

# Reconciling bottom-up inventories and top-down measurements on individual oil and gas sites using continuous monitoring systems

William Daniels, Meng Jia, Dorit Hammerling

Department of Applied Mathematics and Statistics



**COLORADO SCHOOL OF MINES**

# AGU23

San Francisco, CA & Online Everywhere

11-15 December 2023

# Push towards site-level measurement and reconciliation

## 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 and reconciliation

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 methane emissions ...

SEC. 136. (g)(2) ... calculations under subsection (c) of this section are based on **empirical data** that accurately reflect the total 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 and reconciliation

## 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 measure methane emissions ...

SEC. 136. (g)(2) ... calculations under subsection (c) of this section are based on **empirical data** that 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)

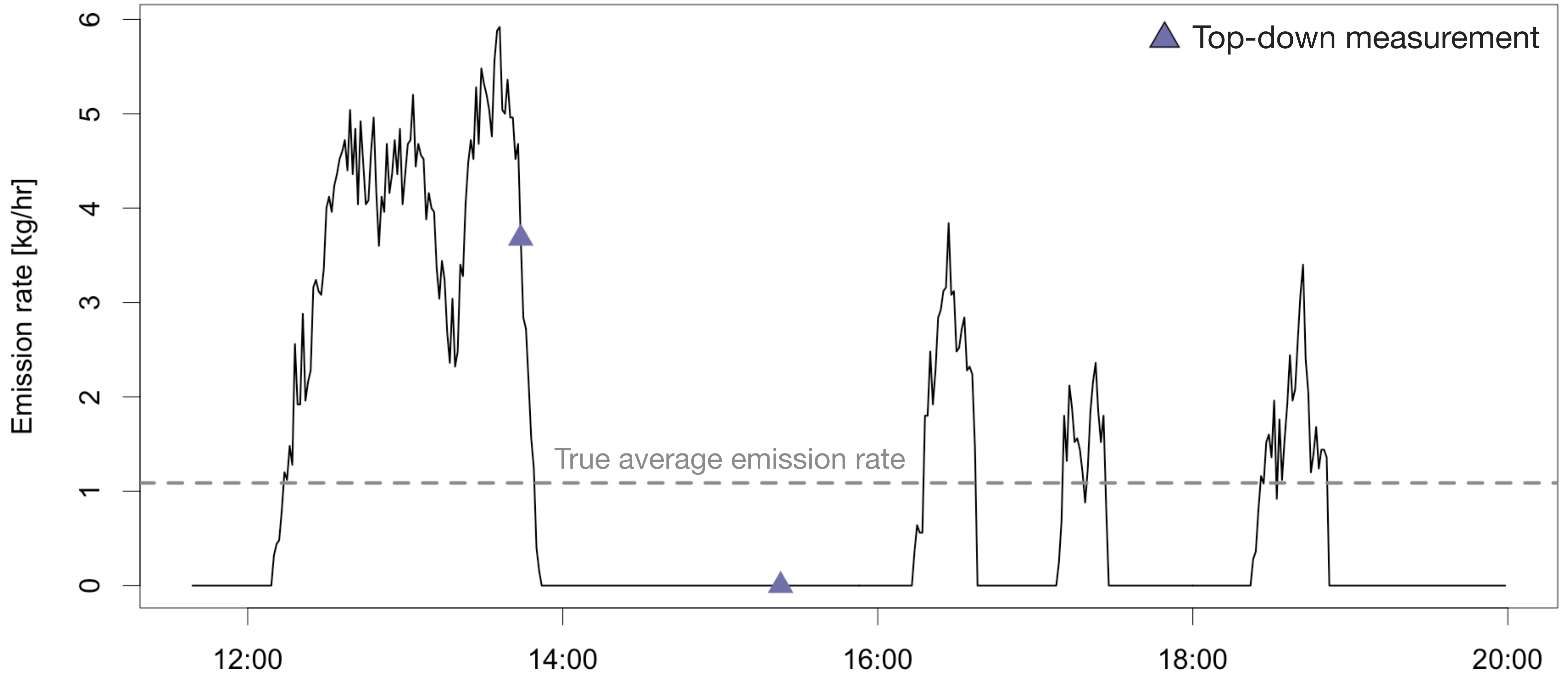
Level 5 – Emissions reported similarly to Level 4, but with the addition of **site-level measurements** (measurements that characterize site-level emissions distribution for a statistically representative population)

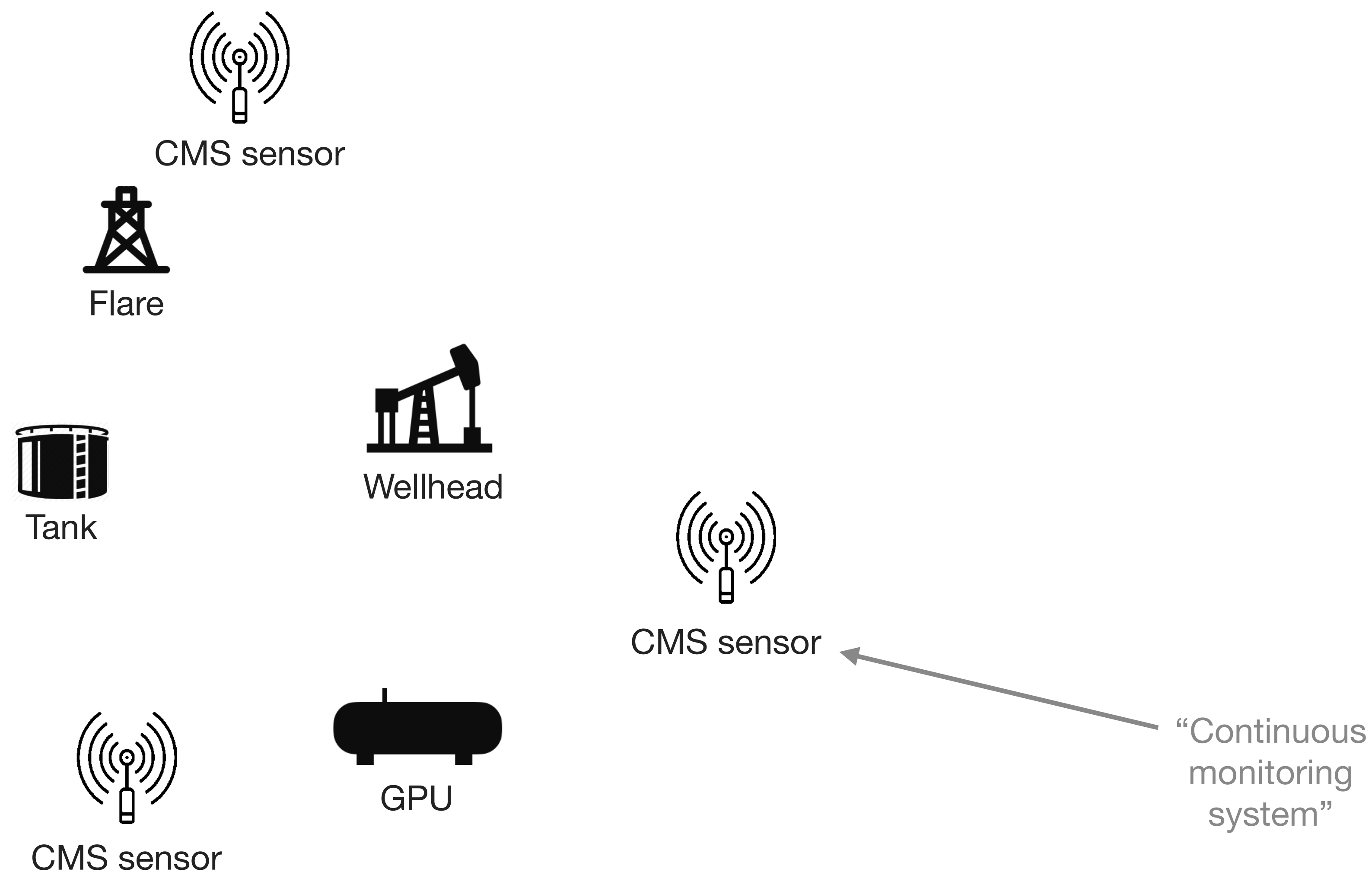
Global Initiatives



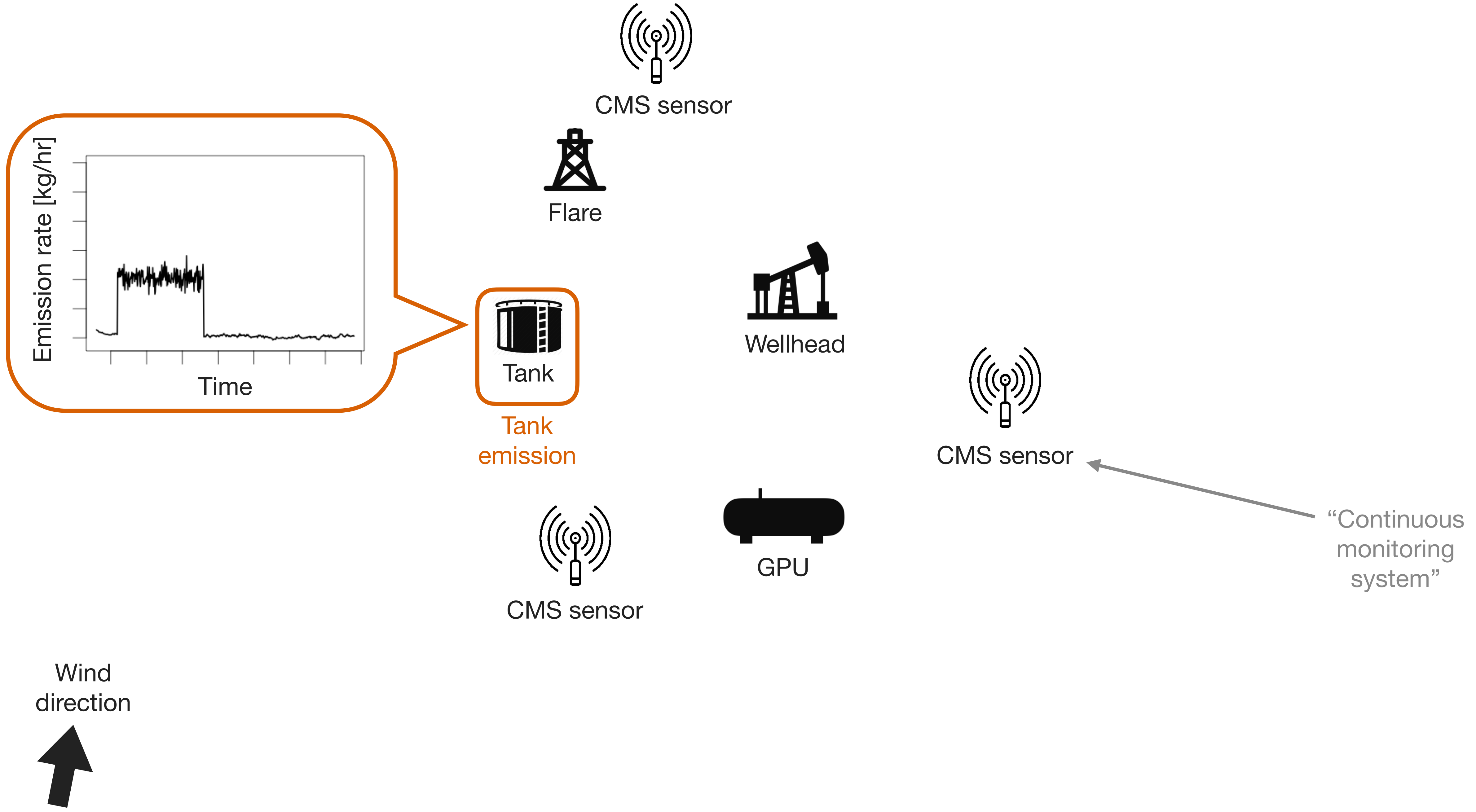
# Emissions can have high temporal variability

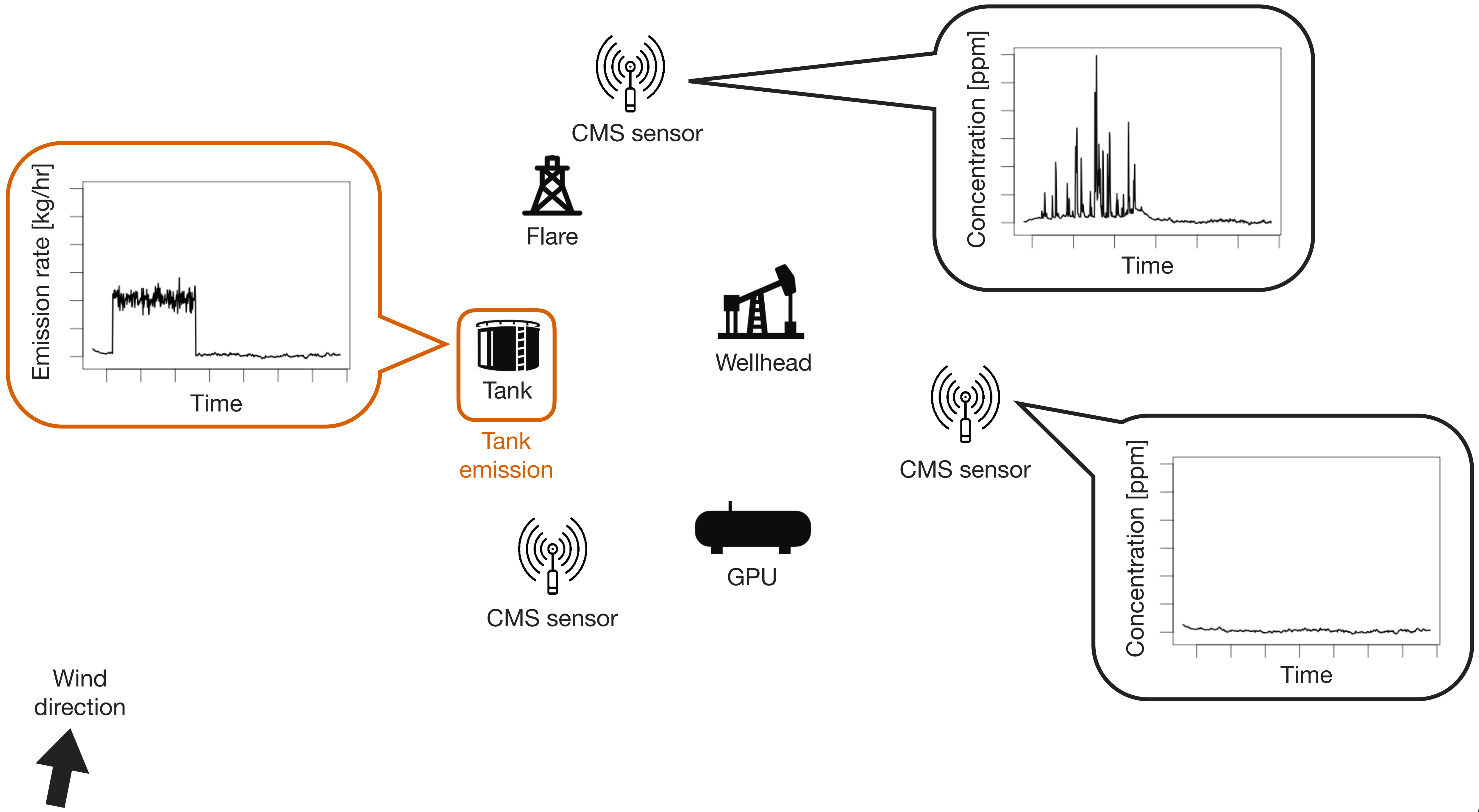
Challenging to interpret small number of measurements using only data from given site



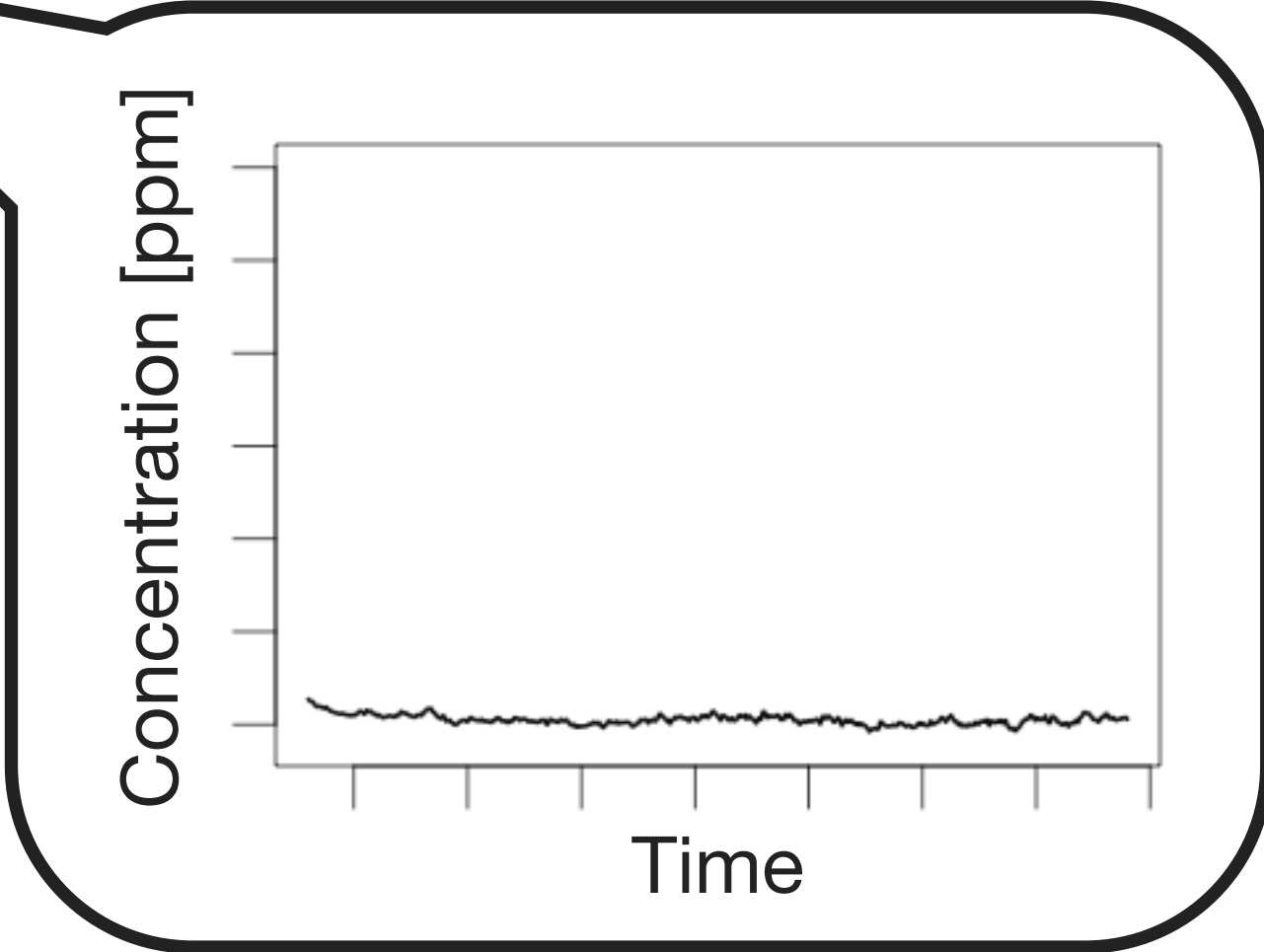
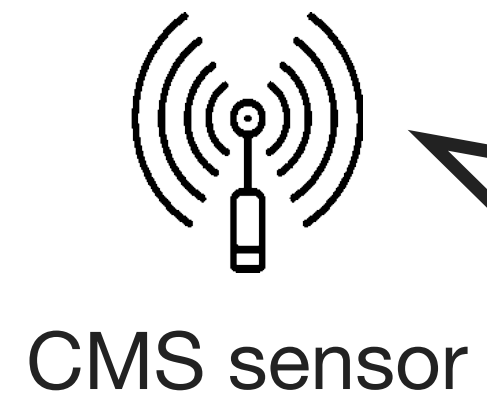
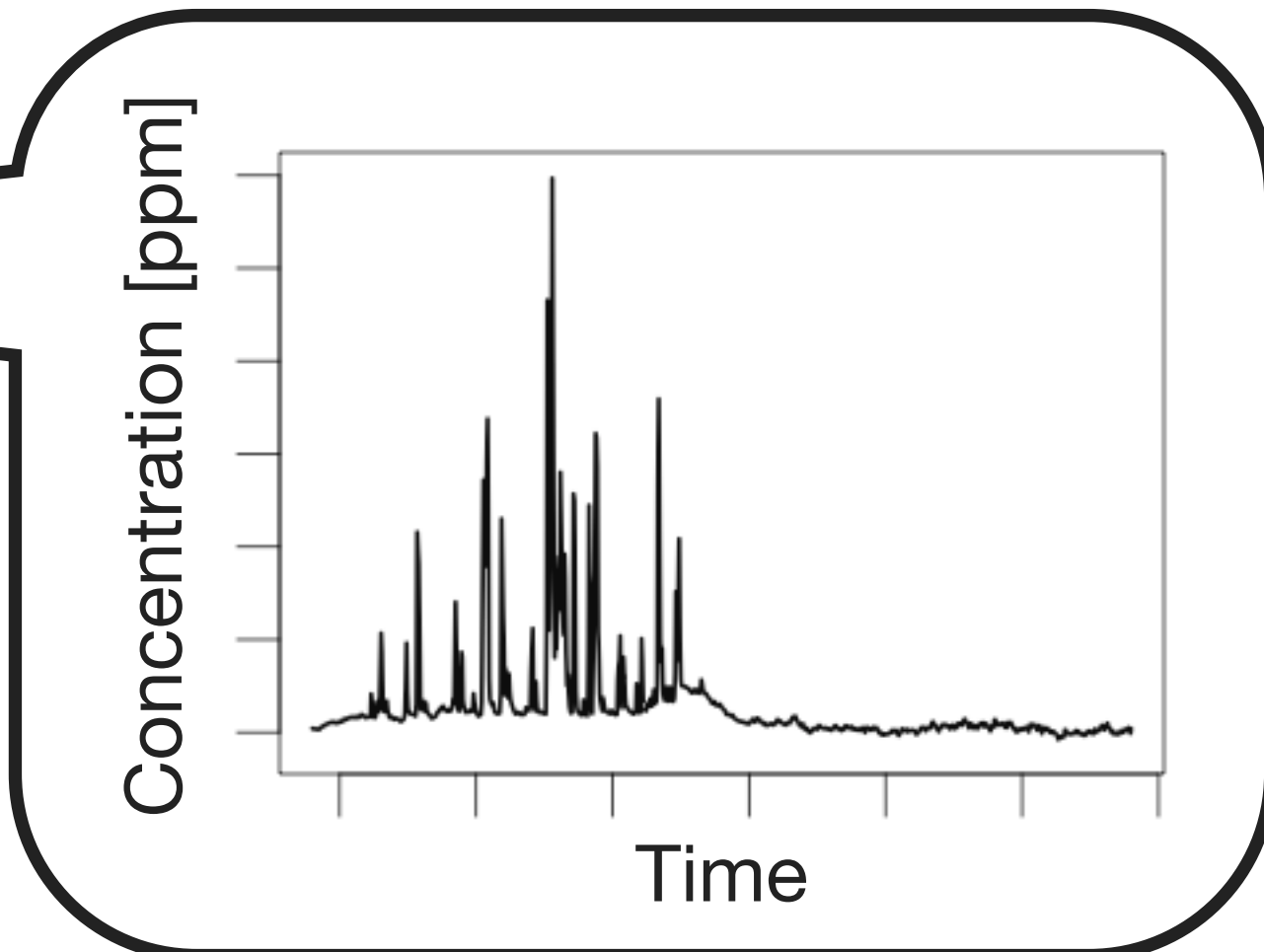
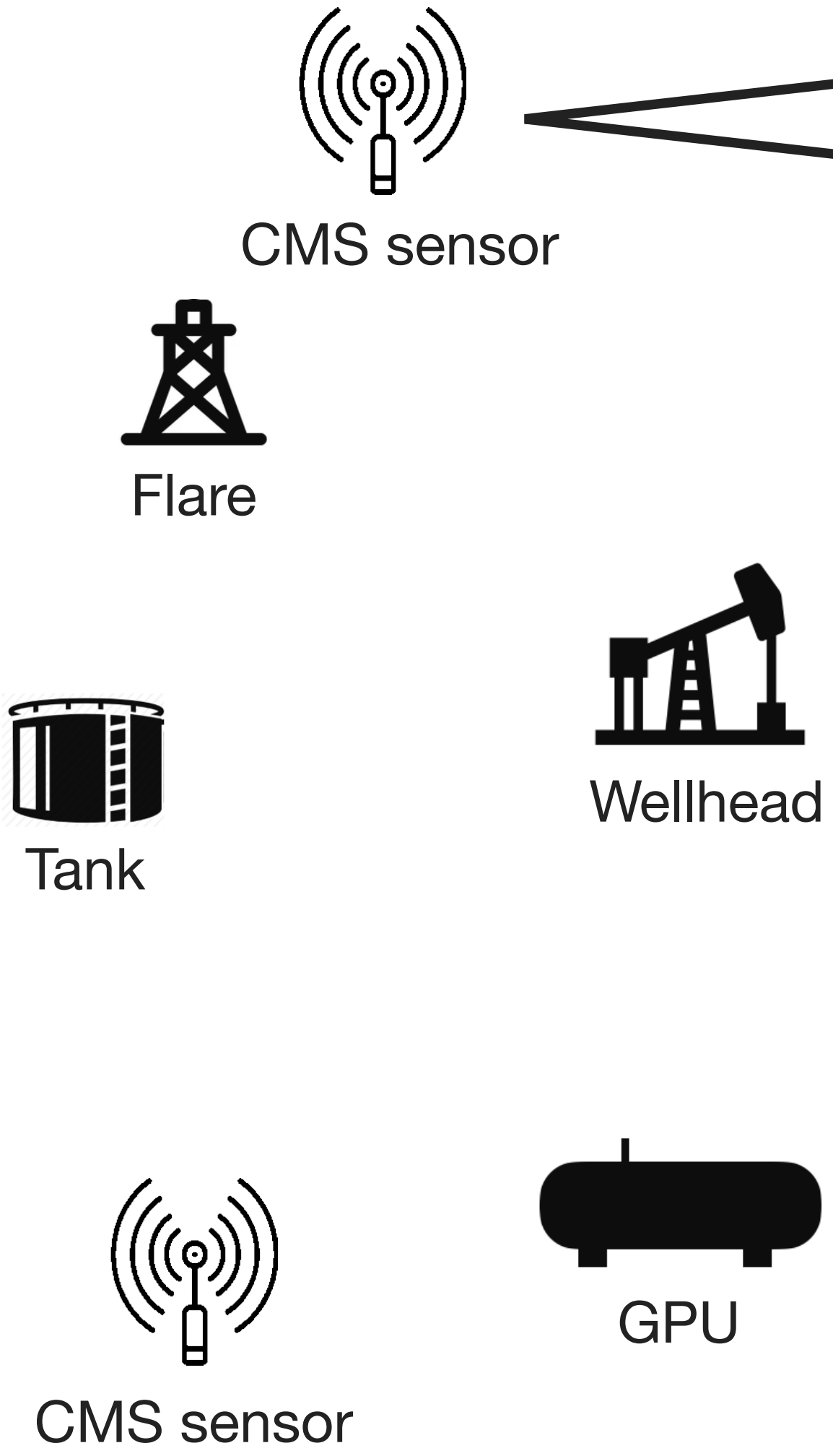
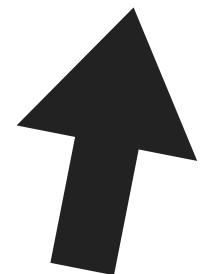


