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

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) … calculations under subsection (c) of this section are based on **empirical data** and accurately reflect the total methane emissions from the applicable facilities.

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

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) … calculations under subsection (c) of this section are based on **empirical data** and accurately reflect the total methane emissions from the applicable facilities.

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

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

Infrequent overflights emerging as a common solution

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

Infrequent overflights emerging as a common solution

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

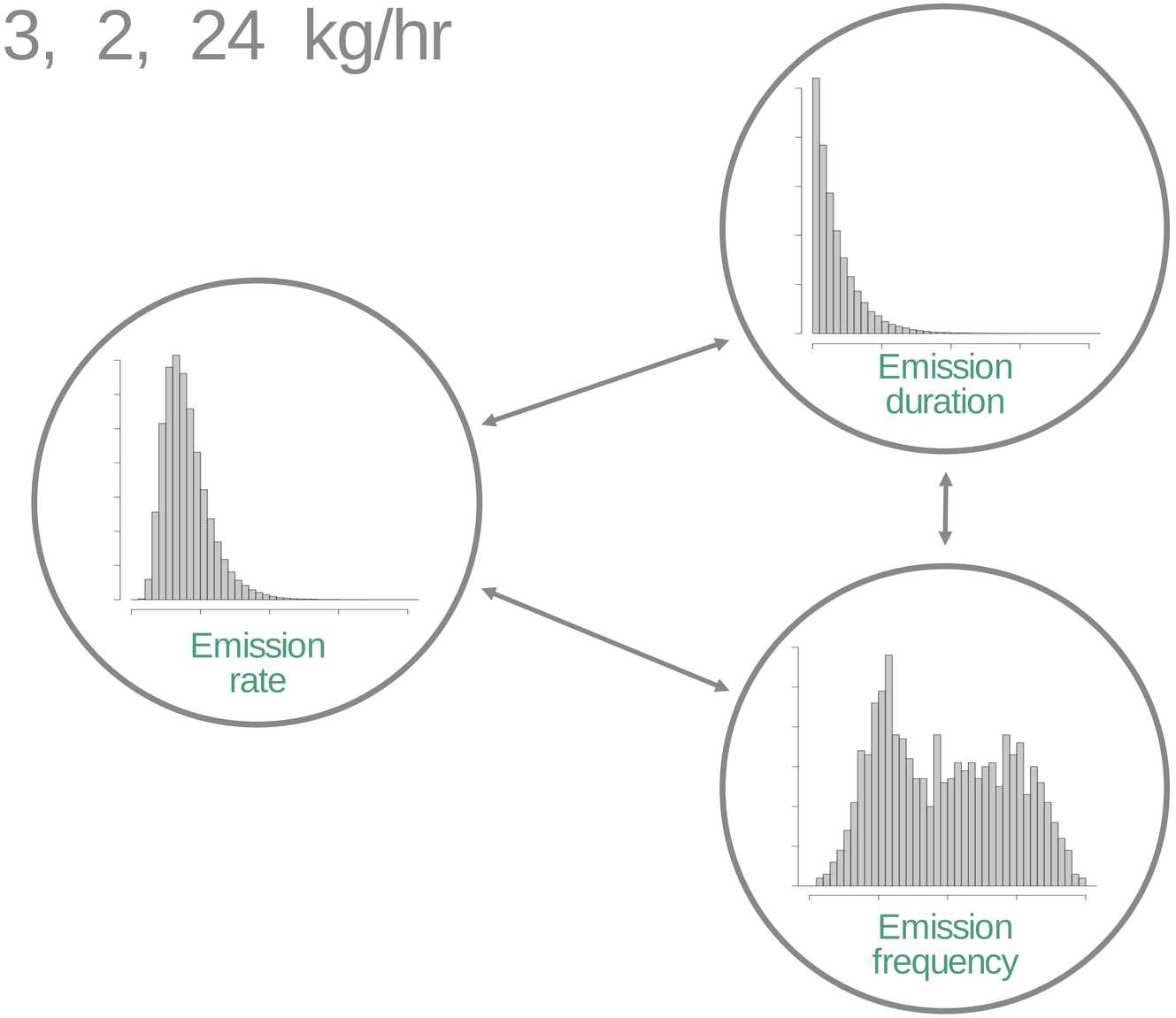
What if we average them?

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.



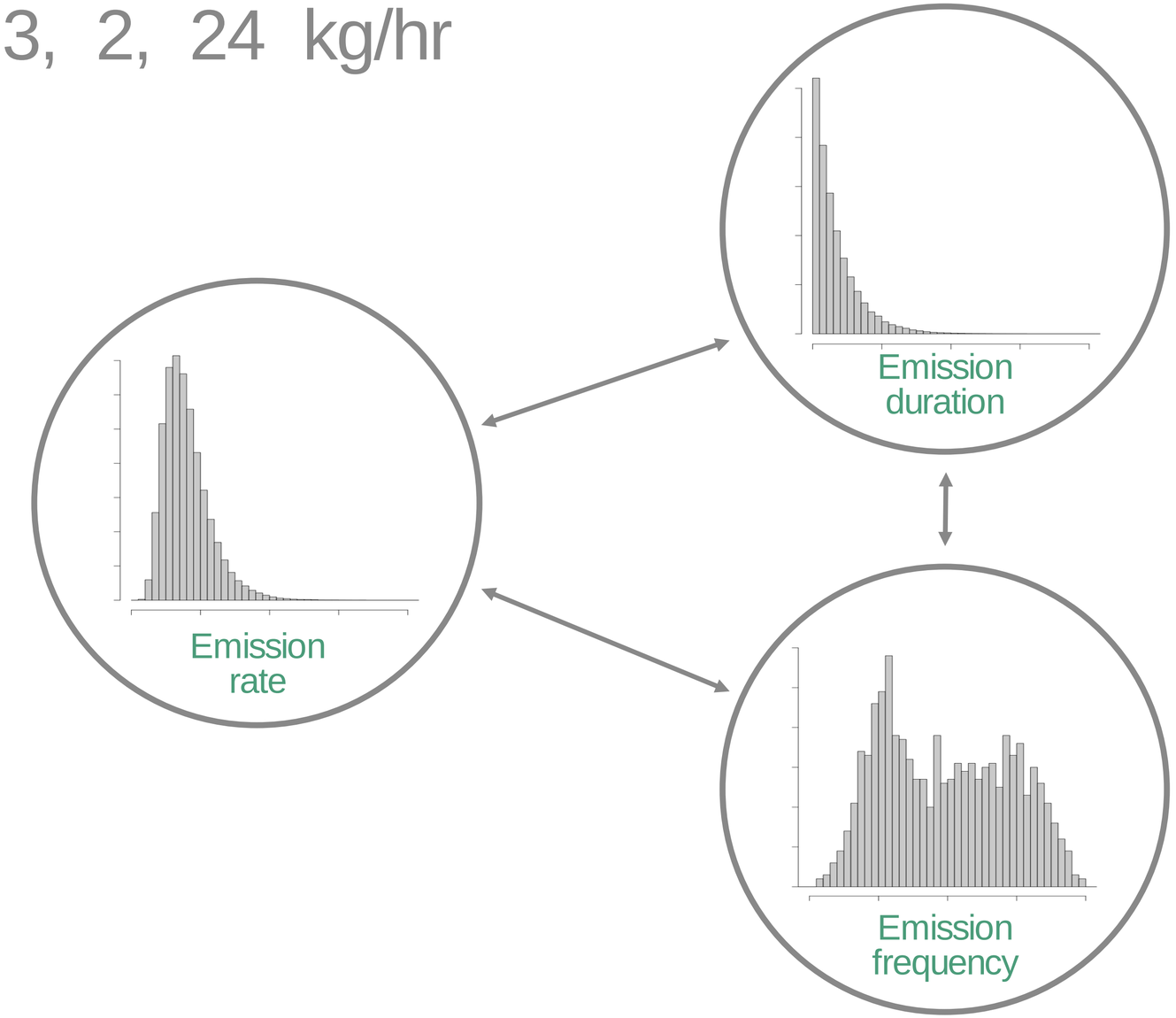
Infrequent overflights emerging as a common solution

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?

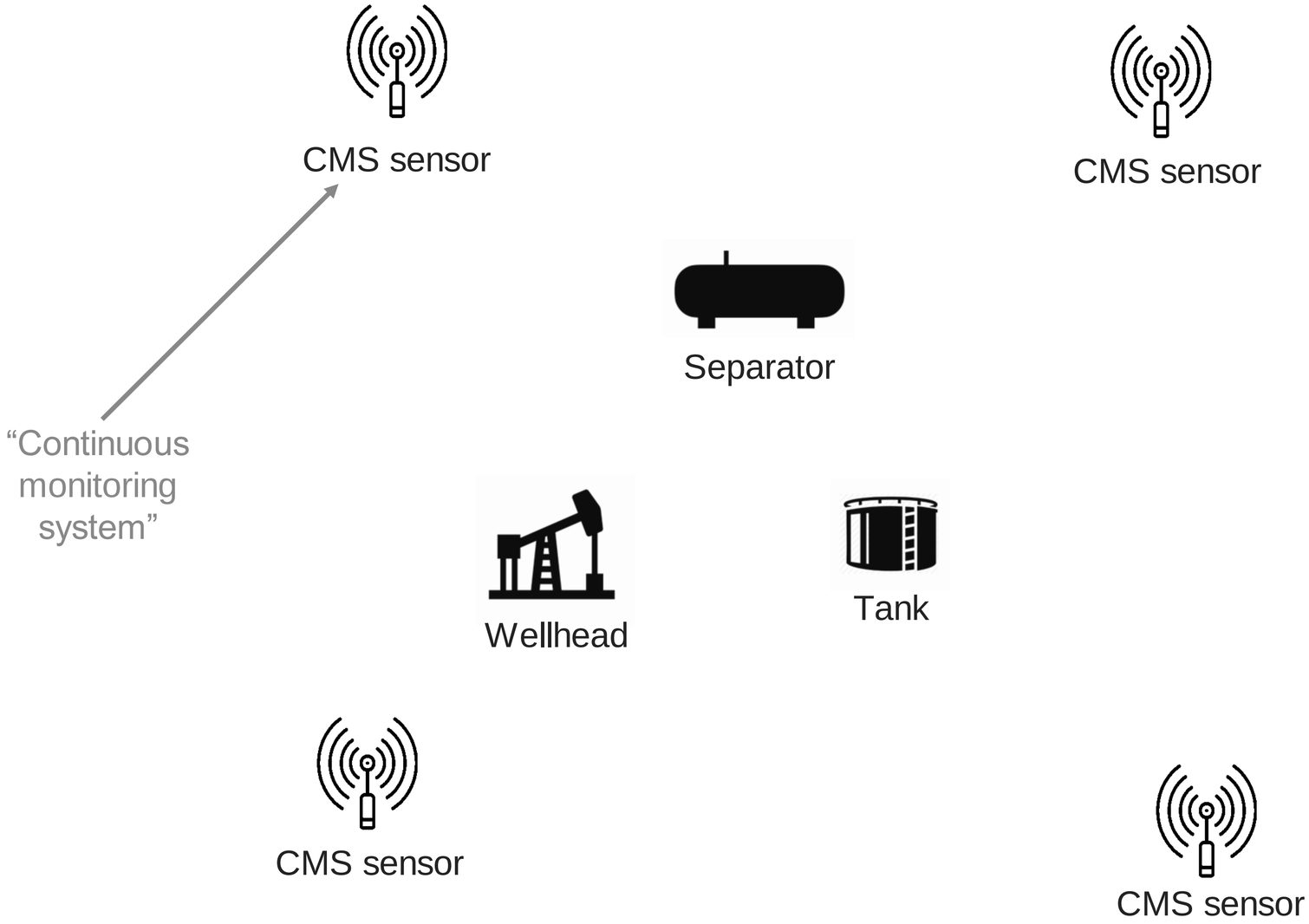


High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

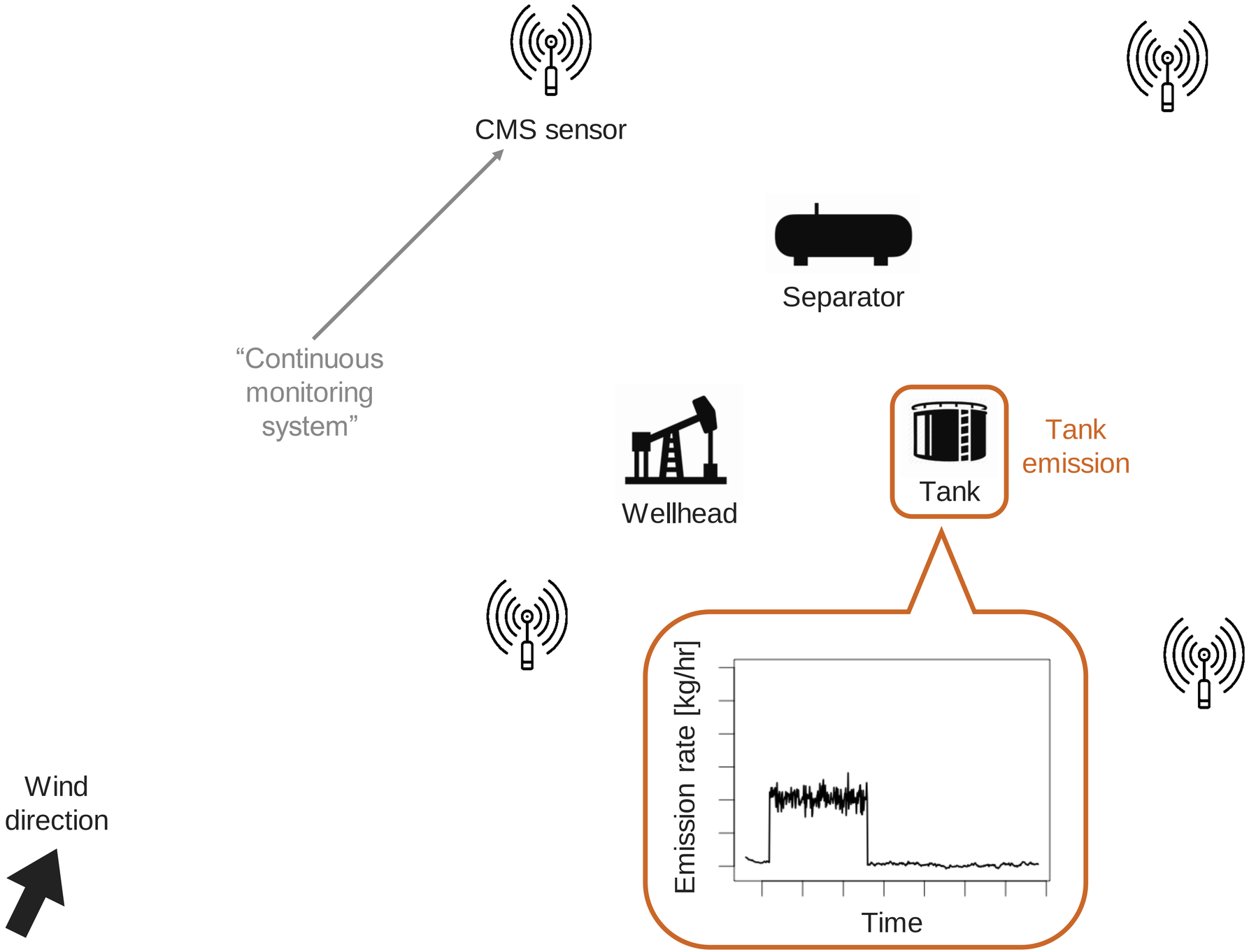
High frequency measurements are an important tool for creating accurate, measurement-informed, site-level inventories

