Priority Products to Support HyspIRI's Science Questions

Overview of the 2012 HyspIRI Data Products Symposium

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HyspIRI Products Symposium

Objectives:

- Identify science/application data products to be derived from HyspIRI measurements;
- Discuss issues underlying data product processing/integration/fusion;
- Prioritize the development of product prototypes.

Science Discipline Areas addressed:

- Ecosystem Function and Composition
- Disturbance and Human Impacts
- Volcano, Natural Hazards and Mineral/Resources

Participants: 100+

HyspIRI Science Questions

(http://hyspIRI.jpl.nasa.gov)

HyspIRI has three top-level science questions [identified in the NRC Decadal Survey] related to:

1) Ecosystem function and composition

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

2) Volcanoes and natural hazards

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

3) Surface composition and the sustainable management of natural resources.

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

Agenda Summary

HyspIRI Mission Update – 4 presentations

Topic 1. Ecosystem Function & Composition Questions (VQ1-3, 5; CQ1, 4), 7 presentations

Discussion of Higher Level Ecosystem Products to prioritize desired products; Discuss methods, tools and resources required

Topic 2. Disturbances & Human Impact Questions (VQ4, TQ3, 5; CQ2, CQ6), 4 presentations

Discussions of Disturbances & Human Impact to prioritize desired products and associated methods, tools and required resources

Topic 3. Volcano, Natural Hazard & Mineral/Resource Questions (TQ1-2, 4; CQ3, 5), 5 presentations

Discussion of Volcanoes, Natural Hazards & Mineral/Resources to prioritize desired products, methods, tools and resources required

Contributed presentations from Technical Community and SSG

- Intelligent Payload Module (IPM): *rapid onboard processing development,* 2 presentations
- Atmospheric Correction Tools and Application Needs: Prototyping Atmospheric Correction Tools and Applications for HyspIRI using EO-1 Onboard & on the Cloud, presentation and demonstration
- Introduction to Geolocation Challenges – 2 presentations

  Discussion on Geo-location knowledge requirements for HyspIRI products & science questions

Interactive Discussion on General Needs & Issues for Higher Level HyspIRI Products

Outcomes of Symposium

We identified the required products to support HyspIRI Science questions and evaluated their current status

Outcomes:

1] Identified science/application data products that could be derived from HyspIRI measurements

2] Prioritized the development of product prototypes

3] Outlined issues underlying data product processing and related to data integration/fusion

HyspIRI Products Required for LPV

LPV Focus Group / Product	VSWIR L 2/ 3	VSWIR L4	VSWIR Global	TIR L4	SWIR / TIR
LAND COVER					
Fractional land cover / veg. cover					
Disturbance, PFT, hazard susceptibility					
SURFACE RADIATION					
Surface Reflectance					
Surface Albedo					
BIOPHYSICAL					
Gross / Net Primary Production					
fPAR					
LAI					
Water content, LUE, Pigments					
FIRE					
Detection of Fire events					
Fire fuel loads					
LAND SURFACE TEMPERATURE					
LST					
Emissivity					
Evapotranspiration					

Existing Val Methods

Research Required

J. Nightingale, 2011

***HyspIRI** will provide explicit mapping of how plants absorb light, as a function of their biophysical characteristics (water, pigments, nitrogen and structural compounds) and local temperature*

The way forward:
- Develop the seasonal products to be ingested
- Adapt the models to ingest new high spectral and spatial reflectance products seasonally, while continue ingesting at high frequency biophysical variables from lower spectral & spatial resolution measurements

Open issues: testing/augmentation of product prototypes, reconcile/develop data assimilation tools, and model development and adaptation

Jose Moreno, 2011 HyspIRI Sci WS

Challenges

High Data volume
Low Latency Data
Atmospheric Correction for L2 Products
Data Processing Chains
Data archives/distribution
Calibration/Validation
Combined VSWIR and TIR products
Regional Collections & Products
Global Collections & Products

What's the problem with making level-1 VSWIR, TIR and combined products?

- By definition level-1 data must be entirely reversible back to the original level-0 data.
  - Geo-tag <u>*radiometrically*</u> corrected data.
  - Re-grid data using nearest neighbor values and geo-tag back to original pixel data positions *(need to deal with multiple values for the TIR)*.
- VSWIR and TIR observations are inherently misaligned in a manner which is both geographically and temporally sensitive.

Ungar 2012

Mature & Ready: *HyspIRI Terrestrial Ecology Products*

(* = Climate Variable; ** = Essential Climate Variables defined by GEO)

VSWIR Imaging Spectrometer ALONE

Level 4 Biophysical & Physiological Products

1. Directional Canopy Albedo [**]
2. Total Canopy Chlorophyll Content [*]
3. Fractional Cover: Green Vegetation, Non-Photosynthetic Vegetation, impervious surfaces, soil [*]
4. Fractional Cover for Vegetation Classes: Coniferous, Deciduous, and Mixed Forests; Grasslands; Wetlands; Crops [*]

VSWIR + TIR Combined

Level 4 Combined Products

1. Biomass for Grasslands [**]
2. Diversity, Coastal Habitats [**]
3. ET by Land Cover Type [*]
4. Functional Types/Species Composition [*]
5. Ecological Disturbance Area (logging, natural disasters) [*]
6. Drought Index (PET/AET) by Land Cover Type [*]

HyspIRI Significantly Improved Products

Require Further Validation *(* = Climate Variable; ** = ECV defined by GEO)*

VSWIR Imaging Spectrometer ALONE

Level 4 Biophysical & Physiological Products

1 Photosynthetic Parameters (LUE, Jmax, Vcmax) [*]
2 Environmental Stress Measurements (response variables) [*]
3 Canopy N content (mass/area) [*]
4 Canopy Water Content [*]
5 Vegetation Pigment Content (Chl a, Chl b, Carotenoids, Anthocyanins)
6 Canopy Lignin and Cellulose

Multi-Spectral TIR Imagery ALONE

L3 Products [Day or Night swath & gridded data]

1 Burn Area (experimental as TIR only)
2 Burn Severity (experimental as TIR only)

VSWIR + TIR Combined

L4 Products – Regional

1 Surface Energy Flux [**]
2 Combusted Biomass [**]
3 Sensible Heat due to Urban Heat Islands (Anthropogenic Heat) [*]
4 LST: Day/Night Differences for Ecosystems & Urban Areas [*]
5 LST Urban/Suburban [*]
6 LST by Functional Groups and Ecosystem Types [*]
7 Surface Topographic Temperature Mapping [*]

L4 Products – Global

1 LST & Emissions by Fractional Land Cover (Vegetation, Soil, Water, Snow, Ice, etc.) [**]
2 Ecosystem/Crop Phenology with Fusion Approaches [*]

Priority HyspIRI Terrestrial Ecology Products

1) Ecosystem nutrients and chemistry (nitrogen, water‡, etc.)

2) Biodiversity (improved species‡ and functional-type†)

3) Ecosystem health (physiological condition)
   - *Canopy structure (improved LAI, fraction of green biomass ‡)*
   - *Canopy pigments (e.g. chlorophyll‡, carotenoids†, anthocyanins†)*
   - *Canopy water ‡*
   - *Lignin & cellulose ‡, crop residue cover ‡*
   - *Nitrogen ‡*
   - *General stress †*

4) Temperature and emissivity estimates by land cover type/components (species/functional groups, urban/sub-urban/rural, volcanoes)

5) Relationships and feedbacks between canopy composition/function and canopy temperatures; predictive relationships between **VSWIR** and **TIR** indicators

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‡advanced *†researched*

HyspIRI Products & Current Issues

1) Many approaches / tools / applications (*need to standardize*)
2) Local to regional studies & pilot projects *(need larger scales)*
3) Application demand for new ecosystem products

Needed:

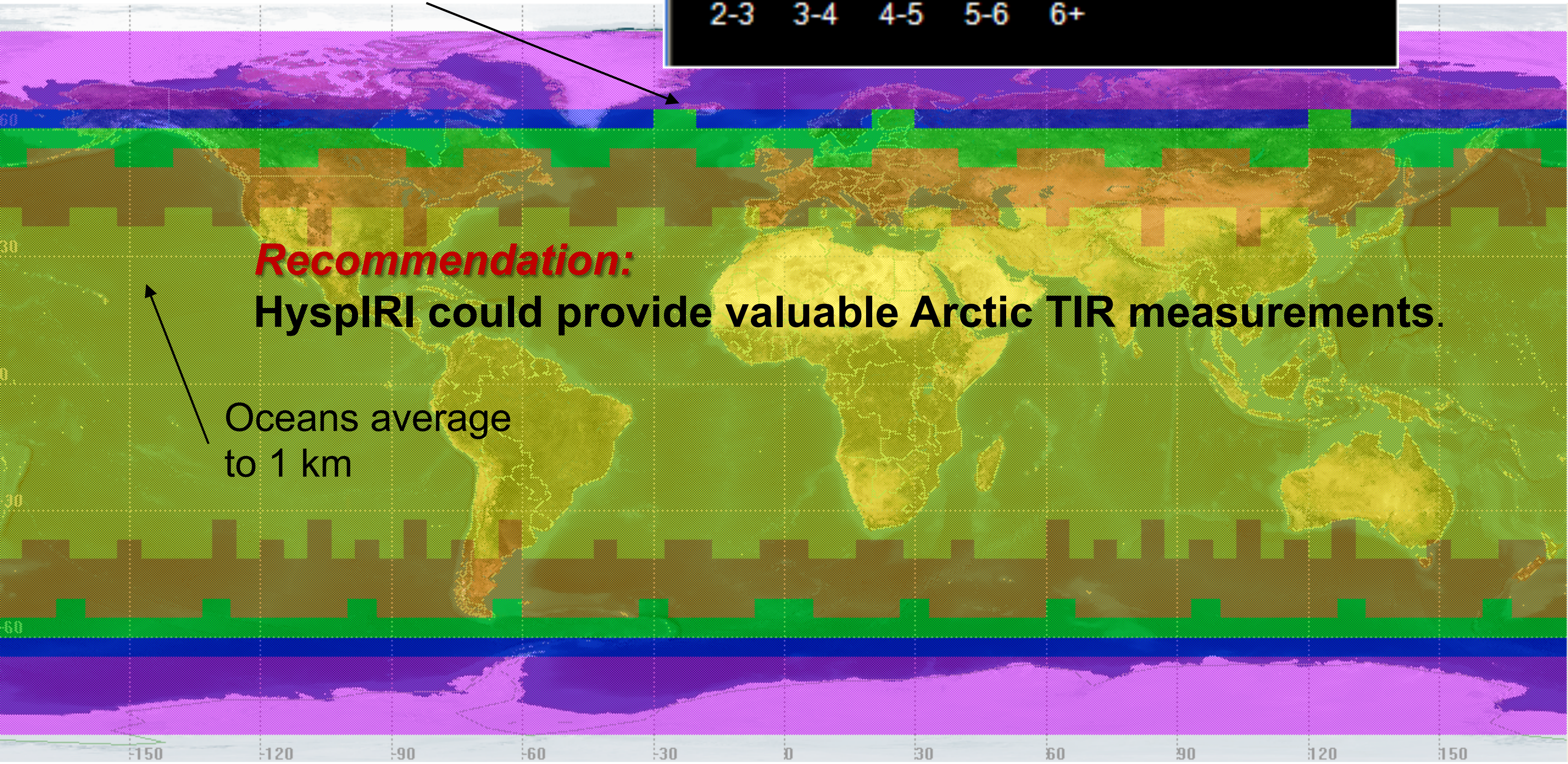
1) To determine their sensitivity and application extend of the existing approaches we need large scale VSWIR/TIR data-sets for variety of ecosystems
2) Calibrated spectral products (establish a network producing *in-situ* bio-physical measurements)
3) Establish seasonal VSWIR/TIR relationships for major species, functional groups, etc.
4) Long term VSWIR/TIR spectral time series to reveal normal & divergent ecosystem patterns

Methods/Tools For Hyperspectral Analysis

Acronyms		VSWIR Methods	Objective / Use	Required
1	ACORN	Atmospheric CORrection Now	radiometric calibration and atmospheric correction	Spectral Hypercubes
2	FLAASH	Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes	radiometric calibration and atmospheric correction	Spectral Hypercubes
3	SS&R	Spectral sensitivity & relationship to *in situ* measurements	knowledge of important spectral information	contiguous spectra
4	CR &FD	Continuum Removal & Feature Depth	analysis on specific absorption features	contiguous spectra
5	SI, P-VI	Physiological Vegetation Indexes (P-VI)	reduce the number of bands but retain the most important spectral information	Spectral Hypercubes, SS&R
6	MNF	Minimum noise fraction (two-stage PCA)	reduce wavelength specific noise and dimensionality of data	Spectral Hypercubes
7	SAM	Spectral Angle Mapper of spectral cubes	comparing spectra of image pixels to the spectra of reference endmembers	Spectral Hypercubes
8	SMA, SUM, MESMA	Spectral Mixture Analysis and Unmixing Methods	derive apparent fractional abundance of specific endmember in a pixel	a priori known endmembers (b-1)
9	MF	Matched Filters	maximizes target-to-background contrast	Spectral Hypercubes, known signatures to match
10	MTMF	Mixture Tuned Matched Filtering	combines the strength of MF with physical constraints imposed by mixing theory	Knowledge of the target species endmembers
11	MLc of MNF	Maximum Likelihood classification of MNF transformed images	species identification	MNF
12	MLc of P-VI	MLc of P_VI Images	identification of physiological state	Physiological Vegetation Index Images

Annual TIR imaging opportunities in a 5-day near-repeating orbit, 1 yr. simulation

Daily coverage at high latitudes

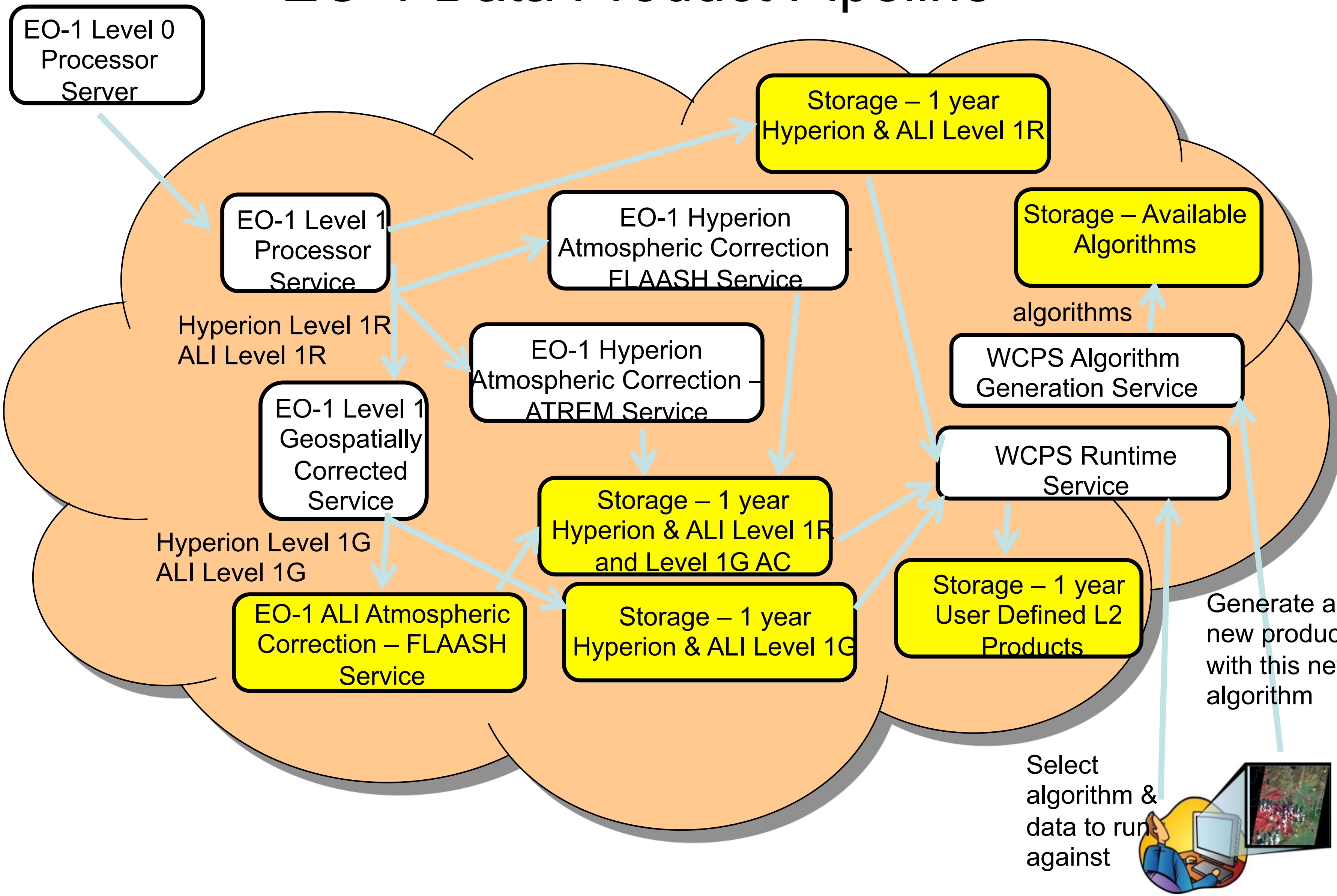


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: +/- 25.46° (60 m pixel GSD at nadir, 9272 cross-track pixels).

