HyspIRI

TIR Science Measurement Baseline and Instrument Concept

NASA Earth Science and Applications Decadal Survey

Simon J. Hook and HyspIRI Team
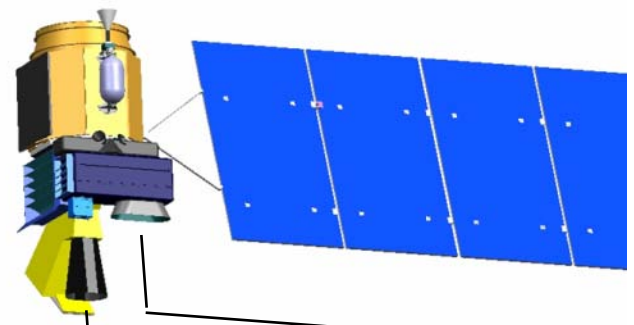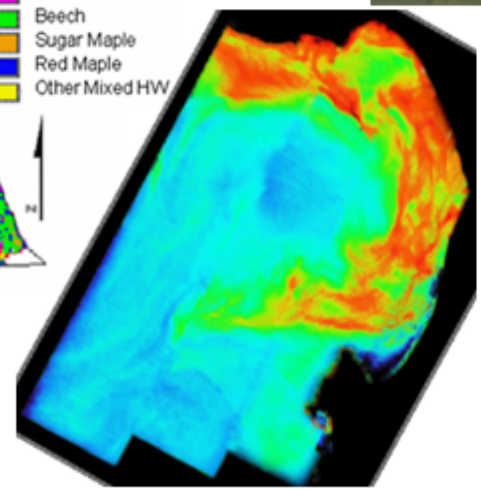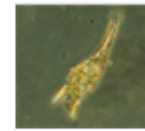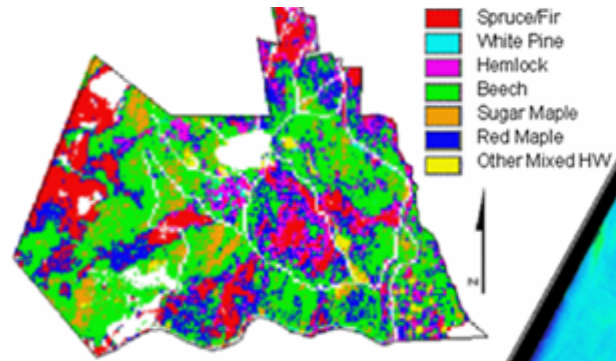
NRC Decadal Survey HyspIRI

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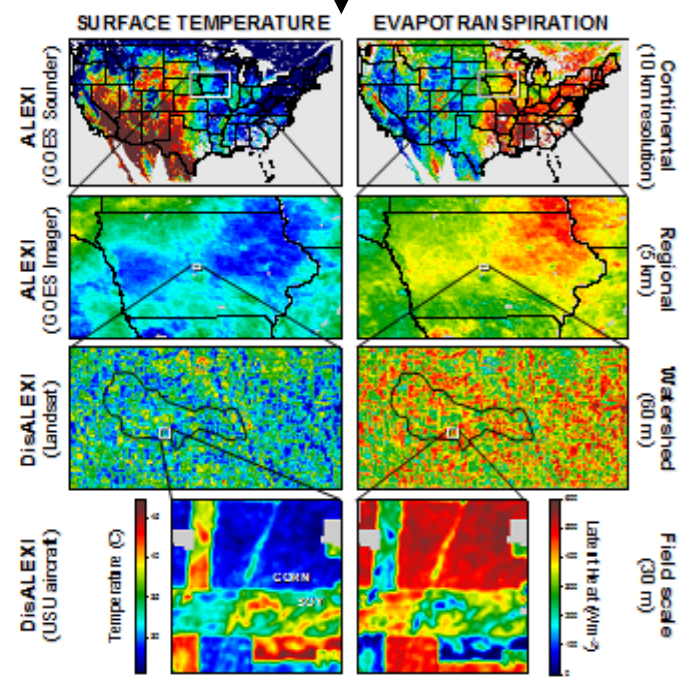**+**
Multispectral Thermal InfraRed (TIR) Scanner

VSWIR: Plant Physiology and Function Types (PPFT)

Multispectral TIR Scanner

Map of dominant tree species, Bartlett Forest, NH

🟥	Spruce/Fir
🟦	White Pine
🟪	Hemlock
🟩	Beech
🟧	Sugar Maple
🟦	Red Maple
🟨	Other Mixed HW

Red tide algal bloom in Monterey Bay, CA

SURFACE TEMPERATURE   EVAPOTRANSPIRATION

ALEXI (GOES Sounder) — Continental (10 km resolution)

ALEXI (GOES Imager) — Regional (5 km)

DisALEXI (Landsat) — Watershed (60 m)

DisALEXI (USU aircraft) — Field scale (30 m)

Temperature (C)   Latent heat (W/m²)

CORN   SOY

HyspIRI Thermal Infrared Multispectral (TIR) Science Measurements

Multispectral Scanner

Schedule: 4 year phase A-D,

3 years operations

High Heritage

TIR

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?

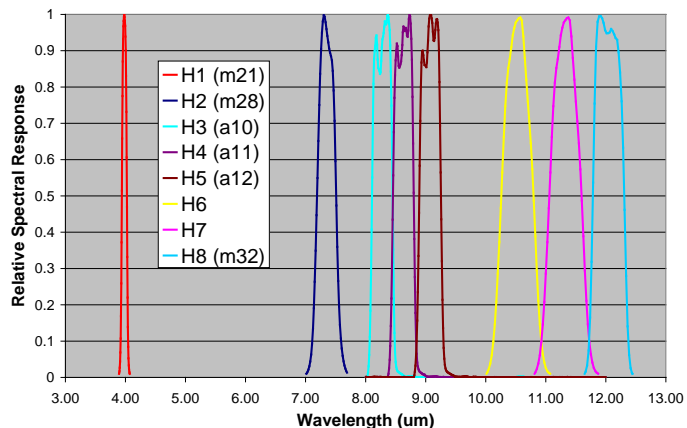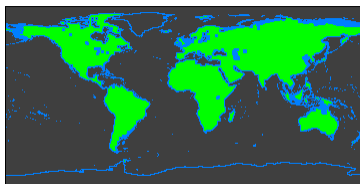*• TQ4. Urbanization/Human Health, (DQ,GG)*

– 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?

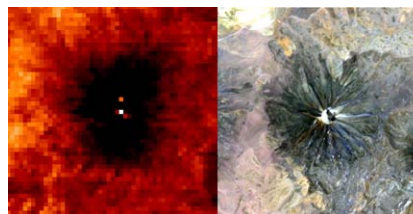*• TQ5. Earth surface composition and change, (AP,JC)*

– 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?
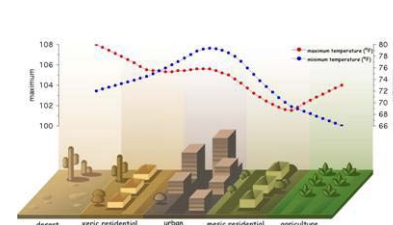
Measurement:

- 7 bands between 7.5-12 μm and 1 band at 4 μm. (4 um band for hot targets)

- 60 m resolution, 5 days revisit

- Global land and shallow water

Legend:
- H1 (m21)
- H2 (m28)
- H3 (a10)
- H4 (a11)
- H5 (a12)
- H6
- H7
- H8 (m32)

x-axis: Wavelength (um)
y-axis: Relative Spectral Response

Andean volcano heats up

Urbanization

Volcanoes

Water Use and Availability

Augustine Volcano
1 February 2006

TIR Dstretch
Color Composite

Surface Temperature

Evapotranspiration

3
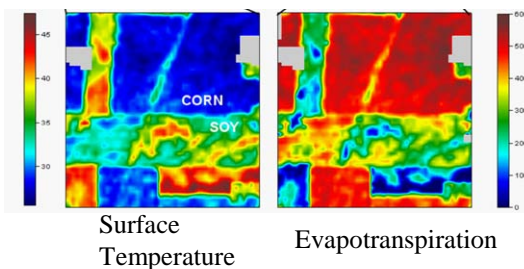
TIR Overarching Science Questions

- **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?

