



Landfill Methane Research Workshop: Methane Remote Sensing for Leak Identification and Mitigation

Dr. Jason Schroeder, CARB

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Methane Technology Assessment

In the mid 2010's, new research demonstrated the ability of *hyperspectral imagers* to detect localized sources of methane

Retrieval techniques for airborne imaging of methane concentrations using high spatial and moderate spectral resolution: application to AVIRIS

A. K. Thorpe^{1,2}, C. Frankenberg², and D. A. Roberts¹

¹Department of Geography, University of California, Santa Barbara, Santa Barbara, California, USA

²Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

Real-time remote detection and measurement for airborne imaging spectroscopy: a case study with methane

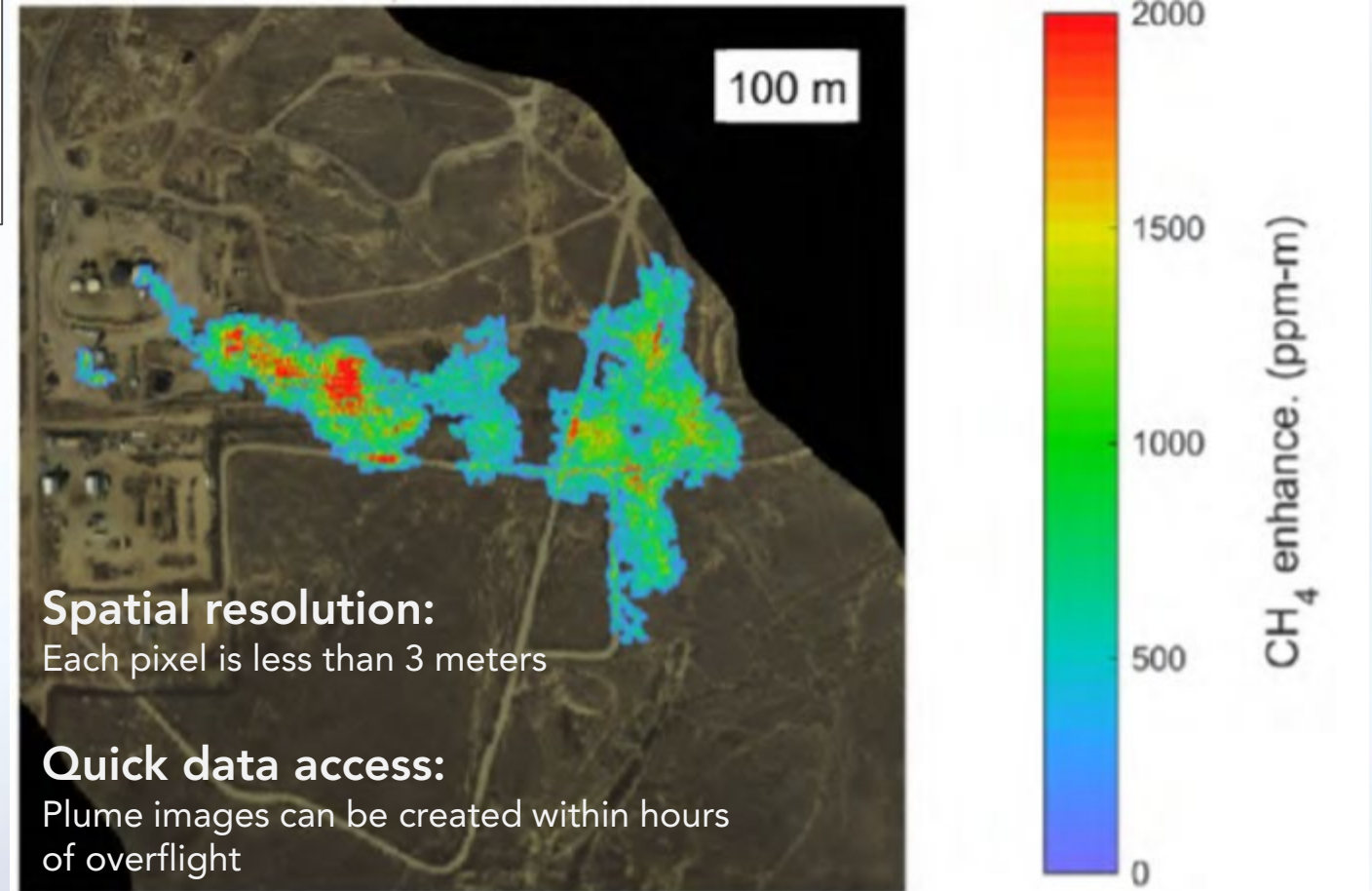
D. R. Thompson¹, I. Leifer², H. Bovensmann³, M. Eastwood¹, M. Fladland⁴, C. Frankenberg¹, K. Gerilowski³, R. O. Green¹, S. Kratwurst³, T. Krings³, B. Luna⁴, and A. K. Thorpe¹

¹Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

²Bubbleology Research International, Solvang, CA, USA

³University of Bremen, Institute of Environmental Physics, P.O. Box 330440, 28334 Bremen, Germany.

⁴NASA Ames Research Center, Moffett Field, CA, USA



Spatial resolution:

Each pixel is less than 3 meters

Quick data access:

Plume images can be created within hours of overflight

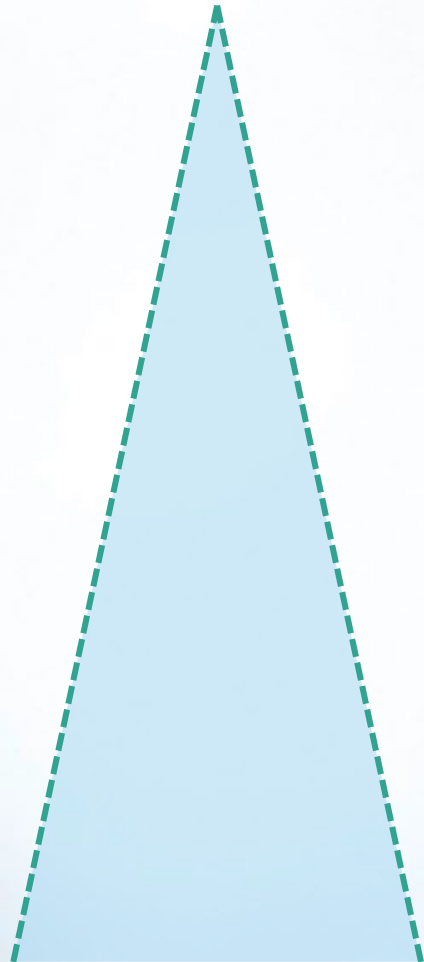
Ex: Diffuse Emissions at a Landfill



"Diffuse" or "area-wide" source:

Small sources of emissions scattered over the landfill property

Ex: Diffuse Emissions at a Landfill



Small/diffuse sources won't be detected

Ex: Diffuse Emissions at a Landfill

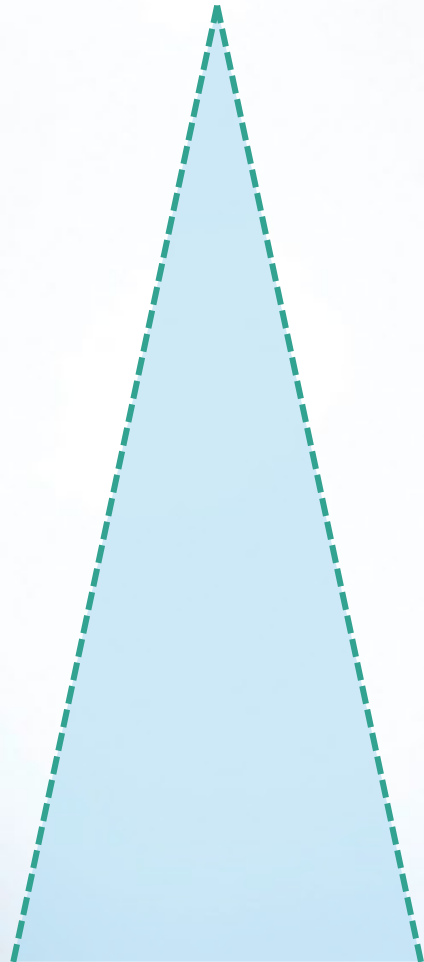


Total Emissions



Sum of Emissions from Area-wide sources

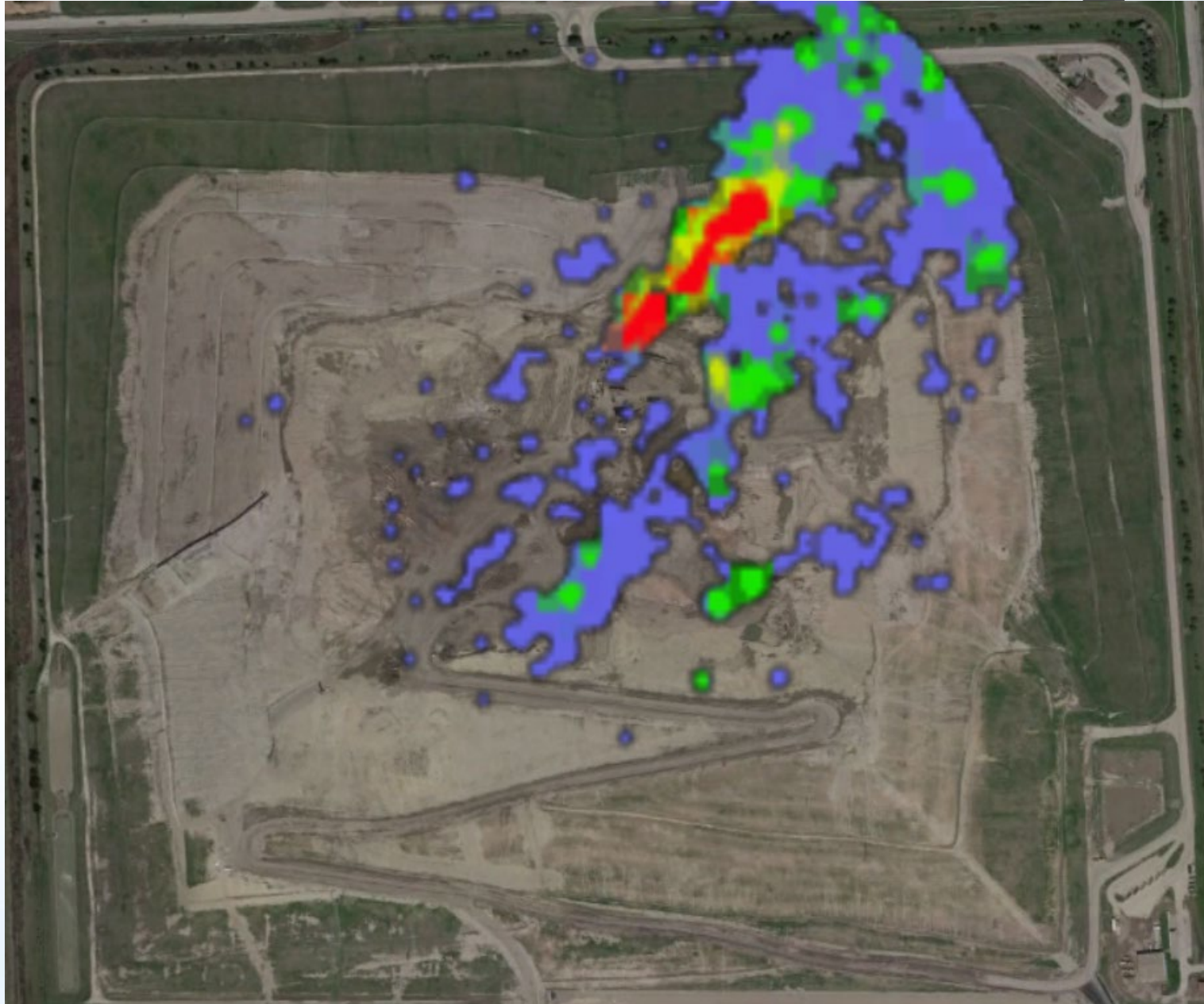
Ex: Diffuse Emissions AND a Large Plume



Large,
localized
source of
emissions

One plume
detection

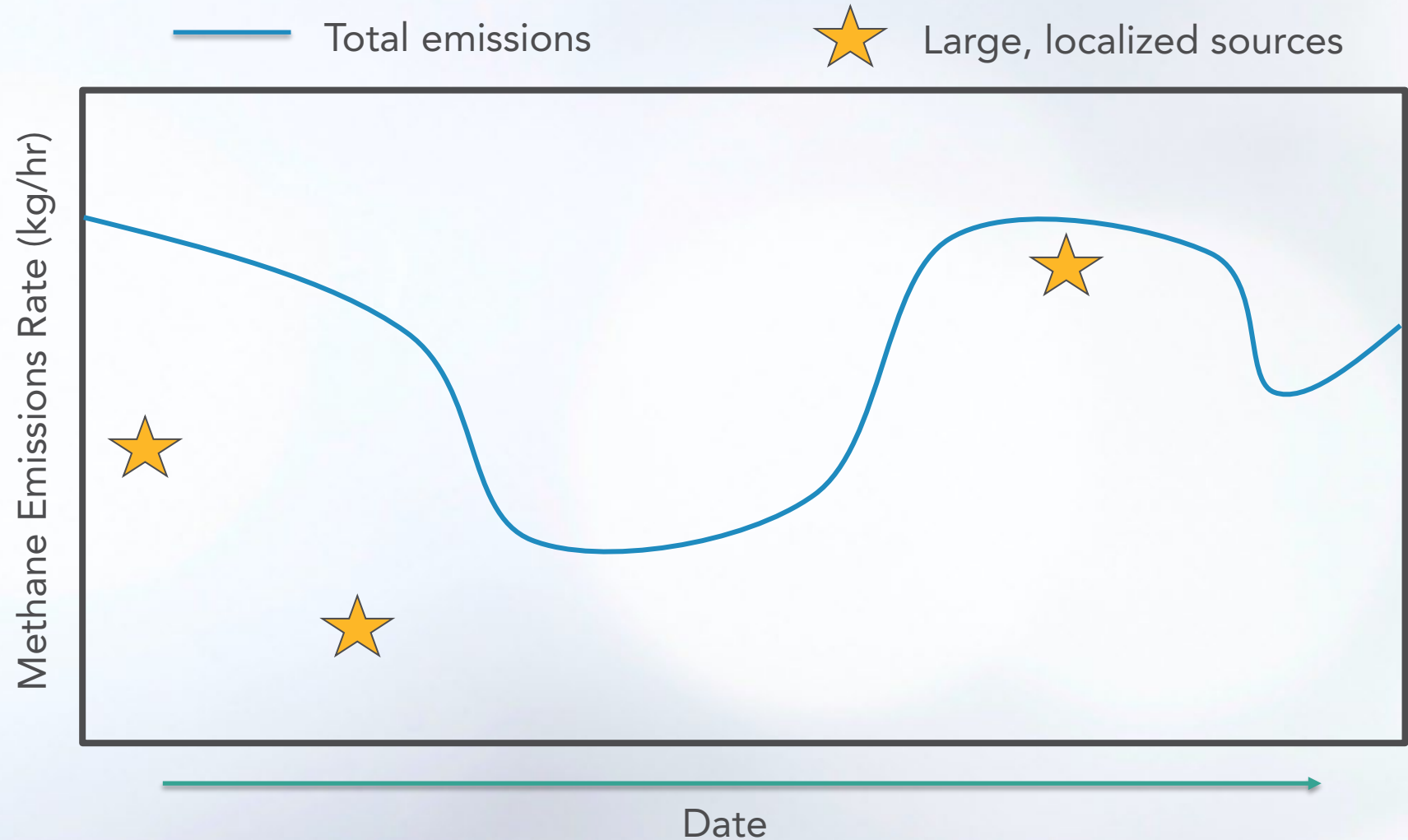
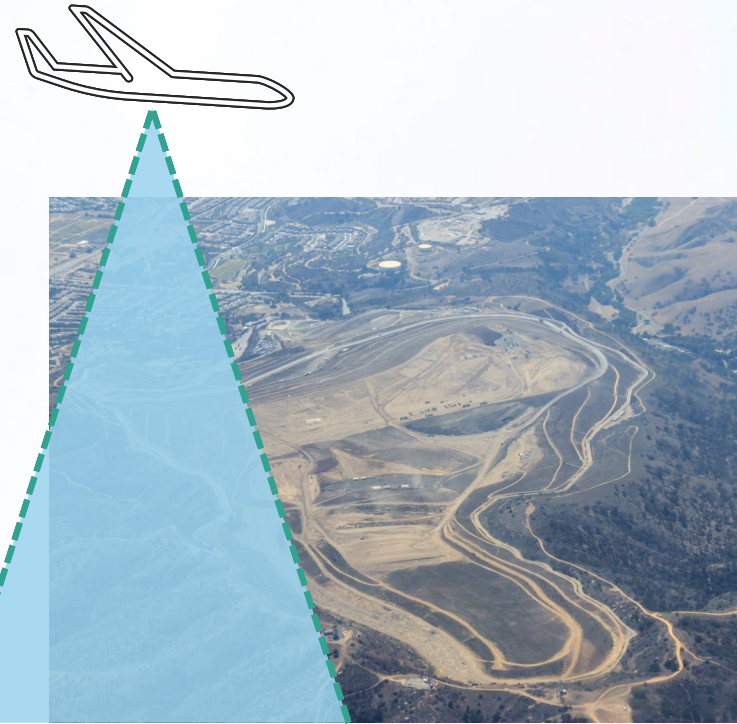
Ex: Diffuse Emissions AND a Large Plume



