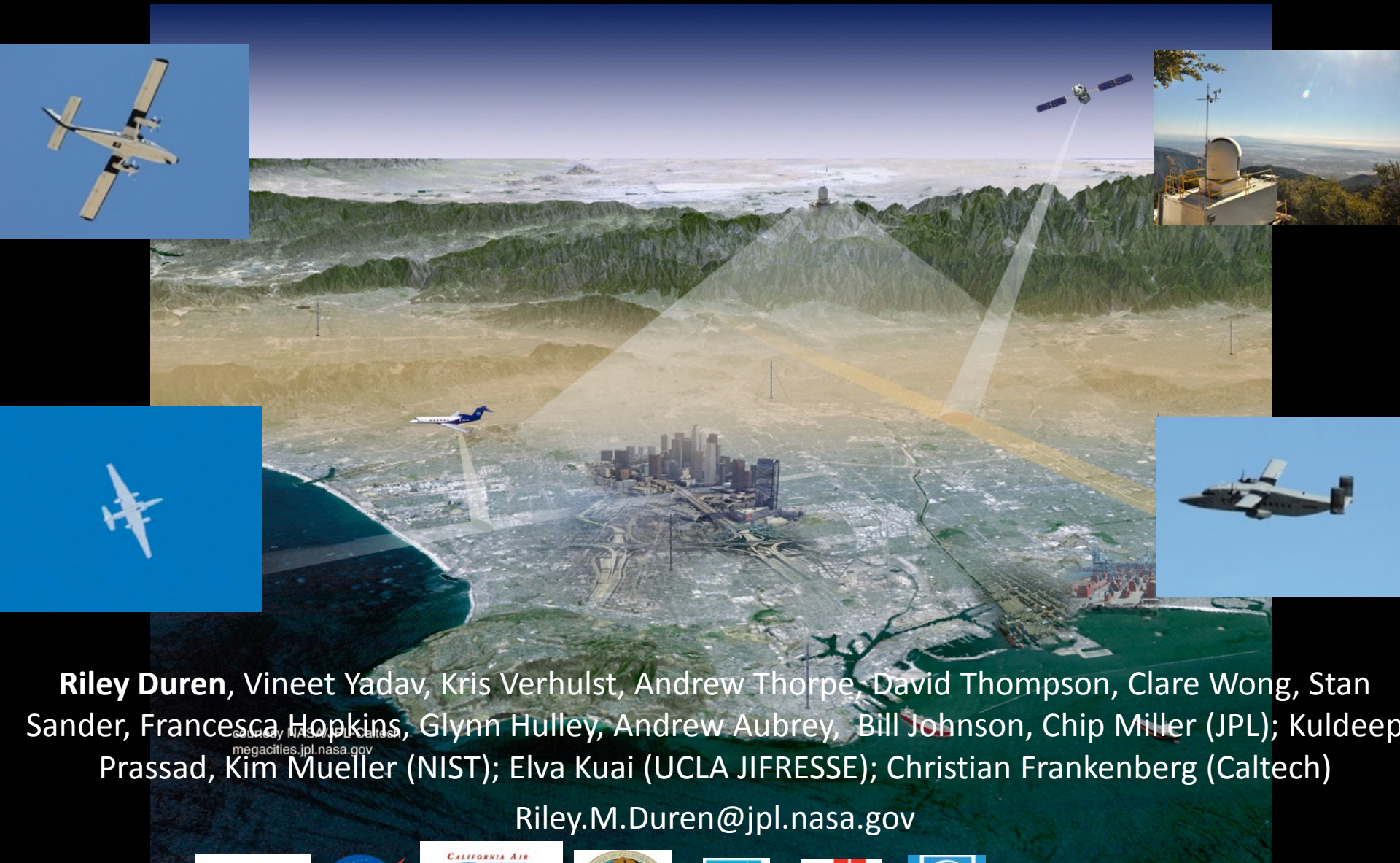


# California methane monitoring for climate action and public safety



**Riley Duren**, Vineet Yadav, Kris Verhulst, Andrew Thorpe, David Thompson, Clare Wong, Stan Sander, Francesca Hopkins, Glynn Hulley, Andrew Aubrey, Bill Johnson, Chip Miller (JPL); Kuldeep Prasad, Kim Mueller (NIST); Elva Kuai (UCLA JIFRESSE); Christian Frankenberg (Caltech)

[Riley.M.Duren@jpl.nasa.gov](mailto:Riley.M.Duren@jpl.nasa.gov)

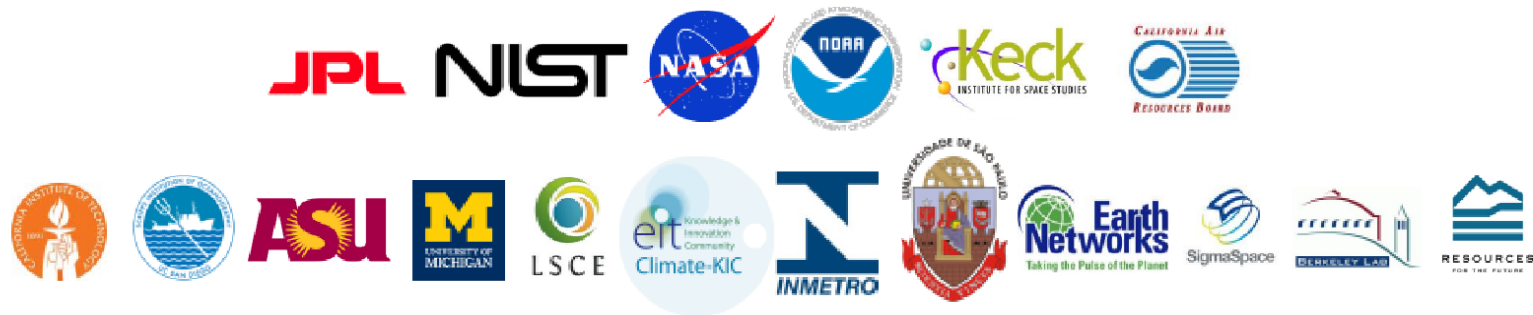


# Initiatives & Partners

## Understanding User Needs for Carbon Information project (NASA Carbon Monitoring Program)



## Megacities Carbon Project



## California Methane Survey (& related pilot efforts)





# Megacities Carbon Project

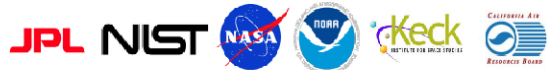
NATURE CLIMATE CHANGE | VOL 2 | AUGUST 2012 | [www.nature.com/natureclimatechange](http://www.nature.com/natureclimatechange)

## Measuring the carbon emissions of megacities

Riley M. Duren and Charles E. Miller

doi:10.1038/nclimate1629

Carbon emissions from cities represent the single largest human contribution to climate change. Here we present a vision, strategy and roadmap for an international framework to assess directly the carbon emission trends of the world's megacities.



