NASA's Future HyspIRI Mission and the EO-1 Hyperion Collections

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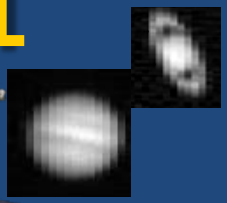
Woody Turner
(NASA HQ)

Hyperspectral Imaging and Sounding of the Environment (HISE)
July 10-14 2011, The Westin Harbour Hotel, Toronto, Ontario, Canada
Session Title: Spectral Analyses, Presider Martin Mlynczak

March 2009

10 Years of Earth Observing-1



NASA

Goddard Space Flight Center Greenbelt, MD

Betsy Middleton & Dan Mandl

Steve Ungar, Lawrence Ong, Stuart Frye, Petya Campbell, Nathan Pollack, Dave Landis, Joe Young, Fred Huemmrich, Yen-Ben Cheng, Qingyuan Zhang & Larry Corp

Event support: Lisa Henderson

EO-1 10th Anniversary, December 1, 2010

http://eo1.gsfc.nasa.gov

EO-1 Beginnings

Original Mission Goals (2000):

● Enable entirely new measurements and science missions from space.

●Fly three revolutionary Land Imaging instruments to ***collect multispectral and hyperspectral scenes*** over the course of the mission ***in coordination with the Landsat-7 Enhanced Thematic Mapper*** (ETM+).

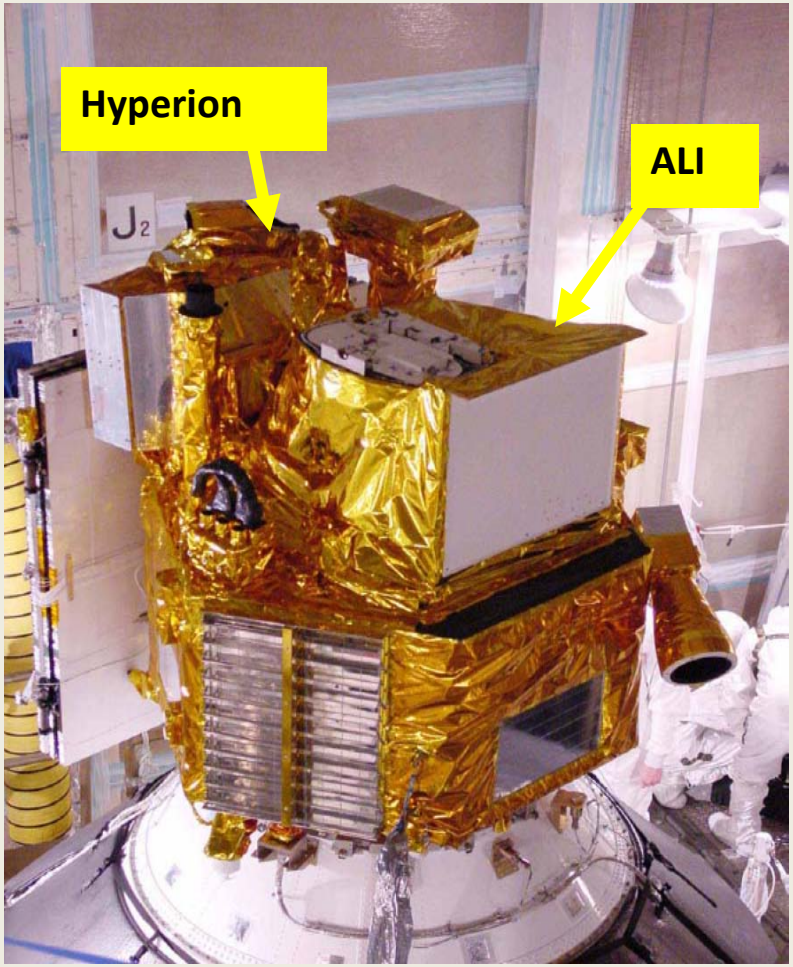
- Detailed comparisons with ETM+ images were carried out to validate these instruments for future missions.

● Reduce costs of future space and Earth science missions with:

- ***Breakthrough technologies in lightweight materials,***
- ***High performance integrated detector arrays, and***
- ***Precision spectrometers.***

Earth Observing-1 (EO-1) Mission

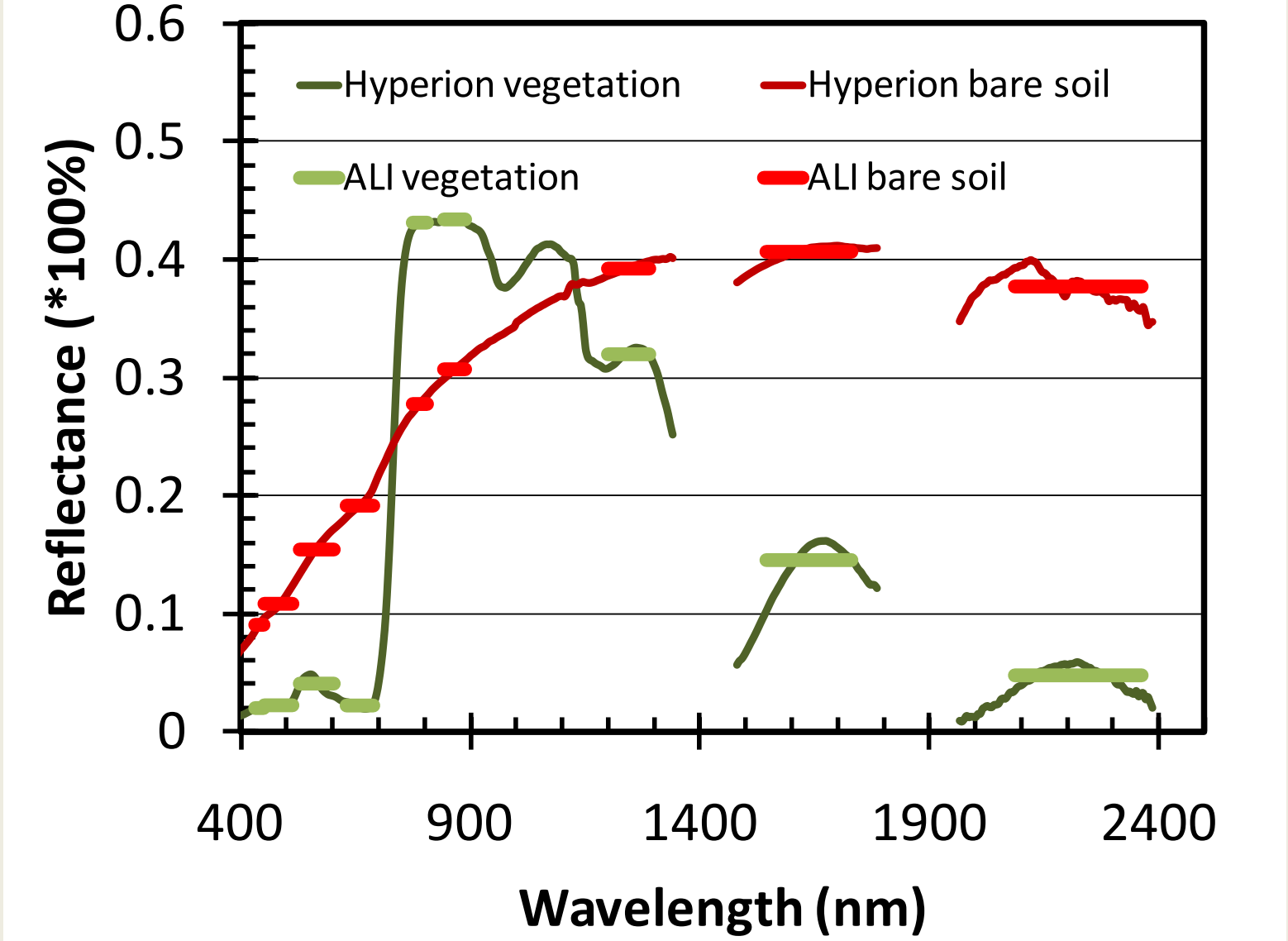
Mission Scientist, Dr. Elizabeth Middleton (NASA/GSFC, 614.4)
Mission Manager, Mr. Daniel Mandl (NASA/GSFC, 581)



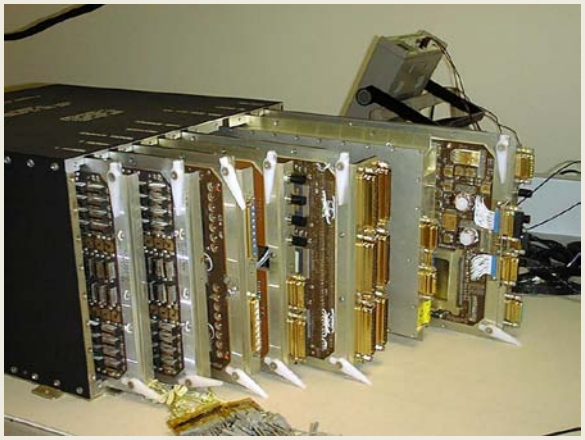
http://eo1.gsfc.nasa.gov/

ALI		Hyperion
Band designations	**Band Names (wavelength, μm)**	
Pan	Pan (0.48 – 0.69)	Continuous Spectra 0.4 – 2.4 μm 242 Bands Bandwidth: 10nm
Blue	MS-1p (0.433 – 0.453)	
	MS-1 (0.450 – 0.515)	
Green	MS-2 (0.525 – 0.605)	
Red	MS-3 (0.633 – 0.690)	
NIR	MS-4 (0.775 – 0.805)	
	MS-4p (0.845 – 0.890)	
SWIR	MS-5p (1.20 – 1.30)	
	MS-5 (1.55 – 1.75)	
	MS-7 (2.08 – 2.35)	
Spatial Resolution	Pan: 10m, MS: 30m	30m
Swath width	~35km	~7.5km

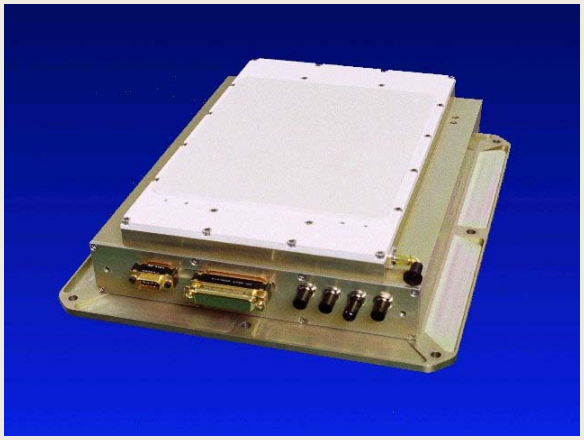
Vegetation and Bare Soil Spectra for Hyperion and ALI



