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. CH₄ & C₂H₆ Mid-IR Absorption Spectrometer
   - Sensitivity: 1 ppb CH₄ (500 ppt C₂H₆) @ 1 Hz
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

Orthogonal 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 \(k\)

\[
f_k = \sum_{i=0}^{n-1} \left( C - C_0 \right)_i \left( \mathbf{u} \cdot \hat{n} \right)_i \Delta s_i
\]

3. Total flux \((F)\) from integration of \(f_k\) and distance between adjacent \(k\) \((\Delta z)\)

\[
F_{tot} = \sum_{k=0}^{K-1} \left( f_k \Delta z_k \right)
\]
Source Attribution

$\text{C}_2\text{H}_6$ more than just attribution of source as biogenic or thermogenic

Thermogenic sources exhibit characteristic and consistent $\text{C}_2\text{H}_6$:$\text{CH}_4$ ratios.

Useful for detangling contributions from complex, distributed, or multi-sector source locations
Distribution of Measured Fluxes by Sector

Participated in Controlled Release (2022):
- *Unbinned* 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)
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