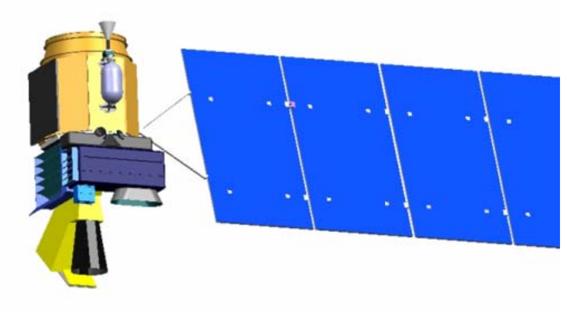
HyspIRI Science Symposium On Ecosystem Data Products



Woody Turner

Co-HyspIRI Program Scientist

Earth Science Division

NASA Headquarters

May 4, 2010

Status of Decadal Survey Missions

- February 1, 2010: President's Budget released with a 5-year, $2.5 Billion total augmentation for NASA Earth Science
- March 18, 2010: NASA ESD sends Climate Augmentation Plan to OMB
- Plan calls for launch of all Tier 1 Missions by 2017 (also the launch of OCO reflight, GRACE follow-on, and SAGE III missions)
- Also, current plans are for Tier 2 missions to launch at the rate of 1 per year starting in 2019
- President's Budget direction requires NASA to obtain USGCRP Review of the Climate Augmentation Plan
- Review is taking place this month
- In the near-term, Tier 2 mission funding to continue; levels still TBD

Plans for HyspIRI

- Stay the course
- Continue to mature our technology and operations
- Strengthen the scientific case for the program
- Focus on the climate-relevance of our mission science
- Explore the potential to build the scientific basis for HyspIRI through utilization of products from airborne systems and upcoming spacecraft missions carrying spectrometers and TIR sensors (doing so will require additional funding)
- Look at results of HyspIRI preparatory activities solicitations
- Be ready!

WELCOME ATTENDEES

PLEASE Check-In at the Table and:

– Get Name Tag & Agenda

– Pay for Lunch (with sticker as receipt)

See table in the back of Room

8:00 -8:30 am: Registration Check-In

Coffee and donuts

Posters Displayed

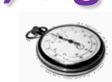
HyspIRI Science Symposium on Ecosystem Data Products

NASA/GSFC, May 4 and 5, 2010
Building 33, Room H114

GSFC EO-1/HyspIRI Team

Betsy Middleton, NASA
Bob Knox, NASA
Steve Ungar, UMBC

Petya Campbell, UMBC
Qingyuan Zhang, UMBC
Fred Huemmrich, UMBC
Ben Cheng, ERT
Larry Corp, Sigma Space



Other Assistants for Symposium:

Hank Margolis, Laval University [TIMEKEEPER]

Sandi Bussard, Jacob Gude, Sheila Humke & Carla Evans
Sigma Space

look for flags on their name tags

LOGISTICS

Restrooms

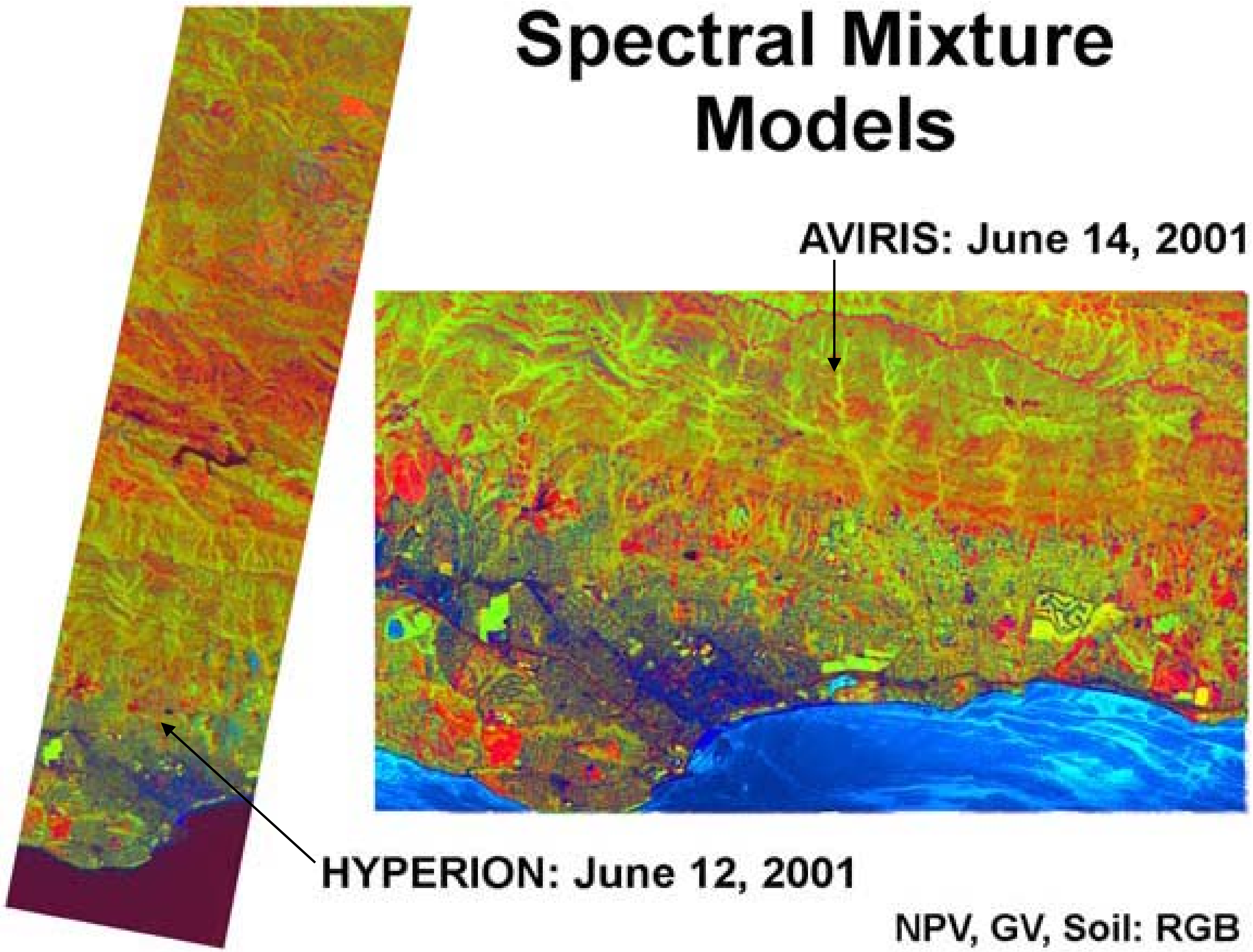
Posters

Lunch

Break-Out Groups

Dinner

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



Roberts et al. (2003)

EO-1 Hyperion Imaging of Eyjafjallajökull Volcano Eruption 17 April 2010

**SWIR - **thermal vent visible

VIS -plumes coating everything to the South-East making the ice brown/gray

HyspIRI Science Symposium on Ecosystem Data Products

Sponsor: NASA/Goddard Space Flight Center

May 4 & 5, 2010

Building 33, Conference Room H114 (and H118, H120)

Focus: Identifying Potential Higher Level Products for Climate/Carbon End Users

Objectives:

Identify science/application data products to be derived from HyspIRI measurements ***by users***;

Discover/Discuss issues underlying data product processing/integration/fusion;

Prioritize the development of product prototypes.

Science Discipline Areas to be addressed: Terrestrial Ecosystems, Agriculture

Science Questions for the HyspIRI Mission (http://hyspIRI.jpl.nasa.gov)

HyspIRI has three top-level science questions [identified in the NRC Decadal Survey] related to:

1) Ecosystem function and composition,

What is the global distribution and status of terrestrial and coastal-aquatic ecosystems and how are they changing?

2) Volcanoes and natural hazards,

How do volcanoes, fires and other natural hazards behave and do they provide precursor signals that can be used to predict future activity?

3) Surface composition and the sustainable management of natural resources.

What is the composition of the land surface and coastal shallow water regions and how can they be managed to support natural and human-induced change?

VSWIR Questions: 6 over-arching questions. VQ1-6 (with 35 sub-questions)

TIR Questions: 5 over-arching questions, TQ1-5 (with 23 sub-questions)

Combined VSWIR and TIR Questions: 6 over-arching questions, CQ1-6 (with 32 sub-questions)

Terrestrial Ecosystems: *HyspIRI Science Questions*

VQ1: Ecosystem Pattern, Spatial Distribution and Components

What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity?

VQ2: Ecosystem Function, Physiology and Seasonal Activity

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 disturbance?

VQ3: Biogeochemical Cycles

How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems and what are the feedbacks with other components of the Earth system?

VQ4: Disturbance Regimes

How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

TQ2 and CQ2: Wildfires

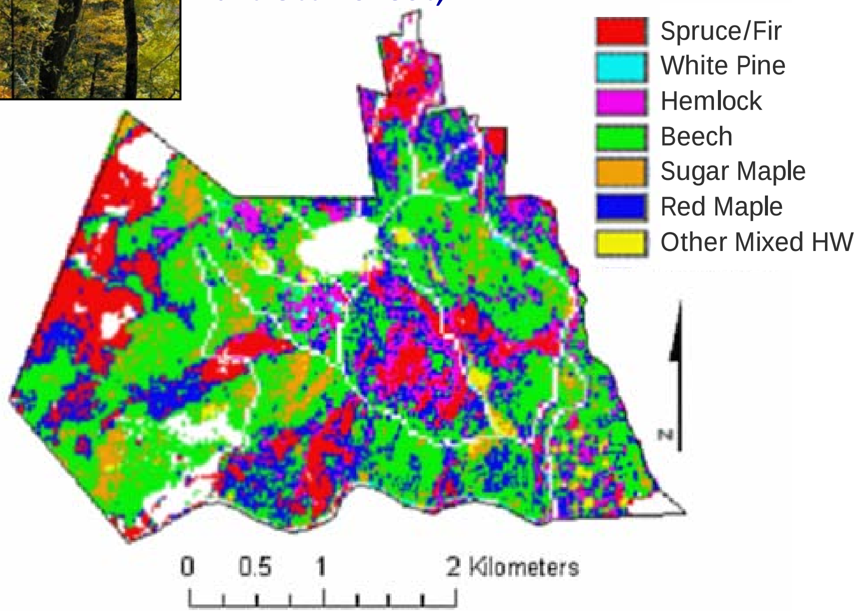
TQ2: What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time? CQ2 How are fires and vegetation composition coupled?

CQ4: Ecosystem Function and Diversity

How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?

Determine the global distribution, composition, and condition of ecosystems, including agricultural lands

Tree species mapping, Bartlett Forest, NH



Societal Issue:

- Forests, farmlands and a variety of other ecosystems are critical to life on the Earth. Many ecosystems are changing in ways that are poorly understood.

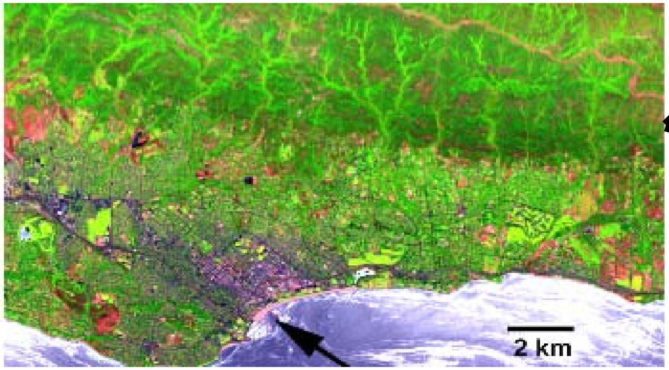
Scientific Issue:

- Understanding the distribution, diversity and status of ecosystems is necessary for understanding how they function and for predicting future changes.

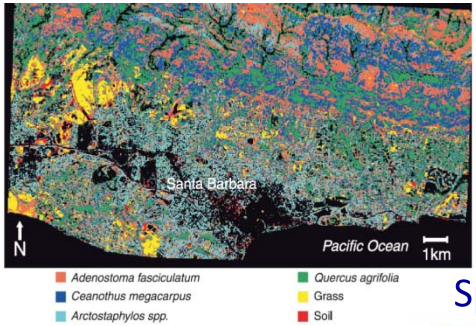
Approach (Why we need HyspIRI):

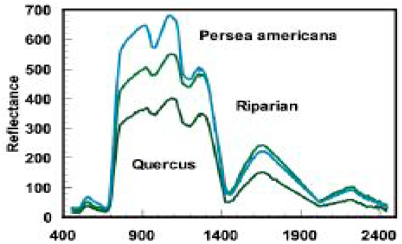
- HyspIRI will provide an important new capability to detect & monitor ecosystem composition and condition globally, with spectroscopic and thermal measurements.

HyspIRI Airborne Simulator Data Set

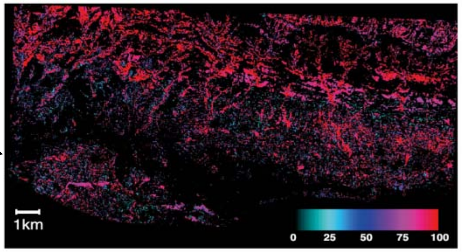


Species Type Determination

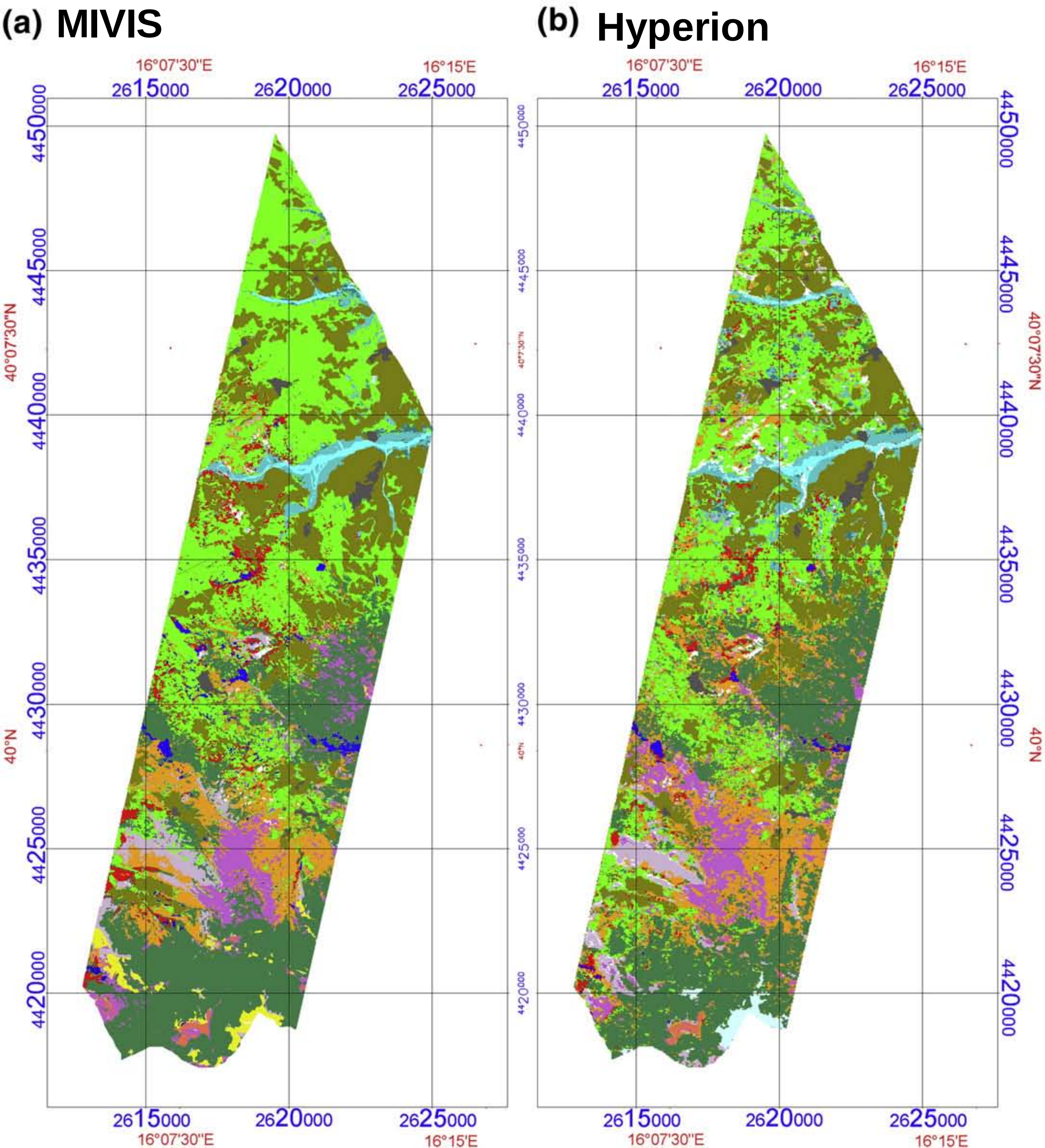


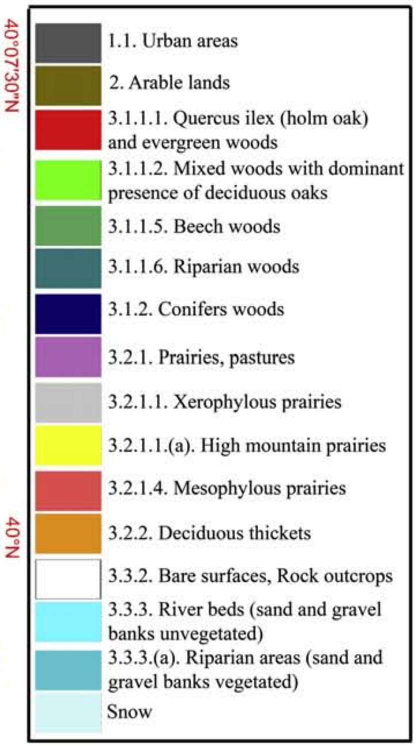


Species Fractional Cover



Mapping land cover and vegetation diversity in a fragmented ecosystem





Ability to map up to the 4th level of the CORINE legend

CORINE Land Cover 2000

Pignatti et al. (2009)

VSWIR Spectrometer (212 contiguous channels)

Level 0: Digital Numbers

Level 1: 1A - Level 0 reconstructed, time-referenced and annotated with ancillary information,
1B : surface radiance spectra & water leaving radiance spectra at TOA. Cloud screened images.

Level 2: *Description* - Swath data. ***Products*** - TOA and Surface Reflectance (%) Spectra.

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Level 3: *Description* - Swath *and* Gridded data, Terrain corrected products.
Products: Albedo, Land cover classifications, Composites (seasonal, regional and global composites), Spectral indices for vegetation function/health, Spectral indicators for canopy contents (pigments, nitrogen, water, Maps of end-member abundance.

Level 4: *Description* – Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types (e.g., ET, Fire fuel & fuel moisture).
Products – Regional Scale (60m-1km)*: For specific sites, watersheds, geographical units or global samples of ecosystems, but potentially for global maps:* Gross Primary or Ecosystem Production (GPP, GEP); Net Primary or Ecosystem Production (NPP, NEP); Fractional land cover; Fractional vegetation cover (FVC), based on: photosynthetic vegetation (PV) and non-photosynthetic vegetation (NPV), Soil, Water, Snow, Ice; Fractional PAR absorption (*f*APAR); Leaf area index (LAI); Water Content; Plant functional types (PFT); Fractional vegetation cover by PFT(FVC); Light-use efficiency (LUE); Canopy stress and Physiology (combining PFT, LAI, canopy water, nutrients, pigments); Ecological disturbance (>10% change); Susceptibility to fires (fire fuels & fuel moisture, FVC, canopy water); Susceptibility to hazards (e.g., landslides).
Products -Global Scale (gridded, ¼-1 deg+)*: For modeling ecosystems/general cover categories:* GPP, GEP; NPP, NEP; Fractional land cover (Veg., Soil, Water, Snow, Ice); *f*APAR; LAI; Water Content; Disturbance (>10% change).

TIR Multiband Sensor (8 discrete bands)

Level 0: Digital Numbers
Level 1: 1A - Level 0, reconstructed, time-referenced and annotated with ancillary information; 1B – surface band radiances at TOA, Cloud screened images. ***Products*** – Brightness temperature.

Level 2: *Description* - Swath data. ***Products*** – Land Surface Temperature, LST (day or night); Surface Spectral Emissivity (day or night); Detection of fire events.

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Level 3: *Description* – Day or night swath and gridded data, Terrain corrected, Day or Night Composites (seasonal, regional and global).

Products – Distribution and variation in land surface temperature, surface spectral emissivity maps, Water stress indicators; Fire severity, directions and associated risks.

Level 4: *Description* - Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types.

Products - Regional (60m-1km): *For specific sites, watersheds, geographical units, agricultural fields, or global samples of ecosystems, but potentially for global maps:* LST (from temperature/emissivity separation) by functional groups and ecosystem types, LST urban/sub-urban, Evapotranspiration (ET).

Products - Global (gridded, ¼-1 deg+): *For modeling ecosystems/general cover categories:* LST and emissions by Fractional land cover (Vegetation, Soil, Water, Snow, Ice), ET, Increase in sensible heat due to Urban Heat Islands (anthropogenic heat).

Synergy between TIR Day & Night and VSWIR & TIR

Level 4 Products: Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types.

TIR, day and night - ***Products - Regional (60m-1km)*** **&** ***Global (1-5 deg. grids)*****:**

Bi-weekly, monthly and/or seasonal averages for day-night temperature & emissivity differences per geographic study unit (watershed, etc.).

VSWIR and TIR – ***Products - Regional (60m-1km) & Global (1-5 deg. grids)*****:**

- Day-night temperature & emissivity differences according to vegetation/ecosystem type,
- LST (from day/night pairs) by functional groups and ecosystem types,
- Water/land boundaries defined,
- Ecosystem & Agricultural Crop Classifications, using both VSWIR & TIR,
- ET per ecosystem or agricultural type, using both VSWIR & TIR,
- Assess fire severity and available fuel by vegetation type,
- Develop spectral Reflectance & Emission libraries by land cover types and/or vegetation functional groups (at regional and global scales),
- Develop *high spectral resolution indicators of ecosystem/crop health,* by combining VSWIR indices and TIR indices; Construct spectral indicators of ecosystem function, disturbance, diversity, maturity to improve modeled predictions.
- Compare high spectral resolution indicators to currently used broadband indicators of ecosystem/crop function.

Expected Outcomes of Symposium

Goal: To Identify and Evaluate Potential Higher Level Products for Climate/Carbon End Users, in Terrestrial Ecosystem & Agriculture Science/Applications.

Objectives/Outcomes:

1] Identify science/application data products that could be derived from HyspIRI measurements ***by users***;

2] Prioritize the development of product prototypes.

3] Discover issues underlying data product processing and related to data integration/fusion.

4] Address the case for relevance of HyspIRI to climate change studies.

5] Develop a report on the community consensus for **1-4** above.

DAY 1 (May 4): Morning Agenda

I. Establish Background

8:30 am: Welcome-- HQ on the HyspIRI mission concept and Decadal Survey status [**Woody Turner**]

8:45 am: Objectives and Outline of the Symposium & Expected Results [**Betsy Middleton**]

8:55 am: Overview of the Mission: Description of the VSWIR and TIR instruments [**Rob Green & Simon Hook**]

9:15 am: Relevance of HyspIRI to Carbon and Climate [**Susan Ustin**]

9:30 am: Orbit & Platform Information, update from Team X [**Bogdan Oaida**]

9:45 am: Description and Examples of Typical VSWIR and TIR Image Collections [**Bob Knox**]

10:00 am: **Questions/Answers** (10 minutes)

10:10 -10:30 am: Coffee Break & Posters

II. Science & Application Products from the User Community: VSWIR & TIR

10:30 am –noon: Proposed VSWIR and TIR High Level Products [7 speakers, 10 min each]

[**Phil Townsend, John Gamon, Anatoly Gitelson, Mary Martin, Ben Cheng, Simon Hook, Martha Anderson, Susan Ustin**]

Noon - 1:00 pm: Lunch and Poster Session (Sandwiches/Drinks in conference serving area)

DAY 1 (May 4): Afternoon Agenda

III. Factors Affecting Product Integrity and Availability **1:00 – 2:30 pm (10 min each)**

* Atmospheric Correction [**Rob Green**]

* Data volume/compression, SpaceCube [**Tom Flatley**]

* Intelligent Payload Module (IPM) & algorithms for upload [**Vuong Ly/Dan Mandl**]

* Low-latency Applications, Science, and Operations for HyspIRI [**Steve Chien**]

* On-line tools to facilitate HyspIRI products and analysis [**Petya Campbell**]

* Hyperspectral Input to models [**Fred Huemmrich**]

* Calibration/Validation & CEOS/GEO [**Joanne Nightingale**]

* Impact of Spectral-Spatial Misalignment on Measurement Accuracy [**Steve Ungar**]

IV. Science & Application Products from the User Community: Combined VSWIR & TIR

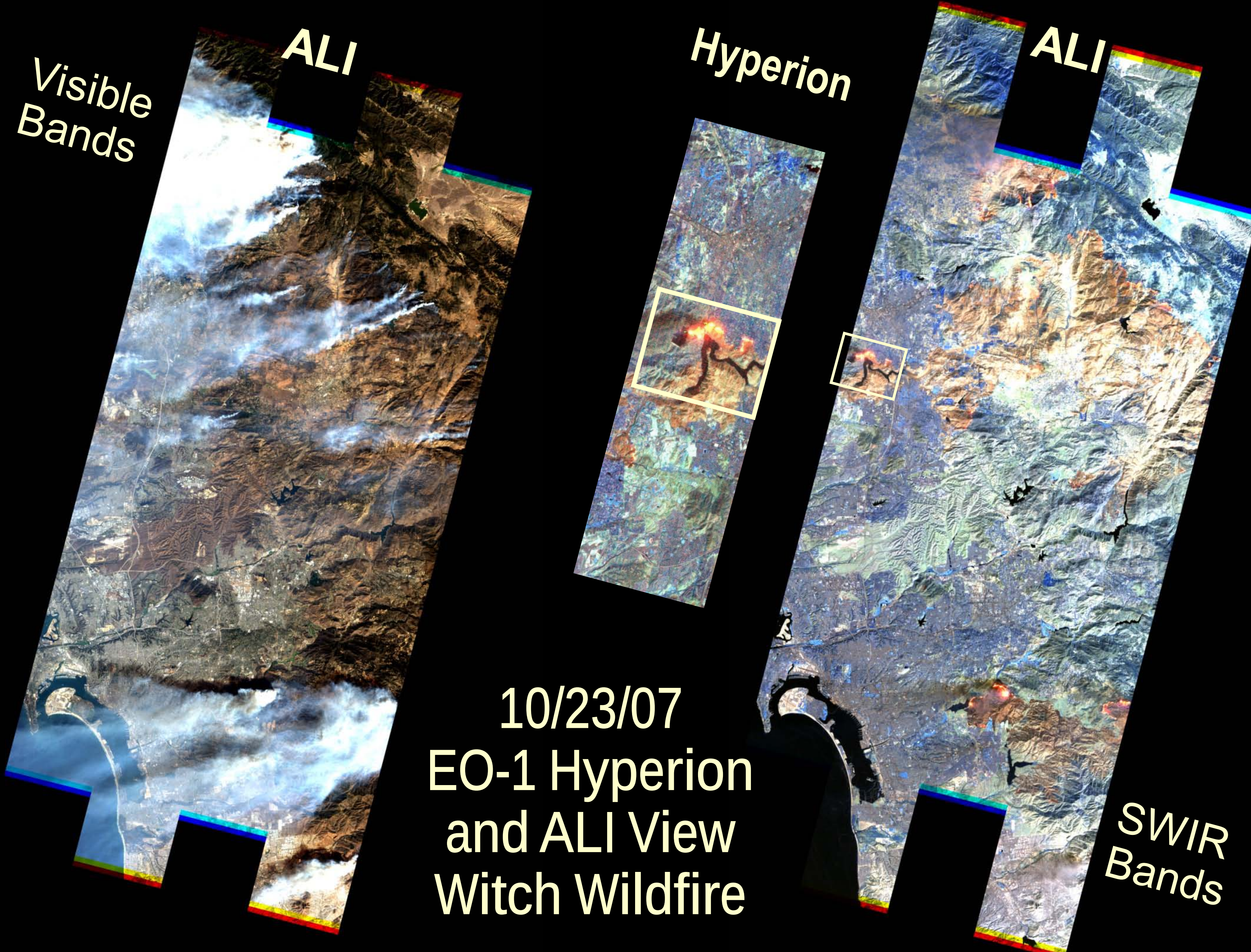
2:30 -2:50 pm: Combined VSWIR/TIR Products Overview: Issues & Examples [**Betsy Middleton/Bob Knox**]

2:50-3:00 pm: **Questions/Answers** (10 minutes)

3:00-3:20 pm – Coffee Break & Posters

3:20- 4:30 pm: Proposed Combined Products (7 speakers, 10 min each)

[**Rasmus Houborg, Louis Giglio, Dar Roberts, Dale Quattrochi, Ben Cheng, Ray Kokaly, Craig Daughtry**]



10/23/07 EO-1 Hyperion and ALI View Witch Wildfire

The Break-Out Group Discussions

[Topics for consideration]

How important is HyspIRI to the User Community, for TE and climate?

What are the most important Products for Terrestrial Ecology?

What are the Tools needed to produce these Products?

What are the road-blocks to having Products that users want?

DAY 1 (May 4): Afternoon Agenda Con’t

V. Special & Potential Observation Capabilities

4:30-4:40 pm: Special Opportunities for Highly Sampled Areas
(orbit overlaps, high latitudes etc.) [**Bob Knox**]

4:40-4:50 pm: Synergy of VSWIR and Lidar for Ecosystem Biodiversity
[**Bruce Cook/Greg Asner**]

VI. Break-Out Discussions (Guidelines, **Betsy)**

4:55 -6:15 pm: Three Simultaneous Break-Out Discussions
(H114, H118, H120)
VSWIR Products [**Phil Townsend/John Gamon**]
TIR Products [**Simon Hook/Kurt Thome**]
Combined Products [**Dar Roberts/Susan Ustin**]

6:20 pm – Adjourn, Dinner at Chevy’s Restaurant, Carpools Organized

Hyperion Imagery of Barrow, Alaska (July 2009)

July 20, 2009
False-Color and True-Color Images from Hyperion
Barrow, Alaska

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

LOGISTICS

Posters

Luggage

Transportation to Main Gate

Lunch

AGENDA – DAY 2 (May 5)

8:00 - 8:20 am: Coffee and donuts, Posters

8:30 -8:40 am: Review of Day 1 [**Betsy**]

<u>VII. Related Activities to HyspIRI Mission</u>

8:40 – 9:00 am: 2 Presentations on 2009 Funded HyspIRI Preparatory Studies
[**Petya Campbell, Phil Townsend**]

9:00 – 9:15 am: International collaborations, ISIS & WGCV [**Rob Green**]

9:15 – 9:35 am: A Mission Calibration Plan to support Products
[**Kurt Thome/Rob Green/Simon Hook**]

9:35 – 10:10 am: Synthesis of the Three Break-out Group Inputs (10 min each)
[**Phil/John, Simon/Kurt, Dar/Susan**]

10:10 -10:30 am: Coffee Break & Posters

AGENDA – DAY 2 (May 5) Con't

<u>VIII. Building a Team Consensus</u>

10:30 – 11:00 am: Plenary Discussion, Aligning HyspIRI with Climate Observations
[**Susan Ustin/Dar Roberts**]

11:00 – 11:30 am: Plenary Discussion on Priority Products, [**led by Betsy, Rob & Simon**]

11:30 am – Noon: Consensus on Draft Products for HyspIRI, Outline of Symposium Report
[**Betsy, Rob, Simon**]

Noon – 12:30 pm: Preparation Activities for 3rd Science Workshop
[**Rob, Simon, Woody Turner**]

12:30 pm: Close General Meeting

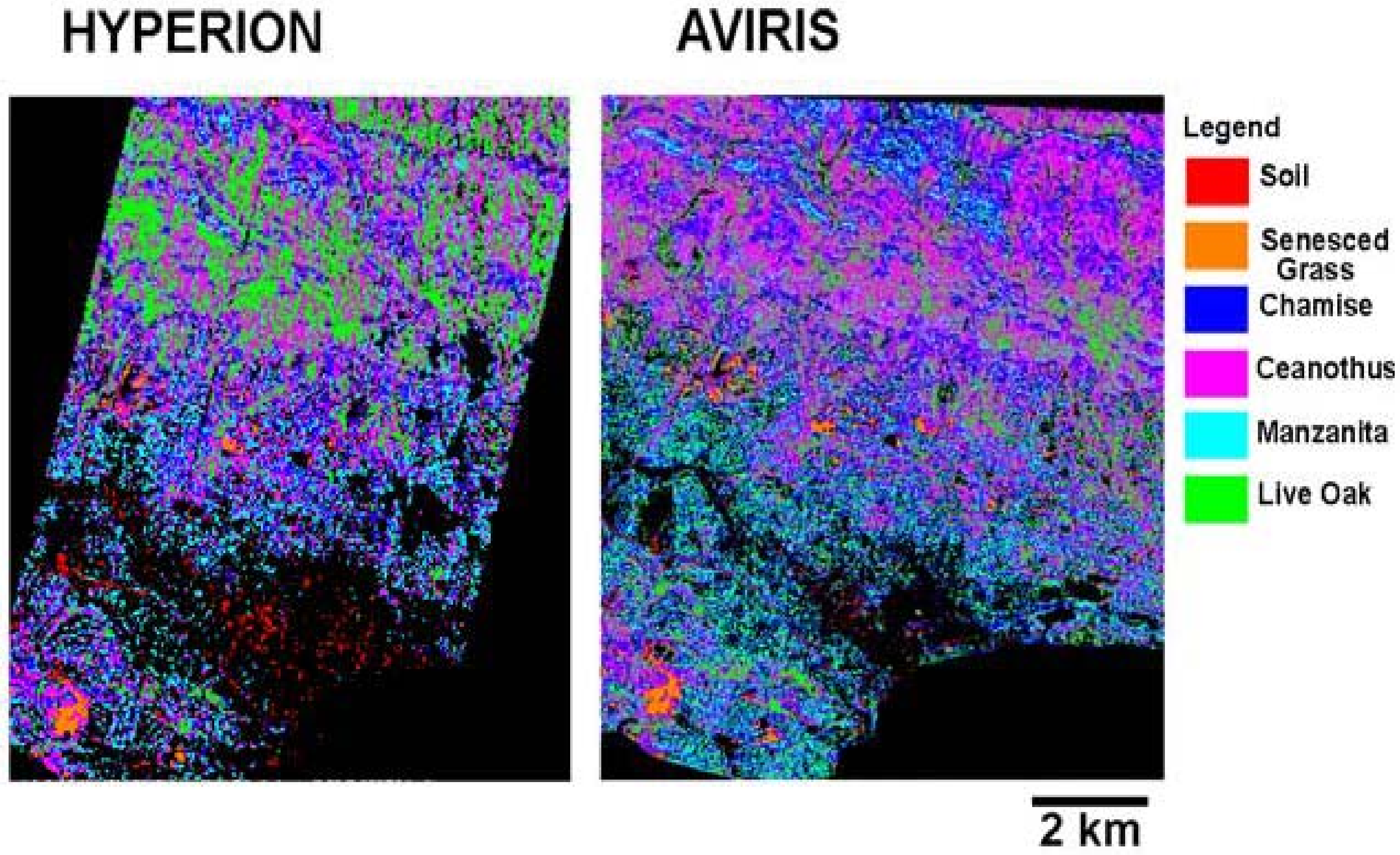
Adjourn, or Lunch at Cafeteria

1:30-3:00 pm: ***<u>Optional</u>*** *Opportunity to show PI presentations in small conference rooms [H118]*

and

Steering Committee Meeting [H120]

Mapping Vegetation Type in a Shrubland



Roberts et al.

HyspIRI

VSWIR Science Measurement Baseline

NASA Earth Science and Applications Decadal Survey

Robert O. Green and HyspIRI Team

HyspIRI Science Study Group

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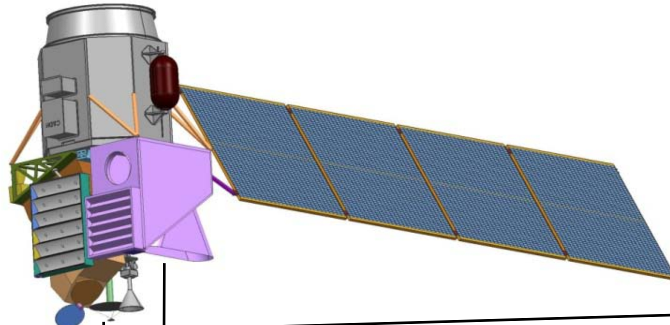
Susan Ustin	UC Davis	susan@cstars.ucdavis.edu	530-752-0621
Rob Wright	UHI	wright@higp.hawaii.edu	808-956 9194

NRC Decadal Survey - HyspIRI

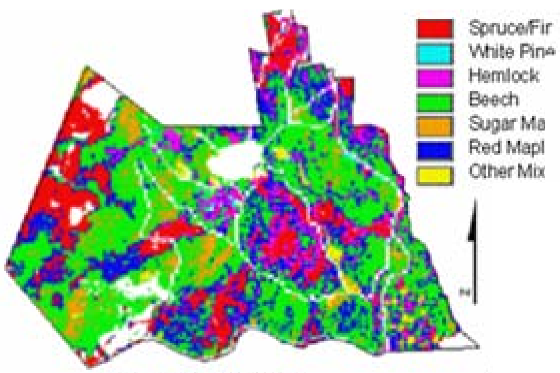
Global vegetation species-type and physiological condition, including agricultural lands, for biosphere feedback and land-atmosphere interactions; Spectroscopically derived terrestrial land cover composition/albedo including snow, ice, dust climate interaction; Fire: fuel, occurrence, intensity and recovery globally, as well as volcano emissions; Fine spatial & temporal scale measures of surface temperature and energy balance, including urban heat Islands.

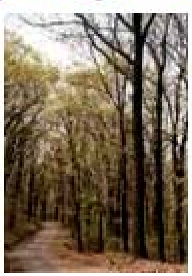
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer



Multispectral Thermal InfraRed (TIR) Scanner

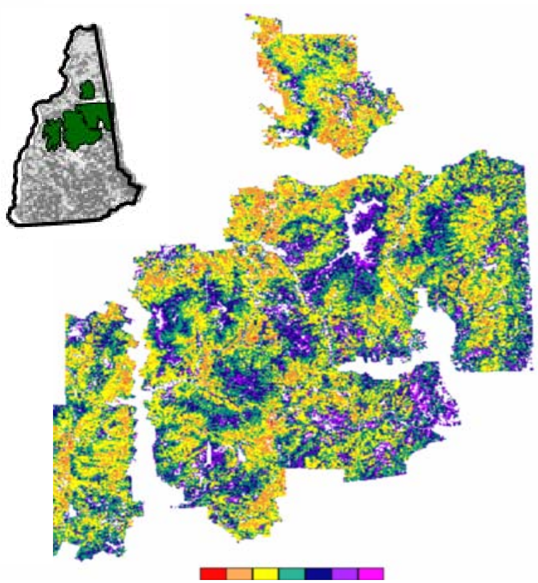
Map of dominant tree species, Bartlett Forest, NH

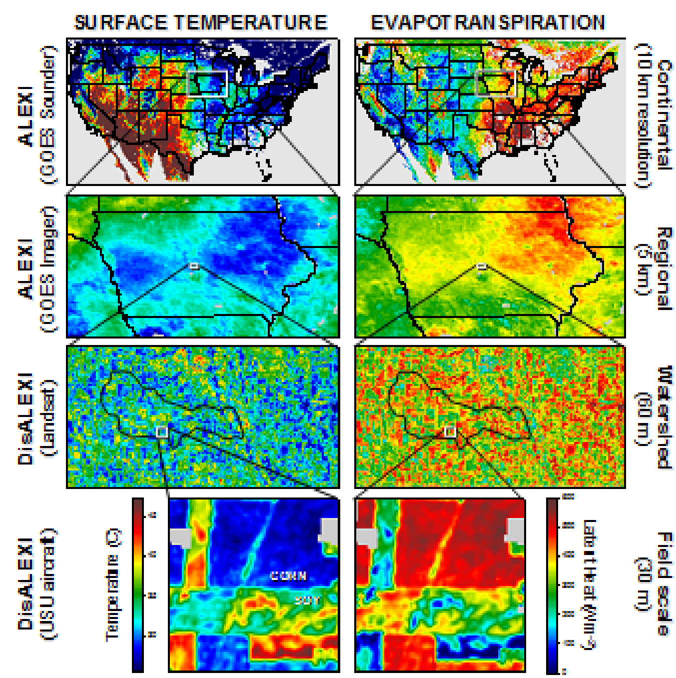




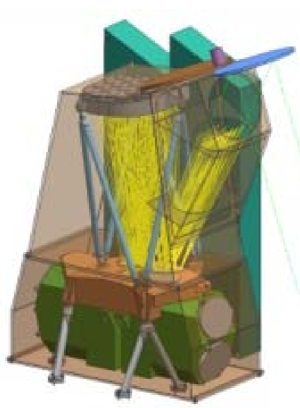
Soil C:N Ratio

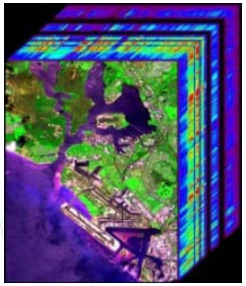
White Mountain National Forest, NH





HyspIRI - Imaging Spectroscopy (VSWIR) Science Measurements





Mature Instrument concept: All components have flown in space.

Imaging spectrometer: 55kg / 41W

Schedule: 4 year phase A-D, 3 years operations (5 years consumables)

Full terrestrial coverage downlinked every 19 days

VQ1. Pattern and Spatial Distribution of Ecosystems and their Components

– What is the pattern of ecosystem distribution and how do ecosystems differ in their composition or biodiversity?

VQ2. Ecosystem Function, Physiology and Seasonal Activity

– 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?

VQ3. Biogeochemical Cycles

– How are biogeochemical cycles for carbon, water and nutrients being altered by natural and human-induced environmental changes?

VQ4. Changes in Disturbance Activity

– How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

VQ5. Ecosystem and Human Health

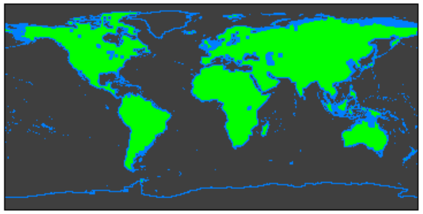
– How do changes in ecosystem composition and function affect human health, resource use, and resource management?

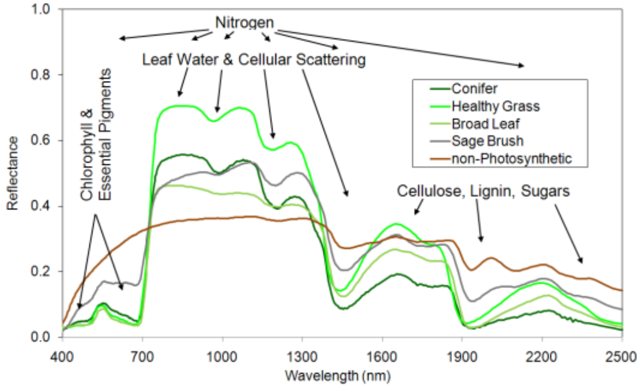
VQ6. Land Surface and Shallow Water Substrate Composition

– What is the land surface soil/rock and shallow water substrate composition?

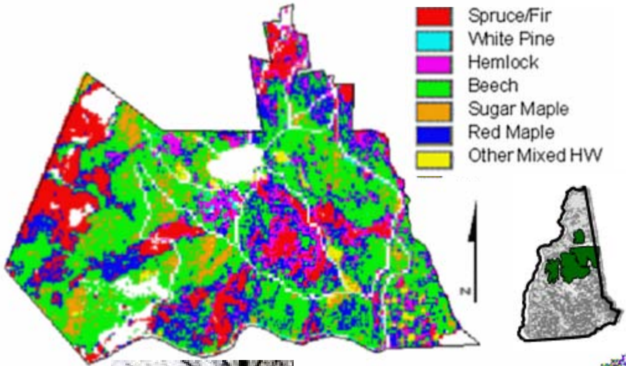
Measurement:

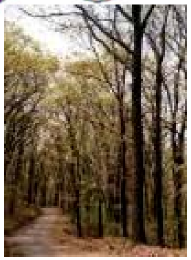
- 380 to 2500 nm at 10 nm
- Accurate 60 m resolution
- 19 days equatorial revisit
- Global land and shallow water





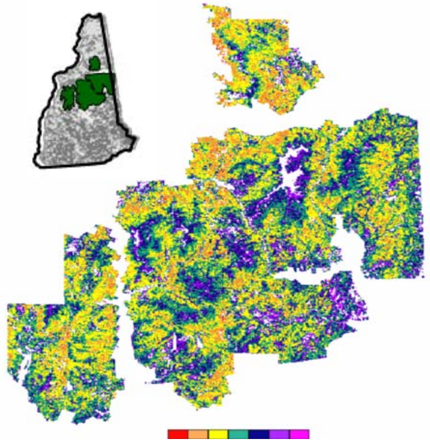
Map of dominant tree species, Bartlett Forest, NH





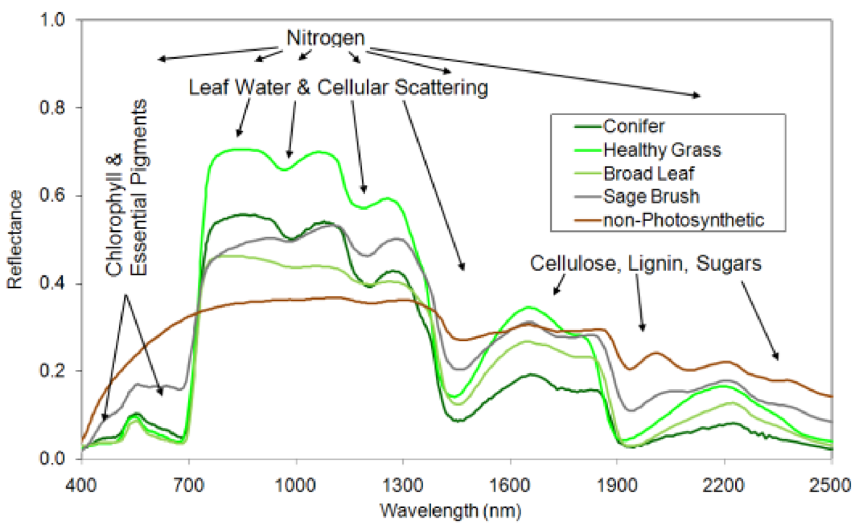
Soil C:N Ratio

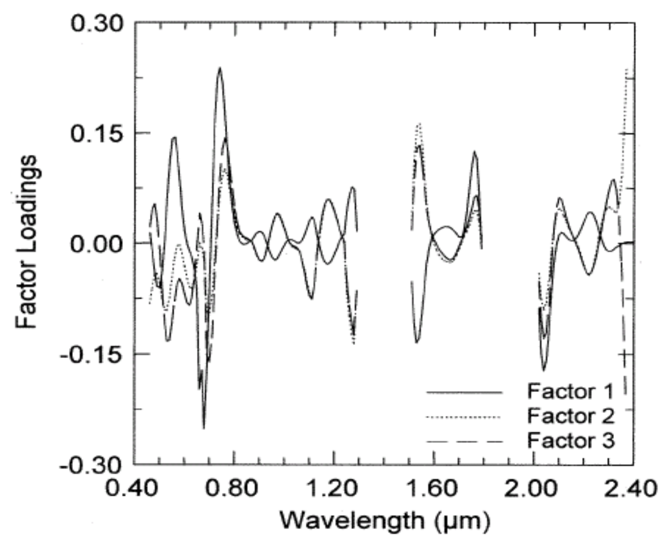
White Mountain National Forest, NH



The Need for Continuous Spectral Measurements

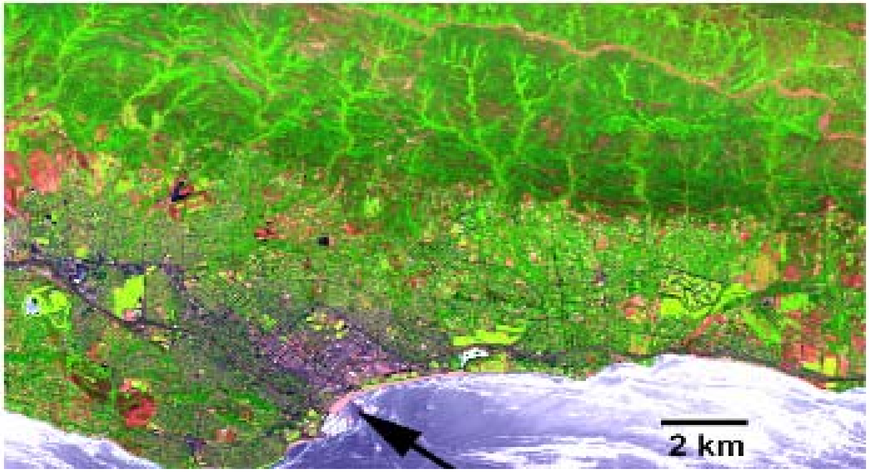
- Plant functional types and species have biochemical and biophysical properties that are expressed as reflectance absorption and scattering features spanning the spectral region from 380 to 2500 nm.
- Individual bands do not capture the diversity of biochemical and biophysical signatures of plant functional types, species or physiological condition.
- Changes in the chemical and physical configuration of ecosystems are expressed as changes in the contiguous spectral signatures related to plant functional types, physiological condition, vegetation health, and species distribution.
- Important atmospheric correction information as well as calibration feedback is contained within the spectral measurement.



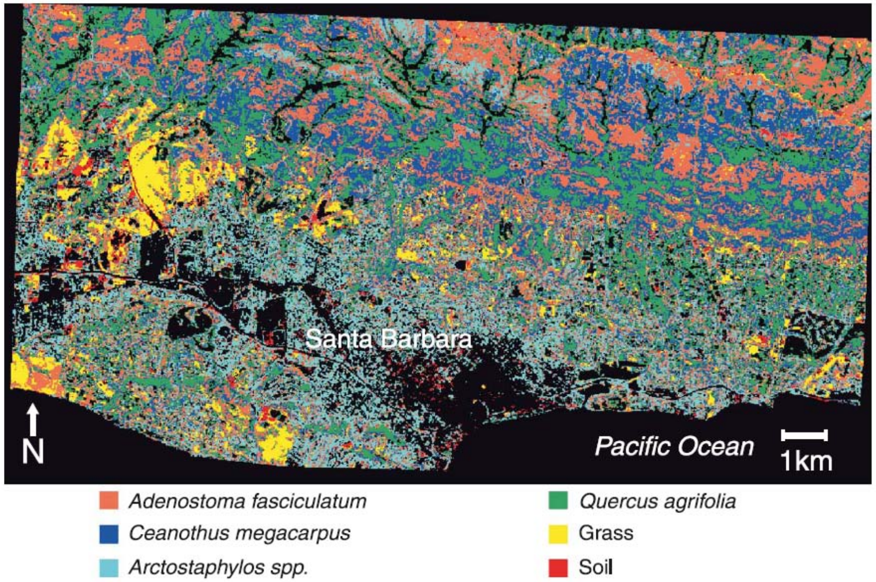


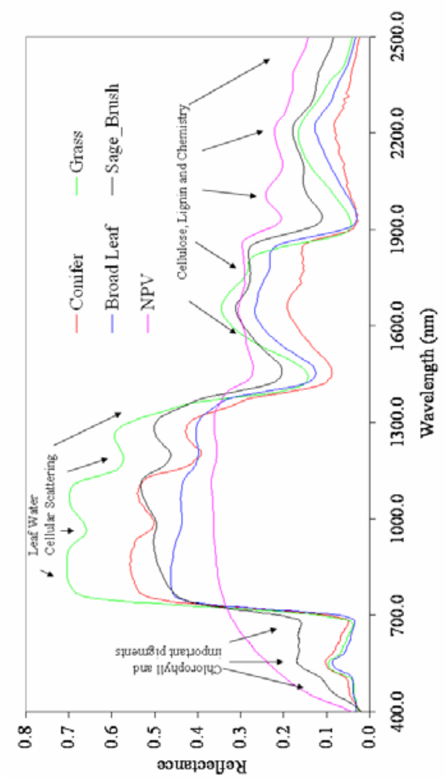
Vegetation Functional Type Analysis, Santa Barbara, CA

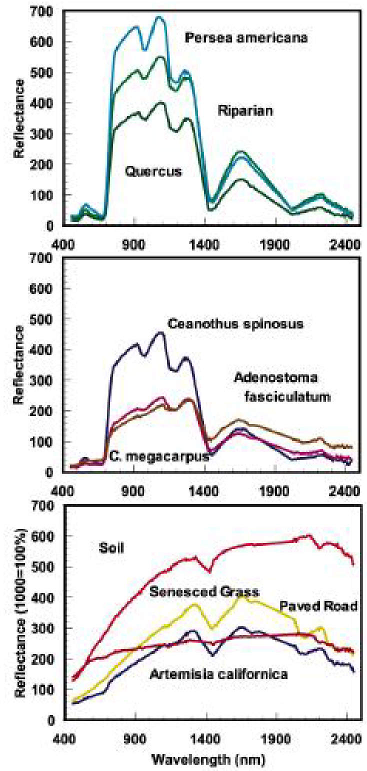
Dar Roberts, et al, UCSB



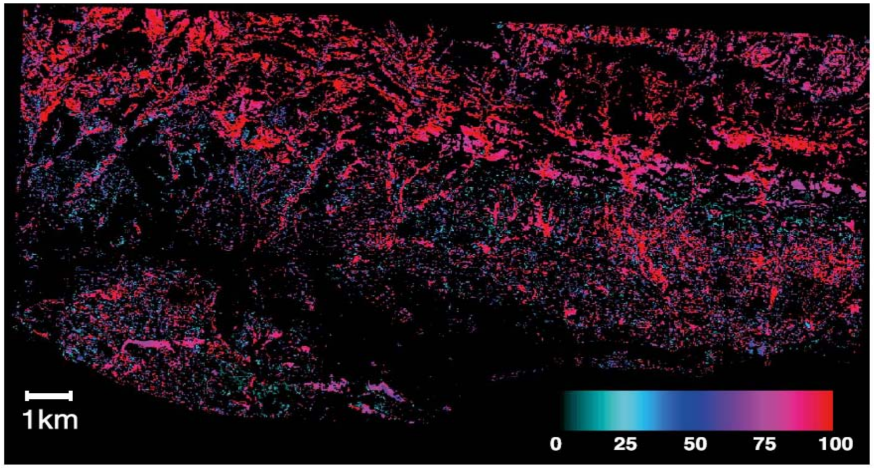
MESMA Species Type 90% accurate





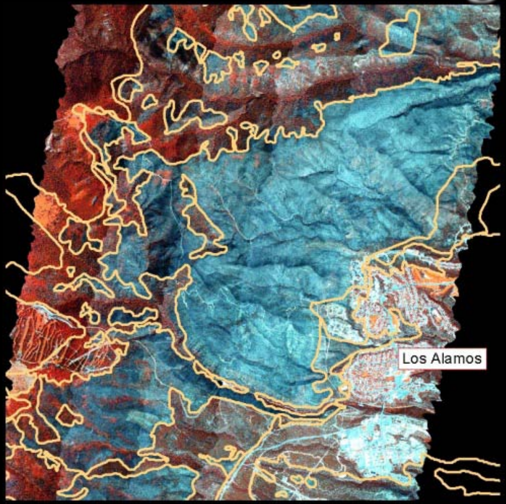


Species Fractional Cover

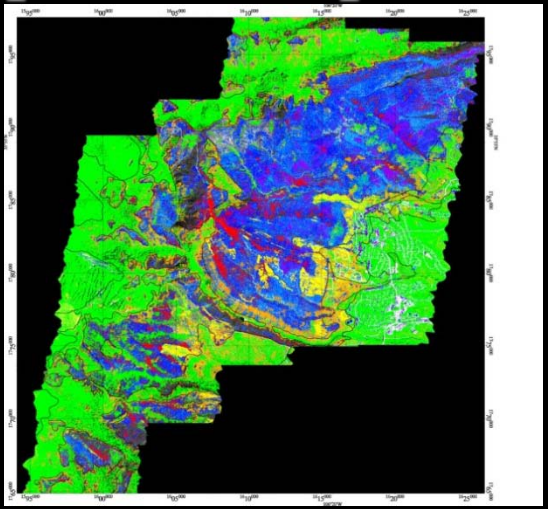


Example Measurement of Plant Biochemistry with Imaging Spectroscopy (Ray Kokaly, USGS)

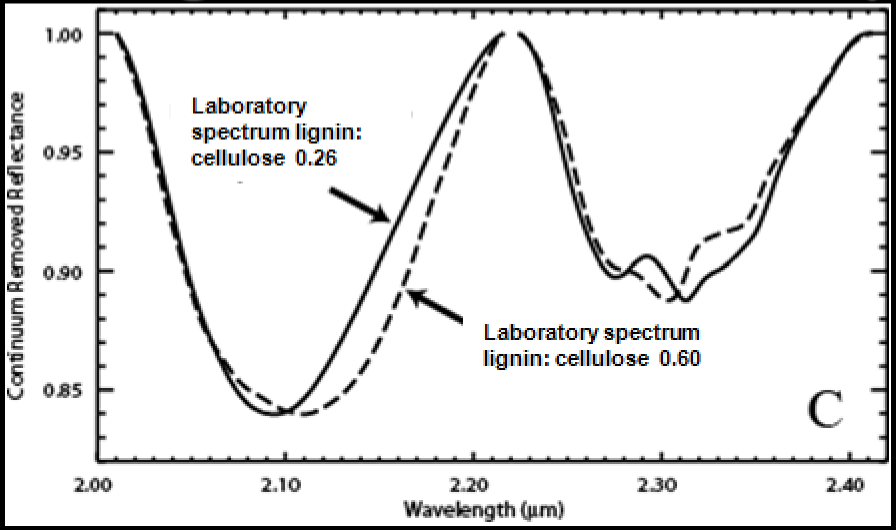
AVIRIS Coverage



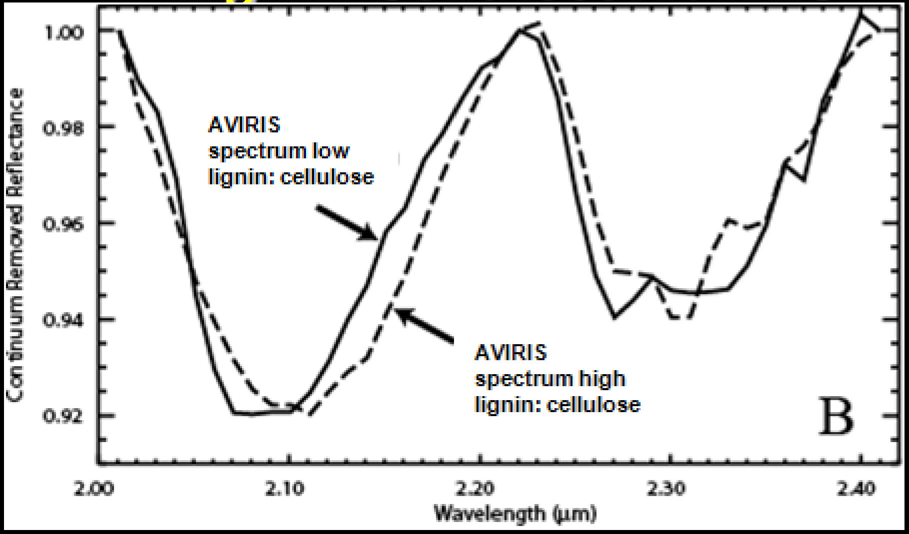
Spectral Composition Map



Lignin-Cellulose Laboratory



Lignin-Cellulose AVIRIS

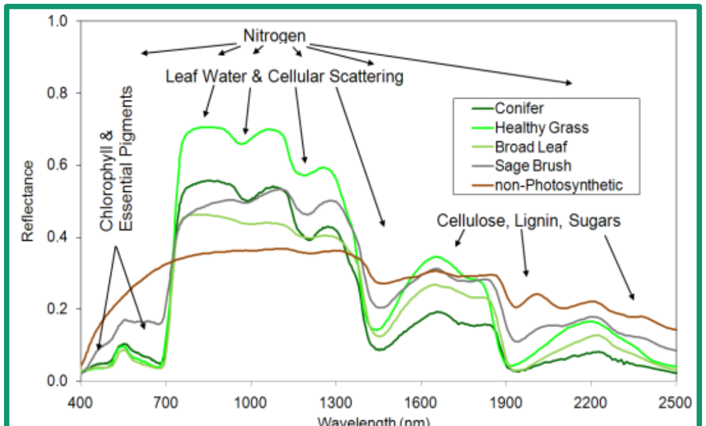


Ecosystem physiological conditions

Imaging spectroscopy measurements are required to measure the <u>physiological condition</u> (PC) of ecosystems for the global terrestrial biosphere to provide understanding and constraint of uncertainties in the climate change.

