Overview of the HyspIRI Mission Concept, Measurements and Science

A Global Coverage VSWIR and TIR Mission

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Center Leads - Robert O. Green, Simon Hook and Betsy Middleton

1Jet Propulsion Laboratory, California Institute of Technology

2Goddard Space Flight Center

Overview

- 2007 Decadal HyspIRI Mission Concept
- Refinement of science with Science Study Group
- Implementation options
  - Original combined
  - ISS options
  - Separate free flyers
  - Latest combined
- High Level overview of latest instrumentation options and product maturity
  - VSWIR and L1 and L2
  - TIR and L1 and L2
  - IPM real time and higher products
- Inputs to the 2017 Decadal
- Summary and Discussion
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.
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<tr>
<th>Name</th>
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<tr>
<td>Mike Abrams</td>
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<td>Lamont-Doherty</td>
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<td>John Mars</td>
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<td>Scott Ollinger</td>
<td>University of New Hampshire</td>
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<tr>
<td>Thomas Painter</td>
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<tr>
<td>Anupma Prakash</td>
<td>University of Alaska, Fairbanks</td>
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<tr>
<td>Dale Quattrochi</td>
<td>Marshall Space Flight Center</td>
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<td>Michael Ramsey</td>
<td>University of Pittsburg</td>
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<tr>
<td>Vince Realmuto</td>
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<tr>
<td>Dar Roberts</td>
<td>University of California, Santa Barbara</td>
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<tr>
<td>Susan Ustin</td>
<td>University of California, Davis</td>
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<tr>
<td>Rob Wright</td>
<td>University of Hawaii</td>
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</tbody>
</table>

*2016 membership*
VQ1. Pattern and Spatial Distribution of Ecosystems and their Components
What is the global spatial pattern of ecosystems and diversity distributions 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 disturbance?

VQ3. Biogeochemical Cycles
How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems, and what are the feedbacks with other components of the Earth system?

VQ4. Changes in and Responses to Disturbance
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. Earth Surface and Shallow-Water Benthic Composition
What is the current land surface soil/rock/cryosphere and shallow-water benthic compositions?
TQ1. Volcanoes and 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 Health
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 thermal property of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?
CQ1. Coastal, ocean, and inland aquatic environments
What is the status of inland and coastal aquatic ecosystems in the context of local and regional thermal climate, land-use change, and other environmental factors?

CQ2. Wildfires
How are fires and vegetation composition coupled?

CQ3. Volcanoes
Do volcanoes signal impending eruptions through changes in the temperature of the ground, rates of gas and aerosol emission, temperature and composition of crater lakes, or health and extent of vegetation cover?

CQ4. Ecosystem Function and Diversity
How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?

CQ5. Earth surface composition and change
What is the composition of exposed terrestrial surface of the Earth and how does it respond to anthropogenic and non anthropogenic drivers?

CQ6 Human Health and Urbanization
How do patterns of human environmental and infectious diseases respond to leading environmental changes, particularly to urban growth and change and the associated impacts of urbanization?
<table>
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<th>QID</th>
<th>Science Objectives</th>
<th>Data Products</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>VQ1</td>
<td>Spatial and Temporal Distribution of Ecosystems and their Components: What is the global spatial pattern of ecosystem distribution and variation in its composition or biodiversity (EIS 115)</td>
<td>Measure at least seasonally through several (10) years to observe baseline and new hazards and changes in traceability matrices.</td>
<td>Measurement of Traceability Matrices (MTM)</td>
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</table>
Level 1 Requirements

Draft Preliminary

**HvspIRI**

Visible to Short Wavelength Infrared Imaging Spectrometer and Thermal Infrared Imager (HvspIRI) Decadal Survey Earth Science and Applications Mission

**Level 1 Requirements and Mission Success Criteria**

Version X-8.0
Date: |

Owner: NASA Decadal Survey HvspIRI Program Executive and Program Scientist
# Key Preliminary Draft Level 1 Requirements*

