Mapping Gas Emissions with the Hyperspectral Thermal Emission Spectrometer (HyTES)

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Outline

- HyTES Objectives and Instrument Characteristics
- Science Campaign sites (Apr 2013)
- Emissivity Validation
- Trace gas detection methods
  - Radiative closure method (Ammonia)
  - Clutter matched filter method (Methane)
- Examples:
  - Ammonia: Salton Sea fumeroles
  - Methane: Santa Barbara marine oil seeps
- Summary

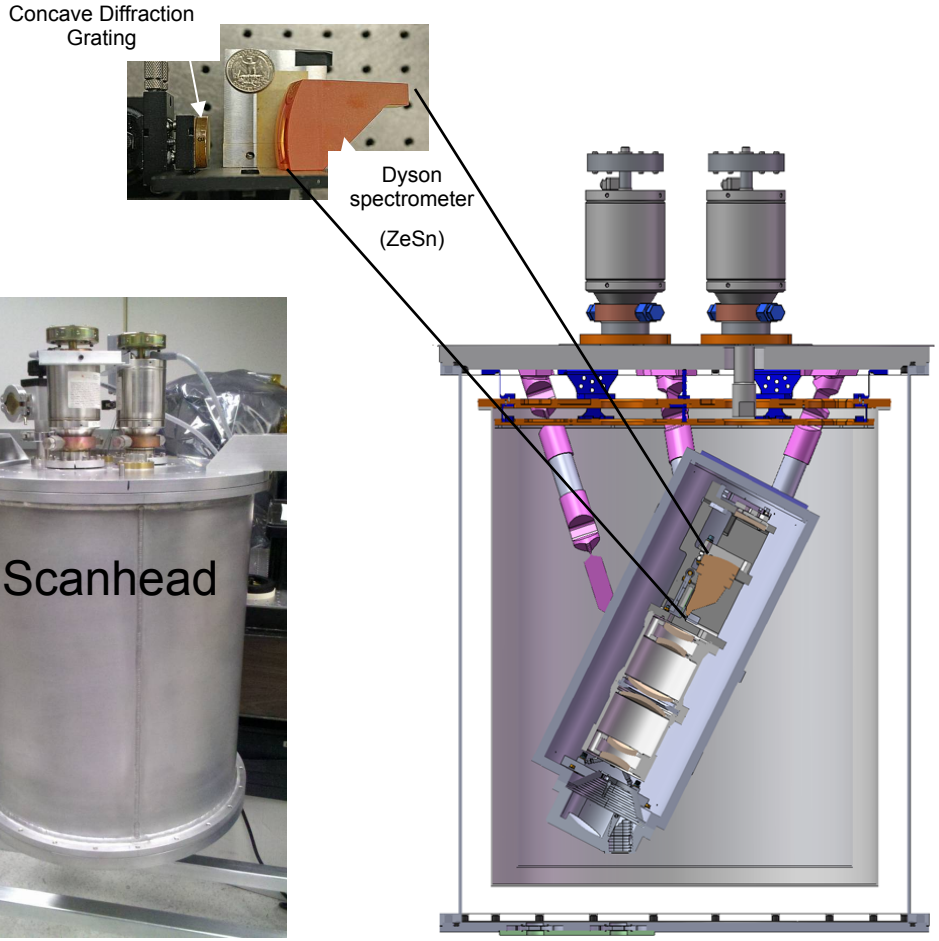
HyTES Overall Objective and Science Goal

- 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)

HyTES Instrument Characteristics

Twin Otter:
Flights in 2012, 2013



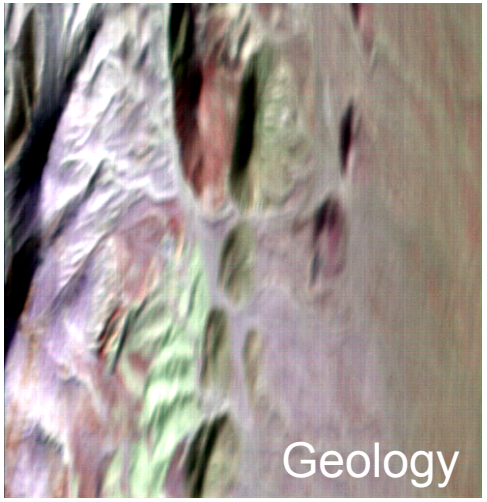
Instrument Characteristic	HyTES
Mass (Scanhead)[1]	12kg
Power	400W
Volume	1m x 0.5m (Cylinder)
Number of pixels x track	512
Number of bands	256
Spectral Range	7.5-12 um
Detector	Multi-stack QWIP
Total Field of View	50 degrees
Calibration (preflight)	Full aperture blackbody
Swath Width	1.8 – 3.6 km
Pixel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

