Overview of the HyspIRI Thermal Infrared (TIR) Science Measurement Characteristics

NRC Decadal Survey Recommended HyspIRI Mission

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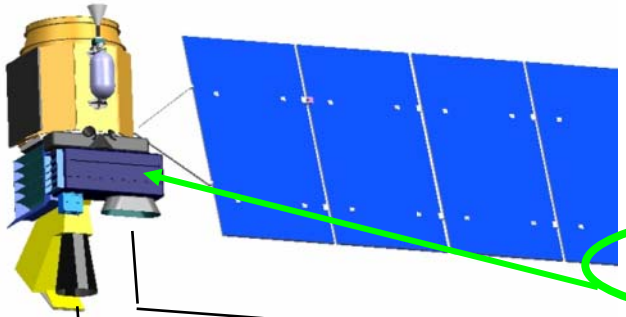
NRC Decadal Survey HyspIRI

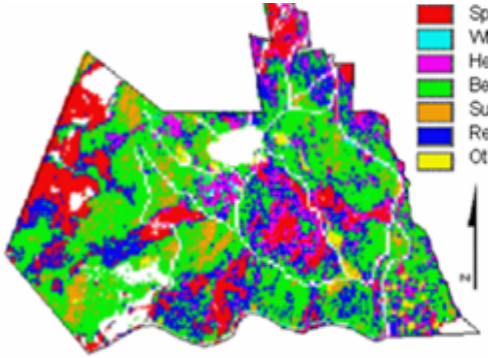
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

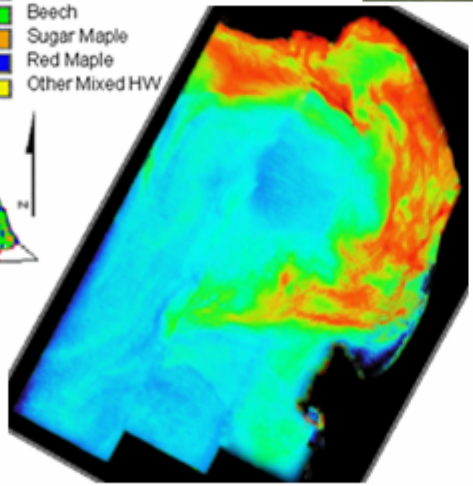


VSWIR: Plant Physiology and Function Types (PPFT)

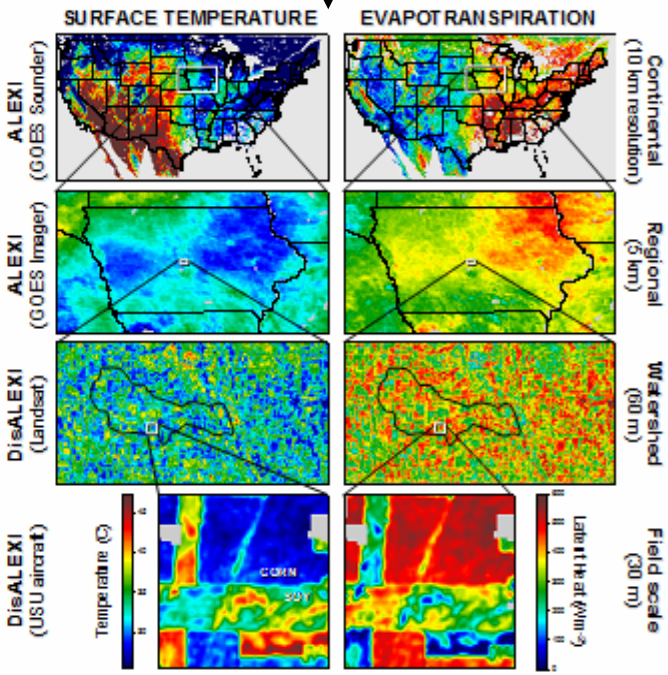
Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH





Red tide algal bloom in Monterey Bay, CA



Overview

- The Decadal Survey Call for HyspIRI
- Mission Concept Studies and Science Study Group
- TIR Science Questions
  - Select examples
- Science Measurements
- Summary

HyspIRI Decadal Survey Mission

The National Academy of Sciences Decadal Survey (2007) placed “critical priority” on a:

“Mission to observe surface composition and thermal properties: Changes in mineralogical composition affect the optical reflectance spectrum of the surface, providing information on the distribution of geologic materials and also the condition and types of vegetation on the surface. Gases from within the Earth, such as CO2 or SO2, are sensitive indicators of impending volcanic hazards, and plume ejecta themselves pose risk to aircraft and to those downwind. These gases also have distinctive spectra in the optical and near IR regions.”

“A multispectral imager similar to ASTER is required in the thermal infrared region. Volcano eruption prediction are high thermal sensitivity, on the order of 0.2 K, and a pixel size of less than 90 m. An opto-mechanical scanner, as opposed to a pushbroom scanner, would provide a wide swath of as much as 400 km at the required sensitivity and pixel size..”

Related Recommendations

Volcanoes:

- "Satellite observations of thermal emission via infrared imagery, which could make a significant contribution to our ability to forecast and manage fires and volcanoes, must be expanded and improved.“ ***The Strategic Plan for the U.S. Integrated Earth Observation System, prepared by the National Science and Technology Council and the Interagency Working Group on Earth Observations (page 90)***

- The basic real time monitoring required to detect and track pre-eruptive and eruptive changes at volcanoes exhibiting moderate to very high threat levels requires, amongst other things, “routine use of multi-channel thermal infrared data from an ASTER-class satellite” *An* ***Assessment of Volcanic Threat and Monitoring Capabilities in the United States: Framework for a National Volcano Early Warning System”, (page 57)***

Mission Concept Studies

HyspIRI Mission Overview

In 2007 two mission concept studies where completed. One focused on plant physiology and functional type (PPFT) the required the science measurements of the VSWIR imaging spectrometer. The other focused on surface temperature and emissivity and atmospheric science traced to multispectral measurements of the thermal infrared (TIR).

Urgency and Focus

Three fundamental components required for understanding ecosystems are: function, composition, and structure. This mission for the first time provides global measurements of ecosystem function with vastly improved measures of composition including biodiversity.

This mission provides the surface temperature and emissivity of the Earth at high spatial and high temporal resolution that will be used to address key science questions in five research areas: volcanoes, wildfires, water use and availability, urbanization, land surface composition and change.

A 2008 Science Measurement and Mission update and refinement activity is underway. This workshop is part of this 2008 activity.

2007 TIR Science Working Group

Mission Concept Study Lead: **Tom Pagano, Francois Rogez** /JPL

NASA Center Science Lead: **Simon Hook** /JPL

Science Working Group: **Mike Abrams** /JPL (Hazards), **Martha Anderson** /USDA (Hydrological studies), **Wendy Calvin** /UNR (Geothermal), **James Crowley** /USGS (Mineral mapping), **Mariana Eneva** / ImageAir (Earthquakes/geothermal), **Luke Flynn** /U Hawaii (Volcanoes), **Louis Giglio** /SSAI (Fires), **Fred Kruse** /Horizon GeoImaging (Mineral mapping) , **Dimitar Ousounov** /GSFC (Earthquakes), Anupma Prakash/UAF (Volcanoes, Fires, Plumes), Dale Quattrochi/MSFC (Urban heat islands) , Vince Realmuto/JPL (Volcanic gases), David Roy/SDSU (Fires), Paul Silver-Carnegie Institution (Earthquakes)

NASA HQ Science POC: **John LaBrecque, Diane Wickland**

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; **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, Diane Wickland

