MethaneSAT L4 CORE:
Conserved and Optimized Retrieval of Emissions

The MethaneSAT and MethaneAIR Science and Engineering Teams
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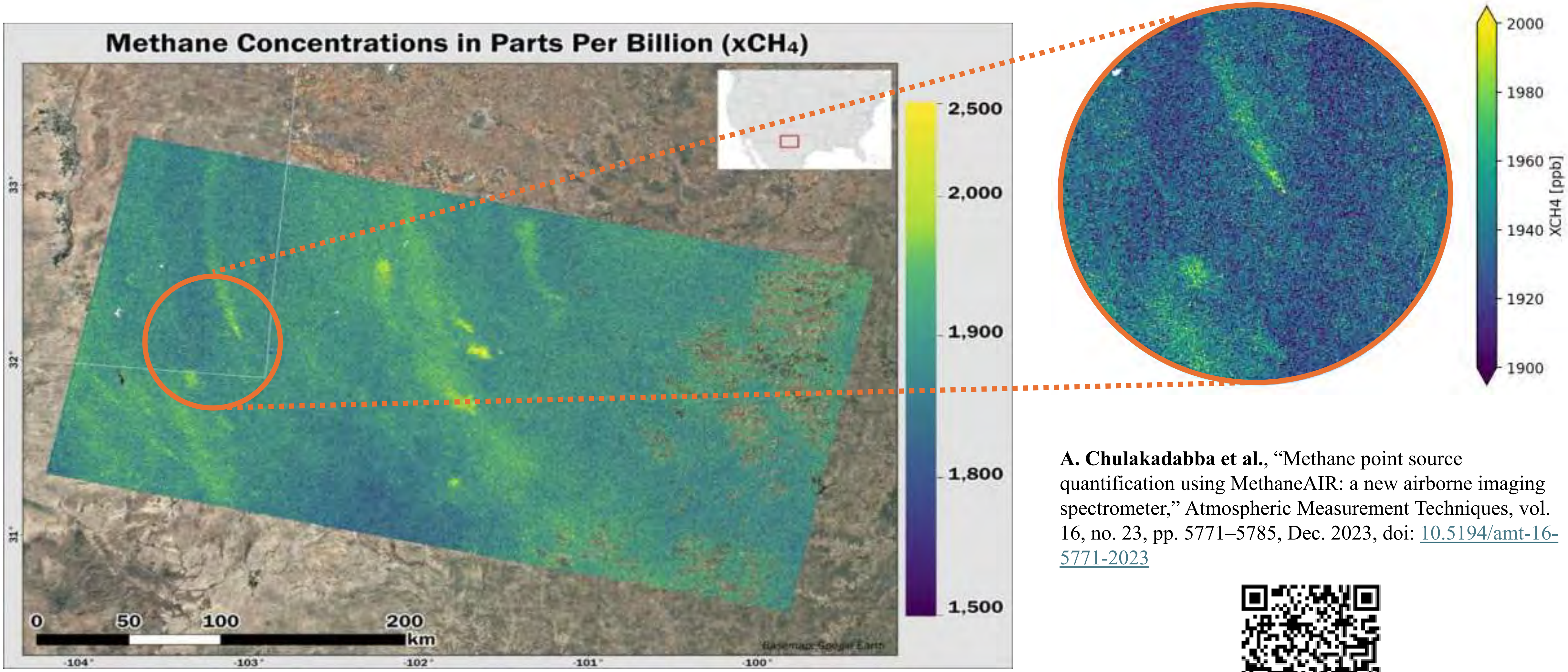
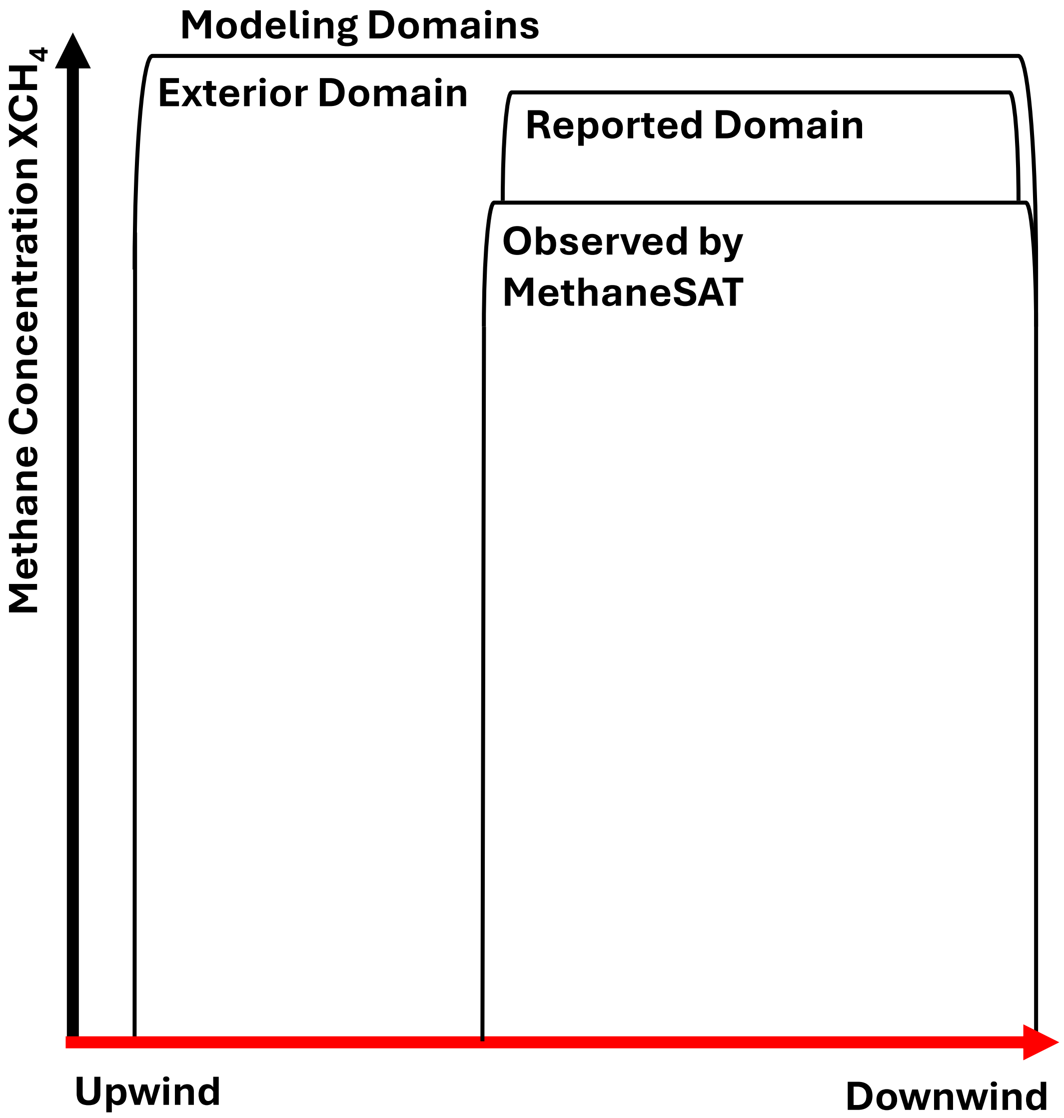
Environmental Defense Fund | MethaneSAT™ | Harvard John A. Paulson School of Engineering and Applied Sciences

The instrument combines high sensitivity and spatial resolution to observe both point and area sources

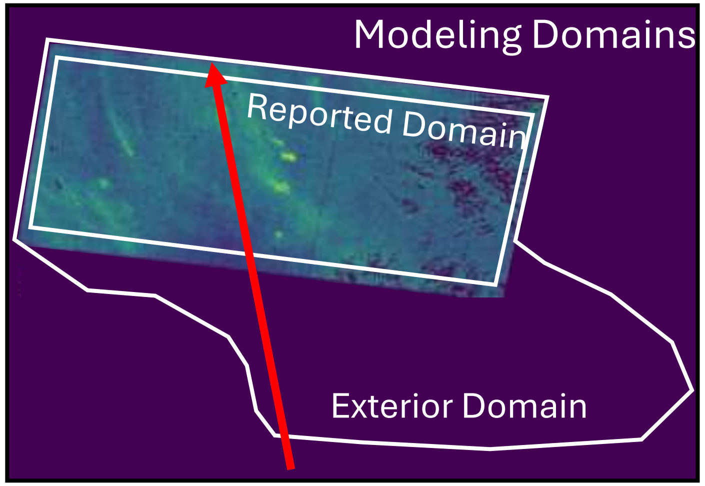


A. Chulakadabba et al., "Methane point source quantification using MethaneAIR: a new airborne imaging spectrometer," Atmospheric Measurement Techniques, vol. 16, no. 23, pp. 5771–5785, Dec. 2023, doi: 10.5194/amt-16-5771-2023

MethaneSAT observations reveal the spectrum of scales of variability of methane concentrations and emissions



Examining variability along a transect



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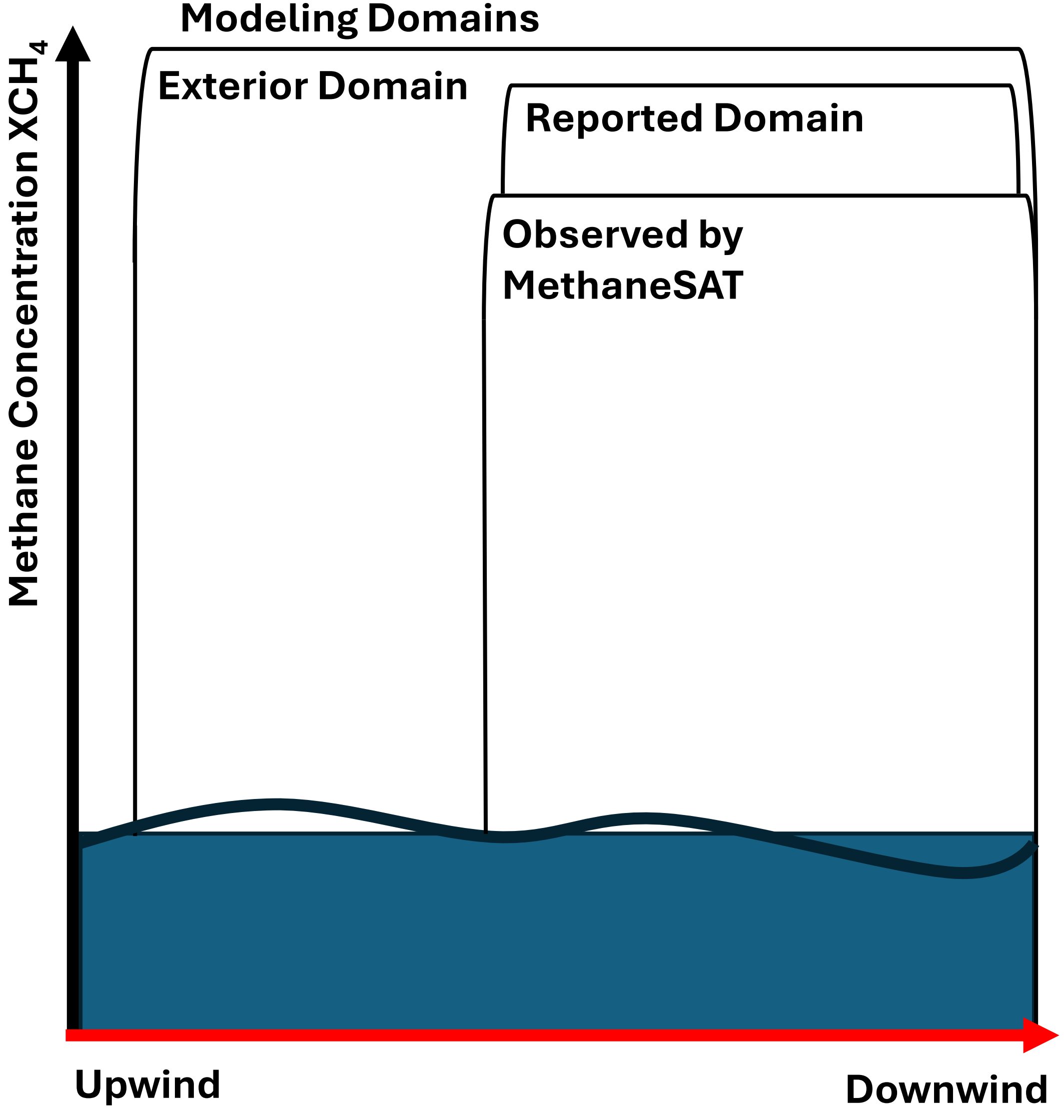

