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

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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

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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
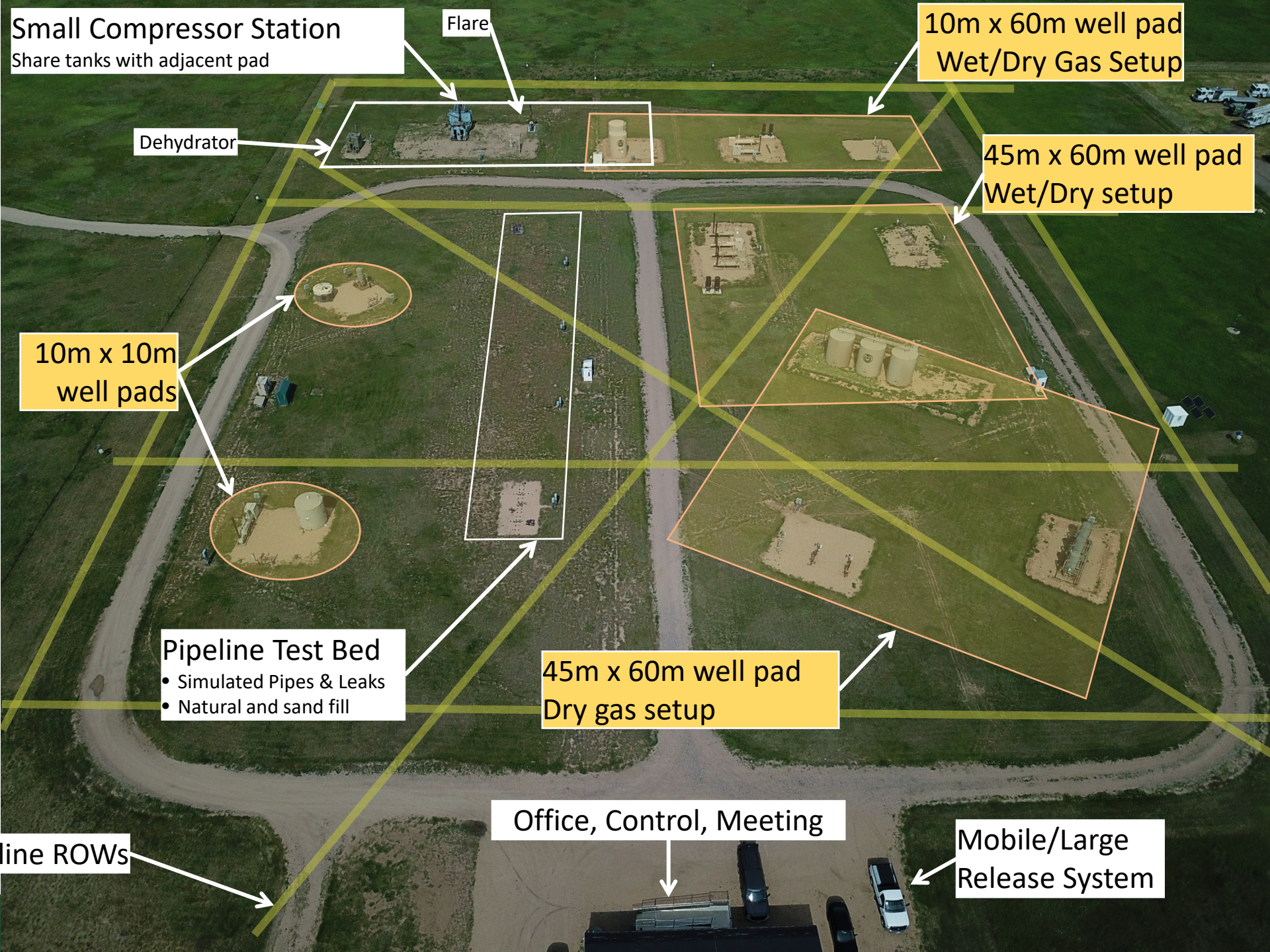- In-kind participation by most surveyor's companies

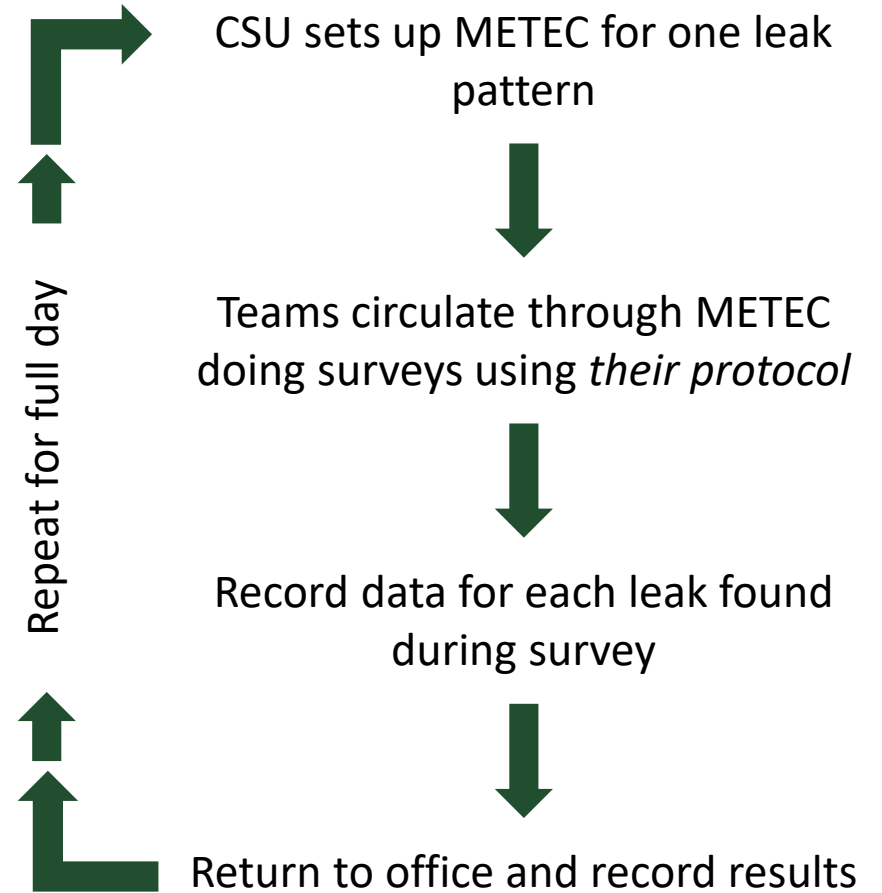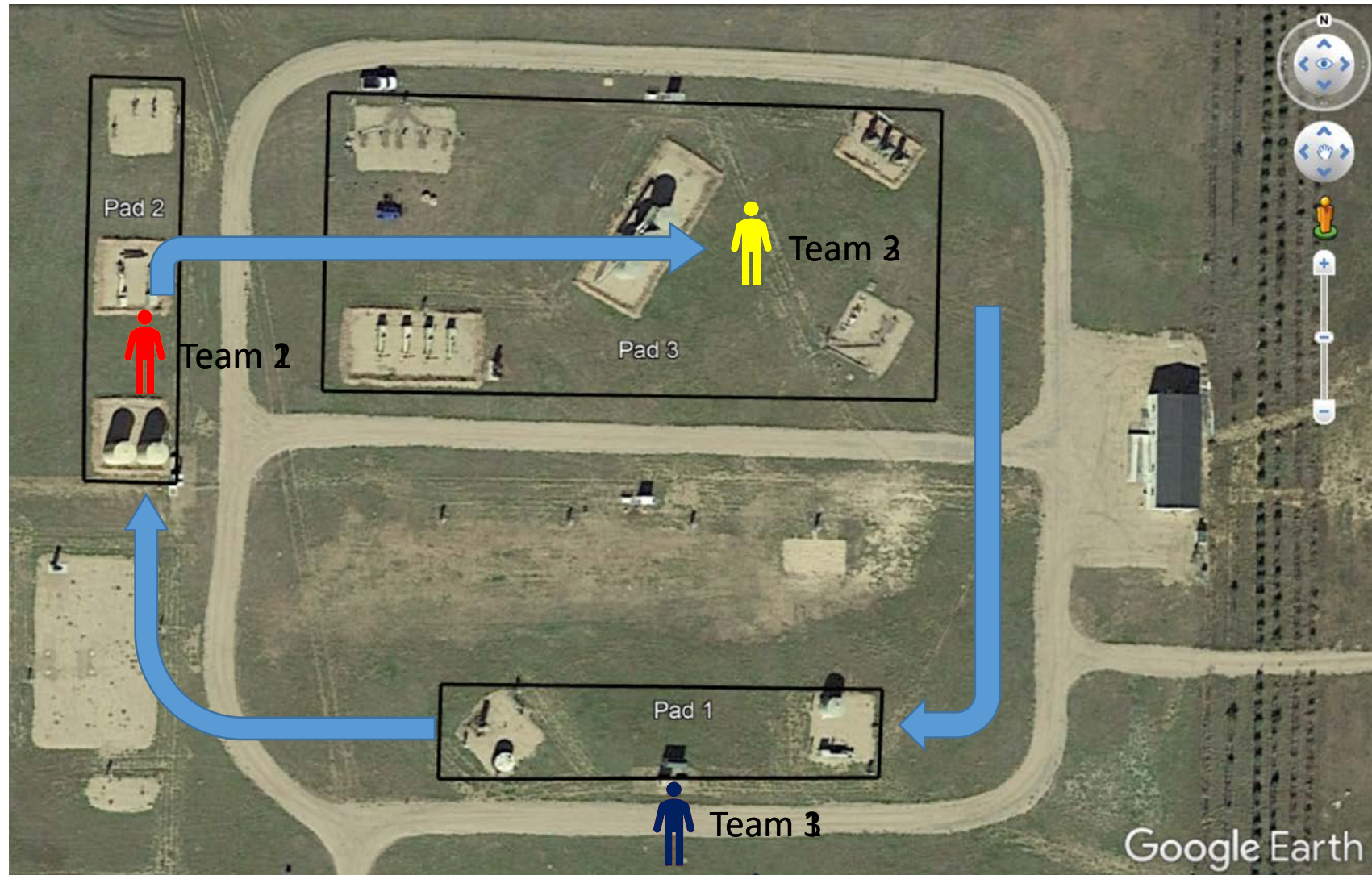ENERGY INSTITUTE
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Testing method