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Threshold (Mission Success)</th>
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<tbody>
<tr>
<td><strong>VSWIR:</strong> 380 to 2500 nm at ≤10 nm sampling at the specified signal-to-noise ratio and accuracy with &gt;95% spectral/spatial uniformity at ≤30 m nadir spatial sampling with &lt;16 day revisit to provide</td>
<td>VSWIR: 380 to 2500 nm at ≤10 nm sampling at &gt;80% of the specified signal-to-noise ratio and accuracy with &gt;90% spectral/spatial uniformity at ≤30 m nadir spatial sampling with &lt;16 day revisit to provide</td>
</tr>
<tr>
<td><strong>VSWIR:</strong> &gt;60% seasonal and &gt;80% annual coverage of the terrestrial and shallow water regions of the Earth</td>
<td>VSWIR: &gt;50% seasonal and &gt;70% annual coverage of the terrestrial and shallow water regions of the Earth</td>
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<tr>
<td>three years with a subset of measurements available near-real-time for designated science and applications.</td>
<td>two years.</td>
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<tr>
<td><strong>TIR:</strong> 8 spectral bands from the 3-5 micron and 8-12 micron regions of the spectrum at the specified noise-equivalent-delta-temperature and accuracy at ≤60 m nadir spatial sampling with ≤5 day revisit</td>
<td>TIR: 8 spectral bands from the 3-5 micron and 8-12 micron regions of the spectrum at &gt;80% the specified noise-equivalent-delta-temperature and accuracy at ≤60 m nadir spatial sampling with ≤5 day revisit</td>
</tr>
<tr>
<td><strong>TIR:</strong> &gt;60% Monthly, &gt;70% seasonal and &gt;85% annual coverage of the terrestrial and shallow water regions of the Earth</td>
<td>TIR: &gt;40% Monthly, &gt;60% seasonal and &gt;70% annual coverage of the terrestrial and shallow water regions of the Earth</td>
</tr>
</tbody>
</table>

*30 m, 16 Day VSWIR*
HyspIRI Measurements

- Global terrestrial and coastal VSWIR spectroscopy and multispectral TIR with real-time downlink of selected products for both.

![HyspIRI VSWIR and TIR](image)

- **HyspIRI VSWIR**
- **HyspIRI TIR**

- **Atmosphere**
  - Solar 1.0 Reflectance
  - Earth 300 K, 1.0 Emisivity

- **Solar Radiance (μW/cm²/nm/sr)**
- **Earth Radiance (μW/cm²/nm/sr)**

- **Wavelength (nm)**
HyspIRI is a global mission, measuring land and shallow aquatic habitats and deep oceans at 1km every 5 days (TIR) and every <=16 days (VSWIR)

HyspIRI’s VSWIR imaging spectrometer (30 m) directly measures the full solar reflected spectrum of the Earth from 380 – 2500nm at 10 nm.

HyspIRI’s TIR (60 m) directly samples the Earth’s emitted thermal energy in 7 bands between 7-12 µm, & 1 band between 3-5 µm
HyspIRI Global Coverage

TIR Coverage after 5 days

VSWIR Coverage after 16 days
HyspIRI Mission Concept Architecture

**Orbit**
- 626 km Altitude
- 10:30 AM LMT Descending Node

**Calibration**
- Daily Solar View (VSWIR)
- Monthly Lunar View (VSWIR + TIR)
- Black Body and Deep Space Views (TIR)
- Vicarious US and International

**SSR**
- 1 Tb for Simple Store and Forward

**VSWIR**
- 30m, 16 Day Revisit

**TIR**
- 5 Day Revisit

**IPM**
- 20 Mbps Direct Broadcast

**Downlink**
- 800 Mbps X Band To Northern Stations (Svalbard and Alaska)

**Fiber Link**
- Data Transmitted to Processing Center within 2 weeks of downlink

**Global Coverage**
- Fine Resolution: Land + Shallow Water (Benthic & Aquatic Vegetation)
HyspIRI Objectives and Approach

Key Global Science and Applications Research

**Climate**: Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/ice; biomass burning; evapotranspiration

**Ecosystems**: Global biodiversity, plant functional types, physiological condition, and biochemistry including agricultural lands

