Multi-scale Methane Measurements at Oil and Gas Facilities Reveal Necessary Framework for Improved Emissions Accounting

META Presentation
9/22/2022

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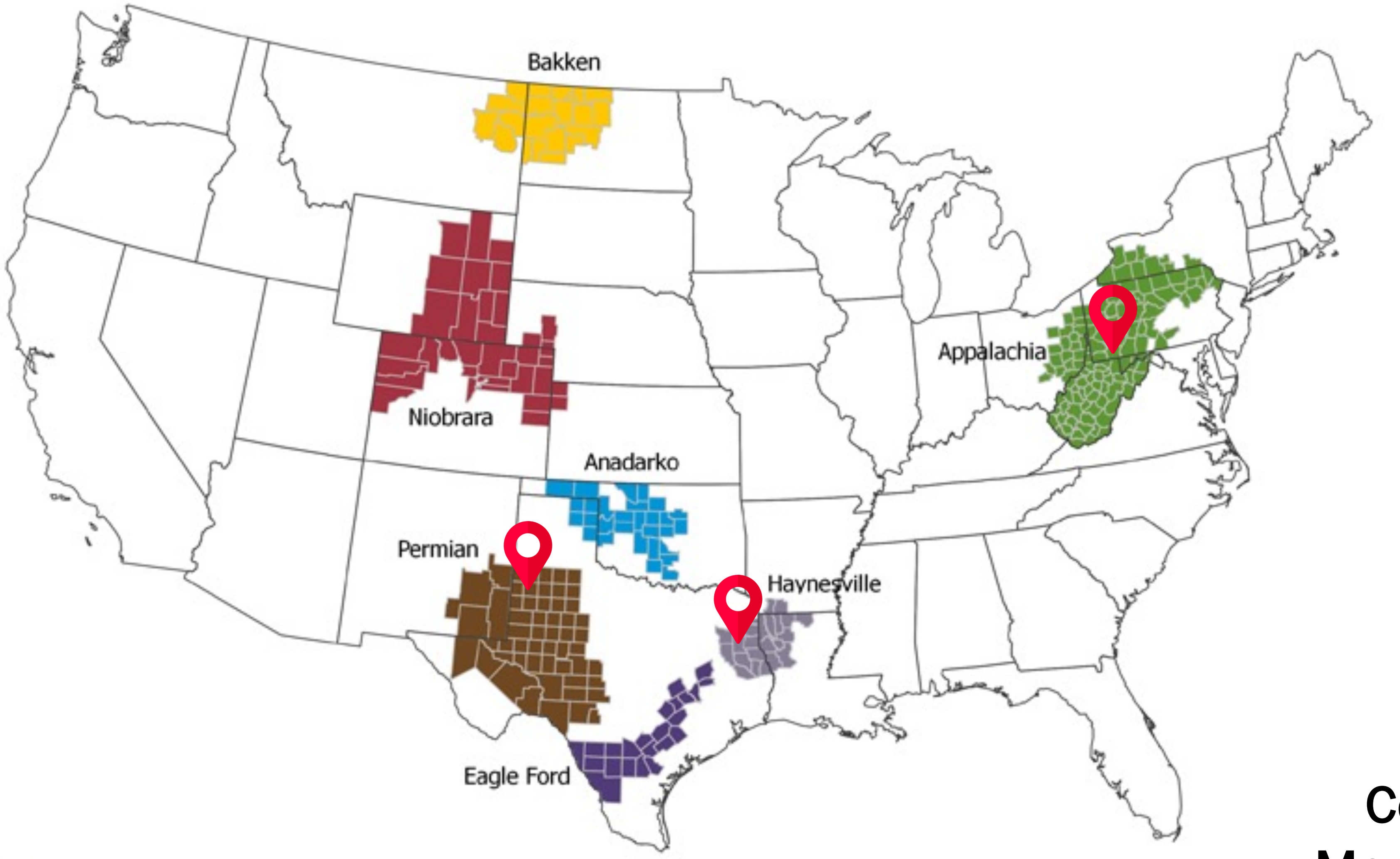
Challenges in Methane Emissions Inventory Estimation in O&G

- Emissions inventories are commonly found to be underestimated compared to measurements
  - Episodic, high-emitting sources contribute to the discrepancy
- Methane emissions at oil and gas facilities exhibit significant spatiotemporal variation across basins, companies, and operational practices
- Recent advancements in detection technologies enable cost-effective methane measurement, however, these technologies have limitations
- The Inflation Reduction Act directs EPA to update current engineering-based reporting requirements with measurement-based data for improved inventories

As operators deploy new technology, measured emissions can be a scalable way to continuously update inventory estimates.

Quantification, monitoring, reporting, and verification (QMRV) study



eia Source: U.S. Energy Information Administration

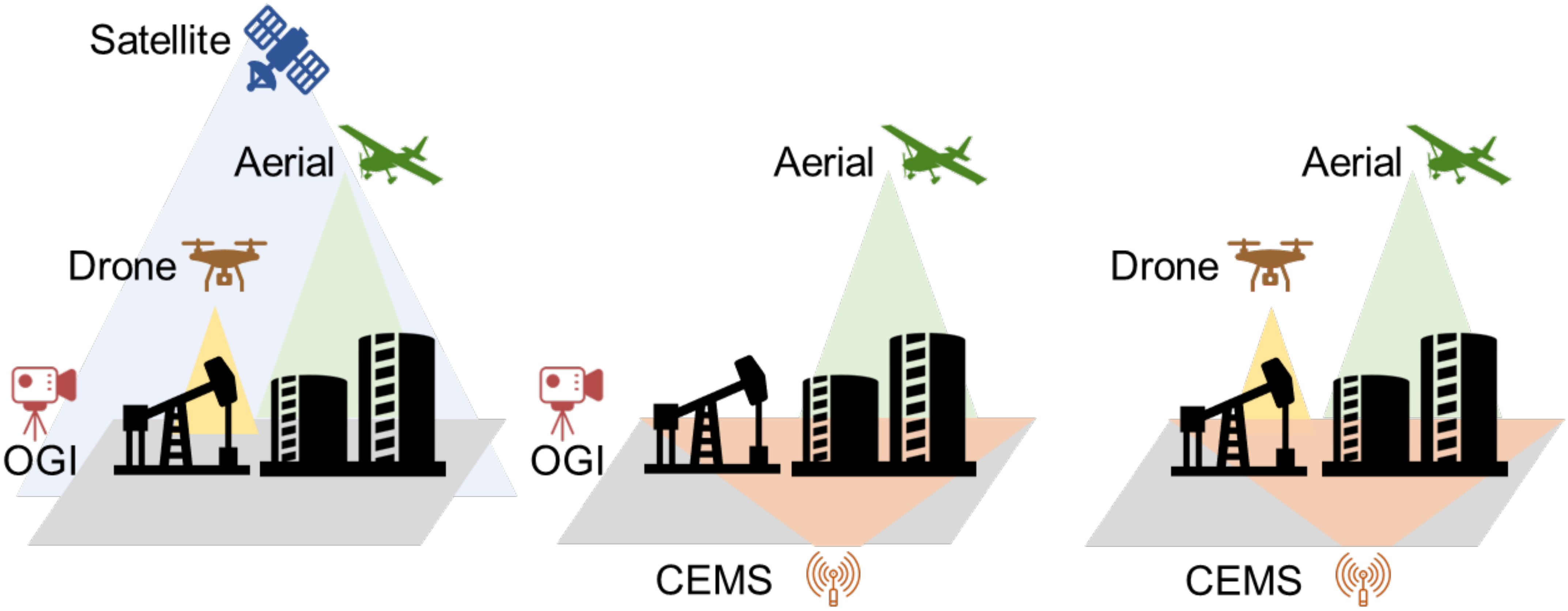
SeekOps

BRIDGER PHOTONICS

GHGSAT

Continuous Emissions Monitoring System (CEMS)

There are three phases in the QMRV study



Baseline

Jun. – Aug. 2021

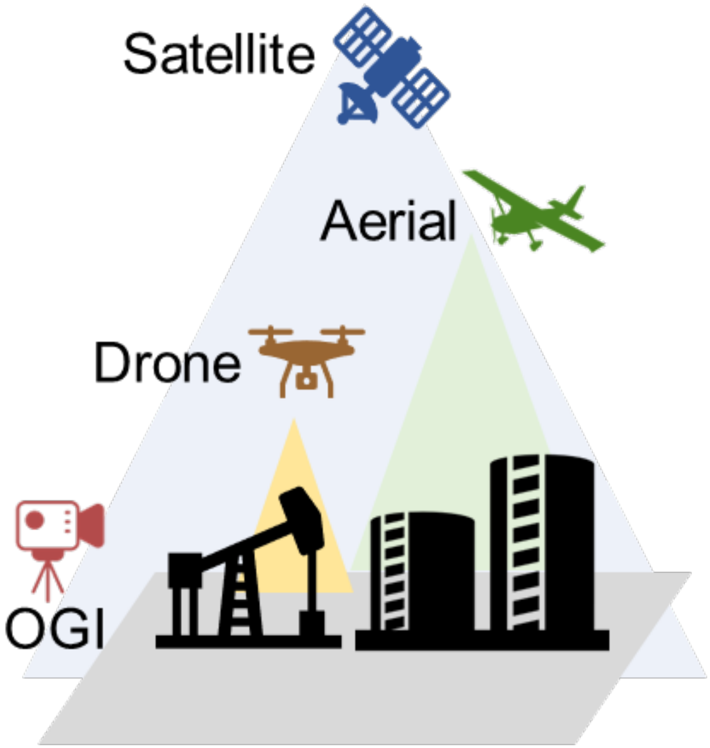
Enhanced Monitoring

Sep. 2021 – Apr. 2022

Verification

Mar. – May 2022

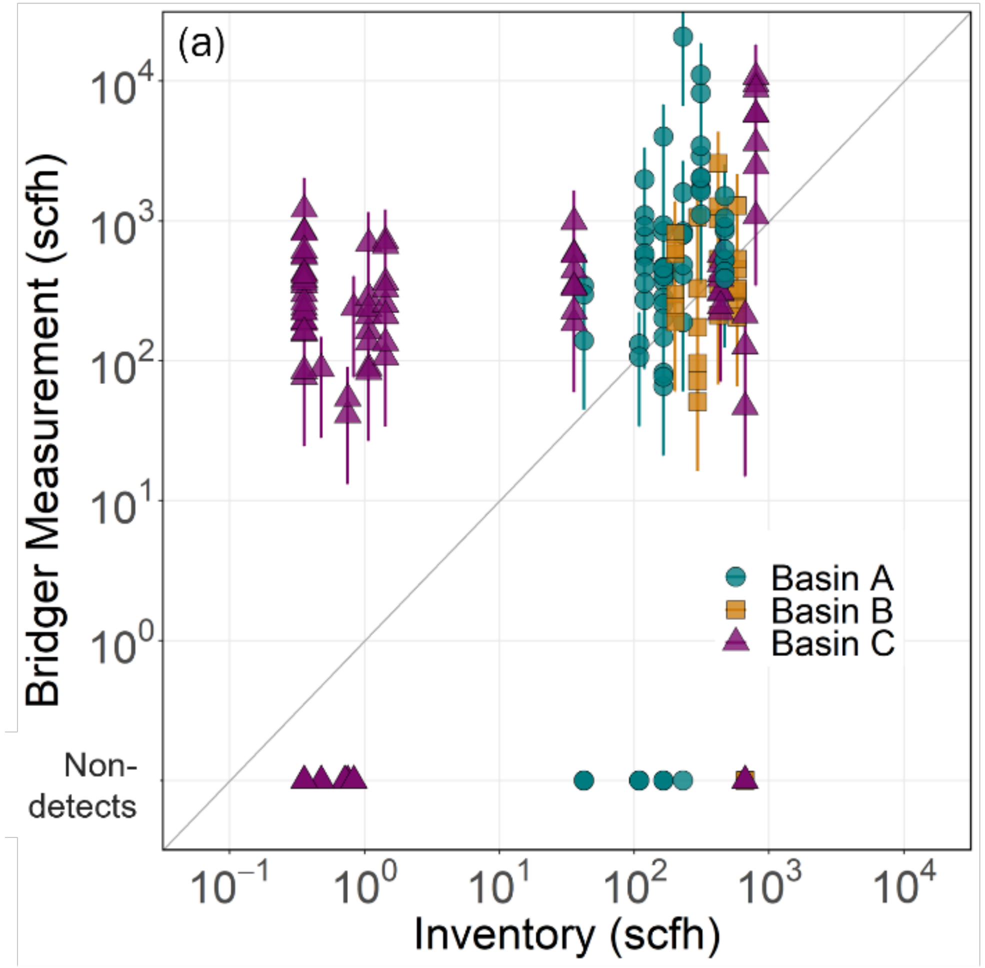
Phase 1: baseline measurements



Baseline

- Compare snapshot measurements against inventory estimates provided by operators
- Investigate daily and intra-day emissions variations
- Explore limitations of snapshot measurement technologies to estimate inventory

Measured emissions can be higher or lower than engineering-based inventory estimates.



