HyTES Science Investigations:

Detection and Mapping of Trace Gases
Surface Compositional Studies

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Gratings: Dan Wilson
Thermal/Mechanical: Jonathan Mihaly, Chris Paine, Andy Lamborn, Kevin Knarr, William Johnson
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Outline

- 2014 Campaign Results
- Instrument Characteristics
- Surface Composition
- Gas Plume Detection Examples:
  - Salton Sea (NH_3 and H_2S)
  - La Brea Tar Pits (CH_4)
  - Kern River Oil Field (CH_4)
  - Ace Cogeneration Plant (SO_2, NO_2)
  - Granada Hills (CH_4)
  - Central Valley Cattle Feedlots (CH_4)

HyTES Key Science Results for 2014

1) Detection of anthropogenic methane over challenging areas, e.g. cities where thermal in-scene clutter makes detection difficult. This includes detection of natural (seeps) and managed systems (e.g. feedlots, pipelines, oil fields, landfills, storage facilities)

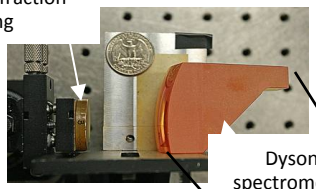
2) Detection of additional gases. Can now detect:
   a) Salton Sea (NH_3 and H_2S)
   b) La Brea Tar Pits (CH_4)
   c) Kern River Oil Field (CH_4)
   d) Ace Cogeneration Plant (SO_2, NO_2)
   e) Granada Hills (CH_4)
   f) Central Valley Dairies/Feedlots (CH_4)

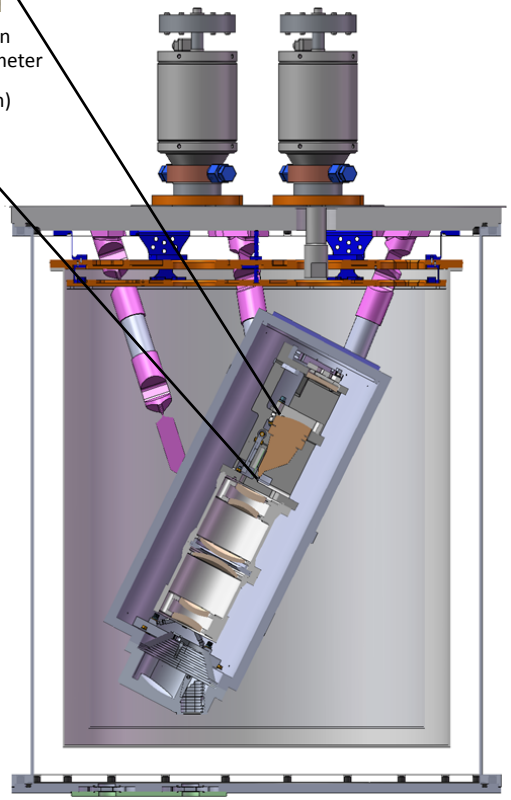
3) Acquisition of data over selected HyspIRI sites e.g. Teakettle, Soaproot Saddle, Tonzi Ranch for evaluation with HyspIRI campaign data

4) Acquisition of data over ecological, agricultural and geological sites for performance evaluation and spectral composition studies (e.g. HyspIRI TIR band optimization)

HyTES Instrument Characteristics

Twin Otter:
Flights in 2012, 2013



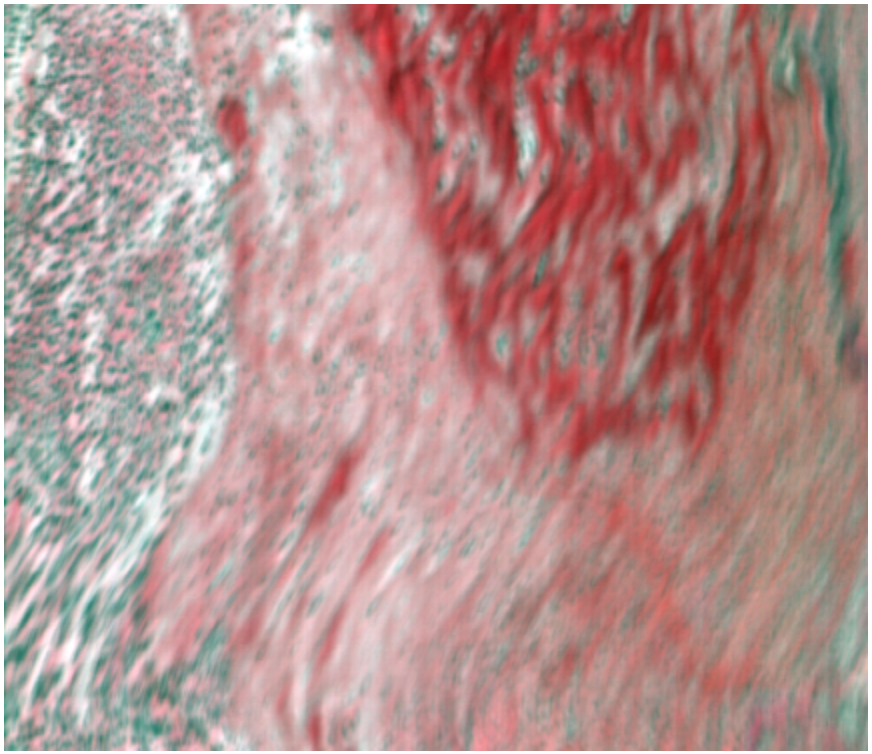


Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 um
Detector	Multi-stack QWIP
Total Field of View	50 degrees
Calibration (preflight)	Full aperture blackbody
Swath Width	1.8 – 3.6 km
Pixel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

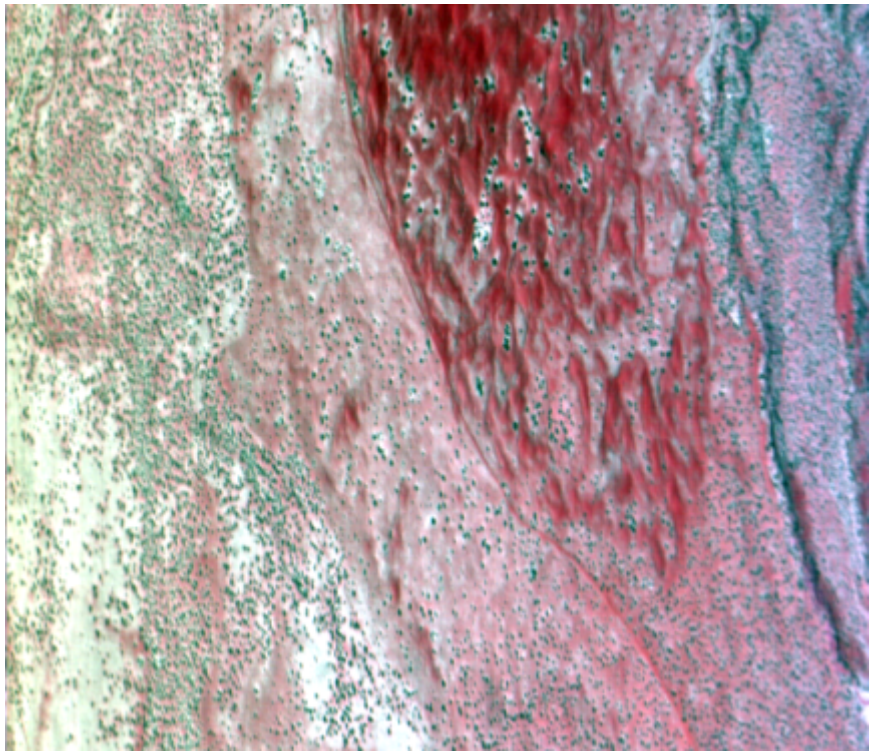
<u>Advanced Instrument Designs:</u>
William Johnson

Imagery from campaign

Coral Pink, UT



2013



2014

L1A: bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm), 58 displayed at RGB each image is 485 x 512 pixels

Death Valley 'Bowtie'

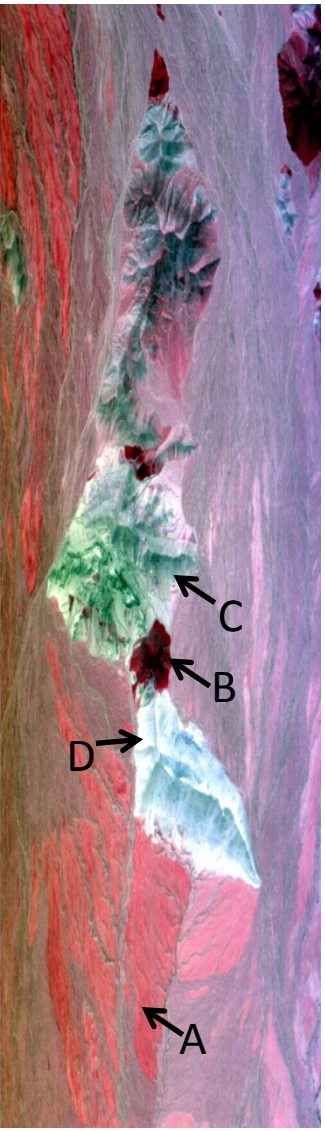
Rock types difficult to distinguish in visible image from Google Earth

HyTES RGB:
bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm)

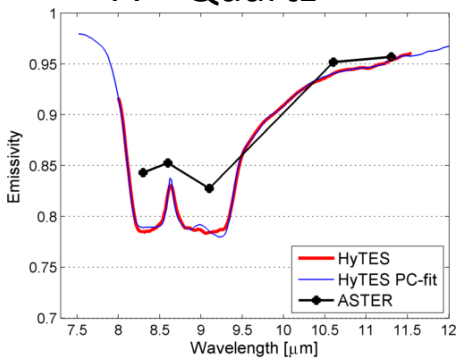
Emissivity Variations allow rock type to be separated:

Red = quartz-rich
Green = carbonate
Purple = quartz-poor rocks
Maroon = quartzite
White = Basalt

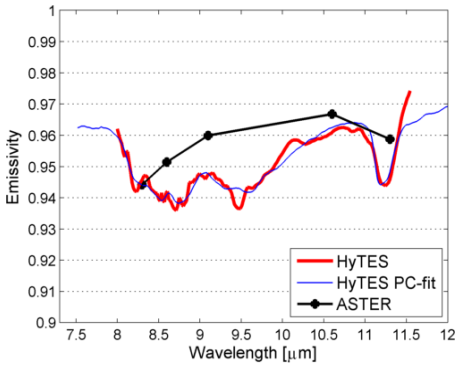
Death Valley 'Bowtie'



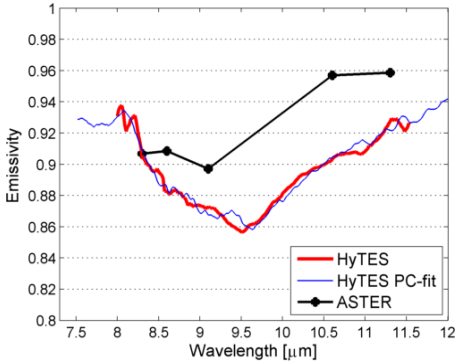
A – Quartz



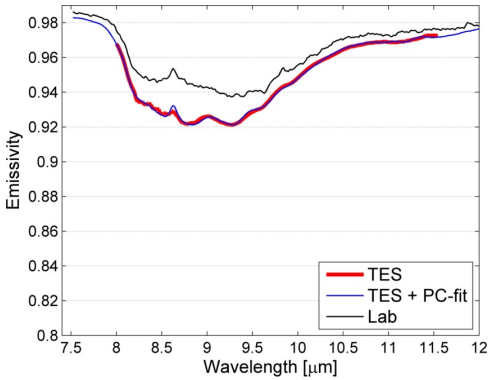
C - Carbonate



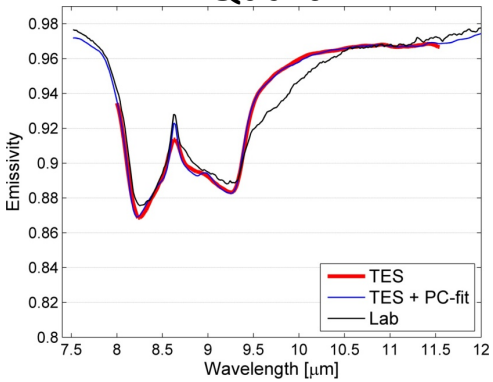
D - Basalt



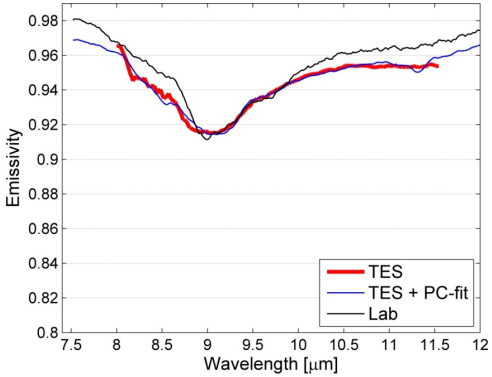
A – Kaolinite



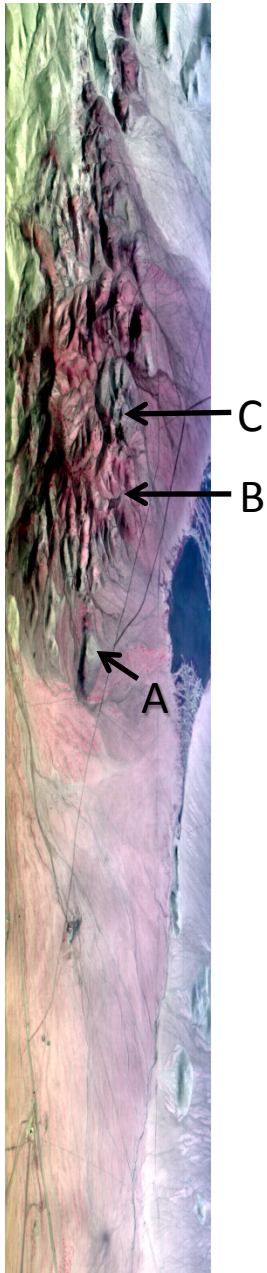
B – Quartz



C – Alunite



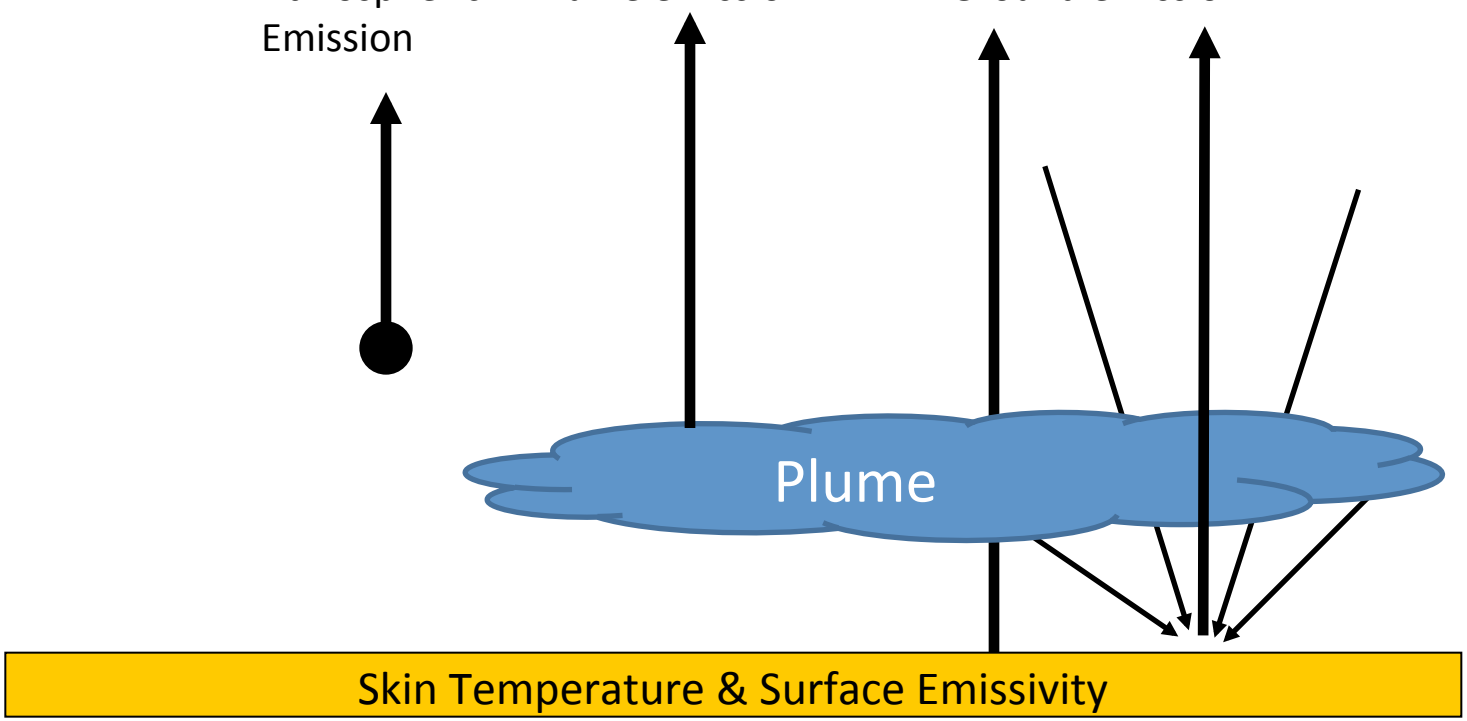
Cuprite, NV



Thermal Infrared 'Plume' Radiative Transfer

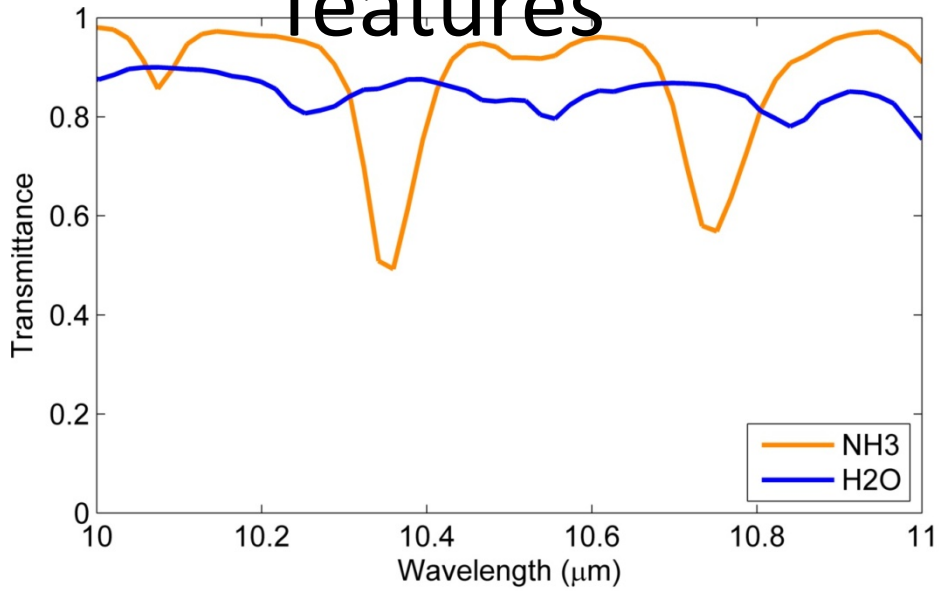
Sensor Radiance

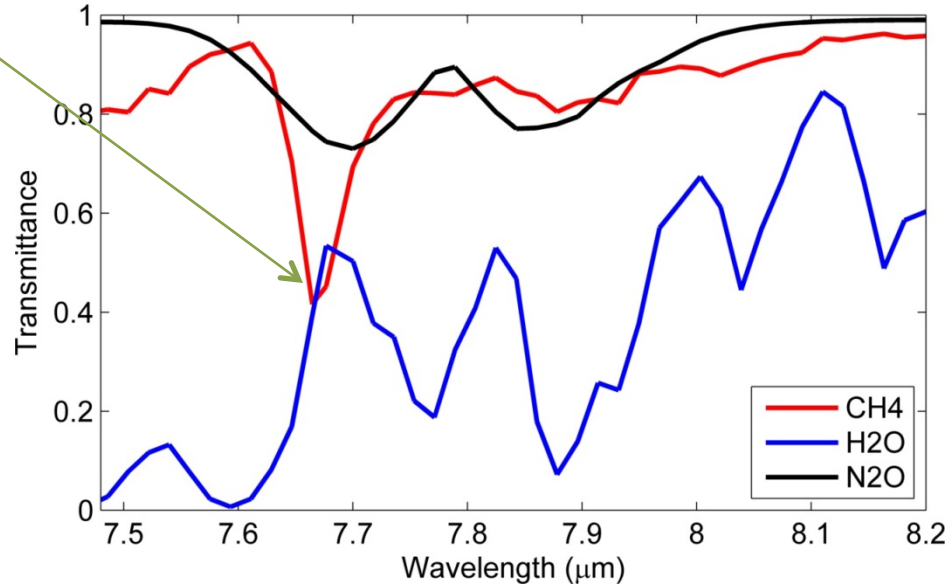
$$L_i(\theta) = \underbrace{L^{path}}_{\text{Atmospheric Emission}} + \boxed{\underbrace{L^{plume}\tau^{atm}}_{\text{Plume emission}}} + \underbrace{L^{gnd}\tau^{atm}\boxed{\tau^{plume}}}_{\text{Ground emission}}$$



Thermal Infrared gas absorption features

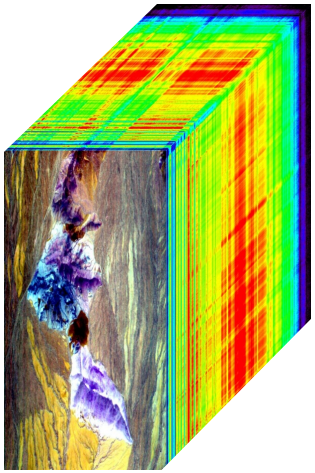
Need accurate atmospheric correction (e.g. ISAC) to remove water vapor absorption effects from signal.





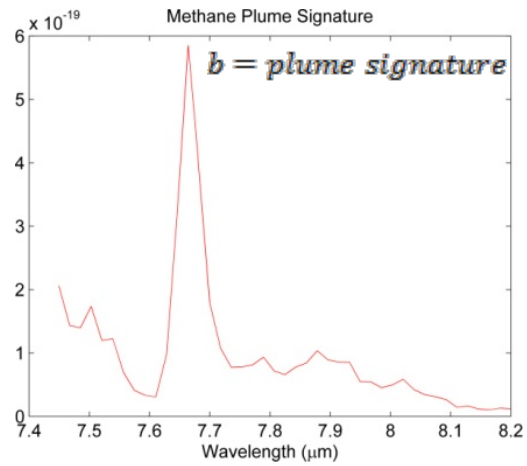
HyTES Plume Detection: Clutter Matched Filter

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



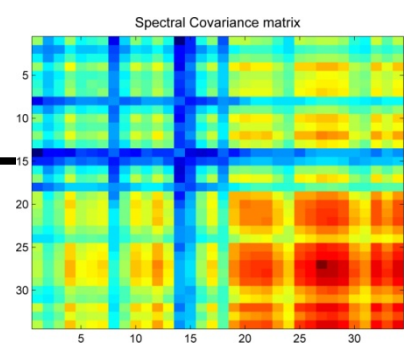
$R \in (N,n)\ N = pixels, n = bands$

2. Search for spectral signature, ***b***, assumed to be linearly superimposed on background signal.
Gas signature ***b*** is extracted from Hitran database.



