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Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions

Colorado State University

Reference:

Zimmerle D, Vaughn T, Bell CS, Bennett K, Deshmukh P, Thoma E (2020) Detection Limits of Optical Gas Imaging for Natural Gas Leak Detection in Realistic Controlled Conditions. *Environmental Science & Technology*, https://doi.org/10.1021/acs.est.0c01285

Study Objective

Assess the performance of the *combined surveyor and camera system* detecting leaks in controlled but realistic upstream gas field conditions.

Motivation:

- Provide basis to compare next generation solutions to OGI surveys
- Better understand the efficacy of OGI surveys
- Provide guidance on improving leak detection performance with OGI

Sponsors & Support:

- EPA/Jacobs Engineering (EPA QAPP: QAPP-2J17-013.0)
- The Environmental Partnership
- In-kind participation by most surveyor's companies

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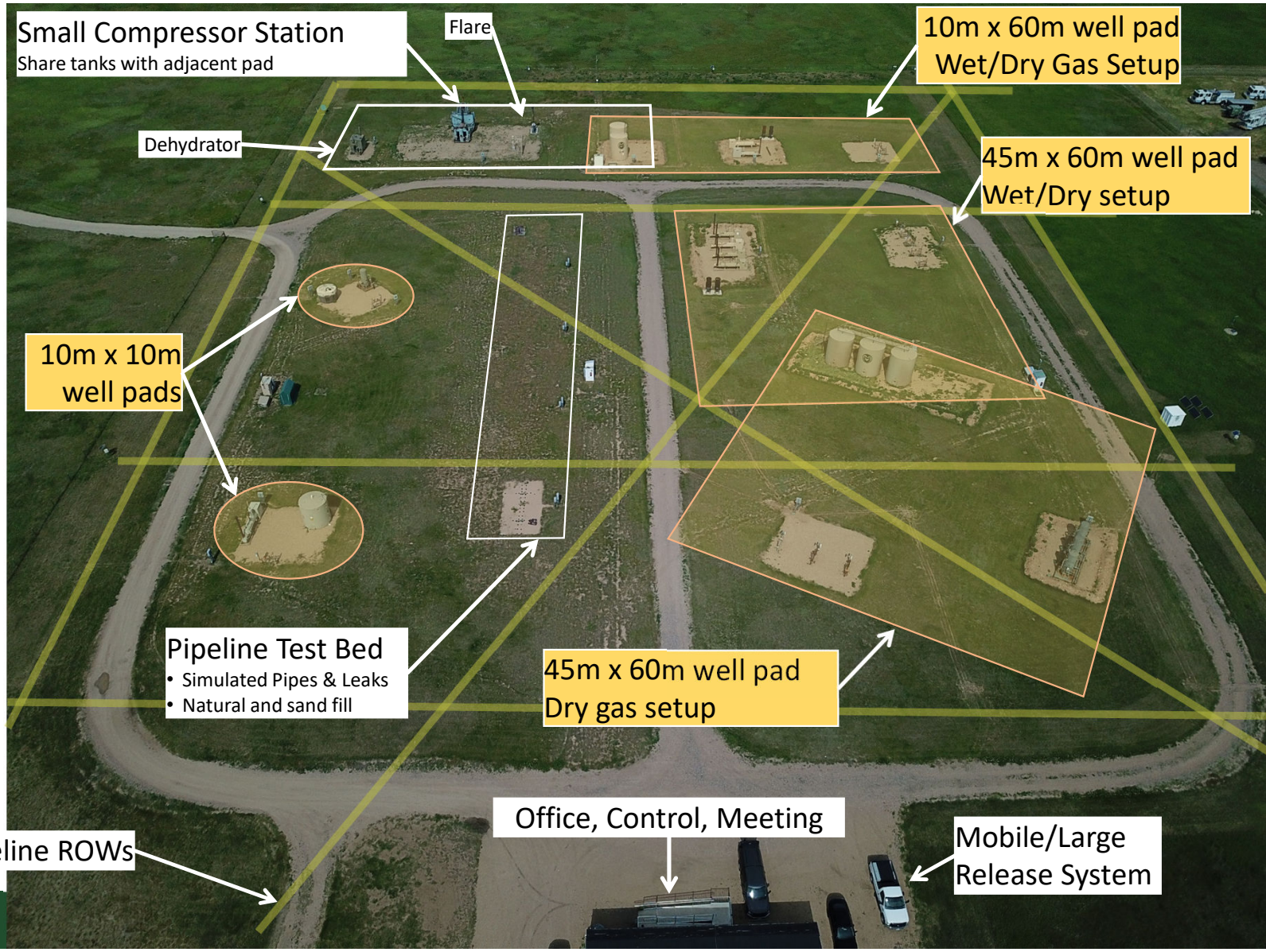
Test Facility:
Methane Emissions Technology Evaluation Center

Shaded Facilities Used for Study

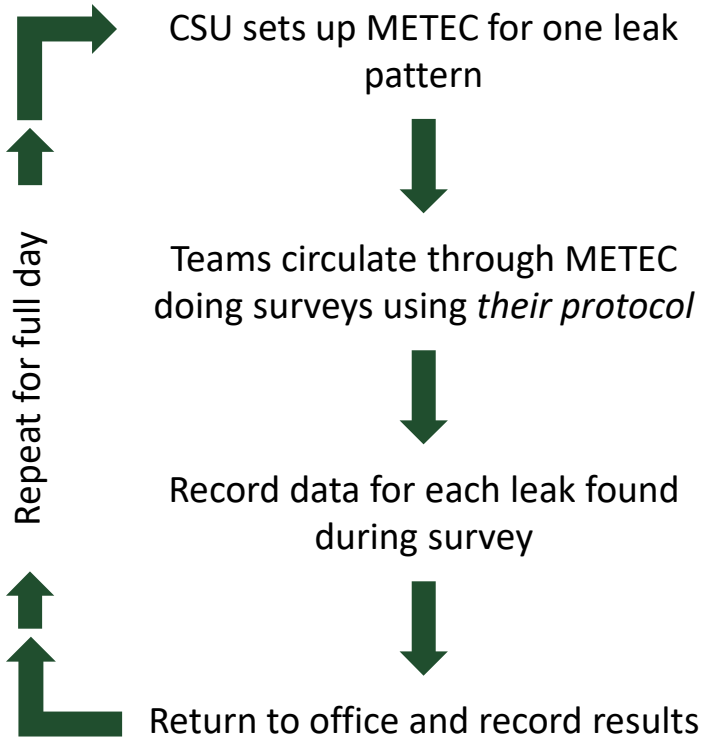
(grouped into different pad configuration for study)