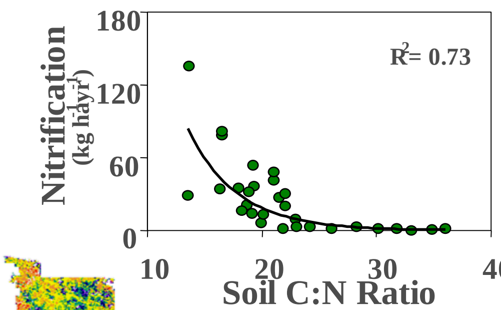
- **Detect and quantify changes in biogeochemical cycles and processes (PC)**
- **Map and monitor productivity changes (PC) at seasonal and spatial scales relevant for policy decisions.**
- **Reduce uncertainties in ecosystem feedbacks from multiple stressors (T, precip., CO_2, N deposition, etc.) to Improve prediction of future ecosystem condition (PC).**

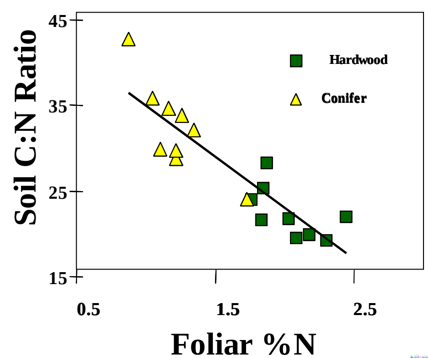
Biosphere-climate feedbacks

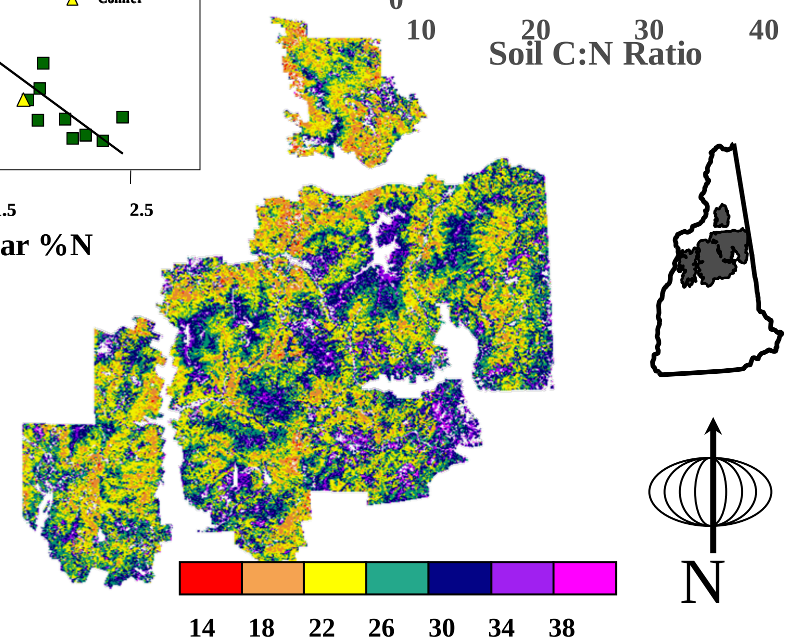


Reflectance spectrum are used to quantify bio-physiological conditions

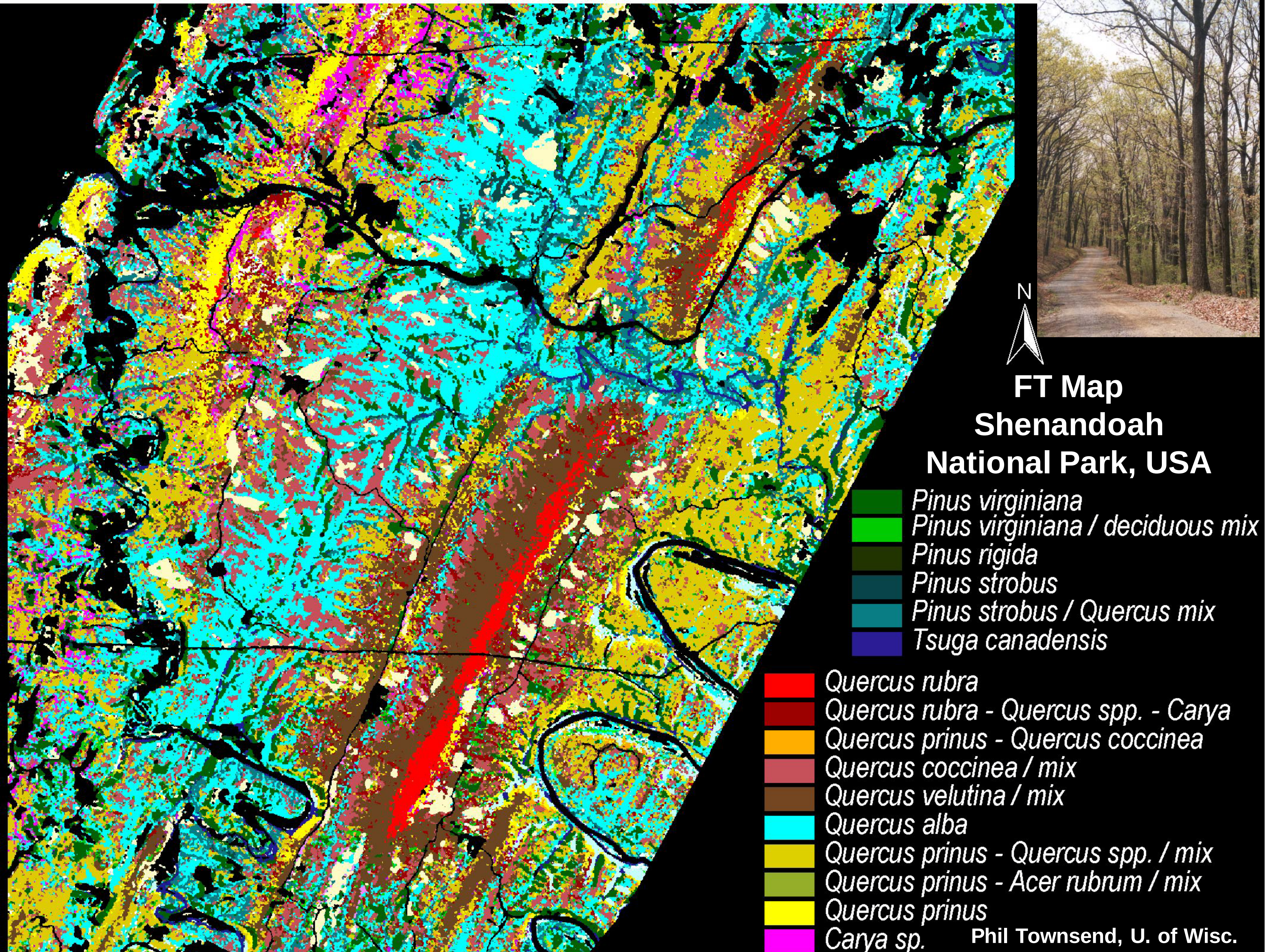
Predicted Foliar Chemistry (PC) from Spectroscopy Is Used to Estimate Soil Nitrogen Cycling







Ollinger et al. 2002



N
FT Map
Shenandoah
National Park, USA
Pinus virginiana
Pinus virginiana / deciduous mix
Pinus rigida
Pinus strobus
Pinus strobus / Quercus mix
Tsuga canadensis
Quercus rubra
Quercus rubra - Quercus spp. - Carya
Quercus prinus - Quercus coccinea
Quercus coccinea / mix
Quercus velutina / mix
Quercus alba
Quercus prinus - Quercus spp. / mix
Quercus prinus - Acer rubrum / mix
Quercus prinus
Carya sp.
Phil Townsend, U. of Wisc.

HyspIRI VSWIR – Science Measurement Characteristics

Spectral

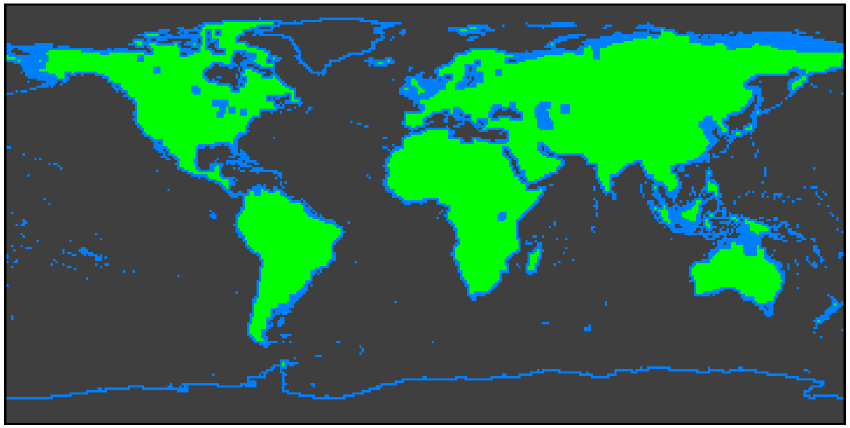
Radiometric

Spatial

Uniformity

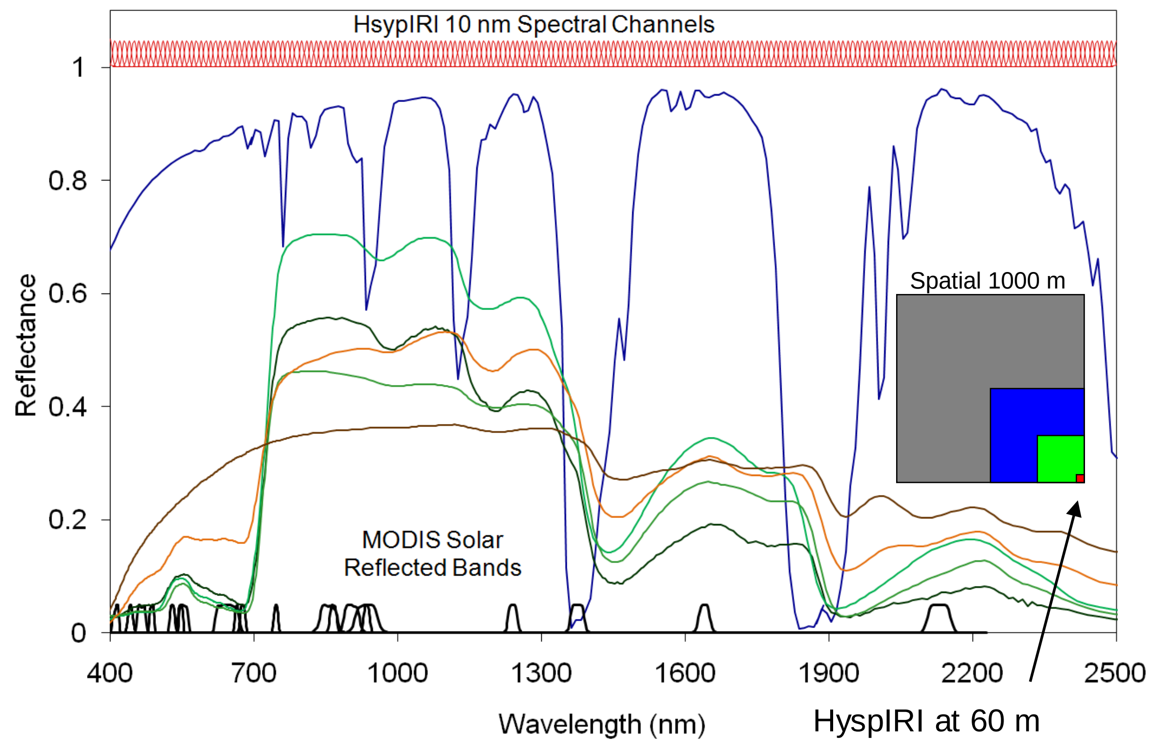
Temporal

HyspIRI VSWIR Science Measurements



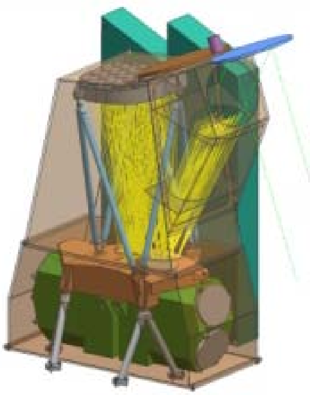
- Measure the **global** land and coastal/shallow water (> -50m).
- 19 day equatorial revisit to generate seasonal and annual products.
- Full terrestrial and shallow water data set returned.

- Measure the molecular absorption and constituent scattering signatures in the spectral range from 380 to 2500 nm at 10 nm, and at 60 m spatial sampling.



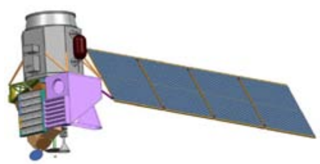
HyspIRI VSWIR
Science Measurement Characteristics

Spectral	
Range	380 to 2500 nm in the solar reflected spectrum
Sampling	<= 10 nm {uniform over range}
Response	<= 1.2 X sampling (FWHM) {uniform over range}
Accuracy	<0.5 nm
Radiometric	
Range & Sampling	0 to 1.5 X max benchmark radiance, 14 bits measured
Accuracy	>95% absolute radiometric, 98% on-orbit reflectance, 99.5% stability
Precision (SNR)	See spectral plots at benchmark radiances
Linearity	>99% characterized to 0.1 %
Polarization	<2% sensitivity, characterized to 0.5 %
Scattered Light	<1:200 characterized to 0.1%
Spatial	
Range	>150 km
Cross-Track Samples	>2500
Sampling	<=60 m
Response	<=1.2 X sampling (FWHM)
Uniformity	
Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}



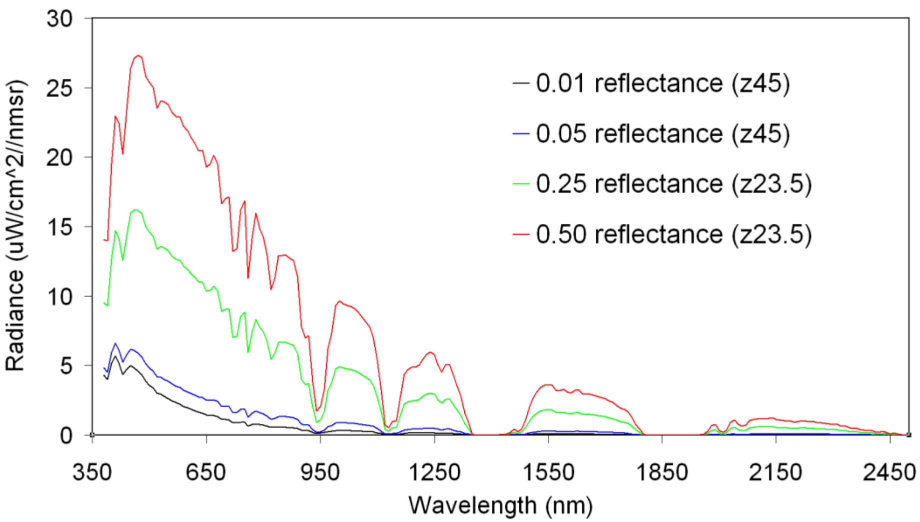
HyspIRI VSWIR Science Measurements Characteristics

Temporal	
Orbit Crossing	10:30 am sun synchronous descending
Global Land Coast Repeat	19 days at equator
Rapid Response Revisit	3 days (cross-track pointing)
Sunglint Reduction	
Cross Track Pointing	4 degrees in backscatter direction
OnOrbit Calibration	
Lunar View	1 per month {radiometric}
Solar Cover Views	1 per day {radiometric}
Dark signal measurements	1 per orbit and edge detector tracking
Surface Cal Experiments	3 per year {spectral & radiometric}
Data Collection	
Land Coverage	Land surface above sea level excluding ice sheets
Water Coverage	Coastal zone -50 m and shallower
Solar Elevation	20 degrees or greater
Open Ocean/Ice Sheets	Averaged to 1km spatial sampling
Compression	>=3.0 lossless

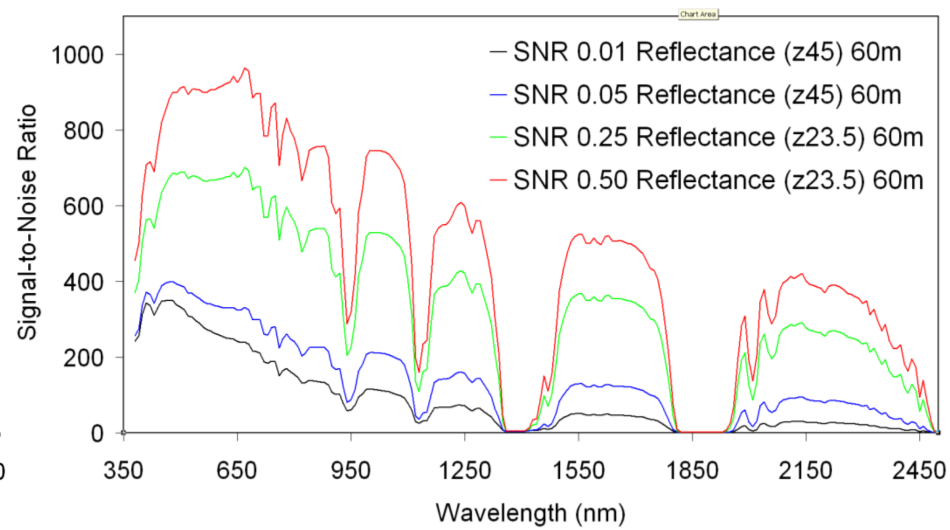


HyspIRI VSWIR Science Measurements
Key SNR and Uniformity Requirements

Benchmark Radiances

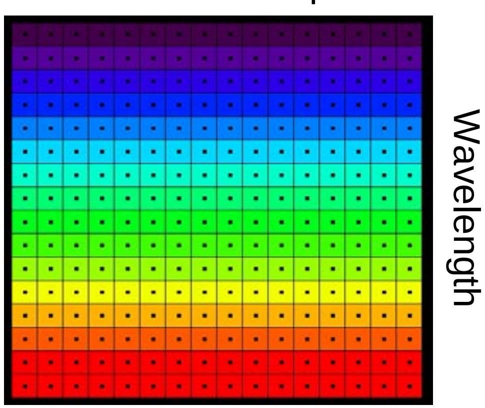


Required SNR



Uniformity Requirement

Cross Track Sample



Depiction

-Grids are the detectors

-dots are the IFOV centers

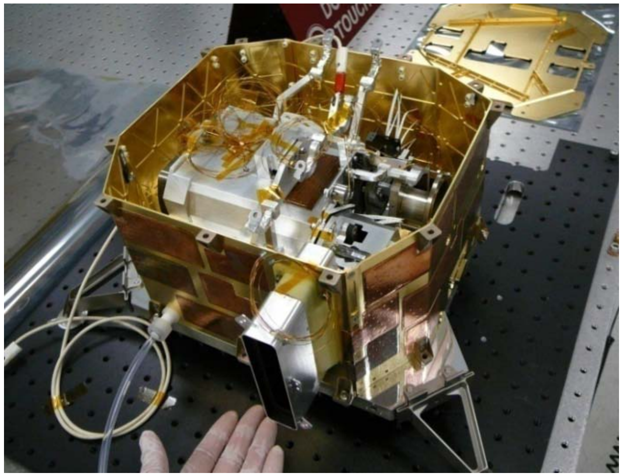
-Colors are the wavelengths

Requirement

Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}

Heritage: NASA Moon Mineralogy Mapper

M3 Spectrometer

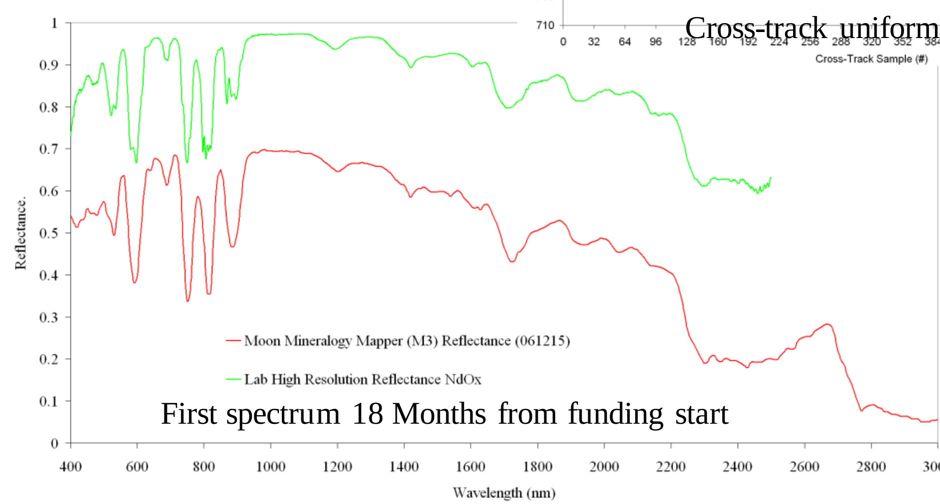


Mass 8 kg, Power 15 Watts

<u>Passed Preship review 3 May 2007</u>

- Mouroulis Offner Design (HyspIRI)
- Convex e-beam grating (HyspIRI)
- 6604a MCT full range detector array, multiplexor & signal chain (HyspIRI)
- Uniform slit (HyspIRI)
- 0.5 micron adjustment mounts lockable for flight
- Aligned to 95% cross-track uniformity (HyspIRI)
- Aligned to 95% spectral IFOV uniformity (HyspIRI)
- Meets high SNR requirements (HyspIRI)
- Passive radiator (HyspIRI)

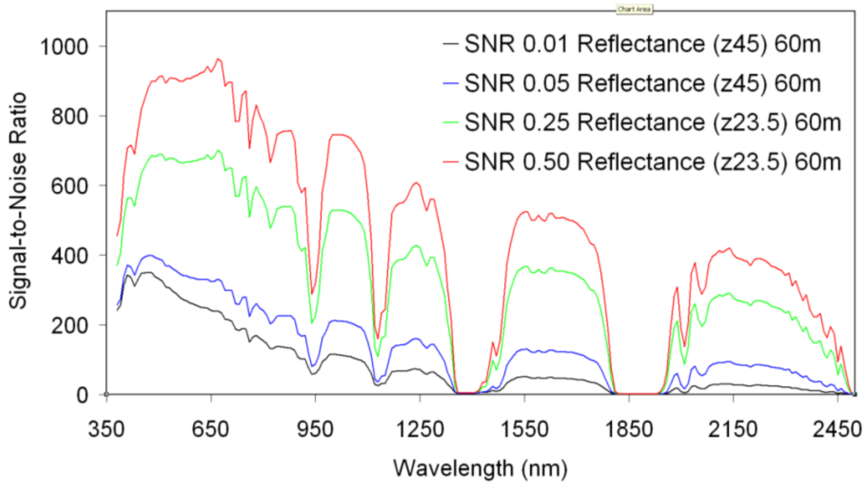
Cross-track uniformity ≥ 95%



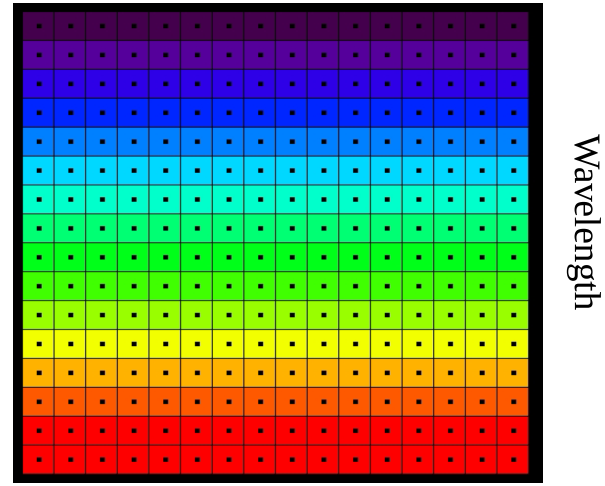
First spectrum 18 Months from funding start

HyspIRI: Building on NASA Hyperion Technology Demonstration

SNR > 10X



Uniformity > 10X

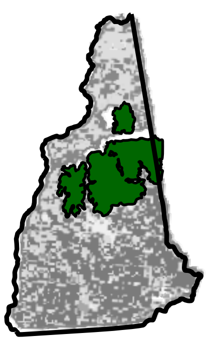


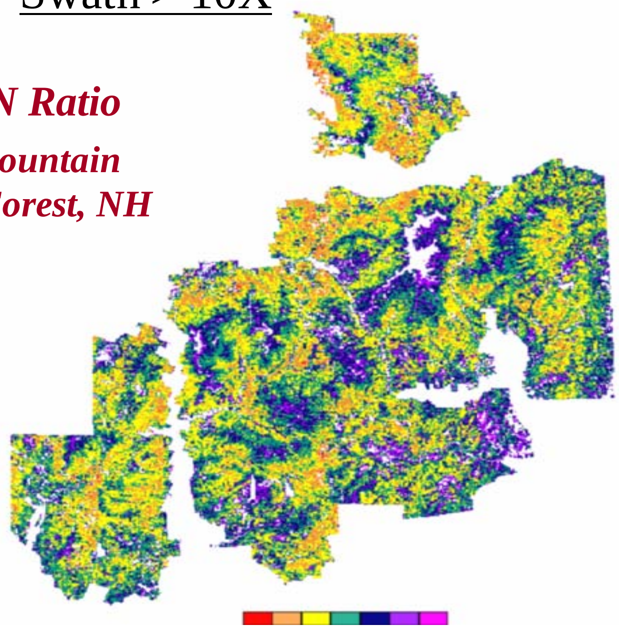
Cross Track Sample

Swath > 10X

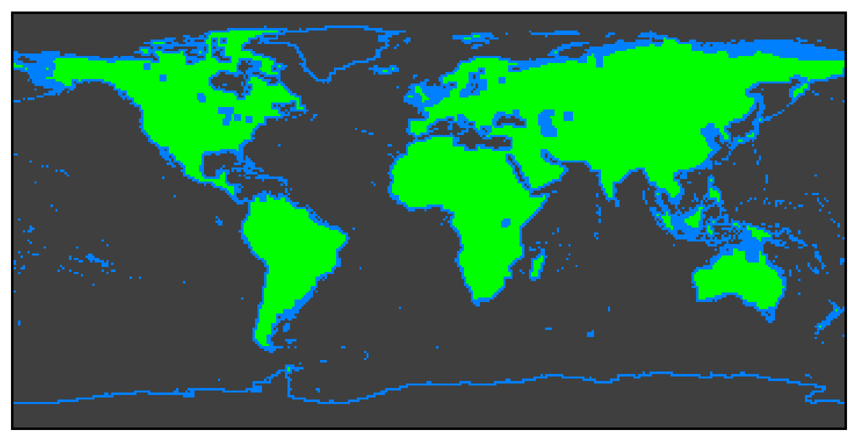
Soil C:N Ratio

White Mountain National Forest, NH



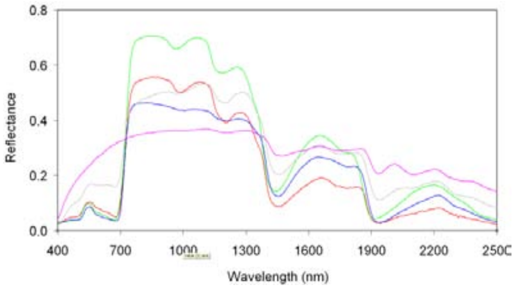


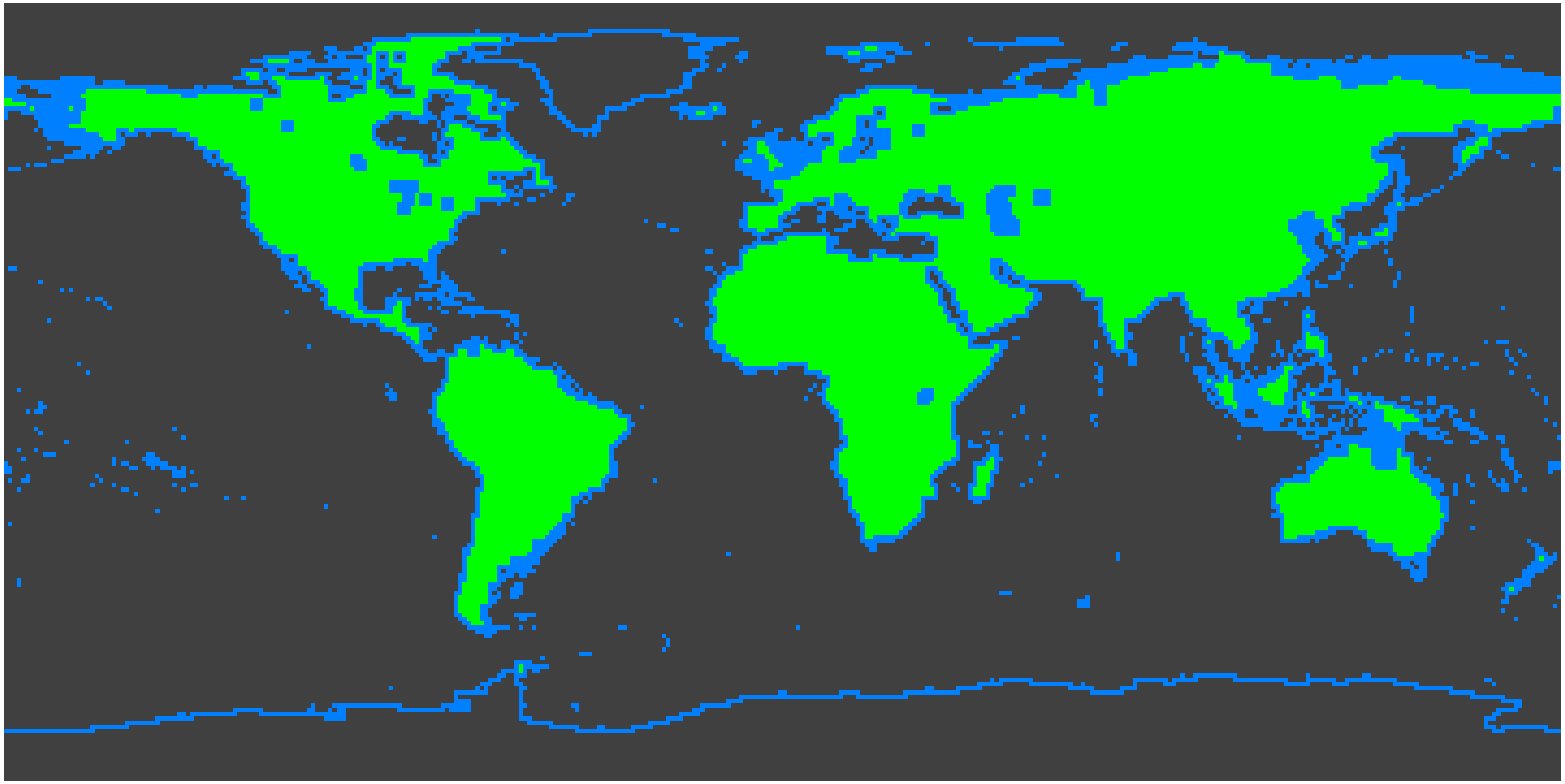
Global Coverage >> 10X



HyspIRI: A Decadal Survey **Global** Mapping Mission (VSWIR)

- Full Spectrum 380 to 2500 at 10 nm
- 60 m spatial with 150 km swath
- Full terrestrial surface downlinked every 19 days





Oceans and ice sheets at 1 km

VSWIR coverage map

HyspIRI compared with possible International Imaging Spectroscopy Missions

Only HyspIRI provides the full spectrum of data required to address climate-carbon cycle feedbacks articulated in the NRC Decadal Survey

HyspIRI Provides Seasonal and Annual Global Coverage that Uniquely Addresses Critical Gaps in Climate Research and Ecosystem Understanding.

>100 years for international mission to equal 1 year of HyspIRI

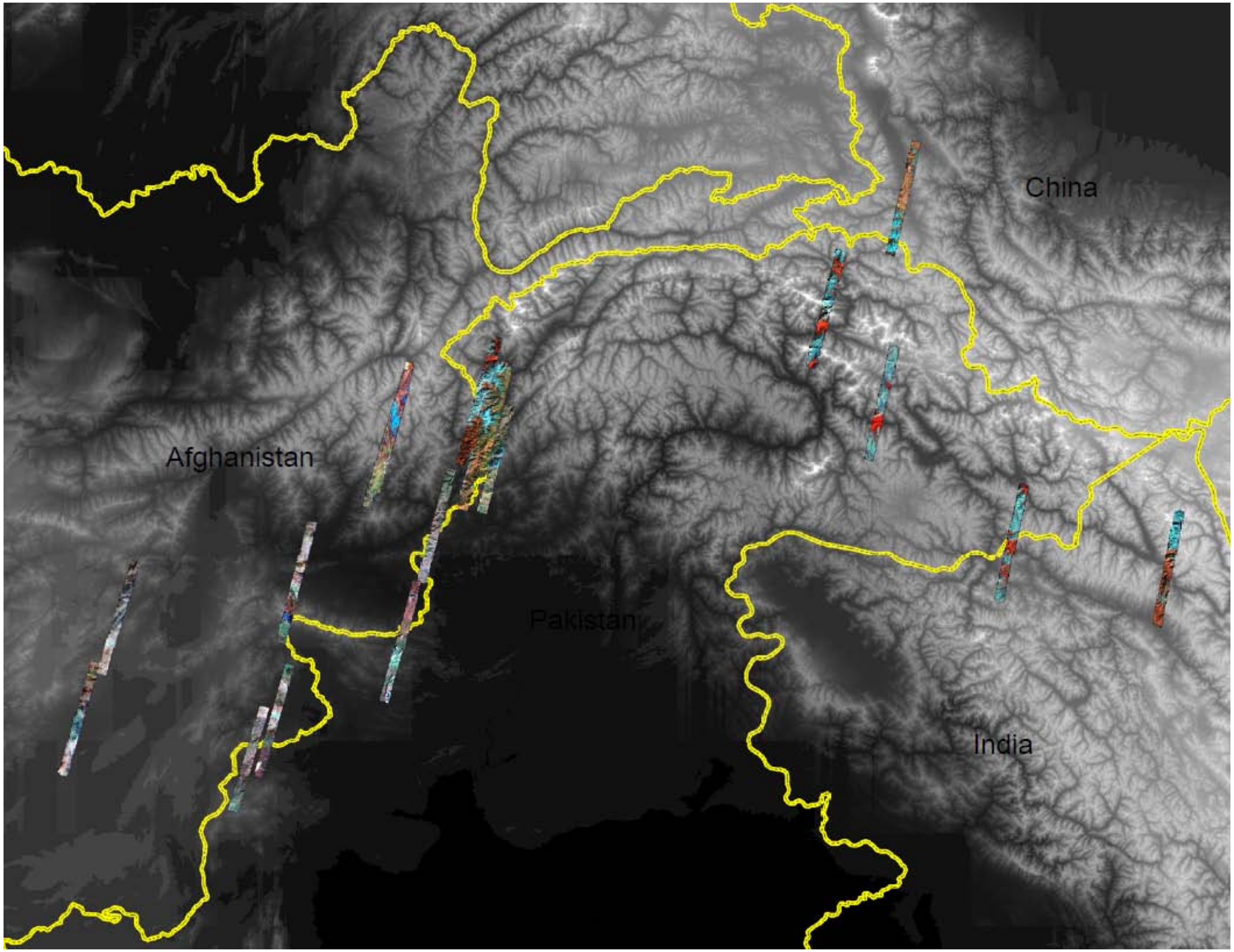
Country	Instrument	Swath km	Pixel Size, m	Terrestrial Coverage in 19 days	Repeat interval, days	TIR capability
USA	**HyspIRI**	**150**	**60**	**100%**	**19**	**8 TIR bands**
Germany	EnMAP	30	30	<1%	--	NO
Italy	PRISMA	30-60	20-30	<1%	--	NO
Japan?	ALOS3	30	30	<1%	--	NO
India?	IMS Resource Sat-3	25	25	<1%	--	1 TIR band

US, HyspIRI: a full spectral range (380 to 2500 at 10 nm), high SNR, uniform, 60m spatial with 150 km swath imaging spectrometer and multiband thermal imager (8 band thermal imager from 3-12 μm).

Other countries are occasionally mentioned (China, South Africa, South Korea, etc.). All are proposing first generation small sample process/application missions with scattered terrestrial coverage and no TIR imager

EO1-Hyperion Coverage for Himalaya Study

- Example of study for snow and ice science in the Himalaya with EO1-Hyperion
  - Coverage is a severe limitation of regional and global **climate** investigations.



- **<u>HyspIRI would measure the full area every 19 days returning all the data</u>**

HyspIRI VSWIR Science Measurement Summary

The National Research Council of the United States National Academies released the Decadal Survey: Earth Science and Applications from Space that included a global mapping imaging spectrometer as part of the HyspIRI Mission.

The NASA designated HyspIRI Science Study Group developed a set of science questions to address the call of the Decadal Survey including critical climate measurements.

From these science question as set of Science Traceability Matrixes were development with corresponding science measurement requirements.

A VSWIR imaging spectrometer instrument concept was developed to meet these science measurement requirements and provide a high heritage and low risk concept for acquiring the HyspIRI VSWIR science measurements.

The science measurement characteristics of the HyspIRI VSWIR instrument have been described in terms of: **Spectral, Radiometric, Spatial, Uniformity, Temporal**

The HyspIRI VSWIR science requires full coverage of the terrestrial and coastal areas at a 19 revisit to address key elements of the Decadal Survey science including critical climate measurements of the terrestrial biosphere.

Backup

HyspIRI Concept - 2010

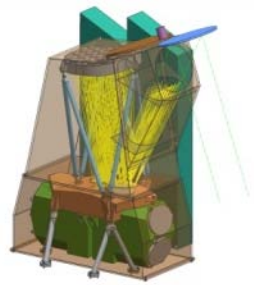
Payload

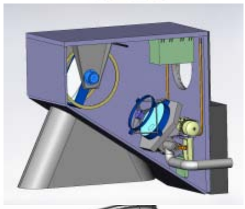
Science Instruments:

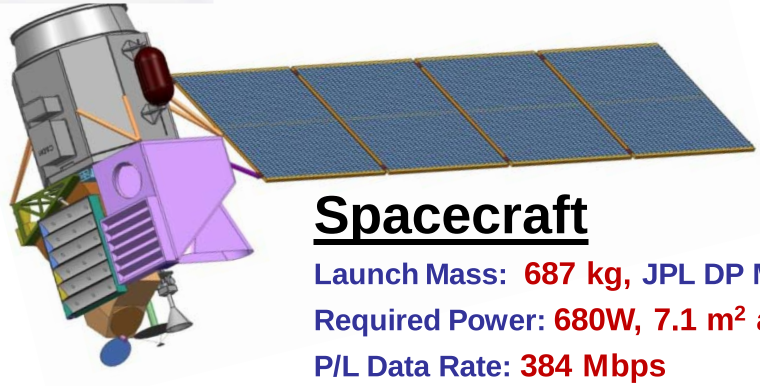
- VSWIR: Imaging Spectrometer
  - 380-2500 nm in 10 nm bands
  - 60m spatial resolution
  - Day-side (23% duty cycle)
  - 55 Kg, 41 W
- TIR: Thermal Infrared Scanner
  - 8 bands between 3-12 μm
  - 60m spatial resolution
  - Day and night-side (100% duty cycle)
  - 60 Kg, 103 W

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

Implementation

Launch Date: ≥ 2016

Lifetime: 3 years, with consumables for 5

Cost Category: Low Cost Decadal Survey

Partners: JPL, GSFC

Mission Class: C, with selected redundancy

Hardware Model: Protoflight

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 = 2 arcsec (Pitch/Yaw axis 3σ);

8 arcsec (Roll axis 3σ)

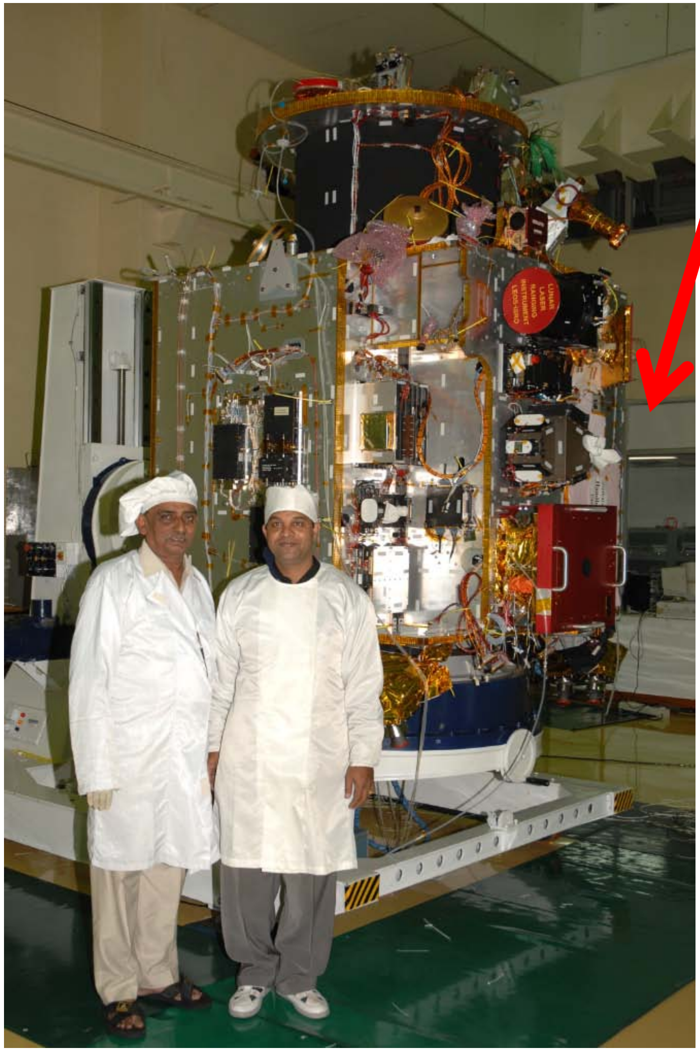
Stability = 5 arcsec/sec (per axis 3σ)

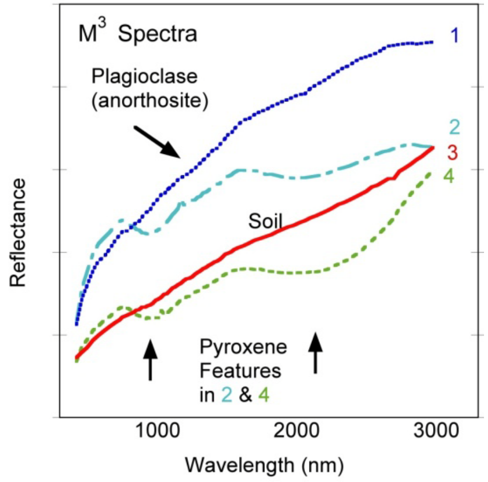
No new technology required

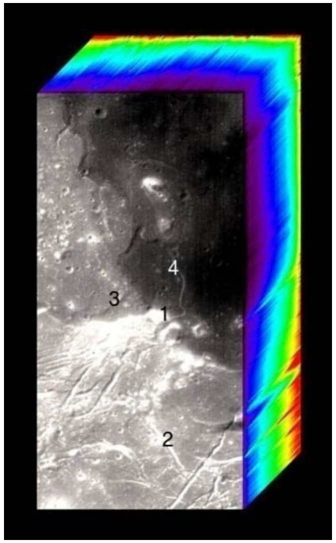
Heritage: M3 NASA Imaging Spectrometer

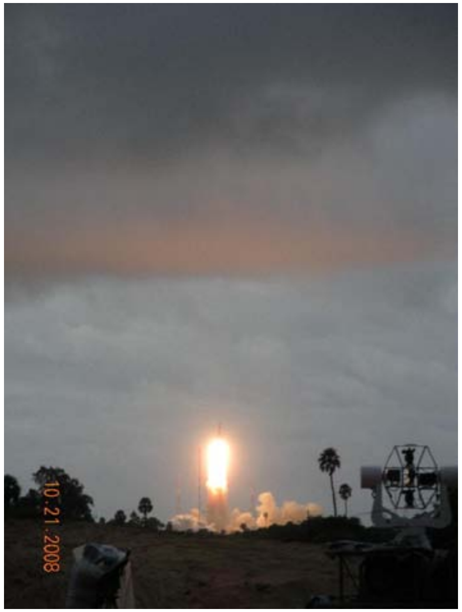
M3 Installed on ISRO Chandraayan-1 spacecraft, Launched 22 Oct 2008

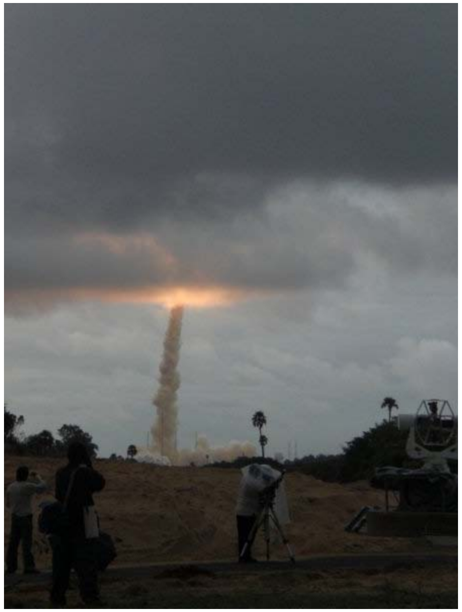
- First light in lunar orbit 19 Nov 2008







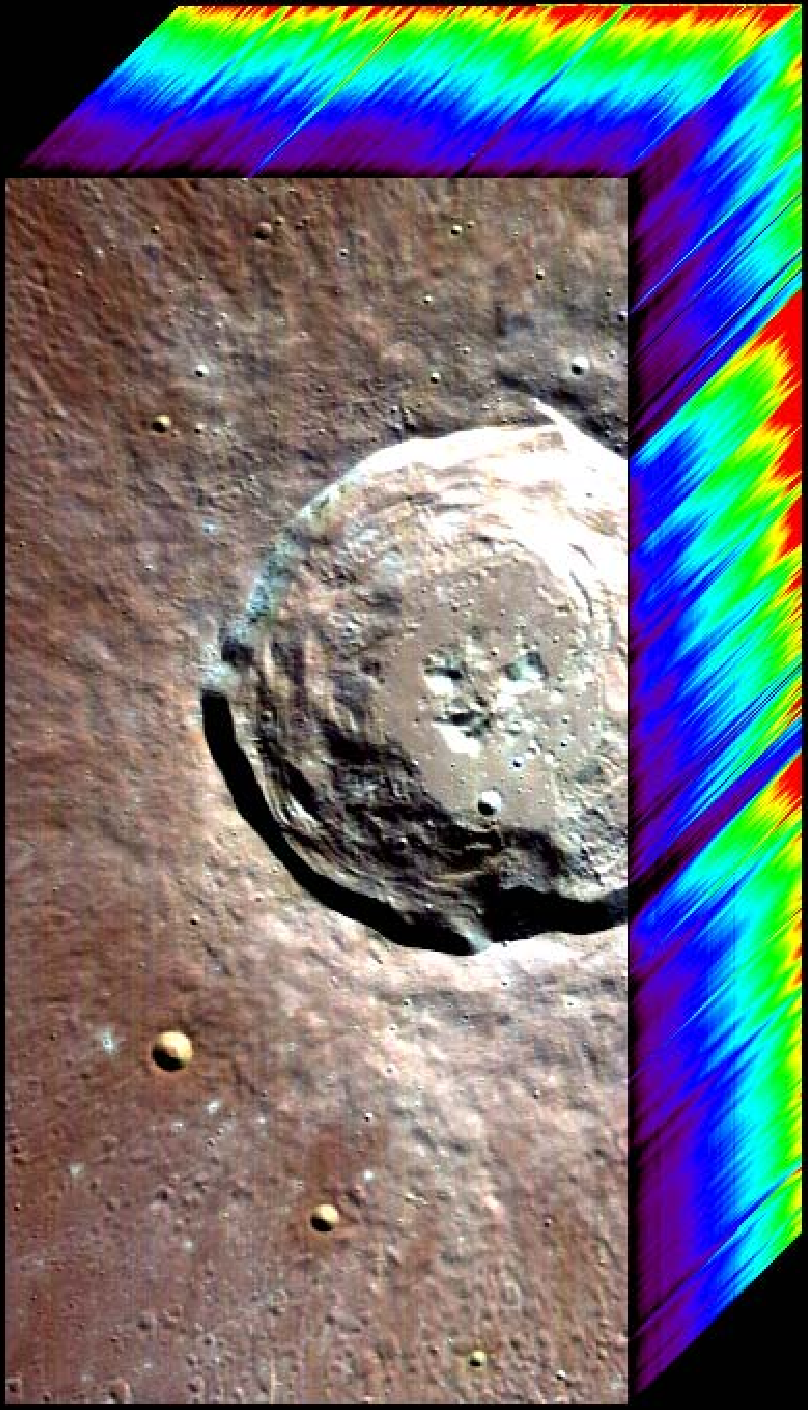




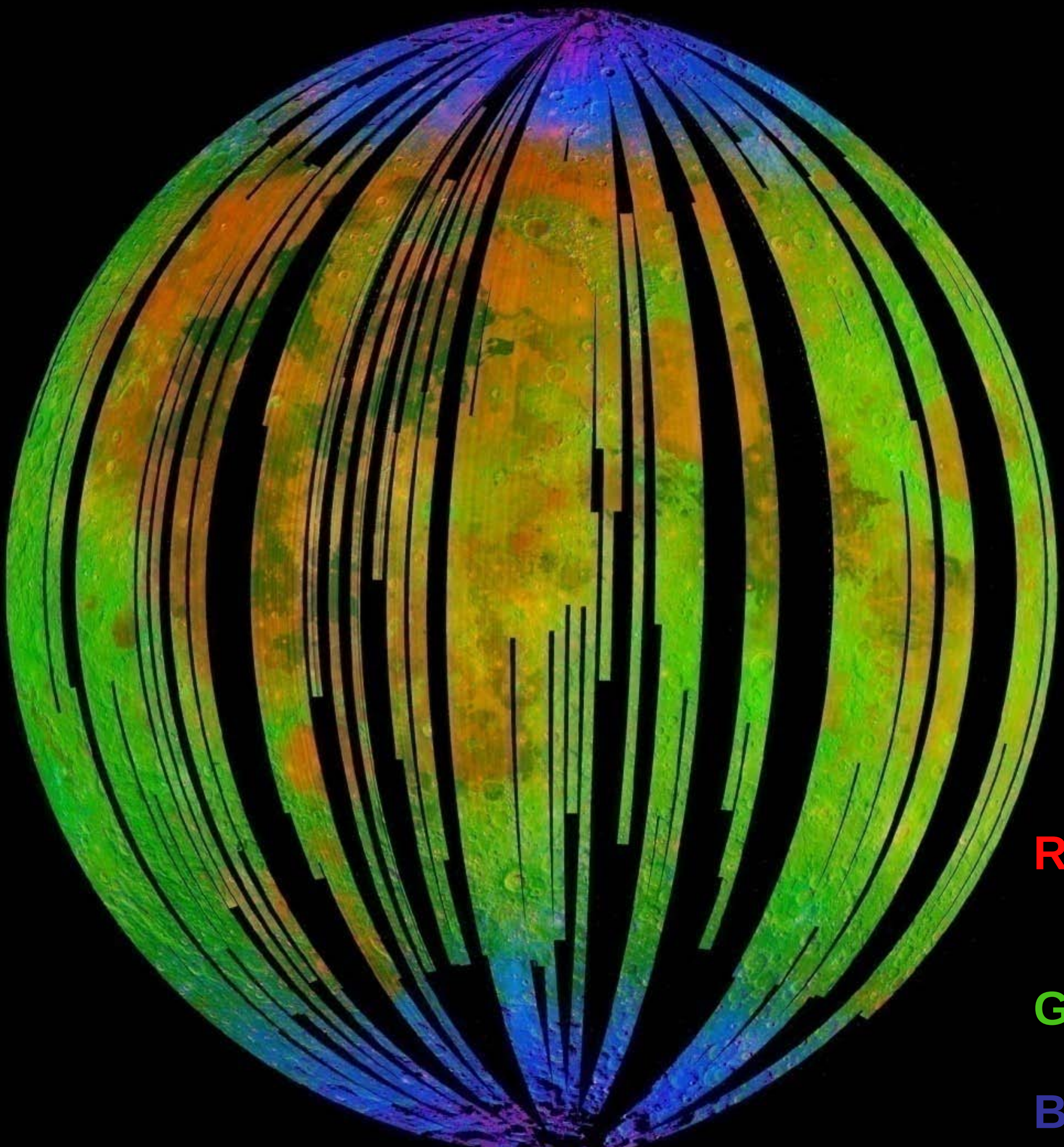
M^3

First Spectral Light

19 Nov 2008



Cover of Science 23 October 2009



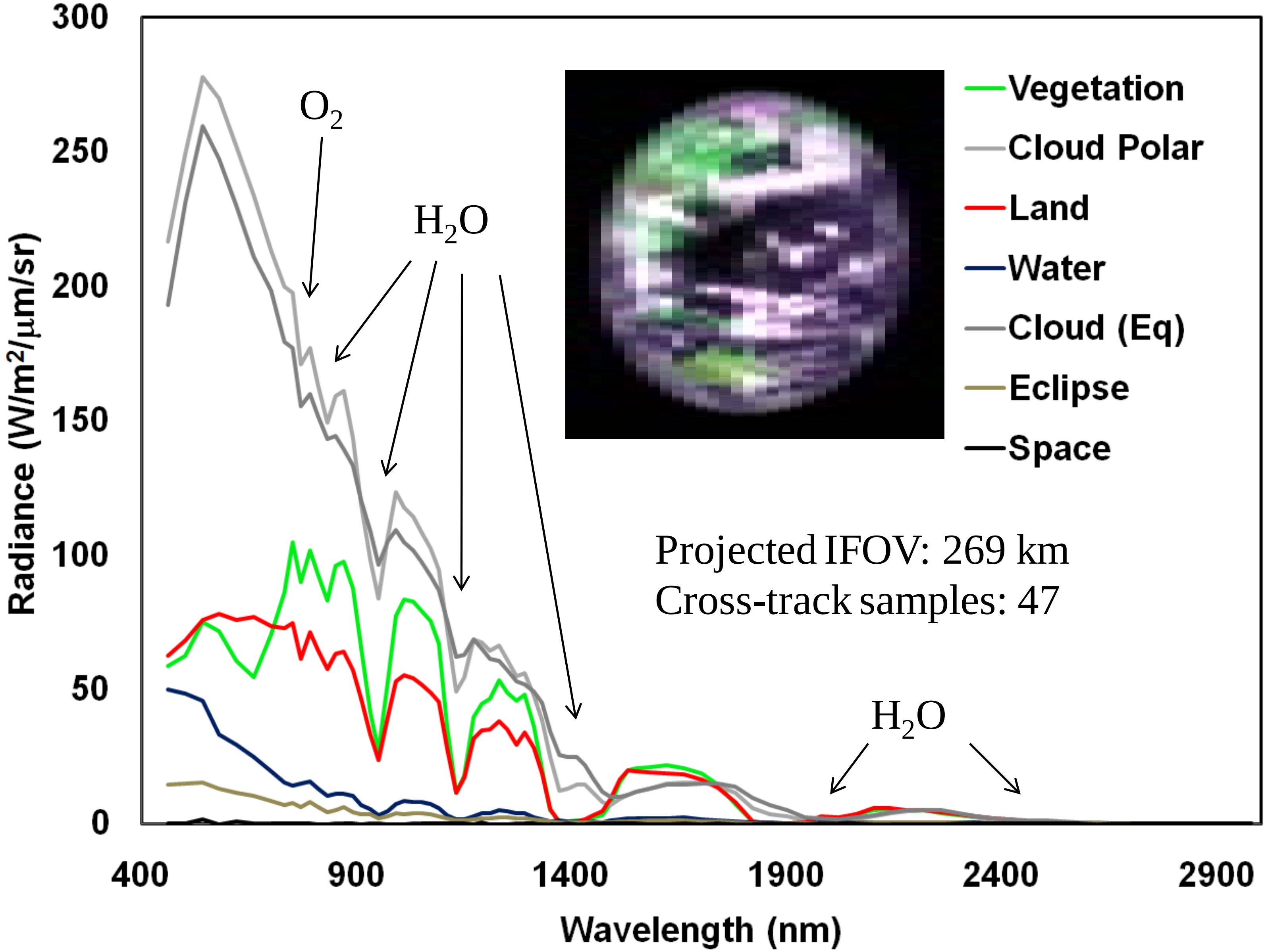
R 2-µm absorption
largely pyroxene

G Brightness

B 3-µm absorption
OH/H2O

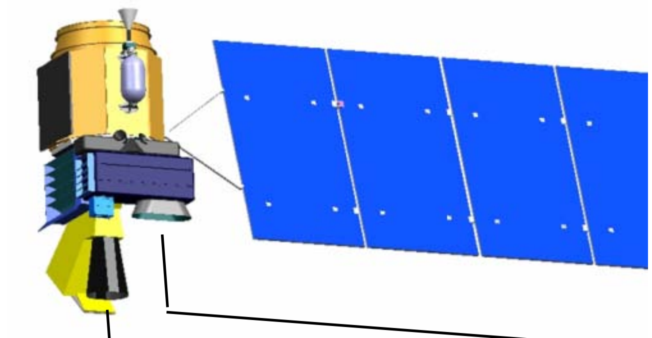
Image of Earth from the Moon acquired by the NASA Discovery Moon Mineralogy Mapper (M3) that is a guest instrument onboard the ISRO Chandrayaan-1 Mission to the Moon. Australia is visible in the lower center of the image. The image is presented as a false color composite with oceans dark blue, clouds white, and vegetation enhanced green. The data were acquired on the 22nd of July 2009.

M^3 On-Orbit Spectral



NRC Decadal Survey HyspIRI

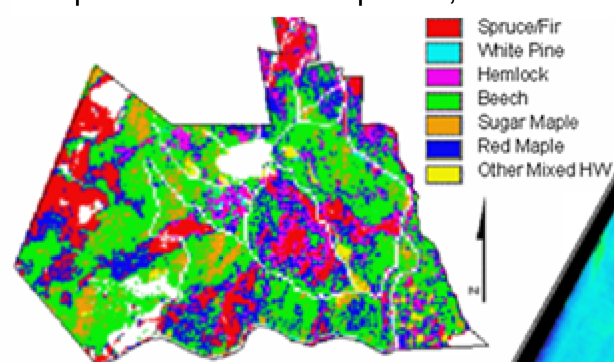
Visible ShortWave InfraRed (VSWIR) Imaging Spectrometer
+
Multispectral Thermal InfraRed (TIR) Scanner

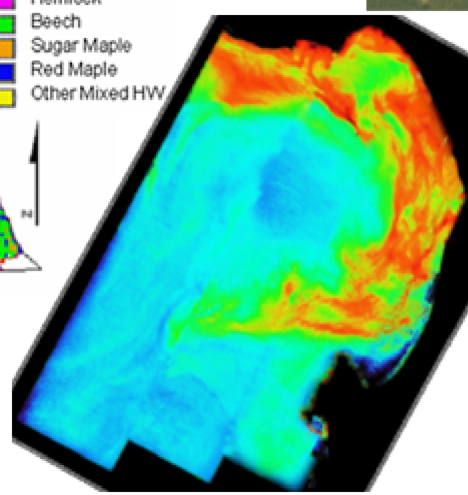


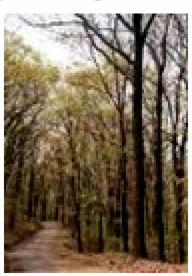
VSWIR: Plant Physiology and Function Types (PPFT)

Multispectral TIR Scanner

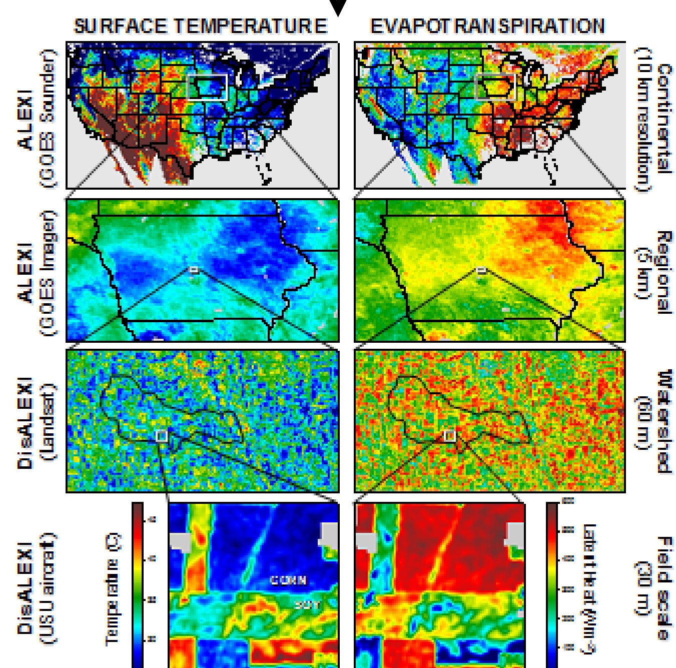
Map of dominant tree species, Bartlett Forest, NH



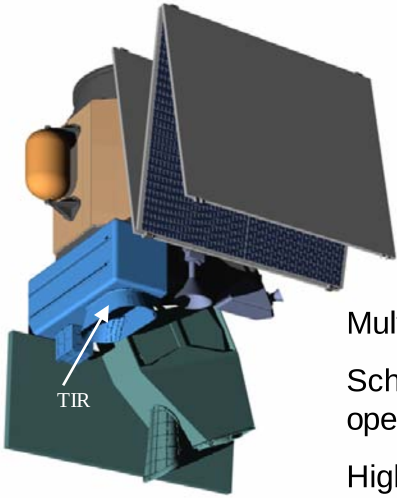


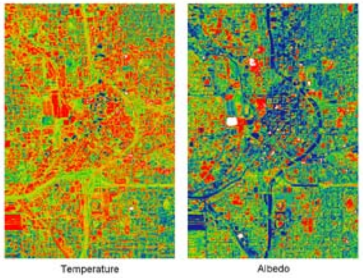


Red tide algal bloom in Monterey Bay, CA



HyspIRI Thermal Infrared Multispectral (TIR) Science Measurements





Atlanta, GA - May 1997

Multispectral Scanner

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)

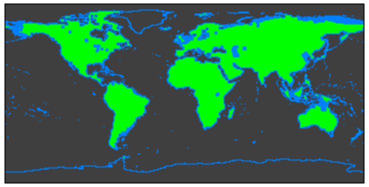
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

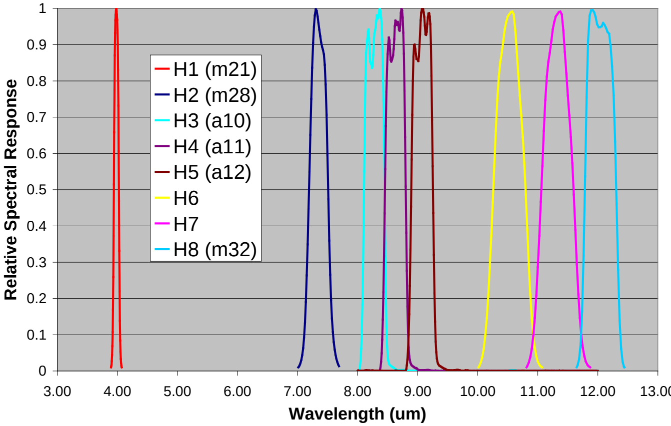
• TQ5. Earth surface composition and change, (AP,JC)

– 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?

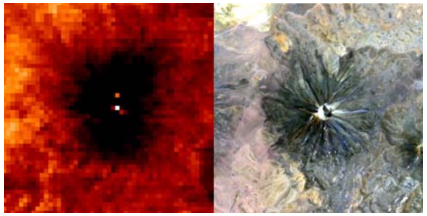
Measurement:

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

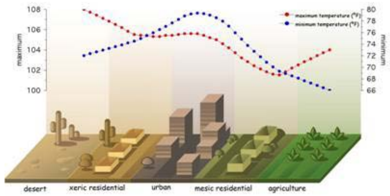




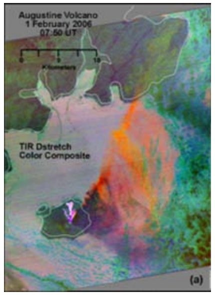
Andean volcano heats up



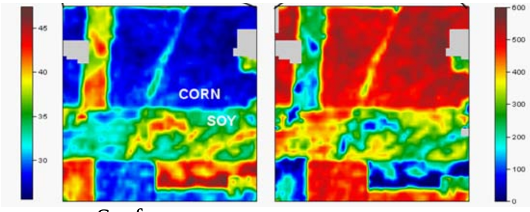
Urbanization



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?