- Inventories are underestimated at basin-level
- Individual round of measurement can be either higher or lower than inventory estimates
- Significant variations are observed at individual facilities

Wang et al. (2022) ES&T Accepted

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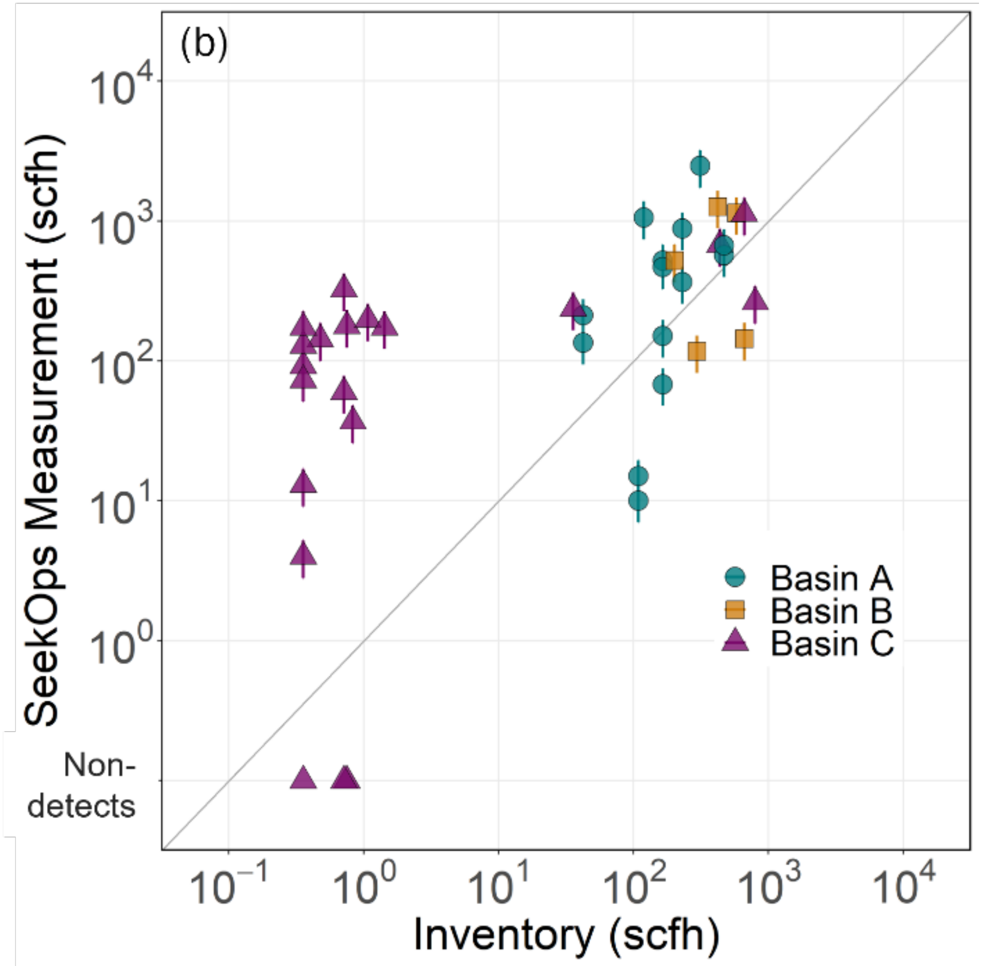

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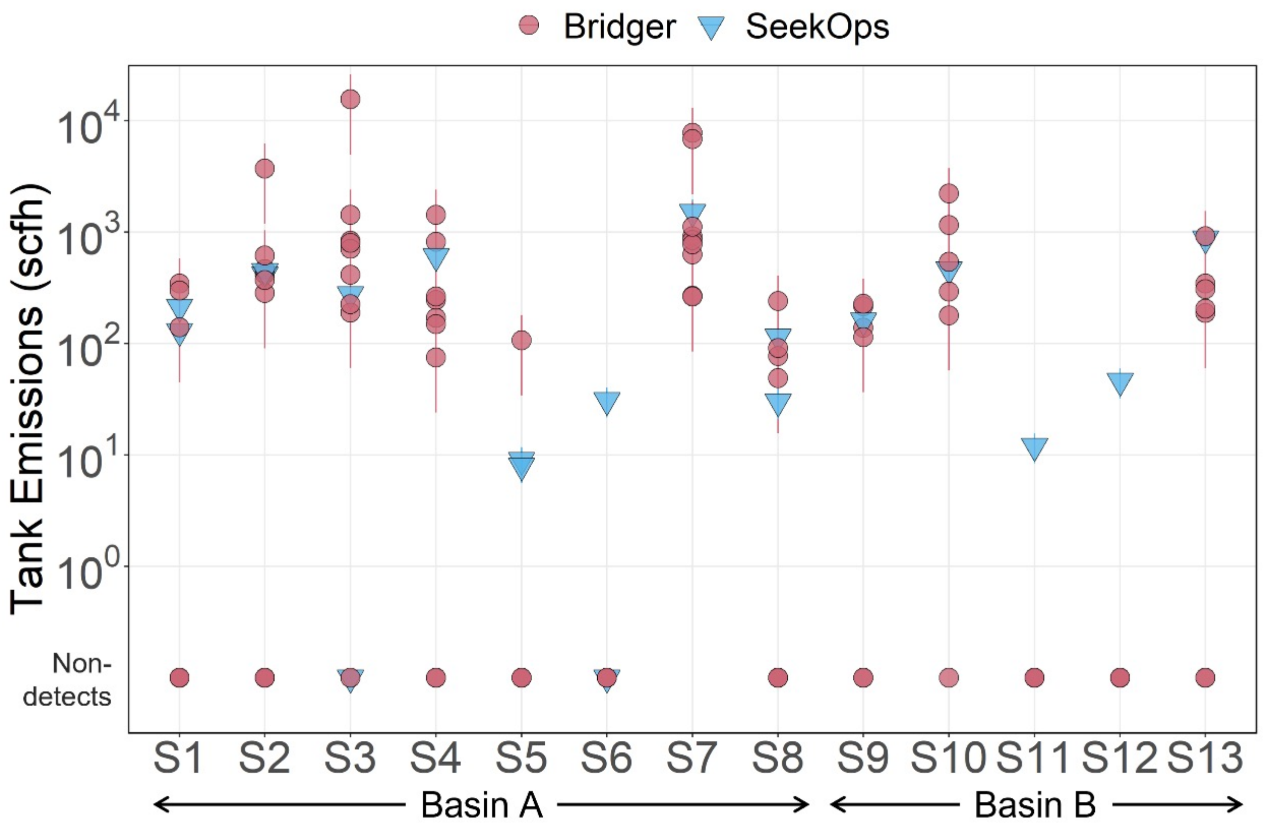
Tank emissions vary by ~3 orders of magnitude because of intermittent, high-volume events.



Basin A average ~597 scfh
Basin B average ~239 scfh

- Individual estimates of tanks emissions can be multiple standard deviations away from the time-averaged emissions estimate
- Accurate estimates of average emissions for sources like tanks require high frequency measurements

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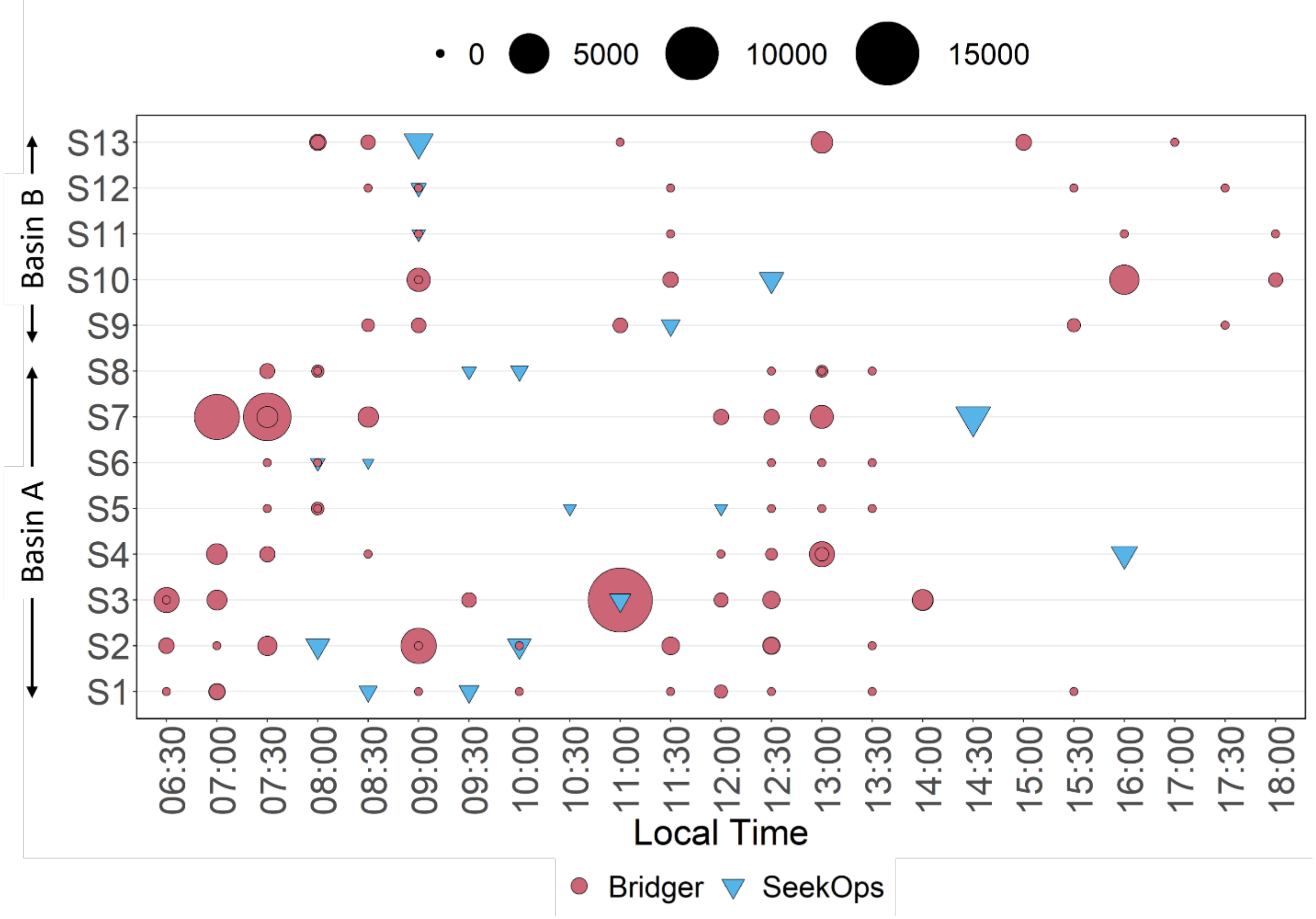
We observed significant tank-related intra-day emissions variations.