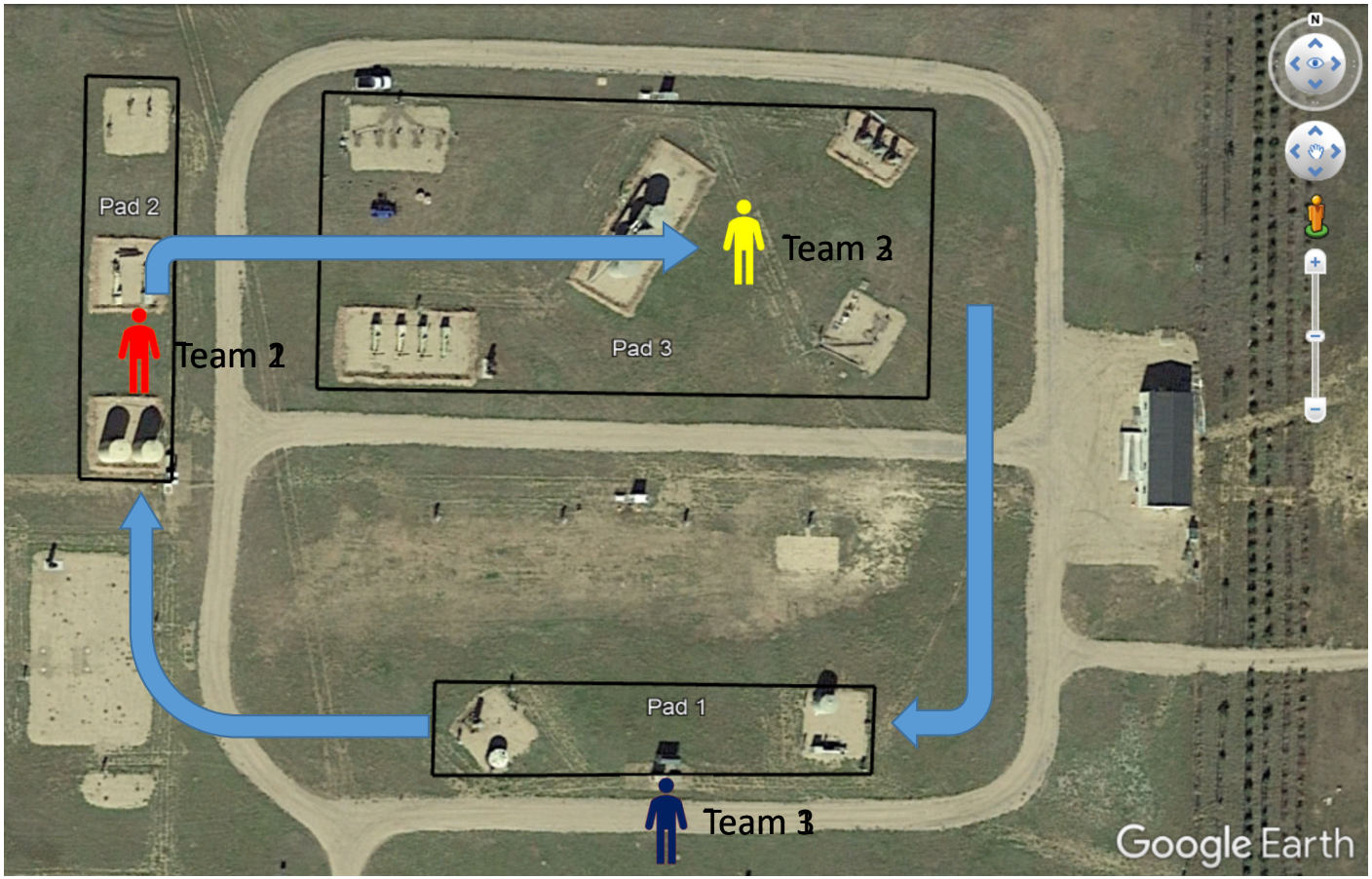
Testing method

- Blind surveys to locate controlled emissions in realistic outdoor environment
- Camera operators bring their own cameras and survey using their normal protocol

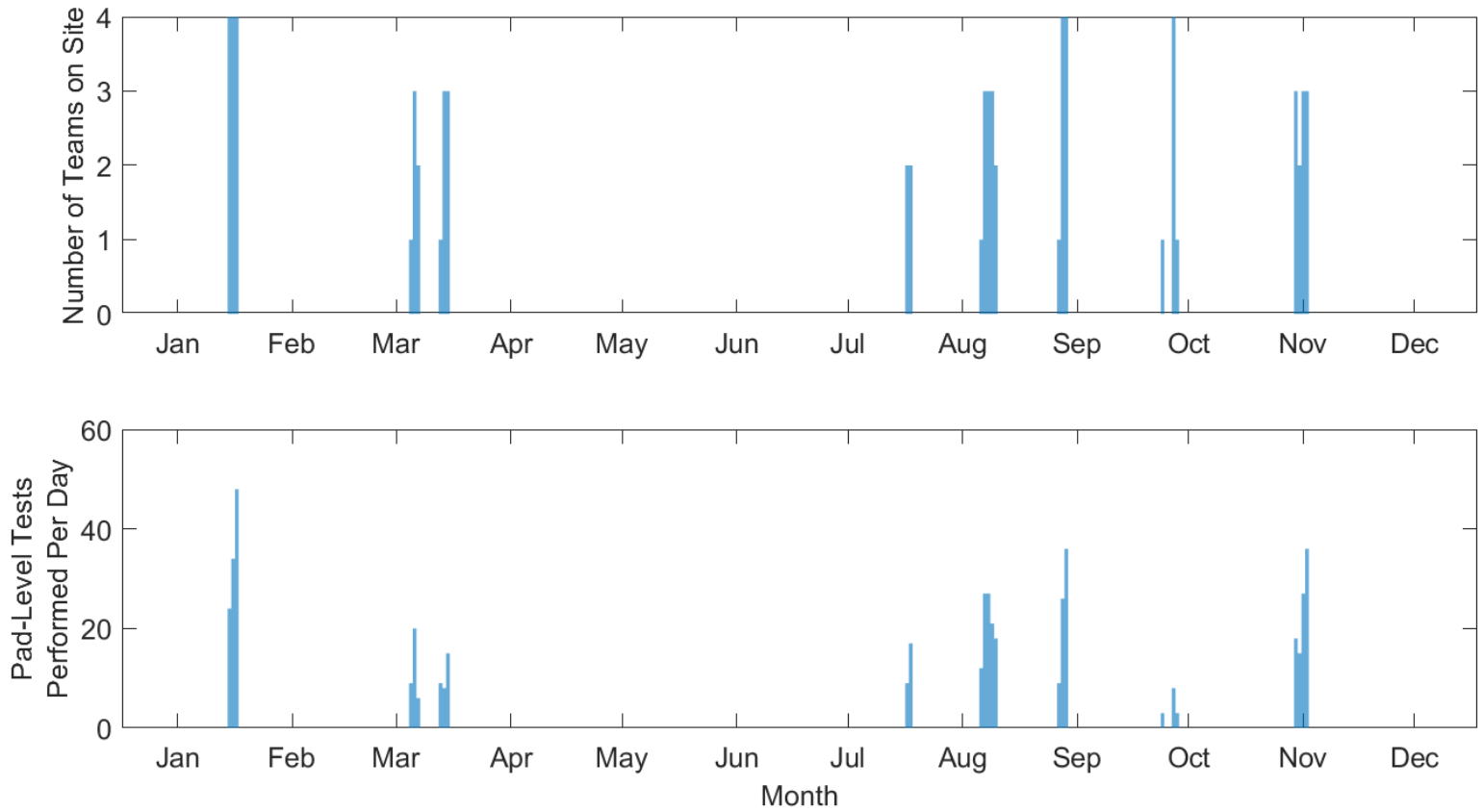
Goal is to simulate, as close as possible, how surveyors work in the field.



