CMS Series #1:

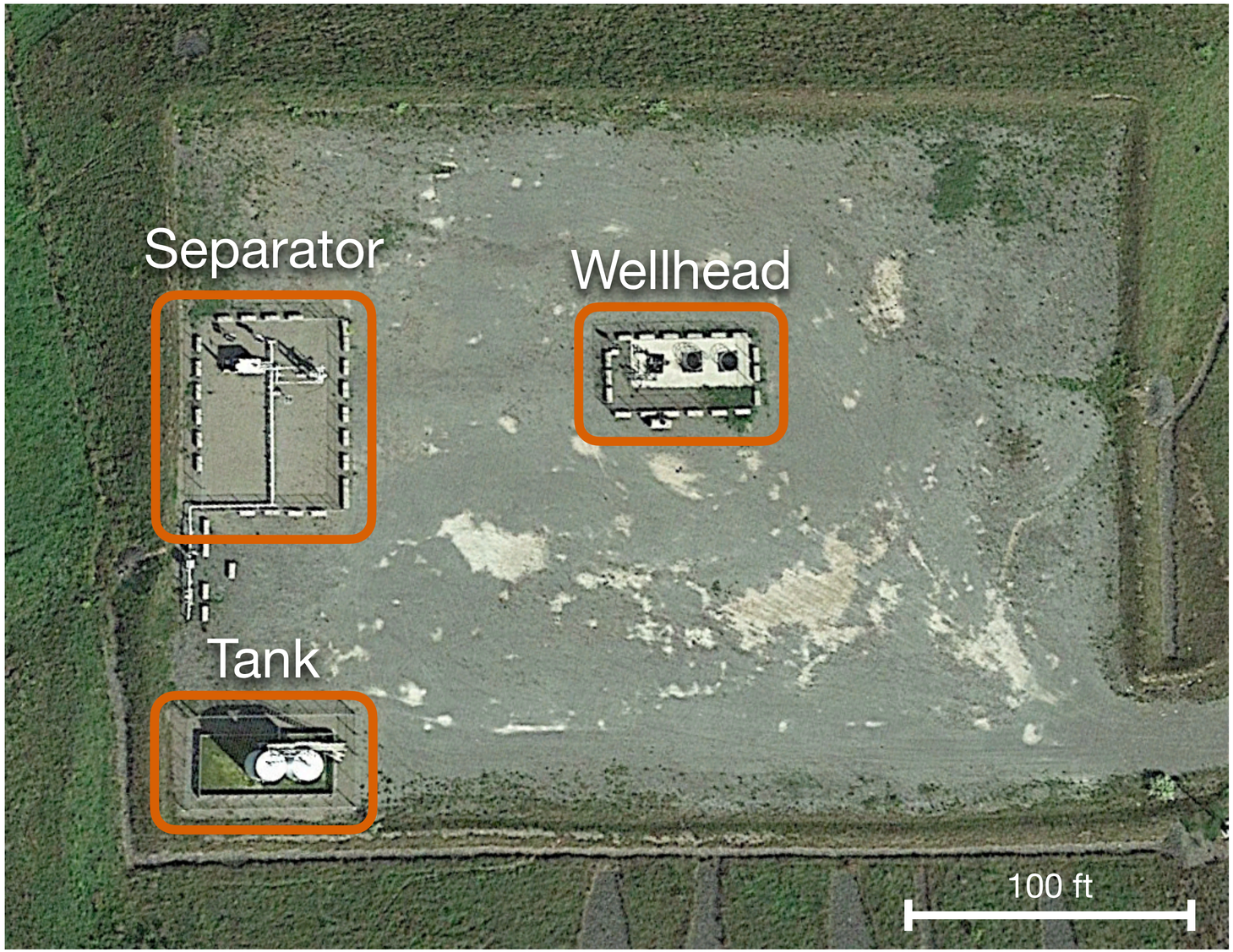
Modeling single-source methane emissions on oil and gas sites

William Daniels

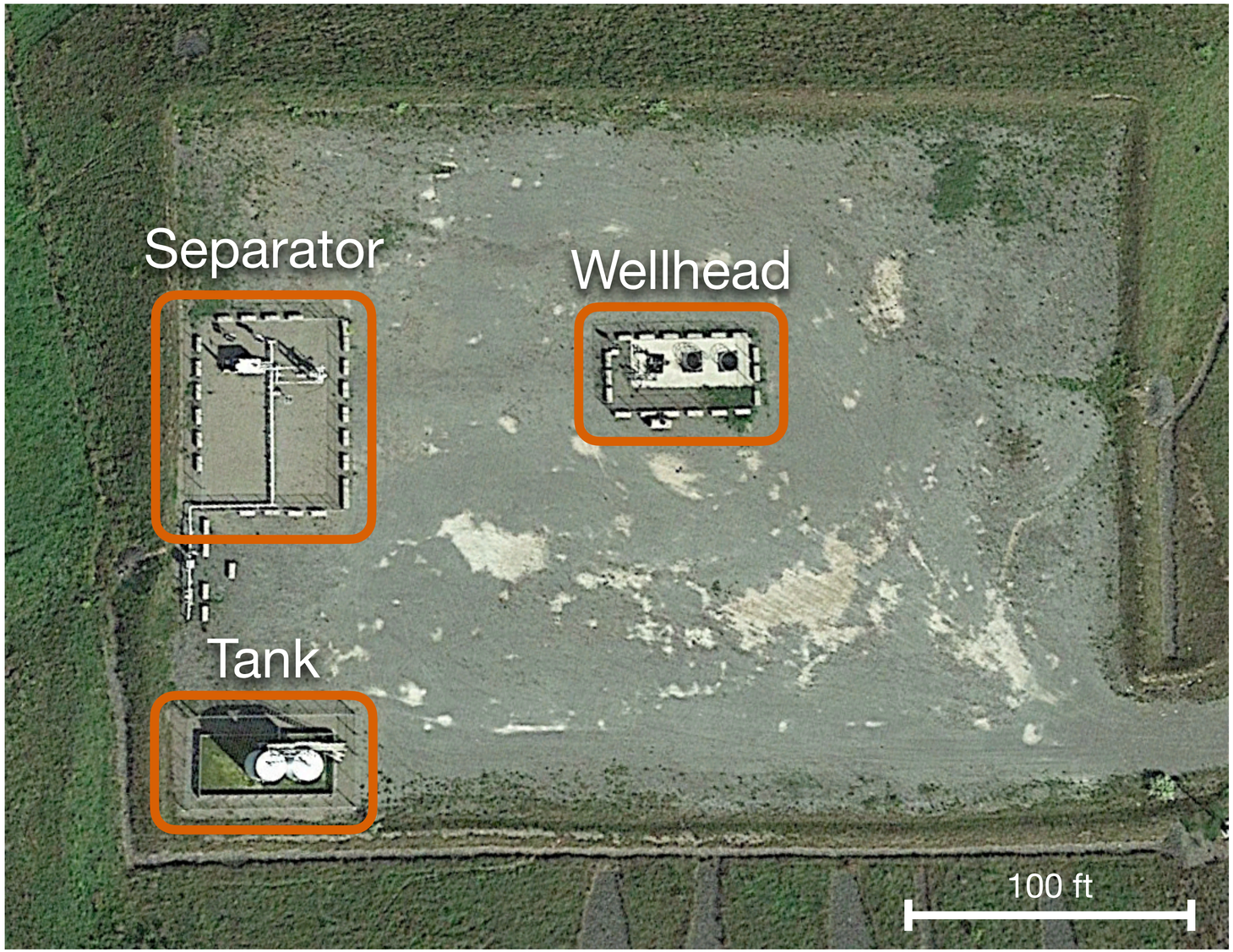
Department of Applied Mathematics and Statistics

