Relating Multi-Scale Plume Detection and Area Estimates of Methane Emissions: A Theoretical and Empirical Analysis

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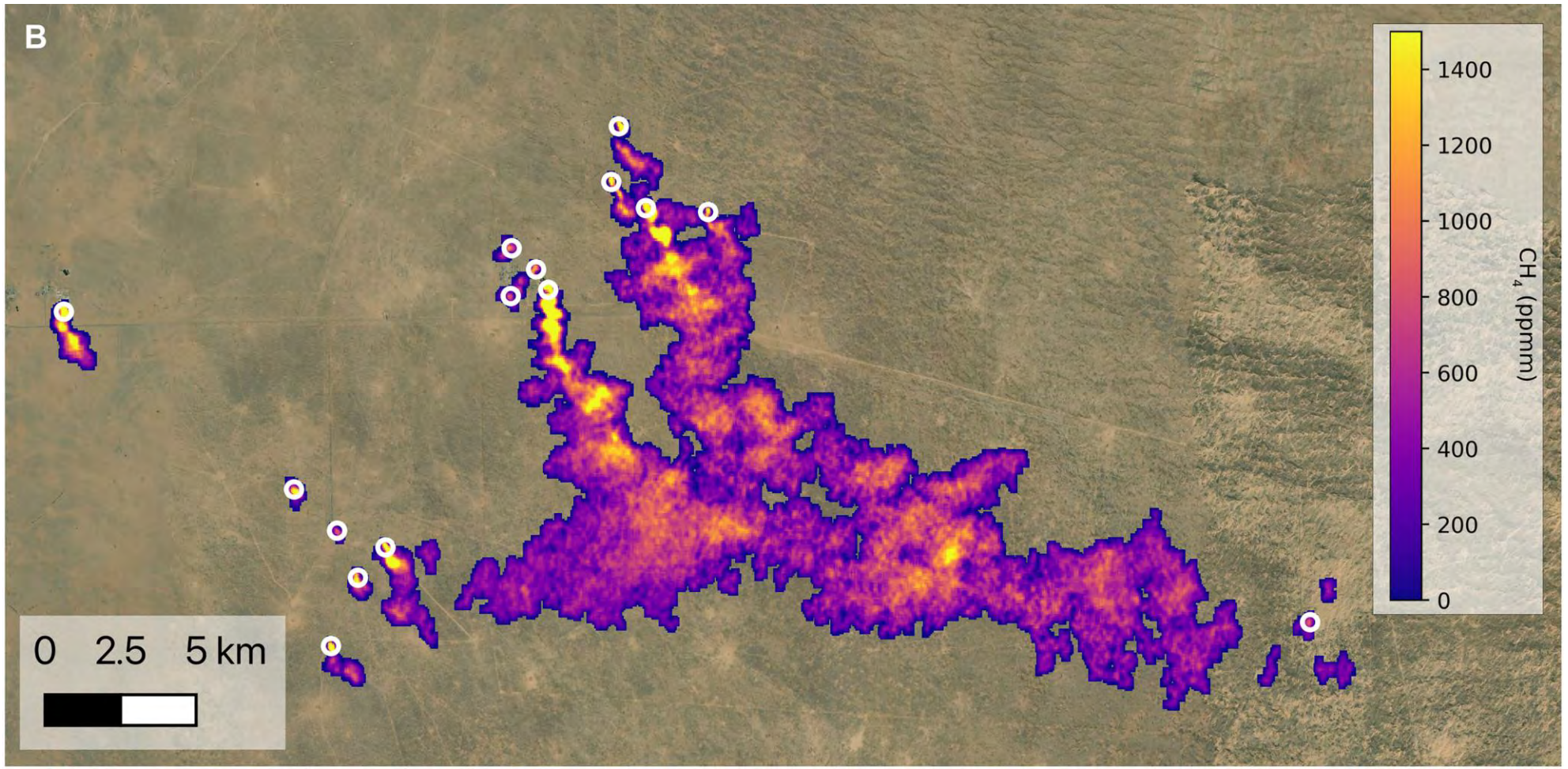
Goal: To Quantify Methane Emissions at Increasingly Finer Spatial and Temporal Resolution

- Funded activity: Methane emissions from TROPOMI and AVIRIS/EMIT data
  - NASA CMS (Colorado and Permian)
  - NASA ECIP-ES (Permian and USA)
  - US GHG Center
- We would like to provide pre and post analysis support to AIRMAPs