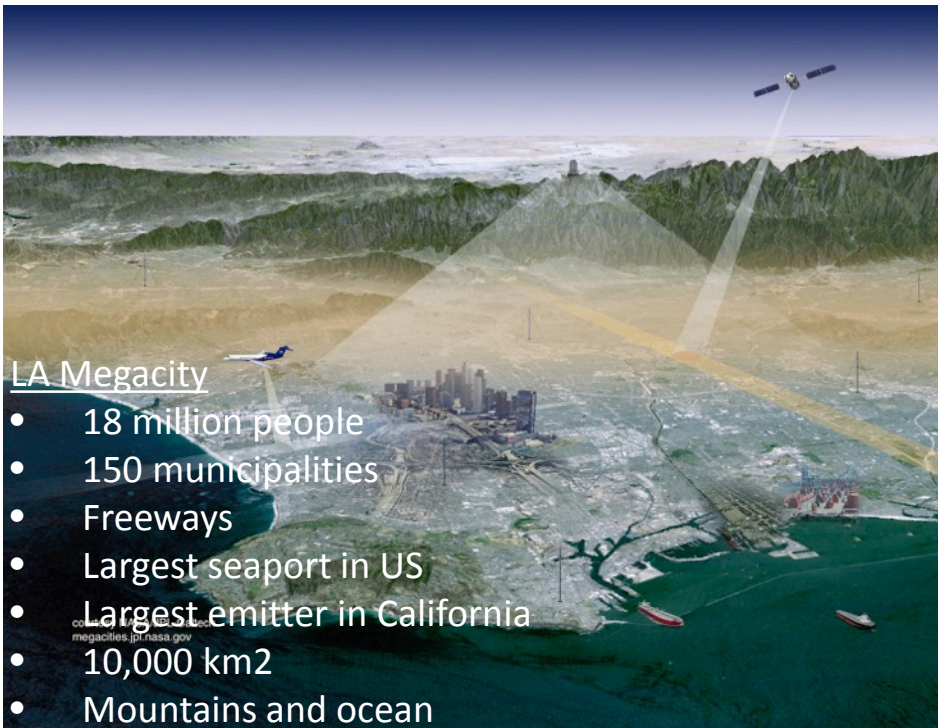
What are the carbon emissions of cities and how are they changing?

Why are emissions changing (which sectors, policies, and behaviors are responsible)?

Are mitigation efforts having the intended effect?

How accurate is urban carbon data (for emission trading)?

Can we share relevant data transparently between cities?

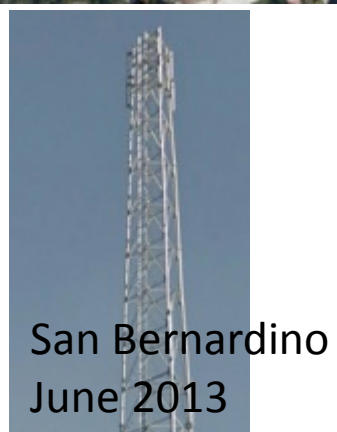
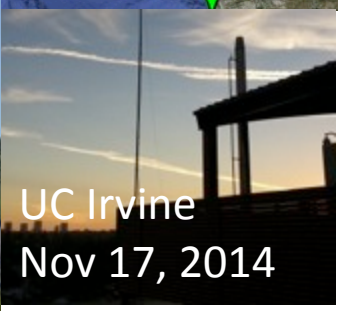
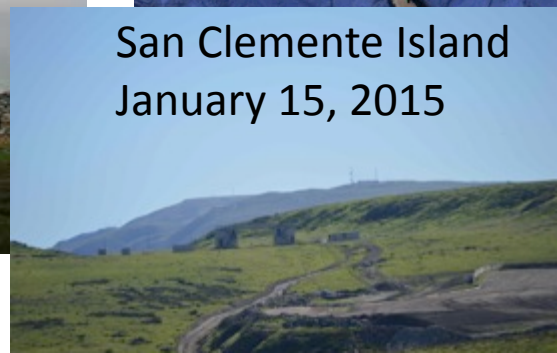
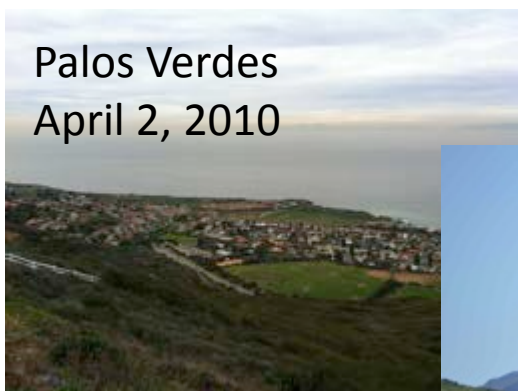
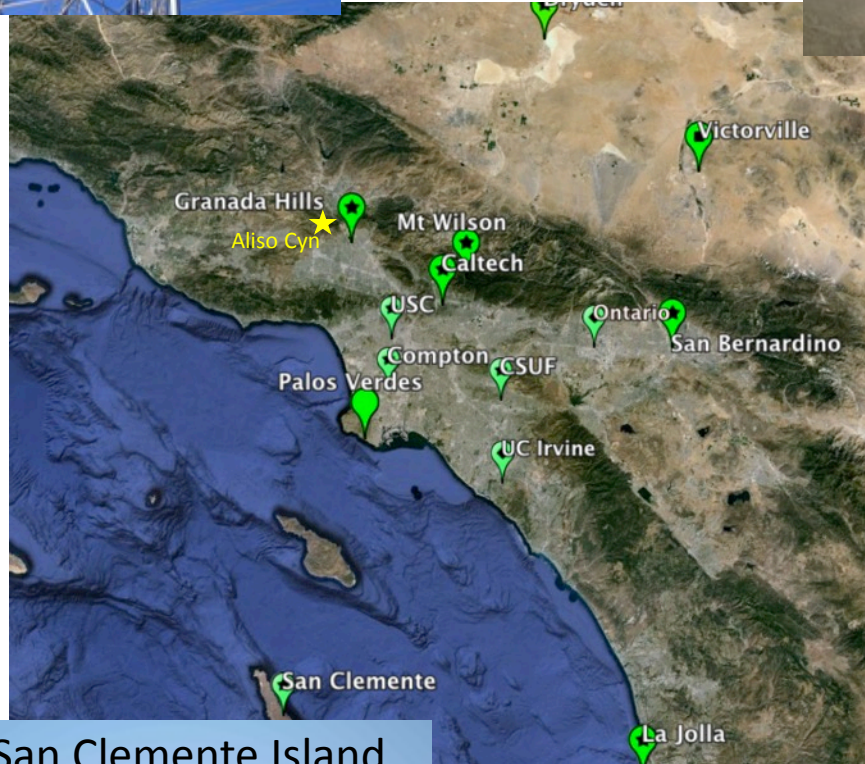
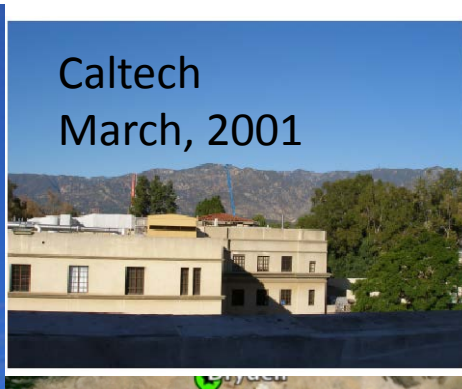
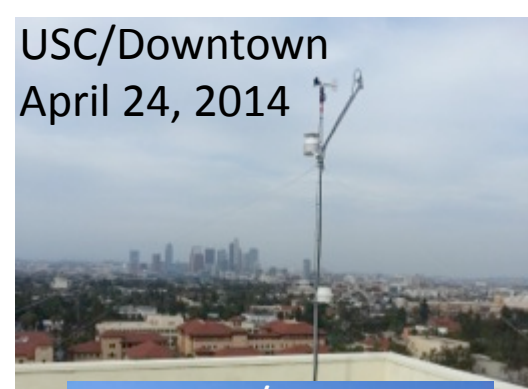