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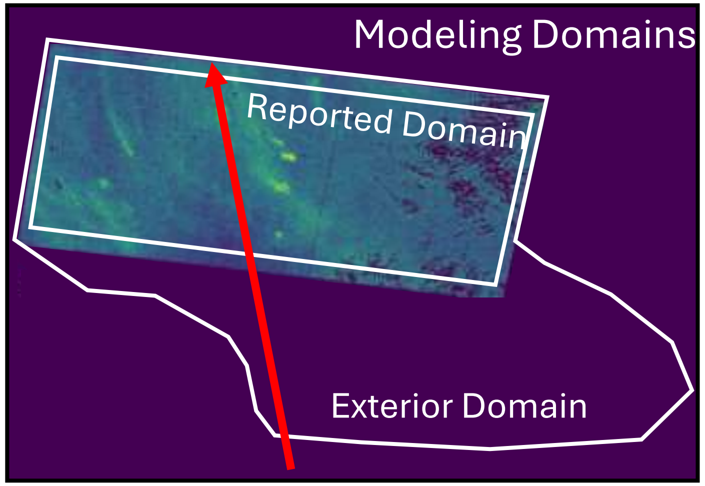
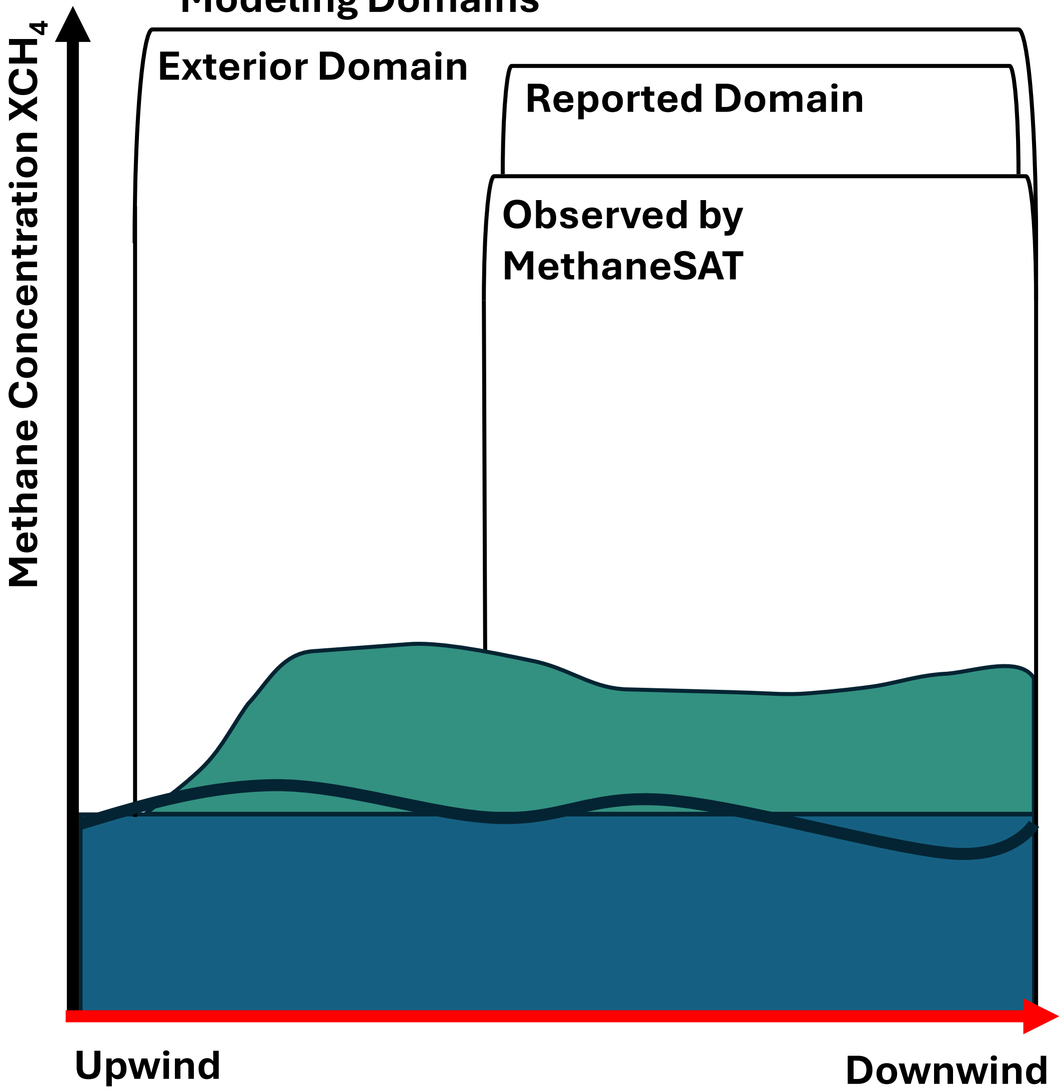


Regional Background

A constant value for the entire scene: the lowest concentrations above measurement noise plus variations due to the topographical column effect.

MethaneSAT observations reveal the spectrum of scales of variability of methane concentrations and emissions



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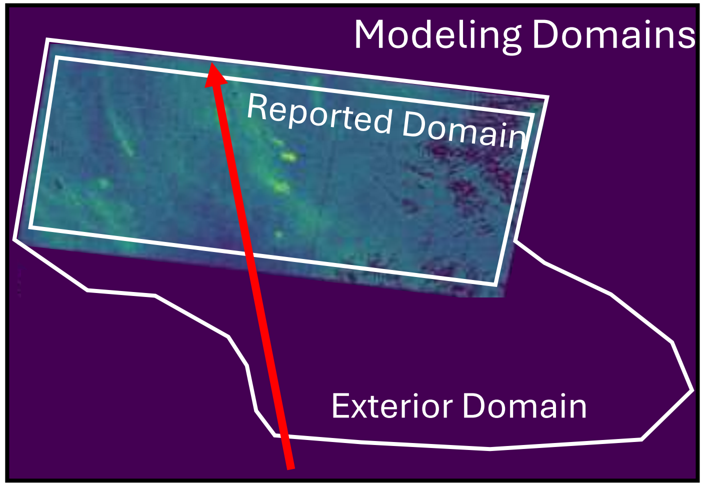

Boundary Inflow
Higher frequencies near the inflowing edge of the reported domain.
Lower frequencies in the interior of the local domain.
Modeled with "pseudo-emissions" in the exterior domain.

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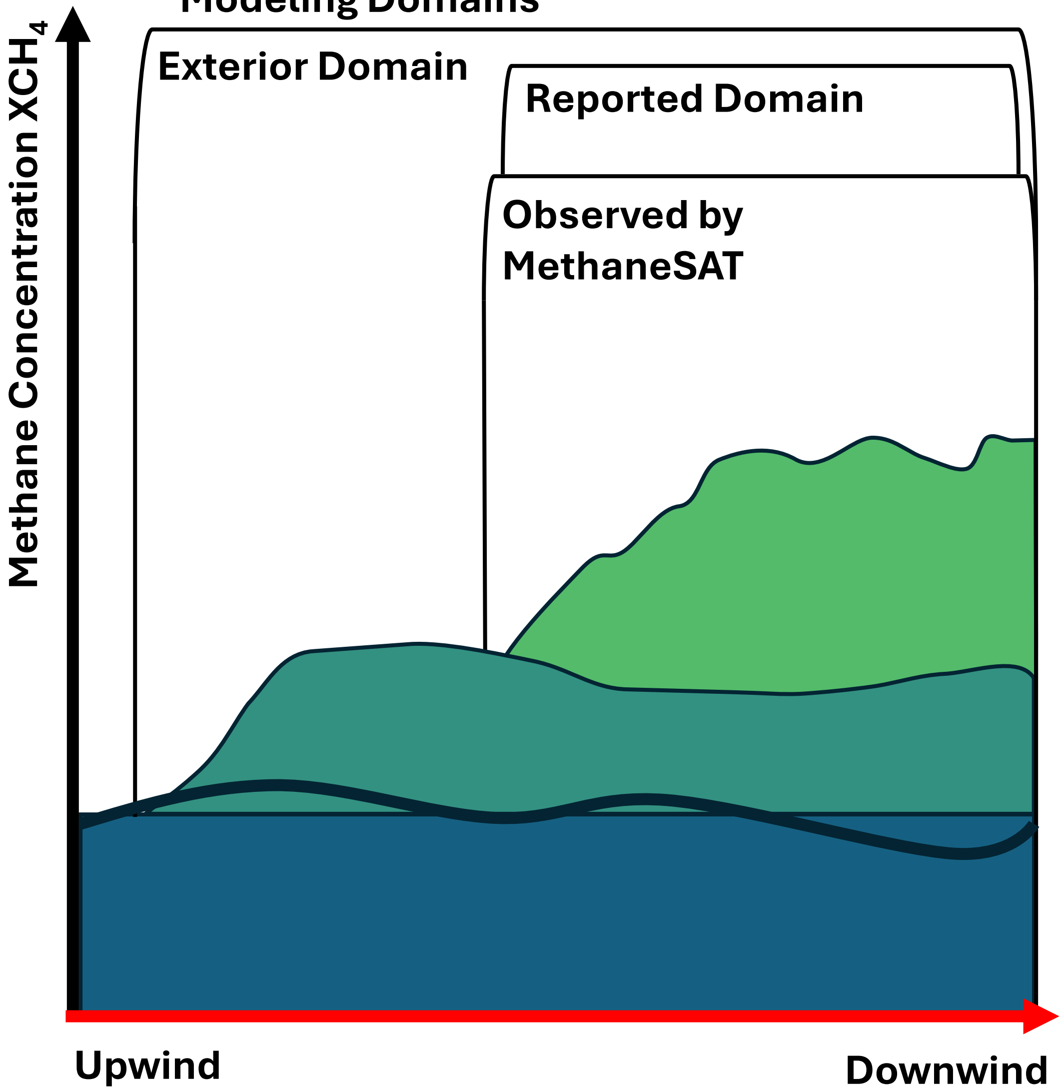

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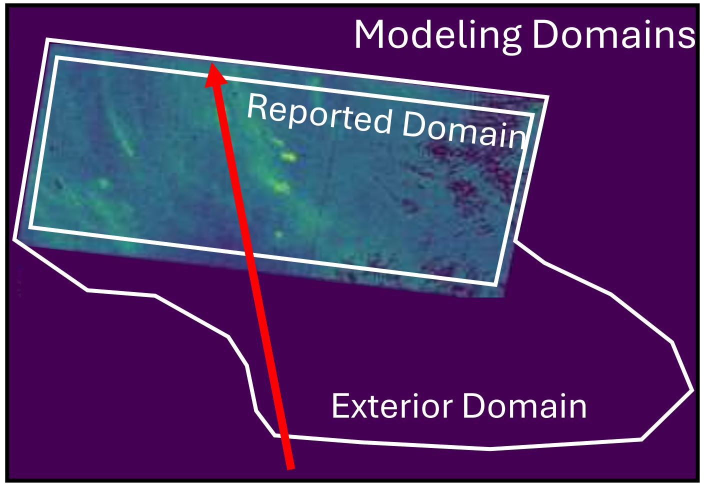

Dispersed Sources — Explained by emissions inside reported domain.