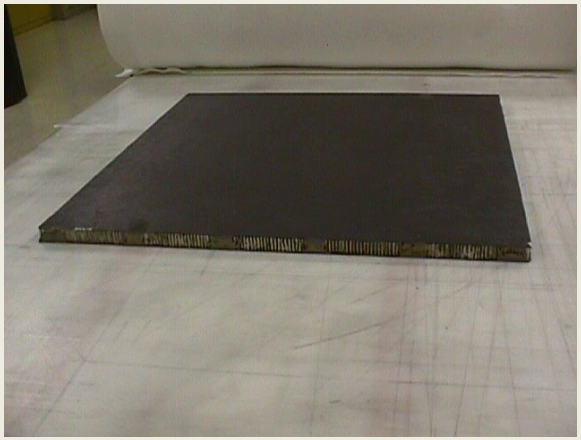
EO-1 Supporting Technologies



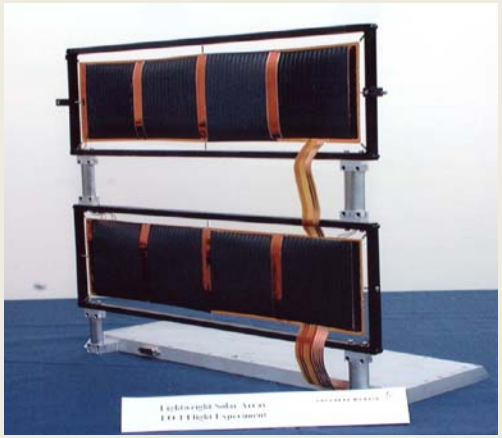
Advanced Recorder Processor



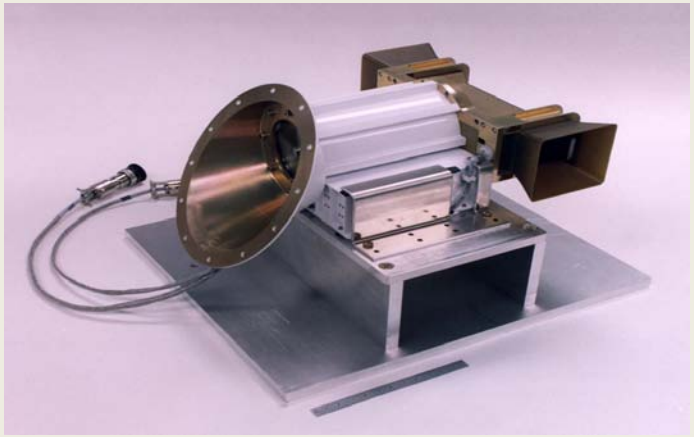
X-Band Phased Array Ant Wideband enna



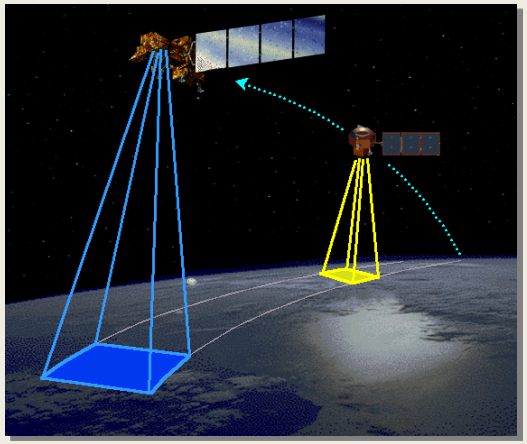
Carbon-Carbon Radiator



Lightweight Flexible Solar Array

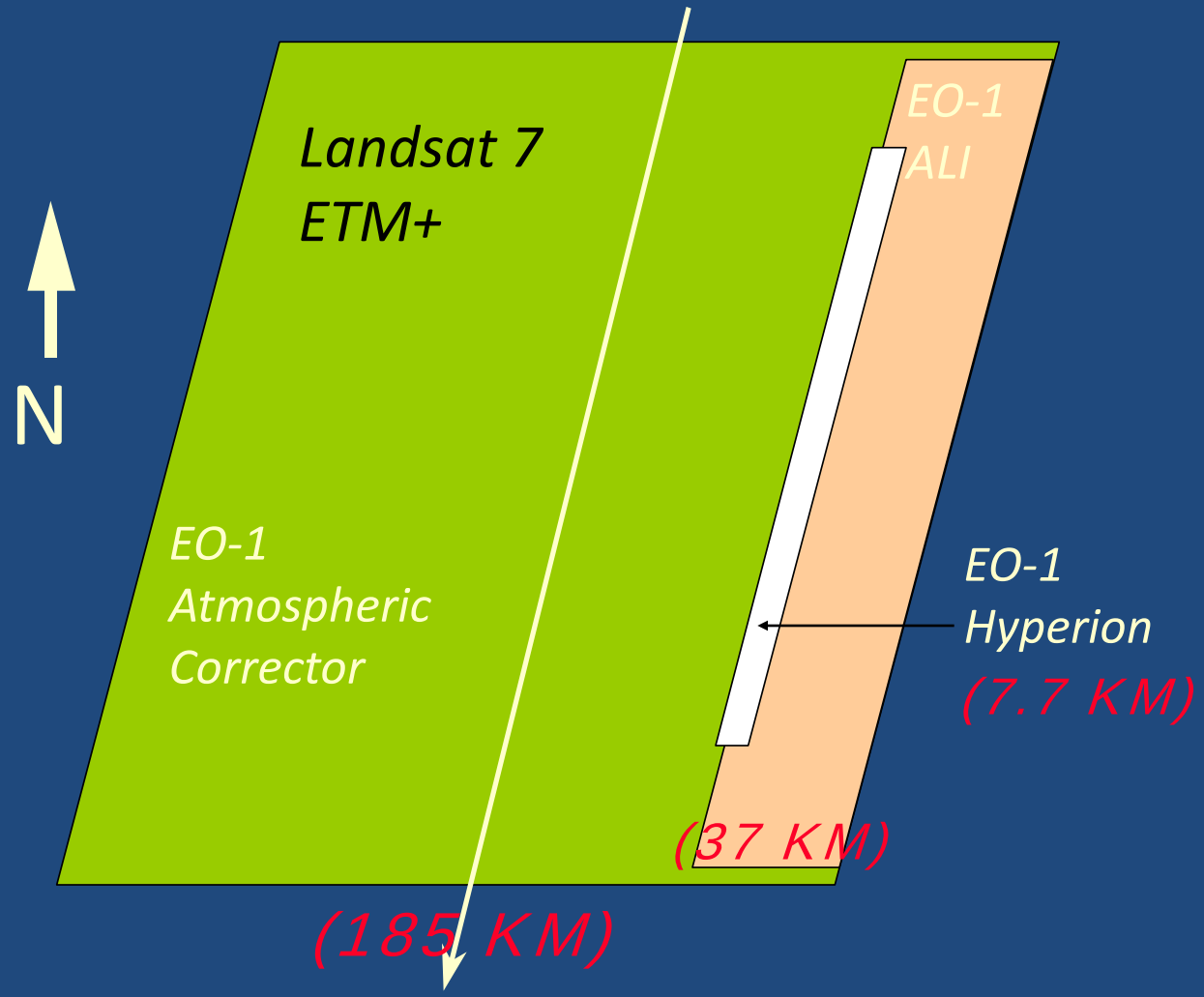


Pulse Plasma Thruster

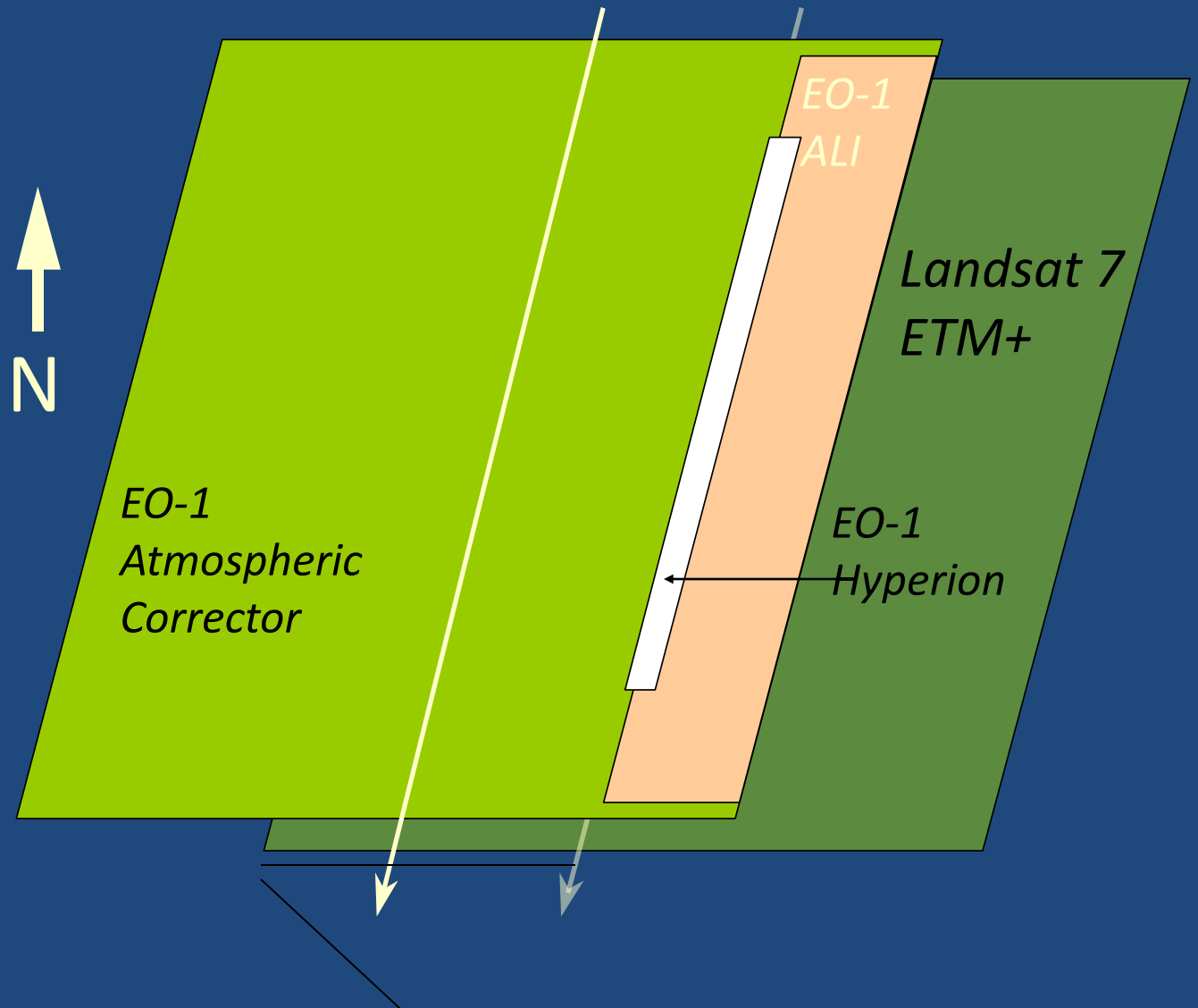


Formation Flying

EO-1 and Landsat 7 Descending Orbit Ground Tracks

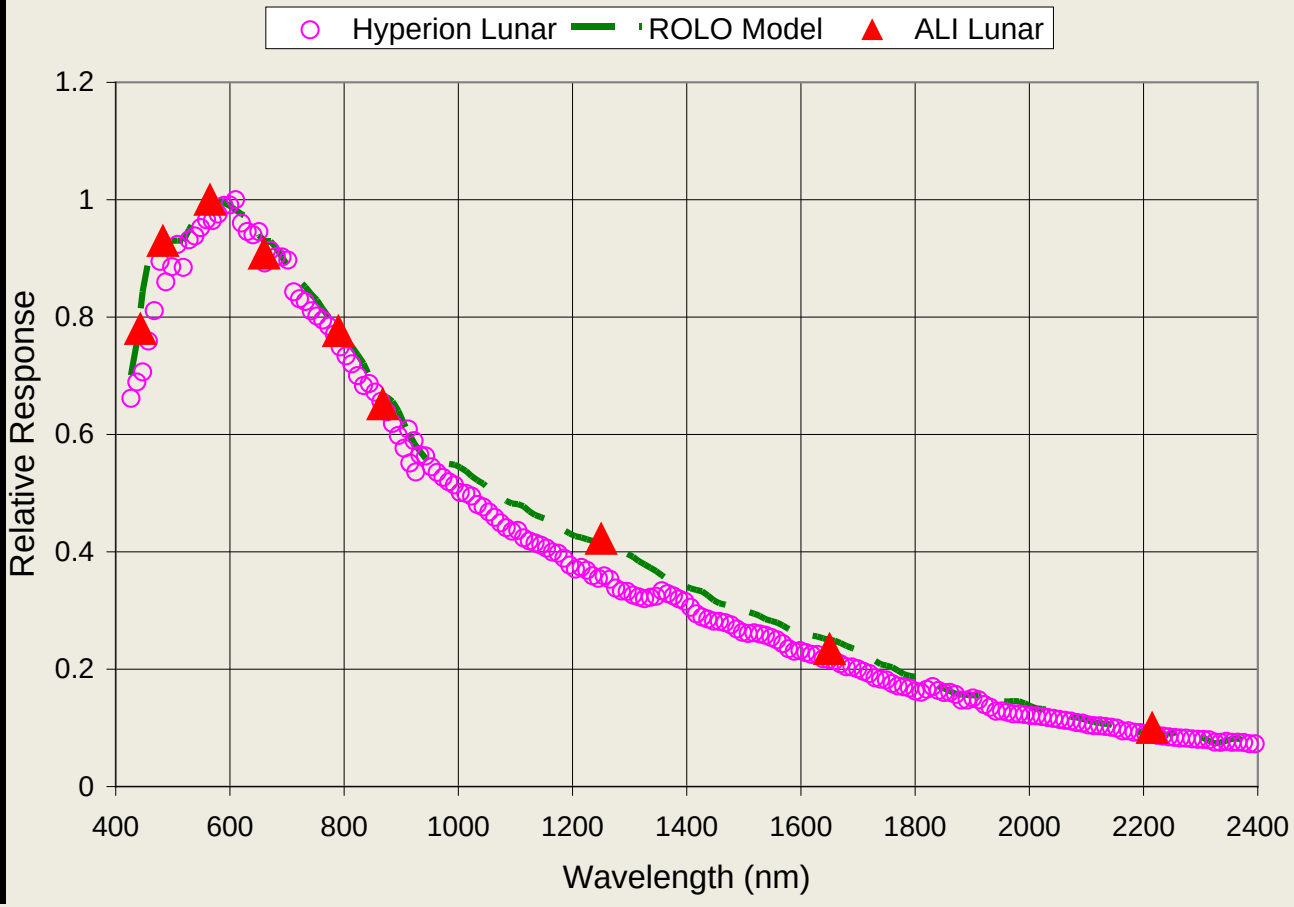


EO-1 Off-Nadir and Landsat 7 Descending Orbit Ground Tracks



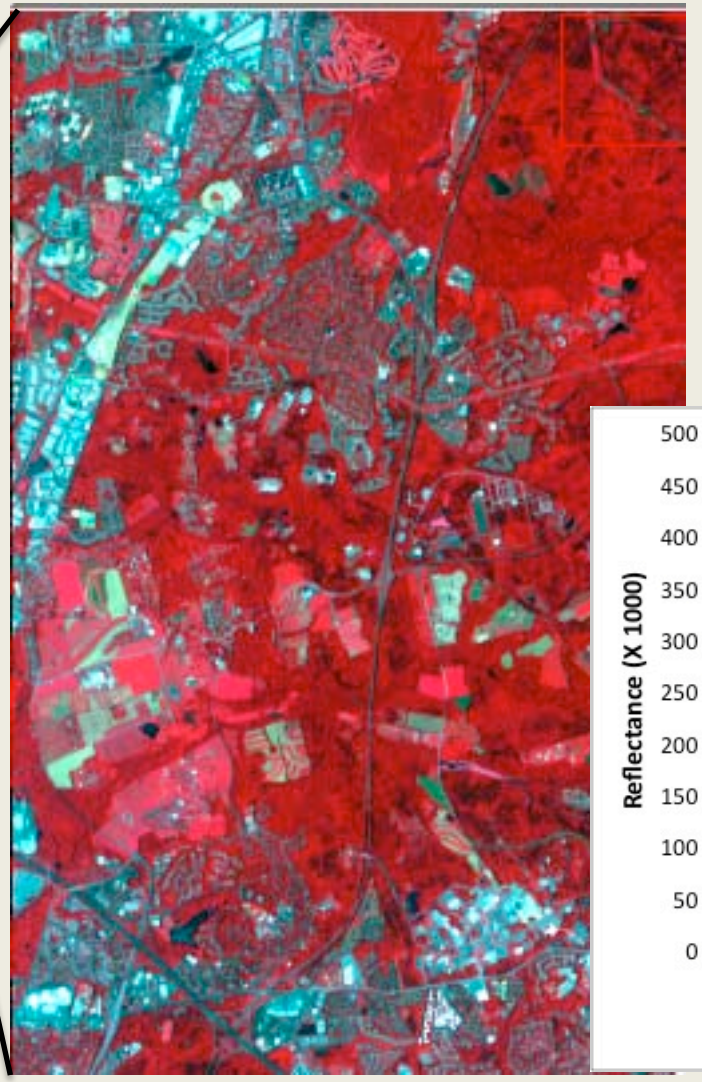
Hyperion Lunar Spectra

March 2010

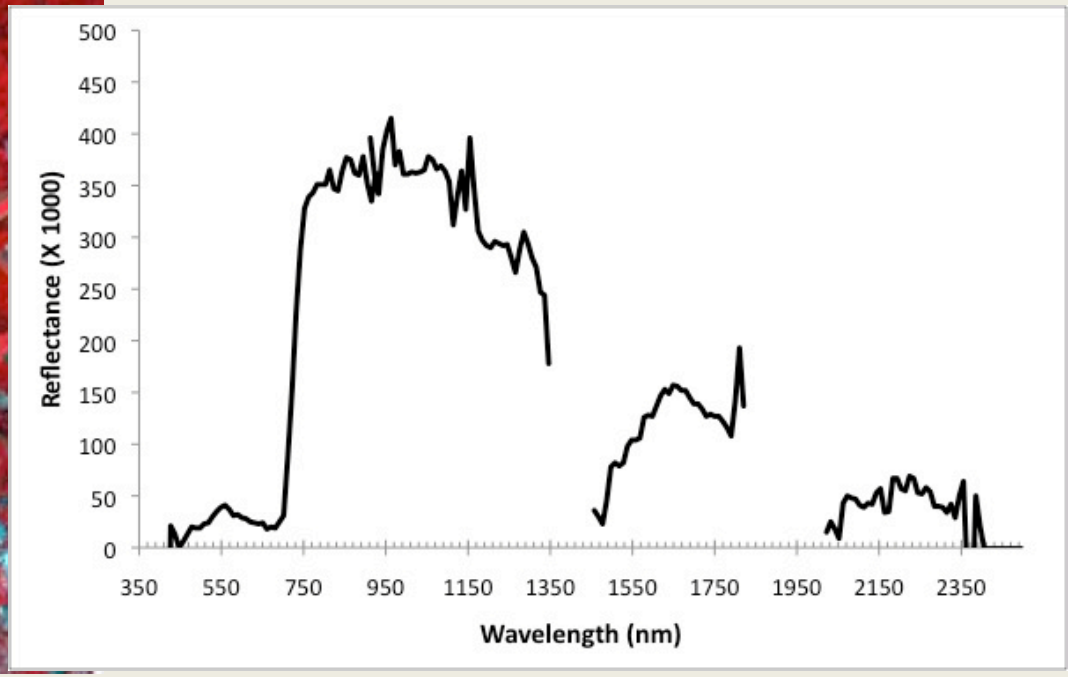


The pitch rate across the moon is the same as that used for earth imaging. This results in a 8X oversampling of the moon.

Hyperion Data Example

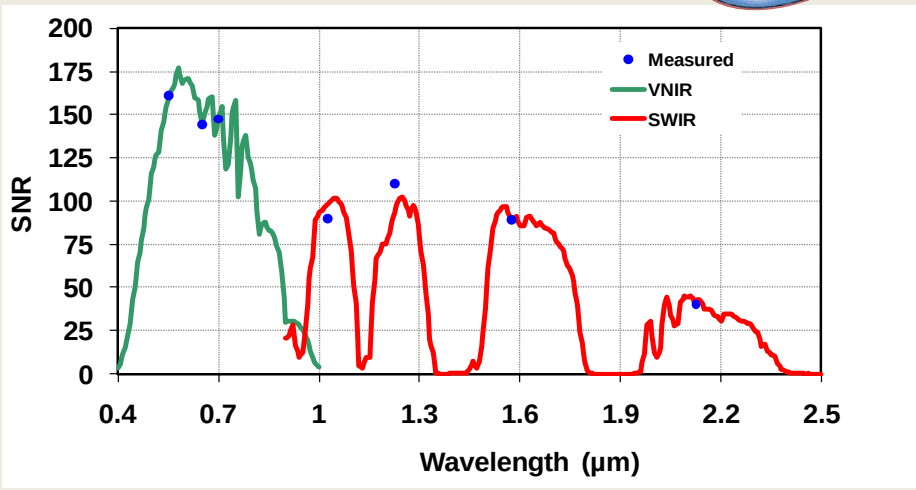


- 30 m pixels
- 7 km swath width
- Hyperspectral
  - -~10 nm bands
  - - 350 – 2500 nm

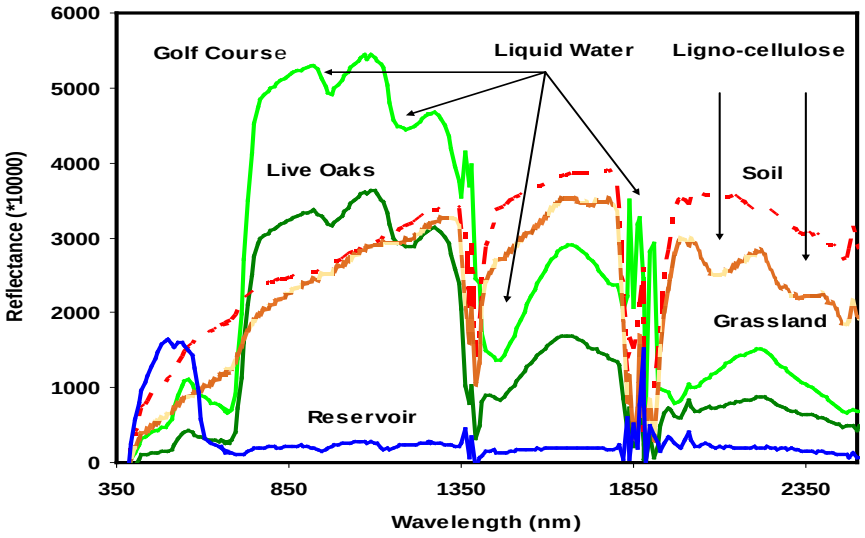


Hyperion Spectral Characteristi

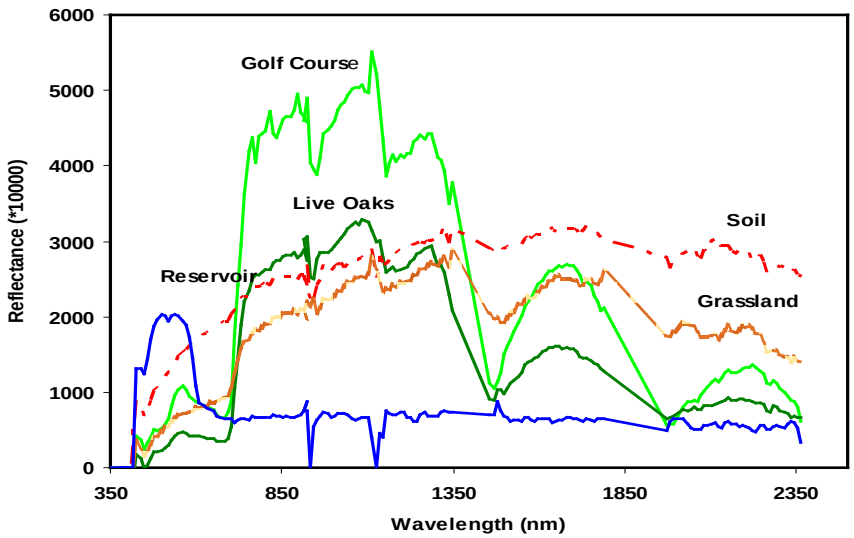
- Radiometric performance model based on a standard mid-latitude summer scene with a 60° Solar zenith angle and 30% surface reflectance



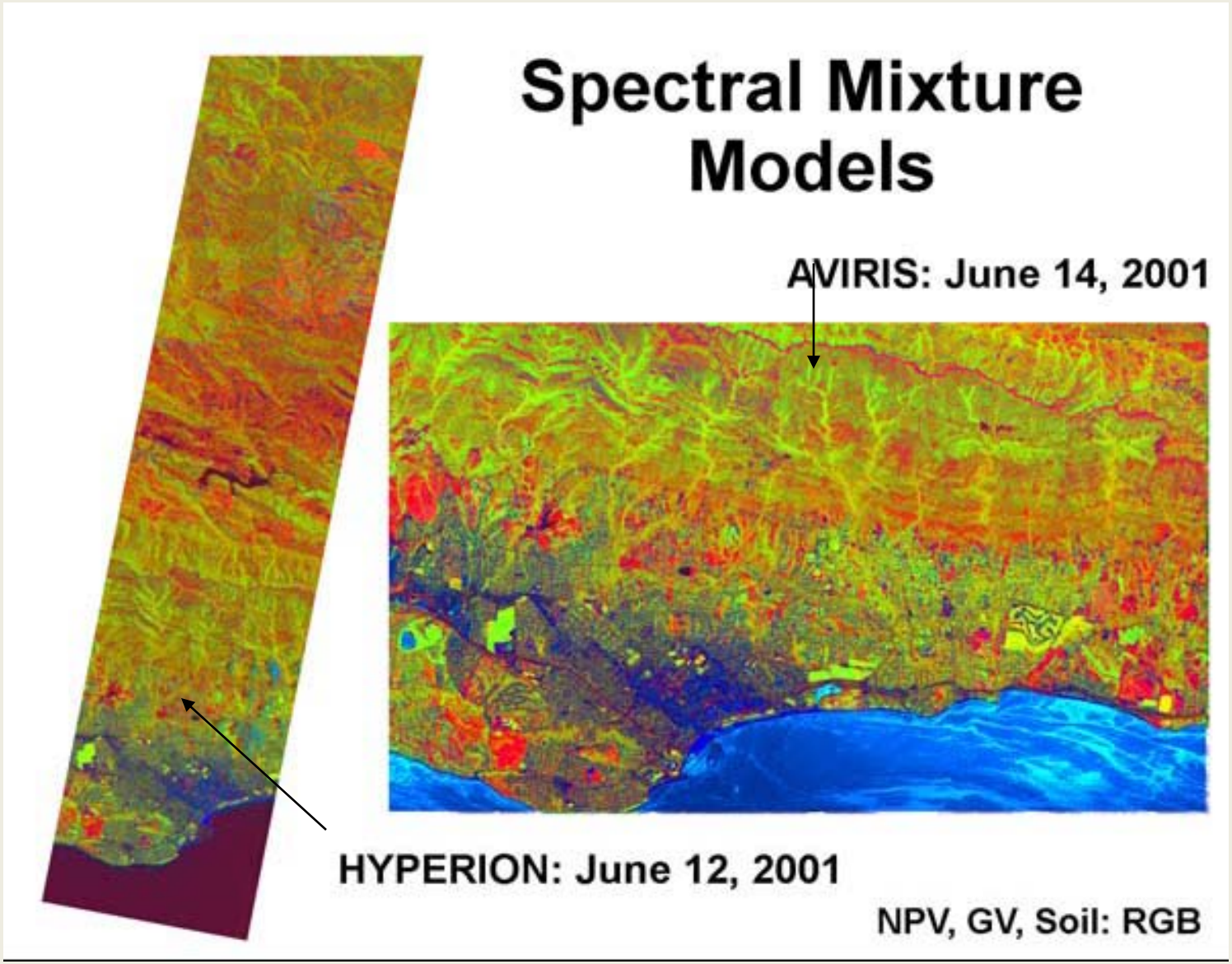
AVIRIS (State of the Art 2002-2004)



Hyperion Performance (~AVIRIS 1992)



Mapping Fuel Condition: Hyperion provides comparable measures to AVIRIS over a larger geographic region



Roberts et al.

Hyperion Science and Technology Applications

Forests

Canada

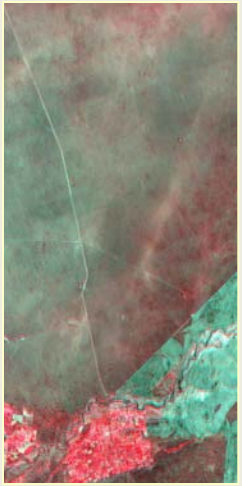
Agriculture

Australia

Minerals

United States

Grasslands



Argentina

Glaciers

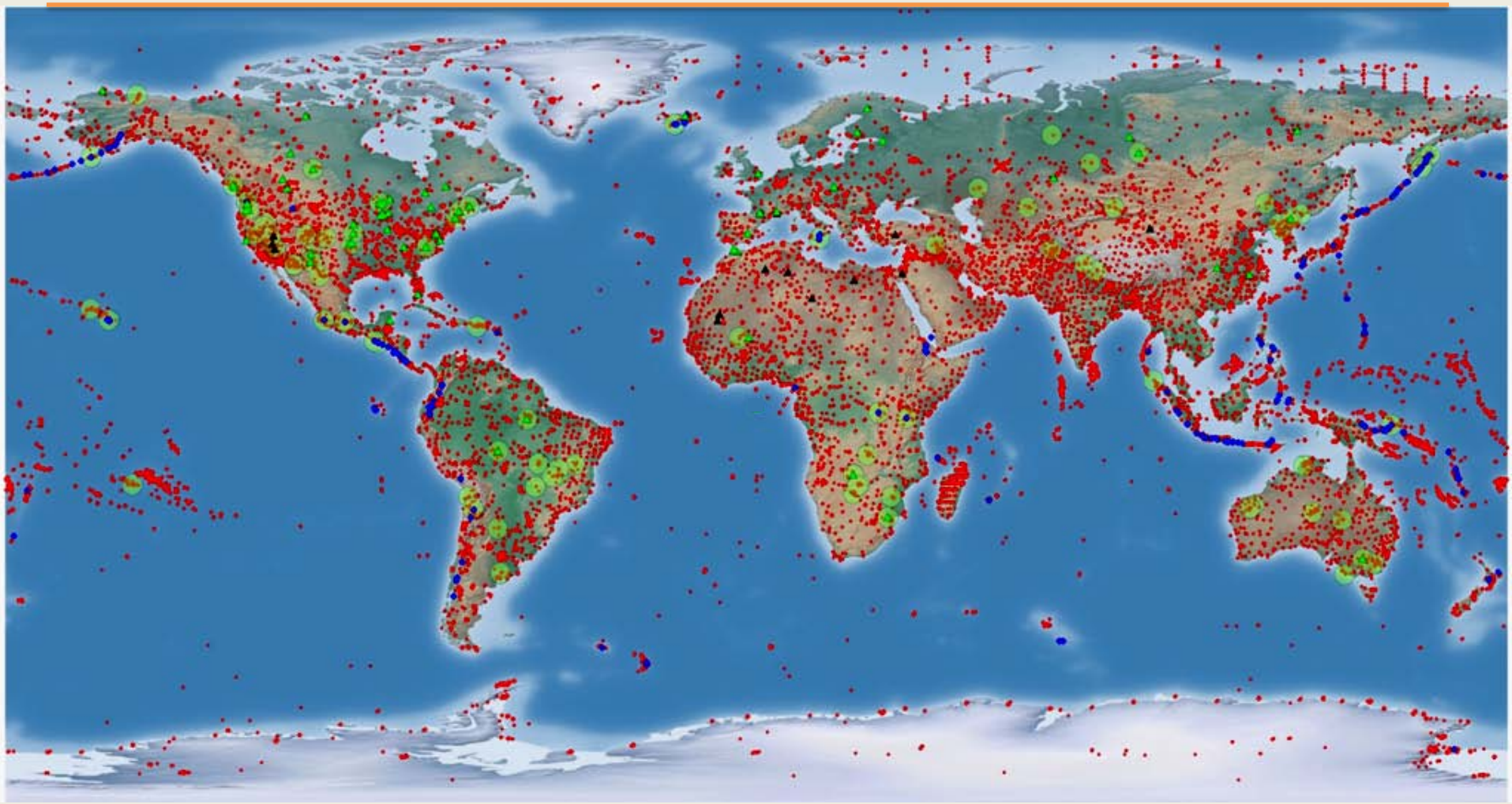
Antarctica

Deserts

Sahara

EO-1 Acquisitions, Dec 2000 – Mar 2011

To date, 52,500+ scenes have been collected



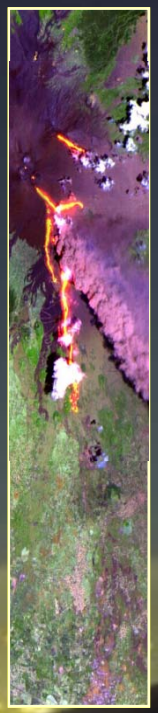
EO-1 Observations ● MSO Sites ▲ CEOS Sites ▲ Volcanoes ◆ > 10 Observations ○

Eruption of Mt. Etna, Sicily

July 22, 2001

ALI Pan Enhanced
Bands 3 -2-1

Hyperion
7-5- 4 Equiv

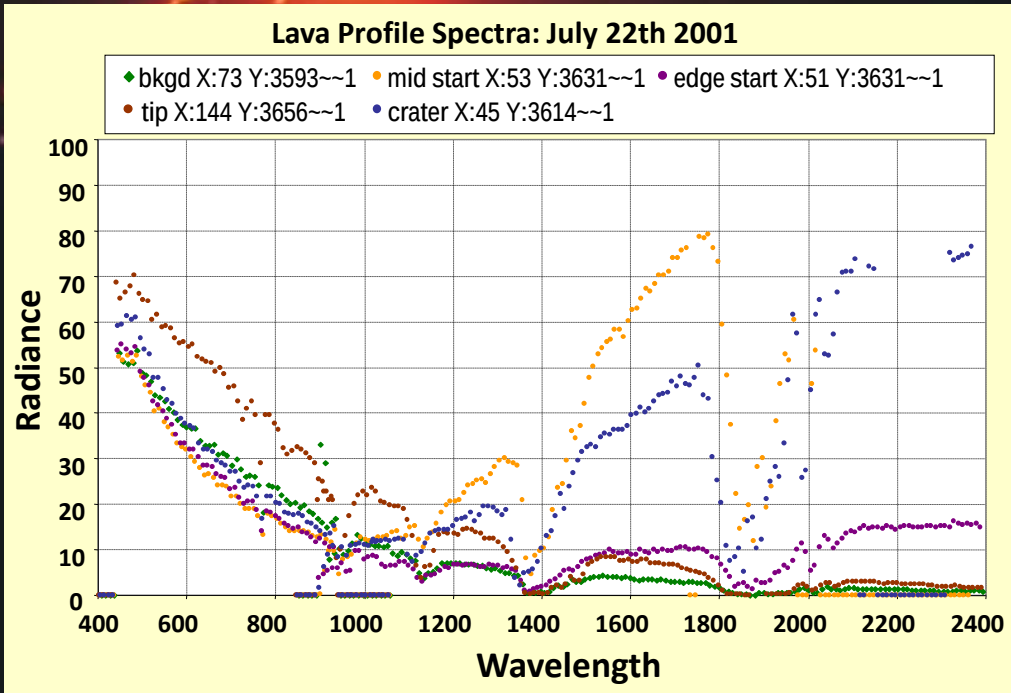


EO - 1 ALI
Bands 7 -5-5'