Measurement set



Testing: When and How Many



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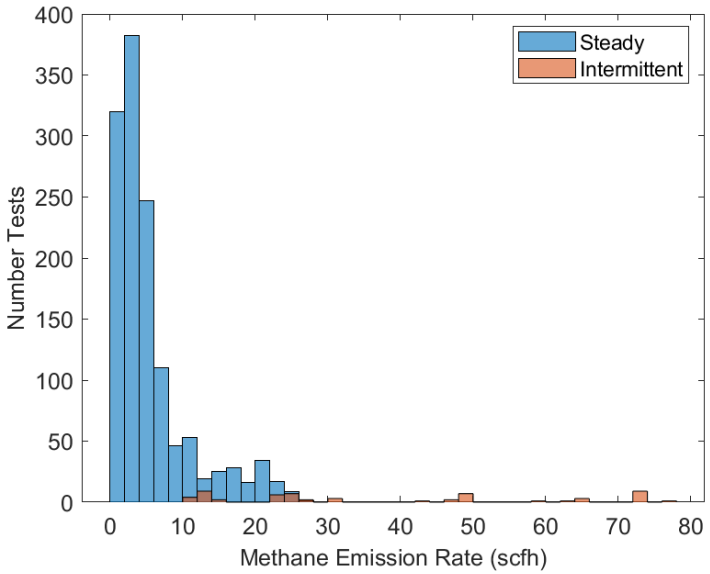
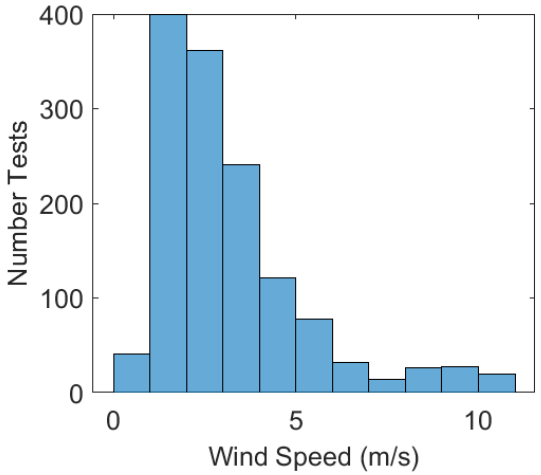
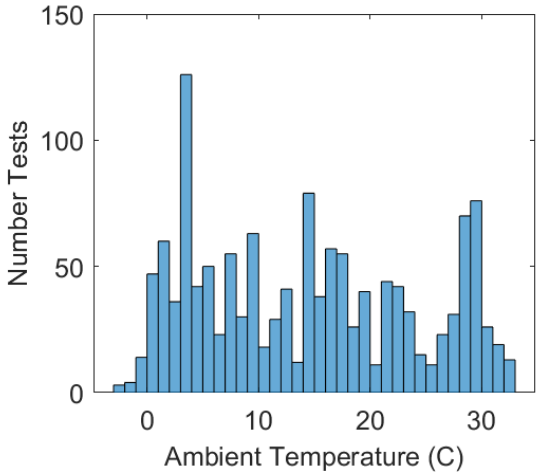
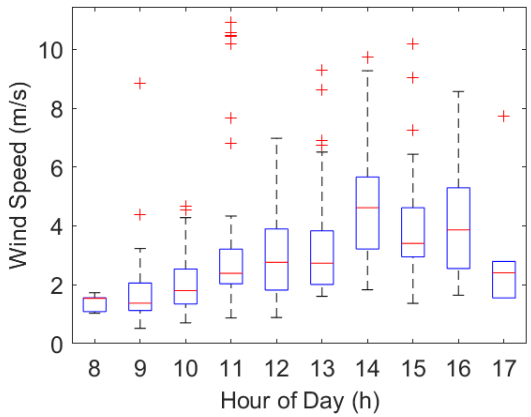
Test Conditions





