A data-driven algorithm to optimize the placement of continuous monitoring sensors on oil and gas sites

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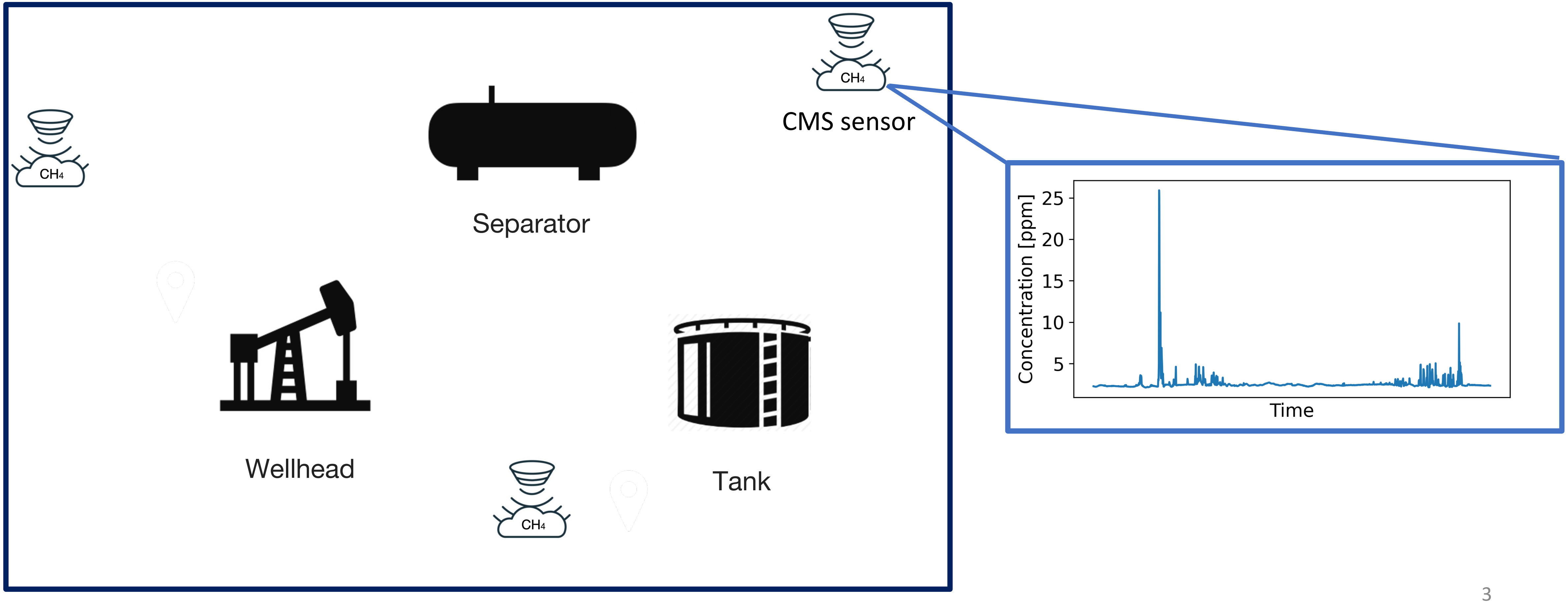
Background

- Methane, CH_4, is the 2nd biggest contributor to global climate change after CO_2.
- CH_4 has higher heat-trapping but shorter lifetime compared to CO_2.
- Rapid reduction of CH_4 has a quick impact on mitigating global warming.
- Oil & gas sector accounts for ~ 22% of global anthropogenic methane emissions.
- Methane emission monitoring technologies: satellite, aerial, ground-based systems

