Science and Application Targets Addressed with the 2007 Decadal Survey HyspIRI Mission Current Baseline

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Description: New and important science and application targets, in this time of rapid environmental change, that are addressed with the evolved 2007 Decadal Survey HyspIRI mission concept with combined global 16 day revisit imaging spectroscopy and 4 day revisit thermal multispectral measurements.

Themes: I. Global Hydrological Cycles and Water Resources; II. Weather and Air Quality; III. Marine and Terrestrial Ecosystems and Natural Resource Management; IV. Climate Variability and Change; and V. Earth Surface and Interior: Dynamics and Hazards.

Section 1. Science and Application targets.

The Hyperspectral Infrared Imager (HyspIRI) is one of the mission concepts with global Earth coverage recommended in the 2007 Decadal Survey (NRC 2007):

"Ecosystems respond to changes in land management and climate through altered nutrient and water status in vegetation and changes in species composition. A capability to detect such changes provides possibilities for early warning of detrimental ecosystem changes, such as drought, reduced habitats of disease vectors, and changes in the health and extent of coral reefs. Through timely, spatially explicit information, the observing capability can provide input into decisions about management of agriculture and other ecosystems to mitigate negative effects. The observations would also underpin improved scientific understanding of ecosystem responses to climate change and management, which ultimately supports modeling and forecasting capabilities for ecosystems. Those, in turn, feed back into the understanding, prediction, and mitigation of factors that drive climate change. Volcanos are a growing hazard to large populations. Key to an ability to make sensible decisions about preparation and evacuation is detection of the volcanic unrest that may precede eruptions, which is marked by noticeable changes in the visible and IR centered on craters. Assessment of soil type is an important component of predicting susceptibility to landslides. Remote sensing provides information critical for exploration for minerals and energy sources. In addition, such environmental problems as mine-waste drainage and unsuitability of soils for habitation, soil degradation, poorly known petroleum reservoir status, and oil-pipeline leakage in remote areas can be detected and analyzed with modern hyperspectral reflective and multispectral thermal sensors."

In addition, the NRC Landsat and Beyond report (NRC 2013) calls for solar reflected energy spectroscopic and thermal IR measurements of the HyspIRI type to support a broad set of advanced science and application targets.

Based on the recommendations of the 2007 Decadal Survey, NASA established the HyspIRI Science Study Group (SSG) in 2008. Since that time the SSG has worked to formalize the corresponding science and application objectives for the HyspIRI mission concept. The HyspIRI SSG developed a set of priority science and applications questions/targets to be addressed with the visible to shortwave infrared (VSWIR) spectroscopic, thermal infrared (TIR), and combined VSWIR-TIR measurements (Table 1).

A diverse set of HyspIRI science and application targets are given in section 4 of the overview paper (Lee et al., 2015) along with more than 100 associated journal article references. The companion papers in this special journal issue (Hochberg et al., 2015) provide additional science and application targets and case studies. Further documentation is contained in the HyspIRI Comprehensive Development Report (http://hyspiri.jpl.nasa.gov/comprehensive-development-report) (Table 2). In this RFI response, it is not feasible to provide details on the full set of science and application targets addressed by HyspIRI.

In summary, the science and application targets identified in the 2007 Decadal Survey (NRC 2007) remain unaddressed and new targets have been identified that in combination provide contributions to all of the 2017 Decadal Survey theme areas.

Section 2. Geophysical variables for achieving the science and application targets.

The questions and objectives associated with the HyspIRI science and application targets are addressed and achieved with VSWIR spectroscopic measurements and TIR emission measurements (Fig 1) for the terrestrial and coastal regions of the Earth. The details of these measurements, e.g. spectral resolution, spatial resolution, revisit etc. were outlined in the 2007 Decadal Survey and refined by the SSG. It is important to note that while a single measurement type at one wavelength may be sufficient to address a particular science question (e.g., sea surface height), the HyspIRI mission is designed to encompass the key measurement requirement suite for multiple questions spanning a range of Earth science and application theme areas, similar to other facility instruments such as the Moderate Resolution Imaging Spectroradiometer (MODIS).

