NASA Satellite Data To Study the Earth:
Past, Present & Future

Jeffrey C. Luvall
NASA Marshall Space Flight Center
Huntsville, AL
jluvall@nasa.gov

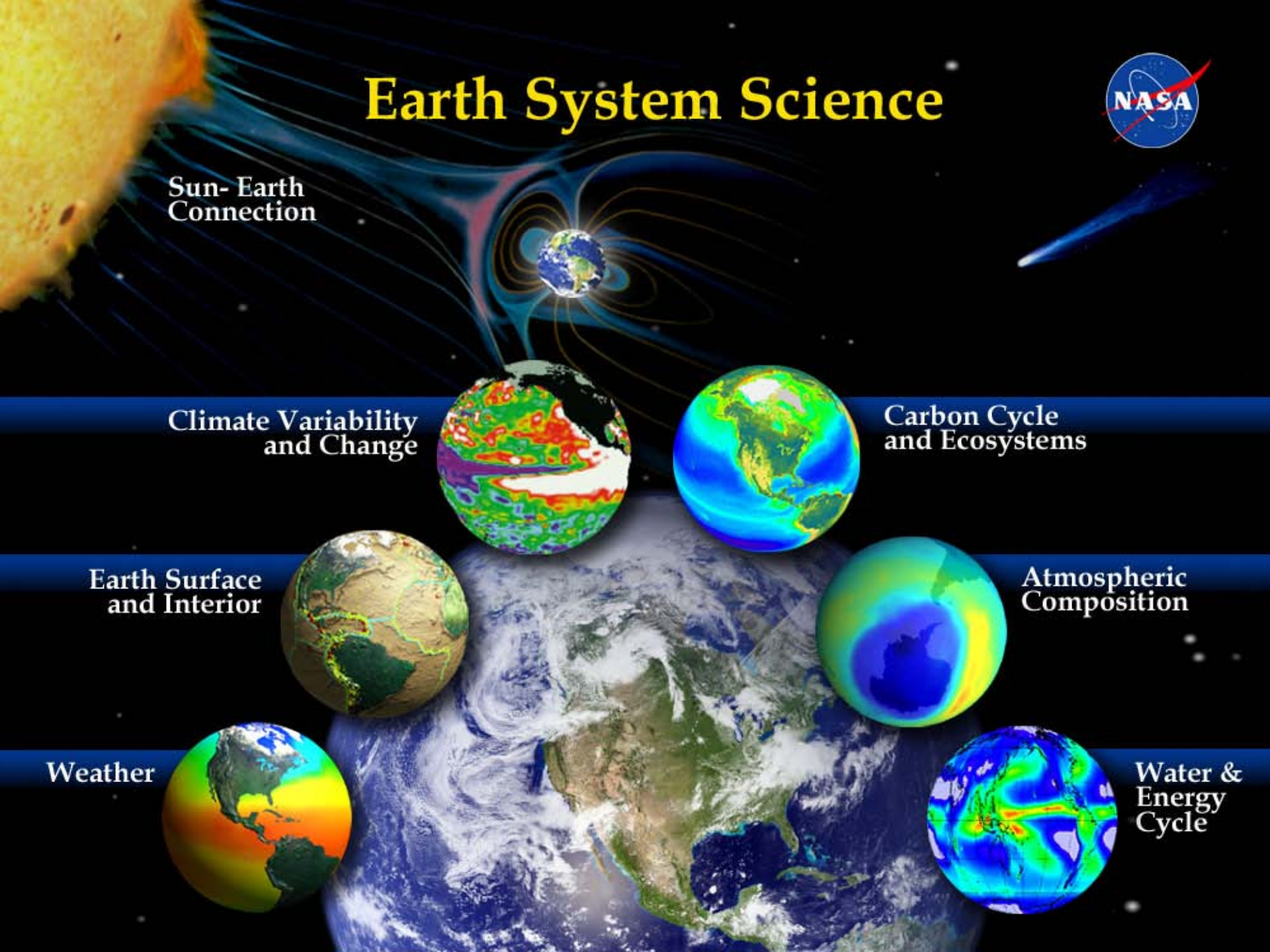
2010 NASA Science Plan

The 2010 Science Plan identifies the direction NASA has received from the Administration and Congress, advice received from the nation's science community, principles and strategies guiding the conduct of our activities, and challenges we face. The plan that results enables NASA, as Administrator Bolden says, to "do the best science, not just more science."

The NASA Earth Science strategic goal is stated as, ***"Advance Earth System Science to meet the challenges of climate and environmental change."***

http://science.nasa.gov/media/medialibrary/2010/08/30/2010SciencePlan_TAGGED.pdf

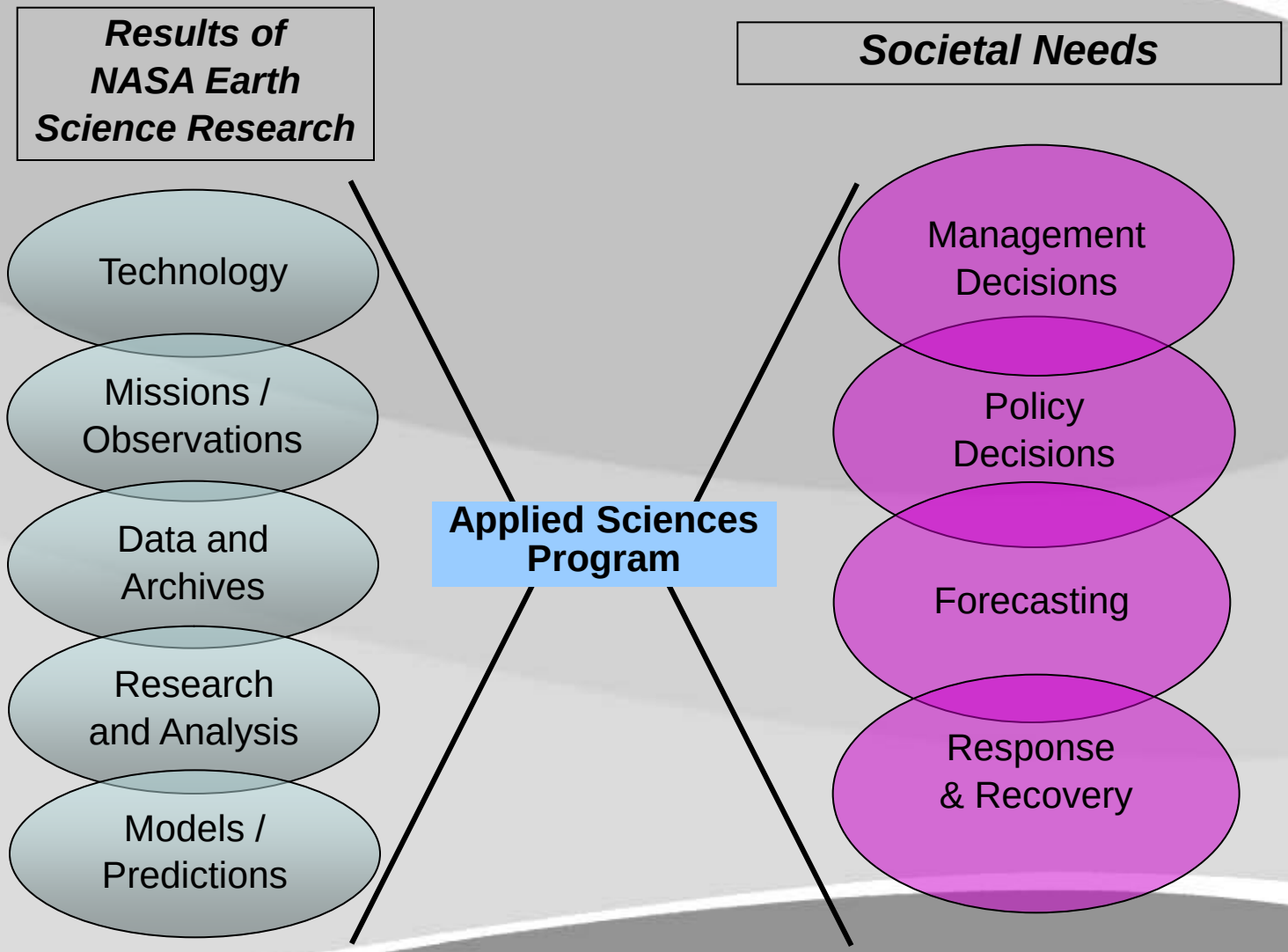
Earth System Science



NASA Applied Sciences Program Mission Statement

Advance the realization of societal and economic benefits from NASA Earth science by identifying societal needs, conducting applied research and development, and collaborating with application developers and users.

NASA Applied Sciences Architecture



Applied Sciences Program

Eight Program Elements

Agricultural Efficiency

Air Quality

Climate

Disaster Management

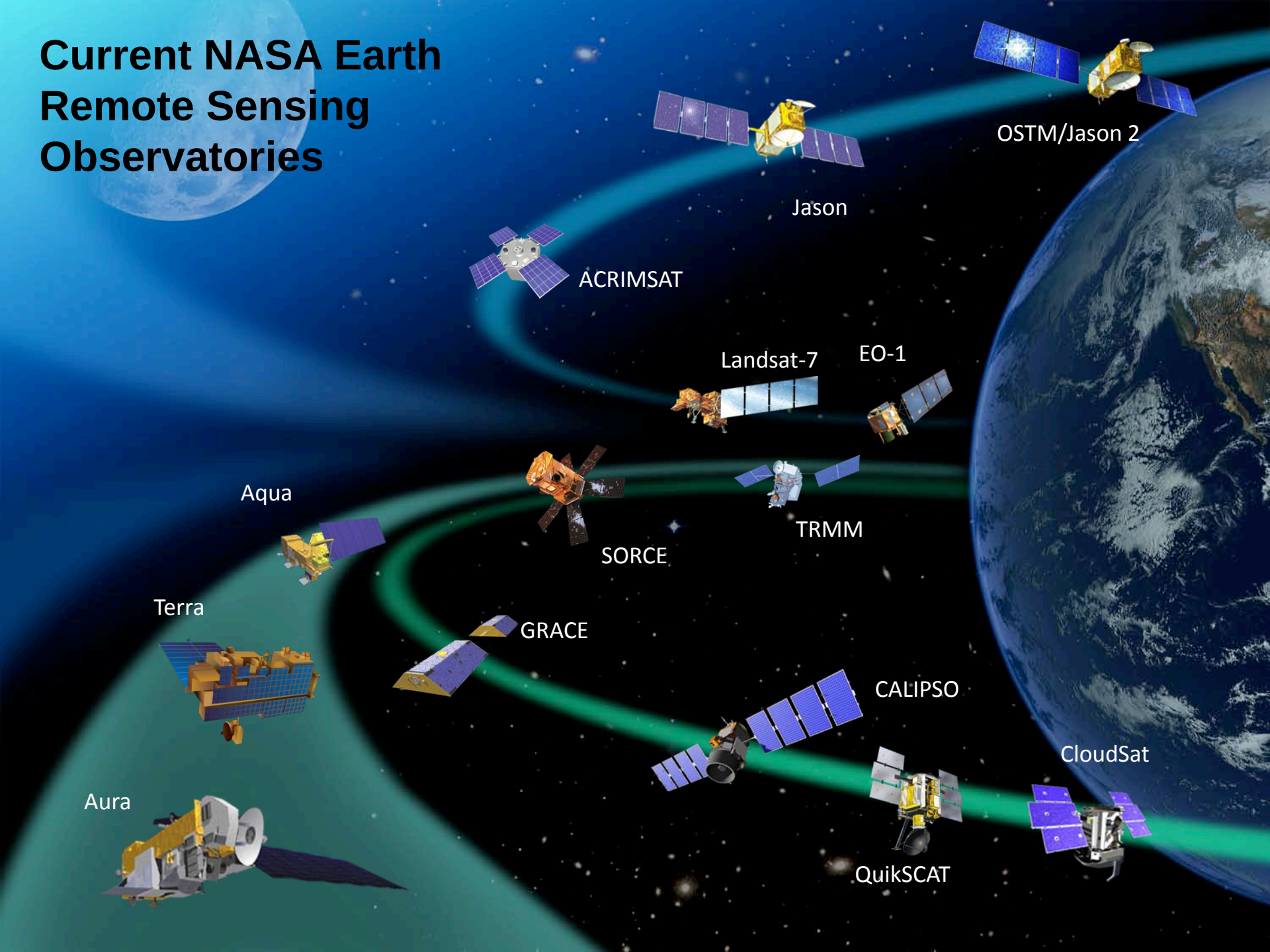
Ecological Forecasting

Public Health

Water Resources

Weather

Current NASA Earth Remote Sensing Observatories



MODIS (Terra & Aqua)