HyspIRI TIR
Science Questions

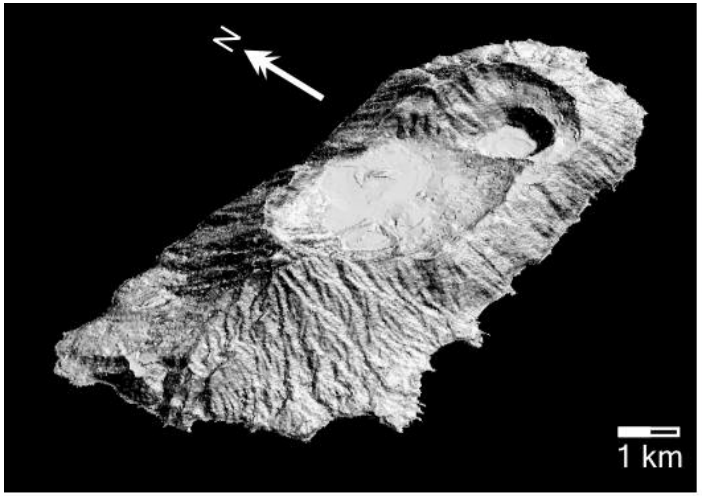
TIR Overarching Science Questions

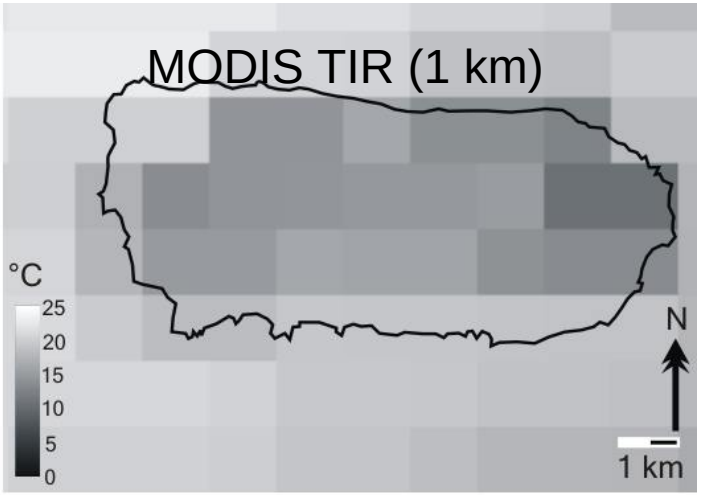
- **TQ1. Volcanoes/Earthquakes (MA,FF)**
  - How can we help predict and mitigate earthquake and volcanic hazards through detection of transient thermal phenomena?
- **TQ2. Wildfires (LG,DR)**
  - What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this 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?

Q1. Volcanoes/Earthquakes:

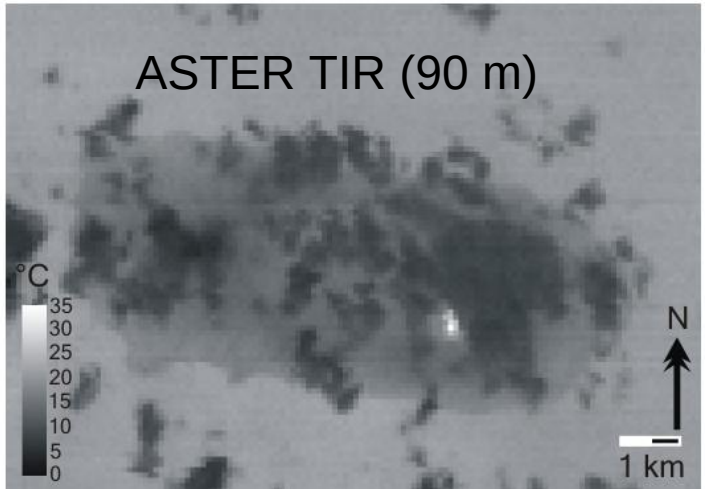
- Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates and are such changes unique to specific types of eruptions? [DS 227]
- What do changes in the rate of lava effusion tell us about the maximum lengths that lava flows can attain, and the likely duration of lava flow-forming eruptions? [DS 226]
- What are the characteristic dispersal patterns and residence times for volcanic ash clouds and how long do such clouds remain a threat to aviation? [DS 224]
- What do the transient thermal anomalies that may precede earthquakes tell us about changes in the geophysical properties of the crust? [DS 227, 229]
- Can the energy released by the periodic recharge of magma chambers be used to predict future eruptions? [DS 227]

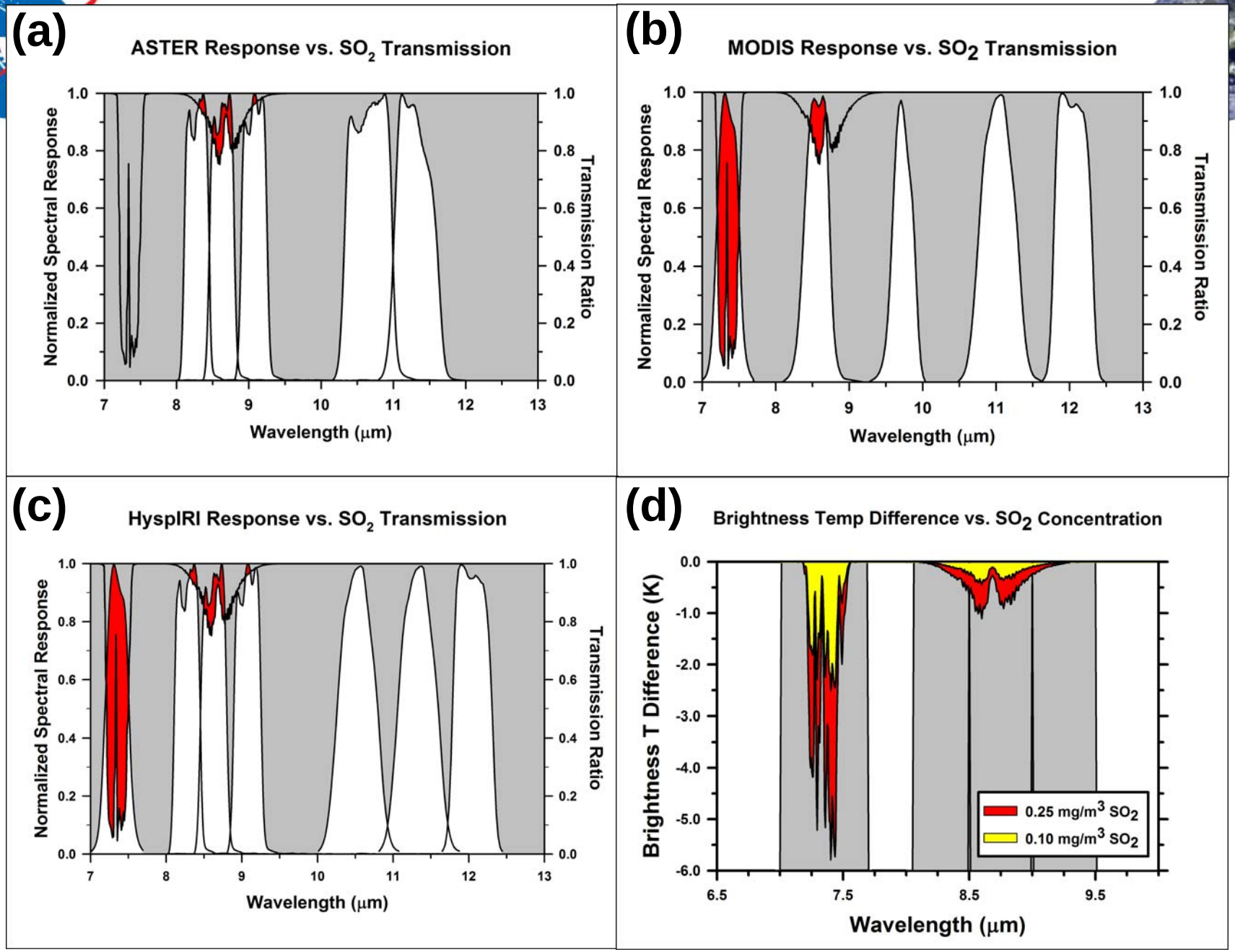
Do volcanoes signal impending eruptions through changes in surface temperature or gas emission rates and are such changes unique to specific types of eruptions?

