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NASA 2009 HyspIRI Science Workshop Report

HyspIRI Group

Prepared for
National Aeronautics and
Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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Abstract

From August 11-13, 2009, NASA held a three-day workshop to consider the Hyperspectral Infrared Imager (HyspIRI) mission recommended for implementation by the 2007 report from the U.S. National Research Council Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (also known as the Earth Science Decadal Survey or, simply, the Decadal Survey). The open workshop provided a forum to present the observational requirements for the mission and assess its anticipated impact on scientific and operational applications; the open forum also offered the opportunity to obtain feedback from the broader scientific community on the mission concept.

The workshop participants concluded that the HyspIRI mission would provide a significant new capability to study ecosystems and natural hazards at spatial scales relevant to human resource use. In addition, participants reviewed the Draft Preliminary HyspIRI Mission Level 1 Requirements and confirmed that they were achievable with the mission concept presented and would provide the necessary data needed to address the science questions identified for the mission and by the Decadal Survey. These requirements could be met using the reference instrument designs and be implemented through the use of current technology.

The workshop participants, like the Decadal Survey itself, strongly endorsed the need for the HyspIRI mission and felt the mission, as defined, would accomplish the intended science.

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Many researchers provided Inputs for this workshop report. Readers seeking more information about particular details and contacting researchers in certain areas may access that information through the following two individuals.

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Preface

In 2004, the National Aeronautics and Space Administration (NASA), the National Oceanic and Atmospheric Administration (NOAA), and the U.S. Geological Survey (USGS) requested that the National Research Council (NRC) identify and prioritize the satellite platforms and associated observational capabilities that should be launched and operated over the next decade for Earth observation. In addition to providing information for the purpose of addressing scientific questions, the committee identified the need to ensure that the measurements helped benefit society and provide policymakers with the necessary information to make informed decisions on future policies affecting the Earth.

The resulting NRC study Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (also known as the Earth Science Decadal Survey or, simply, the Decadal Survey) (NRC, 2007) recommended launching 15 missions in three time phases. These three time phases are referred to as Tier 1, Tier 2, and Tier 3, respectively. The Hyperspectral Infrared Imager (HyspIRI) mission is one of the Tier 2 missions recommended for launch in the 2013–2016 timeframe. This global survey mission provides an unprecedented capability to assess how ecosystems respond to natural and human-induced changes. It will help us assess the status of elements of biodiversity around the world and the role of different biological communities on land, within inland water bodies, and in shallow coastal zones, as well as on the surface of the deep ocean (but at reduced spatial resolution for the latter). Furthermore, the mission will help characterize natural hazards, with an emphasis on volcanic eruptions and associated precursor activities. HyspIRI will also map the mineralogical composition of the exposed land surface. The mission will advance our scientific understanding of how the Earth is changing as well as provide valuable societal benefit through an enhancement of our understanding of dynamic events, such as volcanoes and wildfires.

The HyspIRI mission concept includes two instruments: 1) a visible shortwave infrared (VSWIR) imaging spectrometer operating between 0.38 and 2.5 µm at a spatial scale of 60 m with a swath width of 145 km and 2) a co-aligned thermal infrared (TIR) multispectral scanner operating between 4 and 12 µm at a spatial scale of 60 m with a swath width of 600 km. The VSWIR and TIR instruments have revisit times of 19 and 5 days, respectively. Several of the other Tier 1 and Tier 2 missions provide complementary measurements for use with HyspIRI data; for example, the DesDynI, ACE, ICESat-II, and GEO-CAPE Decadal Survey missions, each of which measures very different properties or spatial scales compared to the features observable at local and landscape scales with HyspIRI. Note that, while the synergy between HyspIRI and other sensors, including those on operational satellites, benefits all missions and would support relevant scientific endeavors, the ability of HyspIRI to achieve its primary mission goals is not dependent on data from the other instruments.

This report documents a NASA-sponsored three-day workshop held in Pasadena, California, in August 2009 to refine the scientific questions, objectives, and requirements of the HyspIRI mission and to identify the priority near-term investments to mature the HyspIRI concept towards a possible Mission Concept Review (MCR) by mid 2010. Initially, some background on the NRC Decadal Survey is provided. This is followed by a discussion of the science, measurement requirements, mission concept, Level 1 requirements, and associated science as presented and discussed at the workshop, along with recommendations for future activities.

Executive Summary

NASA held a three-day workshop on August 11–13, 2009, to consider the Hyperspectral Infrared Imager (HyspIRI) mission recommended for implementation by the 2007 NRC Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond (also known as the Earth Science Decadal Survey or, simply, the Decadal Survey) ((NRC, 2007). The workshop was open to the research community as well as members of other communities with an interest in the HyspIRI mission. The workshop provided a forum for the HyspIRI Science Study Group (SSG) to present their observational requirements, assess the anticipated impact of HyspIRI on scientific and operational applications, and obtain feedback from the broader scientific community.

As part of the ongoing preparatory studies for the HyspIRI mission, the SSG has developed sets of measurement requirements tied to addressing a particular set of science questions. These requirements, together with those already provided by the Decadal Survey, were first presented at the 2008 Workshop and were updated at the 2009 Workshop. The requirements form the basis for the overall instrument and mission requirements. At the 2009 Workshop, participants reviewed the Draft Preliminary HyspIRI Mission Level 1 Requirements and confirmed that a mission developed to address these requirements would enable the science to be addressed by the HyspIRI mission. Breakout sessions provided a forum for participants to review the science questions, as well as measurement requirements, and to suggest additional opportunities for enhanced science or applications that might be achieved through synergies with other planned missions and/or with augmentations to the current mission.

Several key conclusions resulted from the workshop:

- The Preliminary HyspIRI Mission Level 1 Requirements would enable HyspIRI to address the science questions identified for the mission.
- HyspIRI provides a unique capability to address a set of specific scientific questions about local and global ecosystems, habitats, biodiversity, and hazards and their response to anthropogenic or natural changes.
- The reference instrument designs are capable of meeting the scientific measurement requirements.
- There is a stable set of instrument measurement requirements for HyspIRI; these requirements are traceable to the science questions for the mission.
- Significant heritage exists, from both a design and risk-reduction standpoint, for both instruments. This heritage includes missions such as the Moon Mineralogy Mapper and the Advanced Spaceborne Thermal Emission and Reflection Radiometer as well as the associated algorithms to deliver the Level 0 through Level 2 data products.
- There do not appear to be any significant technology “show stoppers,” and the mission is ready for implementation at the earliest opportunity.
- HyspIRI complements measurements from the DesDynI, ACE, and GEO-CAPE missions, each of which measures very different properties or spatial scales compared to the local and landscape scale features observable with HyspIRI.

The research community, like the Decadal Survey, strongly endorsed the need for the HyspIRI mission. There was a strong consensus that the HyspIRI mission, as defined, would accomplish the intended science.

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1 Introduction

1.1 The Decadal Survey

In 2004, NASA, NOAA, and the USGS commissioned the National Research Council (NRC) to conduct a ten-year survey for Earth science and applications from Space. The 2007 report resulting from that survey is titled: *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (herein referred to as the Decadal Survey). The objective of the survey was to generate consensus recommendations from the Earth and environmental science and applications communities regarding an integrated approach to future space-based and ancillary observations.

The NRC appointed a committee to undertake the Decadal Survey. The committee participated in—and synthesized work from—seven thematically organized study panels:

1) Earth-science applications and societal benefits;
2) Land-use change, ecosystem dynamics, and biodiversity;
3) Weather;
4) Climate variability and change;
5) Water resources and the global hydrologic cycle;
6) Human health and security, and
7) Solid-Earth hazards, resources, and dynamics.

Each of these thematic areas identified key science measurements, justified these measurements, and recommended a small number of missions. The Decadal Survey committee consolidated the recommendations from each theme into a short list of prioritized missions. Included in this list as a high priority was the Hyperspectral Infrared Imager (HyspIRI) mission, which would provide global observations of multiple key surface attributes at local and landscape spatial scales (tens of meters to hundreds of kilometers) for a wide array of Earth-system studies, including: integrating assessments of local and landscape changes key to understanding biodiversity in both terrestrial and aquatic (inland, coastal, and shallow oceanic) ecosystems; measuring the condition and types of vegetation on the Earth's surface, and changes in the mineralogical composition of the surface in order to understand the distribution of geologic materials. The mission would help map volcanic gases and surface temperatures, which were identified as indicators of impending volcanic hazards, as well as plume ejecta that pose risks to aircraft and people and property downwind.

The committee recommended that HyspIRI be launched in the 2013–2016 timeframe and include a hyperspectral visible shortwave infrared (VSWIR) imaging spectrometer and a multispectral thermal infrared (TIR) scanner. The mission would provide global coverage from low Earth orbit with a high temporal frequency, especially in the case of the TIR instrument, which would have a revisit time of 6 days or less.

The NRC Decadal Survey participants recognized that both instruments had strong spaceborne heritage through the Hyperion Instrument on the Earth Observing-1 (EO-1) platform, the Moon Mineralogy Mapper (M3) instrument on the Chandrayaan-1 platform, and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument on the Terra platform.

1.2 The HyspIRI Workshop

On October 21-23, 2008, NASA held a three-day workshop to consider the HyspIRI mission. The workshop participants, like the Decadal Survey, strongly endorsed the need for the HyspIRI mission and felt the mission, as defined, would accomplish the intended science.

A second HyspIRI workshop was held on August 11–13, 2009 in Pasadena, California. This workshop was open to all interested parties (US and international). The goals of the workshop were to:

- Review and validate the HyspIRI science questions;
- Review and validate the Draft Preliminary HyspIRI Mission Level 1 requirements;
- Review the list of Level 2 HyspIRI Mission data products;
- List potential Level 3 HyspIRI user data products (with on-line tools), and
- Address and consider options for resolving key issues affecting HyspIRI science, including: Sun glint, spatial resolution in the coastal zone, data processing (on board and ground), partnership opportunities, and identification of key pre-launch science activities.

The workshop agenda is provided in Appendix B. The morning of the first day of the 2009 workshop focused on providing background information on the Decadal Survey and NASA's approach to the HyspIRI mission. This was followed by descriptions of the measurement requirements, which included point designs for the instruments as well as the current science measurement acquisition baseline during normal and low latency operations. Next was a discussion of the Draft Preliminary HyspIRI Mission Level 1 Requirements. The measurement requirements, acquisition baseline, and Draft Preliminary HyspIRI Mission Level 1 requirements are described in sections 2-4.

The remainder of the first day and most of the second day were focused on a series of science presentations and discussions concerning the HyspIRI science questions and associated Science Traceability Matrices as well as potential products and uses for HyspIRI data. The Science Traceability Matrices aim to directly link the science questions to instrument and mission requirements. The start of the second day involved discussion of potential funding opportunities for HyspIRI-related activities, including possible airborne campaigns. There was also a talk on the Intelligent Payload Module as a means to address needs for low-latency data. Section 5 describes the science questions and presentations.

The morning of the third and final day of the workshop began with a review of partnership opportunities with presentations of related international missions. There are several international missions that complement the global mapping provided by the HyspIRI mission. The remainder of the final morning and early afternoon included a discussion of ground data processing and data products (Level 1 and Level 2). The rest of the afternoon included additional science presentations followed by a discussion of the key outcomes of the workshop and next steps. A key outcome of the workshop was a consensus that the Draft Preliminary HyspIRI Mission Level 1 requirements clearly articulated the mission requirements.

Approximately 220 people participated in the workshop, with representatives from academia and industry, including participants from Australia, Canada, India, Japan, and Europe. Presentations given by NASA and academia addressed key aspects of the mission, with additional time for open discussion when appropriate. All the oral presentations can be found on the HyspIRI website at: http://hyspiri.jpl.nasa.gov.

2 Measurement Requirements and Point Designs

The Science Traceability Matrices (STMs) helped determine the system-level requirements for the HyspIRI instruments. The system-level requirements for the VSWIR and TIR instruments are presented in Table 1 and Table 2, respectively.

2.1 VSWIR Instrument Concept

The VSWIR instrument will acquire data between 380 and 2500 nm in 10-nm, contiguous bands. The instrument signal to noise ratio (SNR) was modeled for several different input radiances (see Figure 1). The current instrument model includes representative reflectances and transmissions for all surfaces in the instrument optical train. The model also includes the baseline geometry for the instrument and accounts for thermally generated, instrument background photon flux. The read noise and dark current of the sensor is also included. The instrument design minimizes polarization sensitivity and scattered light. The baseline data collection scenario involves observing the land and shallow (< 50m) water habitats at full spatial and spectral resolution and transmitting these data to the ground.

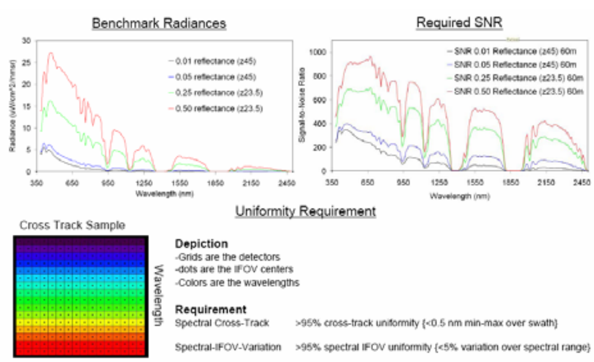

Figure 1: HyspIRI-VSWIR key signal-to-noise and uniformity requirements.

In addition, although not driven by the L1 requirements, the VSWIR will provide data over the deep, open ocean. These data will be summed to a spatial resolution of 1 km and be transmitted to the ground. All data will be quantized at 14 bits. The instrument will have a swath width of 145 km, with a ground data sample of 60 m, resulting in a temporal revisit of 19 days at the equator. The nominal overpass time is 10:30 a.m.; this might, however, be adjusted by as much as ± 30 minutes to help manage certain effects, such as Sun glint on aquatic targets. Note that this swath width and repeating orbit provide timely coverage without frequent pointing maneuvers (cf. DS 2007: HyspIRI concept with 90 km VSWIR swath and rapid pointing). This approach resolves a trade-off between pixel resolution and frequent observation, which was recommend for further study in designing the Ecosystem Function mission recommended by the study panel on land use change, ecosystem dynamics, and biodiversity (DS, 2007), while also limiting the complexity of mission operations.

The absolute radiometric accuracy requirement is greater than 95% this will be maintained by using a variety of approaches, as is described below.

2.1.1 VSWIR Measurement Calibration Approach and Traceability

The VSWIR will be calibrated using an onboard solar reflectance calibration panel as well as monthly lunar views and periodic surface calibration experiments. VSWIR's spectral, radiometric, and spatial calibration characteristics will be determined and reported prior to launch. Spectral response functions will be determined for each spectral channel by recording VSWIR's output as calibrated laboratory monochromator scans from 350 to 2550 nm in 0.5 nm steps. Radiometric response and linearity will be determined by viewing an absolute radiometric source over a range of intensities. The radiometric source is a known reflectance panel illuminated by a National Institute of Standards and Technology (NIST) irradiance lamp. This provides an absolute radiometric calibration for VSWIR with low uncertainties that are traceable to NIST. Spatial response functions will be determined by recording the output of VSWIR as a white light slit is “translated” across the field of view (FOV) in two orthogonal directions. A uniform spatial response with wavelength is required to provide a spectrum where all wavelengths measured originate from the same spatial sample area. For each field of view of the VSWIR instrument, the range, sampling, accuracy and precision (spectrally, radiometrically and spatially) will be determined.

