IR Earth Science Activities at JPL and the HyspIRI Mission

QSIPS 2009

January 22, 2009

Simon Hook, Research Scientist

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Climate, Oceans and Solid Earth Science Section

Jet Propulsion Laboratory

California Institute of Technology

Outline

- IR Earth Science spaceborne sensors developed by JPL
- IR Earth Science spaceborne sensors under development by JPL
- IR Earth Science airborne sensors under development by JPL
- HyspIRI mission

Talking Points

From remote sensing observations…

- Global Climate Change is well documented
- How much is the climate changing at the regional and local scale and what is the impact?
- What should we do next?
  - NRC Decadal Survey Recommendations for Earth Science
    - Passive IR instruments

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JPL Missions to Enable Atmospheric Science

ATMOS & MLS
were instrumental in understanding ozone depletion

ACRIMSAT
is measuring the total amount of solar energy reaching the Earth

MISR
distinguishes different aerosols, and cloud forms to develop 3-D models

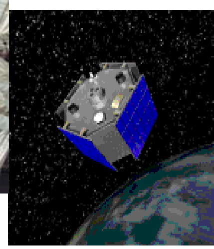
AIRS
measures air temperature and humidity for input into weather forecasts

TES
will make the first-ever measurements of tropospheric ozone from space

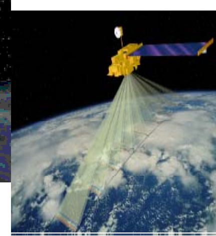
CloudSat
OCO
data will improve estimates of global warming

ATMOS (1985)

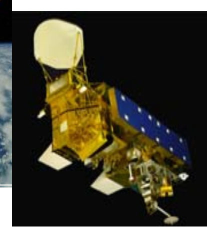
UARS MLS (1991-Present)



ACRIMSAT (1999-Present)



MISR on TERRA (1999-Present)



AIRS on AQUA (2002-Present)

TES on AURA (2004-Present)

MLS on AURA (2004-Present)

CloudSat (2006)

Orbiting Carbon Observatory Mission (2009)

1985 — 1991 — 1999 — 2002 — 2004 — 2005 — 2008

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JPL Missions to Enable Solid Earth and Hydrology Science

SIR
series demonstrated the most advanced radar technology ever flown

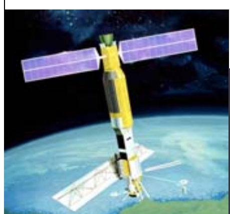
SRTM
data were used to create the most accurate and highest resolution global topographic map

ASTER
Provides critical data for hazard assessment

GRACE
has improved our estimates of Earth's gravity by a factor of 50-100X

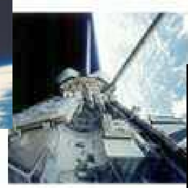
SMAP
will improve estimates of the hydrologic cycle

DESDynI
will improve our understanding of earthquakes and volcanoes



SeaSAT (1978)

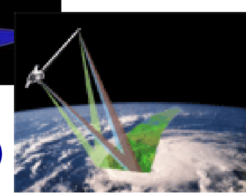
SIR-A (1981)



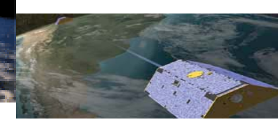
SIR-B (1984)

SIR-C (1994)

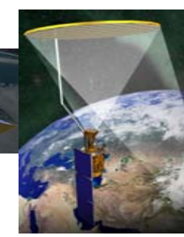
ASTER (1999-Present)



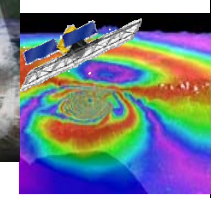
SRTM (2000)



GRACE (2002-Present)



SMAP (2013)



DESDynI (TBD)

1978 — 1981 — 1984 — 1994 — 1999 — 2000 — 2002 — 2010

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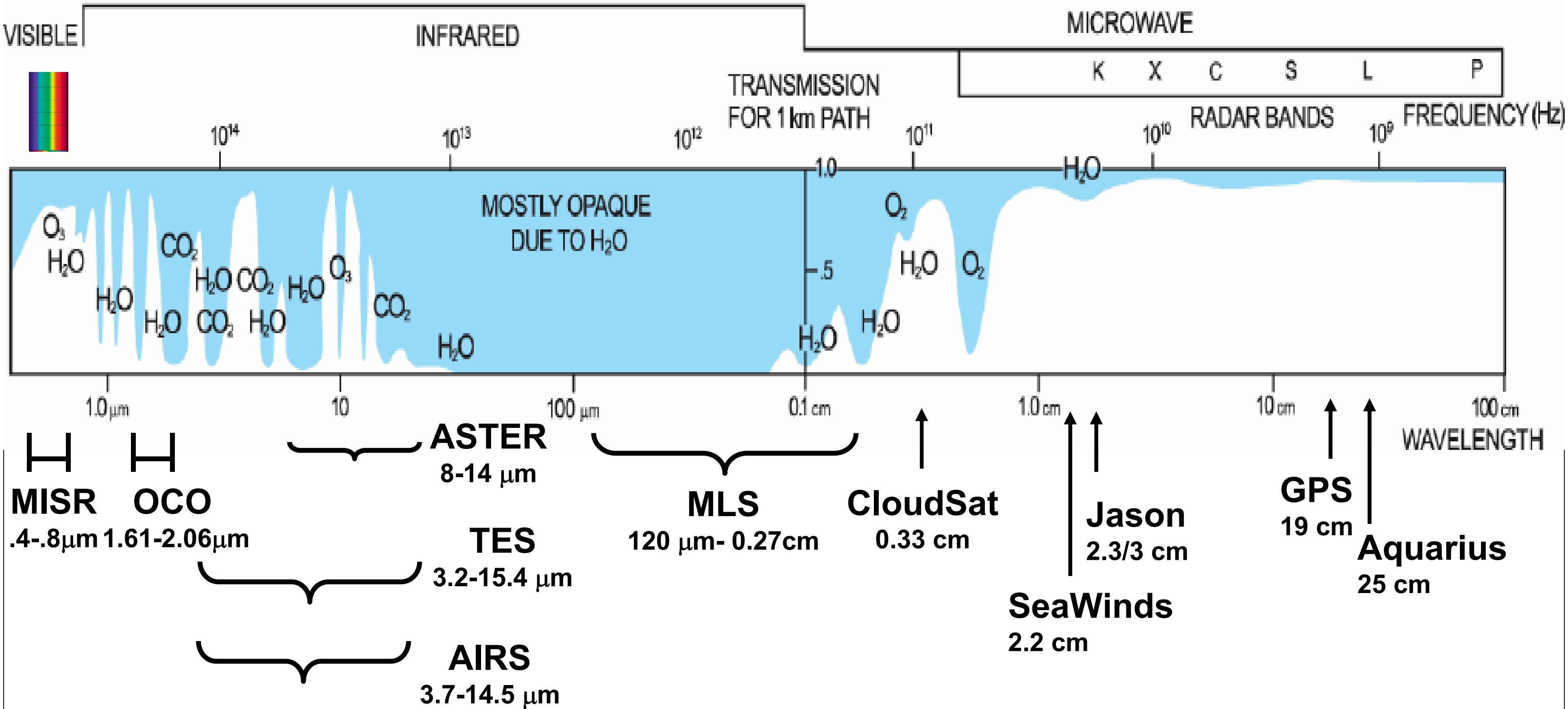
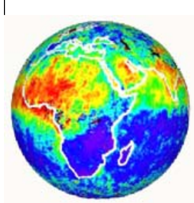
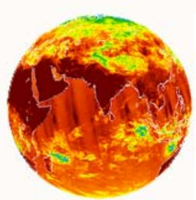
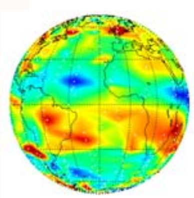
Current JPL Earth Science Measurements