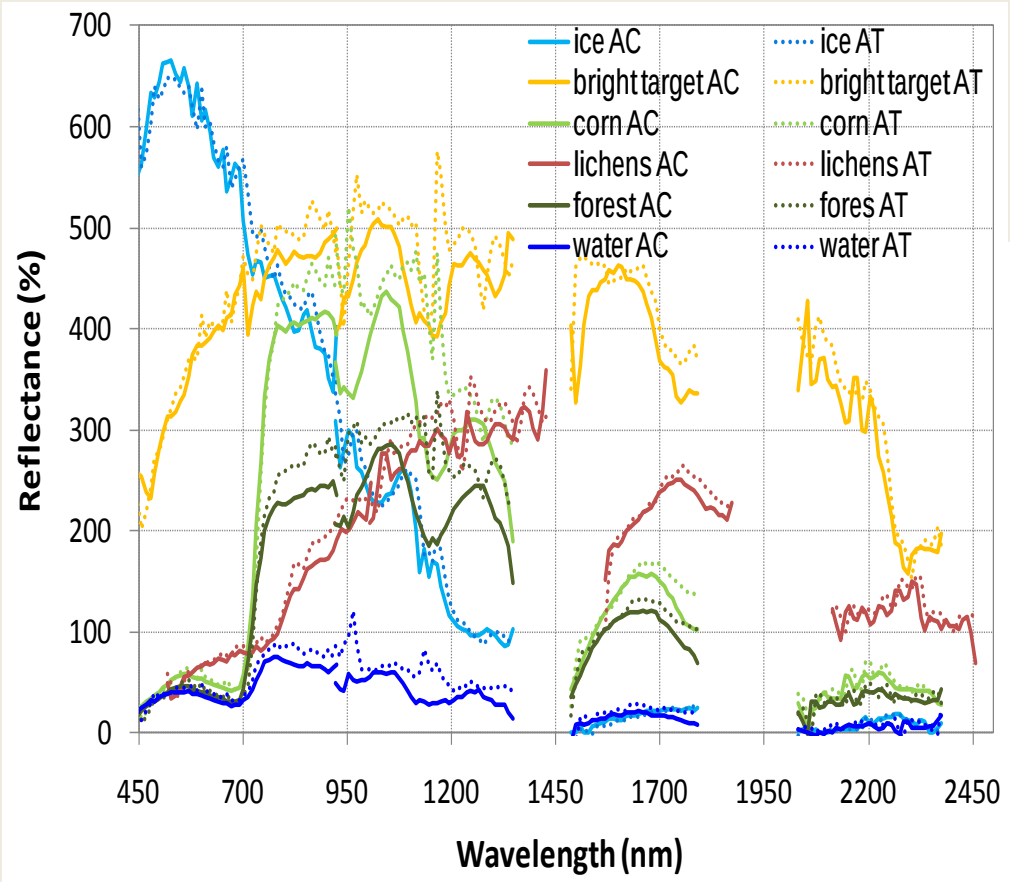
Hyperion Temperatures for Etna

Spectrum	Crust T°C	Hot ToC	Area Hot
J 13-CTB	346 C	994 C	0.0025
J 13-MM	874 C	876 C	0.45
J 13-CTS	976 C	978 C	0.47
J 13-TipX	210 C	900 C	0.00034
J 22-MS	726 C	1075 C	0.090
J 22-CX	487 C	1075 C	0.022
J 22-RS*	1054 C	1058 C	0.690

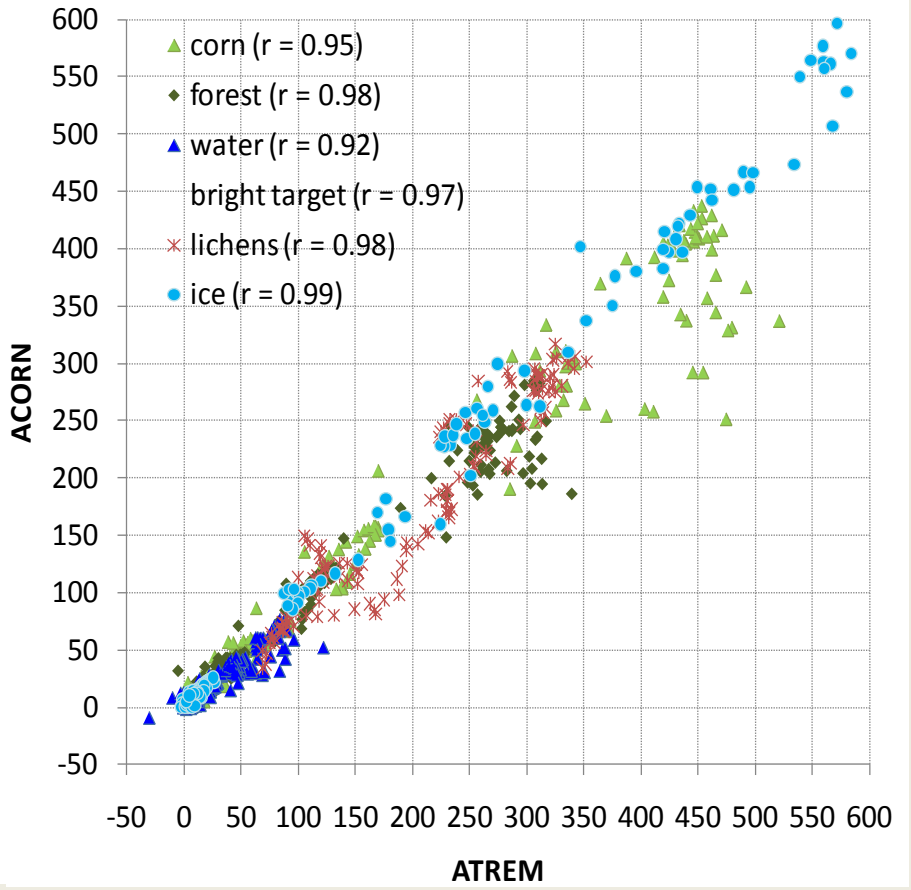
EO-1 Hyperion Spectra



Atmospheric correction of Hyperion spectra with ATREM (AT) and ACORN (AC) for six surface types

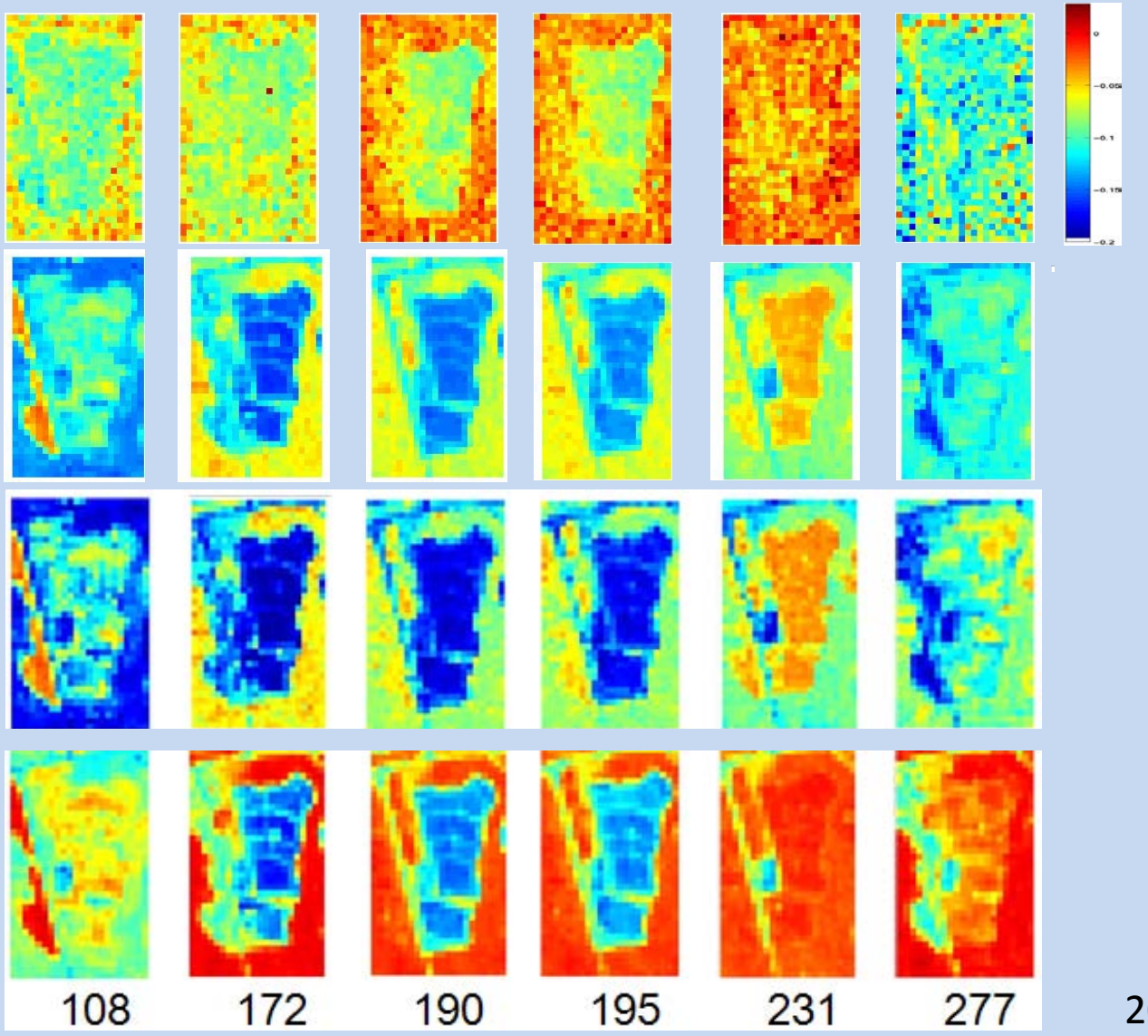


ATREM [AT] = ATmosphere REMoval , and
ACORN [AC] = Atmosphere CORrection Now

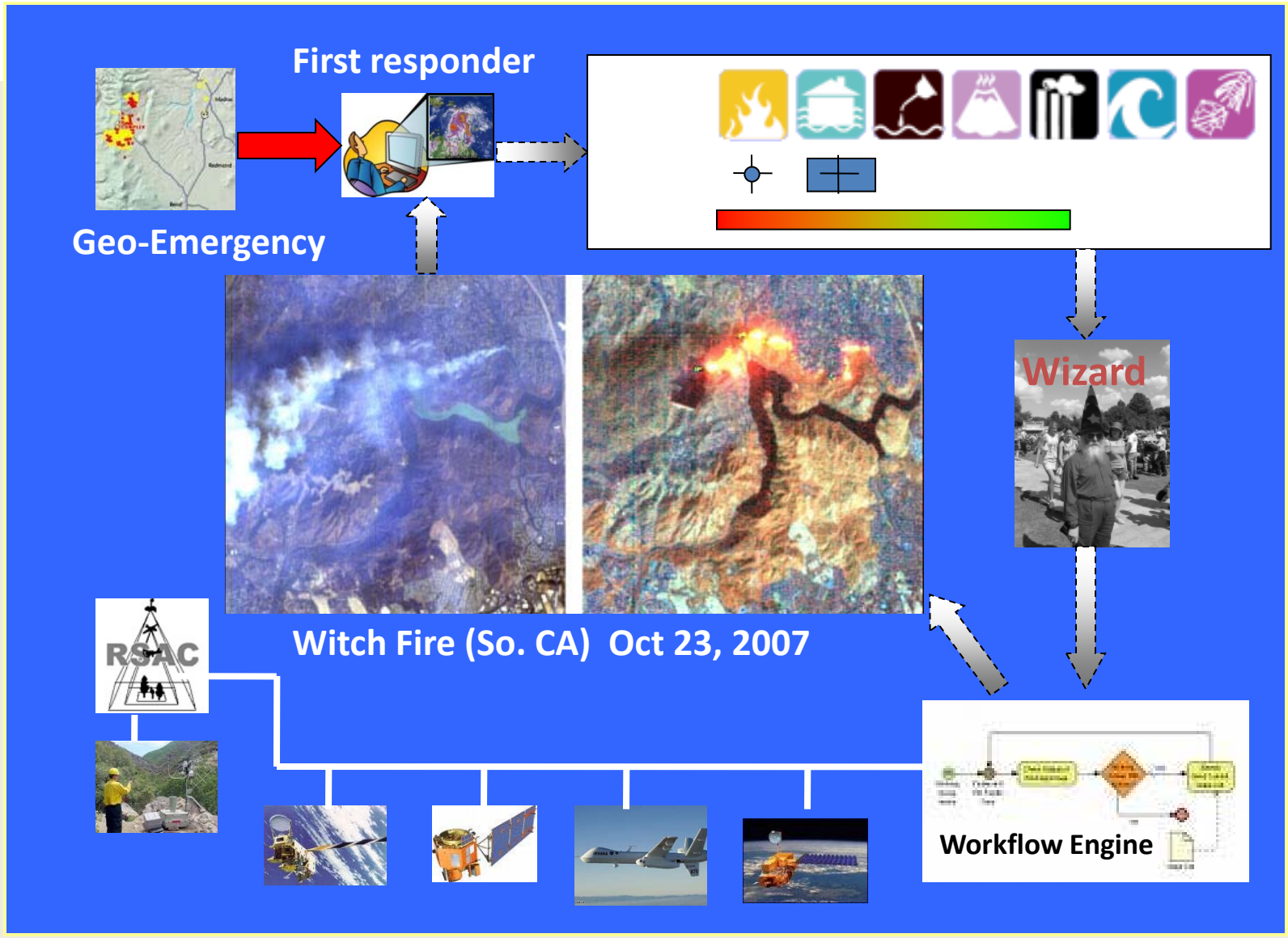


A high overall correlation (r>0.98) was obtained for ACORN vs. ATREM spectra. For individual categories, 0.92 ≤ r ≤0.99.

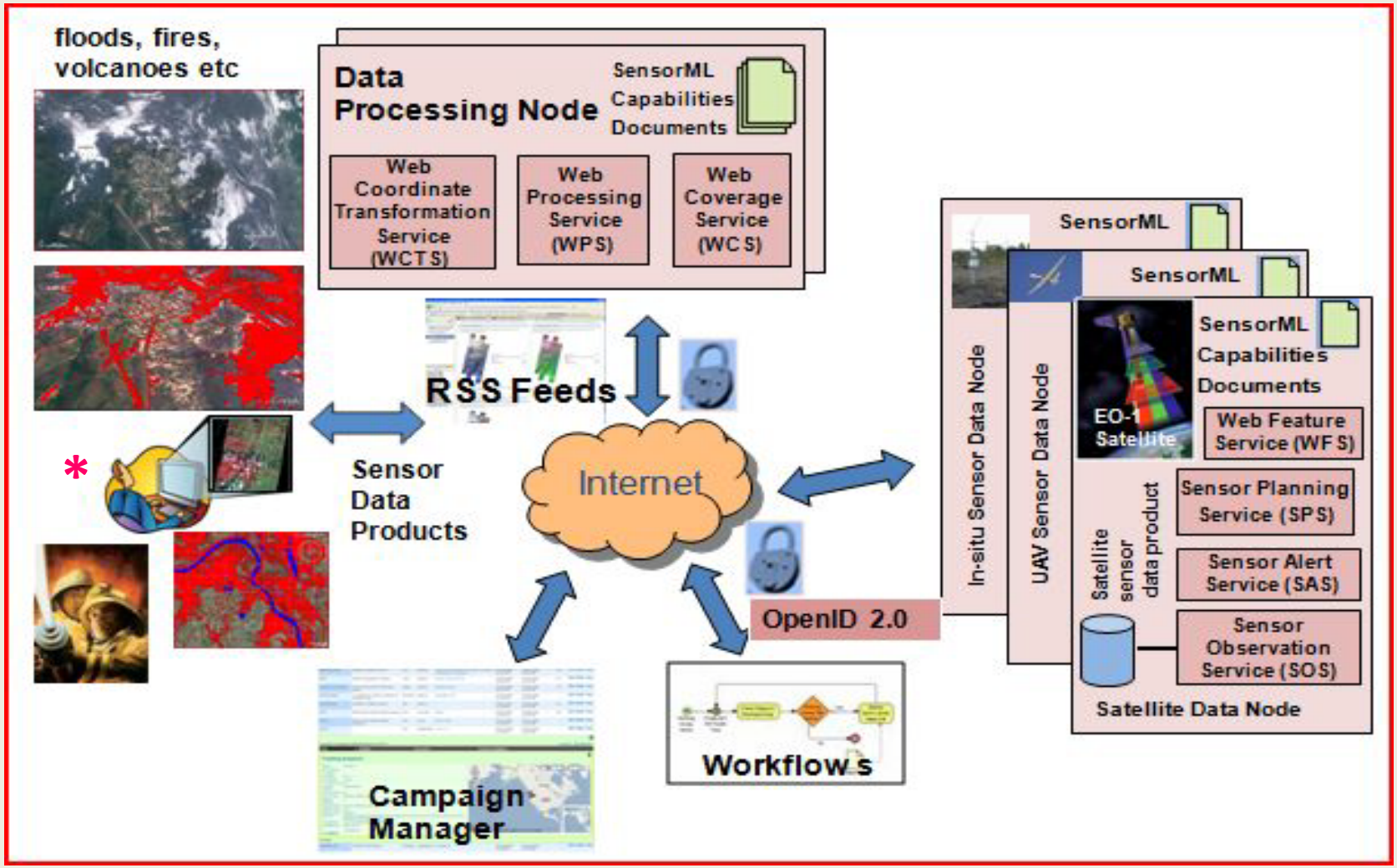
EO-1 Hyperion
(30 m)
6 dates in 2008



EO-1 as a Pathfinder for SensorWebs
Enables Rapid Response with Remote Sensing



SensorWeb: *High Level Architecture*



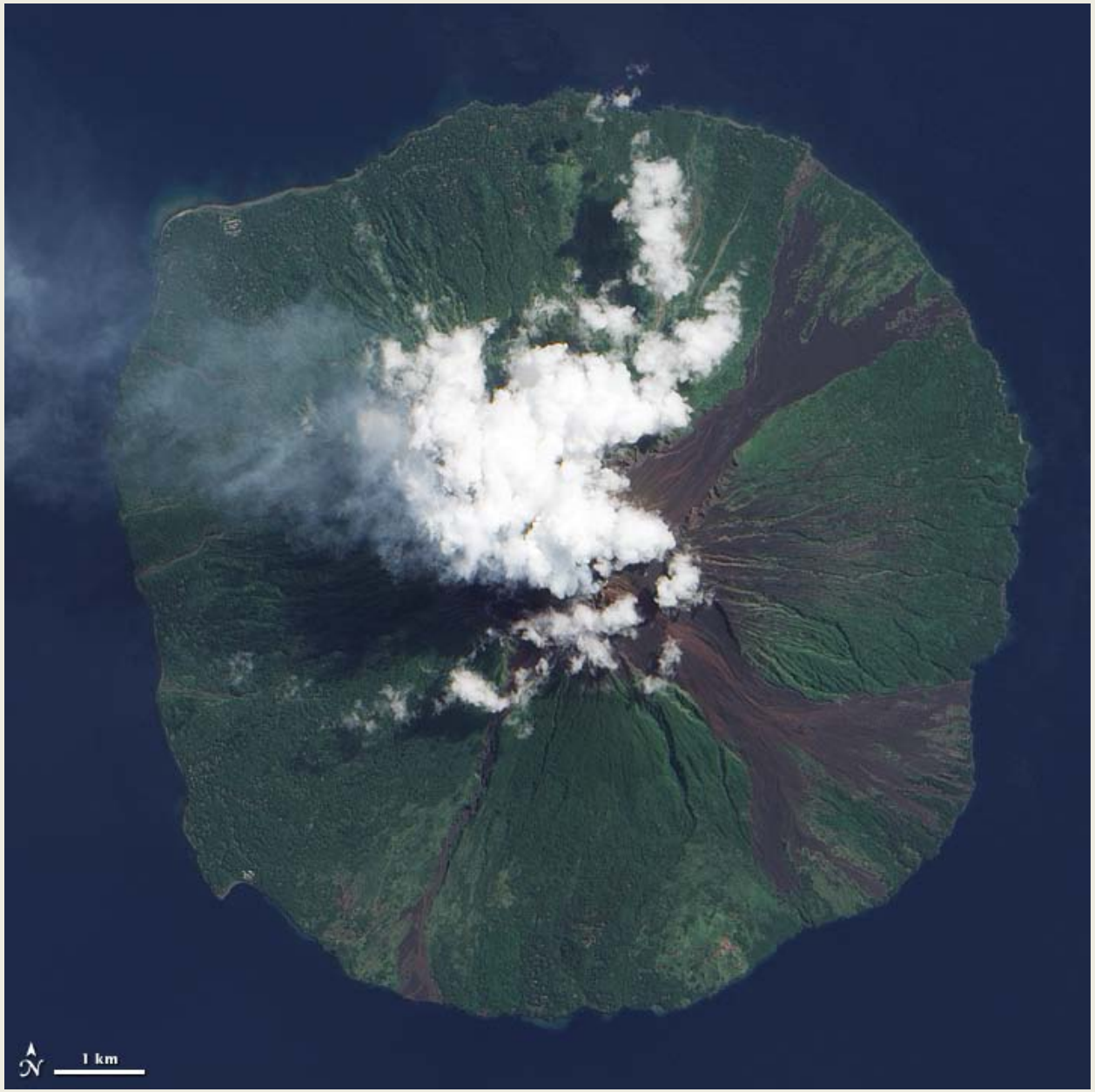
The SensorWeb architecture was developed on EO-1 as a pathfinder effort to encapsulate sensors and data processing algorithms with Open Geospatial Consortium standardized Web 2.0 Service interfaces. Thus, future missions will be able to significantly lower the cost of interoperating, automating procedures and enable rapid customization of data products.

EO-1 Provides Disaster Support

The EO-1 Advanced Land Imager (ALI) observed the BP oil spill in the Gulf of Mexico on June 26, 2010. Captured in this pan-sharpened image are streams and ribbons of oil impacting the Mississippi barrier islands of Horn Island (left) and Petit Bois (right).

June 28, 2009
True-Color Image from ALI
Manam Volcano, New Guinea

Manam Volcano, just off the coast of mainland Papua New Guinea, released a faint plume on June 28, 2009. Bright white clouds hover over the volcano's summit. Clouds often collect over peaks, but these clouds could result from water vapor released by the volcano. Slightly darker in color, a pale blue-gray plume blows west-northwest from the summit and over the Bismarck Sea. The image below is a ground picture of the volcano.