HyspIRI Products & Current Issues

App	Product	Issues & Challenges
Ecosystem	Fractional Cover (PV/NPV/Impervious)	Large Area Data (LAD) for Cal/Val
Ecosystem	Species Composition & Habitat Diversity for Coastal & Terrestrial Ecosystems	LAD & Local Spectral Libraries(LSL) for Cal/Val
Ecosystem	Total Canopy Chlorophyll	Reconcile Approaches
Ecosystem	Vegetation Function and Yield (LUE, WUE, ET, GPP)	LAD & LSL by Phenology & Treatments
Ecosystem	Canopy Bio-chemistry (water, N, lignin & cellulose)	LAD, Phenology & Treatments
Ecosystem	Canopy Bio-chemistry (water, N, lignin & cellulose)	LAD, Phenology & Treatments
Disturbance &	Ecological Disturbance Area (logging, infestation, severe storm, fire, flood, oil and chem spills, and other disasters)	Seasonal LAD & LSL; Locations of points of interest
Disturbance &	Aquatic Thermal Pollution	Point and Diffuse Source Locations
Disturbance &	Heat Flux Dynamics, Stress by Land Cover Type	Factors of Heat stress
Disturbance &	Disease Habitats and Risk Dynamics	LAD & LSL for Disease Habitats
Disturbance &	Emissivity by Cover & Anthropogenic Heat Dynamics (spatial, temporal)	Urban LSL and Long Term Measurements
Hot Targets	Plume Constituents from Fires & Volcanoes	Algorithm Development & Augmentation
Hot Targets	Lava Composition and Direction of Flow	Algorithm Development & Augmentation
Hot Targets	Mapping of Fires and Volcanoes	Algorithm Development & Augmentation
Hot Targets	Fire Severity	Testing and Validation
Hot Targets	Burned Area and Combusted Biomass	Testing and Validation
Aquatic Shallow Water	Remote Sensing Reflectance (Rrs), Water Surface Temperature	Radiometric Accuracy, SNR, Glint, Atmos Corr; *In Situ* Data for Cal/Val
Aquatic Shallow Water	Inherent Optical Properties (IOPs)	Rrs Accuracy; *In Situ* Data for Val
Aquatic Shallow Water	Water-column Optical Constituents(e.g., Chl a, b, c, CPC, CPE, CDOM, Peridinin, Fucoxanthine, Tripton)	Dependent on IOP & Rrs quality; *In Situ* Data, Val
Aquatic Shallow Water	Water-column Composition (Phytoplankton Functional Types)	Water-column Optical Constituents; *In Situ* Data, Val
Aquatic Shallow Water	Subaerial Composition (Separate floating & emergement biota; oil emulsions & mineral suspensions; trash islands)	LSL for Classification and Mixture Decomposition; *In Situ* Obs, Val
Aquatic Shallow Water	Benthic Composition (submerge macro-vegetation, coral, micro-algae cover)	Depends on Rrs; LSL for Mixture Decomposition; *In Situ* Obs, *Val*
Aquatic Shallow Water	Ground and Surface Water Discharges	Location of Sources

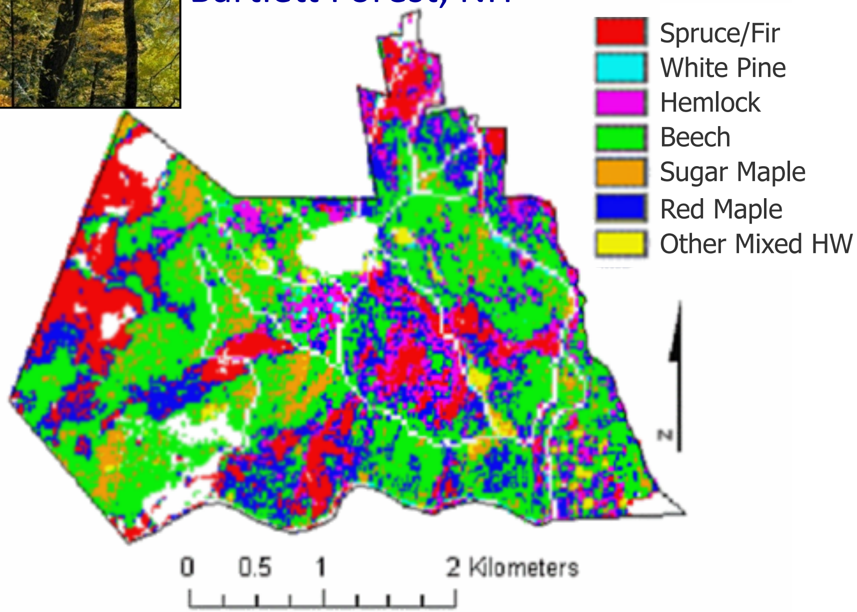
Transformation to On-Demand Product Cloud Part 1
EO-1 Data Product Pipeline



Phase 3 Add Elastic Cloud Ongoing Feb 2011

Determine the global distribution, composition, and condition of ecosystems, including agricultural lands

Tree species mapping, Bartlett Forest, NH



Societal Issue:

- Forests, farmlands and a variety of other ecosystems are critical to life on the Earth. Many ecosystems are changing in ways that are poorly understood.

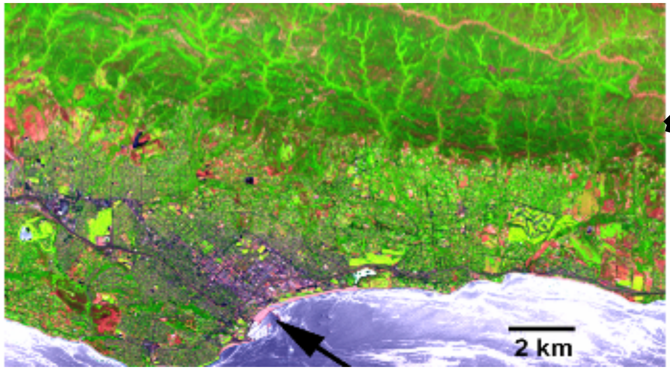
Scientific Issue:

- Understanding the distribution, diversity and status of ecosystems is necessary for understanding how they function and for predicting future changes.

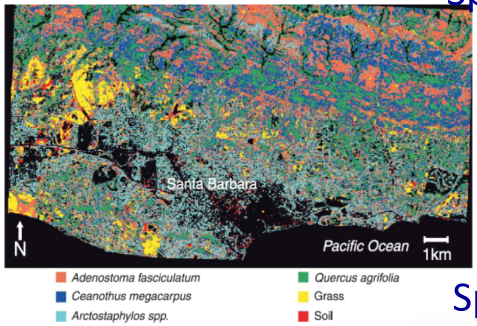
Approach (Why we need HyspIRI):

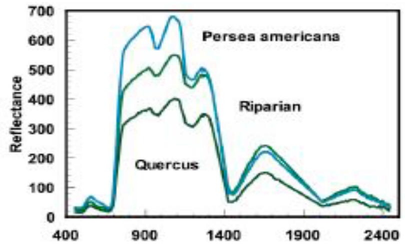
- HyspIRI will provide an important new capability to detect & monitor ecosystem composition and condition globally, with spectroscopic and thermal measurements.

