Building a scientific basis for tackling anthropogenic methane emissions

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Methane mitigation: challenge & opportunity

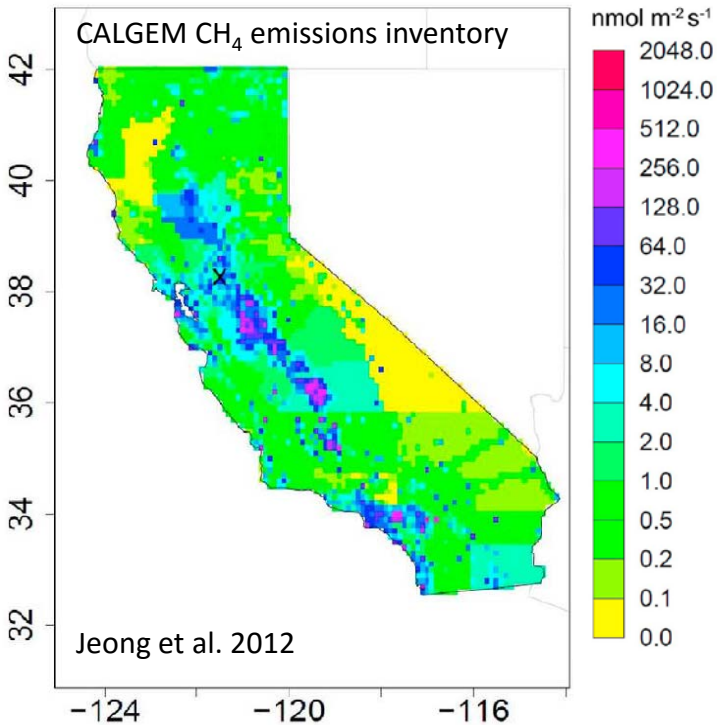
Reasons to mitigate CH_4

- Use natural gas fuel more efficiently
- Reduce global warming
- Improve safety and air quality
- Technologically and economically feasible

AB 32: Global Warming Solutions Act of 2006

California required by law to reduce statewide greenhouse gas emissions by 25% from 2006 levels

Inventory: CH_4 emissions concentrated in the Central Valley and greater Los Angeles



South Coast Air Basin (Greater Los Angeles):
43% of population
35% of CO_2
~30% of CH_4

Methane mitigation: challenge & opportunity

Barriers to mitigating CH_4

We lack basic knowledge of CH_4 emission sources

- Locations
- Relative strengths
- Most effective mitigation solution
- Cost of mitigation
- Who is responsible

Anthropogenic methane emissions

Inventoried global and urban methane emissions by sector for year 2000, from the work of Marcotullio et al. (ref. 103).

Sector	Global Emissions[a]	percent of total CH_4	Urban CH_4 as percent of sectoral CH_4	Urban CH_4 as percent of total CH_4
Agriculture	168	54	5	3
Energy	74	24	42	10
Waste	69	22	40	9
Transportation	1	0	43	<1
Total	312	100		21

[a]Emissions are given as Tg CH_4-y^{-1}.

Hopkins et al., in review

Agriculture is the largest source globally

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Energy, waste, transportation are concentrated in urban areas

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Urban methane emissions

- Large and growing with global urbanization and increasing use of natural gas (and biogas) fuels
- Concentrated in urban setting
- Municipal control/influence over major sources
- Political impetus for action

Urban methane emissions

Why Cities Are Key to Success at the Paris Climate Talks

Local transit and energy initiatives can scale up to significant carbon savings.

LAURA BLISS | @mslaurabliss | Nov 24, 2015 | 9 Comments

Bliss, L. (2015, November 24). Why Cities Are Key to Fighting Climate Change. Retrieved March 24, 2016, from http://www.citylab.com/cityfixer/2014/04/why-cities-are-key-fighting-climate-change/8863/

World mayors sign climate-change pact in Mexico City

NOVEMBER 22, 2010 | 8:23 AM

Hernandez, D. (2010, November 22). World mayors sign climate-change pact in Mexico City. Retrieved March 24, 2016, from http://latimesblogs.latimes.com/laplaza/2010/11/mayors-climate-change-mexico-city.html

California joins other states, provinces in climate change agreement

California Gov. Jerry Brown is surrounded by Chinese delegates after a discussion on energy innovation and reducing carbon emissions in Beijing in 2013. (Andy Wong / Associated Press)

Megerian, C. (2015, May 19). California joins other states, provinces in climate change agreement. Retrieved March 24, 2016, from http://www.latimes.com/local/political/la-me-pc-jerry-brown-california-international-climate-change-20150519-story.html

Framework for methane emissions

Detection: surveys to find large methane emission sources

Attribution: use imagery, spatial patterns and tracer species to determine sources and their contributions to total emissions

Quantification: calculate CH_4 flux using seasonally averaged data and relationships between urban trace gas emissions

Mitigation: how effective are current mitigation approaches

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Mitigation: how effective are current mitigation approaches

Detecting methane emissions at the city scale: mobile laboratory observations

Ford Transit van with modified electrical system and sampling snorkel

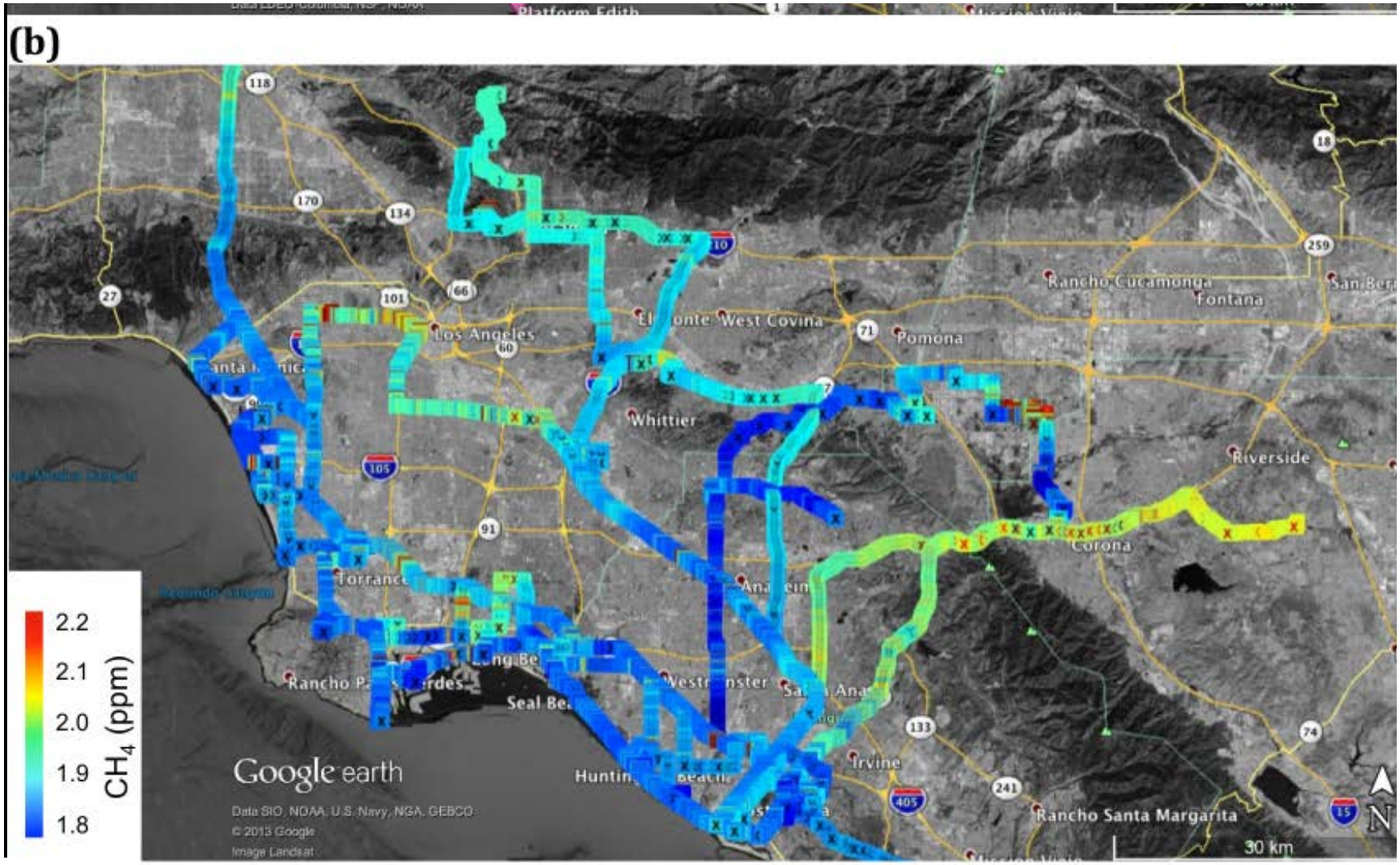
Collaboration between UC Irvine, University of Utah, San Diego State

Deployed in Los Angeles, Salt Lake City, and San Diego

High-frequency trace gas measurements using newly available, state-of-the-art instruments

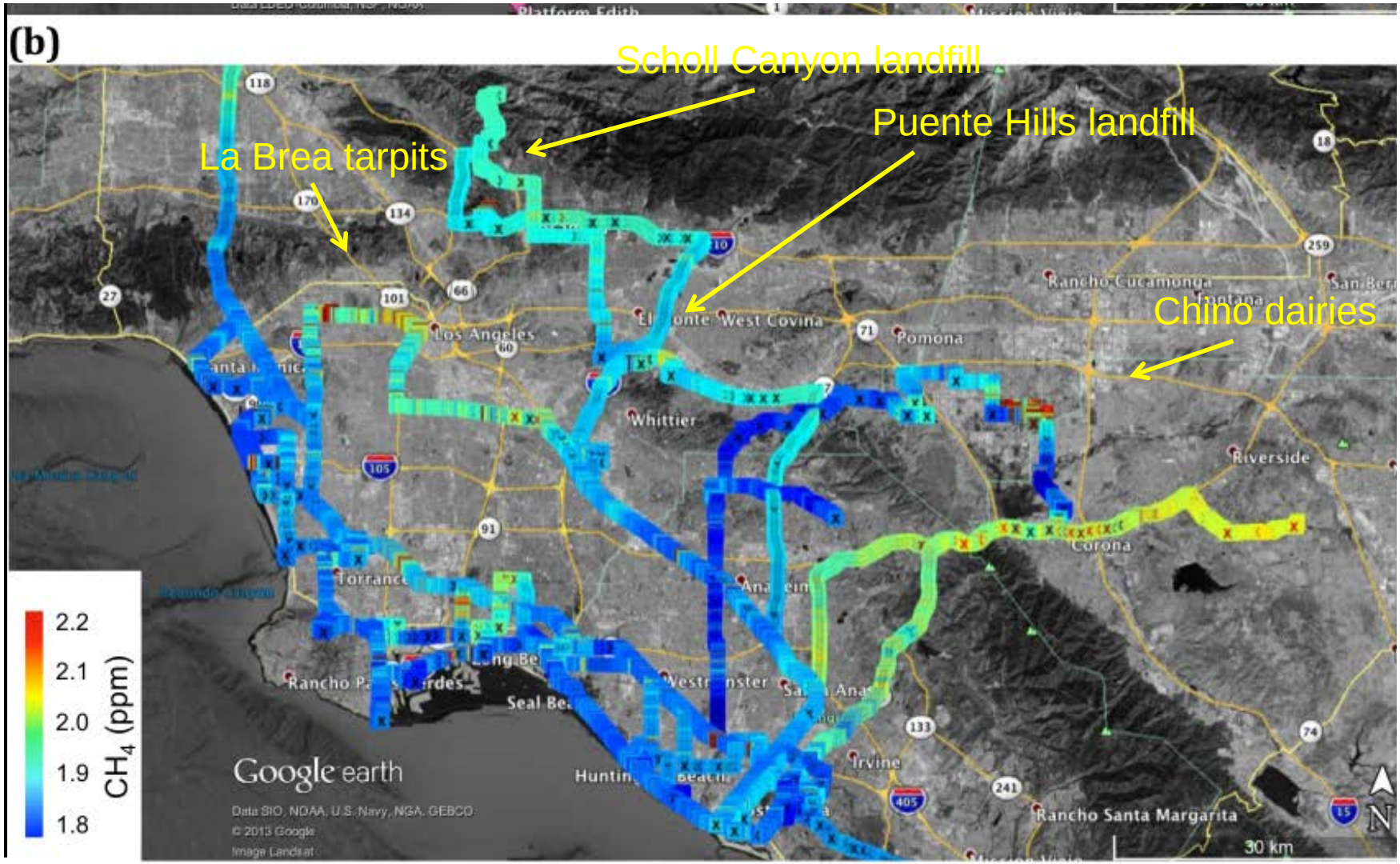
Measurements of greenhouse gases and criteria pollutants: CO_2, CH_4, CO, C_2H_6, O_3