During the course of the mission, the VSWIR spectral, radiometric, and spatial calibration will be assessed, monitored, and updated. Spectral calibration will be assessed by comparing the solar-atmospheric absorption features in measured spectra of the Earth’s atmosphere. A spectral fitting algorithm will be used to determine and report the optimal spectral calibration.

Radiometric calibration will be periodically assessed using a small calibration target on the VSWIR cover. Sunlight will be reflected from this surface into the VSWIR FOV. VSWIR measurements will be corrected to reflectance using a ratio of the measured target spectrum to a measured reference spectrum with a known bi-directional reflectance distribution function.

Less frequently, the spacecraft will orient the VSWIR for scans of the Sun-lit lunar surface. These data will provide a basis for tracking long-term changes to the instrument calibration.

2.2 TIR Instrument Concept

The TIR instrument will acquire data in eight spectral bands: seven of these bands are located in the thermal infrared part of the electromagnetic spectrum between 7 and 12 µm; the remaining band is located in the mid infrared part of the spectrum around 4 µm. The center position and width of each band is given in Table 2. The exact spectral location of each band was based on the measurement requirements identified in the Science Traceability Matrices, which included recognition that related data was acquired by other sensors, such as ASTER and Moderate Resolution Imaging Spectroradiometer (MODIS). HyspIRI will contribute to maintaining a long-time series of these measurements. For example, the positions of three of the TIR bands closely match the first three thermal bands of ASTER, while two of the TIR bands match bands of ASTER and MODIS typically used for split-window type applications (ASTER bands 12–14 and MODIS bands 31 and 32). It is expected that small adjustments to the band positions will be made based on ongoing science activities.

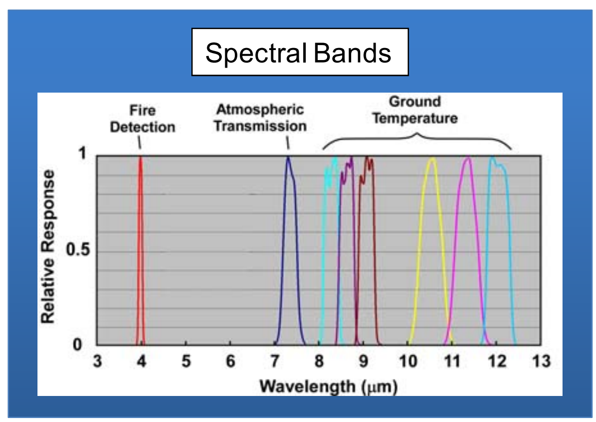

Figure 2: HyspIRI TIR instrument proposed spectral bands.

A key science objective for the TIR instrument is the study of hot targets (volcanoes and wildfires); therefore, the saturation temperature for the 4-µm channel is set high (1200 K) and the saturation temperatures for the thermal infrared channels are set at 500 K.

The TIR instrument will operate as a push-whisk mapper, similar to MODIS but with 256 pixels in the cross-whisk direction for each spectral channel (Figure 3).

A conceptual layout for the instrument is shown in Figure 4. The scan mirror rotates at a constant angular speed. The mirror sweeps the focal plane image across nadir, then to a blackbody target and space, with a 2.2 seconds cycle time.

The f/2 optics design is all reflective, with gold-coated mirrors. The 60-K focal plane will be single-bandgap mercury cadmium telluride, hybridized to a Complementary Metal–Oxide–Semiconductor (CMOS) readout chip, with a butcher block spectral filter assembly over the detectors. Thirty-two analog output lines, each operating at 10-12.5 MHz, will move the data to analog-to-digital converters.

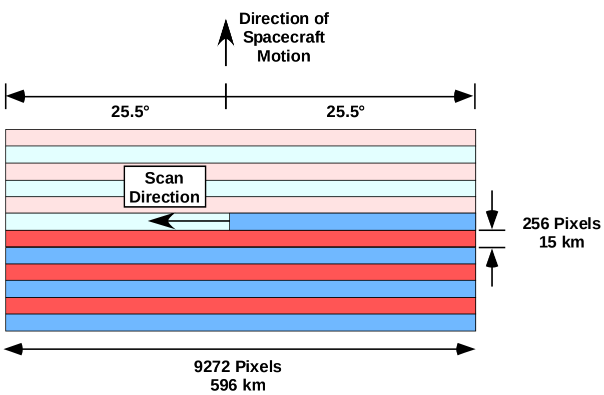

Figure 3: HyspIRI TIR scanning scheme.

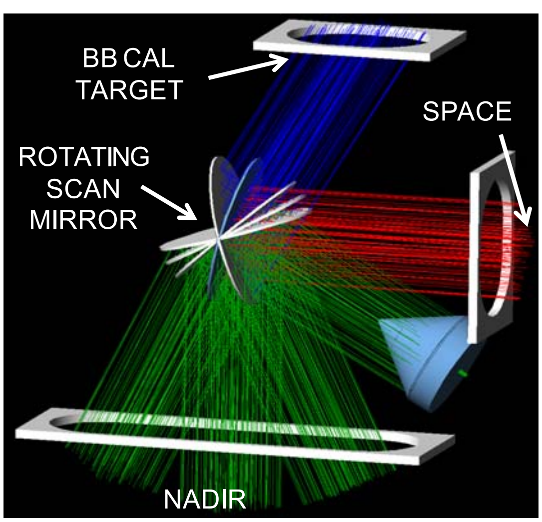

Figure 4: HyspIRI TIR conceptual layout.

The temperature resolution of the thermal channels is much finer than the mid-infrared channel, which (due to its high saturation temperature) will not detect a strong signal until the target is above typical terrestrial temperatures. All the TIR channels are quantized at 14 bits. Expected sensitivities of the eight channels, expressed in terms of noise-equivalent temperature difference, are shown in the following two plots.

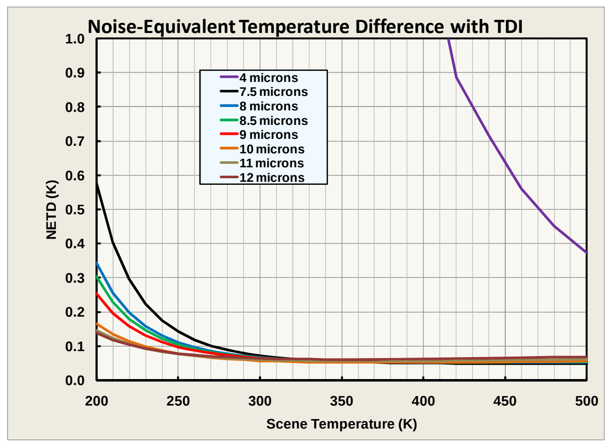

Figure 5: HyspIRI TIR predicted sensitivity 200-500 K.

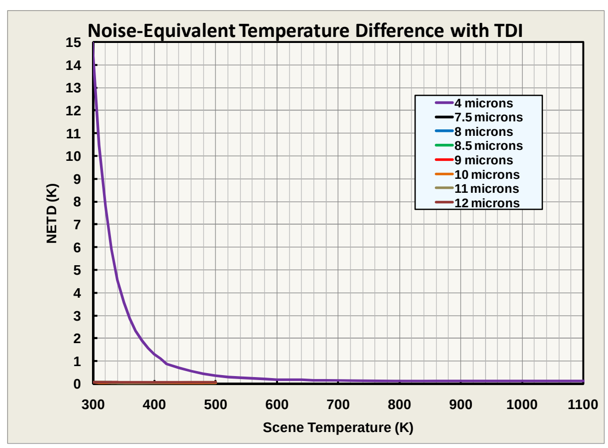

Figure 6: HyspIRI TIR predicted sensitivity 300-1100 K.

The TIR instrument will have a swath width of 600 km, with a pixel spatial resolution of 60 m, resulting in a temporal revisit of 5 days at the equator. The instrument will be on both day and night and will acquire data over the entire surface of the Earth. Like the VSWIR, the TIR instrument will acquire full spatial resolution data over the land and coastal oceans (to a depth of < 50 m); over the open oceans, however, the data will be averaged to a spatial resolution of 1 km. The large swath width of the TIR will enable multiple revisits of any spot on the Earth every week (at least 1 day view and 1 night view). This repeat period is necessary to enable monitoring of dynamic or cyclical events, such as volcanic hotspots or crop stress associated with water availability.

2.2.1 TIR Measurement Calibration Approach and Traceability

The radiometric accuracy and precision of the instrument are 0.5 K and 0.2 K, respectively. This radiometric accuracy will be ensured by using an on-board blackbody and view to space included as part of every 2.2 second sweep (15.4 km × 600 km on the ground). There will also be periodic surface validation experiments and monthly lunar views. The instrument will be calibrated before launch using a cold blackbody to simulate space and with a scene black body that will be varied in temperature from 200 K to more than 400 K. The temperature of both the ground-calibration blackbody and the in-flight blackbody will be measured with NIST-traceable temperature sensors.

Spectral calibration will be performed before launch using a monochromator, which will be calibrated against standards with known spectral features. A Fourier Transform Interferometer (FTIR) system might also be used to measure response over a broad spectral range.

Spatial (field-of-view) calibration will be performed before launch using a target projector with both in-track and cross-track slits. Pointing knowledge will be obtained from theodolite measurements that will measure the angular location of both the target projector slit and a reference cube on the instrument. This cube will then be used to determine the exact orientation of the instrument on the spacecraft. Additional geolocation calibration will be performed in flight by matching maps generated by this instrument to known features on the ground.

Table 1 Preliminary VSWIR Measurement Characteristics

Visible Shortwave Infrared Measurement Characteristics	
Spectral	
Range	380 to 2500 nm in the solar reflected spectrum
Sampling	10 nm {uniform over range}
Response	< 15 nm (full-width-at-half-maximum) {uniform over range}
Accuracy	< 0.5 nm
Radiometric	
Range & Sampling	0 to 1.5 × max benchmark radiance, 14 bits measured
Accuracy and stability	> 95% absolute radiometric, 98% on-orbit reflectance, 99.5%
Precision (SNR)	See spectral plots at benchmark radiances
Linearity	> 99% characterized to 0.1 %
Polarization	< 2% sensitivity, characterized to 0.5 % in sensitive regions
Scattered Light	< 1:100 characterized to 0.1% (next nearest neighbor)
Spatial	
Swath Width	> 145 km
Cross-Track Samples	> 2400
Sampling	60 m (GSD)
Response	70 m (FWHM)
Uniformity	
Spectral Cross-Track	> 95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	> 95% spectral IFOV uniformity {<5% variation over spectral range}
Temporal	
Orbit Crossing	10:30 am Sun synchronous descending
Global Land Coast Repeat	19 days at equator
Rapid Response Revisit Cross Track Pointing	3 days (cross-track pointing) 4 degrees in backscatter direction
On Orbit Calibration	
Lunar View	1 per month {radiometric}
Solar Cover Views	1 per week {radiometric}
Surface Cal Experiments	3 per year {spectral & radiometric}
Data Collection	
Land Coverage	Land surface above sea level excluding ice sheets
Water Coverage	Shallow water habitat – 50 m and shallower
Solar Elevation	20 degrees or greater
Open Ocean	Averaged to approximately 1-km spatial sampling
Compression	3:1 lossless

Table 2: Preliminary TIR Measurement Characteristics

Thermal Infrared Measurement Characteristics	
Spectral	
Bands (8) µm	3.98 µm, 7.35 µm, 8.28 µm, 8.63 µm, 9.07 µm, 10.53 µm, 11.33 µm, 12.05 µm
Bandwidth	0.084 µm, 0.32 µm, 0.34 µm, 0.35 µm, 0.36 µm, 0.54 µm, 0.54 µm, 0.52 µm
Accuracy	<0.01 µm
Radiometric	
Range	Bands 2–8 = 200 K – 500 K; Band 1= 1200 K
Resolution	< 0.05 K, linear quantization to 14 bits
Accuracy	< 0.5 K 3-sigma at 250 K
Precision (NEdT)	< 0.2 K
Linearity	> 99% characterized to 0.1 %
Spatial	
IFOV	60 m at nadir
MTF	> 0.65 at FNy
Scan Type	Push-Whisk
Swath Width	600 km
Cross Track Samples	9,300
Swath Length	15.4 km
Down Track Samples	256
Band to Band Co-Registration	0.2 pixels (12 m)
Pointing Knowledge	10 arcsec (0.5 pixels)
Temporal	
Orbit Crossing	10:30 a.m. Sun synchronous descending
Global Land Repeat	5 days at equator
On Orbit Calibration	
Lunar views	1 per month {radiometric}
Blackbody views	1 per scan {radiometric}
Deep Space views	1 per scan {radiometric}
Surface Cal Experiments	2 (day/night) every 5 days {radiometric}
Spectral Surface Cal Experiments	1 per year
Data Collection	
Time Coverage	Day and Night
Land Coverage	Land surface above sea level
Water Coverage	Coastal zone minus 50 m and shallower
Open Ocean	Averaged to approx 1-km spatial sampling
Compression	2:1 lossless

3 Mission Concept

The HyspIRI satellite will be put in a Sun-synchronous, low-Earth orbit. The local time of the descending node is expected to be 10:30 a.m. ± 30 minutes, due to the benefits it offers in terms of observation geometry and signal to noise ratio at the instrument. As noted in Table 1 and Table 2, the VSWIR has a 19-day revisit at the equator, and the TIR has a 5-day revisit at the equator. Since the TIR is on both day and night, it acquires one daytime image every 5 days and one nighttime image every 5 days for a given ground location. The current altitude for the spacecraft is 626 km at the equator. The number of acquisitions for different parts of the Earth in a 19-day cycle is shown in Figure 2.

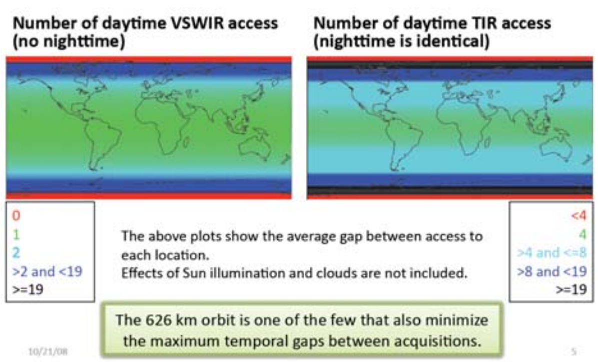

Figure 7: Number of image acquisitions in 19 days.

The figure is color-coded such that areas that are green meet the requirement and areas that are light blue, dark blue, and black exceed the requirement. Examination of the TIR map indicates that as one moves towards the poles the number of acquisitions exceeds the requirements with daily coverage at the poles. Because HyspIRI will travel an inclined orbit, no data will be acquired above and below 83° N and 83° S, respectively, in the VSWIR. Similarly, no data are acquired poleward of 85° N and 85° S in the TIR. The slightly more poleward extension of the TIR instrument is due to its larger swath width.

VSWIR data acquisitions are also limited by the Sun illumination conditions, with no data being acquired when the Sun elevation angle is less than 20 degrees (Figure 8).