- Blind surveys to locate controlled emissions in realistic outdoor environment

- Camera operators bring their own cameras and survey using their normal protocol
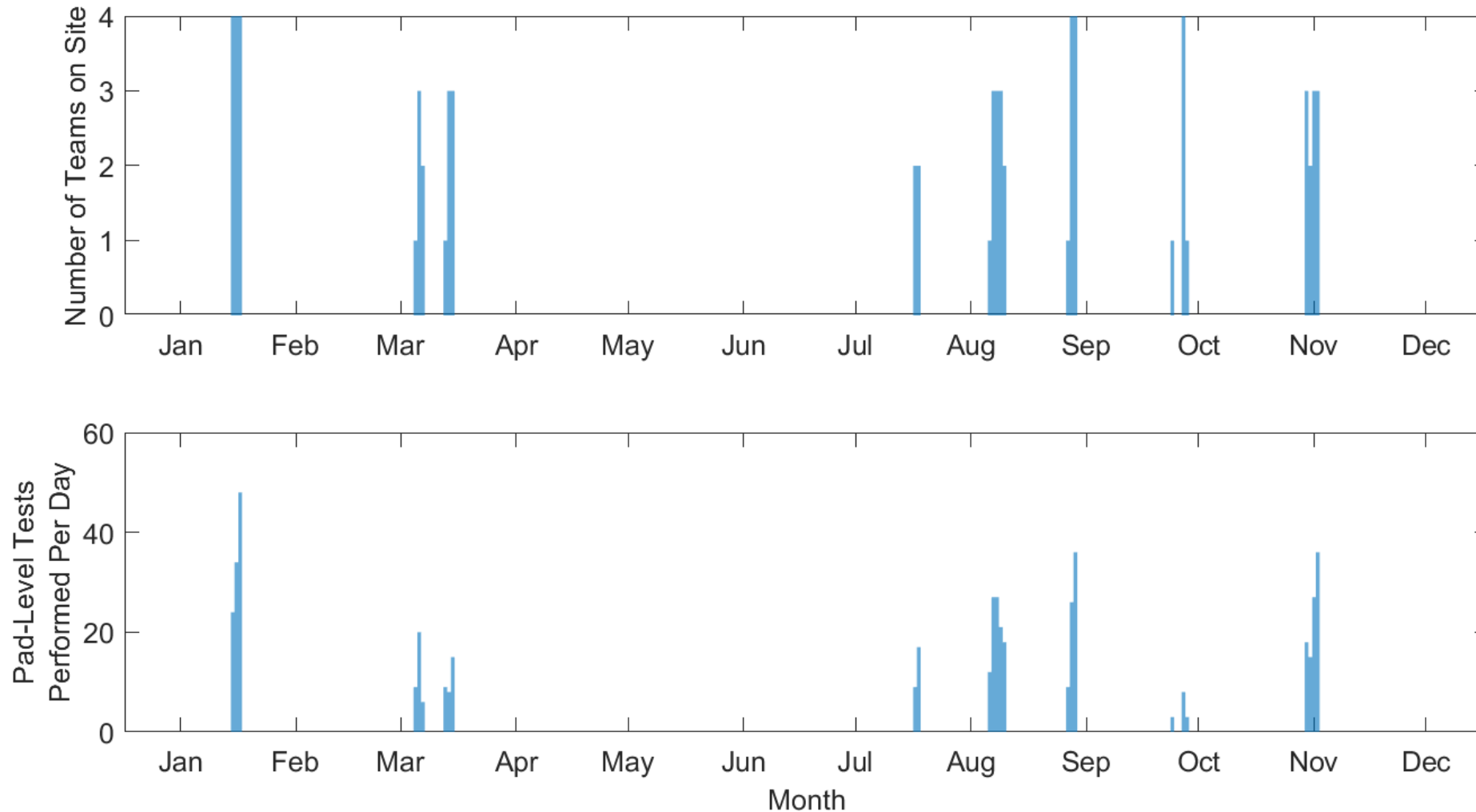
Goal is to simulate, as close as possible, how surveyors work in the field.