COLORADO SCHOOL OF MINES

Example production oil and gas site

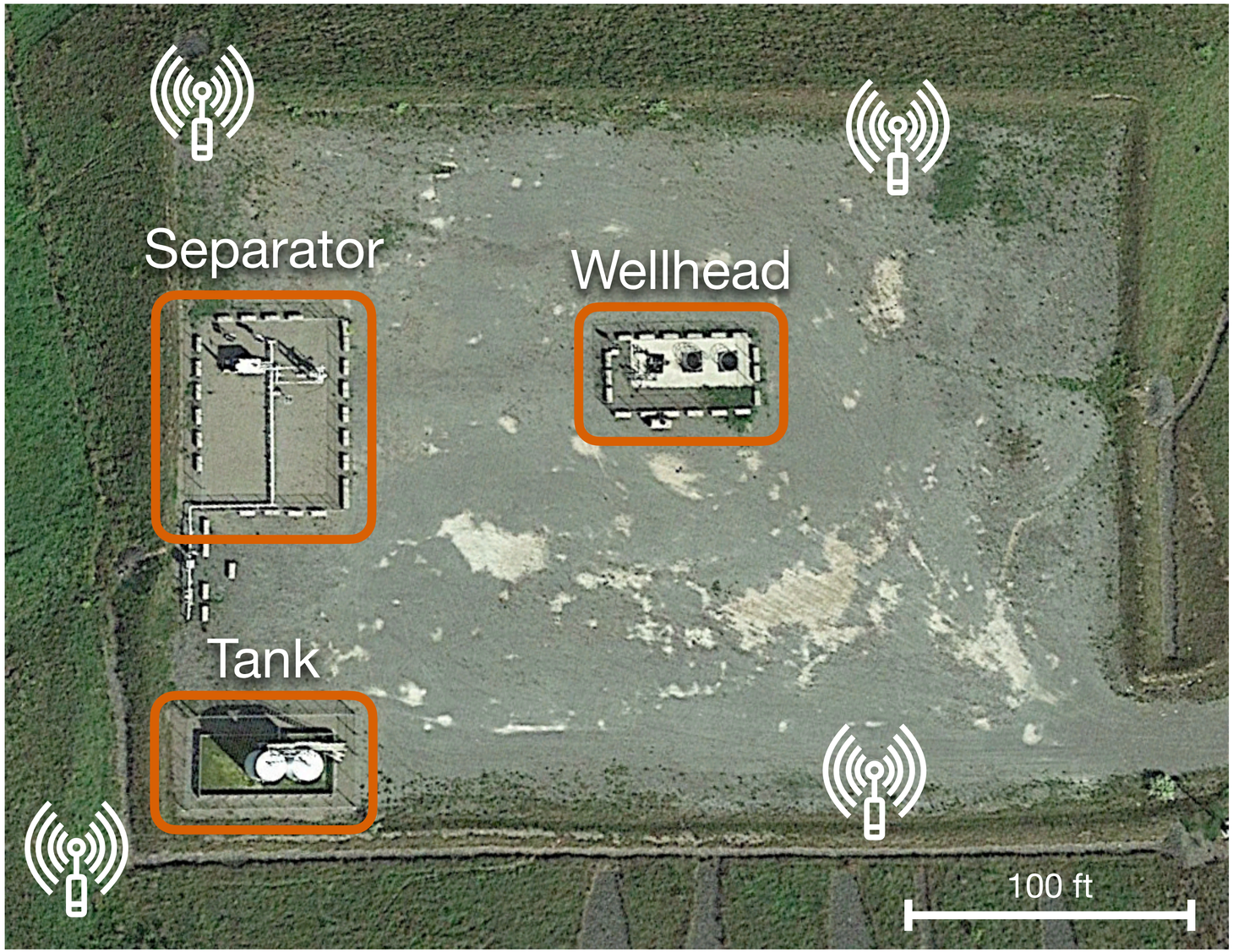


Example production oil and gas site



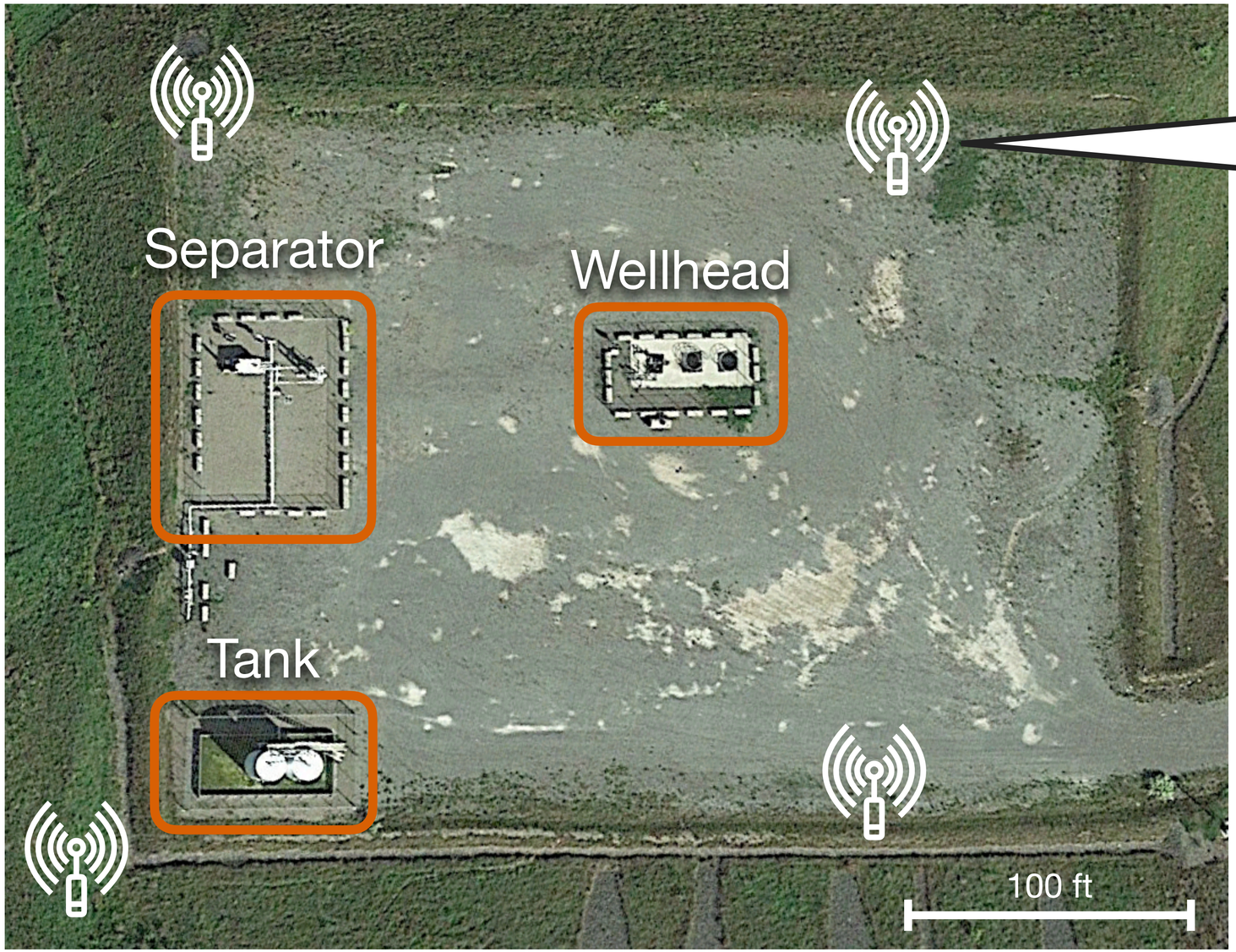
Continuous monitoring system (CMS)

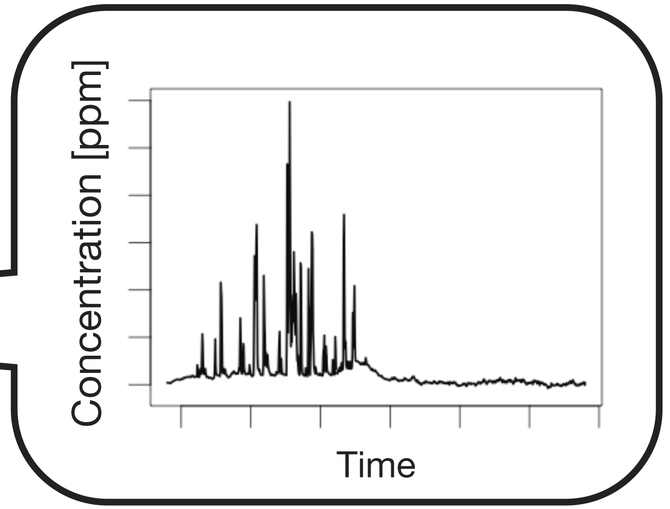
Example production oil and gas site



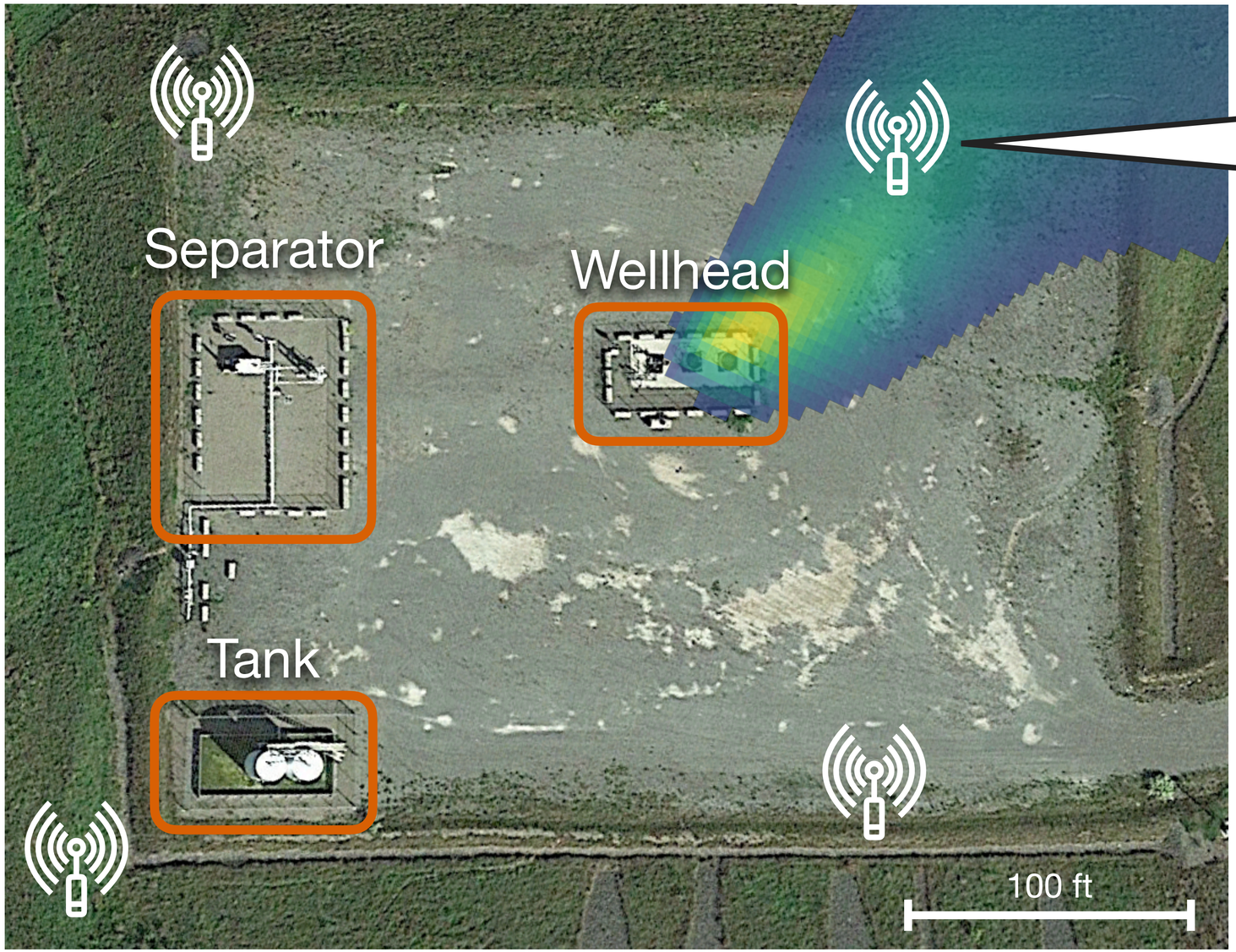
Continuous monitoring system (CMS)

