Leveraging multiple continuous monitoring sensors for emission identification and localization on oil and gas facilities

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Associate Professor

The problem

Given a number of continuous monitoring sensors on an oil and gas facility, can we deliver concise alerts when an actionable event occurs?

Colorado State University's METEC Facility

Oil and gas test facility capable of controlled emissions

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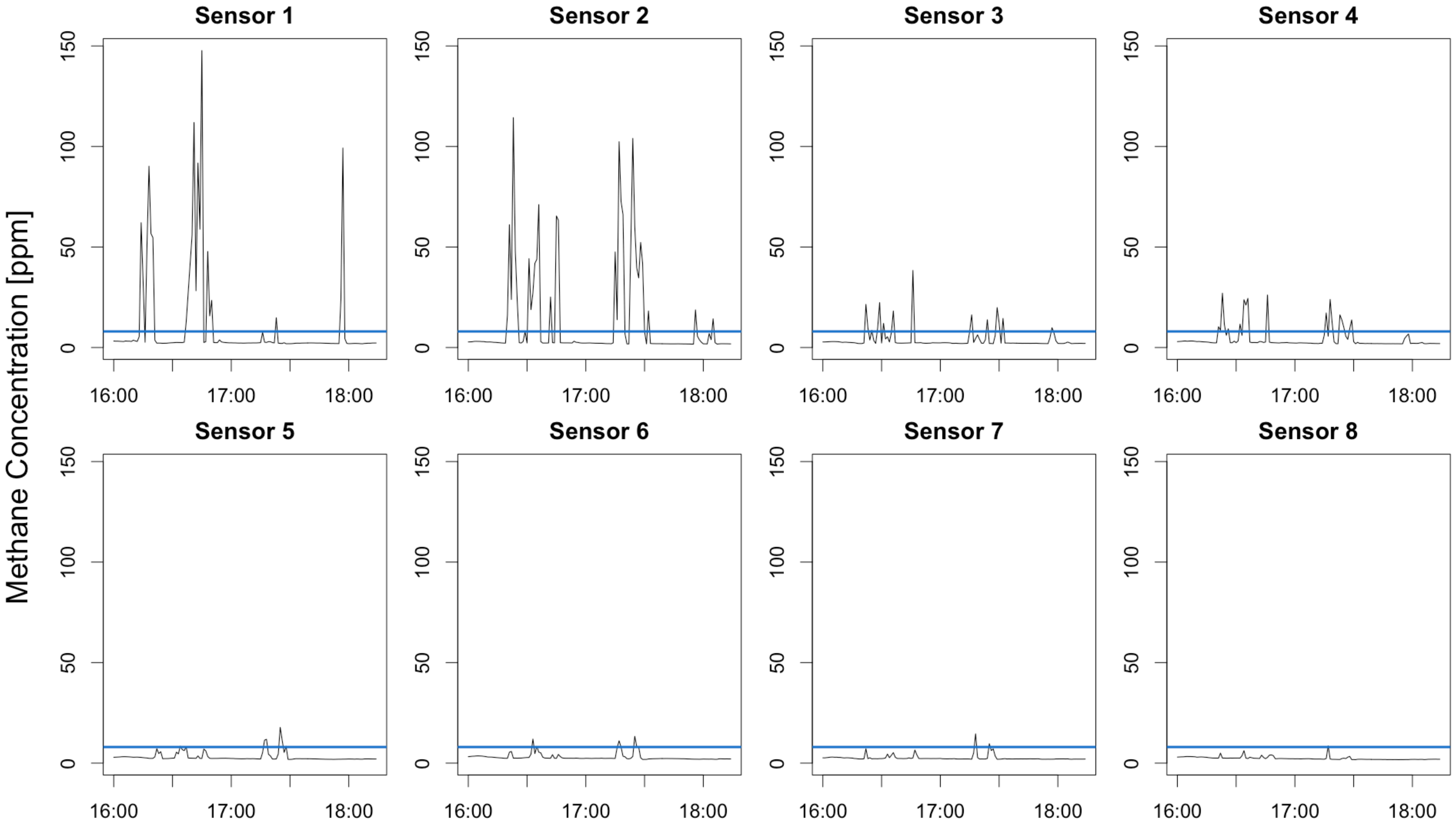
The motivation

Alerting on static thresholds can overwhelm operator and does not utilize information from all units simultaneously



Alert Log

	A	B	C
1	time	sensor	concentration
2	2/16/21 16:14	1	62.12096162
3	2/16/21 16:15	1	32.81096162
4	2/16/21 16:17	1	51.36796162
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23	2/16/21 16:29	3	22.37298755
24	2/16/21 16:31	2	44.24248963
25	2/16/21 16:31	3	12.02098755
26	2/16/21 16:32	2	18.86448963
27	2/16/21 16:32	4	11.6609834
28	2/16/21 16:33	2	27.16248963
29	2/16/21 16:33	6	11.97362448
30	2/16/21 16:34	2	41.88248963
31	2/16/21 16:34	4	23.7939834
32	2/16/21 16:34	5	8.417526971

The plan

Proposed solution: Semi-real time event detection and localization utilizing:

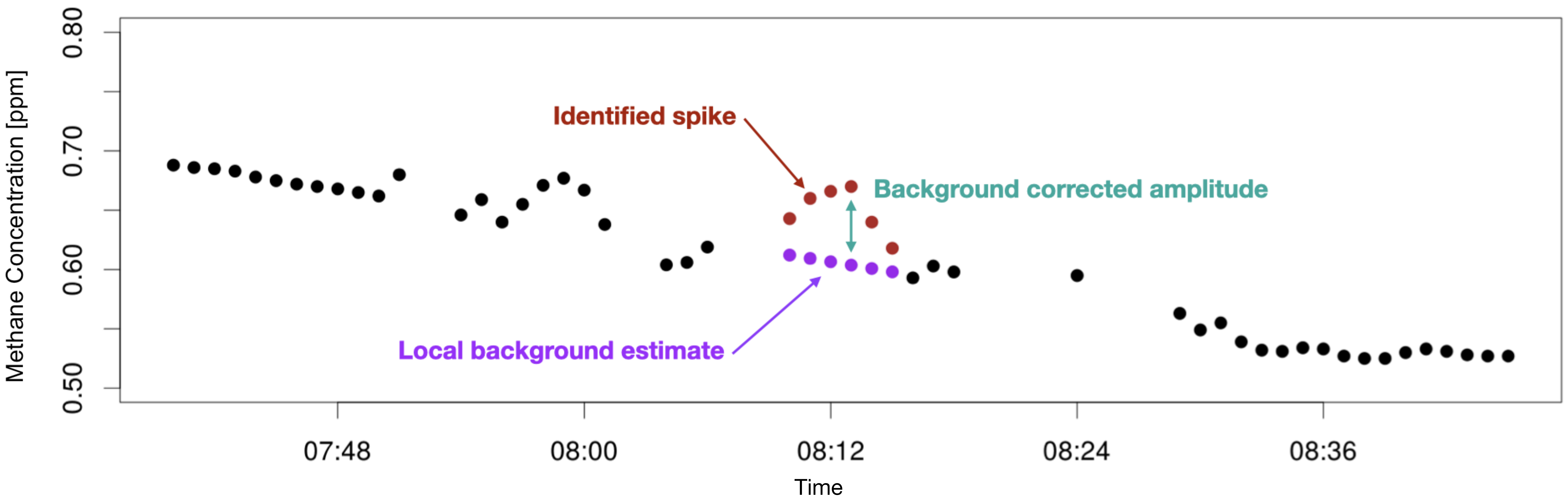
1. Site geometry, including knowledge about all potential sources
2. Information from all available methane and wind sensors

Method:

1. Remove background from sensor observations
2. Simulate concentrations at sensor locations from all potential emission sources
3. Pattern match simulated concentrations and observations via custom metric to identify most likely source for each sensor
4. Use wind data and site geometry to combine information across sensors