- The ability to identify episodic, high-emitting events is critical to develop accurate annualized inventories at the site-level
- Comparing operational data against snapshot measurements for root cause analysis
- A better understanding of frequency and duration from variable sources such as tanks is necessary to explain the observed discrepancy

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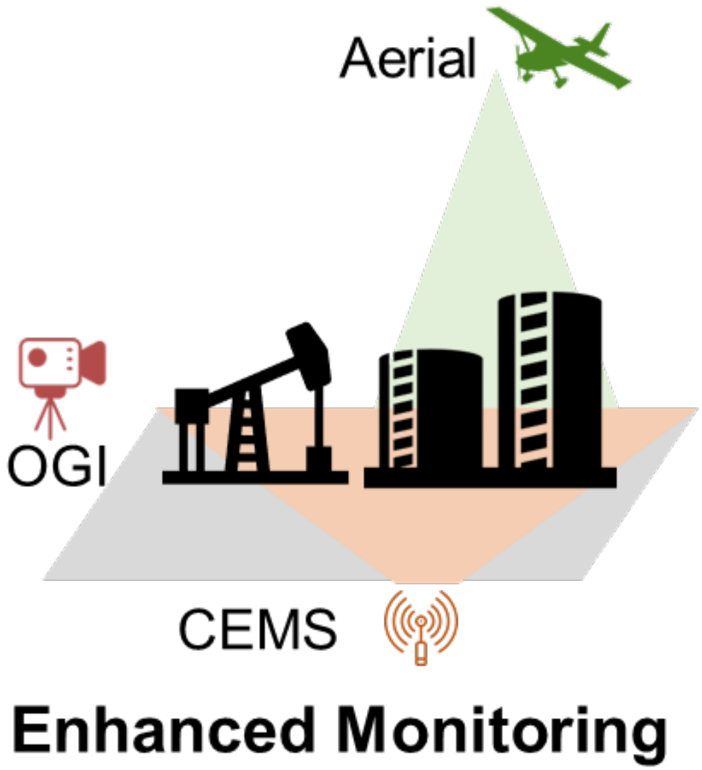
**Data shown in graph is collected over multiple days*

Limitation of snapshot measurements to estimate facility-level inventories

- Infrequent snapshot measurements are insufficient to develop accurate annualized site-level emissions estimates due to the intermittent nature of emissions
- Using near-continuous data to better understand the temporal variation at equipment- and site-level

Phase 2: enhanced monitoring phase

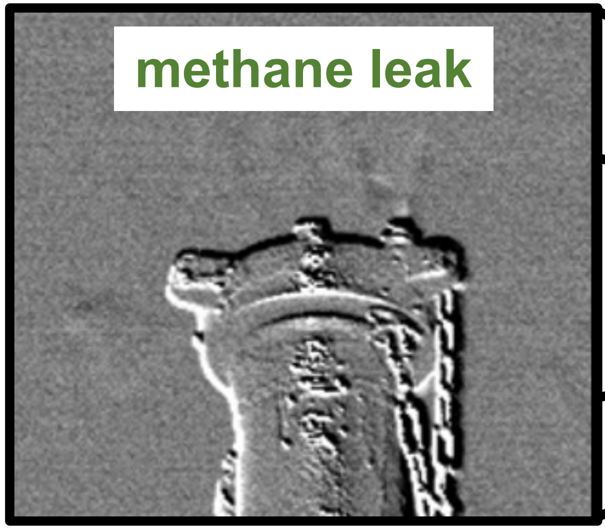


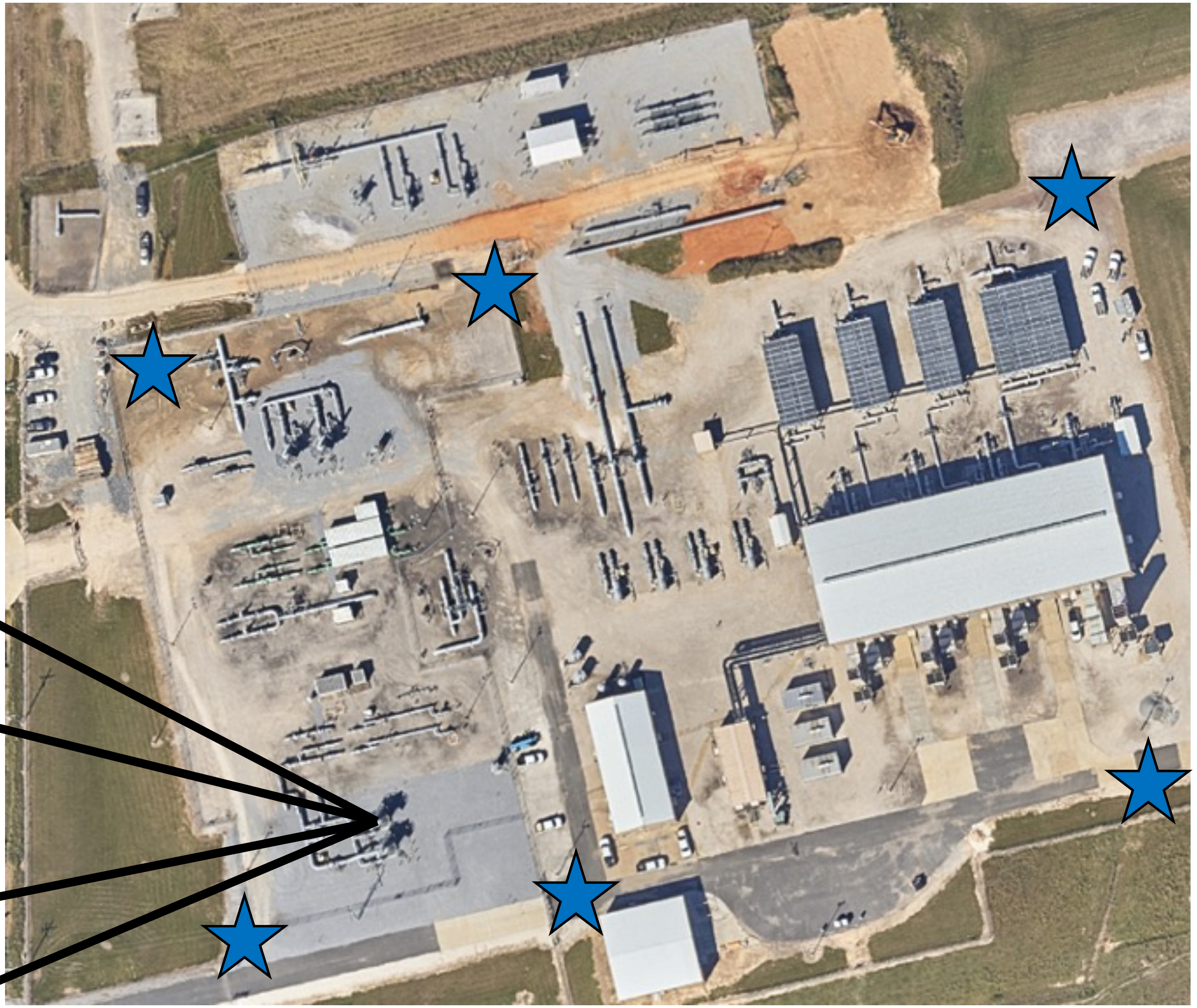
- Use continuous emissions monitoring system (CEMS) data to better compare snapshot measurements to annualized emissions inventory
- Develop event frequency and duration distributions
- Develop a framework to estimate emission location and rate with CEMS data

CEMS overview: sensors do not directly measure methane emissions, but rather ambient methane concentrations

What we want:
methane emission
leak rate and location

What we have:
methane concentrations
measured by CEMS

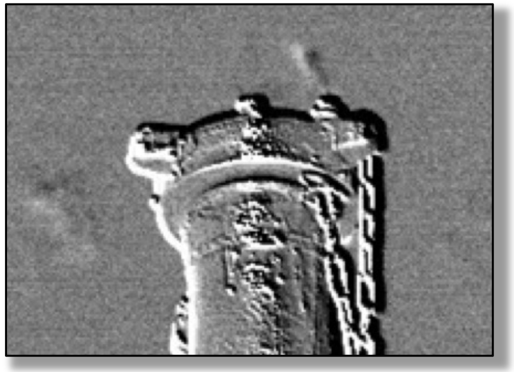


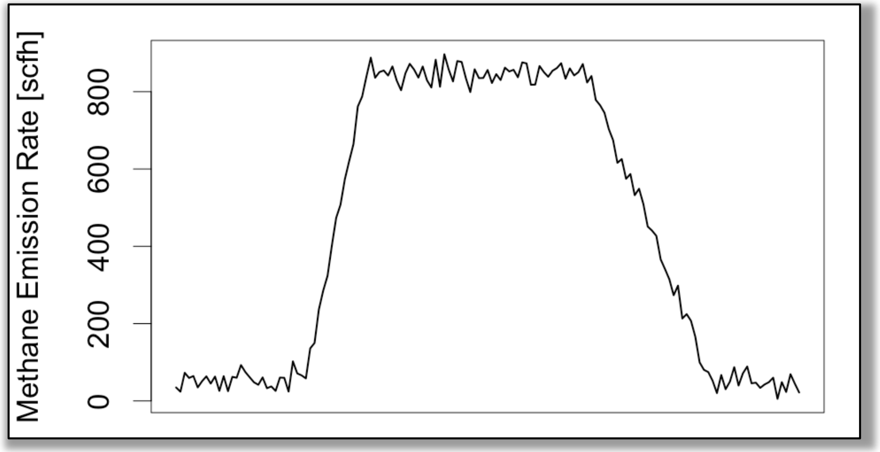


★ = continuous monitoring sensors

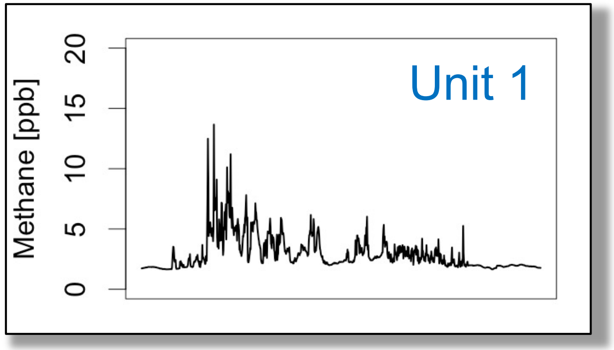
We only indirectly measure what we care about