HyspIRI Airborne Simulator Data Set

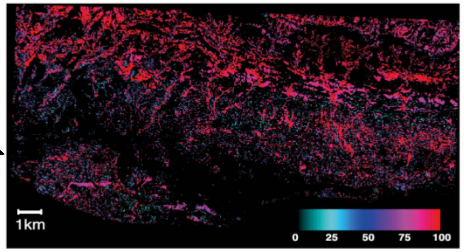


Species Type Determination

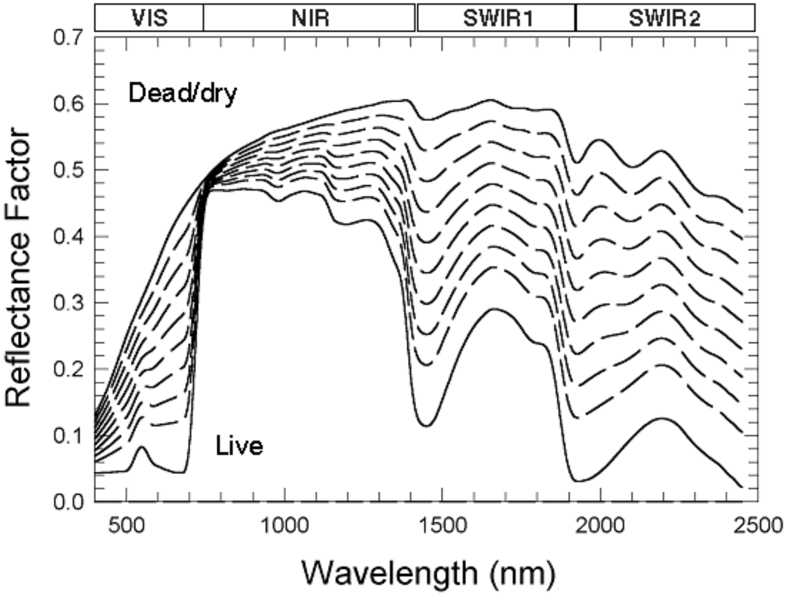


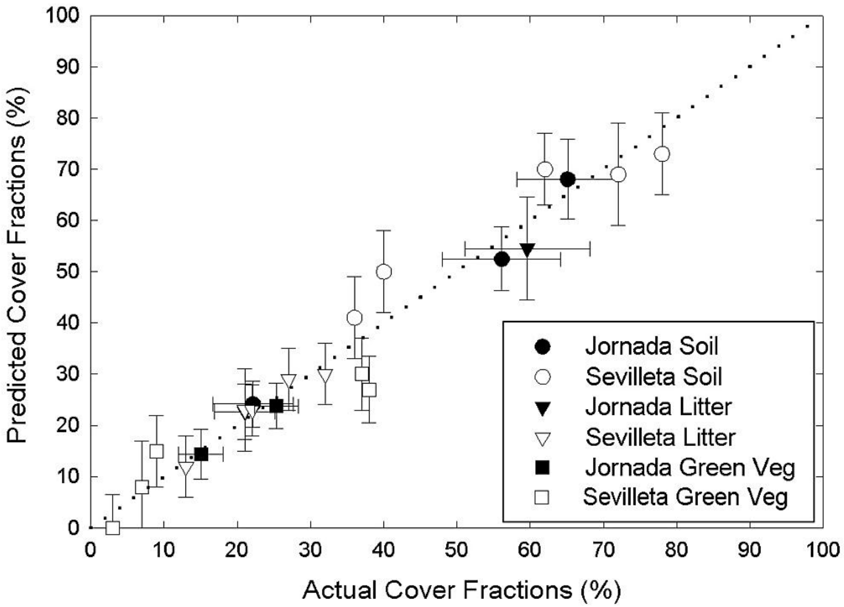


Species Fractional Cover

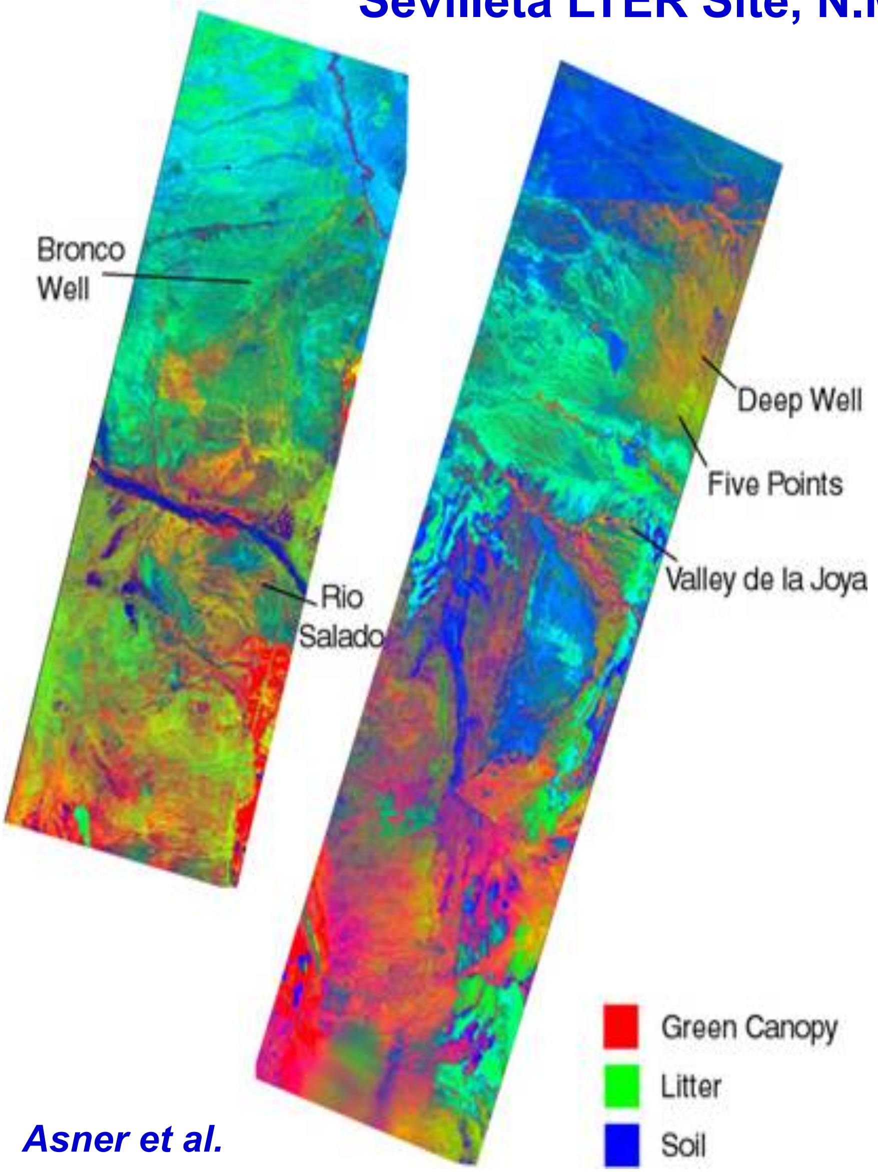


Cover Fractions in Transition from Live/ Green to Dry/Dead



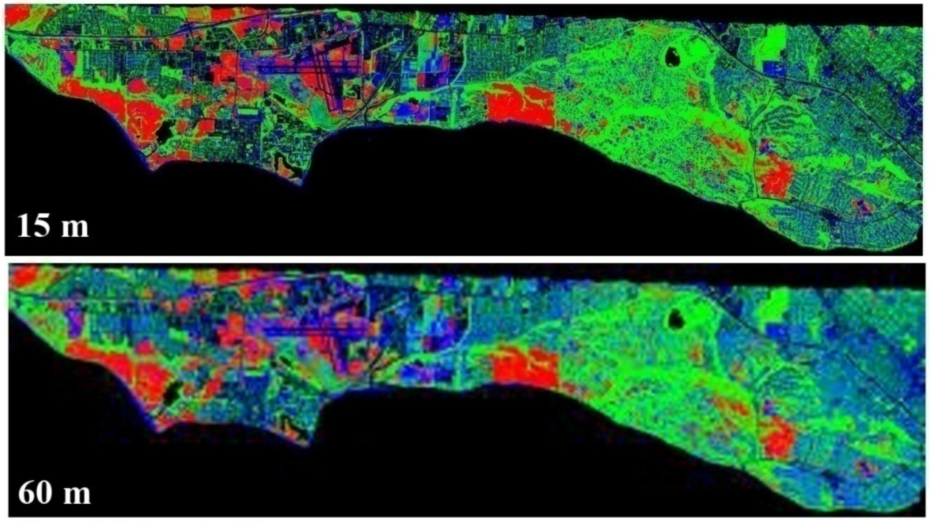


Sevilleta LTER Site, N.M.

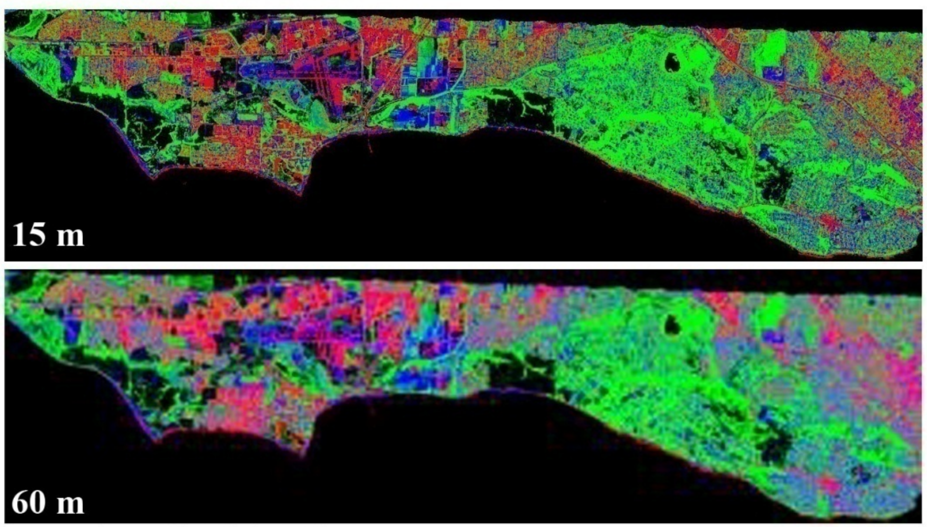


Asner et al.

GV-NPV Fractions (15 and 60 m)



NPV, GV, Soil :RGB



Impervious, GV, Soil: RGB

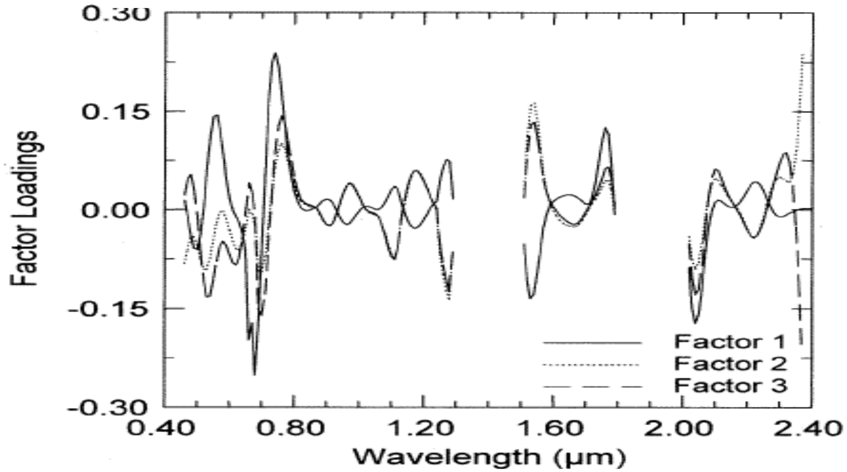
- **GV and NPV fractions scaled well between all spatial resolutions**
  - **7.5, 15 and 60 m**
- **Soil tended to be overmapped at the expense of Impervious at coarser scales**

Two error sources
Asphalt – soil
Red Tile Roof (so variable requires 3 ems)

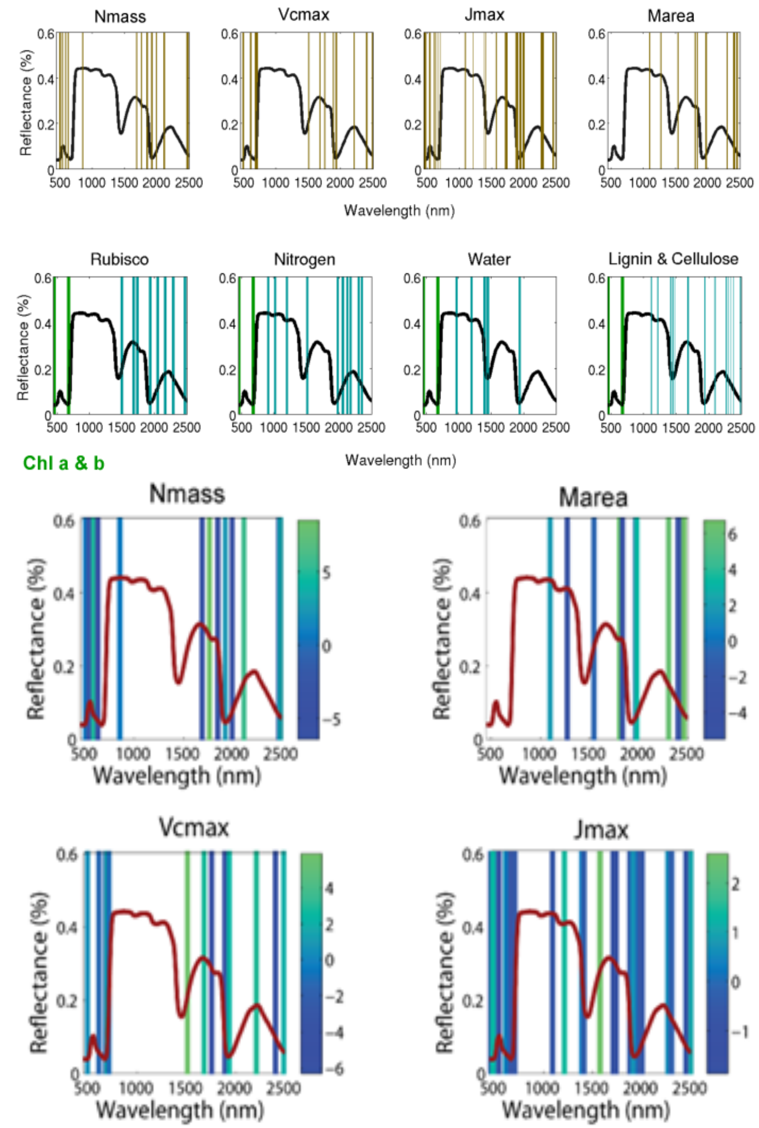
D. Roberts et al. 2012

Spectroscopy for Species/Functional-type, Biogeochemistry and Physiological Condition

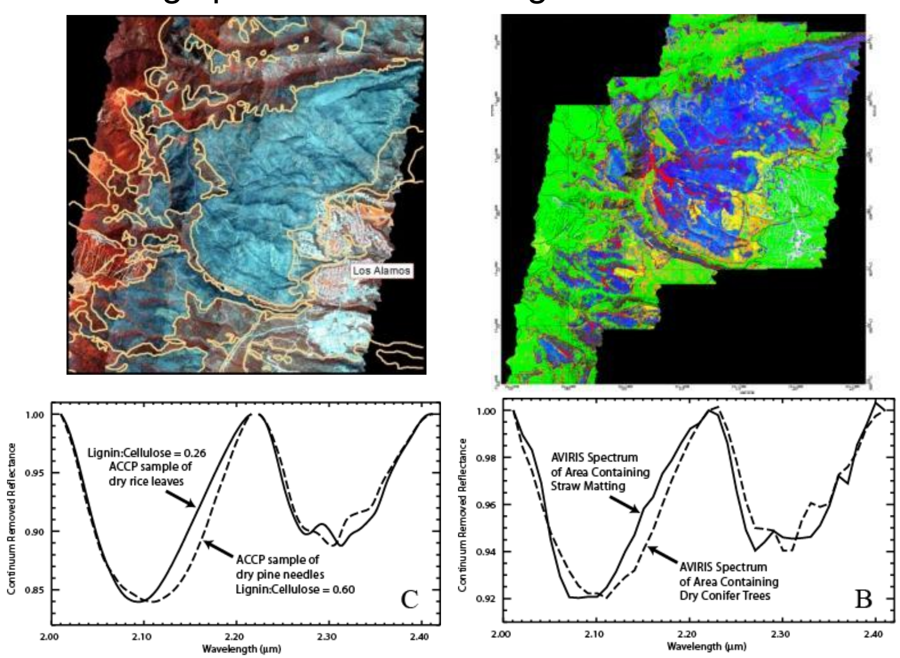
PLSR weighting for foliar Nitrogen



PLSR wavelength selection for one species



Measuring spectral shift from Lignin : Cellulose ratio



Testing Global Approaches for Optical Remote Sensing of Carbon Fluxes Using EO-1 Hyperion

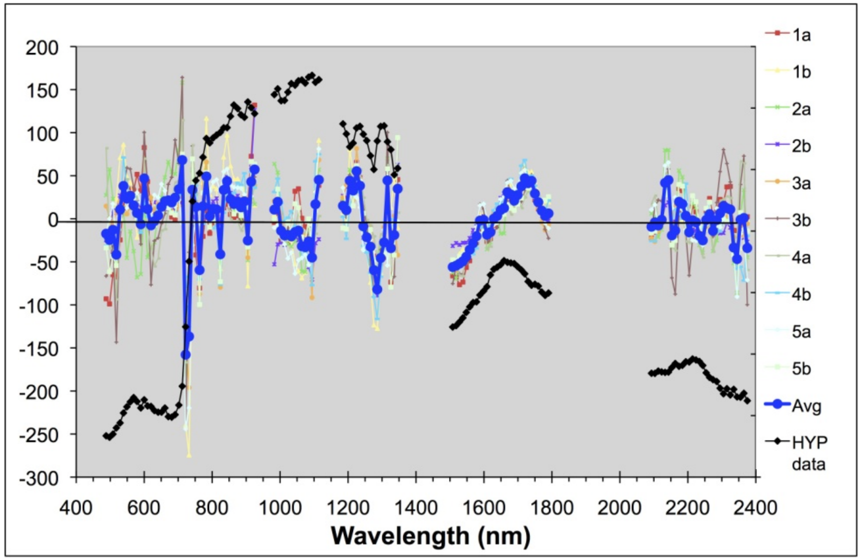
Fred Huemmrich, Petya Campbell, David Landis, Betsy Middleton

Can a single hyperspectral algorithm provide carbon flux variables over a range of sites?