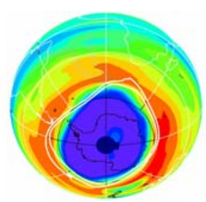


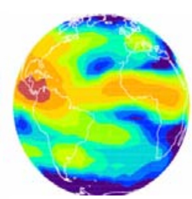

Aerosols

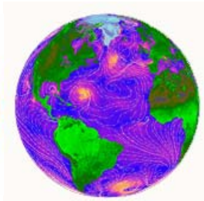

Carbon Dioxide

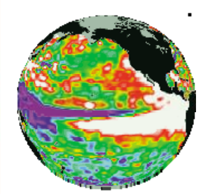

Water Vapor

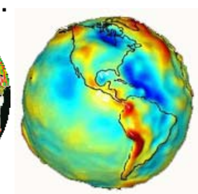


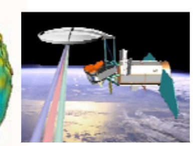

Ozone


Cloud Properties


Ocean Winds


Sea Surface Height


Gravity


Ocean Salinity

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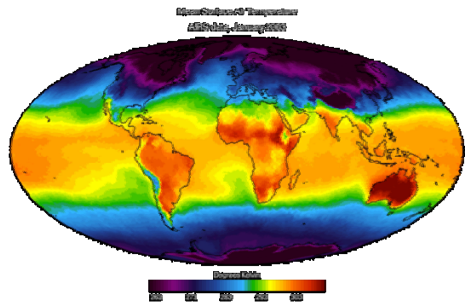
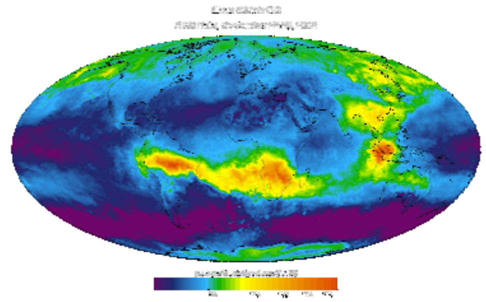
AIRS climate data products

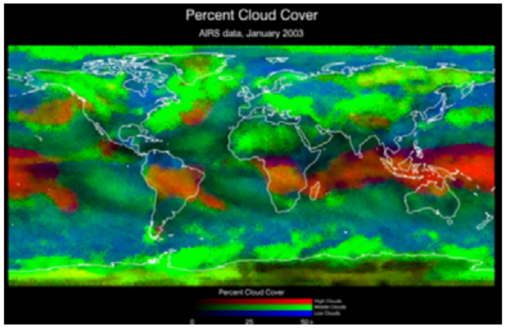
Atmospheric Temperature



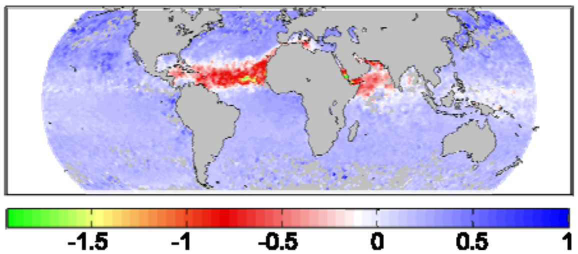
CO



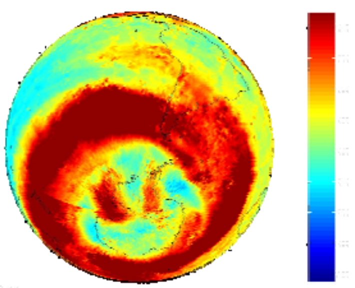
Cloud Properties



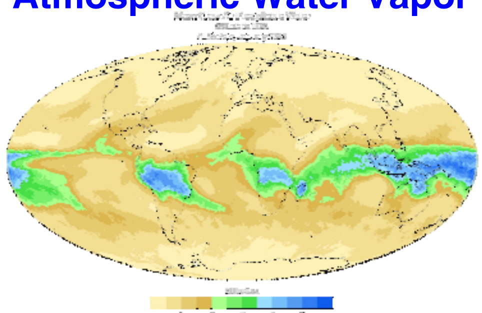
Dust



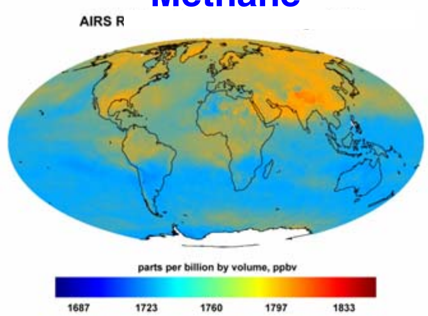
Ozone



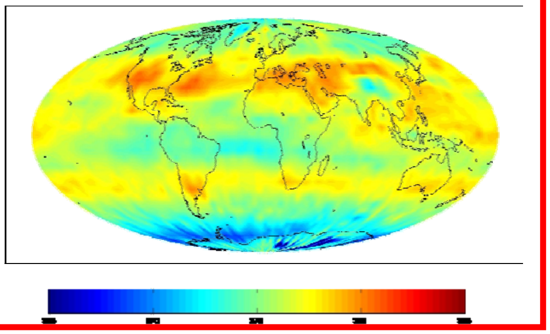
Atmospheric Water Vapor



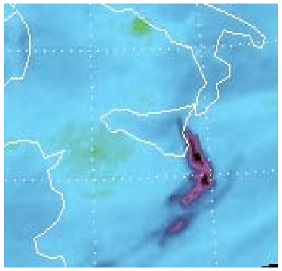
Methane



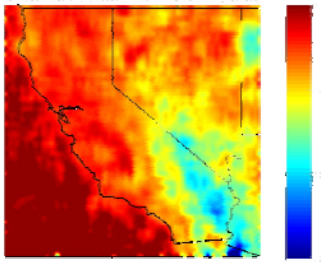
CO_2



SO_2



Emissivity



Courtesy, M. Chahine [JPL]