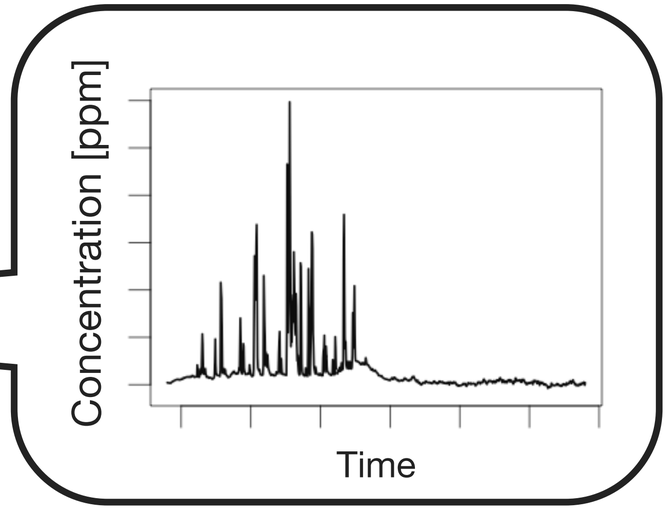
Example production oil and gas site





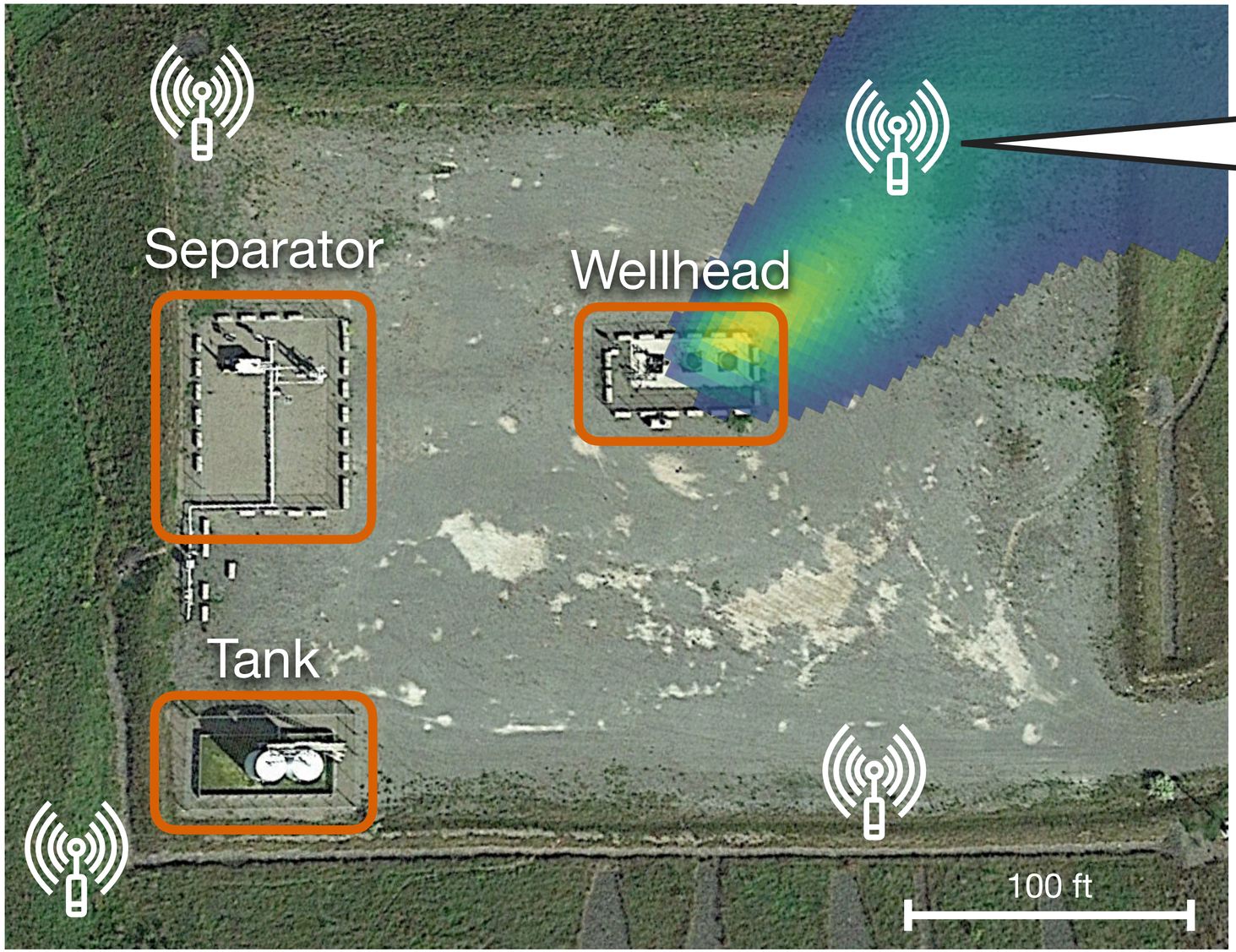
Example production oil and gas site

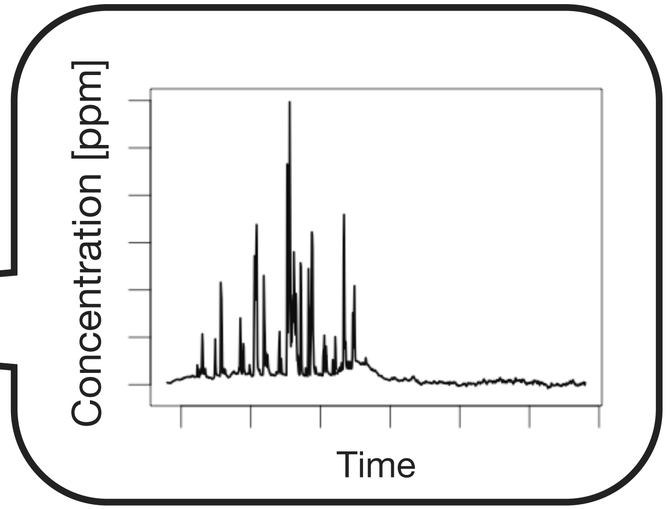




Aerial measurement technology

Example production oil and gas site



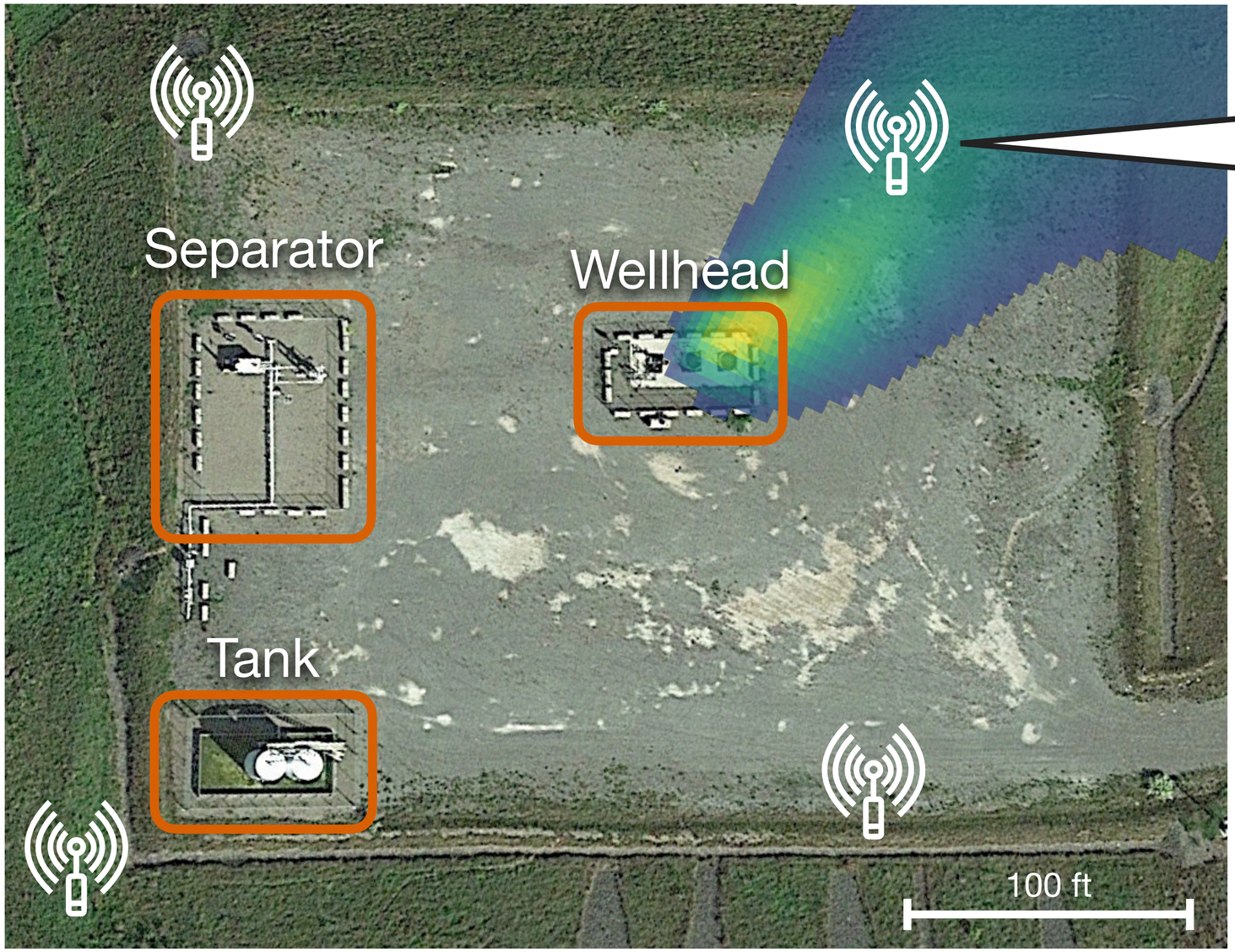


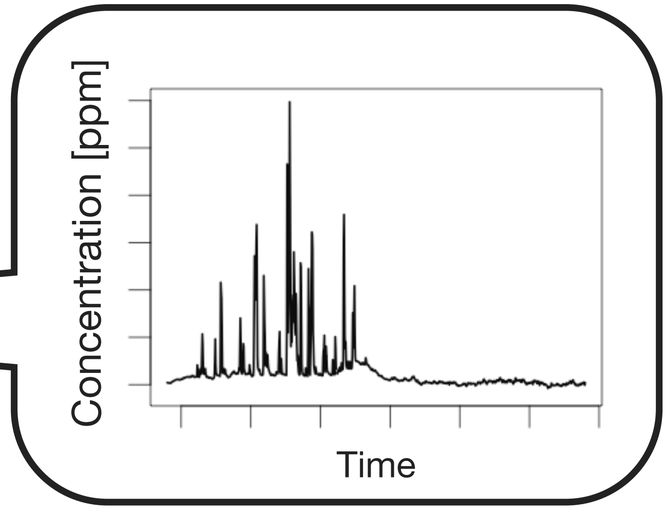
Aerial measurement technology

Bottom-up inventory estimate =

1 wellhead	x	wellhead emission factor	+
1 separator	x	separator emission factor	+
1 tank	x	tank emission factor	

Example production oil and gas site





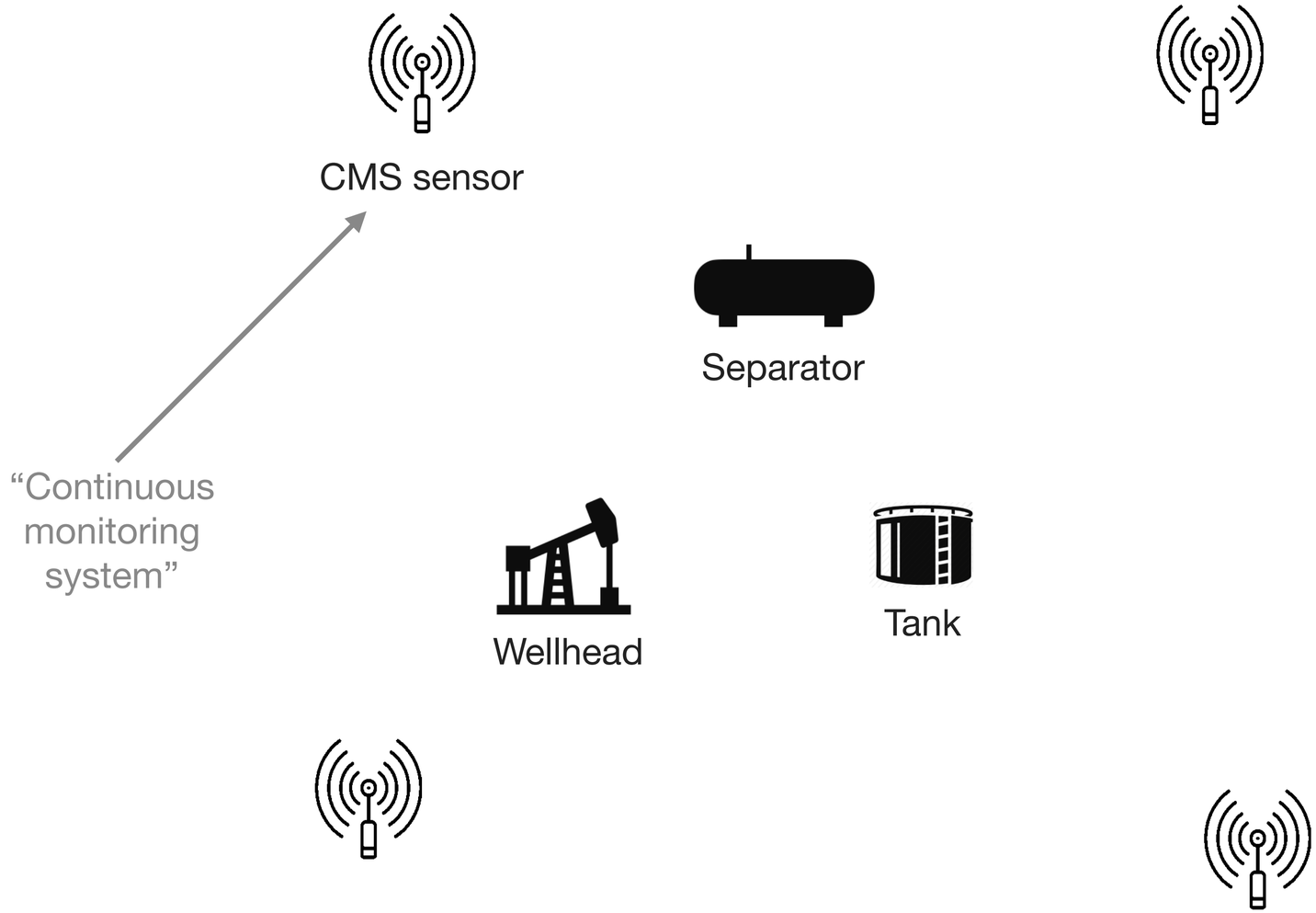
Event detection:
When is an emission happening?

Localization:
Where is the emission coming from?

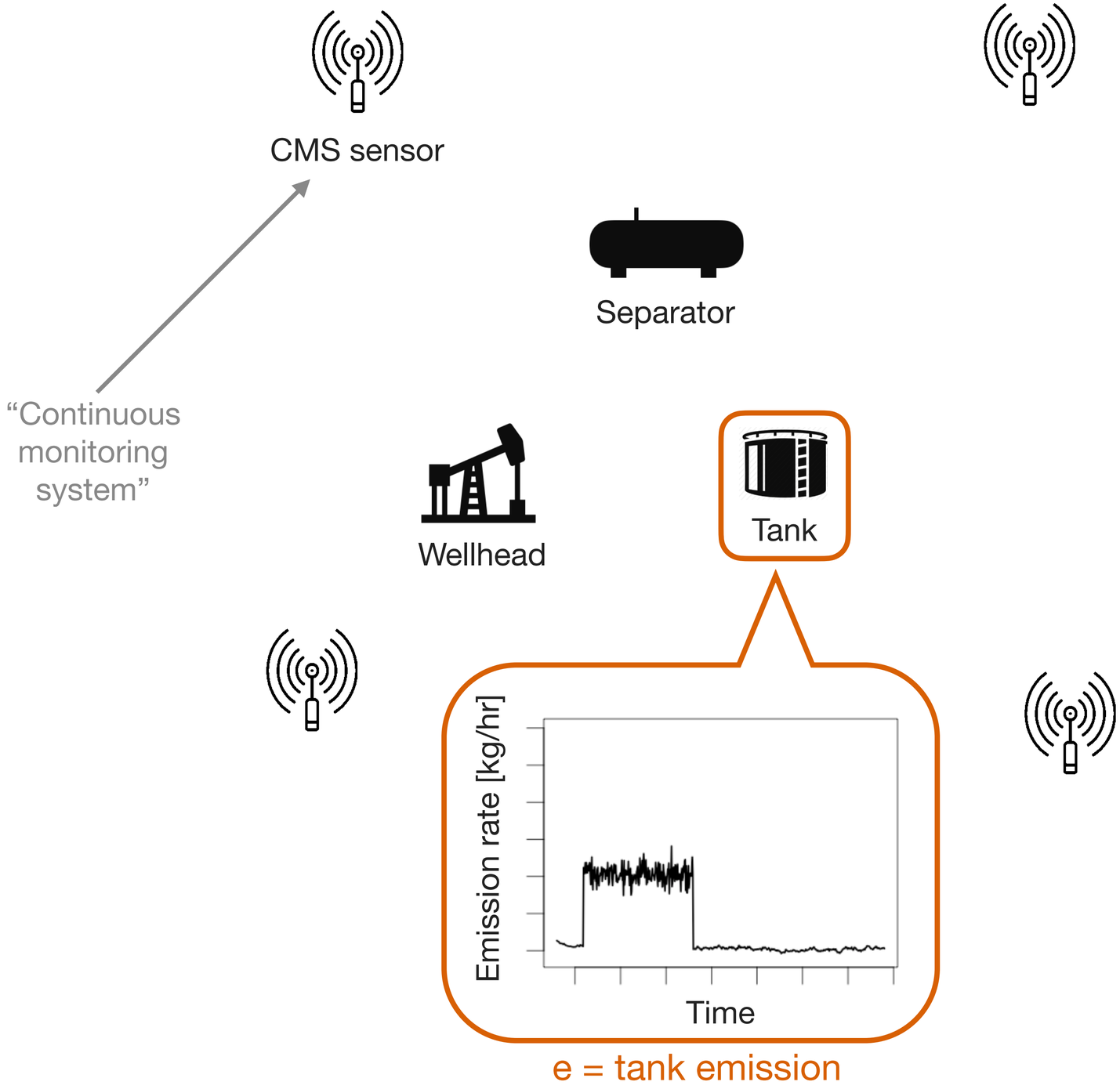
Quantification:
How much is being emitted?

