High spatial resolution imaging of methane and other trace gases with HyTES

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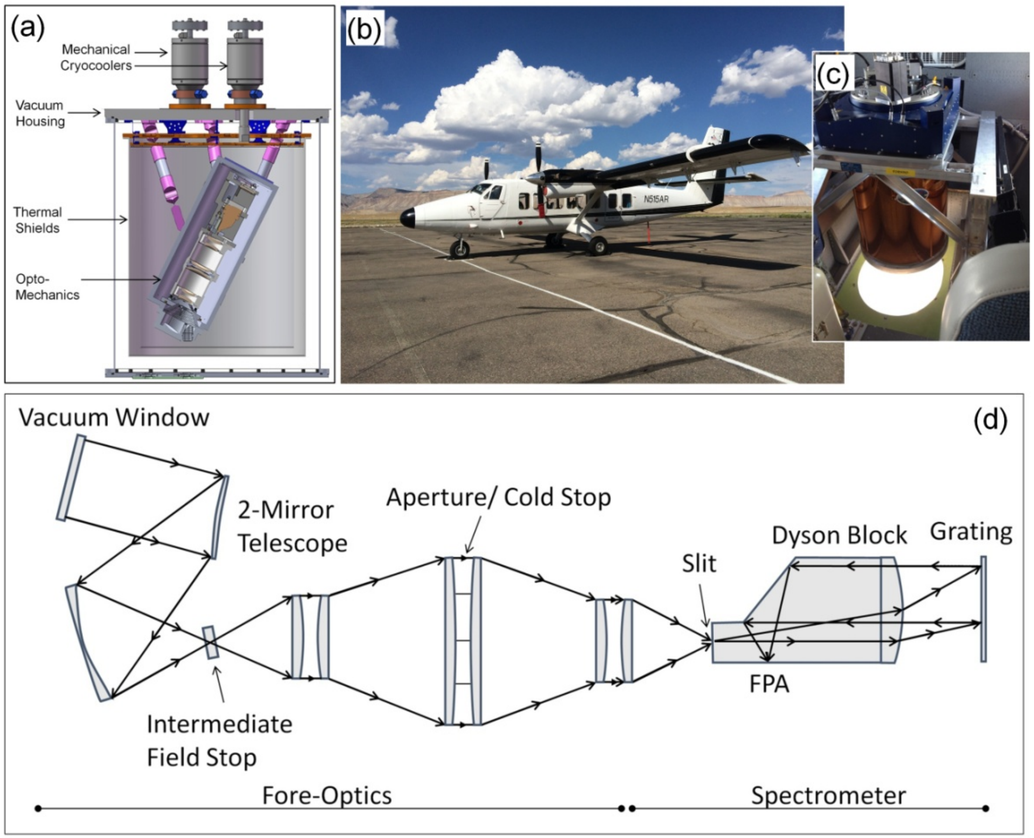
Data recording and storage: Nick Vance, Bjorn Eng

Hyperspectral Thermal Emission Spectrometer (HyTES) Instrument Characteristics



Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 um
Detector	Multi-stack QWIP
Total Field of View	50 degrees
Calibration (preflight)	Full aperture blackbody
Swath Width	1.8 – 3.6 km
Pixel size at 2000 m flight altitude	3.64m
Pixel size at 20,000 m flight altitude	36.4m

<u>Advanced Instrument Designs:</u>
William Johnson

HyTES Science Highlights (2014-2016)

1. Methane mapping: Identification of >100 emission sources of methane in the San Joaquin Valley, CA
   - Oil and gas fields, managed livestock (dairies)
   - Specific attribution of sources, and distribution
   - Quantitative estimates of gas concentration

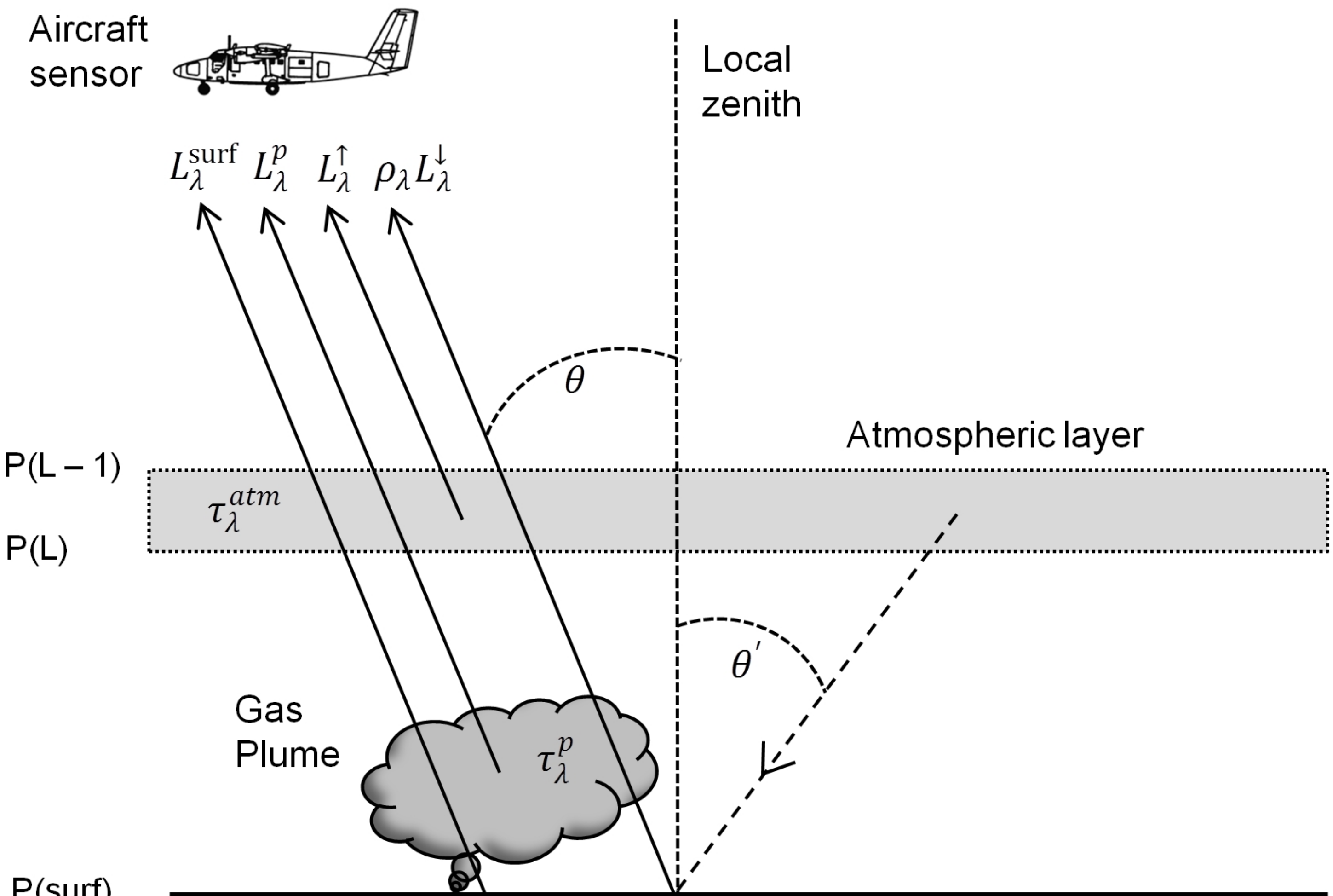
2. Detection of criteria pollutants: NH_3, SO_2, H_2S, NO_2
   - Ability to distinguish between different gas signatures in single plume
   - Monitoring, mitigation, and improving inventories

3. Acquisition of data over selected HyspIRI sites:
   - e.g. Teakettle, Soaproot Saddle, Tonzi Ranch, Salton Sea, Cuprite

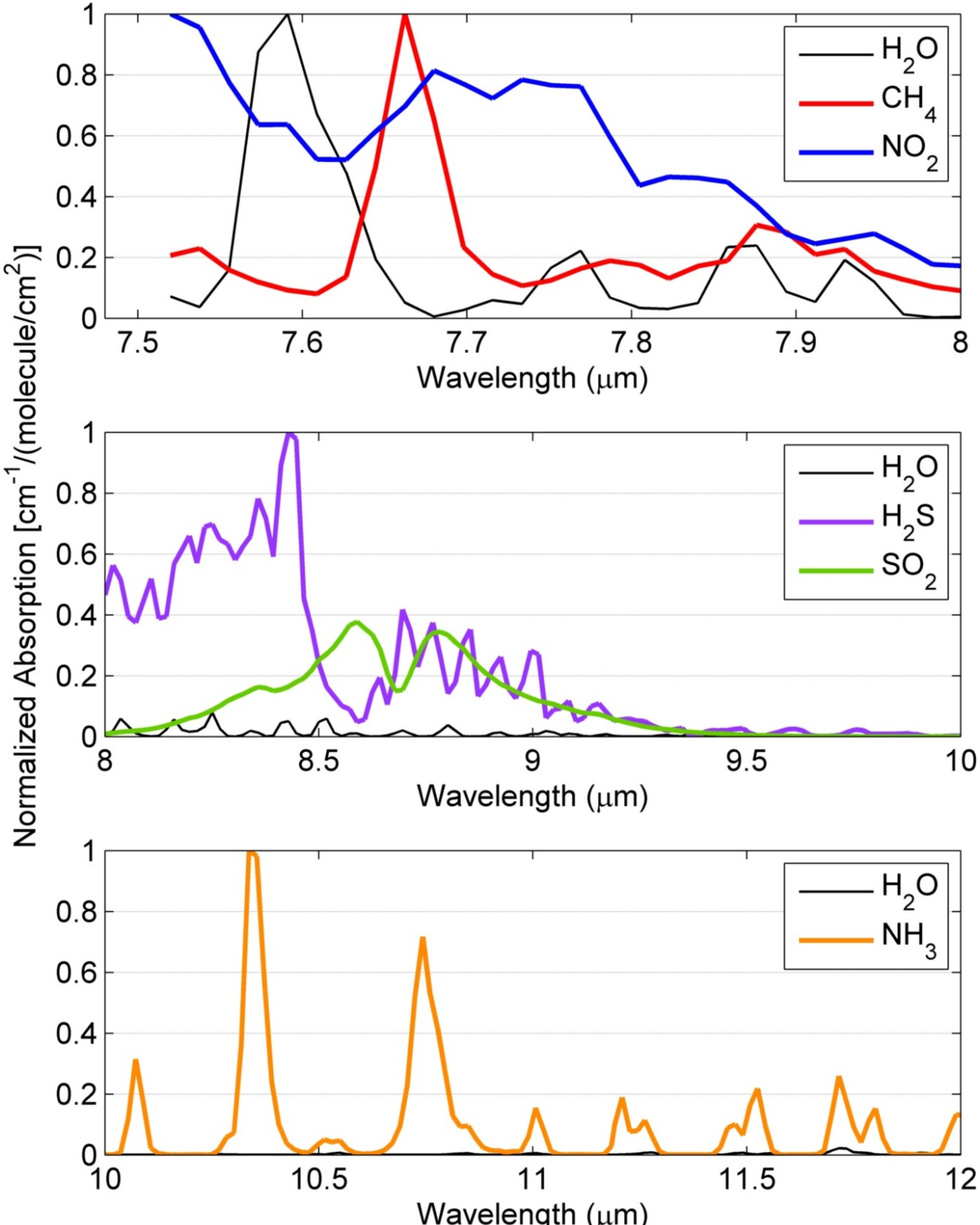
4. Urban acquisitions (LA, Santa Barbara)
   - Urban temperatures (heat islands) and effects of shading
   - Urban materials spectral libraries

