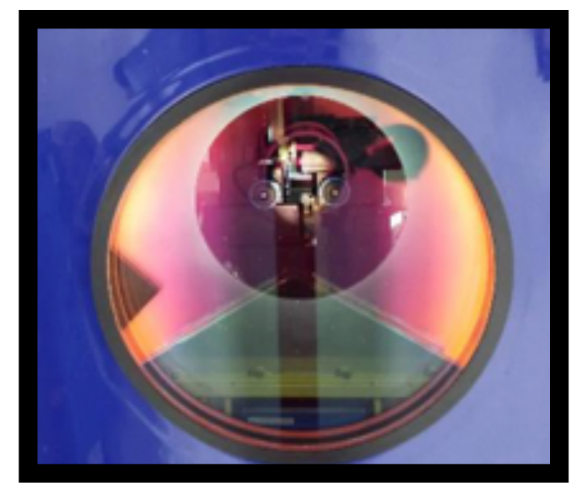

Quantifying Methane Emissions from MethaneAIR and MethaneSAT

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Disclaimer: The algorithms outlined in this poster are intended for discussion and are not necessarily representative of the final MethaneSAT L4 product.

Introduction

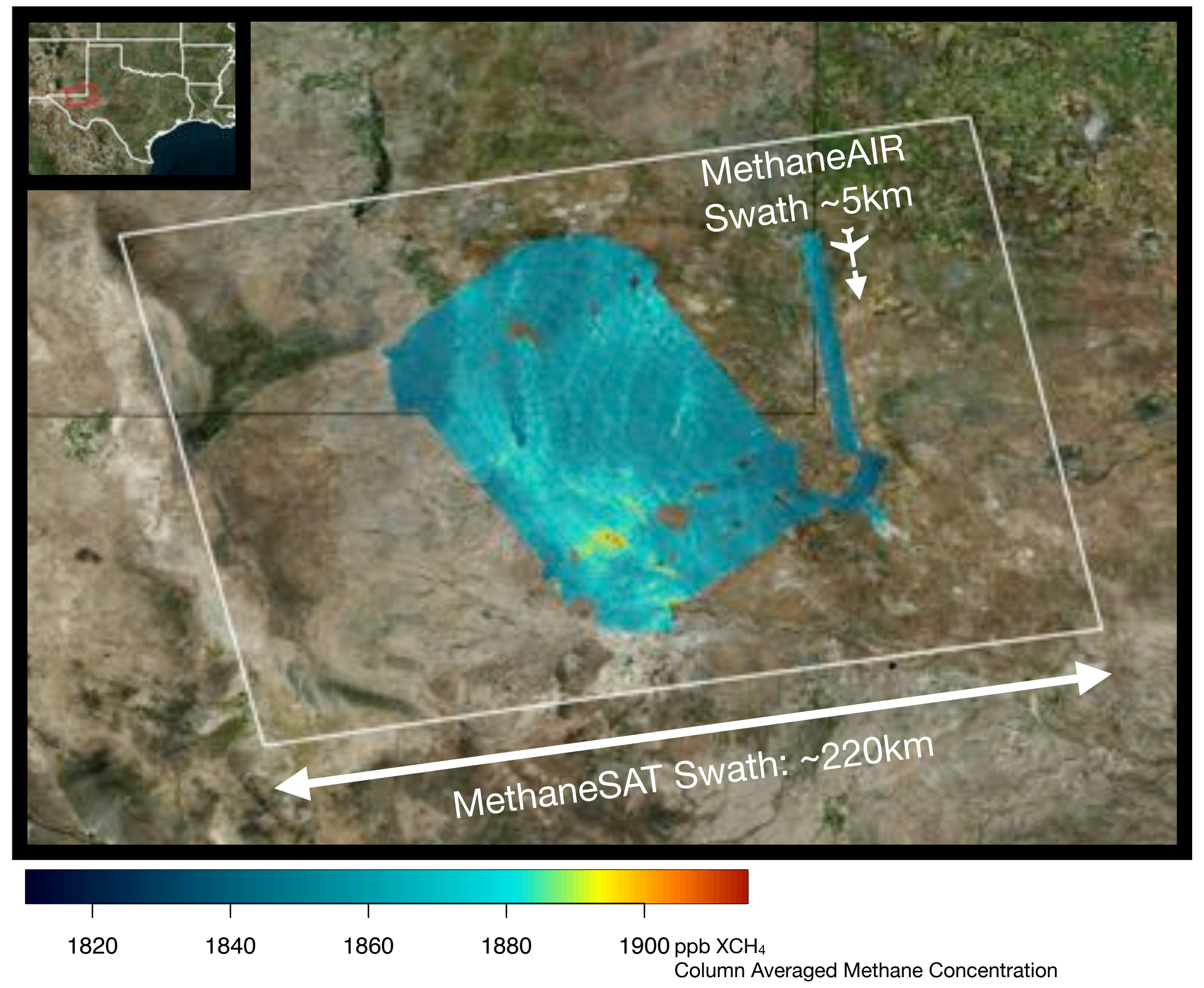
MethaneSAT XCH4 observations offer an unprecedented combination of scale (sweep scans over 200 km x 200 km targets), resolution (~140 m x 400 m), and precision (~2 – 4 ppb @ 1.5 km²).