Orbit:	705 km, 10:30 a.m. descending node (Terra) or 1:30 p.m. ascending node (Aqua), sun-synchronous, near-polar, circular
Scan Rate:	20.3 rpm, cross track
Swath Dimensions:	2330 km (cross track) by 10 km (along track at nadir)
Telescope:	17.78 cm diam. off-axis, afocal (collimated), with intermediate field stop
Size:	1.0 x 1.6 x 1.0 m
Weight:	228.7 kg
Power:	162.5 W (single orbit average)
Data Rate:	10.6 Mbps (peak daytime); 6.1 Mbps (orbital average)
Quantization:	12 bits
Spatial Resolution:	250 m (bands 1-2) 500 m (bands 3-7) 1000 m (bands 8-36)
Design Life:	6 years

MODIS Channels

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required SNR[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110
Ocean Color/ Phytoplankton/ Biogeochemistry	8	405 - 420	44.9	880
	9	438 - 448	41.9	838
	10	483 - 493	32.1	802
	11	526 - 536	27.9	754
	12	546 - 556	21.0	750
	13	662 - 672	9.5	910
	14	673 - 683	8.7	1087
	15	743 - 753	10.2	586
	16	862 - 877	6.2	516
Atmospheric Water Vapor	17	890 - 920	10.0	167
	18	931 - 941	3.6	57
	19	915 - 965	15.0	250

MODIS Channels

Primary Use	Band	Bandwidth[1]	Spectral Radiance[2]	Required NE[delta]T(K)[4]
Surface/Cloud Temperature	20	3.660 - 3.840	0.45(300K)	0.05
	21	3.929 - 3.989	2.38(335K)	2.00
	22	3.929 - 3.989	0.67(300K)	0.07
	23	4.020 - 4.080	0.79(300K)	0.07
Atmospheric Temperature	24	4.433 - 4.498	0.17(250K)	0.25
	25	4.482 - 4.549	0.59(275K)	0.25
Cirrus Clouds Water Vapor	26	1.360 - 1.390	6.00	150(SNR)
	27	6.535 - 6.895	1.16(240K)	0.25
	28	7.175 - 7.475	2.18(250K)	0.25
Cloud Properties	29	8.400 - 8.700	9.58(300K)	0.05
Ozone	30	9.580 - 9.880	3.69(250K)	0.25
Surface/Cloud Temperature	31	10.780 - 11.280	9.55(300K)	0.05
	32	11.770 - 12.270	8.94(300K)	0.05
Cloud Top Altitude	33	13.185 - 13.485	4.52(260K)	0.25
	34	13.485 - 13.785	3.76(250K)	0.25
	35	13.785 - 14.085	3.11(240K)	0.25
	36	14.085 - 14.385	2.08(220K)	0.35

Calibration
(see also: http://mcst.gsfc.nasa.gov/**)**

- MOD 01 - Level-1A Radiance Counts
- MOD 02 - Level-1B Calibrated Geolocated Radiances
- MOD 03 - Geolocation Data Set

Atmosphere
(see also: http://modis-atmos.gsfc.nasa.gov/**)**

- MOD 04 - Aerosol Product
- MOD 05 - Total Precipitable Water (Water Vapor)
- MOD 06 - Cloud Product
- MOD 07 - Atmospheric Profiles
- MOD 08 - Gridded Atmospheric Product
- MOD 35 - Cloud Mask

Land
(see also: http://edcdaac.usgs.gov/dataproducts.asp **and** http://modis-land.gsfc.nasa.gov/**)**

- MOD 09 - Surface Reflectance
- MOD 11 - Land Surface Temperature & Emissivity
- MOD 12 - Land Cover/Land Cover Change
- MOD 13 - Gridded Vegetation Indices (Max NDVI & Integrated MVI)
- MOD 14 - Thermail Anomalies, Fires & Biomass Burning
- MOD 15 - Leaf Area Index & FPAR
- MOD 16 - Evapotranspiration
- MOD 17 - Net Photosynthesis and Primary Productivity
- MOD 43 - Surface Reflectance
- MOD 44 - Vegetation Cover Conversion

Cryosphere
(see also: http://nsidc.org/daac/modis/index.html**)**

- MOD 10 - Snow Cover
- MOD 29 - Sea Ice Cover

Ocean
(Details about ocean products are best obtained by going to: http://oceancolor.gsfc.nasa.gov/**)**

- Angstrom Exponent
- Aerosol Optical Thickness
- Chlorophyll a
- Downwelling diffuse attenuation coefficient at 490 nm
- Level 2 Flags
- Photosynthetically Available Radiation
- Particulate Inorganic Carbon
- Particulate Organic Carbon
- Sea Surface Temperature Quality
- Sea Surface Temperature Quality - 4um
- Remote Sensing Reflectance
- Sea Surface Temperature
- Sea Surface Temperature 4um

MODIS Data Sources

Calibration
http://mcst.gsfc.nasa.gov/

Atmosphere http://modis-atmos.gsfc.nasa.gov/

Land
http://edcdaac.usgs.gov/dataproducts.asp & http://modis-land.gsfc.nasa.gov/

Cryosphere http://nsidc.org/daac/modis/index.html

Ocean
http://oceancolor.gsfc.nasa.gov

Landsat Satellite Series
1972 to 1983

Multispectral Scanner (MSS)			
Landsats 1-3	Landsats 4-5	Wavelength (micrometers)	Resolution (meters)
Band 4	Band 1	0.5-0.6	80
Band 5	Band 2	0.6-0.7	80
Band 6	Band 3	0.7-0.8	80
Band 7	Band 4	0.8-1.1	80

Landsat Satellite Series
1982 to present

Thematic Mapper (TM)		
Landsats 4-5	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.76-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	120*
Band 7	2.08-2.35	30

Landsat Satellite Series
1999 to present

Enhanced Thematic Mapper Plus (ETM+)		
Landsat 7	**Wavelength (micrometers)**	**Resolution (meters)**
Band 1	0.45-0.52	30
Band 2	0.52-0.60	30
Band 3	0.63-0.69	30
Band 4	0.77-0.90	30
Band 5	1.55-1.75	30
Band 6	10.40-12.50	60
Band 7	2.09-2.35	30
Band 8	.52-.90	15

Landsat data Continuity Mission
December 2012

Landsat Data Continuity Mission (LDCM) Projected Launch December 2012	Bands	Wavelength (micrometers)	Resolution (meters)
	Band 1 – Coastal aerosol	0.433 - 0.453	30
	Band 2 – Blue	0.450 – 0.515	30
	Band 3 – Green	0.525 – 0.600	30
	Band 4 – Red	0.630 – 0.680	30
	Band 5 – Near Infrared (NIR)	0.845 – 0.885	30
	Band 6 – SWIR 1	1.560 – 1.660	30
	Band 7 – SWIR 2	2.100 – 2.300	30
	Band 8 – Panchromatic	0.500 – 0.680	15
	Band 9 – Panchromatic	1.360 – 1.390	30
	Band 10 – Thermal Infrared (TIR) 1	10.3 – 11.3	120
	Band 11 – Thermal Infrared (TIR) 2	11.5 – 12.5	120

EO-1

2000 to present

Hyperion

A high resolution hyperspectral imager capable of resolving 220 spectral bands from 0.4 to 2.5 µm with a 30 m resolution.

Advanced Land Imager (ALI)		
Earth Observing-1	Wavelength (micrometers)	Resolution (meters)
Band 1	.048-0.69	10
Band 2	0.433-0.453	30
Band 3	0.45-0.515	30
Band 4	0.525-0.605	30
Band 5	0.63-0.69	30
Band 6	0.775-0.805	30
Band 7	0.845-0.89	30
Band 8	1.2-1.3	30
Band 9	1.55-1.75	30
Band 10	2.08-2.35	30

EO-1 & Landsat Data Products

http://edcsns17.cr.usgs.gov/eo1/

http://landsat.usgs.gov/products_productinformation.php/

HYSPIRI SCIENCE AND APPLICATIONS

Dr Simon J. Hook
Jet Propulsion Laboratory, California Institute of Technology.

With contributions from:
Elizabeth Middleton
Robert O Green

HysplRI and the NRC Decadal Survey

- January 2007: NRC releases Earth Science & Applications from Space report (the Decadal Survey) to NASA, NOAA, & USGS
- Calls for 17 satellite missions as an integrated set of space measurements in the decade 2010-2020 (14 NASA, 2 NOAA, 1 both)
- NRC places missions in 3 temporal tiers (2010-2013, 2013-2016, 2016-2020)
- Tier 2 contains a Hyperspectral Infrared Imager or HysplRI mission: hyperspectral imager in visible to SWIR & thermal multispectral scanner
- Targets:
  - Global ecosystem (terrestrial & aquatic) condition & change
  - Global surface temperature & emissivity measures for hazards, water use & availability, urbanization, & land surface composition & change
- Decadal Survey recommendations set boundary conditions for mission design efforts & discussions. We rarely stray from them & only do so for the most compelling reasons of science, cost, mission design, etc.

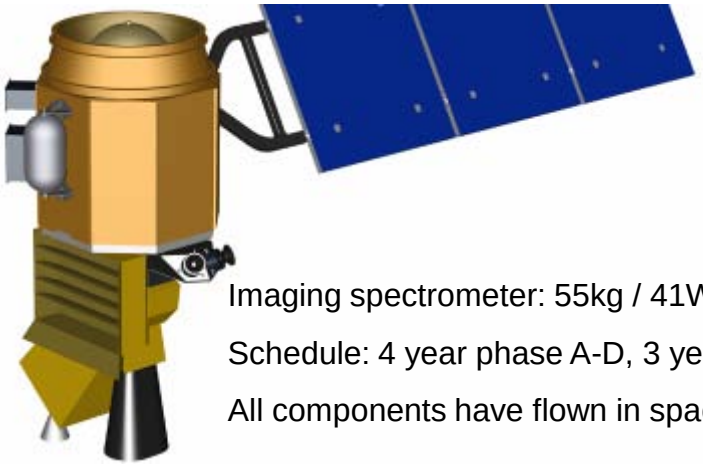
VSWIR Overarching Science Questions

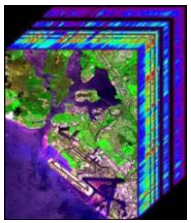
- **VQ1. Pattern and Spatial Distribution of Ecosystems and their Components, (EM,JG)**
  - What is the pattern of ecosystem distribution and how do ecosystems differ in their composition or biodiversity? [DS 195]
- **VQ2. Ecosystem Function, Physiology and Seasonal Activity, (EM,JG)**
  - What are the 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 disturbances? [DS 191, 195, 203]
- **VQ3. Biogeochemical Cycles (SO, SU)**
  - How are biogeochemical cycles for carbon, water and nutrients being altered by natural and human-induced environmental changes?
- **VQ4. Changes in Disturbance Activity (RK,GA)**
  - How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?
- **VQ5. Ecosystem and Human Health, (PT,GG)**
  - How do changes in ecosystem composition and function affect human health, resource use, and resource management?
- **VQ6. Land Surface and Shallow Water Substrate Composition (RG, HD)**
  - What is the land surface soil/rock and shallow water substrate composition?

TIR Overarching Science Questions

- **TQ1. Volcanoes/Earthquakes (MA,FF)**
  - How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?
- **TQ2. Wildfires (LG,DR)**
  - What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time?
- **TQ3. Water Use and Availability, (MA,RA)**
  - 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?
- **TQ4. Urbanization/Human Health, (DQ,GG)**
  - How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?
- **TQ5. Earth surface composition and change, (AP,JC)**
  - 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?