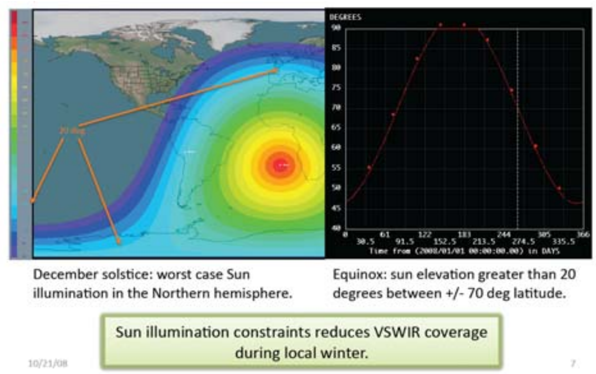

Figure 8: Illustration of the Sun illumination at the winter solstice.

The acquisition scenario for the HyspIRI mission is driven by target maps, with pre-defined maps controlling the acquisition mode. As noted earlier, the instruments are always on; however, they store data at either high-resolution mode (maximum spatial and spectral) or low-resolution mode. High-resolution mode data are acquired over the land and coastal waters shallower than 50 m. Low-resolution mode data are acquired over the rest of the oceans. The low-resolution mode return data are averaged or sub-sampled to about 1 km. This target-map-driven strategy combined with high- and low-resolution modes minimizes the cost of mission operations, allowing the instruments to acquire data in a near-autonomous fashion.

The satellite also includes an Intelligent Payload Module (IPM) with a direct broadcast capability that taps into the data feed from the instruments and allows a small subset of the data to be broadcasted in near real time. The IPM is independent of the onboard data recording and storage system and connects to the data stream to pull out the desired spatial and spectral information for direct broadcast. The IPM is also independent of the spacecraft telecommunications system, as it features its own X-Band antenna designed to maximize the real-time broadcast footprint. The IPM has no significant data storage capacity.

The main spacecraft onboard data recording and storage system takes the data acquired in either low- or high-resolution mode and downlinks them to Earth. These data are then sent to the appropriate Distributed Active Archive Center (DAAC) for further processing into the different data products.

Table 3 shows the HyspIRI data volume, including the rate reduction associated with the VSWIR illumination requirement, compression, and overhead; note, however, that the table excludes the contribution from the low-resolution targets, which represent a minor addition to the total volume.

Table 3: HyspIRI Data Volume, includes illumination constraints for VSWIR, compression and overhead.

	VSWIR	TIR	Combined
Raw Instrument Data (Mbps)	804	130	934
Compression Factor	3	2	-
Compressed Data Rate (Mbps)	268	65	333
Year long averaged Duty Cycle	11.3%	34.6%	-
Compressed Data Rate (average) (Mbps)	30	23	53
Data Volume Per Orbit (average) (Gb)	177	131	308
Daily Data Volume (average) (Gb)	2623	1945	4568
Overhead	10%	10%	-
Packetized Daily Data Volume (Gb)	2,886	2,140	5,026
Cloud Obscuration	20%	0%	-
Usable Daily Data Volume (Gb)	2,309	2,140	4,449
TOTAL DAILY DATA VOLUME (Tb)	2.89	2.14	5.03

The continuous averaged, compressed data rate is 53 Mbps, which results in a data volume of 308 Gb/orbit and 5.03 Tb/day. Compared to the current Earth Observing System (EOS) missions, the HyspIRI data rates are higher, but they are comparable to other, more recently launched satellite missions, such as WorldView-1, which has a data volume of 331 Gb/orbit. The HyspIRI satellite will have an onboard storage capacity of 3 Tb (WorldView-1 has 2.2 Tb of onboard storage). In the current configuration, HyspIRI data will be downloaded using dual-pole X-Band, which will be capable of download rates of upwards of 700 Mbps. Other options, such as Ka-Band, are also being considered. The Ka-Band option has a projected maximum downlink rate of 1 Gbps. This capability, however, is not currently operational.

The mission is currently carrying a three-ground-station solution for down linking the data, with facilities located at Svalbard, Norway; Poker Flats, Alaska; and U. of Tasmania, Australia.

The HyspIRI Flight System is made up of the two scientific instruments, the IPM, and an industry-provided spacecraft bus. The RSDO Catalog SA-200HP (option 6) bus was used in the 2008 TeamX study as an example of a potential bus to identify and cost needed modifications. A summary of the required modifications for this particular example is shown in Table 4.

Table 4: The SA-200HP bus can meet the HyspIRI needs with minimum modifications

	Requirements	RSDO SA-200HP	Modifications
Orbit	626 km 10:30 LTDN	✔	-
Mission duration	3 years, selective redundancy	✔	-
Pointing Knowledge	2 arcsec (3σ/axis)	.5 arcsec (3σ)	Ball CT-602 star tracker to protect against deformation between bus and payload
Pointing Accuracy	165 arcsec (3σ/axis)	16 arcsec (3σ)	
Pointing Stability	5 arcsec/sec (3σ)	0.1 arcsec/sec (3σ)	
Thermal	Passive architecture	✔	-
Downlink	740 Mbps	80Mbps	Dual-pol X-band
Propellant	42 m/s	131 m/s	-
Onboard recorder	3 Tb	100 Gbits	SEAKR SSP-R
Payload mass	132kg	666 kg	-
Payload + SSR power	217 W	650 W	Single wing configuration

The current design calls for HyspIRI to be launched on a Taurus 3210. This launch vehicle provides the closest fit in terms of capabilities among currently NASA-approved launchers. Insertion into a mapping orbit can be achieved through daily launch windows.

The existing baselined point design provides sufficient margin in all significant areas of interest. Tables 5 and 6 summarize the payload accommodation and resource margins.

Table 5 Summary of payload accommodations

Accommodations	VSWIR	TIR
Mass (CBE)	66 kg	85 kg
Mass (w/ contingency)	81 kg	99 kg
Volume	1.6 x 1.6 x 1 m	1.2 x 0.5 x 0.4 m
Power	38 W	78 W
Data Rate (raw)	804 Mbps	130 Mbps
Data Rate (compressed)	268 Mbps	65 Mbps
Avg. Daily Data Volume	2.89Tbits	2.14 Tbits

Table 6 Summary of resource margins

	Required	Design (CBE)	Margin (D-R)/D
Swath width VSWIR	140 km	145 km	4%
Swath width TIR	558 km	600 km	7%
Recorder capacity	1.4 Tb	3 Tb	53%
Downlink capacity	5.0 Tb/day	8.4 Tb/day	31%
Power	217 W	650 W	66%
LV mass capability	561 (includes propellant for EOL maneuver)	790 kg	29%

Future efforts aimed at advancing the maturity of the mission concept will include: the development of a higher-fidelity data budget to allow for optimization of system resources, such as storage space and downlink times; the affect of Sun illumination constraints, and support for a second TeamX study in early 2010.

4 DRAFT Preliminary HyspIRI Mission Level 1 Requirements

A key part of the 2009 workshop was the presentation and discussion of the Draft Preliminary HyspIRI Mission Level 1 Requirements. These mission requirements are ultimately kept by NASA Headquarters and serve as the top-level requirements for the HyspIRI mission. They are the basis for deriving Level 2 requirements, which provide more detail.

The Draft Preliminary HyspIRI Mission Level 1 Requirements document contains several sections. Certain key sections that were discussed in detail at the workshop are summarized below and presented in italic text.

The Mission Imperative comes from the Decadal Survey and summarizes certain key deliverables as well as the communities that the mission will support. The Science Objectives identify what the mission will deliver. In the case of HyspIRI, they are the surface reflectance and water leaving radiance from the VSWIR instrument and the surface radiance, surface emissivity, and surface temperature from the TIR instrument. The Implementation Approach summarizes a point design that will meet the science objectives and provides more detail on the instruments and measurement range, such as the 60-m spatial resolution. The implementation approach also gives the lifetime (3 years) and indicates that both a calibration and validation plan will be developed for the mission. The remaining key section discussed at the workshop was the Requirements and Mission Success Criteria for the Baseline and Minimum Science Mission. Key differences between the baseline and minimum missions relate to the coverage and availability of data; these items are underlined in the text.

Mission Imperative

HYSPIRI is one of the missions recommended by the National Research Council's Committee on Earth Science and Applications from Space, (Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond, Space Studies Board, National Academies Press, 2007). HYSPIRI data have both high scientific value and high applications value. The high accuracy, resolution, and global coverage of HYSPIRI solar reflectance, temperature and thermal emissivity measurements are invaluable across many science and applications disciplines including ecology, biogeochemistry, biodiversity, coastal ocean and inland water research, geology, natural hazards, hydrology, climate, studies of the carbon cycle, and related applications.

Science Objectives

The HyspIRI Project will implement a spaceborne Earth observation mission designed to collect and provide global imaging measurements for surface reflectance, water leaving radiance, thermal emissivity, and surface radiance and temperature that will enable science and applications users to advance the current understanding of the Earth's ecology, biogeochemistry, biodiversity, coastal and inland waters, geology, natural hazards, hydrology, climate, and studies of the carbon cycle.

Implementation Approach

The HyspIRI observatory employs a dedicated spacecraft with a pair of instruments that will be launched into a 10:30 a.m., sun-synchronous orbit on an expendable launch vehicle. The baseline HyspIRI instruments include a visible to *shortwave infrared imaging spectrometer operating between 380 nm and 2500 nm, and a multiband thermal infrared imaging radiometer operating in the 4 – 12 micron range. Observations made with these instruments will be analyzed to yield estimates of surface reflectance, water leaving radiance, thermal emissivity and surface radiance and temperature at a nominal ground sample distance of 60 m. The measurements will be acquired for a period of three years. A Calibration and Validation Plan will be developed and implemented to assess random errors, and spatial and temporal biases in the data.*

Requirements: Baseline Science Mission

a) VSWIR: To address the Decadal Survey and community identified science and application questions related to terrestrial and coastal ocean ecosystem composition, function, and change as well as surface composition (Decadal Survey pp. 113-115), the baseline science mission shall provide global mapping measurements of the surface reflectance and water leaving radiance (for persistently water covered regions) across the solar reflected spectrum from 380 to 2500 nm at ≤10 nm sampling at the specified signal-to-noise ratio and accuracy with >95% spectral/spatial uniformity at ≤60 m spatial sampling with <20 day revisit to provide >60% seasonal and >80% annual coverage of the terrestrial and shallow water regions of the Earth for at least three years with a subset of measurements available near-real-time for designated science and applications.

b) TIR: To address the Decadal Survey and community-identified science and application questions related to volcanoes, wild fires, water usage, urbanization and surface composition (Decadal Survey pp. 113-115), the baseline science mission shall provide global mapping measurements of the surface radiance, temperature and emissivity with 8 spectral bands from the 3-5 micron and 7-12 micron regions of the spectrum at the specified noise-equivalent-delta-temperature and accuracy at ≤60 m spatial sampling with ≤5 day revisit to provide >60% monthly, >70% seasonal and >85% annual coverage of the terrestrial and shallow water regions of the Earth for at least three years with a subset of measurements available near-real-time for designated science and applications.

c) Combined Sensors: To address Decadal Survey and community-identified science and application questions (DS113-115), requiring combined reflectance, emissivity and temperature measurements, the baseline mission shall provide combined global mapping data sets with both reflectance from 380 to 2500 nm at ≤10 nm and emissivity, temperature and surface radiance from the 3-5 and 7-12 micron regions each at ≤60 m spatial sampling with <20 day revisit to provide >60% seasonal and >80% annual coverage of the terrestrial and shallow water regions of the Earth for at least three years with a subset of measurements available near-real-time for designated science and applications.

Requirements: Minimum Science Mission

a) VSWIR: To address the Decadal Survey and community-identified science and application questions related to terrestrial and coastal ocean ecosystem composition, function, and change as well as surface composition (Decadal Survey pp. 113-115), the minimum science mission shall provide global mapping measurements of the surface reflectance and water leaving radiance (for persistently water covered regions) across the solar reflected spectrum from 380 to 2500 nm at ≤10 nm sampling at >90% of the specified signal-to-noise ratio and accuracy with >90% spectral/spatial uniformity at ≤60 m spatial sampling with <20 day revisit to provide >50% seasonal

<u>and >70% annual coverage of the terrestrial and shallow water regions of the Earth for at least two years.</u>

b) TIR: To address the Decadal Survey and community identified science and application questions related to volcanoes, wild fires, water usage, urbanization and surface composition (DS113-115), the minimum science mission shall provide global mapping measurements of the surface temperature as well as emissivity and surface radiance in 8 spectral bands from the 3-5 micron and 7-12 micron regions of the spectrum at >90% the specified noise-equivalent-delta-temperature and accuracy at ≤60 m spatial sampling with <u>≤5 day revisit to provide >40% monthly, 60% seasonal and >70% annual coverage of the terrestrial and shallow water regions of the Earth for at least two years.</u>

c) Combined Sensors: To address Decadal Survey and community identified science and application questions requiring combined reflectance, emissivity and temperature measurements, the minimum mission shall provide combined global mapping data sets with both reflectance from 380 to 2500 nm at ≤10 nm and emissivity, temperature and surface radiance from the 3-5 and 7-12 micron regions each at ≤60 m spatial sampling with <20 day revisit to provide >50% seasonal and >70% annual coverage of the terrestrial and shallow water regions of the Earth for at least two years.

These requirements were thoroughly discussed with the workshop participants. It was concluded they met the mission as described by the Decadal Survey and supported by the HyspIRI Science Study Group and were fully endorsed by the workshop participants.

5 Science Questions and Presentations

The HyspIRI mission is science driven by linking the measurement requirements for the mission to one or more science questions. HyspIRI has three top-level science questions related to 1) ecosystem function and composition, 2) volcanoes and natural hazards, and 3) surface composition and the sustainable management of natural resources. The NRC Decadal Survey called out these three areas. The top-level science questions for the HyspIRI mission are:

Ecosystem function and composition

What is the global distribution and status of terrestrial and shallow–aquatic ecosystems and how are they changing?

Volcanoes and natural hazards

How do volcanoes, fires, and other natural hazards behave; and do they provide precursor signals that can be used to predict future activity?

Surface composition and the sustainable management of natural resources

What is the composition of the land surface and coastal shallow water regions, and how can they be managed sustainably under natural and human-induced change?

These questions provide a scientific framework for the HyspIRI mission. NASA appointed the HyspIRI Science Study Group (SSG) to define and expand these questions to a level of detail that was sufficient to provide the measurement requirements for the HyspIRI mission. In 2007, the first SSGs were formed; note that there was a separate SSG for each instrument (VSWIR and TIR). These groups were then merged in 2008, their overall membership reassessed, and the HyspIRI SSG formed. The SSG represents the scientific community and domestic agencies interested in HyspIRI data, including the NASA centers. Terrestrial and marine ecologists, geologists, geophysicists and atmospheric scientists participate in this group.

The SSG developed a more detailed set of overarching thematic questions that were separated into three groups. The first two groups deal with overarching questions that may be addressed by only one of the two instruments. The third group requires data from both instruments. All three groups may require supporting measurements from other instruments, whether spaceborne, airborne, or ground. The three question groups are referred to as the 1) VSWIR questions (VQ), 2) TIR questions (TQ) and 3) Combined questions (CQ), respectively (Table 7). For each of these overarching thematic questions, there are a set of thematic subquestions; it is these subquestions that provide the necessary detail to understand the measurement requirements (see the 2008 Workshop report).