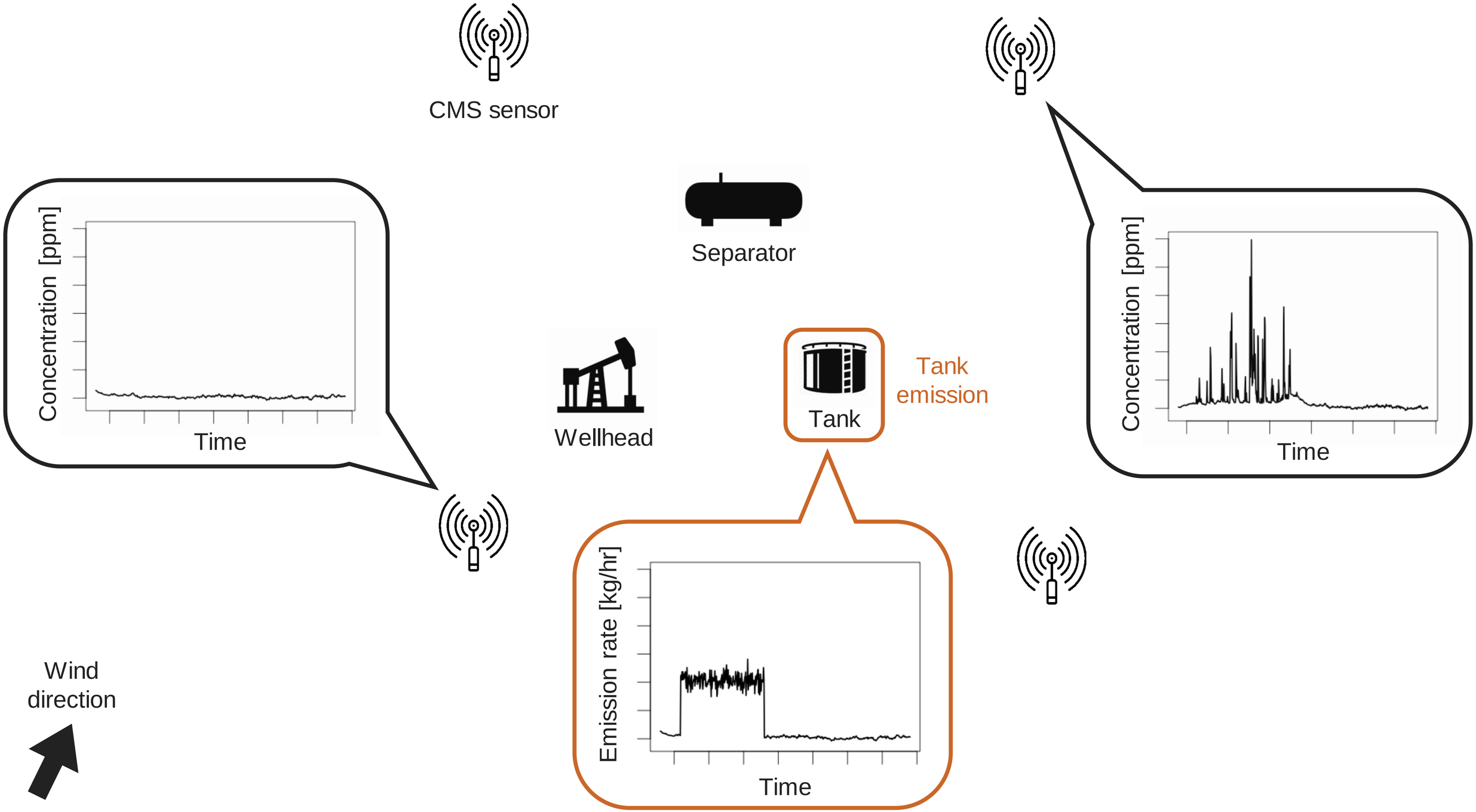
The continuous monitoring inverse problem

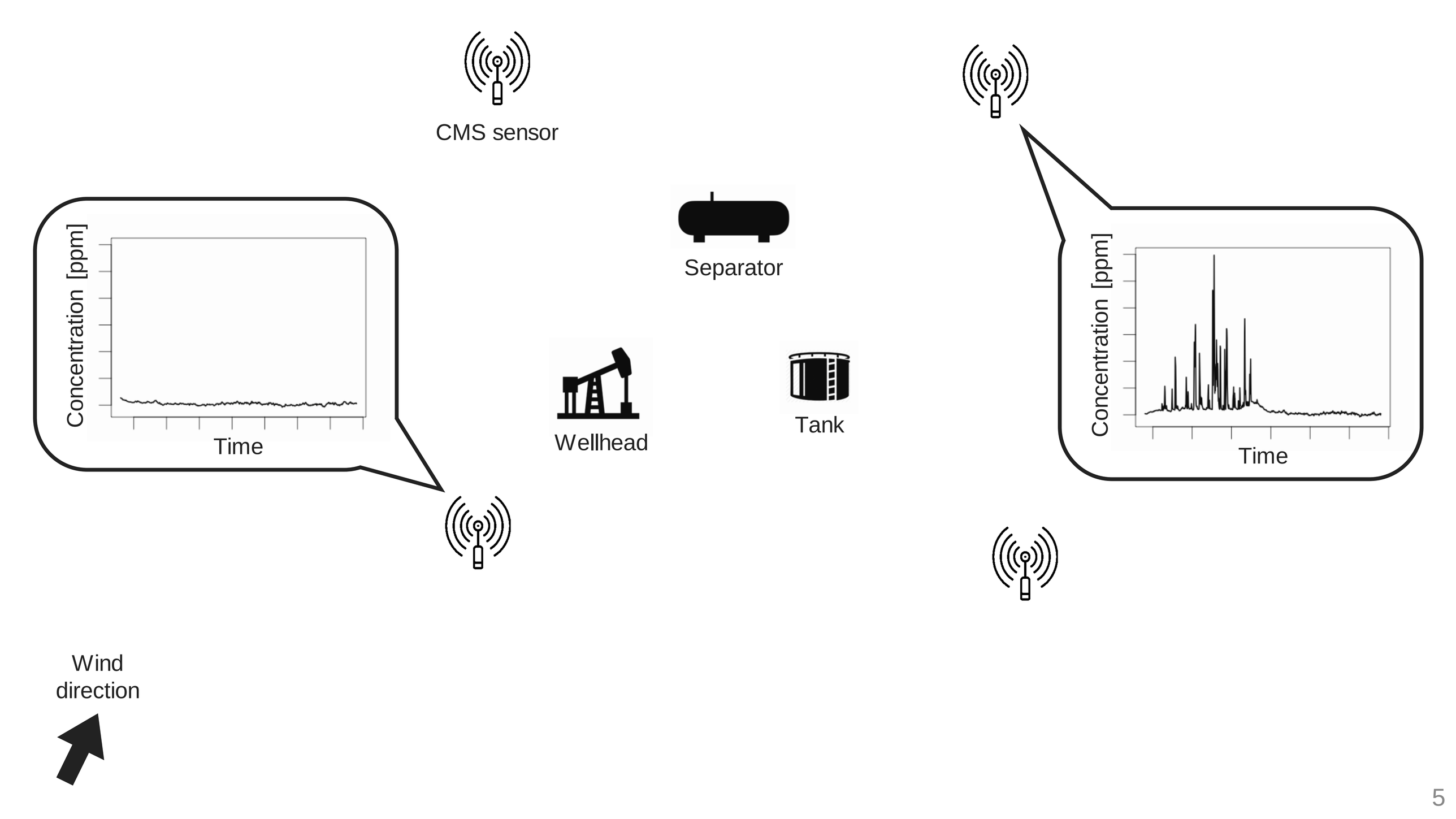
Measurement-informed inventory case study



The continuous monitoring inverse problem

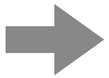

CMS sensor
"Continuous monitoring system"
Separator
Wellhead
Tank
Tank emission
Emission rate [kg/hr]
Time
Wind direction


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

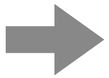

CMS sensor
Separator
Wellhead
Tank
Concentration [ppm]
Time
Concentration [ppm]
Time
Wind
direction

Open source framework for solving inverse problem

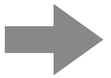
STEP 1:
Background removal
and event detection