# The continuous monitoring inverse problem



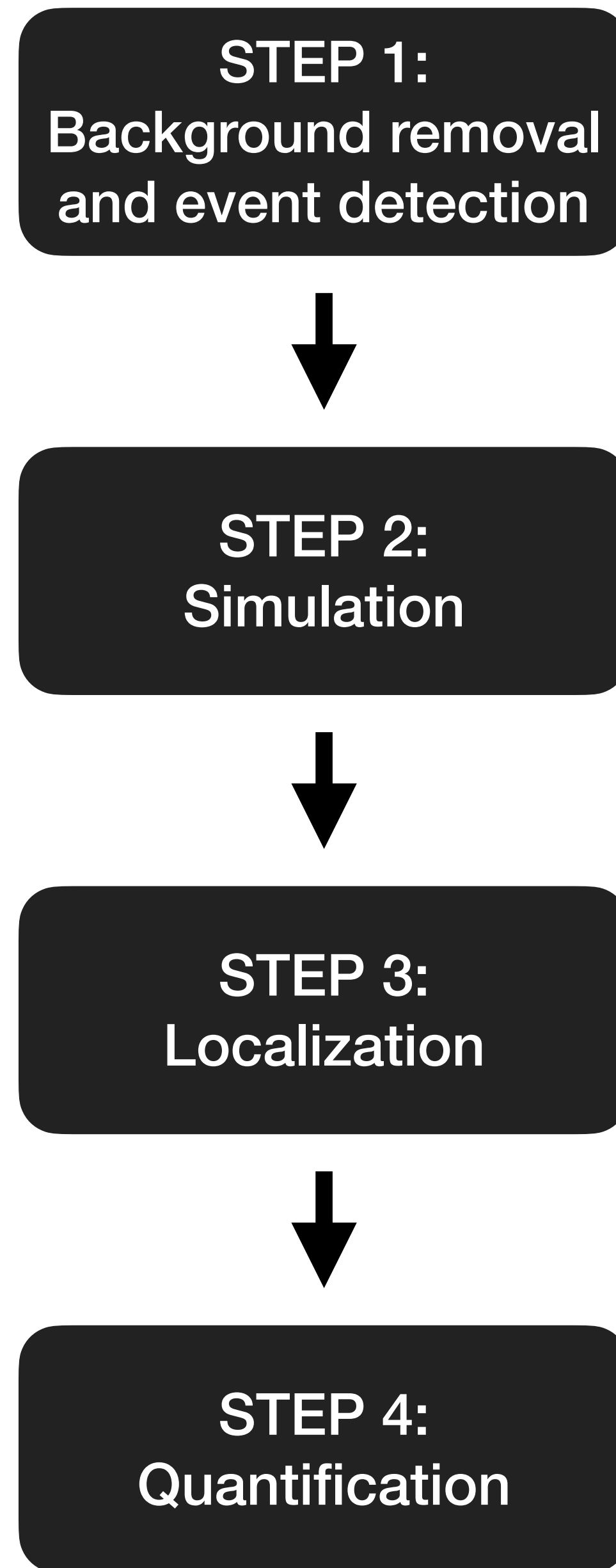


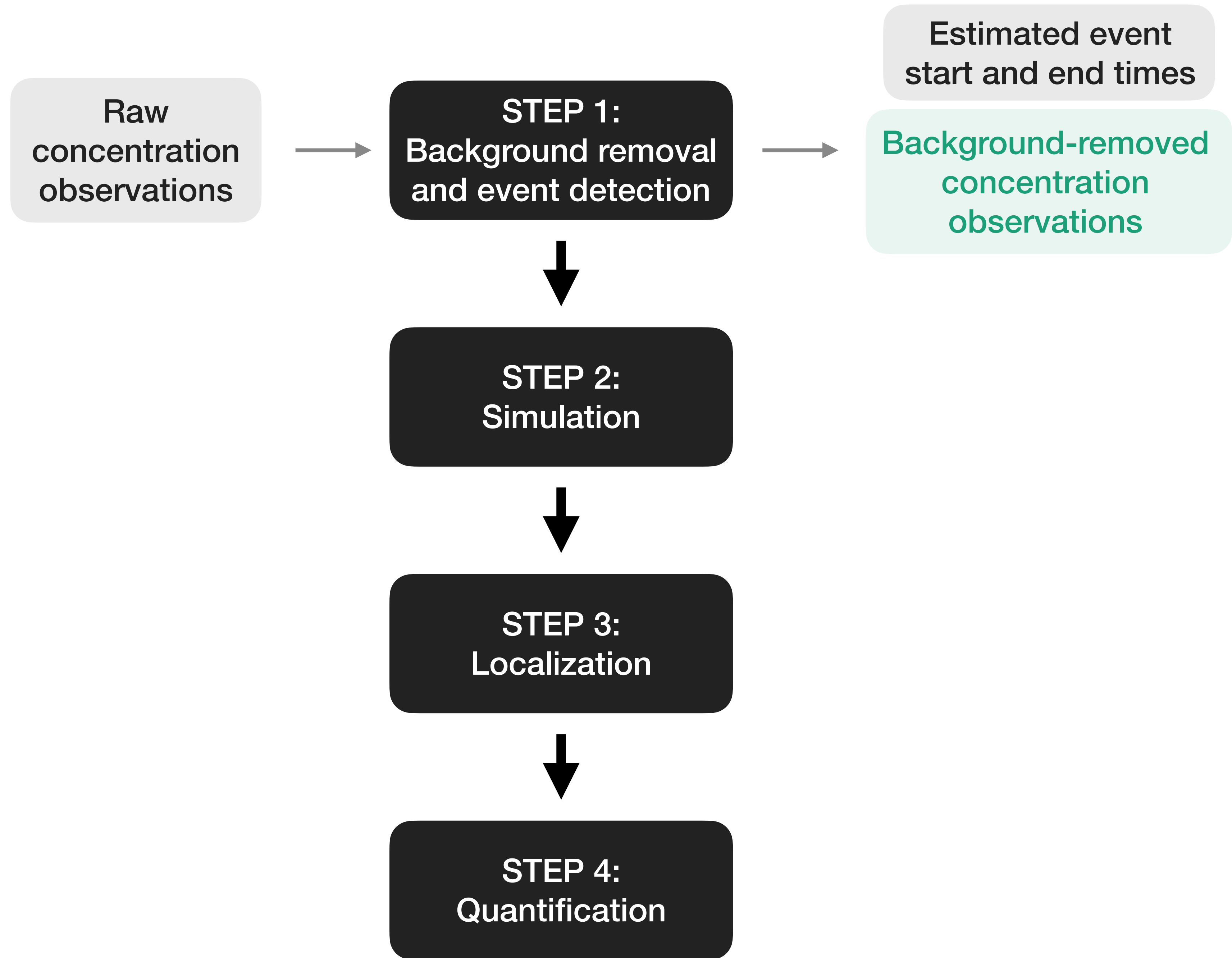
Wind direction

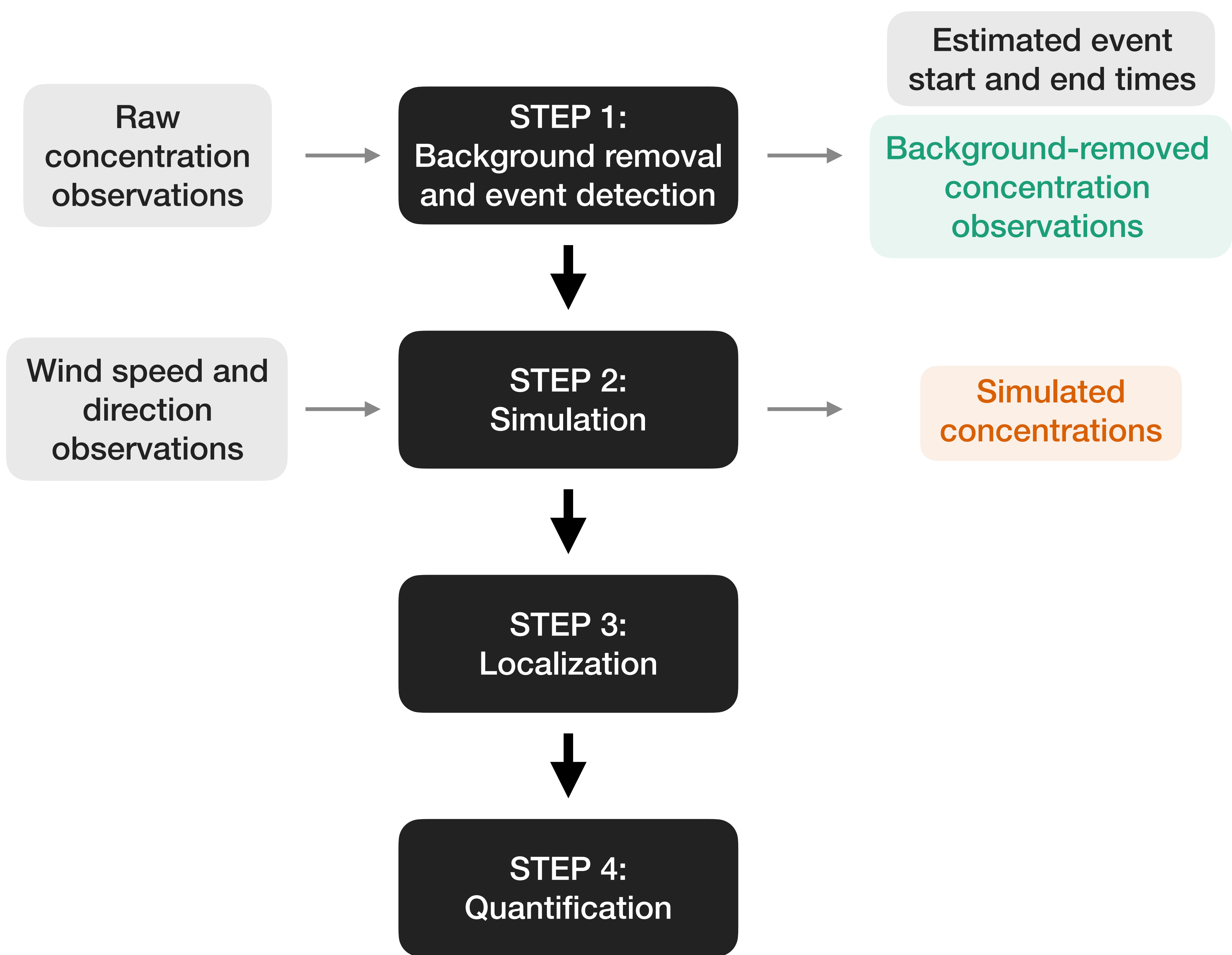


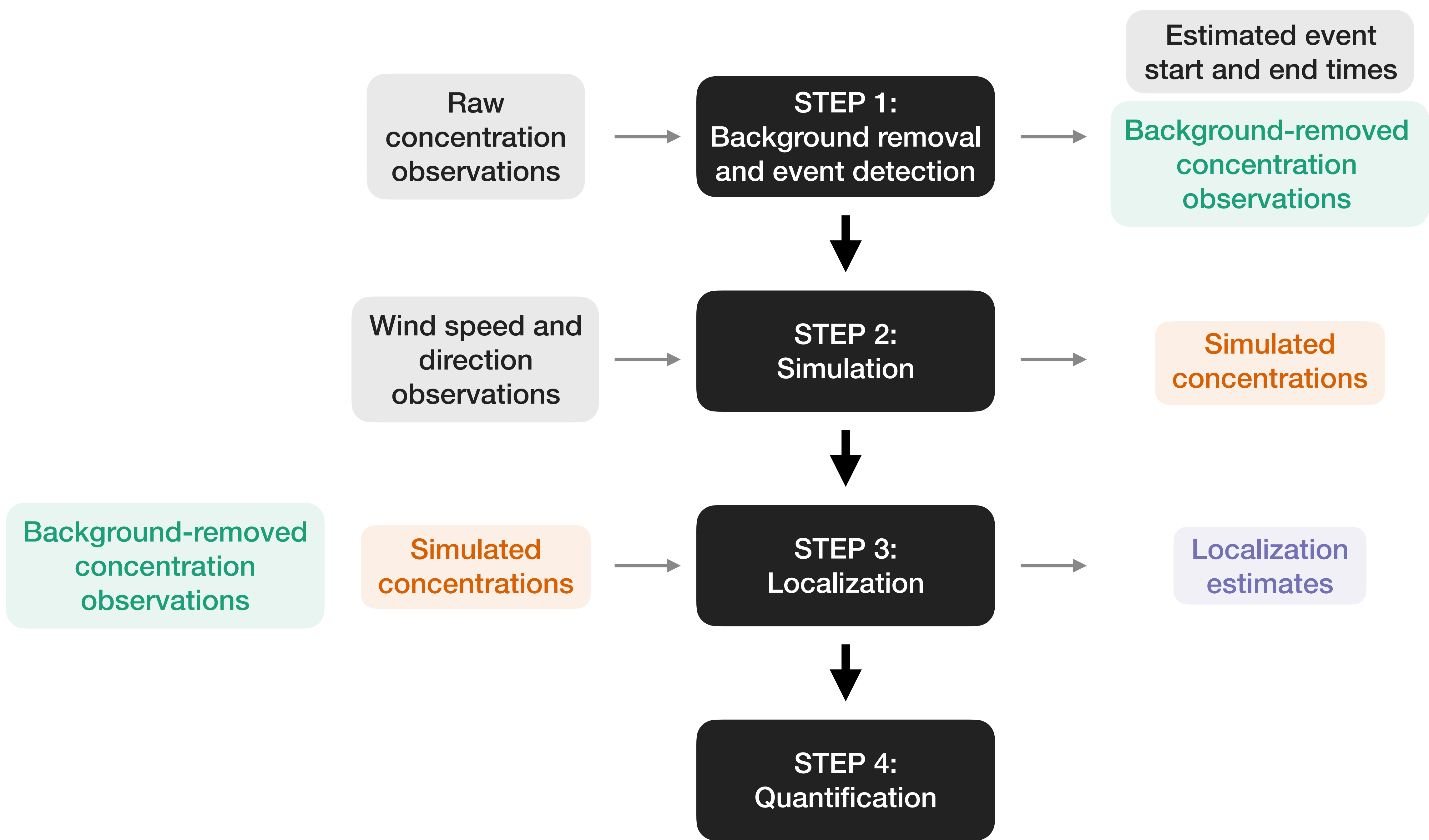


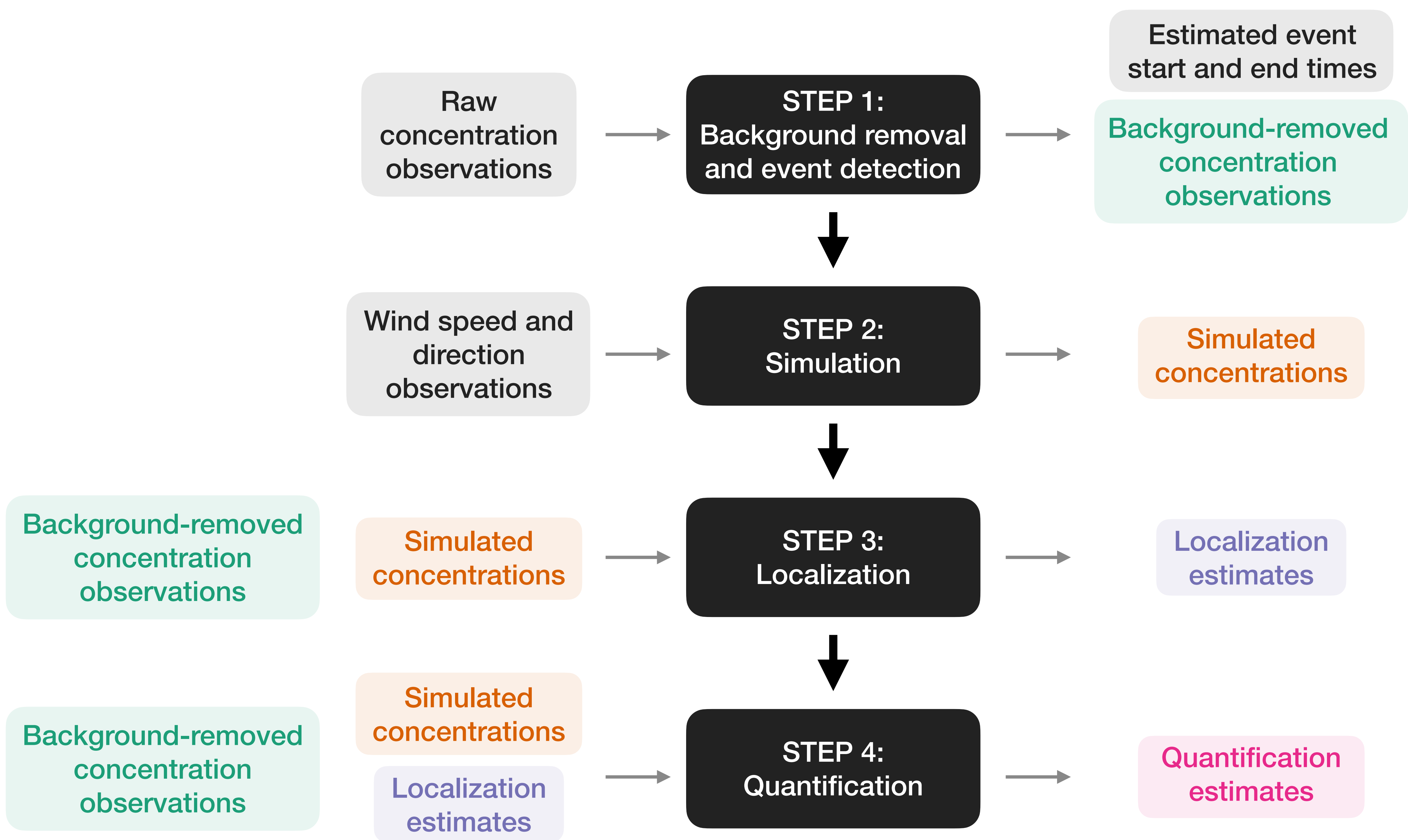
Framework for  
emission event  
detection, localization,  
and quantification  
using CMS