5. HyTES Publications:
   - Hook et al. 2016, Hulley et al. 2016, Kuai et al. 2016, Hopkins et al. 2016

Thermal Infrared Radiative Transfer



In-Scene Atmospheric Correction (ISAC) – Hulley et al. 2016

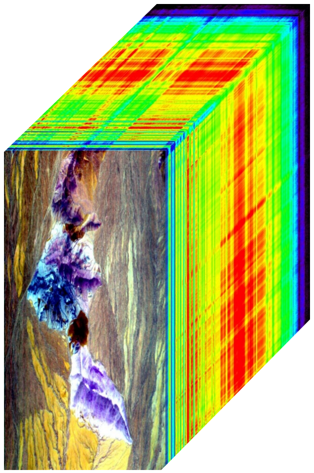


Normalized Absorption [cm^{-1}/(molecule/cm^2)]
Wavelength (μm)
H_2O
CH_4
NO_2
Wavelength (μm)
H_2O
H_2S
SO_2
Wavelength (μm)
H_2O
NH_3

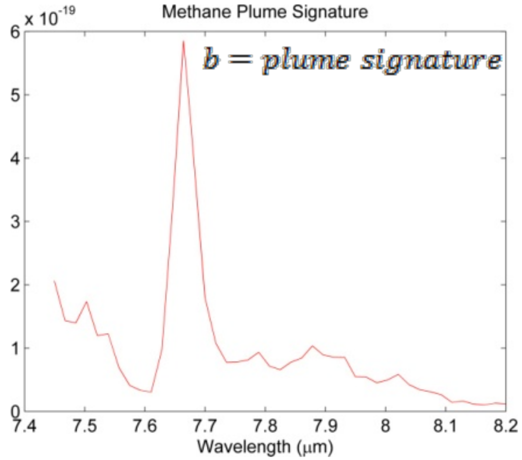
HyTES Plume Detection: Clutter Matched Filter (CMF)

1. HyTES datacube of radiances, ***R***

2. Search for spectral signature, ***b***, assumed to be linearly superimposed on background signal.

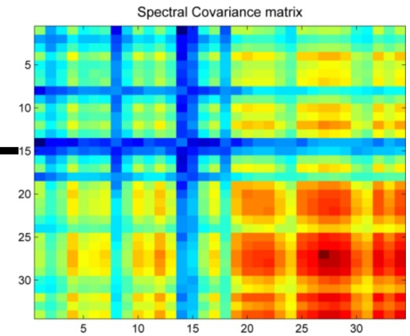


$R \in (N,n)\ N = pixels, n = bands$



3. Calculate the spectral covariance matrix of input radiances, ***K*** :

$$K = \frac{1}{N} R R^T,$$

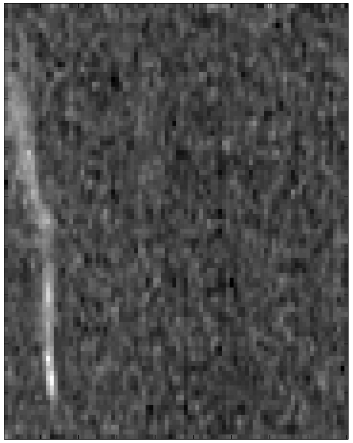


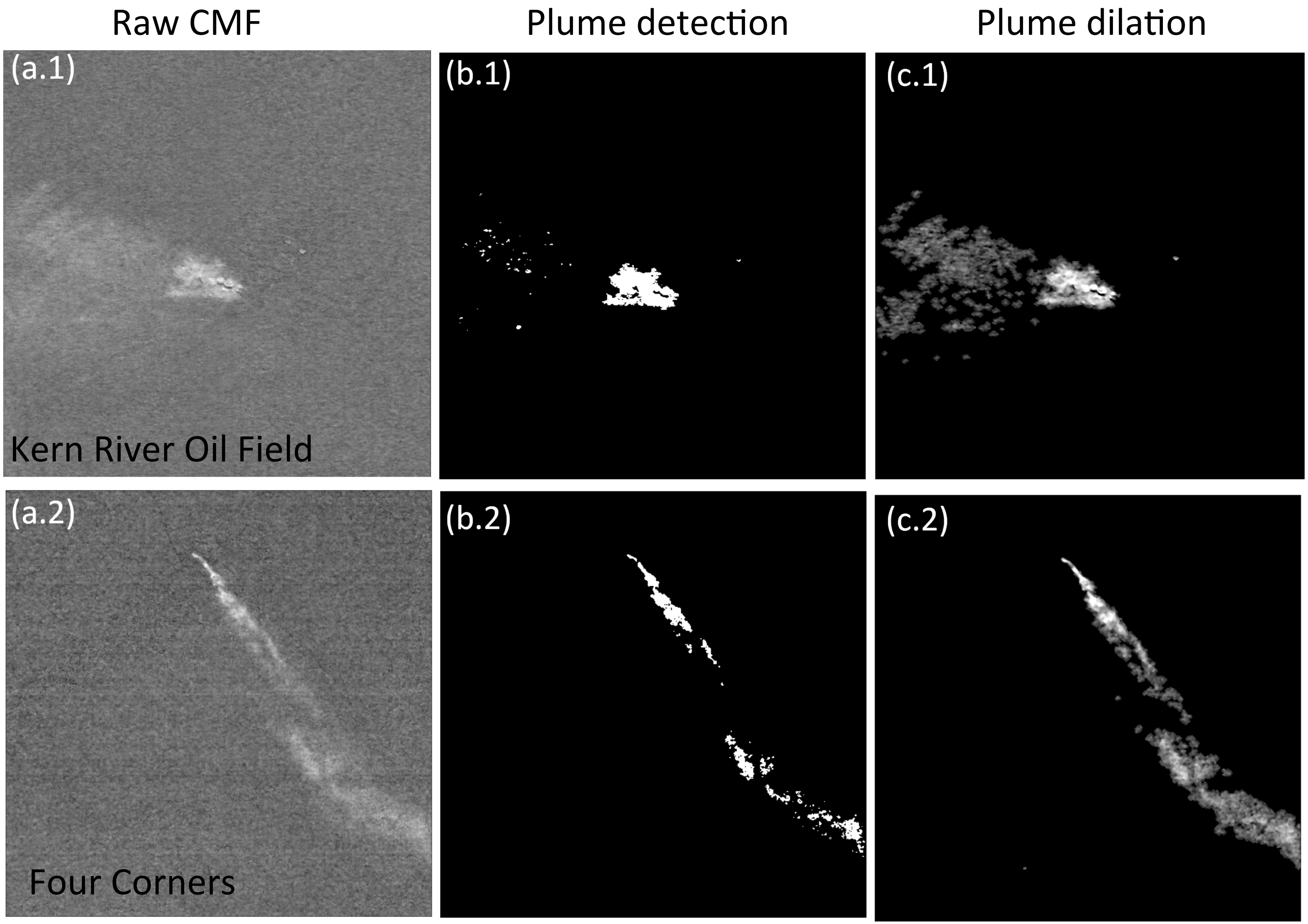
4. Compute signal filter vector, ***q***:

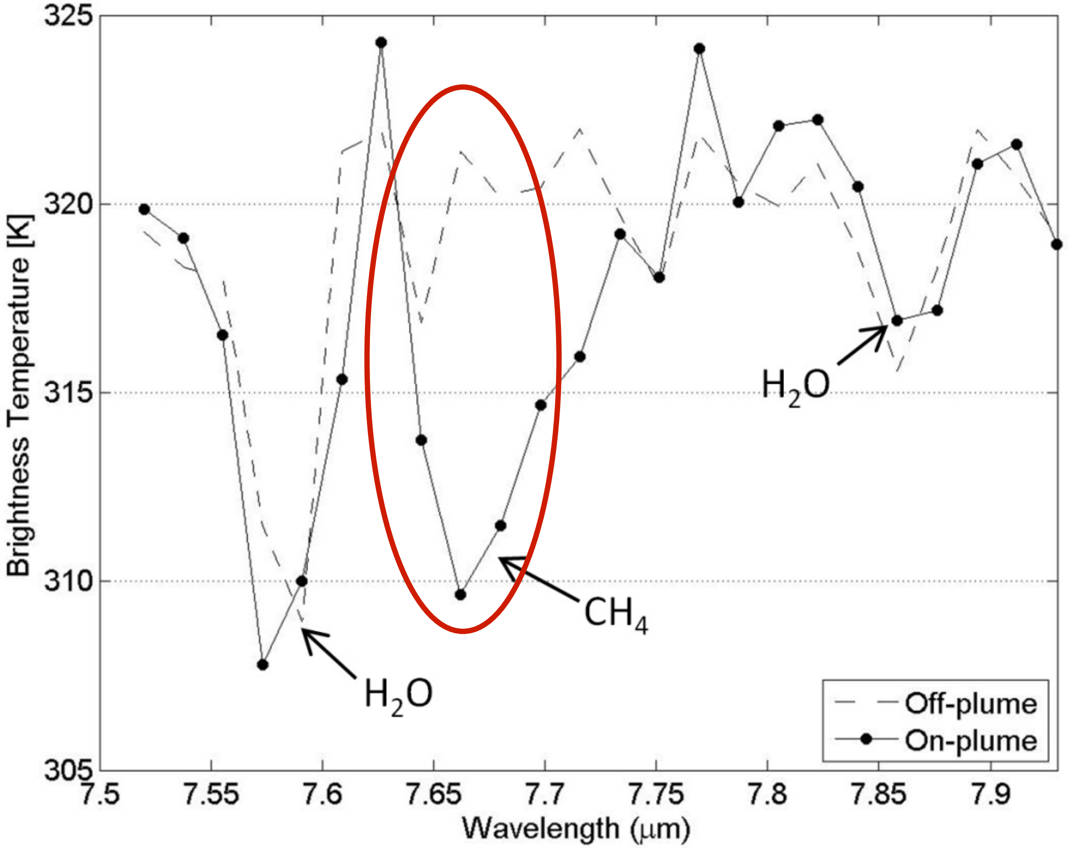
$$q = \frac{K^{-1} b}{\sqrt{b^T K^{-1} b}}$$