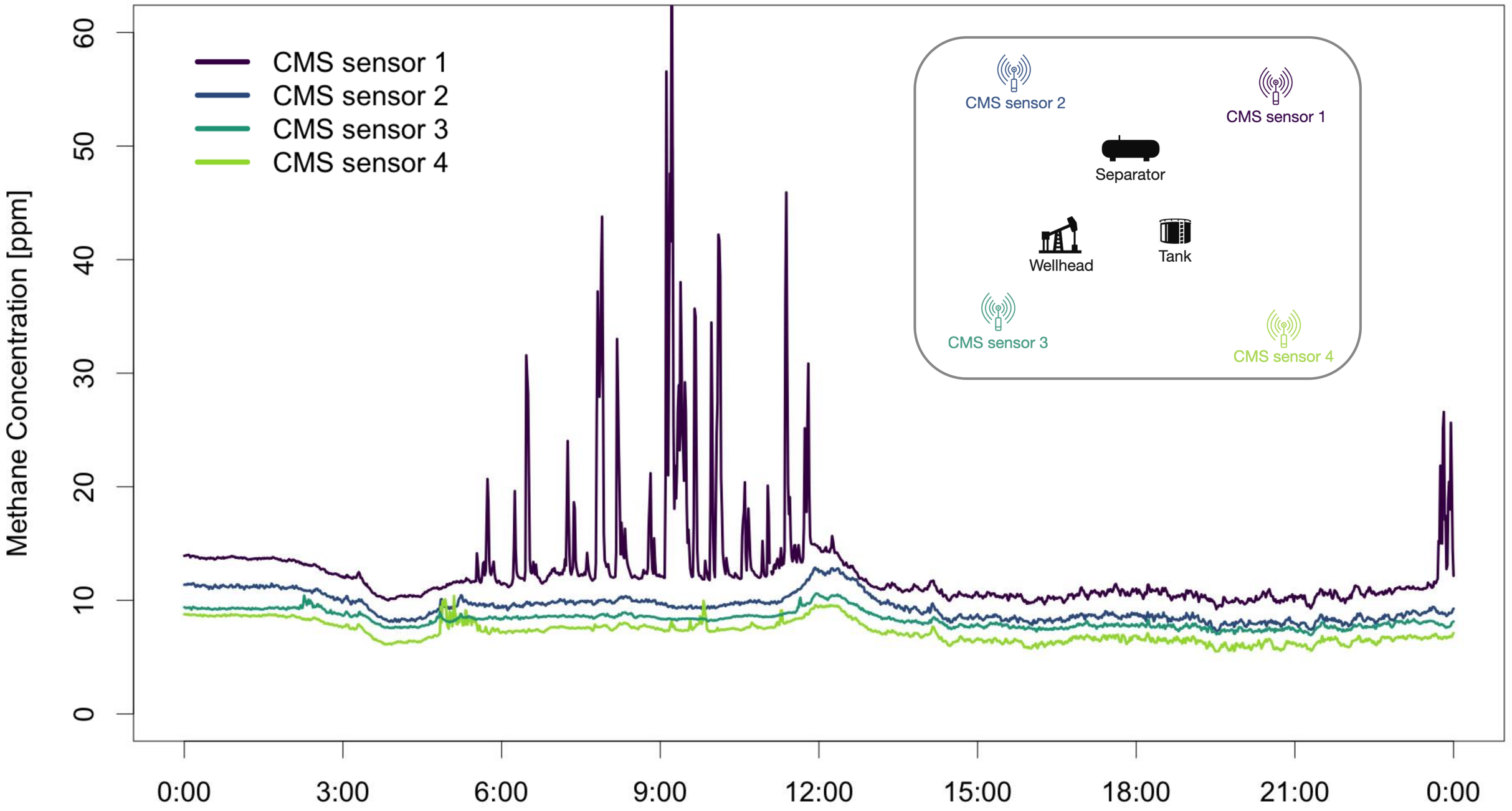
STEP 2:
Simulation

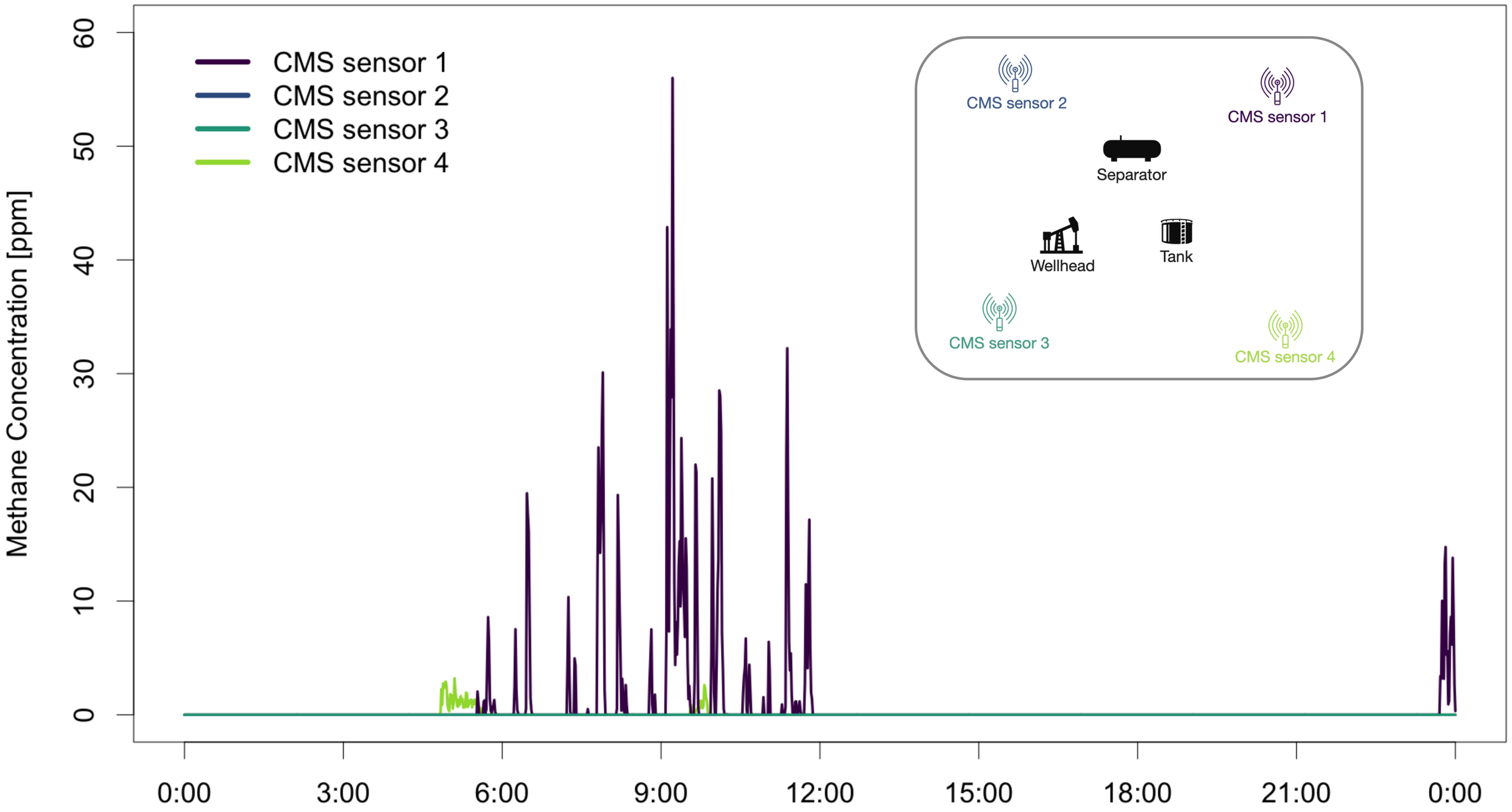


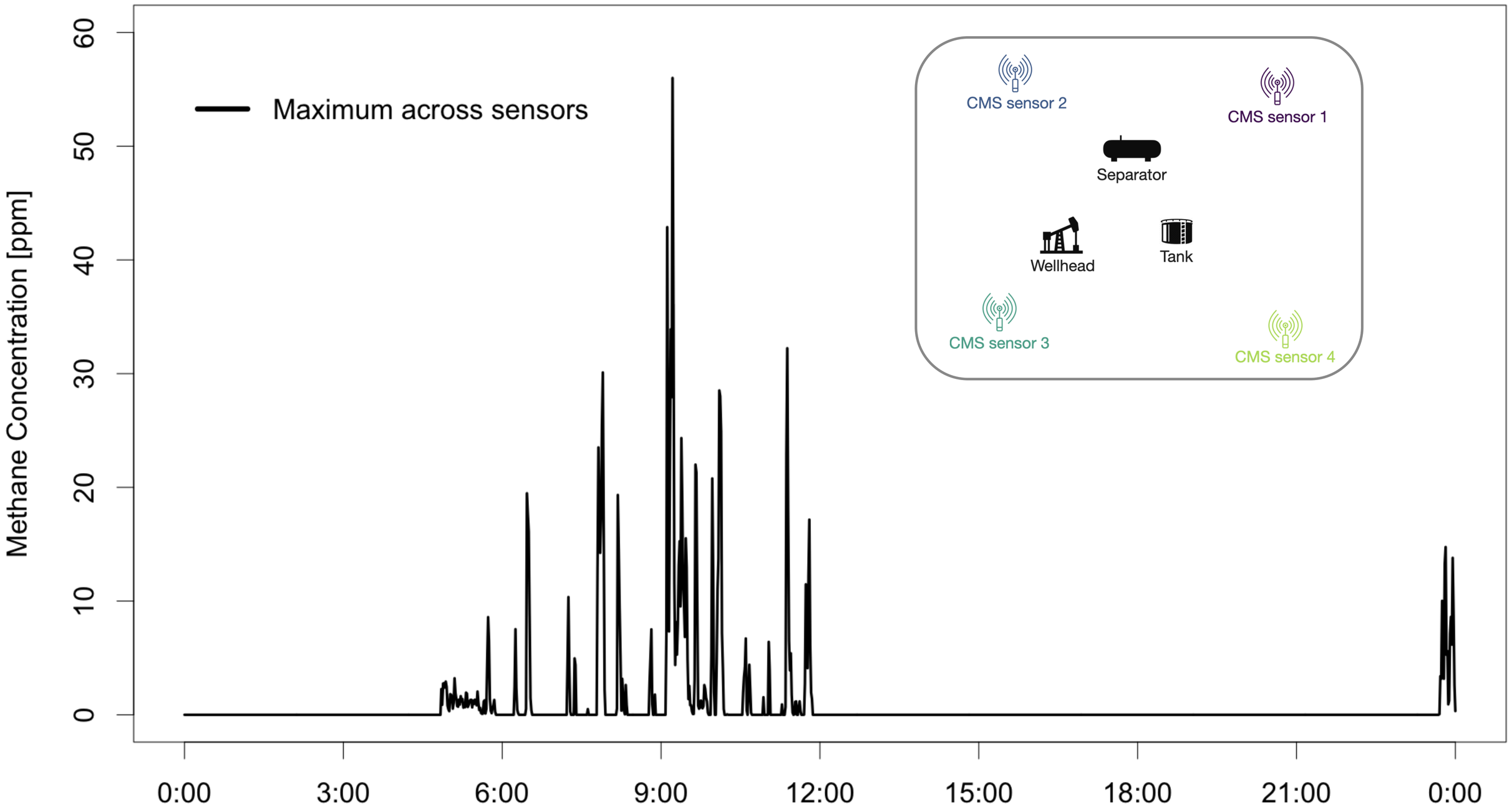
STEP 3:
Localization

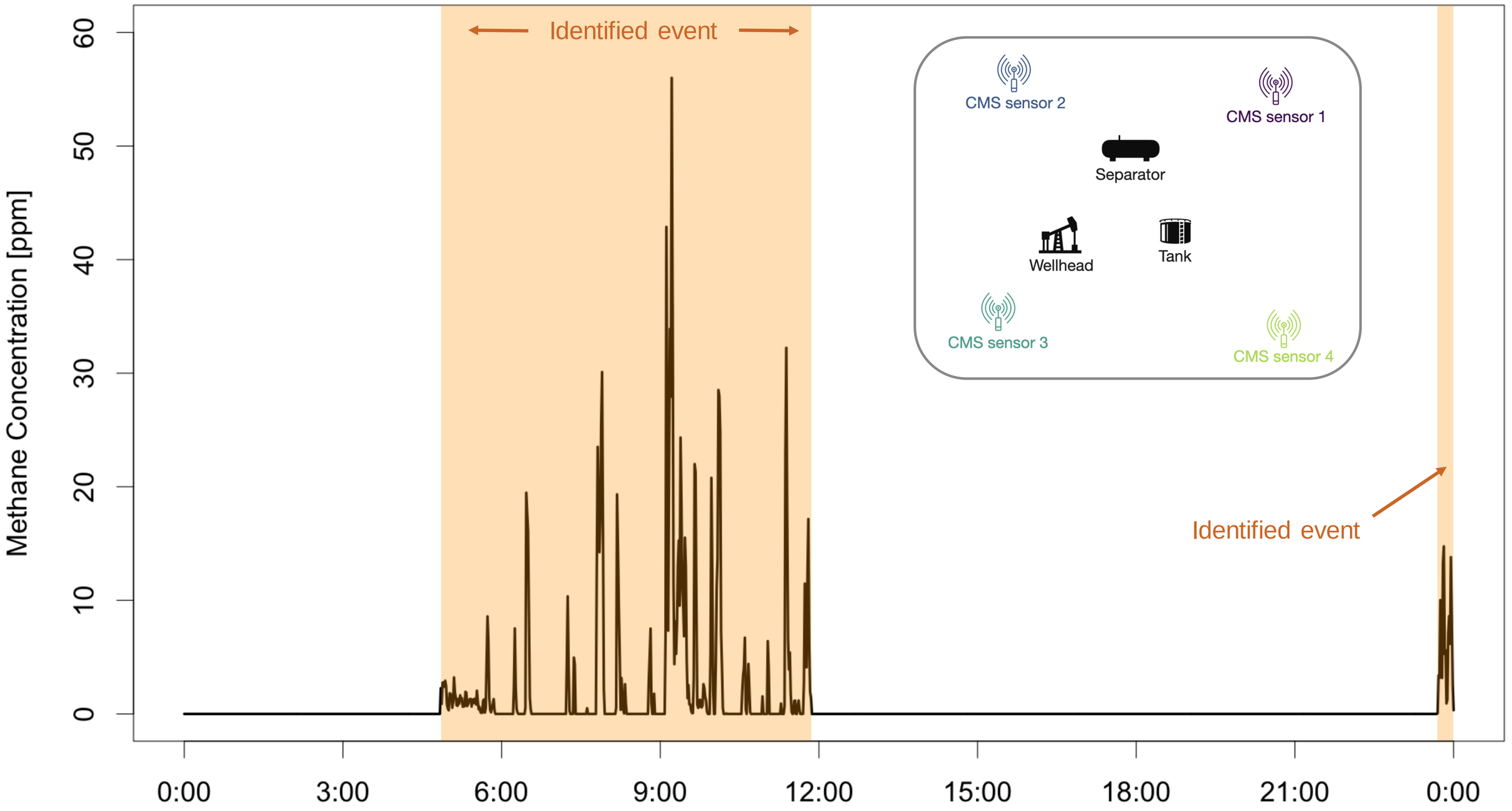


STEP 4:
Quantification

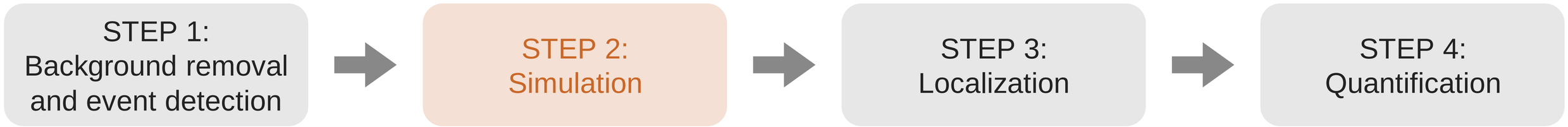

CMS sensor 1
CMS sensor 2
CMS sensor 3
CMS sensor 4
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4