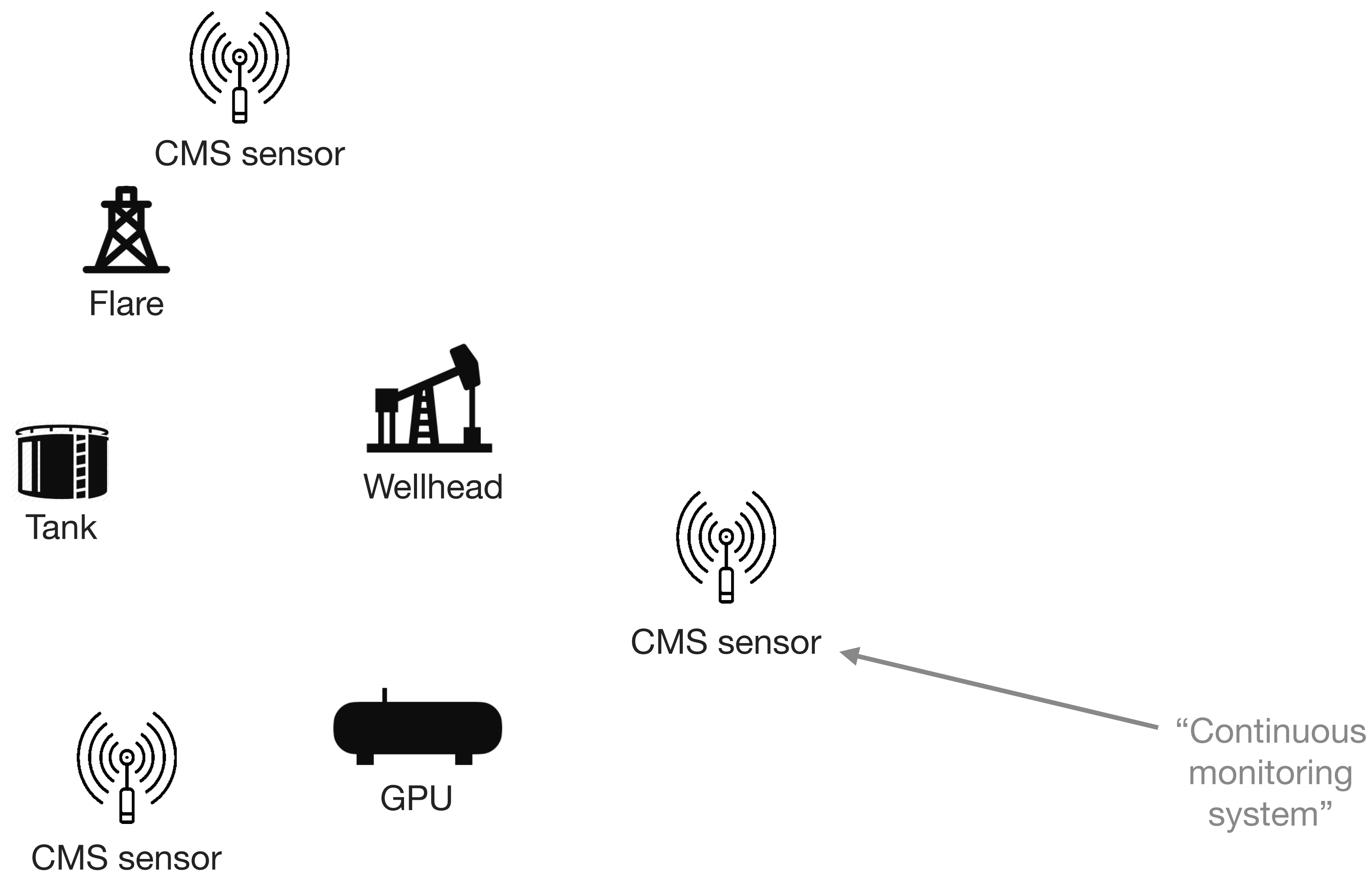




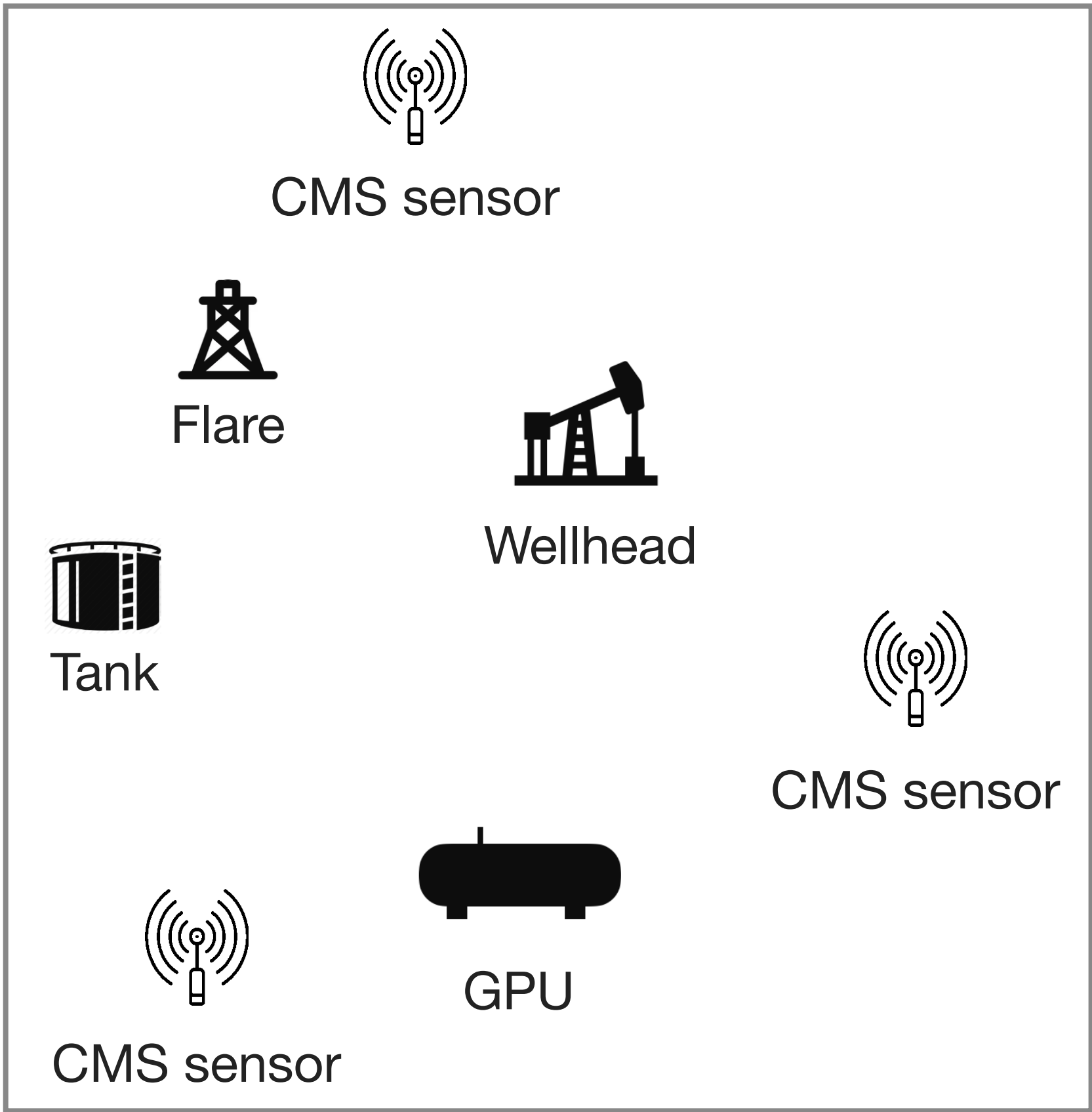




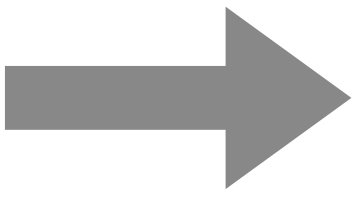




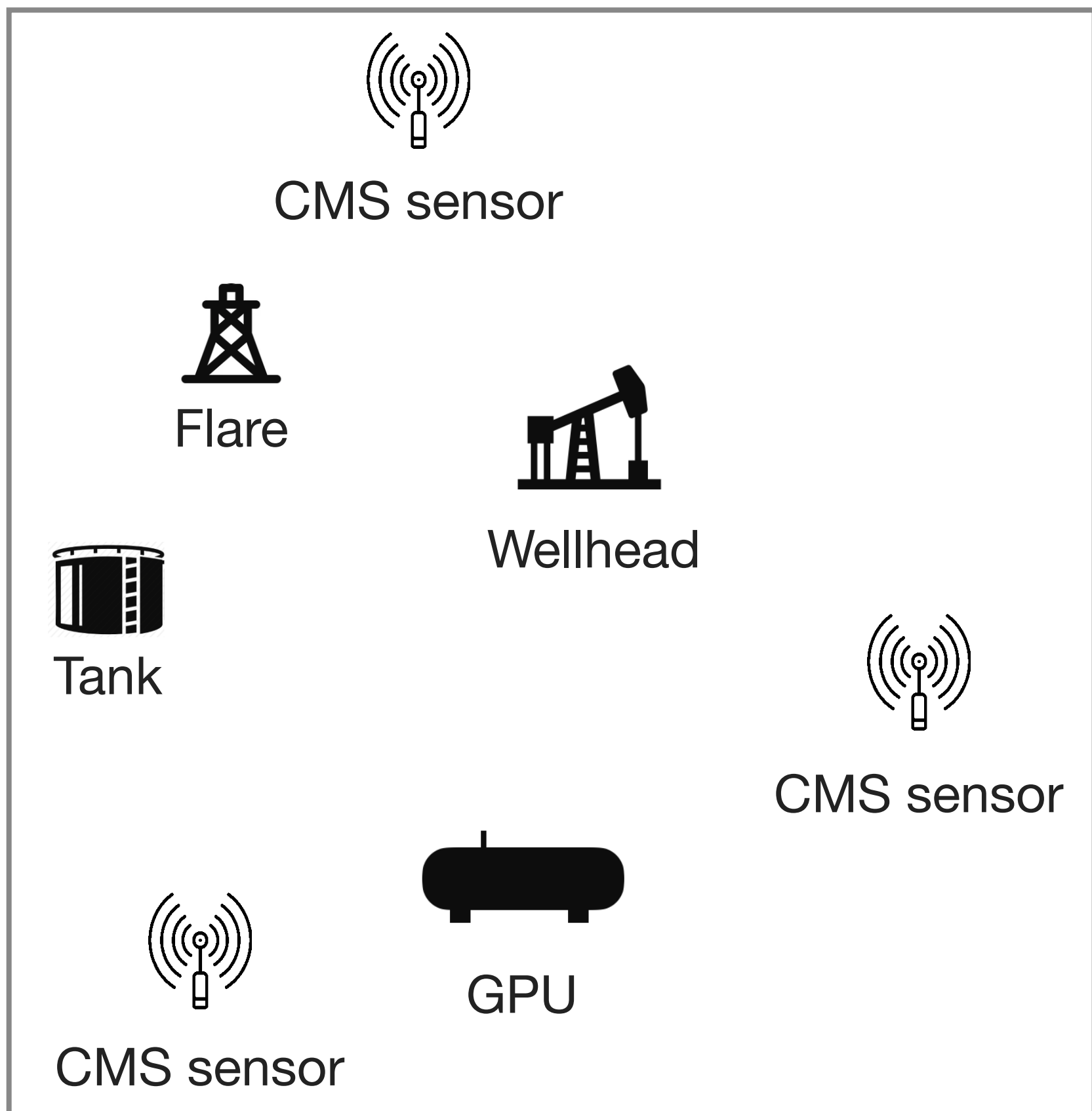
# Site-level reconciliation case study



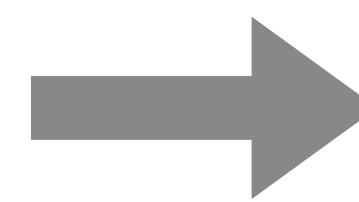
13 top-down  
measurements  
over 4 days