Advanced Instrument Designs:
William Johnson

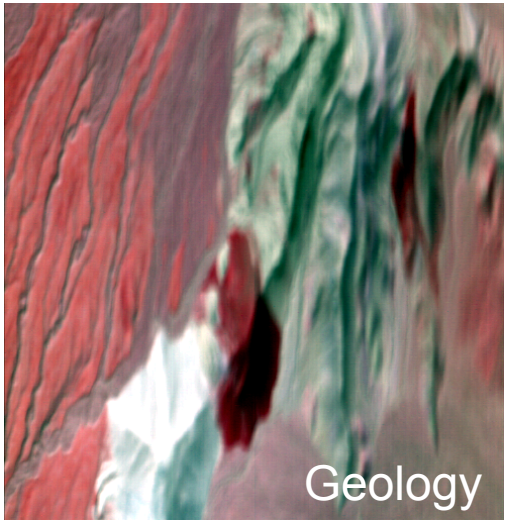
Science Campaign Sites – Apr 2013

April 2013 Campaign Snapshots

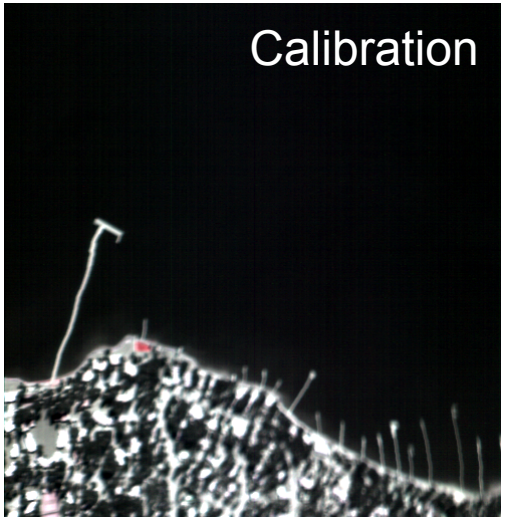
Cuprite, NV



Death Valley, CA

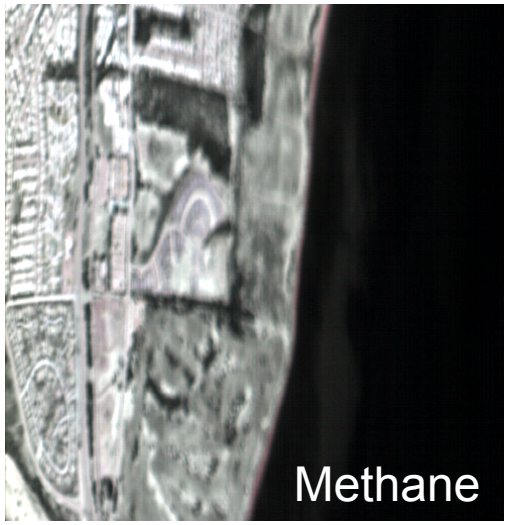


Lake Tahoe, CA/NV



NASA/JPL, CA

Santa Barbara, CA



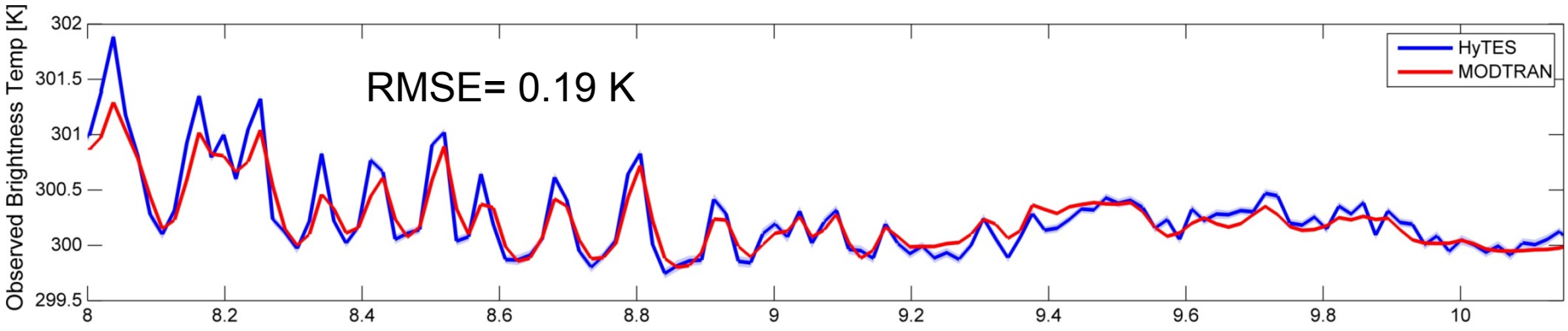
La Brea, CA

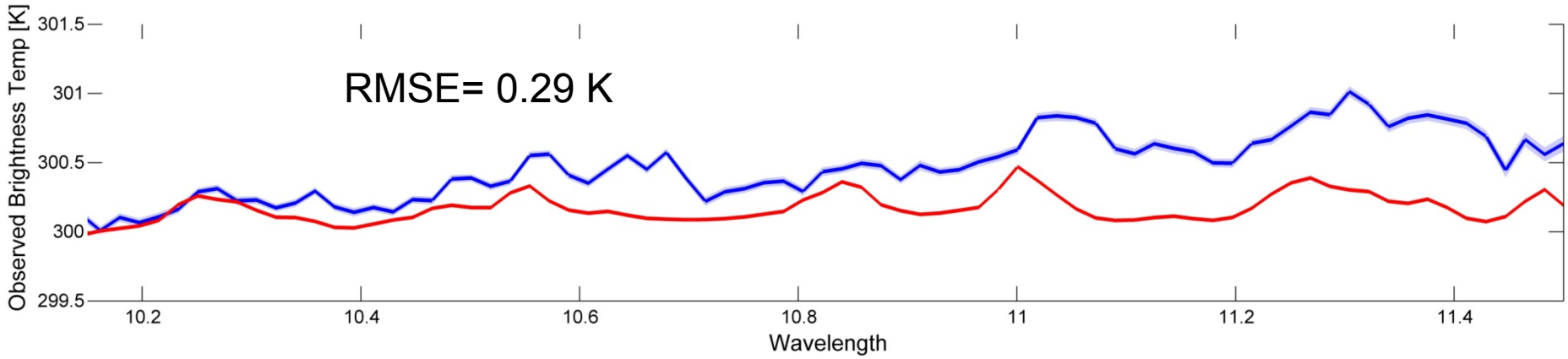
Bands 150 (10.08 μm), 100 (9.17 μm), 58 (8.41 μm), displayed at RGB each image is 495 x 512 pixels

HyTES Calibration: Salton Sea, CA

Salton Sea– 04/29/2013
Line1-Run2-Segment15

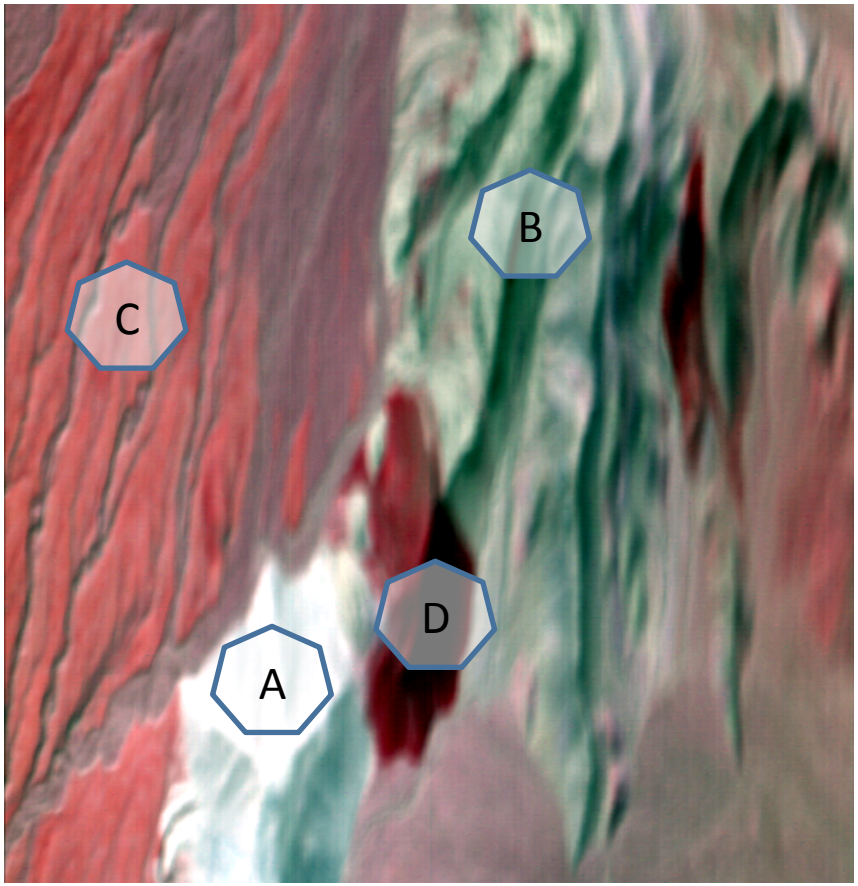
HyTES Tskin = 300.3 K
Radiometer Tskin = 299.7 K