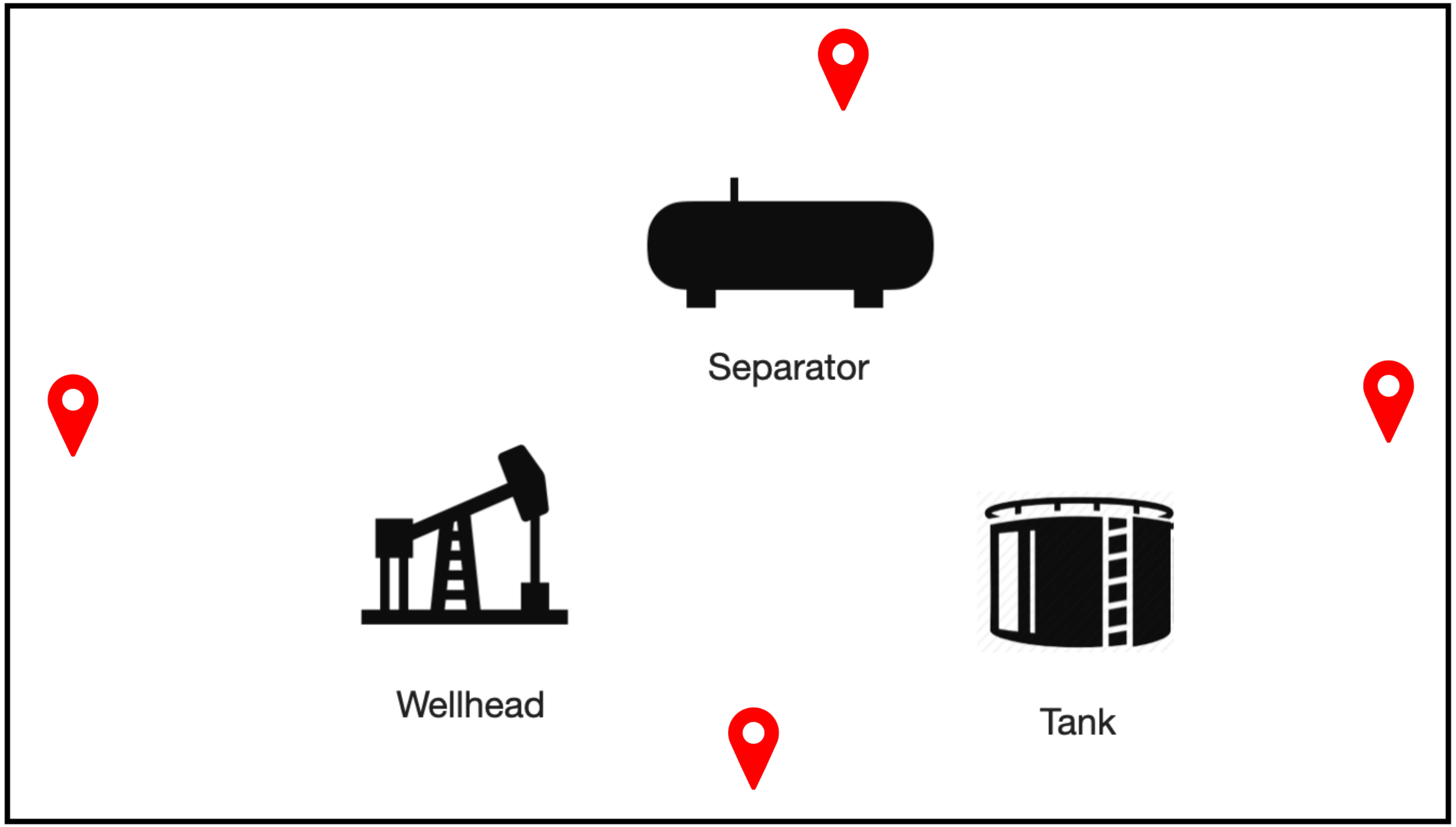
Problem Setup

- Continuous monitoring systems (CMS)