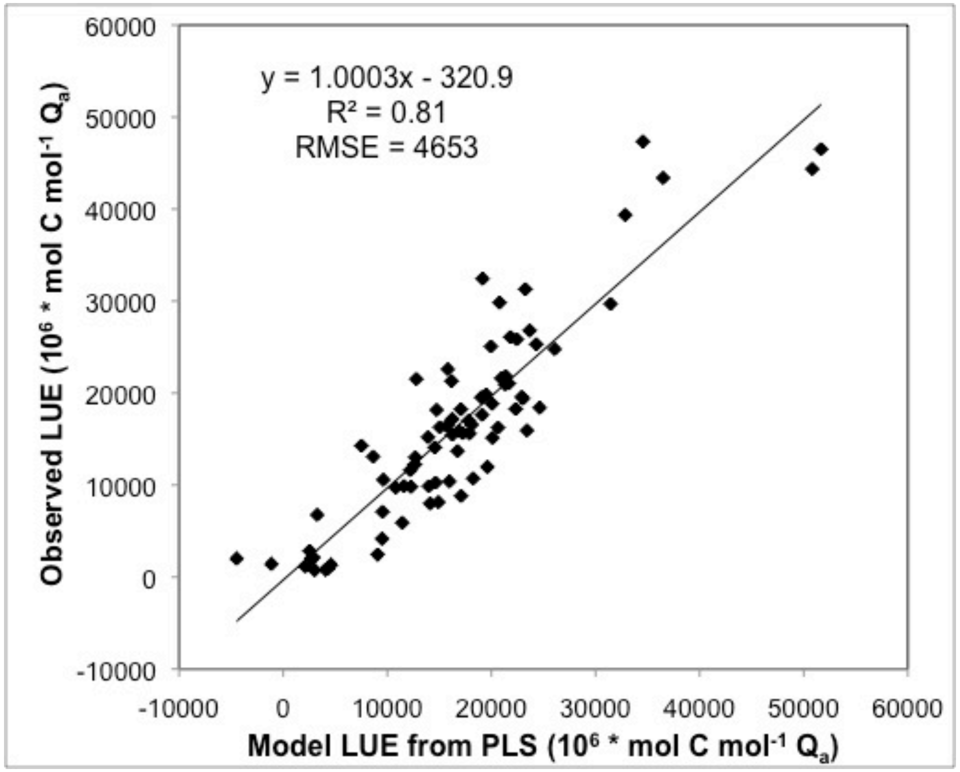
We matched flux data with Hyperion imagery from 33 globally distributed tower sites

Partial Least Squares Regressions from 10 random subsets produced similar weighting factors and good correlations with LUE

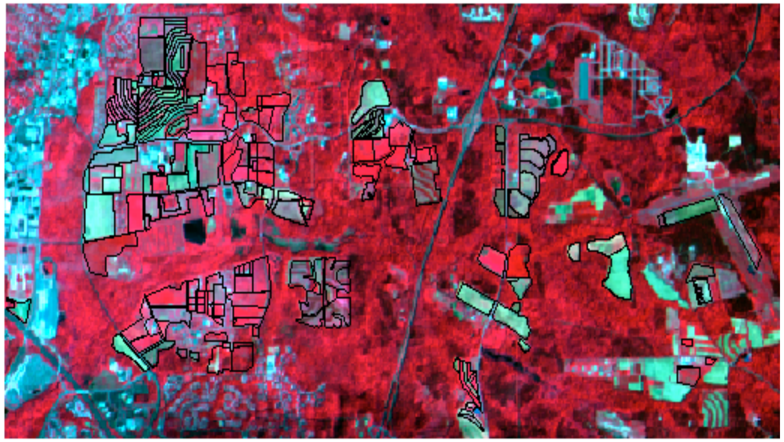
Indicates the possibility of such an algorithm



PLS weighting factors and sample reflectance spectra

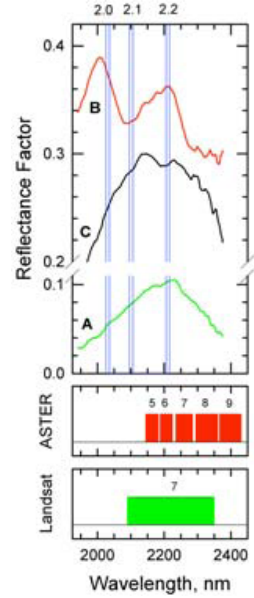


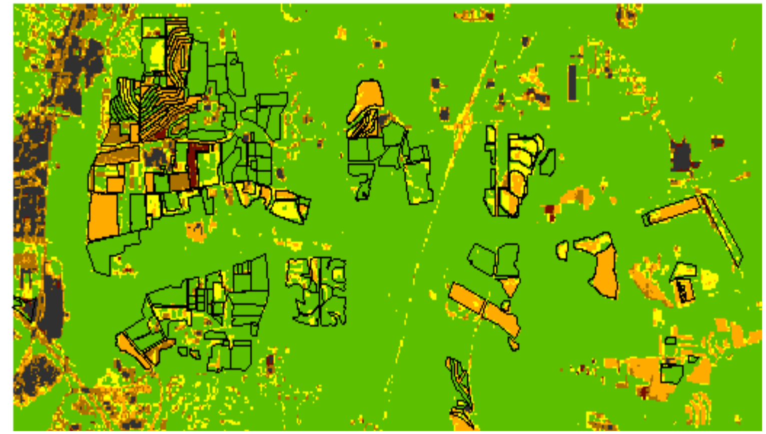
LUE estimate from Reflectance using average PLS weighting factors vs. observed LUE from flux towers

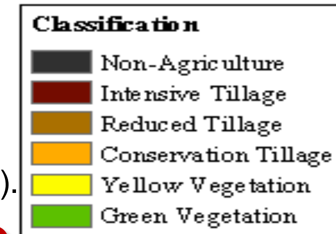


Color Infrared composite AVIRIS image with field boundaries

549 nm -- blue
646 nm – green
827 nm – red

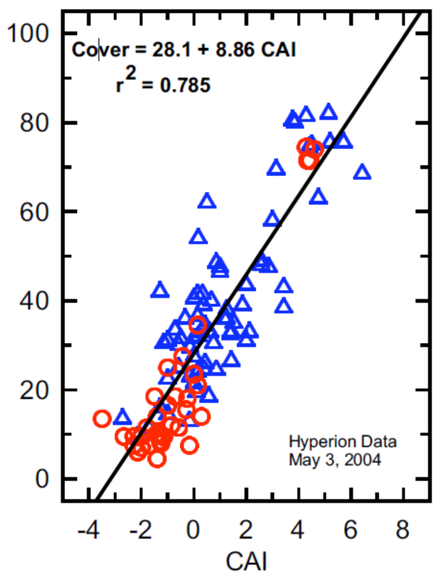




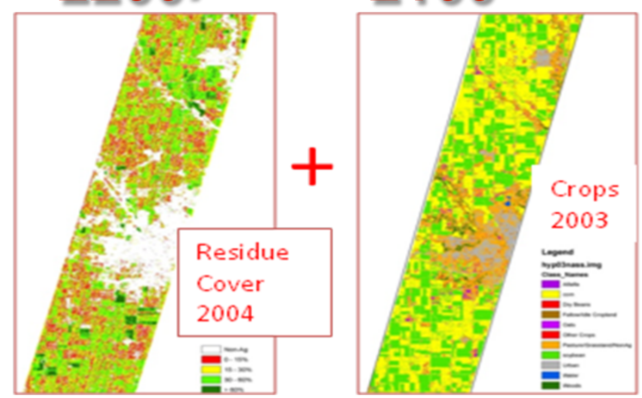


Tillage intensity classification using CAI and NDVI (overall classification accuracy = 92%).

$$CAI = 0.5(R_{2000} + R_{2200}) - R_{2100}$$



Crop Residue Cover vs. CAI for EO-1 Hyperion image Iowa – May 3, 2004



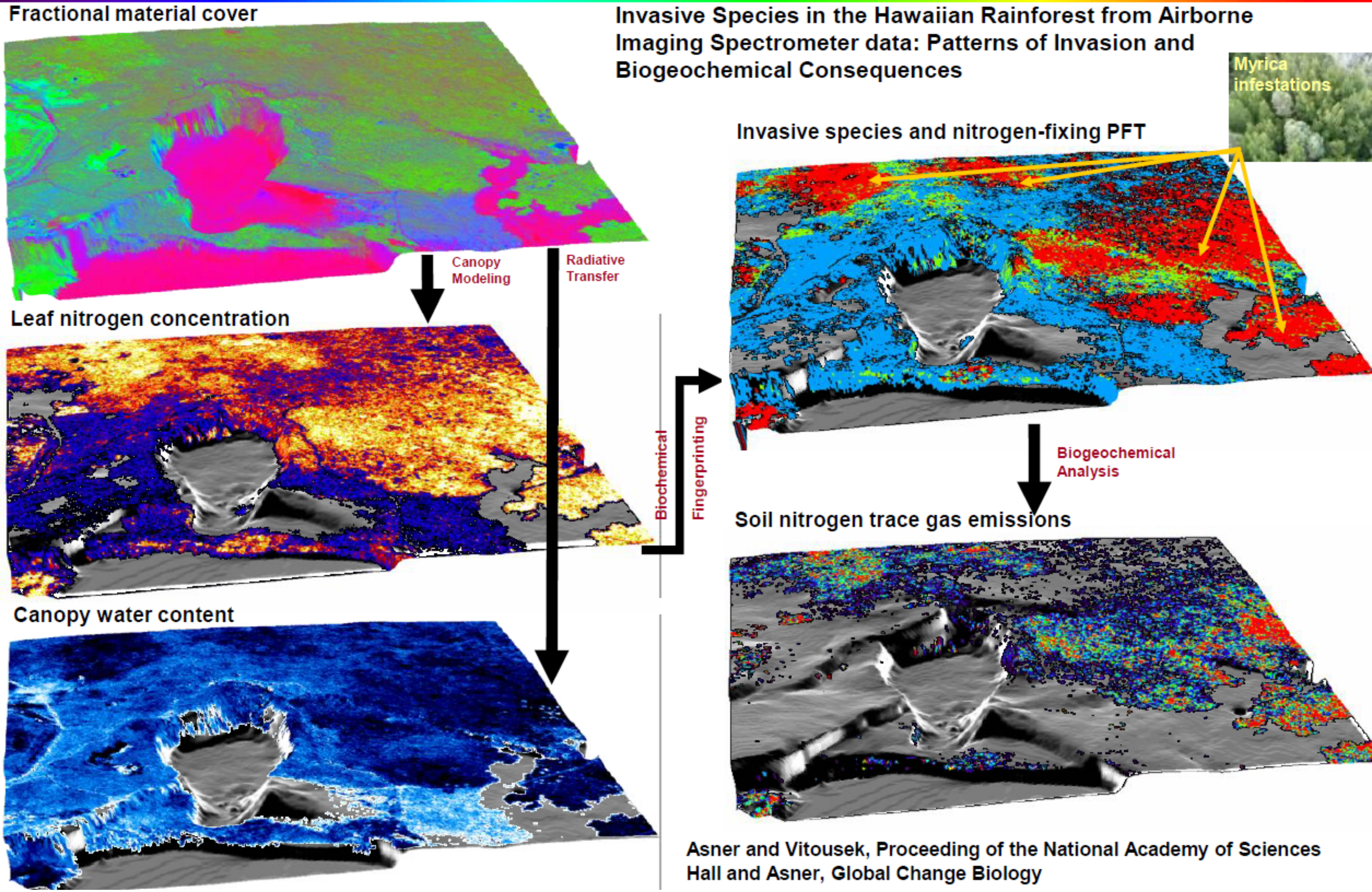
For dry and moist conditions CAI is adequate for assessing crop residue cover

(Daughtry et al. 2001, 2006 and 2010)

Ecosystem Measurements for Climate Feedbacks

Ecosystem Species-type, Chemistry & Condition

Invasive Species in the Hawaiian Rainforest from Airborne Imaging Spectrometer data: Patterns of Invasion and Biogeochemical Consequences



Asner and Vitousek, Proceeding of the National Academy of Sciences
Hall and Asner, Global Change Biology

Generalization: Little Pine Creek Model Applied to Darlington Region

Model 2

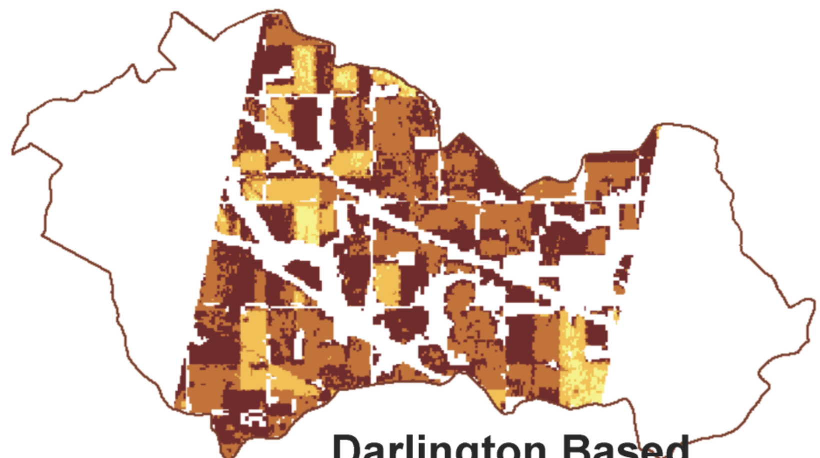
$$y_i = \beta_0 + \beta_2 NDTI_i + \varepsilon_i^2$$

- 0% - 25%
- 26% - 50%
- 51% - 75%
- 76% - 100%

Watershed Scale Evaluation

Residue Cover (%)	ALI (hec)	ACRE Model (hec)
0% - 25%	62.82	0.63
26% - 50%	276.48	195.12
51% - 75%	808.47	149.13
76% - 100%	961.83	1766.16

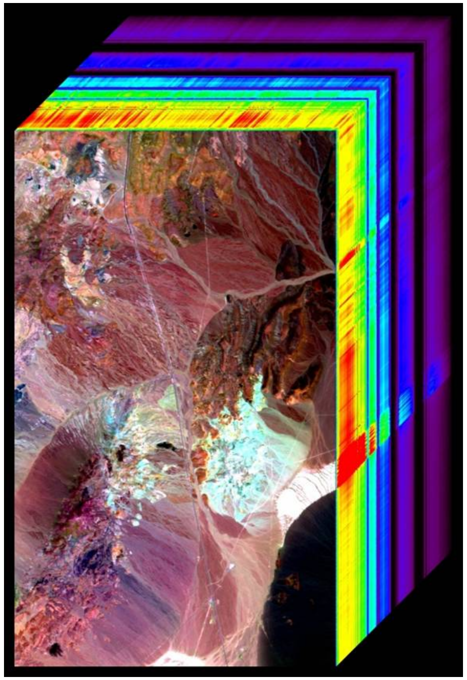
Little Pine Creek Model Applied to Darlington

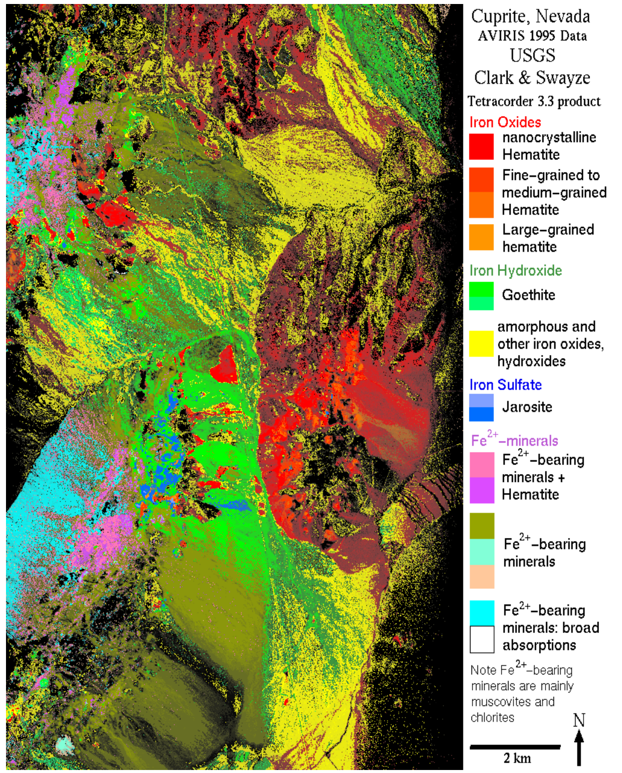


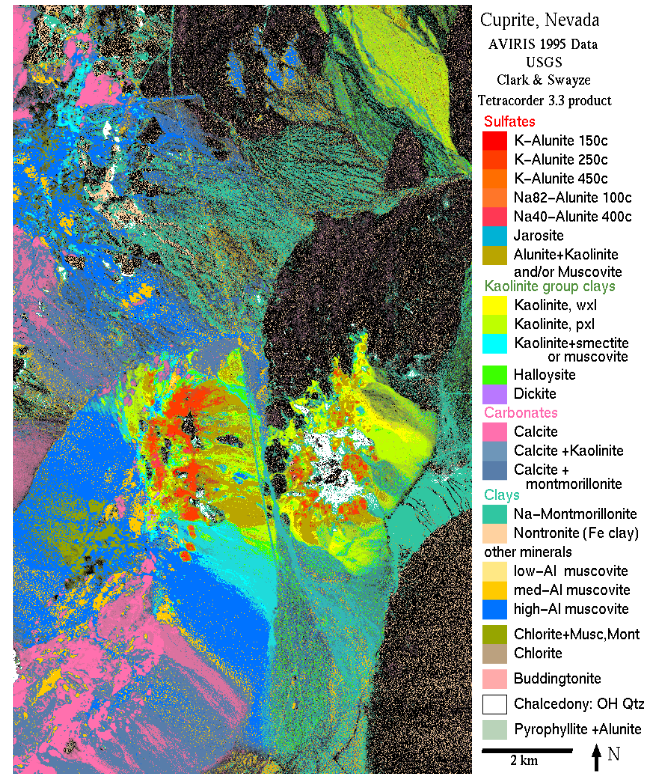
Darlington Based Model (ALI)