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

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

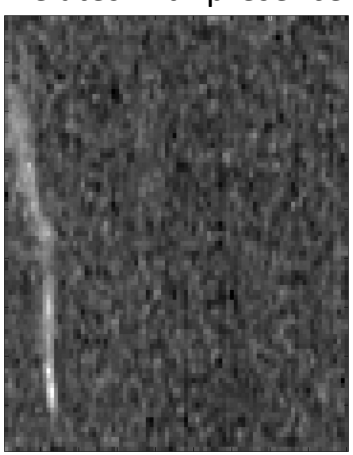


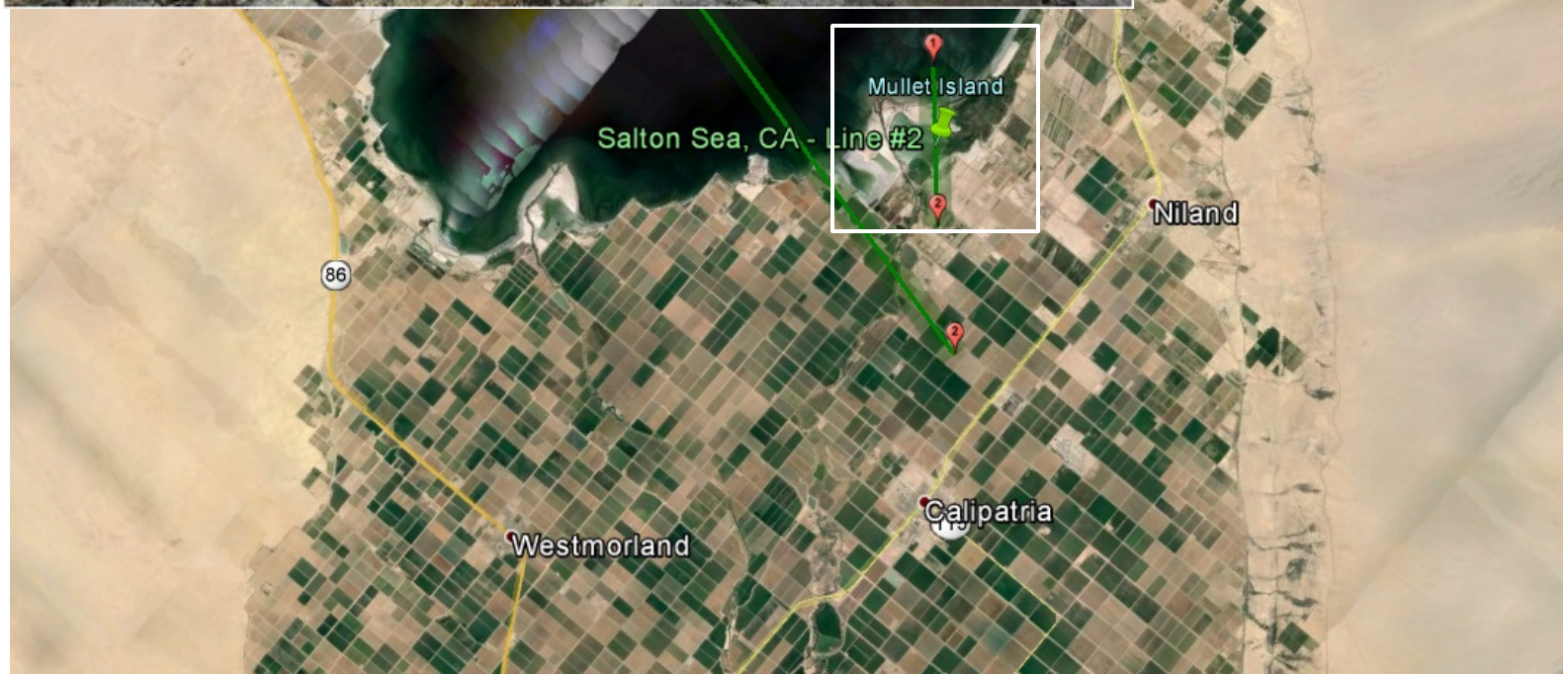
4. Compute signal filter vector, ***q***:

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

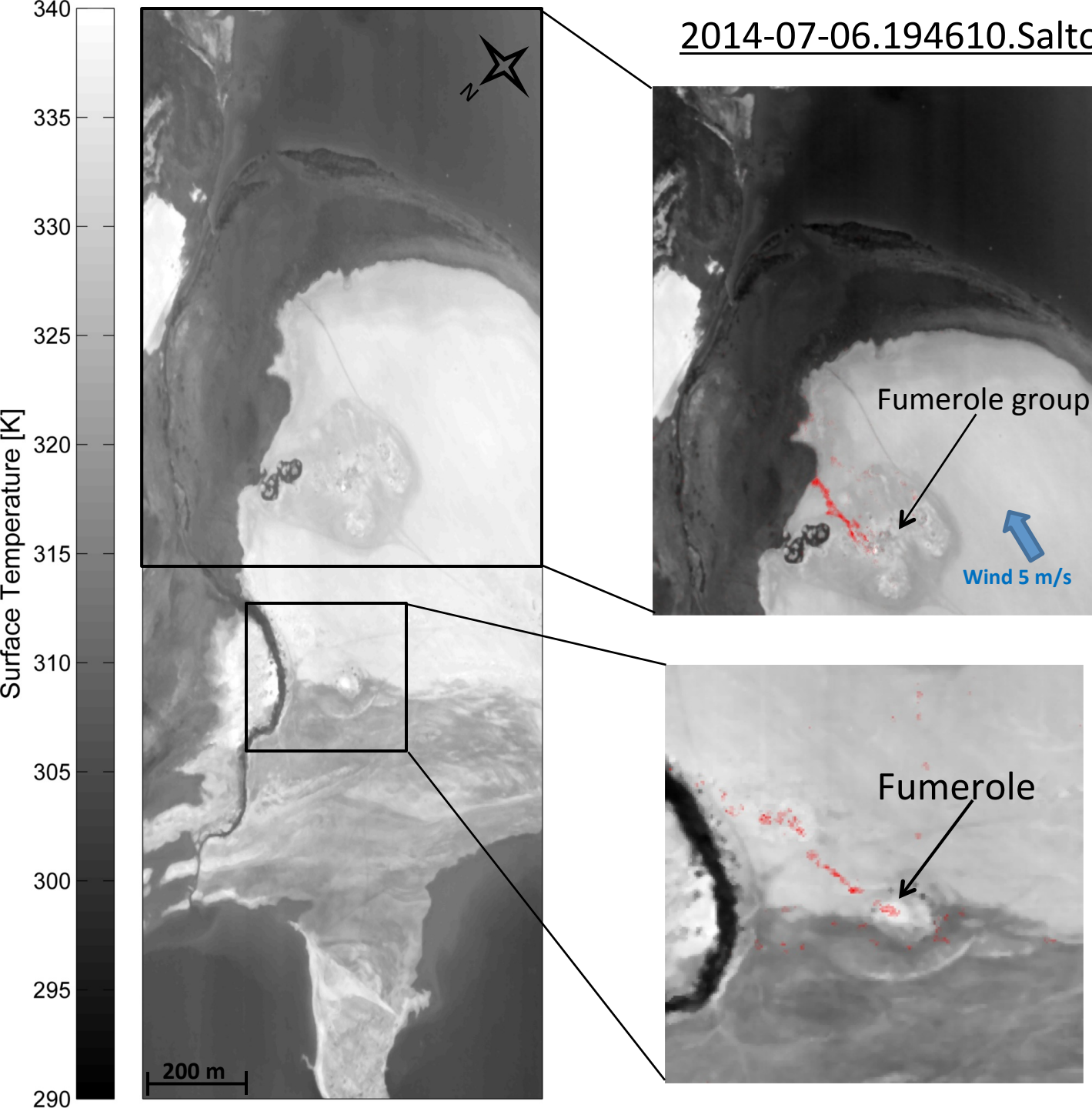
$$Plume = q^T R$$

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




Mullet Island
Salton Sea, CA - Line #2
Niland
86
Calipatria
Westmorland

2014-07-06.194610.SaltonSea.Line2-Run1

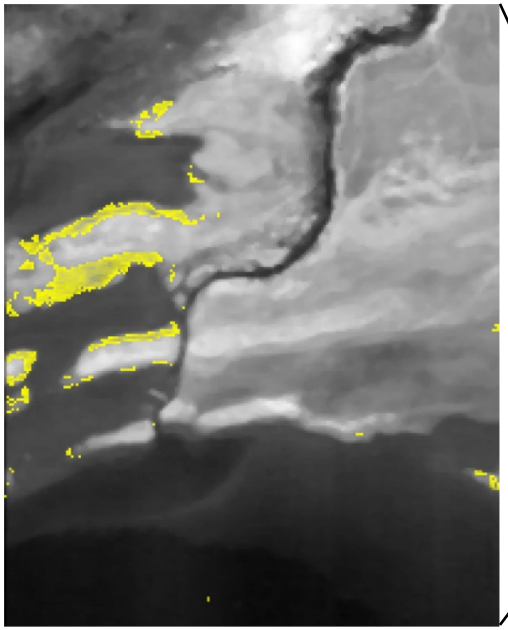


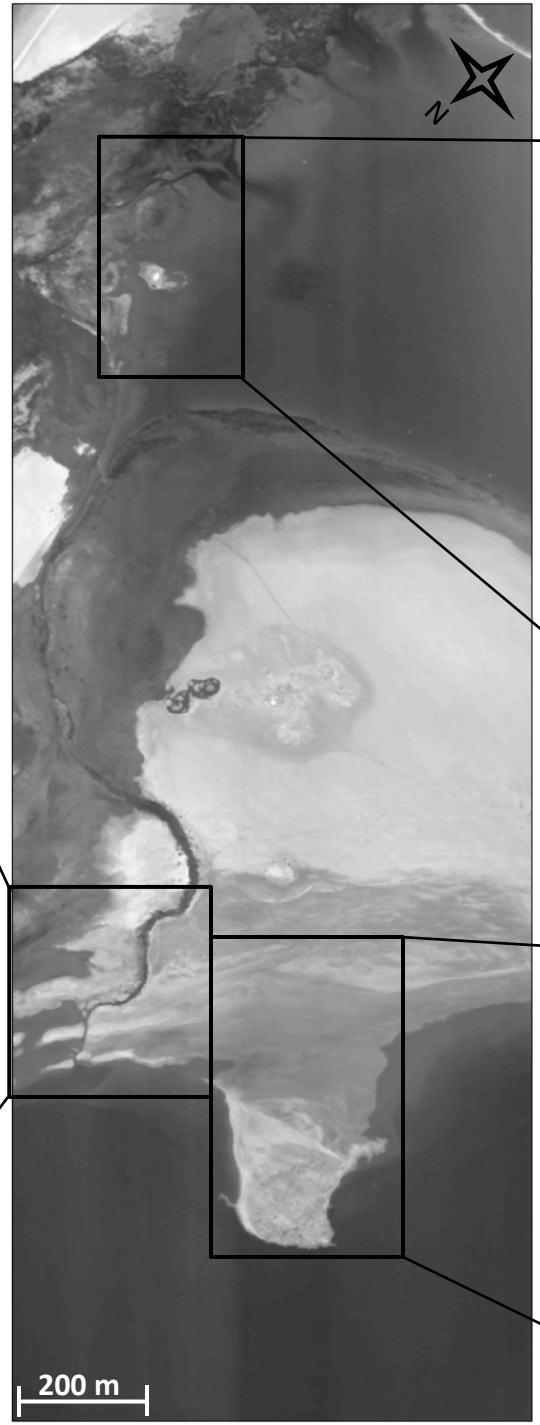
Ammonia (NH3)

Detection in red, Overlay on Surface Temperature image

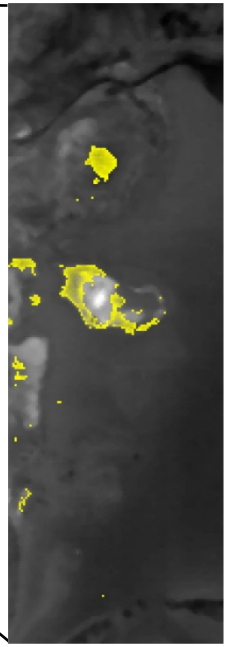
Hydrogen Sulfide (H2S)

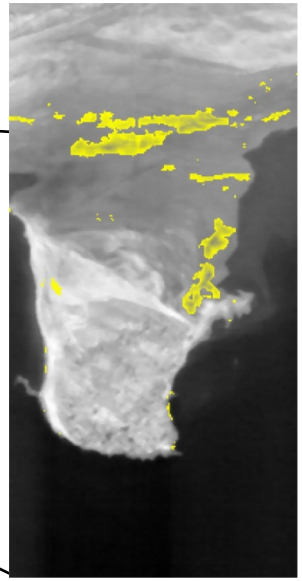
detection in yellow, Overlay on Surface Temperature image





2014-07-06.194610.SaltonSea.Line2-Run1



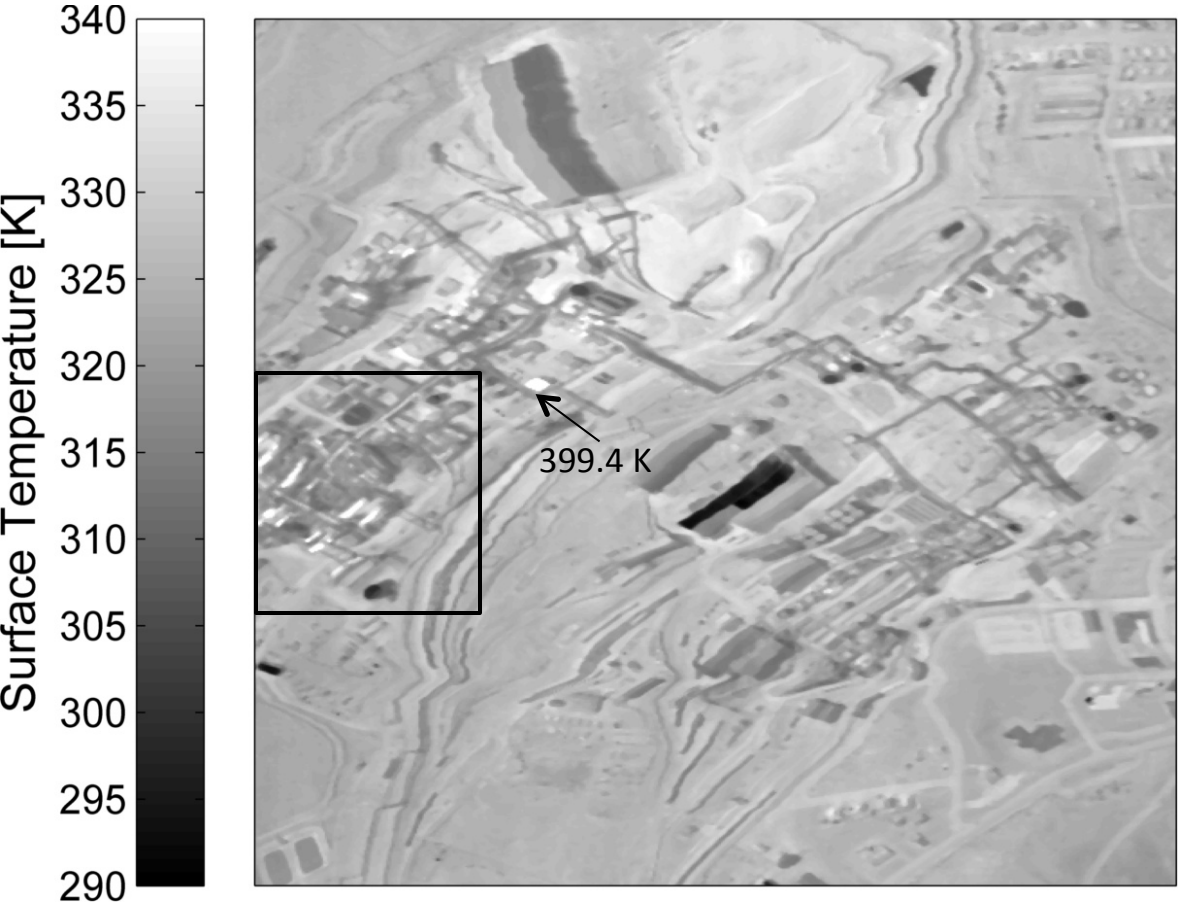


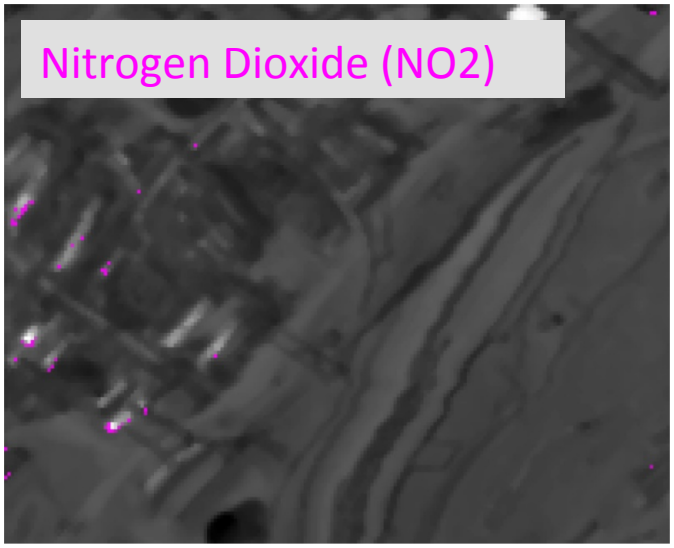
H2S produced from sulfate-reducing bacteria (SRBs) in which energy is obtained by oxidizing organic compounds of hydrogen (H_2) while reducing sulfate (SO2−4) to form hydrogen sulfide (H_2S) - process known as anaerobic respiration.

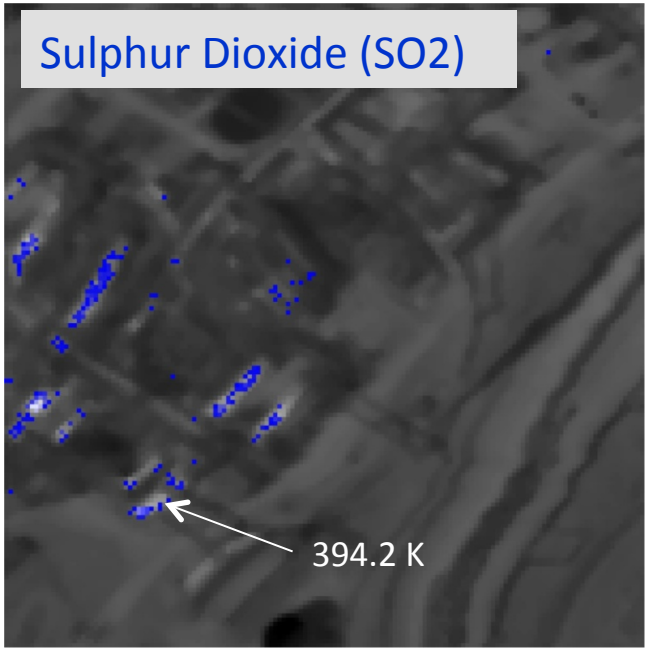
Ace Cogeneration Plant, Trona, CA

Ace Cogeneration Plant, Trona, CA

2014-07-03.230315.Trona.Line1-Run1



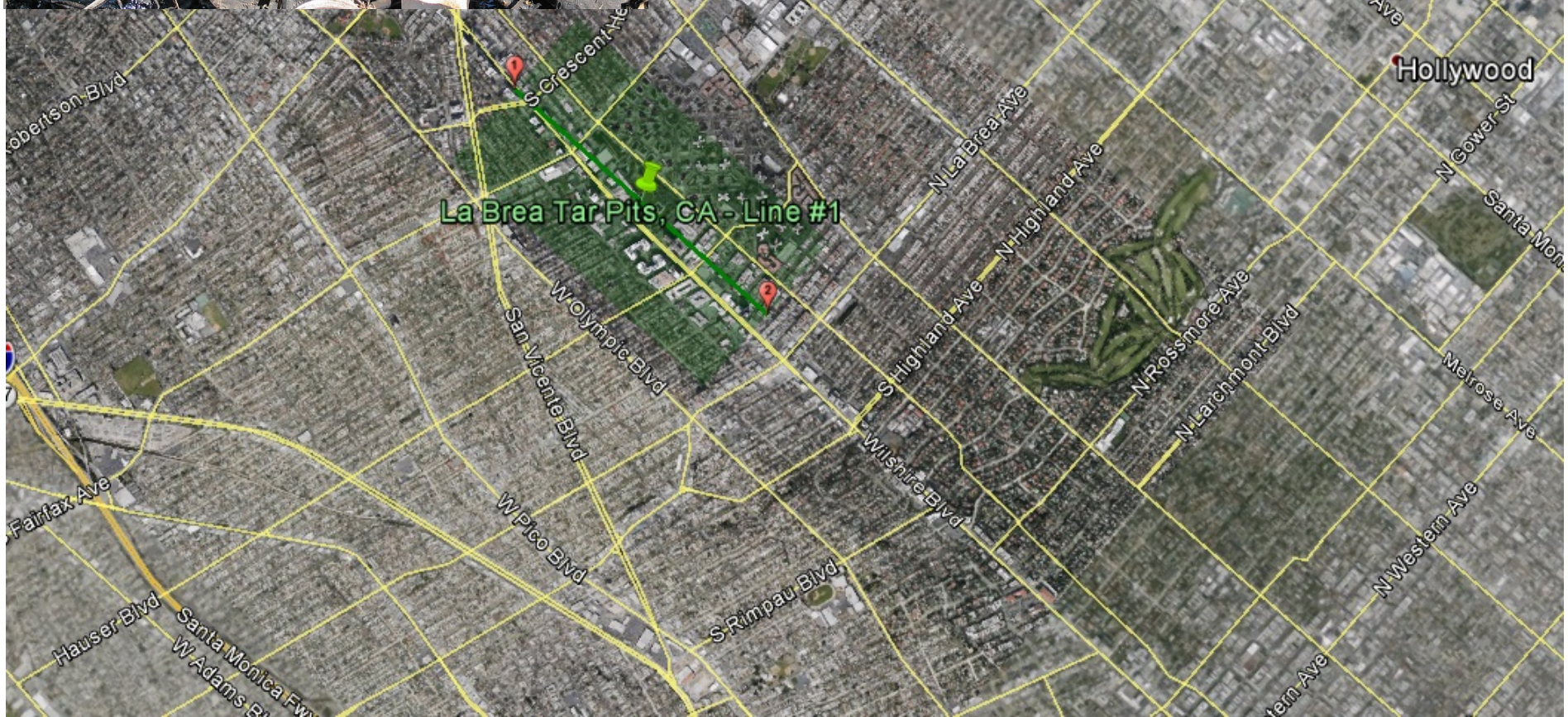




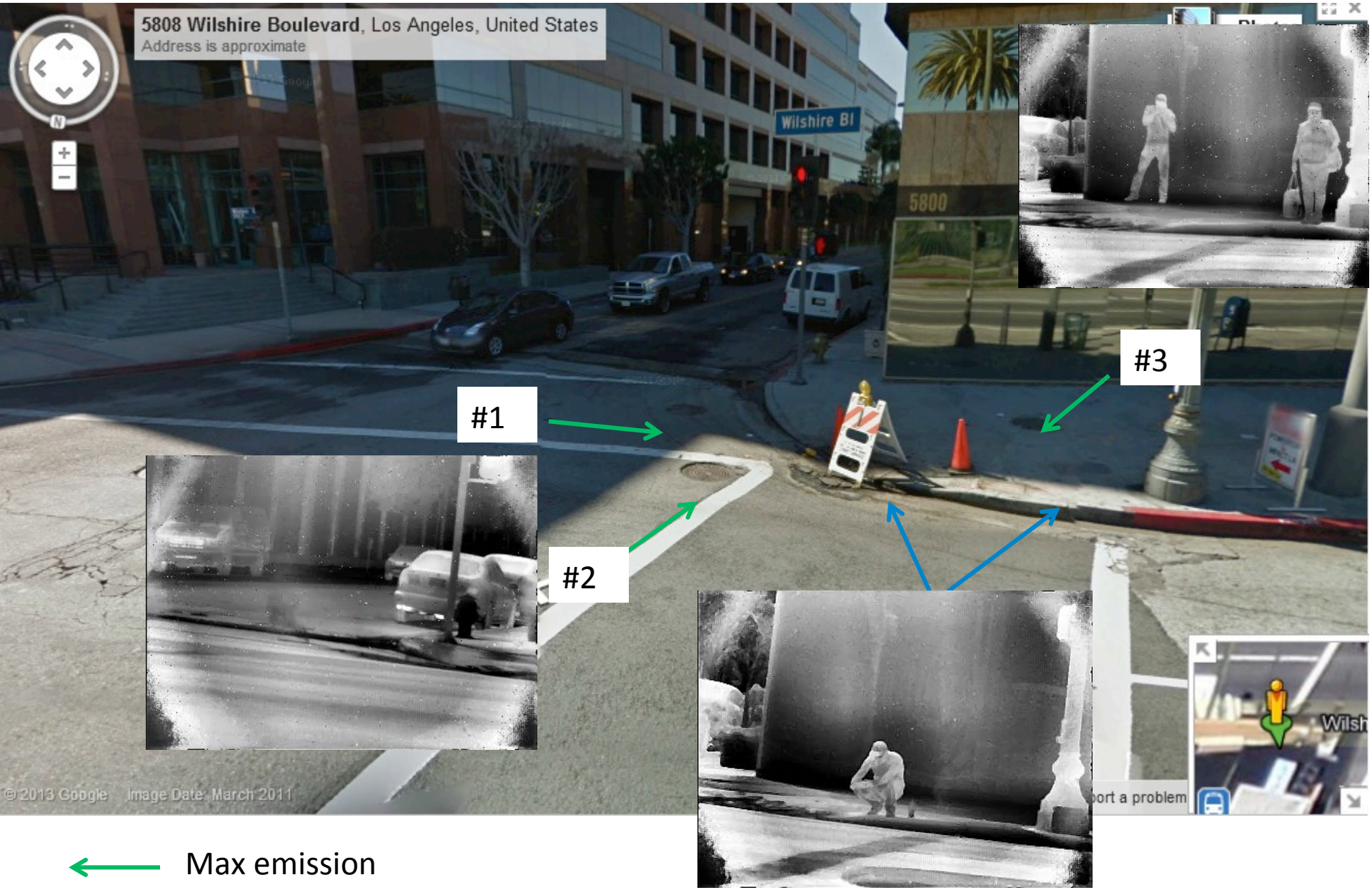
Methane gas detection motivation:

- CH_4 is more potent GHG than CO_2
- Better understanding of fugitive Methane emissions to help balance carbon budget, climate policy etc.
- Large uncertainties exist, likely from unconventional extraction methods (Long-tail)
- Observational sparseness one of largest barriers to reducing uncertainties
- Wide swath, hyperspectral imagers e.g. HyTES could help address these challenges
- Complement existing JPL capabilities, e.g. AVng

La Brea Tar Pits, LA



Map of sources using Thermal Camera (short video clips embedded)



Max emission

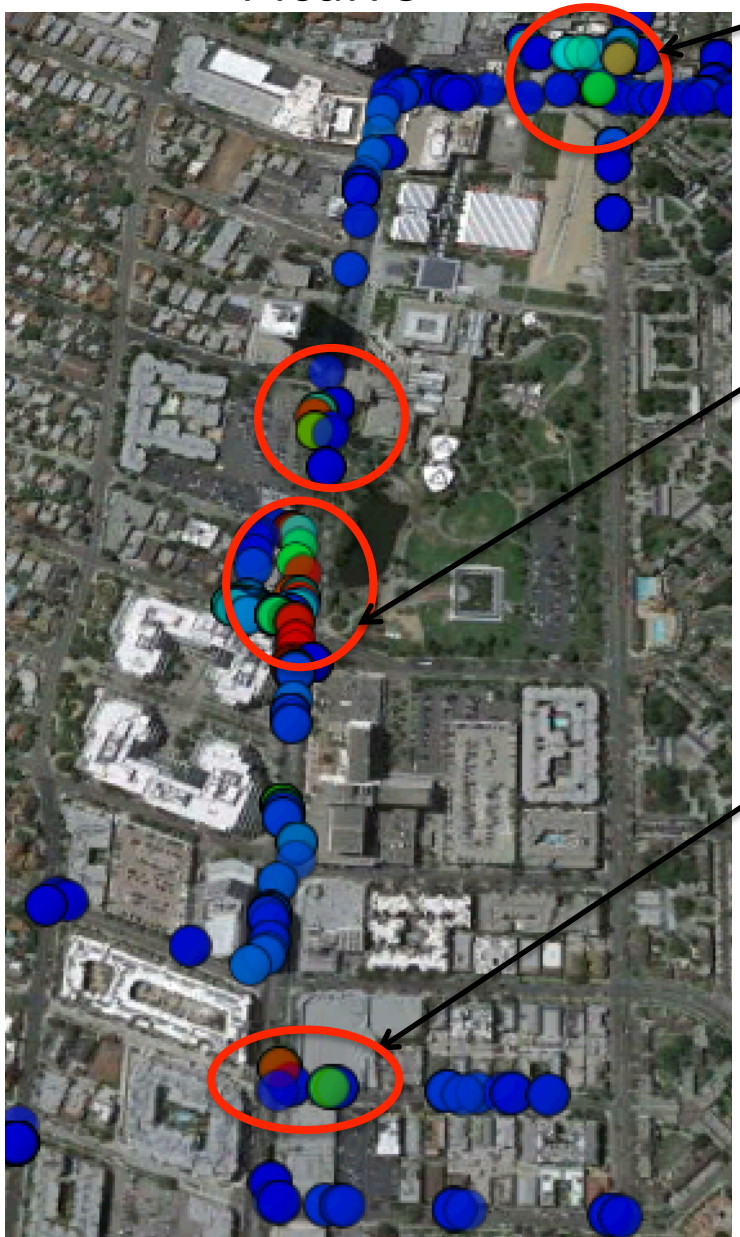
Moderate emission

There's a mix of emission and absorption seen in the videos.

