U.S. DEPARTMENT OF ENERGY
Fossil Energy and Carbon Management

LA-UR-23-29616

Consortium Advancing Technology for Assessment of Lost Oil & Gas Wells.
CATALOG
Locate Characterize Inform

catalog.energy.gov

Safe, Defensible, and Cost-Effective methane emission monitoring at orphan wells

Manvendra Dubey, Sebastien Biraud, Natalie Pekney, Hari Viswanathan, Andrew Govert, DOE WP1 Team & Jeff Sorkin

August 22, 2023

Pictures Source: PADEP

Methane Mitigation Technologies Division Overview

Methane Emissions Mitigation

Advanced materials, data management tools, inspection and repair technologies, and dynamic compressor R&D for eliminating fugitive methane emissions across the natural gas value chain

Methane Emissions Quantification

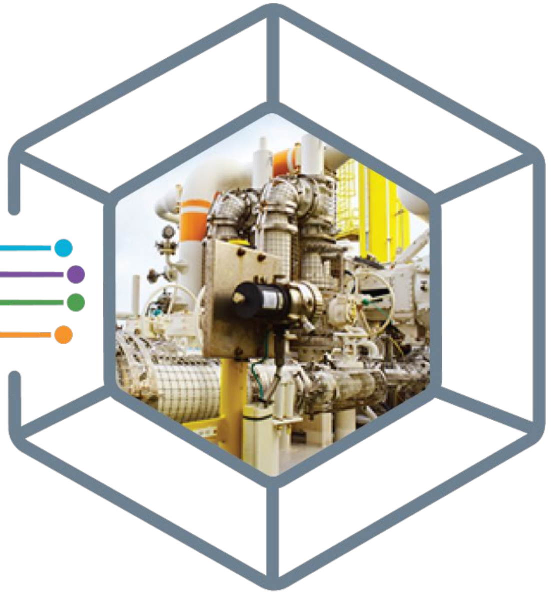
Direct and remote measurement sensor technologies and collection of data, research, and analytics that quantify methane emissions from point sources along the upstream and midstream portion of the natural gas value chain

Decarbonization of Natural Gas Resources

Technologies for carbon-neutral hydrogen production, safe and efficient transportation, and geologic storage technologies supported by analytical tools and models

Undocumented Orphaned Wells Research

Developing tools, technologies, and processes to efficiently identify and characterize undocumented orphaned wells in order to prioritize them for plugging and abandonment.



METHANE MITIGATION TECHNOLOGIES

Administration Goals:

50% emissions reduction by **2030**
100% clean electricity by **2035**
Net-zero carbon emissions by **2050**

Bi-Partisan Infrastructure Legislation

Relevant Appropriations Language

Section H2 (a, b)
Conduct research and development activities in cooperation with the **Interstate Oil and Gas Compact Commission** to assist the Federal land management agencies, **States**, and Indian Tribes in--

(A) identifying and characterizing undocumented orphaned wells; and

(B) mitigating the environmental risks of undocumented orphaned wells;

Program Budget

DOE's Undocumented Orphaned Well Program will be executed over **5 years with $30M** in appropriated budget.

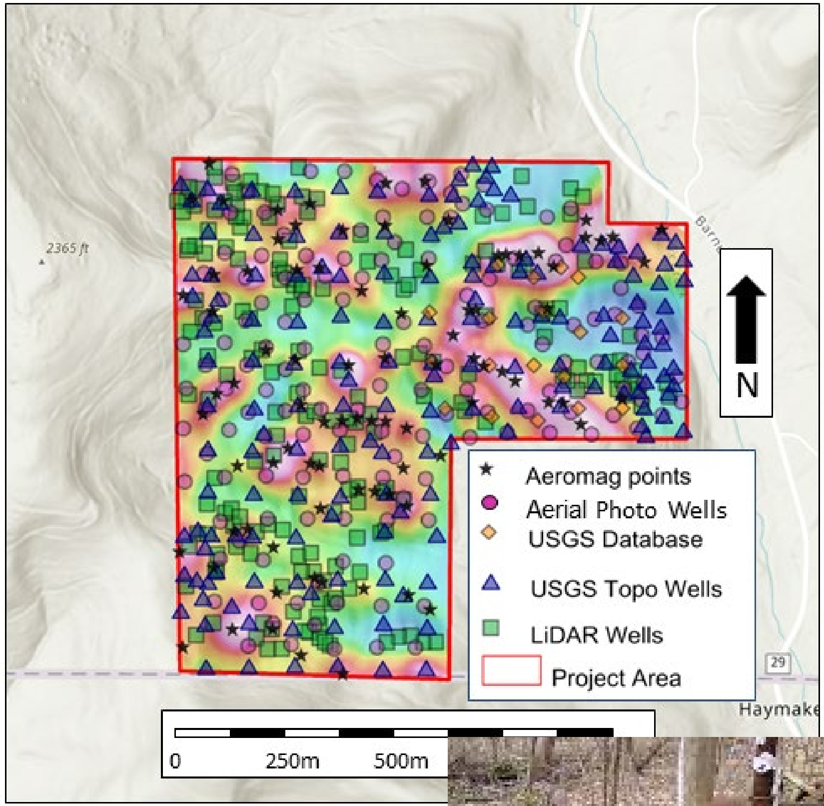
FY2023 Appropriations

Up to $10 million to be spend on identification and characterization of undocumented orphaned wells.

IOGCC 2021 estimate of undocumented orphaned wells is between **310,000** and **800,000**.

There's no silver bullet for *finding* these wells: We have to screen and quantify their emissions to prioritize plugging

- Various methods could be used to locate wells
  - magnetic survey, aerial or satellite photography, LiDAR, methane measurements, historical records
- No method works in all cases
  - Magnetics fail when the well casing is removed (~15,000 wells had casings salvaged during WW2 for the metal) and is challenging in steep terrain or tall vegetation
  - **Methane measurements fail when the well is not emitting (emissions are highly transient) and are not cost-effective**
  - Aerial/satellite photos could be obstructed by vegetation or construction



DOE Undocumented Orphaned Wells Program Priorities

1. **Methane Detection and Quantification**
2. Well Identification
3. Sensor Fusion and Data Integration with Machine Learning
4. Well Characterization
5. Integration and Best Practices
6. Data Management
7. Records Data Extraction
8. Wells Database
9. Field Teams
10. Well Finder App

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Berkeley Lab | Los Alamos National Laboratory EST. 1943 | Lawrence Livermore National Laboratory | National Energy Technology Laboratory | Sandia National Laboratories

Methane Detection and Quantification Purpose

- Provide DOI with accurate, cost-effective methane measurement methods that can be used to report well emission reduction values back to congress as required by the BIL language. (Asked by White house and DOI to develop a rig-hand friendly method.)
- Accurate, cost-effective methane measurement method.
  - Most wells are low emitters; the huge number of emitting wells adds to significant emissions.
  - Flow rate is difficult to measurement to make without complex equipment. Concentration is a much simpler measurement to make.
  - The low level of emissions from individual wells are a challenge for satellites thus require new technologies such as UAVs.
- Understand methane emission distributions and uncertainties from orphan well populations.
- Understand the temporal component of well emissions and the related uncertainty.

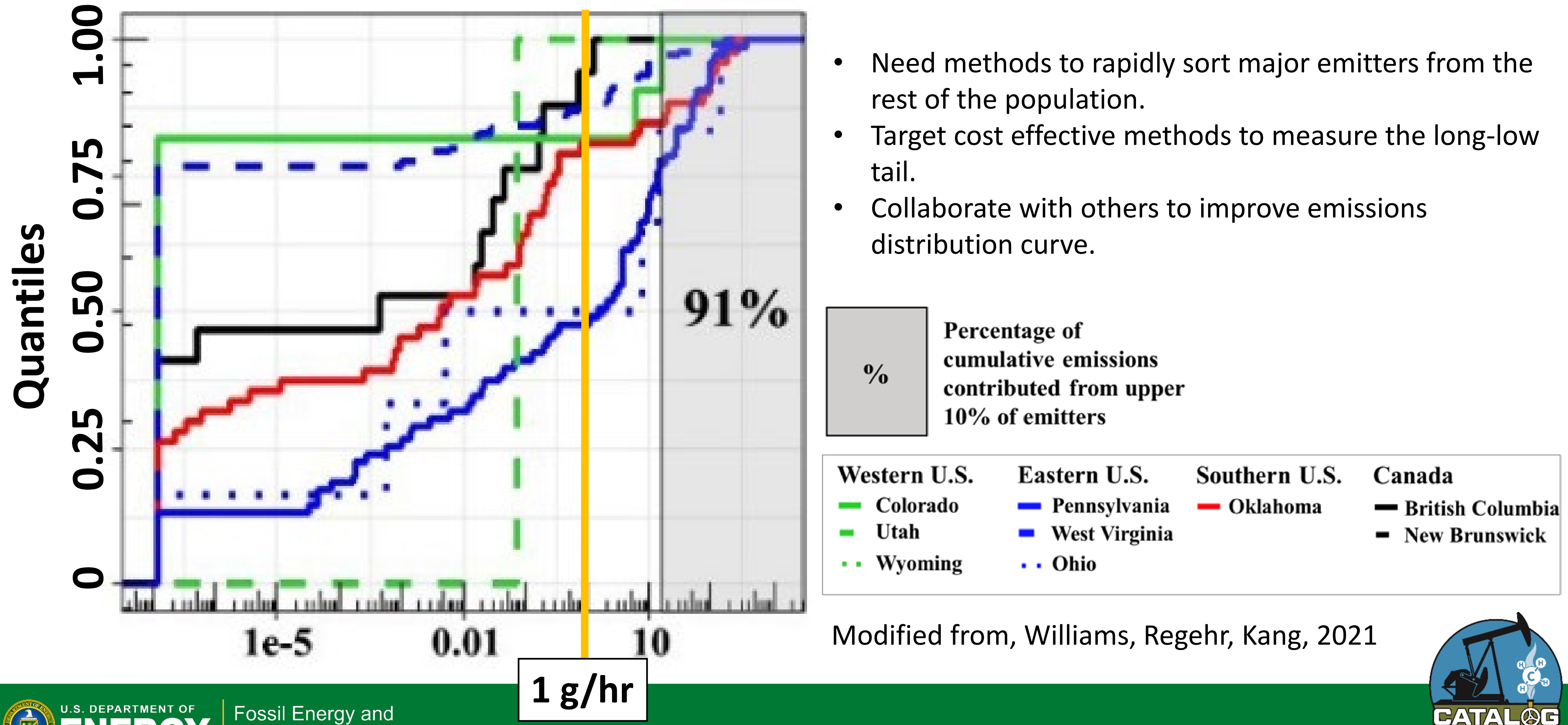
Key Learnings

- Gaussian plume method is viable and our ongoing validation supports its use as a reportable methane measurement method.

- Gaussian plume method simplifies DOI methodology as it can be used for multiple well types.

- The natural system temporal variability of methane emission rates from wells is within an order of magnitude relative to any single point measurement value.

