Overview of the HyspIRI VSWIR Science Measurement Characteristics

NASA Decadal Survey HyspIRI Mission

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2008 HsypIRI Science Study Group

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Overview

• The Decadal Survey Call for HyspIRI
• Mission Concept Study
• Organization and 2008 Science Study Group
• PPFT-VSWIR Science Questions
  ‒ Select examples
• PPFT-VSWIR Science Measurements
• Summary
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer + Multispectral Thermal InfraRed (TIR) Scanner

VSWIR: Plant Physiology and Function Types (PPFT)

Map of dominant tree species, Bartlett Forest, NH

Red tide algal bloom in Monterey Bay, CA
HyspIRI Imaging Spectroscopy (VSWIR)  
Science Measurements

Science Questions:
- What is the composition, function, and health of land and water ecosystems?
- How are these ecosystems being altered by human activities and natural causes?
- How do these changes affect fundamental ecosystem processes upon which life on Earth depends?

Measurement:
- 380 to 2500 nm in 10nm bands
- Accurate location 60m spatial
- 19 days revisit
- Global land and shallow water

Aquatic

Terrestrial

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The Decadal Survey Call for HyspIRI
In its Decadal Survey Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, the National Research Council of the National Academies recommended a satellite mission to produce global observations of multiple Earth surface attributes for a variety of terrestrial and aquatic studies, the management of terrestrial and coastal natural resources, and forecasting ecological changes and natural hazards.

Currently known as HysPIRI, this mission is in the conceptual design phase at NASA. It consists of an imaging spectrometer in the visible to shortwave infrared (VSWIR) regions of the electromagnetic spectrum and a multispectral imager in the thermal infrared (TIR) portion of the electromagnetic spectrum.
Mission Concept Study Focus
In 2007 two mission concept studies were completed. One focused on plant physiology and functional type (PPFT) the required the science measurements of the VSWIR imaging spectrometer. The other focused on surface temperature and emissivity and atmospheric science traced to multispectral measurements of the thermal infrared (TIR).

**Urgency and Focus**

Three fundamental components required for understanding ecosystems are: function, composition, and structure. This mission for the first time provides global measurements of ecosystem function with vastly improved measures of composition including biodiversity.

This mission provides the surface temperature and emissivity of the Earth at high spatial and high temporal resolution that will be used to address key science questions in five research areas: volcanoes, wildfires, water use and availability, urbanization, land surface composition and change.

**A 2008 Science Measurement and Mission update and refinement activity is underway. This workshop is part of this 2008 activity.**
Organization and
2008 Science Study Group
The HyspIRI Working Group (HWG) will be managed by the HyspIRI Steering Committee that representatives of the principal HyspIRI science disciplines. The HWG will coordinate the activities of the Science Study Group, the Partnership Coordination Group and the Mission Design Group.
HyspiRI VSWIR - PPFT
Science Questions
VSWIR Overarching Science Questions

1. Pattern and Spatial Distribution of Ecosystems and their Components, (EM,JG)
   - What is the pattern of ecosystem distribution and how do ecosystems differ in their composition or biodiversity? [DS 195]

2. Ecosystem Function, Physiology and Seasonal Activity, (EM,JG)
   - 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? [DS 191, 195, 203]

3. Biogeochemical Cycles (SO, SU)
   - How are biogeochemical cycles for carbon, water and nutrients being altered by natural and human-induced environmental changes?

4. Changes in Disturbance Activity (RK,GA)
   - How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

5. Ecosystem and Human Health, (PT,GG)
   - How do changes in ecosystem composition and function affect human health, resource use, and resource management?

6. Earth Surface and Shallow Water Substrate Composition (RG, HD)
   - What is the land surface soil/rock and shallow water substrate composition?
Science
Spectroscopy and Photosynthesis

6H₂O + 6CO₂ + photon ⇒ C₆O₆H₁₂ + 6O₂
Vegetation presents different spectral signatures as a function of species-type, biogeochemistry, phenology and health. The full available spectrum is required given the diversity of vegetation composition and status across the globe.
Vegetation Functional Type Analysis, Santa Barbara, CA

Dar Roberts, et al, UCSB

MESMA Species Type 90% accurate

Species Fractional Cover
Phytoplankton groups have different pigment suites that give them unique spectral “fingerprints” that can be used to measure their presence and to understand their roles in aquatic ecosystems.
The Complete PPFT Data Stream for Ecosystem Composition, Function and Health

Invasive Species in the Hawaiian Rainforest from Airborne Imaging Spectrometer data: Patterns of Invasion and Biogeochemical Consequences

Myrica infestations

Canopy water content

Leaf nitrogen concentration

Fractional material cover

Canopy Modeling

Radiative Transfer

Biochemical Fingerprinting

Invasive species and nitrogen-fixing PFT

Soil nitrogen trace gas emissions

Asner and Vitousek, PNAS
Hall and Asner, GCB
Science Questions
Response to Disturbance

Imaging spectroscopy is used to measure the functional types and fractions in a coastal coral ecosystem in order to ascertain the impacts of nutrients on habitat composition.