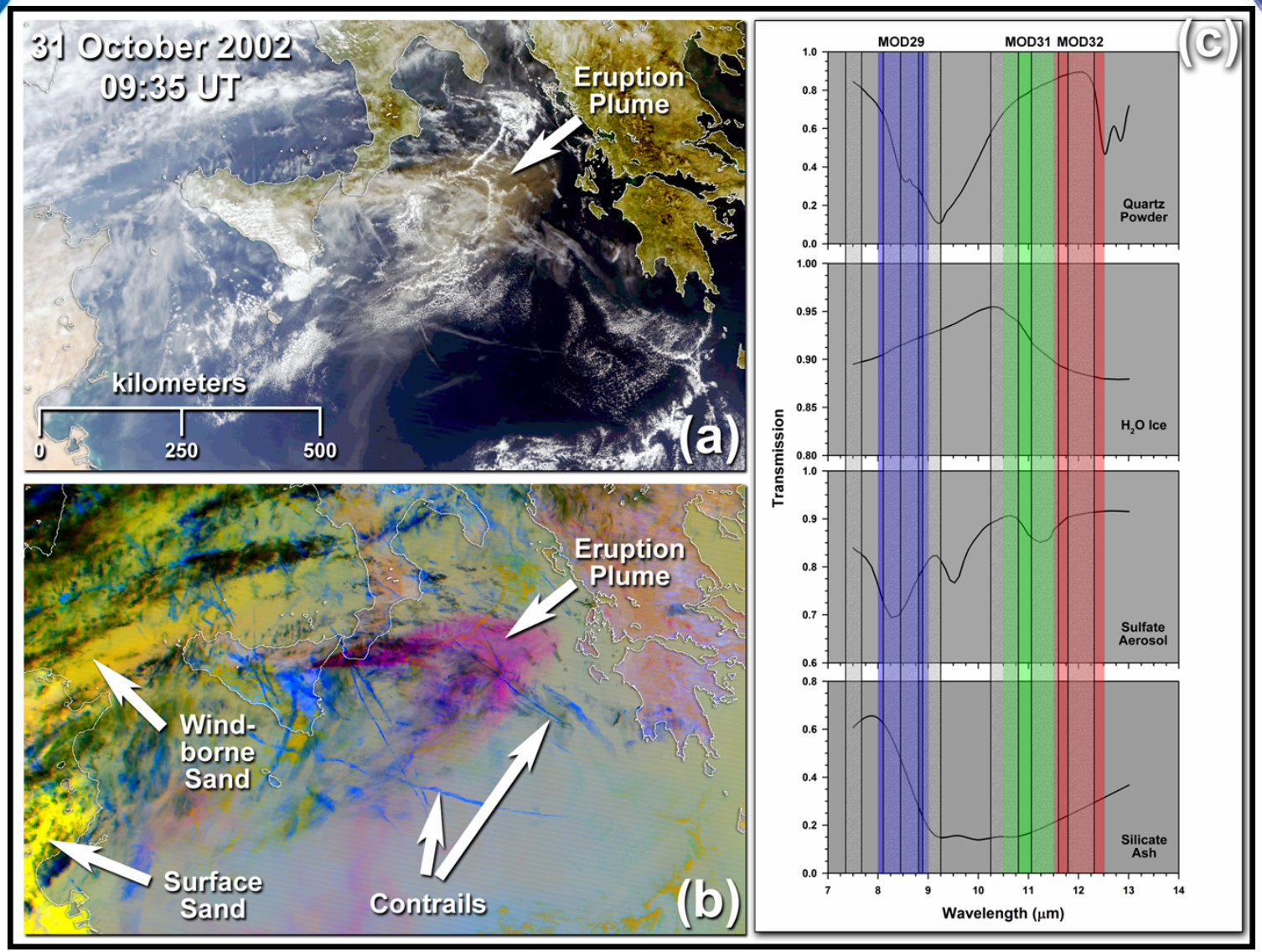




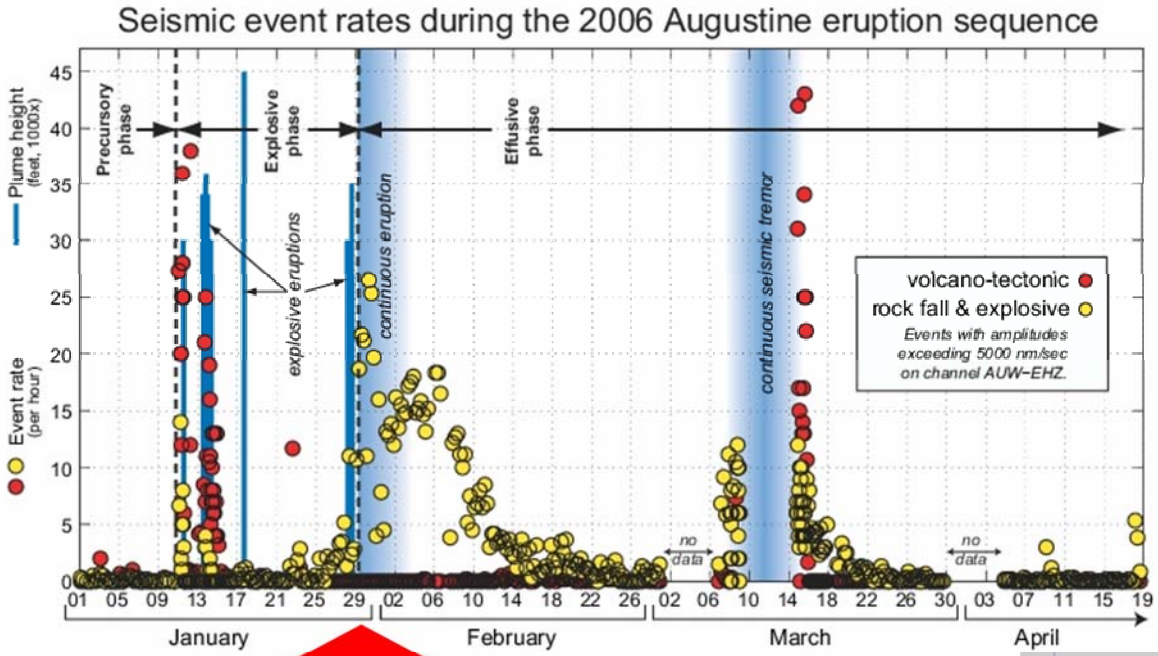
Anatahan, Marianas. Erupted in 2002, no ground instrumentation, caught people by surprise. Upper right image is a nighttime MODIS TIR image, 1 km resolution. Note that elevated thermal radiance in the vicinity of the east crater is not apparent (hydrothermal activity too small/too cool to show up at this resolution). Below is an ASTER TIR image. The hydrothermal activity is clearly visible (although in this case partially cloud obscured).




(a)
ASTER Response vs. SO_2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(b)
MODIS Response vs. SO_2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(c)
HyspIRI Response vs. SO_2 Transmission
Normalized Spectral Response
Transmission Ratio
Wavelength (μm)
(d)
Brightness Temp Difference vs. SO_2 Concentration
Brightness T Difference (K)
0.25 mg/m^3 SO_2
0.10 mg/m^3 SO_2
Wavelength (μm)