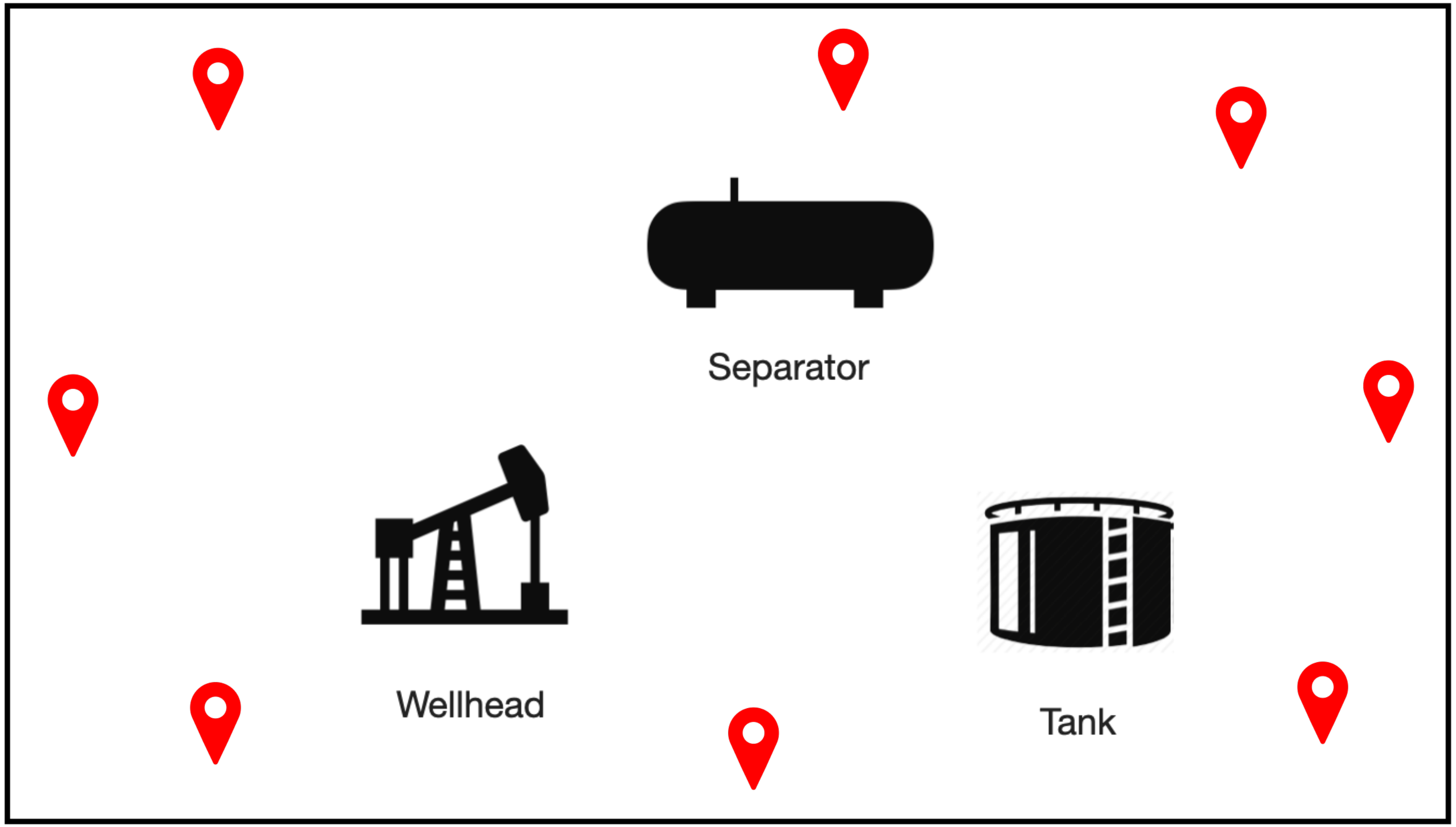
Problem Setup

- CMS sensor placement



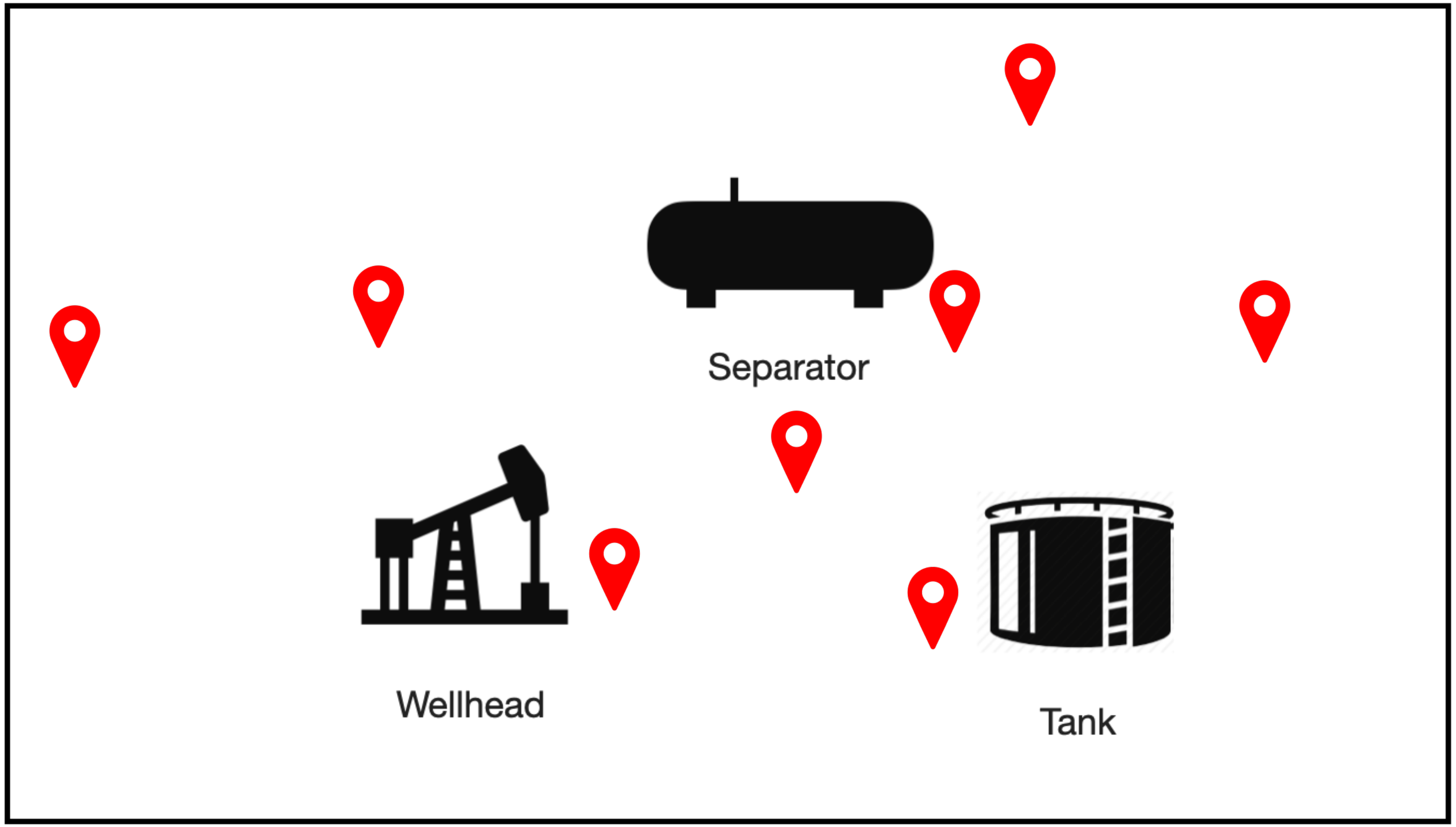
Problem Setup

- CMS sensor placement



Problem Setup

- CMS sensor placement



Problem Setup

- A data-driven algorithm to optimize sensor placement for best emission detection

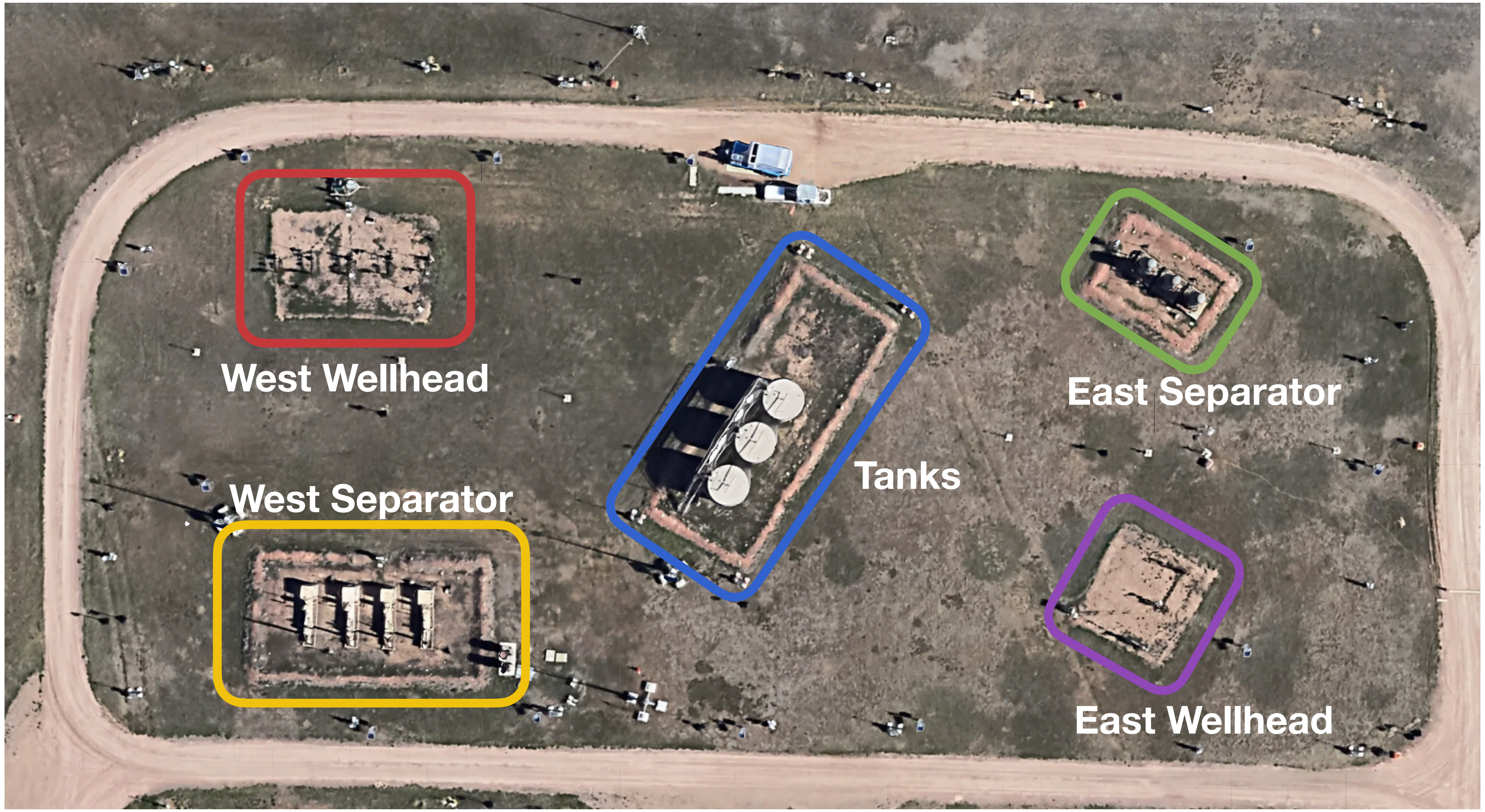
User's inputs (site-specific)