HyspIRI Visible Shortwave Infrared (VSWIR) Science Measurements





Imaging spectrometer: 55kg / 41W

Schedule: 4 year phase A-D, 3 years operations

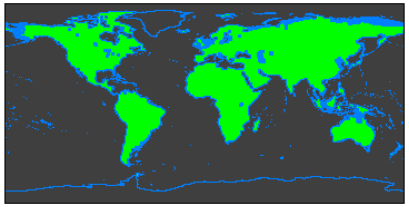
All components have flown in space

Science Questions:

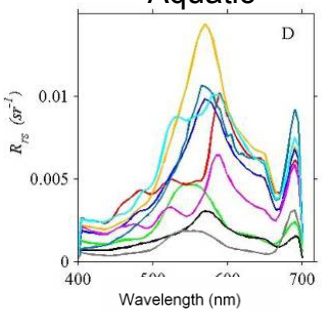
- *What is the composition, function, and health of land and water ecosystems?*
- *How are these ecosystems being altered by human activities and natural causes?*
- *How do these changes affect fundamental ecosystem processes upon which life on Earth depends?*

Measurement:

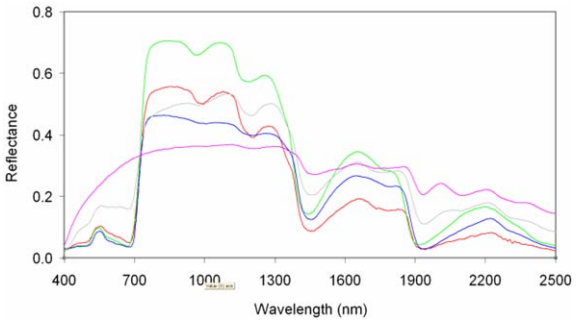
- 380 to 2500 nm in 10nm channels
- Accurate 60 m sampling
- 19 days revisit mapping mission
- Global land and shallow water



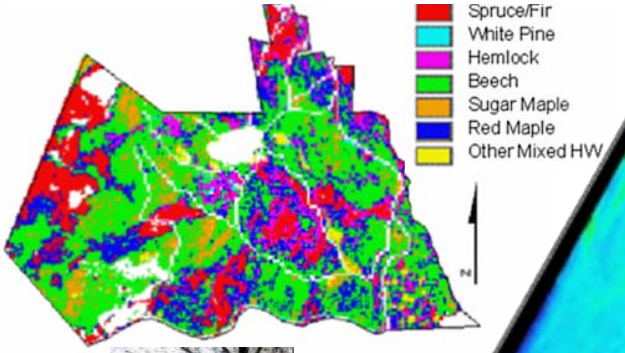
Aquatic

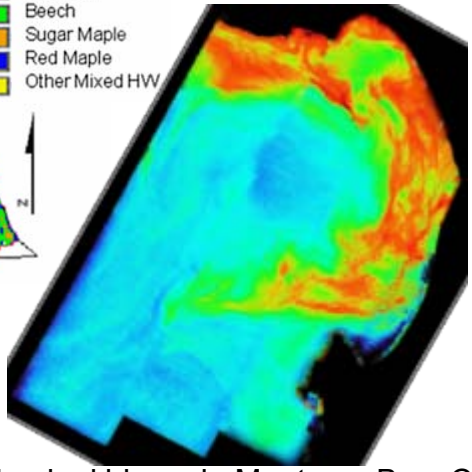


Terrestrial



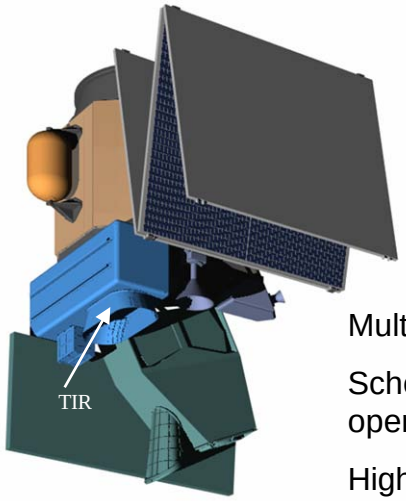
Map of dominant tree species, Bartlett Forest, NH

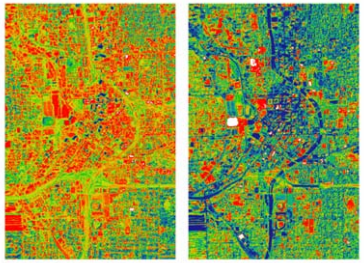




Red tide algal bloom in Monterey Bay, CA

HysplRI Thermal Infrared Multispectral (TIR) Science Measurements





Multispectral Scanner: 60kg / 103W

Schedule: 4 year phase A-D, 3 years operations

High Heritage

Science Questions:

TQ1. Volcanoes/Earthquakes (MA,FF)

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

• TQ2. Wildfires (LG,DR)

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

• TQ3. Water Use and Availability, (MA,RA)

– 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?

• TQ4. Urbanization/Human Health, (DQ,GG)

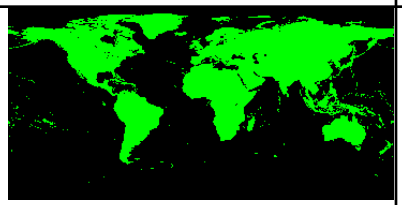
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

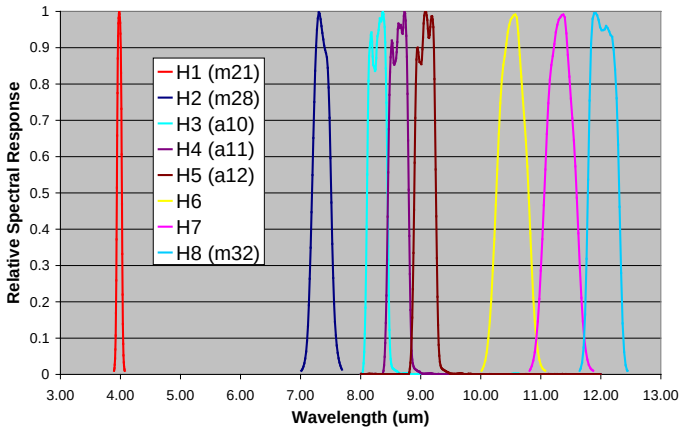
• TQ5. Earth surface composition and change, (AP,JC)

– 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?

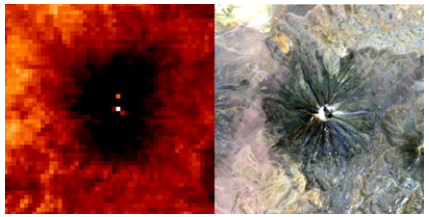
Measurement:

- 7 bands between 7.5-12 µm and 1 band at 4 µm
- 60 m resolution, 5 days revisit
- Global land and shallow water

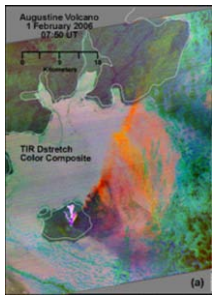




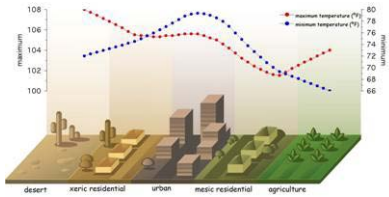
Andean volcano heats up



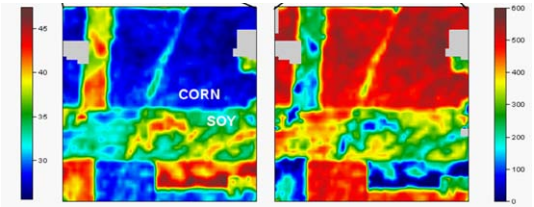
Volcanoes



Urbanization



Water Use and Availability



Surface Temperature

Evapotranspiration

HyspIRI Mission Concept - 2010

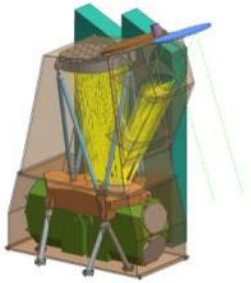
Payload

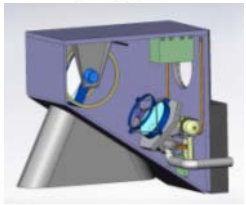
Science Instruments:

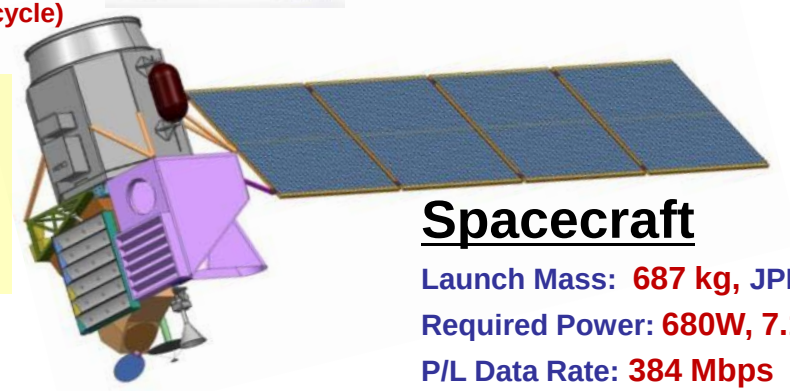
- VSWIR: Imaging Spectrometer
  - 380-2500 nm in 10 nm bands
  - 60m spatial resolution
  - Day-side (23% duty cycle)
  - 55 Kg, 41 W
- TIR: Thermal Infrared Scanner
  - 8 bands between 3-12 µm
  - 60m spatial resolution
  - Day and night-side (100% duty cycle)
  - 60 Kg, 103 W

Intelligent Payload Module (IPM)

- 24/7 Direct Broadcast capability
- subset of science data
- X-band @ 20 Mbps
- 11 Kg, 86 W







Mission Architecture

- Orbit: 626 km Sun-Synchronous, 10:30am LTDN
- Repeat: 19 day VSWIR / 5 day TIR
- Downlink: Contacts nearly every orbit to Svalbard (North) and Troll (Antarctica)
- Science Data: 5.7 Tbits/day
- Launch Vehicle: Taurus 3210, 2m fairing, 790 kg capability

Spacecraft

Launch Mass: 687 kg, JPL DP Margin: 30%

Required Power: 680W, 7.1 m^2 array (965 W capability)

P/L Data Rate: 384 Mbps

Downlink Data Rate: 800 Mbps Dual-pol X-band

Stabilization: 3-axis

Pointing: Control =720 arcsec (per axis 3σ)
Knowledge = 5.6 arcsec (Pitch/Roll axis 3σ);
15 arcsec (Yaw axis 3σ)
Stability = 5 arcsec/sec (per axis 3σ)