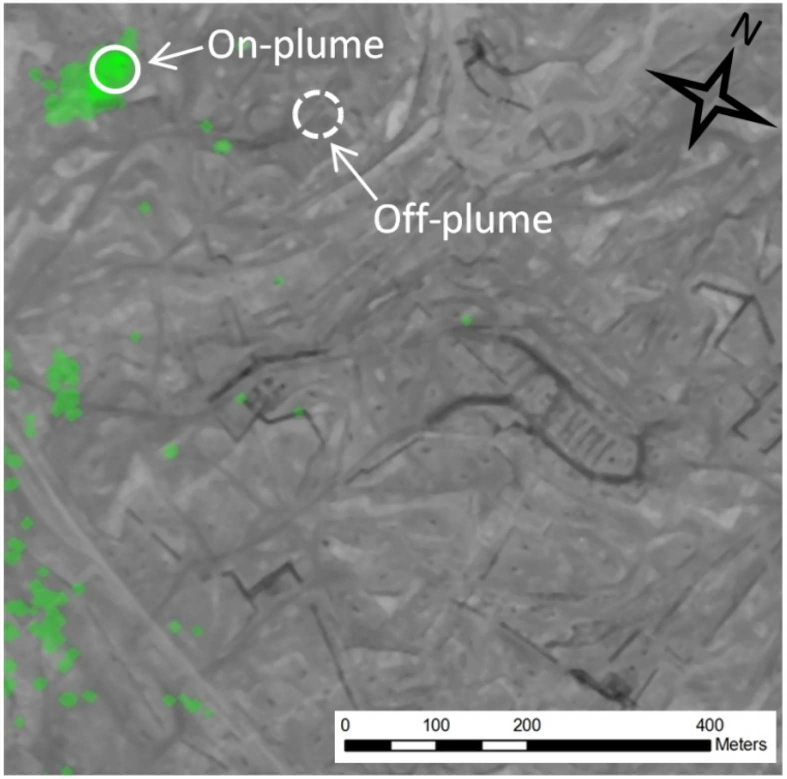
$$Plume = q^T R$$

5. Applying signal filter vector to datacube, ***R*** produces plume signature image (intensity correlates with presence of desired signature)



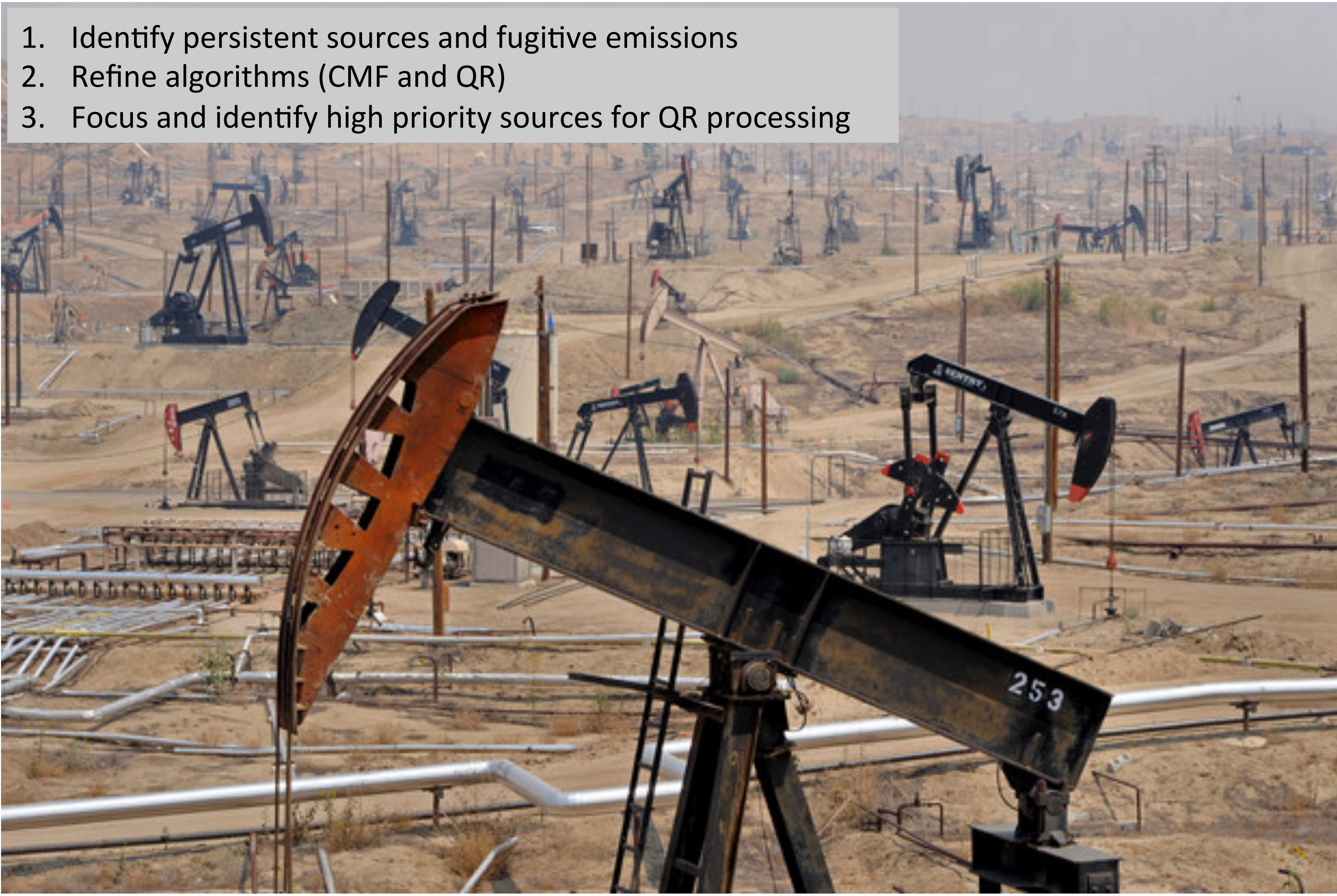

Raw CMF
Plume detection
Plume dilation
(a.1)
Kern River Oil Field
(b.1)
(c.1)
(a.2)
Four Corners
(b.2)
(c.2)

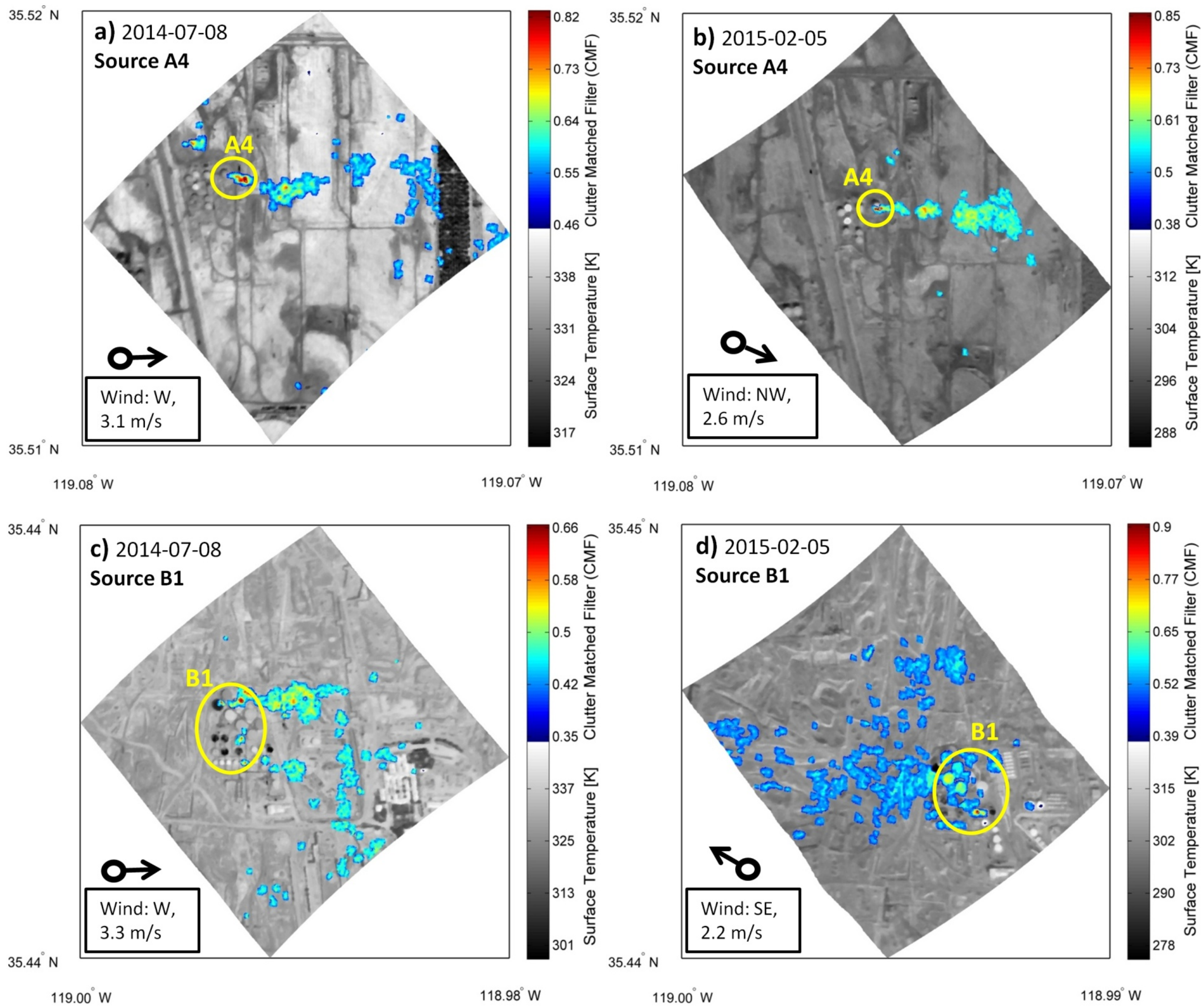

325
320
315
310
305
7.5
7.55
7.6
7.65
7.7
7.75
7.8
7.85
7.9
Wavelength (μm)
Brightness Temperature [K]
H_2O
CH_4
H_2O
Off-plume
On-plume