Airborne imaging spectroscopy measurements of coral reef ecosystem, Hawaii.
Mineral Spectra in the Solar Reflected Spectrum

- Muscovite $K_2A_4[Si_6Al_2O_{20}](OH)_4$  
- Montmorillonite $(Na, Ca)_{0.33}(Al, Mg)_2Si_4O_{10}(OH)_2*nH_2O$
- Alunite $KAl_3(SO_4)_2(OH)_6$
- Kaolinite $Al_4[Si_4O_{10}](OH)_8$
- Gypsum $CaSO_4.2H_2O$
- Goethite $FeO(OH)$
- Jarosite $NaFe^{3+}_3(SO_4)_2(OH)_6$
- Dolomite $CaMg(CO_3)_2$
- Calcite $CaCO_3$
- Hematite $Fe_2O_3$
Plant and phytoplankton functional types and species have biochemical and biophysical properties that are expressed as reflectance and absorption 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 or species.

Changes in the chemical and physical configuration of ecosystems are often expressed as changes in the contiguous spectral signatures that relate directly to plant functional types, vegetation health, and species distribution.

Important atmospheric correction information and calibration feedback is contained within the spectral measurement.
HyspIRI Science Measurements
- VSWIR (aka PPFT)
HyspIRI Imaging Spectroscopy
Science Measurements

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HyspIRI VSWIR
Science Measurements

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

- 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.
HyspIRI VSWIR
Science Measurement Characteristics

Spectral
Range
Sampling <= 10 nm {uniform over range}
Response <= 10 nm (full-width-at-half-maximum) {uniform over range}
Accuracy <0.5 nm

Radiometric
Range & Sampling 0 to 1.5 X max benchmark radiance, 14 bits measured
Accuracy >95% absolute radiometric, 98% on-orbit reflectance, 99.5% stability
Precision (SNR) See spectral plots at benchmark radiances
Linearity >99% characterized to 0.1 %
Polarization <2% sensitivity, characterized to 0.5 %
Scattered Light <1:200 characterized to 0.1%

Spatial
Range >145 km (12 degrees at ~700 km altitude)
Cross-Track Samples >2400
Sampling <=60 m
Response <=60 m sampling (FWHM)

Uniformity
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}
Temporal

- Orbit Crossing: 11 am sun synchronous descending
- Global Land Coast Repeat: 19 days at equator
- Rapid Response Revisit: 3 days (cross-track pointing)

Sunglint Avoidance

- Cross Track Pointing: 4 degrees in backscatter direction

OnOrbit Calibration

- Lunar View: 1 per month {radiometric}
- Solar Cover Views: 1 per week {radiometric}
- 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: Averaged to 1km spatial sampling
- Compression: >=3.0 lossless
HyspIRI VSWIR Science Measurements
Key SNR and Uniformity Requirements

Benchmark Radiiances

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}
Mission Concept
Heritage: NASA Moon Mineralogy Mapper (M3)
Called for in the NRC Decadal Survey

M3 Spectrometer
Passed Preship review 3 May 2007
- Mouroulis Offner Design (PPFT)
- Convex e-beam grating (PPFT)
- 6604a MCT full range detector array, multiplexor & signal chain (PPFT)
- Uniform slit (PPFT)
- 0.5 micron adjustment mounts lockable for flight
- Aligned to 95% cross-track uniformity (PPFT)
- Aligned to 95% spectral IFOV uniformity (PPFT)
- Meets high SNR requirements (PPFT)
- Passive radiator (PPFT)

Mass 8 kg, Power 15 Watts

Cross-track uniformity > 95%

First spectrum 18 Months from funding start
M3 NASA Imaging Spectrometer

- Launch scheduled
- 22 Oct 2008 (21st 5:52pm)
- http://Isro.gov.in
- M3 Installed on spacecraft
Building on NASA Hyperion Technology Demonstration

**SNR > 10X**

![Graph showing SNR vs Wavelength](image)

**Uniformity > 10X**

![Color map showing uniformity](image)

**Swath > 10X**

**Soil C:N Ratio**

![Map of White Mountain National Forest, NH](image)

**Global Coverage >> 10X**

![Map showing global coverage](image)
Summary
Summary – HyspIRI VSWIR

This mission provides the measurement to answer the PPFT (VSWIR imaging spectrometer) and Multispectral TIR NASA Mission Concept Studies.

The science, measurements, and algorithms enabling this mission have been consistently demonstrated with antecedent airborne and ground measurements and experiments.

This HyspIRI mission addresses a set of compelling science questions that have been repeatedly identified as critical to science and society by independent assessments and scientific panels. Recent examples include: the NRC Decadal Survey, the 4th assessment of the IPCC and the U.S. Climate Change Science Program.

The HyspIRI instruments and mission have high relevant heritage, and correspondingly low risk, in conjunction with a modest cost.
Key Thoughts

The HyspIRI Imaging Spectrometer = PPFT = VSWIR

The temporal repeat for the VSWIR at the equator is 19 days

The baseline requirements are closely tied to the Decadal Survey and vetted with two years of science study groups.
   - Requirement growth is to be avoided.
   - Requirement clarification is good.

Objectives of the VSWIR breakout sessions:
   - Refine, strengthen and prioritize the science questions.
   - Assure the science questions are clearly answerable with the VSWIR science measurements.
   - Bring the Science Traceability Matrices forward from current 1st draft
HyspIRI Imaging Spectroscopy
Science Measurements

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NRC Decadal Survey HyspIRI

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VSWIR: Plant Physiology and Function Types (PPFT)

Multispectral TIR Scanner

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