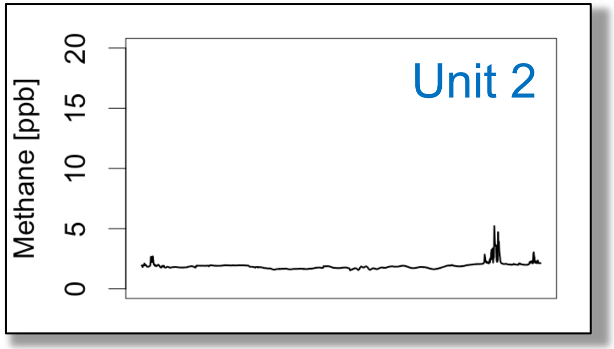
m: methane emission leak rate and location → *F*( ): atmospheric transport model → **d**: methane concentrations from continuous monitors





F^{-1}(**d**) ←





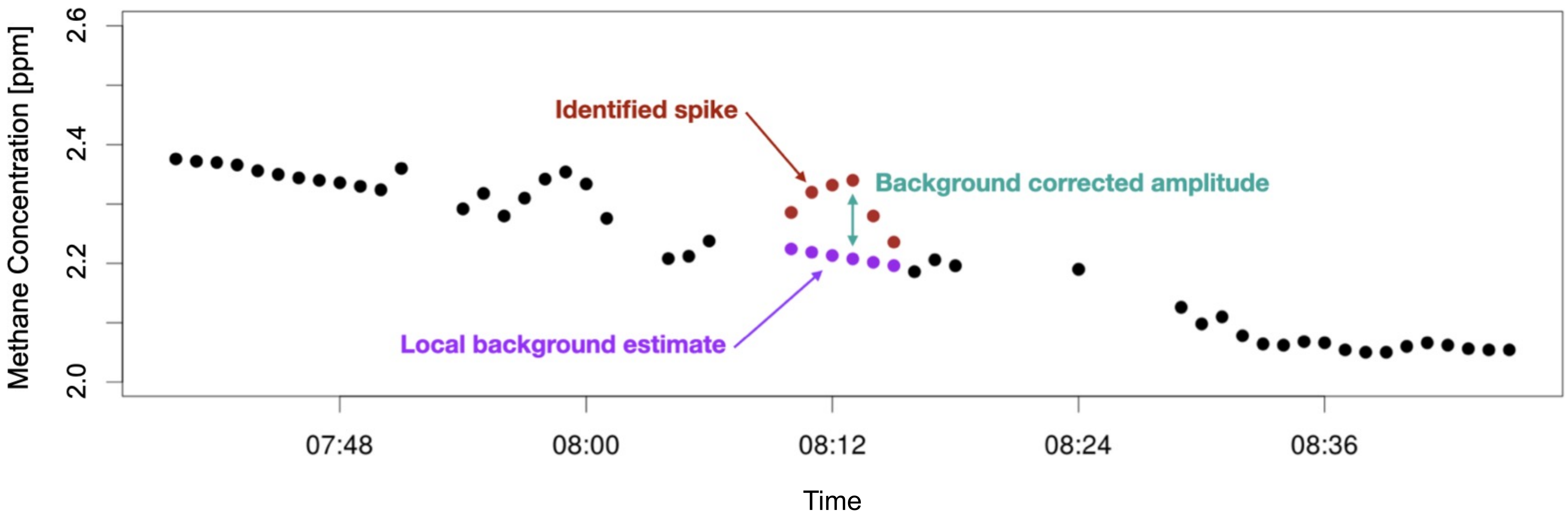
Two options for using high-frequency CEMS data to compare snapshot measurements to annualized emission inventories

1. **Localization and quantification algorithm NOT available:**
   - Can still identify intermittent "events" in raw CEMS concentration data
   - Over time can build distributions for event frequency and duration and use these to scale top-down measurements to better compare to inventory

2. **Localization and quantification algorithm available:**
   - Estimate emission location and rate directly to add context to top-down measurements and compare to inventory

Option 1: Scale snapshot measurements using frequency and duration distributions of intermittent emission events

Gradient-based algorithm for identifying events and removing background



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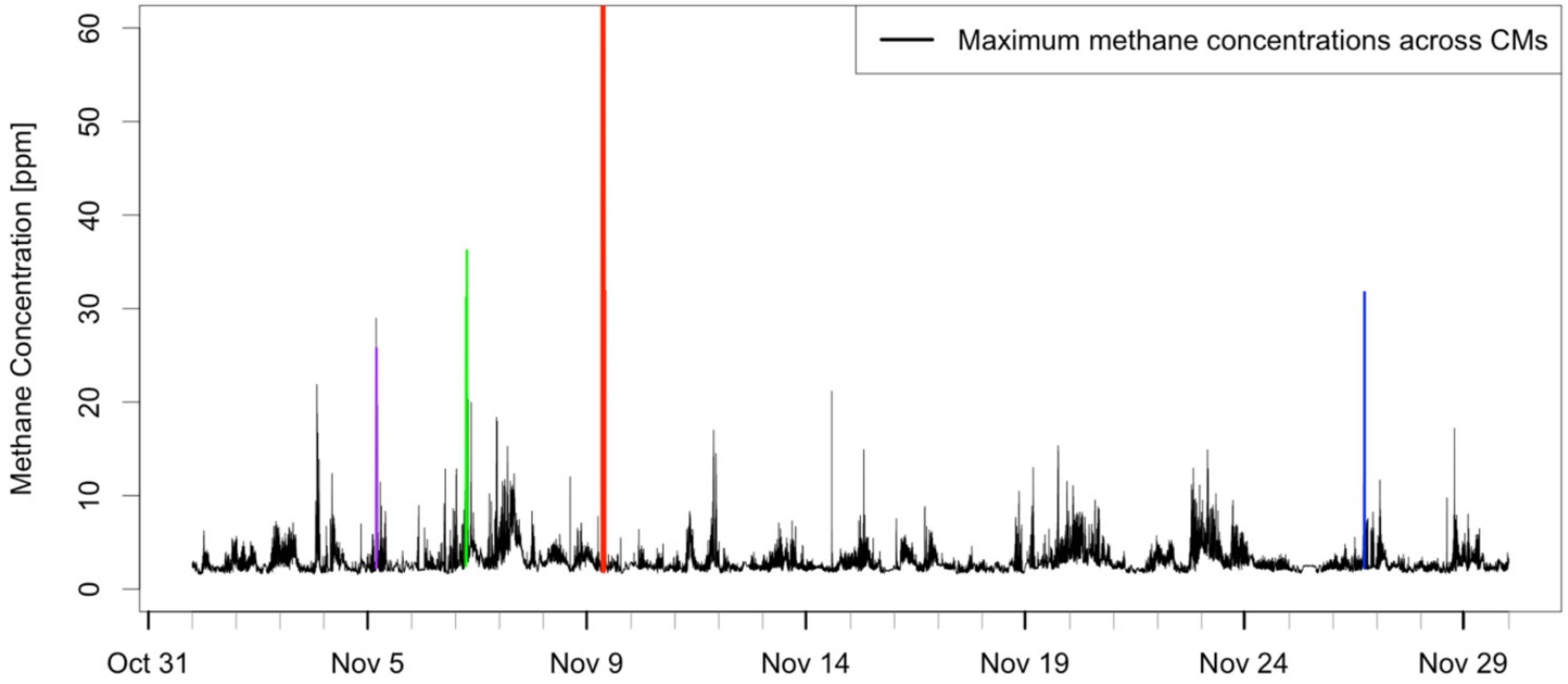

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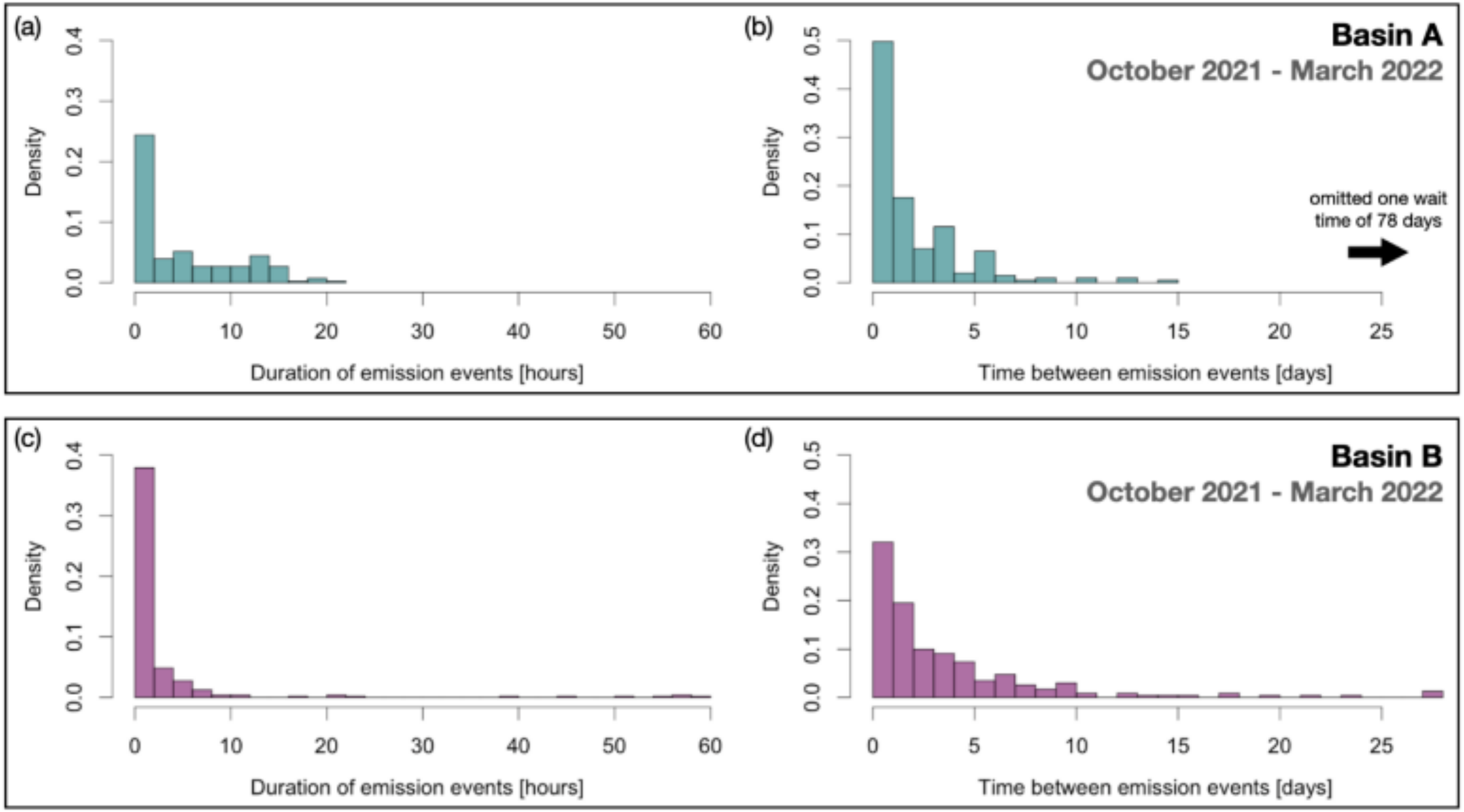

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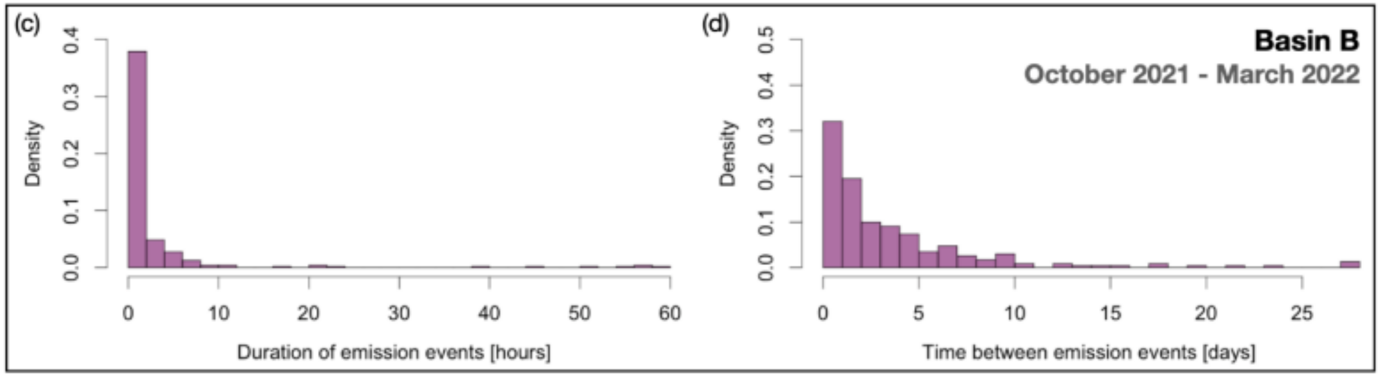
Example: Bridger observes a 3000 SCFH emission from the separators in Basin B. Operator's annualized inventory reports 60 SCFH for the separators.