HyTES Comparisons with Picarro Ground Measurements

HyTES

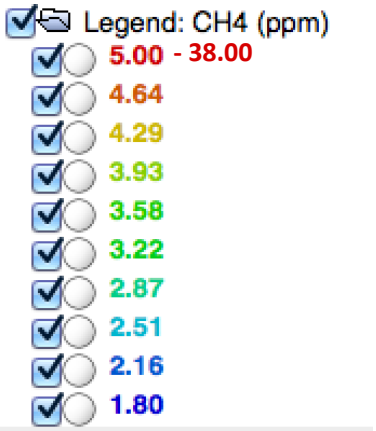
Picarro



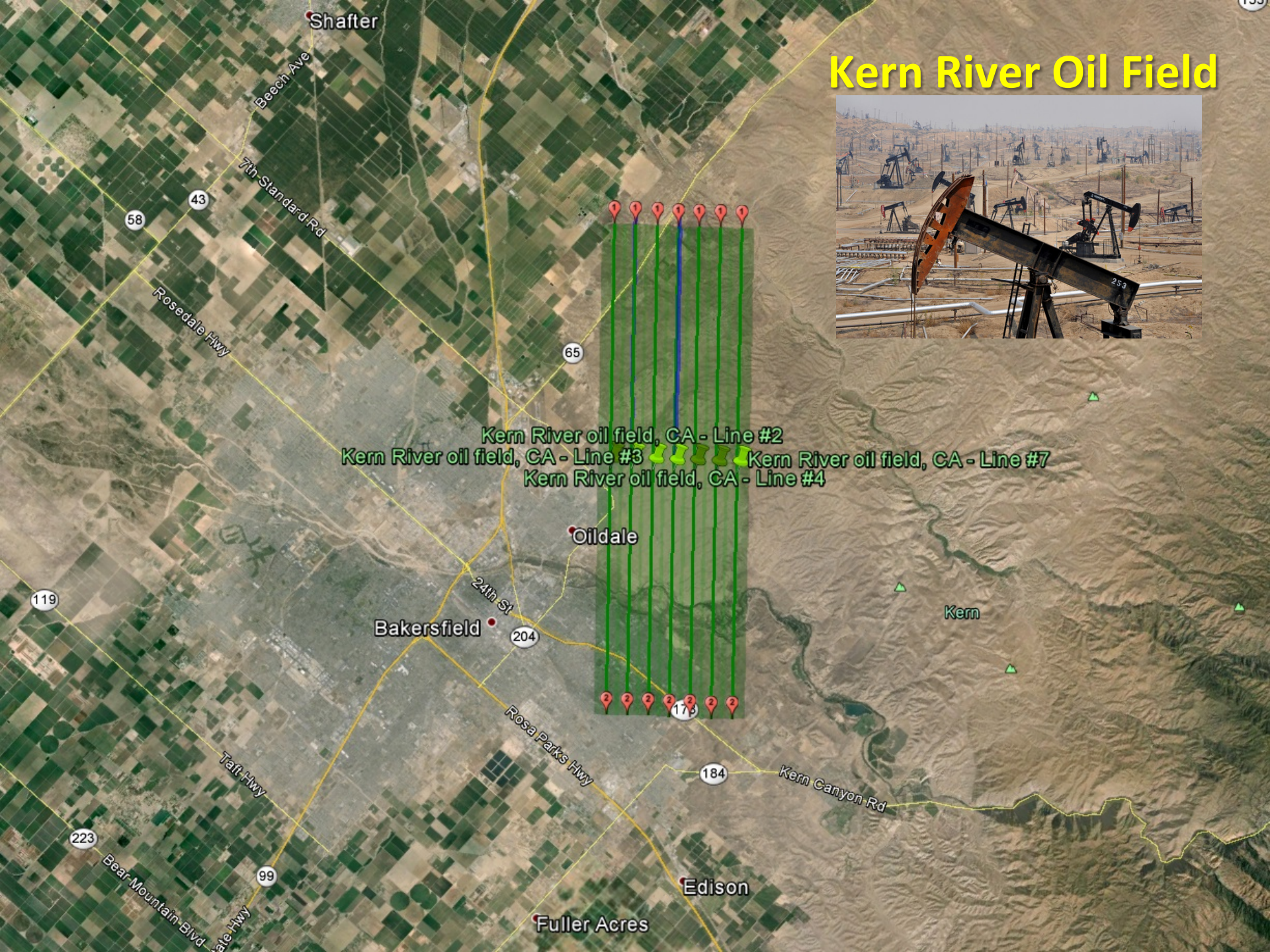
6th and Fairfax
Mean 2.1ppm (10% over background); range: 1.9 – 4.4 ppm

Wilshire & Curson
Mean 3ppm (84% over background); range: 1.9 – 38ppm

Wilshire & S. Ridgeley
range: 1.9 – 5.6 ppm

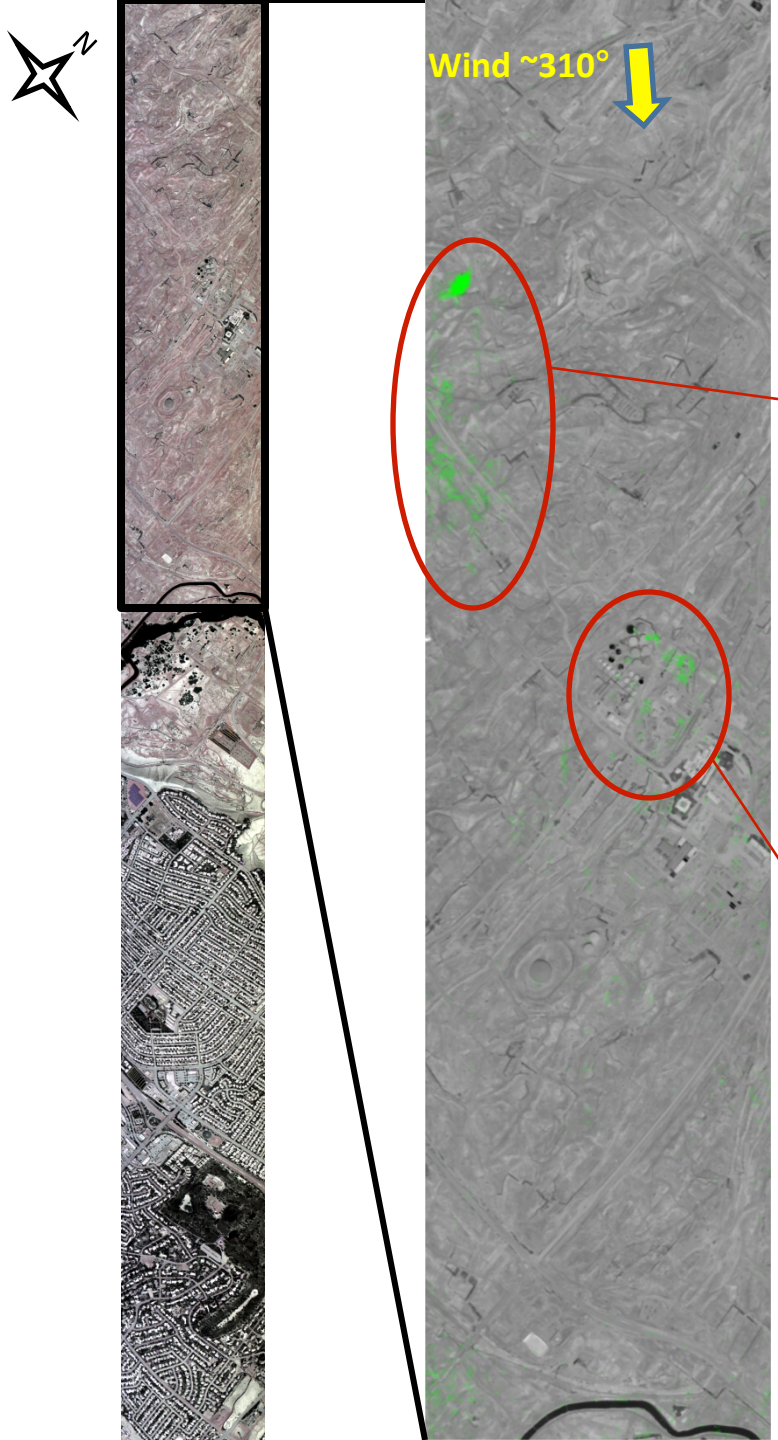


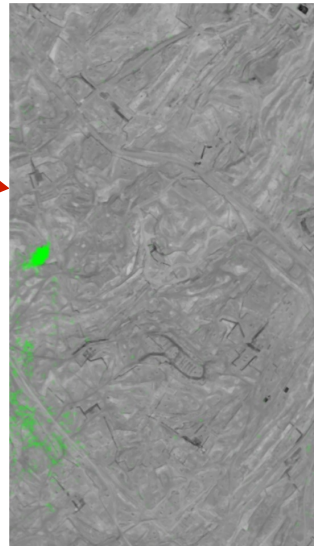
Kern River Oil Field



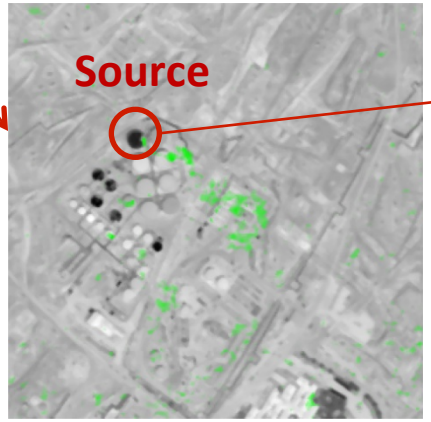
2014-07-08.191611.KernRiverOil.Line3-Run1 Segment 01

Positive CH4 detection in green, Color intensity correlated with plume strength. Overlay on Surface Temperature image calculated from HyTES 8.3 micron band and ASTER emissivity



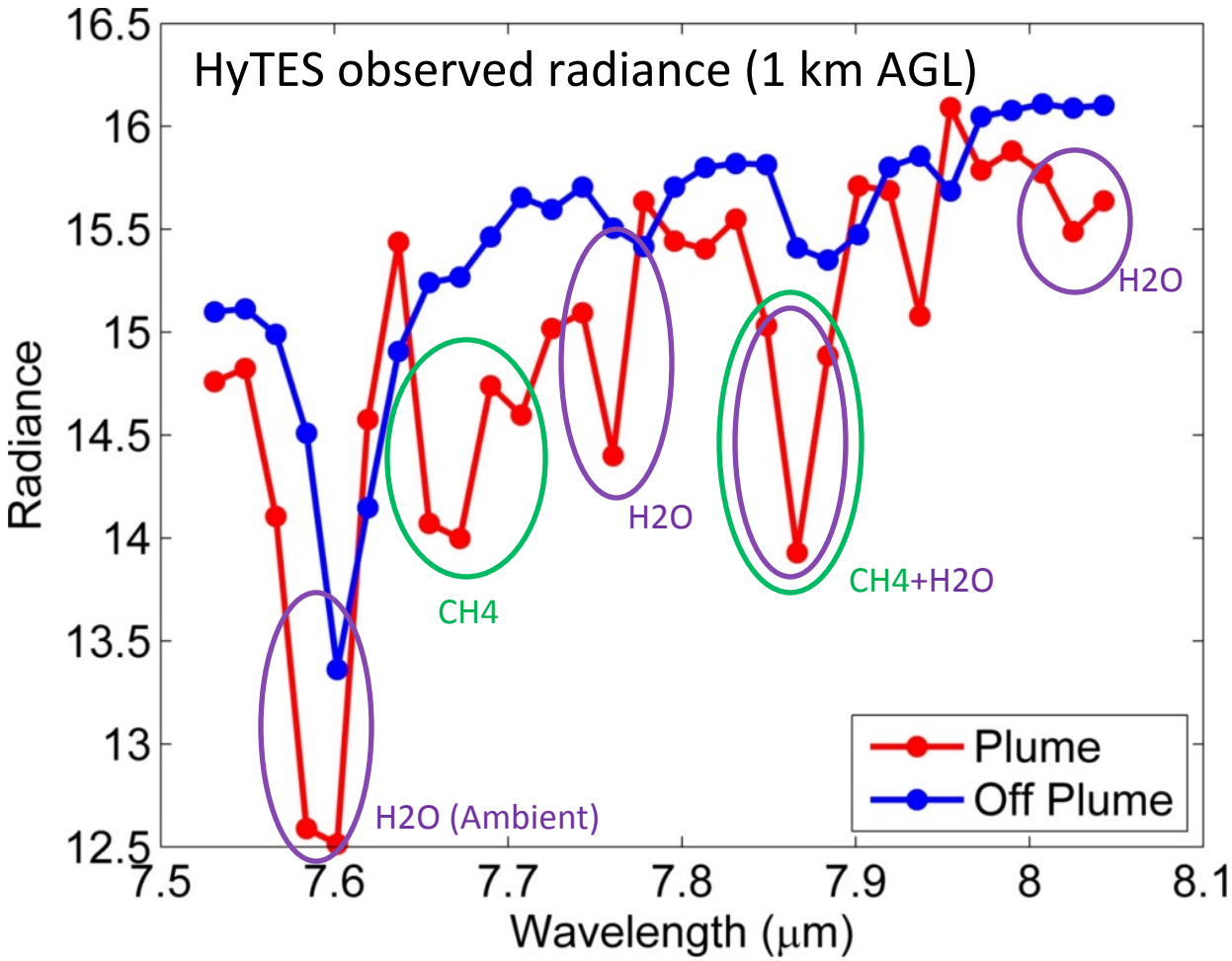


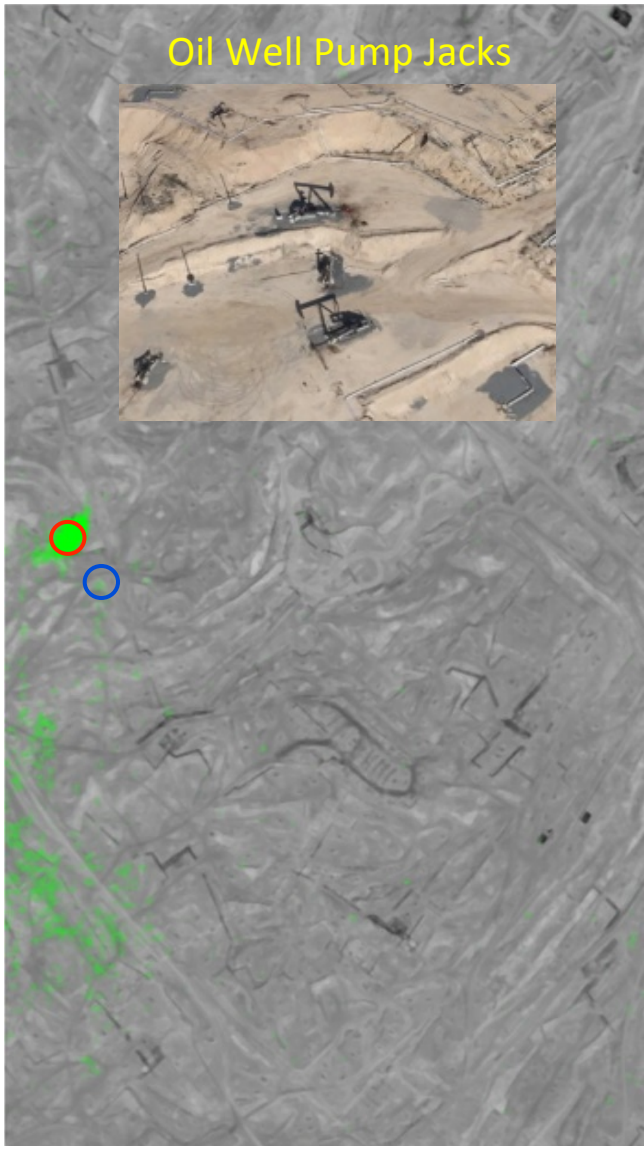
Well site



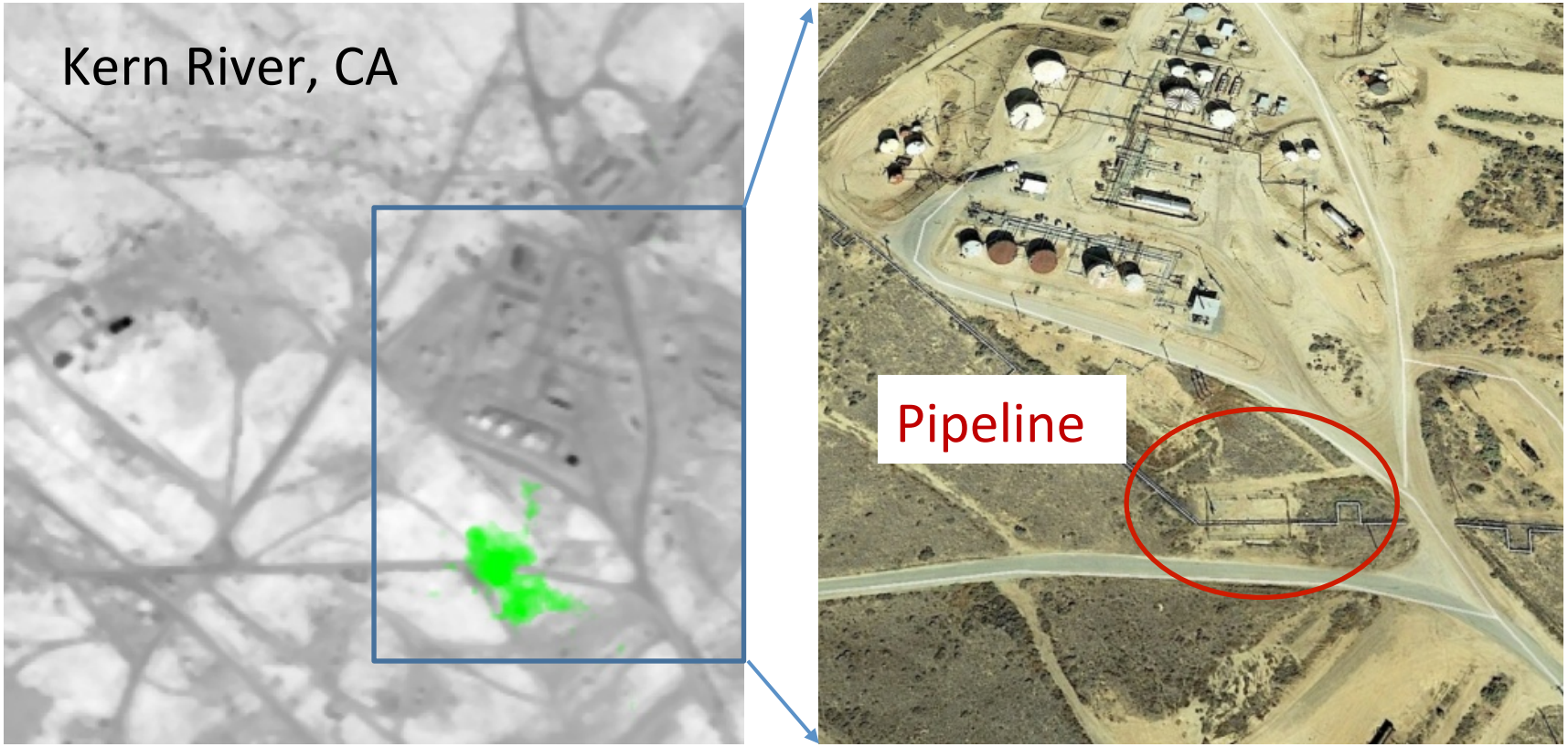
Storage Facility

HyTES Spectral Analysis

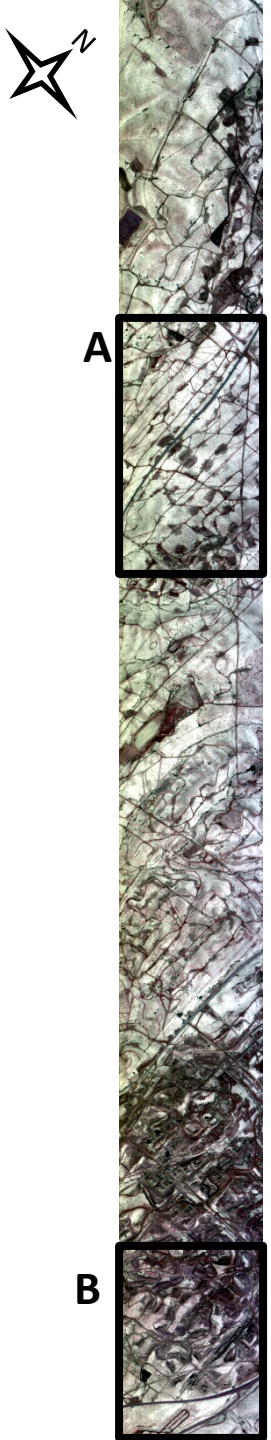


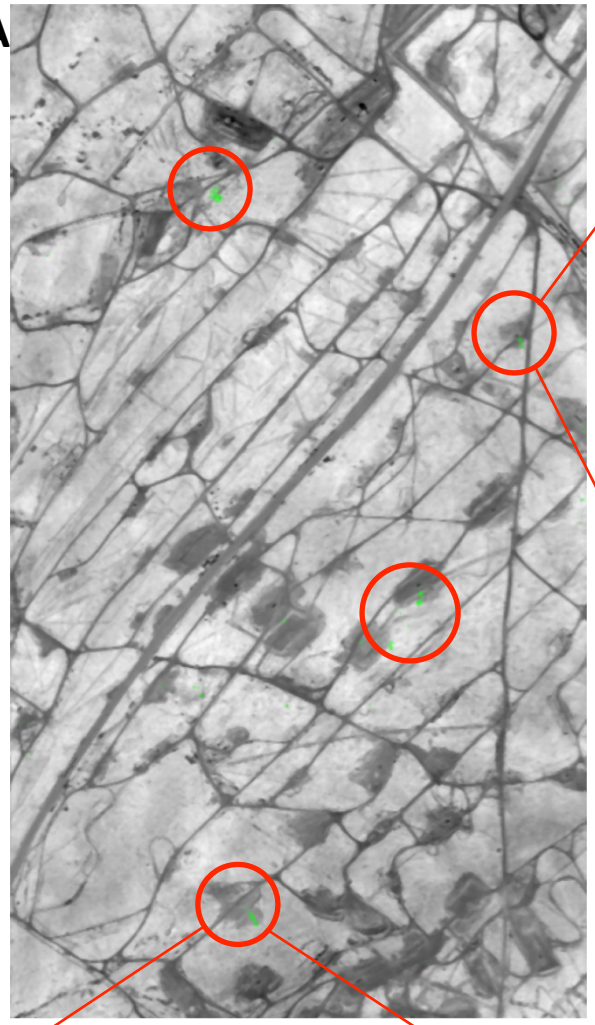


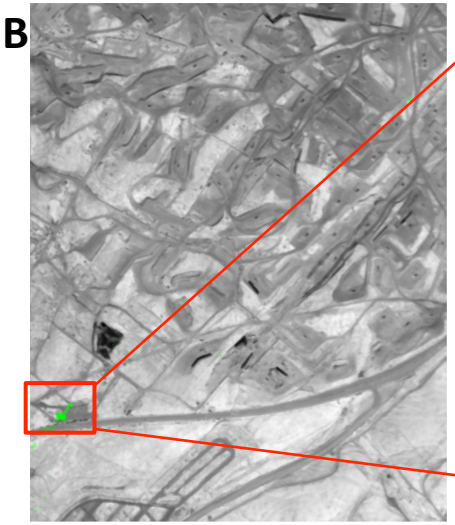
HyTES Surface Temperature (gray)
CH4 Detection (Green)



