From (ppm) to Kg/hr: Using Surface Emissions Monitoring (SEM) Data to Infer Methane Emissions Fluxes from Landfills

Hinkley Center
for Solid and Hazardous
Waste Management

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2023 SWANA FL Summer Conference and Hinkley Center Research Forum

RIDER

FAMU-FSU College of Engineering

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Context and Motivations:

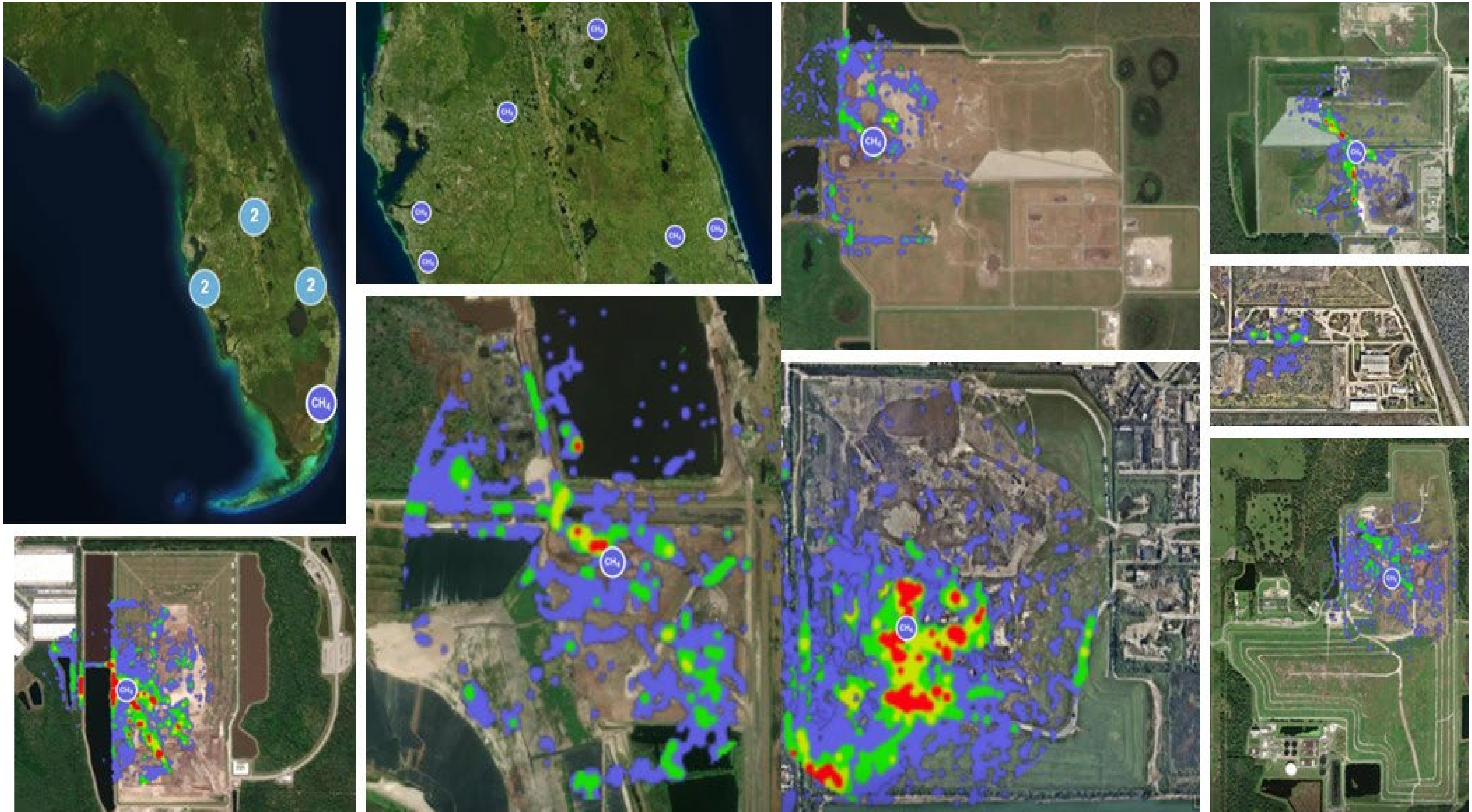
from : Global Waste Management Symposium 2022.

“…..If you do not tell the WORLD how much are YOUR EMISSIONS, someone else will,.. and maybe without accessing your site……...”

“….. You have NO MORE than 2 years to do this…..”

“… the MSW Sector needs to develop a methodology to do so….or some else will……”

~ 18 Florida Landfills were flown by Carbon Mapper in 2022



Research Team Rationale and Background

- **Collected All Carbon Mapper (CM) Reported Plumes 2020 to 2022**

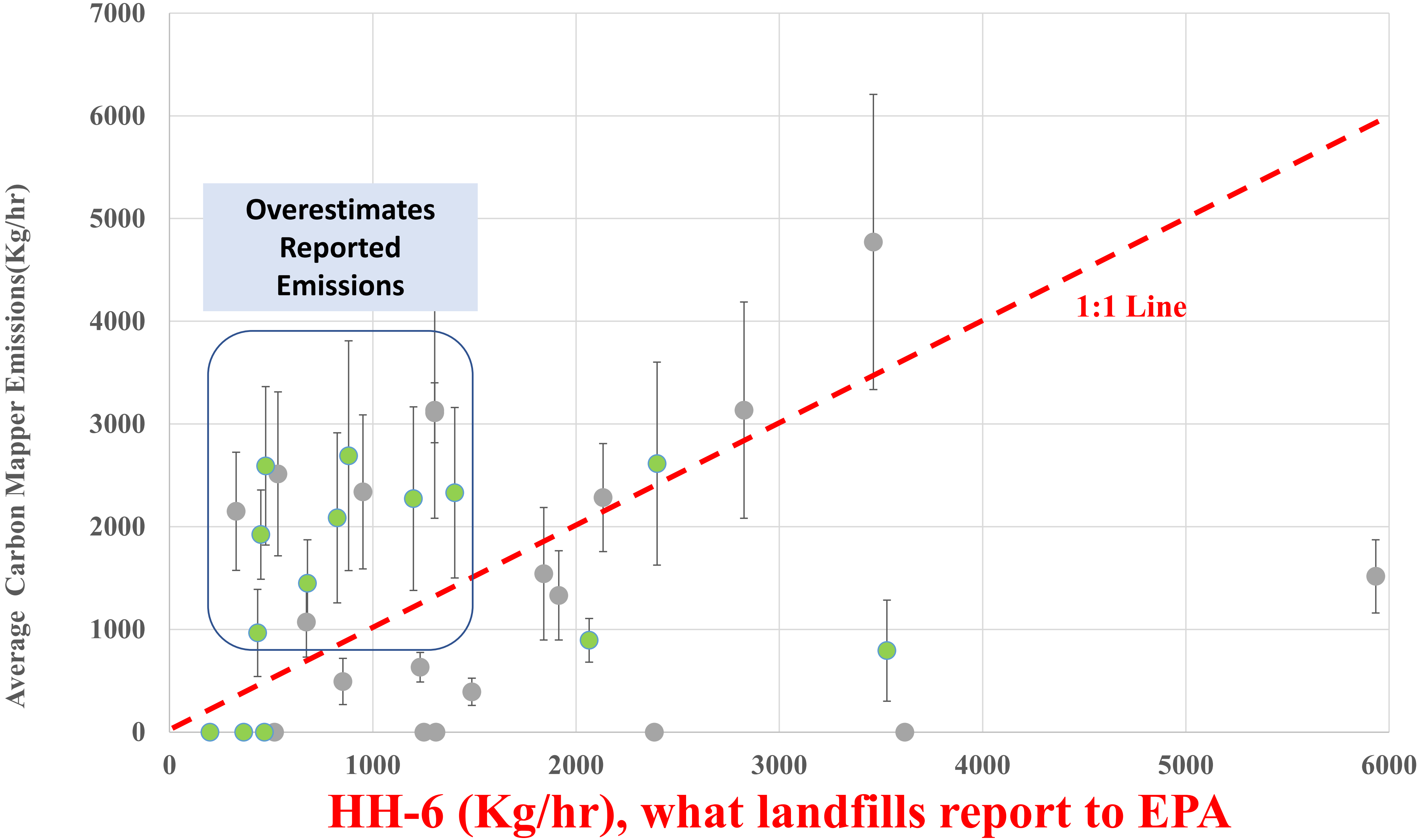
@ Several FL landfills – Methane Plumes were detected by CM Aircraft:

The questions are:

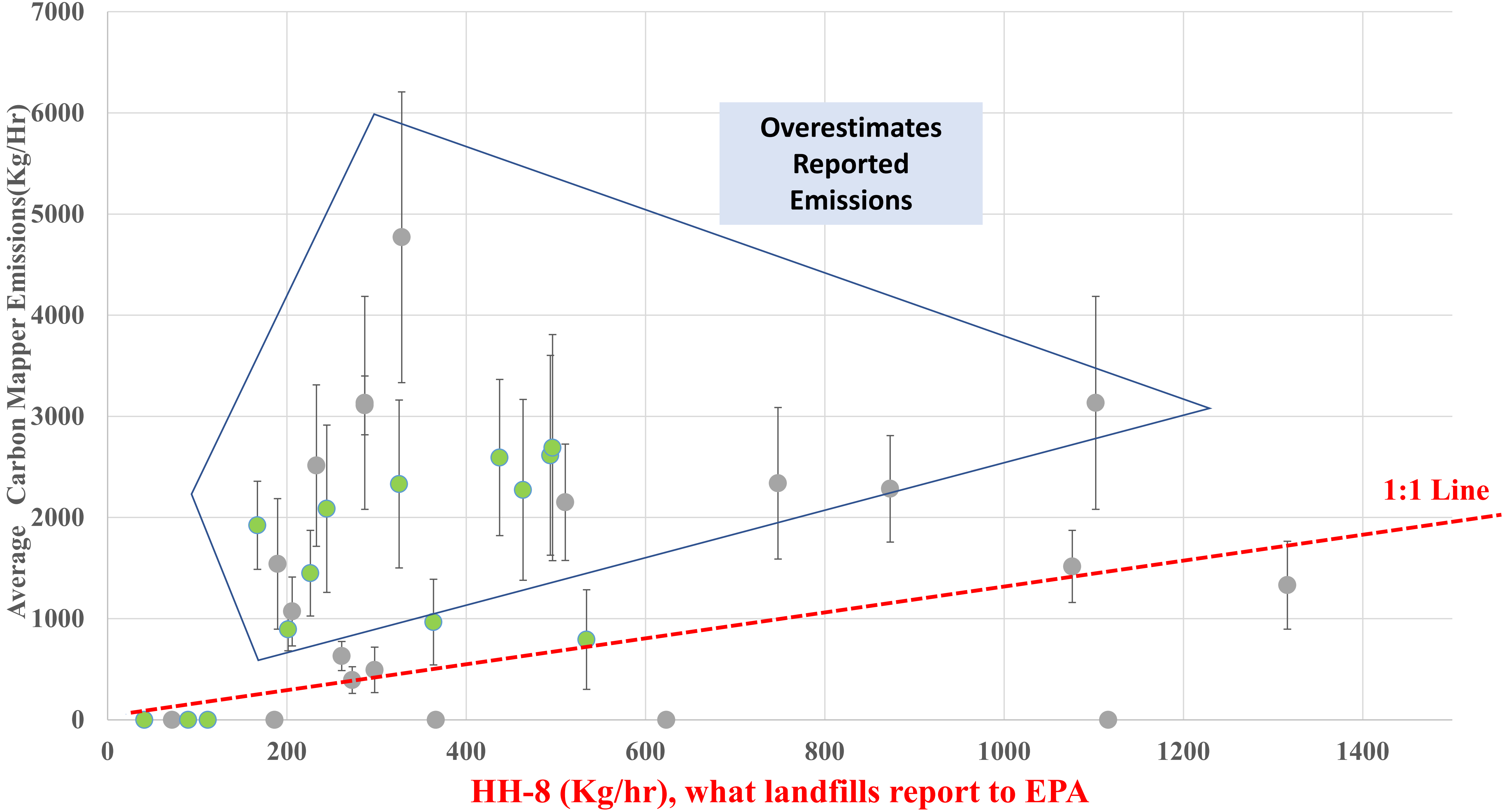
1. **Are these reflective of Year Around Emissions or Are these Temporary LEAKS**
2. **Are these fluxes/emissions accurate? How do they compare to other measurements?**

# of landfills	# of plumes	# of plumes with flux	# of plumes without flux	# Plumes off Waste	# Plumes on Waste	Avg Flux (Kg/Hr)	Avg Error Flux (Kg/Hr)
7	10	6	4	1	9	2,742	842

Average CM Detected Plumes vs HH-6 (Humid Hot Climate)

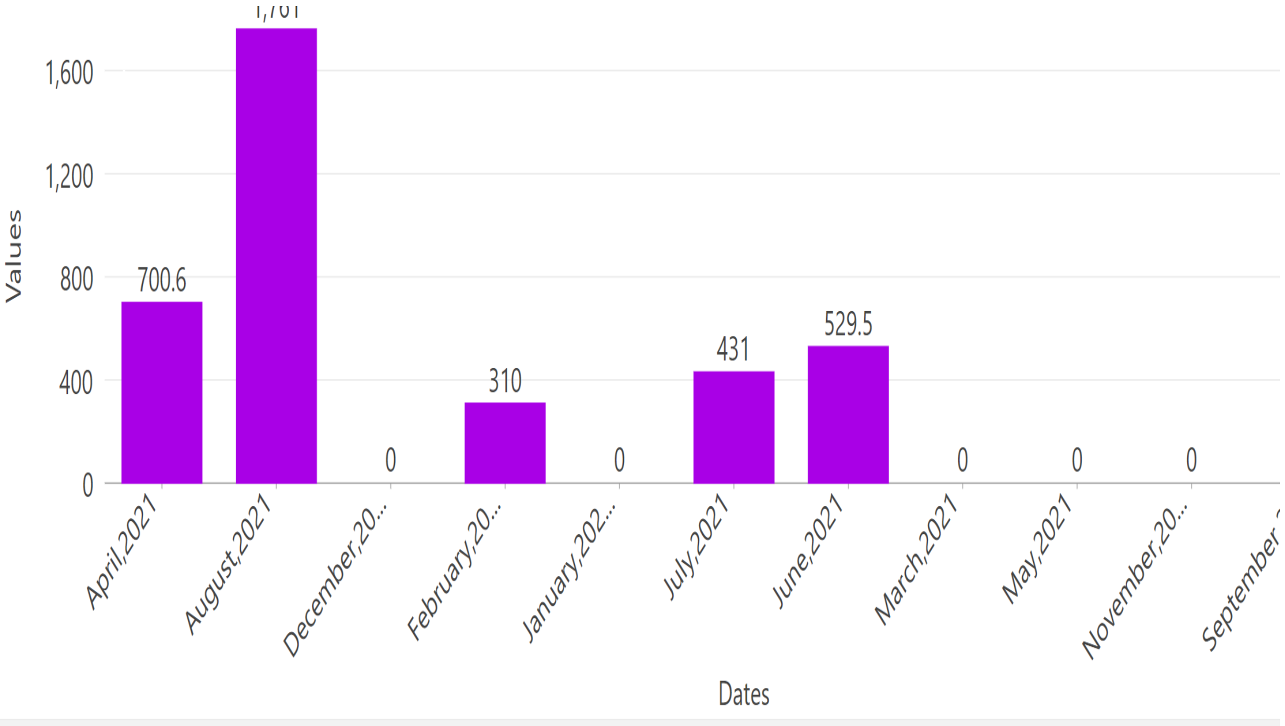


Average CM Detected Plumes vs HH-8 (Humid Hot Climate)



Recently…..Satellite-Based Emissions Rate Estimates

Example Emissions Reporting Products
Hot-Humid Climate Landfill Time Series



Axios

[Tracking methane from space could be key to helping slow global warming]

Satellites are providing data to precisely point to sources of the strong greenhouse gas.

