Direct Quantification of Multi-Scale Methane Emission Rates Using an Unmanned Aerial System

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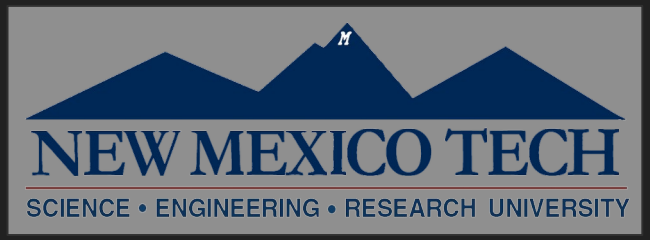


Unmanned Aerial System Design

A. Ultrasonic Anemometer

- 3D vector winds @ 5 Hz
- Temperature, pressure, humidity

B. Vertical mast & Sampling Inlet

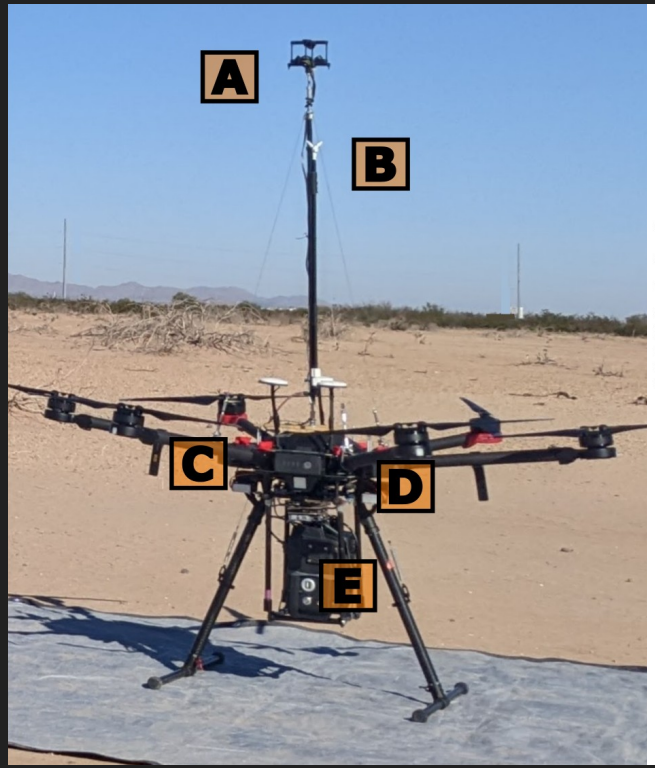
