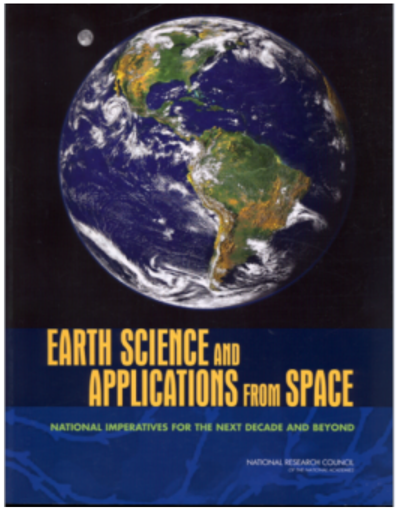
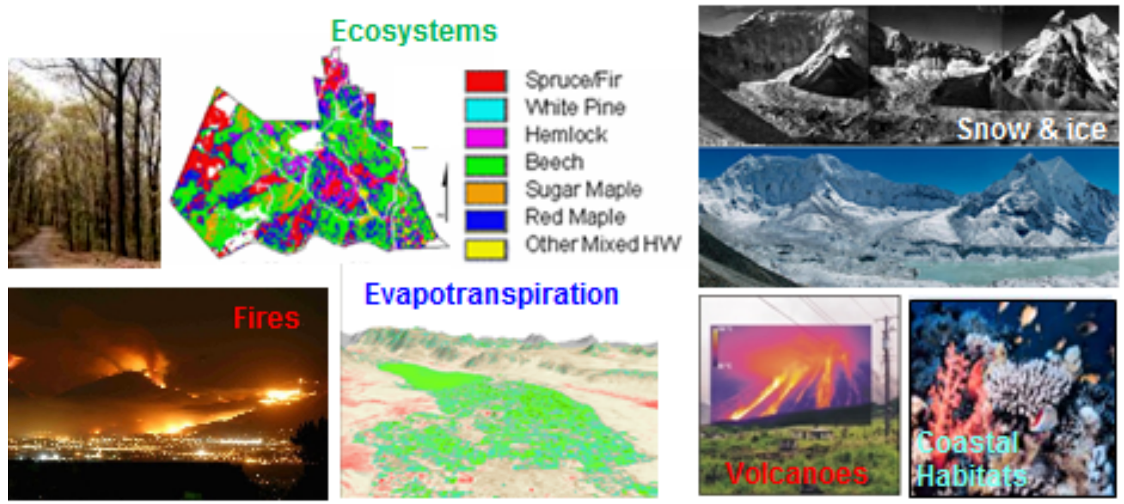




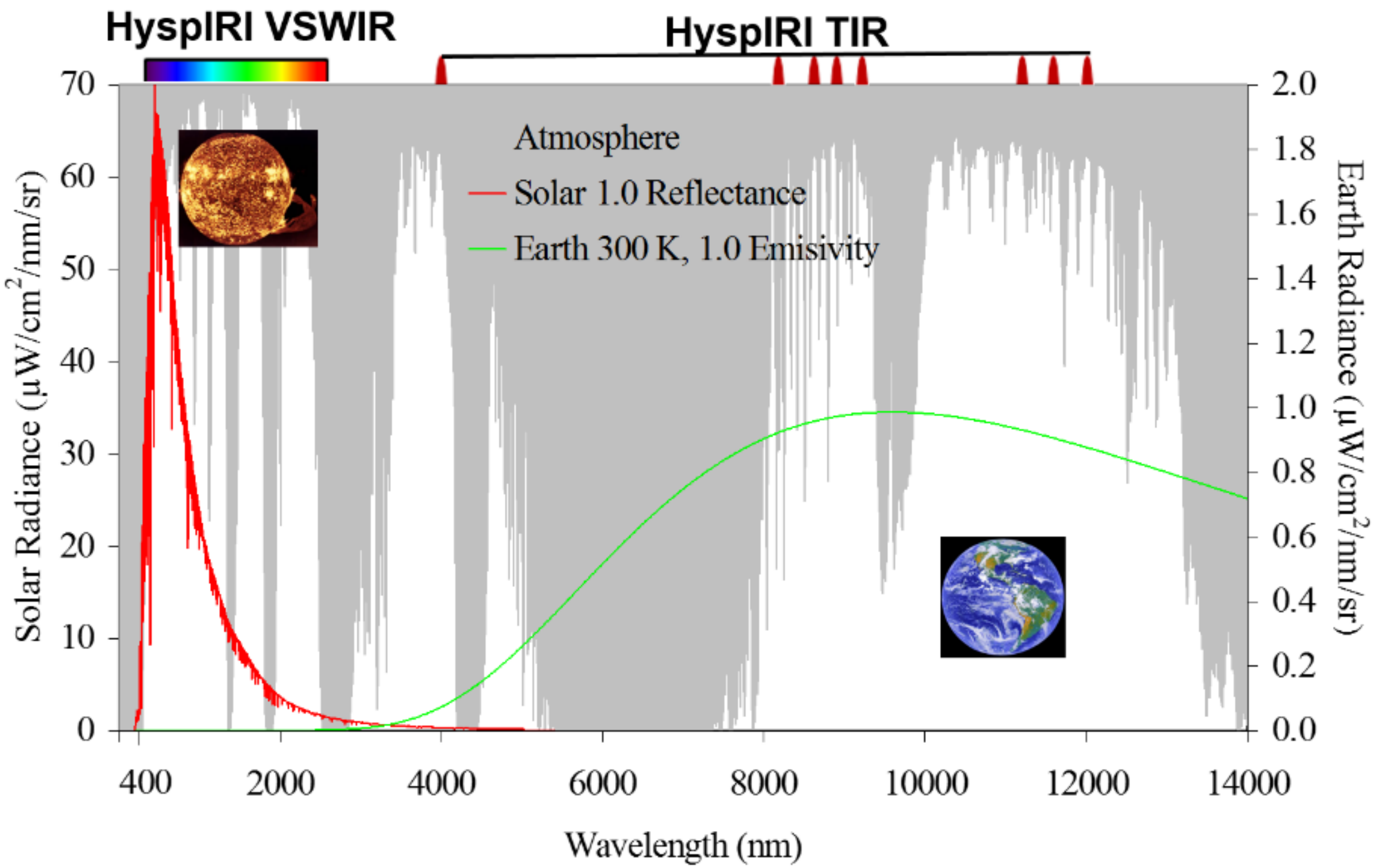
Decadal Survey Status & HyspIRI Inputs

Robert O. Green1 and The HyspIRI Community

1Jet Propulsion Laboratory, California Institute of Technology

HyspIRI Measurements

- Global terrestrial and coastal VSWIR spectroscopy at 30 m, 16 days and multispectral TIR at and 60 m, 4 days with real-time downlink of selected products.



HyspIRI Inputs to the Current Decadal Survey

- A key element of the guidance to HyspIRI this year was for the Science Study Group and Mission Concept Team to support current Decadal Survey by providing inputs based on lessons learned and understanding gained over the past 9 years.

  7. Prepare materials updating the National Research Council's 2017 Earth Science Decadal Survey effort on the status and value of a HyspIRI mission and provide the NRC with options for accomplishing the mission.

- A great deal of this information is documented on the HyspIRI website include results from the year Data Products Symposium and Science and Applications Workshop.

- The HyspIRI community have had multiple research opportunities for analysis of existing measurement and science and applications research with new measurements.

http://hyspiri.jpl.nasa.gov/

HyspIRI 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

http://hyspiri.jpl.nasa.gov/comprehensive-development-report

Data Products Symposium at GSFC

Science and Applications Workshop at Caltech

HyspIRI Article in RSE Special Issue

Remote Sensing of Environment 167 (2015) 6–19

Contents lists available at ScienceDirect

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

ELSEVIER

An introduction to the NASA Hyperspectral InfraRed Imager (HyspIRI) mission and preparatory activities

CrossMark

Christine M. Lee [a,*], Morgan L. Cable [a], Simon J. Hook [a], Robert O. Green [a], Susan L. Ustin [b], Daniel J. Mandl [c], Elizabeth M. Middleton [c]

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A R T I C L E I N F O

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A B S T R A C T

In 2007, the NASA Hyperspectral InfraRed Imager (HyspIRI) mission was recommended in *Earth Science and Applications from Space: National Imperatives for the Next Decade and Beyond* (Decadal Survey) to address critical science questions in multiple areas, in particular ecosystems and natural hazards. HyspIRI is comprised of two instruments, a visible to short-wavelength infrared (VSWIR) imaging spectrometer and a thermal infrared (TIR) multispectral imager, together with an Intelligent Payload Module (IPM) for onboard processing and rapid downlink of selected data. The VSWIR instrument will have 10 nm contiguous bands and cover the 380–2500 nm spectral range with 30 m spatial resolution and a revisit of 16 days. The TIR instrument will have 8 discrete bands in the 4–13 μm range with 60 m spatial resolution and a revisit of 5 days. With these two instruments in low Earth orbit, HyspIRI will be able to address key science and applications questions in a wide array of fields, ranging from ecosystem function and diversity to human health and urbanization.