They provide a unique opportunity for the comprehensive characterization of regional methane emissions, including detection and quantification of large (> 200 kg/hr) point sources and mapping of aggregate and area sources.

While established algorithms exist for the quantification of point sources and mapping aggregate and area sources, these algorithms must be combined carefully to maximize their utility and ensure accurate accounting of total regional emissions.

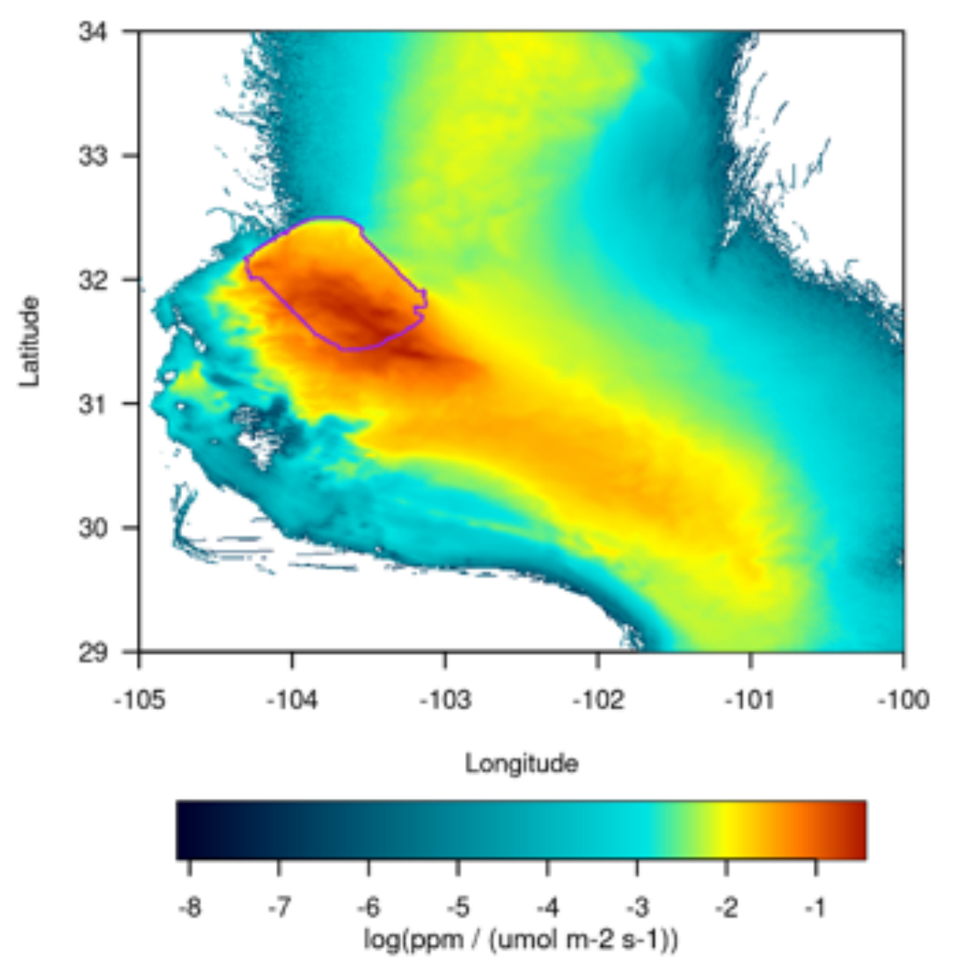
Our approach is staged – we start with point source detection and quantification using the divergence integral method, then remove the enhancement due to point sources from the observations, then quantify aggregate and area sources using a Markov chain Monte Carlo solution to the inverse problem with a Jacobian from the Stochastic Time-Inverted Lagrangian Transport (STILT) model.

