HyspIRI Decadal Survey VSWIR Science Questions

Dar A. Roberts (and a cast of thousands)

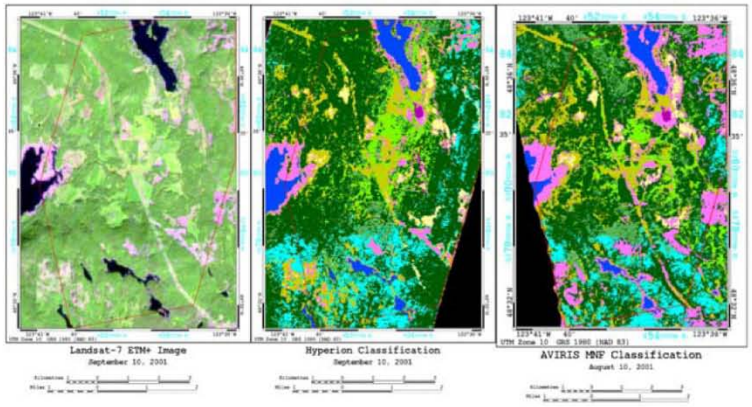
Over Arching Science Questions

- **VQ1 (Roberts/Middleton): 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 (Gamon): Ecosystem Function, Physiology, and Seasonal Activity**
  - **What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups, and diagnostic species? How are these being altered by changes in climate, land use, and disturbance?**
- **VQ3 (Ollinger): 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 (Asner/Knox): Changes in Disturbance Activity**
  - **How are disturbance regimes changing, and how do these changes affect the ecosystem processes that support life on Earth?**
- **VQ5 (Townsend/Glass): Ecosystem and Human Health**
  - **How do changes in ecosystem composition and function affect human health, resource use, and resource management?**
- **VQ6 (Green/Dierssen): Earth Surface and Shallow-Water Benthic Composition**
  - **What are the land surface soil/rock and shallow-water benthic compositions?**

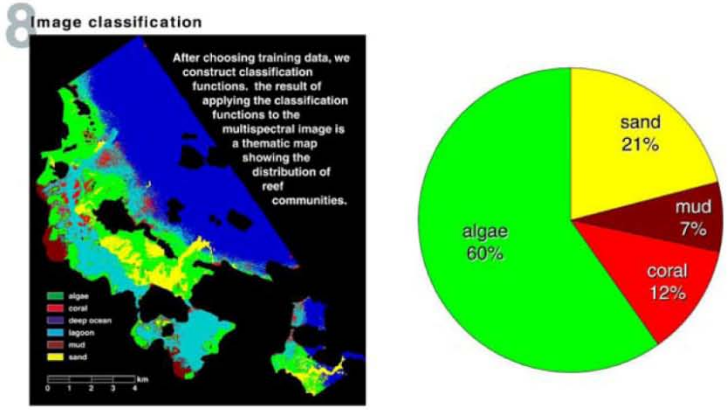
VQ1: Subquestions

- **VQ1a: How are ecosystems organized within different biomes associated with temperate, tropical, and boreal zones, and how are these changing? [DS 191, 203]**
- **VQ1b: How do similar ecosystems differ in size, species composition, fractional cover and biodiversity across terrestrial and shallow aquatic biomes? [DS 195]**
- **VQ1c: What is the current spatial distribution of ecosystems, functional groups, or key species within major biomes including agriculture, and how are these being altered by climate variability, human uses, and other factors? [DS 191, 203]**
- **VQ1d: What are the extent and impact of invasive species in terrestrial and shallow aquatic ecosystems? [DS 192, 194, 196, 203, 204, 214]**
- **VQ1e: What is the spatial structure and species distribution in observable phytoplankton blooms? [DS 201, 208]**
- **VQ1f: How do changes in coastal morphology and surface composition impact coastal ecosystem composition, diversity and function [DS 41]?**

VQ1a: How are ecosystems organized within different biomes associated with temperate, tropical, and boreal zones, and how are these changing? [DS 191, 203]



Classification of dominant plant functional types in the Pacific Northwest using Landsat, Hyperion and AVIRIS. From Goodenough et al., 2003.



Map of the distribution of important reef communities. From Hochberg.

Science Issue:

•Ecosystems play a critical role in the cycling of water, carbon, nitrogen and nutrients and by providing critical habitats to many organisms. While our knowledge of the large scale distribution of ecosystems is good, knowledge of their distributions at finer scales is generally poorer. Furthermore, the rate at which they are changing in response to multiple stressors, including anthropogenic disturbance and climate change is insufficient.

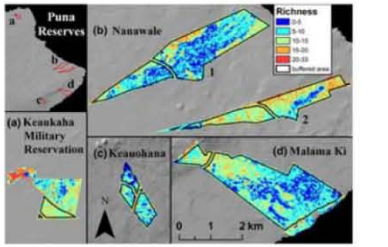
•*Tools:*

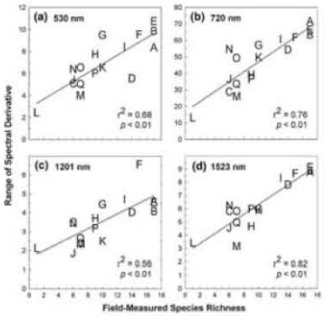
•Satellite observations from HyspIRI. Requires fine spectral sampling (~ 10 nm) from the ultra-violet to Short-Wave-Infrared (380-2500 nm) to discriminate functional types and species in terrestrial and aquatic ecosystems, correct for atmospheric impacts and retrieve bi-directional reflectance. Requires high signal to noise for aquatic systems (300:1 at 45Z, 0.01 reflectance target) and fine spatial resolution (at least 60 m) to map uniform patches in the landscape. Requires high frequency repeat sampling (19 days) to provide a minimum of one acquisition per season globally and improve discrimination of species through phenology.
•Requires radiometric stability for multi-year monitoring.
•Requires supplemental spectral libraries to inform mapping.