- Wind data
- Emission characteristics
- Available sensor locations

Optimization algorithm

Output: optimal sensor placement

Experiment Data



METEC facility, 5 potential emission sources

Algorithm

1. Generate emission scenarios
2. Set possible sensor locations
3. Simulate concentrations & Check detection
4. Optimize sensor placement

Step 1 Generate Emission Scenarios

User's inputs (site-specific)

- Wind data
- Emission characteristics
- Available sensor locations

Optimization algorithm

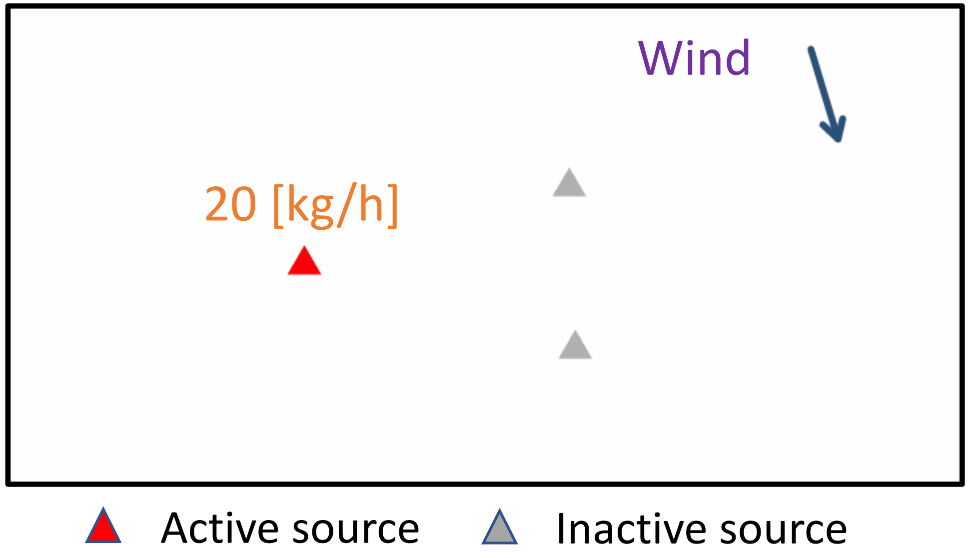
Output: optimal sensor placement

Step 1 Generate Emission Scenarios

A combination of

- wind speed time series
- wind direction time series
- emission source location
- emission rate

defines an emission scenario.



- Estimate probability distributions of wind & emission to sample → 38,130 emission scenarios

Step 2 Set Possible Sensor Locations

User's inputs (site-specific)