Nov 10, 2022

BBC

GHGSat: Commercial satellite will see CO2 super-emitters

Montreal firm GHGSat says its next Earth observer will track carbon dioxide at high resolution.

Jan 31, 2023

Newswire

New Satellites to Accelerate the Fight Against Climate Change Launched Into Orbit With SpaceX

... • GHGSat-C6, C7 and C8 successfully deployed during the SpaceX Transporter-7 rideshare mission • GHGSat's world-leading constellation...

2 weeks ago

SatNews

GHGSat to launch 6 high-resolution emission monitoring satellites in 2023 – SatNews

GHGSat will be launching six additional satellites in 2023 — the first three are GHGSat satellites, named Mey-Lin (C6), Gaspard (C7) and...

Feb 27, 2023

ABC News

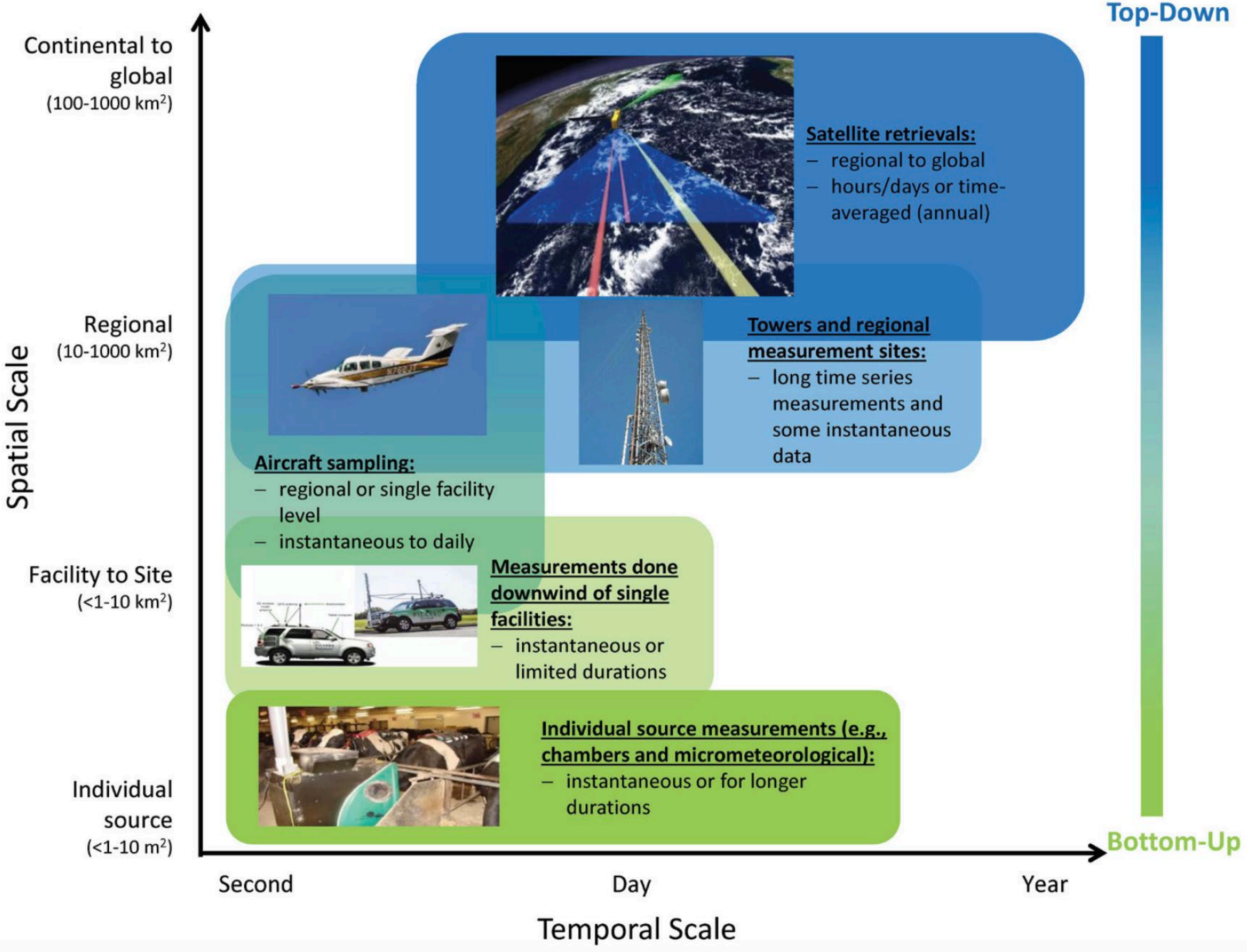
UN launching satellite-based system to detect methane

World leaders are finding new ways to implement science to shape policy and industry changes that will lead to increased mitigation of...

Nov 10, 2022

Emission Measurement Challenges

- So many landfill methane emissions number are being generated every day….
- But we still do not know the **TRUE EMISSIONS**
- Many companies are using ground, drone, aircraft, and satellite Based techniques to estimate emissions:
- Non of them are DIRECT EMISSIONS MEASURMENTS



National Academies of Sciences, Engineering, and Medicine 2018

PPM → Flux: Mass/Time

- Measuring PPM:
  - On surface of landfills
  - Above the surface
  - Fence Line
  - Downwind
  - Aerial surveys
  - Satellites

Standoff Distance of Methane Detectors

- Estimating Flux: (mass/time), (mass/time/area)
  - HIGHER measured PPM, means HIGHER FLUX (most of the time)
  - Closer PPM measurement to source, LESS cost to measure PPM
  - The closer the PPM measurement to the source, the more accurate the localization of emissions source
  - The closer the PPM measurement to the source, the less important the atmospheric conditions for flux estimation (stronger signal, less dilution, etc.)
  - Most fugitive emissions occur from cracks, cover defects, penetrations, etc. (emission sources)

PPM → **Flux: Mass/Time**

- Off-site techniques :
  - No need to have site access
  - Focus on total emissions
  - GHG Reporting applications?
  - Focus on reducing error in estimates
    - All methods rely on either wind/atmospheric modeling
  - Identification of major sources versus all sources
  - Relaying information to site operators?

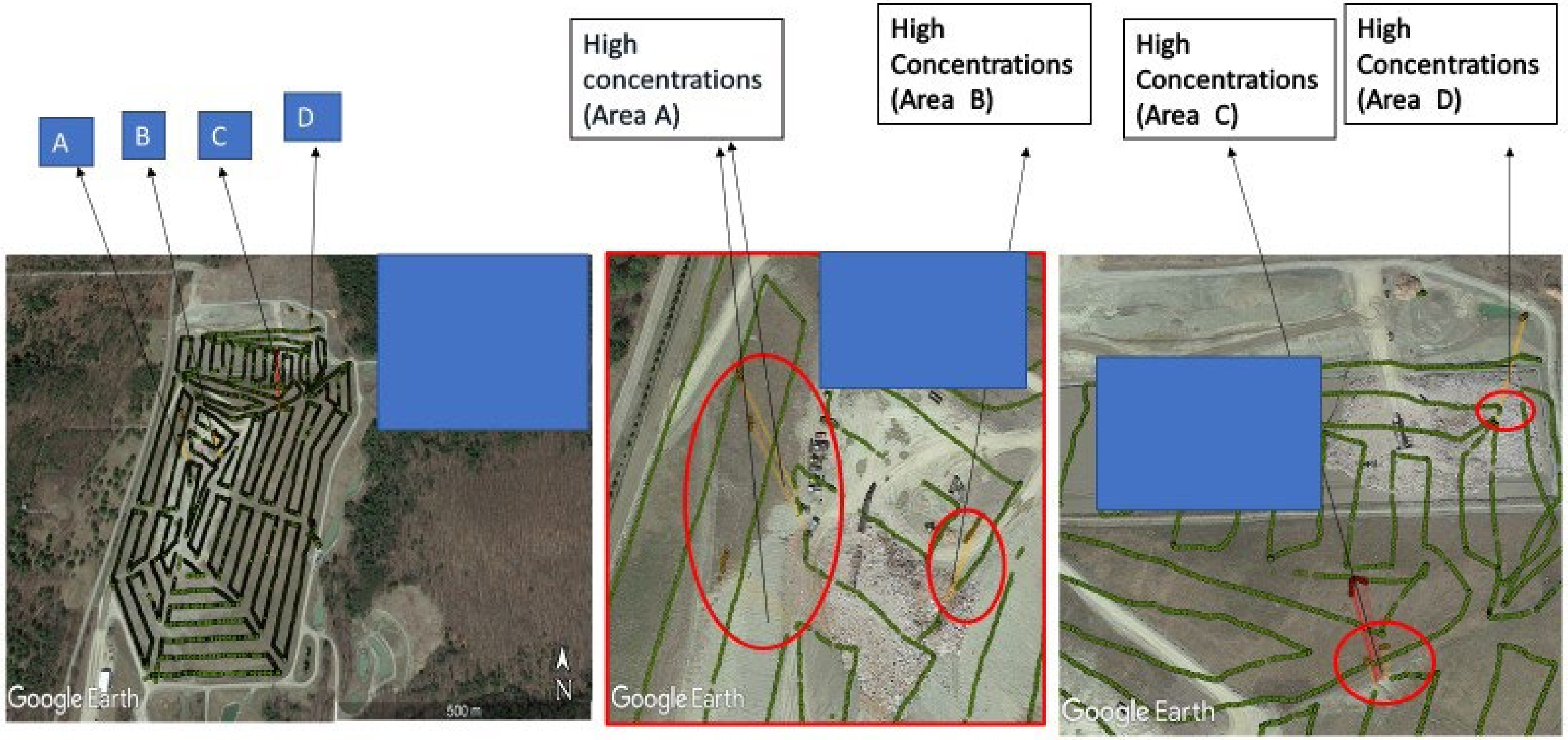
- On-site techniques:
  - Need for site access
  - Can be incorporated into site operation
  - Focus on locating sources of emissions
  - Focus on reducing number of sources contributing to total emissions instead of reducing error on total emissions estimate
  - Existence of surface monitoring protocols that can be extended/improved/modified
    - More extensive path (possible with drones and robots, etc.)
    - Combination of periodic and continuous monitoring in key emissions areas

Example SEM Path

Motivations

- Ambient air CH_4 concentration measurements are already frequently obtained and monitored in many municipal solid waste landfills.
    - Regulatory Purposes
    - Gas Collection Optimization Purposes

Example Data: SEMs and Possible Hotspots



Surface Methane Emission (SEM) monitoring is already used as part of New Source Performance Standards (NSPS), Title 40 Code of Federal Regulations Section 60.755(c) and (d). **Four (4) times per year**

Methodology – Ground SEM Data Collection

- Concentration measurements on foot using flame ionization detector
- Measurements made 4 inches above surface and every 30 meters or less from the previous point
- Movement in a serpentine fashion path
- Deviations from protocol prompted by dangerous conditions at the landfill

Methodology – Drone SEM Data Collection

SnifferDRONE™ drone used for measurement

→

Programmed to follow same measurement protocol

↓

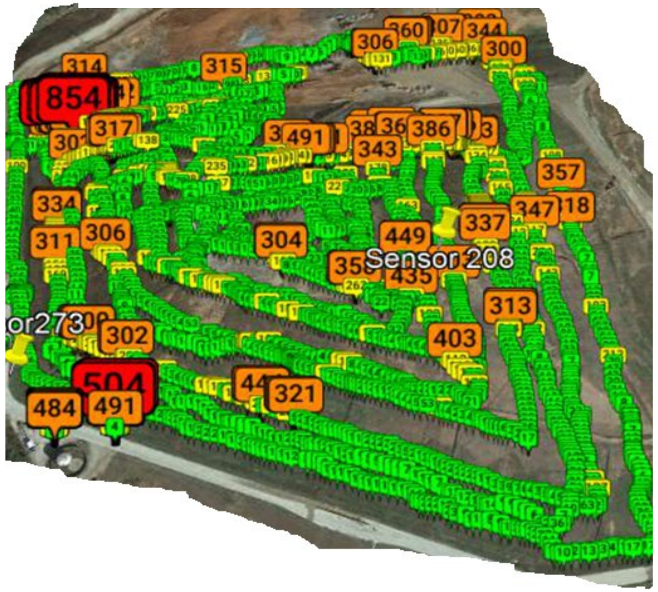
More points measured over larger area and shorter time

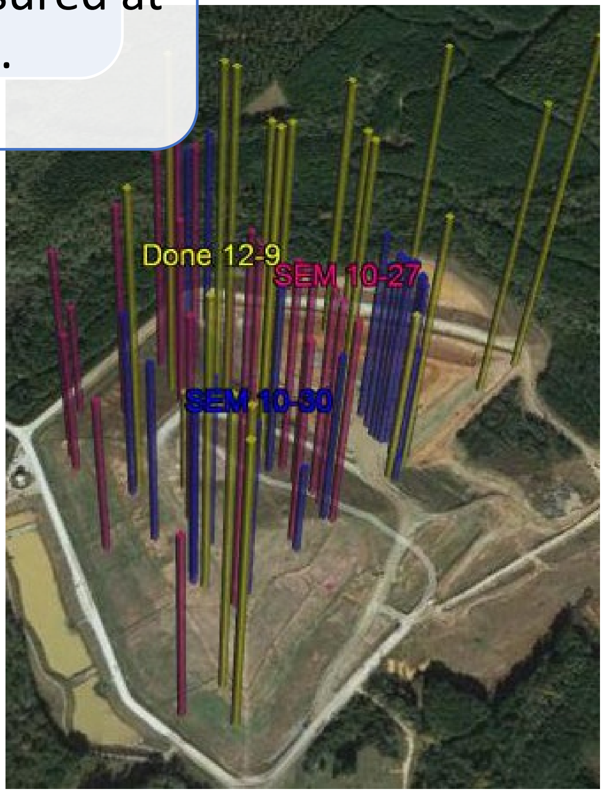
(Nageler-Petritz 2023)

SEM2Flux Tool

Assume measurement locations as ***receptors***, affected by emissions from adjacent area on the landfill: ***sources*** of emissions.