Ex: Diffuse Emissions AND a Large Plume



Plume Rate \neq Total Annual Emissions

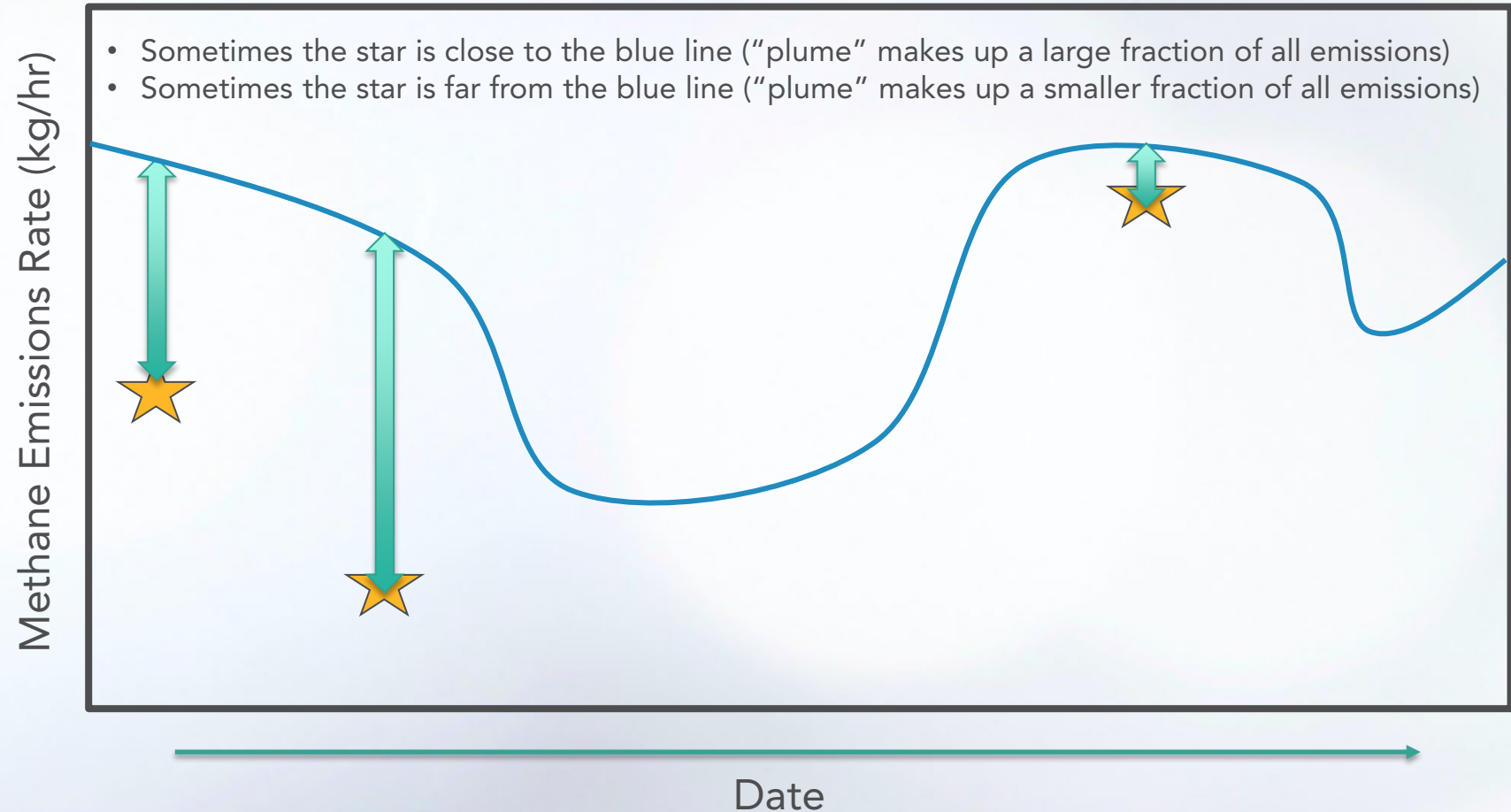


Plume Rate \neq Total Annual Emissions

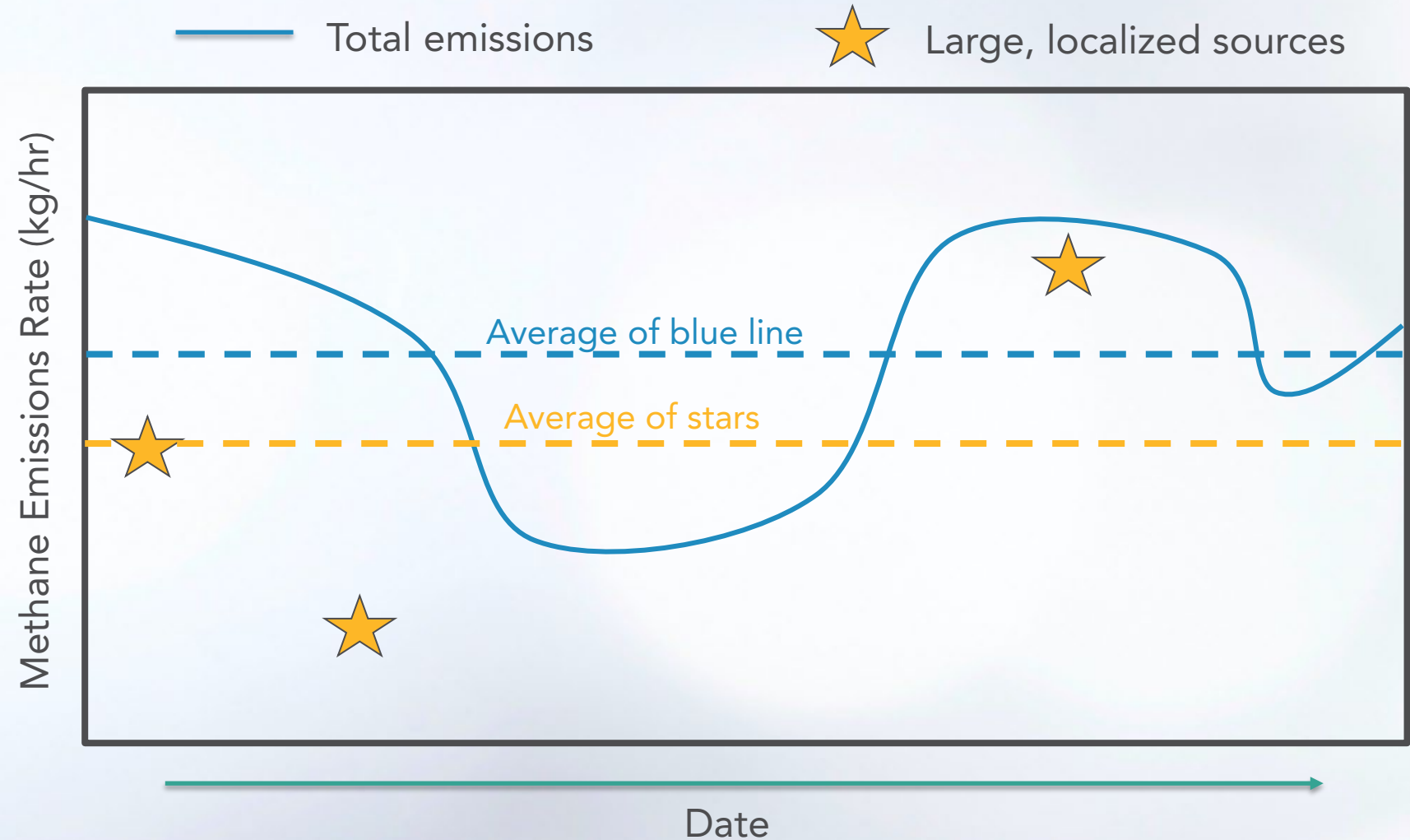


— Total emissions

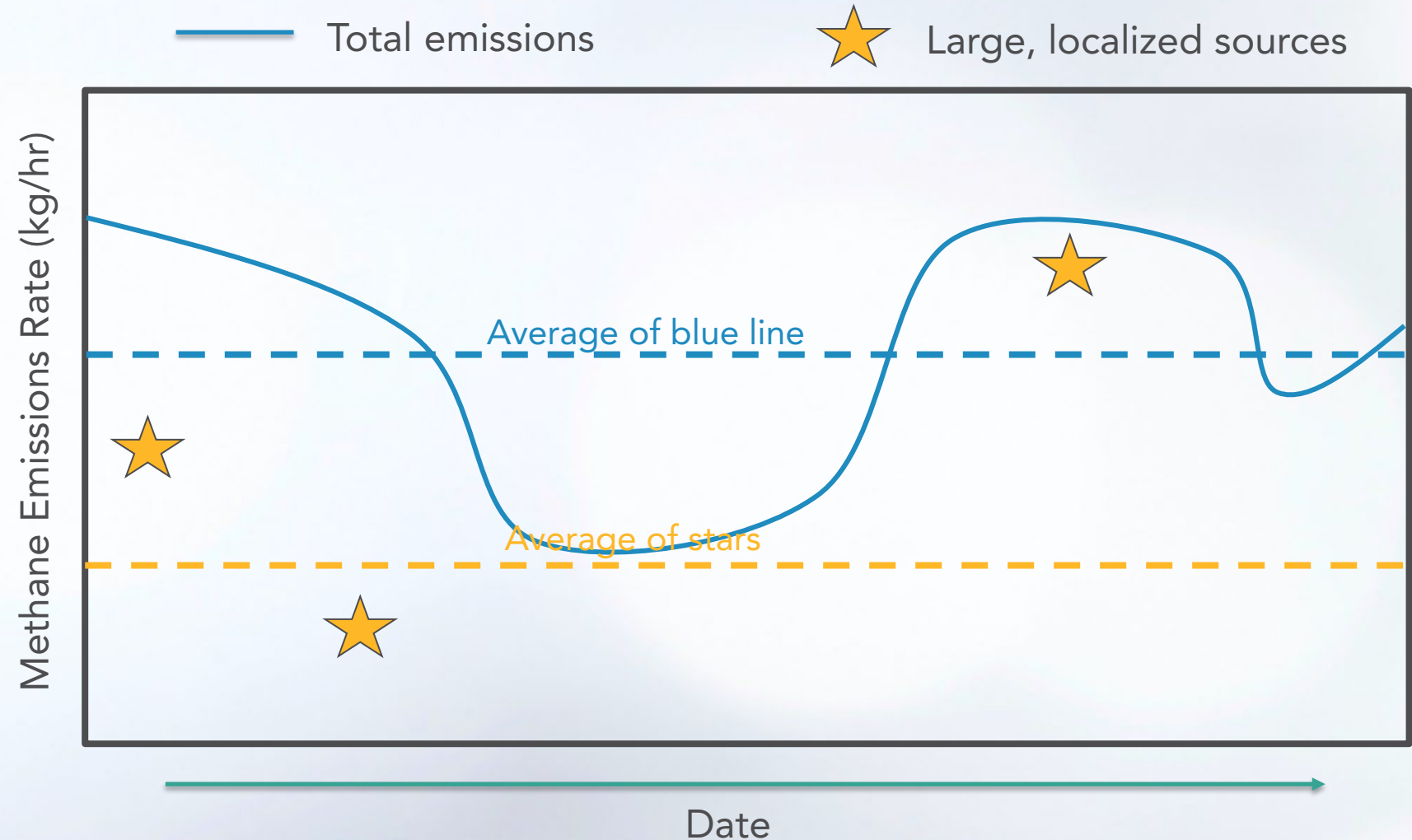
★ Large, localized sources



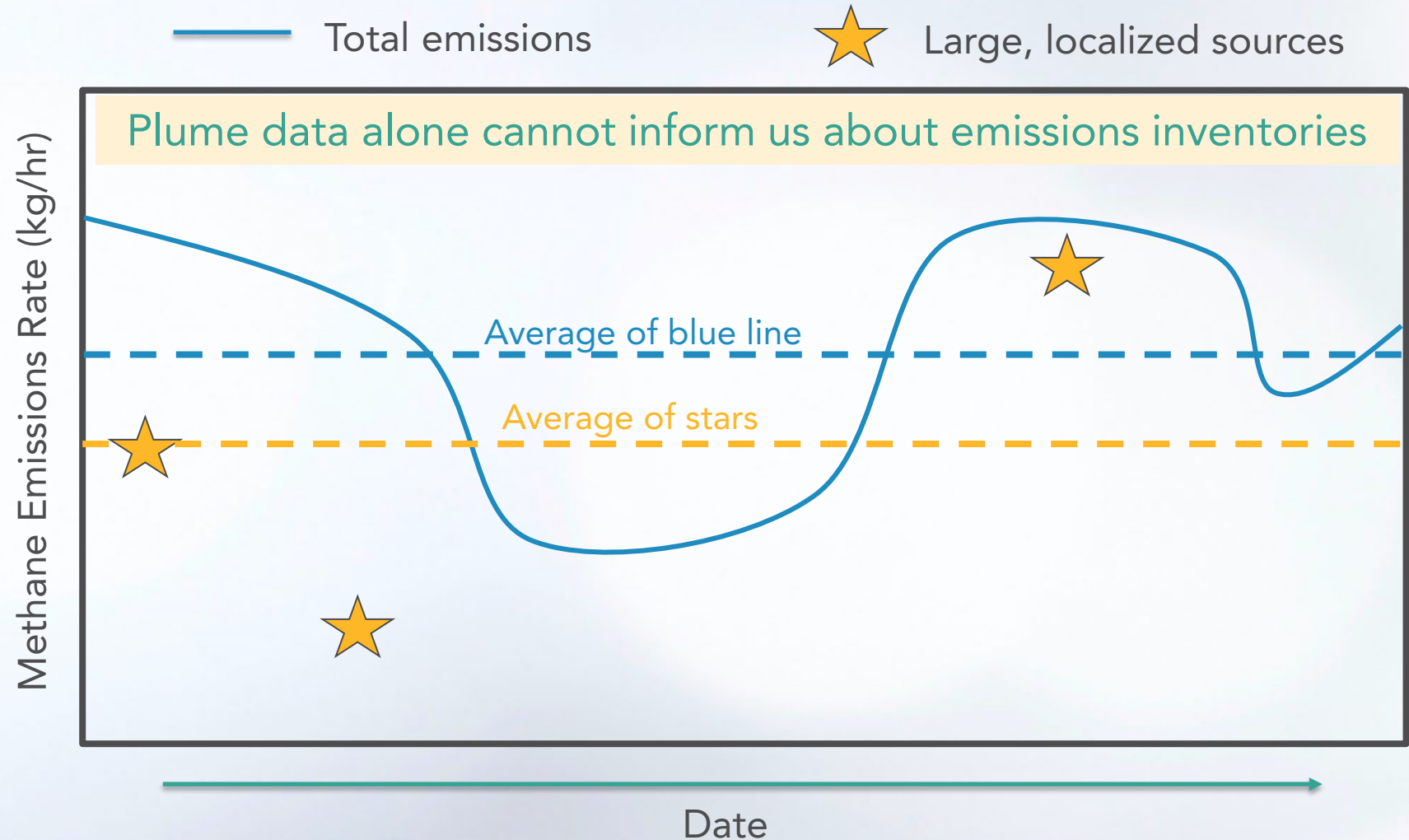