Example MethaneAIR Observations From The Delaware Basin in Texas/New Mexico August 6, 2021

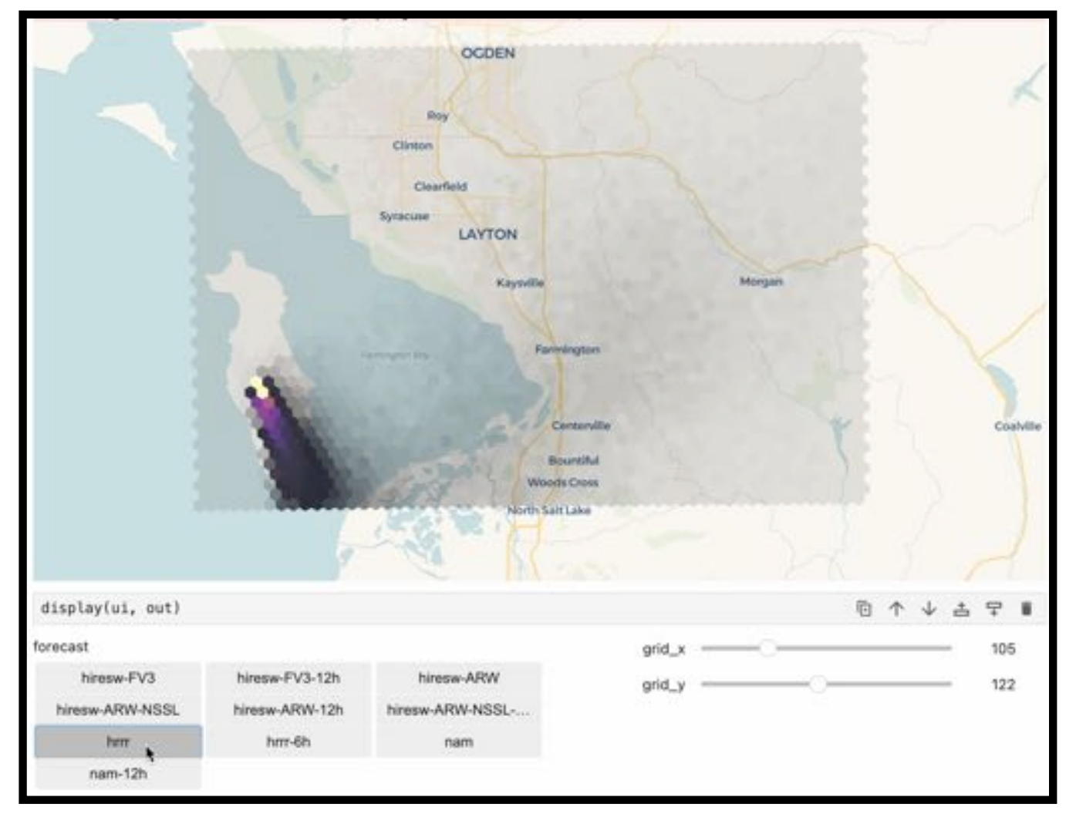