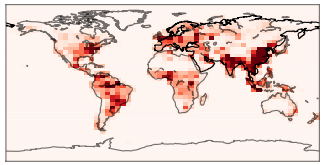
Challenges



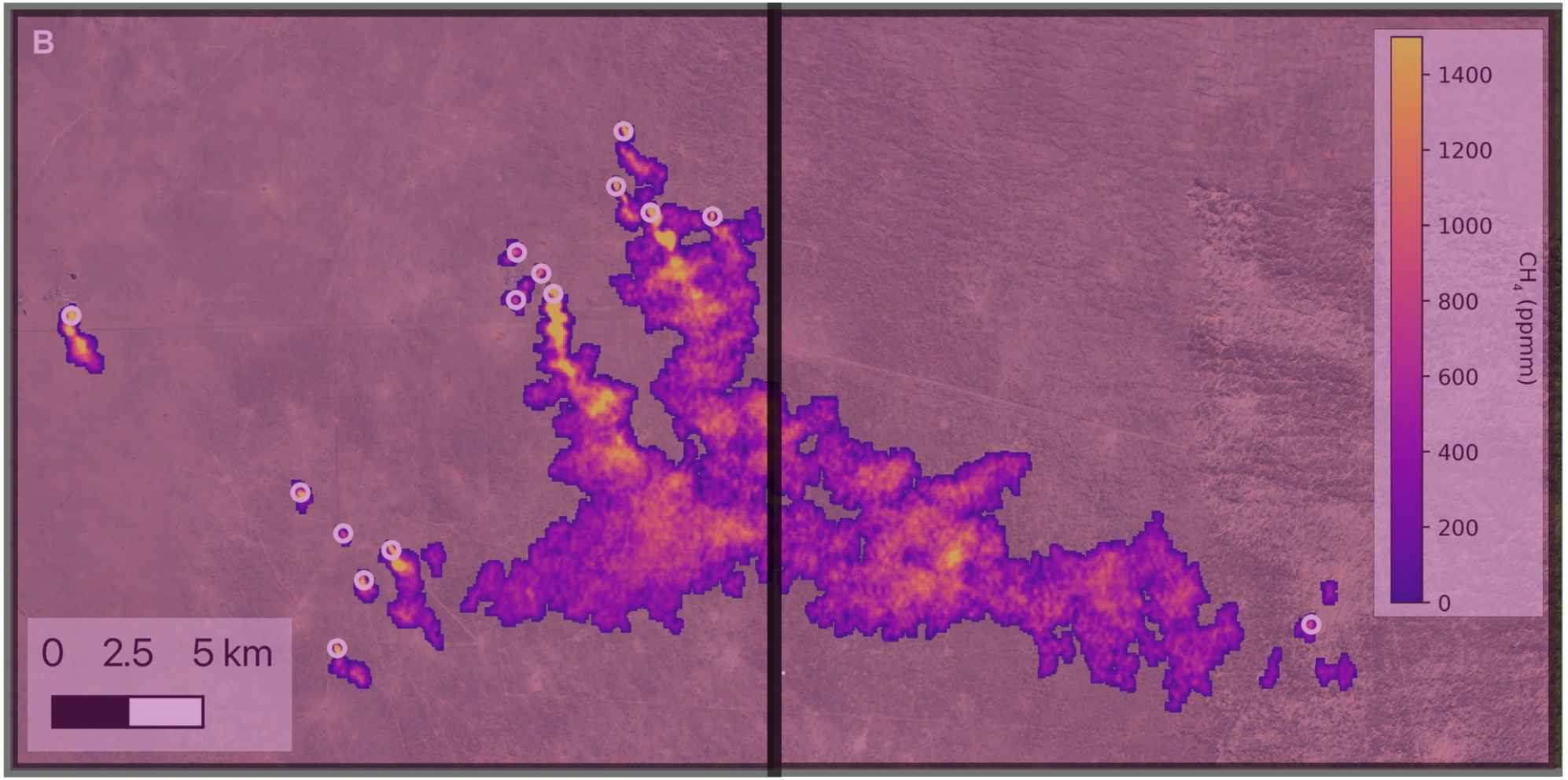
- In dense point source fields, there are sources under the plume.
- We need to account for their effect on plume emission rate.

EMIT Methane Plumes (Thorpe, 2023)

Challenges



Inventory or atmospheric flux inversion

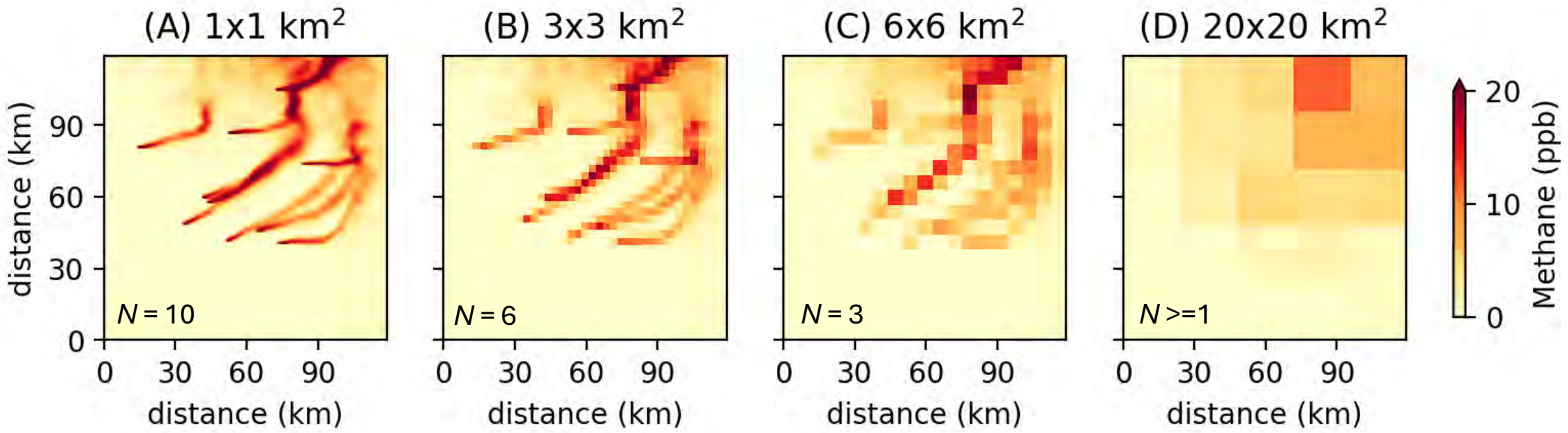


- Area estimates are the emission averages over large temporal and spatial intervals.

EMIT Methane Plumes (Thorpe, 2023)