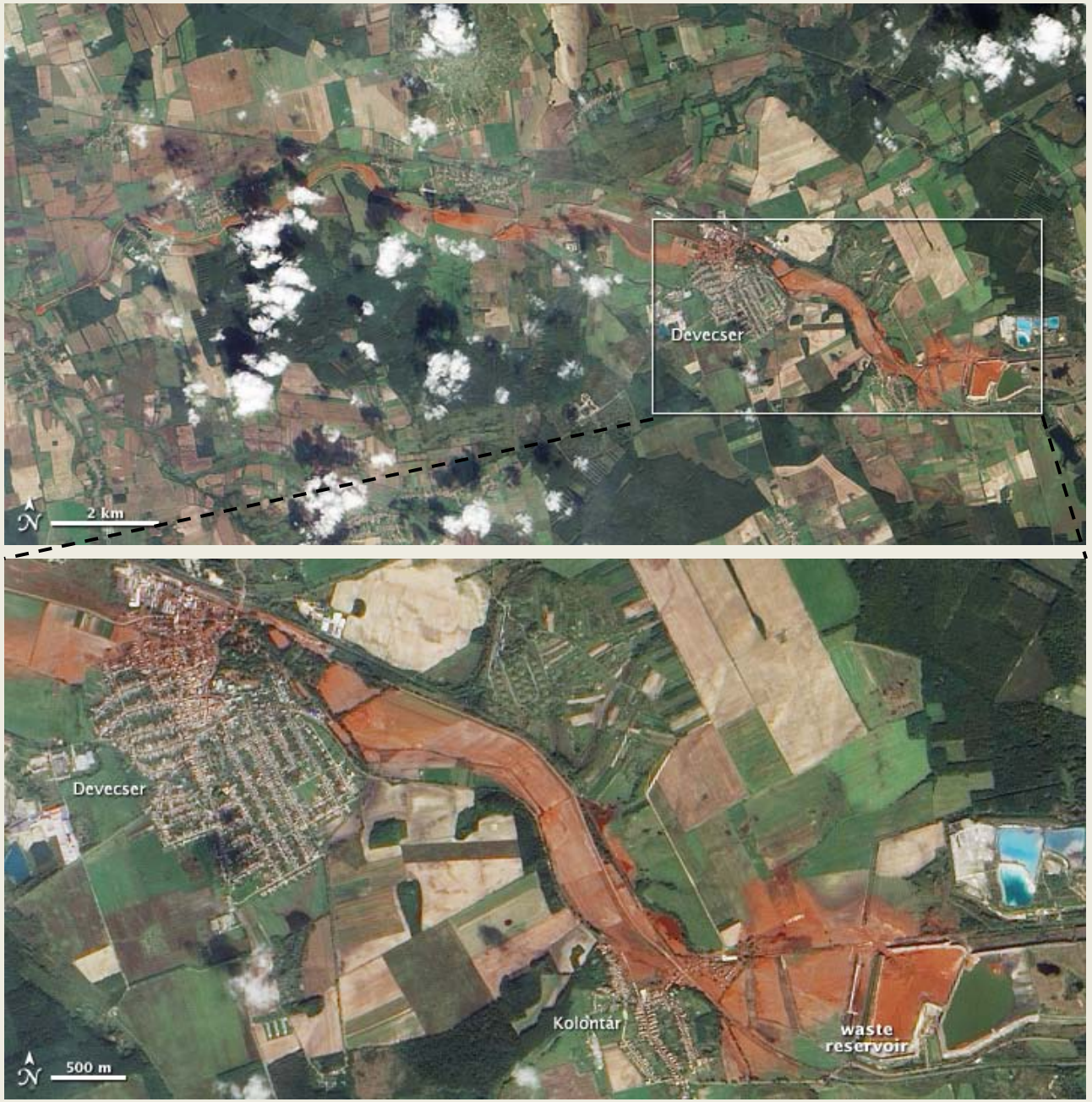


Images are from NASA's Earth Observatory web site (http://earthobservatory.nasa.gov/)

October 9, 2010
True-Color Image from ALI
Toxic Sludge in Hungary

On October 4, 2010, an accident occurred at the Ajkai Timföldgyár alumina (aluminum oxide) plant in western Hungary. A corner wall of a waste-retaining pond broke, releasing a torrent of toxic red sludge down a local stream. Several nearby towns were inundated, including Kolontar and Devecser, where the sludge was 2 meters deep in places. Four people were killed immediately, likely from drowning, and several more were missing. Dozens of residents were hospitalized for chemical burns.

The alumina plant appears along the right edge of both images, and incorporates both bright blue and brick red reservoirs. The breach of the retaining wall is apparent in the close-up view. Sludge cut a channel through the northwest corner of the waste reservoir and spread onto nearby fields. The sludge forms a red-orange streak running west from the plant. The wide-area view shows the spill thinning but remaining discernible for several kilometers to the west. The New York Times reported that the stream nearest the plant empties into larger rivers. The BBC reported that authorities were pouring plaster into the Marcal River in hopes of preventing the sludge from reaching the Danube River.



Images are from NASA's Earth Observatory web site (http://earthobservatory.nasa.gov/)

January 11, 2005
True-Color Image from ALI
Neumayer Glacier, South Georgia Island

South Georgia is an arc-shaped island that lies some 2,000 kilometers east of the southern tip of South America. Neumayer Glacier, on the island's east coast, showed very little positional change for many decades. But the glacier began losing significant mass, retreating by roughly 2 km from 1970 to 2002. From 2005 to 2009 (bottom), the glacier retreated an additional 1 kilometer.

Images are from NASA's Earth Observatory web site (http://earthobservatory.nasa.gov/)

Please flip back and forth between this slide and the next to see the glacier before and after the breakup.

January 4, 2009
True-Color Image from ALI
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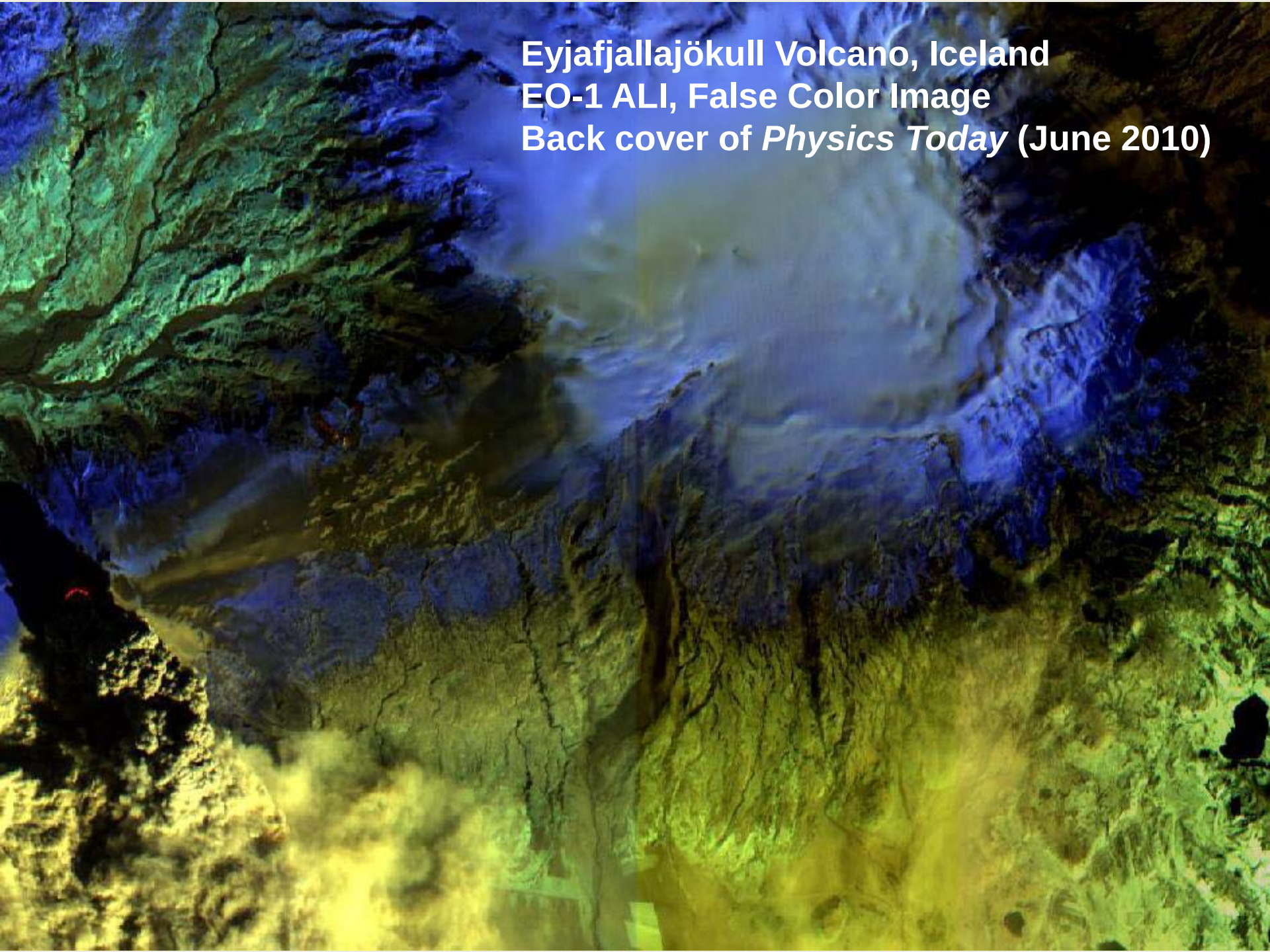
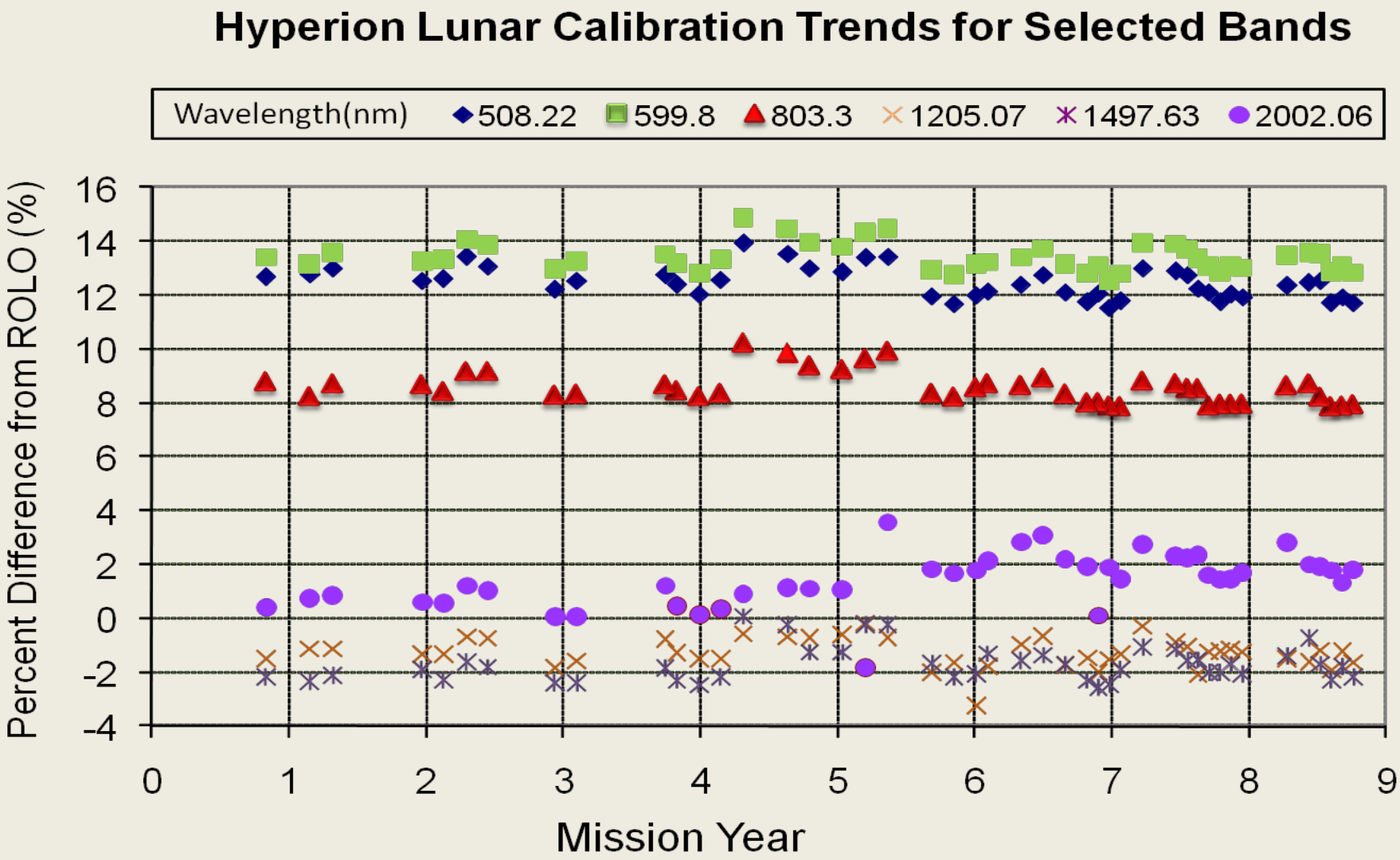
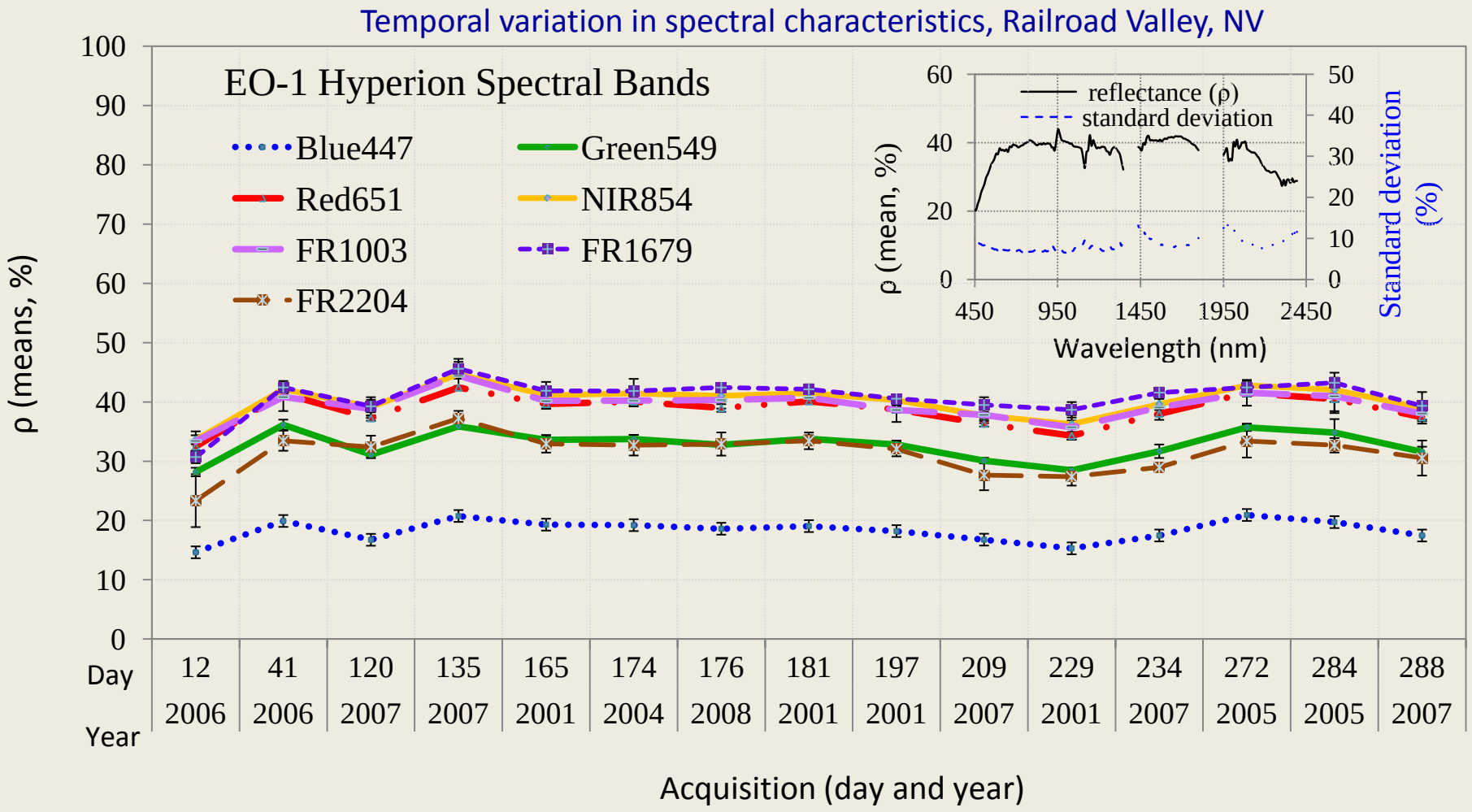

Eyjafjallajökull Volcano, Iceland
EO-1 ALI, False Color Image
Back cover of *Physics Today* (June 2010)

Lunar Calibration Results

Differences *between Rolo model and Hyperion measurements remain stable (within 5%) over time*

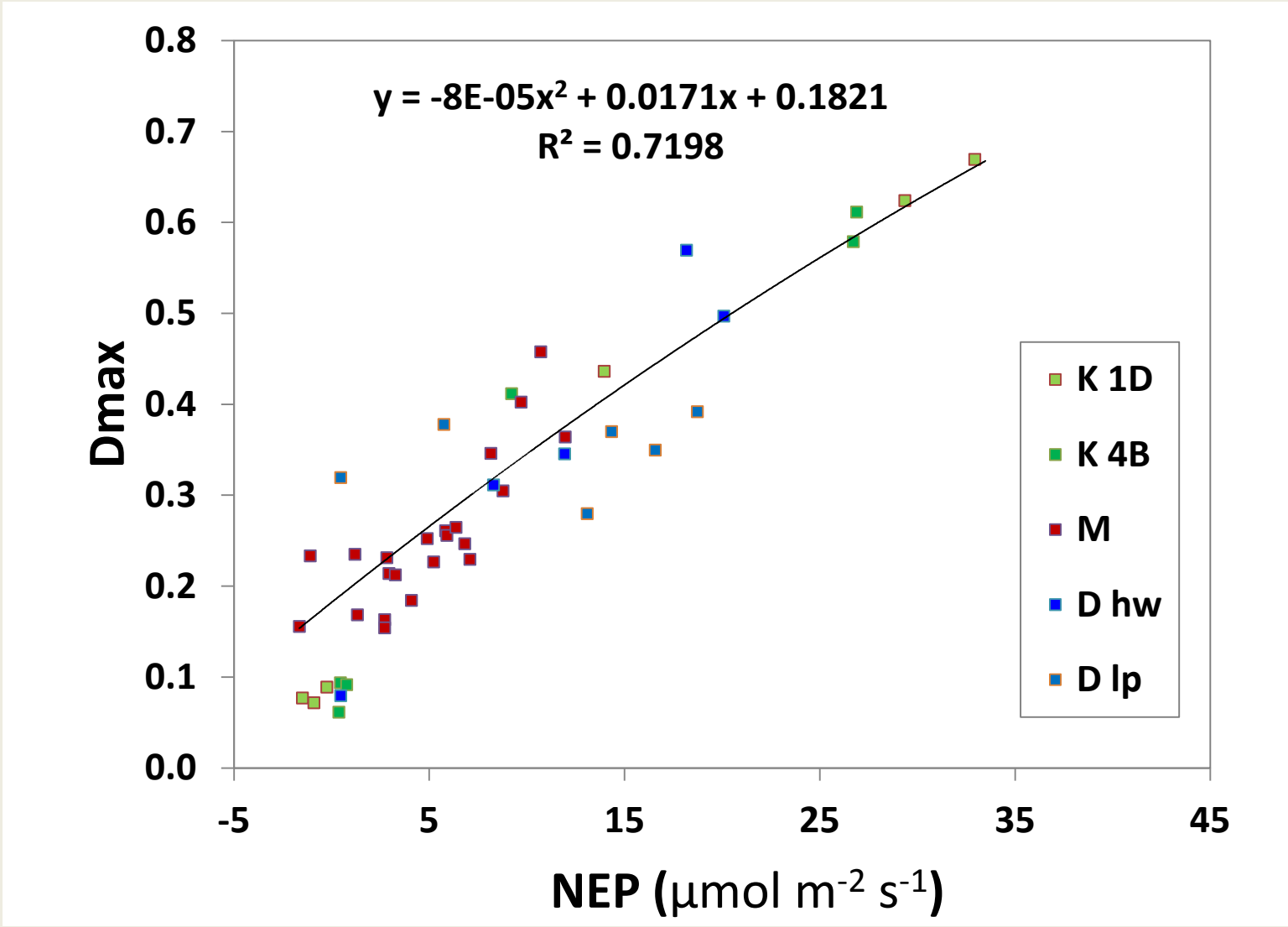


Temporal Profile
Selected Hyperion Bands



Multiple Flux Sites

Konza --1yr burn (K 1D) & 4 year burn (K 4B) Mongu (M),
Duke-- pine (D lp) & hardwoods (D hw)




HYSPIRI
HYPERSPECTRAL-INFRARED IMAGER

NASA's strategic goal

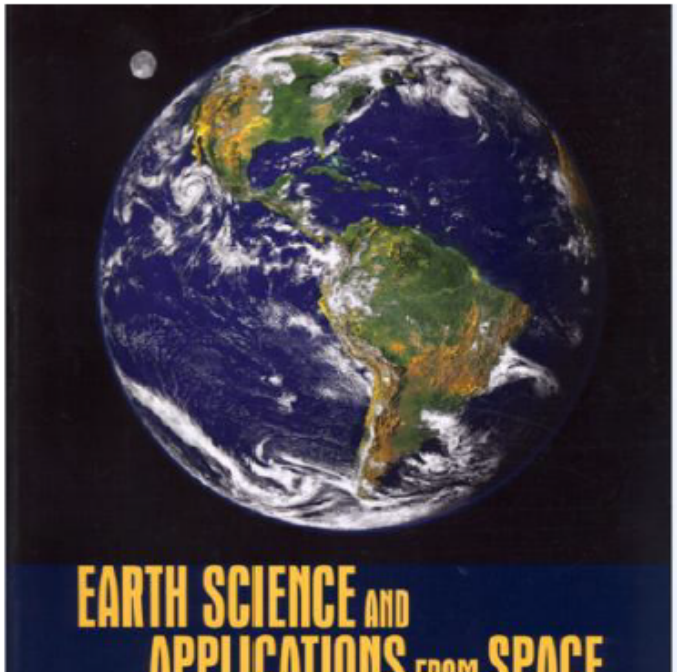
to advance Earth System Science to meet the challenges of climate and environmental change

How is the Earth changing and what are the consequences for life on Earth?

