Surface Biology and Geology (SBG)

Visible to Short Wavelength InfraRed (VSWIR) Imaging Spectroscopy Science Research, Applications, and Instrument Concept

Robert O. Green, David R. Thompson, and Team

Jet Propulsion Laboratory, California Institute of Technology

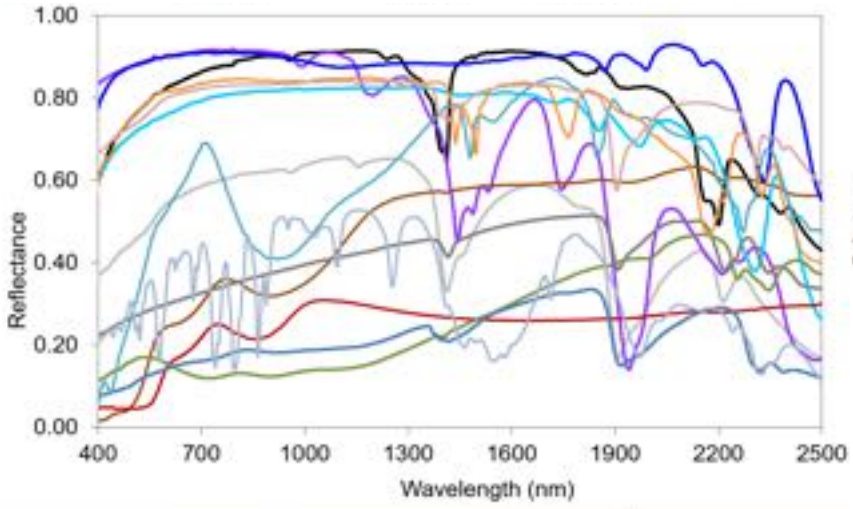
SBG VSWIR Science and Applications Study and Concept Team

Alan Paquette, Ana Pena, Anh Nguyen, Ben Phillips, Benjamin Poulter, Bradley Doorn, Charles Miller, Christine Lee, Dave Schimel, David Thompson, David Young, Gary Jedlovec, Glynn Hulley, Ian Brosnan, James Price, Jeffrey Luvall, Jonathan Chrone, Joseph Coughlan, Julia Breed, Kathleen Dejwakh Kerry Cawse-Nicholson, Kevin Turpie, Kimberley Miner, Kurtis Thome, Laura Lorenzoni, Liane Guild, Mandy Branam, Michael Egan, Michelle Gierach, Nancy Glenn, Paul Lundgren, Paul Speth, Philip Townsend, Raymond Kokaly, Robert Connerton, Robert Green, Ryan Pavlick, Ryan Spackman, Scott Johnston, Shawn Serbin, Simon Hook, Stephanie Schollaert Uz, William Van Orden, Woody Turner, Xu Liu, and others

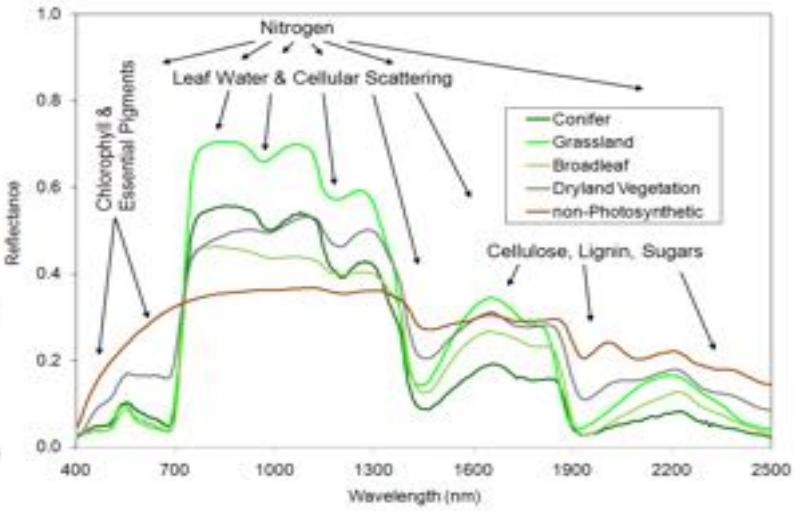
Ames Research Center
Boise State University
Brookhaven National Laboratory
Goddard Space Flight Center
Jet Propulsion Laboratory
Langley Research Center
Marshall Space Flight Center
NASA Headquarters
U.S Geological Survey
University of Maryland, Baltimore County
University of Wisconsin–Madison

The Earth System is Rich with Spectroscopic Signatures for New Global Decadal Survey Science Research and Applications