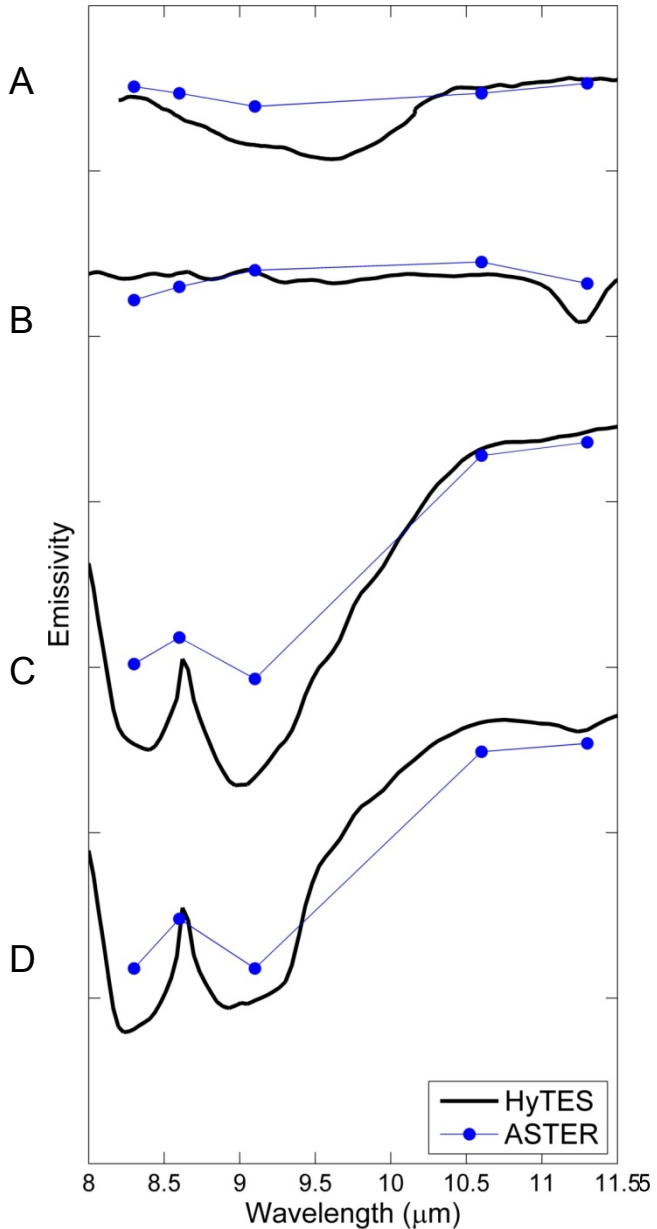




HyTES Spectra: Death Valley, CA

2013-04-24.190040.DeathValley.Line2-Run1-Segment22



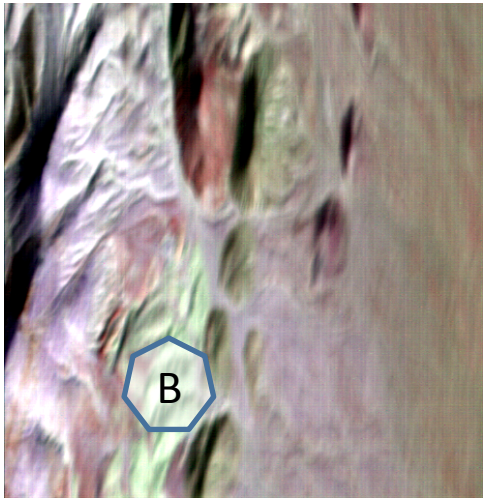


Key:
A – Volcanic (Basalt)
B – Carbonate
C – Quartz alluvial fan
D – Quartzite dome

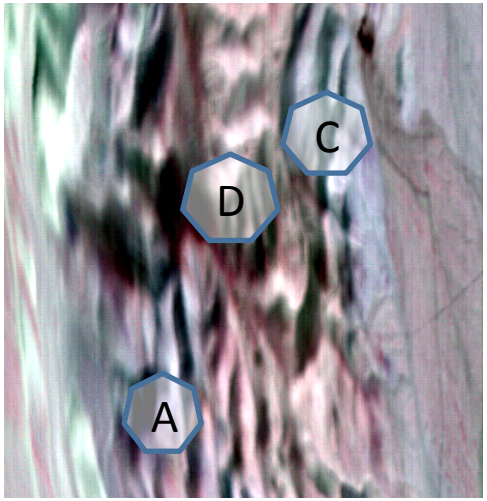
- Single-pixel retrievals
- Atmospheric correction – ISAC
- Ts/emis Retrieval - TES

HyTES Spectra: Cuprite, NV

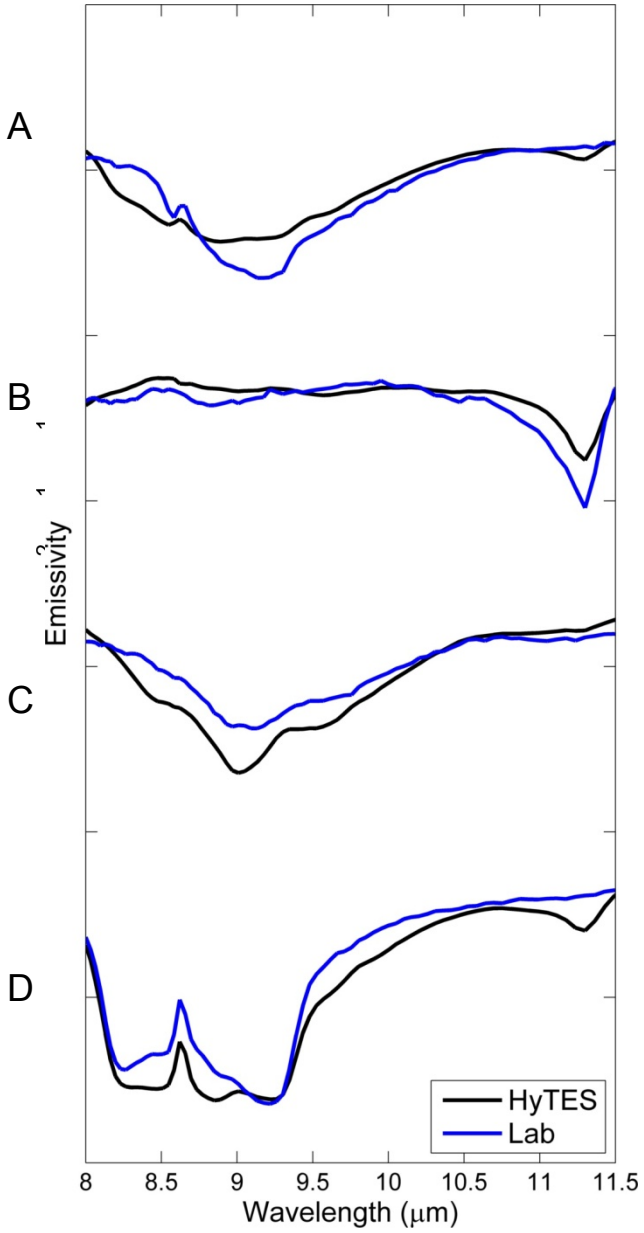
2013-04-24.173326.Cuprite.Line2-Run1



2013-04-24.172629.Cuprite.Line1-Run1

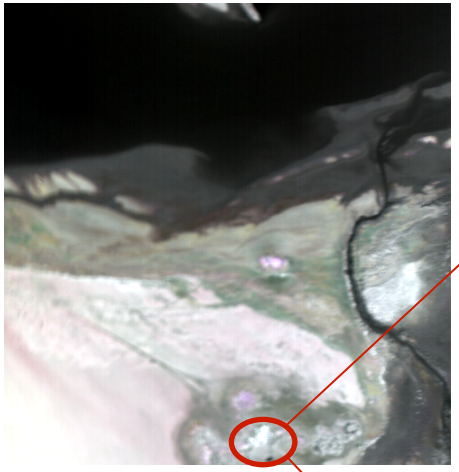


Key:
A – Kaolinite
B – Carbonate
C – Alunite
D – Quartz



Salton Sea: Ammonia (NH3)