Methane hotspots are ubiquitous across the LA Basin



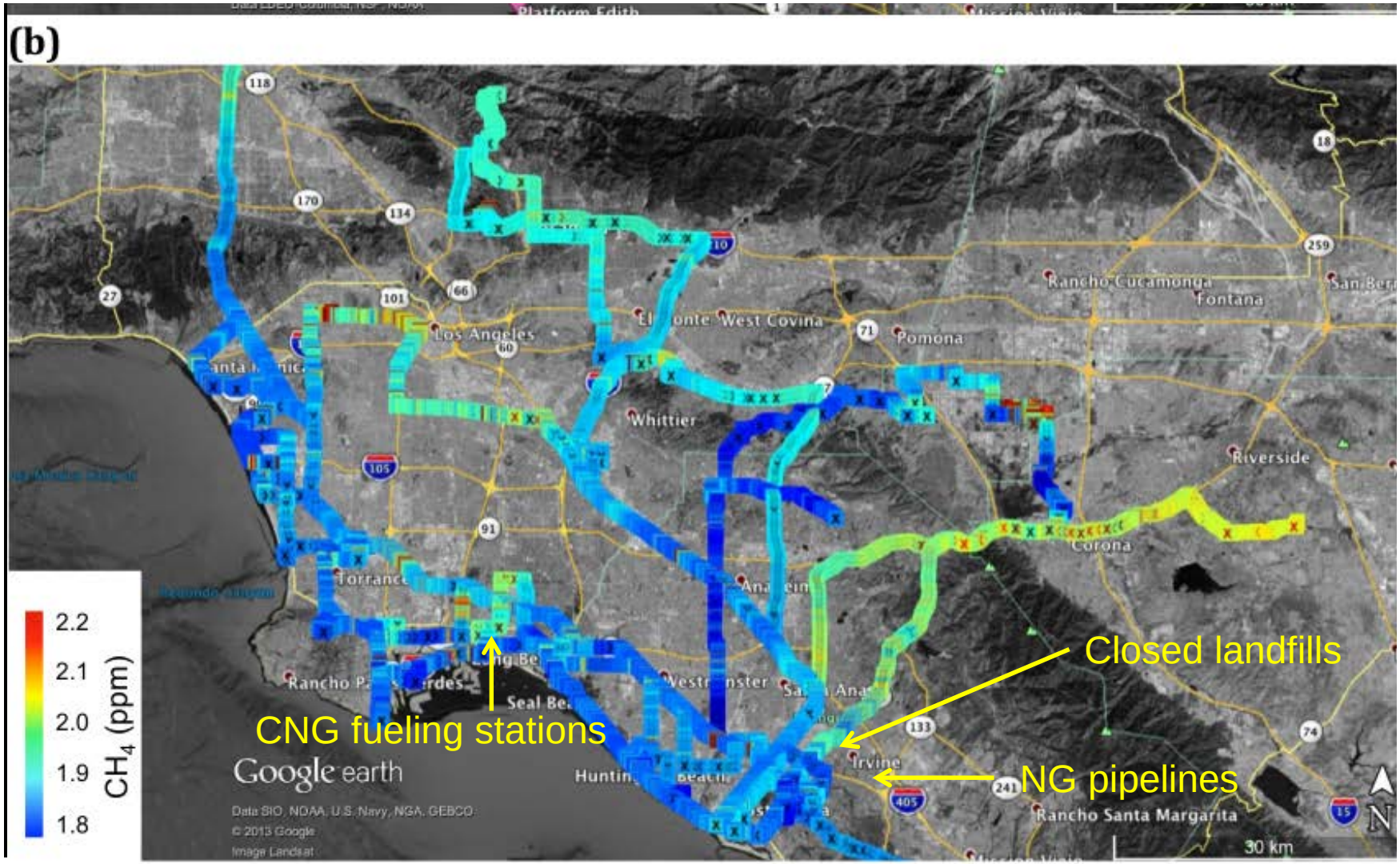
Hopkins et al., 2016

Some methane hotspots are well known



Hopkins et al., 2016

Other methane hotspots are uninventoried



Hopkins et al., 2016

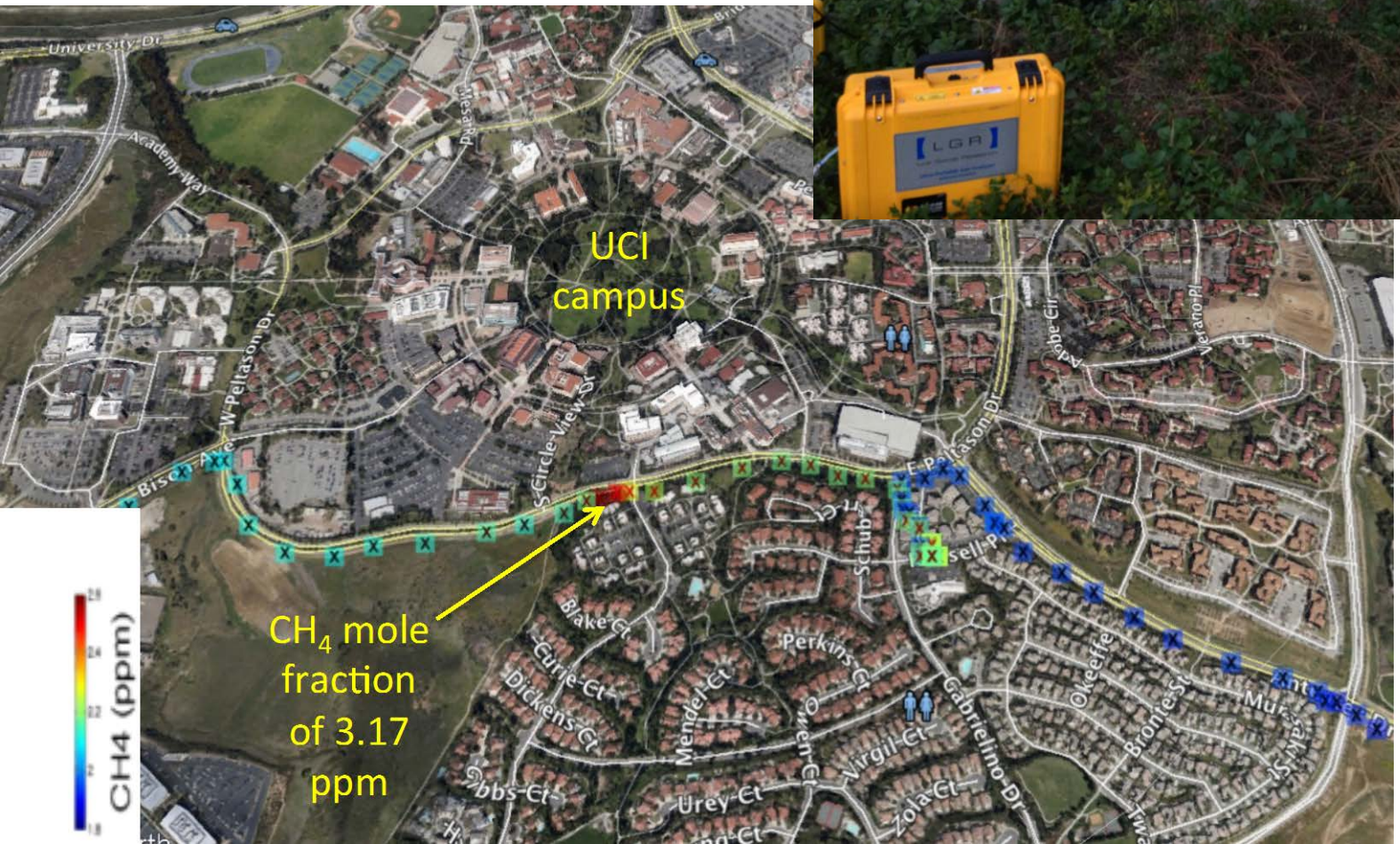
Sources of methane: CNG filling stations

Clean Energy-Santa Ana CNG station

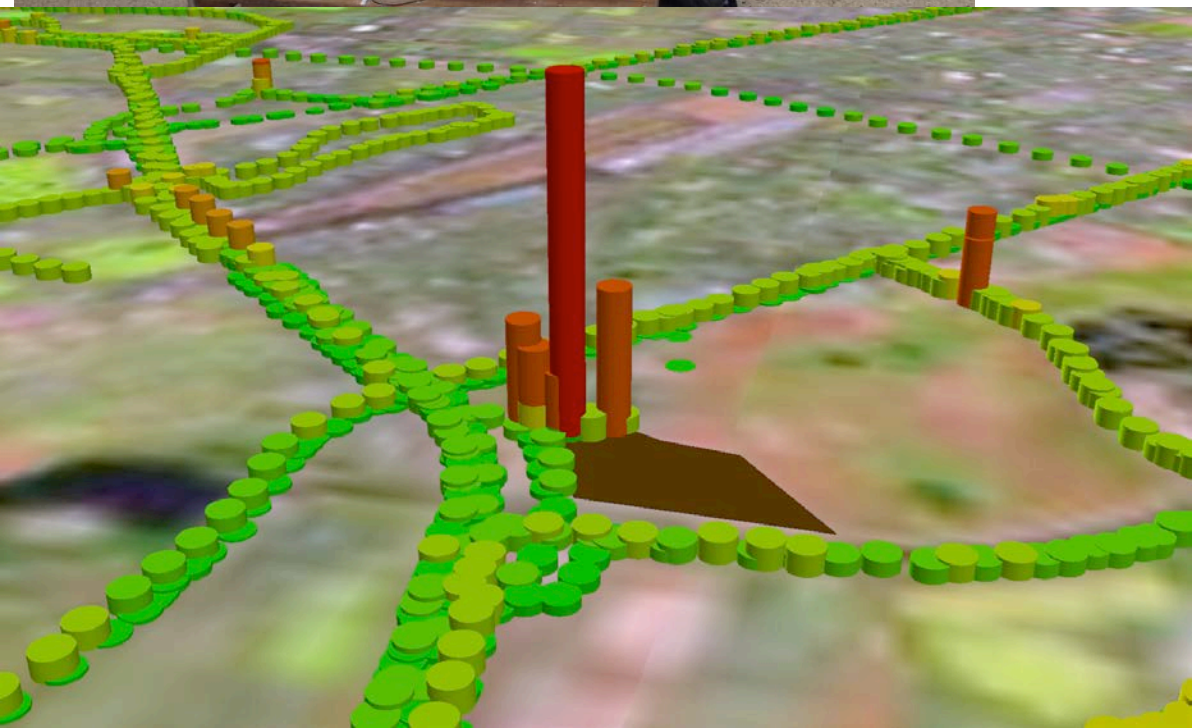
Plot by Valerie Carranza

Not included by most inventories

Natural gas pipeline leaks detected on road: About 100x rarer in LA than in DC or Boston



Old landfill on UC Irvine campus: persistent CH_4 hotspot



Local CH_4 mixing ratio enhancement above background levels

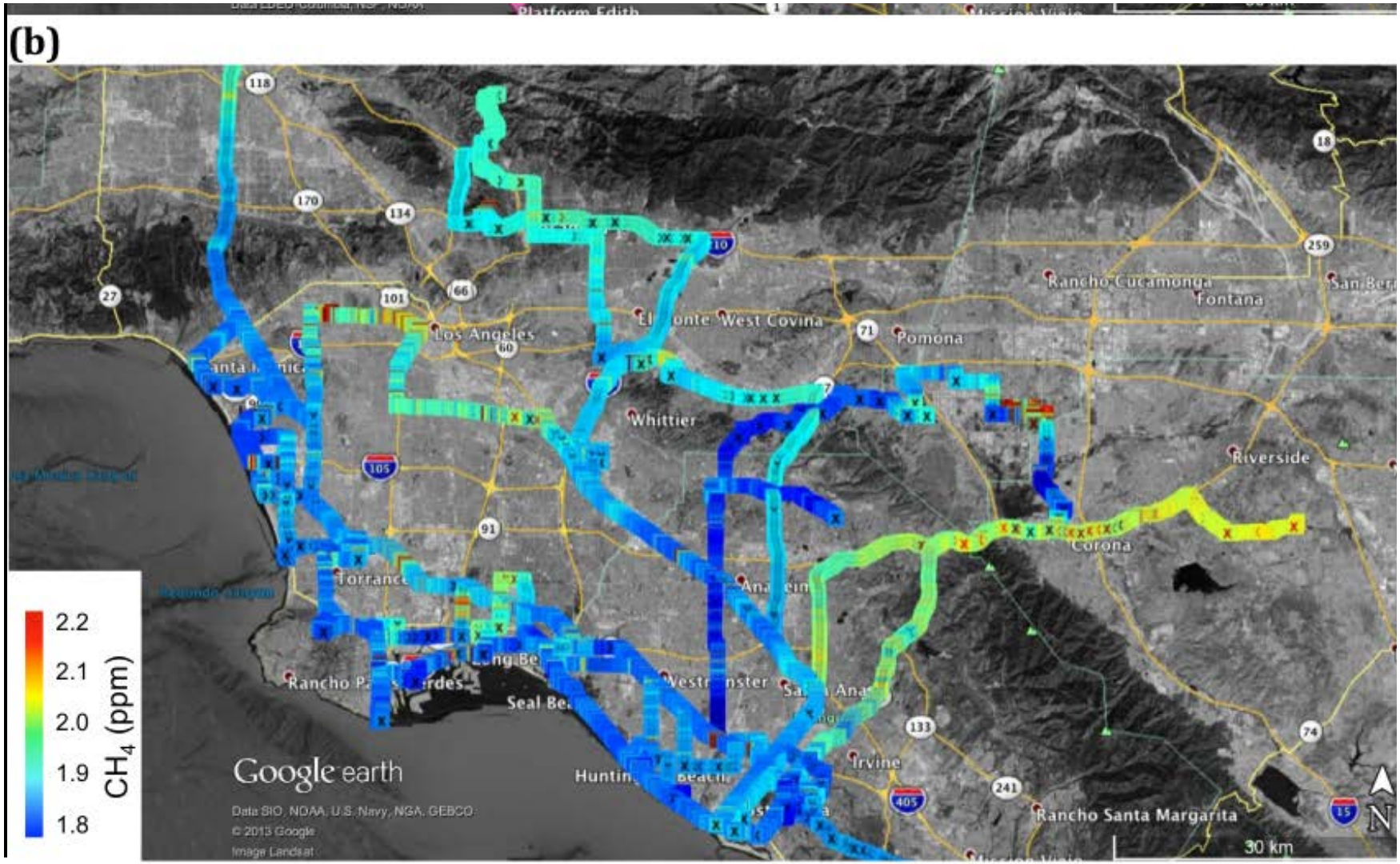
- 0-100 ppb
- 100-200 ppb
- 200-300 ppb
- >300 ppb CH_4

Landfill mitigation practices may not be minimizing CH_4 emissions

- Imaging with long wave infrared camera

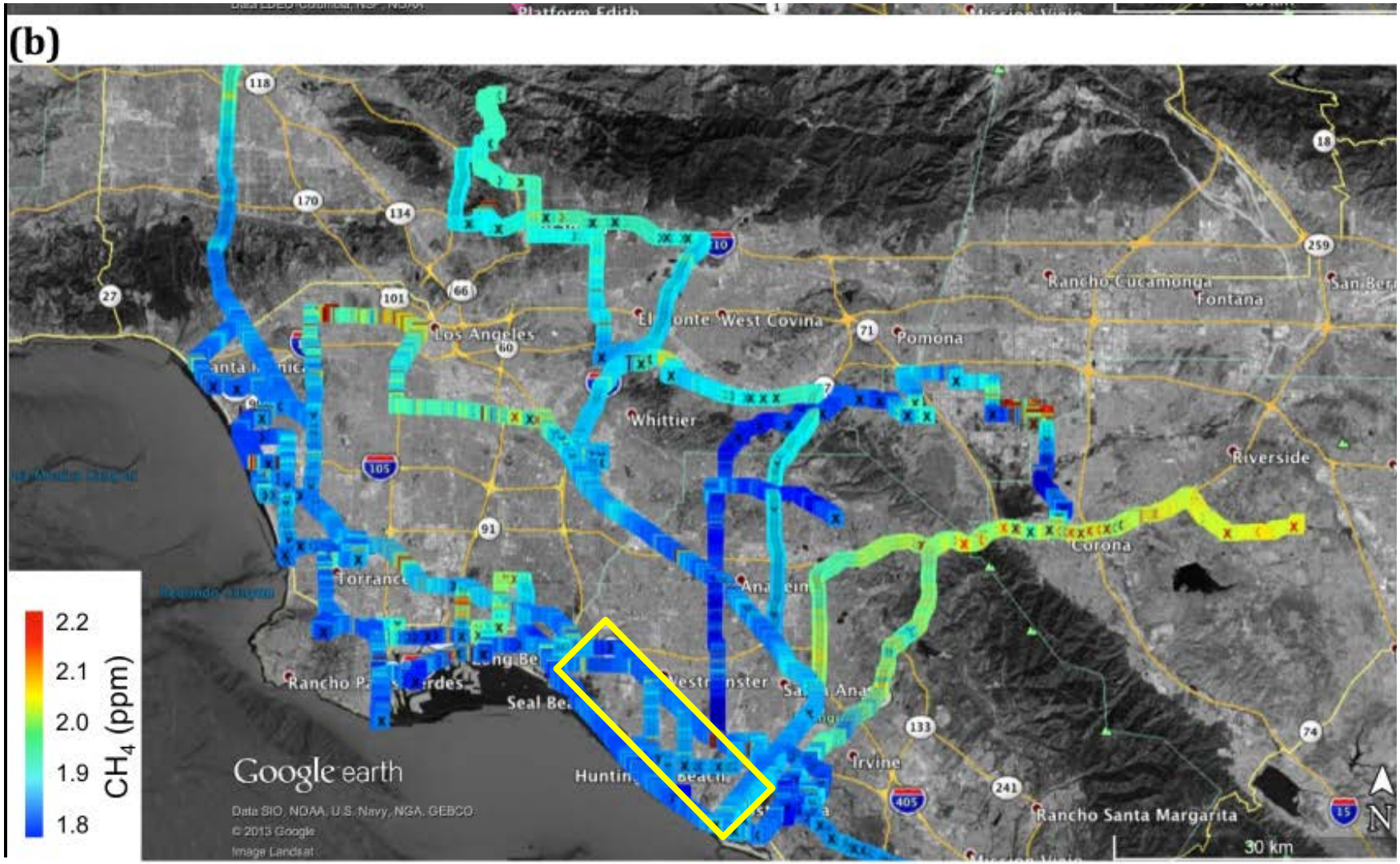
Plume imagery video courtesy of Bill Johnson