2014-07-08.191611.KernRiverOil.Line2-Run1
Segment 01 **CH4 = Green**

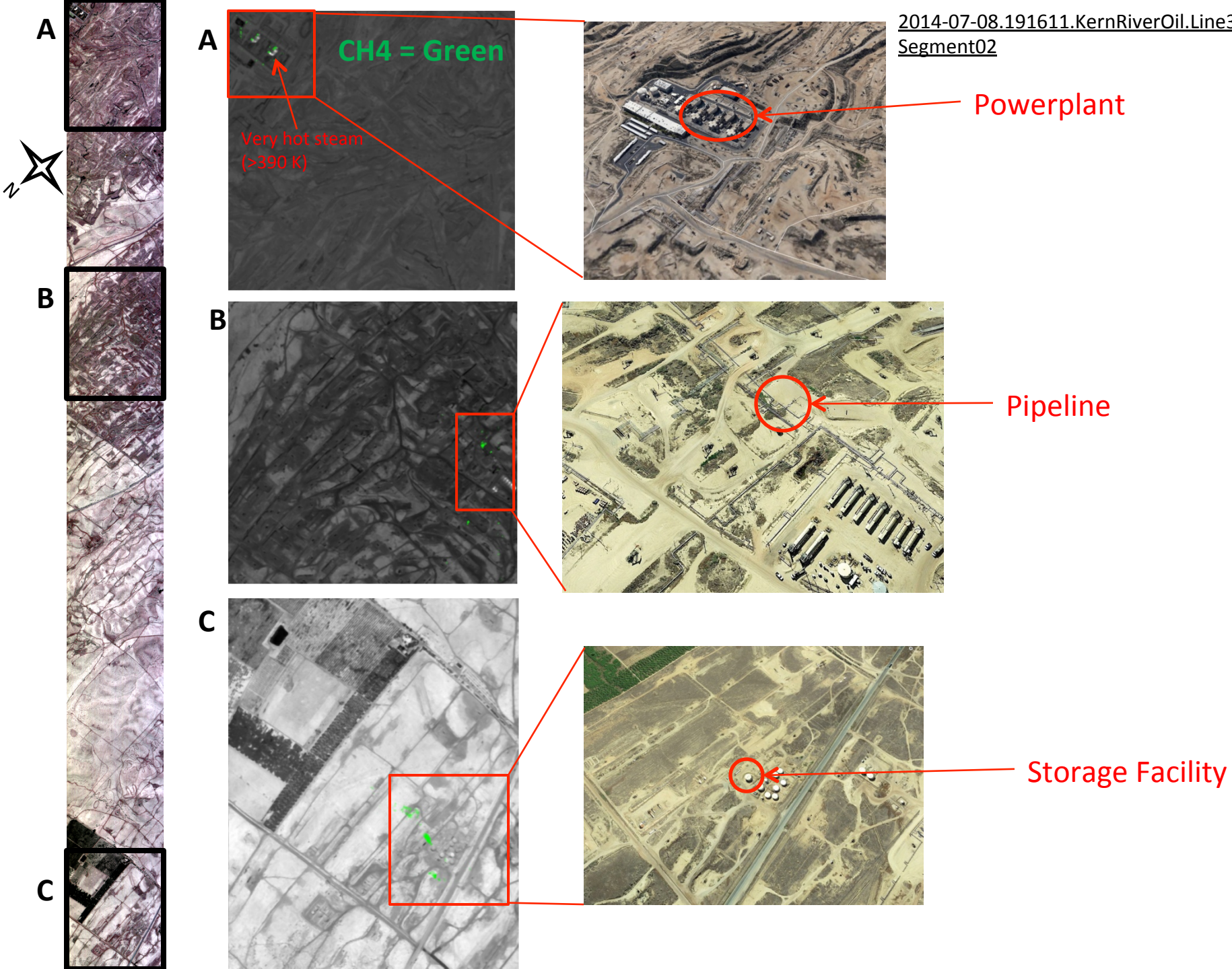


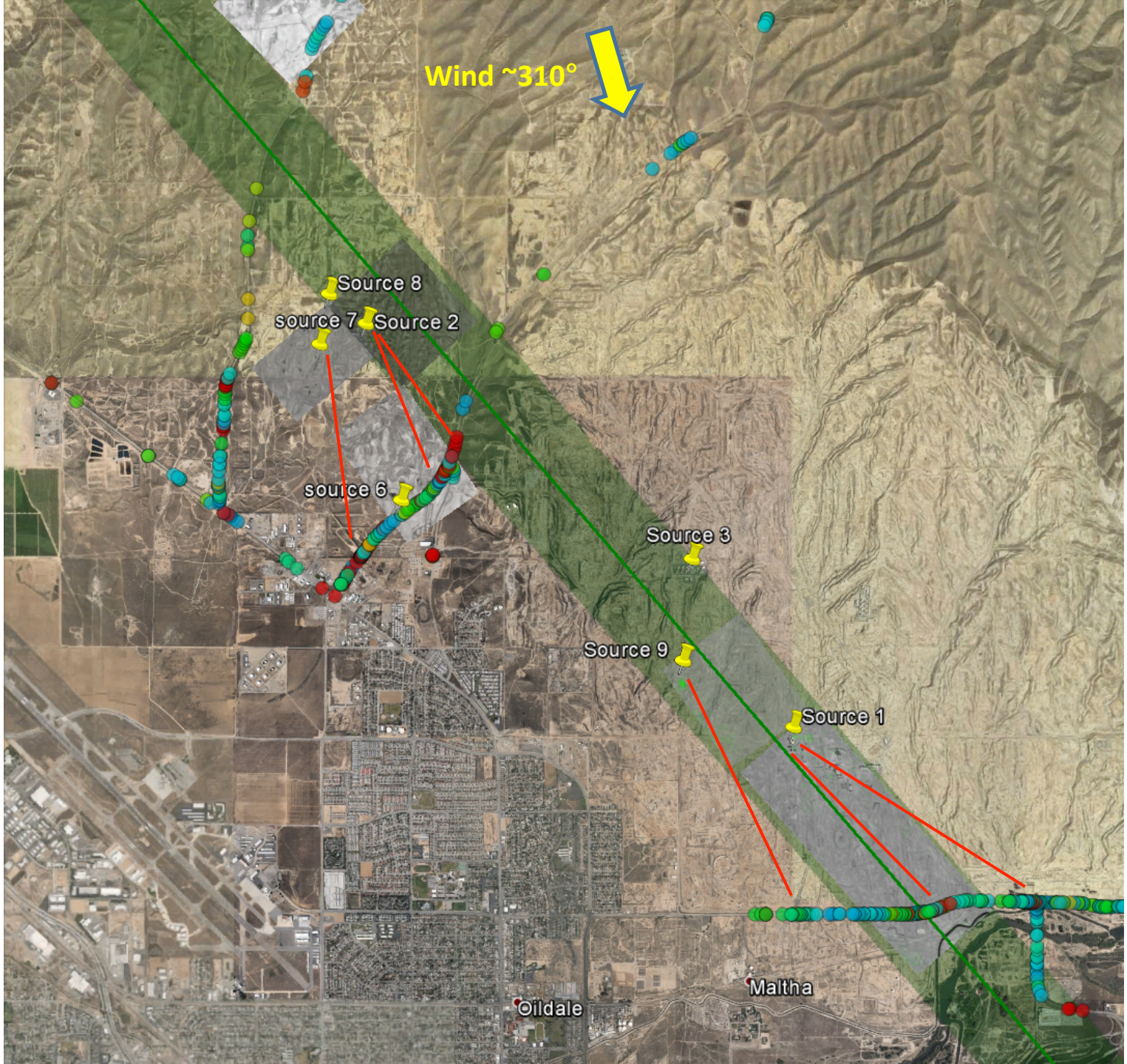




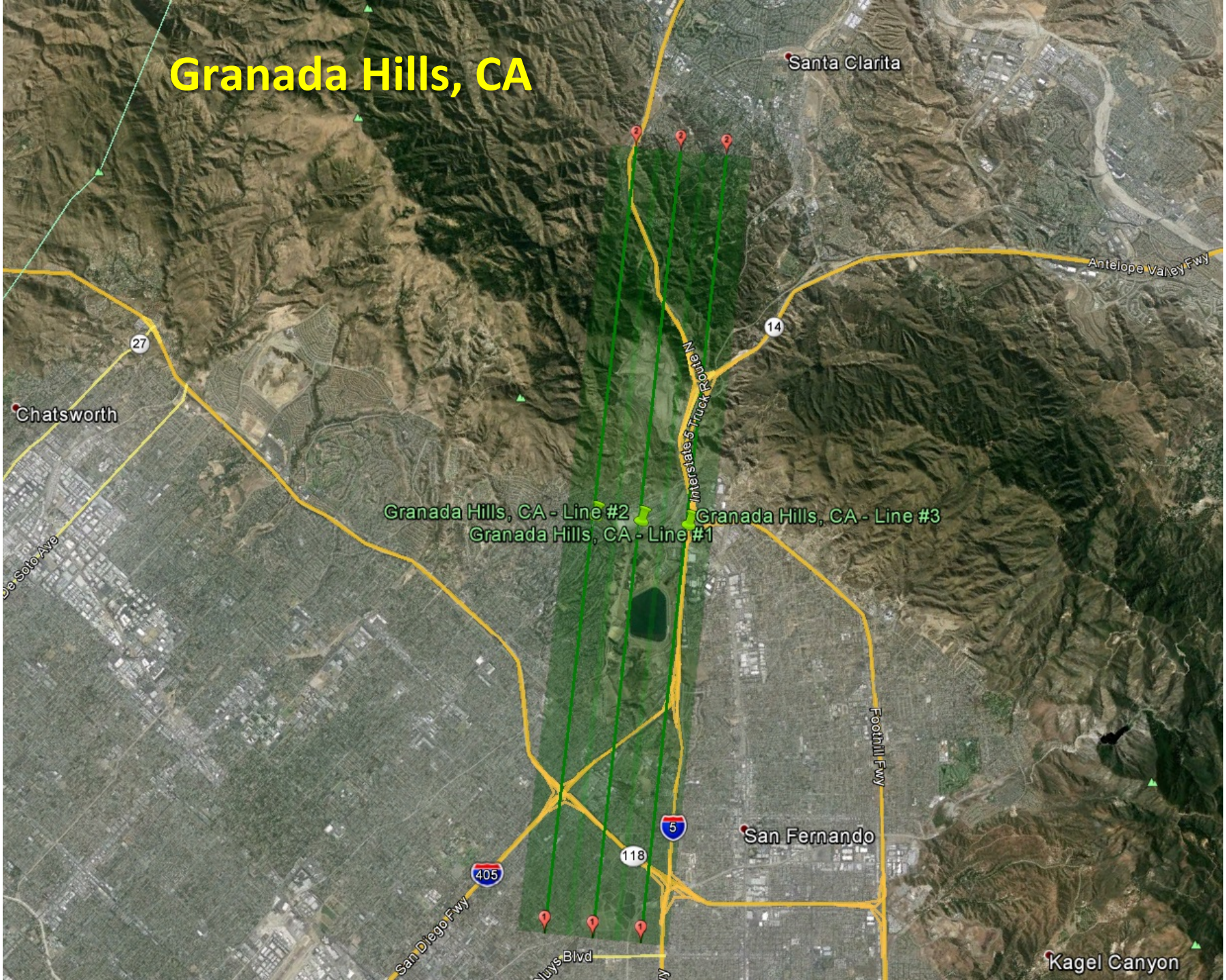
Bakersfield Glenville Rd

2014-07-08.191611.KernRiverOil.Line3-Run1
Segment02



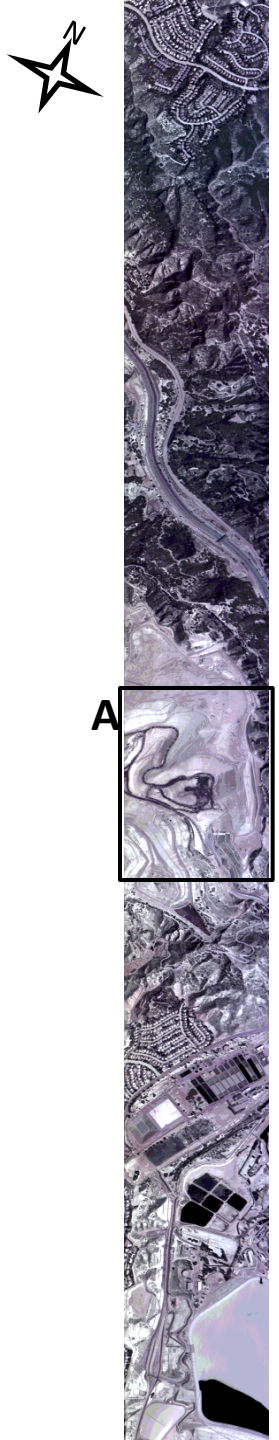

Wind ~310°
Source 8
source 7
Source 2
source 6
Source 3
Source 9
Source 1
Maltha
Oildale

Granada Hills, CA

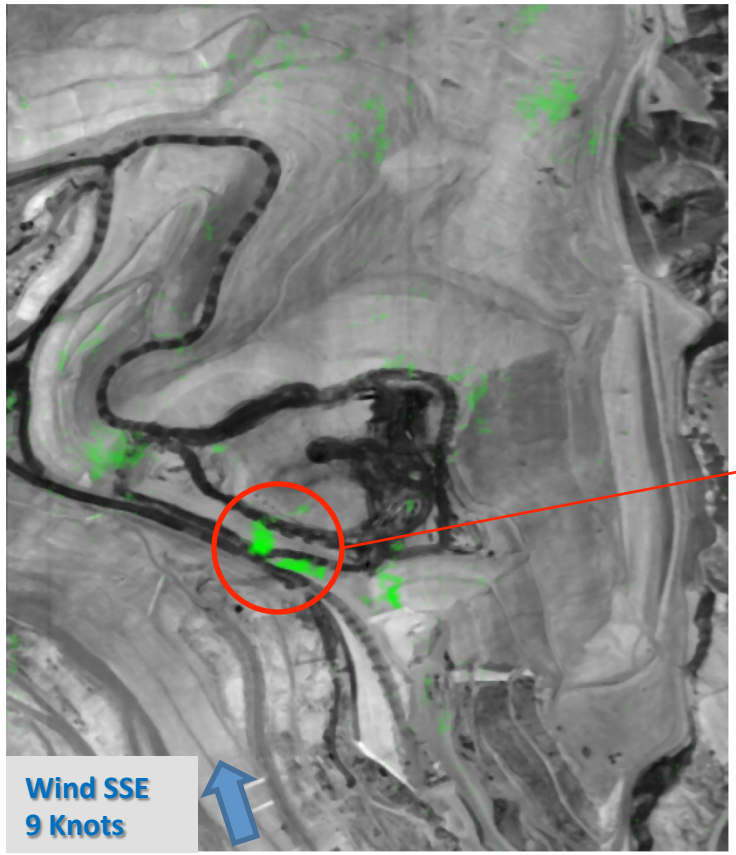


2014-07-07.171528.GranadaHills.Line1-Run1 Segment01

CH4 = Green



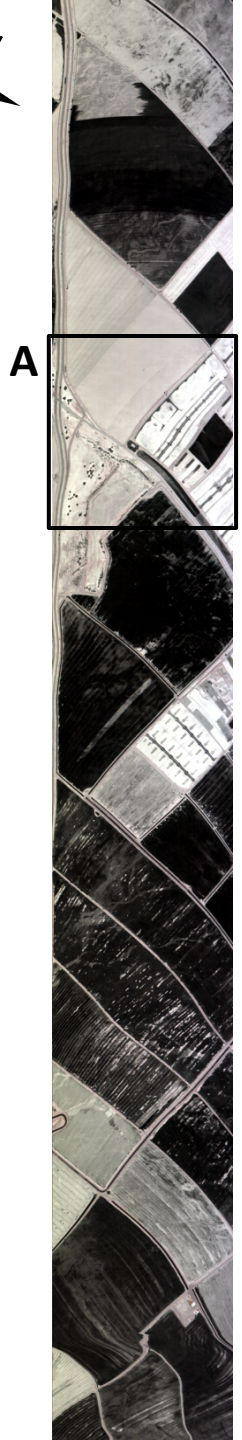
A



Bakersfield Pipeline, CA

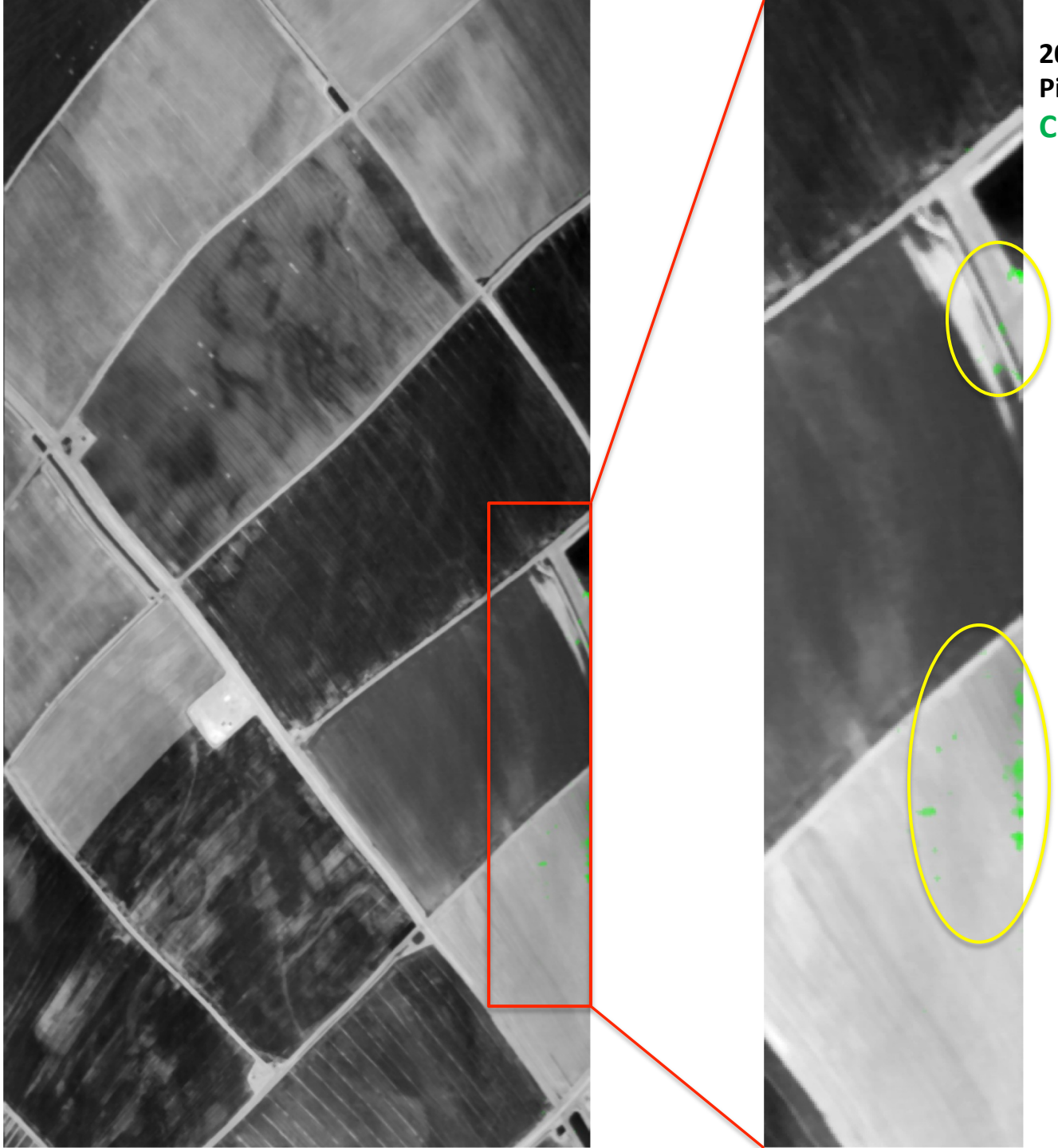
2014-07-07.185041.SBakersfieldPipeline.Line4-Run1 Segment03

CH4 = Green



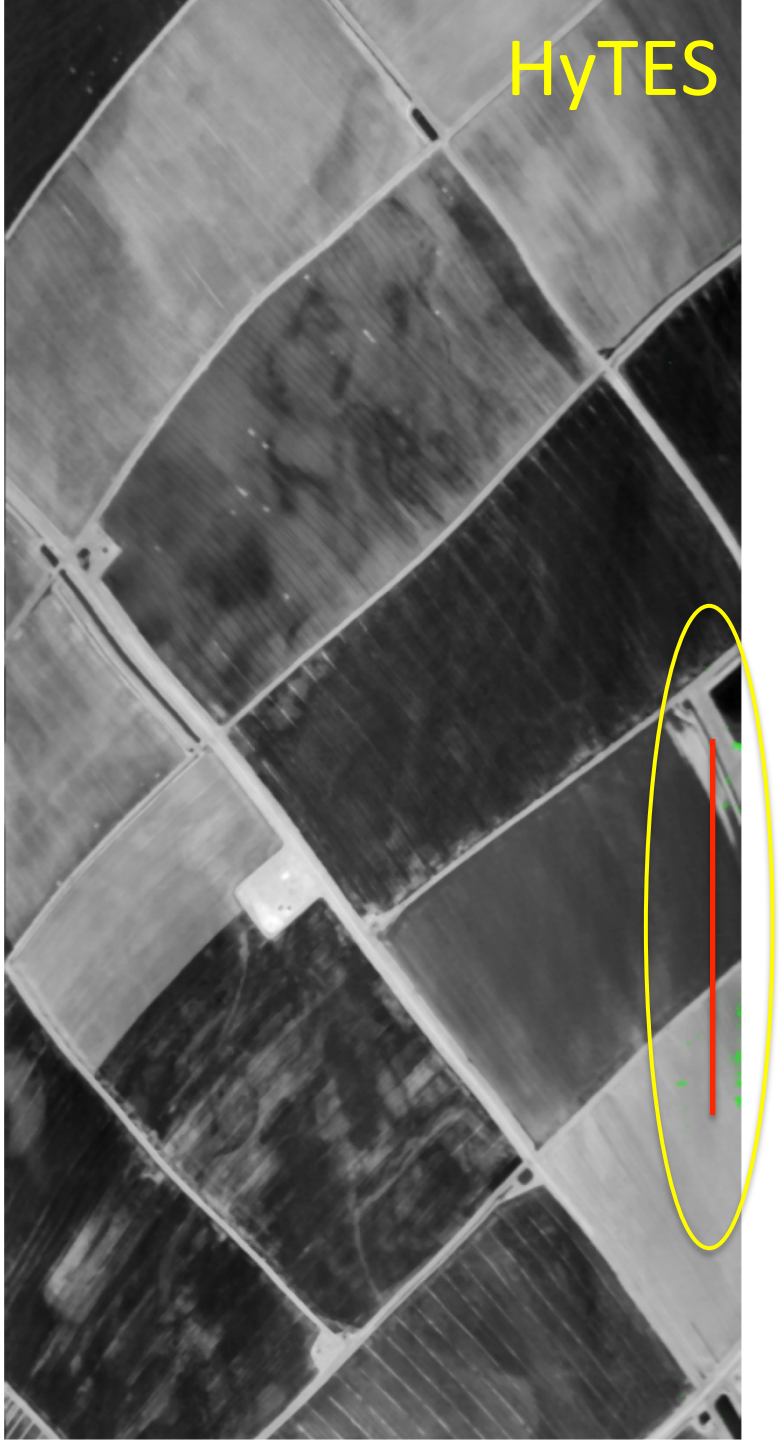
A

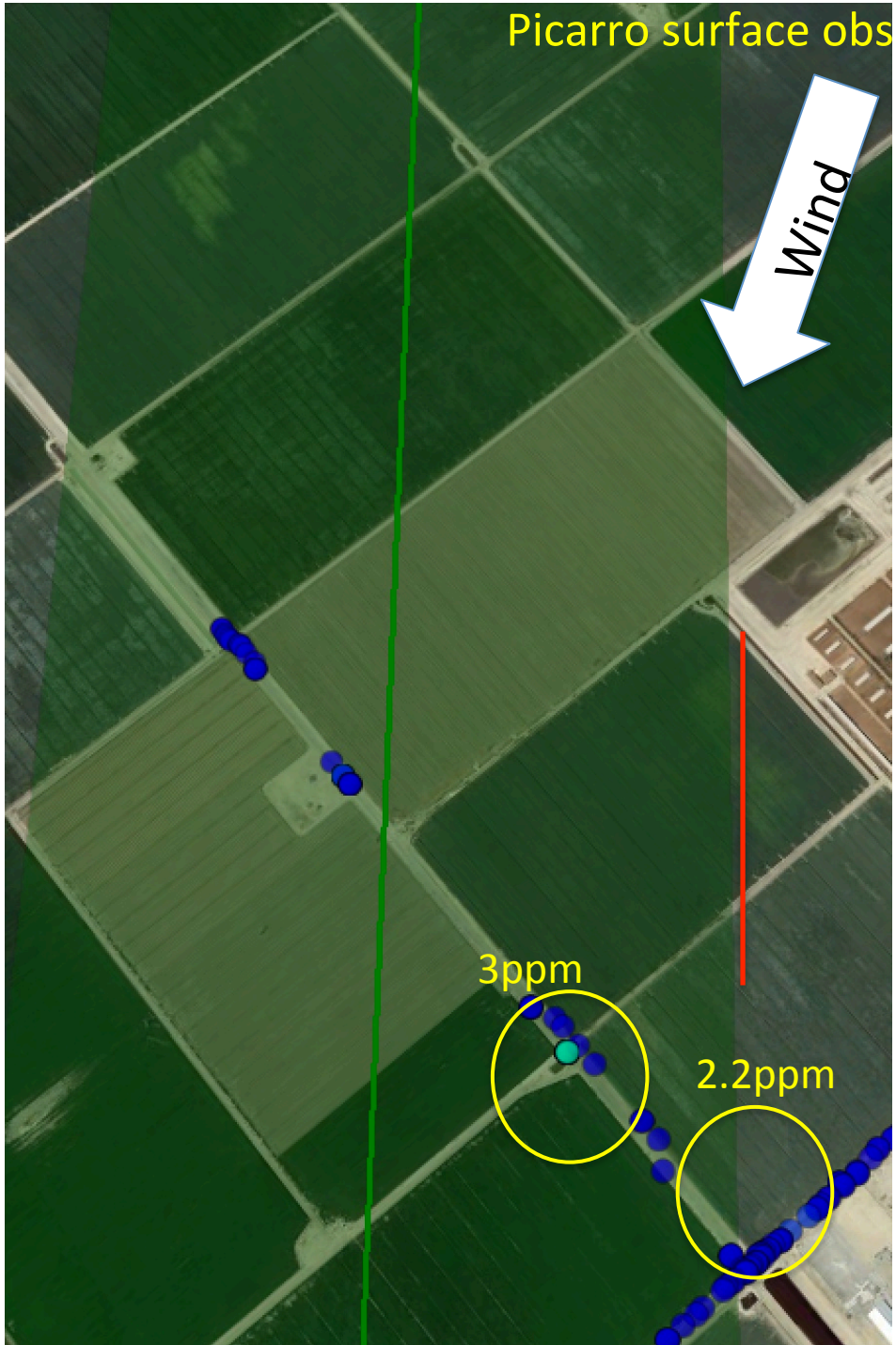
Cows



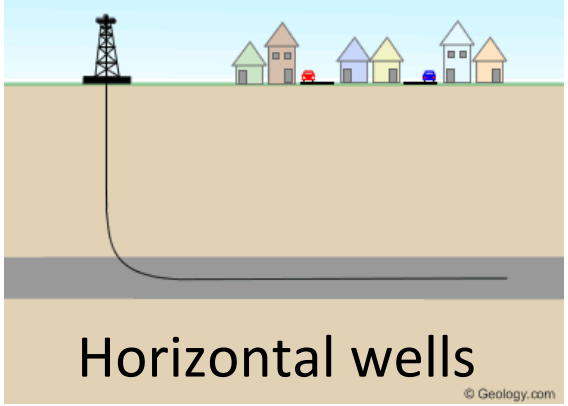
2014-07-08.223023.NBakersfield
Pipeline.Line5-Run1-Segment01

