HyspIRI

VSWIR Science Measurement Baseline

NASA Earth Science and Applications Decadal Survey

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NRC Decadal Survey - HyspIRI

Global vegetation species-type and physiological condition, including agricultural lands, for biosphere feedback and land-atmosphere interactions; Spectroscopically derived terrestrial land cover composition/albedo including snow, ice, dust climate interaction; Fire: fuel, occurrence, intensity and recovery globally, as well as volcano emissions; Fine spatial & temporal scale measures of surface temperature and energy balance, including urban heat Islands.

Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

Multispectral Thermal InfraRed (TIR) Scanner

Map of dominant tree species, Bartlett Forest, NH

Soil C:N Ratio

White Mountain National Forest, NH
HyspIRI - Imaging Spectroscopy (VSWIR) Science Measurements

VQ1. Pattern and Spatial Distribution of Ecosystems and their Components
- What is the pattern of ecosystem distribution and how do ecosystems differ in their composition or biodiversity?

VQ2. Ecosystem Function, Physiology and Seasonal Activity
- What are the seasonal expressions and cycles for terrestrial and aquatic ecosystems, functional groups and diagnostic species? How are these being altered by changes in climate, land use, and disturbances?

VQ3. Biogeochemical Cycles
- How are biogeochemical cycles for carbon, water and nutrients being altered by natural and human-induced environmental changes?

VQ4. Changes in Disturbance Activity
- How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

VQ5. Ecosystem and Human Health
- How do changes in ecosystem composition and function affect human health, resource use, and resource management?

VQ6. Land Surface and Shallow Water Substrate Composition
- What is the land surface soil/rock and shallow water substrate composition?

Measurement:
- 380 to 2500 nm at 10 nm
- Accurate 60 m resolution
- 19 days equatorial revisit
- Global land and shallow water

Map of dominant tree species, Bartlett Forest, NH

Map of dominant tree species, Bartlett Forest, NH

Imaging spectrometer: 55kg / 41W

Schedule: 4 year phase A-D, 3 years operations (5 years consumables)

Full terrestrial coverage downlinked every 19 days

Mature Instrument concept: All components have flown in space.

Soil C:N Ratio
White Mountain National Forest, NH

Map of dominant tree species, Bartlett Forest, NH
Plant functional types and species have biochemical and biophysical properties that are expressed as reflectance absorption and scattering features spanning the spectral region from 380 to 2500 nm.

Individual bands do not capture the diversity of biochemical and biophysical signatures of plant functional types, species or physiological condition.

Changes in the chemical and physical configuration of ecosystems are expressed as changes in the contiguous spectral signatures related to plant functional types, physiological condition, vegetation health, and species distribution.

Important atmospheric correction information as well as calibration feedback is contained within the spectral measurement.
Vegetation Functional Type Analysis, Santa Barbara, CA

Dar Roberts, et al, UCSB

MESMA Species Type 90% accurate

Species Fractional Cover

Adenostoma fasciculatum
Ceanothus megacarpus
Arctostaphylos spp.
Quercus agrifolia
Grass
Soil

Santa Barbara
Pacific Ocean
Example Measurement of Plant Biochemistry with Imaging Spectroscopy (Ray Kokaly, USGS)

AVIRIS Coverage

Spectral Composition Map

Lignin-Cellulose Laboratory

Lignin-Cellulose AVIRIS

Laboratory spectrum lignin: cellulose 0.26

Laboratory spectrum lignin: cellulose 0.60

AVIRIS spectrum low lignin: cellulose

AVIRIS spectrum high lignin: cellulose
Ecosystem physiological conditions

Imaging spectroscopy measurements are required to measure the physiological condition (PC) of ecosystems for the global terrestrial biosphere to provide understanding and constraint of uncertainties in the climate change.

- Detect and quantify changes in biogeochemical cycles and processes (PC)
- Map and monitor productivity changes (PC) at seasonal and spatial scales relevant for policy decisions.
- Reduce uncertainties in ecosystem feedbacks from multiple stressors (T, precip., CO₂, N deposition, etc.) to improve prediction of future ecosystem condition (PC).

Predicted Foliar Chemistry (PC) from Spectroscopy Is Used to Estimate Soil Nitrogen Cycling

Reflectance spectrum are used to quantify biophysiological conditions

Ollinger et al. 2002
FT Map
Shenandoah National Park, USA
Phil Townsend, U. of Wisc.
HyspIRI VSWIR – Science Measurement Characteristics

Spectral
Radiometric
Spatial
Uniformity
Temporal
HyspIRI VSWIR Science Measurements

• Measure the **global** land and coastal/shallow water (> -50m).
• 19 day equatorial revisit to generate seasonal and annual products.
• Full terrestrial and shallow water data set returned.