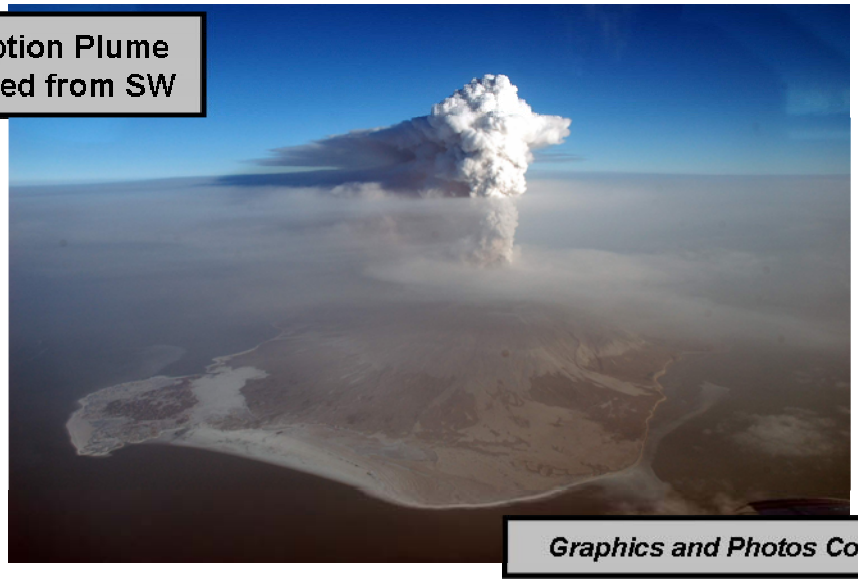


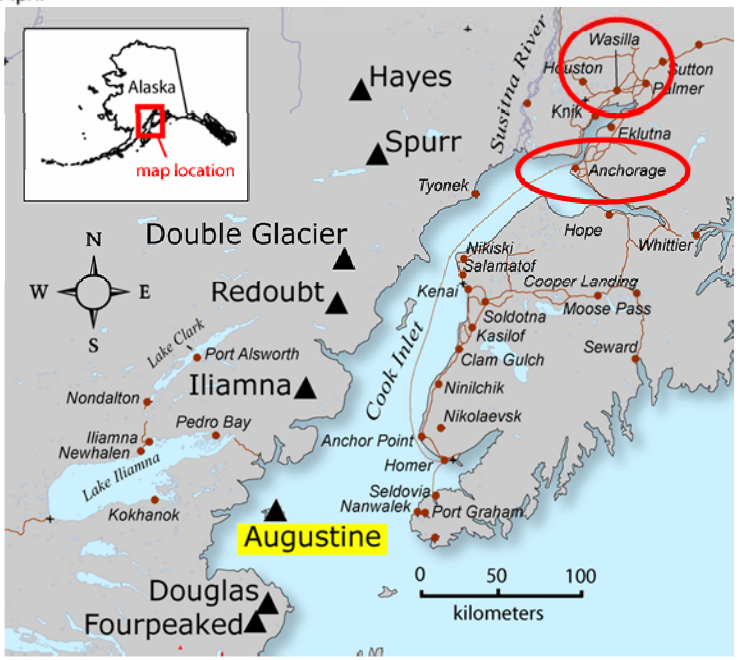
Plume Detection Based on Multispectral TIR Remote Sensing



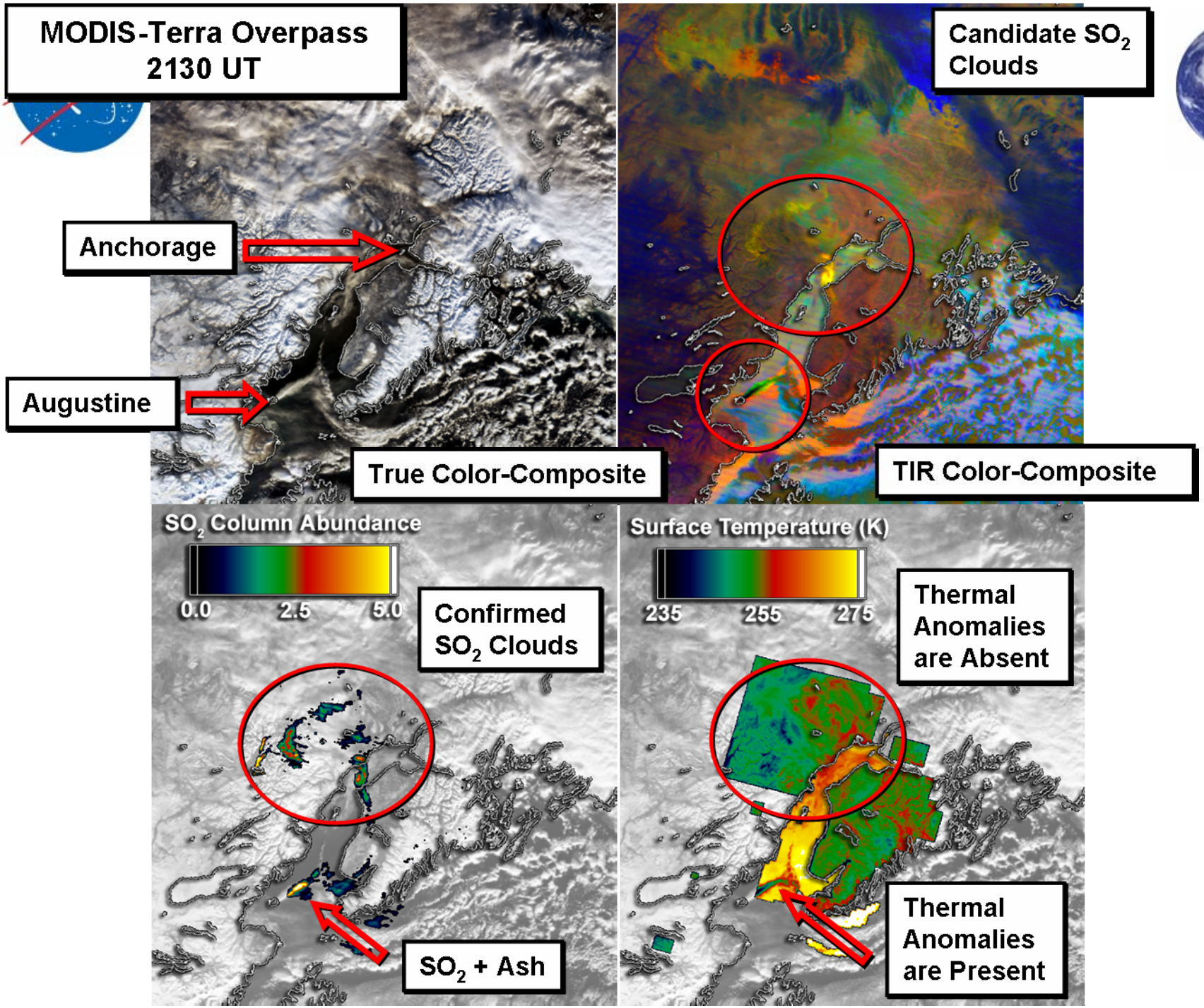
Explosive Event at Augustine Volcano 30 January 2006