Implementation

Launch Date: 2014 - 2020

Lifetime: 3 years, with consumables for 5

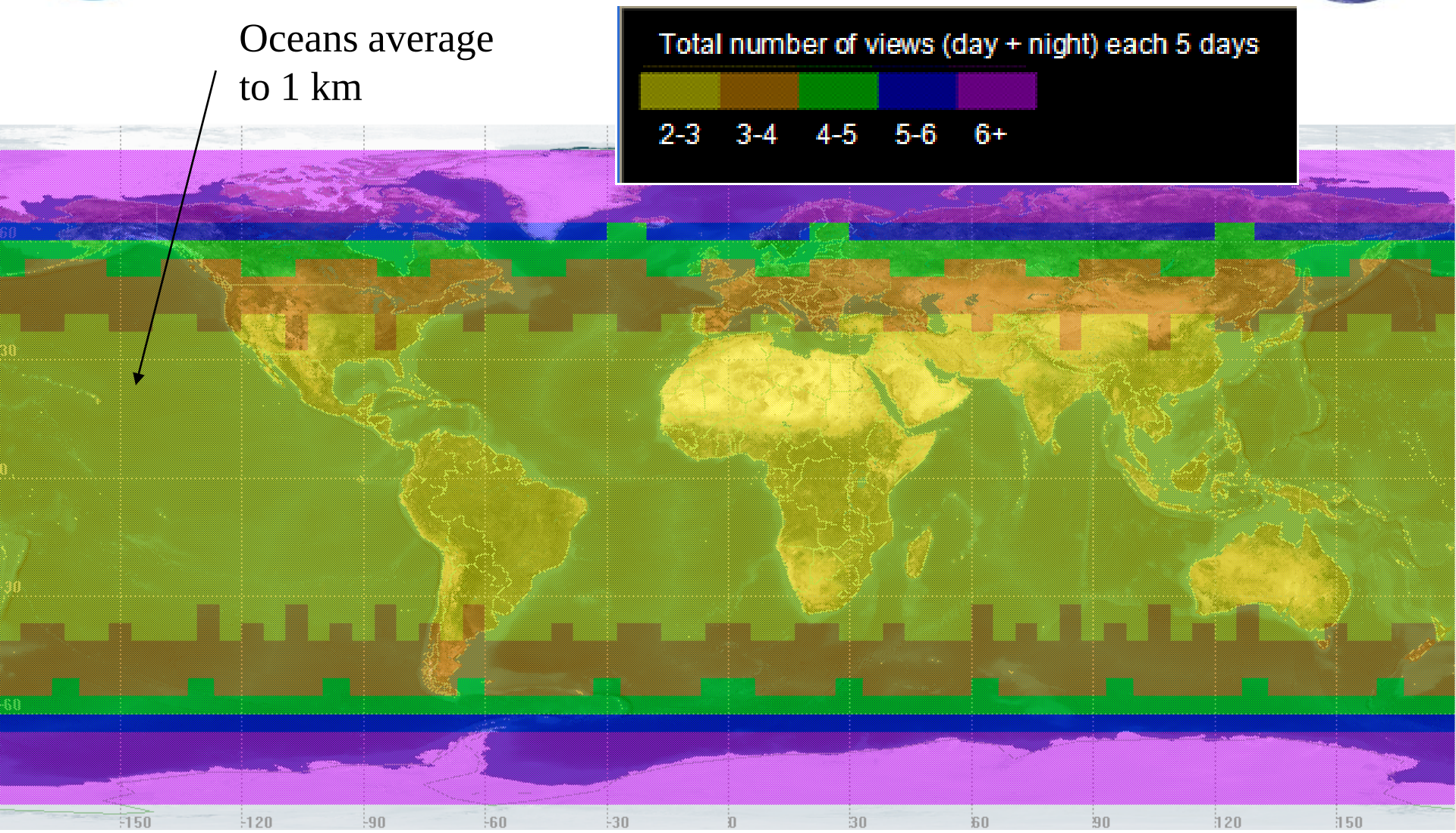
Cost : Low to Moderate cost Mission

Partners: JPL, GSFC

Mission Class: C, with selected redundancy

Hardware Model: Protoflight

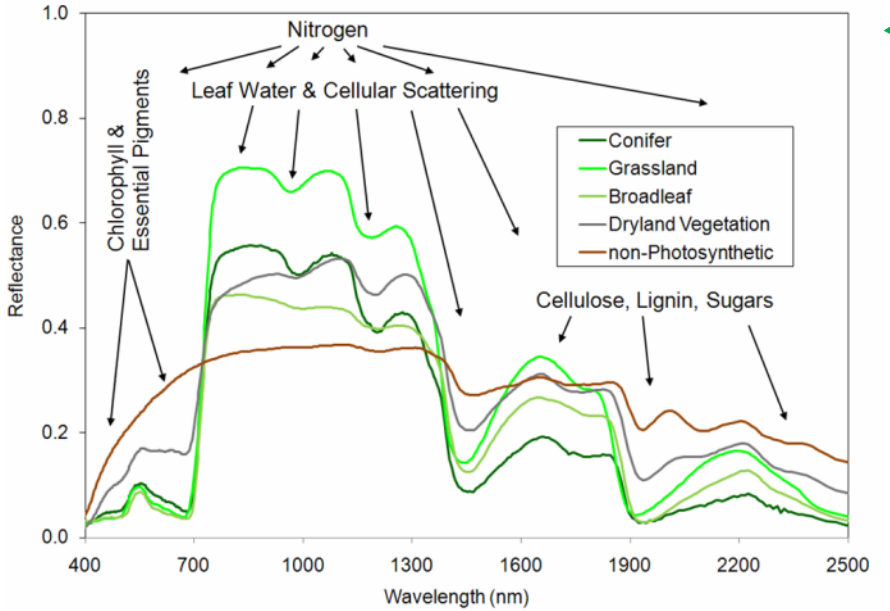
Annual TIR imaging opportunities in a 5-day near-repeating orbit, 1 yr. simulation



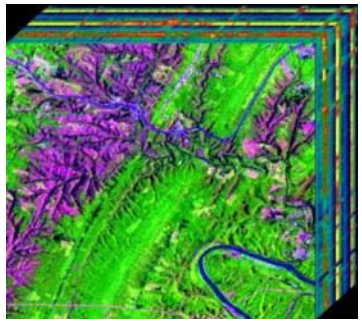
Nominal orbit: average alt. 626.8 km, inclination 97.8˚ . TIR imager FOV: +/- 25.46˚ (60 m pixel GSD at nadir, 9272 cross-track pixels).

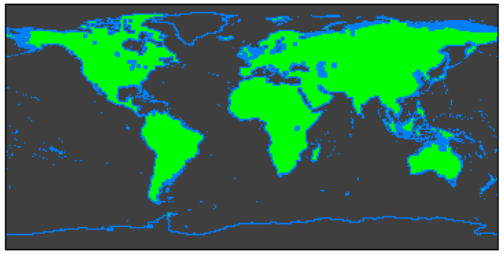
Ecosystem Measurements for Climate Feedbacks

Measuring the Terrestrial Biosphere

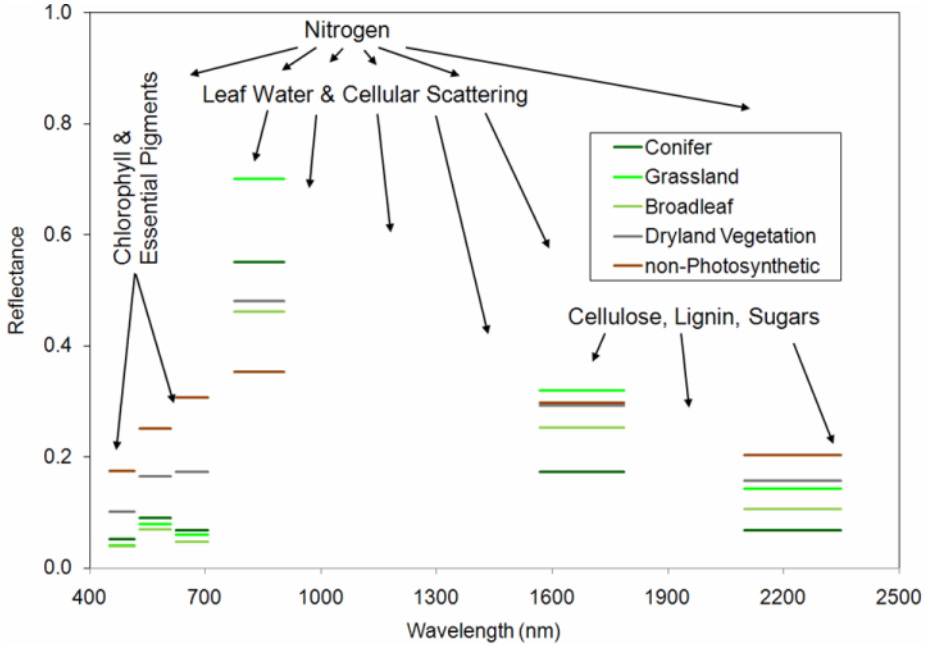


Imaging Spectroscopy is required to measure critical variables of the terrestrial biosphere.





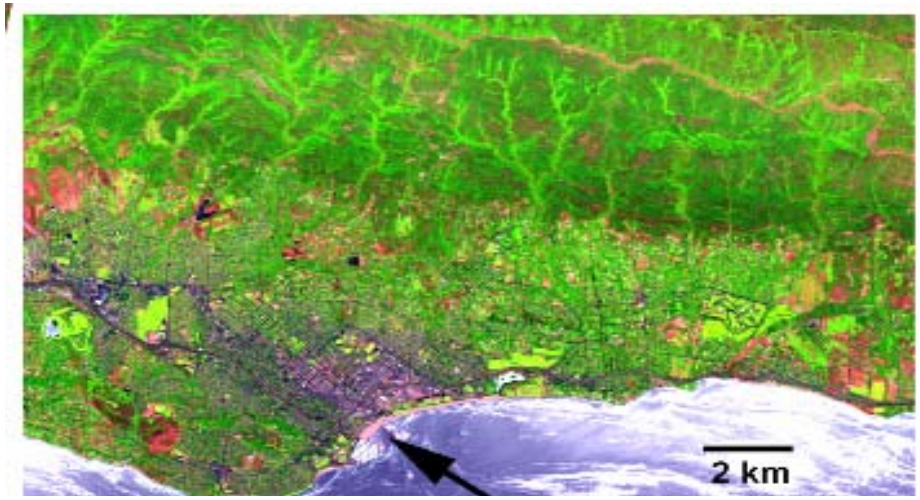
Multi-spectral imaging is insufficient



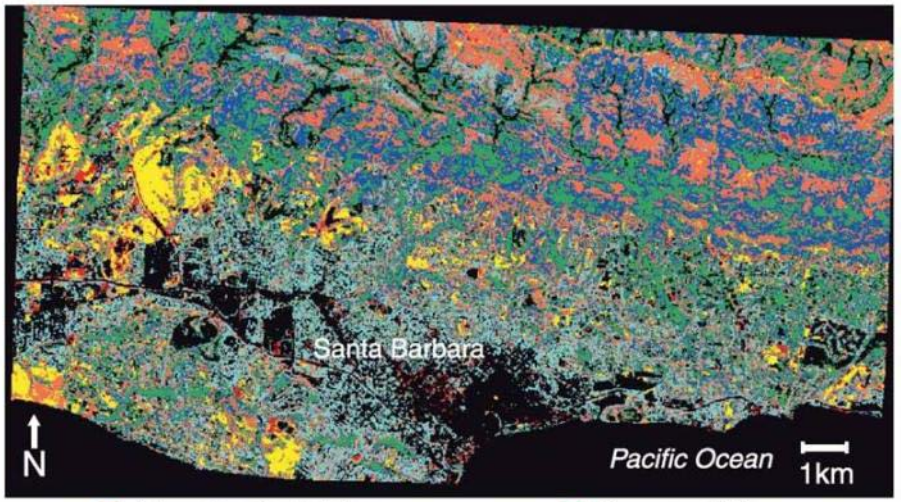
Ecosystem Measurements for Climate Feedbacks

Vegetation Species/Functional-type & Fractional Cover

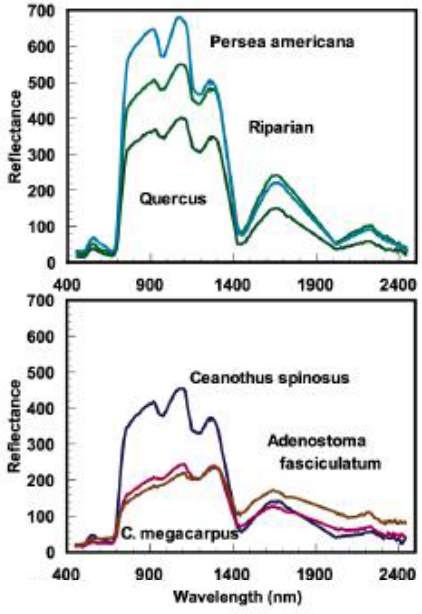
Santa Barbara, CA Coast Range

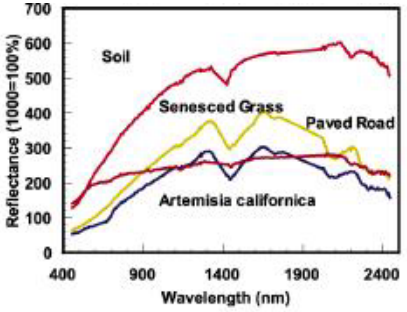


Species Type 90% accurate

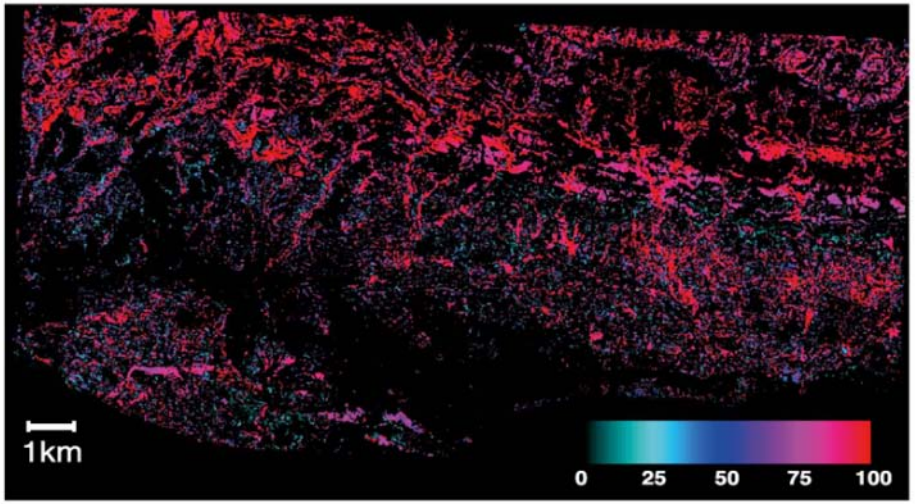


Adenostoma fasciculatum
Ceanothus megacarpus
Arctostaphylos spp.
Quercus agrifolia
Grass
Soil