How can we compare these two values?

- Sample from frequency and duration distributions: draw a duration of 0.5 hours and a wait time of 45 hours



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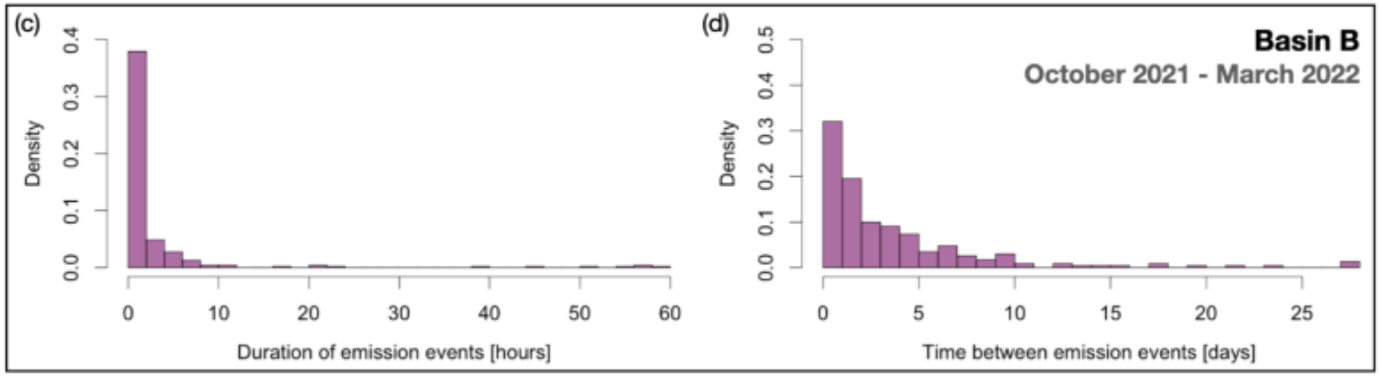
- Assuming a wait time of 45 hours, this event would occur 8760 / 45 = 195 times per year



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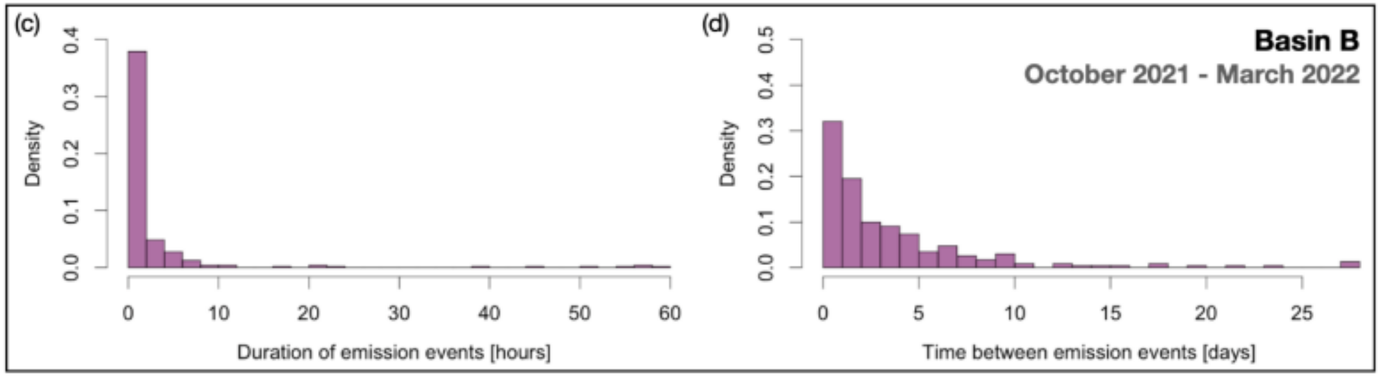

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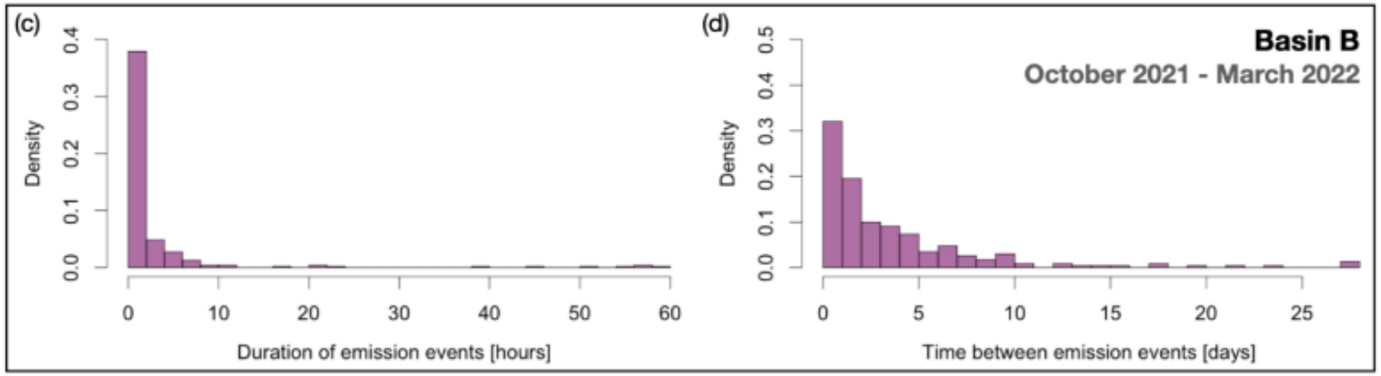
- The scaling factor would then be 97.5 / 8760 = 0.011 and the scaled observation would be 33 SCFH



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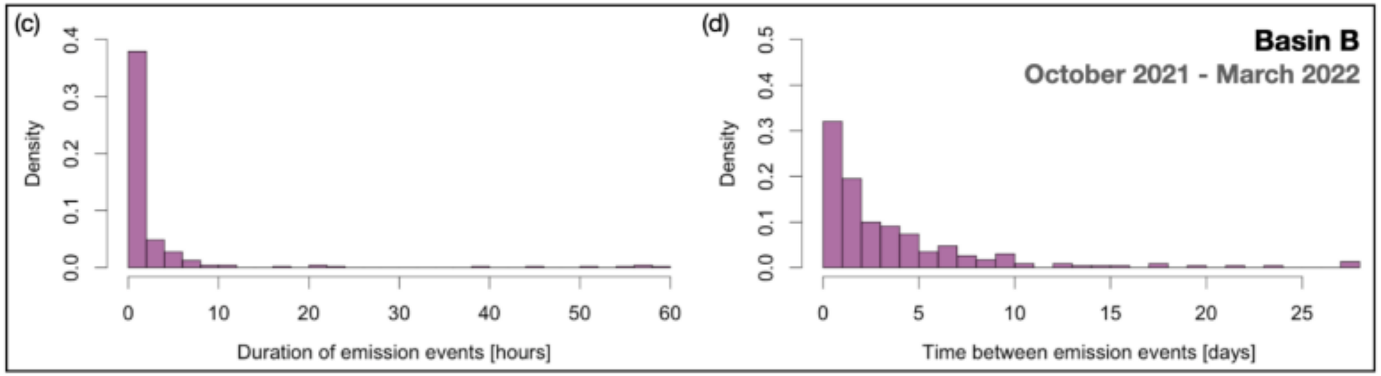
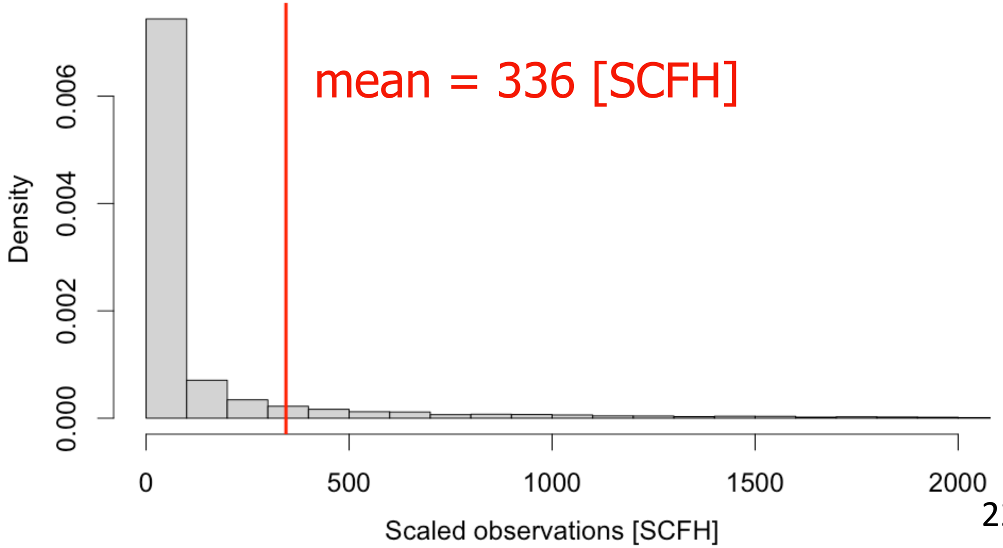
- Repeat this many times, build a distribution of scaled observations:





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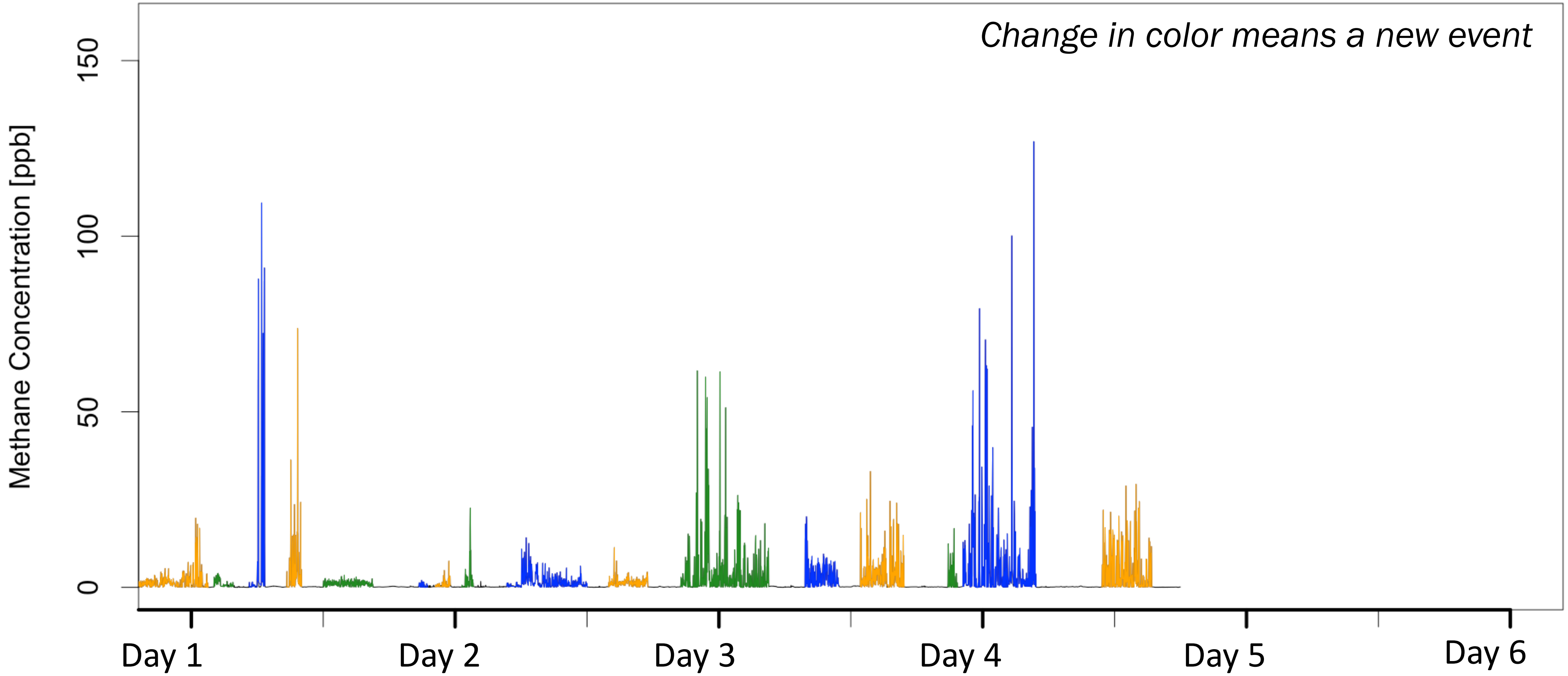
Daniels et al. (2022) In prep
Jia et al. (2022) In prep

Option 2: Directly estimate emission rates using continuous monitoring data

Daniels et al. (2022) In prep

Event detection, localization, and quantification framework

1. Event detection: run event detection algorithm on maximum across all sensors

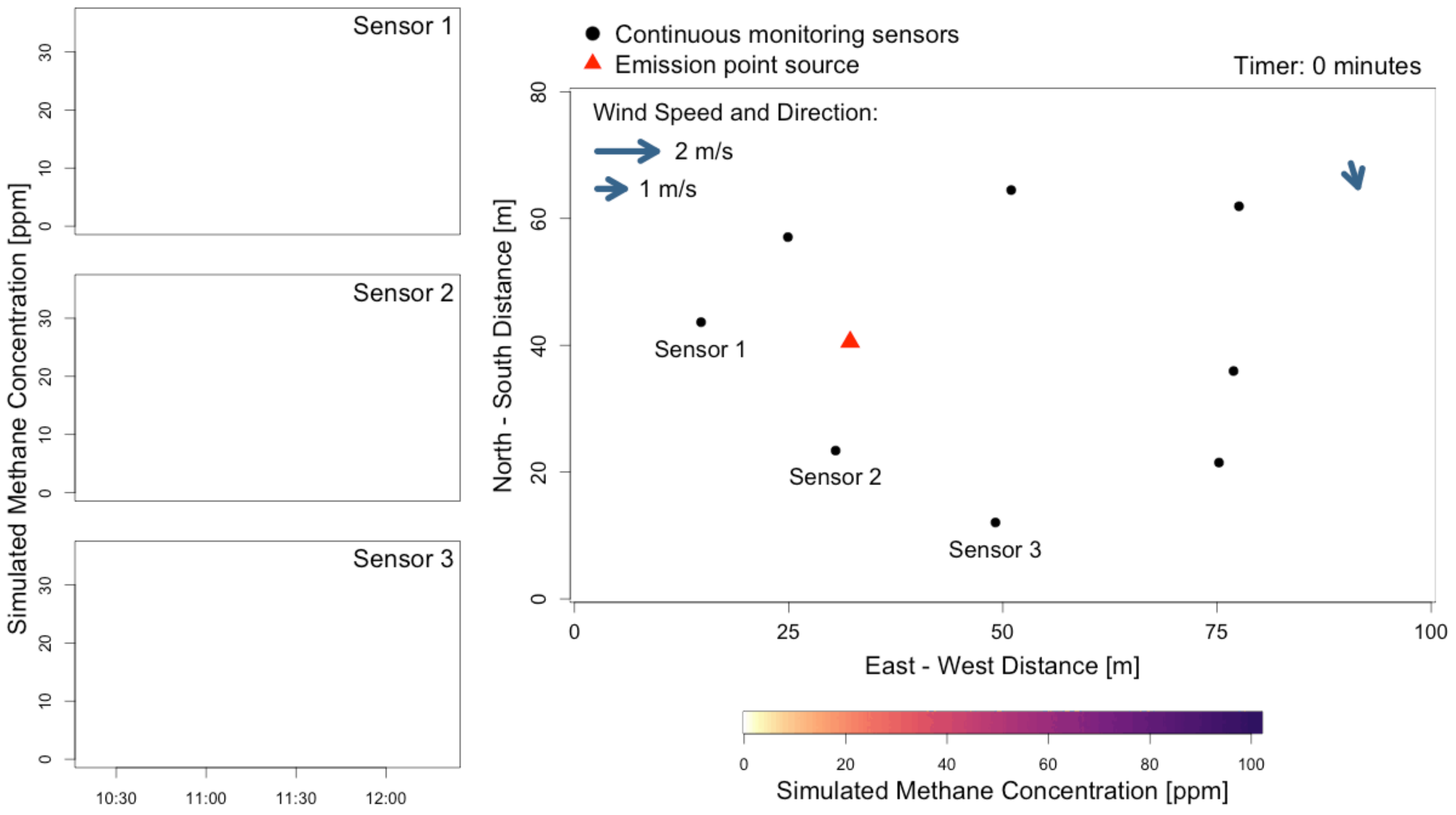


Option 2: Directly estimate emission rates using continuous monitoring data

Jia et al. (2022) In prep

<u>Event detection, localization, and quantification framework</u>

1. Event detection using all sensors jointly
2. Simulate concentrations at all sensors from all potential sources separately



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Daniels et al. (2022) In prep

Event detection, localization, and quantification framework

1. Event detection using all sensors jointly
2. Simulate from all potential sources
3. Localization: pattern match simulation predictions to CEMS observations

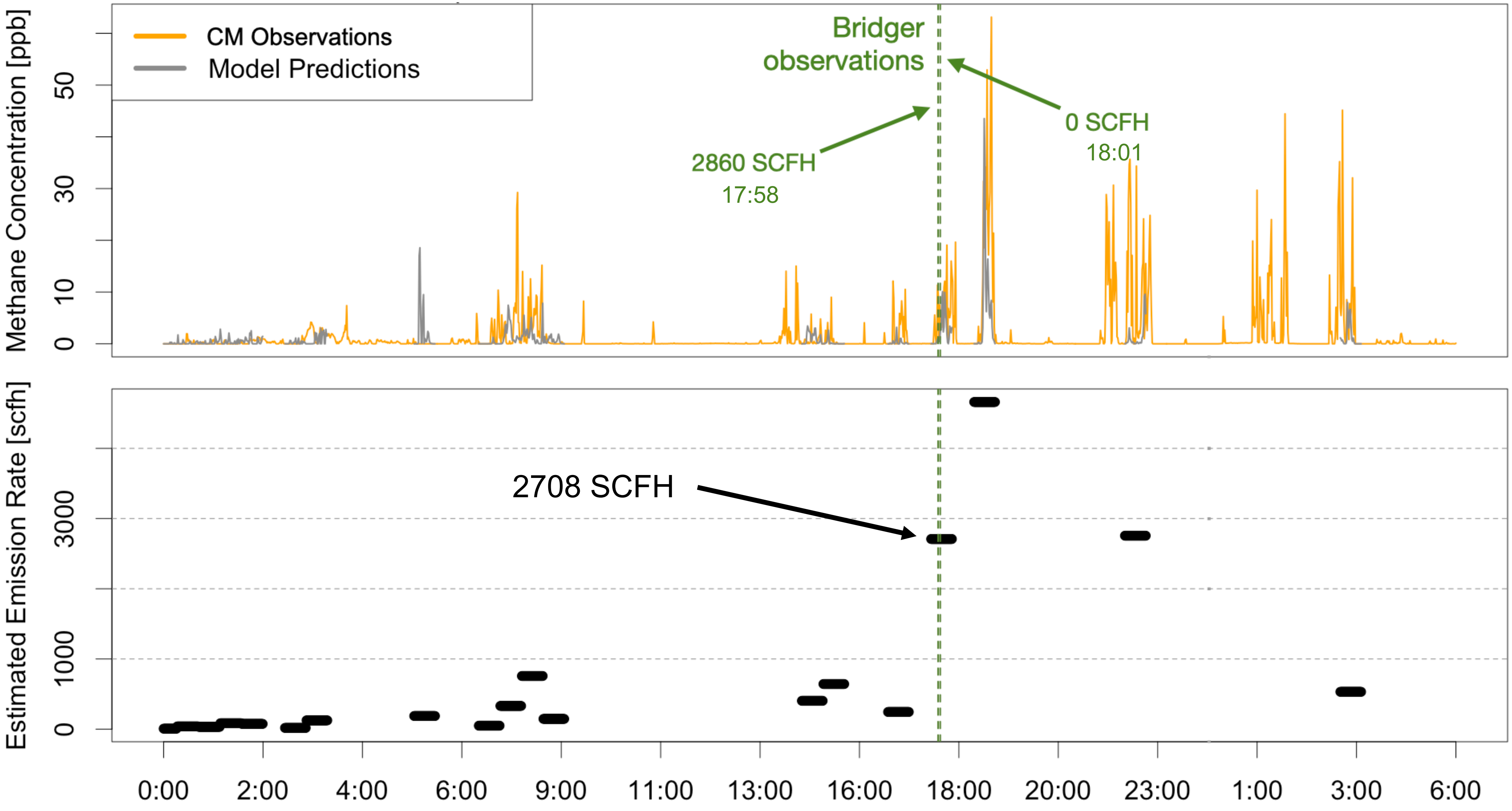
Option 2: Directly estimate emission rates using continuous monitoring data

Daniels et al. (2022) In prep

Event detection, localization, and quantification framework

1. Event detection using all sensors jointly
2. Simulate from all potential sources
3. Localization via pattern matching
4. Quantification: given source from step #3, use simulation predictions and observations to derive optimal emission rate