Boundary Inflow — Higher frequencies near the inflowing edge of the reported domain.
Lower frequencies in the interior of the local domain.
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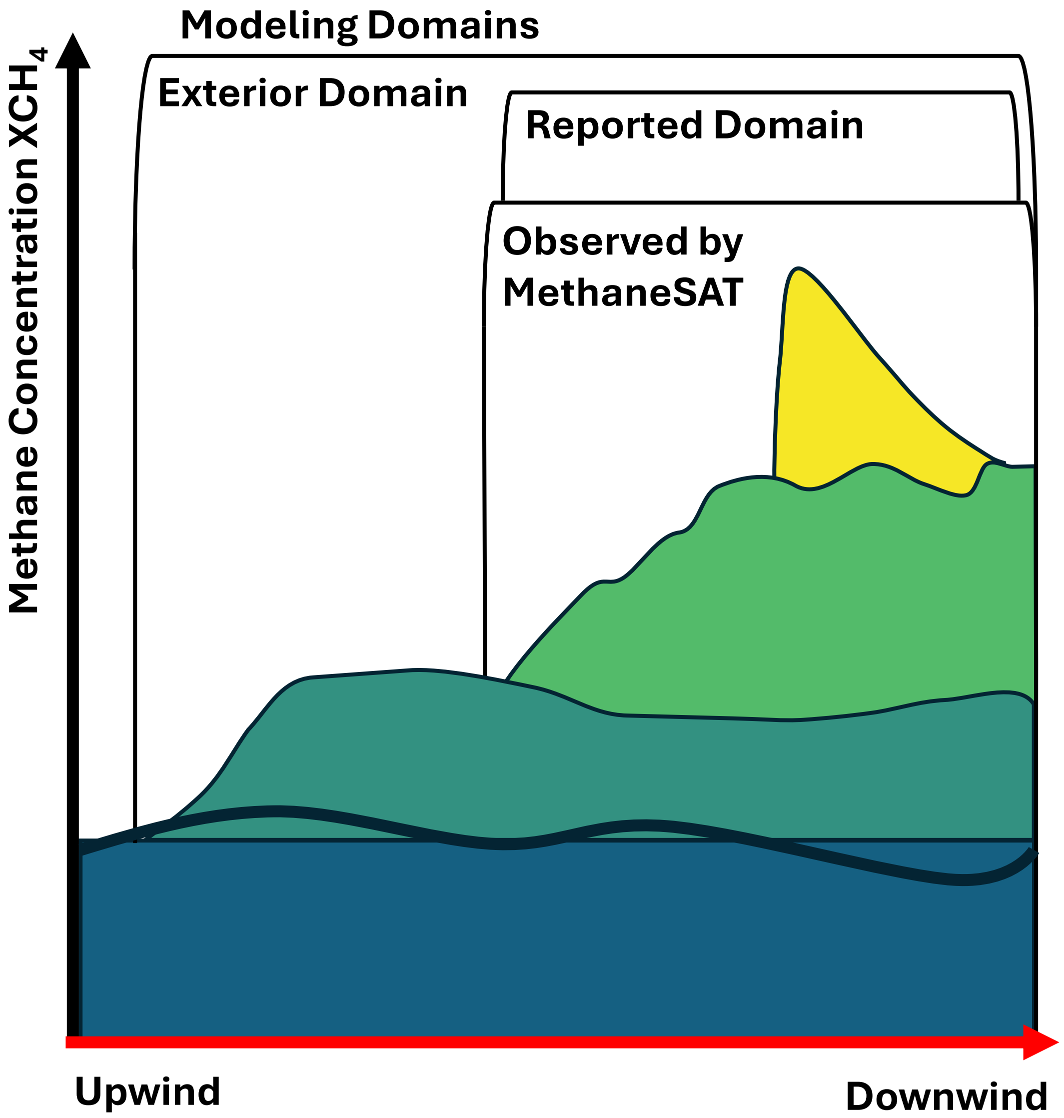
Regional Background — A constant value for the entire scene: the lowest concentrations above measurement noise plus variations due to the topographical column effect.

MethaneSAT observations reveal the spectrum of scales of variability of methane concentrations and emissions



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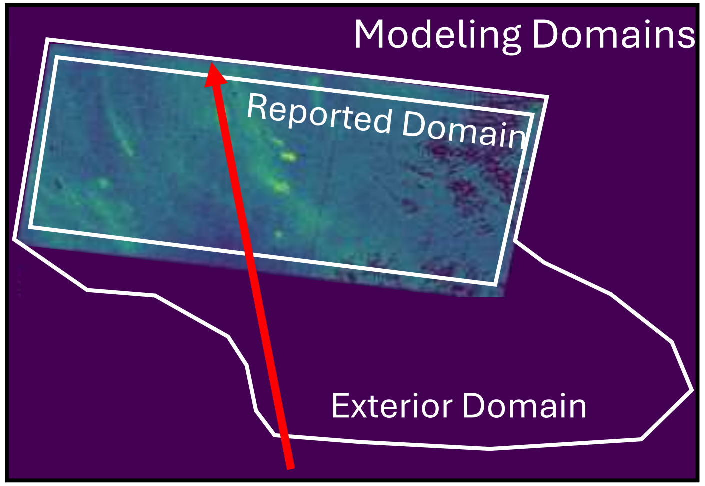

Discrete Sources — Detected and quantified as part of the MethaneSAT L4 Discrete Sources product.

Dispersed Sources — Explained by emissions inside reported domain.

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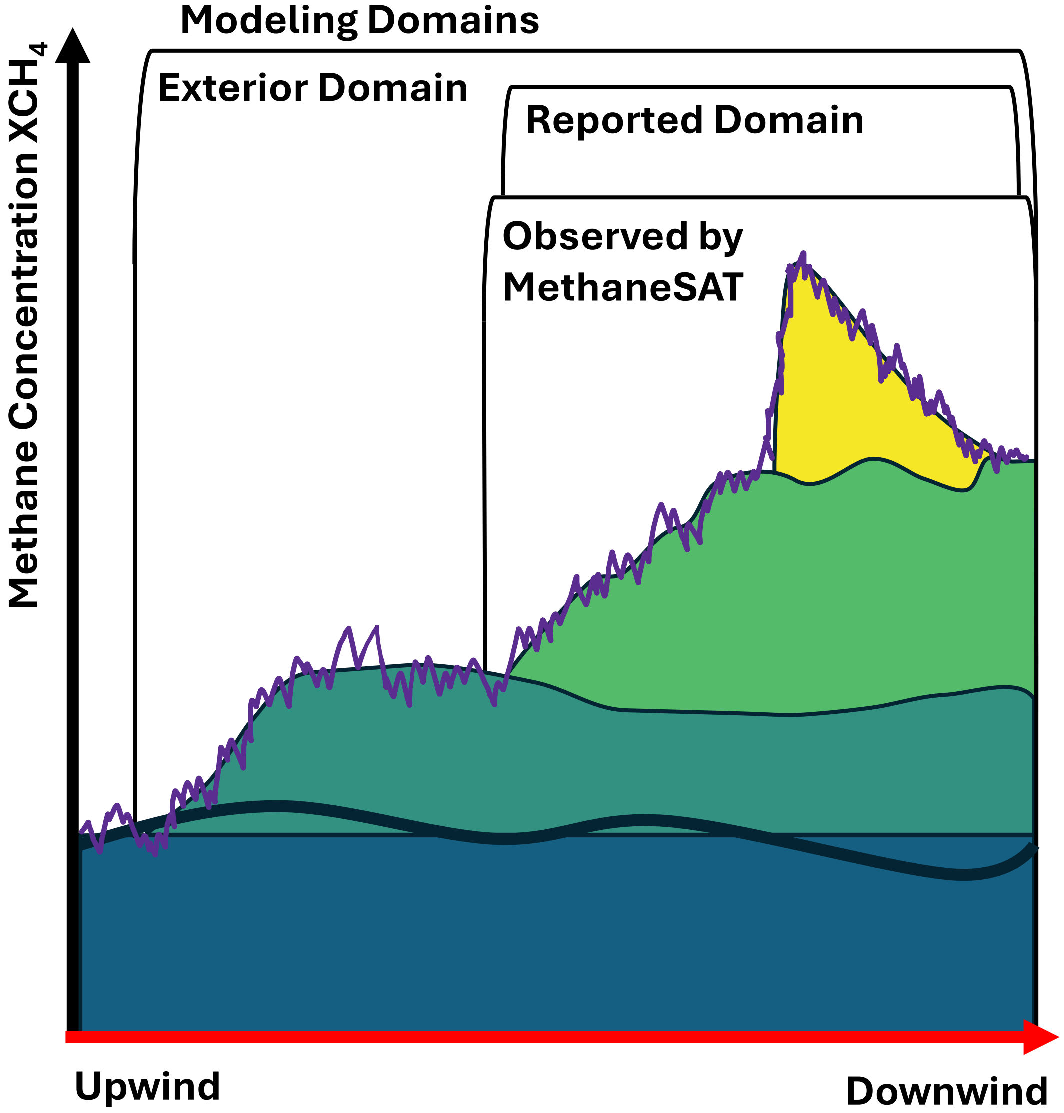
MethaneSAT observations reveal the spectrum of scales of variability of methane concentrations and emissions



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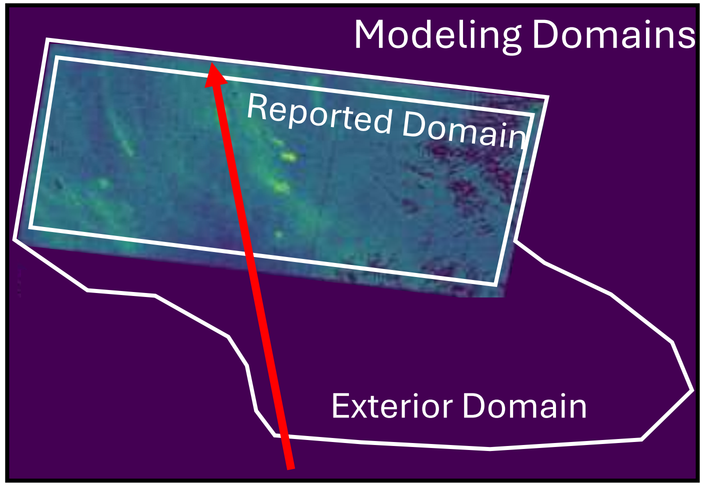

Instrument Noise

Discrete Sources — Detected and quantified as part of the MethaneSAT L4 Discrete Sources product.

Dispersed Sources — Explained by emissions inside reported domain.