VSWIR (380 to 2510 nm) spectroscopic measurements capture absorption and scattering signatures recorded through the interaction of the surface (and atmosphere) with incoming solar energy. Constituents of terrestrial vegetation expressed in this spectral range include: chlorophyll, canopy water, lignin, cellulose, nitrogen, ancillary pigments, canopy structure, etc. For the exposed terrestrial surface, a wide variety of minerals in rocks and soils have unique spectral absorption signatures tied to their composition. In coastal and inland waters, signatures tied to chlorophyll and other phytoplankton pigments provide information about functional types: conditions of emergent vegetation, chromophoric dissolved organic matter (CDOM), tripton, and suspended sediments, bottom cover and composition, floating biotic and abiotic slicks, and bathymetry. For snow and ice covered regions, the VSWIR signals are related to the snow fraction, grain size, impurities, and melting state. Information on the constituents of the atmosphere includes water vapor, cirrus clouds, aerosols, methane, and carbon dioxide. In urban and developed areas, signatures of a diversity of manufactured materials are recorded in this spectral range.

TIR (3-5 and 7.5-12 μm) multispectral measurements capture the absorption and emission of radiances from the surface and the atmosphere. Measurements in the 3-5 μm range provide information on the temperature of hot targets, such as fires and active lava flows. This region is particularly useful for measuring the fire radiative power (FRP) which can be related to the amount of vegetation consumed by a fire and the amount of carbon released. Knowledge of carbon emissions from fires is essential to balance the carbon budget and understand whether climate change is causing acceleration of fire regimes. Measurements in the 7.5 – 12 μm range can be used to derive the temperature and emissivity of the surface. Silicate minerals have their fundamental absorption features in this wavelength range and emissivity variations can be used to determine the composition of the minerals and associated rocks and soils. Other minerals such as sulfates and carbonates also have strong spectral features in this wavelength region. Temperature information is essential to unravel a variety of processes taking place on the Earth. The surface temperature measurement of plant canopies is especially relevant for ecosystem water stress and calculating evapotranspiration. The TIR spectra of important gas species, such as H_2O vapor, O_3, CH_4, and NH_3, have distinct features in the 7.5 – 12 μm range, as do the SO_2 and (silicate) ash plumes emitted from volcanoes and can be used to forecast changes in eruptive behavior. The geophysical variables retrieved with VSWIR and TIR measurements are used to achieve the HyspIRI science and application targets and themes.

Section 3. Key requirements for the measurements.

To achieve the HyspIRI science and application targets, the VSWIR measurement is specified to span the 380 to 2510 nm in ≤10 nm contiguous sampling. The spatial sampling is 30 m nadir with a Landsat type swath and 16 day revisit. Spectral cross-track and spectral instantaneous field of view (IFOV) uniformity are >95% to enable routine physically based parameter retrievals. Absolute radiometric accuracy is >95%, that is monitored with views of pseudo invariant targets on Earth along with periodic surface calibration experiments. Lunar calibration is planned to meet the calibration requirement for dark targets.

The spatial sampling of the VSWIR spectroscopy has been aligned with Landsat at 30 m with a temporal revisit of 16 days at the equator. Reference levels of the signal-to-noise ratio (SNR) are set at 700:1 at 600 nm and 500:1 at 2200 nm. Low polarization sensitivity and low scattered light with good digitization (14 bits) is required to support coastal ocean and inland water observations. The VSWIR measurement would be acquired globally over the terrestrial surface and coastal zones to a depth of ≤50 m at full spatial and spectral resolution every 16 days. Over the open ocean and over ice sheets, measurements would be averaged to a spatial resolution of ~1 km.

For HyspIRI TIR science and application targets, the measurements would continue in the family of sensors such as the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER, more info available at https://asterweb.jpl.nasa.gov/) and the Moderate Resolution Imaging Spectroradiometer (MODIS, http://modis.gsfc.nasa.gov/) (Abrams and Hook 2013) and ECOSTRESS (Lee et al. 2015). The current design for the TIR instrument includes eight spectral bands, one at 4 µm for hot targets and seven bands between 7.5 - 13 µm. Several of these bands are selected to closely match those of ASTER and MODIS. The 4-µm band design has a high saturation limit (1200 K), whereas the longer wavelength bands would saturate at 400-500 K; this configuration enables identification of hotspots from fires, volcanoes and other thermal phenomena (Realmuto et al. 2015). The radiometric accuracy and precision of the measurement is 0.5 K and 0.2 K respectively. The HyspIRI TIR measurement is specified at 60 m spatial sampling and a wide swath to provide revisit every 4 days at the equator. The revisit could be increased to every 2-days with an associated increase in data rate.

