Research Studies of Landfill Methane Emissions

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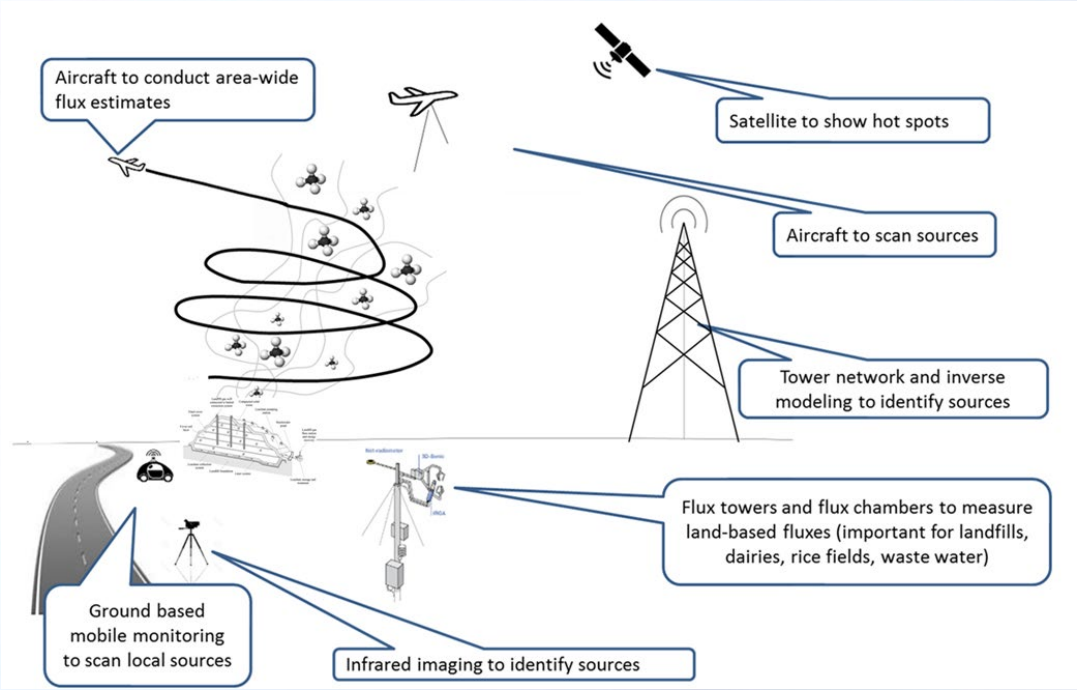
Introduction:
Scientific Research on Methane Emissions



Atmospheric and Remote Sensing Measurements

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Getting from atmospheric measurements to emission estimates

How does it work?

- **Why?** To identify potential gaps in our understanding of methane emissions sources including potentially "missing" sources

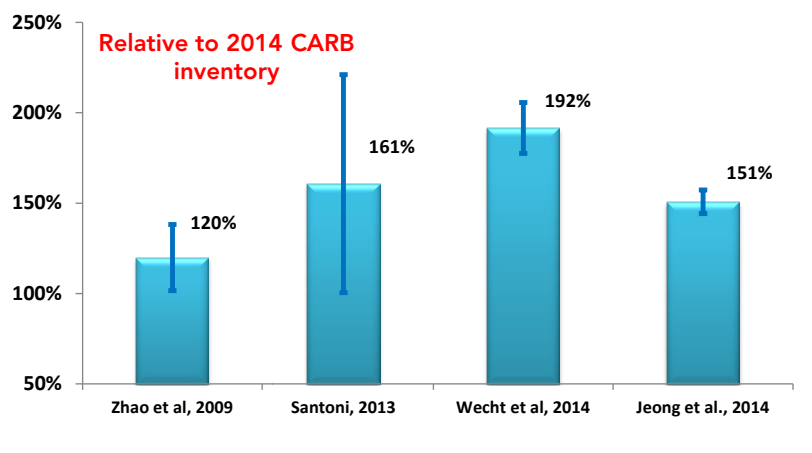
- Inverse modelling:
  - Measuring concentrations at **tower sites** (17 across the state)
  - **Combined with transport models** and **statistical methodologies** to derive the **likely estimates of emissions by region or sector**
  - Use gridded inventories as inputs, unofficial, not endorsed by CARB. Assumptions necessary to disaggregate

- **Getting from atmospheric measurements to emission estimates involves many assumptions and accompanying uncertainties.**

Getting from atmospheric measurements to emission estimates

What are the results?

- **Using atmospheric measurements as the base data,** CARB estimated annual statewide methane emissions were 14% to 47% larger than estimates in CARB's 2014 methane inventory.
- Question: what are some possible explanations for these higher estimates based on atmospheric measurements (e.g. unknown or missing sources, emission rate variability, estimation methodology limitations, etc)?



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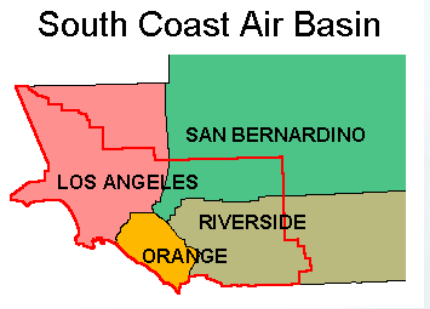
Regional methane emissions

Regional variability exists in estimates:

- **South Coast:**
  - Atmospheric inverse model studies resulted in lower emissions estimates than inventory-based approaches
  - Total emissions were within 20% when comparing both approaches
  - Supported by measurements at Mount Wilson and source apportionment of CH_4, CO, CO_2, and VOCs



- **Bay Area:**
  - Atmospheric-measurement based estimates of landfill and wastewater treatment plant methane were 2x higher than inventory-based estimates
  - Total emissions estimated from atmospheric measurements were 1.3 to 2.3x higher than inventory-based estimates.

- Studying just one region is not enough

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Summary: Tall towers/Inverse modelling methane emissions

- **Inverse modeling**
  - Can produce spatial maps of regional, state-wide or sectorial methane emissions estimates
  - Only as good as the model and inputs
  - Relies on statewide inventory that has to be disaggregated using additional assumptions
- **Studies have uncertainties** due to
  - Uncertainties in underlying measurements, inventories, and gridding processes
  - Models add uncertainties in moving from concentrations to emissions

- Based on **atmospheric concentration measurements with a limited number of sites** throughout the state (17 sites), covering all areas with major anthropogenic emission sources
- If **source apportionment** is possible, can provide some insights on sources, however, not always possible and rely on measurements of other pollutants (e.g. VOCs) – adding uncertainties

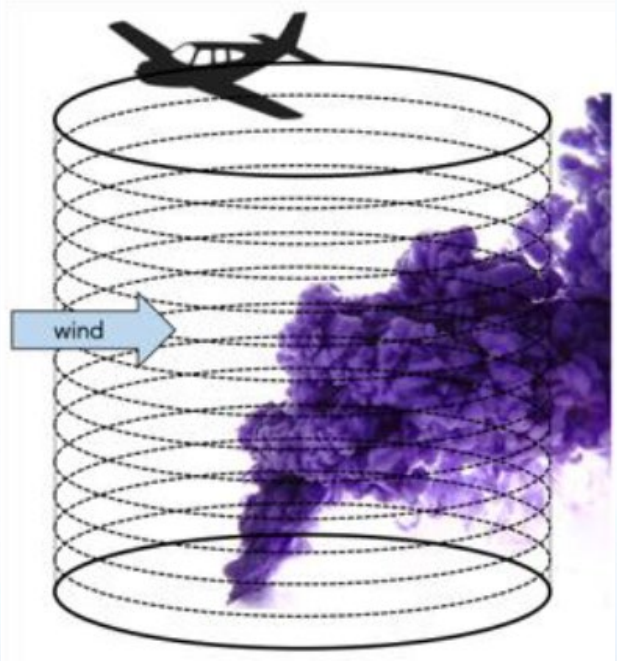
- **Do not provide landfill specific information**

- **Overall**: Provides atmospheric based estimates that can provide a high-level statewide emission estimate, evaluate GHG trends over time as we implement regulations, and inform additional research directions. Satellites may improve abilities in future.

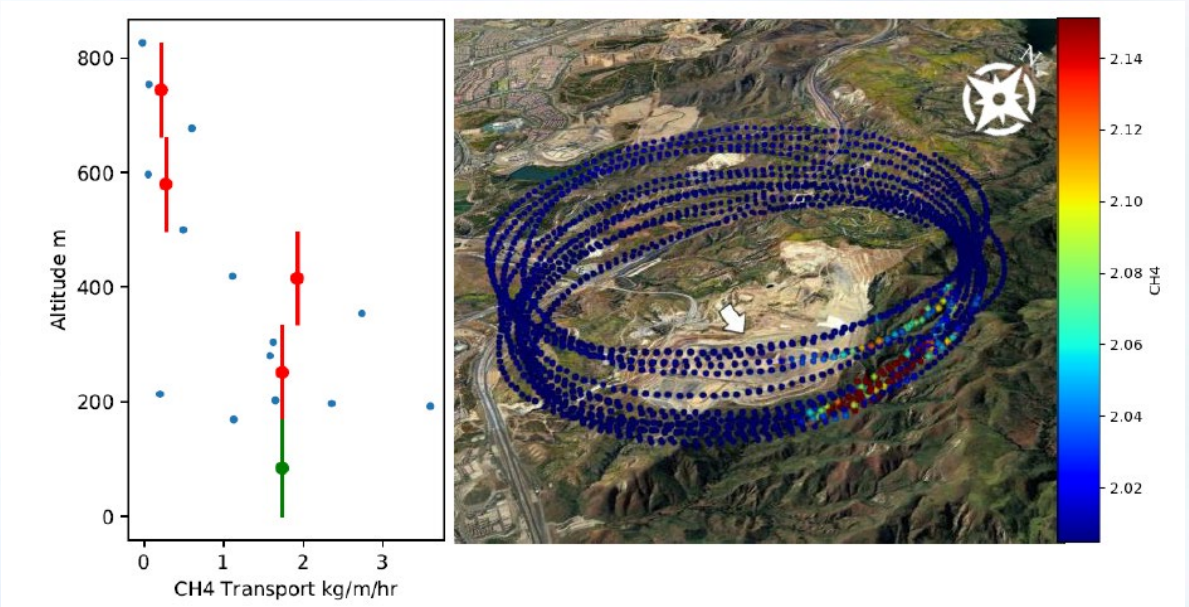
Airborne Mass Balance

What are the results?

General idea



In practice



Emissions = methane leaving the box – methane entering the box

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Airborne Mass Balance

What are the results?

Highlights

- Measured 53 **landfills representing the majority of waste in place** in multiple regions, open and closed landfills
- Overall landfill sites averaged methane emission of 1,026 ± 713 kg hr^{-1} CH_4
- Closed landfill measured emissions were low even for those with large amounts of waste in place

- Report: [Airborne Methane Emissions Measurement Survey (ca.gov)]

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Summary: Airborne Mass Balance

- **Snapshot in time** – each measurement is one hour
- Measures **entire facility emissions hourly** directly at time of overflight, verified via controlled release
- No need for ground-based access but do need an available aircraft, clear airspace and can only fly in certain conditions
- Needs spatially separated facilities
- Measurements are expensive

Eddy Covariance Towers

How does it work?

- Continuous area source emissions from landfills
- Methane, CO_2, and H_20 analyzer and wind sensor
- Tripod mounted sensors, with solar panels

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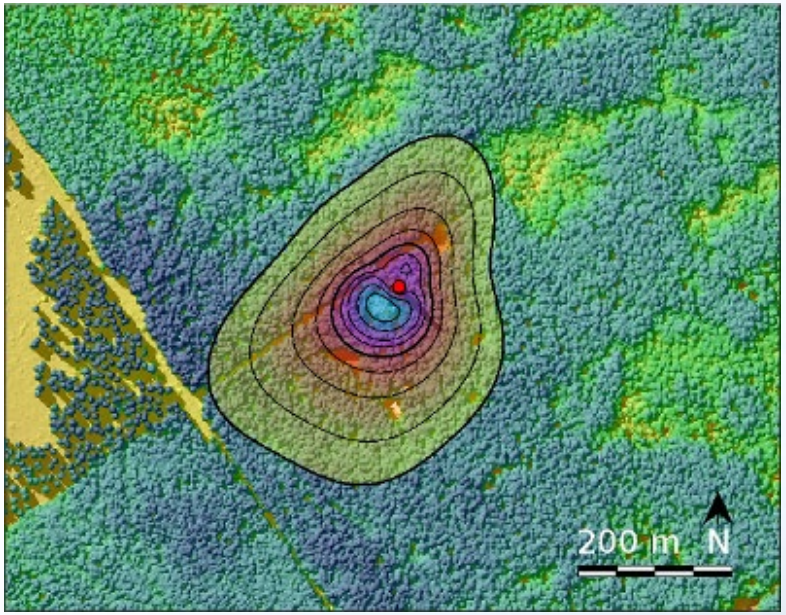
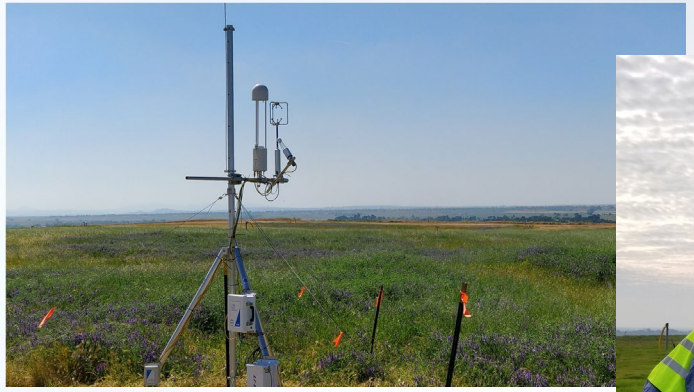
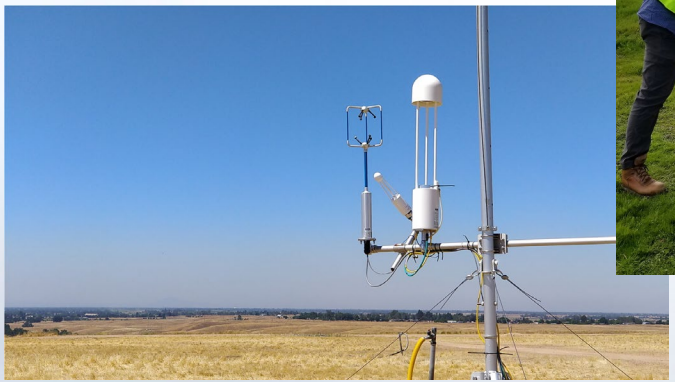
Eddy Covariance Towers

How does it work?



"Footprint"





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Eddy Covariance Towers

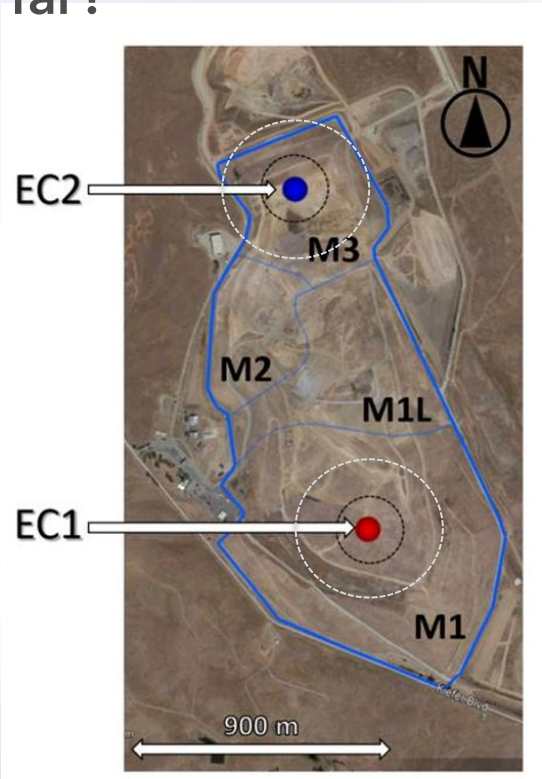
What studies have been done so far?

Objective:

- Comprehensive, long-term study of landfill methane emissions at a LF
- Alongside EC: Emissions assessment using a variety of tools and other methods
- Observe climatic and operational impacts (different cover types etc.) on methane emissions
- Expanding to different landfill with different cover type (membrane)

Results:

- Methane emissions highest at the specific landfills measured during Summer and wet winter months
- Periods of heavy rainfall, high temperatures, and falling pressure
- Active landfill zones: total emissions from the small active zones could be equal to the rest of the landfill



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Summary: Eddy Covariance Towers

- For specific landfill: Self-contained, autonomous measurements, continuous (24/7/365) measurements that measures all sources within footprint
- Footprint is only several acres and only measures upwind of tower
- Requires flat sites and difficult to scale to entire facility much less other facilities
- Overall: Helps understand variability of emissions and the underlying causes (climate, operations, etc.) at a specific landfill but challenging to scale up

Mobile Monitoring of Individual Landfills

How does it work?

- Estimate total facility emissions from landfills
- Vehicle with roof rack
- Methane analyzer and wind sensor
- Highly accurate, state of the art instrumentation

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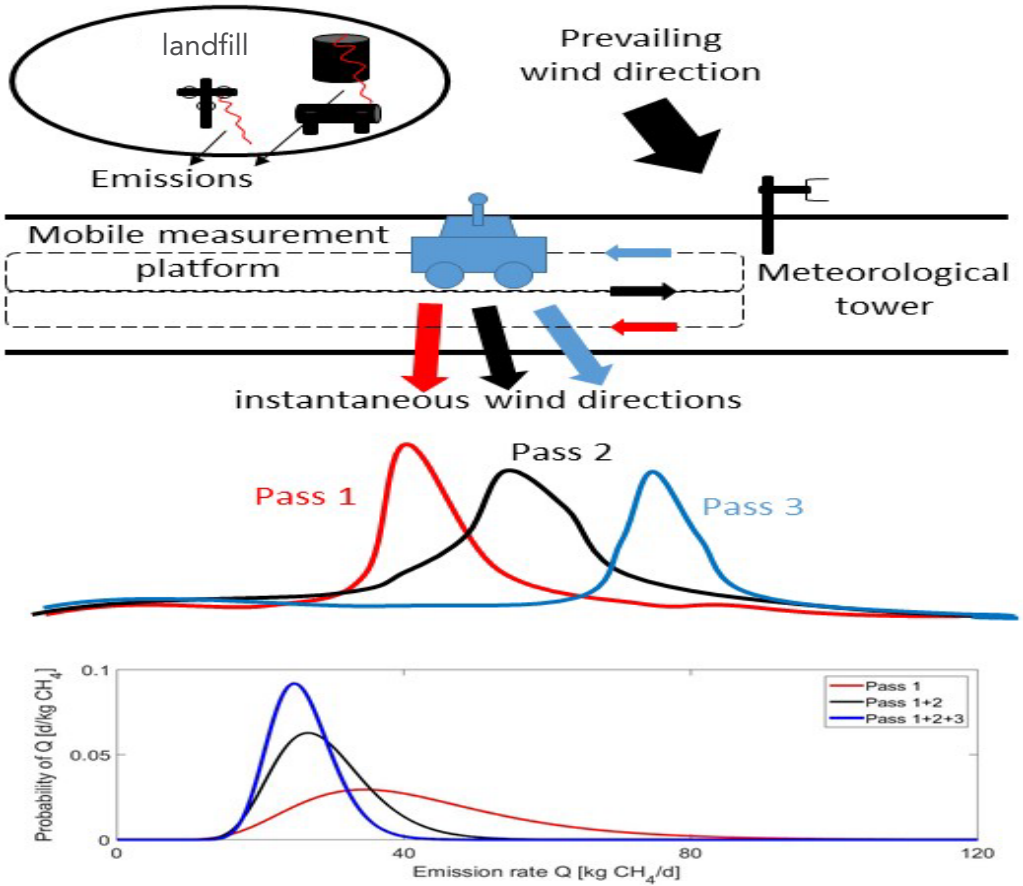
Mobile Monitoring of Individual Landfills