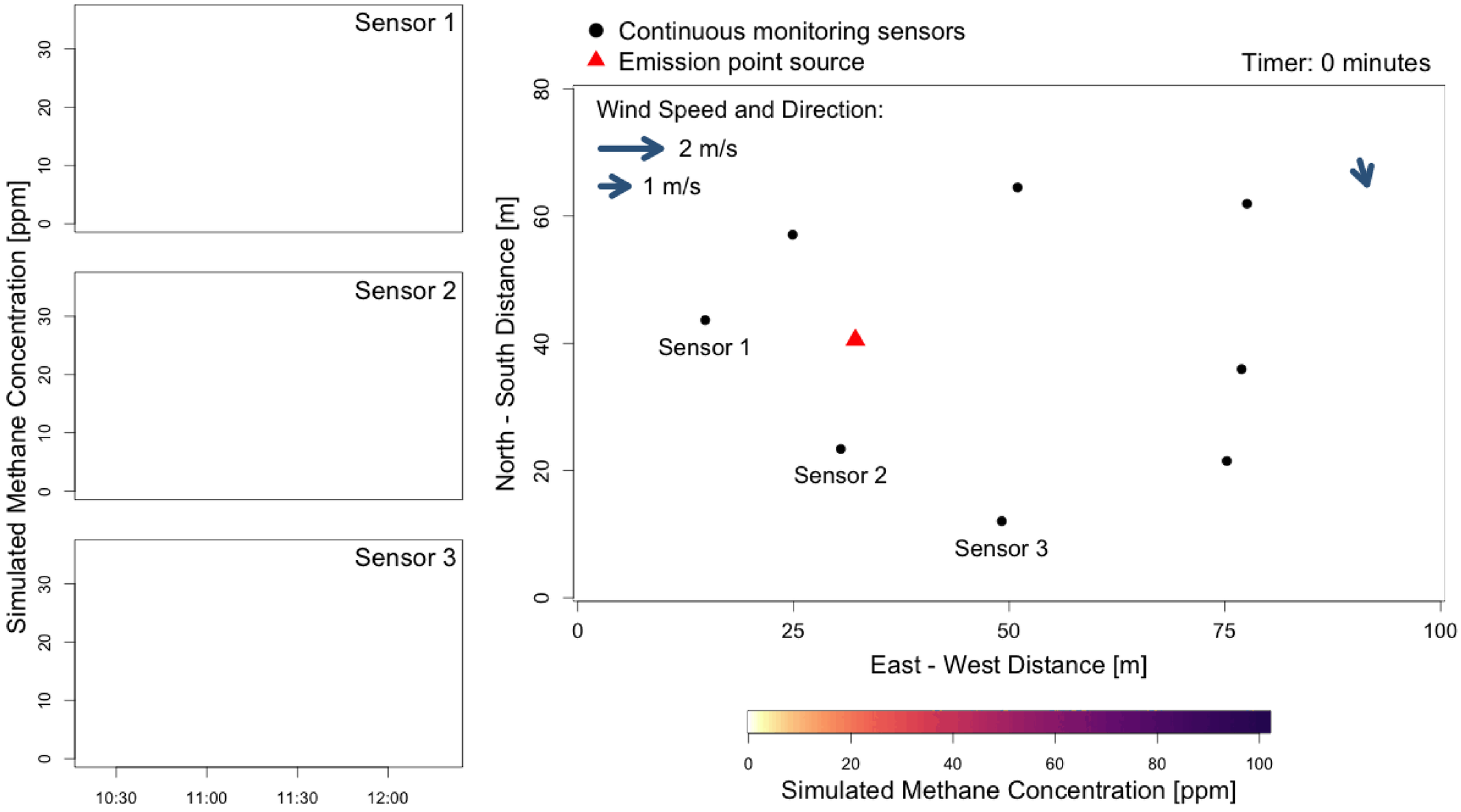

CMS sensor 1
CMS sensor 2
CMS sensor 3
CMS sensor 4
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4

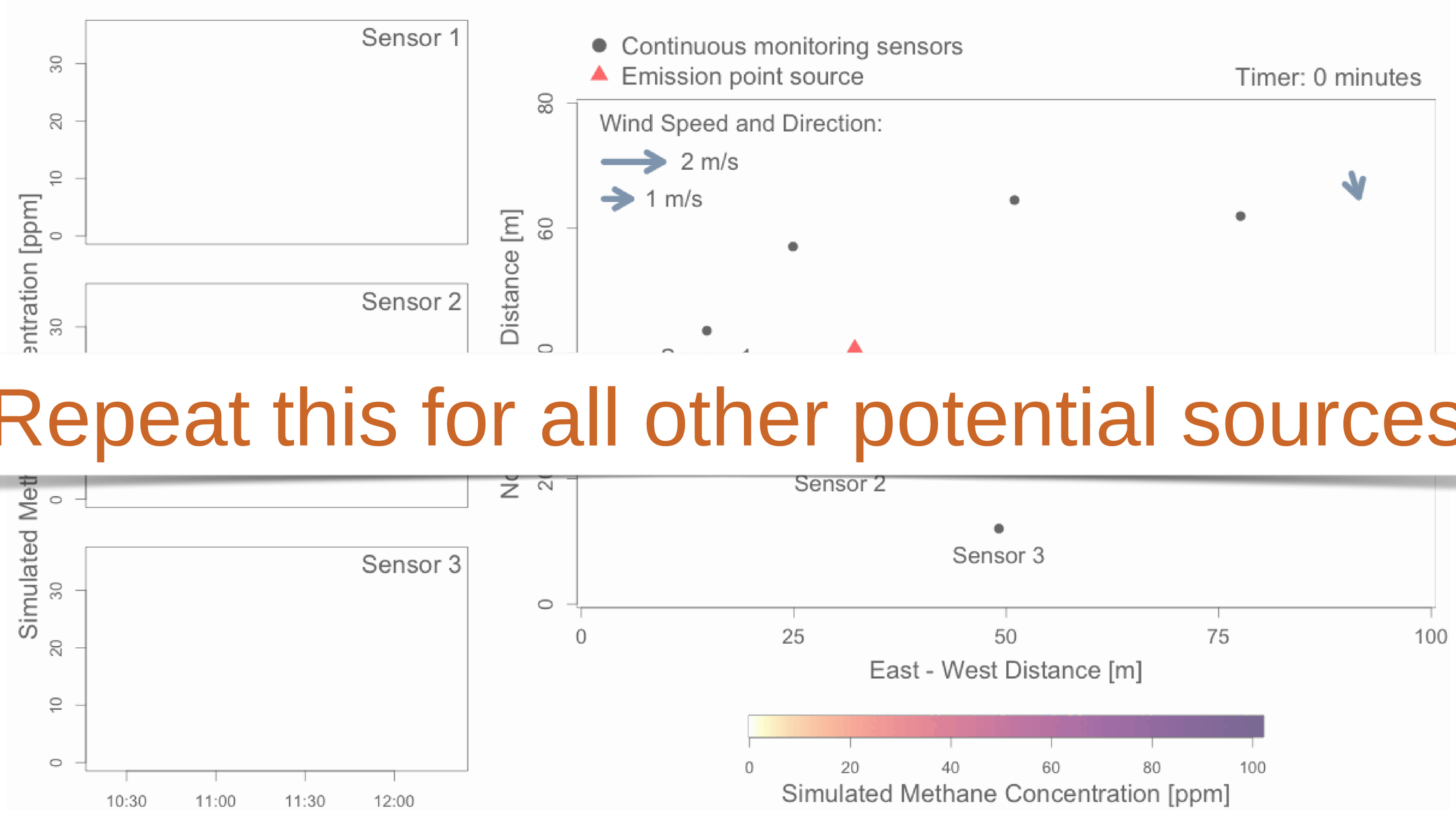

Maximum across sensors
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wellhead
Tank
CMS sensor 3
CMS sensor 4


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

Open source framework for solving inverse problem

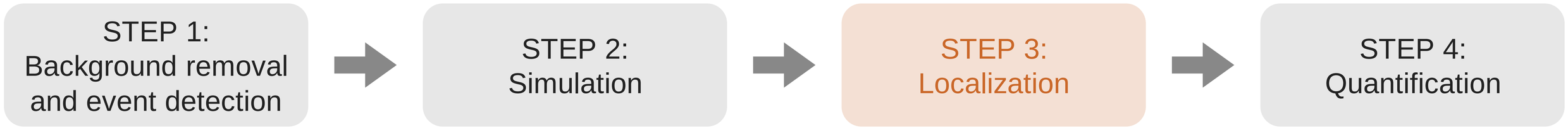



Sensor 1
Sensor 2
Sensor 3
Simulated Methane Concentration [ppm]
0
10
20
30
10:30
11:00
11:30
12:00
Continuous monitoring sensors
Emission point source
Timer: 0 minutes
Wind Speed and Direction:
2 m/s
1 m/s
North - South Distance [m]
0
20
40
60
80
0
25
50
75
100
East - West Distance [m]
Sensor 1
Sensor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