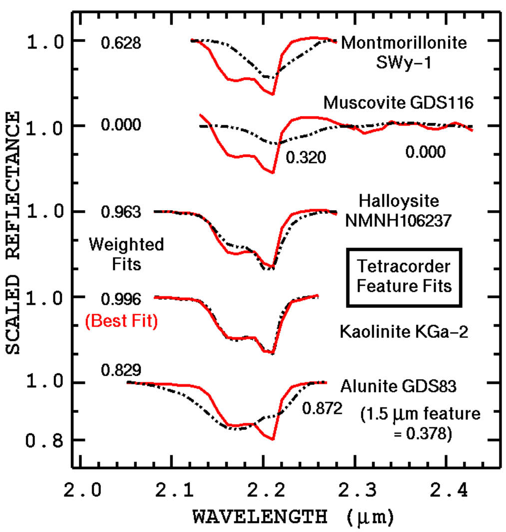
Crawford 2012

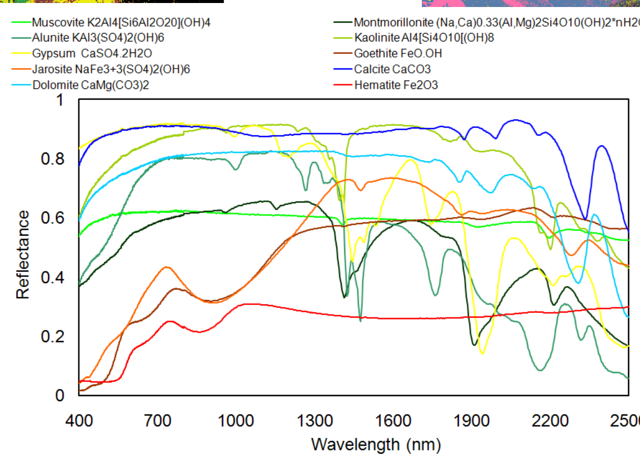
Surface Composition Derived with Imaging Spectrometer Measurements







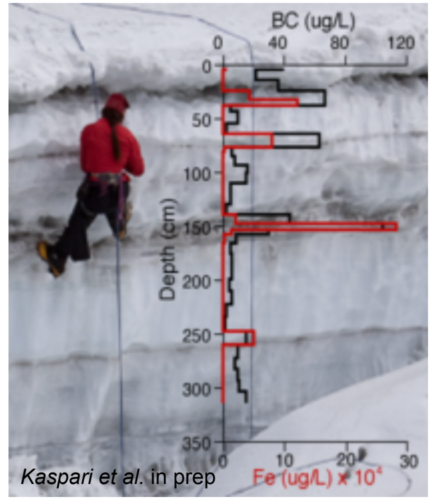


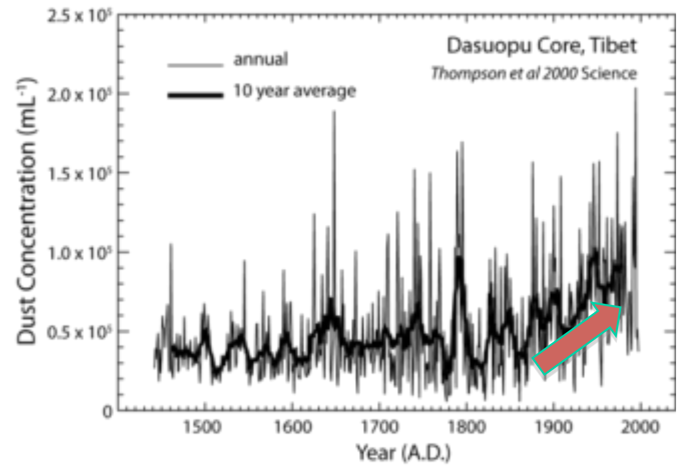


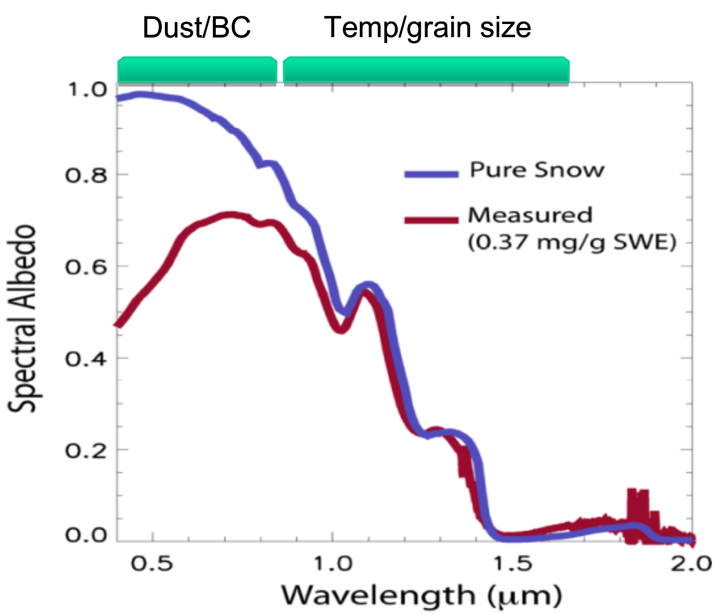
Albedo and Black Carbon/Dust Effects on Snow/Ice

What is causing the downwasting and retreat of Himalayan glaciers and elsewhere?

For snow and ice in the Himalaya, increasing temperatures and increasing dust and soot combine in unknown proportions to accelerate melt through their changes in albedo. Imaging Spectroscopy is the only approach that allows us to attribute changes in albedo into effects from temperature and dust/black carbon and at a fine enough spatial resolution that heterogeneous terrain can be resolved. Multi-band sensors such as NPOESS VIIRS have neither capacity.

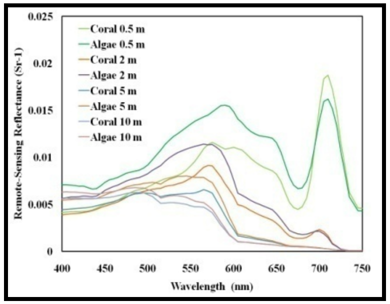


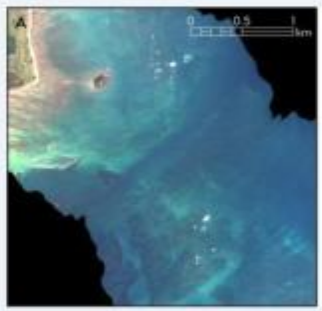


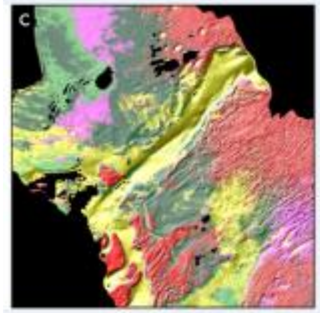


Required Measurement: Global glacial covered area, full solar spectrum, < 100 m spatial, <20 days revisit

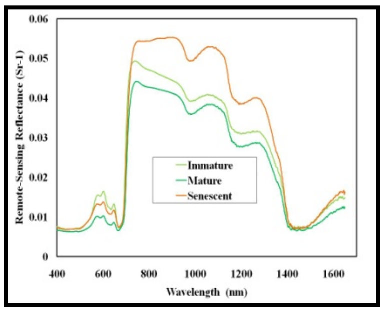
HyspIRI: Coral, Benthic Composition, and Aquatic Vegetation

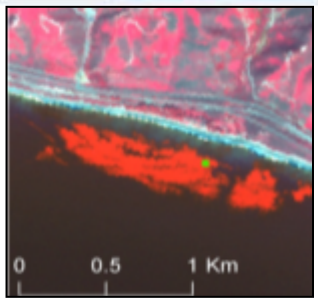




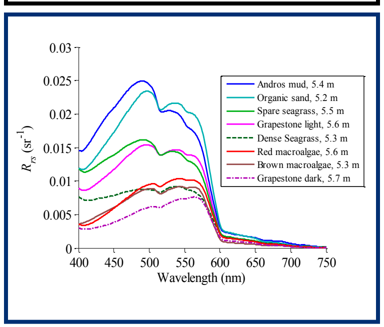


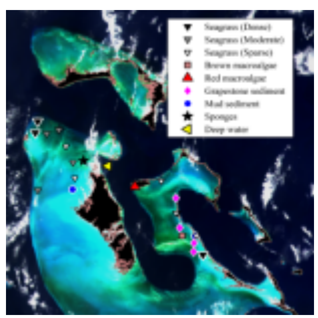
Variation in shallow water HyspIRI-type spectral signatures in coral environments.



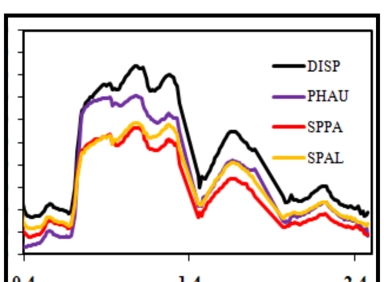


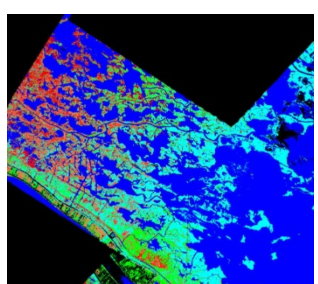
Variation in HyspIRI-type spectral signatures of floating aquatic vegetation (e.g. Kelp)





Variation in shallow water HyspIRI-type spectral signatures in seagrass beds and benthic habitat materials

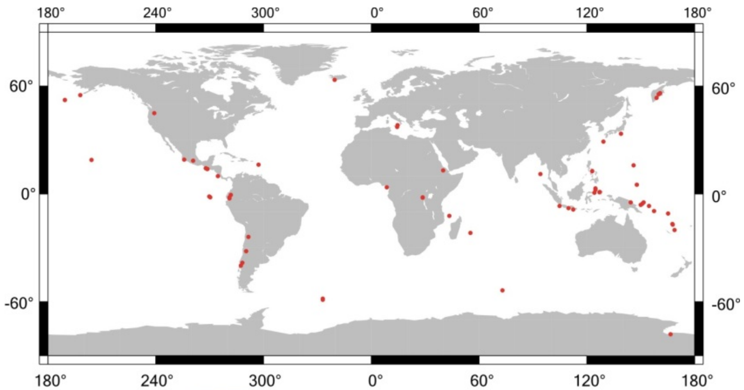




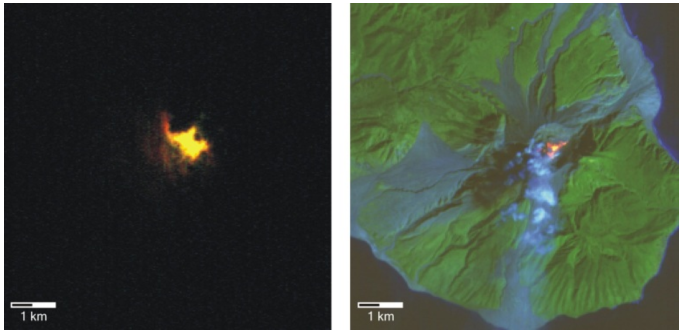
Emergent vegetation signatures are well suited to the HyspIRI measurement. For example mapping in the Gulf of Mexico coastal region with AVIRIS measurements.

Volcanic Activity - Requirements for a Monitoring

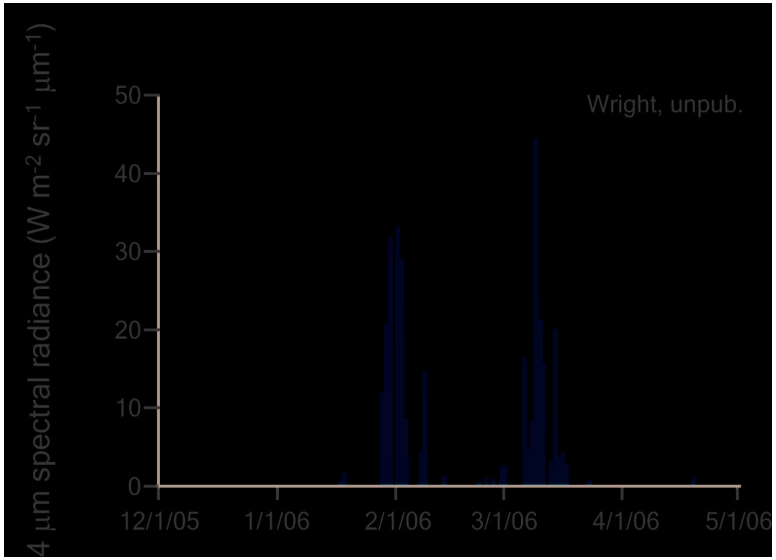
Global mapping mission



Night and day



Timely delivery of information to users (direct broadcast; on-board

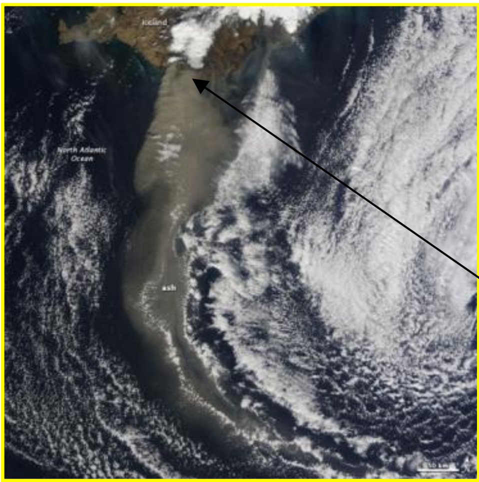


Results/data delivered in a useable (and useful) format

Unix time	Satellite	Longitude	Latitude	L_{21}	L_{22}	L_6	L_{31}	L_{32}
				W m^{-2} sr^{-1} μm^{-1}				
1089853500	A	159.424927	54.047855	0.775	0.802	177.015	7.087	6.790
1089838800	T	159.439728	54.049419	2.228	-10.000	166.546	8.392	7.967
1089853500	A	159.448288	54.052444	1.440	1.453	177.015	7.786	7.453
1089853500	A	159.453903	54.045853	1.218	1.235	177.015	7.558	7.156

