Towards Smart Methane Emission Source Determination of Area Sources Using Drones

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Introduction

Reducing methane emissions today would have a significant impact in the near-term due to its GWP and 10-year lifespan. Rising temperatures from methane area sources (such as thawing permafrost or landfills) create positive feedback loops in the climate. To mitigate methane successfully, we need to be able to measure emissions effectively. Drones equipped with lightweight laser spectrometers are a potential solution to scale this measurement capability. Here we investigate the use of Digital Twins in estimating area source distributions (e.g. landfills) from quantification flights.

Background

Municipal solid waste (MSW) landfills are the third highest emission source of anthropogenic methane. Measurements at MSW landfills consist of surface emission monitoring (SEM) campaigns, typically conducted on foot. In recent works [1], drone-based SEM (DEM) have been used to scan the landfill surface. While DEM shows promise, DEM and SEM approaches still require time consuming scanning of the site.

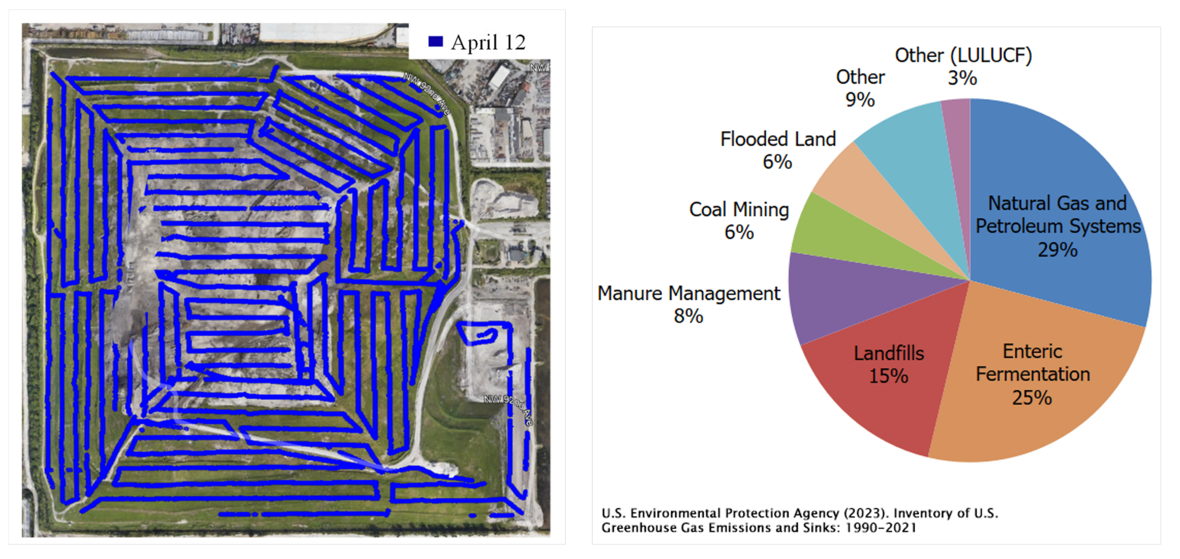

Figure 1: (Left) Drone-based SEM [1]. (Right) Methane emissions by sector [2].