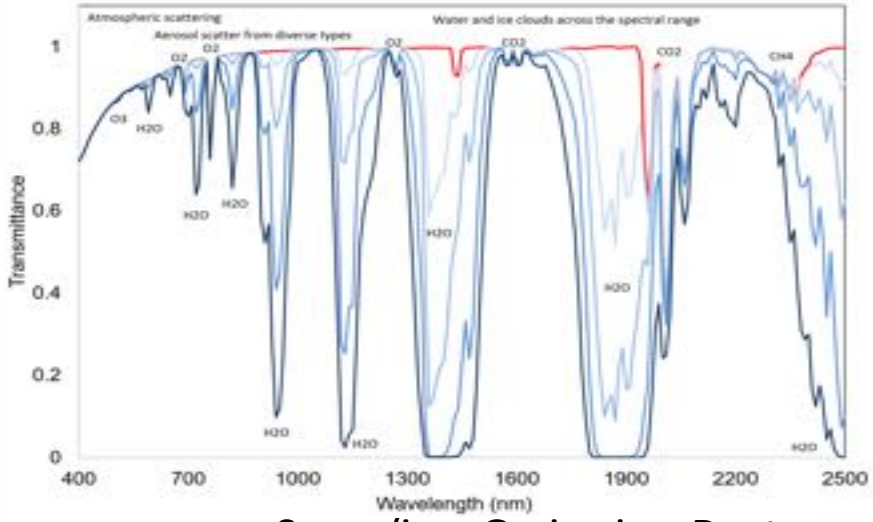
Geology: Mineral Spectral Signatures



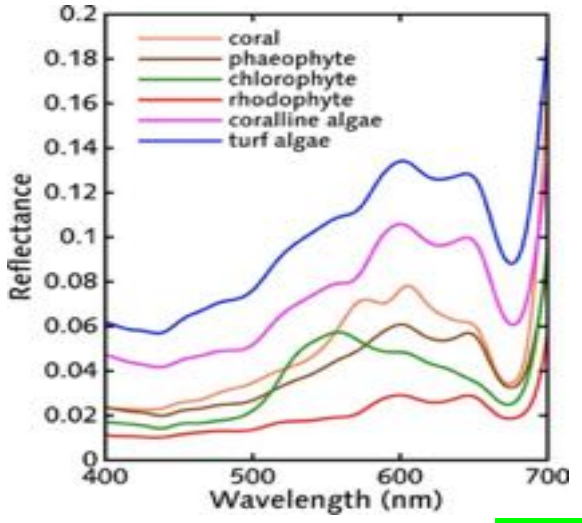
Ecosystems: Diversity of Signatures



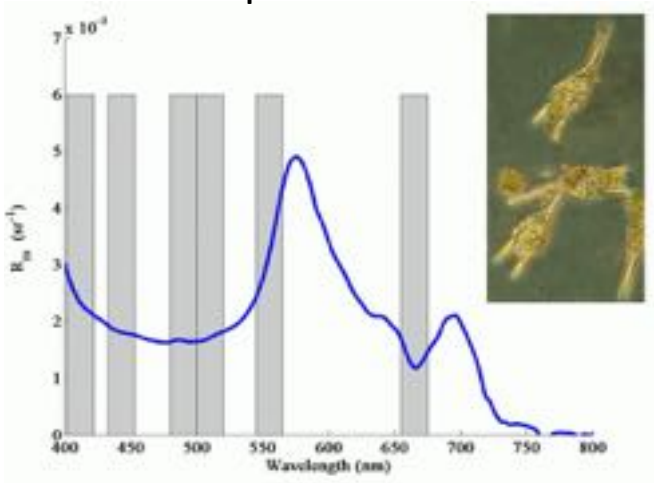
Atmosphere: Gases, Aerosols, Clouds



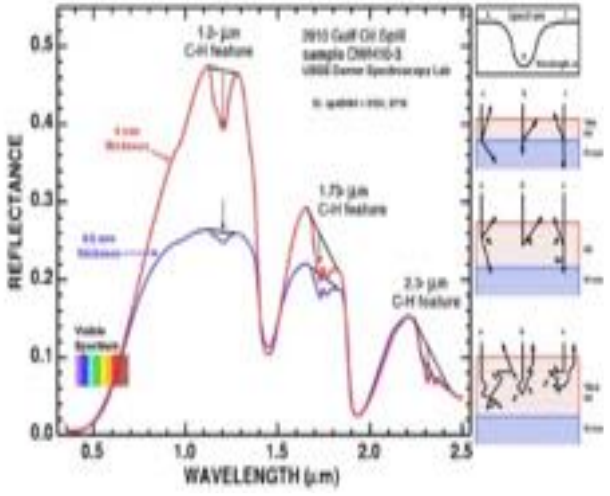
Aquatic: Benthic Materials



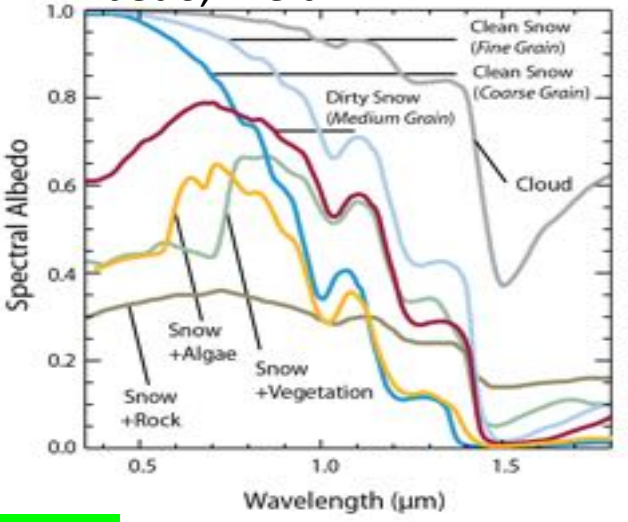
Aquatic: Algal Biomass and Composition



Hazard/Disaster Signatures: Gulf Oil Spill Example



Snow/ice: Grain size, Dust, Albedo, Melt



A Google Scholar search on “AVIRIS” returns > 35,000 results

Decadal Survey SBG VSWIR Imaging Spectroscopy Traceability

Delivers "Most Important and Very Important" Objectives Across the Focus Areas

ECOSYSTEMS AND NATURAL RESOURCES

E-1. What are the structure, function, and biodiversity of Earth's ecosystems, and how and why are they changing in time and space?
E-2. What are the fluxes of carbon, water, nutrients, and energy between ecosystems and the atmosphere, the ocean, and the solid Earth, and how and why are they changing?
E-3. Fluxes within ecosystems. What are the within ecosystems, and how and why are they changing?

SOLID EARTH

S-1. How can large-scale geological hazards be accurately forecast in a socially relevant time frame?
S-2. How do geological disasters directly impact the Earth system and society following an event?

HYDROLOGY

H-1. How is the water cycle changing?
H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally and globally.
H-4. Hazards, extremes, and sea level rise. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events.

CLIMATE

C-3. How large are the variations in the global carbon cycle and what are the associated climate and ecosystem impacts?

WEATHER

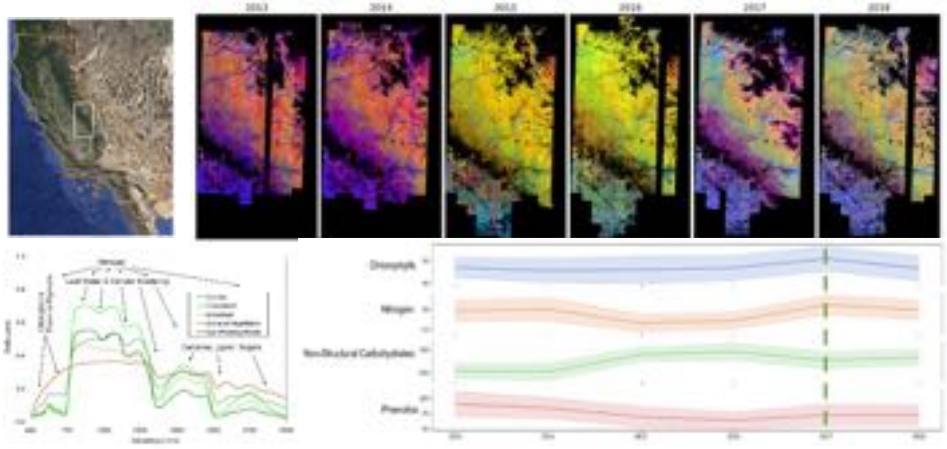
W-3. How do special variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia and water) modify transfer between domains?

Suggested Decadal Survey Observable from page B-17: Primary Observable: Chemical properties of vegetation and aquatic biomass, and Soils Land, inland aquatic, coastal zone, and shallow coral reef: Spectral radiance (10 nm; 380-2500nm); GSD = 30-45 m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms. High-fidelity imaging spectrometer (150-200 km swath from sun-sync LEO).

New Global Science Research Called for in the Decadal Survey Evidence of Low Risk from Completed Local/Regional Studies

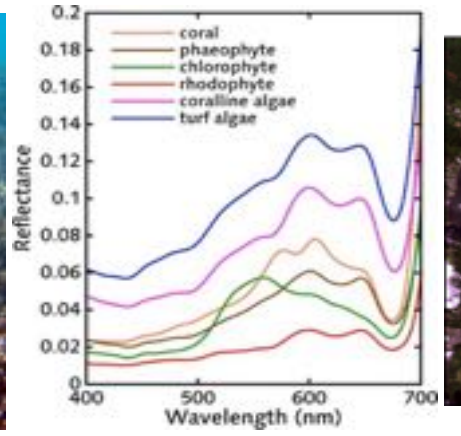
Terrestrial Ecology

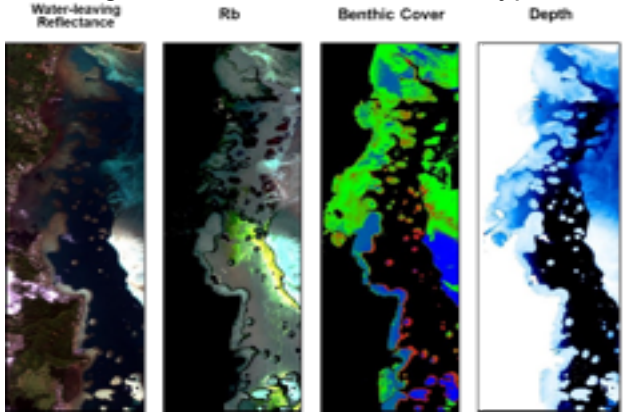
New understanding of drought impact on ecosystem traits.



