The Hyperspectral Thermal Emission Spectrometer (HyTES) - Early Results

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Simon Hook & The HyspIRI/HyTES/PHyTIR Team(s)

Organization: NASA/Jet Propulsion Laboratory

Outline

• Introduction
• Instrument design and characteristics
• Laboratory testing and results
• Airborne testing and results
• Summary and Conclusions
• Future Plans
Science Questions:

TQ1. Volcanoes/Earthquakes
- How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

TQ2. Wildfires
- What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

TQ3. Water Use and Availability
- How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

TQ4. Urbanization/Human
- How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

TQ5. Earth surface composition and change
- What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

Measurement:

- 7 bands between 7.5-12 µm and 1 band at 4 µm
- 60 m resolution, 5 days revisit
- Global land and shallow water

![Multispectral Scanner](image)

Schedule: 4 year phase A-D, 3 years operations
High Heritage

![HyspIRI-TIR Quad Chart](image)
HyspIRI, HyTES and PHyTIR

Hyperspectral Infrared Imager (HyspIRI)

VSWIR

TIR

Science Risk Reduction

Engineering Risk Reduction

Hyperspectral Thermal Emission Spectrometer (HyTES)

Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)
HyspIRI, HyTES and PHyTIR

Airborne Instruments

<table>
<thead>
<tr>
<th>Airborne Name</th>
<th>TIMS</th>
<th>MASTER</th>
<th>QWEST</th>
<th>HyTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of TIR Bands</td>
<td>6</td>
<td>10</td>
<td>56</td>
<td>256</td>
</tr>
</tbody>
</table>

Spaceborne Instruments (incl. lab prototypes)

<table>
<thead>
<tr>
<th>Spaceborne Name</th>
<th>ASTER</th>
<th>Landsat 8 (LDCM)</th>
<th>PHyTIR</th>
<th>HyspIRI-TIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>First Year of Operation</td>
<td>1999</td>
<td>2013</td>
<td>2014</td>
<td>2020</td>
</tr>
<tr>
<td>Number of TIR Bands</td>
<td>5</td>
<td>2</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Swath Width</td>
<td>60 km</td>
<td>185 km</td>
<td>600 km</td>
<td>600 km</td>
</tr>
<tr>
<td>Pixel Size</td>
<td>90m</td>
<td>100 m</td>
<td>60 m</td>
<td>60 m</td>
</tr>
</tbody>
</table>

10/10/2012
Overall Science Goal and Objective

• Provide precursor high spectral and spatial resolution thermal infrared data for the NRC Recommended HyspIRI mission and for use in Earth Science Studies.

• 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.
Hyperspectral Thermal Emission Spectrometer (HyTES)

First Science Flights in April 2013

<table>
<thead>
<tr>
<th>Instrument Characteristic</th>
<th>HyTES</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mass (Scanhead)¹</td>
<td>12kg</td>
</tr>
<tr>
<td>Power</td>
<td>400W</td>
</tr>
<tr>
<td>Volume</td>
<td>1m x 0.5m (Cylinder)</td>
</tr>
<tr>
<td>Number of pixels x track</td>
<td>512</td>
</tr>
<tr>
<td>Number of bands</td>
<td>256</td>
</tr>
<tr>
<td>Spectral Range</td>
<td>7.5-12 µm</td>
</tr>
<tr>
<td>Frame speed</td>
<td>35 or 22 fps</td>
</tr>
<tr>
<td>Integration time (1 scanline)</td>
<td>28 or 45 ms</td>
</tr>
<tr>
<td>Total Field of View</td>
<td>50 degrees</td>
</tr>
<tr>
<td>Calibration (preflight)</td>
<td>Full aperture blackbody</td>
</tr>
<tr>
<td>Detector Temperature</td>
<td>40K</td>
</tr>
<tr>
<td>Spectrometer Temperature</td>
<td>100K</td>
</tr>
<tr>
<td>Slit Length and Width</td>
<td>20 mm x 39 µm</td>
</tr>
<tr>
<td>IFOV</td>
<td>1.7066</td>
</tr>
<tr>
<td>Pixel Size/Swath at 2000 m flight altitude²</td>
<td>3.41m/1868.33m</td>
</tr>
<tr>
<td>Pixel Size/Swath at 20,000 m flight altitude²</td>
<td>34.13m/18683.31m</td>
</tr>
</tbody>
</table>

1. Does not include 1 rack of electronics to operate instruments; 2. Includes ~27 calibration pixels
Key JPL developed technologies

- Current instruments provide high spectral and low spatial OR high spatial and low spectral resolution in thermal infrared. HyTES provides BOTH high spectral and spatial resolution. New design can be made very compact.