These ***sources*** are considered point sources and are responsible for the concentrations measured at the ***receptors***.





SEM2Flux Tool… For very Reading (methane concentration)… There are sources upwind causing the measured concentration

Gaussian Dispersion Equation

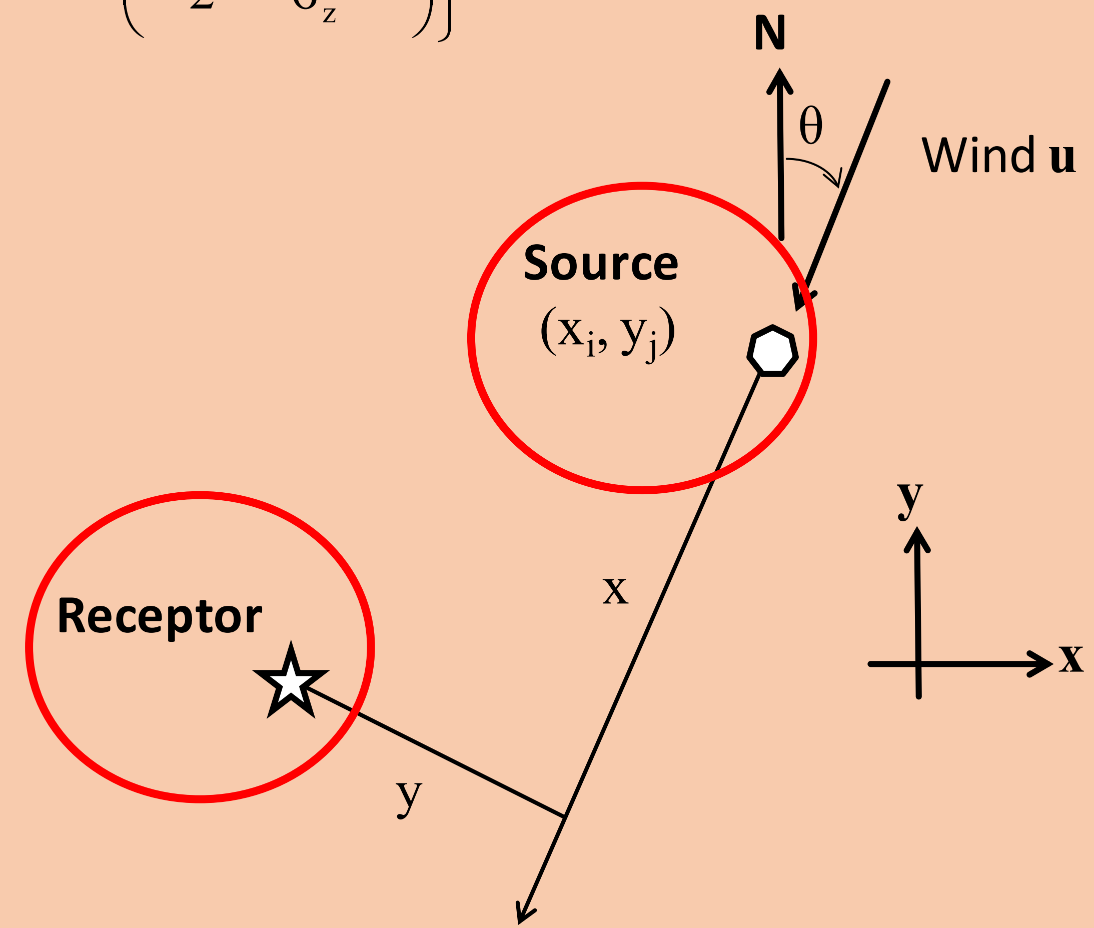
$$C(x,y,z,H)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right)+\exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right\}$$

For ground-level sources and receptors
(*z* = *0* and *H* = *0*)

Source

$$C=\frac{Q}{\pi\mu\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right]$$

Receptor



SEM2Flux Tool

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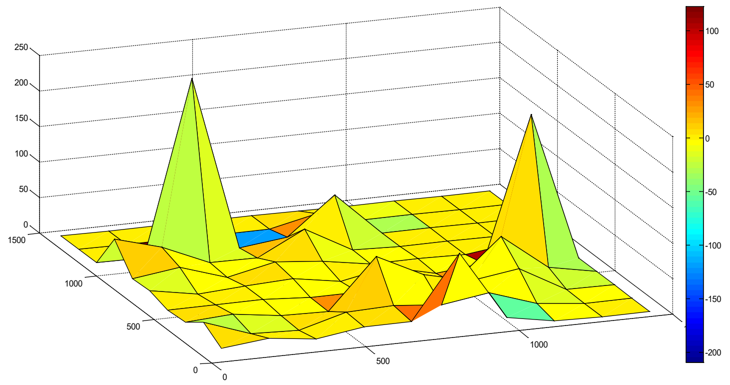
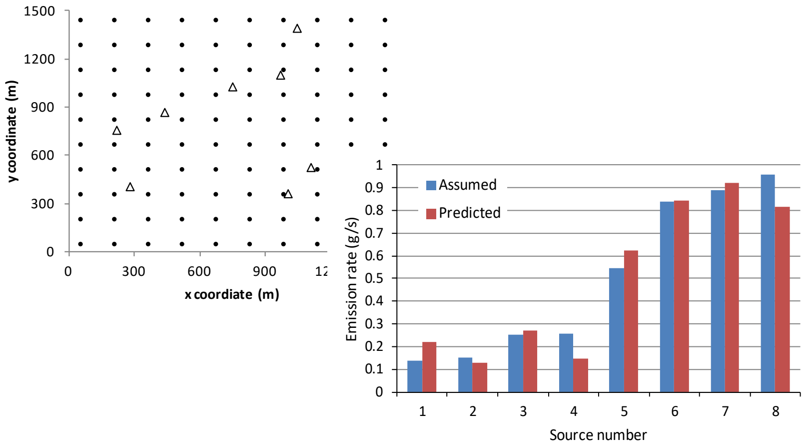
These ***sources*** are considered point sources and are responsible for the concentrations measured at the ***receptors***.



Receptor positions
Methane concentrations
Meteorological conditions

IDENTIFICATION



Source positions and emission rates

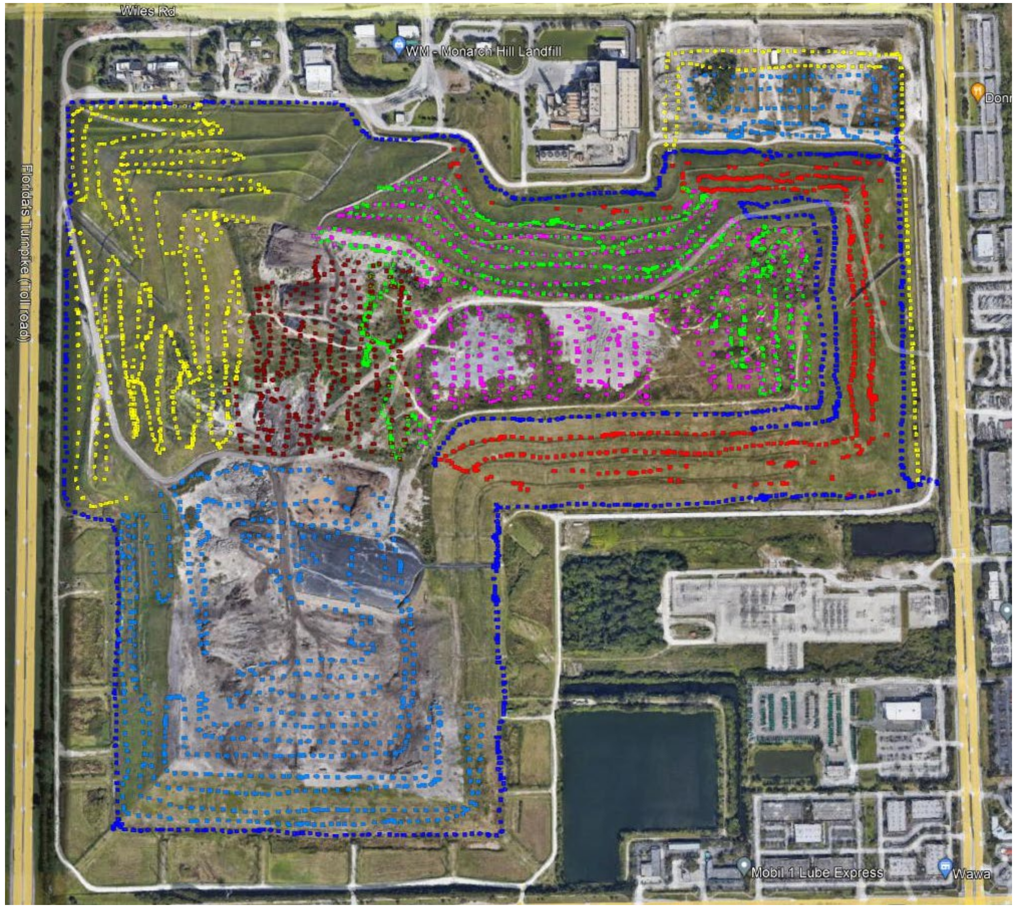
SEM2Flux Tool

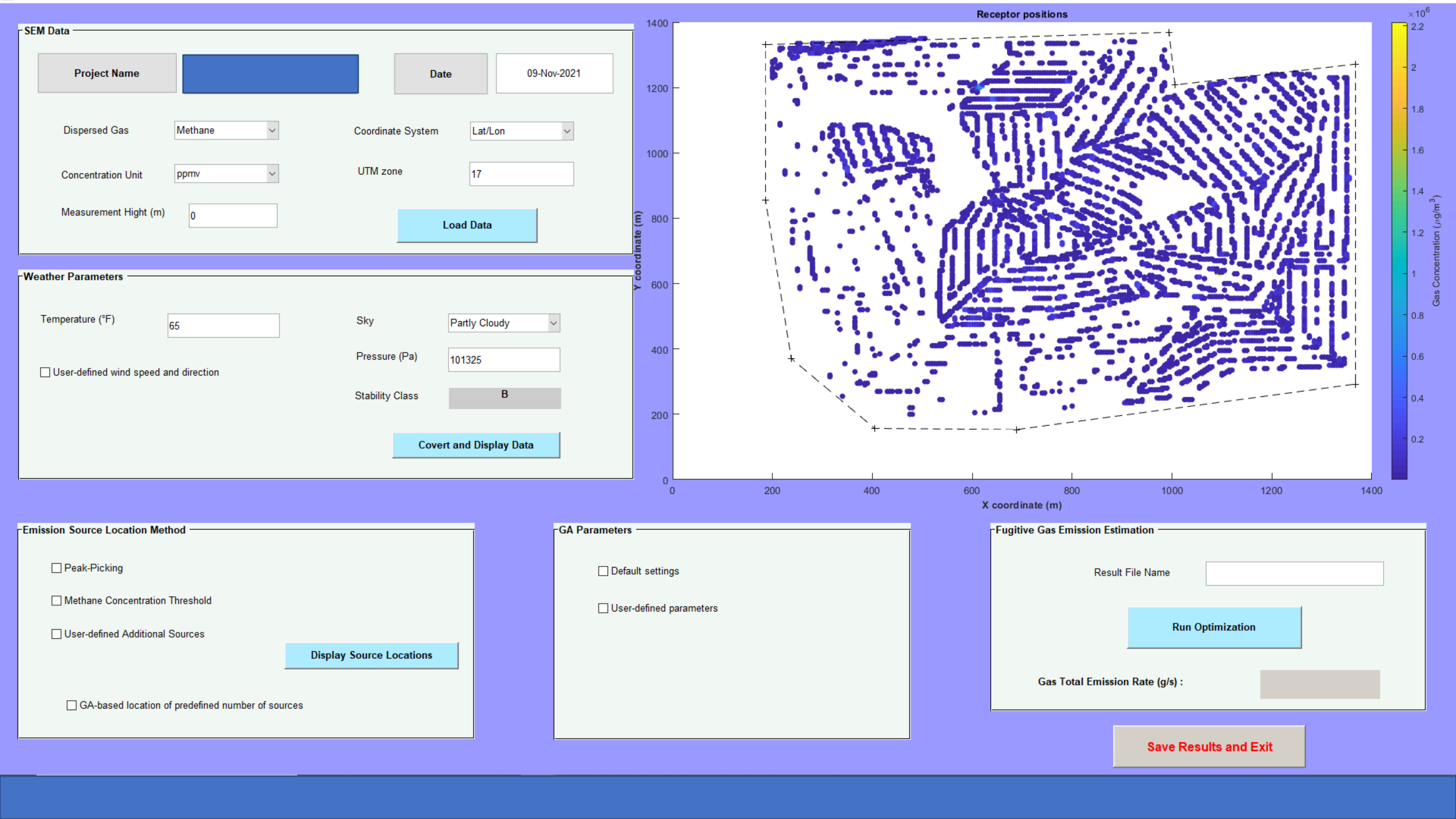
The predicted methane concentration in a receptor point i ($C_{i, predicted}$) is calculated through summing up all contributions (C_{ij}) of assumed source points j ($j=1,..., n$).