Repeat for full day

CSU sets up METEC for one leak pattern

Teams circulate through METEC doing surveys using *their protocol*

Record data for each leak found during survey

Return to office and record results
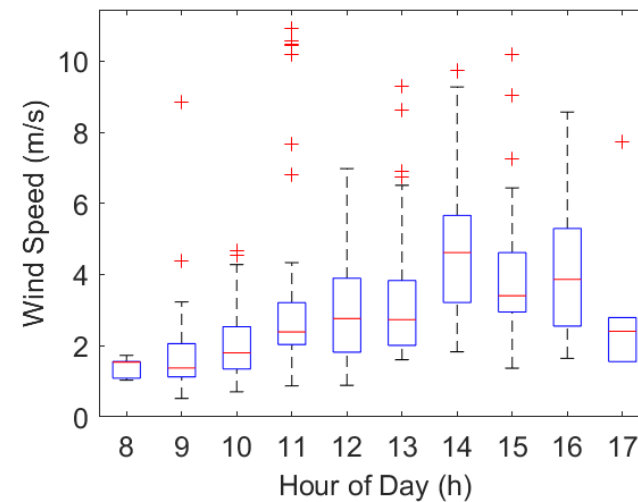
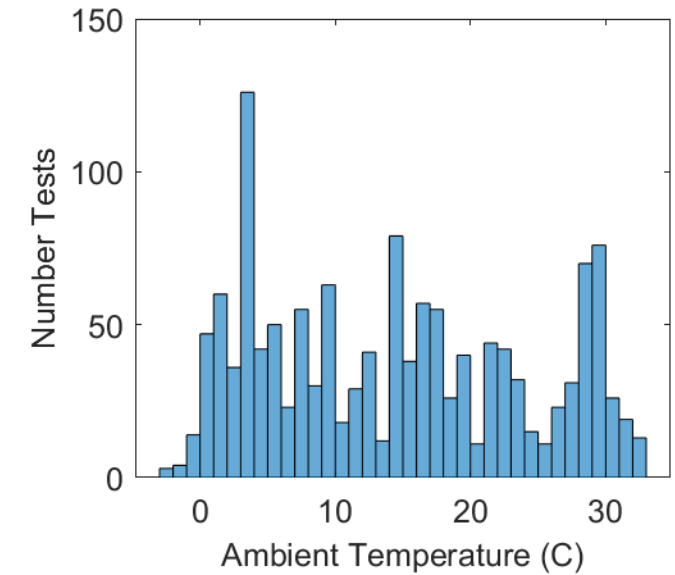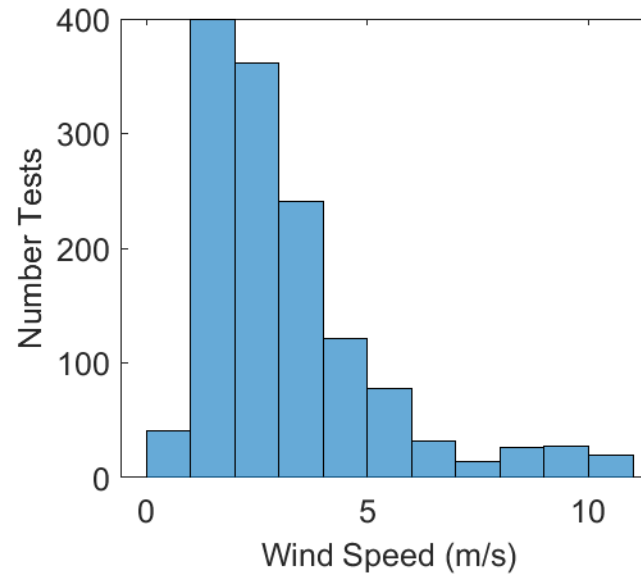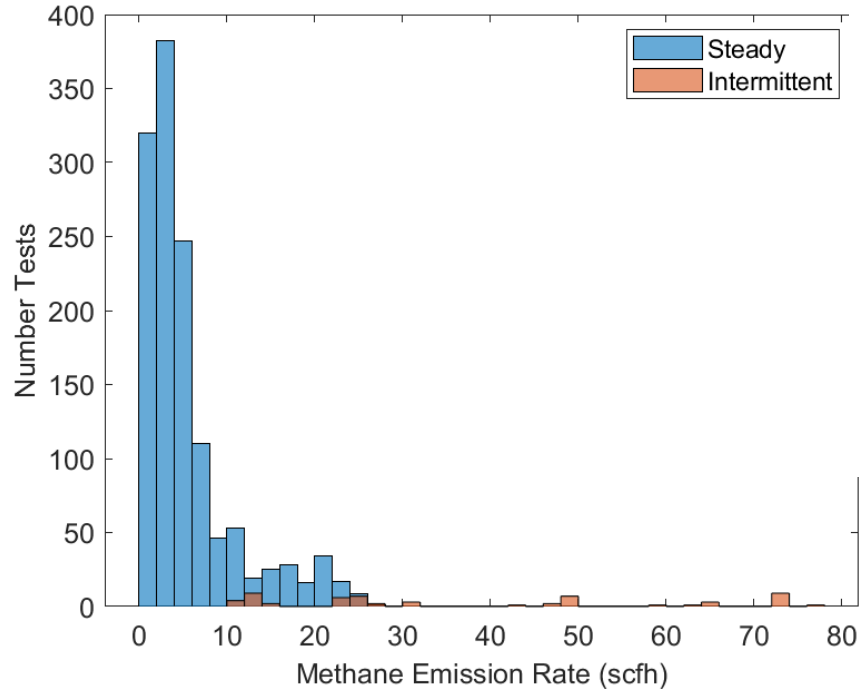ENERGY INSTITUTE
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Measurement set

Testing: When and How Many

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
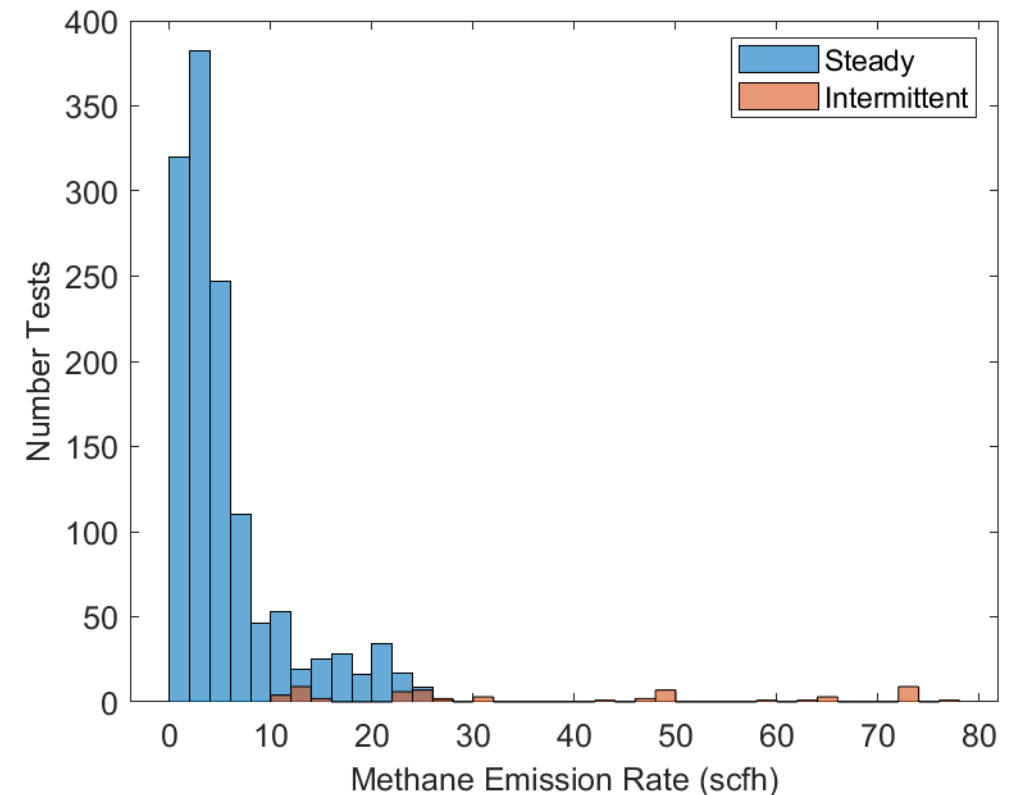
Gas Composition

- 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

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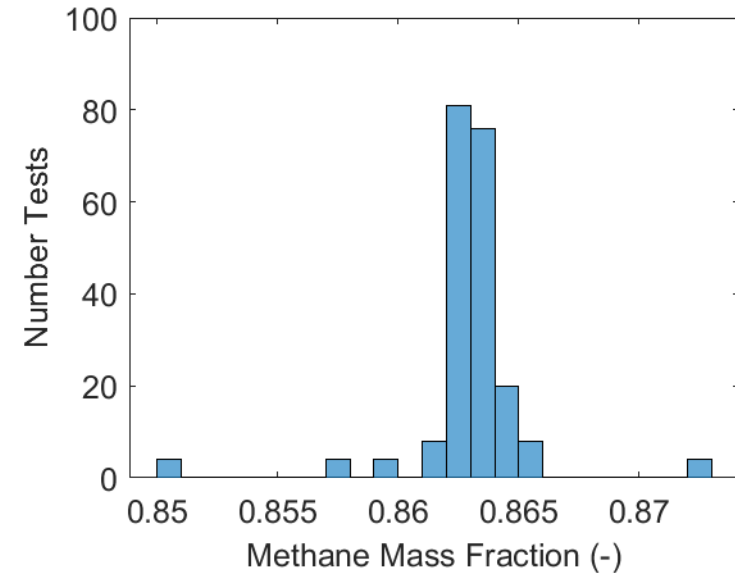
Restrictions

- 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.