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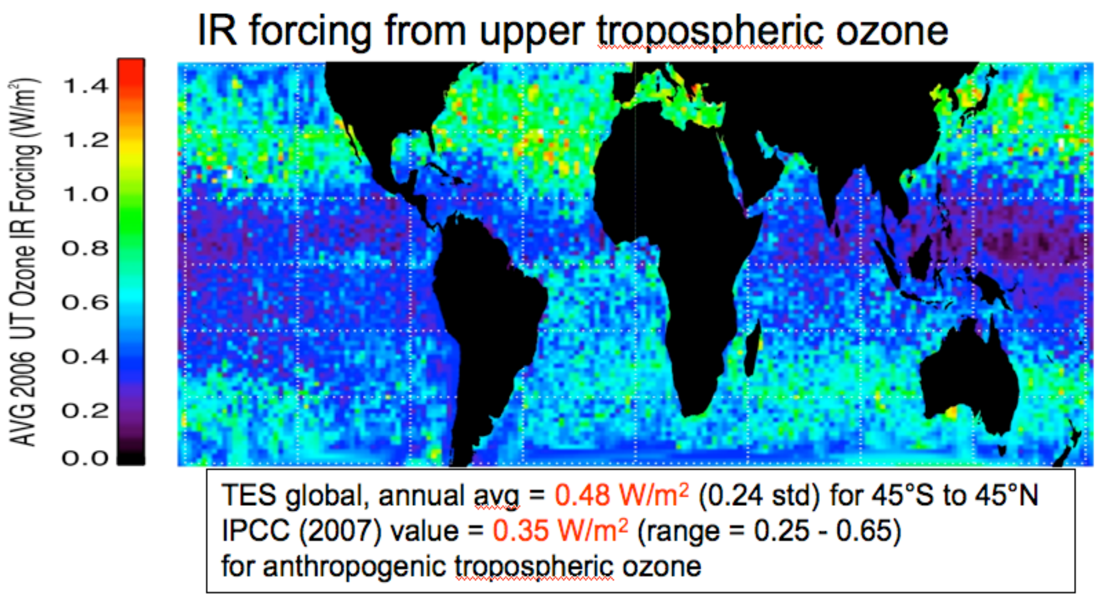
TES Observations of IR Radiative Forcing Due to Tropospheric Ozone



Nature Geoscience
Published online: 20 April 2008 | doi:10.1038/ngeo182

Satellite measurements of the clear-sky greenhouse effect from tropospheric ozone

Helen M. Worden[1], Kevin W. Bowman, John R. Worden, Annmarie Eldering & Reinhard Beer

Problem: Radiative forcing of tropospheric ozone is modeled, but not measured.

Result: In this study, scientists from NCAR and **JPL produced the first global estimate of instantaneous radiative forcing from tropospheric ozone,** the third most important greenhouse gas, based on clear-sky measurements from the NASA Tropospheric Emission Spectrometer (TES) between 45° S to 45° N.

Significance: These data provide critical observational constraints for climate model predictions, such as those used in the IPCC, of human contribution to tropospheric ozone and climate change.

For more details, contact: Annmarie.Eldering@jpl.nasa.gov; tes.jpl.nasa.gov

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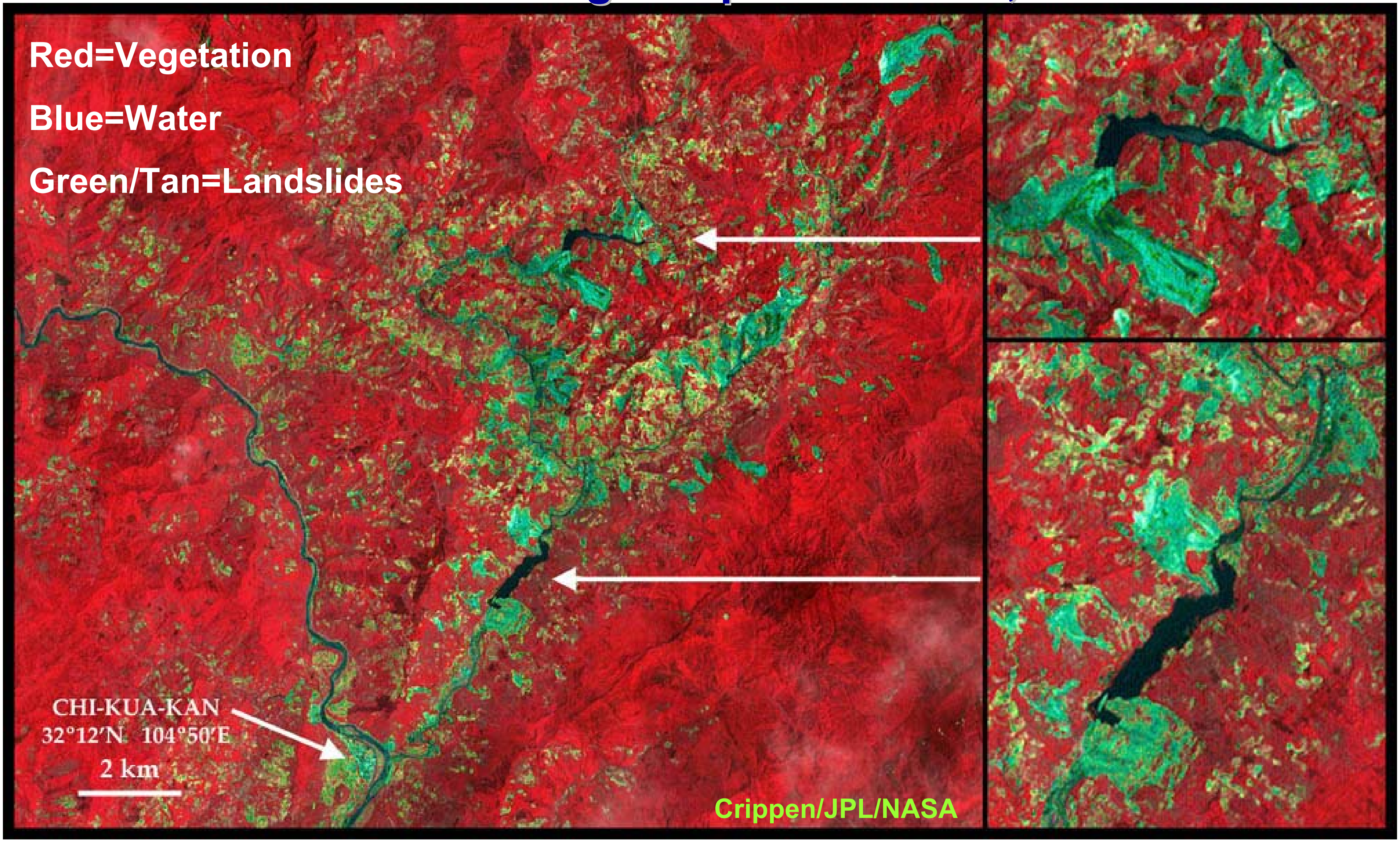
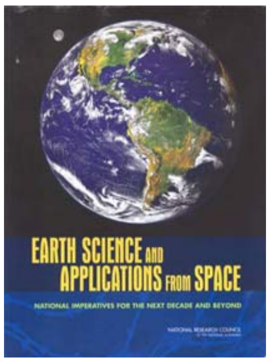
Sichuan Earthquake