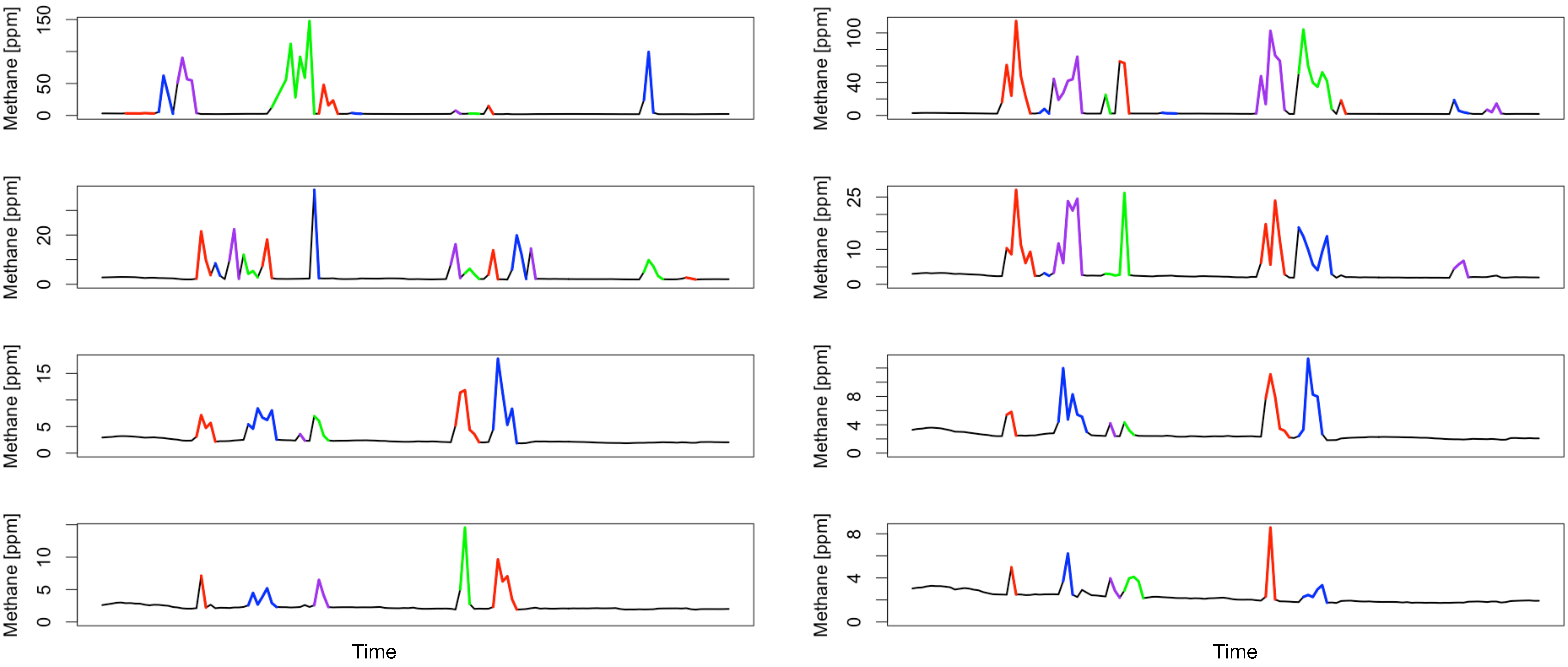
Step 1: Estimate background

- Detect spikes via custom gradient-based method
- Estimate background via non-parametric regression fit to local “non-spike” observations



Step 1: Estimate background

Colors distinguish
between different spikes



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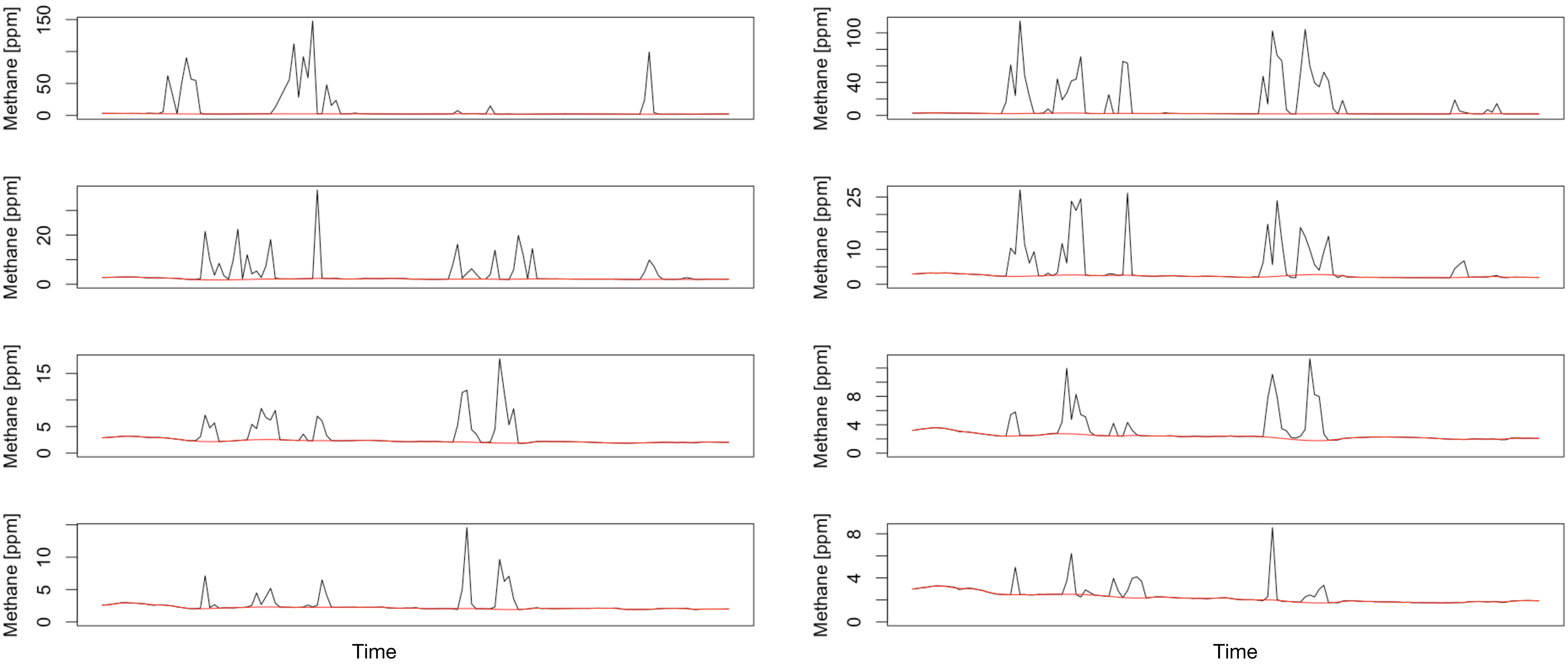

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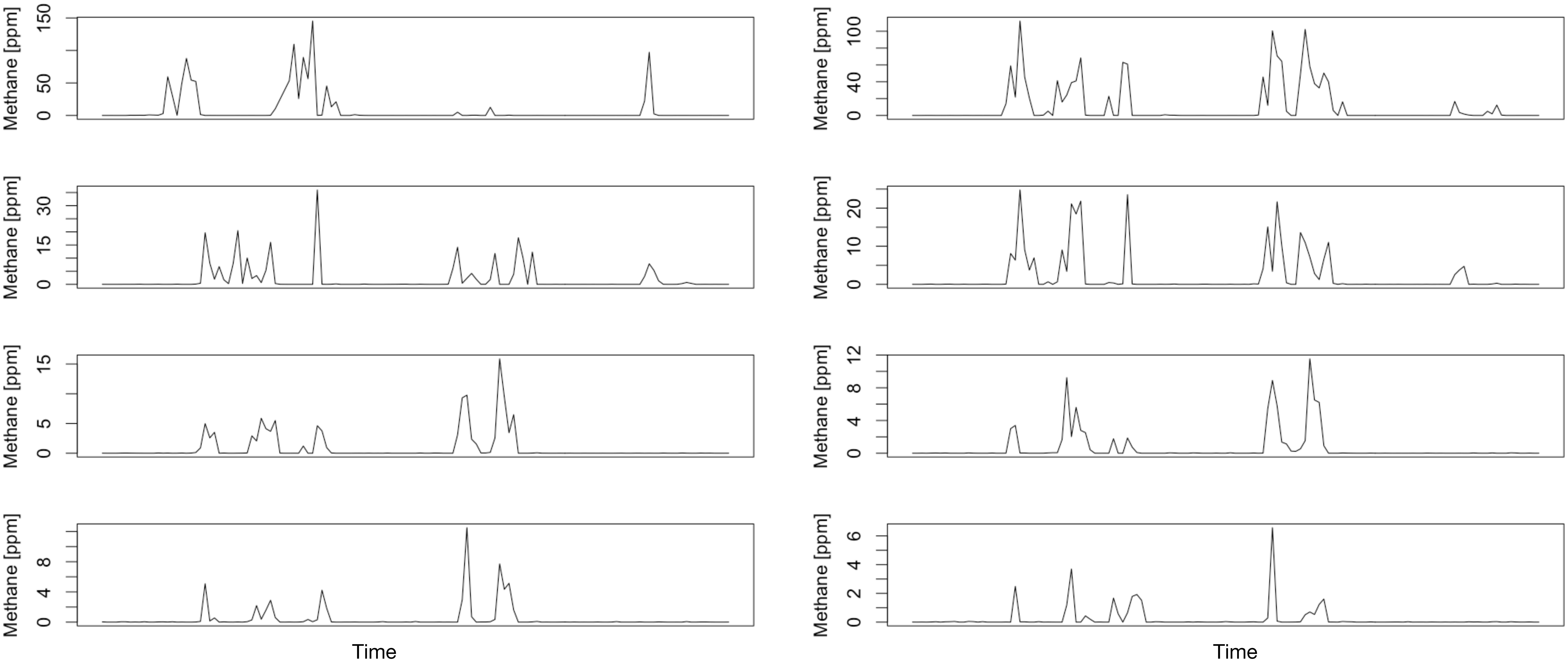