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Lower frequencies in the interior of the local domain.
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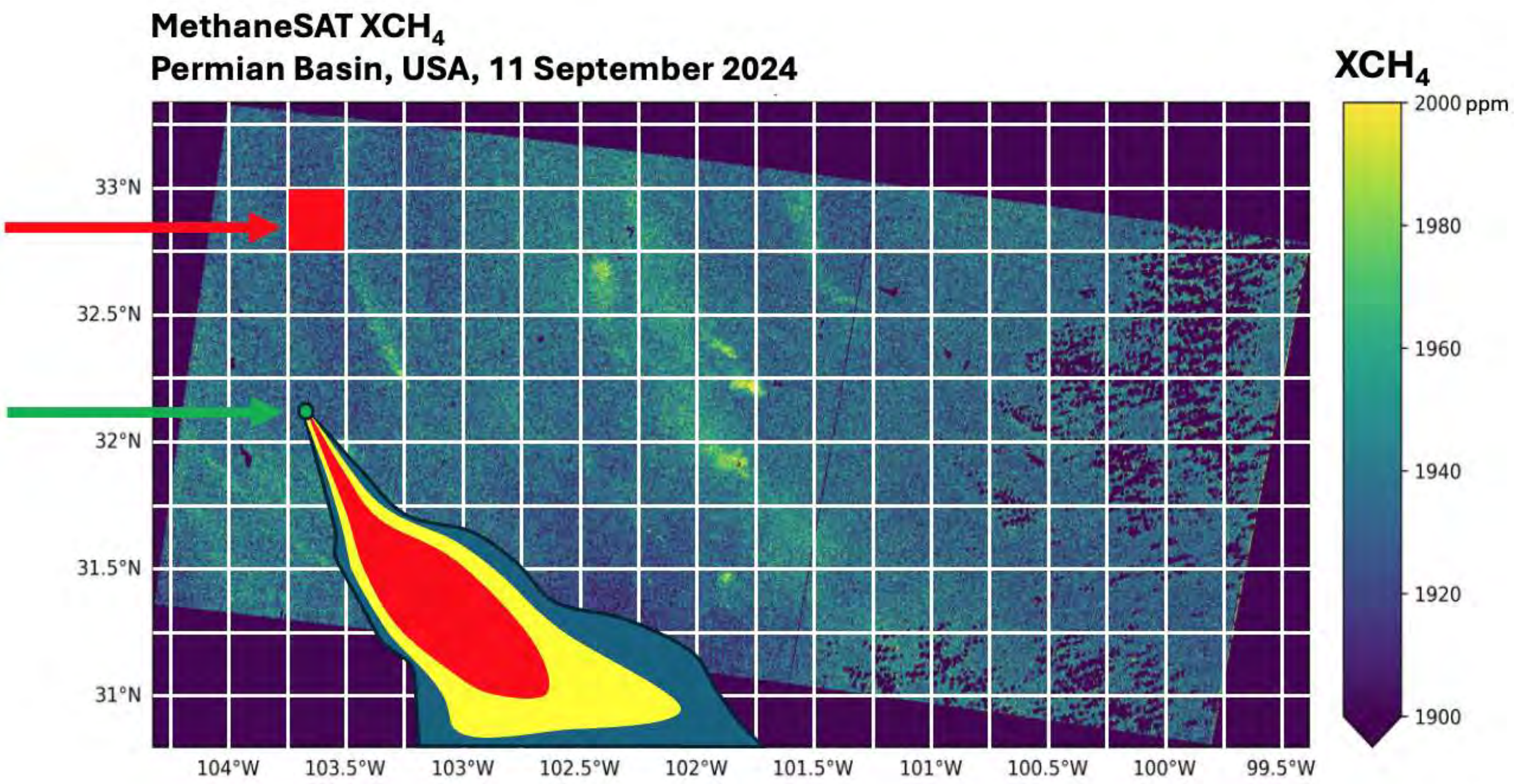
Regional Background — A constant value for the entire scene: the lowest concentrations above measurement noise plus variations due to the topographical column effect.

We use STILT, driven by operational meteorology, to model transport backwards in time

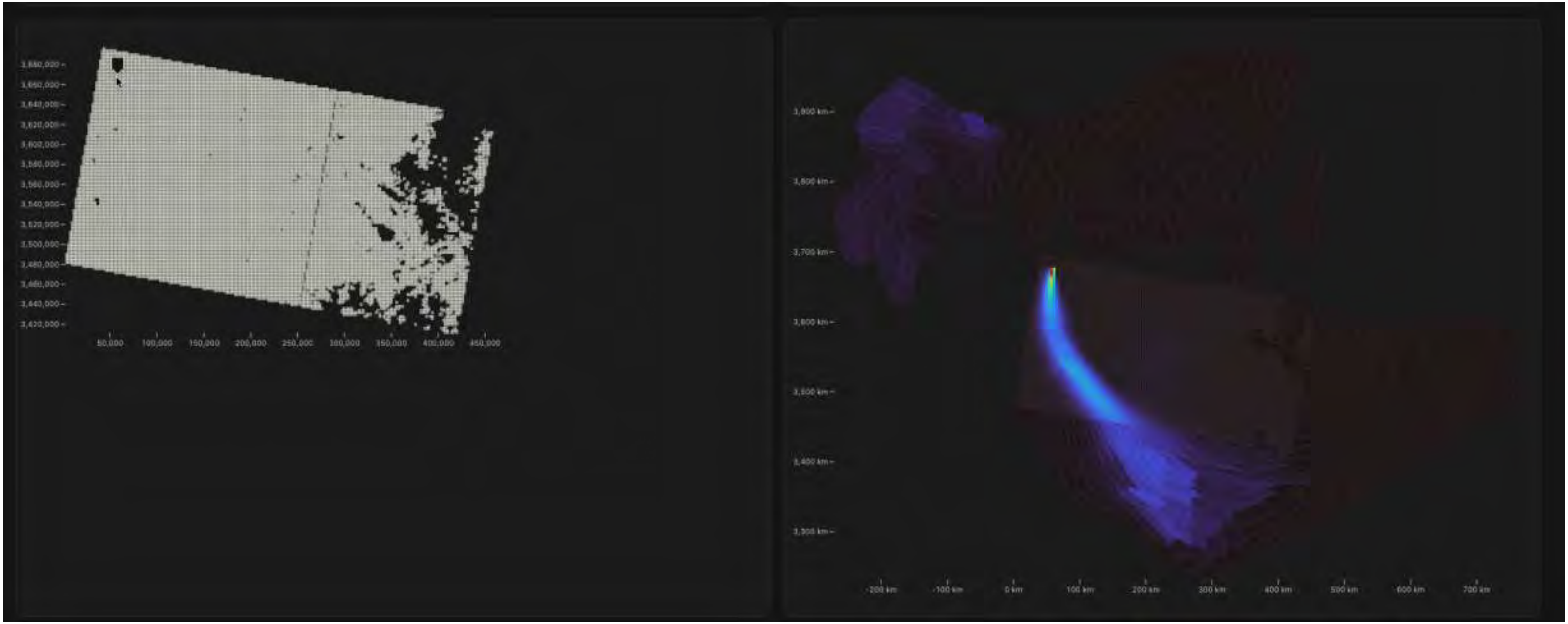
A 0.25° Eulerian grid cannot fully utilize the spatial richness of MethaneSAT data.

The Lagrangian nature of the STILT model resolves sub-grid scale variability.

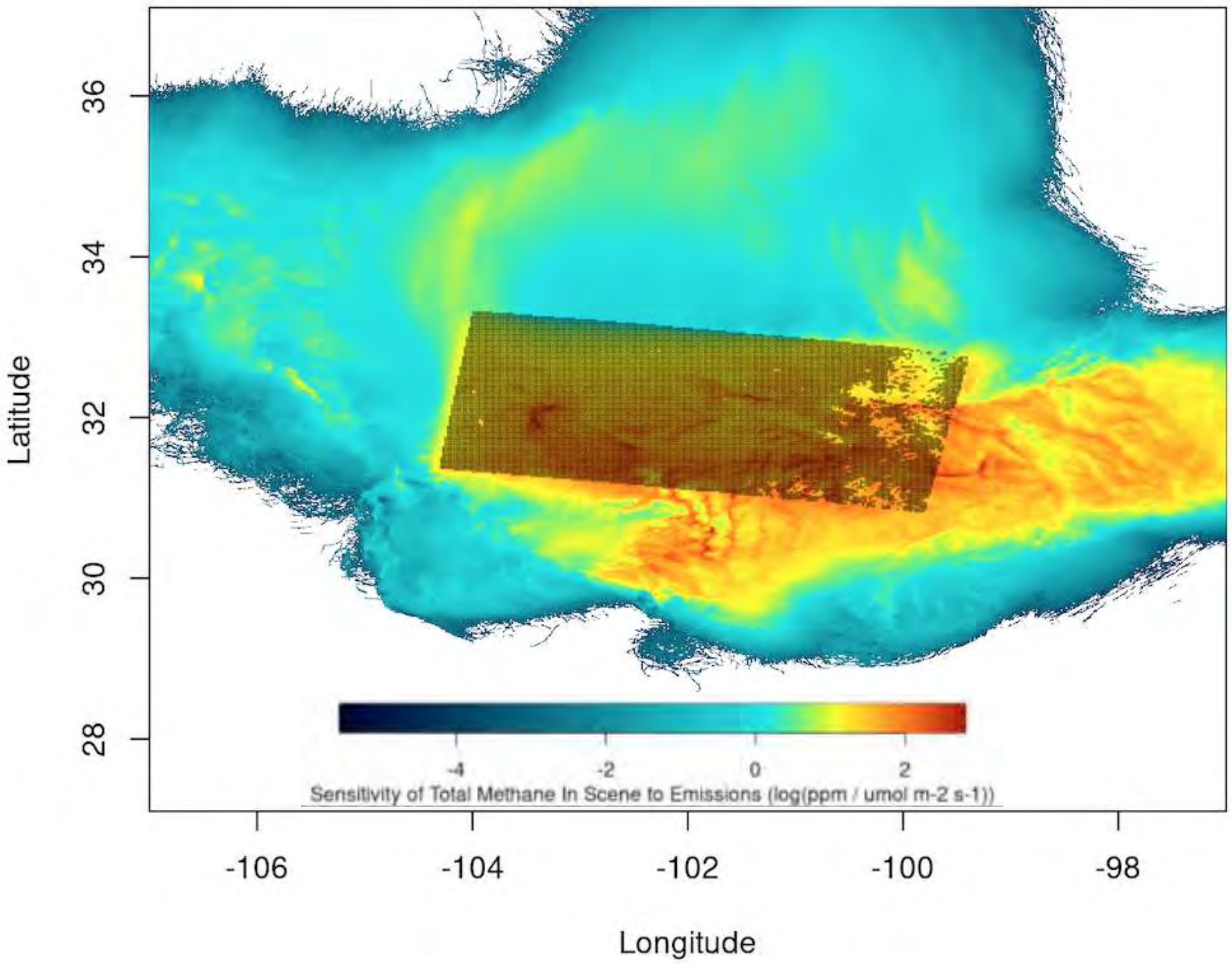


1. Lin et al., 2003
2. Fasoli et al., 2018

We model a footprint for each observation, allowing us to determine the region of influence for emissions



The footprints of influence define the source-receptor relationships which will become our Jacobian matrix



The observations can be decomposed into constituent parts

$$z = Hs + b + \varepsilon_o$$

H = the Jacobian

s = the state-vector (emissions)

b = the background concentration

ε_o = observation error

The observations can be decomposed into constituent parts

$$z = Hs + b + \varepsilon_o$$
$$z = H_i s_i + b_{INFLOW} + b_{EXP} + \varepsilon_o$$

H_i	= the component of the Jacobian in the interior domain
s_i	= the emissions in the interior domain
b_{INFLOW}	= the boundary inflow variation
b_{EXP}	= the expected variation due to topography and albedo

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$$z = Hs + b + \varepsilon_o$$
$$z = H_i s_i + b_{INFLOW} + b_{EXP} + \varepsilon_o$$
$$z = H_i s_i + H_0 s_0 + b_{APRIORI} + A * b_{CONST} + \varepsilon_o$$