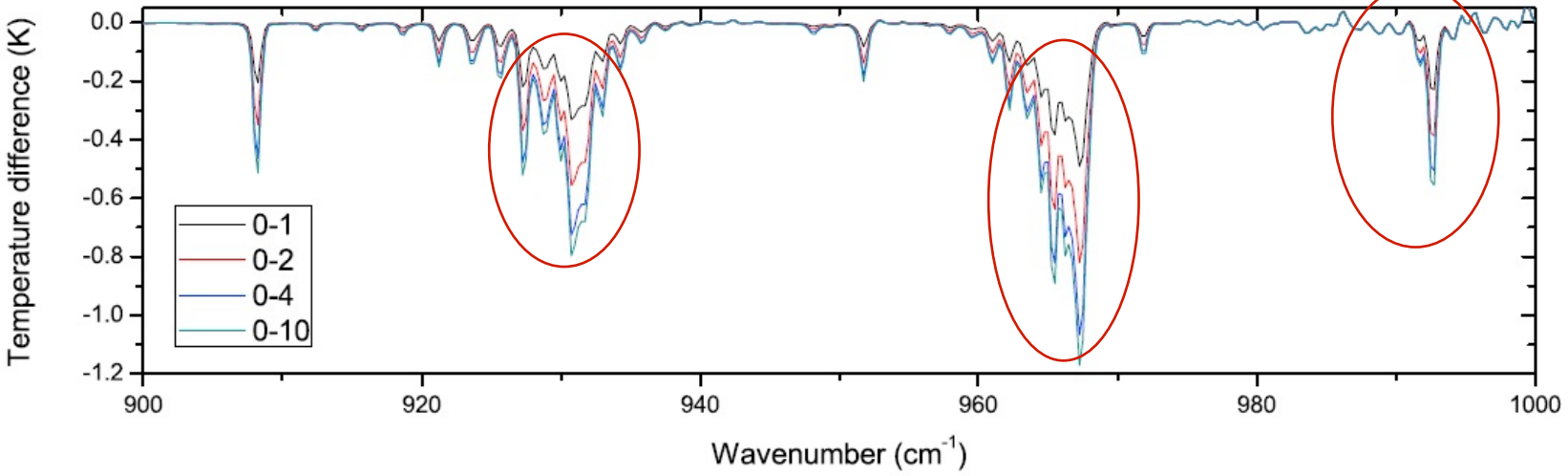
HyTES RGB



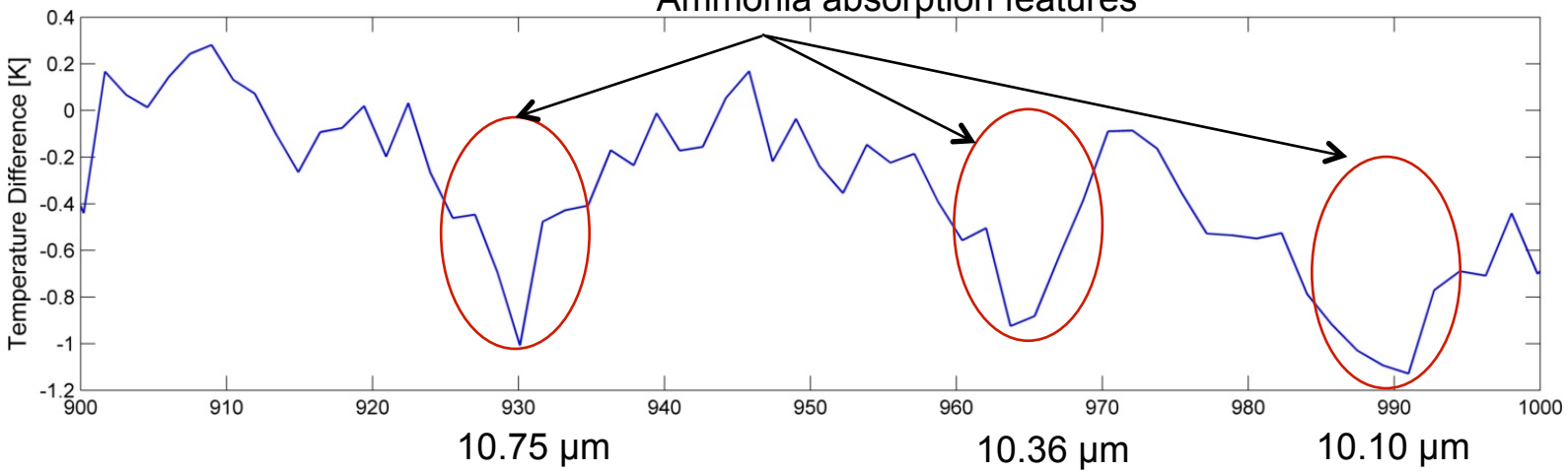
Ammonia emitted from an active fumarole group exposed on a sandbar at the shoreline of the Salton Sea mud bank region.

Salton Sea: Ammonia (NH3)

