HyspIRI

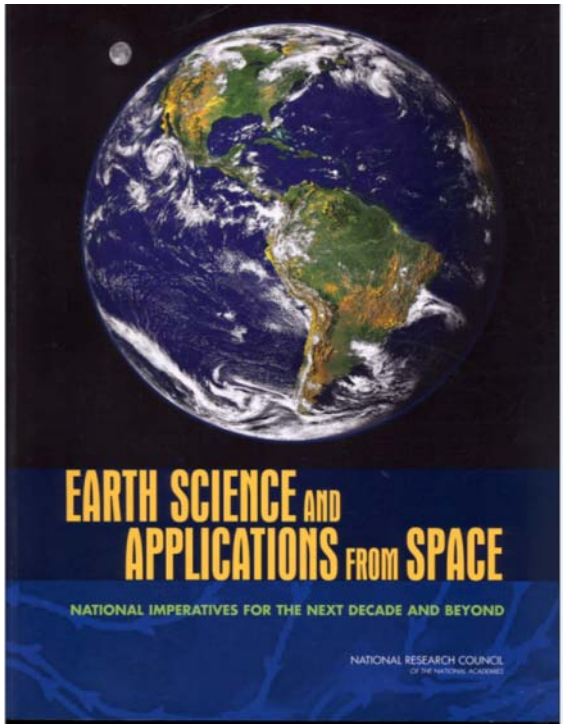
VSWIR Science Measurement Baseline

NASA Earth Science and Applications Decadal Survey

Robert O. Green and HyspIRI Team

HyspIRI Decadal Survey Climate Science

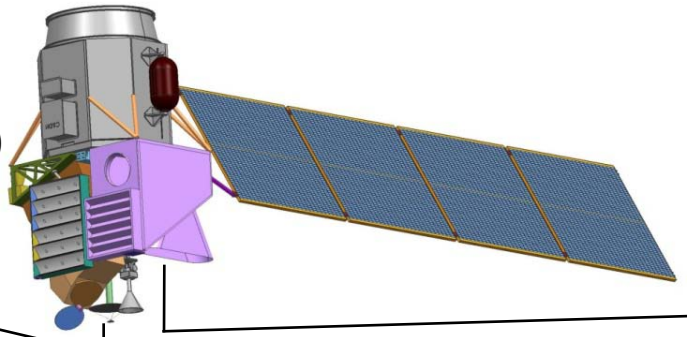
HyspIRI: “A hyperspectral sensor (e.g., FLORA) combined with a multispectral thermal sensor (e.g., SAVII) in low Earth orbit (LEO) **is part of an integrated mission concept** [described in Parts I and II] that is relevant to several panels, **<u>especially the climate variability panel</u>**.”



NRC Decadal Survey - HyspIRI

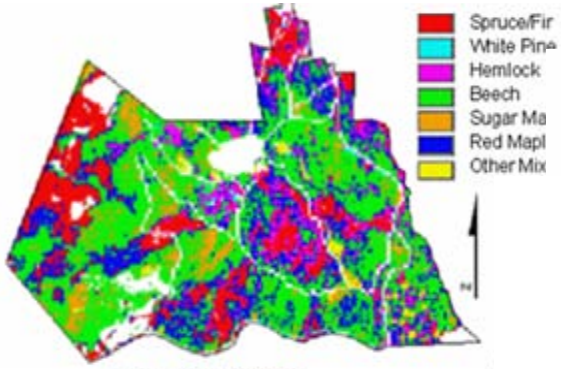
Global vegetation species-type and physiological condition, including agricultural lands, for biosphere feedback and land-atmosphere interactions; Spectroscopically derived terrestrial land cover composition/albedo including snow, ice, dust climate interaction; Fire: fuel, occurrence, intensity and recovery 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



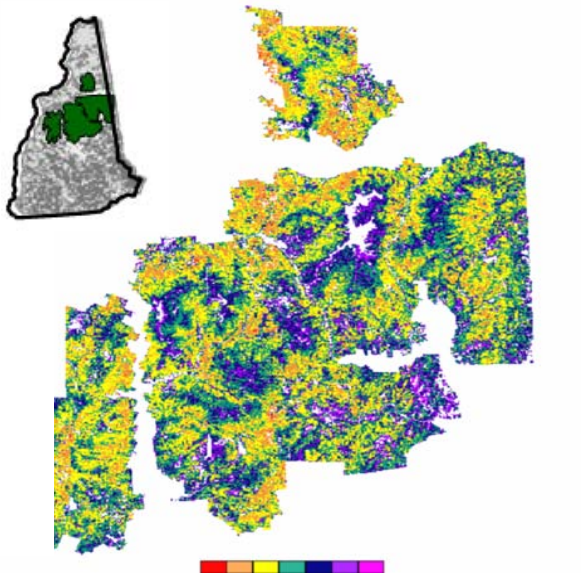
Multispectral Thermal InfraRed (TIR) Scanner

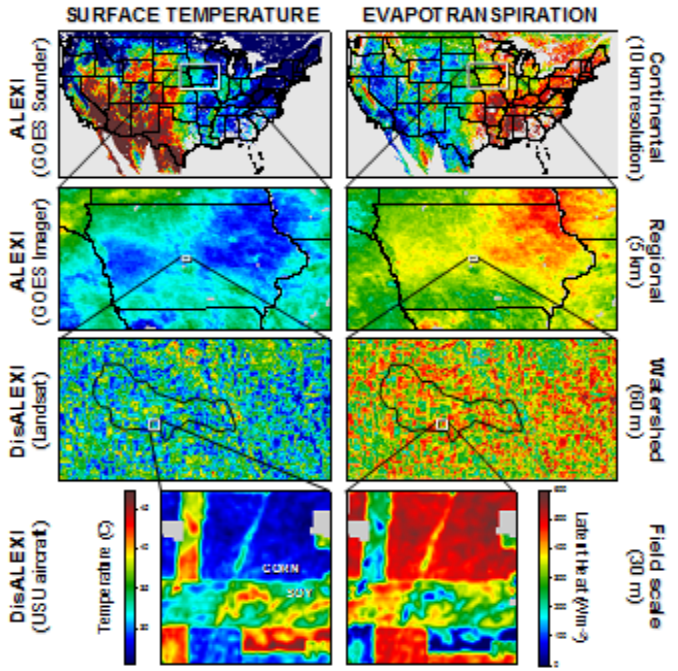
Map of dominant tree species, Bartlett Forest, NH



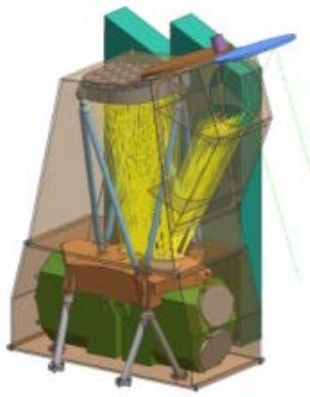
Soil C:N Ratio

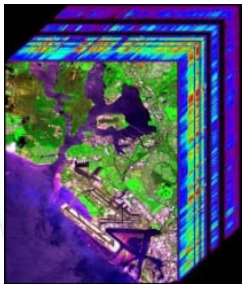
White Mountain National Forest, NH





HysplRI - Imaging Spectroscopy (VSWIR) Science Measurements





Mature Instrument concept: All components have flown in space.

Imaging spectrometer: 55kg / 41W

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

Full terrestrial coverage downlinked every 19 days

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? [DS 195]

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?[DS 191, 195, 203]

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?

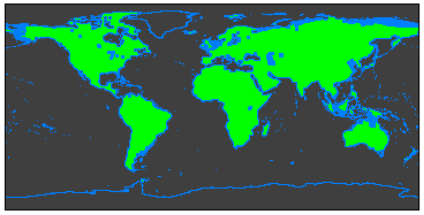
VQ4. Changes in and Responses to Disturbance.
How are disturbance regimes changing, and how do these changes affect the ecosystem processes that support life on Earth?

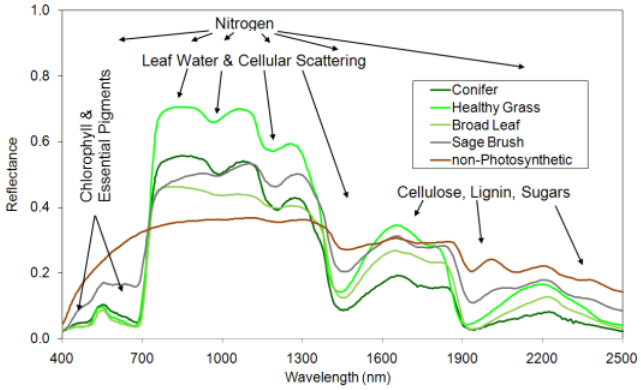
VQ5. Ecosystem and Human Health.
How do changes in ecosystem composition and function affect human health, resource use, and resource management?