On-plume
Off-plume
N
0
100
200
400
Meters

Oil Production Fields – Kern River Oil Field, Bakersfield

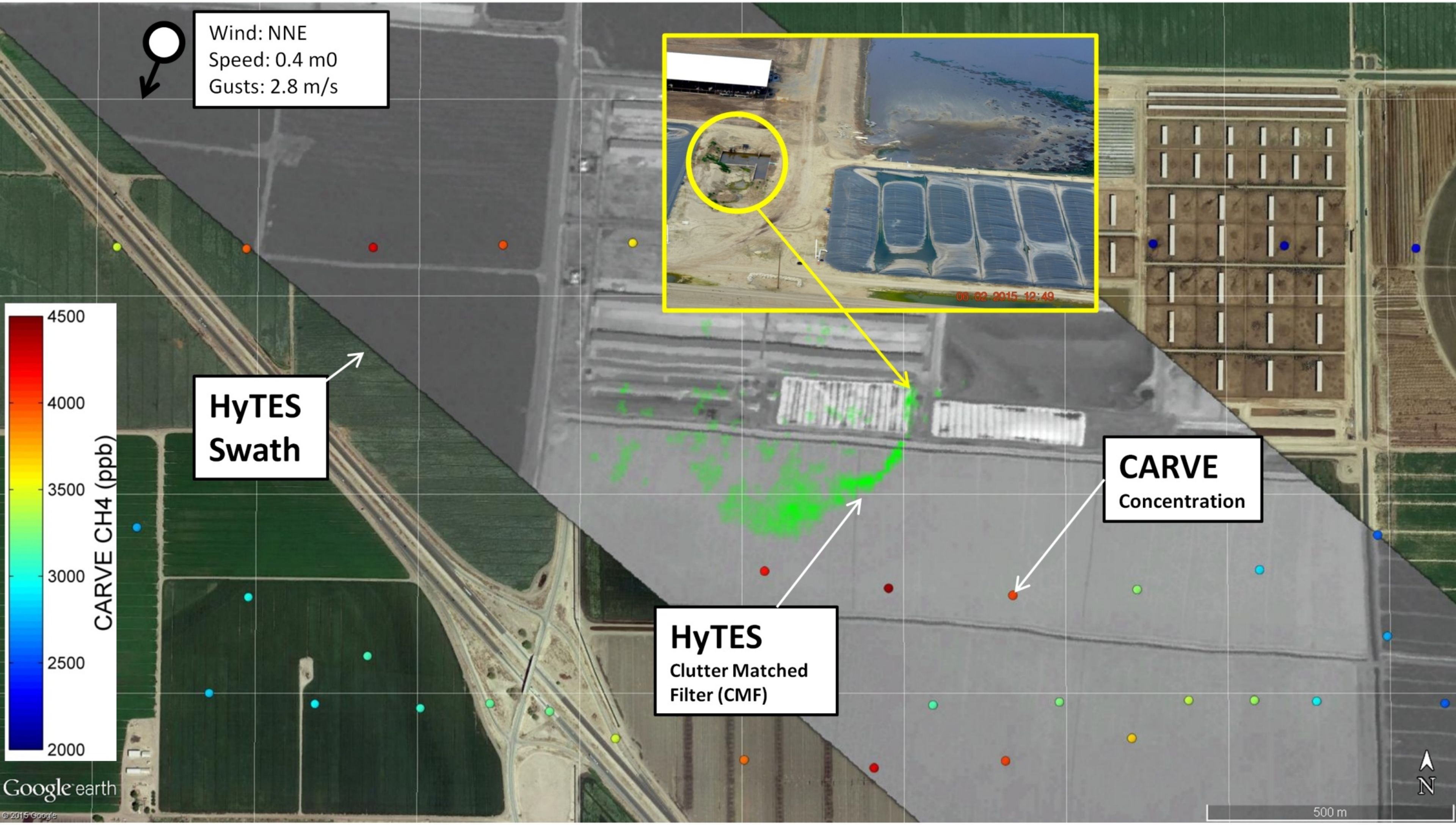
1. Identify persistent sources and fugitive emissions
2. Refine algorithms (CMF and QR)
3. Focus and identify high priority sources for QR processing

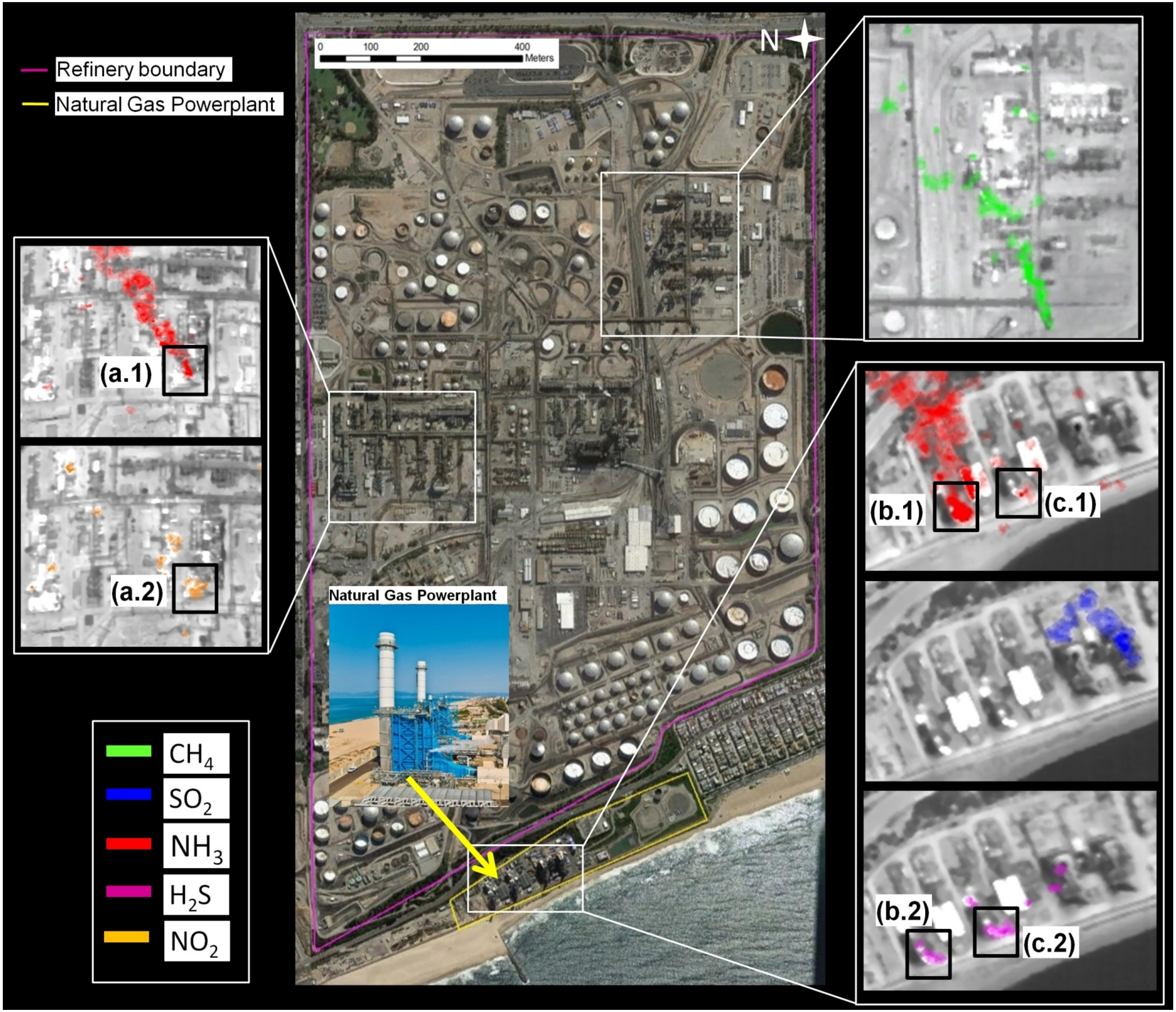




** Majority of emissions are from large infrastructure (storage, processing, distribution), not the active well heads themselves

Managed Agricultural Systems – Bakersfield Dairies



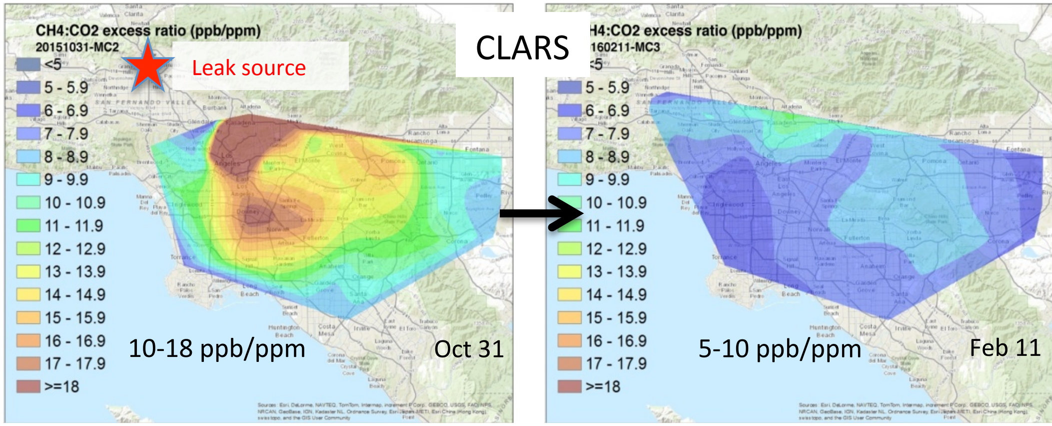


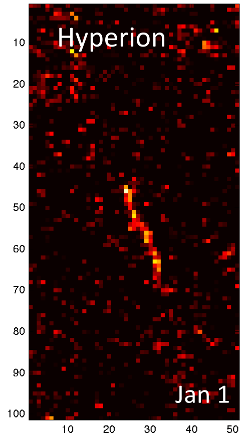
Refinery boundary
Natural Gas Powerplant
0 100 200 400 Meters
N
(a.1)
(a.2)
Natural Gas Powerplant
(b.1)
(c.1)
(b.2)
(c.2)
CH_4
SO_2
NH_3
H_2S
NO_2

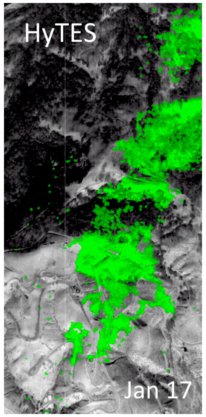
Tracking the Aliso Canyon natural gas leak in Los Angeles

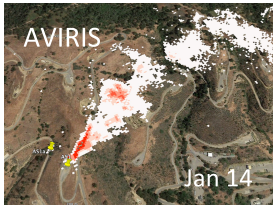
- Began Oct 23; plugged on Feb 11; still outgassing
- Complex, highly variable methane source
- Megacities Carbon Project: sustained monitoring of LA basin methane emissions (pre-leak, ongoing)
- California Laboratory for Atmospheric Remote Sensing (CLARS): prototype geostationary greenhouse gas imager on Mt Wilson
- Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and Hyperspectral Thermal Emission Spectrometer (HyTES) airborne campaign image primary plume and detect new (secondary) plumes
- Hyperion/EO-1 and GOSAT detect methane plume from space (GOSAT result not shown)