Aquatic Ecology

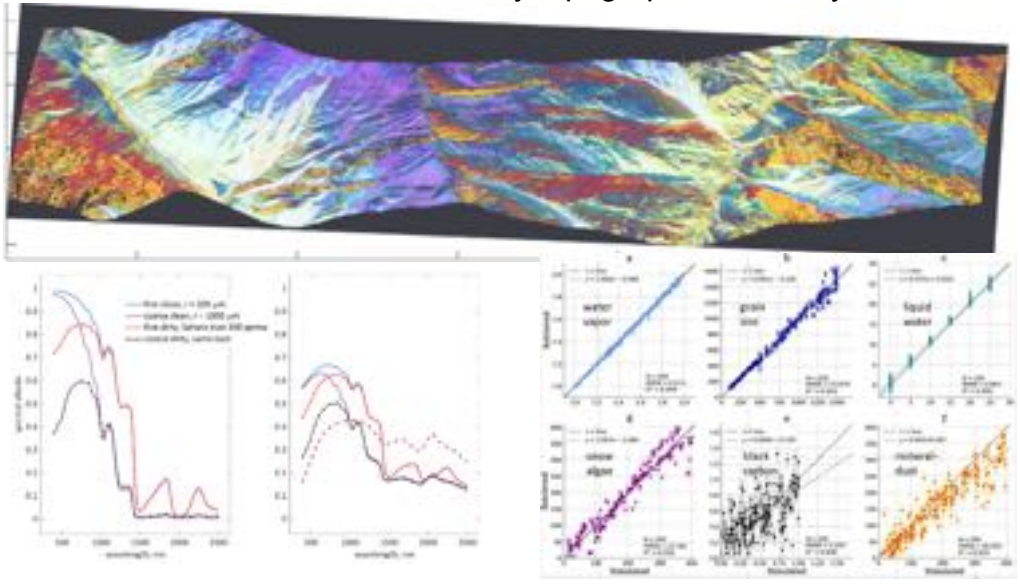
Composition and condition of benthic habitats including corals. Algal biomass and functional type.





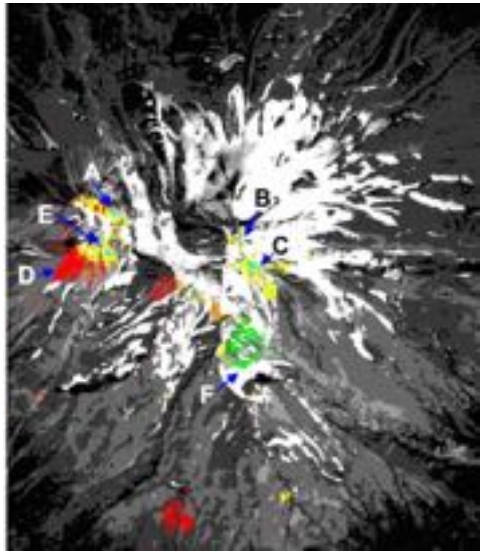
Hydrology

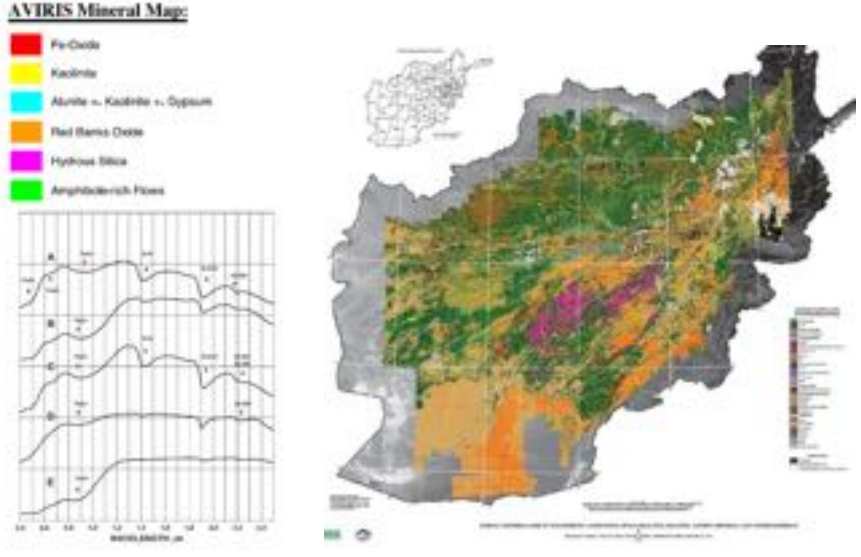
Understand and quantify snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability



Geology

Potential debris flow source areas identified with imaging spectroscopy on Mount Shasta volcano, California. Afghanistan geology from airborne imaging spectrometer observations.





Societal Benefit Applications from Decadal Survey VSWIR Imaging Spectroscopy

AGRICULTURE, FOOD SECURITY AND SURFACE WATER MANAGEMENT

Information on crop health to inform optimized fertilization
Improve water supply management through characterization of snow properties and reservoir inflows
Information to reduce the impacts of drought, such as crop loss and famine, on global scales

WATER QUALITY AND COASTAL ZONES

Support early detection of and response to harmful algal bloom formation
Protect sensitive aquatic habitats by monitoring/reducing water pollutant loading, particular in coral reefs and other sensitive ecosystems

CONSERVATION

Support biodiversity understanding and protections by mapping invasive species composition, structure, distribution; support removal and restoration
Monitoring of endangered species habitat; provide alerts of disease mortality of impacted vegetation, including insect infestation
Biodiversity hotspots, priority conservation areas, 30 x 30 plans

WILDFIRE RISK AND RECOVERY

Fuel mapping (cover type, extent, status) for wildfire danger management
Post fire severity assessment and recovery, including prediction of areas with higher likelihood of debris flows

DISASTERS AND HAZARDS

Detect and track oil spill events and
Mine waste hazard mapping before and after events
Toxic mineral mapping and related airborne dust impacts

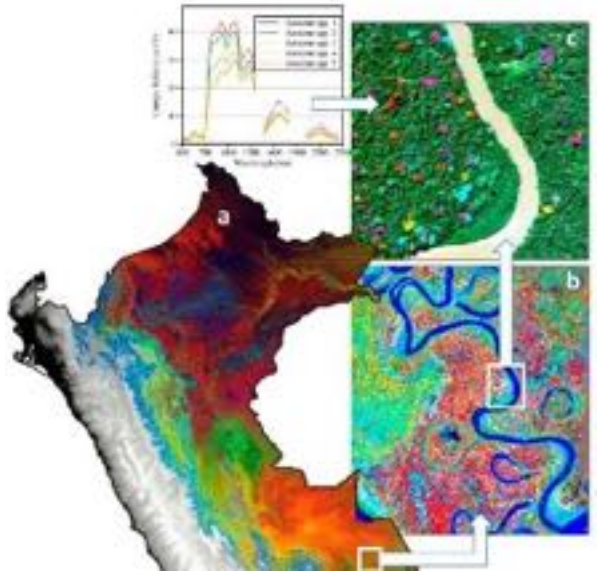
GEOLOGY APPLICATIONS

Mineral mapping for exploration efforts and reduction of environmental hazards
Landslide risk assessment with improved surface mineralogy knowledge and land cover maps
Weak mineral zones in active volcanos to predict debris flow potential