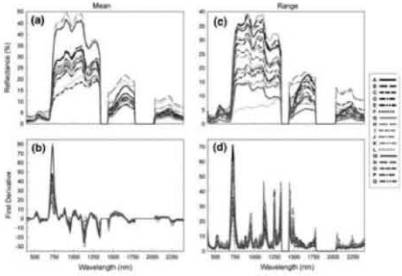
•*Approach:*

•Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer
•Develop seasonal compositing approaches to generate a seamless global product for terrestrial systems and coastal waters.
•Apply standard and developed classification algorithms for mapping ecosystems in terrestrial and coastal aquatic or inland water systems.
•Utilize mixing algorithms to estimate sub-pixel fractions of ecosystems
•Link to well established calibration/validation sites for validation
•Develop products that are readily assimilated in to models.

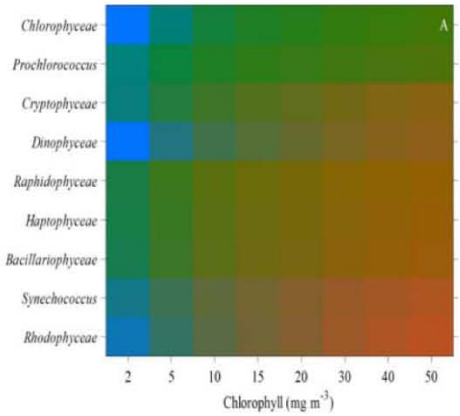
VQ1b: How do similar ecosystems differ in size, species composition, fractional cover and biodiversity across terrestrial and aquatic biomes and on different continents? [DS 195]

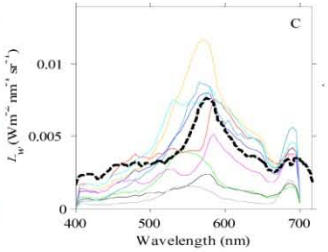






Spectral variability is directly related to canopy species diversity
From Carlson et al., 2007





Phytoplankton functional groups can be discriminated based on spectroscopic differences due to pigments.
From Dierssen et al., 2006.

Science Issue:

•Ecosystems differ in spatial extent, biophysical properties and in the types of organisms within them. The manner in which an ecosystem responds to changing environmental conditions and disturbance is, in part, dependent upon the organisms within the ecosystem. The resilience of an ecosystem to external stressors is also dependent upon organisms within the ecosystem. Biophysical attributes, such as fractional cover, and biodiversity measures are critical elements that quantify ecosystem function and response to environmental change.

•Tools:

•Satellite observations from HyspIRI. Requires fine spectral sampling (~ 10 nm) from the ultra-violet to Short-Wave-Infrared (380-2500 nm) to discriminate functional types and species in terrestrial and aquatic ecosystems, correct for atmospheric impacts and retrieve bi-directional reflectance. Requires high signal to noise for aquatic systems (300:1 at 45Z, 0.01 reflectance target) and fine spatial resolution (at least 60 m) to map uniform patches in the landscape. Requires high frequency repeat sampling (~19 days) to provide at least one acquisition per season globally, with preferably multiple acquisitions within a season.
•Requires radiometric stability for multi-year monitoring.
•Requires supplemental spectral libraries to inform mapping.

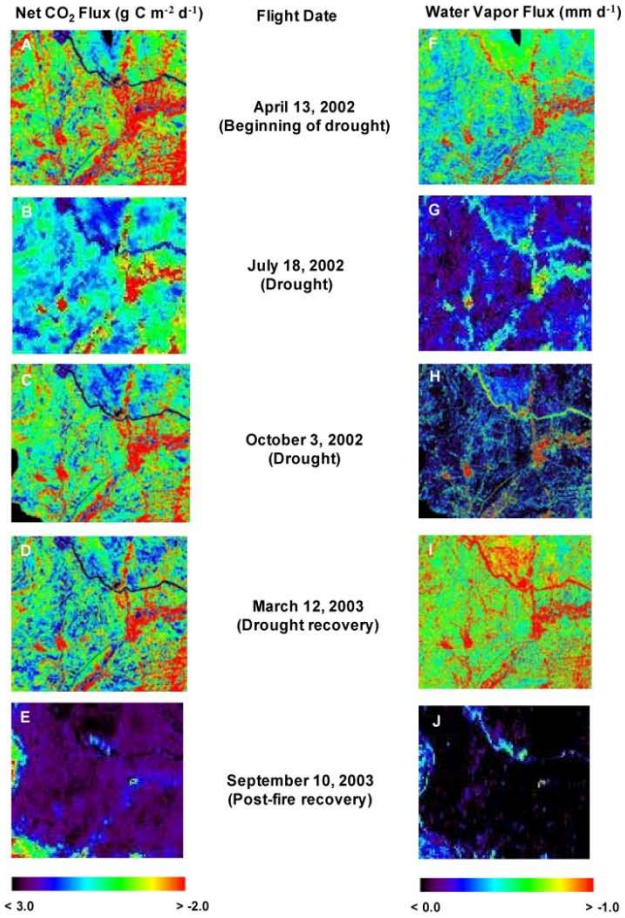
•Approach:

•Retrieve bi-directional reflectance and surface spectral radiance using atmospheric radiative transfer
•Develop seasonal compositing approaches to generate a seamless global product for terrestrial systems and coastal waters.
•Utilize mixing algorithms to estimate sub-pixel fractions of cover, including exposed soil, photosynthetic and non-photosynthetic components
•Develop spectroscopic means for quantifying biodiversity
•Link to well established calibration/validation sites for validation

VQ2: Subquestions

- **VQ2a: How does the seasonal activity of ecosystems and functional types vary across biomes (terrestrial and aquatic), geographic zones, or environmental gradients between the equator and the poles? How are seasonal patterns of ecosystem function being affected by climate change? [DS 205, 206, 210]**
- **VQ2b: How do seasonal changes affect productivity, carbon sequestration, and hydrological processes across ecosystems and agriculture? [DS 195, 205, 210]**
- **VQ2c: How do environmental stresses affect the physiological function of water and carbon exchanges at the seasonal time scale within ecosystems (including agriculture)? [DS 203, 206, 210]**
- **VQ2d: What is the environmental impact of aquatic plants and coral in inland and coastal water environments at the seasonal time scale? [DS 201, 208]**

How do environmental stresses affect the seasonality of physiological function of water and carbon exchanges within ecosystems? [DS 203, 206, 210]



Impacts of drought and fire on carbon and water vapor fluxes (Fuentes et al. 2006)(

Science Issue:

Changing disturbance patterns (drought, fire…) alter surface-atmosphere exchanges.

Tools:

Repeat sampling in key spectral bands providing input to flux models.

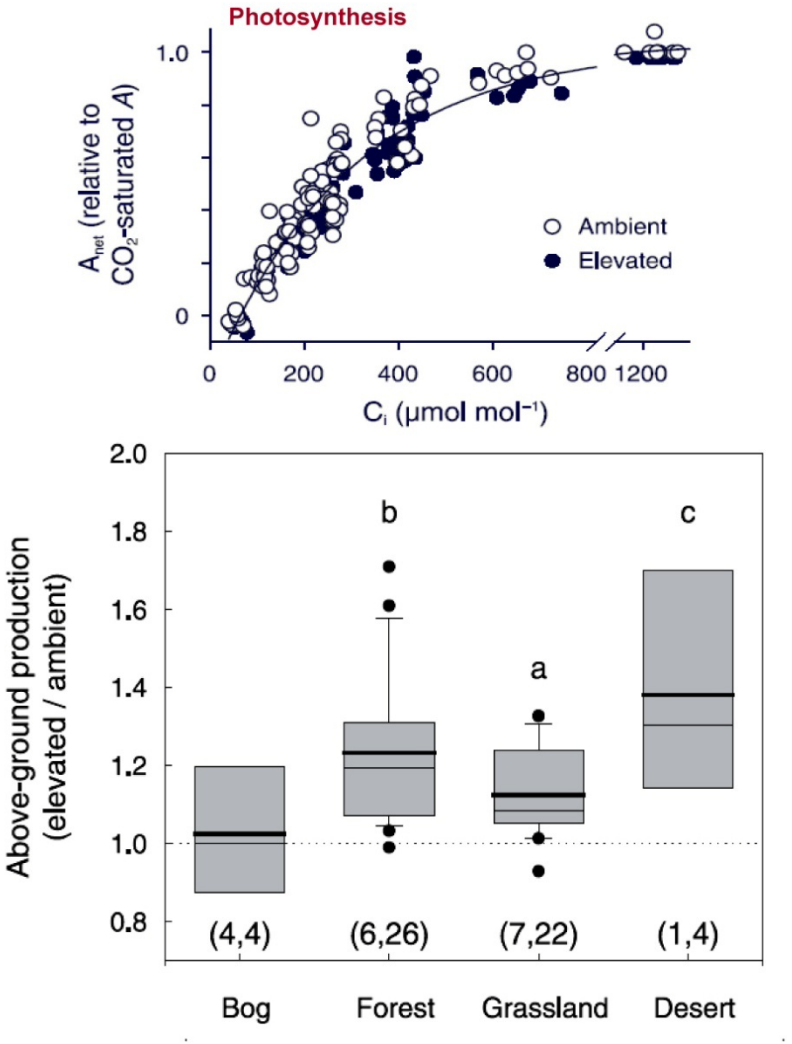
Approach:

Use time series to evaluate changing biosphere-atmosphere gas exchange.

VQ3: Subquestions

- **VQ3a: How do changes in climate and atmospheric processes affect the physiology and biogeochemistry of ecosystems? [DS 194, 201]**
- **VQ3b: What are the consequences of uses of land and coastal systems, such as urbanization and resource extraction, for the carbon cycle, hydrological cycle, nutrient fluxes and biodiversity functional composition? [DS 196, 197]**
- **VQ3c: What are the consequences of increasing nitrogen deposition for carbon cycling and biodiversity in terrestrial and coastal ecosystems? [DS 195, 196]**
- **VQ3d: How do changes in hydrology, pollutant inputs and sediment transport affect freshwater and coastal marine ecosystems? [DS 196]**
- **VQ3e: How do changing water balances affect carbon storage by terrestrial ecosystems? [DS 196]**
- **VQ3f: What are the key interactions between biogeochemical cycles and the composition and diversity of ecosystems? [195, 196]**
- **VQ3g: How do changes in biogeochemical processes feed back to climate and other components of the Earth system? [DS 190, 192, 195]**

VQ3a: How do changes in climate and atmospheric processes affect the physiology and biogeochemistry of ecosystems? [DS 194, 201]



Nowack et al. 2004

Science Issue:

Changes in climate, CO2 and other atmospheric processes can influence ecosystem function through a variety of mechanisms. These include temperature and CO2-induced changes in photosynthesis, altered rates of decomposition and nutrient cycling and changes in species composition and plant tissue chemistry resulting from a combination of the above. HyspIRI will greatly enhance our ability to predict, quantify and detect changes in these factors through a combination of approaches involving the composition, seasonality and canopy chemistry of ecosystems.