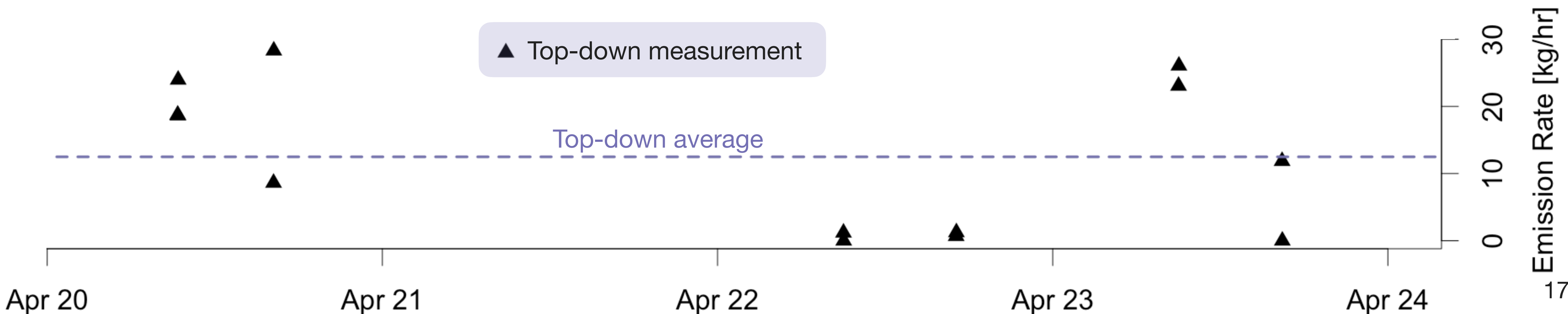
average = 12.5 kg/hr

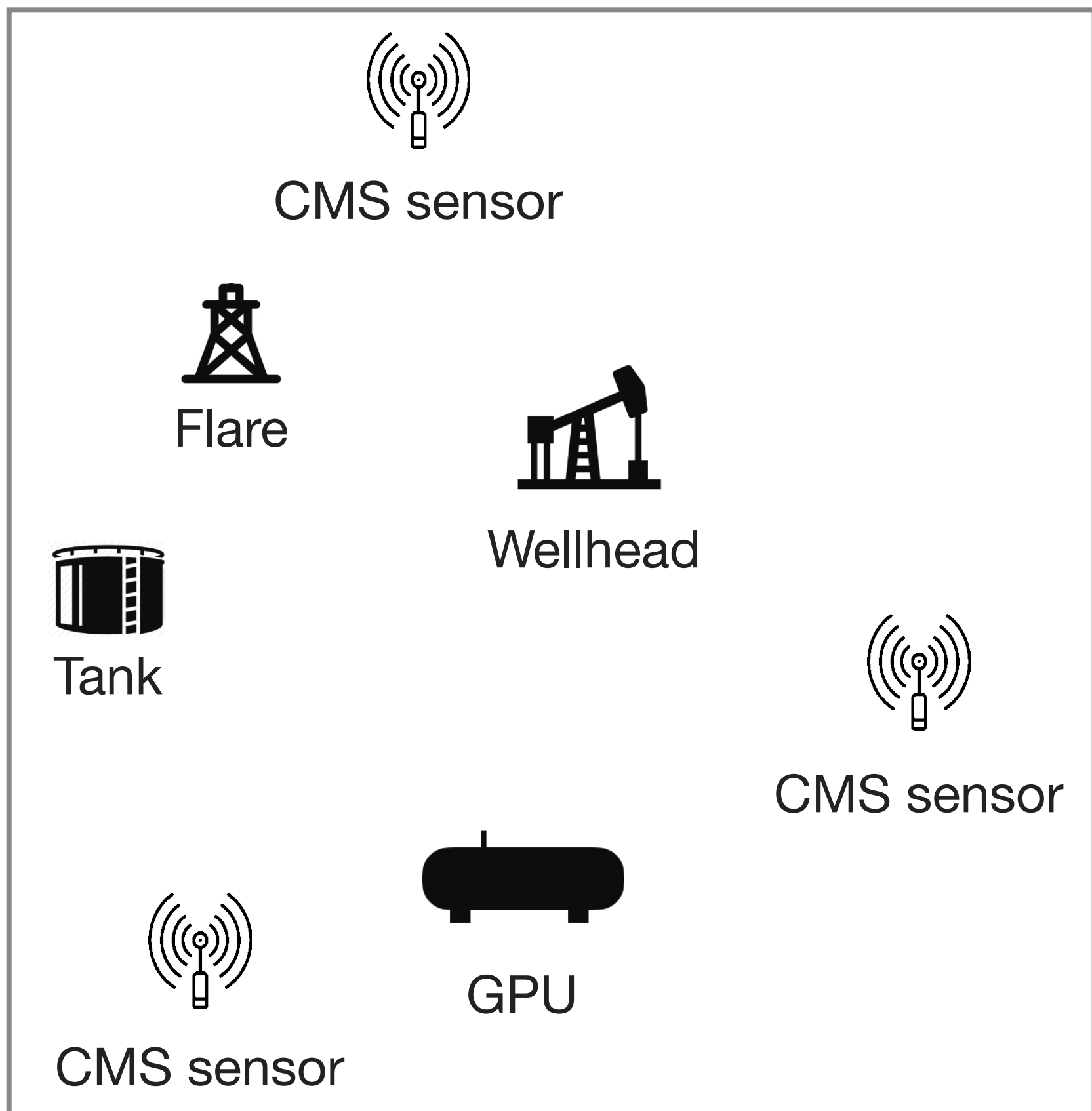


13 top-down measurements over 4 days

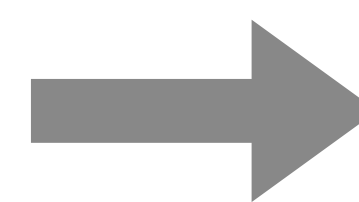


average = 12.5 kg/hr



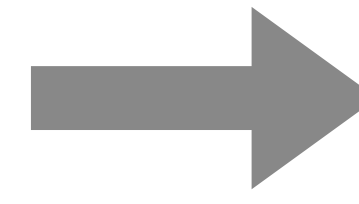


13 top-down measurements over 4 days

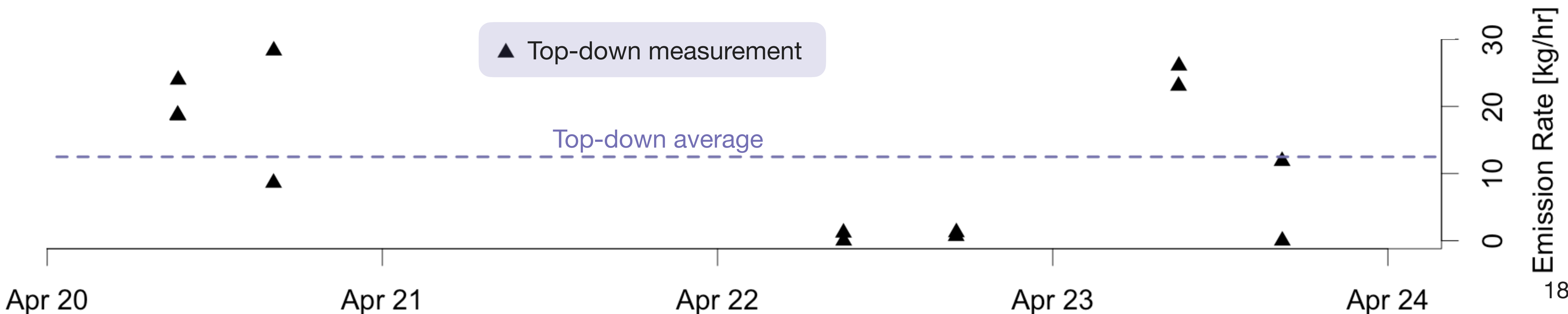


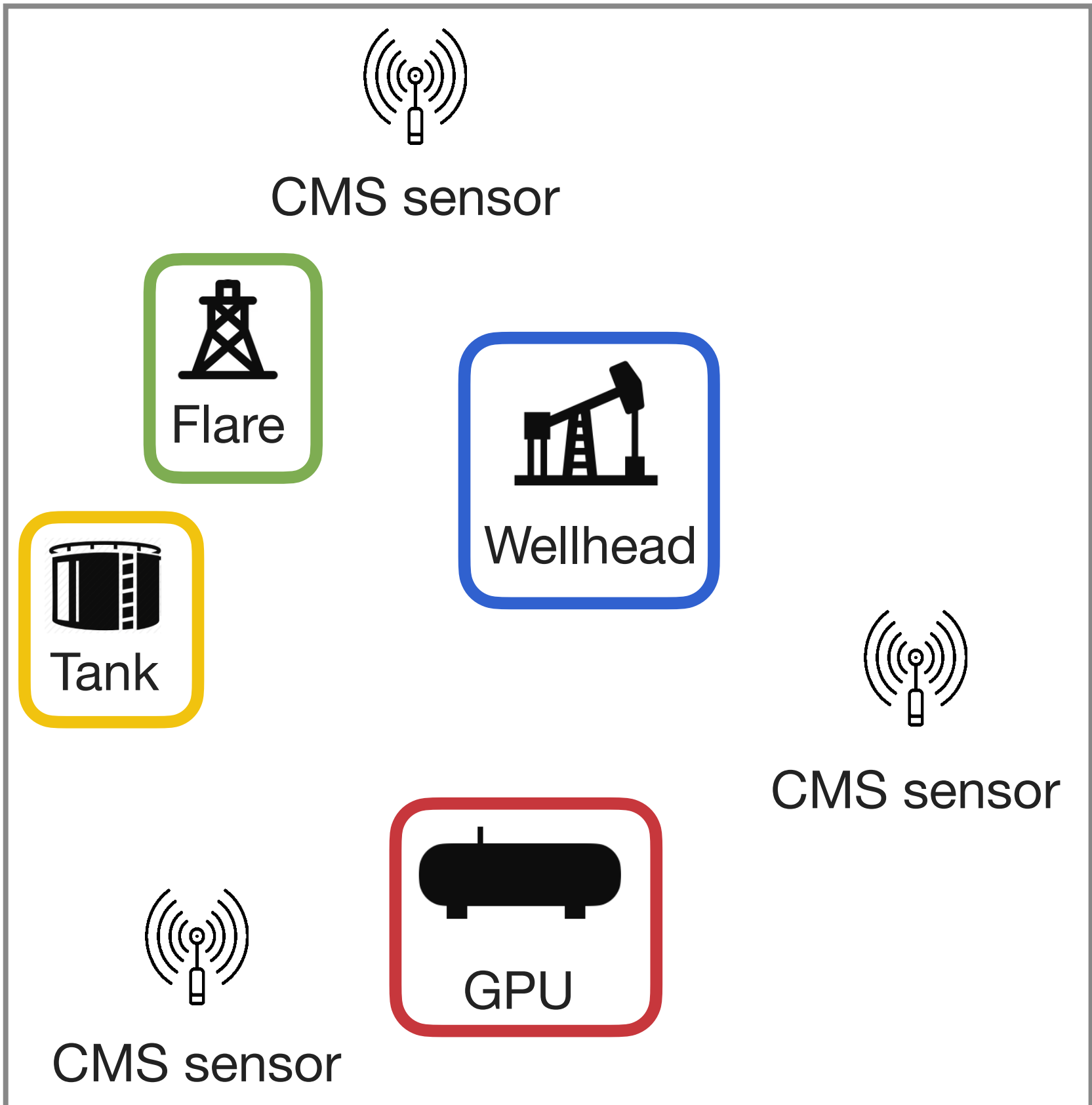
average = 12.5 kg/hr

Bottom-up inventory during top-down measurements

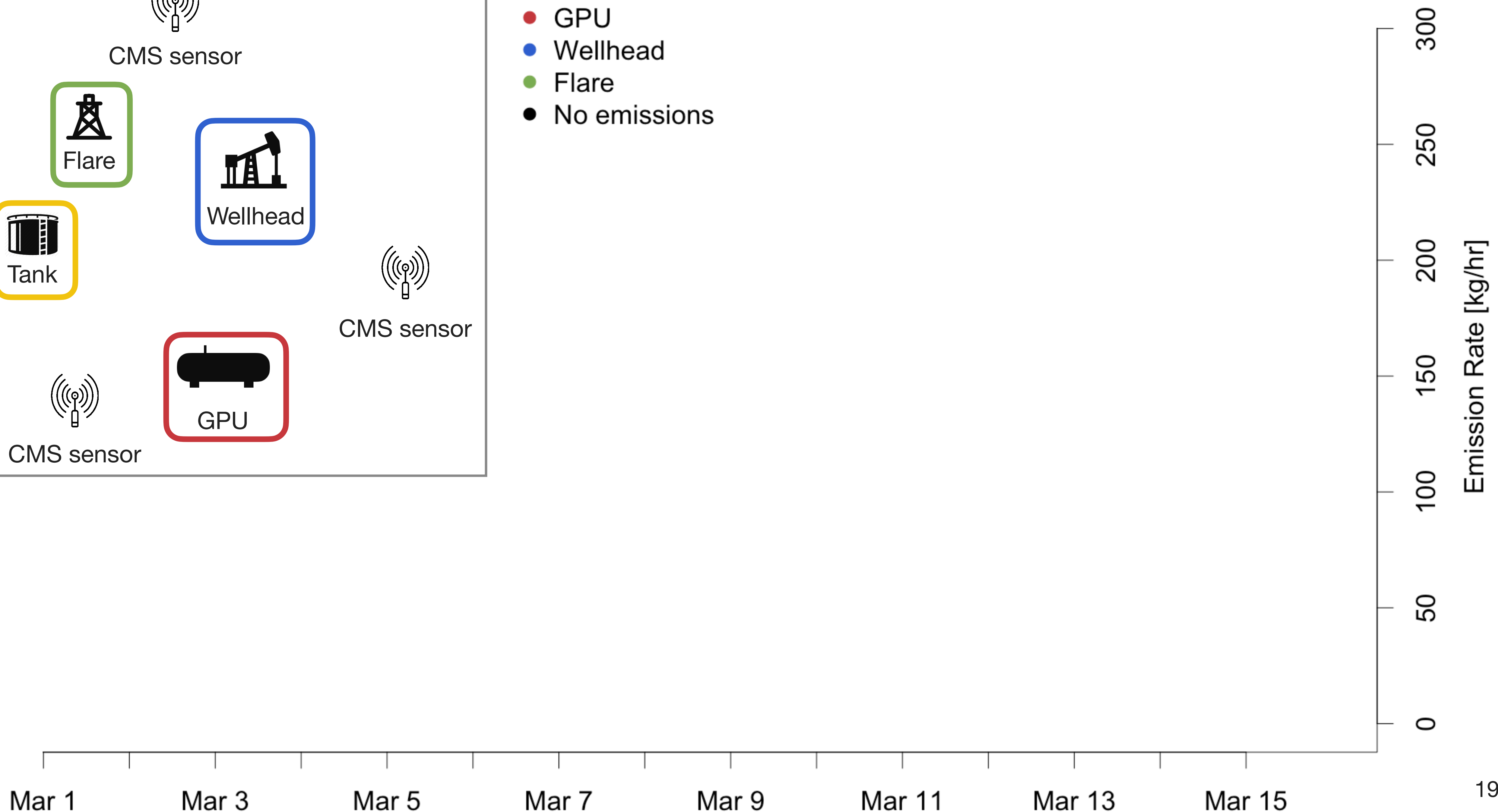


0.8 kg/hr

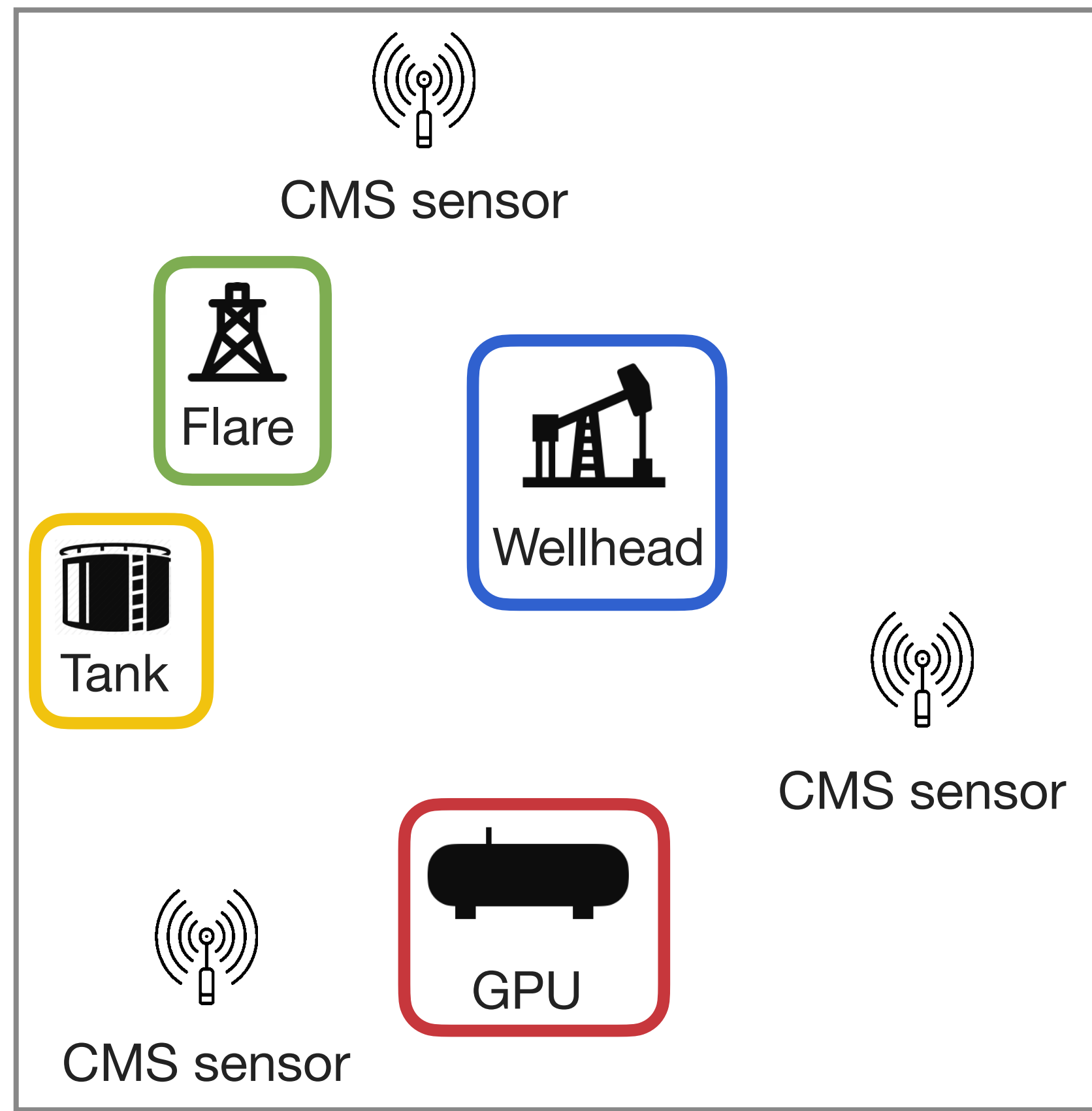




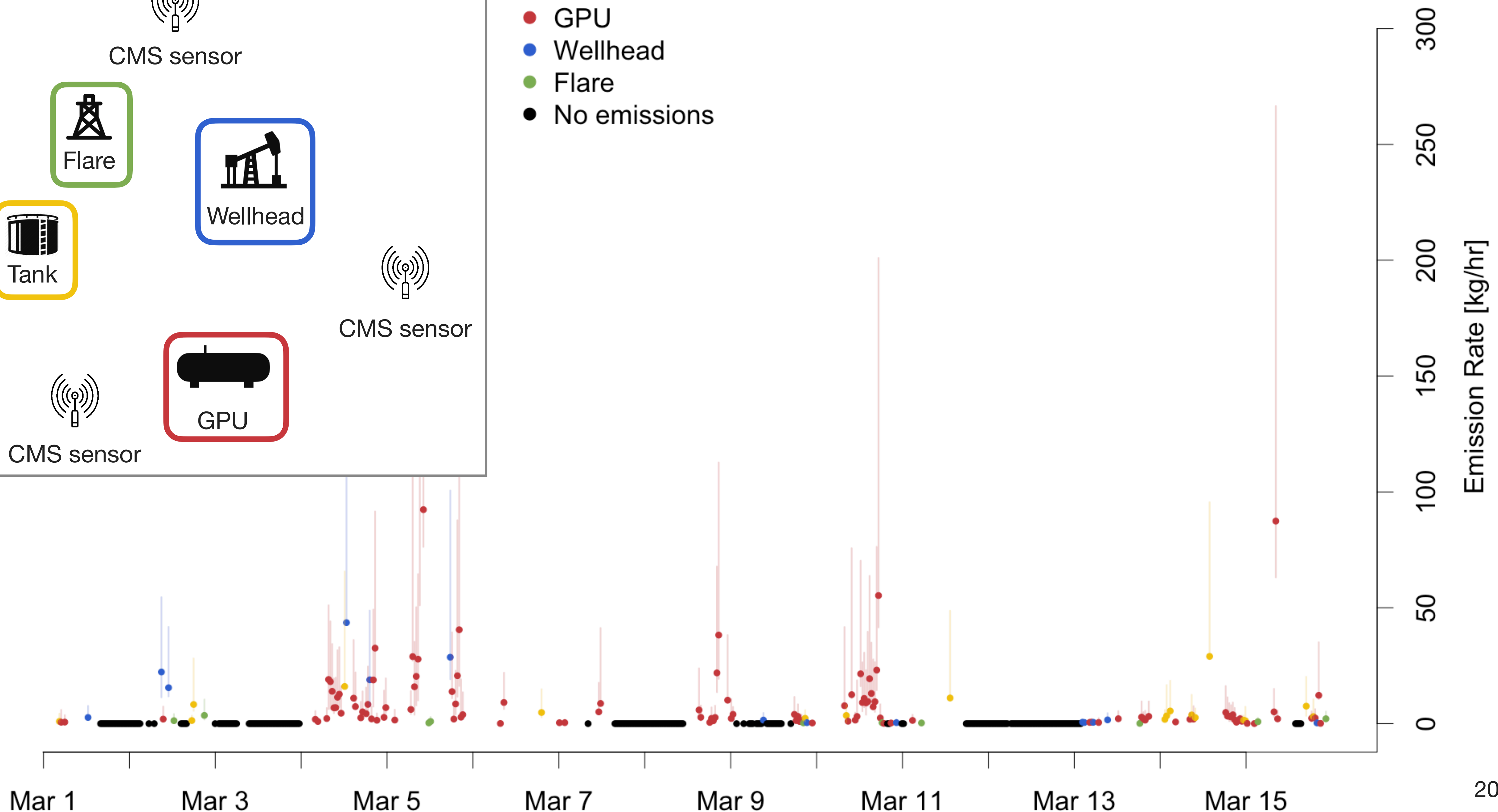
- Tank
- GPU
- Wellhead
- Flare
- No emissions

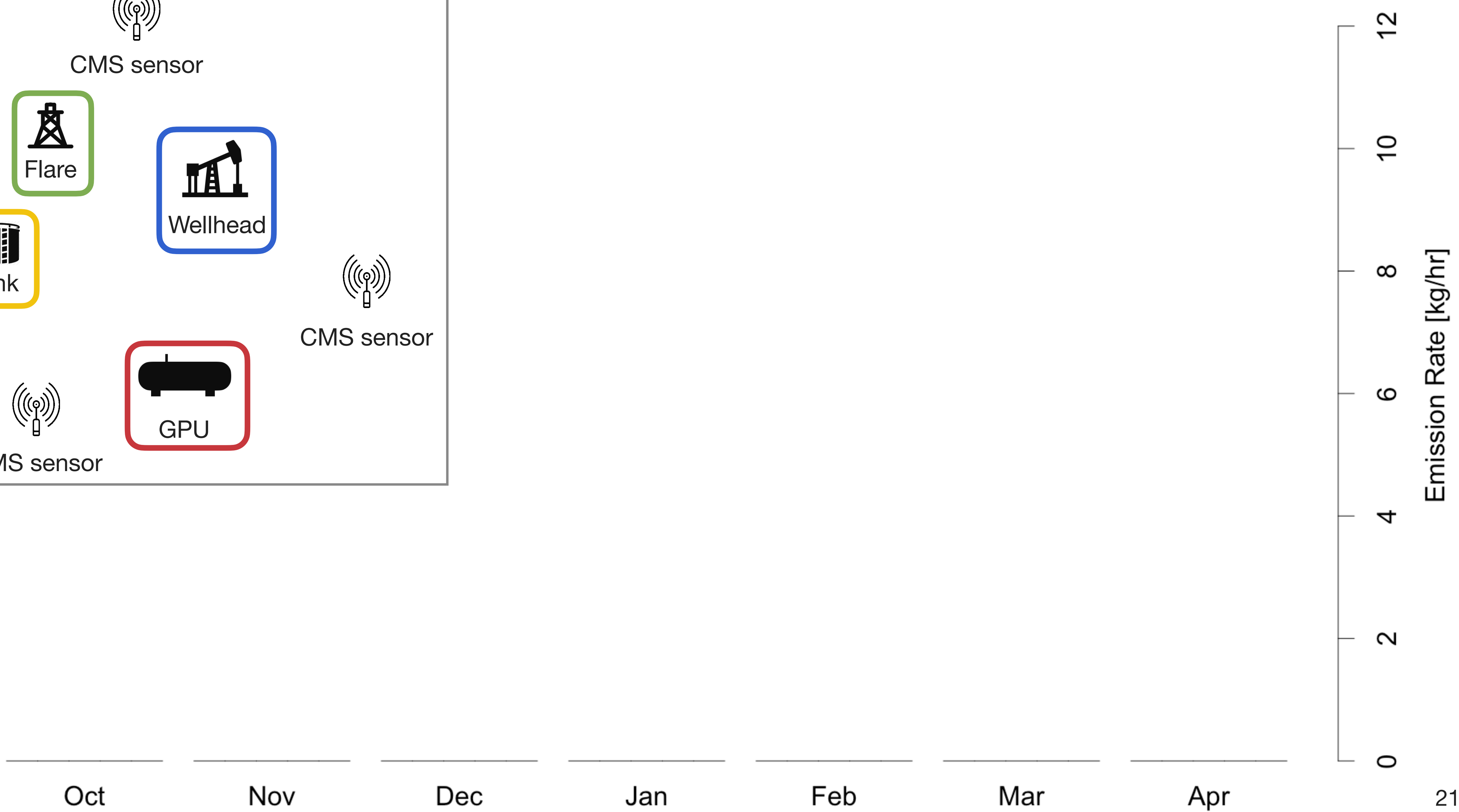
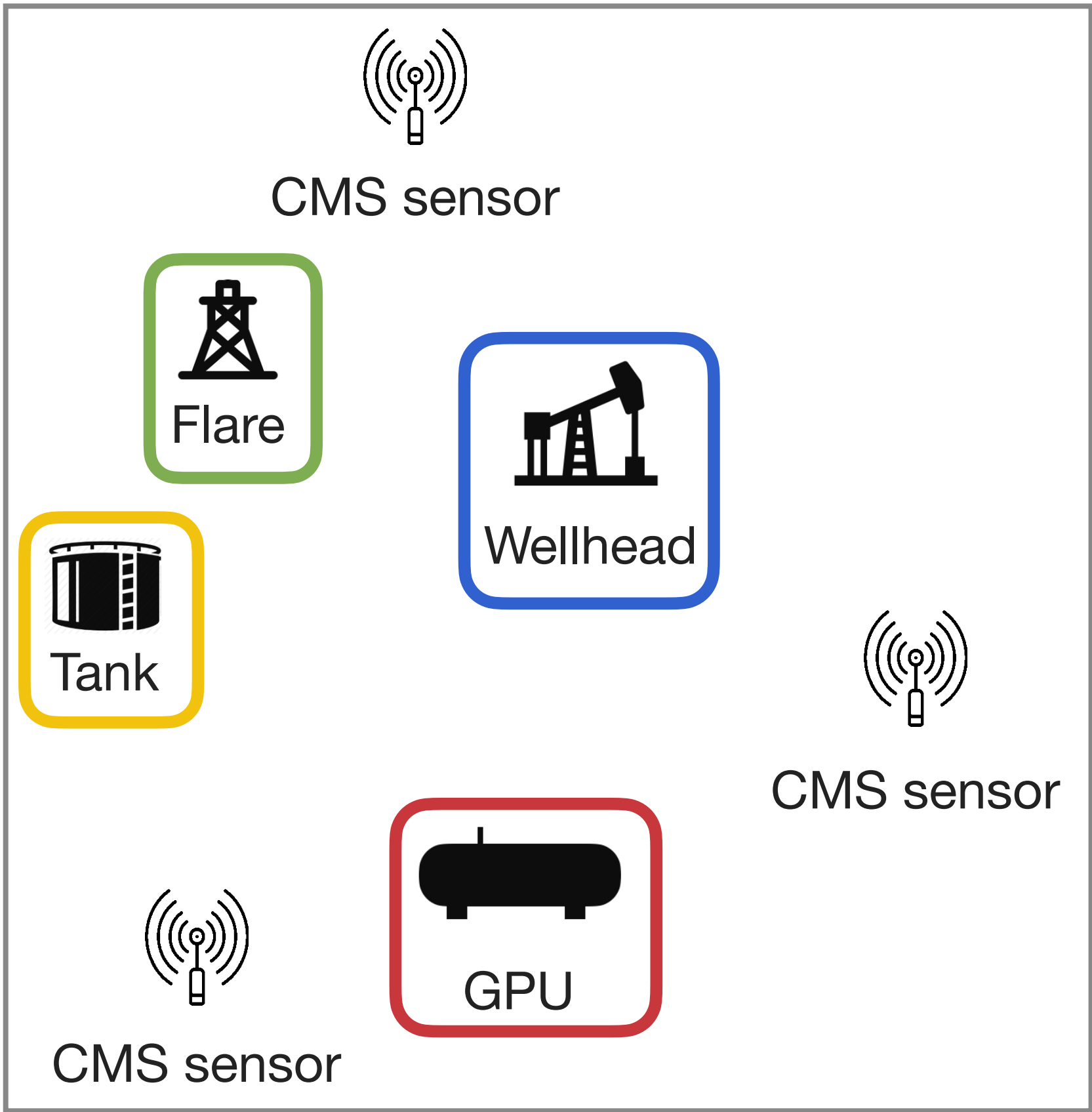


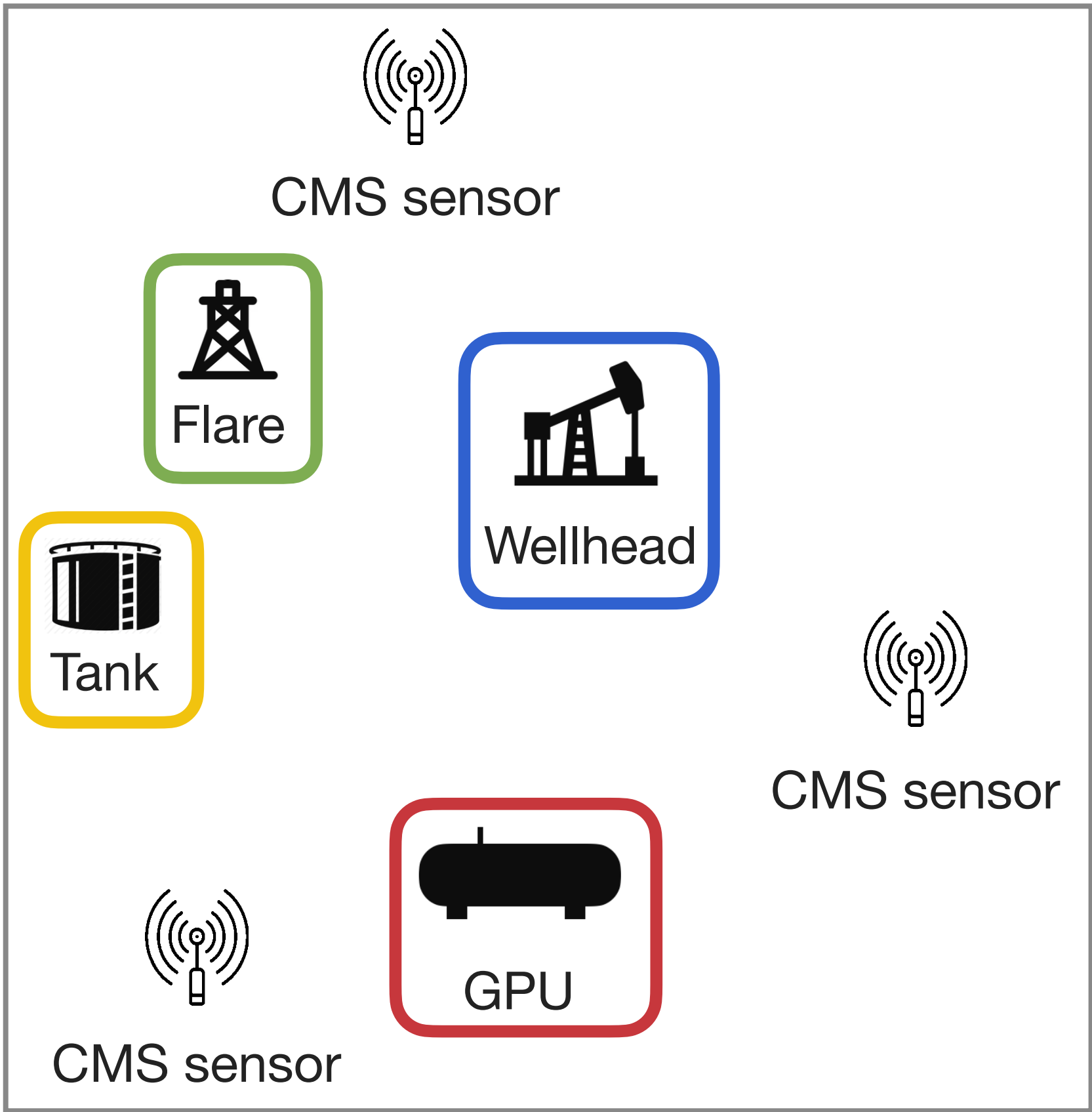




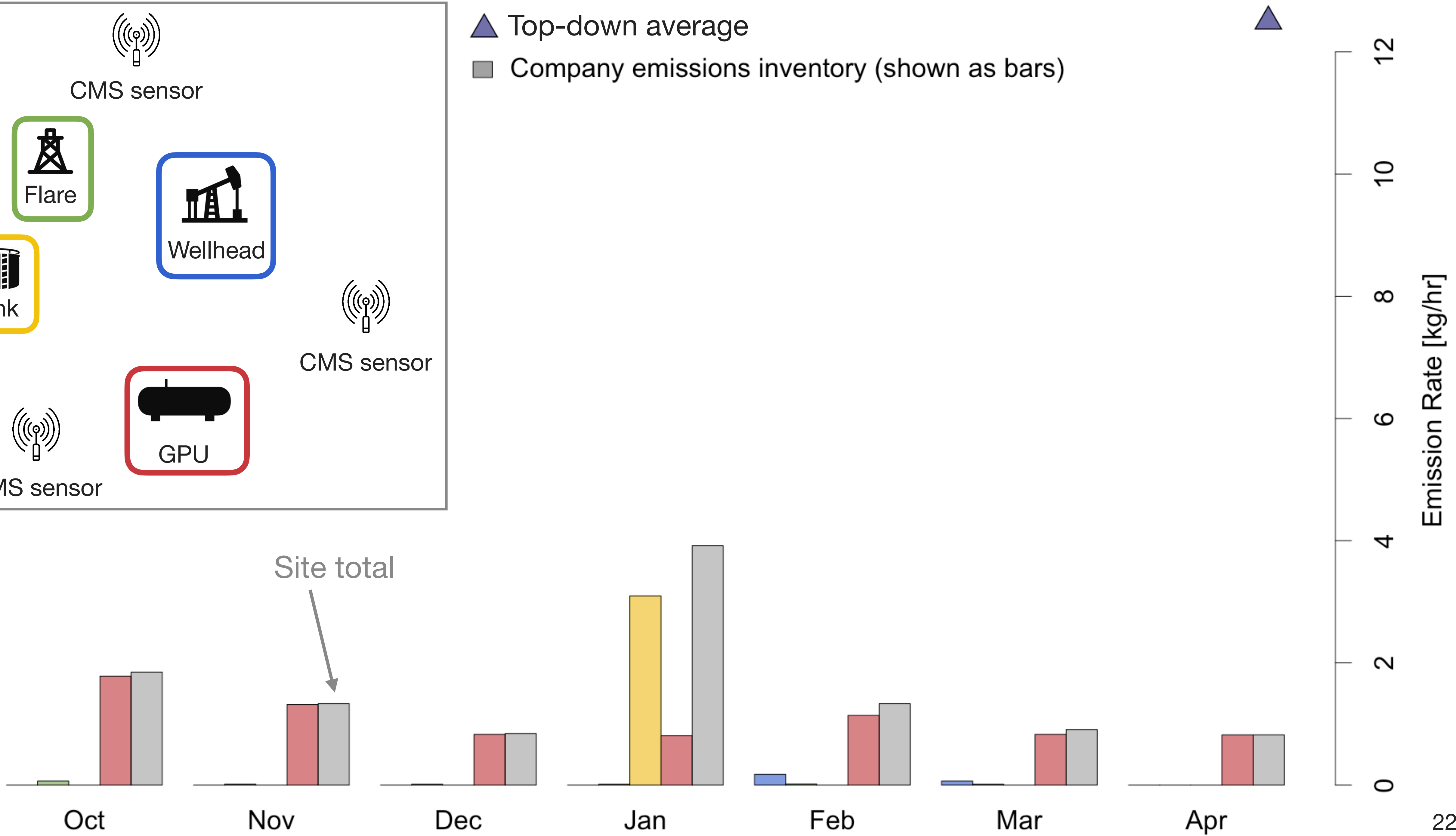
- Tank
- GPU
- Wellhead
- Flare
- No emissions