HyspIRI Related Inputs to RFI2

Wendy	Calvin	Earth Surface Geochemistry and Mineralogy: Processes, Hazards, Soils, and Resources
Philip	Dennison	Global Measurement of Non-Photosynthetic Vegetation
Heidi	Dierssen	Assessing Transient Threats and Disasters in the Coastal Zone with Airborne Portable Sensors
Riley	Duren	Understanding anthropogenic methane and carbon dioxide point source emissions
Joshua	Fisher	Evapotranspiration: A Critical Variable Linking Ecosystem Functioning, Carbon and Climate Feedbacks, Agricultural Management, and Water Resources
Robert	Green	Science and Application Targets Addressed with the 2007 Decadal Survey HyspIRI Mission Current Baseline
Eric	Hochberg	Coral Reefs: Living on the Edge
Simon	Hook	Carbon Emissions from Biomass Burning
Luvall	Jeffrey	A Thermodynamic Paradigm For Using Satellite Based Geophysical Measurements For Public Health Applications
Natalie	Mahowald	Measuring the Earth's Surface Mineral Dust Source Composition for Radiative Forcing and Related Earth System Impacts
Frank	Muller-Karger	Monitoring Coastal and Wetland Biodiversity from Space
Thomas	Painter	Understanding the controls on cryospheric albedo, energy balance, and melting in a changing world
Ryan	Pavlick	Biodiversity
Dale	Quattrochi	High Spatial, Temporal, and Spectral Resolution Instrument for Modeling/Monitoring Land Cover, Biophysical, and Societal Changes in Urban Environments
E. Natasha	Stavros	The role of fire in the Earth System
Philip	Townsend	Global Terrestrial Ecosystem Functioning and Biogeochemical Processes
Kevin	Turpie	GLOBAL OBSERVATIONS OF COASTAL AND INLAND AQUATIC HABITATS
Robert	Wright	PREDICTING CHANGES IN THE BEHAVIOR OF ERUPTING VOLCANOES, AND REDUCING THE UNCERTAINTIES ASSOCIATED WITH THEIR IMPACT ON SOCIETY AND THE ENVIRONMENT

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

Key Global Science and Applications Research

Climate: Ecosystem biochemistry, condition & feedback; spectral albedo; carbon/dust on snow/ice; biomass burning; evapotranspiration

Ecosystems: *Global* biodiversity, plant functional types, physiological condition, and biochemistry including agricultural lands

Fires: Fuel status; fire frequency, severity, emissions, and patterns of recovery *globally*

Coral reef and coastal habitats: *Global* composition and status

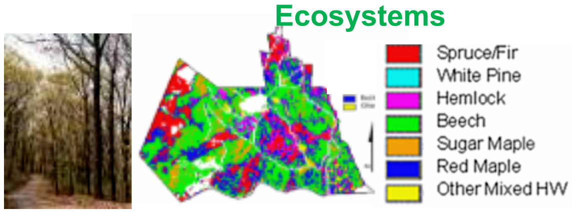
Volcanoes: Eruptions, emissions, regional and *global* impacts

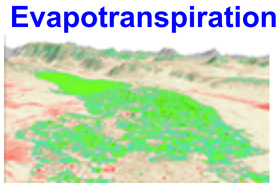
Geology and resources: *Global* distributions of surface mineral resources and improved understanding of geology and related hazards

Applications: Disasters, EcoForecasting, Health/AQ, Water

Global Mission Urgency

The HyspIRI science and applications objectives are critical today and uniquely addressed by the combined imaging spectroscopy, thermal infrared measurements, and IPM direct broadcast.





Measurement

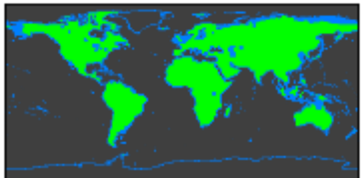
Imaging Spectrometer (VSWIR)

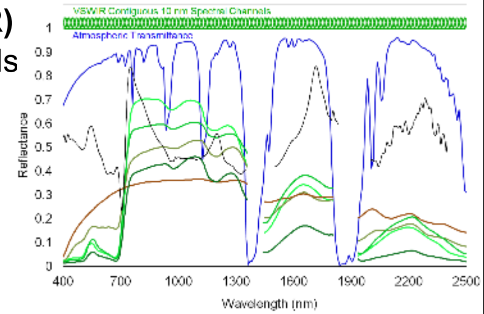
- 380 to 2500nm in ≤10nm bands
- 30 m spatial sampling
- 16 days revisit
- Global land and shallow water

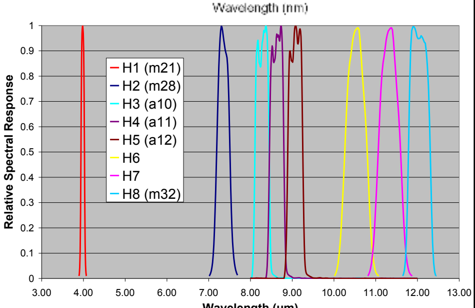
Thermal Infrared (TIR)

- 8 bands between 4-12 μm
- 60 m spatial sampling
- 5 days revisit; day/night
- Global land and shallow water

IPM-Low Latency data subsets







Mission Concept Status

Level 1 Measurement Requirements: Vetted by community at workshops and in literature (100s of refereed journal articles)

Payload: VSWIR Imaging Spectrometer, **TIR** Multi-spectral Radiometer, and **Intelligent Payload Module (IPM)**

Original 60 m DS option: Mature

ISS options: VSWIR & TIR Mature, ECOSTRESS EVI selected

Separate Smallsat Mission option: VSWIR and TIR solutions developed with TEAM I/X

SLI Compatible Option: HyspIRI VSWIR being evolved to 30 m at 185 km swath and 16 day global revisit. Requires Dyson spectrometer architecture and other technologies.

Near term option: Global with 45 km- or 90 km-swath at 30 m

Preparatory airborne campaigns: Measurements used to advance and refine science, applications, algorithms, and data processing

Monitoring Coastal and Wetland Biodiversity from Space

Geophysical Measurements for the Coastal Zone: Changes in the composition and quantity of living and non-living material in the water column and shallow communities (benthos) are directly observable, and can be studied by:

- Measuring the concentration and quality of optically-active constituents in the water column (phytoplankton, suspended and colored dissolved materials);
- Differentiating between diverse phytoplankton functional groups, detritus, and colored dissolved organic matter (CDOM);
- Separating constituents in mixed patches of land and water;
- Characterizing the composition of shallow habitats, including corals and seagrasses;
- Characterizing inundation of wetlands;
- Characterizing the impact of episodic events such as storms on aquatic habitats;
- Differentiating between events and disturbance occurring over weeks to months.
- The relationship between the health of different coastal communities, changes in land cover phenology, and water quality can be studied using remote sensing by characterizing:
- Relationships, including optical and ecological interdependencies, between wetland phenology, water quality, and nutrient and carbon fluxes;
- Spatial distribution and composition of wetland vegetation;
- Pathways of connectivity including lateral transport between habitats;
- Biodiversity by discriminating among phenology traits of organisms.
- The effect of inundation on canopy health and community zonation;
- Natural and human disturbance factors, including invasive or introduced species.