### LA Megacity

- 18 million people
- 150 municipalities
- Freeways
- Largest seaport in US
- Largest emitter in California
- 10,000 km<sup>2</sup>
- Mountains and ocean

*Co-benefits: enhance sustainable planning, air-quality, and public awareness*



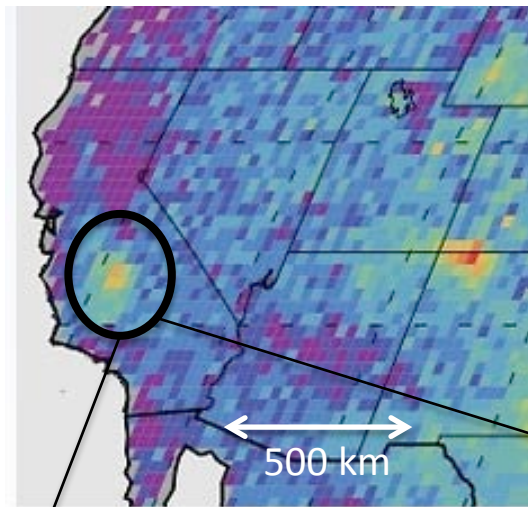




# Methane hotspots seen from space

But where and what are the dominant sources?

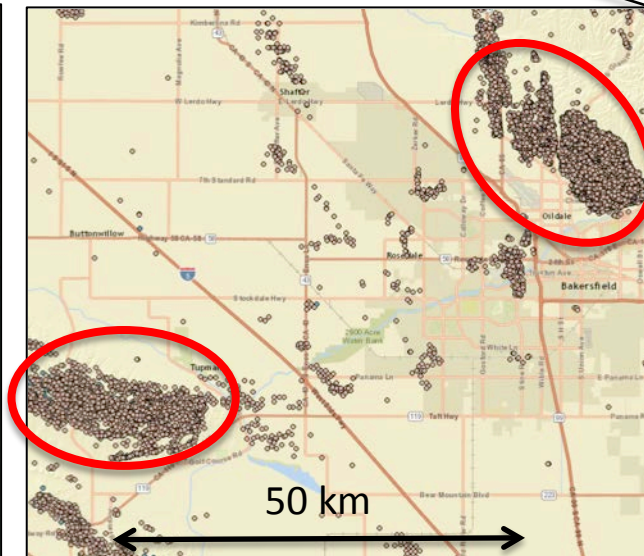
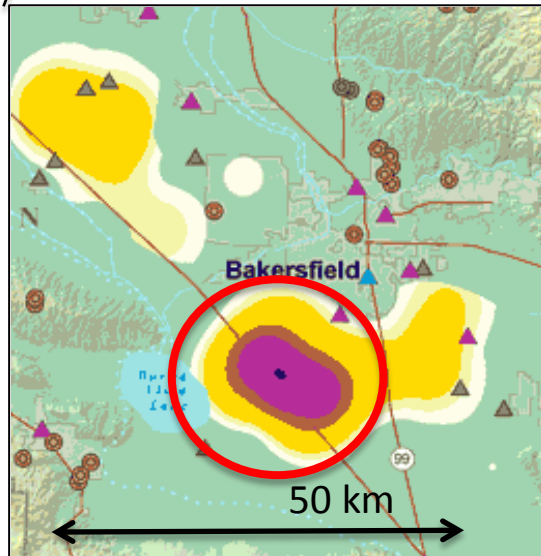
Kort et al 2014  
(2003-2009 SCIAMACHY data)