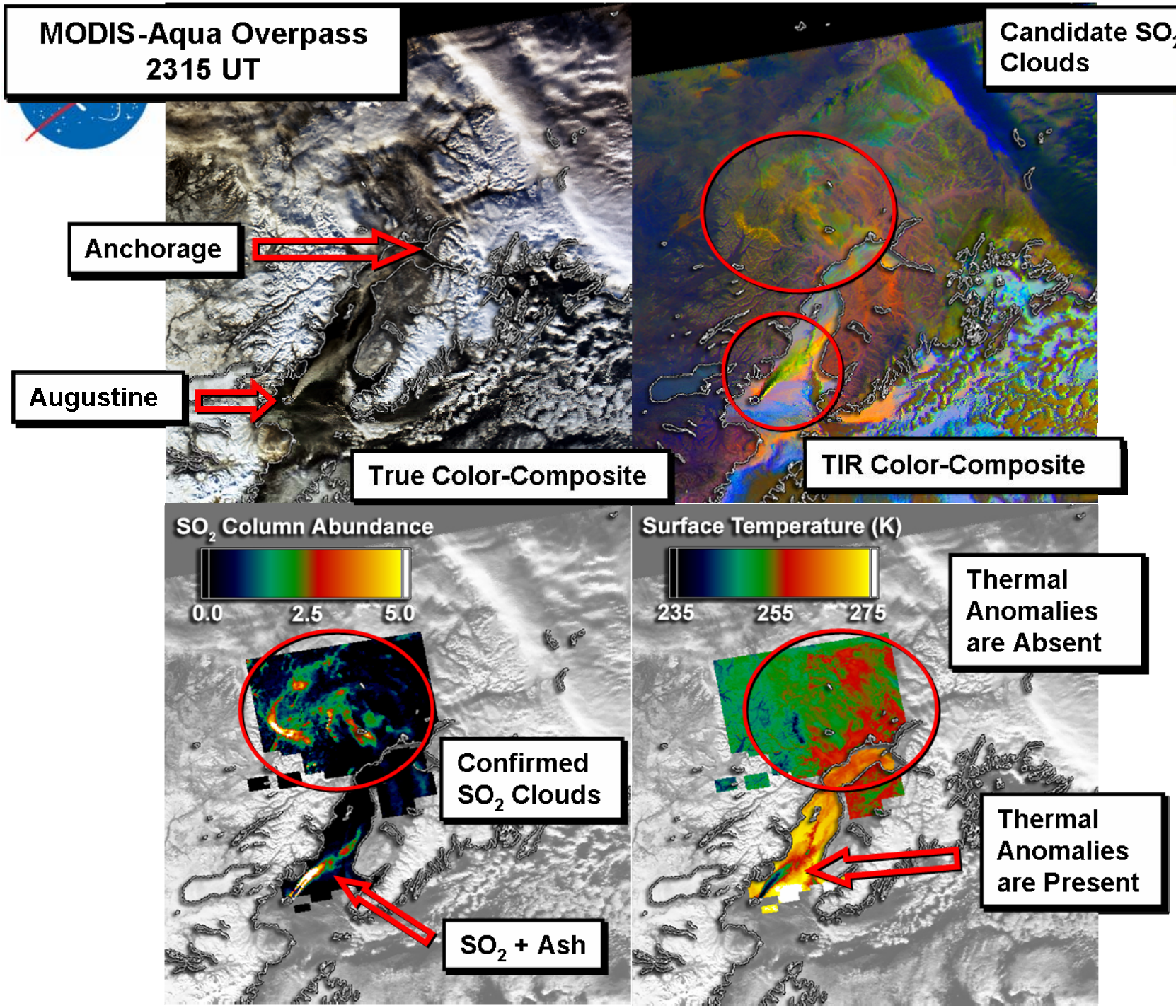
Eruption Plume Viewed from SW





Graphics and Photos Courtesy of Alaska Volcano Observatory


MODIS-Terra Overpass
2130 UT
Anchorage
Augustine
True Color-Composite
Candidate SO_2 Clouds
TIR Color-Composite
SO_2 Column Abundance
0.0
2.5
5.0
Confirmed SO_2 Clouds
SO_2 + Ash
Surface Temperature (K)
235
255
275
Thermal Anomalies are Absent
Thermal Anomalies are Present


MODIS-Aqua Overpass
2315 UT
Anchorage
Augustine
True Color-Composite
Candidate SO_2 Clouds
TIR Color-Composite
SO_2 Column Abundance
0.0
2.5
5.0
Confirmed SO_2 Clouds
SO_2 + Ash
Surface Temperature (K)
235
255
275
Thermal Anomalies are Absent
Thermal Anomalies are Present

Q2. Wildfires:

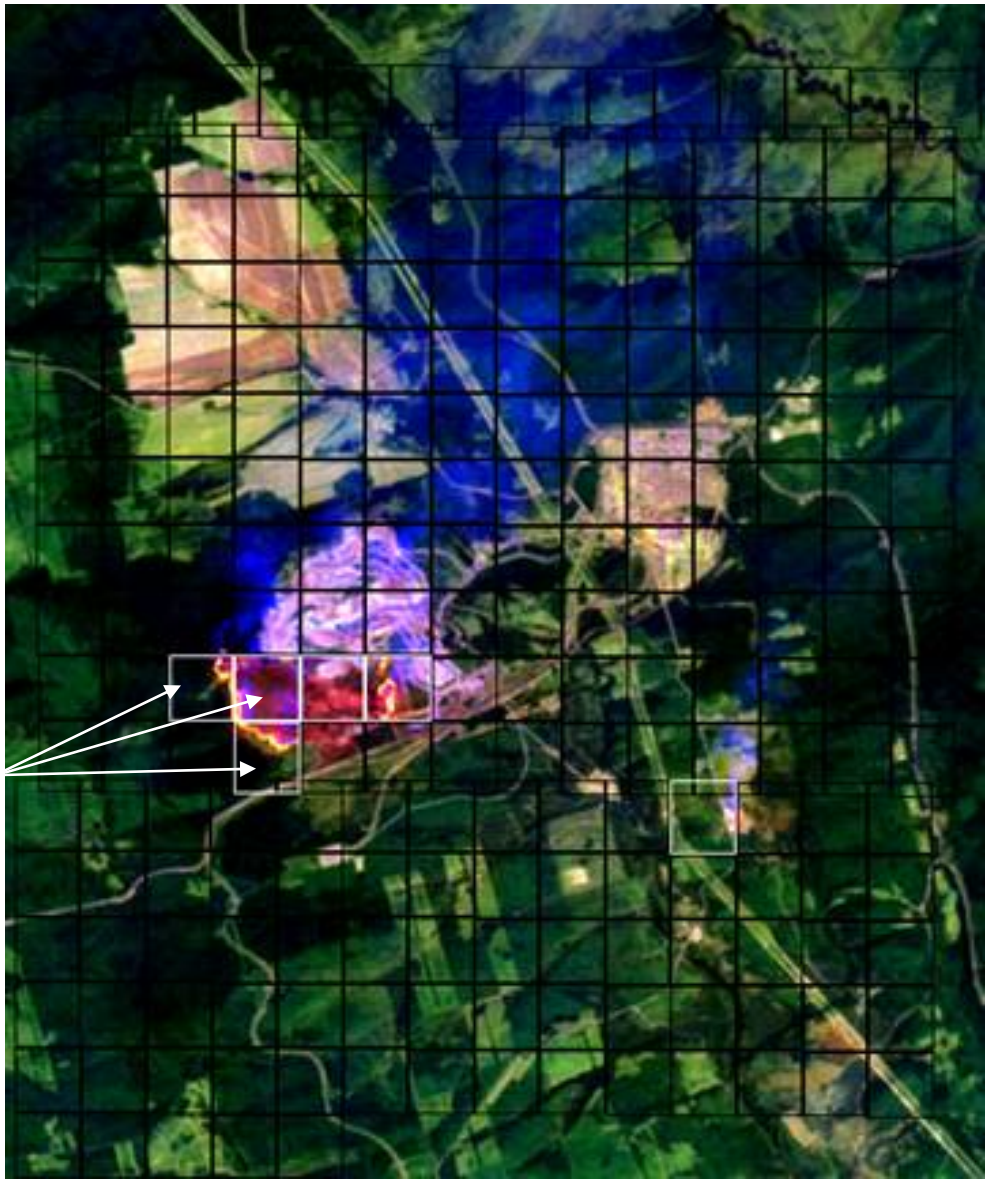
- How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices? [DS 198]
- Are regions becoming more fire prone? [DS 196]
- What is the role of fire in global biogeochemical cycling, particularly atmospheric composition? [DS 195]
- Are there regional feedbacks between fire and climate change?

How are global fire regimes changing?