213 methane hotspots had unknown sources



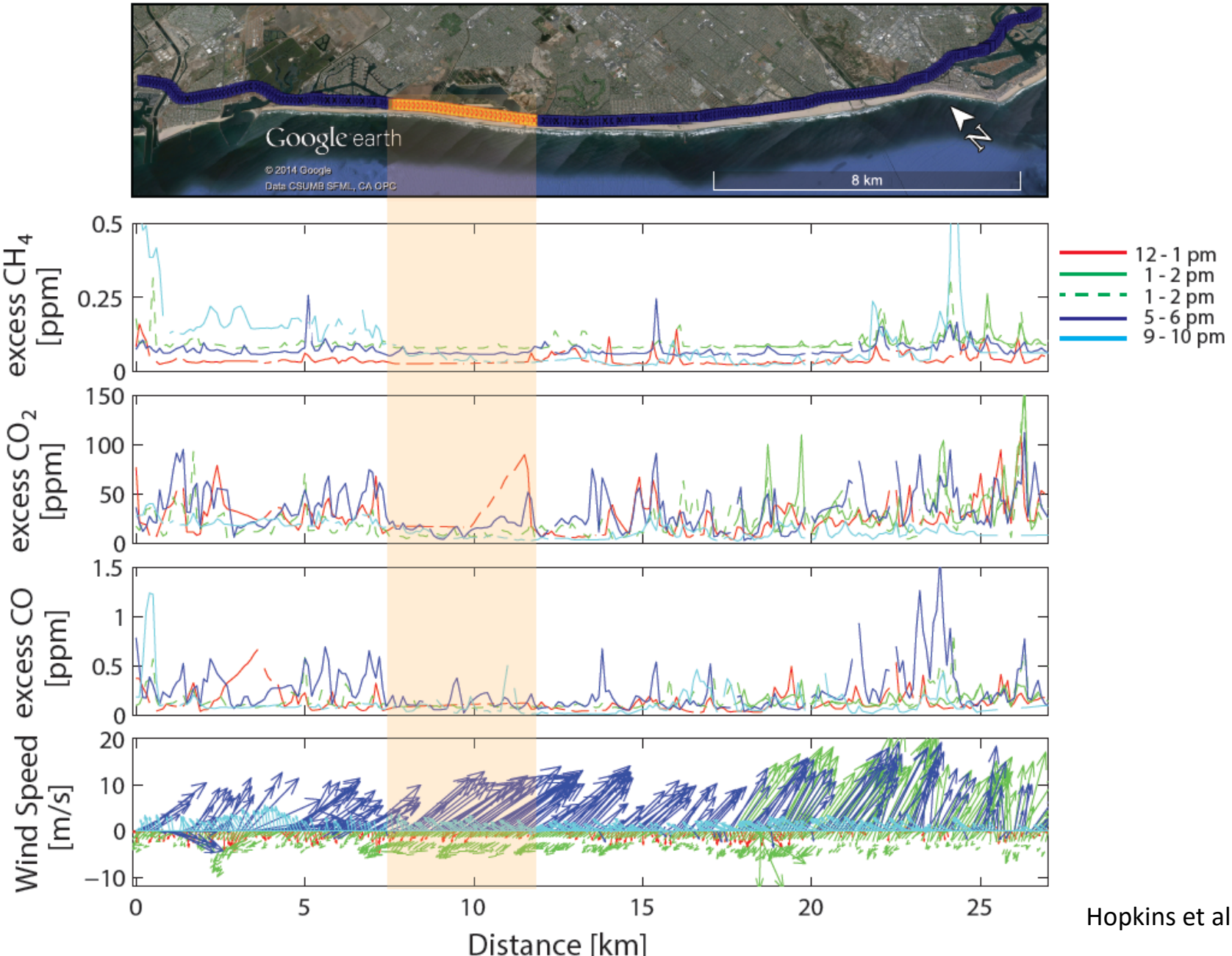
Hopkins et al., 2016

212 methane hotspots had unknown sources



Hopkins et al., 2016

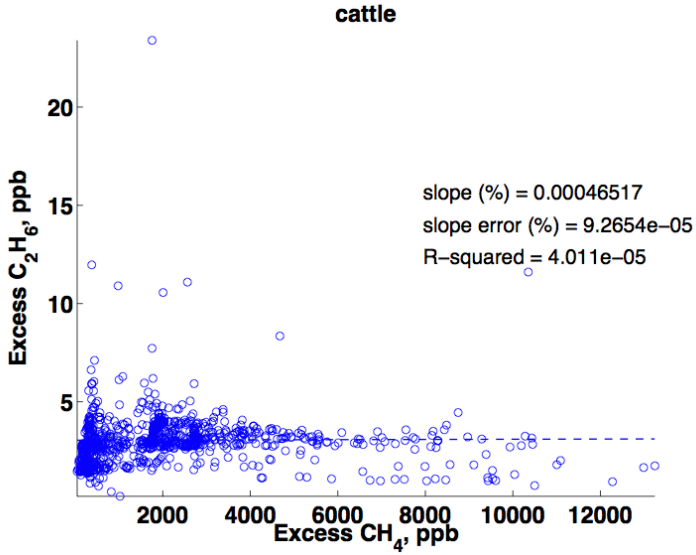
Unknown hotspots: repeatable and of urban origin



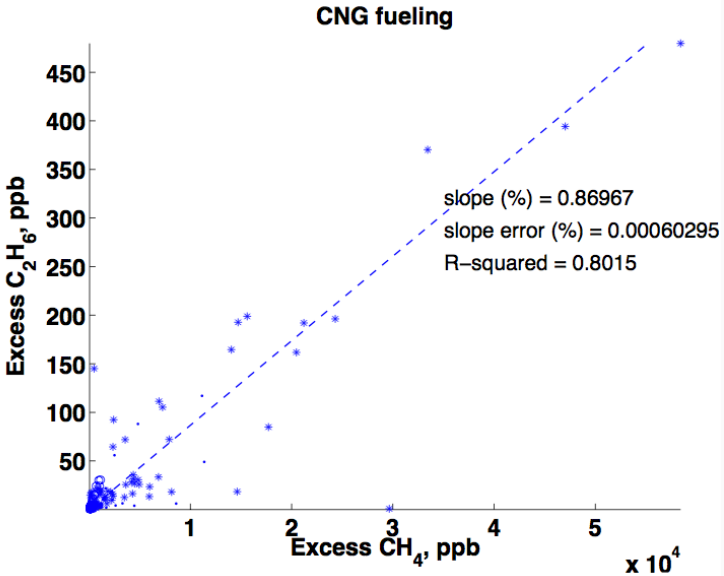
Hopkins et al., 2016

Mobile laboratory: directly measure emissions ratios of C_2H_6 to CH_4 for known CH_4 sources

Biogenic CH_4

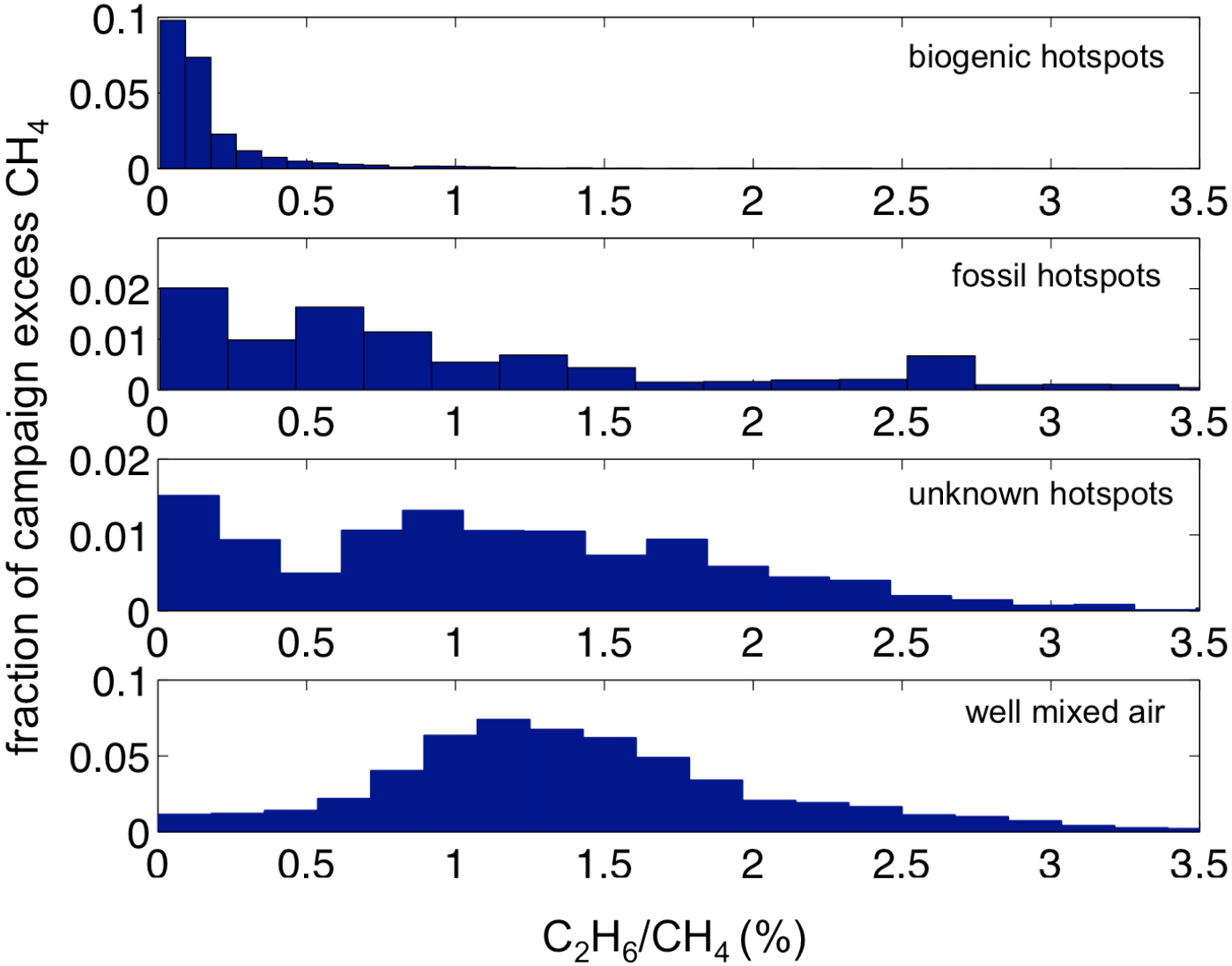


Fossil CH_4

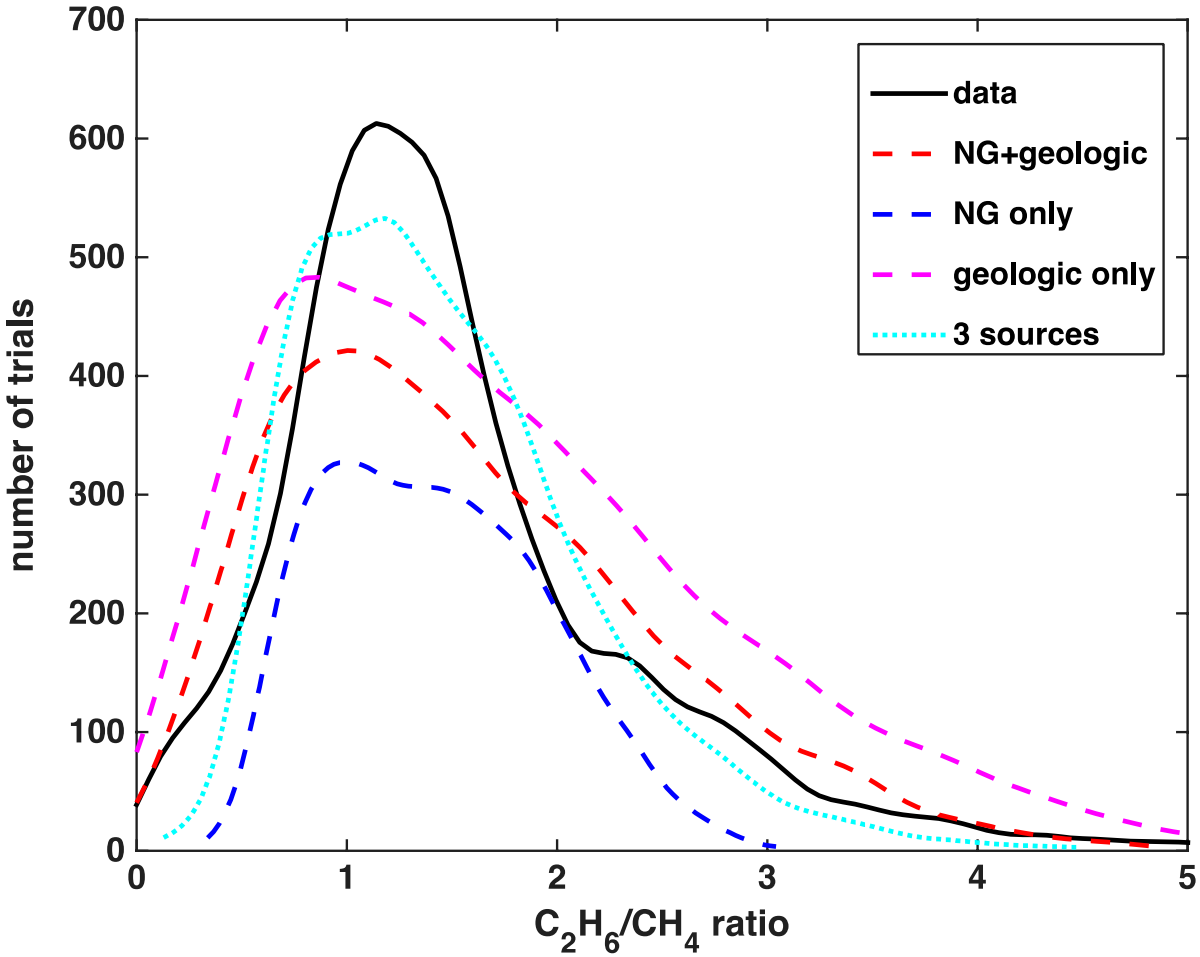


Source apportionment

212 unknown hotspots: 40 biogenic, 161 fossil,
(11 indistinguishable)



Regional scale source apportionment



Fossil source contribution: 62% (59-64%)

Biogenic source contribution: 38% (36-41%)

State inventory: >80% biogenic

Hopkins et al., 2016

Framework for methane emissions

Detection: on road surveys to find the leaks

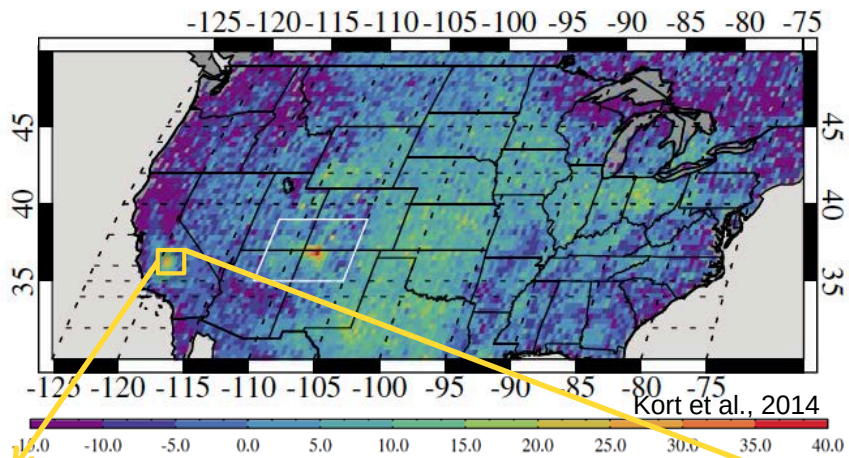
Attribution: use spatial patterns and tracer species to determine sources and their contributions to total emissions

Quantification: calculate CH_4 flux using seasonally averaged data and relationships between urban trace gas emissions

Mitigation: how effective are current mitigation approaches

Satellite CH_4 detection and airborne follow up

SCIAMACHY 2003-2009 avg. CH_4 anomaly (ppb)