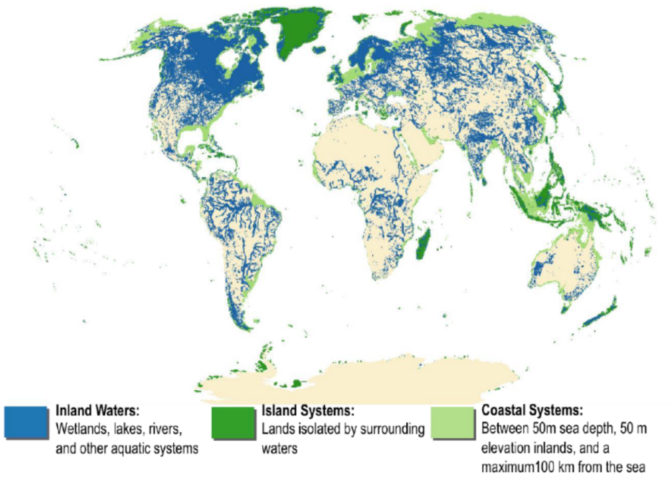
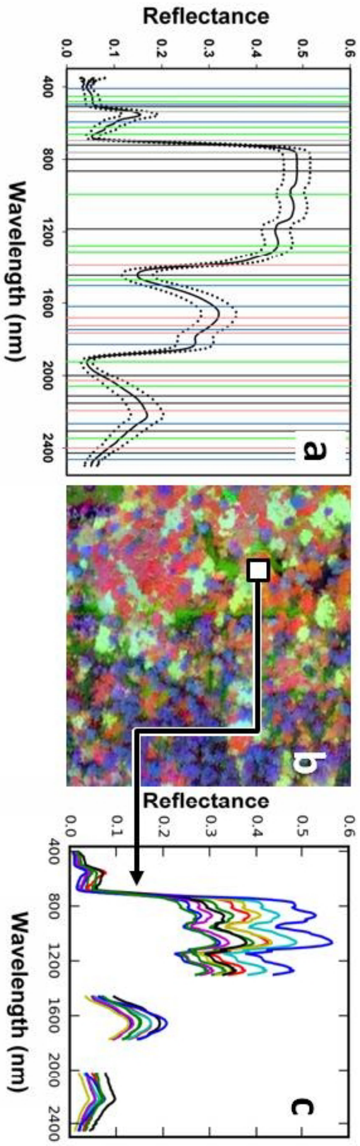


Figure 1: Global distribution of the world's boundary zones between land and water. *Data Sources: Millennium Ecosystem Assessment & FAO-UN.*

Global Terrestrial Ecosystem Functioning and Biogeochemical Processes

Functional characterization[1]	Trait	Example of functional role	Example Citations
Primary	Foliar N (% dry mass or area based)	Critical to primary metabolism (e.g., Rubisco),	Johnson et al. 1994, Gastellu-Etchegorry et al. 1995, Mirik et al. 2005, Martin et al. 2008, Gil-Perez et al. 2010, Goekkaya et al. 2015, Kalacska et al. 2015, Singh et al. 2015
	Foliar P (% dry mass)	DNA, ATP synthesis	Mirik et al. 20015, Mutangao & Kumar 2007, Gil-Perez et al. 2010, Asner et al. 2015
	Sugar (% dry mass)	Carbon source	Asner & Martin 2015
	Starch (% dry mass)	Storage compound, carbon reserve	Matson et al. 1994
	Chlorophyll-total (ng g^{-1})	Light-harvesting capability	Johnson et al. 1994, Zarco-Tejada et al. 1999, 2000a, Gil-Perez et al. 2010, Zhang et al. 2008, Kalacska et al. 2015
	Carotenoids (ng g^{-1})	Light harvesting, antioxidants	Datt 1998, Zarco-Tejada et al. 1999, 2000a
	Other pigments (e.g., anthocyanins; ng g^{-1})	Photoprotection, NPQ	van den Berg & Perkins 2005
	Water content (% fresh mass)	Plant water status	Gao & Goetz 1995, Gao 1996, Thompson et al. 2016, Asner et al. 2016
Physical	Leaf mass per area (g m^{-2})	Measure of plant resource allocation strategies	Asner et al. 2015, Singh et al. 2015
	Fiber (% dry mass)	Structure, decomposition	Mirik et al. 2005, Singh et al. 2015
	Cellulose (% dry mass)	Structure, decomposition	Gastellu-Etchegorry et al. 1995, Thulin et al. 2014, Singh et al. 2015
	Lignin (% dry mass)	Structure, decomposition	Singh et al. 2015
Metabolism	Vcmax (μmol m^{-2} s^{-1})	Rubisco-limited photosynthetic capacity	Serbin et al. 2015
	Photochemical Reflectance Index (PRI)	Indicator of non-photochemical quenching (NPQ) and photosynthetic efficiency, xanthophyll cycle	Gamon et al. 1992; Asner et al. 2004
	Fv/Fm	Photosynthetic capacity	Zarco-Tejada et al. 2000b
Secondary	Bulk phenolics (% dry mass)	Stress responses	Asner et al. 2015
	Tannins (% dry mass)	Defenses, nutrient cycling, stress responses	Asner et al. 2015



Carbon Emissions from Biomass Burning

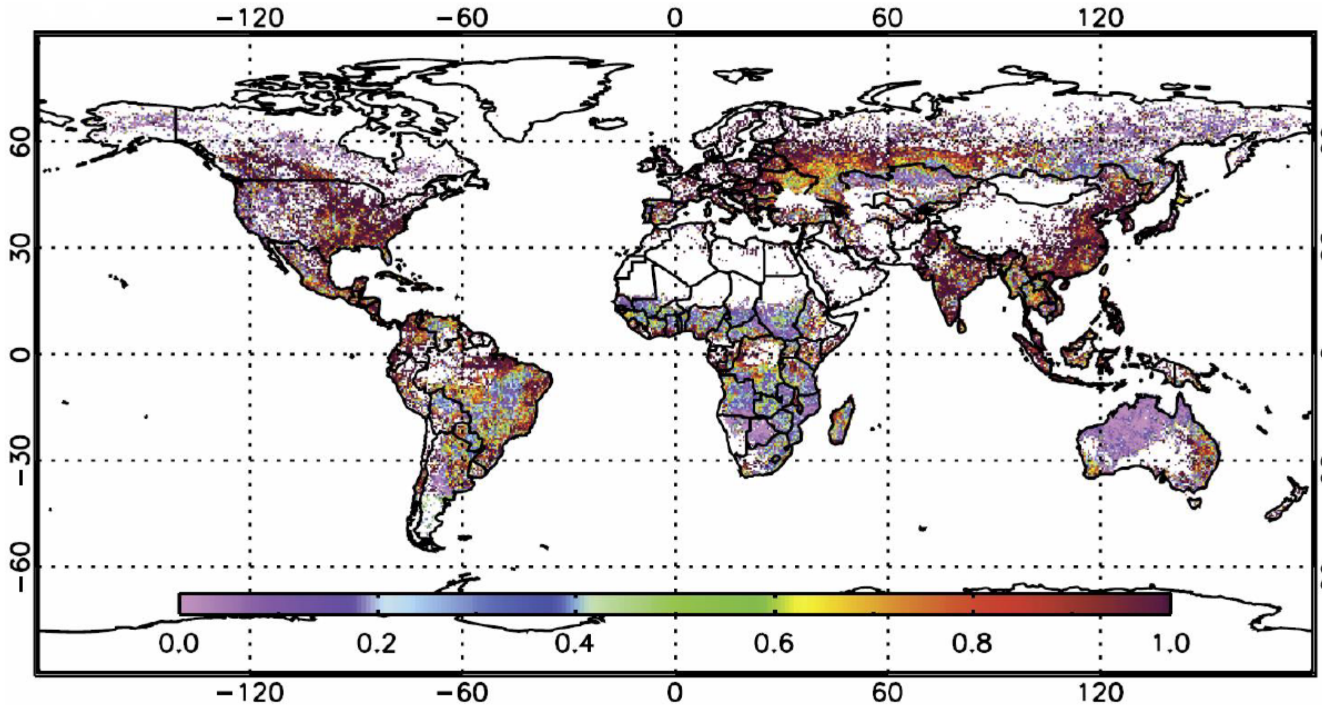


Figure 1 Small fire fraction of total burned area (Randerson et al. 2013). Red and yellows highlight areas where many smaller fires were detected.