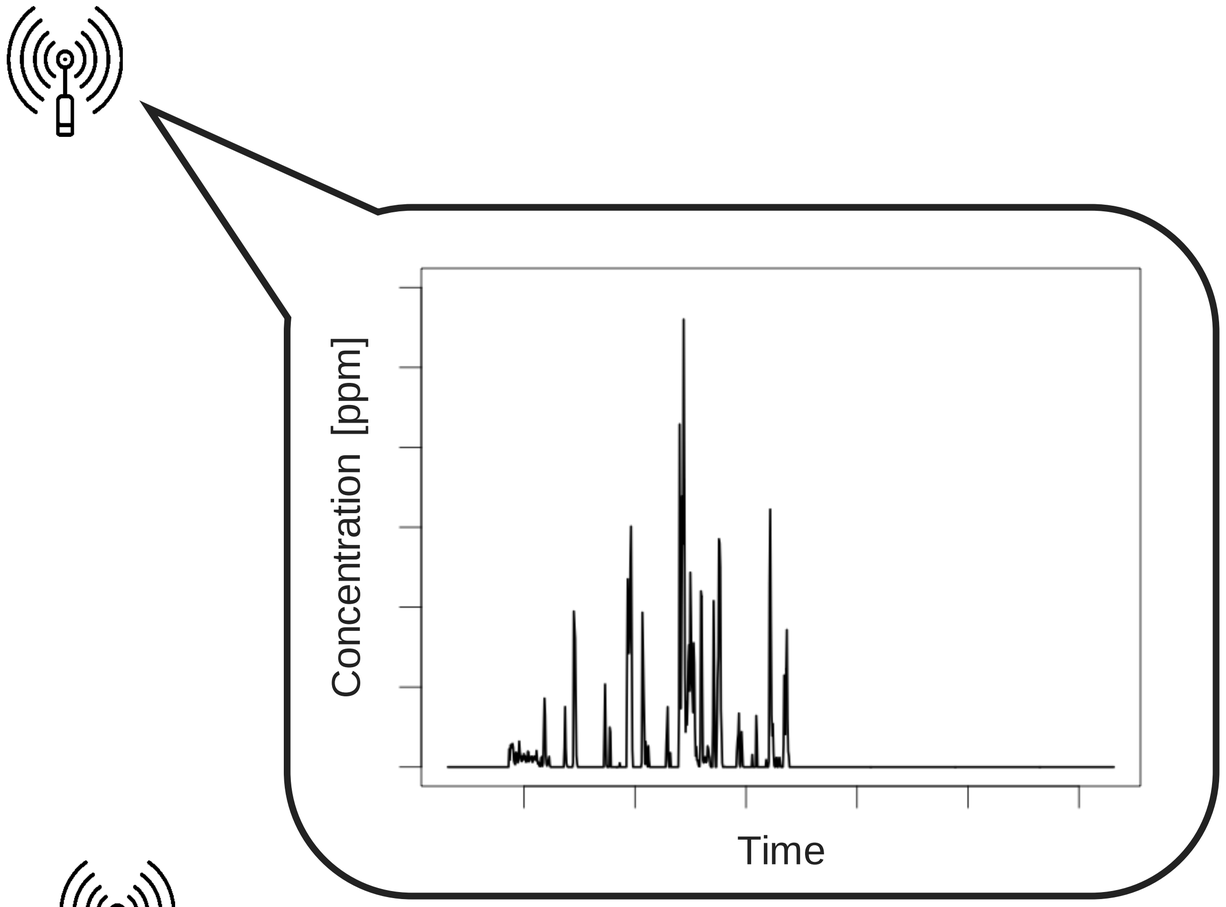
CMS sensor

Separator

Wellhead

Tank

Wind direction



CMS sensor

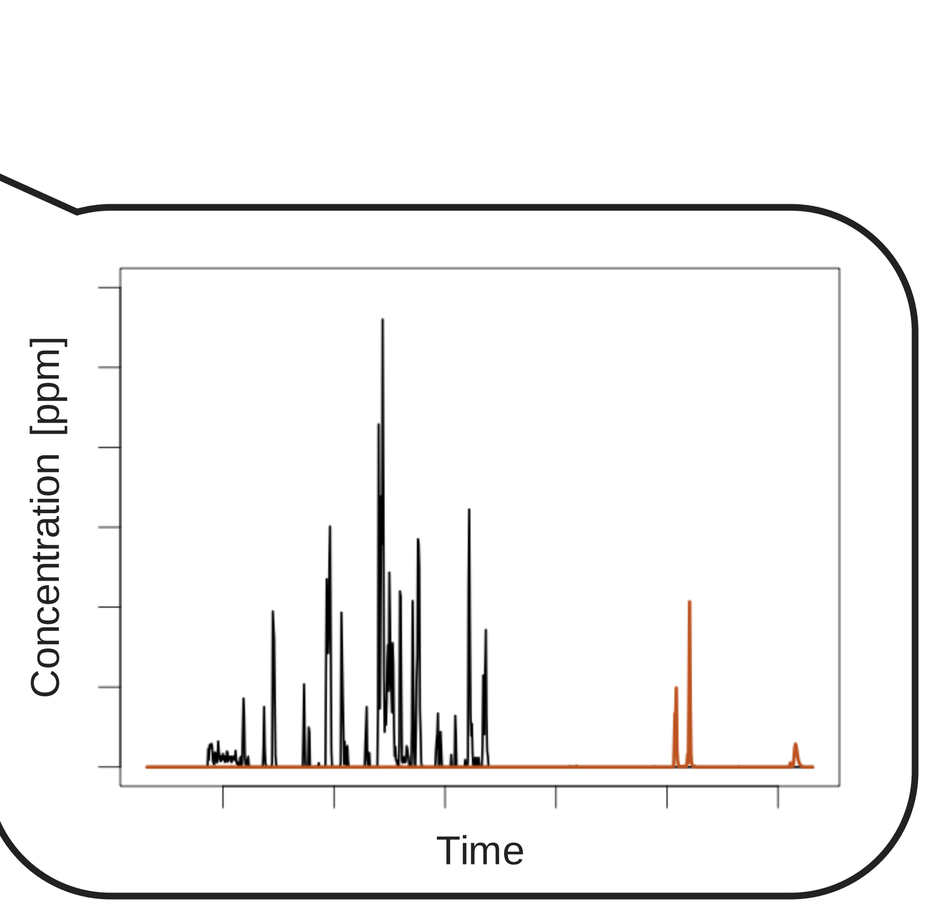
Simulation emission source

Separator

Wellhead

Tank

Wind direction



Background-removed observations

Simulated concentrations

CMS sensor

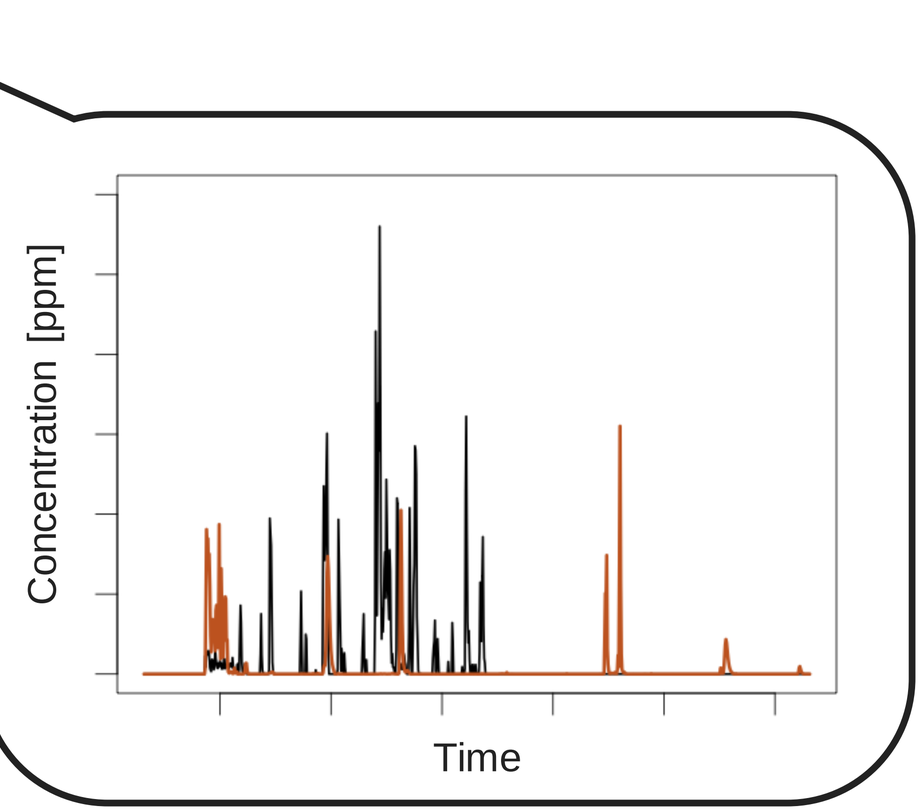
Separator

Wellhead

Simulation emission source

Tank

Wind direction



CMS sensor

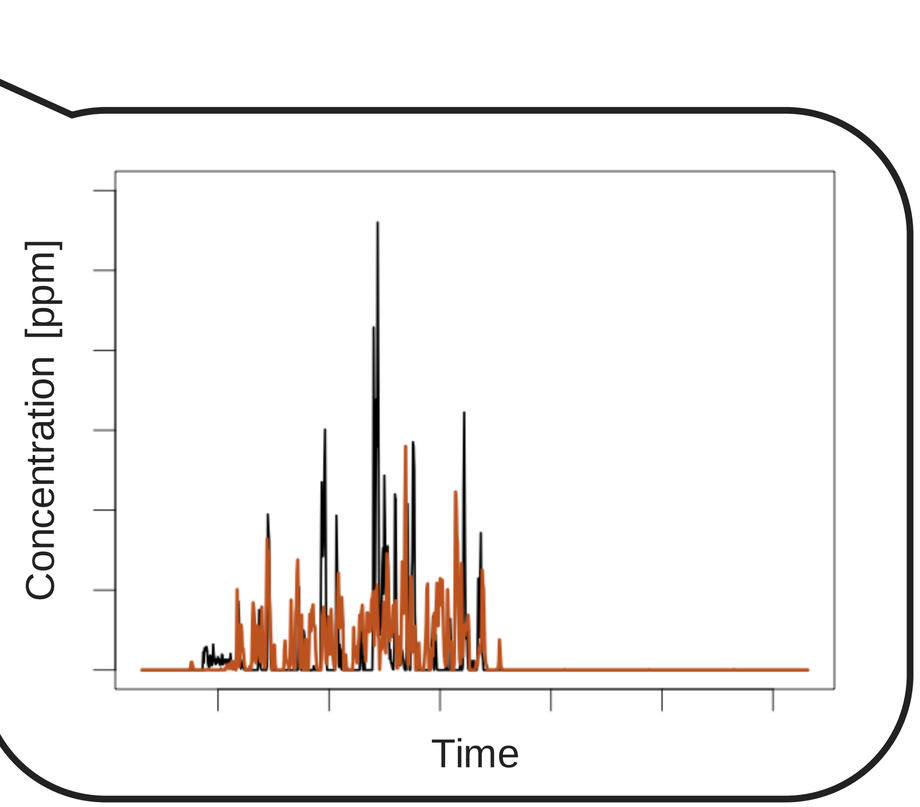
Separator

Wellhead

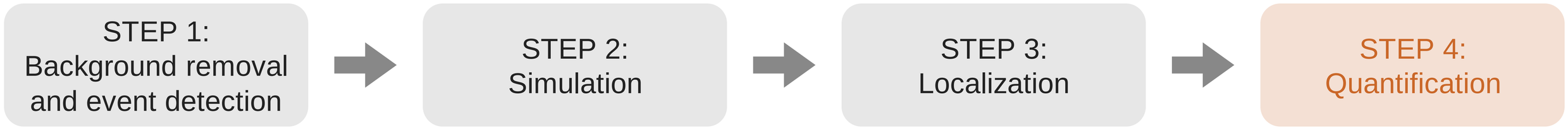
Tank

Simulation emission source

Wind direction



Open source framework for solving inverse problem



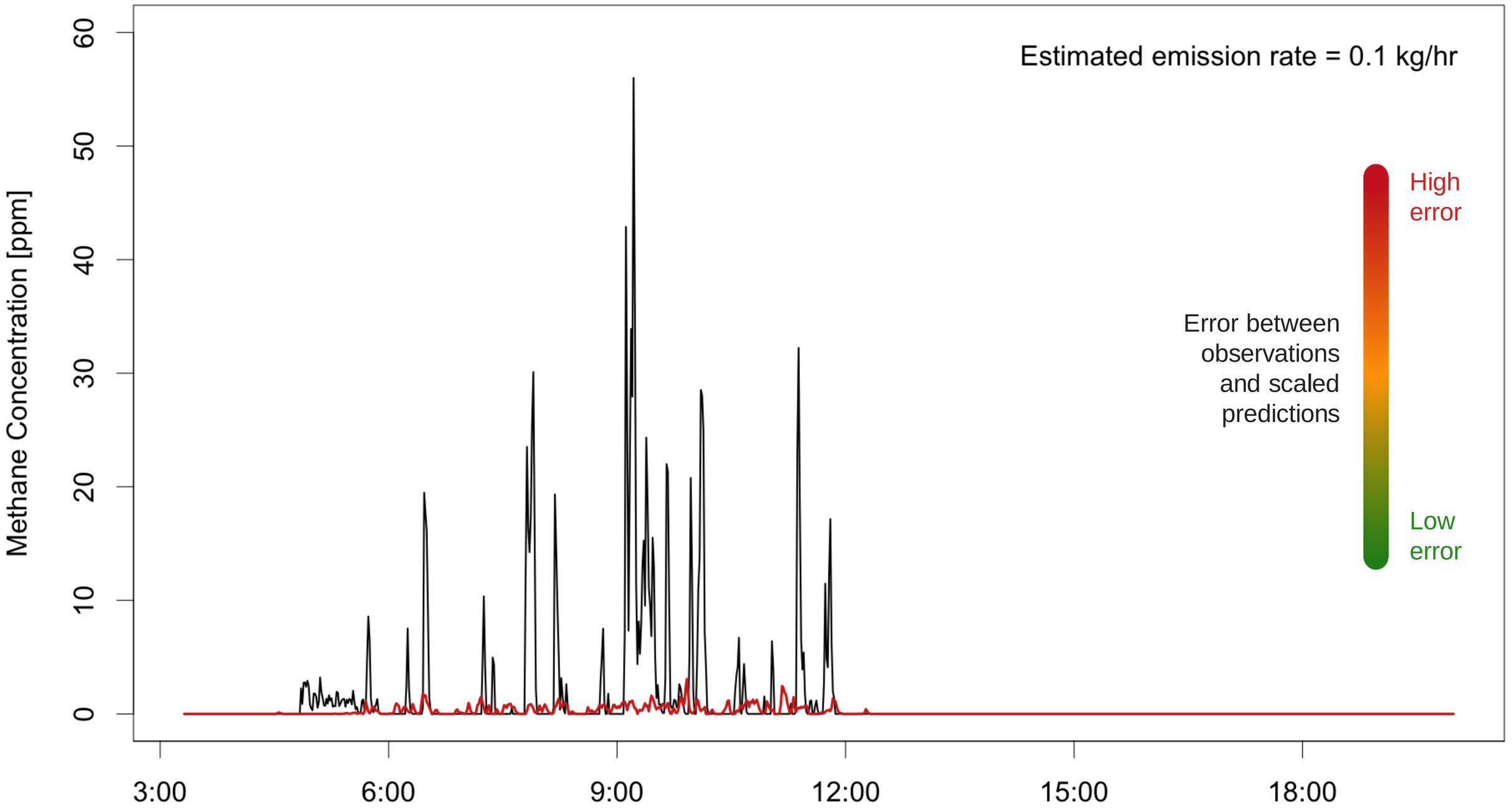
Simulation is a linear function of emission rate