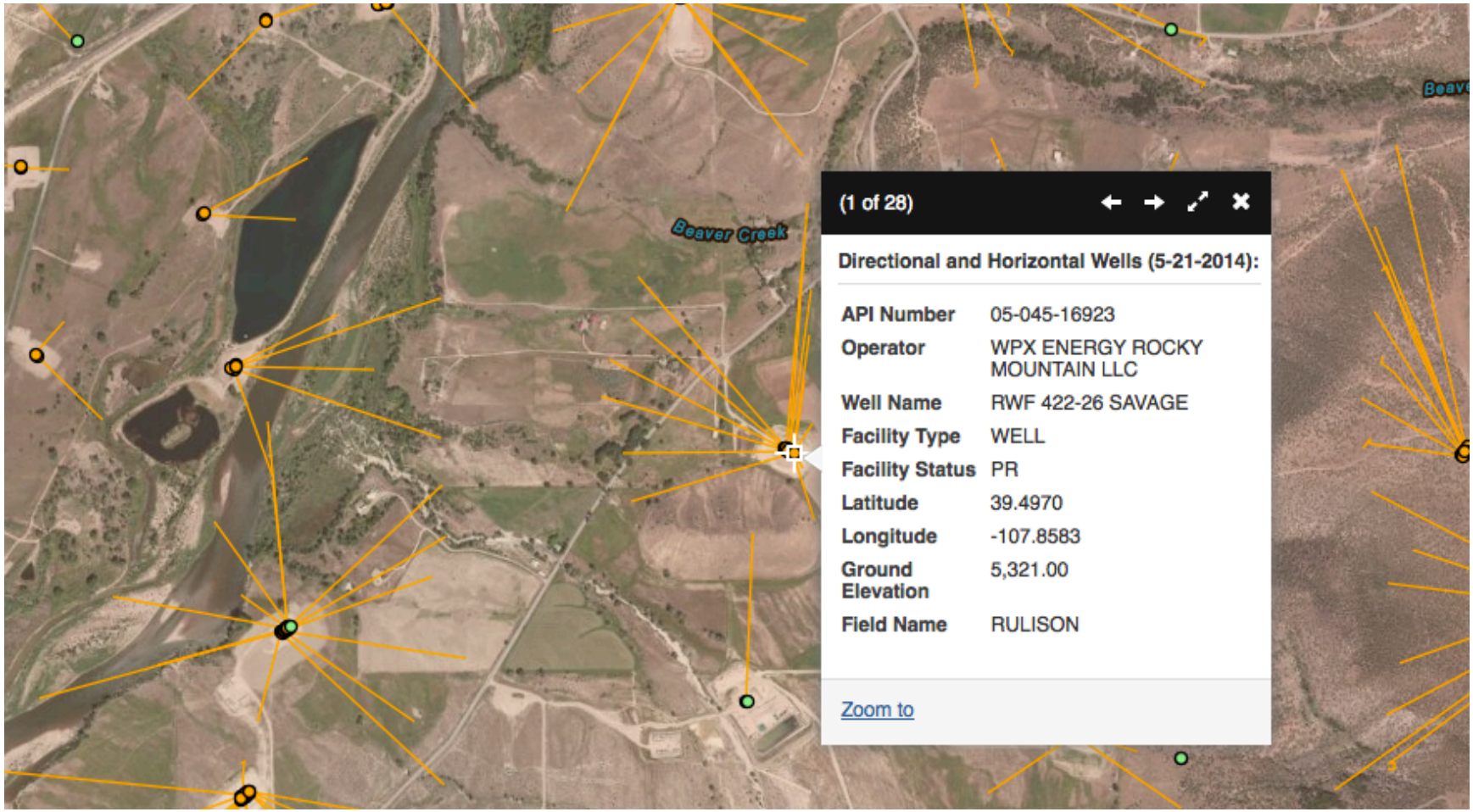
CH4 = Green

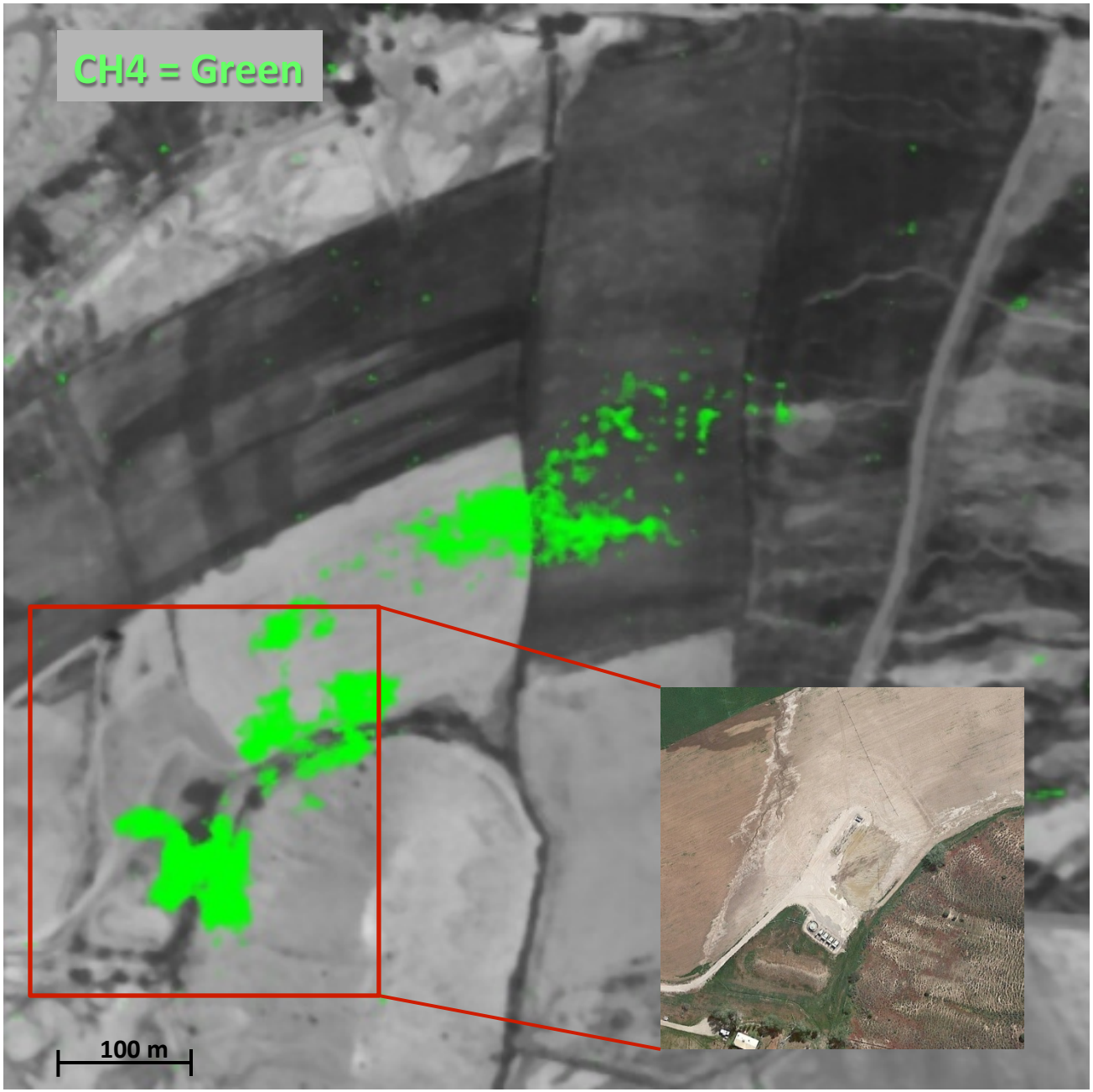

HyTES

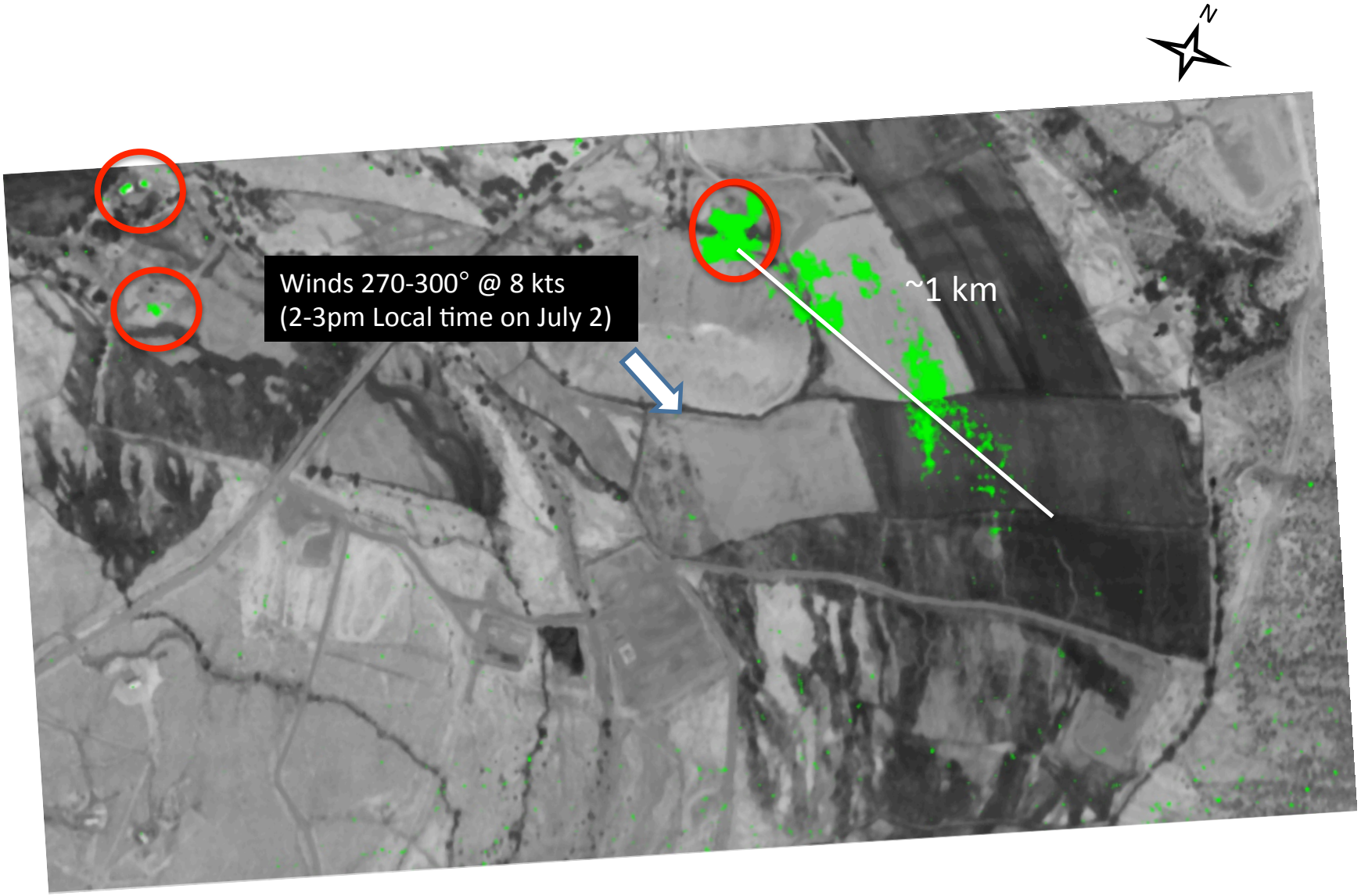

Picarro surface obs
Wind
3ppm
2.2ppm

Garfield County Oil/Gas Field, Colorado






CH4 = Green
100 m

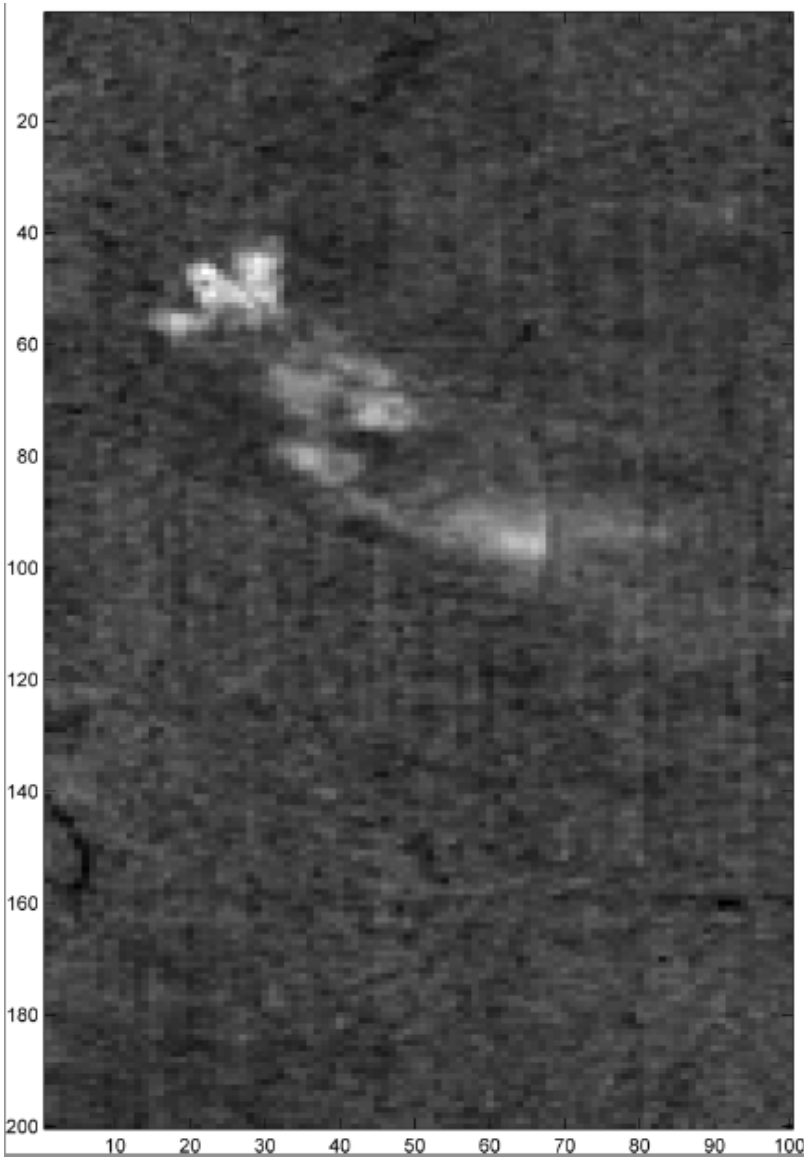

N
Winds 270-300° @ 8 kts
(2-3pm Local time on July 2)
~1 km

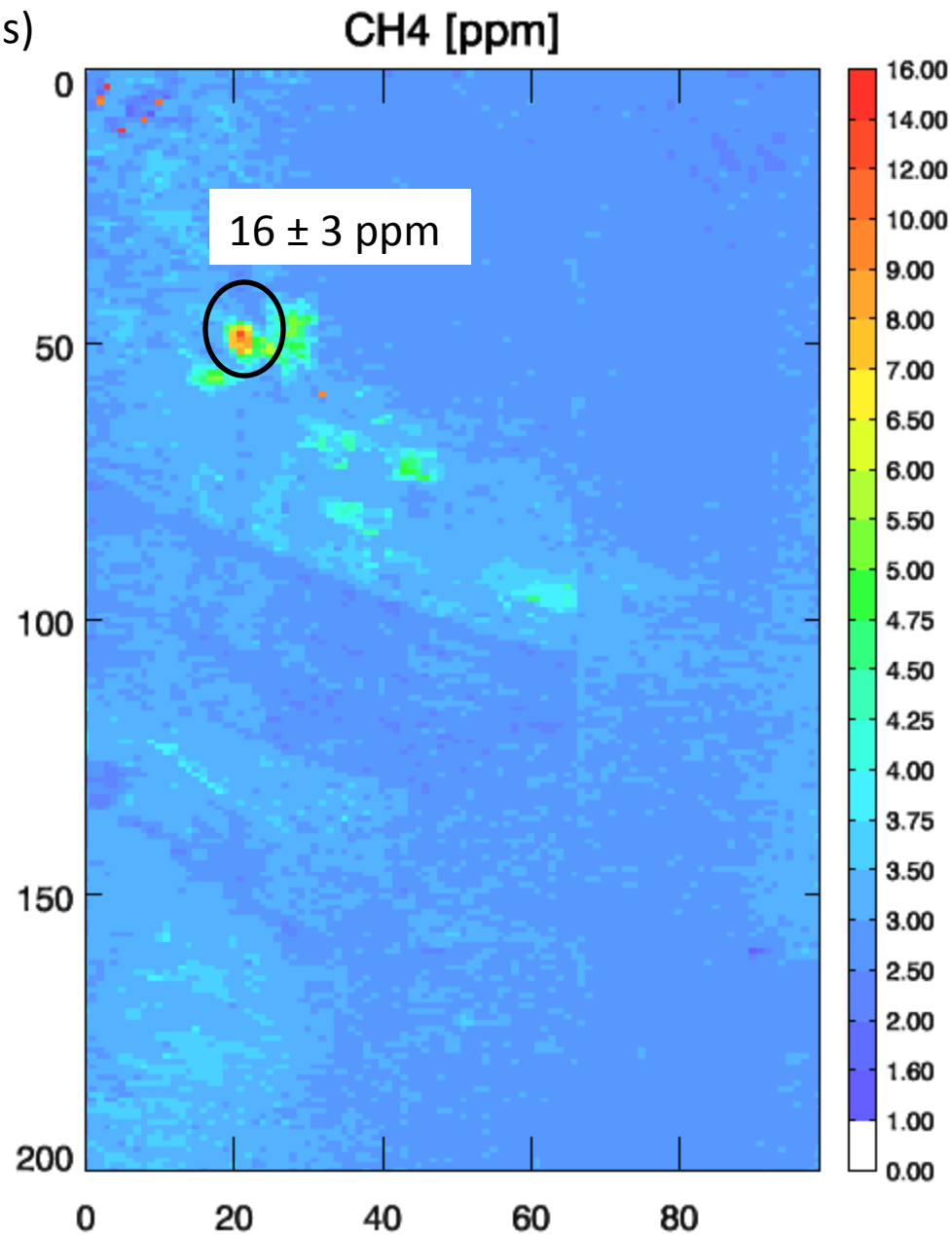
Tropospheric Emission Spectrometer (TES) algorithm applied to HyTES

Le Kuai, John Worden (JPL)

- Algorithm uses forward model (line-by-line RT model) with Levenberg-Marquardt algorithm to minimize cost function
- Retrieves CH4, H2O, N2O, surface temperature, air temperature profile, emissivity
- NCEP data and HyTES LST/Emissivity retrieval used as a priori with assigned uncertainties

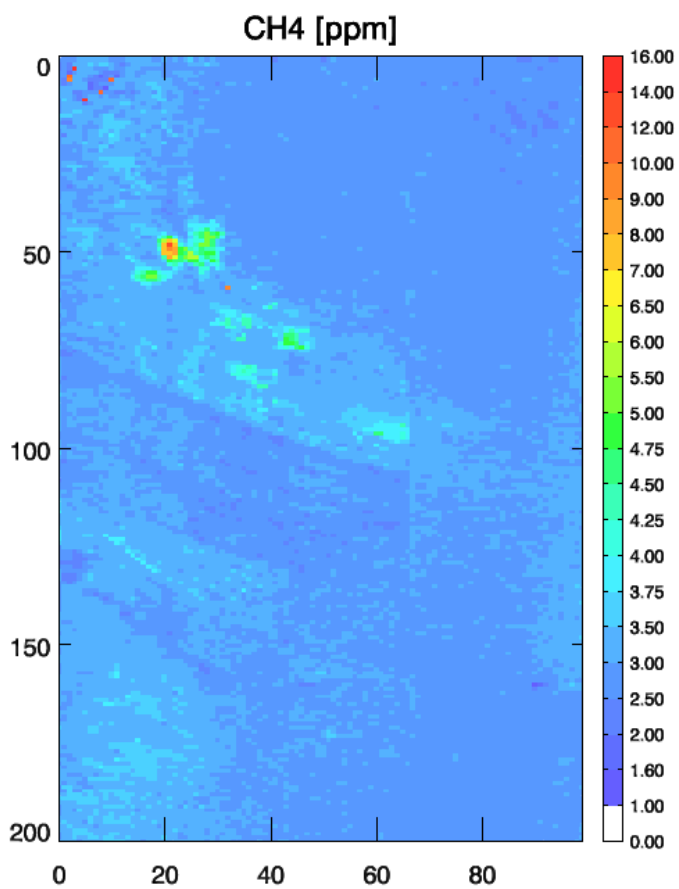
Clutter Matched Filter (Plume = bright pixels)

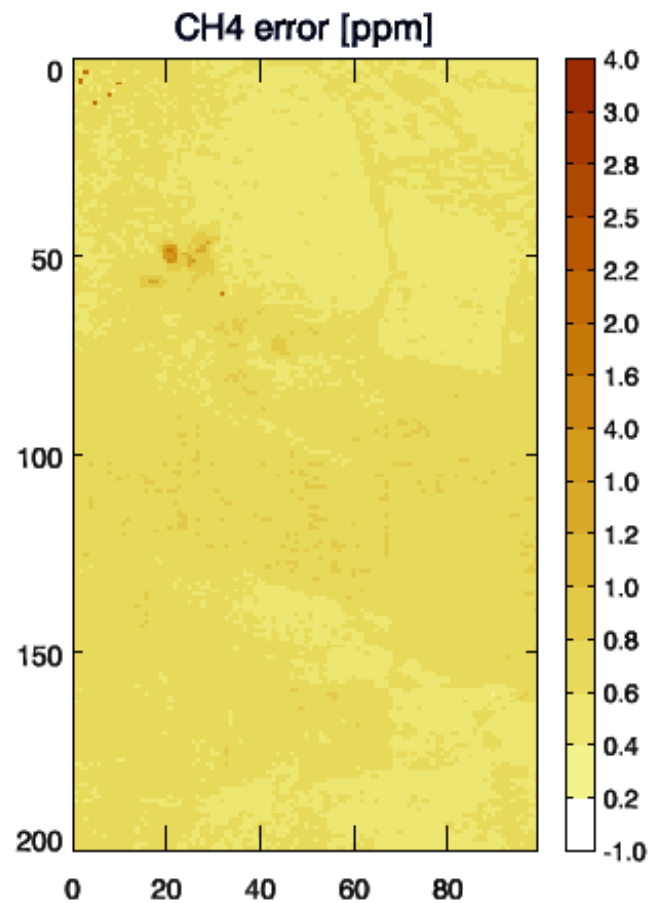




Error Analysis

The Ch4 error is about 20% of CH4 concentration estimate, i.e. the larger the CH4 concentration, the larger the retrieval error.





Summary

- The 2014 science campaign lasted about a week and data were successfully acquired for all the targets. Targets cover a variety of disciplines: Solid Earth, Ecosystems, Atmospheric composition

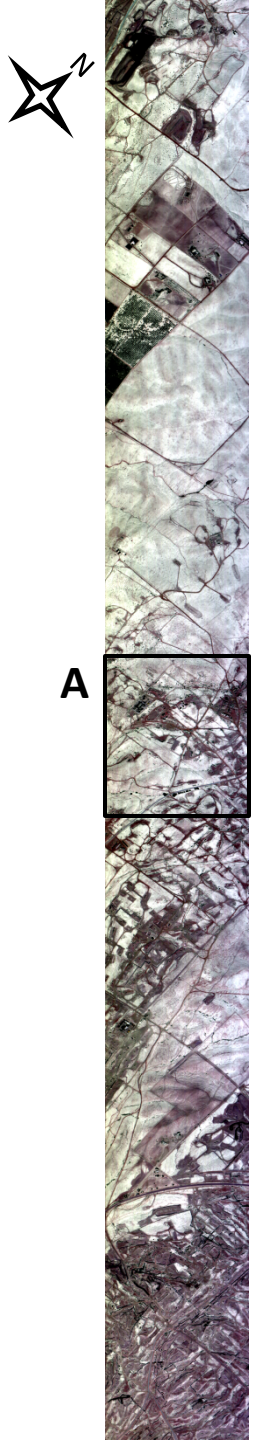
- The instrument performed well and showed significant improvements from the previous science flights, e.g. improved calibration and alignment.