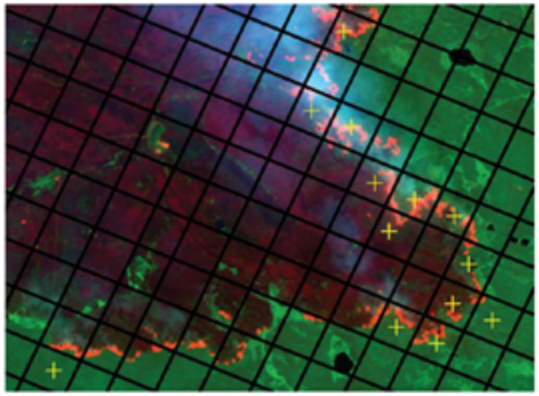


Figure 2. Simultaneous higher resolution 90-m ASTER image with black boxes overlaid corresponding to 1-km MODIS imagery. Yellow crosses represent MODIS pixels where fires were detected. Notice that many pixels where fire is clearly visible in the ASTER image remain undetected in the MODIS image.

Nature Plants 2016

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comment

Monitoring plant functional diversity from space

The world's ecosystems are losing biodiversity fast. A satellite mission designed to track changes in plant functional diversity around the globe could deepen our understanding of the pace and consequences of this change, and how to manage it.

Walter Jetz, Jeannine Cavender-Bares, Ryan Pavlick, David Schimel, Frank W. Davis, Gregory P. Asner, Robert Guralnick, Jens Kattge, Andrew M. Latimer, Paul Moorcroft, Michael E. Schaepman, Mark P. Schildhauer, Fabian D. Schneider, Franziska Schrodt, Ulrike Stahl and Susan L. Ustin

The ability to view Earth's vegetation from space is a hallmark of the Space Age. Yet decades of satellite measurements have provided relatively time that such a mission would provide has the potential to transform basic and applied science on diversity and function, and to pave the way to a more mechanistically mass to leaf area. These attributes are related functionally to the uptake, allocation and use of resources such as carbon and nutrients within the plant, and to the defence against

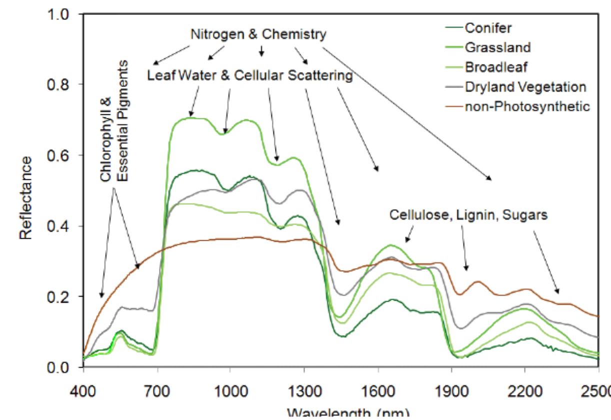
The role of fire in the Earth System

Key questions regarding the role of fire in the Earth system (Figure 1) include:

A. How does fire affect ecosystem services (e.g., clean air and water, habitat, and biodiversity) and which ecosystems are the most vulnerable to changes?
B. What is the radiative forcing of wildfire globally accounting for greenhouse gas and aerosol emissions, post-fire recovery, and changes in surface albedo?
C. How do fuel type, structure, amount, and condition influence fire?
D. How do these smoke emission influence atmospheric dynamics and health and air quality as they are globally transported?

Answering these questions will improve understanding of fire in the Earth system, and will require continued and improved coverage of observations of ecosystems pre- and post-fire. To address these questions, the following science and application targets ("objectives"):

1. Monitoring post-fire recovery using ecosystem composition and 3-D structure
2. Mapping vegetation carbon and nitrogen
3. Mapping ecosystem condition: soil moisture and vegetation productivity, moisture, stress and mortality
4. Mapping fire emissions and smoke transport



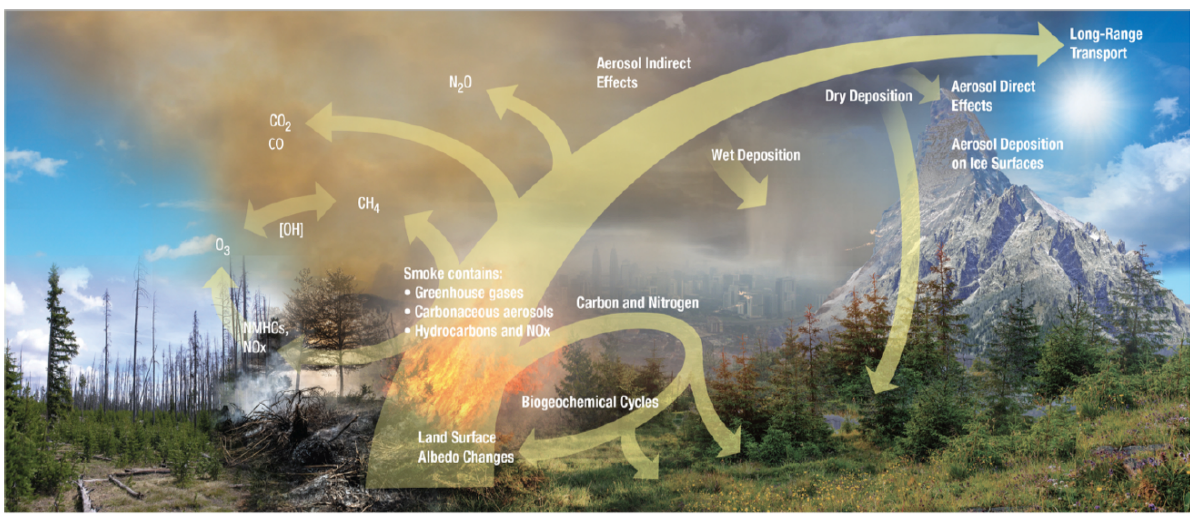
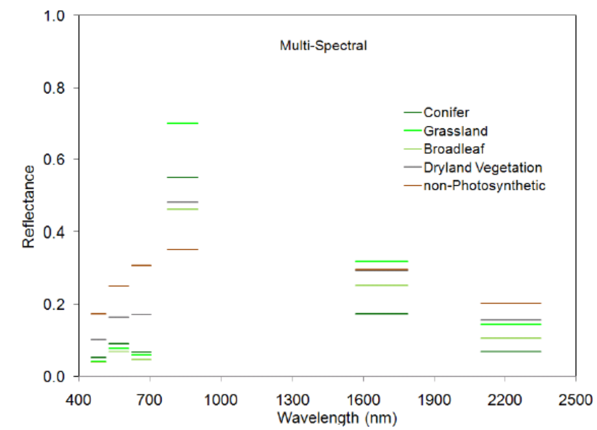


Figure 1. A schematic of the role of fire in the earth system. Figure modified from Ward et al. (2012)[33].



PREDICTING CHANGES IN THE BEHAVIOR OF ERUPTING VOLCANOES, AND REDUCING THE UNCERTAINTIES ASSOCIATED WITH THEIR IMPACT ON SOCIETY AND THE ENVIRONMENT

- Gas emissions:
- Low temperature thermal anomalies:
- The color, temperature, and size of crater lakes:
- Lava effusion rate:
- Temperature and cooling rate of active lavas:
- Spatio-temporal variations in the amount and concentration of ash in the atmosphere:
- The spatio-temporal distribution of H2SO4 aerosol:

Figure 3. SO_2 column abundance calculated from Terra ASTER data at Kilauea volcano (source: https://hyspiri.jpl.nasa.gov/downloads/2013_Workshop/day1/18_HyspIRI_VJR_2013.pdf)

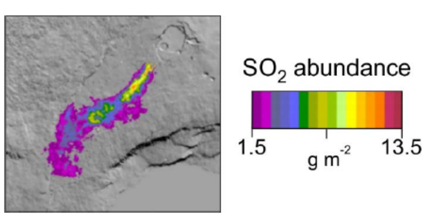


Figure 1. Distribution of Earth's active and potentially active volcanoes (source: Sigurdsson, H. (2015). *Encyclopedia of volcanoes*, 2nd edition. San Diego: Academic Press.