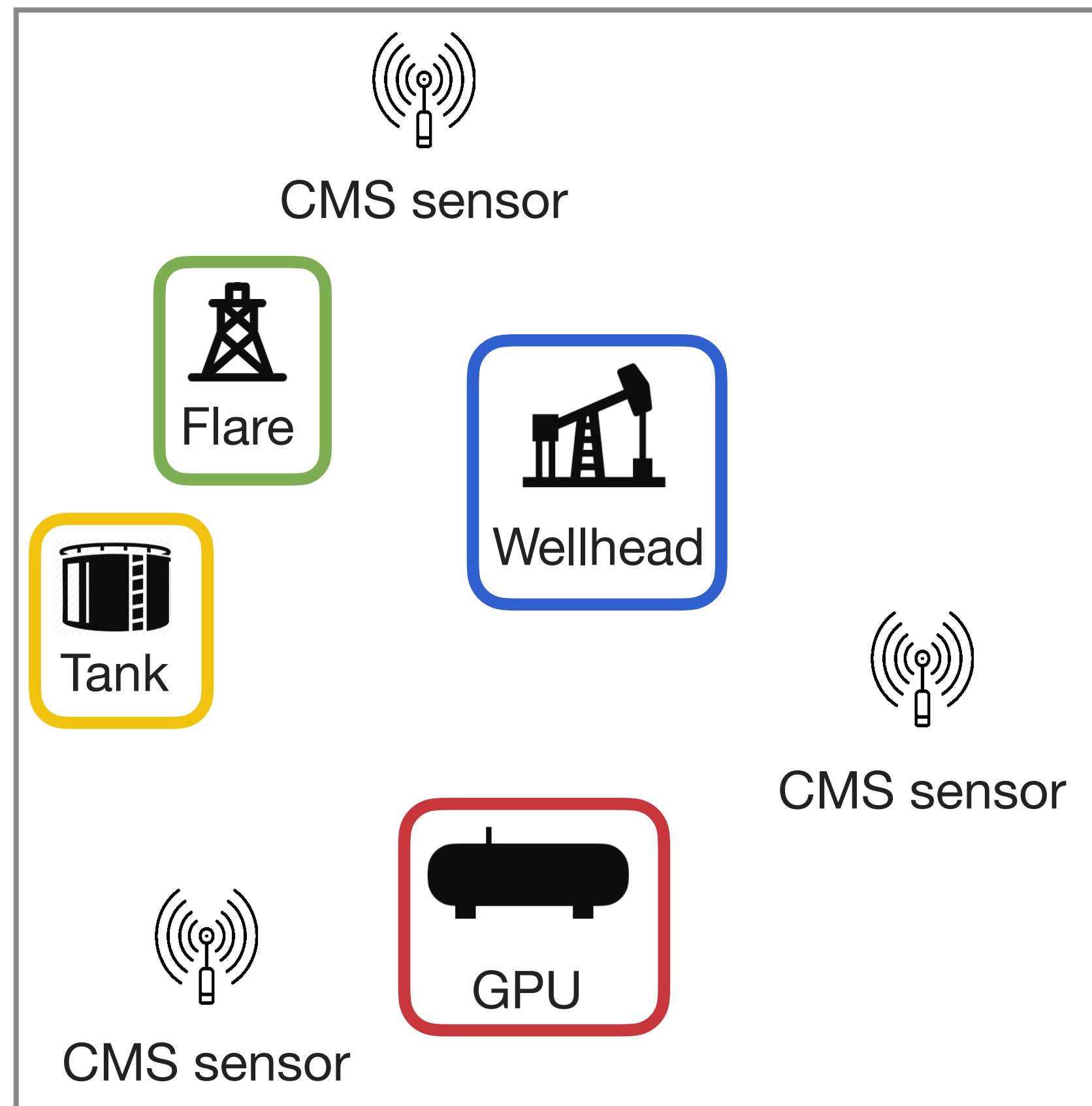




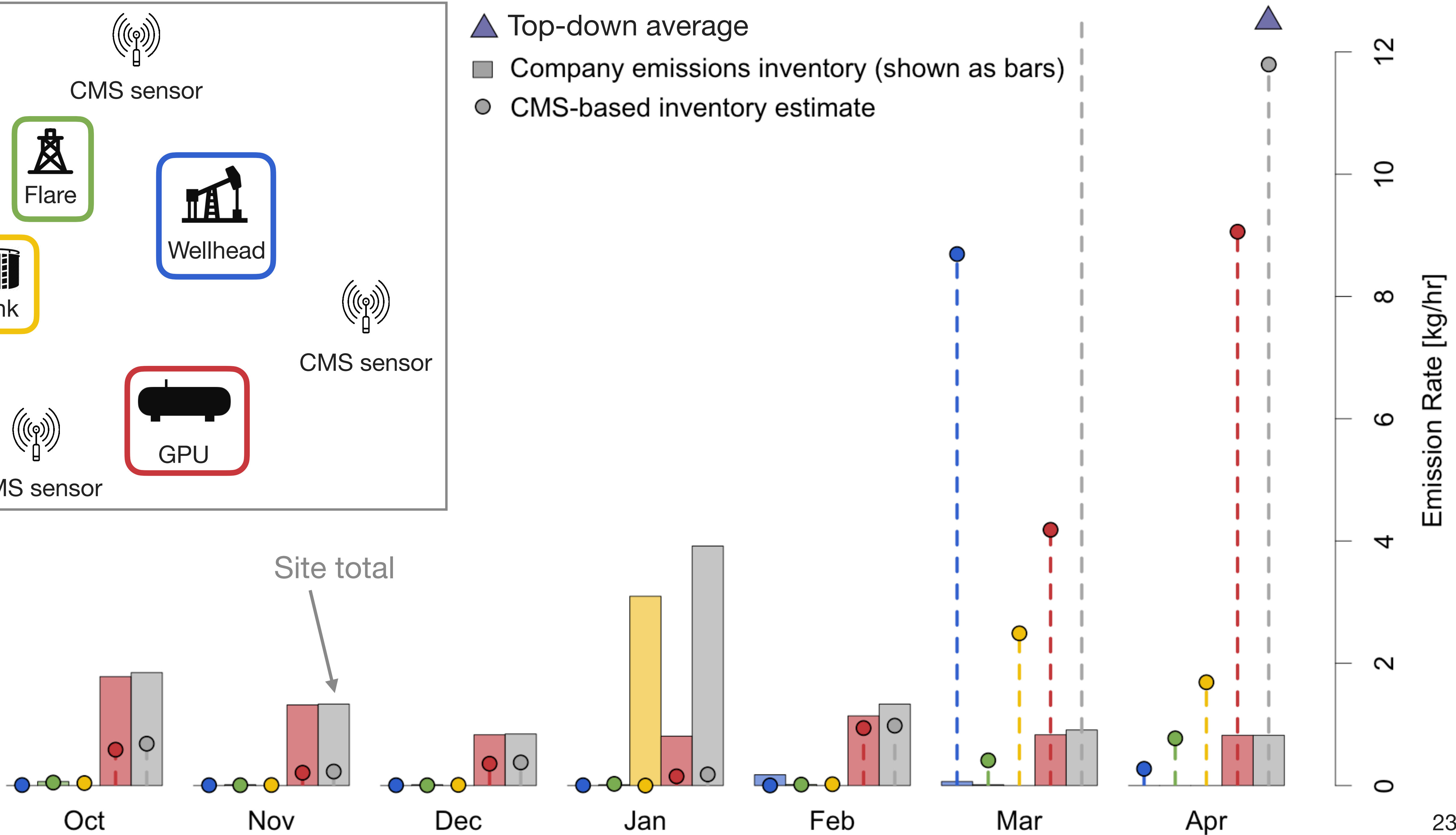


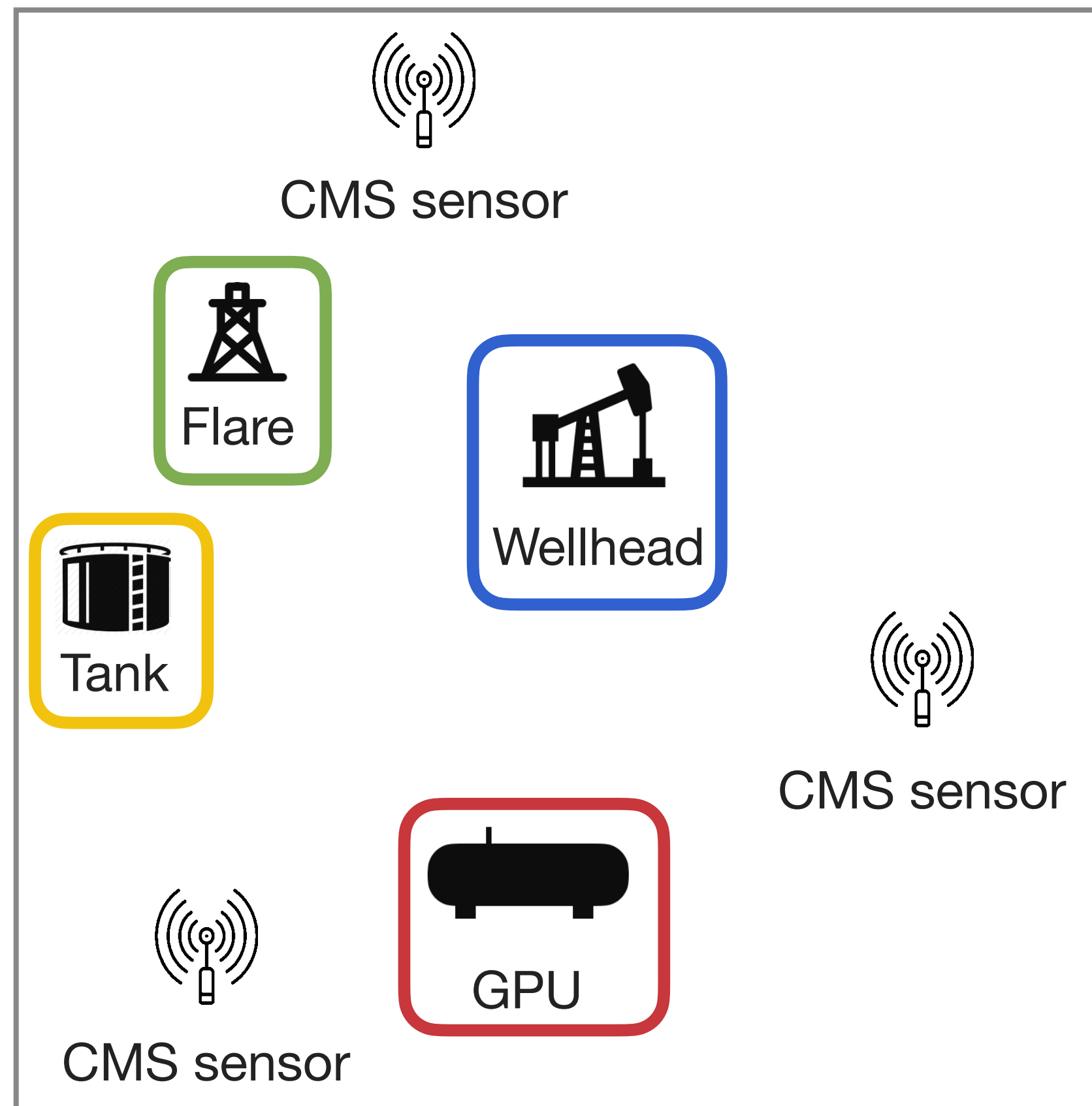
- ▲ Top-down average
- Company emissions inventory (shown as bars)





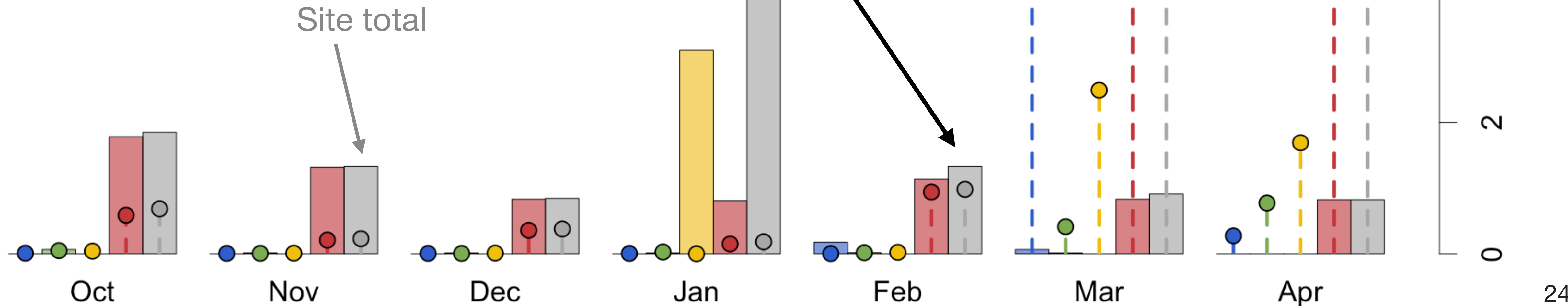
- ▲ Top-down average
- Company emissions inventory (shown as bars)
- CMS-based inventory estimate





- ▲ Top-down average
- Company emissions inventory (shown as bars)
- CMS-based inventory estimate

Equipment change on February 23<sup>rd</sup>





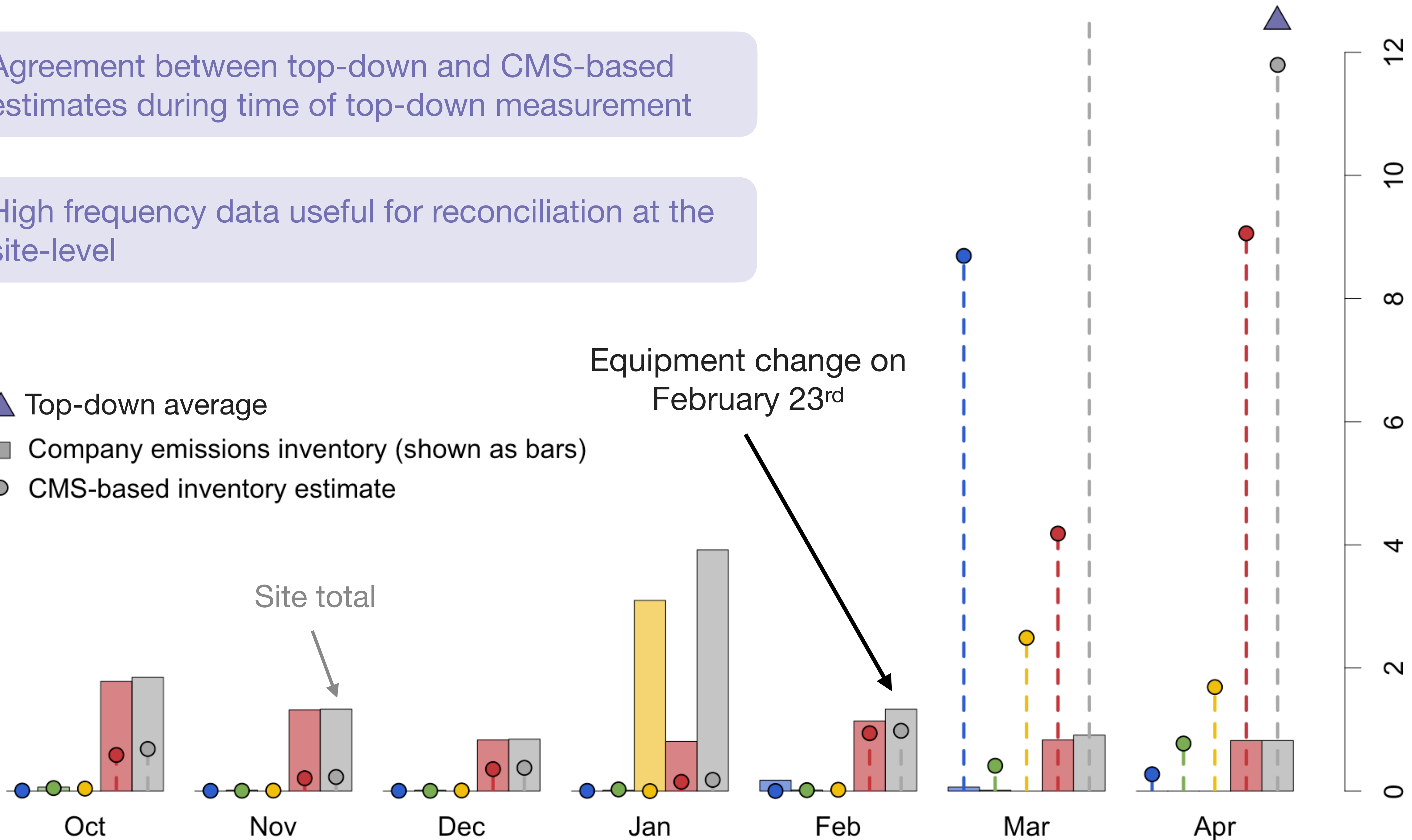
Agreement between top-down and CMS-based estimates during time of top-down measurement

High frequency data useful for reconciliation at the site-level

- ▲ Top-down average
- Company emissions inventory (shown as bars)
- CMS-based inventory estimate

Equipment change on February 23<sup>rd</sup>

Site total



# Thank you!





# 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. *Elementa*, under revision, (2023).

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

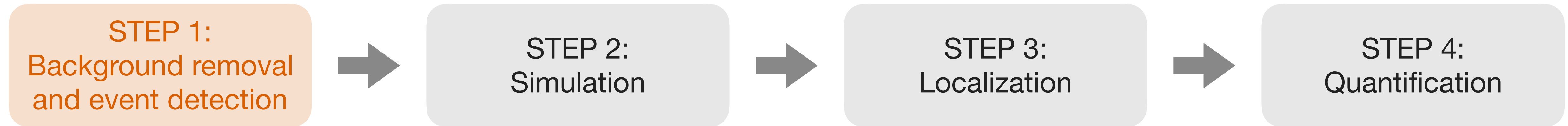
William Daniels, Jiayang (Lyra) Wang, Arvind Ravikumar, Matthew Harrison, Selina Roman-White, Fiji George, Dorit Hammerling. *Environmental Science and Technology*, (2023).