Plume Rate \neq Total Annual Emissions



Plume Rate \neq Total Annual Emissions



Plume Rate \neq Total Annual Emissions

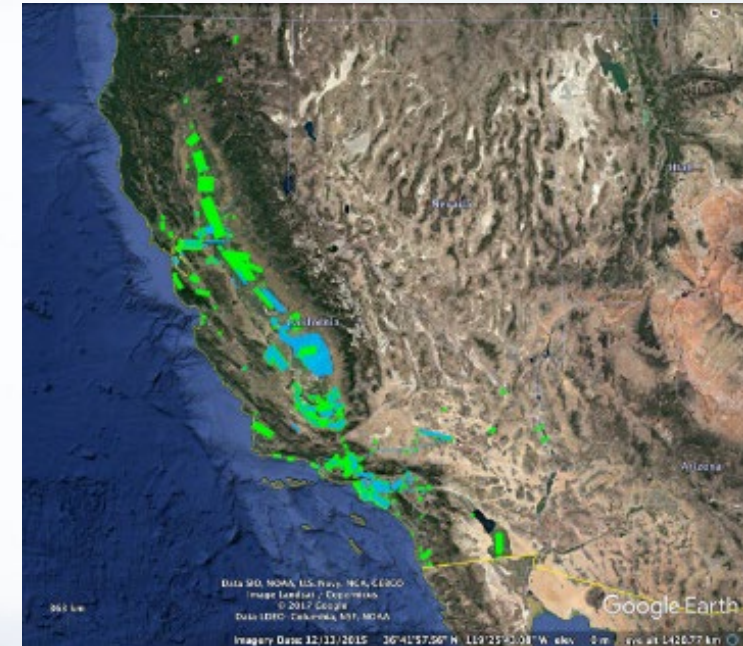


Airborne Research Surveys Conducted in California

Three airborne research campaigns that quantified emissions and demonstrated voluntary mitigation