Step 2: Simulate concentrations

- Forward model: Gaussian puff with different horizontal and vertical variances

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

- Where:
  - $C(x, y, z, t)$ is the predicted concentration at location (x, y, z) and time t
  - Q_t is the amount of methane released at time t
  - u is the wind speed at time t
  - H is the height of the source

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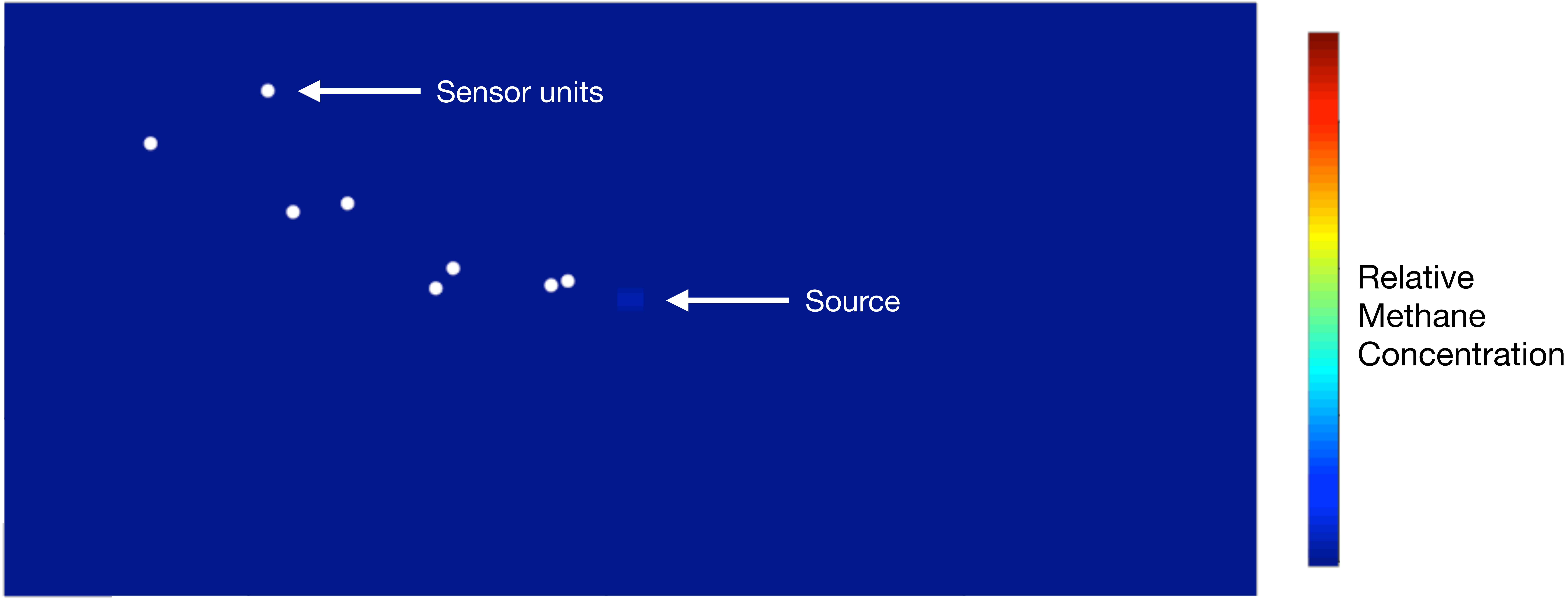
- Variances are a function of stability class and downwind distance

$$\sigma_z = ax^b$$

$$\sigma_y = 465.11628x \tan \Theta$$

$$\Theta = 0.017453293(c - d \ln(x))$$

Step 2: Simulate concentrations



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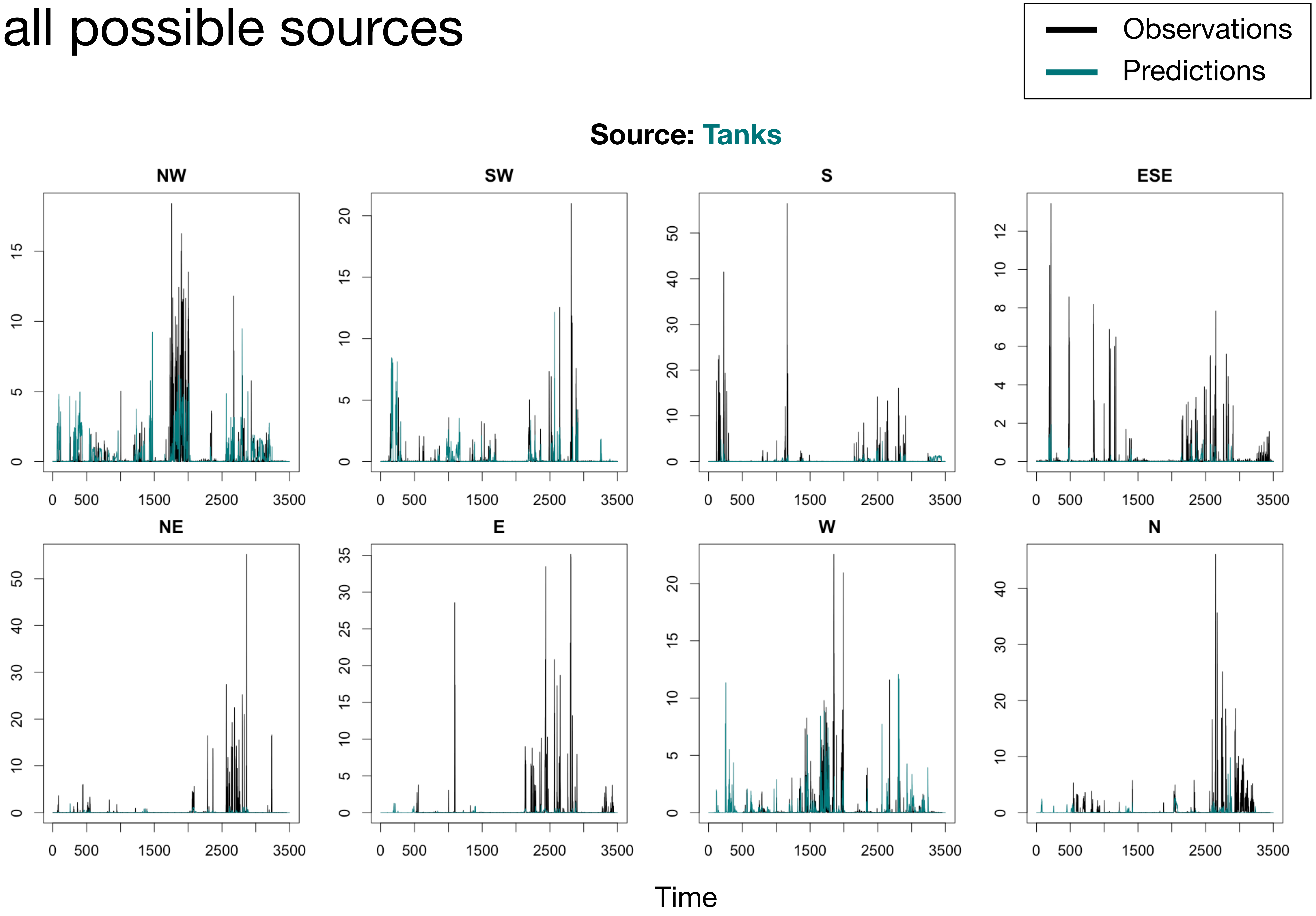