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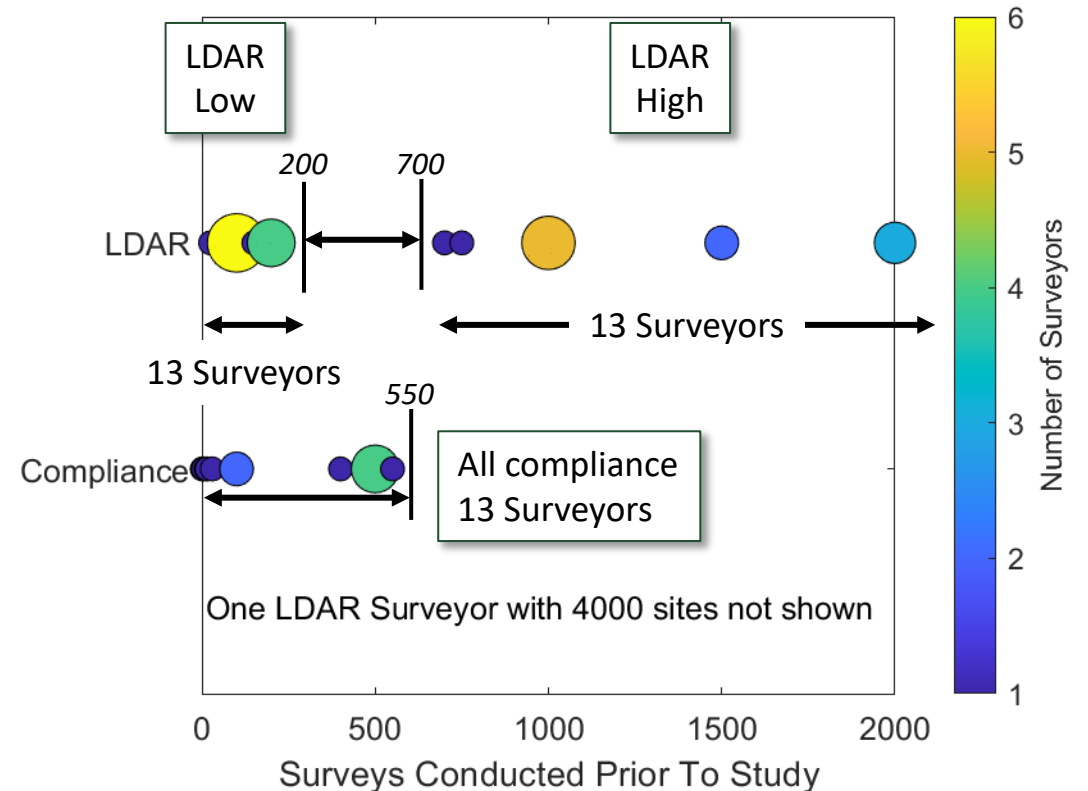
Who Participated
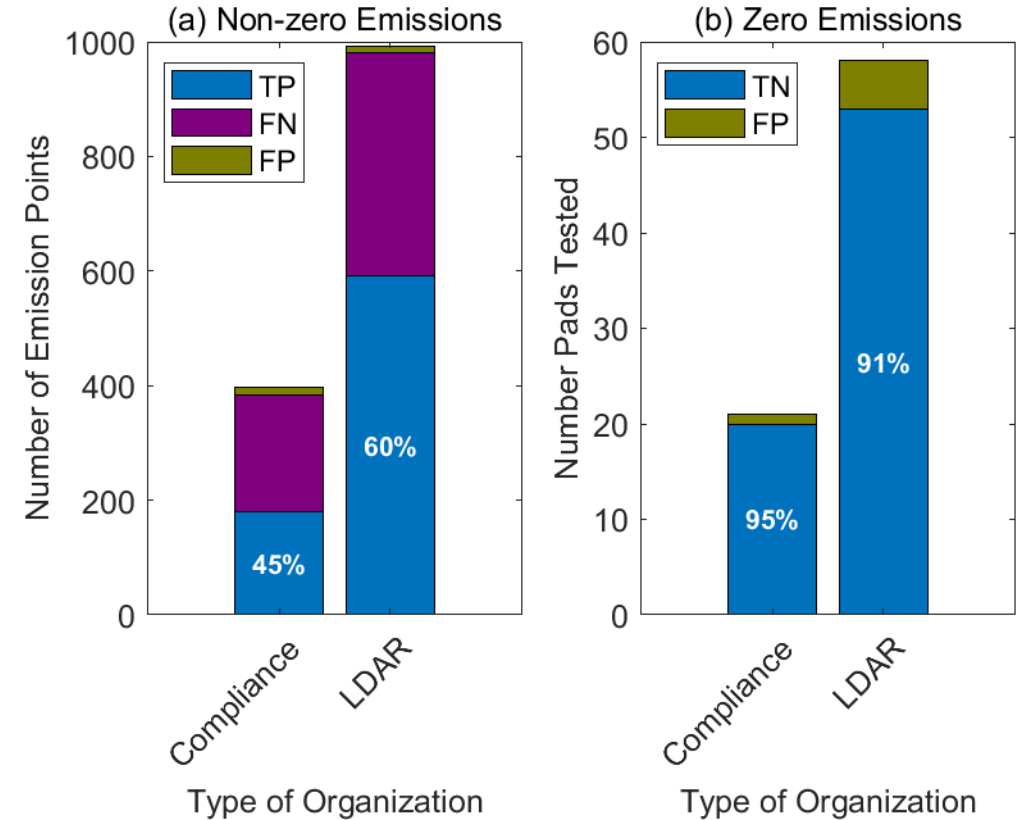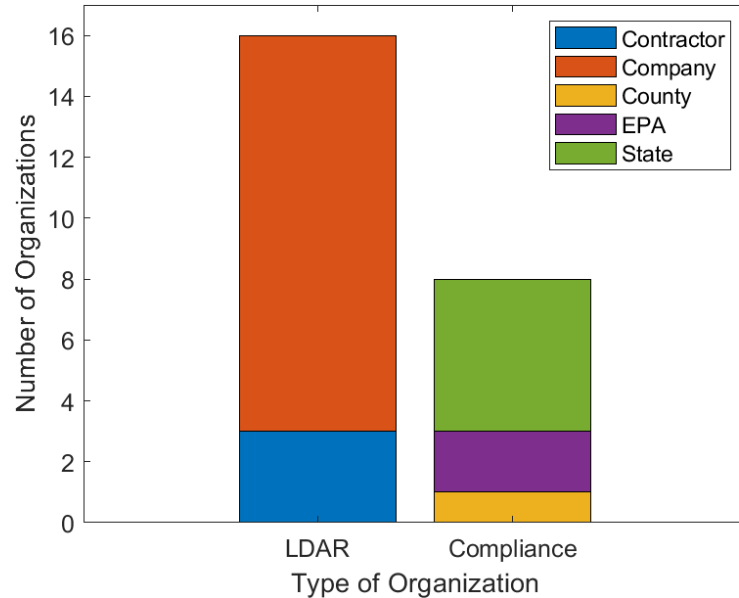
- Compliance Teams
  - Regulatory teams from county, state (includes provincial) & federal jurisdictions
- LDAR
  - LDAR staff from O&G operators
  - LDAR contractors

	Actual	
	No	Yes
Reported No	TN	FN
Reported Yes	FP	TP

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What Did Surveyors See?