Conceptual Illustration: Spatial Resolution Impact on Plume Detection

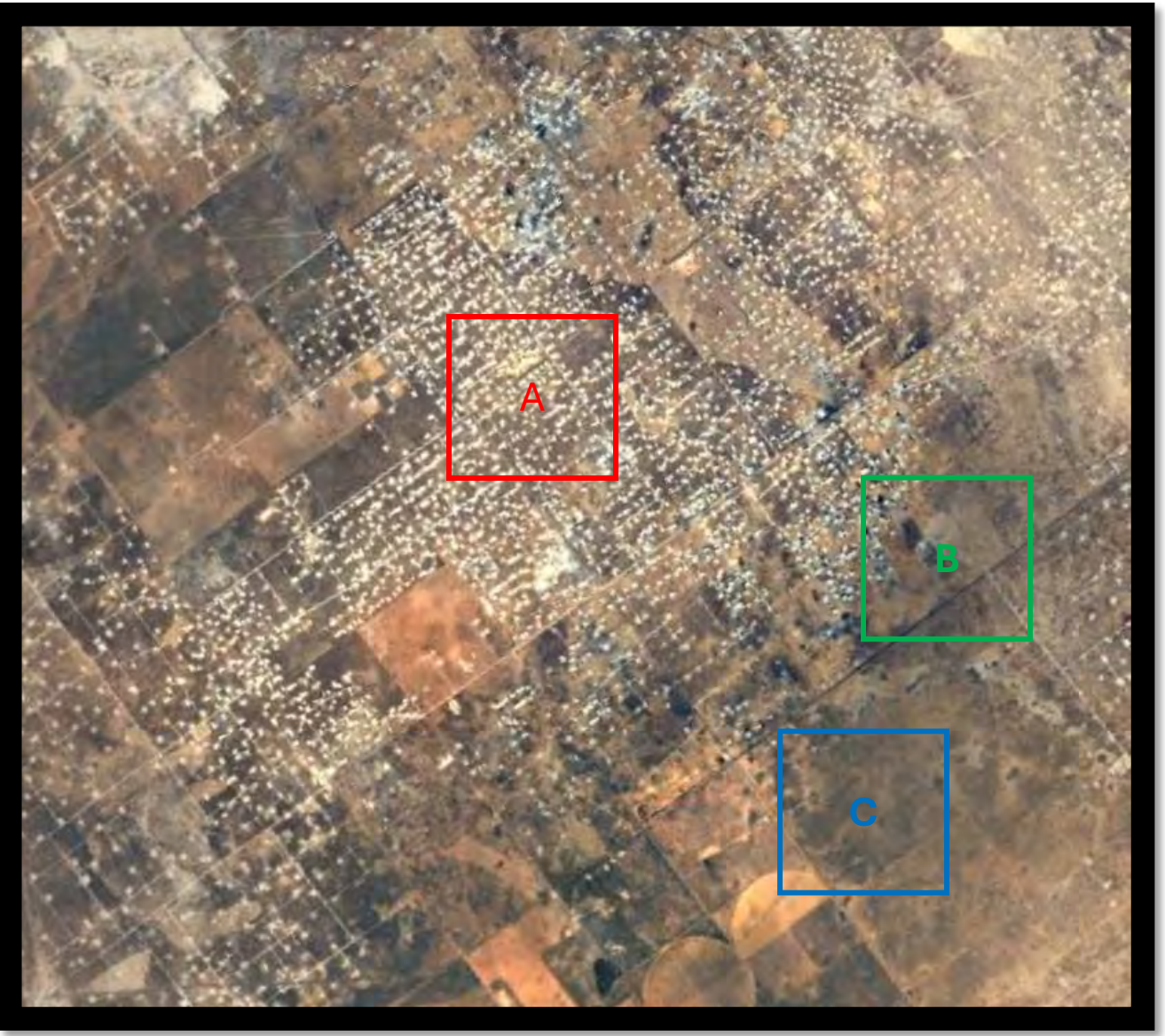
A WRF-CHEM Transport Run with 10 Point Sources

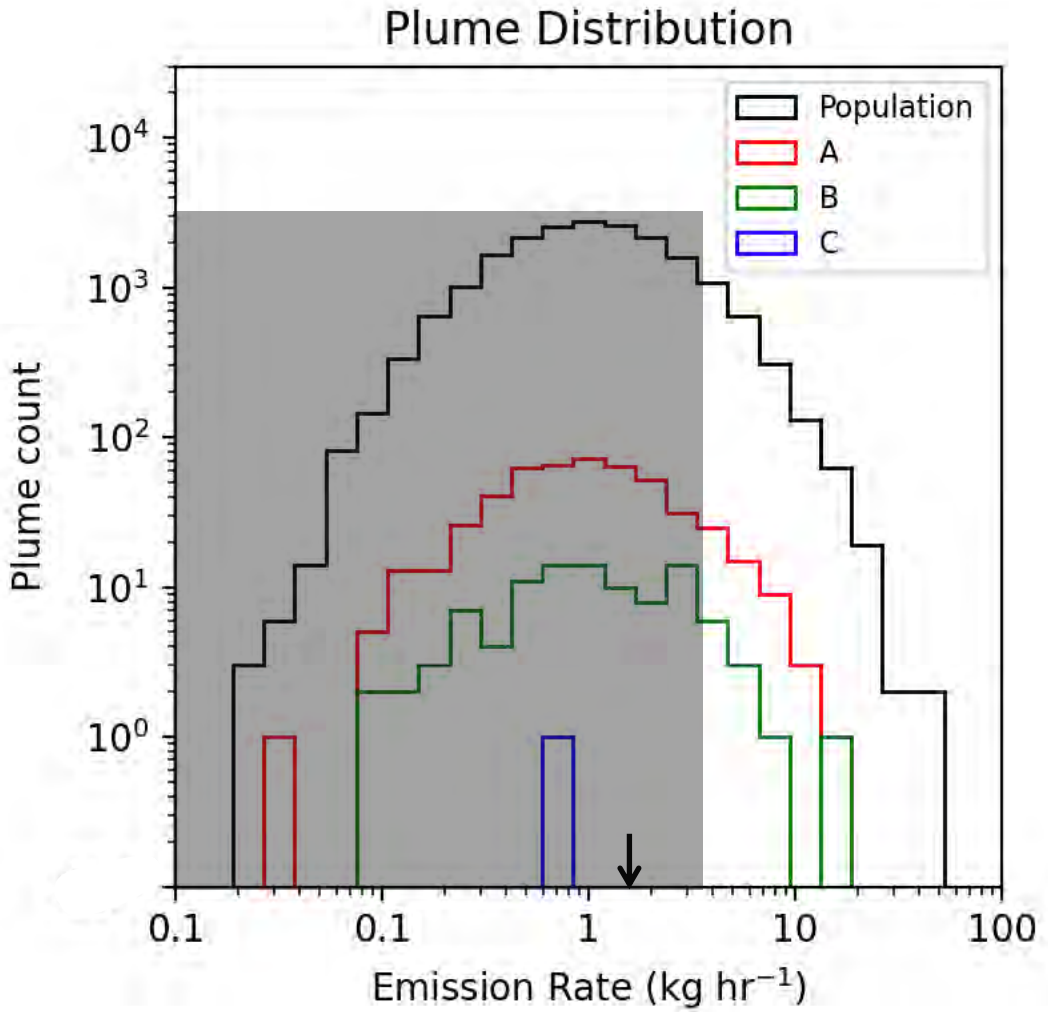


- Coarser resolution instruments observe fewer plumes with a higher emission rate.