Option 2: Directly estimate emission rates using continuous monitoring data



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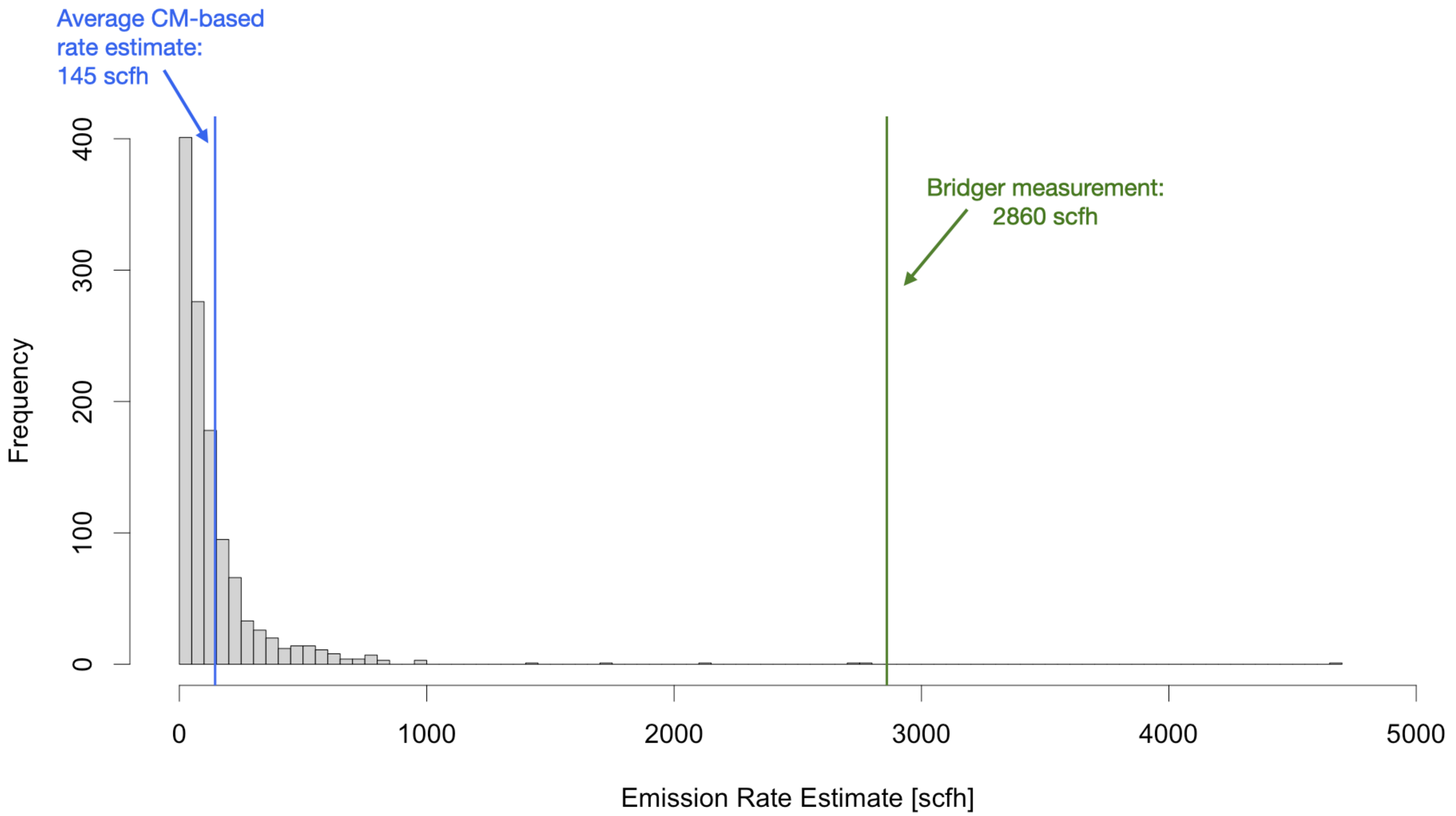
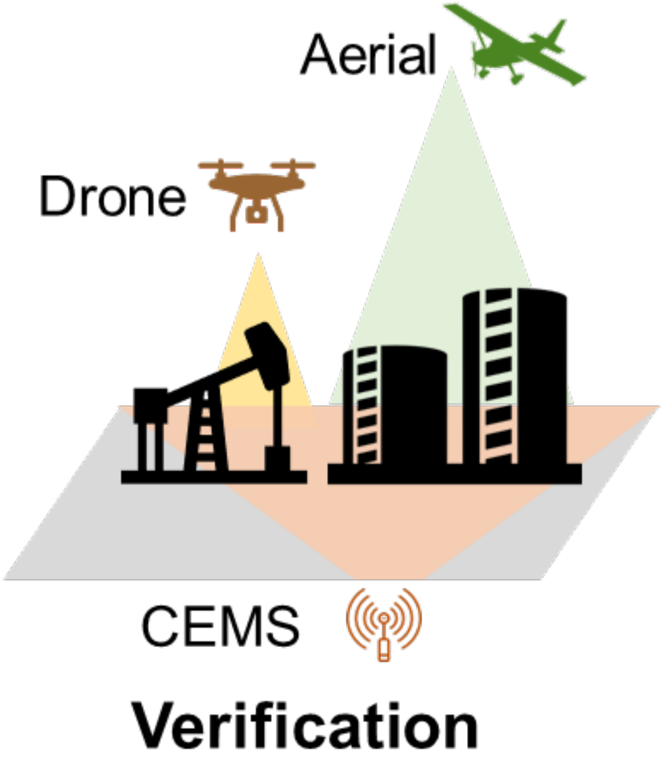
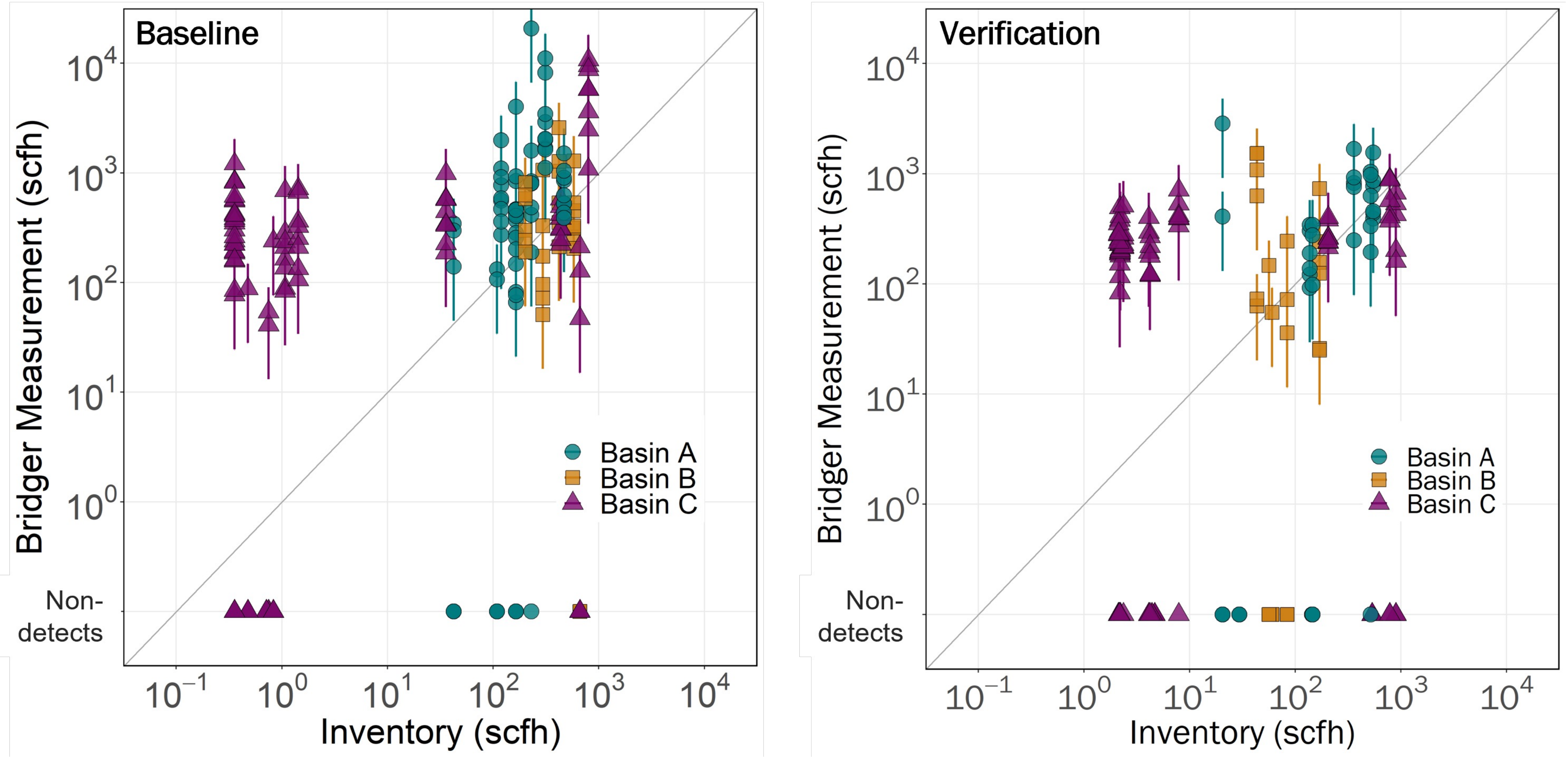


Phase 3: verification measurements



- Compare snapshot measurements against inventory estimates
- Compare verification measurements against baseline measurements
- Conduct root cause analysis of observed differences

We observe a decrease in high-emitting events during verification



We are analyzing the underlying reasons for the observed differences.

Using multi-scale measurements to improve inventory estimation

- Infrequent snapshot measurements are insufficient to develop accurate annualized site-level emissions estimates due to the intermittent nature of emissions
- The frequency and duration distributions of intermitted sources developed from CEMS data is critical to incorporate snapshot measurements to annualized inventory and improve inventory estimates
- A combination of snapshot measurements and continuous monitors can appropriately account for episodic, high-emitting events and provide data to update equipment- and site-level emissions factors

Multi-scale Methane Measurements at Oil and Gas Facilities Reveal Necessary Framework for Improved Emissions Accounting

THANK YOU!