## Super-emitters:

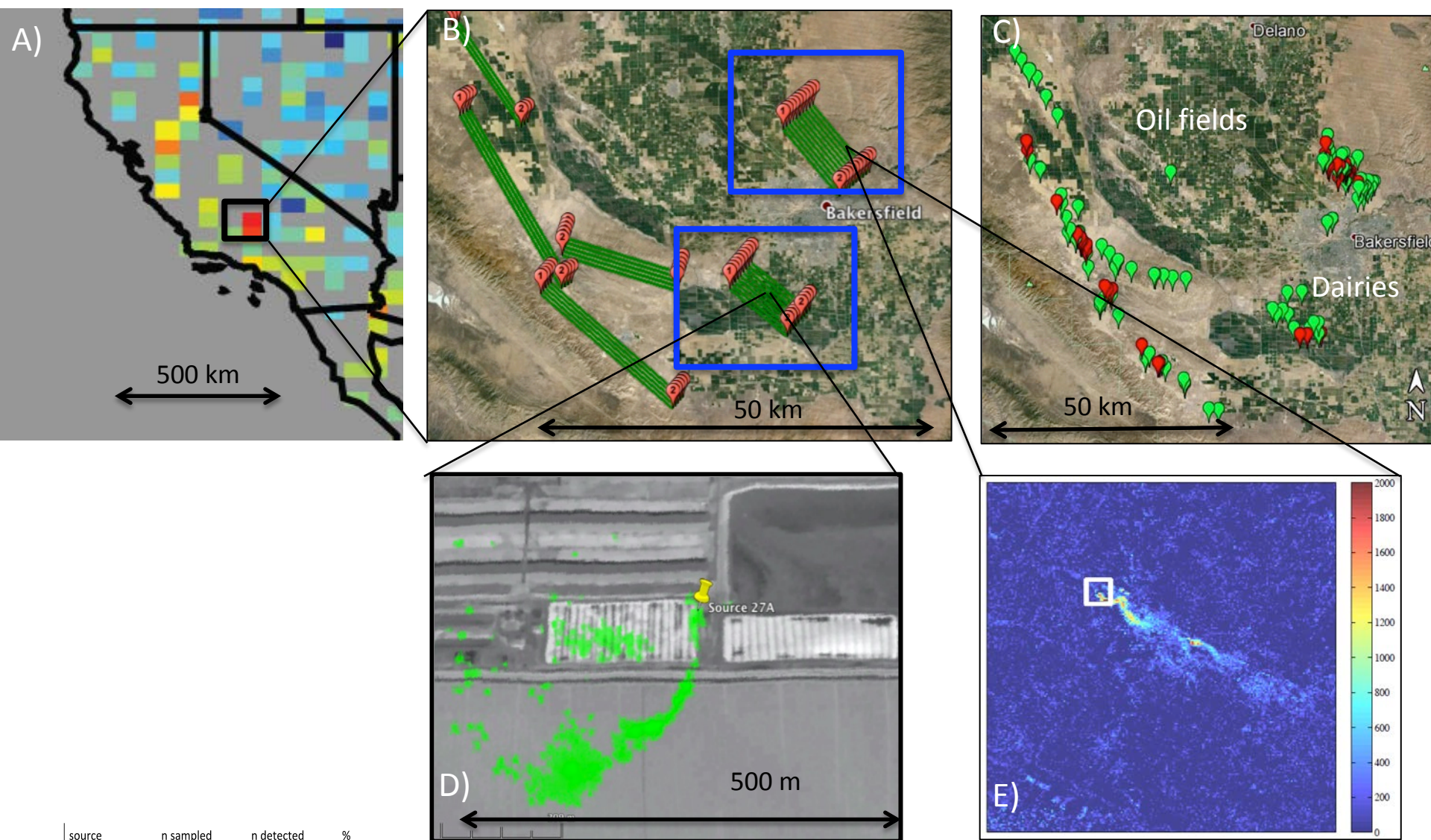
60% of emissions come from 5% of facilities in the Barnett shale

Zavala-Araiza et al et al, Environ. Sci. Technol, 2015



Bakersfield area:  
30,000 oil wells  
vs  
30 mega-dairies  
(172,000 cows)

# Methane Tiered Observing Strategy: Central Valley example



	source	n sampled	n detected	%
Oil field	Wells	14143	9	<0.1
	Tanks	78	10	13
	Facilities	21	7	33
	Waste ponds	3	1	33

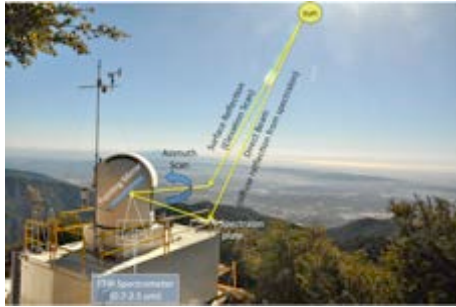
Study area	Number of repeated plumes	Minimum CH <sub>4</sub> flux from imaged sources	CALGEM CH <sub>4</sub> inventory emissions	Minimum percent of total CH <sub>4</sub> emissions from imaged sources
Oil field	28	2.4 kton CH <sub>4</sub> y <sup>-1</sup>	8.3 kton CH <sub>4</sub> y <sup>-1</sup>	≥ 29%
Dairies	11	1.0 kton CH <sub>4</sub> y <sup>-1</sup>	4.8 kton CH <sub>4</sub> y <sup>-1</sup>	≥ 21%