Chapter 1:

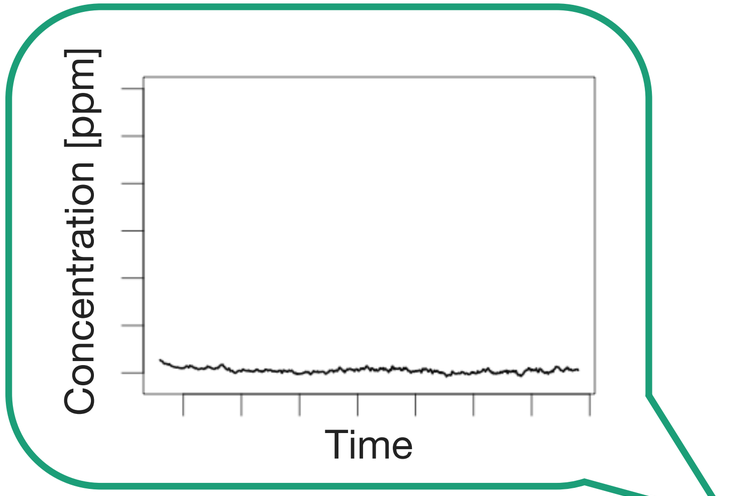
Single-source emission detection, localization, and quantification



The continuous monitoring inverse problem


CMS sensor
Separator
“Continuous monitoring system”
Wellhead
Tank
Emission rate [kg/hr]
Time
e = tank emission