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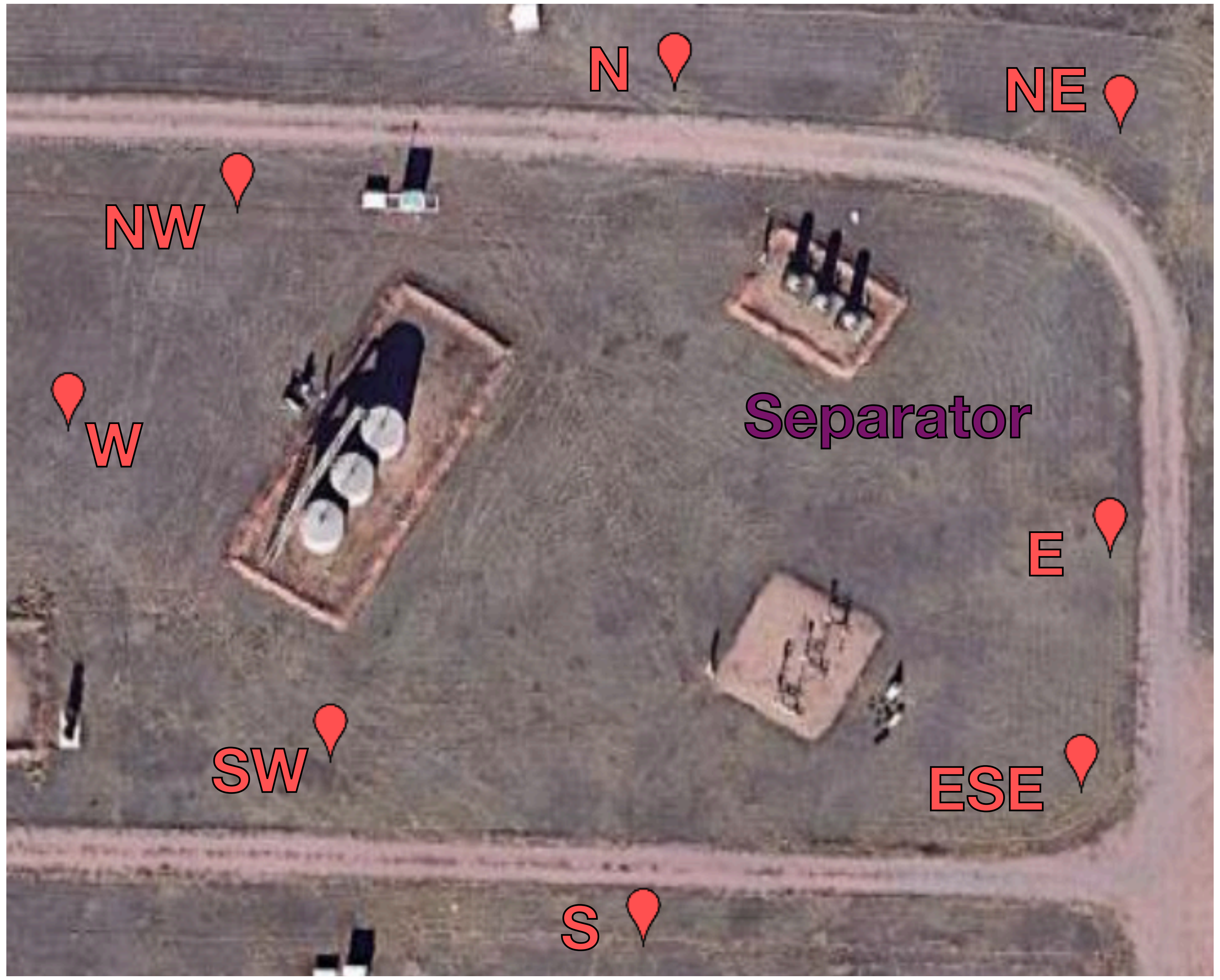

