JPL Publication 14-13

NASA 2014 The Hyperspectral Infrared Imager (HyspIRI) – Science Impact of Deploying Instruments on Separate Platforms

HyspIRI Group

Edited by Simon J. Hook

Question Leads:
CQ1 - Kevin Turpie
CQ2 - Sander Veraverbeke
CQ3 - Robert Wright
CQ4 - Martha Anderson
CQ5 - Anupma Prakash/John "Lyle" Mars
CQ6 - Dale Quattrochi

Prepared for

National Aeronautics and Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

July 2014

This page is intentionally left blank

JPL Publication 14-13

NASA 2014 The Hyperspectral Infrared Imager (HyspIRI) – Science Impact of Deploying Instruments on Separate Platforms

HyspIRI Group

Prepared for

National Aeronautics and Space Administration

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

July 2014

The work described in this publication was performed at a number of organizations, including the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Compiling and publication support was provided by the Jet Propulsion Laboratory, California Institute of Technology under a contract with NASA.

Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not constitute or imply its endorsement by the United States Government, or the Jet Propulsion Laboratory, California Institute of Technology.

Copyright 2014 California Institute of Technology. U.S. Government sponsorship acknowledged

Abstract

The Hyperspectral Infrared Imager (HyspIRI) mission was 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. The HyspIRI mission is science driven and will address a set of science questions identified by the Decadal Survey and broader science community. The mission includes a visible shortwave infrared (VSWIR) imaging spectrometer, a multispectral thermal infrared (TIR) imager and an intelligent payload module (IPM). The IPM enables on-board processing and direct broadcast for those applications with short latency requirements. The science questions are organized as VSWIR-only, TIR-only and Combined science questions, the latter requiring data from both instruments. In order to prepare for the mission NASA is undertaking pre-phase A studies to determine the optimum mission implementation, in particular, cost and risk reduction activities. Each year the HyspIRI project is provided with feedback from NASA Headquarters on the pre-phase A activities in the form of a guidance letter which outlines the work that should be undertaken the subsequent year. The 2013 guidance letter included a recommendation to undertake a study to determine the science impact of deploying the instruments from separate spacecraft in sun synchronous orbits with various time separations and deploying both instruments on the International Space Station (ISS). This report summarizes the results from that study. The approach taken was to evaluate the impact on the **combined** science questions of time separations between the VSWIR and TIR data of <3 minutes, <1 week and a few months as well as deploying both instruments on the ISS. Note the impact was only evaluated for the combined science questions which require data from both instruments (VSWIR and TIR). The study concluded the impact of a separation of <3 minutes was minimal, e.g. if the instruments were on separate platforms that followed each other in a train. The impact of a separation of <1 week was strongly dependent on the question that was being addressed with no impact for some questions and a severe impact for others. The impact of a time separation of several months was severe and in many cases it was no longer possible to answer the sub-question. The impact of deploying the instruments on the ISS which is in a precessive (non-sun synchronous) orbit was also very question dependent, in some cases it was possible to go beyond the original question, e.g. to examine the impact of the diurnal cycle, whereas in other cases the question could not be addressed for example if the question required observations from the polar regions. As part of the study, the participants were asked to estimate, as a percentage, how completely a given sub-question could be answered with 100% indicating the question could be completely answered. These estimations should be treated with caution but nonetheless can be useful in assessing the impact. Averaging the estimates for each of the combined questions the results indicate that 97% of the questions could be answered with a separation of < 3 minutes. With a separation of < 1 week, 67% of the questions could be answered and with a separation of several months only 21% of the questions could be answered.

Document Contact

Many researchers provided Inputs for this report, in particular, the leads for each of the overarching science questions who are named on the next page. Readers seeking more information about the response to particular question can email the contact below:

- Simon J. Hook
  MS 183-503
  Jet Propulsion Laboratory
  4800 Oak Grove Dr.
  Pasadena, CA 91109
  Email: Simon.J.Hook@jpl.nasa.gov
  Office: (818) 354-0974

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 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, (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 assess the status of biodiversity around the world and the role of different biological communities on land and within inland water bodies, as well as coastal zones and at reduced resolution in the ocean. Furthermore, it will help identify natural hazards; in particular volcanic eruptions and any associated precursor activity, and it will map the mineralogical composition of the land surface. The mission will advance our scientific understanding of how the Earth is changing as well as provide valuable societal benefit, in particular, in understanding and tracking dynamic events such as volcanoes and wildfires.

The HyspIRI mission includes two instruments: 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 153 km and a 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 at the equator. Several of the other Tier 1 and Tier 2 missions provide complementary measurements for use with HyspIRI data, in particular, the DESDynI (now NISAR), ACE (now PACE), ICESat-II, and GEO-CAPE Decadal Survey missions each of which addresses very different spatial scales compared to the local and landscape scales observable with HyspIRI. 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 these other instruments.

The primary purpose of this report is to document the science impact of deploying the VSWIR and TIR instruments on separate sun-synchronous platforms separated by <3 minutes, <1 week and a few months as well as deploying both instruments simultaneously from the ISS. Initially, the science behind the current mission concept is described, which is followed by a description of the instrumentation and mission and finally the impact of deploying on separate platforms is assessed on the combined science questions. The combined science questions are those questions that require data from both instruments. The impact on each overarching science question and its associated sub-questions are described followed by a set of tables at the end of the document that provide a semi-quantitative assessment on the impact of the different platform separations on the various sub-questions and overarching question.

Executive Summary

In 2013 NASA Headquarters directed the HyspIRI project to undertake an assessment of the science impact of deploying the visible shortwave infrared (VSWIR) and thermal infrared (TIR) sensors on separate platforms with various time separations in sun synchronous orbits and deploying both sensors on the ISS. The HyspIRI mission is designed to address a set of science questions identified by the Decadal Survey and broader science community. The science questions are organized as VSWIR, TIR and Combined science questions, the latter requiring data from both instruments. The approach taken to address the directive was to evaluate the science impact on the combined science questions of time separations of <3 minutes, <1 week and a few months assuming both instruments were in sun synchronous orbits as well as deploying both instruments from the ISS. It should be noted the science impact was only assessed on the combined science questions which require data from both instruments. The combined science questions address six main research areas, these are: CQ1 - Coastal Ocean, and Inland Water Environments, CQ2 - Wildfire, Fuel and Recovery, CQ3 - Volcanoes and Surface Signatures, CQ4 - Ecosystem Function and Diversity, CQ5 -Surface Composition and Change and CQ6 - Human Health and Urbanization. Each of these six research areas has an overarching science question and a series of sub-questions. The HyspIRI science study group (SSG) was asked to look at each sub-question and discuss the impact of time separations between the VSWIR and TIR data of <3 minutes, <1 week and a few months as well as the impact on addressing the sub-question of deploying both instruments on the ISS. The SSG also provided a semi-quantitative assessment indicating what percentage of the question could be addressed for the different time separation scenarios. It should be emphasized that the semi-quantitative assessment is of a subjective nature; nonetheless it provides valuable information on the impact of placing the instruments on different platforms.

The study concluded the impact of a separation of <3 minutes was minimal, e.g. if the instruments were on separate platforms that followed each other in a train. The impact of a <1 week separation was strongly dependent on the question that was being addressed with no impact for some questions and a severe impact for others. The impact of a time separation of a few months was severe on the majority of combined questions. As part of the study, the SSG were asked to estimate, as a percentage, how completely a given sub-question could be answered with 100% indicating the question could be completely answered. These estimations should be treated with caution but nonetheless are useful in assessing the impact. Averaging the estimates for each of the combined questions the results indicate that 97% of the questions could be answered with a separation of < 3 minutes. With a separation of < 1 week, 67% of the questions could be answered and with a separation of several months only 21% of the questions could be answered.

The impact of deploying the instruments on the ISS, which is in a precessive (non-sun synchronous) orbit, was also very question dependent, in some cases it was possible to go beyond the original question, for example to examine the impact of the diurnal cycle by utilizing the different varying overpass times provided from the ISS whereas in other cases the question could not be addressed for example if the question required observations from the polar regions which are observed from the ISS orbit.

CONTENTS

1 Introduction

The Hyperspectral Infrared Imager (HyspIRI) mission was 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 (DS). The HyspIRI mission is science driven and will address a set of science questions identified by the Decadal Survey and broader science community. The DS 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 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 assess the status of biodiversity around the world and the role of different biological communities on land and within inland water bodies, as well as coastal zones and at reduced resolution in the ocean. Furthermore, it will help identify natural hazards; in particular volcanic eruptions and any associated precursor activity, and it will map the mineralogical composition of the land surface. The mission will advance our scientific understanding of how the Earth is changing as well as provide valuable societal benefit, in particular, in understanding and tracking dynamic events such as volcanoes and wildfires.

The HyspIRI mission includes two instruments and an intelligent payload module (IPM). The instruments are 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 153 km and a 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 IPM enables on-board processing and direct broadcast for the near real-time applications with short latency requirements. The current mission concept has the instruments on the same platform with the IPM. The platform is in a sun-synchronous orbit at an altitude of 626 km at the equator which, given the swath widths of the instruments, results in the the VSWIR and TIR instruments have revisit times of 19 and 5 days, respectively.

The science and applications associated with the HyspIRI mission is organized around a set of science questions identified by the Decadal Survey and broader science community. The science questions are organized as VSWIR-only, TIR-only and Combined science questions depending on whether they require data from just the VSWIR instrument, just the TIR instrument or both instruments (see HyspIRI website for the complete set of questions).

NASA is undertaking pre-phase A studies to determine the optimum mission implementation, in particular, cost and risk reduction activities. Each year the HyspIRI project receives guidance from NASA Headquarters on the pre-phase A activities in the form of a letter which outlines the work that should be undertaken the subsequent year. The 2013 guidance letter included a recommendation to undertake a study to determine the science impact of deploying the instruments from separate spacecraft in sun synchronous orbits with various time separations and deploying both instruments on the International Space Station (ISS). This report summarizes the results from that study.

The approach taken to address this guidance was to evaluate the science impact on the combined science questions of time separations of <3 minutes, <1 week and a few months assuming both instruments were in sun synchronous orbits as well as deploying both instruments from the ISS. It should be noted the science impact was only assessed on the combined science questions which require data from both instruments. The combined science questions address six main research areas, these are: CQ1 - Coastal Ocean, and Inland Water Environments, CQ2 - Wildfire, Fuel and Recovery, CQ3 - Volcanoes and Surface Signatures, CQ4 - Ecosystem Function and Diversity, CQ5 - Land Surface Composition and Change and CQ6 - Human Health and Urbanization. Each of these six research areas has an overarching science question and a series of sub-questions. The HyspIRI science study group (SSG) was asked to look at each sub-question and discuss the impact of time separations between the VSWIR and TIR data of <3 minutes, <1 week and a few months as well as the impact on addressing the sub questions if both instruments were deployed on the ISS. The SSG provided both a narrative and a semi-quantitative assessment indicating what percentage of the question could be addressed for the time separation scenarios. It should be emphasized that the semi-quantitative assessment is of a subjective nature; nonetheless it provides valuable information on the impact of separating the platforms.

The subsequent chapters are arranged to first describe the HyspIRI science, then describe characteristics of the instrument and finally each overarching science question and its associated sub-questions are evaluated in a narrative form with a set of tables at the end of the document that quantifies the impact on the various sub-questions and overarching question.

2 Science and Societal Benefits

The following description of the HyspIRI mission science draws heavily on the 2008 HyspIRI Whitepaper and Science Workshop Report available at http://hyspiri.jpl.nasa.gov/documents.

HyspIRI is a science-driven mission, developed to address a set of science questions called out in the Decadal Survey and further refined by the HyspIRI Science Study Group (SSG). The SSG is appointed by NASA Headquarters and includes scientists with experience on HyspIRI like science and data and provides guidance to the mission. The science questions that HyspIRI will address are arranged into three categories. These are VSWIR only, TIR only and Combined. The combined questions require data from both the VSWIR and TIR instruments and are the focus of this study. The combined questions are arranged into six topic areas.

CQ1. Coastal, Ocean and Inland Aquatic Environments: the oceans and inland aquatic environments are a critical part of global climate, the hydrologic cycle, and biodiversity. HyspIRI will allow for greatly improved separation of phytoplankton pigments, better retrievals of chlorophyll content, more accurate retrievals of biogeochemical constituents of the water, and more accurate determination of physical properties [GEO 2007].

CQ2. Wildfire, Fuel and Recovery: The 4 μm channel will greatly improve determination of fire temperatures, since it will not saturate like almost all other sensors with a similar wavelength channel. Coupling the multispectral TIR data with the VSWIR data will improve understanding of the coupling between fires and vegetation and associated trace gas emissions [Dennison et al 2006].

CQ3. Volcanoes and Surface Signatures: HyspIRI's TIR channels will allow combined measurement of temperature, surface composition, and SO_2 emissions. These three parameters are critical to understand changes in a volcano's behavior that may herald an impending eruption. Fumaroles, lava lakes, and crater lakes often undergo characteristic increases in temperature associated with upwelling magma; SO_2 emissions both increase and decrease before some eruptions. Prediction of lava flow progress depends entirely on knowledge of effusion rate and temperature [Wright et al 2008].

CQ4. Ecosystem Function and Diversity: HyspIRI will provide improved measures of plant physiological function through simultaneous estimates of surface temperature and plant biochemistry, improved estimates of surface biophysical properties (e.g., albedo, crown mortality) and energy balance and improved discrimination of plant species and functional types. No current sensor can simultaneously retrieve canopy temperature and quantify physiological or compositional changes in response to stress.

CQ5. Land Surface Composition and Change: Combining information from the VSWIR and TIR sensors will greatly improve our ability to discriminate and identify surface materials: rocks, soils and vegetation. This is the first step to be able to quantitatively measure change of the land surface, whether naturally caused or of anthropogenic origin. Change detection, monitoring, and mapping forms the basis for formulating numerous policy decisions, from controlling deforestation to open-pit mining. HyspIRI will provide a greatly improved tool to make more informed and intelligent decisions.

CQ6. Human Health and Urbanization: It appears that the world's urban population will grow by over 60% by 2030 [UNIS 2004]. Because of its enhanced hyperspectral capabilities in the VSWIR bandwidths and its multiple channels in the TIR, HyspIRI will provide much better data to improve measurement and modeling of urban characteristics around the world. One of the issues that has been problematic in the past is retrieving accurate measurements of temperature, albedo, and emissivity for specific surfaces across the complex and heterogeneous urban landscape. HyspIRI has the spatial resolution, spectral coverage, and repeat cycle to greatly improve these retrievals.

3 Measurement Requirements

In order to identify the instrument and mission requirements needed to answer the science questions a set of Science Traceability Matrices (STMs) were developed. The trace the performance required for a particular aspect of the instrument or mission to the need to address a particular science question or part of a science question.The STMs, driven by the science questions, determine the system-level requirements for HyspIRI. The system-level requirements for the VSWIR and TIR instruments are presented in Table 1 and Table 2, respectively.

1.1 VSWIR Instrument

The VSWIR instrument will acquire data between 380 and 2500 nm in 10-nm contiguous bands. The position of these bands will be known to 0.5 nm. The instrument performance was modeled for several different input radiances, and these are shown in Figure 1 for several different benchmark radiances. The instrument will have low polarization sensitivity and low scattered light. One of the most challenging measurement conditions is open water where the signal from the water is very small. In addition, open water can produce sunglint under certain viewing geometries, and this can cause instrument saturation. The effect of sunglint is minimized by pointing the instrument 4 degrees in the backscatter direction. The nominal data collection scenario involves observing the land and coastal zone to a depth of < 50 m at full spatial and spectral resolution and transmitting these data to the ground.