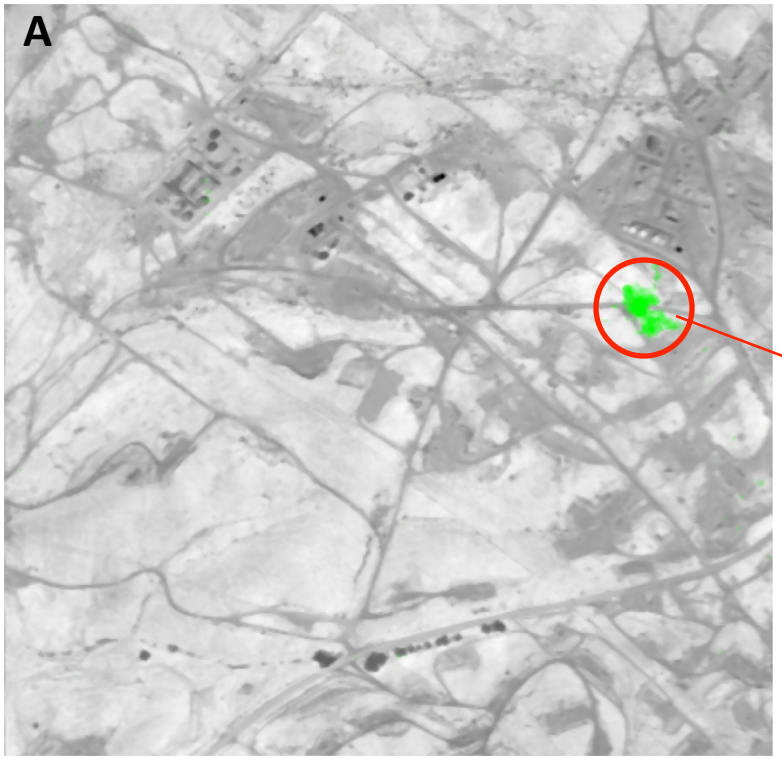
- The L2 retrieval algorithms have been established permitting accurate and stable retrievals of temperature and spectral emissivity for surface composition studies

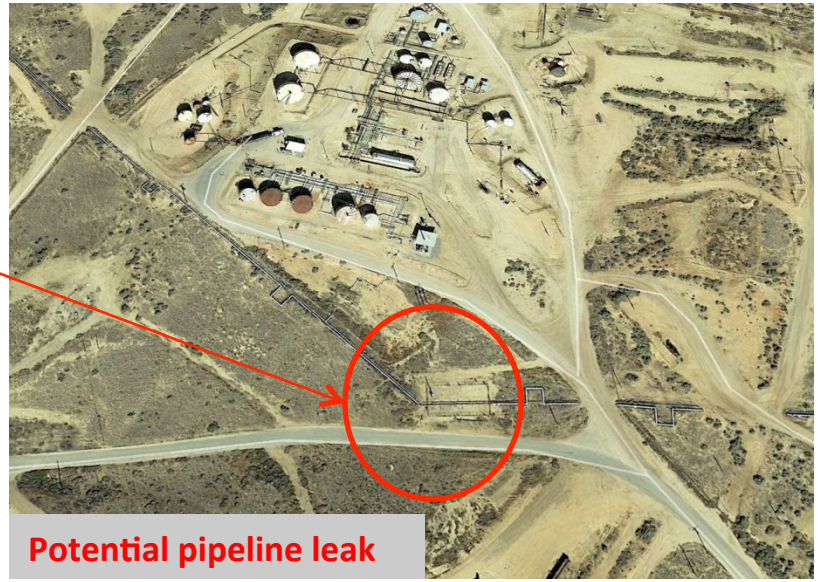
- Data processing and analysis has already found the presence of several trace gases (CH_4, H_2S, NH_3, SO_2) from low altitude (~1300m) flights. In-situ field studies are confirming the presence of these gases at various sites.

2014-07-08.192830.KernRiverOil.Line4-Run1 Segment01

CH4 = Green



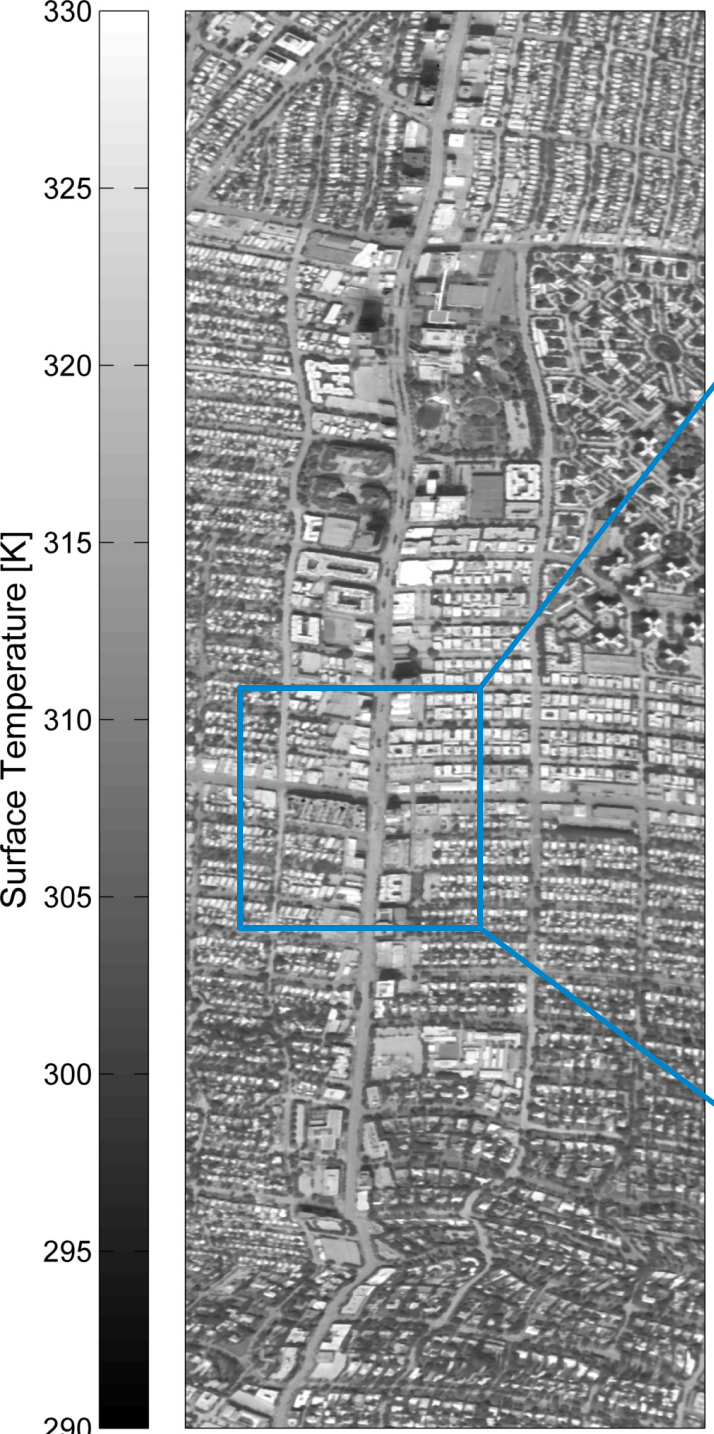




2014-07-05.173225.TarPits.Line1-Run1

Positive CH4 detection in green, Overlay on ST image

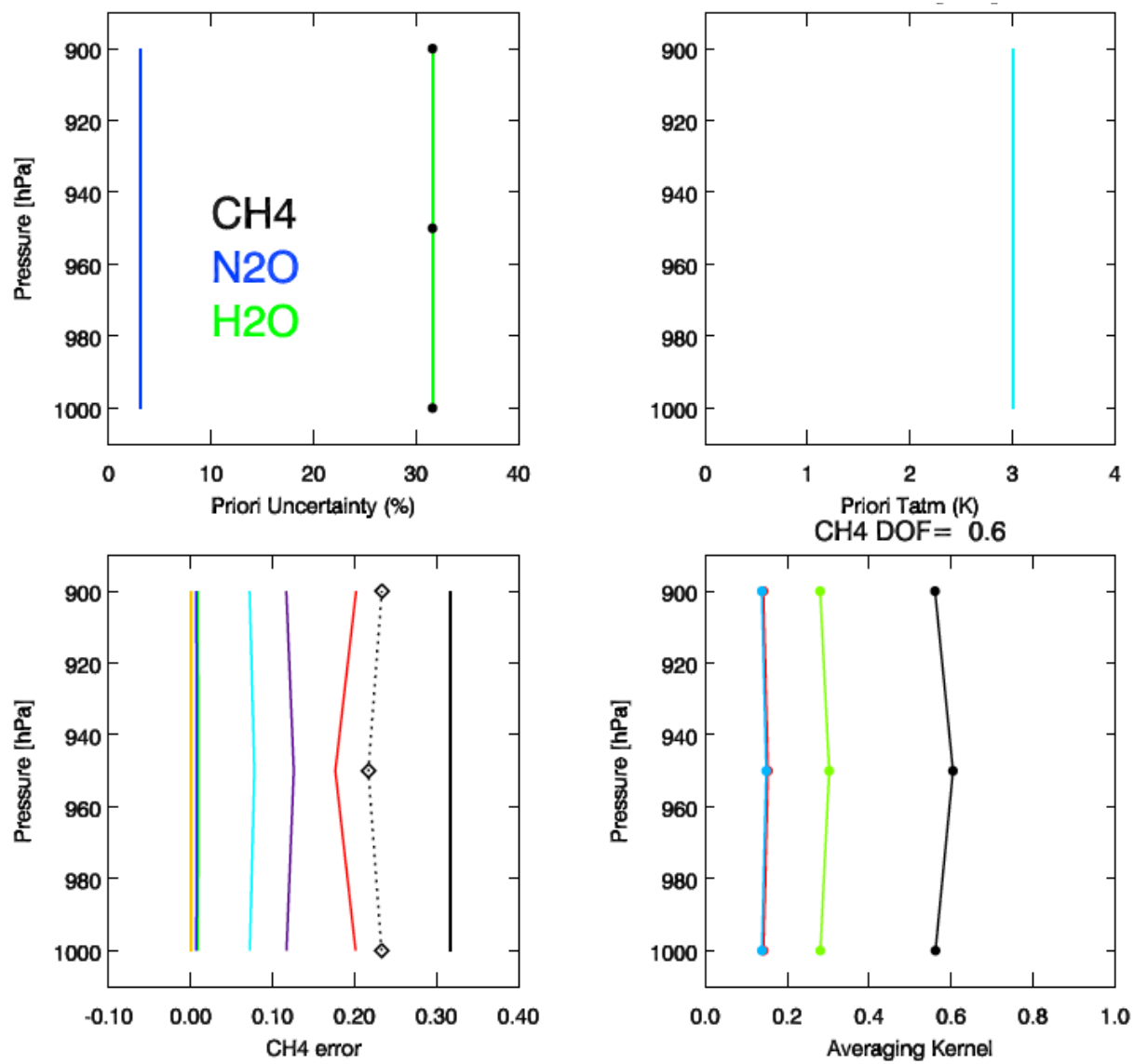
CH4 = Green




320
9.4969,-107.8587


39.4969,-107.8587
53 m

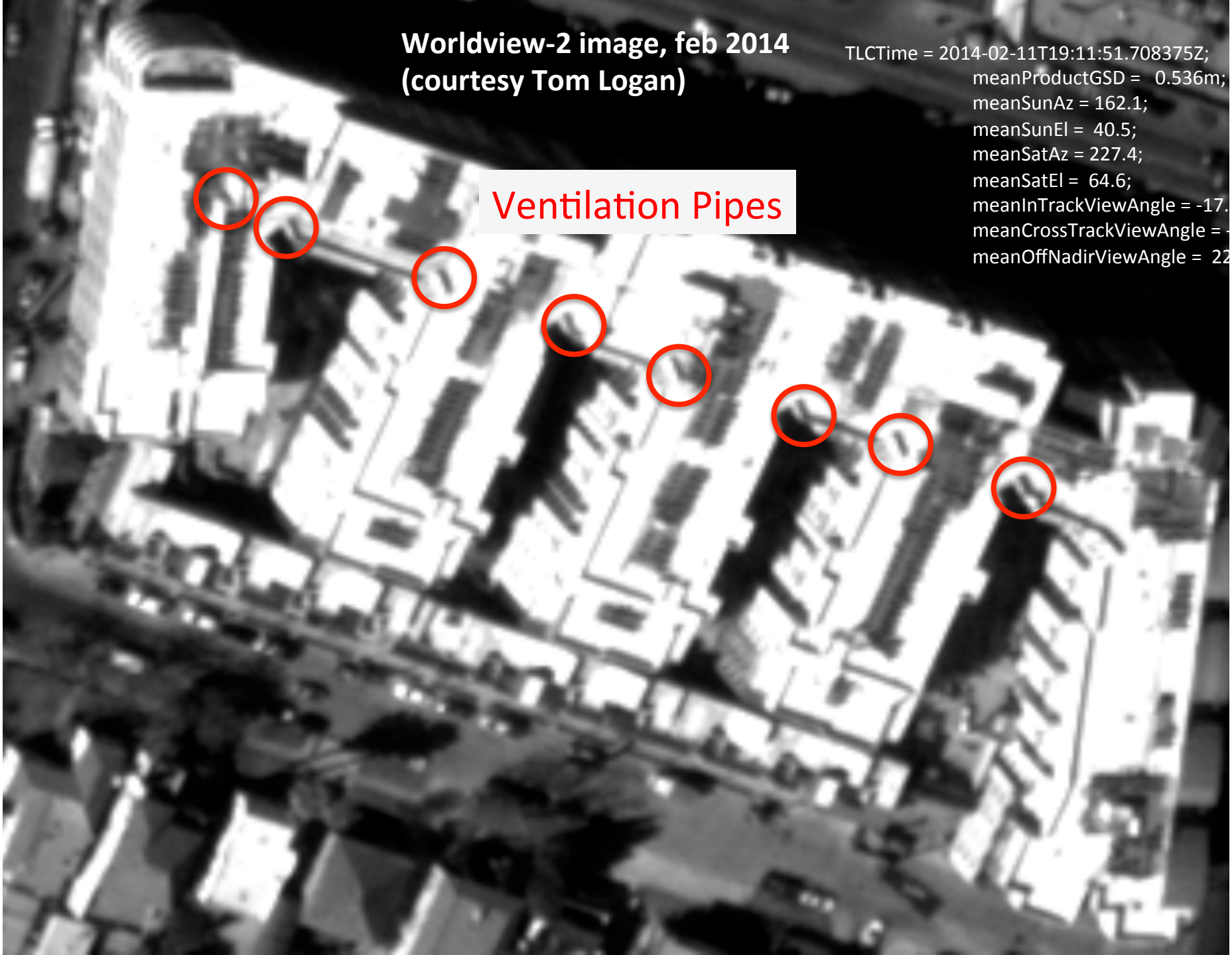
CH4 Priori
Total error (diagmond)
Hassian (dotted line)
Smoothing
Measurement
H2O
N2O
Tsur
Tatm



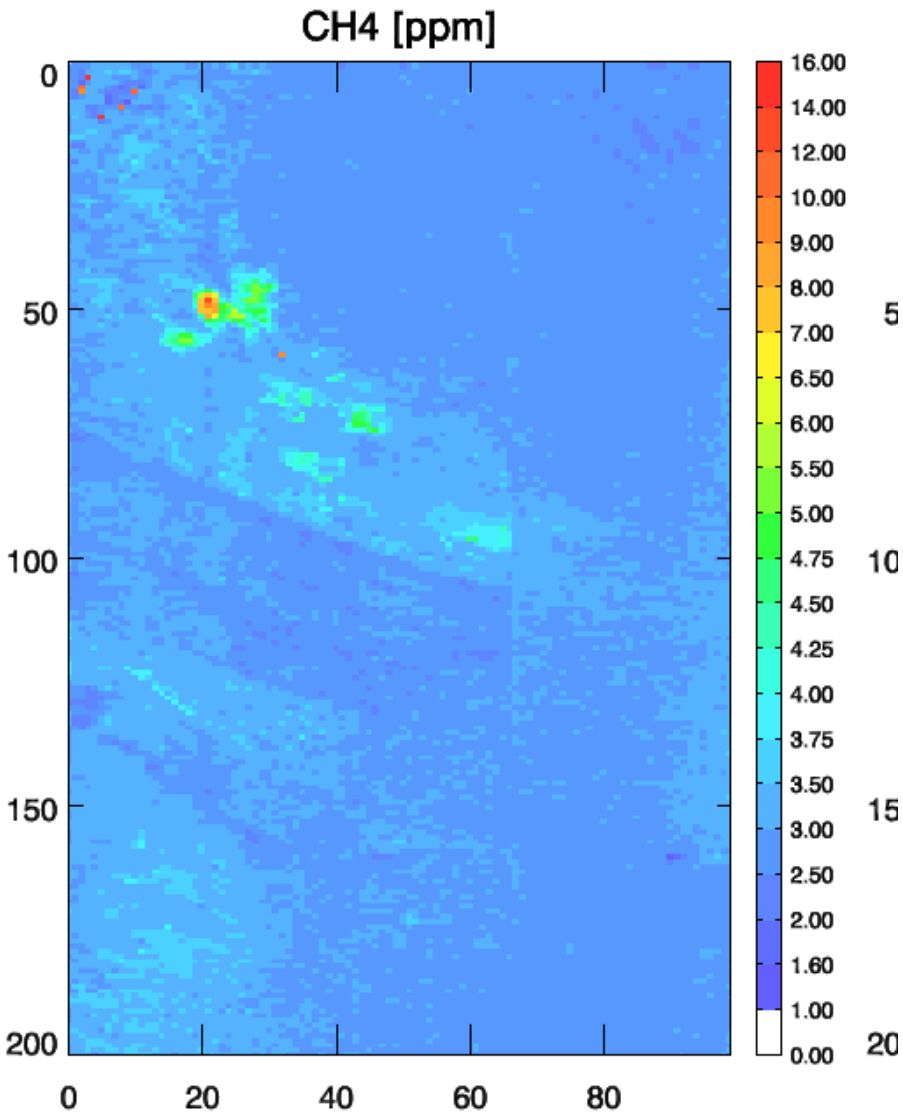

2014-07-05.173225.TarPits.Line1-Run1
Positive CH4 detection in green, Overlay on ST image
CH4 = Green
Multiple CH4 leak source(s)
Surface Temperature [K]
330
325
320
315
310
305
300
295
290

Next Steps…

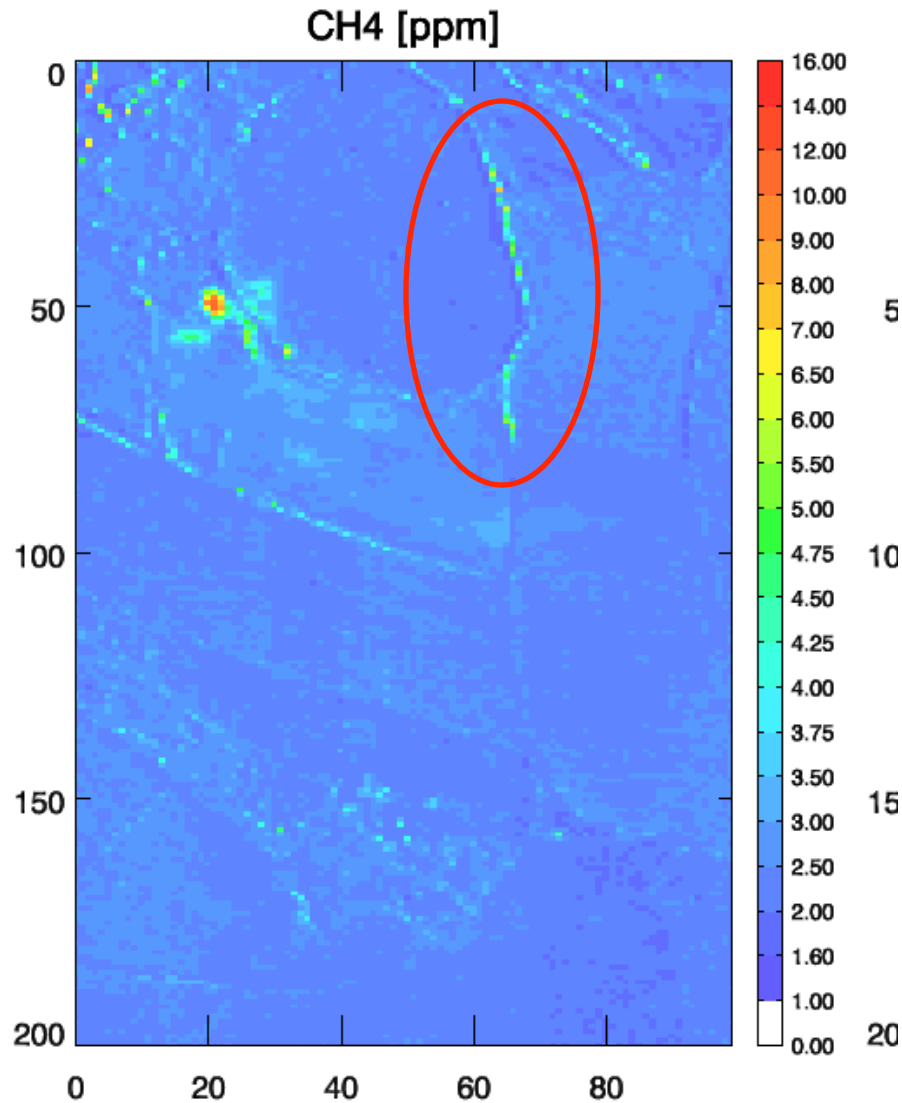
- Search for plumes over remaining target areas (any priorities or suggestions?)
- Automate plume detection algorithm
- Estimate plume concentrations (ppm-m)

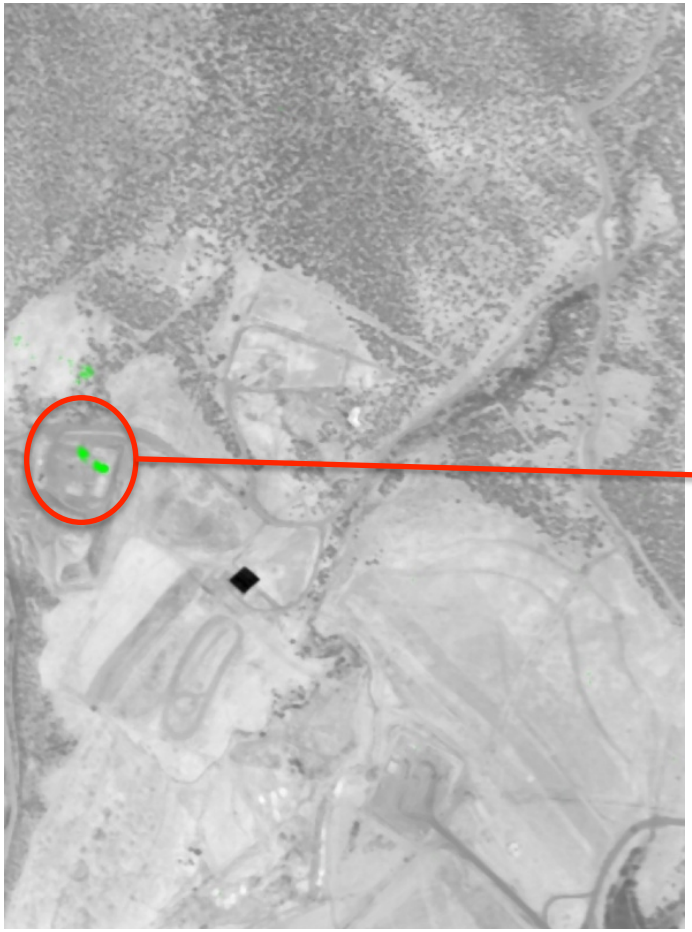

Worldview-2 image, feb 2014
(courtesy Tom Logan)
TLCTime = 2014-02-11T19:11:51.708375Z;
meanProductGSD = 0.536m;
meanSunAz = 162.1;
meanSunEl = 40.5;
meanSatAz = 227.4;
meanSatEl = 64.6;
meanInTrackViewAngle = -17.
meanCrossTrackViewAngle = -
meanOffNadirViewAngle = 22
Ventilation Pipes