**Fires**: Fuel status; fire frequency, severity, emissions, and patterns of recovery globally

**Coral reef and coastal habitats**: Global composition and status

**Volcanoes**: Eruptions, emissions, regional and global impacts

**Geology and resources**: Global distributions of surface mineral resources and improved understanding of geology and related hazards

**Applications**: Disasters, EcoForecasting, Health/AQ, Water

Measurement

**Imaging Spectrometer (VSWIR)**
- 380 to 2510nm in ≤10nm bands
- 30 m spatial sampling
- 16 days revisit
- Global land and shallow water

**Thermal Infrared (TIR)**
- 8 bands between 4-12 µm
- 60 m spatial sampling
- 5 days revisit; day/night
- Global land and shallow water

**IPM-Low Latency data subsets**

Global Mission Urgency

The HyspIRI science and applications objectives are critical today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.

Mission Concept Status

**Level 1 Measurement Requirements**: Vetted by community at workshops and in literature (many refereed journal articles)

**Payload**: VSWIR Imaging Spectrometer, TIR Multi-spectral Radiometer, and Intelligent Payload Module (IPM)

**Original 60 m option**: Mature

**ISS options**: VSWIR & TIR Mature, ECOSTRESS EVI selected

**Separate Smallsat Mission option**: VSWIR and TIR solutions developed with TEAM I/X

**2016 Option**: HyspIRI VSWIR evolved to 30 m and 16 day global revisit. Requires F/1.8 Dyson spectrometer architecture and other current technologies.

**Preparatory airborne campaigns**: Measurements used to advance and refine science, applications, algorithms, and processing

**Current Decadal Survey**: >25 HyspIRI-related Dec. Sur. RFIs
Implementation Options
(1) The HysPIRI Dedicated Combined Polar Orbiter is Available for Implementation

Earth Science and Science Applications
Global: Climate Change, Impact, Adaptation, & Vulnerability

Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

Map of dominant tree species, Bartlett Forest, NH

Biochemistry from Spectroscopy

Multispectral Thermal InfraRed (TIR) Scanner

Map of % Nitrogen
HyspIRI Mission Concept - 2012

**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

**Implementation**

Launch Date:
Lifetime: 3 years, with consumables for 5
Cost: Low to Moderate cost Mission
Partners: JPL, GSFC
Mission Class: C, with selected redundancy
Hardware Model: Protoflight

**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 = 5.6 arcsec (Pitch/Roll axis 3σ); 15 arcsec (Yaw axis 3σ)
  - Stability = 5 arcsec/sec (per axis 3σ)
As Part of the HyspIRI Concept Study, The Team has looked at ISS Options (2013)
HyspIRI SmallSat Compatibility (2015)

**VSWIR-Dyson**
- 30 meter spatial resolution
- 16 day revisit
- Full VSWIR Spectroscopy

**TIR**
- HyspIRI TIR has:
  - 60 m spatial resolution
  - 5 day revisit (day + night)
  - 8 bands

**ECOSTRESS**
- F/1.8 VSWIR Dyson
- 3072 x 512
2016 HyspIRI Mission Concept Study: Combined VSWIR, TIR and IPM With Current Technology
Orbit and Coverage

504 km Sun Synchronous Orbit (10:30 AM LMTDN)

- \( \leq 16 \) day global coverage for VSWIR

- \( \leq 5 \) day global coverage for TIR
  - Full coverage in 5 days
HyspIRI
Instrument Element and Algorithm Maturity
HyspIRI: VSWIR

- VSWIR
  - 2x CWIS Dyson spectrometers
  - 185 km swath
  - 30 m resolution
  - 83 kg
  - 100 W

F/1.8 VSWIR Dyson

CWIS Lab Spectra

AVIRIS-NG Cal/Val Result

Routine L1 and L2 products

L1 Radiance

L2 Reflectance
HyspIRI: TIR

- **TIR**
  - PhyTIR Demo on ECOSTRESS
  - 518 km swath
  - 60 m resolution
  - 48 kg
  - 170 W

### Airborne campaign validation of L1 and L2 algorithms
- Generate MASTER L2 Surface Temperature and Spectral Emissivity products using MASTER LWIR bands 42-50.
- Distribute the data via online ordering tool (http://masterprojects.jpl.nasa.gov/L2_products)

### Testing validation and calibration update approaches
- Calibrate MASTER L1B radiance at sensor using Lake Tahoe and Salton Sea in situ validation data.
- Validate MASTER L2 products using Lake Tahoe and Salton Sea in situ validation data as well as field measurements from pseudo-invariant sand sites.
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?