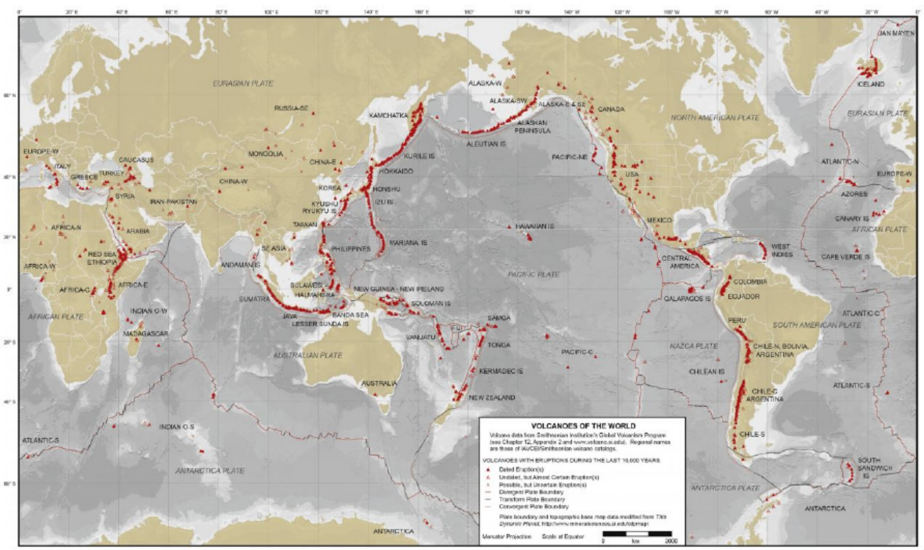
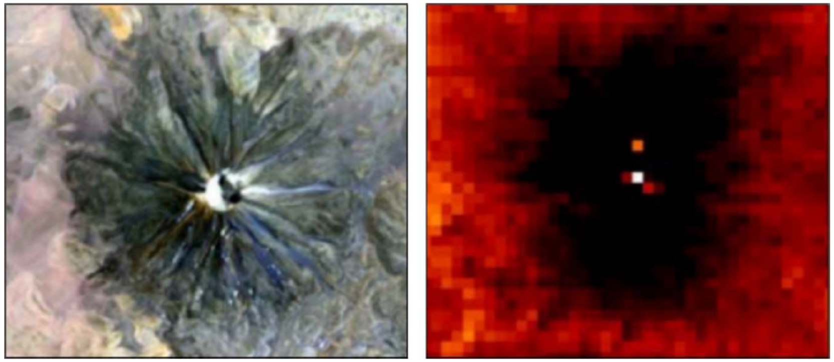


Figure 5. Left: Reflective false color composite of Chiliques Volcano, Chile, obtained by Terra ASTER. Right: thermal infrared night-time image of the same volcano showing subtle thermal anomaly at the summit (source: Pieri, D.C., and Abrams, M. (2004). ASTER watches the world's volcanoes: a new paradigm for volcanological observations from orbit. *J. Volcanol. Geotherm. Res.*, 135, 13-28).



Understanding the controls on cryospheric albedo, energy balance, and melting in a changing world

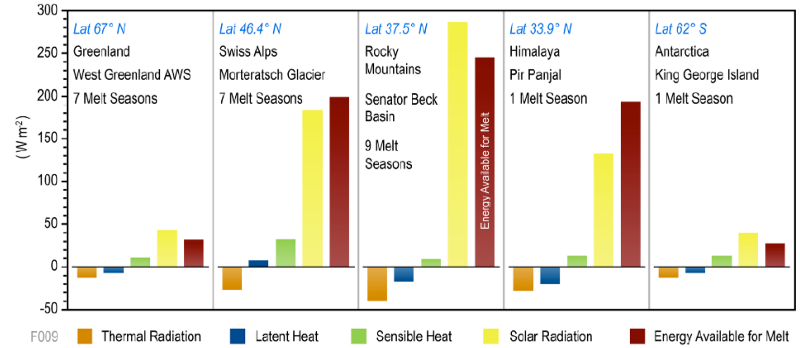


Fig. 1 Quality observations to determine snow/ice albedo changes at instrumented test sites show that the complexities of melt energy are dominated at all latitudes by absorbed sunlight.

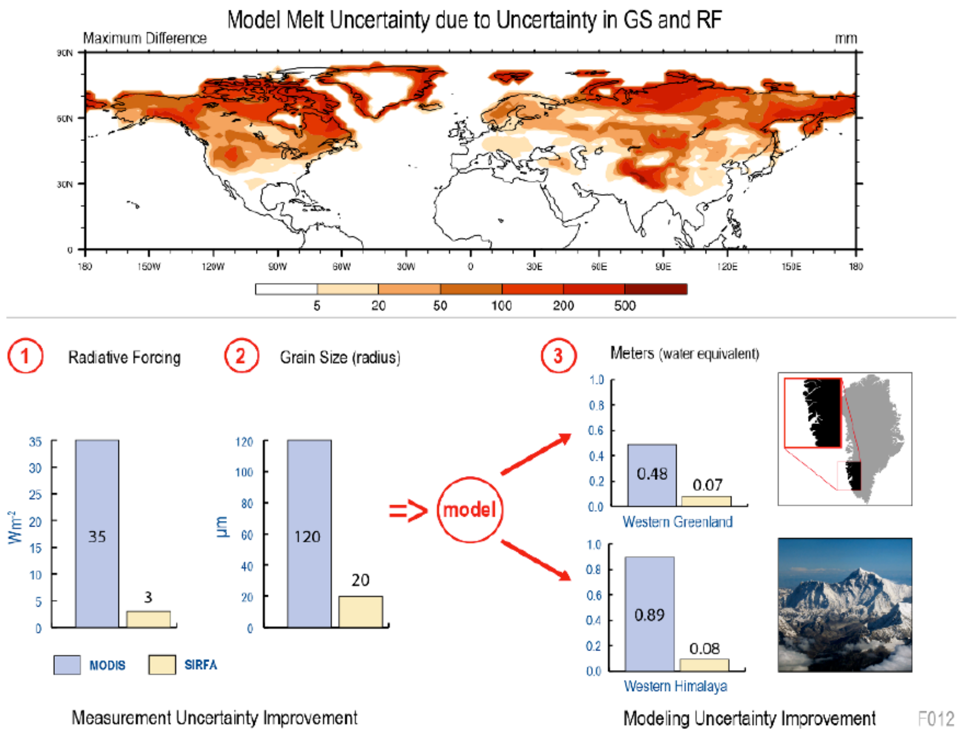


Fig. 3 CESM modeling uncertainties in impurities and grain growth result in large uncertainties in melt rates (top). SIRFA will reduce uncertainties in MODIS retrievals of (1) radiative forcing and (2) grain size leading to (3) order of magnitude reduction in modeling melt uncertainty, allowing better understanding of process importance.

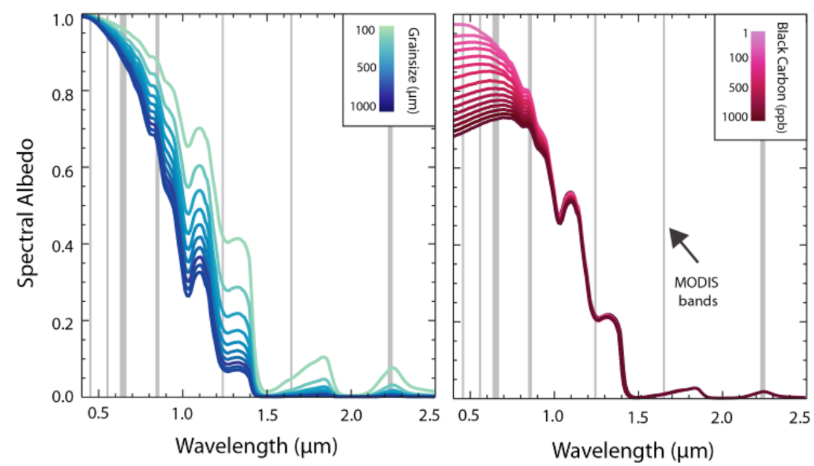
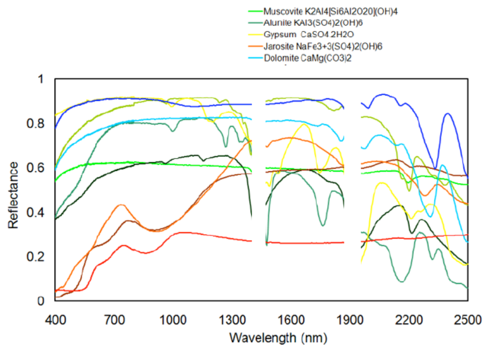


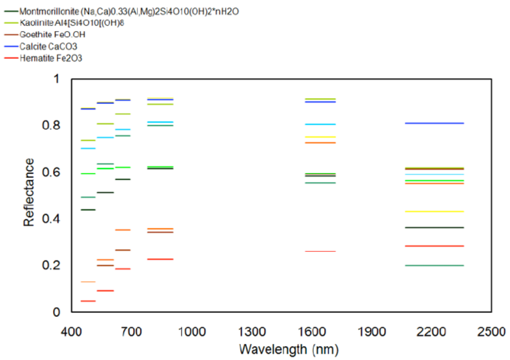
Fig. 2 These spectra show the sensitivity of albedo that requires spectroscopy for improved understanding. MODIS bands can provide qualitative retrievals, but not the accurate atmospheric correction and retrievals acquired by the spectrometer.