H_i = the component of the Jacobian in the interior domain

s_i = the emissions in the interior domain

b_{INFLOW} = the boundary inflow variation

b_{EXP} = the expected variation due to topography and albedo

H_0 = the component of the Jacobian in the exterior domain

s_0 = the emissions in the exterior domain

The observations can be decomposed into constituent parts

$$z = Hs + b + \varepsilon$$

$$z = H_i s_i + b_{INFLOW} + b_{EXP} + \varepsilon$$

$$z = H_i s_i + H_0 s_0 + b_{APRIORI} + A * b_{CONST} + \varepsilon_o$$

H_i = the component of the Jacobian in the interior domain

s_i = the emissions in the interior domain

b_{INFLOW} = the boundary inflow variation

b_{EXP} = the expected variation due to topography and albedo

H_0 = the component of the Jacobian in the exterior domain

s_0 = the emissions in the exterior domain

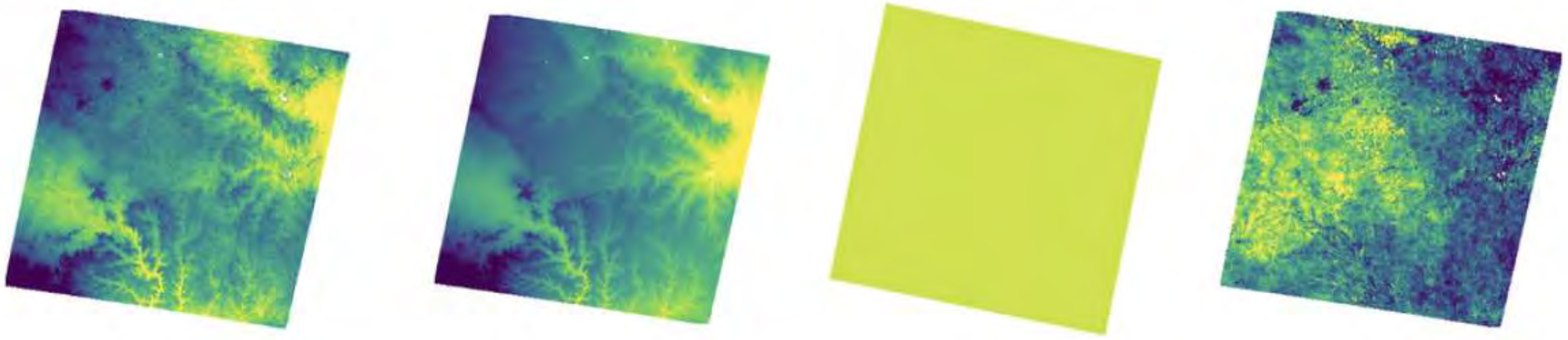
$b_{APRIORI}$ = the apriori XCH_4, with variation only due to topography

b_{CONST} = the constant contribution to the background

We construct a spatially resolved background to be subtracted from observations

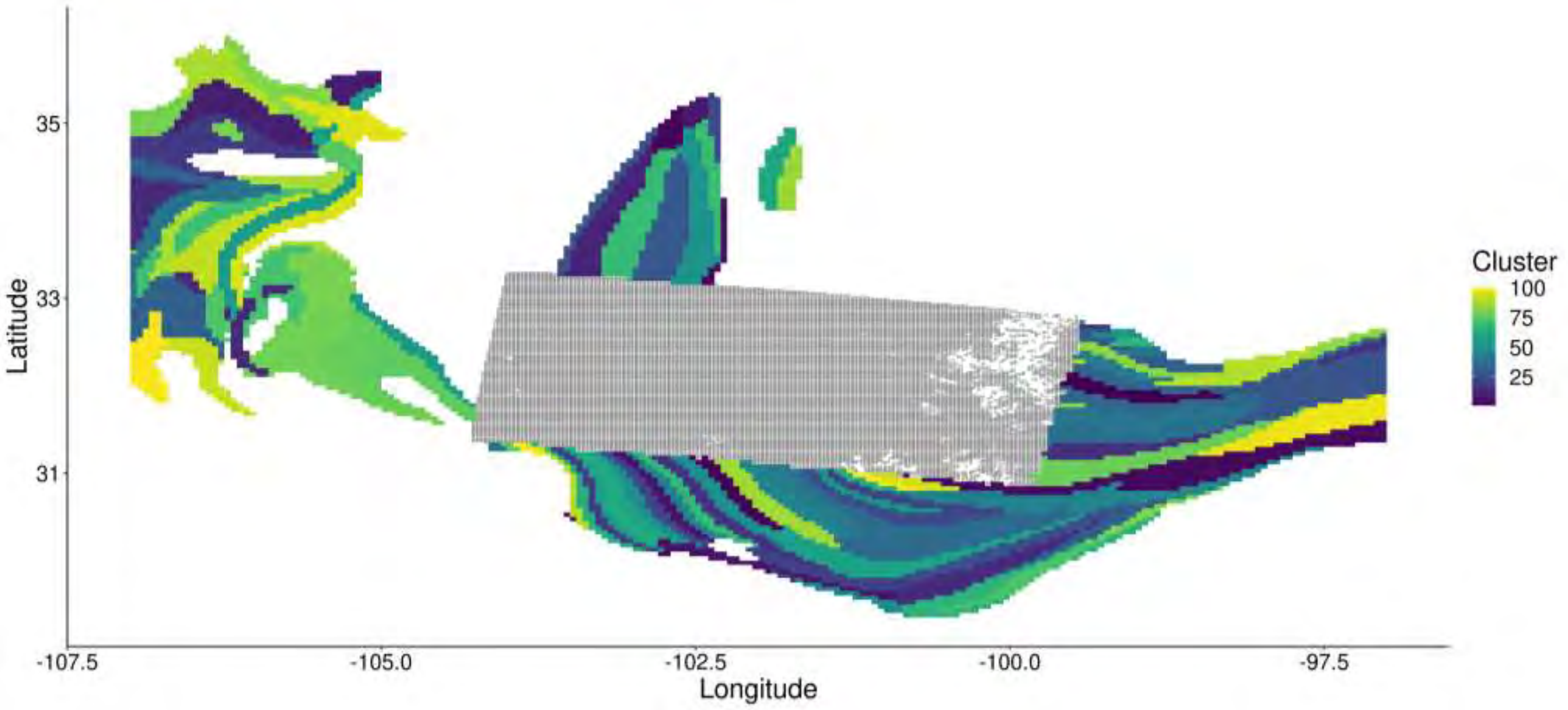
4 main factors to consider in your background:

1. Topographic effect
2. Albedo effect
3. Latitudinal gradient
4. Averaging kernel effect



$$XCH_{4,bg} = XCH_{4,prior} + \boldsymbol{b} \times A$$

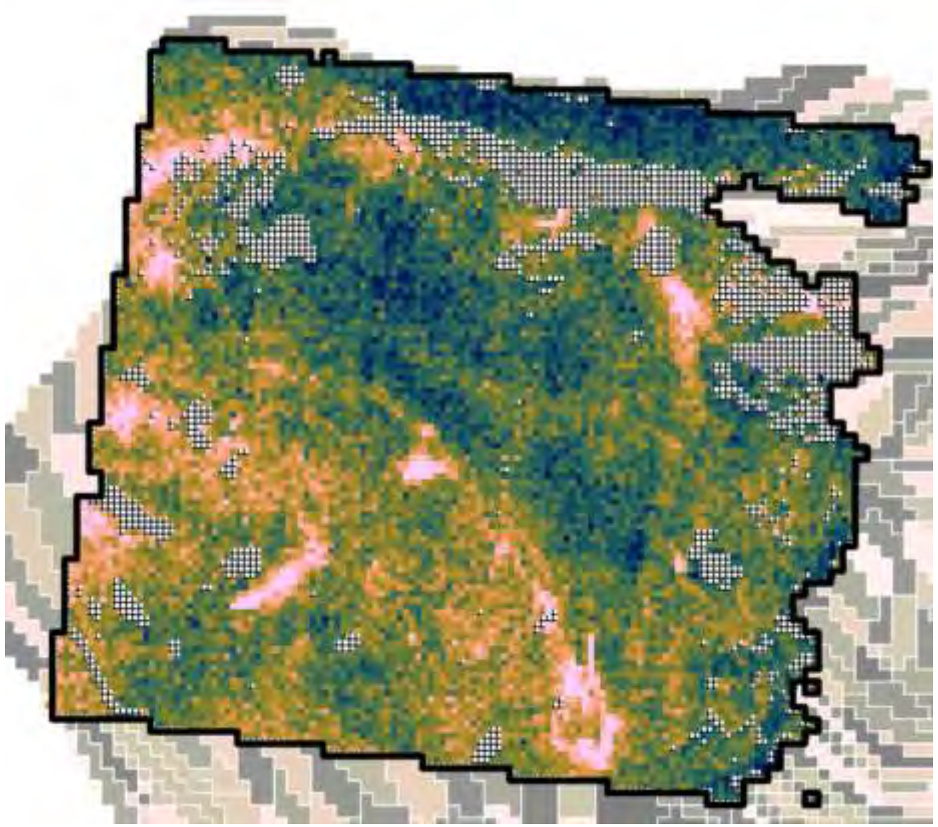
We use KMEANS clustering of cosine distance to group emitters outside of the domain



H_0 = the component of the Jacobian in the exterior domain

s_0 = the emissions in the exterior domain

We use a Hamiltonian Monte Carlo sampler with a diffuse lognormal prior to solve iteratively for emissions



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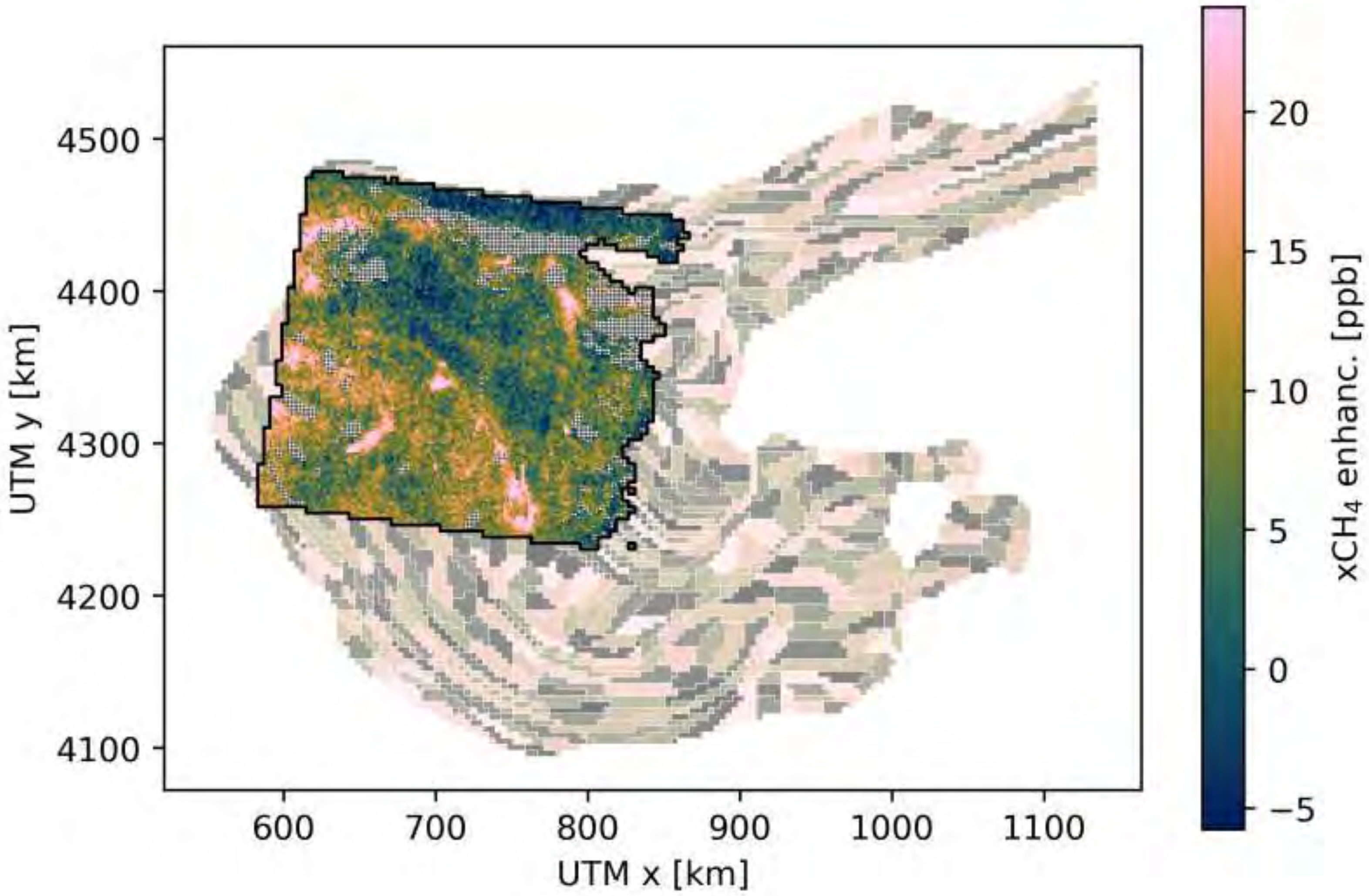