Hopkins, Duren et al, in prep

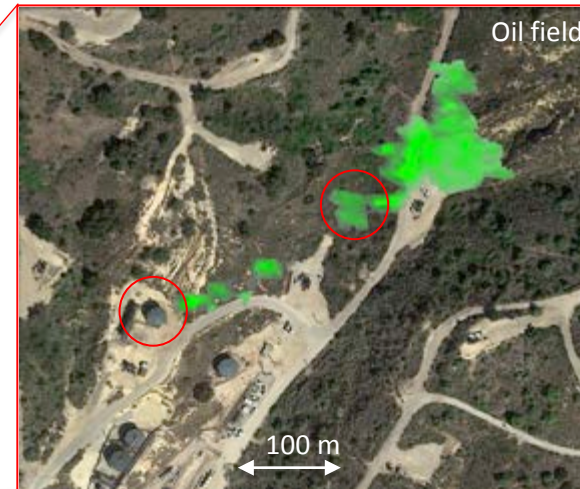
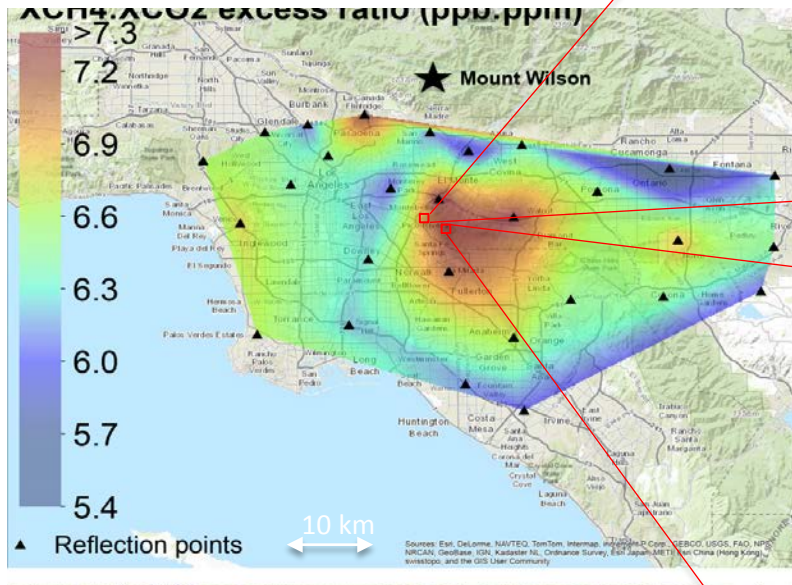


# Los Angeles example

Tier 1: prototype  
“satellite” on Mt  
Wilson identifies  
methane  
hot spot



Tier 2: airborne  
imaging spectrometer  
maps  
point sources

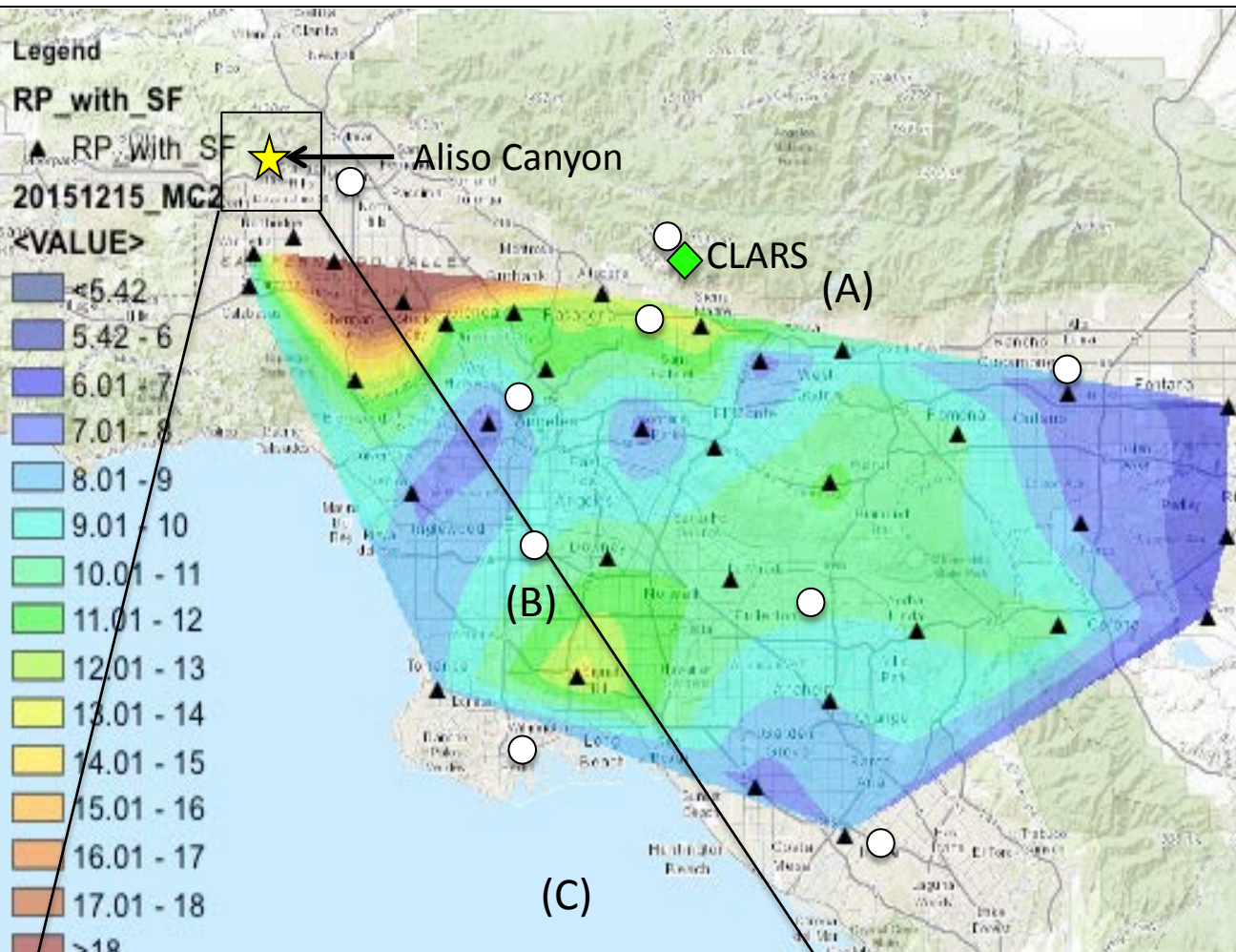


Left: Persistent methane hotspot (central red area) over Los Angeles basin detected by prototype satellite instrument on Mt Wilson (Wong et al, ACP 2015). Right: examples of individual methane leaks (green plumes) from an oil field (upper) and landfill (lower) identified by airborne Hyperspectral Thermal Emission Spectrometer. Courtesy: NASA/JPL-Caltech.