Tools:

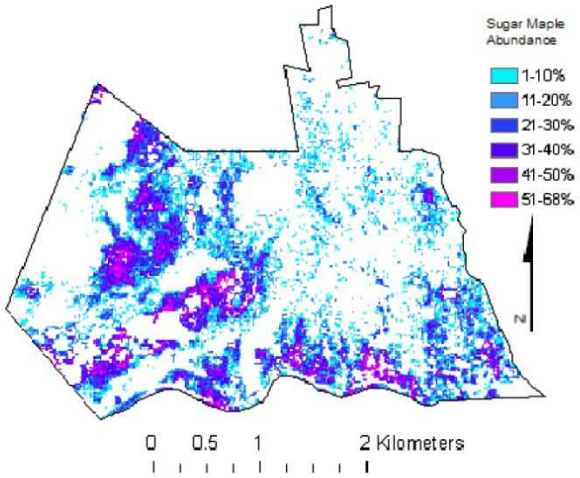
A wide variety of HyspIRI spectral bands used to along with ecosystem models and ancillary climate data.

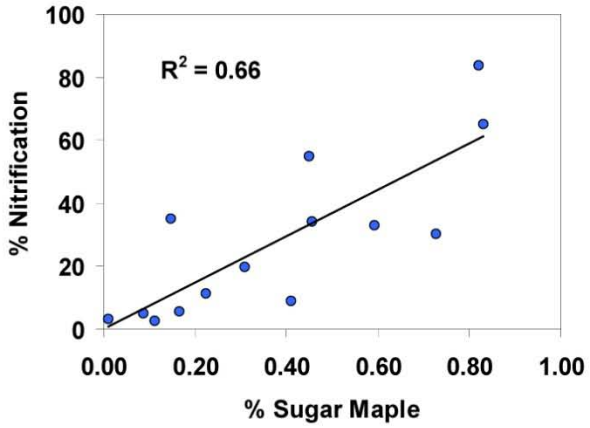
Approach:

HyspIRI-derived estimates of physiological properties and plant functional types combined with models designed to simulate long-term effects of changing climate and CO2.

VQ3f: What are the key interactions between biogeochemical cycles and the composition and diversity of ecosystems? [195, 196]

Species Composition and Biogeochemistry: Effects of Sugar Maple on the Nitrogen Cycle





Plourde et al. 2007

Science Issue:

Because plant species and functional groups often have distinct nutrient requirements and tissue chemistries, species composition and diversity are integral components of biogeochemical cycles. Plant species distribution and abundance have become vital to studies in biogeochemistry, where there is increasing evidence that changes in health and distribution of individual tree species have implications to C and N cycling.

Tools:

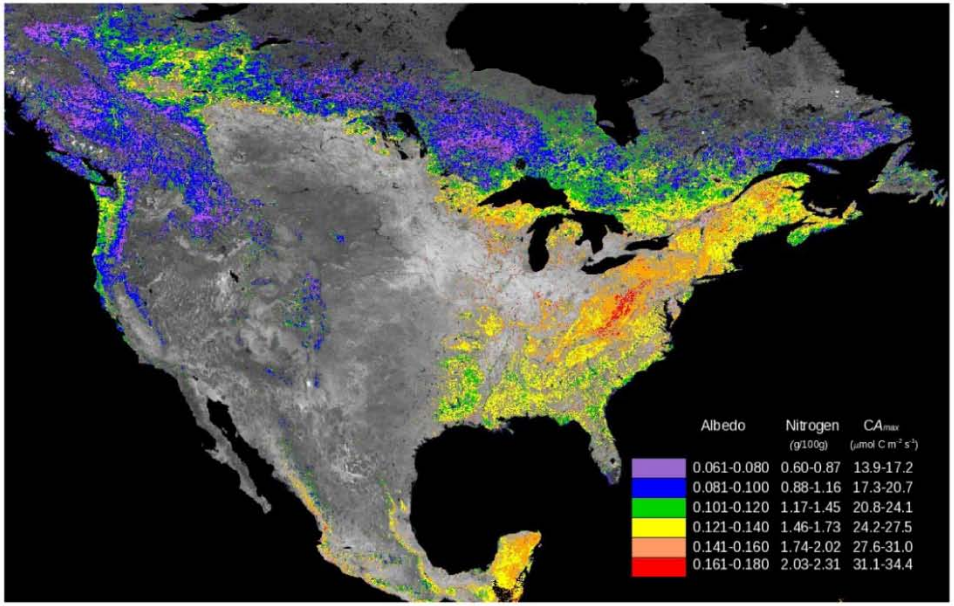
•HyspIRI's VSWIR sensor data, as well as data from airborne hyperspectral sensors and multispectral satellite data, such as Landsat.