2016-2018 – California Methane Survey

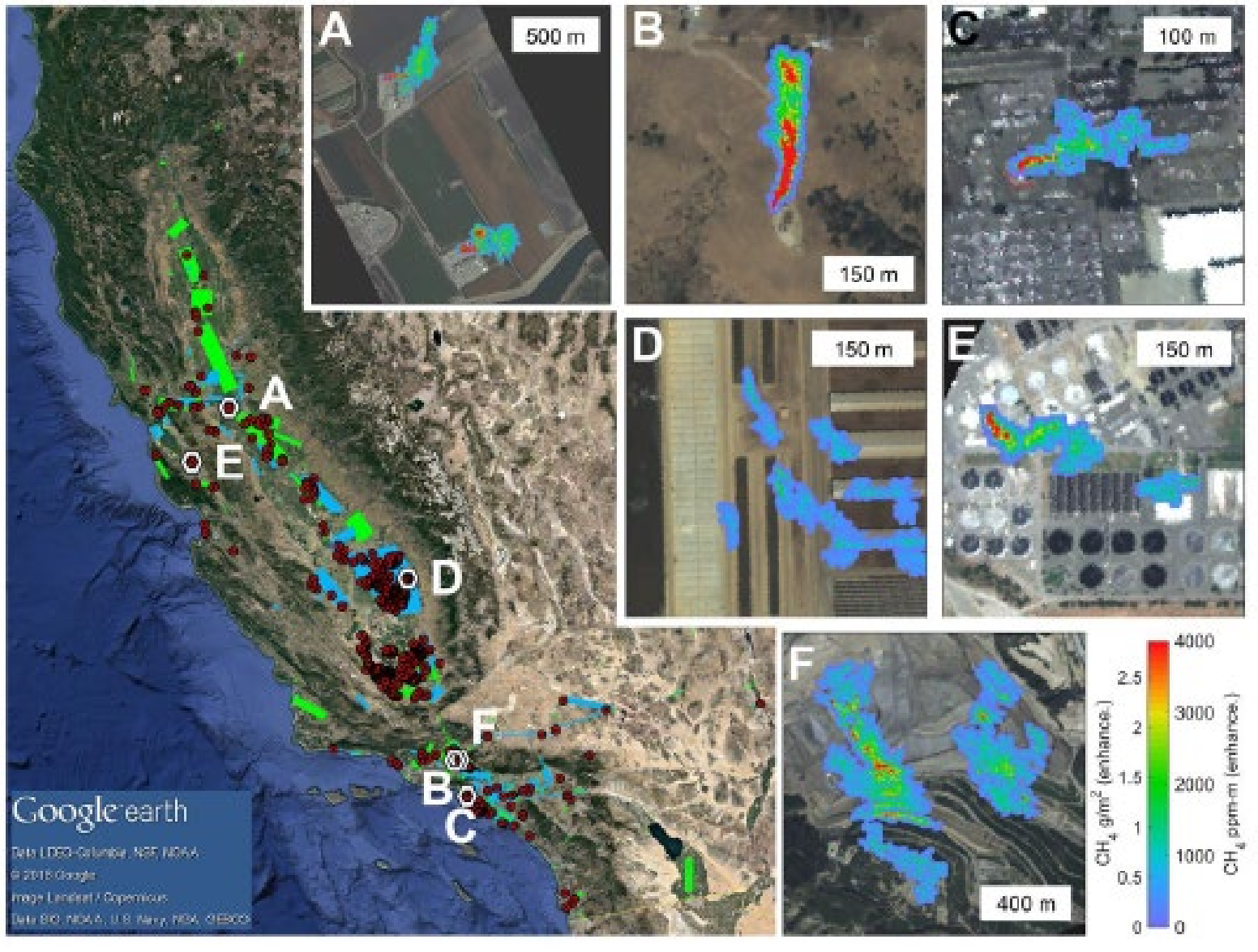
- Funded by CEC and CARB
- Several months of combined flights in 5 separate deployments, cost \$2m
- Surveyed 272,000 facilities and components (80% of known methane-emitting infrastructure) with multiple revisits.
- Plumes were found in all sectors
- First large-scale demo of hyperspectral remote sensing of methane
- **Landfills:**
 - Surveyed 436 waste disposal in California
 - Methane plumes were found at 30 landfills and two composting facilities



The California Methane Survey was the first large-scale demonstration of this methane-detection technology

Research Flights - California Methane Survey (2016-2018)