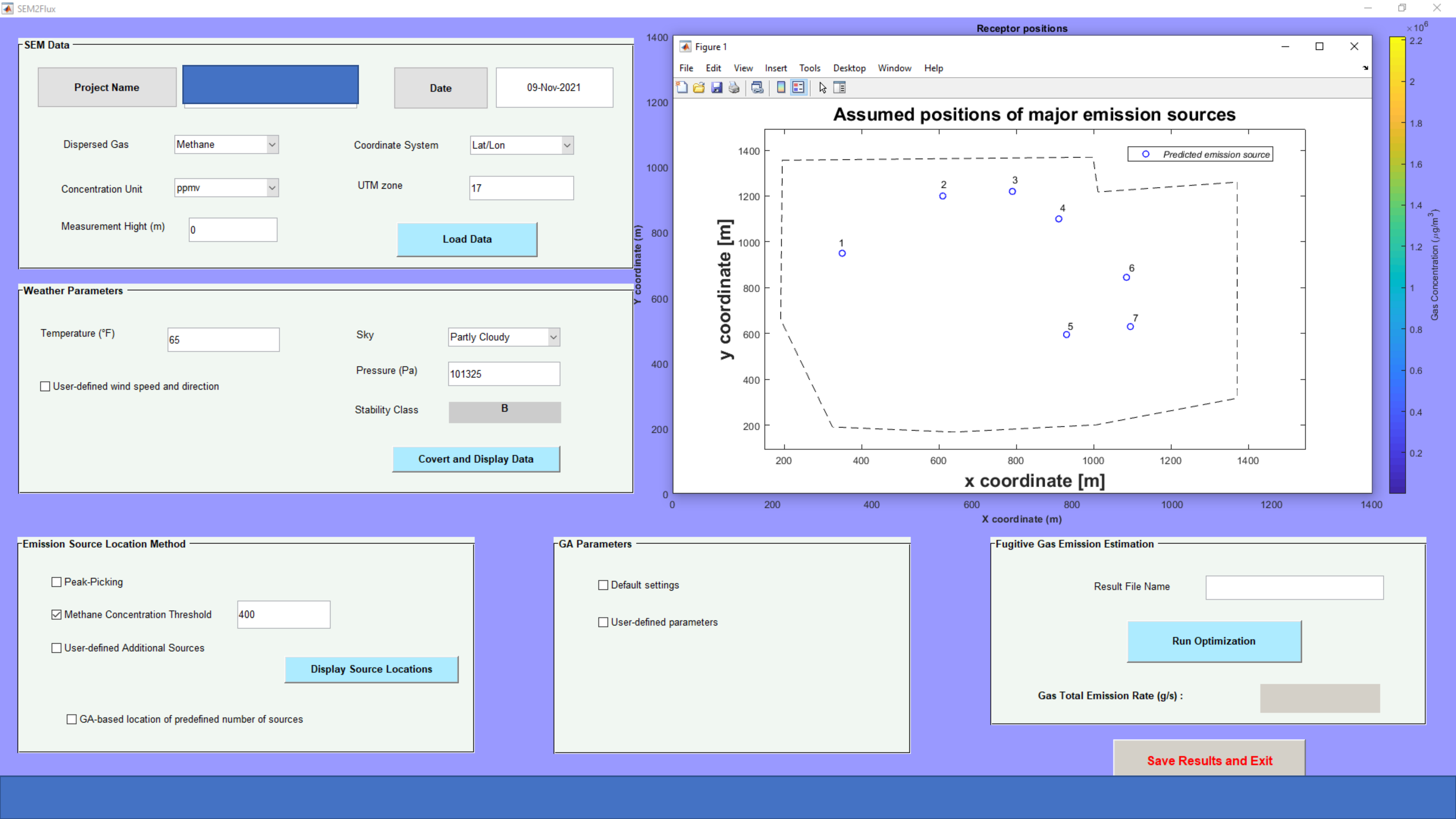
$$C_{i,\text{predicted}} = \sum_{j=1}^{n} C_{i,j}$$

Calculating predicted concentration for all receptor points ($i=1, .., m$) results in a vector of predicted concentration ($C_{predicted}$).

Search for the ***best-fit source configuration*** is formulated as an optimization problem that consists of residual minimization under bound constraints.




SEM Data
Project Name
Date
09-Nov-2021
Dispersed Gas
Methane
Coordinate System
Lat/Lon
Concentration Unit
ppmv
UTM zone
17
Measurement Hight (m)
0
Load Data
Weather Parameters
Temperature (°F)
65
Sky
Partly Cloudy
Pressure (Pa)
101325
User-defined wind speed and direction
Stability Class
B
Covert and Display Data
Receptor positions
Y coordinate (m)
X coordinate (m)
Gas Concentration (μg/m3)
x10^6
Emission Source Location Method
Peak-Picking
Methane Concentration Threshold
User-defined Additional Sources
Display Source Locations
GA-based location of predefined number of sources
GA Parameters
Default settings
User-defined parameters
Fugitive Gas Emission Estimation
Result File Name
Run Optimization
Gas Total Emission Rate (g/s) :
Save Results and Exit


SEM2Flux
SEM Data
Project Name
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Dispersed Gas
Methane
Coordinate System
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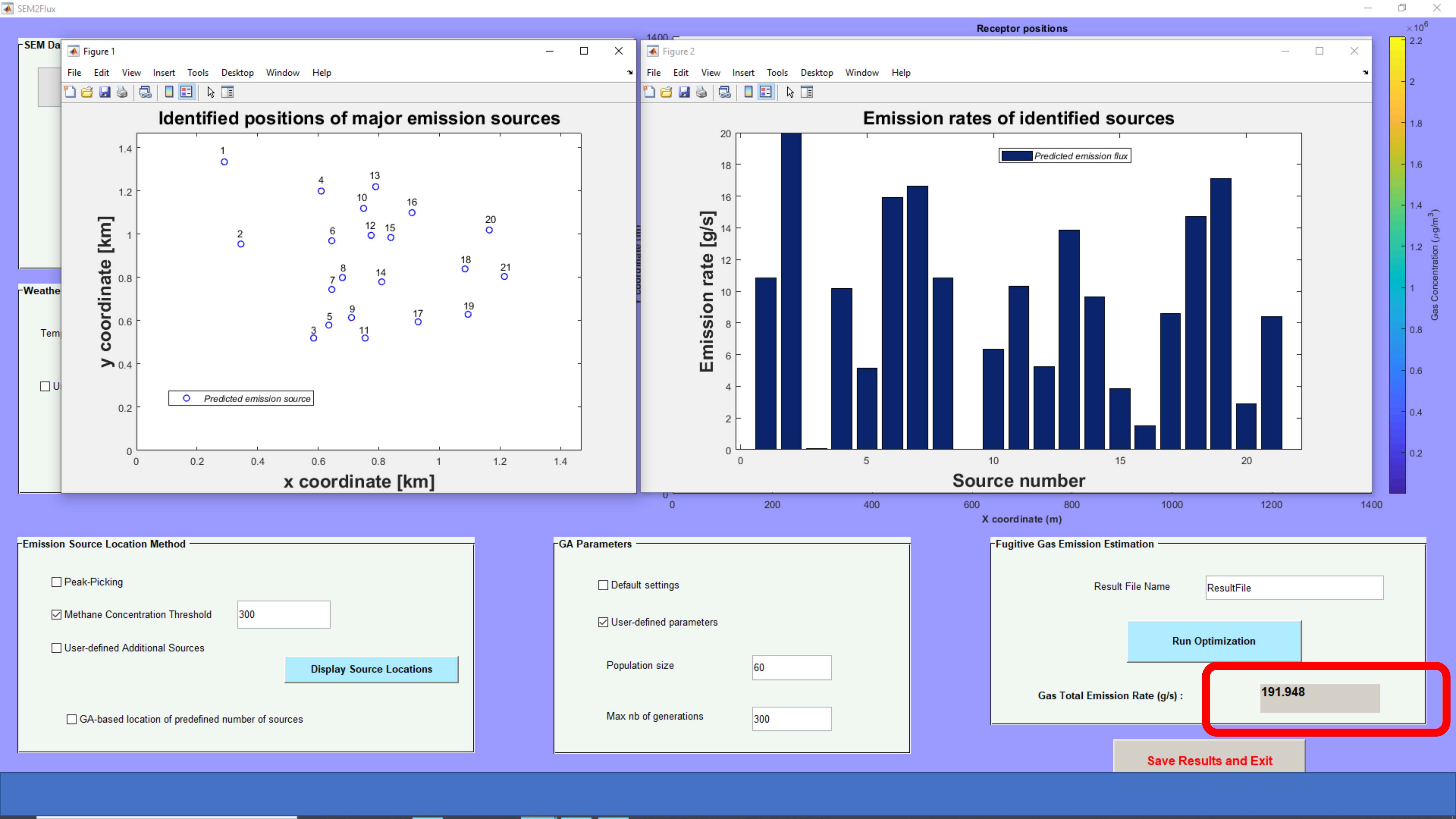
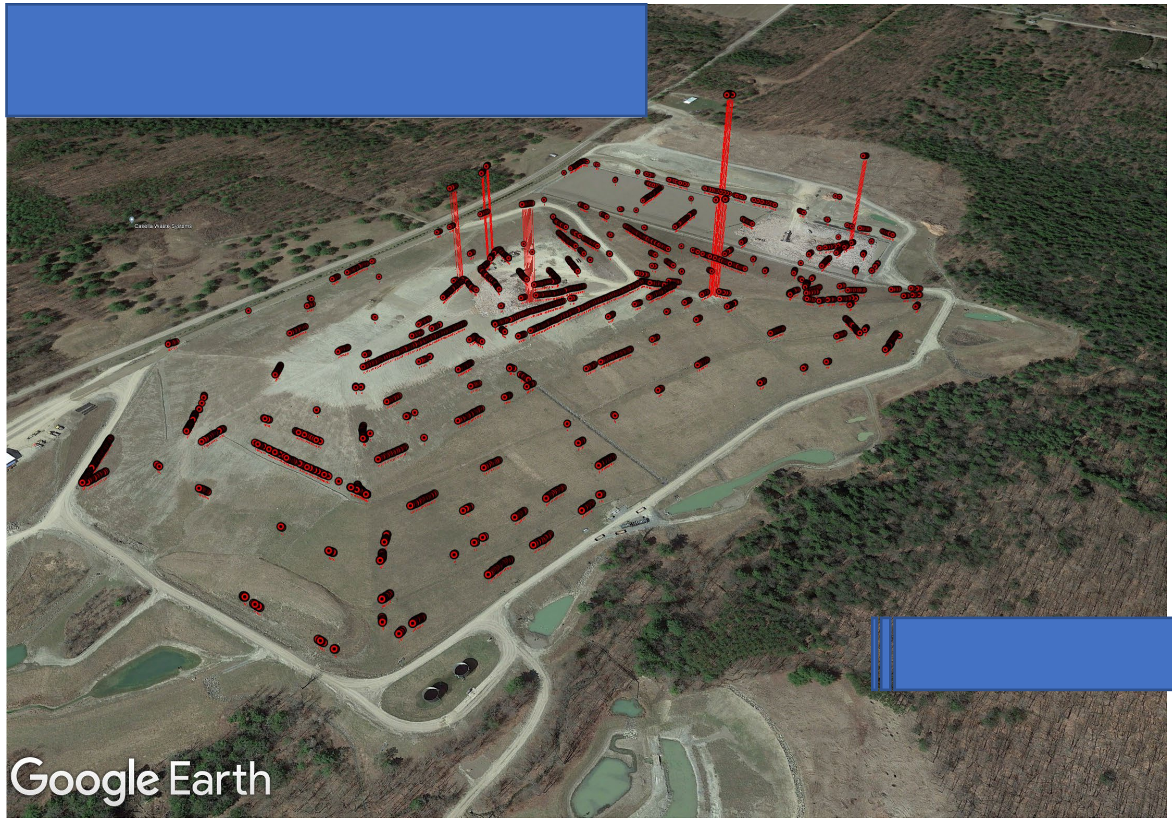
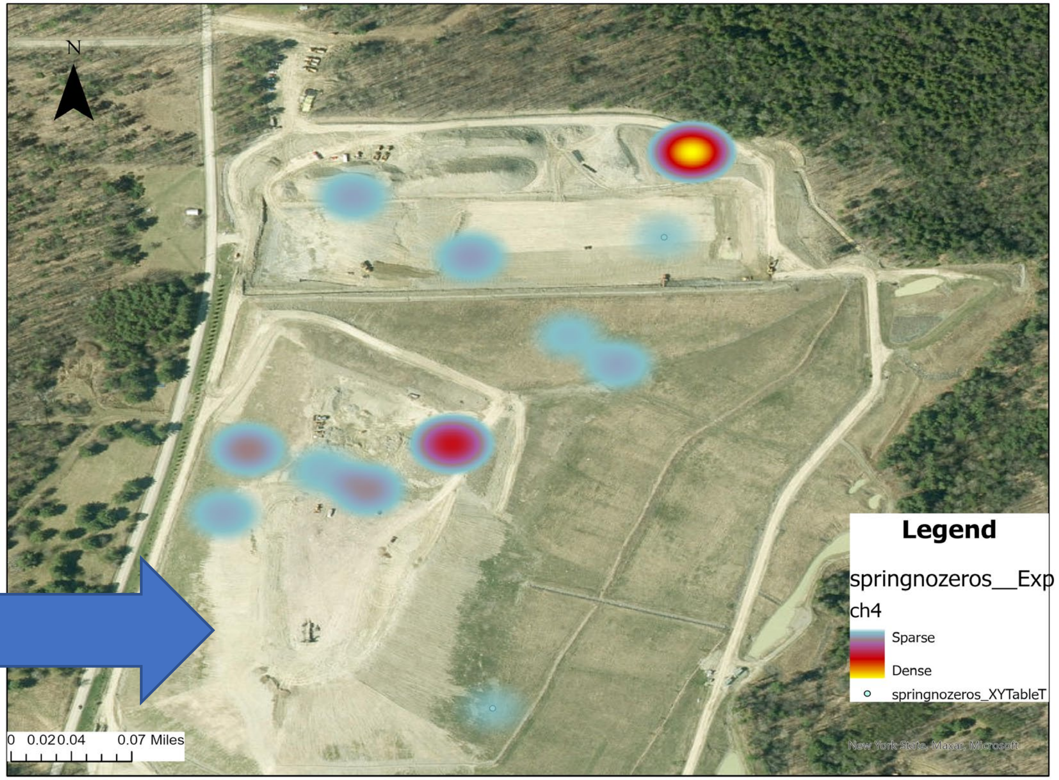
Pressure (Pa)
101325
User-defined wind speed and direction
Stability Class
B
Covert and Display Data
Receptor positions
Figure 1
File Edit View Insert Tools Desktop Window Help
Assumed positions of major emission sources
Predicted emission source
y coordinate [m]
x coordinate [m]
Y coordinate (m)
X coordinate (m)
Gas Concentration (µg/m³)
Emission Source Location Method
Peak-Picking
Methane Concentration Threshold
400
User-defined Additional Sources
Display Source Locations
GA-based location of predefined number of sources
GA Parameters
Default settings
User-defined parameters
Fugitive Gas Emission Estimation
Result File Name
Run Optimization
Gas Total Emission Rate (g/s) :
Save Results and Exit