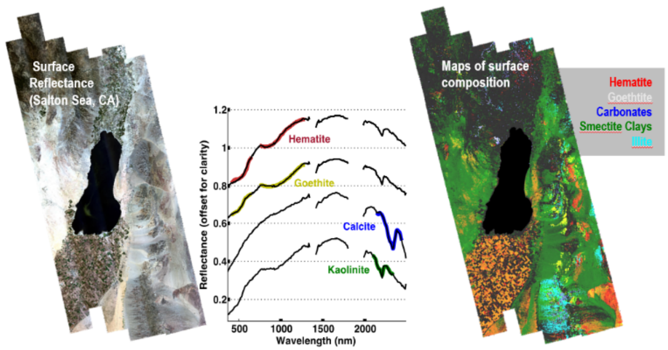
Earth Surface Geochemistry and Mineralogy: Processes, Hazards, Soils, and Resources

Science and Applicaitons Target	Objectives	Physical Parameter	Observable	Measurement Requirements	Other Measurement Characteristics
V. Earth Surface and Interior: Dynamics and Hazards: Core, mantle, lithosphere, and surface processes, system interactions, and the hazards they generate. **Earth Surface Geochemistry and Mineralogy for Geologic Processes, Hazards, Soils, and Resources**	O1. New insights and constraints on fundamental geological processes O2. Assessment and response to natural and anthropogenic hazards O3. Advance soil composition and process knowledge O4. Surface Resource Identification and Policy Support	Occurrence and fractional abundance estimate (0-1.0 with uncertainty) of minerals and geochemicals expressed at exposed surface: • Iron oxides • Sulfates • Clays • Carbonates • Amphiboles • Mafic minerals • Hydrocarbons Estimation of confounding factors: • Fractional surface cover for green and non-photosynthetic vegetation • Water vapor, cirrus clouds, and aerosols	Spectral reflectance of the exposed surface from atmospherically corrected top of atmosphere spectral radiance	Spectral • 450 to 2450 nm range • ≤ 10 nm sampling • ≤ 15 nm FWHM • ≤ 1 nm calibraiton uncertainty Radiometric • 0 to max Lambert range • 99% linear of 5 to 95 % of range • SNR see figures 5, 6 • ≤ 5% calibraiton uncertainty Spatial • ≥ 90 km swath • ≤ 30 m sampling • ≤ 30 m 16 uncertainty Uniformity • ≤10% cross-track spectral variation • ≤10% spectral IFOV variation	Sun synchronous ~11am crossing for good illumination and prior to cloud build up. Cloud free measurement for ≥ 80% terrestrial exposed surface. At least two years of measurement for capture of seasonal low vegetation states and fallow agricultural fields. Pointable for 3 day revisit for event response.

Table 1. The detailed traceability from science and applications targets to physical parameters, to observables, and to measurement requirements has been enabled by over a decade of imaging spectroscopy observations of the Earth, the Moon, Mars and other bodies in the Solar System.

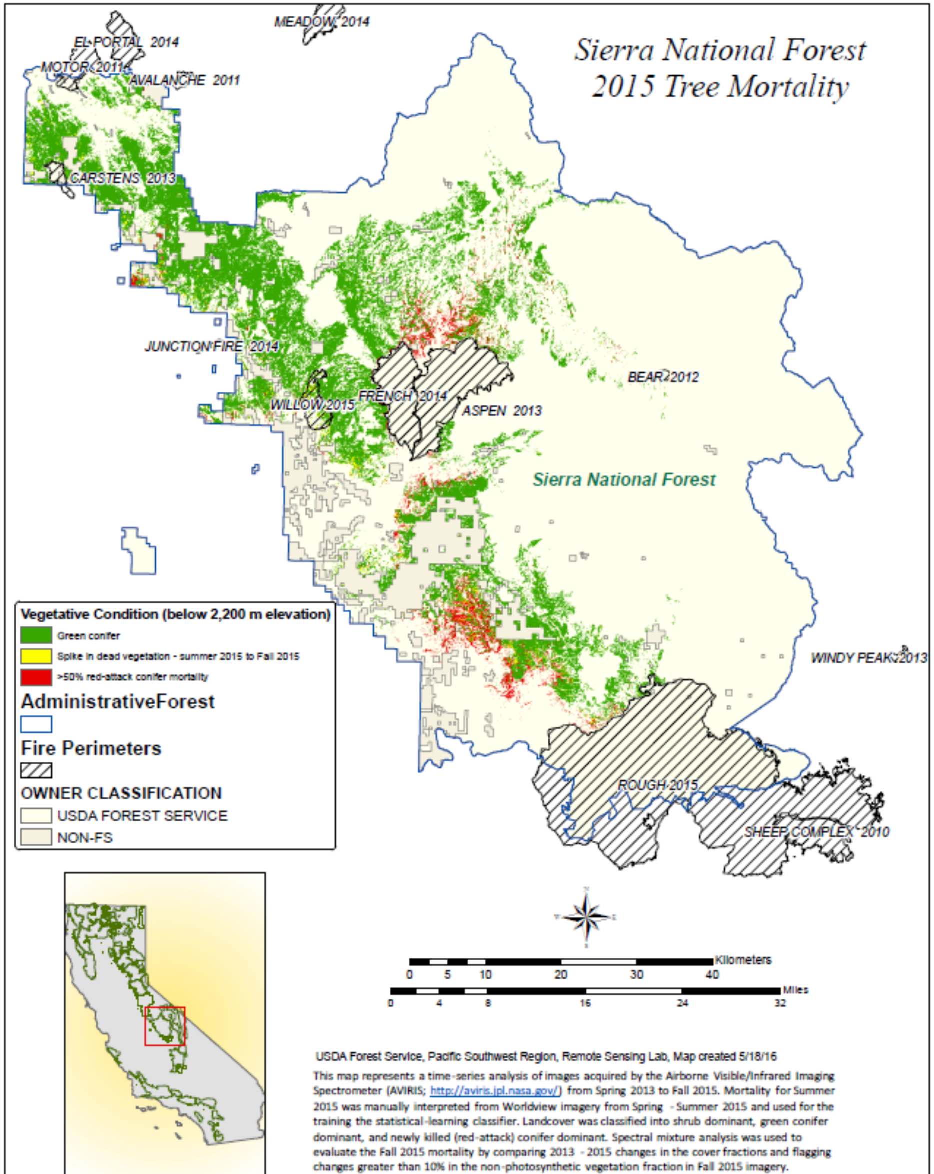






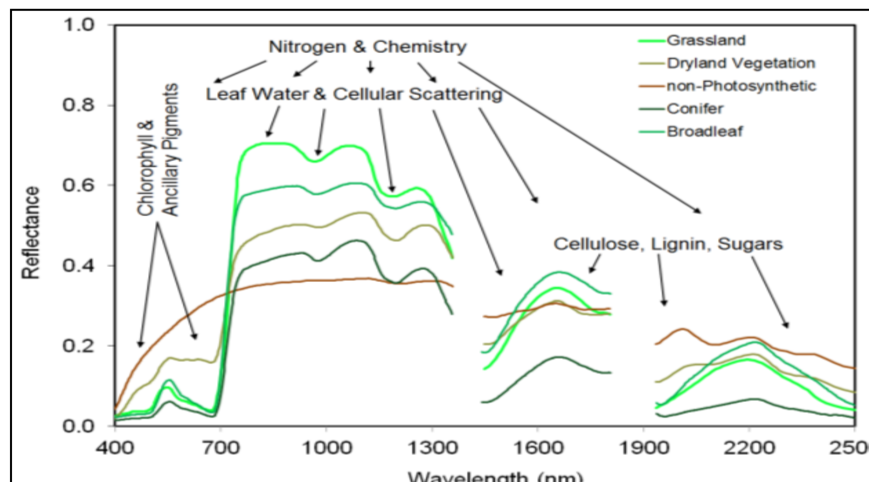
Global Measurement of Non-Photosynthetic Vegetation