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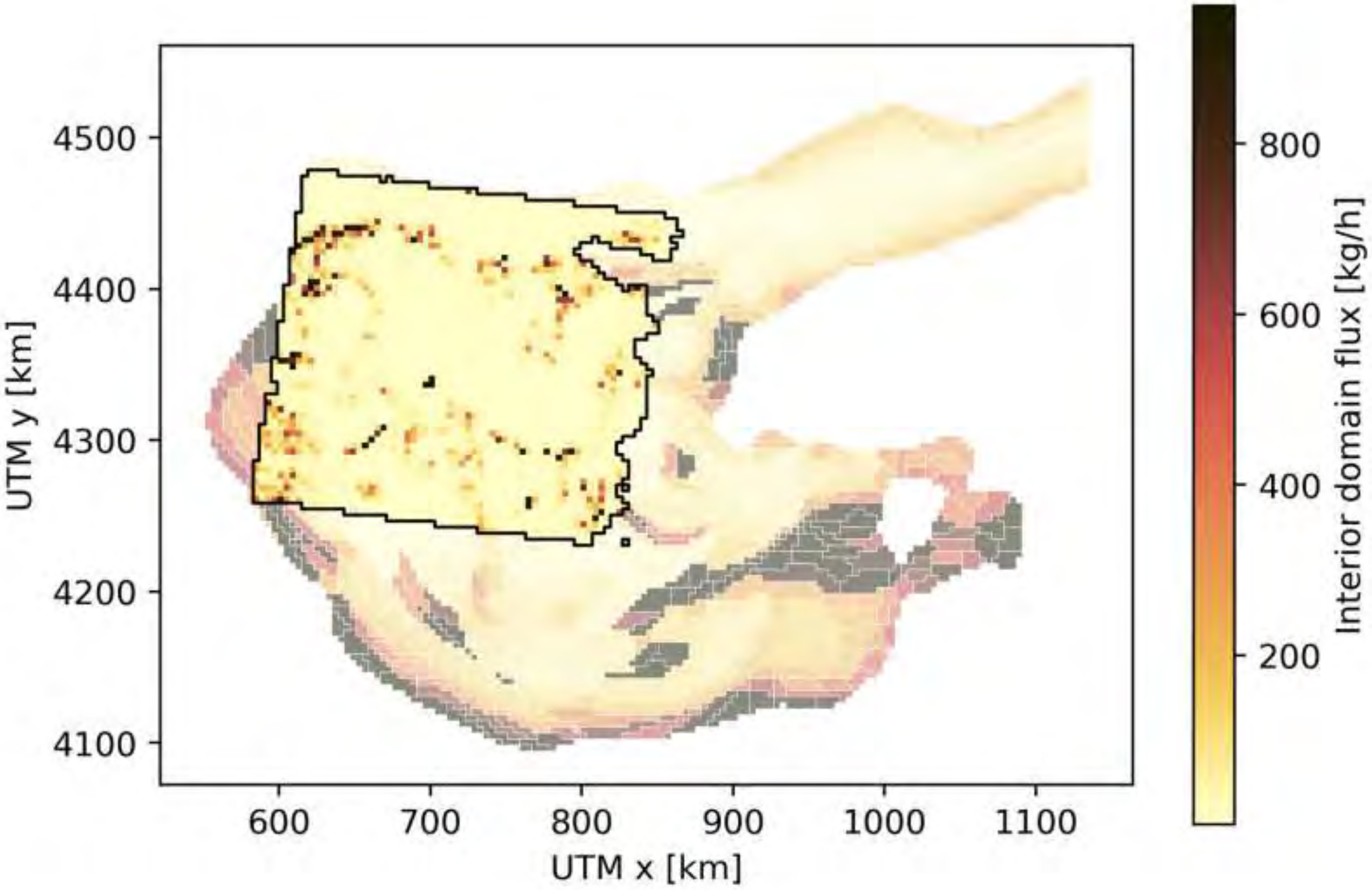

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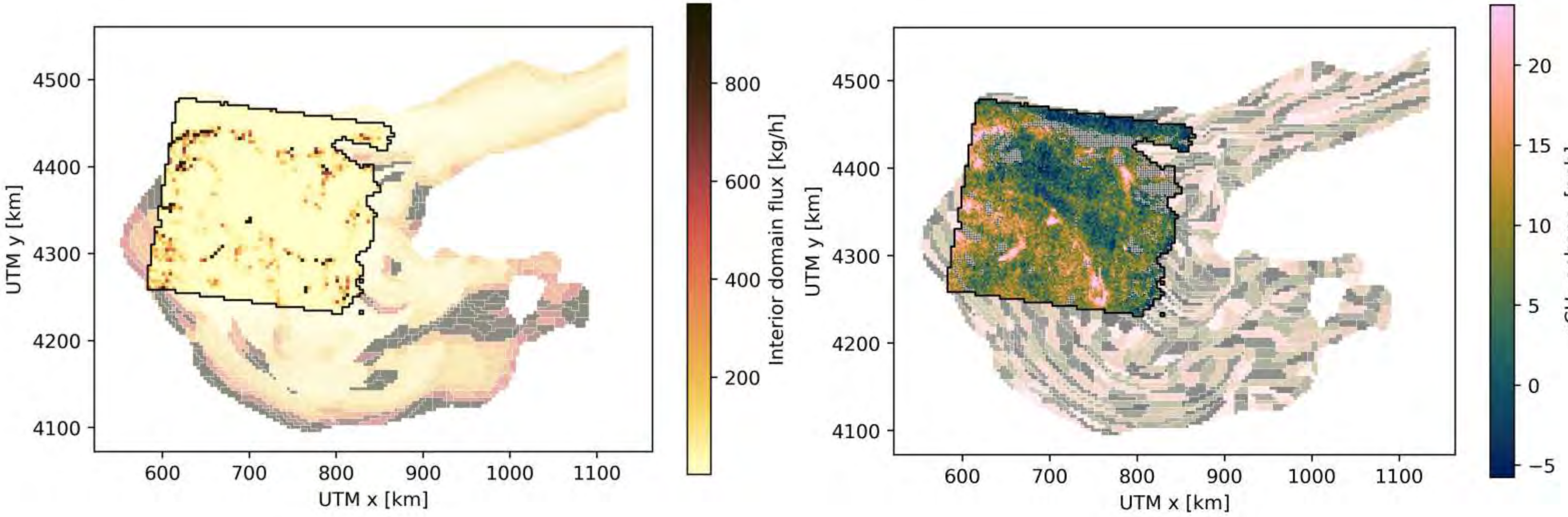
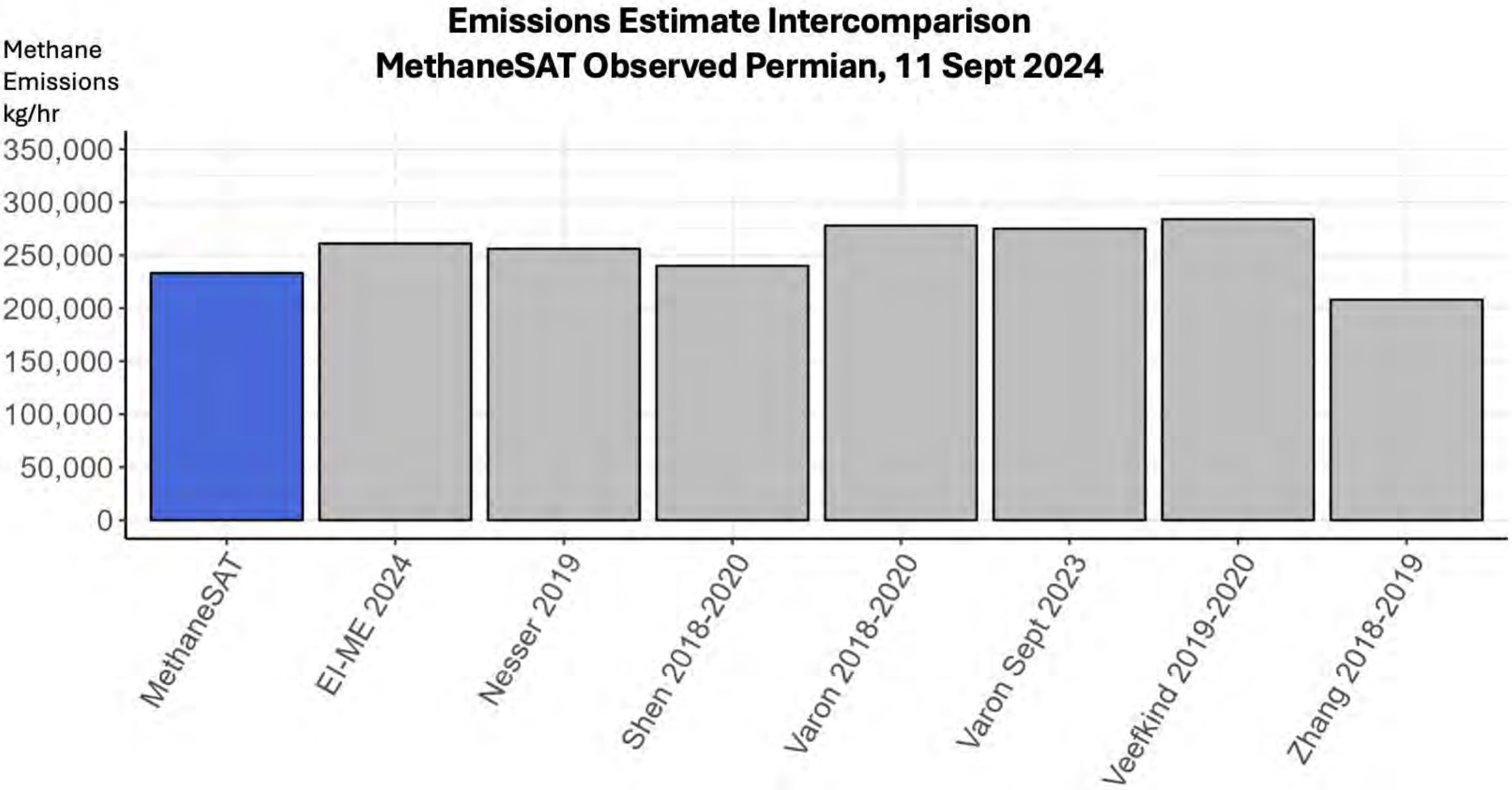