IASA/Metop (simulated) – *Clarisse et al. 2009*

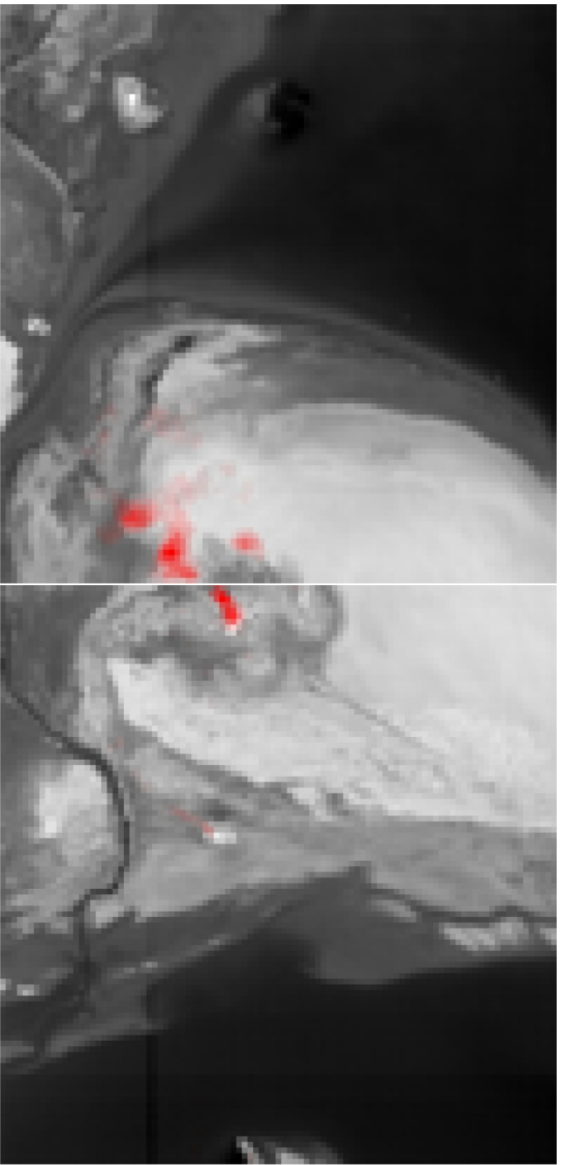


HyTES

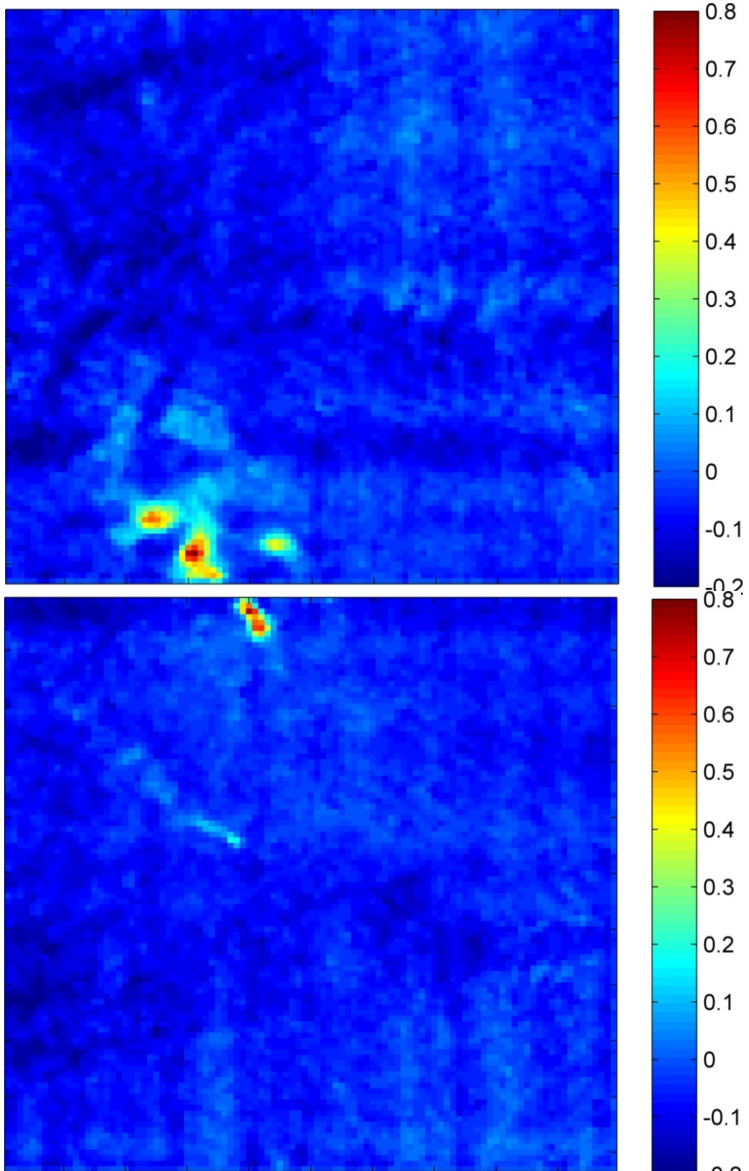


Salton Sea: Ammonia (NH3)

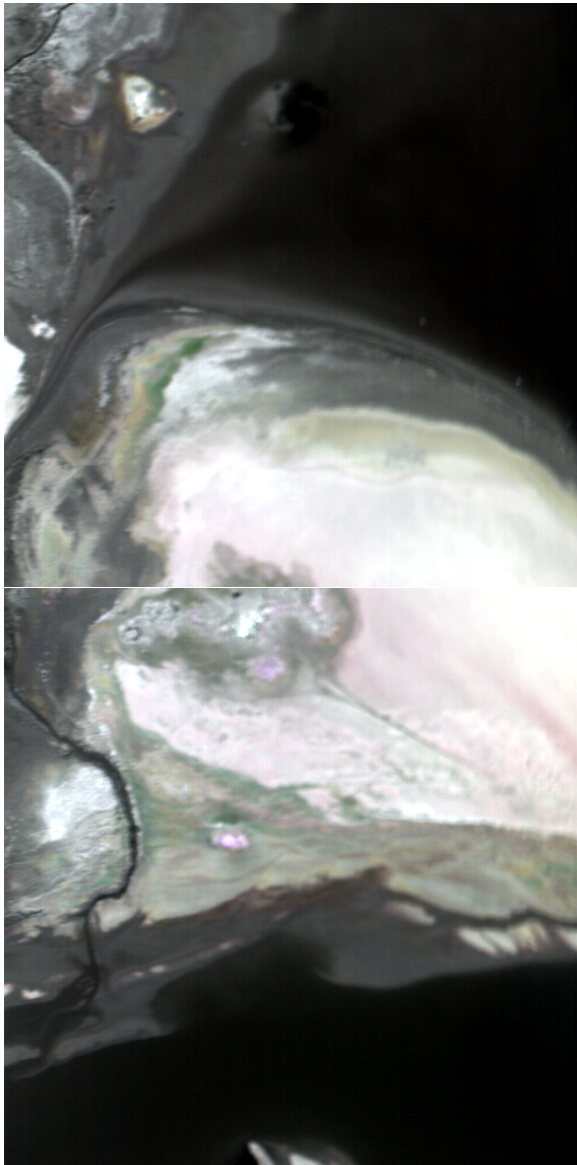
Ammonia positive detection (red) overlayed on Tskin map (gray)



Brightness temperature difference [K] between observed and simulated data (band 187)



Radiance image plotted as RGB using bands [150, 100, 80]

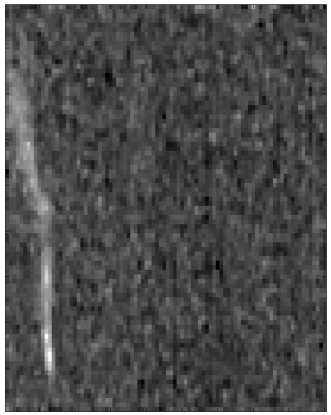


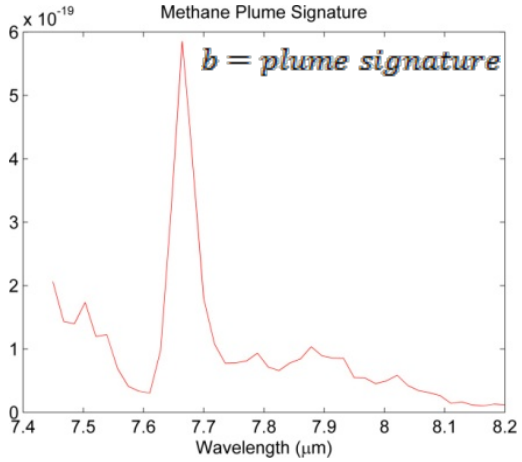
Methane Plume Detection: Clutter Matched Filter

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 clutter. Gas signature ***b*** is extracted from Hitran database.





Applying signal filter vector to datacube, ***R*** produces plume signature image.