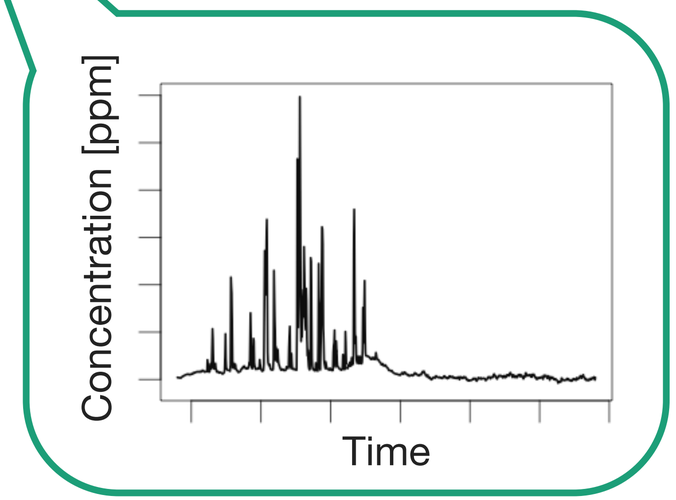
CMS sensor



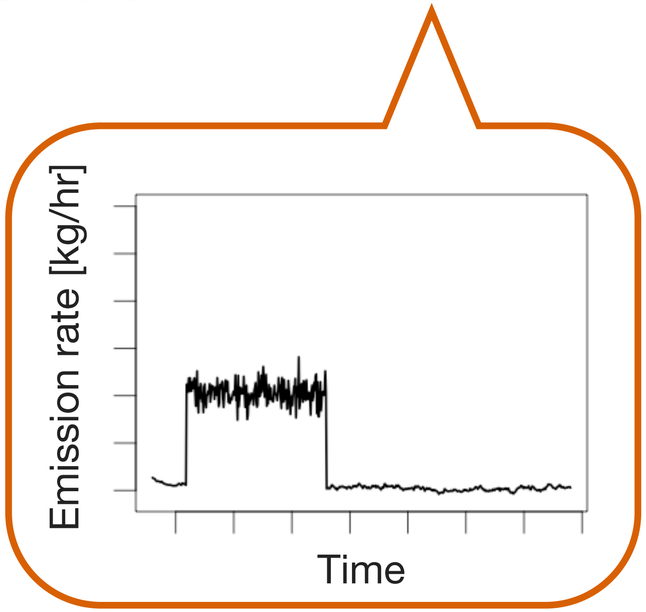
Separator

Wellhead

Tank



d = concentration data

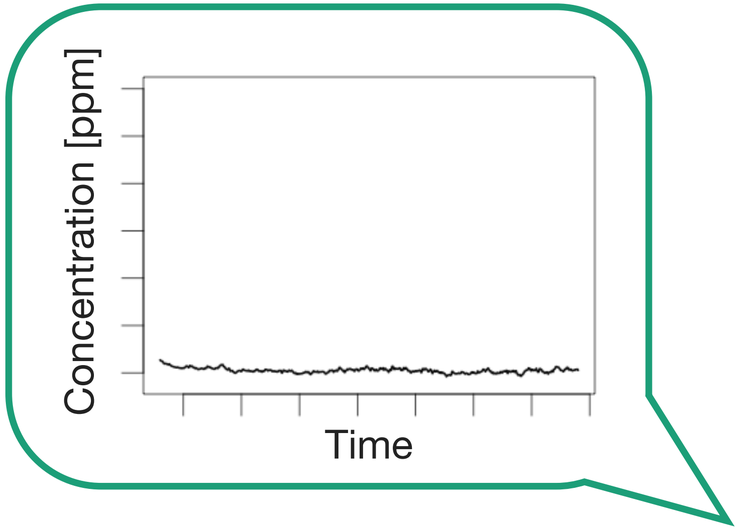


e = tank emission

Wind direction

$d = F(e)$

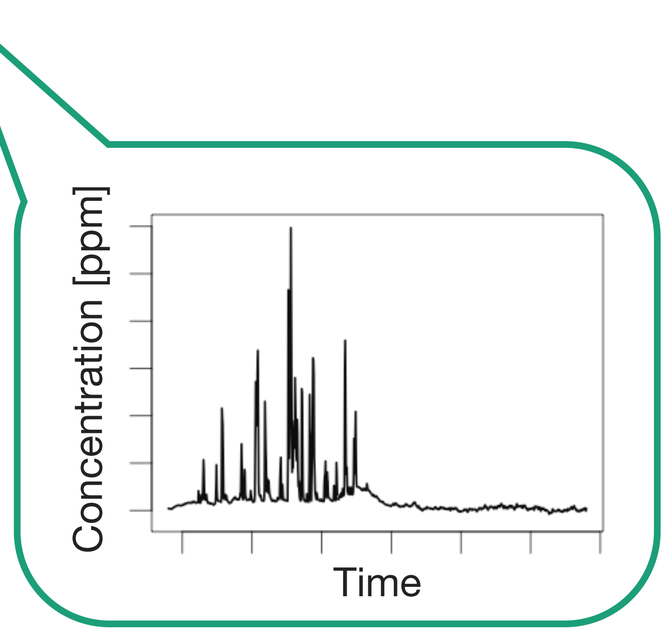
CMS sensor



Separator

Wellhead

Tank



d = concentration data

Wind direction

$d = F(e)$

$e = F^{-1}(d)$

Open source framework for solving inverse problem

STEP 1:
Background removal
and event detection

→

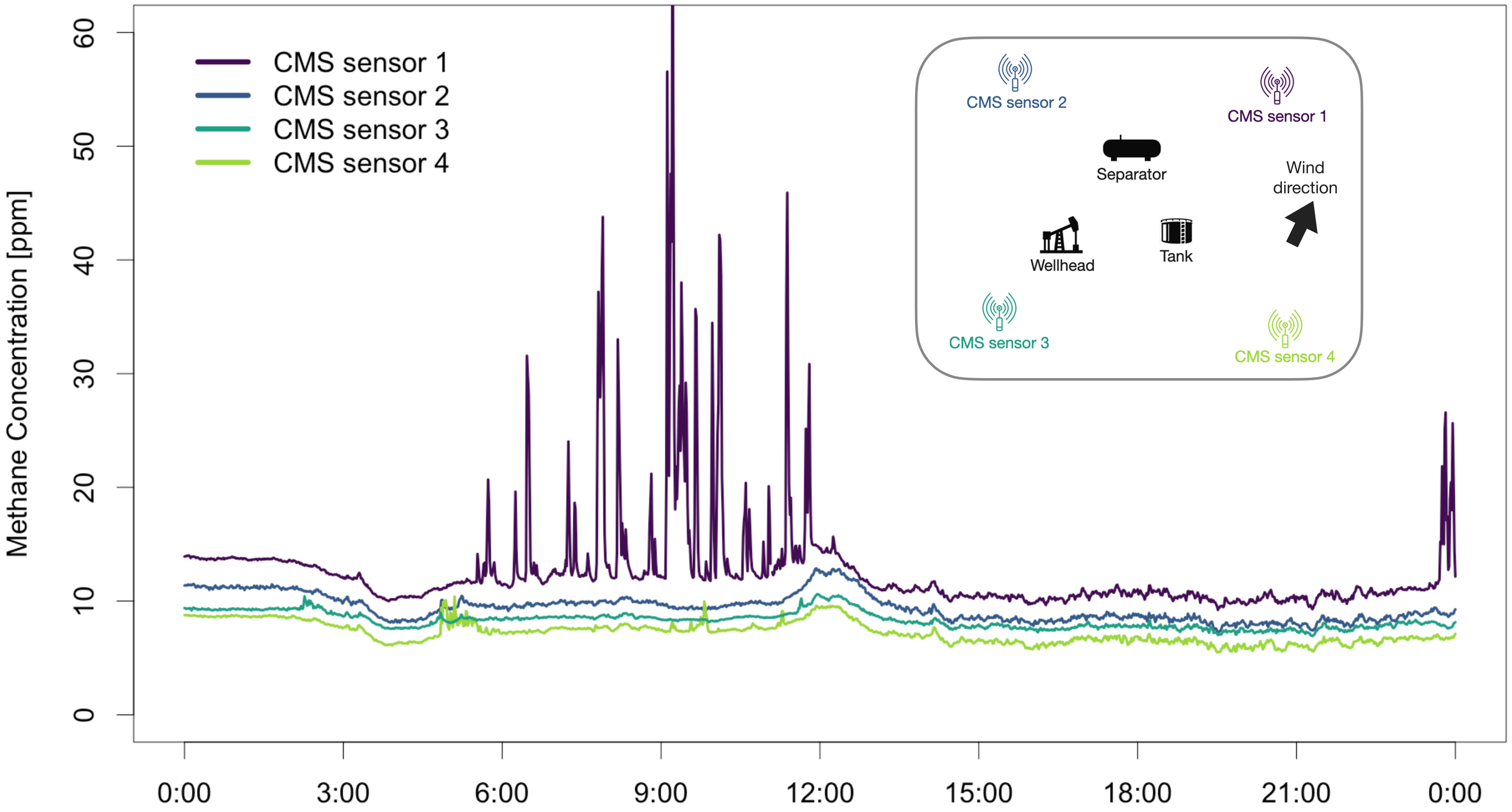
STEP 2:
Simulation

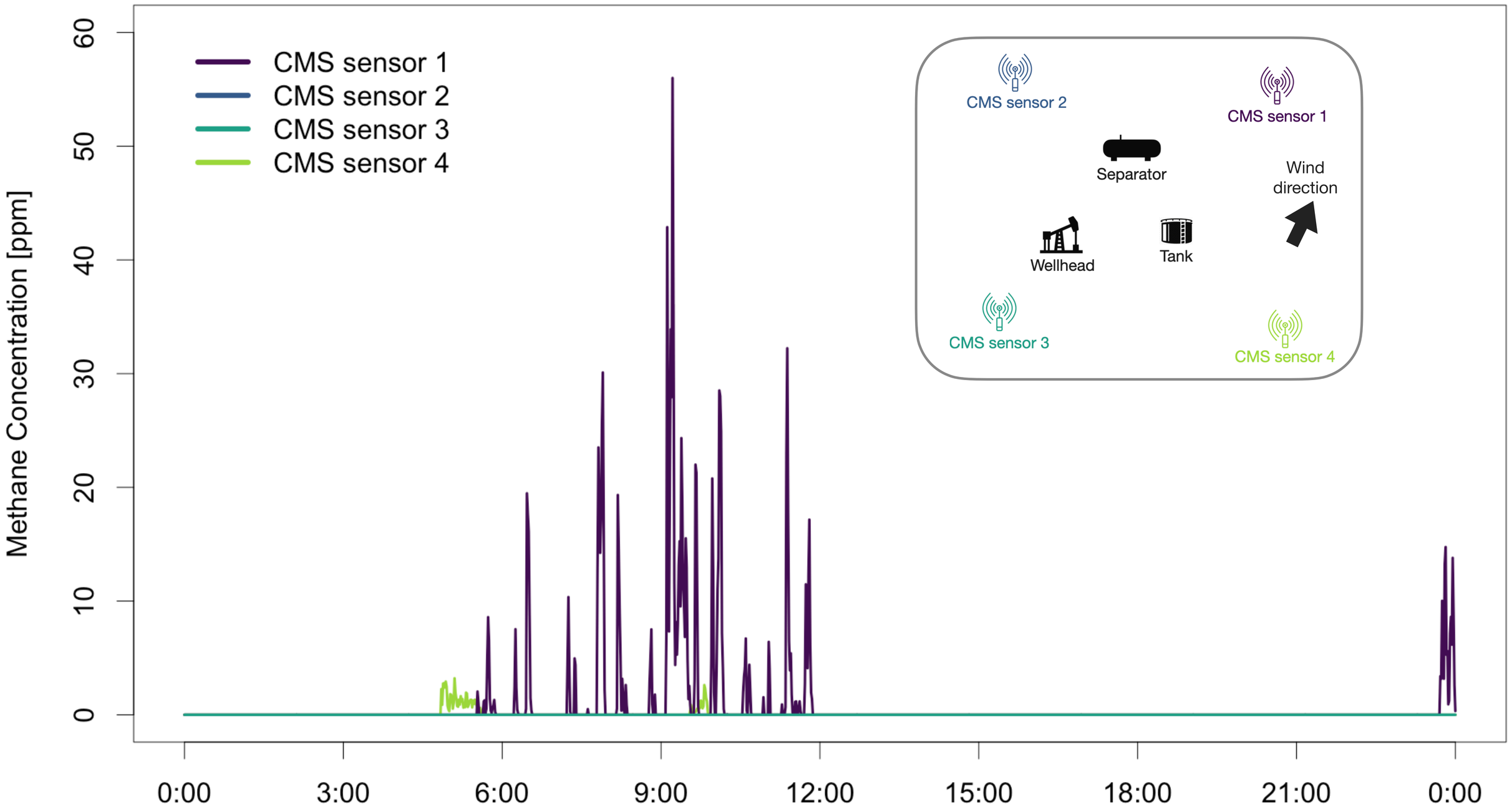
→

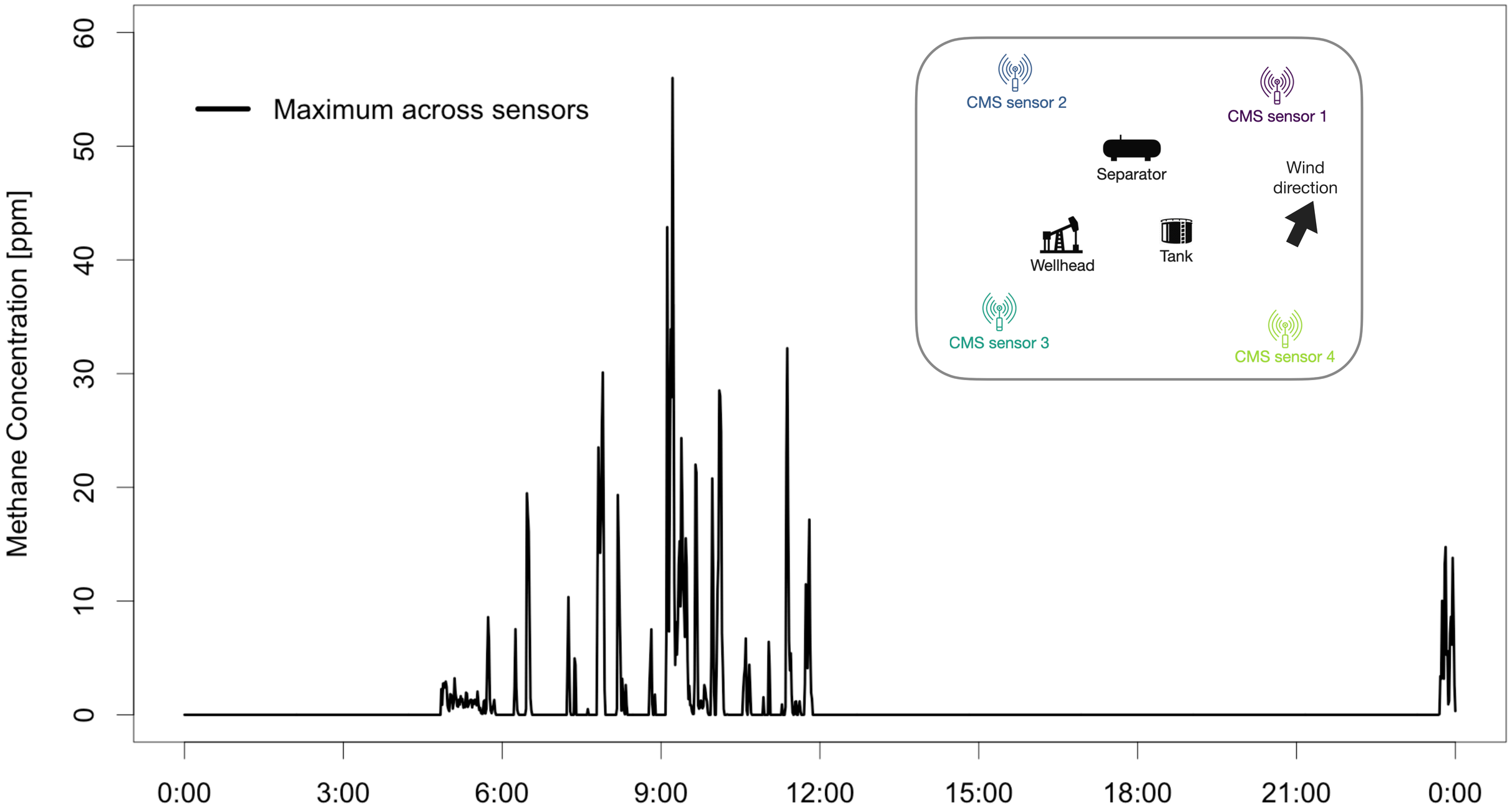
STEP 3:
Localization

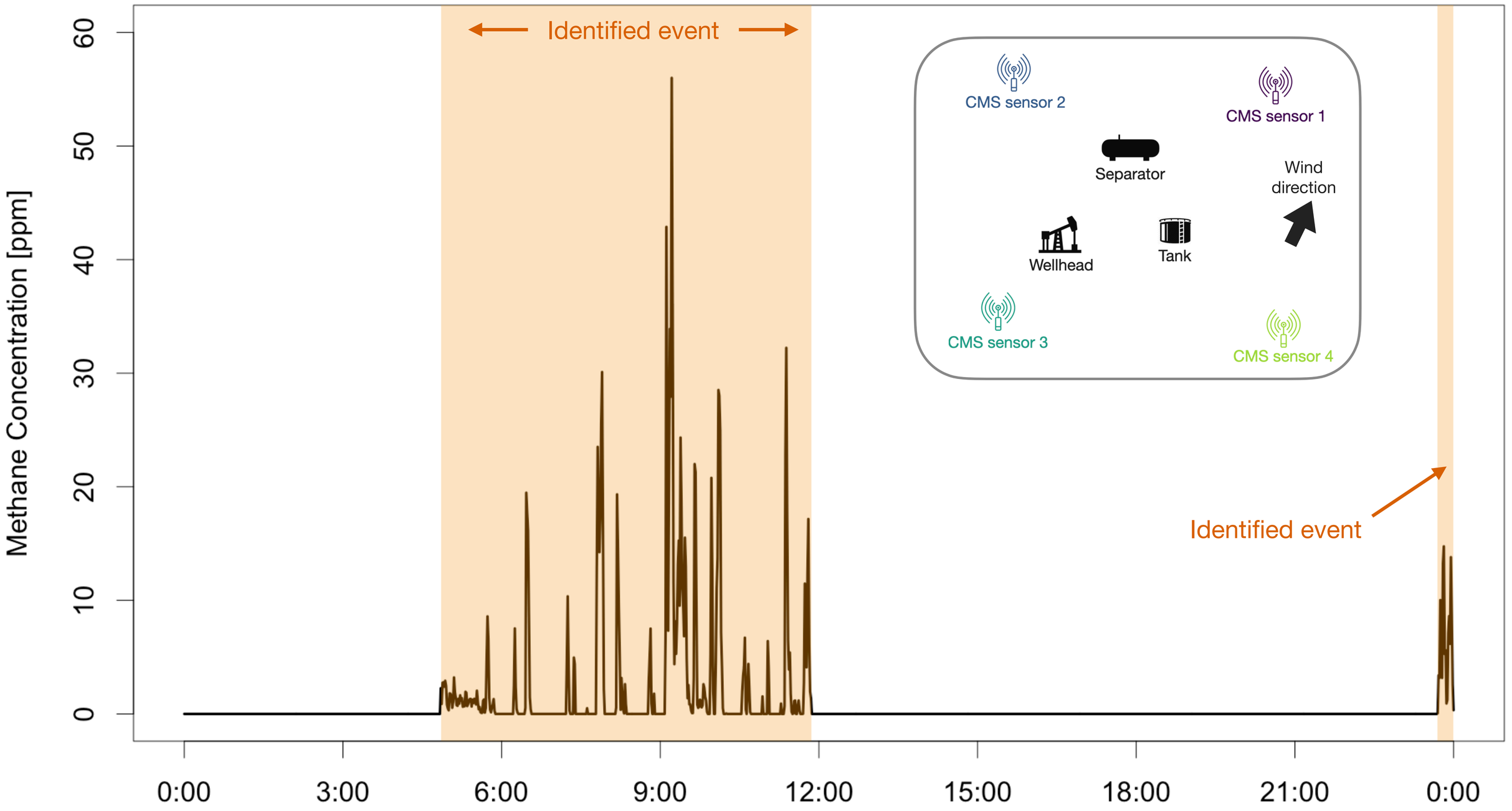
→

STEP 4:
Quantification

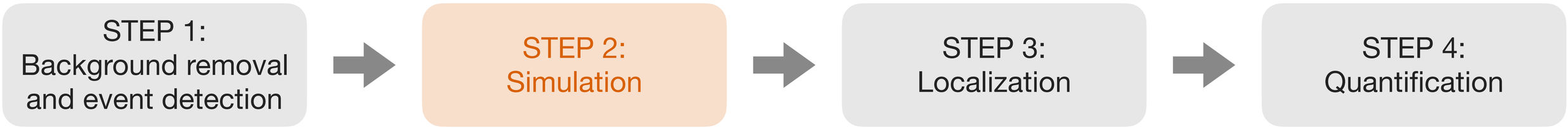

CMS sensor 1
CMS sensor 2
CMS sensor 3
CMS sensor 4
Methane Concentration [ppm]
0
10
20
30
40
50
60
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
CMS sensor 2
CMS sensor 1
Separator
Wind direction
Wellhead
Tank
CMS sensor 3
CMS sensor 4


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
Wind direction
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
Wind direction
Wellhead
Tank
CMS sensor 3
CMS sensor 4


Identified event
CMS sensor 2
CMS sensor 1
Separator
Wind direction
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



Gaussian puff atmospheric dispersion model

Total volume of methane contained in puff p

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

Concentration contribution of puff p

Decay in puff concentration in horizontal plane (x, y)

Decay in puff concentration in vertical dimension (z)

Gaussian puff atmospheric dispersion model

Total volume of methane contained in puff p

Total concentration at (x, y, z, t)

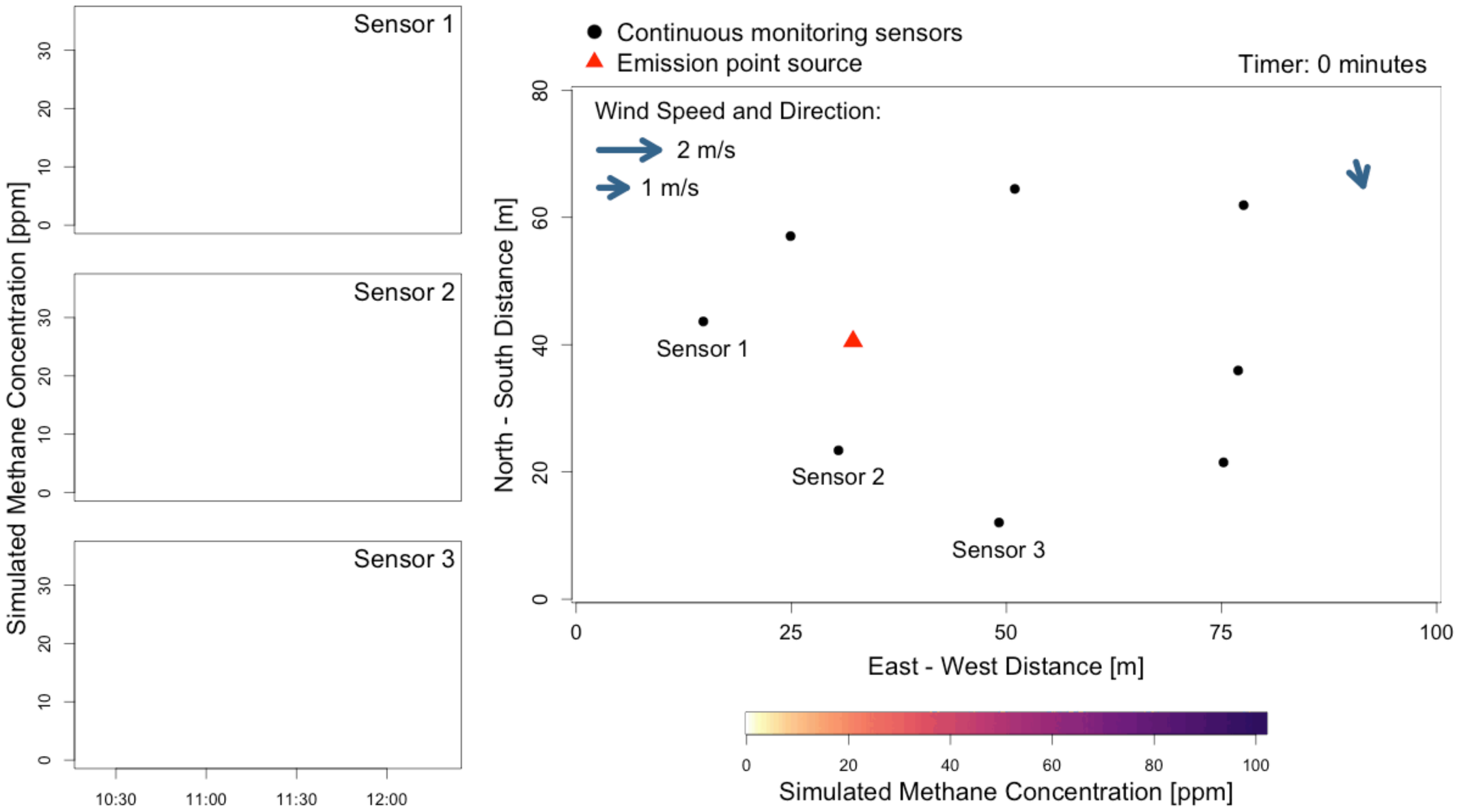
$$c(x, y, z, t, Q) = \sum_{p=1}^{P} c_p(x, y, z, t, Q)$$