Kort et al., 2014

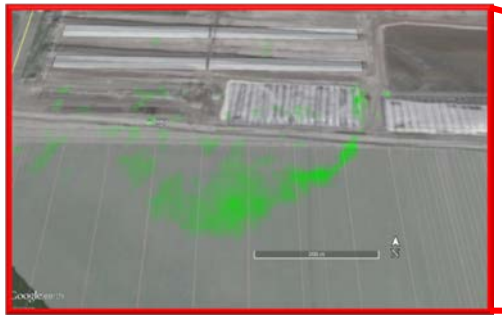
A methane hotspot in the Central Valley has been observed from space (Kort et al. 2014)

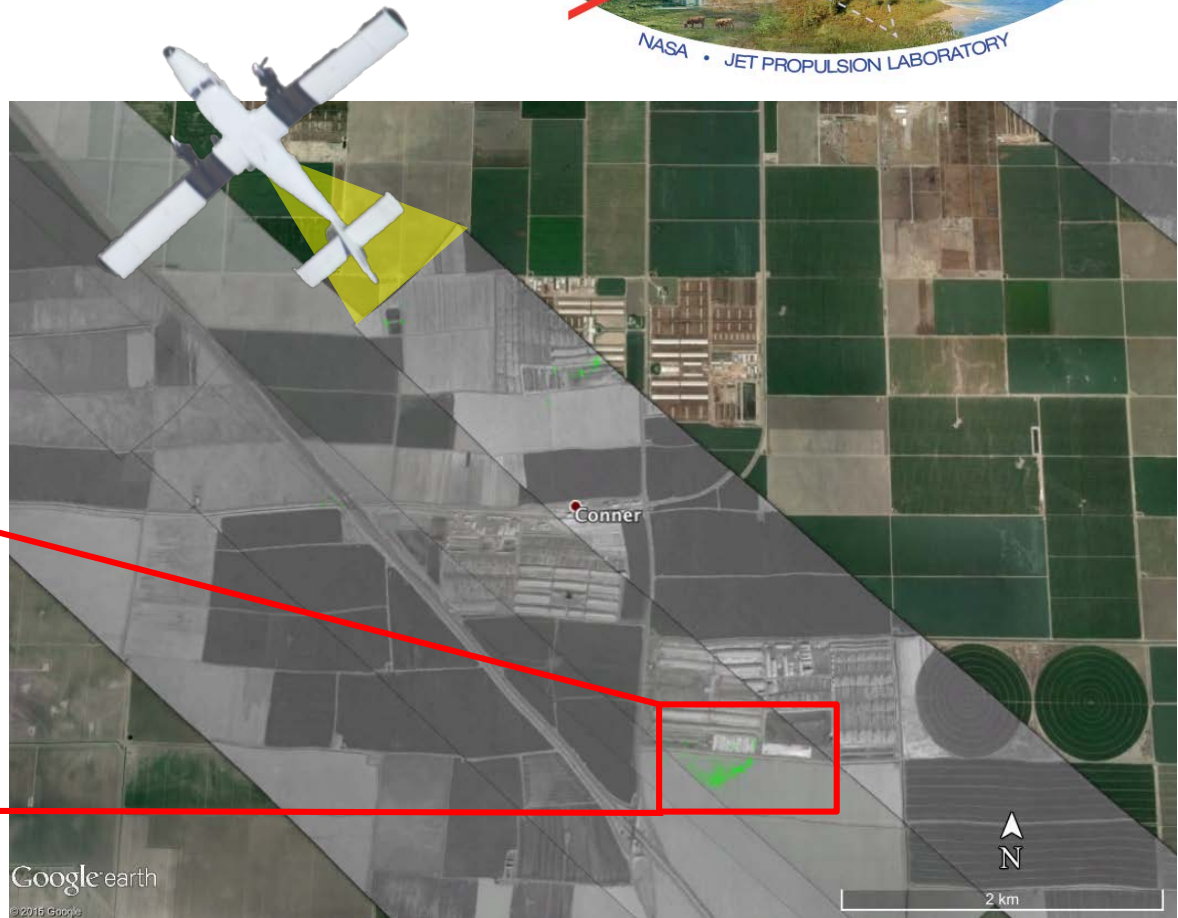
Large areas of oil extraction and dairies are large methane sources

Airborne CH_4 imaging: detection and attribution

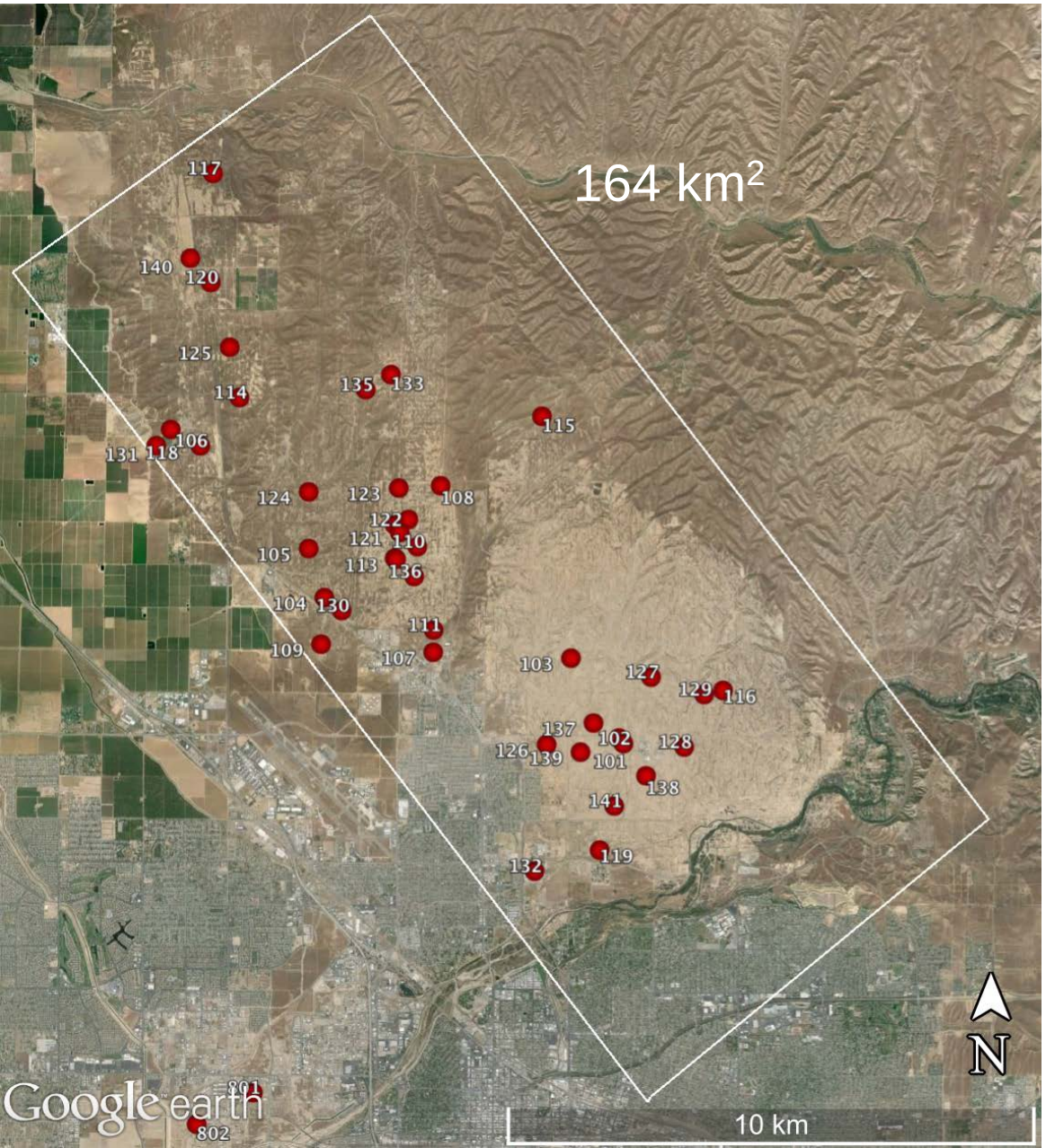
HyTES: airborne imaging spectrometer
256 spectral channels between 7.5 and 12 μm
512 pixels cross track

Line-by-line retrievals (Glynn Hulley, JPL): Repeated surveys to image CH_4 plumes





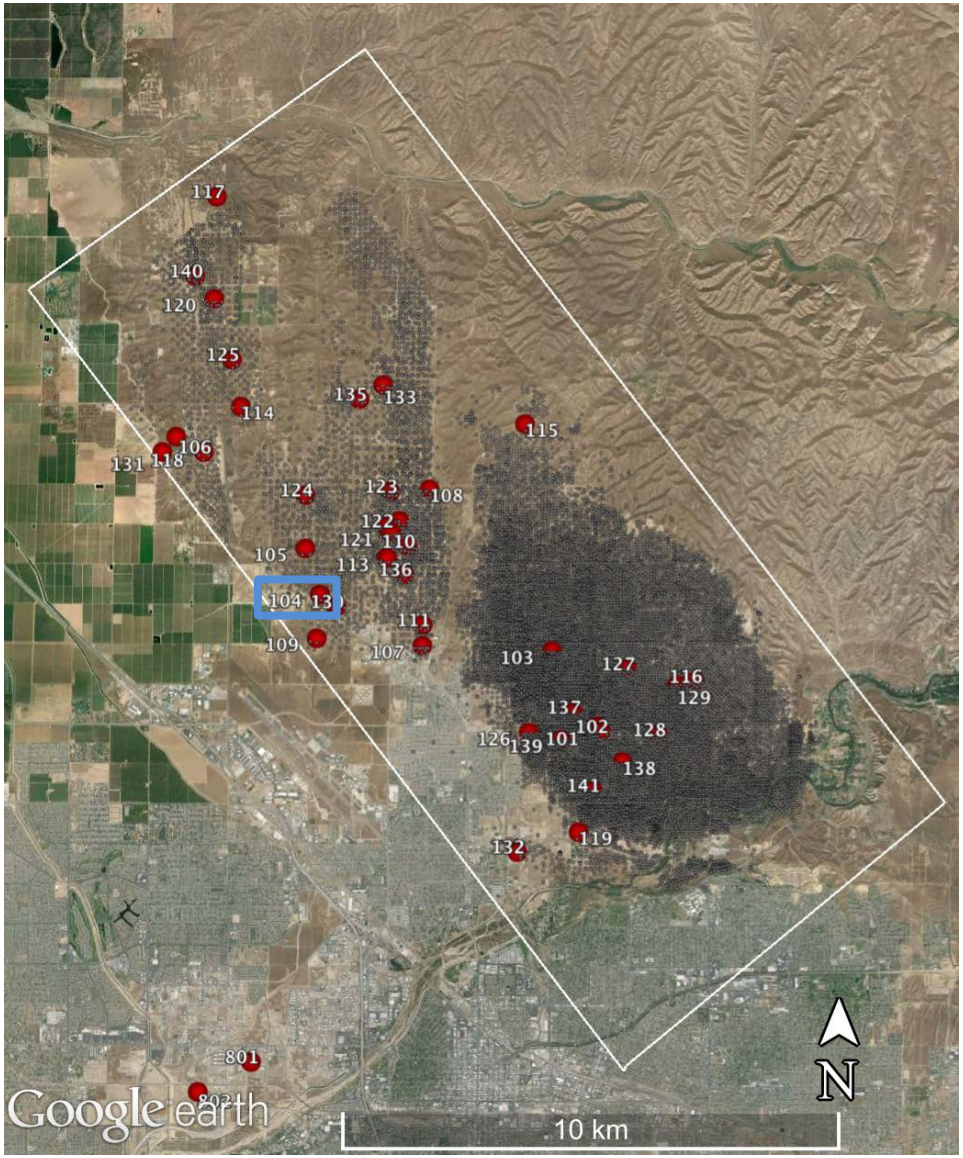
Kern River oil field

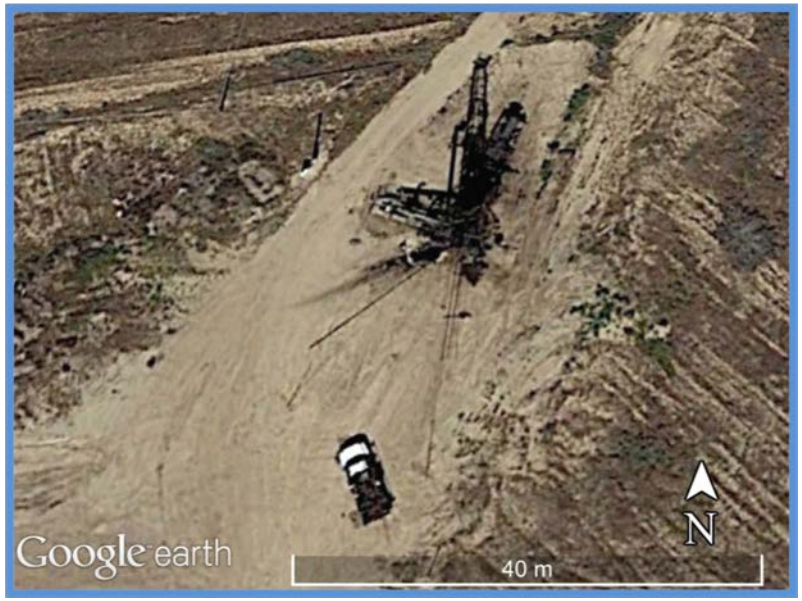


- 40 plumes in distinct locations
- 28 plumes were repeatable (n≥2)
- Several different source types