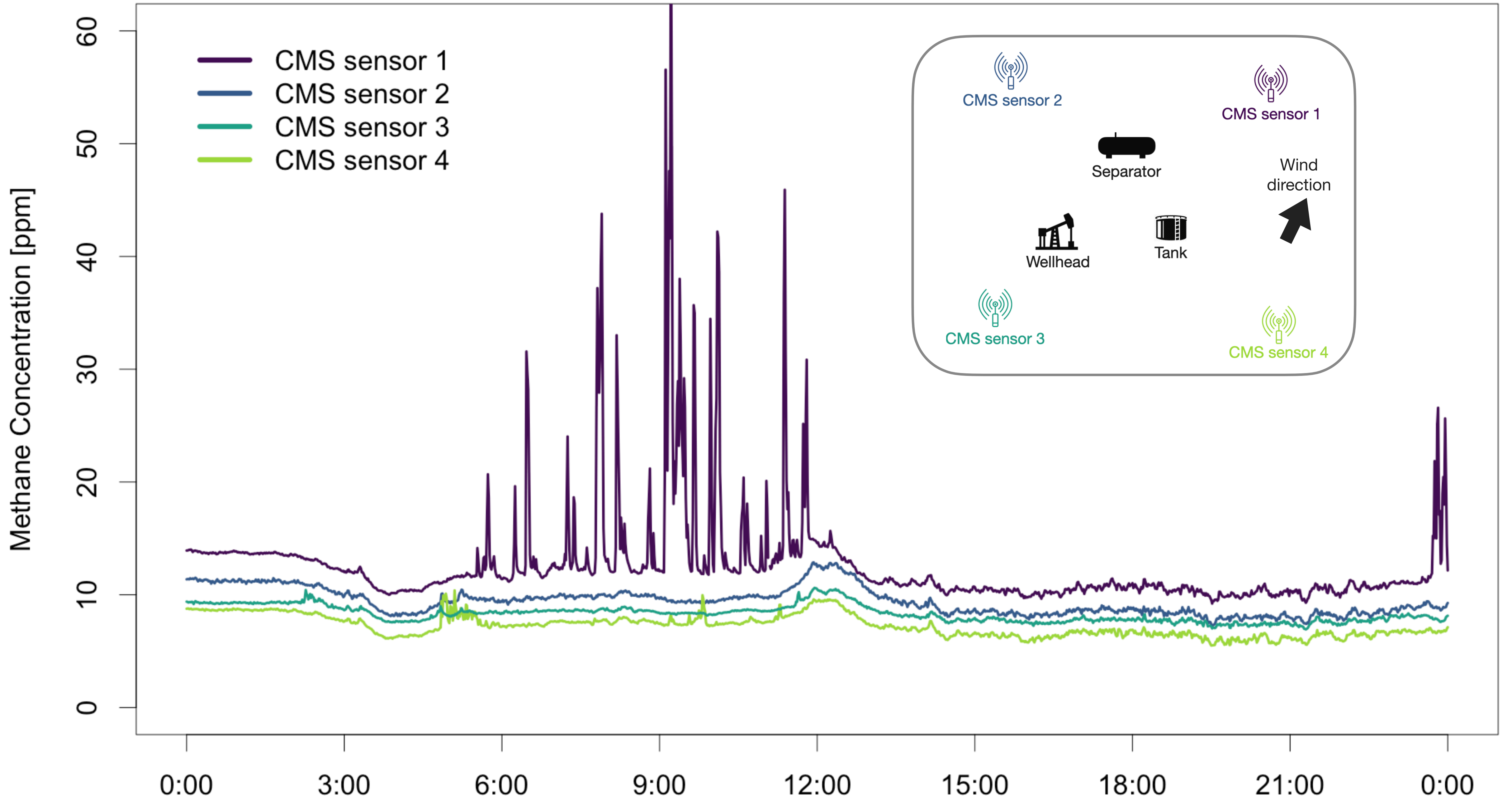


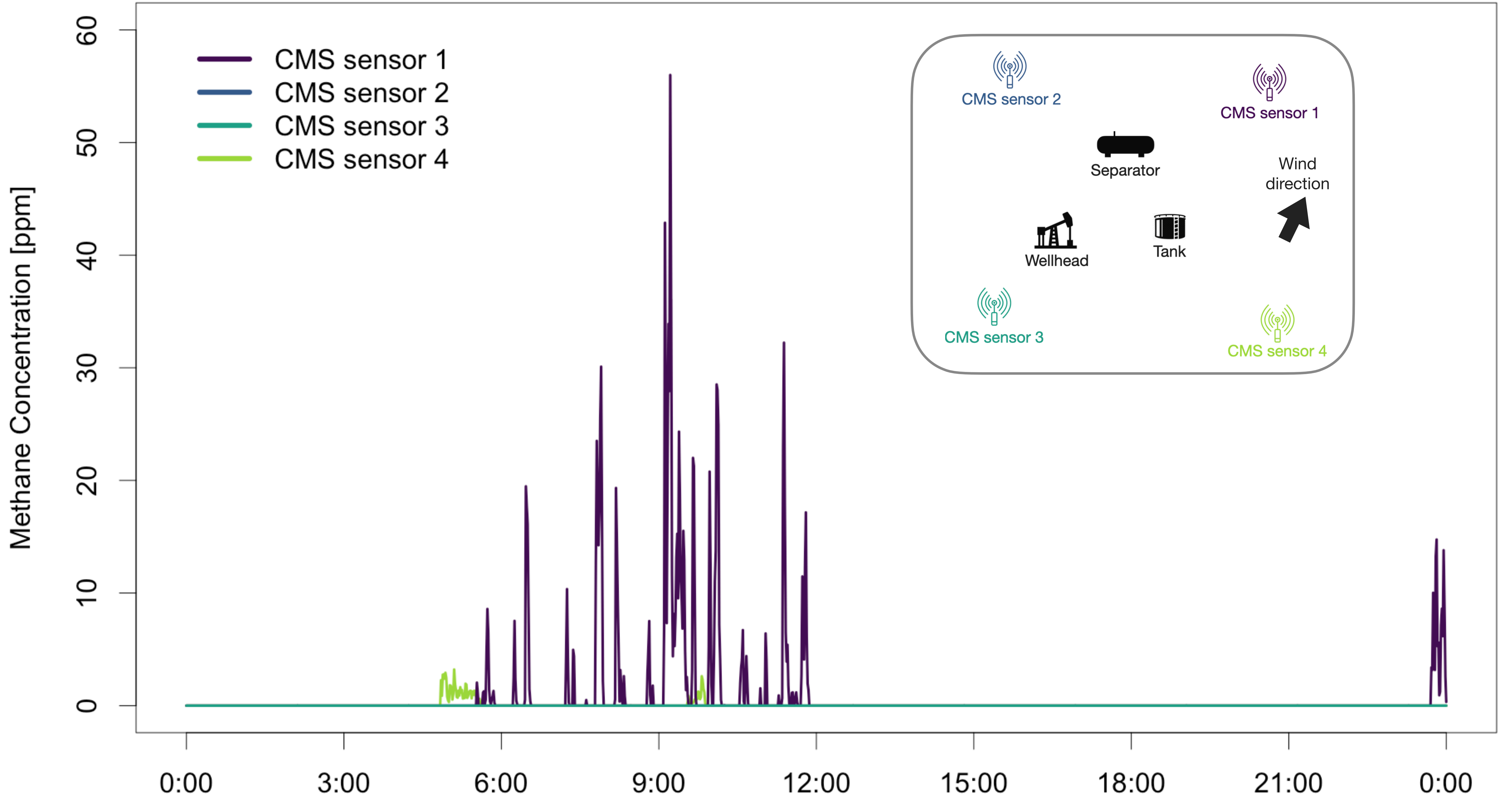
[wdaniels@mines.edu](mailto:wdaniels@mines.edu)

Backup

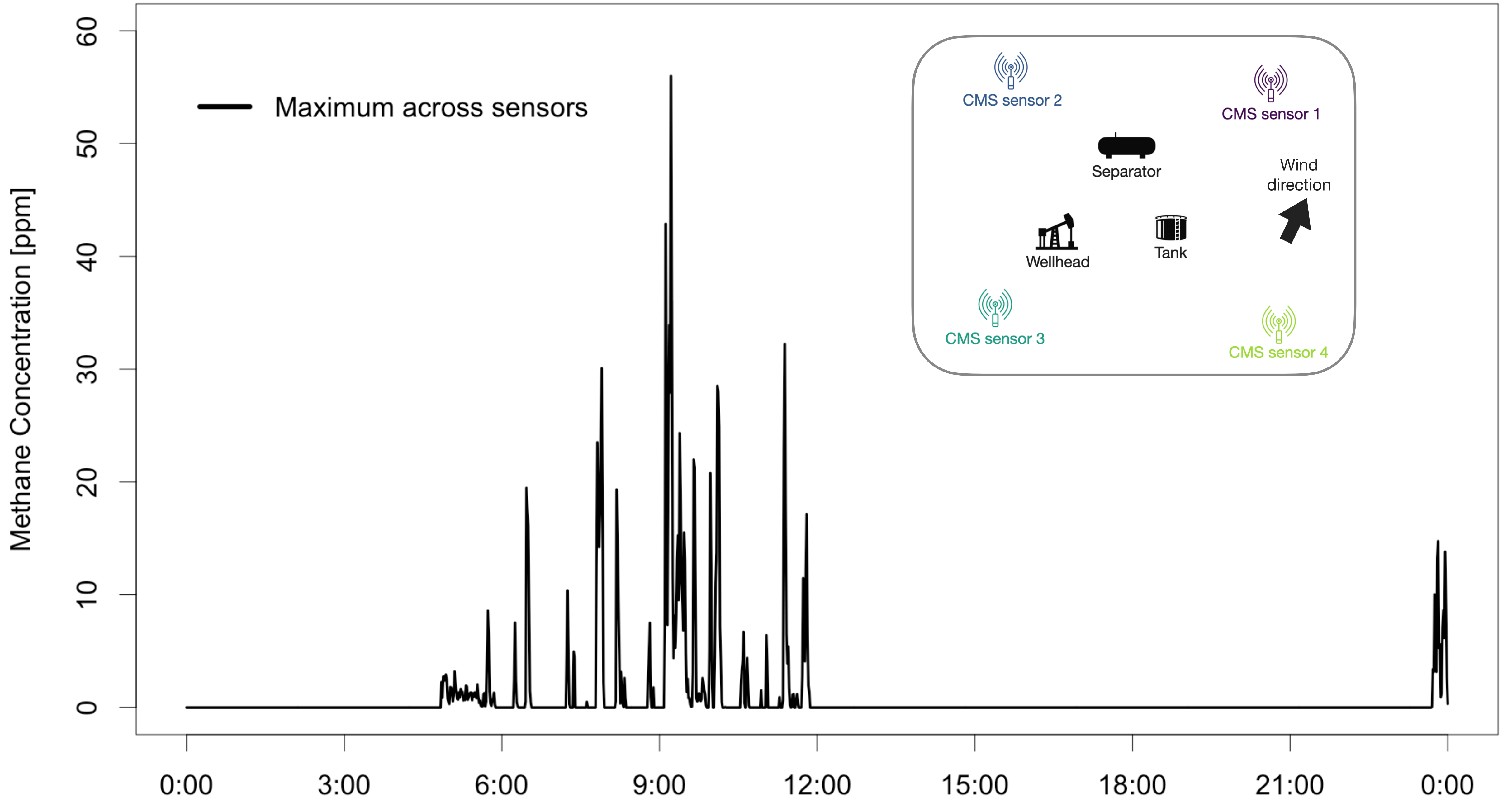
# Open source framework for solving inverse problem

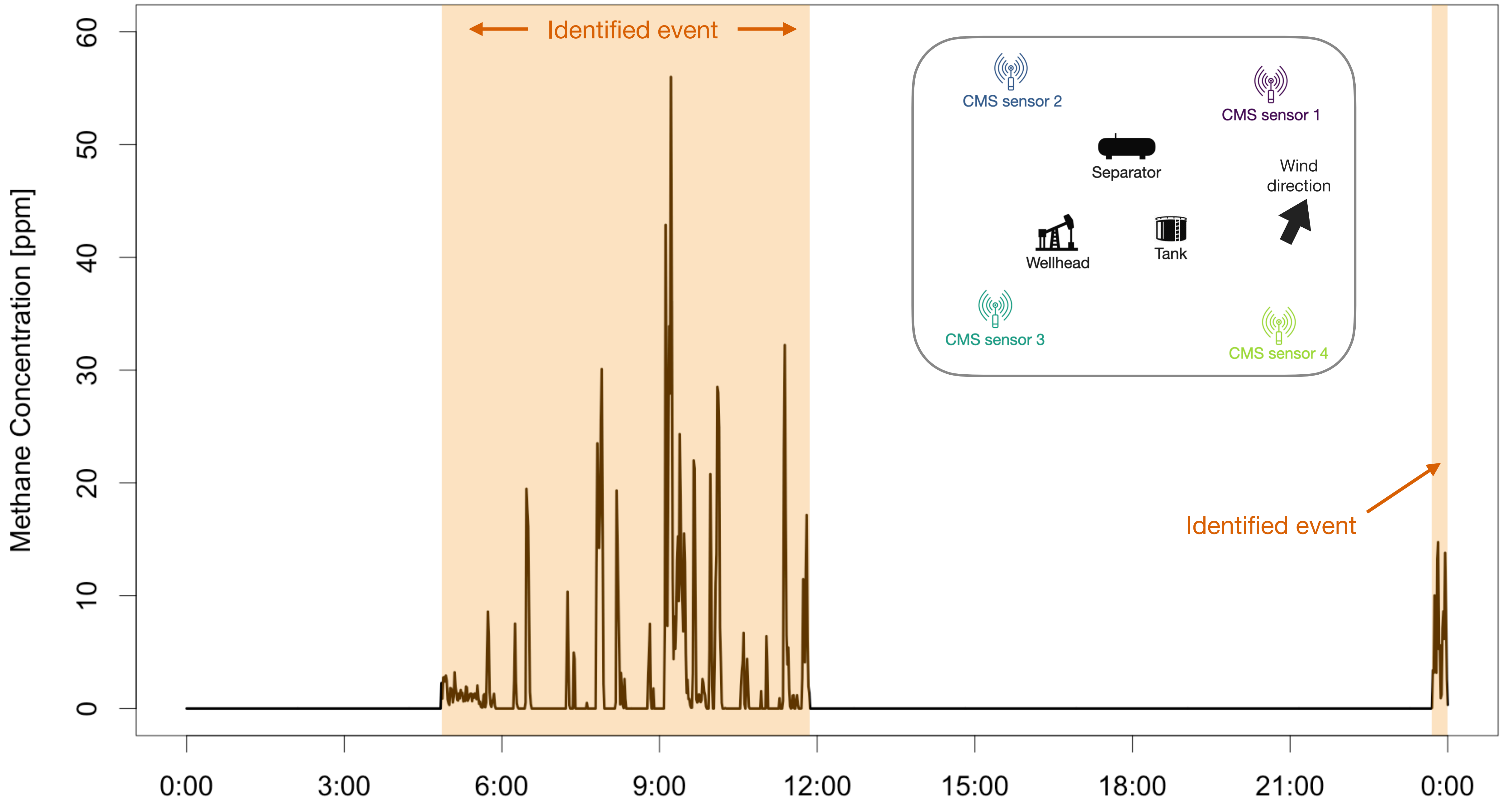




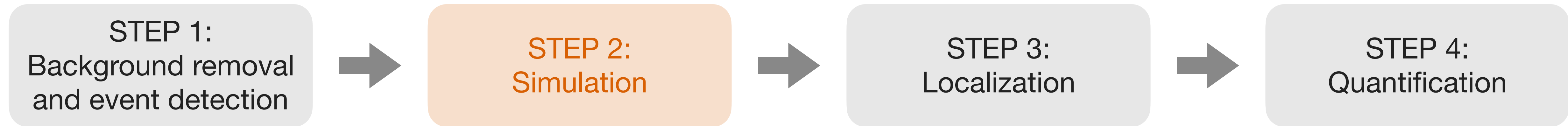






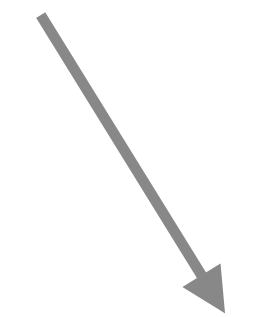


# Open source framework for solving inverse problem



# Gaussian puff atmospheric dispersion model

Total volume  
of methane  
contained in  
puff p



Q

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

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)

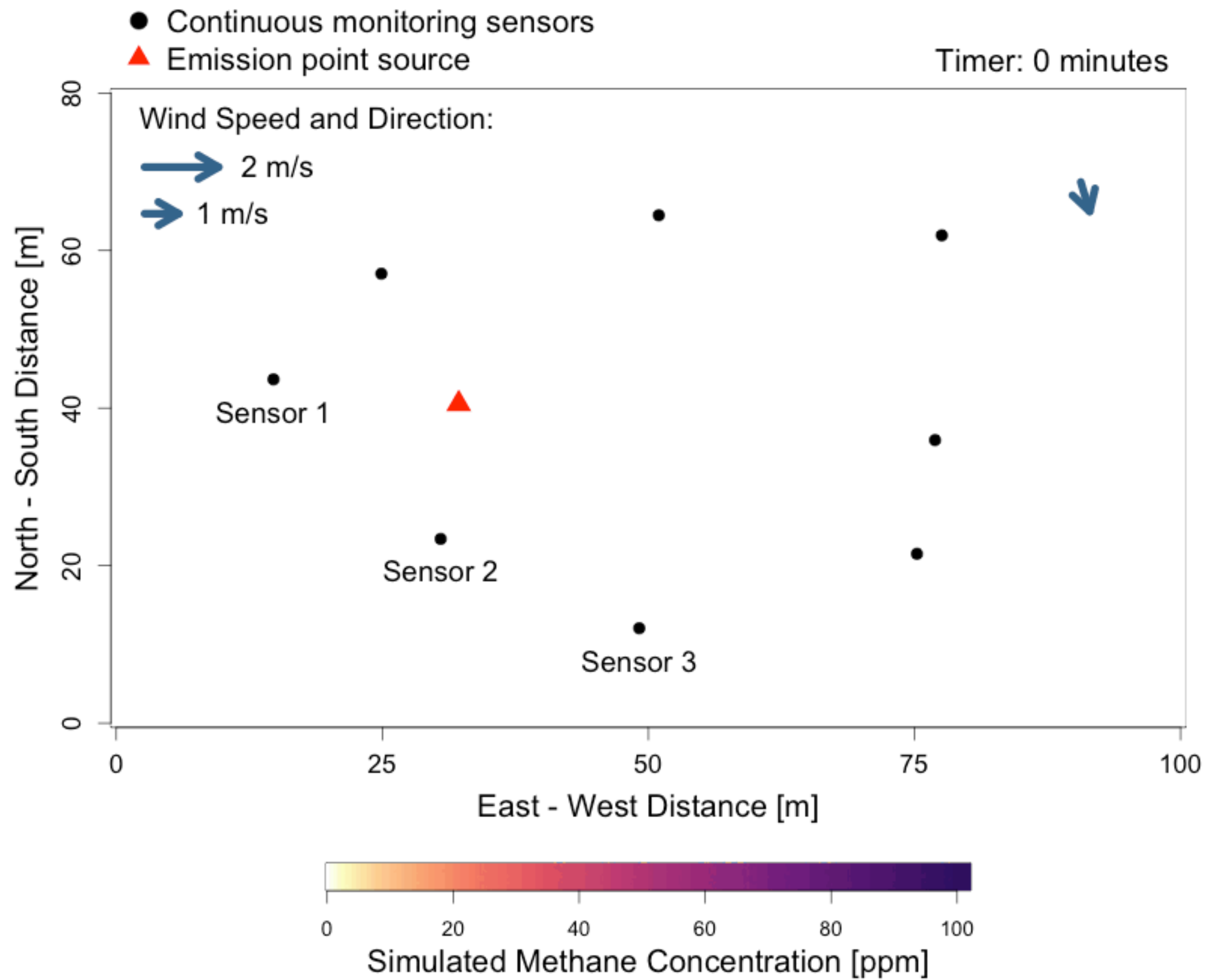
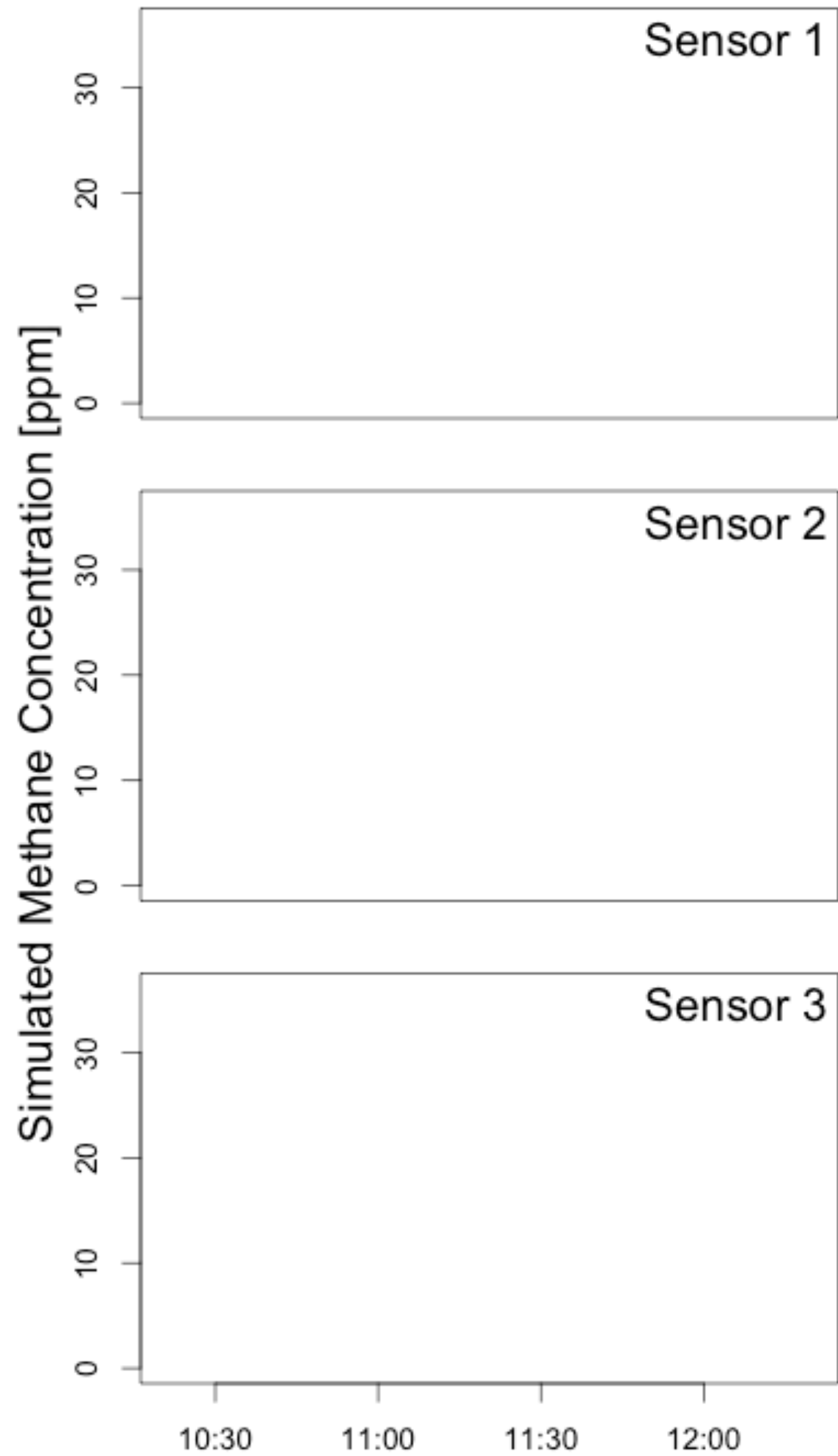
$$c(x, y, z, t) = \sum_{p=1}^P c_p(x, y, z, t)$$