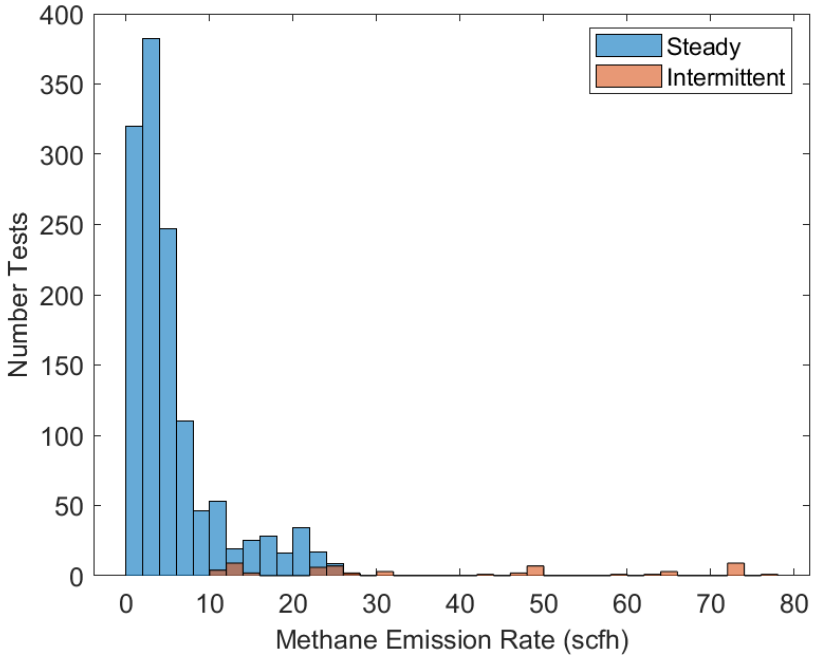




Note that wind speed is correlated with time of day

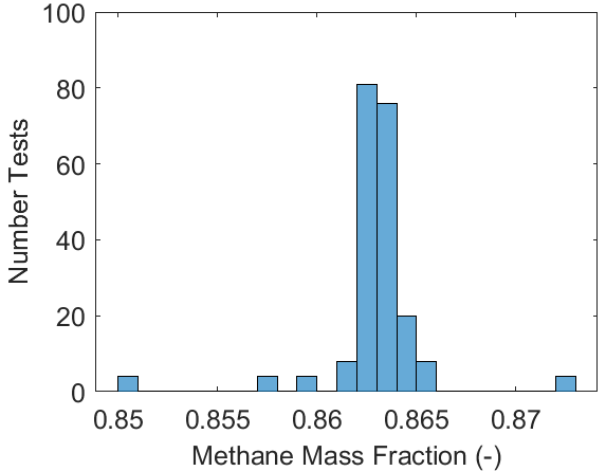
Intermittent & Closely Spaced Emitters

- Small number of tests with intermittent emissions
  - Much larger emission rates, simulating intermittent pneumatics
  - Proved problematic to analyze and dropped from most analysis
- Closely spaced emitters
  - One emitter pair.
  - Surveyors could not use soap bubbles to isolate emitter from nearby components
  - Combined these two into one emission location



Gas Composition

- Early testing days used odorized gas … later days used methane only
- 19% of all tests used odorized market gas
  - 49% of compliance team tests
  - 3.7% of LDAR team tests



Restrictions

- No equipment was heated by the gas burners attached to equipment
  - In field conditions, separators may be heated for process reasons.
  - Heated equipment may provide more background contrast than unheated equipment in some conditions
  - Leaks on heated equipment may release heated vapors that are more visible in an OGI camera against cold backgrounds.
- Gas is not released under pressure
  - In some field conditions, leaking gas may be emitted at high pressure and velocity, forming a small jet near the point of the leak. For this study, gas was emitted at near atmospheric pressure and no jets were formed.
  - Jets are smaller (harder to detect) but expansion cooling may increase the thermal contrast versus background.

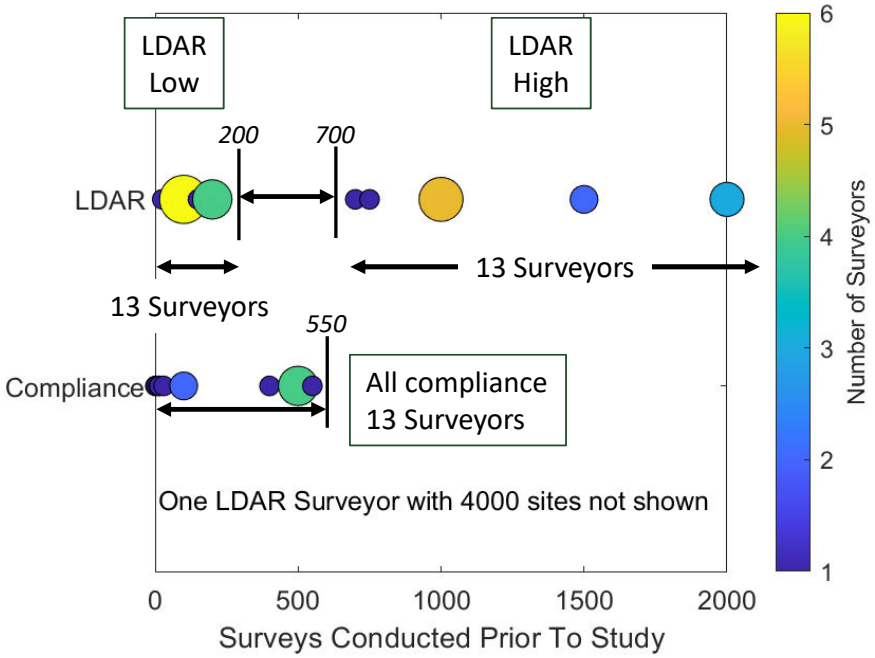
Restrictions (cont'd)

- Leaks at METEC were industrial methane with no odor
  - Emissions were industrial-grade, nonodorized, CH4 in most tests
  - In some field conditions, gas contains VOCs which raises plume visibility in OGI cameras.
  - In fields with significant liquid production, produced gas has a noticeable odor. Both visibility and increased odor increase the potential for detecting an emitter.
- Human factors differed from field operations.
  - In study at METEC, surveyors tended to be strongly focused, and typically 'exhibited a competitive spirit' to detect as many leaks as possible.
  - Surveyors also knew there would be leaks.
  - In field conditions, surveyors may be less motivated or more distracted, which could lead to different effective performance.
- METEC contains only well pad equipment
  - OGI is also utilized on more complex facilities (more closely packed, higher noise levels, more vibration) where leaks may be more difficult to detect.

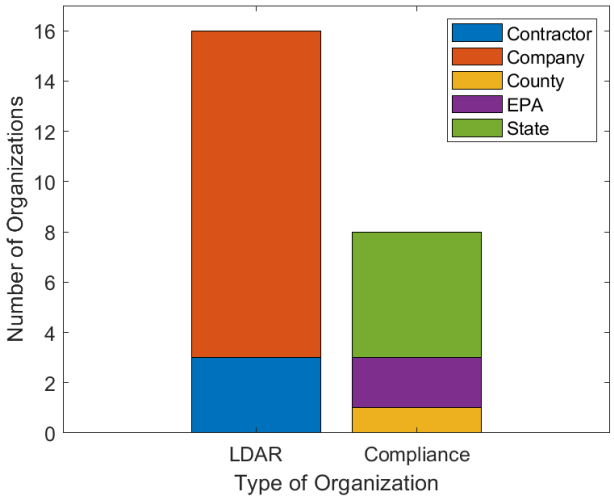
Results: Who Participated?