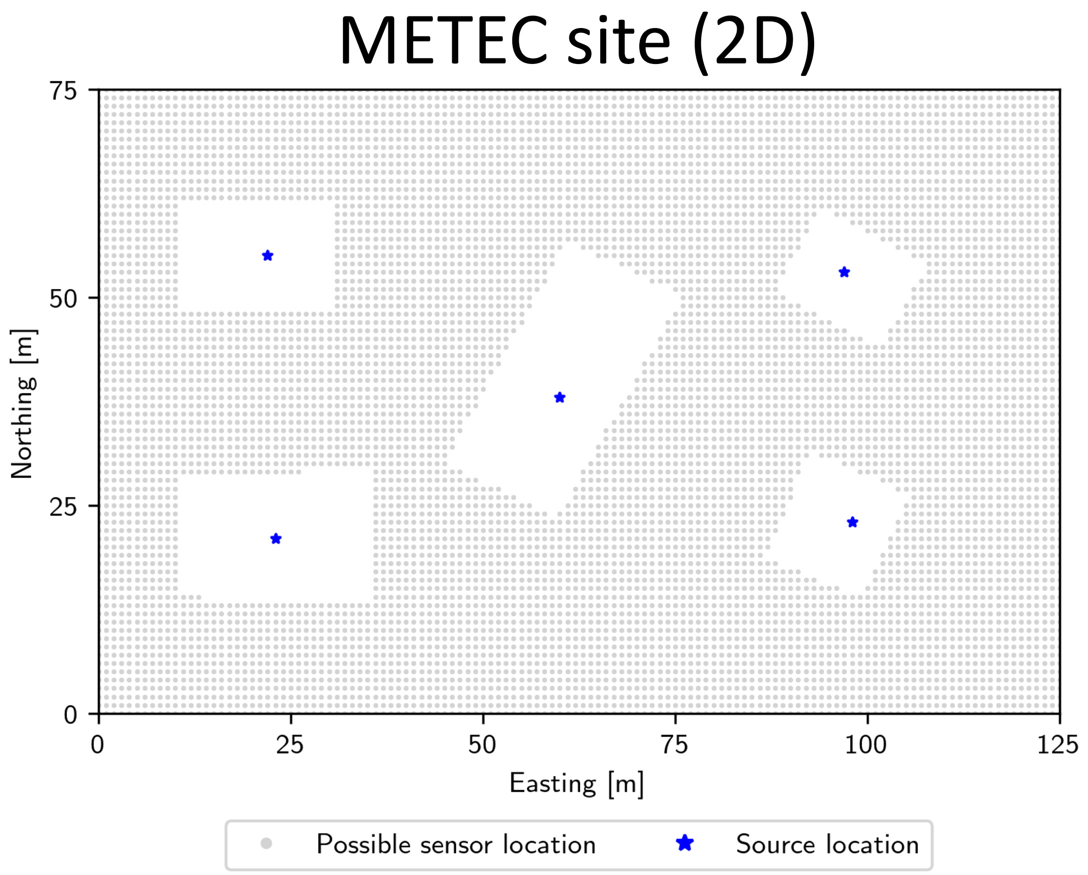
Optimization algorithm

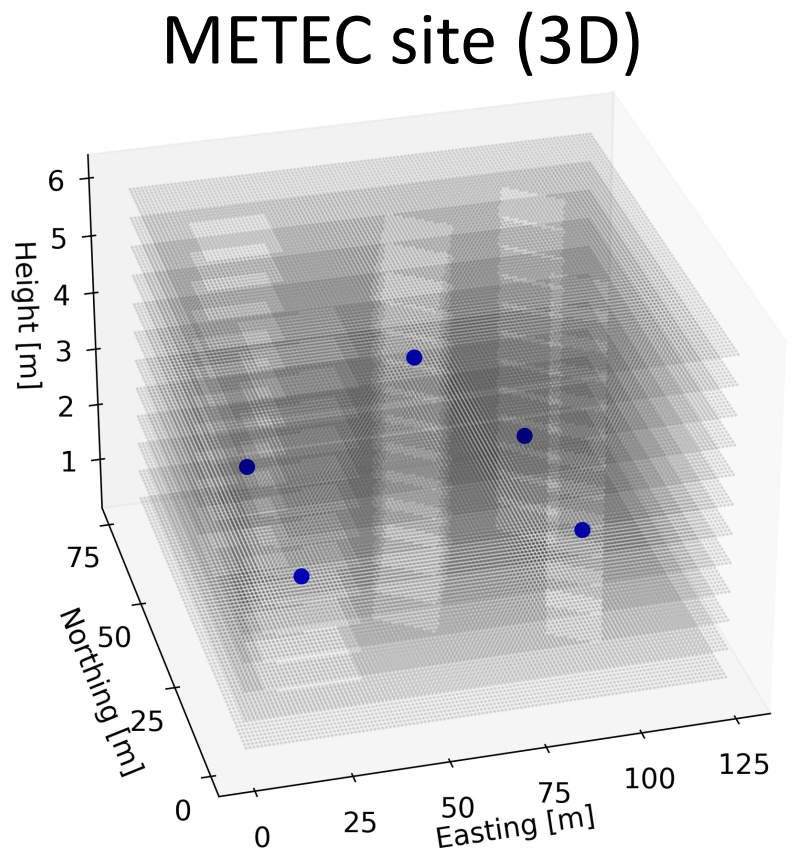
Output: optimal sensor placement

Emission scenarios
(# = 38,130)

Available
sensor locations

Step 2 Possible Sensor Locations





resolution = 1 m for Northing & Easting; = 0.5 m for vertical

possible locations = 96,840

Step 3 Concentration Simulation & Detection

User's inputs (site-specific)