Q2. Wildfires:

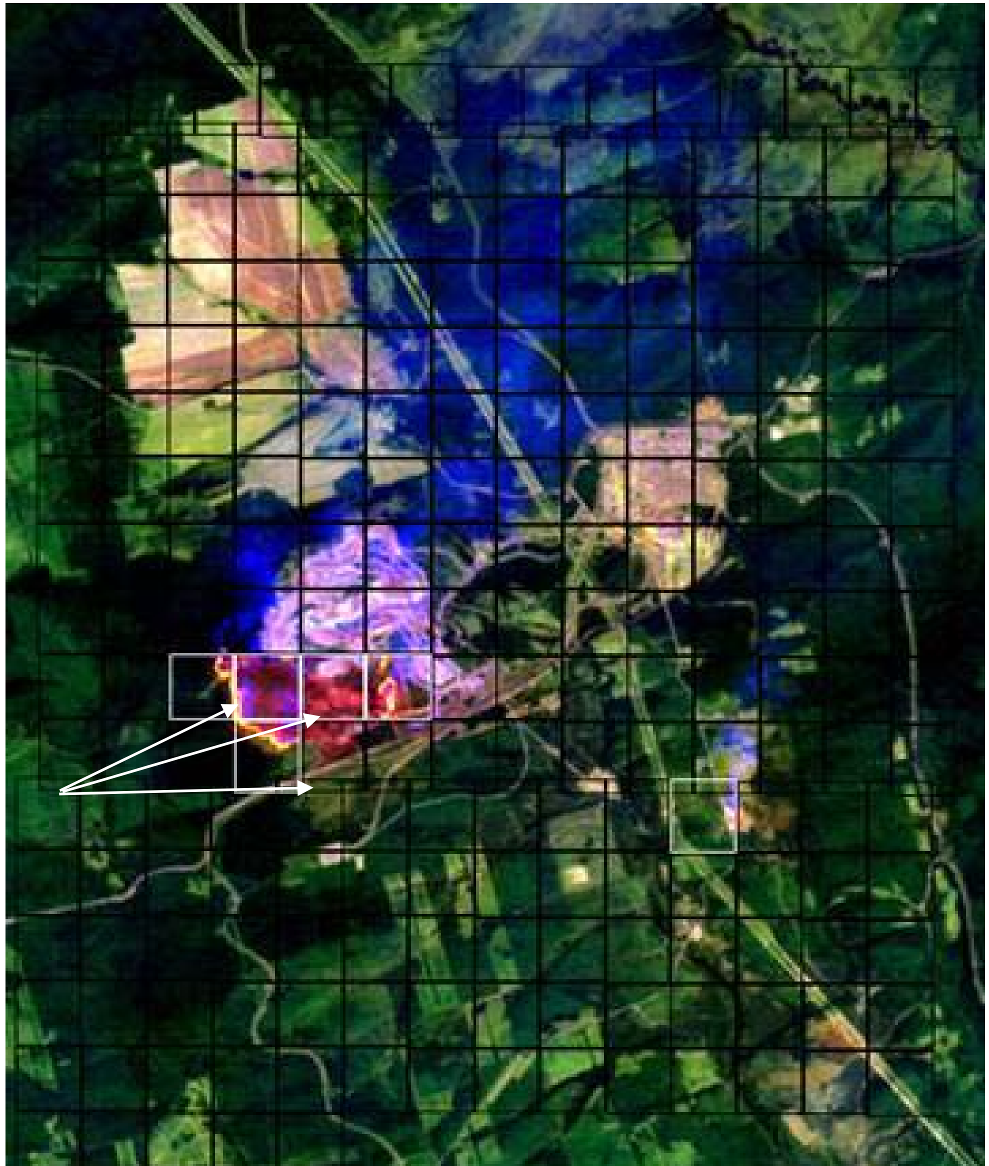
- How are global fire regimes (fire location, type, frequency, and intensity) changing in response to changing climate and land use practices? [DS 198]
- Are regions becoming more fire prone? [DS 196]
- What is the role of fire in global biogeochemical cycling, particularly atmospheric composition? [DS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

Wildfires:
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

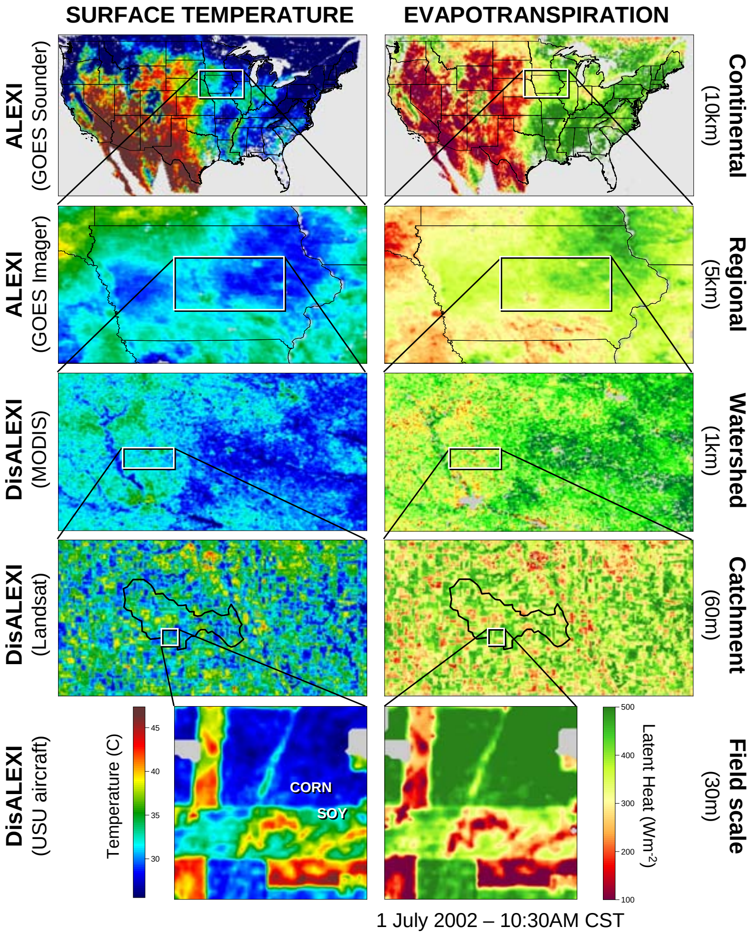
HyspIRI will provide high spatial resolution mid to thermal infrared data for determining the fire regime and allowing flux estimation on a weekly basis

Science Questions
Topic Areas

Q3. Water Use and Availability:

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

TQ3a: How is climate variability impacting the evaporative component of the global water cycle over natural and managed landscapes? (DS 166, 196, 203, 257, 368; WGA)



Multi-scale ET maps for 1 July 2002 produced using surface temperature data from aircraft (30-m resolution), Landsat-7 ETM+ (60-m), Terra MODIS (1-km), and GOES Imager (5-km) instruments (Anderson and Kustas (2008), Eos, 89, 233-234)

Science Issue:

• Based on principles of surface energy balance, the land-surface temperature signal conveys valuable information about the evaporative component of the hydrologic cycle and its response to varying climatic drivers. If we can accurately monitor this response in relationship to land-use and land-cover conditions, we will improve our ability to forecast water consumption and demand and to develop effective climate adaptation strategies for our water systems.

Tools:

• HyspIRI TIR observations of surface brightness temperature at <100m resolution to resolve field-scale land use, preferably with 3+ bands in the 8-12μm region for atmospheric and emissivity corrections. The weekly revisit of HyspIRI will improve accuracy of seasonally integrated ET estimates.
• Collocated/contemporaneous maps of vegetation index and landuse.
• Insolation data to estimate net radiation.
• Regional scale ET maps using coarser resolution TIR imagery from geostationary satellites and MODIS/VIIRS provide spatial context for local assessments.

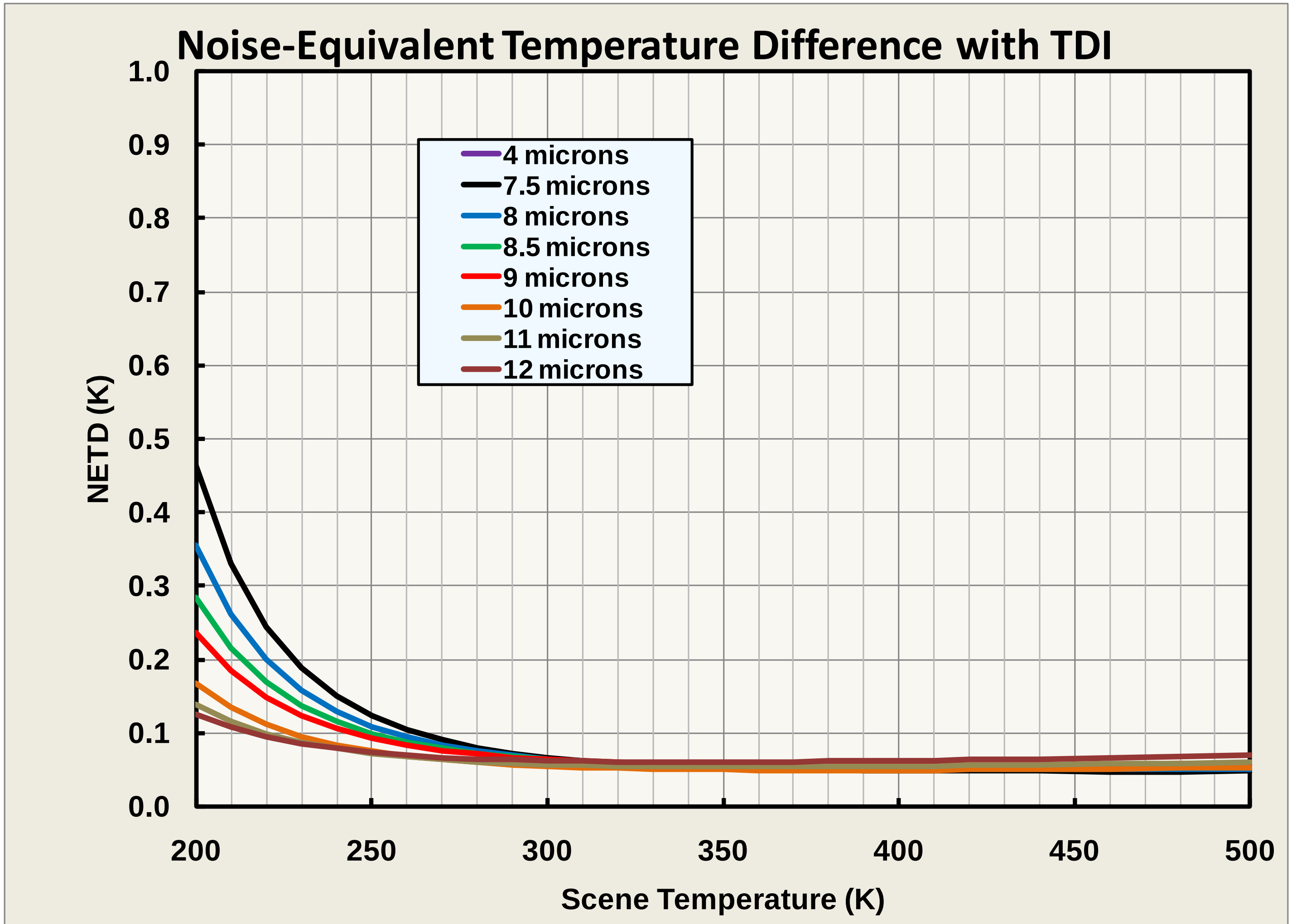
Approach:

• Periodic maps of instantaneous clear-sky ET from a TIR-based surface energy balance algorithm can be interpolated to produce daily ET maps using time-continuous observations of reference ET or available energy from met stations or geostationary satellites.
• Record of daily ET at scales resolving major land use patterns can be analyzed in conjunction with gridded climate data.

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 – 500K; 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	10 arcsec (50 microrad, 05 pixels, 30m on ground)

TIR Estimated Performance

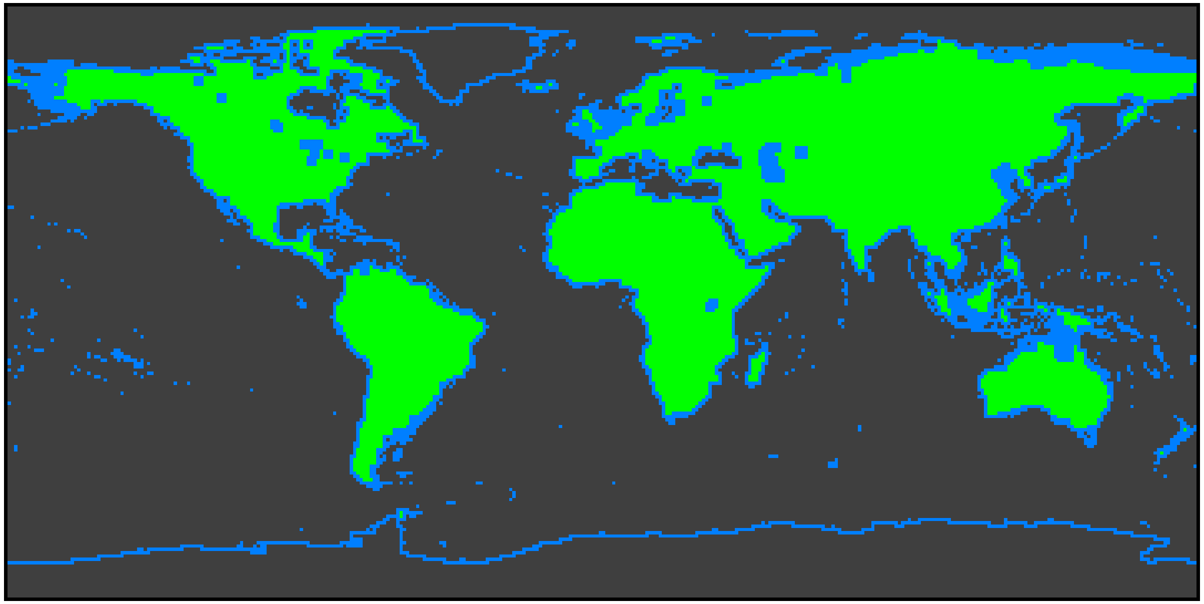


Science Measurements
Characteristics Continued

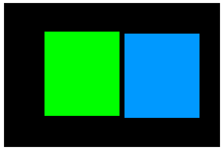
Temporal	
Orbit Crossing	10:30 am sun synchronous descending
Global Land Repeat	5 days at equator
OnOrbit Calibration	
Lunar View	1 per month {radiometric}
Blackbody Views	1 per scan {radiometric}
Deep Space Views	1 per scan {radiometric}
Surface Cal Experiments	2 (d/n) every 5 days {radiometric}
Spectral 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

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

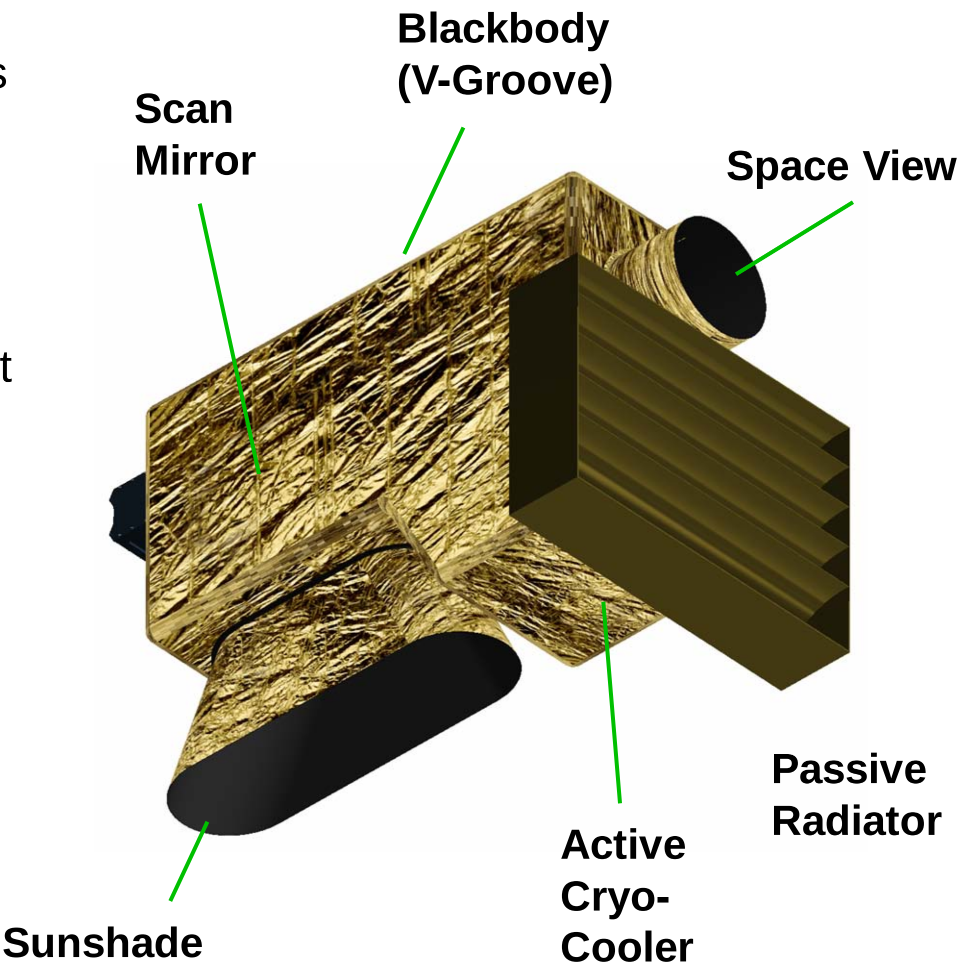


Land and coastal acquisition



Mission Concept
TIR Overview

- Duration: 4 years development, 3 years science
- Coverage: Global land and shallow water 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



Mission Concept
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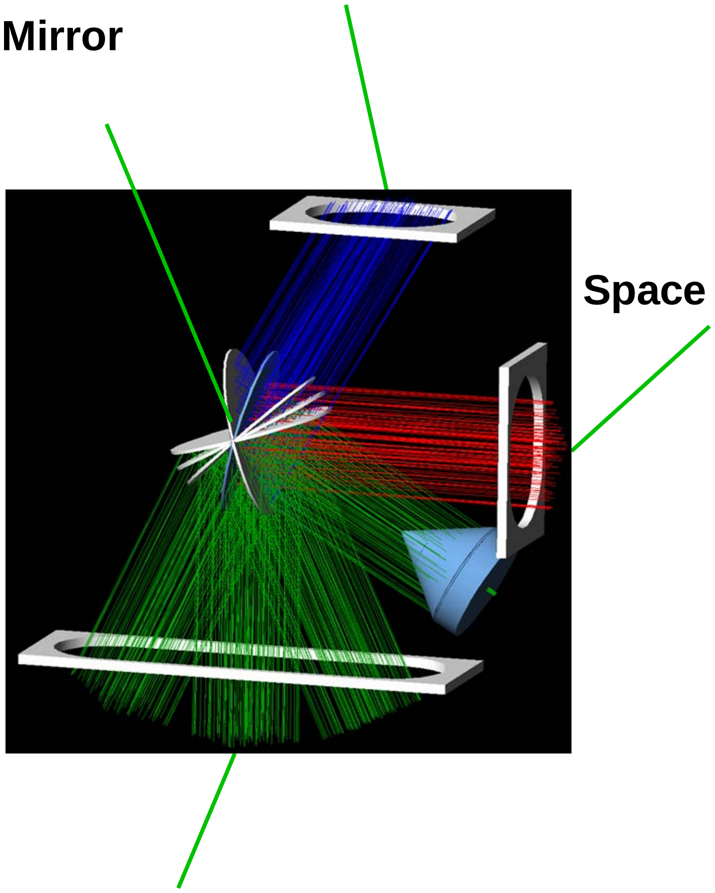


Summary

We have developed a set of TIR science questions that are well aligned with the HyspIRI Mission called for in the NASA Earth Science and Application Decadal Survey.

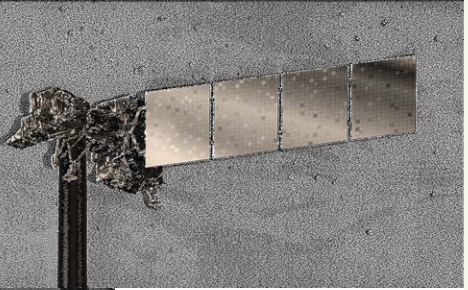
We have reviewed and refined these questions that relate to both science and application objectives and developed traceability to a set of science measurements.

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

Backup

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



Relevance of HyspIRI to Carbon and Climate Science

Susan L. Ustin

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

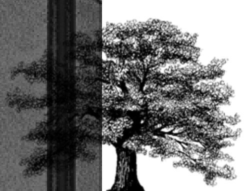
Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry

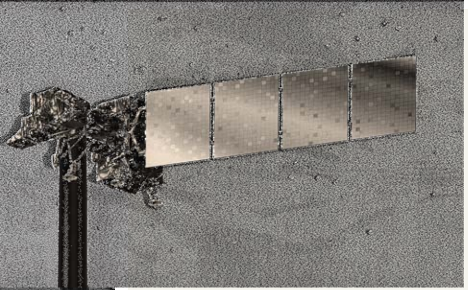
Executive Summary:

"Nonlinear interactions between the climate and biogeochemical systems could amplify (positive feedbacks) or attenuate (negative feedbacks) the disturbances produced by human activities."

Decadal Survey Box 1.3 Abundant Challenges: Protecting Ecosystems

"And yet there are no adequate spatially resolved estimates of the planet's biomass and primary production, and it is not known how they are changing and interacting with climate variability and change." (P.25).





Predicting Future Ecosystems Under Global Changes in Climate and Land Use

Nonlinear interactions between climate and complex systems create uncertainty

Human Elements

- Roads
- Land Ownership
- Population Density
- Resource use
- Land Cover
- Economics, Policy

Biological Elements

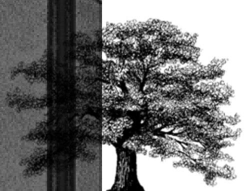
- Food webs
- Vegetation types
- Rare and endangered species
- Stress tolerance
- Time since major disturbance
- Species distributions

Future Human Elements

- Urban expansion
- Change in crop production
- Agricultural practices
- Extractive resource use
- Conservation policy; Restoration

Future Biological Elements

- Species distribution changes
- Species invasions & extinctions
- Changes in productivity, water use, phenology
- Polinator, pest dynamics



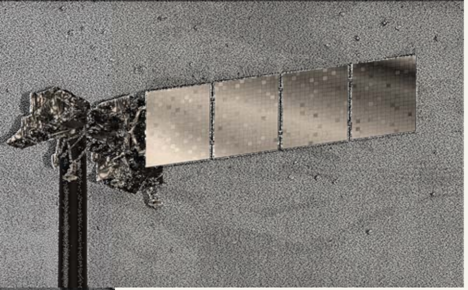
IPCC Climate Change 2007: Working Group I: The Physical Science Basis

Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

The Land Surface and Climate

- Changes in the land surface (vegetation, soils, water) resulting from human activities can affect regional climate through shifts in radiation, cloudiness and surface temperature.
  - Changes in vegetation cover affect surface energy and water balances at the regional scale, from boreal to tropical forests.
  - The impact of land use change on the energy and water balance may be very significant for climate at regional scales over time periods of decades or longer.

Land Carbon. Understanding land carbon storage is a critical factor in predicting the growth of atmospheric CO_2 and subsequent global climate change. P. 273 , DS.



Relevance of HyspIRI to Carbon and Climate Science

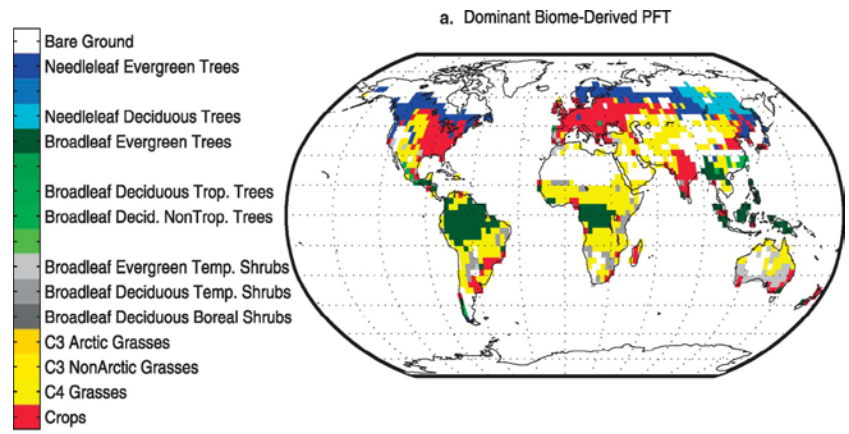
Monitoring Vegetation Type and Functions

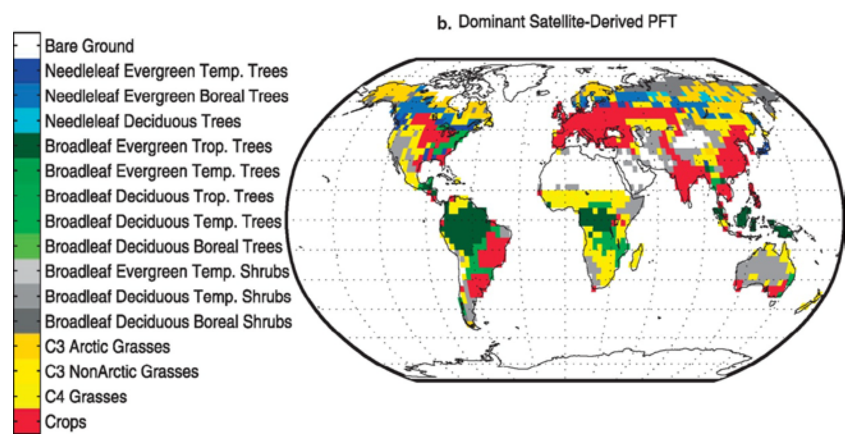
Global Land Cover Maps based on climate potential have biased Distributions

- Coarse Spatial Resolution data do not agree with actual land cover types

Satellite Based plant functional type maps have higher spatial resolution and are derived from actual measurements

- Maps remain too spatially coarse to monitor ecosystem changes
- Limited number of cover types; no subgrid elements



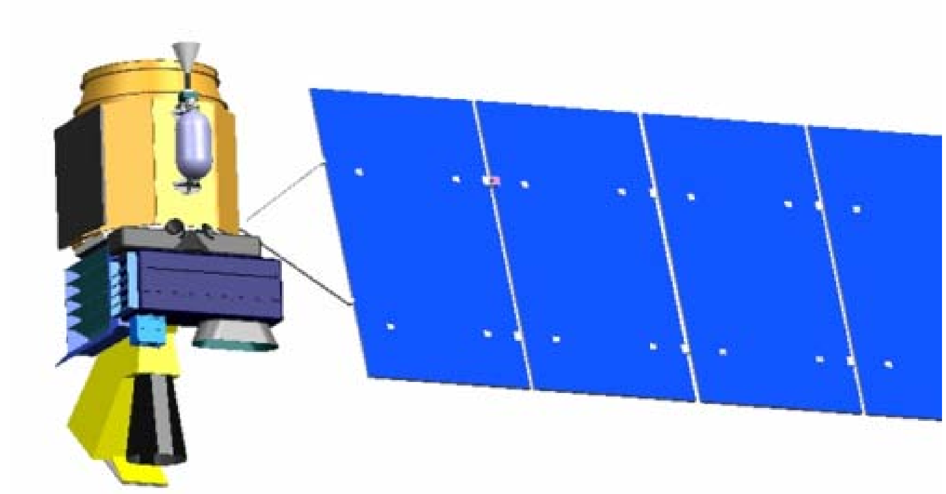


From: Bonan, GB, Levis S, Sitch S, Vertenstein M, Olson KW (2003). Global Change Biology 9: 1543-1556, Figure b from: Ramankutty N. and Foley JA. (1999). Global Biogeochemical Cycles 13: 997-1027.

Decadal Survey: HyspIRI Recommendation
by Ecosystem, Climate and Land Use Change Panels

"A hyperspectral sensor (e.g., FLORA) combined with a multispectral thermal sensor (e.g., SAVII) in low Earth orbit (LEO) **is part of an integrated mission concept [**described in Parts I and II] that is relevant to several panels, ***especially the climate variability panel***." p. 368.

HyspIRI Concept



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

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

Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

The Carbon Cycle and Climate

- Interannual and inter-decadal variability in the growth rate of atmospheric CO_2 **is *dominated by the response of the land biosphere to climate variations***.

- A combination of techniques gives an estimate of the flux of CO_2 to the atmosphere from land use change of 1.6 (0.5 to 2.7) GtC yr^{-1} for the 1990s [ ] and ***continuing uncertainty in the net CO_2 emissions due to land use change***.

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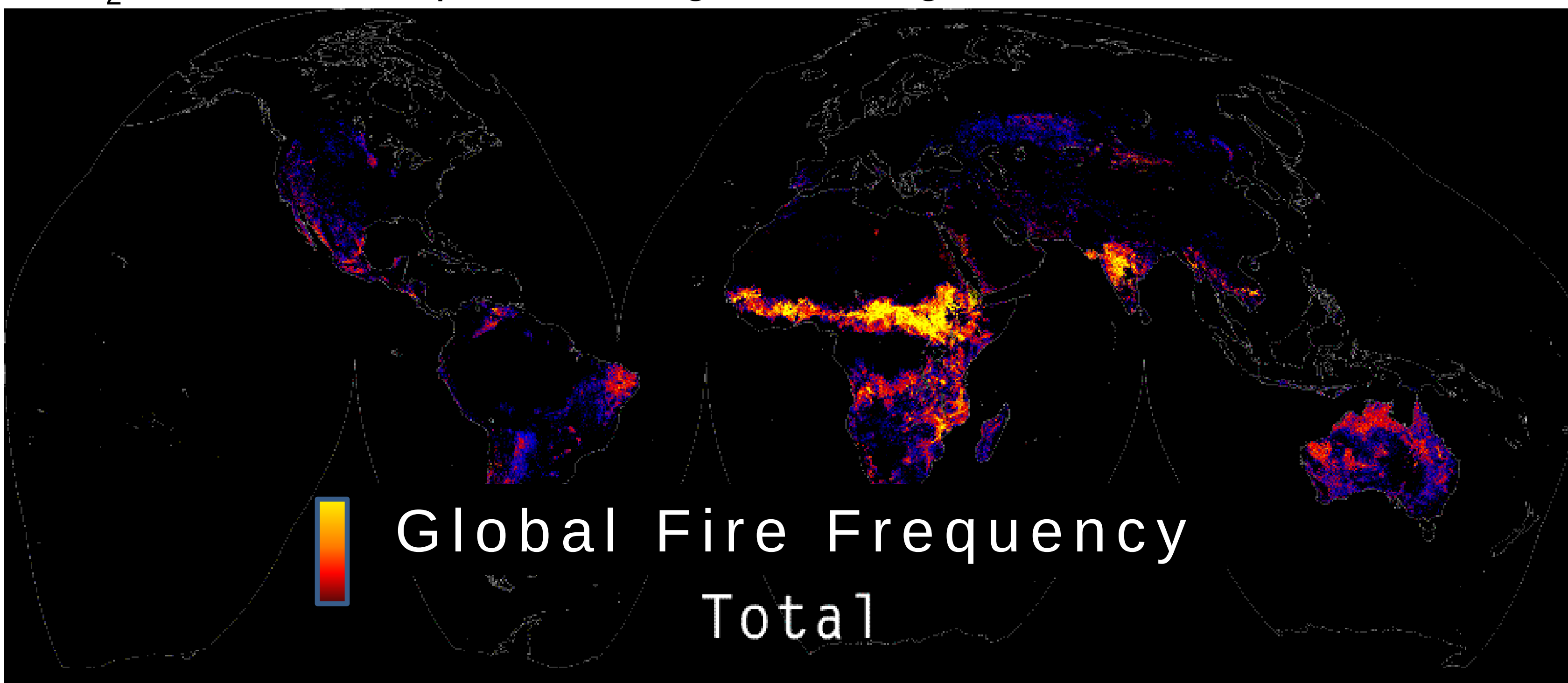
Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

The Carbon Cycle and Climate

- If fire frequency and extent increase with a changing climate, a net increase in CO_2 emissions is expected during this fire regime shift.



Global Burned Area 1981-2000 from NOAA-NASA Pathfinder Data

Riaño et al. 2007. Global Change Biology

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

Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

7.3.3 Terrestrial Carbon Cycle Processes and Feedbacks to Climate

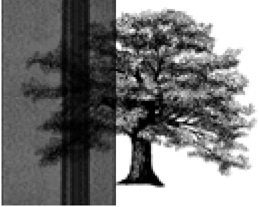
To understand the reasons for CO_2 uptake and its likely future course, it is necessary to understand the underlying processes and their dependence on the key drivers of climate, atmospheric composition and human land management.

Drivers that affect the carbon cycle in terrestrial ecosystems can be classified as:

(1) direct climate effects (changes in precipitation, temperature and radiation regime);

(**2) atmospheric composition effects** (CO_2 fertilization, nutrient deposition, damage by pollution); and

(3) land use change effects (deforestation, afforestation, agricultural practices, and their legacies over time).



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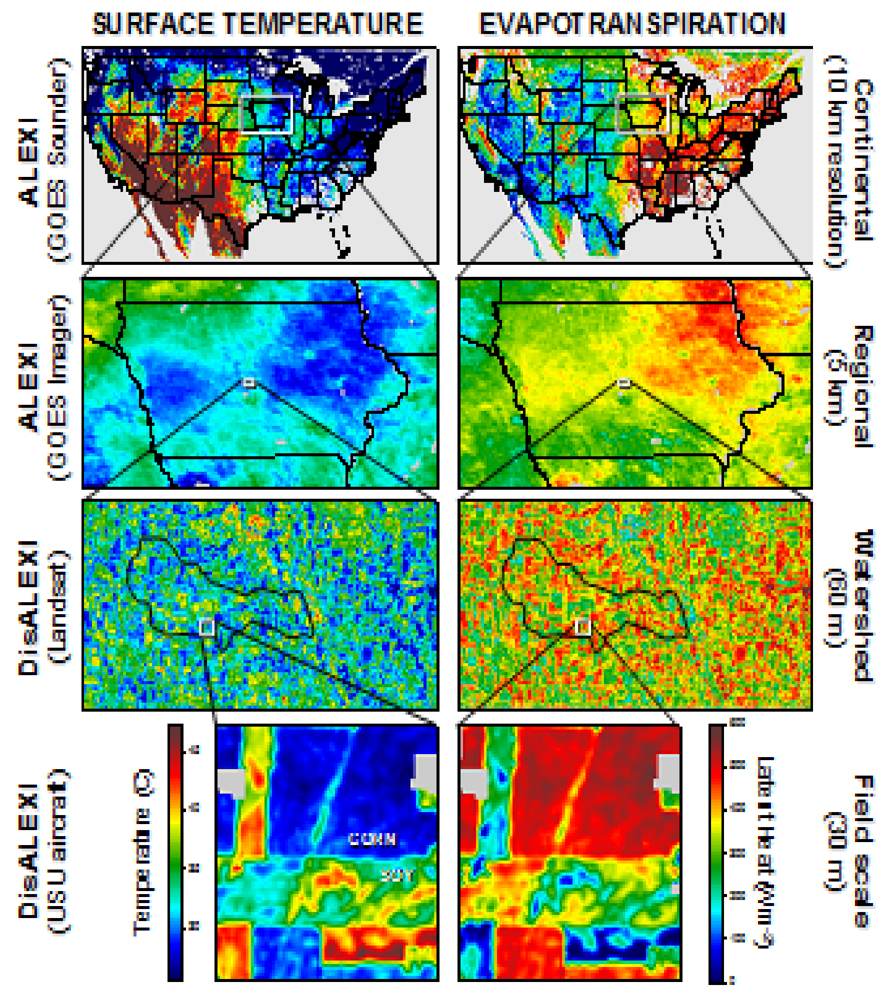
Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

7.1.1 Terrestrial Ecosystems and Climate

The terrestrial biosphere interacts strongly with the climate, providing both positive and negative feedbacks due to biogeophysical and biogeochemical processes.

Some of these feedbacks, at least on a regional basis, can be large. Both radiative and non-radiative terms are controlled by details of vegetation.



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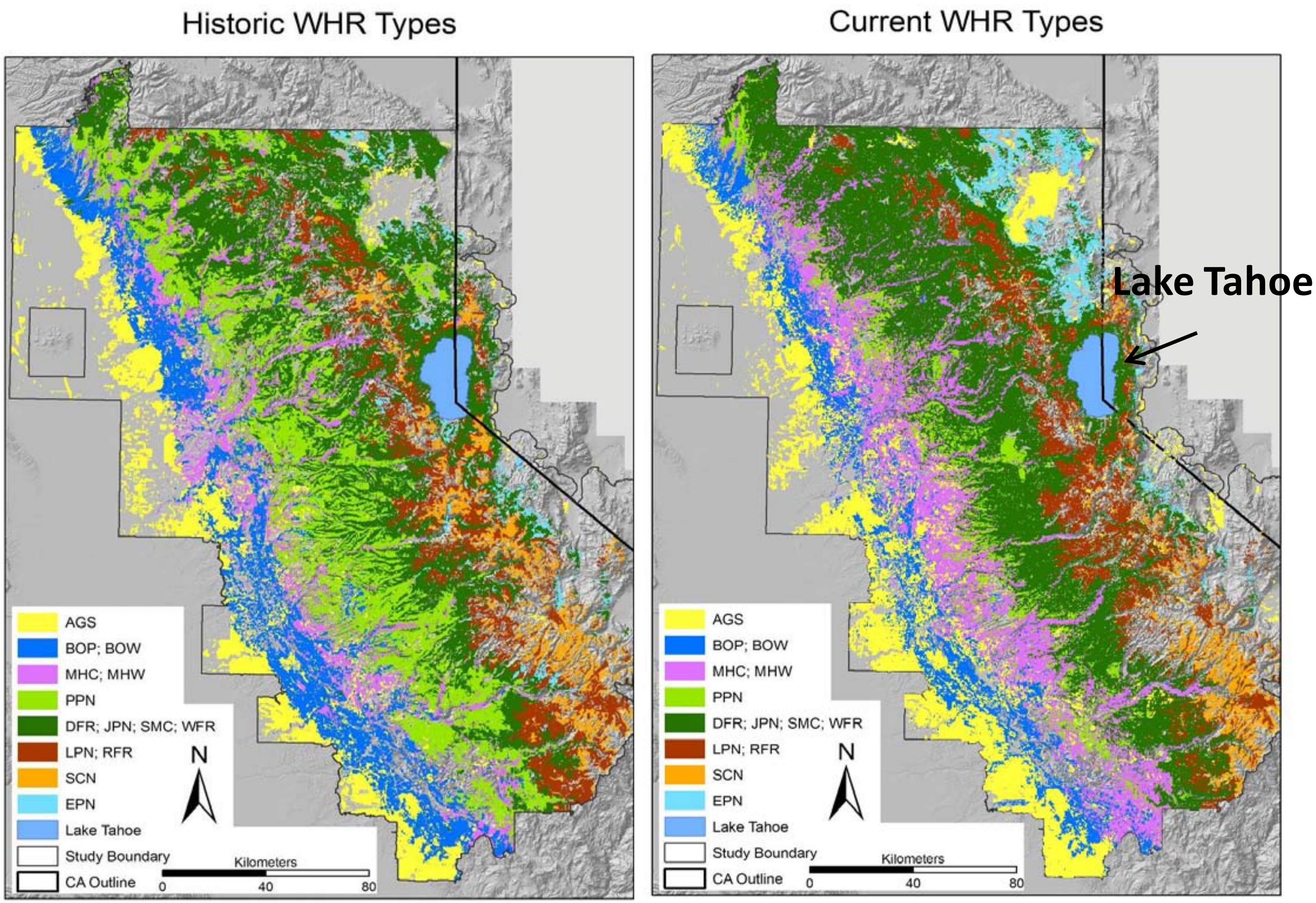
Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

7.1.1 Terrestrial Ecosystems and Climate: Carbon Cycle Drivers

Changing Plant Functional Types in California from 1934 to 1996

Grasslands
Mixed oak-pine savanna
Ponderosa pine forest
Mixed Montane Hardwod & Conifer
Mixed conifer
Lodgepole pine, red fir
Subalpine conifers



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

2.5.8 Effects of Carbon Dioxide Changes on Climate via Plant Physiology: ‘Physiological Forcing’

Radiative Forcing and Physiological Forcing

As well as exerting an RF on the climate system, increasing concentrations of **atmospheric CO_2 can perturb the climate system through direct effects on plant physiolog**y.

A decrease in **moisture flux modifies the surface energy balance**, increasing the ratio of sensible heat flux to latent heat flux and therefore warming the air near the surface (Sellers et al., 1996; Betts et al., 1997; Cox et al., 1999). Betts et al. (2004) proposed the term ‘physiological forcing’ for this mechanism.

Increased CO_2 concentrations can ‘fertilize’ plants by stimulating photosynthesis, Models suggest this has contributed to increased vegetation cover and leaf area over the 20th century (Cramer et al., 2001).

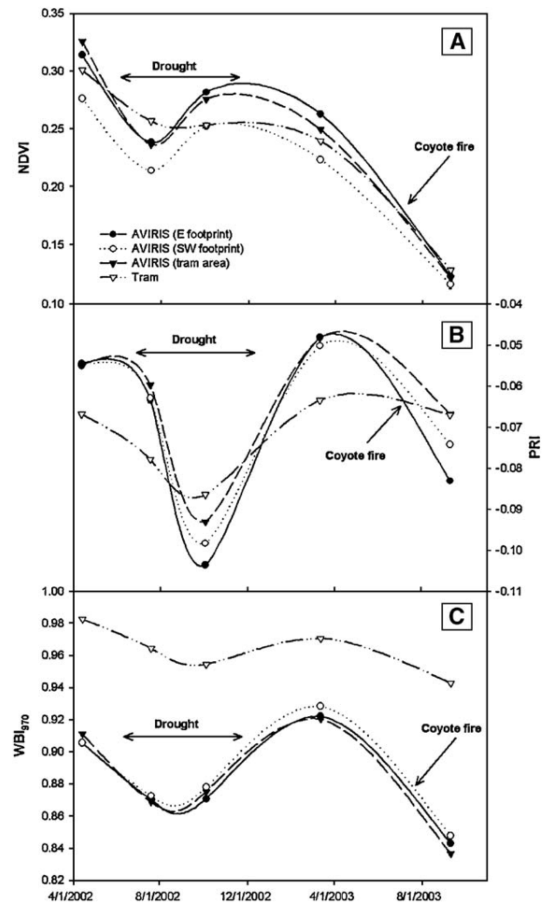
IPCC Climate Change 2007: Working Group I: The Physical Science Basis

2.5.8 Effects of Carbon Dioxide Changes on Climate via Plant Physiology: ‘Physiological Forcing’

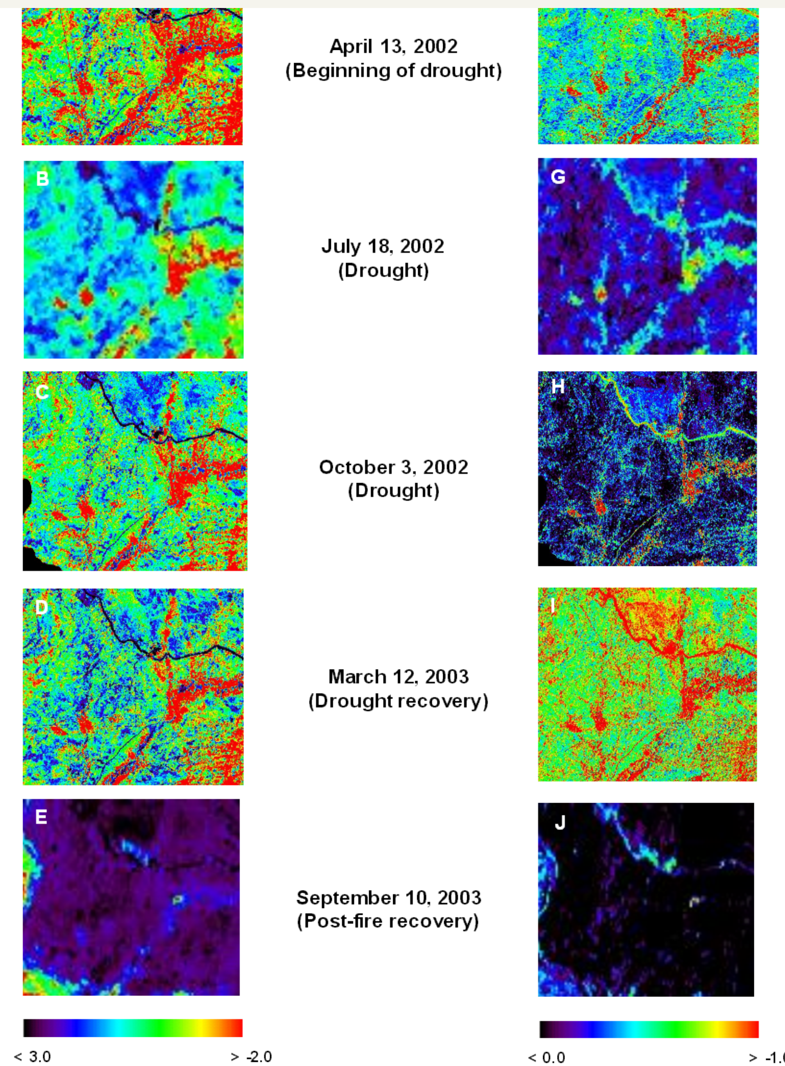
Radiative Forcing and Physiological Forcing

Interactions bertween water and carbon

Spatial and temporal patterns of carbon and water vapor fluxes,
Sky Oaks, CA



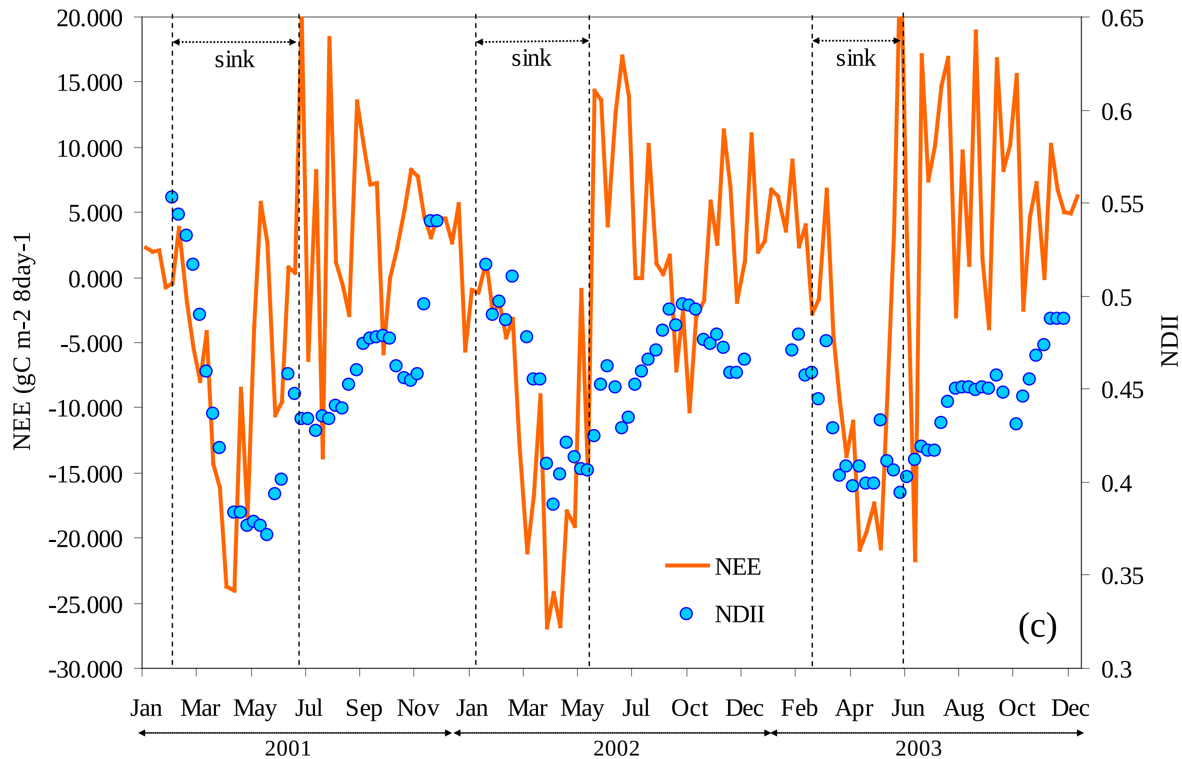
Fuentes et al. 2006



Role of HyspIRI: detect responses of ecosystems to human land management and climate change and variability (Decadal Survey, P. 114)

Drought affects the magnitude and timing of water and carbon fluxes, causing plant water stress and death and possibly wildfires and changes in species composition

- Detect early signs of ecosystem change through altered physiology, including agricultural systems

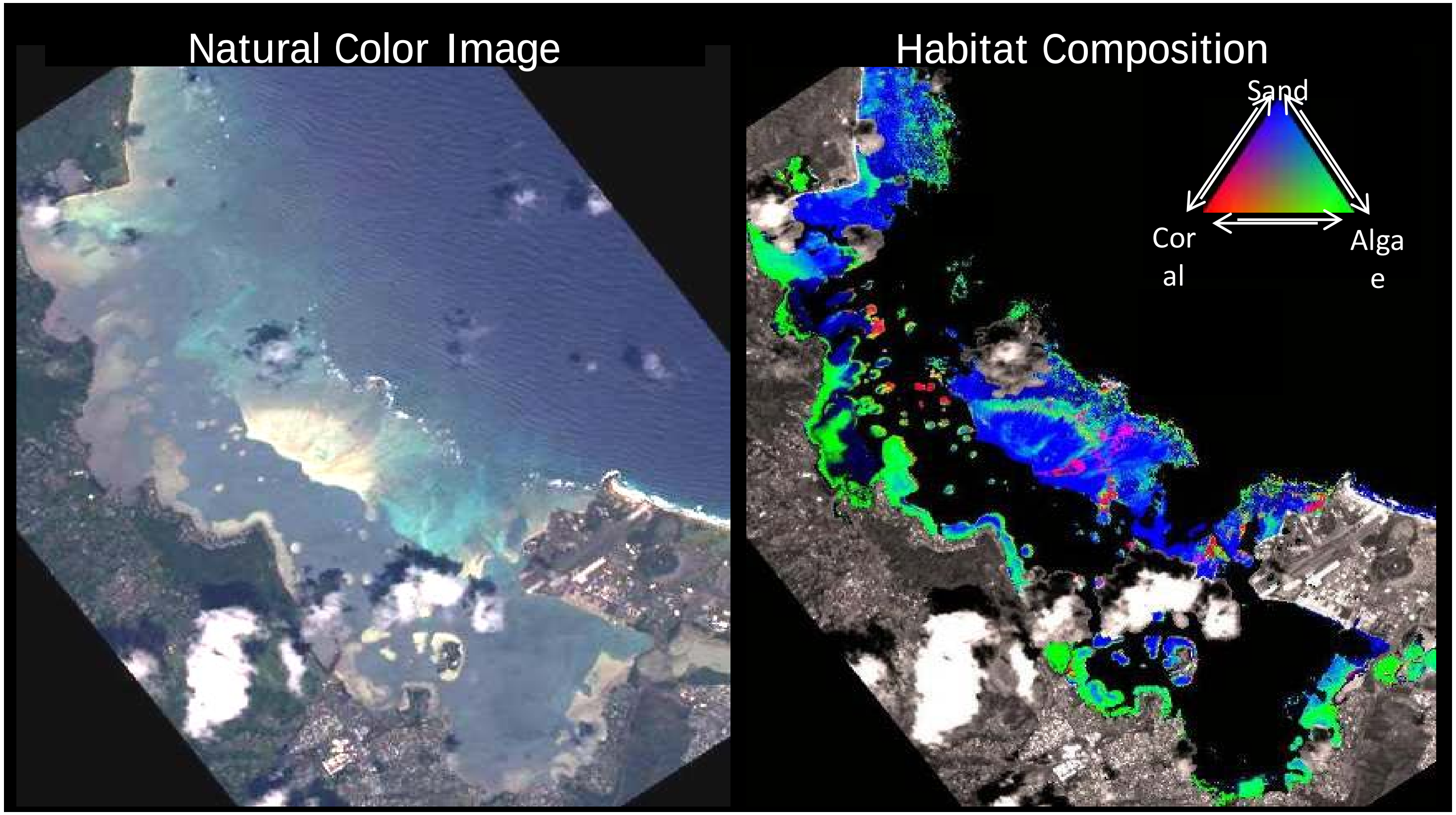


3 Years of NEE and canopy water content (NDII) from an old growth conifer forest

Cheng, Y-B., P.J. Zarco-Tejada, S.L. Ustin, S. Wharton, M. Falk, and K. T. Paw U. International Journal of Applied Remtoe Sensing 2007

Role of HyspIRI: Detect responses of ecosystems to human land management and climate change and variability (Decadal Survey, P. 114)

Detect changes in the health and extent of coral reefs, a bellwether of climate change.



J. Goodman and S. Ustin, Int. J. Applied Remote Sensing, 2007

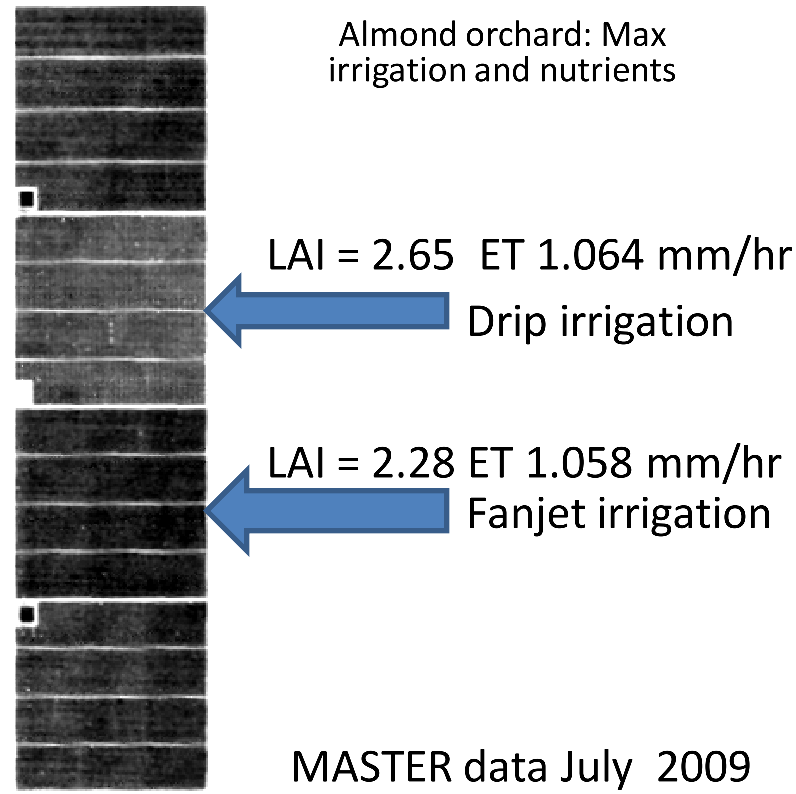
IPCC Climate Change 2007: Working Group I: The Physical Science Basis

Chapter 7: Couplings Between Changes in the Climate System and Biogeochemistry: Executive Summary

Reactive Gases and Climate

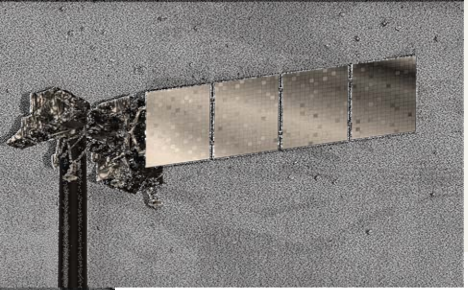
•Observed increases in atmospheric methane concentration, compared with pre-industrial estimates, ***are directly linked to human activity, including agriculture, energy production, waste management and biomass burning***.

Observed increases in NO_x and nitric oxide emissions, compared with pre-industrial estimates, are very likely ***directly linked to 'acceleration' of the nitrogen cycle driven by human activity, including increased fertilizer use, intensification of agriculture*** and fossil fuel combustion.

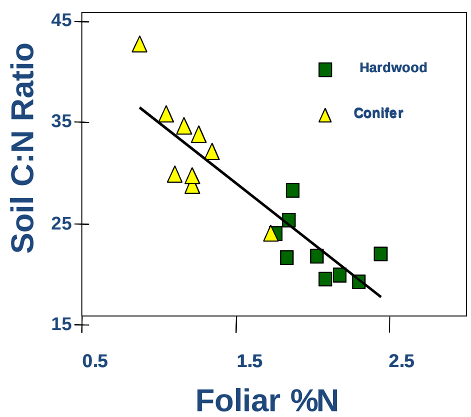


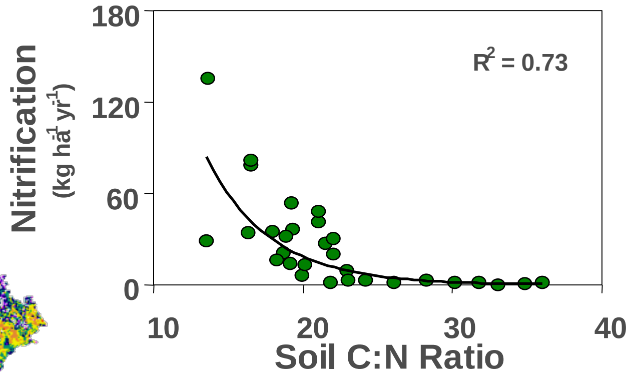
Decadal Survey: Relevance of HyspIRI to Carbon and Climate Science:

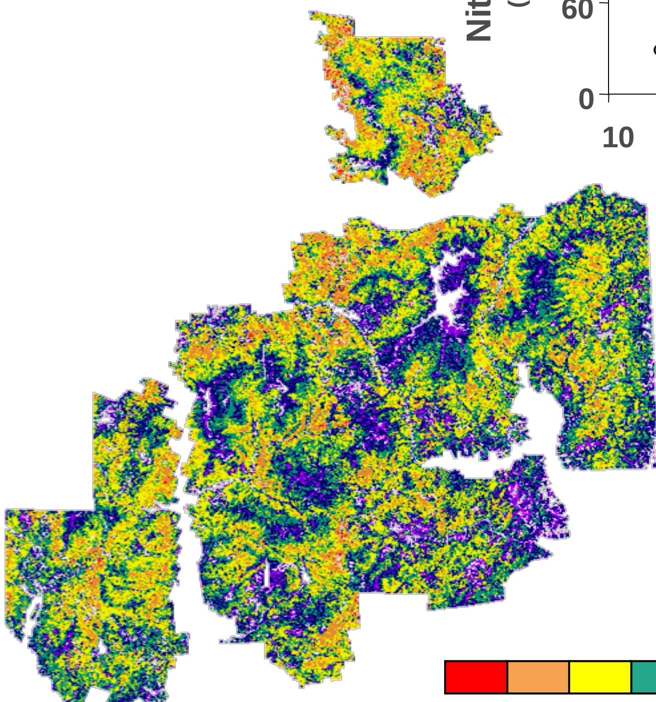
Ecosystem Function and Services

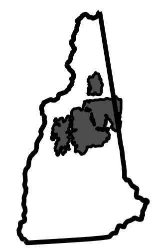


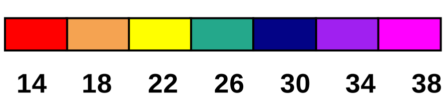
HyspIRI is required to detect and diagnose changes in ecosystem function, such as water and nutrient cycling and species composition (Decadal Survey p. 29).

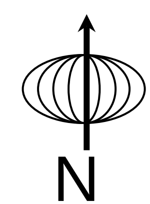




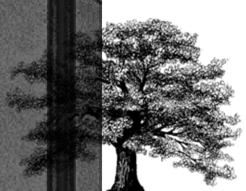








Predicted Foliar Chemistry (PC) from Spectroscopy Is Used to Estimate Soil Nitrogen Cycling



Decadal Survey: HyspIRI

BOX 7.2 SCIE NCE THEMES AND Key Questions (Page 192)

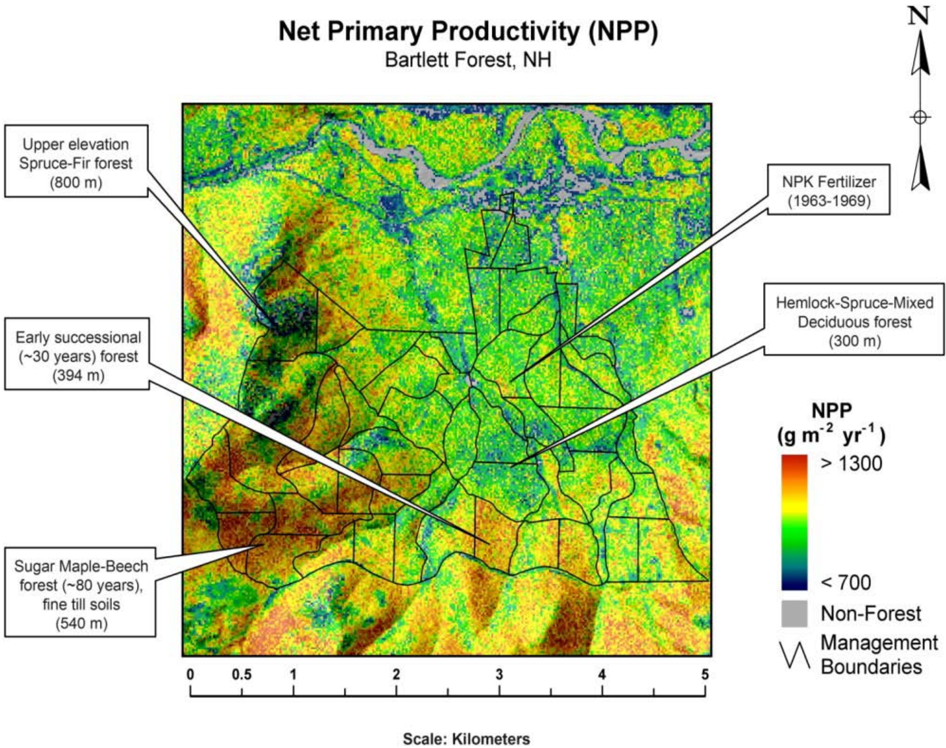
Disruption of the Carbon, Water, and Nitrogen Cycles

Key Questions for Identifying Priorities for Satellite Observations for Understanding and Managing Ecosystems

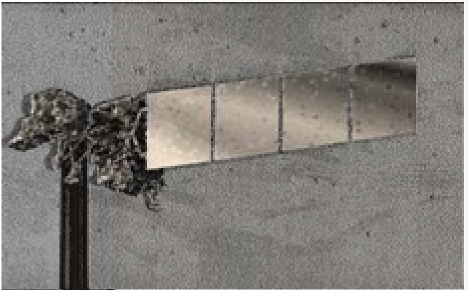
How does climate change affect the carbon cycle?

How does changing terrestrial water balance affect carbon storage by terrestrial ecosystems?

How do increasing nitrogen deposition and precipitation affect terrestrial and coastal ecosystem structure and function and contribute to climate feedbacks?



Net primary production (NPP) **scales with Nitrogen NOT leaf area index (LAI)** as derived from imaging spectroscopy data over the Bartlett National Forest, New Hampshire. Figure adapted from S.V. Ollinger and M.L. Smith, (2005) *Ecosystems* **8** (2005), pp. 760–778.



Decadal Survey: HyspIRI

BOX 7.2 SCIE NCE THEMES AND Key Questions

Changing Land Resource Use (Page 192)

Key Questions for Identifying Priorities for Satellite Observations for Understanding and Managing Ecosystems

What are the consequences of uses of land and coastal systems, such as urbanization and resource extraction, for ecosystem structure and function?

- How does land use affect the carbon cycle, nutrient fluxes, and biodiversity?
- What are the implications of ecosystem changes for sustained food production, water supplies, and other ecosystem services?
- What are the options for diminishing potential harmful consequences on ecosystem services and enhancing benefits to society?