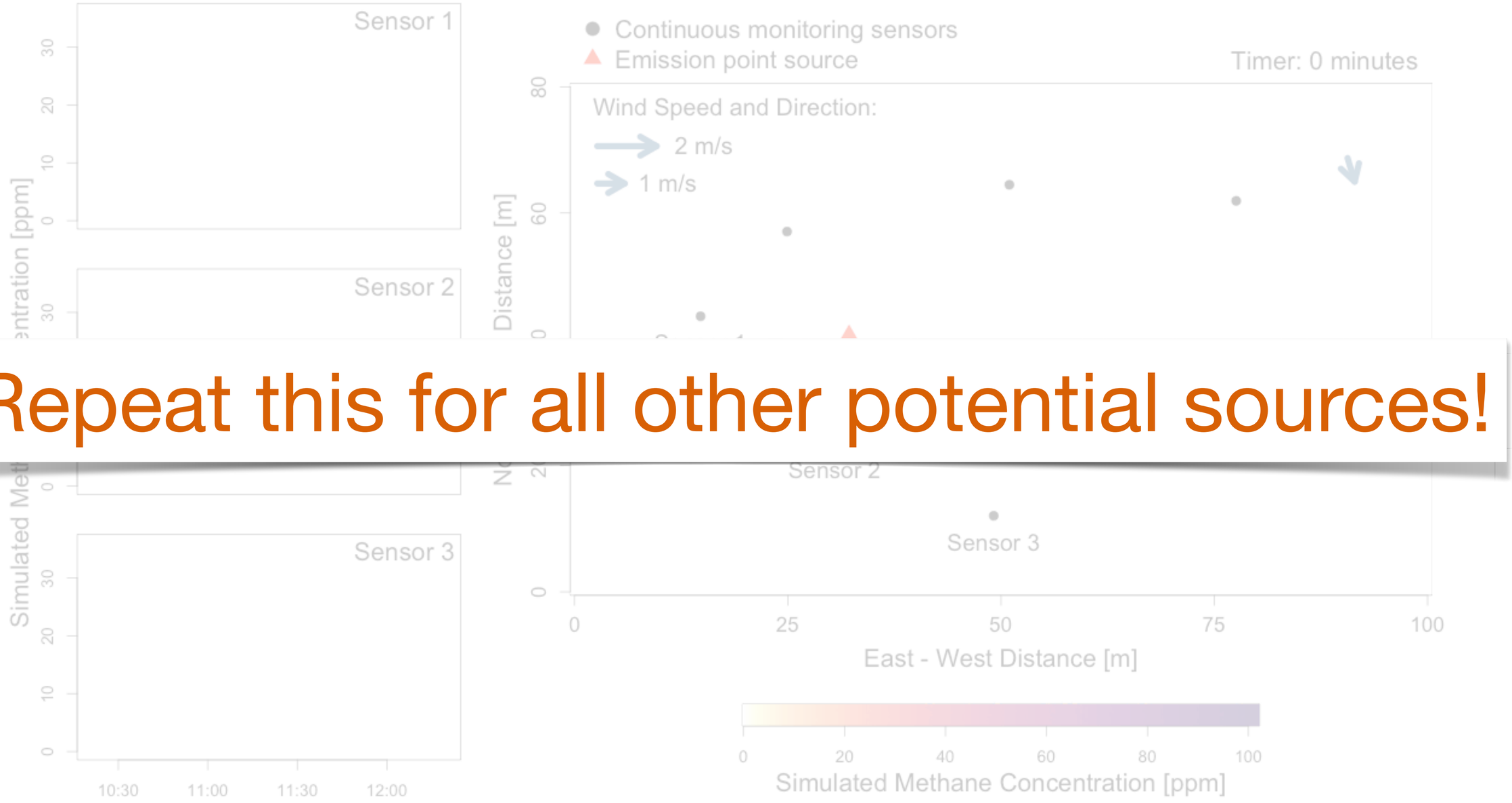
$$c_p(x, y, z, t, Q) = \frac{Q}{(2\pi)^{3/2}\sigma_y^2\sigma_z} \exp\left(-\frac{(x-ut)^2 + y^2}{2\sigma_y^2}\right)\left[\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right]$$

Concentration contribution of puff p

Decay in puff concentration in horizontal plane (x, y)

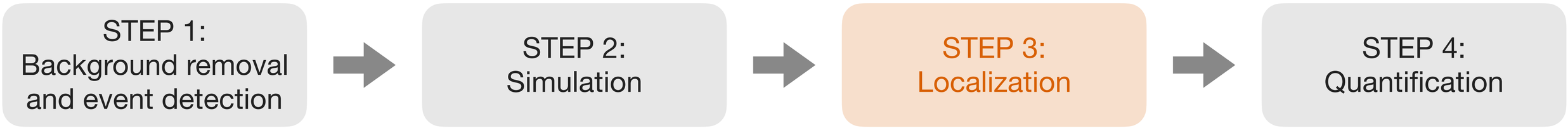
Decay in puff concentration in vertical dimension (z)