Lakes from earthquake induced landslides

ASTER image acquired June 1, 2008



Recommended NASA Missions



Decadal Survey Mission	Mission Description	Orbit	Instruments	Rough Cost Estimate
Timeframe 2010 – 2013, Missions listed by cost				
CLARREO (NASA portion)	Solar radiation: spectrally resolved forcing and response of the climate system	LEO, Precessing	Absolute, spectrally-resolved interferometer	$200 M
SMAP	Soil moisture and freeze/thaw for weather and water cycle processes	LEO, SSO	L-band radar L-band radiometer	$300 M
ICESat-II	Ice sheet height changes for climate change diagnosis	LEO, Non-SSO	Laser altimeter	$300 M
DESDynI	Surface and ice sheet deformation for understanding natural hazards and climate; vegetation structure for ecosystem health	LEO, SSO	L-band InSAR Laser altimeter	$700 M
Timeframe: 2013 – 2016, Missions listed by cost				
HyspIRI	Land surface composition for agriculture and mineral characterization; vegetation types for ecosystem health	LEO, SSO	Hyperspectral spectrometer	$300 M
ASCENDS	Day/night, all-latitude, all-season CO_2 column integrals for climate emissions	LEO, SSO	Multifrequency laser	$400 M
SWOT	Ocean, lake, and river water levels for ocean and inland water dynamics	LEO, SSO	Ka-band wide swath radar C-band radar	$450 M
GEO-CAPE	Atmospheric gas columns for air quality forecasts; ocean color for coastal ecosystem health and climate emissions	GEO	High and low spatial resolution hyperspectral imagers	$550 M
ACE	Aerosol and cloud profiles for climate and water cycle; ocean color for open ocean biogeochemistry	LEO, SSO	Backscatter lidar Multiangle polarimeter Doppler radar	$800 M
Timeframe: 2016 -2020, Missions listed by cost				
LIST	Land surface topography for landslide hazards and water runoff	LEO, SSO	Laser altimeter	$300 M
PATH	High frequency, all-weather temperature and humidity soundings for weather forecasting and SST[a]	GEO	MW array spectrometer	$450 M
GRACE-II	High temporal resolution gravity fields for tracking large-scale water movement	LEO, SSO	Microwave or laser ranging system	$450 M
SCLP	Snow accumulation for fresh water availability	LEO, SSO	Ku and X-band radars K and Ka-band radiometers	$500 M
GACM	Ozone and related gases for intercontinental air quality and stratospheric ozone layer prediction	LEO, SSO	UV spectrometer IR spectrometer Microwave limb sounder	$600 M
3D-Winds (Demo)	Tropospheric winds for weather forecasting and pollution transport	LEO, SSO	Doppler lidar	$650 M

[a] Cloud-independent, high temporal resolution, lower accuracy SST to complement, not replace, global operational high accuracy SST measurement.

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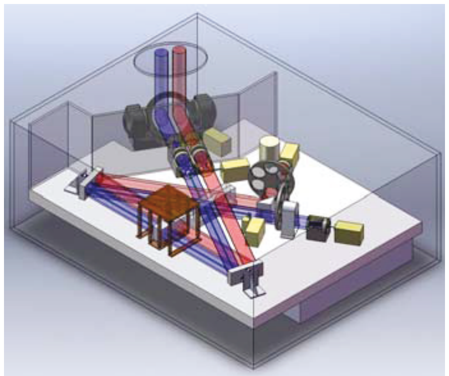
GEO-CAPE: Panchromatic Fourier Transform Spectrometer (PanFTS)

PanFTS Instrument



PanFTS Specs (for flight)	
Characteristic	**Value**
Size	130 x 100 x 50 cm
Mass	150 kg
Power	120 W
Data rate	150 MB/s
Field of view	±7.3 deg. off-nadir
Pointing required	~1 arcsec
Operational lifetime	5 years

PanFTS mechanical layout and flight instrument specs

Mission Concept

- GEO-CAPE is a second-tier Decadal Survey Mission aimed at measuring long-range transport of air pollutants and aerosols, and ocean biogeochemistry in the coastal zone.
- The spacecraft will be in geostationary orbit at 80° W. longitude, mapping North and South America from 50° N to 45° S latitude at hourly intervals.
- Spatial resolution 7x7 km (air quality), 250x250 m (ocean color)
- Key scientific questions addressed:

  How are pollutants transported across/between continents?

  What are the sources, sinks of ozone and aerosols?

  How are coastal ecosystems changing?

Measurement Objectives

- Provide the first synoptic-scale view of "chemical weather"
- Improve model simulations of long-range transport of criteria air pollutants such as O_3 (ozone), NO_2 (nitrogen dioxide), CO (carbon monoxide), aerosols, and other important species including HCHO (formaldehyde) and HNO_3 (nitric acid).
- Provide regional measurements of sources and sinks of greenhouse gases such as CO_2 (carbon dioxide), CH_4 (methane), H_2O (water vapor) and N_2O (nitrous oxide).
- Using the technique of ocean colorimetry, quantify the response of ecosystems to storms and tidal mixing, monitor river outflows of biotic and abiotic materials, detect transient events such as oil spills, algal blooms and waste spills.

Instrument Summary

- PanFTS is an imaging Fourier Transform Spectrometer with extraordinary capabilities:

  Extremely wide spectral coverage:UV (.25 μm) to IR (15 μm)

  High spectral resolution (resolving power up to 500,000)

  Spatial resolution 250 m for coastal ocean event monitoring and 7 km for air quality applications
- Innovative high speed, high resolution CMOS focal plane arrays
- Integrates the functionality of several instruments in a single package.

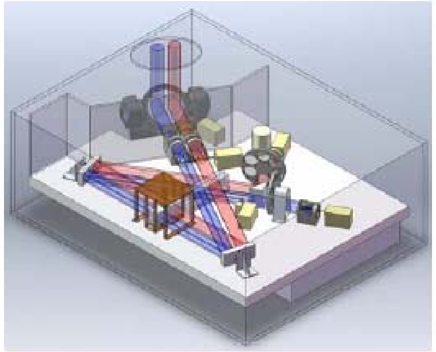
Sander, 2008

Panchromatic Fourier Transform Spectrometer (PanFTS) Instrument for the GEO-CAPE Mission

PI: Stanley P. Sander / JPL

Objective

- Define a science plan for the GEO-CAPE mission which makes use of the enhanced vertical profiling capability of imaging Fourier Transform Spectroscopy (FTS) over the 0.25 – 15 μm spectral range.
- Develop a lab PanFTS instrument which demonstrates two key enabling technologies: high-speed, high-dynamic range CMOS hybrid focal plane arrays (FPAs), and parallel, co-aligned optical trains for the ultraviolet/visible/near-infrared (UV/V/NIR), and mid-IR bands.
- Verify the performance of PanFTS by acquiring and analyzing atmospheric spectra from JPL's California Laboratory of Atmospheric Remote Sensing (CLARS).