• Measure the molecular absorption and constituent scattering signatures in the spectral range from 380 to 2500 nm at 10 nm, and at 60 m spatial sampling.
<table>
<thead>
<tr>
<th><strong>Spectral</strong></th>
<th><strong>Radiometric</strong></th>
<th><strong>Spatial</strong></th>
<th><strong>Uniformity</strong></th>
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</thead>
<tbody>
<tr>
<td>Range</td>
<td>Range &amp; Sampling</td>
<td>Range</td>
<td>Spectral Cross-Track</td>
</tr>
<tr>
<td></td>
<td>380 to 2500 nm in the solar reflected spectrum</td>
<td>0 to 1.5 x max benchmark radiance, 14 bits measured</td>
<td>&gt;95% cross-track uniformity {&lt;0.5 nm min-max over swath}</td>
</tr>
<tr>
<td>Sampling</td>
<td>0 to 1.5 x max benchmark radiance, 14 bits measured</td>
<td>&gt;150 km</td>
<td>&gt;95% spectral IFOV uniformity {&lt;5% variation over spectral range}</td>
</tr>
<tr>
<td>Response</td>
<td>&lt;= 10 nm (uniform over range)</td>
<td>&gt;2500</td>
<td></td>
</tr>
<tr>
<td>Accuracy</td>
<td>&lt;= 1.2 X sampling (FWHM) (uniform over range)</td>
<td>&lt;=60 m</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;0.5 nm</td>
<td>&lt;=1.2 X sampling (FWHM)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;99% characterized to 0.1%</td>
<td>&gt;150 km</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;95% absolute radiometric, 98% on-orbit reflectance, 99.5% stability</td>
<td>&lt;=60 m</td>
<td></td>
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<tr>
<td></td>
<td>&gt;95% cross-track uniformity {&lt;0.5 nm min-max over swath}</td>
<td>&lt;=1.2 X sampling (FWHM)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;95% spectral IFOV uniformity {&lt;5% variation over spectral range}</td>
<td>&lt;=1.2 X sampling (FWHM)</td>
<td></td>
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</table>
HyspIRI VSWIR Science Measurements Characteristics

Temporal
- Orbit Crossing: 10:30 am sun synchronous descending
- Global Land Coast Repeat: 19 days at equator
- Rapid Response Revisit: 3 days (cross-track pointing)

Sunglint Reduction
- Cross Track Pointing: 4 degrees in backscatter direction

OnOrbit Calibration
- Lunar View: 1 per month {radiometric}
- Solar Cover Views: 1 per day {radiometric}
- Dark signal measurements: 1 per orbit and edge detector tracking
- Surface Cal Experiments: 3 per year {spectral & radiometric}

Data Collection
- Land Coverage: Land surface above sea level excluding ice sheets
- Water Coverage: Coastal zone -50 m and shallower
- Solar Elevation: 20 degrees or greater
- Open Ocean/Ice Sheets: Averaged to 1km spatial sampling
- Compression: >=3.0 lossless
HyspIRI VSWIR Science Measurements
Key SNR and Uniformity Requirements

Benchmark Radiances

Required SNR

Uniformity Requirement

Depiction
- Grids are the detectors
- Dots are the IFOV centers
- Colors are the wavelengths

Requirement
Spectral Cross-Track  >95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation >95% spectral IFOV uniformity {<5% variation over spectral range}
Heritage: NASA Moon Mineralogy Mapper

Passed Preship review 3 May 2007
- Mouroulis Offner Design (HyspIRI)
- Convex e-beam grating (HyspIRI)
- 6604a MCT full range detector array, multiplexor & signal chain (HyspIRI)
- Uniform slit (HyspIRI)
- 0.5 micron adjustment mounts lockable for flight
- Aligned to 95% cross-track uniformity (HyspIRI)
- Aligned to 95% spectral IFOV uniformity (HyspIRI)
- Meets high SNR requirements (HyspIRI)
- Passive radiator (HyspIRI)

M3 Spectrometer

Mass 8 kg, Power 15 Watts

Cross-track uniformity > 95%

First spectrum 18 Months from funding start
HyspIRI: Building on NASA Hyperion Technology Demonstration

**SNR > 10X**

**Uniformity > 10X**

**Swath > 10X**

**Soil C:N Ratio**

*White Mountain National Forest, NH*

**Global Coverage >> 10X**

**Cross Track Sample**
HyspIRI: A Decadal Survey **Global**
Mapping Mission (VSWIR)

- Full Spectrum 380 to 2500 at 10 nm
- 60 m spatial with 150 km swath
- Full terrestrial surface downlinked every 19 days

Oceans and ice sheets at 1 km

**VSWIR coverage map**
**HyspIRI compared with possible International Imaging Spectroscopy Missions**

Only HyspIRI provides the full spectrum of data required to address climate-carbon cycle feedbacks articulated in the NRC Decadal Survey.

HyspIRI Provides Seasonal and Annual Global Coverage that Uniquely Addresses Critical Gaps in Climate Research and Ecosystem Understanding.