Detection Rate by Emission Location

Underground leak point on a well pad

Always Found

Never Found
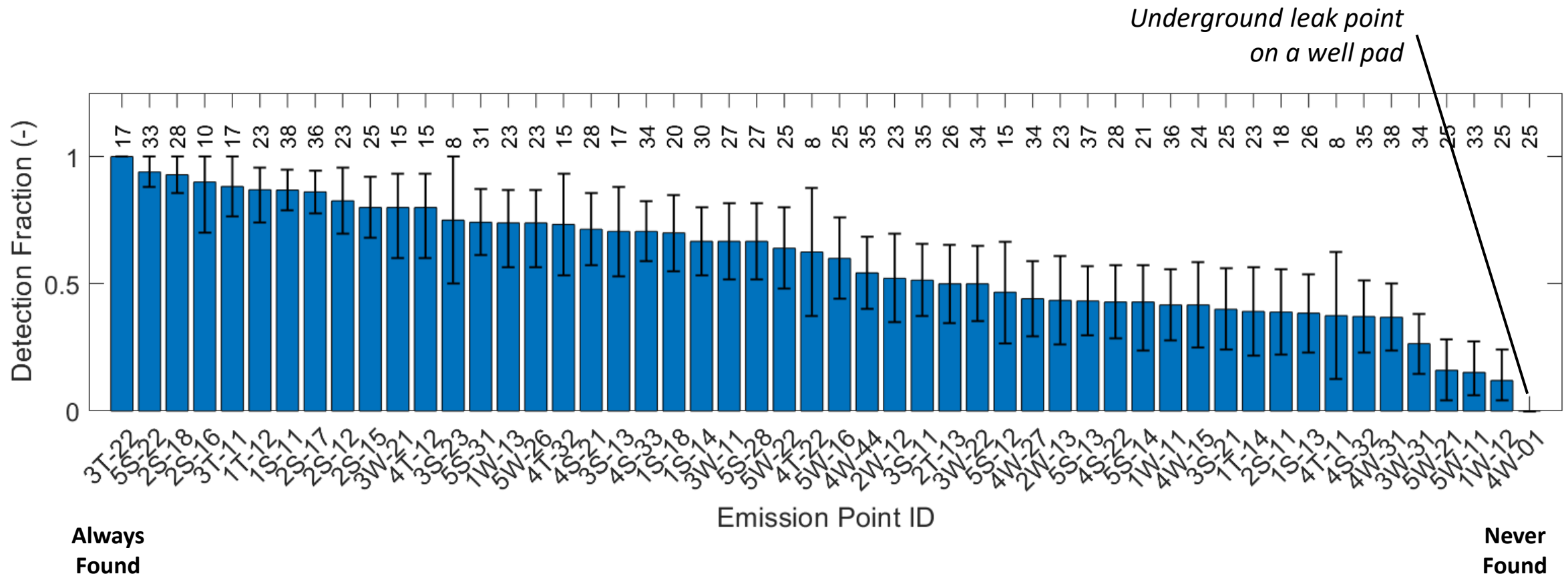
Key: xE-ny … x = METEC pad ID, E = equipment type (Tank, Wellhead, Separator), n = equipment ID number, y = leak location ID number

No obvious pattern by emitter or size …
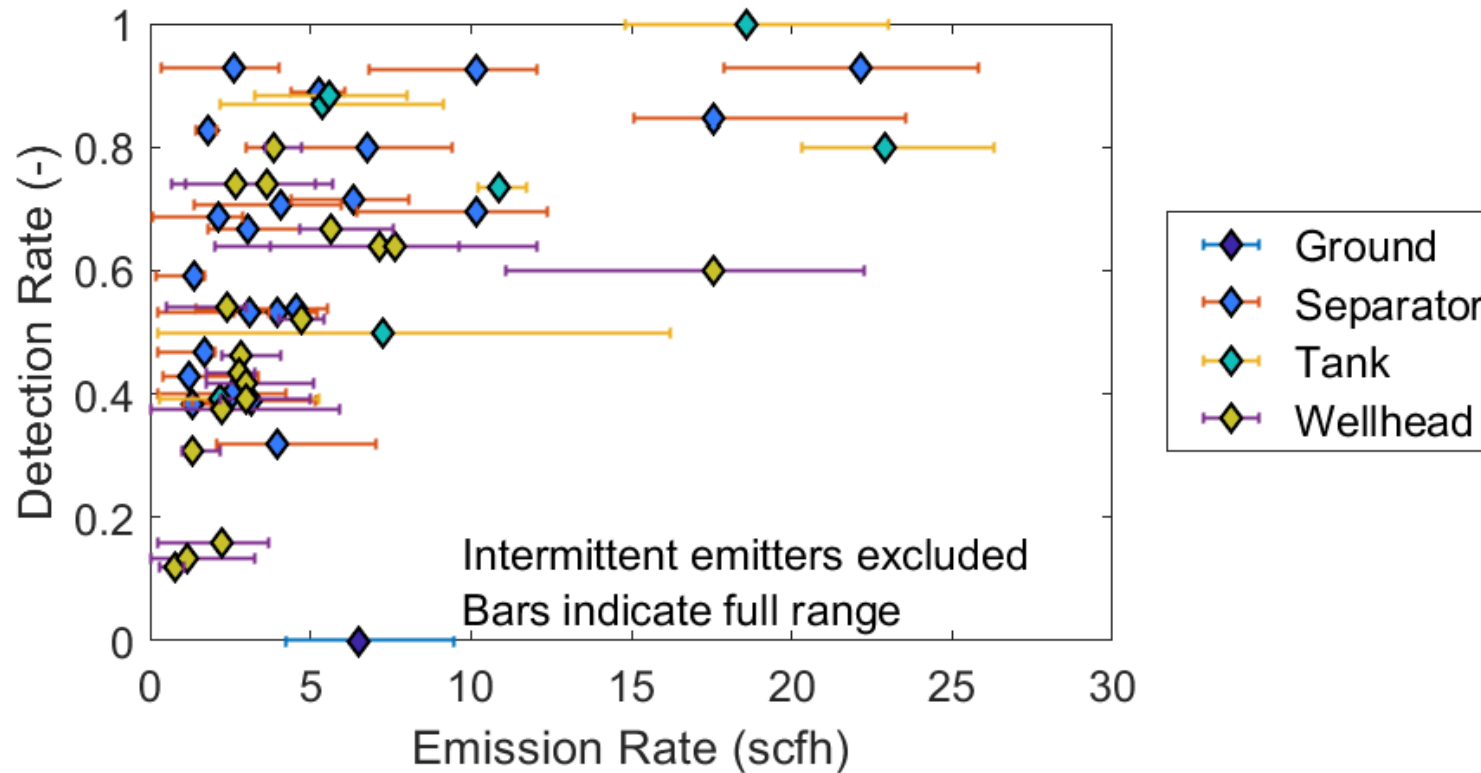
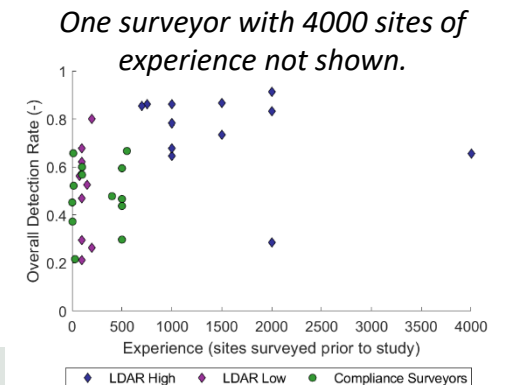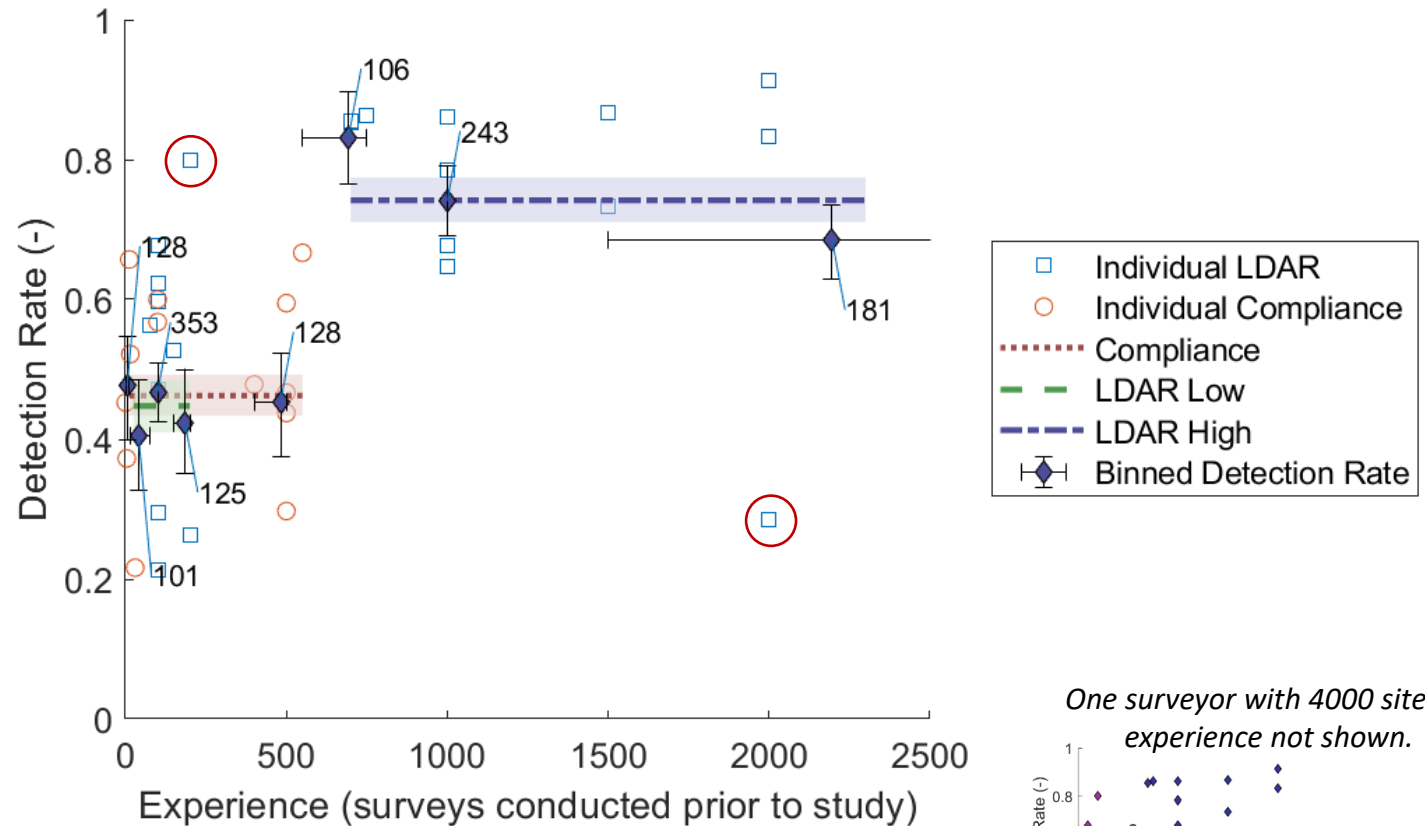# What Drives Detection Rates?