VQ6. Earth Surface and Shallow-Water Benthic Composition.
What are the land surface soil/rock /cryosphere and shallow-water benthic compositions,?

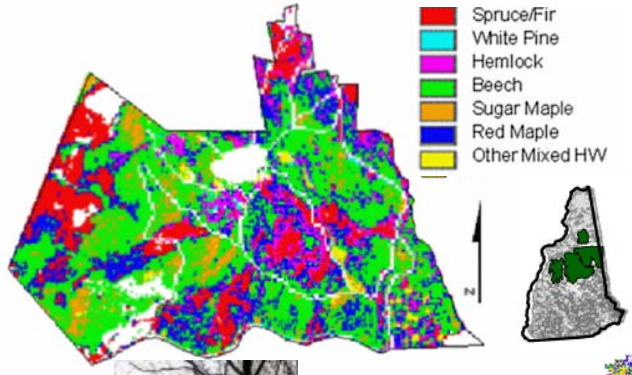
Measurement:

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

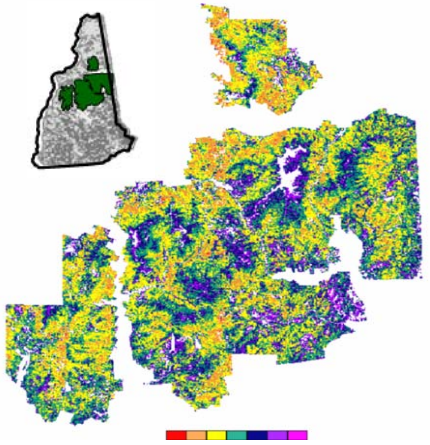




Map of dominant tree species, Bartlett Forest, NH

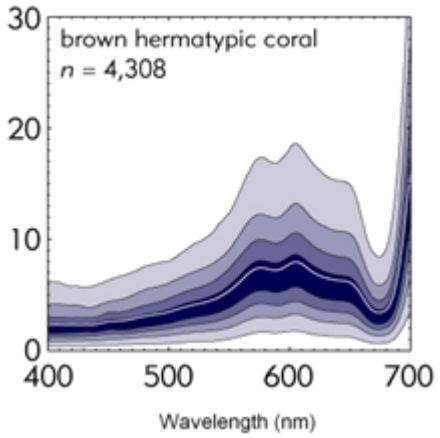


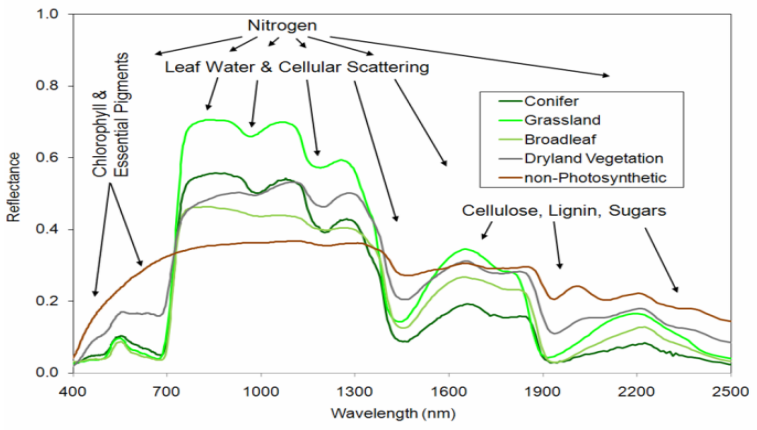
Soil C:N Ratio
White Mountain National Forest, NH

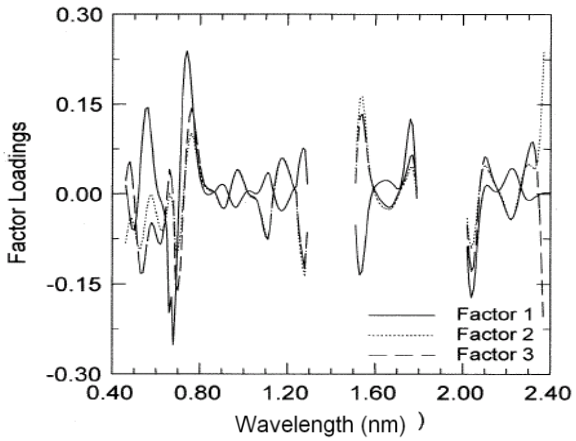


Basis for Continuous Spectral Measurement

- Plant 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.
- Other constituents of the Earth system (Minerals, Soils, Snow, etc) have spectral characteristics allowing use of this spectroscopic measurement approach for corresponding science questions.
- Important atmospheric correction information and calibration feedback is contained within the spectral measurement.

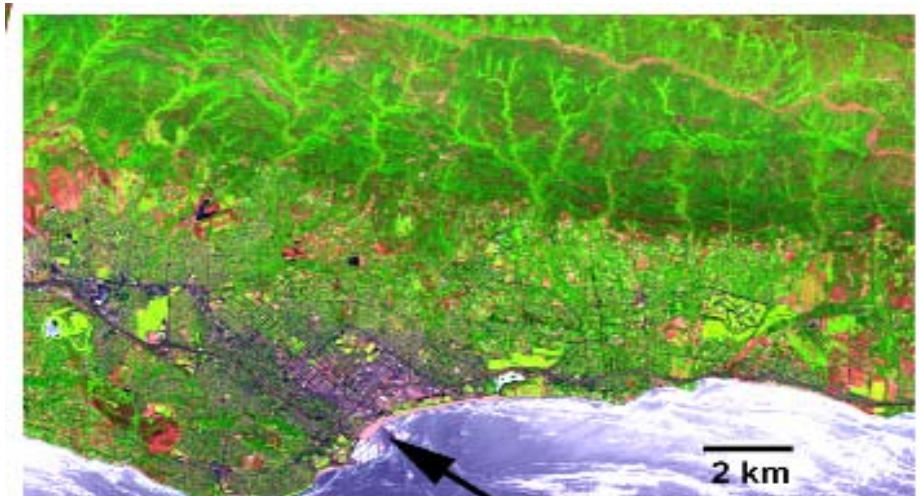




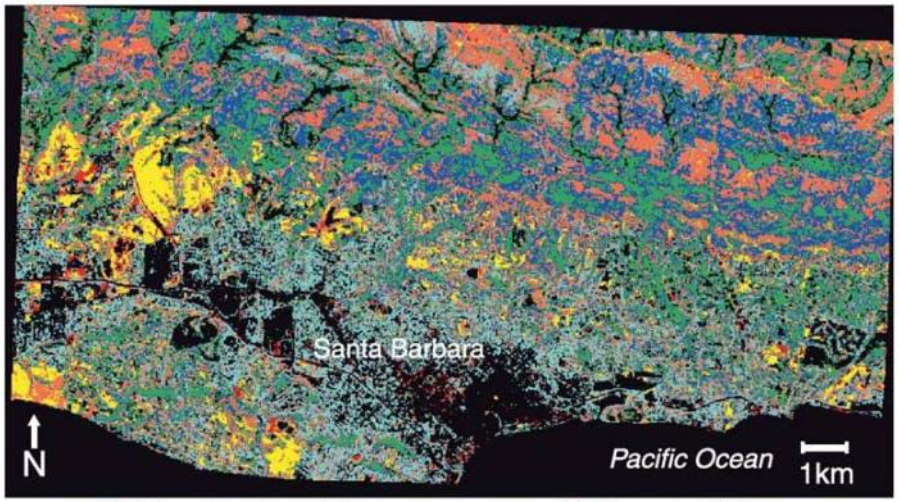


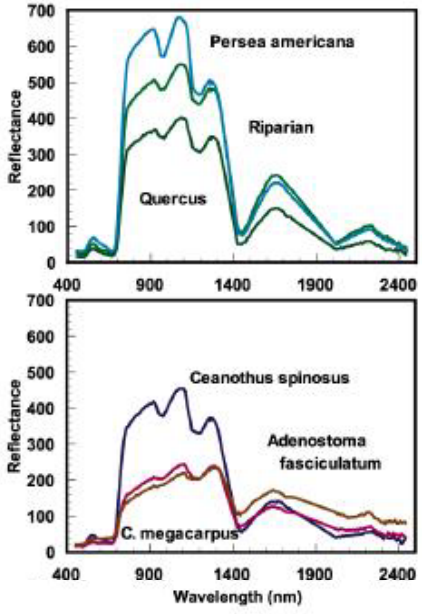
Vegetation Species/Functional-type & Fractional Cover