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- 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
HyspIRI Risk Reduction - PHyTIR and HyTES

VSWIR

TIR

Hyperspectral Infrared Imager (HyspIRI)

Science Risk Reduction

Engineering Risk Reduction

Hyperspectral Thermal Emission Spectrometer (HyTES)

Prototype HyspIRI Thermal Infrared Radiometer (PHyTIR)
ECOsystem Spaceborne Thermal Radiometer Experiment on Space Station
## ECOSTRESS Science Data Products

<table>
<thead>
<tr>
<th>Data Product</th>
<th>Description</th>
<th>Initial Availability to NASA DAAC</th>
<th>Median Latency in Product Availability to NASA DAAC after Initial Delivery</th>
<th>NASA DAAC Location</th>
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</thead>
<tbody>
<tr>
<td>Level 0</td>
<td>Raw collected telemetry</td>
<td>6 months after IOC</td>
<td>12 weeks</td>
<td>To be assigned by NASA SMD/ESD</td>
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<tr>
<td>Level 1</td>
<td>Calibrated Geolocated Radiances</td>
<td>6 months after IOC</td>
<td>12 weeks</td>
<td>To be assigned by NASA SMD/ESD</td>
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<tr>
<td>Level 2</td>
<td>Surface temperature and emissivity</td>
<td>6 months after Level 1 data products are available</td>
<td>12 weeks</td>
<td>To be assigned by NASA SMD/ESD</td>
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<tr>
<td>Level 3</td>
<td>Evapotranspiration</td>
<td>2 months after Level 2 data products are available</td>
<td>12 weeks</td>
<td>To be assigned by NASA SMD/ESD</td>
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<td>Level 4</td>
<td>Water use efficiency and evaporative stress index</td>
<td>2 months after Level 3 data products are available</td>
<td>12 weeks</td>
<td>To be assigned by NASA SMD/ESD</td>
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</tbody>
</table>
HyspIRI: IPM

- **IPM**
  - Four Card Flight Unit
  - 5 x 7 x 9 inches
  - 5.8 kg
  - 20 watts (typical)
- **VSWIR Level 2 products.**
  - Land Surface Reflectance
  - Water RS Reflectance

- **TIR Level 2 products.**
  - Surface Radiance
  - Temperature and Emissivity
## HyspIRI Comprehensive Development Report

### Comprehend Report
- Comprehensive Development Report

### HyspIRI Mission TRL Assessment
- Comprehensive Development Report

### Appendix

#### Reports and Whitepapers
- Compiled Reports and Whitepapers from 2008-2014

#### Individual Report files
- 2014 HyspIRI Separate Platforms Whitepaper
- 2014 PhTIR Test Results
- 2012 Workshop Report
- 2012 TIR Band Study Report
- 2011 Workshop Report
- 2011 Symposium Report
- 2011 Sun Glint Report
- 2011 High Temperature Saturation Report
- 2010 Workshop Report
- 2009 Workshop Report
- 2008 Whitepaper and Workshop Report
- TRL Assessment Report

### HyspIRI Workshop Material
- 2014 Compiled Workshop
- 2013 Compiled Workshop
- 2012 Compiled Workshop
- 2011 Compiled Workshop
- 2010 Compiled Workshop
- 2009 Compiled Workshop
- 2008 Compiled Workshop

#### Individual Workshop files
- 2014 Workshop Agenda and Presentations
- 2013 Workshop Agenda and Presentations
- 2012 Workshop Agenda and Presentations
- 2011 Workshop Agenda and Presentations
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### TeamX ISS Accommodation Studies
- VSWIR ISS Study
- TIR ISS Study