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
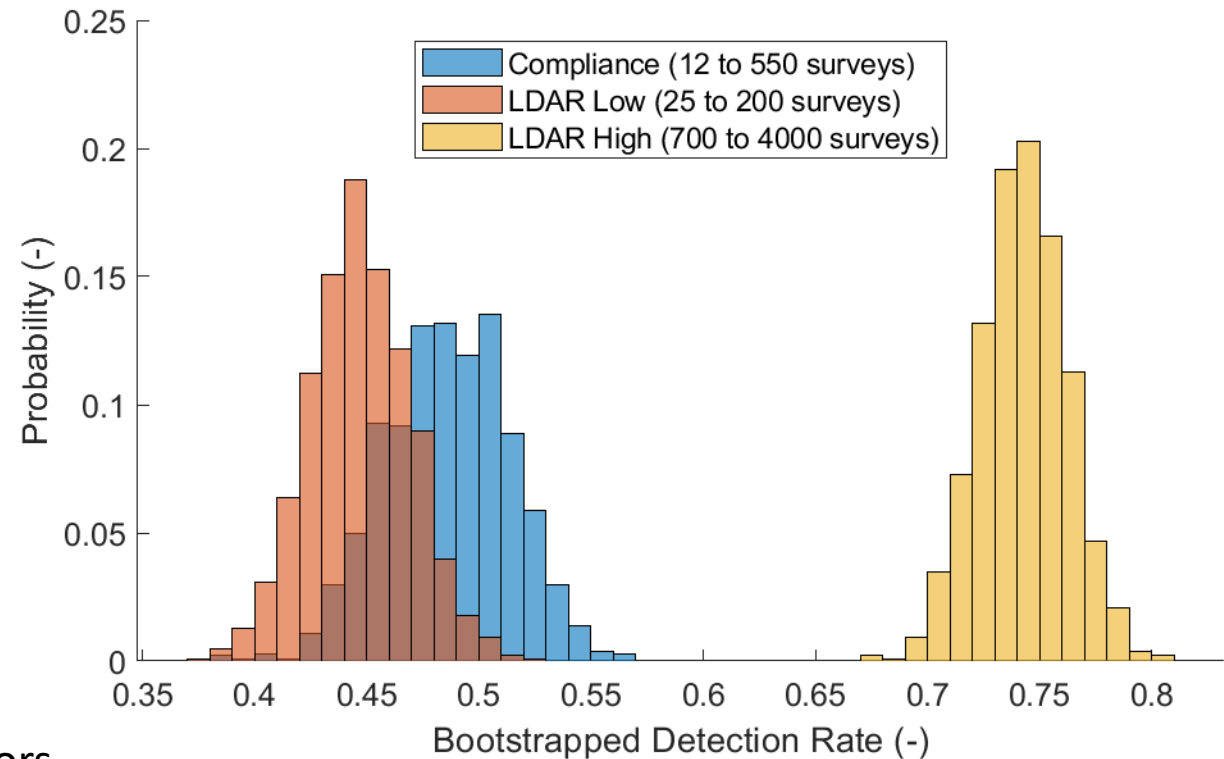
Is Wind Speed *The Thing?*