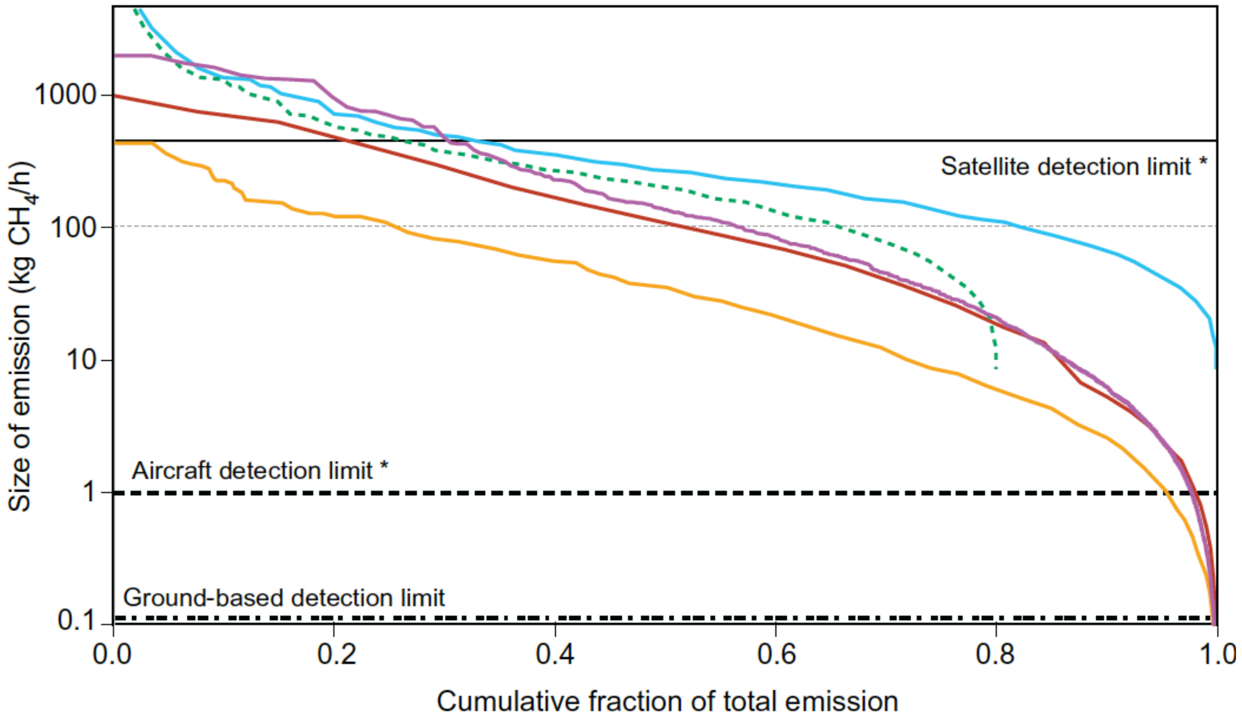
Few wells dominate the net emissions and there are many wells: Need rapid screening methods followed by targeted quantification

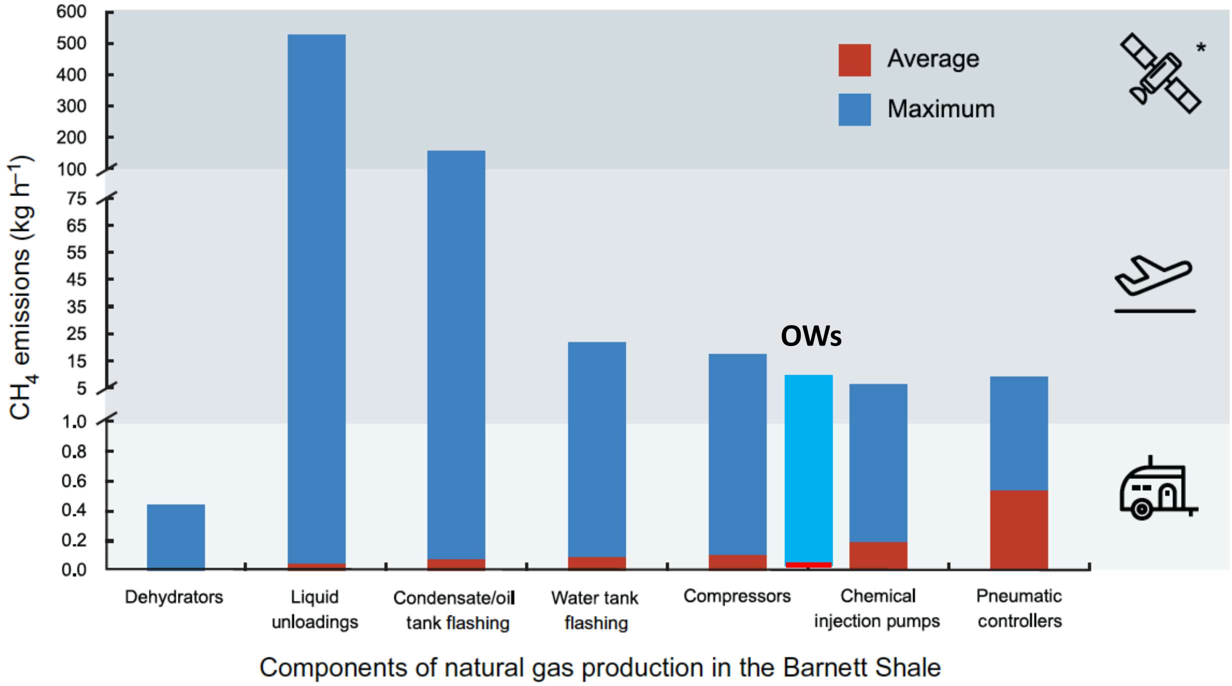


- Need methods to rapidly sort major emitters from the rest of the population.
- Target cost effective methods to measure the long-low tail.
- Collaborate with others to improve emissions distribution curve.

Modified from, Williams, Regehr, Kang, 2021

Observations focused on big O&G leaks: Small OW leaks are hard to measure but there are many of them





Collins et al., 2021

Orphan wells demand much higher sensitivity CH_4 techniques than what satellite or UAVs currently deliver. In situ sensors near the OW source are needed, but we do not know the UOW locations so other location methods are needed.

Outline

- Gaussian Plume Measurement Methodology (Dubey)
- Gaussian Plume Model Validation (Sebastien and Dubey)
- Temporal Measurements (Natalie)
- Future Work (Natalie)

Cost-effective estimation of methane emission rates from undocumented orphan wells

- The state-of-the-art uses flux chambers ($20K) to measure the emissions rate. It costs *$2500+ per well (travel & time), is labor intensive, unsafe for mid-high leaks, and cumbersome.*
  - Measuring CH_4 emission rates before and after plugging and abandonment is a top priority for the White House – "How much methane did we keep out of the atmosphere?"
- We need to drive this cost down dramatically to efficiently use DOI's $4.7B budget
- *White house asked CATALOG to develop a screening methodology to estimate flow rate from low-cost CH_4 concentration measurements*: **defensible, simple procedure and cost effective**

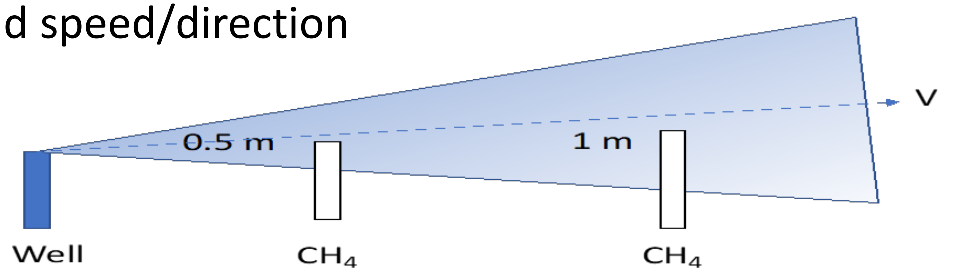
Flux Chamber

$$Q = \frac{C_c V}{C_L t_e} E$$

Developing Plume Model Data Collection & Analysis Protocols

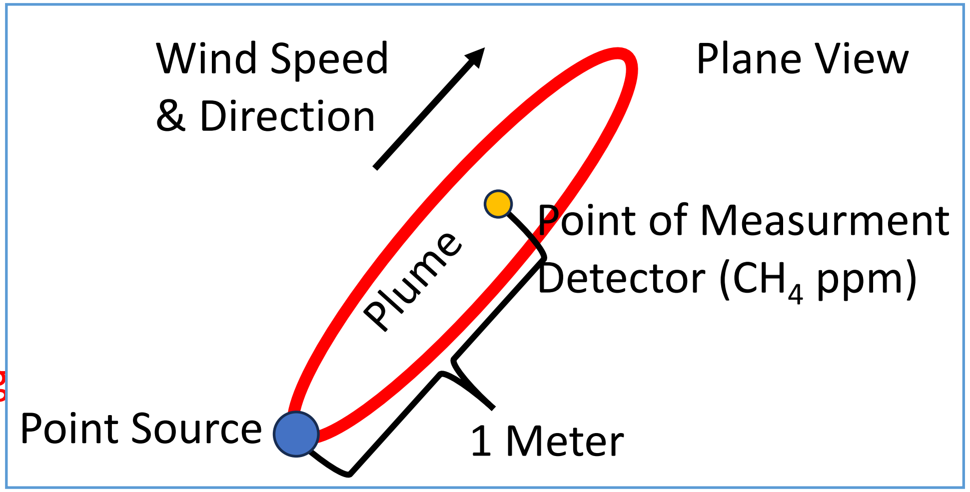
Equipment

- PPM-level sensitivity, calibrated & compact CH_4 sensor (solid-state MOS or spectroscopic)
- Handheld anemometer (vane, thermal, sonic or wind-sock) measures wind speed/direction
- Tape to measure distance



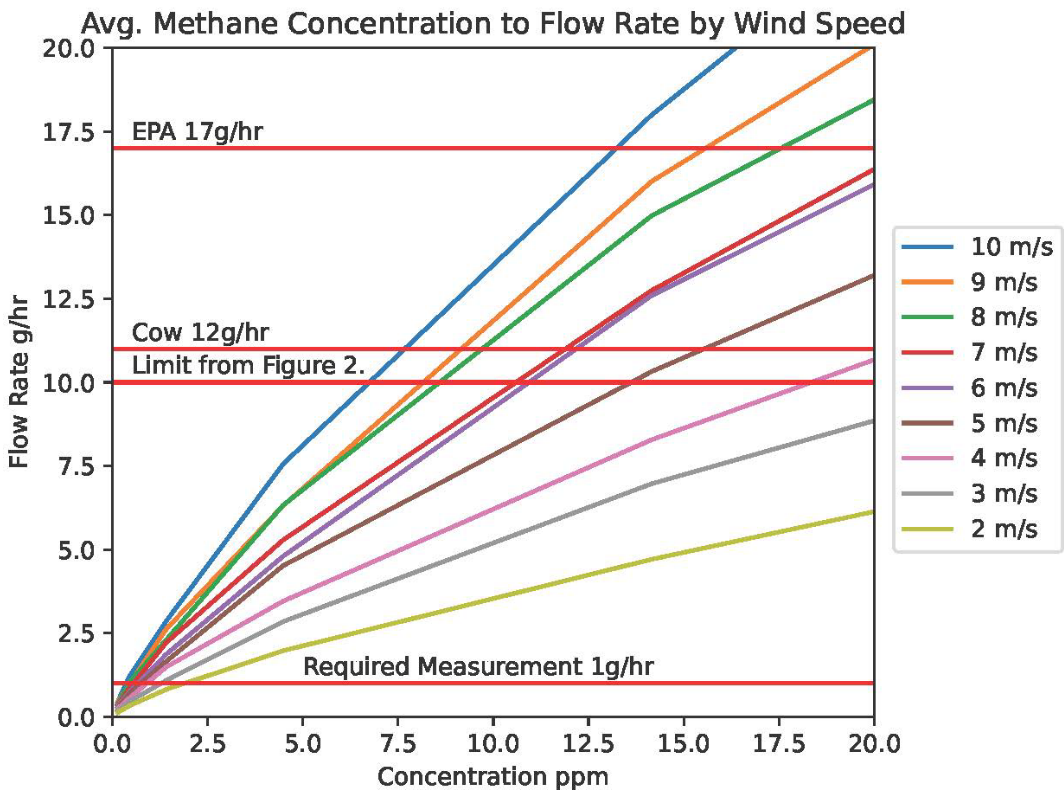
Protocol

- Locate orphan well source and determine wind direction
- Ensure *winds are stable* or *create them by use a fan upwind* of the well
- Measure CH_4 downwind at > 2 points downwind near the source (<1 m)
- Can sample over minutes with a single sensor during stable winds
- Record wind speed, distance downwind, and CH4 concentrations
- Park service is using 2-point (source, 0.3 m) measurements for screening
- *DOE is developing a calibrated CH_4 increase to flux conversion method*