Recent Applications Result from HyspIRI Airborne Campaign



USDA Forest Service, Pacific Southwest Region, Remote Sensing Lab, Map created 5/18/16

This map represents a time-series analysis of images acquired by the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS; http://aviris.jpl.nasa.gov/) from Spring 2013 to Fall 2015. Mortality for Summer 2015 was manually interpreted from Worldview imagery from Spring - Summer 2015 and used for the training the statistical-learning classifier. Landcover was classified into shrub dominant, green conifer dominant, and newly killed (red-attack) conifer dominant. Spectral mixture analysis was used to evaluate the Fall 2015 mortality by comparing 2013 - 2015 changes in the cover fractions and flagging changes greater than 10% in the non-photosynthetic vegetation fraction in Fall 2015 imagery.



Measuring the Earth's Surface Mineral Dust Source Composition for Radiative Forcing and Related Earth System Impacts

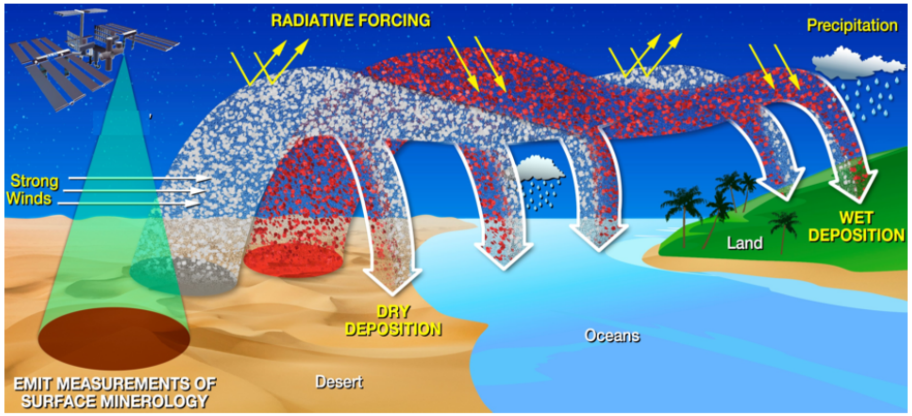
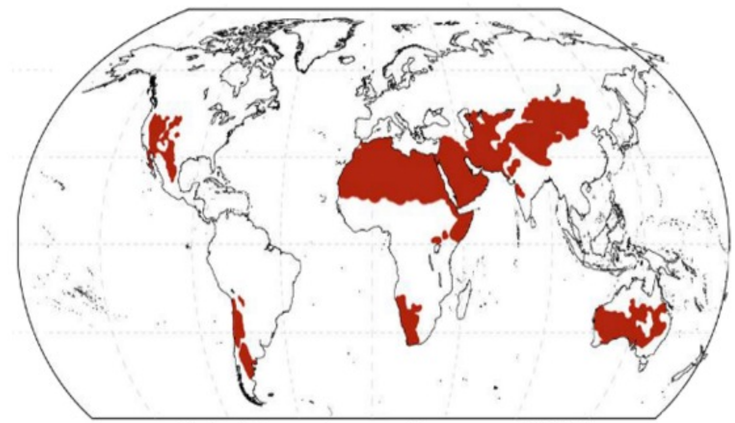
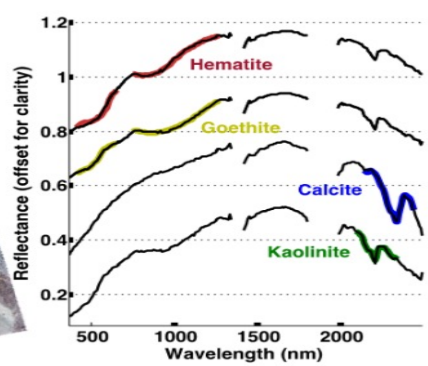
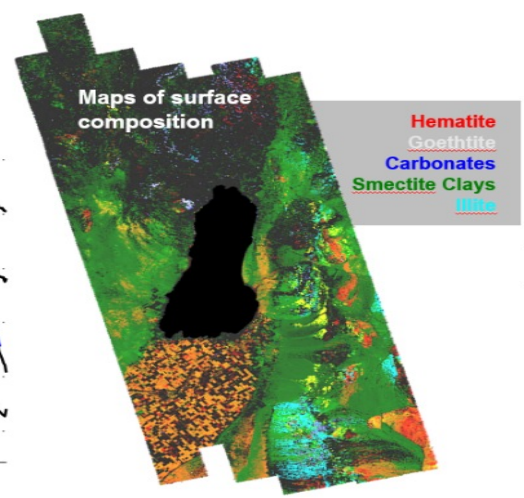


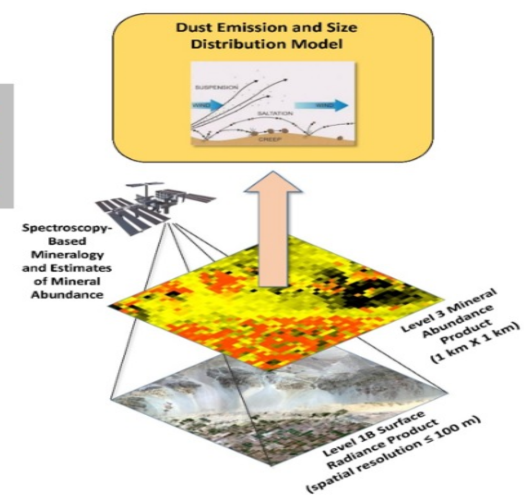
Figure 1. Modeling the role of mineral dust in RF requires consideration of the generation, emission, radiative properties, and deposition of dust particles. The composition of dust aeros can be traced back to the source region on the surface. Dust particles can reflect (white) or absorb (red) solar radiation, based on the composition of the particles. In addition to direct radiative forcing, mineral dust impacts the Earth system by modifying cloud properties, enhancing snow/ice melt, changing precipitation patterns, modifying atmospheric composition, supplying nutrients to terrestrial and aquatic ecosystems as well as direct societal impacts to air quality, visibility, and respiratory health.



Global Dust Source Regions (WMO)