- Above shallow inflow layer

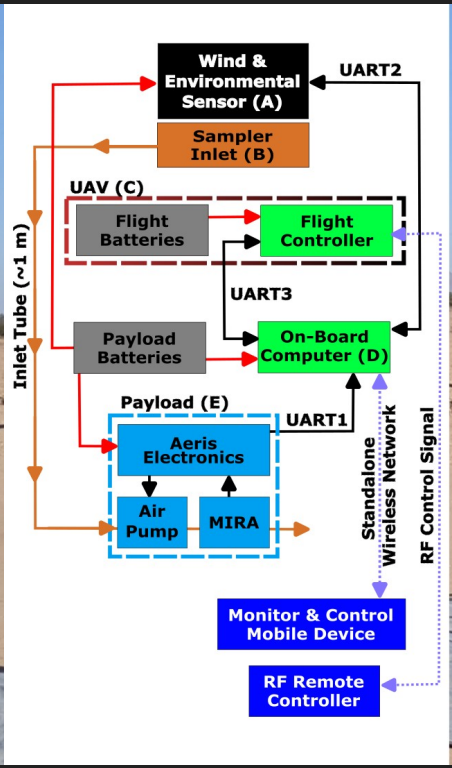
C. Vertical takeoff hexacopter

- Altitude range ~3 to 120 m
- 15-25 minute flight time
- Up to *5 kg* payload

D. Onboard Computer

- Sensor synchronization
- Built-in modularity

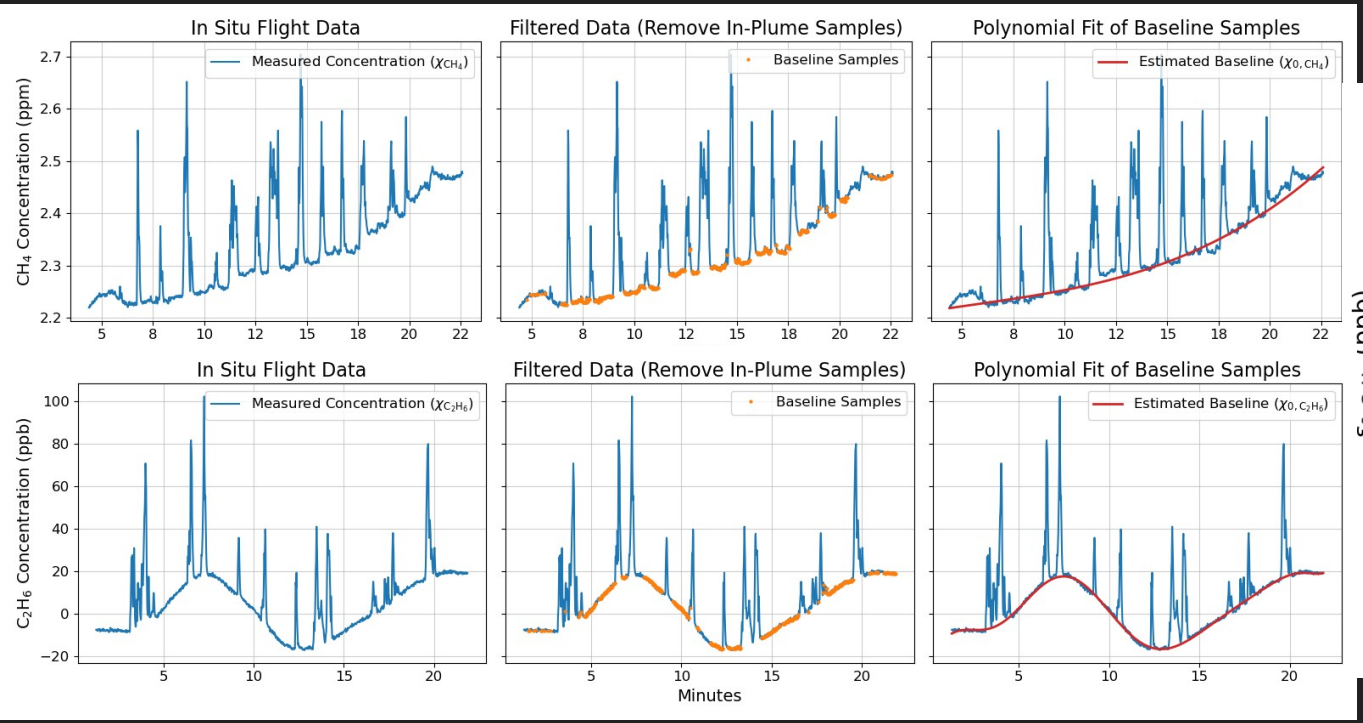


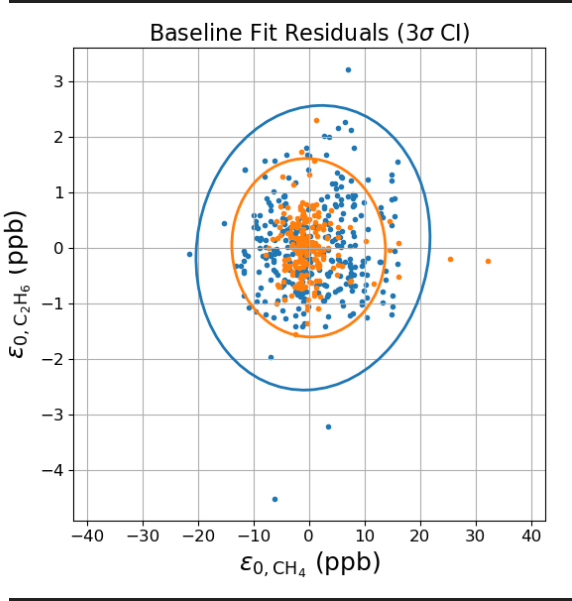