Cost-effective CH_4 emission rate estimation from UOW using concentration, wind speed, and gaussian plume model

- Innovations: Combine Gaussian plume models, inverse analysis and uncertainty quantification to develop a relationship between concentration and flow rate as a function of wind speed
- Provides a cost-effective way to screen wells and filter out low emitters
  - High emitters can still be measured with a flux tower, if desired
- Our approach is being validated by CATALOG and DOI and initial results are promising

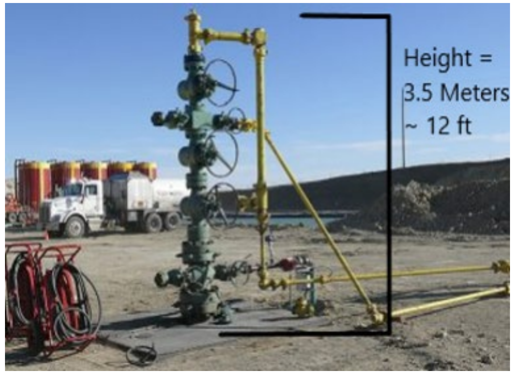


Well Head Types (point sources): Difficulty of CH_4 monitoring

Measurable via Plume Method

Type 1
Easy Access
Chamber
Hi Flow
Ambient CH4

Type 2
Legacy Infrastructure
Hi Flow
Ambient CH4
Remote Imager

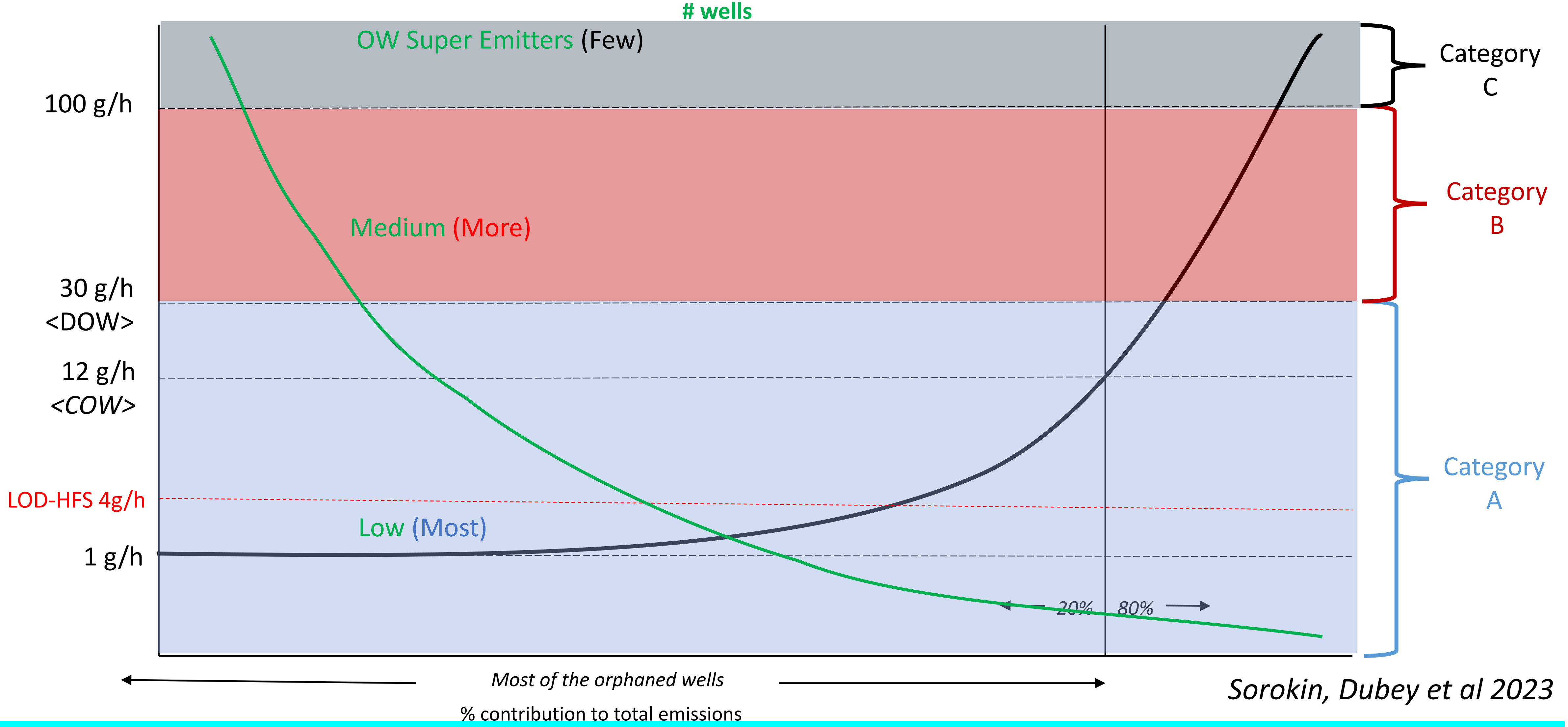


Type 3
Legacy Infrastructure
Ambient CH4 (tower/UAV)
Remote Imager

Type 4
Impractical
Underwater, Frozen
Unsafe, High H_2S

Classification of well head leaks by DOI to guide operators and help facilitate screening and plugging

Well Classification for Prioritization



Sorokin, Dubey et al 2023

Broad classification reduces precision, time and costs of leak quantification for screening to prioritize plugging

Lab Control Release Experiments

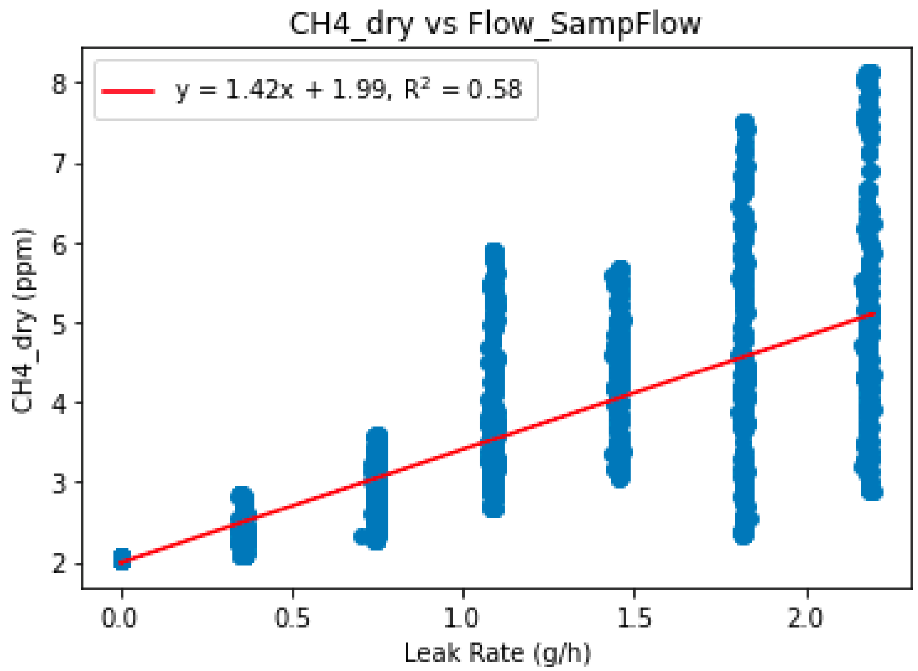
<u>Setup</u>:

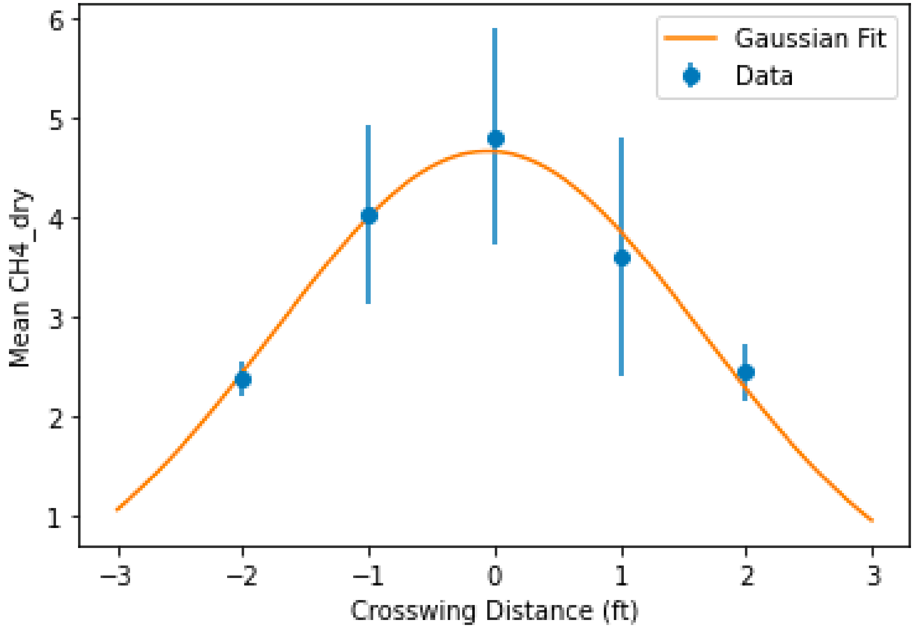
- Picarro gas analyzer (model G2301)
- 5% methane (in N_2) delivered via mass flow controller
- Gill 3D sonic anemometer (model R3-50)

Working towards development of "FAST" method = Forced Advection Sampling Technique, using a fan to generate plume with known wind speed

Mohit Dubey, Biraud 2023 (in prep.)