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- **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?

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
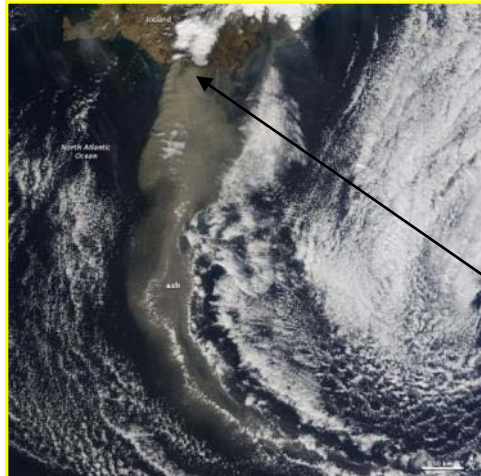
Eyjafjallajökull Iceland Volcano Eruption
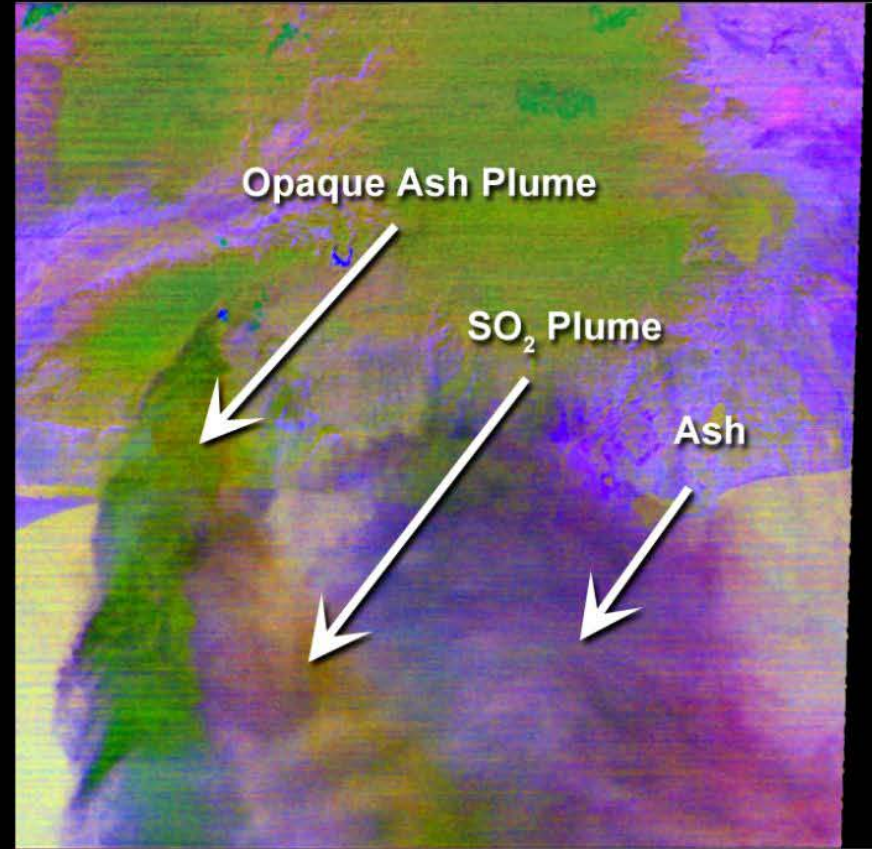
April 19 2010 MODIS image of ash plume.
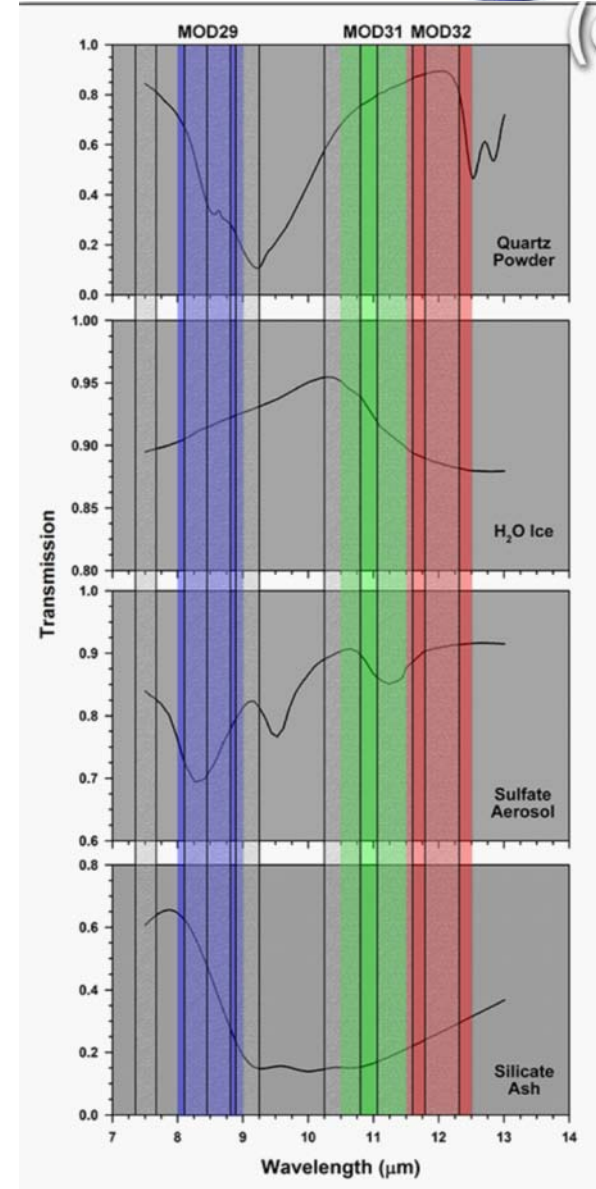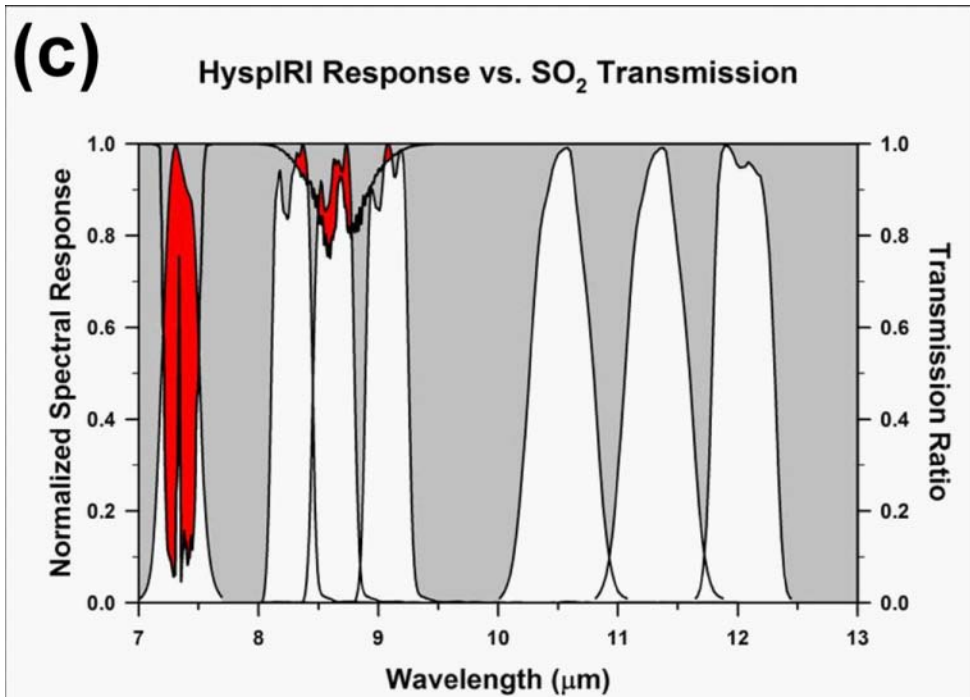
ASTER Observations of the Eyjafjallajökull Eruption
19 April 2010 - 12:51 UTC