Conceptual Illustration: Emission Rate Distribution of Plume Observations

Permian Basin image (Google Earth)





- Both area emission and plume counts scale with activity in oil and gas point source emissions fields.

Relation Between Plume Sums and Area Estimates

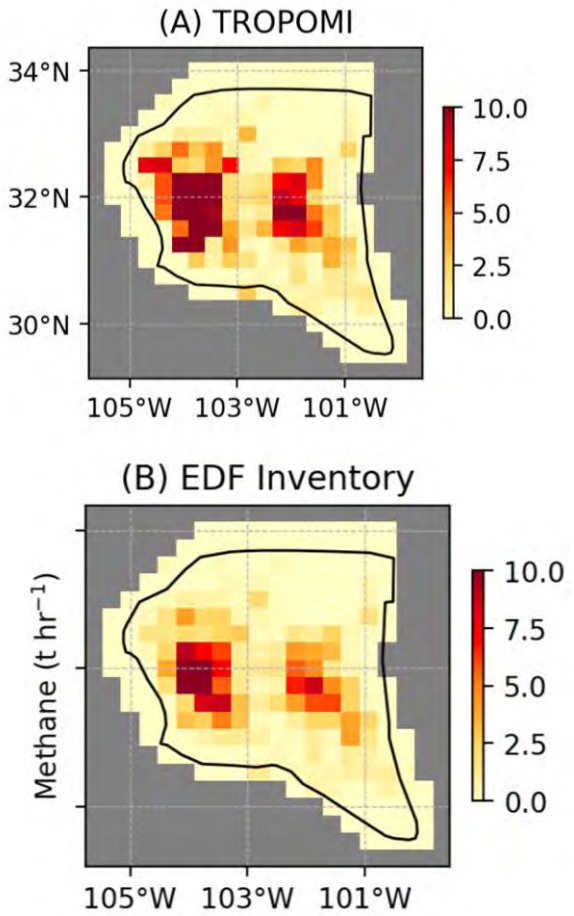
$$y_{ics} = \tau_{ics} \cdot \kappa_{is} \cdot \eta_{ic} \cdot x_{cs}$$

- i : Plume instrument index
- s : Sector component index
- c : Emission grid cell index
- y_{ics}: Sum of plume emissions rate
- x_{cs}: Total emissions
- τ_{is} : $\in [0, 1]$, plume fraction
- κ_{is} : Periodicity correction
- η_{ic} : Sampling

- We derived a statistical relation between area estimates and plumes.
- This forward model is the critical component needed for cross evaluation and plume assimilation.

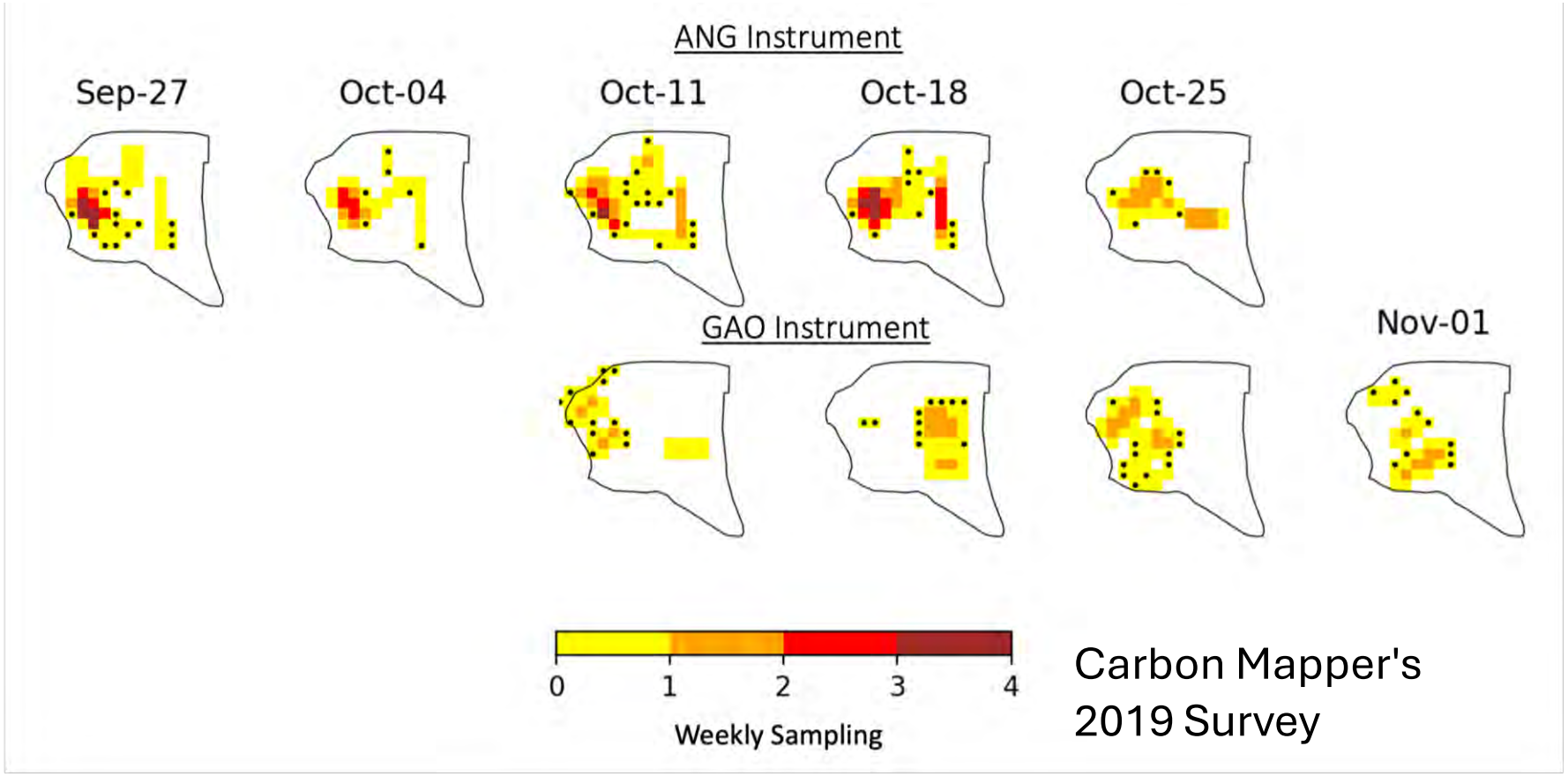
Data: Permian Oil and Gas Methane Emissions