ASTER June 2002

Decadal Survey: HyspIRI

BOX 7.2 SCIE NCE THEMES AND Key Questions (Page 192)

Changes in Disturbance Cycles

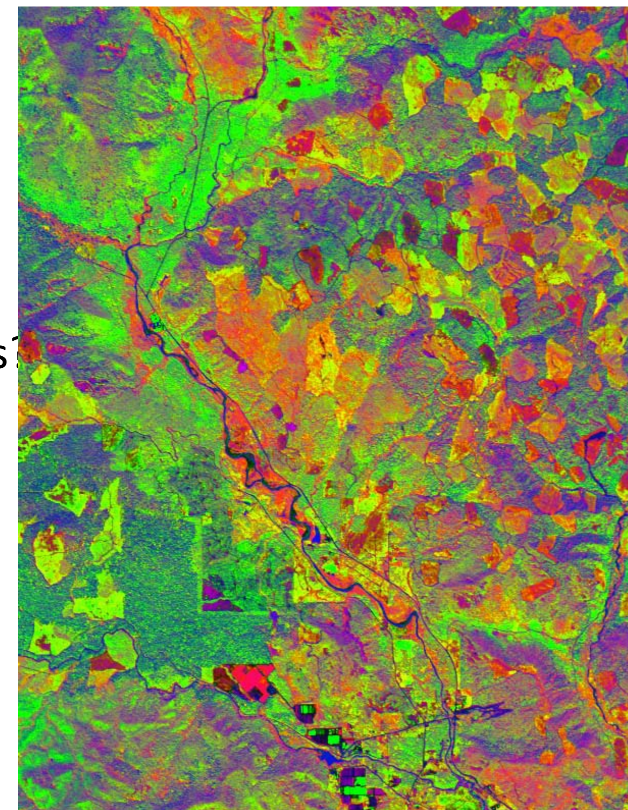
How does climate change affect such disturbances as fire and insect damage?

What are the effects of disturbance on productivity, water resources, and other ecosystem functions and services?

How do climate change, pollution, and disturbance interact with the vulnerability of ecosystems to invasive species?

How do changes in human uses of ecosystems affect their vulnerability to disturbance and extreme events?

AVIRIS, MNF image TT Munger Research Site, Gifford Pinchot NF, Washington



Ustin and Trabucco, 2000

Swiss Needle Cast

Decadal Survey: Relevance of HyspIRI to Carbon and Climate Science

Decadal Survey Recommendation:

A hyperspectral sensor combined with a multispectral thermal sensor in low Earth orbit (LEO**) is part of an integrated mission concept** described in DS Parts I and II that is relevant to several panels, ***especially the climate variability panel***. p. 368, DS,

HyspIRI Mission Concept

Bogdan Oaida, with contributions from many

[bogdan.oaida@jpl.nasa.gov]

Jet Propulsion Laboratory
California Institute of Technology

National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

HyspIRI Mission Concept

Orbit Selection

- Key Orbit Design Considerations
  - Local time of observations
    - Sun-synchronous
    - 10:30 AM LTDN
  - Altitude
    - Low Earth Orbit
    - Repeating Ground track
  - Global coverage in a minimum number of days given the swath-width of each instrument.
    - VSWIR: 19 days revisit at the equator
    - TIR: 5 day revisit at the equator (1 day + 1 night)
- 626 km altitude at equator suits the needs of both instruments

Orbit selection and operations concept meet science requirements with very infrequent ground commanding or maintenance.

Operations Concept

- Systematic mapping vs. pointing capability
- Target map driven - No need for uploading acquisition sequences
- High resolution mode and Low resolution mode
- Direct Broadcast capability
  - Uses Intelligent Payload Module
  - Applications-driven

Operational Requirement	VSWIR	TIR
10:30 am sun-sync orbit	✓	✓
626 km altitude at equator	✓	✓
19 days revisit at the equator	✓	
5 day revisit at the equator		✓
Day Observation	✓	✓
Night Observation		✓
Pointing strategy to reduce sun glint	✓	
Surface reflectance in the solar reflected spectrum for elevation angles >20	✓	
Avoid terrestrial hot spot	✓	
Monthly Lunar View calibration	✓	✓
Weekly Solar View Calibration	✓	
Blackbody View Calibration		✓
Deep Space View Calibration		✓

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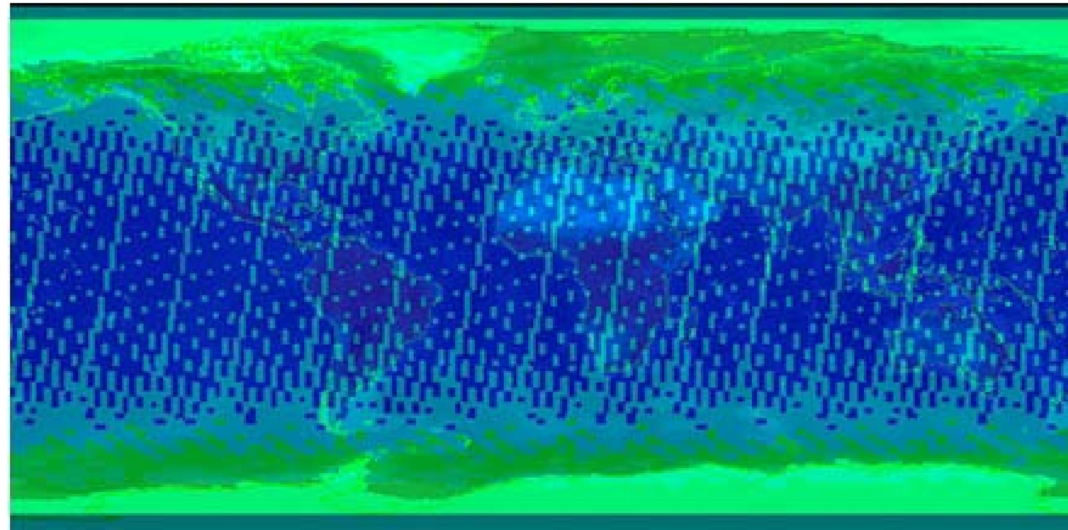
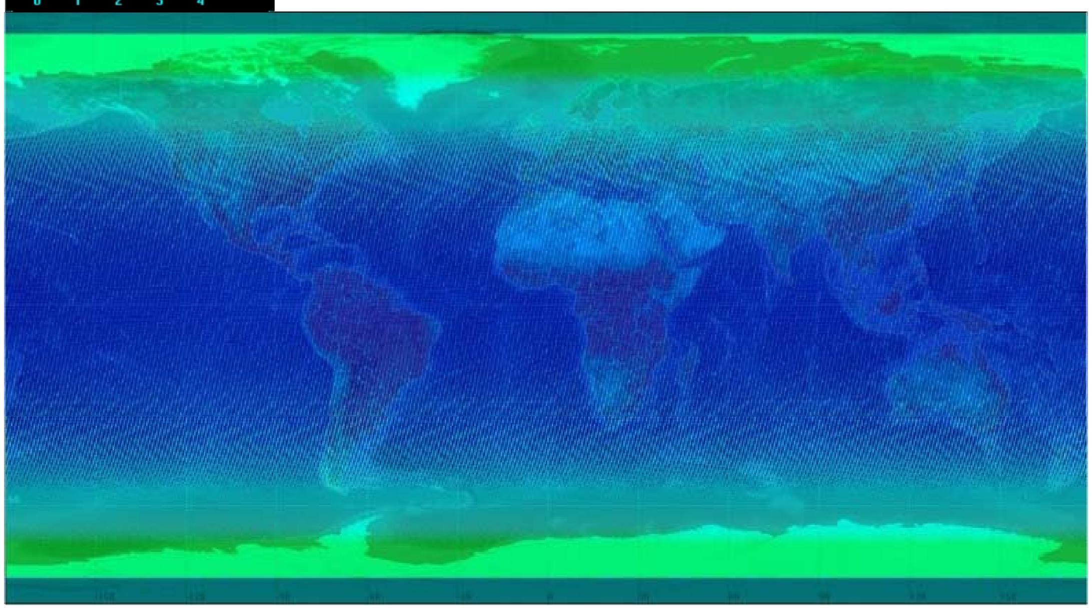
HyspIRI Global Coverage

- Due to the min 20 deg Sun elevation angle constraint on the VSWIR acquisition, the latitudes covered change with the seasons



TIR Coverage after 5 days

VSWIR Coverage after 19 days



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Pasadena, California

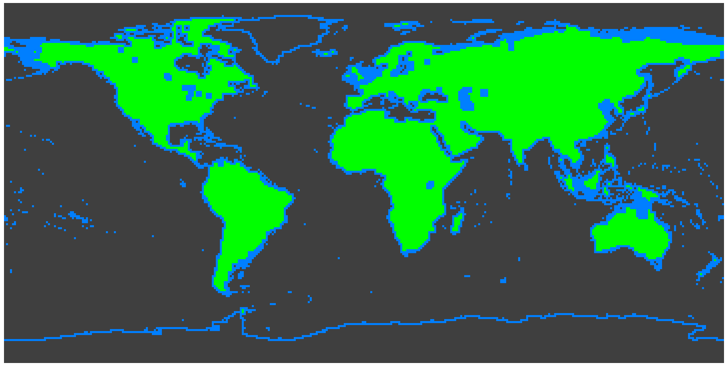
Data Acquisition Scenario

- Systematic mapping vs. pointing capability
- Target map driven - No need for uploading acquisition sequences
- Data acquisition driven by land and coastal aquatic (<50m depth) coverage
  - Impact by low resolution modes on data volume is relatively small
- Both instruments on 24/7, but VSWIR not acquiring data at 100% duty cycle
- Low-latency products available via Direct Broadcast system
  - Applications (not science) driven

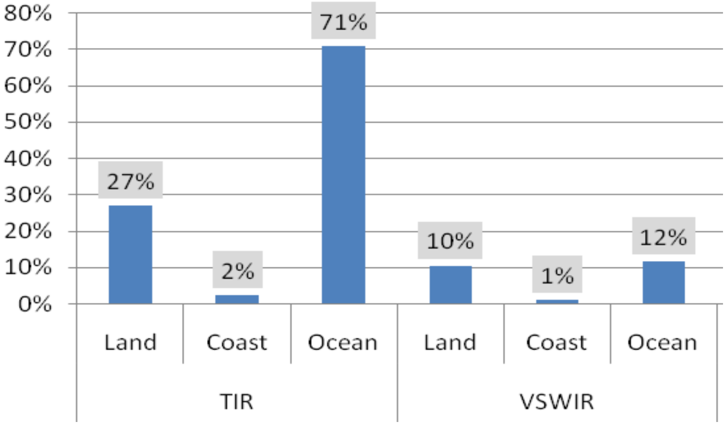
Imaging Mode

Instrument	Land	Coastal	Deep Ocean	Greenland	Antarctica
VSWIR	60 m	60 m	1 km	1 km	1 km
TIR	60 m	60 m	1 km	1 km	1 km

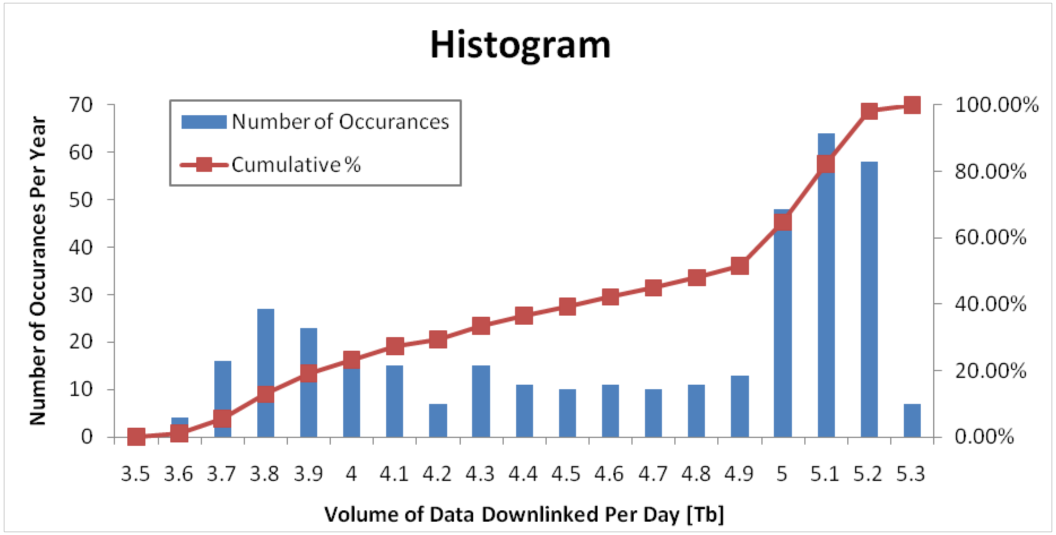
Target Map



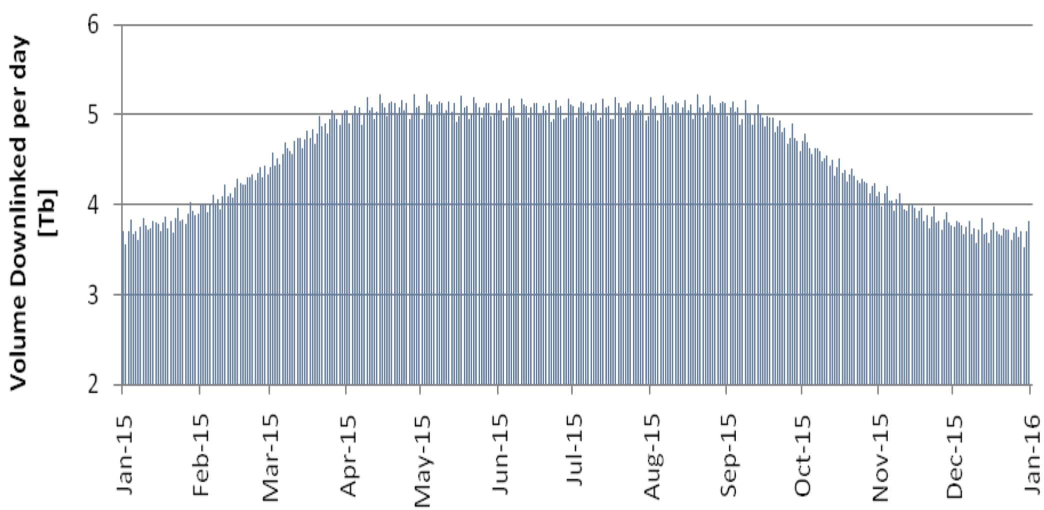
Duty Cycle



HyspIRI Data Volume



	Rate (Mbps)	On-board Compression
VSWIR: land	804.1	3:1
VSWIR: shallow	865.9	3:1
VSWIR: ocean	3.9	3:1
TIR: land	130.2	2:1
TIR: shallow	130.2	2:1
TIR: ocean	0.6	2:1



	Avg (Tb)	Min (Tb)	Max (Tb)
Per Day	4.59	3.53	5.22
Per Orbit	0.30	0.00	0.73

Total data volume for the 3 year mission: 5024 Tbits

Managing Data Volume

- On-board storage (current baseline)
  - 3.1 Tb capacity (~65% used nominally)
  - WorldView-1 and -2 have 2.2 Tb SSR
    - WorldView1: 0.33 Tb/orbit
    - WorldView2: 0.52 Tb/orbit
- Downlink method
  - X-band (current baseline)
    - 800 Mbps, dual-pole, to Svalbard and Trollsat (KSAT); Poker Flats used as backup
    - WorldView-1 and GeoEye-1 use similar downlink architecture
- Ground communications / latency
  - Back end infrastructure may need upgrading to ensure timely delivery of data

HyspIRI will require more capabilities than currently used by NASA. Suitable solutions are being used by existing commercial missions.

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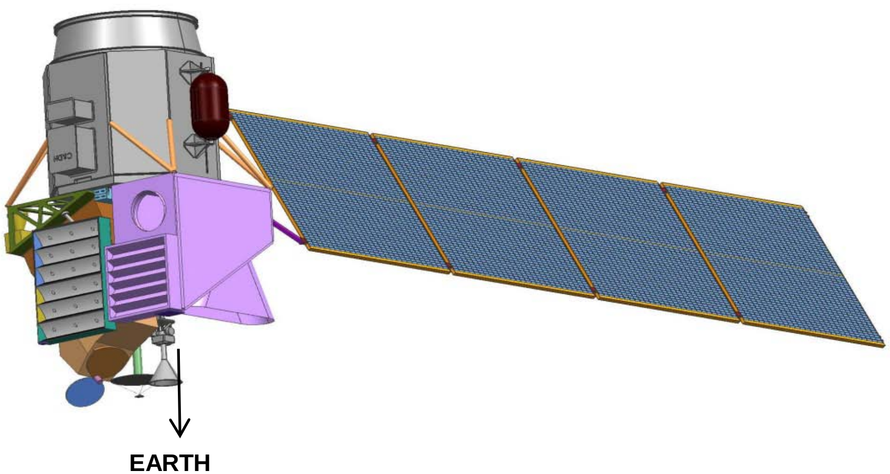
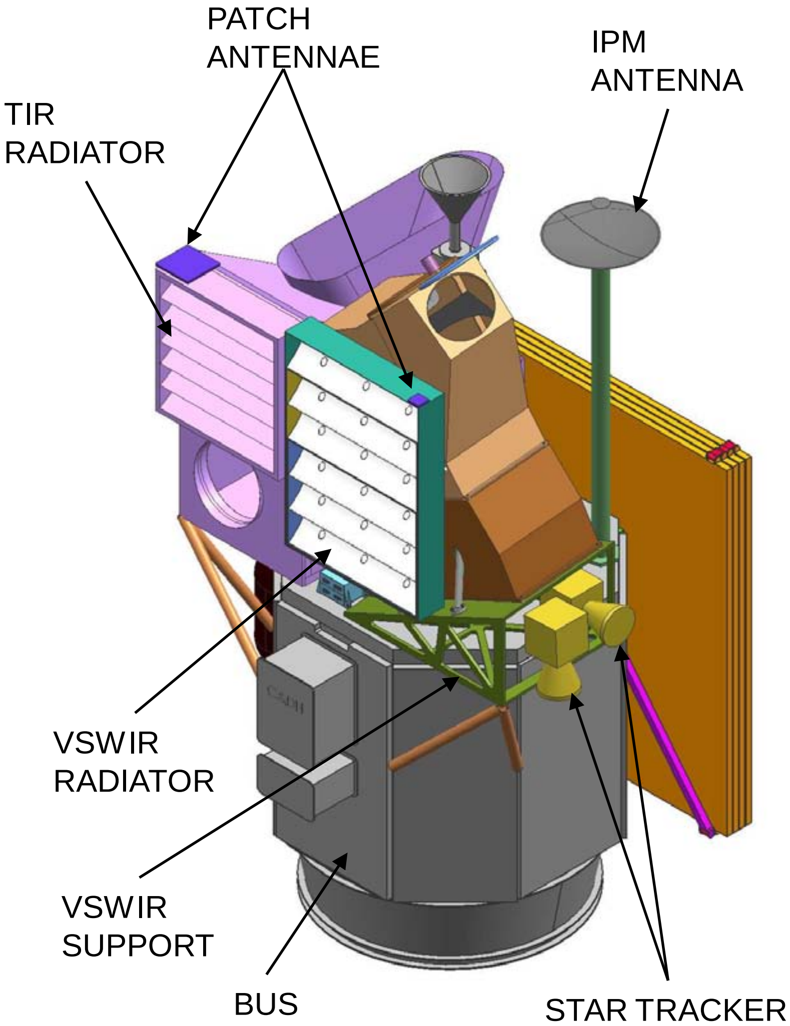
Flight System Concept

- Industry procured spacecraft bus
  - SA-200HP used as an example for the study to identify and cost needed modifications
- HyspIRI specific
  - Payload integrated on the top plate (TIR, VSWIR) and inside the S/C
  - Configuration chosen to minimize/eliminate thermal impacts on the payload radiators
  - Spacecraft Dry Mass (CBE): 530 kg
  - Launch Mass: 693 kg
  - JPL DP Margin: 30%
  - Required Power (CBE): 620W
  - Available Power: 965W, 7.2 m^2 array





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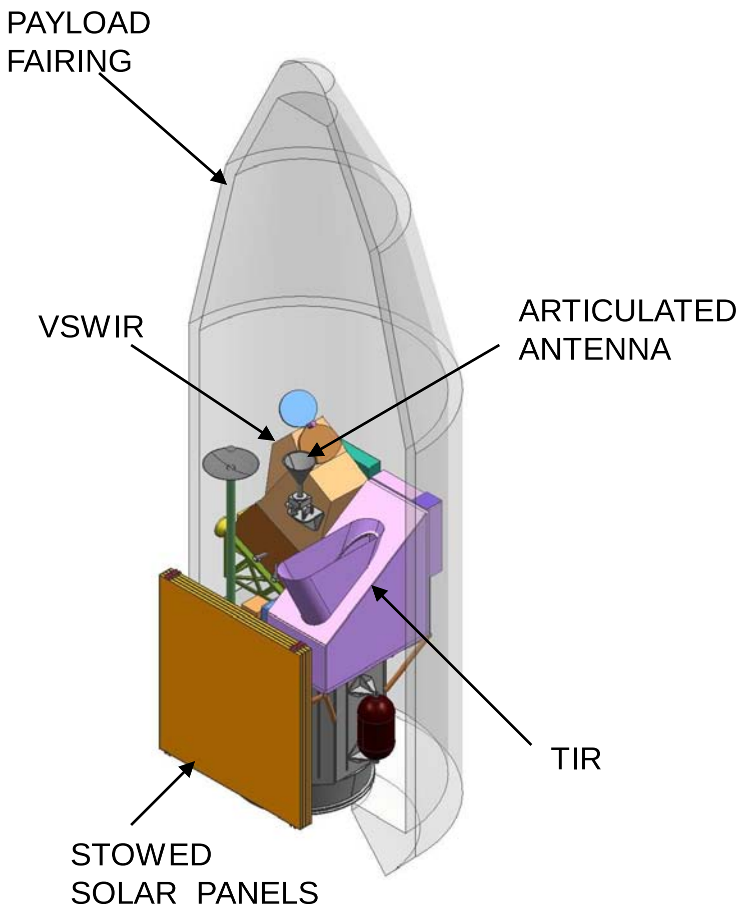
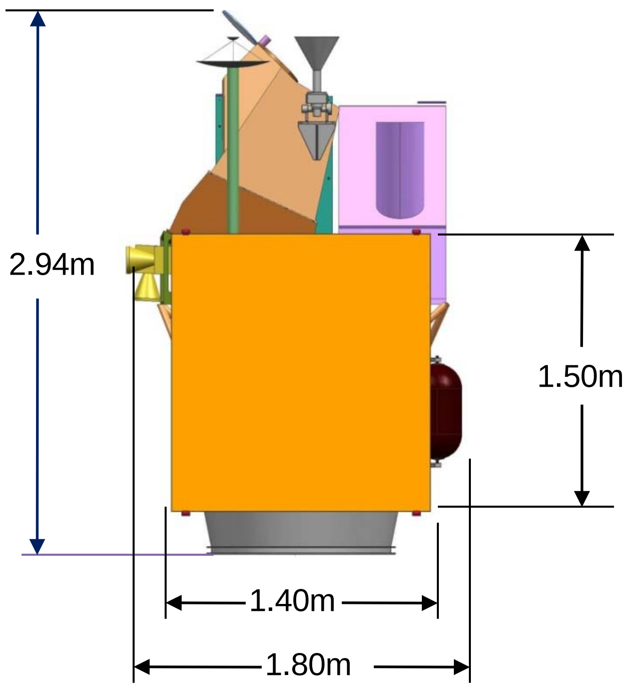
Launch Vehicle Concept



- Taurus 3210 can meet the mission needs
  - Closest fit among currently NASA approved launchers
  - 30% margin (dry-mass CBE) with a Taurus-class launch vehicle
  - Fits dynamic volume envelope
  - 790 Kg launch capacity for HyspIRI Orbit
- Launch window
  - Mapping orbit reachable once per day



Payload Accommodation and System Margins

Accommodations	VSWIR	TIR
Mass (CBE)	60 kg	64 kg
Volume	1.1 x 0.5 x 0.8 m	1.2 x 1.1 x 0.6 m
Power	41 W	103 W
FOV (crosstrack)	13.62 deg	50.7 deg
FOV (alongtrack)	95.9 microrad	95.9 microrad
Orientation	4 deg to starboard	nadir
Pointing		
Accuracy	165 arcsec (3σ/axis)	
Knowledge	2 arcsec (Pitch/Yaw axis 3σ); 8 arcsec (Roll axis 3σ)	
Stability	5 arcsec/sec (3σ)	

	Required	Design	Margin (D-R)/D
Swath width VSWIR	141km	151 km	6%
Swath width TIR	536km	600 km	11%
Recorder capacity	2.0 Tb	3.1 Tb	37%
Power	620 W (CBE)	965 W	36%
LV mass capability	530 (CBE, dry)	790 kg	32%

BACKUP

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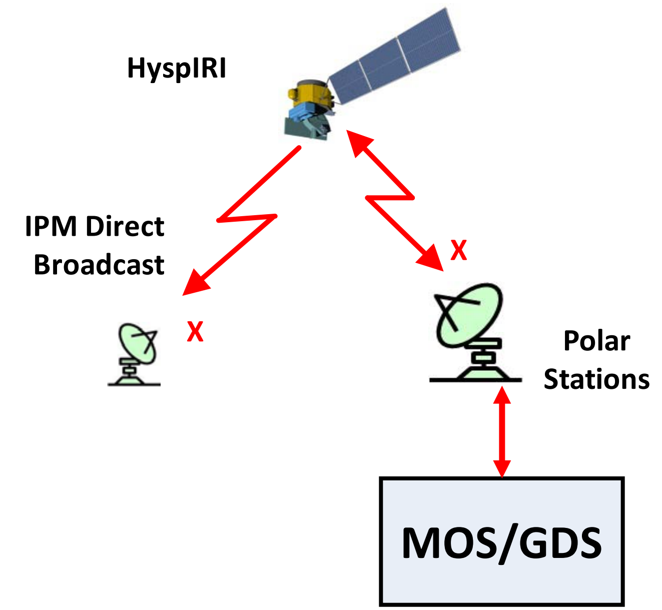
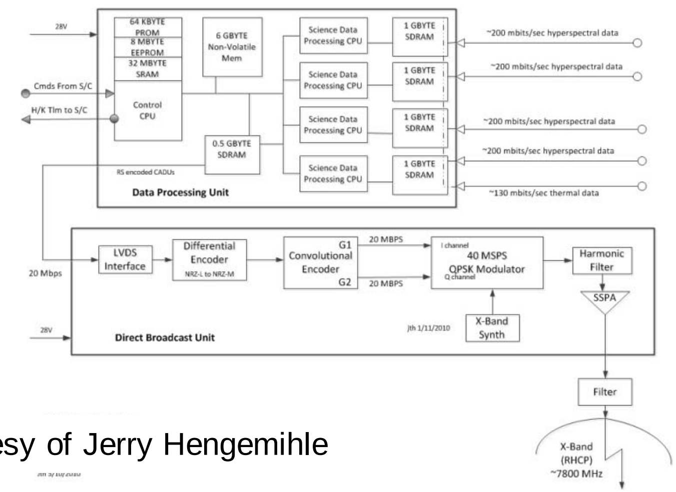
Low Latency Data – Direct Broadcast

- Direct Broadcast Capability
- Low latency data (<6hrs)
- Applications Driven, Targeted Science
  - Non-stop data acquisition
  - Decision making capability
- Not tech development
- Design taken from NPP's high rate data (HRD) broadcast system
- Baseline design
  - 20 Mbps X-band
  - An Earth-coverage dish estimated at 0.5 m diameter
    - Reflector is shaped to provide peak gain at ~60 degrees off boresight
- Any user should be able to receive data when S/C is above 5 degrees





Courtesy of Jerry Hengemihle

The DB capability will make use of high heritage technology and existing algorithms to enable the development of low latency data products and applications.

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Ground Station Capability

NASA

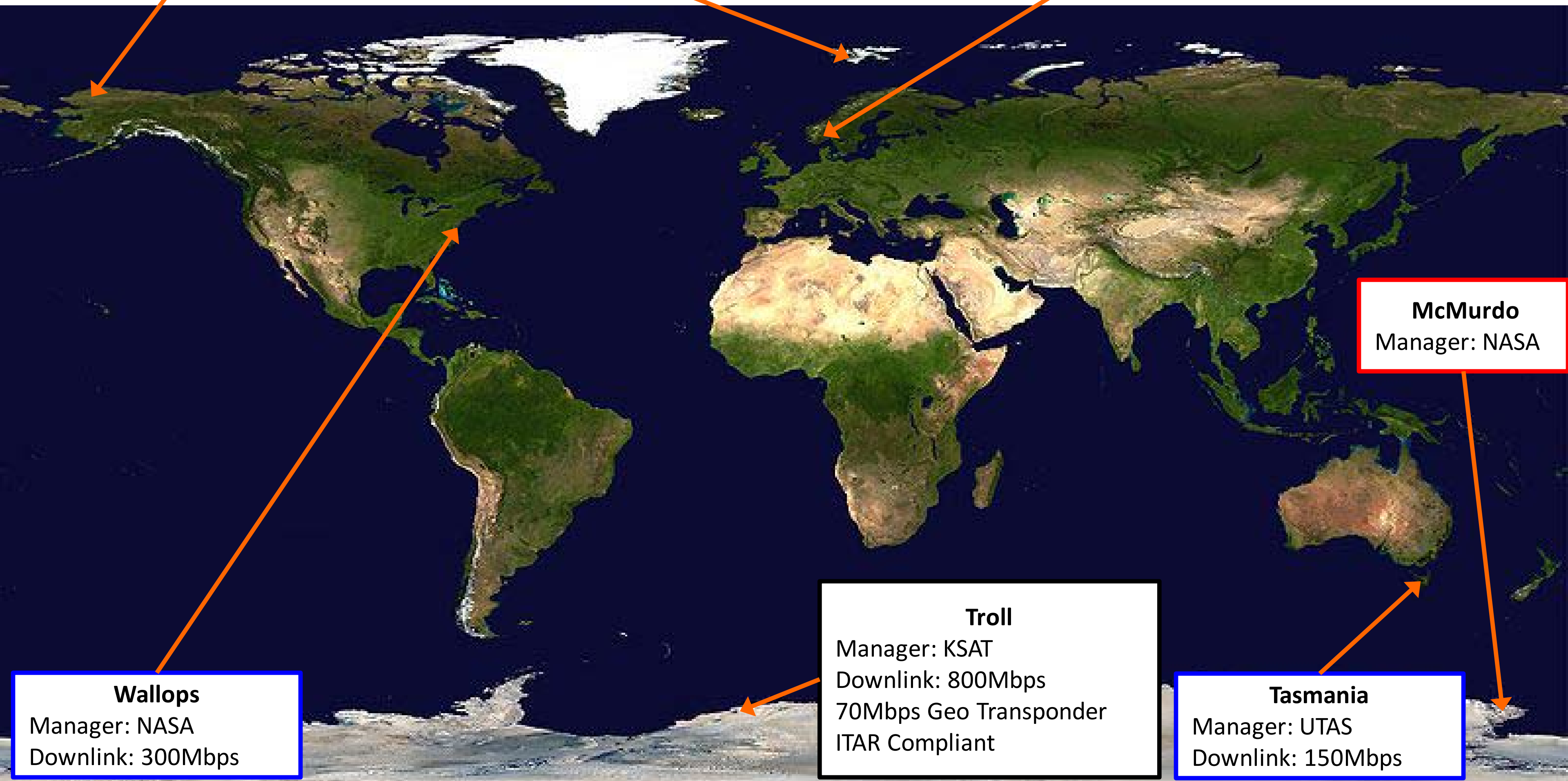
Non-NASA

Not Used

Poker Flats
Manager: USN
Downlink: 150Mbps

Svalbard
Manager: KSAT
Downlink: 800Mbps

Tromsø
Manager: KSAT
Downlink: 800Mbps



McMurdo
Manager: NASA

Wallops
Manager: NASA
Downlink: 300Mbps

Troll
Manager: KSAT
Downlink: 800Mbps
70Mbps Geo Transponder
ITAR Compliant

Tasmania
Manager: UTAS
Downlink: 150Mbps

Description and Examples of Typical VSWIR and TIR Image Collections

Robert G. Knox, for the HyspIRI concept study team

NASA's Goddard Space Flight Center,

Biospheric Sciences Branch, Code 614.4

Greenbelt, MD

HyspIRI Science Symposium on Ecosystem Data Products

May 4, 2010

Introduction

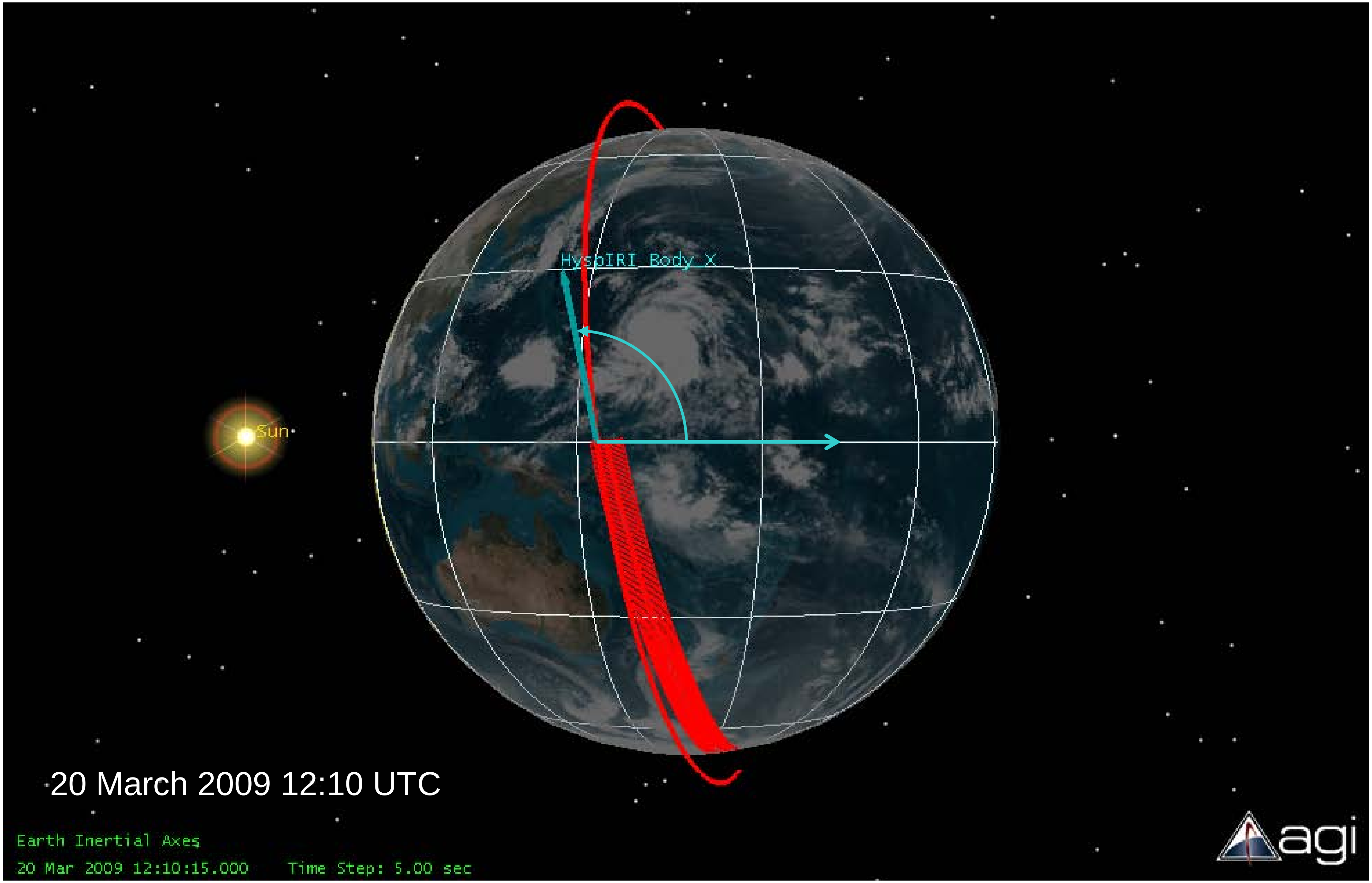
Context

- The HyspIRI mission, as budgeted, provides level 0, 1, and 2 products.
- Investigators, multi-investigator teams, or broad collaborations need to develop the level 3 or 4 data products that will meet HyspIRI's wider objectives.
- Level 2 data are provided at the native resolution (spatial and temporal) of HyspIRI's sensors.

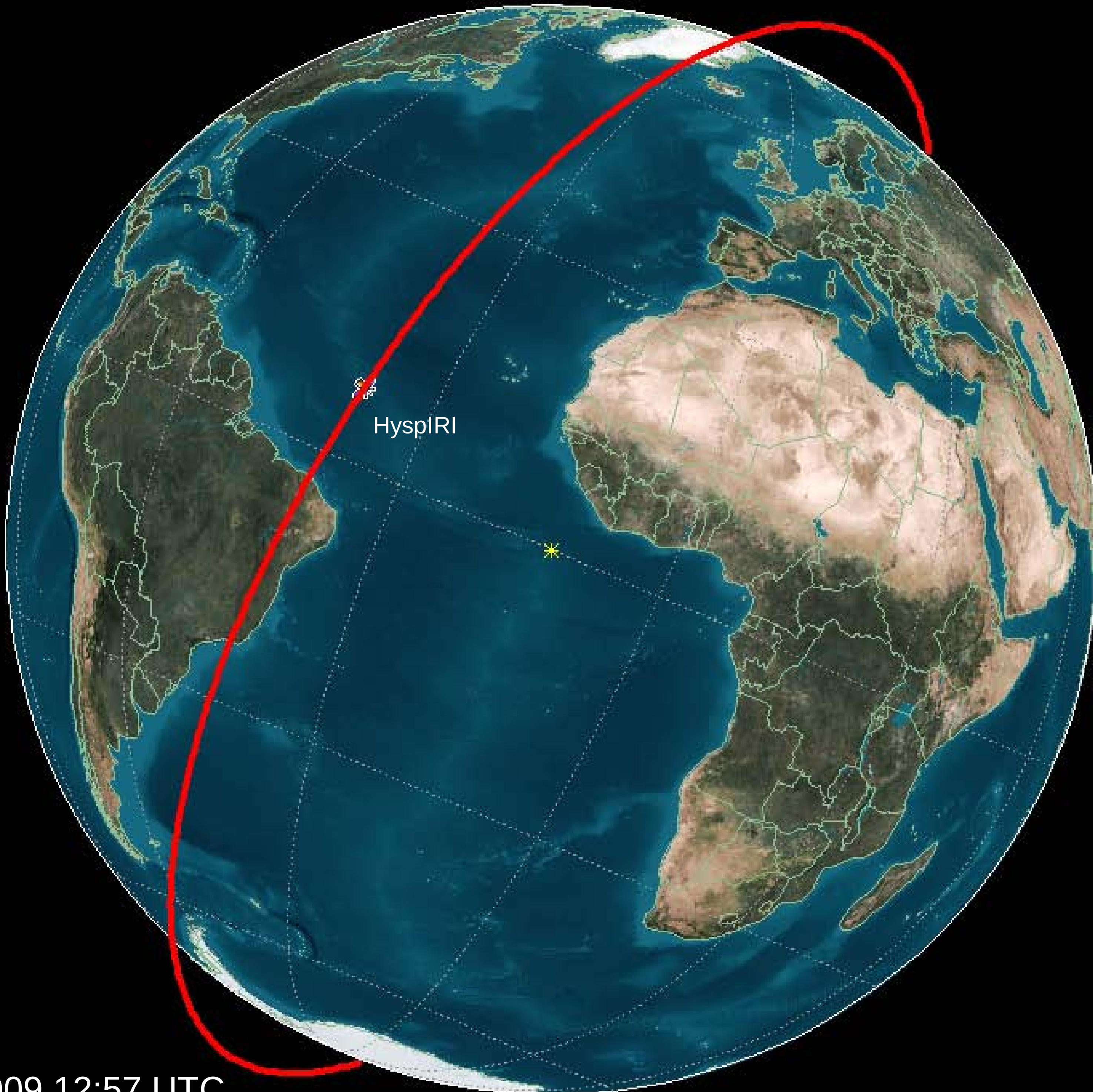
Outline

- Orbital geometry and repeat cycles for a suitable reference orbit
- Imaging opportunities for each sensor (TIR & VSWIR)
  - Variation in frequency with latitude
  - Overpass times/dates for example sites
- Issues for developers of level 3/4 data products.

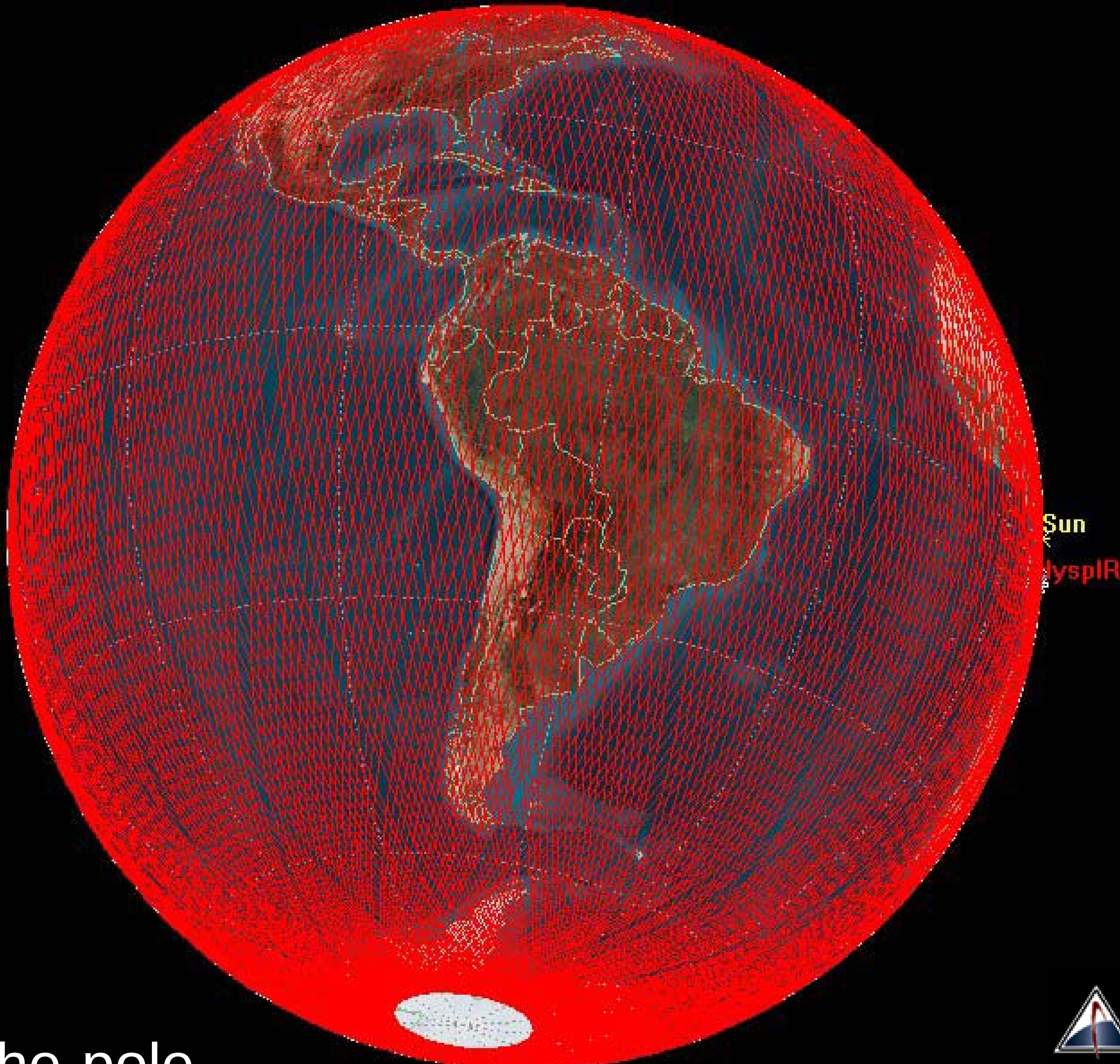
Orbital inclination (97.9°) represents the angle between the Earth's equatorial plane, and the orbit plane, measured (by convention) at an ascending node.



Night-side view, looking towards the Sun in the plane of the equator. Note spacecraft X axis in direction of along-track motion (blue), also see orbit track (red, 626.8 km altitude), spacecraft ground track & swath of TIR sensor (red).

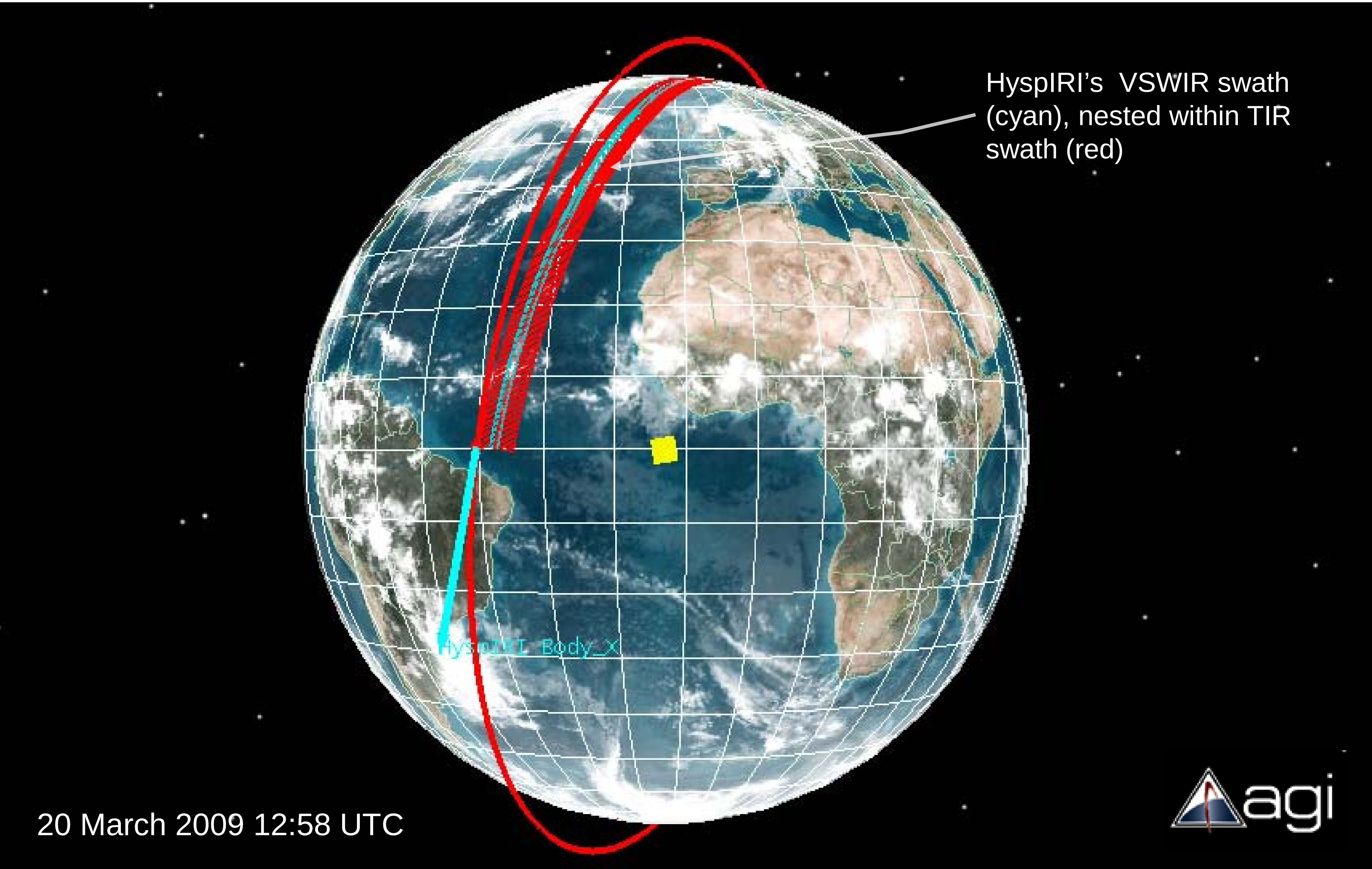


20 March 2009 12:57 UTC

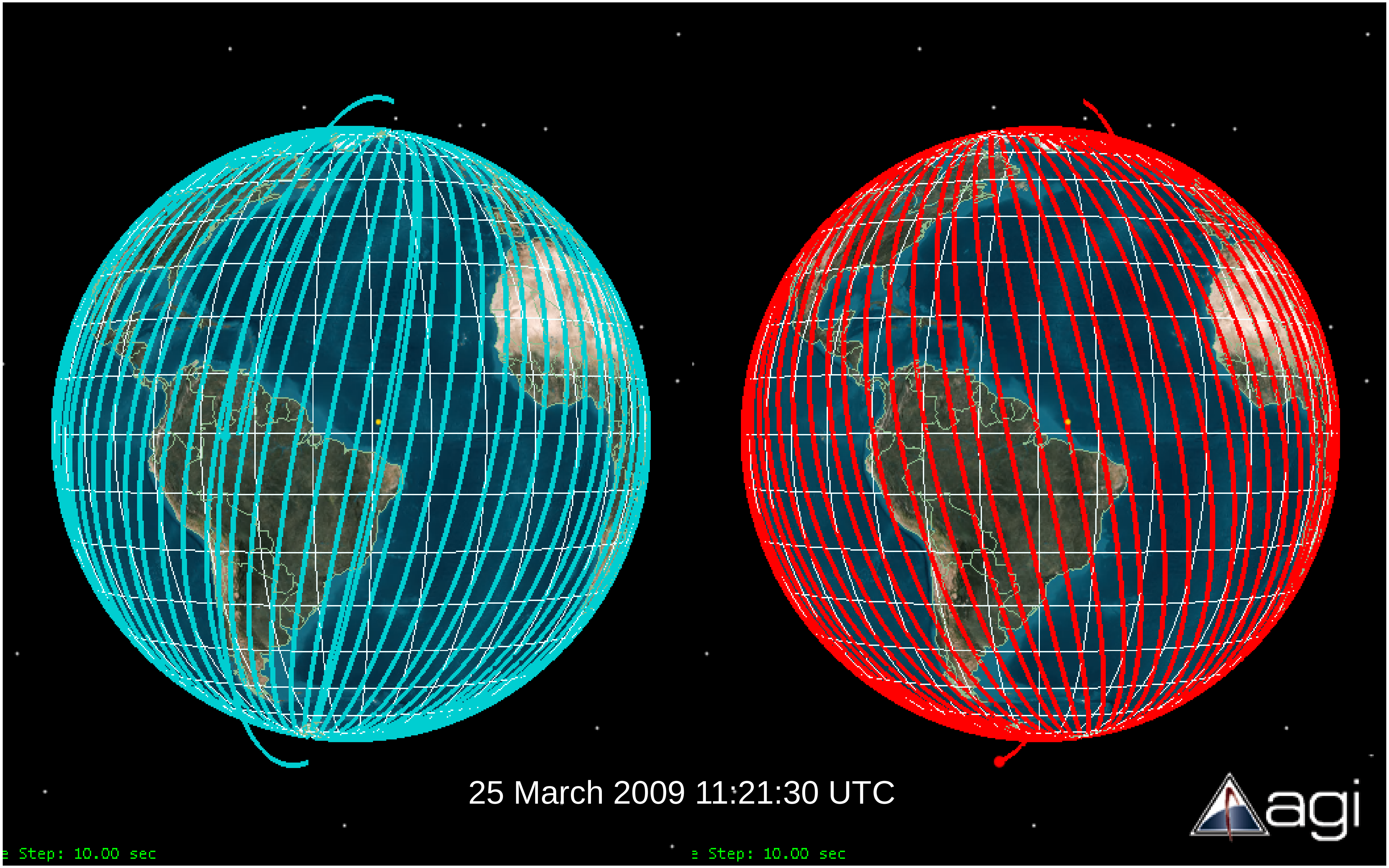


Hole-at-the-pole

Daylight side of a sun-synchronous reference orbit, with 10:30 AM equatorial crossing (mean local time) at a descending orbit node. The sub-solar point (yellow) shows the location on Earth where the Sun is directly overhead, east of the ground track.

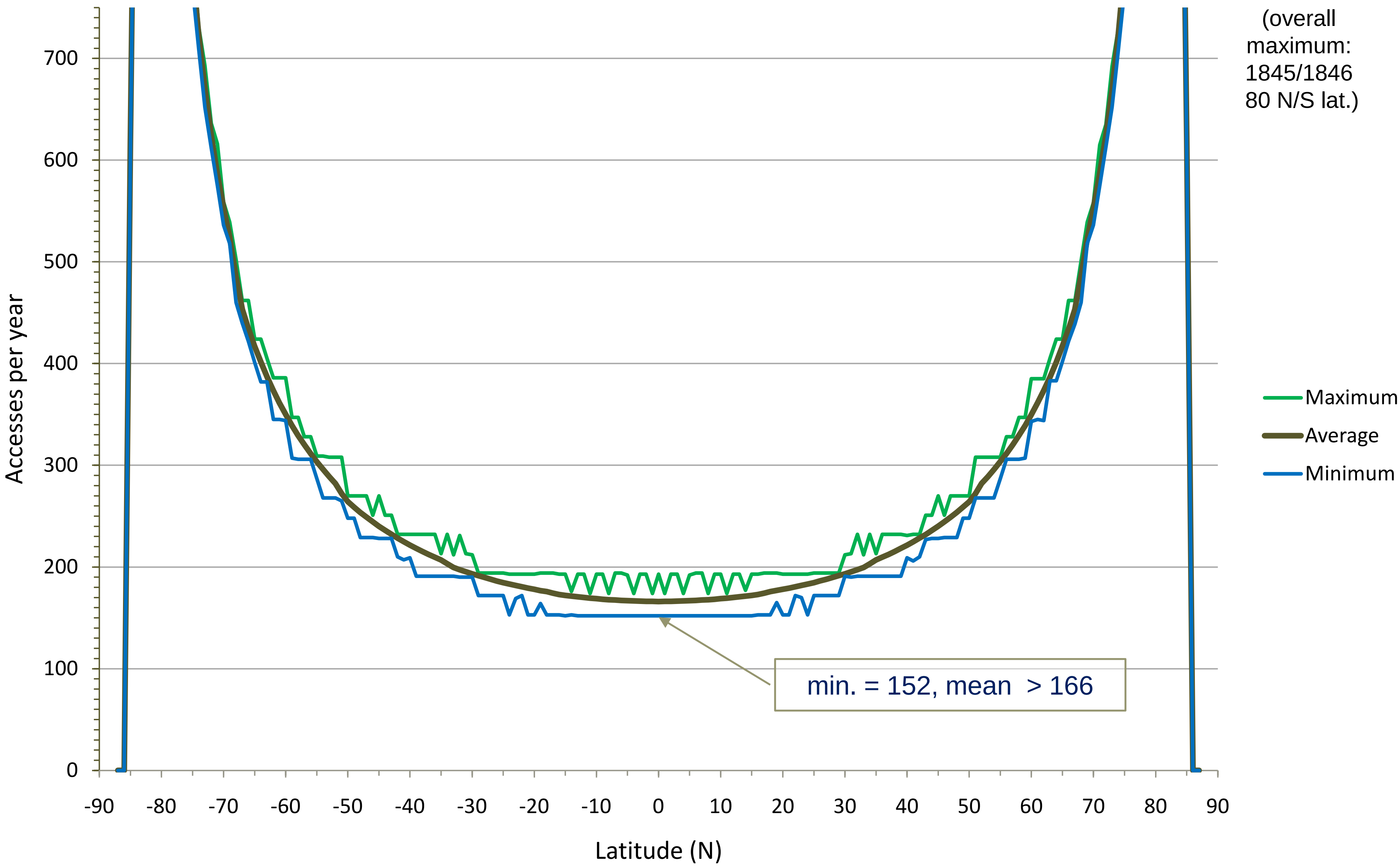


HyspIRI ground tracks shortly after completing a 5-day near repeat pattern:
(a) blue – descending (day) passes and orbit track;
(b) red – ascending (night) passes and orbit track.

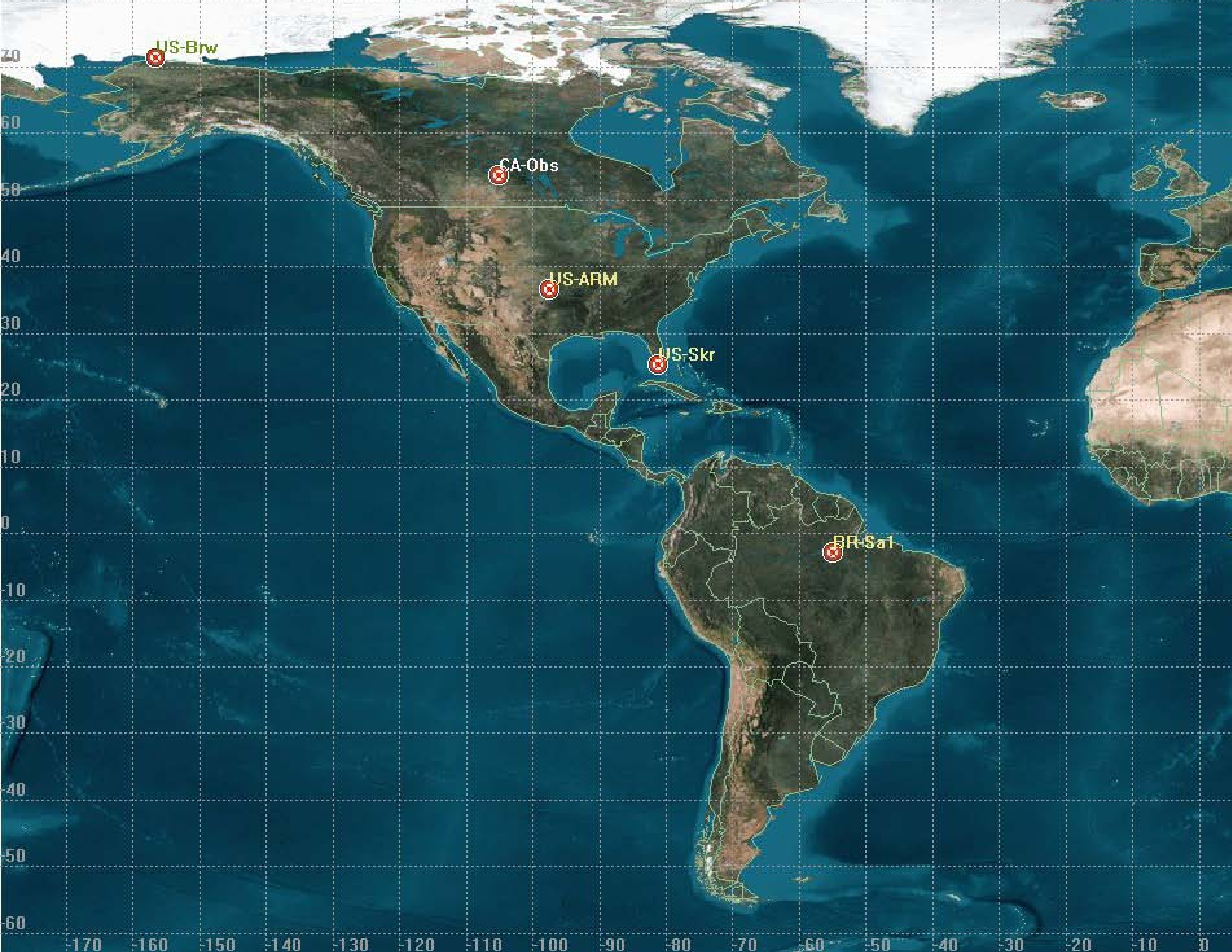


R.G. Knox simulation with STK v8.1.3. Orbit: alt. 626.8 km, inclination: 97.8°. Earth graphics courtesy of Analytical Graphics Inc.

Annual TIR imaging opportunities in a 19/5-day repeat HyspIRI reference orbit
Swath: 50.92°, symmetric about nadir. Sampled using a 1 by 1 deg. coverage.

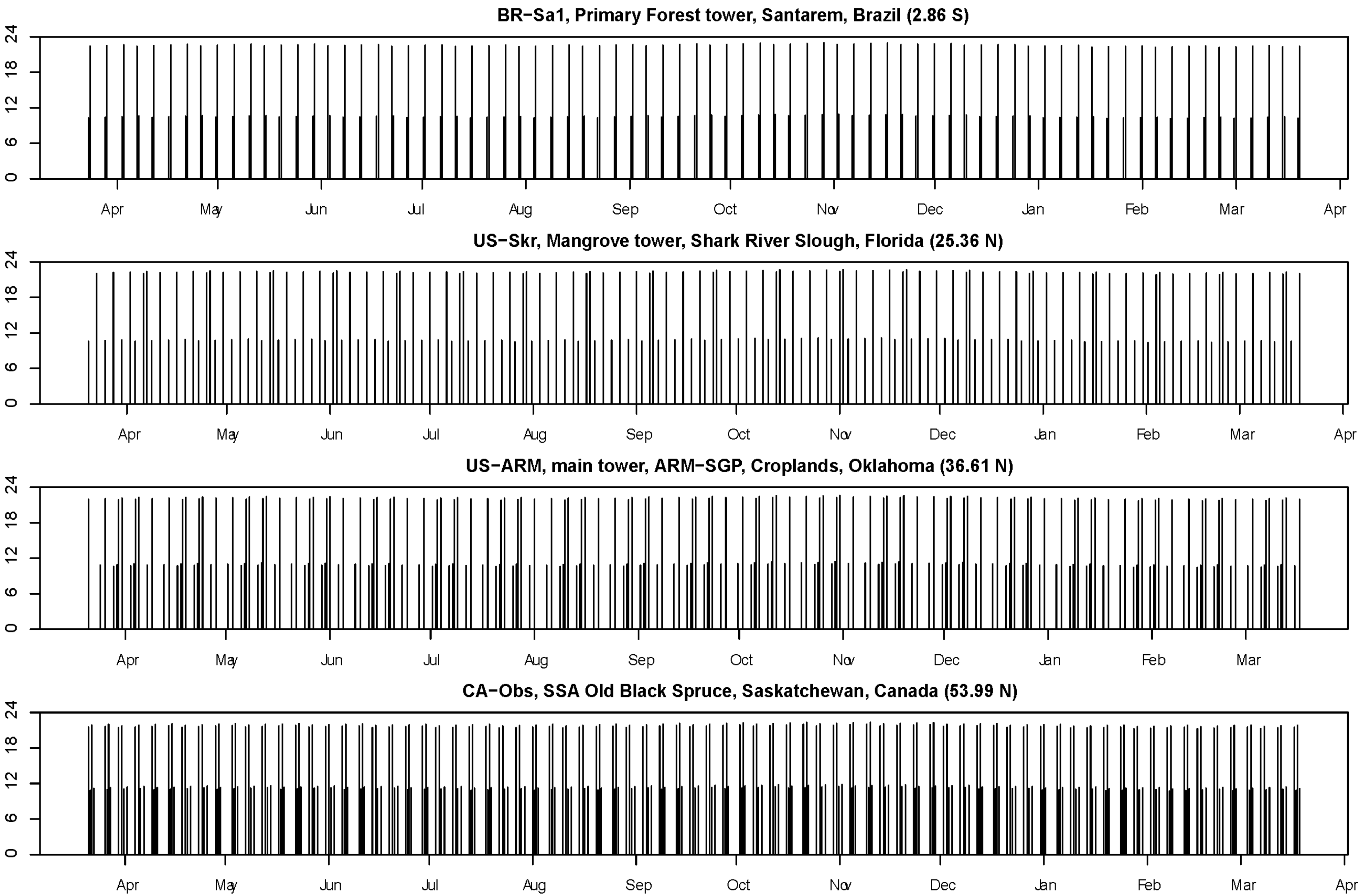


Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: +/- 25.46° (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010.