- How is the global Earth system changing?*(Characterize)*
- What are the sources of change in the Earth system and their magnitudes and trends? *(Understand)*
- How will the Earth system change in the future?*(Predict)*
- How can Earth system science improve mitigation of and adaptation to global change? *(Apply)*

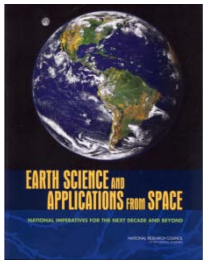
HysplRI Decadal Survey Climate Scien

HysplRI: "A hyperspectral sensor (e.g., FLORA) com
with a multispectral thermal sensor (e.g., SAVII) in lo
Earth orbit (LEO) **is part of an integrated mission
concept [**described in Parts I and II] that is relevant
several panels, **especially the climate variability p**

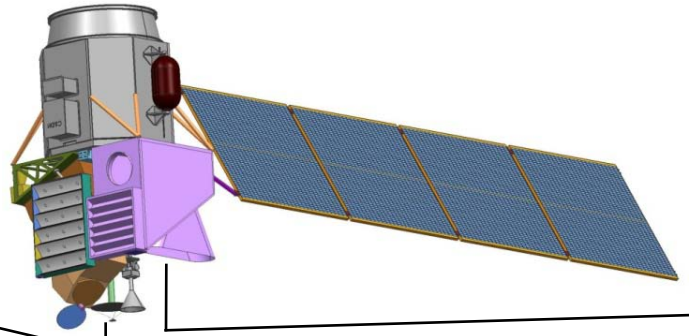


National Aeronautics and Space Administration

NRC Decadal Survey - HyspIRI



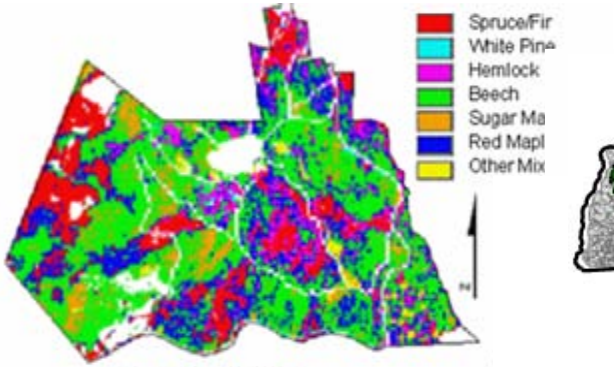
HyspIRI: "A hyperspectral sensor (e.g., FLORA) combined with a multispectral thermal sensor (e.g., SAVII) in low Earth orbit (LEO) **is part of an integrated mission concept** [described in Parts I and II of the Decadal Survey] that is relevant to several panels, **<u>especially the climate variability panel</u>**."



Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer

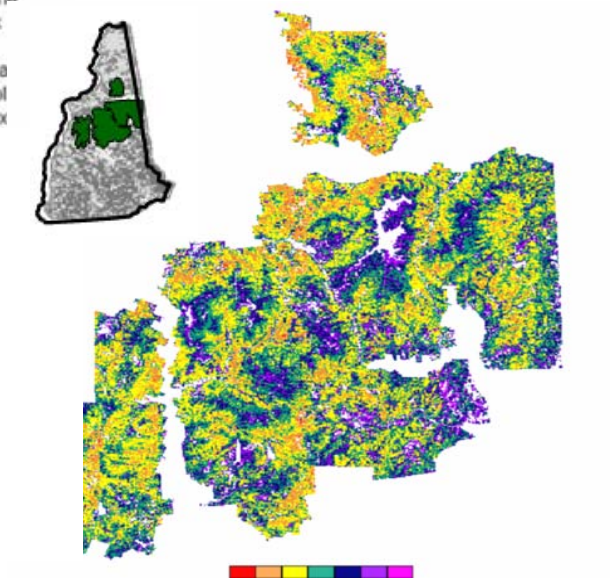
Multispectral Thermal InfraRed (TIR) Scanner

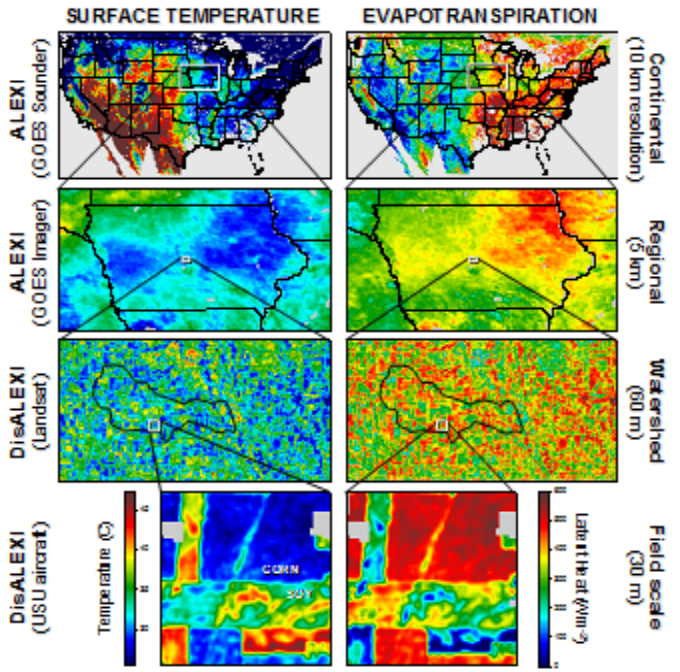
Map of dominant tree species, Bartlett Forest, NH



Soil C:N Ratio

White Mountain National Forest, NH

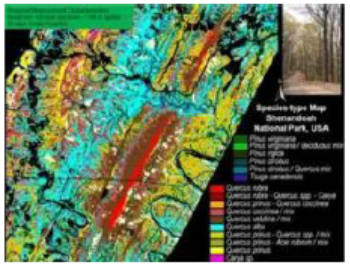




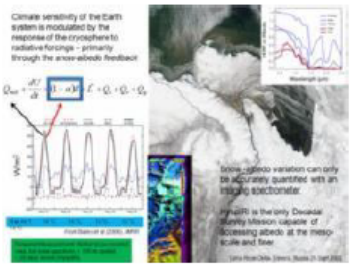
Key HyspIRI Climate Objectives from the Decadal Survey and IPCC

- Ecosystem Measurements for Climate Feedbacks
- Black Carbon/Dust Effects on Snow and Ice
- Carbon Release from Biomass Burning
- Evapotranspiration and Water Use and Availability
- Critical Volcanic Eruption Parameters

All HysplRI Decadal Survey Science and DS Climate Science is Achieved

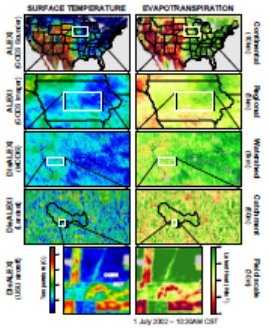


- **Imaging Spectrometer (VSWIR)**
  - Pattern and Spatial Distribution of Ecosystems and their Components
  - Ecosystem Function, Physiology and Seasonal Activity
  - Biogeochemical Cycles
  - Changes in Disturbance Activity
  - Ecosystem and Human Health
  - Earth Surface and Shallow Water Substrate Composition



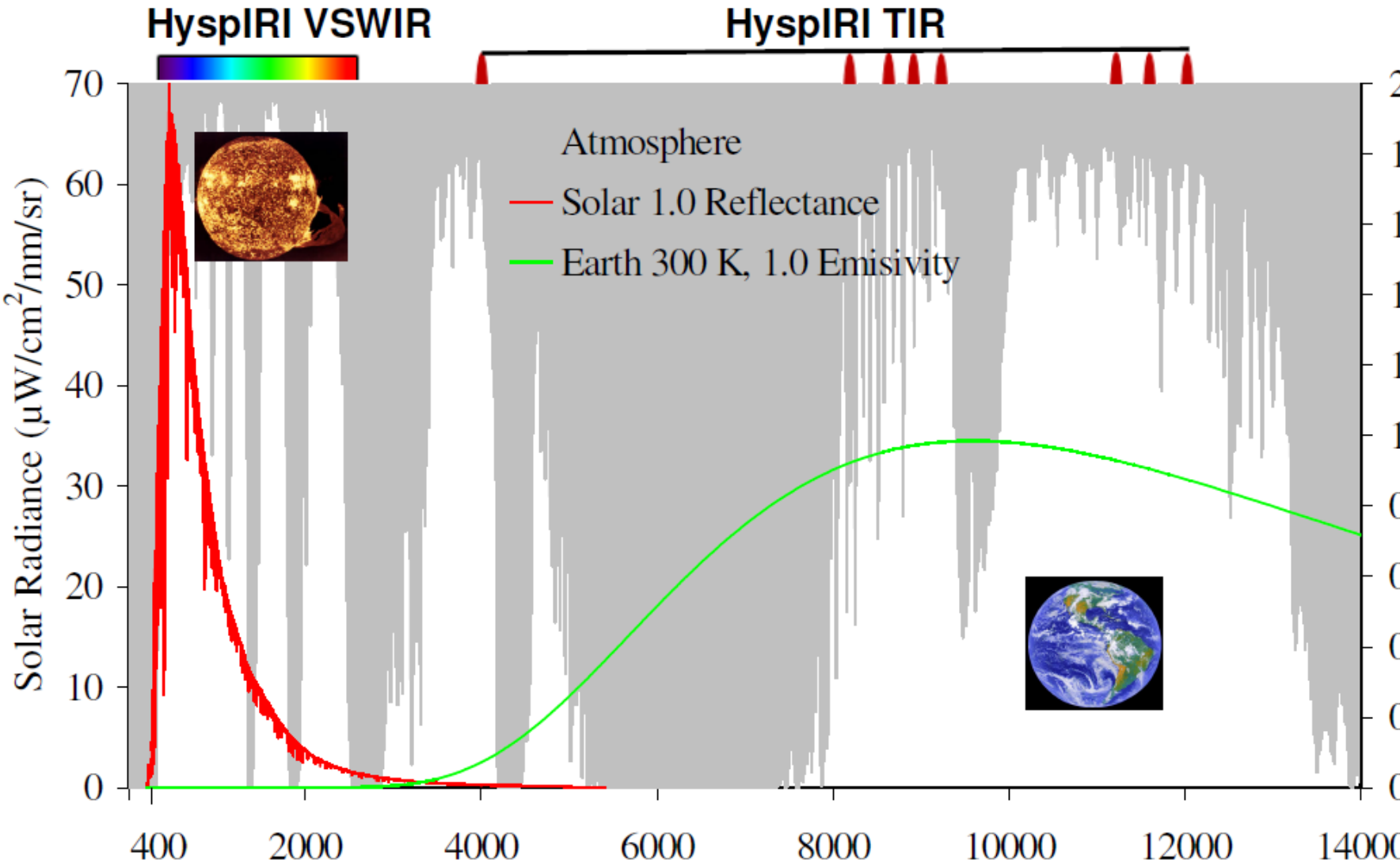
- **Multi-Spectral Thermal InfraRed (TIR)**
  - Volcanoes/Earthquakes
  - Wildfires
  - Water Use and Availability,
  - Urbanization/Human Health
  - Earth surface composition and change

- **Combined Imaging Spectrometer and Multi-Spectral Thermal Science**
  - Coastal habitats, and inland aquatic environments
  - Wildfires
  - Volcanoes
  - Ecosystem Function and Diversity
  - Land surface composition and change
  - Human Health and Urbanization



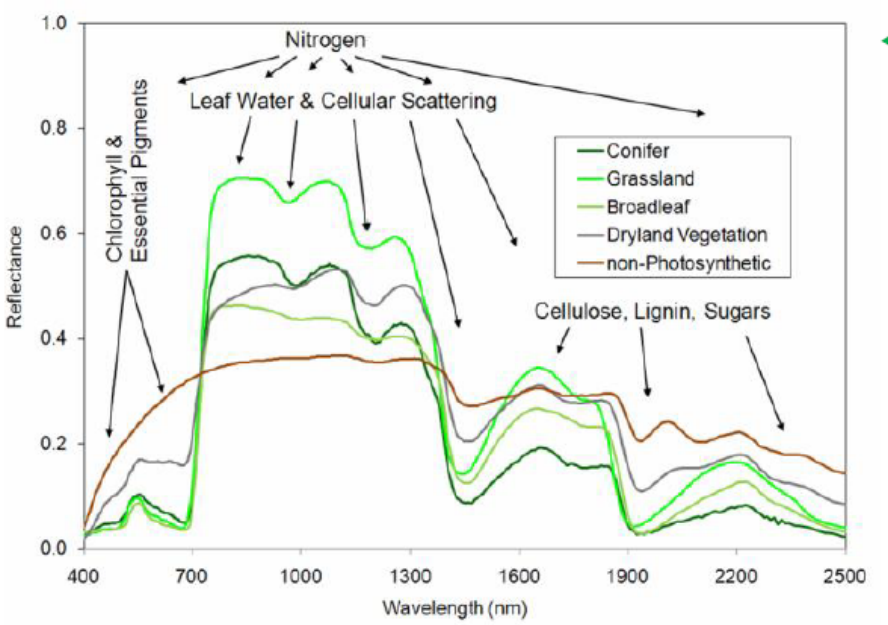
- **Key HysplRI climate objectives from the Decadal Survey and IPCC**
  - Ecosystem Measurement for Climate Feedback
  - Black Carbon/Dust Effects on Snow and Ice
  - Carbon Release from Biomass Burning
  - Evapotranspiration and Water Use and Availability
  - Critical Volcanic Eruption Parameters

HysplRI Measures the Optical Spectrum

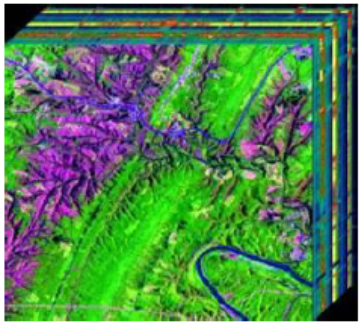


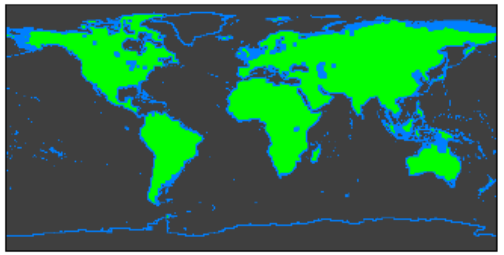
Ecosystem Measurements for Climate Feedbacks

Measuring the Terrestrial Biosphere

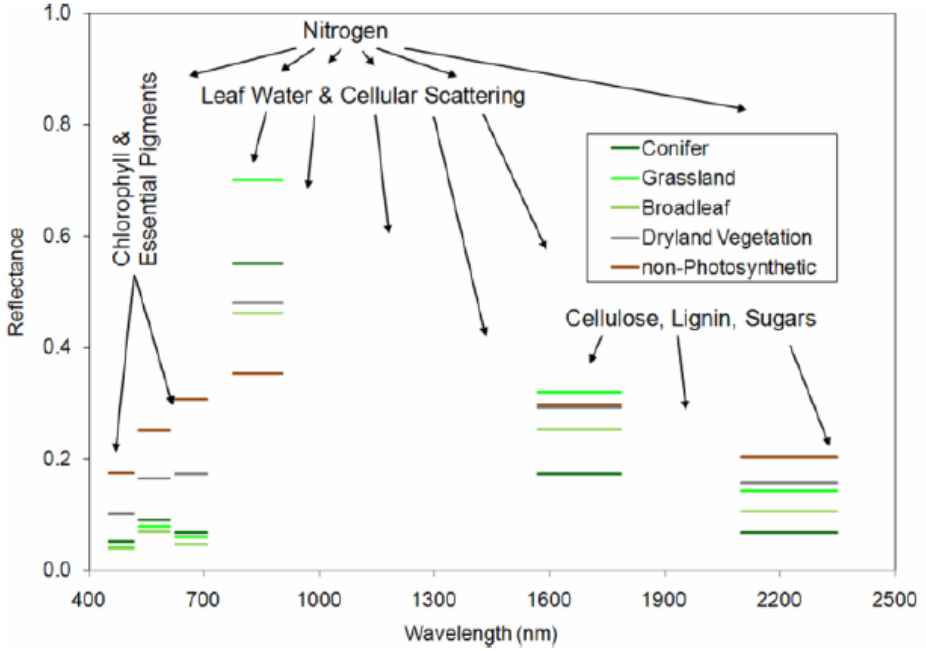


Imaging Spectroscopy is required to measure critical variables of the terrestrial biosphere.

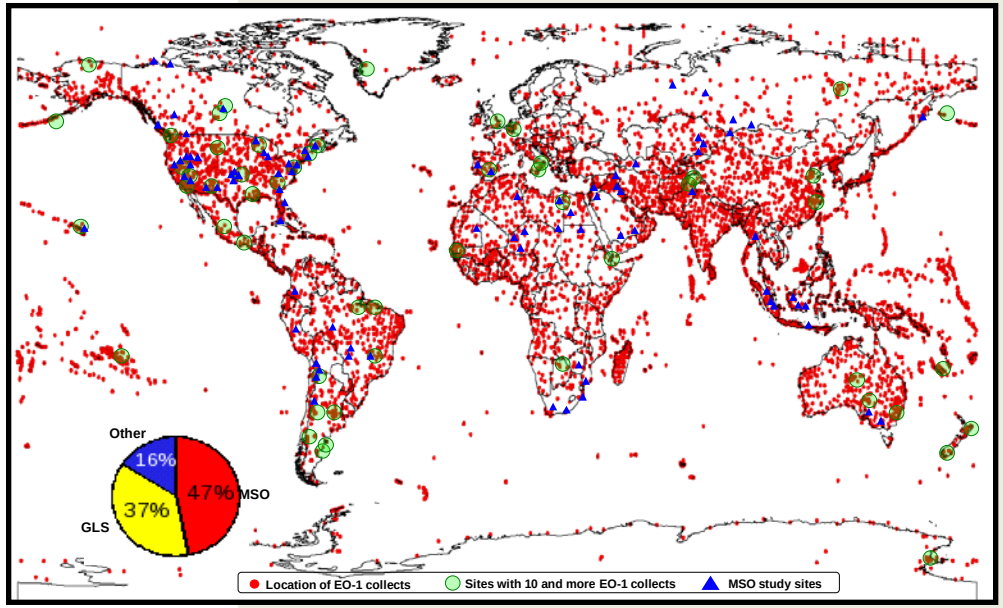




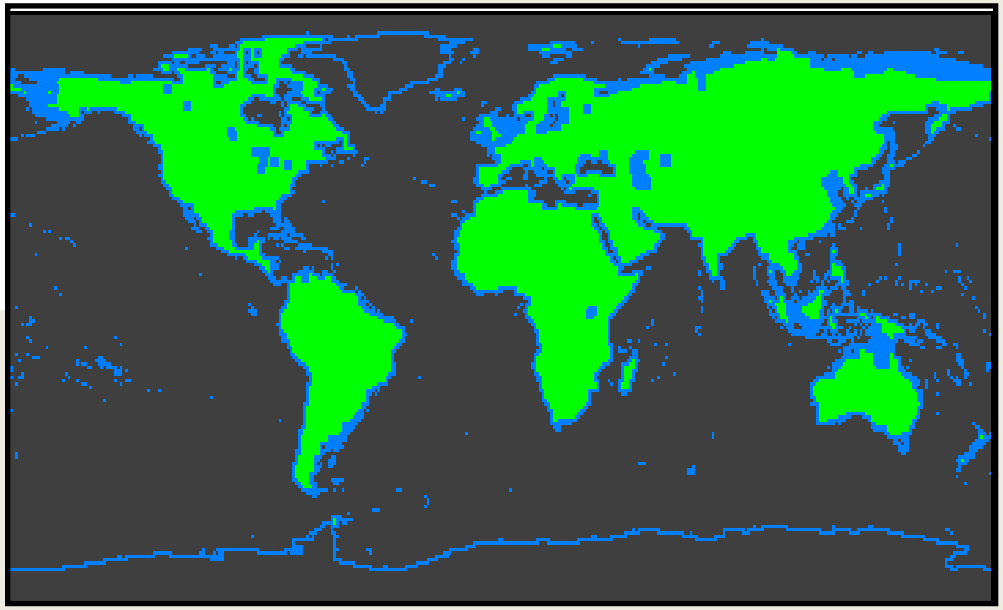
Multi-spectral imaging is insufficient



To Achieve the HyspIRI Climate Contribution, Global Coverage is Required with Revisit <20 Days



- EO-1 Hyperion acquisitions in 10 years. Hyperion is a fully successful NASA Technology sampling Mission.