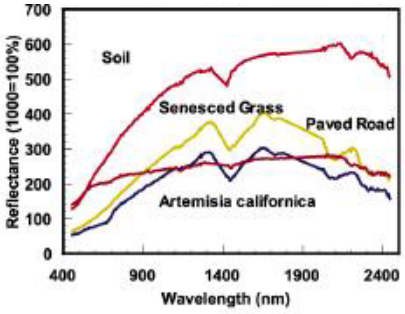
Santa Barbara, CA Coast Range



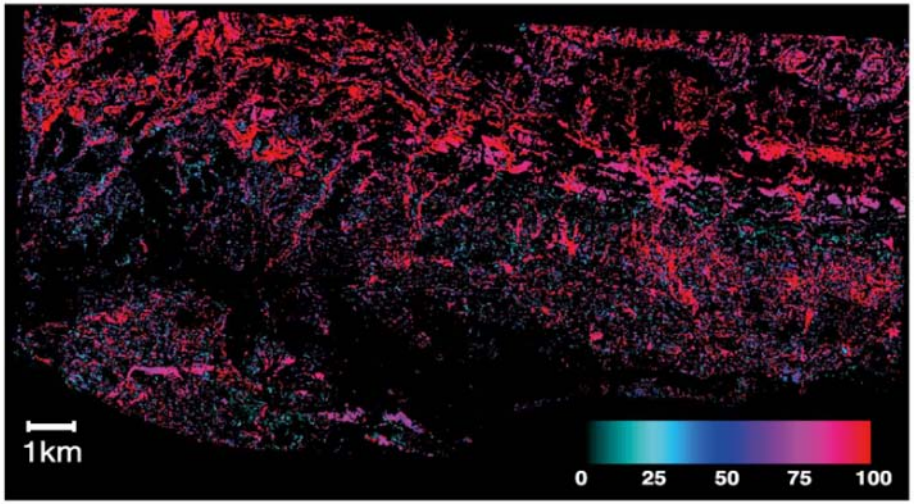
Species Type 90% accurate





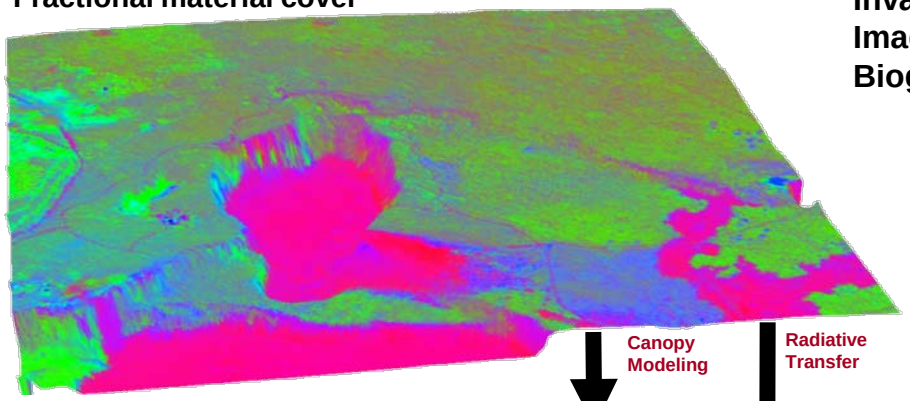


Species Fractional Cover (Quercus agrifolia)



Ecosystem Species-type, Chemistry & Condition

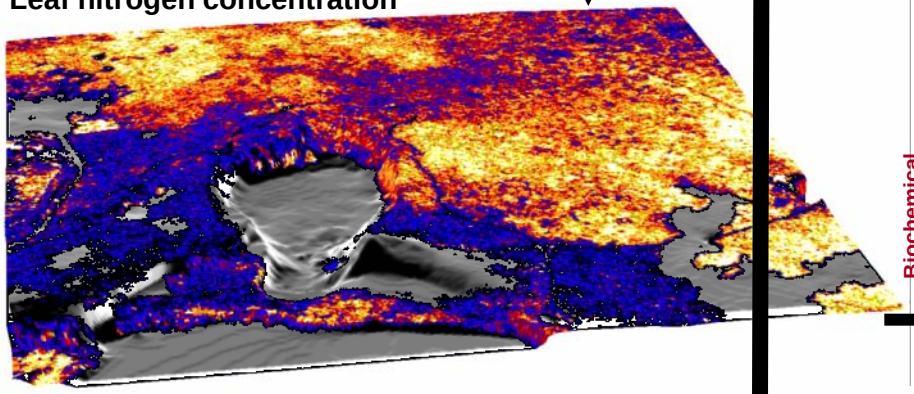
Fractional material cover



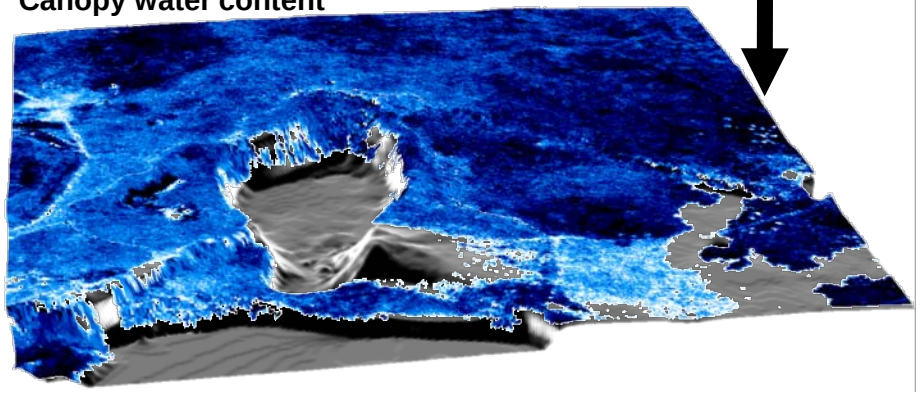
Canopy Modeling

Radiative Transfer

Leaf nitrogen concentration



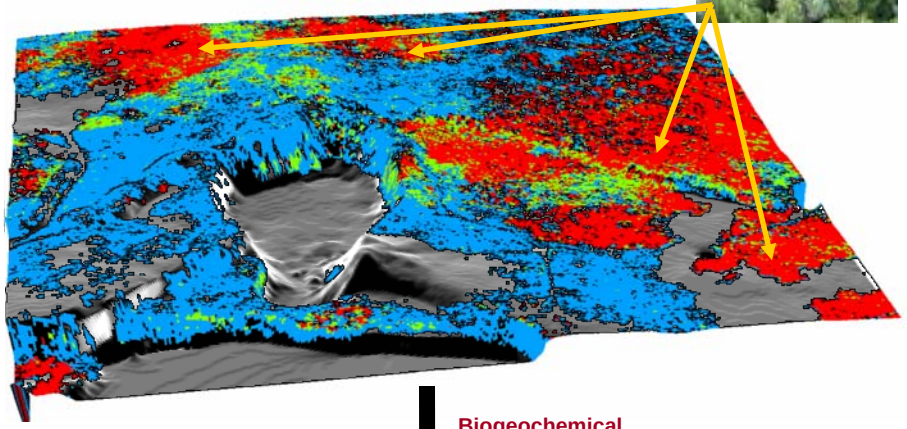
Canopy water content



Biochemical Fingerprinting

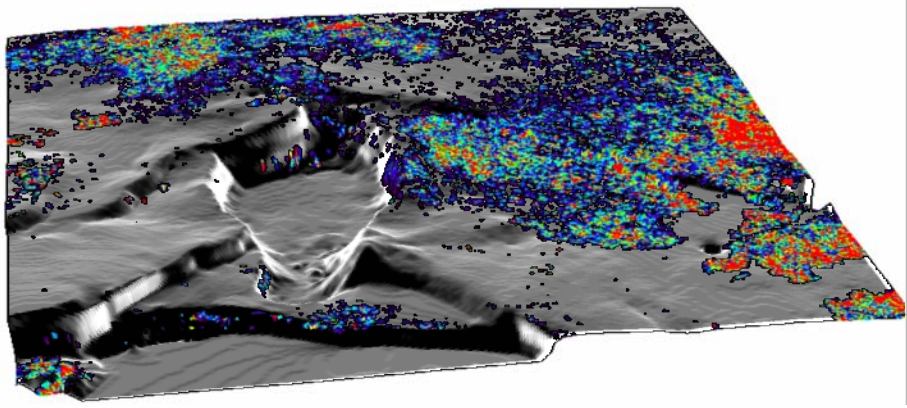
Invasive Species in the Hawaiian Rainforest from Airborne Imaging Spectrometer data: Patterns of Invasion and Biogeochemical Consequences