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

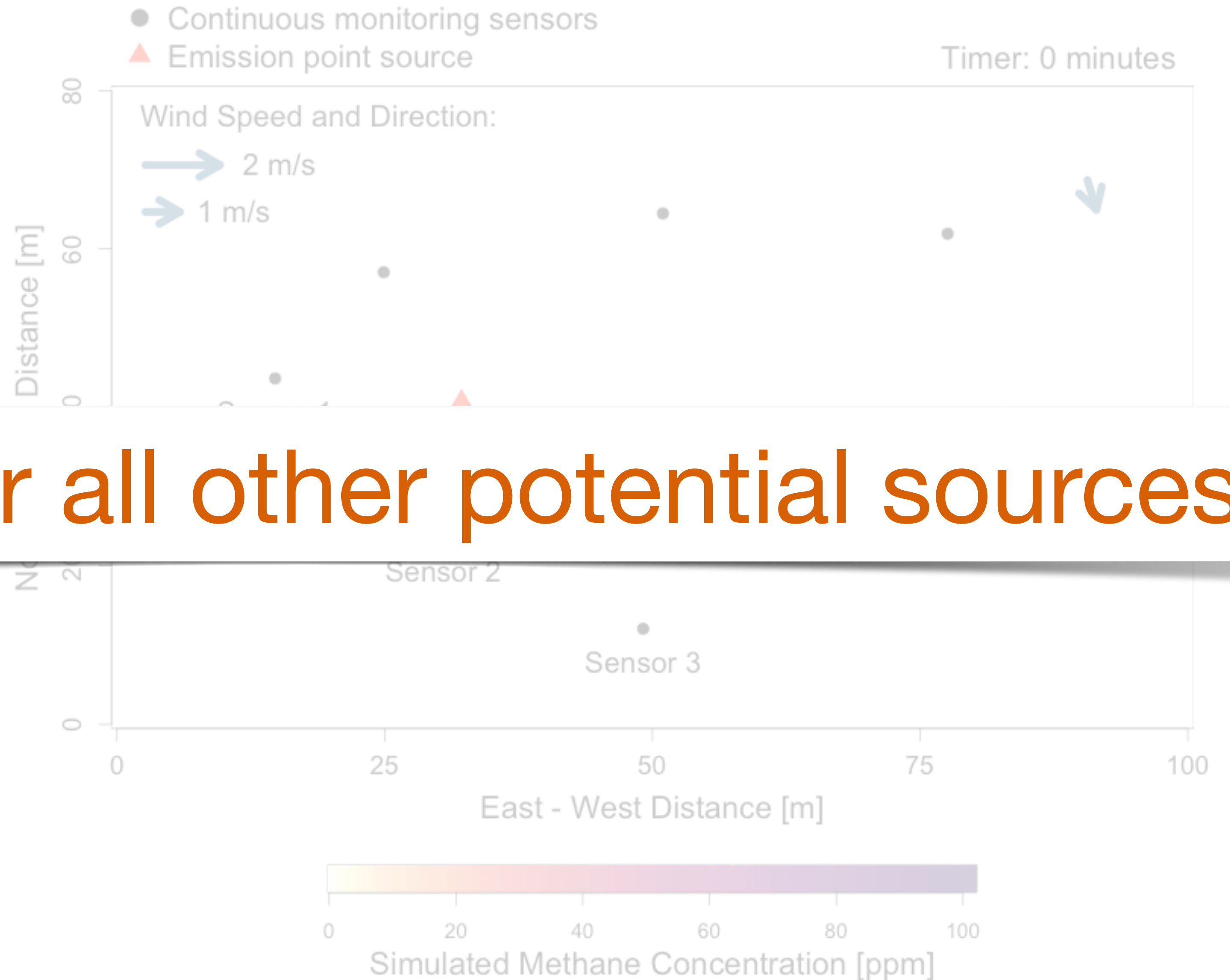
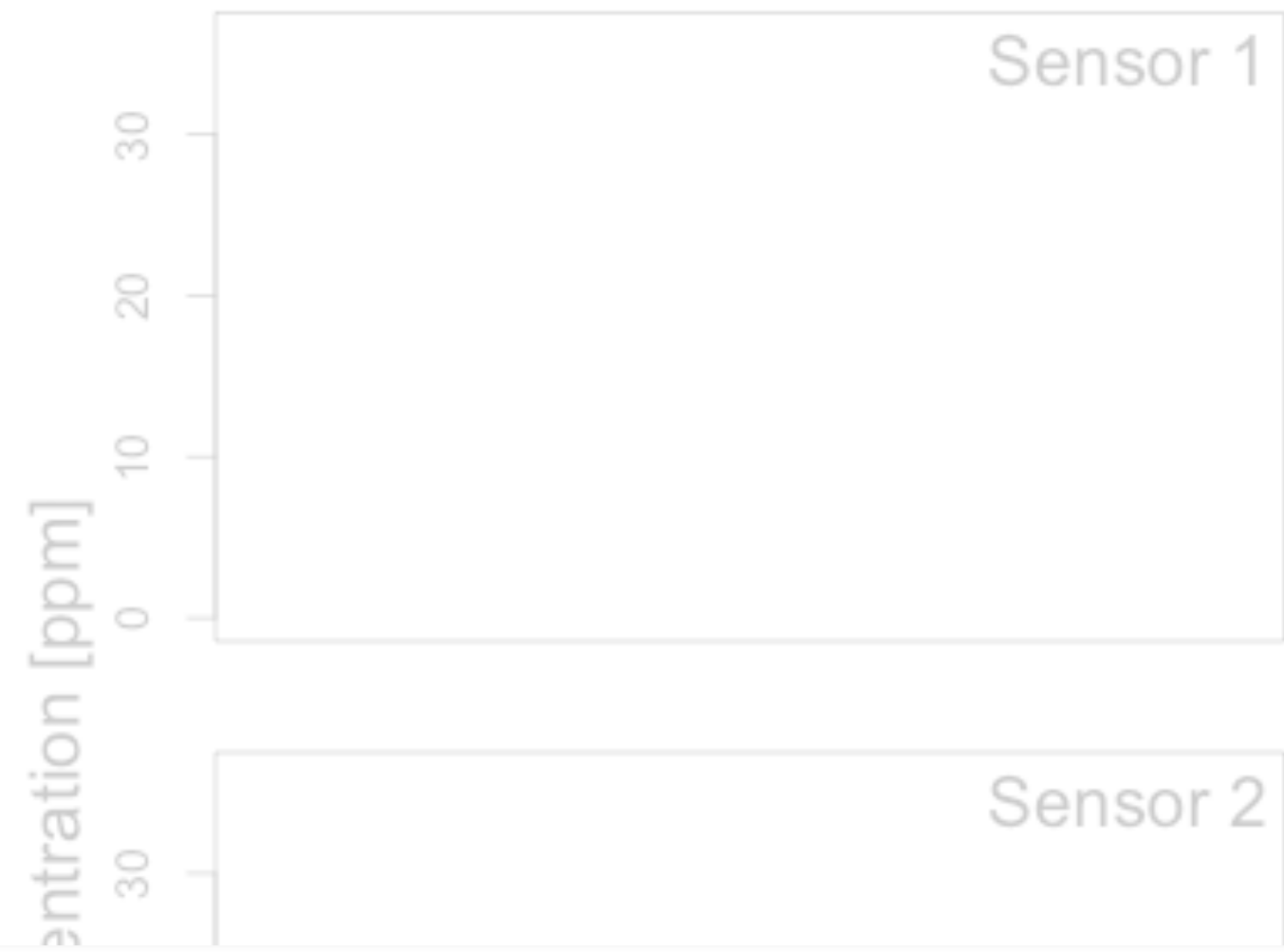
Concentration contribution of puff p

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

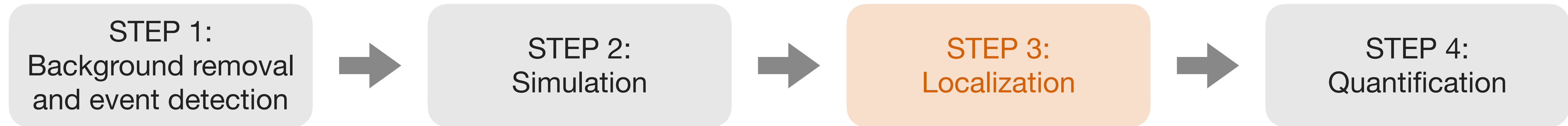
Decay in puff concentration in vertical dimension (z)



Repeat this for all other potential sources!



# Open source framework for solving inverse problem







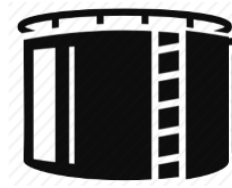
CMS sensor



Separator



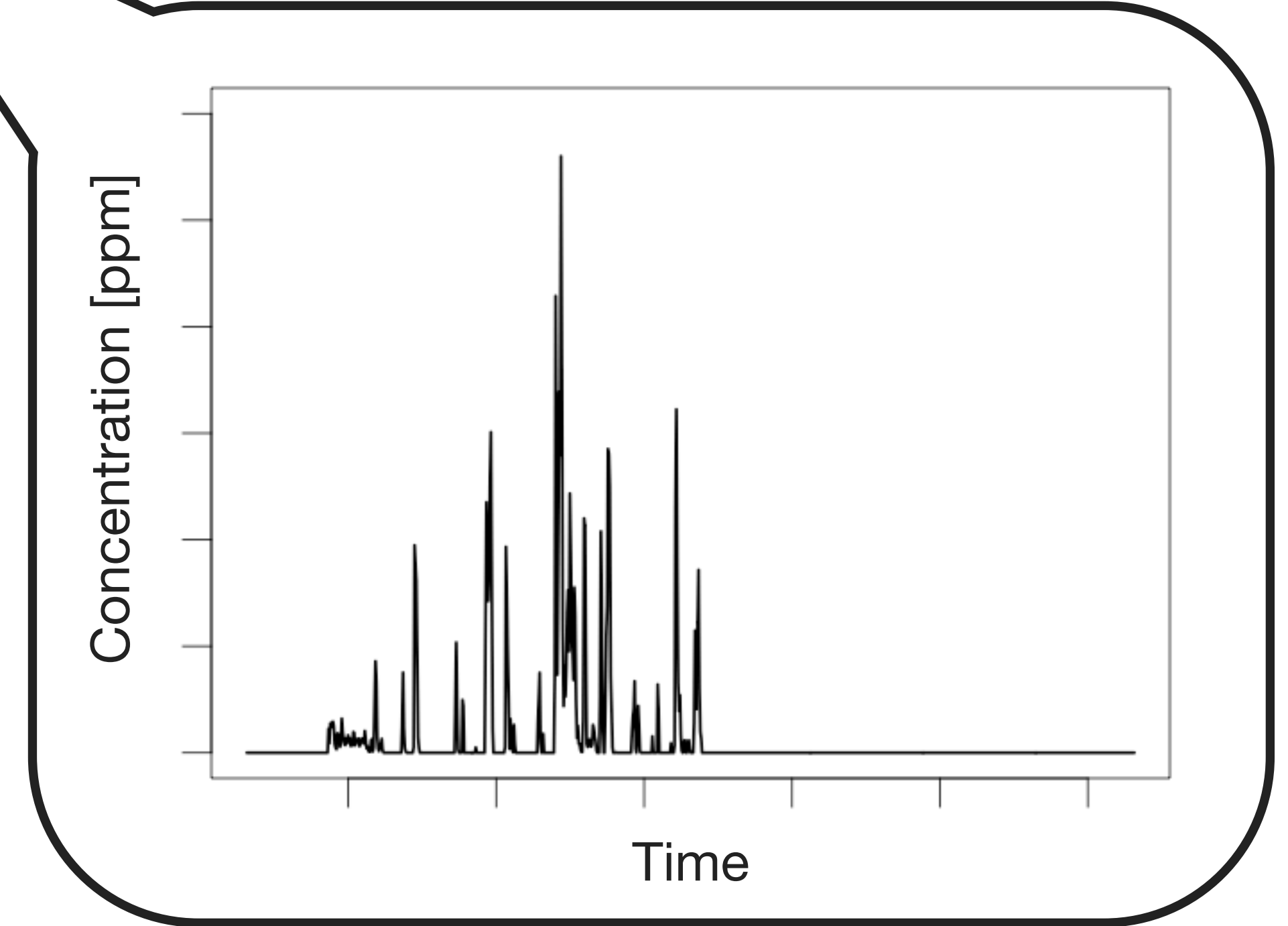
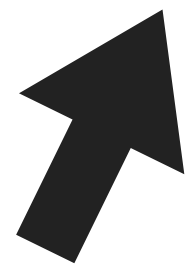
Wellhead

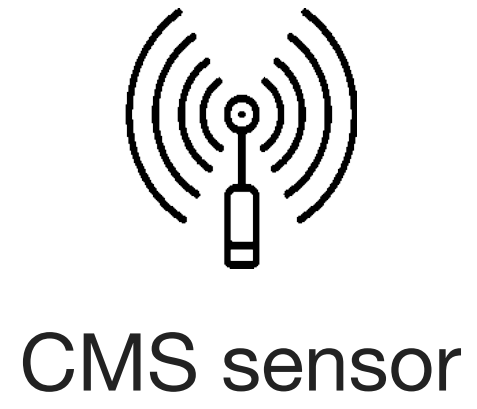


Tank

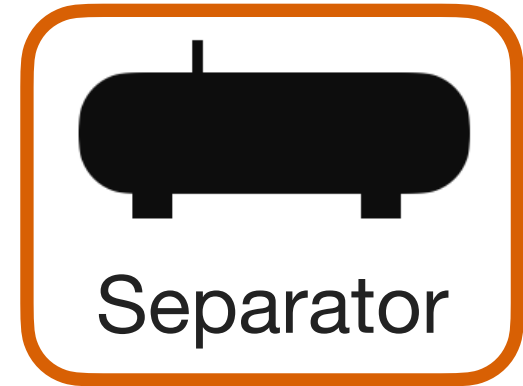


Wind  
direction

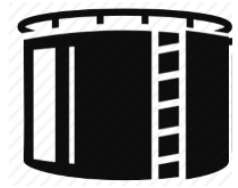




Simulation  
emission  
source



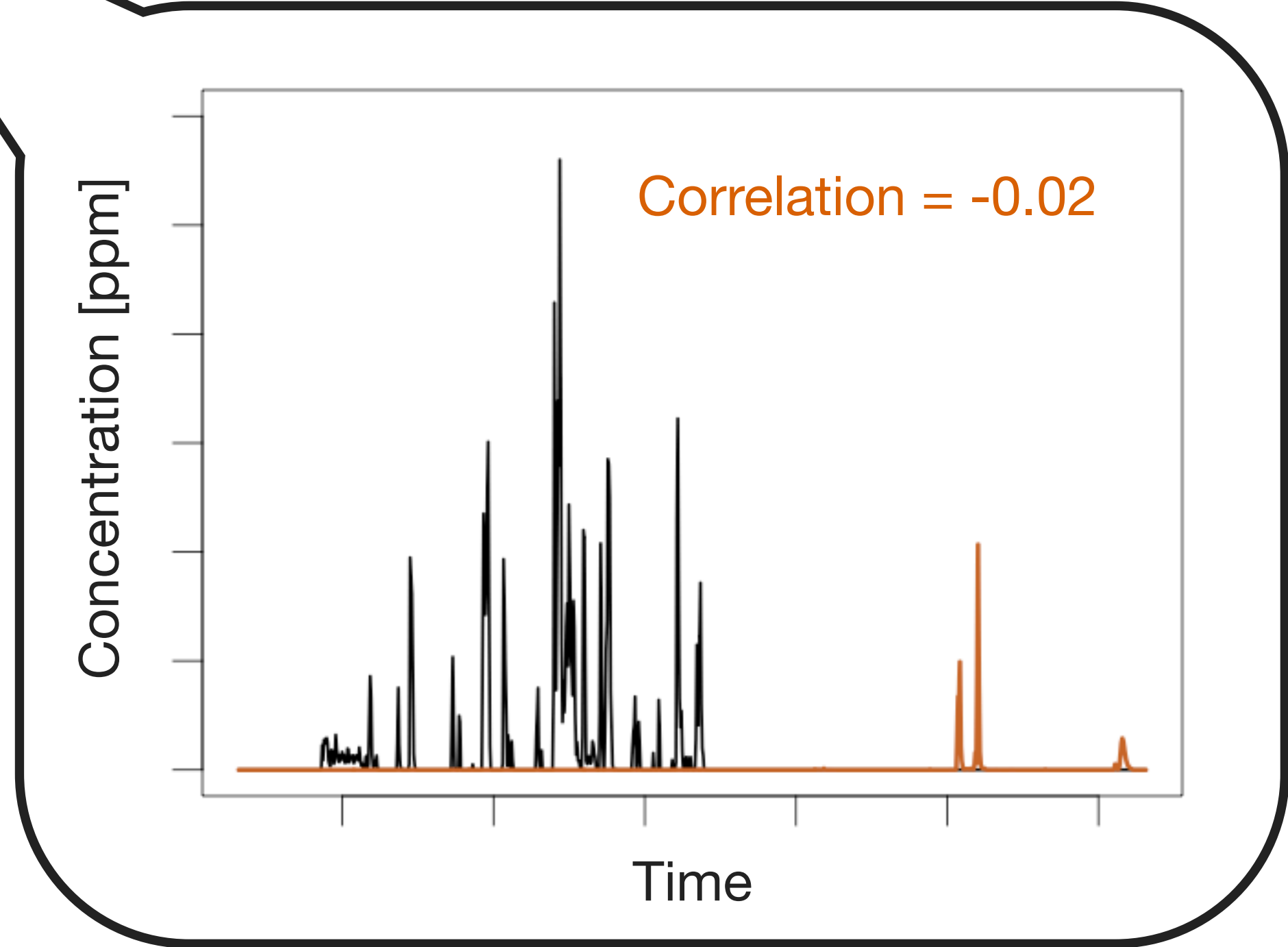
Wellhead



Tank

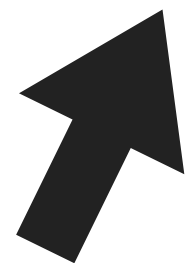


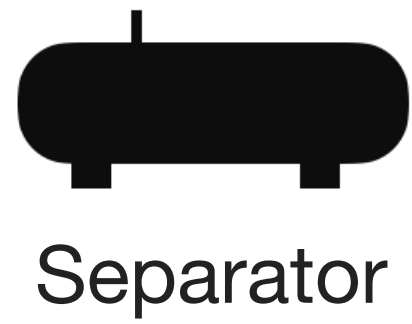
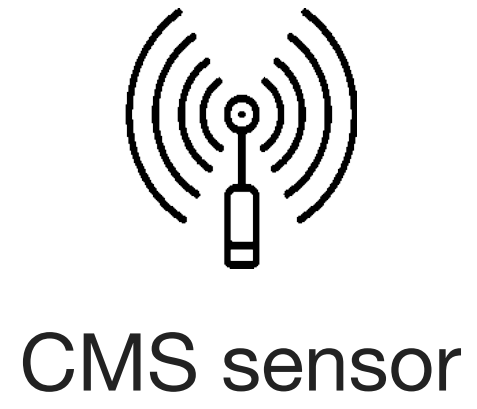
Pick source estimate using  
correlation coefficient



- Background-removed observations
- Simulated concentrations

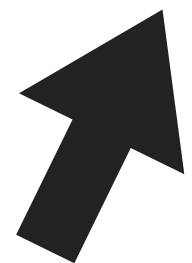
Wind  
direction



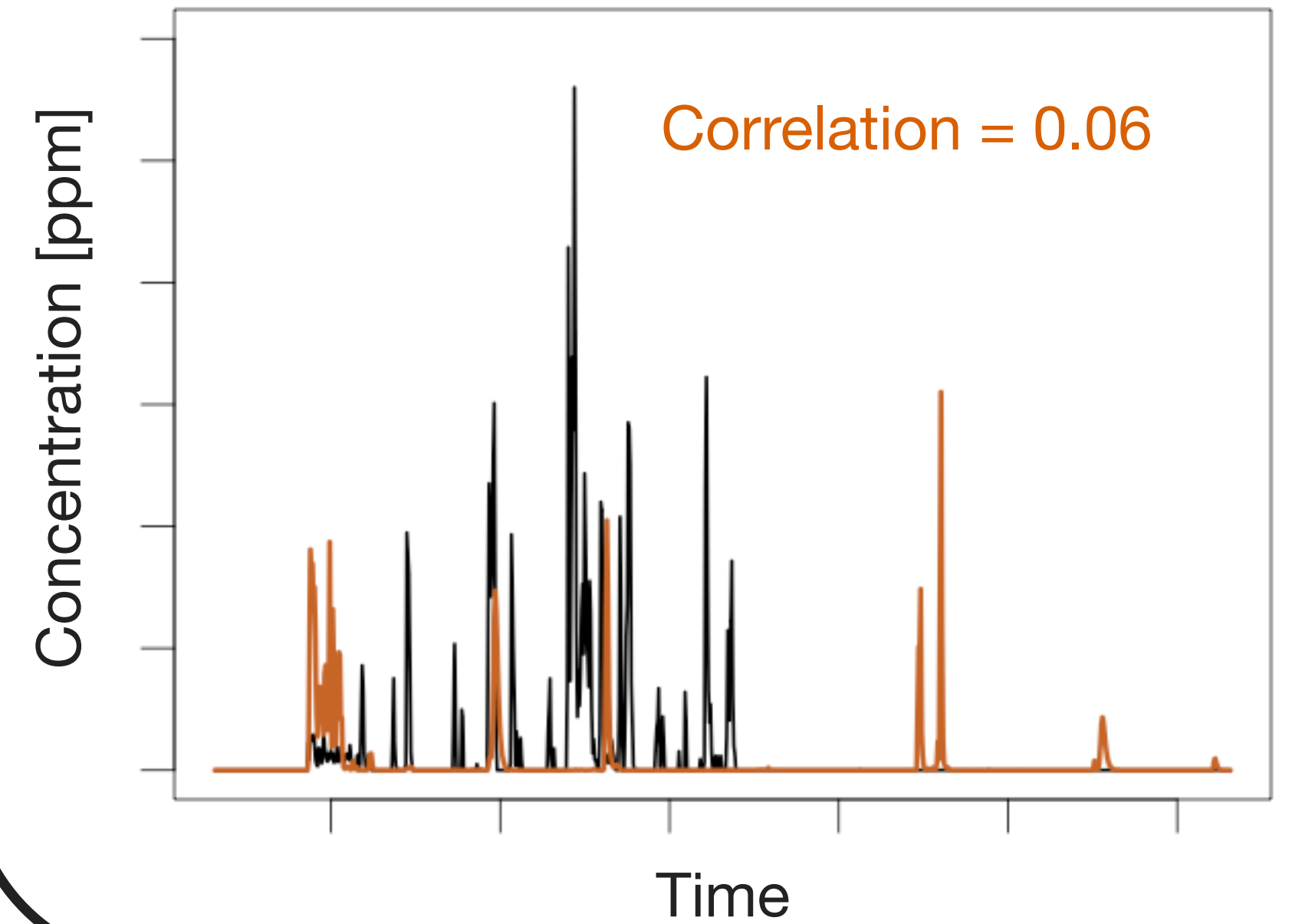


Simulation  
emission  
source

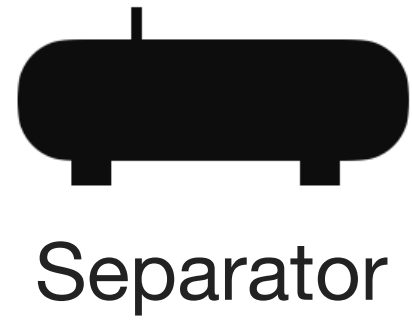
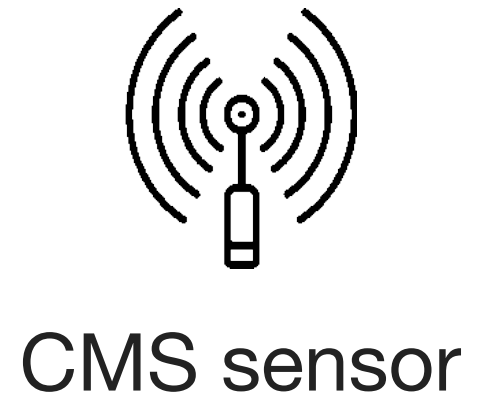
Wind  
direction



Pick source estimate using  
correlation coefficient



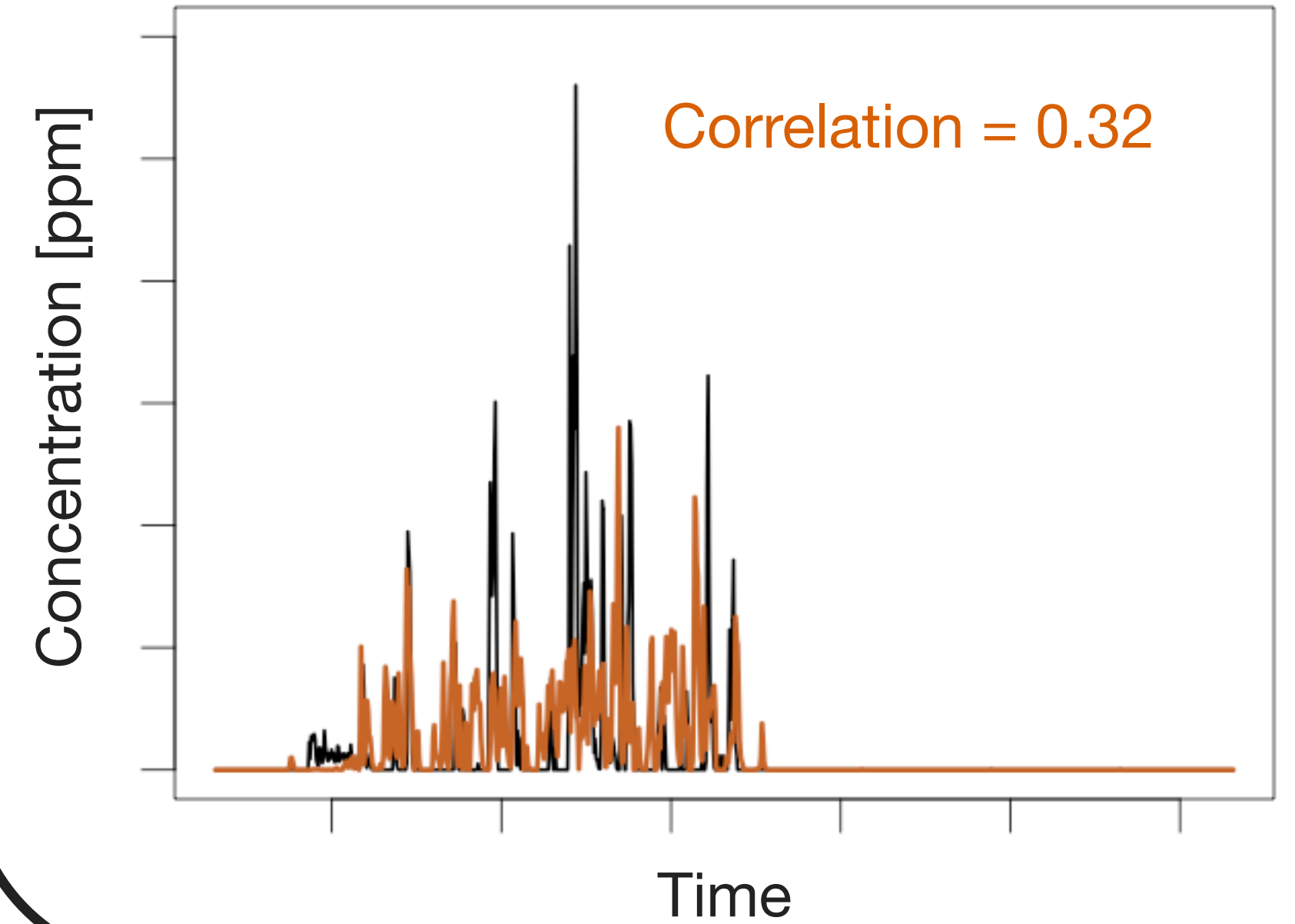
- Background-removed observations
- Simulated concentrations