Lab Control Release Experiments: No Fan





Left: linear fit of increasing downwind concentrations (at 1m) at low leak rates

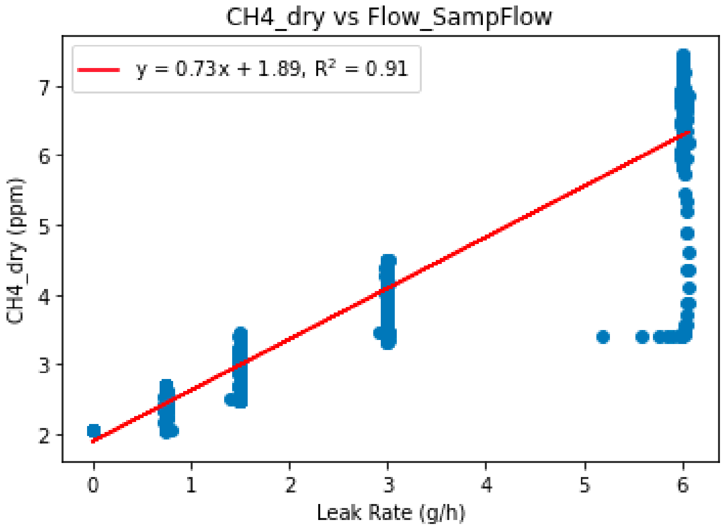
Right: time averages of transects at 1m downwind, exhibiting Gaussian profile

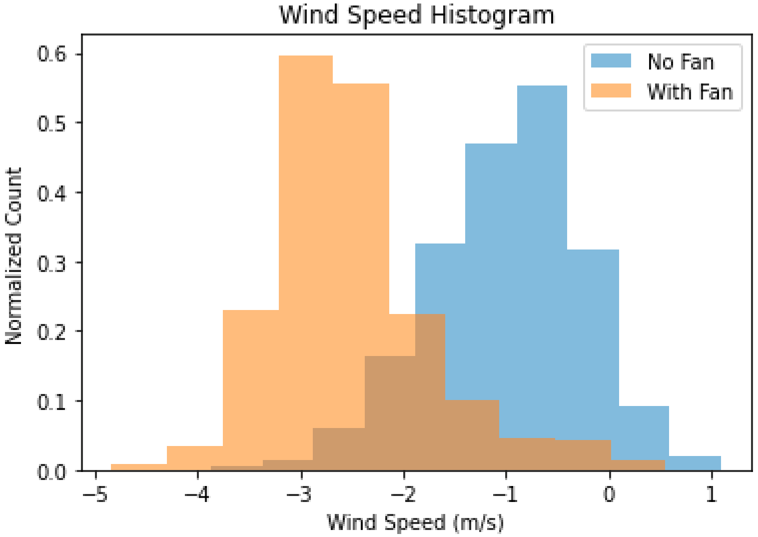
Lab Control Release Experiments: with Fan

Setup:

- Fan is placed 1m upwind of point source,
- Gas analyzer inlet is placed 1m downwind of point source.

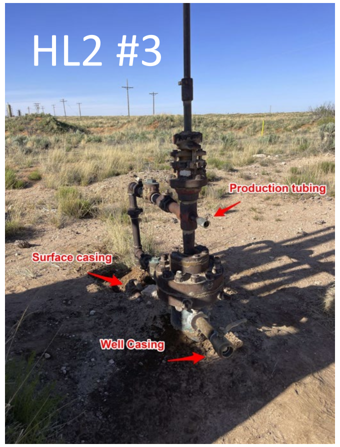
=> Based on measured concentrations (5-minute average) and known Fan speed, a leak rate can quickly be estimated.

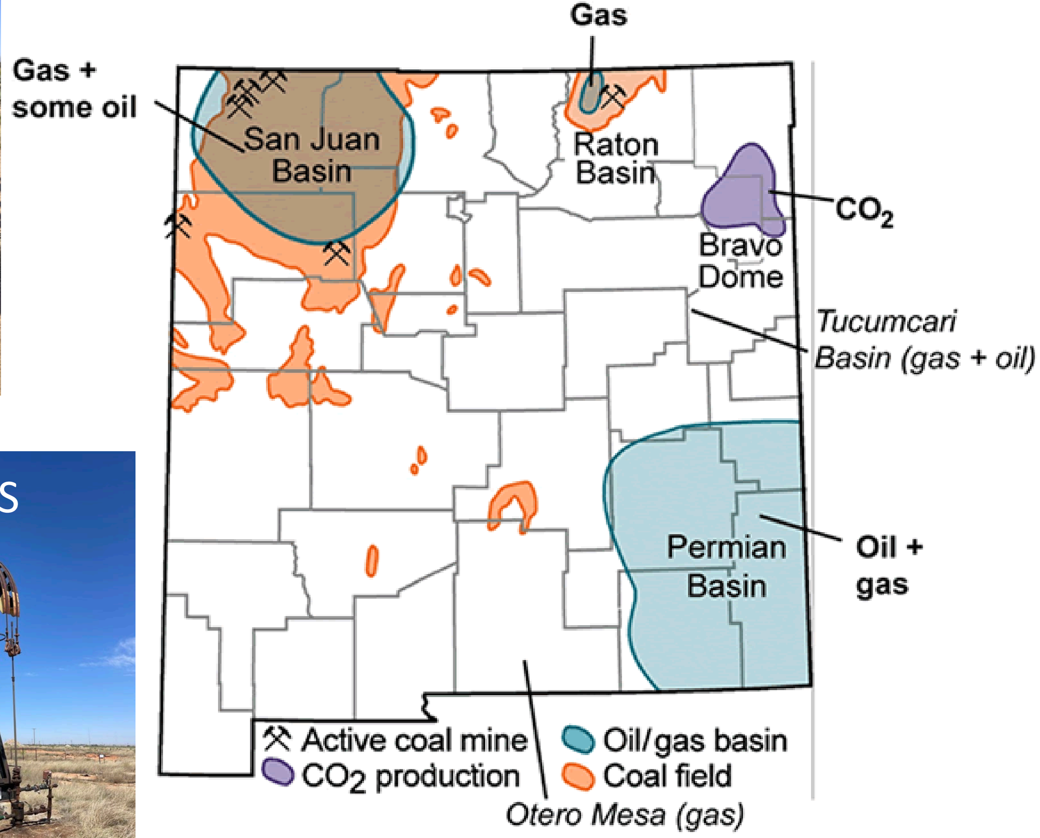




Field Control Release Experiments: Permian and San Juan OW

- <u>Permian basin: Hobbs, NM</u>
  - HL2 #3: 32.68855N, -104.05294E
    - Estimated flow rate from WellDone **147 g** (CH_4)/hr, composition 60% CH_4 (m/m), production depth 3150 ft
  - HL2 #1: 32.69244N, -104.05294E
    - Small leak, no documentation
  - Foster 1S: 32.69125N, -103.07491E
    - Estimated flow rate **4000 g/hr**, composition 60% CH_4 (m/m), production depth 3700 ft
- <u>San Juan basin: Farmington, NM</u>
  - Visited four wells, one was confirmed small leak
  - NE Hogback #5 Unit C: 36.820362N, -108.517998E
    - Production depth 1537 ft





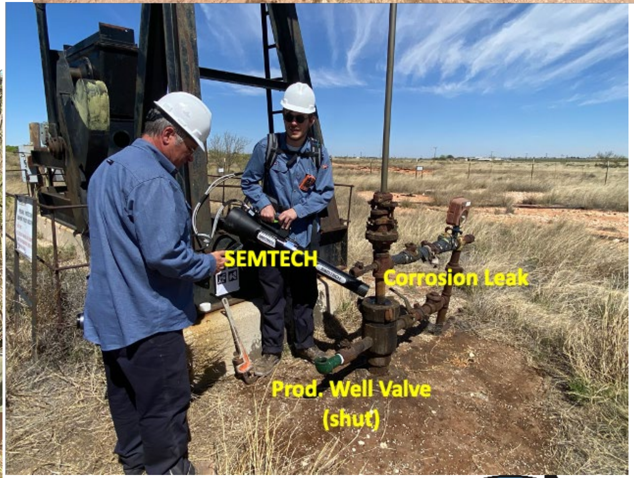
Learn methods plug operators use to measure leaks assess time, costs. 7 leak stats: 1 very-high, 1 high, 2 low, 3 none

Cost-effective estimation of methane emission rates from undocumented orphan wells

- Orphan well gas concentration and composition (ppm) measurements from orphan wells to prioritize plugging in Hillman Park, PA, ***Hobbs, NM,*** and San Juan NM
- Observed Welldone's direct (Vent-buster) protocols in Hobbs, NM
- Plume concentration to emission rate method tested and evaluated at Hobbs, NM
- Picarro G4301 & RMLD to detect leaks.
- Deployed FLIR used to find leakage point.
- Xplorobot LIDAR & SEMTEC HI-FLOW2 to quantify CH_4 leak rate at the well head.
- Leak rates range between 0 and 4000 g/hr