Visible - Near Infrared

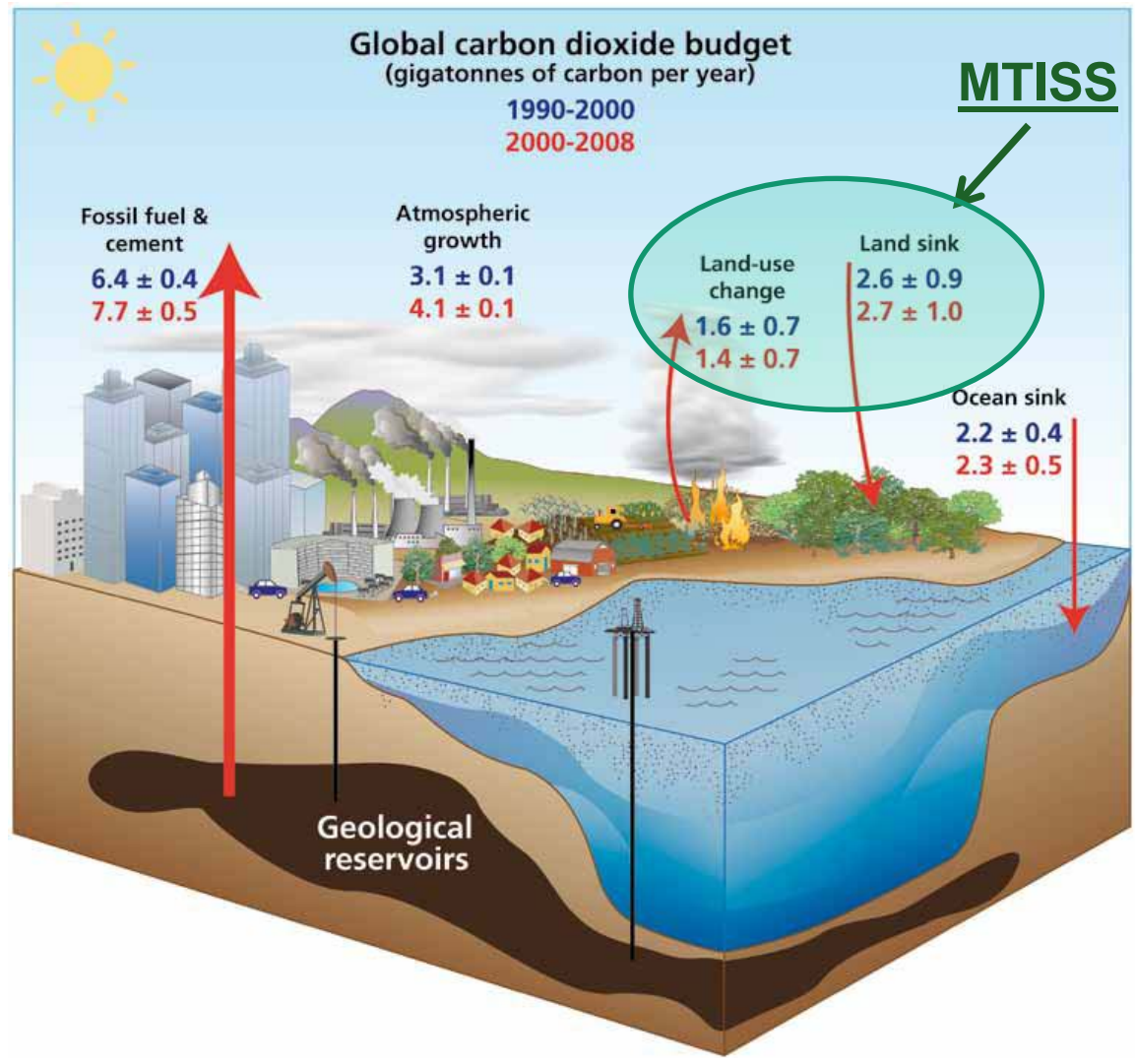Thermal Infrared

kilometers

0   36

Wildfires

- How are global fire regimes changing in response to, and driven by, changing climate, vegetation, and land use practices? [DS 198]

- Is regional and local scale fire frequency changing? [DS 196]

- What is the role of fire in global biogeochemical cycling, particularly trace gas emissions? [DS 195]

- Are there regional feedbacks between fire and climate change?

Large error in carbon budget exists due to poor knowledge of Carbon release from fires

Global carbon dioxide budget
(gigatonnes of carbon per year)
1990-2000
2000-2008

MTISS

Fossil fuel & cement
6.4 ± 0.4
7.7 ± 0.5

Atmospheric growth
3.1 ± 0.1
4.1 ± 0.1

Land-use change
1.6 ± 0.7
1.4 ± 0.7

Land sink
2.6 ± 0.9
2.7 ± 1.0

Ocean sink
2.2 ± 0.4
2.3 ± 0.5

Geological reservoirs

Global CO2 budget for 1990-2000 (blue) and 2000-2008 (red) (GtC per year). Emissions from fossil-fuel and land-use 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.

Measuring global fire emission is necessary for reducing the uncertainty in carbon emissions from biomass burning

Global average biomass burning estimates range from <u>20 – 40 %</u> of all global C emissions.

0   50   100   150   200   250   >300
1997 - 2001 mean annual fire emissions (g C / m² / yr)
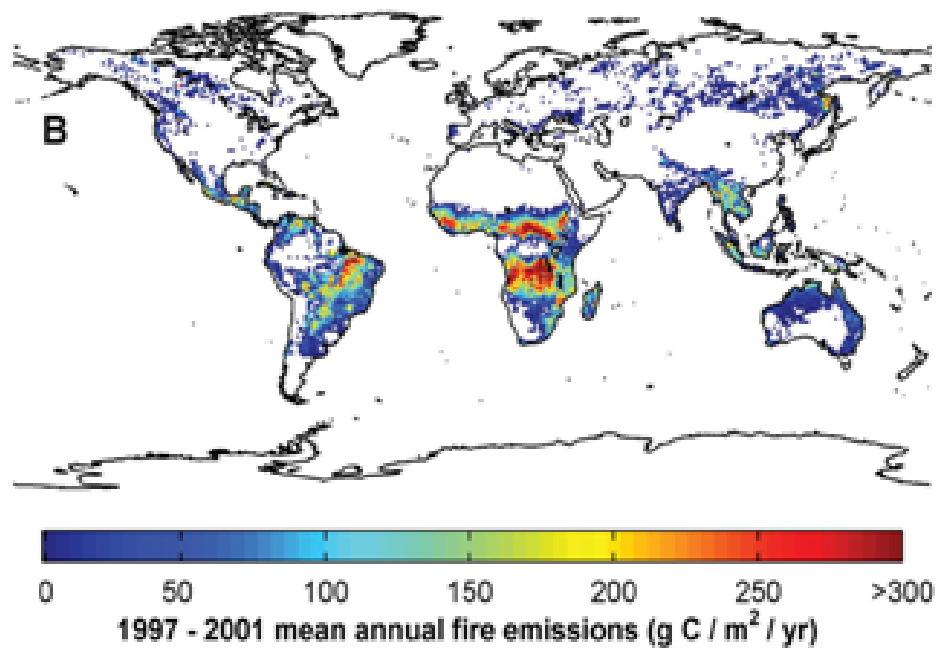
Van der Werf et al., 2010

Fires occur worldwide need a GLOBAL Mapping Mission, emissions vary regionally

HyspIRI-TIR will measure Radiative Energy that has been shown to yield precise estimates of Biomass Combusted