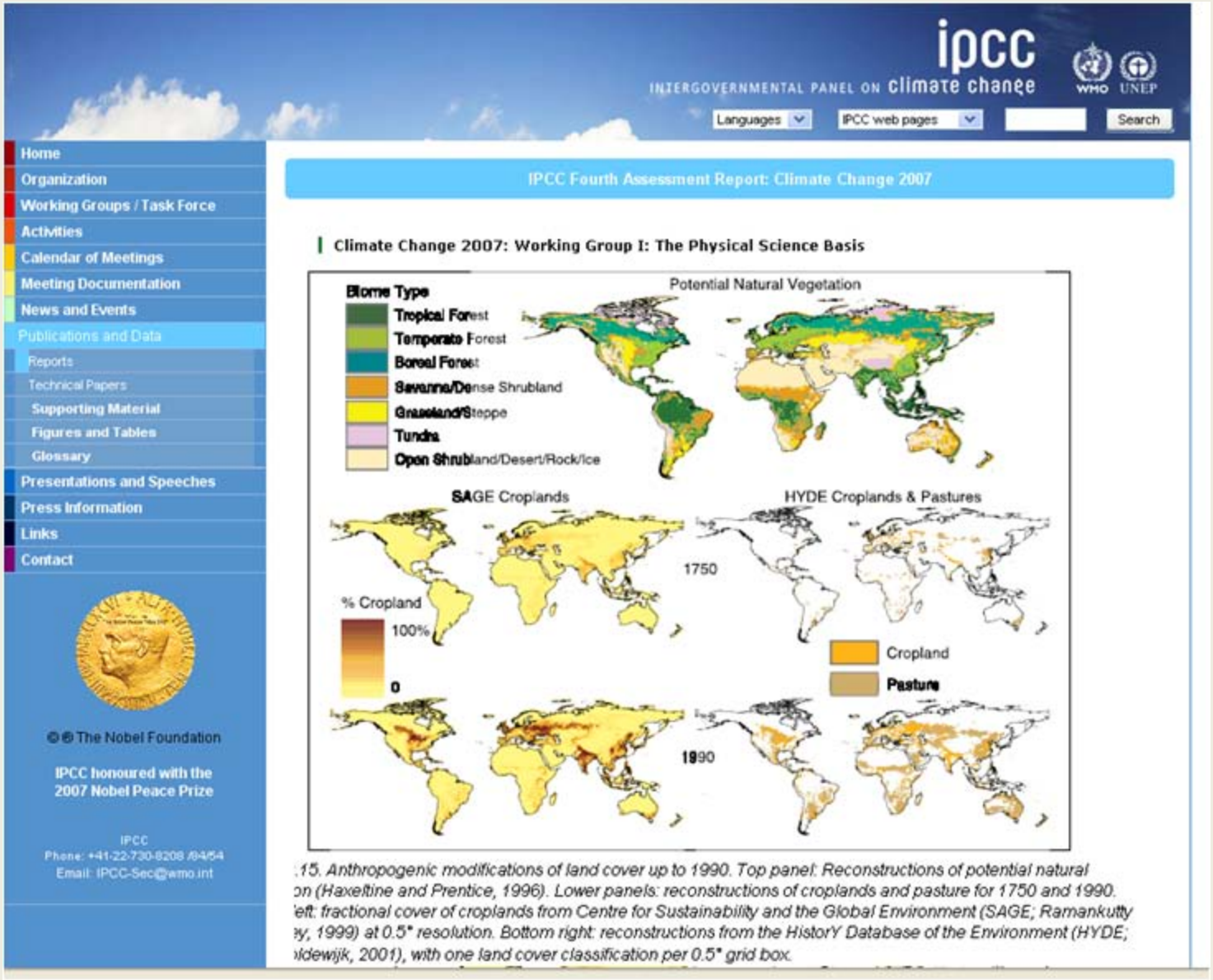


- HyspIRI VSWIR provides complete terrestrial coverage every 19 days.
- It would take Hyperion 100 years to acquire what HyspIRI measures in 1 year.
- **For climate, impact, adaptation and vulnerability measurements, HyspIRI (VSWIR and TIR) has orders of magnitude more scientific coverage and quality than any planned international mission.**

NASA HyspIRI NRC Decadal Survey Mission

(1) Vegetation Functional Type (species-type)

(2) Vegetation physiological condition (health, status)



NASA HyspIRI NRC Decadal Survey Mission

ipcc
INTERGOVERNMENTAL PANEL ON climate change
WMO UNEP

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IPCC honoured with the 2007 Nobel Peace Prize

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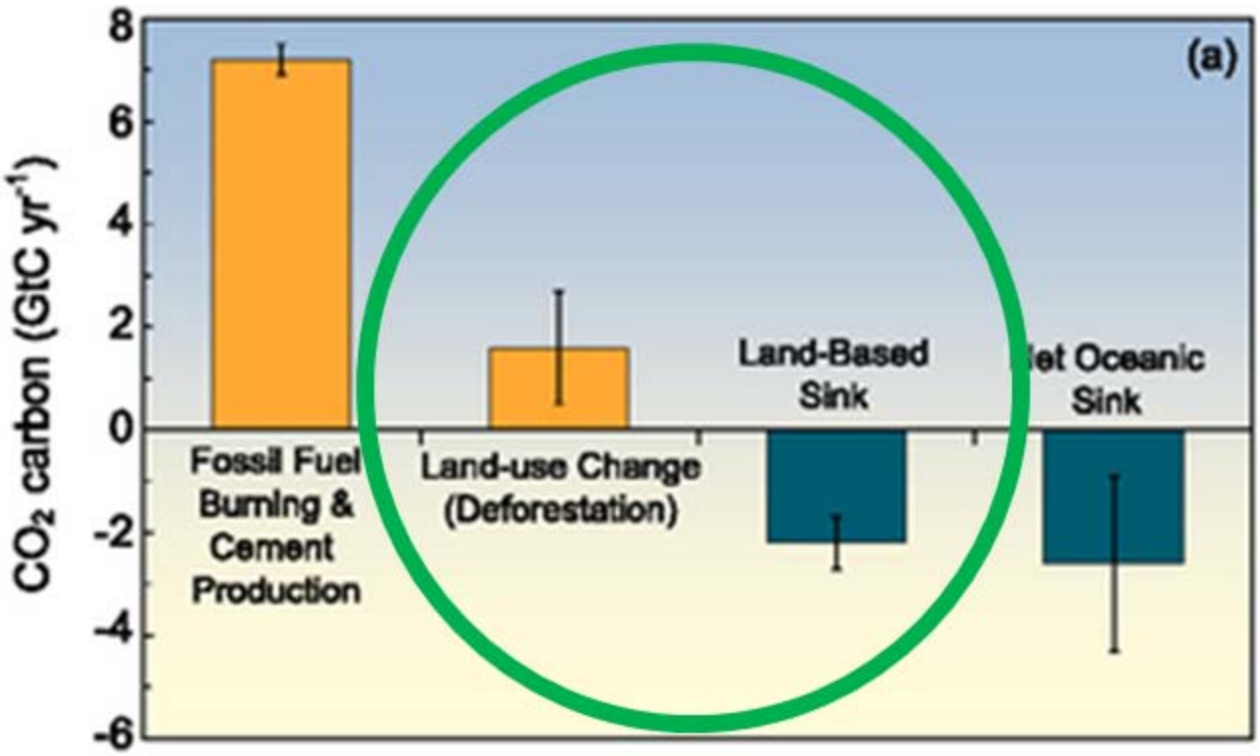
IPCC Fourth Assessment Report: Climate Change 2007

Climate Change 2007: Working Group I: The Physical Science Basis

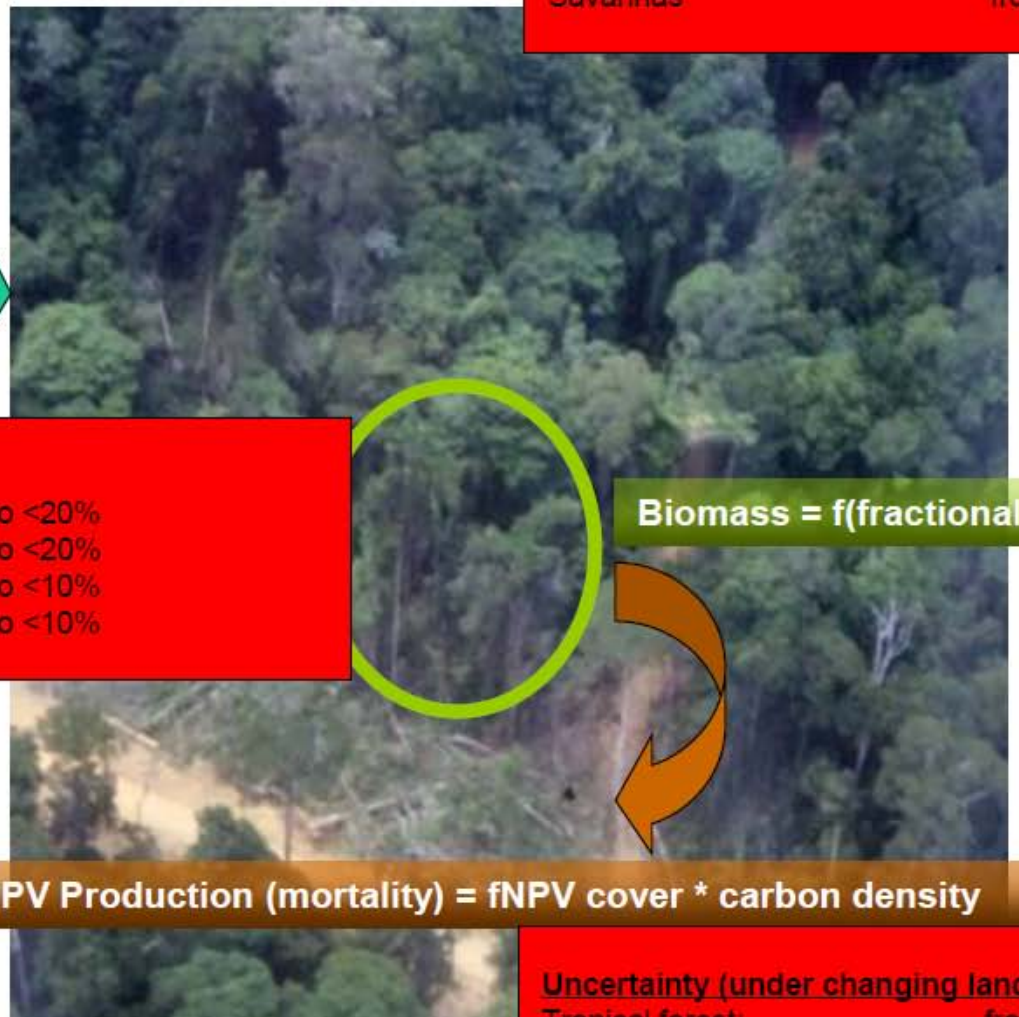


HyspIRI Critical Role in Climate Carbon Cycle Scie

Uncertainty

Tropical forest:	from +50% to <10%
Temperate forest	from +30% to <10%
Shrublands	from unknown to <1
Savannas	from +50% to <10%

NPP = PARi * fAPAR * LUE



Uncertainty (under changing land use)

Tropical forest:	from +40% to <20%
Temperate forest	from +40% to <20%
Shrublands	from +30% to <10%
Savannas	from +30% to <10%

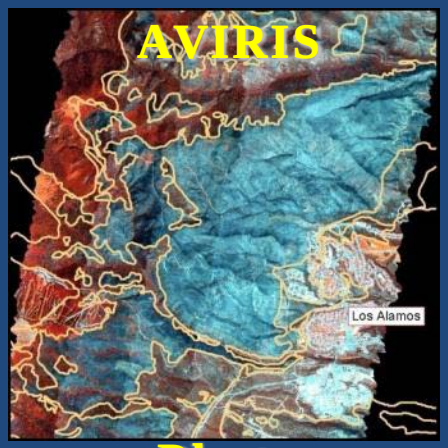
Biomass = f(fractional cover, height,

NPV Production (mortality) = fNPV cover * carbon density

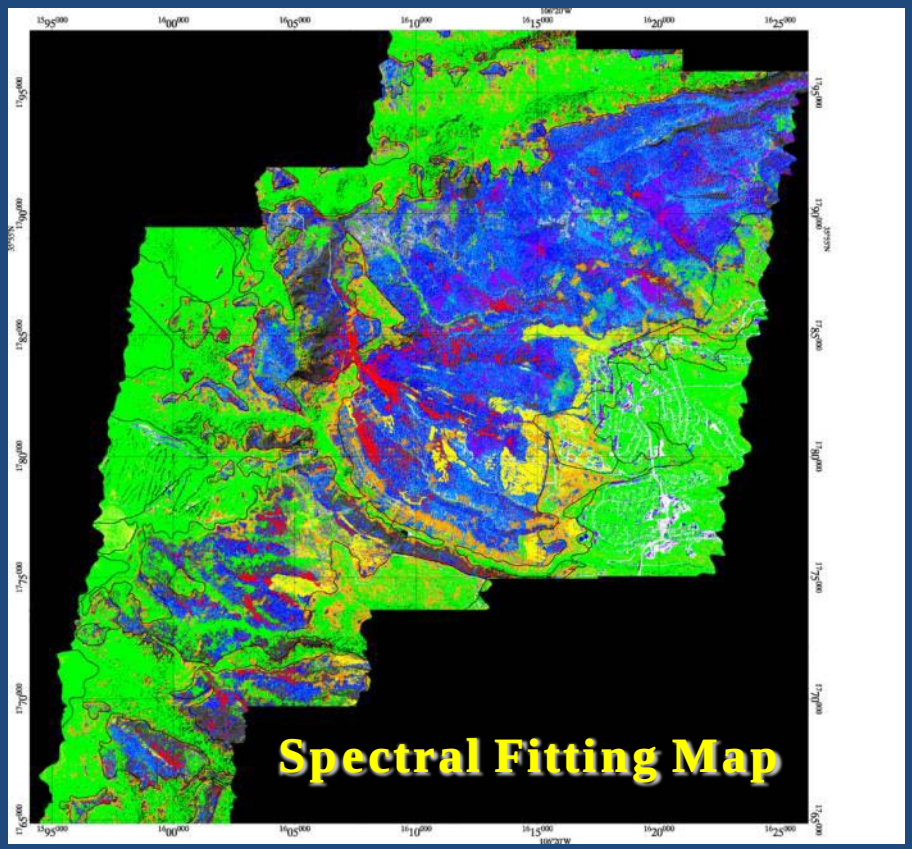
Uncertainty (under changing land use)

Climate: Response to Disturbance

Cerro Grande Fire Severity, Los Alamos, NM, Ray Kokaly

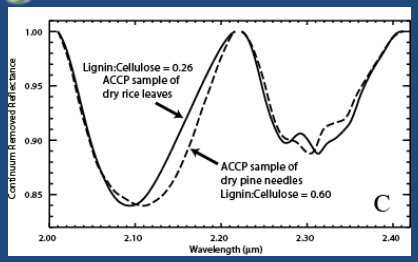


Photo

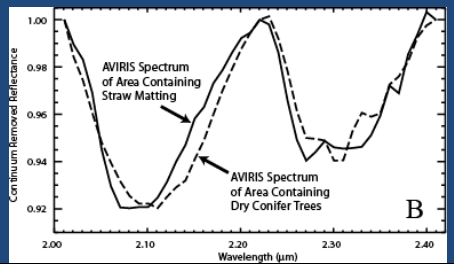


- Ash/Charcoal
- Mineral/Ash
- Mineral-1μm
- Mineral-2μm
- Dry Conifer
- Dry & Green Conifer
- Straw matting
- Straw matting & Green grass
- Green Vegetation

Lignin-Cellulose Lab



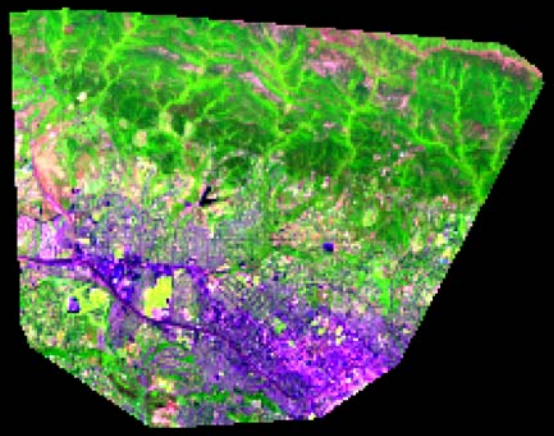
Lignin-Cellulose AVIRIS



Ray Kokaly, USGS

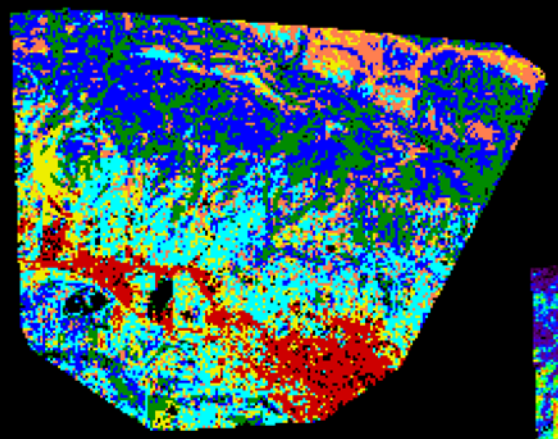
Spatial Resolution

This Science Working Group has found 60 m in conjunction with excellent measurement position knowledge to be optimal to answer these science question globally.

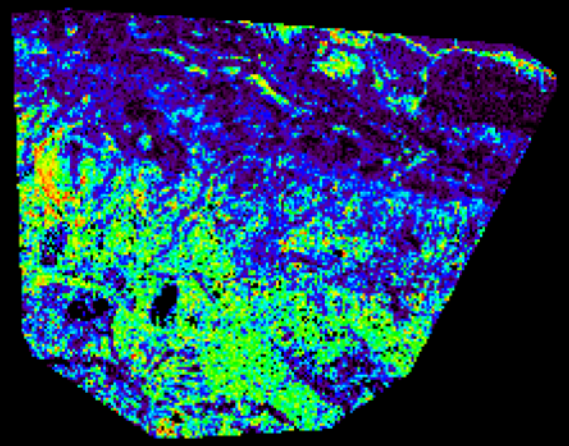


Santa Barbara, CA
Front range and city

Functional type result
60 m



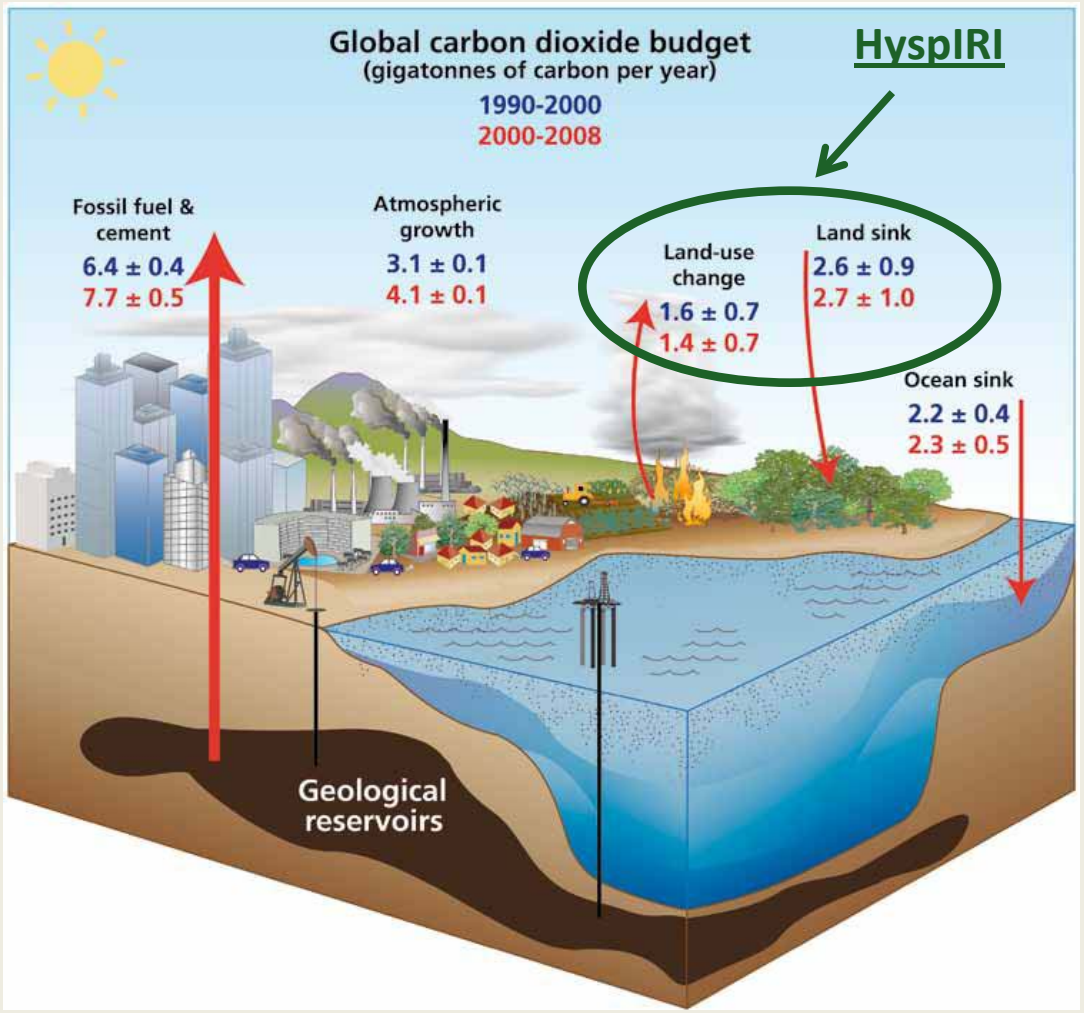
- Chamise
- Ceanothus
- Manzanita/Mixed
- Coast Live Oak
- Grass
- Urban



Non photosynthetic vegetation fraction

100%
50%
0%

HyspIRI is Required to Reduce Uncertainties in the Land Carbon Fluxes



Accurate constraint of Carbon fluxes associated with land-use and terrestrial vegetation are key missing elements for closing the carbon budget.

The HyspIRI based improvement is essential for sound policy decision making and understanding climate impacts.

Addresses critical climate carbon feedback uncertainty (IPCC WG-2)

Global CO2 budget for 1990-2000(blue) and 2000-2008 (red) (GtC per year). Emissions from fossil-fuel and landuse change are based on economic and deforestation statistics. Atmospheric CO2 growth is measured directly. The land and ocean CO2 sinks are estimated using observations for 1990-2000 (Denman *et al.* IPCC 2007). For 2000-2008, the ocean CO2 sink is estimated using an average of several models, while the land CO2 sink is estimated from the balance of the other terms.

Four Mainstream Land Carbon Models Curr

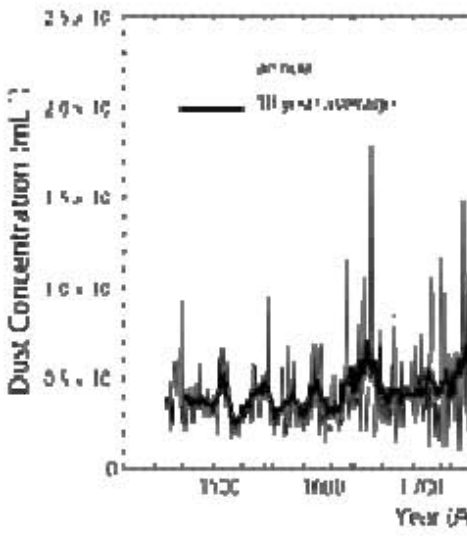
Major Model Inputs	CENTURY	CASA	SiB3
Vegetation Type	Prescribed	General Land Cover	General Land Cover
Plant Functional Types	Prescribed	---	Prescribed
Fractional Carbon Cover	---	---	---
Vegetation Greenness	---	NDVI	NDVI
Fractional PAR Absorption	---	NDVI	NDVI
Leaf Area Index (0-4 LAI units)	Prescribed	NDVI	NDVI
Leaf Area Index (4-10 LAI units)	---	---	---
Canopy Gap Frequency and Size	---	---	---
Light-use Efficiency (leaf water, N)	---	---	---
Live vs. Senescent Biomass	---	---	---
Woody vs. Leaf Biomass	Prescribed	Prescribed	Prescribed
Canopy Allometry	Prescribed	Prescribed	Prescribed

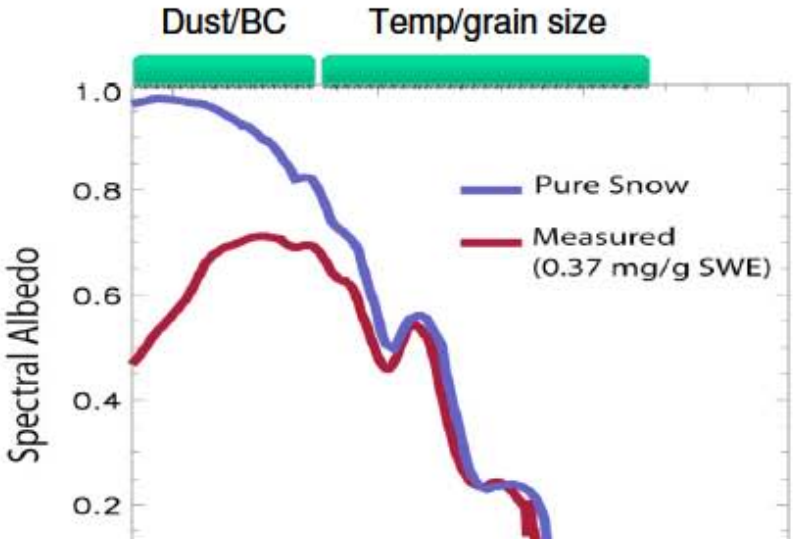
An urgent Global Science Issue Identified by IPCC

Albedo and Black Carbon/Dust Effects in Snow/Ice

Example: What is causing the downwasting and retreat of Himalayan glaciers?