With HyTES Emissivity used as a priori

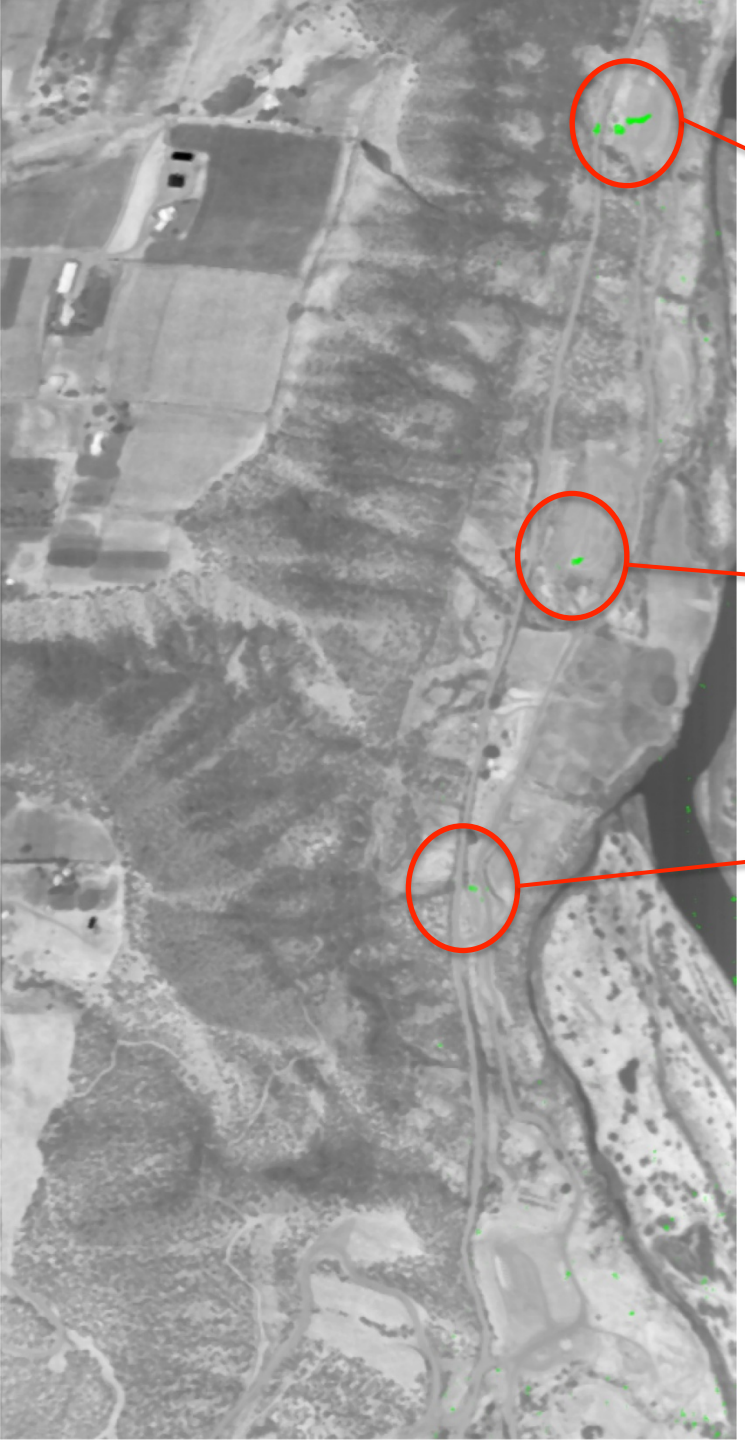


Emissivity assumed = 1

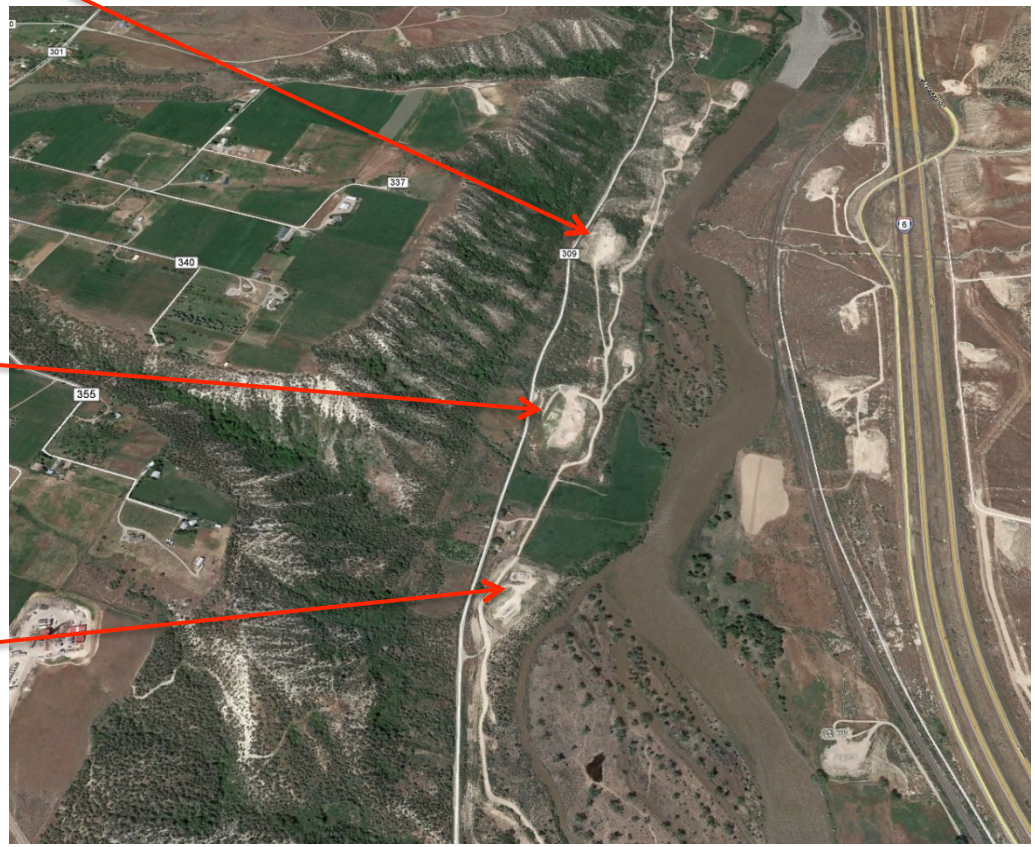


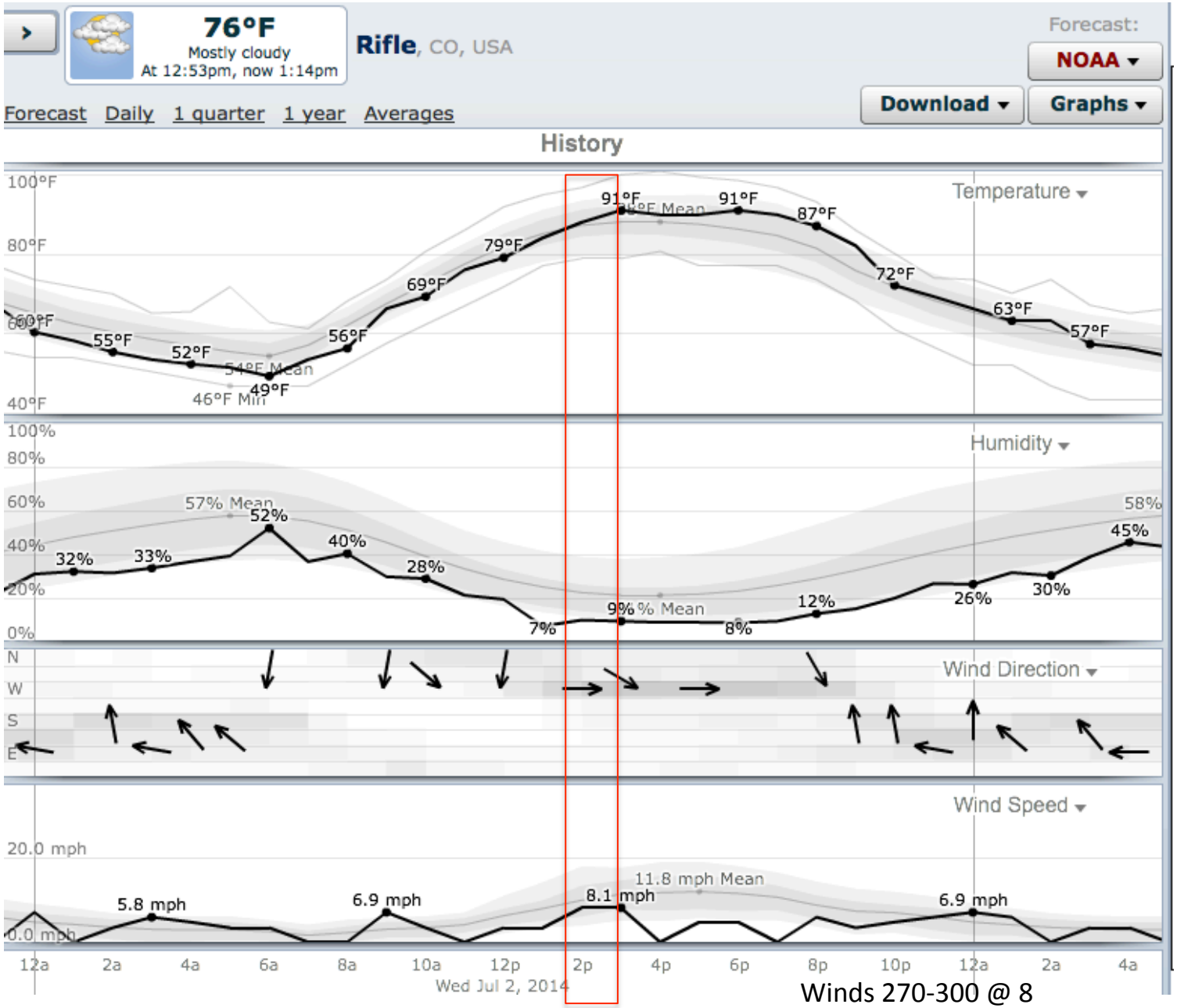


39.5357, -107.6030



39.4703, -107.986



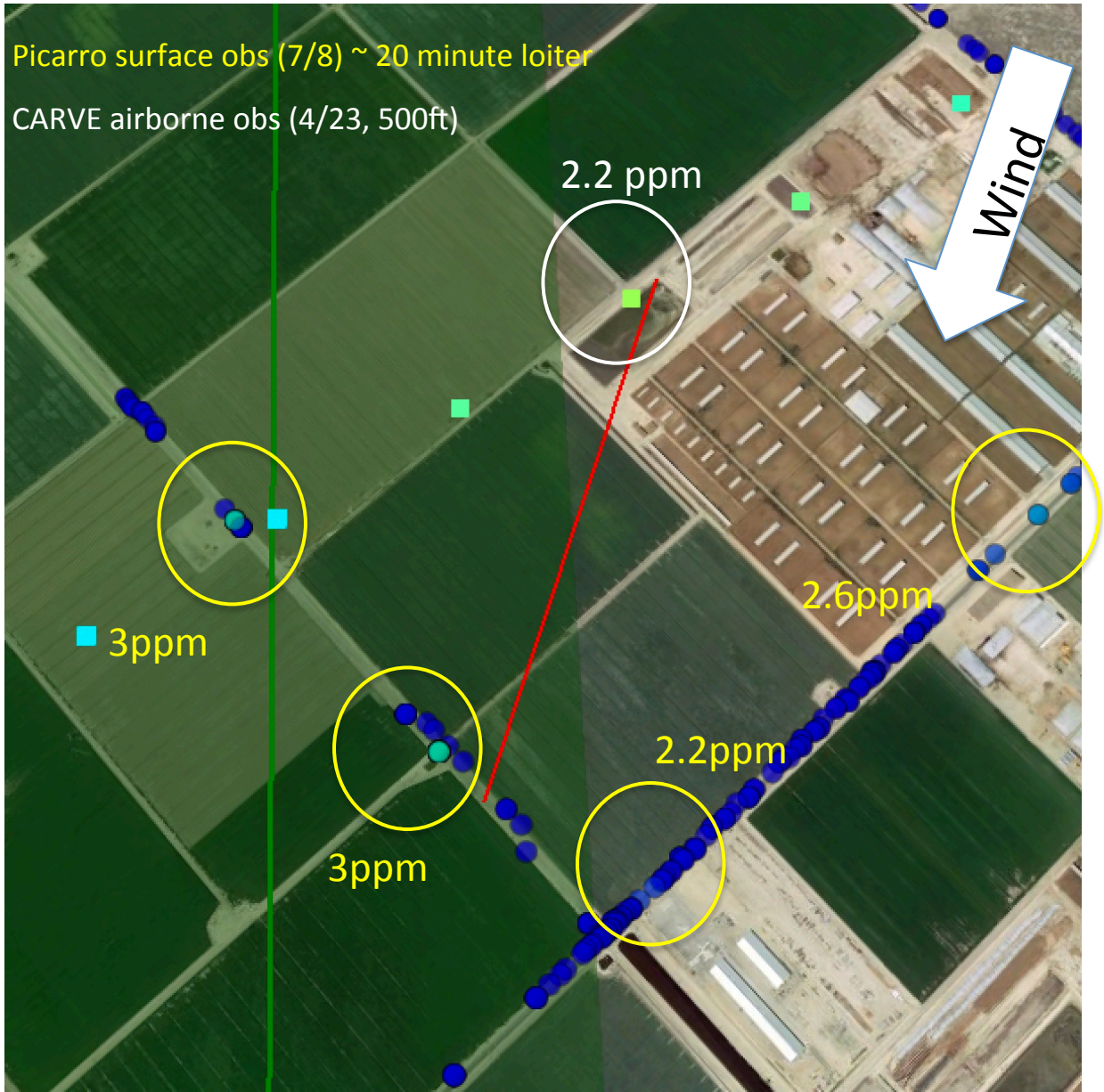


Winds 270-300 @ 8
(2-3pm Local time on July 2)

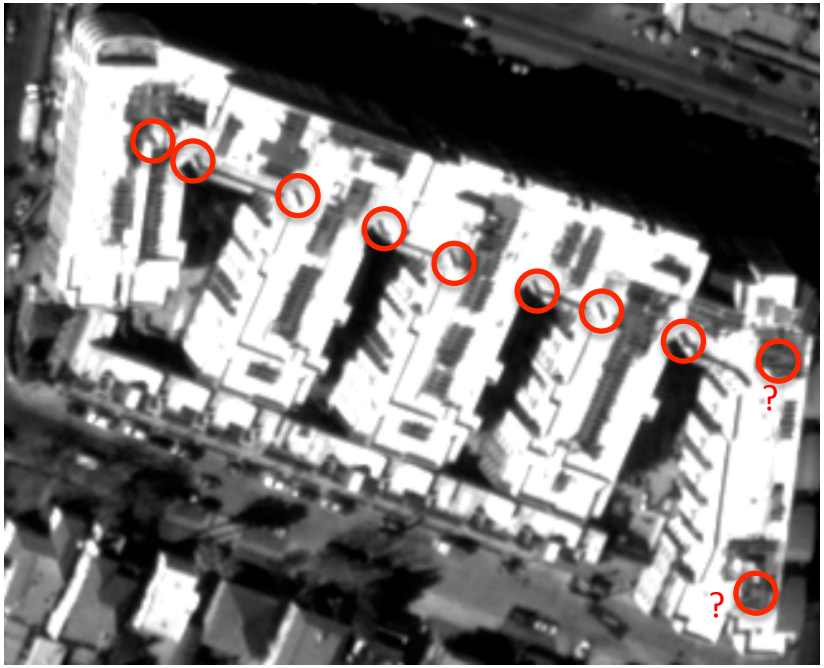
CARVE flights in April show ~ 200ppb CH4 enhancement at 500 ft AGL over feedlots

Feedlots – SW of Shafter

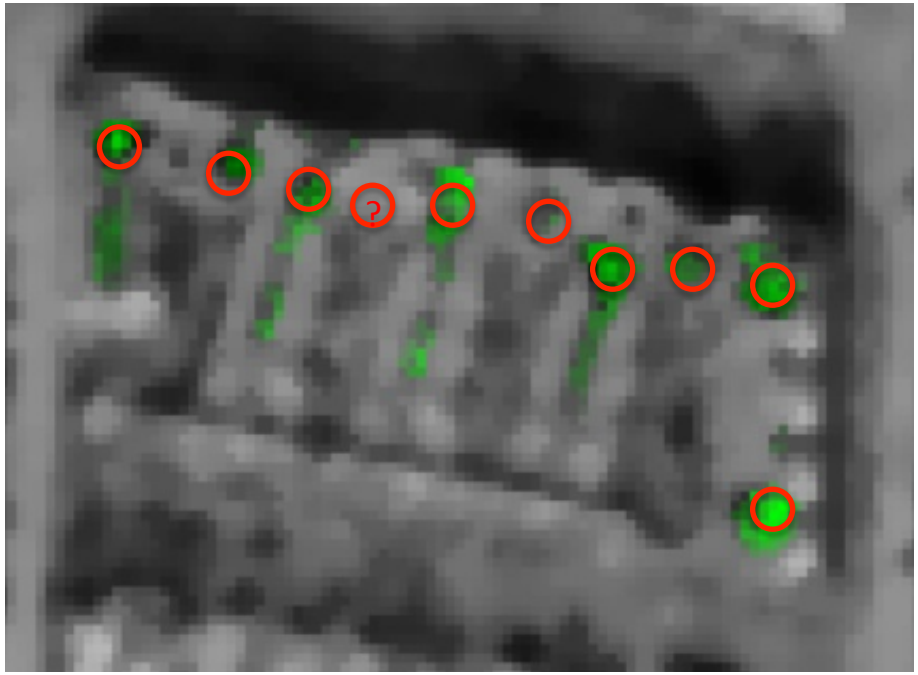
(arrow – mean wind direction)



Worldview-2



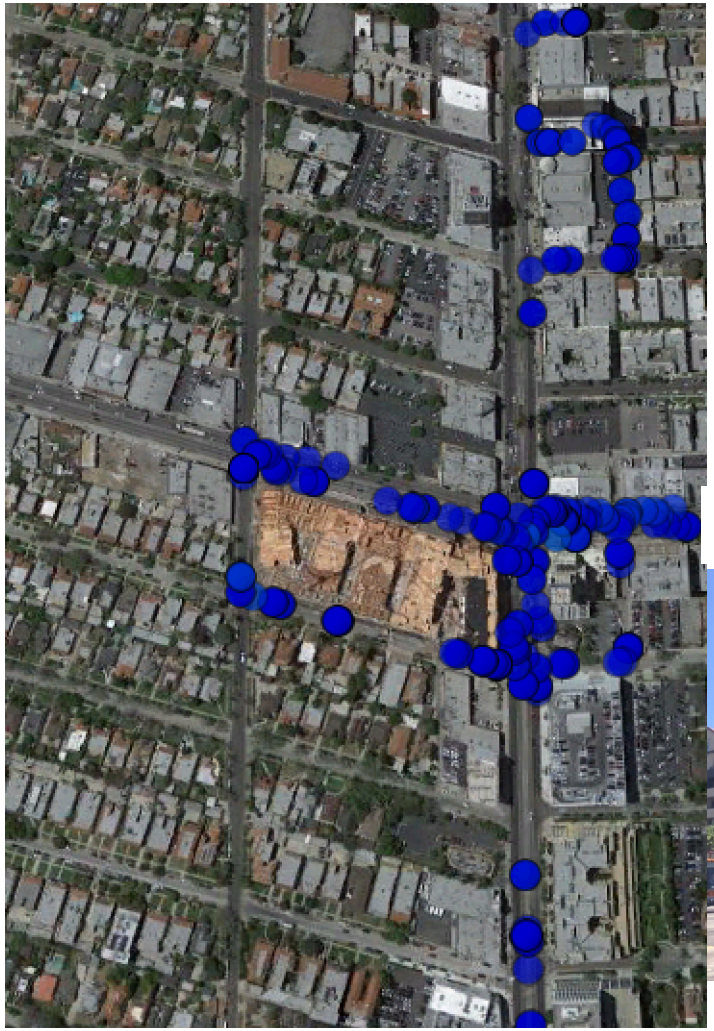
HyTES: CH4 = Green



HyTES Comparisons with Picarro Ground Measurements

HyTES

Picarro



Wilshire and La Brea

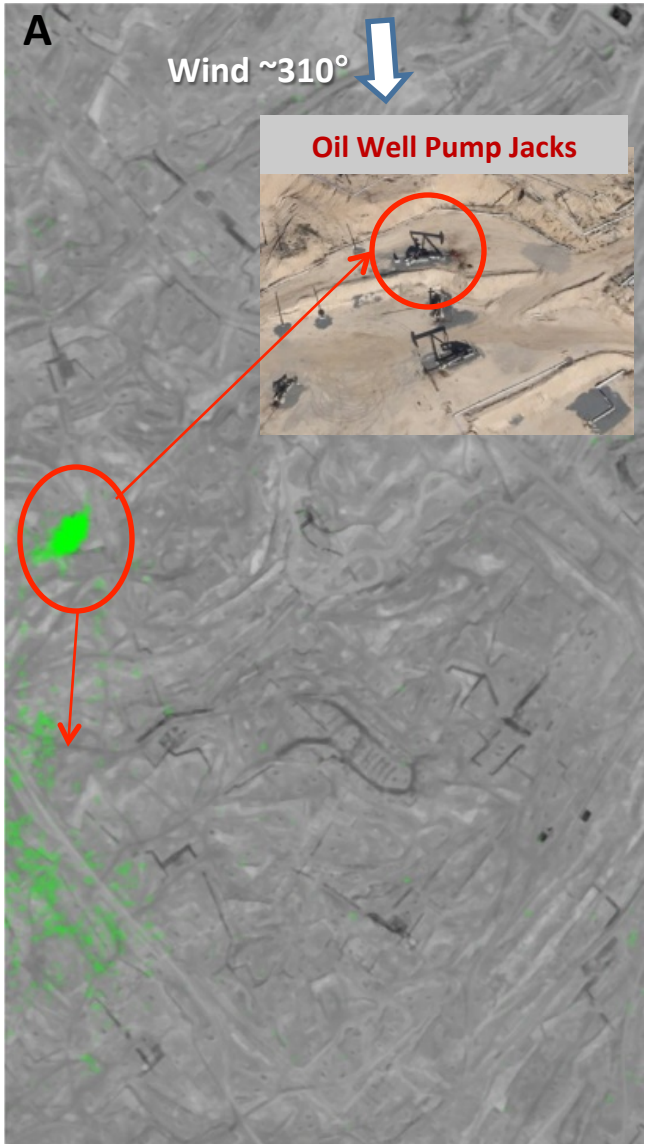
No surface enhancements detected

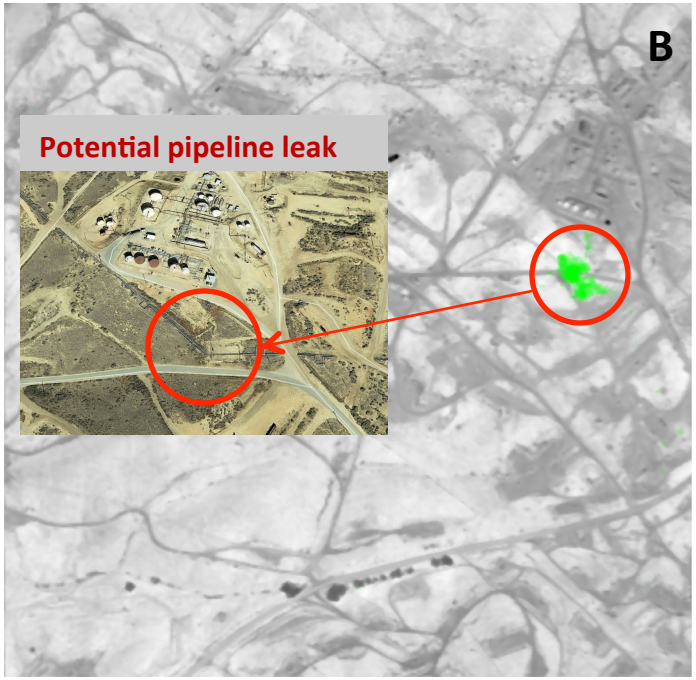
new apartment building

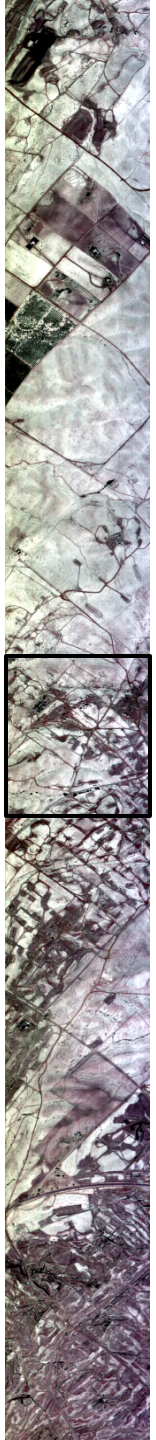
These features seem aligned with building structure - HyTES might be seeing individual plumes from roof-top sewer vents (fluxes not reaching street level)

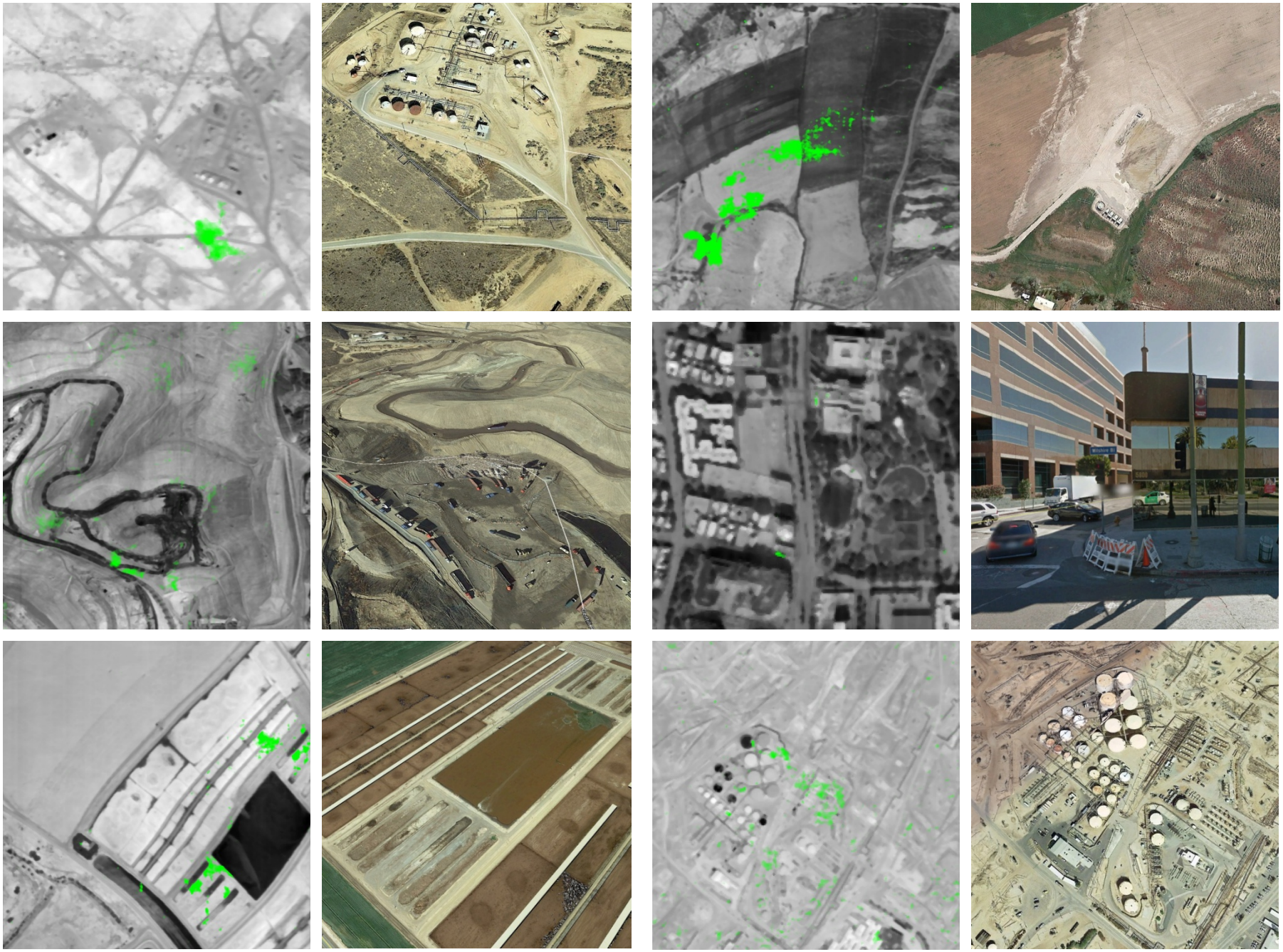
2014-07-08.191611.KernRiverOil.Line3-Run1 Segment 01

Positive **CH4** detection in **green**, Color intensity correlated with plume strength. Overlay on Surface Temperature image calculated from HyTES 8.3 micron band and ASTER emissivity