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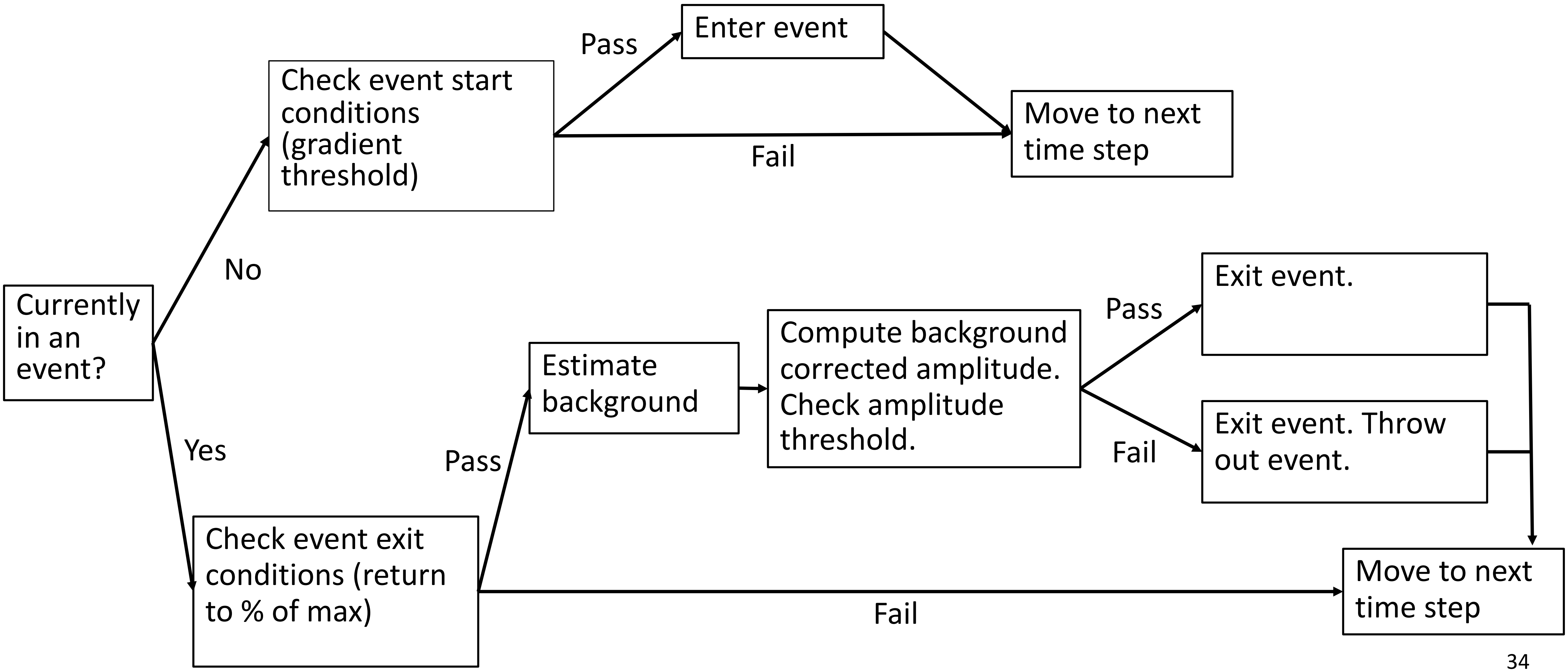
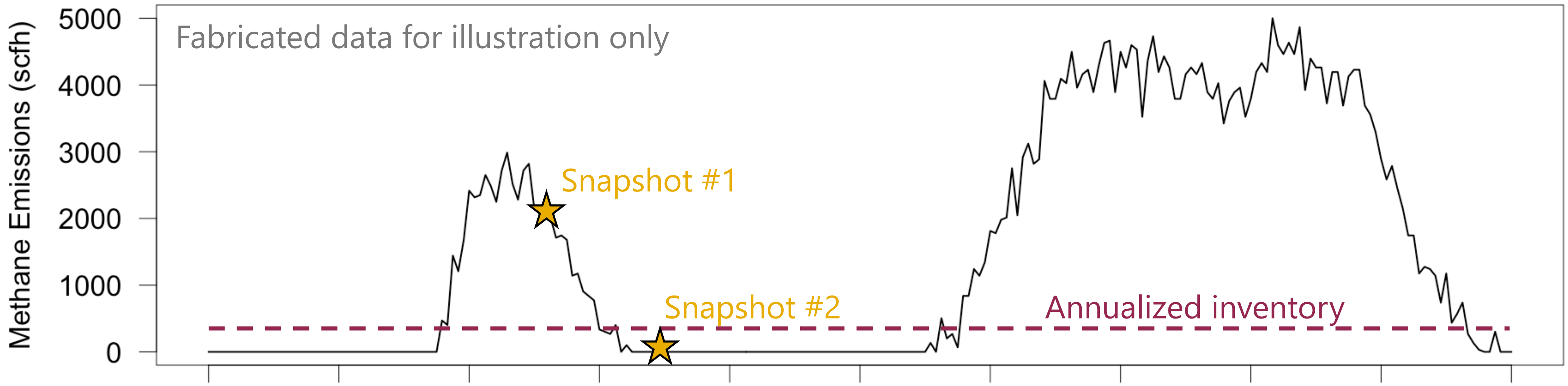
Spike detection algorithm

One loop through time steps. At each time step:



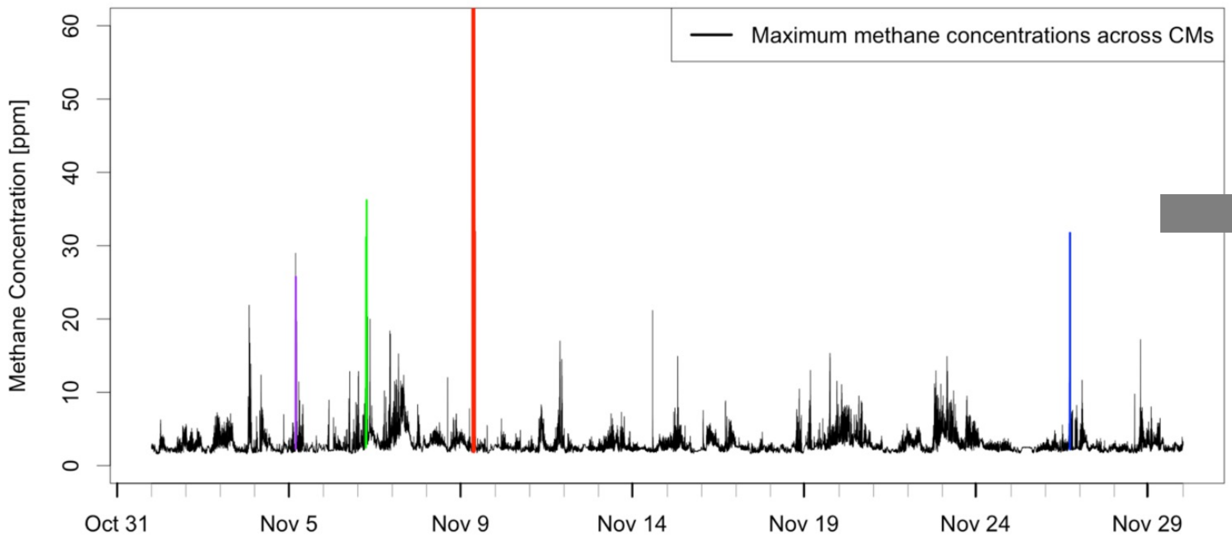
Incorporating intermittent emissions events into inventory using continuous measurements

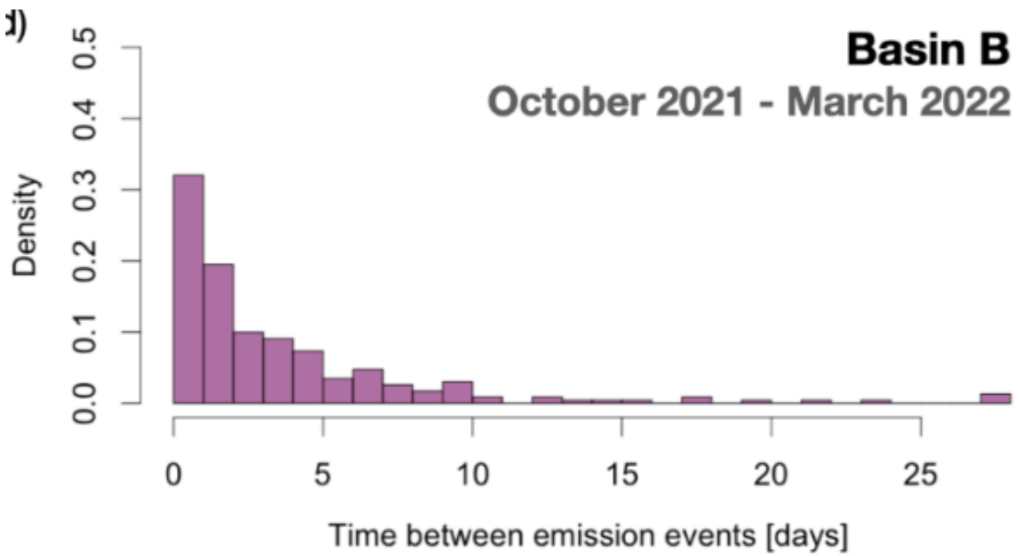
- **Inventory estimates and snapshot measurements are unable to characterize variability**
  - Engineering-based inventories may best represent basin-wide, annual averages
  - Snapshot measurements might capture a "peak" or "valley" in emissions profile
- Better understanding of variability is necessary for site-specific, differentiated inventories

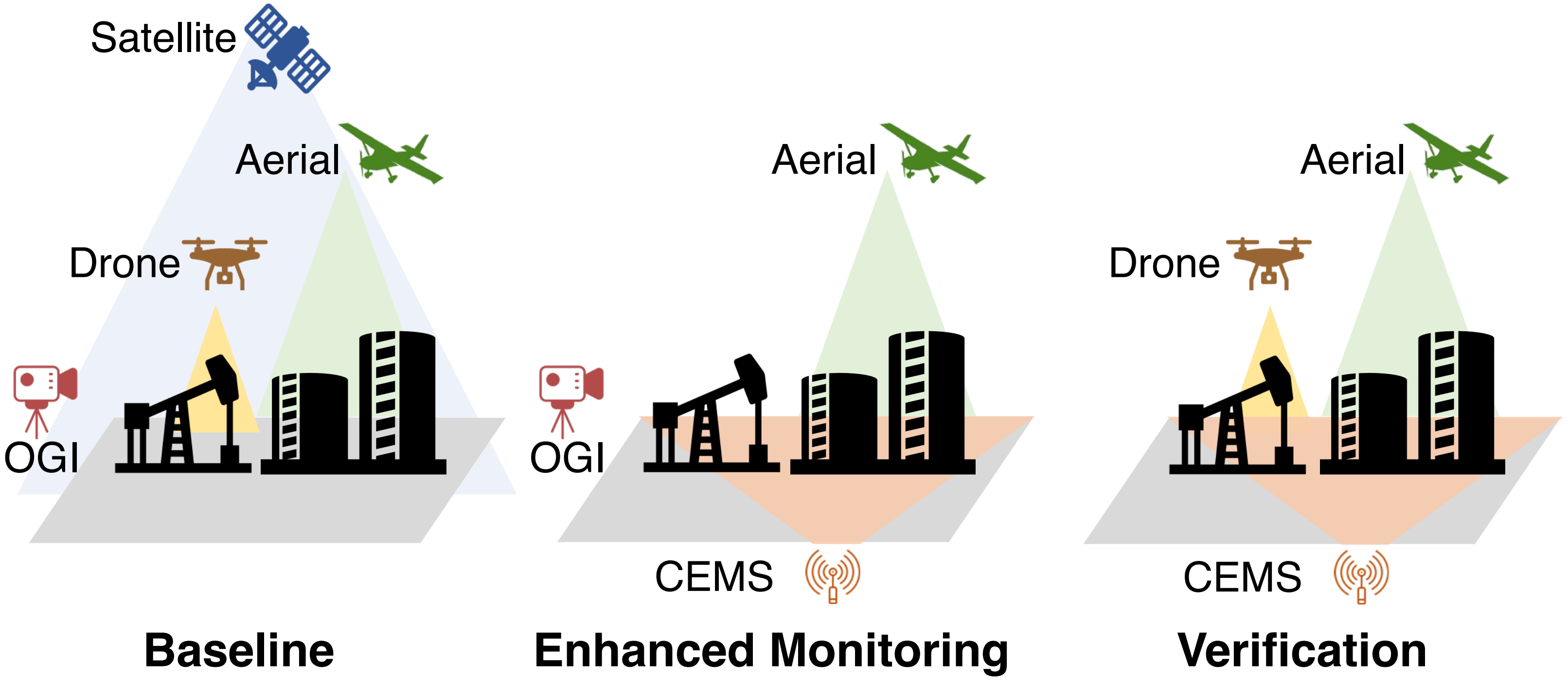


Empirical distributions of event frequency and duration can be obtained through high-frequency measurements.

- Probabilistic framework to evaluate occurrence of intermittent high-emitters
  - Can be used to continuously improve distributions and develop basin-specific scaling factors for snapshot measurements
- Detect emissions events using a spike detection algorithm → develop distributions over time as many events are logged from a specific site






Satellite
Aerial
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OGI
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