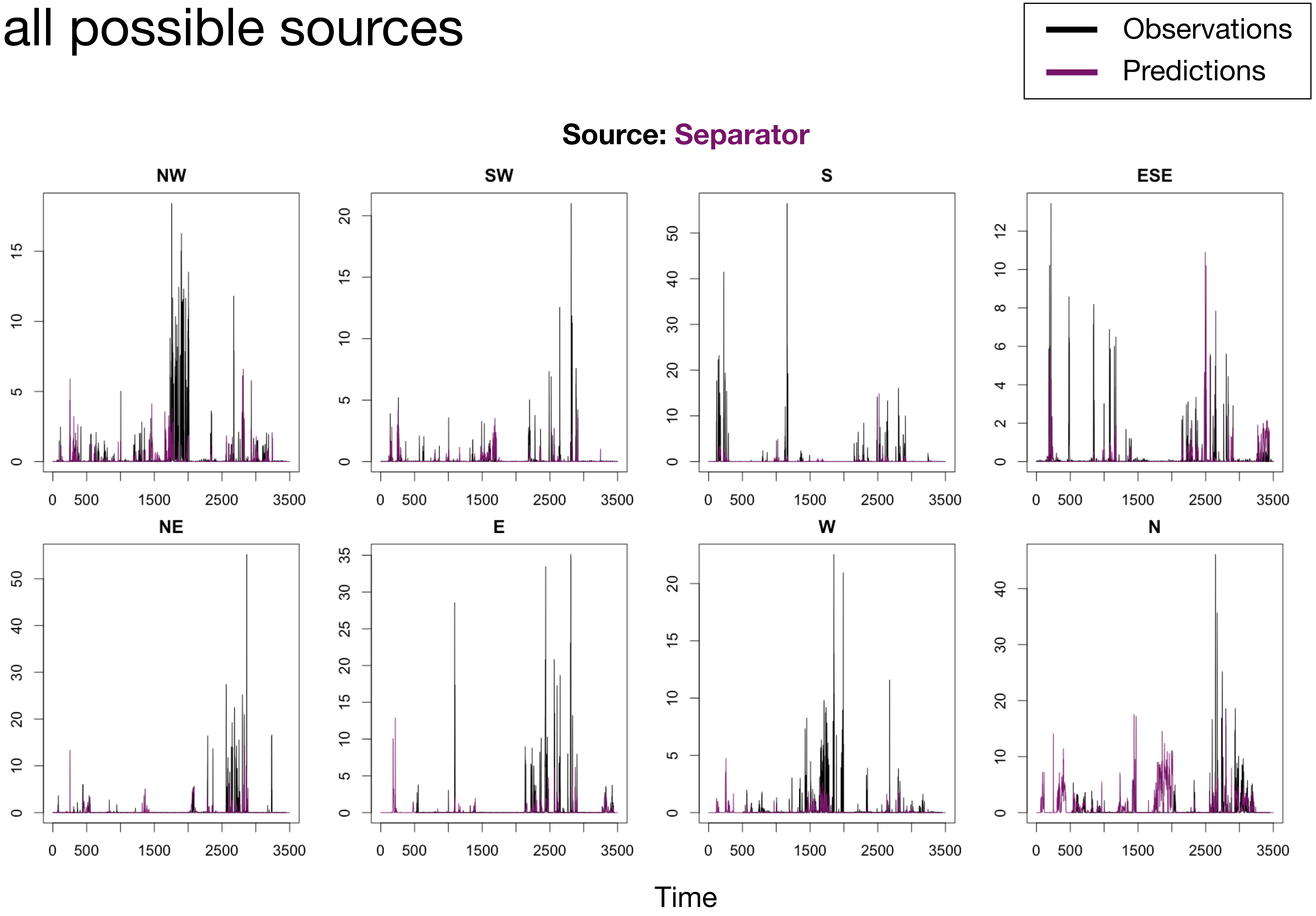

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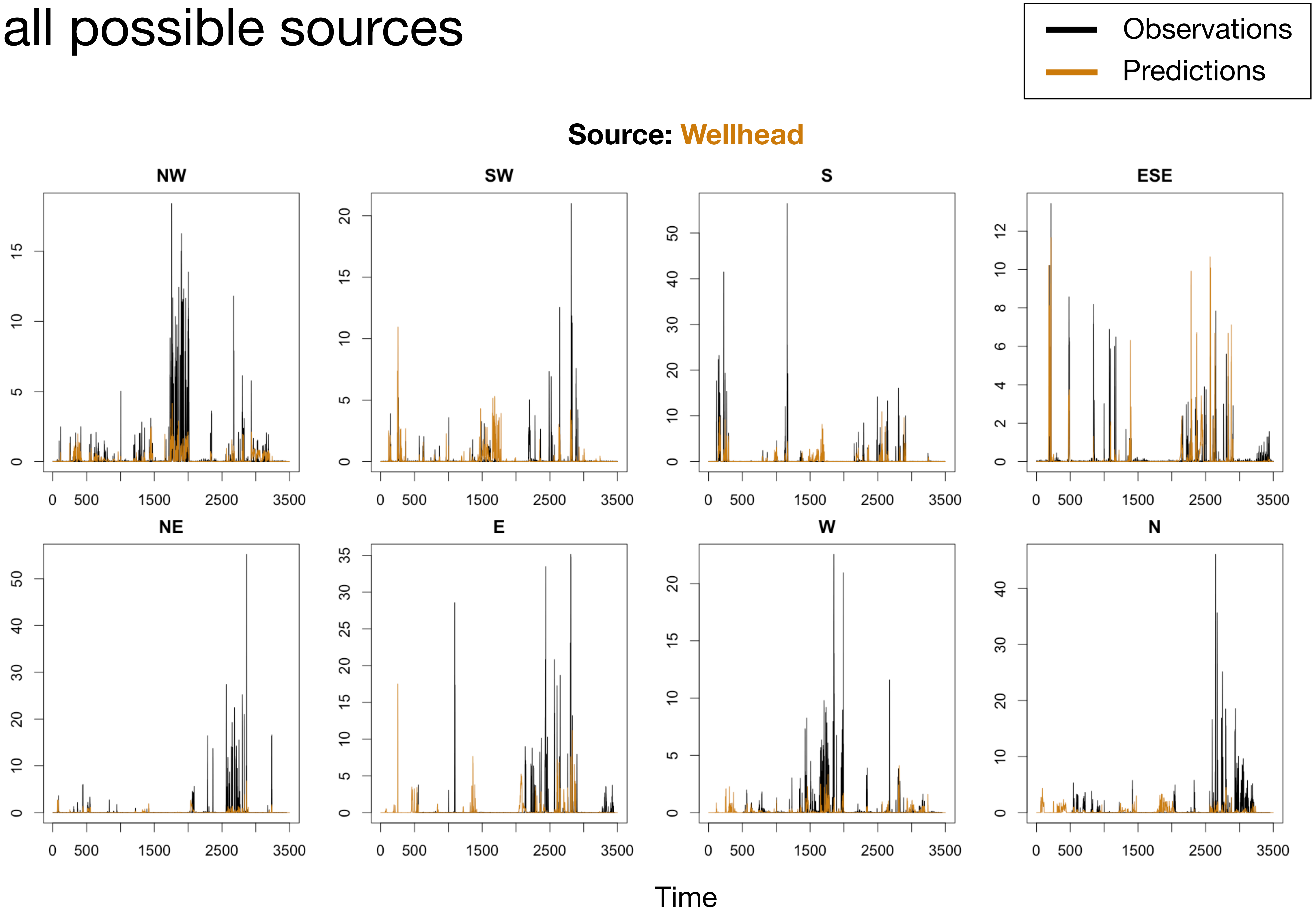
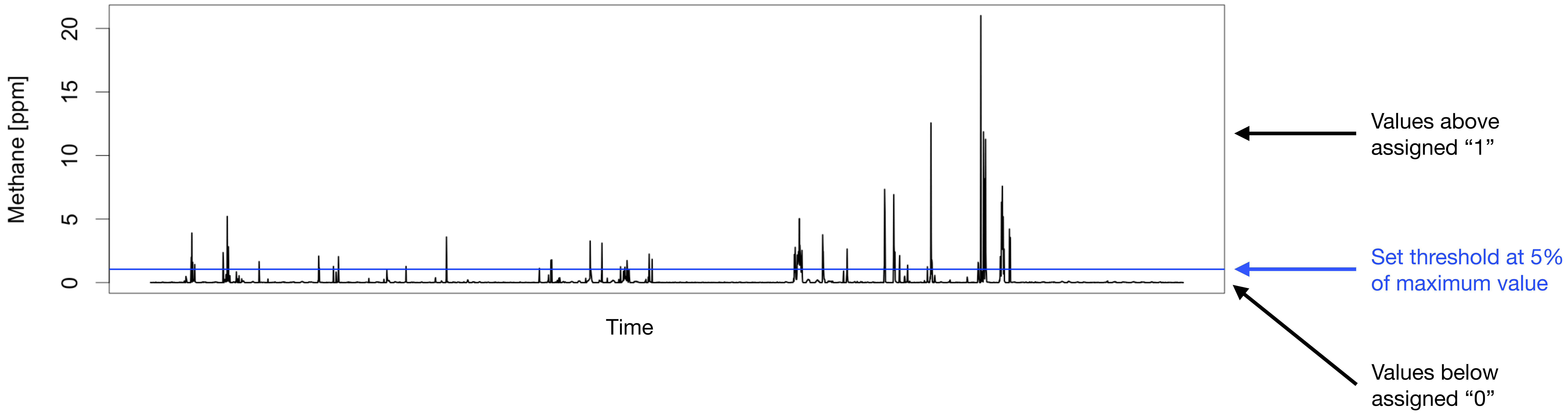


Step 3: Pattern match

- True emission rate unknown in practice: focus on spike alignment, not on amplitude alignment

- Convert observations and predictions into a binary representation: high or low



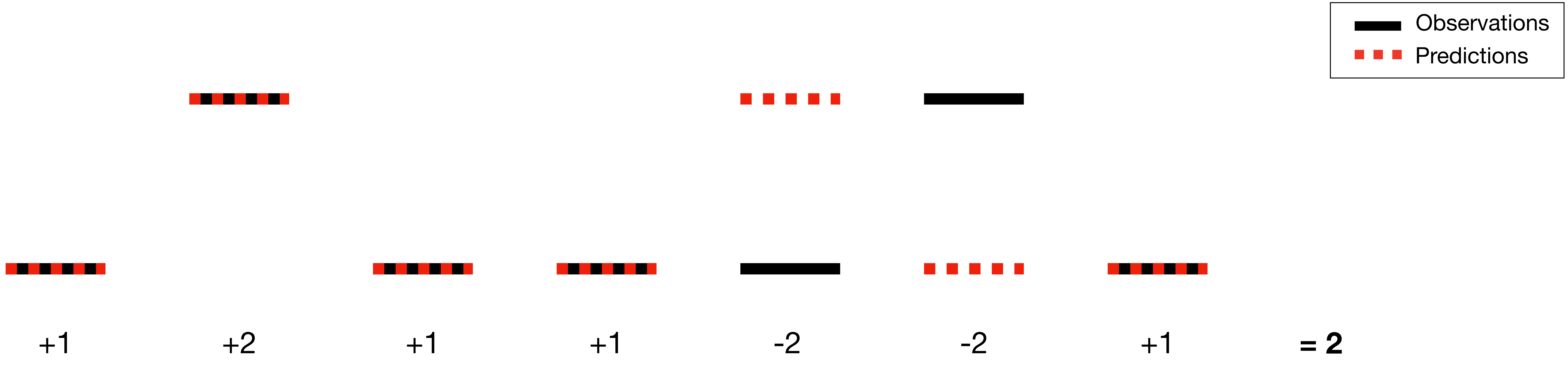
Step 3: Pattern match

- True emission rate unknown in practice: focus on spike alignment, not on amplitude alignment
- Convert observations and predictions into a binary representation: high or low
- For each simulation, compute “points” in the following manner

High values aligned	Obs high, preds low	Obs low, preds high	Low values aligned
+2	-2	-2	+1