Jacobian: STILT Lagrangian Particle Dispersion Model

Total Footprint in Each Grid Cell



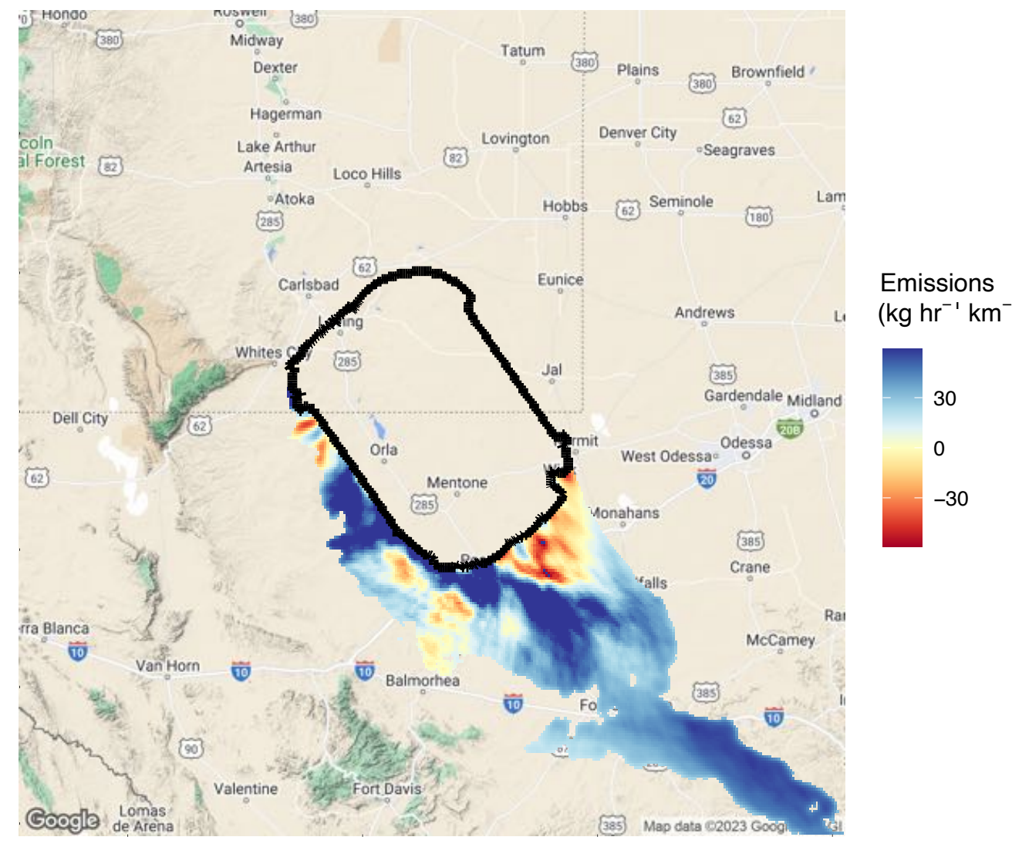
Flyte Implementation of Met Ensemble Jacobians