References

[1] Abichou, T. et. al. *Methane*, 2(4):440–451, 2023.
[2] Environmental Protection Agency, 2024.
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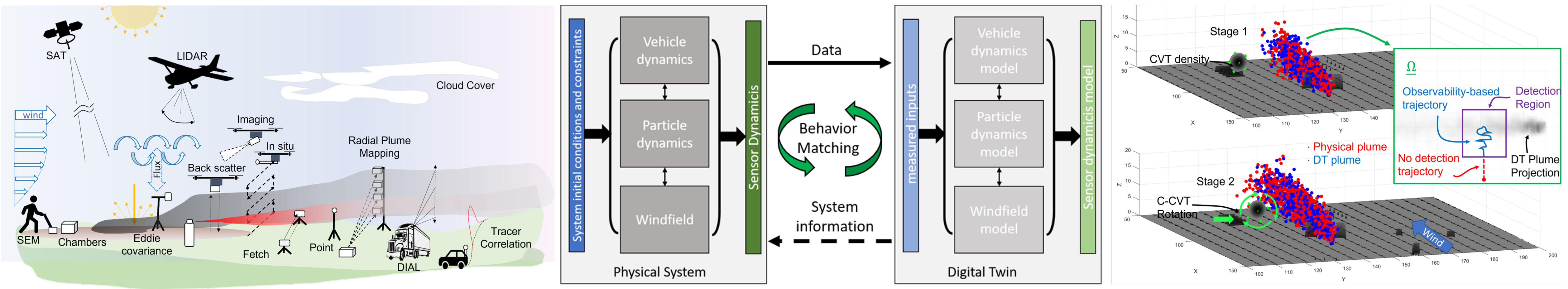
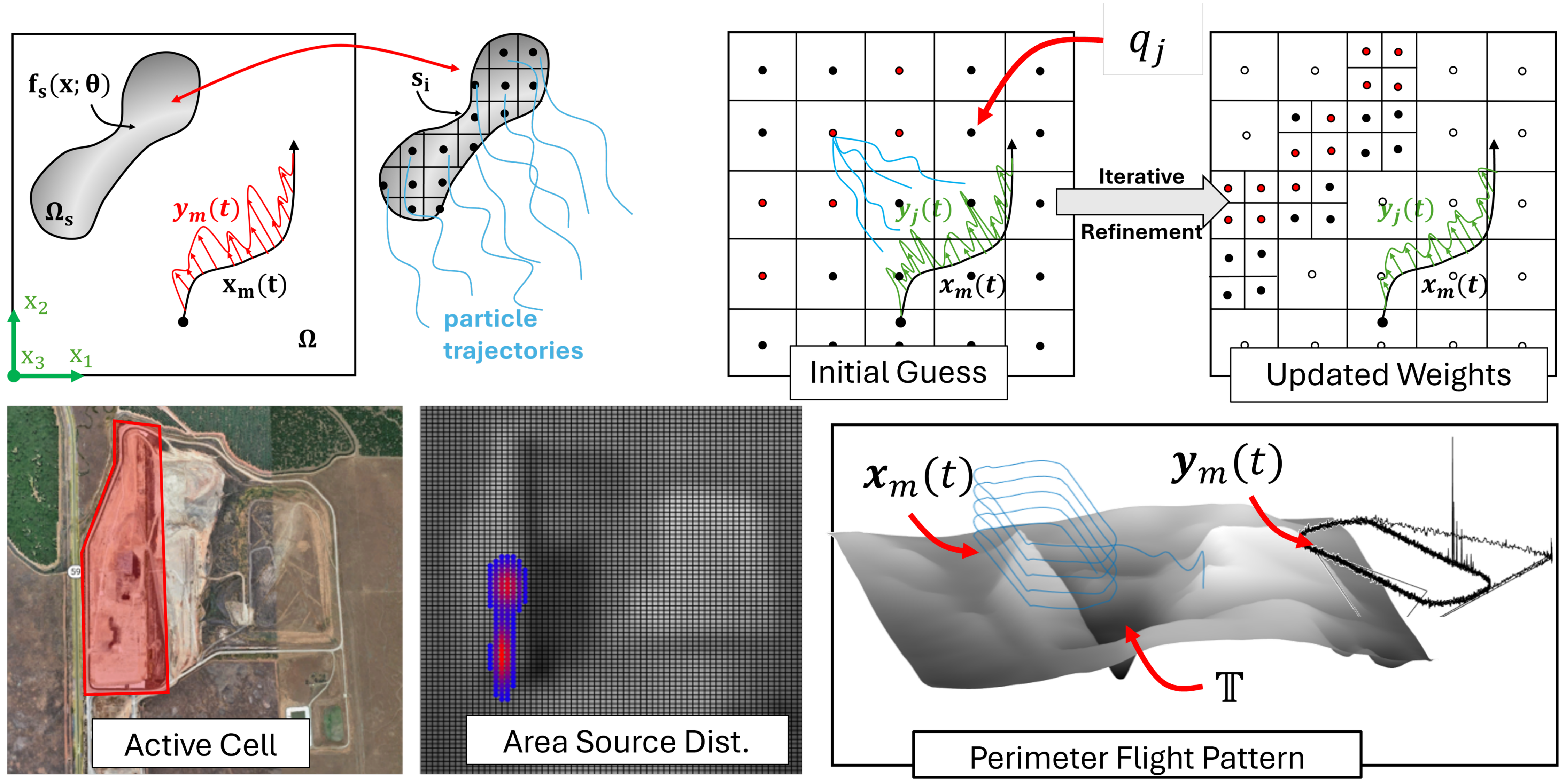
Methane Odor Abatement Simulator (MOABS/DT)

Digital Twins (DT) have been used in environmental sensing applications to represent plume dynamics of an emission source. DT's consist of a physical system, a digital system, and an interconnection between the two. DT's are behavior matched with physical observation data, such that the DT can sufficiently represent the physical system. The MOABS/DT platform is developed from solving the advection diffusion equation (in the stochastic sense) and 3D wind field (2D viscous Burgers equation and atmospheric wind profile). The plume dynamics interact with the terrain using a collision model. Using the DT to gain insight is called smart sensing.