Area Estimates



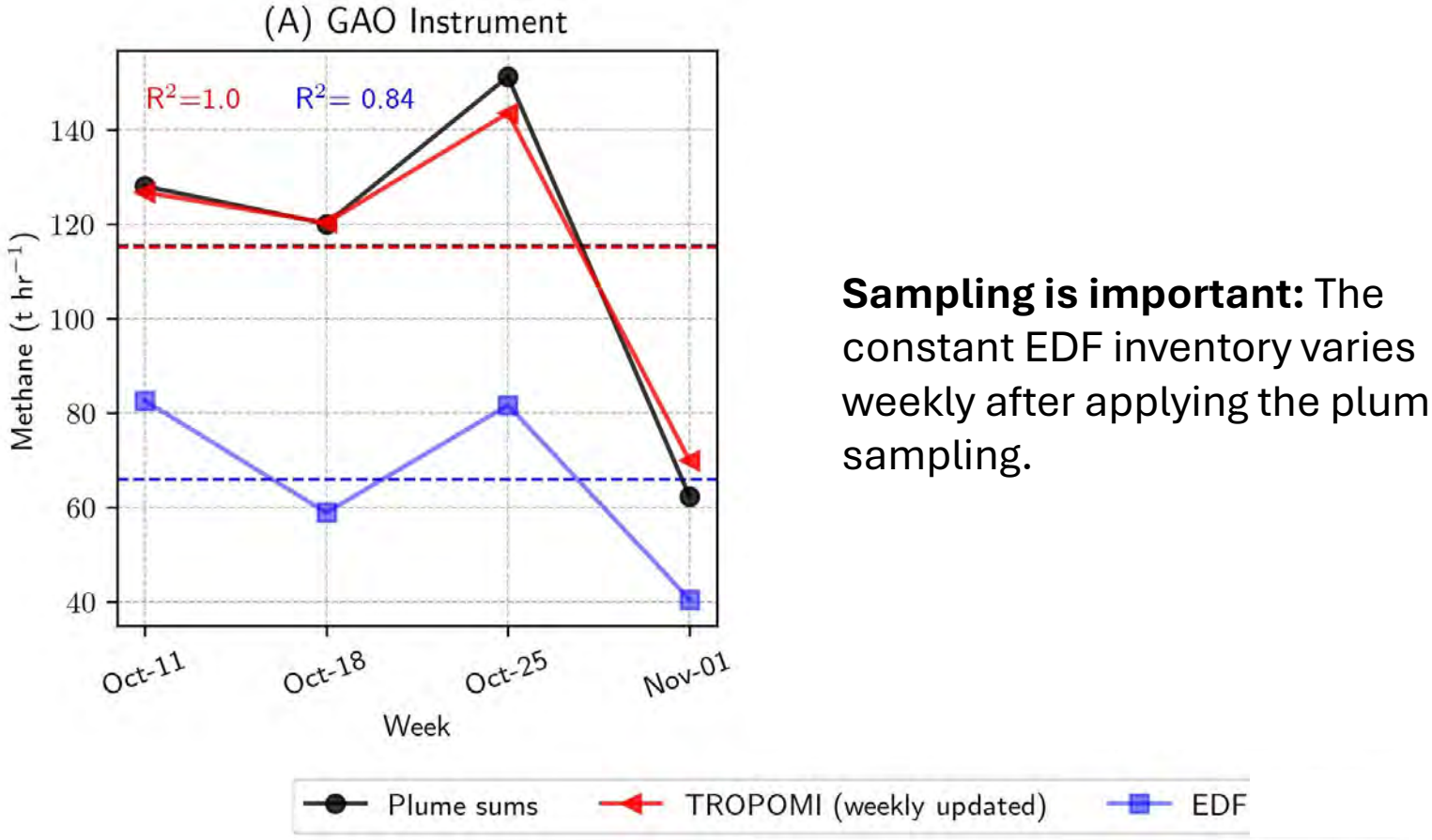
Varon (2023)

Plume Instruments' Weekly Sampling (AVIRIS-NG)