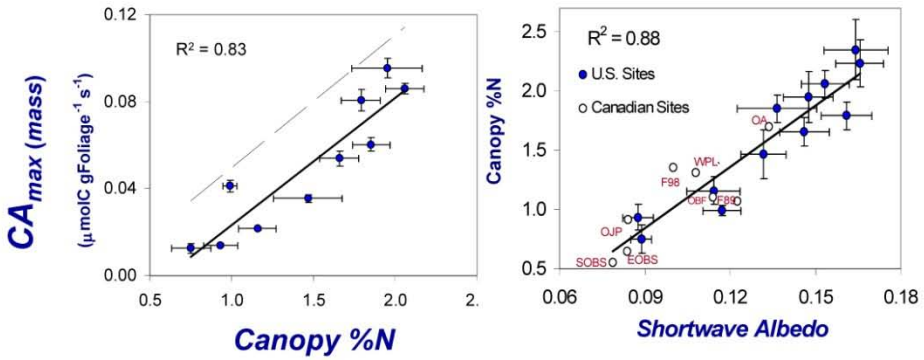
•Ecosystem models such as PnET.

Approach:

By identifying the distribution of species and functional groups, patterns in nutrient cycling can be identified and changes monitored over time. Species distribution data can also serve to better parameterize ecosystem models, resulting in improved predictions of numerous biogeochemical transformations.

VQ3g: How do changes in biogeochemical processes feed back to climate and other components of the Earth system? [DS 190, 192, 195]





Ollinger et al. 2008

Science Issue:

Because ecosystems are an integral component of the Earth's climate system, changes in composition and biogeochemistry can have important consequences for regional and global patterns of climate. Ecosystem-climate feedbacks can take place through alterations to the carbon cycle, which influences atmospheric CO2, or through changes in vegetation surface properties such as albedo.

Tools:

The high resolution and full spectral coverage of HyspIRI's VSWIR bands allows simultaneous detection of physiological properties that control C assimilation such as the the photochemical reflectance index (PRI) and foliar %N as well as vegetation albedo and other surface properties.

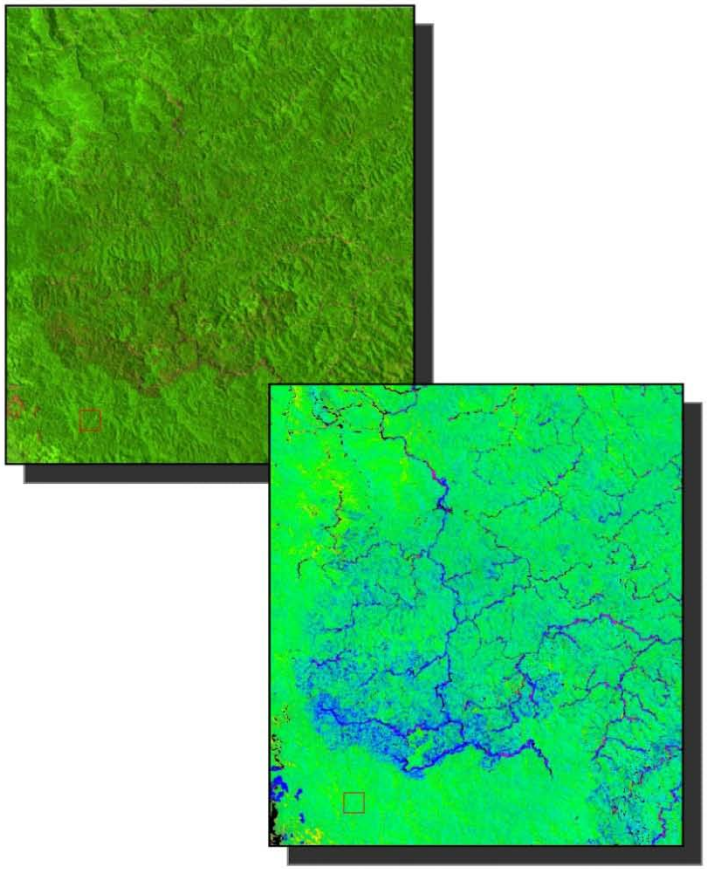
Approach:

Improved detection of vegetation physiology and surface properties to **(a)** provide input for land surface-climate models and (b) provide a baseline for future change detection analyses.

VQ4: Subquestions

- **VQ4a: How do patterns of abrupt (pulse) disturbance vary and change over time within and across ecosystems?**
- **VQ4b: How do climate changes affect disturbances such as fire and insect damage? [DS 196]**
- **VQ4c: What are the interactions between invasive species and other types of disturbance?**
- **VQ4d: How are human-caused and natural disturbances changing the biodiversity composition of ecosystems, e.g.: through changes in the distribution and abundance of organisms, communities, and ecosystems?**
- **VQ4e: How do climate change, pollution and disturbance augment the vulnerability of ecosystems to invasive species? [DS 114,196]**
- **VQ4f: What are the effects of disturbances on productivity, water resources, and other ecosystem functions and services? [DS 196]**
- **VQ4g: How do changes in human uses of ecosystems affect their vulnerability to disturbance and extreme events? [DS 196]**

VQ4a: How do patterns of abrupt (pulse) disturbance vary and change over time within and across ecosystems?



Hyperion's spectral measurements from the NASA EO-1 technology demonstration mission reveal rainforest disturbance caused by logging and fire.