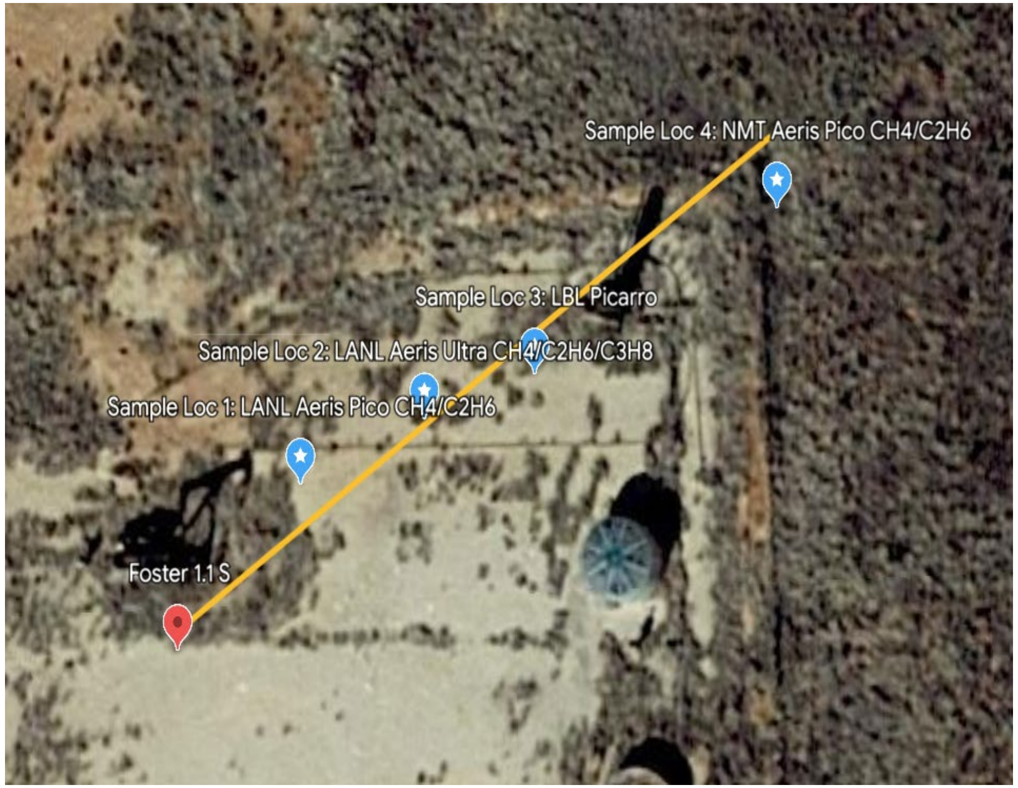
San Juan, NM

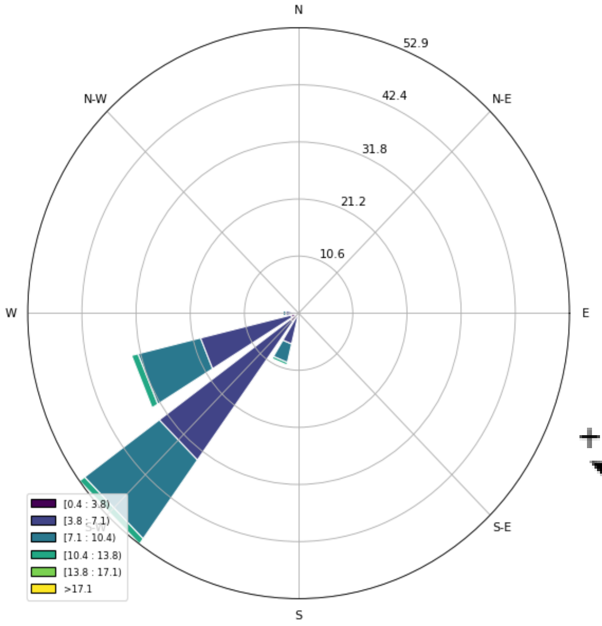
Hillman Park, PA

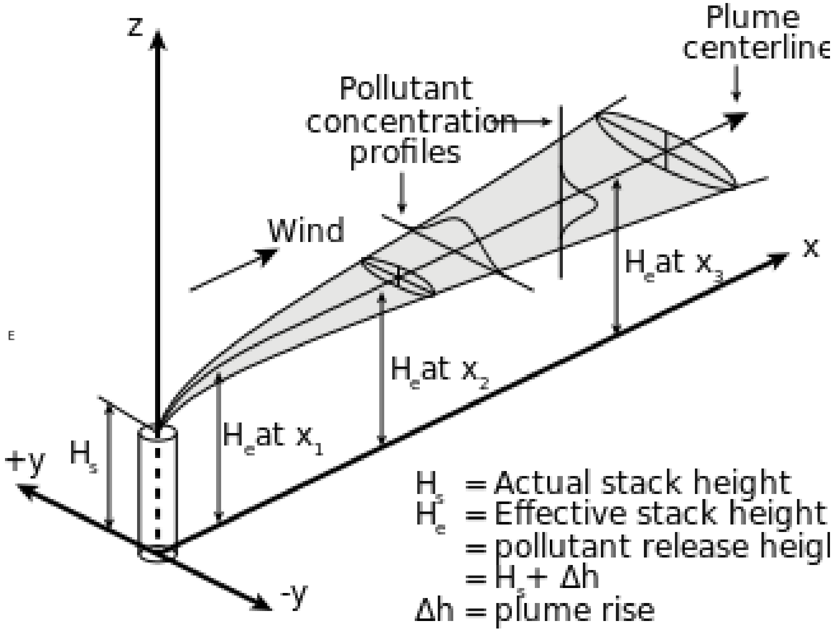


Hobbs, NM

Hobbs, NM Experimental Setup and Plume Strategy







Steady, stable and high winds were used to measure CH_4 concentrations at 4 locations downwind of a very leaky orphan well and collect data to develop and evaluate a plume model to infer emission rates

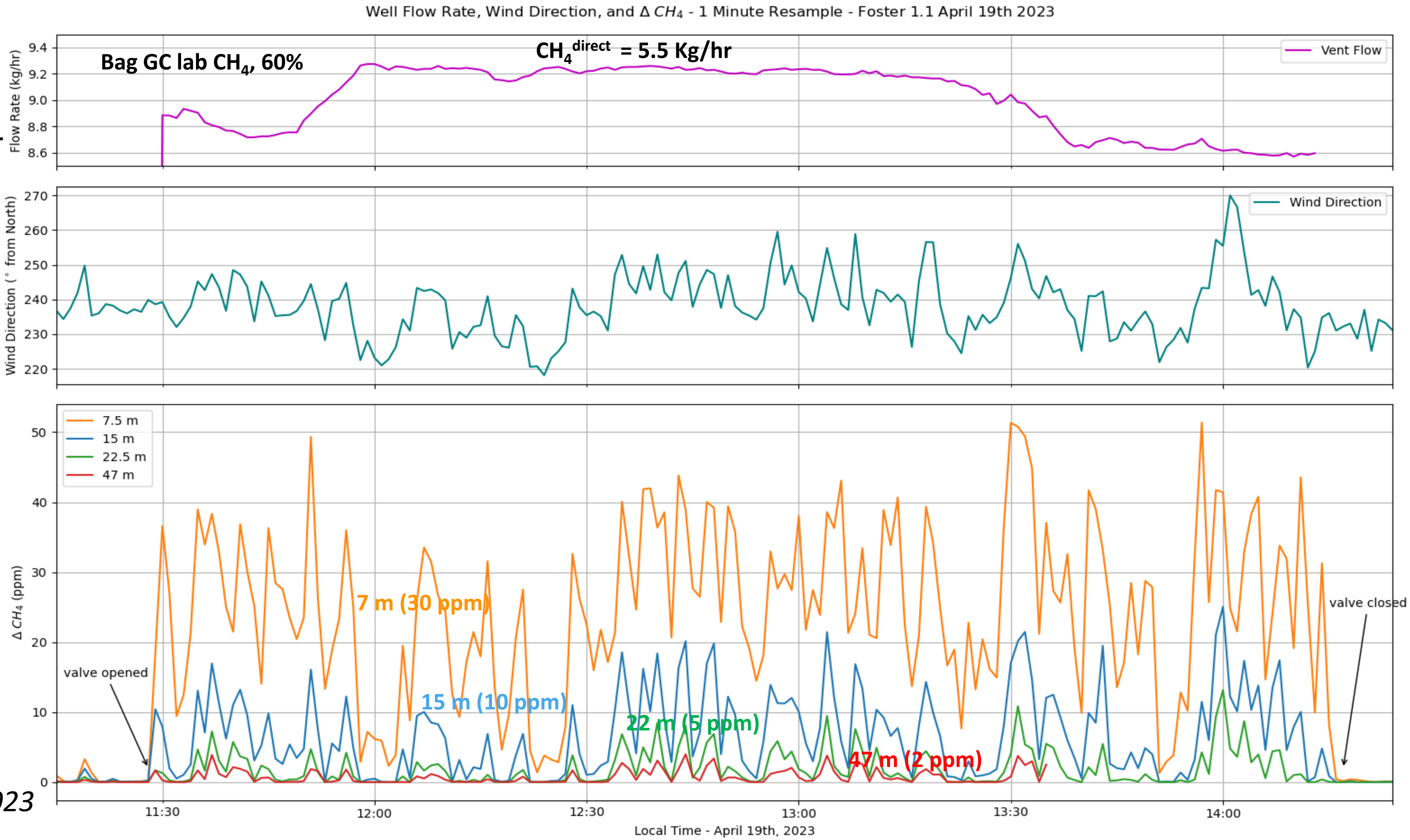
Data

Flow-rate
Ventbuster

Direction 240 N
Speed (6-7 m/s)