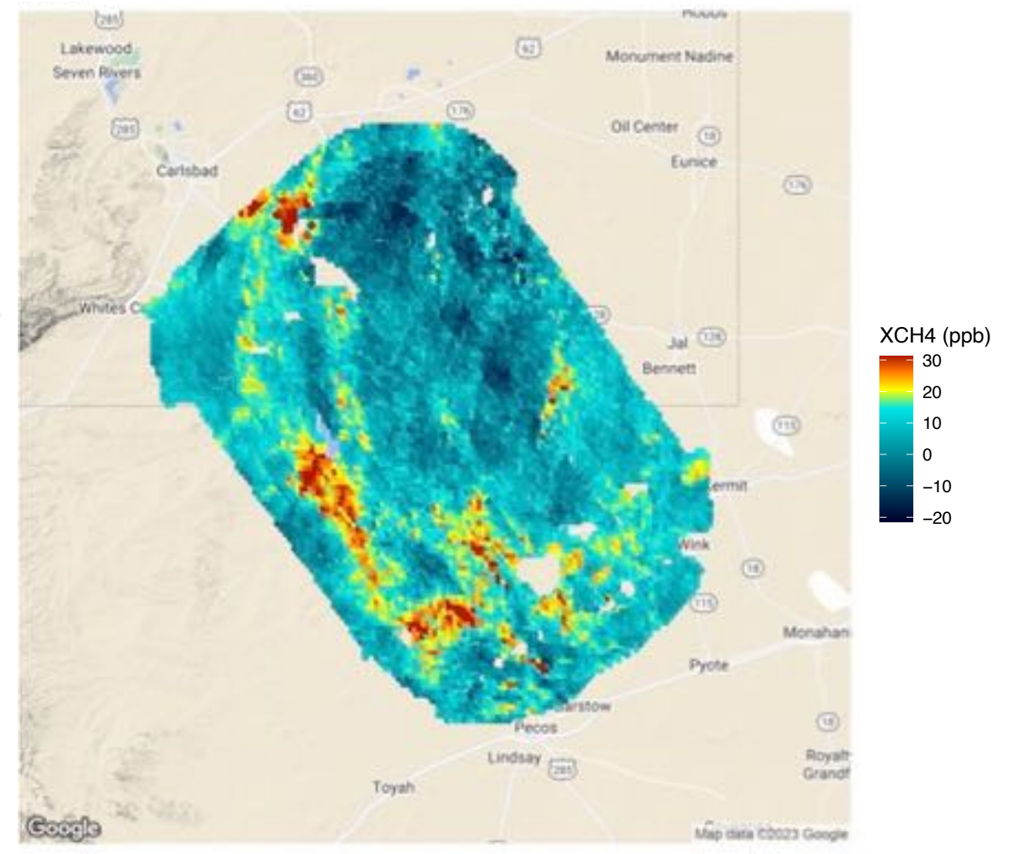
- Regional influence of emissions modeled using column-weighted STILT model (Lin et al., 2003, Fasoli et al., 2018).
- STILT for production is deployed on Google Cloud with Flyte.
- An ensemble of meteorological models is available for STILT.

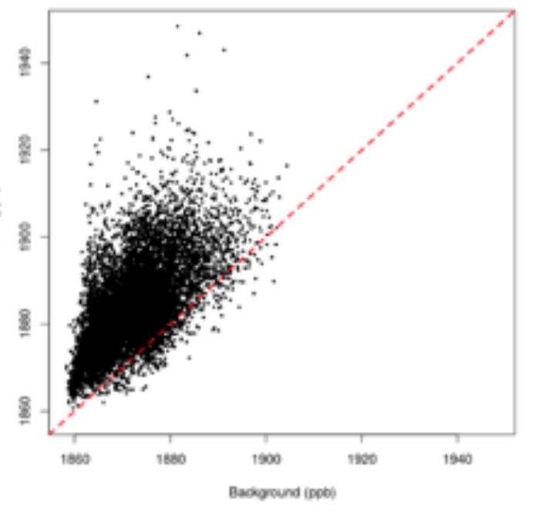
Background/Boundary Inflow: Inverse model of fluxes outside the domain

Boundary Inflow Pseudo-Fluxes



Enhancement (Obs. - Bg.)