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



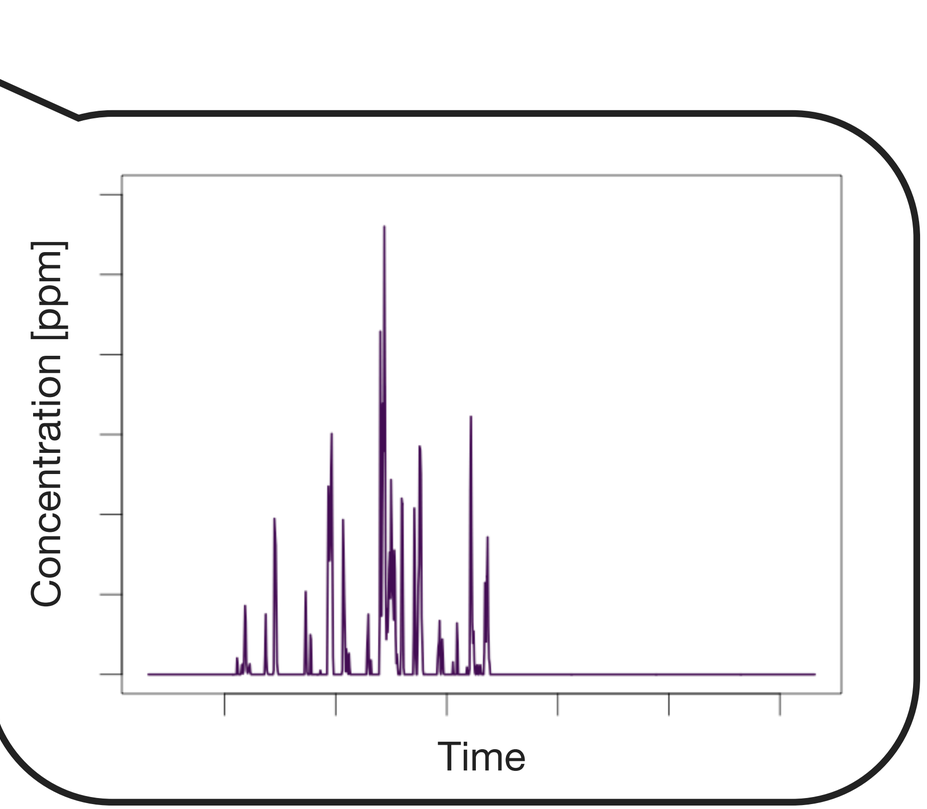
CMS sensor

Separator

Wellhead

Tank

Wind direction



CMS sensor

Simulation emission source

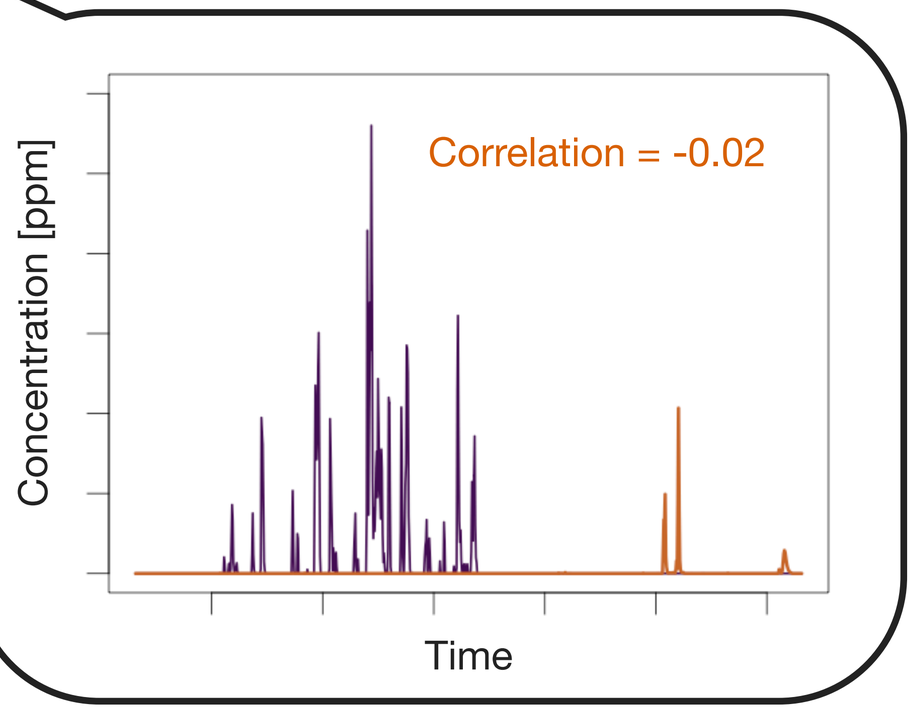
Separator

Wellhead

Tank

Wind direction

Pick source estimate using correlation coefficient



Background-removed observations

Simulated concentrations

CMS sensor

Separator

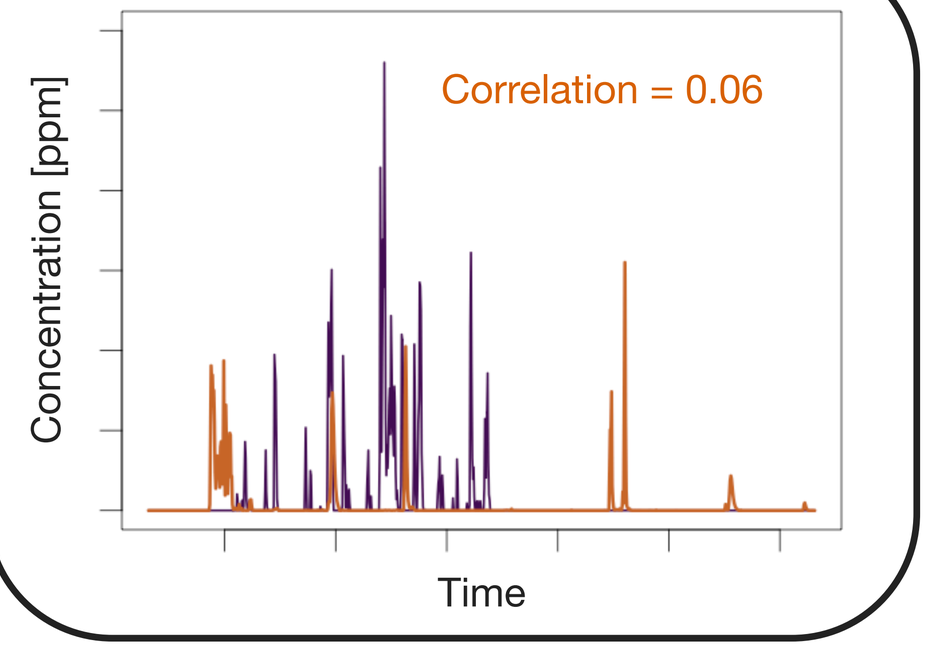
Wellhead

Simulation emission source

Tank

Wind direction

Pick source estimate using correlation coefficient



Background-removed observations

Simulated concentrations

CMS sensor

Separator

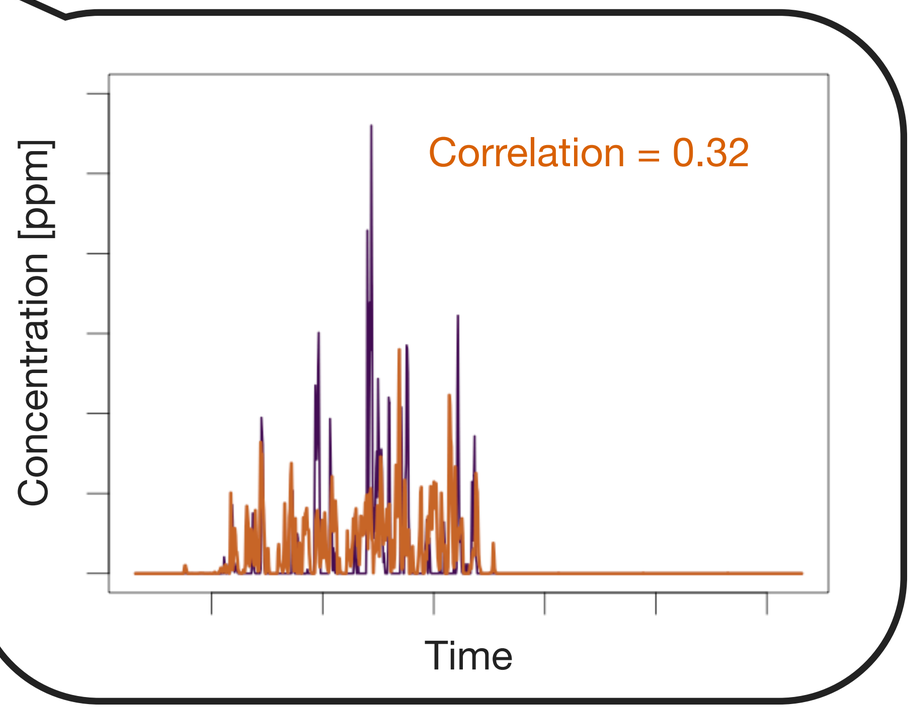
Wellhead

Tank

Simulation emission source

Wind direction

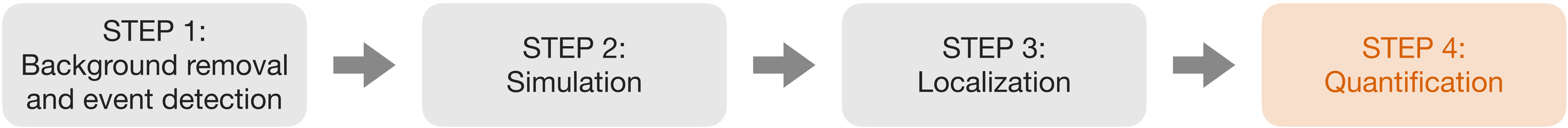
Pick source estimate using correlation coefficient



Background-removed observations

Simulated concentrations

Open source framework for solving inverse problem



Simulation is a linear function of emission rate

Volume of methane contained in puff p

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

Concentration contribution of puff p

$$c(x, y, z, t, Q) = \sum_{p=1}^{P} c_p(x, y, z, t, Q)$$

Total concentration at (x, y, z, t)

Simulation is a linear function of emission rate

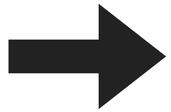
Volume of methane contained in puff p

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

Concentration contribution of puff p

$$c(x, y, z, t, Q) = \sum_{p=1}^{P} c_p(x, y, z, t, Q)$$

Total concentration at (x, y, z, t)

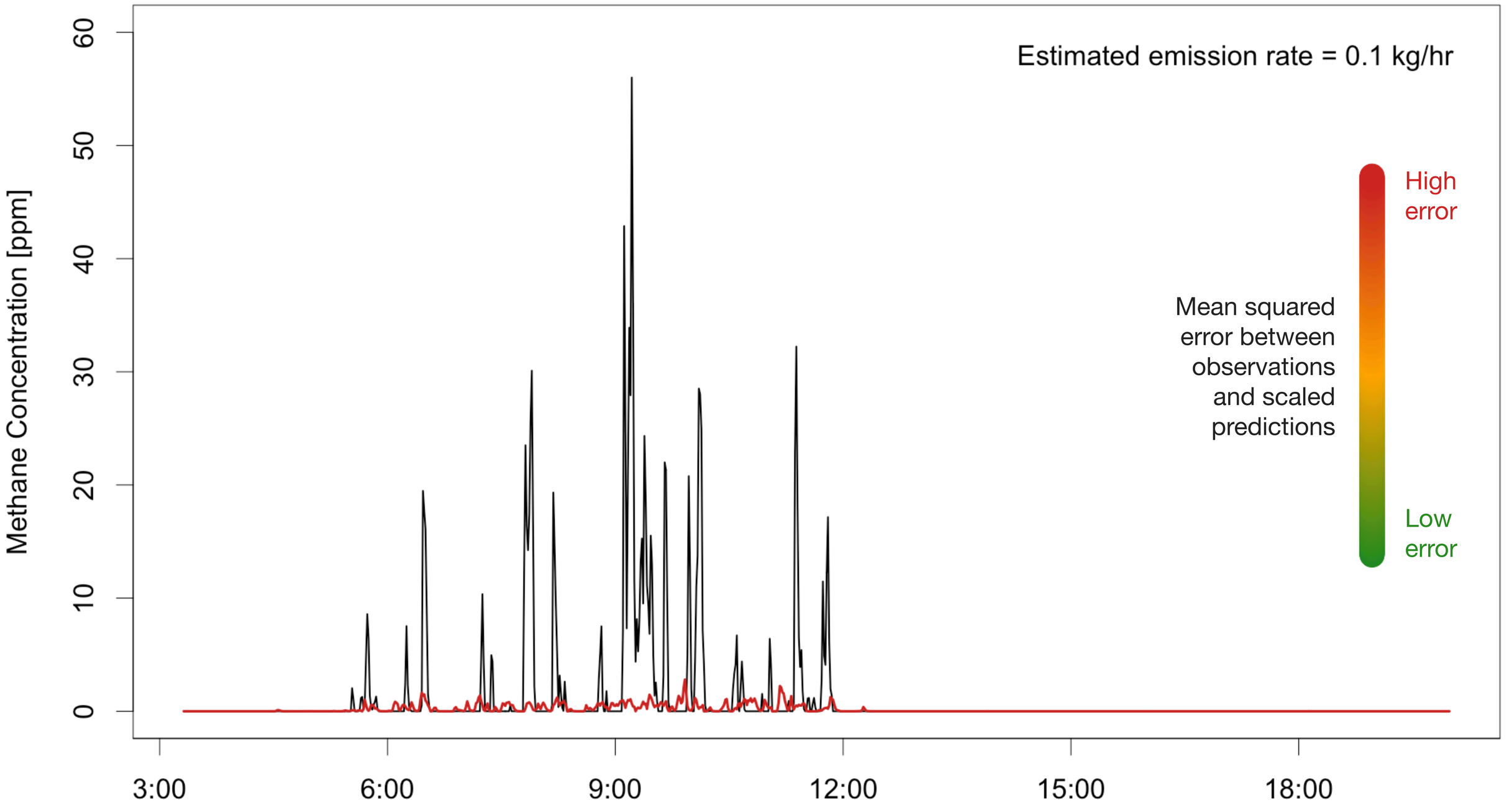


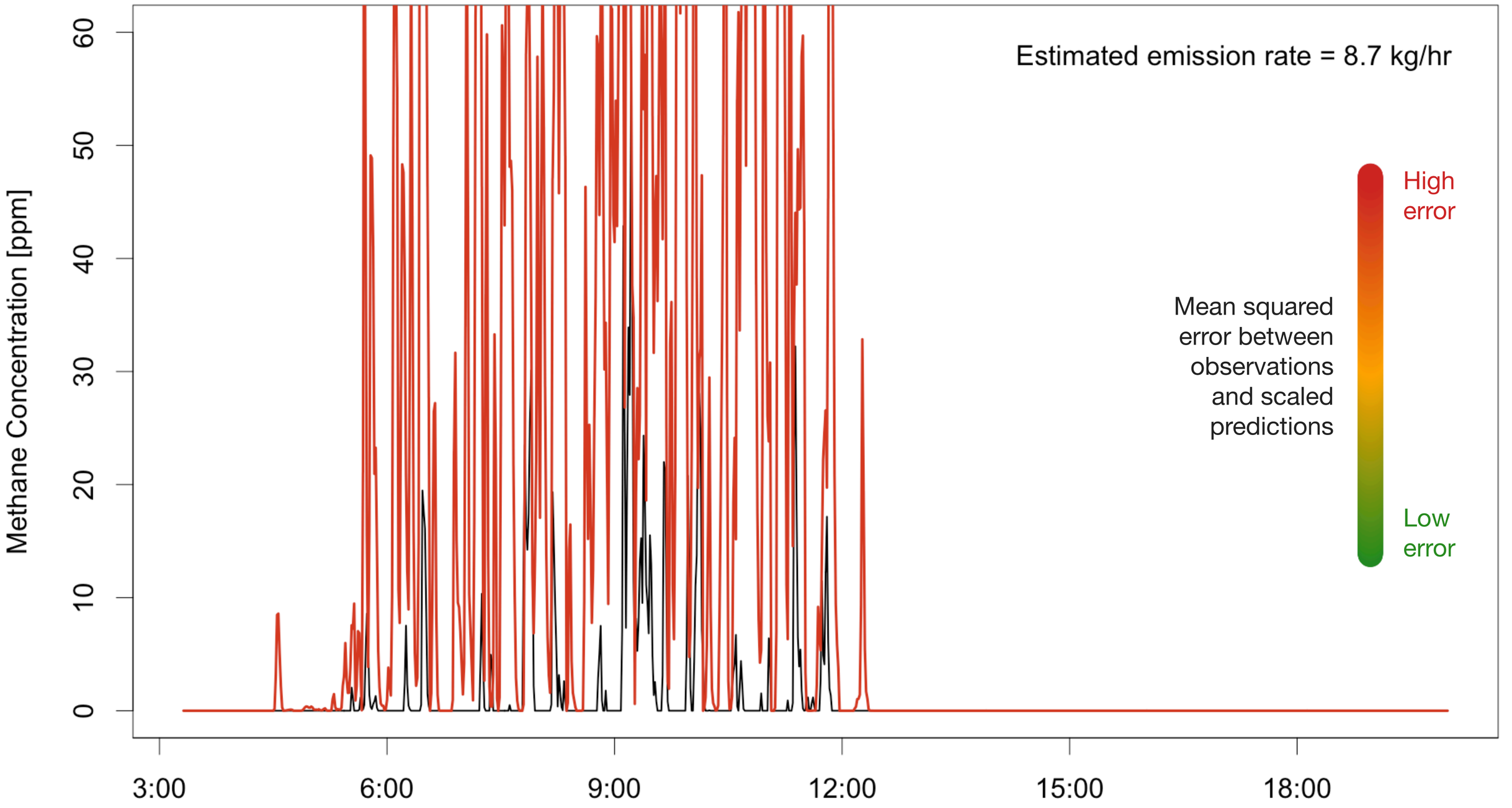
Concentration data

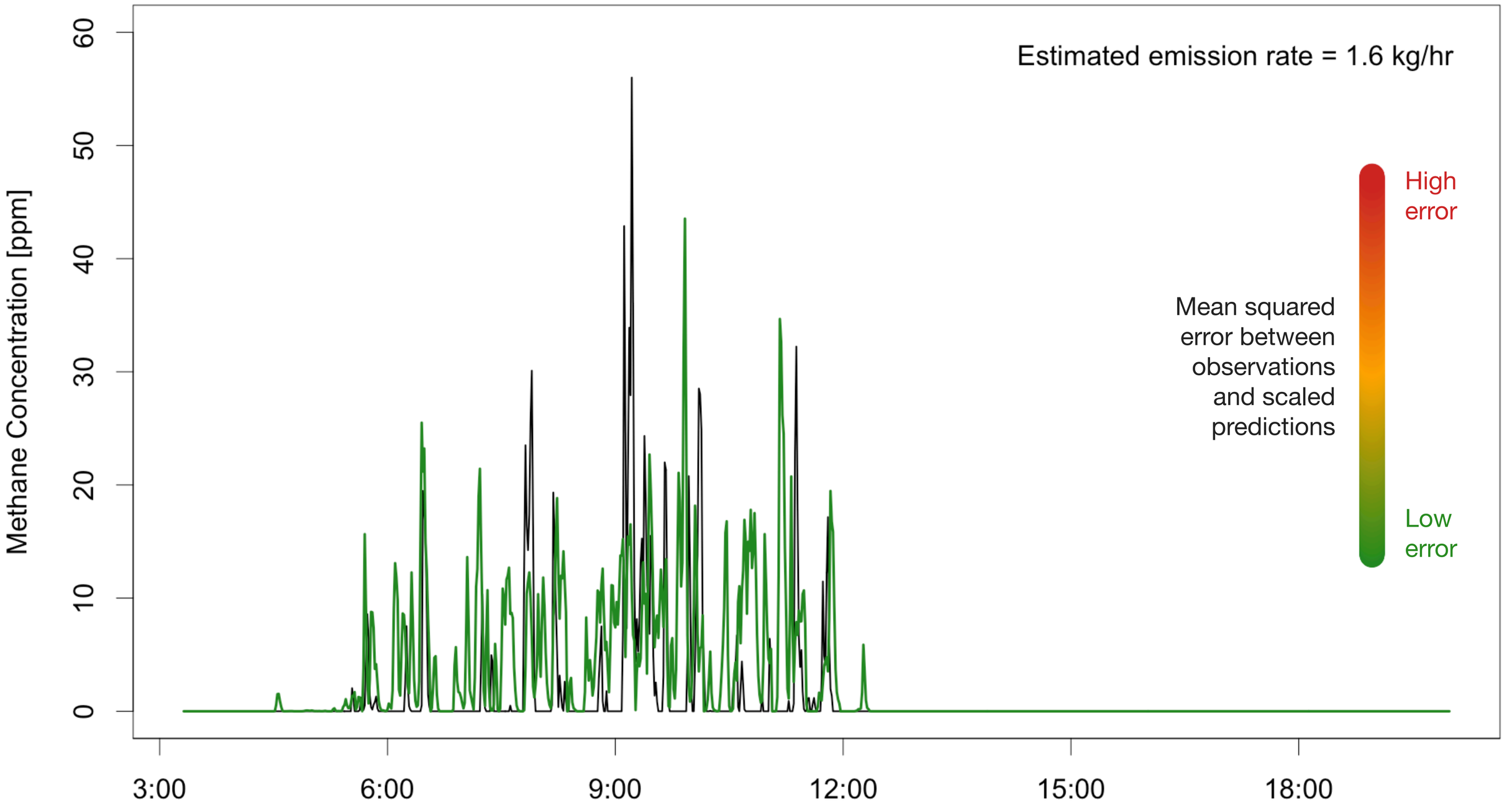
$$\hat{Q} = \underset{Q}{\operatorname{argmin}} \left\{ \frac{1}{n} \sum_{t=1}^{n} \left(d(x, y, z, t) - c(x, y, z, t, Q) \right)^2 \right\}$$