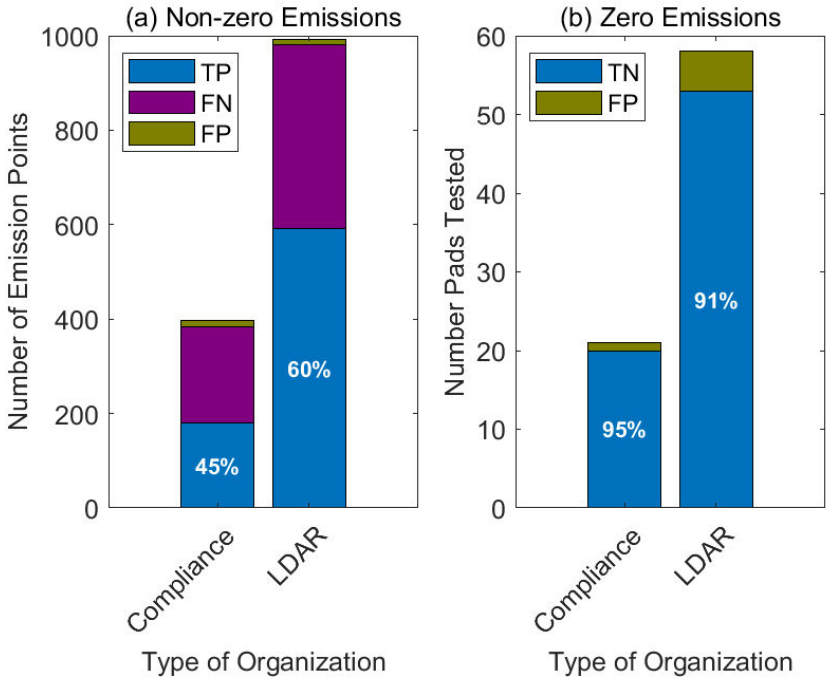
Primary Participant Grouping

- Substantial differences in protocol between:
  - **Compliance** → survey from 'outside the berm', don't open equipment
  - "**LDAR**" →allowed to ascend catwalks, open equipment, etc.
- Experience divides with noticeable gaps above / below 500 surveys
- Divided into three groups:
  - LDAR High (700-4000 surveys)
  - LDAR Low (25-200 surveys)
  - Compliance (1-550 surveys)



Who Participated



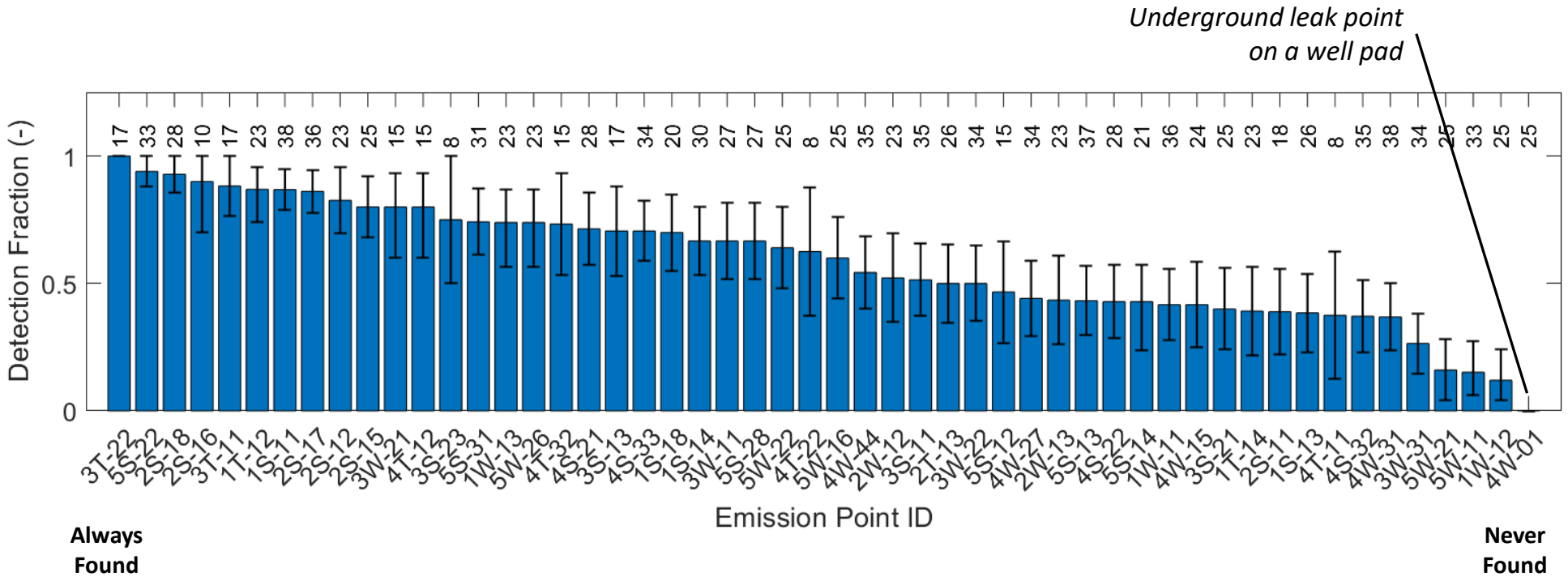


- Compliance Teams
  - Regulatory teams from county, state (includes provincial) & federal jurisdictions
- LDAR
  - LDAR staff from O&G operators
  - LDAR contractors

Reported \ Actual	No	Yes
No	TN	FN
Yes	FP	TP

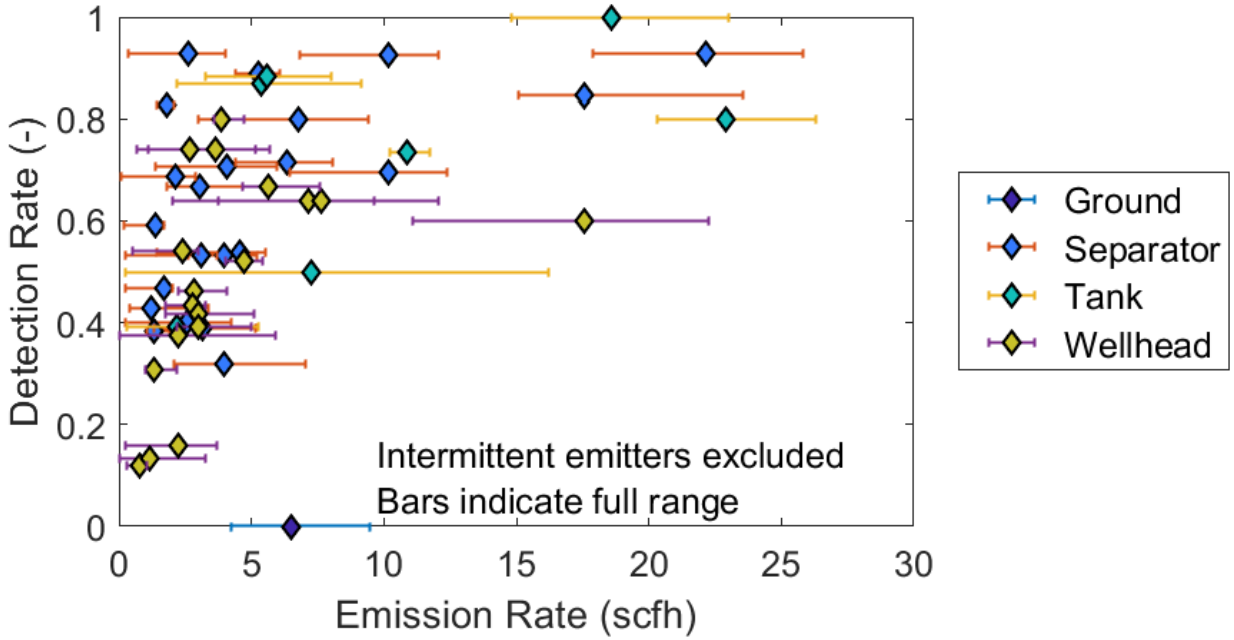
What Did Surveyors See?