Examples of methane plumes at different sources



A: Compressor Station at Natural Gas Storage Facility

B: Oil Well

C: LNG Tank

D: Dairy Manure Management

E: Wastewater Treatment Plant

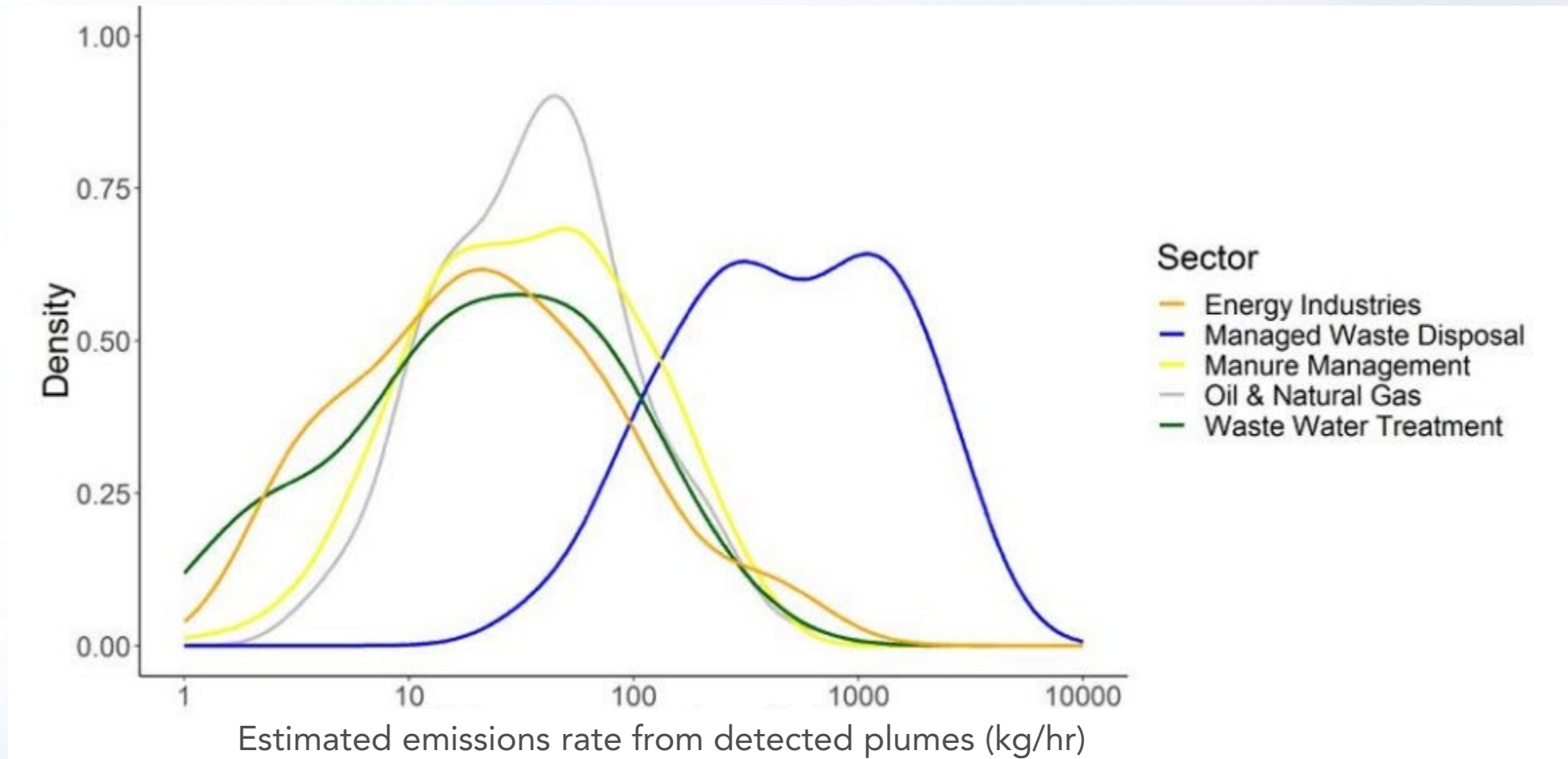
F: Landfill

California Methane Survey

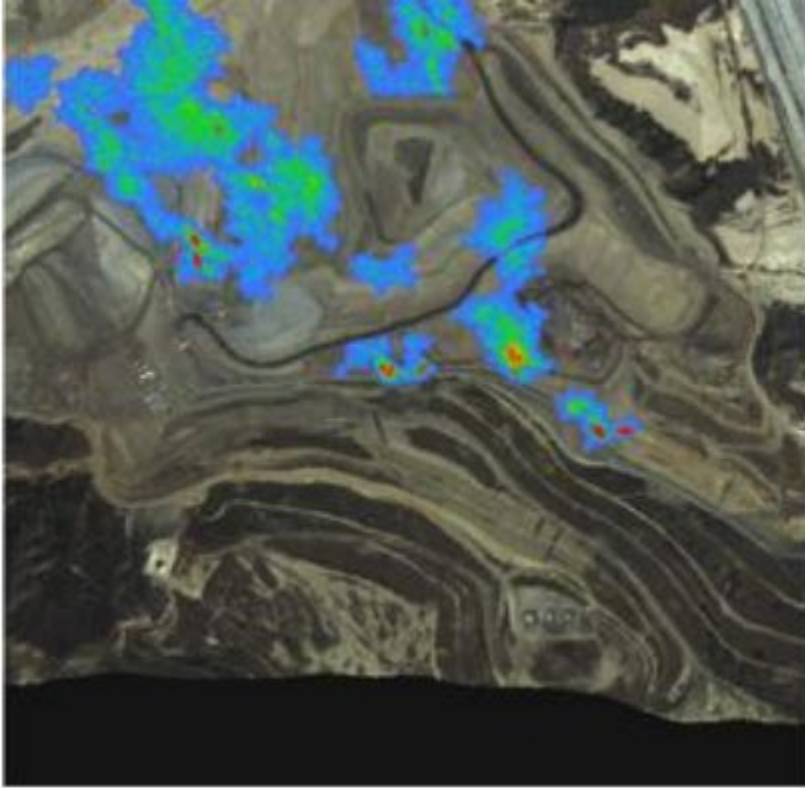
Lessons Learned About Landfills

Result	Key Takeaway
Methane plumes were detected at 32 out of 436 waste disposal sites	The majority of waste disposal sites emit as <i>area-wide sources</i> only and are not detectable with this technology
Detected landfill emissions rates: 41 – 3,000 kg/hr (average: 818 kg/hr)	When landfills have detectable plumes, they are large on average
For landfills with methane plume detections, detectable emissions were highly persistent BUT emission rates and spatial patterns were highly variable	Landfills that have detectable emissions once tend to have detectable emissions again but high variability means they are not representative of average conditions over a year (“snapshotty”)

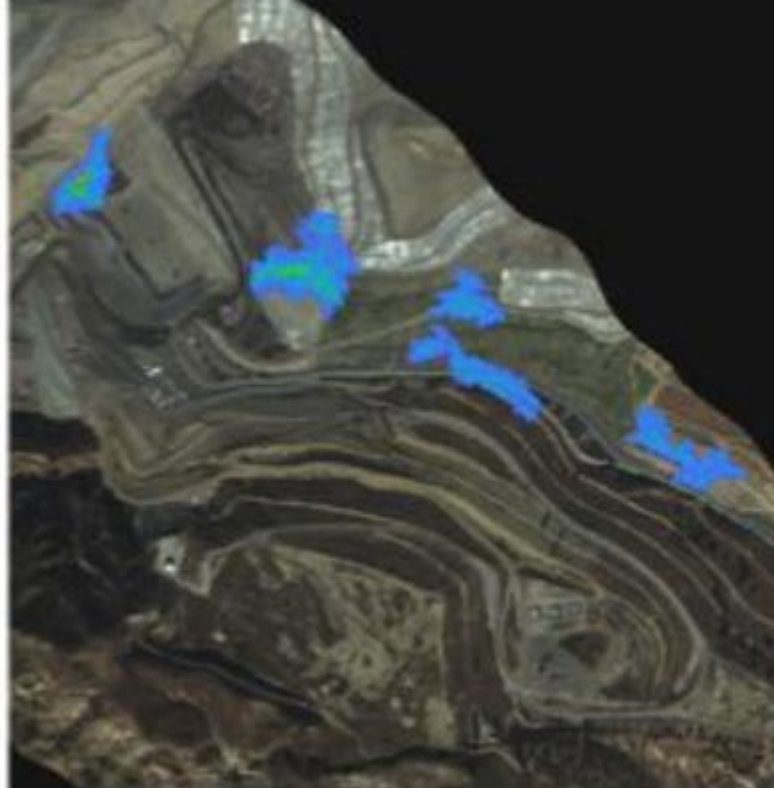
Detectable emissions from Landfills tend to be larger than other detectable emissions



Example of landfill with different plume patterns and different emissions



October 2016
Sum of Emissions:
~3,000 kg/hr

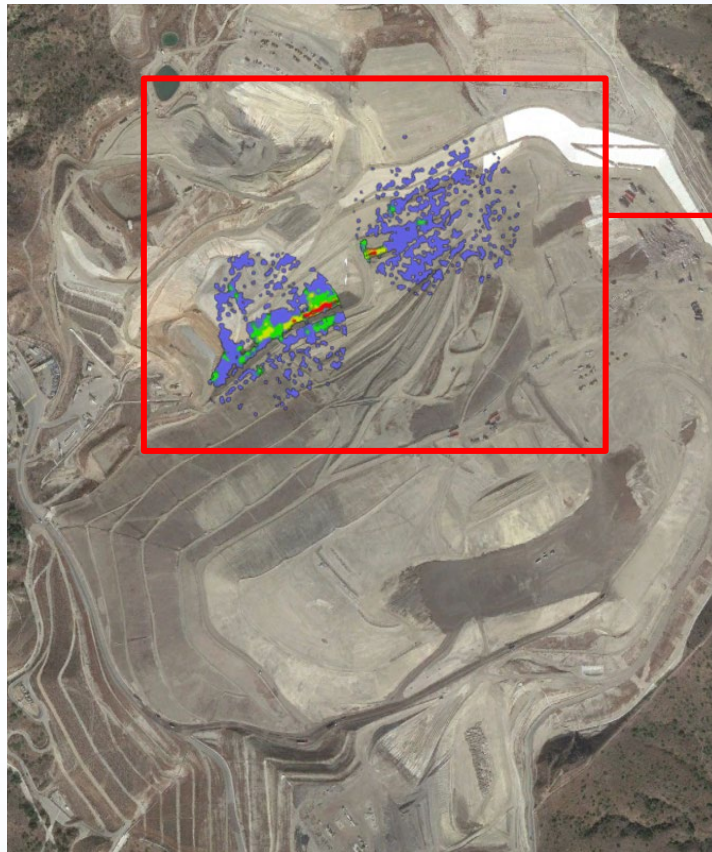


October 2017
Sum of Emissions:
~1,000 kg/hr



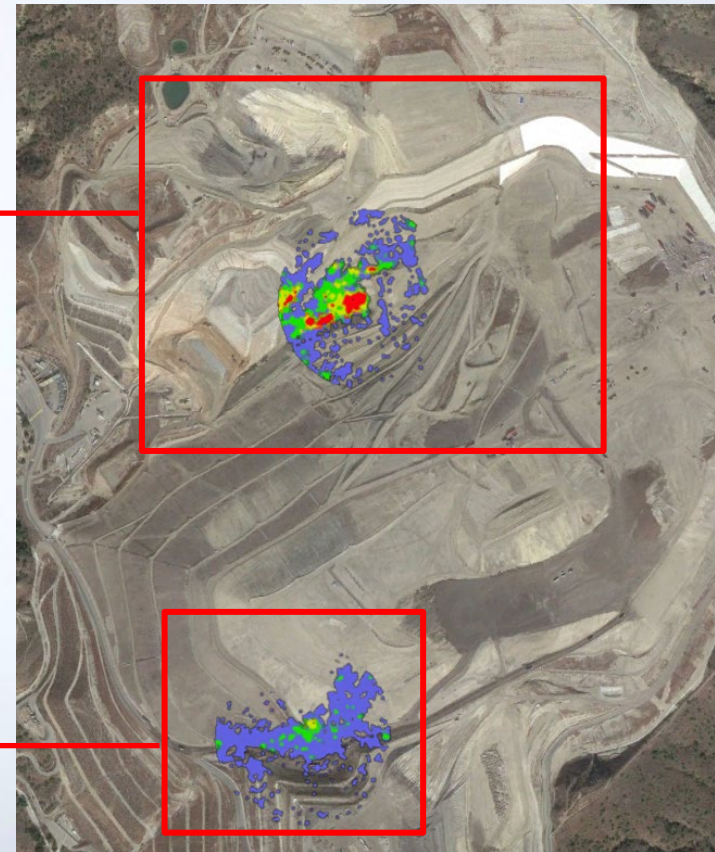
October 2018
Sum of Emissions:
~1,500 kg/hr