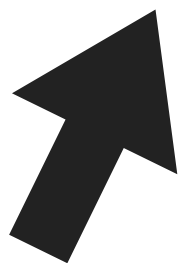
Simulation  
emission  
source



Pick source estimate using  
correlation coefficient

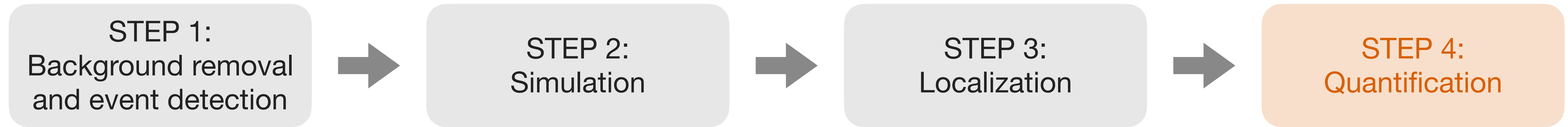


Wind  
direction



— Background-removed observations  
— Simulated concentrations

# Open source framework for solving inverse problem



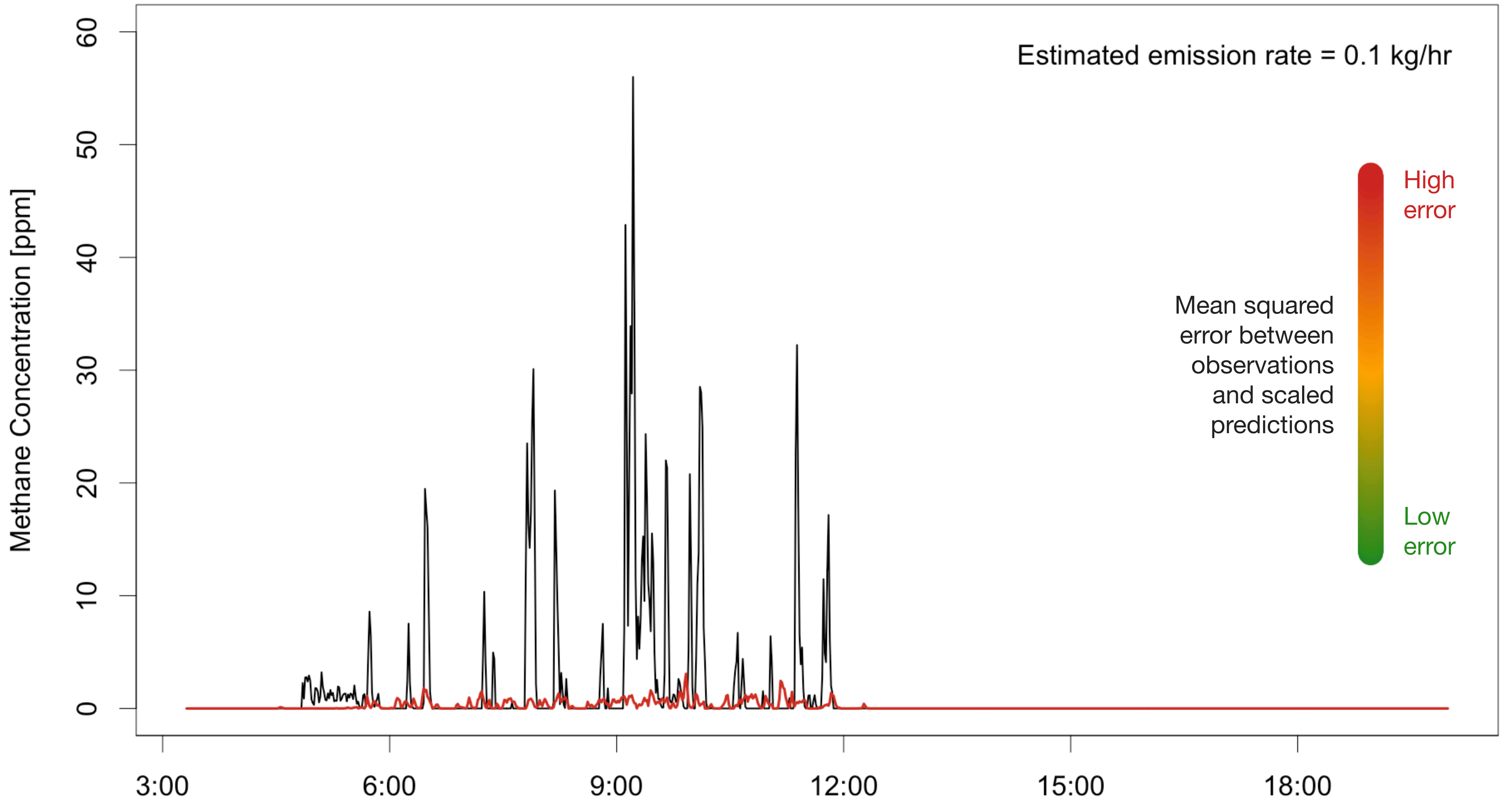
# Simulation is a linear function of emission rate

Emission rate

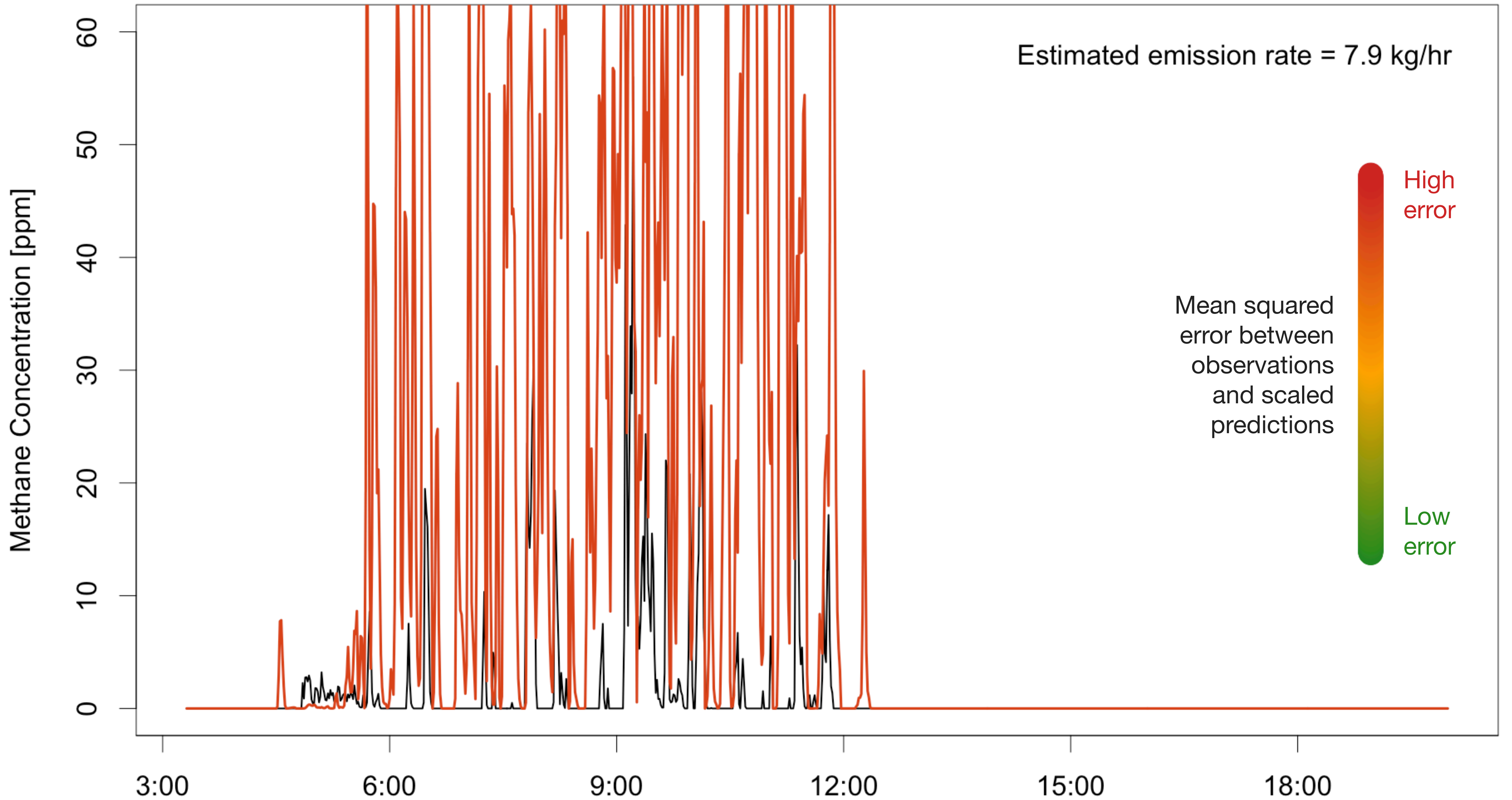
$$c_p(x, y, z, t) = Q \frac{1}{(2\pi)^{3/2} \sigma_y^2 \sigma_z} \exp\left(-\frac{(x - ut)^2 + y^2}{2\sigma_y^2}\right) \left[ \exp\left(-\frac{(z - H)^2}{2\sigma_z^2}\right) + \exp\left(-\frac{(z + H)^2}{2\sigma_z^2}\right) \right]$$

Simulation output:  
concentrations

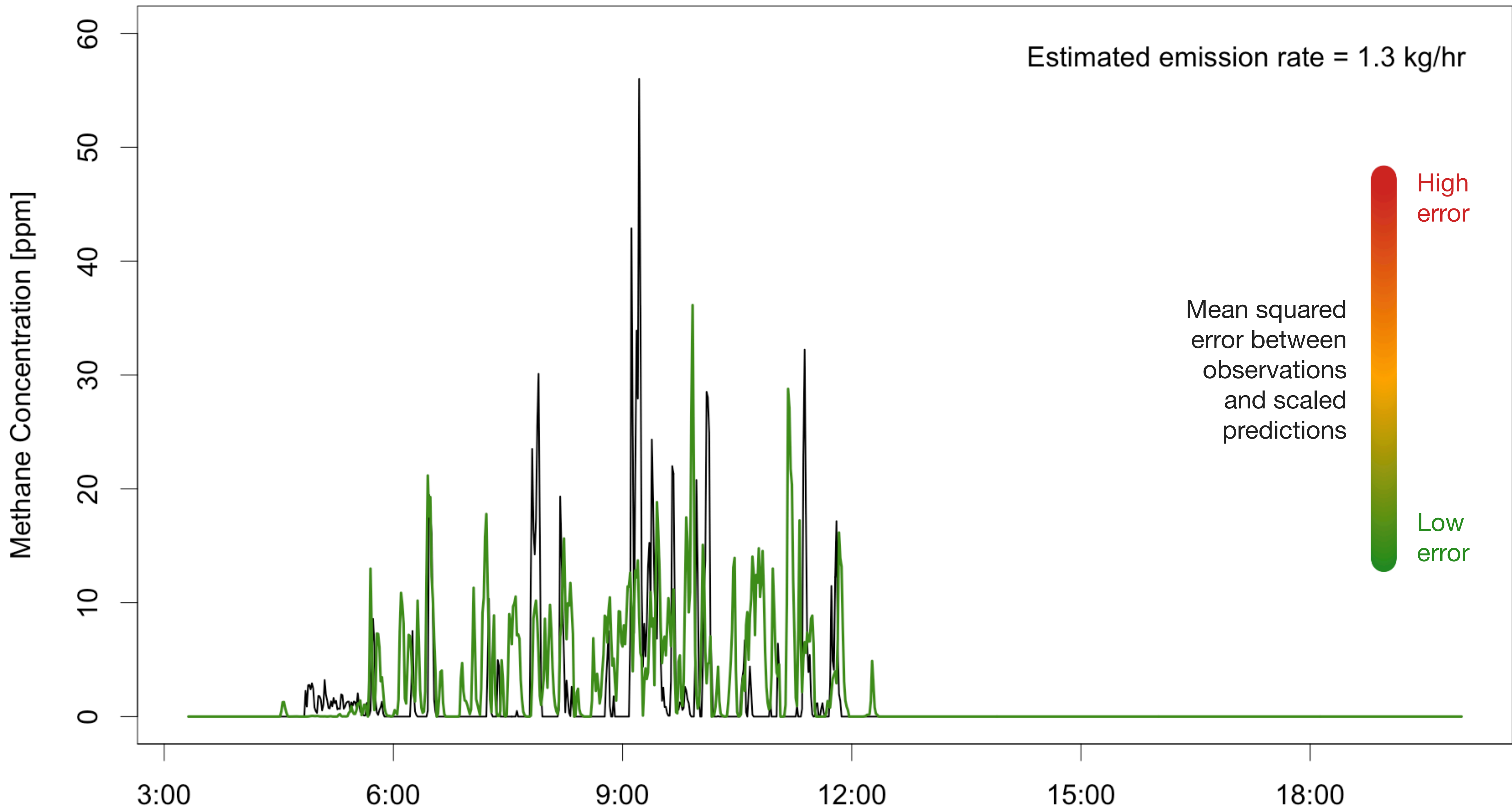
“Everything else”



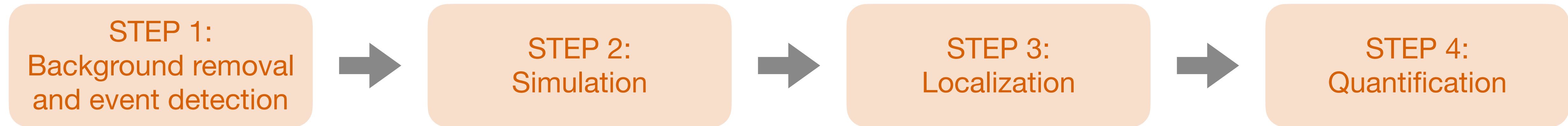








# Open source framework for solving inverse problem





# 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**




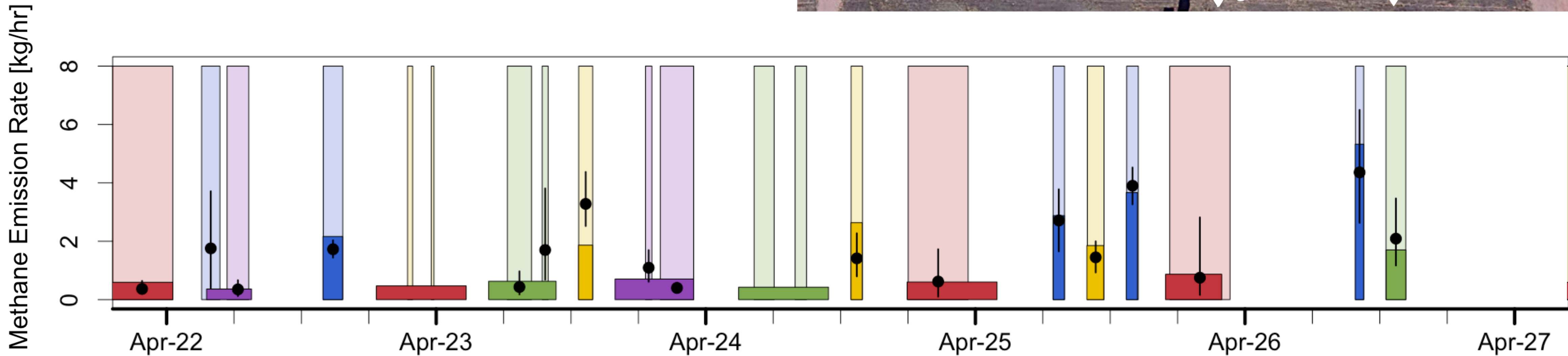
# Evaluation on single-source controlled releases

 Solid box: controlled release ("truth" data)

 Transparent box: our estimates

-  Tanks
-  West Wellhead
-  West Separator
-  East Wellhead
-  East Separator

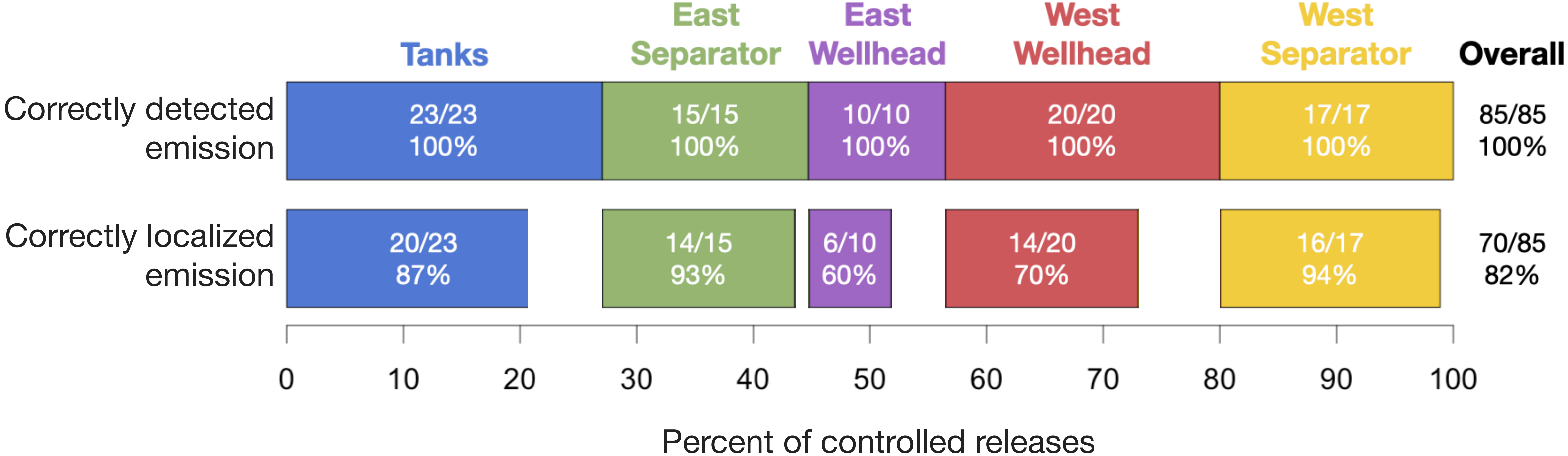
 Rate Estimate with Error Bound



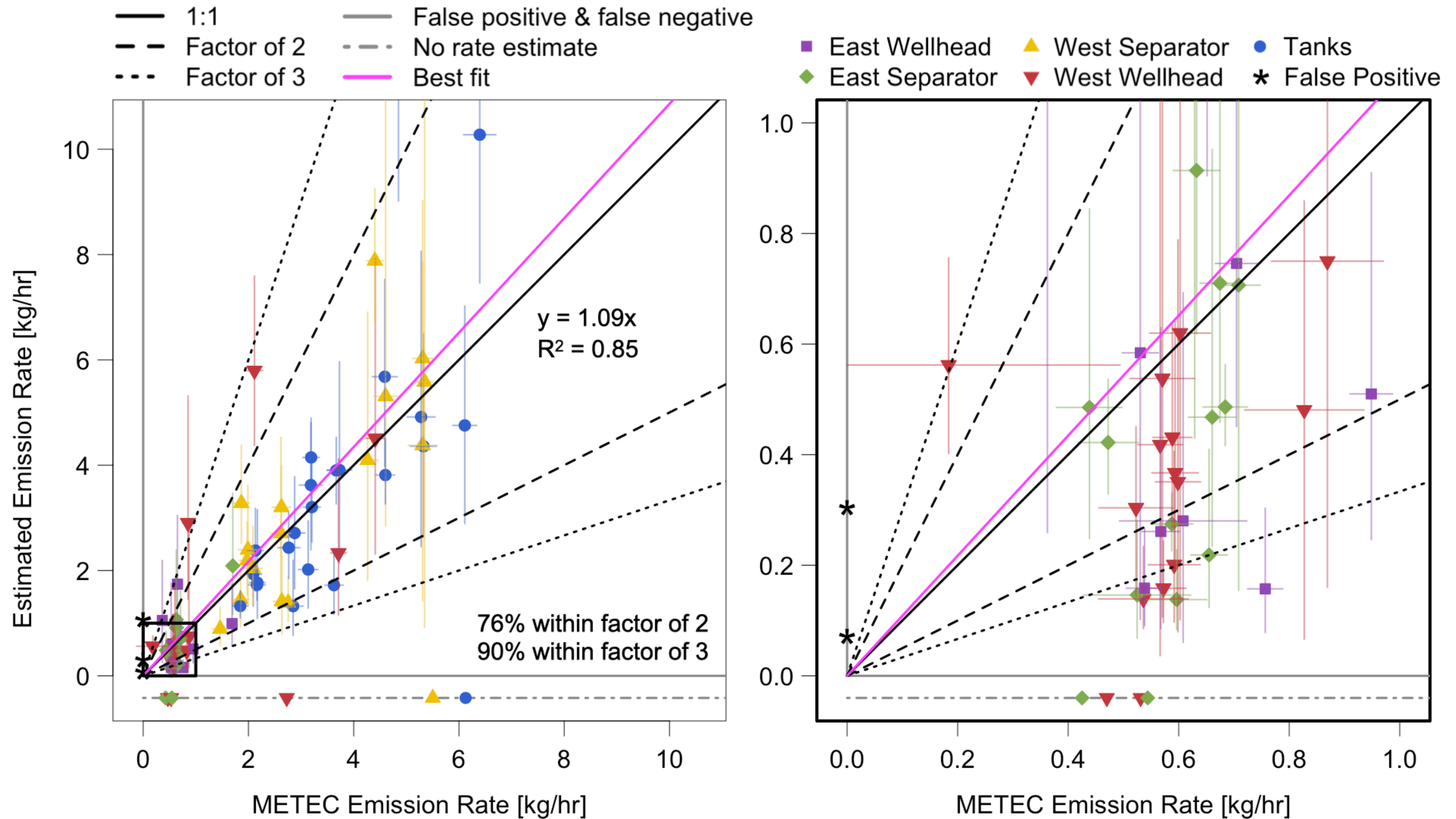


# Evaluation on single-source controlled releases

Event-level false positive rate: 5.5%



# Evaluation on single-source controlled releases



# Evaluation on single-source controlled releases