Section 4. Near Term Success and Affordability

The measurements can be achieved affordably in the decadal timeframe, due to NASA investments for the HyspIRI mission concept and other initiatives. The VSWIR builds on a history of space instruments: NIMS (Carlson et al., 1992), VIMS (Brown et al., 2004), Deep Impact (Hampton et al., 2005), CRISM (Murchie et al., 2007), EO-1 Hyperion (Ungar et al, 2003, Middleton et al., 2013), M3 (Green et al., 2011) and MISE, the imaging spectrometer now being developed for NASA's Europa mission. The high heritage TIR instrument follows in a long line of thermal infrared space instruments and especially the NASA ECOSTRESS Mission that is now in development.

The combined JPL and GSFC HyspIRI concept team has worked to provide affordable options. Key results of this decade of effort are documented in the HyspIRI Comprehensive Development Report (http://hyspiri.jpl.nasa.gov/comprehensive-development-report) (Table 2). NASA-guided engineering studies in 2014 and 2015 focused on smallsat implementations to acquire the VSWIR and TIR measurements for the HyspIRI science and application targets.

Mature affordable concepts for both were developed and are described below. These could be launched together or separately to appropriate compatible orbits. It is also possible to package the two instruments on a single spacecraft for a dedicated combined mission.

Based on these studies, a VSWIR (380 to 2510 nm @ ≤10 nm sampling imaging spectrometer instrument with a 185 km swath, 30 m spatial sampling, and 16 day revisit with high SNR and the required spectroscopic uniformity can be implemented affordably for a ≥three year mission with instrument mass (98 kg), power (112 W), and volume compatible with a Pegasus launch or rideshare (Fig 2). The key for this measurement is an optically fast spectrometer providing high SNR and a design that can accommodate the full spectral and spatial ranges (Mouroulis et al., 2016). A scalable prototype F/1.8 full VSWIR spectrometer (van Gorp et al., 2014) has been developed, aligned, and is being qualified (Fig 3).

Companion NASA directed studies have shown the path for development of a TIR with 4 day revisit that meets all the HyspIRI requirements that can be implemented affordably for a ≥three year mission with instrument mass (91 kg), power (168 W), and volume compatible with a Pegasus class launch or rideshare (Fig 4). The key for this measurement is the NASA IIP PHYTIR instrument that is now the core of the NASA EVI ECOSTRESS Mission (Fig 5 and Fig 6). The ECOSTRESS instrument will be completed in 2017 and all required technologies will be mature at TRL9 once deployed on the International Space Station in 2018.

Data rate and volume challenges have been addressed by development and testing of a lossless compression algorithm for these types of measurements (Klimesh et al., 2006, Aranki et al., 1009ab, Keymeulen et al., 2014). This algorithm is now a CCSDS standard (CCSDS 2015). With compression and the current Ka band downlink offered by KSAT and others, all terrestrial/coastal measurements can be downlinked. In addition, the HyspIRI payload will include an Intelligent Payload Module (IPM) to perform on-board generation of products for direct downlink to support science and application targets in need of real-time information. All measurements will be downlinked at the high latitude stations.

Algorithms for calibration (Green et al., 1998) and atmospheric correction (Gao et al., 1993, 2009, Thompson et al., 2014, 2016) of large diverse data sets have been benchmarked as part of the HyspIRI preparatory airborne campaign (Lee et al., 2015) as well as for the AVIRIS-NG India and Greenland campaigns and elsewhere. To enhance affordability and accelerate measurement availability, there is good potential for international partnerships.

5.0 Summary.

The pre-Phase A 2007 Decadal Survey HyspIRI mission has progressed to a mature stage of readiness, with affordable implementation options, to deliver new global terrestrial and coastal measurements to achieve a broad set of new and important science and application targets that are essential in this time of rapid environmental change.