New Global Applications for Societal Benefit
Evidence of Low Risk from Local/Regional Studies

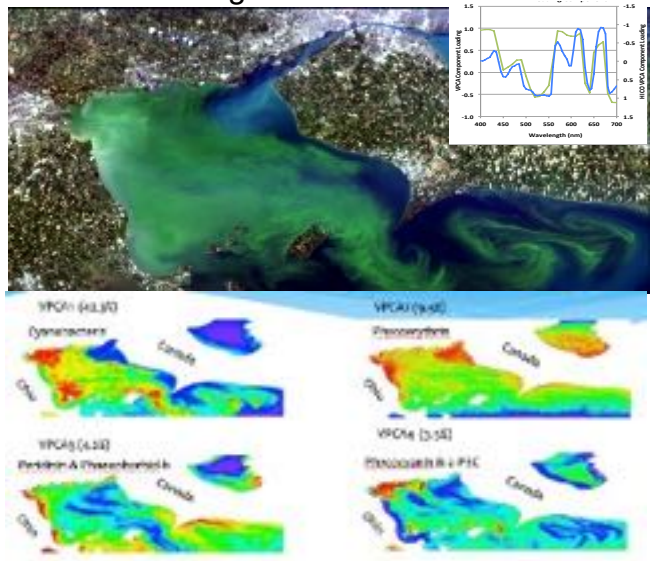
Biodiversity

Biodiversity mapping in Peru for conservation



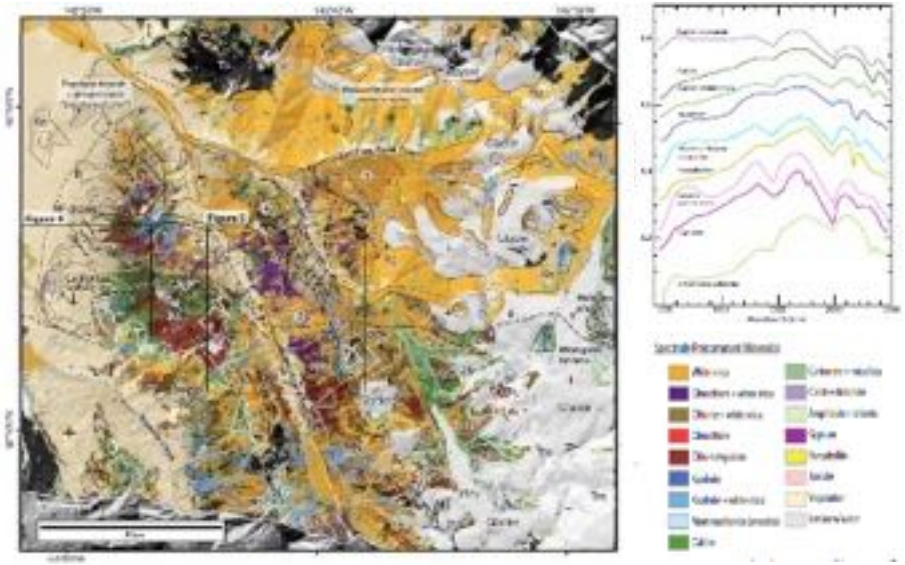
Harmful Algal Blooms

Harmful algal blooms in lake Erie



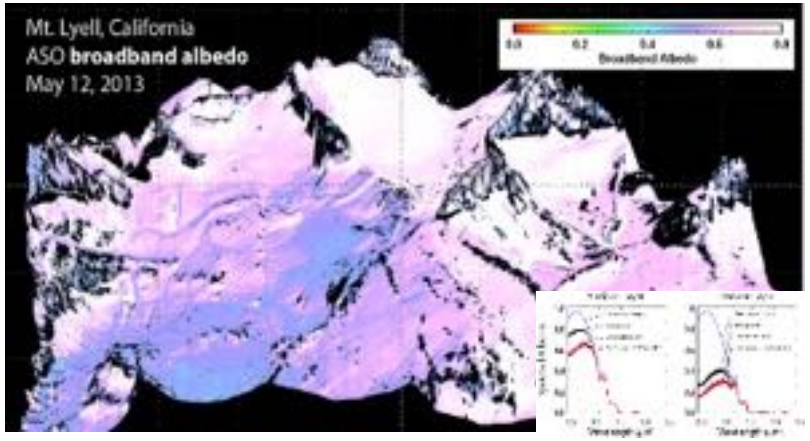
Mineral Resources

Mineral exploration in Alaska



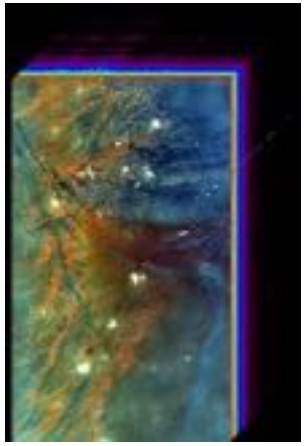
Water Resources

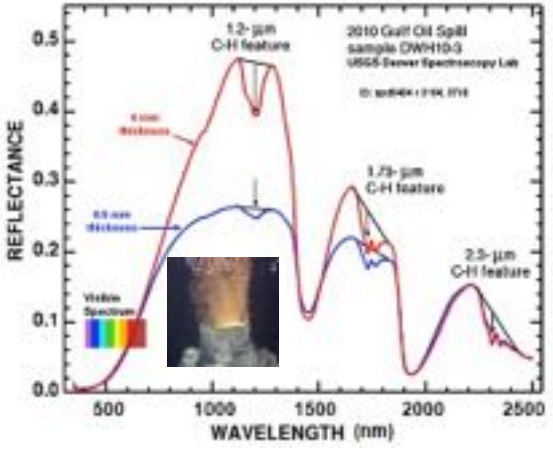
Snow melt prediction in California



Disasters/Hazards

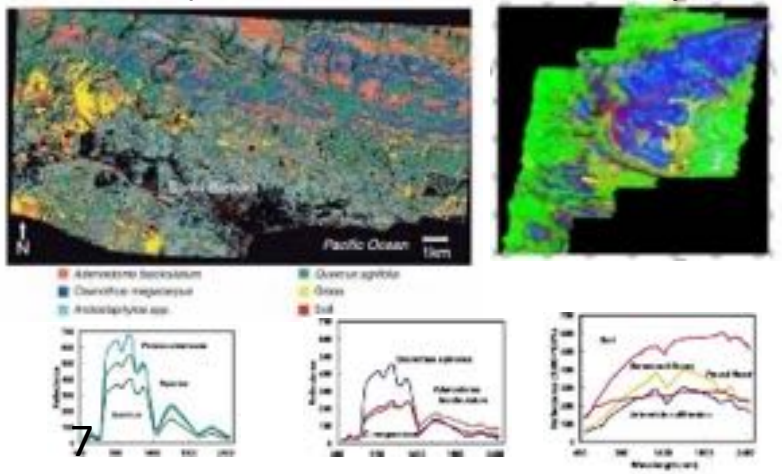
Gulf oil spill extend, thickness, and volume.