Detection Rate by Emission Location



Key: xE-ny … x = METEC pad ID, E = equipment type (Tank, Wellhead, Separator), n = equipment ID number, y = leak location ID number

No obvious pattern by emitter or size …



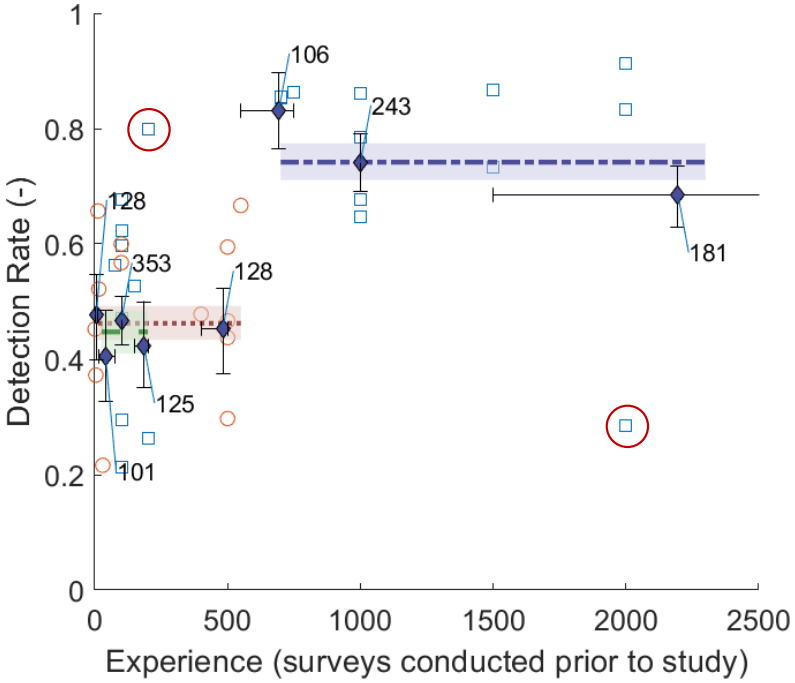
What Drives Detection Rates?

Detection Rates: Experience Counts

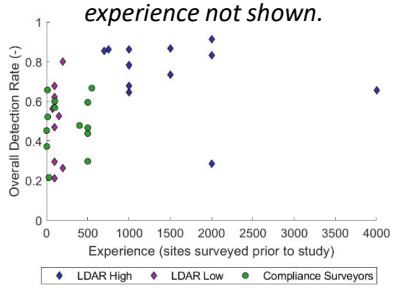
- Experience had a substantial impact on detection rate
- On average …
  - LDAR Low ≈ compliance

    45% [41% to 49%] 49% [44% to 54%]
  - LDAR High 1.6x other two

    75% [72% to 78%]
- Outliers in both LDAR groups (◯ on figure)

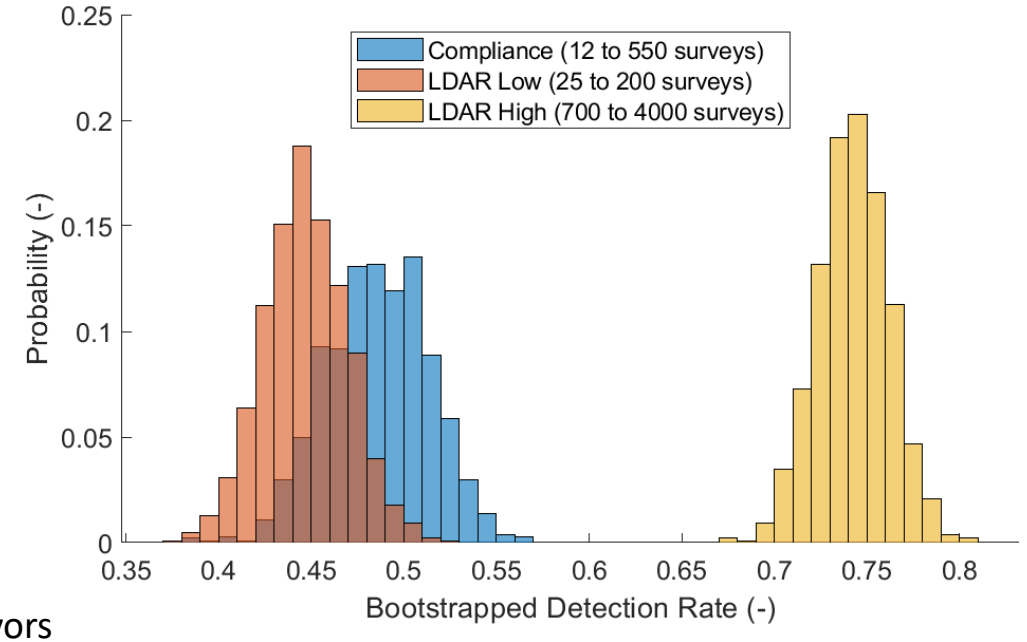


One surveyor with 4000 sites of experience not shown.



Experience-Driven Differences Are Statistically Significant

- Difference between compliance and LDAR driven, in part, by protocol and 'the objective of survey' differences
- Indicates that 'leaks found' numbers may have different meanings when looking at compliance data