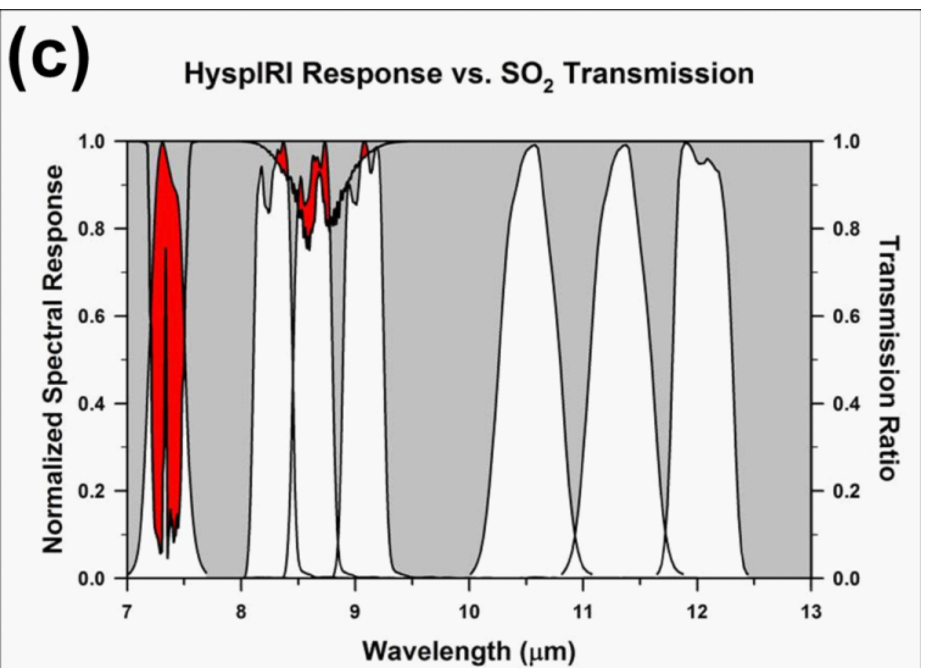
R. Wright, 2012

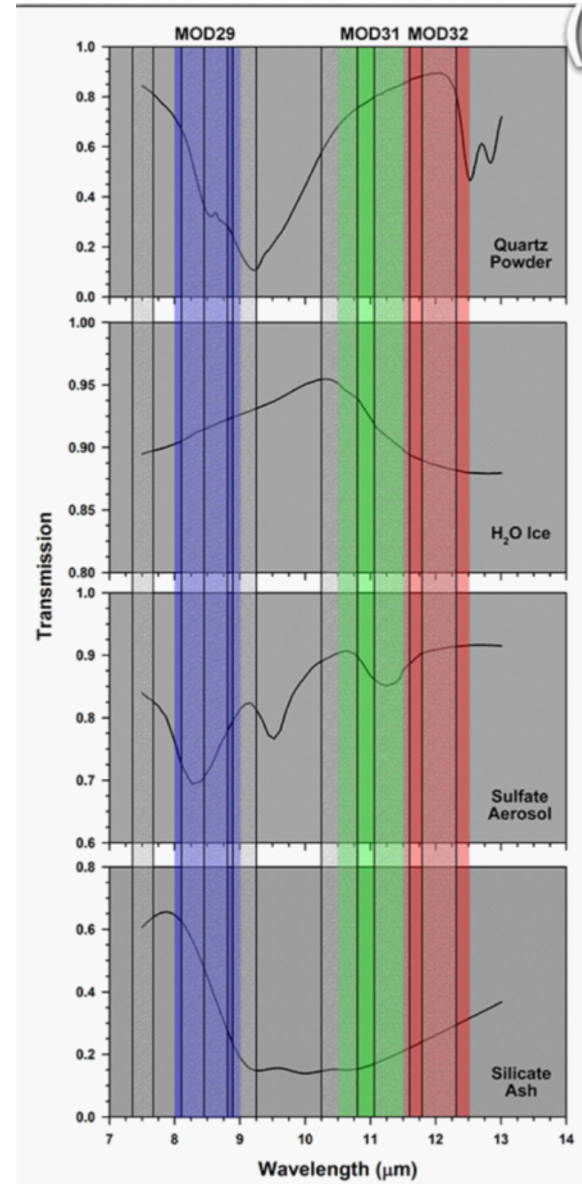
TQ1. Volcanoes/Earthquakes



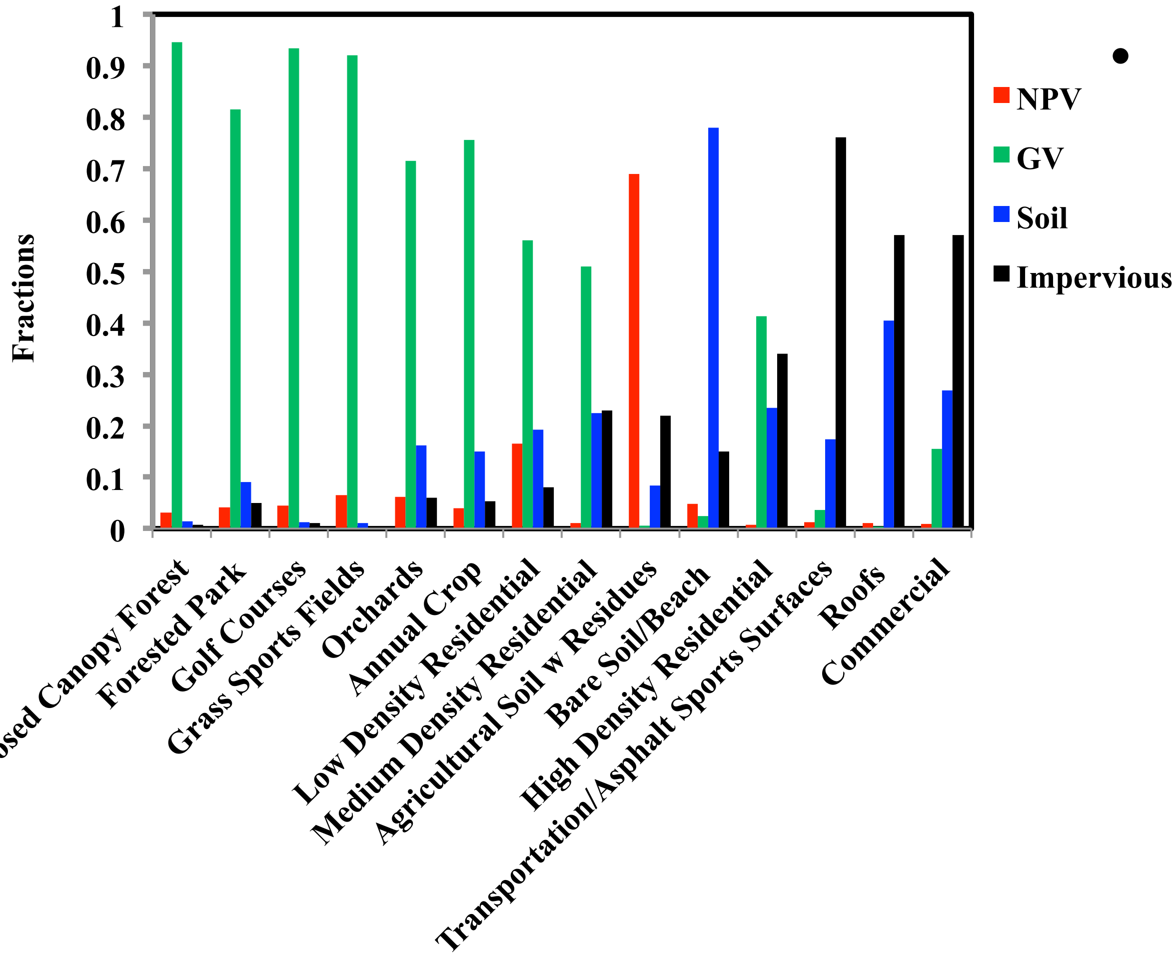
Eyjafjallajökull Iceland Volcano Eruption

April 19 2010 MODIS image of ash plume.





Land-cover Composition and LST



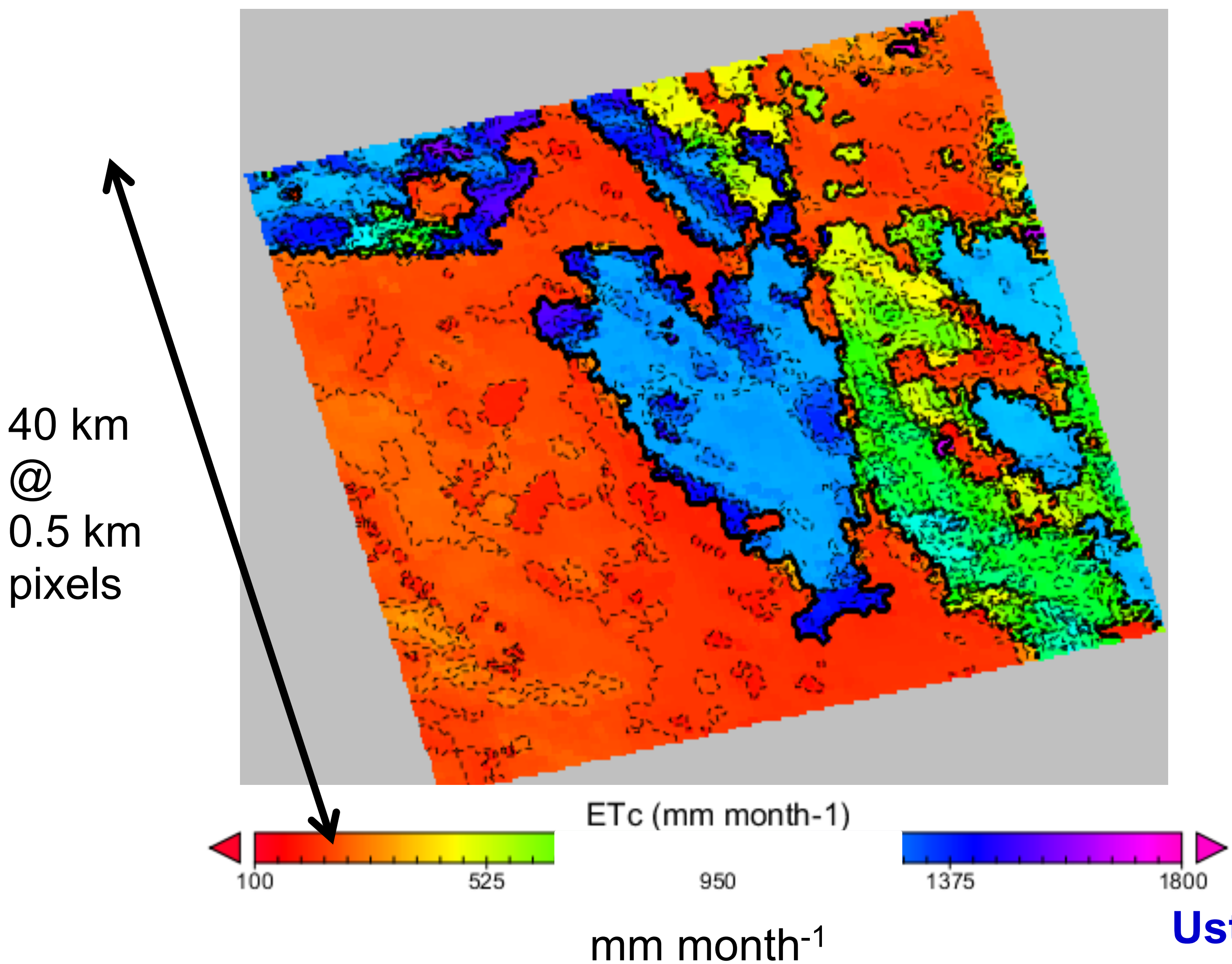
- Cover fractions follow the expected pattern
  - High GV, low Temperature
  - High Impervious, high Temperature
  - Residential
    - Low density, high GV, Low T, low Imp
    - High density, low GV, High T, High Imp

306K  325K

D. Roberts et al. 2012

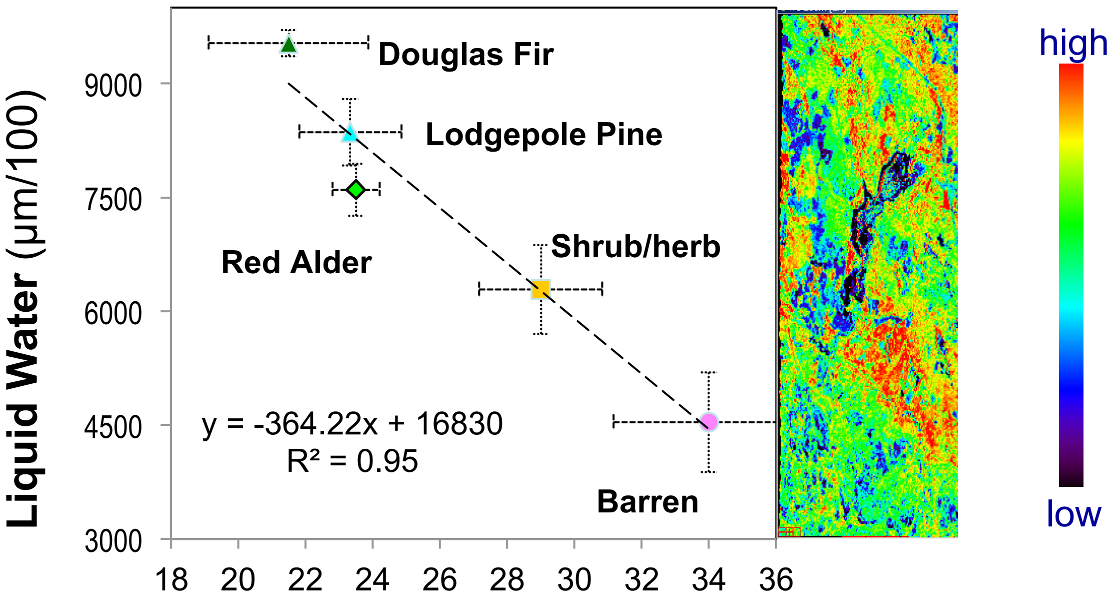
Improving the Evapotranspiration Estimates and Fluxes: Predictions and Estimates

Total Seasonal Crop Evapotranspiration (ETc) for Almond Orchards in the San Joaquin Valley, April 1st through August 31st 2008