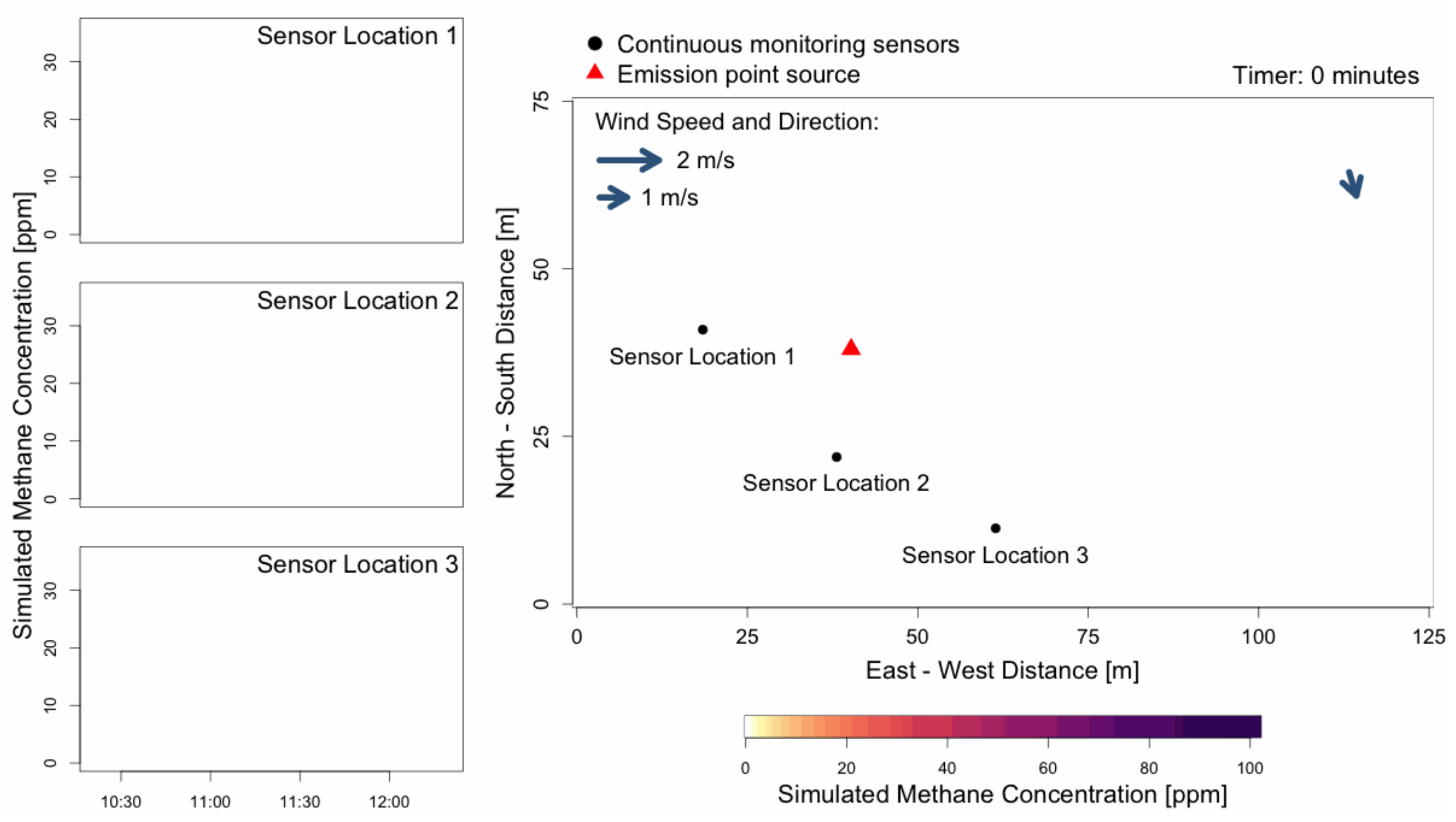
Optimization algorithm

Output: optimal sensor placement

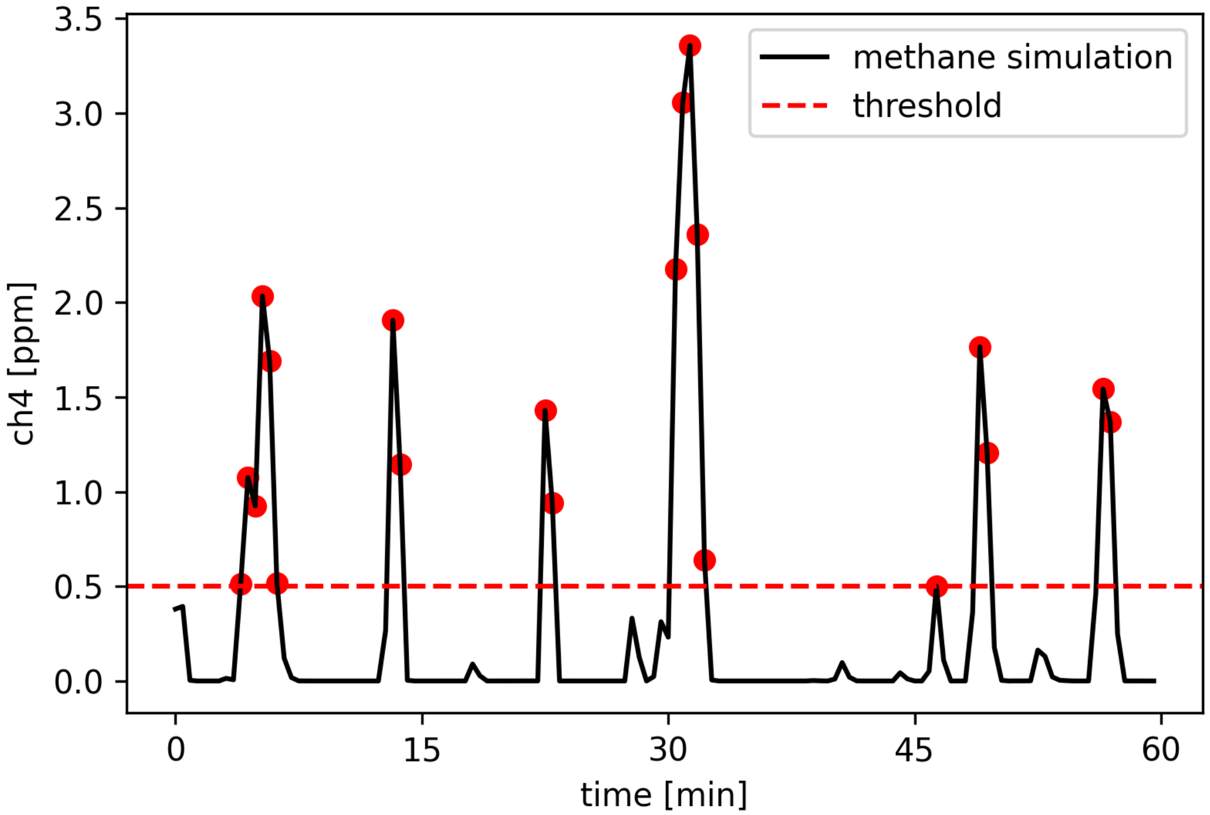
Emission scenarios (# = 38,130)

Sensor locations (# = 96,840)