Emission rate estimate

Simulated concentrations

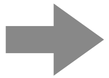

Estimated emission rate = 0.1 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Mean squared error between observations and scaled predictions
High error
Low error


Estimated emission rate = 8.7 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Mean squared error between observations and scaled predictions
High error
Low error

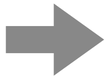

Estimated emission rate = 1.6 kg/hr
Methane Concentration [ppm]
0
10
20
30
40
50
60
3:00
6:00
9:00
12:00
15:00
18:00
Mean squared error between observations and scaled predictions
High error
Low error

Open source framework for solving inverse problem

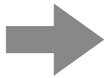
STEP 1:
Background removal
and event detection



STEP 2:
Simulation

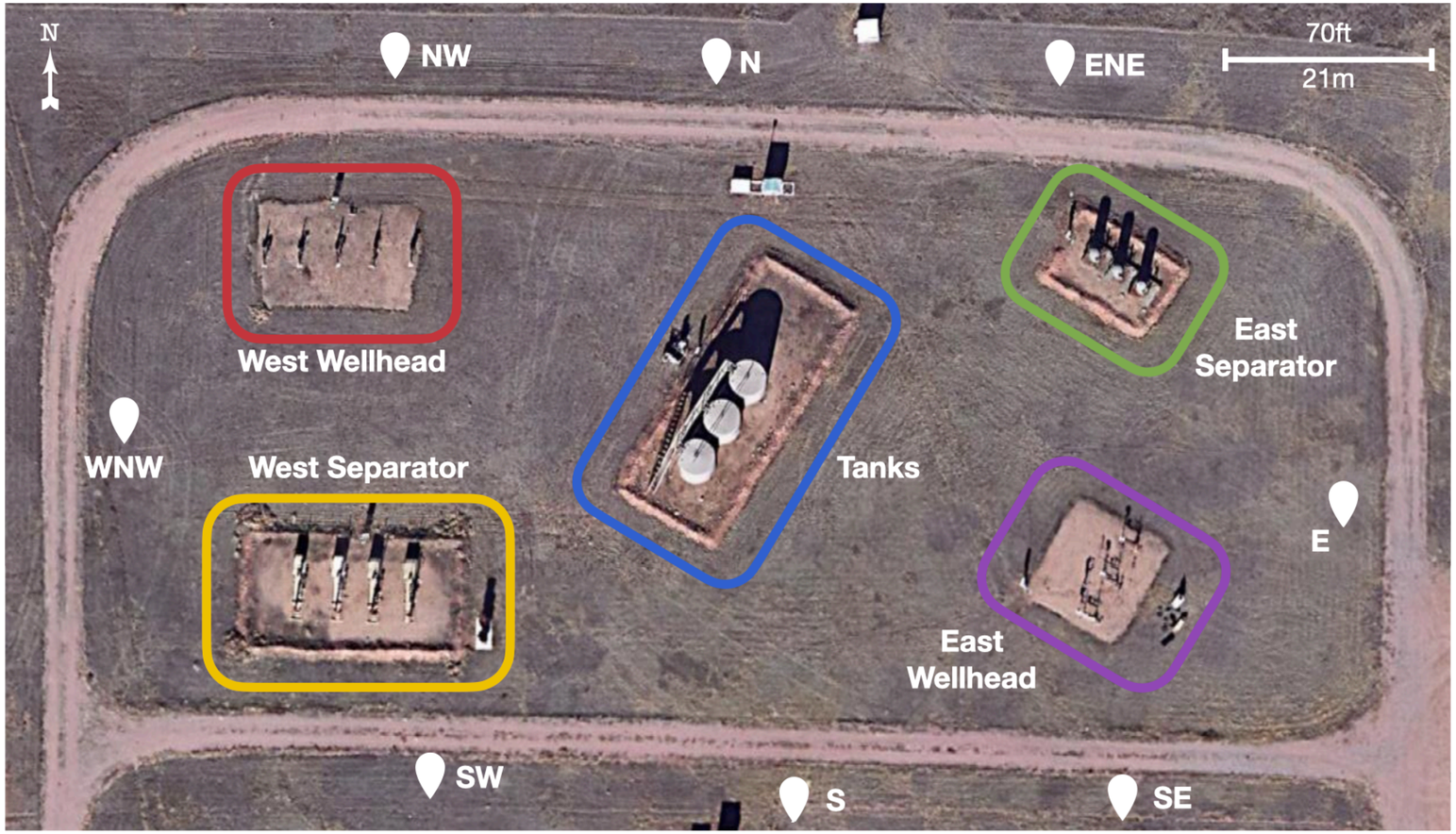


STEP 3:
Localization



STEP 4:
Quantification

Evaluation on single-source controlled releases



85 single-source controlled releases

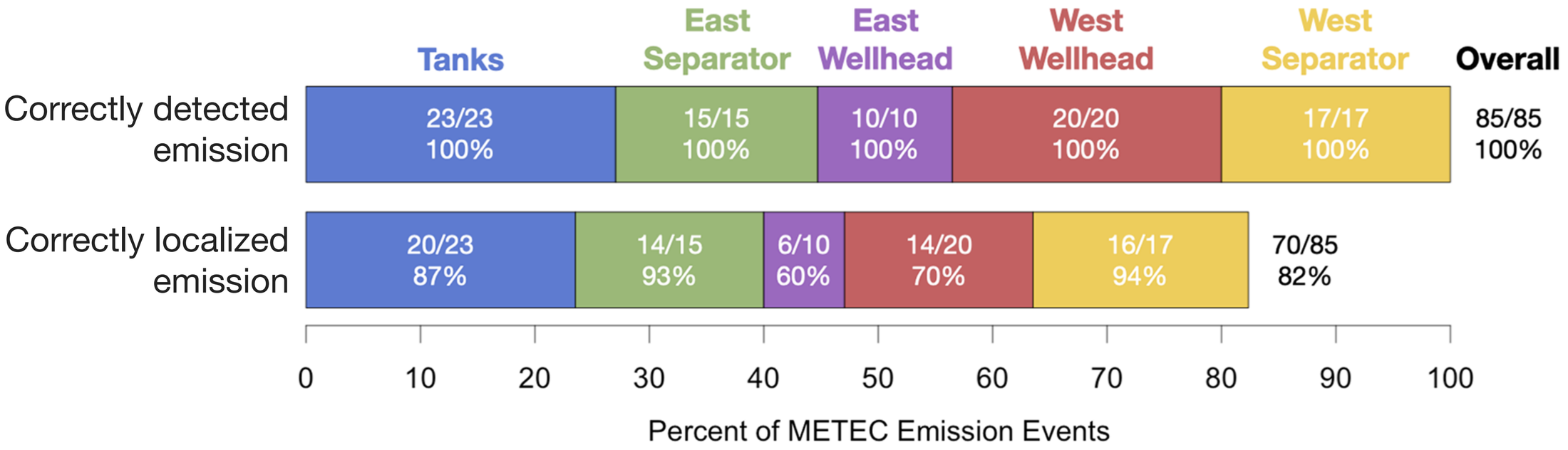
Emission rates range from
0.2 to **6.4** kg/hr

Emission durations range from
0.5 to **8.25** hours

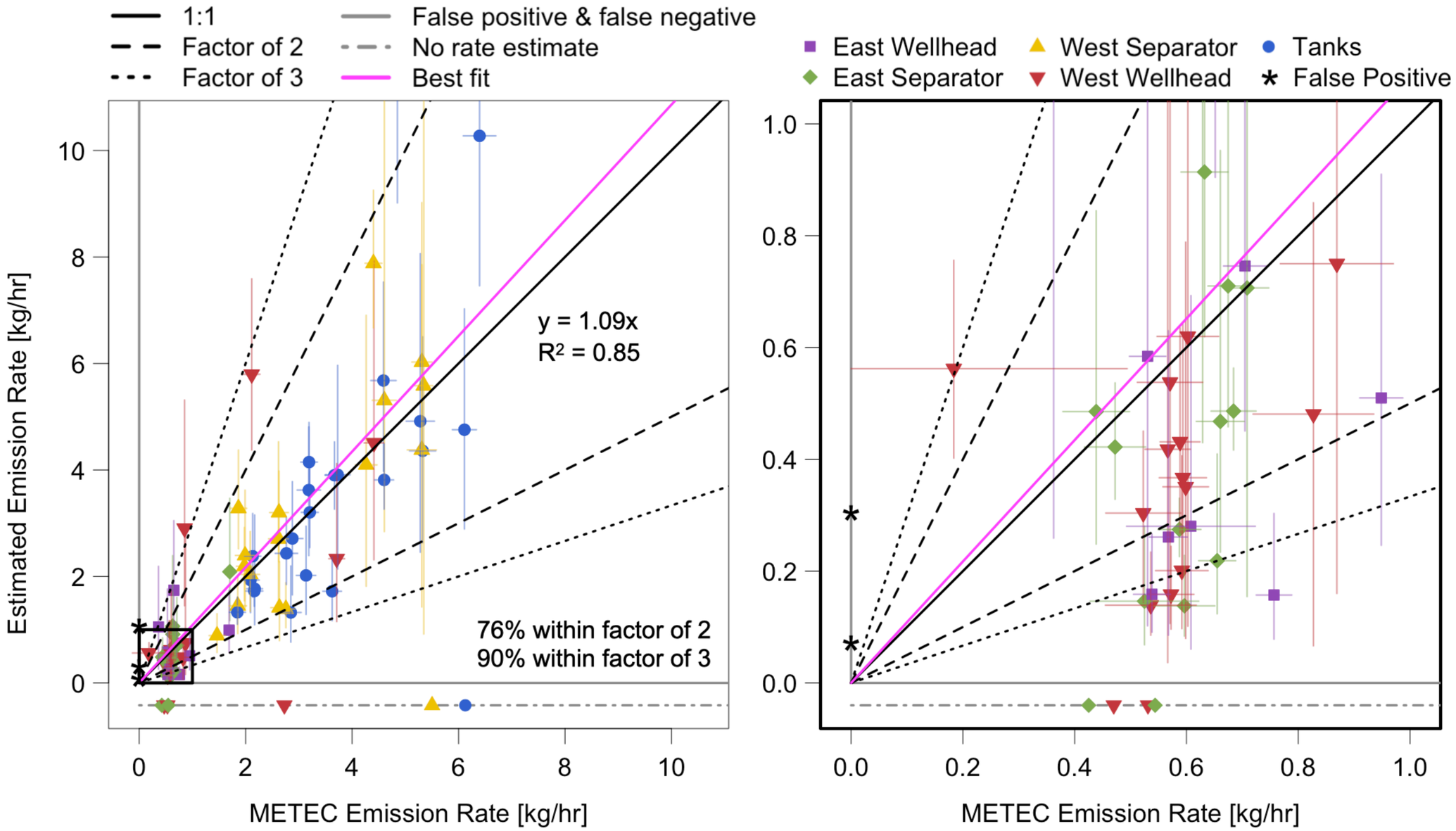
Methane Emissions Technology Evaluation Center (METEC)

Evaluation on single-source controlled releases

Event-level false positive rate: 5.5%



Evaluation on single-source controlled releases



CMS Series #1:

Single-source emission detection, localization, and quantification

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.
Elementa: Science of the Anthropocene, 12(1), 00110, (2024).

Filling a critical need: a lightweight and fast Gaussian puff model implementation.

Meng Jia, Ryker Fish, **William Daniels**, Brennan Sprinkle, Dorit Hammerling.
Scientific Reports, 15, 18710 (2025).

Thank you!

COLORADO SCHOOL OF MINES

EEMDL
Energy Emissions Modeling and Data Lab

U.S. DEPARTMENT OF ENERGY