Example of Landfill with plumes that changed between flyovers in the same day



Estimated
Emission rate:
~1,000 kg/hr

Oct 23, 10:30 am
Total emissions: ~1,000 kg/hr



Estimated
Emission rate:
~300 kg/hr

Oct 23, 12:50 pm
Total emissions: ~1,300 kg/hr

Additional Airborne Research Surveys Conducted in California

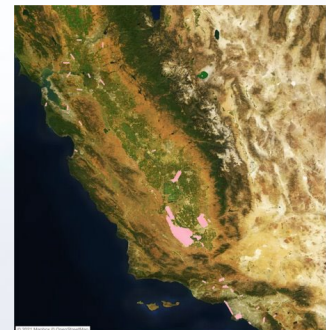
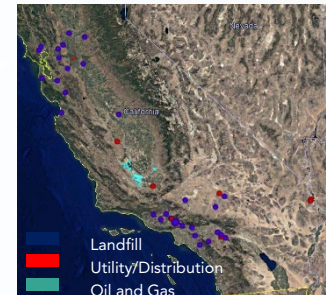
Voluntary program participation as well as overall response rates must be considered with the underpinning of a strong California air quality and climate regulatory environment

Campaign #2 – 2020

- 15 days of flight. Funded by CARB
- Worked with industry prior to voluntarily 'enroll' their infrastructure
- Industry voluntarily provided feedback on what was leaking and why

Campaign #3 - 2021

- 11 days of flight. Funded by Carbon Mapper
- Let industry know we were flying but did not 'enroll' volunteers.
- Automated identification of infrastructure owner and some of the communication
- Worked closely with non-research CARB staff for communication and other actions



Mitigation Research Studies Statistics

Year	Number of Plumes	Number of Operators	Number of Incidences sent to Operators
2020	53	9	30
2021	23	7	15
Grand Total	76	16	45

Example of Voluntary Action from Nov 2021



CARB Methane Satellite Dry Run – Landfill Follow-up

Fill out this form for each notification from CARB of a plume identified from the plane. Complete all fields if possible. *Items in italics are optional but preferred.*

Facility/Flight Survey Info	
Name of Facility:	[REDACTED]
Contact information (name, phone number, email address):	[REDACTED]
Plume ID (provided by CARB):	GAO20211111203239p0000-A_r208_c692
Lat/Lon coordinates (provided by CARB):	34.1595/-118.1932
Date of follow-up ground survey	11/19/21
Follow-up Ground Survey	
Instrument used to locate the leak (e.g., Method 21 instrument like TVA2020):	TVA2020
Was an emission source identified?	Yes
What was the nature of the emission source (well, surface crack etc.):?	In response to the aerial survey, vertical PVC pipe markers were found to be compromised due to bird activity (see additional comments below).
Was this location included in the previous quarterly/annual Landfill Methane Regulation (LMR) surface emission monitoring?	Yes
If not please state why the area was not monitored (construction, active working face, steep slope, etc.):	
Is this location planned for inclusion in the next quarterly/annual LMR monitoring?	Yes
If not please state why the area will not be monitored (construction, active working face, steep slope, etc.):	
Was the source of emissions a leak (unintentional) or a vent (intentional)?	Unintentional
Concentration of the leak:	1,892 ppm methane
Follow-up Actions	
Mitigation actions taken (if it was a leak):	The vertical PVC pipe markers were removed, and the new gas trenches were connected to vacuum on 11/19/21.
Concentration of the leak after repair:	28.8 ppm methane (maximum instantaneous reading)

This looks like a plume at Landfill X, belonging to Company Y

Wed	Thurs	Fri	Sat	Sun	Mon	Tues
10	11 Plume Detected	12	13	14	15	16 Operator Notified
17	18	19	20	21	22	23

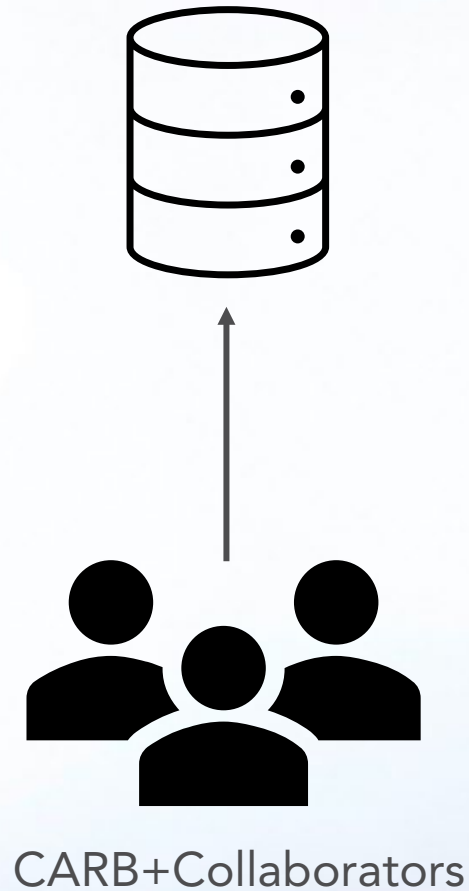


CARB+Collaborators



An example of a landfill

Example of Voluntary Action from Nov 2021



Wed	Thurs	Fri	Sat	Sun	Mon	Tues
10	11 Plume Detected	12	13	14	15	16 Operator Notified
17 Operator inspected	18 Operator repaired source	19	20	21	22	23

We found the source of the plume. We found damaged PVC pipe markers, which were repaired

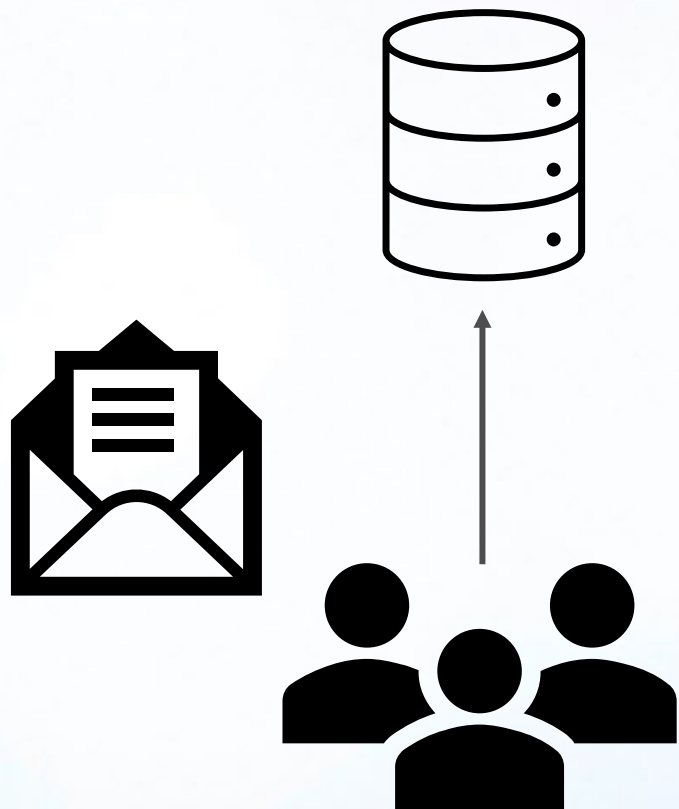


An example of a landfill

Example of V

Fill out this form for each notification from CARB of a plume identified from the plane. Complete all fields if possible. *Items in italics are optional but preferred.*

rom Nov 2021



CARB+Collaborators



Facility/Flight Survey Info	
Name of Facility:	[REDACTED]
Contact information (name, phone number, email address):	[REDACTED]
Plume ID (provided by CARB):	GAO20211111t203239p0000-A_r208_c692
Lat/Lon coordinates (provided by CARB):	[REDACTED]
Date of follow-up ground survey	11/19/21
Follow-up Ground Survey	
Instrument used to locate the leak (e.g., Method 21 instrument like TVA2020):	TVA2020
Was an emission source identified?	Yes
What was the nature of the emission source (well, surface crack etc.)?	In response to the aerial survey, vertical PVC pipe markers were found to be compromised due to bird activity (see additional comments below).
Was this location included in the previous quarterly/annual Landfill Methane Regulation (LMR) surface emission monitoring?	Yes
If not please state why the area was not monitored (construction, active working face, steep slope, etc.)	
Is this location planned for inclusion in the next quarterly/annual LMR monitoring?	Yes
If not please state why the area will not be monitored (construction, active working face, steep slope, etc.)	
Was the source of emissions a leak (unintentional) or a vent (intentional)?	Unintentional
Concentration of the leak:	1,862 ppm methane
Follow-up Actions	
Mitigation actions taken (if it was a leak):	The vertical PVC pipe markers were removed, and the new gas trenches were connected to vacuum on 11/18/21.
Concentration of the leak after repair:	28.6 ppm methane (maximum instantaneous reading)

Additional comments: The [REDACTED] Landfill is an open municipal solid waste facility equipped with an active gas collection system. This gas collection system consists of 540 vertical gas wells and approximately 81,000 linear feet of gas collection trenches. Upon receiving CARB's notification on November 17, 2021 [REDACTED] staff immediately surveyed the areas identified as potential point sources (i.e., areas shown in green on the plume images provided). Instantaneous measurements of these areas showed maximum concentration of 209 ppm methane.

To identify other potential sources, staff also surveyed an area to the south of the tentatively identified plume, where new gas trenches were recently installed. The maximum concentration in this area was 1,862 ppm methane. Four new trenches were installed in this area and trenching activities were completed on July 30, 2021. As part of the construction process, markers were installed at 100-foot intervals along the length of each trench for surveying purposes. These markers are 1 1/2" and 2" PVC pipes extending vertically from the outside of the trench to about 3 to 5-feet above grade. Each pipe was sealed using tape to avoid potential emissions. Upon searching for potential emission sources, staff observed some of the markers and the tape seals had been compromised by birds. The entire length of each new trench was monitored, the only source identified was from compromised markers.

In response to the discovery of compromised markers [REDACTED] removed all markers and applied a vacuum to the new trenches on November 18, 2021. On November 19, 2021 the area above the new trenches was surveyed using a TVA2020 and no exceedances of Rule 1150.1 limits were observed. Accordingly, the emission source was identified and completely remediated on November 18, 2021. Please note that [REDACTED] Rule 1150.1 monitoring program did not identify any exceedances in the trench construction area prior to the CARB aerial survey. As a result, we believe that the subject pipes were recently compromised and the source of the emissions. Moreover, [REDACTED] will use PVC caps to seal any markers in the future to avoid any reoccurrence.

Leak Stopped or Repaired

Component:
GCCS Well/Pipes

Example: Emission from Surface Cover Cracks

Key Event	Date
First Plume Detection	Nov 10, 2021
Operator Notified by CARB	Nov 16, 2021
Operator Response Date	<i>March 1, 2022</i>



Operator Response:

The leak was found to be due to surface crack emissions. Soil in the area was re-compacted on Dec 1, 2022. Methane concentrations in the area after soil re-compaction were 20 ppm.

About Half of Incidences Shared With Operators Resulted in Mitigation

Year	Number of Incidences sent to Operators	Stopped or Repaired
2020	30	15
2021	15	7
Total	45	22 (49%)

- More than 90% of operators replied to our voluntary requests

Whats Next?

Methane data to CA for free from two philanthropically funded satellites being launched by Carbon Mapper (est: 2023)

California Budget: \$100 Million for methane-detecting satellites

- Will go through competitive bid process

Why is California invested in this?

California has served as the testbed for demonstrating that this technology can be used to support real-world methane mitigation in a timely manner

Additional Projects:

Carbon Mapper consortium

public-private partnership based around plume-mapping satellites

Airborne Flights

More plume-mapping flights are being planned for 2023 and beyond.

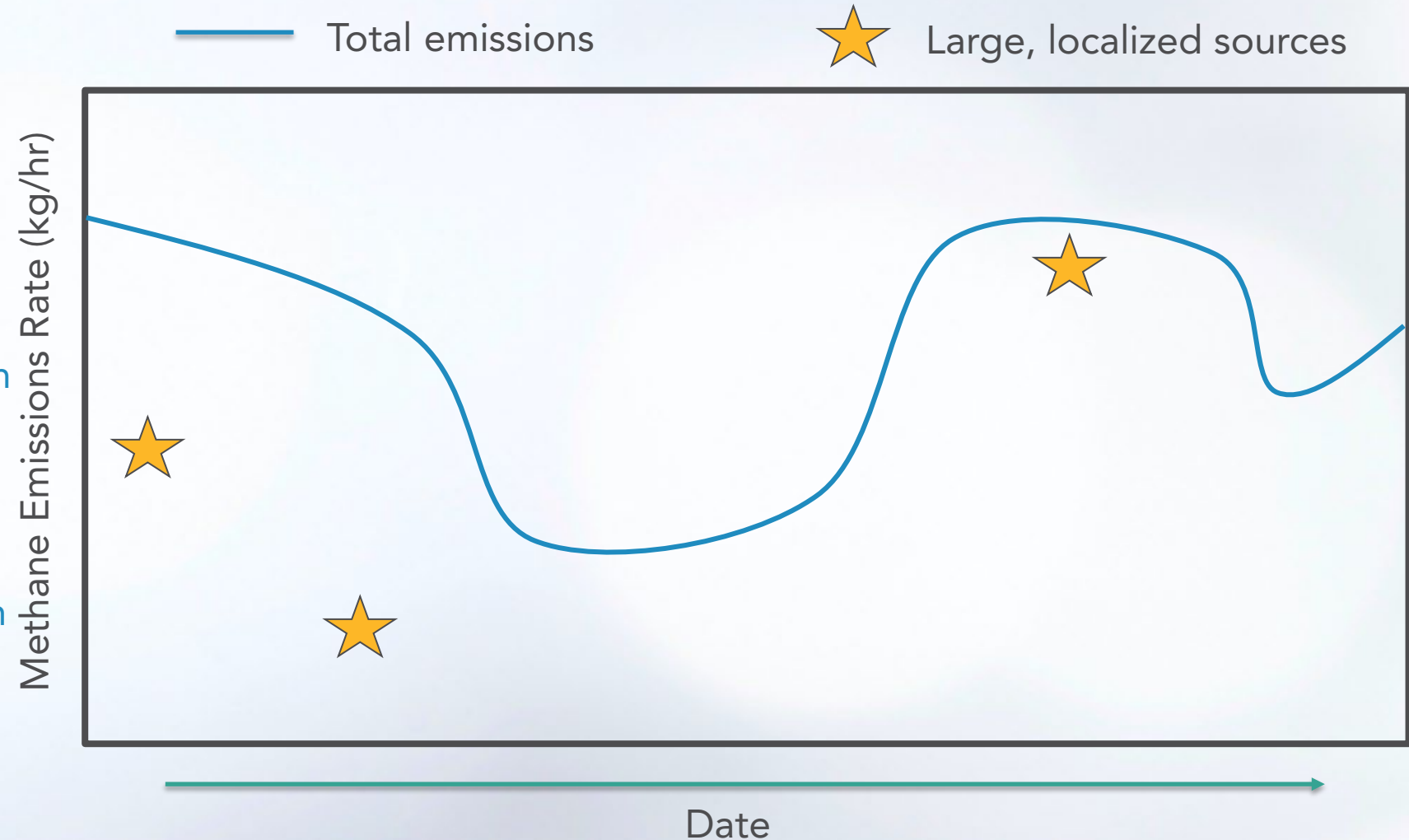
Potential Satellite Monitoring

Example from Carbon Mapper



Which Types of Research Studies would enable better stock take?

1. *Technology demonstration:* Is there a reliable technology that can give us continuous monitoring of total landfill emissions?
2. *Scaling up:* Can we place this technology on a statistically robust number of landfills? Can we leverage these data to provide statewide insights?
3. *Optimization:* Which complimentary data can be best used on coordination with these data? Which conditions and practices are associated with lower emissions?





Thank You!