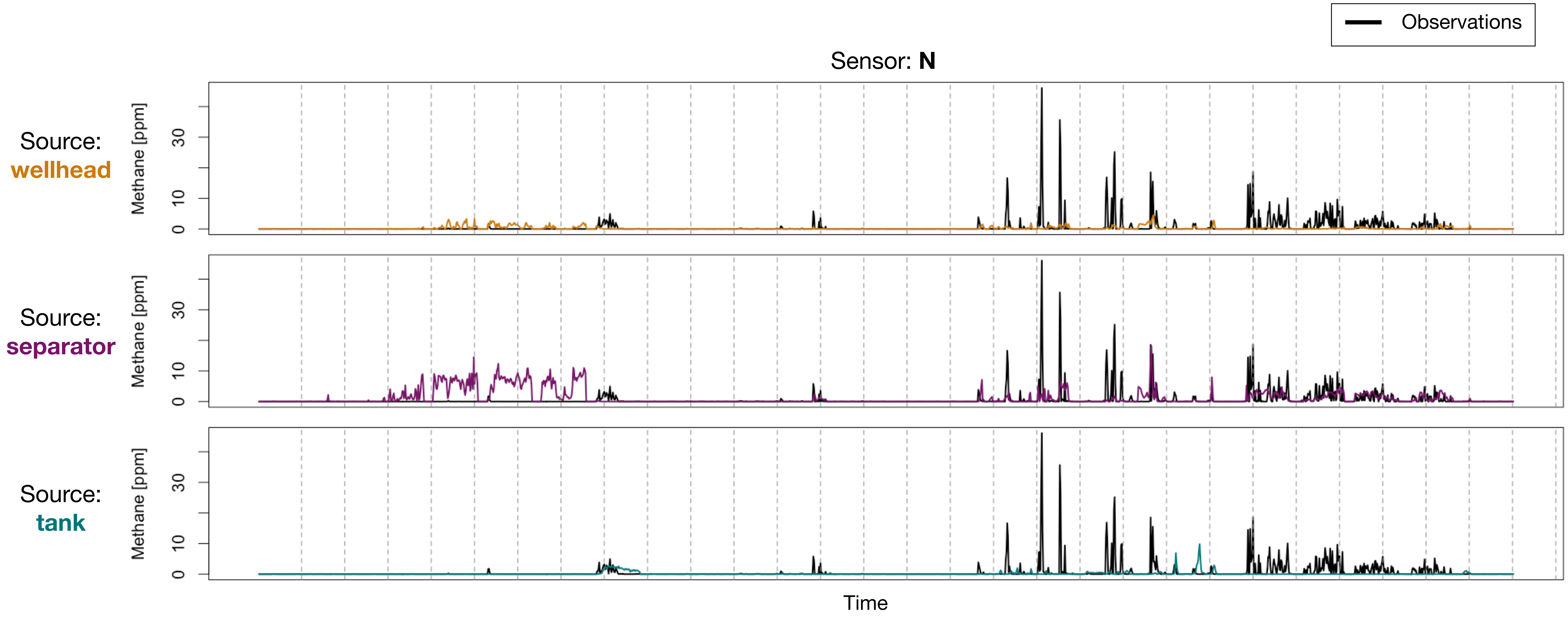
Step 3: Pattern match

- True emission rate unknown in practice: focus on spike alignment, not on amplitude alignment
- Convert observations and predictions into a binary representation: high or low
- Pattern match example:



Step 3: Pattern match

- Perform pattern matching algorithm on small time chunks to account for time varying sources



Step 4: Combine sensors

For every time chunk, we have a metric value for each simulation source and each sensor:

Time chunk 1

	Source 1	**Source 2**	**Source 3**
Sensor 1	$m_{1,1}$	$m_{2,1}$	$m_{3,1}$
…	…	…	…
Sensor 8	$m_{1,8}$	$m_{2,8}$	$m_{3,8}$

•••

Time chunk n

	Source 1	**Source 2**	**Source 3**
Sensor 1	$m_{1,1}$	$m_{2,1}$	$m_{3,1}$
…	…	…	…
Sensor 8	$m_{1,8}$	$m_{2,8}$	$m_{3,8}$

Want an overall localization estimate for each time chunk:

Time chunk 1

Source 1	**Source 2**	**Source 3**
m_1	m_2	m_3

•••

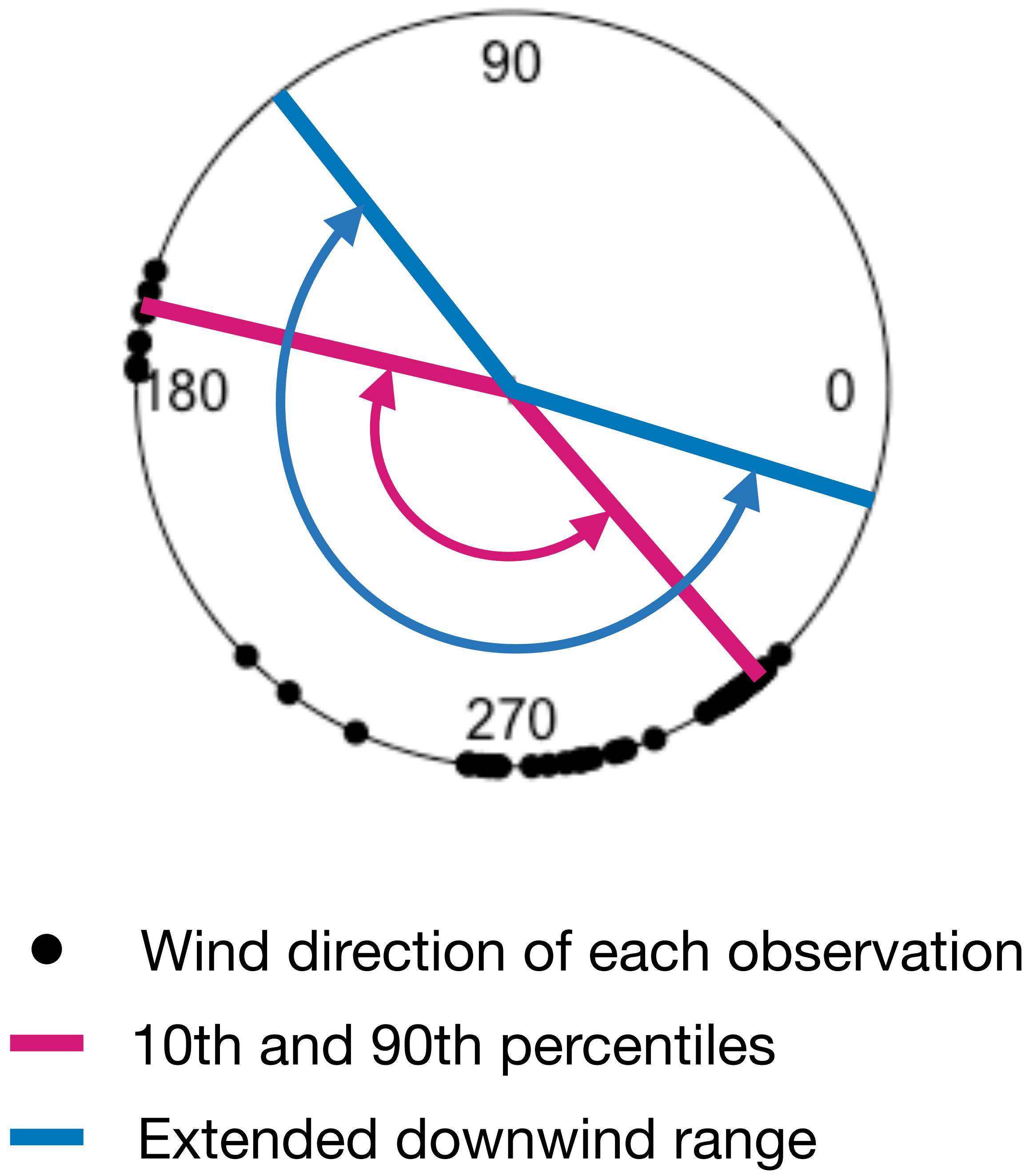
Time chunk n

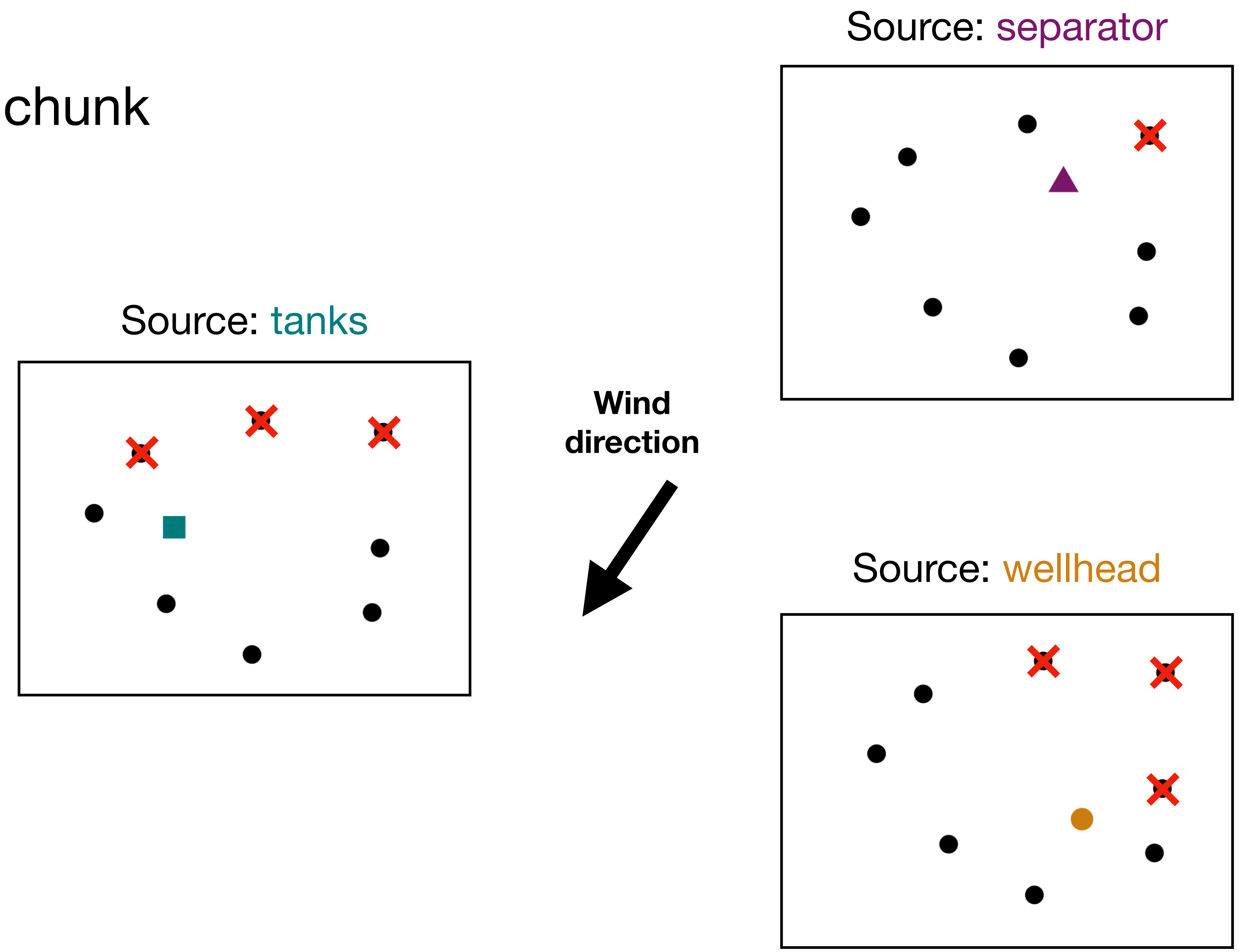
Source 1	**Source 2**	**Source 3**
m_1	m_2	m_3