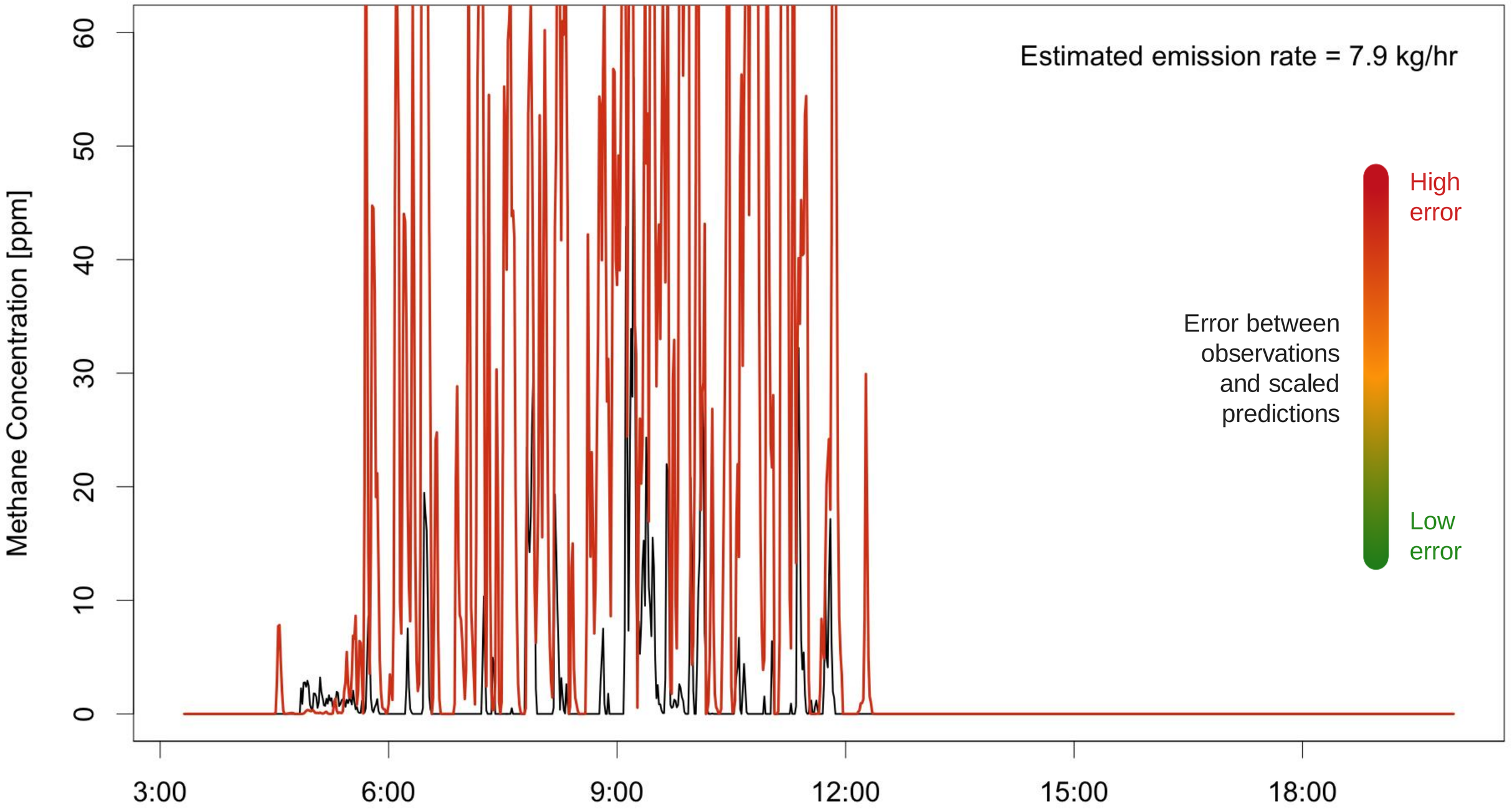
Emission rate

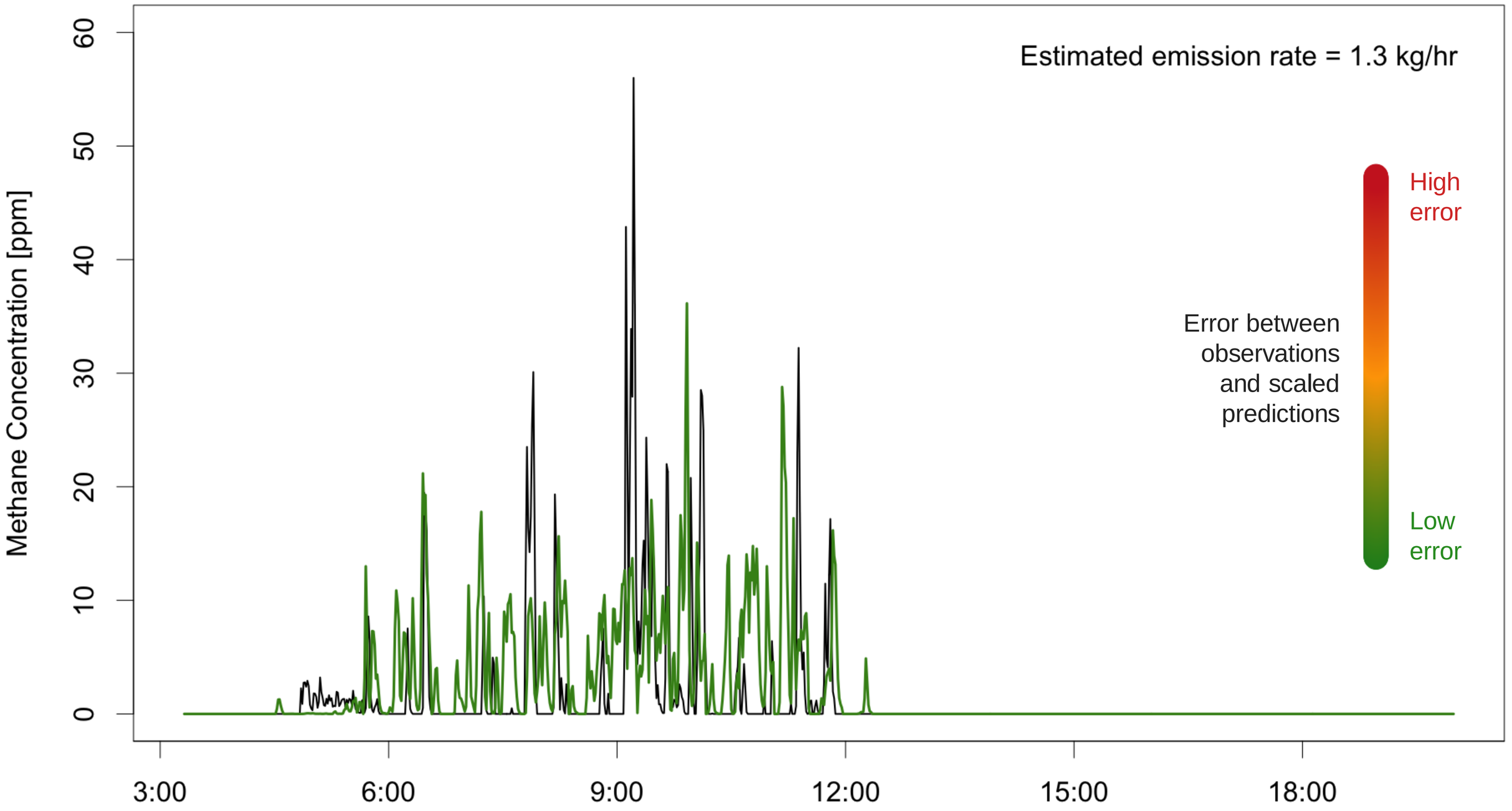
$$c_p(x,y,z,t) = Q\,\frac{1}{(2\pi)^{3/2}\sigma_y^2\sigma_z}\exp\left(-\frac{(x-ut)^2+y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

Simulation output: concentrations

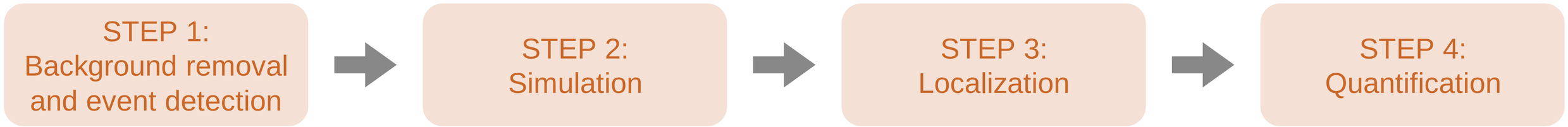
"Everything else"


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

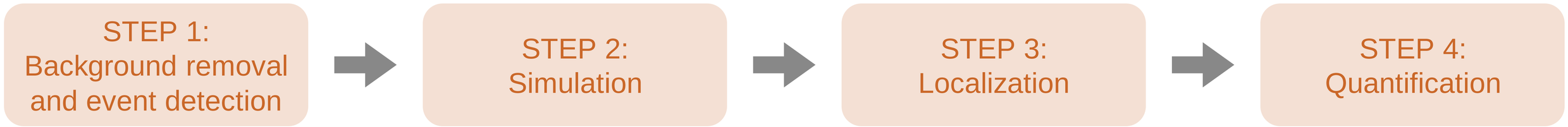

Estimated emission rate = 7.9 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Error between observations and scaled predictions
High error
Low error


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

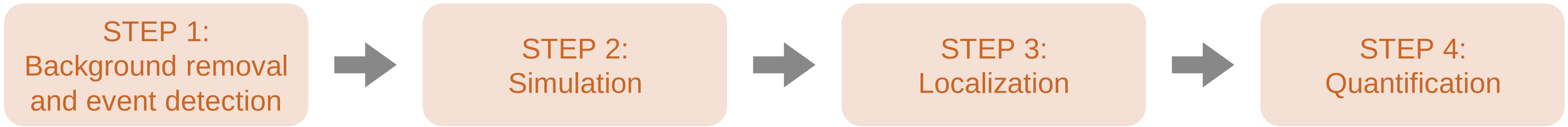


Open source framework for solving inverse problem

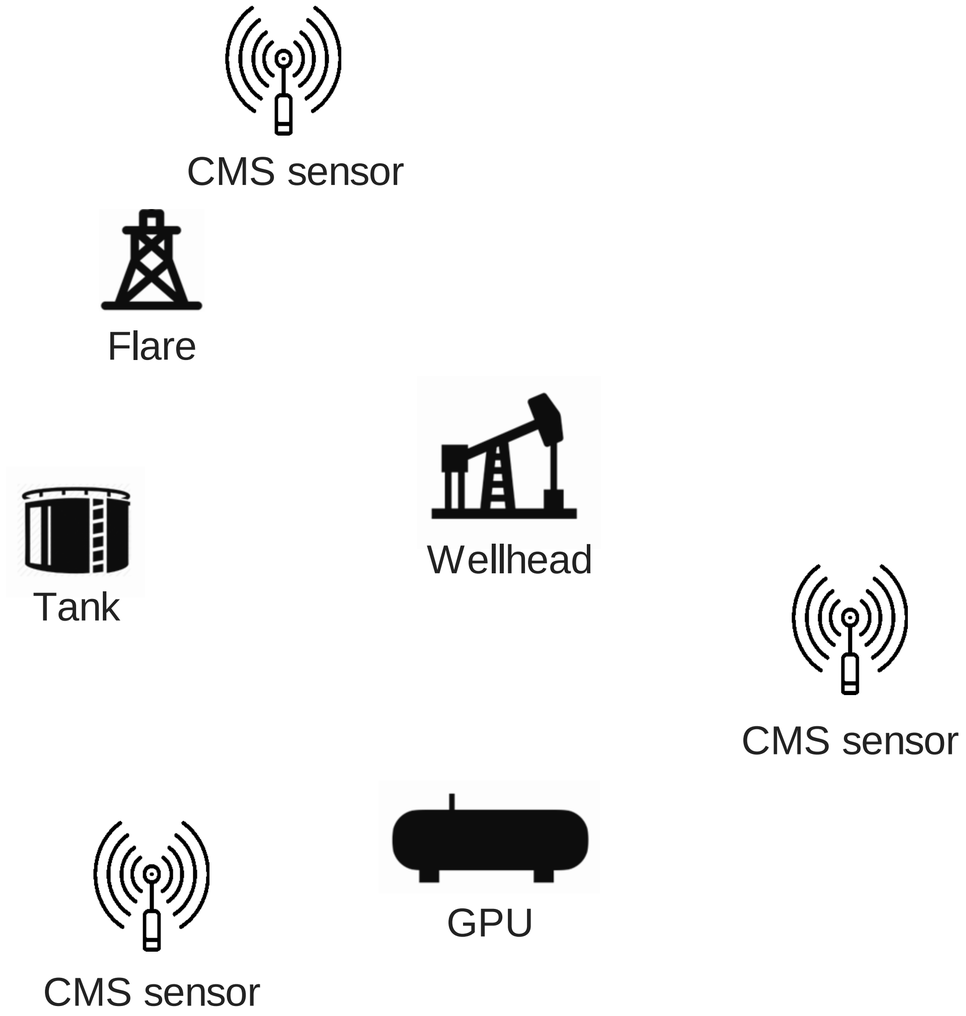


1. Open source and transparent!

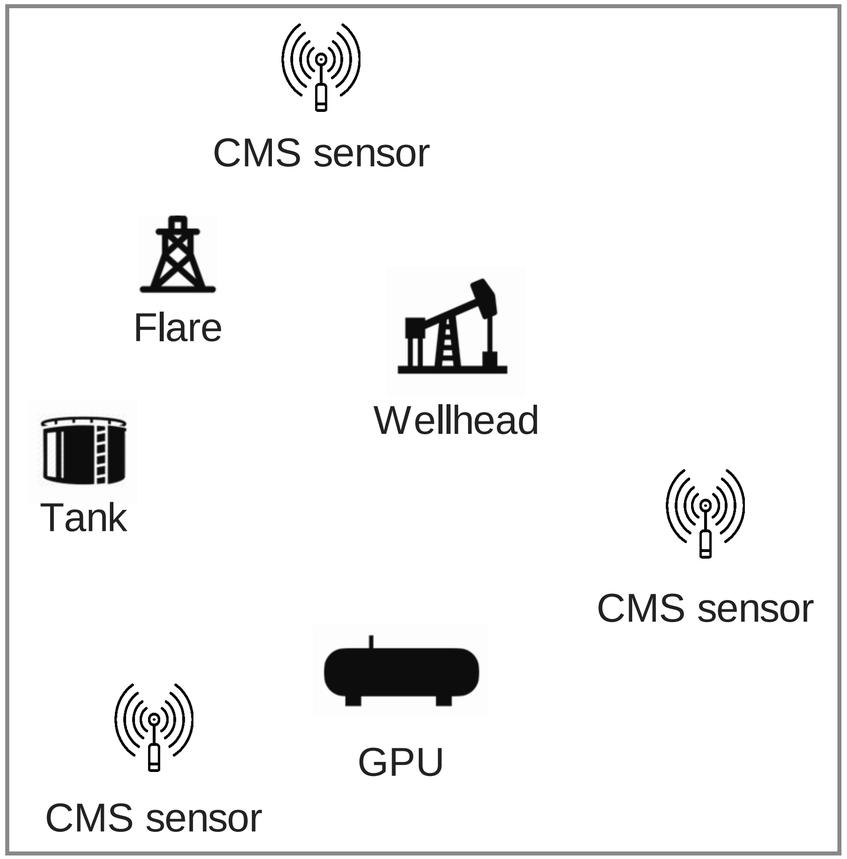
Open source framework for solving inverse problem



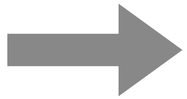
1. Open source and transparent!
2. Single-source emissions only. Currently developing a multi-source upgrade.



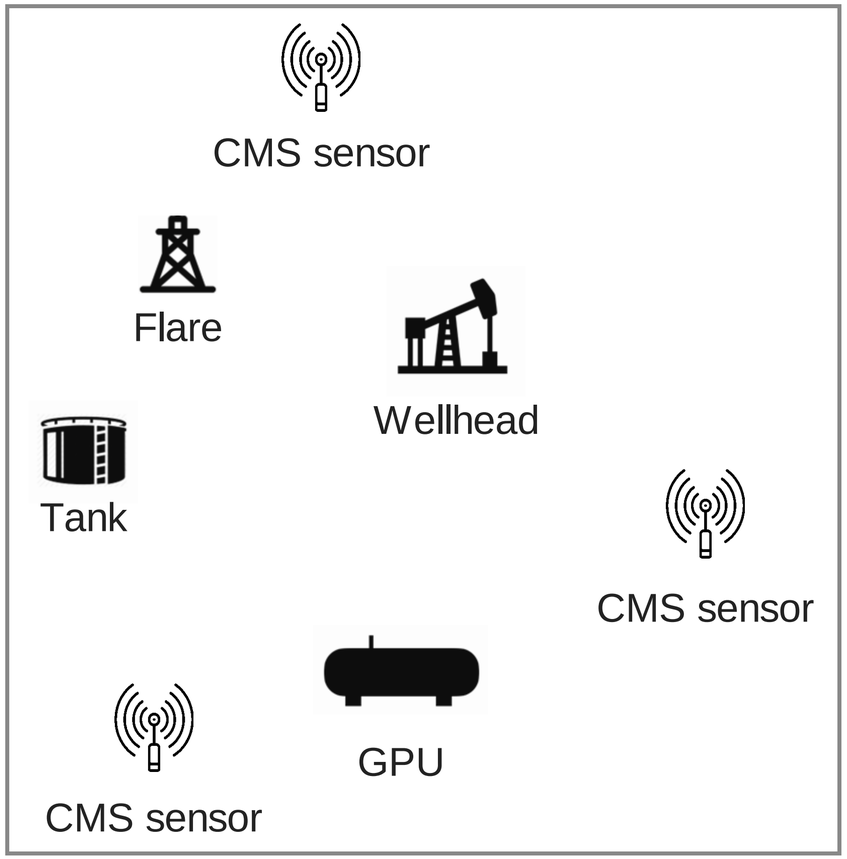
Measurement-informed inventory case study