Simulation: Iterative Refinement Method

The adaptive refinement method (IRM) is motivated by probablistic quadtree method [3] and the ability to determine landfill area source distributions from quantification flights. We simulate area sources at landfills by first generating a terrain map $\mathbb{T}$ using Google earth and kriging. The area source distribution is generated given a desired number of Gaussian distributions, all of which are normalized to give total source rate, S. Let us assume that emission quantification is done via the flight trajectory, such that, the area source distribution is only unknown. An a priori guess is used to start the iterative refinement routine. A mapping is used to rewrite the DT and physical system measurements as a linear problem, subject to noise. Since this problem is ill-posed and the solution we want is sparse, we aim utilize the LASSO regression. The new weights are calculated and used to update the refinement step before a new forward model is run. This process is repeated until the desired resolution is obtained.

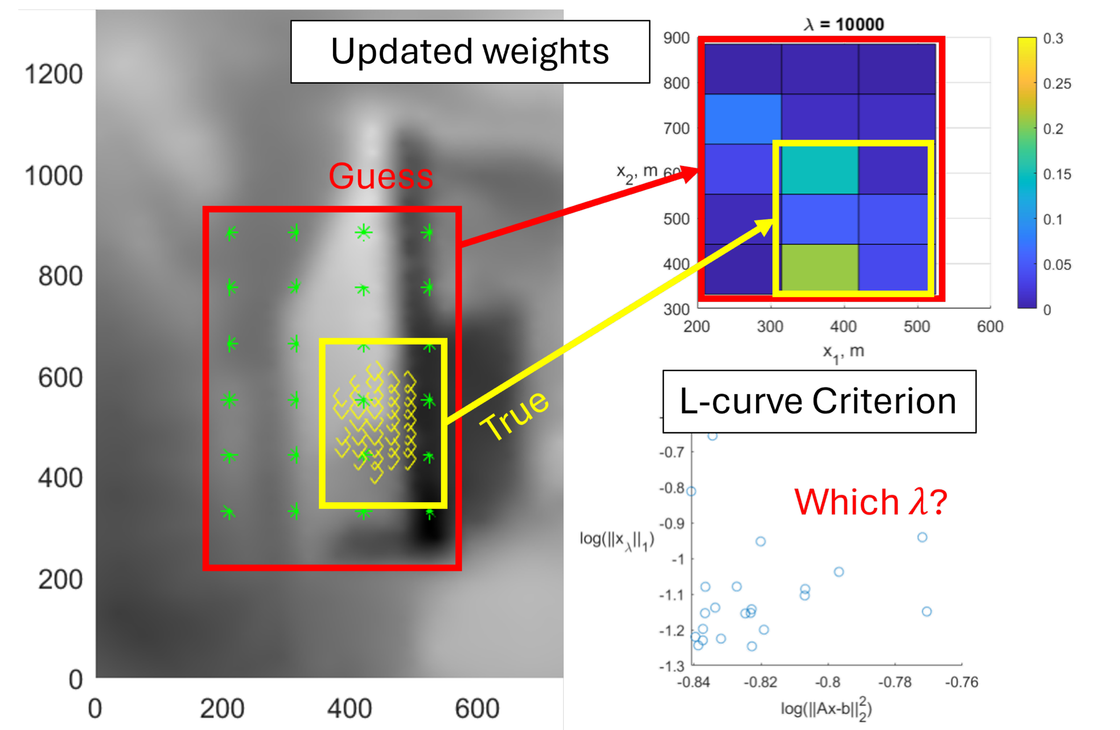


Challenges & Limitations

Challenges:

1. Regularization parameter, λ, selection given $\min_x\{\|Ax-b\|_2^2+\lambda\|x\|_1\}$, subject to $x_j \geq 0$ and $\sum x_j = 1 \forall j$. Potential directions include: L-curve criterion, Generalized Cross-Validation, Landweber/Crimmino iteration, Kaczmarz's method (i.e. ART), and Projection methods.
2. Selecting appropriate mapping to linearize the problem for regularization. Utilize detection and non-detection events into optimization and likelihood functions. Introduction of Bayesian iteration approaches and probability functions that contain prescribed covariance matrices.

Limitations:
The MOABS/DT platform satisfies a degree of simulation fidelity and runtime to show interactions with topology and buildings. However, stochastic plume models do not scale well with the number of DT's – making it difficult to apply traditional Bayesian approaches (e.g. fast running forward models)



Future Research

To build on this work, future work seeks to: (1) further develop how to choose parameter λ and the likelihood function for the iterative refinement method; (2) investigate mesh-free methods (e.g. radial basis function); and (3) implement penalty/barrier functions to improve regression optimization solution;