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. HyspIRI is the only sensor 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.



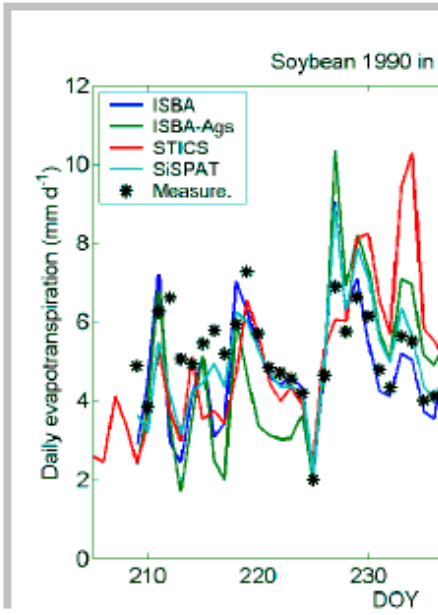


High Spatial and Temporal Resolution Requ
to Accurately Measure Evapo-transpiration (

HysplRI

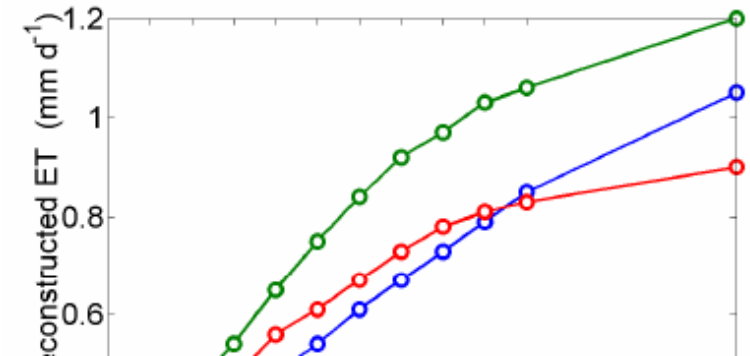
High spatial resolution: access to the local scale (field, urban district…)

1 km box

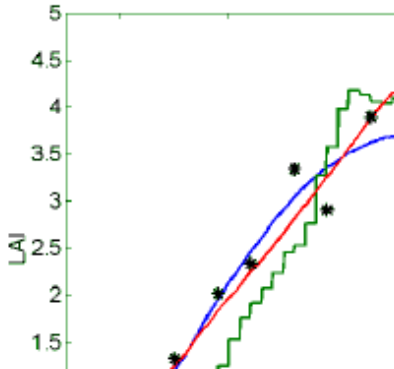


1 km data does not capture field scale variation

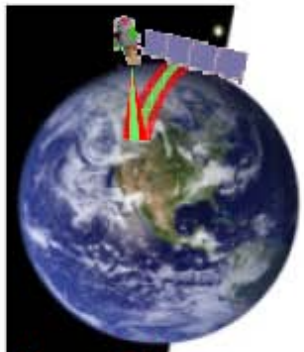
ET is very dynamic co



High revisit: rapid response to surface

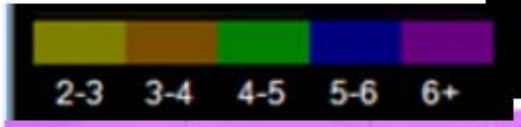


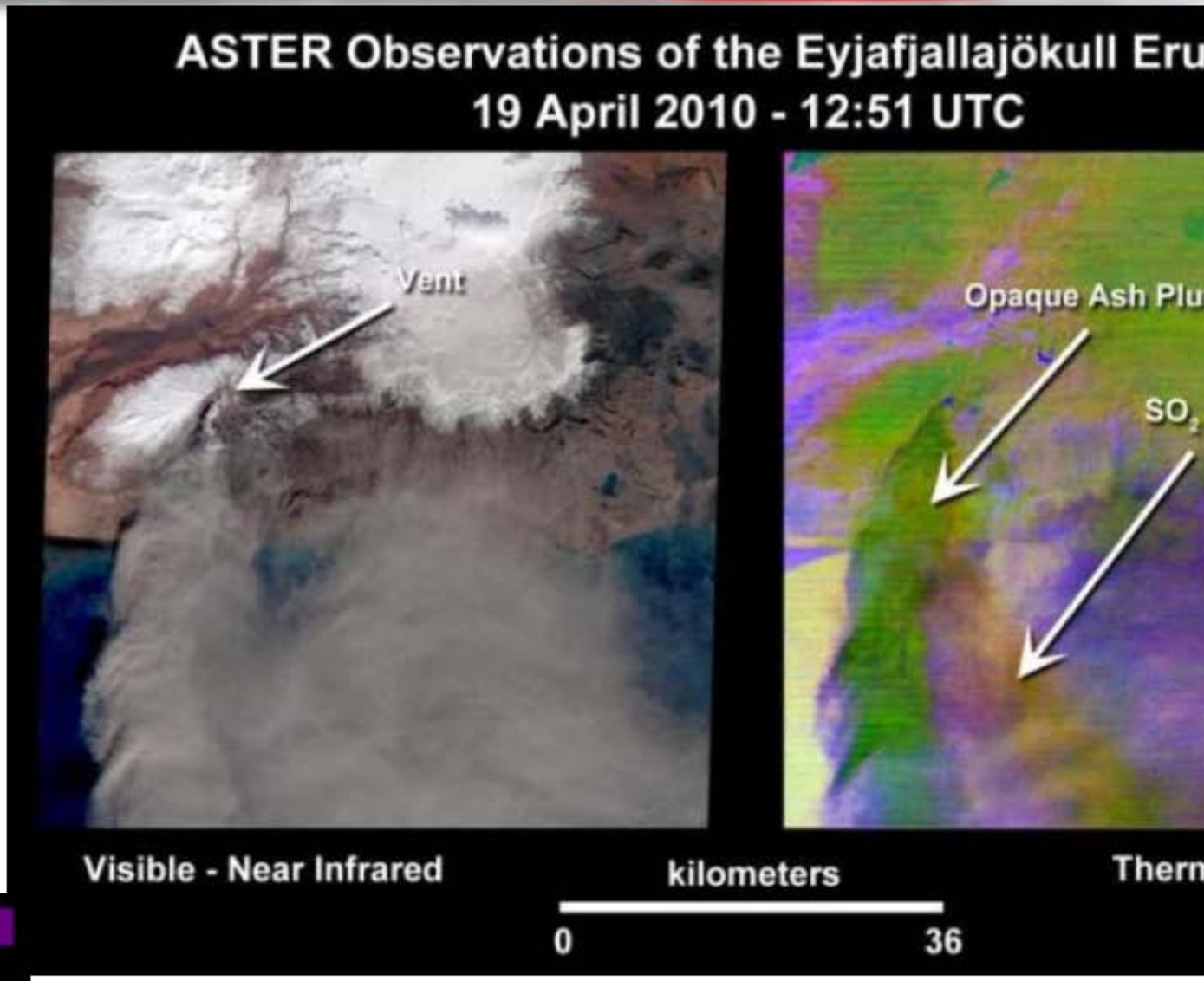
Critical Volcanic Eruption Parameters



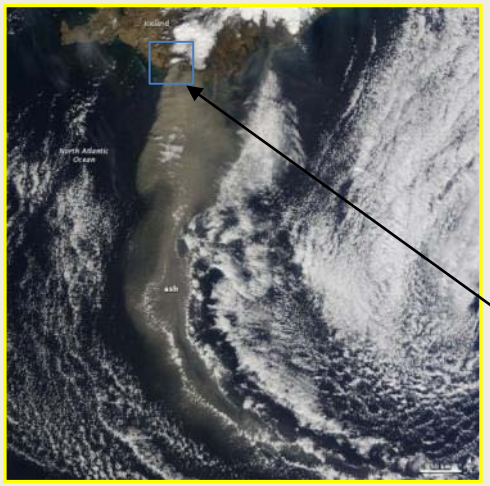
HyspIRI –TIR will provide daily data for Iceland eruptions

Total Views in 5-days



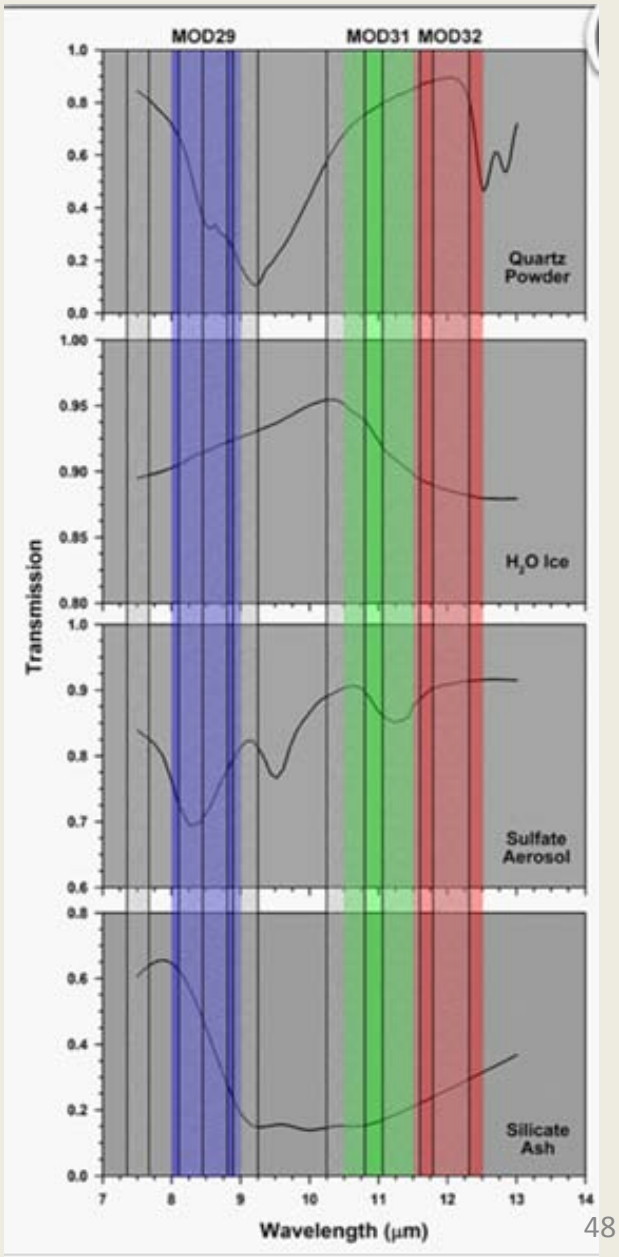


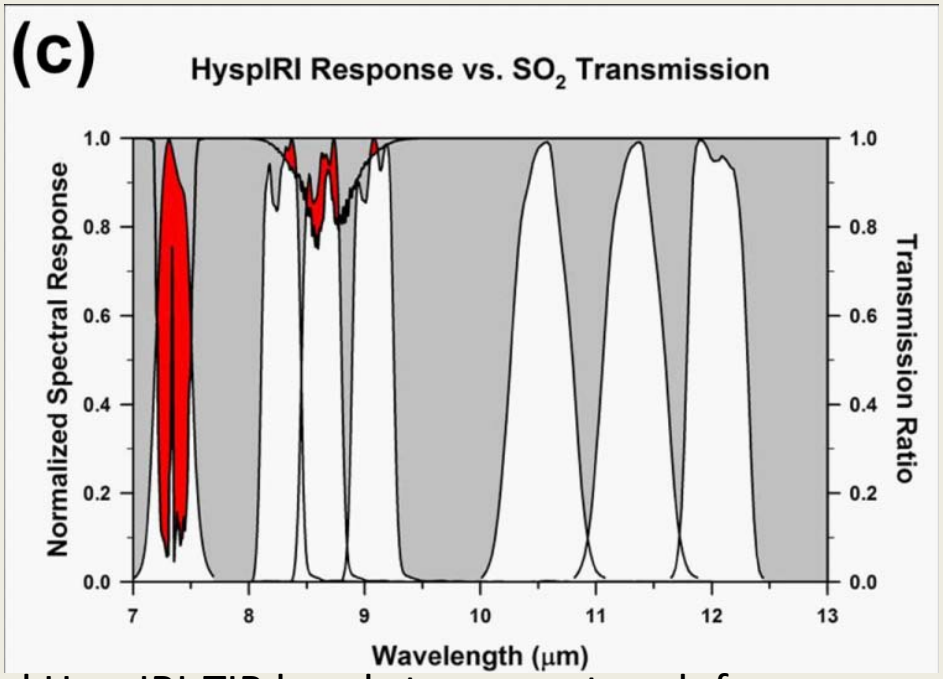
Critical Volcanic Eruption Parameters



Eyjafjallajökull Iceland Volcano Eruption

April 19 2010 MODIS image of ash plume.

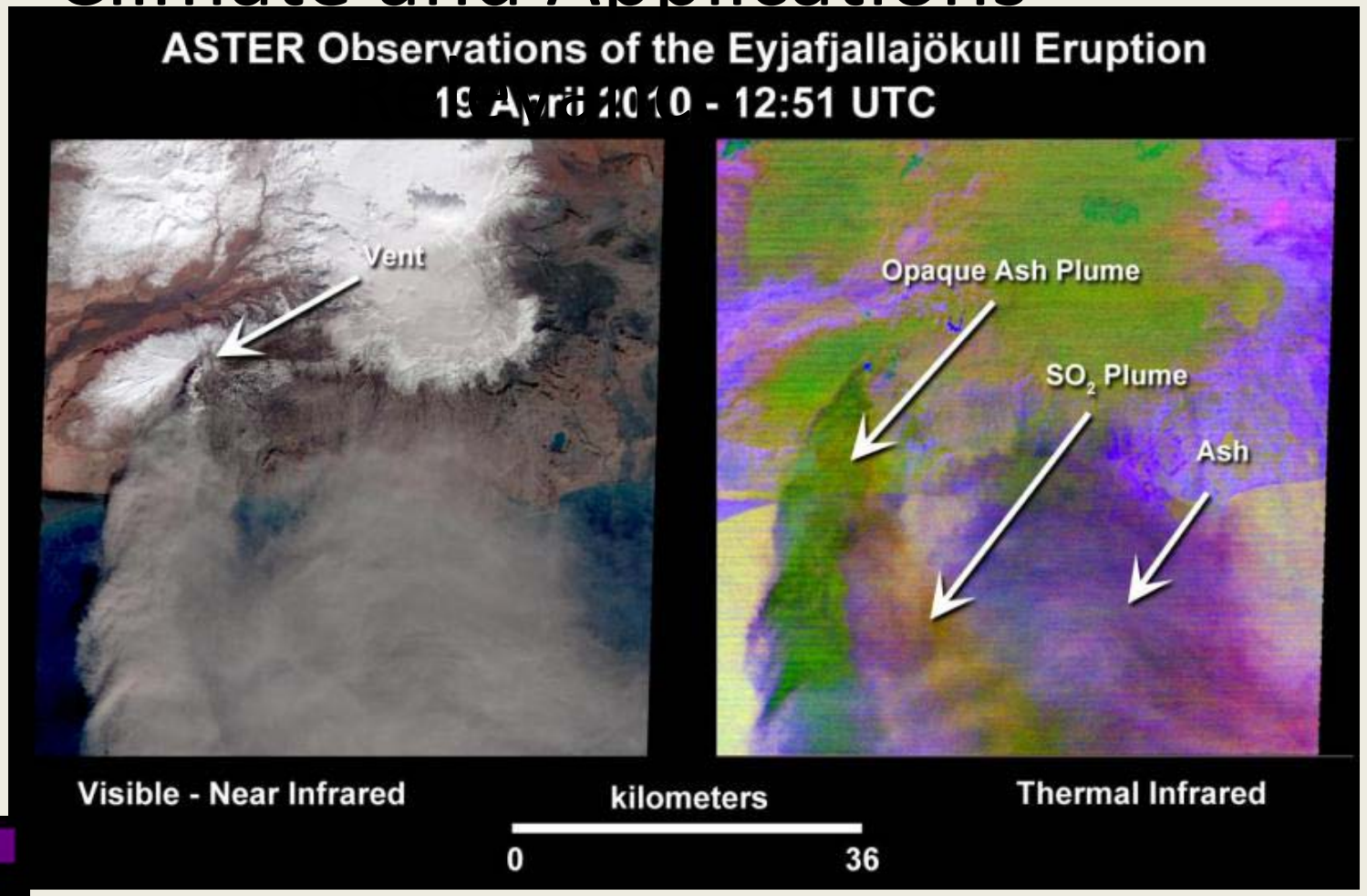




Need HysplRI-TIR bands to separate ash from gas

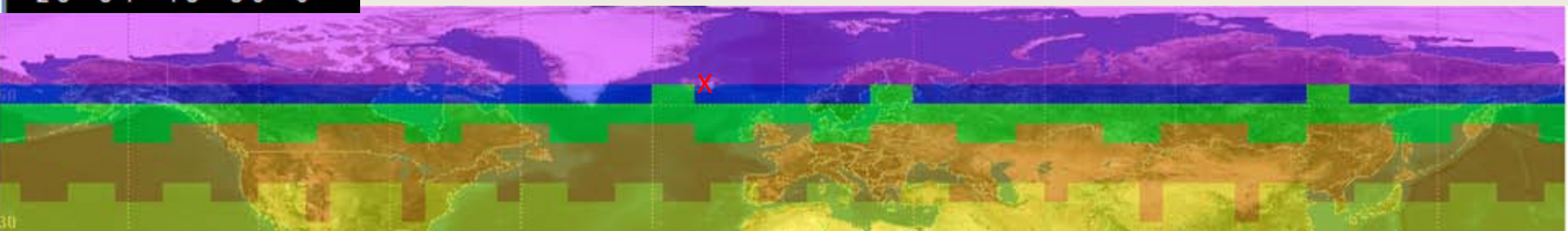
Parameters

Climate and Applications

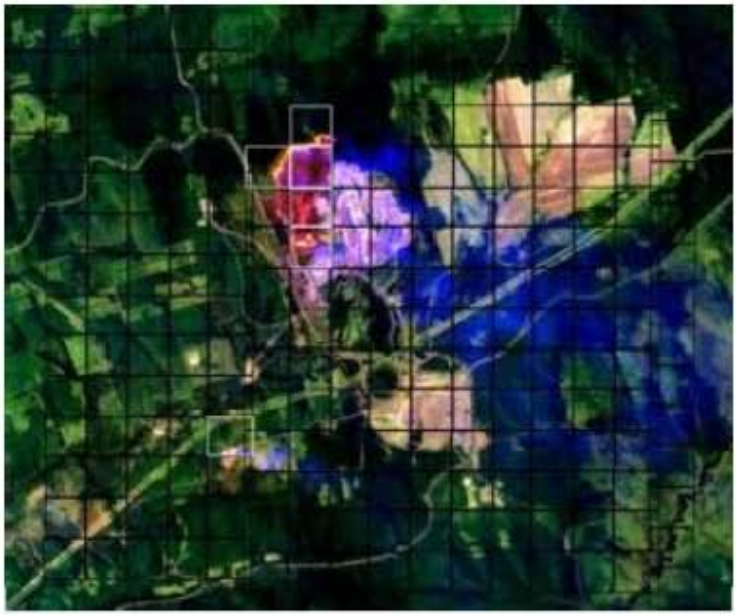


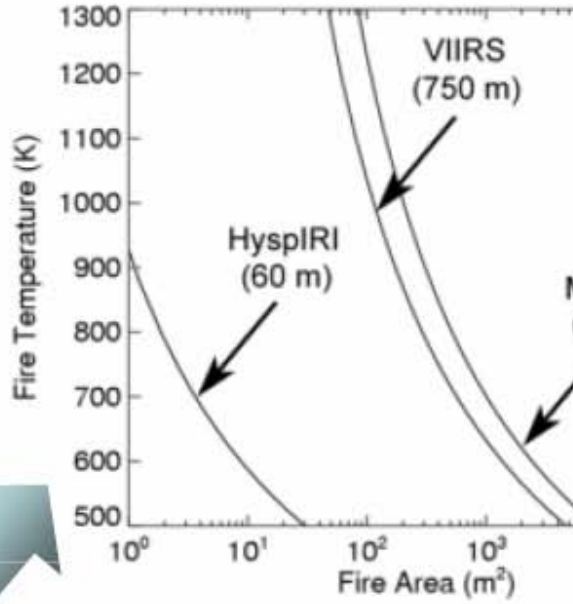
HyspIRI –TIR will provide daily data for Iceland eruptions

Total Views in 5-days

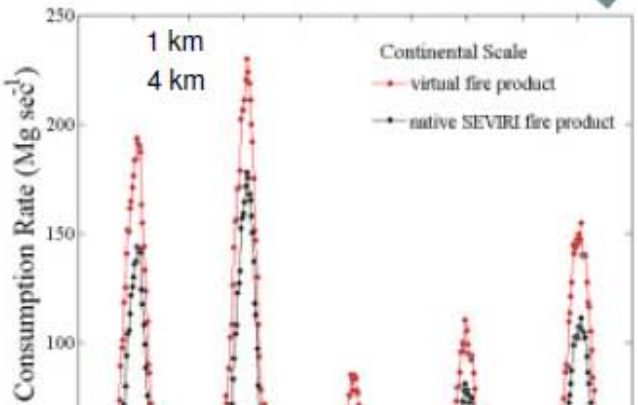


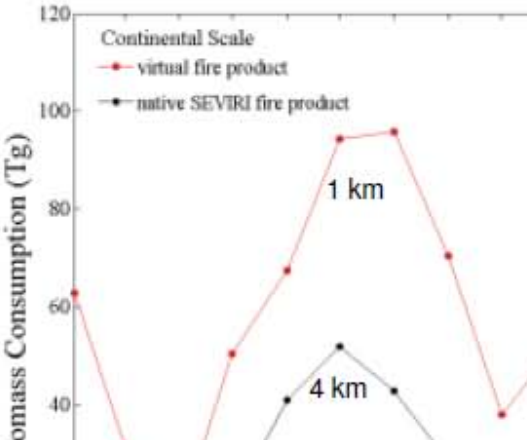
HysplRI-TIR Provides Orders of Magnitu
Improvement in Detection