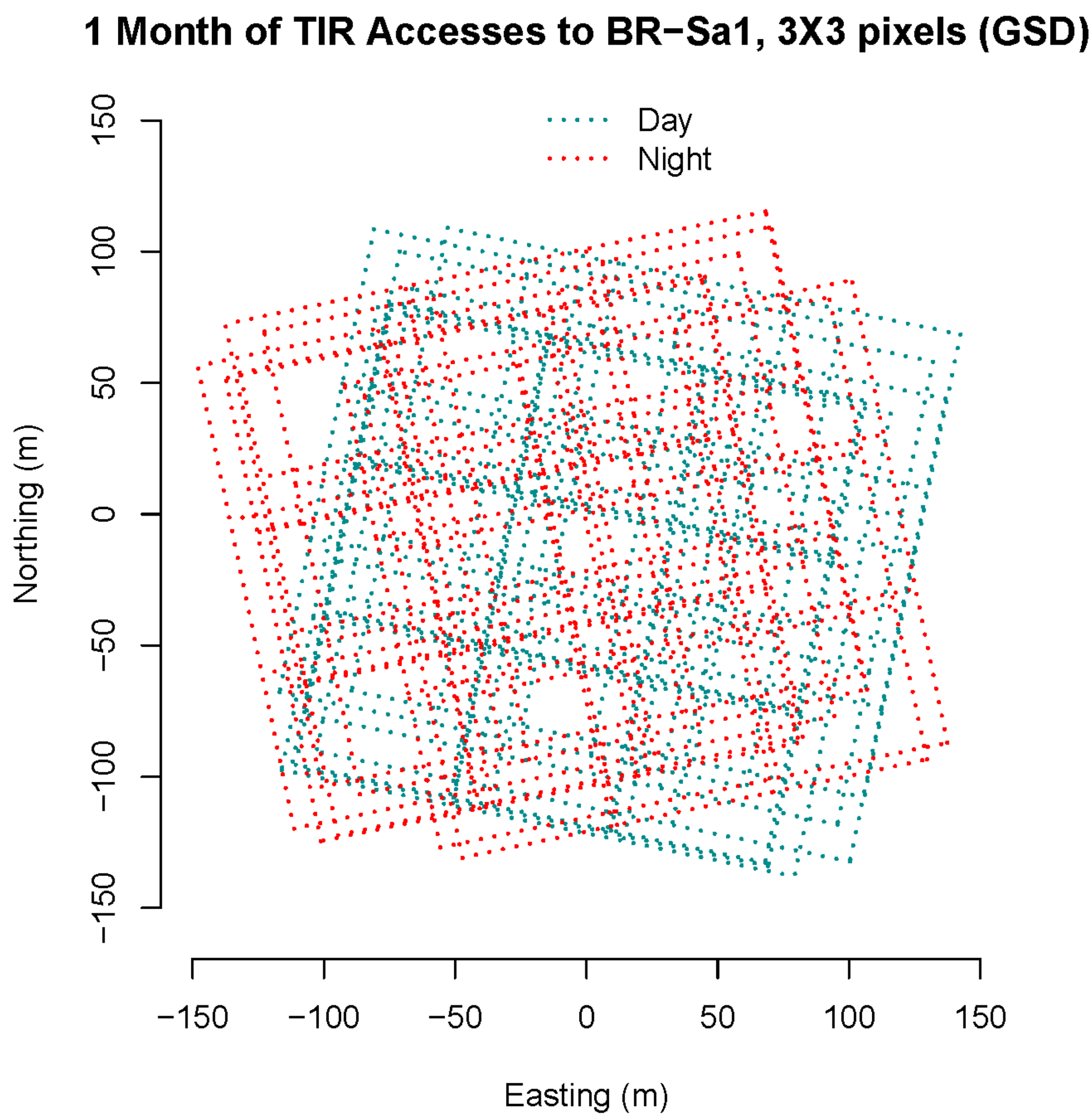
US-Brw
CA-Obs
US-ARM
US-Skr
BR-Sa1
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-170
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0

TIR imager accesses to four selected FLUXNET sites
1 simulated mission year: date & local apparent time



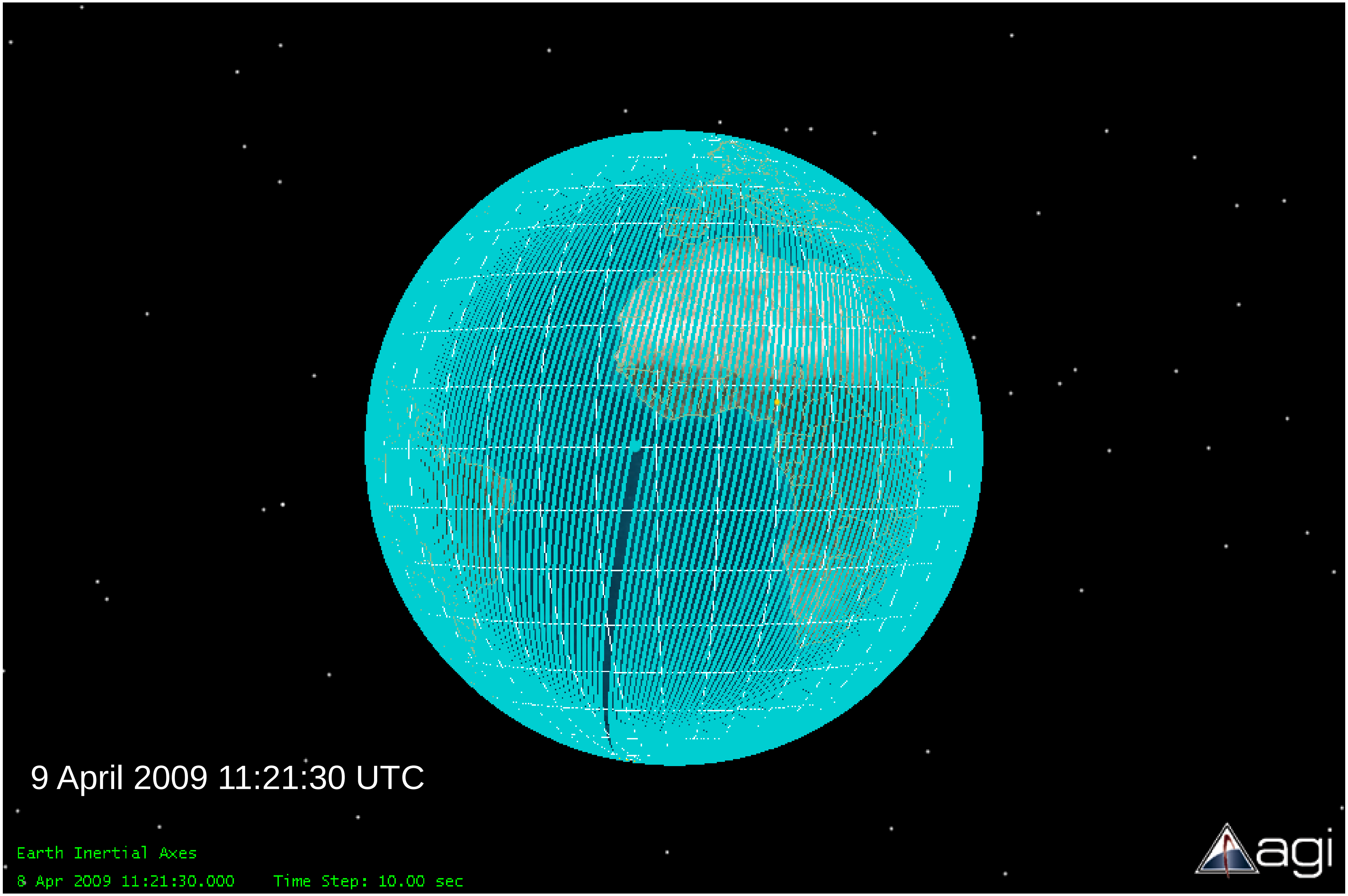
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 8, 2010.

14 potential image collects for 1 simulated month (equatorial site)



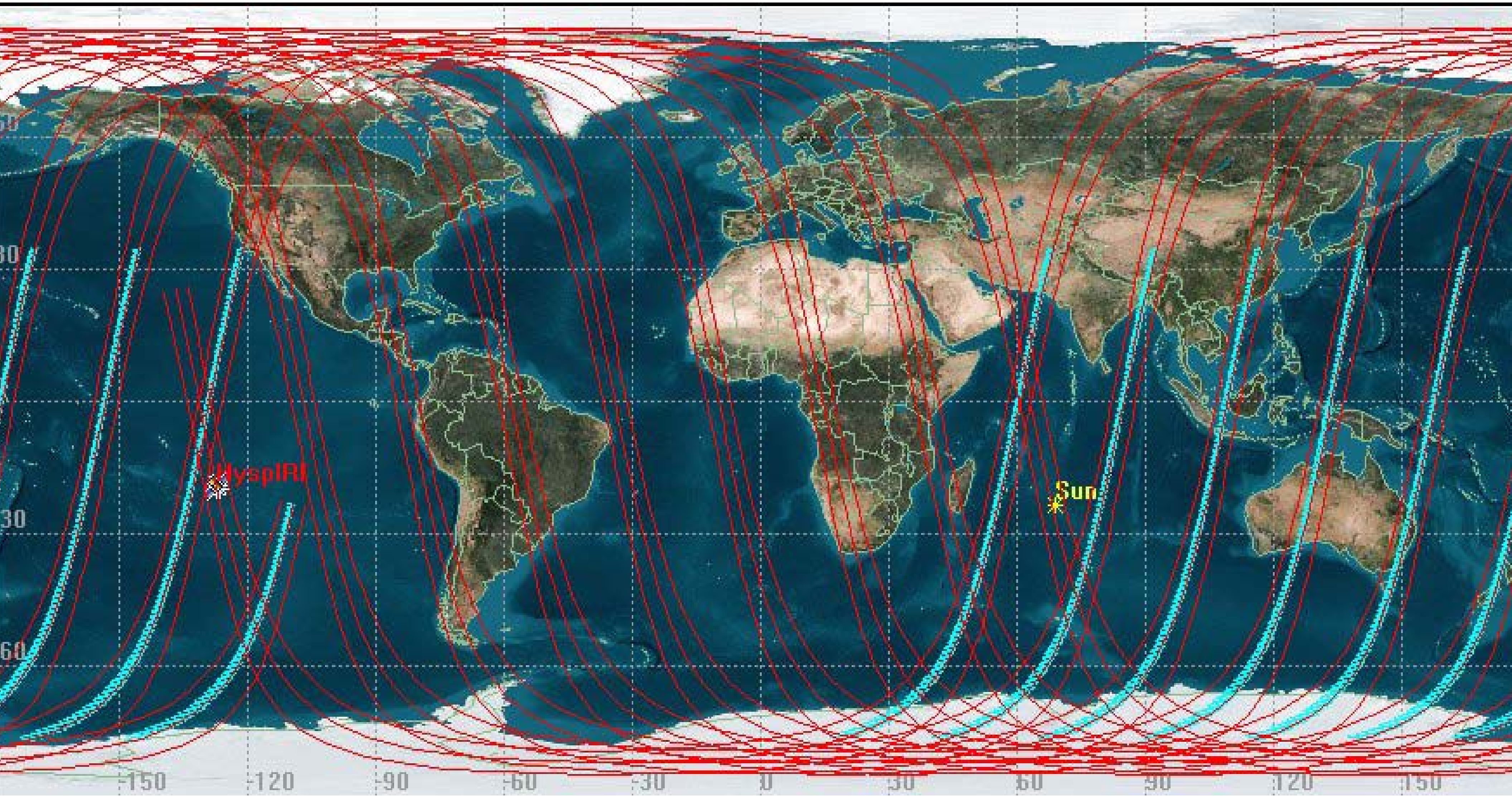
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

HyspIRI ground-track pattern when a 19-day repeat cycle is almost complete, showing only ground tracks with descending nodes. (VSWIR swaths overlap.)



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

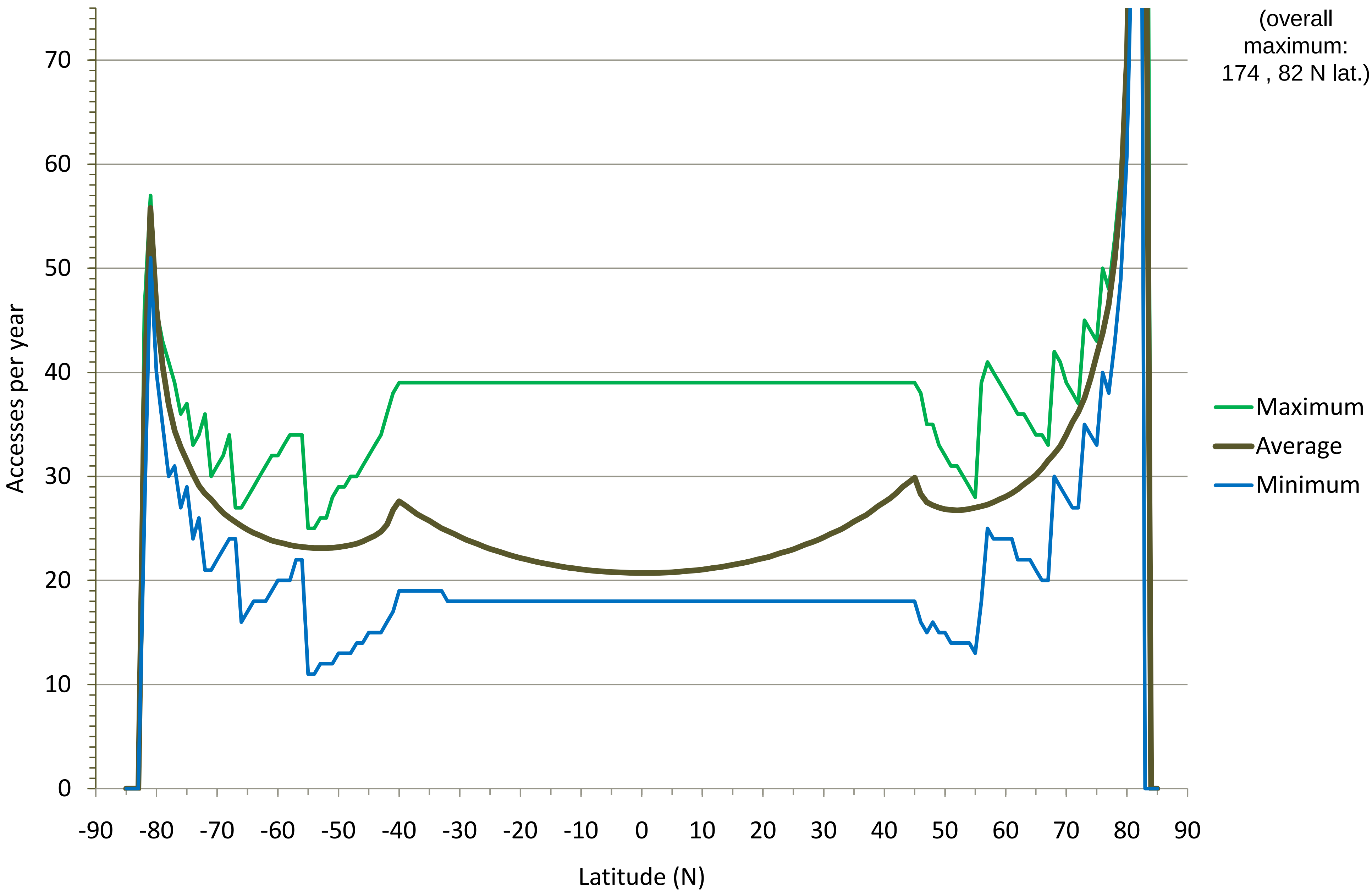
VSWIR's Local solar illumination constraint (SZA < 70 deg.) Northern Hemisphere Winter Solstice



National Aeronautics and Space Administration

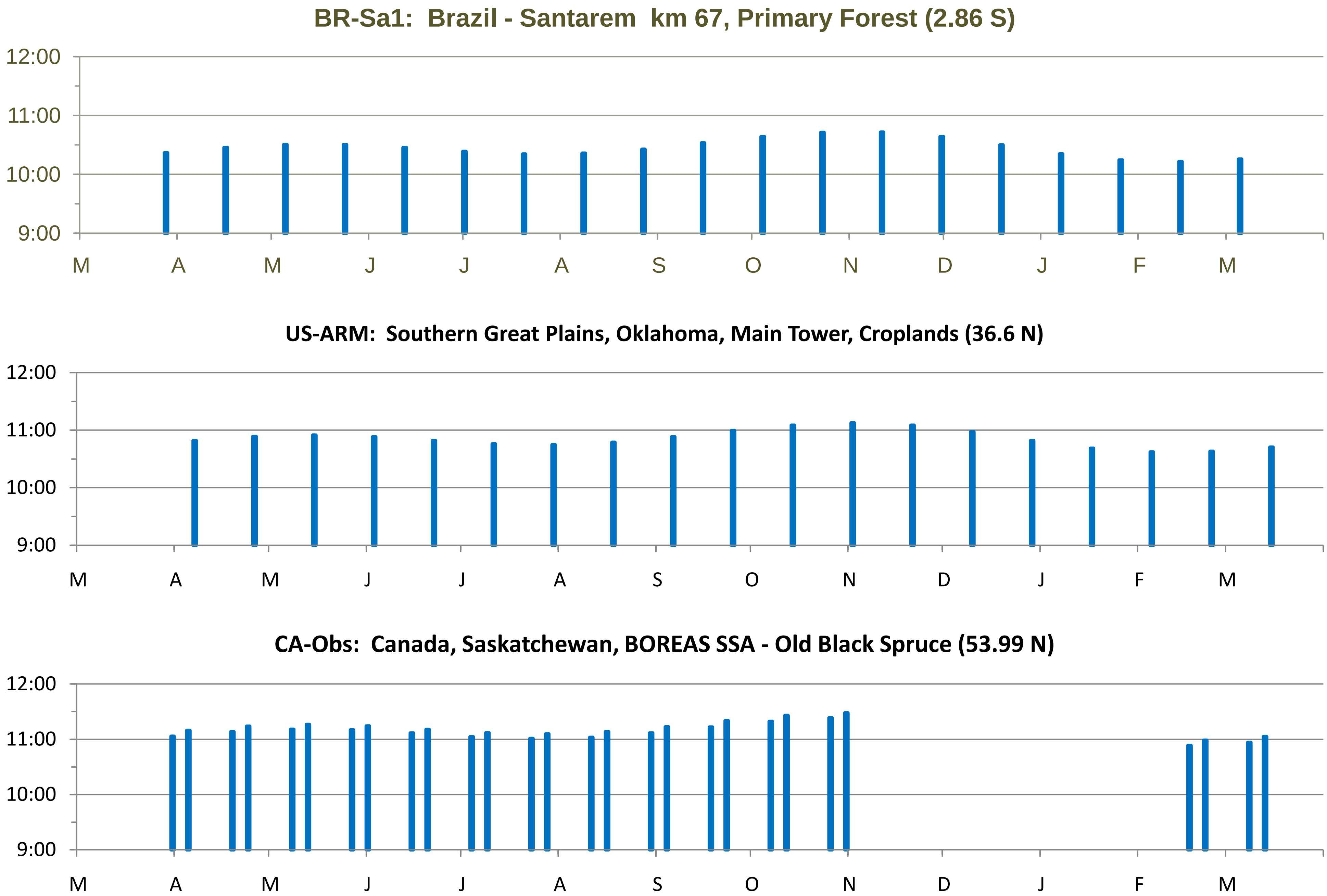
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Annual VSWIR imaging opportunities in a 19-day repeat HyspIRI reference orbit
Swath: 13.62°, pointed 4° west; local solar elevation angles > 20°; 1° by 1° coverage



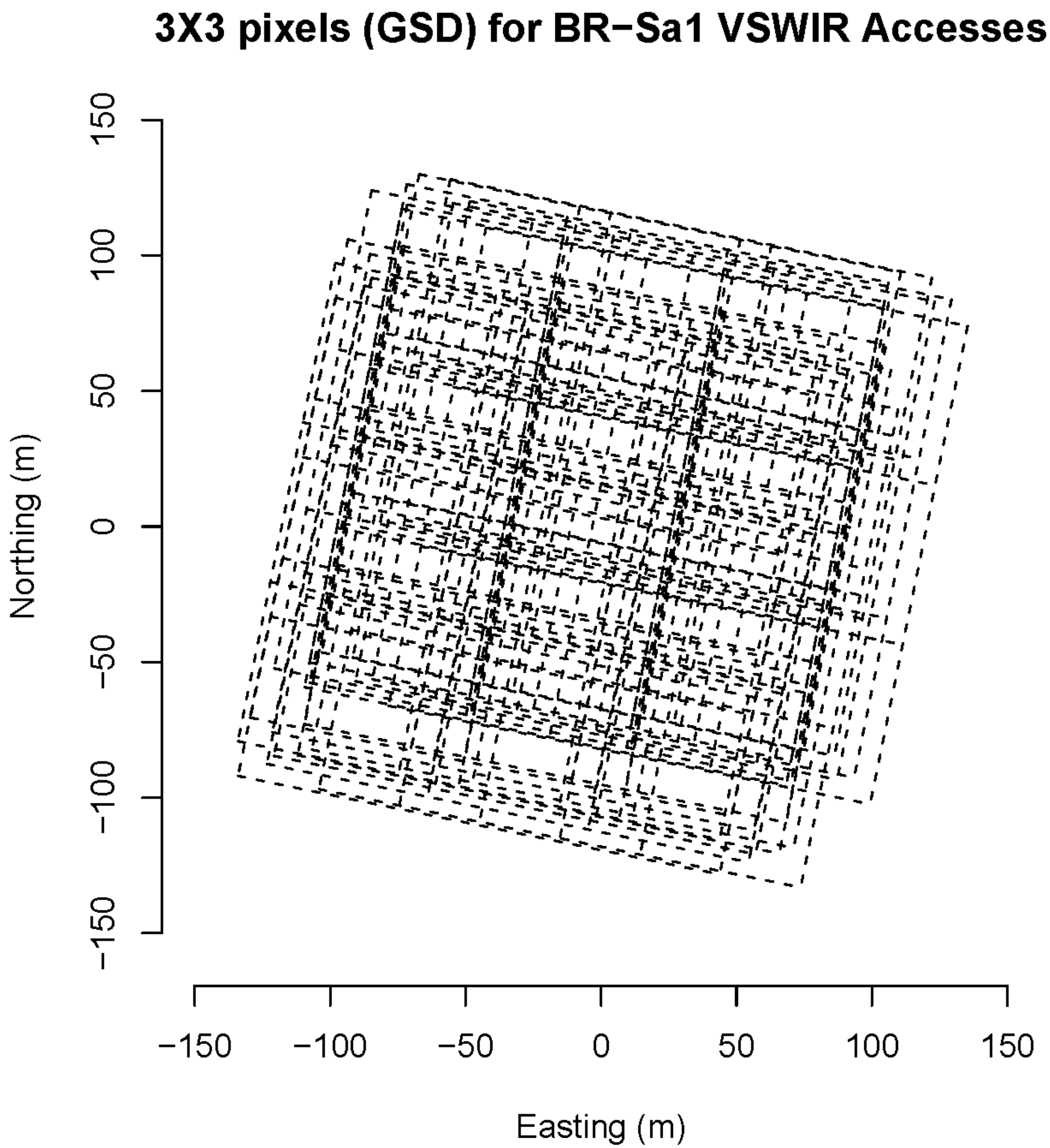
Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010.

VSWIR spectrometer accesses to three selected FLUXNET sites
1 simulated mission year: date & local apparent time



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 8, 2010.

19 potential image collects for 1 simulated year (equatorial site)



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Some issues & options: VSWIR or TIR data products

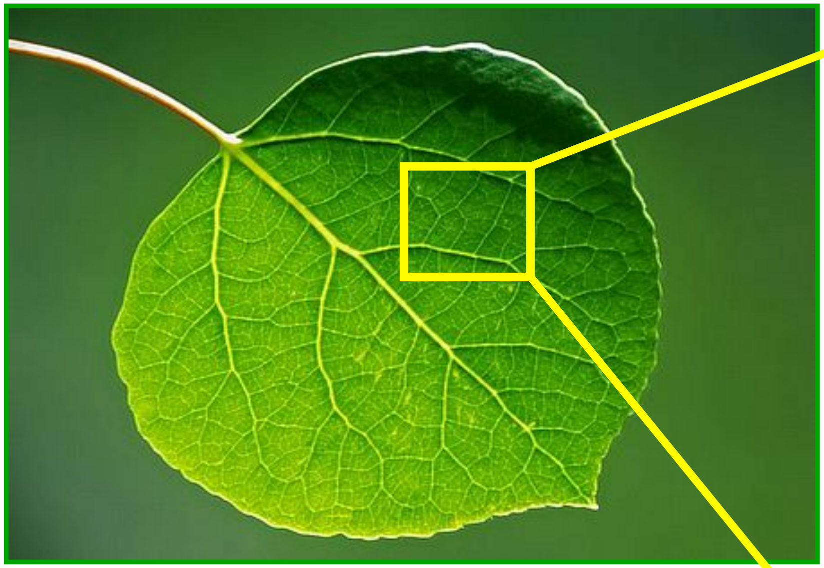
- Providers of **global** level 3/4 data products will see full level 2 data stream(s).
- Where cloud cover is common, compositing will produce more complete seasonal and/or annual global data products.
- Level 2 products feeding multi-temporal level 3 and 4 products will have their pixels geolocated but are not re-sampled to a fixed resolution or grid.

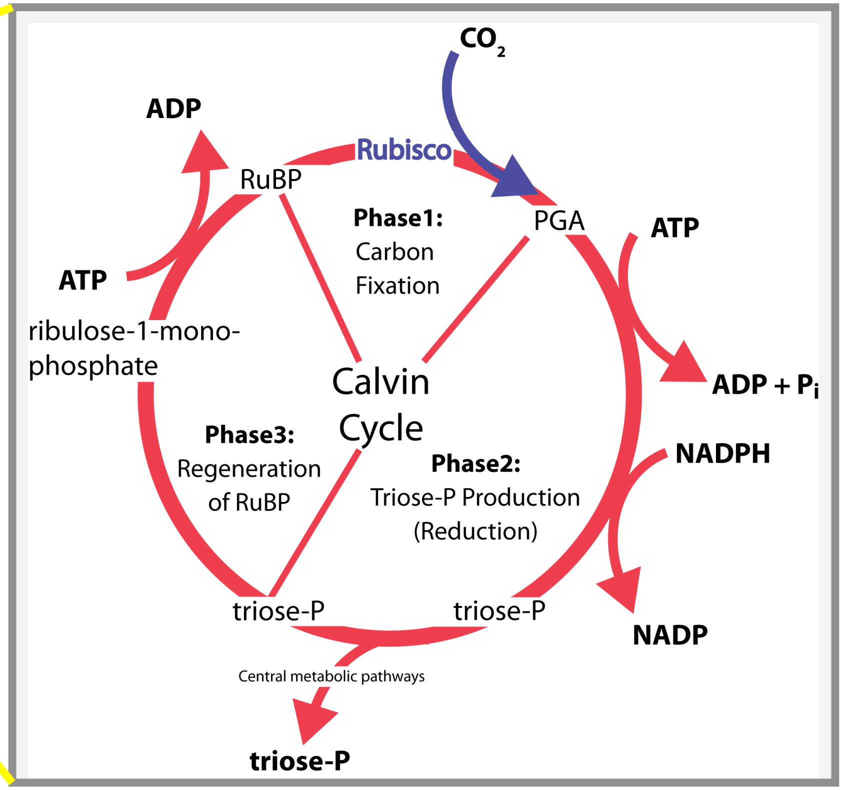
- Questions:
  - *When will it be more appropriate to composite results of intermediate level 3 algorithms, rather than level 2 products?*
  - *What level 3 VSWIR products can be derived directly from level 2 pixels, before spatial re-sampling?*
  - *How critical is data latency for particular level 3/4 products? (For which time-critical products is it viable to use on-board processing and direct broadcast?)*

NASA

HyspIRI: Photosynthesis Products V(c)max and Jmax

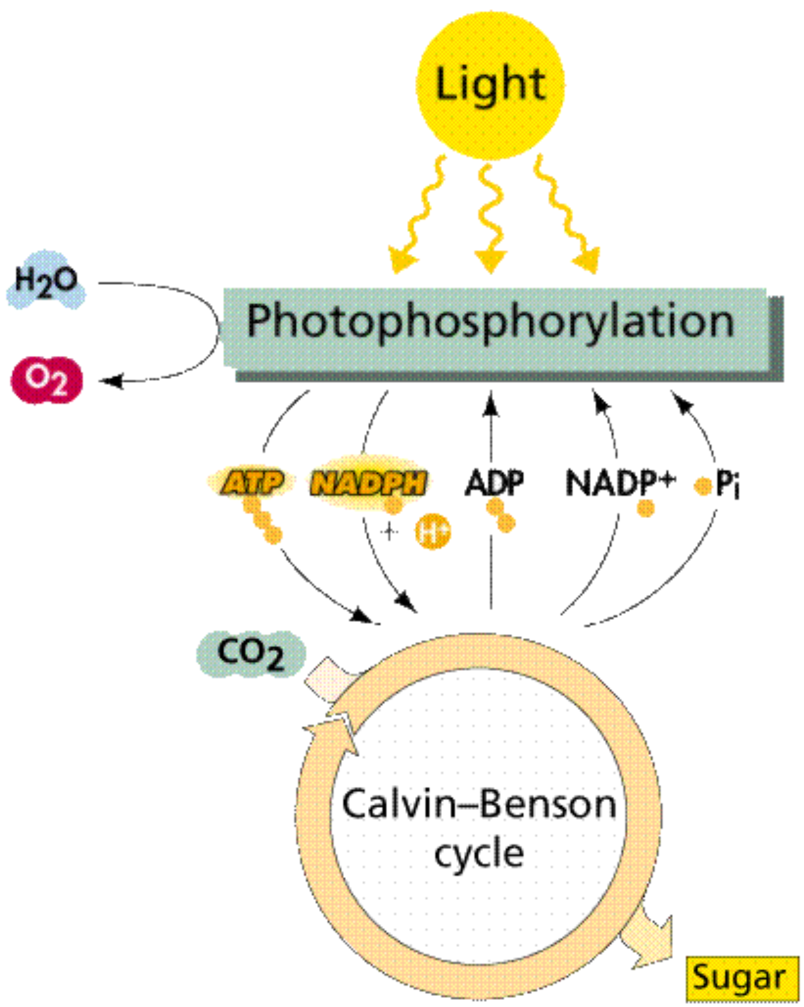
Phil Townsend, Shawn Serbin, Aditya Singh, Eric Kruger

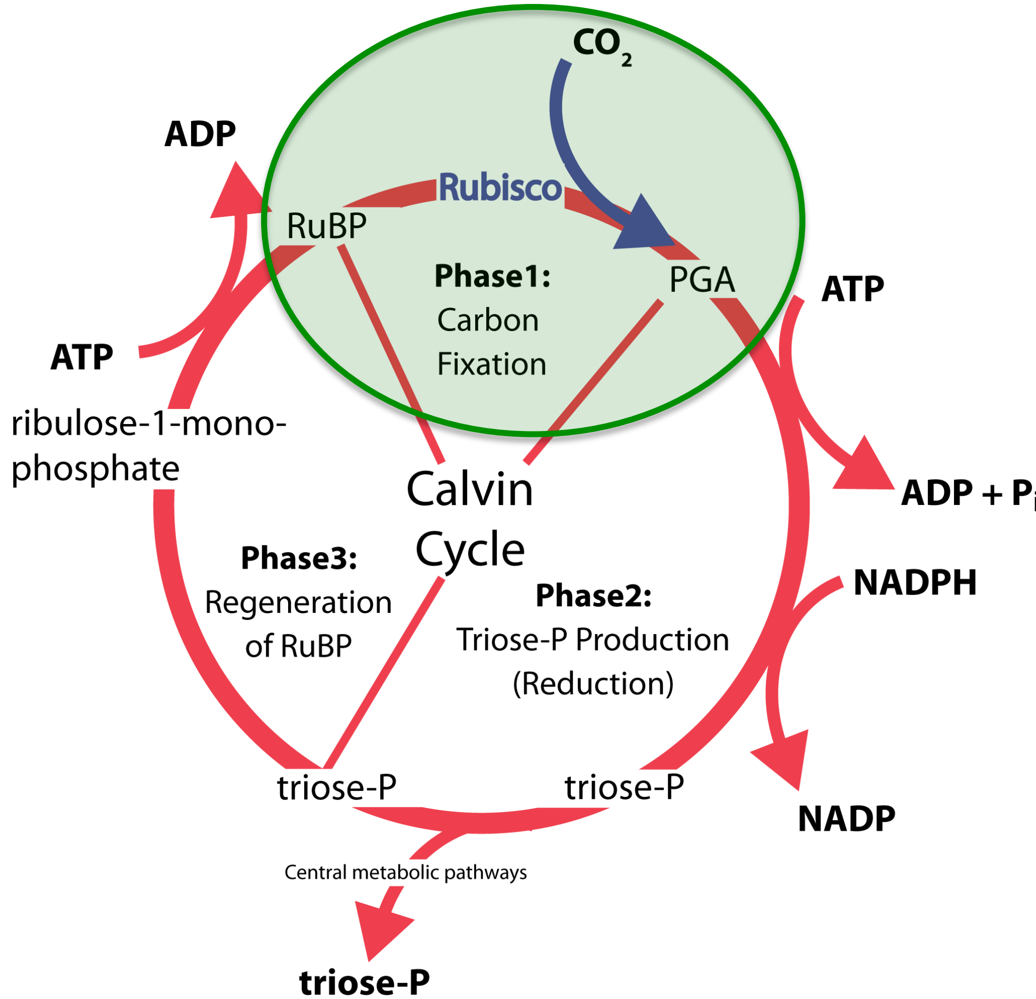




A temperature-mediated photo-chemical reaction.

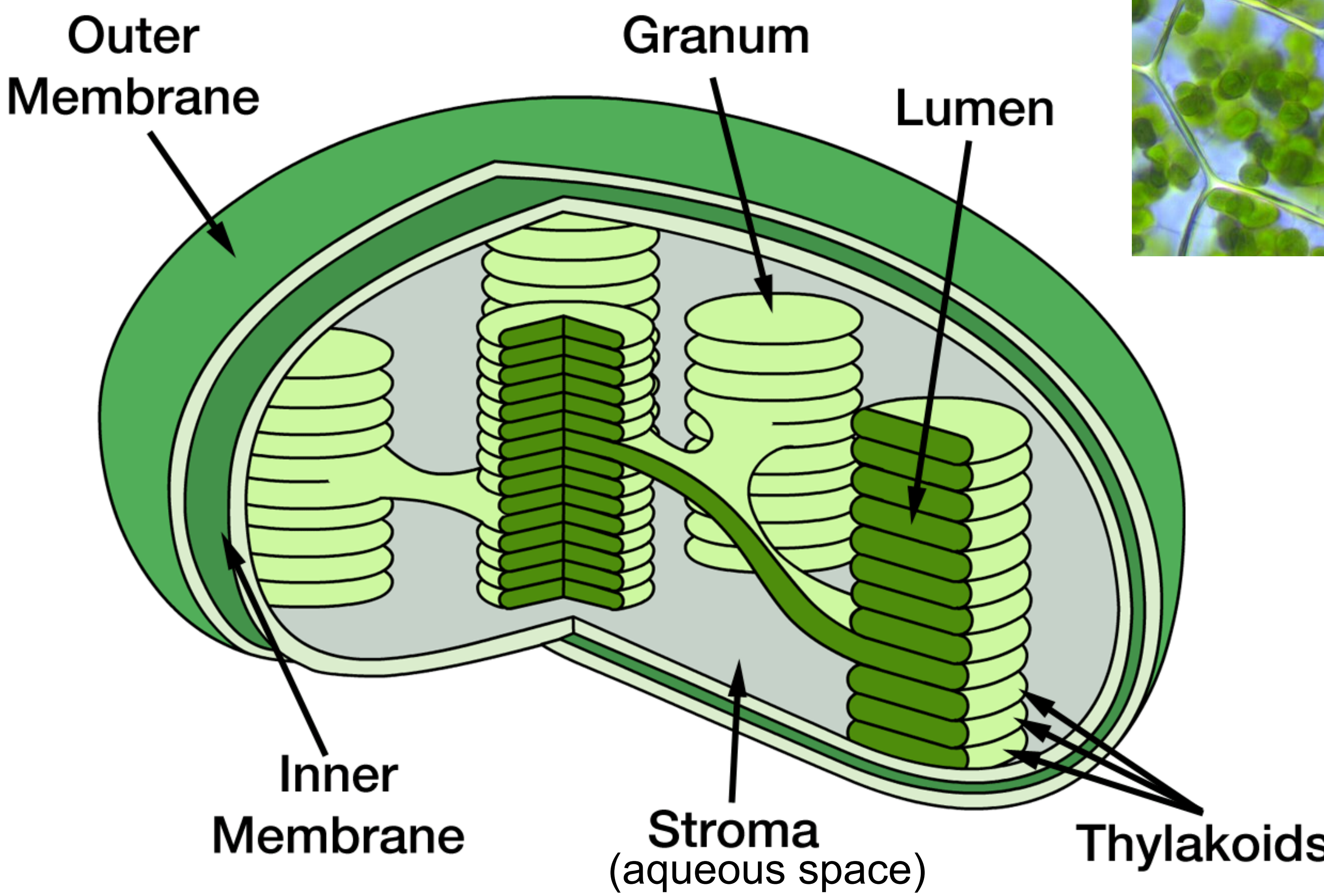
Define the product: V(c)max – maximum rate of carboxylation

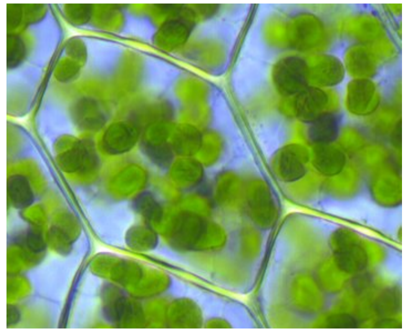




Carboxylation – initial addition of CO_2 to RuBP (catalyzed by RuBisCO). Addition of ATP and NADPH → triose phosphate

Photosynthesis – The Chloroplast





http://photoprotection.clinuvel.com/custom/uploads/LUV_fig4_chloroplast_v(1).gif

Define the Product: Jmax – electron transport rate

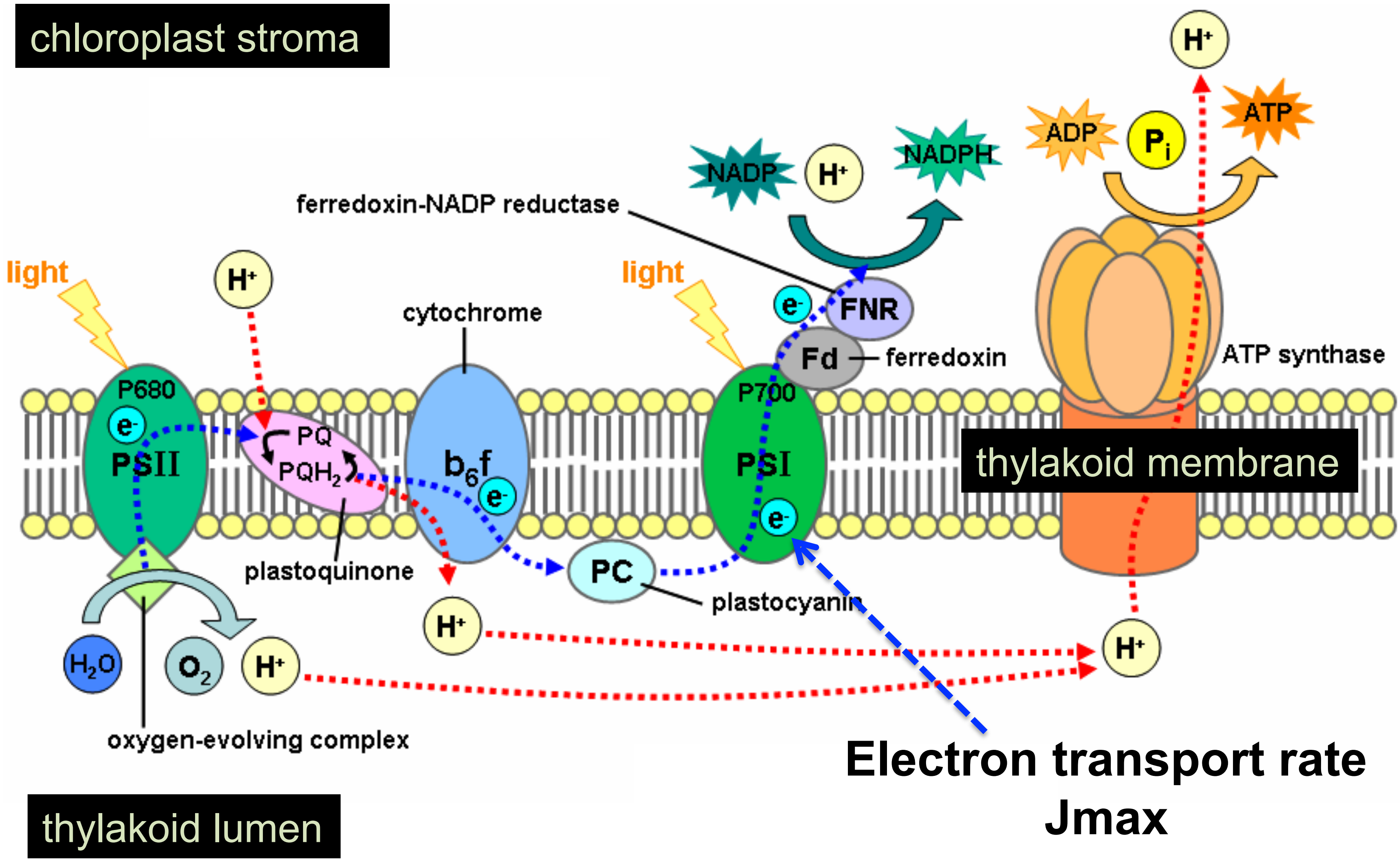


Diagram from wikipedia commons

Reason/Justification for the Product

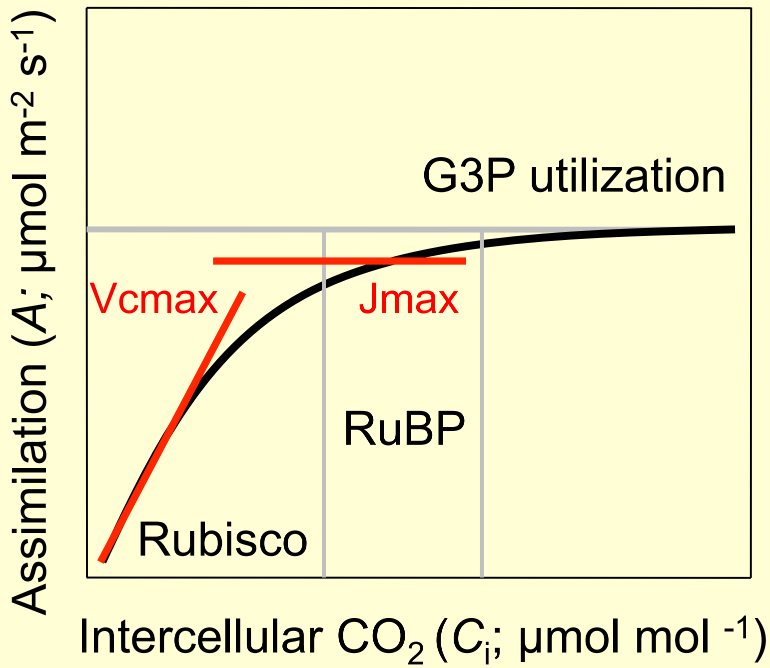
$V_{(c)max}$: Measurement of process by which Rubisco catalyzes RuBP with CO_2 to produce the carbon compounds that eventually become triose phosphates (G3P, PGAL)

Triose phosphates are the building block for sugars and starches.

J_{max}: Transport of electrons through the thylakoid membrane is critical to producing NADPH and ATP, which are provide the metabolic energy necessary to produce triose phosphates.

Biochemical modeling of photosynthesis

$$A_n = \min(A_c, A_j, A_p) - R_d$$



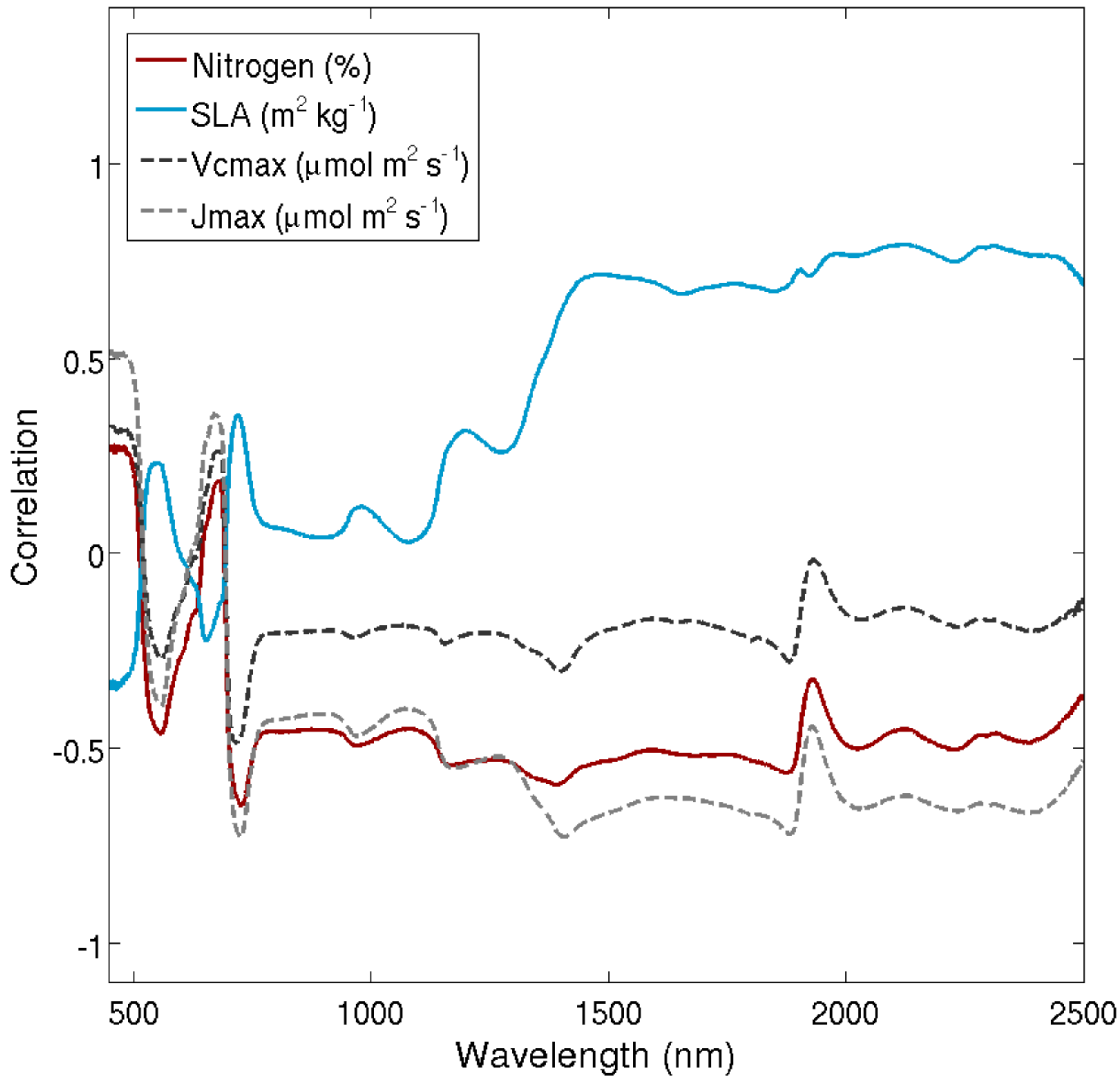
- Limited by
  - Rubisco
  - RuBP regeneration
  - triose phosphate utilization
- Determine key metabolic variables
  - **Vcmax**: Rubisco activity
  - **Jmax**: Electron transport

Relevance to climate, data continuity, Decadal Survey, etc.

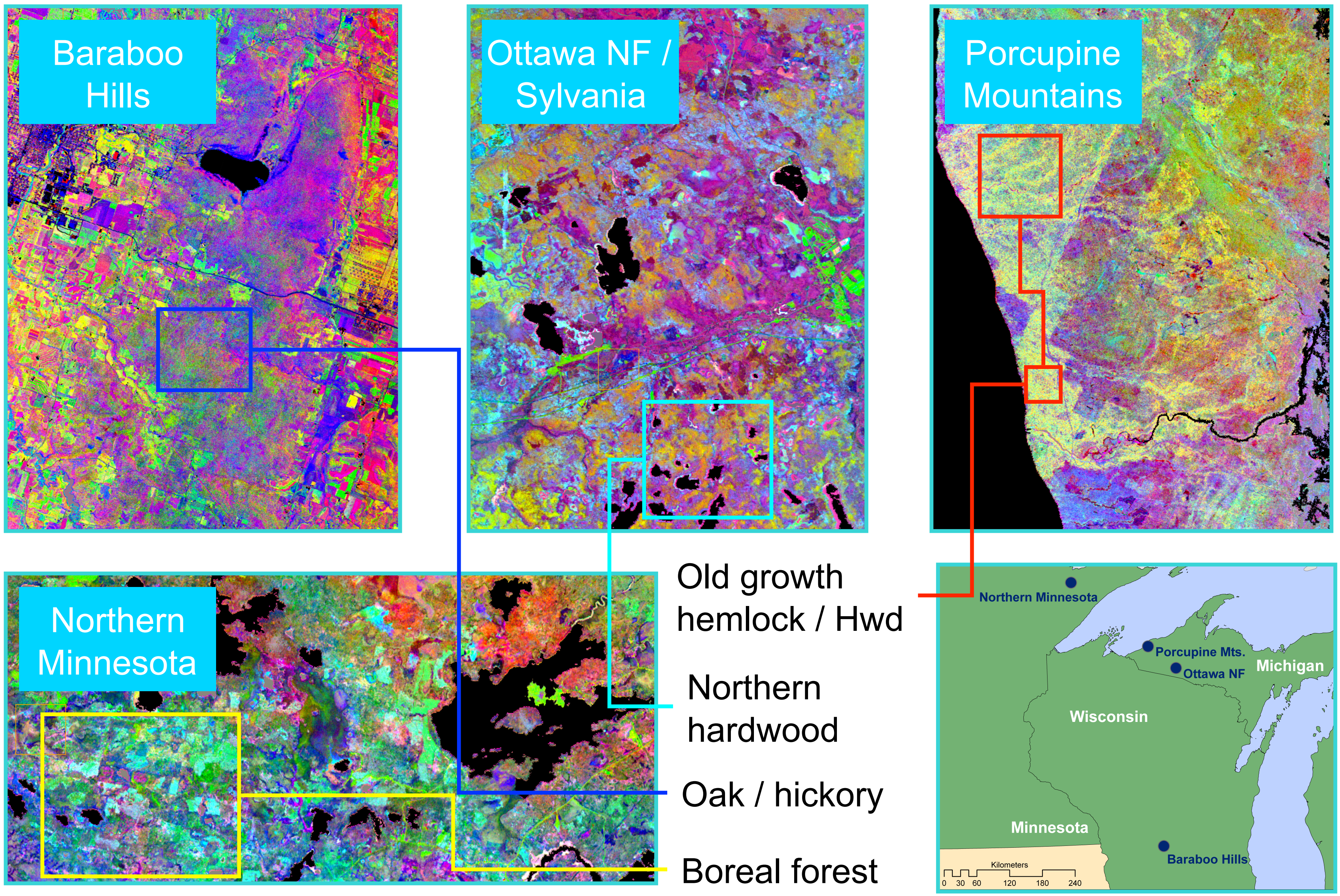
HyspIRI spectral and thermal measurements provide the opportunity to directly measure the photochemical processes associated with carbon assimilation (e.g., A_{max}) and respiration by plants.

These HyspIRI products provide the potential to identify changes in photosynthetic processes associated with climate change (e.g., temperature), especially within species, but potentially across species.

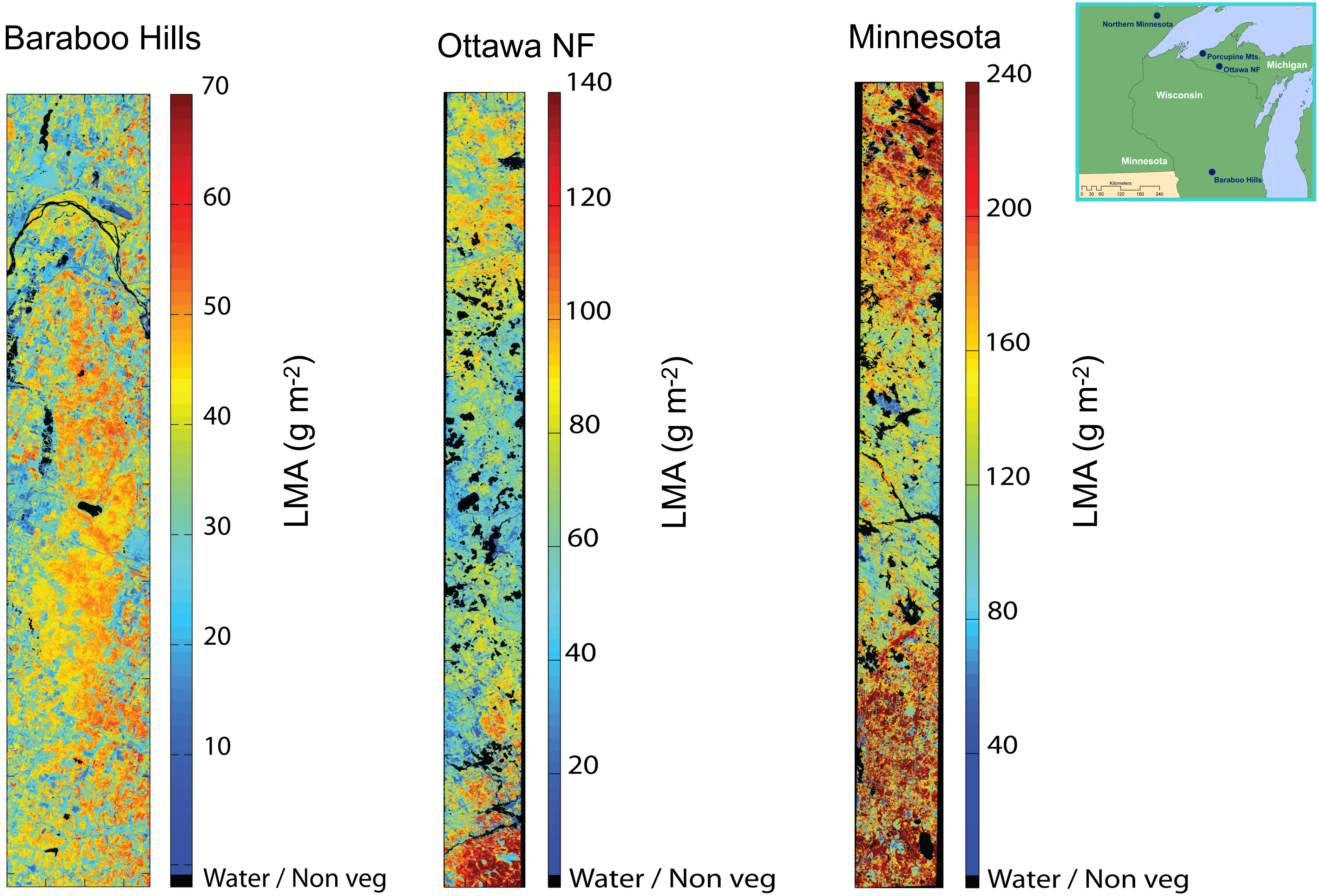
Empirical evidence: Aspen (*Populus tremuloides*)



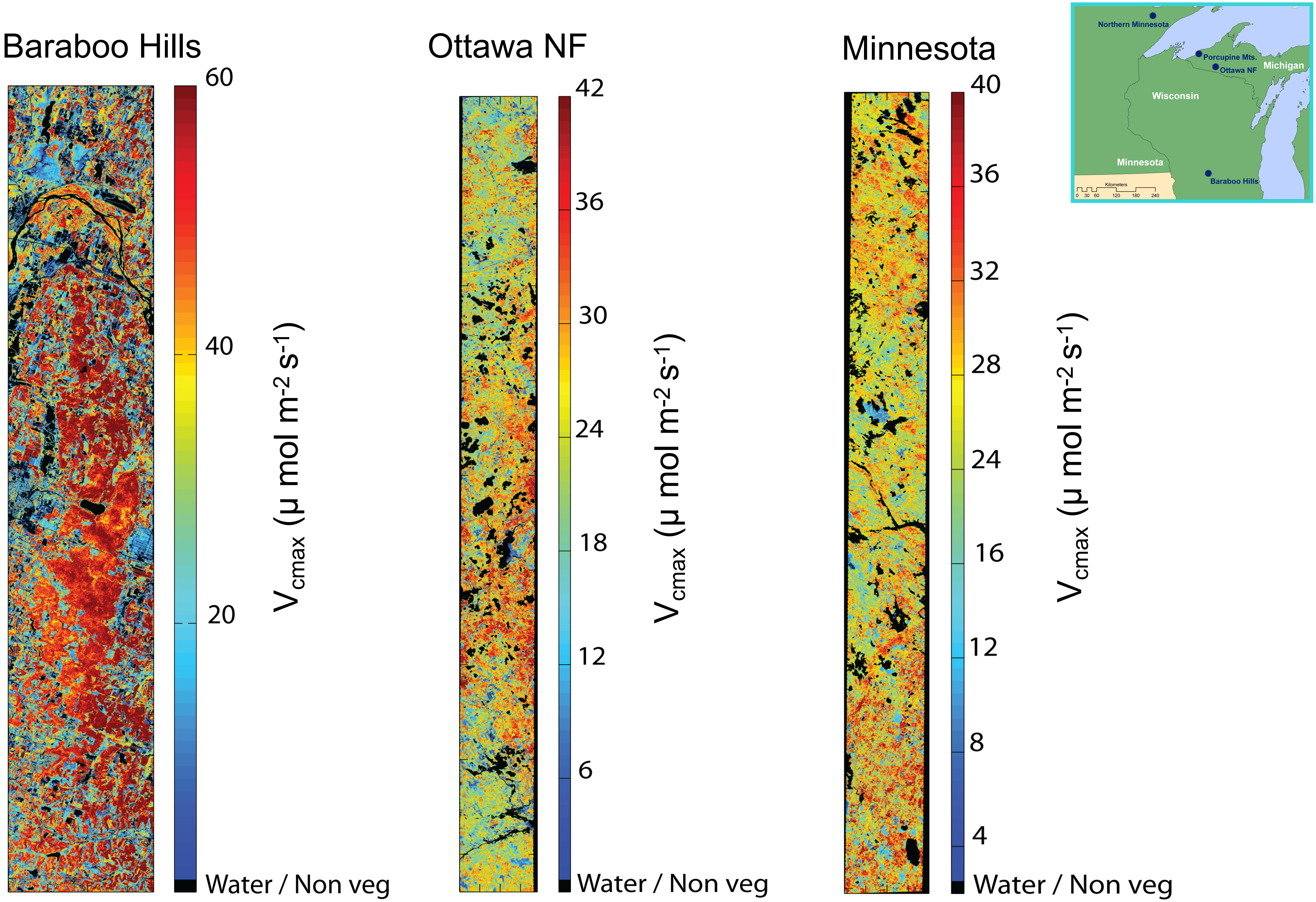
Examples: AVIRIS imagery from the Upper Midwest



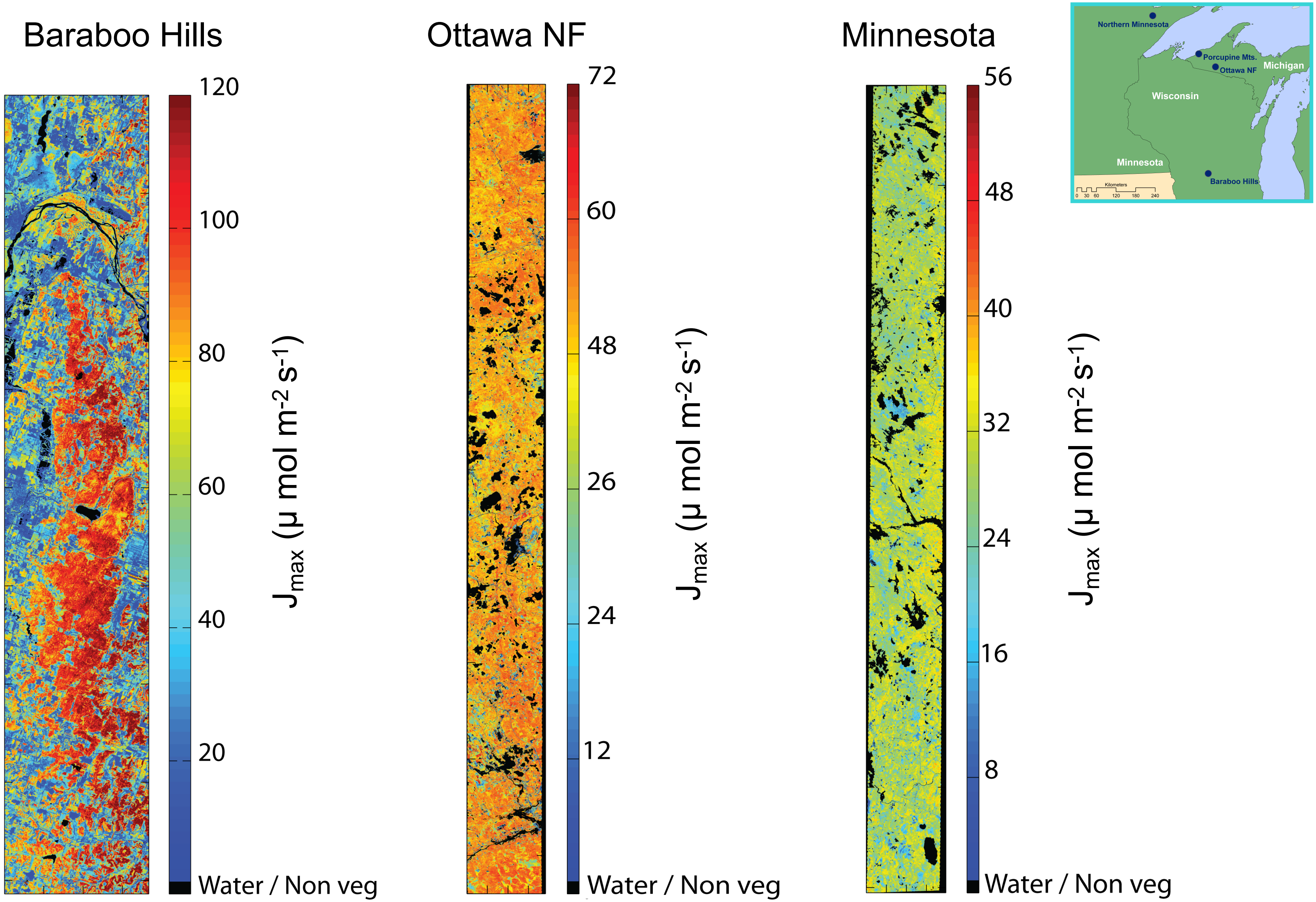
Examples: LMA – based on hypothesized relationships



Examples: V(c)max – based on hypothesized relationships



Examples: Jmax – based on hypothesized relationships



How will the product will be produced?