Science Issue:

Natural and human-driven disturbances are not rare occurrences in ecosystems; they are the norm. Disturbances such as storms, mud slides, water spouts, fire and insect outbreaks shape ecosystems and the flow of materials between terrestrial and aquatic realms, yet it remains difficult to resolve the responses of ecosystems to these and many other types of disturbance. Biophysical and chemical attributes of ecosystems change with and respond to disturbance, thus large-scale measurements of key parameters such as fractional material cover, nutrients and water properties can reveal changing disturbance patterns over time.

Tools :

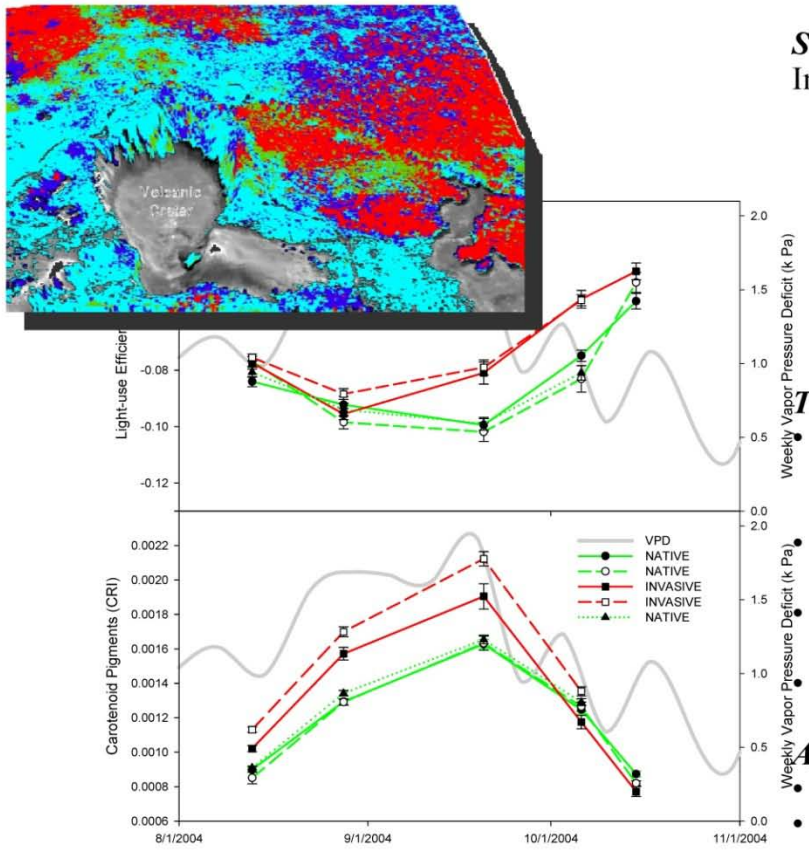
Spectral measurements from HyspIRI covering the 400 to 2500 nm wavelength range at 10 nm intervals (terrestrial); 380 to 900 nm at 10nm intervals (aquatic)

- 95% spectral cal uniformity
- SNR 600 VNIR, 300 SWIR (23.5ZA 0.25R)
- 14 bit precision: >95% abs cal: > 98% on-orbit stability
- no saturation of ecosystem targets
- < 2% polarization sensitivity 380 to 700 nm
- > 99% linearity 2 to 98% saturation
- ≤ 60 m spatial sampling
- > 95% spectral IFOV uniformity
- < 20 day revisit to minimize cloud obscuration

Approach:

- Measure the spectral properties of ecosystems over time.
- Use spectral signature-based algorithms and modeling approaches to convert spectra to structural and chemical properties of ecosystems.
- Accurate atmospheric characterization and correction is a critical enable requirement.

VQ4c: What are the interactions between invasive species and other types of disturbance?



Combining NASA AVIRIS (top) and multi-temporal Hyperion (graphs) revealed that invasive trees (red lines) out-grow native trees (green lines) during periods of climate stress (gray line)

Science Issue:

Invasive species are both a cause and consequence of ecological disturbance. Climate change, air and water pollution, and physical disturbance can alter the vulnerability of ecosystems to the introduction and proliferation of invasive species. Spatially extensive, multi-temporal information is required to quantify, track and understand how human activities change the distribution of invasive species at regional and global scales.

Tools :

- Multi-temporal measurements from HyspIRI covering the 400 to 2500 nm wavelength range at 10 nm intervals (terrestrial); 380 to 900 nm at 10nm intervals (aquatic)
- Ground network and atmospheric measurements of climate variables, pollutant concentrations, winds, etc.
- Spectral libraries of plant functional types and key invasive species
- Regional (mesoscale) climate models

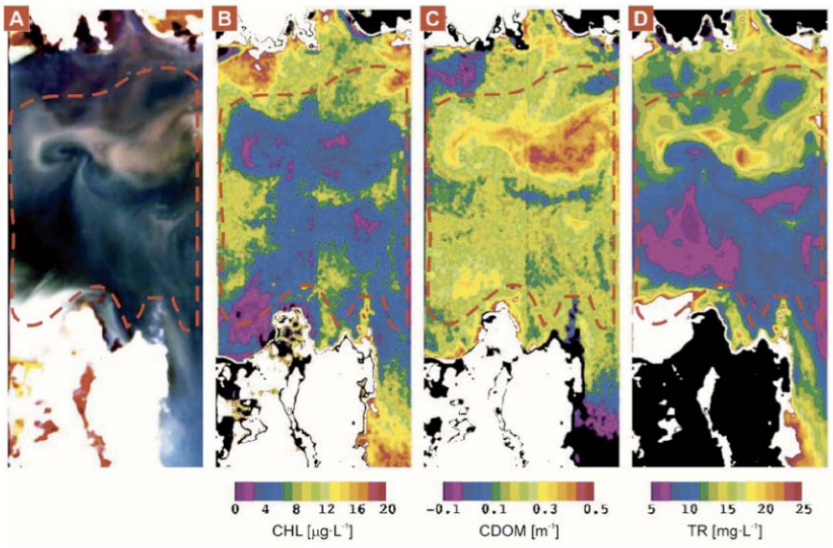
Approach:

- Measure the spectral properties of ecosystems over time.
- Use spectral signature-based algorithms and modeling approaches to convert spectra to plant functional types (often species) and spectral-biochemical metrics of vegetation growth and mortality.
- Combine data derived from HyspIRI with data from climate sensors, ground observation networks, and models.