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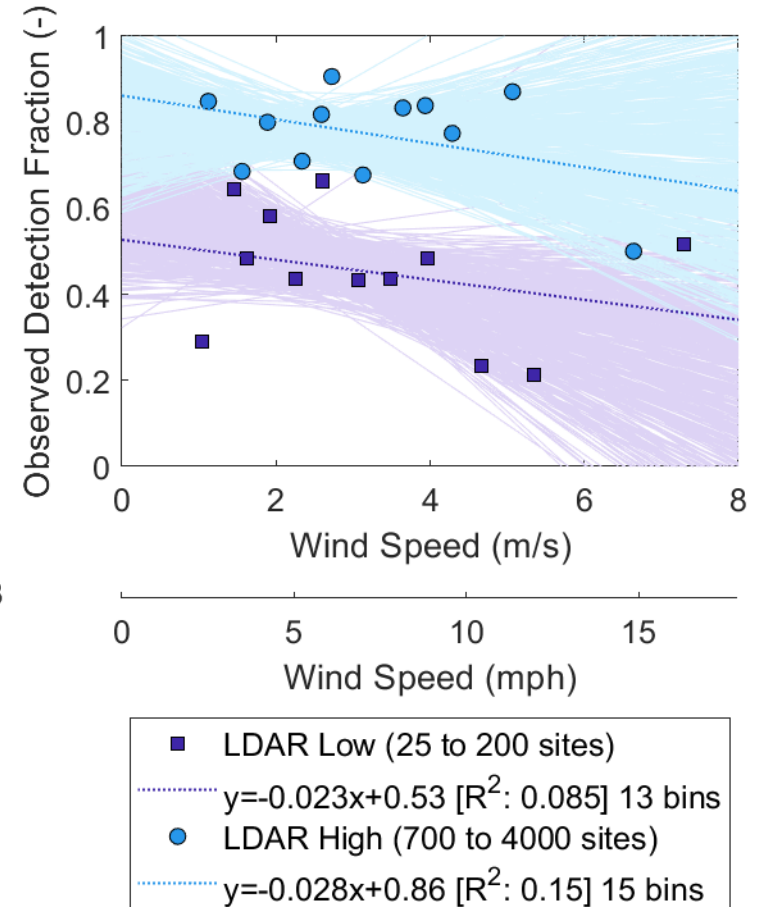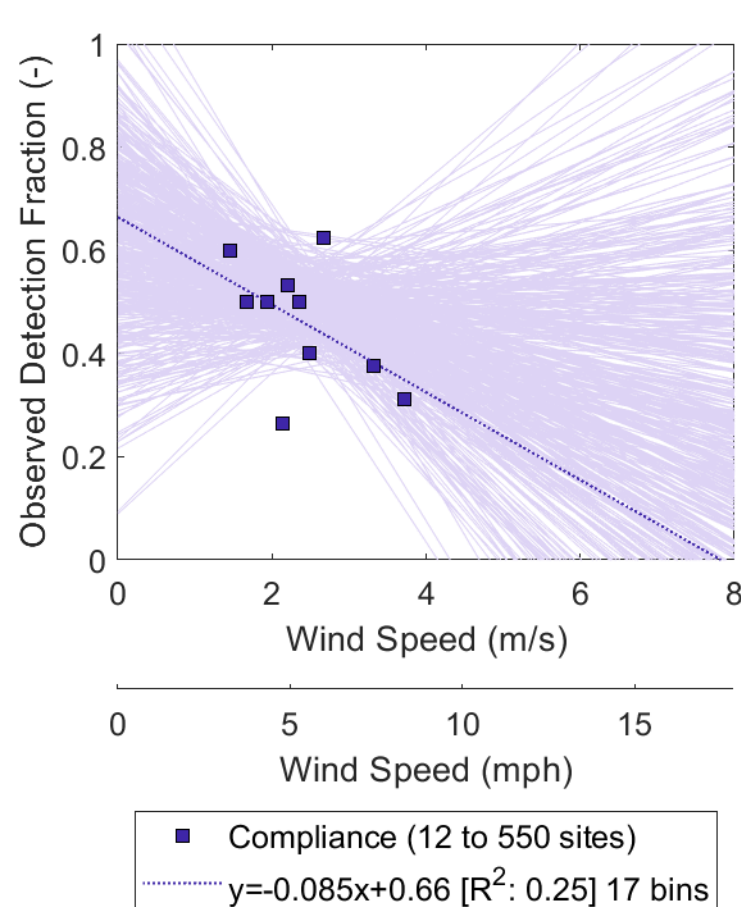
Of 39 surveyors, 17 reported a specfic wind speed cutof, ranging from 4.5 to 16 m/s.

Compliance (12 to 550 sites)
y=-0.085x+0.66 [R^2: 0.25] 17 bins

LDAR Low (25 to 200 sites)
y=-0.023x+0.53 [R^2: 0.085] 13 bins
LDAR High (700 to 4000 sites)
y=-0.028x+0.86 [R^2: 0.15] 15 bins

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

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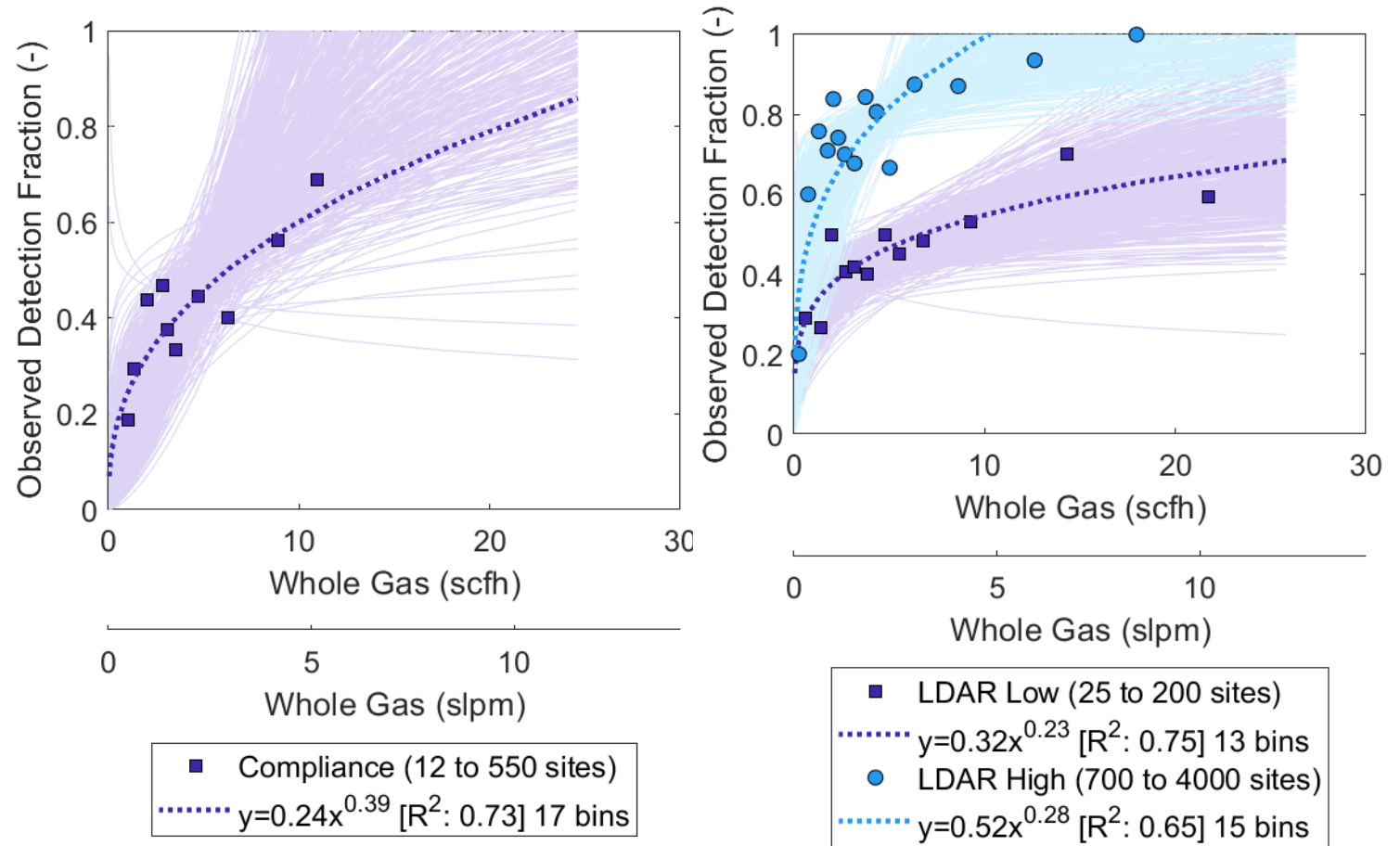
Results Differ From Camera-Focused Studies