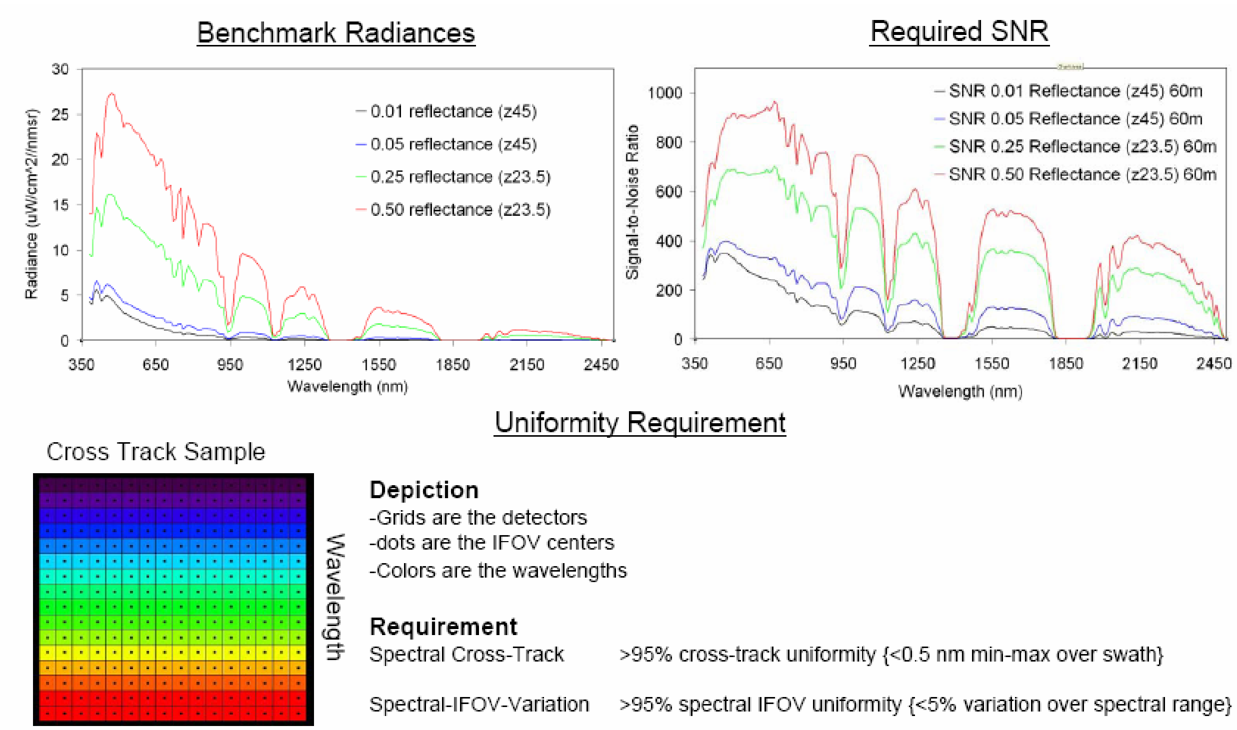

Figure 1: HyspIRI-VSWIR Key Signal-to-Noise and Uniformity Requirements.

Over the open ocean, data will be averaged 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 swath width of 153 km with a pixel spatial resolution of 60 m resulting in a temporal revisit of 19 days at the Equator. The nominal overpass time is 10:30 a.m., but this may be adjusted by as much as ± 30 minutes to minimize the effects of sunglint.

The absolute radiometric accuracy requirement is greater than 95%, and this will be maintained by using an onboard calibrator as well as monthly lunar views and periodic surface calibration experiments.

1.2 TIR Instrument

The TIR instrument will acquire data in eight spectral bands, seven of these are located in the thermal infrared part of the spectrum between 7 and 13 µm, and the remaining band is located in the mid infrared part of the electromagnetic spectrum around 4 um. 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 STMs, which included recognition that other sensors were acquiring related data such as ASTER and 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 (bands 12–14), and the positions of two of the TIR bands of MODIS (bands 31 and 32) typically used for split-window type applications and.

A key science objective for the TIR instrument is the study of hot targets (volcanoes and wildfires), so the saturation temperature for the 4-µm channel is set high (1200 K) whereas the saturation temperatures for the thermal infrared channels are set at 400 K (see High Temperature Saturation Report available on the HyspIRI website). 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.

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 it 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), but over the open oceans 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 is necessary to enable monitoring of dynamic or cyclical events such as volcanic hotspots or crop stress associated with water availability.

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 row of pixels (60 m × 600 km) observed on the ground. There will also be periodic surface validation experiments and monthly lunar views.

Table 1: 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	<10 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 %
Scattered Light	<1:200 characterized to 0.1%
Spatial	
Range	>153 km (14 degrees at ~626 km altitude)
Cross-Track Samples	>2400
Sampling	60 m
Response	60 m sampling (FWHM)
Uniformity	
Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}
Temporal	
Orbit Crossing	10:30 am sun synchronous descending
Global Land Coast Repeat	19 days at equator
Rapid Response Revisit	3 days (cross-track pointing)
Sunglint Avoidance	
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	Coastal zone –50 m and shallower
Solar Elevation	20 degrees or greater
Open Ocean	Averaged to 1-km spatial sampling
Compression	3:1 lossless

Table 2: 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 – 400 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
MTF	>0.65 at FNy
Scan Type	Push-Whisk
Swath Width	600 km (±25.5° at 623 km altitude)
Cross Track Samples	10,000
Swath Length	15.4 km (± 0.7 degrees at 623 km altitude)
Down Track Samples	256
Band to Band Co-Registration	0.2 pixels (12 m)
Pointing Knowledge	1.5 arcsec (0.1 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 1-km spatial sampling
Compression	2:1 lossless

4 Current Mission Concept

The HyspIRI satellite will be put in a Sun synchronous, low Earth orbit. The overpass time is expected to be 10:30 a.m. ± 30 minutes. 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 1 daytime image every 5 days and 1 nighttime image every 5 days. 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 1. 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 poleward the number of acquisitions exceeds the requirements with daily coverage at the poles. No data will be acquired poleward of 83° N and 83° S in the VSWIR since this is an inclined orbit. 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.

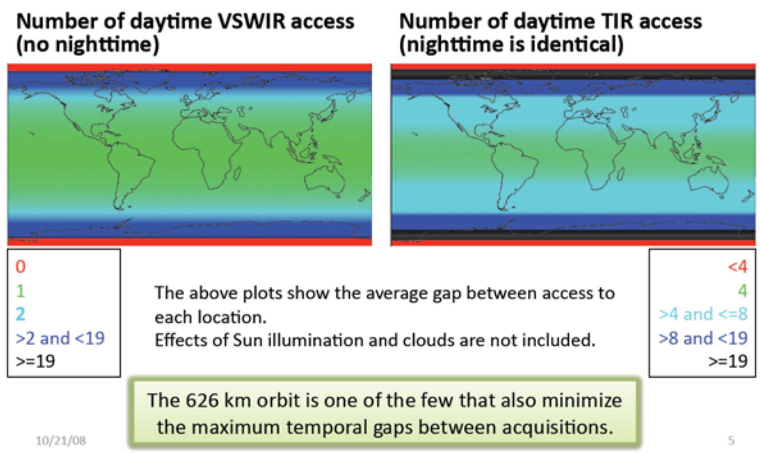

Figure 1: Number of image acquisitions in 19 days.

VSWIR data acquisitions are also limited by the maximum Sun elevation angle with no data being acquired when the Sun elevation angle is less than 20 degrees (Figure 2).

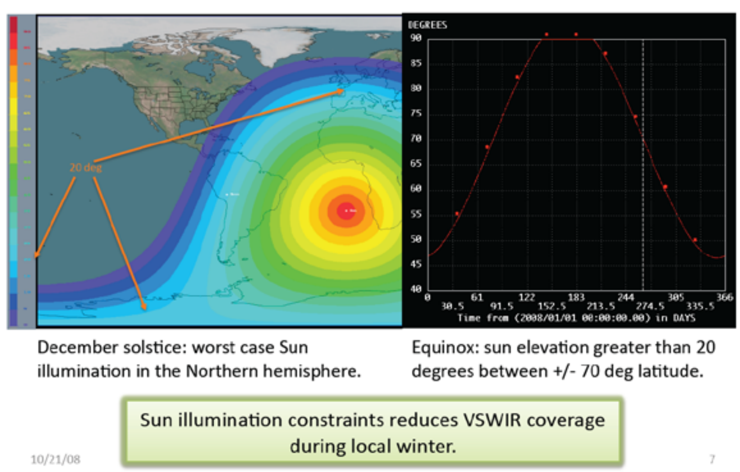

Figure 2: Illustration of the Sun illumination at the winter solstice.

The acquisition scenario for the HyspIRI mission is driven by target maps, with pre-defined maps controlling the acquisition. 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 returns data are averaged or sub-sampled to 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 downloaded in real time. The IPM is independent of the onboard data recording and storage system, and it connects to the data stream to pull out the desired wavelengths for direct broadcast. The IPM has no storage capacity. The 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. The continuous averaged data rate is 65 Mbps, which results in a data volume of 372 Gb/orbit and 5.2 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 with a data volume of 331 Gb/orbit. The HyspIRI satellite will have an onboard storage capacity of 1 Tb (WorldView-1 has 2.2 Tb of onboard storage).

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

	VSWIR	TIR
Rate (Mbps)	268	66.1
Duty cycle ratio	0.113	0.346
Effective rate	30.4	22.9
Overhead	10%	10%
Average rate with overhead	33.44	25.19

In the current configuration HyspIRI data will be downloaded using Dual X band, which will be capable of download rates of 800 Mbps. Other options, such as Ka band, are also being considered.

5 Impact of Independent Platforms on Combined Science

5.1 CQ1. Coastal Ocean, and Inland Water Environments

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing the Coastal Ocean, and Inland Water Environments Questions

5.1.1 General Comments

For open water, the aquatic combine questions are designed to look at how physical processes and biological processes connect. Given that the physical conditions are changing rapidly and the consequential change in the biosphere is as least as fast, separation of the VSWIR and TIR measurements over any period of time is detrimental to answering these questions at the 60-meter spatial resolution. However, many aspects of the HypIRI science questions can still be addressed, even if the VSWIR and TIR measurements are not contemporaneous.

During the HyspIRI mission, the VSWIR spectrometer would primarily be used to observe the aquatic biosphere while the TIR sensor would be solely used to establish physical conditions in the water by providing water surface temperature, wetland soil temperature, and estimates of evapotranspiration. In wetlands, however, a lag between TIR and VSWIR measurements are less deleterious. However, in open water, the biological response to changing physical conditions would be largely observed using visible bands because water absorption strongly extinguishes light at longer wavelength, although high turbidity of highly productive waters or from high sediment loads can be detected into the NIR and possibly in the SWIR bands in extreme cases that can occur in coastal and inland waters. In most cases though, the NIR and SWIR bands (possibly in concert with UV measurements) would facilitate biospheric observations by supporting the removal of the atmospheric signal to facilitate retrieval of the water column optical properties. Surface temperature from the TIR bands would help identify sources of biogeochemical fluxes by highlighting upwelling processes, ground water discharges, and surface water and river plumes. Separation of the VSWIR spectroscopy and TIR observations would in effect cause a significant lag between observed physical conditions and the measured biospheric response, hampering studies of how these connect.

The issue of cloud cover remains nontrivial and could be problematic for many cloud cover types (e.g, fields of "popcorn" cumulus) if the VSWIR and TIR bands are taken at separate times, or with very different viewing geometries. Note that historically, adjacency effects and instrument stray light around clouds or other bright targets in the instrument field-of-regard radiometrically and spectrally contaminate neighboring VisNIR measurements over dark water. Therefore, aquatic remote sensing image processing over open water often employs aggressive masking around cloud edges. This in turn can possibly reduce the concern of simultaneous cloud cover mapping for aquatic images in the VSWIR and TIR slightly. The aggressiveness of the cloud mask for aquatic applications will largely depend on the stray light and spatial response function of the instrument.

The aquatic biosphere is very dynamic, responding to rapid fluctuations in resources and conditions that are driven by currents, tides, terrestrial efflux, atmosphere, and solar illumination at the surface. HyspIRI can observe only snapshots of these processes given its 19-day equatorial revisit period. However, these snapshots can provide information regarding the how these dynamic processes interrelate spatially. HyspIRI's hyperspectral VSWIR and multi-band TIR observations at 60-meter spatial resolution would provide investigators a detailed picture of how coastal and inland water physical and biological processes interact. However, these responses and the changes that drive them can vary within hours or even minutes at a 60-meter scale. For instance, moderately strong currents can move water hundreds of meters in less than three minutes, dramatically shifting the position of surface physical features, such as eddies, plumes, and fronts. This could lead to offsets in features between images in the VSWIR and TIR, which in effect would significantly reduce the spatial resolution of information about biospheric response to physical processes. Persistent patterns could still be composited over time to show relationships between physical and biopheric processes. This also effectively reduces the resolution of the data, but may be appropriate for climate studies.

As mentioned, there are persistent open water ecosystem processes along coasts for which averaged behavior could be composited over longer periods, reducing the impact of a lag between the VSWIR and TIR instruments. Likewise, more stationary coastal and inland aquatic ecosystems, including wetlands and benthic communities, are less susceptible to a lag. In the case of wetlands, the TIR bands can be employed to estimate evapotranspiration and soil moisture. For those parameters, the presence of important diurnal processes can also factor into the impact of a lag. Thus, the impact of a lag for observing these parameters for wetlands is largely subject to the same constraints identified for questions under CQ4. However, the effect of tidal inundation in a tidal marsh or mangrove forest could cause the hydrological characteristics of those ecosystems to change more frequently and differently than other terrestrial canopies. This could undermine any expected advantages of separating the VSWIR and TIR measurements in time for affected studies. Finally, wetlands are subject to seasonal and episodic fires and subsequent recovery, as many terrestrial vegetation systems are, and seasonally and inter-annually accumulate fuel. In this case, the impact of a lag for wetlands is largely subject to the same constraints identified for CQ2 questions.

5.1.2 Each Sub-question - Separated by a < 3 minutes

CQ1-1 What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?

It is critical to have short intervals such as <3 minutes for understanding the relationship between the physical environment (e.g., thermal conditions in open water or soil moisture in wetlands) and the VSWIR data, which provides information on aquatic community composition and structure (e.g., phytoplankton, coral reefs). These data can be used to establish baselines against which to monitor and understand impacts of climate change and other disturbances.

The TIR measurements provide water and land surface temperature, but also can provide soil moisture and evapotranspiration for wetlands. Wetlands studies related to this question are much less sensitive to <3 minutes separation. For open water, the linkage with climate using persistent patterns in water surface temperature and biospheric response, the time separation <3 minutes would not be important. Diurnal fluctuation in surface conditions may lead to aliasing, *however, it is not clear what the optimal sampling phase would be to link conditions to the biospheric response. Conversely, as previously mentioned, studies that require analysis of unaggregated imagery would lose spatial resolution (e.g., studies evaluating the impact of post-storm hydrology and water quality on shallow water habitats, as connected to global climate change).*

An important question related to CQ1-1 is regarding how the flux of ground water discharges and surface water and river plumes affect phytoplankton and benthic communities. This is an important instance of CQ1-1 because it directly relates to monitoring natural and anthropogenic nutrient fluxes that can lead to eutrophication and subsequent hypoxic conditions or harmful algal blooms in estuaries and lakes. Understanding and quantifying diffuse sources of nutrient efflux from non-point sources (e.g., agriculture) has been a major challenge in determining the effectiveness of state policies and best management practices in estuary and lake conservation. To answer this question, it would be ideal to capture the fine spatial detail of terrestrial waters into aquatic environments and the biospheric response. However, even a <3 minute lag could significantly reduce the resolution of such a study given the rapid changes expected.

CQ1-2 What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?

The VIS and TIR observations would be used to understand how small-scale physics and biology interact. This includes scales of turbulence and small-scale patchiness. Surface temperature can be used also to determine open water evaporation rates, wetland evapotranspiration rates, and soil moisture. VSWIR would be used to identify the presence of phytoplankton; wetland canopy structure, composition, and status; and aerosol composition. A 19-day snap shot cannot capture short-term linkages referred to in this question, but the 60-meter resolution would provide important information on spatial linkages and ecosystem structure. A corresponding study would need to composite images over long periods of time. Therefore, a lag of <3 minutes would have high impact on this question as it would hamper understanding of physical-biological interactions at small spatial scales.