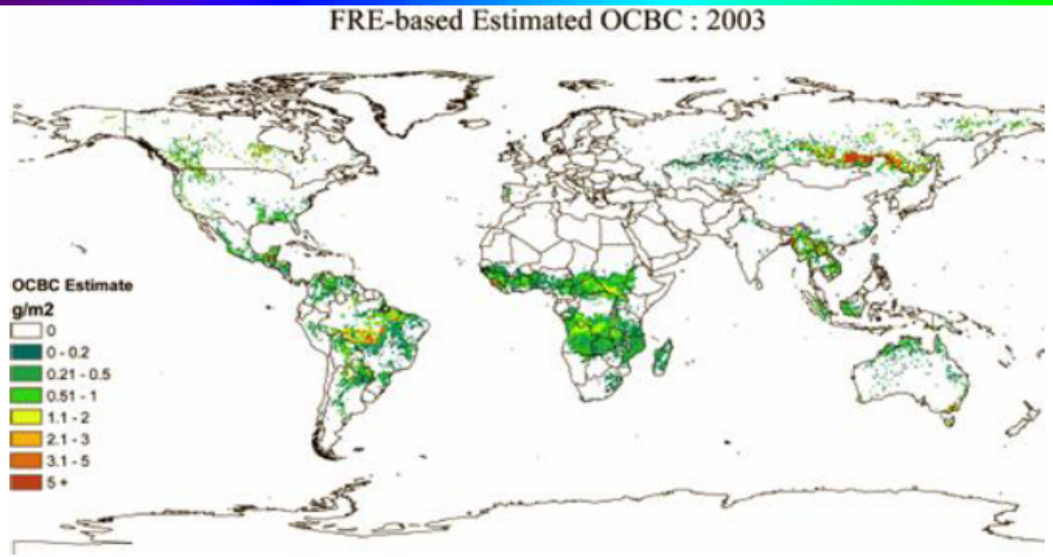


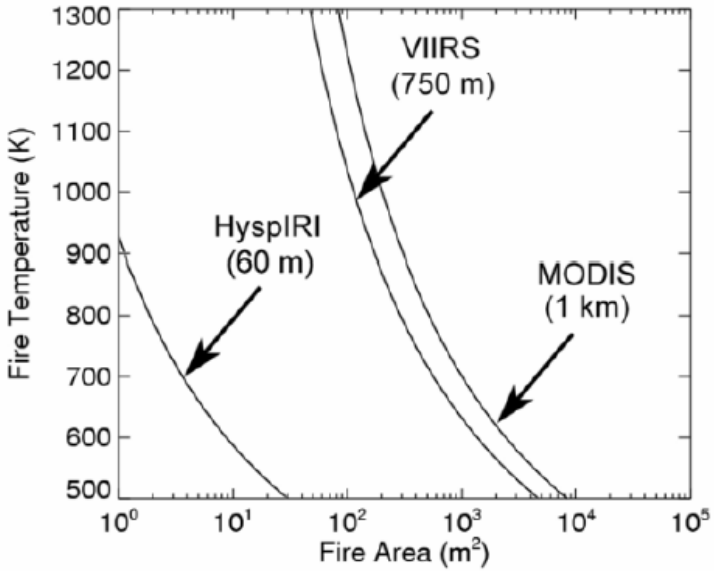
HysplRI detects agricultural fires which are a major carbon contributor and cannot be reliably detected



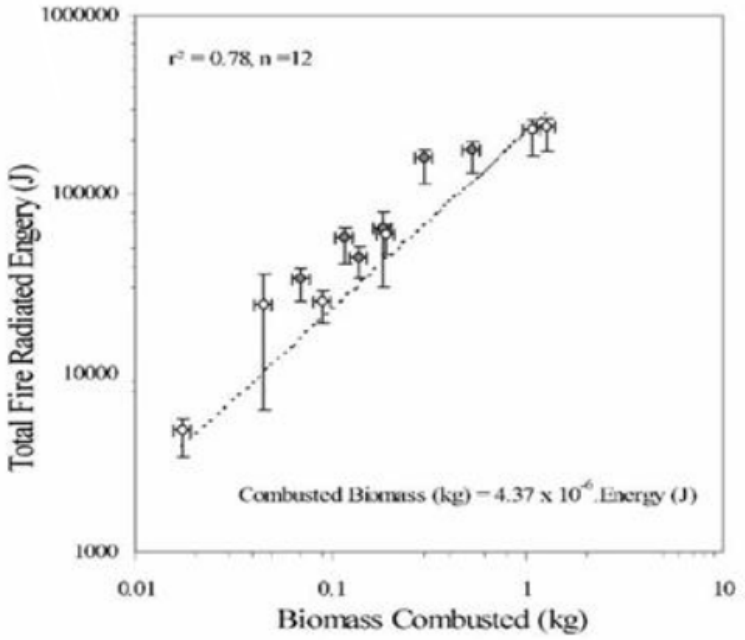


Fire Radiative Energy





90% probability of detection; boreal forest; nadir view



Use Fire Radiative Energy to estimate combusted biomass: Need 3-5 um data

Ellicott et al 2009

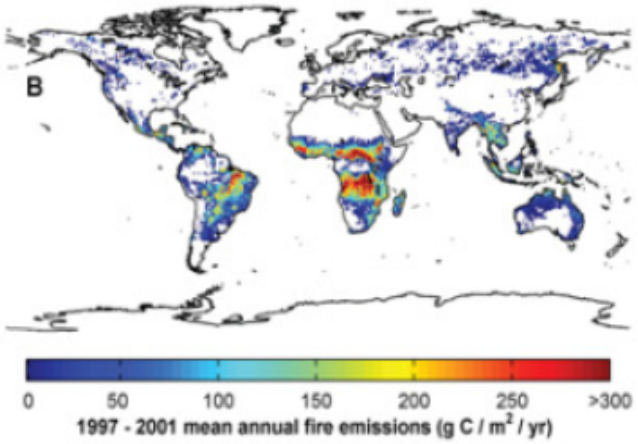
Wooster et al 2002 and 2003

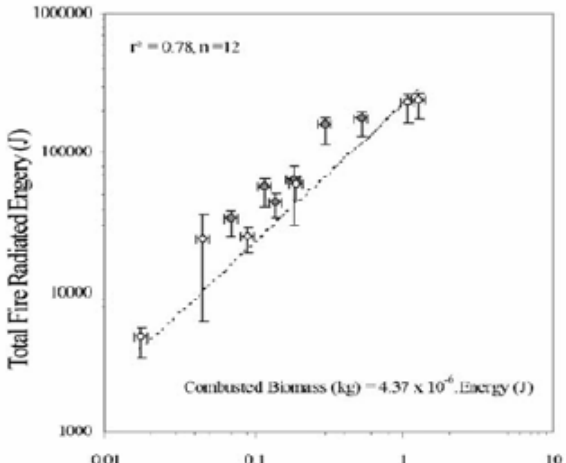
Global Fire Emission Estimates

HyspIRI

Biomass burning and fossil fuel emissions release ~10^{15} g of ca (C) to the atmosphere each year. Biomass burning constitutes ~25% of all global C emissions.

Region	Fire emissions 1997-2009 average (10^{15} g C yr^{-1})
Central and northern South America	0.04
Southern South America	0.27
Northern Africa	0.48
Southern Africa	0.27
Southeast Asia	0.04
Boreal (north of 38°N)	0.18
Other	0.73
Global	2.01



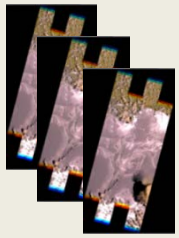


Need 4 u
to measu
Radiative
(FRP) to
determin
Biomass
Combust

Challenges

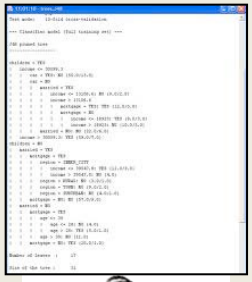
High Data volume
Low Latency Data
Atmospheric Correction for L2 Products
Data Processing Chain
Data archive/distribution
Calibration/Validation
Combined VSWIR and TIR
Global Collections
Regional Collections

SensorWeb Design for User-Defined L2 Products Prototype for HyspIRI Using EO-1



SCIENCE USER

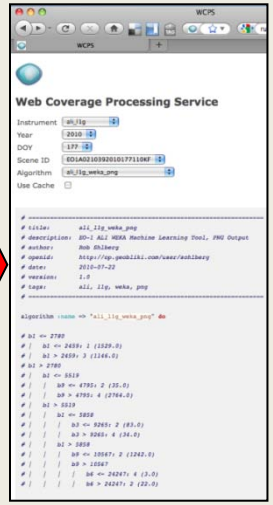
Machine Learning
Supervised Classifier
(Regression Tree)
Refined Offline



Weka to WCPS Translator

Agent Converts Weka Tree Object to WCPS Algorithm

Parse tree

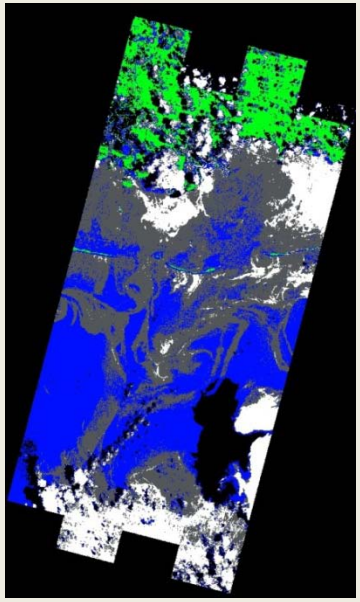


Dynamic Upload

EO-1, HyspIRI …

GlobalHawk,
Ikhana, B200 …

NASA Cloud Infrastructure As A Service



Custom Data Product (KMZ, PNG…)

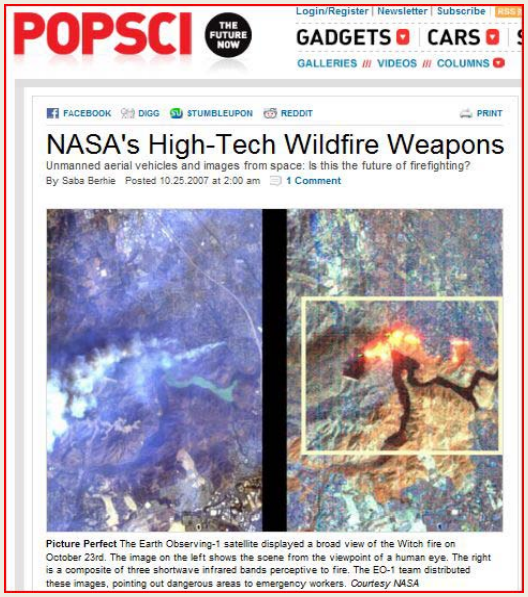
Data Distribution And Notification

Custom Algorithm Upload
With Satellite Tasking,
Image Acquisition & Processing
And Data Delivery

WCPS – web coverage processing service

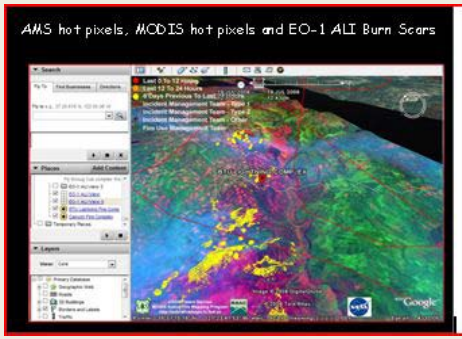
Fire SensorWeb Experiments with U.S. Forest Service

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.

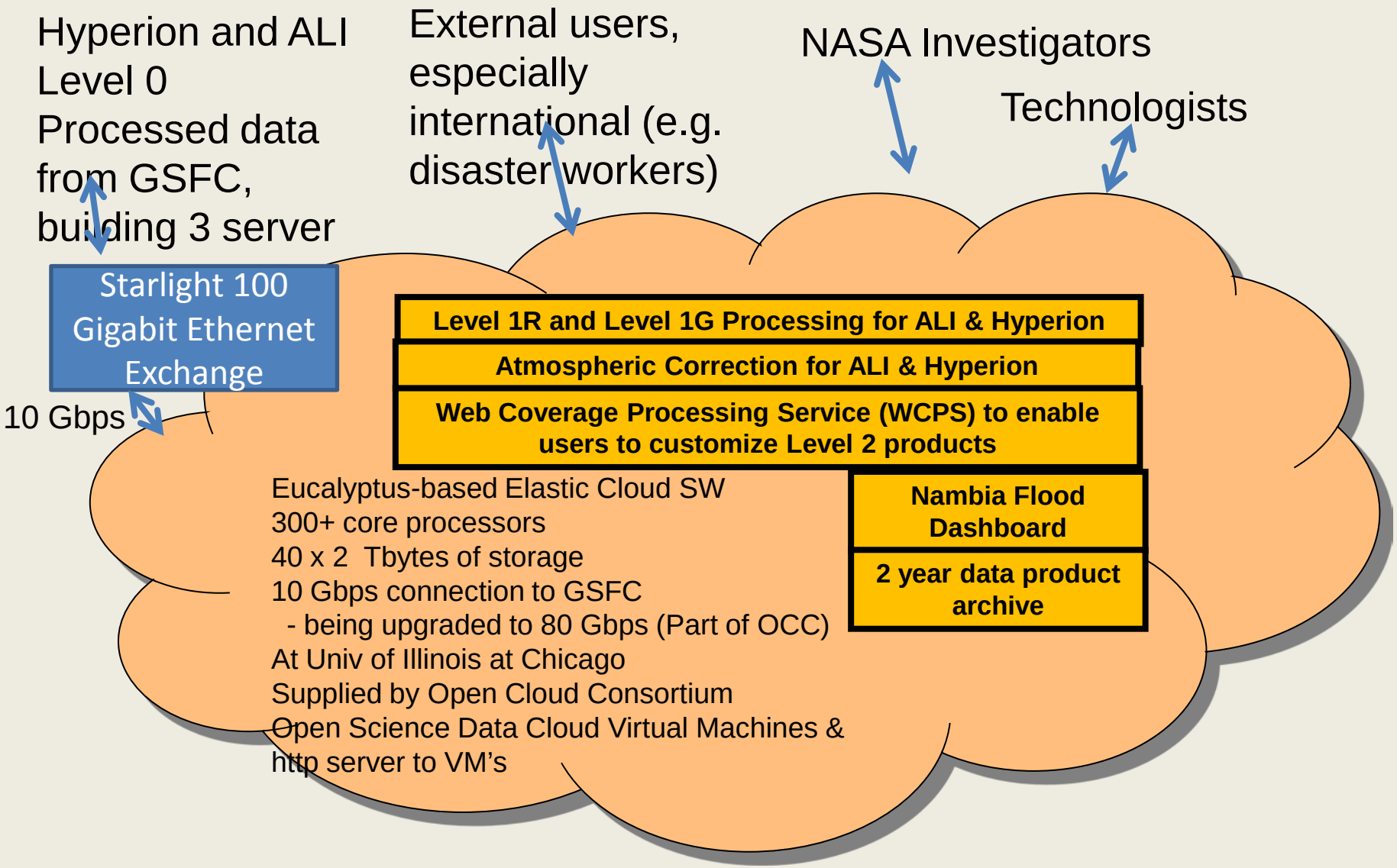


Detect: National Fire Interagency Center (NIFC) large fire map and MODIS daily hot pixel maps acted as triggers
Respond: Trigger EO-1 and Unmanned Aerial System (UAS) images automatically to take a detailed look
Product Generation: Active fire maps, burn scar maps
Delivery: Experimented with various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



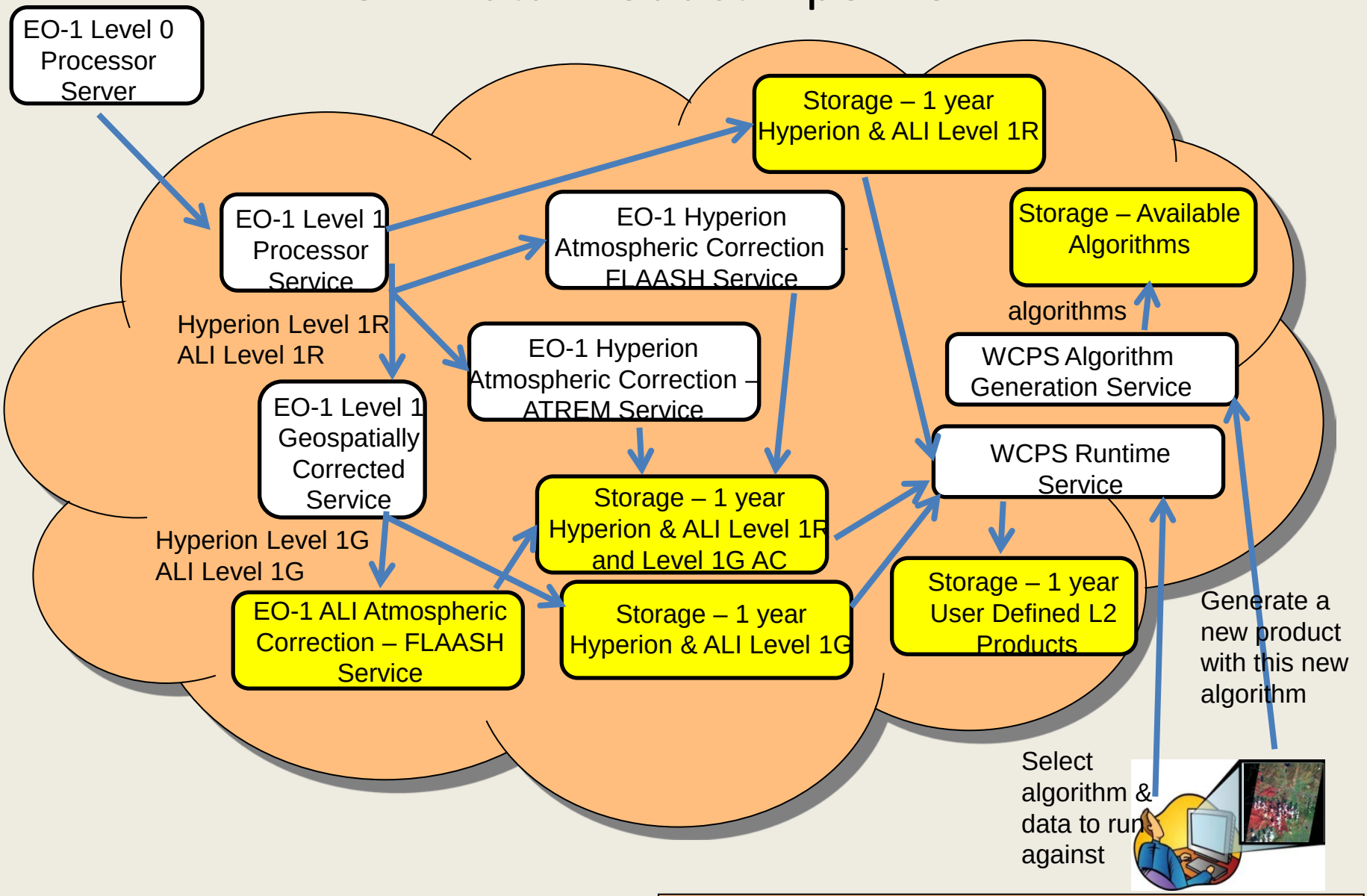
Step 3 Improvement for EO-1 - Overview



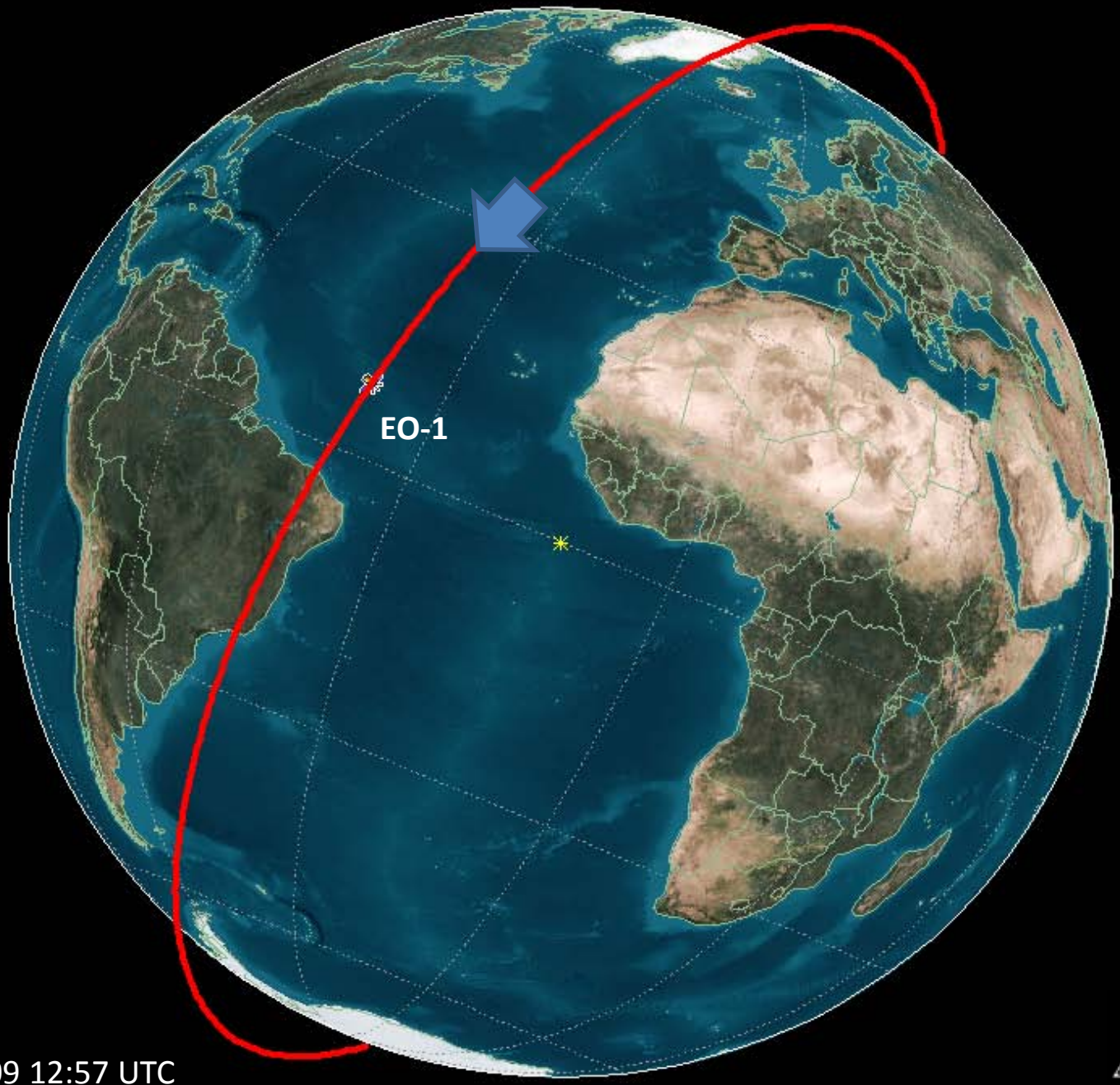
OCC = Open Cloud Consortium

Phase 3 Add Elastic Cloud Ongoing Feb 2011

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



Phase 3 Add Elastic Cloud Ongoing Feb 2011



20 March 2009 12:57 UTC