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

Q3. Water Use and Availability:

- How is climate change impacting the evaporative component of the global water cycle over natural and managed landscapes? [DS 166, 196, 203, 257, 368]
- How can information about evapotranspiration and its relationship to land-use/land-cover be used to facilitate better management of freshwater resources? [DS 196, 203, 368]
- How can we improve early detection, mitigation, and impact assessment of droughts at local to global scales? [DS 166, 196, 203, 368]
- What is the current global irrigated acreage, how is it changing with time, and are these changes in a sustainable balance with regional water availability? [DS 196, 368]
- Can we increase food production in water-scarce agricultural regions while improving or sustaining environmental access to water? [DS 196, 368]

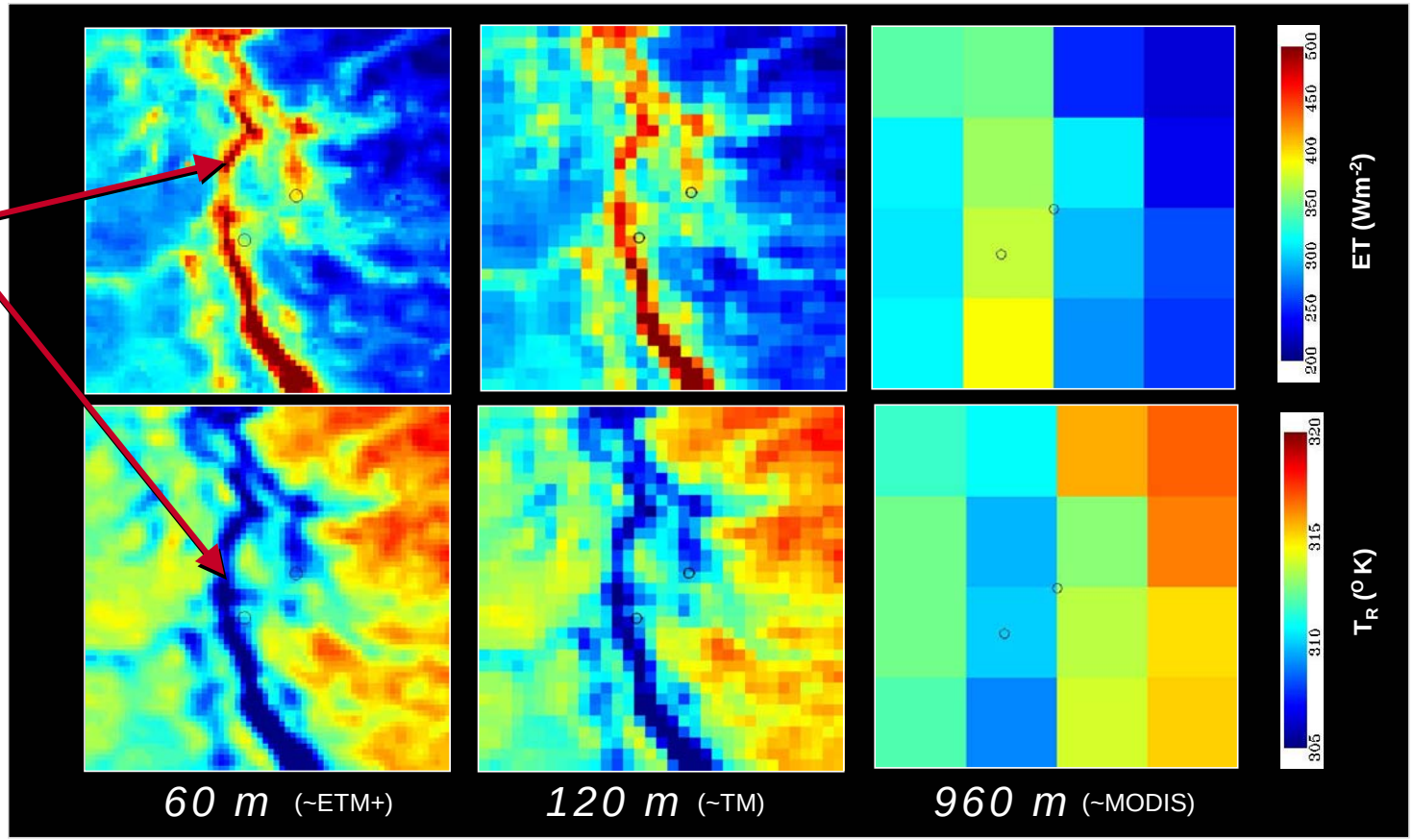
How can we improve spatial information about evapotranspiration (water loss to the atmosphere) to facilitate better management of our Earth's freshwater resources?

MONITORING RIPARIAN WATER LOSSES

San Pedro River Basin

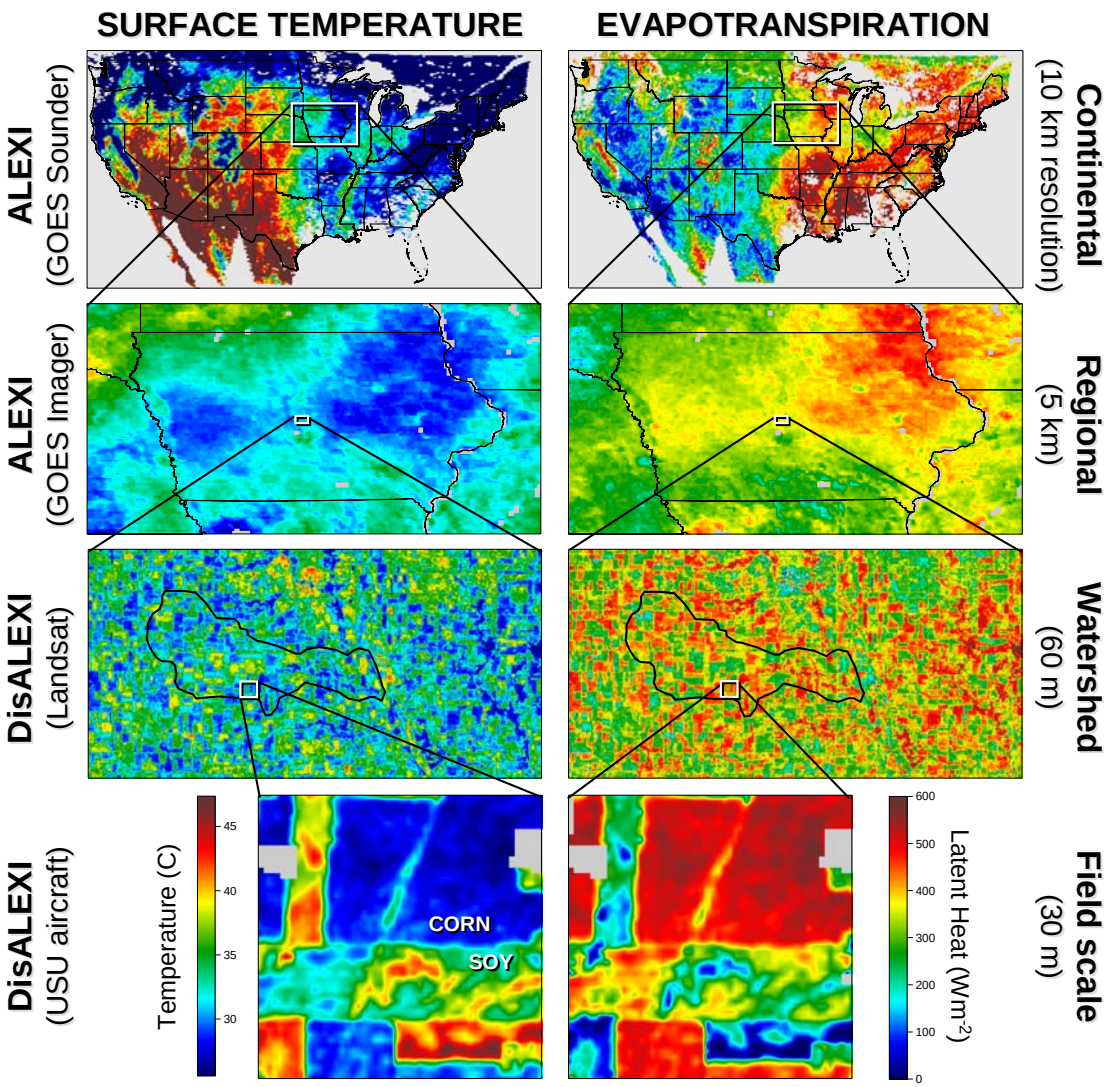
Higher rates of evapotranspiration (ET) lead to lower temperatures along the San Pedro River.

Estimates of consumptive water use by riparian vegetation is important for river water management decisions and for negotiation and regulation of interstate water contracts



≤100m resolution required to resolve riparian zone

How can we obtain better information about vegetation water stress conditions at spatiotemporal scales that are beneficial for global drought early detection, mitigation, and impact assessment efforts?