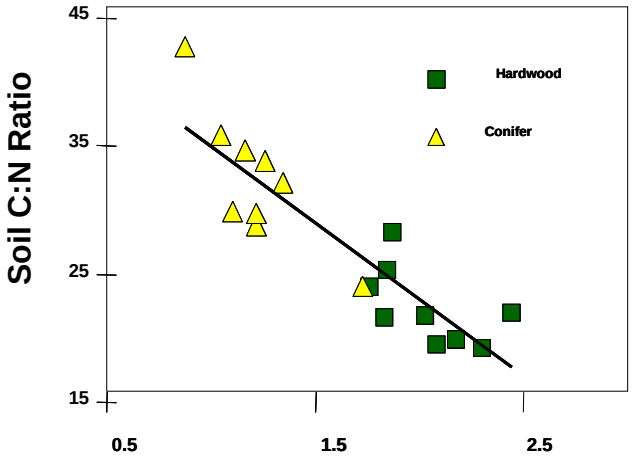


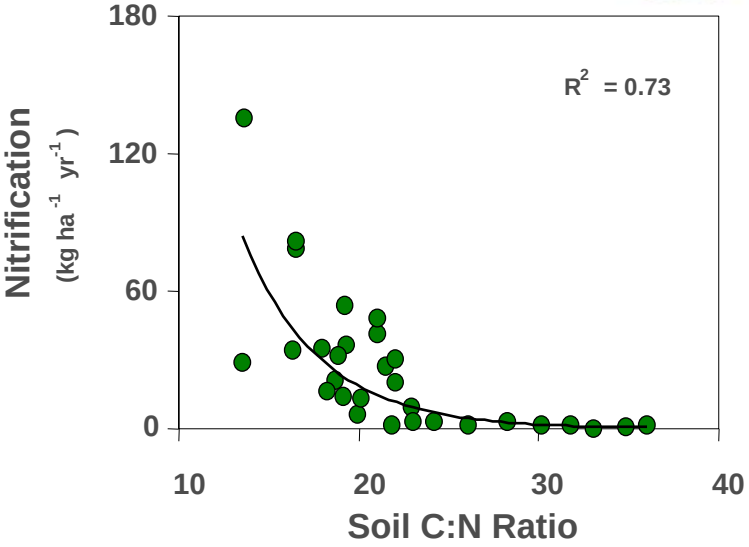
Species Fractional Cover (Quercus agrifolia)

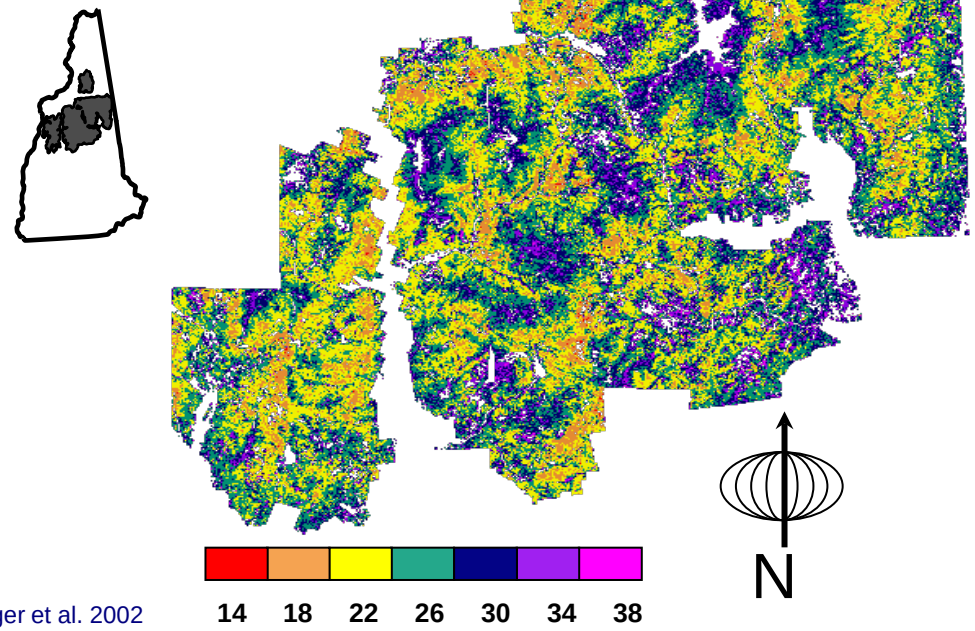


Ecosystem Measurements for Climate Feedbacks

Imaging Spectroscopy Foliar Chemistry Used to Estimate Soil Nitrogen Cycling

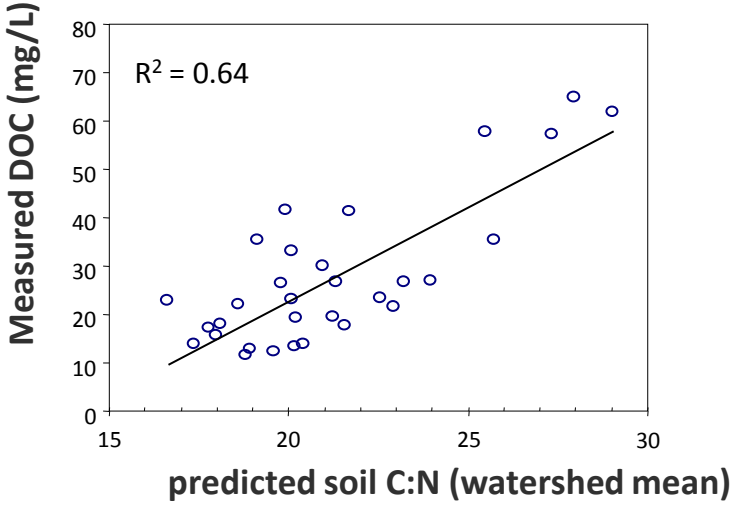




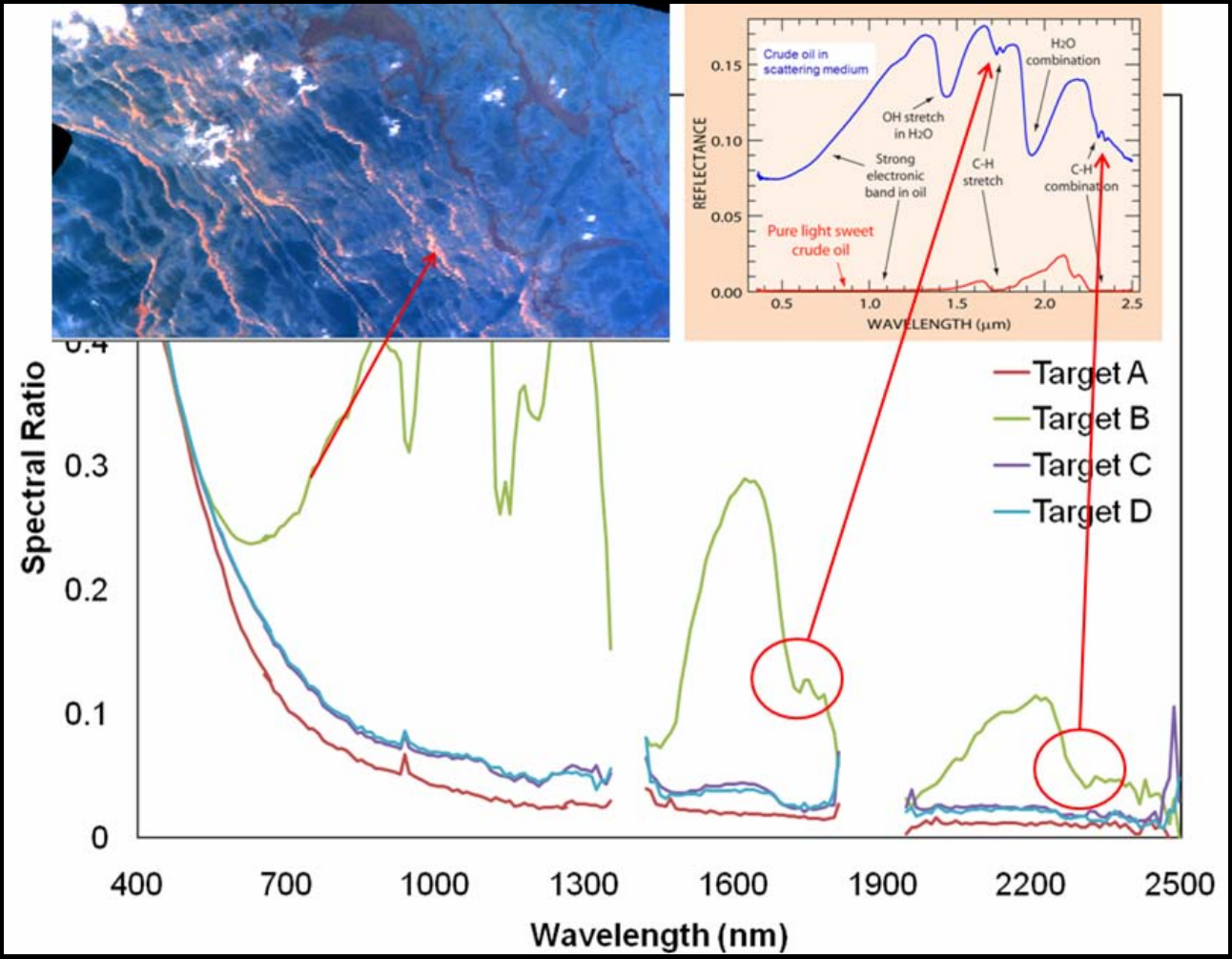


Ollinger et al. 2002

Predicted C:N versus Stream DOC



AVIRIS Measurements of Carbon-Hydrogen Bond Spectral Signature in Gulf Oil Spill

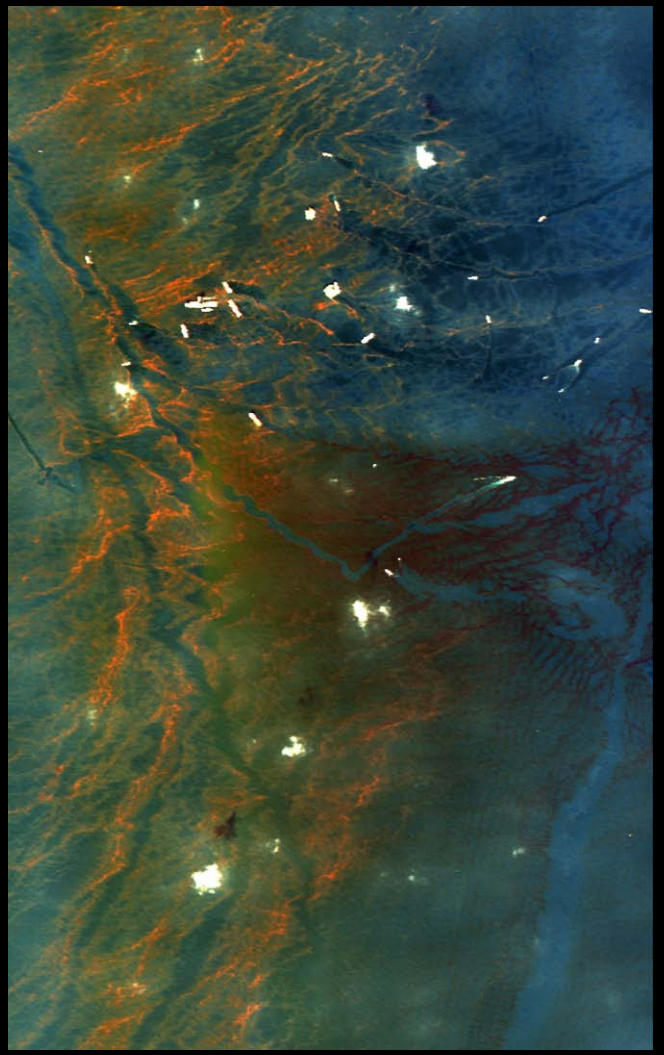


Early science results from AVIRIS over the Gulf Oil Spill that show the spectroscopic signature of the crude oil carbon-hydrogen bond absorption features in the near infrared portion of the spectrum. This infrared spectral signature enables estimation of the location, type, and indicates aspects of the thickness of the oil on the water.