Fires

Fuel composition/condition and burn severity



Portion of Refined SBG Research and Applications Traceability Matrix (V24)

Decadal Survey Science Topics, Questions, Objectives, and Geophysical Observables					SBG Example Geophysical Variables and Capabilities							
Topic	DS Science Question	DS Science/Application Objective	Priority	DS Suggested Biogeophysical Parameters	Key SBG Geophysical Parameters	VSWIR Spatial	VSWIR Temporal	VSWIR Range	VSWIR Sensitivity	VSWIR/TIR Coincidence	References	Enabled Applications * = With 48 hr Latency	DO Synergies
Global Hydrological Cycles and Water Resources	**H-1**. How is the water cycle changing? Are changes in evapotranspiration and precipitation accelerating, with greater rates of evapotranspiration and thereby precipitation, and how are these changes expressed in the space-time distribution of rainfall, snowfall, evapotranspiration, and the frequency and magnitude of extremes such as droughts and floods?	H-1a. Develop and evaluate an integrated Earth system analysis with sufficient observational input to accurately quantify the components of the water and energy cycles and their interactions, and to close the water balance from headwater catchments to continental-scale river basins.	Most Important	Energy and water fluxes in the boundary or surface layer: solar (direct and reflected) and longwave radiation (downwelling and emitted), sensible and latent heat exchange, and soil heat flux.	Sensible and latent heat exchange, and soil heat flux - See H-2a, R35							
		H-1c. Quantify rates of snow accumulation, snowmelt, ice melt, and sublimation from snow and ice worldwide at scales driven by topographic variability.	Most Important	Snow and glacier albedo and surface temperature. Spectral albedo of suxbpixel snow and glaciers at weekly intervals to an accuracy to estimate absorption of solar radiation to 10%.Ice/snow temperature to ± 1K. At spatial resolution of 30 to 100 m.	Snow and ice coverage fraction (cryosphere)	≤30 m	≤8 days for global coverage*	≤380 - ≥2500 nm, @ ≤10nm	≤10% Absolute accuracy		R1, R8, R12, R26	EA1, EA2, EA4*, EA5*, EA6*	
					Snow spectral albedo From Visible to Thermal (cryosphere)	≤30 m	≤8 days for global coverage*	≤380 - ≥2500 nm, @ ≤10nm	≤10% Absolute accuracy	VNIR within 3 days	R1, R8, R12, R26	EA1, EA2, EA4*, EA5*, EA6*	
					Snow surface temperature (cryosphere)						R4, R5, R8, R26	EA3	
	H-2. How do anthropogenic changes in climate, land use, water use, and water storage, interact and modify the water and energy cycles locally, regionally and globally and what are the short- and long-term consequences?	**H-2a.** Quantify how changes in land use, water use, and water storage affect evapotranspiration rates, and how these in turn affect local and regional precipitation systems, groundwater recharge, temperature extremes, and carbon cycling.	Very Important	Latent heat flux. 3 (desirable) to 6 hour (useful) resolution during daytime intervals and at 1 km spatial scale with better than 10 W/m2 accuracy. Requires temperature of soil and vegetation separately at 40-100m spatial resolution, accuracy of +/- 1K, at temporal frequency to resolve the diurnal cycle. Albedo of soil and vegetation separately to an accuracy to estimate absorption of solar radiation to 10 W/m2, at weekly intervals at field scale, 30-60m spatial resolution.	VSWIR Spectral surface reflectance	≤60 m	≤8 days for global coverage*	≤380 - ≥2500 nm, @ ≤10nm			R2, R3, R7, R8, R14, R27,R28	EA3, EA8*, EA9, some E1 a. applications.	A-CCP
					Evapotranspiration rates of vegetation canopies with 10% uncertainty (multiple times of day)	≤30 m		VNIR multiband		VNIR within 3 days	R4, R5, R8, R13, R23, R27, R32, R36	EA3, EA7*, EA12, EA13, EA23	A-CCP
					Surface temperature (multiple times of day)						R4, R5, R8, R27	EA8*, EA12, EA13, EA14*, EA30*	A-CCP
	H-4. Hazards, Extremes, and Sea-level Rise. How does the water cycle interact with other Earth system processes to change the predictability and impacts of hazardous events and hazard chains (e.g., floods, wildfires, landslides, coastal loss, subsidence, droughts, human health, and ecosystem health), and how do we improve preparedness and mitigation of water-related extreme events?	**H-4a.** Monitor and understand hazard response in rugged terrain and land margins to heavy rainfall, temperature and evaporation extremes, and strong winds at multiple temporal and spatial scales.	Very Important	Magnitude and frequency of severe storms. Depth and extent of floods. Precipitation, snowmelt, water depth, and water flow in soil at time and space scales consistent with events.	See H1-c								
	W-3. How do spatial variations in surface characteristics (influencing ocean and atmospheric dynamics, thermal inertia, and water) modify transfer between domains (air, ocean, land, cryosphere) and thereby influence weather and air quality?	**W-3a.** Determine how spatial variability in surface characteristics modifies regional cycles of energy, water, and momentum (stress) to an accuracy of 10 W/m2 in the enthalpy flux, and 0.1 N/m2 in stress, and observe total precipitation to an average accuracy of 15% over oceans and/or 25% over land and ice surfaces averaged over a 100 × 100 km region and 2- to 3-day time period.	Very Important	**Land SurfaceTemperature.** 0.6 K random uncertainty in 25 × 25 km area, 80% daily coverage, 3-5 km resolution, with 1 km resolution desired.	Land surface temperature (global 3-5 day repeat)						R4, R5, R8, R27	EA8*, EA12, EA13, EA14*, EA43	A-CCP
					Land surface temperature (derived, global daily repeat)						R4, R5, R8, R27	EA8*, EA12, EA13, EA14*, EA43	A-CCP
					Biogeochemical traits of aquatic biomass, including ocean color pigmentation and productivity (coastal)	≤30 m	≤16 days for global coverage*	≤380 nm - ≥1000 nm, @ ≤10nm	SNR ≥400 VNIR, SNR ≥250 SWIR, accuracy ≤10%		R17, R8, R41, R42, R43	EA27, EA28*, EA29*, EA43	
					Phytoplankton functional type (coastal)	≤30 m	≤16 days for global coverage*	≤380 nm - ≥1000 nm, @ ≤10nm	SNR ≥400 VNIR, SNR ≥250 SWIR,		R17, R8, R41, R42, R43	EA27, EA28*, EA29*, EA43	
									SNR ≥400				

...