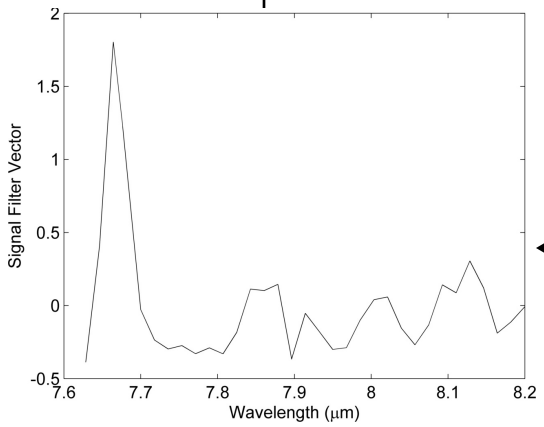
$$Plume = q^T R$$

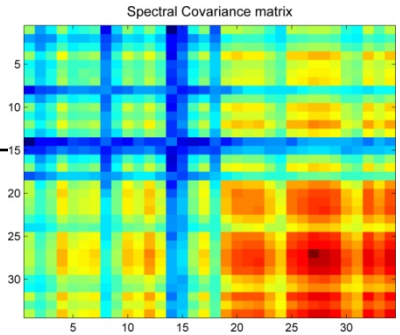
3. Calculate the spectral covariance matrix, ***K*** :

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

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

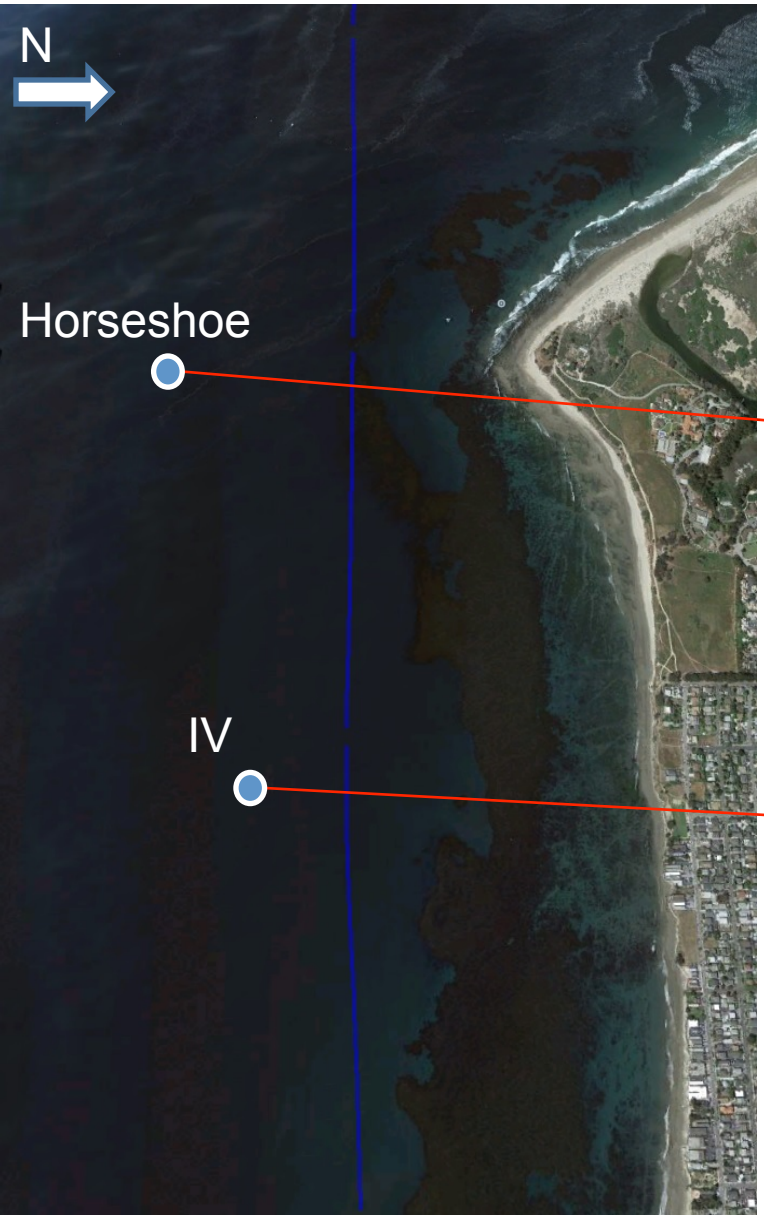
$$q = \frac{K^{-1}b}{\sqrt{b^T K^{-1} b}}$$