• To test the viability of product, calibrations are required across species, and across thermal gradients.
• We hypothesize that general relationships for different T regimes (TIR) can be derived from image spectra.

Who will benefit from the product?

• Anyone interested in CO2 assimilation by plants, and how it changes within species across temperature gradients!
• Those interested in modeling photosynthesis and ecosystem dynamics.

Links and synergy with other products

• Links to most vegetation products and products based on radiative transfer modeling.

Time is short!

More on the empirical evidence and modeling in the research talk later in the workshop.

Brainchild of Shawn Serbin, with credit to Shawn and Dylan Dillaway for conducting preliminary tests.

Thanks to a new NASA HyspIRI-funded grant (1-year grant starting soon), in which we will further test this idea.

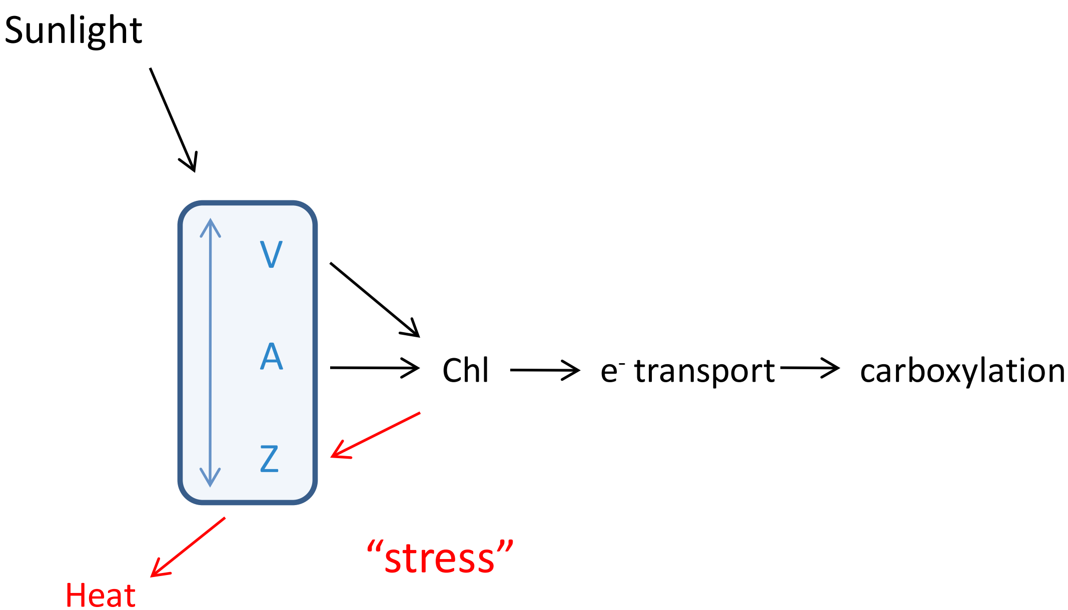
The Photochemical Reflectance Index (PRI) – a measure of photosynthetic *light-use efficiency*

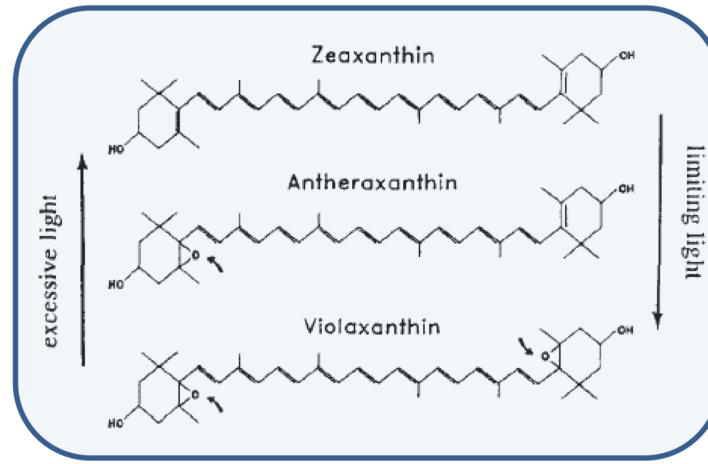
John A. Gamon
jgamon@gmail.com
University of Alberta

(HyspIRI meeting, May 4, 2010)

PRI Defined

PRI was originally defined as an index of the *xanthophyll cycle activity* on a diurnal time scale.



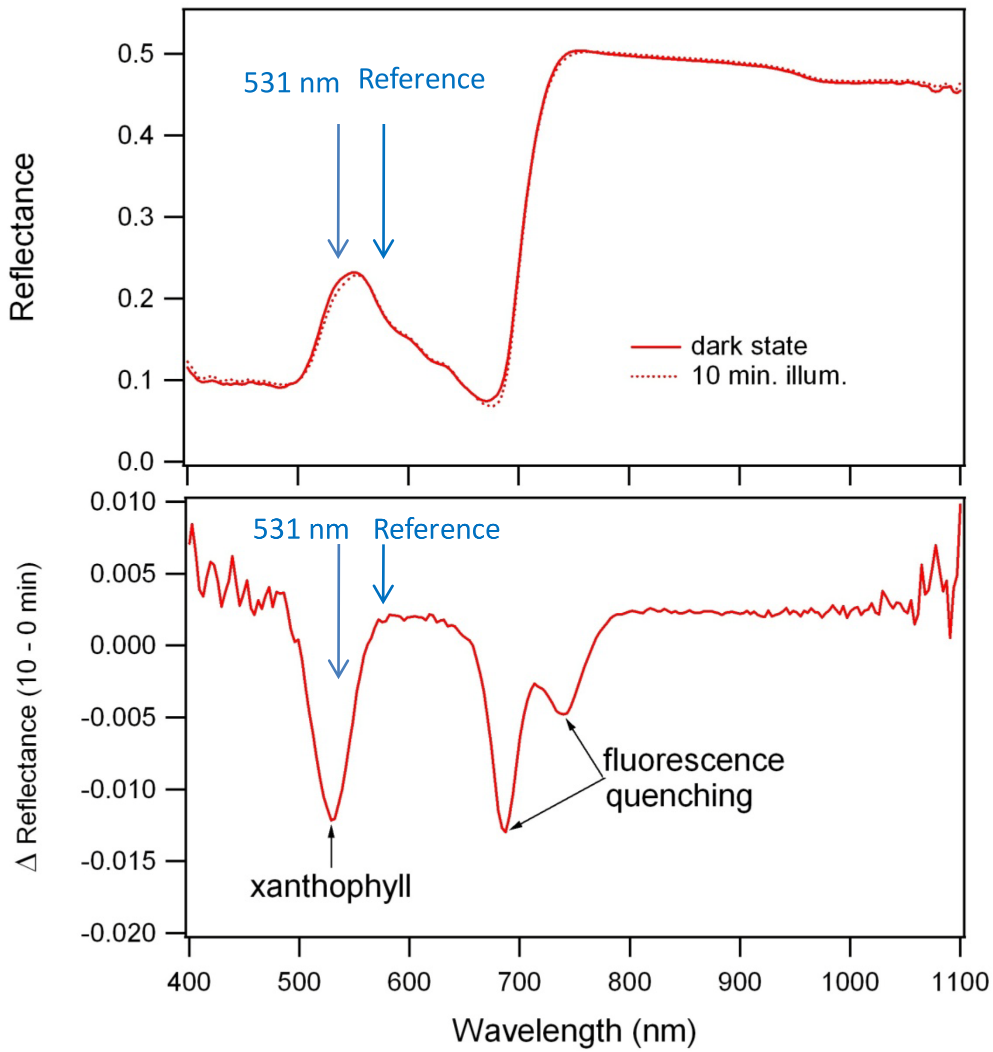


Gamon et al. 1992

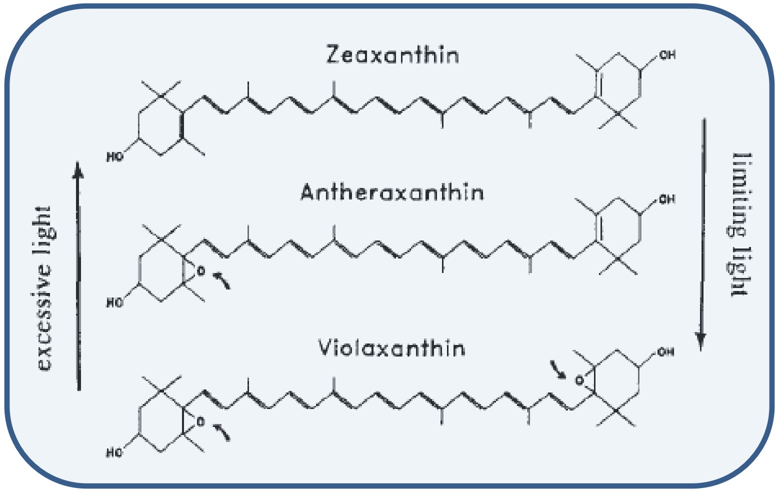
Because xanthophyll cycle pigments adjust the energy distribution at the photosynthetic reaction center, they provide a measure of photosynthetic light-use efficiency (LUE) and indicator of stress.

PRI Defined

The Photochemical Reflectance Index (PRI) measures xanthophyll cycle activity



Gamon & Qiu 1999



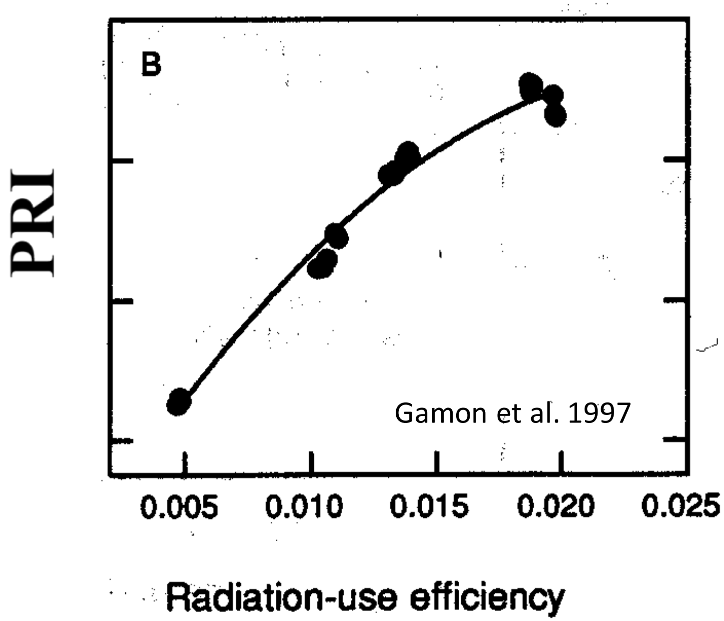
$PRI = (R_{531}-R_{ref})/(R_{531}+R_{ref})$

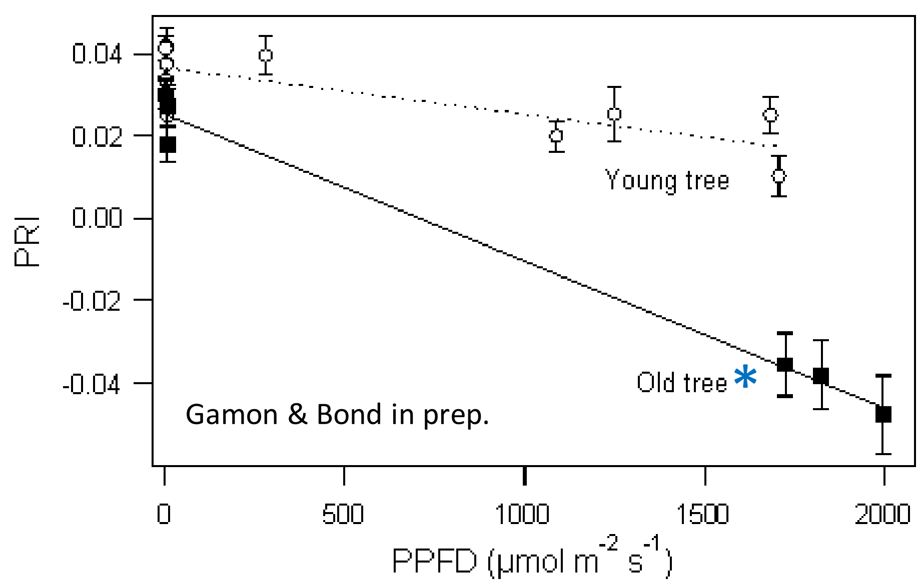
Where reference =
550 nm
570 nm
etc.

Gamon et al. 1992

PRI as a measure of LUE

Because xanthophyll cycle pigments adjust the energy distribution at the photosynthetic reaction center, they provide a measure of photosynthetic light-use efficiency (LUE) .

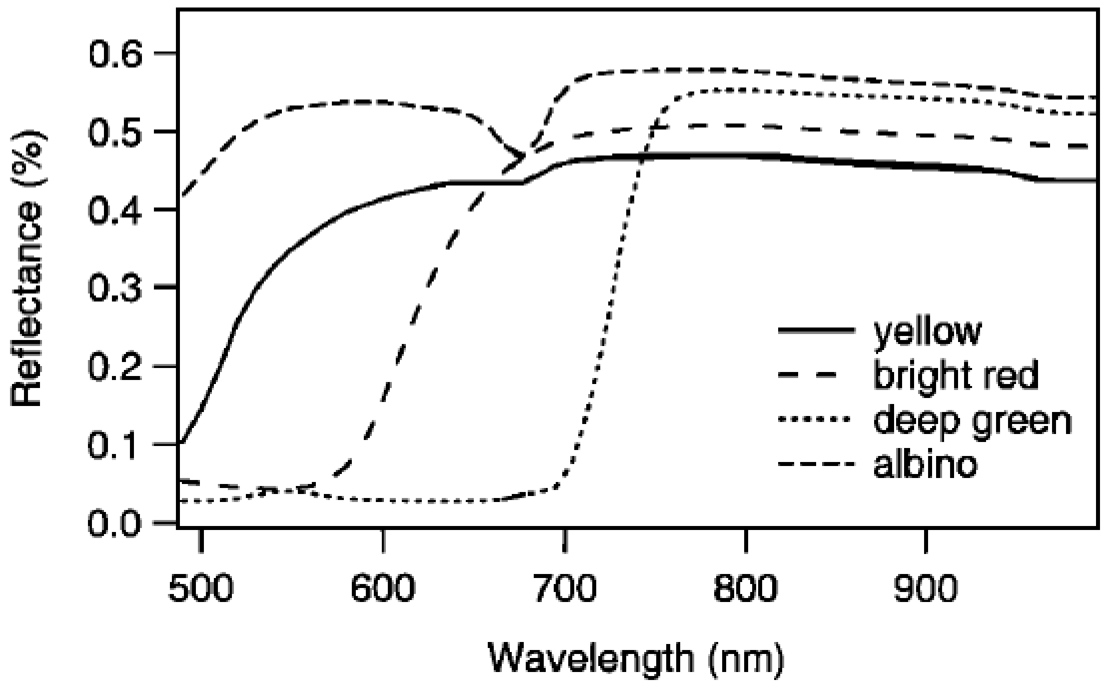




***Midday LUE is reduced for stressed vegetation (downregulation & reduced evapotranspiration)**

PRI Defined

At larger time spans and at progressively larger spatial scales PRI is strongly influenced by other factors (e.g. leaf color, determined by bulk pigment pools, stand structure)



These effects can either confound or amplify the xanthophyll signal

Fuentes et al. 2001

Justification for PRI-type product

Amount of "Green stuff"

Physiological state (stress)

Photosynthetic rate = f(*APAR*) x *ε*

PRI – carotenoids
Canopy water
Temperature

NDVI

Note synergy

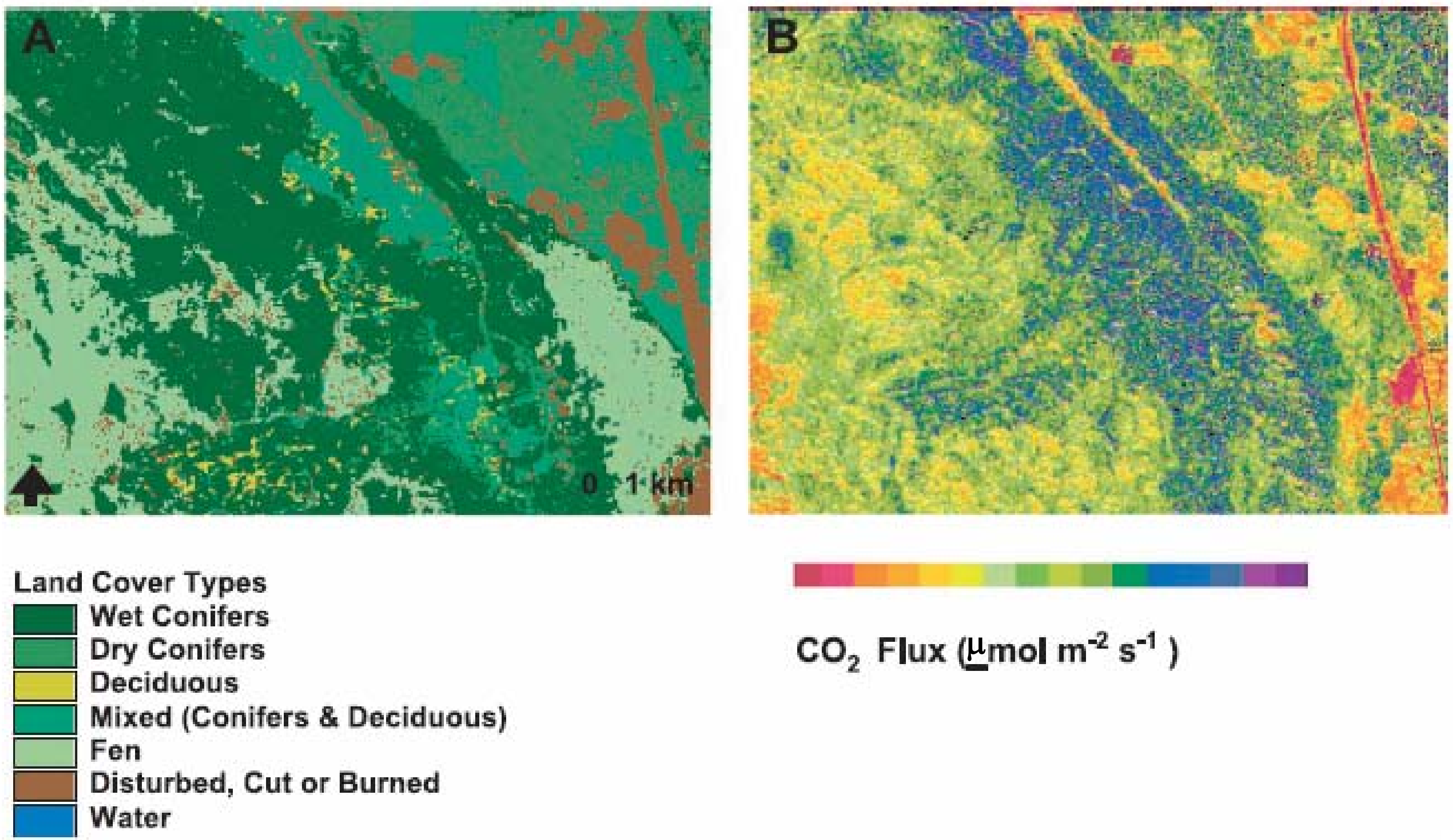
Where:

APAR = Absorbed photosynthetically active radiation

ε = *Efficiency* with which absorbed radiation is converted to fixed carbon

Determination of ε remains a primary challenge
(Field et al. 1998, Running et al. 2009)

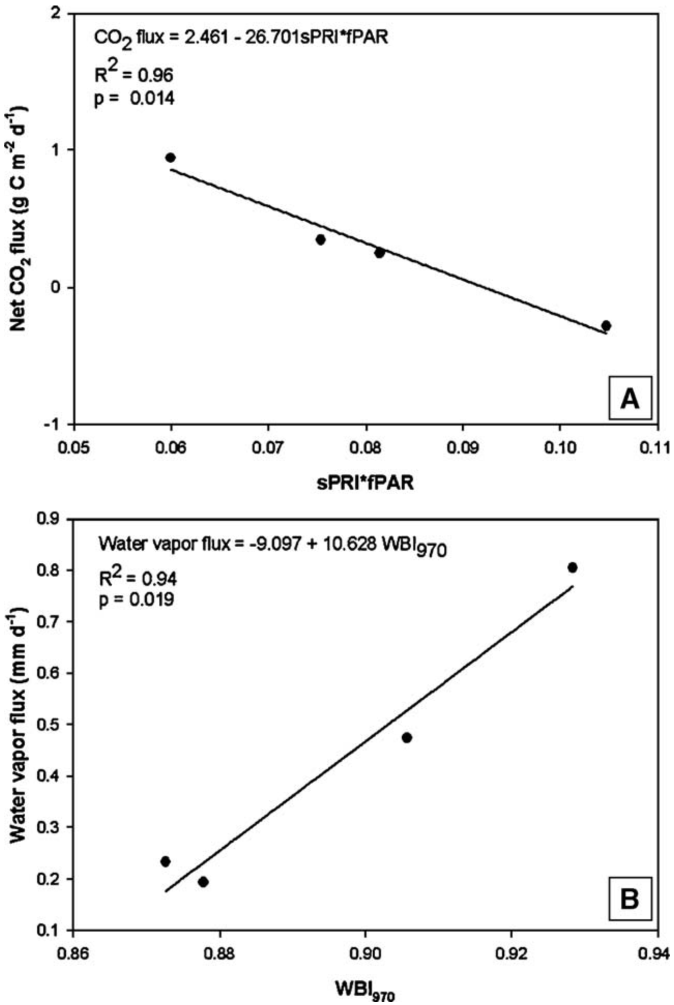
An operational PRI product could improve ecosystem carbon flux estimates, capturing physiological change under disturbance, stress, and changing vegetation composition



Fuentes et al. 2001

Rahman et al. 2001

Mapping disturbance impacts on carbon and water vapor fluxes



sink

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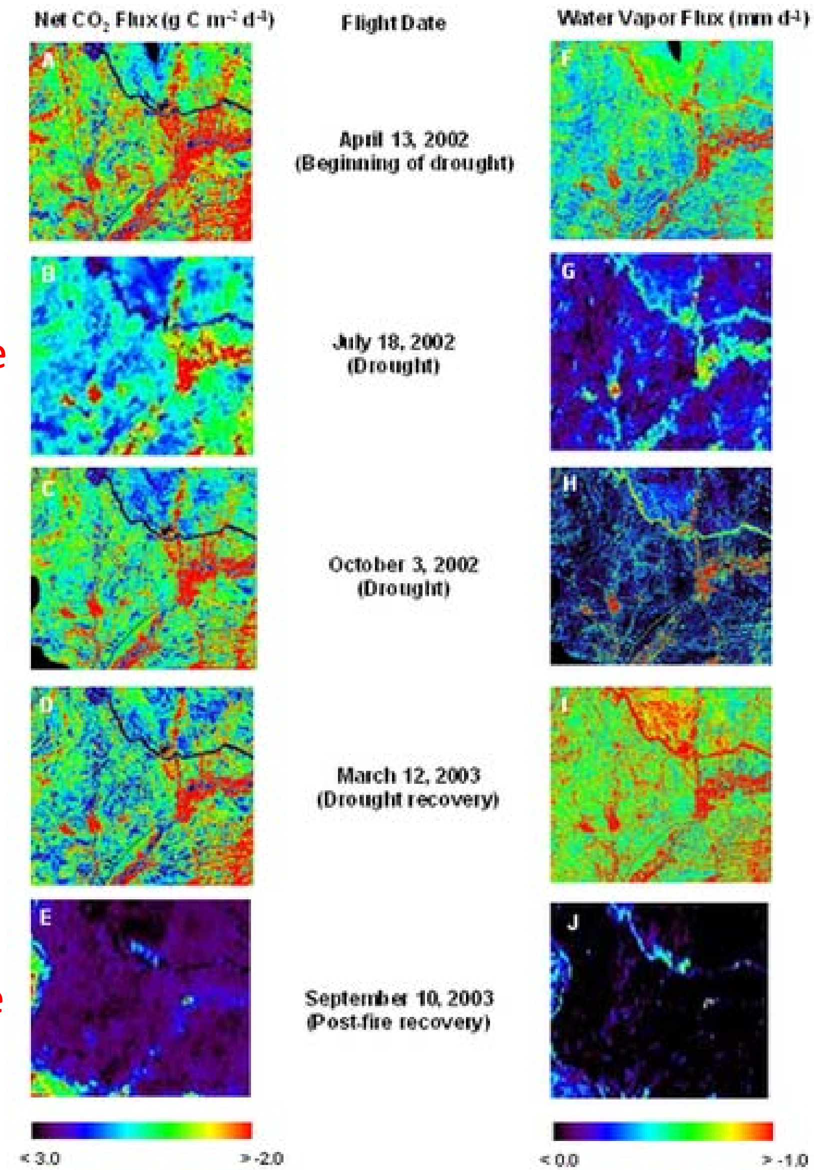


Fuentes et al. 2006

PRI-LUE relationships strongest in backscatter direction (hot spot)

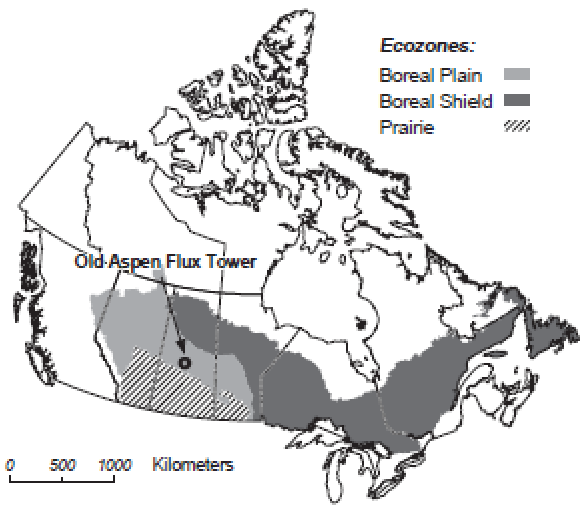
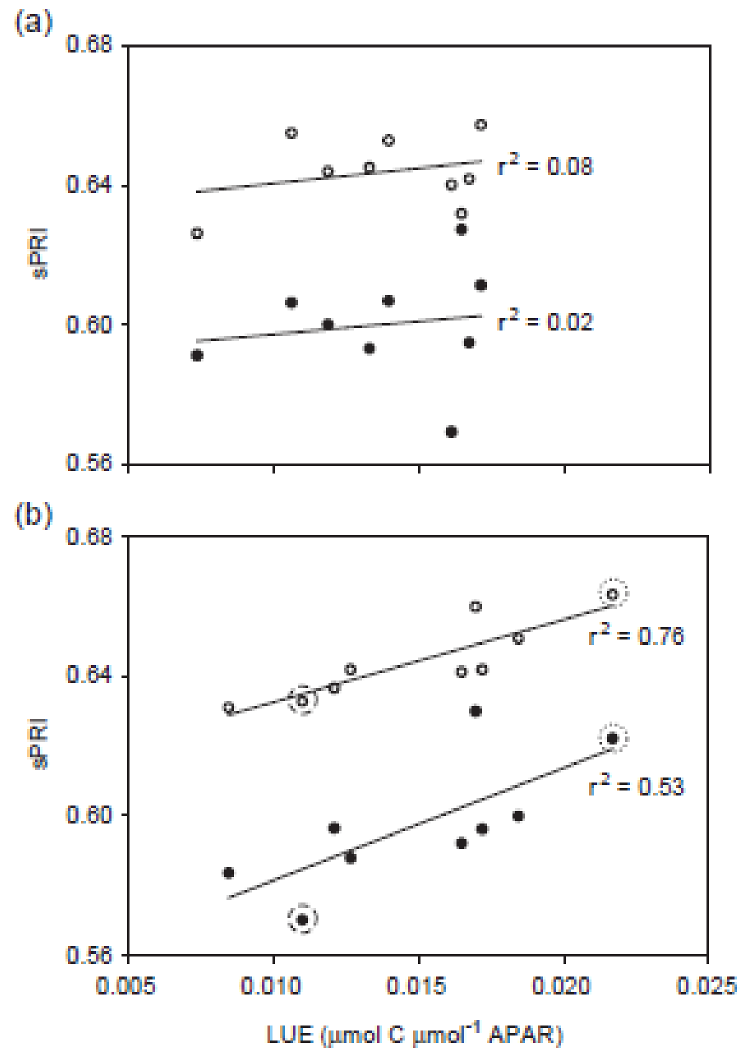
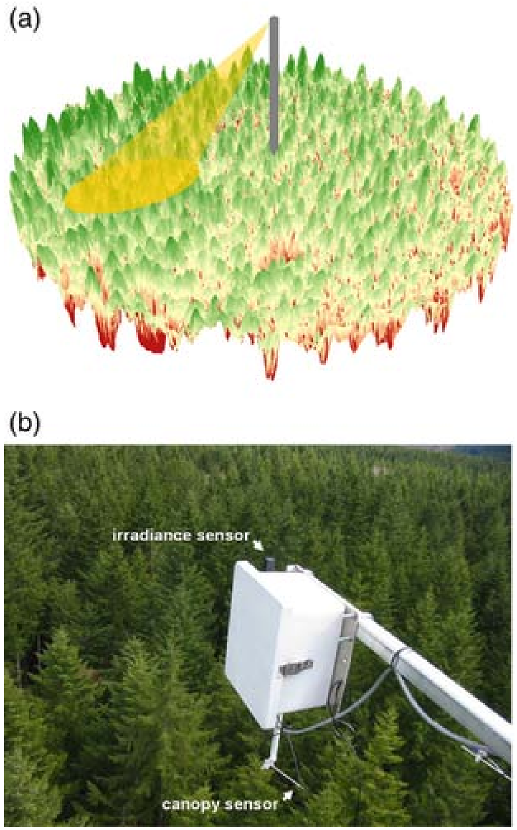


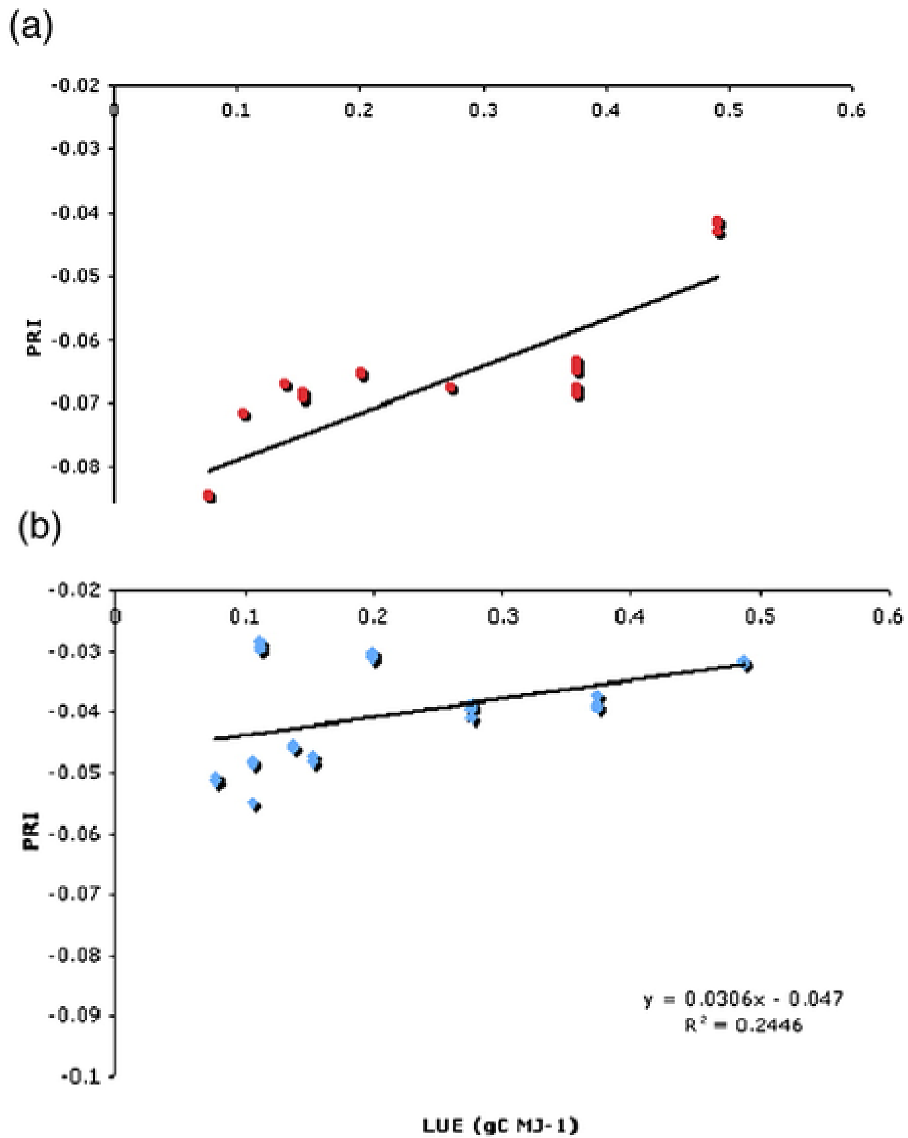
Fig. 1. Location of the study site in Canada.



Drolet et al. 2005

PRI-LUE relationship strongest in backcatter direction (hotspot) where sun exposure is highest





Hall et al. 2008
Hilker et al. 2008
Middleton et al. 2009

Why HyspIRI?

- High Spectral resolution needed*
- Multiple bands provide essential spectral “context”*
  – Choice of reference bands
  – Normalize for green cover
  – Correct for sunlit canopy fraction
  – Synergy with other products
- Spatial resolution needed to resolve uniform vegetation stands
- Temporal coverage can resolve seasonal patterns

**Critical features*

Producing a LUE Product from PRI

$$\mathbf{PRI = (R_{531} - R_{ref})/(R_{531} + R_{ref})}$$

$$\mathbf{sPRI = (PRI + 1)/2}$$

- Normalize to vegetation “greenness” (pigments, LAI…)
- Correct for sunlit fraction (hotspot effects)
- Stratify for look angle, sun angle (?)

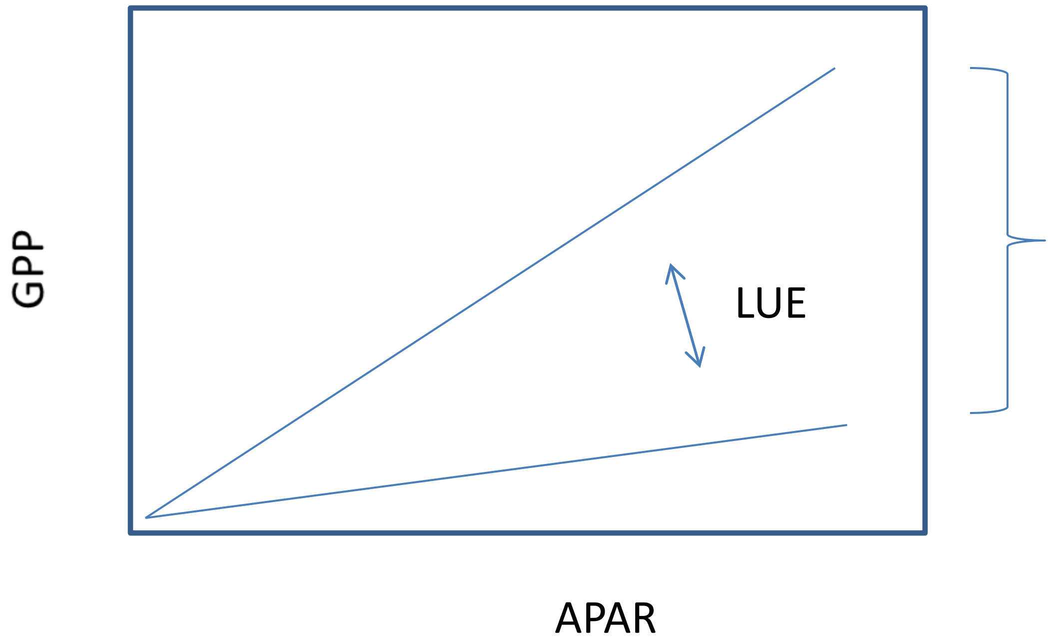
Operational LUE product

?

Canopy temperature & water content

Airborne & field validation still needed

(FLUXNET, SpecNet, BioSpec, COST, SensorVeg)



A "global" LUE metric should be able to account for slope differences between vegetation types or across seasons

Synergy & Links to other products

- Vegetation greenness (e.g. NDVI, EVI, green vegetation fraction…)
- Canopy water content (Water indices, EWT, …)
- Temperature (thermal bands)

<u>Benefits</u> of a HyspIRI LUE product

- Better mapping of *carbon dynamics* (carbon balance) via improved "stress detection" (physiology)
- *Explicit links between carbon, water, and temperature* dynamics (VSWIR-TIR synergy)
- Better characterization of *surface-atmosphere energy feedbacks* (climate modeling)
- Improved *vegetation mapping* (functional diversity)
- Key metric of *"vegetation health"* (economic and human impacts)

Techniques for remote estimation of pigment contents and composition in terrestrial vegetation

Anatoly Gitelson
University of Nebraska-Lincoln
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4-5 May, 2010
HyspIRI/GSFC

Products: Contents and composition of pigments in terrestrial vegetation

- Total chlorophyll content
- Total carotenoids content
- Anthocyanin content

Justification

Pigments relate to both the physiological status and the photosynthetic capacity of vegetation

- Chlorophylls absorb solar radiation and provide mechanisms for its utilization in photosynthetic reactions.

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- Carotenoids contribute to light-harvesting and also play a photo-protective role, preventing damage to the photosynthetic apparatus in leaves.

Justification

Pigments relate to both the physiological status and the photosynthetic capacity of vegetation

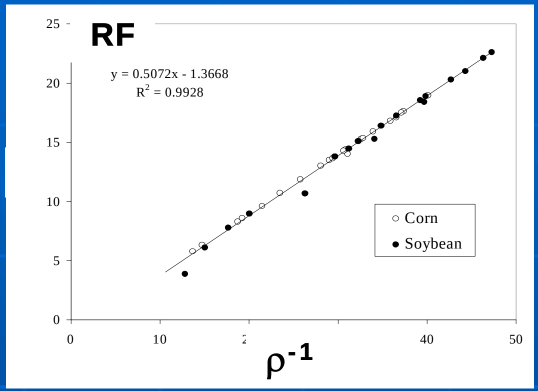
- Chlorophylls absorb solar radiation and provide mechanisms for its utilization in photosynthetic reactions.
- Carotenoids contribute to light-harvesting and also play a photo-protective role, preventing damage to the photosynthetic apparatus in leaves.
- The induction of anthocyanins biosynthesis occurs as a result of deficiencies in nitrogen and phosphorus, wounding, pathogen infection, desiccation, low temperature, UV-irradiation etc. Anthocyanins fulfil important physiological functions by being involved in the adaptation to numerous stresses and environmental strain reduction.

Basis for the product:

Three-band model for pigment content estimation

Kubelka-Munk remission function

$$f(\rho_\infty) = (1 - \rho_\infty{}^2)/2\rho_\infty \cong \rho_o{}^{-1}$$



Thus, ρ^{-1} relates to inherent optical properties of vegetation, a and b_b, at canopy level:

$$\rho^{-1}(\lambda) \propto [a_{pigm}(\lambda) + a_0(\lambda) + b_b]/b_b$$

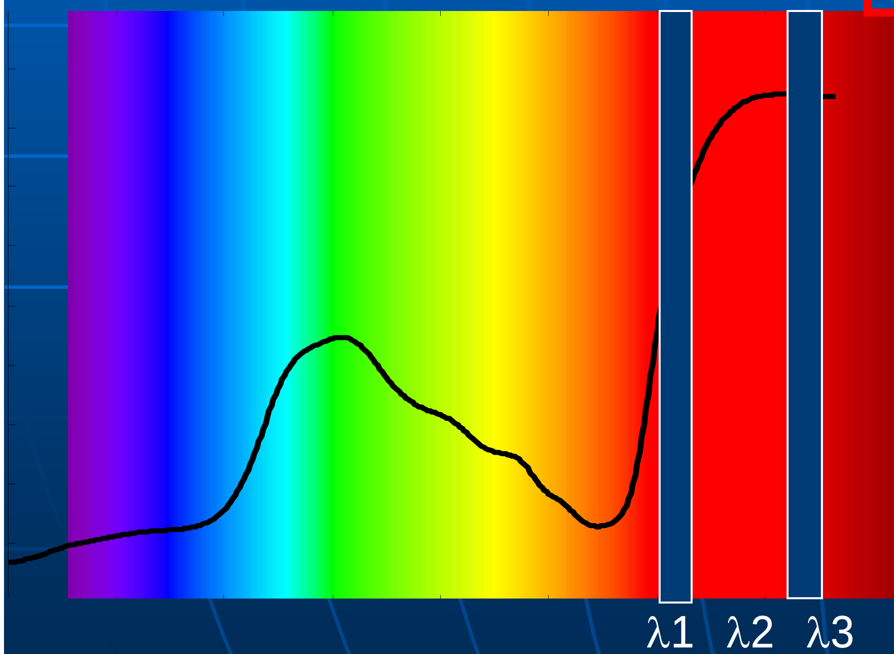
$$\boxed{\text{Pigment} \propto [\rho^{-1}(\lambda_1) - \rho^{-1}(\lambda_2)] \times \rho(\lambda_3)}$$

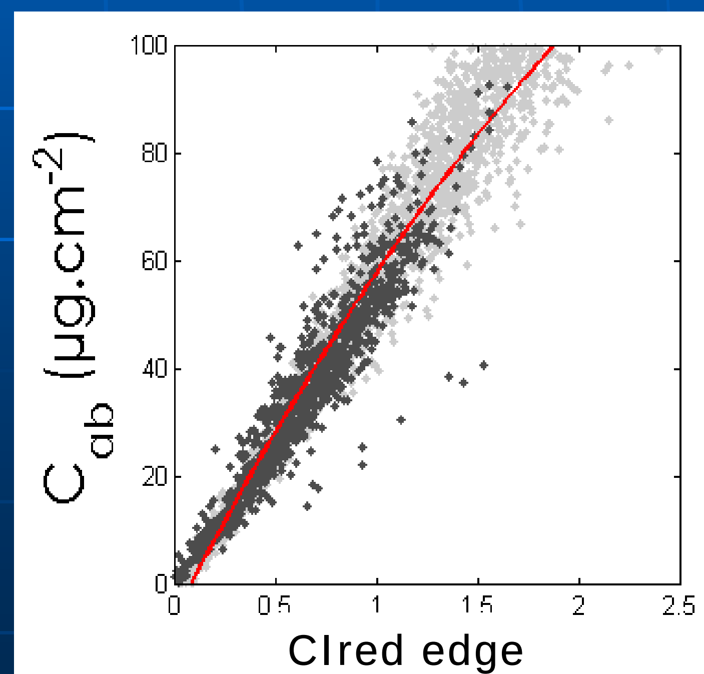
$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Chlorophyll-*a* Reflectance Index

$$CI_{chl\text{-}a} \propto [\underbrace{\rho^{-1}(\lambda_1)} - \underbrace{\rho^{-1}(\lambda_2)}]\times\underbrace{\rho(\lambda_3)}$$

$$\boxed{CI \propto Chl\text{-}a = (\rho_{NIR}/\rho_{red\ edge}) - 1}$$





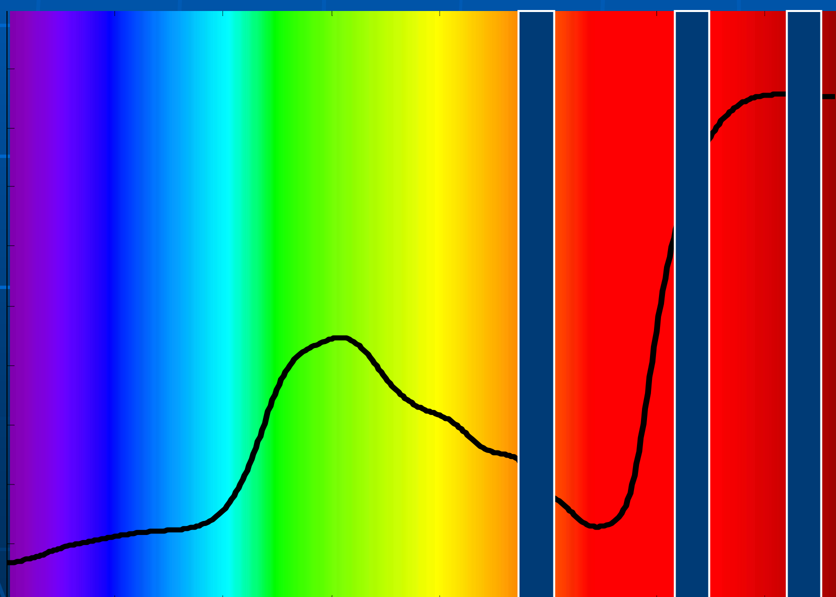
Gitelson et al., GRL, 2005, Feret et al., RSE, 2009

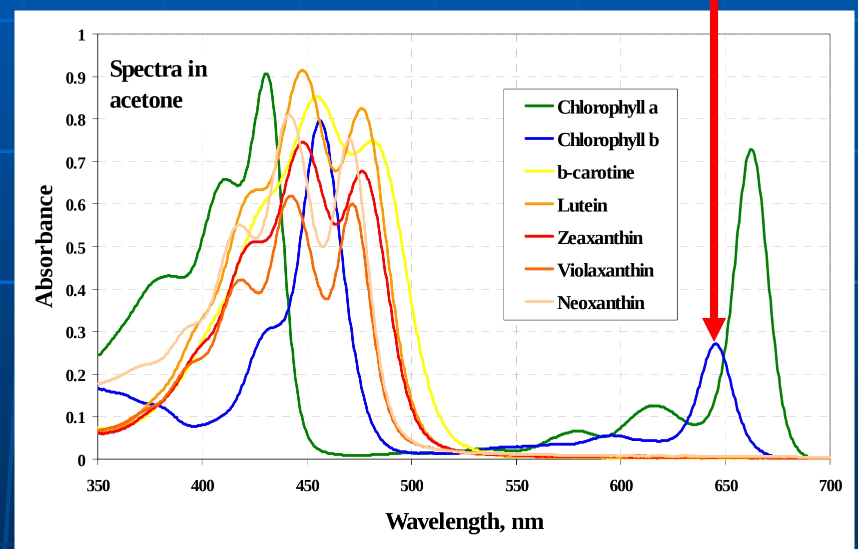
Why and how is HyspIRI able to <u>uniquely</u> provide it

$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Chlorophyll-*b* Reflectance Index

$$CI_{chl\text{-}b} \propto \underbrace{[\rho^{-1}(\lambda_1)}_{a_{chl\text{-}a}\,+\,a_{chl\text{-}b}} - \underbrace{\rho^{-1}(\lambda_2)]}_{a_{chl\text{-}a}} \times \underbrace{\rho(\lambda_3)}_{b_b}$$





$$\boxed{Chl\text{-}b \propto CI_{chl\text{-}b} = (\rho^{-1}_{650} - \rho^{-1}_{720}) \times \rho_{NIR}}$$

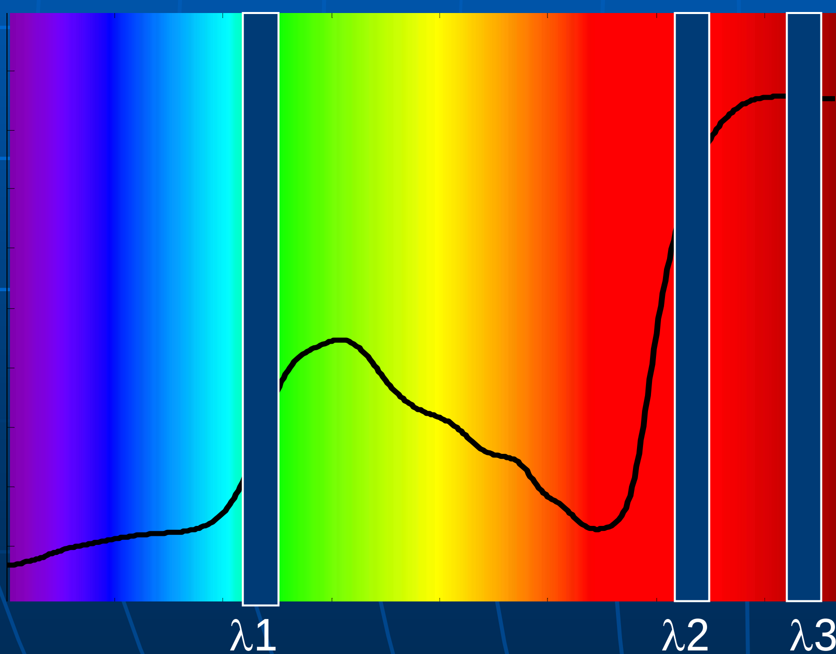
Why and how is HyspIRI able to uniquely provide it

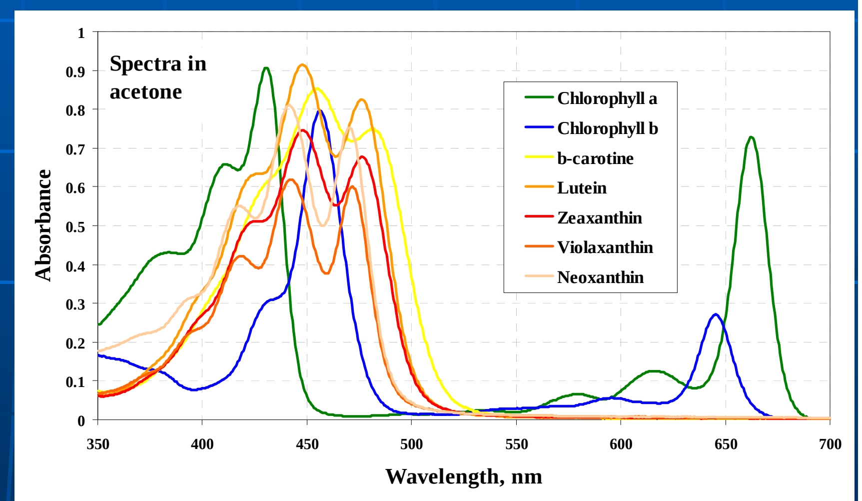
$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Carotenoids Reflectance Index

$$\mathrm{CRI} \propto [\underbrace{\rho^{-1}(\lambda_1)}_{a_{car} + a_{chl}} - \underbrace{\rho^{-1}(\lambda_2)}_{a_{chl}}]\times\underbrace{\rho(\lambda_3)}_{b_b}$$

Gitelson et al., 2002





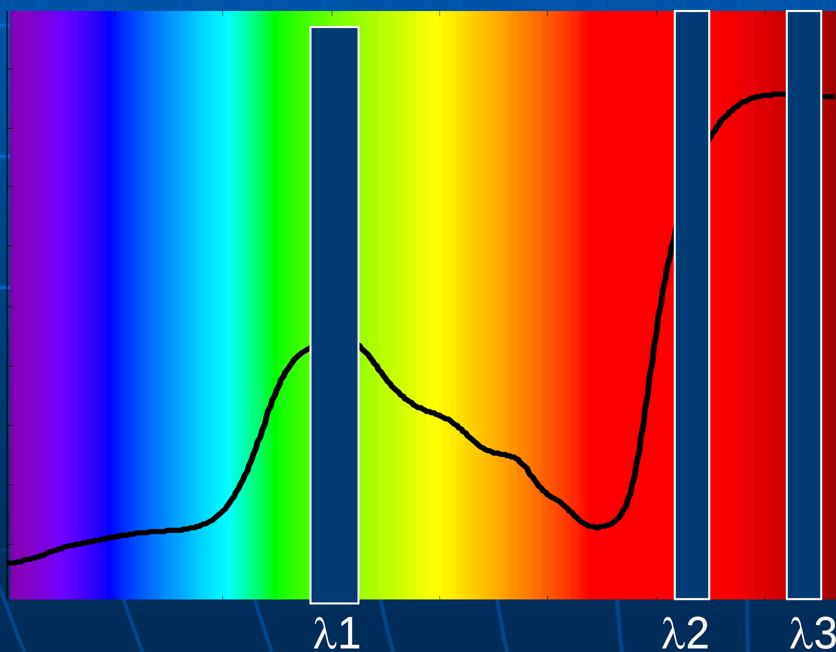
$$\boxed{\mathrm{Car} \propto \mathrm{CRI} = (\rho^{-1}{}_{515} - \rho^{-1}{}_{720})\times\rho_{NIR}}$$

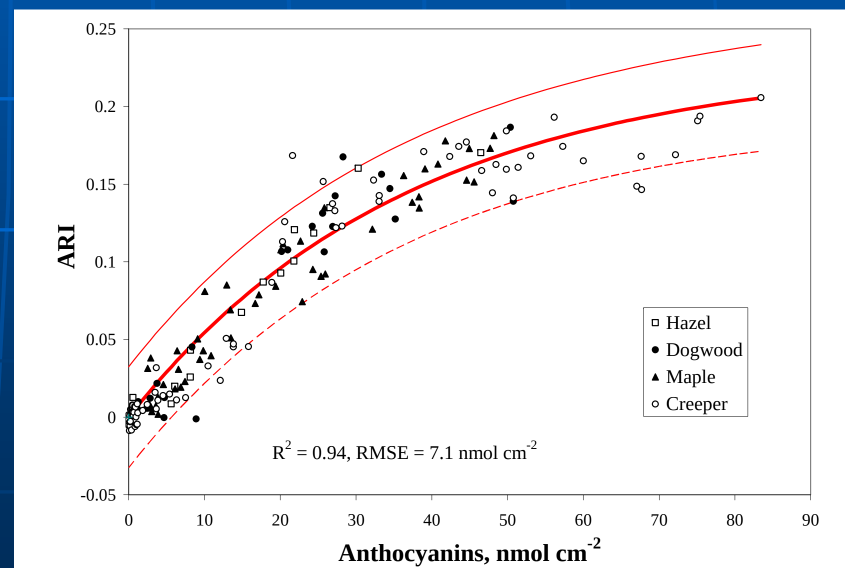
$$\rho^{-1}(\lambda) \propto [a_{chl}(\lambda) + a_0(\lambda) + b_b]/b_b$$

Anthocyanin Reflectance Index

$$ARI_{red\ edge} \propto [\underbrace{\rho^{-1}(\lambda_1)}_{a_{anth} + a_{chl}} - \underbrace{\rho^{-1}(\lambda_2)}_{a_{chl}}] \times \underbrace{\rho(\lambda_3)}_{b_b}$$

Gitelson et al., 2001



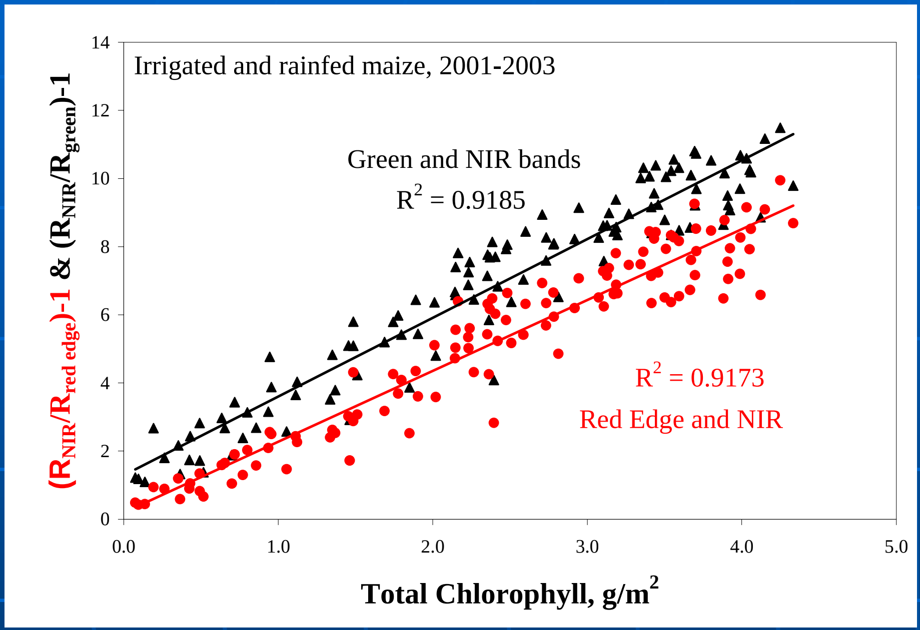


Gitelson et al., 2009

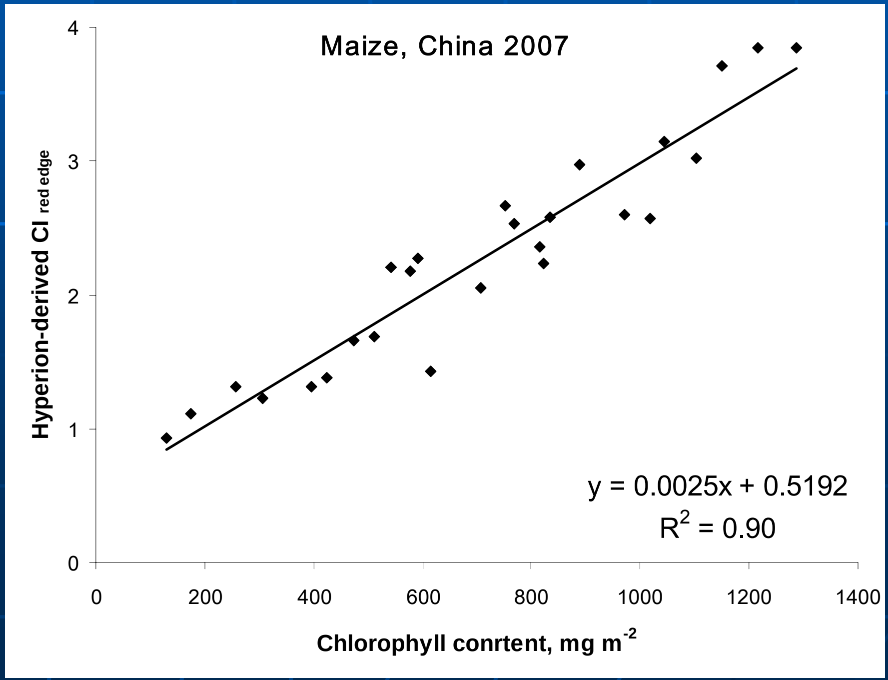
Anthocyanin levels (ARI) indicate physiological and biochemical changes from water stress (Asner, PNAS, 2004)

How does it work?

$$CI_{red\ edge} \propto [(\rho_{red\ edge})^{-1} - (\rho_{NIR})^{-1}] \times \rho_{NIR}$$



Gitelson et al., GRL, 2005



Wu et al., IJRS, 2010

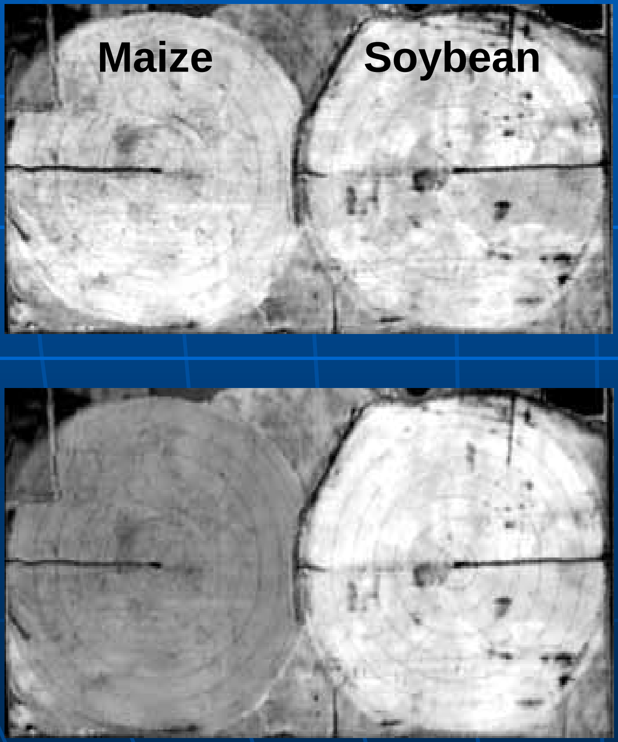
Is the model species-specific?

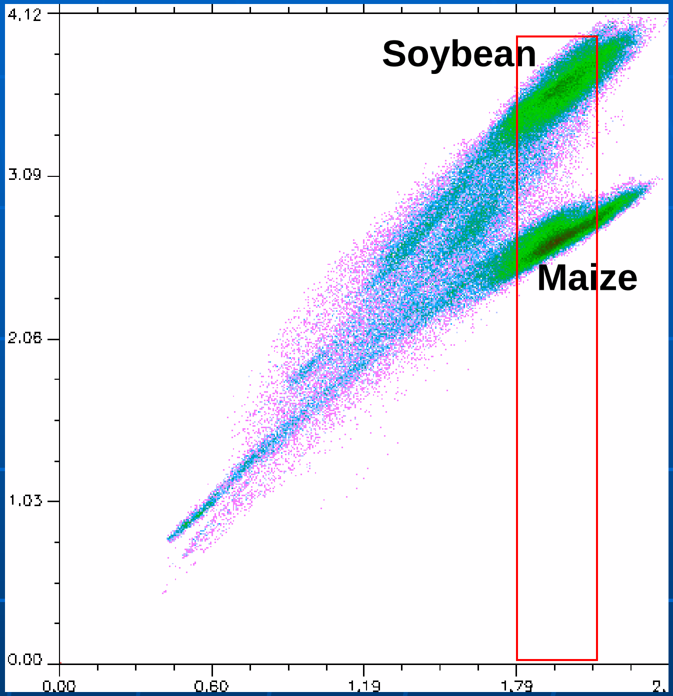
Chlorophyll content and green LAI were the same in both maize and soybean sites

AISA-Eagle Hyperspectral Imager

Red edge Model

Green Model





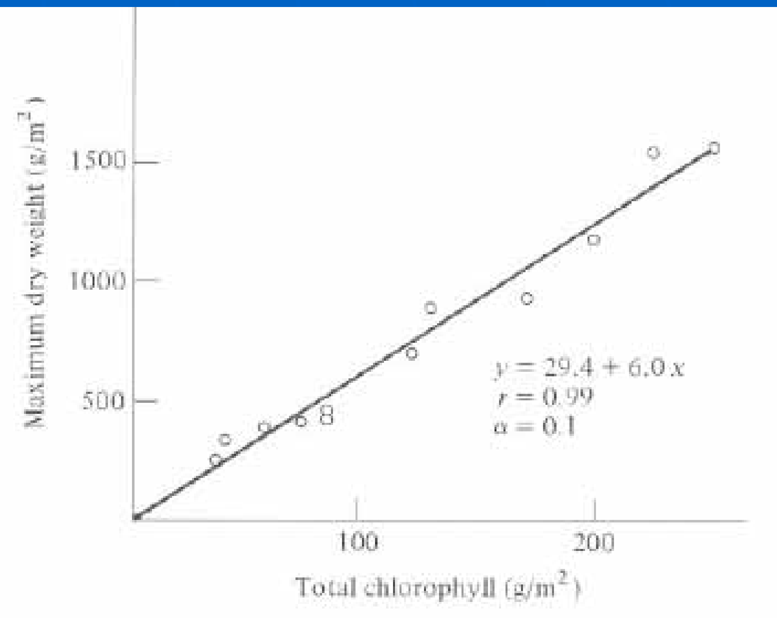
Green Model

Red-edge Model

Narrow band red edge model is not species specific

GPP vs. Chlorophyll Content

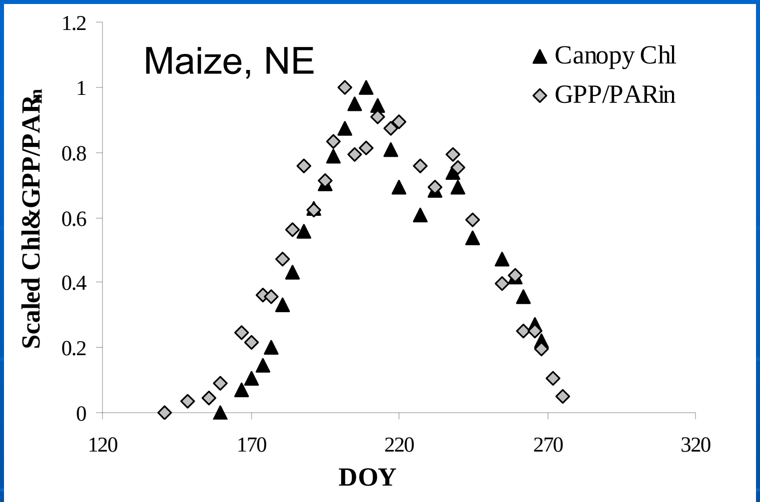
FIGURE 4–7. Relationship of productivity (as indicated by the seasonal maximum biomass) in meadows to total chlorophyll content at the same time. From Medina and Lieth (1964).