VQ5: Subquestions

- **VQ5a: How do changes in ecosystem composition and function affect the spread of infectious diseases and the organisms that transmit them[DS155, 160, 161]? For Example, tracking malaria by water fraction, Hantavirus**
- **VQ5b: How will changes in pollution and biogeochemical cycling alter coastal and inland water quality?**
- **VQ5c: How are changes in ecosystem distribution and productivity linked to resource use, and resource management? Forestry management, fire effects, biofuels, agricultural management**
- **VQ5d: How will changes in climate and pollution affect the health and productivity of aquatic and agricultural resources?**
- **VQ5e: What are the economic and human health consequences associated with the spread of invasive species?**
- **VQ5f: How does the spatial pattern of policy, environmental management, and economic conditions correlate with the state and changes in ecosystem function and composition? (DS 155 [5-5]?, 230 [8-7])**
- **VQ5g: What are the impacts of flooding and sea-level rise on ecosystems, human health, and security? [DS 195, 224, 227, 348, 357]**

VQ5b: How will changes in pollution and biogeochemical cycling alter coastal and inland water quality?



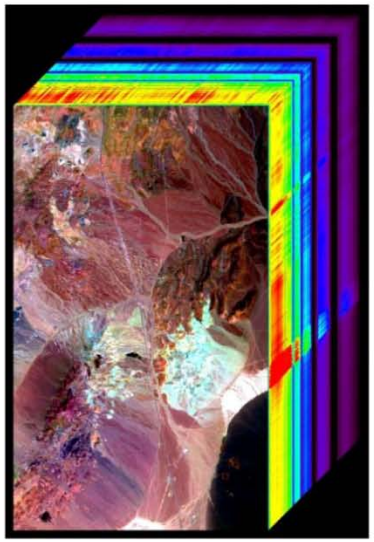
(a) Image derived from filtered Hyperion scene over Deception Bay and processed to estimate concentrations of (b) Chlorophyll, (c) Chromophoric Dissolved Organic Material (CDOM), and (d) tripton (TR). The dashed red line delimits the clear-sky, optically deep water pixels in this scene.

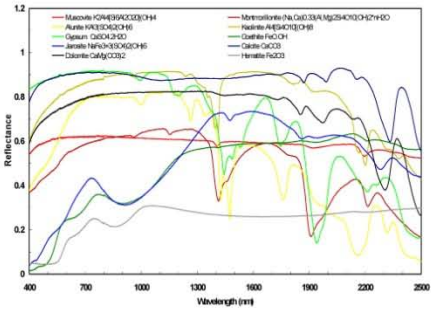
- Science Issue
  - Characterize conditions associated with microorganisms as well as suspended inorganic materials in areas at water/land interface
- Tools
  - Contiguous spectral measurement from 400 to 2500 nm at 10 nm spatial sampling at 60 m with high signal-to-noise ratio and with excellent spectral and IFOV uniformity.
- Approach
  - Measure and monitor
    - Chlorophyll concentration (related to eutrophication)
    - CDOM
    - Particulate matter
    - Harmful algae blooms
  - Ability to capture seasonal variations is critical

VQ6: Subquestions

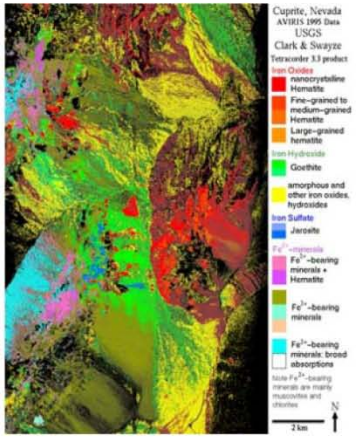
- **VQ6a: What is the distribution of the primary minerals and mineral groups on the exposed terrestrial surface? [DS 218]**
- **VQ6b: What is the bottom composition (sand, rock, mud, coral, algae, SAV, etc) of the shallow water regions of the Earth?**
- **VQ6c: What fundamentally new concepts for mineral and hydrocarbon research will arise from uniform and detailed global geochemistry of the exposed rock/soil surface [DS227]**
- **VQ6d: What changes in bottom substrate occur in shallow coastal and inland aquatic environments? [DS 25]**
- **VQ6e: How can measurements of rock and soil composition be used to understand and mitigate hazards? [DS 114,227]**

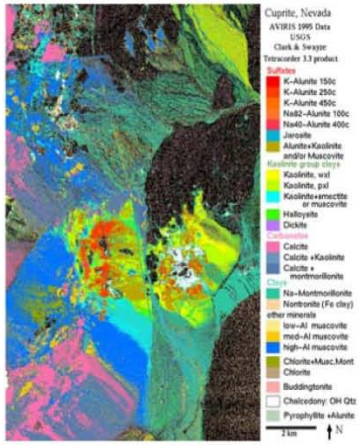
VQ6a: What is the distribution of the primary minerals and mineral groups on the exposed terrestrial surface? [DS 218]





Left: Imaging spectrometer measurements of exposed rock and soil. Above: Spectral signatures of select rock and soil forming minerals.