FIGURES

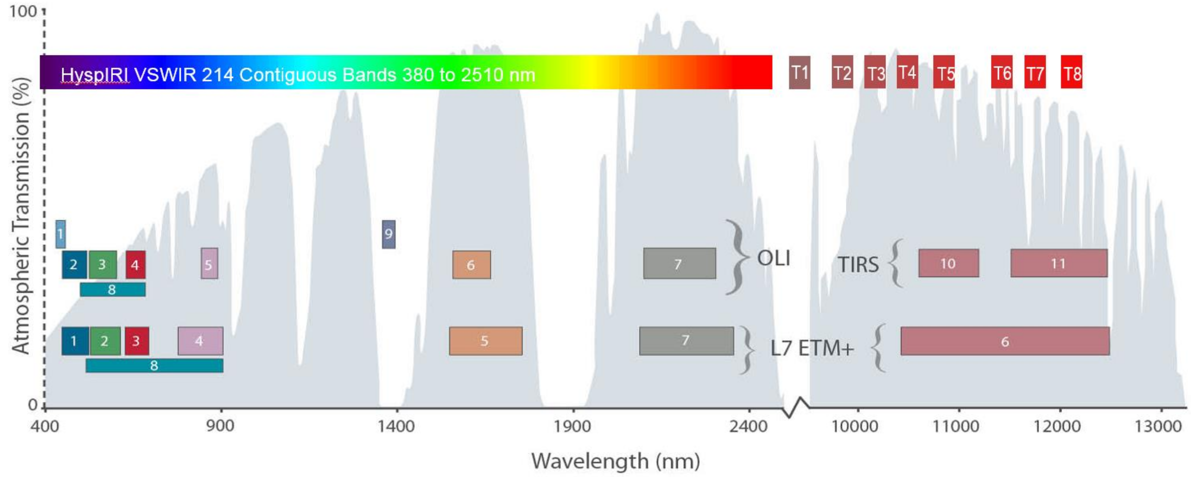

Figure 1. Measurement range of the HyspIRI 2007 Decadal Survey mission with full spectroscopy from 380 to 2510 nm and 8 thermal infrared bands from 4 to 12.5 µm. The overlap and continuity with Landsat measurements is also indicated.

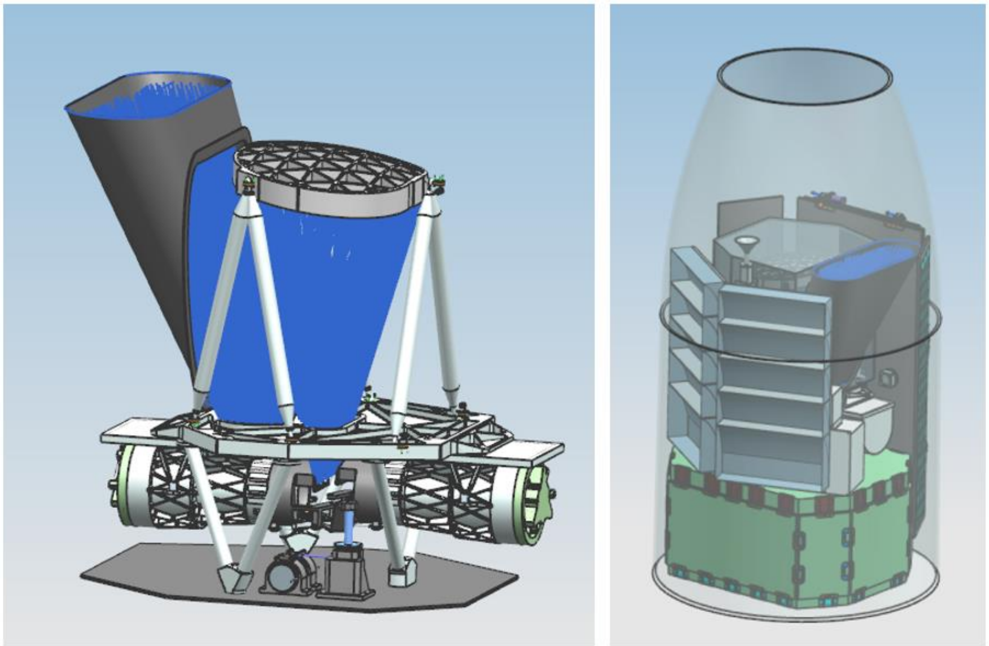

Figure 2. (left) Opto-mechanical configuration with one telescope feeding two field split wide swath F/1.8 VSWIR Dyson spectrometer providing 185 km swath and 30 m sampling. (right) Imaging spectrometer with spacecraft configured for launch in a Pegasus shroud.