SEM2Flux
Receptor positions
Figure 1
File Edit View Insert Tools Desktop Window Help
Identified positions of major emission sources
y coordinate [km]
x coordinate [km]
Predicted emission source
Figure 2
Emission rates of identified sources
Emission rate [g/s]
Source number
Predicted emission flux
X coordinate (m)
Gas Concentration (μg/m³)
SEM Da
Weathe
Tem
Emission Source Location Method
Peak-Picking
Methane Concentration Threshold
300
User-defined Additional Sources
Display Source Locations
GA-based location of predefined number of sources
GA Parameters
Default settings
User-defined parameters
Population size
60
Max nb of generations
300
Fugitive Gas Emission Estimation
Result File Name
ResultFile
Run Optimization
Gas Total Emission Rate (g/s) :
191.948
Save Results and Exit

Ground SEM PPM....to..............Flux: Mass/Time

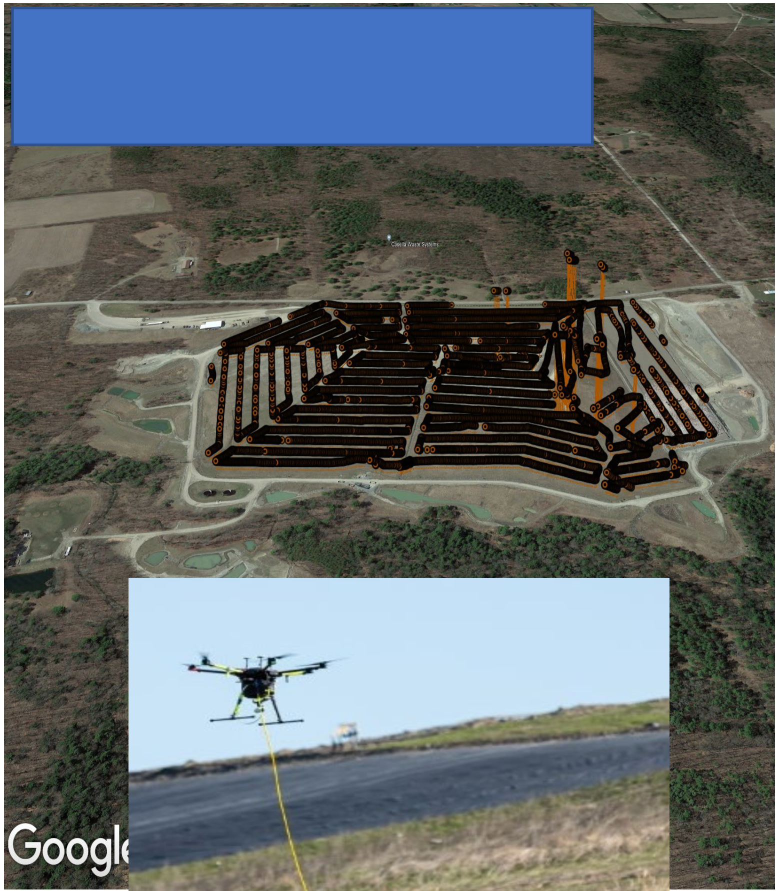


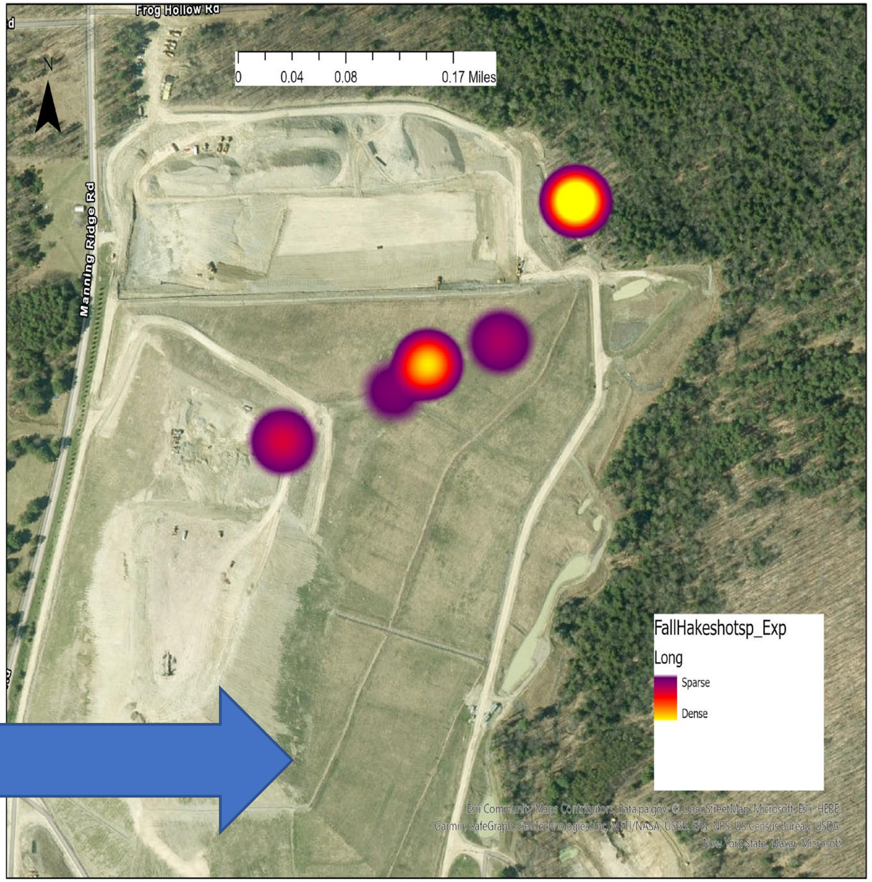
SEM2Flux Run for Spring Run 2



Flux(Kg/hr)	Error(Kg/hr)
147	11

Drone SEM PPM….to……. …….Flux: Mass/Time

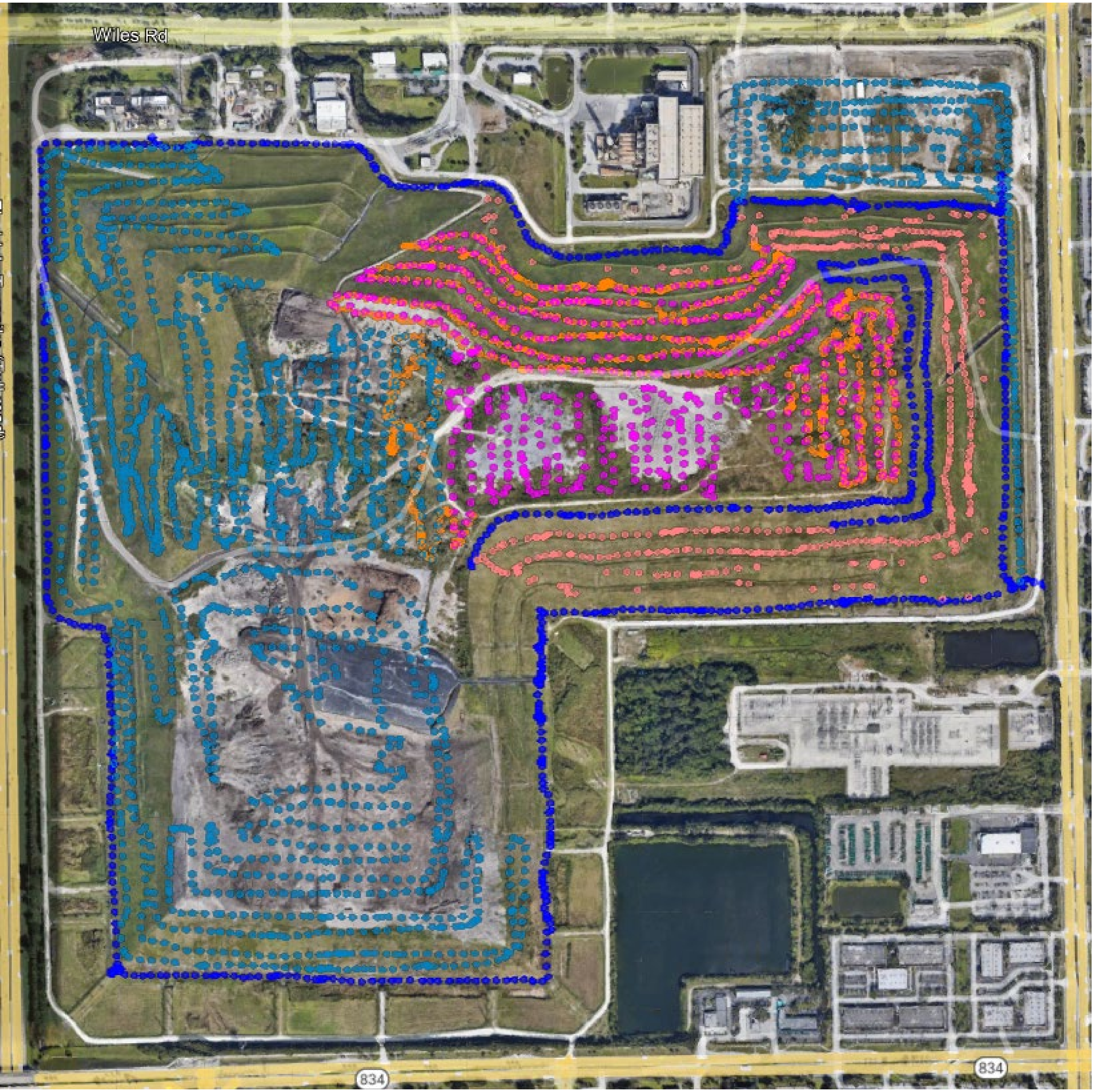




Flux (Kg/hr)	Error (Kg/hr)
23	5

A look at the data
Florida Landfill 1
April-2022
CM Flight SEM and TCM
Case Study 1

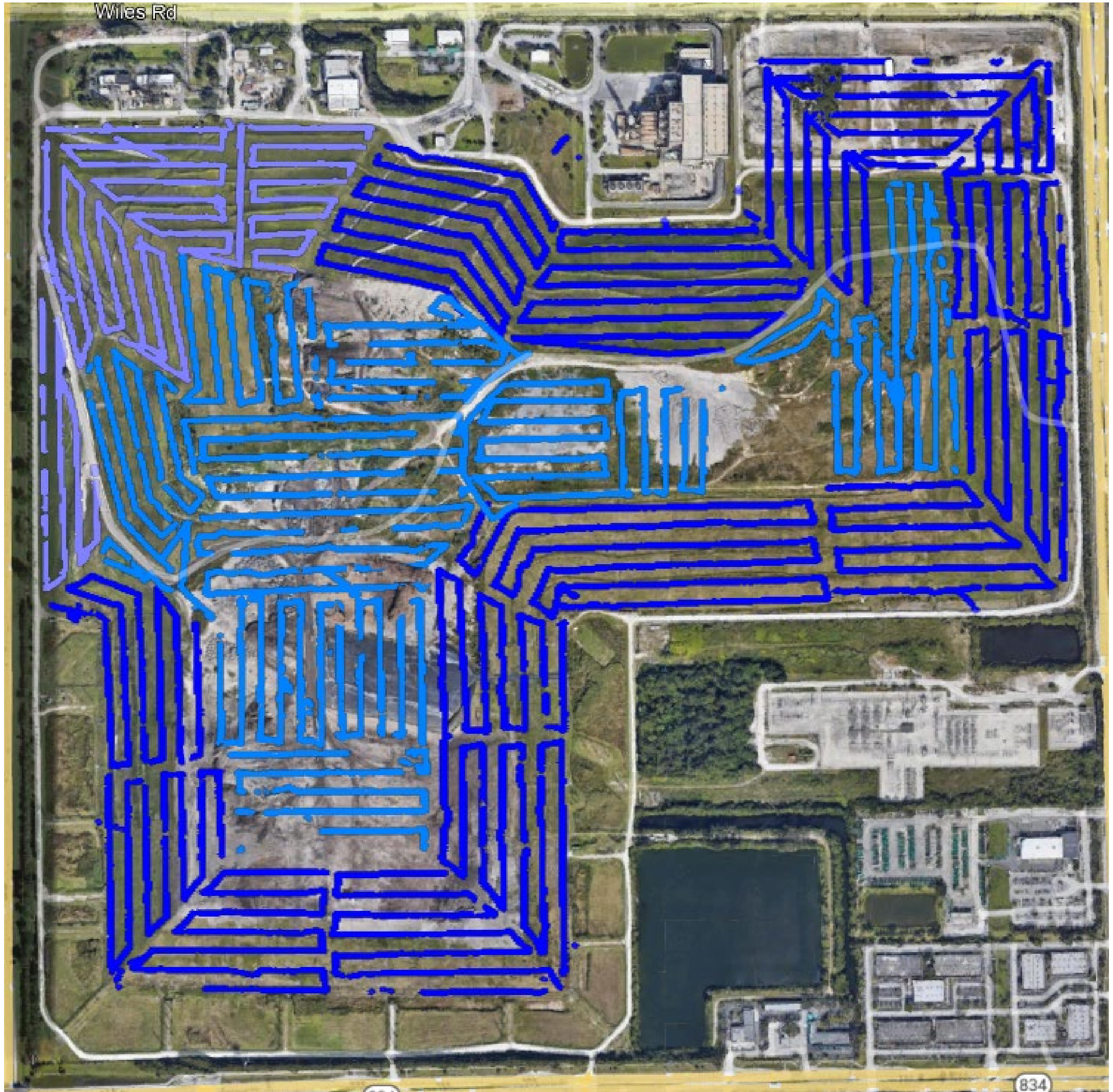
Case Study 1: Ground-SEM Florida Landfill 1



During the SEM campaign, methane concentrations were collected in **4894** points. This is equivalent to a measurement density of **27 readings per hectare**. Measured concentrations showed **21 readings exceeding 500ppm**.