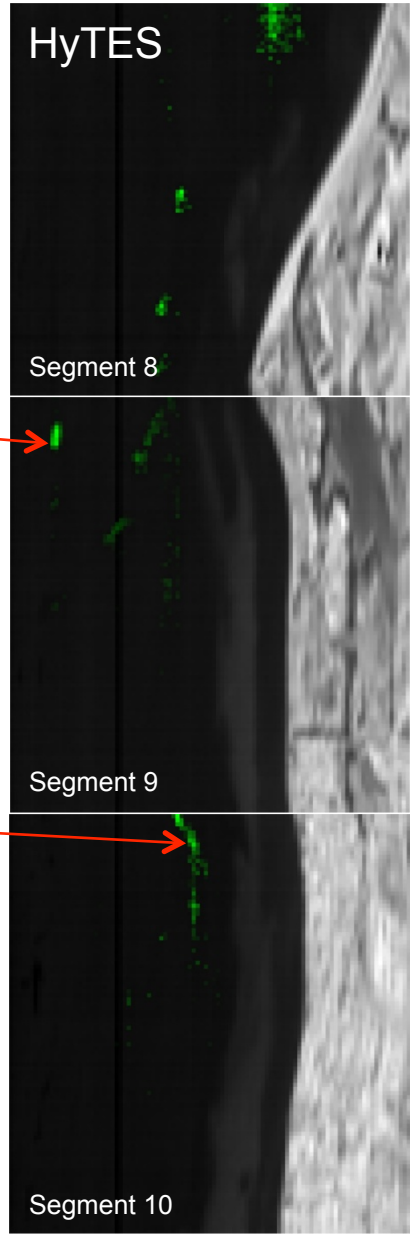


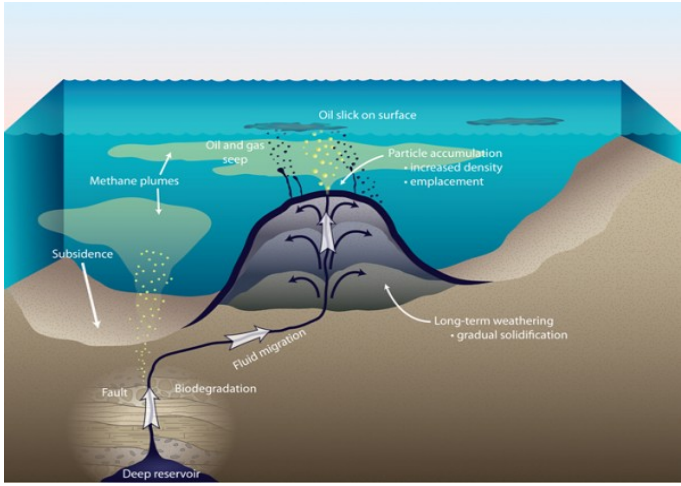


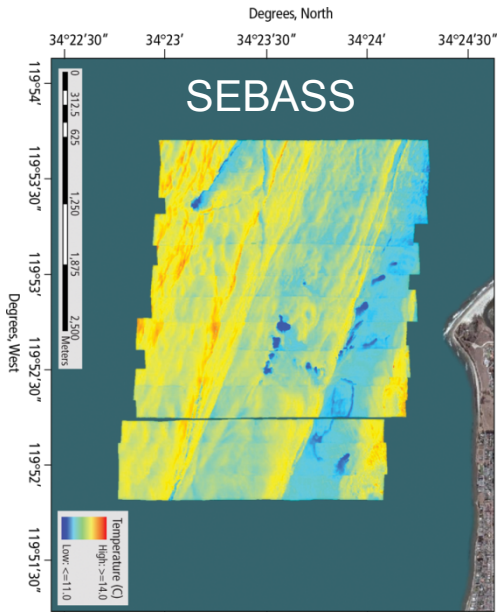
Santa Barbara: Methane

2013-04-26.205141.SantaBarbara.Line2-Run1









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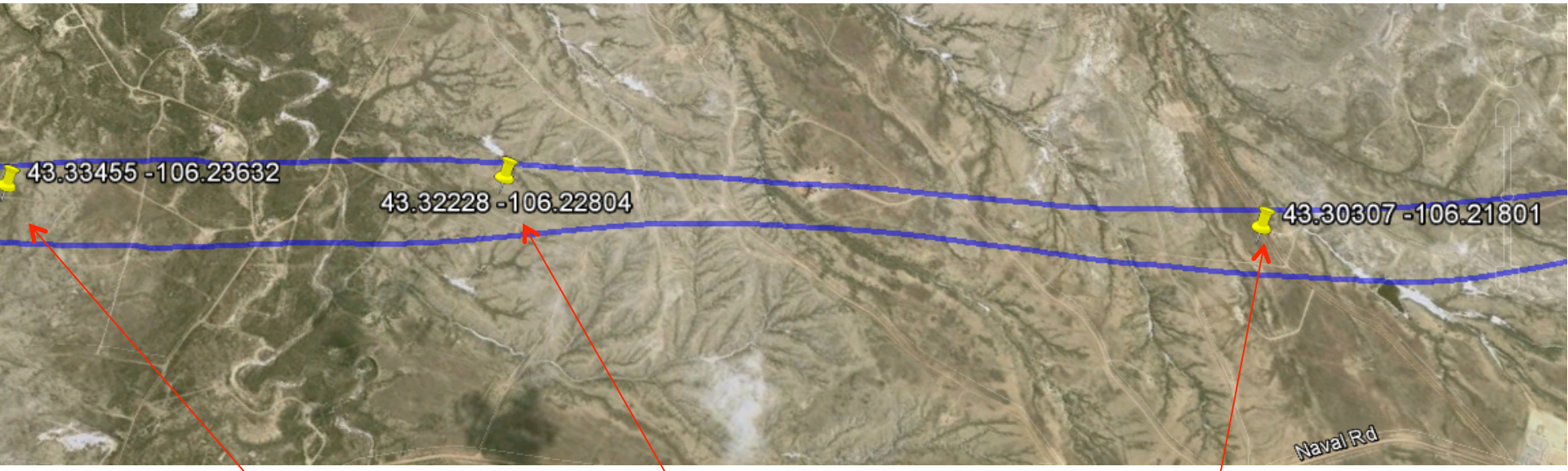
Summary

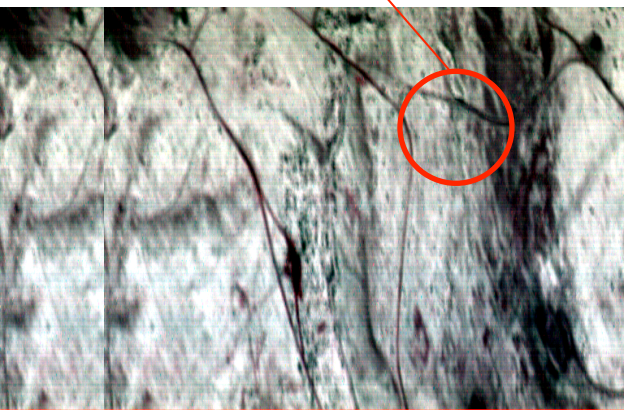
- HyTES science campaign showed promising results
  - Radiance spectral calibration
  - Emissivity retrieval validation
- Demonstrated two gas plume detection techniques using HyTES longwave infrared data (7.4-12 μm).
- Ammonia detected using radiative closure technique between 10-11 micron.
- Methane detected using clutter matched filter method between 7.5-8 micron.
- Optimum detection altitude for methane was ~2 km.

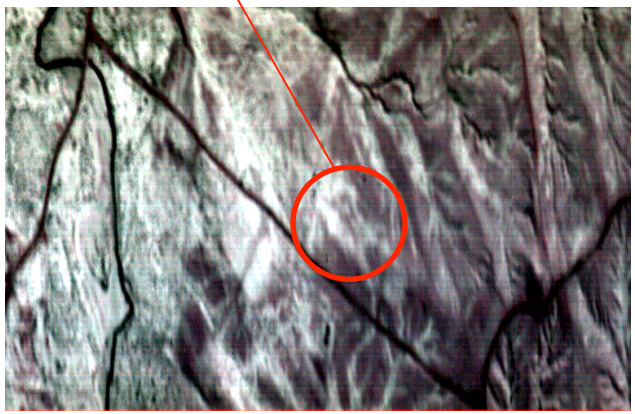
Rocky Mountain Oilfield Test Center (RMOTC) Methane Campaign

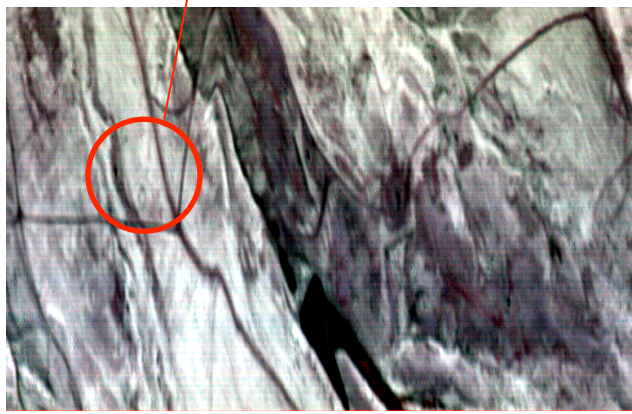
- Critical to constrain natural/anthropogenic CH4 sources
- JPL and collaborators conducted field test campaign in Casper, WY at RMOTC during June 2013
- Series of three controlled release points setup over 6 days:
  - Point source flux rates varied from 50 LPM to 2400 LPM
  - In situ measurements made from field towers (including met)
  - Small unmanned aerial system (sUAS)
- Three airborne sensors flew:
  - CARVE – Fourier Transform Spectrometer (FTS)
  - AVIRIS-ng – Imaging spectrometer (SWIR)
  - HyTES – Thermal Infrared (7.5 – 8.5 micron)