Leak in progress | After leak plugged









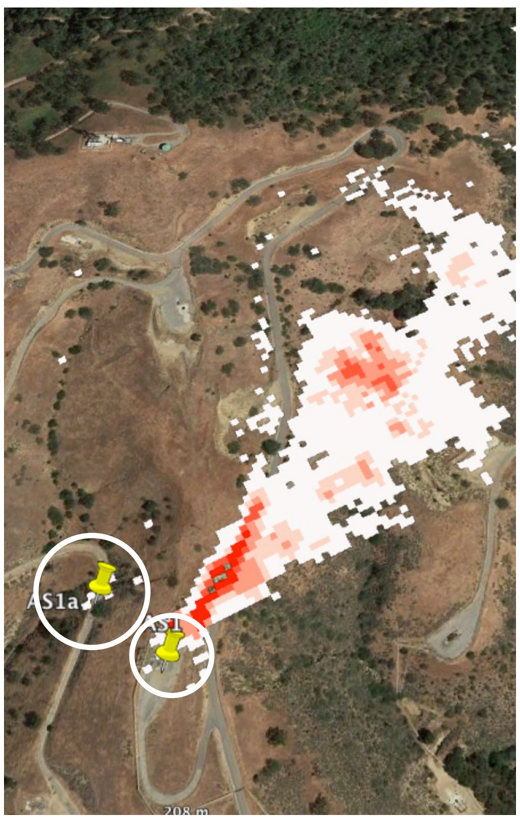
- Implications: demonstrates tiered observational strategy (surface, air and space) for addressing a persistent challenge – understanding methane fluxes
- Future work: complete data processing, validation, and synthesis analysis

https://megacities.jpl.nasa.gov

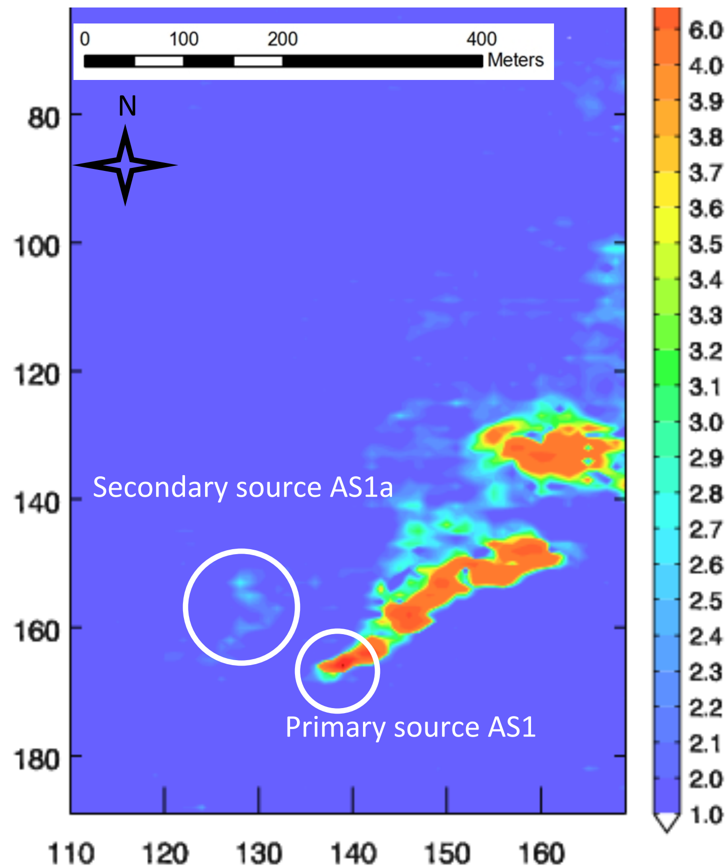
HyTES Quantitative Retrieval (QR) – Kuai et al. 2016

- Adapted for HyTES from Tropospheric Emission Spectrometer (TES) algorithm
- Simultaneous retrieval of surface and atmospheric quantities
- Full error statistics
- Ability to retrieve CH4 to ~20% total error

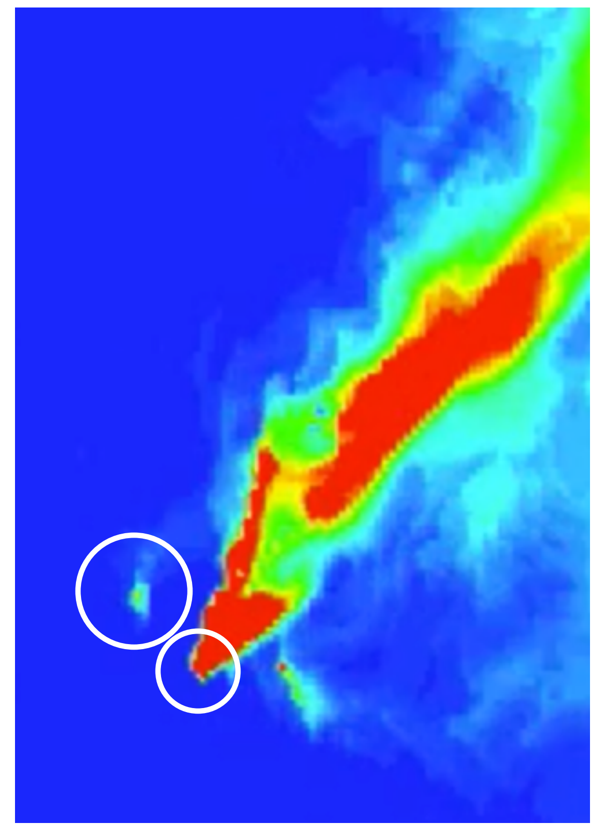
AVIRIS



HyTES



NIST LES Model



Tracking the Aliso Canyon natural gas leak in Los Angeles

May 31: public release of methane data products

	AVIRIS	HyTES	CLARS
Product type	Georectified maps of CH_4 mixing ratio lengths (units ppm-m)	Georectified CH_4 CMF intensity maps and CH_4 mixing ratios (units ppm)	Gridded basin wide XCH_4:XCO_2 correlation maps (units ppb:ppm); wind vectors
Spatial coverage	Multiple 5km x 30 km lines centered on Aliso Canyon	Multiple 100 km2 surveys of Aliso Canyon and surrounding areas	~ 50% of LA basin (incl San Fernando Valley starting Dec 15)
Spatial resolution	6.6 m	3.8 m	1000 m
Dates	2016 Jan 12, 14, Feb 9, 19	2016 Jan 14, 17, 25, 26	2015 June – 2016 March
Frequency	6-8 lines per flight day	1-2 surveys per flight day	5 samples per day (when cloud, aerosol clear)

https://megacities.jpl.nasa.gov
http://hytes.jpl.nasa.gov/
http://aviris.jpl.nasa.gov/

***Preliminary** findings (to be confirmed)*

- Multiple secondary sources (complex sub-surface); outgassing continues
- Highly variable, complex leak in first 30 days (perhaps significantly larger than initial reports)
- Exploring possibility that Aliso Canyon was a persistent methane source for months-years preceding the October 23 blow-out event

Follow-up: JPL will conduct statewide airborne methane survey this summer (funded by CA agencies) http://hytes.jpl.nasa.gov/order

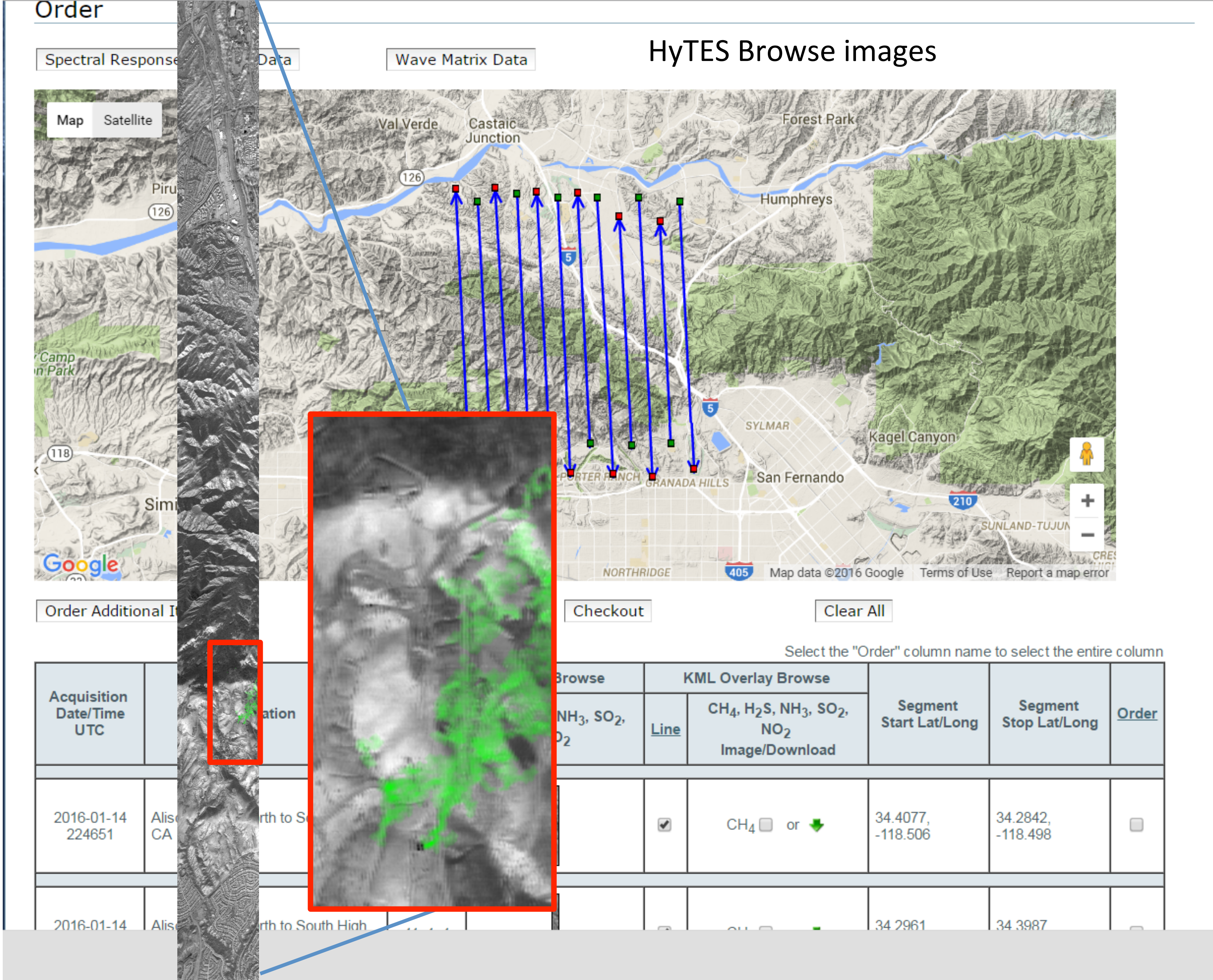
HyTES
Hyperspectral Thermal Emission Spectrometer