Carbon Mapper's 2019 Survey

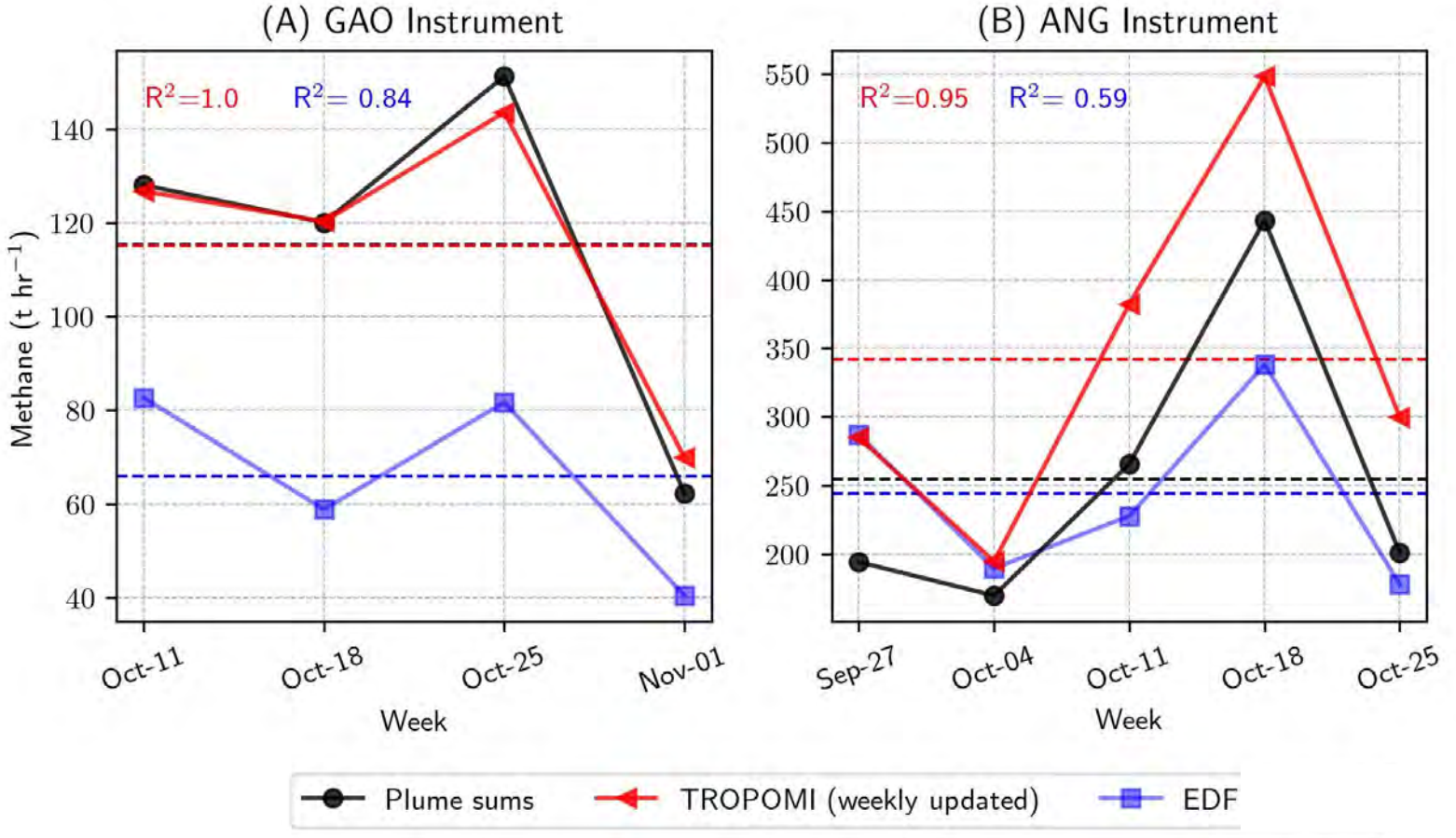
Application: Area Emission Evaluation using Plume Data



Sampling is important: The constant EDF inventory varies weekly after applying the plume sampling.

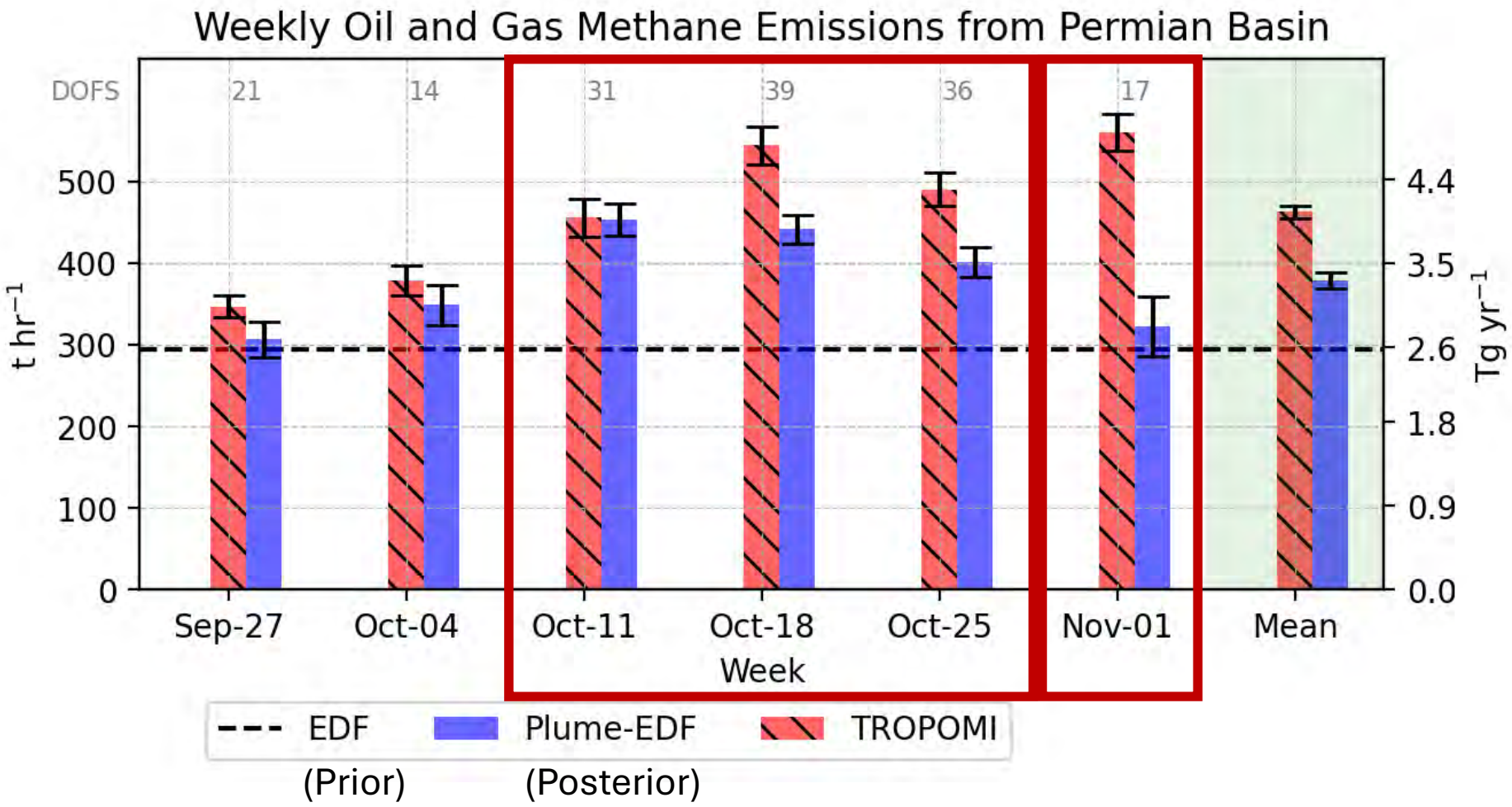
- Strong agreement between plume and TROPOMI estimates after applying forward model.