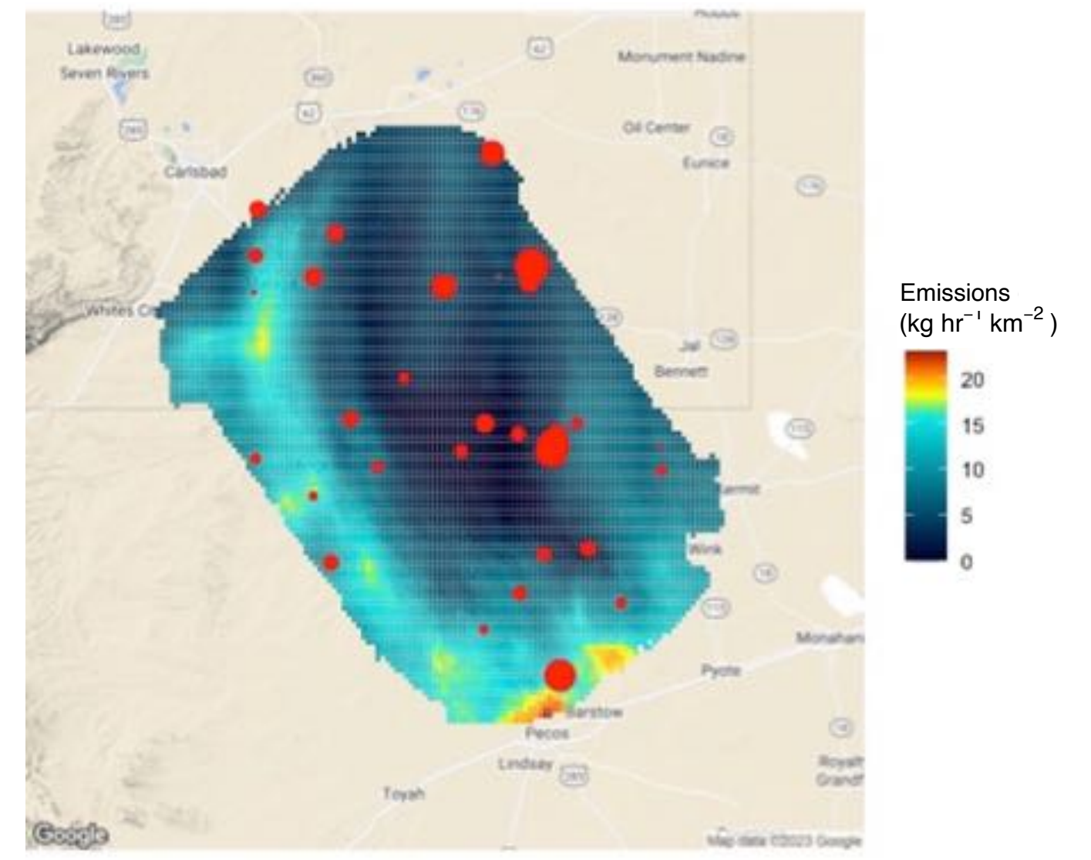




- The background concentration is not constant at the scale of a MethaneSAT/AIR scene.
- We use an inverse model of boundary inflow "pseudo-" fluxes outside domain plus intercept.
- This model acts as a high pass filter with a bandwidth that increases towards the downwind.

Area Source Emissions: Non-negative MCMC Inverse Model

Posterior Emissions



Point sources:
30 plumes
31,100 kg/hr (15,600 - 46,700)