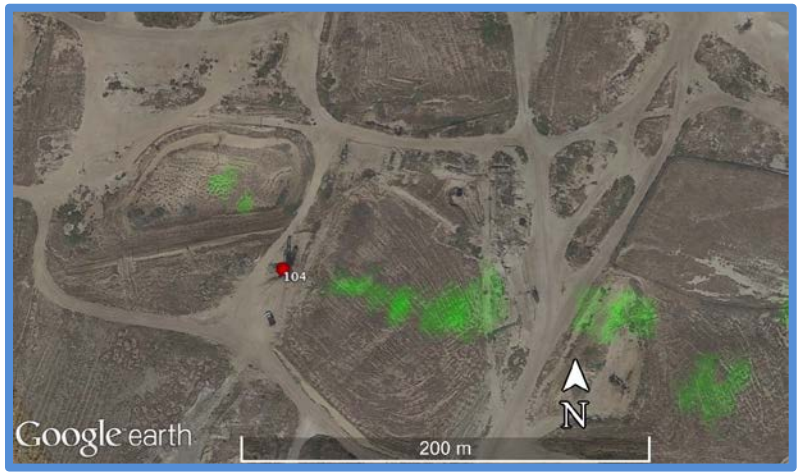
Kern River oil field: oil wells

Plumes observed at 9 of 14143 wells sampled



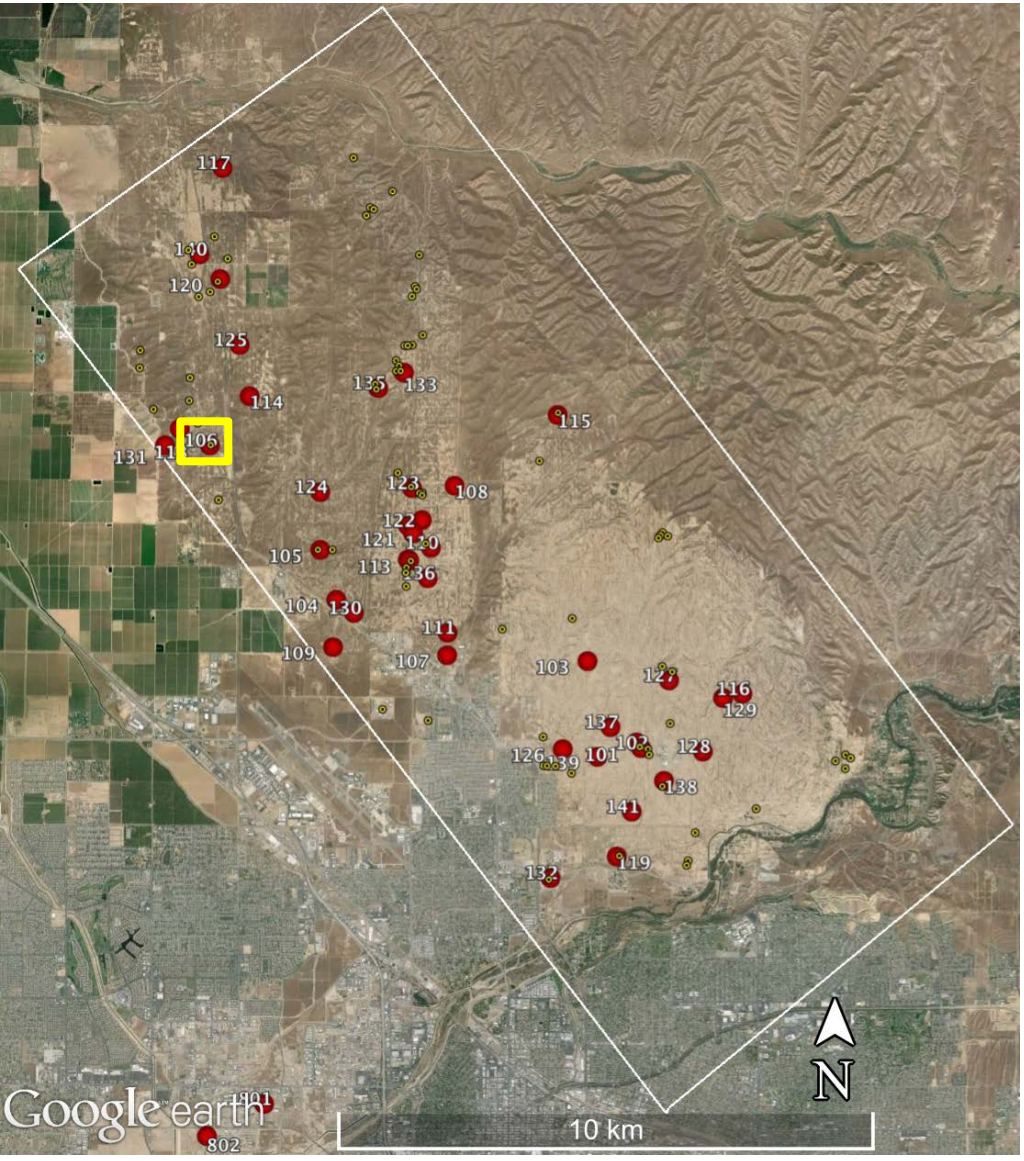


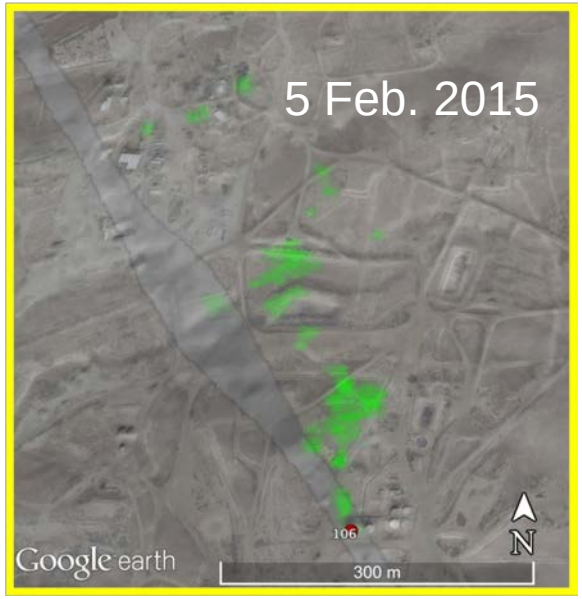
9 Feb. 2015



Kern River oil field: tanks

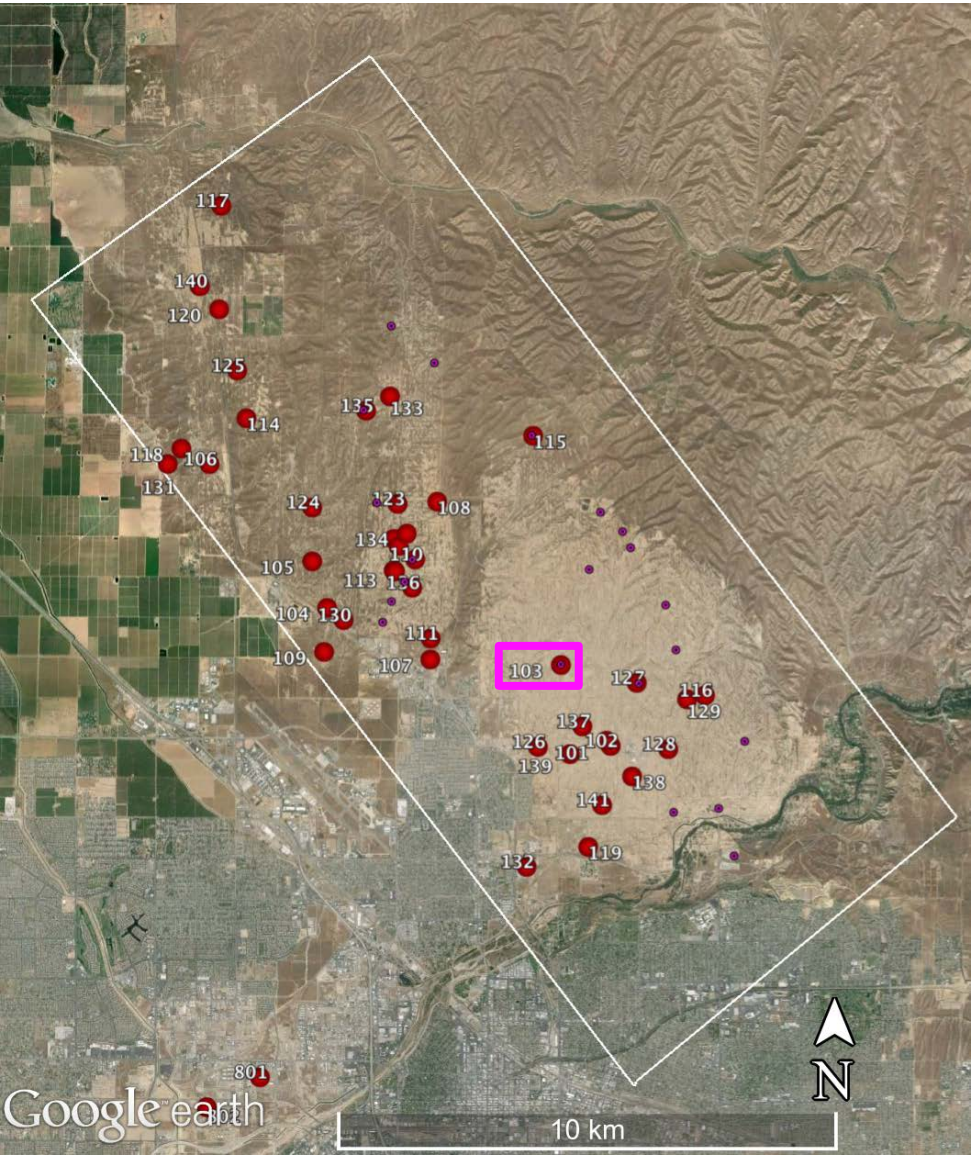
Plumes observed at 10 of 78 tanks sampled





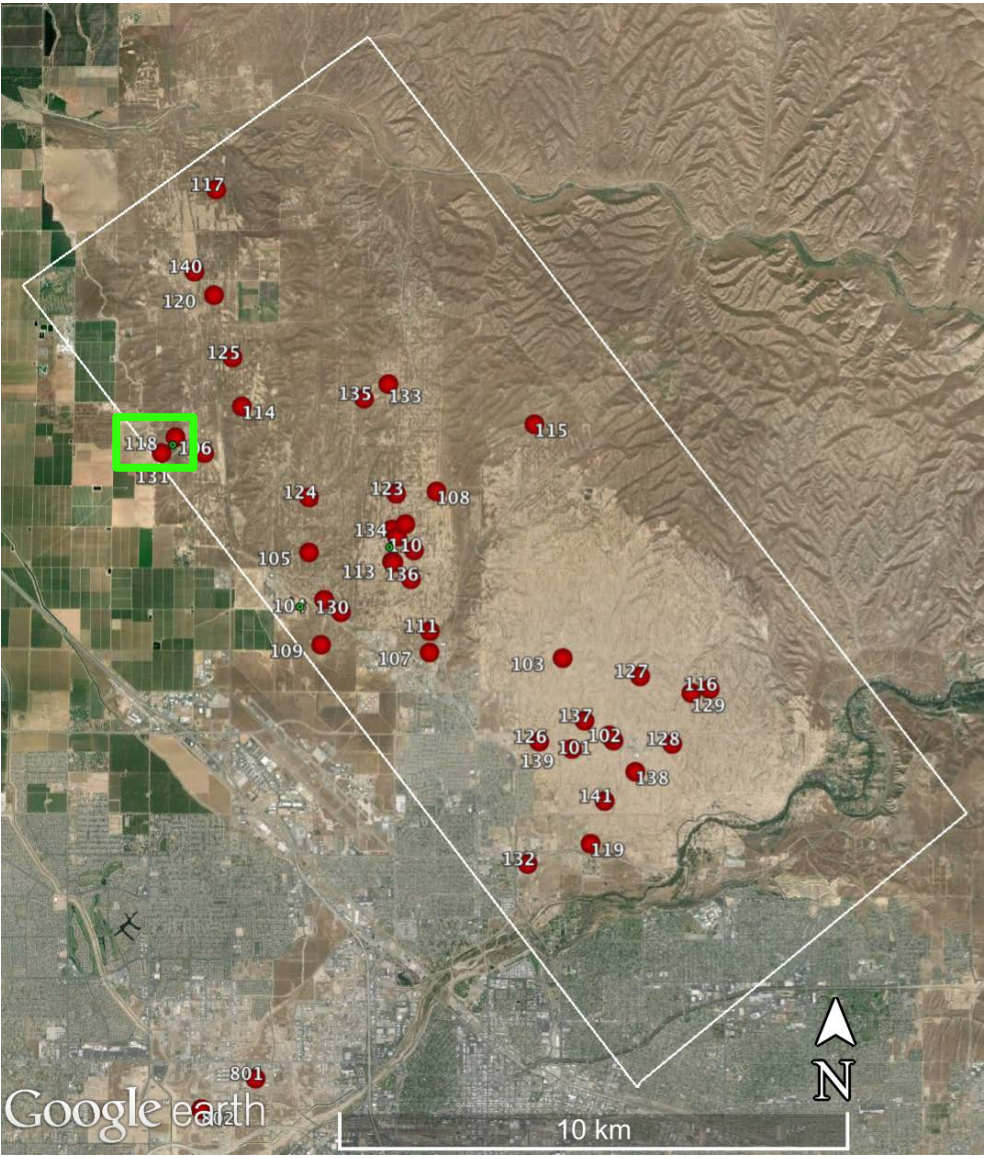
Kern River oil field: facilities

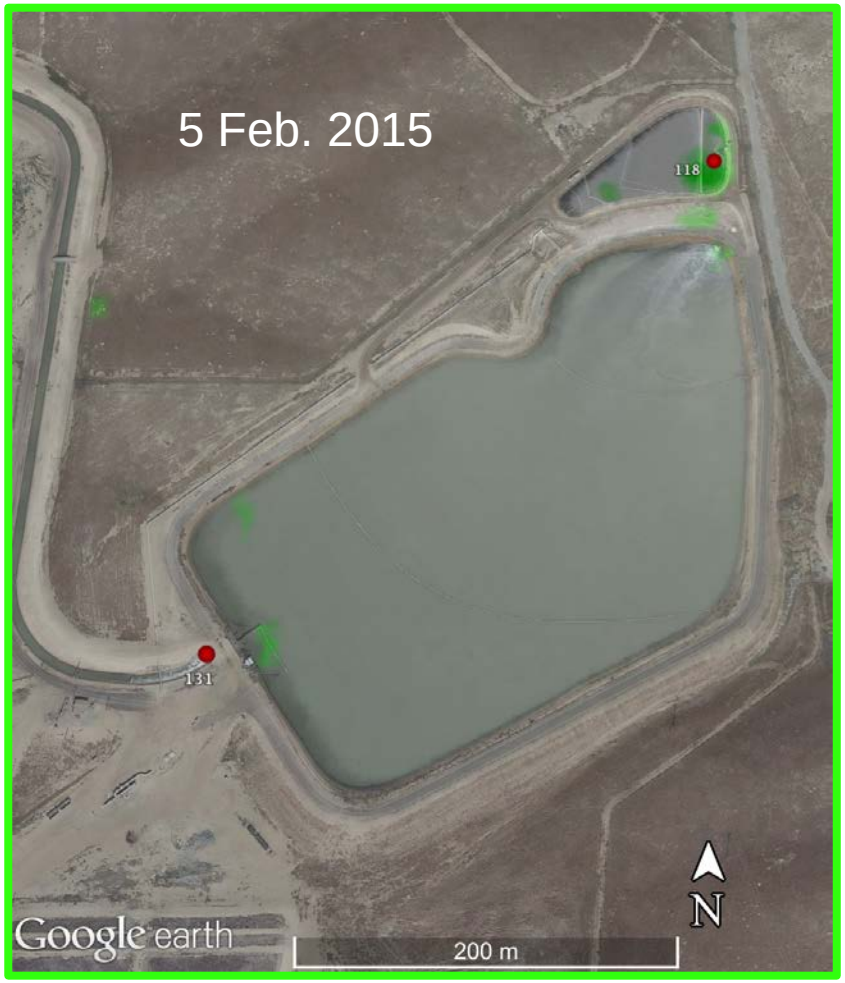
Plumes observed at 7 of 21 facilities sampled