CQ1-3 How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?

Most parameters for benthic habitat conditions that are mentioned in this question are determined by the VSWIR spectrometer and likewise for the benthic community response. The TIR bands only provide critical water surface temperature data. Corals and submerged aquatic vegetation do not respond instantaneously to environmental changes, therefore a <3 min lag would have minimal impact to answering aspects of this question.

CQ1-4 How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?

This question simply assumes that some observations are available and wishes to connect them to management and utilization of resources. Therefore, this question does not care whether there is a lag or not. However, small-scale information with <3 minute lag between VIS, SWIR and TIR is extremely important to help resource managers understand where important physical pressure may be occurring on ecosystems. These data will also help establish critical baseline maps in a number of ecosystem properties that will facilitate detecting change.

CQ1-5 What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?

The combination of VSWIR and TIR measurements is very important for this question. Seasonal changes in ecosystem structure need to be differentiated from other change, thus establishing seasonal baselines of interactions between the physical and biological interactions. The TIR bands can be used to observe climatic changes in surface temperature, soil moisture (wetlands), and evapotranspiration (wetlands) while the VSWIR spectrometer can be used to capture brief snapshots of the biospheric response. It is doubtful that the 19-day revisit time could support a temporal resolution that is fine enough to detect changes in biospheric responses to anomalies in the onset of seasons, nor would the mission duration provide a sufficiently long enough time series to conduct climate studies. However, it may be possible to observe the small-scale biospheric response, as observed by the VSWIR spectrometer, to seasonal changes in the environment, as observed through the TIR bands. This type of study would not be affected by <3 minute lag between the VSWIR and TIR instrument measurements.

CQ1-6 What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?

The combined measurements are critical to develop the baselines needed to examine ecosystem in any context of disturbance. The TIR measurements provide climate parameters via surface temperature, but also can provide soil moisture and evapotranspiration for wetlands. Wetlands studies related to this question are also not sensitive to <3 minutes separation.

For open water, the linkage with climate based on using persistent patterns in water surface temperature and biospheric response, the time separation <3 minutes is critical in the sense of developing baselines and an understanding of a relationship between physics and biology. However, TIR composites establishing seasonal or climatic changes would not be less sensitive to a lag of <3 minutes. Diurnal fluctuation in surface temperature may cause aliasing, but it is not clear what the optimal sampling phase would be to understand the biospheric response. Conversely, as previously mentioned, studies that require or would benefit from analysis of un-aggregated imagery at 60 m resolution would lose some spatial resolution (e.g., studies evaluating the impact of post-storm hydrology and water quality on shallow water habitats, as connected to global climate change).

5.1.3 Each Sub-question - Separated by a < 1 week

CQ1-1 What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?

Aquatic systems research would suffer by having VIS, SWIR and TIR observations that are not concurrent. The scales of variability of aquatic ecosystems are small, and we would not be able to observe the direct interaction of physical and biological processes at small time and space scales. We would only be able to make uncertain inferences about whether a change in the physical environment may have been related to a change in the biological system.

The TIR measurements provide climate parameters via surface temperature, but also can provide soil moisture and evapotranspiration for wetlands. Wetlands studies related to this question are also not sensitive to <1 week separation, provided the measurements are averaged over time. For open water, the linkage with climate using persistent patterns in water surface temperature and biospheric response, the time separation <1 week would not be important. Diurnal fluctuation in surface conditions may lead to aliasing, however, it is not clear what the optimal sampling phase would be to link conditions to the biospheric response. Conversely, as previously mentioned, studies that require analysis of unaggregated imagery would lose significant spatial resolution. For instance, a lag of <1 week could inhibit studies evaluating the impact of post-storm hydrology and water quality on shallow water habitats, as connected to global climate change.

An important question related to CQ1-1 is regarding how the flux of ground water discharges and surface water and river plumes affect phytoplankton and benthic communities. This is an important instance of CQ1-1 because it directly relates to monitoring natural and anthropogenic nutrient fluxes that can lead to eutrophication and subsequent hypoxic conditions or harmful algal blooms in estuaries and lakes. Understanding and quantifying diffuse sources of nutrient efflux from non-point sources (e.g., agriculture) has been a major challenge in determining the effectiveness of state policies and best management practices in estuary and lake conservation. To answer this question, it would be ideal to capture the fine spatial detail of terrestrial waters into aquatic environments and the biospheric response. However, a <1 week lag would constrain this type of study to persistent fluxes that can be observed with long-term composites.

CQ1-2 What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?

The TIR observations would be used to get surface temperature to determine open water evaporation rates, wetland evapotranspiration rates, and soil moisture. VSWIR would be used to identify the presence of phytoplankton; wetland canopy structure, composition, and status; and aerosol composition. A 19-day snap shot cannot capture small-scale linkages referred to in this question. Instead, a corresponding study would need to composite images over long periods of time. However, a lag of <1 week may begin to impact the quality of study that can be done.

CQ1-3 How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?

Most parameters for benthic habitat conditions that are mentioned in this question are determined by the VSWIR spectrometer and likewise for the benthic community response. The TIR bands only provide water surface temperature. Because corals and submerged aquatic vegetation do not respond instantaneously to environmental changes, a <1 week lag would require temporal compositing of imagery, which would likely only have minor to moderate impact to answering aspects of this question.

CQ1-4 How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?

This question simply assumes that some observations are available and wishes to connect them to management and utilization of resources. Therefore, this question does not care whether there is a lag or not. However, small-scale information with <1 week lag between VIS, SWIR and TIR is extremely important to help resource managers understand where important physical pressure may be occurring on ecosystems. These data will also help establish critical baseline maps in a number of ecosystem properties that will facilitate detecting change.

CQ1-5 What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?

As previously mentioned, the need for a thermal component is not strong for this question. Most studies answering this question using composited imagery should not be strongly affected by a <1 week lag between the VSWIR and TIR instrument measurements.

CQ1-6 What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?

The TIR measurements provide climate parameters via surface temperature, but also can provide soil moisture and evapotranspiration for wetlands. Most global wetlands studies related to this question would only be moderately affected by a <1 week separation. For open water, the determination of a linkage with climate based on using persistent patterns in water surface temperature and biospheric response would be moderately impacted by a time separation of <1 week. Diurnal fluctuation in surface temperature may cause aliasing, but it is not clear what the optimal sampling phase would be to understand the biospheric response. Conversely, as previously mentioned, studies that require or would benefit from analysis of un-aggregated imagery at 60 m resolution would significantly lose spatial resolution and possibly severely limit many such efforts.

5.1.4 Each Sub-question - Separated by a few months

CQ1-1 What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?

Because coastal and inland water environments are very dynamic, a separation of the VSWIR and TIR observation by a few months would severely limit most studies related to this question.

CQ1-2 What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?

Because coastal and inland water environments are very dynamic, a separation of the VSWIR and TIR observation by a few months would severely limit most studies related to this question.

CQ1-3 How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?

Because coastal and inland water environments are very dynamic, a separation of the VSWIR and TIR observation by a few months would severely limit most studies related to this question.

CQ1-4 How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?

This question simply assumes that some observations are available and wishes to connect them to management and utilization of resources. Therefore, this question does not care whether there is a lag or not. However, the assumption that viable combined VSWIR and TIR observations would be available may be extremely limited by a lag of a few months. In fact, using more contemporaneous thermal data from a more coarse resolution instrument, such as VIIRS, would probably be a better choice. Contemporaneous, small-scale information between VIS, SWIR and TIR is extremely important to help resource managers understand where important physical pressure may be occurring on ecosystems. These data will also help establish critical baseline maps in a number of ecosystem properties that will facilitate detecting change.

CQ1-5 What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?

Because coastal and inland water environments are very dynamic, a separation of the VSWIR and TIR observation by a few months would severely limit most studies related to this question.

CQ1-6 What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?

Because coastal and inland water environments are very dynamic, a separation of the VSWIR and TIR observation by a few months would severely limit most studies related to this question.

5.1.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Coastal Ocean, and Inland Water Environments Questions

Aside from the temporal lags covered in the previous section, there are two obvious issues to having one or both instruments in an inclined orbit. The first is the limited latitudinal coverage (e.g., for the ISS, lat < 45°), which preclude global coastal or inland water studies. Measurements in important regions that are highly vulnerable to climate change, such as boreal wetlands and high latitude coastal and inland waters, would be excluded from study that depends on the instrument or instruments in the inclined orbit.

The second issue would be that the grid orientation and resolution would be much different between the instruments. Therefore, combined VSWIR and TIR data could experience a greater loss of spatial resolution than if the instruments were on the same platform with ostensibly much closer to the same resolution and orientation. For aquatic questions, HyspIRI's high spatial resolution is an important capability and its reduction impacts the mission's ability to answer coastal and inland water questions.

In addition, there is no great benefit gained in aquatic environments to having taken observations at various phases during the diurnal cycle with HyspIRI. Although these cycles clearly exist and do pose potential aliasing issues, HyspIRI only has a 19-day revisit, thus it would be difficult to separate short-term and seasonal variations in these environments from diurnal ones. Instead, the mix of these different variations will likely increase the noise in the seasonal to inter-annual signal.

CQ1-1 What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?

This question depends on the high resolution of both instruments (e.g., it includes habitat structure, which is highly variable spatial in coastal and inland aquatic environments). Therefore, this question would be adversely affected by having one or more instrument on an inclined orbit. Likewise, important ecosystems would be excluded as previously mentioned. Also, tidal and other diurnal cycles will increase the variation in the seasonal to inter-annual signal. Thus, it would be more difficult to ascertain feedbacks between climate and the coastal and inland aquatic environments.

CQ1-2 What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?

This question depends the high resolution of both instruments (e.g., it includes habitat structure, which is highly variable spatial in coastal and inland aquatic environments). Therefore, this question would be adversely affected by having one or more instrument on an inclined orbit. Likewise, important ecosystems would be excluded as previously mentioned. Also, tidal and other diurnal cycles will increase the variation in the seasonal to inter-annual signal. Therefore, identifying and quantifying the linkages mentioned in this question would be adversely affected.

CQ1-3 How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?

This question depends the high resolution of both instruments (e.g., it includes habitat structure, which is highly variable spatial in coastal and inland aquatic environments). Therefore, this question would be adversely affected by having one or more instrument on an inclined orbit. Likewise, some benthic ecosystems, such as submerged aquatic vegetation in high-latitude environments, would be excluded as previously mentioned. Conversely, coral reefs are less likely to be excluded, as they tend to occur primarily at lower latitudes. Tidal and other diurnal cycles will increase the variation in the seasonal to inter-annual signal. Therefore, identifying and quantifying the linkages mentioned in this question would be adversely affected.

CQ1-4 How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?

This question simply assumes that some observations are available and wishes to connect them to management and utilization of resources. Therefore, this question does not directly care about coverage, spatial resolution, or temporal sampling. However, connections to applications in areas not covered by an inclined orbit, including management of climate change sensitive high-latitude coastal and inland water (e.g., Scandinavian fiord water quality) and wetlands (e.g., Boreal wetlands responses to global warming). Also, contemporaneous small-scale information between VIS, SWIR and TIR is extremely important to help resource managers understand where important physical pressure may be occurring on ecosystems. These data will also help establish critical baseline maps in a number of ecosystem properties that will facilitate detecting change.

CQ1-5 What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?

As previously mentioned, the need for a thermal component is not strong for this question. However, and increased loss of spatial in imagery would be problematic for tracking responses to functional groups and diagnostic species in wetlands. Also, high-latitude coverage loss would limit or prohibit evaluation of seasonal expressions and cycles high-latitude ecosystems (but below 60°, above which seasonal darkness already limits season studies).

CQ1-6 What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?

Increased loss of spatial in imagery would be problematic for evaluating changes to wetland and benthic ecosystems in response to land use and disturbance. Also, high-latitude coverage loss would limit or prohibit evaluation of the response of high-latitude aquatic ecosystems to global warming.

5.1.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Coastal Ocean, and Inland Water Environments Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

Given heritage aquatic remote sensing missions, there has been no significant preference between an afternoon or morning orbit with respect to any of these science questions. Nor are there any obvious advantages to in-water ecosystem questions to move the TIR and VSWIR observations to morning and afternoon, or visa versa. However, advantages of such assignments for wetlands are largely covered by CQ4 questions.

CQ1-1 What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?

No known advantage for studying feedbacks between climate and ecosystem processes in shallow aquatic habitats.

CQ1-2 What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?

No known advantage for in-water studying ecological linkages to environmental forcing. Clouds tend to form over water in the morning, but formation tends to peak over land during the afternoon.

CQ1-3 How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?

No known advantage for studying shallow benthic habitats and their relationship to changes in environmental characteristics.

CQ1-4 How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?

This question simply assumes that some observations are available and wishes to connect them to management and utilization of resources. There are no apparent advantages to placing on instrument in an afternoon orbit and the other in a morning orbit.

CQ1-5 What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?

No known advantage for studying season expression or cycles.

CQ1-6 What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?

No known advantage for studying ecosystem susceptibility to climate, land use, or disturbance.

5.2 CQ2. Wildfire, Fuel and Recovery

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing the Wildfire, Fuel and Recovery Questions

5.2.1 General Comments

The combined science questions on Wildfire, Fuel and Recovery of the VSWIR and MTIR HyspIRI instruments require data sampled in the different temporal phases of the fire continuum: before, during and after the fire. Pre-fire data are used to characterize fuels (e.g. type, load, moisture content, etc.). Active fire data are used to detect fires and to estimate fire temperature and instantaneous emissions. Post-fire data acquired shortly after the fire are used to map burn scars and fire severity, while long post-fire time series enable to define ecosystem recovery traits. The estimation of some of these fire characteristics only requires data from one instrument. For example VSWIR imaging spectroscopy is optimal for detailed fuel mapping, whereas the 4 µm MTIR band is optimal during the active fire phase. Estimates of other fire characteristics (e.g. burned area) profit from a synergy between the VSWIR and MTIR data to achieve higher accuracies than would be possible by using data from a single sensor. The impact of different time separations and orbits on the combined Wildfire, Fuel and Recovery science questions are discussed below within the fire continuum framework.

5.2.2 Each Sub-question - Separated by a < 3 minutes

In summary
VSWIR data will be used to characterize pre- and post-fire vegetation characteristics.
MTIR data will be used to characterize active fire characteristics. Alternatively, VSWIR data can be used to estimate active fire characteristics
A separation of <3 minutes has no impact on the science questions as formulated before. A short time delay (< 3 minutes) may be an advantage because of having two independent measures of fire temperature.

CQ2-1 How does the timing, temperature and frequency of fires affect long-term ecosystem health?

Pre- and post-fire VSWIR data will be used to determine ecosystem health based on reflectance characteristics that relate to vegetation abundance, moisture, fire severity, etc. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP

Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire temperature. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

CQ2-2 How does vegetation composition and fire temperature impact trace gas emissions?

Pre-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to fuel characteristics (fuel type, load, moisture content, etc.). MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire temperature. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

CQ2-3 How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?

Post-fire VSWIR data will be used to assess water clarity and productivity in estuarine and coastal regions. MTIR data of active fires will be used to detect fires in coastal biomes at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used for active fire detection, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire detection. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

CQ2-4 What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?

Pre-fire and post-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to vegetation characteristics and fire severity. MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire detection. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

CQ2-5 On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?

Post-fire VSWIR data will be used to map vegetation cover, clay-rich soils and debris flows. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire detection. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

CQ2-6 How does invasive vegetation cope with fire in comparison to native species?

Pre-fire and post-fire VSWIR data will be used to map native and invasive species, and succession. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <3 minutes has no impact on this science question. In these cases that the active fire is captured by the MTIR (5-day revisit) and VSWIR (19-day revisit) with a short time delay (< 3 minutes), this may be an advantage because of having two independent measures of fire detection. Because of the short time delay, two subsequent observations may allow for an estimate of the velocity of the fire spread.