Invasive species and nitrogen-fixing PFT



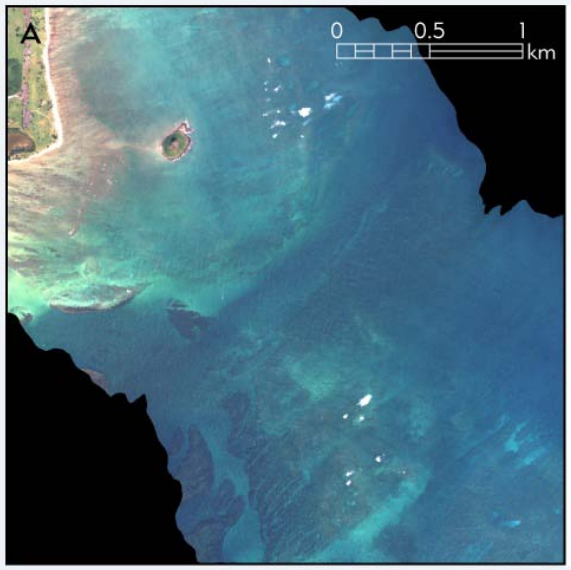
Biogeochemical Analysis

Soil nitrogen trace gas emissions

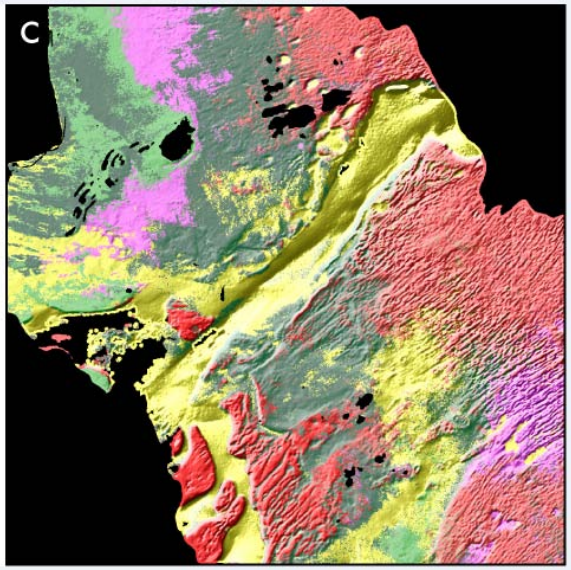


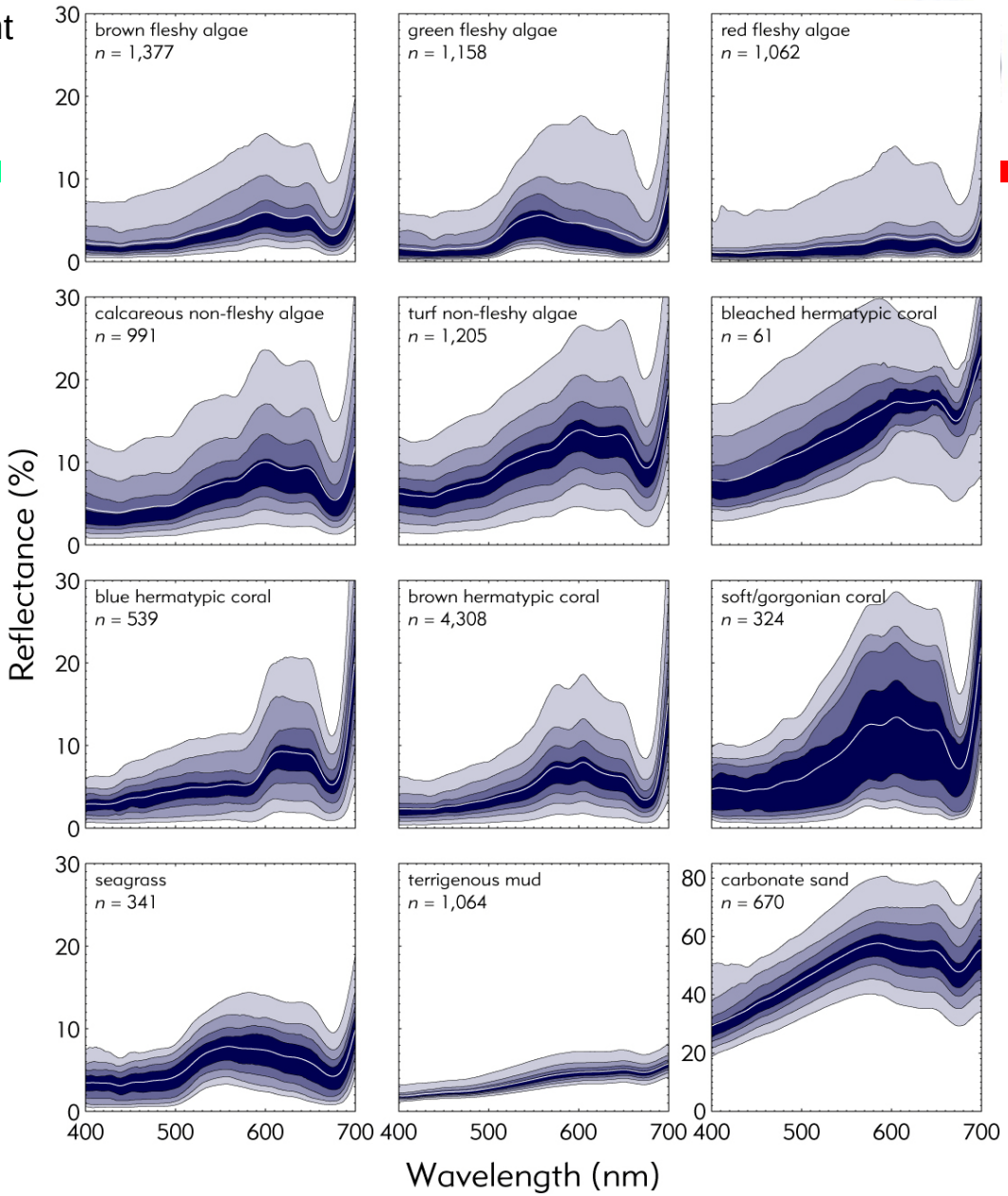
Asner and Vitousek, Proceeding of the National Academy of Sciences
Hall and Asner, Global Change Biology