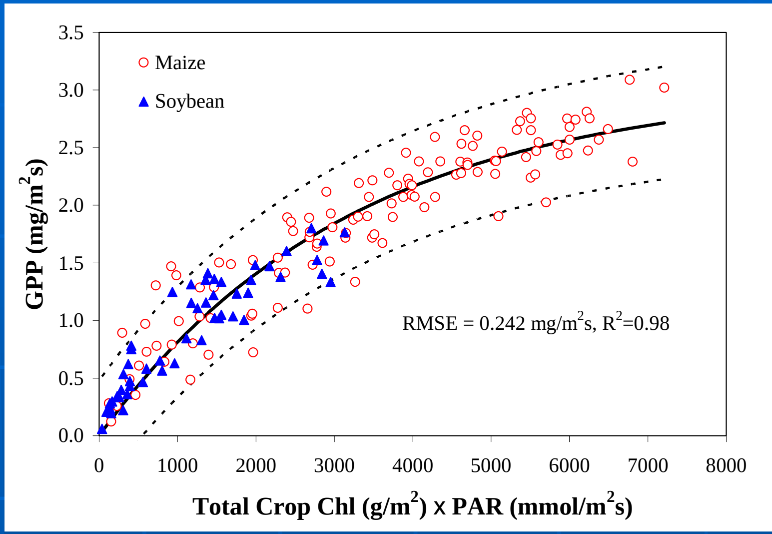


Medina and Lieth, Beitraege zur Biologie der Pflanzen, 1964

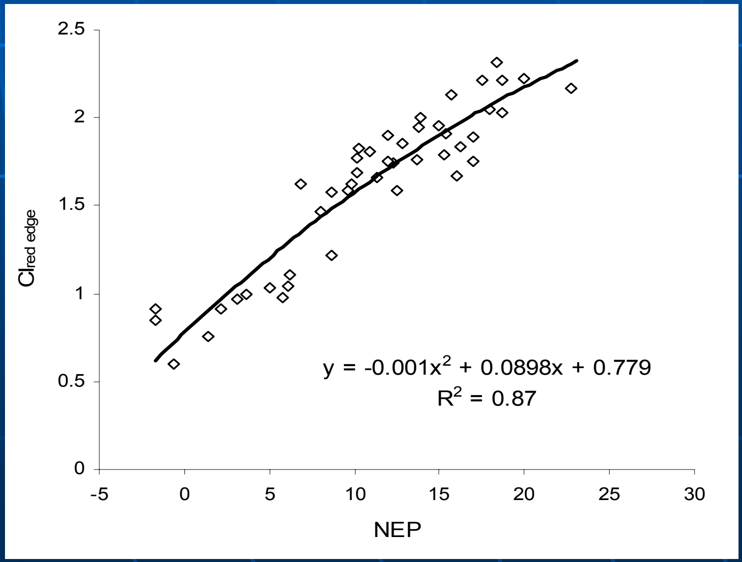
Primary Productivity of the Biosphere, (Lieth and Whittaker, Eds), Fig. 4-7, p. 102, 1975,

GPP vs. Chl



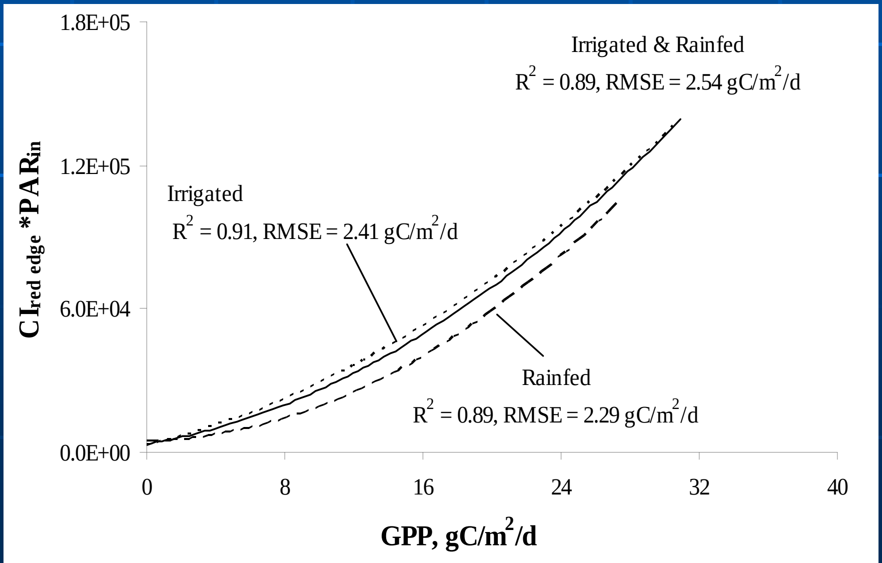


Gitelson et al., JGR, 2006



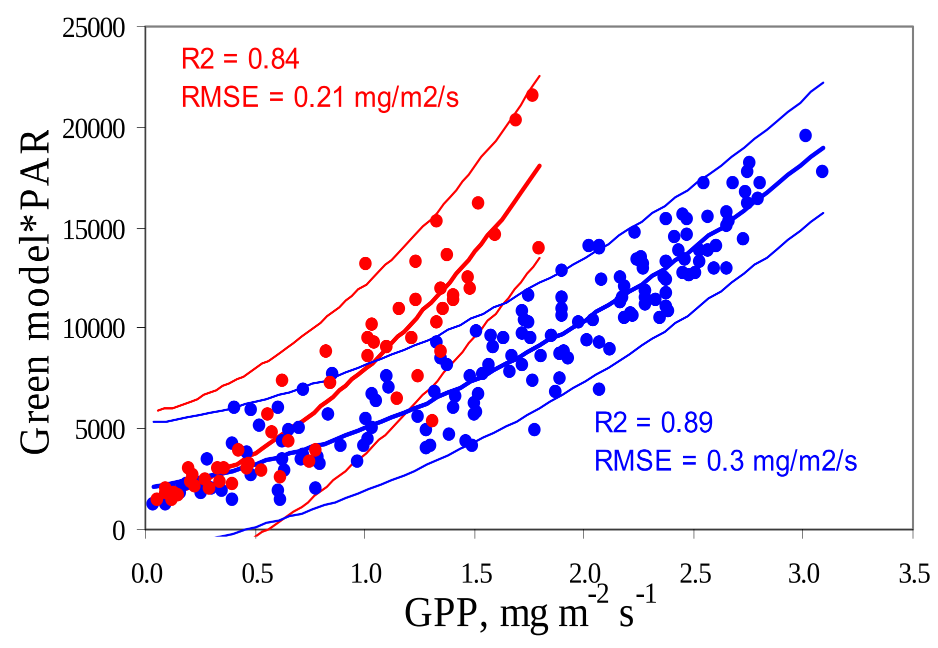
Deciduous forest, BC Canada

Courtesy of Thomas Hilker

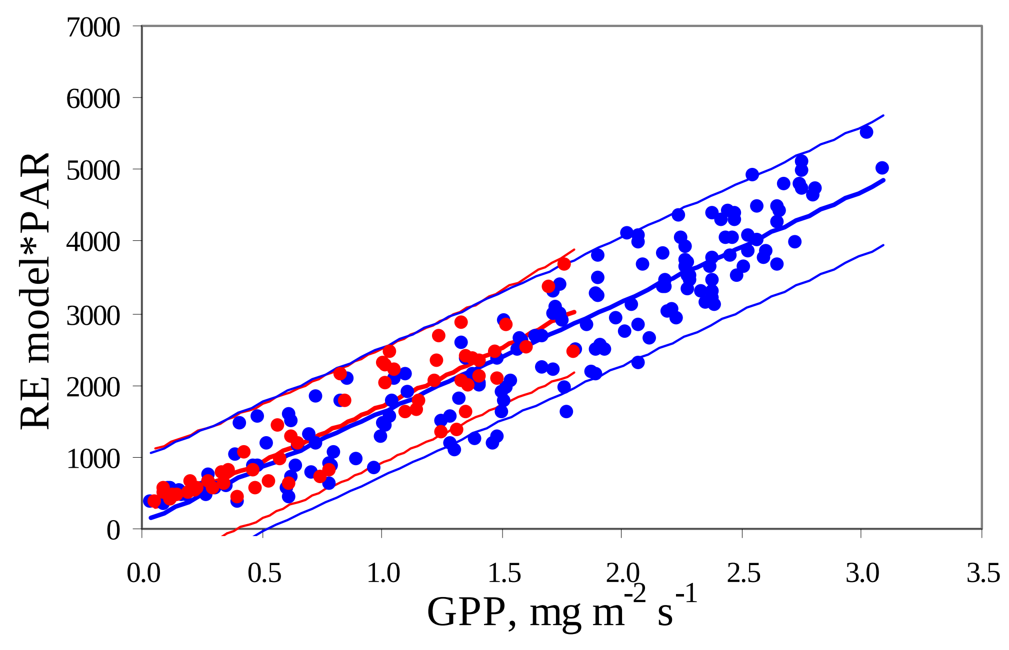


Yi et al., 2010

GPP estimation via Chl

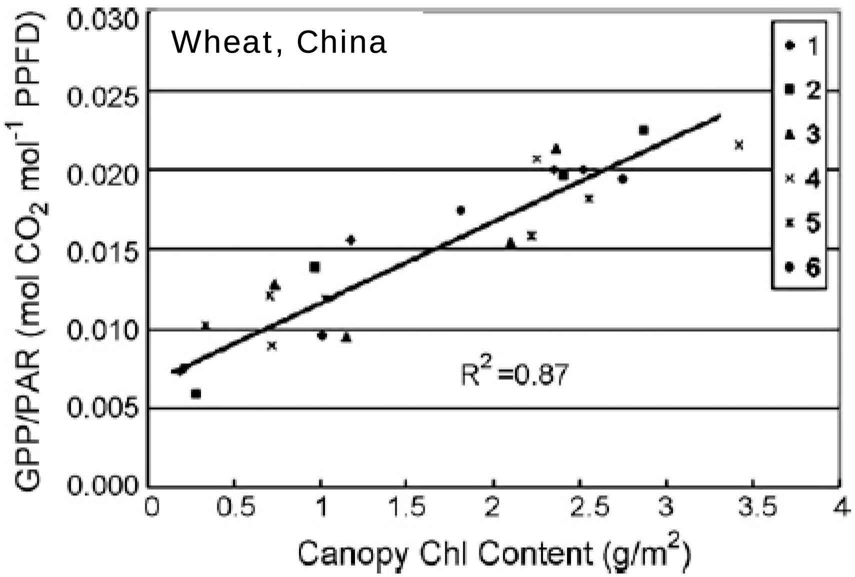


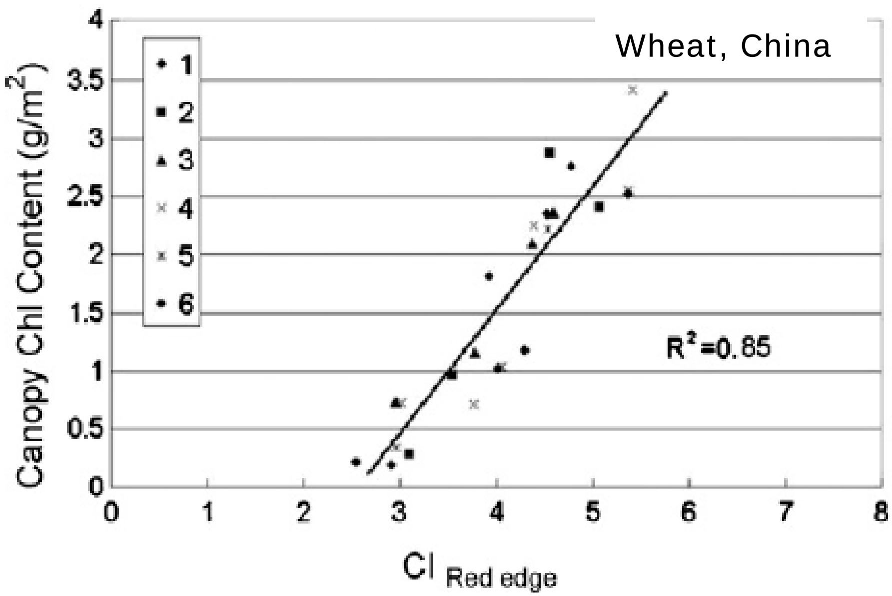
Maize
Soybeans



Chl → GPP → CI

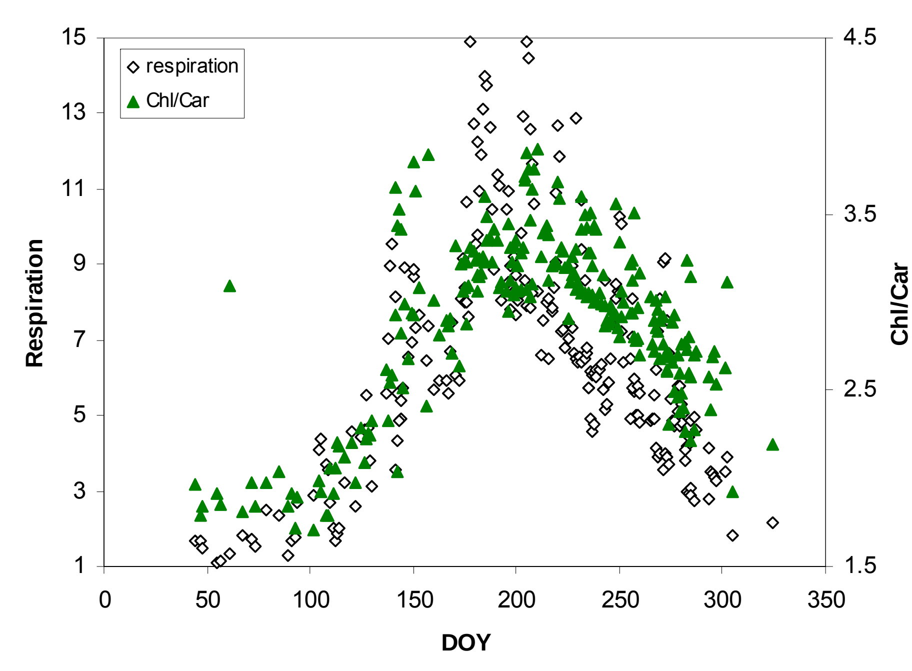
Relevance to climate





Car/Chl → Respiration

Coniferous forest, BC Canada



4-5 May, 2010
HyspIRI/GSFC

Wu et al, AFM, 2009

Courtesy of Thomas Hilker

1. Non-destructive detection of pigment contents in plant leaves

$$C_{pigment} \propto [R^{-1}(\lambda_1) - R^{-1}(\lambda_2)] \times R(\lambda_3)$$

Gitelson et al., 2003

Chlorophyll

710 - 770 - 770

Gitelson et al., 1994; 1996; 2003

Anthocyanins

550 - 700 - 770

Gitelson et al., 2001, 2009

Carotenoids

510 - 700 - 770

Gitelson et al., 2002

2. Non-destructive retrieval of chlorophylls, carotenoids and anthocyanins contents from canopy transmittance spectra

Thanks

agitelson2@unl.edu

Ecosystem Data Products:

Canopy Nitrogen and Albedo

Mary Martin, Scott Ollinger, Lucie Lepine

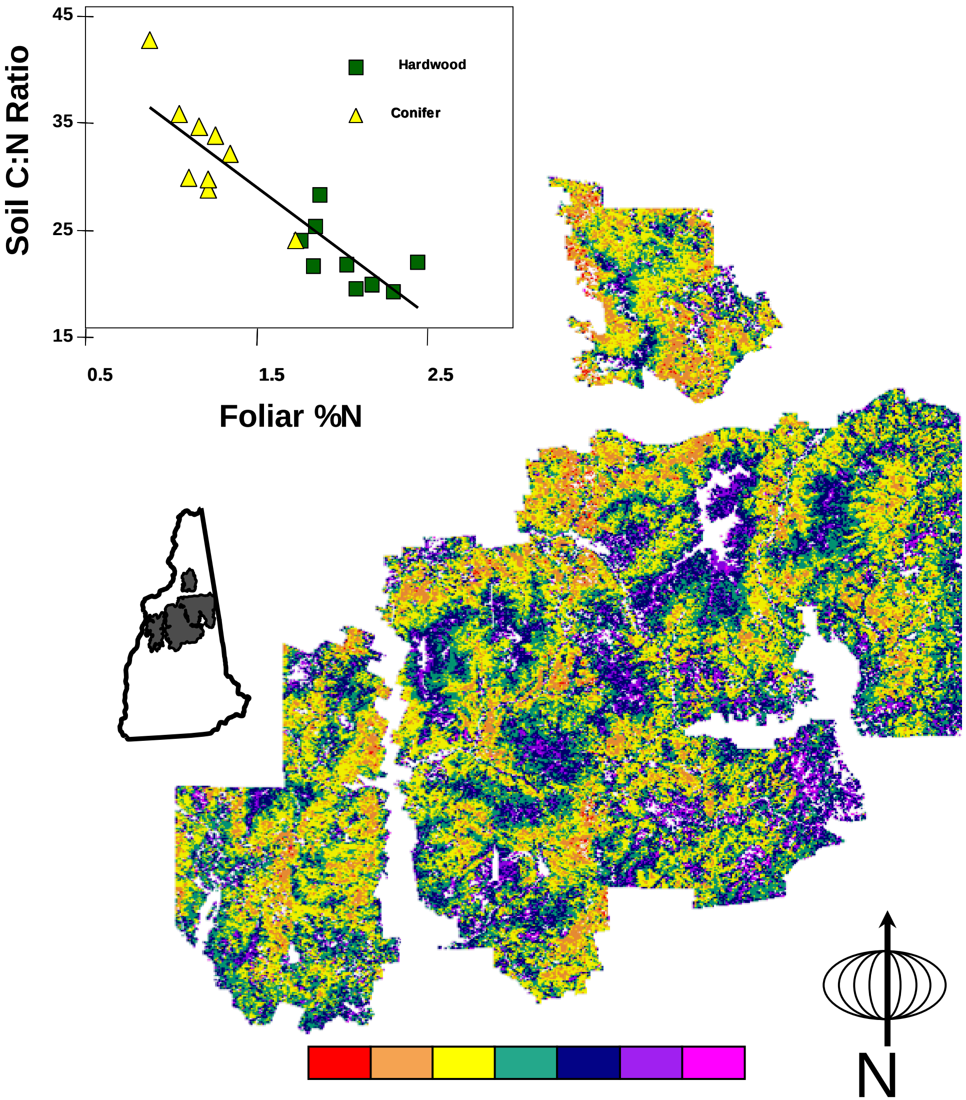
University of New Hampshire

HyspIRI Science Symposium on Ecosystem Data Products

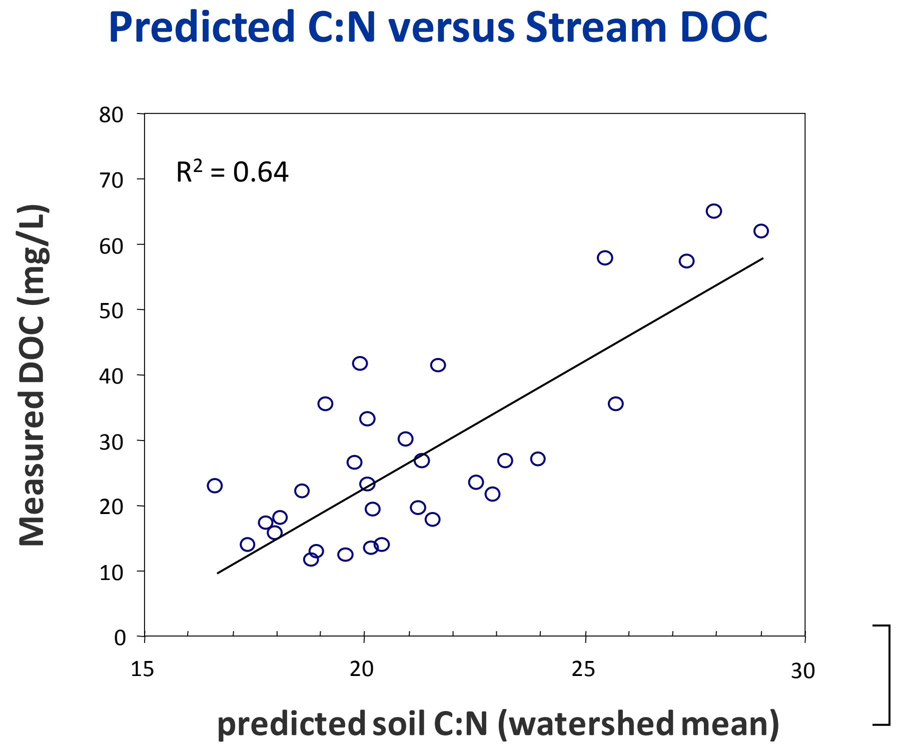
5/4/2010

UNIVERSITY of NEW HAMPSHIRE

AVIRIS-Predicted Foliar Chemistry Used to Estimate Soil Nitrogen Cycling

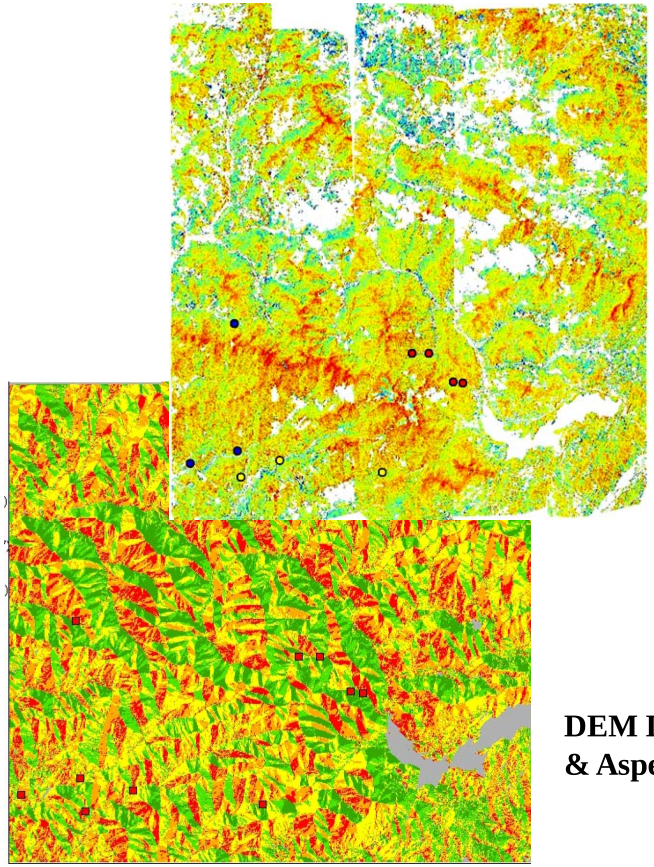


Ollinger et al. 2002



Forest N status and Susceptibility to the Hemlock Wooly Adelgid

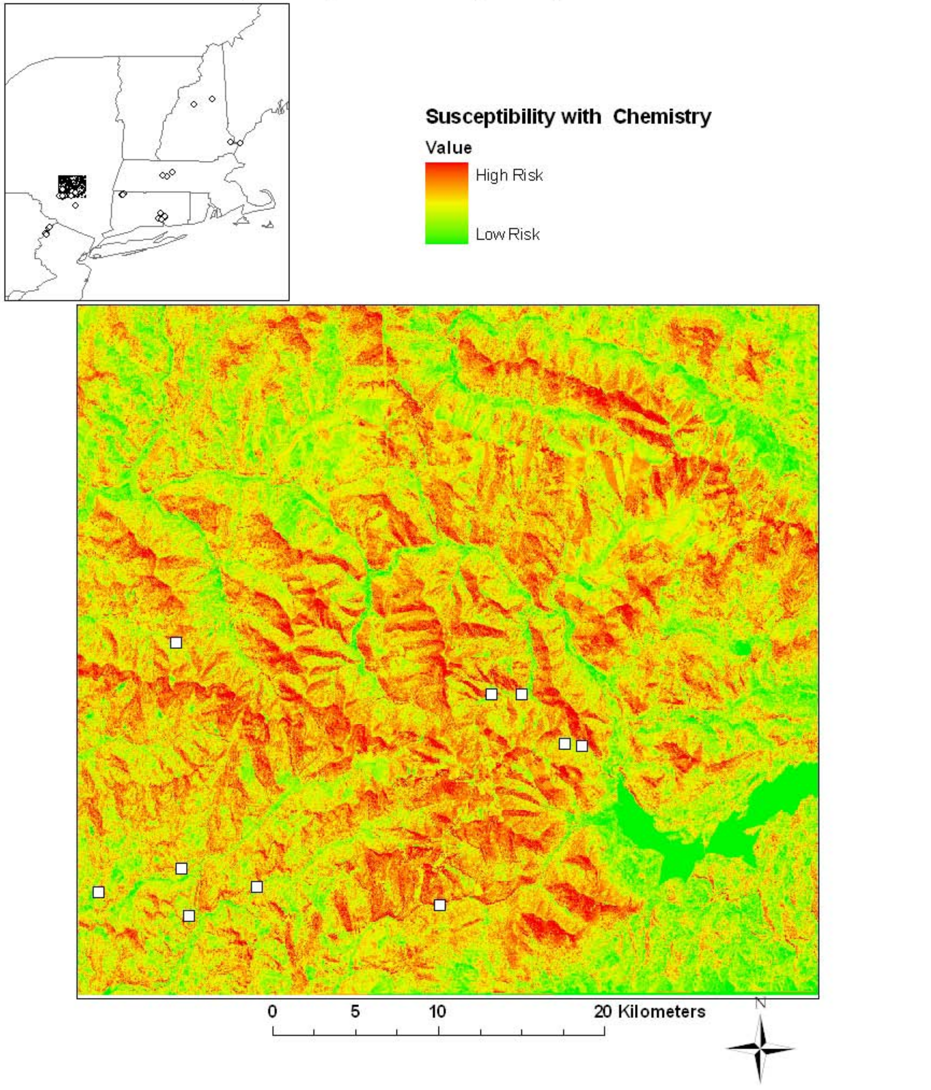
Input Data Layers



AVIRIS-Derived Foliar %N

DEM Derived Slope & Aspect

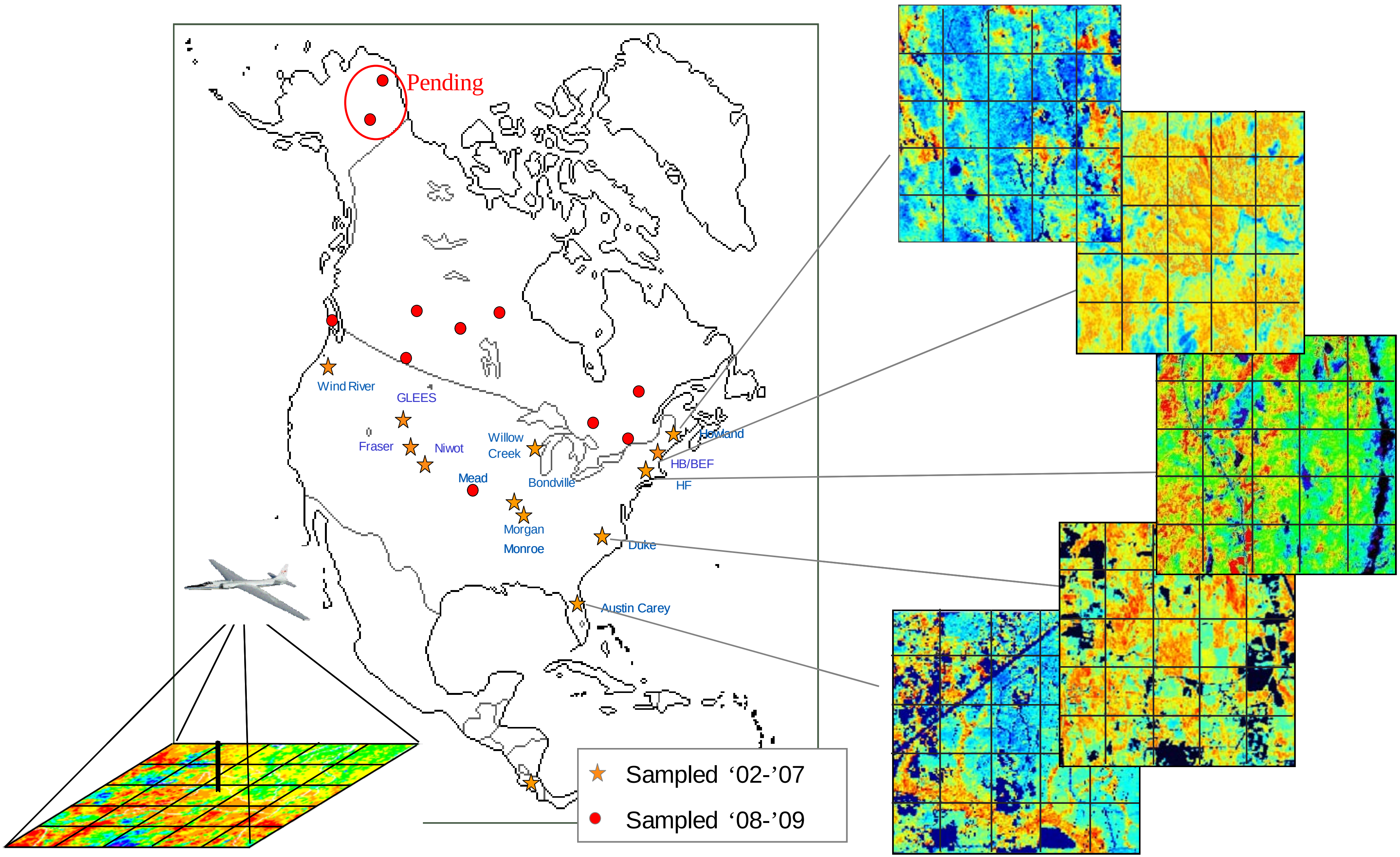
Susceptibility Risk: Slope/Aspect/Foliar N



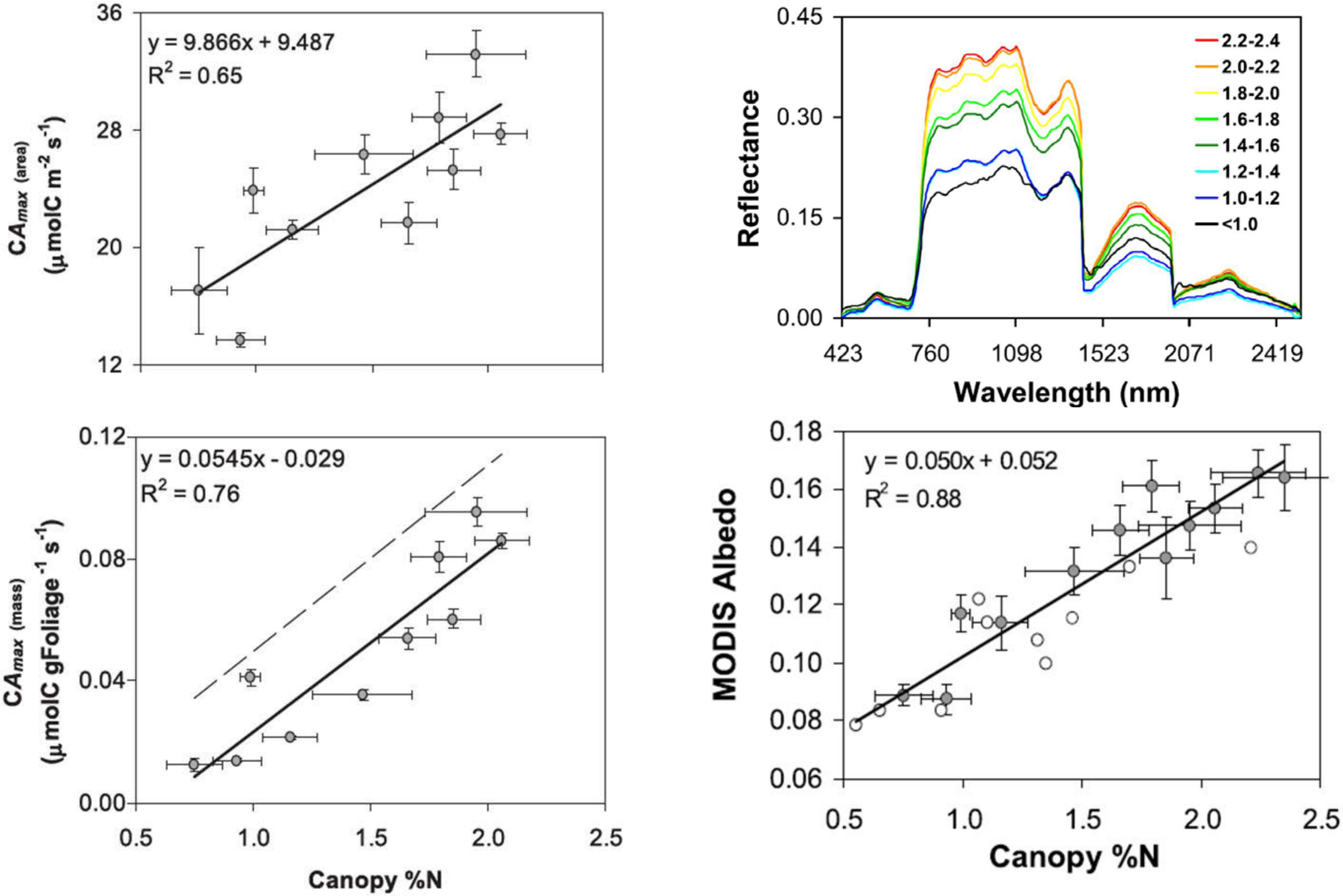
Pontius et al. 2008

The resulting model explained 51% of the variability in observed hemlock decline

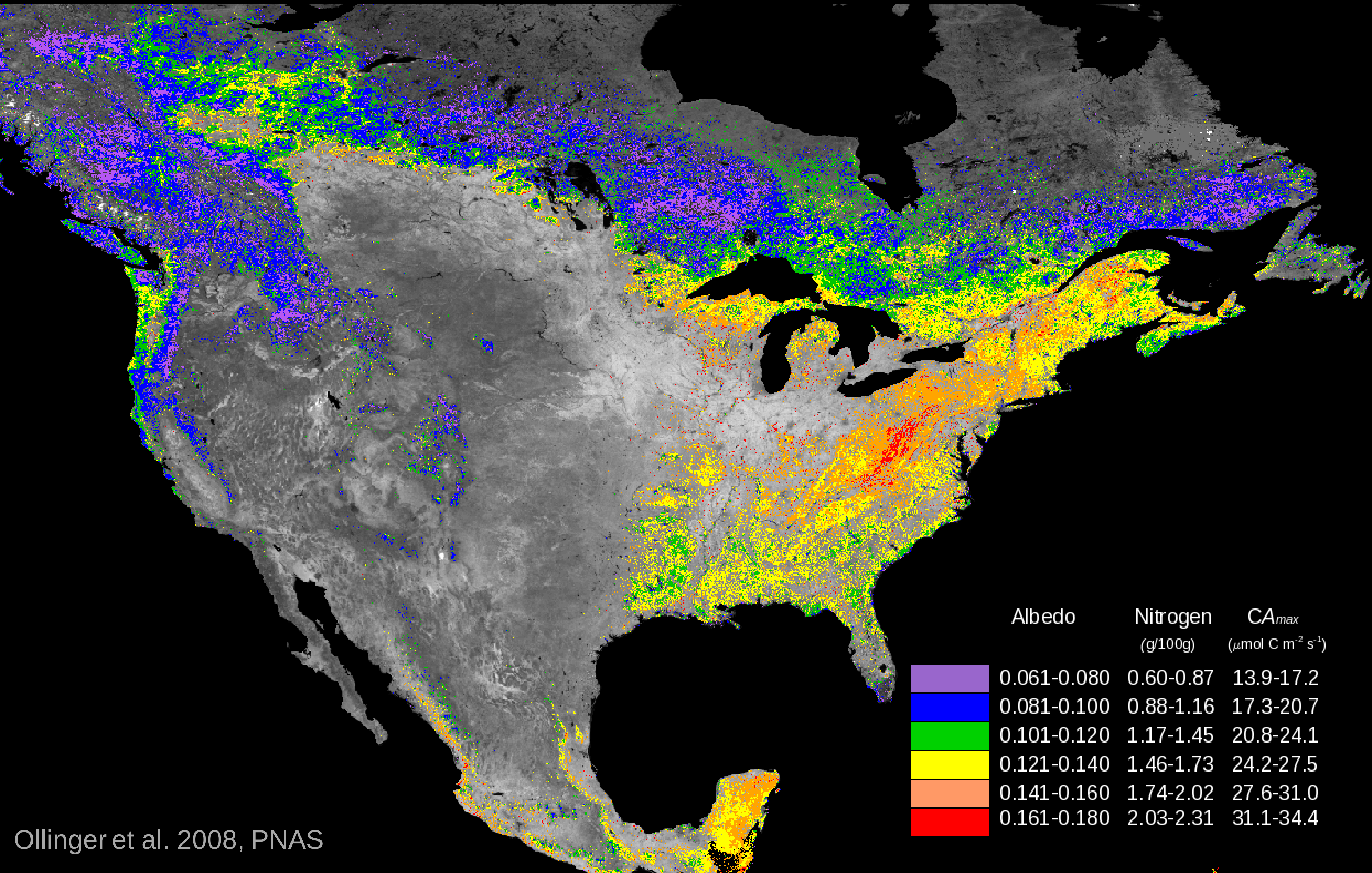
Continental synthesis of CO_2 Flux data, field measurements, imaging spectroscopy and global satellite sensors



Canopy nitrogen, photosynthetic capacity (Amax) and shortwave albedo are inter-related in N. American forests

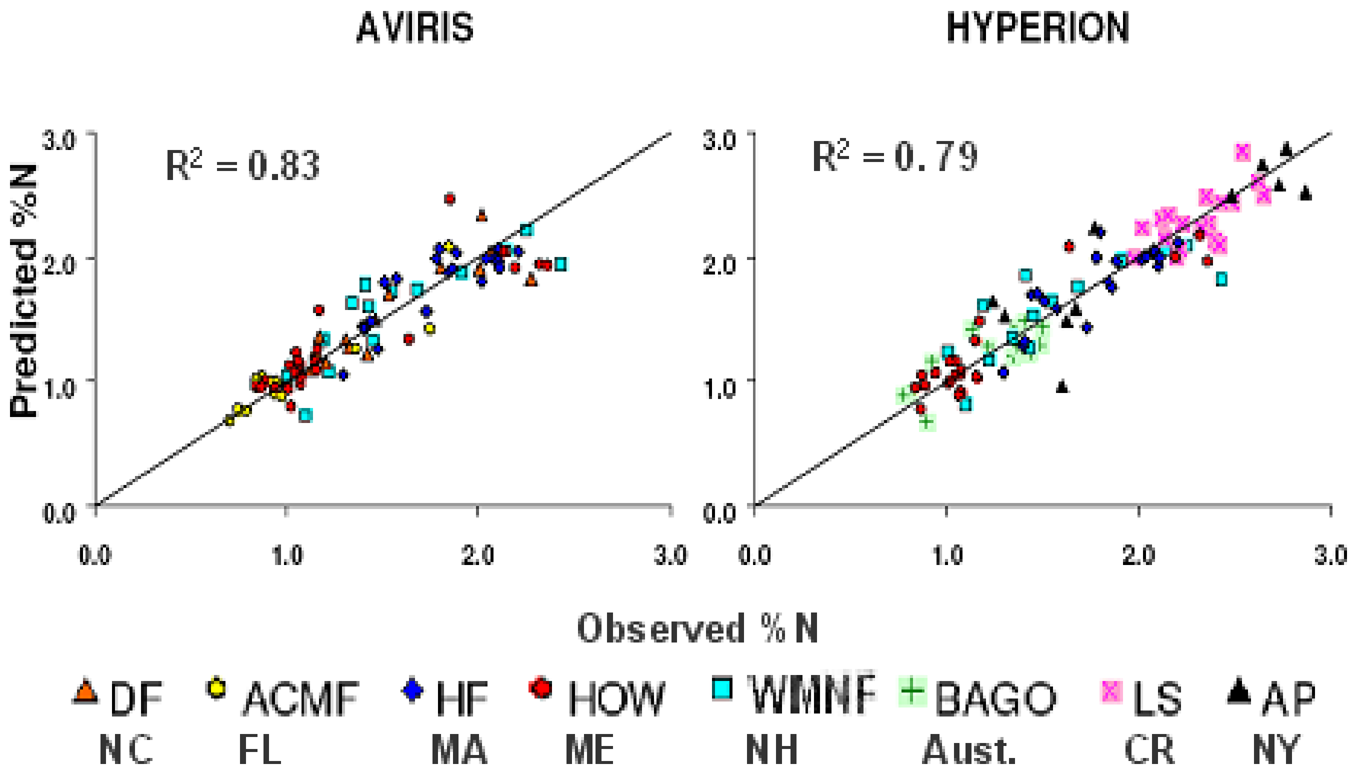


Predicted Canopy Nitrogen and Photosynthetic Capacity in N. American Forests



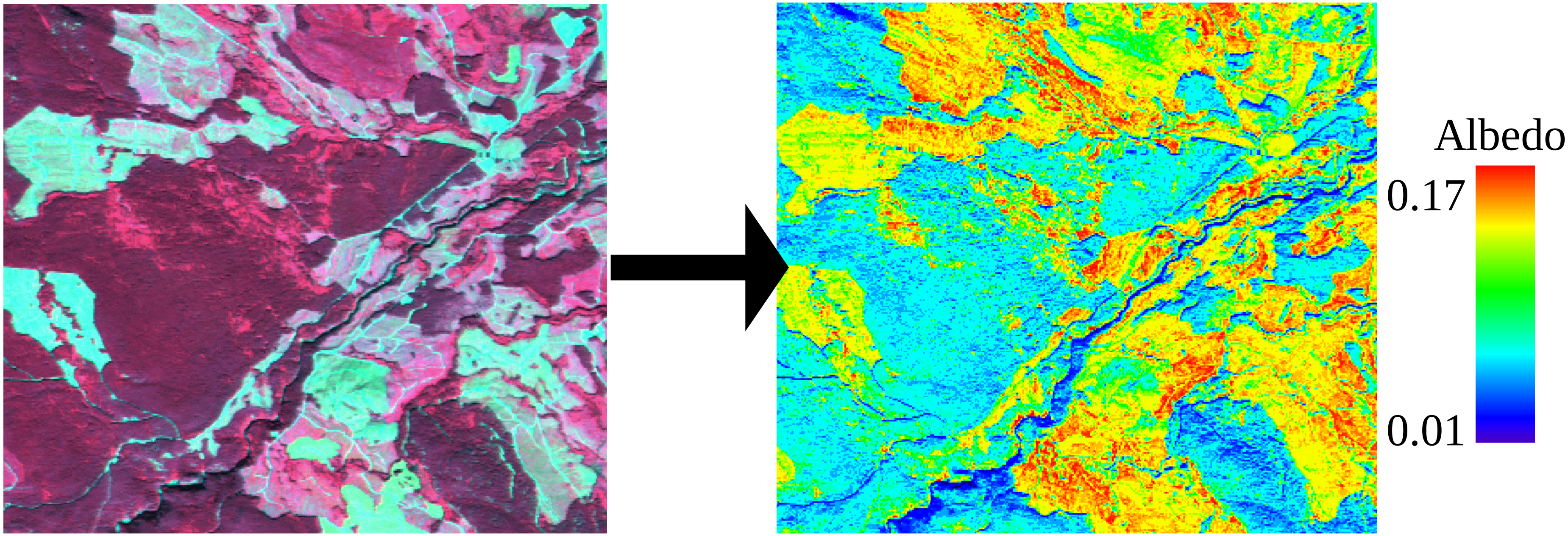
Ollinger et al. 2008, PNAS

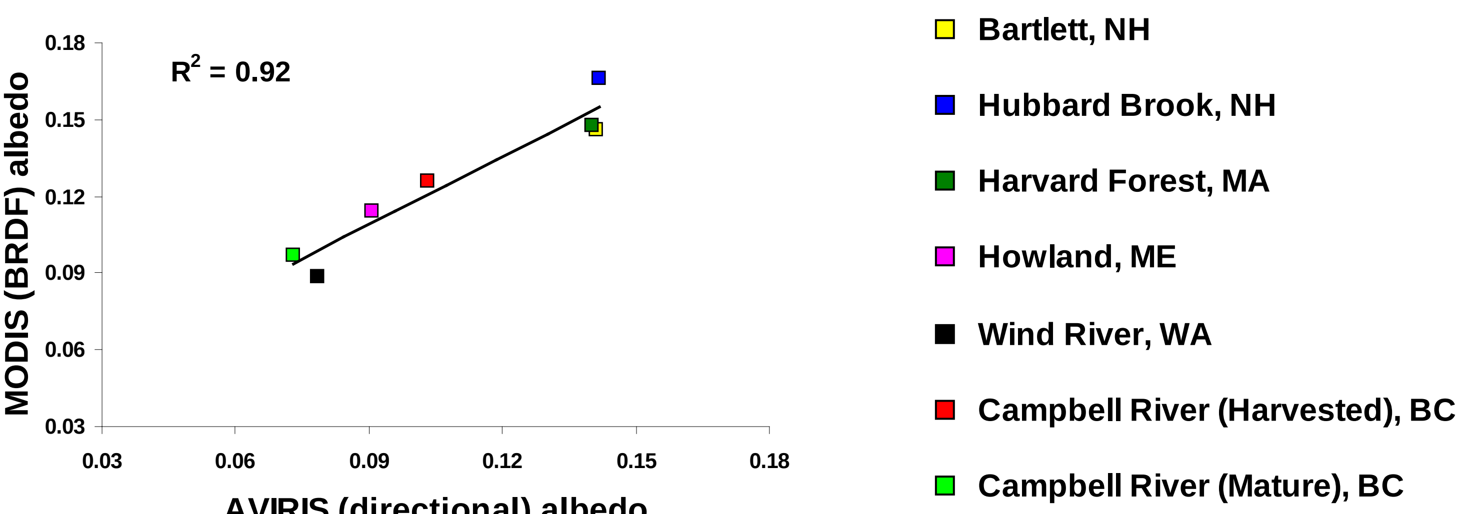
Developing a multi-site generalized equation to predict canopy nitrogen concentration



Martin et al. 2008 RSE

AVIRIS reflectance (left) used to calculate shortwave surface albedo (right).





Ongoing Research Questions:

1. Do the trends observed in NA forests also apply across other biomes?

2. Do they also apply at local as well as continental scales?

3. Do regional patterns in N deposition and other disturbances have an influence on patterns of albedo?

4. What is the mechanism driving the N-albedo relationship?
   - Leaf angle distribution
   - Foliar spatial patterning (e.g. needle and leaf clumping)
   - Leaf or canopy level trait that we haven’t yet examined.

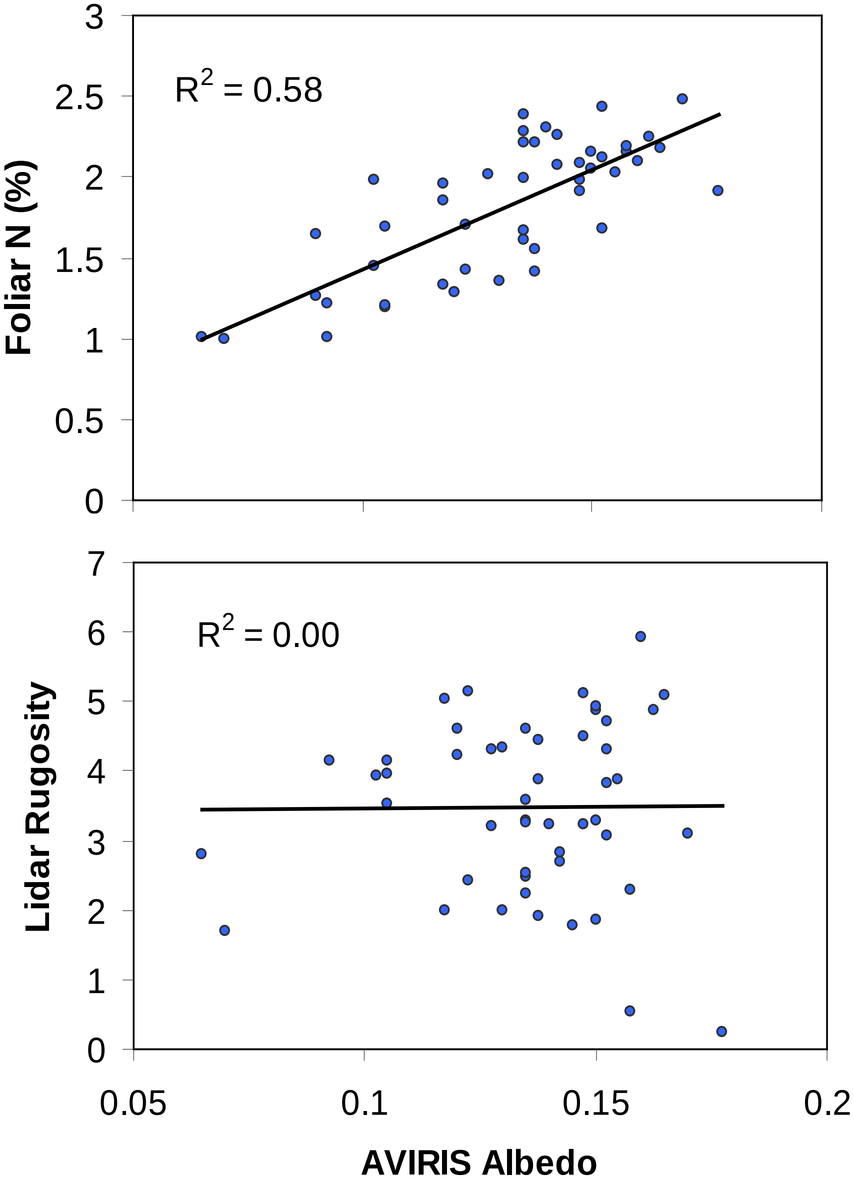
Role for HyspIRI data:

1. Ideal scale/coverage to bridge the gap between isolated AVIRIS datasets and continental scale MODIS data products

2. Nitrogen and Albedo data products can be generated as with AVIRIS.

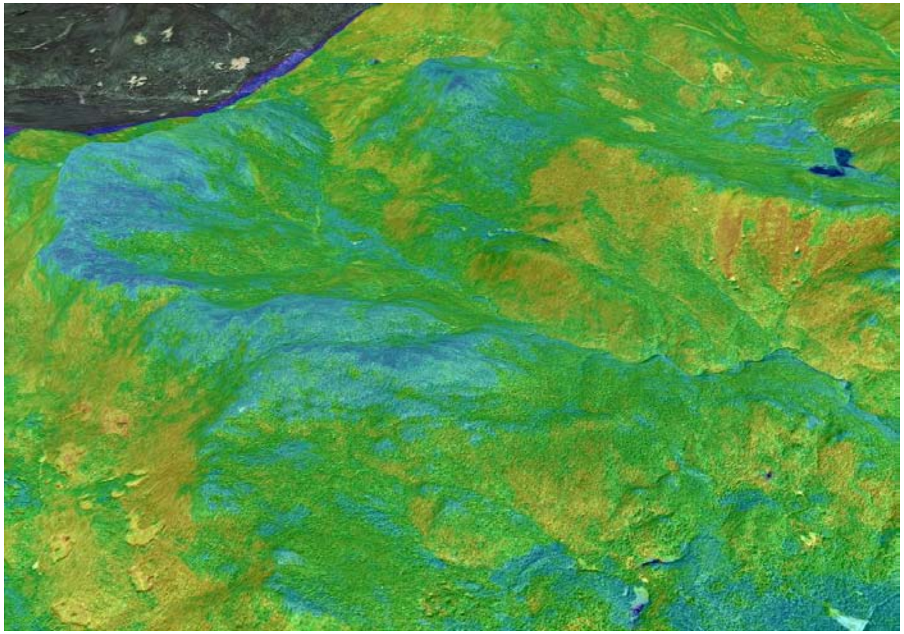
3. Provides an opportunity to better understand potential feedbacks in the climate system involving the N cycle as a regulator of both C cycling AND energy exchange.

Landscape-scale patterns of %N and canopy structure

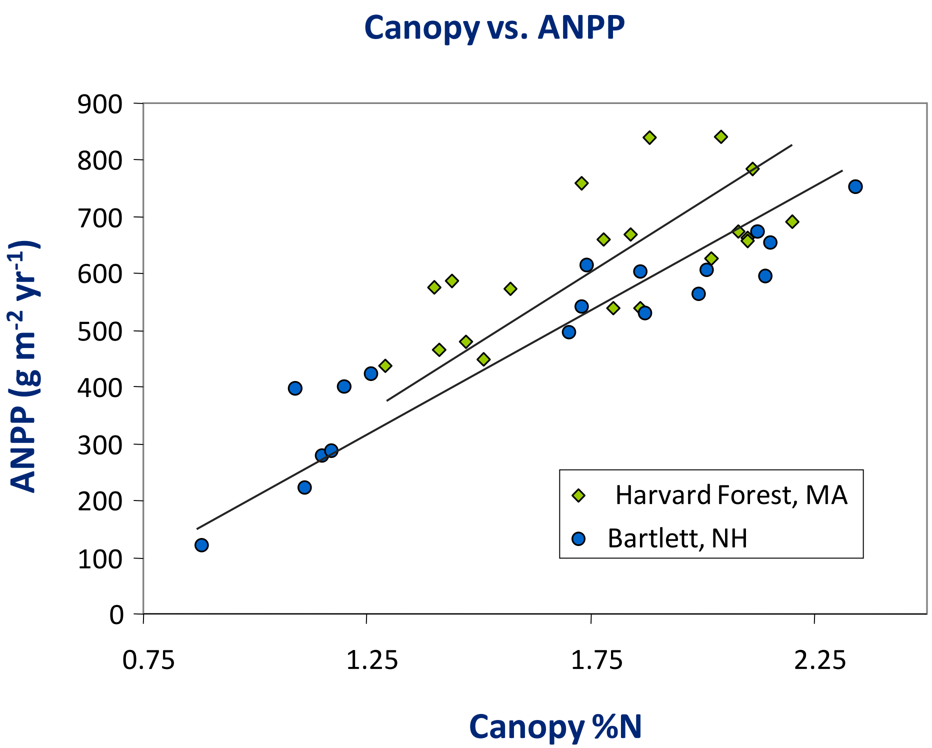


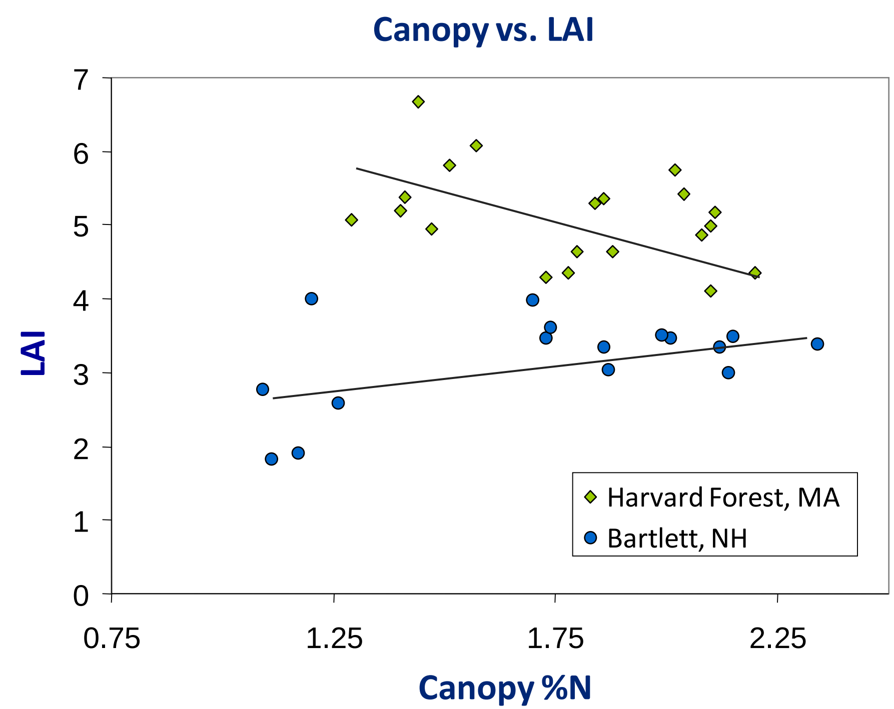
At 20 m spatial resolution, the N-based relationship holds.

No effect of canopy surface roughness (Rugosity)

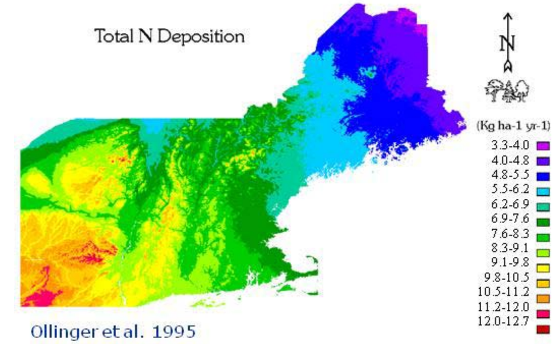


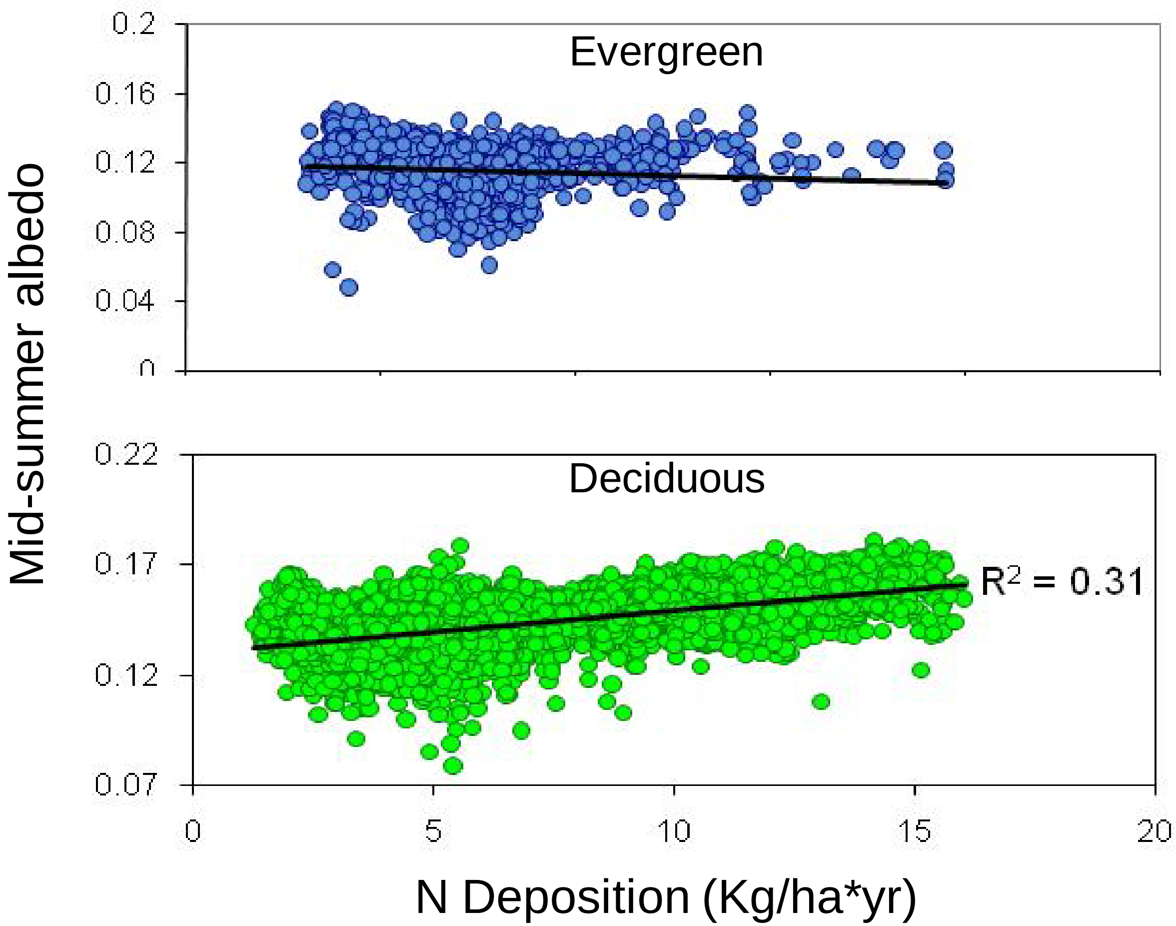
ANPP in Most Eastern U.S. Temperate Forests Scales with N Status, not LAI.