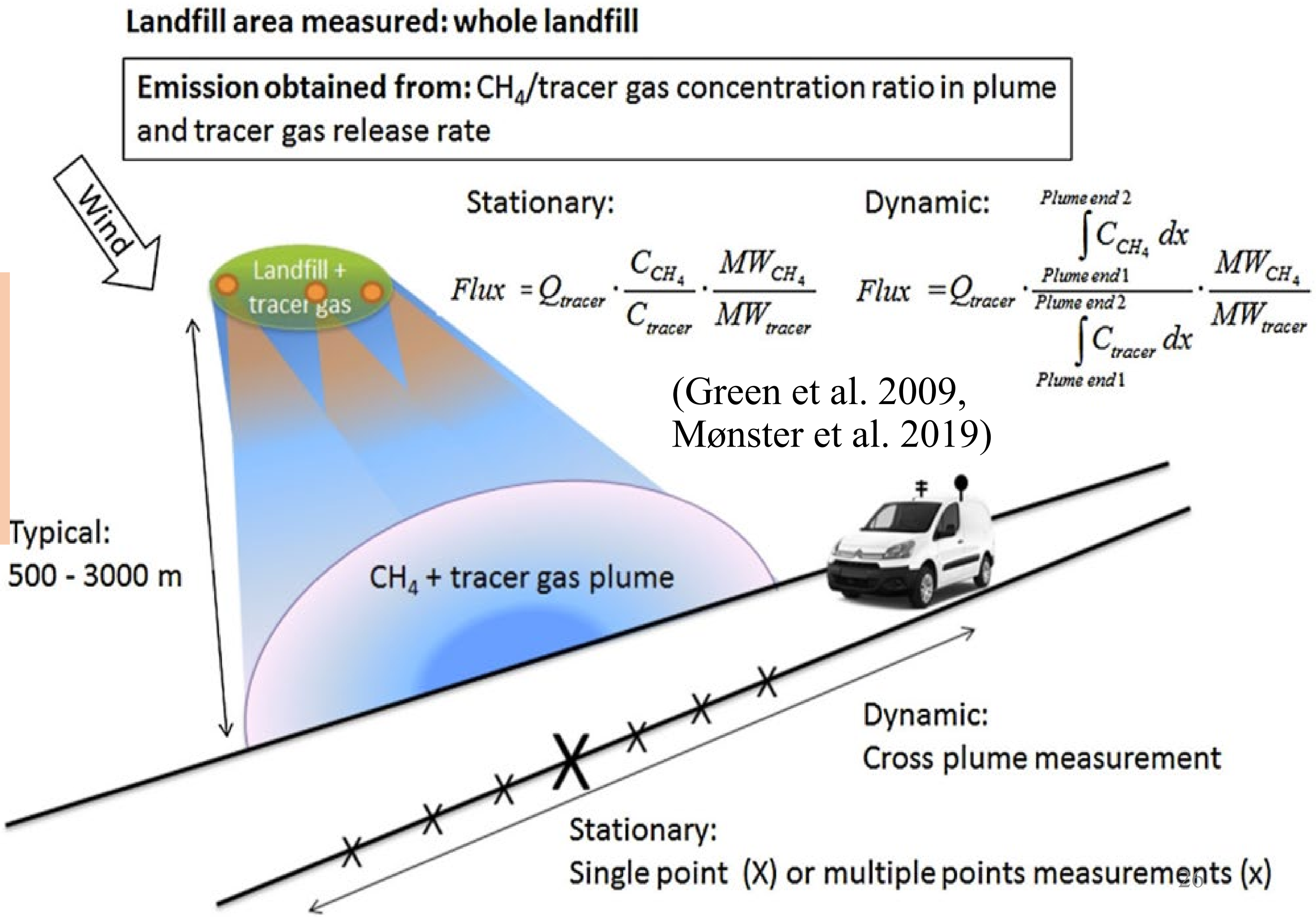
D-SEM Landfill 1

The drone-based survey allowed for a more comprehensive coverage of the landfill area with **51867** measurement points. The measurement density is nearly **285 readings per hectare** which is approximately ten times higher than the reading density of the G-SEM



Ground Truthing: Performed mobile Tracer Correlation Method (TCM) tests to obtain "most likely estimate" of true total emissions from the landfill during SEM, and DEM. FSU have this capability (Unique in the USA and Canada)

Performed TCM Method testing at few landfills that participated in the study

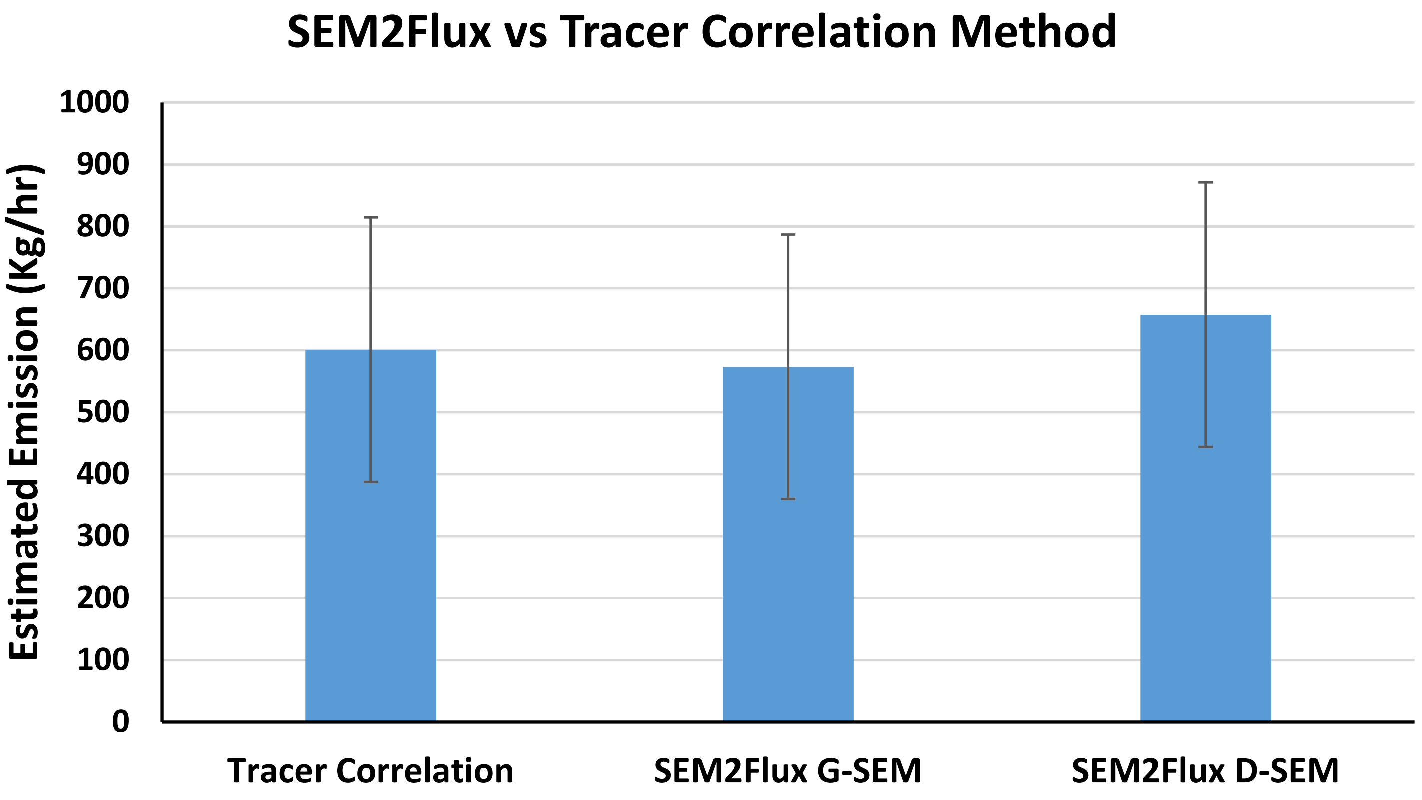


(Green et al. 2009, Mønster et al. 2019)

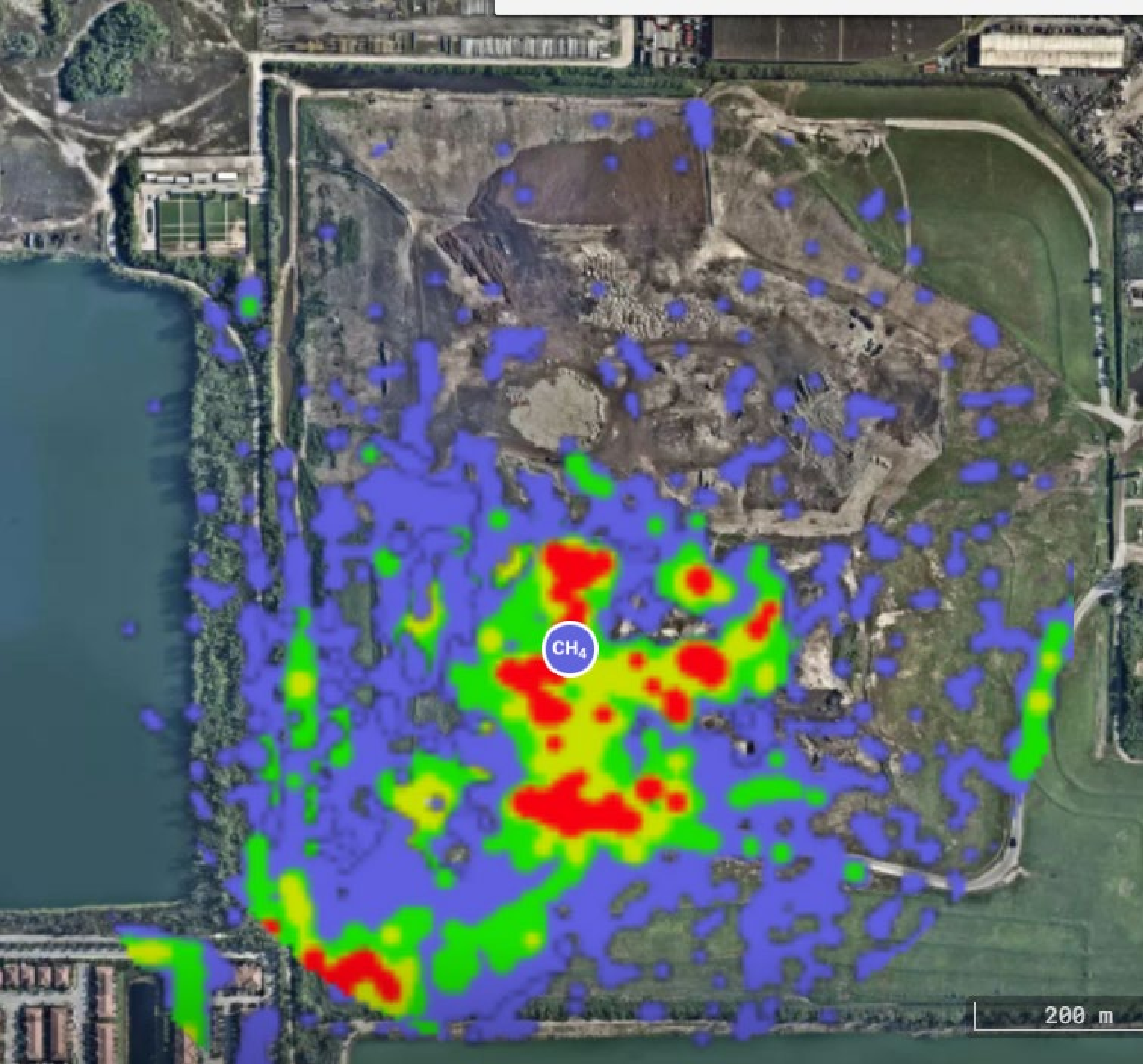
D-SEM Landfill 1:

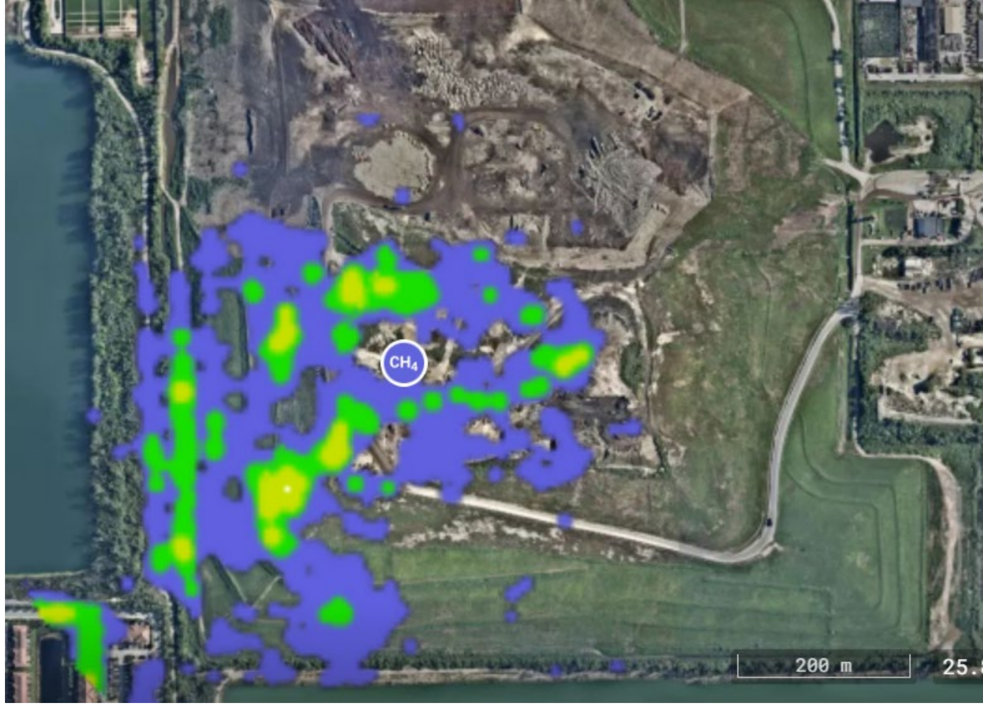
Major Source Locations Emissions Estimates

Note: Carbon Mapper Reported *No Flux* from this Landfill flown during the same week



A look at the data
Florida Landfill 2
April-2022
CM Flight SEM and TCM
Case Study 2


CH4
200 m

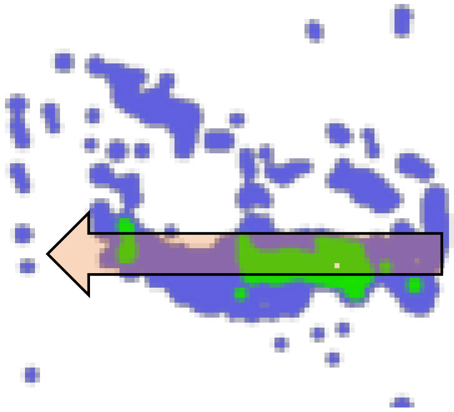

CH4
200 m


CH4

Plume Based Flux Estimation: Carbon Mapper Plumes April 2022

April 13, 2022
13:52 UTC = 9:52 Local Time

CM Emissions = 1664 ± 430 kg/hr



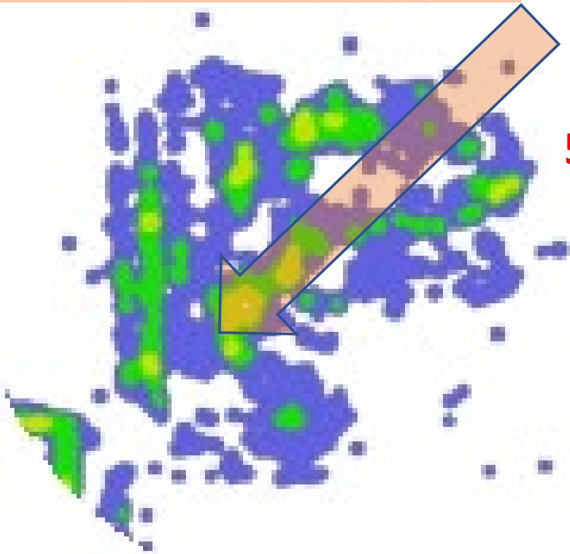
Onsite Wind Station @ 2 m	
MPH	Degree
Avg. WS	Avg. WD
17.2	91.3