Imaging Spectrometer Measurement



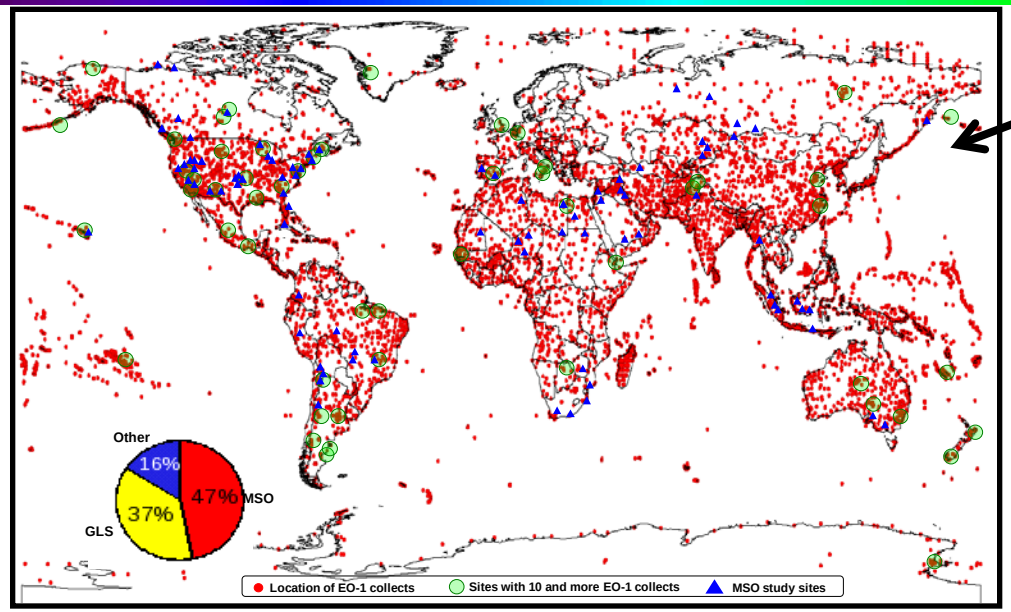
Benthic Compositional Mapping





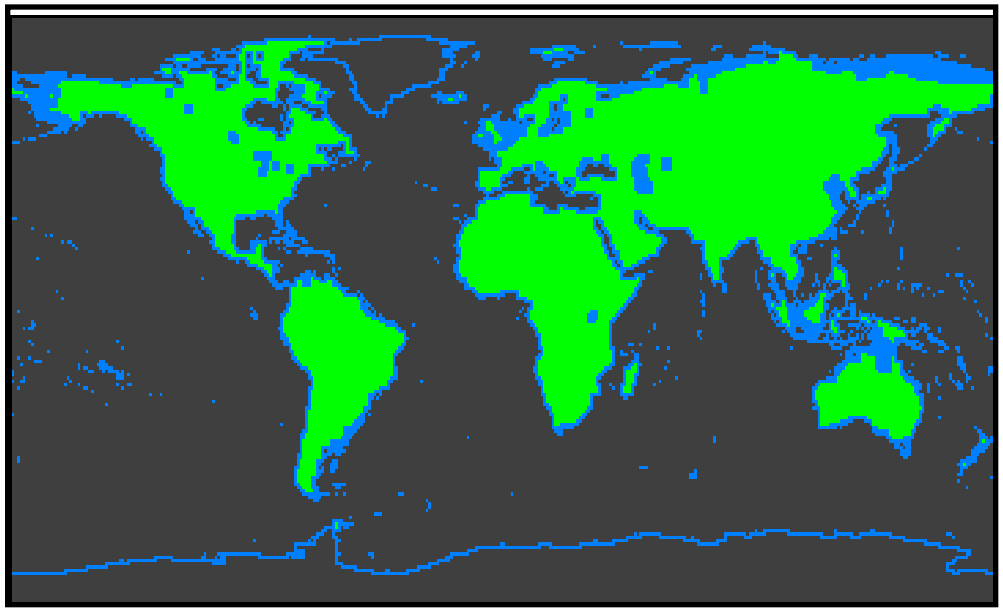
Spectral Measurements of Shallow Water Benthic Composition (E. Hochberg, Nova Southeastern University, FL)

To achieve the HyspIRI VSWIR climate contribution, global coverage is required with revisit <20 days



- EO-1 Hyperion acquisitions in 10 years.

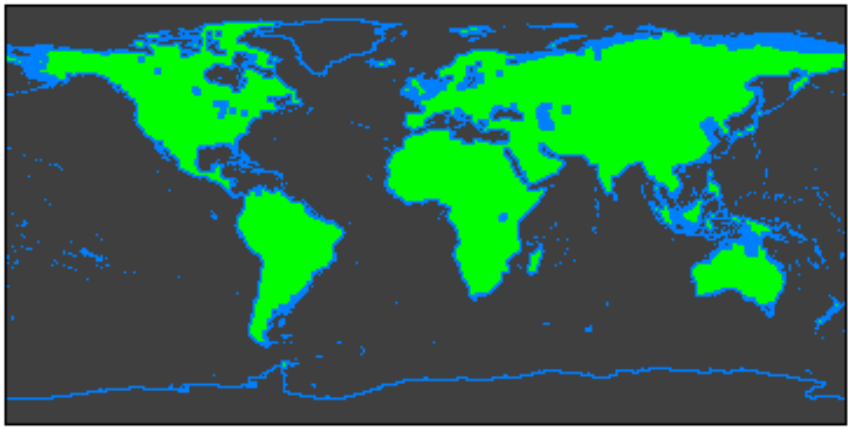
- HyspIRI provides complete terrestrial and shallow water coverage every 19 days.



- **<u>It would take Hyperion 100 years to acquire what HyspIRI measures in 1 year.</u>**

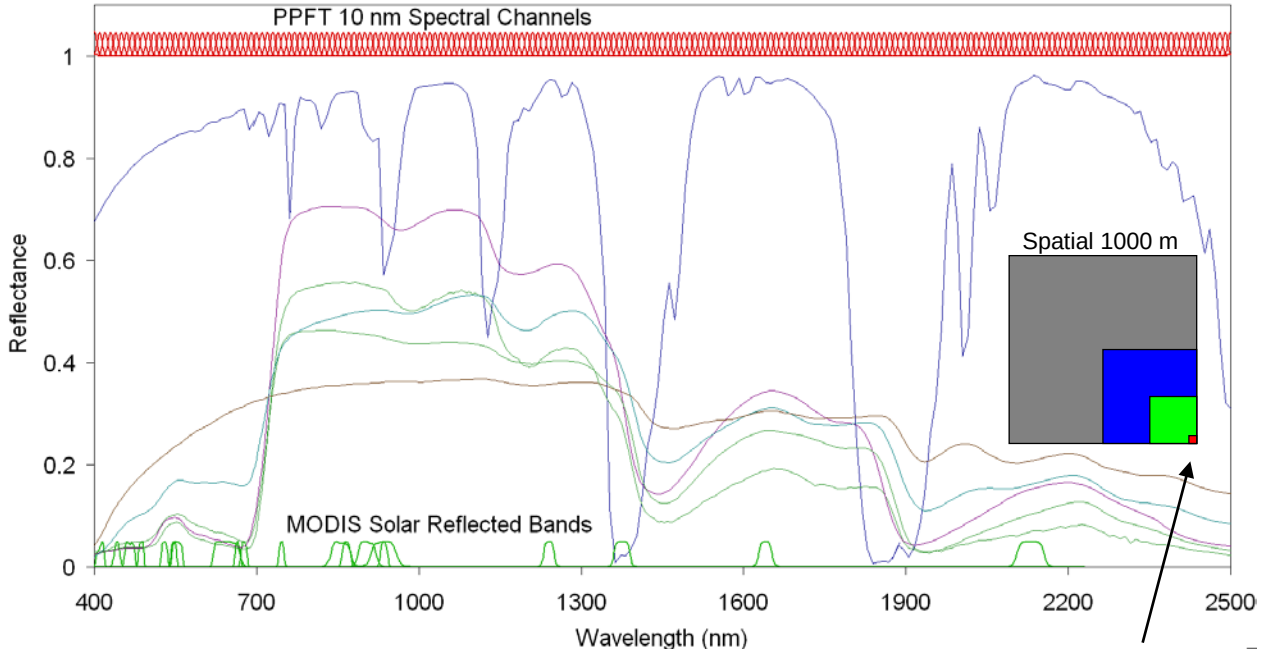
HysplRI VSWIR
Imaging Spectrometer
Measurement Characteristics

HysplRI 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.



PPFT at 60 m

HysplRI VSWIR
Science Measurement Characteristics

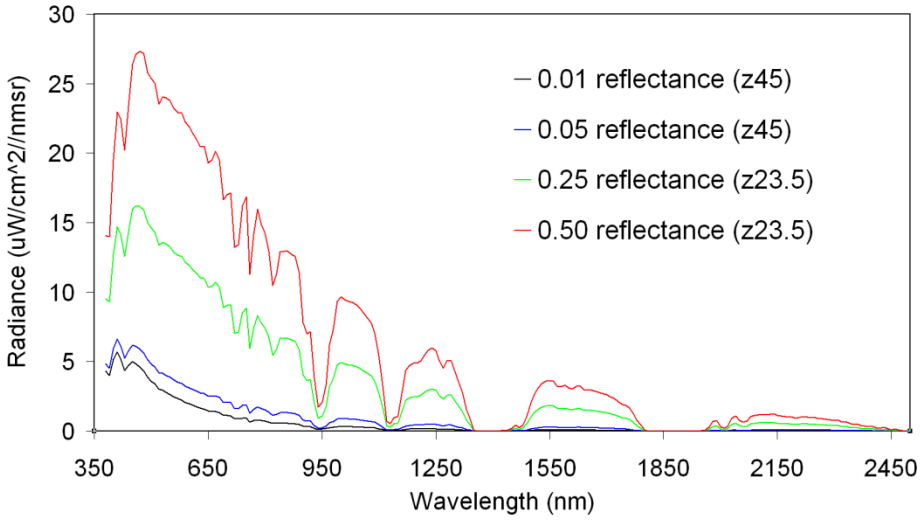
Spectral	
Range	380 to 2500 nm in the solar reflected spectrum
Sampling	<= 10 nm {uniform over range}
Response	<= 1.2 X sampling (FWHM) {uniform over range}
Accuracy	<0.5 nm
Radiometric	
Range & Sampling	0 to 1.5 X max benchmark radiance, 14 bits measured
Accuracy	>95% absolute radiometric, 98% on-orbit 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	>150 km
Cross-Track Samples	>2500
Sampling	<=60 m
Response	<=1.2 X 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}