5.2.3 Each Sub-question - Separated by a < 1 week

In summary
VSWIR data will be used to characterize pre- and post-fire vegetation characteristics.
MTIR data will be used to detect active fires. Alternatively, VSWIR data can be used to detect active fires.
A separation of <1 week has no significant impact on the science questions as formulated before. A time delay of less than a week may be an advantage because of potentially having more active fire observations (both detections from VSWIR and MTIR) at high spatial resolution.

CQ2-1 How does the timing, temperature and frequency of fires affect long-term ecosystem health?

Pre- and post-fire VSWIR data will be used to determine ecosystem health based on reflectance characteristics that relate to vegetation abundance, moisture, fire severity, etc. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <1 week has no significant impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

CQ2-2 How does vegetation composition and fire temperature impact trace gas emissions?

Pre-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to fuel characteristics (fuel type, load, moisture content, etc.). MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <1 week has no significant impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

CQ2-3 How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?

Post-fire VSWIR data will be used to assess water clarity and productivity in estuarine and coastal regions. MTIR data of active fires will be used to detect fires in coastal biomes at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used for active fire detection, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR. A separation of <1 week has no impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

CQ2-4 What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?

Pre-fire and post-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to vegetation characteristics and fire severity. MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.A separation of <1 week has no significant impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

CQ2-5 On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?

Post-fire VSWIR data will be used to map vegetation cover, clay-rich soils and debris flows. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.A separation of <1 week has no significant impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

CQ2-6 How does invasive vegetation cope with fire in comparison to native species?

Pre-fire and post-fire VSWIR data will be used to map native and invasive species, and succession. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of <1 week has no significant impact on this science question. A separation of less than a week will allow additional fire detection opportunities with the 19-day VSWIR system, in complement to the 5-day MTIR system. This may be an advantage since it will increase the probabilities for fires to be detected at high spatial resolution.

5.2.4 Each Sub-question - Separated by a few months

In summary
VSWIR data will be used to characterize pre- and post-fire vegetation characteristics.
MTIR data is used to characterize active fire characteristics. Alternatively, VSWIR data can be used to characterize active fire characteristics.
A separation of a few a months could potentially limit the number of pre-and post-fire VSWIR images available for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by the both the MTIR and VSWIR sensors.

CQ2-1 How does the timing, temperature and frequency of fires affect long-term ecosystem health?

Pre- and post-fire VSWIR data will be used to determine ecosystem health based on reflectance characteristics that relate to vegetation abundance, moisture, fire severity, etc. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of a few a months could potentially limit the number of pre-and post-fire VSWIR images available for the ecosystem health determination for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by both the MTIR and VSWIR sensors.

CQ2-2 How does vegetation composition and fire temperature impact trace gas emissions?

Pre-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to fuel characteristics (fuel type, load, moisture content, etc.). MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of

the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of a few a months could potentially limit the number of pre-fire VSWIR images available for the vegetation composition determination for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by both the MTIR and VSWIR sensors.

CQ2-3 How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?

Post-fire VSWIR data will be used to assess water clarity and productivity in estuarine and coastal regions. MTIR data of active fires will be used to detect fires in coastal biomes at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used for active fire detection, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
It is anticipated that most of the fluxes into estuarine and coastal waters and consequent effects for water clarity and productivity will occur after the first significant post-fire rainfall event. A separation of a few a months has a higher probability to miss these events. Fire events may also be missed by both the VSWIR and MTIR sensors.

CQ2-4 What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?

Pre-fire and post-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to vegetation characteristics and fire severity. MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR. A separation of a few a months could potentially limit the number of pre-fire and post-fire VSWIR images available for the vegetation composition determination for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by both the MTIR and VSWIR sensors.

CQ2-5 On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?

Post-fire VSWIR data will be used to map vegetation cover, clay-rich soils and debris flows. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR

system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of a few a months could potentially limit the number of post-fire VSWIR images available for the vegetation cover and debris flow assessment for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by both the MTIR and VSWIR sensor.

CQ2-6 How does invasive vegetation cope with fire in comparison to native species?

Pre-fire and post-fire VSWIR data will be used to map native and invasive species, and succession. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
A separation of a few a months could potentially limit the number pre- and post-fire VSWIR images available for the species and recovery mapping for an active fire characterized by MTIR or VSWIR imagery. Fire events may also be missed by the both VSWIR and MTIR sensor.

5.2.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Wildfire, Fuel and Recovery

In summary
VSWIR data will be used to characterize pre- and post-fire vegetation characteristics.
MTIR data will be used to characterize active fire characteristics. Alternatively VSWIR data can be used to characterize active fire characteristics.
Higher latitude fires cannot be studied with an ISS orbit. Although less frequent and with smaller annual burned areas than lower latitude fires, the carbon released during high latitude fires is significant (due to high fuel loads in the surface organic layer).
Active fire detections at a given place would occur at different times of the day. Averaged over larger areas this allows to sample the diurnal fire cycle, however, for individual fire events this may obscure relations between fire and ecosystem characteristics.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-1 How does the timing, temperature and frequency of fires affect long-term ecosystem health?

Pre- and post-fire VSWIR data will be used to determine ecosystem health based on reflectance characteristics that relate to vegetation abundance, moisture, fire severity, etc. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP

Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
Higher latitude fires cannot be studied with an ISS orbit.
Active fire detections at a given place would occur at different times of the day. Averaged over larger areas this allows to sample the diurnal fire cycle, however, for individual fire events this may obscure relations between fire temperature/intensity and ecosystem health.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-2 How does vegetation composition and fire temperature impact trace gas emissions?

Pre-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to fuel characteristics (fuel type, load, moisture content, etc.). MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
Higher latitude fires cannot be studied with an ISS orbit.
Active fire detections at a given place would occur at different times of the day. Averaged over larger areas this allows to sample the diurnal fire cycle, however, for individual fire events this may obscure relations between fire temperature, emissions and vegetation composition.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-3 How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?

Post-fire VSWIR data will be used to assess water clarity and productivity in estuarine and coastal regions. MTIR data of active fires will be used to detect fires in coastal biomes at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used for active fire detection, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
Higher latitude fires cannot be studied with an ISS orbit.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-4 What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?

Pre-fire and post-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to vegetation characteristics and fire severity. MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR. Higher latitude fires cannot be studied with an ISS orbit.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-5 On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?

Post-fire VSWIR data will be used to map vegetation cover, clay-rich soils and debris flows. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.Higher latitude fires cannot be studied with an ISS orbit.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

CQ2-6 How does invasive vegetation cope with fire in comparison to native species?

Pre-fire and post-fire VSWIR data will be used to map native and invasive species, and succession. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
Active fire detections at a given place would occur at different times of the day. Averaged over larger areas this allows to sample the diurnal fire cycle, however, for individual fire events this may obscure relations between fire temperature and post-fire recovery traits.
Higher latitude fires cannot be studied with an ISS orbit.
Images with low solar zenith angles may cast shadow effects in mountainous areas that could hinder retrievals.

5.2.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Wildfire, Fuel and Recovery Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

In summary
VSWIR data will be used to characterize pre- and post-fire vegetation characteristics.
MTIR data will be used to characterize active fire characteristics. Alternatively, VSWIR data can be used to characterize active fire characteristics.
An afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-1 How does the timing, temperature and frequency of fires affect long-term ecosystem health?

Pre- and post-fire VSWIR data will be used to determine ecosystem health based on reflectance characteristics that relate to vegetation abundance, moisture, fire severity, etc. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
An afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-2 How does vegetation composition and fire temperature impact trace gas emissions?

Pre-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to fuel characteristics (fuel type, load, moisture content, etc.). MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.

An afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-3 How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?

Post-fire VSWIR data will be used to assess water clarity and productivity in estuarine and coastal regions. MTIR data of active fires will be used to detect fires in coastal biomes at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used for active fire detection, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
An afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-4 What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?

Pre-fire and post-fire VSWIR data will be used to determine vegetation composition based on reflectance characteristics that relate to vegetation characteristics and fire severity. MTIR data of active fires will be used to detect fires and estimate their temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR. An afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-5 On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?

Post-fire VSWIR data will be used to map vegetation cover, clay-rich soils and debris flows. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data

can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIRAn afternoon overpass would be beneficial for the active fire detection, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

CQ2-6 How does invasive vegetation cope with fire in comparison to native species?

Pre-fire and post-fire VSWIR data will be used to map native and invasive species, and succession. MTIR data of active fires will be used to derive fire timing and temperature at 60 m resolution. It may be necessary to complement the active fire data with data from other sensors (e.g. MODIS, NPP Suomi) to increase the temporal detail on the fire occurrence. Alternatively, VSWIR data can be used to estimate fire timing and temperature, however, the 19-day revisit of the VSWIR system will lower the active fire detection probability, and the Planck curves of blackbodies show that the 4 µm region has higher sensitivity to estimate fire temperature than the VSWIR.
An afternoon overpass would be beneficial for the active fire characterization, since acquisitions would capture the afternoon peak in fire activity.
A morning acquisition followed by an afternoon acquisition would allow for two independent fire detections that then subsequently could be used to estimate fire spread rates.
Afternoon images would be cloudier than morning images in many regions of the world.

5.3 CQ3 Volcanoes and Surface Signatures

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing the Volcanoes and Surface Signatures Questions

5.3.1 General Comments

The volcanology science questions identified below leverage VSWIR and TIR data to provide complementary information about active processes. There are no mathematical models that require inputs derived from the VSWIR and TIR at the same point in time, so the separation of VSWIR and TIR onto different platforms (and the loss of truly simultaneous VSWIR and TIR data acquisitions), will not result in a substantive decrease in the science attainable, until the separation between acquisitions increases to several months.

These volcanic processes do not vary diurnally and for many the time of day (or night) at which data are acquired is irrelevant, and there is little cost associated with moving from a sun-synchronous orbit, in most instances. In fact, the quasi-random imaging opportunities afforded by the ISS would allow for some unique observations to be made, given that volcanoes are *known to exhibit variations in mass and gas fluxes on time scales much shorter than those that have been previously sampled by high resolution sensors such as Landsat TM, ETM+, Terra ASTER, and EO-1 Hyperion. Questions for which a non-sun-synchronous orbit may impact the science achievable include those that look for subtle changes in temperature (of the water in volcanic crater lakes) or changes in reflectance (e.g. volcanic lake water color). In these cases changes in solar heating and solar irradiance produced by acquiring data at random times of day would complicate isolation of the volcanogenic signal.*

With respect to hosting the instruments on a platform such as the ISS, most of the Earth's active volcanoes lie within the relevant latitudinal band visible to the ISS, so the impact on the science attainable is not great, as the full spectrum of volcanic phenomena is represented by the volcanoes that would be sampled. However, there would be loss of operational value of the HyspIRI instrument suite. A great deal of the planet's air traffic passes over the high northern latitudes, which are also home to a number of explosive volcanoes, in Alaska and Kamchatka particularly. An ash forming eruption similar to the 2010 Eyjafjallajökull eruption, which had obvious societal and economic impact, would not be visible to an instrument suite on the ISS. In addition, the role that HyspIRI can play in monitoring the large number of volcanoes that are in the ISS footprint is greatly reduced when the timing of acquisitions is not regular, and in fact may include gaps of several months between clusters of acquisitions.

There are some specific impacts of having the sensors on different platforms that might be addressed in more detail. For example, simultaneous VSWIR and TIR data sets would provide emission spectra for the VSWIR, MIR and TIR from which more complex sub-pixel thermal mixture models could be developed. Such information (i.e. cooling rates estimated from sub-pixel temperature distributions) would be useful for i) cross-calibrating the lava flow cooling rates estimated using the HyspIRI 4 μm channel and the Kaufman-Wooster approximation and ii) providing information about sub-pixel lava surface temperature distribution and the structural integrity of the surface crusts of active lava flows. A full emission spectrum will not be attainable without simultaneous measurements. However, information regarding sub-pixel lava surface temperature distributions and crustal structure have been obtained previously using VSWIR data alone (e.g. Wright et al., 2011). A modelling exercise could determine the extent to which the temperatures derived from the VSWIR measurements alone are inferior to those obtained from a whole spectrum VSWIR, MIR, and TIR measurement.

VSWIR data acquired simultaneously with the TIR data would also be of benefit to the algorithms required for estimating volcanic SO_2 gas fluxes, insofar as they would provide an independent estimate of water vapor in the atmosphere. However, current approaches rely solely on the TIR for determining SO_2 column abundance, and so appear adequate. Again, a modelling study could be conducted that would show how much potential improvement might be lost through flying the VSWIR and TIR sensors on different platforms.

An increase in the lag time between VSWIR and TIR acquisition will have an impact on studies of ash and aerosol plumes. For example, most IR-based plume retrieval techniques are based on transmission of surface radiance through the plume en-route to the sensor. Since plumes tend to be more opaque near their source vents, it would be useful to measure the surface reflectance of the plume, in addition to the surface emissivity, to map the composition of ash and aerosols. Similarly, the VSWIR measurements could be used to constrain the size, and size distribution, of particulates and aerosols. The TIR estimates of mass loading (ash content) are *biased towards small particles (effective radius < 5 µm), so an independent, VSWIR-based estimate of particle size are important.*

The following discussion relates to the impact on volcanological science that a HyspIRI instrument re-configuration would have. For context, a summary of the science measurements required to answer the questions (and whether the relevant measurements are derived from the VSWIR, TIR, or both) is provided (in section 5.3.2).

5.3.2 Each Sub-question - Separated by a < 3 minutes

CQ3-1 What do comparisons of thermal flux and SO_2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

This question aims to establish i) the volume of magma that arrives within ~500 m of the surface (i.e. shallow enough for SO_2 to exsolve), and ii) what percentage of this is erupted onto the surface as lava flows (the volume of which can be estimated from thermal measurements of the rate at which the lava cools). The remaining volume must remain within the volcanic edifice, being either recycled back to the shallow chamber or emplaced as shallow intrusions.

Here, the amount of magma that arrives at shallow depths is obtained from observations of SO_2 flux (derived from TIR data). The lava flux rate (proportional to the area and cooling rate of the active flows that are erupted at the surface) is also obtained from the TIR data, specifically the low gain 4 µm channel. As such, both measurements come from the same instrument and our ability to answer this question is not impacted by the sensors flying on different platforms. The VSWIR data play a supplementary role here, insofar as they can be used to constrain the integrity of the lava's surface crust. Physics-based modelling of active lava flows (Crisp and Baloga, 1990) indicates that large changes in the area of the flow surface occupied by high temperature fractures (i.e. how fractured or intact the chilled lava crust is) can exert significant influence on the nature of the active lava area-flux rate relationship, and may explain the scatter which is commonly observed in satellite-derived lava effusion rate time-series.

In cases where portioning of magma between the surface and the subsurface has been estimated previously (e.g. Harris et al., 1998; Steffke et al., 2010), the primary SO_2 and lava flux measurements have been obtained independently from ground and satellite-based observations. Furthermore, the individual mass flux estimates are integrated over extended periods of time (often the duration of the eruptions themselves, which is often weeks, perhaps months). Obtaining these measurements from the TIR data simultaneously will therefore constitute an improvement. The ability of the VSWIR data to play the supplementary role required of it is not impacted by a separation of less than three minutes, as changes in mass flux rate cannot be identified on these time scales (using the 4 µm channel and associated method; Wright et al., 2001). We will still be able to determine whether large changes in the integrity of a lava flows surface crust impact our ability to estimate the mass flux rate at which it is being erupted.

CQ3-2 Does pressurization of the shallow conduit produce periodic variations in SO_2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?

This question aims to establish when a lava dome forming volcano may be experiencing an increase in pressurization with the dome/shallow conduit, that might ultimately be released in an explosive eruption. When the dome is permeable, SO_2 will freely escape into the atmosphere, and fumaroles/fractures on the surface through which the gas passes will be heated to near-magmatic temperatures as a result. When the dome permeability decreases (generating potentially explosive overpressures), so will the SO_2 flux, and the previously high temperature fractures on the dome surface will cool to ambient temperature.