	Weather Station	MPH	
		Speed	Gust
8:53 AM	ESE	14 mph	23 mph
9:53 AM	E	18 mph	0 mph
10:53 AM	ESE	16 mph	0 mph

April 10, 2022

15:38 UTC = 11:38 Local time

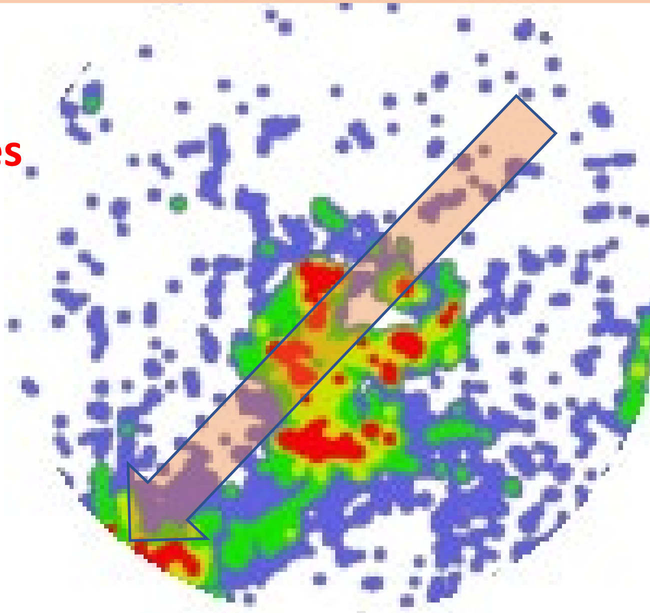
CM Emissions = 2000 ± 807 kg/hr



5 Minutes

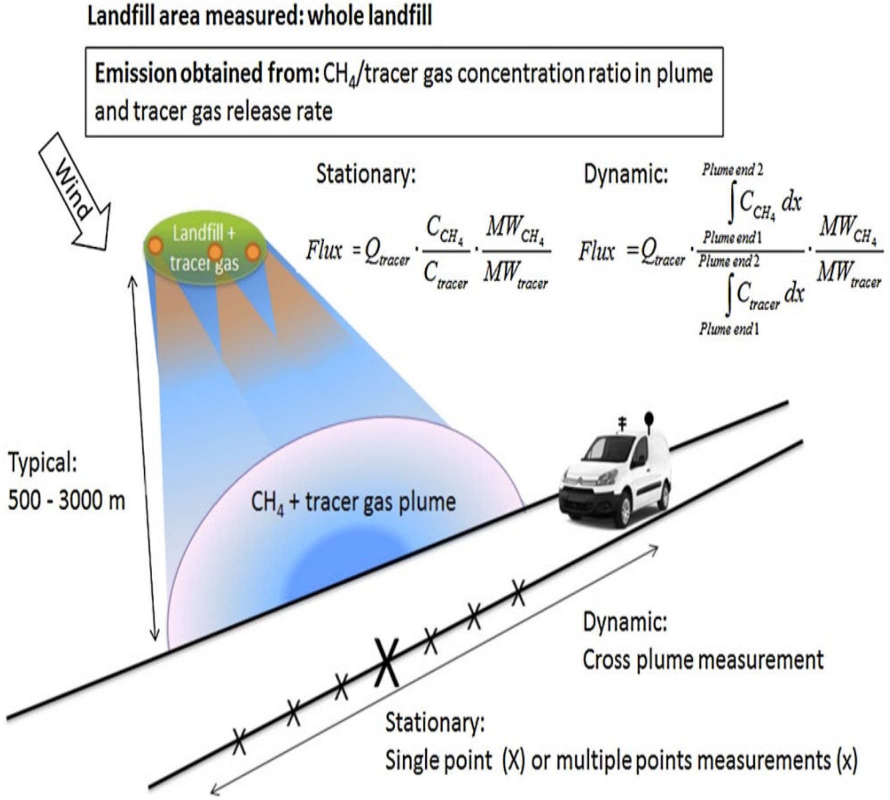
15:33 UTC = 11:33 Local Time

CM Emissions = 3352 ± 1010 kg/hr



	Weather Station	MPH	
		Speed	Gust
10:53 AM	N	9 mph	0 mph
11:53 AM	NE	9 mph	18 mph

Tracer Correlation Method (TCM) performed for 3 days

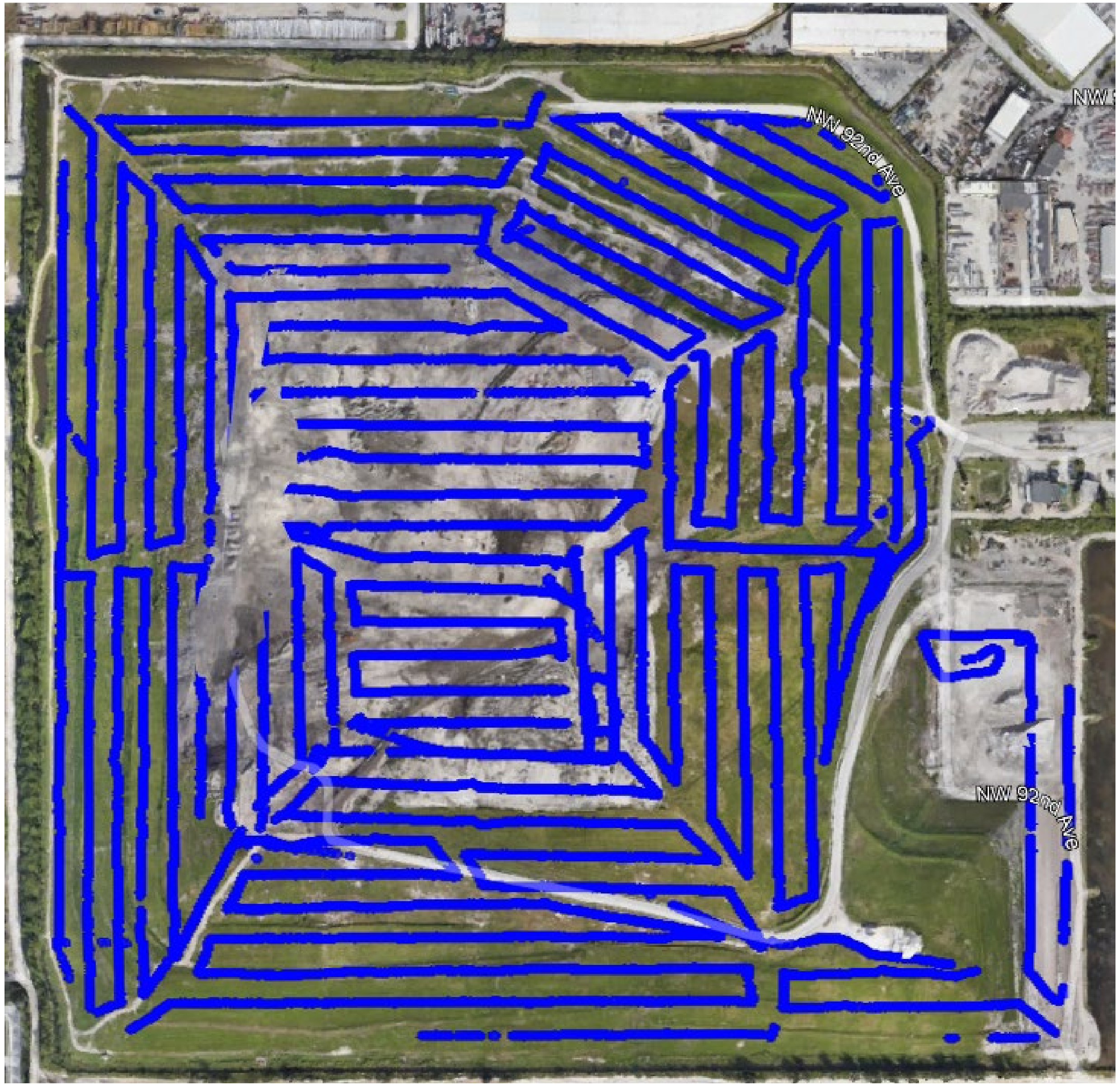


	Mean (>.80, <.20)	STDEV	Mean (>.75, <.30)	STDEV
CM Emissions = 2000 ± 807 kg/hr		5 Minutes	CM Emissions = 3352 ± 1010 kg/hr	
4/11/2022	1239	339	1239	339
4/12/2022	1205	323	1153	284
4/13/2022	1091	150	960	242
CM Emissions = 1664 ± 430 kg/hr				

Drone SEM April 13 2022, FL Landfill 2

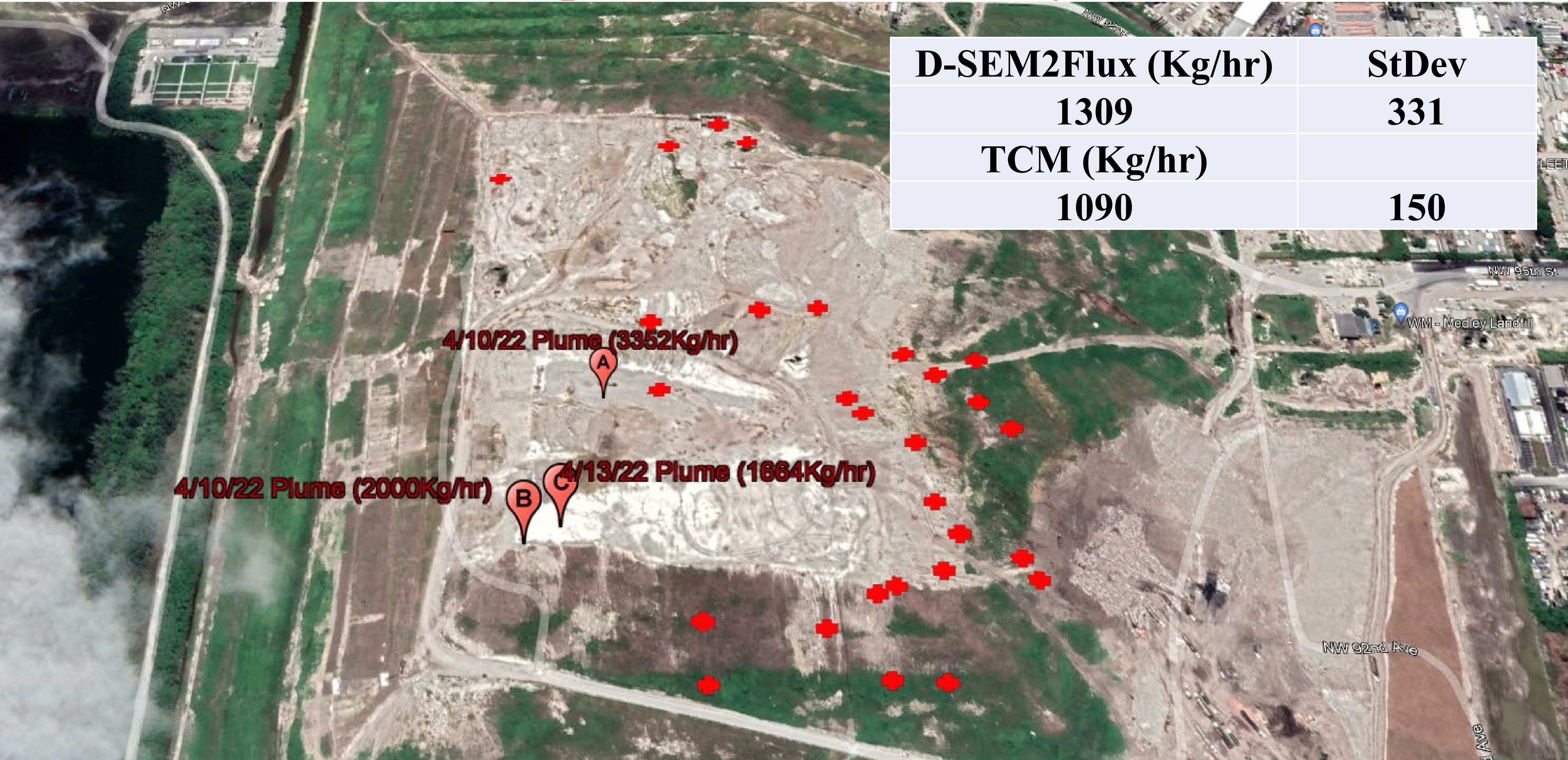
Number of data points : 23398
Data points with ppm>1000 : 15
Data points with 500<ppm<999 : 83
Data points with 200<ppm<499 : 1359
Data points with 100<ppm<199 : 2438
Data points with 1<ppm<99 : 11169
Data points with zero ppm : 8146

#Exceedances (>500 ppm) = 98
Area Covered ~ 270,000 m^2
Measurement Density ~ 0.08666 per m^2
867 measurement per Hectare



Drone SEM2Flux Output
Leak Locations April 13, 2022 (same day as TCM, CM)