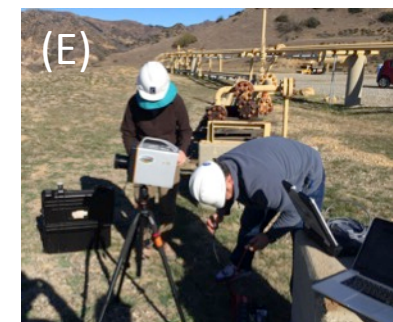
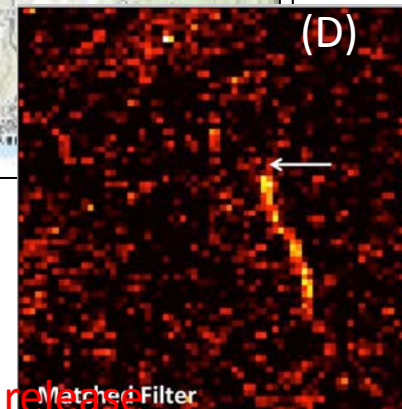
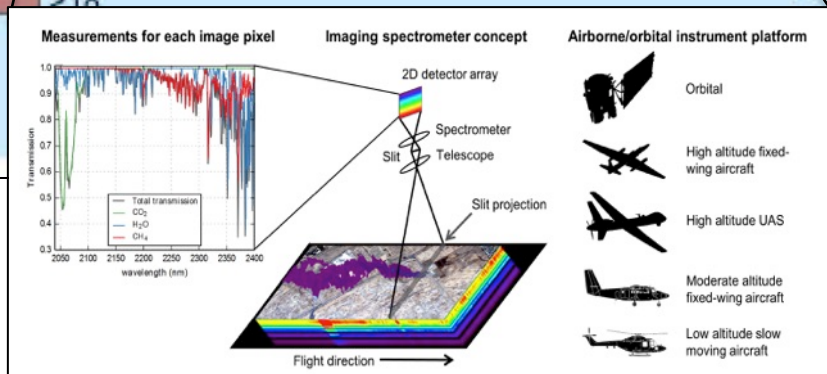
# Aliso Canyon gas leak: motivating questions

- How much gas was lost during initial, dynamic leak phase?
- What was the spatial extent of the source and how did it evolve over time?
- Was there a systemic leakage issue or precursor event prior to Oct 23?
- Are there systemic issues with other underground gas storage facilities?





**Aliso Canyon - Five tiers of observations:** (A) CLARS basin-wide CH<sub>4</sub> mapping (5X/day); (B) continuous tower network measurements (white dots – 9 of 13 shown); (C) 11 airborne imaging spectrometer surveys (AVIRIS & HyTES); (D) Satellite observations (GOSAT & Hyperion); (E) mobile surface surveys (Picarro, Flasks, IR cameras)