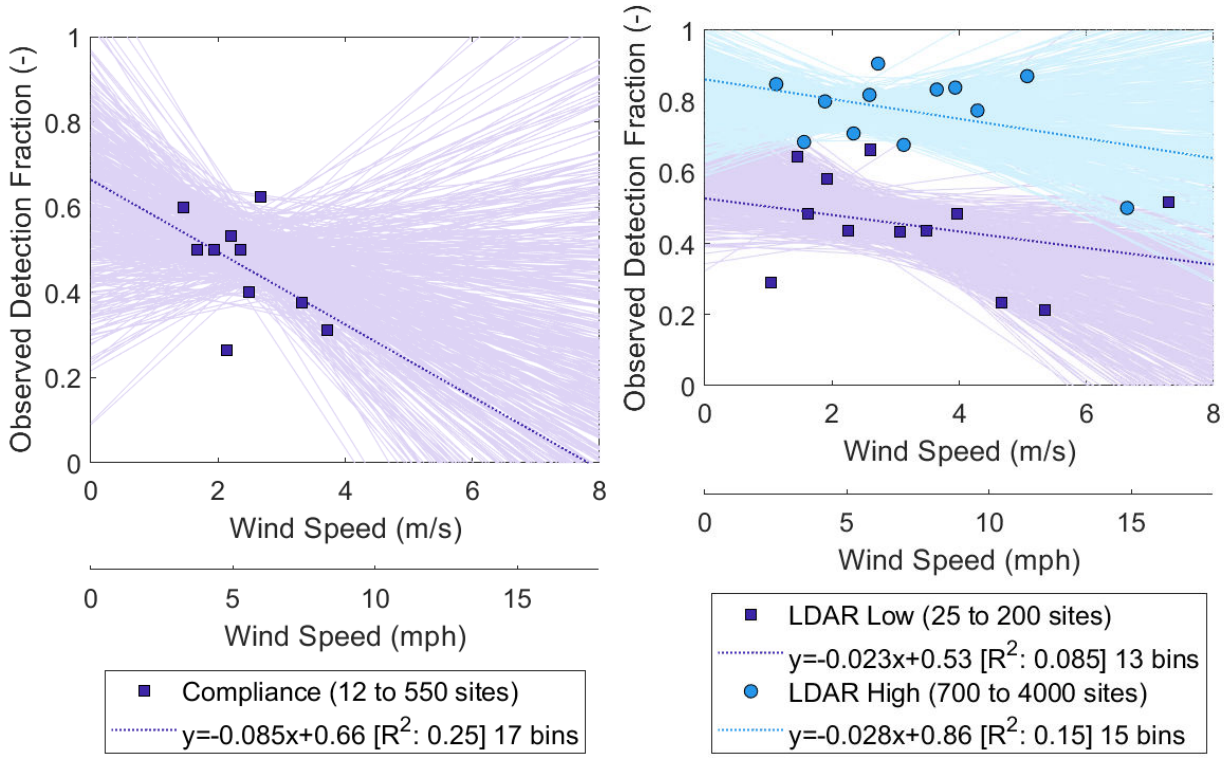
Detection Rates > 60%:

- 11 of 12 (92%) high-experience LDAR surveyors
- 3 of 10 (30%) low-experience LDAR
- 3 of 13 (23%) compliance

Is Wind Speed *The Thing?*

- Wind speed is not the predominant indicator commonly thought
- Higher winds:
  - 47 tests with wind speeds >9 m/s
  - leaks averaged 7.5 [0.06 to 30] scfh
  - 51% were detected

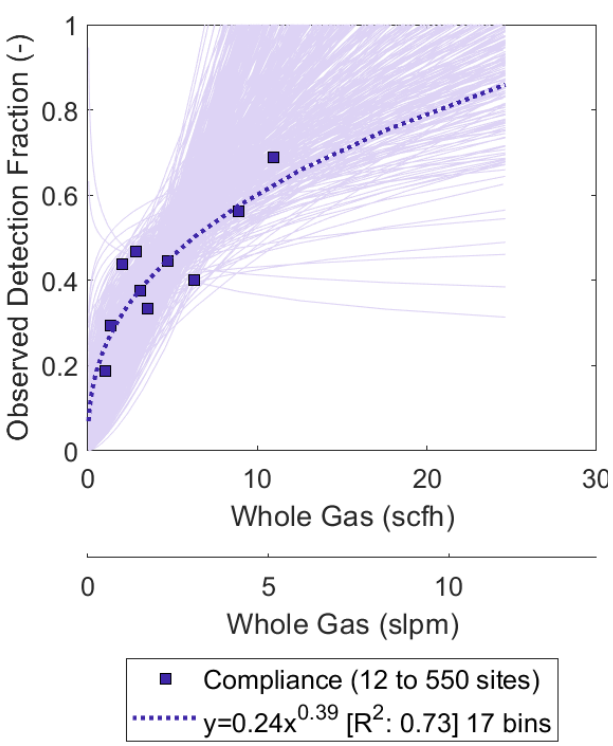
  … same as <9 m/s

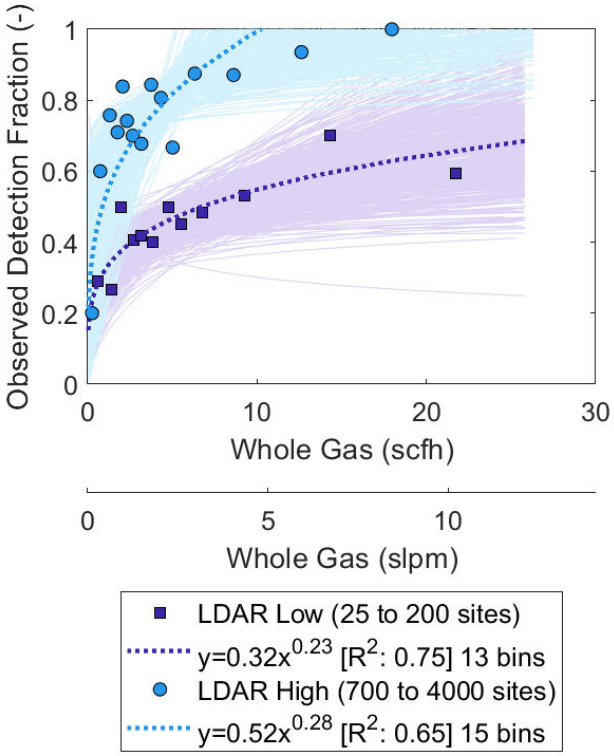


Of 39 surveyors, 17 reported a specfic wind speed cutof, ranging from 4.5 to 16 m/s.

Emission Size is More Predictive

- In *hindsight …* emission rates did not get large enough to exercise full performance range
- LDAR Low surveyors *did not* reached 90% detection rates for emission rates tested