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PanFTS mechanical layout and flight instrument specs

Approach

- Develop detailed instrument design specifications on FPAs, FTS scan mechanism and interferometer optics
- Issue Request for Information to industry for FPA detectors and electronics
- Verify scan mechanism by life testing
- Procure key components, build/test lab instrument
- Field deployment/test at CLARS Facility

Co-Is:

- R. Beer, J-F Blavier, K. Bowman, A. Eldering, D. Rider, G. Toon, W. Traub, J. Worden (JPL)
- Task Manager: R. Key (JPL)

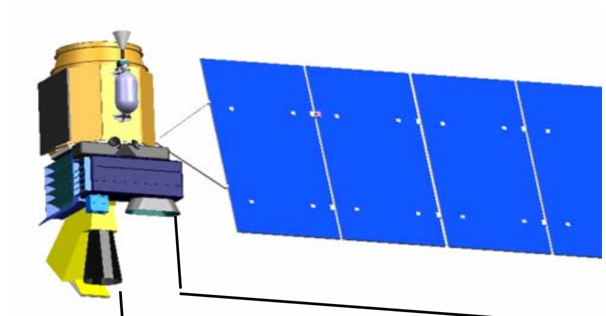
Key Milestones

- Complete instrument requirements definition 09/08
- Complete instrument design 03/09
- Deliver UV FPA 12/09
- Deliver IR FPA 04/10
- Deliver Scan Mechanism 10/09
- Complete instrument assembly 07/10
- Complete field testing at CLARS Facility 06/11

TRL_{in} = 3

HyspIRI Mission

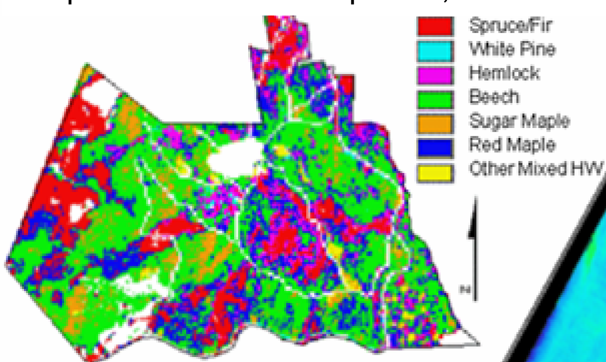
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

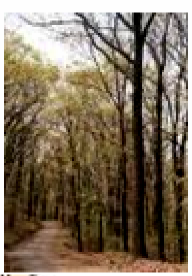


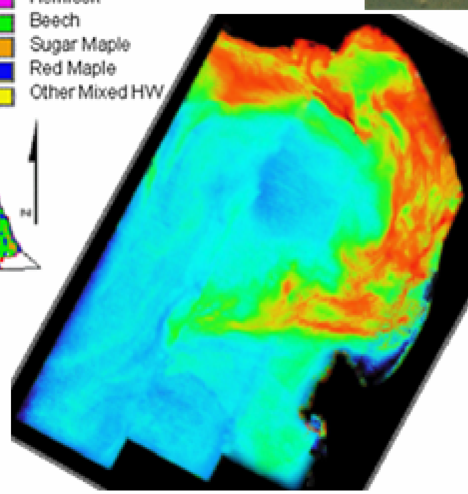
VSWIR: Plant Physiology and Function Types (PPFT)

Multispectral TIR Scanner

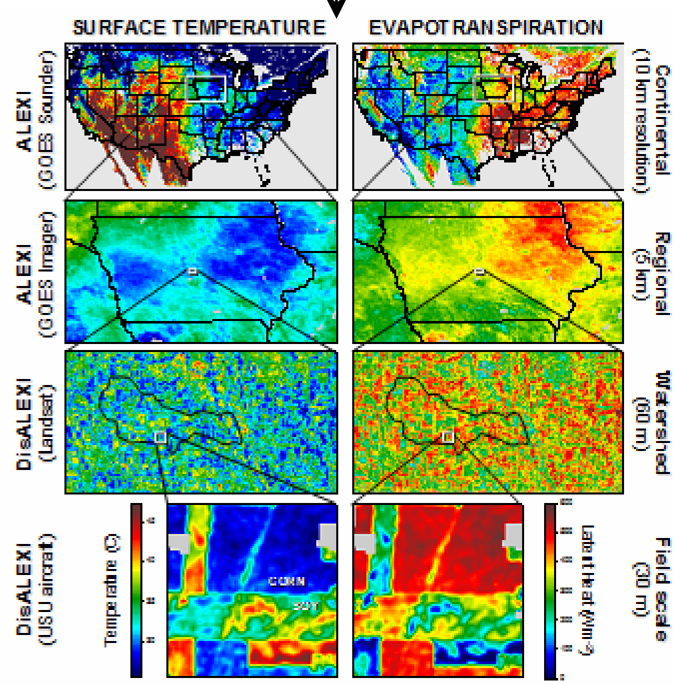
Map of dominant tree species, Bartlett Forest, NH







Red tide algal bloom in Monterey Bay, CA



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2008+ HsypIRI Science Study Group

Science Study Group: **Mike Abrams,** JPL; **Rick Allen,** UID; **Martha Anderson,** USDA; **Greg Asner,** Stanford; **Bryan Bailey,** USGS EROS; **Paul Bissett,** FERI; **Alex Chekalyuk,** Lamont-Doherty**; James Crowley,** USGS; **Ivan Csiszar,** NOAA; **Heidi Dierssen**, U. Conn.; **Friedmann Freund**, Ames; **John Gamon**, UA; **Louis Giglio,** UMD; **Greg Glass,** JHU; **Robert Green,** JPL; **Simon Hook,** JPL; **James Irons,** GSFC; **Bob Knox,** GSFC; **John "Lyle" Mars,** USGS; **David Meyer,** USGS-EROS; **Betsy Middleton,** GSFC; **Peter Minnett,** U. Miami; **Frank Muller Karger,** Univ. Massachusetts Dartmouth; **Scott Ollinger**, UNH ; **Anupma Prakash,** UAF; **Dale Quattrochi,** MSFC; **Mike Ramsey**, University of Pittsburgh; **Vince Realmuto,** JPL; **Dar Roberts,** UCSB; **Dave Siegel,** UCSB**; Phil Townsend,** University of Wisconsin; **Kevin Turpie,** GSFC; **Steve Ungar,** GSFC; **Susan Ustin,** UCD ; **Rob Wright** UHI