E. CH_4 & C_2H_6 Mid-IR Absorption Spectrometer

- Sensitivity: 1 ppb CH_4 (500 ppt C_2H_6) @ 1 Hz

Background & Sensor Baseline Estimation



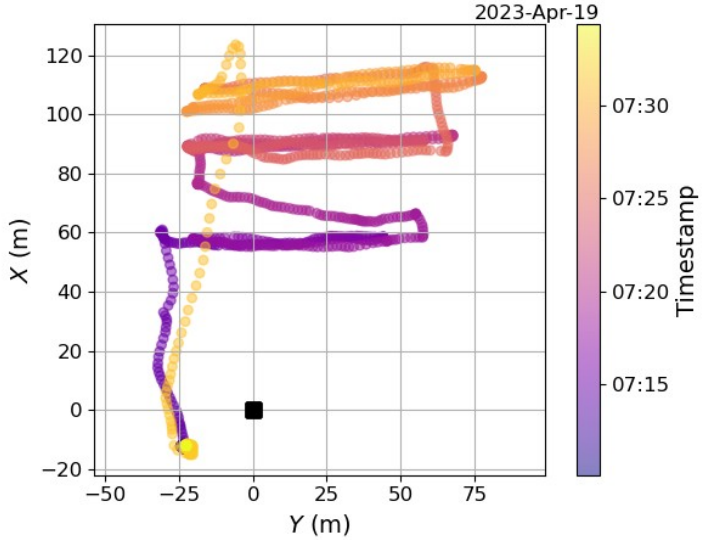


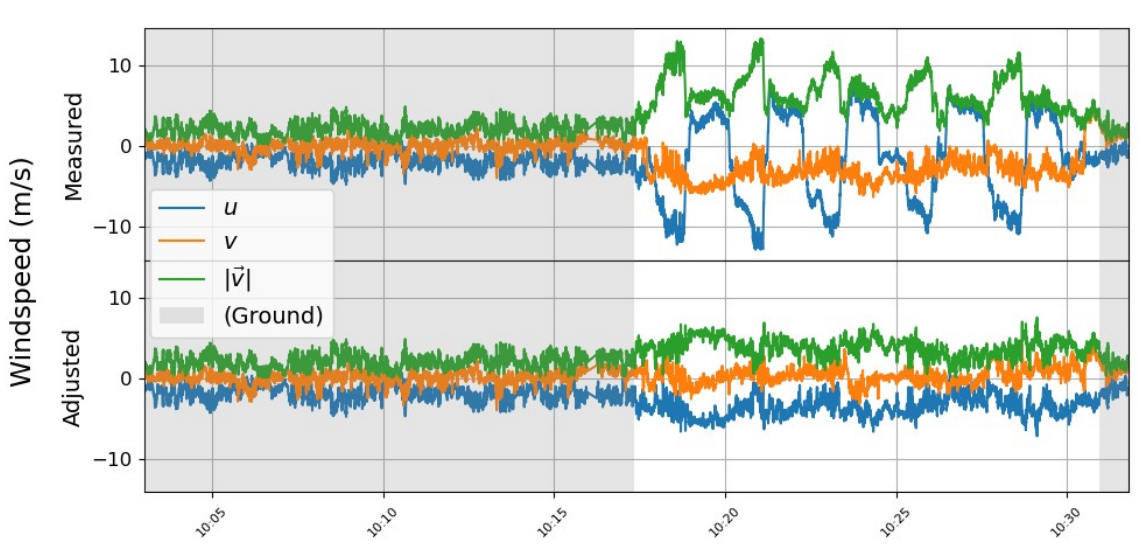
Raw measurement composed of two terms: ***1)*** True ambient background mixing ratio and ***2)*** Slow, time-variant sensor drift (5-10 min)