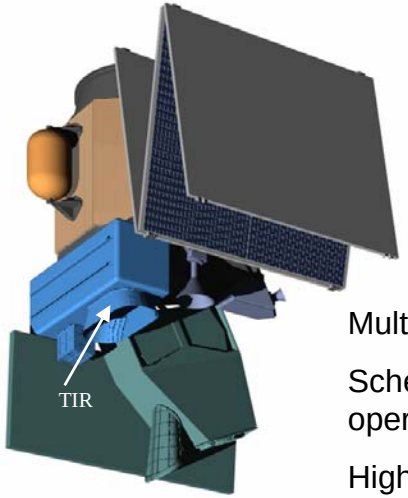
Scale-dependent factors driving ET variability:

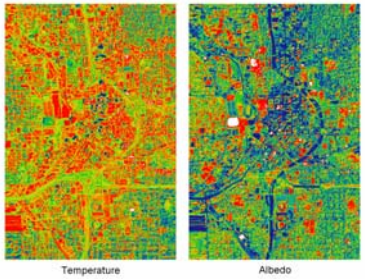
- *gradients in climate and vegetation cover*
- *spatial distribution of antecedent precipitation*
- *cropping patterns (corn vs. soybean; partial vs. full cover)*
- *soil textural properties and field management activities*

The thermal band carries critical information for determining ET.

HyspIRI Science Measurements
- Thermal Infrared (TIR)

HyspIRI Thermal Infrared Multispectral (TIR) Science Measurements





Multispectral Scanner: 66kg / 78W

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

High Heritage

Science Questions:

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• TQ2. Wildfires (LG,DR)

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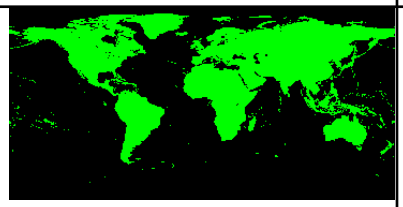
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

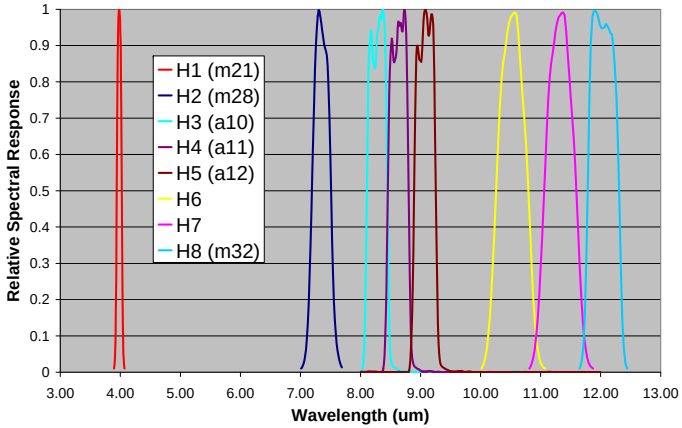
• TQ5. Earth surface composition and change, (AP,JC)

– 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?

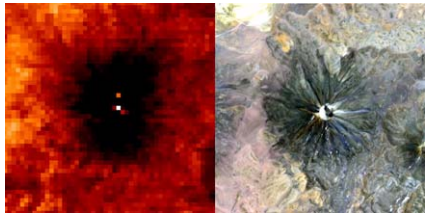
Measurement:

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

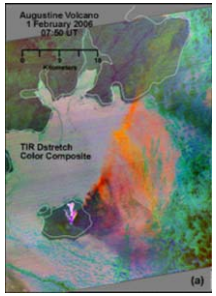




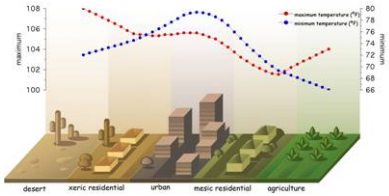
Andean volcano heats up



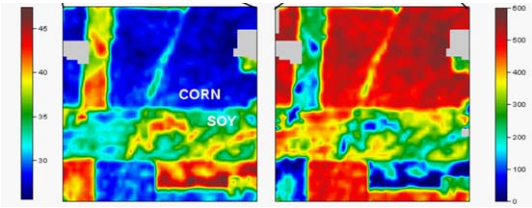
Volcanoes



Urbanization



Water Use and Availability



Surface Temperature

Evapotranspiration

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

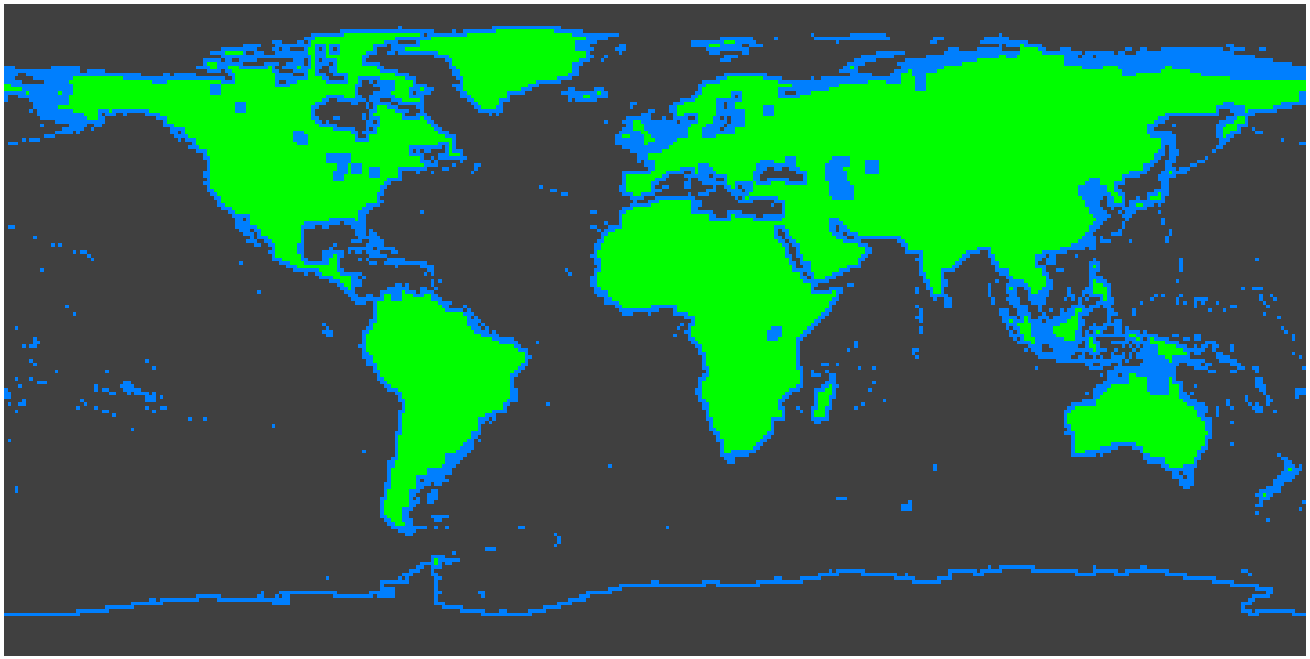
Characteristics Continued

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

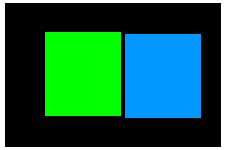
Mission Concept

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



TIR Instrument Concept

- Spatial
  - 623 km Orbit
  - 60 m IFOV, MTF = 0.2 @ f_{Ny}
  - Swath: 600 km (±25.5º), Paddle Mirror Scanner
  - 15.4 km Along Track Swath Width (256 Elements)
- Multispectral
  - 8 Bands
  - 3.9 – 12.3 μm
  - Dielectric Bandpass Filters
- Radiometric
  - NEdT < 0.2K
  - 30 cm Aperture
- Calibration
  - Full Aperture Blackbody
  - Space View