Order

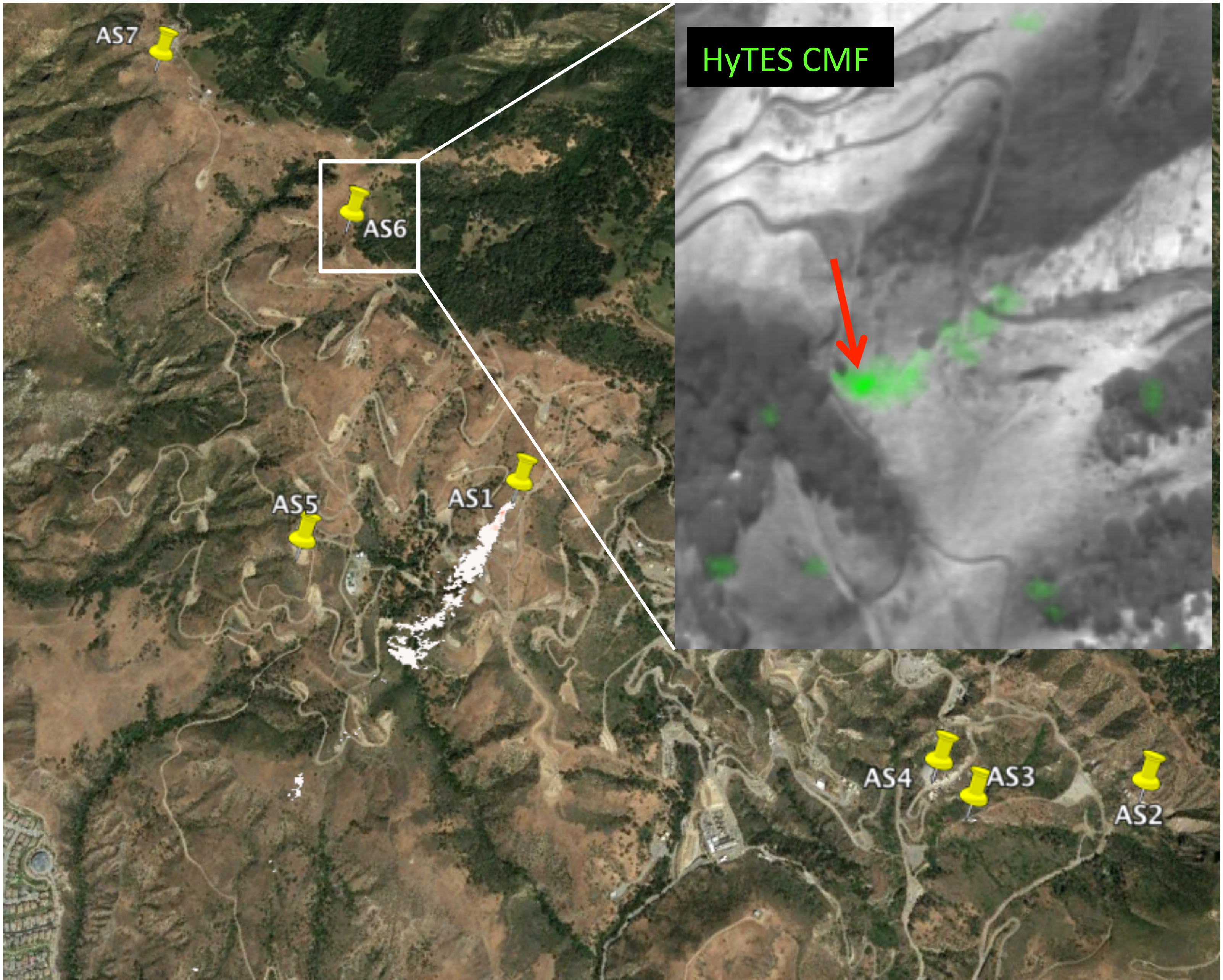
Filter by Year: All ▾ **Filter by Month:** All ▾ View Cart Checkout Campaign Summary

Acquisition Date	Location (Browse and Order)	L1 & L2 Data Products	L3 Data Products	Planned Start Latitude/Longitude	Planned Stop Latitude/Longitude	Segments	AGL (m)	Approx Pixel Size (m)
2016-01-26	Aliso Canyon Northeast to Southwest Low, CA	Version 2	Version 1.1	34.3669, -118.554	34.2716, -118.602	1	1805.54	3.29
2016-01-26	Honor Rancho, CA	Version 2	Version 1.1	34.4265, -118.594	34.4823, -118.59	1	976.312	1.78
2016-01-25	Huntington Gardens near Pasadena, CA	Version 2	Not Avail	34.1411, -118.117	34.1043, -118.109	1	1024.78	1.87
2016-01-25	Jet Propulsion Laboratory, CA	Version 2	Not Avail	34.1976, -118.192	34.2028, -118.143	1	3130.08	5.7
2016-01-25	Aliso Canyon North to South Low, CA	Version 2	Version 1.1	34.2844, -118.579	34.365, -118.583	1	1815.66	3.31
2016-01-25	Hyperion Coast - Marina Del Rey, El Segundo, & Manhattan Beach, CA	Version 2	Version 1.1	33.9896, -118.463	33.8778, -118.406	1	1080.11	1.97
2016-01-25	Playa in Marina Del Rey, CA	Version 2	Version 1.1	33.978, -118.457	34.0081, -118.402	1	924.964	1.68
2016-01-21	Honor Rancho, CA	Version 2	Version 1.1	34.4748, -118.648	34.427, -118.563	1	892.561	1.63
2016-01-17	Aliso Canyon North to South Low, CA	Version 2	Version 1.1	34.3583, -118.566	34.2711, -118.562	1	1776.94	3.24
2016-01-14	Aliso Canyon Northeast to Southwest High, CA	Version 2	Version 1.1	34.2643, -118.618	34.3552, -118.48	1	2179.82	3.97
2016-01-14	Aliso Canyon North to South High, CA	Version 2	Version 1.1	34.2959, -118.556	34.4117, -118.563	1	2178.55	3.97
2016-01-12	Aliso Canyon North to South High, CA	Version 2	Version 1.1	34.2942, -118.579	34.372, -118.583	1	2087.34	3.8
2015-05-03	Cuprite Hills in Esmeralda County, NV	Version 2	Not Avail	37.4927, -117.224	37.6318, -117.221	1	4985.54	9.08
2015-05-02	Vintage Dairy, CA	Version 2	Version 1.1	36.4882, -120.105	36.4743, -119.967	1	1093.41	1.99
2015-05-02	Schilling, CA	Version 2	Version 1.1	36.408, -119.874	36.4398, -120.029	1	1123.55	2.05
2015-05-02	Edenvale Dairy, CA	Version 2	Version 1.1	36.4096, -119.808	36.3533, -119.863	1	1117.11	2.03
2015-05-02	Tipton, CA	Version 2	Version 1.1	36.0108, -119.36	36.3635, -119.481	1	1096.85	2.0

HyTES Browse images



Source AS6?

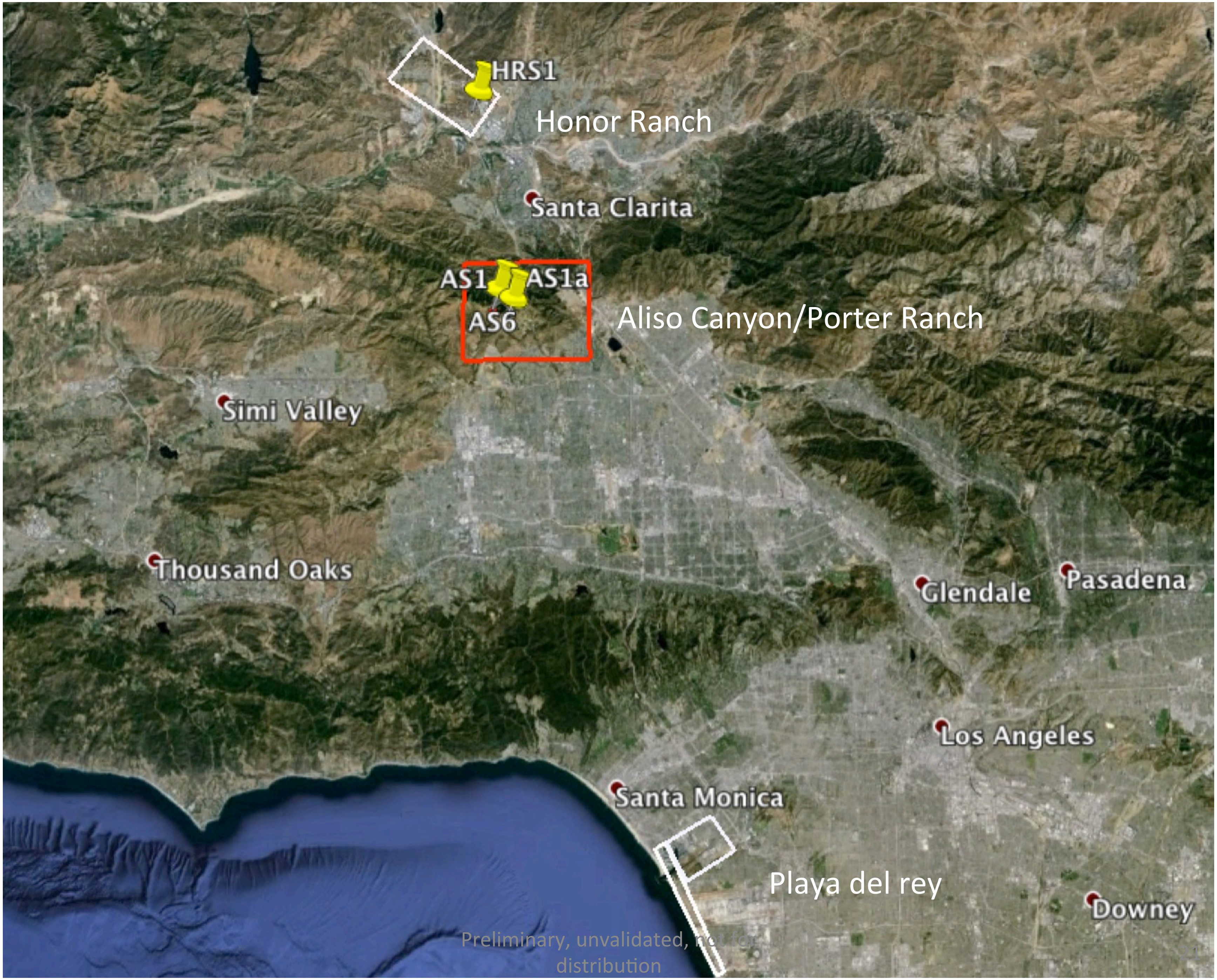


Summary

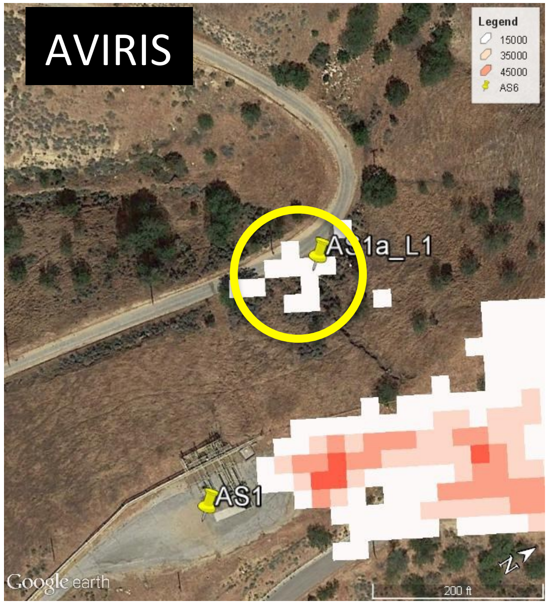
- HyTES provides wide-swath (1-2 km), high spatial (~2m at 1-km) and spectral (256 bands, 7.5 -12 micron) TIR images.
- Clutter Matched Filter and Quantitative Retrievals developed (Hulley et al. 2016, Kuai et al. 2016)
- Ability to characterize spatial distribution and identify point sources of methane
- Capability to detect multiple chemical species (CH4, NO2, H2S, NH3, SO2) in single plume
- Complement other satellite and in situ observational platforms in tiered observation strategy to improve scientific understanding and decision-making with methane emission sources