Step 3.1 Gaussian puff simulation

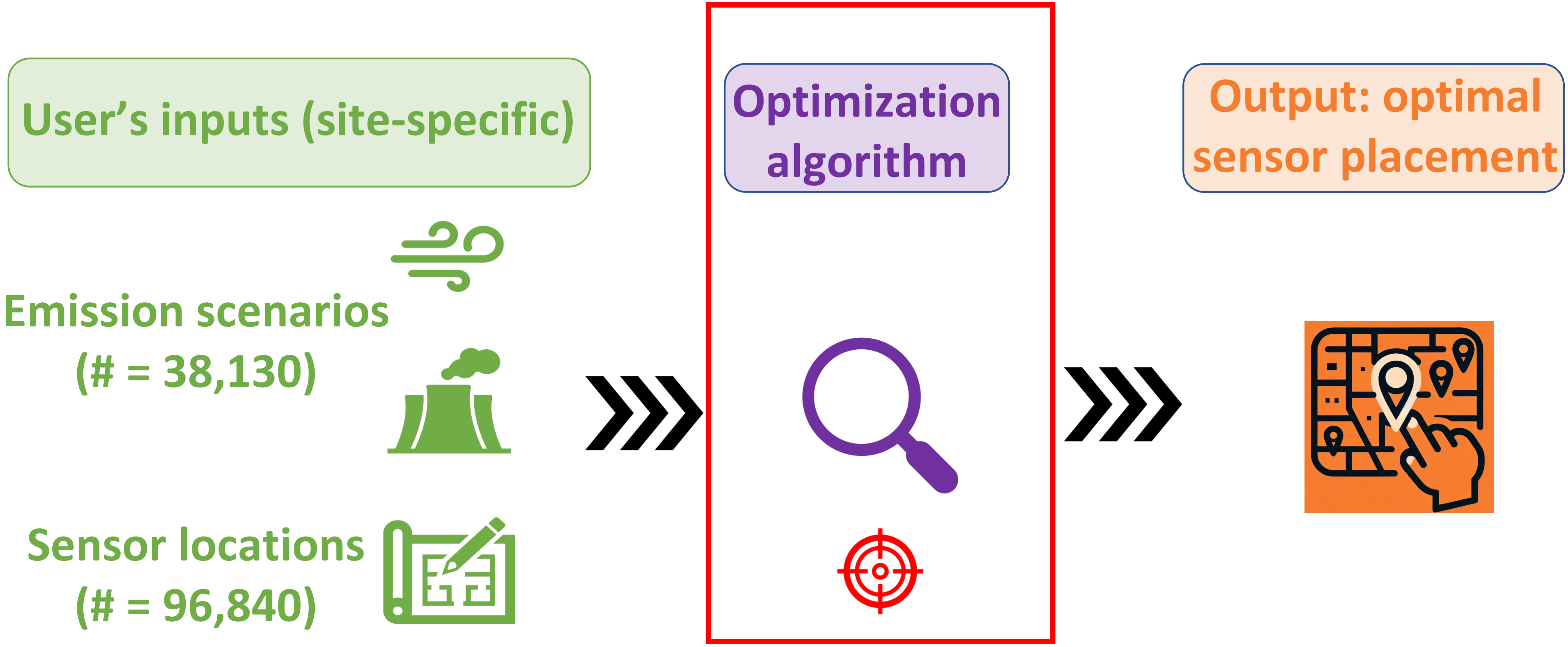


Step 3.2 Detection



Example of simulated concentrations and detection for Emission Scenario j at Sensor Location i

Step 4 Optimize Sensor Placement



Step 4 Optimization

Rows of D: Sensor Locations (SL)

Cols of D: Emission Scenarios (ES)

$D_{ij} = 0$, if $\mathrm{SL_i}$ can detect ES_j;

$D_{ij} = 1$, otherwise

Evolutionary Algorithms

+

Pareto Optimization

	ES_1	ES_2	$\cdots$	ES_j	$\cdots$	ES_M
✓ SL_1	1	1	$\cdots$	0	$\cdots$	1
✓ SL_2	1	0	$\cdots$	0	$\cdots$	1
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
✓ SL_i	0	0	$\cdots$	1	$\cdots$	1
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\ddots$	$\vdots$
SL_N	1	1	$\cdots$	1	$\cdots$	1

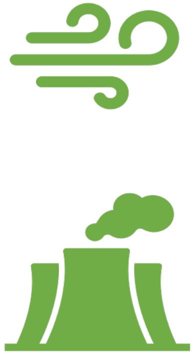
Detection Matrix D

$\mathrm{N} = 96{,}840; M = 38{,}130$

Results

User's inputs (site-specific)