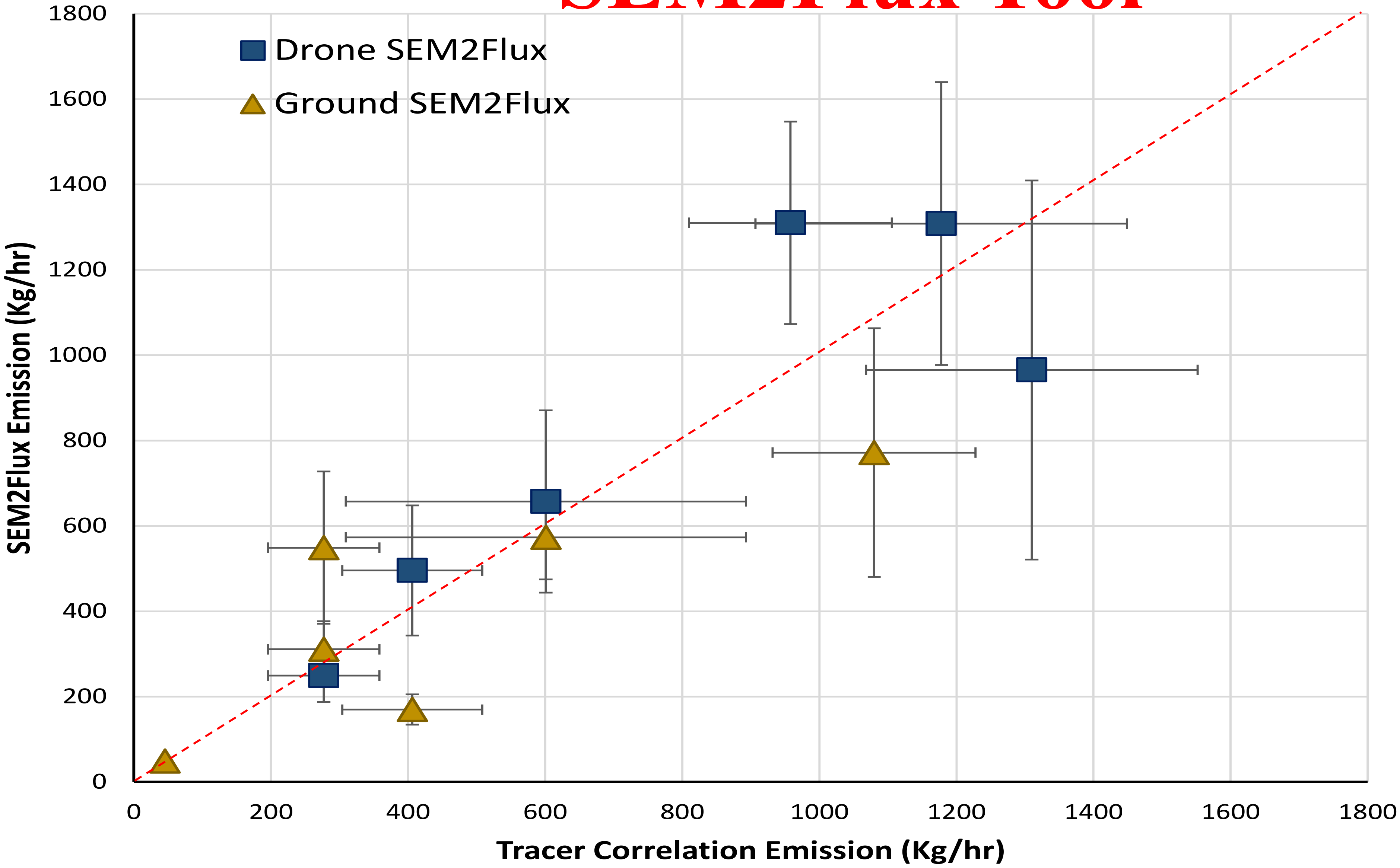
D-SEM2Flux (Kg/hr)	StDev
1309	331
TCM (Kg/hr)	
1090	150



Summary Fluxes April 2022 Landfill Florida 2

Total Emissions Mesuared by Different Technologies in Kg/Hr									
	TCM	StDev	CM	Error	D-SEM2Flux	StDev	Plume-Based	Reported Collection	Satellite
4/10/2022			2000	807			608	3535	
4/10/2022			3352	1010			758		
4/11/2022	1239	339							
4/12/2022	1205	323							
4/13/2022	1091	150	1664	430	1309	331	403		
5/1/2022									0

SEM2Flux Tool



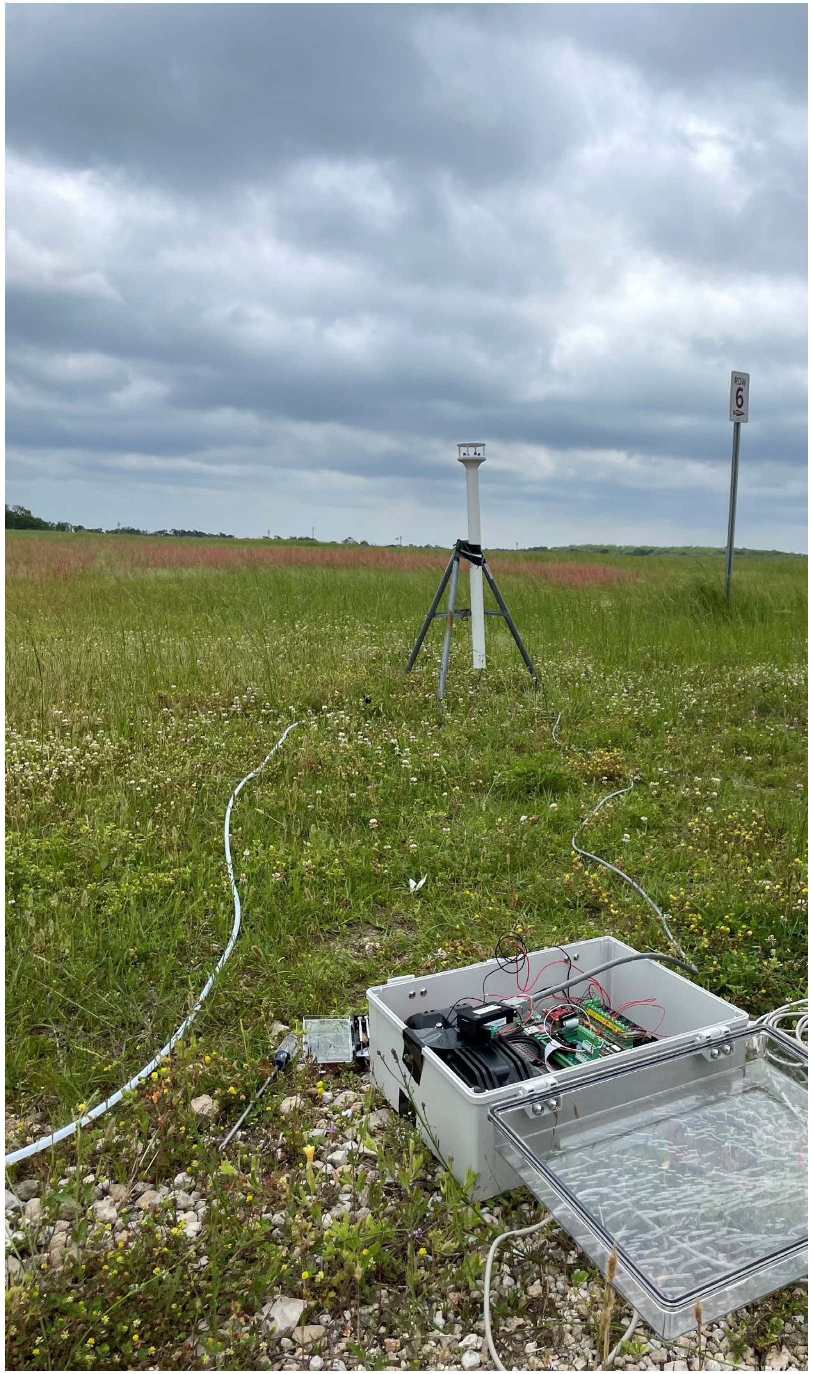
Comparison of Side-by-Side Emissions Estimated Using the Tracer Correlation Method versus SEM2Flux (Ground Based and Drone Based)

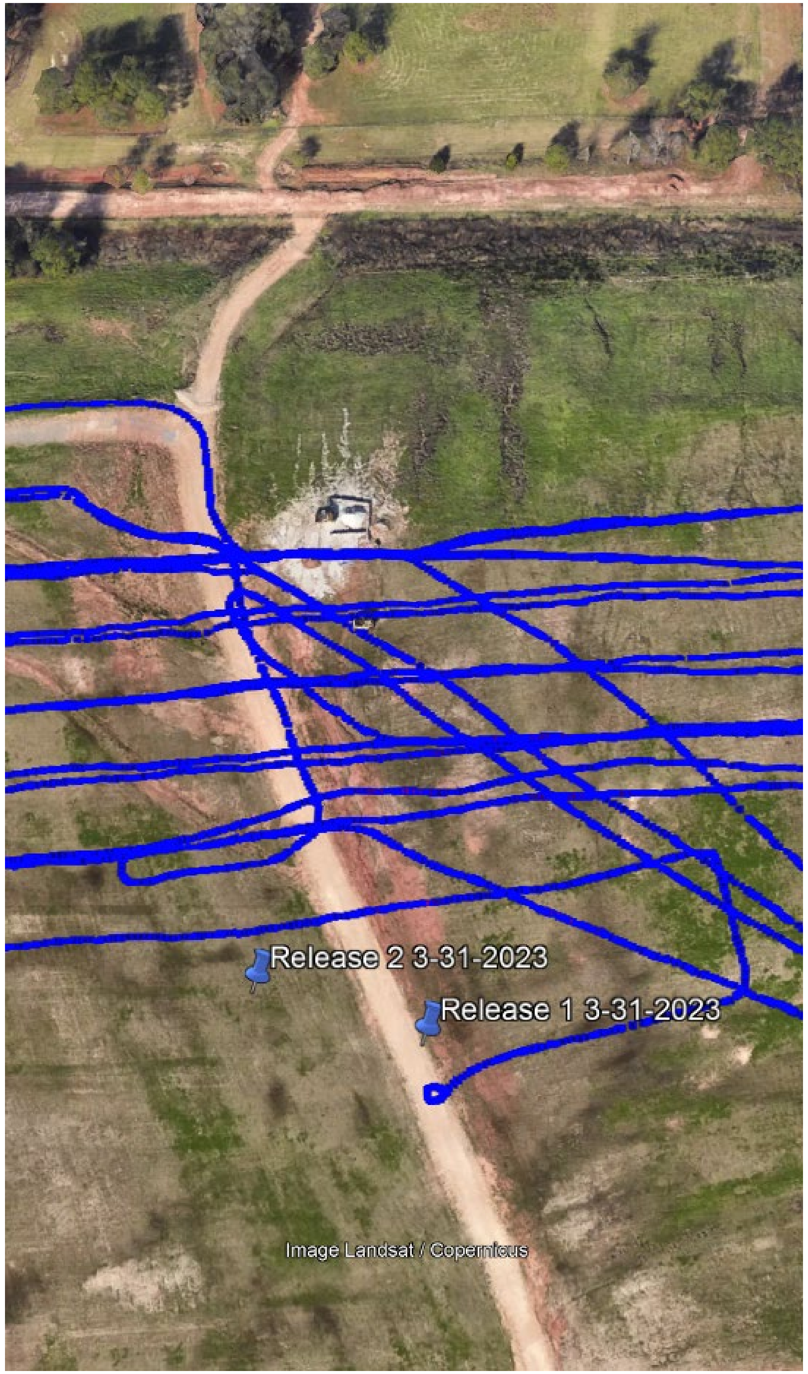
SEM2FLux Calibration Source Locating (Curent Work)

- **Task 1 :** Perform controlled acetylene release experiments and monitor acetylene and methane concentrations on the landfill surface to characterize plume dispersion at the micro-scale (under landfill conditions)
- **Task 2 :** Collect ambient air methane and acetylene concentrations measured via Surface emissions monitoring (**SEM**) campaigns, and (2) drone emissions monitoring (**DEM**) campaigns, if available


ROW
3
E-Z-GO
A Textron Company


ALICAT
ALICAT
FLOW


6


Release 2 3-31-2023
Release 1 3-31-2023
Image Landsat / Copernicus

Task 3: Use the collected data in Task 1 and 2 to calibrate the inverse plume modeling approach in identifying and locating hotspots approach and in estimating source strength in our methodology. **(Just Started Working on it)**

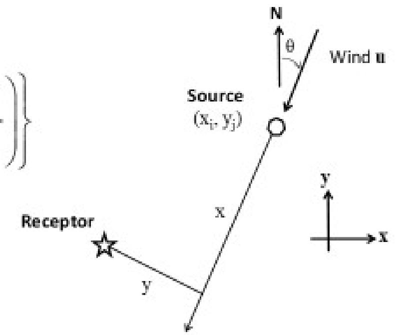
SEM2Flux Tool

Gaussian Dispersion Equation

$$C(x,y,z,H)=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right)+\exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right\}$$

For ground-level sources and receptors ($z = 0$ and $H = 0$)

$$C=\frac{Q}{\pi\mu\sigma_y\sigma_z}\exp\left[-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right]$$

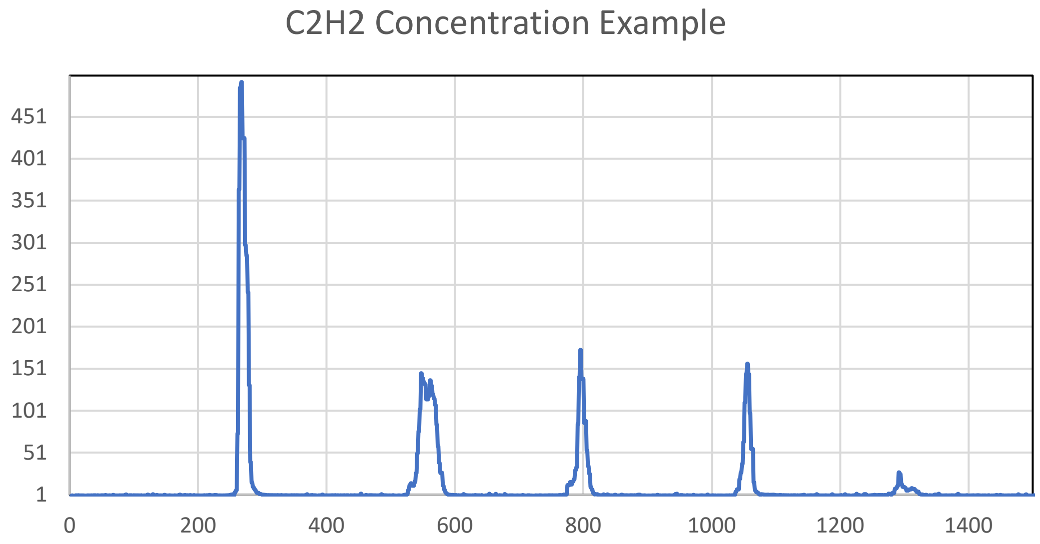


The predicted methane concentration in a receptor point i ($C_{i,\,predicted}$) is calculated through summing up all contributions (C_{ij}) of assumed source points j ($j=1,.., n$).

$$C_{i,\text{predicted}}=\sum_{j=1}^{n}C_{i,j}$$

Calculating predicted concentration for all receptor points ($i=1, .., m$) results in a vector of predicted concentration ($C_{predicted}$).

Search for the ***best-fit source configuration*** is formulated as an optimization problem that consists of residual minimization under bound constraints.



Going Forward….

- Developed Tool has potential to make use of quarterly SEMs and provide another use
- Approach could be used on partial landfill areas or for landfill total emissions
- Approach could be used to assess the reduction in emissions after a certain improvement or change in gas management system
- More work needs to be done in terms other ambient concentration monitoring such as continuous monitoring: might need more sensors or movable sensors, etc.
- We need more validation/verification testing our tool with other techniques especially when Tracer tests are being performed

Questions?

Thank You
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