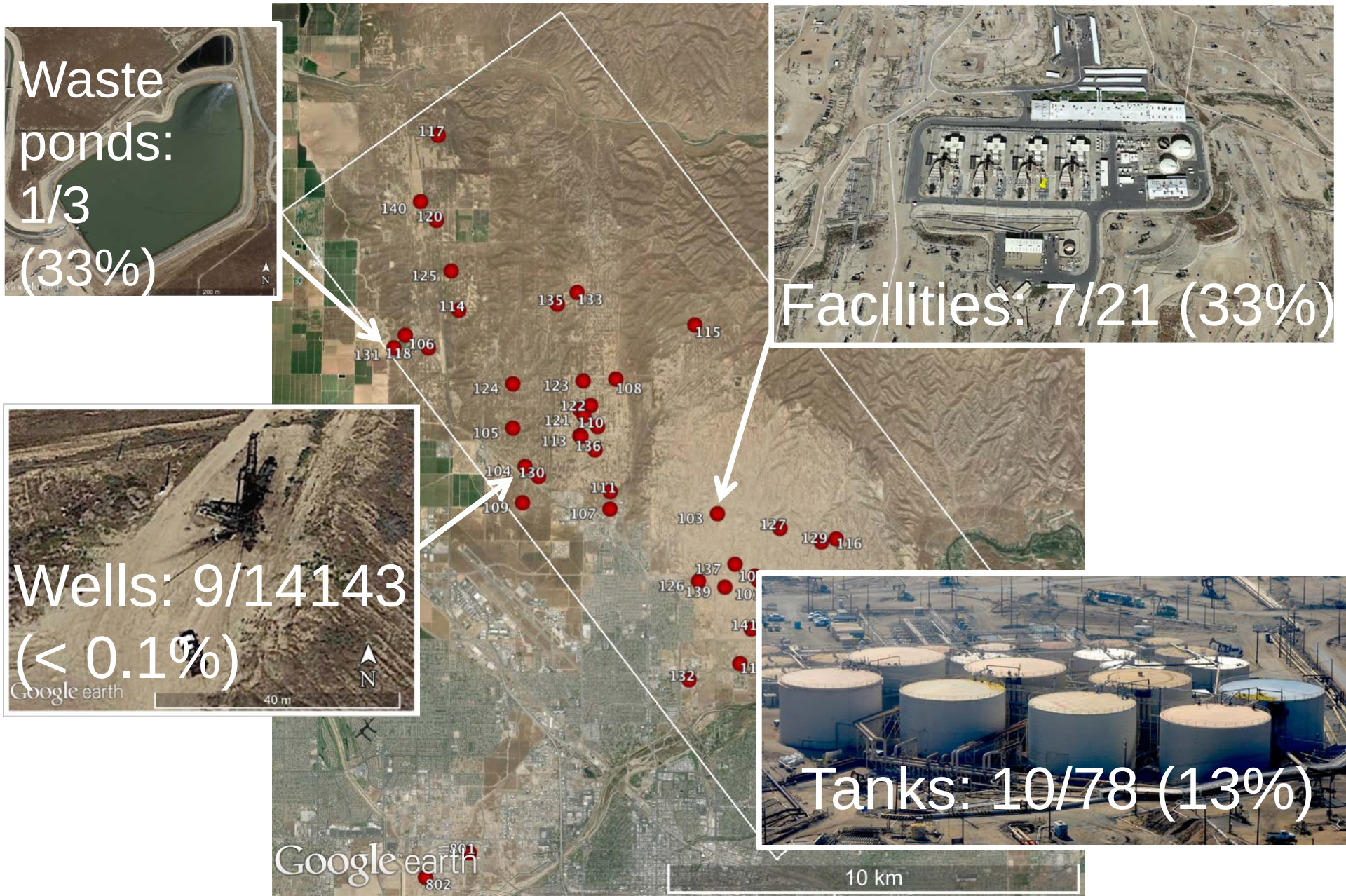
Kern River oil field: waste ponds

Plumes observed at 1 of 3 waste ponds sampled



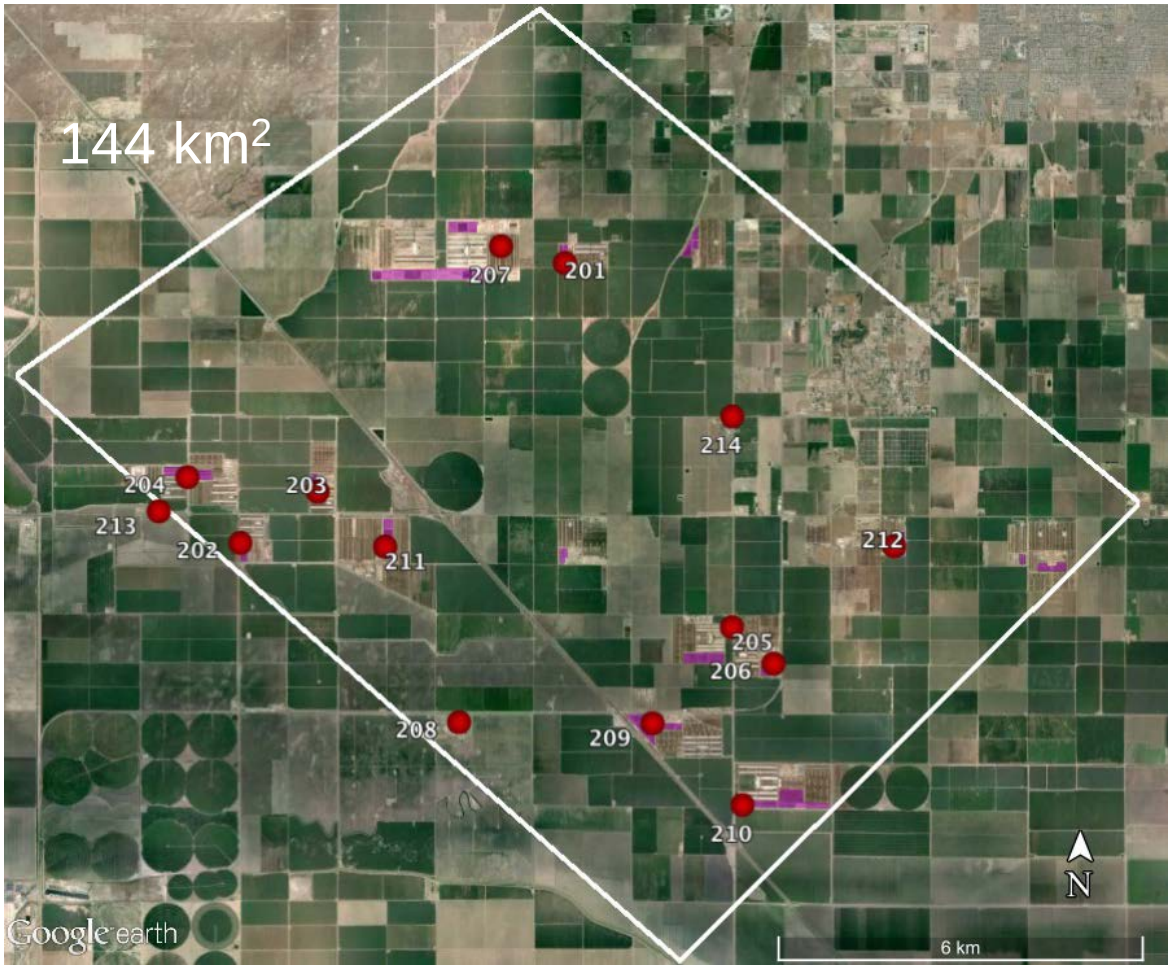


HyTES observations: Kern River oil field

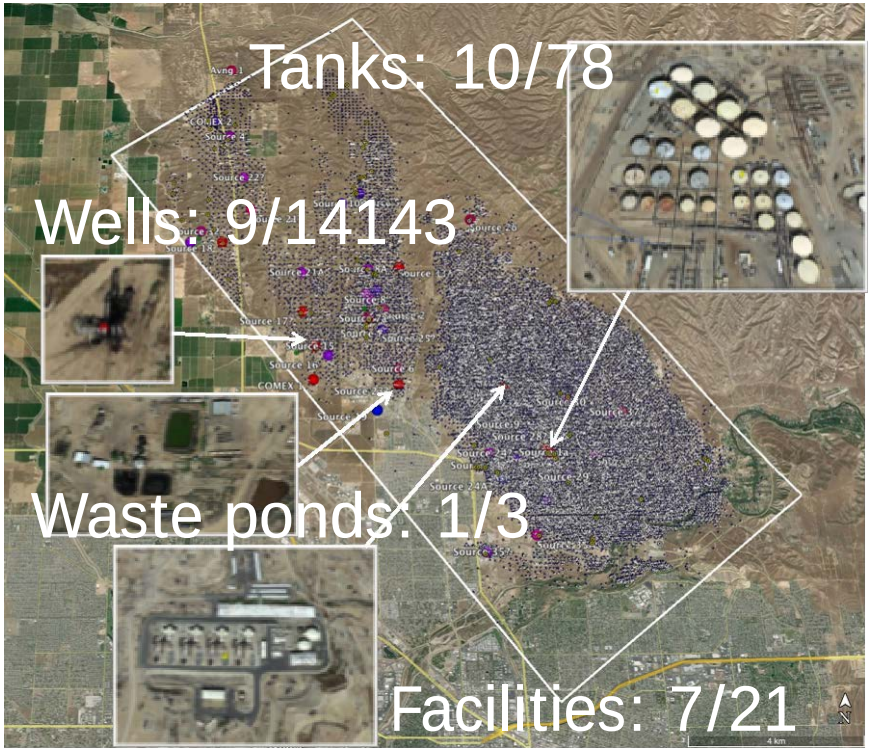


HyTES observations: Kern County dairies

14 plumes in distinct locations
11 plumes were repeatable (n≥2)
All plumes appear to come from manure lagoon systems

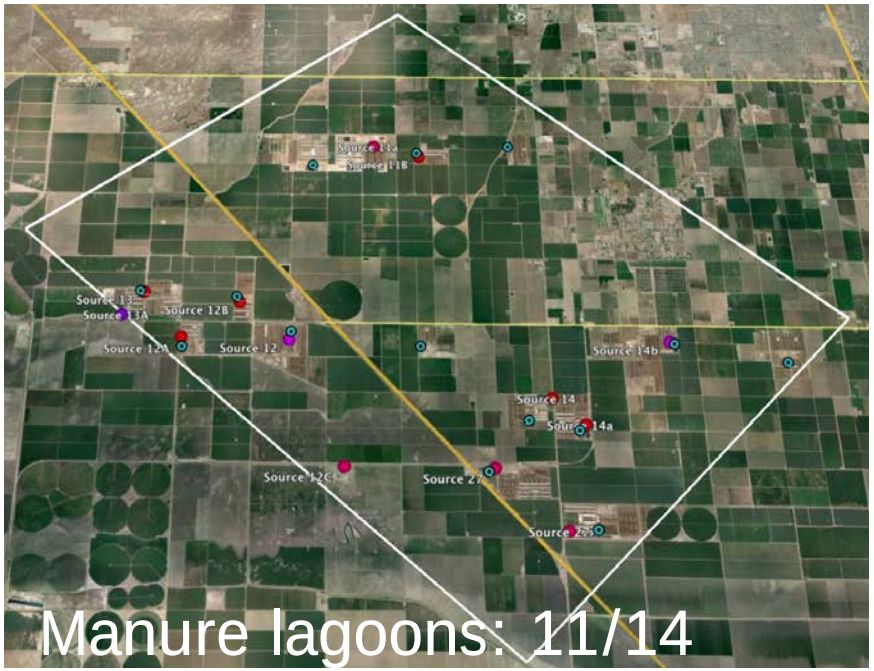


CH_4 observations in California's Central Valley



Dairies:

- CH_4 sources are all associated with wet manure management
- Most lagoons are leaky

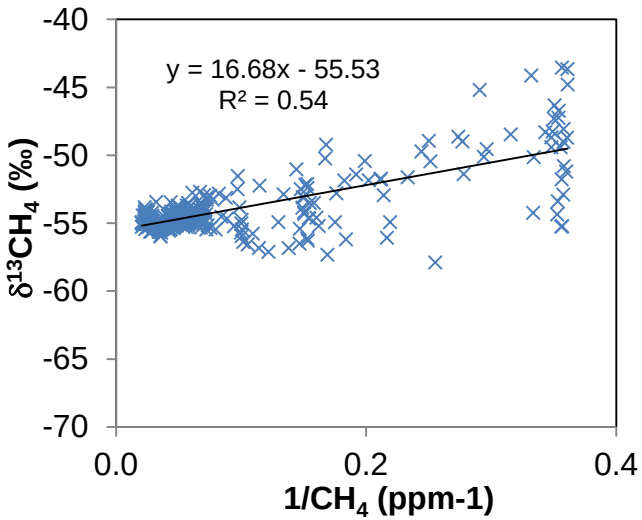


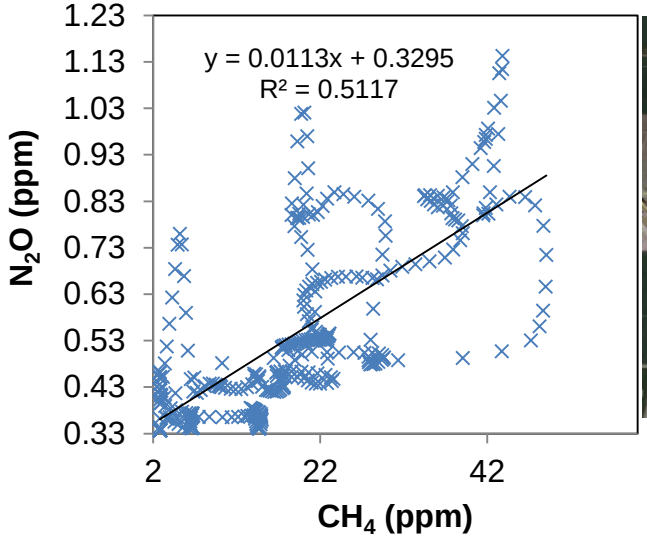
Oil field:

- several different CH_4 sources
- different sectors have different leak rates

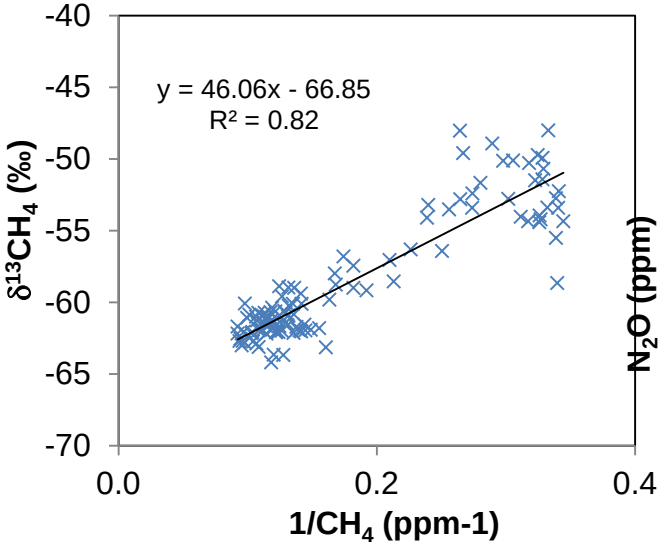
San Joaquin Valley mobile measurements of methane tracers