Step 4: Combine sensors

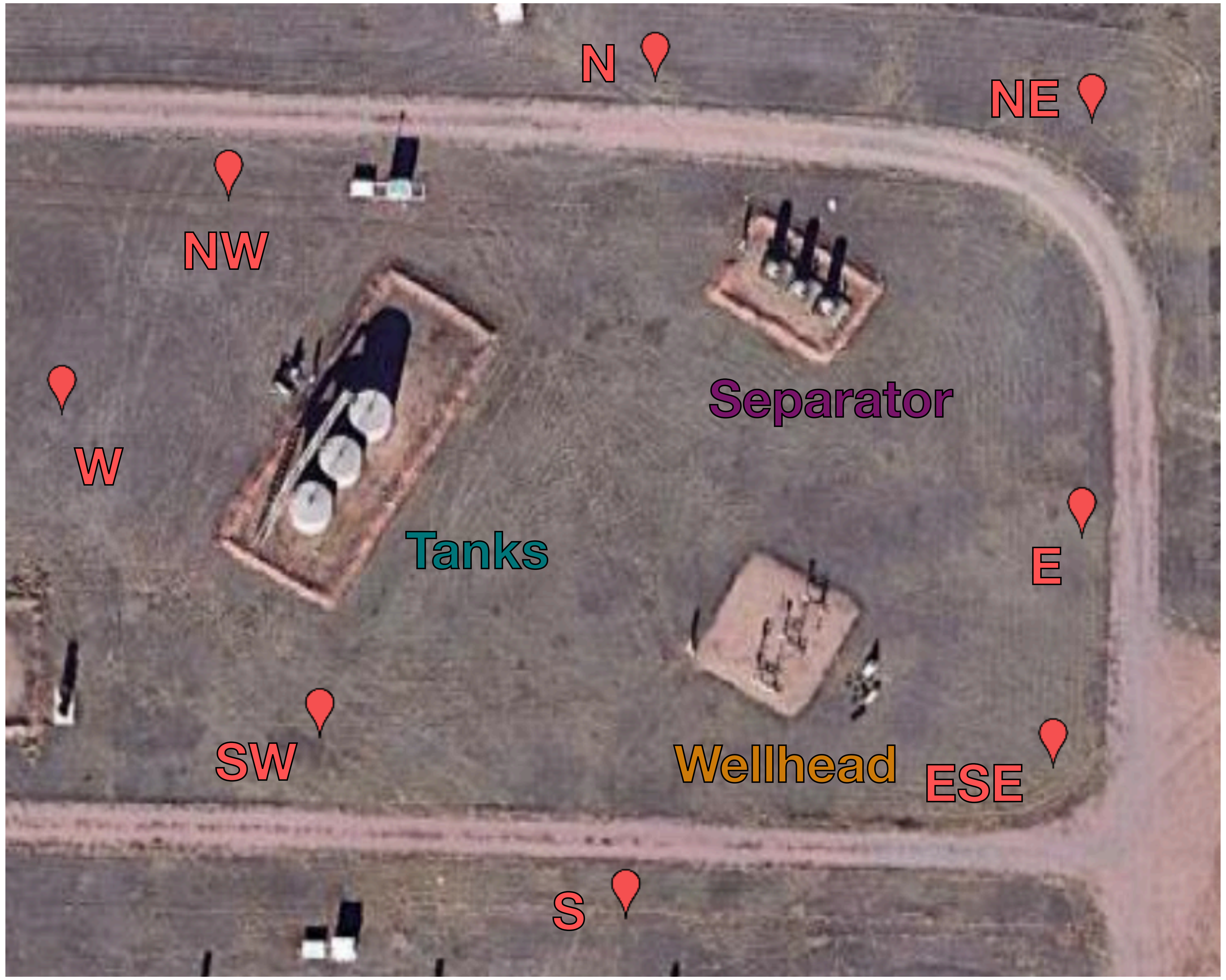
The plan: For each time chunk and for each source, omit data from upwind sensors and average metric across downwind sensors

Example: Consider a single 60 minute time chunk





Results



Experimental setup

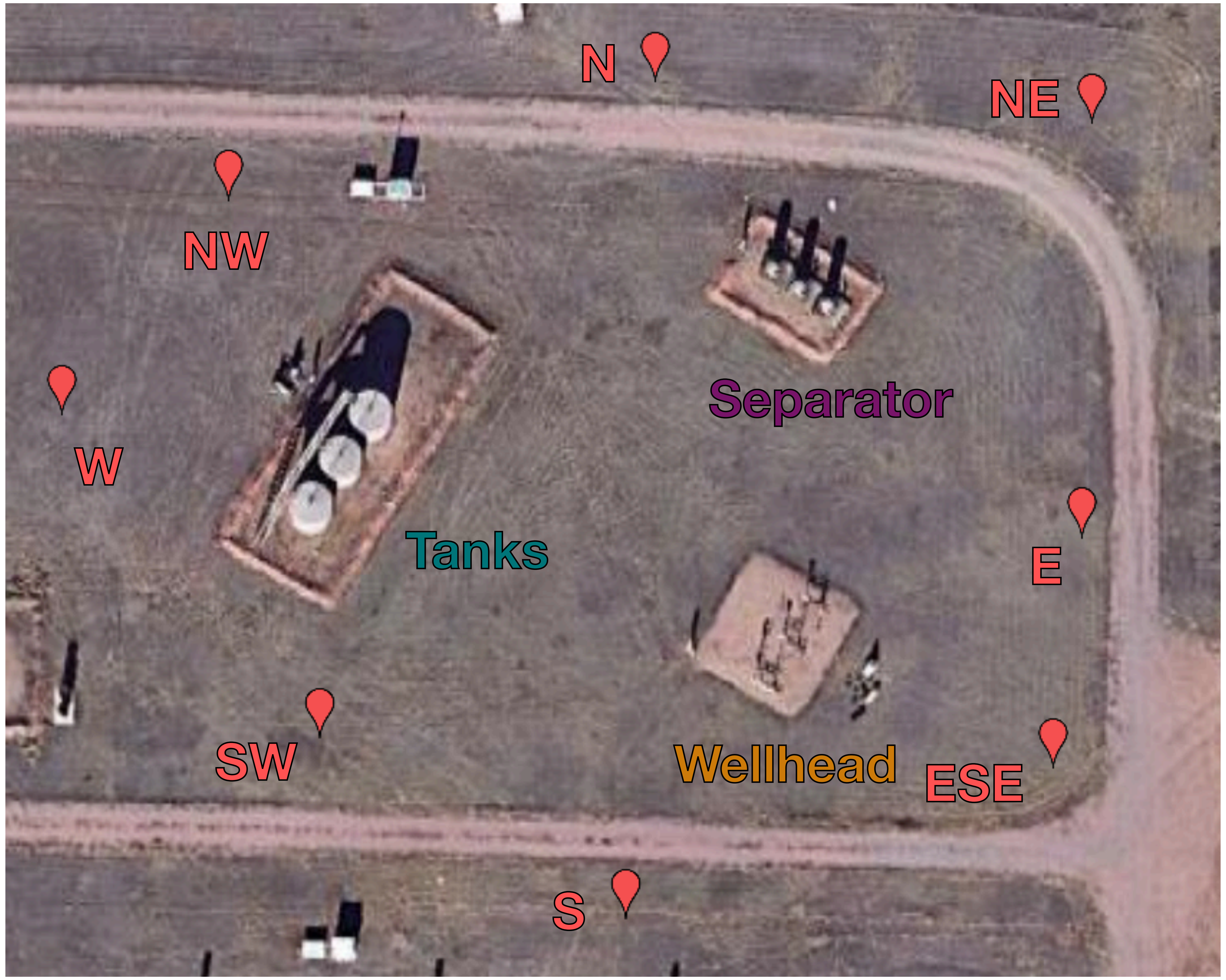
- 3 potential sources: tanks, separator, wellhead
- 8 sensors
- 58 hours of data (observations taken every minute)

Emission profile

- Controlled experiment
- Only one source emits at a time
- True source and emission rate changes over time

Tanks
Separator
Wellhead
No Source
Incorrect Est.
True source
Source estimates: 67% correct
Spike Alignment Metric
Confidence
Time chunks
0.0
0.2
0.4
0.6
0.8
1.0
0.00
0.10
0.20
0
10
20
30
40
50
60

Results



What about a more realistic sensor arrangement?