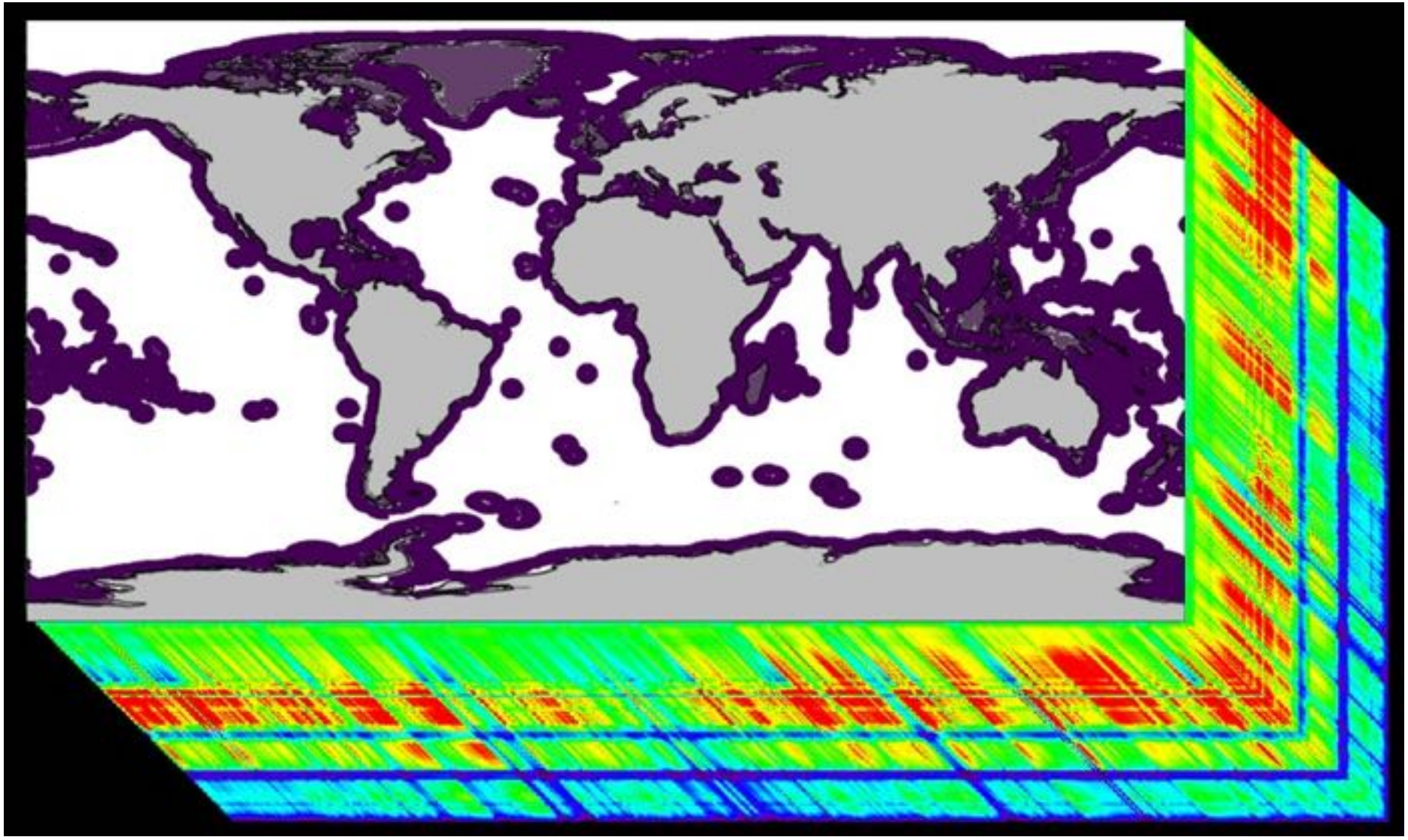
SBG VSWIR Observation Requirements from Decadal Survey Substantiated and Refined with Studies

The SBG Research and Applications Traceability Matrix (SATM) follows the National Academies 2017 decadal survey directions for desired capabilities. Key performance parameter ranges for the VSWIR instrument, derived from the SATM are shown below.

1. Spectral Range: 380-2500 nm
2. Spectral Bands: ≤10 nm with continuous spectral coverage, 210+ bands
3. Radiometric and Signal to noise (SNR) performance: SNR ≥400 VNIR and SNR ≥250 SWIR at 25% reflectance, <5% absolute radiometric uncertainty with high uniformity, low stray-light, and low polarization sensitivity needed to meet key RA objectives
4. Ground Sampling Distance (GSD) at nadir: 30 m
5. Revisit Period: ≤16 days at the equator
6. Coverage: All global land, inland waters, and coastal oceans
7. Local Time for Acquisition: Between 10:30 to 11:30 AM
8. Stability and duration: Measurements must be able to detect changes for addressing dynamics of the Earth System over the prime mission lifetime of 3 years with possible extensions

Consistent with notional DS Observable from page B-17: Primary Observable: Chemical properties of vegetation and aquatic biomass, and Soils Land, inland aquatic, coastal zone, and shallow coral reef: Spectral radiance (10 nm; 380-2500nm); GSD = 30-45 m; Revisit = ~15 days; SNR = 400:1 VNIR/250:1 SWIR @ 25% reflectance; IT of ~5 ms. High-fidelity imaging spectrometer (150-200 km swath from sun-sync LEO).

SBG VSWIR Coverage Mask for Decadal Survey Traced Global Research and Applications

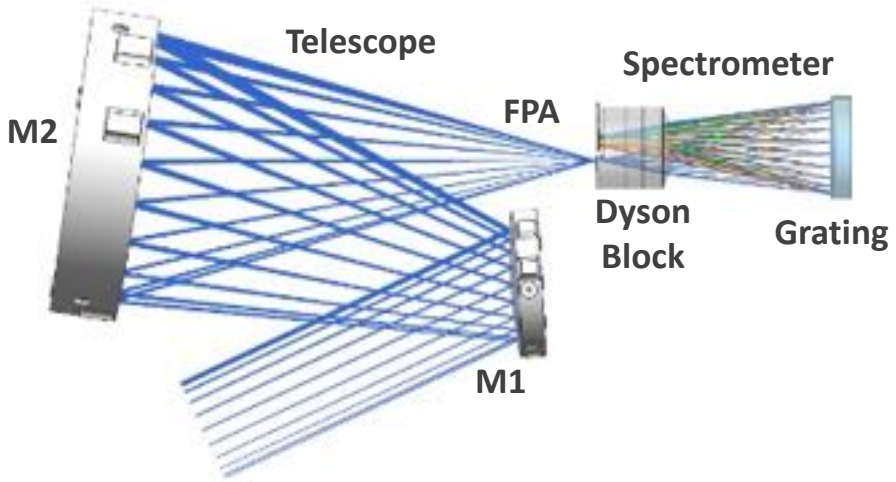


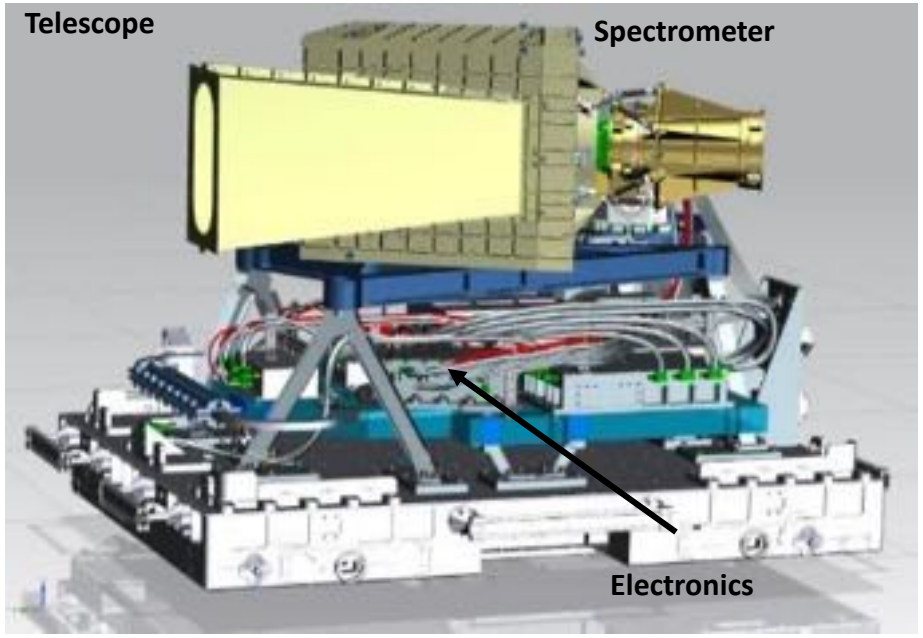
30 m sampling land, inland-water, snow/ice and coastal