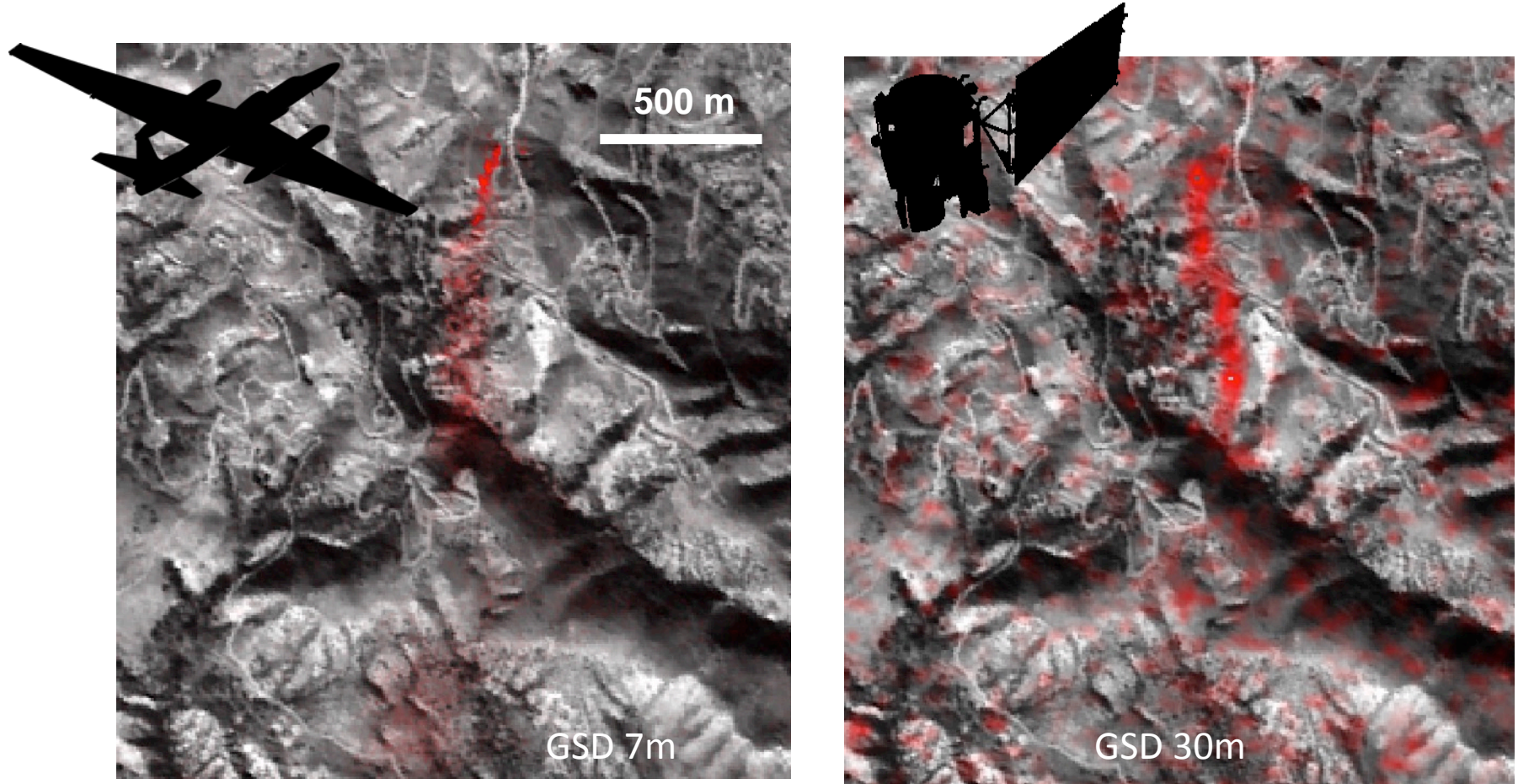


Preliminary, unvalidated data – not for distribution or release



# Plume detected (and quantified) from 28,000 ft and low-earth orbit

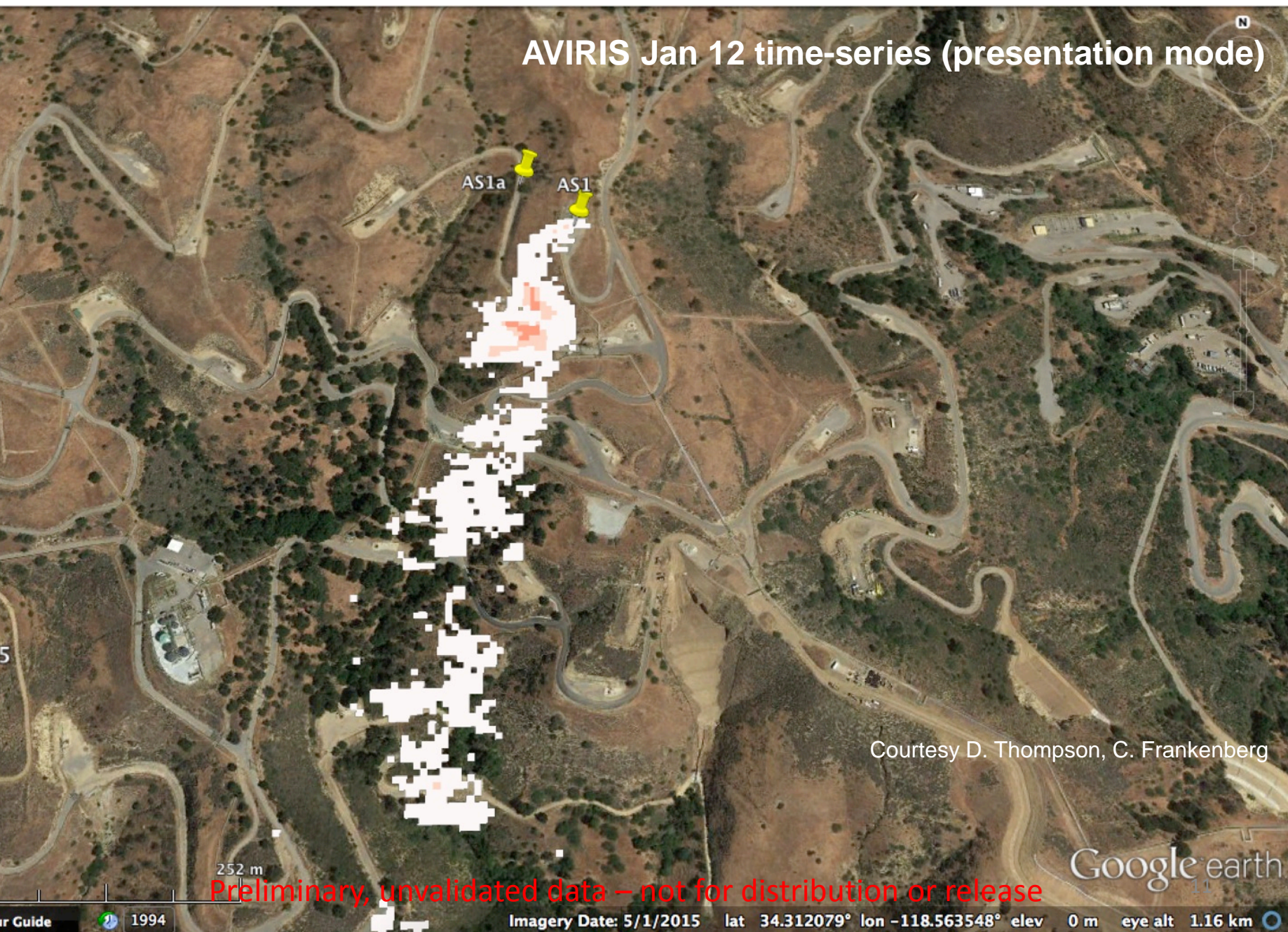
Comparison of detected plumes from AVIRIS-C on  
1/12/2016 (Left) and Hyperion on 1/1/2016 (Right)



Thompson, D.R., A. Thorpe, C. Frankenberg, R. O. Green, R. Duren, L. Gaunter, A. Hollstein, E. Middleton, L. Ong, S. Ungar, Orbital Spectroscopy of the Aliso Canyon CH<sub>4</sub> Super-emitter, GRL, 2016, accepted.