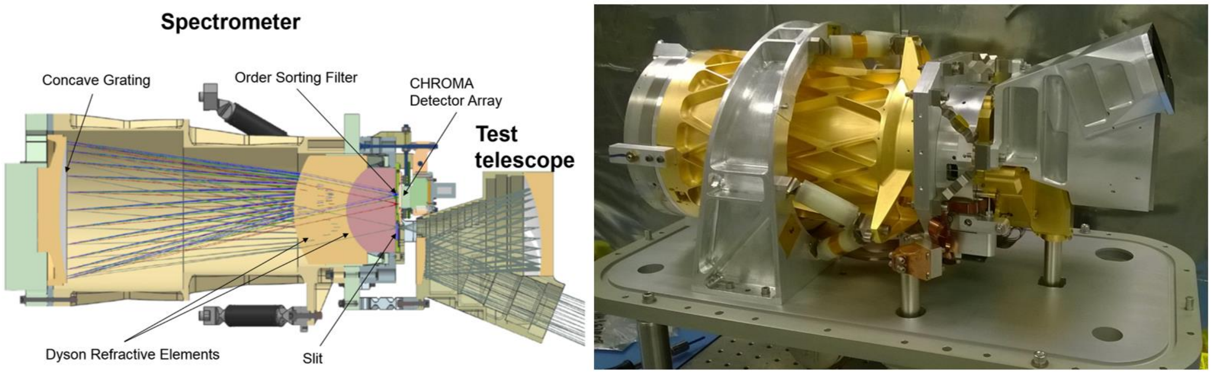

Figure 3. (left) Design of a wide swath F/1.8 VSWIR Dyson covering the spectral range from 380 to 2510. (right) Dyson imaging spectrometer in qualification that uses a full spectral range HgCdTe detector array.

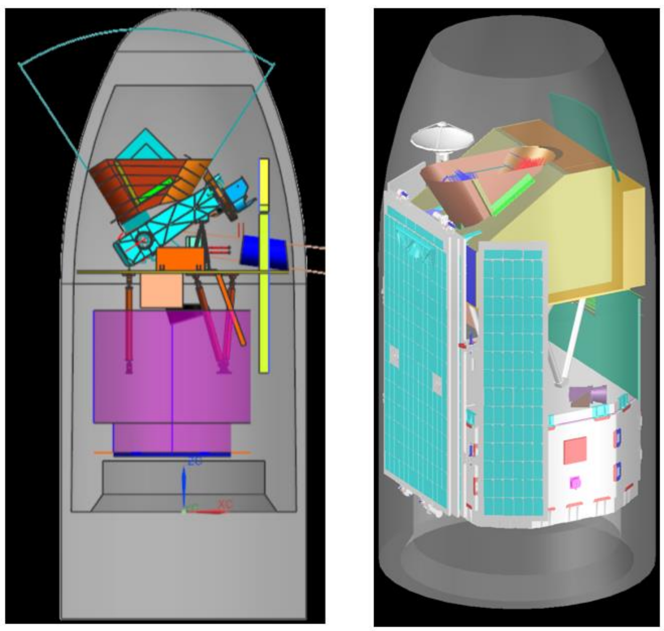

Figure 4. (left) Opto-mechanical configuration for TIR providing 4 day terrestrial surface revisit. (right) TIR with ECOSTRESS heritage configure with spacecraft configured for launch in a Pegasus shroud.

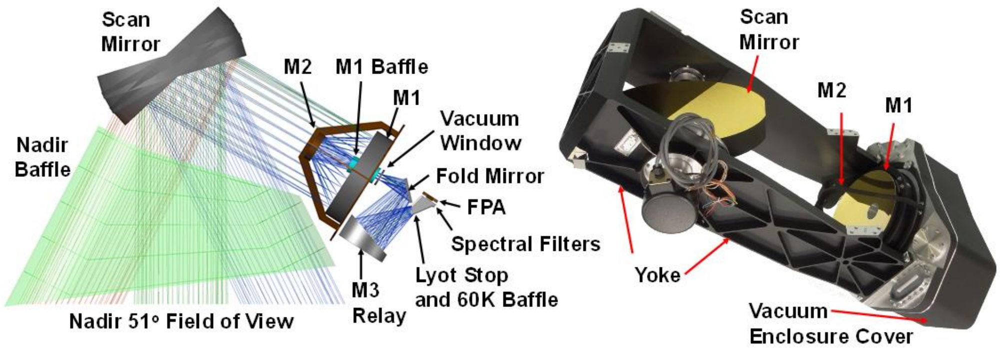

Figure 5. (left) Design of the TIR instrument. (right) Implementation of the TIR instrument for PHYTIR that is qualified and will be flown as part of NASA ECOSTRESS mission.