- Historically calculated using Seiler & Crutzen (1980) approach:

Biomass combusted = Area Burnt x Fuel Load x Combustion Efficiency

- More recently Fire Radiative Energy approach

Biomass combusted = Radiative energy or heat yield

(Since the heat yield (*kJ/kg*) of vegetation fuel is ~ constant, measuring the energy released on burning and knowing the heat yield allows the amount of biomass burned to be calculated.)
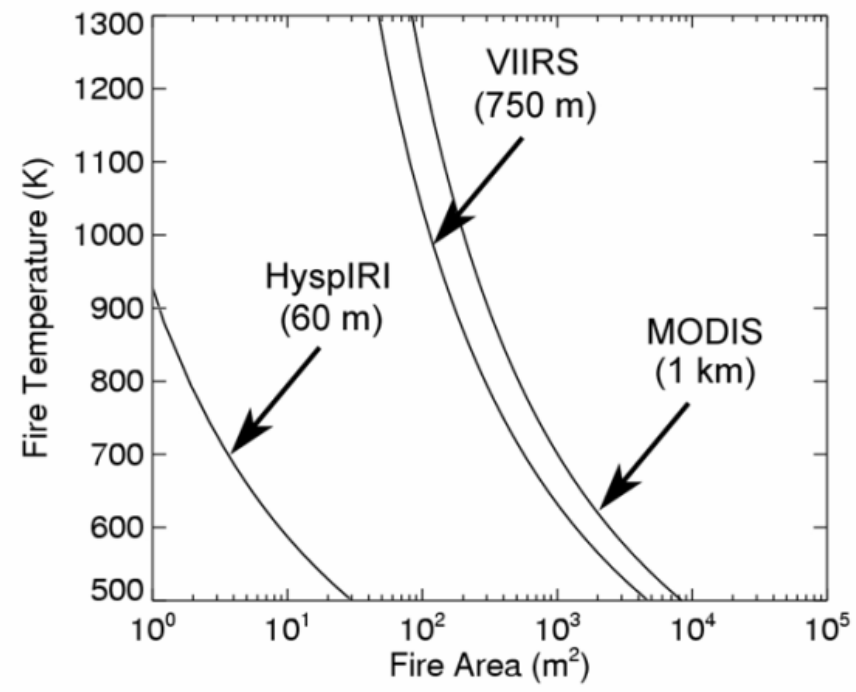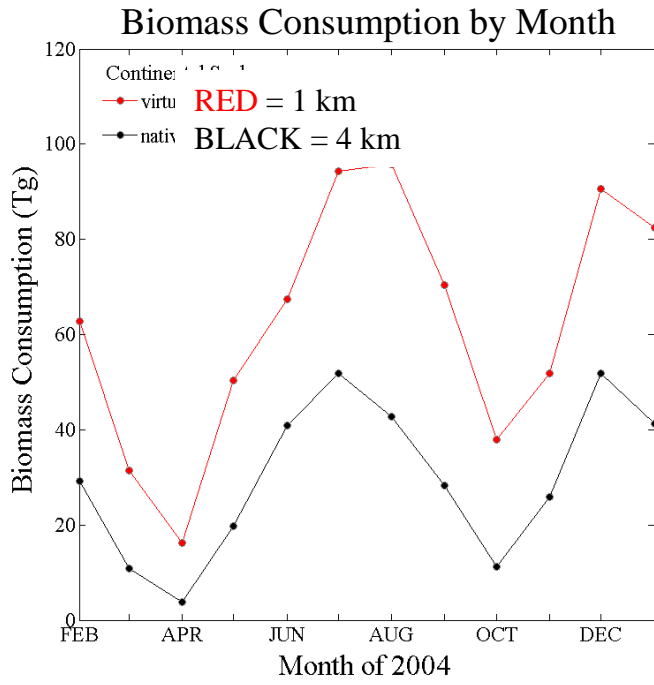
- For both methods:

Biomass combusted x Emission factor = Carbon released

Emission factors are obtained for given cover type e.g. forest vs peat

HyspIRI-TIR Provides Orders of Magnitude Improvement in Measurement Capability

Biomass Consumption by Month

RED = 1 km
BLACK = 4 km

- HyspIRI-TIR measures very small fires as well as large fires. Small fires have a disproportionately large carbon contribution
- Global carbon contribution from peat, agricultural and deforestation fires unknown because cannot be measured with current sensors but see a large discrepancy between 1km MODIS and 4km GOES

Measuring carbon fire emissions requires measurements in the Mid and Thermal Infrared

- Greater sensitivity due to shift in emission peak with temperature
- Measure radiance rather than temperature and avoid mixed pixel problem
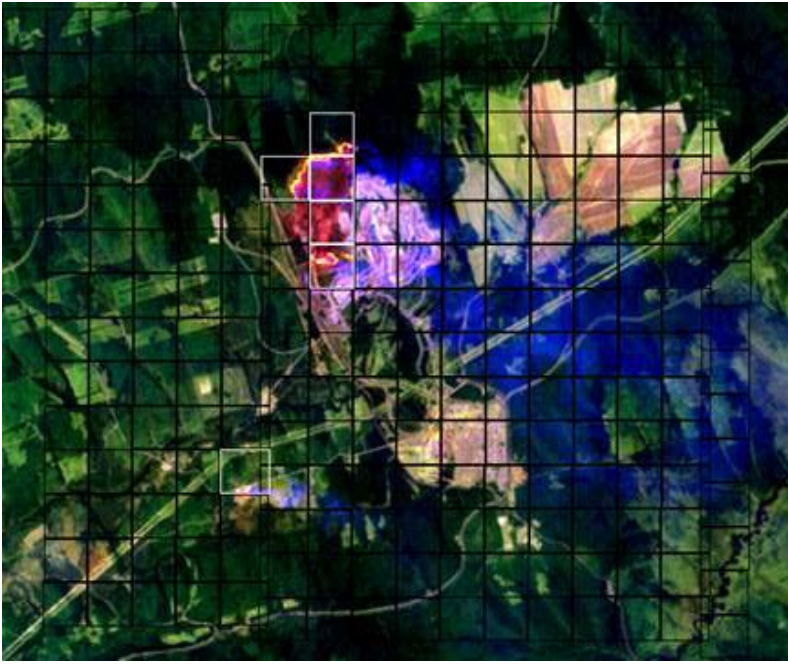
MODIS only detects white boxes (1kmX1km) does not provide information on the fire front or smouldering part of fire

HyspIRI-TIR bands capture the Planck curve

7 TIR Bands
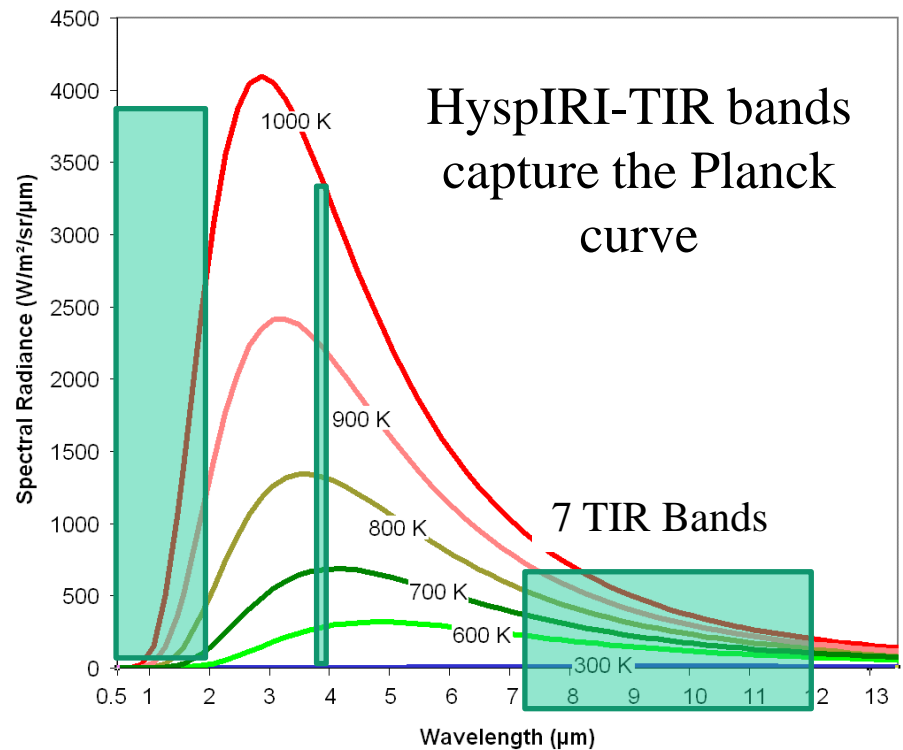
Thermal emission peaks in the MIR (3-5 μm) region for fire temperatures ranging from ~ 650 K (weak smouldering) to ~ 1400 K (strong flaming). MIR is far more sensitive to hot targets than TIR.