As noted in Section 1, the 2009 HyspIRI Workshop included a large number of science-related presentations. These began with two parallel sessions in the afternoon of the first day focused on the VSWIR and TIR, respectively. The VSWIR and TIR sessions examined each of the overarching science questions in sequence (see Table 7). Each speaker presented the science sub questions and applications associated with the overarching question and discussed enabling data products and the associated Science Traceability Matrix. There were very few substantive updates to the Science Traceability Matrices presented in 2008, which the community felt accurately summarized that science that would be addressed by the HyspIRI mission. At the end of each session the Level 1 measurement calibration approach and traceability was described followed by the Level 2 products. The Level 1 measurement calibration approach and traceability is described in Section 2 of the report; the Level 2 data products are described in Section 6. The second day also included two parallel sessions that addressed the Combined questions and followed a similar format to the VSWIR and TIR questions, with the exception that there are no Science Traceability Matrices for the combined questions since their requirements are consistent with requirements captured in the VSWIR and TIR Science Traceability Matrices. The second and third days included several presentations by individuals or groups of individuals that highlighted key science applications with HyspIRI data, such as characterizing geothermal resources or assessing change in coral reef ecosystems.

Table 7: Overarching Thematic Science Questions

Question #	Area	Question	Lead and Co-Lead
VQ1	Pattern and Spatial Distribution of Ecosystems and their Components	What is the global spatial pattern and diversity of ecosystems and how do ecosystems differ in their composition or biodiversity?	Roberts, Middleton
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?	Gamon
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?	Ollinger
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?	Asner, Knox
VQ5	Ecosystem and Human Health	How do changes in ecosystem composition and function affect human health, resource use, and resource management?	Townsend, Glass
VQ6	Earth Surface and Shallow-Water Substrate Composition	What is the land surface soil/rock and shallow-water substrate composition?	Green, Dierssen
TQ1	Volcanoes and Earthquakes	How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?	Abrams, Freund
TQ2	Wildfires	What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?	Giglio
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?	Anderson, Allen
TQ4	Urbanization and 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?	Quattrochi, Glass
TQ5	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?	Prakash, Mars
CQ1	Coastal, ocean, and inland aquatic environments	How do inland, coastal, and open-ocean aquatic ecosystems change due to local and regional thermal climate, land-use change, and other factors?	Muller-Karger
CQ2	Wildfires	How are fires and vegetation composition coupled?	Giglio
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?	Wright, Realmuto
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?	Roberts, Anderson
CQ5	Land surface composition and change	What is the composition of the exposed terrestrial surface of the Earth, and how does it respond to anthropogenic and non anthropogenic drivers?	Mars, Prakash
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?	Quattrochi, Glass

6 Data Products and Algorithms

The product-level definitions for the HyspIRI mission are very similar to those currently in use by EOS missions. These data product levels are briefly summarized below.

- Level 0 - Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artifacts (e.g., synchronization frames, communications headers) removed.
- Level 1A - Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform attitude and ephemeris) computed and appended, but not applied, to the Level 0 data.
- Level 1B - Level 1A data that have been processed to sensor units.
- Level 2 - Derived geophysical variables at the same resolution and location as the Level 1 source data.
- Level 3 - Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
- Level 4 - Model output or results from analyses of lower-level data (i.e., variables derived from multiple measurements).

For the HyspIRI mission, it is anticipated that the project will provide the Level 0 through Level 2 data; the Level 3 and above data will be provided by the scientific community. The Level 1B data for HyspIRI will be geolocated radiance at sensor. Note that the data will not be orthorectified. In other words, we will know the latitude and longitude for any given pixel, but the image pixels will not be resampled to be on a defined grid and of equal size. The Level 2 data will include surface radiance, surface reflectance (land and water), surface temperature, and surface emissivity. There will also be two cloud masks: one for the VSWIR and one for the TIR. Two masks are necessary due to the difference in the swath width of the VSWIR and TIR sensors. The size of data granules has not been determined yet; they will, however, be selected to make it straightforward to work with both the VSWIR and TIR products. The Level 0 through Level 2 products will be treated as standard products (i.e., produced for all scenes). The Level 3 and above products will be considered as special products(i.e., produced for a specified time-frame or region).

It is expected that the Level 0 through Level 2 data will be produced at the Science Data System and will be stored at a Distributed Active Archive Center (DAAC). The Science Data System will be developed later in the project.

The VSWIR and TIR Level 2 products, together with the low latency data products, are described in more detail below

6.1 VSWIR Level 2 Products

6.1.1 Introduction

HyspIRI will produce two Level-2 VSWIR products: Terrestrial and Aquatic Surface Reflectances.

There is growing interest in hyperspectral remote sensing for research and applications in a variety of fields, including geology, agriculture, forestry, coastal and inland water studies, environment hazards assessment, and urban studies (Gao et al. 2009).

In order to study surface properties using hyperspectral data, accurate removal of atmospheric absorption and scattering effects is required. This process, called atmospheric correction, is essential to convert radiances measured by the sensors to reflectances of surface materials (Gao et al. 2009).

6.1.2 Terrestrial Surface Reflectance

The solar radiation on the Sun-surface-sensor path is affected by absorption and scattering effects from atmospheric gases and aerosols. Accurate modeling of these effects is required to derive surface reflectance spectra from VSWIR data.

An operational version of Atmosphere Removal Algorithm (ATREM) developed by Gao et al. (1993) is the current choice for hyperspectral VSWIR data. The algorithm is based on approximate radiative transfer calculations and a look-up table procedure and does not require field measurements of reflectance spectra. The ATREM was distributed to more than 300 researchers worldwide and has been extensively used for land surface reflectances (Gao et al. 2000; Gao et al. 2009).

ATREM uses a theoretical radiative transfer modeling technique that simulates explicitly the absorption and scattering effects of atmospheric gases and aerosols, as follows: 1) the integrated water vapor amount is derived on a pixel by pixel basis using a channel ratio technique (Gao et al., 1993); a fast line-by-line atmospheric transmittance model (Gao & Davis, 1997) and the HITRAN2000 line database (Rothman et al., 2003, 2005) are used to calculate atmospheric gaseous absorption; 2) the scattering effect due to atmosphere and aerosols is modeled using 6S computer code (Tantre et al., 1986; Gao et al., 2009).

The measured radiances are divided by solar irradiances above the atmosphere to obtain the apparent reflectances. The scaled surface reflectances are derived from the apparent reflectances using the simulated atmospheric gaseous transmittances and the simulated molecular and aerosol scattering data. The “absolute” surface reflectance is obtained from the scaled surface reflectance multiplied by a combined factor of the slope and aspect of the surface (Gao et al. 2009).

The standard output from the ATREM code includes a water vapor image and a surface reflectance data cube.

More advanced features, such as spectral smoothing, topographic adjacency effect (Richter, 1998) correction, and atmospheric adjacency effect (Tanre et al., 1979) correction are not mature enough to be added to the current ATREM code during the development phase but will be considered once they are mature.

6.1.3 Aquatic Surface Reflectance

The ATREM algorithm designed for hyperspectral data over land is not suitable for that over shallow aquatic regions. Because aquatic surfaces are much darker than land surfaces and the air/water interface is not Lambertian, very accurate modeling of atmospheric absorption and scattering effects and the specular aquatic surface reflection effects is required to derive the aquatic surface reflectance or water leaving reflectance (Gao et al., 2009).

The current choice for the atmospheric correction of hyperspectral remote sensing data for water leaving radiance is the Tafkaa algorithm developed at the Naval Research Laboratory in the late 1990s (Gao et al., 2000).

The algorithm uses lookup tables, corresponding to various aerosol models, generated with a vector radiative transfer code (Ahmad & Fraser, 1982) and uses a spectral matching technique based on gaseous transmission spectra generated from ATREM code ported over for data processing. Tafkaa has been successfully demonstrated with hyperspectral imaging data acquired with the Portable Hyperspectral Imager for Low Light Spectroscopy (PHILLS) (Davis et al., 2002), the AVIRIS, and the Hyperion instrument on EO-1 (Ungar, 1997).

6.2 TIR Level 2 Products

6.2.1 Introduction

HyspIRI will produce three Level-2 Thermal Infrared (TIR) products: surface radiance, land surface temperature, and emissivity. The surface radiance product is used for temperature emissivity separation and requires an atmospheric correction using a radiative transfer model. The atmospheric correction is necessary to isolate land surface features from the effects of atmospheric emission, scattering, and absorption in the Earth's atmosphere. Once the surface radiance is known, the ASTER Temperature Emissivity Separation (TES) algorithm will be implemented to estimate the land surface temperature and emissivity (Gillespie et al. 1998).

6.2.2 Surface Radiance

The radiance leaving the surface is a combination of two terms: self emission from the Earth's surface and reflected downward irradiance from the sky and surroundings. The approach for computing surface radiance involves two steps. First, the atmosphere must be characterized by obtaining profiles of temperature, water vapor, and ozone at the HyspIRI observation time and location of the measurement. Ideally the profiles should be obtained from a validated, mature product with sufficient spatial resolution and close enough in time with the HyspIRI observation to avoid interpolation errors. Second, the atmospheric profiles need to be input to a radiative transfer model to estimate three atmospheric parameters necessary for atmospheric correction: the path radiance, transmittance, and downward sky radiance. The current choice of radiative transfer model is the latest version of the Moderate Resolution Atmospheric Radiance and Transmittance Model (MODTRAN) (Kneizys et al. 1996). MODTRAN has been sufficiently tested and validated and meets the speed requirements necessary for high spatial resolution data processing. The latest version (5.3) uses an improved molecular band model (SERTRAN), with much finer spectroscopy from previous versions — down to 0.1 cm-1 — resulting in more accurate modeling of band absorption features in the longwave TIR window regions. Furthermore, validation with Line-by-Line (LBL) models have shown good accuracy.

6.2.3 Surface Temperature and Emissivity

Land surface temperature and emissivity (LST&E) products are essential for a wide range of global climate change studies that include the Earth's radiation budget, surface-atmosphere interactions, climate modeling, cryospheric research, and land cover, land use change monitoring. Knowledge of the surface emissivity is also critical for accurately recovering the surface skin temperature, a key climate variable in many scientific studies, from climatology to hydrology and modeling the greenhouse effect.

The Temperature-Emissivity-Separation algorithm (TES) is applied to the land-leaving TIR radiances that are estimated by atmospherically correcting the at-sensor radiance on a pixel-by-pixel basis using the MODTRAN radiative transfer code. TES uses an empirical relationship to predict the minimum emissivity that would be observed from a given spectral contrast, or Minimum-Maximum Difference (MMD) (Kealy and Hook 1993; Matsunaga 1994). The empirical relationship is referred to as the calibration curve and is derived from a subset of spectra in the ASTER spectral library. A new calibration curve, applicable to HyspIRI TIR bands will be computed with the latest version of the ASTER spectral library. TES has been shown to accurately recover temperatures within 1.5 K and emissivities within 0.015 for a wide range of surfaces (Gillespie et al. 1998). The ASTER TES algorithm is well established, produces seamless images with no artificial discontinuities; emissivities in the

North American ASTER Land Surface Emissivity Database (NAALSED) (Hulley and Hook, 2009) have been validated at nine validation sites with mean differences for all five ASTER TIR bands of 0.016 (1.6 %), equivalent to ~1 K error in surface temperature for a material at 300 K (Hulley et al. 2009). Accurate atmospheric correction, particularly in humid atmospheric conditions, is critical for retrieving accurate TES LST&E products over graybody surfaces. As a consequence, the Water Vapor Scaling (WVS) method will be used to improve the water vapor atmospheric profiles on a band-by-band basis for each observation (Tonooka, 2005). The WVS method results in improved atmospheric corrections, and resulting emissivities have better accuracy and reduced spectral contrast over vegetation and waterbodies.

6.3 Low Latency Data Products

The current HyspIRI mission concept includes a direct broadcast capability, which will allow any user with the appropriate antenna to download a subset of the HyspIRI data stream to a local ground station. It is expected that distributed software will be developed to mimic the software that produces the standard products. This will enable direct broadcast users access to some HyspIRI data in near real time. The data latency for the standard products has not been determined, but it is anticipated that it will be on the order of a few days to one week.

6.3.1 Hardware investigation

A number of onboard processing algorithms used on Earth Observing One (EO-1) have been bechmarked on a range of hardware platforms, including the Mogoose M5, Rad750, Leon, SpaceCube (Vertex) and Opera (Tilera) platforms. These benchmarks are quite preliminary, but indicate that the more than conventional flight processor options (e.g., SpaceCube, Opera, Iboard, and FPGA) options are the most promising in terms of being able to provide the necessary computing to keep up with the large (roughly 934 Mbits per second raw) data rate from the HyspIRI instruments. Current work involves refining benchmarks as well as solidifying a baseline datapath and transmission (e.g., antenna, transmitter) design. These further efforts are targeting formulation of a baseline hardware design with options and costs for design trades. Current transmission options are based on existing heritage direct broadcast designs with a potential for 15 Megabit/s downlink rates; note, however, that effective rates might be less (refining this number is an area of current work).

6.3.2 Science and Applications

On the software/science/applications side, a number of applications and users groups have been discussed among members of the HyspIRI Science Study Group. With these groups, a range of options have been discussed including: (1) specific bands common to other successful missions, (2) downlink of a spectral subset based on pre-defined spatial masks, and (3) derivation of selected low latency data products onboard. Fundamentally, the data can be reduced spatially, spectrally, or in context based on analysis. The primary applications for the rapid data delivery are wildfires and volcanoes. For active fire mapping and volcanic thermal detection, well understood temperature inversion methods can be used to detect activity and trigger downlink of low-latency data products. Rapid delivery of other products would support applications identified in the Decadal Survey (DS, 2007). For example, vegetation products based on plant color and thermal data can be used for drought and crop yield products and modeling disease vectors.

6.3.3 Operations Concepts

The HypIRI study team has developed a preliminary operations concept for the IPM option (Chien, 2009). In this concept, the science team would have the ability to specify regions of interest that can be spatially and temporally restricted and have an associated priority. For example, coastal masks might specify downlink of shallow water habitat information. Land masks might specify downlink of selected vegetation information. Depending on the product type, reduced spatial resolution data of specific bands might be downlinked (e.g., sea surface temperature information) or an algorithm might be run searching for specific signatures (volcanic activity, drought stress) and, when the signature is found in a region of intestest, full spectral information for the triggered pixels downlinked. Based on the operations constraints of onboard computing, onboard computing setup, and dowlink, the highest priority requests for each overpass of an area that can be accommodated are scheduled. In most cases, multiple low-latency data products could be supported; however, for some high-contention areas, where the swath covers a range of targets, prioritization might be needed to resolve oversubscription (e.g., a coastal region could easily include: forest fire areas, coastal sediment plumes, shallow ocean algal blooms, and drought-stresses crops). The HyspIRI science and applications team would provide or review criteria for prioritizing targets.

7 Conclusions and Recommendations

The HyspIRI workshop re-affirmed the importance and desirability of the HyspIRI mission concept to conduct new science targeted at 1) ecosystem function and composition, 2) volcanoes and natural hazards, and 3) surface composition and sustainable management of natural resources.