Motion and Environmental Adjustments

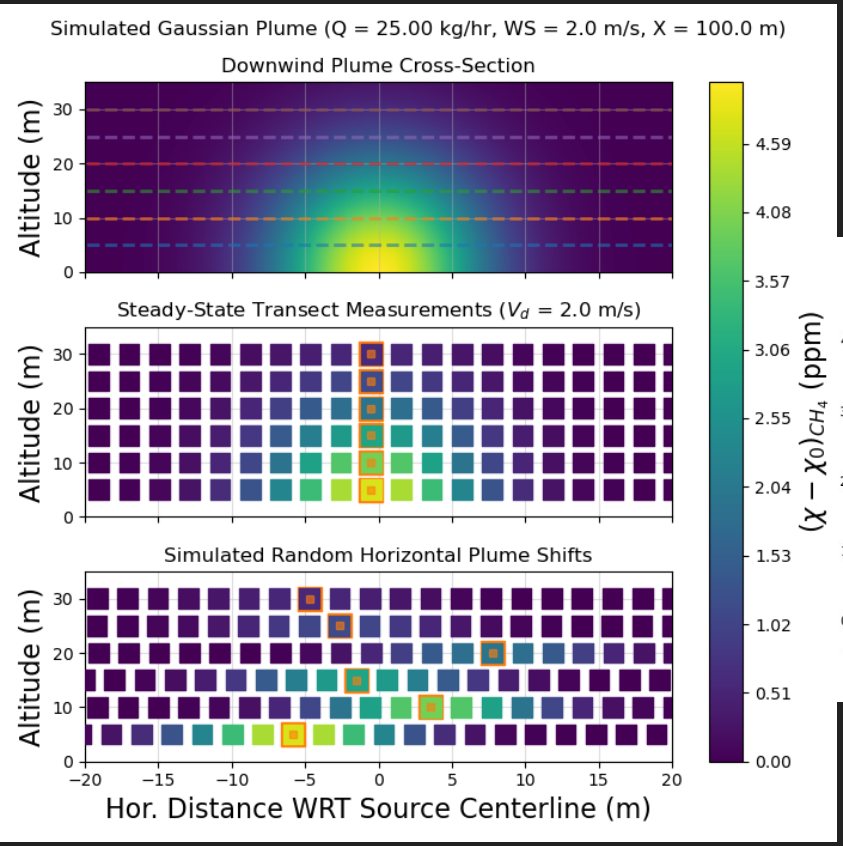
Typical flight path: Multiple horizontal legs downwind of target source, transecting plume at various altitudes.

Onboard anemometer records ***relative wind*** due to UAS heading and velocity; rotation matrices used to back out vector winds in static reference frame