Emission scenarios

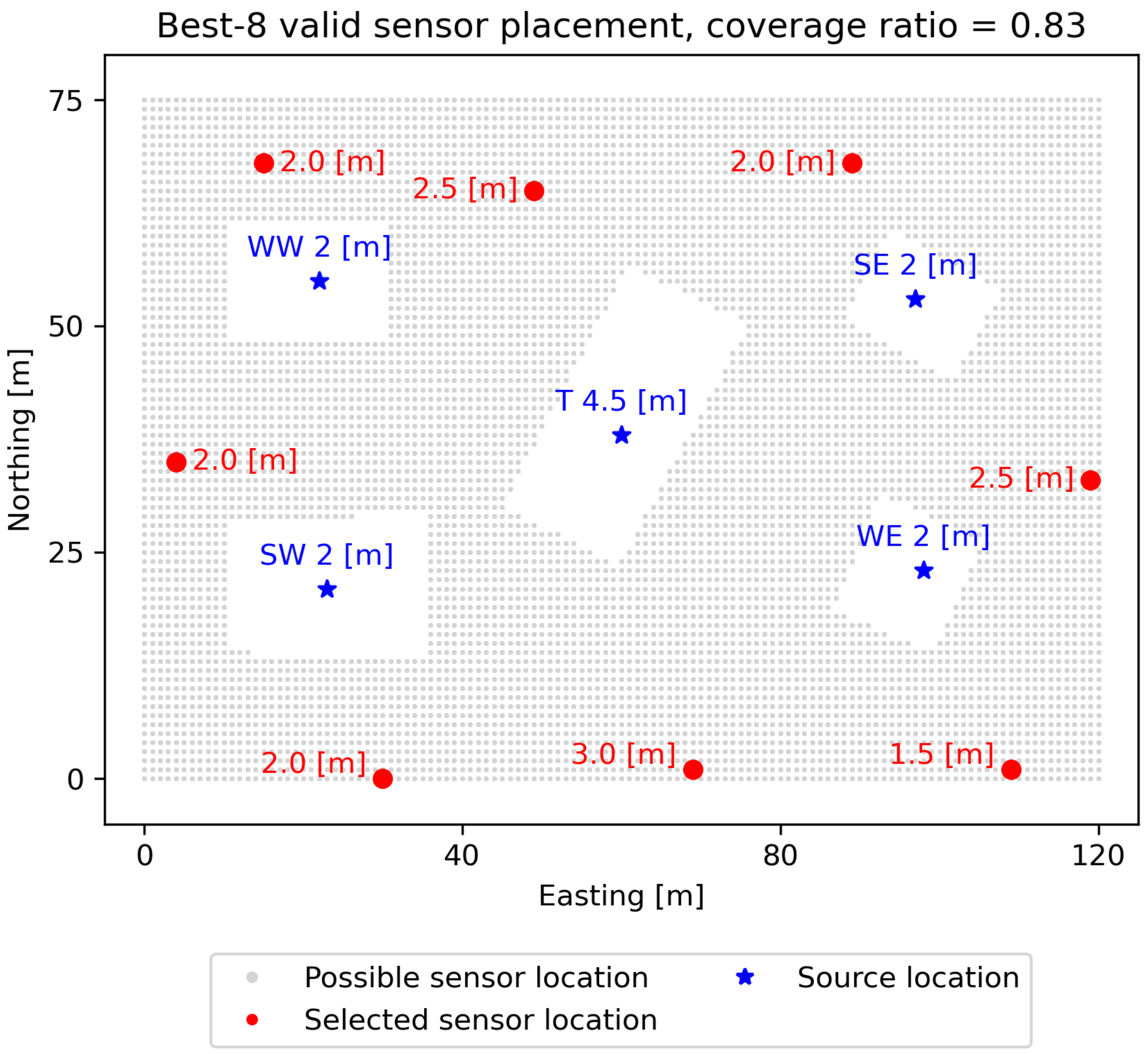


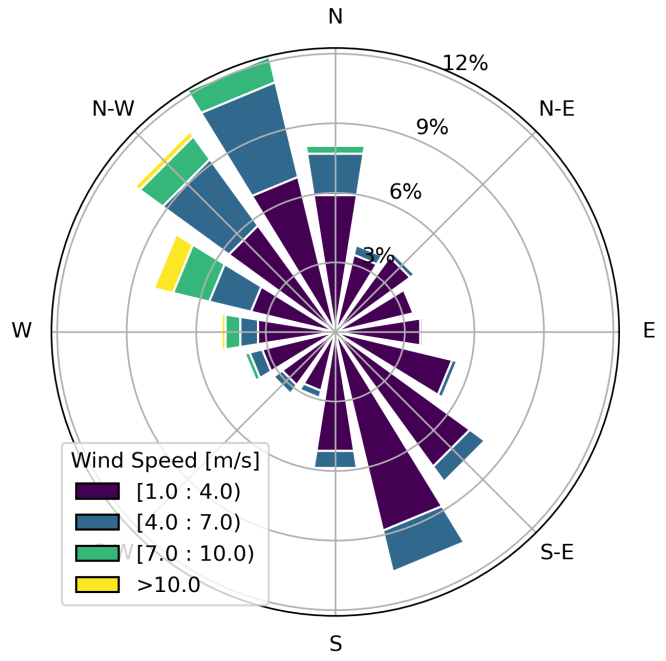
Available sensor locations

Optimization algorithm

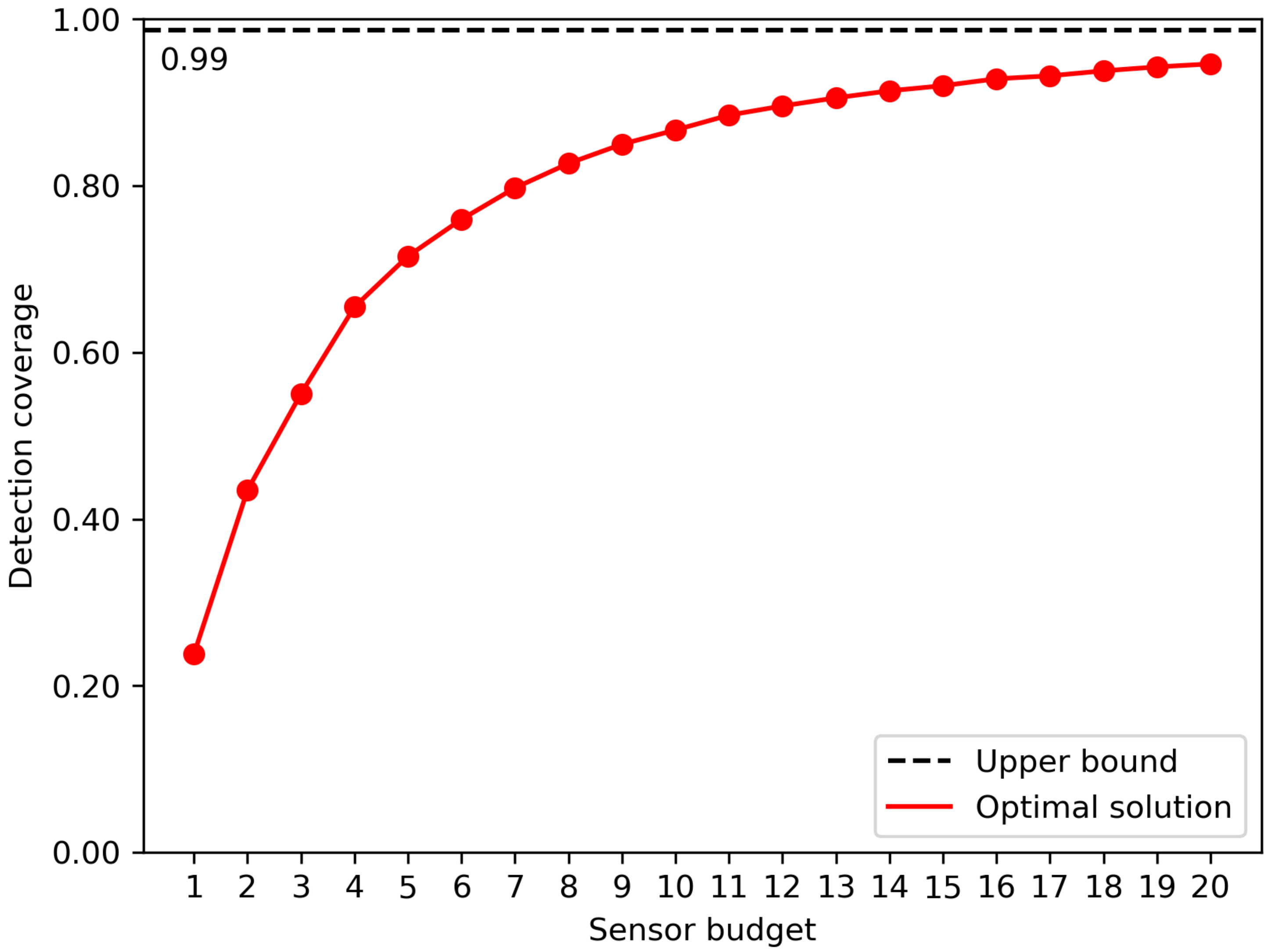
Output: optimal sensor placement

Results: Best 8-sensor placement





Results: Budget vs. coverage



Summary

- We propose a data-driven algorithm for optimizing sensor placement on oil and gas sites.
- Our algorithm's high modularity allows users to incorporate their own methods and models.
- The algorithm can be expanded for wider applications such as emission localization and quantification by changing the objective functions.

Relevant Presentations in GRADS

- **Dynamic spatiotemporal thresholds for the Gaussian Puff atmospheric dispersion model using dynamic spatiotemporal thresholds** – Ryker Fish
- **Exploring Optimal Continuous Monitoring Sensor Configurations on a Prototypical Midstream Oil and Gas Site** – Troy Sorensen
- **Estimating methane emission duration with continuous monitoring systems** – William Daniels
- **Sampling Frequency Strategies for Methane Emissions from Oil & Gas** – Olga Khaliukova
- **Estimating Theoretical Error Distributions for Overflight Methane Measurements** – Cal Richards-Dinger

Thank you for attending! Questions?

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