The concept would provide high spatial, spectral, and temporal resolution visible through thermal infrared data of the land surface of the Earth and aquatic regions (defined by a water depth of < 50m). Data with the same spectral and temporal resolution but lower spatial resolution would be provided for the open ocean with a depth of > 50m. The measurements would be used to extract the surface radiance, spectral reflectance, emissivity, and temperature that would be used to address a core set of scientific questions related to research, applications, and their associated societal benefits. The concept study has found that the mission recommended by the Decadal Survey could be readily implemented with some minor modifications that optimize the science return from the mission.

Several key conclusions resulted from the workshop:

- HyspIRI provides a unique capability to address a set of specific scientific questions about global ecosystems, habitats, biodiversity, and hazards and their response to anthropogenic or natural changes.
- HyspIRI will help integrate terrestrial and aquatic (inland, coastal, and shallow oceanic) ecosystem studies and allow assessments at spatial scales relevant to resource use by humans.
- The reference instrument designs are capable of meeting the initial science measurement requirements.
- There is an initial set of instrument measurement requirements for HyspIRI that are traceable to the maturing scientific requirements for the mission.
- Significant heritage exists from both a design and risk-reduction standpoint for both candidate instruments. This heritage includes missions, such as the Moon Mineralogy Mapper and EO-1, and the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER), as well as the associated algorithms to deliver the Level 0 through Level 2 data products.
- There are no technology "show stoppers," and the mission is ready for implementation at the earliest opportunity.
- The Draft Preliminary HyspIRI Mission Level 1 Requirements would enable HyspIRI to address the science questions identified for the mission. These requirements were evaluated and fully endorsed by the workshop participants and, by extension, the research community.
- HyspIRI complements measurements from the DesDynI, ACE, and GEO-CAPE missions, each of which addresses very different properties or spatial scales compared to the local and landscape scale features observable with HyspIRI.

Next steps identified by the Science Study Group and affirmed at the workshop include:

- Defining the requirements for *in situ*, tower, and aircraft instrumentation to support HyspIRI;

- Developing spectral libraries to support the reduction and analysis of HyspIRI data;
- Developing simulated HyspIRI data sets for algorithm development and testing;
- Evaluating how data from HyspIRI can be used synergistically with data from other instruments;
- Preparing for the Mission Concept Review (MCR) planned for June of 2010.
- Undertaking studies to evaluate:
  - Sun glint,
  - Saturation of mid and thermal channels,
  - The TIR band positions to determine the optimum band placement, and
  - Compression algorithms for VSWIR/TIR;
- Develop 3-5 key questions that we can take to the public (questions of obvious importance to people);
- Start to define metadata for Level 1 and 2 data products;
- Start to define level 3 products, and
- Develop validation approaches for products.

There was a strong consensus that the HyspIRI mission as recommended by the Decadal Survey would enable the intended science. The mission is clearly defined and ready for implementation at the first available opportunity.

8 References

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9 Appendices

Appendix A – Acronyms

abs cal: Absolute Calibration
AC: Coastal Aquatic
ACE: Aerosol-Cloud-Ecosystems (Mission)
ALEXI/DisALEXI: Atmosphere-Land Exchange Inverse / Disaggregated Atmosphere-Land Exchange Inverse
ASTER: Advanced Spaceborne Thermal Emission and Reflection Radiometer
AVHRR: Advanced Very High Resolution Radiometer
AVIRIS: Airborne Visible Infrared Imaging Spectrometer
cal/val: Calibration/Validation
CCSP: Climate Change Science Program
CDOM: Colored Dissolven Organic Matter
CQ: Combined Question(s)
DAAC: Distributed Active Archive Center
DesDynI: Deformation, Ecosystems Structure, and Dynamics of Ice
DS: Decadal Survey
EO-1 Earth Observing–1
EOS : Earth Observing System
ET: Evapotranspiration
FG: Functional Group
FRP: Fire Radiative Power
FWHM: Full Width at Half Maximum
GDP: Gross Domestic Product
GEO: Group on Earth Observations
GEO-CAPE: Geostationary Coastal and Air Pollution Events
GEOSS: Global Earth Observation System of Systems
GOES: Geostationary Operational Environmental Satellite
HAB: Harmful Algal Bloom
HyspIRI: Hyperspectral Infrared Imager
HyTES: Hyperspectral thermal emission spectrometer
ICESat-II: Ice, Cloud, and Land Elevation Satellite II
IDP : Intelligent Data Payload
IFOV: Instantaneous Field of View
InSAR: Interferometric Synthetic Aperture Radar
IOOS: Integrated Ocean Observing System
IPM: Intelligent Payload Module
IR: Infrared
IOOS: Integrated Ocean Observing System
LDCM: Landsat Data Continuity Mission
LEO: Low Earth Orbit
LST: Land Surface Temperature
M3: Moon Mineralogy Mapper
MASTER: MODIS/ASTER Airborne Simulator
MCR: Mission Concept Review
MODIS: Moderate Resolution Imaging Spectroradiometer

NAS: National Academy of Sciences
NASA: National Aeronautics and Space Administration
NDVI: Normalized Difference Vegetation Index
NE: Noise-Equivalent
NEΔT: Noise-Equivalent Delta Temperature
NPOESS/VIIRS: National Polar-orbiting Operational Environmental Satellite System / Visible Infrared Imaging Radiometer Suite
NOAA: National Oceanographic and Atmospheric Administration
NPV: Non–Photosynthetic Vegetation
NRC: National Research Council
PET: Potential Evapotranspiration
PFT: Plant Functional Type
PV: Photosynthetic Vegetation
NPV: Non photosynthetic vegetation
ROSES: Research Opportunities in Space and Earth Sciences
SAV: Submerged Aquatic Vegetation
SCOPE: Scientific Organization on Problems of the Environment
SEVIRI: Spinning Enhanced Visible and InfraRed Imager
SNR: Signal-to-Noise Ratio
SSG: (HyspIRI) Science Study Group
STM: Science Traceability Matrix
SWIR: Short-Wave Infrared
T-E Separation: Temperature-Emissivity Separation
TIR: Thermal Infrared
TM: (Landsat) Thematic Mapper
TQ: Thermal Infrared Question(s)
UHI: Urban Heat Island
UNIS: United Nations Information Service
USCOP: U.S. Commission on Ocean Policy
VIIRS: Visible Infrared Imager Radiometer Suite
VNIR : Visible and Near Infrared
VQ : Visible Shortwave Infrared Question(s)
VSWIR: Visible Shortwave Infrared
WGA: Western Governors Association

Appendix B - Workshop Agenda

11 Aug 2009 ==

8:00 Registration

8:45 Welcome and Objectives of HyspIRI Science Workshop

- Woody Turner, John LaBrecque

9:00 Overview of Decadal Survey Missions and Context for HyspIRI

- John LaBrecque

Review of Current Baseline HyspIRI Science Measurements Characteristics

9:30 - VSWIR Current Science Measurement Baseline - Rob Green

9:45 - TIR Current Science Measurement Baseline - Simon Hook

10:00 Break

10:30 Review of HyspIRI Mission Characteristics with HyspIRI Mission Current Science Measurement Acquisition Baseline (VSWIR, TIR) - Carl Bruce, Marc Foote, Bogdan Oaida

11:10 - Low latency (Dan Mandl, Steven Chien)

11:30 Draft Preliminary HyspIRI Mission Level 1 Requirements - Robert Green, Simon Hook

12:00 Lunch

VSWIR and TIR Parallel Sessions

VSWIR Afternoon Session

1:00 VQ1 – Pattern and Spatial Distribution of Ecosystems and their Components - John Gamon, Phil Townsend Dar Roberts

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

1:30 VQ2 – Ecosystem Function, Physiology and Seasonal Activity - Susan Ustin

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:00 VQ3 - Biogeochemical Cycles - Scott Ollinger, John Gamon

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

on hold at authors request

2:30 VQ4 - Ecosystem Response to Disturbance - Dar Roberts, Greg Asner

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

3:00 Break

3:30 VQ5 – Ecosystems and Human Well-being - Betsy Middleton

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

4:00 VQ6 - Earth Surface and Shallow Water Benthic Composition - Robert Green, Heidi Dierssen

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

4:30 VSWIR Special Topics

- Level 1 Measurement (Radiance) Calibration Approach and Traceability - Michael Eastwood

- Level 2 Product, terrestrial and aquatic surface reflectance - Bo-Cai Go

5:30 VSWIR Session Close

TIR Afternoon Session

1:00 TQ1 – Volcanoes - Mike Abrams

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

1:30 TQ2 – Wildfires - Ivan Csiszar

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:00 TQ3 – Water Use and Availability- Rick Allen

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:30 TQ4 – Human Health and Urbanization - Dale Quattrochi

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

3:00 Break

3:30 TQ5 – Earth surface composition and Change - Anupma Prakash

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

4:00 TIR Special Topics

- Measurement (Radiance) Calibration Approach and Traceability - Marc Foote

- Level 2 Product, surface radiance, temperature, emissivitiy - Glynn Hulley

5:30 TIR Session Close

7:00 Social Gathering

12 Aug 2009 ===

8:00 HyspIRI Data Analysis ROSES call Status and Upcoming HyspIRI Science Research Opportunities - Woody Turner

8:20 HyspIRI related airborne campaigns - Woody Turner, Simon Hook, Robert Green

8:40 Science Prototype Activities using Hyperion Data and Existing Airborne and Spaceborne Data Sets - Betsy Middleton

9:00 Mapping Floating Aquatic Vegetation (Kelp) with Imaging Spectroscopy at Spatial Scales from 4 to 60 m using Linear Spectral Mixture Modeling - Phil Dennison

9:20 Biogeochemistry measurements for HyspIRI - Scott Ollinger

10:00 Break

10:30 Intelligent Payload Module for low latency measurements and parameters - Dan Mandl, Steven Chien

11:00 Characterization and Monitoring of Geothermal Resources Using Simulated HyspIRI Data - Fred Kruse

11:20 Assessing change in coral reef ecosystems using hyperspectral remote sensing - James Goodman

11:40 HyspIRI Spatail Scale for Coastal Ocean Science - Richard Zimmerman

12:00 Lunch

12:30 Space Grant Students Presentation (30 min)

Combined Question Parallel Sessions

CQ 1-3 Afternoon Session 12 Aug 2009

1:00 CQ1 – Coastal, ocean, and inland aquatic environments - Frank Muller-Karger

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

1:30 CQ2 – Wildfires - Ivan Csiszar

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:00 CQ3 – Volcanoes - Rob Wright

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:30 Break

CQ 4-6 Afternoon Session 12 Aug 2009

1:00 CQ4 – Ecosystem Function and Diversity - Dar Roberts

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

1:30 CQ5 – Land surface composition and change - Lyle Mars

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:00 CQ6 – Human Health and Urbanization - Mike Ramsey

- Science Questions & Applications, Enabling Data Products, Science Traceability Matrix review

2:30 Break

Return to Combined Session

3:00 - Shallow benthic habitat mapping opportunities in both continental nearshore and remote marine park islands; spatial-spectral and temporal scale issues of benthic health and processes - Arnold Dekker, CSIRO, Australia

3:20 Remote Sensing of Volcanic Thermal Features with HyspIRI - Greg Vaughan

3:40 Use of Imaging Spectroscopy to Detect Plant Physiological Traits - Phil Townsend

4:00 Use of VIS/NIR/SWIR/TIR Remote Sensing for U.S. Wildland Fire Characterization and Management: Potential for HyspIRI - Rob Sohlberg

4:20 Imaging spectroscopy for coastal benthic ecosystems: algae and seagrass - Heidi Dierssen

4:40 Evapotranspiration Estimation with ASTER & MASTER over the Jornada Experiment Range, New Mexico, USA - Andy French

5:00 Utility of HyspIRI for Coral Reef Studies and a Case Study of Sun Glint Correction in a Coral Reef Environment - Eric Hochberg

5:20 Close, 7:00 Social Gathering

13 Aug 2009 ==

Partnership Discussion (International and Domestic)

8:00 - Australia - Alex Held

8:20 - Canada - Alan Hollinger

no slides

Related International Missions

8:40 - ENMAP, Germany - Hermann (Charly) Kaufmann

9:00 - PRISMA, Italy - Cristina Ananasso

9:20 - APEX - Michael Schaepman

9:40 - ISRO Imaging Spectroscopy Plans - AS Kiran Kumar

10:00 - JAPAN imaging spectroscopy plans

10:20 Break

10:40 HyspIRI Ground Data Processing Baseline and Options - Robert Knox and Bogdan Oaida

Level 1 Validation of on orbit Radiance Calibration

11:00 - VSWIR - Carol Bruegge, Sven Geier, Robert O. Green

11:20 - TIR - Simon Hook

11:40 - Hyperion lessons learned - Steve Ungar

12:00 Lunch

Level 2 Product Validation and discussion

1:00 - VSWIR - Kevin Turpie, Robert O. Green

1:20 - TIR - Glynn Hulley, Simon Hook

1:40 Canopy small scale variability from HyspIRI for ecological applications - Yuri Knyazikhin

2:00 Anticipated Contributions of HyspIRI to the Remote Sensing of Volcanic Plumes - Vince Realmuto

2:20 Towards an assessment of photosynthetic light use efficiency from space: Upscaling PRI reflectance using an automated multi-angular spectroradiometer - Thomas Hilker

2:40 Deriving soil moisture and sediment mobility using future HyspIRI-derived thermal inertia - Mike Ramsey

3:00 Break

3:20 Use of ASTER Images to Study the Outbreak of West Nile Virus and its Relations with Environmental Variables in Indianapolis, Indiana: Implications for HyspIRI - Qihao Weng

3:40 The NEON Project and Potential Parameter/Algorithm Validation for HyspIRI - Tom Kampe

4:00 Key results and discussion Simon Hook, Robert O. Green

5:00 Review and Discussion of Draft Preliminary HyspIRI Mission Level 1 Requirements -Robert O. Green and Simon Hook

5:20 Review of Workshop and Next Steps - Woody Turner, John LaBrecque, Robert O. Green, Simon J. Hook

5:40 Close

Appendix C – List of Participants

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Abbott	Elsa	JPL
Abrams	Michael	JPL
Algiers, Jr.	Joseph G.	NPS
Allen	Richard G.	U of Idaho
Amici	Stefania	Istituto Nazionale de Geofifica e Vulcanologia (INGV)
Ananasso	Christina	Italian Space Agency
Armstrong	Edward	
Arroyo-Mora	J. Pablo	McGill University
Bagheri	Sima	New jersey institute of technology
Baldauf	Brian	
Baldridge	Alice M.	JPL
Bauer	David	Northrop Grumman
Bernard	William L.	SpecTIR
Binder	Holly	JPL
Block	Gary L.	JPL
Bontempi	Paula	NASA/HQ
Bowen	Jacob A.	JPL
Bradley	Eliza S.	UCSB
Bras	Rafael L.	UC Irvine
Brown	Jacob	JPL
Bruce	Carl F.	JPL
Bruce	Lori	Mississippi State University
Bruegge	Carol	JPL
Buckner	Janice L.	GSFC
Campbell	Petya	UMBC, Earth Science Technology Office
Carlson	Jennifer	
Castle	John	
Cavanaugh	Kyle	UCSB
Cetinic	Ivona	University of Southern California
Cheng	Samuel R.	JPL
Chien	Steve A.	JPL/California Institute of Technology