For this question, the pertinent observations are a TIR data set (to estimate changes in SO_2 flux) and a VSWIR observation (to estimate the surface thermal structure of the lava dome). Separation in time by <3 minutes will have no impact on the ability of scientists to determine if changes in these parameters are correlated in such a way as to constitute precursors to explosive eruptions. Previously published work on this subject (e.g. Oppenheimer et al., 1993; Matthews et al., 1997; Wooster and Rothery, 1997), found that the time scales on which these processes took place to be of the order of months to several months.

CQ3-3 Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

This question is concerned with how VSWIR and TIR data can be used to accurately constrain lava flow cooling rates. Numerical models that simulate lava flow hazards do so by allowing the simulated flows to cool from their surfaces, and lose internal energy. As they do, their internal temperature decreases, and the viscosity and yield strength of the lava increases. Eventually a condition is met whereby the rheology of the lava has changed so much that it is too stiff to flow any further.

The lava surface temperature distribution (i.e. what is the temperature of the crust? How does it vary with time and distance from the vent? To what extent is the lava crust fractured, exposing high temperature material from the flow interior?) is an important boundary condition for such numerical flow simulations, but little real data have been available to accurately parameterize this because of the spatial scale of active lavas and their temporal variability.

The gross rate at which the lava cools can be estimated solely from the TIR data (using the 4 μm channel and the Kaufman-Wooster approximation) or the VSWIR data (using a mixture modelling approach. E.g. Wright et al., 2011). Additionally, the VSWIR data can also be used to provide further data for calibrating lava flow simulation models as they can be used to estimate the temperature and integrity of the lava crust at the sub-pixel scale (which the TIR data alone cannot). As such there is no requirement that the data be acquired simultaneously, and data acquired within three minutes of each other can be sensibly compared (perhaps not at the pixel scale, but at the flow or flow-field scale). The benefits of combining data from both instruments (i.e. obtaining a complete emission spectrum) will be lost when TIR and VSWIR data are not acquired simultaneously. As previously discussed, the extent to which this may have improved our ability to constrain lava flow cooling, lava surface temperature, and the integrity of the lavas surface crust is undetermined but could be assessed via a modelling study.

CQ3-4 Does the temperature and composition of volcanic crater lakes change prior to eruptions?

The temperature, color, and volume of water hosted in craters atop active volcanoes has been observed to change prior to eruptions. These lakes act as calorimeters and condensers for energy and chemical elements obtained from the shallow magma bodies that lie beneath them. Changes in temperature, commonly of the order of 10 degrees or more, have been observed prior to eruptions, due to heating of lake water circulating through heated rocks. Changes in lake color (due to increased turbidity as a result of gases passing through the lake bottom lofting fines into the water, or chemical reactions) have been observed. Lake volume (and hence lake surface area as a proxy, assuming a typically shaped crater) have also been observed to change when volcanoes enter new phases of enhanced activity (e.g., the lake volume decreases as water is evaporated following an increase in volcanogenic heat into the system).

While answering this question relies on both VSWIR and TIR data there is no requirement for them to be acquired simultaneously. Thermal and visual changes in these lakes occur on much longer time scales than minutes. For example, over a 15 year period, Christensen and Wood (1993) observed five cycles of increasing temperature prior to eruptions at Ruapehu in New Zealand (although other published examples indicate time-scales significantly shorter than this, on the order of months, e.g. Delmelle and Bernard, 2000).

CQ3-5 Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?

Emissions of heat and gas from active volcanoes impact surrounding ecosystems. Deposition of H_2S0_4 (formed by combination of volcanic SO_2 and water) in downwind regions can adversely affect vegetation. As such, changes in vegetation health can act as markers of increased activity at volcanoes.

Again, this question relies on VSWIR data (for quantifying vegetation health) and TIR data (for quantifying subtle changes in surface temperature, and SO_2 gas flux) but does not require simultaneous acquisition of the data sets.

5.3.3 Each Sub-question - Separated by a < 1 week

CQ3-1 What do comparisons of thermal flux and SO_2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

Correlation of lava mass eruption rate (derived from TIR data) with changes in the integrity of the surface crust (obtained from VSWIR data) is likely to become problematic as the time separation moves towards one week. Dramatic changes in effusion rate and flow surface area can take place on these time scales, rendering any correlations of limited use. Certainly, effusion rate can still be computed, as could an index of crustal fracturing. But the direct effect that the latter has on the former would be less easy to determine.

CQ3-2 Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?

For the reasons given in 5.3.2, this question can still be answered using VSWIR and TIR data acquired with a temporal frequency of about one week. The cycles identified by the previously cited authors indicate that the processes responsible for the remotely measured patterns operate on a longer time-scale.

CQ3-3 Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

When time separation between the information about gross surface lava flow heat loss (obtained from the TIR instrument) and the detailed information regarding surface temperature distribution and crustal integrity (obtained from the VSWIR) become separated by about one week, our ability to add value by combining the data sets is hampered. Significant changes in lava flow effusion rate and surface area can take place on these time scales. However, the separate measurements still have value as the lava flow prediction models require inputs (lava effusion rate) and generate outputs (surface temperature) that vary throughout the duration of the simulations.

CQ3-4 Does the temperature and composition of volcanic crater lakes change prior to eruptions?

Once more, the time scales that the changes of interest take place are of the order of weeks to months, and VSWIR and TIR data acquisitions separated by less than one week will be adequate to resolve and correlate them. For example, temperature increases of 10°C were observed in over periods of three to four months at eruptions at Taal (Philippines, Moore et al., 1966) and Kelut (Indonesia, Badrudin, 1994); if concomitant changes in lake color and/or area took place, separation in time by less than one week would not reduce our ability to observe them, and correlate them.

CQ3-5 How does vegetation composition influence wildfire severity? Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?

Once more, the time scales that the changes of interest take place are of the order of weeks to months, and VSWIR and TIR data acquisitions separated by less than one week will be adequate to resolve and correlate them.

5.3.4 Each Sub-question - Separated by a few months

CQ3-1 What do comparisons of thermal flux and SO_2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

While the TIR and VSWIR would still yield useful information in isolation, the synergy would be totally lost.

CQ3-2 Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?

<Section lead provide input here> *This appears to be at the limit for which useful information regarding the processes of interst can be derived. Oppenheimer et al. (1993) resolved changes in lava dome surface structure at Lascar using Landsat data acquired at an average rate of two scenes per year. However, the remote signature that they found indicative of dome over-pressurization was best exemplified in their time-series during the first two years, where eight Landsat scenes were used (i.e. at approximately three month separation). Assuming the field based model established to explain the Oppenheimer observations is valid, three month separation between VSWIR (dome structure) and TIR (SO_2 emissions) could yield enough data to recognize a decreasing trend in both. However, at volcanoes where cloud cover is an issue (at Lascar it is not) the declining trend in these variables (and the correlation between them) might become difficult to discern.*

CQ3-3 Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

Following from section 5.3.3, the influence that flow surface thermal structure and changes in crustal integrity have on effusion rate would be impossible to discern at this time separation. Each measurement would still, however, provide information that could be used in isolation to i) drive flow simulations (effusion rate – TIR), and ii) validate model predictions regarding flow surface temperature (VSWIR).

CQ3-4 Does the temperature and composition of volcanic crater lakes change prior to eruptions? *The time scales of which increases in temperature have occurred prior to eruptions is of the order of a few months. VSWIR (water color) and TIR (water temperature) measurements separated by this much time will provide no useful information about how the two variables together might provide a reliable indicator of volcanic unrest.<Section lead provide input here>*

CQ3-5 Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?

The time-scales over which vegetation is impacted by volcanic gases depends on the amount of deposition and the duration over which it occurs, so temporal separation of several months might still yield useful information as one would expect a temporal lag between the former and the latter. <Section lead provide input here>

5.3.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Volcanoes and Surface Signatures Questions

CQ3-1 What do comparisons of thermal flux and SO2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

Since the measurements are of an active process with no diurnal variations (the ascent and degassing of magma and the eruption of lava), the time of data at which the measurements are *made is of little consequence, and a sun-synchronous orbit is not required. As effusion rate and gas fluxes can vary on a daily basis, a quasi-random sampling (high temporal resolution for a relatively short period of time) has the potential to yield interesting information about these processes on time scales that have been thus far unattainable from orbit, for a large number of volcanoes.*

CQ3-2 Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?

Similarly, studying the process does not require a sun-synchronous orbit, and high temporal resolutions (i.e. night and day, many observations during a several week window) would yield interesting information about how the apparent permeability of lava domes (to the passage of gas) varies over short time scales. Of course, large gaps in sampling (e.g. many months) will reduce our ability to identify changes that may lead to eruptions. Wright et al. (2002) found that these cycles occurred on time scales of days to weeks at Popocatepetl volcano in Mexico (although the work of Oppenheimer et al, 1993, Matthews et al., 1997, and Wooster and Rothery, 1997, indicate that times scales of several months were apparent at Lascar volcano in Chile).

CQ3-3 Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

Once more an active process that does not exhibit any diurnal cycle and does not require data acquired from a sun-synchronous orbit. The potential for acquiring many data sets within a relatively short period of time would yield important insights into how lava flow surface temperature, fracturing and cooling vary on short time scales. Large gaps in coverage do not impact the value of the science which would largely be concerned with determining how well these parameters could be determined, such as they may be incorporated into physics-based lava flow simulation codes (to improve their performance).

CQ3-4 Does the temperature and composition of volcanic crater lakes change prior to eruptions?

A non-sun-synchronous orbit becomes an issue for this question, which relies on resolving perhaps subtle changes in lake water color and temperature. Variations in both caused by sampling at different times of day (i.e. differences in solar heating; differences in solar irradiance) would complicate identifying real volcanogenic trends in temperature and color.

CQ3-5 Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?

A non-sun-synchronous orbit is also likely to be an issue for this question, which relies on resolving perhaps subtle changes in the reflectance of vegetation and low temperature thermal anomalies on volcano surfaces, which can easily be masked by solar heating, making acquisitions at a wide range of day times undesirable, when attempting to search for subtle changes over time.

5.3.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Volcanoes and Surface Signatures Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

CQ3-1 What do comparisons of thermal flux and SO2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?

The processes do not follow a diurnal cycle. While SO_2 retrievals might be aided by warmer solar heated surfaces beneath the plume, this is likely to be negated by the higher incidence of clouds.

CQ3-2 Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions? <Section lead provide input here> *The processes do not follow a diurnal cycle. While SO_2 retrievals might be aided by warmer solar heated surfaces beneath the plume, this is likely to be negated by the higher incidence of clouds.*

CQ3-3 Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?

Aside from the higher likelihood that the target is obscured by cloud in the afternoon, the lava effusion rate estimates can be computed from data acquired at any time of day.

CQ3-4 Does the temperature and composition of volcanic crater lakes change prior to eruptions? *The changes in temperature and color are likely to be relatively subtle. As such, increased solar heating (as the day progresses) will complicate isolation of the volcanogenic thermal flux from the lake water. However, the increased signal afforded by making reflectance measurements in the afternoon might make the resolution of lake water color changes easier (notwithstanding the higher incidence of clouds)*

CQ3-5 Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?

Subtle changes in surface temperature will be harder to resolve in afternoon acquisitions because of solar heating of bare rock surfaces. Changes in vegetation health/state will not be impacted by an afternoon overpass. Previous comments about SO_2 retrievals apply.

5.4 CQ4. Ecosystem Function and Diversity

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing the Ecosystem Function and Diversity Questions

5.4.1 General Comments

TIR and VSWIR imagery provide valuable synergistic information about landcover type, vegetation density and health/stress, and impacts on energy balance and carbon/water exchanges that can be productively used to address a broad spectrum of questions regarding ecosystem function. TIR is the primary constraint in methods to retrieve surface energy balance and evapotranspiration, and is a useful diagnostic tool for estimating limitations on the effective canopy resistance governing both assimilation of carbon and loss of water through transpiration. Photosynthesis (i.e., enzyme kinetics) involves a set of temperature-driven (in addition to light) chemical reactions. Therefore, estimates from HyspIRI associated with enzyme kinetics will be sentitive to the timing of temperature measurements. TIR-based energy balance algorithms require VSWIR albedo information to estimate net radiation, and many additionally require estimates of LAI or green cover fraction. Additional physiological stress signals derived from red edge or other parts of the shortwave spectrum complement the temperature based stress signal conveyed by the TIR measurement. In addition, hyperspectral VSWIR data enable detailed classification of landcover type required to better understand observed carbon/water responses to various stressors at the pixel level.

These functions benefit from near-simultaneous collection of TIR and VSWIR datasets. From a phenology standpoint, a few day separation between TIR and VSWIR might be acceptable for ET mapping under "normal circumstances" and for retrospective applications. Problems will arise with 1) abrupt changes in LAI (e.g., harvest, burns); 2) realtime applications during periods of rapid vegetation change, where we cannot interpolate LAI/albedo/cover fraction and would have to project forward in time from the last VSWIR collection. All of these factors will add error to ET retrievals, which could be huge in areas of abrupt change occurring between TIR and VSWIR collections. From a stress standpoint, TIR and VSWIR information regarding stress condition can become decorrelated in a matter of minutes depending on time of day and current conditions. Significant temporal separation will disenable examination some of the synergistc utility of collecting both datastreams.

5.4.2 Each Sub-question - Separated by a < 3 minutes

CQ4-1 How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?

Stress signals conveyed by TIR and VSWIR can become confounded by time-of-day effects in a matter of a fraction of an hour depending on time of day and current surface and microclimate conditions. Uncertainties created by non-simultaneous imaging will be most significant in areas of primary interest to the HyspIRI mission – where vegetation is entering into a rapidly degrading stress condition. Expected uncertainties created by 3-minute time separations can be *studied using local time-continuous measurements made under different stress conditions. Measured plant stress is sensitive to temperature, but likely not at 3 minute scale.*

Additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-2 How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?

Separation of VSWIR and TIR by < 3 minutes should not significantly affect this science question. However, additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-3 How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?

As with CQ4-1, any significant temporal separation between TIR and VSWIR stress signals reduces our ability to ascertain how these signals can be most effectively combined. Given that driving environmental conditions do not change rapidly in three minutes, this affect is minimal. Note that measurements of physiology are instantaneous.

Additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-4 What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?

Separation of VSWIR and TIR by < 3 minutes should not significantly affect this science question. However, additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-5 What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?

Separation of VSWIR and TIR by < 3 minutes should not significantly affect this science question. However, additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-6 How do climate-induced temperature and moisture changes impact the distribution and spread of invasive and native species?

Separation of VSWIR and TIR by < 3 minutes should not significantly affect this science question. However, additional uncertainty may be incurred due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

Since climate-induced temperature and moisture changes occur at periods longer than 1 year, VSWIR and TIR data collected over a few months will not impact the analysis of this science question.

5.4.3 Each Sub-question - Separated by a < 1 week

CQ4-1 How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?

Stress impacts on canopy carbon and water exchange can ramp up quickly, with significant changes in light-use efficiency and canopy resistance apparent at daily timescales. Separation of TIR and VSWIR by one to several days will significantly negatively impact studies of combined use for stress detection.

CQ4-2 How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?

Surface energy balance evaluations can be impacted by < 1 week separation of LST (sensible heat boundary condition) and VSWIR used to estimate net radiation and cover fraction (used to partition LST between soil and vegetation components). Error in energy balance may not be severe in areas of slowly changing vegetation cover, but will be more significant in areas of rapid growth, senescence, abrupt changes due to harvest, frost or death, and abrupt changes in wetness of canopy and soil caused by rain events and irrigation. The latter can substantially change values for albedo, reflectances, vegetation indices and surface temperature, especially in areas having sparse vegetation.etc. To most robustly associate changes in energy balance partitioning with changes in fractional cover, TIR and VSWIR should be collected within the same day.