There is good agreement between MethaneSAT total emissions and other empirical data



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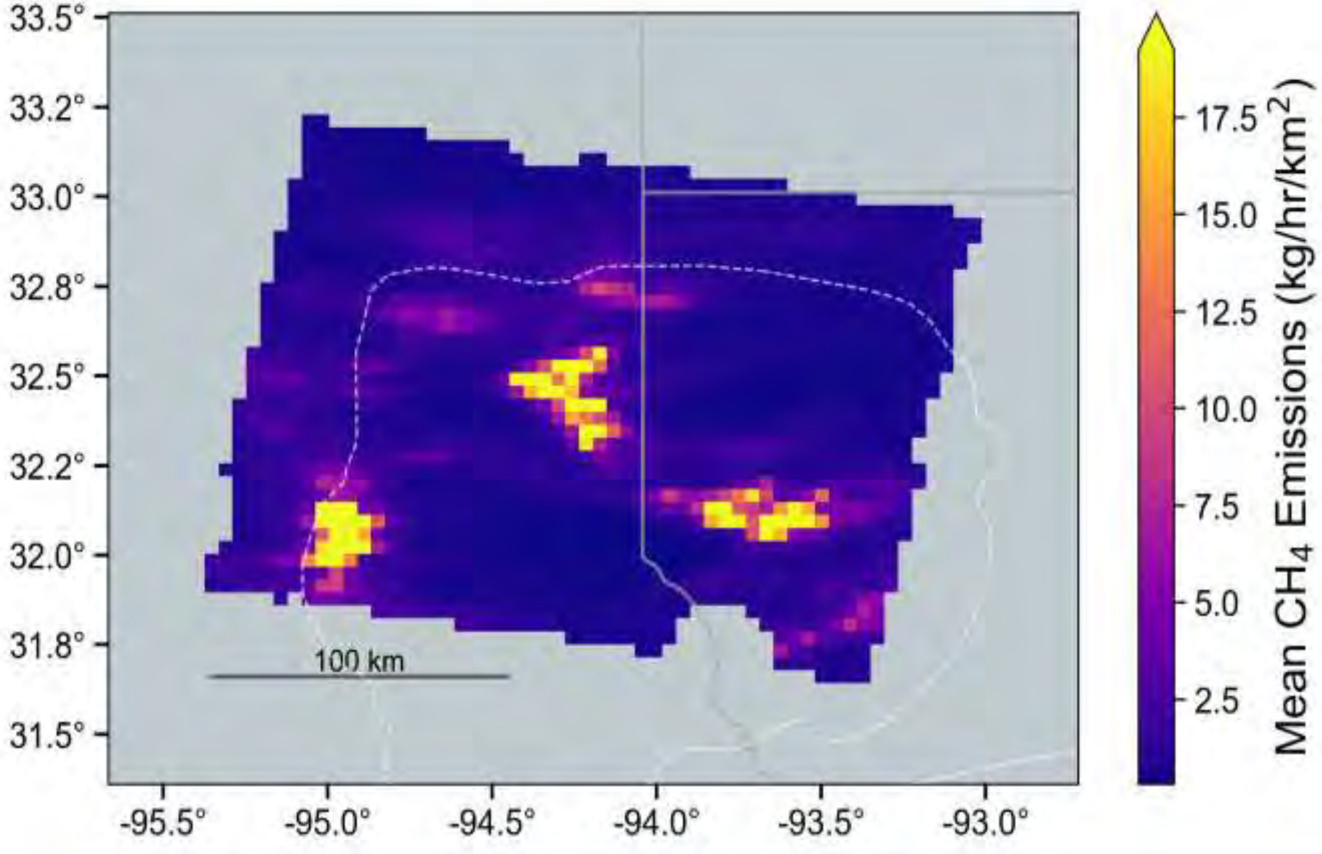
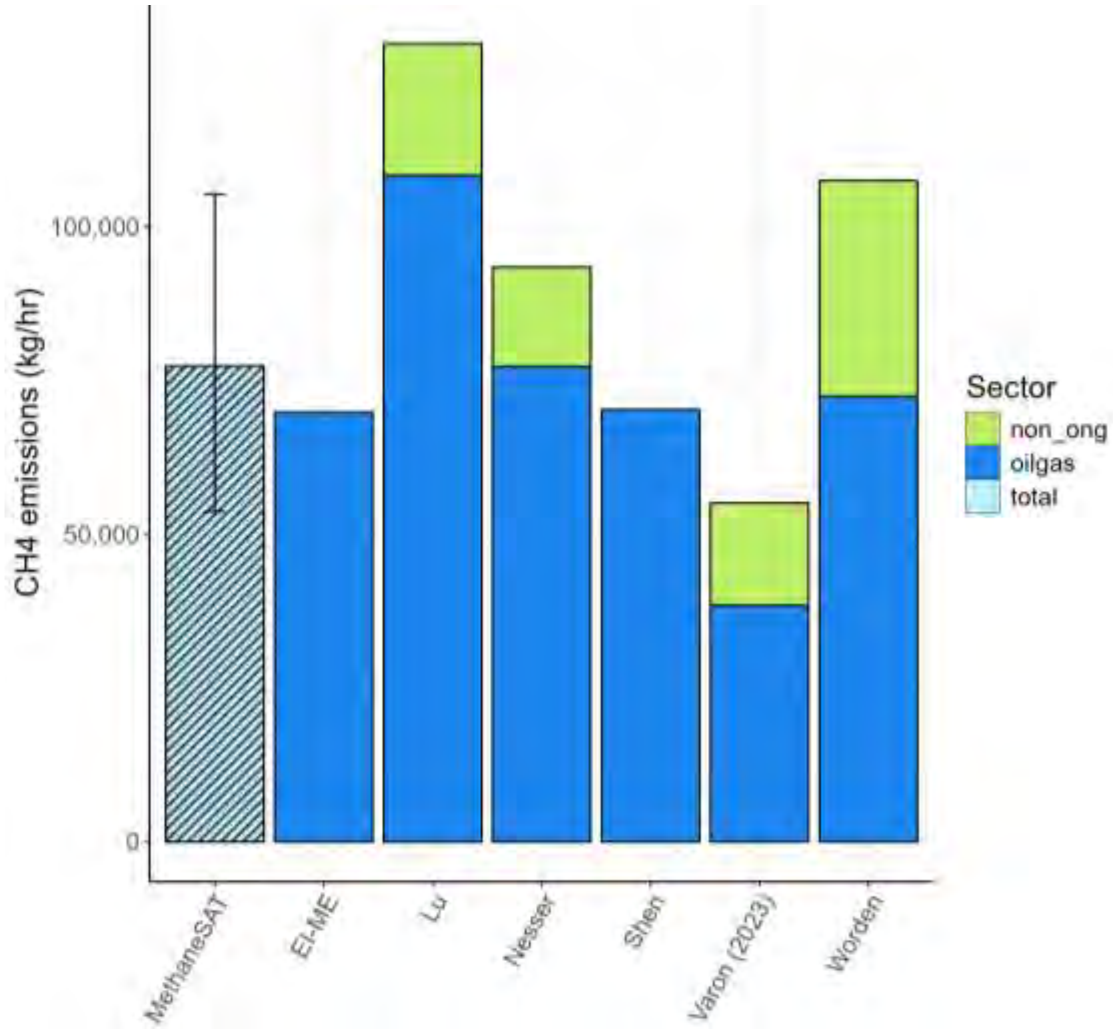
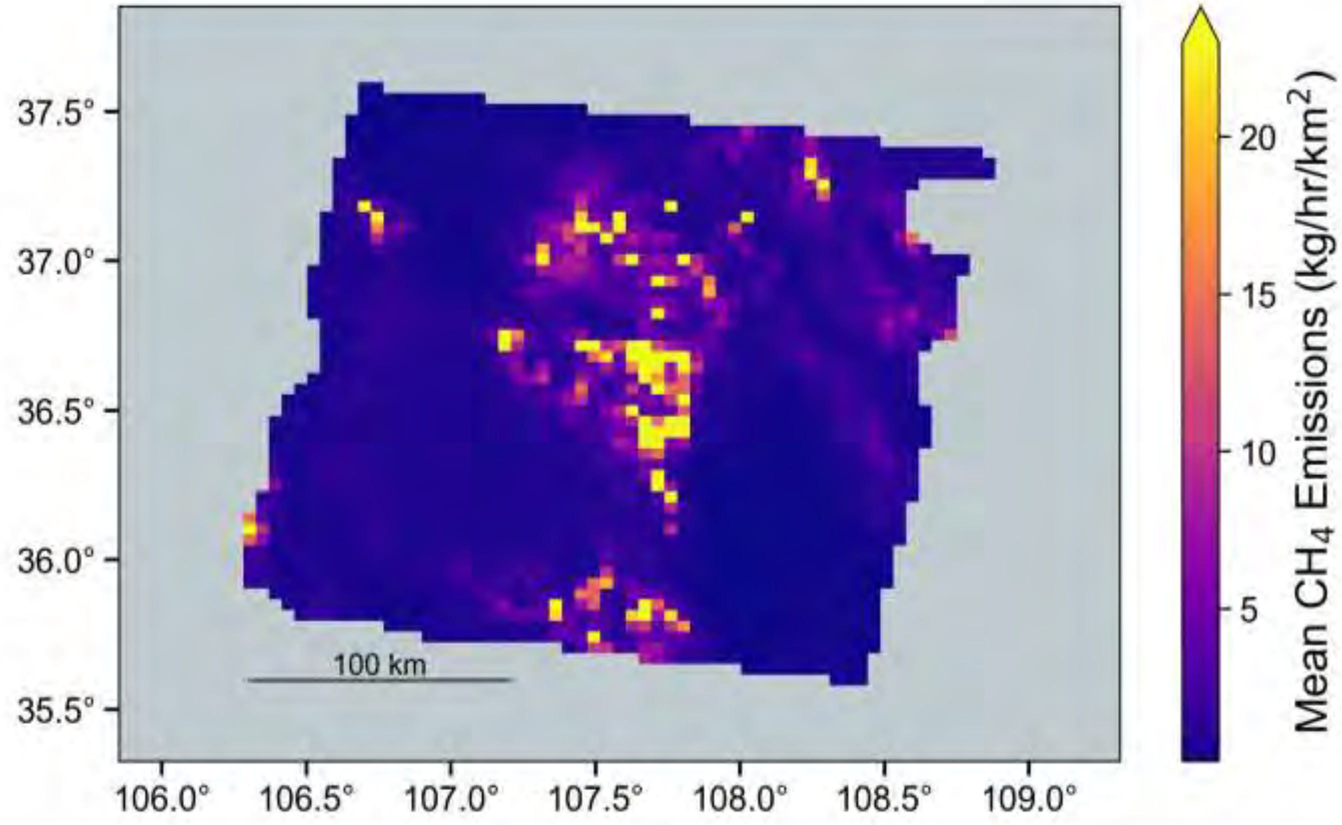
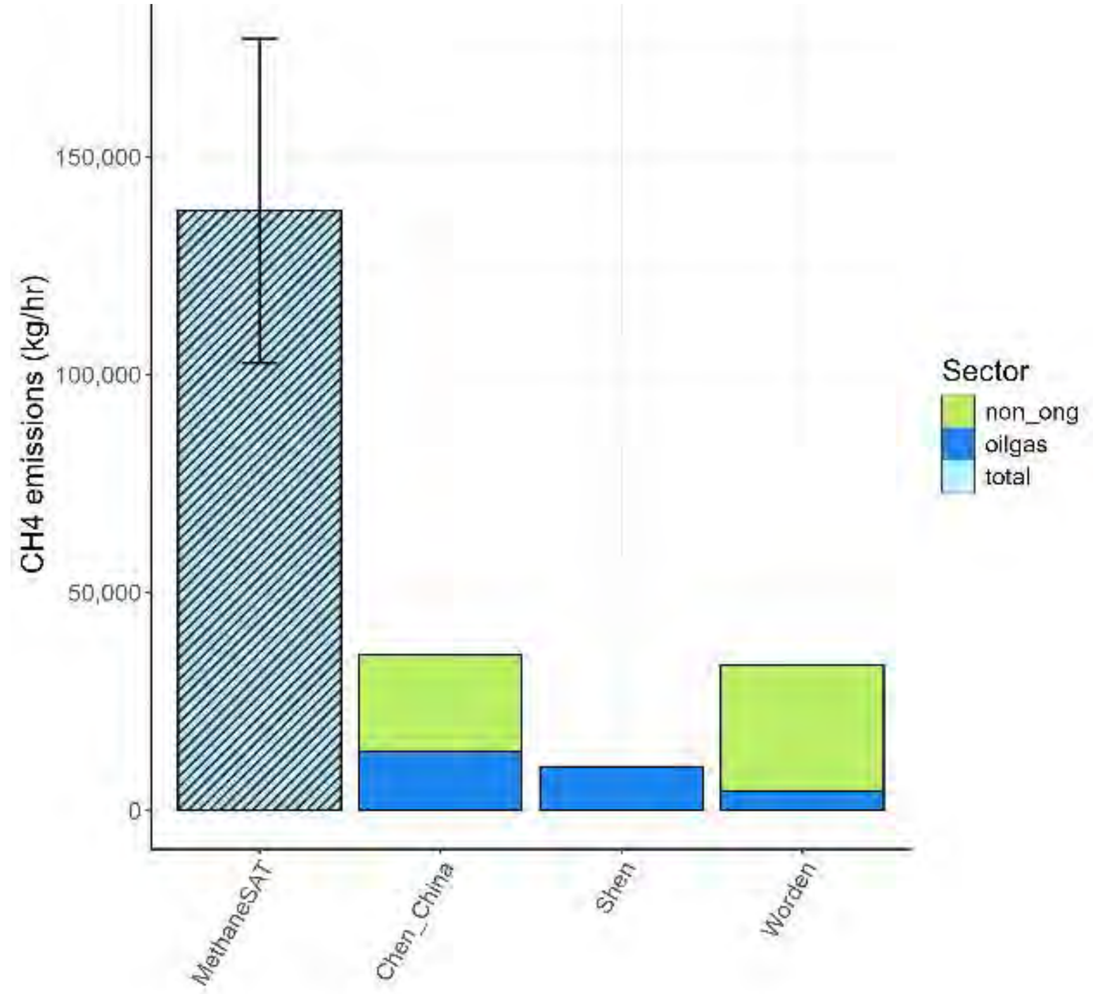