AVIRIS 17 May 2010, FL11

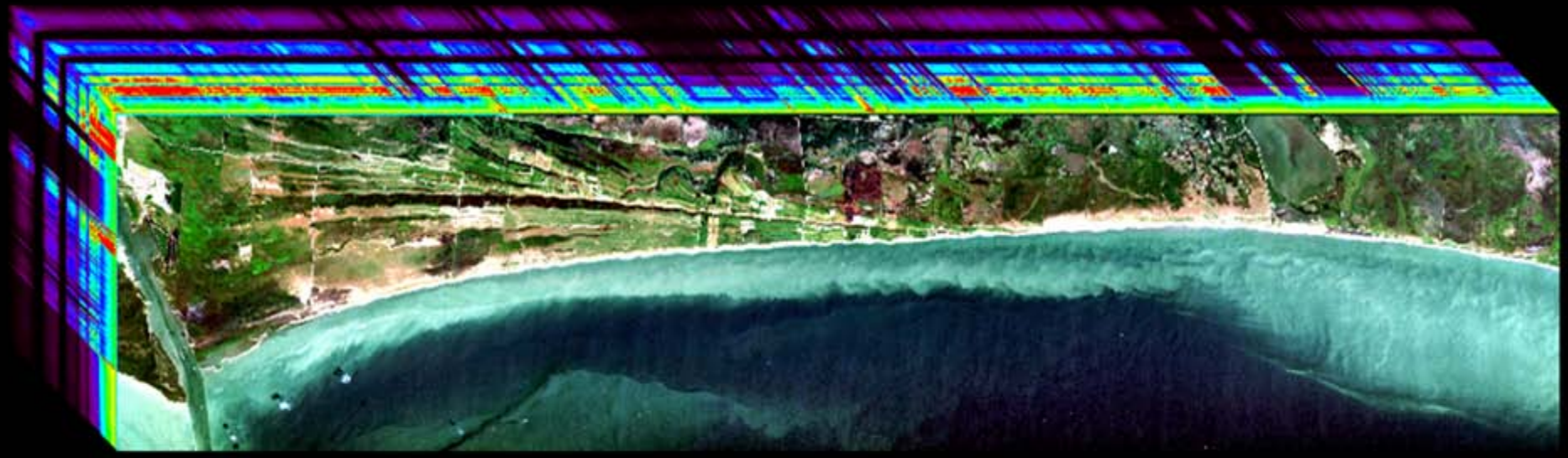
Blue Water

Spill Source Region



The spectral signature of the oil measured in the infrared portion of the spectrum enables a new spectroscopically based approach to measure the occurrence, type, and estimate the thickness of oil on the surface of the water.

Example AVIRIS Baseline Measurements Along the Gulf Coast



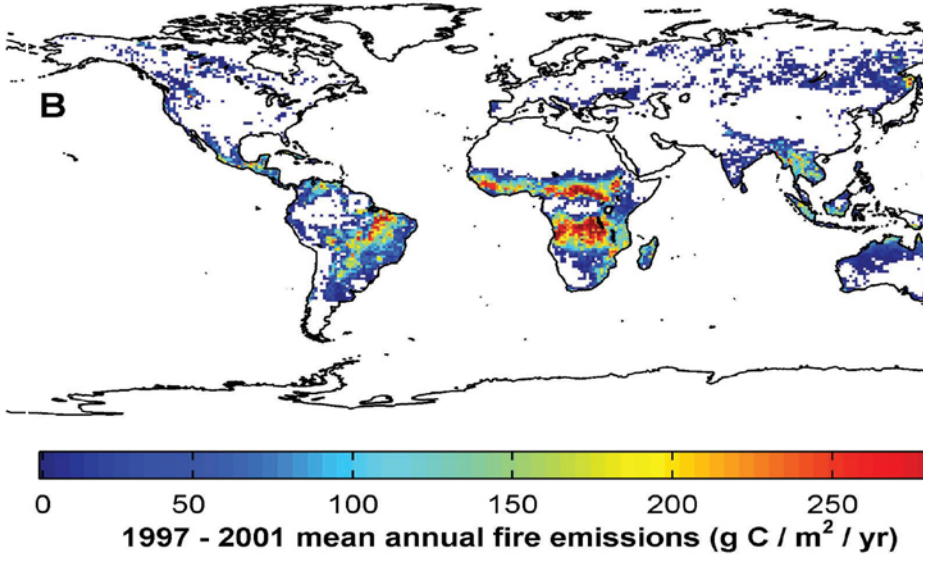
AVIRIS imaging spectrometer measurements along the Gulf coast to measure the ecosystem and habitat characteristics and condition before possible oil contamination and impact. The location is near Johnson's Bayou and along the Gulf Beach Highway, between Port Arthur, LA to the west and Cameron, LA to the East. The west corner includes part of the Texas Point National Wildlife Refuge. The 224 wavelengths of light measured by AVIRIS from the visible to infrared are depicted in the top and left panels. The spectrum measured for each point in the image will be used to help assess the characteristics and conditions of the coastal ecosystems and habitats.

Carbon Release from Biomass Burning

Global Characterization of Fire Emission Sources

Biomass burning and fossil fuel emissions release ~10^{15} g of carbon (C) to the atmosphere each year. Biomass burning constitutes ~36% of all global C emissions.

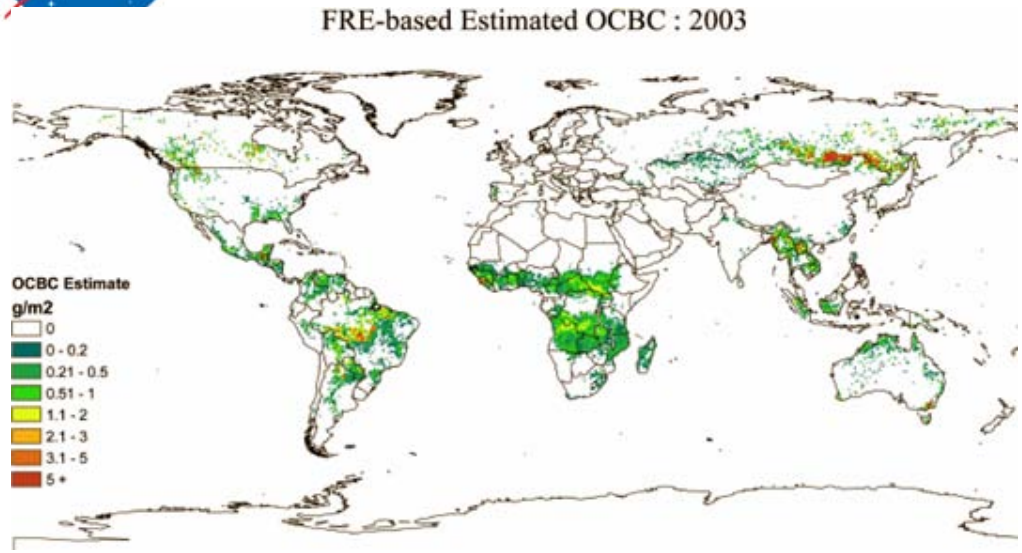
Region	Fire emissions 1997-2001 average (10^15g C yr^{-1})
Central and northern South America	0.27
Southern South America	0.80
Northern Africa	0.80
Southern Africa	1.02
Southeast Asia	0.37
Boreal (north of 38°N)	0.14
Other	0.13
Global	3.53