Above left and right: Spectroscopically derived maps of minerals in the 400 to 1500 nm and 1500 to 2500 nm spectral regions.

•

cience Issue

–

he composition and distribution of the exposed rock and soil substrate of the terrestrial surface is not accurately known globally. Surface rock and soil composition is closely linked to an understanding of resources, hazards and is a major critical element of the Earth system.

•

ools

–

ontiguous spectral measurement from 400 to 2500 nm at 10 nm spatial sampling at 60 m with high signal-to-noise ratio and with excellent spectral and IFOV uniformity.

•

pproach

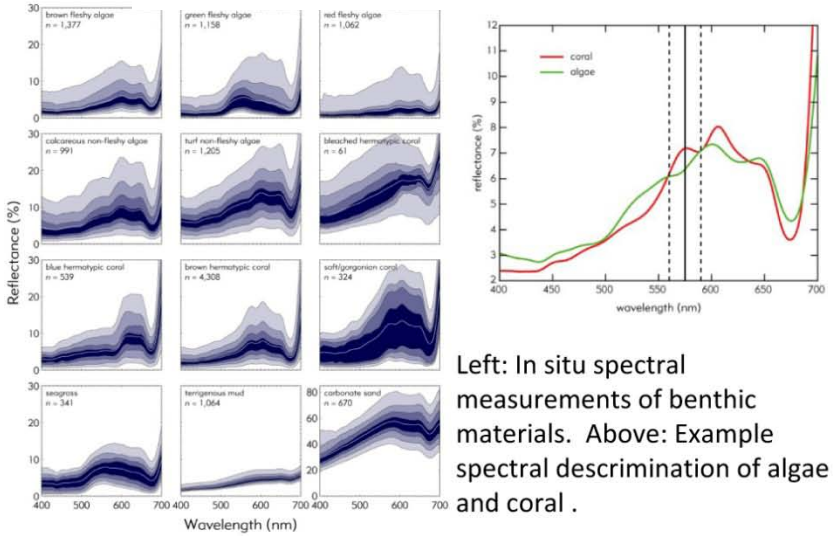
–

easure the exposed surface rock and soil compostions globally.

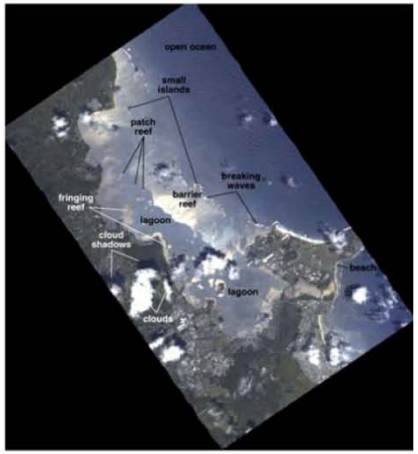
–

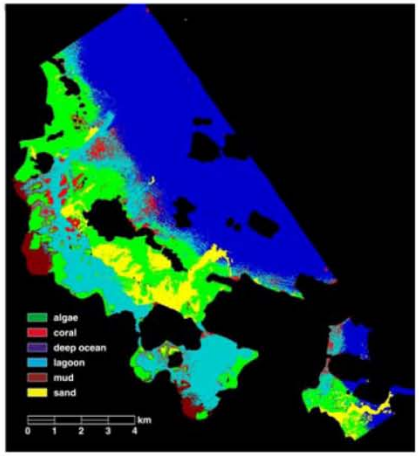
easure the available rock forming and

VQ6b: What is the bottom composition (sand, rock, mud, coral, algae, SAV, etc) of the shallow water regions of the Earth?



Left: In situ spectral measurements of benthic materials. Above: Example spectral descrimination of algae and coral .





Above left: Imaging spectrometer measurements of Kaneoe Bay, Hawaii. Right: Shallow water bottom composition derived from spectral measurements

•

cience Issue

–

he composition, distribution and seasonal variability of the materials in the observable shallow water coastal regions are poorly understood globally. The habits and resources of the coastal zone is close tied to the composition and structure of the substrate.

•

ools

–

easonal measurement of the contiguous spectral signature from 400 to 800 nm at 10 nm spatial sampling at 60 m with high signal-to-noise ratio and with excellent spectral and IFOV uniformity.

•

pproach

–

easure the optically available spectral signature of the coastal zone globally through several seasons

–

se spectral signature based algorithms and forward inversion approach to measure and

Climate Relevance

- **Climate plays the central role in controlling the distribution of organisms and their function and plays a major role in weathering, soils and biogeochemical inputs**
- **Climate-surface feedbacks represent some of the greatest uncertainties in our knowledge of the consequences and drivers of climate change**
  - **Biospheric feedbacks**
  - **Ice-albedo feedbacks**
- **Improved compositional and biogeochemical mapping and physiological monitoring is critical to establish a baseline for global ecosystems and quantify change in response to climate variability**
  - **HyspIRI provides the most comprehensive set of measurements to quantify these**
    - **HyspIRI VSWIR will measure and return data for the entire terrestrial surface every 19 days**
      - **Other planned missions return 1-2%**
    - **HyspIRI is a third generation, high fidelity heritage instrument with very high SNR and uniformity**

Questions?