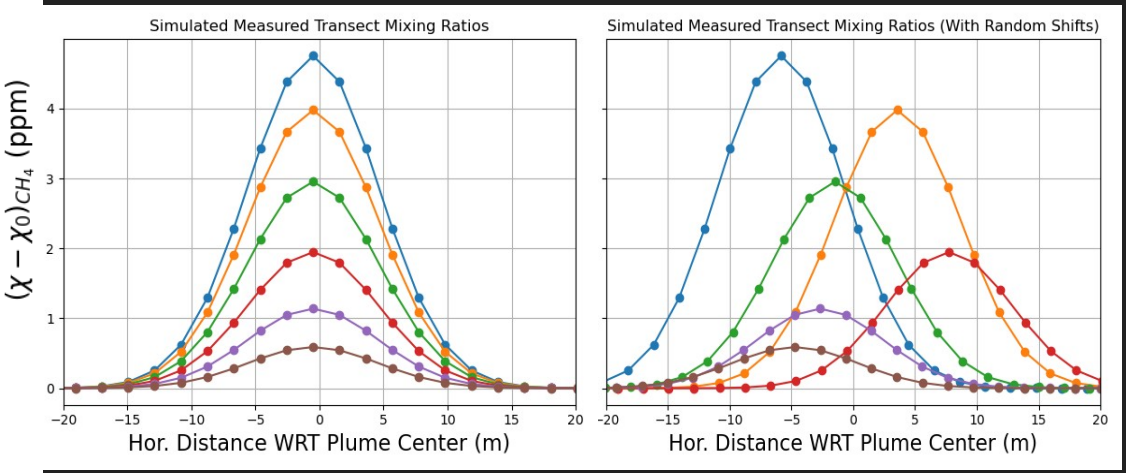


Deployment



Gaussian plume models for first-approximation concentration estimation & flight planning

Ground-based measurements miss a significant portion of dispersing plume; UAS raster scans show vertical profile of source plume



Gaussian modelling is ***not*** used for source flux estimates

Plume Cross Sections Downwind of Orphan Well

Orthonormal views of flight path

- *Top Right:* Aerial View
- *Bottom Left:* West-Facing
- Bottom Right: North-Facing

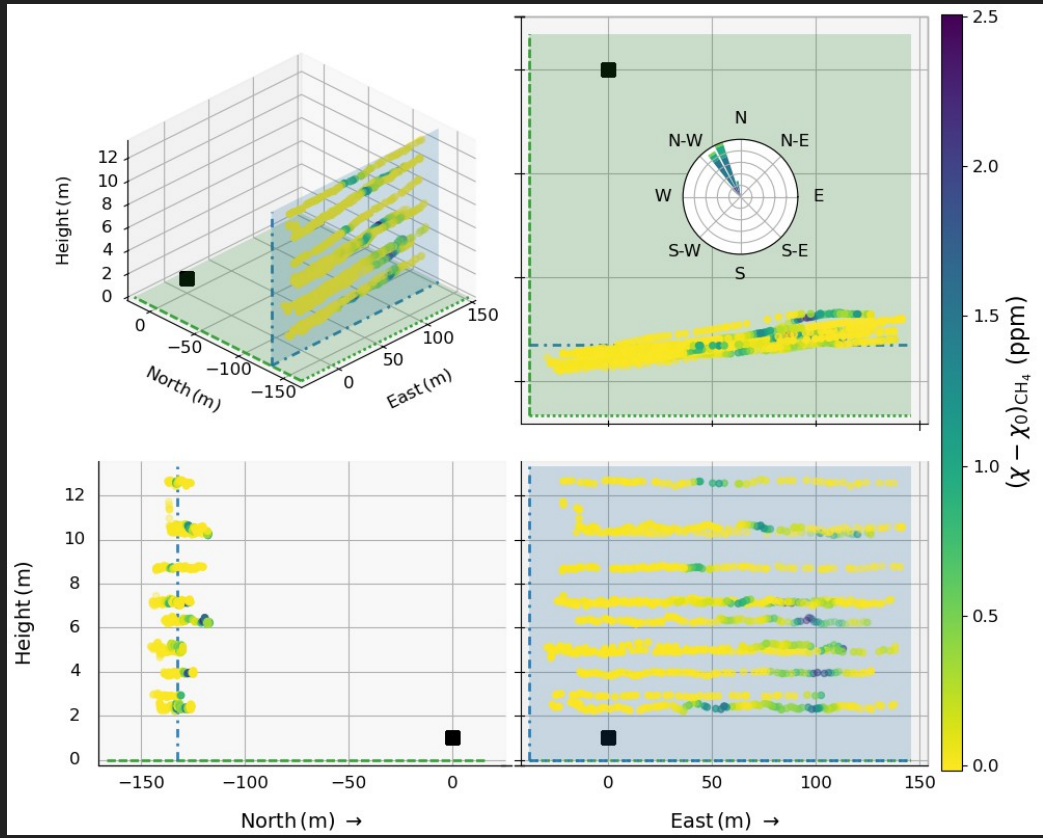
Flux Calculation Process:

1. Individual transects segmented & labelled (*k*)
2. 'Transect-Integrated Flux' (f_k) for each *k*

$$f_k = \sum_{i=0}^{n-1} (C - C_0)_i (\boldsymbol{u} \cdot \hat{n})_i \Delta s_i$$

3. Total flux (*F*) from integration of f_k and distance between adjacent *k* (Δz)

$$F_{tot} = \sum_{k=0}^{K-1} (f_k \Delta z_k)$$

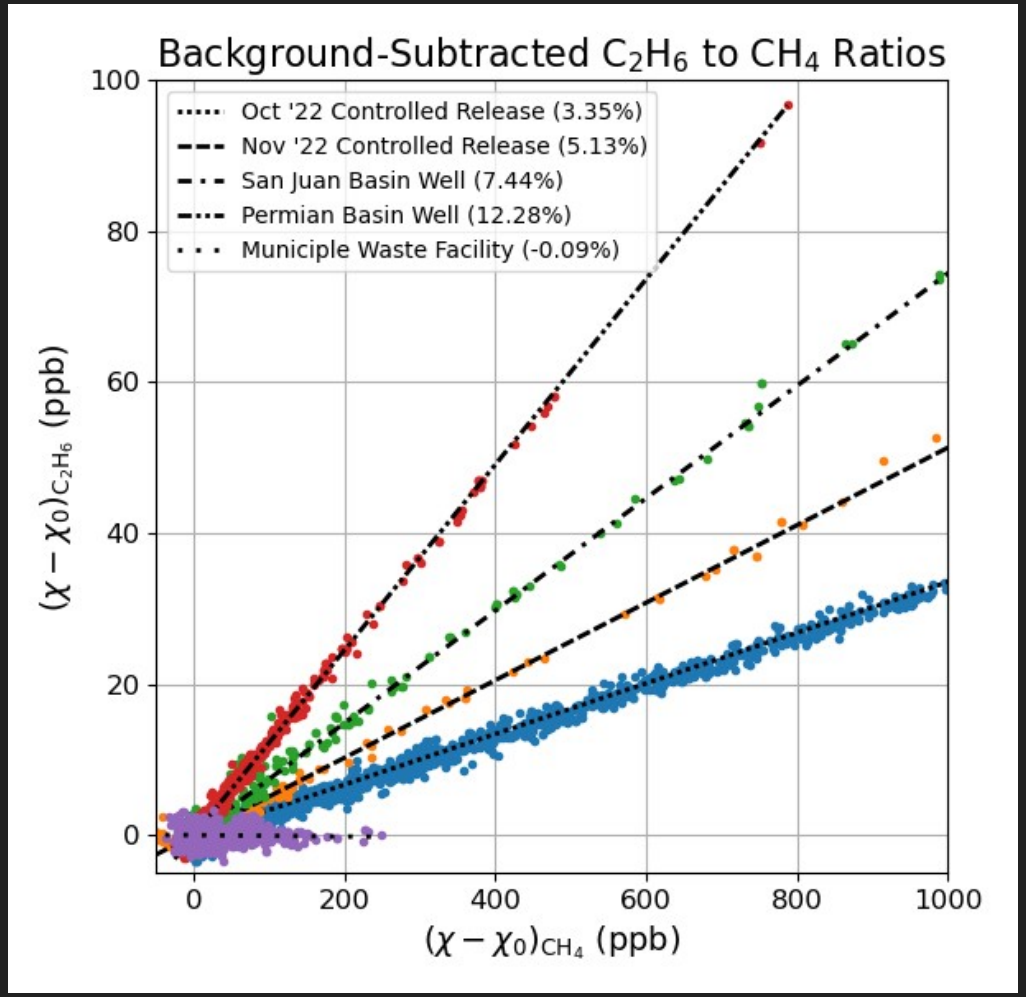


Source Attribution

C_2H_6 more than just attribution of source as biogenic or thermogenic

Thermogenic sources exhibit characteristic and consistent C_2H_6:CH_4 ratios.