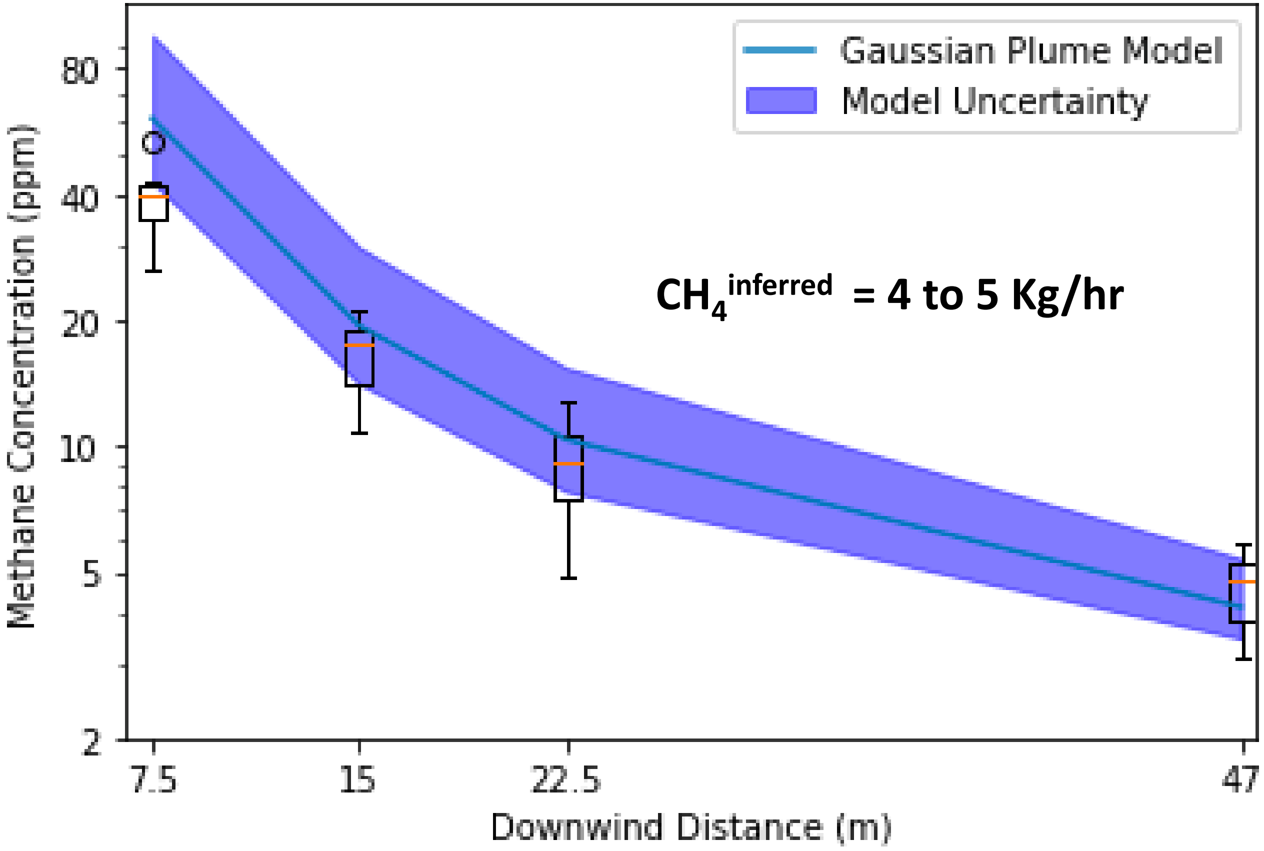
CH_4

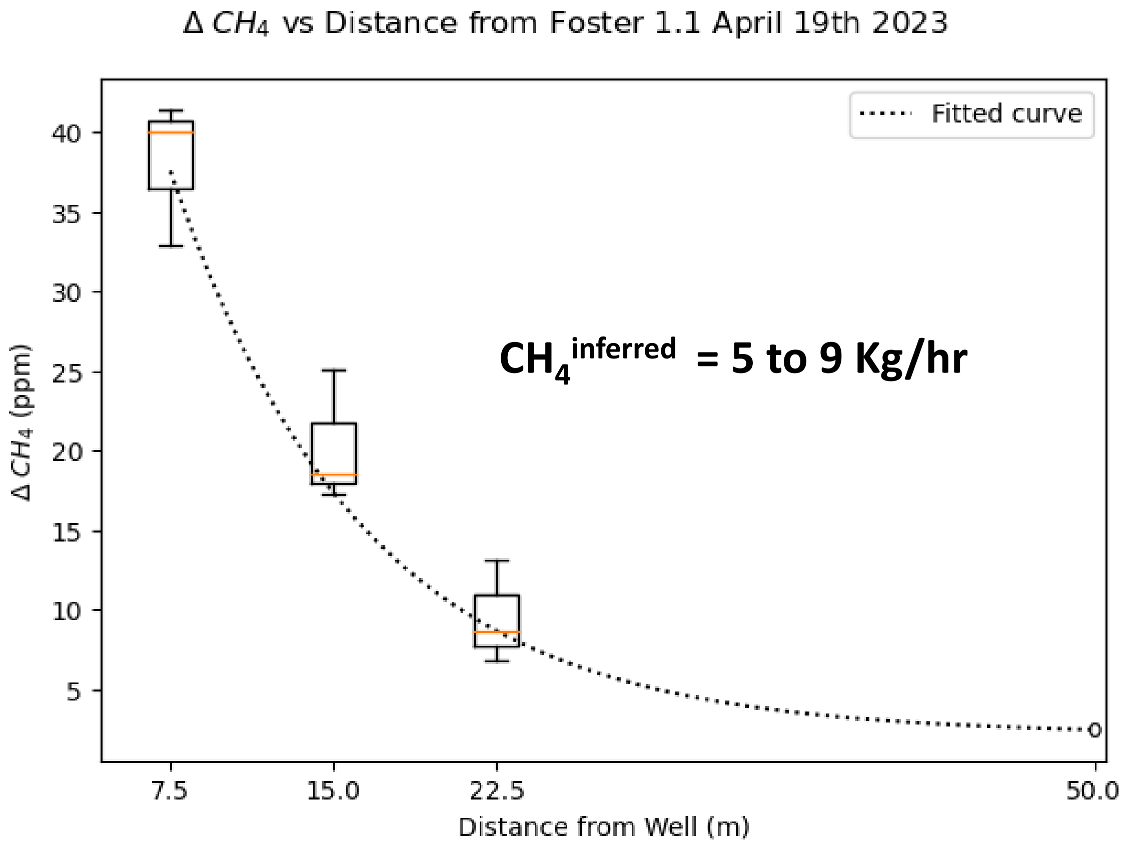
7.5m
15 m
22.5 m
47 m



Follansbee 2023

Gaussian Model Emission Inference from downwind CH_4 concentrations

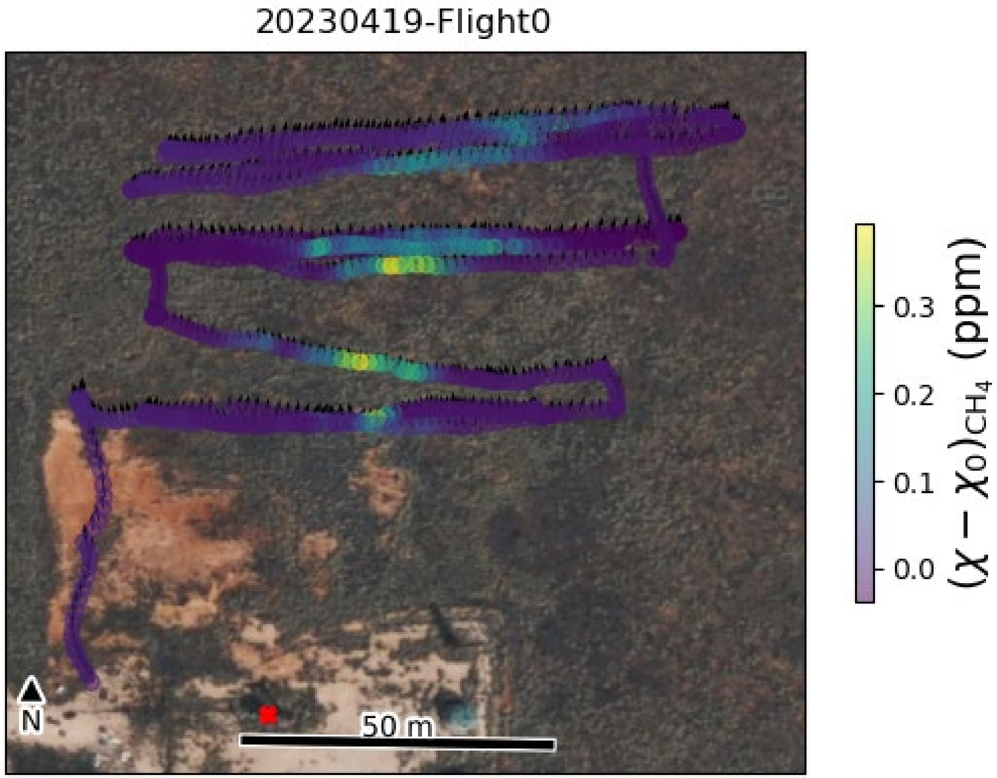




Follansbee, Dubey, Biraud 2023 (in prep)

The blue is a gaussian model fit with uncertainties in observed wind speeds right is an empirical fit with no atmospheric constraint. We estimated leaks from CH_4 concentration measurements to better than a factor of 2.

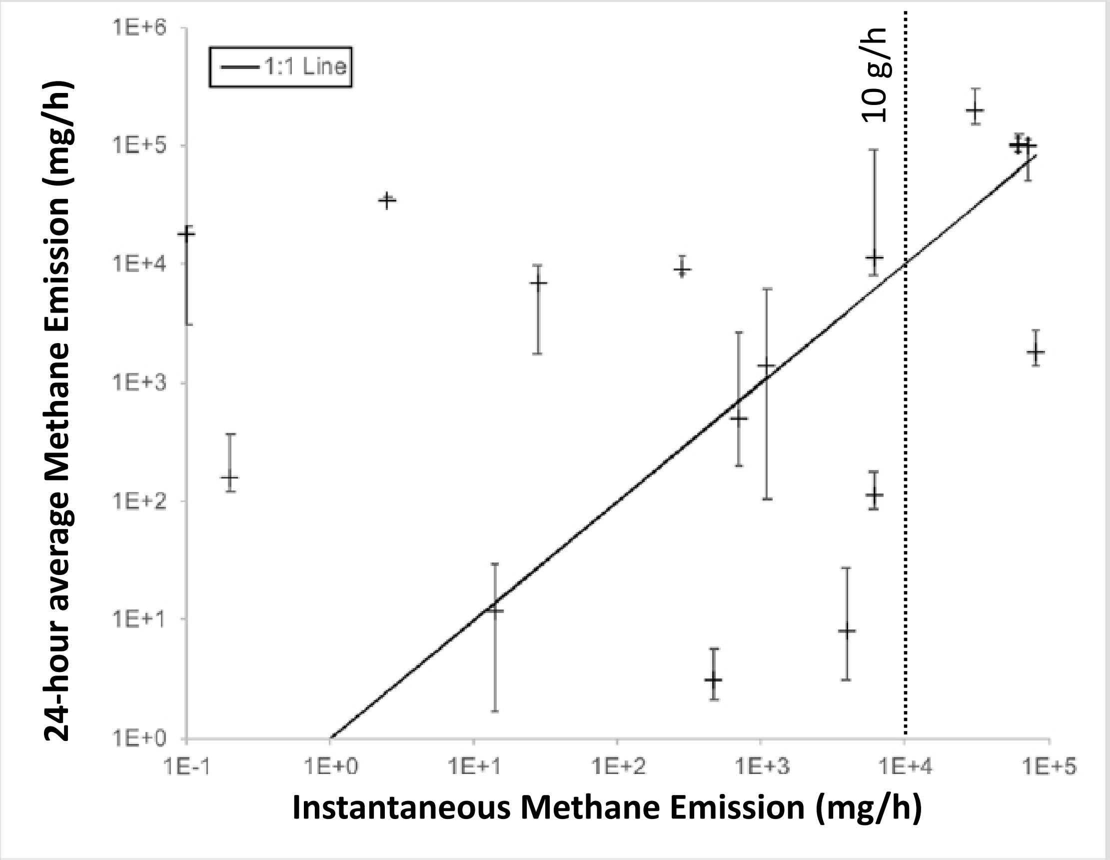
UAV capability to monitor/locate leaky OW in excess of 100m



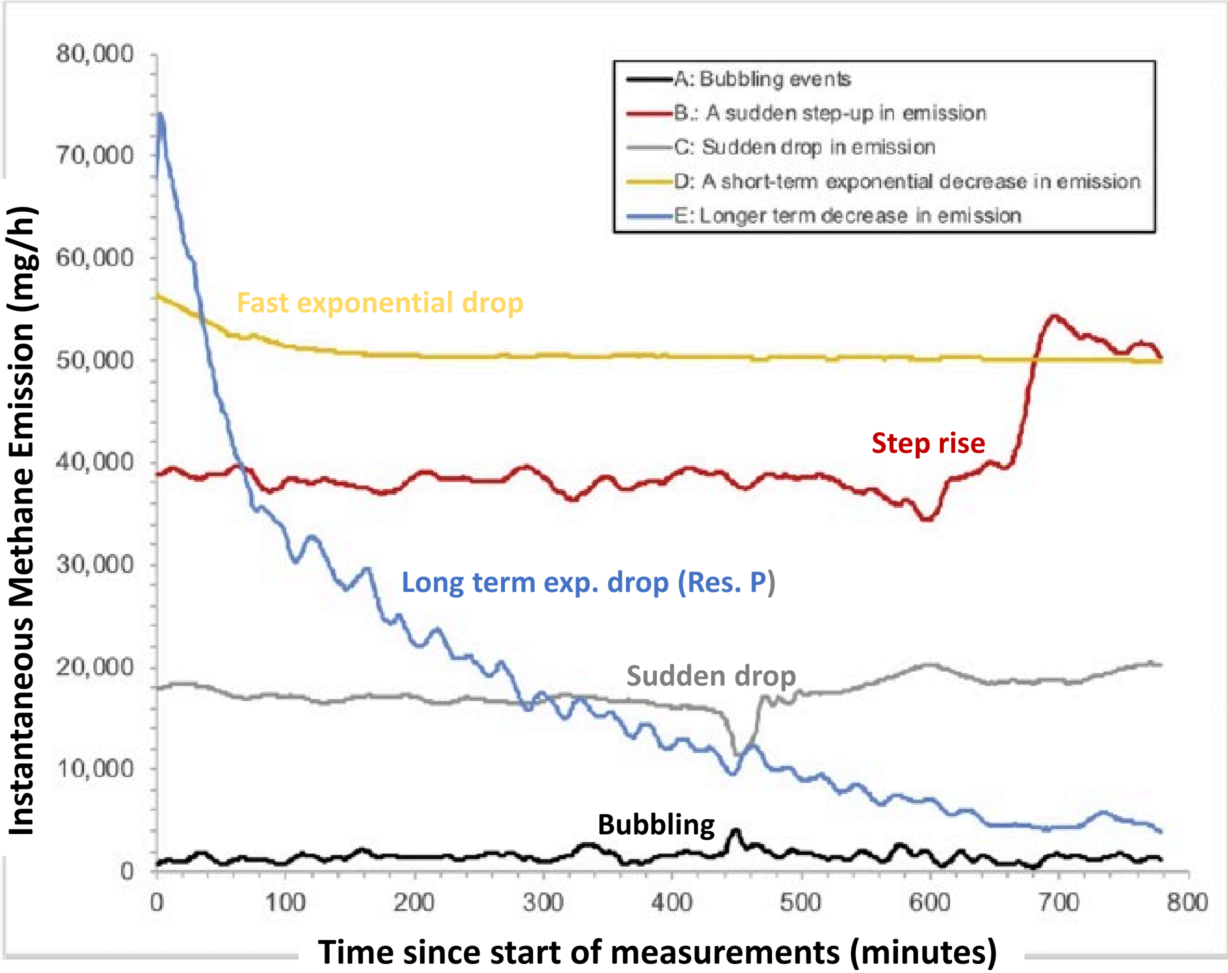
Dooley 2023

Our drone observed CH_4 excess 100 m away and directly measured the surface casing leak to be 300-500 gm/h in agreement with our ground observations (pre-valve open). UAVs can be used to find UOWs.