10/25/2011

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Water Use and Availability

- How is climate variability (and ENSO) impacting the evaporative component of the global water cycle over natural and managed landscapes? [DS 166, 196, 203, 257, 368]

- What are relationships between spatial and temporal variation in evapotranspiration and land-use/land-cover and freshwater resource management? [DS 196, 203, 368]

- Can we improve early detection, mitigation, and impact assessment of droughts at local to regional scales anywhere on the globe? [DS 166, 196, 203, 368]; How does the partitioning of Precipitation into ET, surface runoff and ground-water recharge change during drought?

- What areas of Earth have water consumption by irrigated agriculture that is out of balance with sustainable water availability? [DS 196, 368]

- Can we increase food production in water-scarce agricultural regions while improving or sustaining quality and quantity of water for ecosystem function and other human uses? [DS 196, 368]

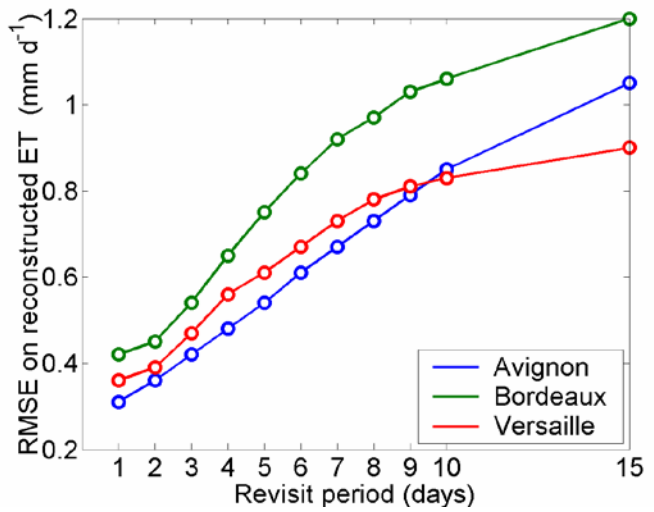# High Spatial and Temporal Resolution Required to Accurately Measure Evapotranspiration (ET)

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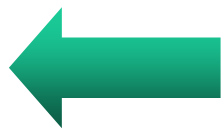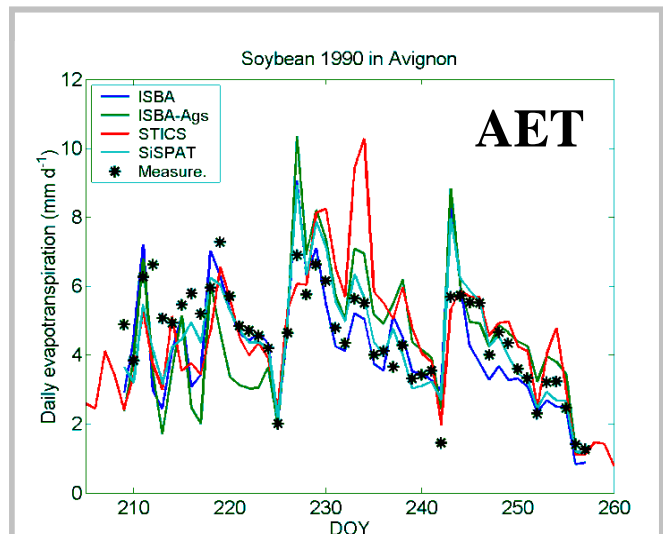
1 km box

1 km data does not capture field scale variation
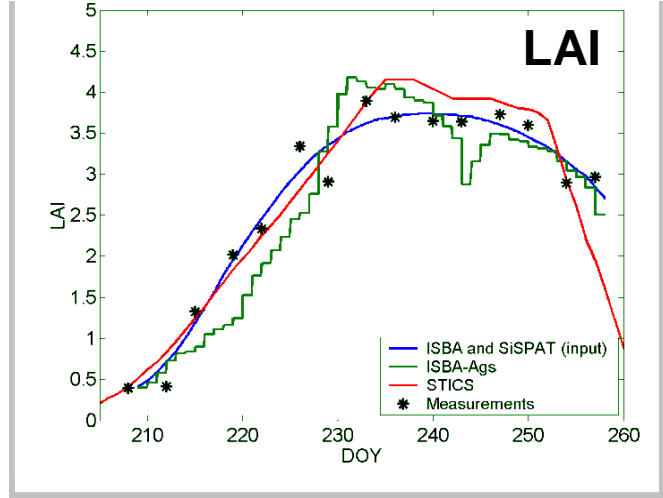

ET is very dynamic compared with LAI

High revisit: rapid response to surface forcing (water status, meteorological conditions…)

5-day revisit minimizes error on ET Estimation

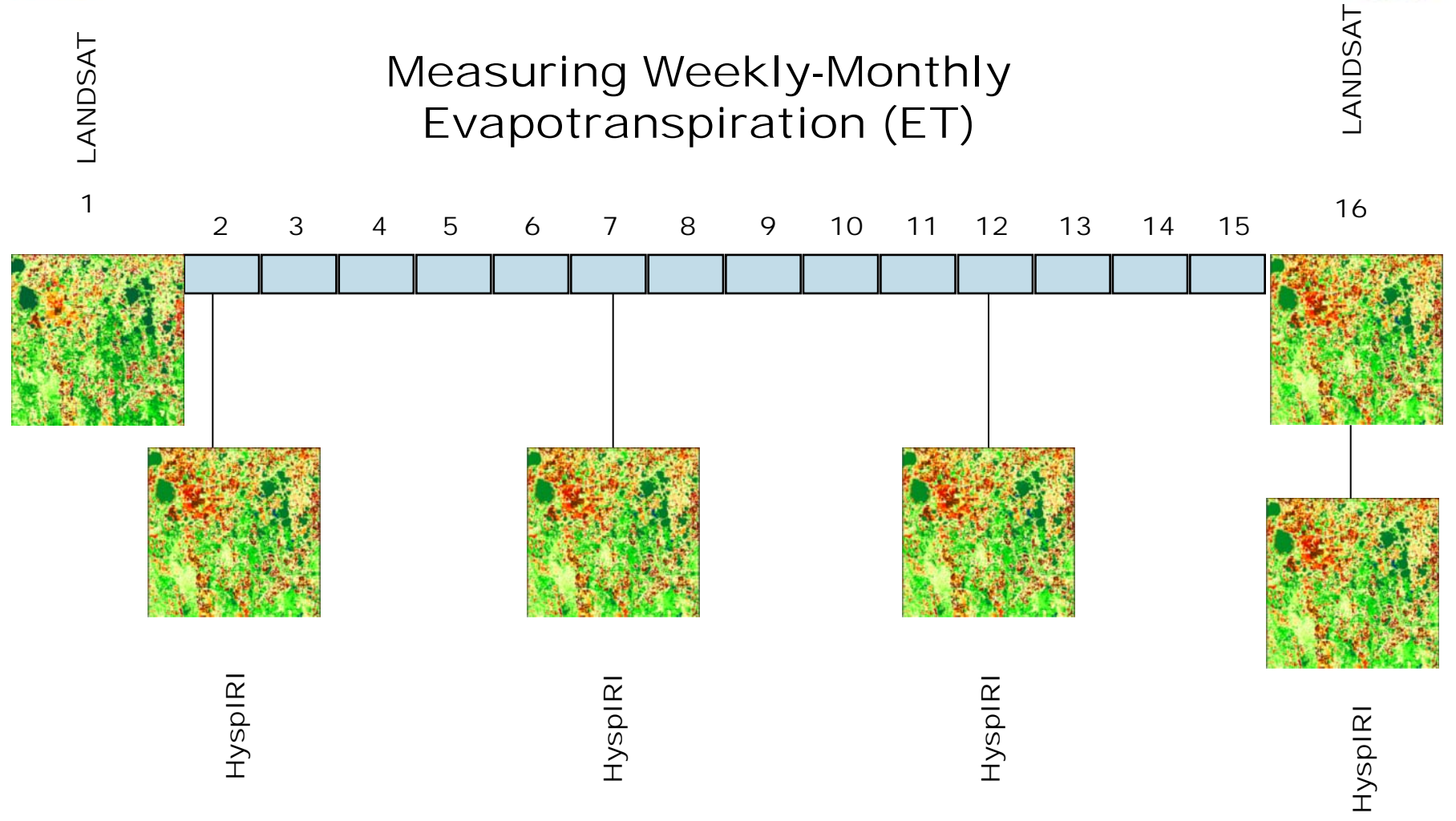Courtesy Jean-Pierre Lagouarde, INRA, France