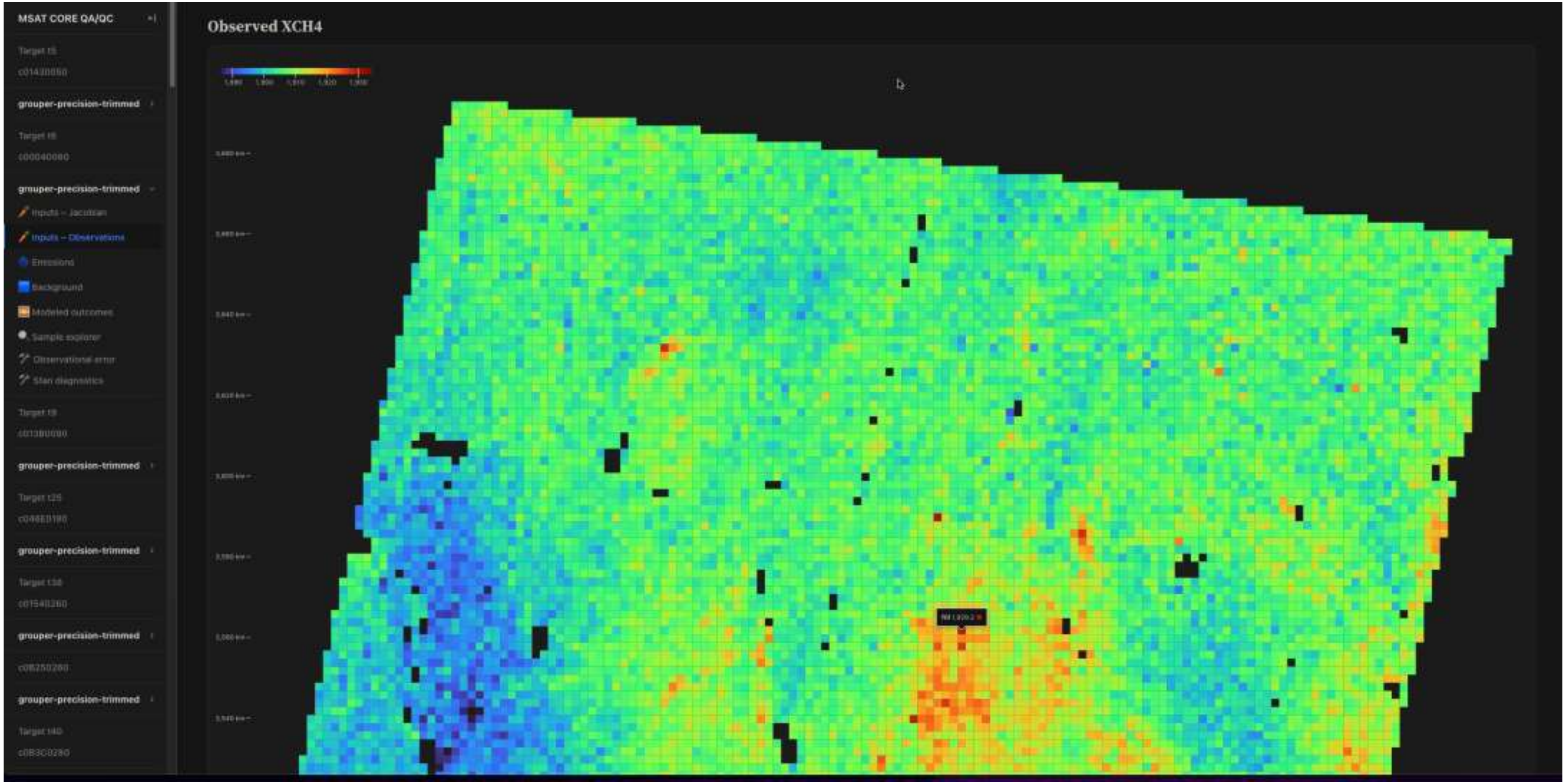


Regional scale variations in emissions may be missed by national or global inversions

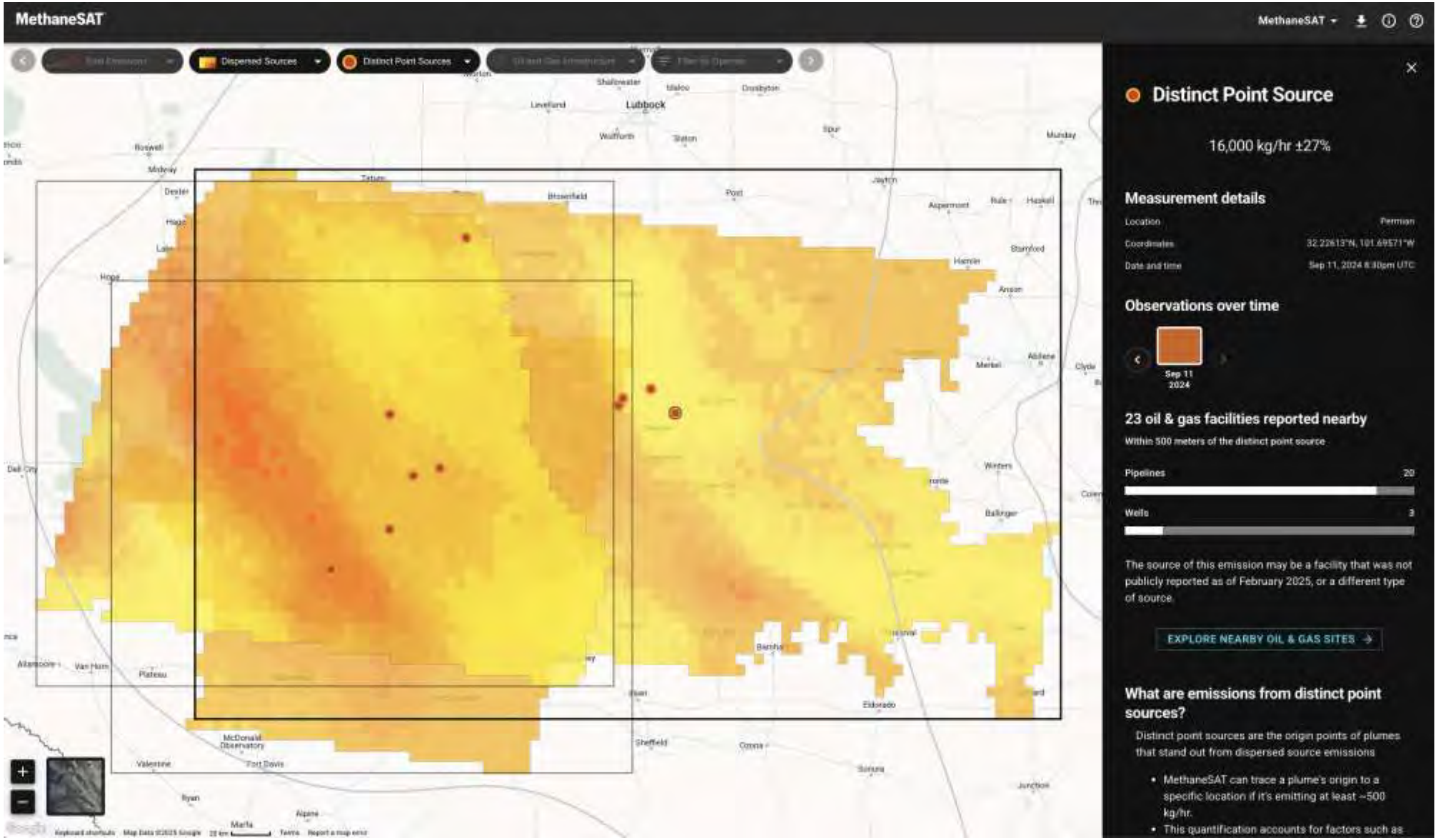




Thanks to the work of our scientific programmers we are in the process of scaling up our inverse modeling capabilities



MethaneSAT enables comprehensive characterization of methane emissions from oil and gas basins



Data Portal:

The success of MethaneSAT is thanks to numerous partners and collaborators

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Javier Roger
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Jasna Pittman
Bruce Daube
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Raia Ottenheimer
Marcus Russi
Sasha Ayvazov
Nick Lofaso
MethaneSAT Back End Software Engineering Team

Partners and Collaborators

Data Portal: