# Developing methane emissions inventories for oil and gas production sites using point-in-space continuous monitors

William Daniels
Department of Applied Mathematics and Statistics
Colorado School of Mines

# Push towards site-level, measurement-informed inventories

**H. R. 5376 (Inflation Reduction Act)**

SEC. 136. (a) The Administrator shall impose and collect a fee from the owner or operator of **each applicable facility** that is required to report methane emissions …

SEC. 136. (g)(2) … calculation of fees under subsection (c) of this section, are based on **empirical data** and accurately reflect the total methane emissions from the applicable facilities.

United States

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United States

**Amendments adopted by the European Parliament on 9 May 2023 on the proposal for a regulation of the European Parliament**

… importers must provide a report with the following information for **each site** from which the import to the Union has taken place …

… information specifying the exporter's, or where relevant, the producer's **direct measurements of site-level methane emissions**, conducted by independent service provider …

European Union

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European Union

**The Oil & Gas Methane Partnership 2.0 (OGMP 2.0)**

Level 5 – Emissions reported similarly to Level 4, but with the addition of **site-level measurements** (measurements that characterize site-level emissions distribution for a statistically representative population)

Global Initiatives

# Infrequent overflights emerging as a common solution

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Snapshot measurements: 0, 3, 2, 24 kg/hr

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What if we average them?

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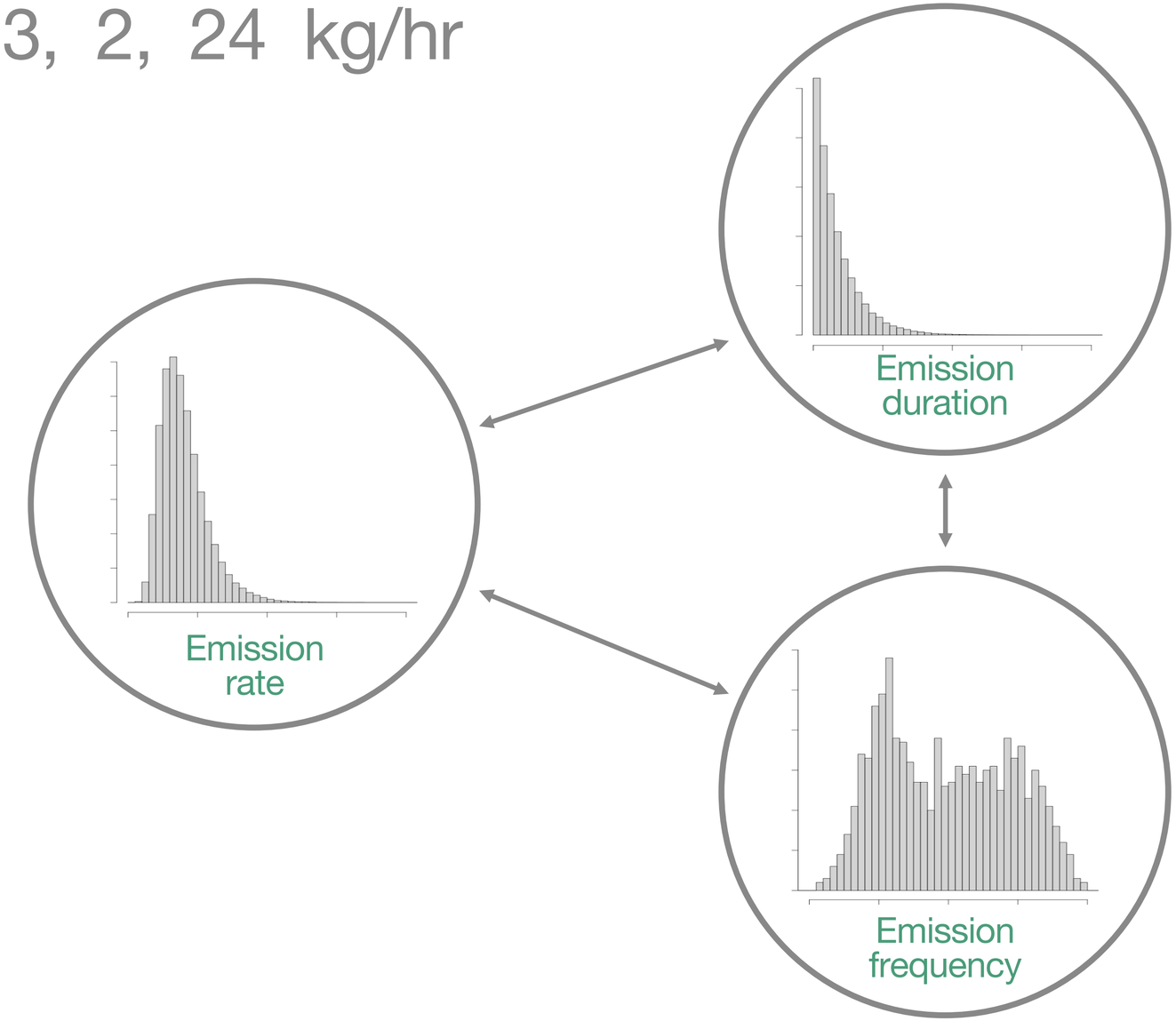
What if we average them?

This would use only four measurements to attempt to capture potentially complex emission characteristics.



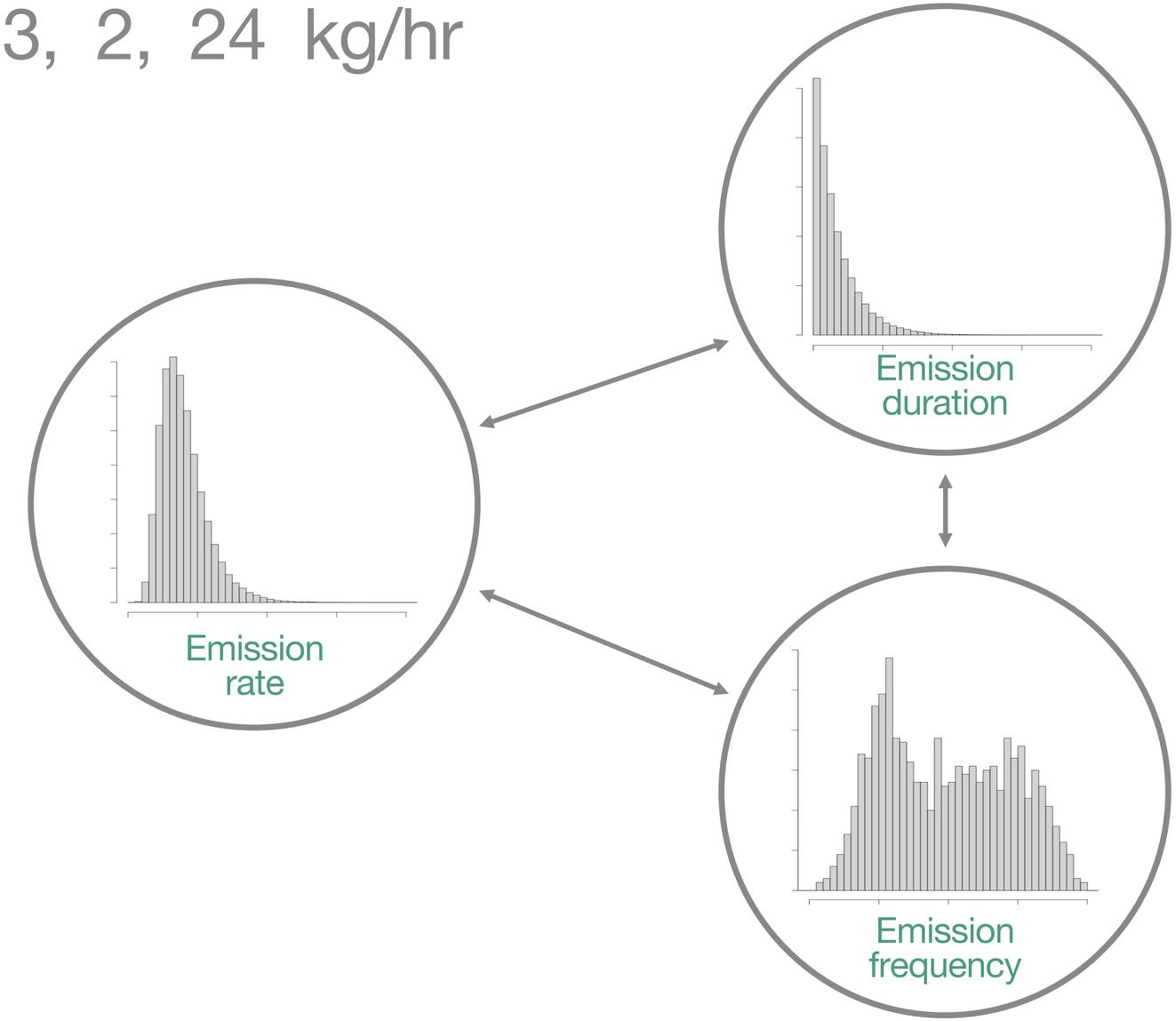
# Infrequent overflights emerging as a common solution

## Snapshot measurements: 0, 3, 2, 24 kg/hr

What if we average them?

This would use only four measurements to attempt to capture potentially complex emission characteristics.

If the 24 kg/hr measurement captured a rare event, should it be included?

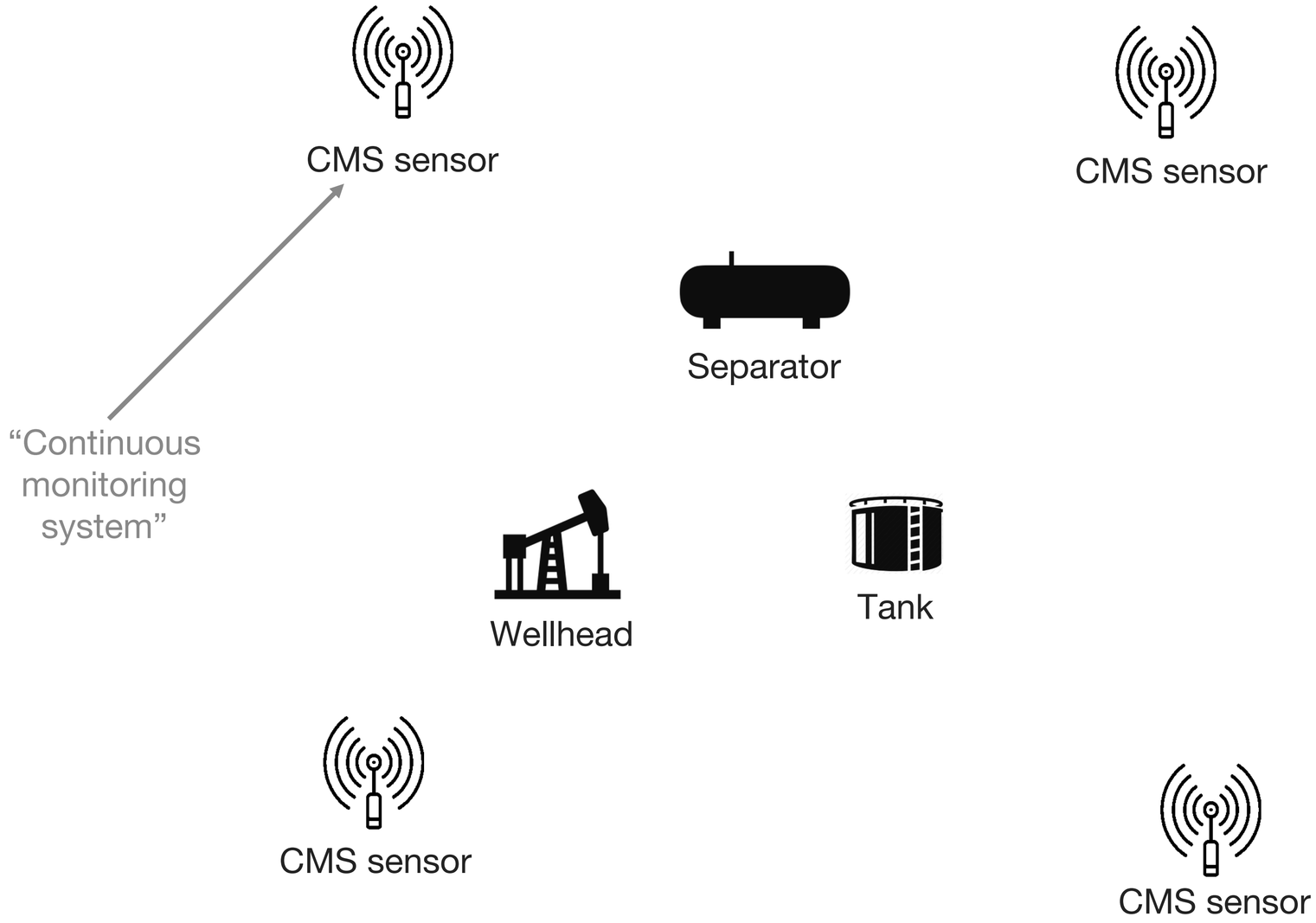


High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

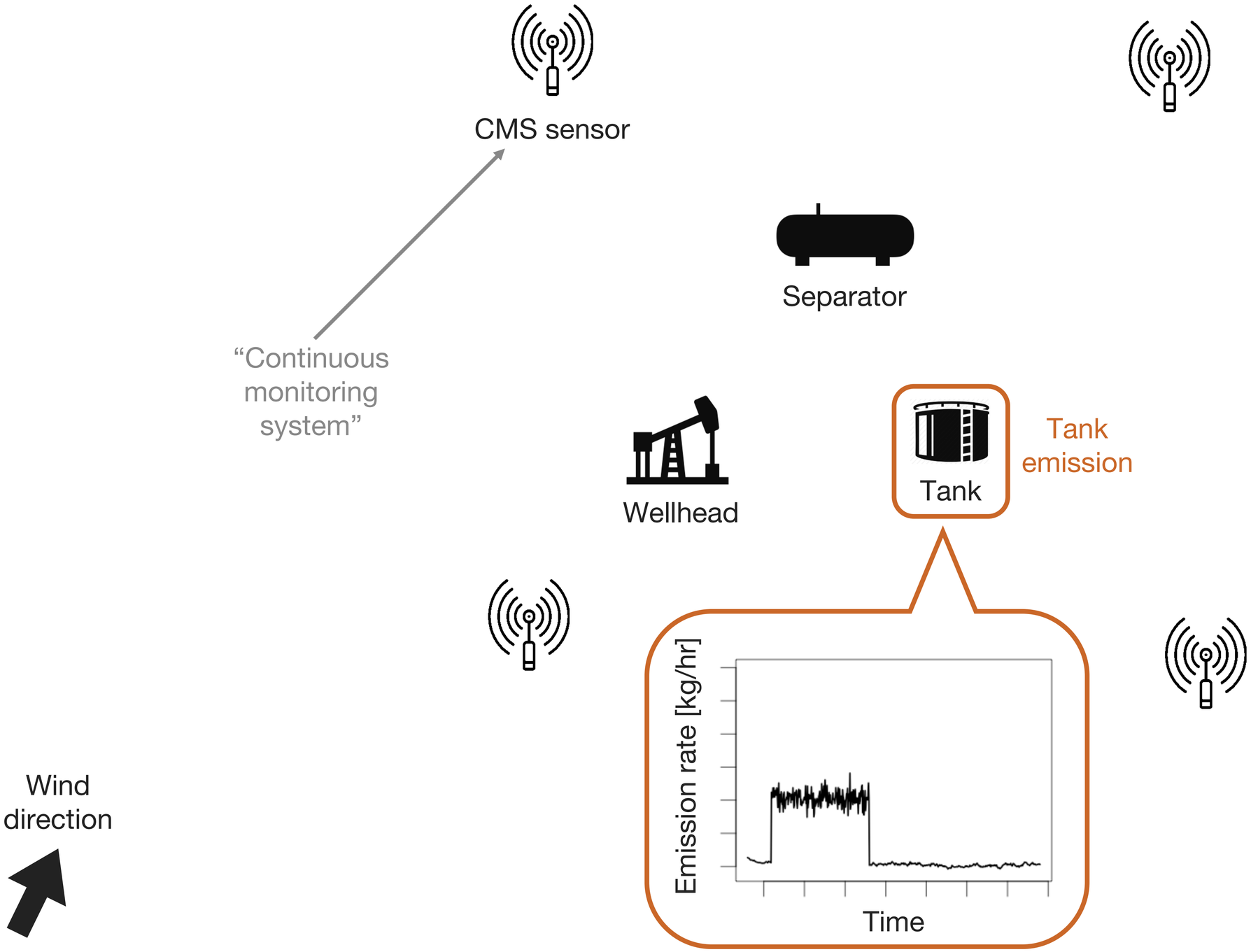
# High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

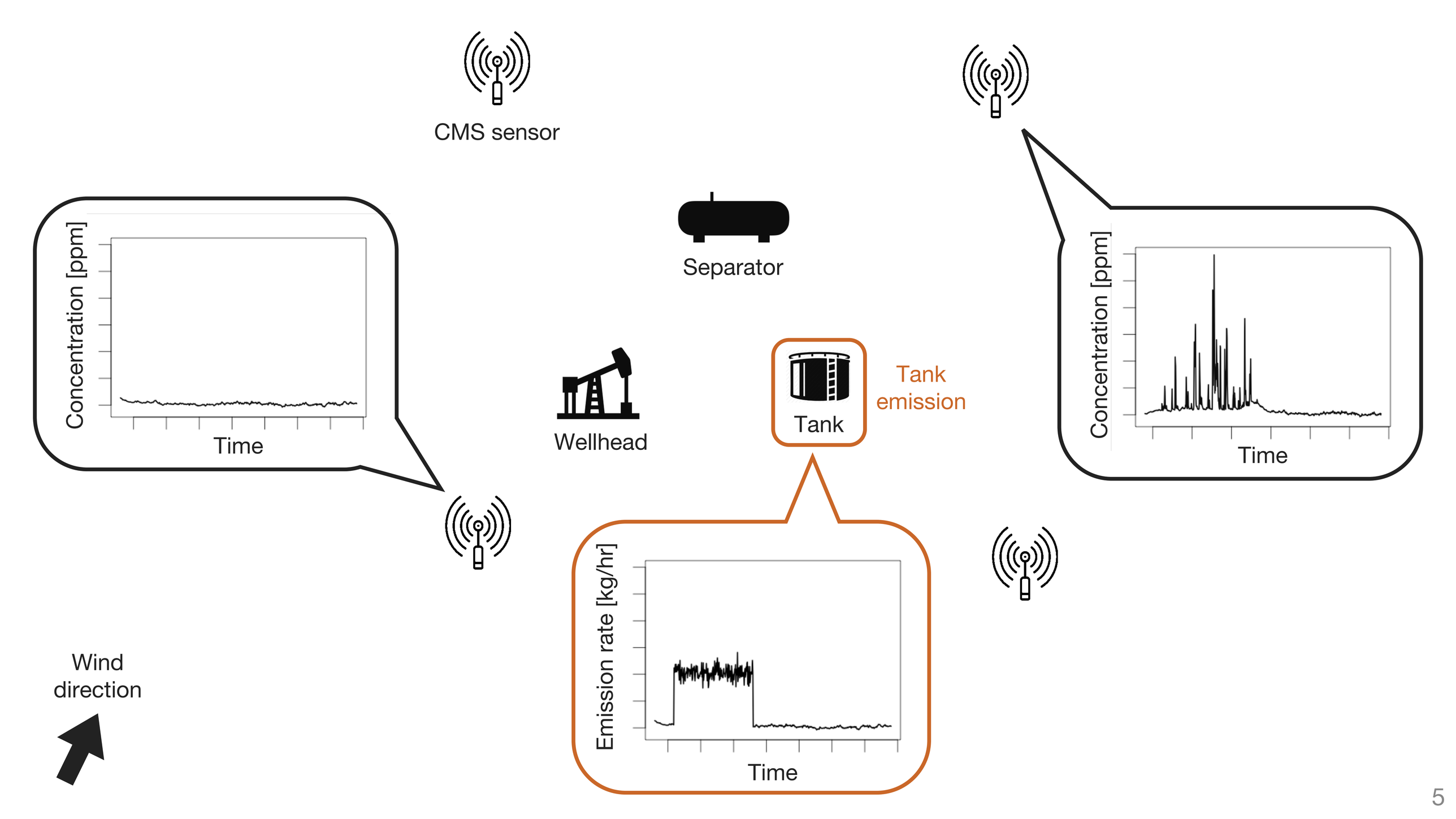
The continuous monitoring inverse problem

Measurement-informed inventory case study

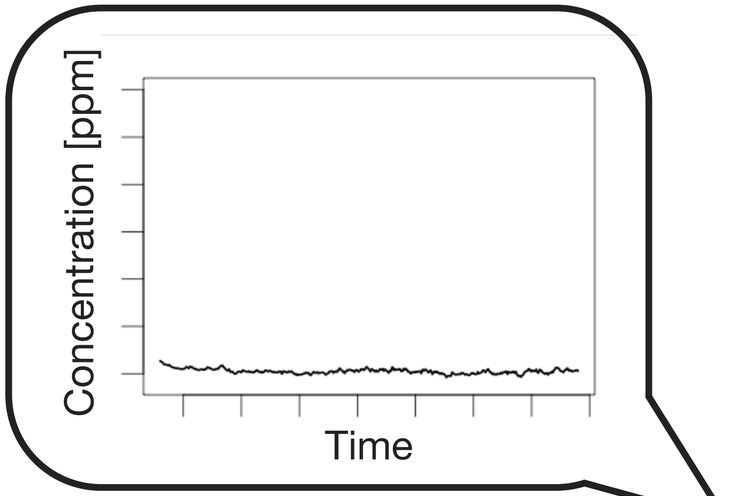



# The continuous monitoring inverse problem


CMS sensor
"Continuous monitoring system"
Separator
Wellhead
Tank
Tank emission
Emission rate [kg/hr]
Time
Wind direction


CMS sensor
Separator
Concentration [ppm]
Time
Wellhead
Tank
Tank emission
Concentration [ppm]
Time
Emission rate [kg/hr]
Time
Wind direction

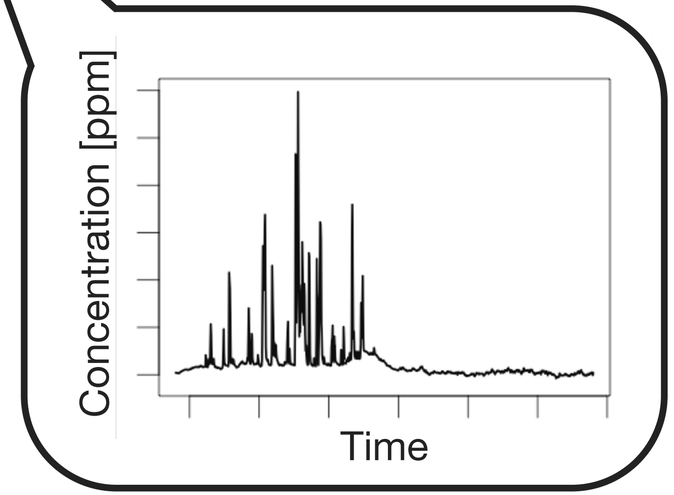
CMS sensor




Separator

Wellhead

Tank




Wind direction

# Open source framework for solving inverse problem

STEP 1:
Background removal
and event detection

→

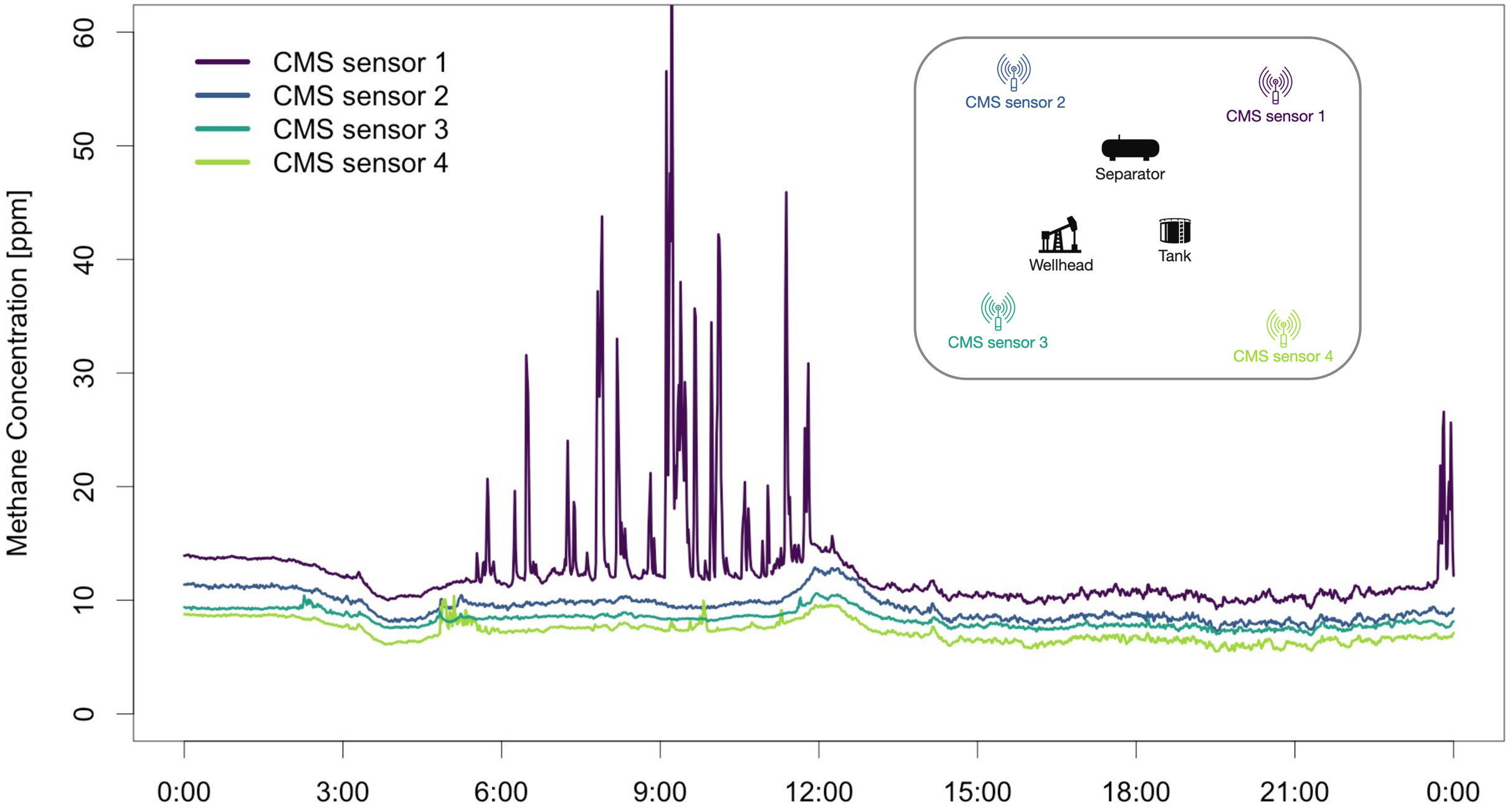
STEP 2:
Simulation

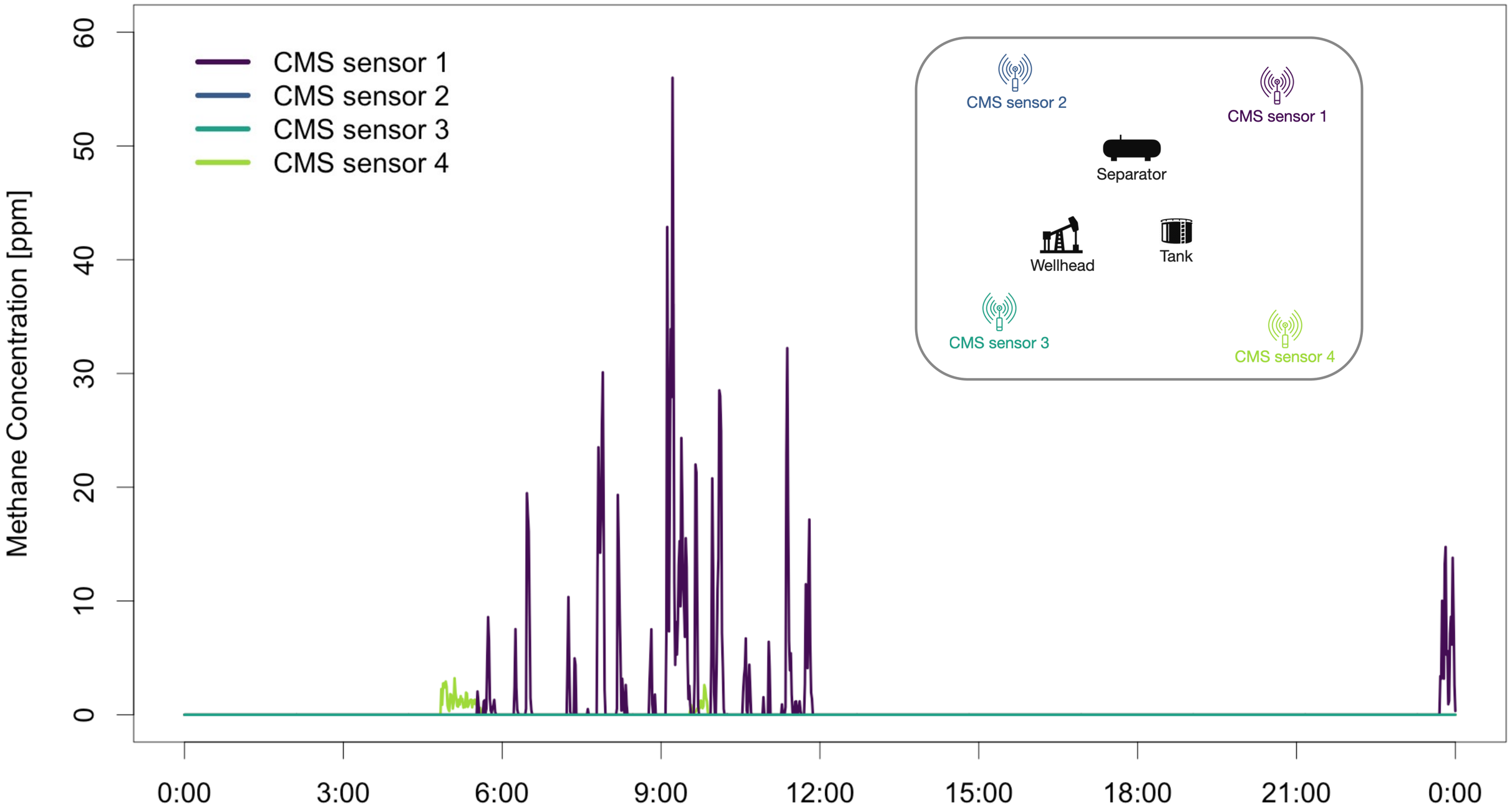
→

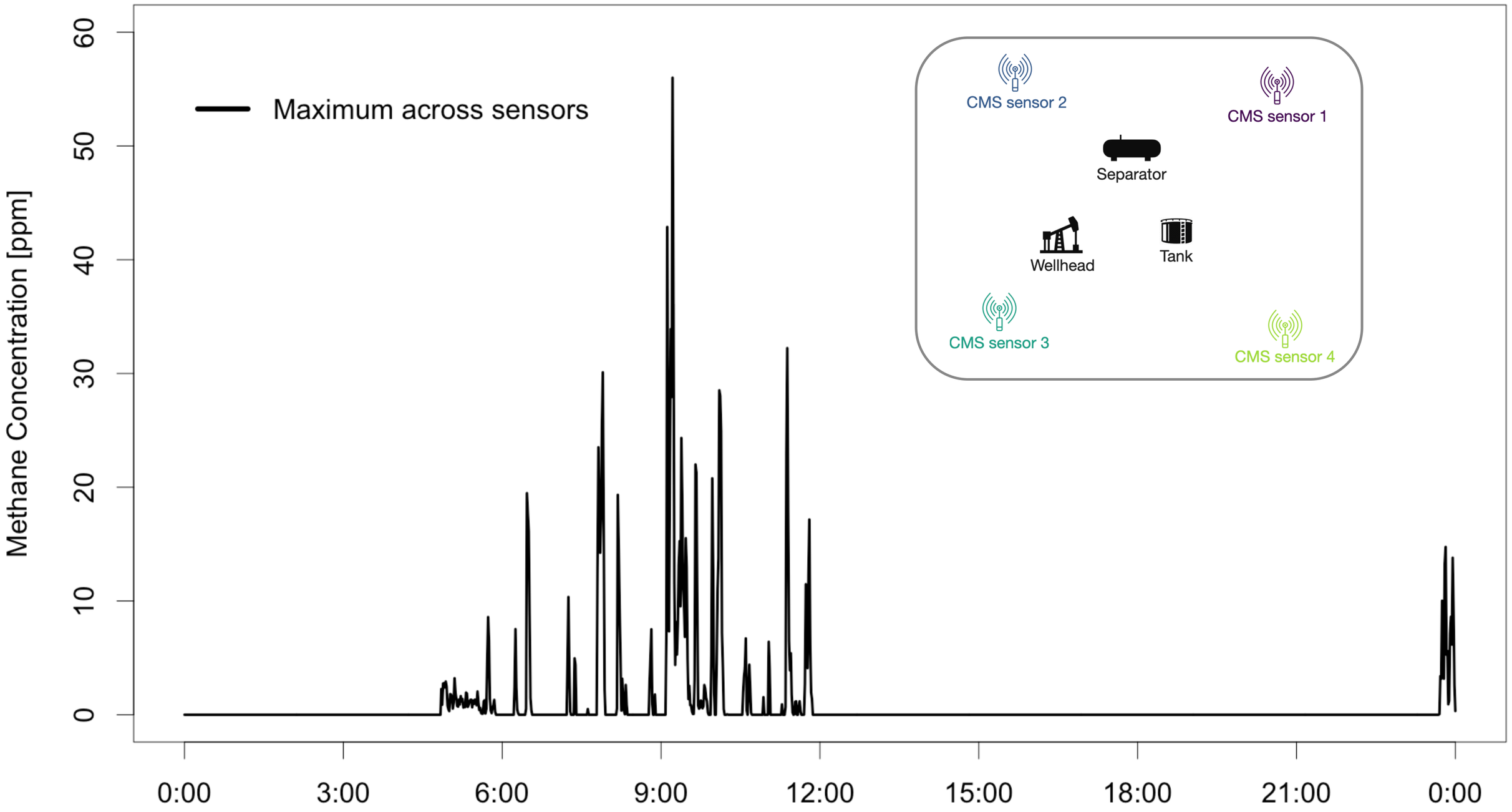
STEP 3:
Localization

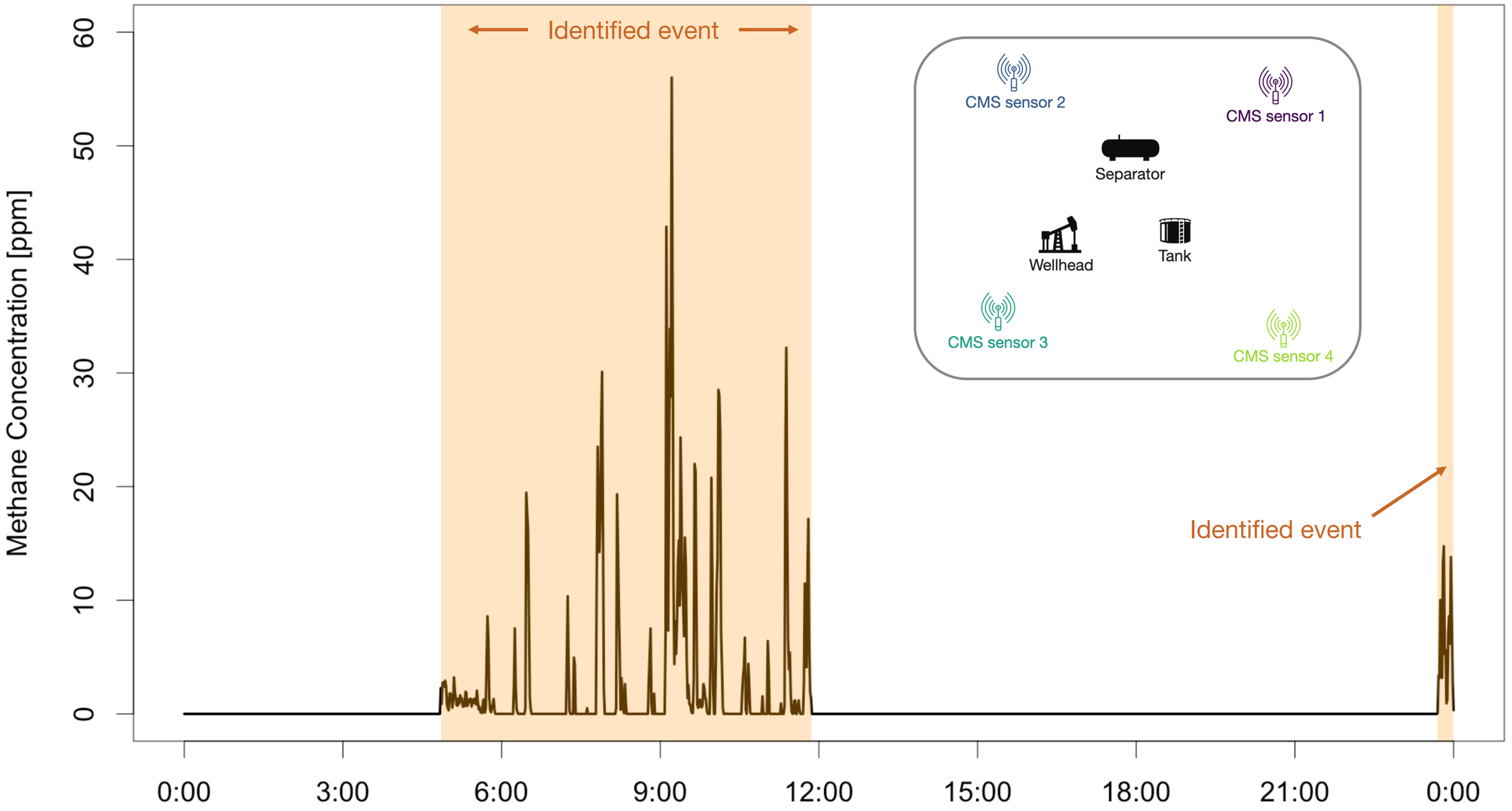
→

STEP 4:
Quantification


CMS sensor 1
CMS sensor 2
CMS sensor 3
CMS sensor 4
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4


CMS sensor 1
CMS sensor 2
CMS sensor 3
CMS sensor 4
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4


Maximum across sensors
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4


Identified event
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4
Identified event
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00

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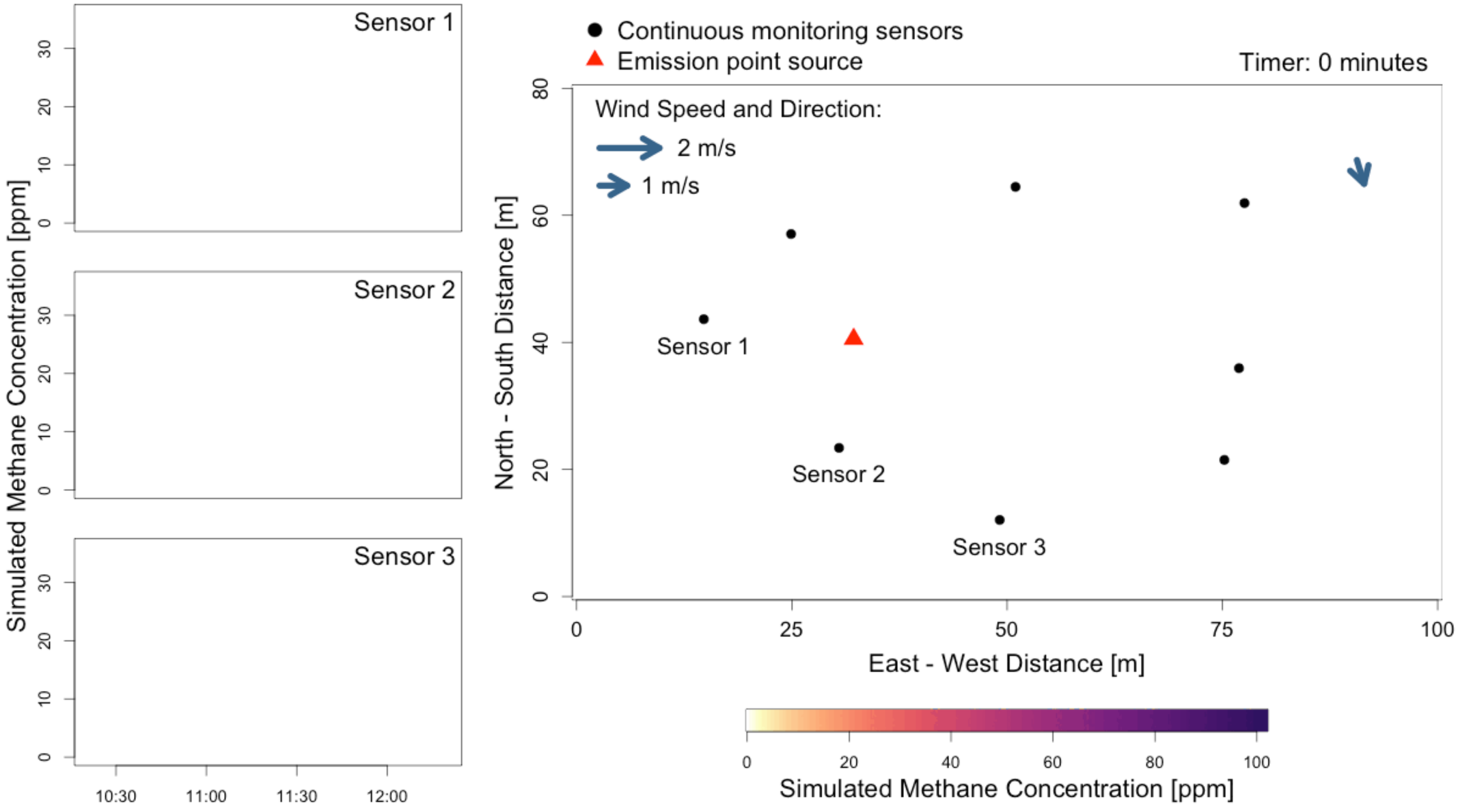
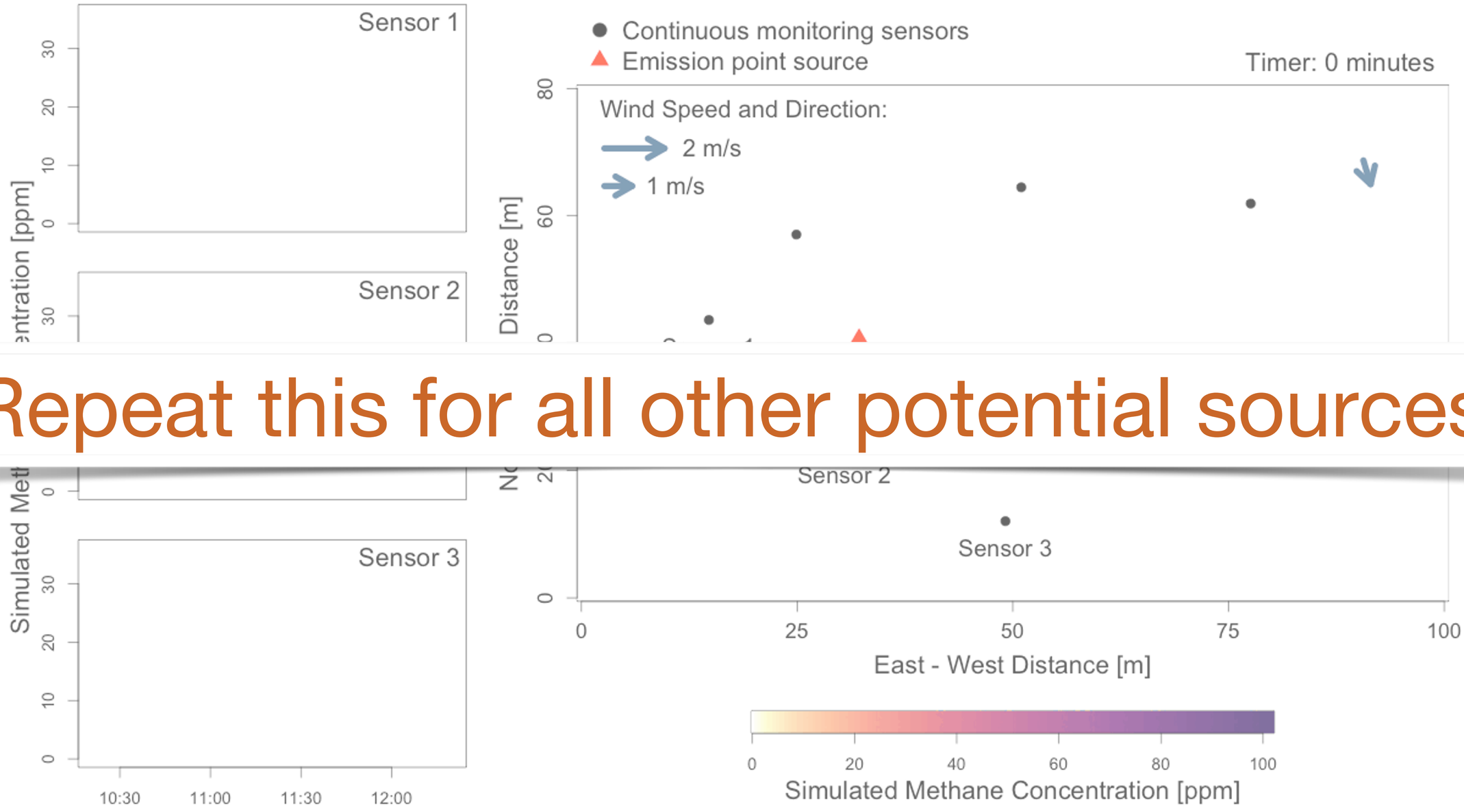

Sensor 1
Sensor 2
Sensor 3
Simulated Methane Concentration [ppm]
0
10
20
30
10:30
11:00
11:30
12:00
Continuous monitoring sensors
Emission point source
Timer: 0 minutes
Wind Speed and Direction:
2 m/s
1 m/s
North - South Distance [m]
0
20
40
60
80
0
25
50
75
100
East - West Distance [m]
Sensor 1
Sensor 2
Sensor 3
0
20
40
60
80
100
Simulated Methane Concentration [ppm]




# Repeat this for all other potential sources!

# Open source framework for solving inverse problem

STEP 1:
Background removal
and event detection

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Simulation

→

STEP 3:
Localization

→

STEP 4:
Quantification

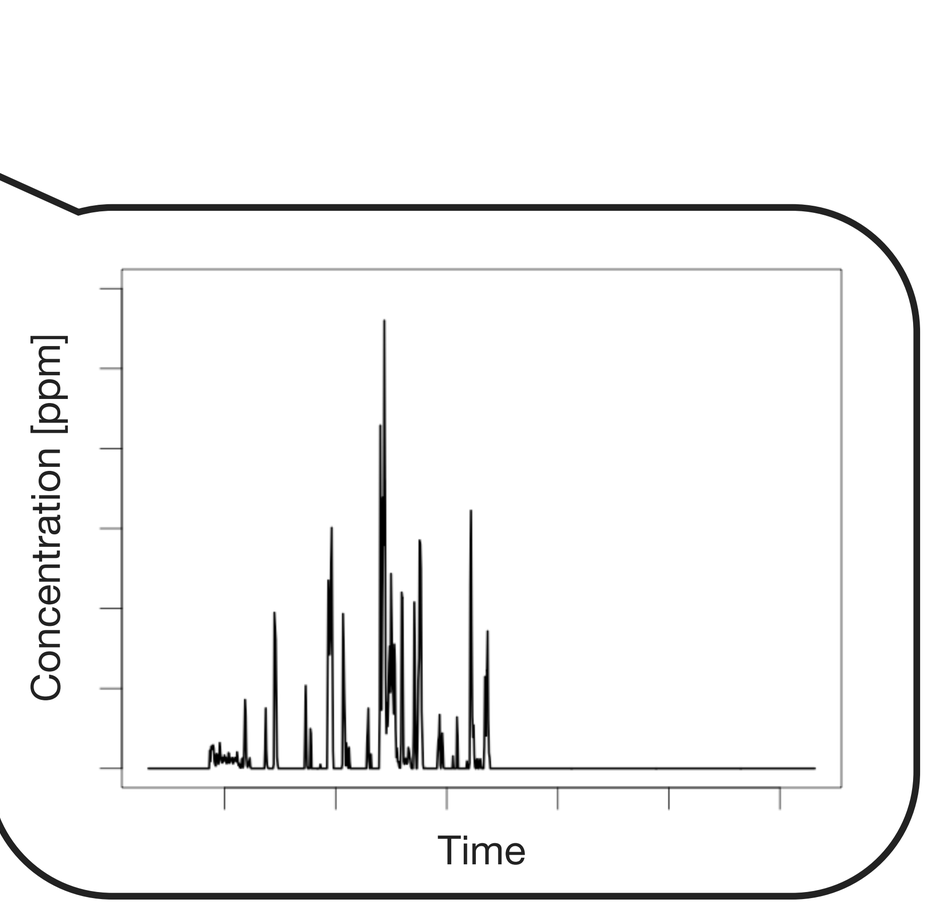
CMS sensor

Separator

Wellhead

Tank

Wind direction



CMS sensor

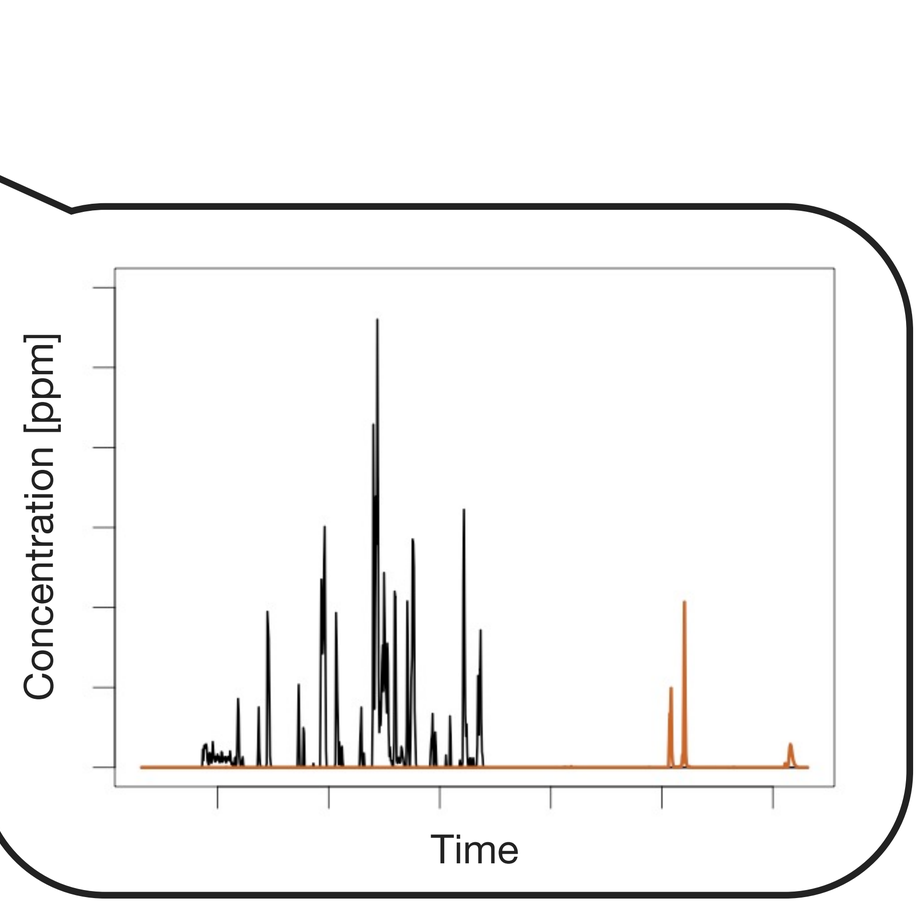
Simulation emission source

Separator

Wellhead

Tank

Wind direction




Background-removed observations

Simulated concentrations

CMS sensor

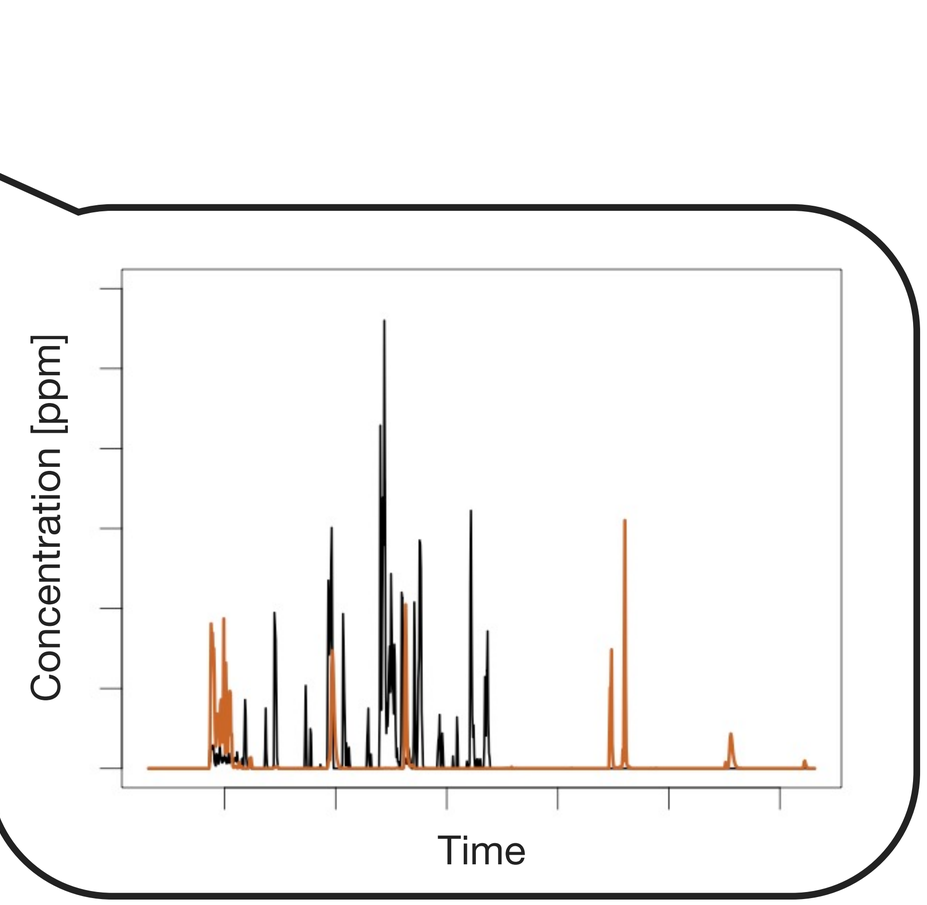
Separator

Wellhead

Simulation emission source

Tank

Wind direction



CMS sensor

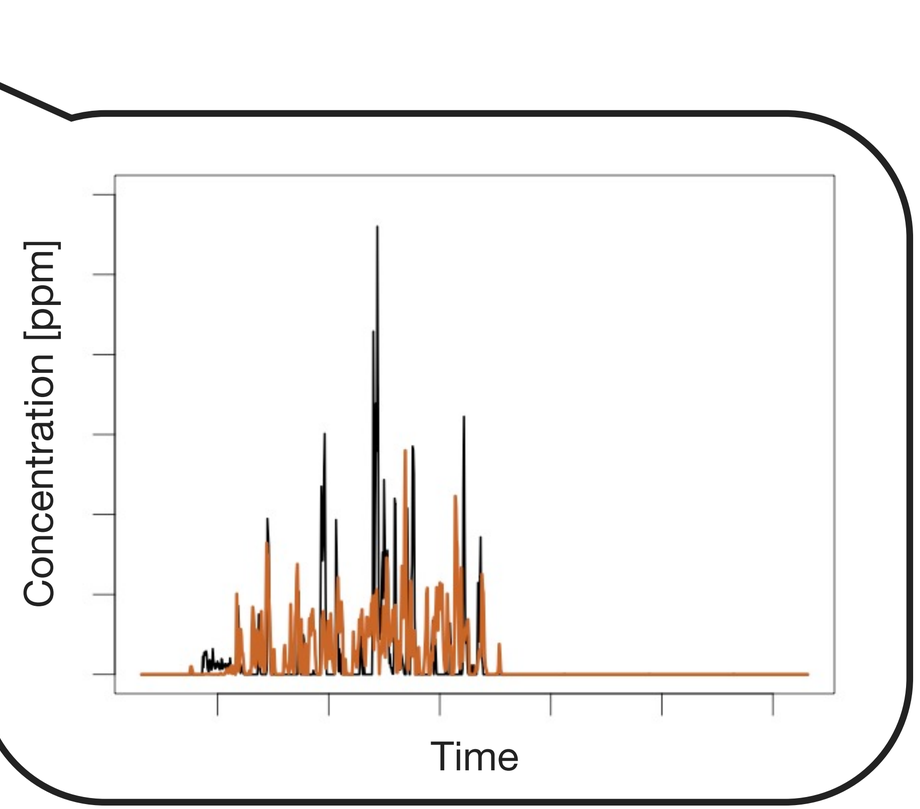
Separator

Wellhead

Tank

Simulation emission source

Wind direction



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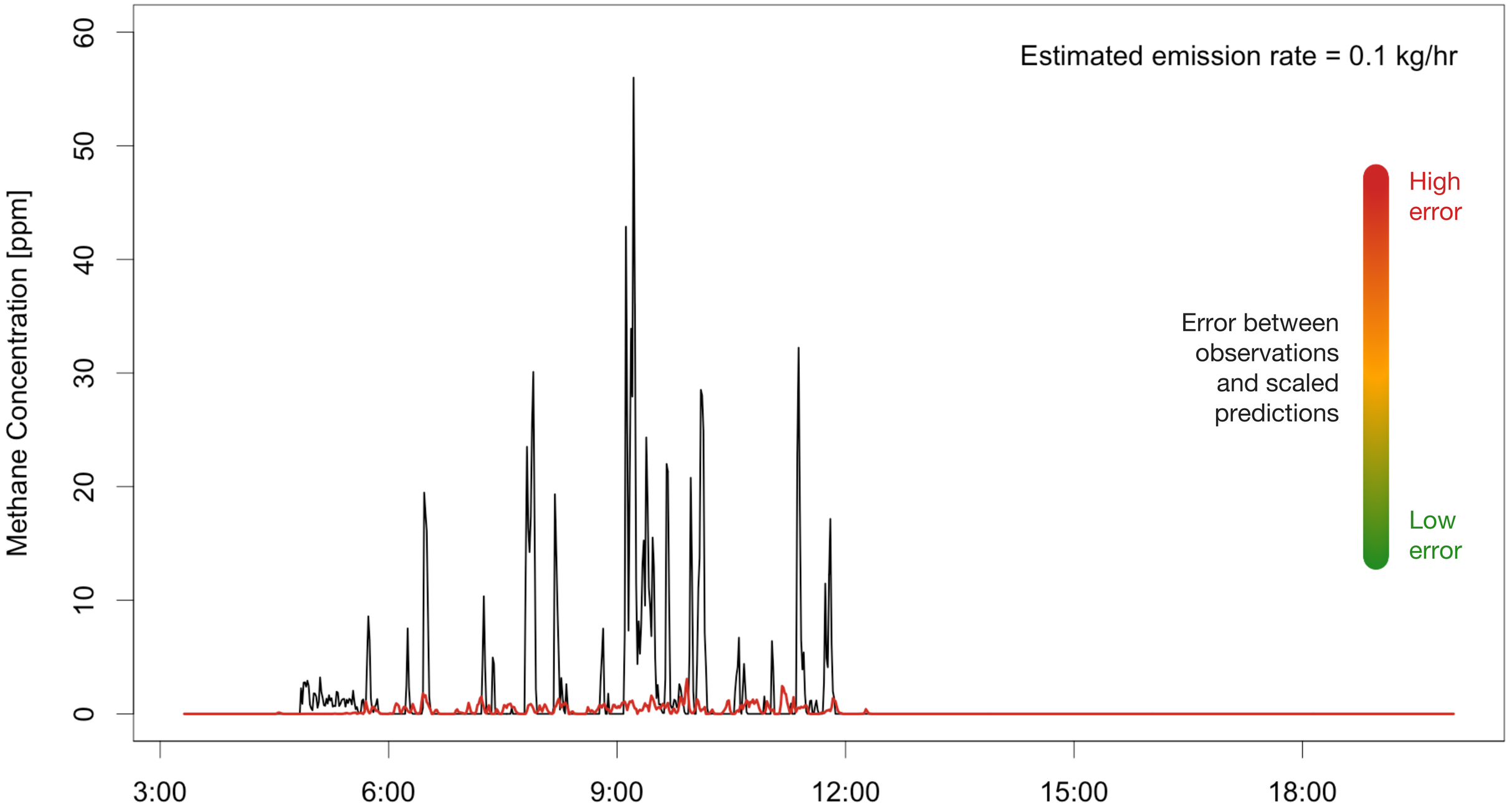
# Simulation is a linear function of emission rate

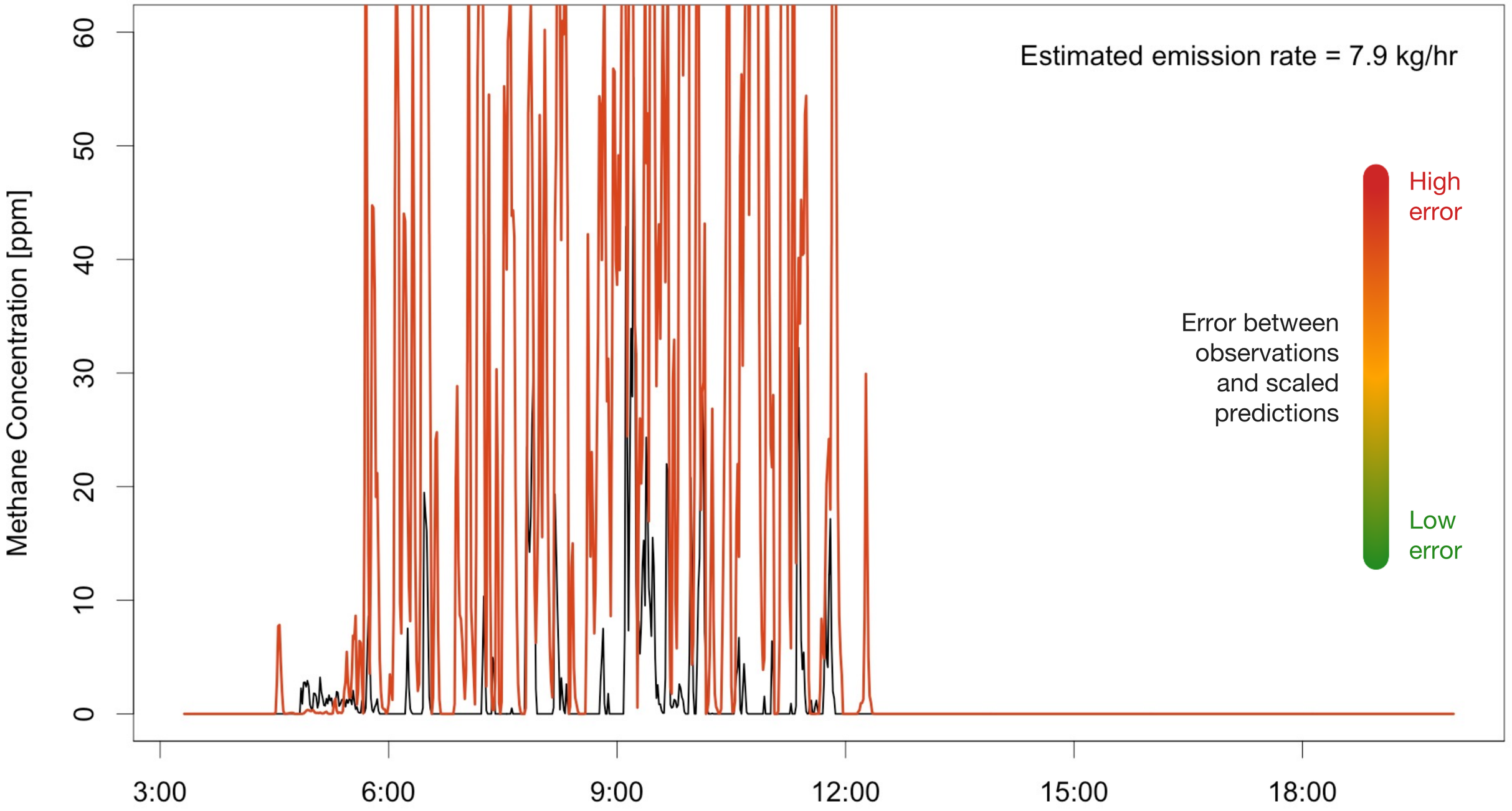
Emission rate

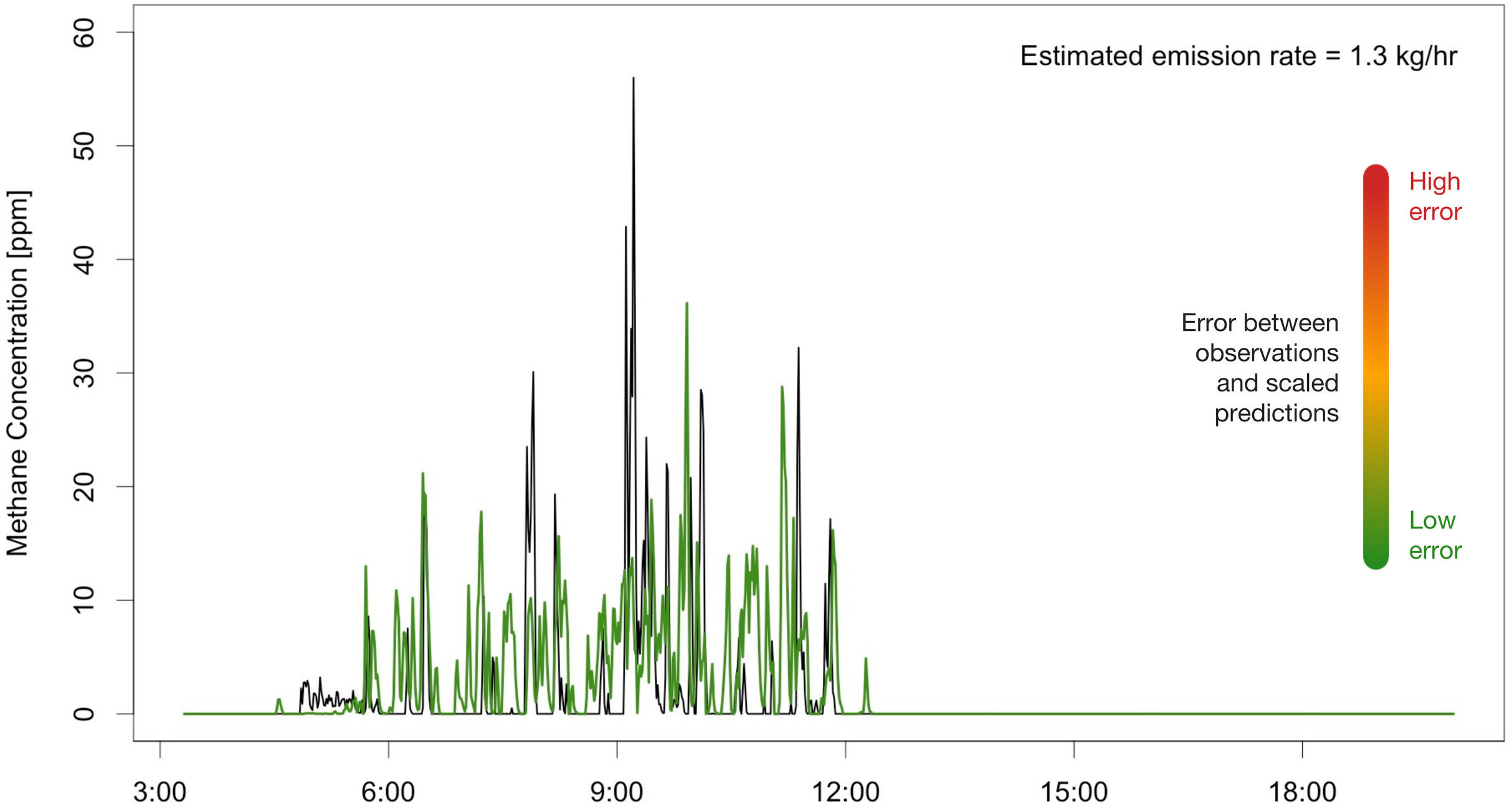
$$c_p(x,y,z,t) = Q\frac{1}{(2\pi)^{3/2}\sigma_y^2\sigma_z}\exp\left(-\frac{(x-ut)^2+y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

Simulation output: concentrations

"Everything else"


Estimated emission rate = 0.1 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Error between observations and scaled predictions
High error
Low error


Estimated emission rate = 7.9 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Error between observations and scaled predictions
High error
Low error


Estimated emission rate = 1.3 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Error between observations and scaled predictions
High error
Low error

# Open source framework for solving inverse problem

STEP 1:
Background removal
and event detection

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Simulation

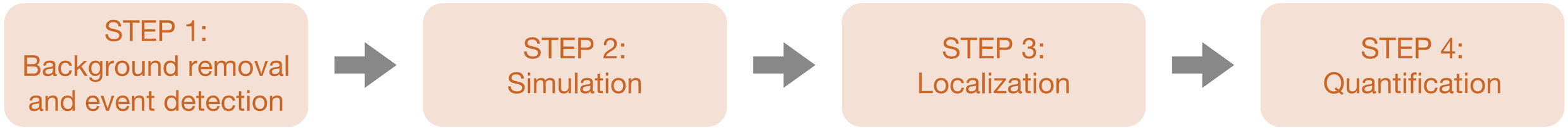
→

STEP 3:
Localization

→

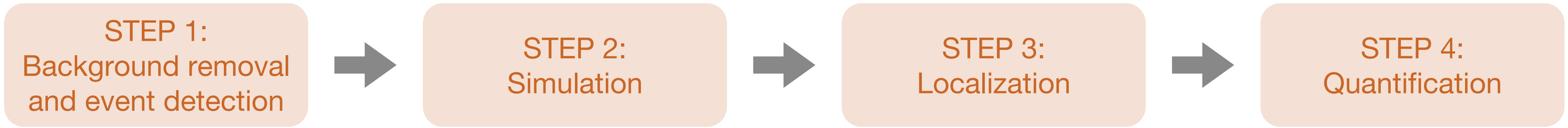
STEP 4:
Quantification

# Open source framework for solving inverse problem

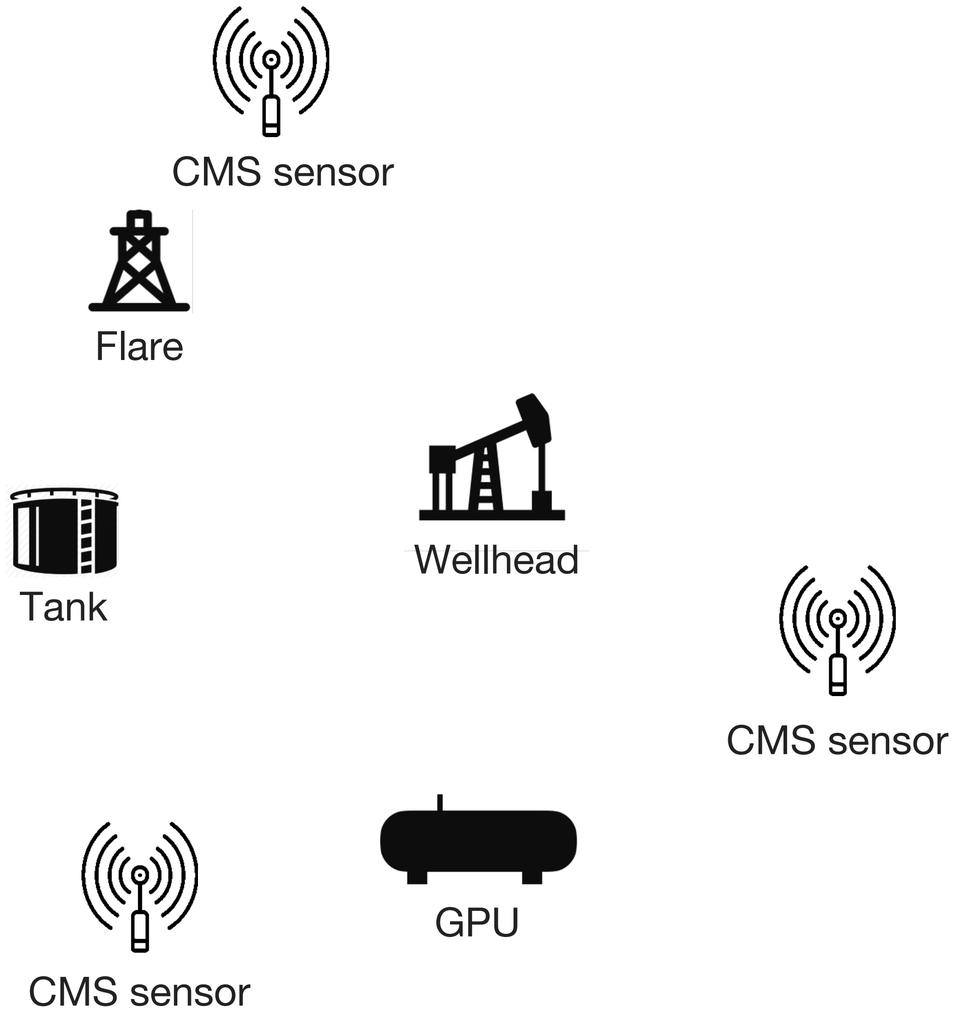



1. Open source and transparent!

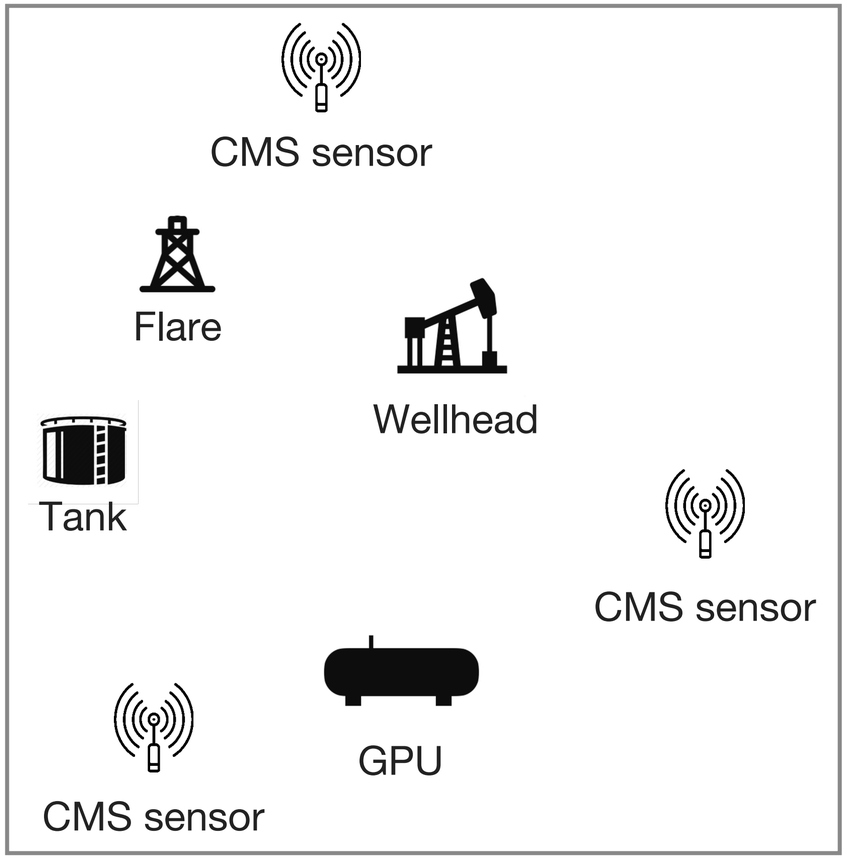
# Open source framework for solving inverse problem




1. Open source and transparent!
2. Single-source emissions only. Currently developing a multi-source upgrade.

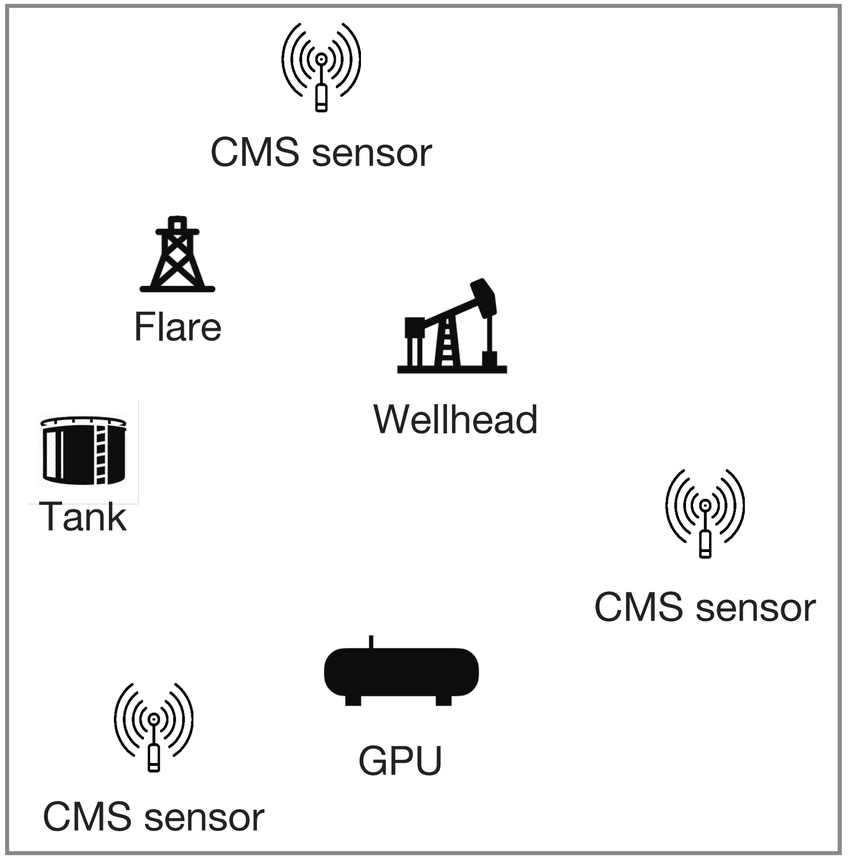



# Measurement-informed inventory case study



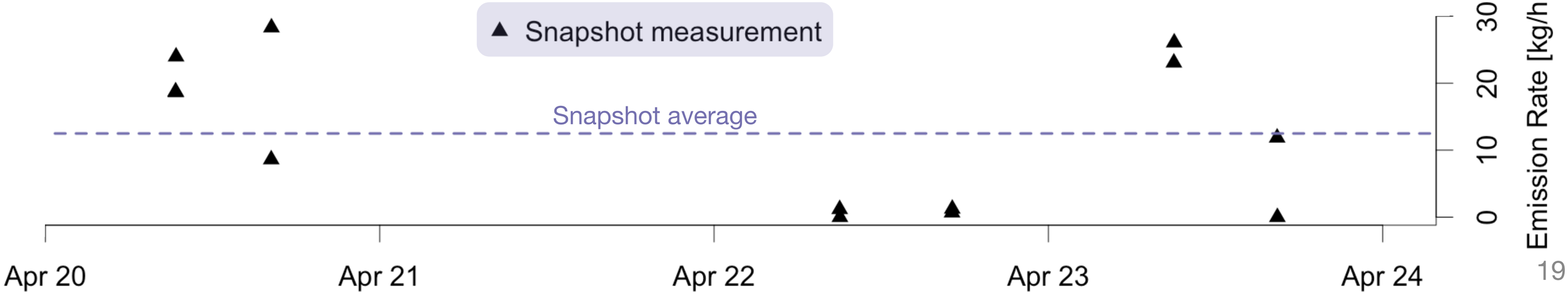

13 snapshot measurements over 4 days

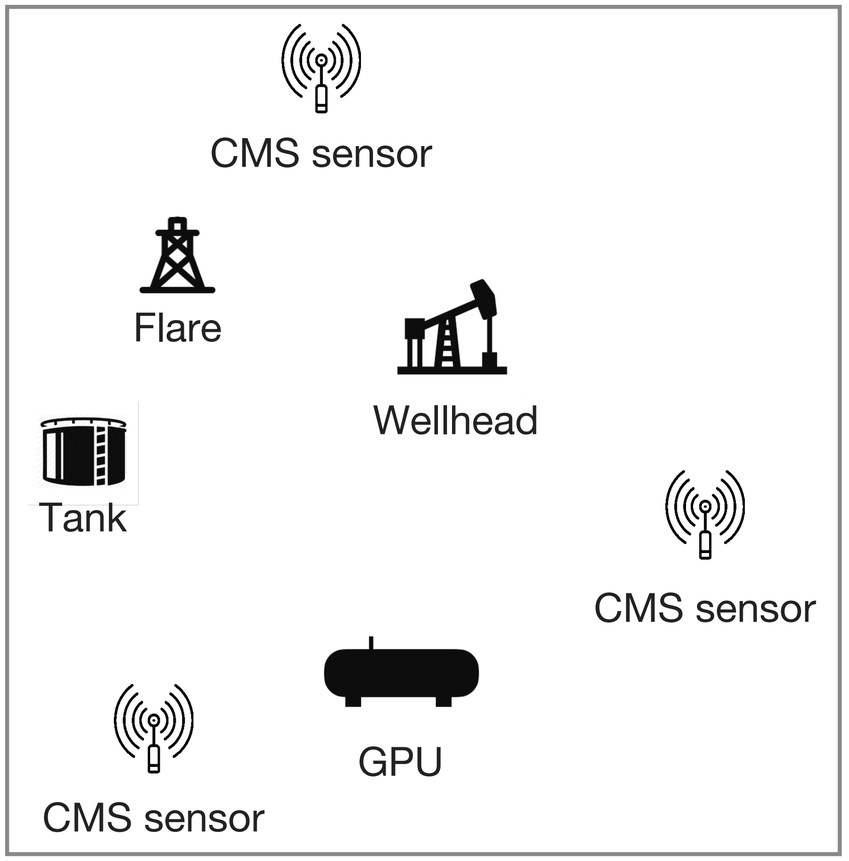
average = 12.5 kg/hr




13 snapshot measurements over 4 days

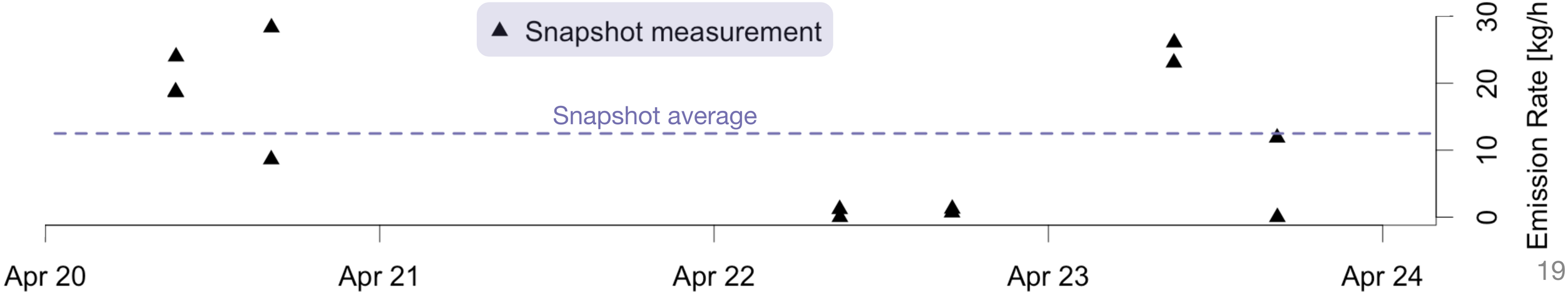
average = 12.5 kg/hr

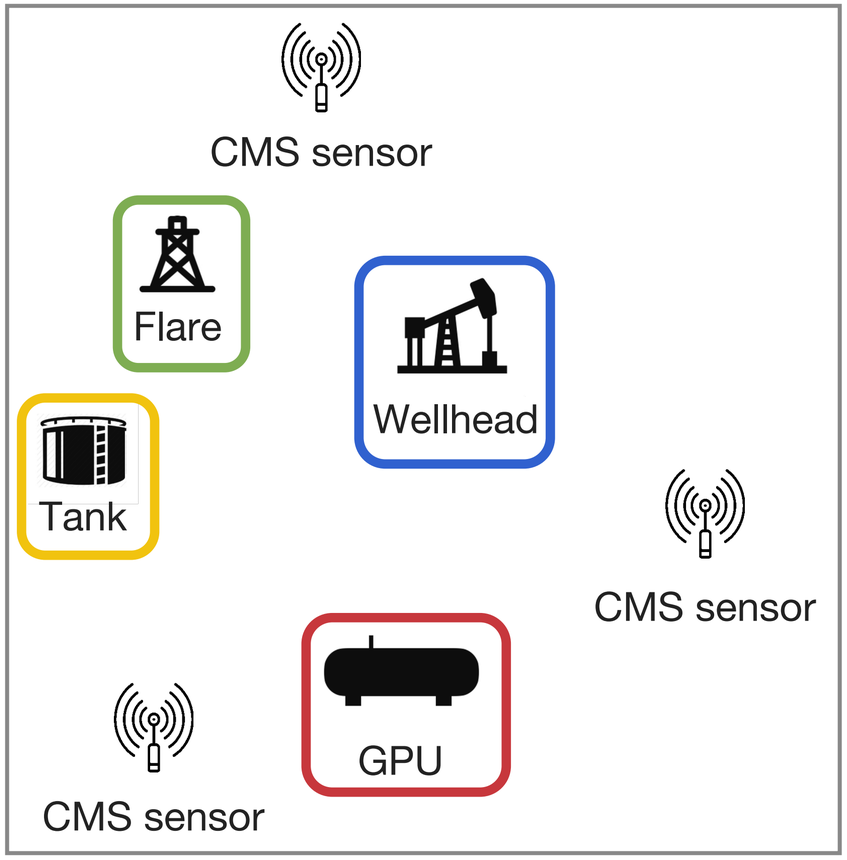





13 snapshot measurements over 4 days → average = 12.5 kg/hr

Bottom-up inventory during snapshot measurements → 0.8 kg/hr



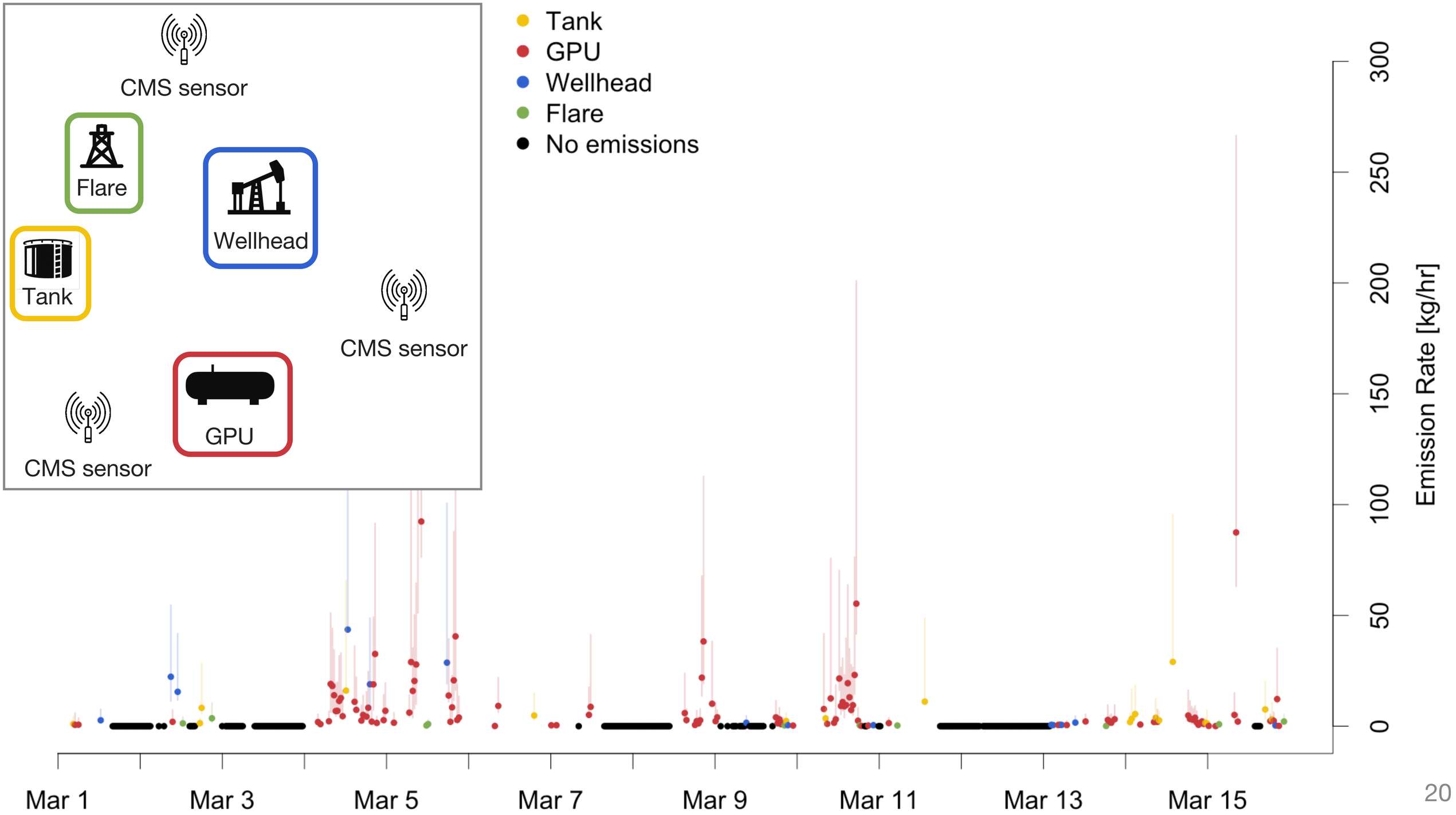


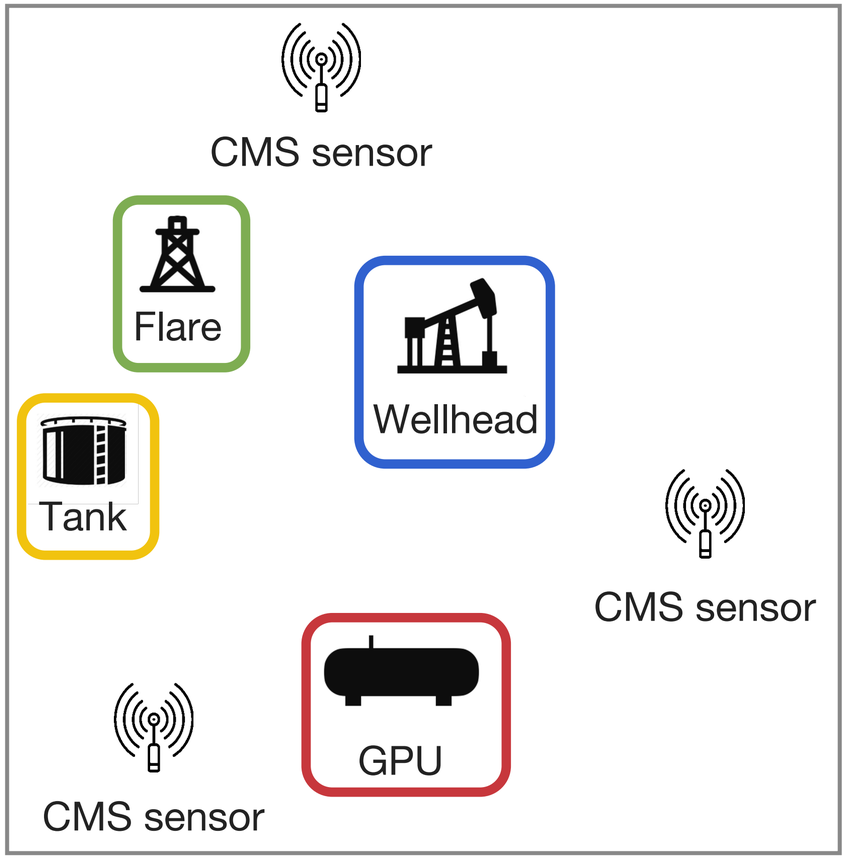

Tank
GPU
Wellhead
Flare
No emissions

300
250
200
150
100
50
0

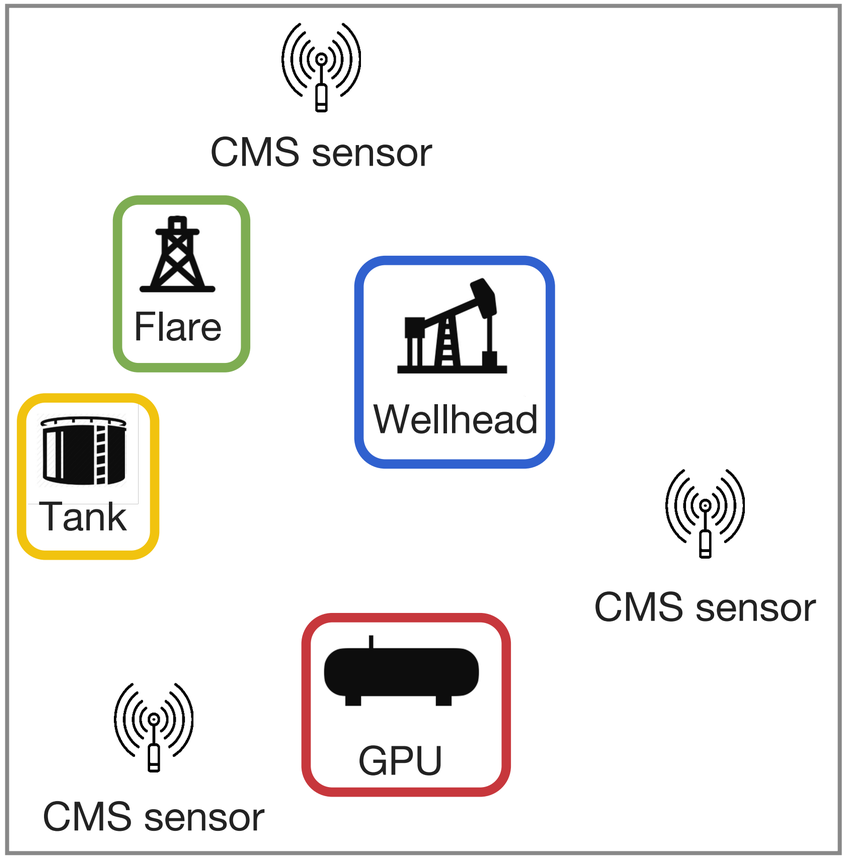
Emission Rate [kg/hr]

Mar 1
Mar 3
Mar 5
Mar 7
Mar 9
Mar 11
Mar 13
Mar 15


CMS sensor
Flare
Wellhead
Tank
CMS sensor
GPU
CMS sensor
Tank
GPU
Wellhead
Flare
No emissions
Emission Rate [kg/hr]
0
50
100
150
200
250
300
Mar 1
Mar 3
Mar 5
Mar 7
Mar 9
Mar 11
Mar 13
Mar 15


CMS sensor
Flare
Wellhead
Tank
CMS sensor
GPU
CMS sensor


0
2
4
6
8
10
12
Emission Rate [kg/hr]
Oct
Nov
Dec
Jan
Feb
Mar
Apr



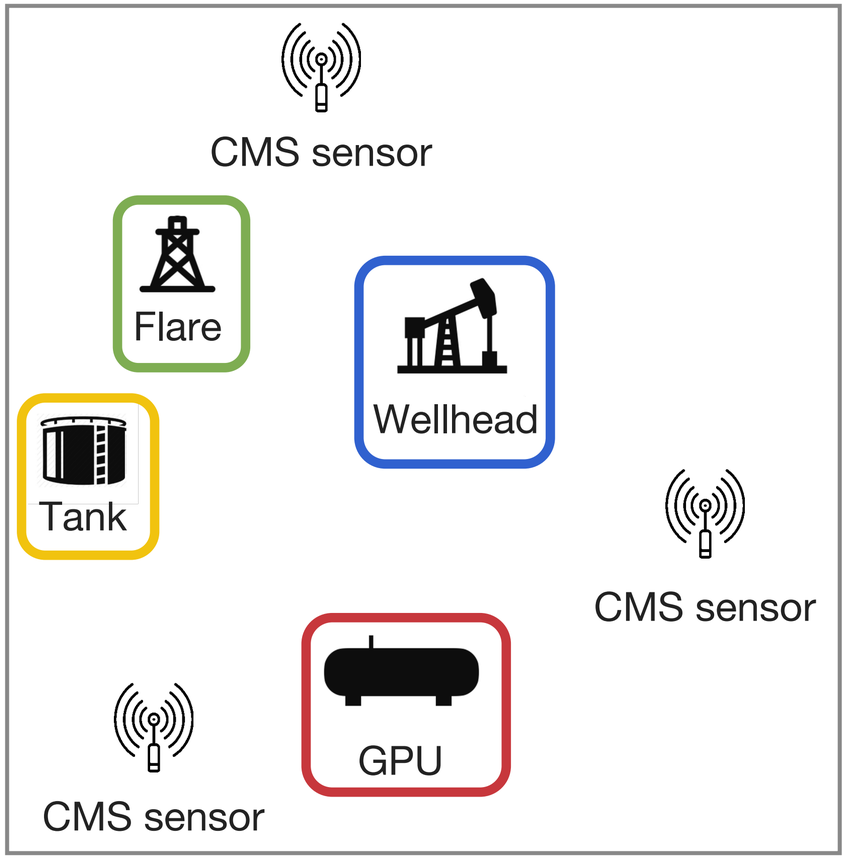

Company emissions inventory (shown as bars)

Site total

Emission Rate [kg/hr]

0
2
4
6
8
10
12

Oct
Nov
Dec
Jan
Feb
Mar
Apr




Company emissions inventory (shown as bars)

CMS-based inventory estimate

Site total

Oct

Nov

Dec

Jan

Feb

Mar

Apr

Emission Rate [kg/hr]

0

2

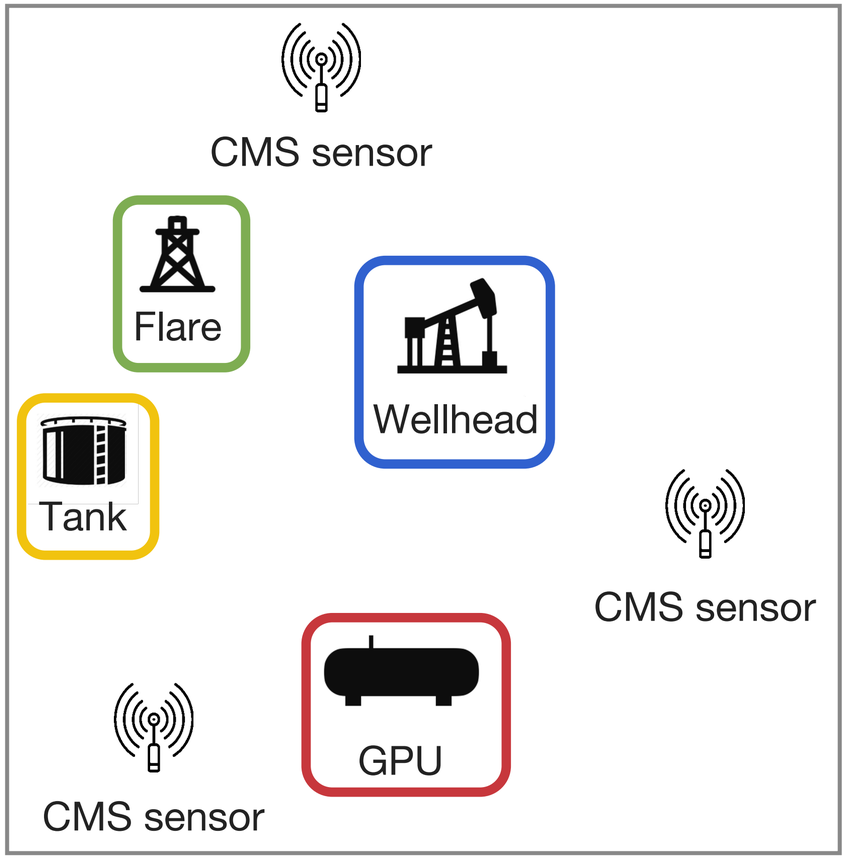
4

6

8

10

12




Company emissions inventory (shown as bars)

CMS-based inventory estimate

Equipment change on February 23rd

Site total

Oct

Nov

Dec

Jan

Feb

Mar

Apr

0

2

4

6

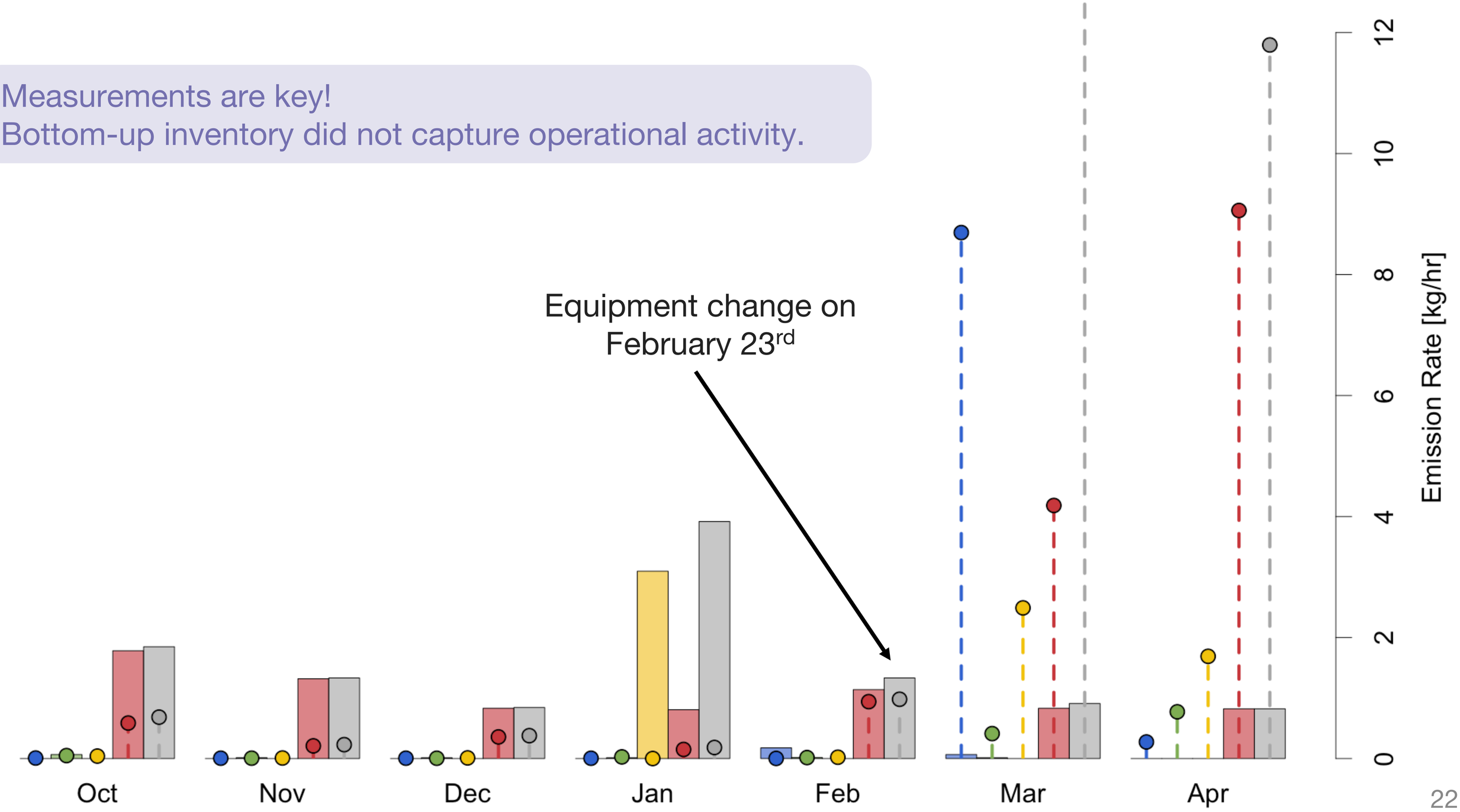
8

10

12

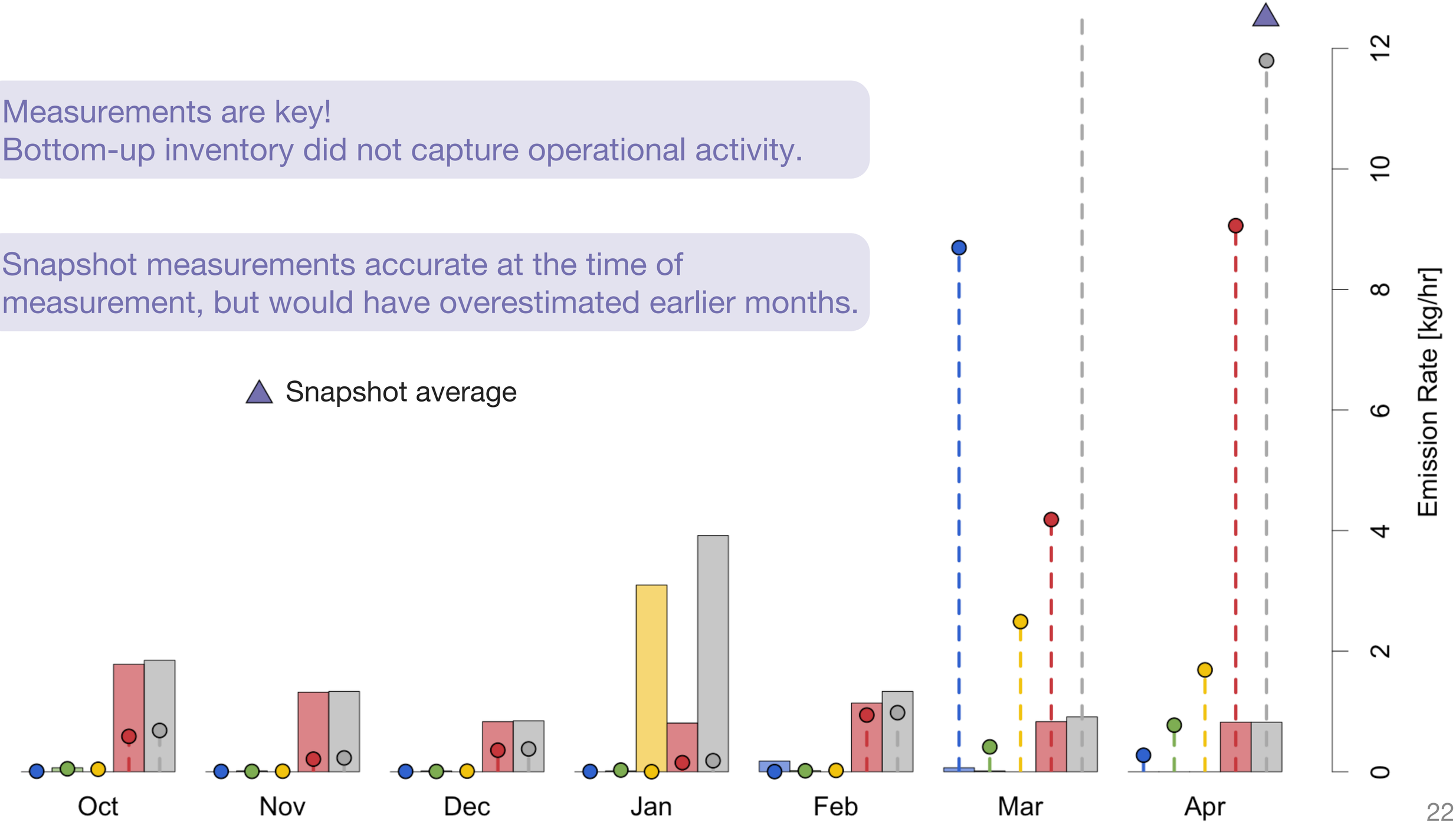
Emission Rate [kg/hr]

Measurements are key!
Bottom-up inventory did not capture operational activity.



Measurements are key!
Bottom-up inventory did not capture operational activity.

Snapshot measurements accurate at the time of measurement, but would have overestimated earlier months.



# High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

The continuous monitoring inverse problem

Measurement-informed inventory case study

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CMS show promise for simple sites.

Measurement-informed inventory case study

# High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

CMS show promise for simple sites.

Measurements are key. Snapshot measurements can miss temporal variability.

# Thank you!

COLORADO SCHOOL OF MINES

TEXAS
The University of Texas at Austin

CHENIERE

# Thank you!
# Questions?

Detection, localization, and quantification of single-source methane emissions on oil and gas production sites using point-in-space continuous monitoring systems.

William Daniels, Meng Jia, Dorit Hammerling. *Under Review*, (2023).

Towards multiscale measurement-informed methane inventories: reconciling bottom-up site-level inventories with top-down measurements using continuous monitoring systems.

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wdaniels@mines.edu