NASA HQ Science POC: Woody Turner, John LaBrecque

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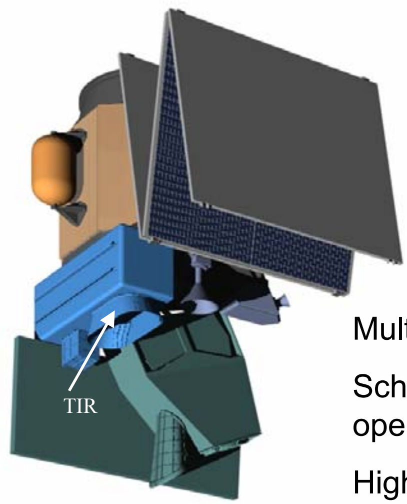
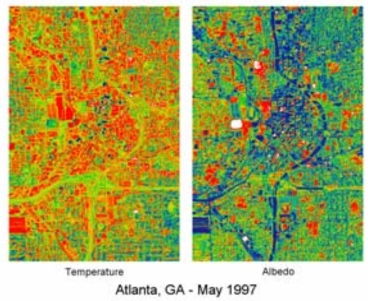
HyspIRI: Thermal Infrared Radiometer





Multispectral Scanner: 66kg / 78W

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)

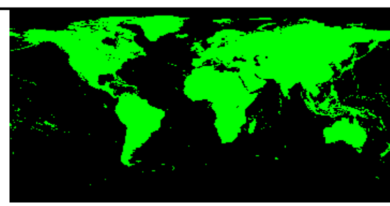
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

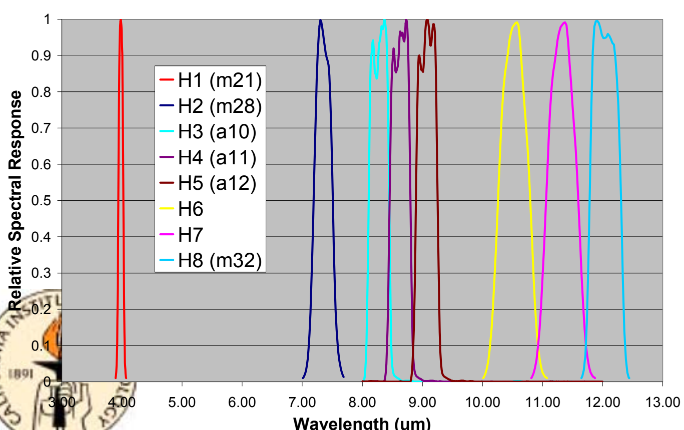
• TQ5. Earth surface composition and change, (AP,JC)

– 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?

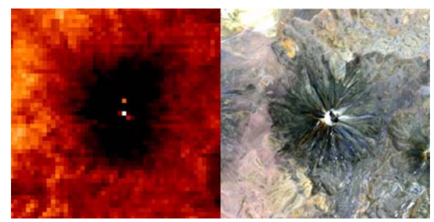
Measurement:

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

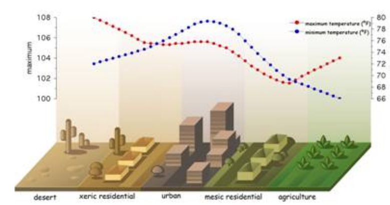




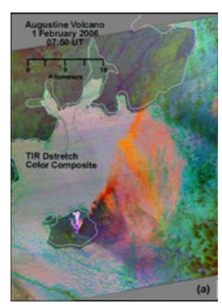
Andean volcano heats up



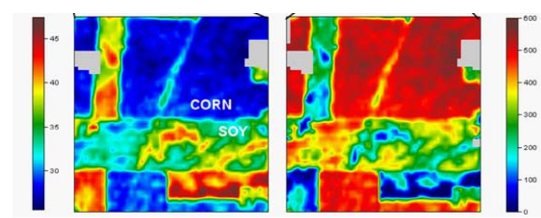
Urbanization



Volcanoes



Water Use and Availability



Surface Temperature

Evapotranspiration

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?

TIR Science Questions: TQ1

TQ1. Volcanoes/Earthquakes:

- TQ1a. Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates, and are such changes unique to specific types of eruptions?
- TQ1b: What do changes in the rate of lava effusion tell us about the maximum lengths that lava flows can attain, and the likely duration of lava flow-forming eruptions?
- What do the transient thermal infrared anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust?
- TQ1d: What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long do such clouds remain a threat to aviation?

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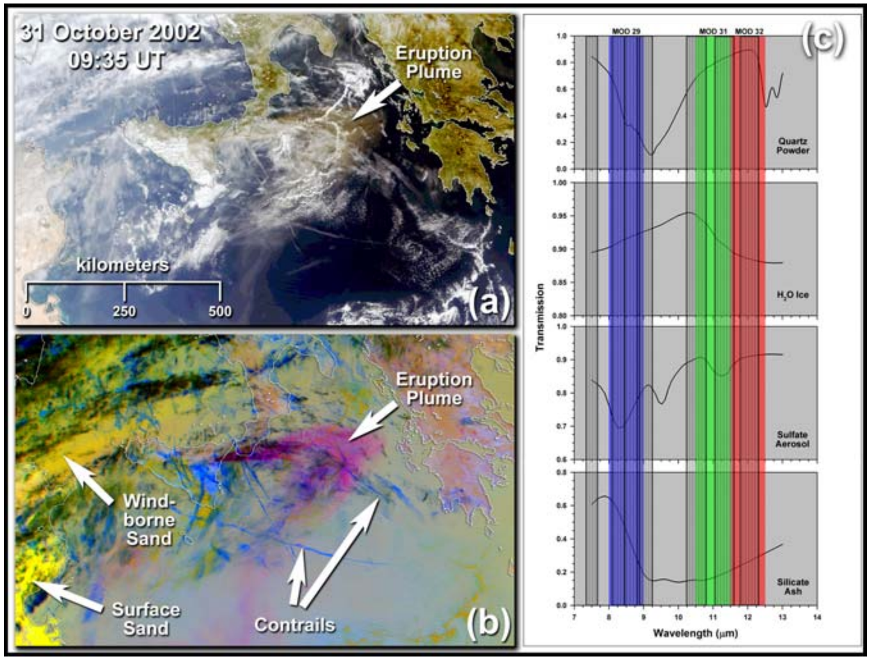

Detection of Eruption Plumes in the Thermal Infrared (TIR)

(a) MODIS true-color composite of data acquired over Mount Etna illustrating the difficulty of distinguishing a plume from surrounding meteorological clouds; (b) False-color composite of MODIS TIR data (Ch. 29, 31, 32 displayed in blue, green, and red, respectively) illustrating the unique spectral signatures of the eruption plume (silicate ash), jet contrails (ice), and windborne sand; (c) Model transmission spectra for silicate ash, sulfate aerosol, ice, and quartz powder (representing sand). The blue, green, and red color bars represent MODIS Ch. 29, 31, and 32, respectively; the shaded bars represent the proposed HyspIRI TIR channels. HyspIRI will have three channels in place of MODIS Ch. 29 and three channels in place of MODIS Ch. 31 and 32, enhancing our ability to detect and track eruption plumes and clouds.

Science Issue

The ash plumes generated by explosive volcanic eruptions pose a significant hazard to jet aircraft. Current air traffic protocol is to clear the airspace in the vicinity of the erupting volcano, but the ash plumes may be transported hundreds to thousands of kilometers from their sources. The use of true-color images to discriminate volcanic plumes from meteorological (met) clouds, and other suspended aerosols and particulates, is problematic (Panel (a), at left).