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Chilenski	Mark A.	JPL
Christensen	Phil	Arizona State University
Chull	Mitch	
Cristo	Alejandro	U of Extremadura
Csiszar	Ivan A.	NESDIS Center for Satellite Applications & Research (NOAA)
Corp	Lawrence A.	GSFC
Crippen	Robert E.	JPL
Cristina	Ananasso	Italian Space Agency
Czapla-Myers	Jeff	University of Arizona
Dalton	James B.	JPL
David	Valencia	U of Extremadura
Dawson	Jason	JPL
Dekker	Arnold G.	CSIRO / Land & Water
De Jong	Steven M.	Utrecht University/Faculty of Geosciences
Dennison	Philip e.	University of Utah
Dierssen	Heidi	
Domanguez Larios	Nieves	U of Extremadura
Donnallen	Andrea	Jet Propulsion Laboratory
Dungan	Jennifer L.	NASA/Ames Research Center
Eastwood	Cathleen	Jet Propulsion Laboratory
Eastwood	Michael	Jet Propulsion Laboratory
Estrada	Miguel	
Farmer-Toro	Gerardo	University of Southern California
Farrand	William H.	(SSI) Space Science Institute
Fitch	Robert A.	(DLR) German Space Agency
Fladeland	Matthew	NASA/Ames
Flatley	Tom	NASA/GSFC Research Center
Foote	Marc C.	Jet Propulsion Laboratory
Frederick	Christina A.	UT Austin
Freeman	Anthony	Jet Propulsion Laboratory/Cal Tech
French	Andrew N.	USDA/ARS
Freund	Friedemann T.	NASA ARC/SETI
Gamon	John A.	U of Alberta

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Gao	Bo-Cai	Naval Research Lab.
Garcia	Luz	
Geller	Gary	
Geier	Sven	Jet Propulsion Laboratory
Goodman	James	Univ. Puerto Rico & Mayaguez
Goulden	Michael L.	UC Irvine
Green	Robert O.	Jet Propulsion Laboratory
Guild	Liane	NASA Ames Research Center
Guess	Abigail	RSAC
Gunapala	Sarath	Jet Propulsion Laboratory
Gunderson	Adam K.	Jet Propulsion Laboratory
Habib	Shahid	NASA/GSFC
Hall	Gavin	Jet Propulsion Laboratory
Hall	Jeff L.	The Aerospace Corp.
Hamilin	Louise	Jet Propulsion Laboratory
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Harris	Sarah L.	Jet Propulsion Laboratory
Hartzell	Christine	Univ. Colorado
Held	Andrew A.	
Henebry	Geoffrey M.	S Dakota State University
Hengemihle	Jerry T.	Microtel LLC
Hepner	George	University of Utah
Hernandez	Luz M.	U of Extremadura
Hernandez	Marco	Jet Propulsion Laboratory
Hartzell	Christnie	JPL/University of Colorado, Boulder
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Hiker	Thomas	University of British Columbia
Ho	Shen-Shyang	Jet Propulsion Laboratory/Cal Tech
Hochberg	Eric J.	Nova Southeastern Univ.
Hollinger	Allan	Canadian Space Agency
Hook	Simon J.	Jet Propulsion Laboratory
Houborg	Rasmus	NASA/GSFC
Huete	Alfredo	U of Arizona

HyspIRI Science Workshop 2009 Attendance Rpt.

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Hulley	Glynn	Jet Propulsion Laboratory
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Johnson	Brian R.	
Johnson	William R.	Jet Propulsion Laboratory
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Kaufmann	Hermann J.	German Research Centre (GFZ)
Keely	Roth	UCSB
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Knyazikhin	Yuri	Boston Univ.
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Lau	Gary K.	Jet Propulsion Laboratory
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Lee	Krista R.	Naval Postgraduate School
Leifer	Ira S.	University of California @ Santa Barbara (UCSB)
Leung	Kon	Jet Propulsion Laboratory
Lieuallen	Athena E.	Oregon State University/JPL
Lopez	Maria P.	University of Extremadura
Lopez-Carrasco	Picar	
Lundeen	Sarah R.	Jet Propulsion Laboratory
Mandl	Daniel	NASA/GSFC
Mann	Lauri Bruce	Mississippi State University
Margolis	Jack S.	Prakash Institut

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Marraco	Hugo G.	Comision Nacional de Actividades Espaciales (CONAE)
Mars	John C.	USGS
Matsunaga	Tsuneo	National Institute of Environmental Studies
McCorke	Joel	NEON/U of Arizona
Merino	Jesus Mr.	U of Extremadura
Meyer	David	
Myers	Lynn	NASA/GSFC
Middleton	Elizabeth M.	NASA/GSFC
Moersch	Jeffrey	U of Tennessee
Mouroulis	Pantazis	Jet Propulsion Laboratory
McCubbin	Ian B.	DRI/Storm Peak Laboratory
Muller-Karger	Frank E.	University of South Florida (USF)/Marine Science
Myers	Jeff	UC Santa Cruz
Myers	Lynn	NASA/GSFC
Myneni	Ranga	Boston University
Navaro	Robert	NASA Dryden Flight Research Center
Nightingale	Joanne M.	NASA/GSFC
Njoku	Eni G.	Jet Propulsion Laboratory
Nuding	Danielle L.	Jet Propulsion Laboratory
Oaida	Bogdan	Jet Propulsion Laboratory
Ollinger	Scott V.	University of New Hampshire
Ong	Lawrence	NASA/GSFC - SSAI
Otero	Richard E.	Jet Propulsion Laboratory
Paine	Christopher G.	Jet Propulsion Laboratory
Painter	Thomas H.	U of Utah
Pestak	Christopher	Battele Memorial Institute
Pieri	David C.	Jet Propulsion Laboratory
Policelli	Fritz S.	NASA/GSFC
Porter	David	
Porter	Michael	
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Prasad	Lela C.	Arizona State University
Prasad	Saurabh	Mississippi State University

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	**First**	**Institution**
Quattrochi	Dale A.	NASA/MSFC
Quirk	Bruce K.	USGS
Radocinski	Robert G.	Jet Propulsion Laboratory
Ramsey	Michael	Univ. Pittsburgh
Realmuto	Vincent J.	Jet Propulsion Laboratory
Rice	Joseph P.	NIST
Richardson	Brandon S.	Jet Propulsion Laboratory
Rivera	Geraldo	JPL/Test
Roberts	Dar A.	University of California @ Santa Barbara (UCSB)
Ross	Arwen E.	Naval Postgraduate School
Roth	Keely L.	University of California @ Santa Barbara (UCSB)
Sarde	Uday s.	Government of Maharashtra, India
Sarture	Charles M.	Jet Propulsion Laboratory
Savelyev	Alexander A.	Univ. Northern Iowa
Schaepman	Michael e.	Remote Sensing Lab/Univ. of Zurich
Schneider	Philipp	Jet Propulsion Laboratory
Schoenung	Susan M.	Ames Research Center
Schull	Mitchell	
Schulze	William	Jet Propulsion Laboratory
Seelin	Karen	
Serbin	Shawn P.	U of Wisconsin-Madison
Shu	Peter K.	NASA/GSFC
Silverman	Dorothy L.	Jet Propulsion Laboratory
Singh	Aditya	U of Wisconsin
Sohlberg	Robert A.	University of Maryland
Staenz	Karl	U of Lethbridg
Stone	Tom	US Geological Survey (USGS)
Su	Yi	(ICET) Mississippi State University
Takahashi	Duke	
Thomas	Alys C.	University of California @ Irvine (UCI)
Thomas	Valeria A.	Virginia Tech.
Tratt	David M.	The Aerospace Corp.
Tao	Tony s.	Jet Propulsion Laboratory

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Thome	Kurtis	NASA/GSFC
Townsend	Phil	U of Wisconsin
Tran	Daniel	Jet Propulsion Laboratory
Tulaczyk	Slawek	University of California @ Santa Cruz
Turmon	MIchael	Jet Propulsion Laboratory
Turner	Woody	NASA Hq
Turpie	Kevin R.	NASA/GSFC
Ungar	Stephen	NASA/GSFC
Ustin	Susan L.	UC Davis
Van Gorp	Brian	
Vande Castle	John R.	University of New Mexico
Vasudevan	Gopal	
Vatsavai	Ranga R.	Oak Ridge Nat. Lab.
Vaughan	Greg	USGS
Valencia	David	
Valerie	Thomas	Virginia Tech
Velez-Reyes	Miguel	UPRM-IRISE
Wang	Jingfeng	University of California
Wang	Jinxue	Raytheon Vision Systems (RVS)
Wang	Kaicun	U of Maryland, College Park
Watson	Gail	Jet Propulsion Laboratory
Weng	Qihao	Marsospace
Wessels	Rick	USGS Alaska Volcano Observatory
West	Terrance R.	Mississippi State University
Wilcox	Eric	NASA/GSFC
Witter	Marti	National Park Service (NPS)
Woodruff	Robert A.	Lockheed Martin
Wright	Robert	Hawaii Institute of Geophysics & Planetology (HIGP)
Wu	Dong L.	Jet Propulsion Laboratory
Wiberg	Dean Y.	Jet Propulsion Laboratory
Wynne	Randolph	Virginia Tech
Xiao	Xiangming	University of Oklahoma
Xu	Liang	

HyspIRI Science Workshop 2009 Attendance Rpt.

Last	First	Institution
Yang	Wenze	Hunter College Dept of Geography
Zhang	Qingyuan	GEST/UMBC
Zimmerman	Richard C.	Old Dominion University

Appendix D – Science-Traceability Matrices

The DS cross-references in the Science Objectives column (first column includes the page number(s) of relevant material in the 2007 Decadal Survey)

Pattern and Spatial Distribution of Ecosystems and their Components: What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity? [DS 195]			
How are ecosystems organized within different biomes associated with temperate, tropical, and boreal zones, and how are these changing? [DS 191, 203]	Measure globally vegetation covered regions seasonally and on a multi-year scale. Derive Fractional Cover of Plant Functional Types and Species where possible (terrestrial): e.g. tree, shrub, herbaceous, cryptogam; thick/thin leaves; broad/needle leaves; deciduous/evergreen; nitrogen-fixer/non-fixer; C3/C4 physiology.	Measure diagnostic spectral signature (400-2500@10nm) with high precision and accuracy to derive plant functional type and species where possible. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure patch scales of <100 m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 am sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge;
How do similar ecosystems differ in size, species composition, fractional cover and biodiversity across terrestrial and aquatic biomes? [DS 195]	Measure globally fraction of dominant Plant Functional Types and Species where possible (terrestrial): e.g. tree, shrub, herbaceous, cryptogam; thick/thin leaves; broad/needle leaves; deciduous/evergreen; nitrogen-fixer/non-fixer; C3/C4 physiology. Sample globally dominant aquatic phytoplankton functional types e.g. phytoplankton (diatoms, dinoflagellates, coccolithophores, N-fixers) Measure dominant submerged aquatic communities (i.e., coral, sea grass, kelp) Sample aquatic biogeochemical constituent: (phytoplankton, sediment, CDOM, benthos)	Measure diagnostic spectral signature (400-2500@10nm) with high precision and accuracy to derive terrestrial functional groups, species and critical measurable Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) to derive aquatic functional groups, species and critical measurable abiotic components. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure with spatial resolution of <100 m. Measure seasonally (90 day revisit) through several (3) years to capture baseline Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge ;
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?	Measure Fractional Cover of Plant Functional Types and Species where possible (terrestrial): e.g. tree, shrub, herbaceous, cryptogam; thick/thin leaves; broad/needle leaves; deciduous/evergreen; nitrogen-fixer/non-fixer; C3/C4 physiology.	Measure diagnostic spectral signature (400-2500@10) with high precision and accuracy to derive plant functional type and species. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure patch scales of <100 m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge

VQ1

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
Pattern and Spatial Distribution of Ecosystems and their Components: What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity? [DS 195]			
What are the extent and impact of invasive species in terrestrial and aquatic ecosystems? [DS 192, 194, 196, 203, 204, 214]	Measure globally vegetation covered regions seasonally and on a multi-year scale. Derive Fractional Cover of Plant Functional Types and Species where possible focusing on invasive species types (terrestrial and aquatic)	Measure diagnostic spectral signature (400-2500@10nm) with high precision and accuracy to derive terrestrial functional groups, species and critical measurable abiotic components. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) to derive aquatic functional groups, species and critical measurable abiotic components. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure with spatial resolution of <100 m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 am sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge;
What is the spatial structure and species distribution in a phytoplankton bloom? [DS 201, 208]	Sample globally algal blooms (including harmful) species and spatial structure in the coastal regions and in the deep oceans with reduced spatial resolution.	Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic vegetation in coastal regions. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to allow atmospheric correction. Measure deep ocean with spatial resolution of <1000 m. Measure coastal aquatic with spatial resolution of <100 m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 am sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge;
How do changes in coastal morphology and surface composition impact coastal ecosystem composition, diversity and function [DS 41]?	Measure coastal ecosystem functional characteristics and diversity at the seasonal and multiyear time scale.	Measure diagnostic spectral signature (400-2500@10) with high precision and accuracy of terrestrial vegetation in coastal regions. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic ecosystems in coastal regions. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure with spatial resolution of <100 m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 am sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Parameter Ground Validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; latency: seasonal, multi-year; 30m (3s) Pointing knowledge;

VQ1

Science Question	*Scientific (Measurement) Objective*	*Scientific Measurement Requirement*	*Mission Functional Requirement*
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 disturbances? [DS 191, 195, 203]			
How does the seasonal activity of ecosystems and functional types vary across biomes, 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] (include agriculture?)	Measure the functional type composition of ecosystems at spatial scales that capture regional and global distributions and temporal scales that capture seasonal and multi-year trends.	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic ecosystems in coastal regions. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; H42Daily solar cals; 6 per year vcals; ~700mbs downlink; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge
How do seasonal changes affect productivity, carbon sequestration, and hydrological processes across ecosystems and agriculture? [DS 195, 205, 210]	Measure seasonal changes and status of natural ecosystem and agricultural lands over the seasonal and multiyear scale.	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; ~700mbs downlink; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge
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]	Measure the physiological function indicators of ecosystems related to water and carbon exchange over the seasonal and multiyear time frame.	Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic ecosystems in coastal regions. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; ~700mbs downlink; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge
What is the environmental impact of aquatic plants and coral in inland and coastal water environments at the seasonal time scale? [DS 201, 208]	Measure the distribution and type of algal bloom in a sampling sense globally over the seasonal and multiyear timescale.	Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic ecosystems in coastal regions. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; ~700mbs downlink; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge

VQ2

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
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			
How do changes in climate and atmospheric processes affect the physiology and biogeochemistry of ecosystems? [DS 194, 201] ["Physiology" considered elsewhere (VQ2) so may not be needed here]	Measure absorption and scattering properties related to biogeochemistry of photosynthetic and non-photosynthetic vegetation.	Measure surface reflectance in the VSWIR region (400-2500@10nm) that is shown to be sensitive to vegetation canopy chemistry at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10) with high precision and accuracy of aquatic ecosystems in coastal regions. Measure Nitrogen and other components in the spectral region 1300 to 2500 nm at 10 nm. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the consequences of uses of land and coastal systems, such as urbanization, agriculture, and resource extraction, for the carbon cycle, hydrological cycle, nutrient fluxes and biodiversity functional composition [DS 196, 197] [We need to broaden this to include other uses (e.g. agriculture and related soil and water issues) and other cycles (e.g. water cycle). Biodiversity per se (as biologists define it) may not be the right word; "functional composition" or some other term may be more appropriate here.]	Measure biological component and state of land and coastal ecosystems globally at the seasonal to several year time scale. Relate these to sources, conduits and sinks of relevant elements.	Measure surface reflectance in the VSWIR region (400-2500@10) with high precision and accuracy that allows mapping of land ecosystem elements. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10) with high precision and accuracy that allows mapping of coastal ecosystem elements. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the consequences of increasing nitrogen deposition for carbon cycling and biodiversity in terrestrial and coastal ecosystems? [DS 195, 196] ["Biodiversity" may not be the right term here (biodiversity is treated elsewhere, and we may not be assessing biodiversity per se. Perhaps "functional composition" might be a better term. Also, we might want to rephrase the aquatic terminology to "marine, coastal and inland waterways" since coastal marine ecosystems are not the only aquatic concern.]	Measure ecological components of terrestrial and coastal ecosystem including elements of biodiversity. Measure ecological signatures closely tied to nitrogen deposition.	Measure surface reflectance in the VSWIR region (400-2500@10) with high precision and accuracy that allows mapping of land ecosystem elements. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10) with high precision and accuracy that allows mapping of coastal and aquatic ecosystem elements. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;

VQ3

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
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			
How do changes in hydrology, pollutant inputs and sediment transport affect freshwater and coastal marine ecosystems? [DS 196]	Measure diagnostic elements of freshwater and coastal marine ecosystem including sediments, chlorophyll, algal communities, and CDOM.	Measure at high accuracy and precision the spectral signatures (380-900@10nm) that allow derivation of key elements of freshwater and coastal marine ecosystems. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How do changing water balances affect carbon storage by terrestrial ecosystems? [DS 196]	Measure water content of canopies. Measure signals of evapotranspiration.	Measure at high accuracy and precision the surface reflectance in the VSWIR region (400-2500@10nm) that allow derivation of canopy liquid water. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure at high accuracy and precision the spectral region (380-900@10nm) where liquid water and water vapor are expressed. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the key interactions between biogeochemical cycles and the composition and diversity of ecosystems? [195, 196]	Measure biogeochemistry elements as well as composition and diversity of ecosystems.	Measure at high accuracy and precision the surface reflectance in the VSWIR region (400-2500@10nm) that is shown to be sensitive to vegetation canopy chemistry and ecosystem composition. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure Nitrogen and other components in the spectral region 1300 to 2500 nm at 10 Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How do changes in biogeochemical processes feed back to climate and other components of the Earth system? [DS 190, 192, 195]	Measure global biogeochemical constituents related to processes involved in feedback to climate and other environmental factors.	Measure at high accuracy and precision the surface reflectance in the VSWIR region (400-2500@10nm) that is shown to be sensitive to vegetation canopy chemistry and ecosystem composition. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/-50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure Nitrogen and other components in the spectral region 1300 to 2500 nm at 10 nm. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;

VQ3

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
Changes in Disturbance Activity : How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?			
How do patterns of abrupt (pulse) disturbance vary and change over time within and across ecosystems?	Measure changes (<10%) in fractional cover (from clearing, logging, wetland drainage, fire, weather related, etc.) at the seasonal and multiyear time scales, to characterize disturbance regimes in global ecosystems (e.g., conditional frequencies and/or return intervals for VQ1 ecosystem classes). Measure the seasonal and multi-year change in abundance and fractions of biotic and abiotic components of the aquatic environment.	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; ~700mbs downlink; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; accurate enough to simulate historical satellite data through band synthesis; Atmospheric Correction; AC validation; Geolocation: 10 m (1 sigma); Ground processing; Seasonal latency; 30m (3s) Pointing knowledge ;
How do climate changes affect disturbances such as fire and insect damage? [DS 196]	Measure changes in vegetation canopy cover, pigments, and water content in ecosystems globally at the seasonal and multiyear time scale. Make measurements in such a way that they are backward compatible with pre-existing estimates and algorithms (e.g., band synthesis for historical vegetation indexes), as well as allowing more advanced algorithmic approaches. (Measure PV, NPV and Soil (+/- 5%) using full VSWIR and SWIR algorithms.) (Measure characteristic changes or differences in plant pigments (10% changes in total chlorophyll,	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy (i.e. coral bleaching, storm damage). Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the interactions between invasive species and other types of disturbance?	Measure the distribution and cover of key invasive species that introduce novel life histories or functional types, in concert with disturbance measurements. Measure (disturbance related) changes in vegetation canopy cover, pigments, and water content in ecosystems globally at the seasonal and multiyear time scale. (Measure PV, NPV and Soil using full VSWIR and SWIR algorithms.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy (i.e. coral bleaching, storm damage). Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
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?	Measure the composition of ecosystems and ecological diversity indicators globally and at the seasonal and multiyear time scale. (Measure PV, NPV and Soil using full VSWIR and SWIR algorithms.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy (i.e. coral bleaching, storm damage). Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;

VQ4

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
Changes in Disturbance Activity : How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?			
How do climate change, pollution and disturbance augment the vulnerability of ecosystems to invasive species? [DS 114,196]	Measure disturbances and ecosystem status. Measure invasive trends. Measure at the seasonal to multiyear time scale. (Measure PV, NPV and Soil using full VSWIR and SWIR algorithms.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy (i.e. coral bleaching, storm damage). Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the effects of disturbances on productivity, water resources, and other ecosystem functions and services? [DS 196]	Measure disturbances and productivity indicators including ecosystem function and services on the seasonal to multiyear time scale. (Measure PV, NPV and Soil using full VSWIR and SWIR algorithms.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How do changes in human uses of ecosystems affect their vulnerability to disturbance and extreme events? [DS 196]	Measure status of ecosystems globally and relation to disturbances and major events at the seasonal to multiyear time scale. (Measure PV, NPV and Soil using full VSWIR and SWIR algorithms.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How do active and post-fire disturbances impact ecosystem processes and related human decisions.	Measure the fuel and intensity properties of actively burning fires and post fire recovery.	Measure surface reflectance in the VSWIR region (400-2500@10nm) at high precision and accuracy (for spectral mixture algorithms to give insight to subpixel events). Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends. Measure with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; 6 hr latency; 30m (3s) Pointing knowledge;

VQ4

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
Ecosystem and Human Health: How do changes in ecosystem composition and function affect human health, resource use, and resource management?			
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	Measure the ecosystem composition and function globally at the seasonal and multiyear timescale. Relate these to measures of infectious diseases and organisms that transmit them. Understand the impact of climate change on the disease vectors environments and interaction with human settlement changes	Measure surface reflectance of terrestrial ecosystems in the VSWIR region (400-2500@10nm) at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure diagnostic spectral signature (380-900@10nm) of biotic and abiotic components of the aquatic environment with high precision and accuracy Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How will changes in pollution and biogeochemical cycling alter water quality? Water quality monitoring, algal blooms, eutrophication	Measure biogeochemical, pollution, and water quality indicators globally at the seasonal and multiyear time scale.	Measure terrestrial vegetation biogeochemical signatures in the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure costal aquatic vegetation biogeochemical signatures in the VSWIR spectral signature (380-900@10nm) acquired at high precision and accuracy to capture turbidity and water clarity, algal and cyanobacterial growth as well as the size and health (biodiversity) of wetlands. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How are changes in ecosystem distribution and productivity linked to resource use, and resource management? Forrestry management, fire effects, biofuels, argicultural management	Measure ecosystem composition, productivity and distribution globally at the seasonal and multiyear time scale. Relate these to measures of resource use and management. Map the function types (communities) of the forestry resources, biofuel (corn, sugar cane, etc.) Also regionally and locally. Measure seasonal changes in productivity	Measure terrestrial vegetation composition, function and production in the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure costal aquatic vegetation composition, function and production in the VSWIR spectral signature (380-900@10nm)acquired at high precision and accuracy. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
How will changes in climate and pollution affect the health and productivity of aquatic and agricultural resources? Agriculture and Aquaculture.	Measure aquatic and agricultural resource systems globally and through the seasonal and multiyear time frame. Relate these to measures of climate and pollution to detect trends and make predictions. Baseline and monitor changes in the environs on the "culture" area	Measure the composition and productivity of agricultural resource ecosystems using the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure the composition and productivity of aquatic resource ecosystems using the VSWIR spectral signature (380-900@10nm) acquired at high precision and accuracy and capture turbidity and water clarity, algal and cyanobacterial growth as well as the size and health (biodiversity) of associated wetlands. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;

VQ5

Science Question	*Scientific (Measurement) Objective*	*Scientific Measurement Requirement*	*Mission Functional Requirement*
Ecosystem and Human Health: How do changes in ecosystem composition and function affect human health, resource use, and resource management?			
What are the economic and human health consequences associated with the spread of invasive species? Mapping invasive species.	Measure the global distribution and seasonal variation of invasive terrestrial and costal aquatic species from one to several years. Relate this to economic and human health factors to support both direct assessment and future trend prediction. Distinguish the invasive species from the natural species	Measure the distribution of invasive terrestrial species using the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure the distribution of invasive aquatic species using the VSWIR spectral signature (380-900@10nm) acquired at high precision and accuracy. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge; Knowledge of local situation vis-à-vis active invasive species of import. Local spectral databases of natural and invasive species.
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]) Cross border examples of biodiversity (us-mexico, haiti-domician republic.	Measure ecosystem composition, function, and distribution globally and seasonal and multiyear time scale. Relate this to the spatial pattern of environmental management and economic conditions for direct assessment and future prognostication.	Measure terrestrial ecosystem vegetation composition, function and distribution using the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure aquatic ecosystem vegetation composition, function and distribution using the VSWIR spectral signature (380-900@10nm) acquired at high precision and accuracy. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;
What are the impacts of flooding and sea-level rise on ecosystems, human health, and security? [DS 195, 224, 227, 348, 357] Coastal zone use mapping.	Measure ecosystem composition, function and distribution in the coastal regions globally at the seasonal and multiyear timescale. Relate these measurements to the status of coastal ecosystem and the human health and security implications. Measure of the global, regional and local scales	Measure coastal ecosystem vegetation composition, function and distribution in the terrestrial domain using the VSWIR spectral signature (400-2500@10nm) acquired at high precision and accuracy. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measure coastal ecosystem vegetation composition, function and distribution in the aquatic domain using the VSWIR spectral signature (380-900@10nm) acquired at high precision and accuracy. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measure globally at spatial resolution patch scale relevant for ecosystem 10^4 to 10^6 m^2. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; F340Atmospheric Correction; AC validation; Geolocation; Pointing strategy to minimize sun glint; Avoid terrestrial hot spot; Ground processing; Seasonal latency; 30m (3s) Pointing knowledge;

VQ5

Science Question	Scientific (Measurement) Objective	Scientific Measurement Requirement	Mission Functional Requirement
Earth Surface and Coastal Benthic Composition: What is the land surface soil/rock and shallow coastal benthic compositions?			
What is the distribution of the primary minerals and mineral groups on the exposed terrestrial surface? [DS 218]	Measure the exposed surface rock and soil compositions globally. Measure the available rock forming and alteration minerals and subtle changes in composition via spectral absorption position and shape. Derive fractional abundance through spectral mixture analysis and related approaches.	Measure surface reflectance in the VSWIR region (400-2500@10nm) with high precision and accuracy to capture the diagnostic absorptions features of clay, iron, carbonate and other rock/soil forming minerals. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measurements at a spatial scale to resolve material patches at <100m. Measure yearly (365 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 80 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Atmospheric Correction; Atmospheric Correction validation; Geolocation: Ground processing; latency: yearly; 30m (3s) Pointing knowledge;
What is the bottom composition (sand, rock, mud, coral, algae,SAV, etc) of the shallow water regions of the Earth?	Measure globally the shallow water regions and inland waters. Derive the composition of the optically available (e.g. non-turbulent) shallow water bottom regions of the coastal oceans and inland waters.	High precision and accuracy spectral signatures in the visible to near infrared (380-900 @10nm sampling) to capture the bottom composition interaction with light. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measurements at a spatial scale to resolve material patches at <100m. Measure yearly (365 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 80 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Atmospheric Correction; Atmospheric Correction validation; Geolocation: Ground processing; latency: yearly; 30m (3s) Pointing knowledge;
What fundamentally new concepts for mineral and hydrocarbon research will arise from uniform and detailed global geochemistry of the exposed rock/soil surface [DS227]	Measure the exposed surface rock and soil compositions globally. Derive geochemical information (i.e. Ion substitution expressed as spectral signature shifts.)	Measure surface reflectance in the VSWIR region (400-2500@10nm) with high precision and accuracy to capture the diagnostic absorptions features shifts of clay, iron, carbonate and other rock/soil forming minerals due to variations in geochemistry. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measurements at a spatial scale to resolve material patches at <100m. Measure yearly (365 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 80 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Radiometric calibration; Atmospheric Correction; AC validation; Geolocation; Ground processing; latency: yearly; 30m (3s) Pointing knowledge;
What changes in bottom substrate occur in shallow coastal and inland aquatic environments? [DS 25]	Measure the composition of the optically available shallow water bottom regions of the coastal oceans and inland waters. Bottom substrate composition of sand, coral, mud, SAV,etc. More detailed specificity as possible with the available signal.	Measure surface reflectance in the visible to near infrared (380-900 @10nm) at high precision and accuracy to capture the bottom composition interaction with light. Selected wavelengths in the short wavelength infrared (1250, 1650, 2250) to enable atmospheric correction for aquatic observations. Measurements at a spatial scale to resolve material patches at <100m. Measure seasonally (90 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 20 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Atmospheric Correction; Atmospheric Correction validation; Geolocation; Ground processing; latency: seasonal; 30m (3s) Pointing knowledge;
How can measurements of rock and soil composition be used to understand and mitigate hazards? [DS 114,227]	Measure the exposed surface rock and soil compositions globally to determine the occurrence of hazard associated minerals (For example, Acid generating minerals, Asbestos, etc.). Derive fractional abundance of hazardous minerals through spectral mixture analysis and related approaches.	Measure surface reflectance in the VSWIR region (400-2500@10nm) with high precision and accuracy to capture the diagnostic absorptions features of acid generating (sulfates), asbestos, minerals. Selected wavelengths (760+/-20 - oxygen for surface pressure and atm aerosols; 940 +/- 50 and 1150+/-50 - for water vapor; 1380 +/-20 for cirus clouds) to allow for atmospheric correction for terrestrial and aquatic observations. Measurements at a spatial scale to resolve material patches at <100m. Measure yearly (365 day revisit) through several (3) years to observe the seasonal regional occurrence and trends in the coastal regions. Measure regionally-important Plant Functional Type with a revisit time of at most 80 days.	Surface reflectance in the solar reflected spectrum for elevation angles >20; Rigorous cal/val program; Monthly lunar cals; Daily solar cals; 6 per year vcals; >3X zeroloss compression; ~10:30 AM sun sync LEO orbit; Atmospheric Correction; Atmospheric Correction validation; Geolocation; Ground processing; latency: yearly; 30m (3s) Pointing knowledge;