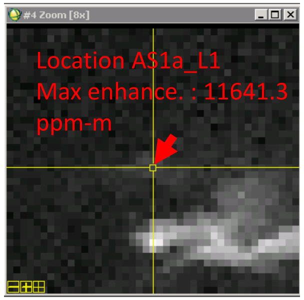
Outline

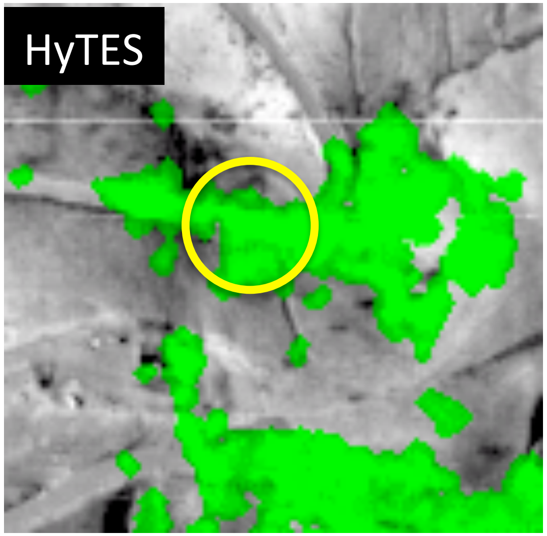
- Instrument characteristics
- Science highlights
- Plume detection methodology
- Methane examples in SJV
- Multi-species detection example
- Aliso Canyon (Porter Ranch) leak


HRS1
Honor Ranch
Santa Clarita
AS1
AS1a
AS6
Aliso Canyon/Porter Ranch
Simi Valley
Thousand Oaks
Glendale
Pasadena
Los Angeles
Santa Monica
Playa del rey
Downey

Secondary source AS1a

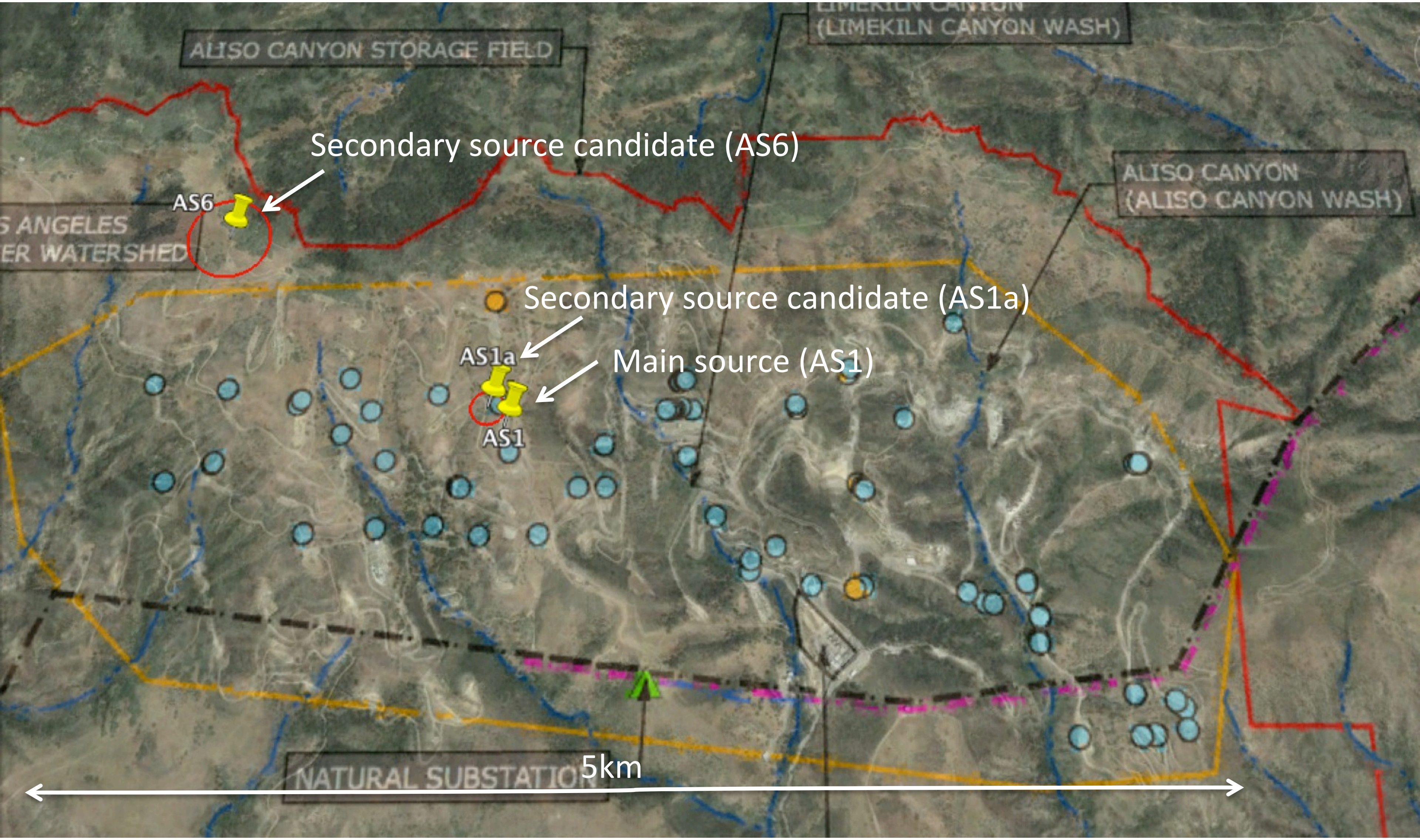


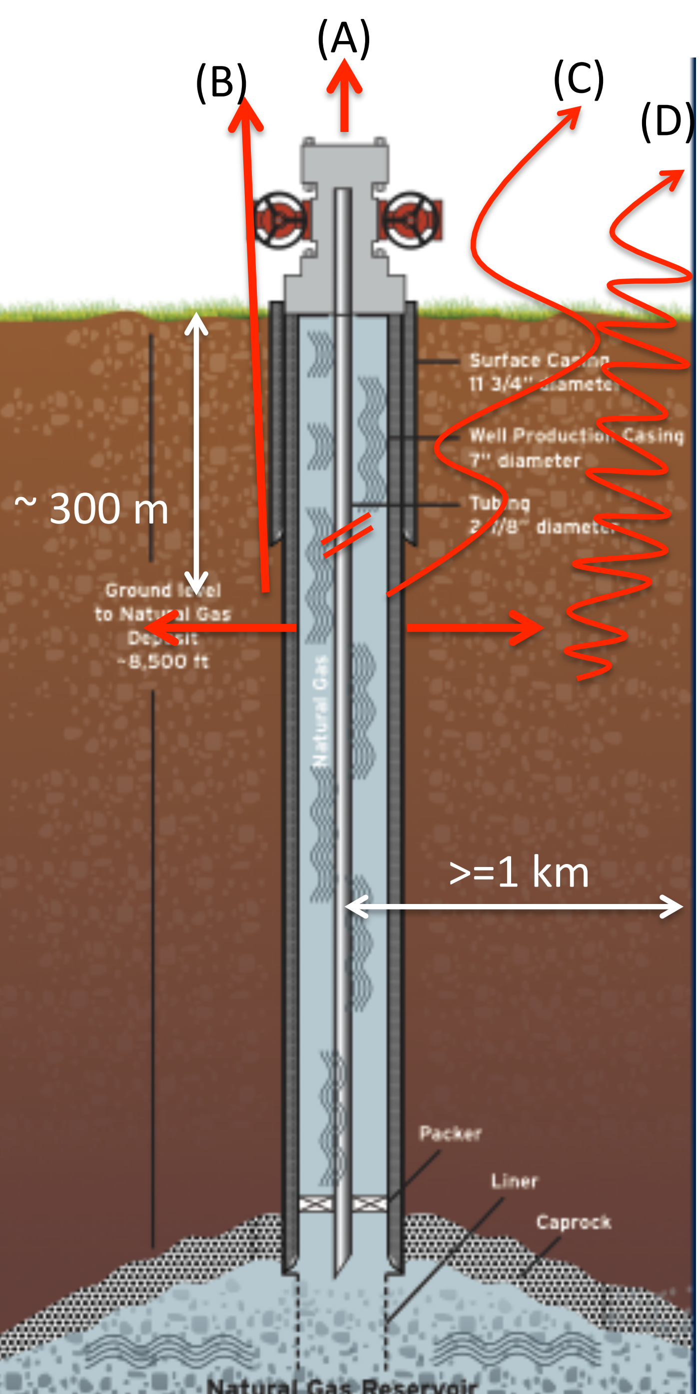




Courtesy A. Thorpe, G. Hulley, N. Vance, B. Johnson

AVIRIS and HyTES both detect 2 secondary CH_4 sources at Aliso Canyon





Potential pathways for CH_4 gas (leak modes)

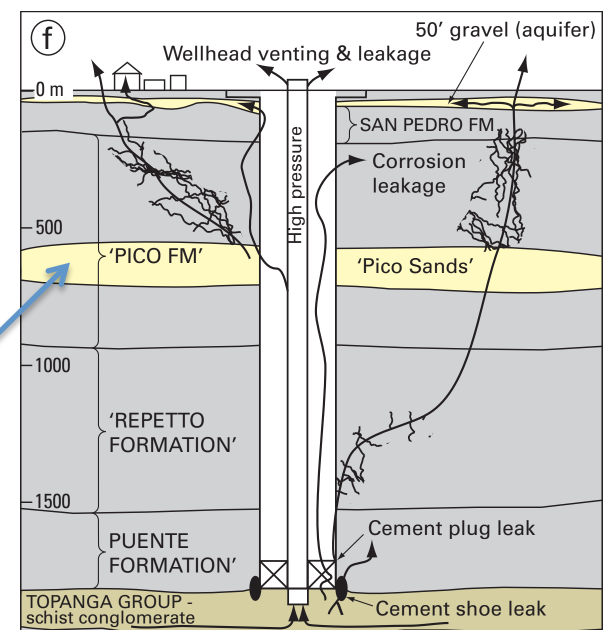
(A) Direct venting from well head (inside casing)
(B) Venting along/around well bore via casing-soil gaps*
} Point source