Application: Area Emission Evaluation using Plume Data



- Strong agreement between plume and TROPOMI estimates after applying forward model.

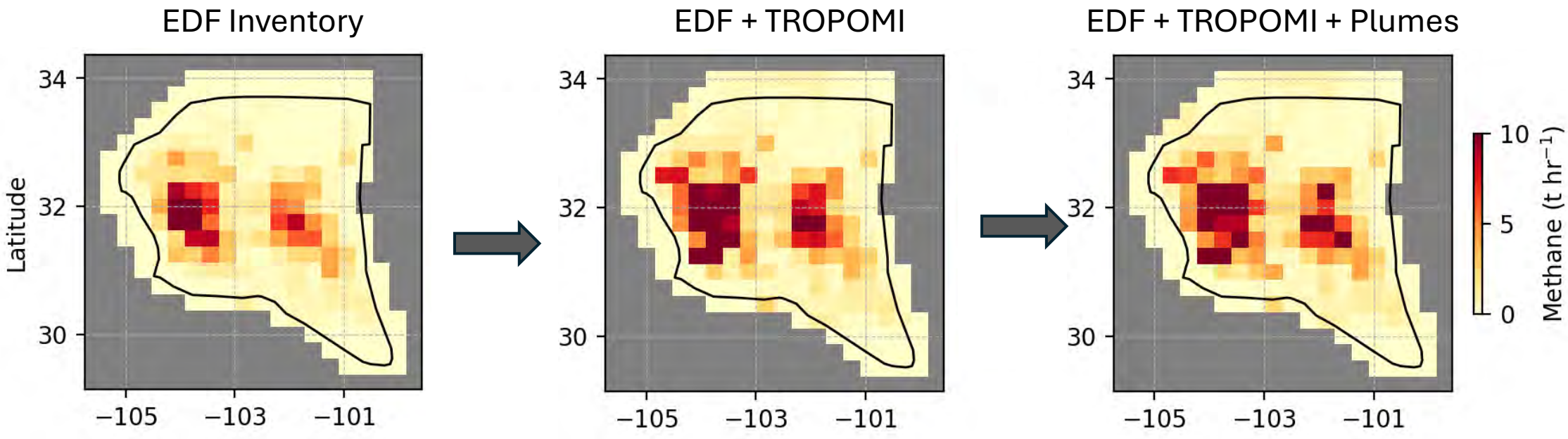
Application: Bayesian Plume Assimilation



- After plume assimilation, EDF inventory agrees with weekly TROPOMI flux inversion.
- Strong improvement in weeks Oct-11, Oct-18, and Oct-25 due to better plume constraint (both ANG and GAO observing).

Application: Bayesian Plume Assimilation

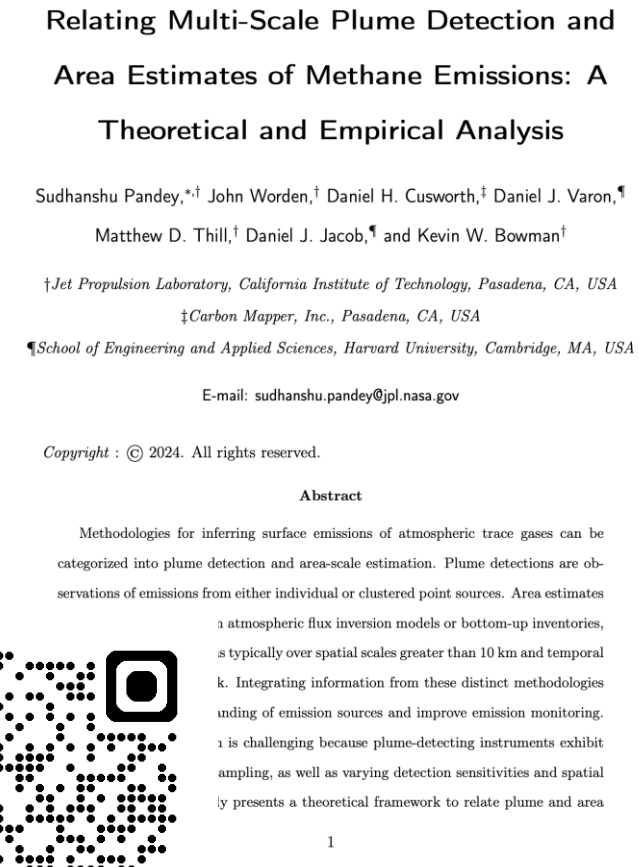
Spatial Distributions of 6-week Average Methane Emissions



- Plumes have better spatial specificity than area estimates, and thus provide better fine-scale constraint.

Summary

- We have shown that we can combine TROPOMI inventory and facility-scale sparse plume observations to estimate methane emissions at fine resolution (manuscript under review at EST).
- We are funded to develop and demonstrate this algorithm for Permian and Colorado using TROPOMI–AVIRIS (NASA-CMS) and using TROPOMI–EMIT (NASA-ECIPES) for USA.
- We would like to use this new capability to provide pre and post analysis support to AIRMAPs.



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Abstract

Methodologies for inferring surface emissions of atmospheric trace gases can be categorized into plume detection and area-scale estimation. Plume detections are observations of emissions from either individual or clustered point sources. Area estimates
ı atmospheric flux inversion models or bottom-up inventories,
s typically over spatial scales greater than 10 km and temporal
k. Integrating information from these distinct methodologies
ınding of emission sources and improve emission monitoring.
ı is challenging because plume-detecting instruments exhibit
ampling, as well as varying detection sensitivities and spatial
y presents a theoretical framework to relate plume and area