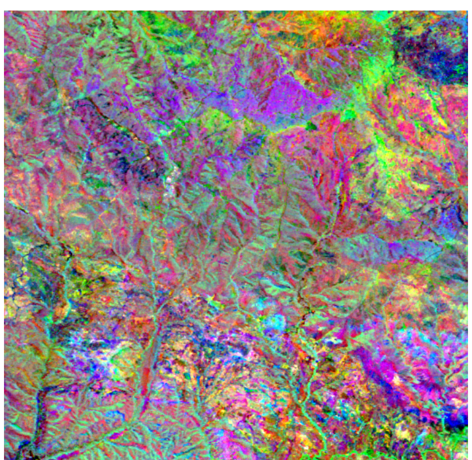






Dimensionality of the Earth System Captured with Imaging Spectroscopy

NASA HyspIRI Preparatory Campaign

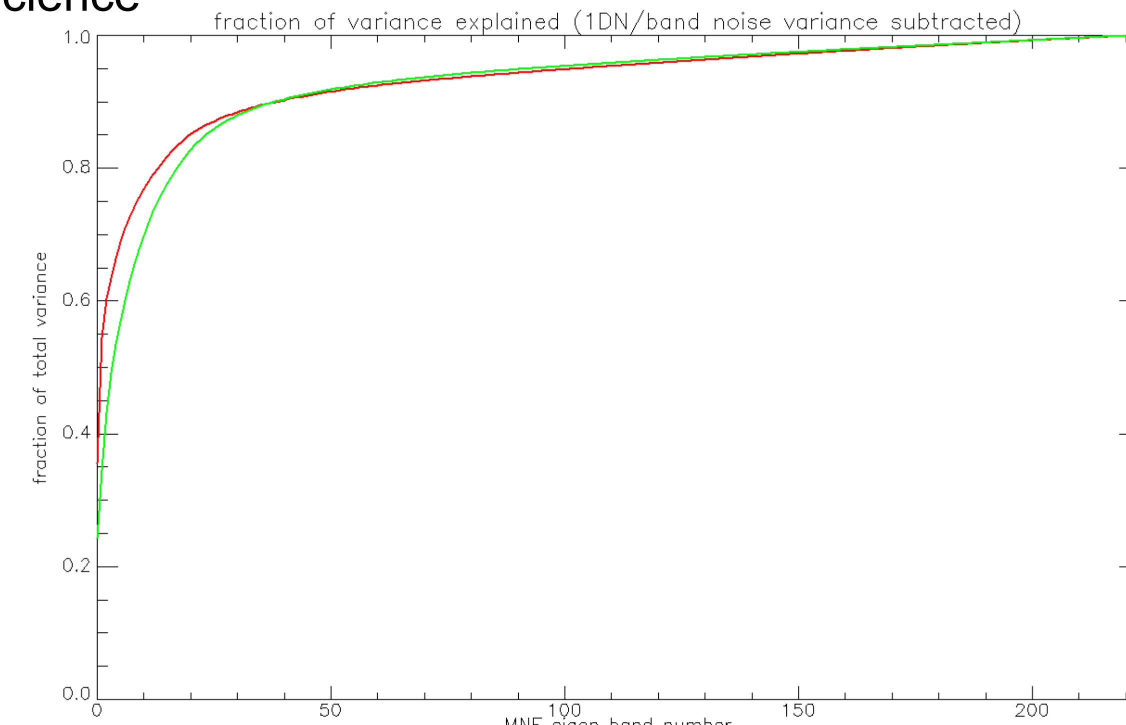


AVIRIS Flight line from Mono Lake to Santa Barbara, CA

A single HyspIRI airborne campaign flight line has 50 content rich eigen images.

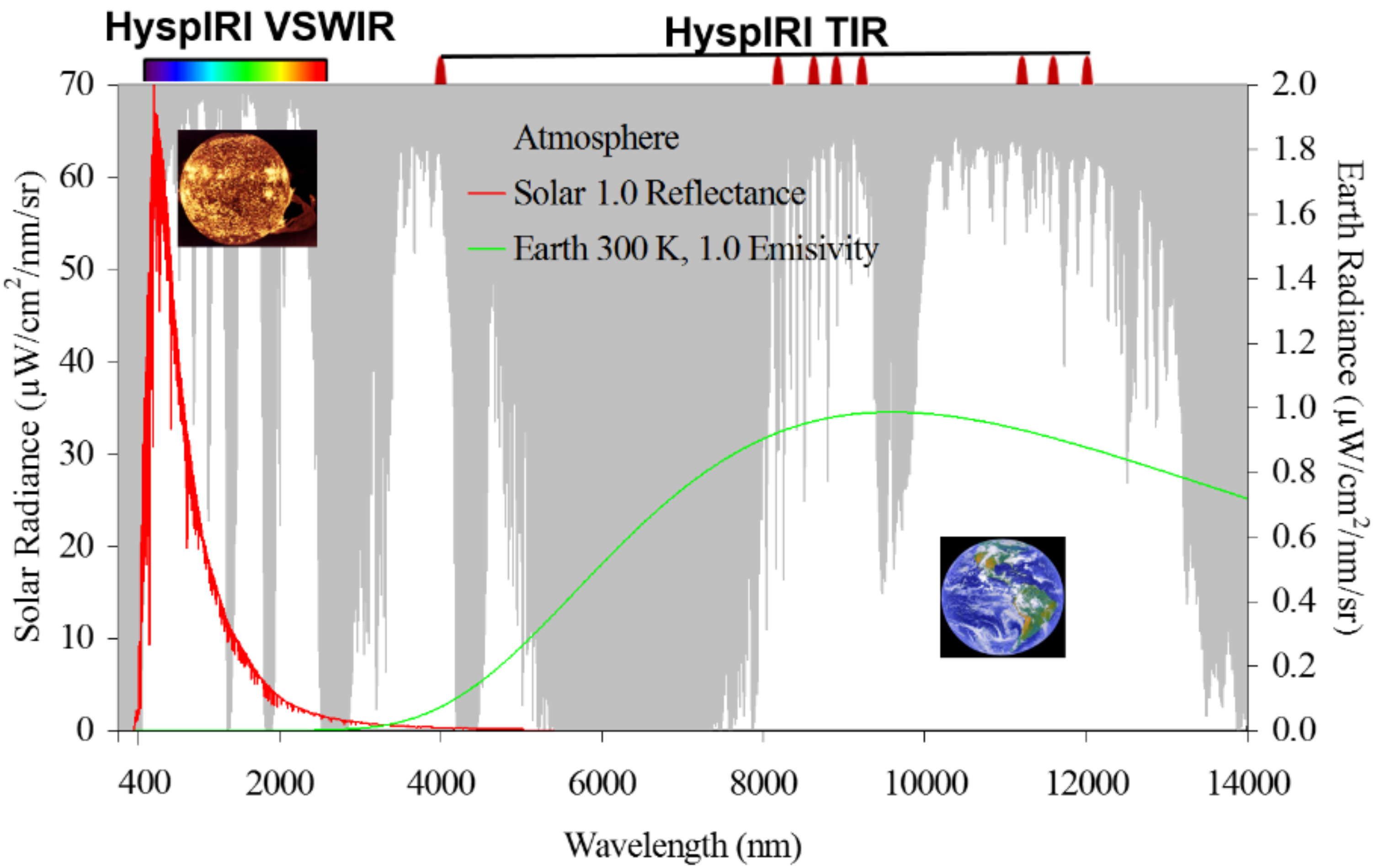
A single scene show up to 30 content rich eigen images.

This demonstrates huge dimensionality available for access with imaging spectroscopy for new Earth system science



HyspIRI Measurements

- Global terrestrial and coastal VSWIR spectroscopy at 30 m, 16 days and multispectral TIR at and 60 m, 4 days with real-time downlink of selected products.



HyspIRI Related Inputs to RFI2

Wendy	Calvin	Earth Surface Geochemistry and Mineralogy: Processes, Hazards, Soils, and Resources
Philip	Dennison	Global Measurement of Non-Photosynthetic Vegetation
Heidi	Dierssen	Assessing Transient Threats and Disasters in the Coastal Zone with Airborne Portable Sensors
Riley	Duren	Understanding anthropogenic methane and carbon dioxide point source emissions
Joshua	Fisher	Evapotranspiration: A Critical Variable Linking Ecosystem Functioning, Carbon and Climate Feedbacks, Agricultural Management, and Water Resources
Robert	Green	Science and Application Targets Addressed with the 2007 Decadal Survey HyspIRI Mission Current Baseline
Eric	Hochberg	Coral Reefs: Living on the Edge
Simon	Hook	Carbon Emissions from Biomass Burning
Luvall	Jeffrey	A Thermodynamic Paradigm For Using Satellite Based Geophysical Measurements For Public Health Applications
Natalie	Mahowald	Measuring the Earth's Surface Mineral Dust Source Composition for Radiative Forcing and Related Earth System Impacts
Frank	Muller-Karger	Monitoring Coastal and Wetland Biodiversity from Space
Thomas	Painter	Understanding the controls on cryospheric albedo, energy balance, and melting in a changing world
Ryan	Pavlick	Biodiversity
Dale	Quattrochi	High Spatial, Temporal, and Spectral Resolution Instrument for Modeling/Monitoring Land Cover, Biophysical, and Societal Changes in Urban Environments
E. Natasha	Stavros	The role of fire in the Earth System
Philip	Townsend	Global Terrestrial Ecosystem Functioning and Biogeochemical Processes
Kevin	Turpie	GLOBAL OBSERVATIONS OF COASTAL AND INLAND AQUATIC HABITATS
Robert	Wright	PREDICTING CHANGES IN THE BEHAVIOR OF ERUPTING VOLCANOES, AND REDUCING THE UNCERTAINTIES ASSOCIATED WITH THEIR IMPACT ON SOCIETY AND THE ENVIRONMENT