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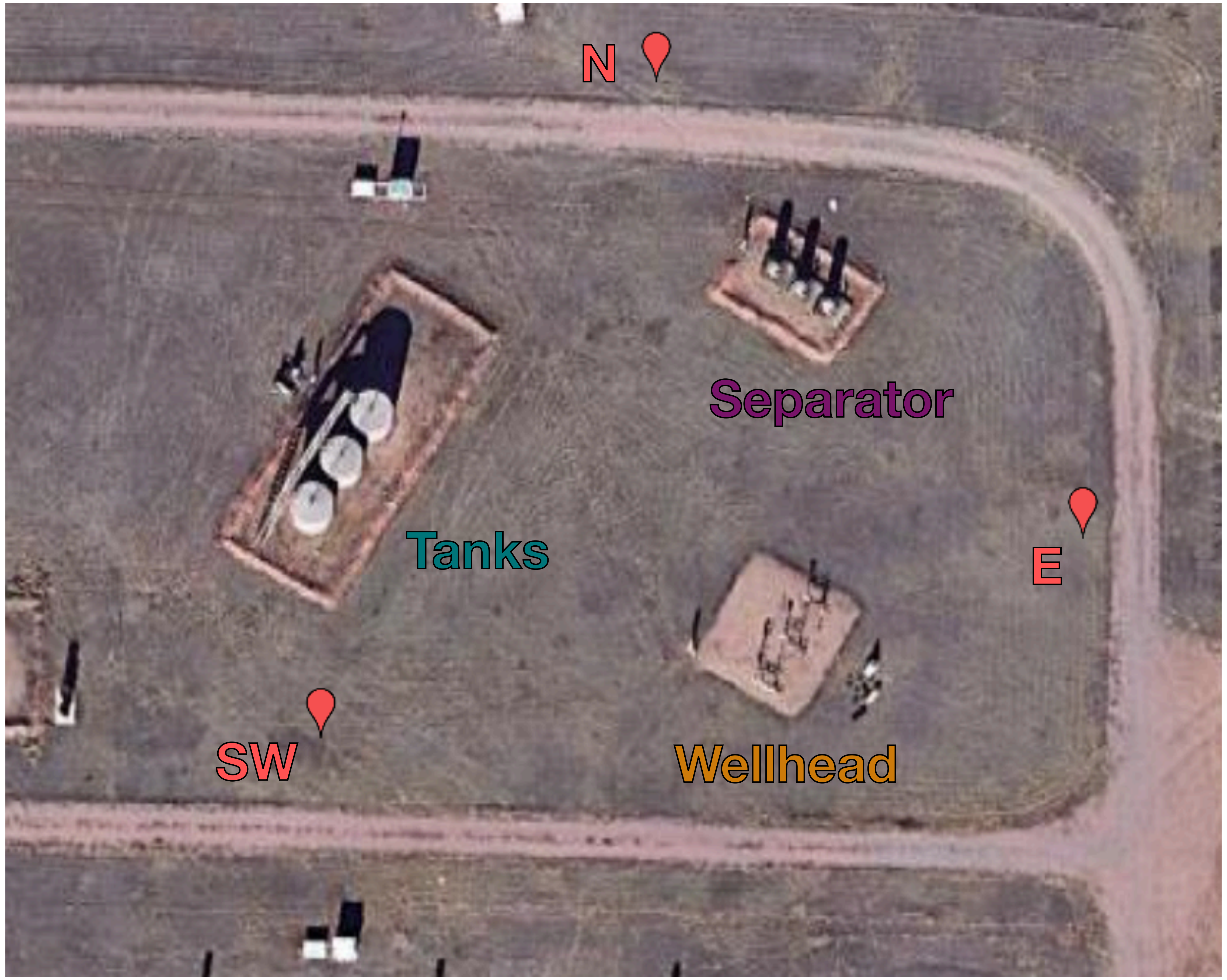

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Separator
Wellhead
No Source
Incorrect Est.
True source
Source estimates: 62% correct
Spike Alignment Metric
Confidence
Time chunks
0.0
0.2
0.4
0.6
0.8
1.0
0
10
20
30
40
50
60

Summary

1. Not doing a full inversion, but using a forward model for each potential source to inform localization
2. Using wind direction when combining sensors maximizes contribution of meaningful signal
3. Framework performs well in practical scenario
4. Framework does not depend on true emission rate

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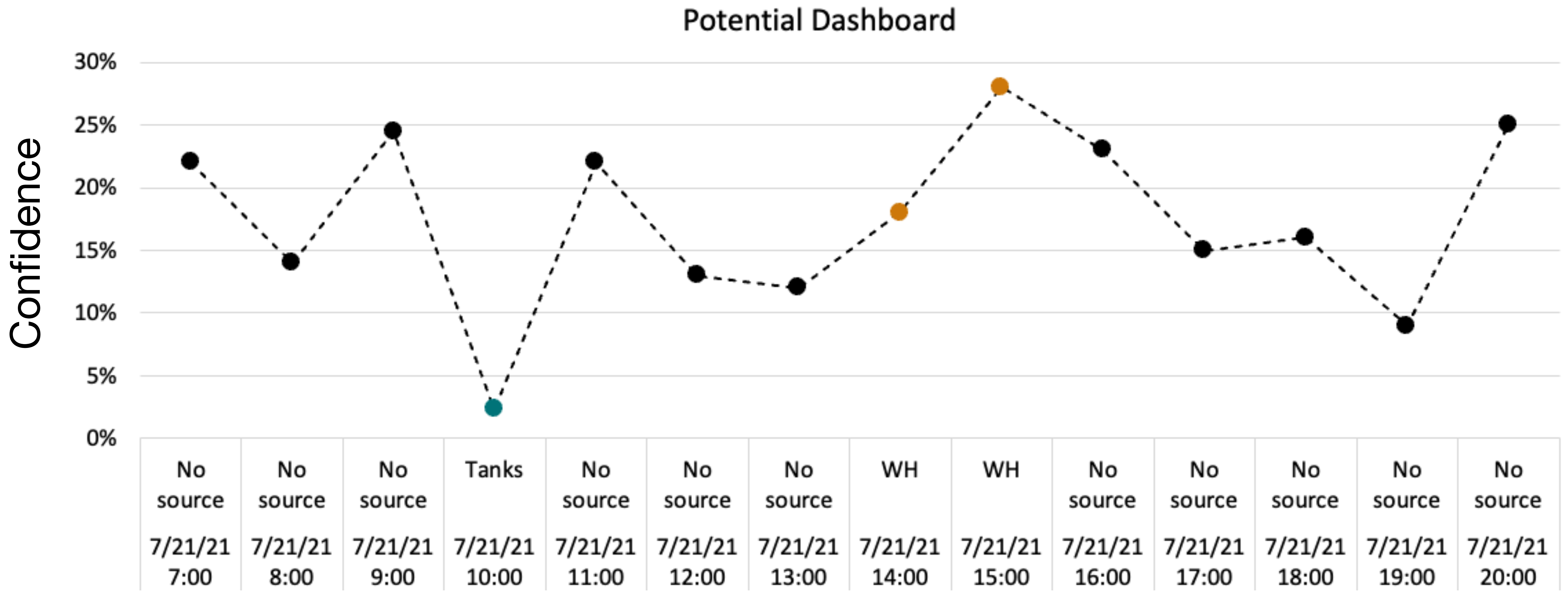

Thank you! Questions?

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