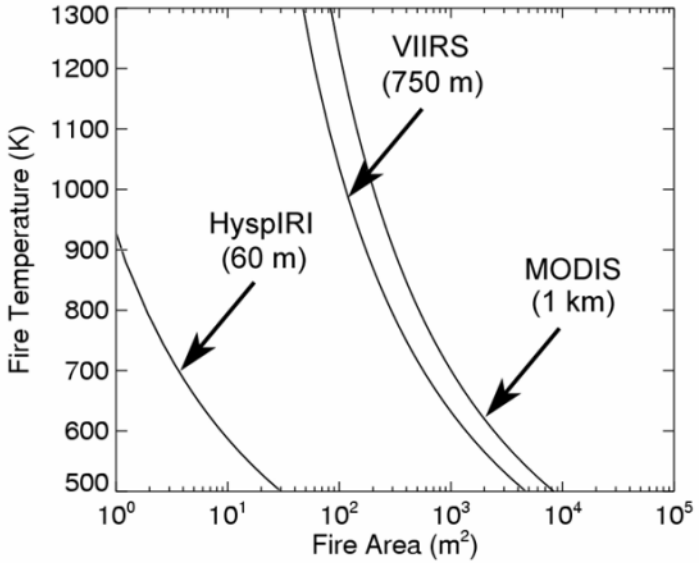


Van der Werf et al., 2004

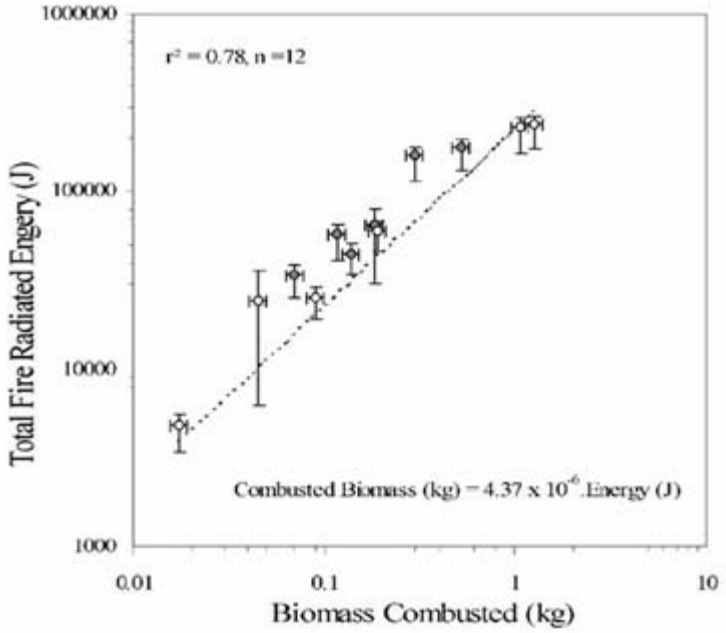
Carbon Release from Biomass Burning

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

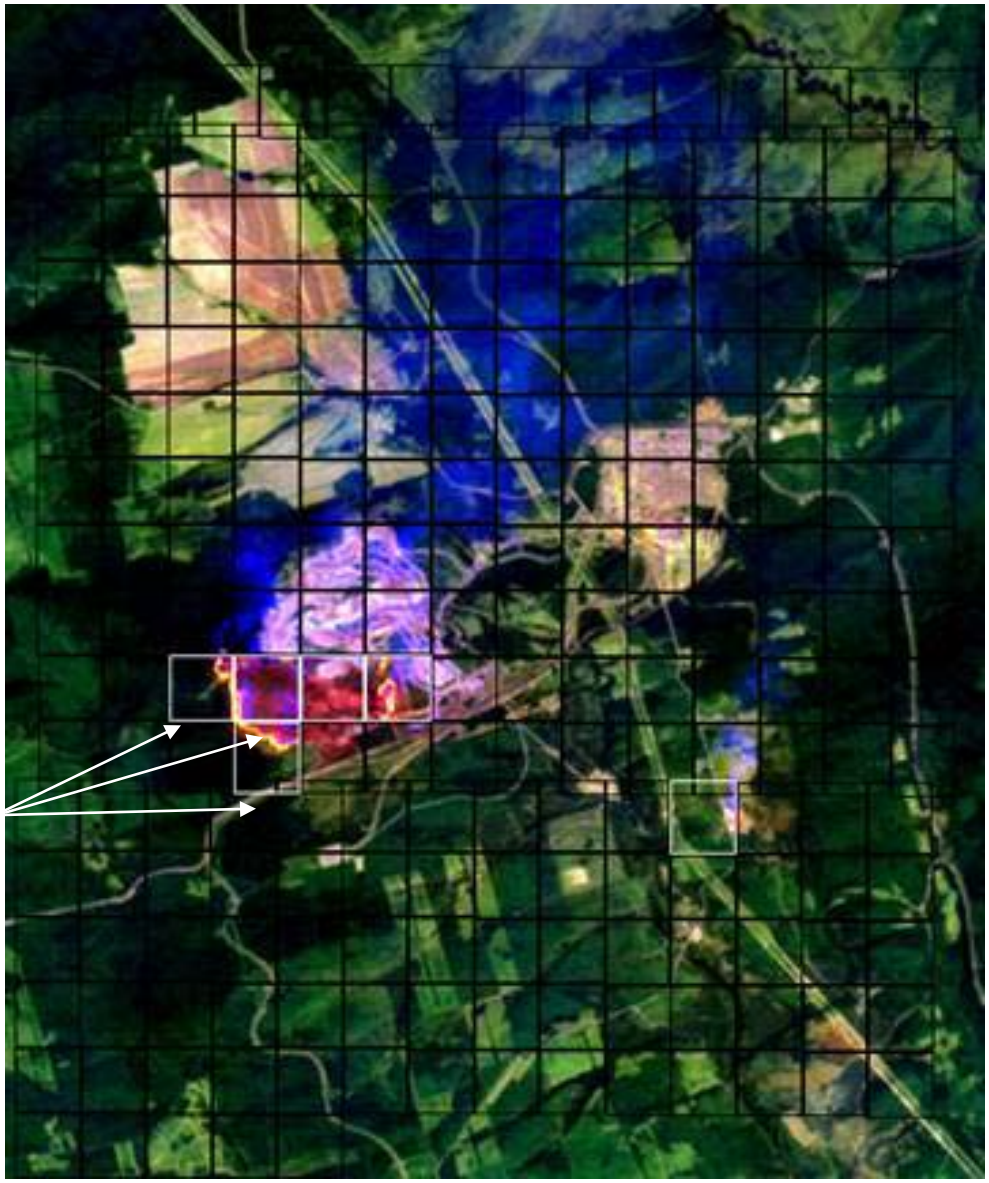
Carbon Release from Biomass Burning

How are global fire regimes changing? (patterns of fire occurrences, frequency, size, severity)

High resolution thermal instrument can distinguish between the forest and non-forest parts of the flaming front allowing the fire type, intensity, etc., to be determined which indicates fire regime.

White squares show fire pixels detected by MODIS. Insufficient information to detect fire type

MIR band provides radiant flux to estimate rate at which biomass combusted and instantaneous emission estimate



30 m ASTER scene with MODIS pixels superimposed (black squares)

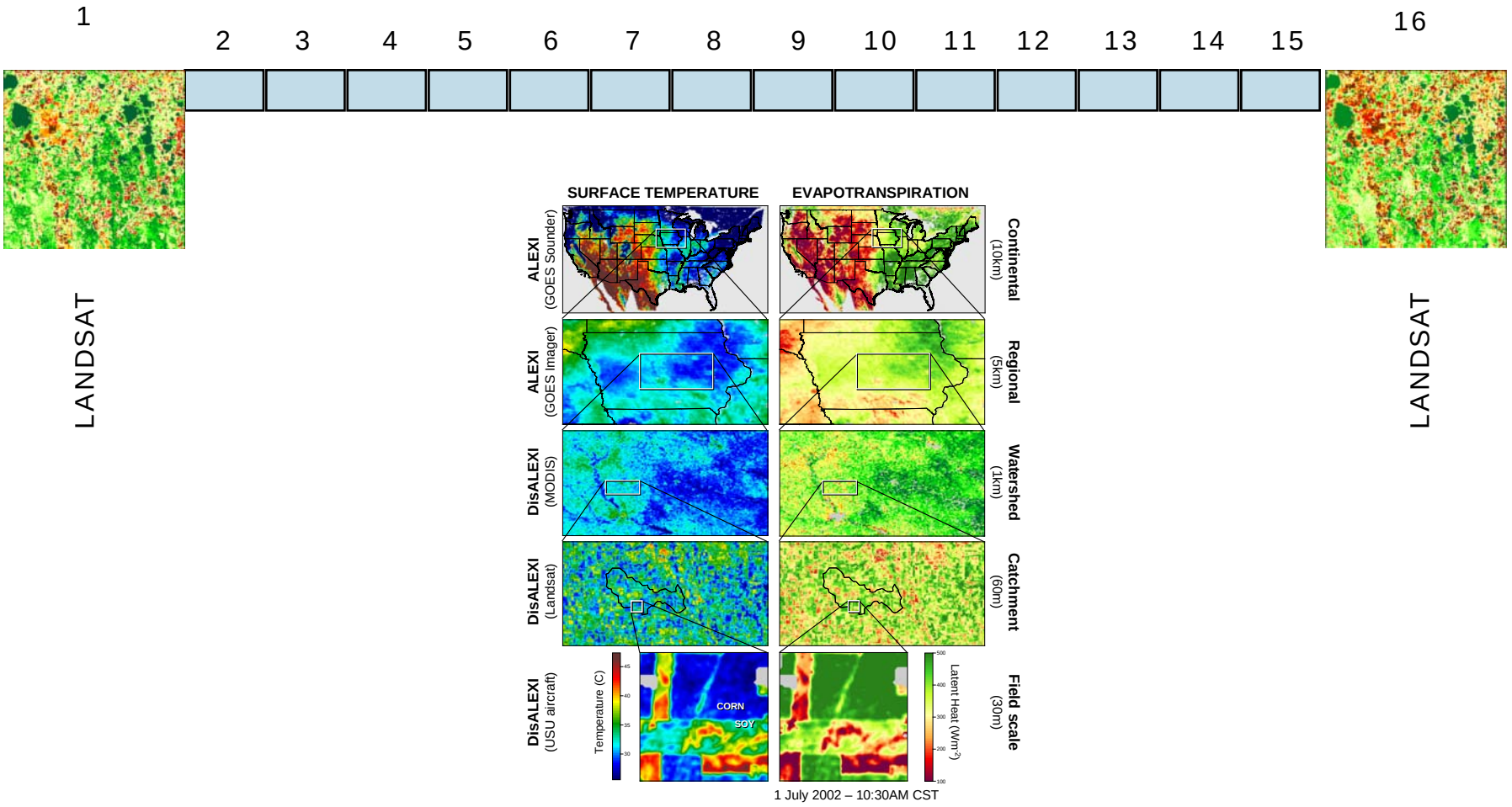
Central Siberia

30 May 2001

Evapotranspiration and Water Use and Availability

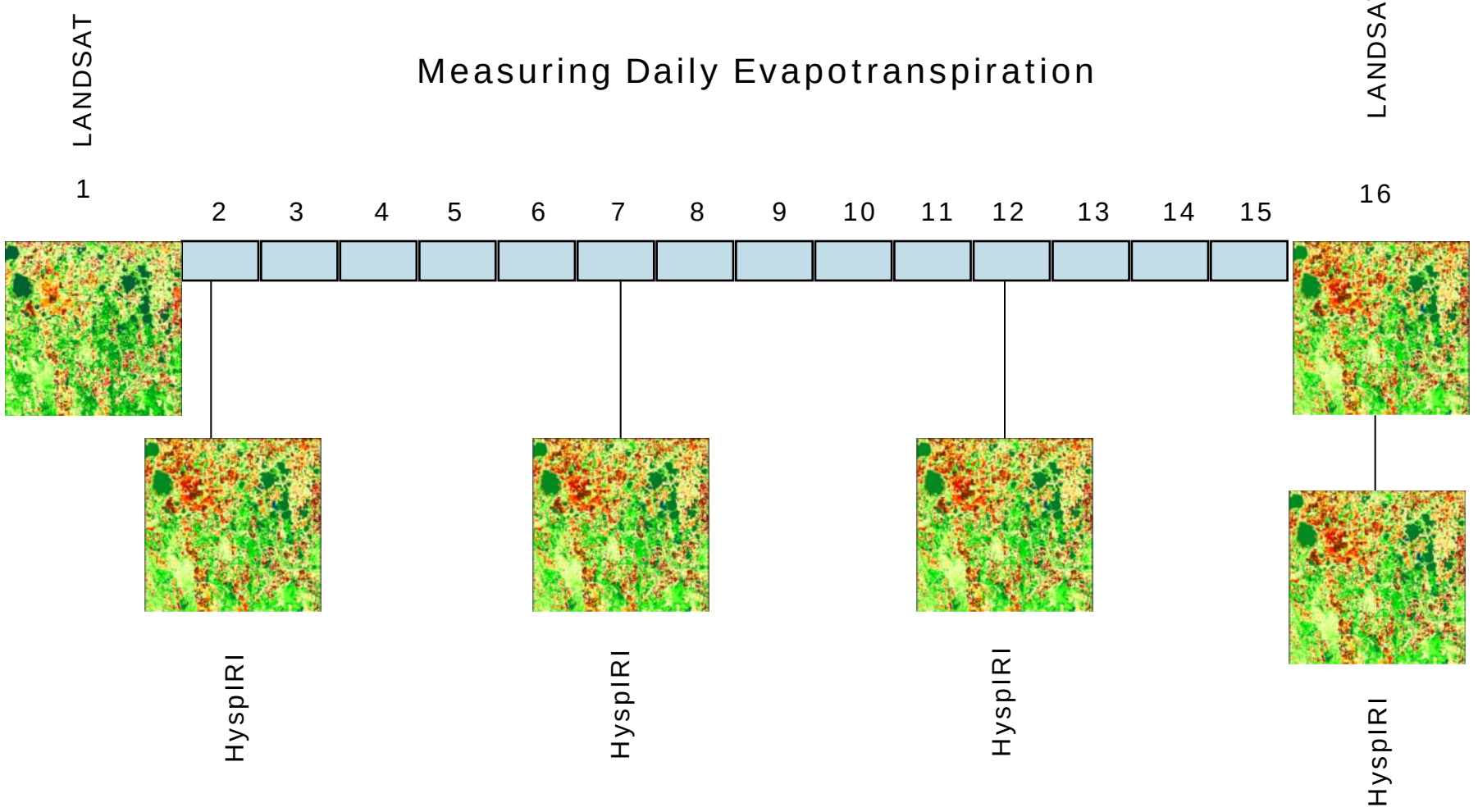
HIGH-RESOLUTION EVAPOTRANSPIRATION

Measuring Daily Evapotranspiration



Evapotranspiration and Water Use and Availability

HIGH-RESOLUTION EVAPOTRANSPIRATION



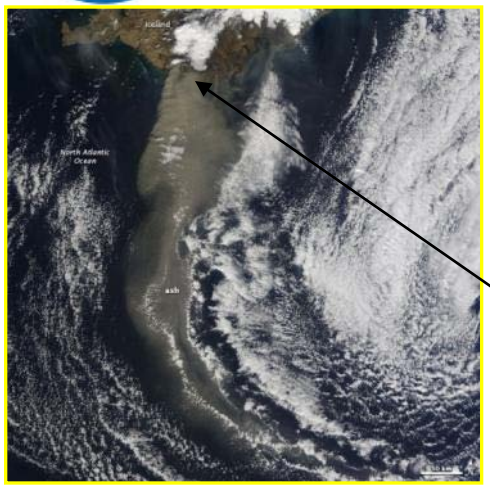
Gas and thermal anomalies, plume composition including SO2 and ash content on weekly basis

Characterizing and Understanding Volcanic Eruptions

"Likewise, the Tier 2 **Hyperspectral Infrared Imager (HyspIRI)** mission would include measurements over a range of optical and infrared wavelengths useful for detecting volcanic eruptions, determining the ash content of volcanic plumes, and identifying the occurrence and effects of associated landslides."