VQ6

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
TQ1. Volcanoes and Earthquakes: How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?				
Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates and are such changes unique to specific types of eruptions? [DS 227]	Detect, quantify and monitor subtle variations in: 1) surface temperatures 2) surface emissivity 3) sulfur dioxide concentrations at low, non-eruptive flux background levels. Compilation of long-term baseline data sets.	1) Temperature measurements in the range 243- 573 K. Requires atmospheric correction band and at least three thermal IR bands. 2) Atmospheric correction band and at least five thermal IR bands. 3) Atmospheric correction band, SO_2 band with one band on either side. 7 day repeat.	Spatial resolution: < 100m Number Spectral channels: 4 Spectral range: 7-12 um. Channel centers: 7.3, 8.5, 11, 12 Channel width: undefined NEΔT @ 300K 4 um: undefined NEΔT @ 300K 8-12 um: < 0.2K Radiometric accuracy: < 5% Geolocation accuracy: < 30 m Saturation temperature (4 um): undef. Saturation temperature (7-12 um): undef. Bright target recovery: undefined	Temporal resolution: < 7 days Nighttime data acquisitions.
What do changes in the rate of lava effusion tell us about the maximum lengths that lava flows can attain, and the likely duration of lava flow-forming eruptions? [DS 226]	Area covered by active lava flows; Lava flow surface temperatures; Radiant flux from lava flow surfaces.	Temperature measurements in the range 273 to 1473K (active lava), and 273-323K (ambient background). 5 day repeat.	Spatial resolution: < 60m Number spectral channels: 4 Spectral range 4-12 um Channel centers: 4, and 3 between 8-12 Channel width: undef. NEΔT @ 300K 4 um:< 1-2 K NEΔT @ 300K 8-12 um: < 0.2K Radiometric accuracy: undef. Saturation temperature (4 um): 1200 K Saturation temperature (7-12 um): 373 K Bright target recovery: <2 pixels at 4 um	Temporal resolution: undefined Nighttime data acquisitions. NIR/SWIR hyperspectral data is beneficial. Rapid response off nadir pointing capability. Rapid re-tasking for acquisition of targets of opportunity.
What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long do such clouds remain a threat to aviation? [DS 224]	Discrimination of volcanic ash clouds from meteorological clouds (both water and ice), in both wet and dry air masses. Day and night measurements	Four spectral channels at 8.5, 10, 11, and 12 μm; Nedt of 0.2 K @ 300K Max. repeat cycle of 5 days.Temperature measurements in the range 253.15 to 473.15K.	Spatial resolution: undef Number spectral channels: 4 Spectral range 8-12 um Channel centers: 8.5, 10, 11, 12 Channel width: 50nm at 8.5, 100 nm others NEΔT @ 300K 4um: undefined NEΔT @ 300K 8-12um: < 0.5K Radiometric accuracy: < 5% Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef	Temporal resolution: < 5 days NIR/SWIR hyperspectral data valuable to assist in recognition of meteorological clouds and estimation of plume height. Night-time data acquisitions to increase the frequency of observation.
What do the transient thermal anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust? [DS 227, 229]	Detect and monitor increases in TIR surface radiance surface temperatures along potentially active faults.	Temperature measurements in range 248.15-320.15K 5 day repeat (or better); nighttime data	Spatial resolution: <100 m Number spectral channels: 3 Spectral range 7-12 Channel centers: 8-8.5; 7.3-8,10 Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: < 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef	Temporal resolution: 5 days Nighttime acquisitions
Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions? [DS 227]How can the release of energy at the surface of volcanic edifices be used to understand magma processes at depth and over time?	Detect and monitor temperature changes of volcanic edifices	Temperature measurements in range of 248.15-1200K; 5 day repeat	Spatial resolution: < 90 m Number spectral channels: 3 Spectral range: 4-12 Channel centers: 4, 10.5, 11.5 Channel width: undef NEΔT @ 300K 4um: <1-2K NEΔT @ 300K 8-12um: undef Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef	Temporal resolution: 5 day Nighttime acquisitions

TQ1

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
Wildfires: What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?				
How are global fire regimes changing in response to, and driven by, changing climate, vegetation, and land use practices? [DS 198]	Fire monitoring, fire intensity, fire extent, spatio-temporal variations in location, fire duration	Monitor smoldering fires as small as ~10 sq. m in size, monitor fire boundary, fire radiative power, fire temperature and area, 4-10 day repeat cycle	Spatial resolution: 50-100m Number spectral channels: 2 Spectral range: 4-12 Channel centers: 4, 11 Channel width: undef NEΔT @ 300K 4um: <2-3K NEΔT @ 300K 8-12um: <0.2K Radiometric accuracy: undef Saturation temperature (4 um): 1200K Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: < 0.25/pixel	Temporal resolution: 4-10 days Daytime and nighttime data acquisition, direct broadcast capability, onboard processing, pre and post burn thematic maps. Opportunistic validation.
Is regional and local scale fire frequency changing? [DS 196]	Fire detection	Detect flaming and smoldering fires as small as ~10 sq. m in size, 4-10 day repeat cycle	Spatial resolution: 50-100m Number spectral channels: undef Spectral range: 8-12 Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: < 0.2K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: undef Daytime and nighttime data acquisition (thermal inertia). LEO orbit. Requires historical context from other sensors. Pre and psot fire thematic maps. Requires measurement intercalibration (e.g. MODIS vs HyspIRI). HyspIRI establishes a baseline.
What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]	Fire monitoring, fire intensity, fire extent, spatio-temporal variations in location, fire duration.	Detect flaming and smoldering fires as small as ~10 sq. m in size, fire radiative power, 4-10 day repeat cycle	Spatial resolution: 50-100m Number spectral channels: 2 Spectral range: 4-12 Channel centers: 4,11 Channel width: undef NEΔT @ 300K 4um: <2-3K NEΔT @ 300K 8-12um: <0.2K Radiometric accuracy: undef Saturation temperature (4 um): 1200K Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: < 0.25/pixel	Temporal resolution: undef Daytime and nighttime data acquisition, sun synchronous orbit. Ancilliary global geochemical model to evaluate importance of fire input. Requires fire fuel modeling element.
Are there regional feedbacks between fire and climate change?	Measurement location and extent of fire front. Confirmation of burn scars and their extent.	Detect flaming and smoldering fires as small as ~10 sq. m in size, fire radiative power, 4-10 day repeat cycle	Spatial resolution: 50-100m Number spectral channels: 2 Spectral range: 4-12 Channel centers: 4,11 Channel width: undef NEΔT @ 300K 4um: <2-3K NEΔT @ 300K 8-12um: <0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: undef Daytime and nighttime data acquisition, sun synchronous orbit

TQ2

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
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 sustaining water resources?				
How is climate variability (and ENSO) impacting the evaporative component of the global water cycle over natural and managed landscapes? [DS 166, 196, 203, 257, 368]	Evapotranspiration (surface energy balance) at scales resolving the typical lengthscales of landsurface moisture heterogeneity	Global coverage of surface radiometric temperature; ~weekly to monthly; resolving land-use components; Surf. Rad. Temp. accurate to <1K; ~10-11 AM local overpass	Spatial resolution: < 100m Number spectral channels: 3 Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: < 5% Saturation temperature (4 um): undef Saturation temperature (7-12 um): 360K Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Maps of vegetation index; broadband albedo retrievals (from integrated VSWIR or 3 or more wide bands in green, red, nearIR); landuse; insolation data; Landsat-like mid-morning sun-synchronous overpass. Cloud detection mechanism, (including cirrus); Ancillary meteorological data (varies with process)
What are relationships between spatial and temporal variation in evapotranspiration and land-use/land-cover and freshwater resource management? [DS 196, 203, 368]	Evapotranspiration at scales resolving the typical length scales of land surface moisture and vegetation heterogeneity	Global coverage; resolving e.g., field, riparian patches, reservoirs, water rights (ag. field sized) polygons; LST accurate to <1K; ~10:30AM overpass	Spatial resolution: < 100 m Number spectral channels: 3 Spectral range: 8.5, 11, 12 Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): 360K Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Maps of vegetation index; landuse; insolation data; Landsat-like mid-morning sun-synchronous overpass
Can we improve early detection, mitigation, and impact assessment of droughts at local to regional scales anywhere on the globe? [DS 166, 196, 203, 368]; How does the partitioning of Precipitation into ET, surface runoff and ground-water recharge change during drought?	Stress index at field scales	Global coverage; resolving field-scale (1 ha) patches; LST accurate to <1K; ~10:30AM overpass	Spatial resolution: < 100m Number spectral channels: 3 Spectral range: 8-12 Channel centers: 8.5,11,12 Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): 360 Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days As above; some methods require potential evapotranspiration (based on meteorological data and/or satellite-based insolation); hyperspectral stress signatures will provide supplemental stress info
What areas of Earth have water consumption by irrigated agriculture that is out of balance with sustainable water availability? [DS 196, 368]	Robust detection of pixels with water consumption in excess of rainfall and regional fresh water availability (surface and ground water)	Global coverage; resolving irrigation patches; ~10:30 AM overpass	Spatial resolution: < 100 m Number spectral channels: 3 Spectral range: 8-12 um Channel centers: 8.5, 11, 12 Channel width: undef NEΔT @ 300 4um: undef NEΔT @ 300 8-12um: undef Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um):360K Bright target recovery: undef Interband registration acc: undef	Temporal resolution: weekly to monthly detailed land cover classification (can be improved using hyperspectral); vegetation indices; regional hydrologic water balances and stores; ET quantification

TQ3-1

Can we increase food production in water-scarce agricultural regions while improving or sustaining quality and quanitity of water for ecosystem function and other human uses? [DS 196, 368]	Accurate evapotranspiration at sub-field scales	irrigation patches well resolved; LST accurate to 0.5K; ~10:30AM overpass	Spatial resolution: < 50m Number spectral channels: 8.5,11,12 Spectral range: 8-12 um Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): 360K Bright target recovery: undef Interband registration acc: undef	Temporal resolution: weekly Vegetation index; accurate local meteorological forcing conditions; means to partition ET into E and T would be valuable
What is the ecological impact of thermal plumes and elevated water temperature stemming from water uses, including desalinization, in inland and coastal water bodies?	thermal plumes and elevated water surface temperature	Multiple TIR channels to detect plumes	Spatial resolution: < 60m Number spectral channels: undef Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: <0.1K Radiometric accuracy: < 0.5K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 5 days Atmospheric correction

TQ3-2

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
Urbanization and 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?				
How do changes in local and regional land cover and land use, in particular urbanization affect surface energy balance characteristics that impact human welfare [DS: 160-161, 166-167, 196, 198]	Surface temperature Surface energy fluxes Surface emissivity terrestrial coverage		Spatial resolution: < 60 m Number spectral channels: 4 Spectral range: 8-12 Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: undef Radiometric accuracy: < 1 K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Long term validation sites (incl. emissivity targets) and periodic urban campaigns
What are the dynamics, magnitude, and spatial form of the urban heat island effect (UHI), how does it change from city to city, what are its temporal, diurnal, and nocturnal characteristics, and what are the regional impacts of the UHI on biophysical, climatic, and environmental processes? [DS: 158, 166-168]	Day and night surface temperature Urban coverage Intra-seasonal measurements	Min T/Max T 260-360K	Spatial resolution: < 60 m Number spectral channels: 4 Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2-0.3 K Radiometric accuracy: < 1K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: 0.2/pixel	Temporal resolution: 7 days Cloud masking at night Day and night imaging
How can the factoros influencing heat stress on humans be better resolved and measured. [DS: 156, 158, 160, 183-184]	Surface temperature Urban coverage	Vegetated/non-vegetated surfaces	Spatial resolution: < 60 m Number spectral channels: >4 Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2-0.3K Radiometric accuracy: < 1K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Air temperature Day and night imaging
How can the characteristics associated with environmentally related health effects,-that affect vector-borne and animal-borne diseases, be better resolved and measured? [DS: 156, 158, 160, 183-184]	Surface temperature Terrestrial coverage	Detection of wet/dry surfaces Vegetated/non-vegetated surfaces	Spatial resolution: < 60 m Number spectral channels: 3 Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2-0.3K Radiometric accuracy: 1K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Soil moisture or precipitation Air temperature water inundation Day and night imaging
How do horizontal and temporal scales of variation in heat flux and mixing relate to human health, human ecosystems, and urbanization? [DS: 156, 160-161, 166-167, 179,184]	Surface temperature Surface energy balance Surface energy fluxes Global coverage		Spatial resolution: < 60 m Number spectral channels: 3 Spectral range: undef Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um:0.2-0.3K Radiometric accuracy: 1K Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Day and night imaging

TQ4

Science Objectives	Measurement Objectives	Measurement Requirements	Instrument Requirements	Other Mission and Measurement Requirements
Earth Surface Composition and Change: What is the composition and thermal properties of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?				
What is the spectrally observable mineralogy of the Earth's surface and how does this relate to geochemical and surficial processes? [DS 114]	*Mapping spectral* emissivity variations associated with mineralogy and rock type in exposed terranes	Variation in silica content and non-silicate *minerals* based on 8-12 um band shape. (Spectral emissivities towithin 0.5%)	Spatial resolution: 60 m Number spectral channels: 7 Spectral range: 8-12 um Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: Quarterly Geolocation to subpixel accuracy Band to band calibration must be validated, in-flight and radiometric calibration
What is the nature and extent of man-made disturbance of the Earth's surface associated with exploitation *of renewable* and non-renewable resources? How do these vary over time? [DS 227]	Surface *temperature and* emissivity variations associated *with hydrocarbon and mineral extraction (dumps and pits)*	Variation in mineral content based on 8-12 um band shape including detection of sulfate spectral features. *At scale of mining activities.*	Spatial resolution: 60 m Number spectral channels: 5 Spectral range: 8-12 Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: < 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: Monthly Geolocation to subpixel accuracy Band to band calibration must be validated, preferably in-flight and radiometric calibration
How do surface temperature anomalies relate to deeper thermal sources, such as *hydrothermal systems,* buried lava tubes, underground coal fires and engineering structures? How do changes in the surface temperatures relate to changing nature of the deep seated hot source? [DS 243]	Surface temperatures corrected for emissivity variations *for temperature anomalies*	*Measure* variations in temperature with high *accuracy and* precision and spatial resolution	Spatial resolution: 60m Number spectral channels: 3 Spectral range: 8-12 um Channel centers: undef Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 30K0 8-12um: 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Nightime data necessary to minimize radiant interference due to solar heating
What is the spatial distribution pattern of surface temperatures and emissivities and how do these influence the Earth's heat budget?	Surface emissivity variations and temperatures of all surficial cover materials	Complex surface emissivity properties based on 8-12 um band shape	Spatial resolution: 60-500m Number spectral channels: 8 Spectral range: 3-12 Channel centers: 3.98 and 7 in 8-12 Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Accurate methods of temperature emissivity separation applicable to wide range of materials needed.
What are the water surface temperature *distributions* in coastal, ocean, and *inland water bodies, how do they change, and how do they influence aquatic ecosystems* ? [DS 378]	Spatial and temporal variation in *surface* temperatures	*Measure* variations in temperature with high *accuracy (<0.5 K) and* precision and good to moderate spatial resolution	Spatial resolution: 50-100 m Number spectral channels: 4 Spectral range: 3-12 Channel centers: 3.98 and 3 in 8-12 um Channel width: undef NEΔT @ 300K 4um: undef NEΔT @ 300K 8-12um: 0.2K Radiometric accuracy: undef Saturation temperature (4 um): undef Saturation temperature (7-12 um): undef Bright target recovery: undef Interband registration acc: undef	Temporal resolution: 7 days Day and night measurements preferable

TQ5