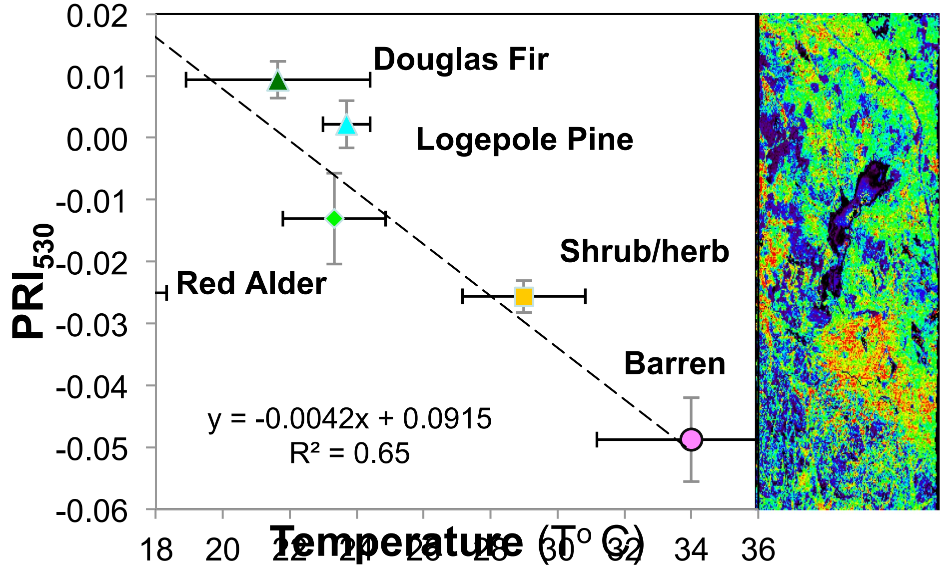


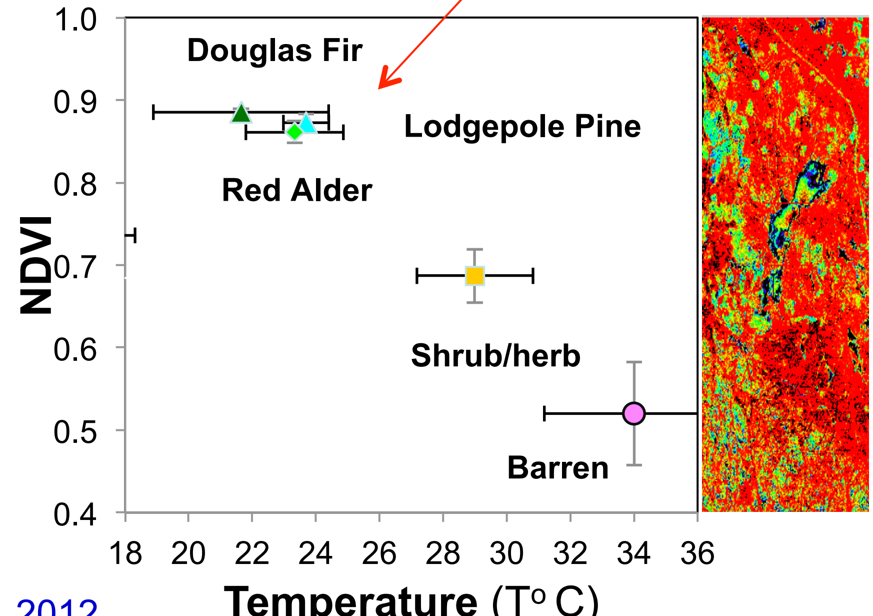
Ustin et al. 2012

Canopy Water, Function, Structure & Temperature



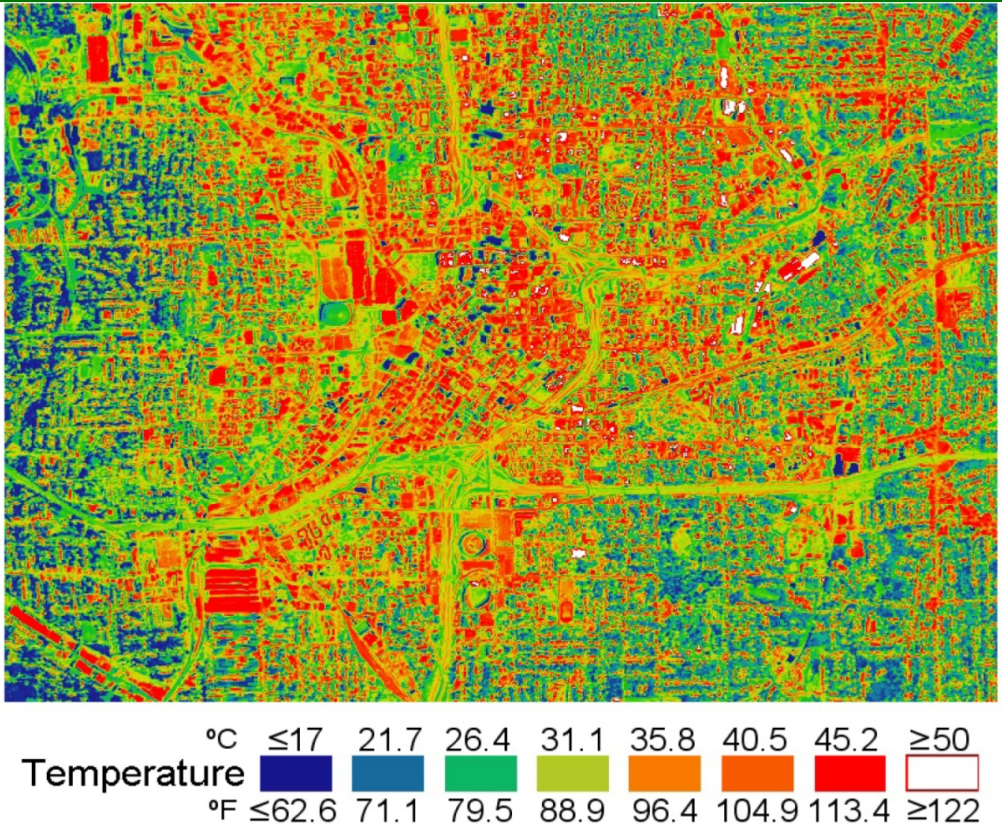
Canopy temperature differences of 3-6 ° C were due to canopy water content (Liquid Water) and function (PRI), at very similar high NDVI.





Campbell, 2012

Urban Heat Islands

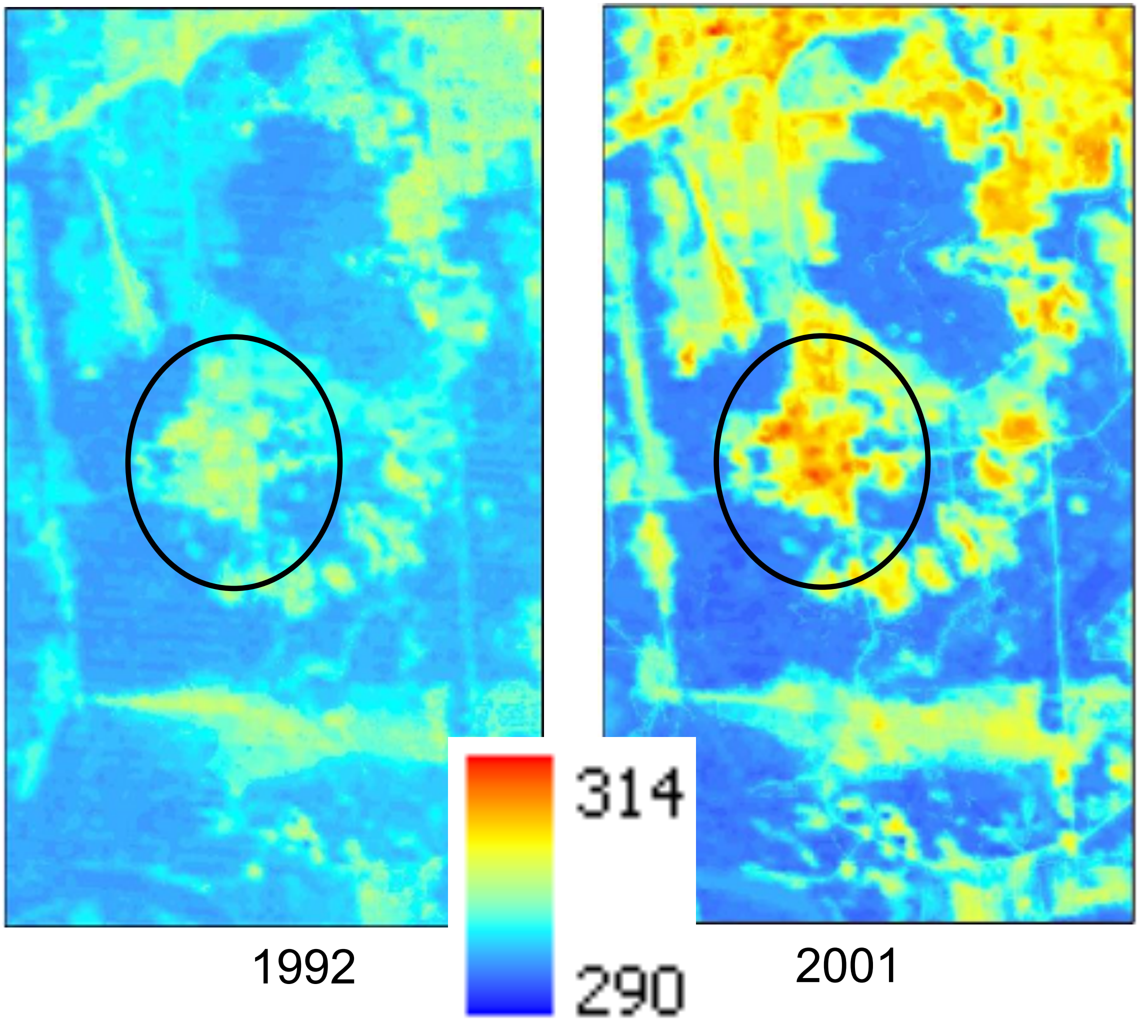


1997 Day time TIR image of Atlanta Georgia
Source: Quattrochi, "HyspIRI Thermal IR (TQ4) Science Questions …."
Image source: Atlas, May 1997

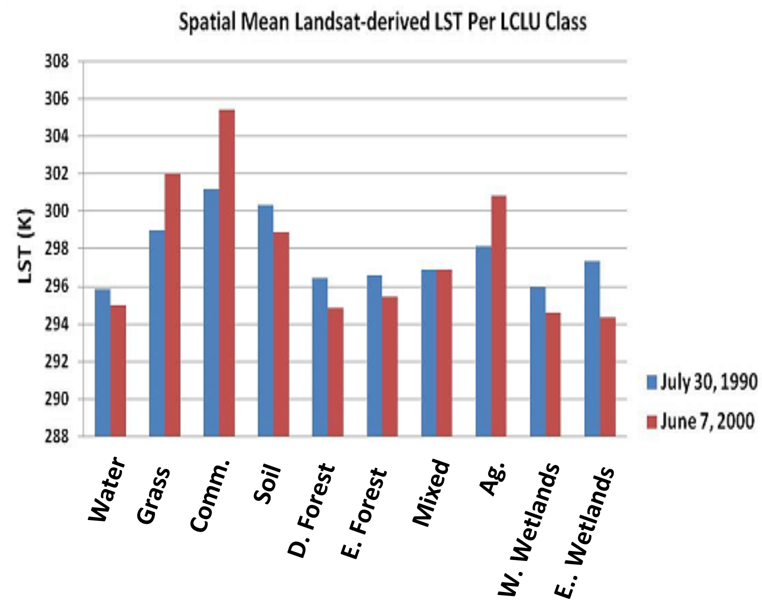
Atlas: 15 channel system
6 TIR, 1 MIR, 8 VNIR-SWIR
http://www.ghcc.msfc.nasa.gov/atlanta/

- **Urban areas are warmer than natural areas**
  - **Low albedo surfaces**
  - **Lack of vegetation cover and shading**
- **Urban areas can create their own weather**

Land Use Change Drives Thermal Change



Conversion of forest, shrub, and agricultural land to MSFC infrastructure substantially changes surface thermal signatures

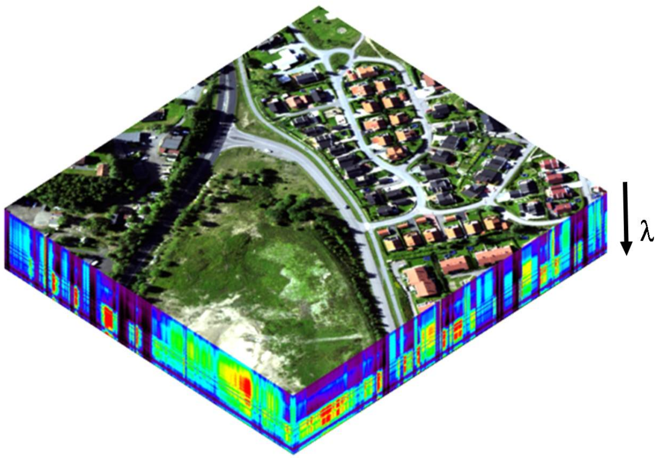


Need to determine impact on local temperatures

(Quattrochi 2012)

Human health, Human ecosystems and Urbanization
Potential Higher Level Products

Through Time



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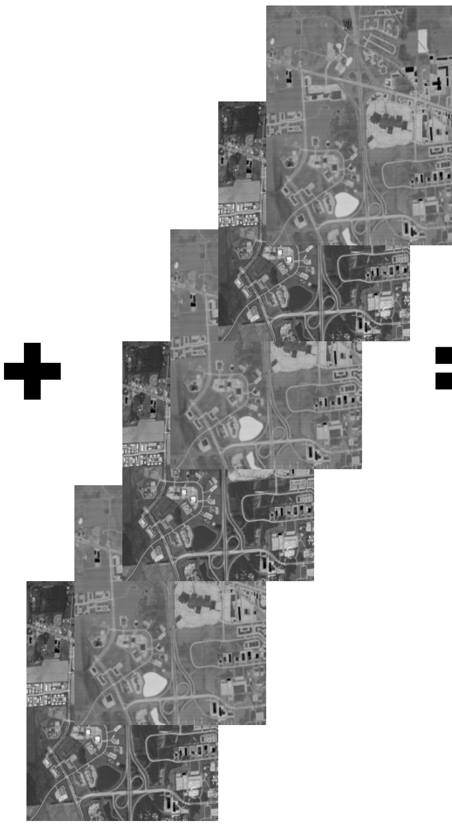

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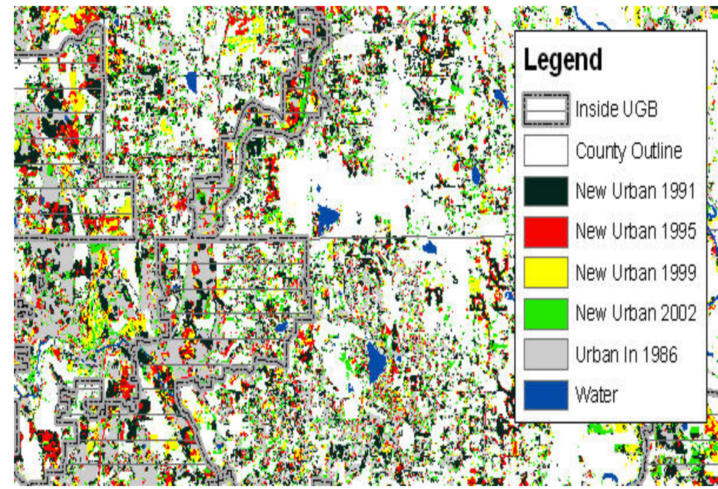


HyspIRI Hyperspectral VSWIR Level II Product
(NDVI, fPAR, surface reflectance characteristics)