Tools

•HyspIRI multispectral TIR image data, 5-day revisit cycle (daytime acquisitions) at equator, spatial resolution of 60 m, and spectral channels as shown in Panel (c) (at left).

•Profiles of atmospheric temperature and water vapor, measured with radiosondes and spaceborne sounding instruments or model predictions.

•Radiative transfer model to predict radiance at the sensor given atmospheric profiles, length of optical path, and surface temperature, emissivity, and elevation (provided by DEM).

Approach

•Develop Internet portal to provide interactive plume analysis tools and on-demand modeling.

•Statistics-based enhancement of spectral contrast to discriminate eruption plume from met clouds (Panel (b), at left).

•Radiative transfer-based analysis tools to confirm presence of eruption plume and materials derived from plume

Results

On-demand detection and tracking of eruption plumes via Internet portal, with 2 (1 day + 1 night) HyspIRI revisits per 5 day cycle at equator, and more frequent coverage at higher latitudes.

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Science Measurements
Summary Measurement Characteristics

Spectral	
Bands (8) µm	3.98 µm, 7.35 µm, 8.28 µm, 8.63 µm, 9.07 µm, 10.53 µm, 11.33 µm, 12.05
Bandwidth	0.084 µm, 0.32 µm, 0.34 µm, 0.35 µm, 0.36 µm, 0.54 µm, 0.54 µm, 0.52 µm
Accuracy	<0.01 µm
Radiometric	
Range	Bands 2-8= 200K – 400K; Band 1= 1400K
Resolution	< 0.05 K, Linear Quantization to 14 bits
Accuracy	< 0.5 K 3-sigma at 250K
Precision (NEdT)	< 0.2K
Linearity	>99% characterized to 0.1 %
Spatial	
IFOV	60 m
MTF	>0.65 at FNy
Scan Type	Push-Whisk
Swath Width	600 km (±25.5° at 623 km altitude)
Cross-Track Samples	10,000
Swath Length	15.4 km (+/- 0.7-degrees at 623km altitude)
Down-Track Samples	256
Band-to-Band Co-registraion	0.2 pixels (12 m)
Pointing Knowledge	1.5 arcsec (0.1 pixels)

Science Measurements
Characteristics Continued

Temporal	
Orbit Crossing	11 am sun synchronous descending
Global Land Repeat	5 days at equator
OnOrbit Calibration	
Lunar View	1 per month {radiometric}
Blackbody Views	1 per scan {radiometric}
Deep Space Views	1 per scan {radiometric}
Surface Cal Experiments	2 (d/n) every 5 days {radiometric}
Spectral Surface Cal Experiments	1 per year
Data Collection	
Time Coverage	Day and Night
Land Coverage	Land surface above sea level
Water Coverage	Coastal zone -50 m and shallower
Open Ocean	Averaged to 1km spatial sampling
Compression	2:1 lossless

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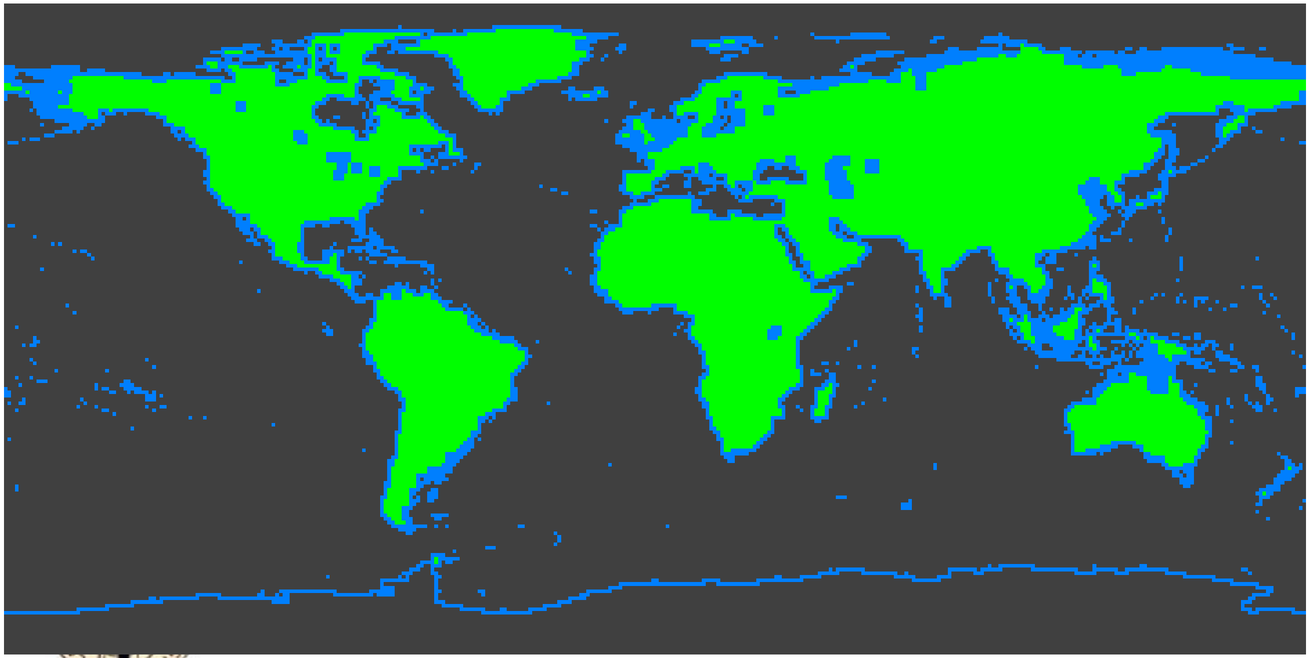
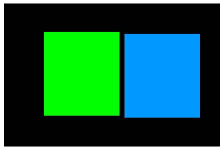
Mission Concept
Operational Scenario

- Following arrival at science orbit, the baseline data acquisition plan is established. Collect data for entire land surface excluding sea ice (Arctic and Antarctic) every 5 days at 60 m spatial resolution in 8 spectral bands
- Data are downlinked and transferred to the science data processing center where calibration and baseline processing algorithms are applied.
- Level 1, 2 products are delivered to the scientific community and general users to pursue the science questions
  - With appropriate cloud screening, compositing, spatial, and temporal subsetting