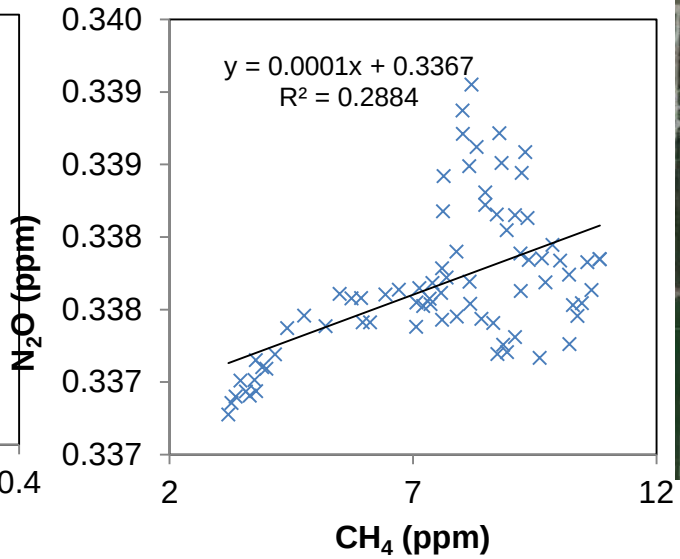
Manure management



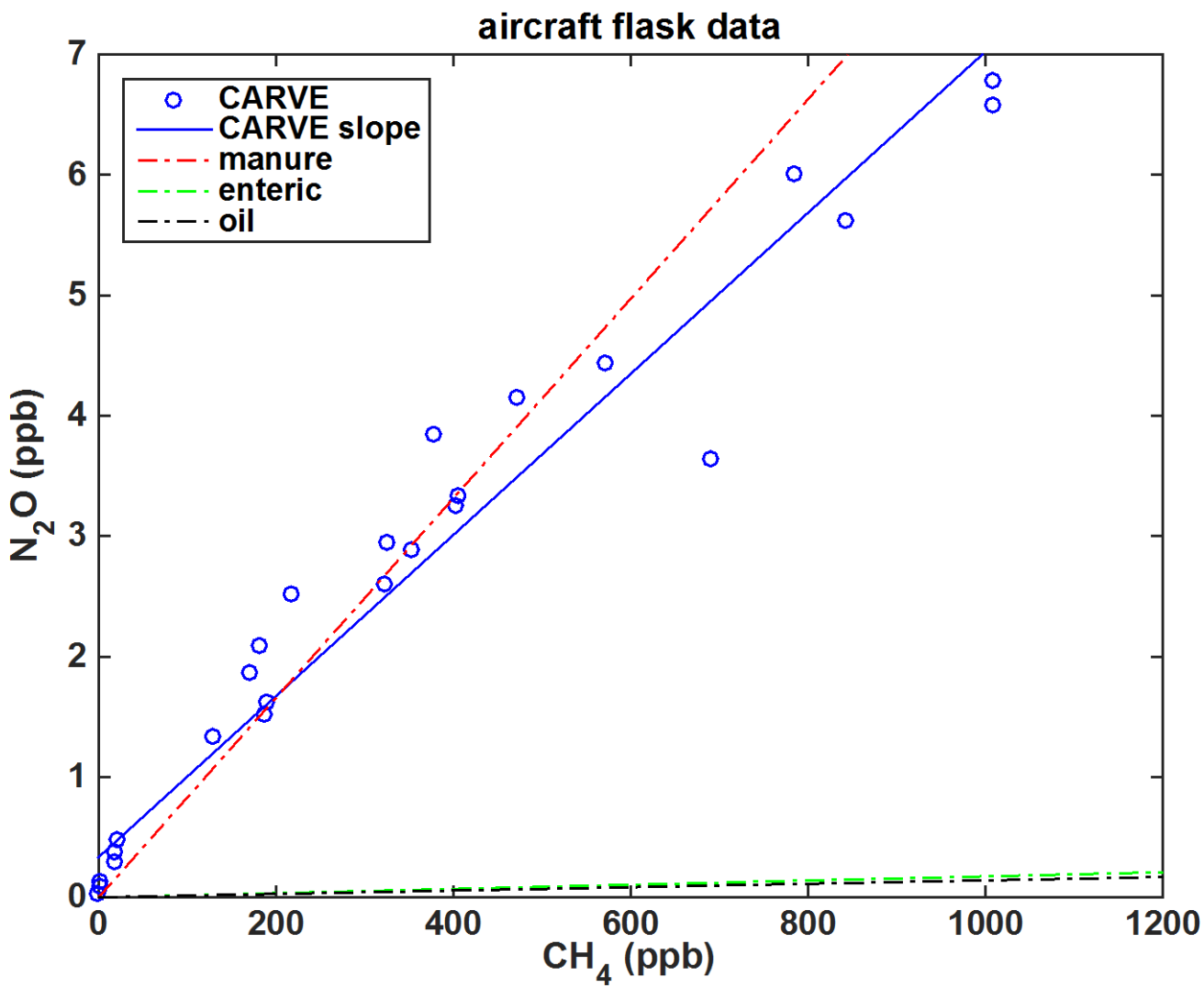


Enteric fermentation





Source apportionment: aircraft flask data



Framework for methane emissions

Detection: on road surveys to find the leaks

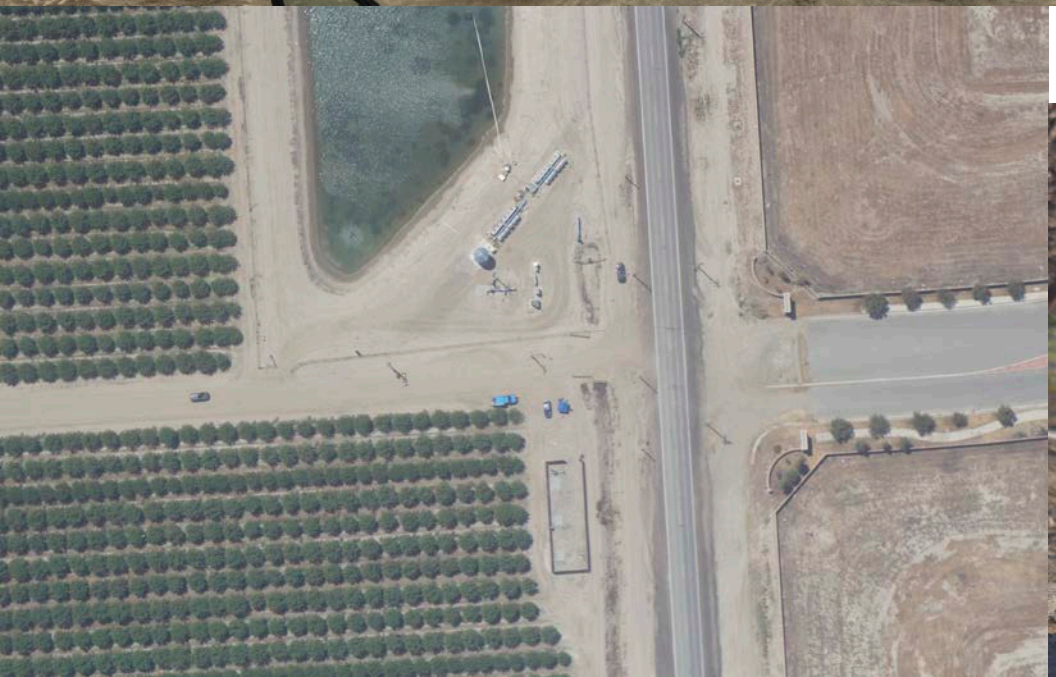
Attribution: use spatial patterns and tracer species to determine sources and their contributions to total emissions

Quantification: calculate CH_4 flux using seasonally averaged data and relationships between urban trace gas emissions

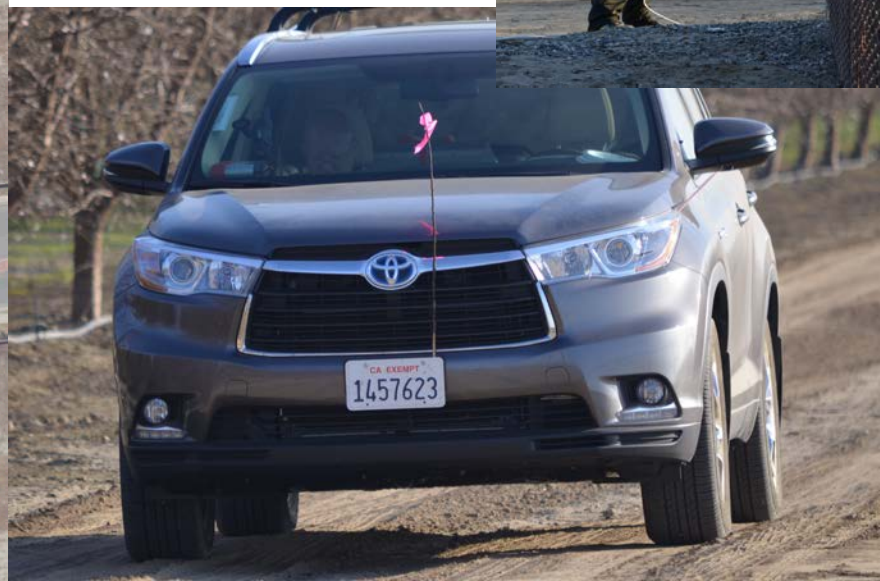
Mitigation: how effective are current mitigation approaches

HyTES controlled release experiment

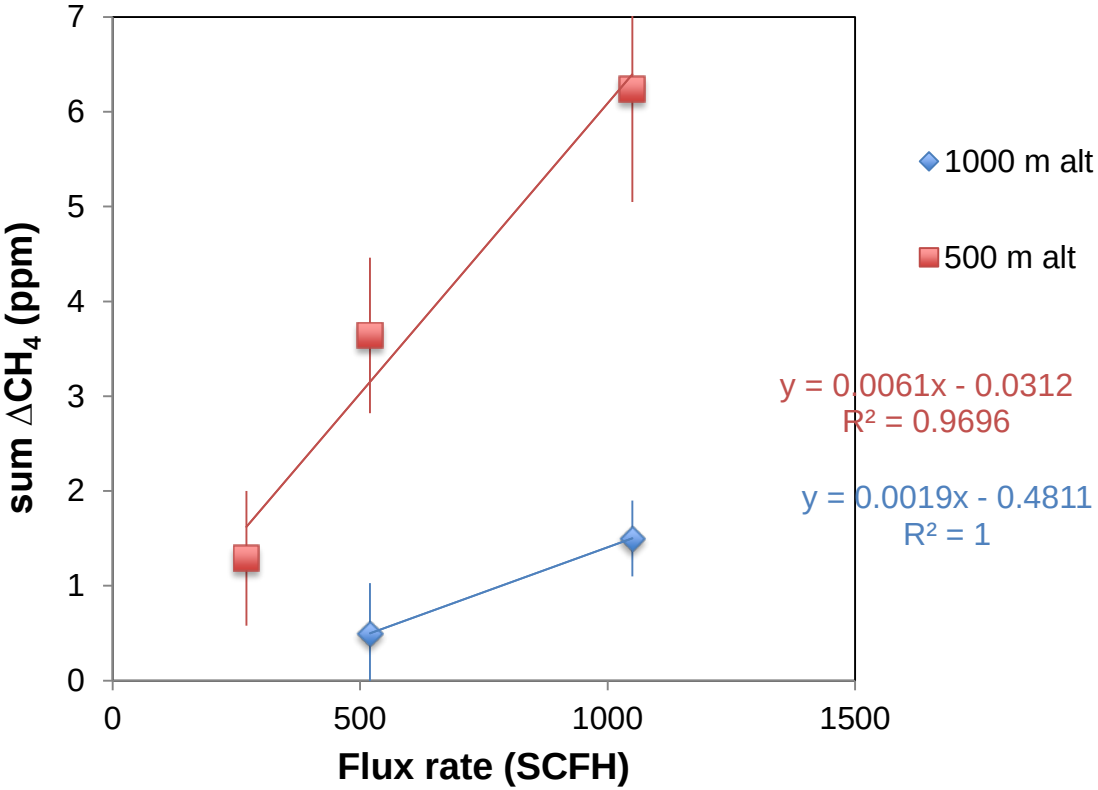
Can HyTES detections be used to estimate fluxes?



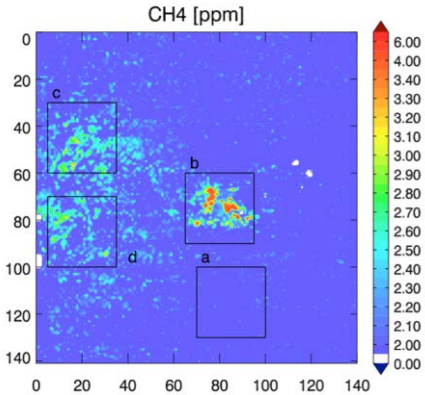
Photos courtesy of Andrew Aubrey, Matthias Falk, Scott Nolte



HyTES detection threshold: controlled release experiment



Quantitative retrievals
(L.Kuai and J. Worden)



Kuai et al., 2015

Intercept for 1000 m flight data: 233 SCFH (range 0-490 SCFH)

Detection with confidence: ≥ 500 SCFH

Quantitative retrievals: plumes are 3-240x the size of largest controlled release rate

Observed plumes as a proportion of total emissions

Repeated plume observations with HyTES CMF retrieval

Controlled release detection limit: 500 SCFH = 85 tons CH_4 y^{-1}

California 0.1° CH_4 inventory (Jeong et al. 2012; 2014)

Study area	Number of repeated plumes	Minimum CH_4 flux from imaged sources	CALGEM CH_4 inventory emissions	Minimum percent of total CH_4 emissions from imaged sources
Oil field	28	2.4 kton CH_4 y^{-1}	8.3 kton CH_4 y^{-1}	≥ 29%
Dairies	11	1.0 kton CH_4 y^{-1}	4.8 kton CH_4 y^{-1}	≥ 21%

Lessons for CH_4 mitigation science

- Methane hotspots are ubiquitous from anthropogenic infrastructure
- Attribution suggests large fugitive emissions from engineered infrastructure
- Super-emitters compose a large fraction of methane emissions
- Inventories don’t get sources or attribution correct at any scale

Framework for methane emissions

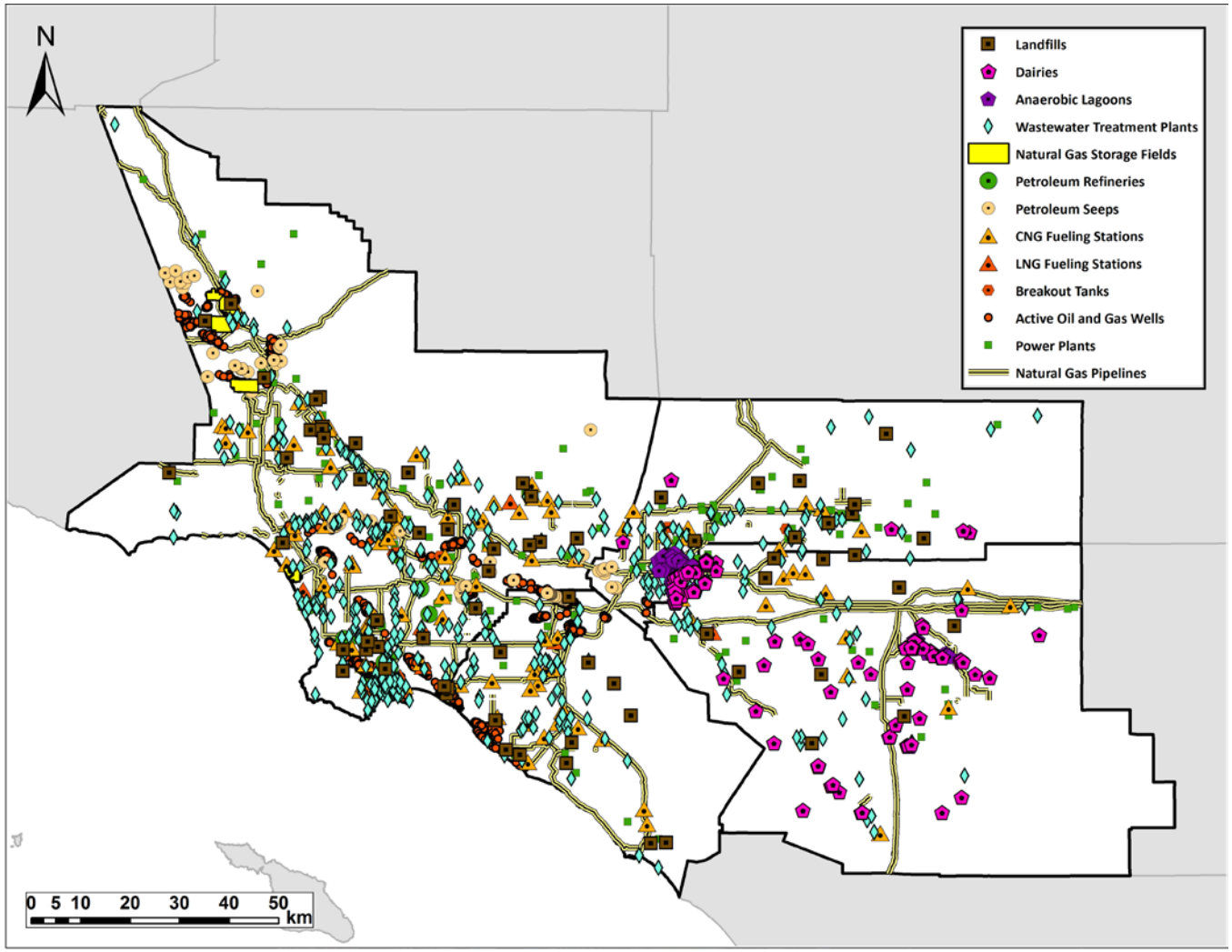
Detection: on road surveys to find the leaks

Attribution: use spatial patterns and tracer species to determine sources and their contributions to total emissions

Quantification: calculate CH_4 flux using seasonally averaged data and relationships between urban trace gas emissions