HyspIRI VSWIR Science Measurements Characteristics

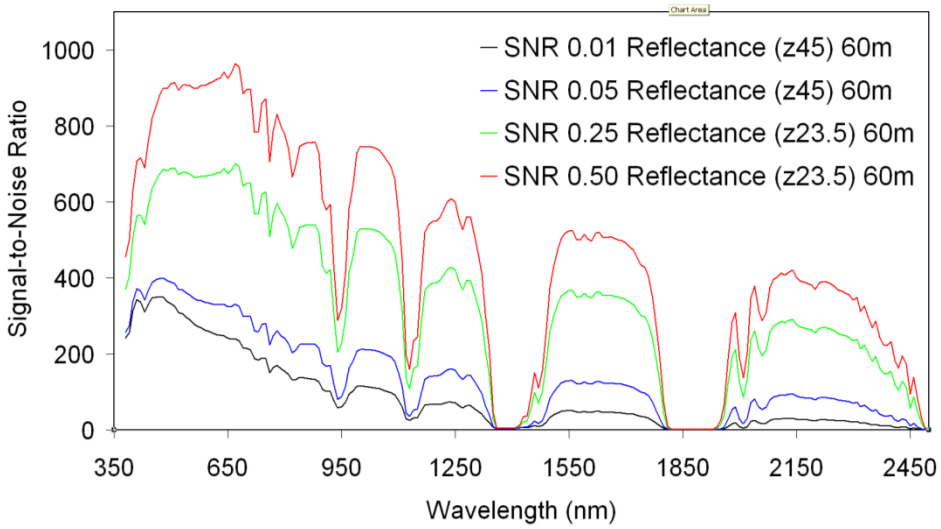
Temporal	
Orbit Crossing	10:30 am sun synchronous descending
Global Land Coast Repeat	19 days at equator
Rapid Response Revisit	3 days (cross-track pointing)
Sunglint Reduction	
Cross Track Pointing	4 degrees in backscatter direction
OnOrbit Calibration	
Lunar View	1 per month {radiometric}
Solar Cover Views	1 per day {radiometric}
Dark signal measurements	1 per orbit and edge detector tracking
Surface Cal Experiments	5 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° or greater (10° Trade study)
Open Ocean/Ice Sheets	Averaged to ~1 km spatial sampling
Compression	>=3.0 lossless

HyspIRI VSWIR Science Measurements
Key SNR and Uniformity Requirements

Benchmark Radiances

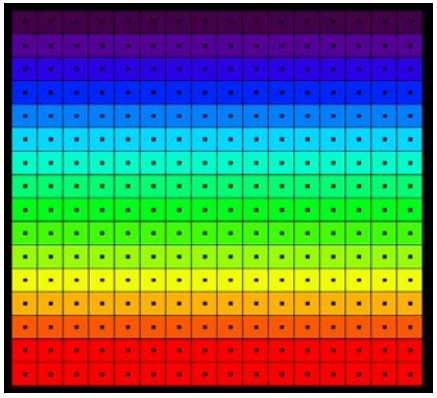


Required SNR



Uniformity Requirement

Cross Track Sample



Depiction

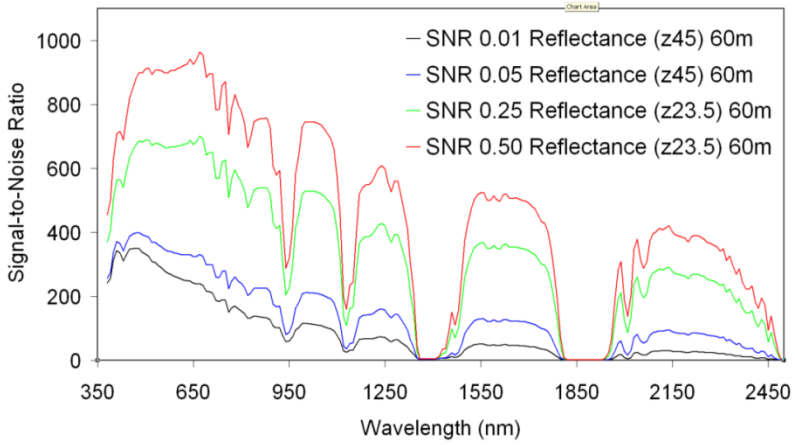
-Grids are the detectors
-Dots are the IFOV centers
-Colors are the wavelengths

Requirement

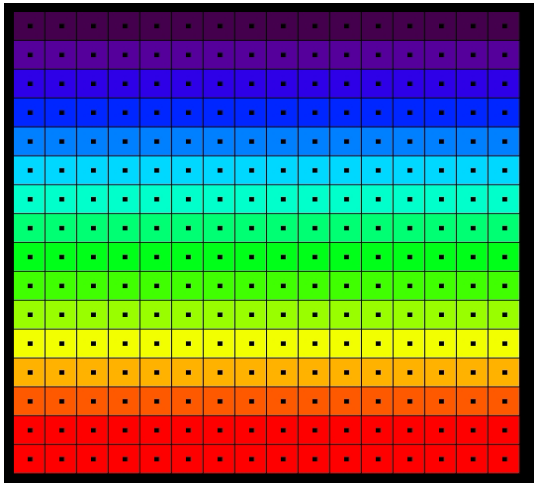
Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}