1

Evapotranspiration and Water Use and Availability

Measuring Weekly-Monthly Evapotranspiration (ET)

LANDSAT

1

LANDSAT

16

2 3 4 5 6 7 8 9 10 11 12 13 14 15

HyspIRI

HyspIRI

HyspIRI

HyspIRI

HyspIRI-TIR provides ET data every 5 days, allows weekly-monthly measurement
And expectation for a cloud-free scene (typically 1 in every 3 data takes)

Mission Concept and Instrument
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
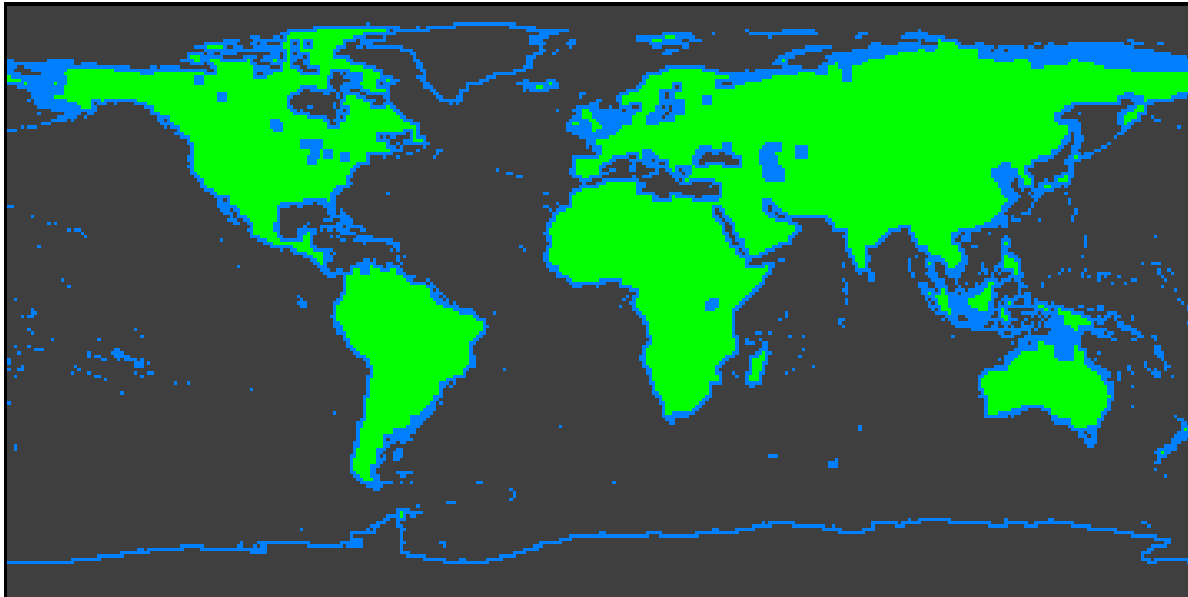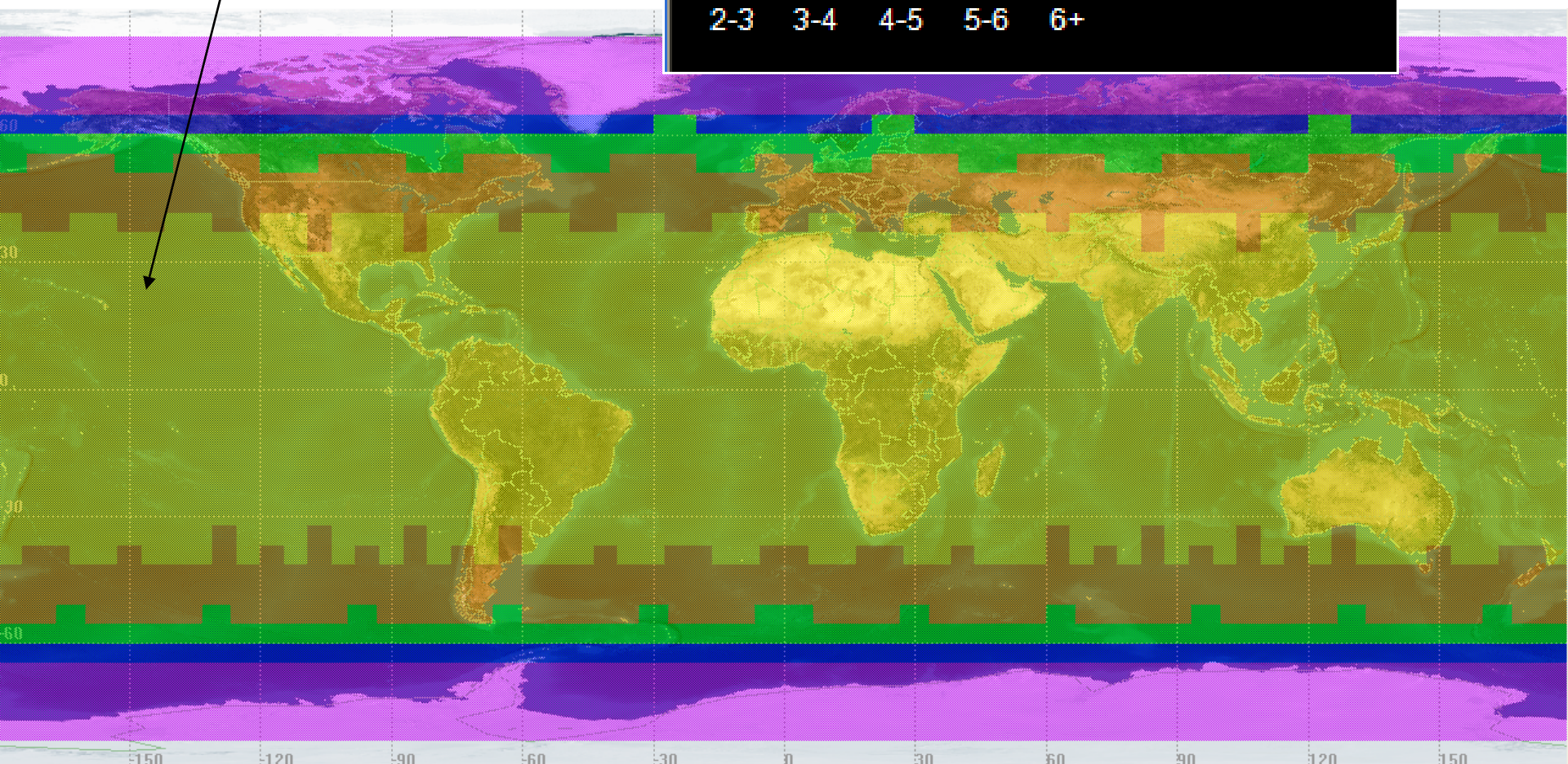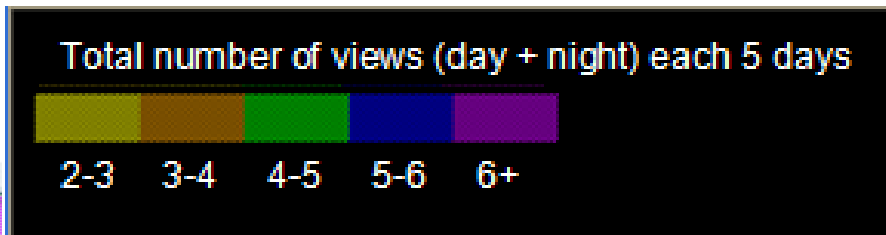
Land and coastal acquisition
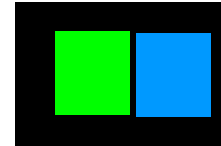
Annual TIR imaging opportunities in a 5-day near-repeating orbit, 1 yr. simulation