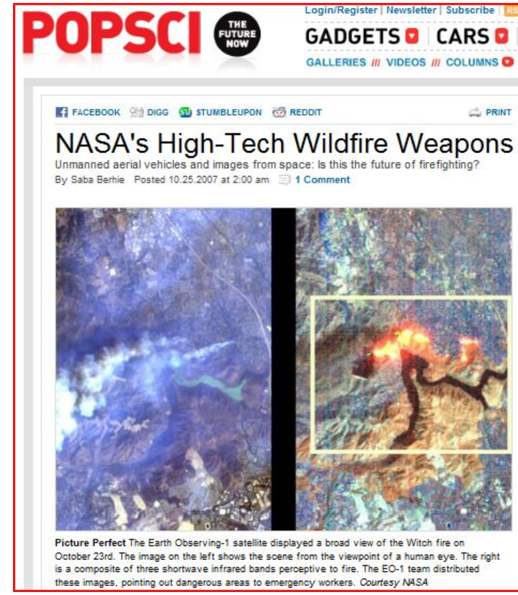
HyspIRI TIR multispectral Level II product (8 TIR Bands)
(surface temperature, radiance, [day/night], emissivity)

HyspIRI VSWIR/TIR composite land cover change data set
(quantitative integrative measurement of urban surface reflectances, temperatures, and emissivity across the urban ecosystem as they change through time)

Quattrochi 2012

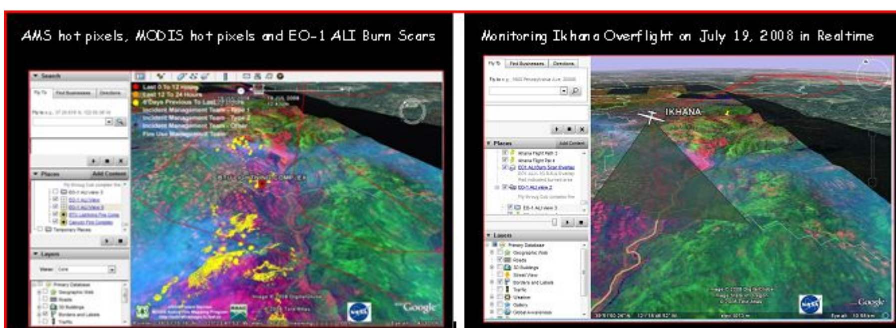
Fire SensorWeb Experiments with U.S. Forest Service

From 2003 to 2009, SensorWeb team conducted a variety of experiments to identify how best to inject SensorWeb technology into assisting Forest Service to manage large wildfires and assist decision makers. This involved interoperating satellite sensors and an Unmanned Aerial System sensors to produce useful data products to assist U.S Forest Service emergency managers.



Detect: National Fire Interagency Center (NIFC) large fire map and MODIS daily hot pixel maps acted as triggers
Respond: Trigger EO-1 and Unmanned Aerial System (UAS) images automatically to take a detailed look
Product Generation: Active fire maps, burn scar maps
Delivery: Experimented with various web based delivery such as mash up displays and RSS feeds

"An exciting aspect of the SensorWeb capability is the ability to automatically image, process and deliver higher resolution satellite imagery products online with little effort."
Everett Hinkley
National Remote Sensing Program Manager



NASA Decadal Survey HyspIRI

Higher Level Products for HyspIRI – Discussion Summary

#	Product	Level (L2/3/4)	Maturity	MODIS	Landsat	Models	Notes
Reflectance & TIR Products							
A.	***Global Products for Data Continuity***						
1	Convolved Reflectance to other sensors (long term data recors; narrowband/broadband)	3	yes	yes	progress	yes	R(%), LEDAPS, WELD algorithms
2	Symulated LST for other sensors (e.g. MODIS, LDCM/TIRS)	2	yes	yes	yes	yes	LST (T C^o)
3	Fractional land cover type (FLC) [continuous fields, % of land cover: soil, water, vegetation, ice&snow]	3	yes	yes	yes	yes	for long term records continue MODIS product, test f(PV, NPV) for vegetation cover
4	Thermal Anomalies	4	yes		yes/limited	yes	
B.	***Terrestrial (veg. & soil)***						
I.	**Spectral End-member Abundance**	3	in progress	no	no	no	Local Spectral libraries (cal/val) needed
	- mineral maps, veg type maps						
II.	**Vegetation Spectral Bio-indicators (VIs)**	3/4	in progress	EVI, NDVI	TM 5/4, 4/3 etc.	progress	
	- water, cellulose, chlorophyll, general stress	3	in progress	yes/limited	no	no	
	- nitrogen	4	in progress	no	no	yes	Local Spectral libraries and chemistry (cal/val)
	- hot spots	4	in progress	yes/limited	yes	no	
	- LST per VFC and LC	4	in progress	yes/limited	in progress	no	
III.	**Canopy function Yield (CO2 sequestration, GPP, NEP)**						
	- LUE, WUE	4	in progress		no	yes	
	- ET	4	in progress		no	yes	
IV.	**Classifications**						
1	**Fractional vegetation cover (FVC)** *[photosynthetic vegetation [PV] or non-photosynthetic vegetation [NPV], Soil]*	3	yes	no	limited		AutoMCU or equivalent (SWIR and red-edge with tied spectra)
2	**Fractional cover by plant functional type (PFTs)**	4	in progress	see below	no	yes	Required by DVGM (dynamic global vegetation models) end ESM (Earth system models); At launch 2-6 types/km^2, goal 6-10 resolved
V.	**Terrestrial Products Supporting Long Term Data Records**						For HyspIRI products context, and for long term records continuity
1	**MODIS Vegetation Continuous Fields (VCF - cotext &**	4	yes	yes			
	- life form (proportion of woody vegetation, herbaceous	4	yes			yes	
	- leaf type (proportion of woody vegetation that is needle	4	yes			no	
	- leaf longevity (proportion of woody vegetation that is	4	yes			no	
2	**Ecological disturbance (NPV increase)**	4	yes, global on progress	Fire product	LEDAPS		Based on PV, spectral change diagnosing disturbance type; decline/recoveery; for land history
	- Land cover conversions	4	yes, global in progress	yes	yes/limited	yes	Terrestrial ECVs: LC, permafrost, glaciers/ice, LAI, fire
	- Severe wind, deought, insect, etc.	4	in progress	yes	yes/limited	yes	False alarm a possibility
	- Fires (VISWIR detection, severity)	4	in progress	yes	yes/limited		
VI.	**Biodiversity**						
	- Optical types diversity	4	initialized	no	no	yes	see publication on the topic by Usting and Gammon
	- Plant functional diversity	4	initialized	no	no	yes	see publication on the topic by Asner, Wright, et al.
	- Biodiversity indicators	4	in progress	no	no	yes	Spectral corelation with bio-diversity

#	Product	Level (L2/3/4)	Maturity	MODIS	Landsat	Models	Notes
C.	***Aquatic [shallow water, rivers, lakes]***						
1	Remote Sensing Reflectance (Rrs)	2 or 3	yes, operational	yes	no		Remote Sensing Reflectance = water-leaving radiance (Lw) / downwelling irradiance (Ed); (Rrs, units sr-1, 400–800 nm) ; This is the result
2	Sea Surface Temperature	2-Jan	yes, operational	yes	no		Routine product from many satellites.
3	Seafloor Spectral Reflectance (units %, 400–??? nm)	3	in progress	no	no		Combined results from aquatic retrieval
4	Water Depth	3	in progress	no	no		There are several candidate algorithms in
5	Water Optical Properties	3	in progress	yes	no		-"-
6	Retrieval Quality Flags	3	in progress	na	no		-"-
7	Fractional Cover	3	in progress	na	no		Derived from Rrs, mixture decomposition methods need scaling to HyspIRI data
8	Pigments (e.g. chlorophyll)	3	mature, work in progress to separate aquatic sources	yes	no		Derived from Rrs, work in progress to separate contributions of planktonic, submerged and emerged aquatic sources
9	Light-Use Efficiencies (for (1) Productivity and (2) Calcif	3	in progress	yes	no		There are few investigations for shallow
	- Productivity (Gross/Net)	4	in progress	yes	no		Investigations for fresh water bodies, needs synthesis of fresh, coastal and deep ocean
	- Calcification	4	not initialized	na	no		There are no existing algorithms, and there have been (virtually) no investigations
10	Water content Dissolved Organic Mater (DOM)	4	in progress	yes	no		Investigations for fresh water bodies, needs synthesis of fresh, coastal and ocean methods
11	Degree Heating Weeks	3	mature	yes	no		Routine product from many satellites.
D.	***Snow/Ice [high latitudes, high***						**Input to be obtained from:**
	Snow cover, Ice caps, Glaciers	3/4	no experts present				**Dorothy Hall, Jeff Dozier, Thomas Painter**
Top of Atmosphere and Localized Products, and By-products of Level 2 Processing							
1	TOA Optical and TIR Radiance (bands)	1B	yes	yes/limited	yes/limited		
2	Volcanoes eruption, size, prognosis	4	yes	yes/limited	yes/limited	yes	
3	Clouds (masks)	3	yes	yes	yes/limited		
4	Incident PAR (direct, diffuse PAR)	3				yes	
5	Water vapor product	3	yes			yes	
6	Aerosol optical depth product	3	yes	no	no	no	
7	Albedo	4	in progress	yes	no		

Topic 1. Ecosystem Function & Composition Questions

VQ1. Ecosystems Pattern and Spatial Distribution and Components

What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity?

VQ2. Ecosystem Function, Physiology and Seasonal Activity

What are the seasonal expressions and cycles for terrestrial and aquatic ecosystems, functional groups, and diagnostic species? How are these being altered by changes in climate, land use, and disturbance?

VQ3. Biogeochemical Cycles

How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems and what are the feedbacks with other components of the Earth system?

VQ5. Ecosystems and Human Well-being

How do changes in ecosystem composition and function affect human health, resource use, and resource management?

CQ1. Coastal, ocean, and inland aquatic environments

How are local and landscape-scale changes in inland, coastal, and open ocean aquatic ecosystems related to changes in variability in regional and global climate?

CQ4. Ecosystem Function and Diversity

How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?

Topic 2. Disturbances & Human Impact Questions

VQ4. Ecosystem Response to Disturbance

How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

TQ3. Water Use and Availability

How is consumptive use of global freshwater supplies responding to changes in climate and demand, and what are the implications for sustainable management of water resources?

TQ5. Earth surface composition and Change

What is the composition and temperature of the exposed surface of the Earth? How do these factors change over time and affect land use and habitability?

CQ2. Wildfires

How are fires and vegetation composition coupled?

CQ6. Human Health and Urbanization

How do patterns of human environmental and infectious diseases respond to leading environmental changes, particularly to urban growth and change and associated impacts of urbanization?

Topic 3. Volcano, Natural Hazard & Mineral/Resource Questions

TQ1. Volcanoes

How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?

CQ3. Volcanoes

Do volcanoes signal impending eruptions through changes in the temperature of the ground, rates of gas and aerosol emission, temperature and composition of crater lakes, or health and extent of vegetation cover?

TQ2. Wildfires

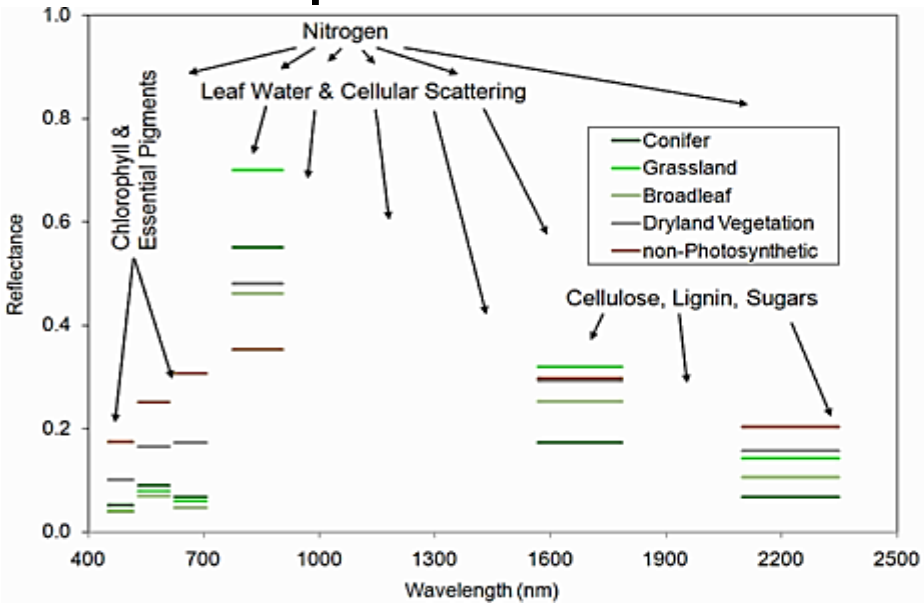
What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?

CQ5. Land Surface Composition and Change

What is the composition of exposed terrestrial surface of the Earth and how does it respond to anthropogenic and non anthropogenic drivers?

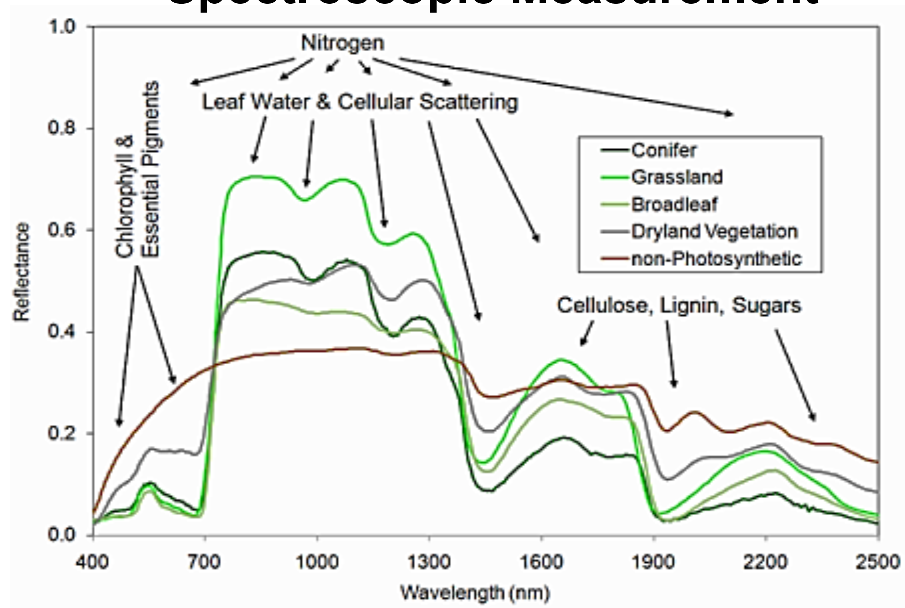
Spectral Measurements are Required for Global Ecosystem Assessments

Multi-Spectral Measurements



Multi-spectral imaging is insufficient to derive the required terrestrial surface compositional parameters accurately.

Spectroscopic Measurement



Full range imaging spectroscopy is required to measure composition, chemistry, health and change of ecosystems.

- *Plant species and functional types have biochemical and biophysical properties that are expressed as **reflectance, absorption and scattering features** spanning the spectral region from 380 to 2500 nm.*
- *Individual bands do not capture the **diversity of biochemical and biophysical signatures** of plant functional types, species or physiological condition.*
- *Changes in the chemical and physical configuration of ecosystems are expressed as **changes in the contiguous spectral signatures** related to plant functional types, physiological condition, vegetation health, and species distribution.*

Green et al.