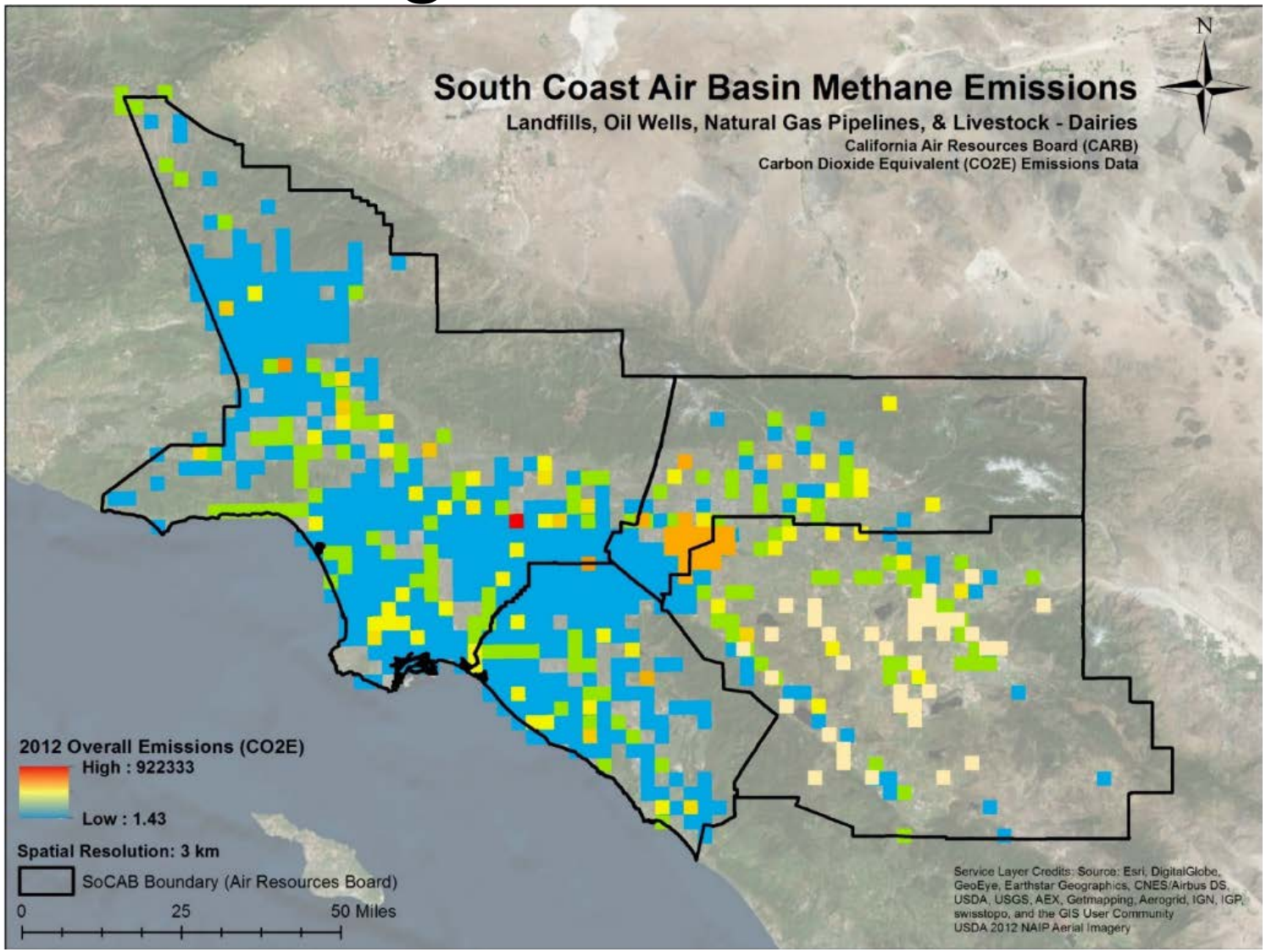
Mitigation: how to get this information to decision makers

Fine scale spatial map of methane emitting infrastructure in the LA Basin



Carranza et al., *in prep*

Fine-scale methane inventory: link to regional observations



Carranza, Vicencio-Frausto, Rafiq: NASA DEVELOP program

Improving methane inventories

Traditional inventories:

- Keep track of process emissions
- Emissions modeled as EF x A

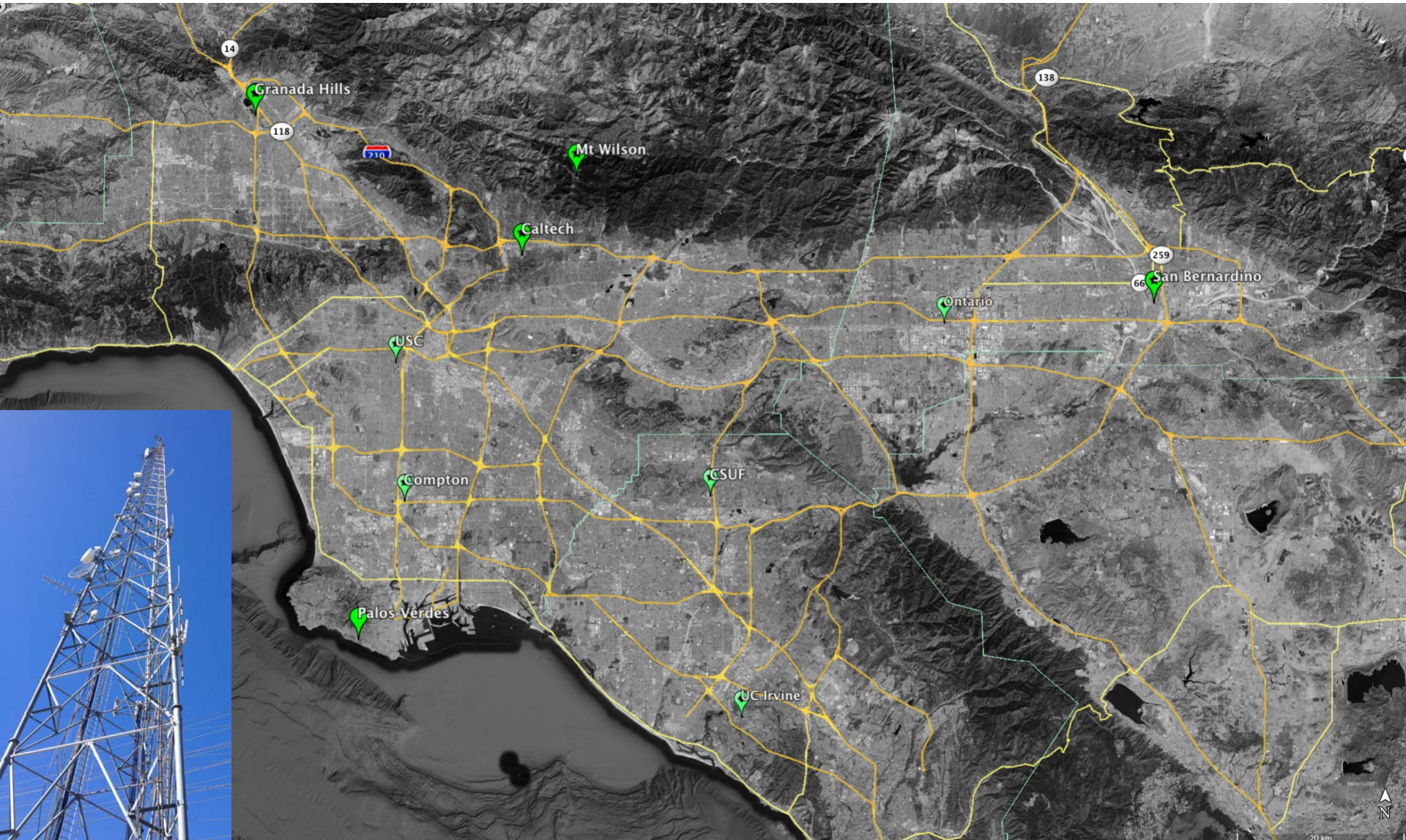
Methane inventory requirements:

- Predominance of fugitive emissions
- Fugitive emissions: thought to be a function of infrastructure, not activity
- First step for future study: understanding locations of potential methane emission sources

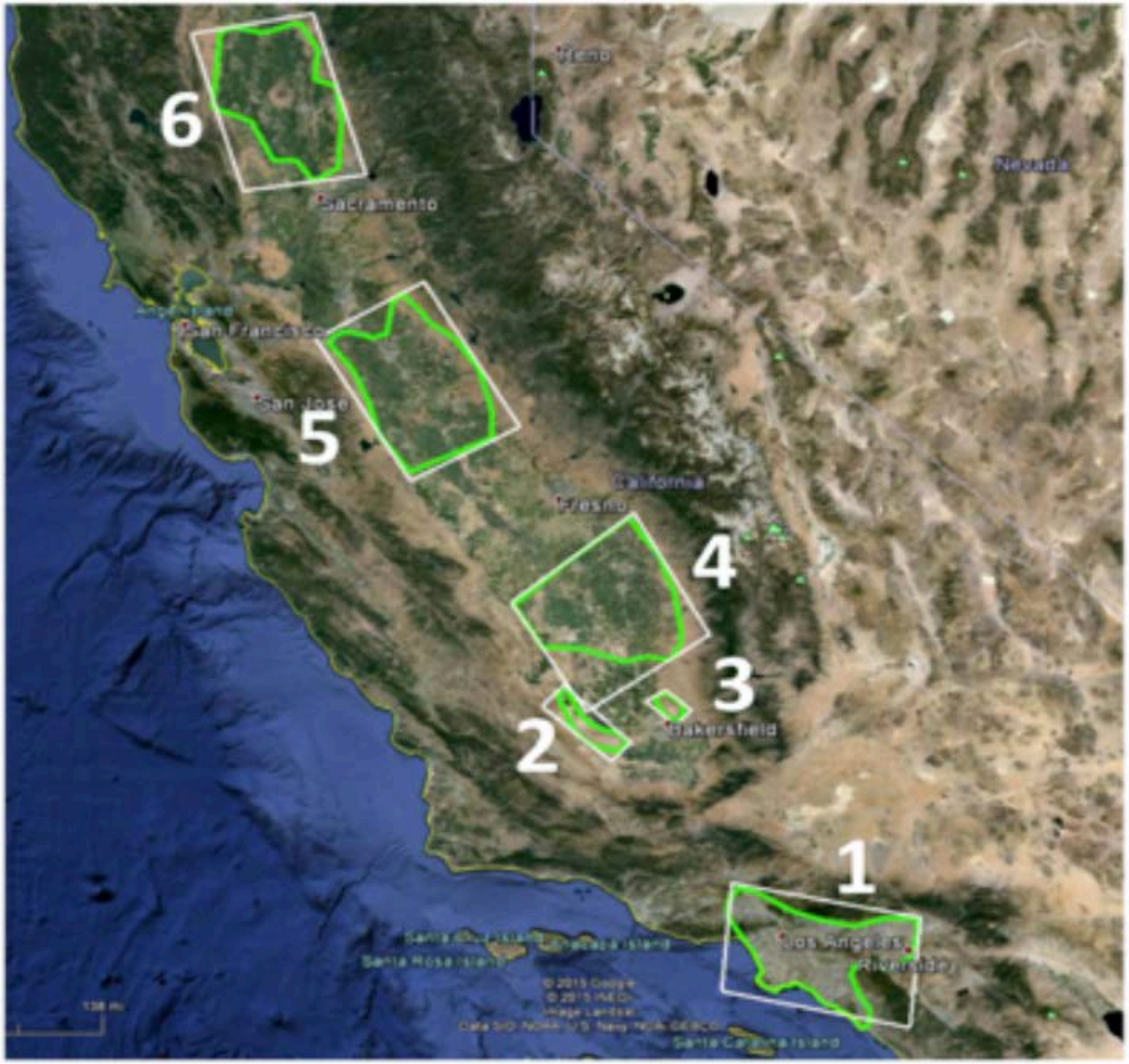
Key future hypotheses

- *Urban methane emissions are poised to grow*
  - *Ineffective current mitigation practices*
  - *Increasing use of natural gas and biogas fuels*
- *Fugitive emissions are a function of infrastructure, not activity*
- *Mitigating urban methane emissions will require new measurements, data products, and partnerships between scientists and policy makers*
- *Cities differ greatly in their methane emissions, and require unique mitigation approaches*

Trend detection:
LA Megacities Tower Network



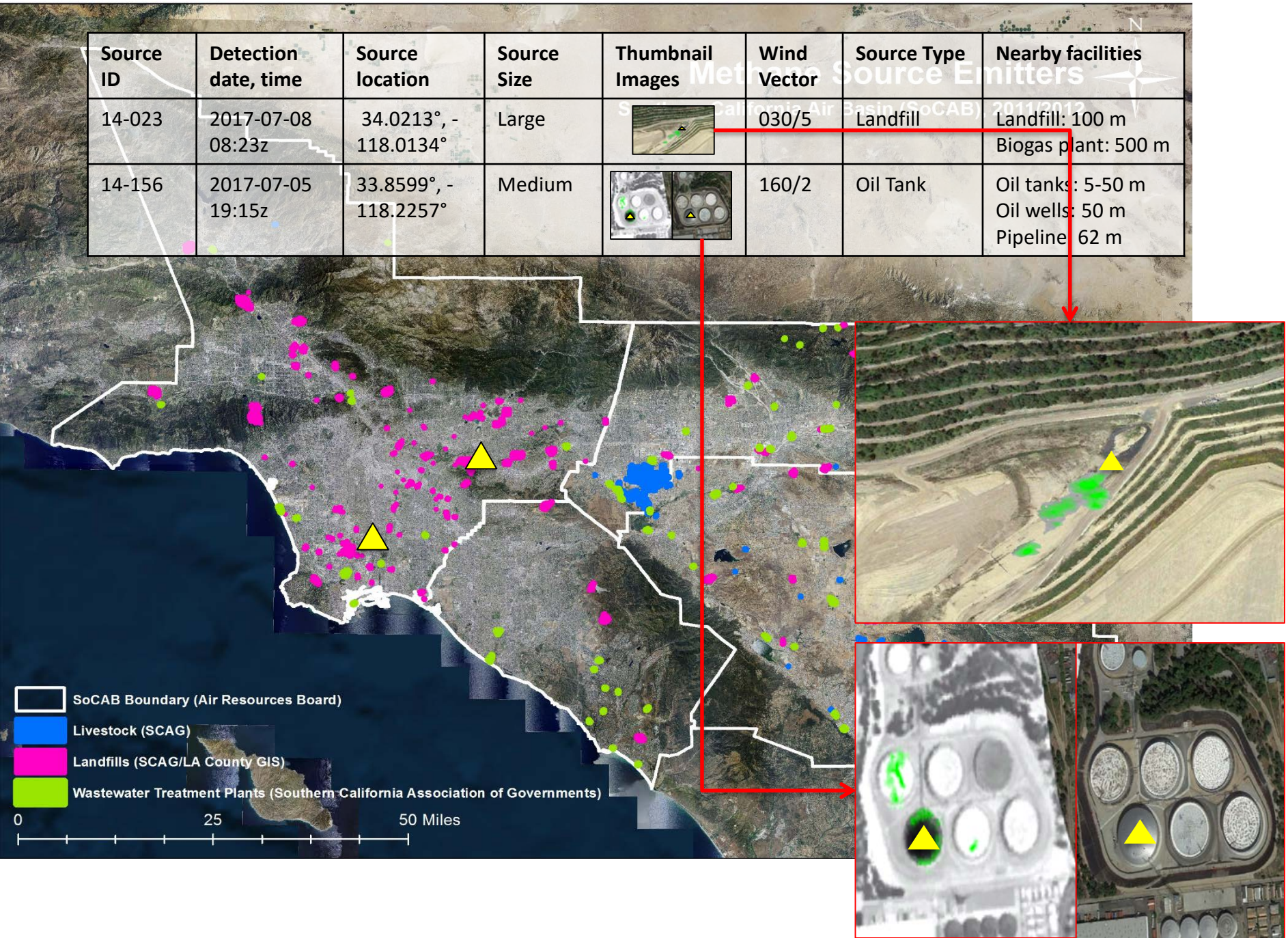
Future work: California HyTES-AVIRIS NG statewide campaign, summer 2016



Methane Source Emitters

South Coast Air Basin (SoCAB), 2011/2012

Source ID	Detection date, time	Source location	Source Size	Thumbnail Images	Wind Vector	Source Type	Nearby facilities
14-023	2017-07-08 08:23z	34.0213°, -118.0134°	Large		030/5	Landfill	Landfill: 100 m Biogas plant: 500 m
14-156	2017-07-05 19:15z	33.8599°, -118.2257°	Medium		160/2	Oil Tank	Oil tanks: 5-50 m Oil wells: 50 m Pipeline: 62 m



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