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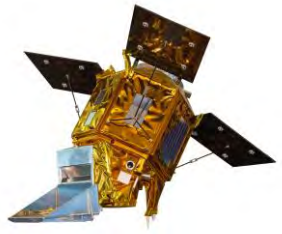
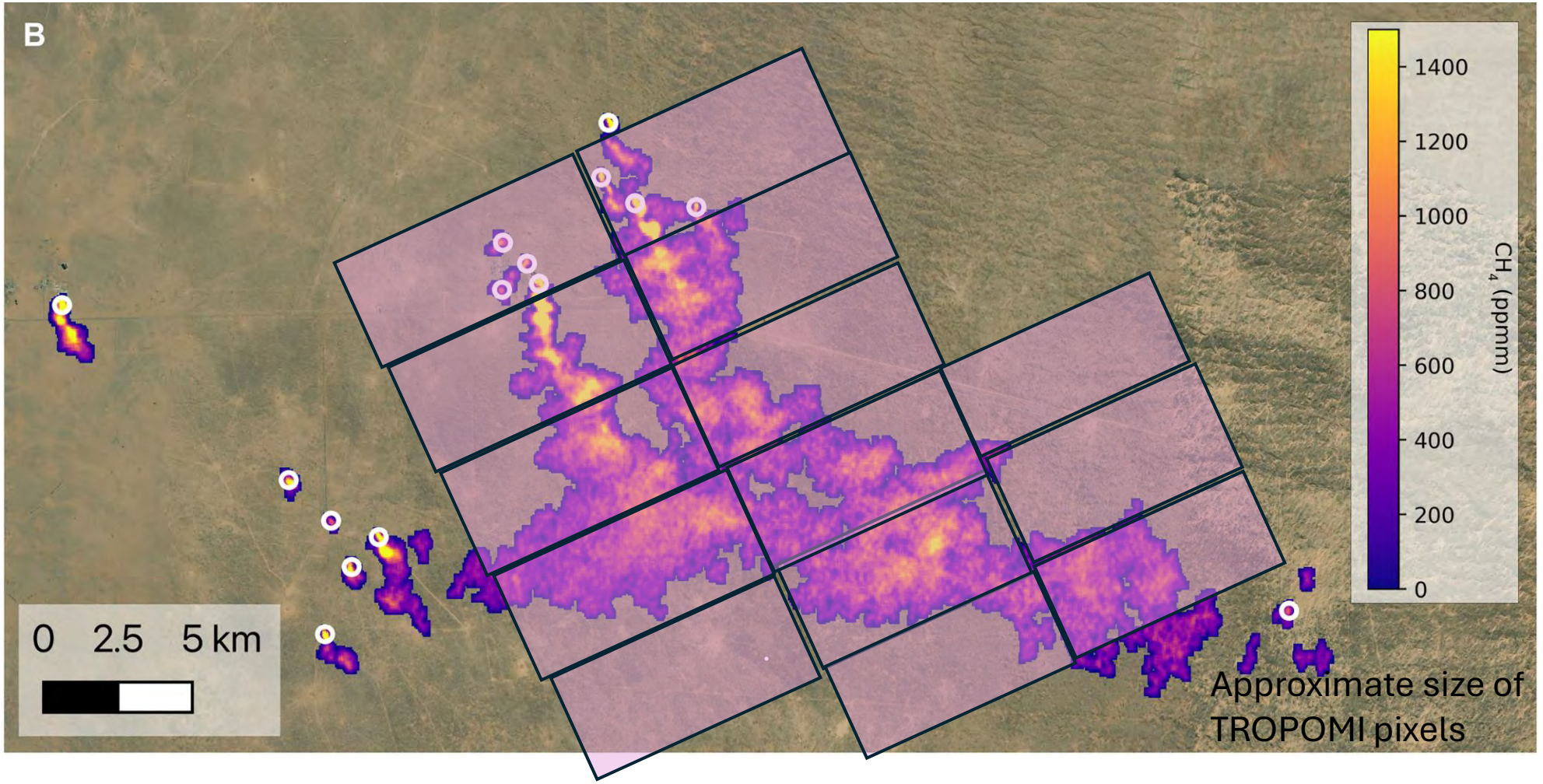
Challenges



TROPOMI



EMIT Methane Plumes (Thorpe, 2023)

Periodicity of Emissions in Oil/Gas Production

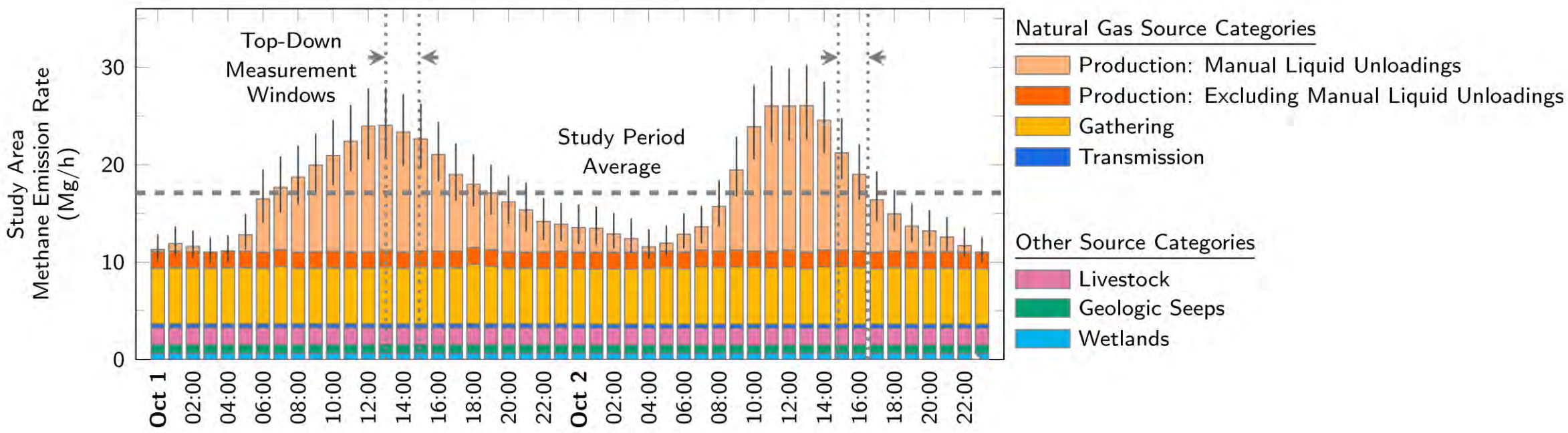


Figure: Hourly averaged methane emissions for the study area estimated by Fayetteville Shale

Vaughan et al. (2018) PNAS