Long, straight slits: Victor White
Compact Dyson Spectrometer: Zakos Mouroulis
Concave E-beam diffraction Grating: Dan Wilson

Advanced Designs: William Johnson

Multi-stack large format QWIP arrays: Sarath Gunapala
HyTES Optical Layout
(The entire system is cold, so there’s no real “cold stop” in the traditional fashion)
HyTES Laboratory Setup

Lab Test Procedure

• Cycle Blackbody Through Temperatures of 5, 10, 15, 20, 25, 30, 35, 40 and 45 °C
• Blackbody DN’s at 5 and 45 °C used to Calculate 2-Point Calibration Coefficients
• Calculate Radiance and Brightness Temperature for Blackbody at 25 °C.

HyTES shown with high accuracy cavity blackbody. This is the set-up used for measuring system linearity, brightness temperature and NEDT.
HyTES Temperature Linearity

Excellent linearity measured (<+/- 0.1C)

HyTES Measured Linearity

<table>
<thead>
<tr>
<th>Actual Temp (C)</th>
<th>Measured Temp (C)</th>
<th>ΔT (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>45</td>
<td>45.00</td>
<td>0</td>
</tr>
<tr>
<td>40</td>
<td>40.01</td>
<td>0.0054</td>
</tr>
<tr>
<td>35</td>
<td>34.94</td>
<td>-0.0594</td>
</tr>
<tr>
<td>30</td>
<td>29.92</td>
<td>-0.0769</td>
</tr>
<tr>
<td>25</td>
<td>24.95</td>
<td>-0.05225</td>
</tr>
<tr>
<td>20</td>
<td>19.97</td>
<td>-0.02695</td>
</tr>
<tr>
<td>15</td>
<td>14.96</td>
<td>-0.03695</td>
</tr>
<tr>
<td>10</td>
<td>10.00</td>
<td>0</td>
</tr>
</tbody>
</table>

10/10/2012
HyTES measured spectral response. A monochromator was cycled through each spectral band while positioned at the entrance aperture.
HyTES Spectral Response

Predicted spectral response

Arrow on measured response shows a FWHM of about 4 pixels (or 2 effective pixels) which is 35.2 nm.
Alignment 6

- Brightness Temperature Within 0.5 °C of 25 °C (Black-body Set Point)
- Sensitivity (NEDT, Modeled as Standard Deviation) Better than 0.2 °C Between 8.5 – 11.5 μm
- Two-Layer QWIP Detector Array
HyTES Outside Setup

Test Procedure in Direct Sunlight

- Obtain spectral calibration from downwelling radiance using diffuse gold.
- Observe mineralogical species: Quartz, Silicon Carbide
HyTIES Spectral Accuracy

HyTIES spectral calibration is very good. Wavelength determination for each features is well within one bandwidth.
HyTES Measured Spectra

Previously measured field radiance of Quartz (micro-FTIR)

HyTES radiance measurement of Ottawa sand in direct sunlight.
HyTSES Measured Spectra

Similar mineralogical species shown at different spatial locations (same temperature assumed for all spatial samples).

Excellent shape agreement.
HyTES Measured Spectra

Similar mineralogical species shown at different spatial locations (same temperature assumed for all spatial samples).