HyspIRI: Building on NASA Hyperion Technology Demonstration

SNR > 10X



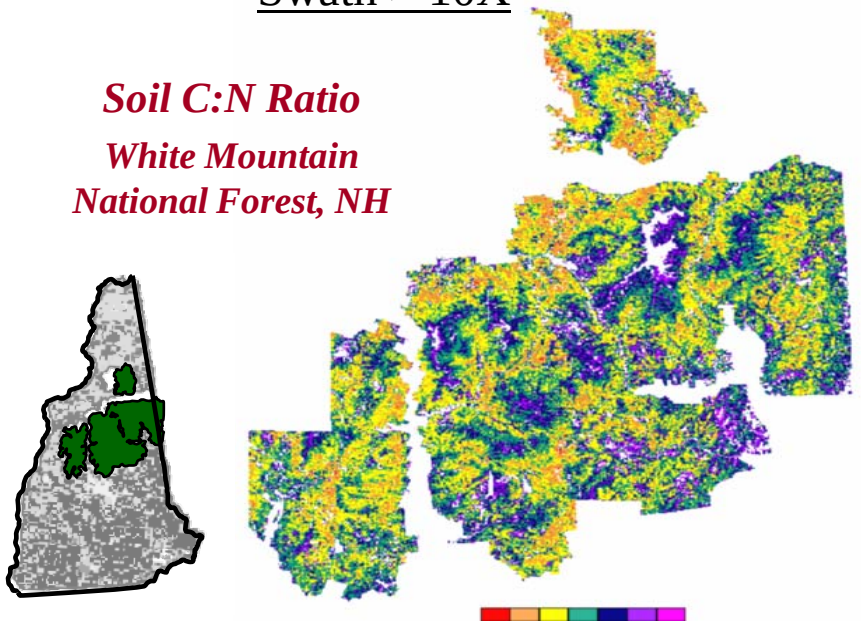
Uniformity > 10X



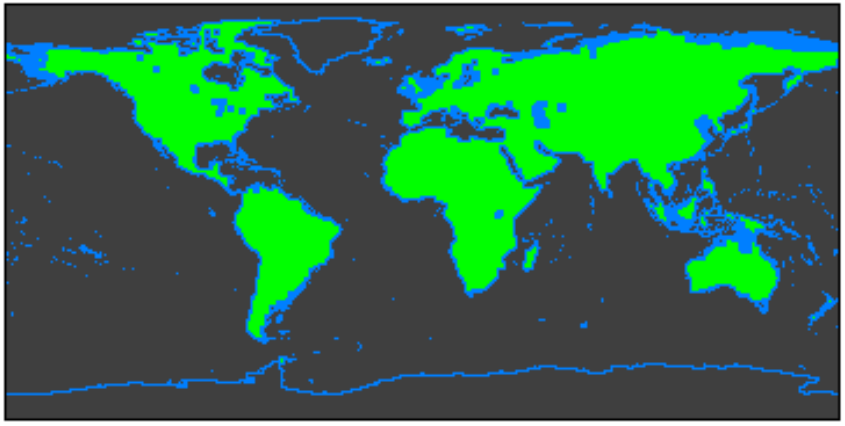
Swath > 10X

Soil C:N Ratio

White Mountain National Forest, NH

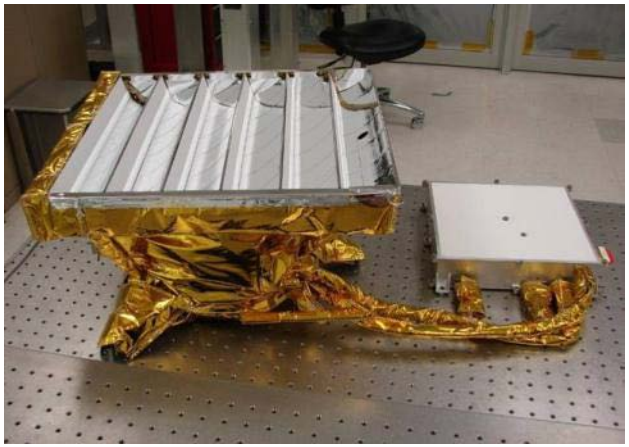


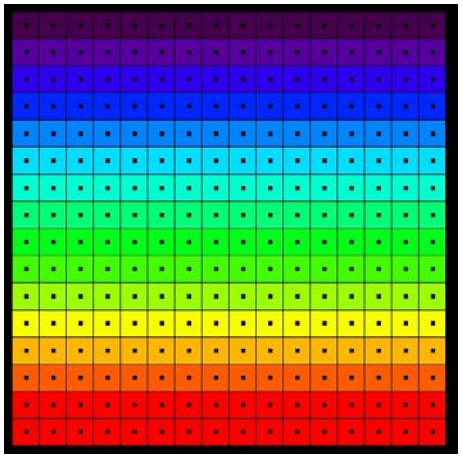
Global Coverage >> 10X



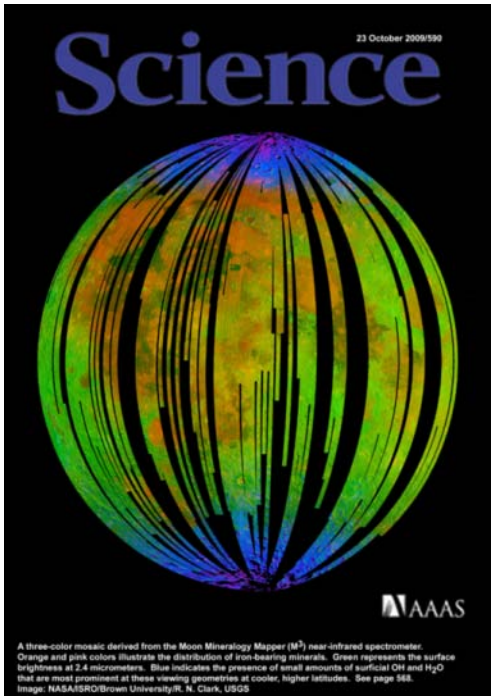
Example Heritage Imaging Spectrometer

8 Kg, 15 watts, 24 Month Build





High uniformity and high SNR design by P. Mouroulis



Offner Spectro-meter Spherical Mirror

Baffles

Fold Mirror

Baffle

TM-1

TM2

TM-3

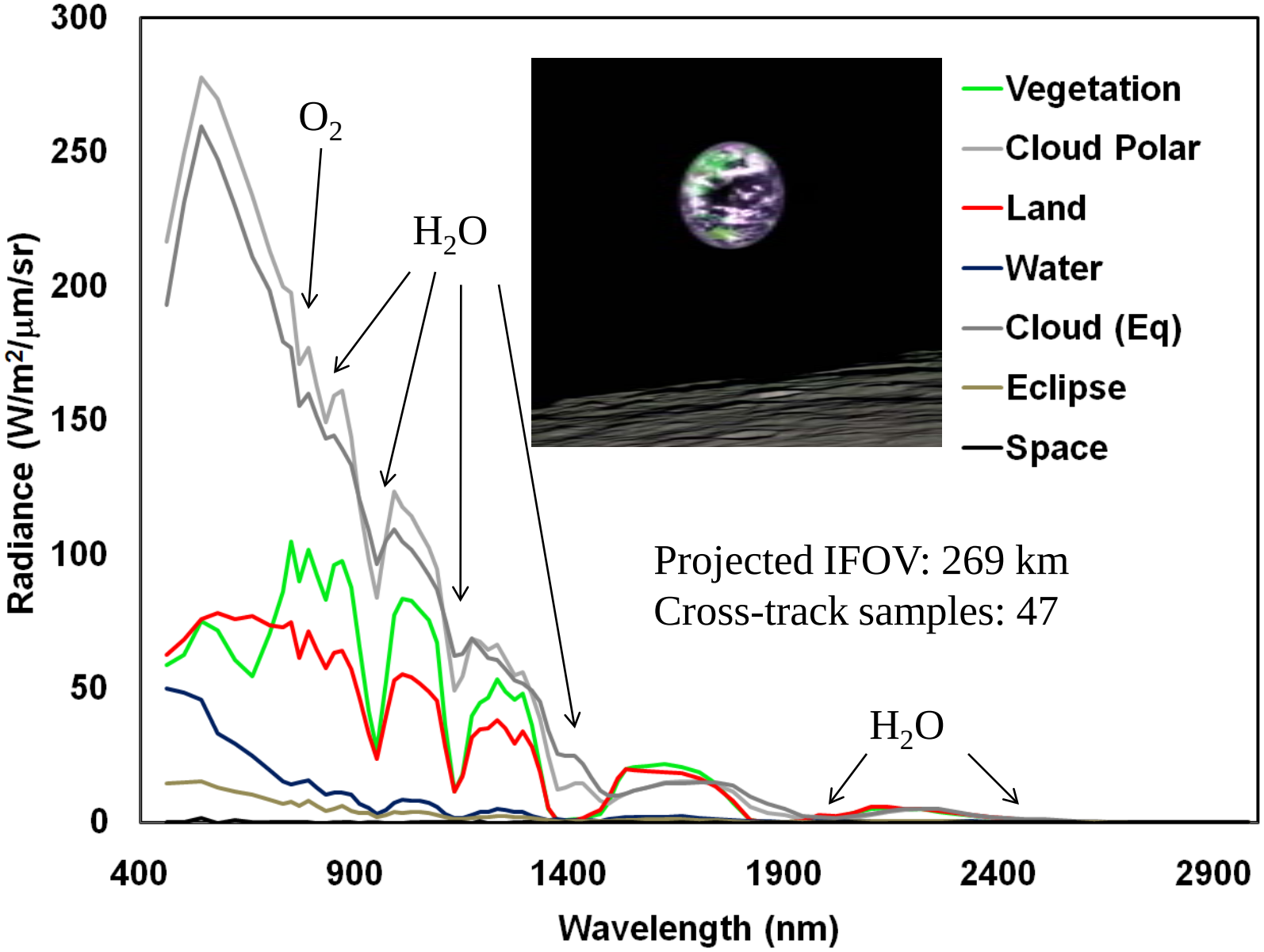
Uniform Slit

Convex Multi Facet Blazed Grating

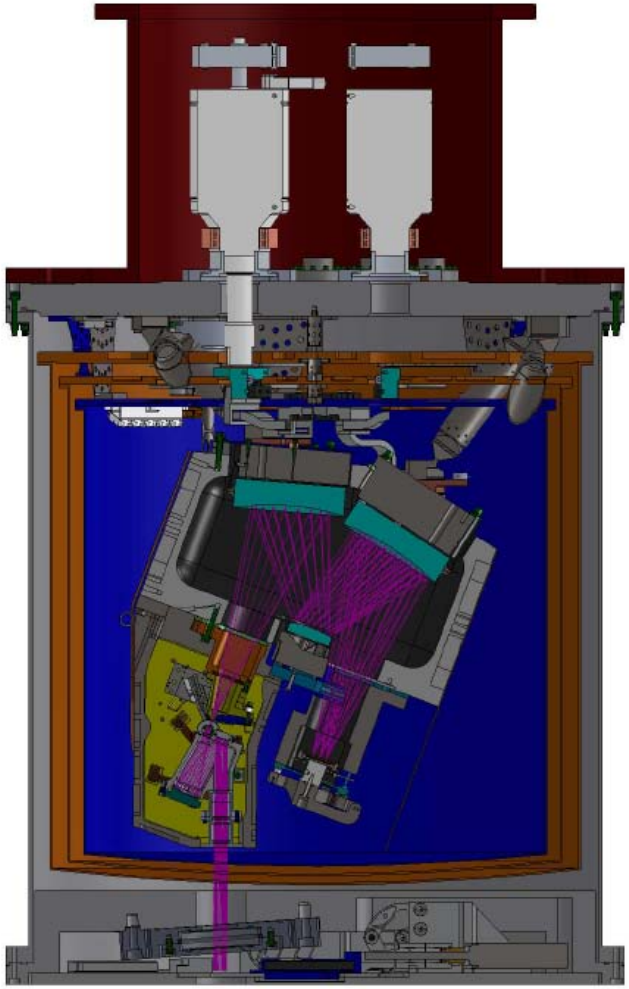
Order Sorting Filter and Focal Plane Detector Array

Baffle

M^3 Measurement of Earth



AVIRIS Next Generation

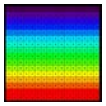


- Spectral
  - Range 380 to 2500 nm
  - Position 5 nm
  - Response 1 to 1.5 X sampling
  - Calibration +-0.1 nm
- Radiometric
  - Range 0 to specified saturation radiance
  - Precision >2000 @ 600 nm
    >1000 @ 2200 nm
  - Accuracy 95% (<5% uncertainty)
  - Linearity >=99% characterization
- Spatial (at 100km)
  - Range 36 degree field-of-view
  - Sampling 1 milliradian
  - Response 1 to 1.5 X sampling
  - Slit Projection3 Axes cosines projected slit
- Uniformity
  - Spectral Cross-Track >95% cross-track non-uniformity
  - Spectral-IFOV-Variation >95% spectral IFOV non-uniformity

Imaging Spectrometer Instrument Innovation for NASA Science and Discovery

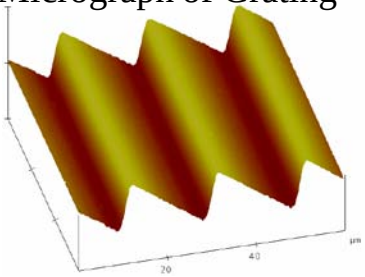
- Two decades of integrated investment
  - Designs, electron-beam lithography gratings & slits, mounts, alignment/calibration
- Advanced spectrometer designs are enabled by curved multi-blaze e-beam grating.