Oceans average to 1 km

Total number of views (day + night) each 5 days

2-3   3-4   4-5   5-6   6+

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).

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 – 500K; Band 1= 1200K
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)

Temporal

Orbit Crossing	10:30 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

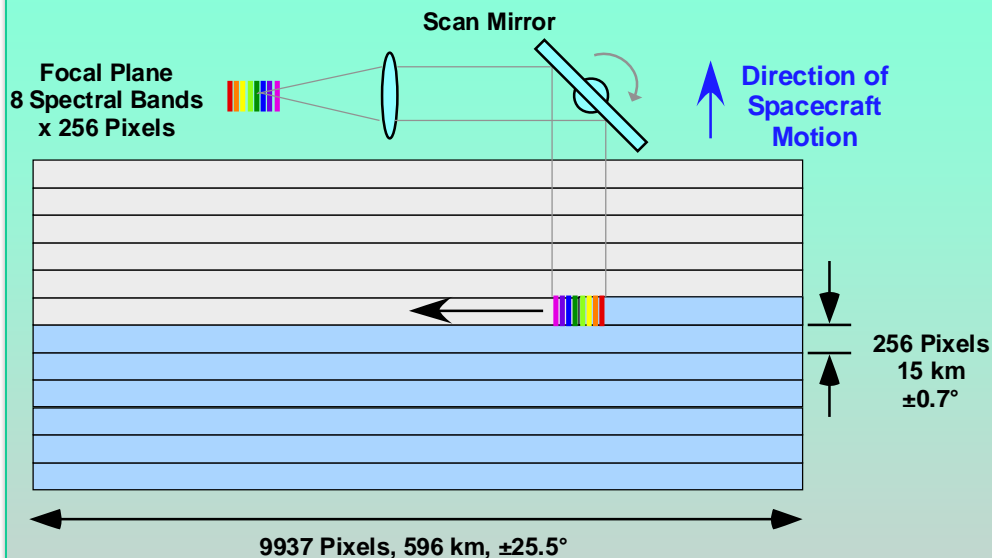|	
Time Coverage	Day and Night
Land Coverage	Land surface above sea level
Water Coverage	Coastal zone -50 m and shallower
Open Ocean	Averaged to 1km spatial sampling
Compression	2:1 lossless

TIR Instrument Concept

Scanning and Data Rate

Scan Mirror

**Focal Plane
8 Spectral Bands
x 256 Pixels**

**Direction of
Spacecraft
Motion**

**256 Pixels
15 km
±0.7°**

9937 Pixels, 596 km, ±25.5°
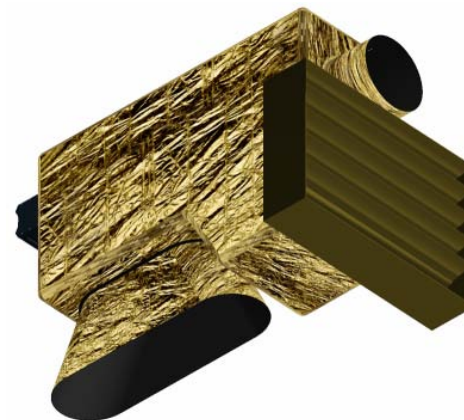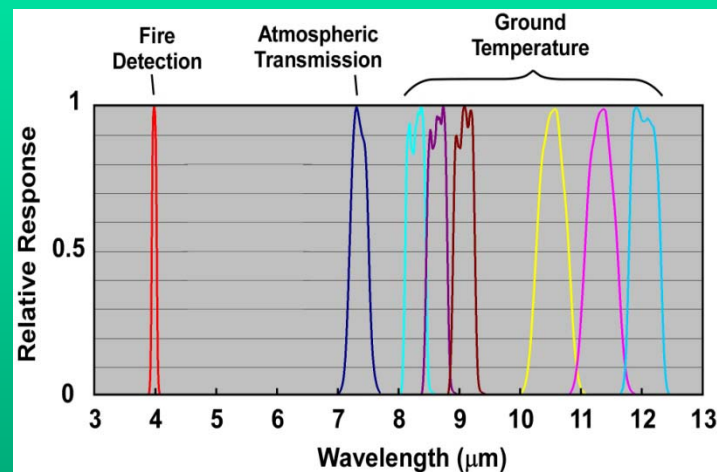
- 60 m Pixel Footprint
- Time-Averaged Science Data Rate 0.024 Gbps
- Assuming 14 bits, 2:1 Compression
- Scan Mirror Rotation Rate 13 RPM
- Pixel Dwell Time 32 microseconds

Mass and Power (JPL Team X)

- Mass CBE 60 kg
- Power CBE 109 W

Spectral Bands

Fire Detection | Atmospheric Transmission | Ground Temperature

Relative Response vs Wavelength (μm)