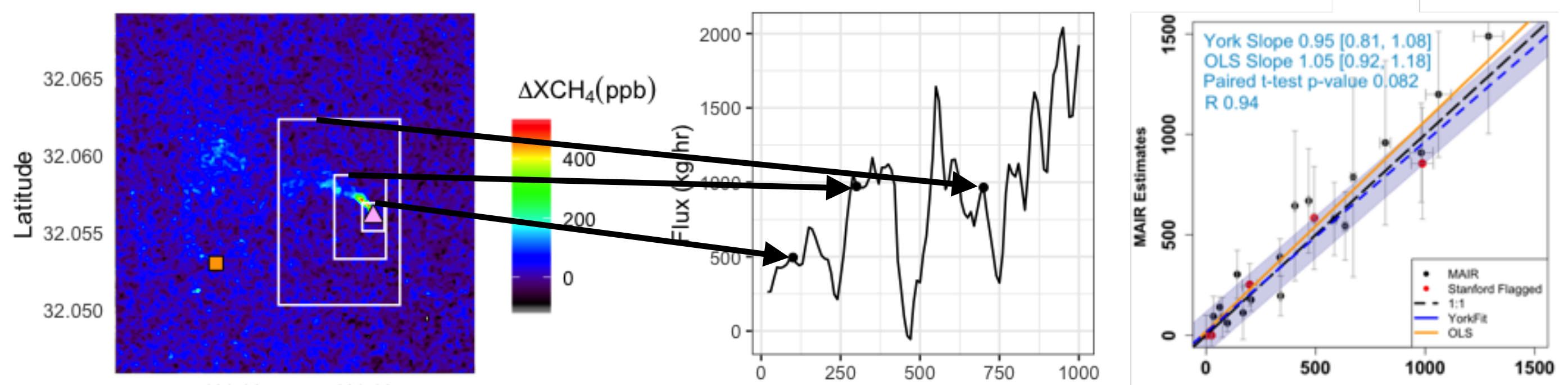
Area sources:
57,600 kg/hr (40,300 - 74,900)

Total emissions:
88,700 kg/hr (62,100 - 115,300)

- We use a Markov chain Monte Carlo method to solve non-negative area fluxes (following Miller et al., 2014), reporting the median to avoid model bias.
- We apply an uninformative prior since inventories represent long term means and MethaneSAT/AIR data can swamp a prior.
- We use the Stan software for high quality MCMC optimization.

Point Source Emissions: Divergence Integral Method

- Point source emissions are estimated independently using a method developed specifically for point source estimation.



- We apply Gauss' Theorem to compute total flux out of box around point source.

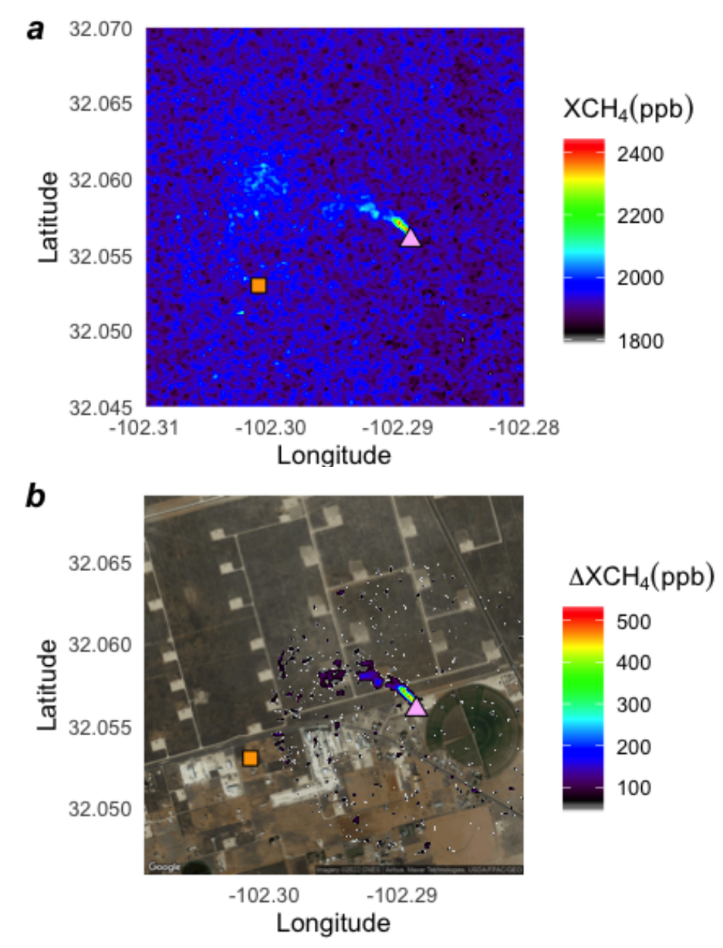
$$\Phi_{surf} = \oint_{\partial V = S} v \cdot \hat{n}((XCH_4 - \langle XCH_4 \rangle_{rect.}) * n_{column} * M_{CH4})dS$$

- Growing the box to different scales captures atmospheric variation and characterizes uncertainty.
- Results validated by blind controlled release.