Excellent shape agreement.
HyTES Gas Measurement Set-up

- 200mm cell length
- ZnSe transmission optics with anti-reflection coatings for maximum transmission.
- All gas species are held at 50torr pressure
HyTIES Gas Measurement

CH$_4$ and SO$_2$ raw signals measured in the field and in the lab before flight.
HyTES Gas Measurement

CH$_4$ and SO$_2$ raw signal converted to transmission spectra. Absorption spectra agree with spectra in NIST and PNNL databases.
Airborne Testing

• Platform: Twin Otter
  – Flight at 2000-4000m
  – Frame rate = variable 15 to 30 FPS
  – Swath Width = 1.8km-3.6km
  – Pixel size = 2.9-5.8m

Operator has console to monitor instrument status, change frame rate, start and stop acquisition

Data are stored on removable hard drives.
HyTES Aircraft Hardware

CMIGITS

Z/I Gyro Stabilization Mount

Twin Otter Aircraft Mount

HyTES Scan head

Shipping mount
Twin Otter 300 Series with NADIR View Port

Arriving at Grand Junction
## Test Sites and Purpose

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<th>Sitename</th>
<th>Purpose</th>
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</thead>
<tbody>
<tr>
<td>La Brea Tarpits</td>
<td>Urban/Methane</td>
</tr>
<tr>
<td>Salton Sea</td>
<td>Calibration/Ammonia</td>
</tr>
<tr>
<td>Huntington Gardens</td>
<td>Ecosystems</td>
</tr>
<tr>
<td>Cuprite</td>
<td>Surface Composition</td>
</tr>
<tr>
<td>Death Valley</td>
<td>Surface Composition</td>
</tr>
<tr>
<td>Navajo Generating Station</td>
<td>Sulfur dioxide</td>
</tr>
</tbody>
</table>
First Science Campaign April 2013

• Objectives
  – Acquire data from a range of targets for evaluation in various disciplines: Solid Earth, Ecosystems, Atmospheric composition
  – Evaluate upgrades made to instrument after previous engineering campaign
  – Evaluate whether current detector has sufficient sensitivity to detect enhanced methane emissions

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<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Duration</td>
<td>7 days</td>
</tr>
<tr>
<td>Hours</td>
<td>40 hours</td>
</tr>
<tr>
<td>Area</td>
<td>Southwest USA</td>
</tr>
<tr>
<td>Aircraft</td>
<td>Twin Otter (Commercial) – Grand Junction Co</td>
</tr>
</tbody>
</table>
April 2013 Campaign Snapshots

Cuprite, NV

NASA/JPL, CA

Geology

Death Valley, CA

Santa Barbara, CA

Geology

Lake Tahoe, CA/NV

La Brea, CA

Calibration

bands 150 (10.08 µm), 100 (9.17 µm), 58 (8.41 µm), 58 displayed at RGB each image is 485 x 512 pixels
HyTES has two coolers, one controls the focal plane the other controls the optics. In 2012 there was significant striping due problems controlling the temperature of the focal plane. This was addressed by upgrading the coolers (adding cooling jackets) and adding an additional chiller so each cooler had its own chiller.
HyTES Spectra: Death Valley, CA

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

- Single-pixel retrievals
- Atmospheric correction – MODTRAN and NCEP profiles
- Retrieval - Online/Offline
HyTES Spectra: Cuprite, NV

Key:
A – Kaolinite
B – Carbonate
C – Alunite
D – Quartz
HyTES Calibration: Salton Sea, CA

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

- Retrieved surface temperature = 300.1 K
- Measured surface temperature = 299.7 K
- ASTER spectral library saltwater spectrum used
- Mean spectra from one scan line

RMSE= 0.19 K

RMSE= 0.31 K
Ammonia emitted from an active fumarole group exposed on a sandbar at the shoreline of the Salton Sea mud bank region.
Ammonia Plume Detection: Salton Sea

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 Detection: Santa Barbara

2013-04-26.205141.SantaBarbara.Line2-Run1

Methane positive detection (green) using HyTES band 38 (8.128 µm) overlayed on Tskin map (gray)

Google image at left and Hytes images not to scale.
Current Status

• HyTES completed its First Science Campaign on April 30th, 2013
• The 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 engineering flights, e.g. improved calibration
• Data processing and analysis has begun. Results indicate can now retrieve excellent spectra from geological targets and gas targets: methane, ammonia
• Find out more at http://hytes.jpl.nasa.gov