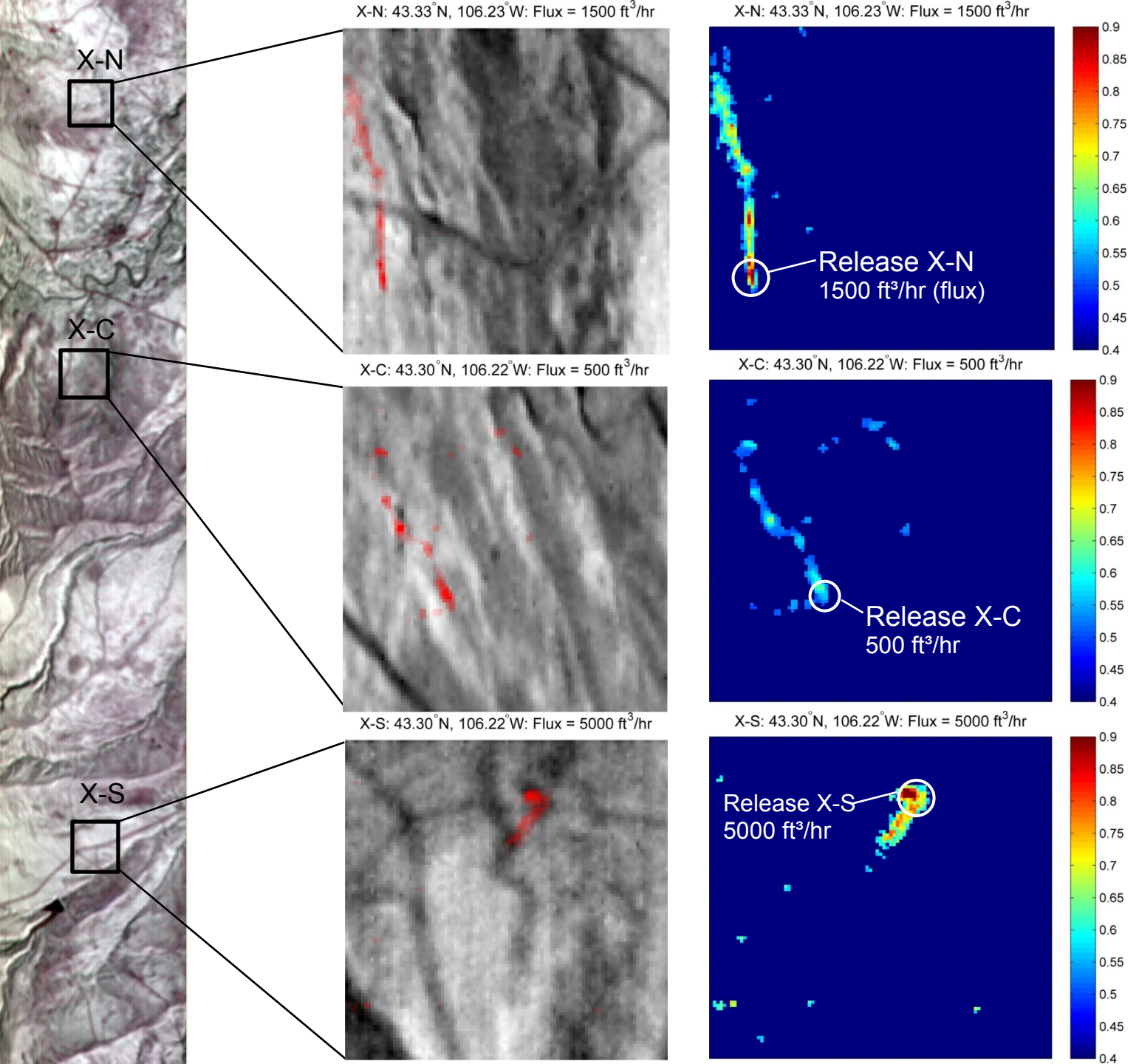
HyTES flight tracks - RMOTC









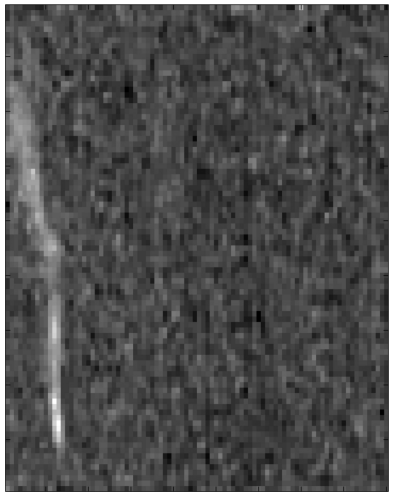


RMOTC

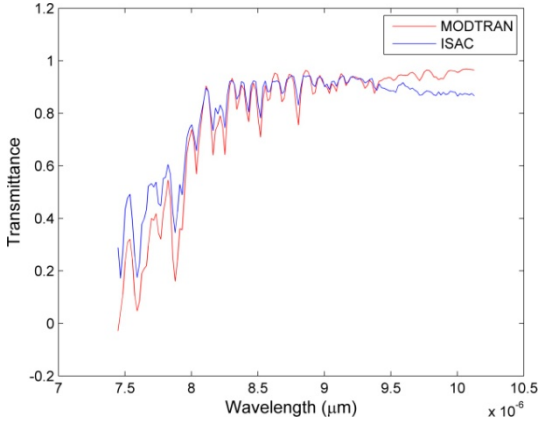
Altitude: 2000-3000 m
Resolution: ~3.5 m

Plume Concentration Retrieval

1. Plume Detection:
Covariance matrix method



2. Atmospheric Correction: ISAC
Tailored for HyTES data



3. Plume concentration retrieval:
On-plume/Off-plume least squares regression

$$L^{at-sensor-on} = \varepsilon b + x$$

$$\varepsilon = n_o \tau^{atm} [B(T^{plume}) - L^{gnd}]$$

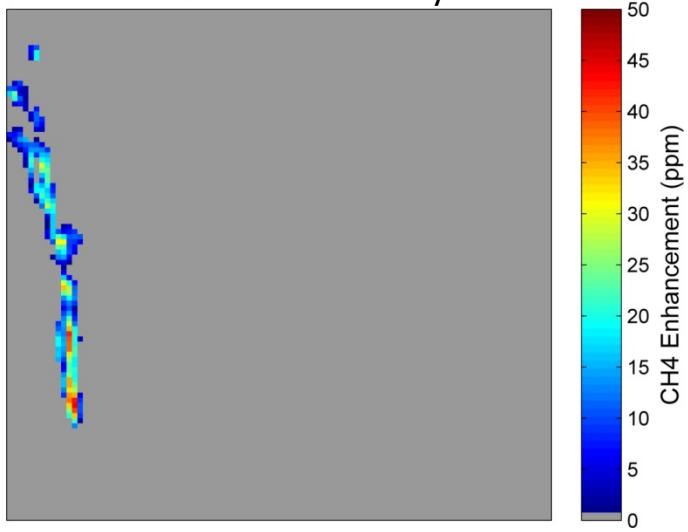
Plume 'strength'

Plume signature
(Hitran)

$$x = [L^{path} + L^{gnd} \tau^{atm}]$$

Background 'clutter'

Plume column density



HyTES Performance: RMOTC

Flux Rate ft^3/hr	Site	Day	Altitude (km)	Detection	Signal to Clutter Ratio (SCR)
100	X-S	06/24	1.9	Partial	0.45
500	X-C	06/25	2.7	Yes	0.67
1000	X-S	06/24	1.9	Yes	0.68
1500	X-N	06/24	1.9	Yes	0.67
5000	X-S	06/25	2.7	Yes	0.79