> 100 years for international mission to equal 1 year of HyspIRI

<table>
<thead>
<tr>
<th>Country</th>
<th>Instrument</th>
<th>Swath km</th>
<th>Pixel Size, m</th>
<th>Terrestrial Coverage in 19 days</th>
<th>Repeat Interval, days</th>
<th>TIR Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>HyspIRI</td>
<td>150</td>
<td>60</td>
<td>100%</td>
<td>19</td>
<td>8 TIR bands</td>
</tr>
<tr>
<td>Germany</td>
<td>EnMAP</td>
<td>30</td>
<td>30</td>
<td>&lt;1%</td>
<td>--</td>
<td>NO</td>
</tr>
<tr>
<td>Italy</td>
<td>PRISMA</td>
<td>30-60</td>
<td>20-30</td>
<td>&lt;1%</td>
<td>--</td>
<td>NO</td>
</tr>
<tr>
<td>Japan?</td>
<td>ALOS3</td>
<td>30</td>
<td>30</td>
<td>&lt;1%</td>
<td>--</td>
<td>NO</td>
</tr>
<tr>
<td>India?</td>
<td>IMS Resource Sat-3</td>
<td>25</td>
<td>25</td>
<td>&lt;1%</td>
<td>--</td>
<td>1 TIR band</td>
</tr>
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**US, HyspIRI:** a full spectral range (380 to 2500 at 10 nm), high SNR, uniform, 60m spatial with 150 km swath imaging spectrometer and multiband thermal imager (8 band thermal imager from 3-12 μm).

Other countries are occasionally mentioned (China, South Africa, South Korea, etc.). All are proposing first generation small sample process/application missions with scattered terrestrial coverage and no TIR imager.
• Example of study for snow and ice science in the Himalaya with EO1-Hyperion
  – Coverage is a severe limitation of regional and global climate investigations.

• HysPIRI would measure the full area every 19 days returning all the data
The National Research Council of the United States National Academies released the Decadal Survey: Earth Science and Applications from Space that included a global mapping imaging spectrometer as part of the HyspIRI Mission.

The NASA designated HyspIRI Science Study Group developed a set of science questions to address the call of the Decadal Survey including critical climate measurements.

From these science question as set of Science Traceability Matrixes were development with corresponding science measurement requirements.

A VSWIR imaging spectrometer instrument concept was developed to meet these science measurement requirements and provide a high heritage and low risk concept for acquiring the HyspIRI VSWIR science measurements.

The science measurement characteristics of the HyspIRI VSWIR instrument have been described in terms of: Spectral, Radiometric, Spatial, Uniformity, Temporal

The HyspIRI VSWIR science requires full coverage of the terrestrial and coastal areas at a 19 revisit to address key elements of the Decadal Survey science including critical climate measurements of the terrestrial biosphere.
Backup
Payload

Science Instruments:
- VSWIR: Imaging Spectrometer
  - 380-2500 nm in 10 nm bands
  - 60m spatial resolution
  - Day-side (23% duty cycle)
  - 55 Kg, 41 W
- TIR: Thermal Infrared Scanner
  - 8 bands between 3-12 µm
  - 60m spatial resolution
  - Day and night-side (100% duty cycle)
  - 60 Kg, 103 W

Intelligent Payload Module (IPM)
- 24/7 Direct Broadcast capability
- subset of science data
- X-band @ 20 Mbps
- 11 Kg, 86 W

Mission Architecture
- Orbit: 626 km Sun-Synchronous, 10:30am LTDN
- Repeat: 19 day VSWIR / 5 day TIR
- Downlink: Contacts nearly every orbit to Svalbard (North) and Troll (Antarctica)
- Science Data: 5.7 Tbits/day
- Launch Vehicle: Taurus 3210, 2m fairing, 790 kg capability

Spacecraft
- Launch Mass: 687 kg, JPL DP Margin: 30%
- Required Power: 680W, 7.1 m² array (965 W capability)
- P/L Data Rate: 384 Mbps
- Downlink Data Rate: 800 Mbps Dual-pol X-band
- Stabilization: 3-axis
- Pointing: Control = 720 arcsec (per axis 3σ)
  - Knowledge = 2 arcsec (Pitch/Yaw axis 3σ);
  - 8 arcsec (Roll axis 3σ)
  - Stability = 5 arcsec/sec (per axis 3σ)

Implementation
- Launch Date: ≥ 2016
- Lifetime: 3 years, with consumables for 5
- Cost Category: Low Cost Decadal Survey
- Partners: JPL, GSFC
- Mission Class: C, with selected redundancy
- Hardware Model: Protoflight

No new technology required
Heritage: M3 NASA Imaging Spectrometer

M3 Installed on ISRO Chandraayan-1 spacecraft, Launched 22 Oct 2008
- First light in lunar orbit 19 Nov 2008
M³
First Spectral Light
19 Nov 2008
Image of Earth from the Moon acquired by the NASA Discovery Moon Mineralogy Mapper (M3) that is a guest instrument onboard the ISRO Chandrayaan-1 Mission to the Moon. Australia is visible in the lower center of the image. The image is presented as a false color composite with oceans dark blue, clouds white, and vegetation enhanced green. The data were acquired on the 22\textsuperscript{nd} of July 2009.
M³ On-Orbit Spectral

Projected IFOV: 269 km
Cross-track samples: 47