13 snapshot measurements over 4 days

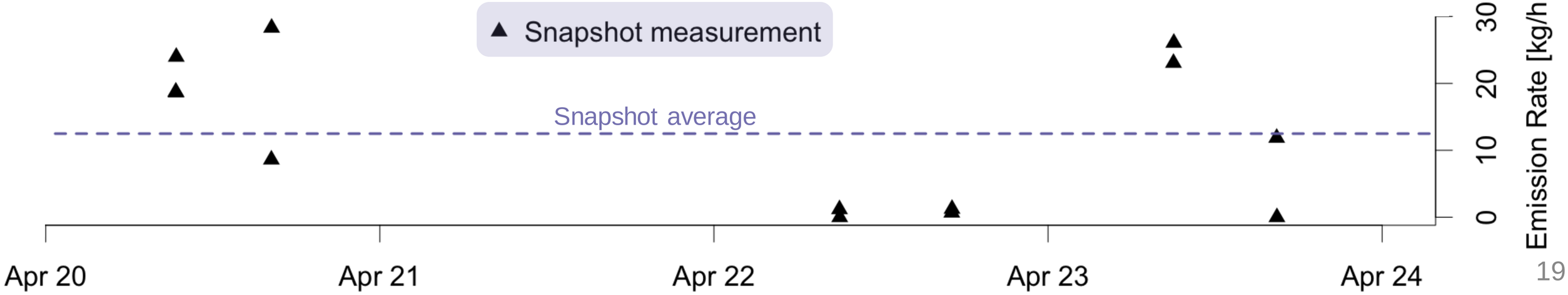


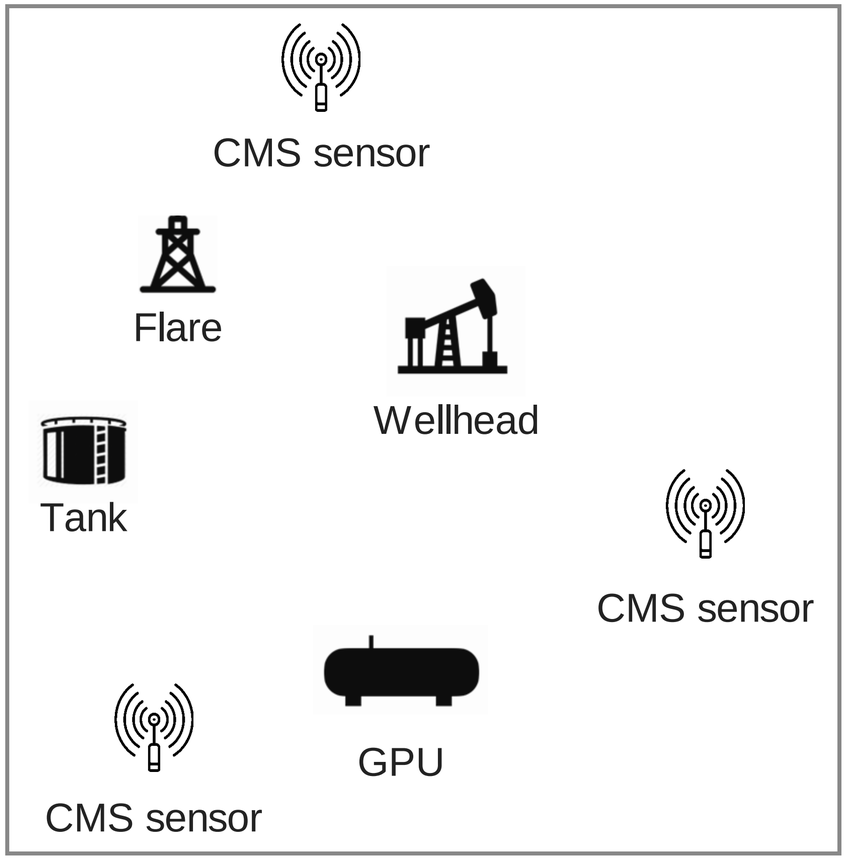
average = 12.5 kg/hr



13 snapshot measurements over 4 days

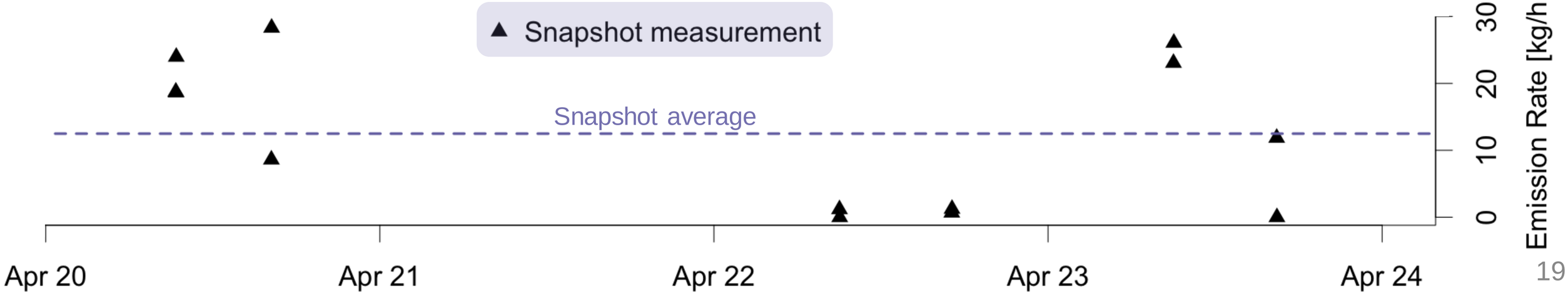
average = 12.5 kg/hr

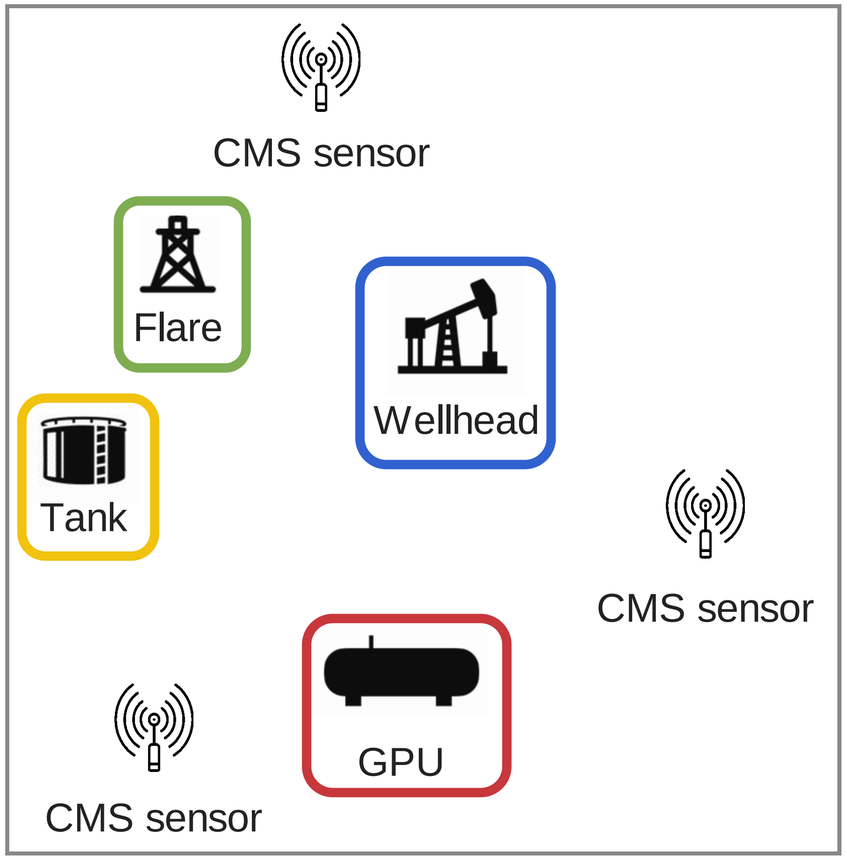




13 snapshot measurements over 4 days → average = 12.5 kg/hr

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



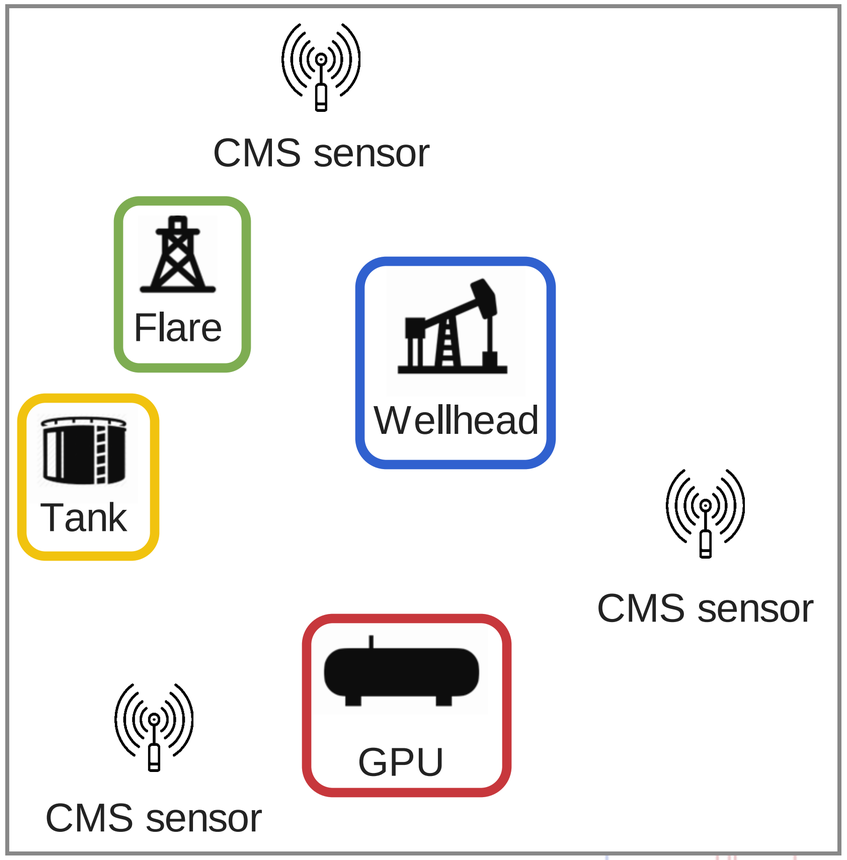


Tank
GPU
Wellhead
Flare
No emissions

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

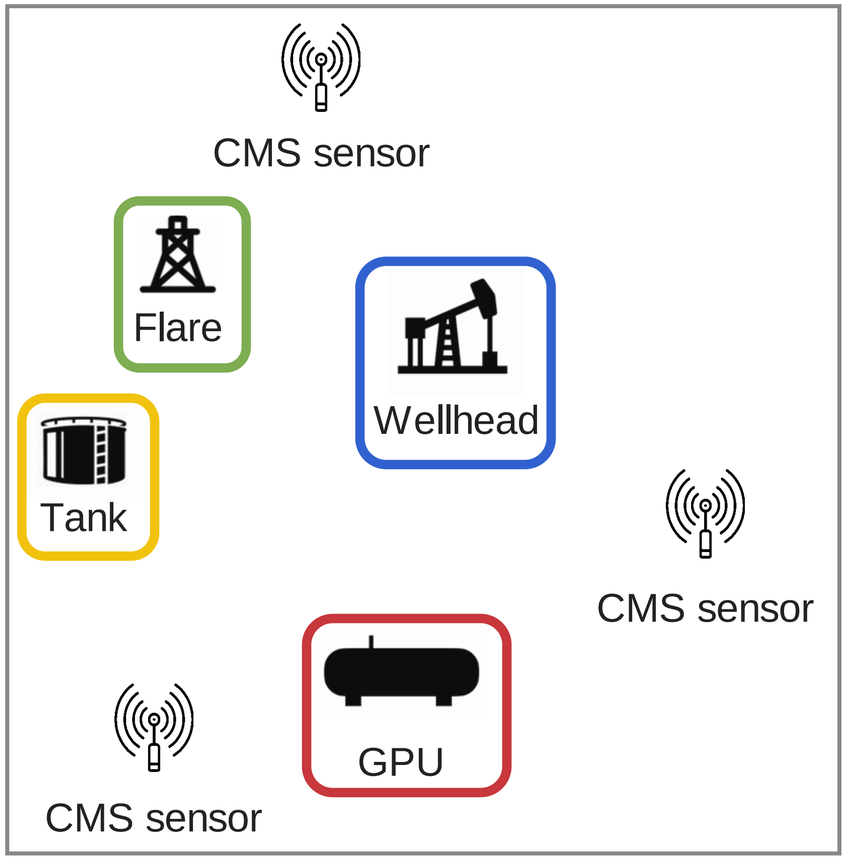


Tank
GPU
Wellhead
Flare
No emissions

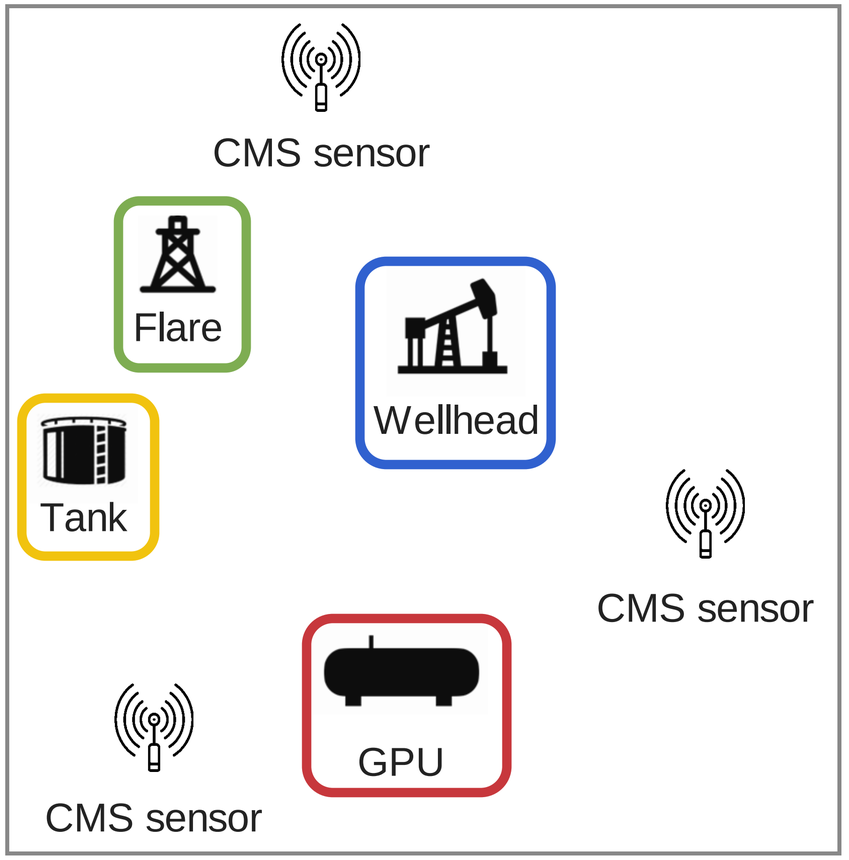
Emission Rate [kg/hr]