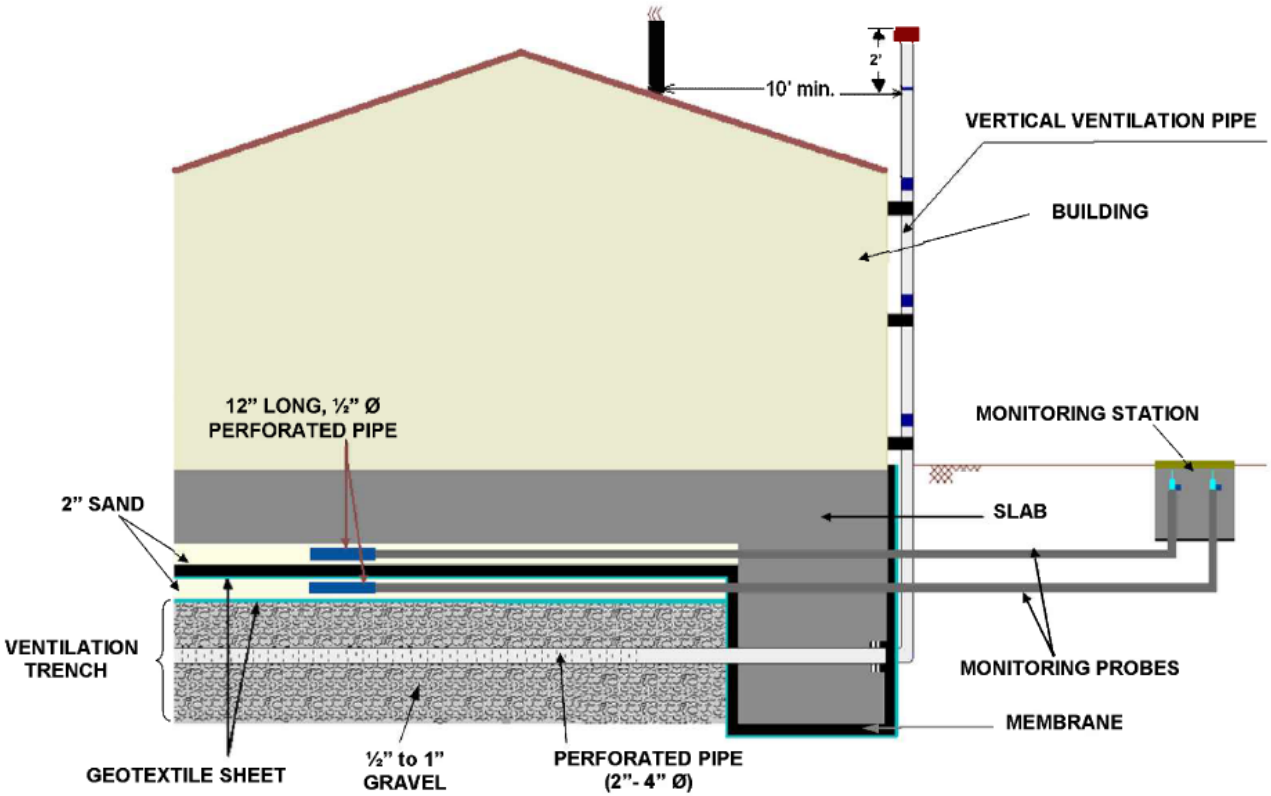






Source: Likely from sewer vents:

(Riley personal communication with building engineer)



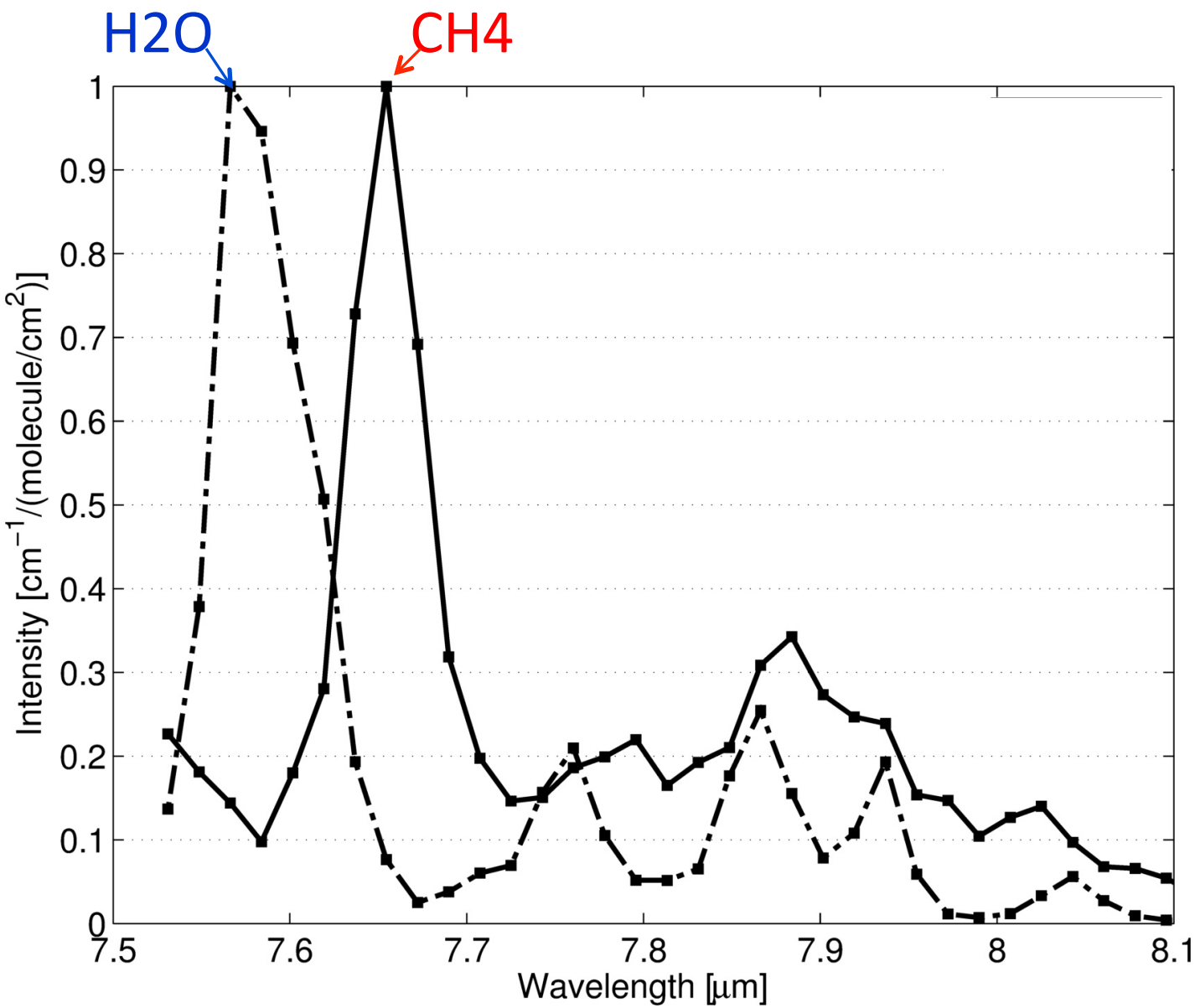
METHANE GAS CONTROL SYSTEM
PASSIVE SYSTEM

NTS

Methane Mitigation System

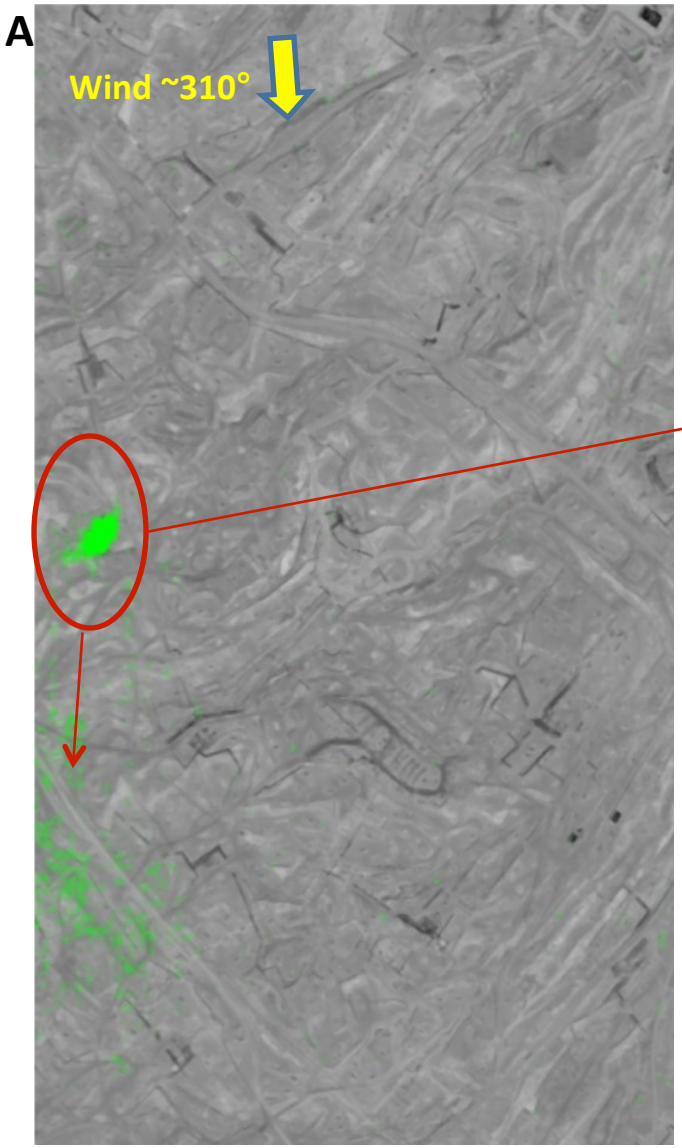
PLATE 1

HITRAN absorption coefficients



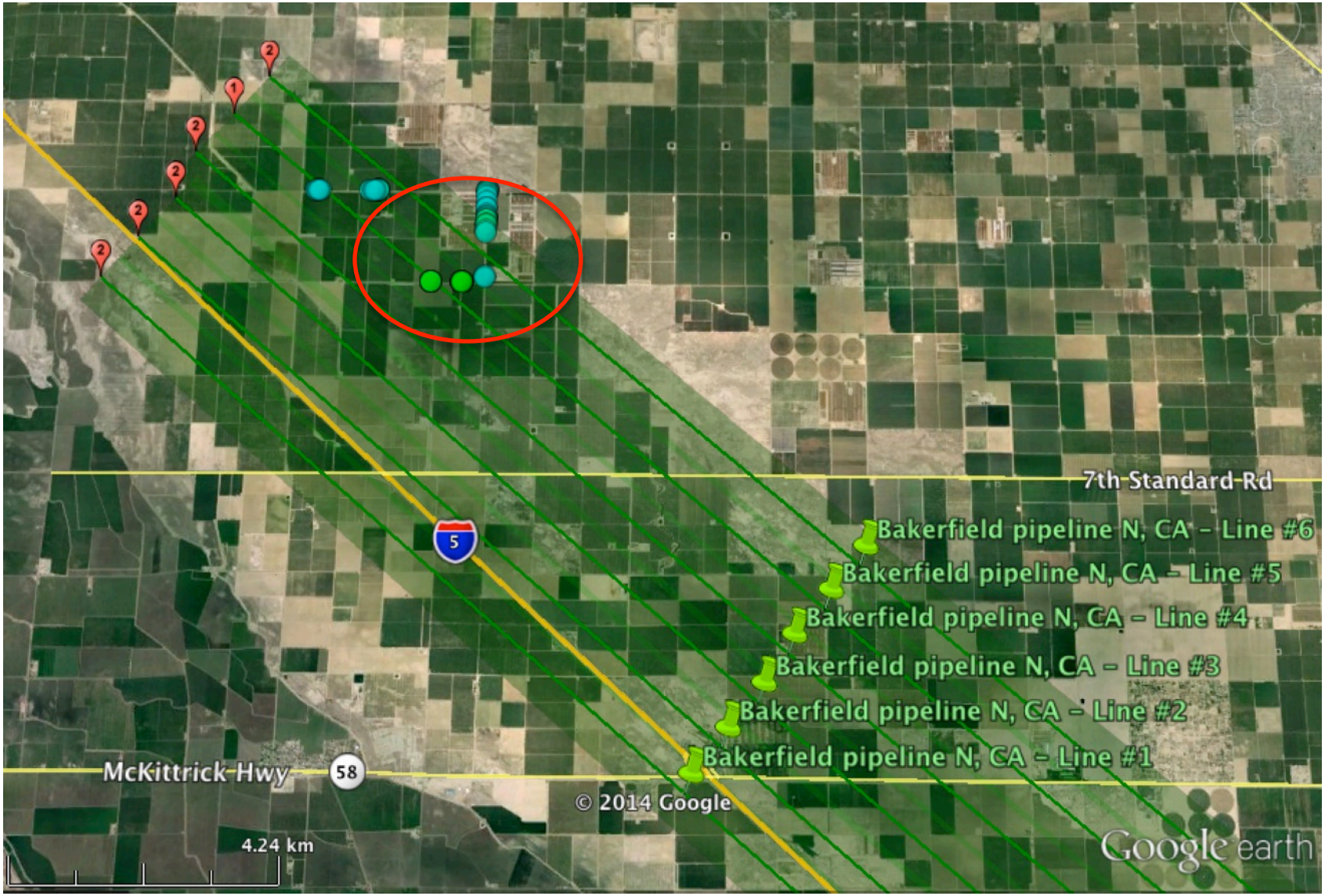
2014-07-08.191611.KernRiverOil.Line3-Run1 Segment 01

Positive CH4 detection in green, Color intensity correlated with plume strength. Overlay on Surface Temperature image calculated from HyTES 8.3 micron band and ASTER emissivity



Oil Well Pump Jacks

Surface CH_4: 2,200-3000 ppb around feedlots (7/8/2014) – Bakersfield NORTH



HyTES Overall Objective and Science Goal

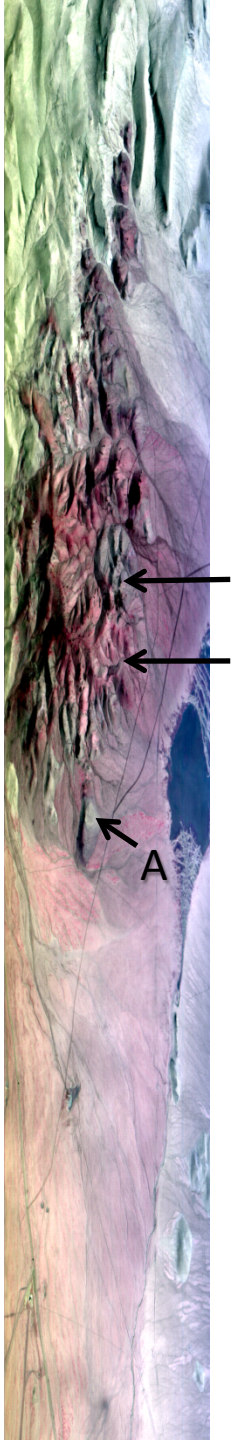
- Objective: Build and deploy an airborne Hyperspectral Thermal Emission Spectrometer (HyTES) with 512 pixels across track with pixel sizes in the range of 5 to 50 m (depending on aircraft flying height) and 256 spectral channels between 7.5 and 12 µm.

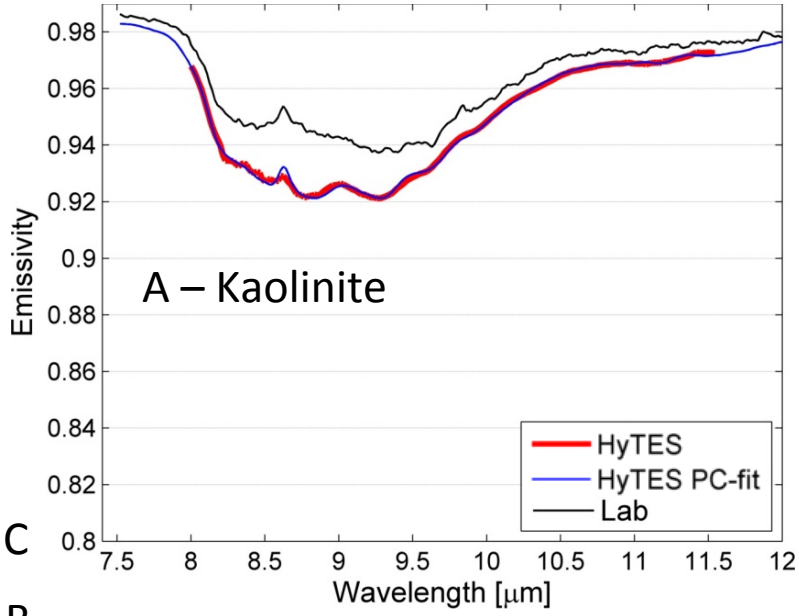
- Science Goal: Provide precursor high spectral and spatial resolution thermal infrared data for the NRC Recommended HyspIRI mission and for use in Earth Science Studies
  - Optimal band placement for HyspIRI TIR for surface compositional mapping and volcanic ash/gas detection (e.g. SO2)
  - Prelim Band Study report available at HyspIRI website (Ramsey, Realmuto, Hulley, Hook)

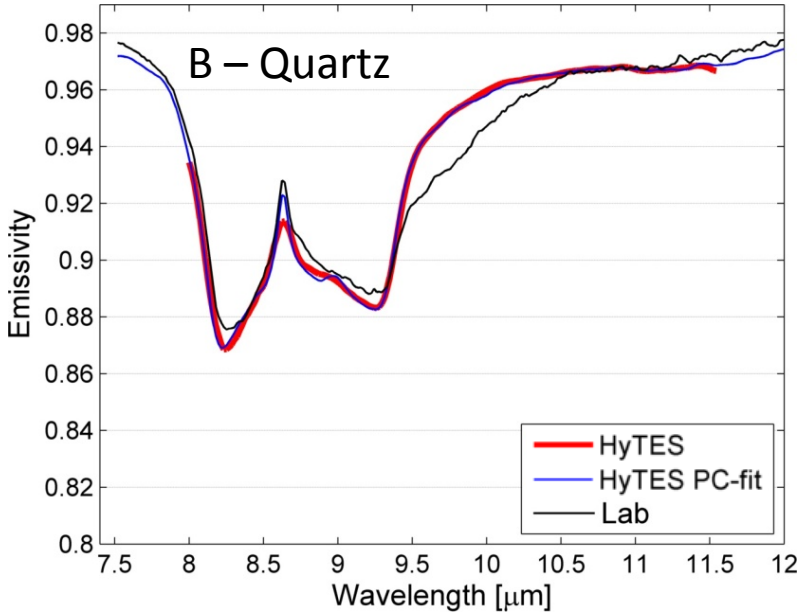
Mullet Island, Salton Sea, CA

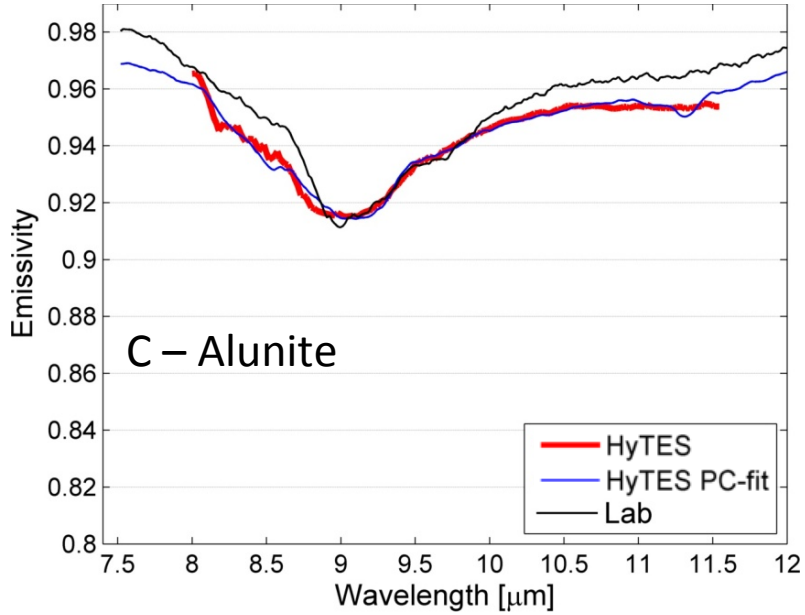
View looking back across natural bridge. Bridged formed to Mullet Island due to receding shore line .

View looking towards Mullet Island.


C
B
A

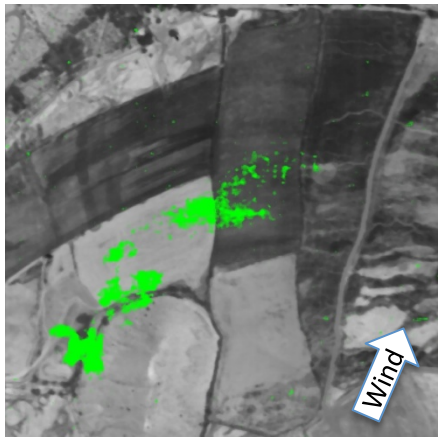

A – Kaolinite
Emissivity
Wavelength [μm]
HyTES
HyTES PC-fit
Lab


B – Quartz
Emissivity
Wavelength [μm]
HyTES
HyTES PC-fit
Lab

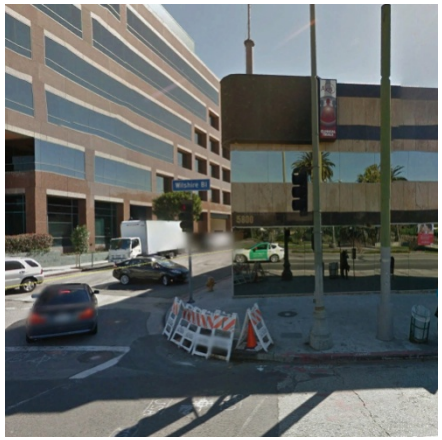

C – Alunite
Emissivity
Wavelength [μm]
HyTES
HyTES PC-fit
Lab

Cuprite, NV

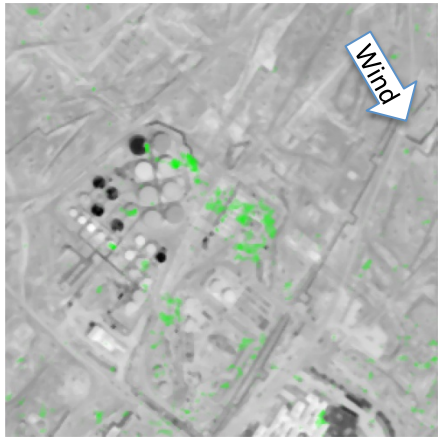
Anthropogenic Methane Emission Source Examples



Well pads, Garfield county, CO

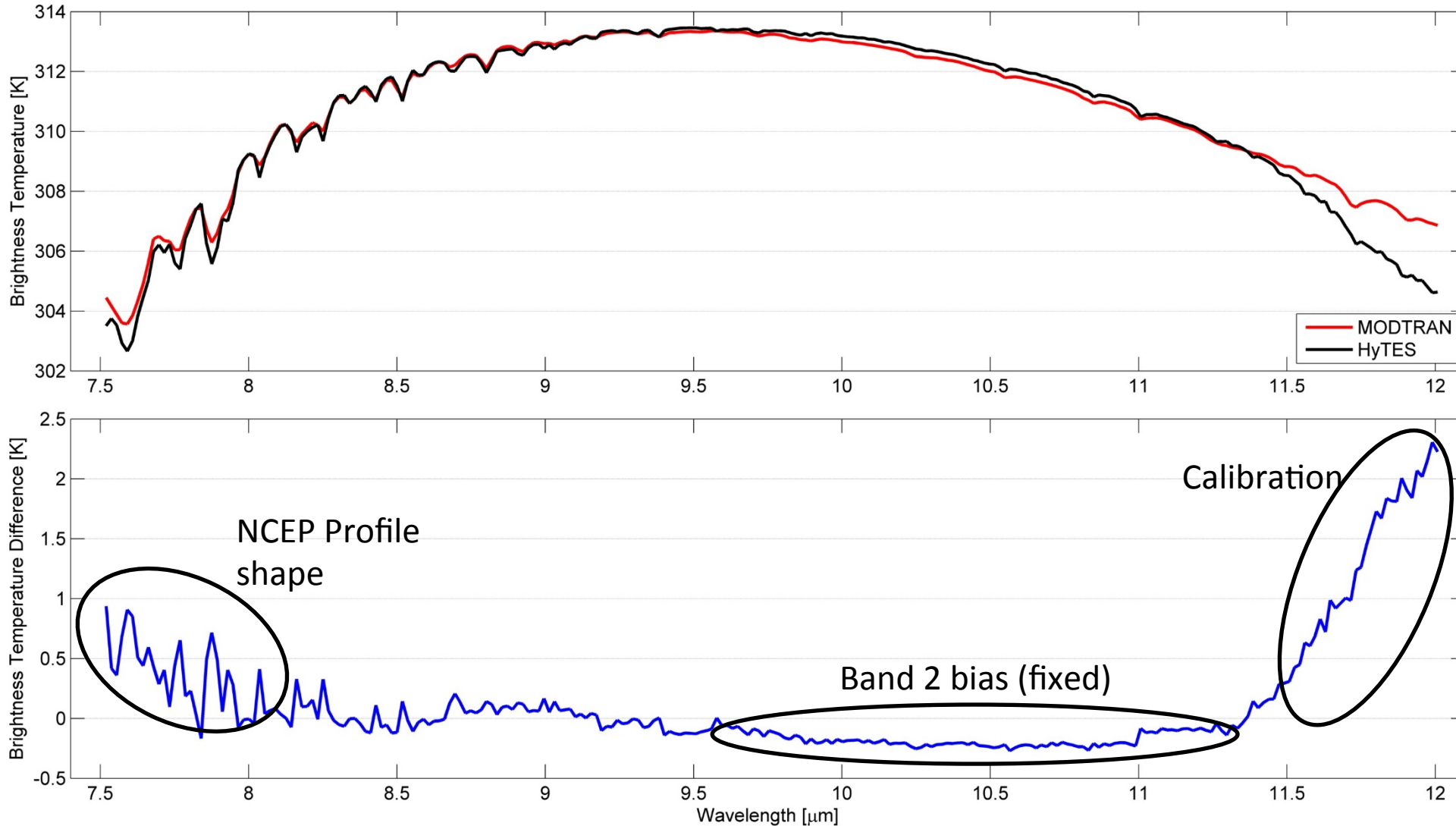


La Brea Tar Pits, LA



Hydrocarbon Storage Facilities, Kern River, CA

HyTES Calibration: Salton Sea, CA



Imagery from campaign

Jet Propulsion Laboratory

2013

2014

L1A: bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm), 58 displayed at RGB each image is 485 x 512 pixels