CQ4-3 How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?

Stress impacts on canopy carbon and water exchange can ramp up quickly, with significant changes in light-use efficiency and canopy resistance apparent at daily timescales. Separation of TIR and VSWIR by one to several days will significantly negatively impact studies of combined use for stress detection. Detection of processes related to photosynthesis (i.e., enzyme kinetics) are temperature-mediated. Estimates related to temperature context will not be possible without nearly-concurrent data (within minutes).

CQ4-4 What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?

Climatological (long-term mean) assessments of relationships between phenology and temperature/moisture condition changes may be reasonably conducted with under a week separation in TIR/VSWIR. In areas of most interest however, where drivers of changing response are most active, this requires near-concomitant retrieval of surface moisture/temperature and vegetation cover for reasons outlined in CQ4-2 above. Phenology in grasslands and deciduous forest can change significantly over the course of one week, particularly under stress leaf-out and senescence. In addition, near-concomitant retrievals may be necessary when comparing estimated responses from remote sensing with ground-based measurements.

CQ4-5 What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?

Studies of impacts of feedbacks between canopy temperature and canopy condition/composition will be hindered by separation of TIR/VSWIR of < 1week in cases of impulse disturbance. Longer term recovery studies may be less affected.

CQ4-6 How do climate-induced temperature and moisture changes impact the distribution and spread of invasive and native species?

This question deals with slower timescale evolution in canopy composition, and will be less affected by TIR/VSWIR separation of < 1week, except through impacts on ET/surface moisture retrieval accuracy by using non-commensurate TIR/albedo information as detailed above.

Temperature and moisture changes affected by climate as they impact the distribution and spread of invasive and native species over long periods of time (>1 year). However, the study of incremental changes in temperature and moisture for impacts on invasive and native species is influenced on at least a seasonal basis. It is anticipated, therefore, that TIR data separated by a few months would not severely affect the utility of these data for analysis of the distribution and spread of invasive and native species as a result of climate change. A non sun synchronous orbit would have significant impact on the detection and observation of the distribution of invasive and native species since sunlight is required to identify and differential invasive and native species from other vegetation. This would greatly impair the assessment of climate-induced changes in the distribution and extent of invasive and native species.

5.4.4 Each Sub-question - Separated by a few months

CQ4-1 How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?

Accurate characterization of phenology requires acquisitions every two weeks or more frequently.Stress characterization requires daily observations at consistent times of day. Thus this question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

CQ4-2 How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?

Time scales for fluxes are non-linear functions of cover and plant type.
This question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

CQ4-3 How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?

Plant physiological functions operate at multiple time scales. Variations in these functions would not be resolvable. This question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

CQ4-4 What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?

Vegetation phenology is an integrative response to hourly and daily changes in temperature and soil moisture. Given large year-to-year variations in surface environmental conditions, this question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

CQ4-5 What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?

With several month separation, it would be difficult to unambiguously associate feedbacks with specific disturbance events. The period of recovery right after disturbance would be unsampled. This question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

CQ4-6 How do climate-induced temperature and moisture changes impact the distribution and spread of invasive and native species?

With several month separation, it will be difficult to associate cause and effect in this science question. This also suggests infrequent revisit interval, which will not allow sufficient sampling of dynamic variables such as temperature and moisture change. This question would not be addressable with TIR/VSWIR acquisitions separated by a few months.

5.4.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Ecosystem Function and Diversity Questions

CQ4-1 How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?

Quasi-random orbits create scientific trade-offs with uncertain effects. Sampling of stress conditions during different times of the day enables an assessment of optimal overpass time-of-day for discriminating between stressed and non-stressed canopies. Contrast in conditions are usually most extreme in the afternoon, after stress-induced midday stomatal closure has set in. However, effects of varying sun angles/shadows (topographic and in-canopy) will confound reflective and emitted stress signals Midday and afternoon retrievals will be most valuable when directly associated with midmorning retrievals on the same day and at the same spatial resolution to monitor the change in stresses and their impacts with time of day.

CQ4-2 How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?

See response to CQ4-1 in this subsection. Some currently used remote-sensing processes for partitioning latent and sensible heat fluxes rely on using an image-wide 'frozen snapshot' of land surface temperature to derive extreme temperatures associated with the energy partitioning extremes. The temperature extremes are developed via inverse modeling and benefit from application to 'snapshots' of approximately 100 km x 100 km to 160 km x 160 km for operational efficiency and accuracy, where the application area (100 or 160 km x 100 or 160 km) has nearly the same solar radiation geometry and in-fluxes (i.e., they occur at the same acquisition time). These procedures would suffer under an inclined orbit where the solar altitude would be continuously changing over a matter of km along the acquisition path and a dynamic calibration strategy would have to be adopted, with likely less accuracy.

CQ4-3 How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?

See response to CQ4-1 in this subsection.

CQ4-4 What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?

Impact of non sun-synchronous orbit is unclear.

CQ4-5 What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?

Impact of non sun-synchronous orbit is unclear.

5.4.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Ecosystem Function and Diversity Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

CQ4-1 How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?

Afternoon acquisitions may improve contrast in stress conditions across a landscape. However acquisition of TIR and VSWIR at different times of day will significantly hinder analyses of synergistic use of multi-band stress signals.

CQ4-2 How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?

Afternoon acquisitions may improve contrast in energy balance partitioning across a landscape. Separation of VSWIR and TIR by < 1 day will introduce uncertainty due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-3 How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?

Afternoon acquisitions may improve contrast in stress conditions across a landscape. However acquisition of TIR and VSWIR at different times of day will significantly hinder analyses of synergistic use of multi-band stress signals.

CQ4-4 What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?

Afternoon acquisitions may improve contrast in retrieved moisture conditions across a landscape. Separation of VSWIR and TIR by < 1 day will introduce uncertainty due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

CQ4-5 What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?

Afternoon acquisitions may improve contrast in retrieved canopy temperature conditions across a landscape. Separation of VSWIR and TIR by < 1 day will introduce uncertainty due to misregistration of images from separated VSWIR-TIR sensors, and to movement of clouds between acquisitions.

5.5 CQ5. Surface Composition and Change

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing the Surface Composition and Change Questions

5.5.1 General Comments

The exposed terrestrial surface of the Earth is composed of materials that exhibit diagnostic spectroscopic absorption features in the 3.25 to 12.0 micrometer region. These materials undergo gradual change over geologic time through natural processes. Characterizing and mapping the surface composition benefits from combined spectral response in the VSWIR and TIR channels, though coincidence between these channels is not as critical.

The soil and rock substrate influence the vegetation cover and vice-versa. Migrating hydrothermal fluids and hydrocarbon rich fluids alter composition of the rocks and soils aiding in recognition of mineralized zones and hydrocarbon reservoirs. These processes are also gradual. Coincident VSWIR and TIR is not critical for studying these processes or their influence on the Earth surface composition.

The exposed terrestrial surface can however undergo a rapid change under the influence of certain anthropogenic and non-anthropogenic drivers. Flash floods, mass movements and prescribed burns can change the exposed surface within a few days. Acid mine drainage and other mining activities, logging, chemical treatments of agricultural lands can cause surface changes within time spans of weeks. Seasonal influences on surface composition can also be significant. Depending on the driver, mapping such changes will require VSWIR and TIR data to be collected within a few days to a few weeks apart.

None of the science applications under the CQ5 category critically require the data to be coincident or even minutes apart.

5.5.2 Each Sub-question - Separated by a < 3 minutes

CQ5-1 What is the composition of the exposed terrestrial surface of the Earth?

Most common minerals present in the exposed surface of the earth are quartz, carbonates, clays, oxides and evaporites. These minerals have diagnostic spectral response in different parts of the spectrum. The combined spectral response from VSWIR and TIR regions is therefore important to characterize the composition of the exposed surface of the Earth. Typically this surface composition undergoes gradual change, and time lapse in the order of less than three minutes between VSWIR and TIR acquisitions is inconsequential to address this science question.

CQ5-2 How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?

Plants uptake minerals and other nutrients from the underlying soil substrate, primarily through their roots. However, there is no instantaneous influence on the plant physiology or function due to this uptake. Therefore, a less than three minute time delay between VSWIR and TIR is not an issue to address this science question.

CQ5-3 How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?

Natural processes and anthropogenic activities are constantly changing the Earth's terrestrial surface. Many natural processes such as weathering and desertification operate over years and decades, while others such as flooding and fires can cause rapid changes. Though the latter are drivers of rapid change, monitoring efforts will not be hampered if VSWIR and TIR images are <3 minutes apart.

CQ5-4 How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?

Combined VSWIR TIR spectra are important to identify and delineate hydrothermally altered regions which hold clue for mineral exploration and help to construct hydrothermal deposition models. However, a separation of <3minutes between the VSWIR and TIR will not impact the applicability of these data to address this science question.

CQ5-5 How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?

Migrating hydrocarbons and hydrocarbon seeps cause some alteration of host rocks. The thermal maturity of the host rock, an important indicator for discovery of hydrocarbon reserves, can also be ascertained from vitrinite reflectance that can be linked to reflectance signature in the VSWIR and TIR regions. Therefore, combined VSWIR and TIR spectra are important to address this question. However, as alteration and thermal maturation of host rocks is a gradual process, the VSWIR TIR spectra do not need to be simultaneous or closely spaced in time. As far as the VSWIR and TIR data are well co-registered, this science application can be addressed without compromise.

5.5.3 Each Sub-question - Separated by a < 1 week

CQ5-1 What is the composition of the exposed terrestrial surface of the Earth?

As far as the VSWIR and TIR images can be carefully co-registered with sub-pixel accuracy, and no natural or anthropogenic drivers have caused significant changes during the interim period, a <1 week separation in VSWIR and TIR acquisitions will not be a barrier in addressing this science question. Most natural processes that change the general composition of the exposed surface operate over many years.

CQ5-2 How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?

There is a lag before there is a detectable influence on plant physiology and function due to uptake of minerals and other nutrients from the underlying soil substrate. A < 1 week time delay between VSWIR and TIR will not pose a major problem to address the linkage between surface mineralogy and soil composition to plant physiology and function.

Changes in the soil composition due to moisture changes will influence the vegetation, especially the rapidly stressing vegetation. This influence is separately addressed in the ecosystems section in CQ4-2, where a VSWIR and TIR acquisition within the same day is recommended.

CQ5-3 How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?

Certain natural and anthropogenic drivers can change the composition of the exposed terrestrial surface of the Earth with rapidity. Flash floods, mass movements, prescribed burns, wild fires, all can change the exposed surface within a few days. Seasonal factors and local weather can also influence the surface composition significantly, for example by producing a surface coating of moss or rust on the exposed surface, making it hard to extract meaningful information from VSWIR and TIR spectra retrieved 3 to 7 days apart.

CQ5-4 How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?

Combined VSWIR TIR spectra are important to identify and delineate hydrothermally altered regions which hold clue for mineral exploration and help to construct hydrothermal deposition models Using VSWIR and TIR images acquired <1 week apart will work to address this science question as far as the VSWIR and TIR images can be carefully co-registered with sub-pixel accuracy,

CQ5-5 How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?

VSWIR and TIR spectra are important to address this question as elaborated in the previous case for CQ5-5. However, as alteration and thermal maturation of shales is a gradual process, the VSWIR TIR spectra do not need to be simultaneous or closely spaced in time. As far as the VSWIR and TIR data are well co-registered, this science application can be addressed without compromise.

5.5.4 Each Sub-question - Separated by a few months

CQ5-1 What is the composition of the exposed terrestrial surface of the Earth?

Most of the exposed terrestrial surface of the Earth is composed of rocks and soils that undergo very gradual weathering and change in composition. No significant change is expected within days or even weeks, but longer time duration increases the likelihood of surficial change due to anthropogenic and non-anthropogenic drivers. Seasonal influences from rainfall, dust storms, surface rusting, moss growth can change the surface spectral signature. However, if due care is taken that these external influences are kept to the minimum, robust atmospheric corrections are performed, and the VSWIR and TIR data are well co-registered to sub-pixel accuracy, then this science question can be addressed even with VSWIR and TIR data acquired a few months apart.

CQ5-2 How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?

Vegetation cover over unaltered soils can show a spectral response considerably different from the spectral response of vegetation cover over hydrothermally altered areas. As hydrothermal alteration is a slow process (see CQ5-4) the detectable differences in plant physiology and function as a consequence of the differences in underlying material type are also not time sensitive.

Changes in the soil composition due to moisture changes will influence the vegetation, especially the rapidly stressing vegetation. This influence is separately addressed in the ecosystems section in CQ4-2, where a VSWIR and TIR acquisition gap of several months will have a significant impact.

CQ5-3 How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?

Our ability to address this science question will be hampered if the VSWIR and TIR data are acquired several months apart. Over a time span of few months, local to regional landscape level changes can occur due to seasonal effects, land degradation, winds causing sand dune migration, floods etc. Anthropogenic activities such as logging, mining, prescribed burns etc. can also cause significant change in surface composition. Should VSWIR and TIR data be acquired several months apart, they will not represent the same feature on the ground. Characterizing the composition of the exposed terrestrial surface, that requires a combined response from VSWIR and TIR, will not be possible.

CQ5-4 How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?

No significant change in surface manifestation of hydrothermal alterations or alteration patterns is anticipated within a few month time. In principle, VSWIR and TIR data taken a couple of months apart should still be applicable to address this science question.

The usual issues that come into play when VSWIR and TIR data are separated that far in time exist in this case too. For example, seasonal influences from rainfall, dust storms, surface rusting, algal growth on rocks etc. can change the surface spectral signature making it difficult *to extract VSWIR and TIR spectra that represents the same target. If due care is taken that these external influences are kept to the minimum, robust atmospheric corrections are performed, and the VSWIR and TIR data are well co-registered to sub-pixel accuracy, then this science question can be addressed even with VSWIR and TIR data acquired a few months apart.*

CQ5-5 How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?

Regional trends of minerals and shale thermal maturity undergo no conspicuous change within a period of months. In principle, VSWIR and TIR data taken a couple of months apart should still be applicable to address this science question.

The usual issues that come into play when VSWIR and TIR data are separated that far in time exist in this case too. For example, seasonal influences from rainfall, dust storms, surface rusting, algal growth on rocks etc. can change the surface spectral signature making it difficult to extract VSWIR and TIR spectra that represents the same target. If due care is taken that these external influences are kept to the minimum, robust atmospheric corrections are performed, and the VSWIR and TIR data are well co-registered to sub-pixel accuracy, then this science question can be addressed even with VSWIR and TIR data acquired a few months apart.

5.5.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Surface Composition and Change Questions

CQ5-1 What is the composition of the exposed terrestrial surface of the Earth?

Knowing the composition of the exposed terrestrial surface of the Earth provides critical information for resource exploration. Vast reserves of oil and gas, and of economic and strategic minerals occur in the high latitude regions. The limited latitudinal coverage of the ISS orbit, or similar non-sun synchronous orbits, will preclude coverage of these resource rich areas. This is an obvious limitation of an ISS type platform.

In extracting the VSWIR and TIR spectral response from the same target, there will be the added complexity of differing spectral impurity due to integration of the signal over different ground areas. Data processing that relies on mathematical operations between VSWIR and TIR bands will be adversely affected, adding complexities to surface composition mapping.

CQ5-2 How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?

The inherent difficulties in reliably mapping the surface composition of the Earth are equally applicable to mapping the influence of these compositions of plant physiology and function.

CQ5-3 How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?

Climate change is arguably one of the main drivers modifying the composition of the Earth's surface. Though the response to climatic forcings is global in nature, the response is amplified in the high latitude areas. An ISS orbit completely misses this important region. Impact of non sun-synchronous orbit on understanding the influence of anthropogenic drivers is unclear.

CQ5-4 How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?

The different spatial resolution and geometry of VSWIR and TIR will increase complexity in data processing and in alteration mapping.

CQ5-5 How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?