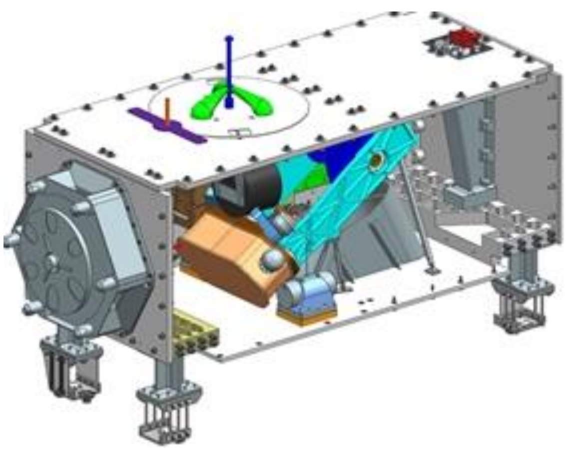

Figure 6. ECOSTRESS instrument scheduled for completion in 2017.

Tables

Table 1. Science and application targets and related questions formulated by the HyspIRI science study group.

VSWIR Measurement Questions	1) What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity?
	2) What are the seasonal expressions and cycles for terrestrial and aquatic ecosystems, functional groups, and diagnostic species? How are these being altered by changes in climate, land use, and disturbance?
	3) How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems and what are the feedbacks with other components of the Earth system?
	4) How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?
	5) How do changes in ecosystem composition and function affect human health, resource use, and resource management?
	6) What are the land surface soil/rock, snow/ice and shallow-water benthic compositions
TIR Measurement Questions	1) How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?
	2) What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?
	3) How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?
	4) How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?
	5) What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?
Combined Measurement Questions	1) How do Inland, Coastal, And Open Ocean Aquatic Ecosystems Change Due To Local and Regional Thermal Climate, Land-Use Change, And Other Factors?
	2) How are fires and vegetation composition coupled?
	3) Do volcanoes signal impending eruptions through changes in the temperature of the ground, rates of gas and aerosol emission, temperature and composition of crater lakes, or health and extent of vegetation cover?
	4) How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?
	5) What is the composition of exposed terrestrial surface of the Earth and how does it respond to anthropogenic and non-anthropogenic drivers?
	6) How do patterns of human environmental and infectious diseases respond to leading environmental changes, particularly to urban growth and change and the associated impacts of urbanization?

Table 2. Contents of the HyspIRI Comprehensive Development report that documents the science, applications research and technical effort over the past decade. http://hyspiri.jpl.nasa.gov/comprehensive-development-report

Comprehensive Report

- Comprehensive Development Report

HyspIRI Mission TRL Assessment

- Comprehensive Development Report

Appendix

Reports and Whitepapers

- Compiled Reports and Whitepapers from 2008-2014

Individual Report files

- 2014 HyspIRI Separate Platforms Whitepaper
- 2014 PHyTIR Test Results
- 2012 Workshop Report
- 2012 TIR Band Study Report
- 2011 Workshop Report
- 2011 Symposium Report
- 2011 Sun Glint Report
- 2011 High Temperature Saturation Report
- 2010 Workshop Report
- 2009 Workshop Report
- 2008 Whitepaper and Workshop Report
- TRL Assessment Report

HyspIRI Workshop Material

- 2014 Compiled Workshop
- 2013 Compiled Workshop
- 2012 Compiled Workshop
- 2011 Compiled Workshop
- 2010 Compiled Workshop
- 2009 Compiled Workshop
- 2008 Compiled Workshop

Individual Workshop files

- 2014 Workshop Agenda and Presentations
- 2013 Workshop Agenda and Presentations
- 2012 Workshop Agenda and Presentations
- 2011 Workshop Agenda and Presentations
- 2010 Workshop Agenda and Presentations
- 2009 Workshop Agenda and Presentations
- 2008 Workshop Agenda and Presentations

HyspIRI Symposium Material

- 2014 Compiled Symposium
- 2013 Compiled Symposium
- 2012 Compiled Symposium
- 2011 Compiled Symposium
- 2010 Compiled Symposium

Individual Workshop files

- 2014 Symposium Agenda and Presentations
- 2013 Symposium Agenda and Presentations
- 2012 Symposium Agenda and Presentations
- 2011 Symposium Agenda and Presentations
- 2010 Symposium Agenda and Presentations

TeamX ISS Accommodation Studies

- VSWIR ISS Study
- TIR ISS Study

2014 Small Spacecraft Vendor Presentation

Algorithm Theoretical Basis Documents (ATBDs)

- TIR Level 2 Surface Radiance
- TIR Level 2 Surface Temperature and Emissivity
- TIR Cloud Mask
- VSWIR Level 2 Water Leaving Reflectance
- VSWIR Level 2 Land Surface Reflectance

Science Application Summaries

- Disasters
- Water resources
- Health and Air Quality

Science Application White Papers

- Hyspiri Volcanoes
- Public Health

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