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

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



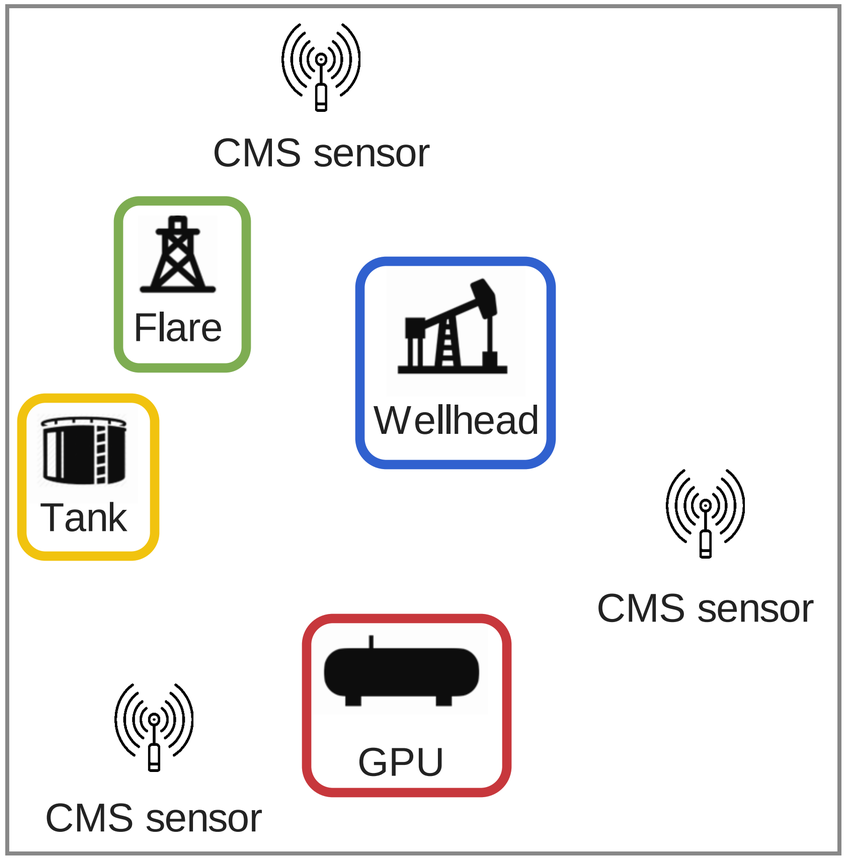
Company emissions inventory (shown as bars)

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

0

2

4

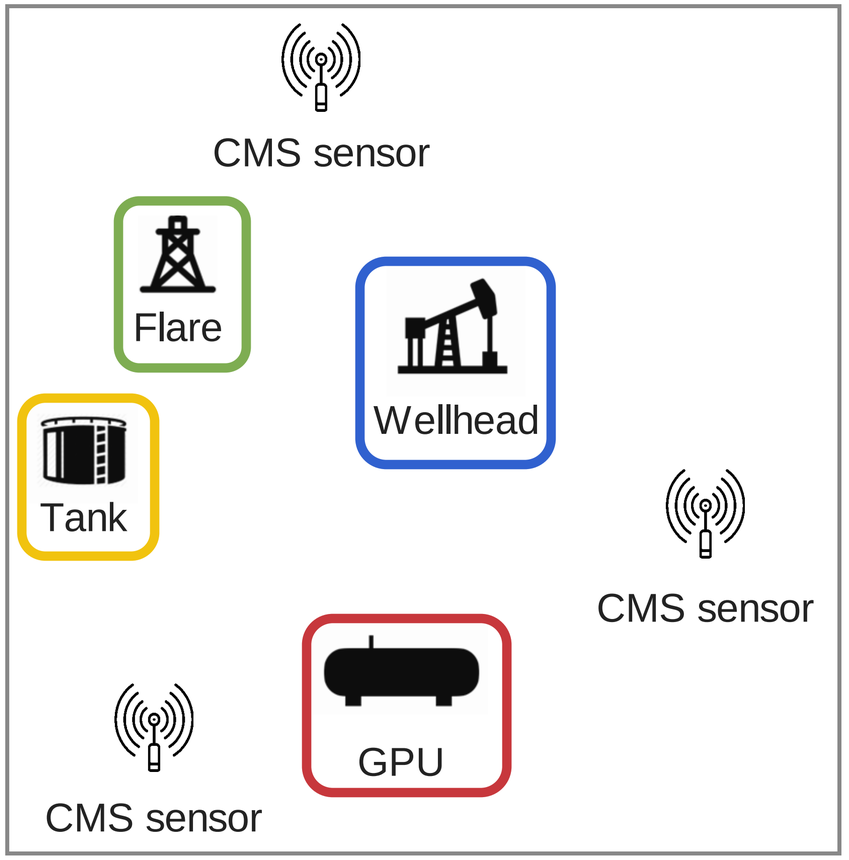
6

8

10

12

Emission Rate [kg/hr]



Company emissions inventory (shown as bars)

CMS-based inventory estimate

Equipment change on February 23rd

Site total

Oct

Nov

Dec

Jan

Feb

Mar

Apr

Emission Rate [kg/hr]

0

2

4

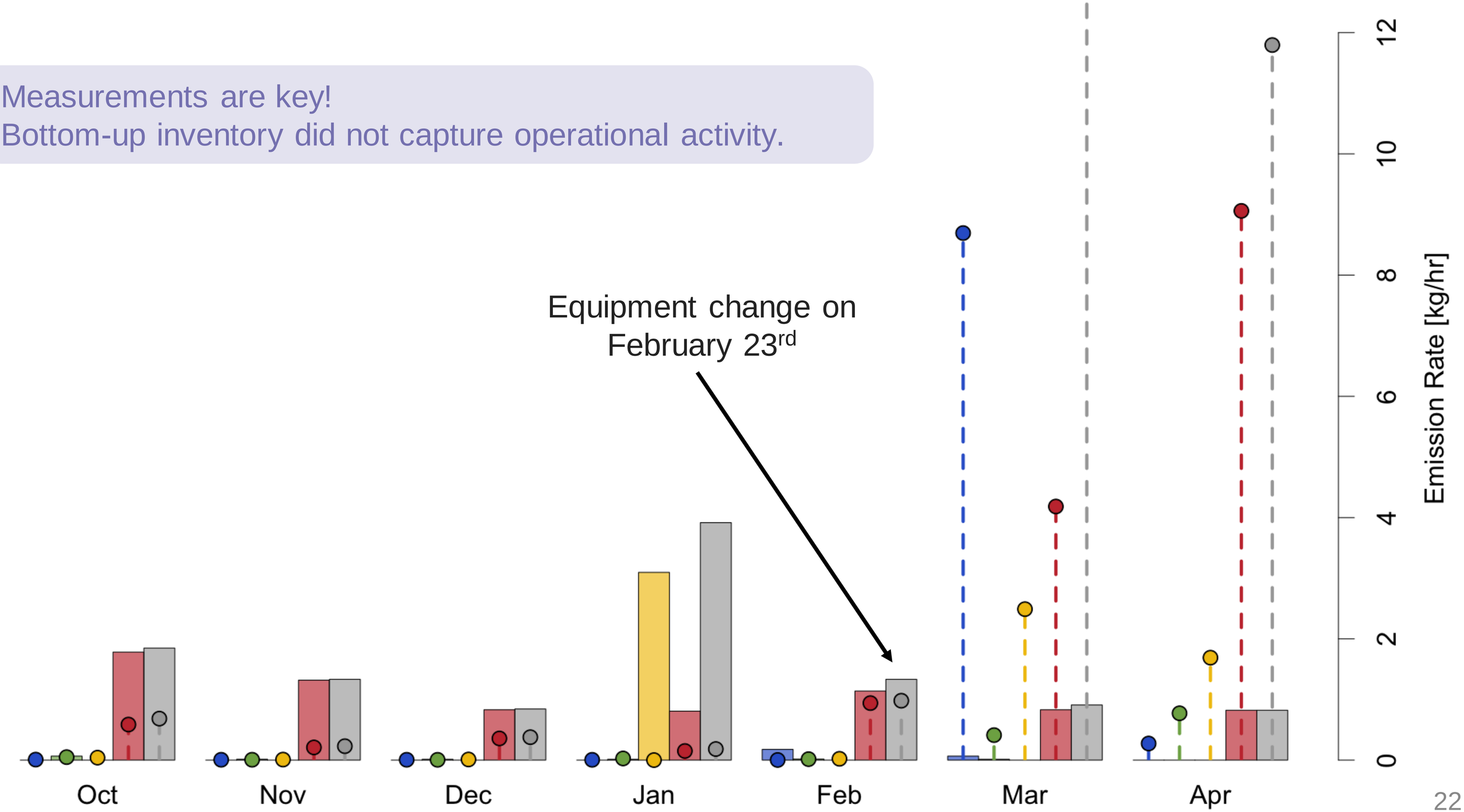
6

8

10

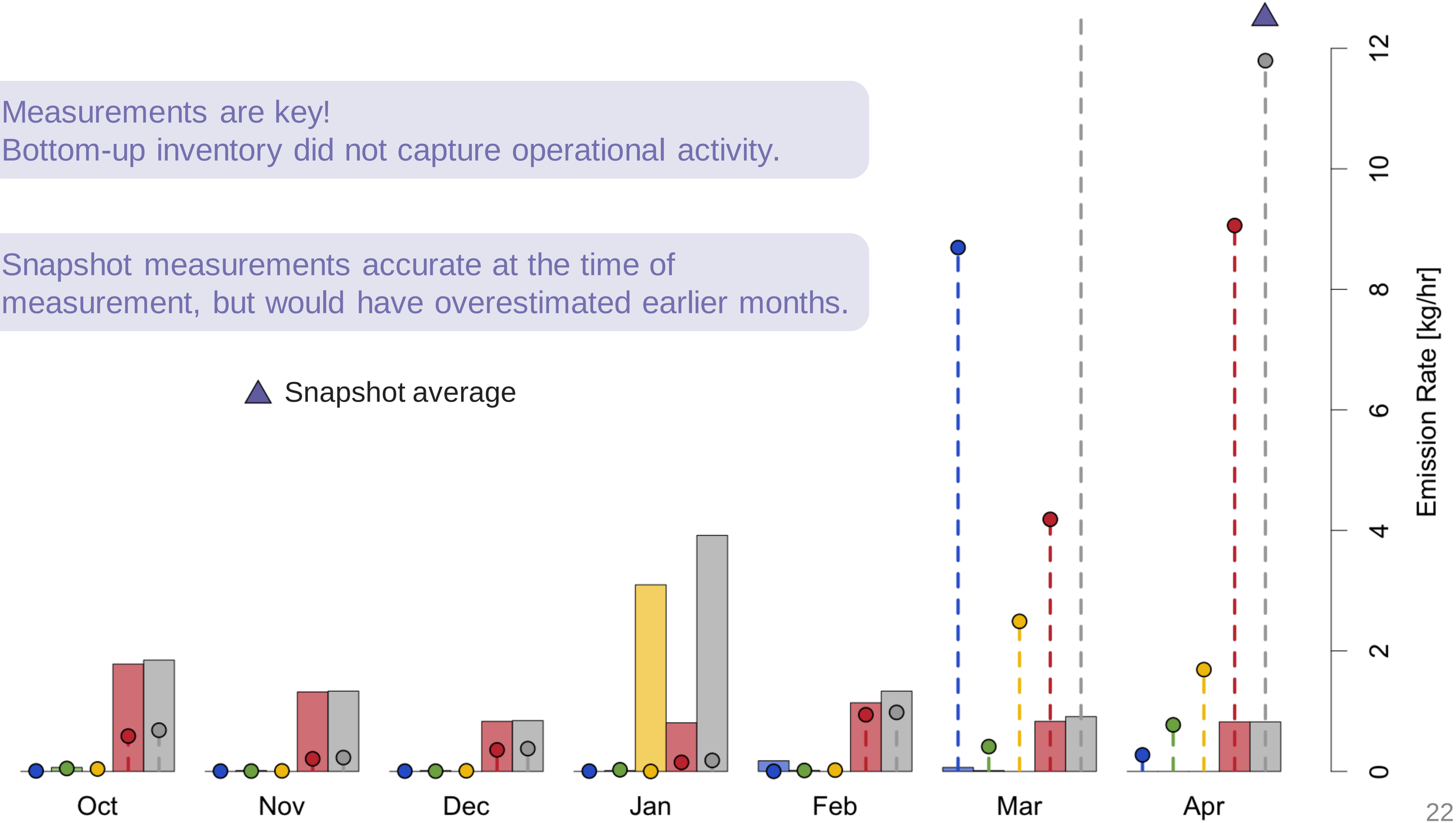
12

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

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

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.

William Daniels, Jiayang (Lyra) Wang, Arvind Ravikumar, Matthew Harrison, Selina Roman-White, Fiji George, Dorit Hammerling. *Environmental Science and Technology*, (2023).

wdaniels@mines.edu