The different spatial resolution and geometry of VSWIR and TIR will increase complexity in data processing, alteration mineral mapping, and in deriving a proxy for vitrinite reflectance and thermal maturity of host rocks.

5.5.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Surface Composition and Change Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

CQ5-1 What is the composition of the exposed terrestrial surface of the Earth?

Different overpass time has no specific advantage or disadvantage.

CQ5-2 How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?

Different overpass time has no specific advantage or disadvantage.

CQ5-3 How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?

Different overpass time has no specific advantage or disadvantage.

CQ5-4 How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?

Different overpass time has no specific advantage or disadvantage.

CQ5-5 How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?

Different overpass time has no specific advantage or disadvantage.

5.6 CQ6. Human Health and Urbanization

Excluding cloud cover mapping (where it's obviously critical to acquire TIR and VSWIR data within seconds), what is the real requirement for time coincidence between the VSWIR and TIR channels for addressing Human Health and Urbanization Questions

5.6.1 General Comments

Human health can be affected by changes in environmental parameters ranging from dynamic (e.g., hourly) to long term (e.g., years) depending upon the characteristics of the environment or vectors that impact human health. For example heat waves, which kill more people in the U.S. than any other environmental impact, occur over hours or days. Therefore, the collection of timely TIR data to quantify surface temperatures as they increase as a result of prolonged heat exposure is critical on at least a weekly temporal period. Changes in local to regional environmental characteristics such as land cover change, soil moisture or vegetation type and extent as they impact human health can be assessed at weekly, monthly, yearly temporal periods. Critical to the analysis of vector- or animal-borne diseases such as Lime disease, dengue fever, or West Nile Virus, are both VSWIR and TIR data which are needed to detect land cover and environmental characteristics. Thus, soil moisture and vegetative factors that affect the proliferation of vectors (e.g., mosquitoes) are vital to assessing the distribution of vector habitat for diseases of this type. The changes in and distribution of vegetation, soil moisture and land cover characteristics is also critical to the detection of animal-borne diseases such as Hantavirus, in identifying the range and distribution of habitat of the animals that carry zoonotic diseases (e.g, rodents). Given that vegetation and land cover must be derived from Earth observation platforms in sun synchronous orbits, the repeatability of obtaining consistent and long-term data would be significantly impacted by mounting the VSWIR and TIR on a platform such as the ISS because of its non sun synchronous and asymmetric orbit.

5.6.2 Each Sub-question - Separated by a < 3 minutes

CQ6-1 How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?

Vector and animal-borne diseases are directly related to the interaction of the land surface with meteorological and climatic factors. The type, distribution, and characteristics of the vegetation present along with soil moisture and temperature, create environments that are conducive to harboring the vectors and animal attributes that contribute to and cause diseases in humans. Vegetation and soil moisture in conjunction with specific land cover densities and patterns define the habitat for the initiators and carriers of vector- and animal-borne diseases. For example, Dengue Fever is caused by one of four viruses carried by mosquitoes in tropical and subtropical areas. Cases have increased dramatically in the past few decades and there are currently ~100 million infections annually around the world. The only vector for Dengue Fever is the Aedes Aeygypti mosquito which has specific habitat requirements and limitations. It appears that vegetation and soil moisture are critical for establishing the habitat for Aedes Aegypti. With climate change, it is anticipated that Dengue Fever will move into locations that heretofore were not suitable habitat for its vector (Dengue Fever is now moving into the southern U.S. as a result of warming and vegetation change caused by climate variability). VSWIR and TIR data for detection of land cover and vegetation change, and soil moisture and surface temperature are critical to identifying and observing the distribution of suitable habitats for Aedes Aegypti. Since the changes in these factors as they affect mosquito habitat occur at multiday to weekly time scales, VSWIR and TIR data collected at <3 minutes will not be of consequence for analysis of Dengue Fever vector habitat. This also holds for other types of vector-borne diseases such as Lime or West Nile Virus. Animal habitats also change in a similar fashion such that <3 minute VSWIR/TIR data collection will not hamper the assessment of habitat characteristics that harbor animal-borne diseases.

CQ6-2 What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?

The emissivity of the urban surface is complex as it is a function of the heterogeneous surface material types that comprise the city landscape. Emissivity is also an important quantitative input for accurately calculating land surface temperature from TIR data. The emissivity of a surface in the urban environment can be affected by environmental factors such as dust or atmospheric residue (e.g., pollutants) that are collected on that surface. VSWIR data, therefore, are necessary for calculating the emissivity of complex urban surface. Moreover, how emissivity changes as a function of time for specific urban surfaces is not well understood. for example, with time, asphalt surfaces become lighter in color due to weathering which can change its emissivity. Additonally. building rooftops are comprised of many different types of building materials (e.g., asphalt shingle, metal) which have different emissivities. Analysis of differences in emissivity for rooftops as well as other urban surface types is key to developing spectral libraries for spectrally separating these surfaces using VSWIR and TIR data. Emissivities do not change over short periods of time (<3 minutes), so collecting VSWIR and TIR at time intervals separated by <3 minutes should not affect their analysis. Given that VSWIR data are necessary to compute emissivities, a non sun synchronous orbit would be detrimental to the assessment of urban surface emissivities. An asymmetrical orbit would not severely impact the analysis of changes in urban surface emissivity, as long as there is a data repeat cycle within a reasonable period of time (e.g., several months, seasonally).

CQ6-3 How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?

Given that the urban surface is extremely heterogeneous with different surface types juxtaposed against each other, each surface has a specific energy balance between the land and the atmosphere. Definition of the surface temperature via TIR data is required to adequately quantify and model surface energy flux interrelationships. In turn, these energy fluxes are affected by, or affect the hydrologic and biogeochemical fluxes that are part of the overall land-atmosphere interaction. The urban landscape is comprised largely of impervious surfaces (e.g, pavement) that alter surface energy, hydrologic, and biogeochemical fluxes as compared to pervious (e.g., 'natural') surfaces. Understanding the surface energy flux dynamics of impervious surfaces, therefore, is paramount in developing quantitative models of how the urban surface interacts with the lower atmosphere. The energy flux cycles of impervious surfaces impact ecosystems within and surrounding cities through altering hydrologic and biogeochemical characteristics and cycling. Inputs to modeling of energy fluxes occur at time intervals that are longer than 3 minutes; as a consequence VSWIR and TIR data collection at intervals of <3 minutes will not impact quantification and modeling of these fluxes and assessment of their impacts on the environment that surrounds urban areas.

CQ6-4 What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?

To sustain humans and the biophysical environment, it is imperative to have freshwater. Therefore, it is critical to know how much freshwater is available to support life and its status (e.g., amount of pollution affecting freshwater, potability of the water). It is also requisite to understand how climate change will potentially impact the availability and status of freshwater; whether conditions will be wetter or dryer than what are extant today as a result of climate; change. Land use change affects the availability and status of freshwater in a number of ways including how the land surface utilizes water (e.g., changes in vegetation that require more freshwater) and population pressure via increased population growth on water quantity and availability. It is expected that climate change will also affect the quantity of snow and ice available due to increased temperatures causing the melting of Arctic and Antarctic ice packs. VSWIR data are important for evaluating factors that affect freshwater status and availability (change in freshwater reservoirs or changes in the extant of freshwater that is available for use). TIR data are of utility in assessing water temperature and pollutant input into freshwater resources. Freshwater resources do not change over short time periods so collecting VSWIR and TIR data at intervals <3 minutes will not impact their use for assessing water status and availability's

5.6.3 Each Sub-question - Separated by a < 1 week

CQ6-1 How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?

Soil moisture can change over a short period of time (daily or over a few days) depending upon precipitation events (e.g., hurricane) but for most purposes, analysis and quantification of land cover characteristics, vegetation, soil moisture, temperature, and land cover composition should only be minimally impacted by VSWIR and TIR data collection of <1 week.

CQ6-2 What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?

In reality, emissivity can be affected on a short term time period by dust or pollutants which coat the surface under analysis. However, for in-depth analysis of emissivities of different surface types and for constructing spectral signatures for specific surfaces, VSWIR and TIR data collection of <1 week will not be a significant impact.

CQ6-3 How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?

Changes in the type and distribution of urban and peri-urban impervious surfaces are usually not significant at time periods of <1 week; these are longer-term dynamic processes and will not have impact on analyses of VSWIR and TIR data.

CQ6-4 What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?

Although freshwater quantity and quality can potentially change over periods of <1 week (e.g., via heavy precipitation events or point or area-wide real time pollution events), VSWIR and TIR data collection at intervals of <1 week will most likely have a minimal impact on analysis of freshwater availability.

5.6.4 Each Sub-question - Separated by a few months

CQ6-1 How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?

Acquisition of VSWIR and TIR data separated by a few months would impair the understanding of relationships between vegetation state, soil moisture, temperature and to some extent, land cover composition, which would affect analyses of heat and drought conditions as they impact the distribution of vector- and animal-borne diseases. Since key factors in determining the habitat conditions suitable to support vector- or animal-borne disease vectors can change at interval <few months (e.g., due to increase in rainfall or persistent drought), the collection of VSWIR and TIR data separated by a few months would impact the identification of the habitat area and distribution of disease vectors for decision making by public health agencies and

officials. This would be a critical deficiency in protecting public health in response to outbreaks of vector- or animal-borne diseases.

CQ6-2 What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?

Changes in emissivity that would be significant for developing quantitative spectral models and libraries for specific urban surfaces occur in most cases (except for affects of dust or pollutants blown in and over urban surfaces) over periods of >1 year. Therefore, collection of VSWIR and TIR data separated by a few months should not have dramatic consequences in the analysis of emissivities as they impact the urban heat island and associated land-atmosphere energy balance characteristics.

CQ6-3 How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?

Energy fluxes for urban and peri-urban surfaces can be altered by meteorological and environmental factors such as heavy precipitation events and associated factors (e.g., wind). Although VSWIR data is not particularly sensitive to changes of several months (because VSWIR data is primarily used for land cover analysis and classification), analysis of TIR data as it relates to energy fluxes or hydrologic processes will be impacted if data are collected at intervals greater than 1 month. Energy fluxes and hydrologic processes are dynamic and can change rapidly depending upon factors associated with seasonal to even daily influences. Consequently, impacts on ecosystem processes can be expected to vary over a several month time period.

CQ6-4 What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?

Freshwater availability can be volatile over periods greater than 1-2 months, for example as a function of extended drought. Snow and ice are particularly sensitive to changes over monthly to multi-monthly temporal extents, given potential melting as a result of climate change. Although land use change and population growth impacts on freshwater availability as derived from VSWIR data will not be overly affected by collection cycles of several months, analysis of TIR data for water temperature and point and non-point pollution observation will be impacted by data collection separated by several months because changes in these factors can occur ephemerally. Additionally, short-term meteorological events can significantly affect water quantity as a result of precipitation events (heavy storms, hurricanes).

5.6.5 Non Sun Synchronous Orbits e.g. International Space Station

An inclined orbit provides quasi-random diurnal sampling vs. sun-synchronous orbit (same time of day with measurements separated by a fixed number of days for answering the Human Health and Urbanization Questions

CQ6-1 How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?

Acquisition of VSWIR and TIR data assessment of vector- and animal-borne diseases from an asymmetrical orbit, such as on the ISS although acceptable if necessary, would not be ideal for public health decision-making. The deficiency of an asymmetrical, non-sun synchronous orbit would be inadequate revisit cycles on a multi-diurnal basis and the need for sun synchronous orbit for analysis of VSWIR data. In times of vector- or animal-borne disease outbreak, consistent revisit times over the same point on Earth are critical to evaluating the changes in factors that contribute to the habitat for disease vectors such as soil moisture and temperature. An asymmetrical orbit (i.e., ISS) would not permit repeatable TIR data collection, which is crucial input to assessing the distribution of disease habitats. A non-sun synchronous orbit combined with an asymmetrical orbit would not be useful for detecting land cover changes that could impact disease vector habitat especially over short time intervals (e.g., forest clear cutting).

CQ6-2 What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?

An asymmetrical orbit would not be overly detrimental, although not desirable, for quantification of surface emissivity or for analysis of the urban heat island effect, since changes in emissivity occur over extended time periods (e.g., >1 year). There are few urban areas of consequence that exist between 45^o North or South latitudes so an asymmetrical orbit should provide adequate coverage of the vast majority of populated places. Interludes of non-sun synchronous data collection also should not significantly impair assessment of changes in emissivity for the urban surface.

CQ6-3 How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?

The distribution of urban and peri-urban surfaces that affect local and regional energy balances occur at time periods greater >1 year. Therefore, an orbit such as the ISS's would not be an important factor over the short-term in evaluating hydrologic and biogeochemical energy fluxes from these surfaces. However, repeat cycles for VSWIR and TIR data collection on at least a monthly or bi-monthly basis are necessary. The collection of nighttime TIR data provides advantageous information for calculating diurnal variations in surface energy fluxes for impervious and peri-urban surfaces. Additionally, there may be some advantage to collecting off-nadir VSWIR and TIR data to evaluate spectral reflectance at different angles and anisotropy for quantification of bidirectional reflectance distribution from urban and peri-urban surfaces.

CQ6-4 What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?

Quasi-random sampling of VSWIR and TIR data could be a limiting factor in assessment of freshwater resources depending upon local meteorological factors, which would influence water quantity and quality. Therefore, sampling may not occur at times when data are needed to obtain real-time data on precipitation events that could influence freshwater availability and quantity. A non-sun synchronous orbit is not conducive for acquiring data on freshwater resources since the observation of freshwater distribution is primarily obtained through VSWIR instruments. Limited latitude coverage by the ISS (it does not cover anything above 45 º North or South latitudes) would definitely be a limiting factor in observing changes in polar ice packs. Off-nadir viewing is not a particular advantage for observing and quantifying freshwater resources and factors that affect freshwater resources.

5.6.6 Different Overpass Time e.g. afternoon overpass

Would a different overpass time be better suited to answering the Human Health and Urbanization Questions? This could include getting the VSWIR data at one time and the TIR data at another, e.g. morning acquisition of VSWIR and afternoon acquisition of TIR

CQ6-1 How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?

VSWIR and TIR data collection coincidently are optimal for assessing the factors that contribute to vector- and animal-borne diseases and public health decision-making. However, time of day acquisition is more critical to TIR data analysis than for VSWIR. Land surface characteristics that are observed by VSWIR data can be evaluated only through sunlit diurnal periods. Optimal quantification of surface temperatures that influence soil moisture would be obtained from afternoon data acquisition, particularly at the hottest part of the day (e.g., mid-afternoon).

CQ6-2 What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?

Derivation of surface emissivity can be derived with VSWIR and TIR data obtained at different times of the day (during sunlight), although for assessment of the urban heat island, solar noon or later is most advantageous since the UHI is driven by surface heating.

CQ6-3 How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?

Surface energy balance dynamics are critical to assessing the responses of ecosystems to changes in hydrologic and biogeochemical energy fluxes from urban and peri-urban and *pervious surfaces. Optimal VSWIR and TIR data collection (especially TIR data) should occur at relatively frequent repeat cycle (e.g., ≤16 days). Although not requisite, VSWIR and TIR data should be acquired in coincidence to adequately relate and quantify surface energy fluxes with land cover conditions and changes in land covers that affect hydrologic and biogeochemical cycling. TIR data should be collected at solar noon or later to capture energy fluxes at their maximum to best evaluate the dynamics of parameters that drive energy fluxes. Solar noon or later TIR data acquisition is also requisite for quantifying urban heat island dynamics; the UHI effect is greatest in the mid- to late afternoon. Nighttime TIR data collection at frequent repeat cycles (≤16 days) is also desired to quantify the diurnal change in energy fluxes between day and night.*

CQ6-4 What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?

VSWIR and TIR overpass times can be staggered at different times of the day, but data should be repeated on a consistent, regular basis to capture changes in freshwater resources (e.g., reservoir or lake levels). Regular revisit cycles are more critical to TIR data than to VSWIR data to observe and quantify freshwater characteristics such as surface temperature. TIR repeat cycles should be ≤16 days to adequately cover weather events that affect freshwater quantity (e.g., heavy precipitation events). Regular revisit cycles are also necessary to observe and evaluate freshwater resources and snow and ice extent with VSWIR data.

