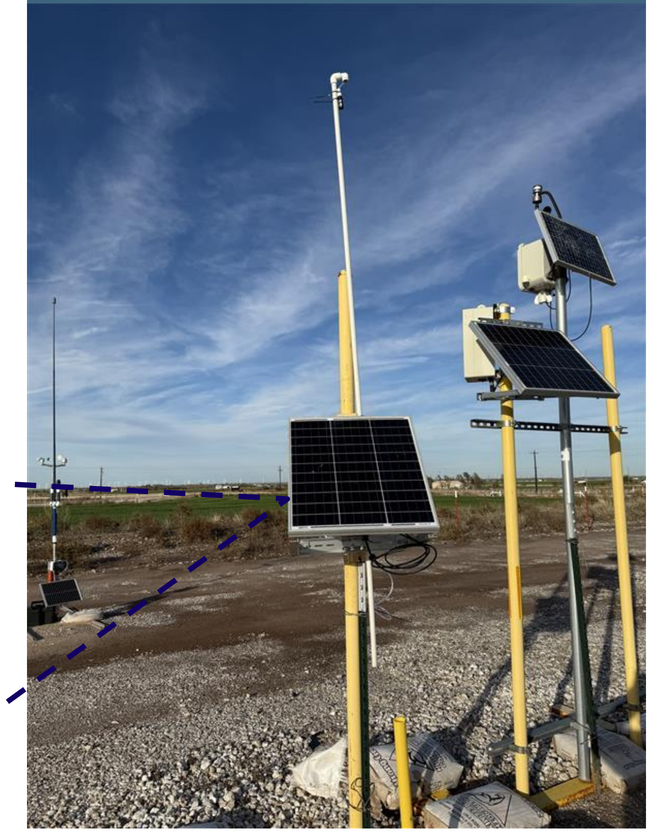
Sensor Measurement



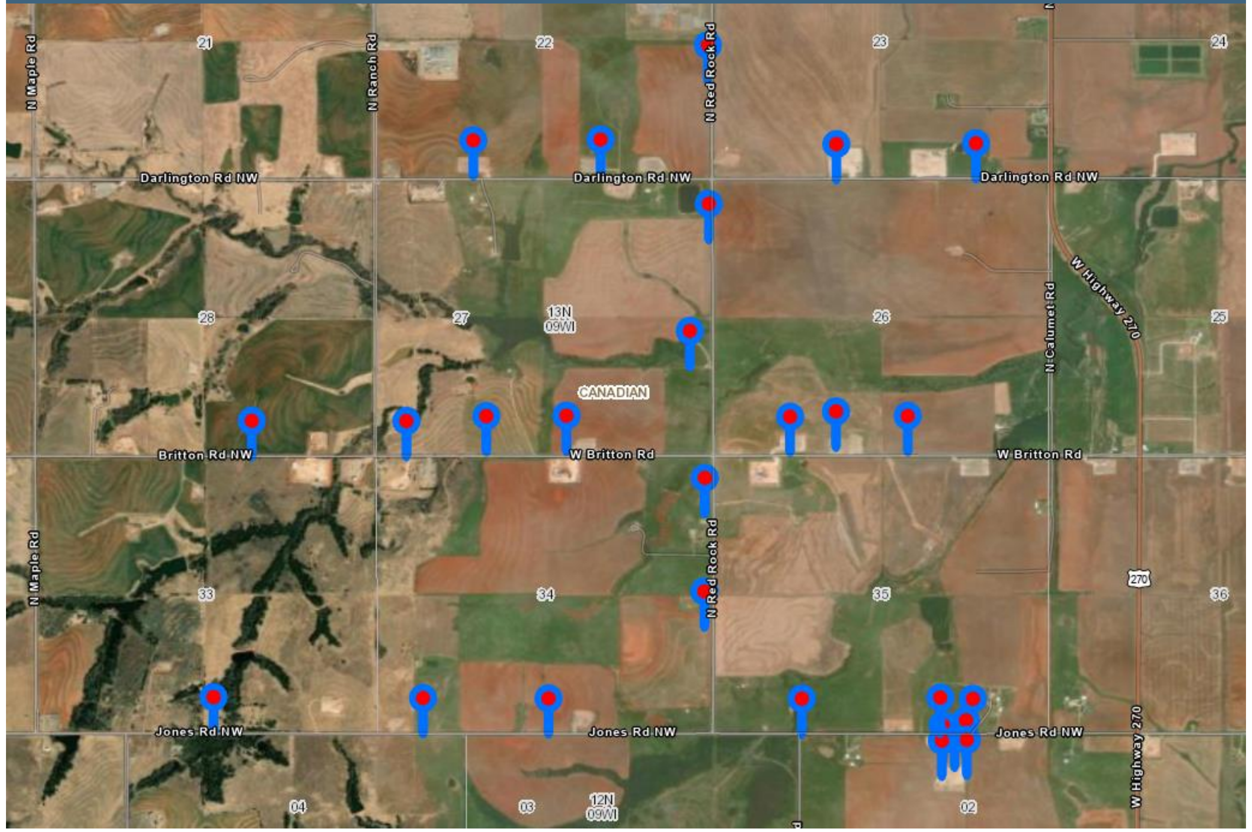
Practical Examples – Static Sensor Deployment in Field Conditions