Temporal Variability (<day) in OW Emissions: Reservoir-P, structure/composition; Atm. P

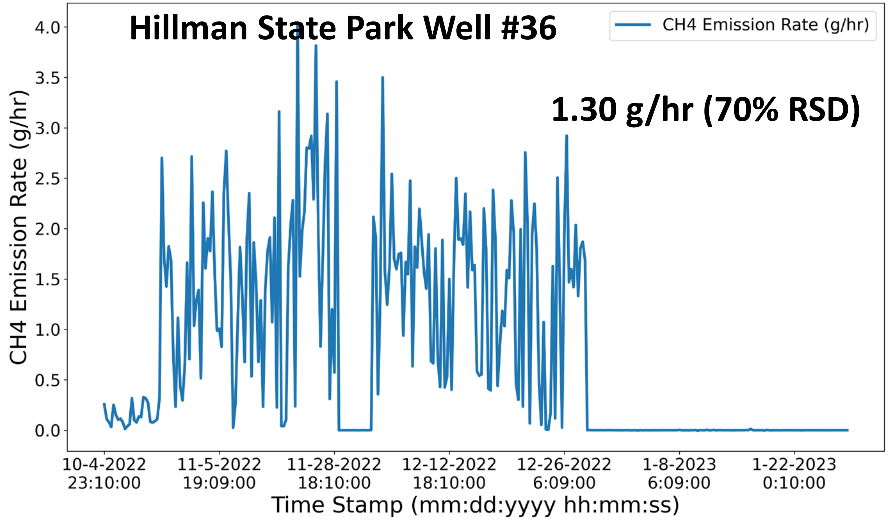


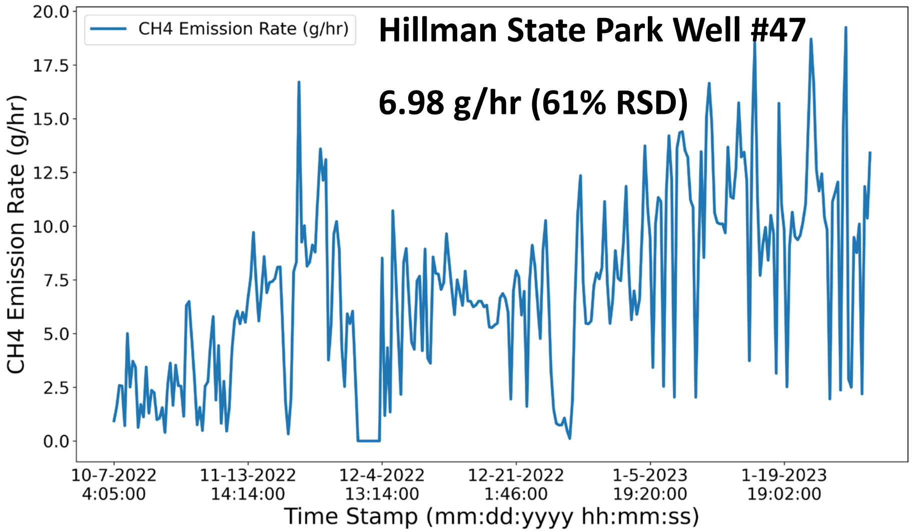
Riddick IJGGC 2020

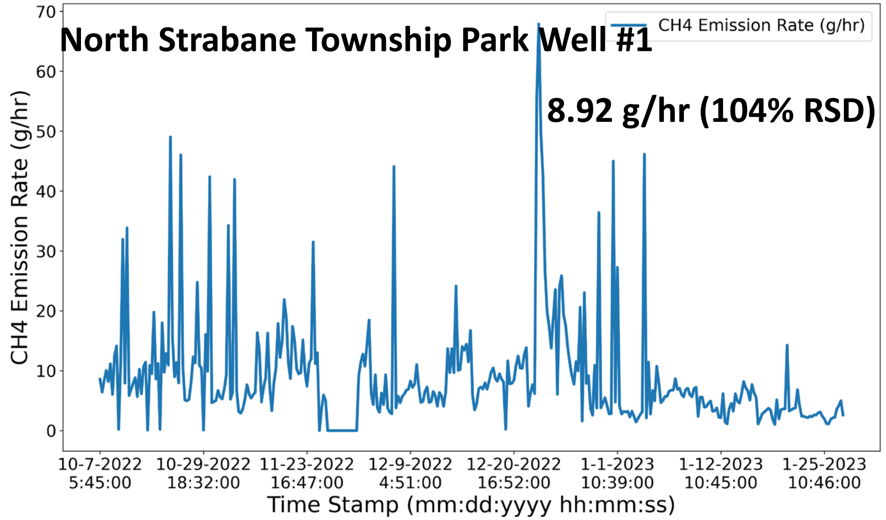


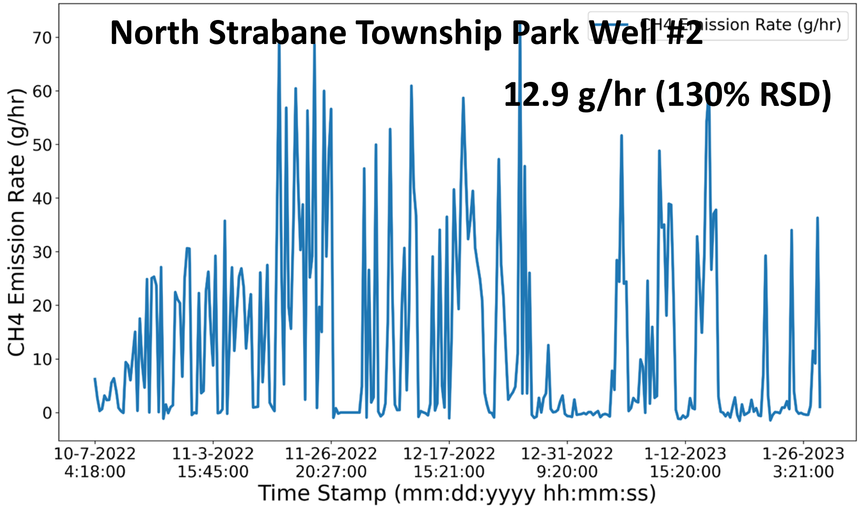
Evidence for short-term (<day) variations in DOW CH_4 emissions of various types. Use solid state MQ4 ($10) sensor

Long term Temporal Variability of Winter CH_4 Emissions





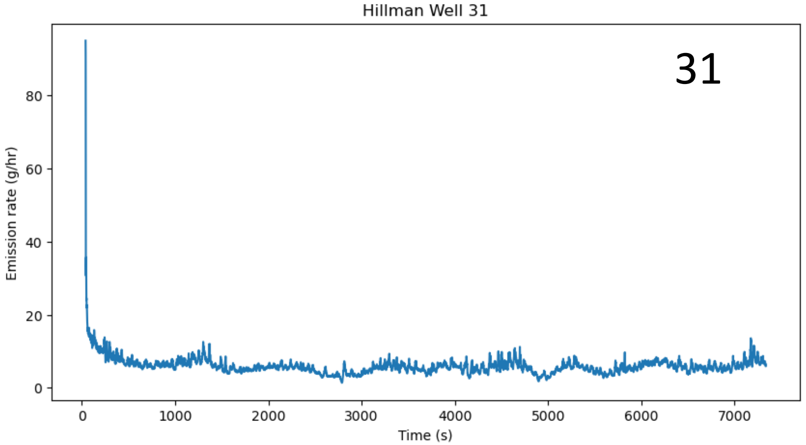


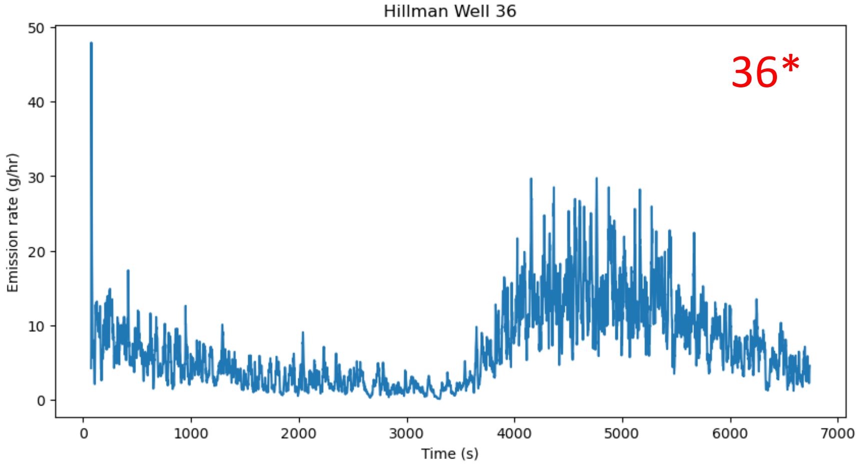


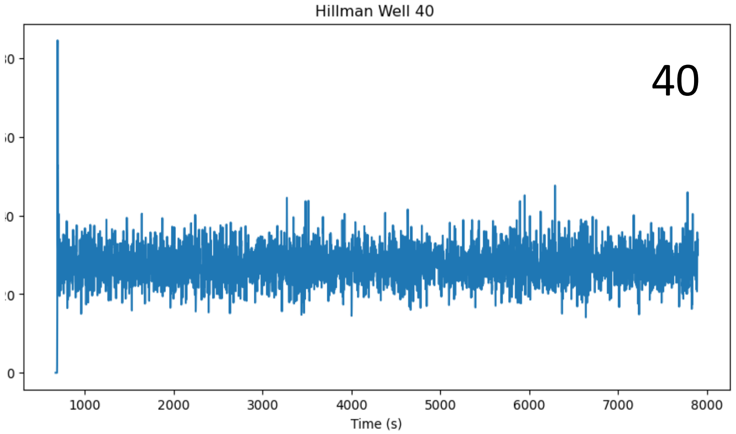
Pekney 2023 (in prep)

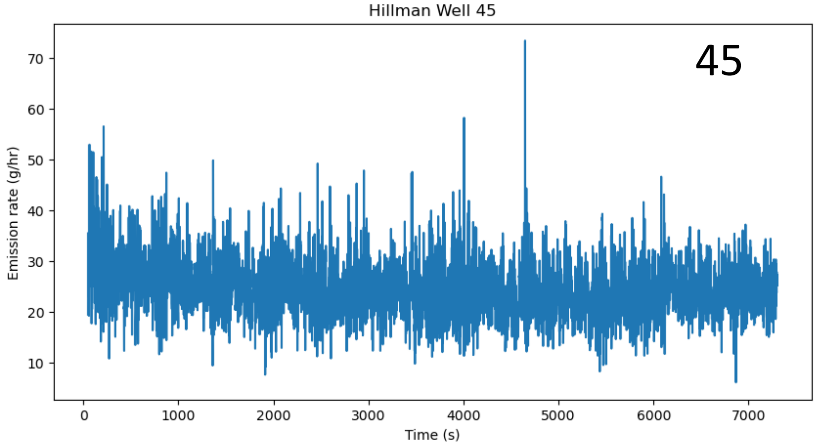
Long-term CH_4 winter emission variability (RSD) is lower than a factor of 1.5

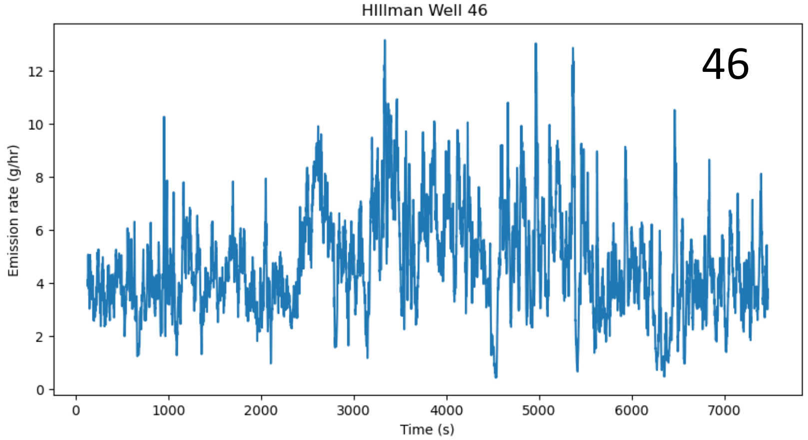
Short-term Temporal Variability of Winter CH_4 Emissions











- Well 31: 5.68 g/hr
- Well 36: 4.81 g/hr*
- Well 40: 27.73 g/hr
- Well 45: 24.26 g/hr
- Well 46: 4.38 g/hr

Pekney 2023 (in prep.)