### 2014 Small Spacecraft Vendor Presentation

#### Algorithm Theoretical Basis Documents (ATBDs)
- TIR Level 2 Surface Radiance
- TIR Level 2 Surface Temperature and Emissivity
- TIR Cloud Mask
- VSWIR Level 2 Water Leaving Reflectance
- VSWIR Level 2 Land Surface Reflectance

#### Science Application Summaries
- Disasters
- Water resources
- Health and Air Quality

#### Science Application White Papers
- HyspIRI Volcanos
- Public Health

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**http://hyspiri.jpl.nasa.gov/comprehensive-development-report**

**Data Products Symposium at GSFC**

**Science and Applications Workshop at Caltech**
**HyspIRI Objectives and Approach**

**Key Global Science and Applications Research**

**Climate:** Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/ice; biomass burning; evapotranspiration

**Ecosystems:** *Global* biodiversity, plant functional types, physiological condition, and biochemistry including agricultural lands

**Fires:** Fuel status; fire frequency, severity, emissions, and patterns of recovery *globally*

**Coral reef and coastal habitats:** *Global* composition and status

**Volcanoes:** Eruptions, emissions, regional and *global* impacts

**Geology and resources:** *Global* distributions of surface mineral resources and improved understanding of geology and related hazards

**Applications:** Disasters, EcoForecasting, Health/AQ, Water

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2017 Decadal Survey

EARTH SCIENCE AND APPLICATIONS FROM SPACE

URGENT NEEDS AND OPPORTUNITIES TO SERVE THE NATION

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES
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<th>Author</th>
<th>Title</th>
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<tr>
<td>Luvall</td>
<td>A Thermodynamic Paradigm For Using Satellite Based Geophysical Measurements For Public Health Applications</td>
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<tr>
<td>Heidi</td>
<td>Assessing Transient Threats and Disasters in the Coastal Zone with Airborne Portable Sensors</td>
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<td>Ryan</td>
<td>Biodiversity</td>
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<td>Simon</td>
<td>Carbon Emissions from Biomass Burning</td>
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<td>Eric</td>
<td>Coral Reefs: Living on the Edge</td>
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<td>Wendy</td>
<td>Earth Surface Geochemistry and Mineralogy: Processes, Hazards, Soils, and Resources</td>
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<tr>
<td>Joshua</td>
<td>Evapotranspiration: A Critical Variable Linking Ecosystem Functioning, Carbon and Climate Feedbacks, Agricultural Management, and Water Resources</td>
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<td>Tamlin</td>
<td>From the Mountains to the Sea: Interdisciplinary Science and Applications Driven by the Flow of Water, Sediment, and Carbon II</td>
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<td>Philip</td>
<td>Global Measurement of Non-Photosynthetic Vegetation</td>
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<td>Kevin</td>
<td>Global Observations of Coastal and Inland Aquatic Habitats</td>
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<td>Global Terrestrial Ecosystem Functioning and Biogeochemical Processes</td>
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<td>Natalie</td>
<td>Measuring the Earth’s Surface Mineral Dust Source Composition for Radiative Forcing and Related Earth System Impacts</td>
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<td>Frank</td>
<td>Monitoring Coastal and Wetland Biodiversity from Space</td>
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<tr>
<td>Robert</td>
<td>Predicting Changes in the Behavior of Erupting Volcanoes, and Reducing the Uncertainties Associated with their Impact on Society and the Environment</td>
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<td>Robert</td>
<td>Science and Application Targets Addressed with the 2007 Decadal Survey HyspIRI Mission Current Baseline</td>
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<tr>
<td>Natasha</td>
<td>The role of fire in the Earth System</td>
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<tr>
<td>Riley</td>
<td>Understanding anthropogenic methane and carbon dioxide point source emissions</td>
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<tr>
<td>Thomas</td>
<td>Understanding the controls on cryospheric albedo, energy balance, and melting in a changing world</td>
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Questions and Discussion

Overview of the HyspIRI Mission Concept, Measurements and Science

A Global Coverage VSWIR and TIR Mission