# Plume space-time structure

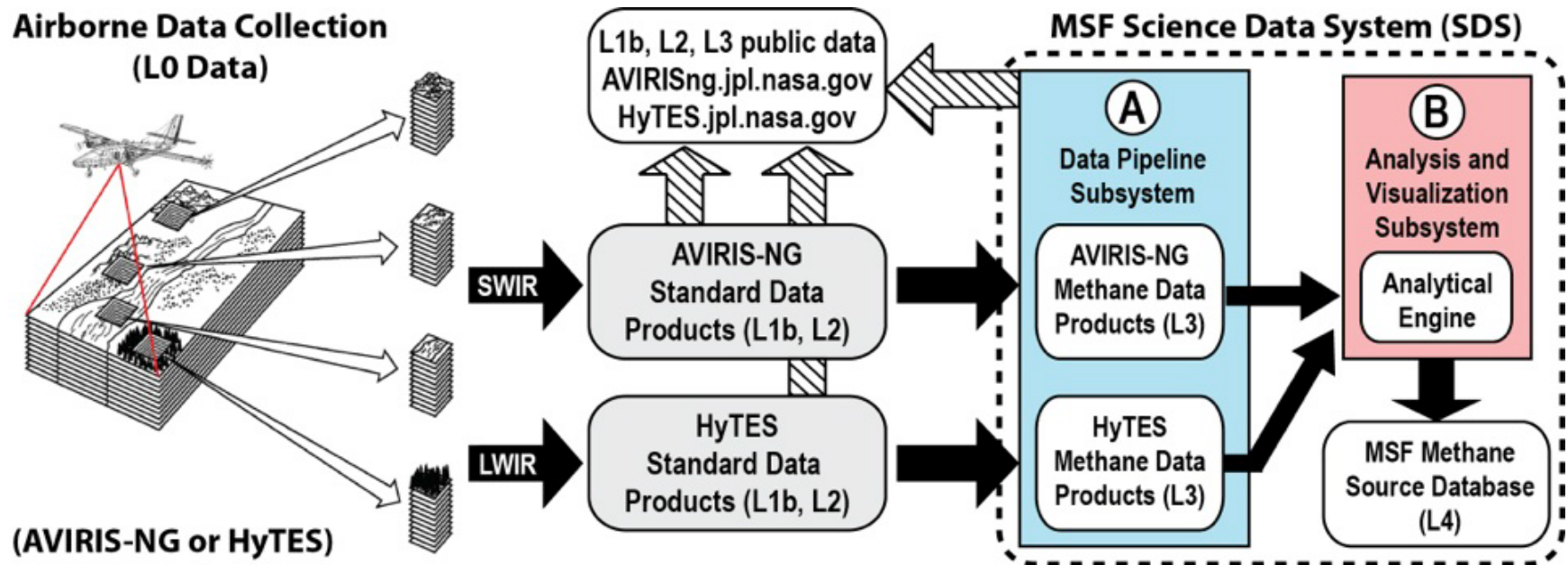




# Methane Source Finder (MSF)

## Data Processing, Analysis & Visualization

The ability of NASA imaging spectrometers (AVIRIS-NG and HyTES) to rapidly survey large areas, detect and map methane plumes and pinpoint source locations is a transformative advance, but requires fast, efficient data processing, analysis and visualization









# California Baseline Methane Survey summer 2016



Planned\* airborne coverage (green outlines) for 2016 California Baseline Methane Survey: South Coast Air Basin (1), key sections of San Joaquin Valley (2-3), key sections of Sacramento Valley (4), and San Francisco Bay Area Air Basin (5). Based on combining information from California stakeholders and gridded greenhouse gas these areas are likely responsible for at least 80% of the state's methane emissions. 14

[\*preliminary and subject to change]



# Earthquake response: Real-time gas detection onboard airplane supports rapid response



D. Thompson



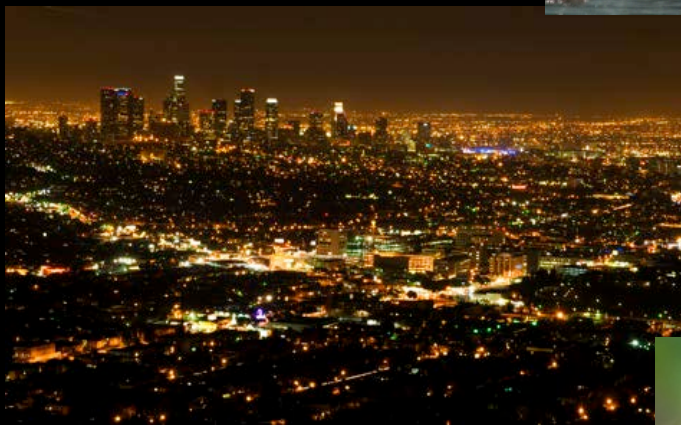
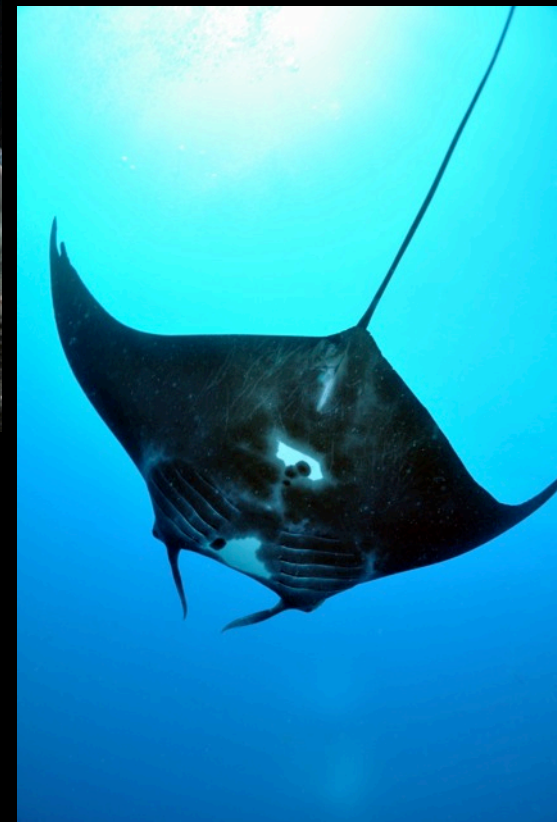
Text msg:  
GPS coordinates,  
plume strength



# Summary

- Small number of super-emitters likely dominate overall methane budget for many sectors → major implications for mitigation (agriculture, not just oil & gas)
- Potential source population in California > 100,000 – spread over >30,000 km<sup>2</sup>
- Remote sensing can identify methane super-emitters for mitigation
- Aircraft offer agility for quickly surveying large areas
- Pilot efforts in Central Valley and LA are demonstrating the Tiered Observing System strategy works for detecting and quantifying fugitive methane emissions
- Approach is scalable for sustained monitoring for California and elsewhere





# Thank you

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<http://megacities.jpl.nasa.gov>  
<https://cmsun.jpl.nasa.gov>  
<http://carbon.nasa.gov>