Heritage: MODIS, Landsat, M3

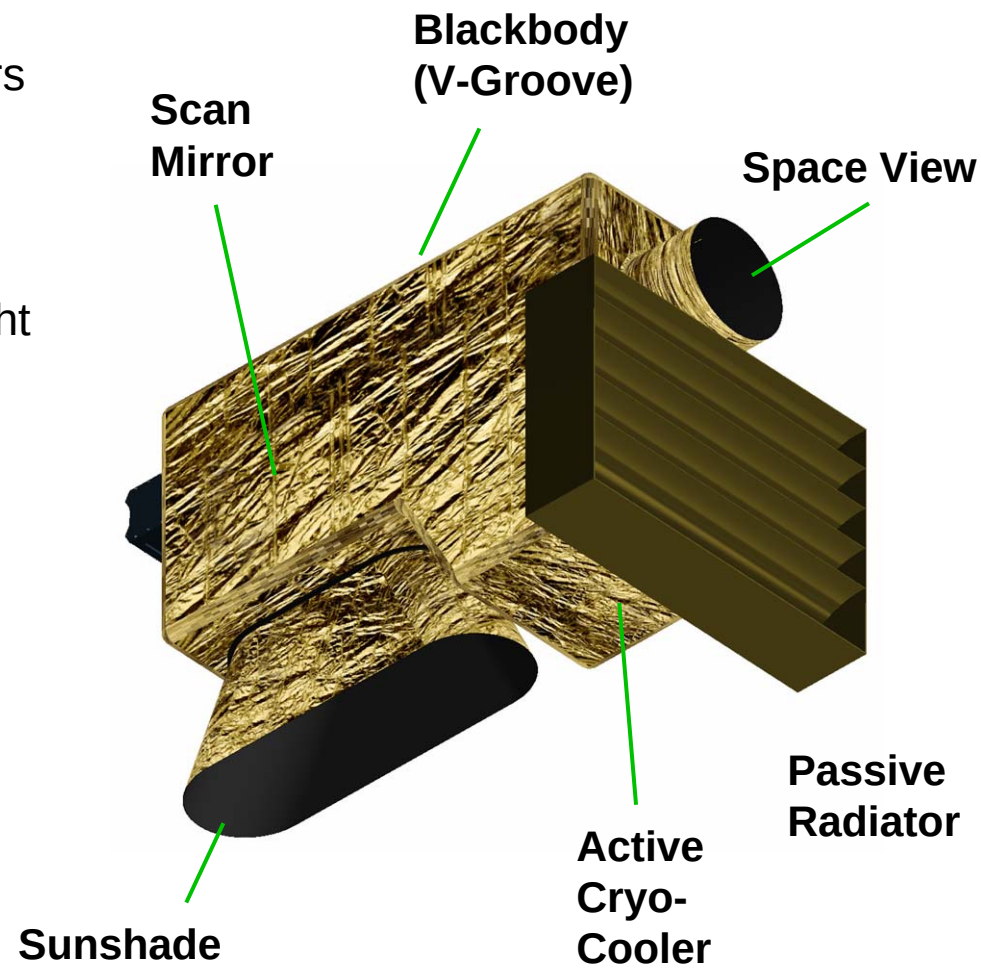
λ min	λ max	λ center	Band Width
3.940	4.024	3.982	0.084
7.190	7.509	7.350	0.319
8.107	8.450	8.278	0.344
8.455	8.801	8.628	0.345
8.894	9.254	9.074	0.361
10.258	10.798	10.528	0.540
11.058	11.598	11.328	0.540
11.784	12.308	12.046	0.524

TIR TRL is High

Subsystem	TRL	Comments
Scanner	9	Flight Proven on Numerous Designs
Telescope	9	Flight Proven on Galileo SSI, MGS-TES, CZCS, Cassini VIMS, HiRISE
Optical Filters	9	Flight Proven on MODIS, ASTER, Landsat
Focal Plane Assembly	6-7	Similar Detector Materials and ROIC's Demonstrated on Ground and in Space
Active Cooler	9	Proven on Numerous Flight Programs
Passive Cryocoolers	9	Proven on M3, AIRS. More advanced forms flown on many programs.
Blackbody	9	Proven on MODIS
Mechanical / Thermal Systems	9	Proven on numerous flight missions
Scan Line Corrector	N/A	There is no scan line corrector!
Electronic Subsystems	6, 9	Exact form proven in Lab, Similar Designs flown on other Space Programs

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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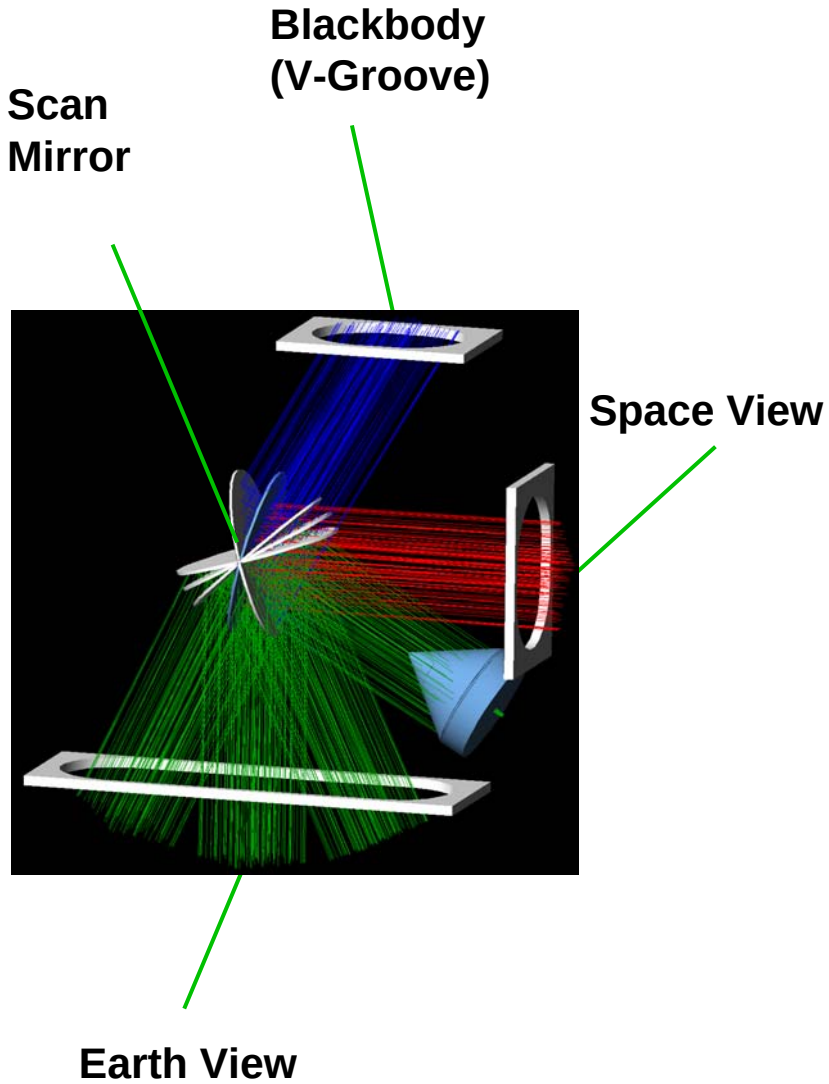

Summary

Summary – HyspIRI TIR

This mission provides the measurement to answer the PPFT (VSWIR imaging spectrometer) and Multispectral TIR NASA Mission Concept Studies.

The science, measurements, and algorithms enabling this mission have been consistently demonstrated with antecedent airborne and ground measurements and experiments.

This HyspIRI mission addresses a set of compelling science questions that have been repeatedly identified as critical to science and society by independent assessments and scientific panels. Recent examples include: the NRC Decadal Survey, the 4th assessment of the IPCC and the U.S. Climate Change Science Program

The HyspIRI instruments and mission have high relevant heritage, and correspondingly low risk, in conjunction with a modest cost.