Short-term CH_4 emission variability (RSD) is below a factor of 2 except for Hillman #36

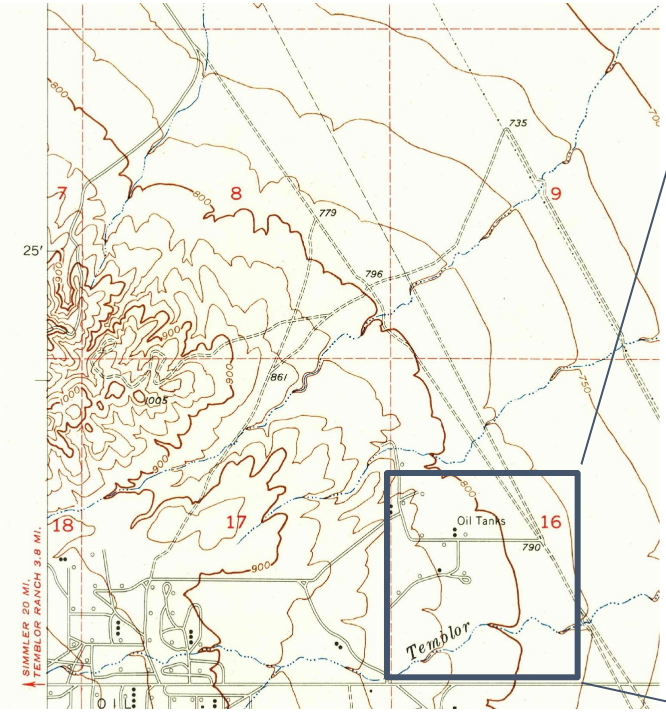
Locating UOWs using DOW patterns and AI

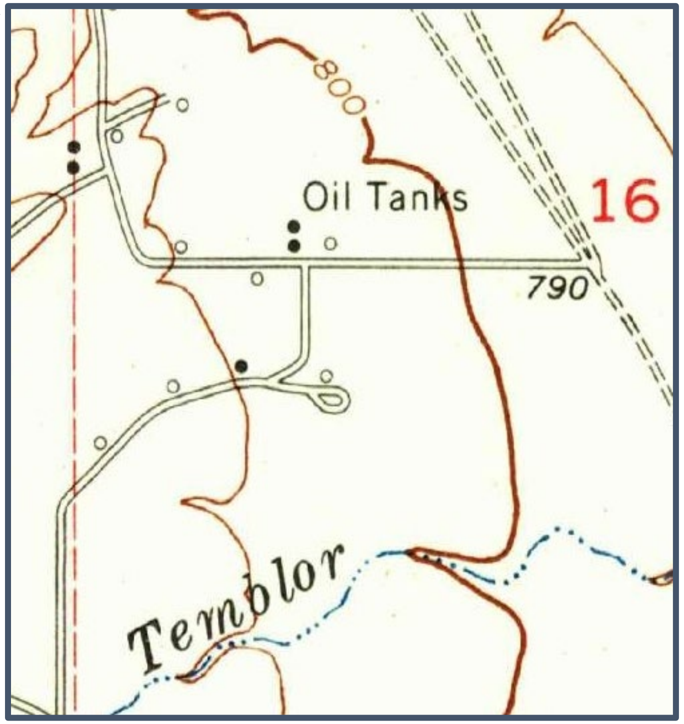
USGS historical topographic maps contain information about the past

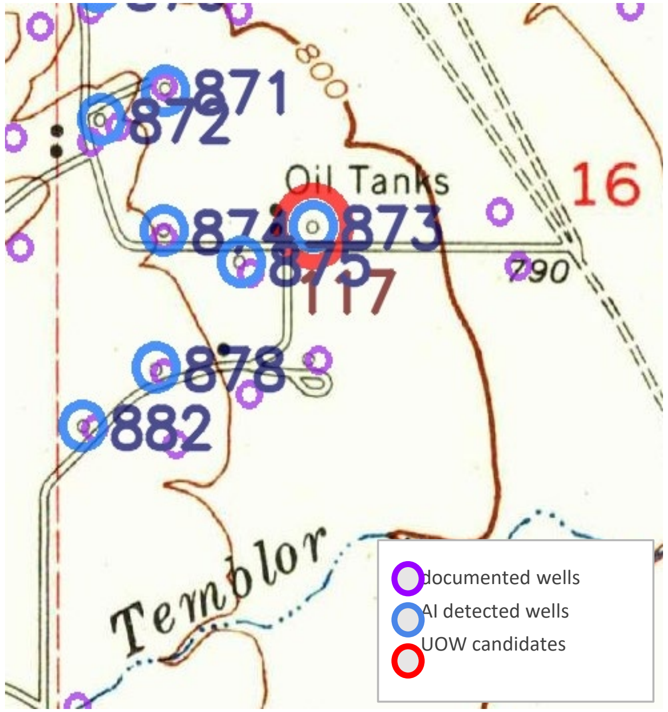
Oil and gas wells are identified by black circles

An AI algorithm:

- identifies wells in maps
- compares locations with doc. wells
- tags UOW candidates

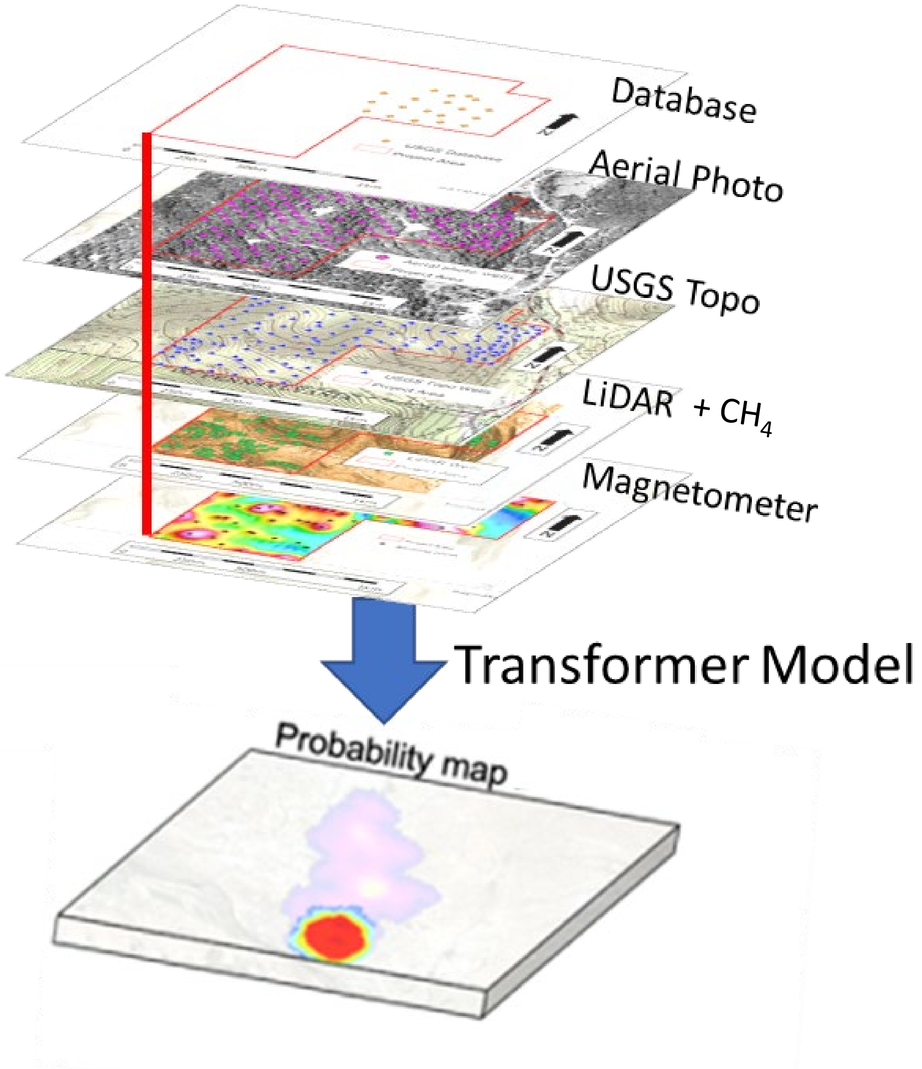




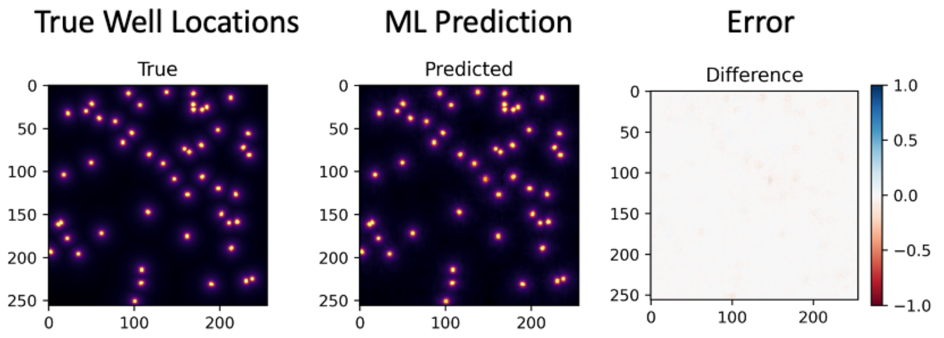


Ciulla et al., 2023 (in prep.)

Can we use multiple noisy signals to find wells?



- Machine Learning models have shown impressive results in fusing data from different sources (e.g., text and images).
- Our approach suggests that having two data sources (compared to just a methane sensor) increases the accuracy of the model by a wide margin. *Next steps:* Advancing towards NETL data from Hillman State Park and tests in Four Corners NM
- Initial ML model shows accurate prediction of well location based on environmental data, which can be used for undocumented well locating and identification



Key Learnings

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- Gaussian plume method simplifies DOI methodology as it can be used for multiple well types.
- The natural system temporal variability of methane emission rates from wells is within an order of magnitude relative to any single point measurement value.

Questions

- What methods is IOGCC and states using to estimate CH_4 emissions?
- Can you help us cover more basins?
- Can we help with Undoc. to Doc. OW protocols for tracking?
- How best to provide states assistance?
- What is the quantification target cost model for OW plugging?
- How can we help demonstrate the value of plugging?

Contacts

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