Offner Design



E-Beam Grating

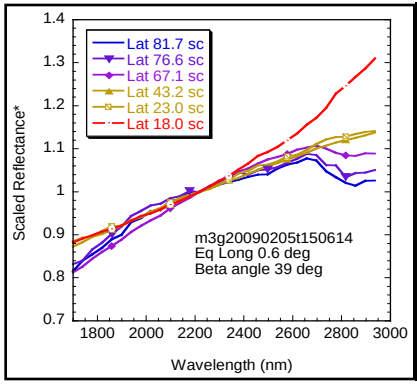
Atomic Force Micrograph of Grating

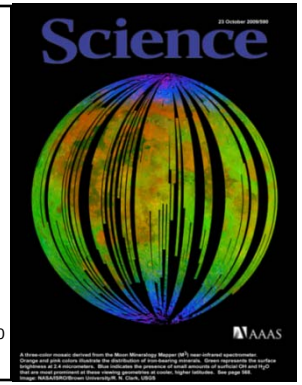


- In 1989, the proposed HIRIS Imaging Spectrometer was **970 Kg, 879 W** and the size of small car.
- Today, the HyspIRI Earth Decadal Survey instrument is **55 Kg and 41 W**, compact and provides a superior science measurement.

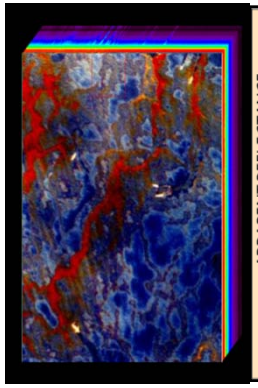
Imaging Spectroscopy Science

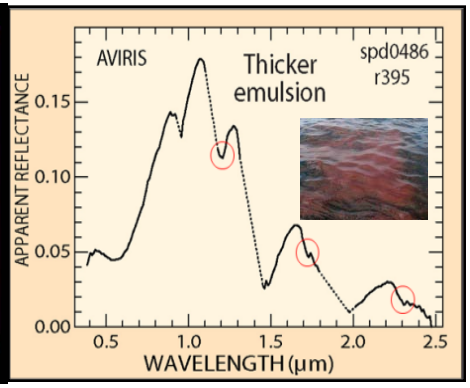
2009 Discovery of water/OH on the Illuminated Surface of the Moon



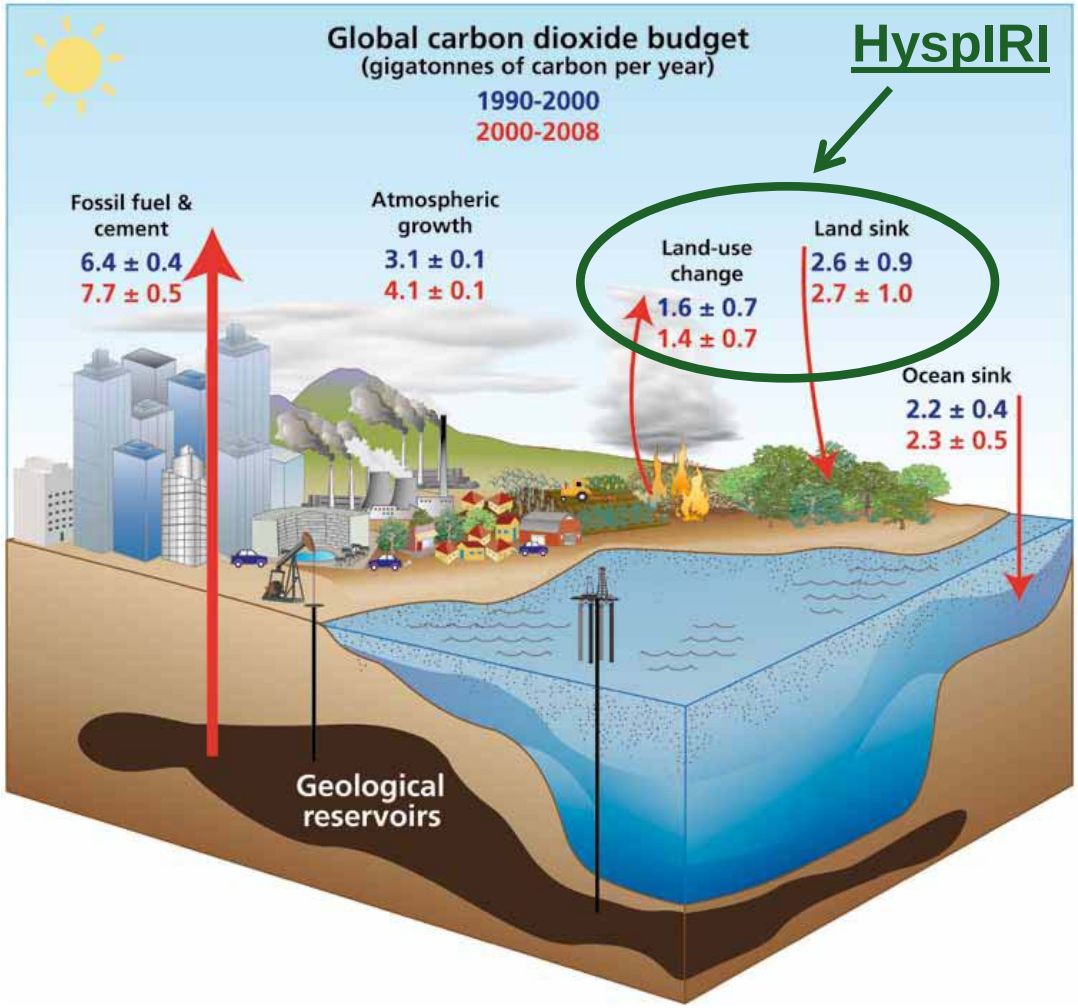


2010 Gulf Spill Volume Estimates of Surface Oil with NOAA and USGS





HyspIRI is Required to Reduce Uncertainties in the Land Carbon Fluxes



Accurate constraint of Carbon fluxes associated with land-use and terrestrial vegetation are important missing elements today for closing the carbon budget.

The HyspIRI based improvement is essential for sound policy decision making.

Global CO2 budget for 1990-2000(blue) and 2000-2008 (red) (GtC per year). Emissions from fossil-fuel and landuse change are based on economic and deforestation statistics. Atmospheric CO2 growth is measured directly. The land and ocean CO2 sinks are estimated using observations for 1990-2000 (Denman *et al.* IPCC 2007). For 2000-2008, the ocean CO2 sink is estimated using an average of several models, while the land CO2 sink is estimated from the balance of the other terms.

Summary

We have developed a set of VSWIR science questions that are carefully aligned with the HyspIRI Mission called for in the NASA Earth Science and Applications Decadal Survey.

We have reviewed and refined these questions that relate to both science and applications objectives and developed traceability to a set of science measurements.

We have addressed the roles of the HyspIRI mission in climate, global change, societal impact and adaptation.

In preparation for a NASA HyspIRI mission we have established a high heritage and low risk approach for acquiring the HyspIRI VSWIR science measurements

HyspIRI Decadal Survey Climate Science

HyspIRI: “A hyperspectral sensor (e.g., FLORA) combined with a multispectral thermal sensor (e.g., SAVII) in low Earth orbit (LEO) **is part of an integrated mission concept** [described in Parts I and II] that is relevant to several panels, **<u>especially the climate variability panel</u>**.”