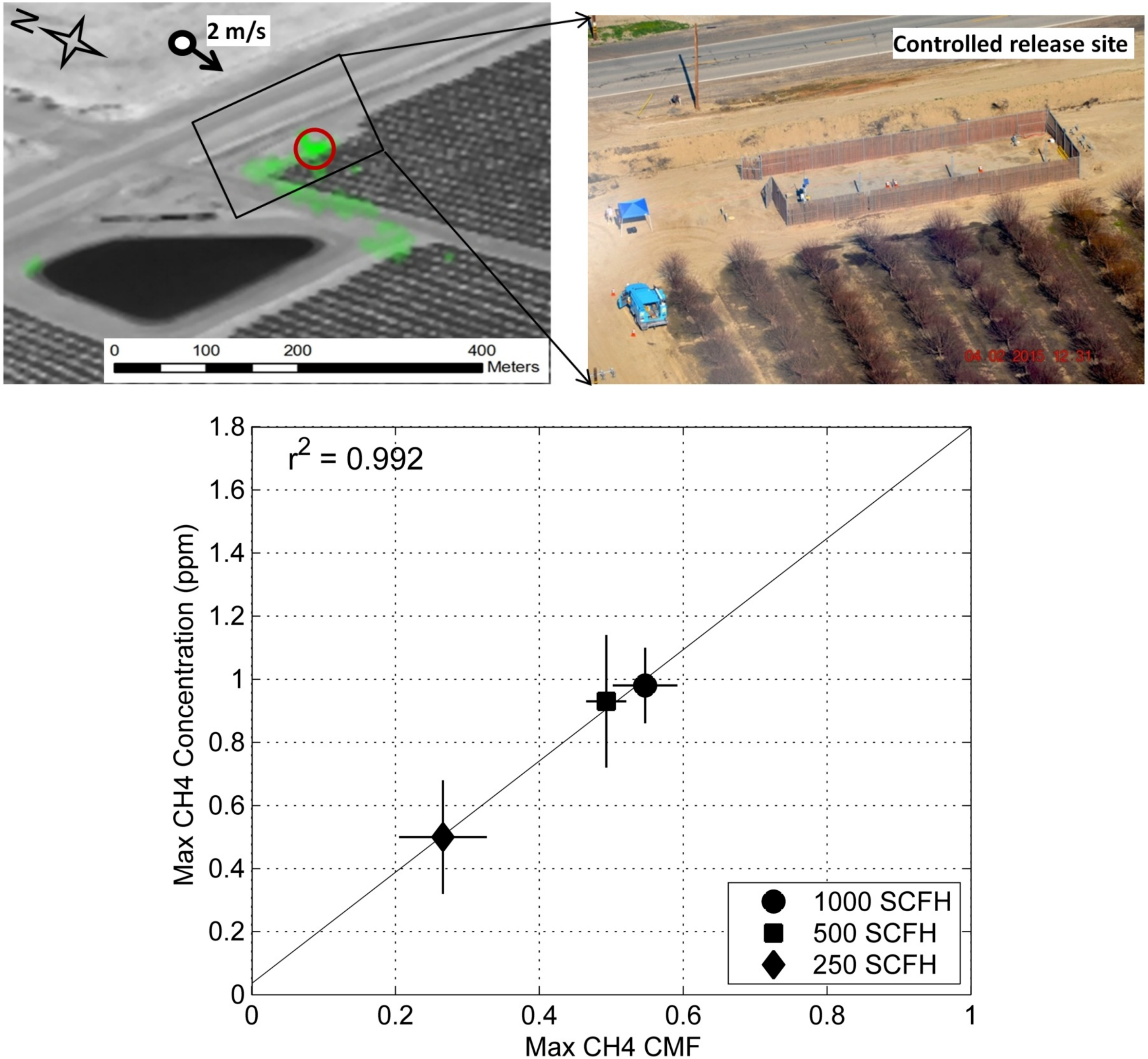
(C) Venting through many low-impedance paths (macro seep)
(D) Slow out-gassing (micro seep)
} Many point sources or area source ?

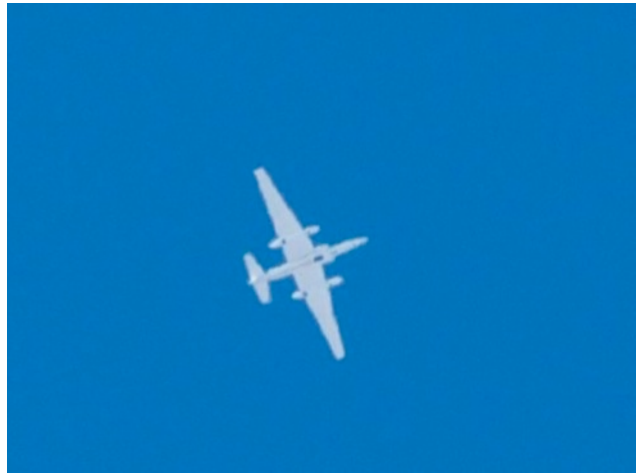
*outer casing (cement) limited to top 990 ft and bottom 500 ft of well

same Pico formation overlies the Aliso Canyon reservoir

From UK report on
Playa del rey storage facility leaks




N
2 m/s
0
100
200
400
Meters
Controlled release site
r^2 = 0.992
Max CH4 Concentration (ppm)
Max CH4 CMF
1000 SCFH
500 SCFH
250 SCFH
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8

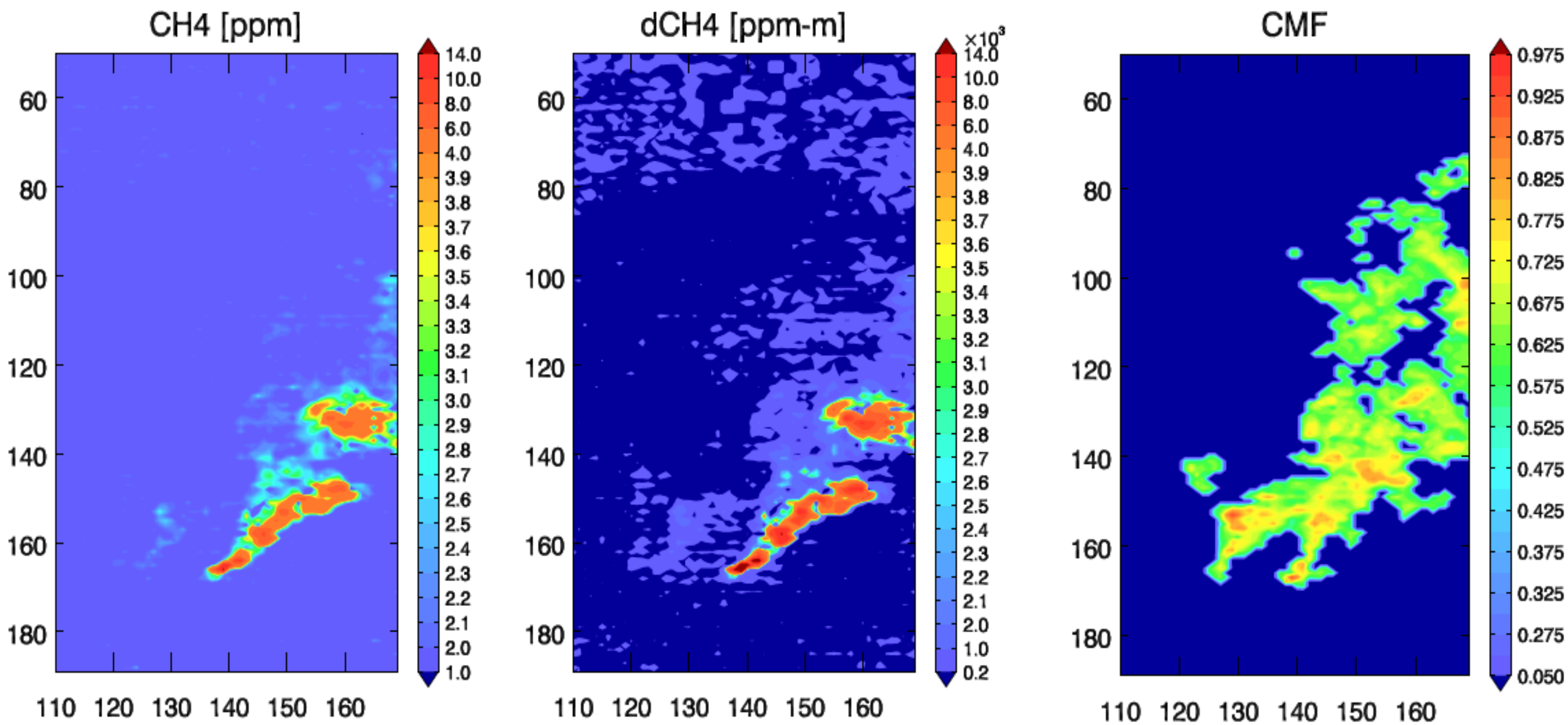
  

Porter Ranch gas leak
airborne campaign
25 Jan 2016 update

Riley Duren, Francesca Hopkins, David Thompson, Nick Vance, Glynn Hulley, Bill Johnson, Bjorn Eng, Andrew Aubrey, Christian Frankenberg, Andrew Thorpe, Seth Chazanoff, Charles Sarture, John Mihaly, Zak Staniszewski, Michael Eastwood, Rob Green, Simon Hook, Chip Miller and the ARFC and Twin Otter flight crews

Quantitative Retrieval (QR) – Kuai et al. 2016

- Adapted for HyTES from Tropospheric Emission Spectrometer (TES) algorithm
- Simultaneous retrieval of surface and atmospheric quantities
- Full error statistics
- Ability to retrieve CH4 to ~20% total error



Airborne Hyperspectral Thermal Infrared Systems

Instrument	First Deployed	Bands	Spectral Range (µm)	Spectral Resolution (nm)	IFOV*** (mrad)	Max Scan (°)	Pixels X-track	NEDT* (K)	Detector
AISA-OWL[1]	2014	96	7.7-12.3	100	1.10	±24	384	25**	HgCdTe
HyTES[2]	2013	256	7.5-12	18	1.70	±25	512	0.20	QWIP
MAGI[3]	2011	32	7.1-12.7	175	0.53	±42	2800	0.10	HgCdTe
Sieleters B3[4]	2011	38	8-11.5	80	0.25	±7	-	0.15	HgCdTe
MAKO[5]	2010	128	7.45-13.5	47	0.55	±45	400-2750	0.05	Si:As
SEBASS[6]	1995	128	7.6-13.5	46	1.10	±3.6	128	0.05	Si:As
LWHIS[7]	2003	128	8-12.5	35	0.9	±3.25	128	0.035	HgCdTe

*NEDT = Noise Equivalent Differential Temperature (K)
** NESR = Noise Equivalent Spectral Radiance (mW/m2/sr/µm)
*** IFOV = Instantaneous Field of View
[1] Specim (Finland)
[2] Jet Propulsion Laboratory (USA)
[3,5,6] The Aerospace Corporation (USA)
[4] Onera (France)
[7] Northrop Grumman Space Technology (USA)