- 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: $r = 1.845 d^{1.975}$, where d is the observation distance in meters, and r is the flowrate of gas in g/h

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Why are Experienced Surveyors better?
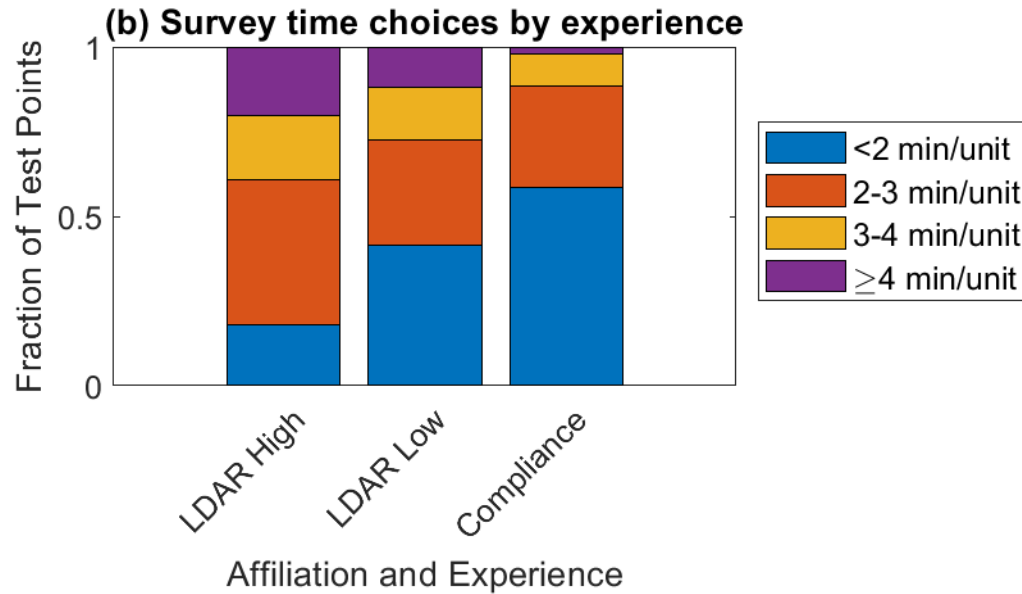
Experienced surveyors take more time
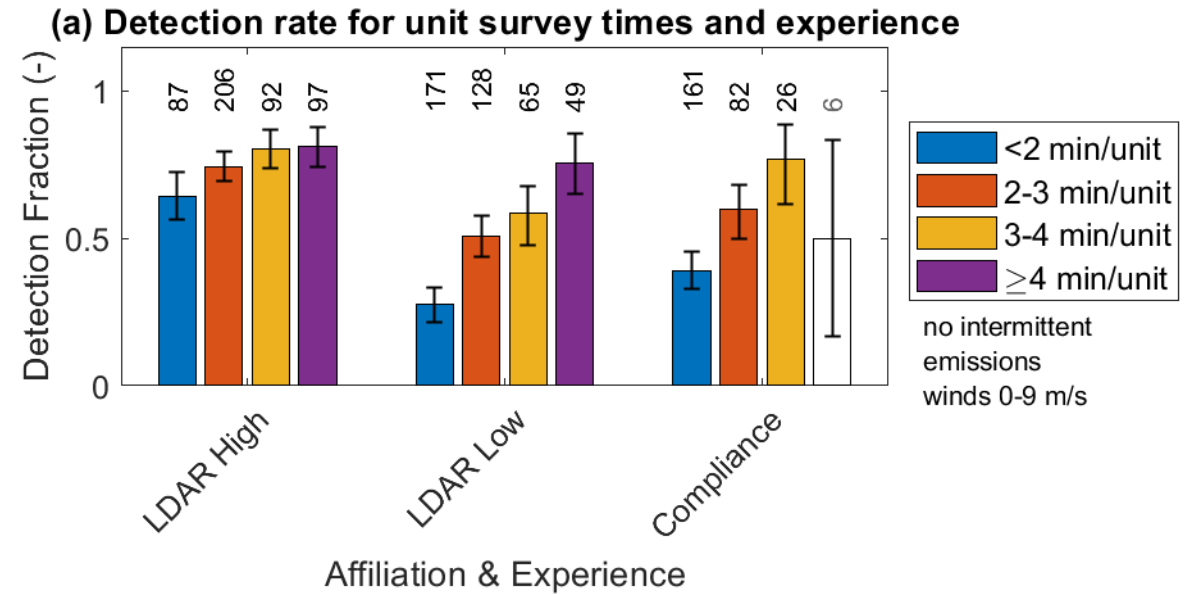
Taking less time has less impact on the effectiveness of experienced surveyors

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

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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%)

no intermittent emissions
All surveyors
winds 0-9 m/s
Rate < 8 scfh
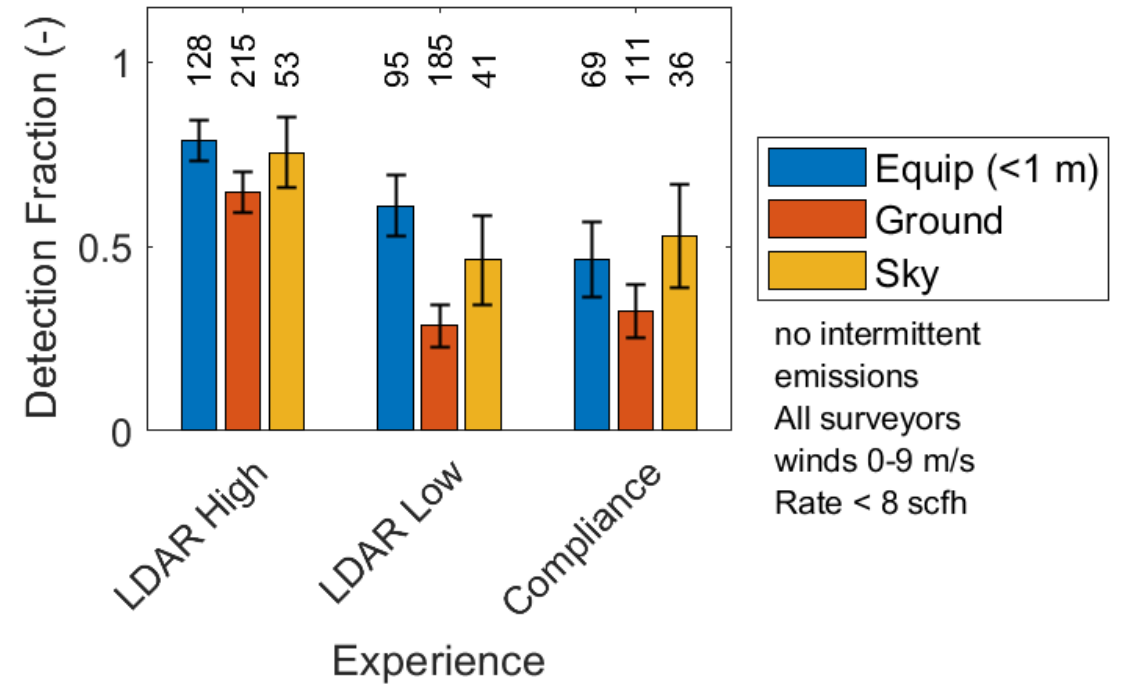
Includes only emission <8 scfh so that mean emission rate for sky backgrounds (3.4 scfh) ≈ emission rate for other backgrounds (3.1 and 3.3 scfh)

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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>

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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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