1000 m binned open ocean (TBC)

SBG Imaging Spectrometer Concept Draws from EMIT

Optically Fast F/1.8 Dyson Imaging Spectrometer





Optical Bench

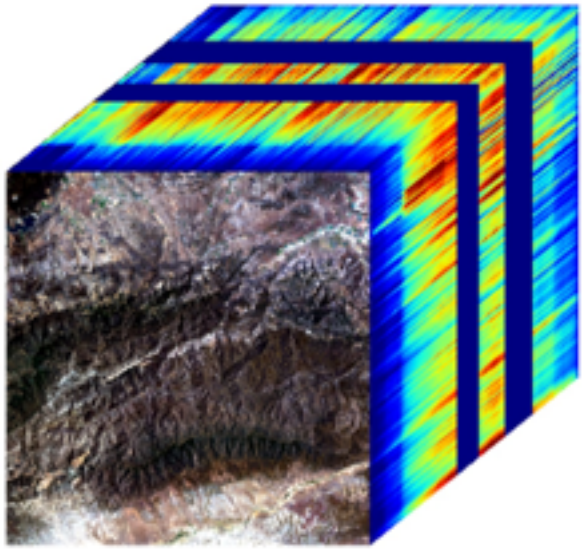
Alignment

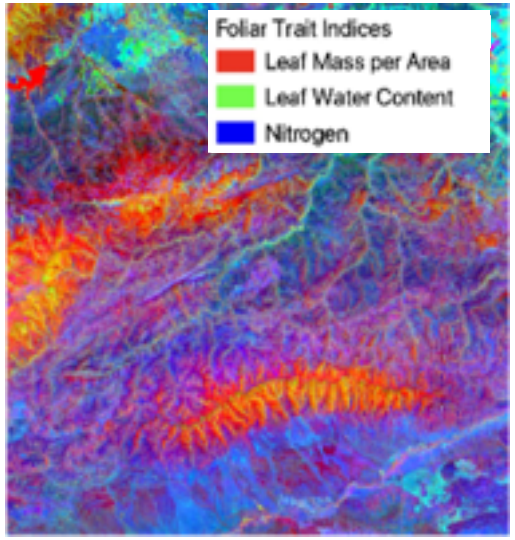
On the ExPA

Complete at JPL

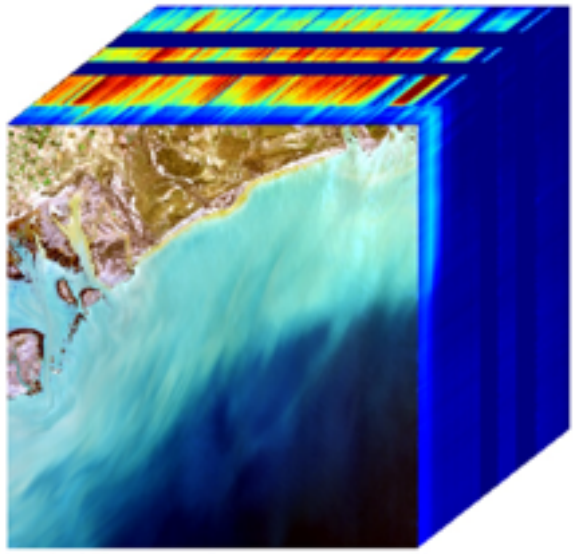
Calibration, Atmospheric Correction and Algorithm Risk Reduction for SBG VSWIR from EMIT