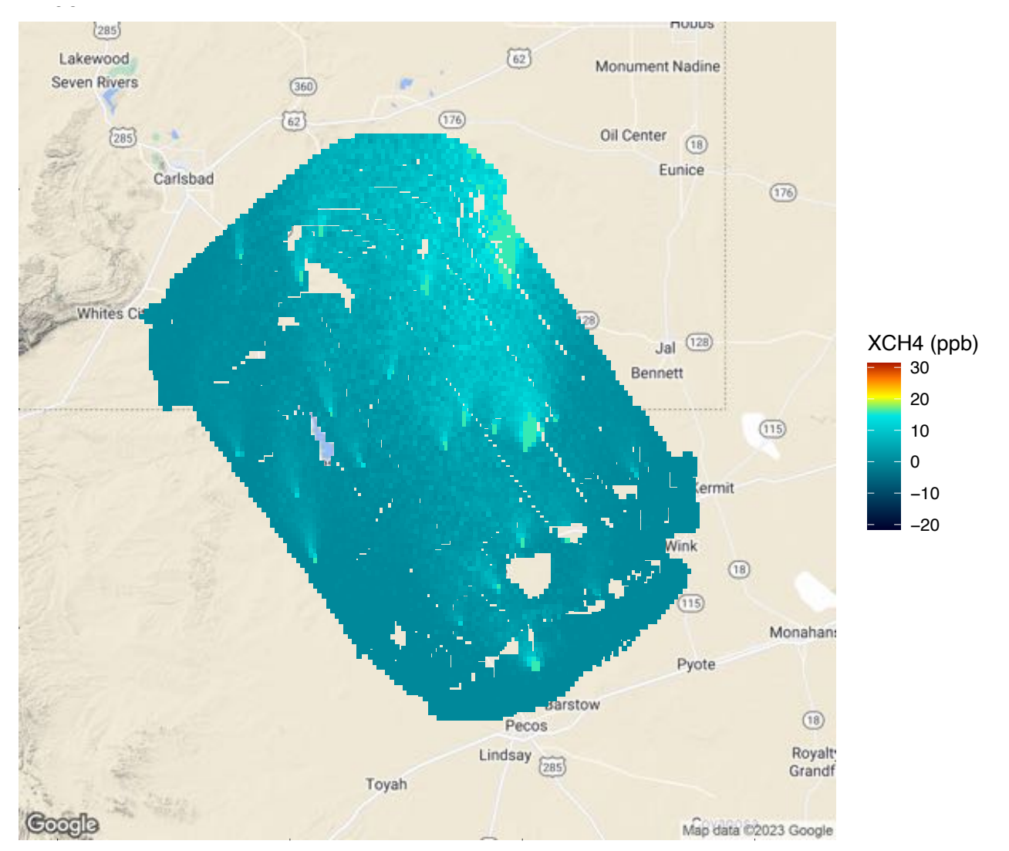
Chulakadabba et al., 2023

Remove Point Sources From Observations to Condition Area Source Inversion

Masking a Plume



Propagated Point Sources



- It is essential to account for entire contribution of point sources, which goes beyond what is detectable as a mask.
- We model the impact of point sources by propagating them through the Jacobian. This conserves the total enhancement.
- We apply a blur to the sources to reduce error dipoles.

Conclusions

- The greatest challenges to emissions retrievals at the scale of MethaneSAT/AIR are:
  - accurately modeling transport in spite of meteorological error.
  - accounting for point sources in the area source inversion without double counting methane or inducing dipoles.
  - modeling the boundary inflow concentration.
  - optimizing inverse estimates reliably at scale.
- The strategies in this poster present the MethaneSAT/AIR solutions to these challenges.
- A reliable operational L4 product is possible and will be made public with a goal of early 2025.

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