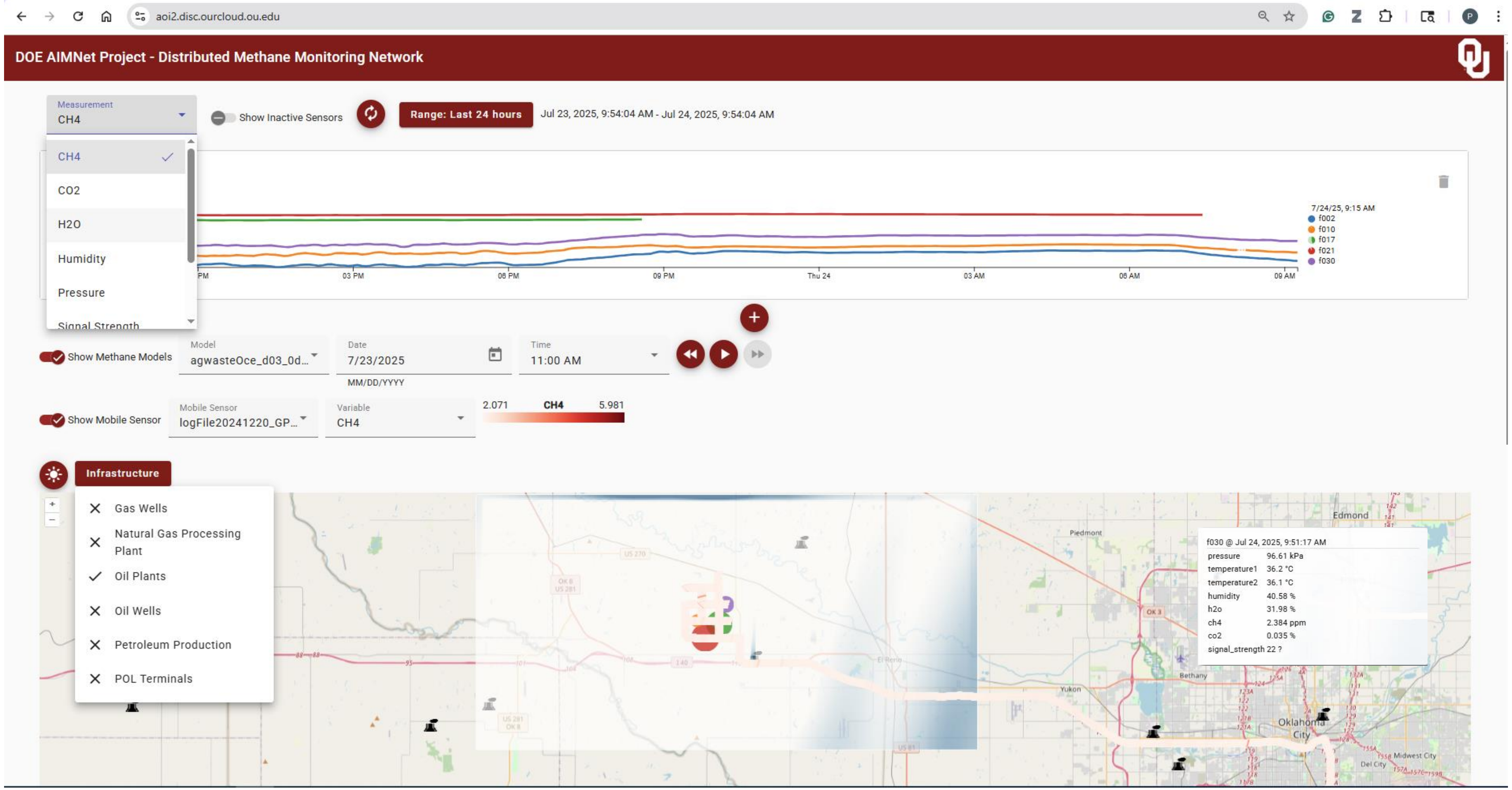
Sensor & solar panel



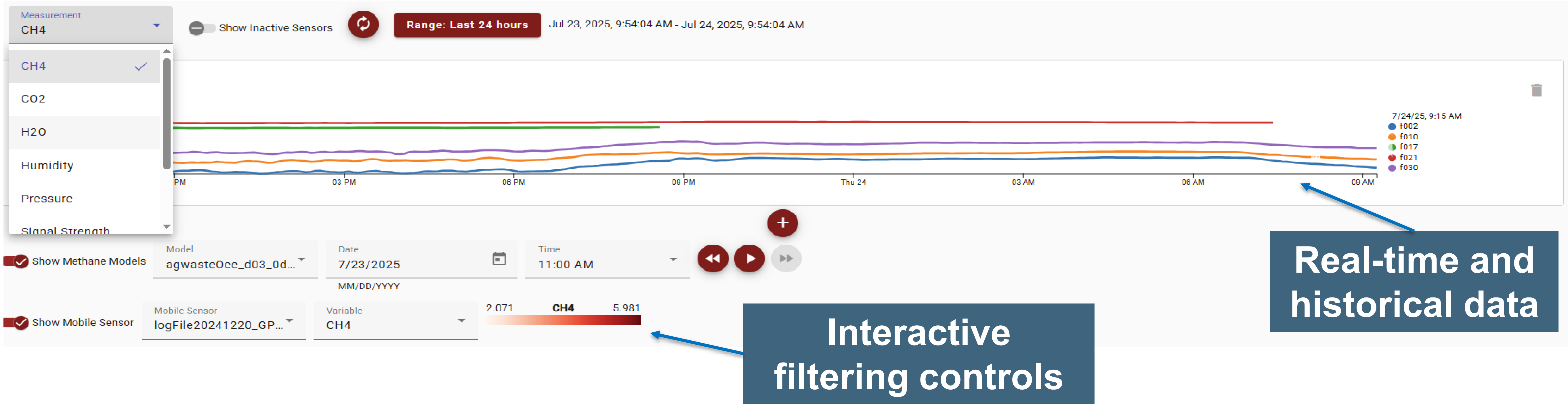
Field Sensors



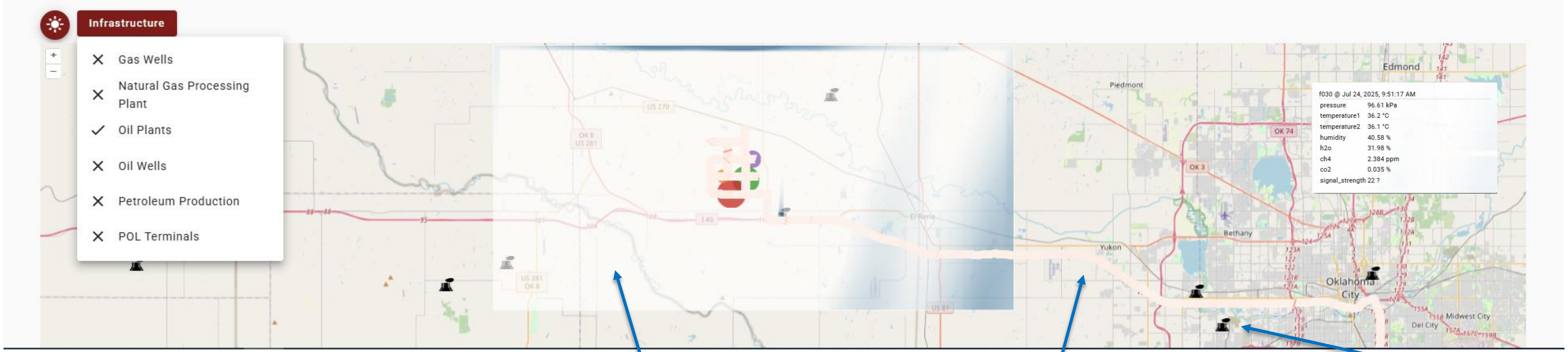
AIMNET Platform – Sensor and Model Visualization



AIMNET Platform – Sensor and Model Visualization



AIMNET Platform – Sensor and Model Visualization



WRF model visualization

Mobile sensor Data Integration

Infrastructure Overlays

Key Takeaways

- **The Challenge**: Individual monitoring methods provide **incomplete coverage**
- **Our Approach**: IMS bridges bottom-up and top-down methods through visual analytics
- **Key Innovation**: **Modeling** plays a crucial role in **pinpointing** the emission **source** location and intensity
- **Validated Platform**: AIMNET system proven with real-world Oklahoma field data
- **Next Steps**: Scaling to industry partners for continuous regulatory compliance

Thank You For Your Attention

Thanks to the Department of Energy and Data Institute for Societal Challenges for their support