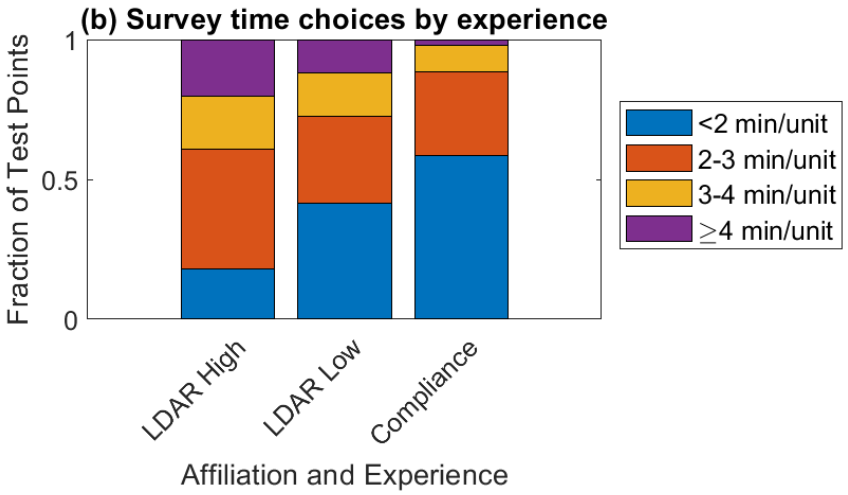


Results Differ From Camera-Focused Studies

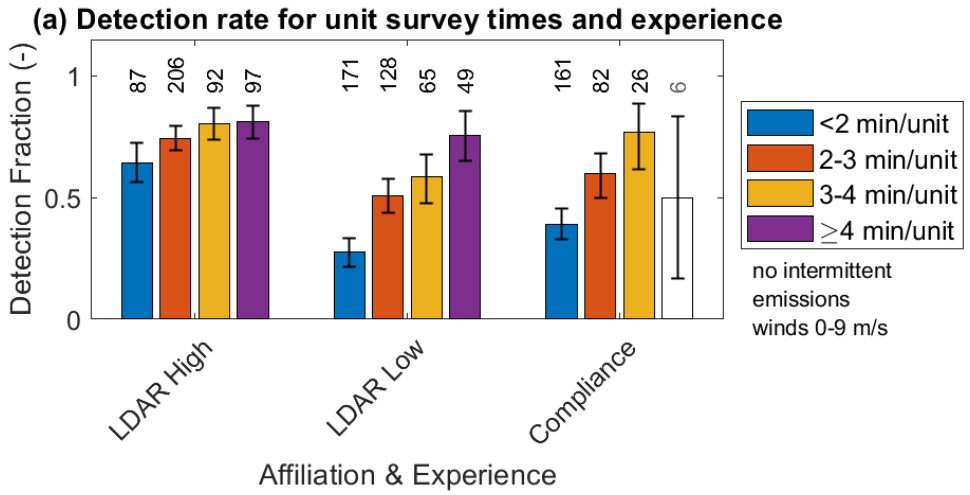
- Detection rates are order of magnitude lower than other studies that focused on camera performance
  - Consider 90% probability of detection @ mean observation distance (2.7 m)
  - Ravikumar et al.*: **0.7 scfh** or 13 g/h
    - Camera on tripod, market gas, known locations, 1 week, same weather:
  - This study:
    - Humans, handheld camera, methane only, unknown locations, many teams, variable weather
    - LDAR High: **7 [5.62 to 19.5]** scfh 3.29 [2.64 to 9.16] slpm
    - Compliance: **27.7 [7.84 to 40.4]** scfh 13 [3.69 to 19] slpm
- Never achieved 100% detection for the flow rates tested

*Ravikumar, A. P.; Wang, J.; McGuire, M.; Bell, C. S.; Zimmerle, D.; Brandt, A. R. Good versus Good Enough? Empirical Tests of Methane Leak Detection Sensitivity of a Commercial Infrared Camera. Environmental Science & Technology 2018, 52, 2368-2374.
Flow rate for 90% detection rate: $r = 1.845d^{1.975}$, where d is the observation distance in meters, and r is the flowrate of gas in g/h

Why are Experienced Surveyors better?



Experienced surveyors take more time



Taking less time has less impact on the effectiveness of experienced surveyors

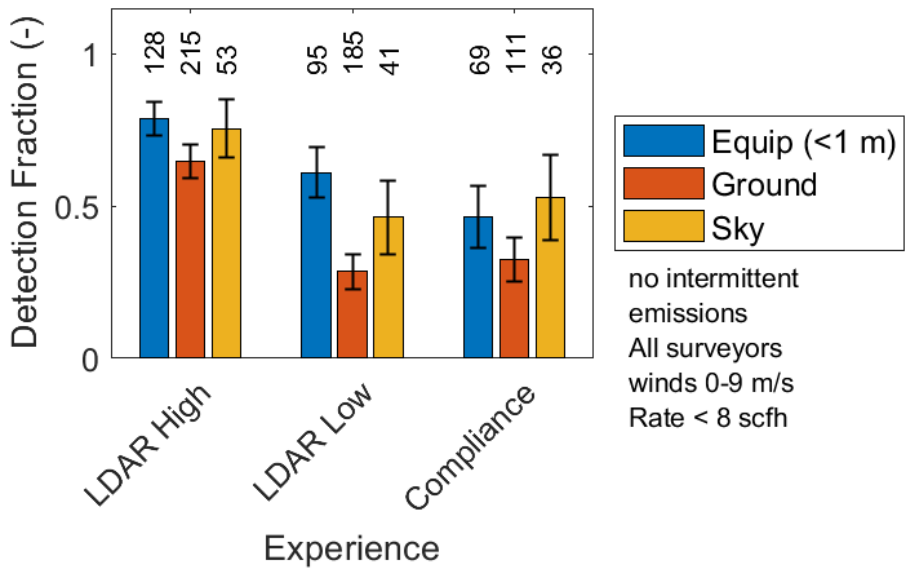
Experience = Know when to slow down + better at finding leaks at any survey speed

Where You're Looking Matters

- A large fraction of possible emission points in upstream are:
  - Below eye level
  - On separate equipment units - naturally viewed against ground
- Detecting against ground is harder
- Background impacts inexperienced operators more
  - Sky-to-ground:

    High Experience: -10% (from 75% to 65%)

    Low Experience: -17% (from 46% to 29%)



Includes only emission <8 scfh so that mean emission rate for sky backgrounds (3.4 scfh) ≈ emission rate for other backgrounds (3.1 and 3.3 scfh)

False Positives

- Overall: 4% [1.3% to 7.9%].
- False positive rate – pads with no leaks present
  - Experienced: 1 of 30 tests (3.3% [0% to 9.7%])
  - Inexperienced: 1 of 23 tests (4% [0% to 13%])
- False positive rate – add'l leaks on pads with leaks present
  - Experienced: 9 of 490 tests (1.8% [0.8% to 2.8%])
  - Inexperienced: 1 of 453 tests (0.21% [0% to 0.66%])
  - Higher detection rate of experienced surveyors also means higher false positives
- Novices have *lots* of false positives:
  - Pads with no leaks: 1 of 5 tests (16% [0% to 33%])
  - Pads with leaks: 9 of 89 tests (9.2% [4.1% to 14%])
- <u>Bottom line: For surveyors with even modest experience … false positives are not an issue</u>

Key Learnings

- Leak detection rates of 'camera + operator' are much lower than indicated by 'is the plume visible in a camera view'
- Experience counts: More experienced surveyors find nearly 2X the number of leaks
- Why? Experienced surveyors …
  - know how to frame components against backgrounds to make leaks more visible.
  - know when to take more/less time to survey

METEC has developed a *hands-on OGI training course*

→Practice surveys at METEC

→Immediate feedback on performance + detection tips

Thank You

Contact

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