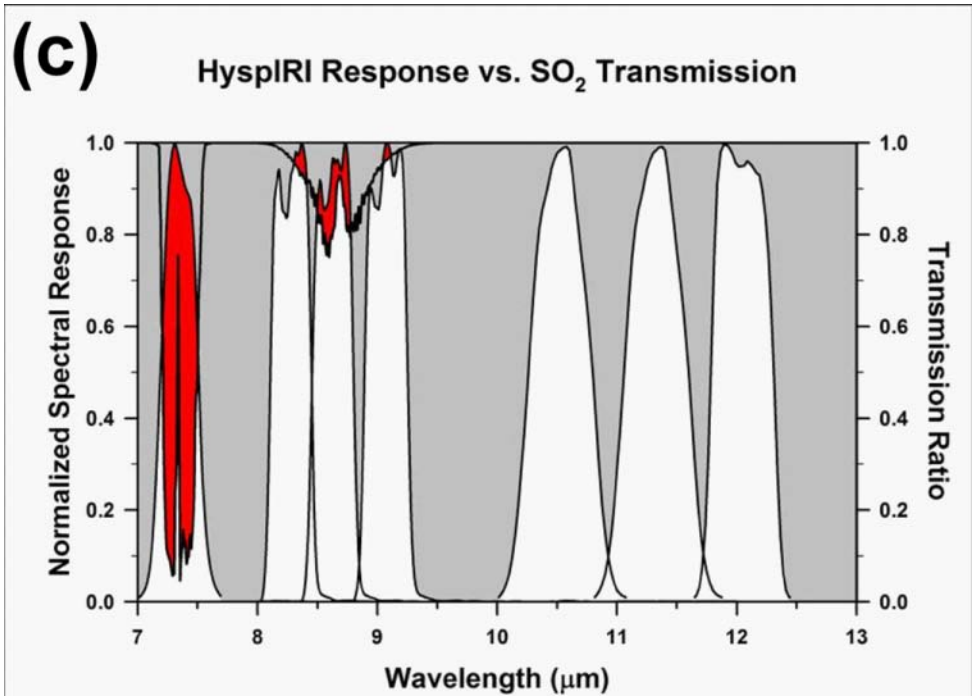
Source: Dr Jack Kaye, Presented to
Subcommittee on Space and Aeronautics
Committee on Science and Technology
United States House of Representatives,
May 5, 2010

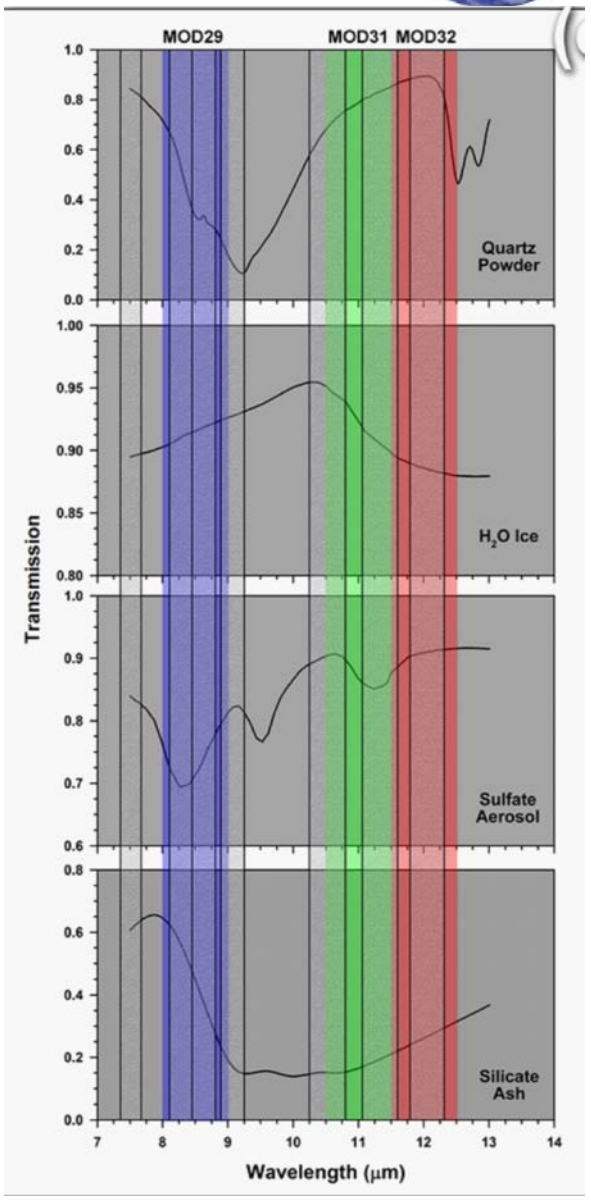
Characterizing and Understanding Volcanic Eruptions



Eyjafjallajökull Iceland Volcano Eruption

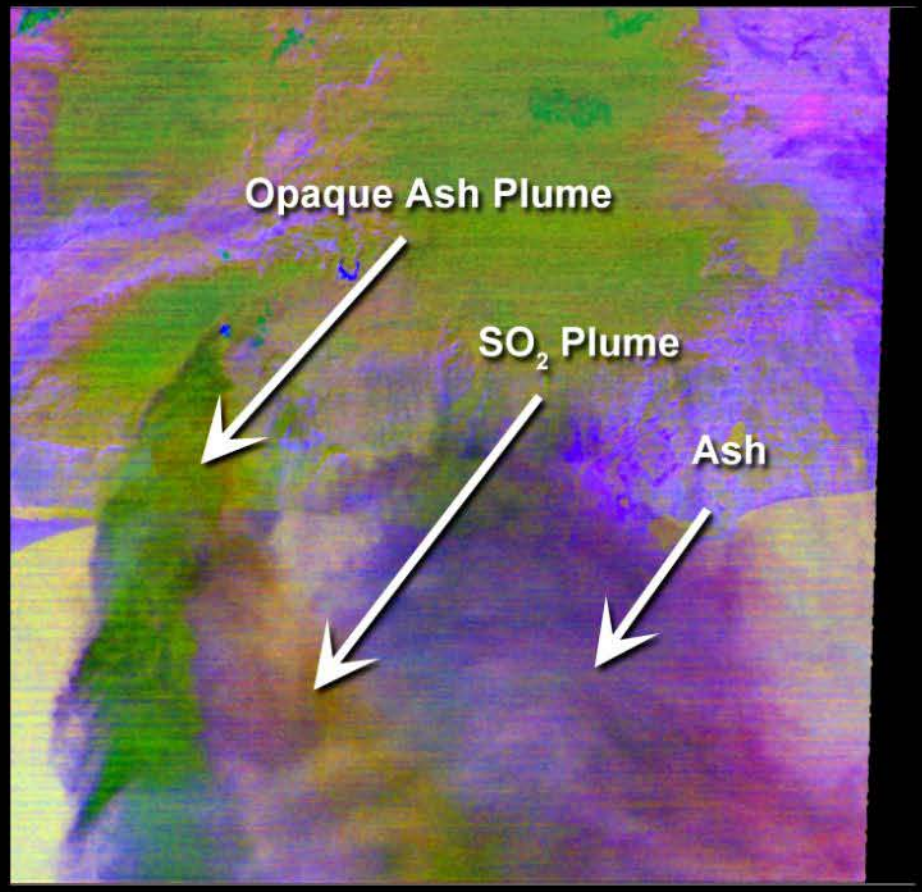
April 19 2010 MODIS image of ash plume.





Characterizing and Understanding Volcanic Eruptions

ASTER Observations of the Eyjafjallajökull Eruption
19 April 2010 - 12:51 UTC



Visible - Near Infrared

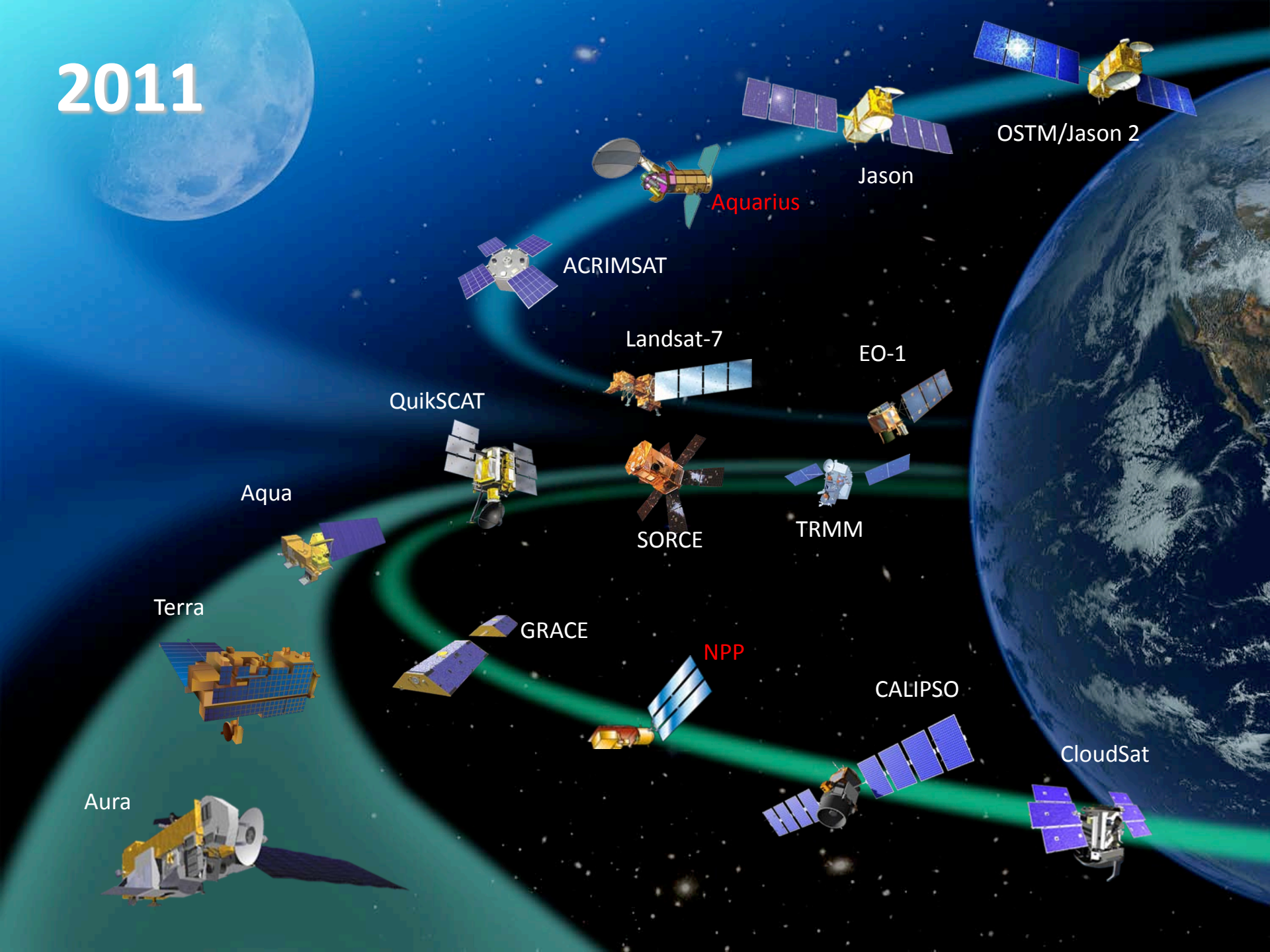
kilometers

0 36

Thermal Infrared

HyspIRI Webpage

http://hyspiri.jpl.nasa.gov


2011
OSTM/Jason 2
Jason
Aquarius
ACRIMSAT
Landsat-7
EO-1
QuikSCAT
Aqua
SORCE
TRMM
Terra
GRACE
NPP
CALIPSO
CloudSat
Aura


2012
OSTM/Jason 2
Jason
Aquarius
Landsat-7
LDCM
Aqua
SORCE
TRMM
Terra
GRACE
NPP
CALIPSO
CloudSat
Aura


2013
OSTM/Jason 2
OCO-2
Aquarius
GPM
Landsat-7
Aqua
SORCE
TRMM
Terra
NPP
LDCM
CALIPSO
CloudSat
Aura


2014
OCO-2
Aquarius
OSTM/Jason 2
Landsat-7
Aqua
SORCE
NPP
LDCM
SMAP
GPM