Land and coastal acquisition



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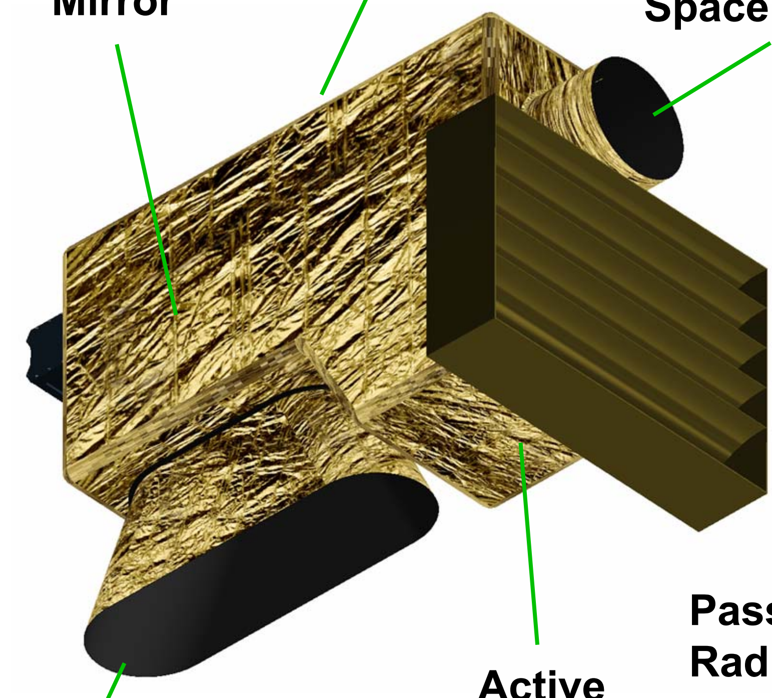
Mission Concept
TIR Overview

- Duration: 4 years development, 3 years science
- Coverage: Global land every 5 days
- Day and Night imaging (1 day and night image at a given location obtained every 5 days)
- Data download using dual-polarization X-band at high-latitude stations
- Instrument: 66kg / 78W
- Spacecraft: LEO RSDO bus (SA-200HP)
- Launch: Taurus-class launch vehicle



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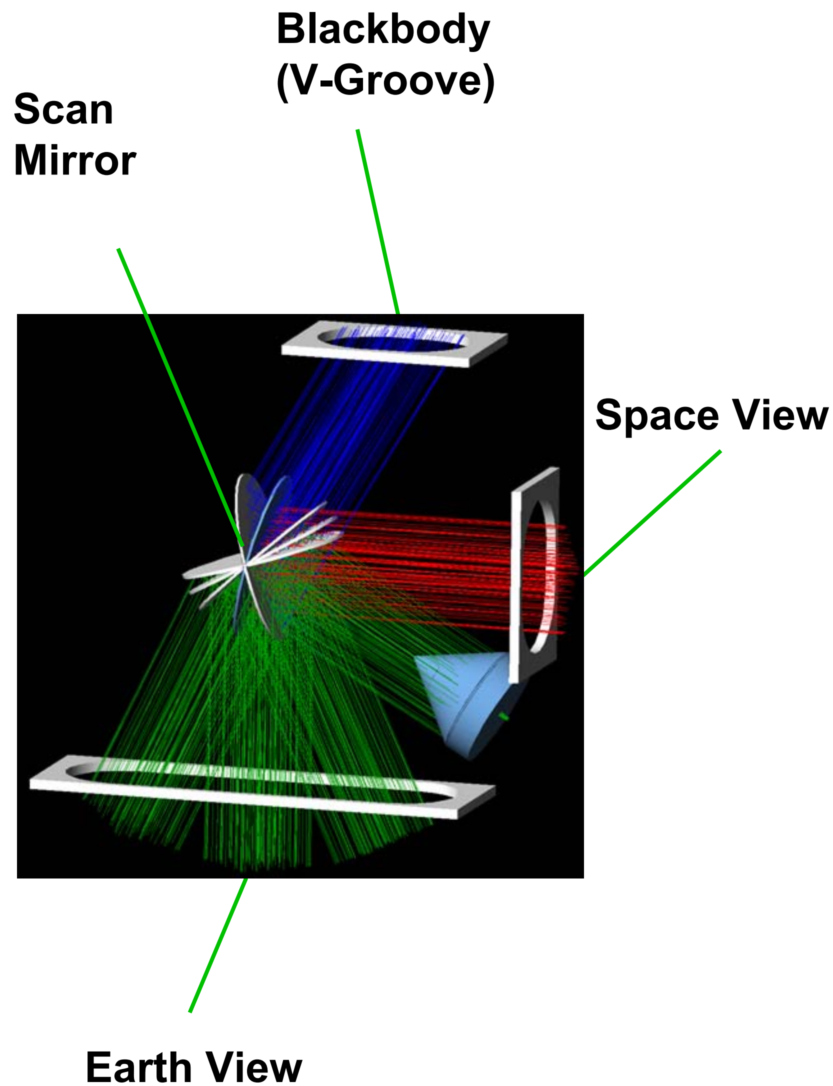

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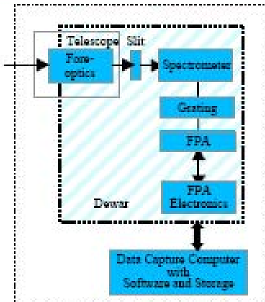
HyTES: Hyperspectral Thermal Emission Spectrometer for HyspIRI-TIR Science

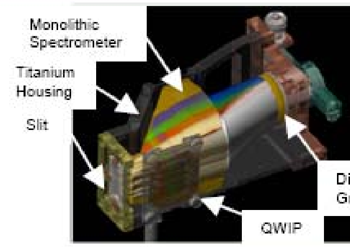
PI: Simon Hook / JPL

Objective

- Develop a thermal infrared imaging spectrometer with high spatial and spectral resolution to support the HyspIRI mission. This mission will address key science questions related to the Solid Earth and Carbon Cycle and Ecosystems focus areas .
  - The instrument will use at its base a cooled Dyson spectrometer that acquires 256 spectral channels of image data between 8 and 12 μm when used in conjunction with a Quantum Well Infrared Photodetector (QWIP) array
- Verify the performance in the laboratory as well as on an airborne platform.

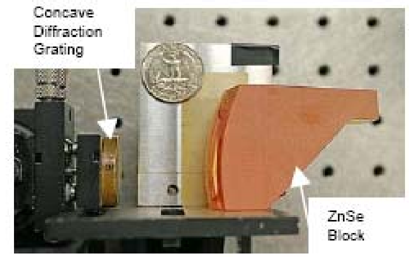


1) Block Diagram Concept



2) Graphical Concept

3) Concave Diffraction Grating



4) Dyson Spectrometer

Approach

- Develop opto-thermo-mechanical system design requirements.
- Develop analytical system model and design for a cryocooler dyson spectrometer.
- Fabricate/procure spectrometer system (QWIP, grating, optics, thermal and mechanical components, test equipment).
- Integrate and test in the laboratory and on an airborne platform to verify performance.

Co-Is (JPL):

- Bjorn T. Eng, Sarath D. Gunapala, Cory J. Hill, William R. Johnson, Pantazis Mouroulis, Vincent J. Realmuto, Daniel W. Wilson.

Key Milestones

Complete science & prelim. instrument design requirement	10/08
Complete Preliminary Design Review (PDR)	03/09
Complete Critical Design Review (CDR)	06/09
Complete procurement of critical components	12/09
Complete fabrication	06/10
Complete static, dynamic and force tests	12/10
Complete calibration I&T	12/10
Complete performance & science verification	05/11

TRL_{in} = 4