Overarching Notes

1. At < 3min separation information, VSWIR can be used to help atmospherically correct and detect clouds in TIR and vice versa.
2. At < 1 week separation may be easier to align VSWIR and TIR but this remains to tested, also need to understand impact of time of day
3. At < 1 week separation VSWIR data **cannot** be used to help atmospherically correct and detect clouds in TIR and vice versa but plant phonological changes can be used, e.g. greening
4. At > 1 year separation VSWIR cannot be used as described in 1) and 2) but can be used for long-term trending

CQ1. Coastal Ocean, and Inland Water Environments	VSWIR and TIR instruments (HyspIRI)	VSWIR and TIR separated by < 3 minutes	VSWIR and TIR separated by < 1 week	VSWIR and TIR separated by a few months
	Percent Science Accomplished [%]			
What are the feedbacks between climate and habitat structure, biogeochemical cycling, biodiversity, and ecosystem productivity of shallow aquatic habitats?	100	90	10	0
What are the ecological linkages of landscape-scale ocean-atmosphere interactions including the hydrologic cycle, aerosol production and transport, and cloud radiative forcing?	100	90	10	0
How are small-scale processes in shallow benthic habitats related to changes in functional community types (coral reefs, submerged aquatic vegetation and floating aquatic vegetation), productivity, and biogeochemical cycling including material fluxes and water quality?	100	90	10	0
How can these observations be used to guide the management and utilization of resources in the shallow aquatic environment?	100	90	10	0
What are the seasonal expressions and cycles for terrestrial and shallow aquatic ecosystems, functional groups and diagnostic species?	100	90	10	0
What is the susceptibility and likely response in the context of changes in climate, land use, and disturbance?	100	90	10	0

1. Some connection between physical and biospheric processes is lost with decorrelaton of some small-scale, dynamic features.
2. More relationships, e.g. surface temperature to chlorophyll concentration, are limited to persistent processes.
3. At > 1 week separation, all general relationships are lost.

CQ2. Wildfire, Fuel and Recovery	**VSWIR and TIR instruments (HyspIRI)**	**VSWIR and TIR separated by < 3 minutes**	**VSWIR and TIR separated by < 1 week**	**VSWIR and TIR separated by a few months**
	Percent Science Accomplished [%]			
How does the timing, temperature and frequency of fires affect long-term ecosystem health?	100	100	100	10
How does vegetation composition and fire temperature impact trace gas emissions?	100	100	100	10
How do fires in coastal biomes affect terrestrial biogeochemical fluxes into estuarine and coastal waters and what is the subsequent biological response?	100	100	100	5
What are the feedbacks between fire temperature and frequency and vegetation composition and recovery?	100	100	100	10
How does vegetation composition influence wildfire severity?	100	100	100	10
On a watershed scale, what is the relationship of vegetation cover, soil type, and slope to frequency of debris flows?	100	100	100	10
How does invasive vegetation cope with fire in comparison to native species?	100	100	100	10

1. Need VSWIR and TIR within a few weeks to relate any changes in vegetation composition to fire temperature
2. Need VSWIR and TIR data within a few weeks of the fire accurately estimate emissions
3. Need VSWIR and TIR data within a few weeks to trace fire to fluxes and response
4. Need VSWIR and TIR data in same season to tie temperature to severity
5. Need VSWIR and TIR data within a few weeks to tie cover to moisture (debris flows)

CQ3. Volcanoes and Surface Signatures	VSWIR and TIR instruments (HyspIRI)	VSWIR and TIR separated by < 3 minutes	VSWIR and TIR separated by < 1 week	VSWIR and TIR separated by a few months
	Percent Science Accomplished [%]			
What do comparisons of thermal flux and SO2 emission rates tell us about the volcanic mass fluxes and the dynamics of magma ascent?	100	100	90	70
Does pressurization of the shallow conduit produce periodic variations in SO2 flux and lava dome surface temperature patterns that may act as precursors to explosive eruptions?	100	100	100	0
Can measurements of the rate at which lava flows cool allow us to improve forecasts of lava flow hazards?	100	90	80	70
Does the temperature and composition of volcanic crater lakes change prior to eruptions?	100	100	100	0
Do changes in the health and extent of vegetation cover indicate changes in the release of heat and gas from crater regions?	100	100	100	0

1. If obtaining thermal flux from a combination of VSWIR and TIR data need near simultaneity of measurements. If have high saturation MIR band as on HyspIRI-TIR then simultaneity is not required
2. Need near simultaneity to ensure that lake color relates to a specific temperature; not true; changes in color not necessarily related to temperature
3. Need near simultaneity to be able to relate changes in temperature to changes in vegetation; again not true; it will take a while for the vegetation to respond to a change in gas/temperature

CQ4. Ecosystem Function and Diversity	**VSWIR and TIR instruments (HyspIRI)**	**VSWIR and TIR separated by < 3 minutes**	**VSWIR and TIR separated by < 1 week**	**VSWIR and TIR separated by a few months**
	Percent Science Accomplished [%]			
How can we enhance phenological & stress characterization through synergy between reflective and emitted radiation with higher frequency temporal sampling?	100	95	20	0
How is energy partitioned between latent and sensible heat fluxes as a function of different plant types and fractional cover and how does this impact hydrology?	100	95	40	0
How is physiological function affecting water and carbon exchange expressed at the ecosystem scale, especially seasonal down-regulation due to environmental stress factors?	100	95	10	0
What is the vegetation phenological response to seasonal and interannual changes in temperature and moisture due to climate change and how does this response vary at the community/species level?	100	95	40	0
What are the feedbacks between changes in canopy composition, mortality and retrieved canopy temperatures resulting from disturbances (e.g., disease, moisture deficiency, insect attack, fire, land degradation, fragmentation) in natural and managed ecosystems?	100	95	40	0
How do climate-induced temperature and moisture changes impact the distribution and spread of invasive and native species?	100	95	40	0

1. Phenology and stress are closely tied, but since phenology usually follows stress so need to examine if <1week is adequate.
2. Near simultaneity required to match fluxes to fractional cover
3. Near simultaneity required to match water-carbon exchange

4. Need data in same season to match interannual changes to phonological response
5. Need near simultaneity between composition and temperature.

CQ5. Surface Composition and Change	VSWIR and TIR instruments (HyspIRI)	VSWIR and TIR separated by < 3 minutes	VSWIR and TIR separated by < 1 week	VSWIR and TIR separated by a few months
	Percent Science Accomplished [%]			
What is the composition of the exposed terrestrial surface of the Earth?	100	100	90	80
How does the surface mineralogy and soil composition relate to the plant physiology and function on the terrestrial surface of the Earth?	100	100	90	40
How is the composition of exposed terrestrial surface responding to anthropogenic and non anthropogenic drivers (desertification, weathering, disturbance e.g. logging, mining)?	100	100	30	0
How do types and distributions of altered rocks define regional trends in hydrothermal fluid flow for magmatic arcs and tectonic basins, better define hydrothermal deposit models, and assist in the discovery of new economic deposits?	100	100	100	90
How do regional trends of minerals and shale thermal maturity within basins better define depositional models and assist in the discovery of new hydrocarbon reserves?	100	100	100	90

1. In case an event of quick change occurs in the interim period, there will be limitations in mapping the surface composition
2. Changes in the soil composition due to moisture changes will influence the vegetation as discussed in CQ4-2
3. Certain anthropogenic and non-anthropogenic drivers (e.g. flash floods, mass movement) cause rapid change in the surface composition, that require data within a week separation
4. Need data in same season to see to tie anthropogenic effects to composition
5. Some issues in combined spectral analysis due to seasonal influences

CQ6. Human Health and Urbanization	**VSWIR and TIR instruments bore-sighted (HyspIRI)**	**VSWIR and TIR separated by < 3 minutes**	**VSWIR and TIR separated by < 1 week**	**VSWIR and TIR separated by a few months**
	Percent Science Accomplished [%]			
How do land surface characteristics such as vegetation state, soil moisture, temperature, and land cover composition affect heat and drought, and vector- and animal-borne diseases?	100	100	80	25
What changes can be observed and measured in emissivity's of urban surfaces and how do emissivity's change for different cities around the world as they impact the urban heat island and associated land-atmosphere energy balance characteristics?	100	100	90	50
How does the distribution of urban and peri-urban impervious surfaces affect regional energy balance fluxes, hydrologic processes, biogeochemical fluxes, and what is the response of ecosystems to these changes?	100	100	90	25
What is the status and availability of freshwater resources including snow and ice and how is this related to climate variability, land-use, and population growth?	100	100	80	25

6.

1. 1 week separation is probably limit to tie temperature and land cover
2. Beyond 1 year surfaces will have changed

6 References

GEO 2007. GEO Inland and nearshore coastal water quality remote sensing workshop. Switzerland.http://www.earthobservations.org/meeting/20070327_29_water_quality_workshop_report.pdf.

HyspIRI Group (2009) NASA 2008 HyspIRI Whitepaper and Workshop Report. JPL Publication 09-19. Jet Propulsion Laboratory, Pasadena CA.

NRC, (2007) Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond. Committee on Earth Science and Applications from Space: A Community Assessment and Strategy for the Future. National Academies Press. Referred to as the Decadal Survey or NRC 2007, 456pp.

UNIS (2004) UN report says world urban population of 3 billion today expected to reach 5 billion by 2030. URL: http://www.unis.unvienna.org/unis/pressrels/2004/pop899.html, United Nations Inforamtion Service, Vienna Austria.

Wright R, Garbeil H, Harris A (2008). Using infrared satellite data to drive a thermo-rheological/stochastic lava flow emplacement model: a method for near-real-time volcanic hazard assessment. GRL 35:L19307. doi:10.1029/2008GL035228.

REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

The public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.
PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
24-07-2014		

4. TITLE AND SUBTITLE	**5a. CONTRACT NUMBER**
The Hyperspectral Infrared Imager (HyspIRI) – Science Impact of Deploying Instruments on Separate Platforms	NAS7-03001
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	**5d. PROJECT NUMBER**
HyspIRI Group, Simon Hook	103932
	5e. TASK NUMBER
	H08.1
	5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	**8. PERFORMING ORGANIZATION REPORT NUMBER**
Jet Propulsion Laboratory California Institute of Technology 4800 Oak Grove Drive Pasadena, CA 91009	JPL Publication 14-13
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	**10. SPONSORING/MONITOR'S ACRONYM(S)**
National Aeronautics and Space Administration Washington, DC 20546-0001	**11. SPONSORING/MONITORING REPORT NUMBER**

12. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified—Unlimited

Subject Category

Availability: NASA CASI (301) 621-0390 Distribution: Nonstandard

13. SUPPLEMENTARY NOTES

14. ABSTRACT

The Hyperspectral Infrared Imager (HyspIRI) mission was 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. The HyspIRI mission is science driven and will address a set of science questions identified by the Decadal Survey and broader science community. The mission includes a visible shortwave infrared (VSWIR) imaging spectrometer, a multispectral thermal infrared (TIR) imager and an intelligent payload module (IPM). The IPM enables on-board processing and direct broadcast for those applications with short latency requirements. The science questions are organized as VSWIR-only, TIR-only and Combined science questions, the latter requiring data from both instruments. In order to prepare for the mission NASA is undertaking pre-phase A studies to determine the optimum mission implementation, in particular, cost and risk reduction activities. Each year the HyspIRI project is provided with feedback from NASA Headquarters on the pre-phase A activities in the form of a guidance letter which outlines the work that should be undertaken the subsequent year. The 2013 guidance letter included a recommendation to undertake a study to determine the science impact of deploying the instruments from separate spacecraft in sun synchronous orbits with various time separations and deploying both instruments on the International Space Station (ISS). This report summarizes the results from that study. The approach taken was to evaluate the impact on the combined science questions of time separations between the VSWIR and TIR data of <3 minutes, <1 week and a few months as well as deploying both instruments on the ISS. Note the impact was only evaluated for the combined science questions which require data from both instruments (VSWIR and TIR). The study concluded the impact of a separation of <3 minutes was minimal, e.g. if the instruments were on separate platforms that followed each other in a train. The impact of a separation of <1 week was strongly dependent on the question that was being addressed with no impact for some questions and a severe impact for others. The impact of a time separation of several months was severe and in many cases it was no longer possible to answer the sub-question. The impact of deploying the instruments on the ISS which is in a precessive (non-sun synchronous) orbit was also very question dependent, in some cases it was possible to go beyond the original question, e.g. to examine the impact of the diurnal cycle, whereas in other cases the question could not be addressed for example if the question required observations from the polar regions. As part of the study, the participants were asked to estimate, as a percentage, how completely a given sub-question could be answered with 100% indicating the question could be completely answered. These estimations should be treated with caution but nonetheless can be useful in assessing the impact. Averaging the estimates for each of the combined questions the results indicate that 97% of the questions could be answered with a separation of < 3 minutes. With a separation of < 1 week, 67% of the questions could be answered and with a separation of several months only 21% of the questions could be answered.

15. SUBJECT TERMS
HyspIRI, VSWIR, TIR, Hyperspectral Infrared Imager, Decadal Survey, ISS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			STI Help Desk at help@sti.nasa.gov
U	U	U	UU	80	19b. TELEPHONE NUMBER (Include area code) (301) 621-0390

JPL 2659 R 10 / 03 W

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39-18

NASA Supplementary Instructions To Complete SF 298 (Rev. 8-98 version)

NASA uses this inter-governmental form that does not allow customization. Look for special notes (NOTE) if NASA's procedures differ slightly from other agencies.

Block 1 NOTE: NASA uses month and year (February 2003) on the covers and title pages of its documents. However, this OMB form is coded for block 1 to accept data in the following format: day, month, and year (ex.: day (23), month (02), year (2003) or 23-02-2003, which means February 23, 2003. For this block, use the actual date of publication (on the cover and title page) and add 01 for the day. Example is March 2003 on the cover and title page, and 01-03-03 for block 1.

Block 2: Technical Paper, Technical Memorandum, etc.

Block 3: Optional for NASA

Block 4: Insert title and subtitle (if applicable)

Block 5a: Complete if have the information

b: Complete if have the information

c: Optional for NASA

d: Optional for NASA; if have a cooperative agreement number, insert it here

e: Optional for NASA

f: Required. Use funding number (WU, RTOP, or UPN)

Block 6: Complete (ex.: Smith, John J. and Brown, William R.)

Block 7: NASA Center (ex.: NASA Langley Research Center)
City, State, Zip code (ex.: Hampton, Virginia 23681-2199)
You can also enter contractor's or grantee's organization name here, below your NASA center, if they are the performing organization for your center

Block 8: Center tracking number (ex.: L-17689)

Block 9: National Aeronautics and Space Administration
Washington, DC 20546-0001

Block 10: NASA

Block 11: ex.: NASA/TM-2003-123456

Block 12: ex.:
Unclassified – Unlimited
Subject Category http://www.sti.nasa.gov/sscg/subcat.html

	Availability: NASA CASI (301) 621-0390
	Distribution: (Standard or Nonstandard)
Block 13:	If restricted/limited, also put restriction/limitation on cover and title page (ex.: Smith and Brown, Langley Research Center. An electronic version can be found at http:// ________________________ , etc.)
Block 14:	Self-explanatory
Block 15:	Use terms from the NASA Thesaurus http://www.sti.nasa.gov/thesfrm1.htm, Subject Division and Categories Fact Sheet http://www.sti.nasa.gov/subjcat.pdf, or Machine-Aided Indexing tool http://www.sti.nasa.gov/nasaonly/webmai/
Block 16a,b,c:	Complete all three
Block 17:	UU (unclassified/unlimited) or SAR (same as report)
Block 18:	Self-explanatory
Block 19a:	STI Help Desk at email: help@sti.nasa.gov
Block 19b:	STI Help Desk at: (301) 621-0390