- 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

- Spacecraft: LEO RSDO bus (SA-200HP)
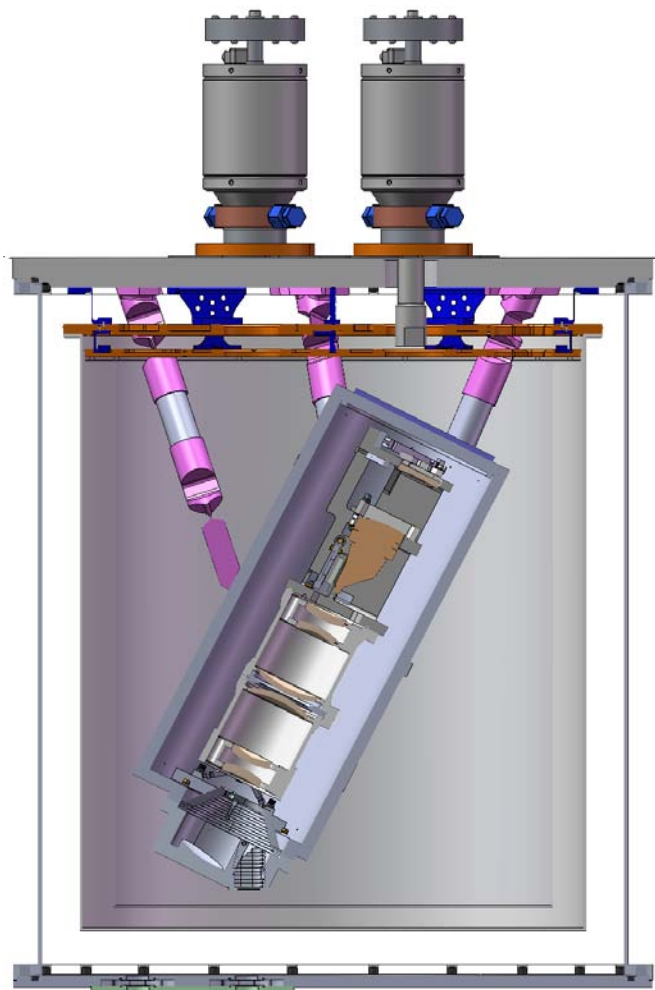
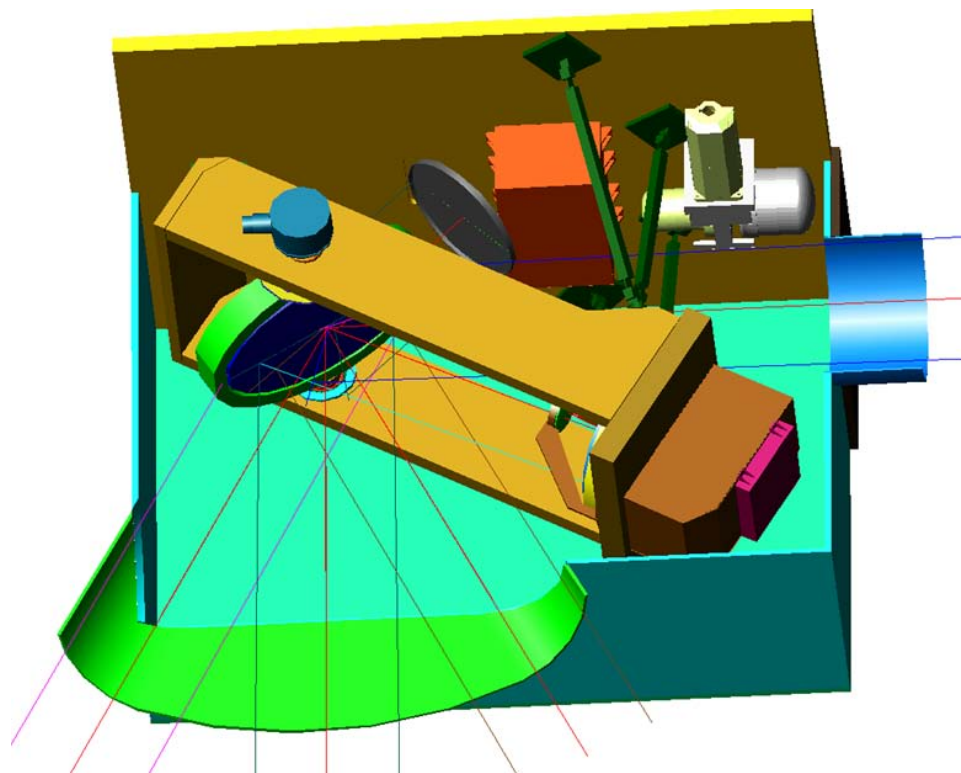- Launch: Taurus-class launch vehicle
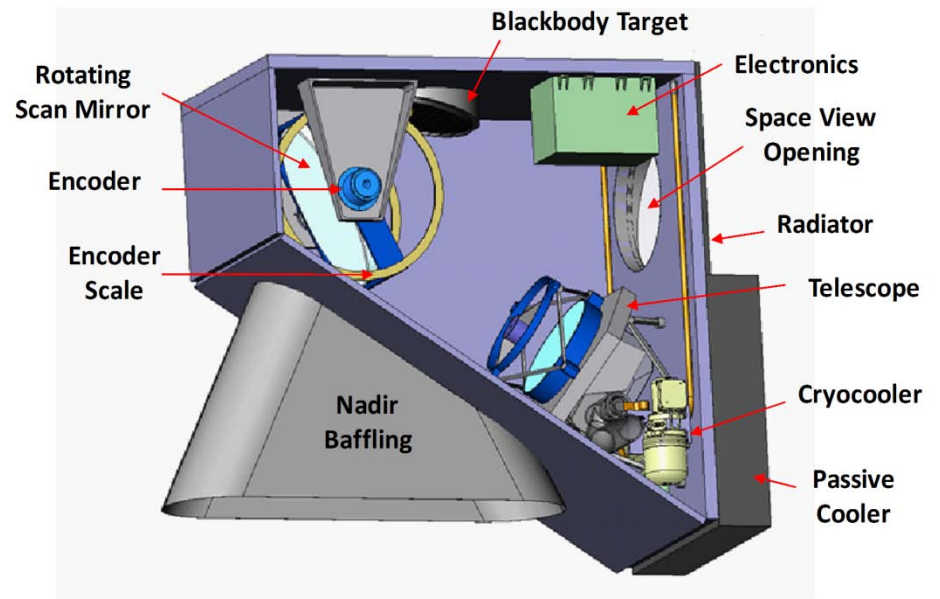
Technology Readiness

Hyperspectral Thermal Emission
Spectrometer (HyTES)

Prototype HyspIRI Thermal
Infrared Radiometer (PHyTIR)

Elevator Speech

- *Quantify carbon and other emissions from fires to balance carbon budget*

- *Determine if heat, gas and lava emissions from volcanoes can be used to understand their future behavior*

- *Quantify evaporative loss from vegetated regions to balance water budget*

Summary

We have developed a sets of science questions that are well aligned with the HyspIRI Mission called for in the NASA Earth Science and Applications Decadal Survey. The mission has strong relevance to both climate and society.

We have reviewed and refined these questions that relate to both science and applications objectives and developed traceability to a set of science measurements.

We have established a high heritage and low risk approach for acquiring the HyspIRI VSWIR and TIR science measurements
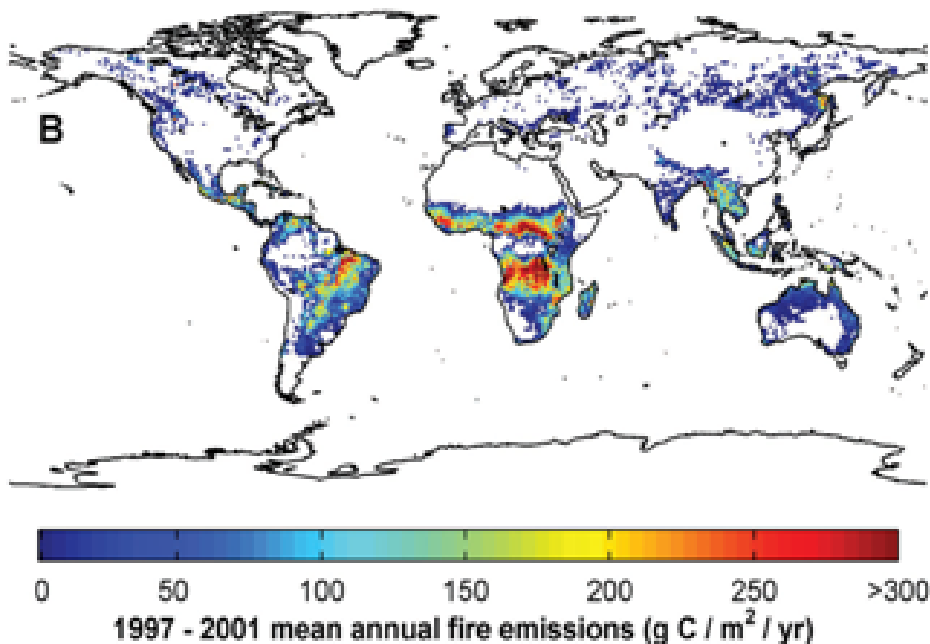
Backup

Measuring global fire emission is necessary for reducing the uncertainty in carbon emissions from biomass burning

Global average biomass burning estimates range from 20 – 40 % of all global C emissions.

B

1997 - 2001 mean annual fire emissions (g C / m² / yr)

Van der Werf et al., 2010

Fires occur worldwide need a GLOBAL Mapping Mission, emissions vary regionally