Useful for detangling contributions from complex, distributed, or multi-sector source locations



Distribution of Measured Fluxes by Sector

Participated in Controlled Release (2022)

- *Unbinded* results helped with system development & flux quantification methodology

Municipal Waste Facility (2022-2023):

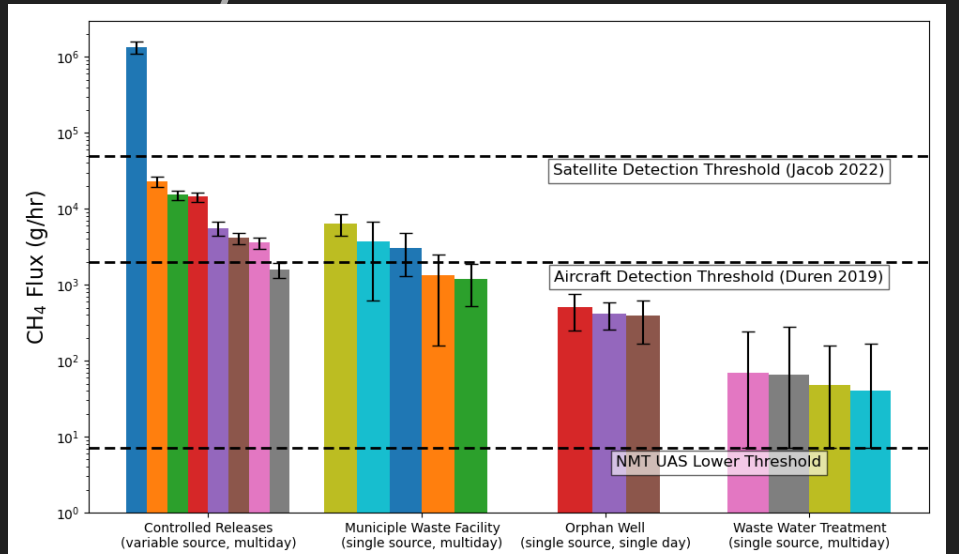
- Small, local landfill at or below most aircraft system detection limits (~10 kg/h)

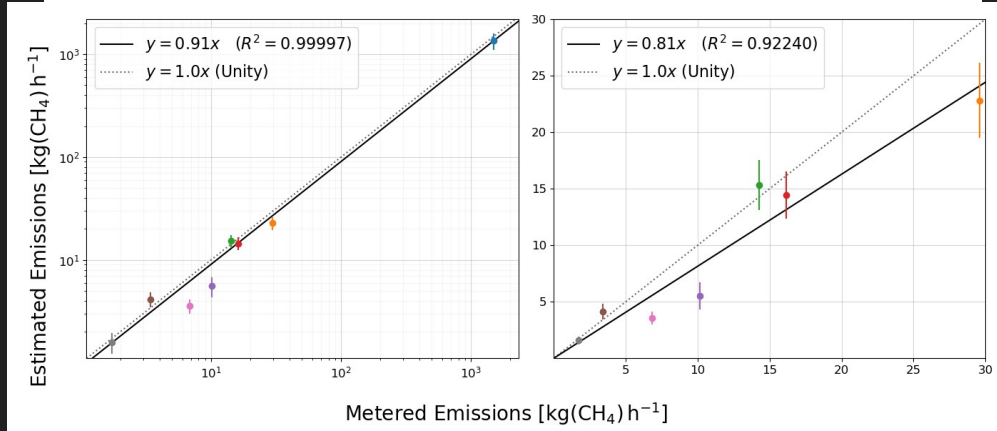
Permian Basin Orphan Well (2023):

- Abandoned O&NG wells, emitting methane & other gases at low but constant rates

Wastewater Treatment Plant (2022-2023):

- Very small emission rate around the estimated UAS lower quantification limit (~7 g/h)





Acknowledgements & Further Info

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THANK YOU

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