(a): Emission Sources

(b): Measurement system

(c): Measured plume concentrations

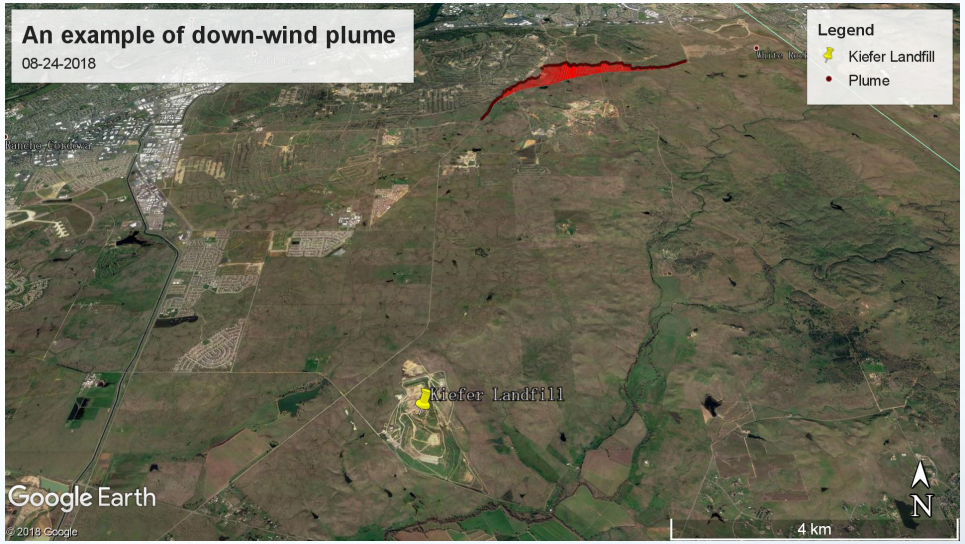
(d): Source characterization



Mobile Monitoring of Individual Landfills

How does it work?

Downwind



On site

Facility level emission estimate

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Mobile Monitoring of Individual Landfills

What studies have been done so far?

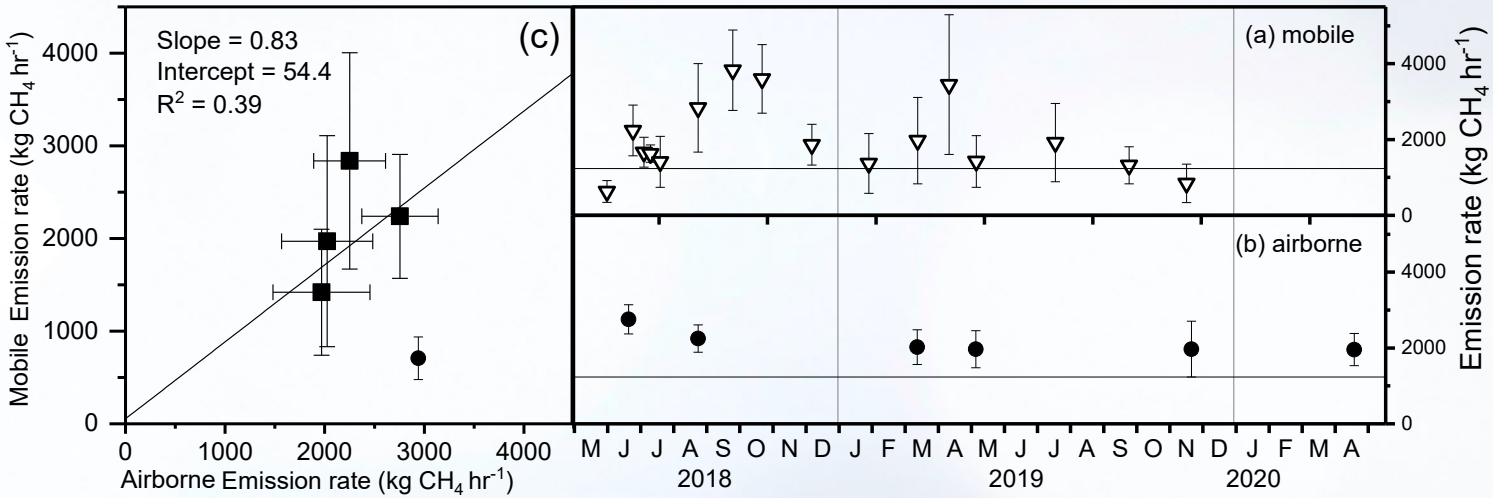
Objective:

- Follow seasonal variation of landfill emissions at a facility with flux-towers
- Compare relationship between mobile measurements of landfills emission and airborne mass balance flights

Mobile Monitoring of Individual Landfills

What are the results?

Landfill: mobile vs. airborne



- Concurrent downwind mobile and airborne measurements showed good agreement
- Downwind mobile showed greater uncertainty, but allows more frequent sampling

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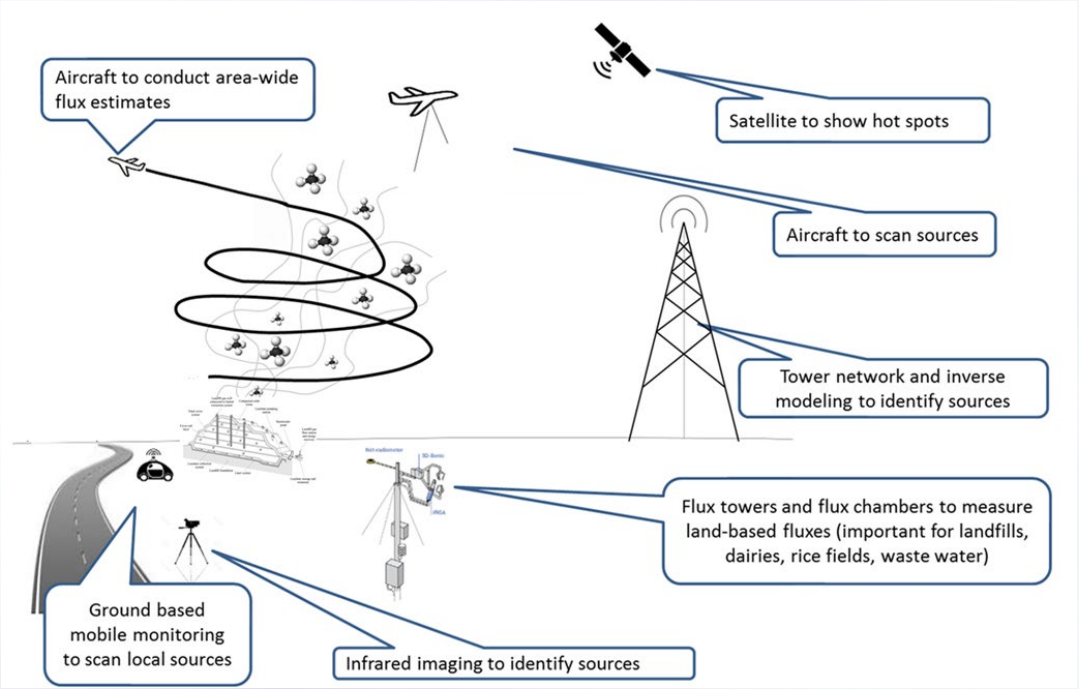
Summary: Mobile Monitoring of Individual Landfills

- **Snap-shot in time** total facility emissions under the right conditions
- Mobile platform can be deployed quickly
- Doesn't require facility access but does require road access immediately downwind.
- Time intensive (each single measurement will take hours)
- Uncertainties remain due to approximation of emissions plume
- Overall provides support of other approaches

Summary

- Different methods complement each other but all are either snapshots in time or lack specificity/higher uncertainties
  - Facility level measurements provide **snapshots** but not annual emissions
  - Flux towers provide **seasonality** but are difficult to scale
  - Regional studies provide insights in which **regions or sector** emit but lack detail on specific sources
  - Each method has its own **uncertainties**, that have to be considered
- Future research?
  - New technologies may enable continuous emission monitoring
  - Higher resolution top-down studies using new data



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