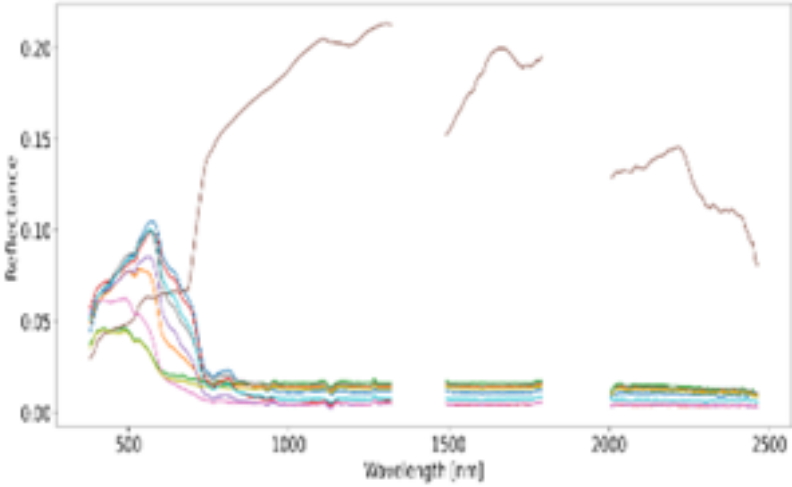
Terrestrial Ecosystem Biology

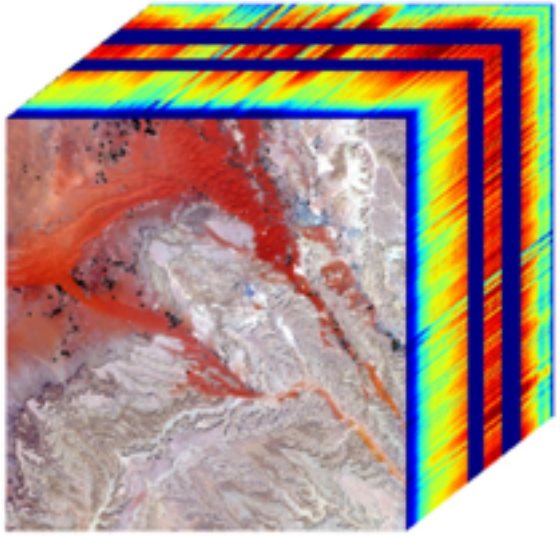




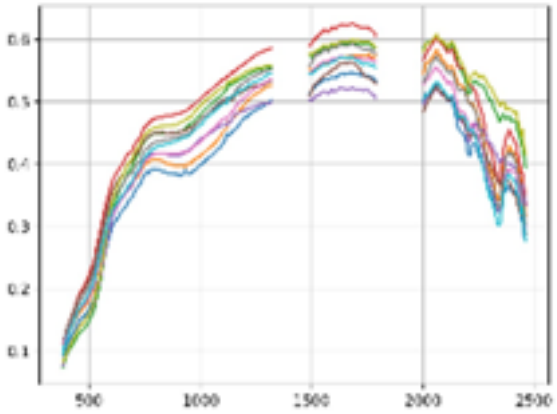
Aquatic Ecosystem Biology

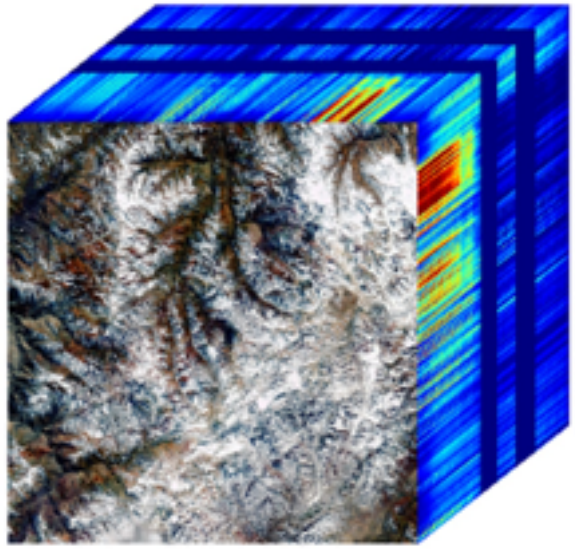




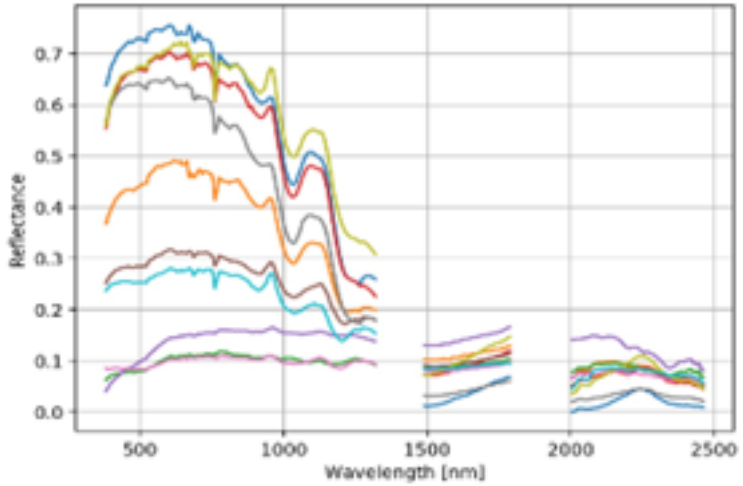


Geology



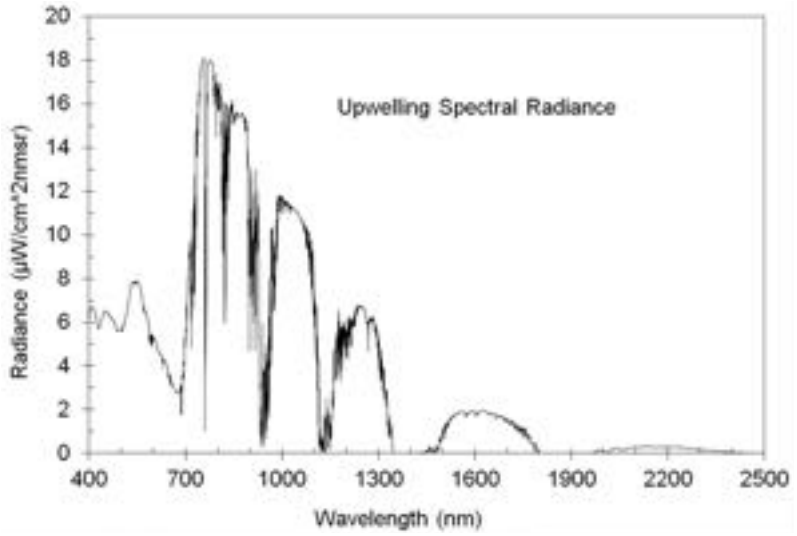


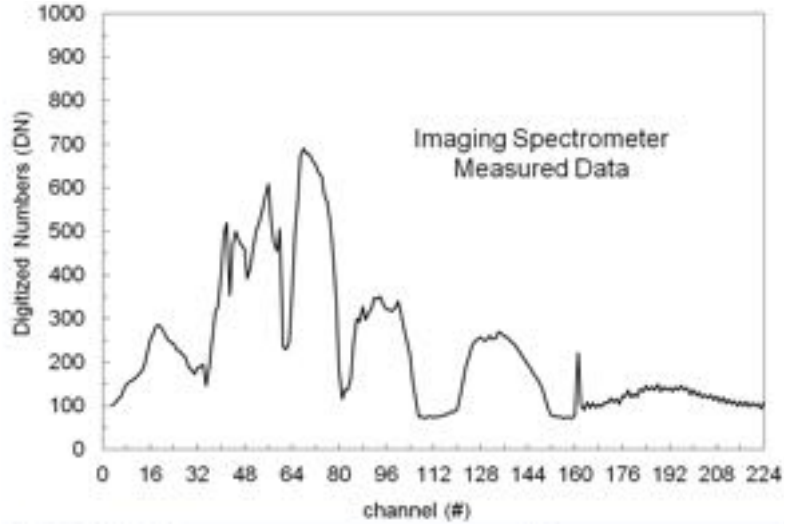
Hydrology

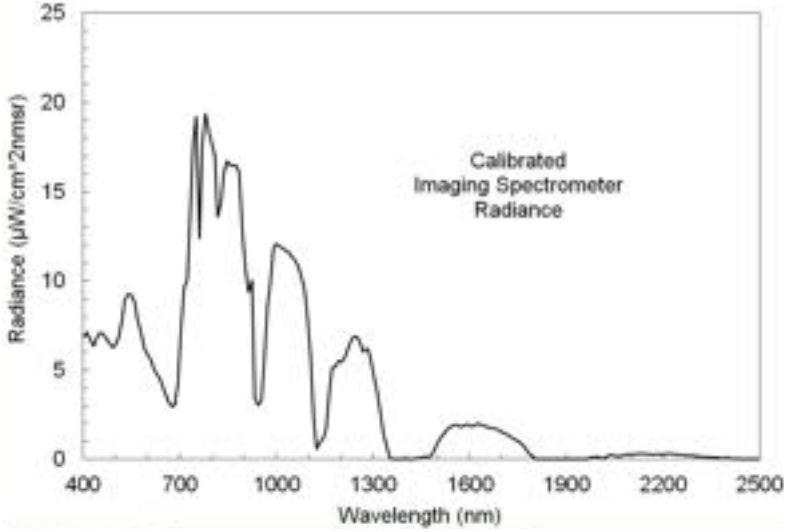


Imaging Spectrometer Calibration and In-Flight Validation

Calibration: Determine the spectral, radiometric, spatial, and uniformity properties of the imaging spectrometer such that the recorded signals can be converted to scientifically usable measurements with units, response functions, and corresponding uncertainties at levels that meet requirements.







Validation: Confirm the flight measurements have the calibration characteristics determined/expected.

In-Flight Update: As needed update the calibration characteristics with traceable sources and uncertainties.

Summary: SBG VSWIR Science Research and Application

- The SBG VSWIR research and application objectives are traceable to the Decadal Survey and address identified “most important” and “very important” questions and others
- Past and ongoing airborne campaigns and space demonstrations (e.g. Hyperion) demonstrate the maturity of the research and applications objectives at the local/regional scale, lowering risk for the SBG VSWIR global mission
- SBG studies and sensitivity analysis confirm the needed VSWIR observations
- The calibration and validation approach is mature and low risk based on the investments, lessons, and refinements over decades
- Research and applications data processing algorithms are mature and extensively tested at the local and campaign scale in regions around the globe
- Collaborative synergies are strong and evolving with other ESO elements and the broader national and international Earth observing communities
- These elements provide the basis traced from the Decadal Survey for the SBG VSWIR Research and Applications requirements and VSWIR payload concept

SBG VSWIR Science Research, Applications, and Imaging Spectrometer concept is ready to proceed