Nitrogen Deposition and Mid-Summer Shortwave Albedo





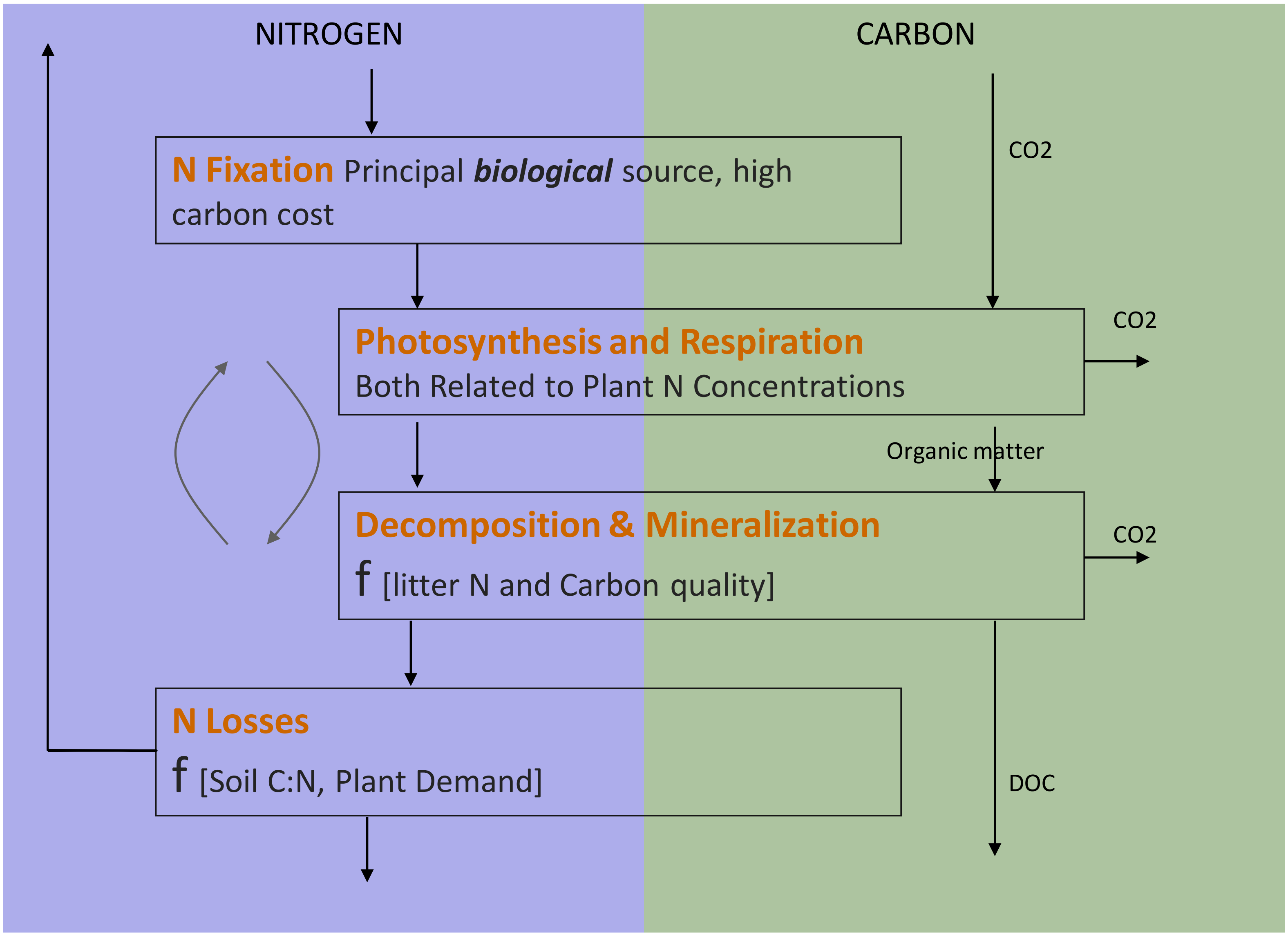
DOES NITROGEN PLAY A PREVIOUSLY UNRECOGNIZED ROLE IN THE CLIMATE SYSTEM?

- C cycle effects and albedo effects typically viewed as separate mechanisms.

- Our results indicate that they are more intimately related and are linked via plant nitrogen status.

- This suggests a potential feedback in the climate system involving the N cycle as a regulator of both C cycling *AND* energy exchange.

C & N: Joined by a Shared Set of Biological Reactions



Nitrogen availability is a key constraint on carbon cycling in terrestrial ecosystems and it is largely in this capacity that the role of nitrogen in the climate system has been considered.

Nevertheless, broad-scale analyses rarely include spatial variation in plant N status as a driving variable. ***WHY?***

1. *Uncertainty about how leaf-level photosynthesis-nitrogen relationships aggregate to whole canopies and ecosystems.*

2. *There are no methods to remotely sense canopy nitrogen concentrations at broad spatial scales.*

Modeling fAPAR by Chlorophyll throug a Canopy ($fAPAR_{chl}$) and Leaf Water Content (LWC)

Qingyuan Zhang

Yen-Ben Cheng

Elizabeth M. Middleton

HyspIRI Science Symposium on Ecosystem Data Products

NASA Goddard Space Flight Center, May 4&5, 2010

Vegetation Photosynthesis

- **Remote Sensing approaches to estimate GPP: Monteith (1972,1977):**

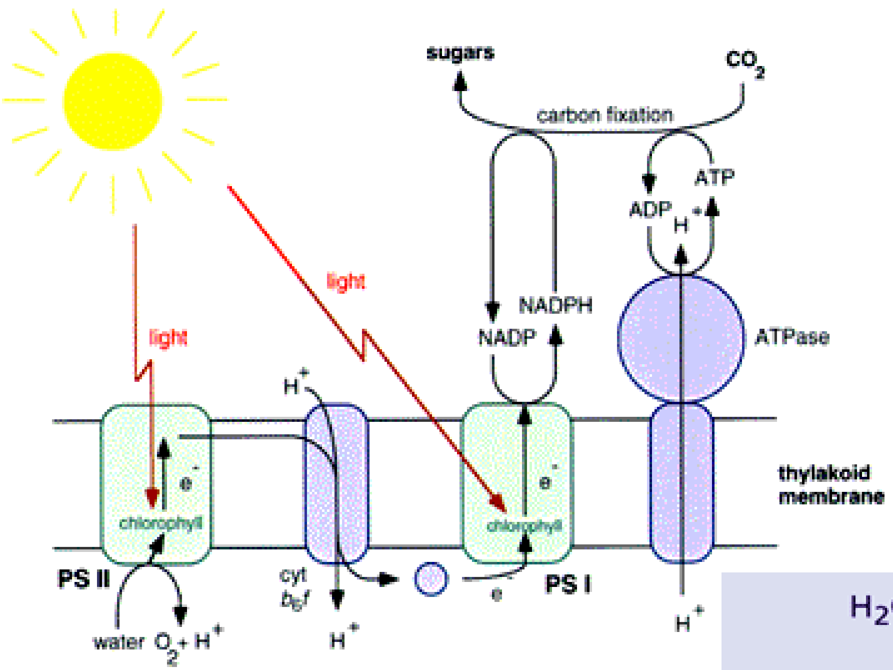
$$GPP = LUE \times fPAR \times PAR$$

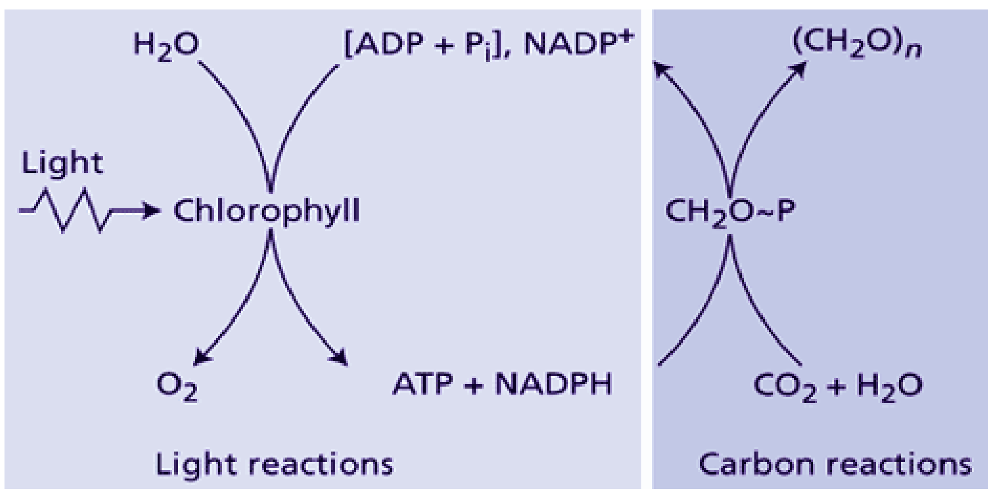
- **GLO-PEM (Prince et al., 1995) and PSN (Running et al., 1999, MODIS standard product):**

$$GPP = LUE_{canopy} \times APAR_{canopy}$$
$$APAR_{canopy} = fAPAR_{canopy} \times PAR$$

- **Are the Remote Sensing models consistent with plant physiological processes?**

Why $fAPAR_{chl}$, not $fAPAR_{canopy}$





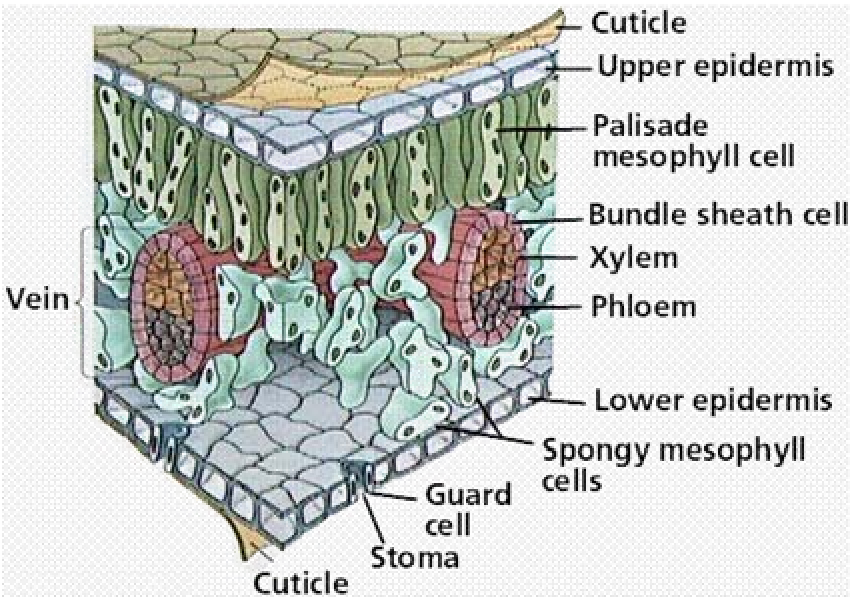
$$6\ CO_2 + 12\ H_2O \xRightarrow{\text{light energy}} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2O$$

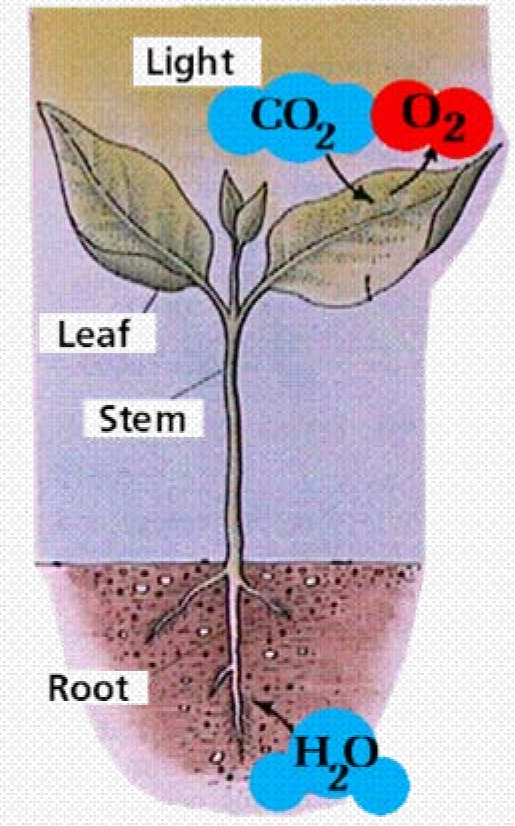
http://photoscience.la.asu.edu/photosyn/education/photointro.html

Why fAPAR$_{chl}$, not fAPAR$_{canopy}$

A leaf contains non-photosynthetic vegetation (NPV) component, including non-photosynthetic pigments, cell walls, veins, etc.

A canopy includes leaf, and non-photosynthetic vegetation (NPV), including stems, branches, senescent leaves.





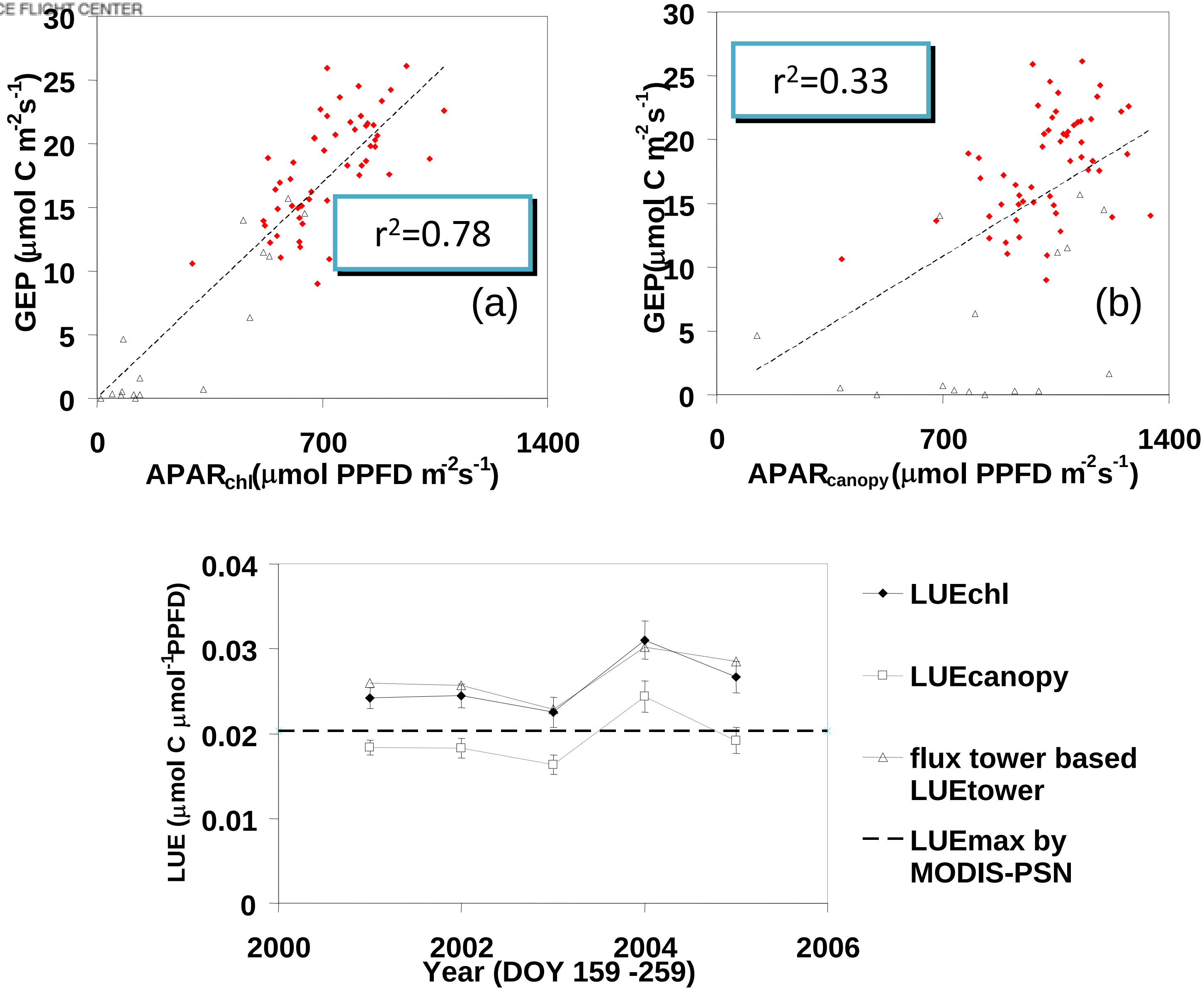
http://photoscience.la.asu.edu/photosyn/education/photointro.html

Why $fAPAR_{chl}$, not $fAPAR_{canopy}$

$$APAR_{canopy} = APAR_{chl} + APAR_{dry\ \ matter} + APAR_{brown\ \ pigment} + APAR_{stem}$$

$$fAPAR_{canopy} = \frac{APAR_{canopy}}{PAR_0}$$

$$fAPAR_{chl} = \frac{APAR_{chl}}{PAR_0}$$



Zhang, Q., Middleton, E.M., Margolis, H.A., Drolet, G.G., Barrd, A.A., & Black, T.A. (2009). Can a satellite-derived estimate of the fraction of PAR absorbed by chlorophyll (FAPARchl) improve predictions of light-use efficiency and ecosystem photosynthesis for a boreal aspen forest? *Remote Sensing of Environment, 113, 880-888*

NASA Goddard SPACE FLIGHT CENTER

USDA ars United States Department Of Agriculture Agricultural Research Service

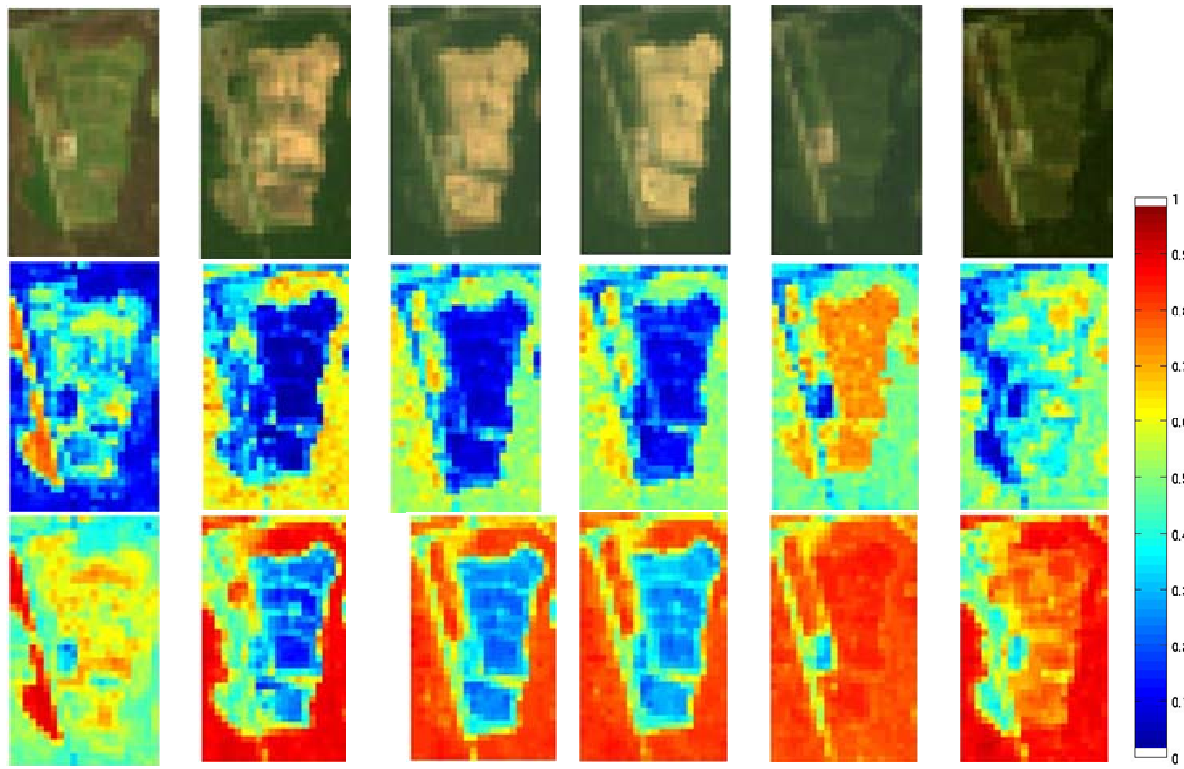
USDA-ARS HRSL Hydrology & Remote Sensing Lab Beltsville, Maryland, USA

OPE3 Optimizing Production Inputs for Economic and Environmental Enhancement (OPE3)

EO-1 Hyperion True color

$fAPAR_{chl}$

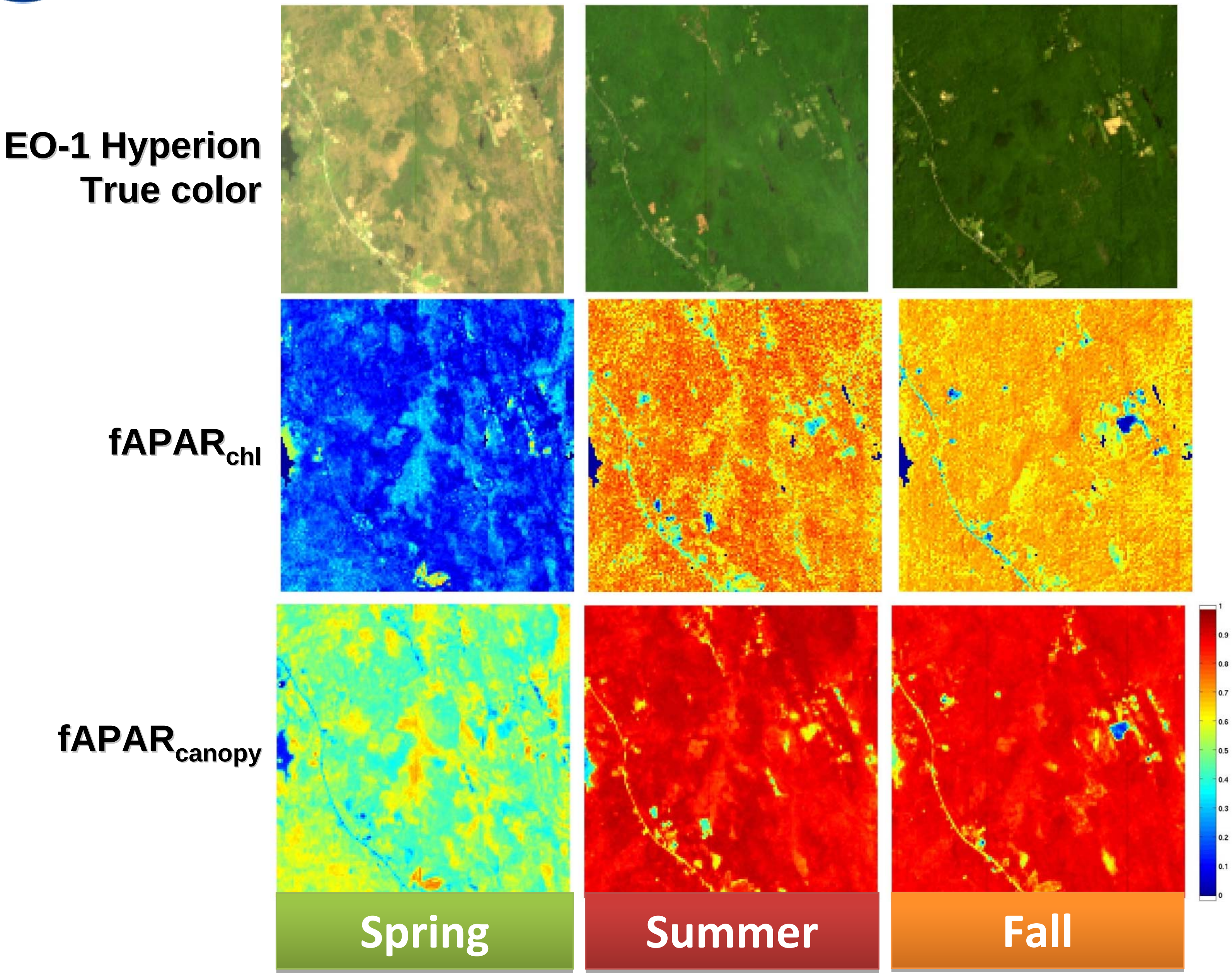
$fAPAR_{canopy}$



DOY 108 172 190 195 231 277 2008

Spring **Summer** **Fall**

Harvard Forest, MA



$$LWC = \frac{LW}{LW + DM} = \frac{\frac{LW}{A}}{\frac{LW}{A} + \frac{DM}{A}} = \frac{C_w}{C_w + C_m}$$

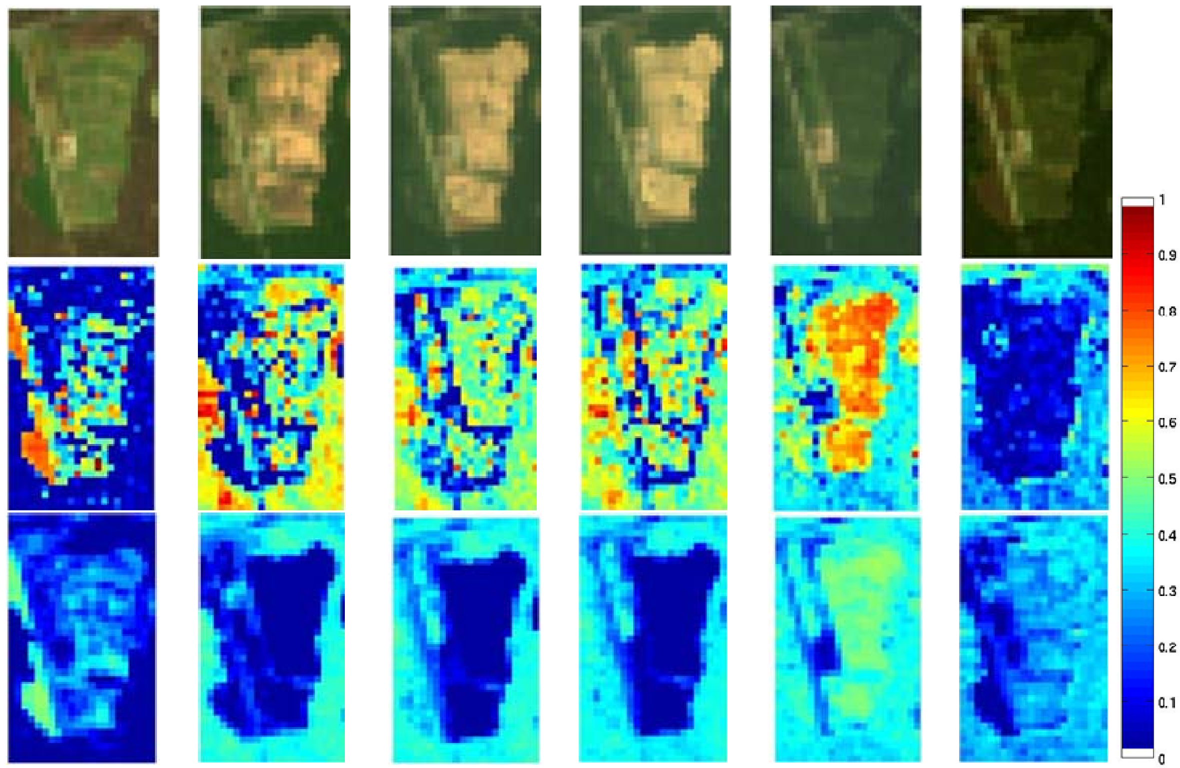
LWC is useful:

- Drought monitoring
- Plant health status (water stress)
- One of the factors that down-regulate vegetation photosynthesis
- Timing of greening-up and senescence

EO-1 Hyperion True color

LWC

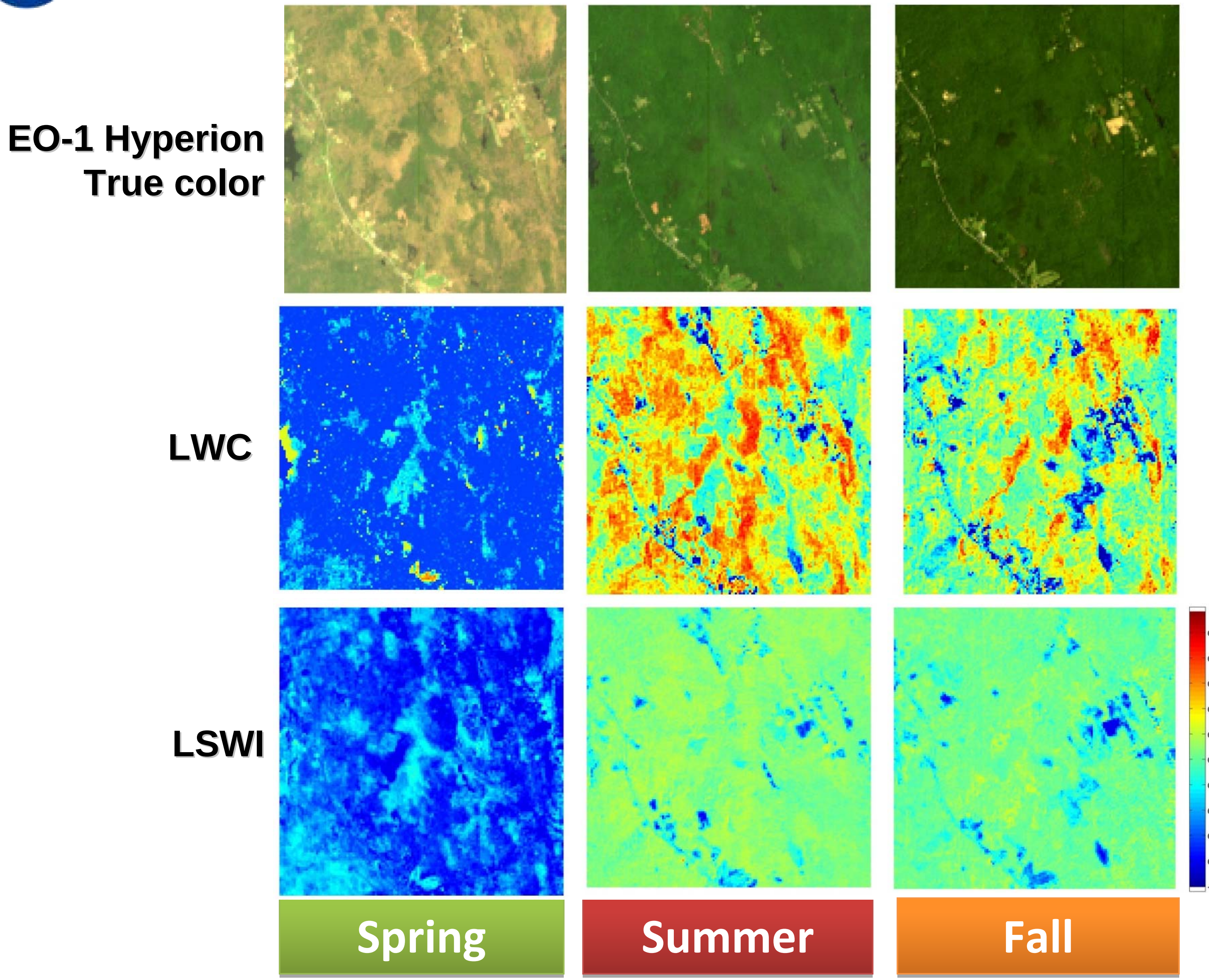
LSWI



DOY 108 172 190 195 231 277 2008

Spring **Summer** **Fall**

Harvard Forest, MA



fAPAR$_{chl}$ and LWC link to:

- VQ1. Pattern and spatial distribution and ecosystems and their components [DS 195]
- VQ2. Ecosystem Function, Physiology and Seasonal Activity [DS 191,195,203]
- VQ3. Biogeochemical Cycles
- VQ4. Ecosystem Response to Disturbance
- CQ4. Ecosystem Function and Diversity [DS 194,195, 203]

Accurate assessment of spatial and temporal distribution of $fAPAR_{chl}$ and LWC will

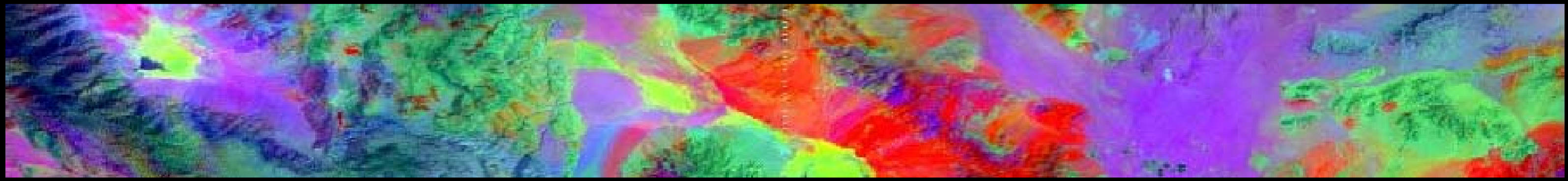
•Provide key input parameters to carbon and climate modeling

•Understand the effects of climate change to terrestrial ecosystems

•Assess feedbacks from ecosystems to the atmosphere

Thank you!!

HyspIRI Level-2 TIR Products
Surface Radiance
Land Surface Temperatrue
Land Surface Emissivity



Simon Hook, Glynn Hulley

Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA

HyspIRI - ASTER - MODIS

TIR Product Characteristics

	HyspIRI	Terra ASTER	Terra MODIS
Sensor Calibration:	0.1-0.2 K	< 0.3 K	< 0.2 K
Cloud Contamination:	Cloud Detection	Cloud Detection	Cloud Detection
Retrieval Type:	TES + WVS	TES	Day/Night (V4) Split-Window(V5)
Temporal Sampling:	11:00 AM, PM 5 days	10:30 AM, PM 16 days	10:30 AM, PM Twice daily
Spatial Resolution:	60 m	90 m	1 km
Swath Width	600 km	60 km	2300 km
View angle:	25	8.55	55
MTIR Bands:	8 bands	5 bands	7 bands

HyspIRI TIR Level-2 Products

1. Cloud Mask
   a. Approach
   b. ASTER examples
2. Surface Radiance
   a. Infrared Radiative Transfer
   b. Atmospheric Correction
   c. Validation
3. Land/Ocean Surface Temperature and Surface Emissivity (LST&E)
   a. Algorithm Development
   b. TES examples
   c. Validation

1. Cloud Mask

- Accurate, reliable and automatic cloud detection is critical
- Use same approach as the New ASTER Cloud Mask Algorithm (NACMA)
- Hybrid algorithm, clear-sky conservative:
  - Landsat-7 two pass approach
  - MODIS shadow test
  - AVHRR thin cirrus test
- HyspIRI VSWIR repeat is 19 days, but TIR is 5 days
- Propose using VIIRS for visible data (250 m) when VSWIR not available

** **Hulley G.C., S.J. Hook,** 2008, A New Methodology for Cloud Detection and Classification with Advanced Spaceborne Thermal Emission and Reflection (ASTER) Data , *Geophys. Res. Lett.*, 35, L16812, doi:10.1029/2008GL034644

ASTER Cloud Spectral Tests

Table 1. Pass-1 Filters and Threshold Tests Using Reflectance, r_i and Temperature, T_{sat}, Values From Equations (1) and (2)

Filter	Threshold Test	Function
1 Brightness Threshold	$r_2 > 0.08$	Eliminates low reflectance, dark pixels
2 Snow Threshold	$\text{NDSI} = (r_1 - r_4)/(r_1 + r_4) < 0.7$	Eliminates snow
3 Temperature Threshold	$T_{sat} < 300$	Eliminates warm surface features
4 Band 4/5 Composite	$(1 - r_4)T_{sat} < 240 \Rightarrow$ snow present $(1 - r_4)T_{sat} < 250 \Rightarrow$ snow absent	Eliminates cold surfaces - snow, tundra
5 Growing vegetation	$\frac{r_3}{r_2} < 2$	Eliminates reflective growing vegetation
6 Senescing vegetation	$\frac{r_3}{r_1} < 2.3$	Eliminates reflective senescing vegetation
7 Rocks and Sand	$\frac{r_3}{r_4} > 0.83$	Eliminates reflective rocks and sand
8 Warm/Cold Cloud	$(1 - r_4)T_{sat} > 235 \Rightarrow$ warm cloud $(1 - r_4)T_{sat} < 235 \Rightarrow$ cold cloud	Warm and cold cloud classificiation
Cloud Shadow	$r_3 < 0.05$ and $\frac{r_3}{r_1} > 1.1$	Detects cloud shadows

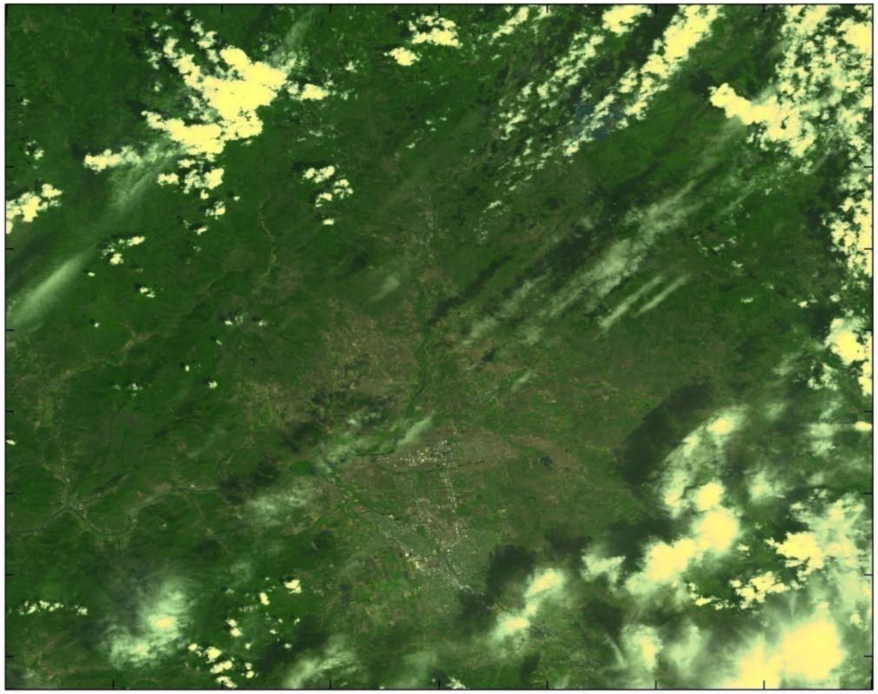
Thin cloud/cirrus test

Table 2. Brightness Temperature Thresholds for the Thin Cloud/Cirrus Test

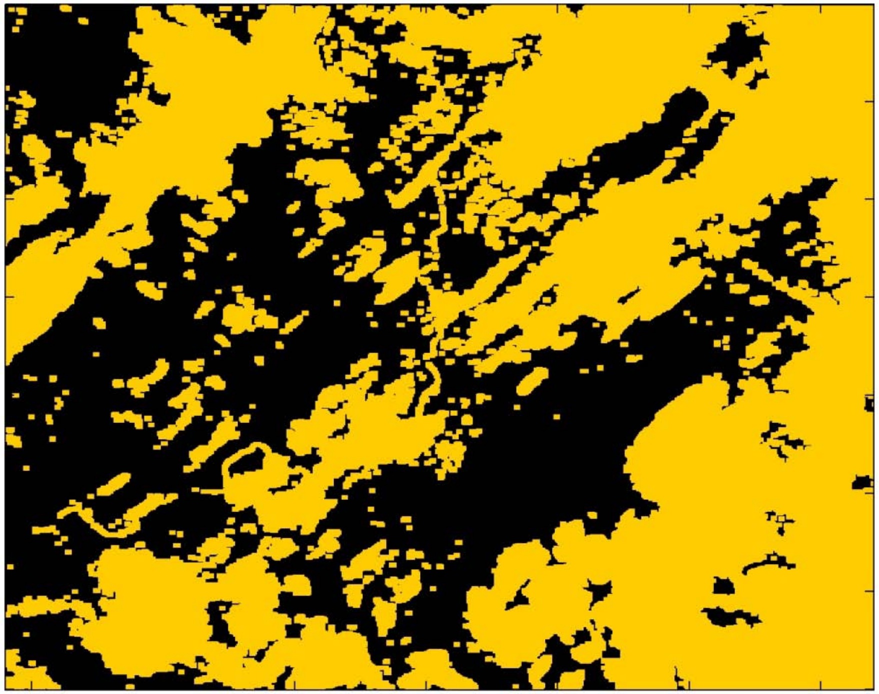
	$BT_{10.6-11.3}$ (K)	
$BT_{10.6}$ (K)	Snow > 50%	Snow < 50%
260	0.55	0.50
270	1.00	0.51
280	1.20	0.53
290	1.30	1.00
300	1.50	2.00
310	3.00	3.00
320	4.00	4.00
330	5.00	5.00

Cumulus + thin cirrus example

ASTER visible image



ASTER Cloud Mask + Fill



Shadow – **Cyan**

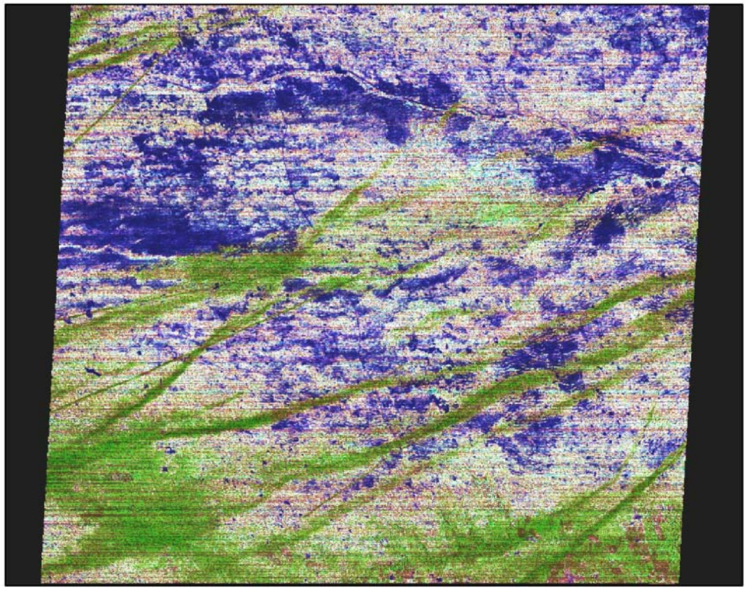
Cloud – **Gold**

Clear – **Black**

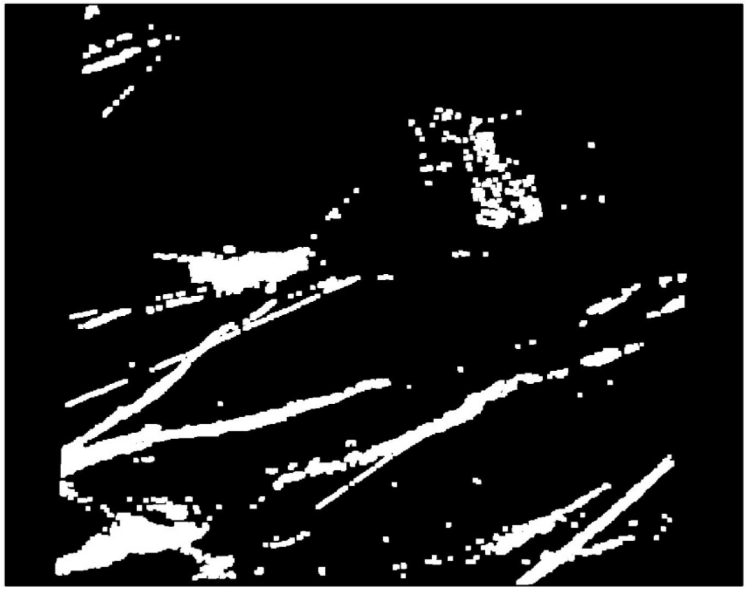
ASTER Visible image

Jet Contrails
Sub-visible cirrus

Emissivity (R=10, G=12, B=14)



Cloud Mask

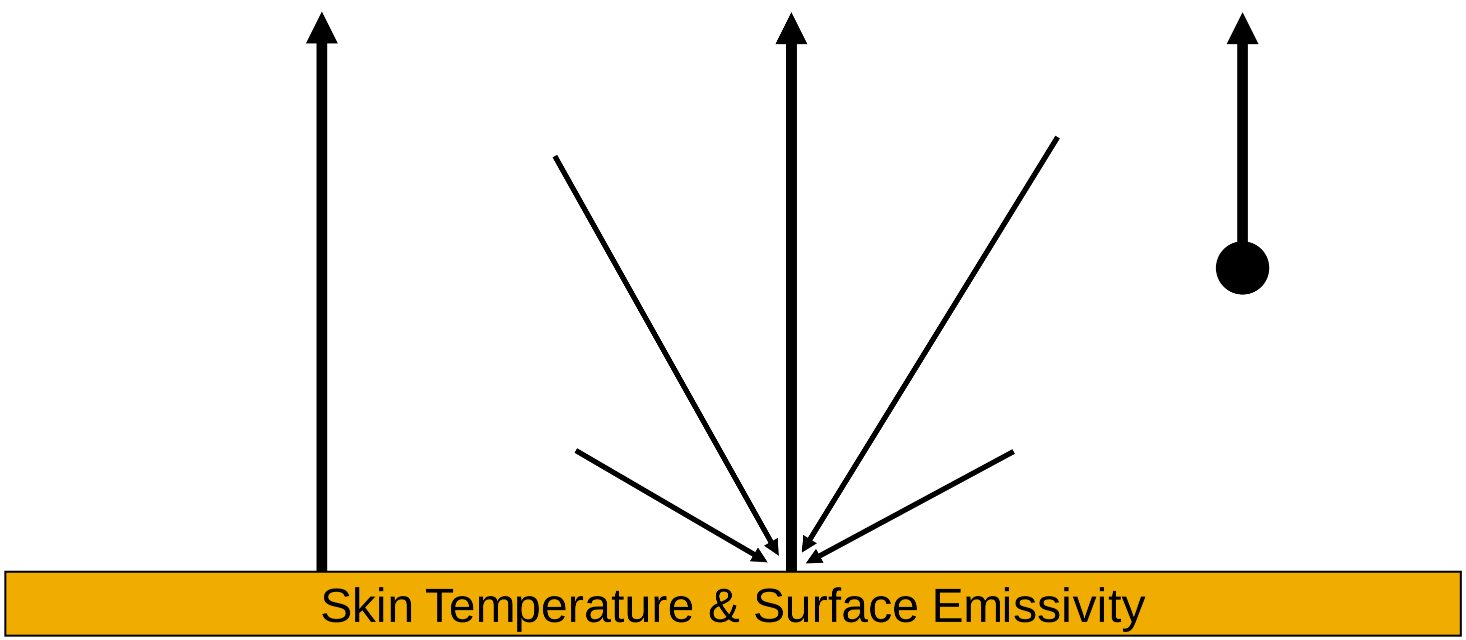


2. Surface Radiance

- Surface radiation is combination of direct surface emission and reflected radiance from sky and surrounding
- Atmospheric corrections necessary to isolate surface features, which are obscured by atmospheric attenuation
- Approach
  1. Choose a radiative transfer model to estimate magnitude of atmospheric emission, absorption and scattering
     - eg. MODTRAN 4, 5.3 (beta), CRTM – JCSDA
  2. Acquisition of atmospheric profiles (eg. Temperature, water vapor, ozone, aerosol) at time and location of observation
     - VIIRS (MODIS follow-on) or CrIS (AIRS follow-on) on NPP/NPOESS
     - NCEP GDAS as backup (currently used for ASTER)
     - OMI (ozone)

Infrared Radiative Transfer

$$L_i(\theta) = \overbrace{\underbrace{\tau_i(\theta)\cdot e_i \cdot B_i(T_S)}_{\text{Surface Emission}} + \underbrace{\tau_i(\theta)\cdot(1-e_i)\cdot \overline{L}_i^{\downarrow}}_{\text{Surface Reflection}}}^{\text{Surface Radiance}} + \underbrace{\int B_i(T(P))\,d\tau_i}_{L_i^{atm\uparrow}}$$



Radiative Transfer Model

- MODTRAN 5.3 (beta)
  - Finer spectroscopy: resolution down to 0.1 cm^{-1}
  - DISORT multiple scattering speed and accuracy improved
  - Option for including auxiliary molecules
  - Several tape5 input files can be processed with single execution
- Maintain close communication with developers on updates and improvements (Gail Anderson)
- Other radiative transfer models will be explored, eg. Community Radiative Transfer MODEL (CRTM) – open source through JCSDA

Surface Radiance: Validation

- Water Surface Targets:
  1. Lake Tahoe automatic Cal/Val facility (Cool, 0 - 25° C)
  2. Salton Sea (Hot, >30° C!)
- Land Surface Targets:
  1. DOME-Argus, Antarctica (high, and cold, <-60° C)
  2. Valencia site (>30 km^2), homogenous rice fields (cool)
  3. Sand dune sites in southwestern USA (hot)
     - Emissivity measured and well characterized
     - Multiple balloon launches to control temperature and water vapor
     - Sun photometer for aerosol optical depth and column water
- Airborne Instruments
  - HyTES, MASTER

3. Land Surface Temperature and Emissivity (LST&E)

- Key Earth System Data Records (ESDR) in climate change studies
  - Climate modeling, estimating heat radiation budgets
  - Surface-atmosphere interactions
  - Cryospheric studies and hydrology
  - Earth surface composition and change
- Emissivity is critical for determining LST (1.5% = 1 K error)
- Goals:
  1. Estimate accurate and precise LST (<1 K)
  2. Recover accurate emissivity for mineral exploration and geologic mapping (<1%)
  3. Produce seamless products, with no artificial discontinuities, which exist in split-window, land class approach.

LST&E Retrieval Algorithms

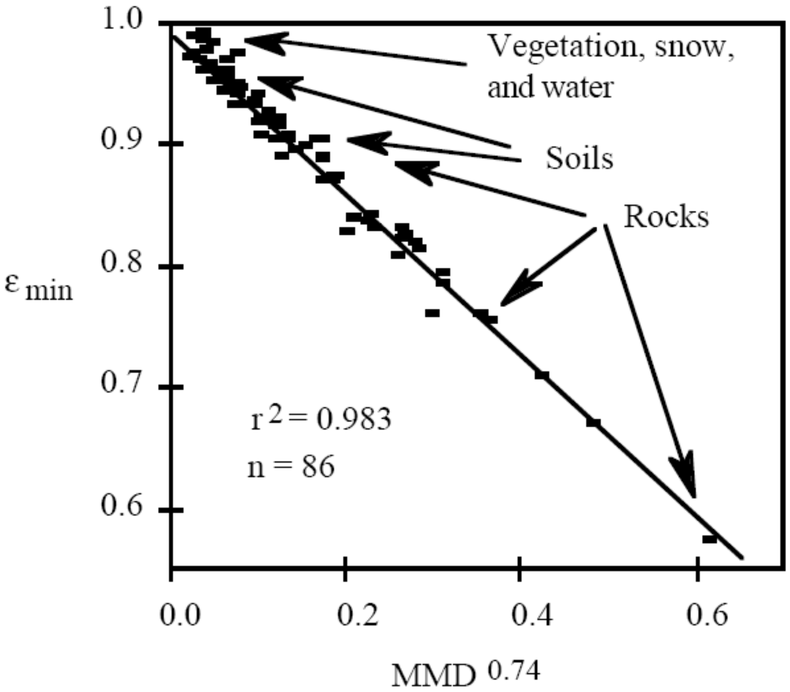
- Temperature Emissivity Separation (TES, ASTER)

  Relies on empirical relationship between spectral contrast and minimum emissivity, determined independently from laboratory measurements

  - PROS:
    - LST and emissivity in all bands are physically determined
    - High accuracy over low emissivity, high contrast areas (eg. Deserts)
    - Validated with ground truth using sand dune sites to 1.6%
  - CONS:
    - Atmospheric profiles are required for atmospheric correction
    - Accuracy is dependent on atmospheric correction
    - Accuracy degraded over graybody surfaces as a result, since errors in atmospheric correction resulted in larger 'apparent' contrast

Temperature Emissivity Separation (TES)

- Inversion of T and ε are underdetermined
- Additional constraint arises from minimum emissivity vs spectral contrast
- Three error sources:
  - Reliance on empirical function
  - Atmospheric corrections
  - Radiometric calibration errors
- Reported accuracy for ASTER:
  - LST is 1.5 K
  - ε is 0.015 (1.5 %)



$$\varepsilon_{min} = 0.994 - 0.687 * MMD^{0.74}$$

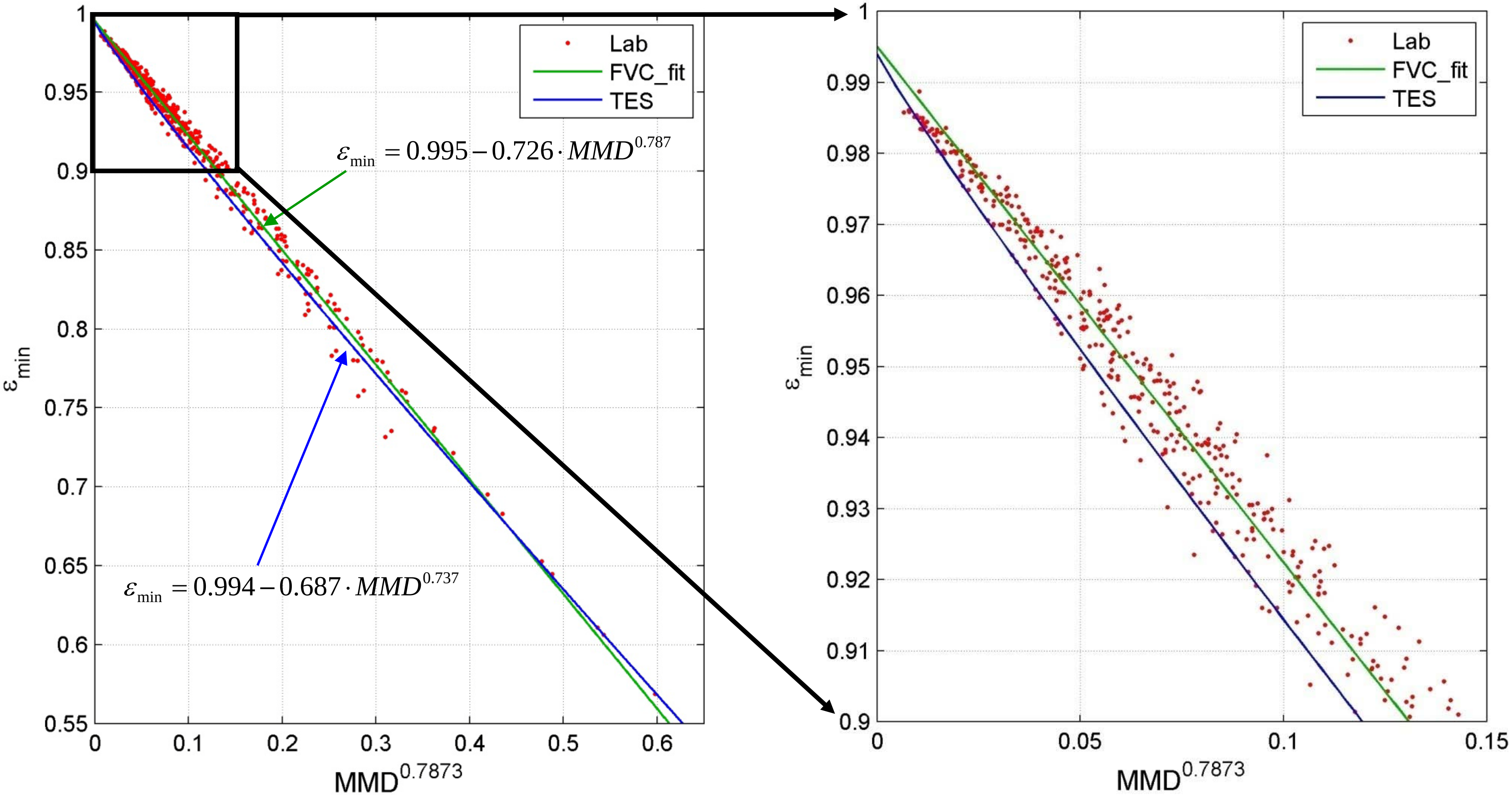
TES Vegetation Adjustment

$$\varepsilon_b = \varepsilon_b^{veg} \cdot FVC + \varepsilon_b^{soil} \cdot (1 - FVC)$$

ε_b^{veg} - Conifer spectra

ε_b^{soil} - 59 soil/sand spectra

FVC = 0:5:100%



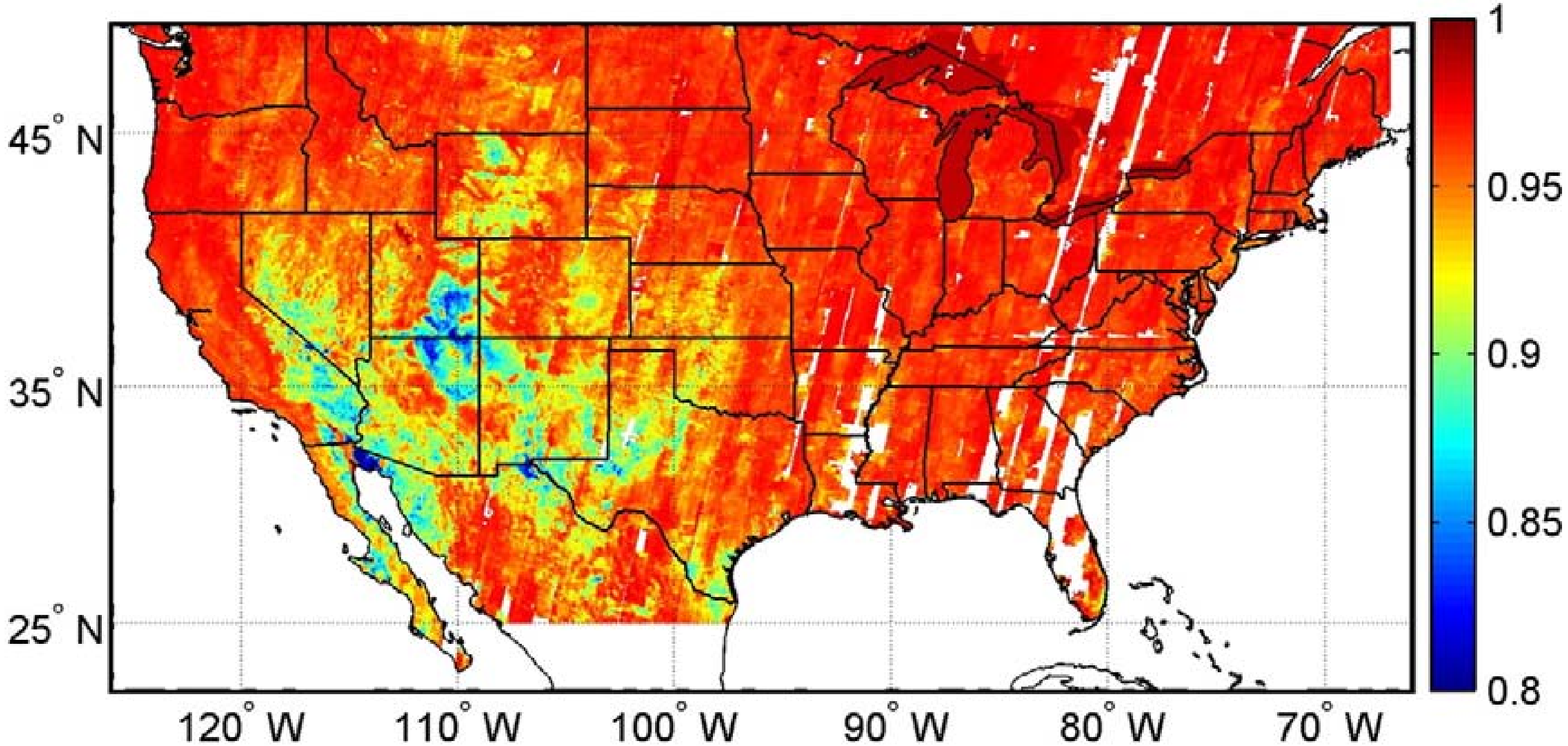
TES underestimates vegetation from 1.5-2% in emissivity

FVC curve reduces this down to <1% (~0.7 K)

NAALSED Mean Summer (Jul-Sep) Emissivity:

Band 12 (8.6 µm): 2000-2008: 50,075 scenes

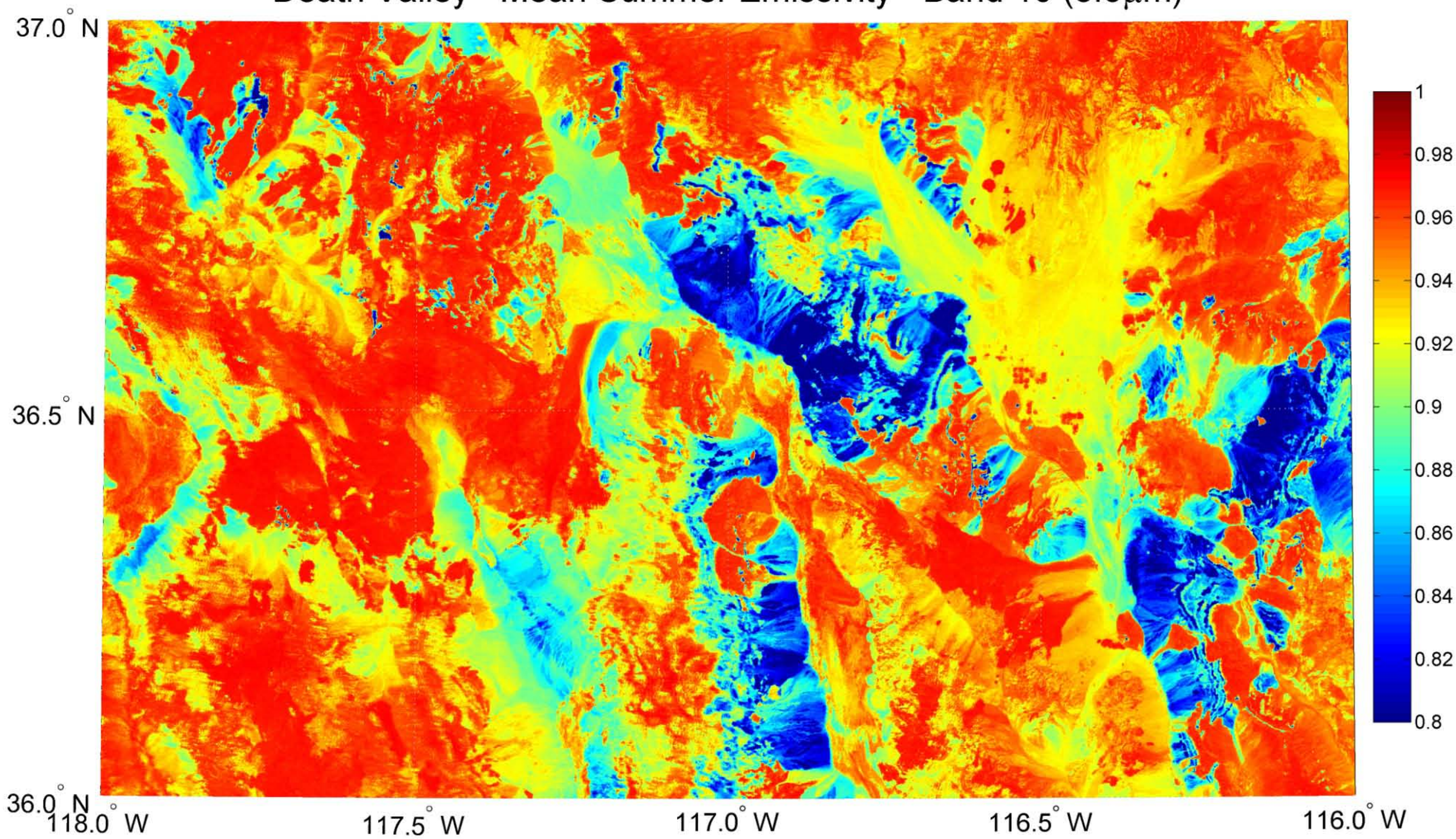
http://emissivity.jpl.nasa.gov



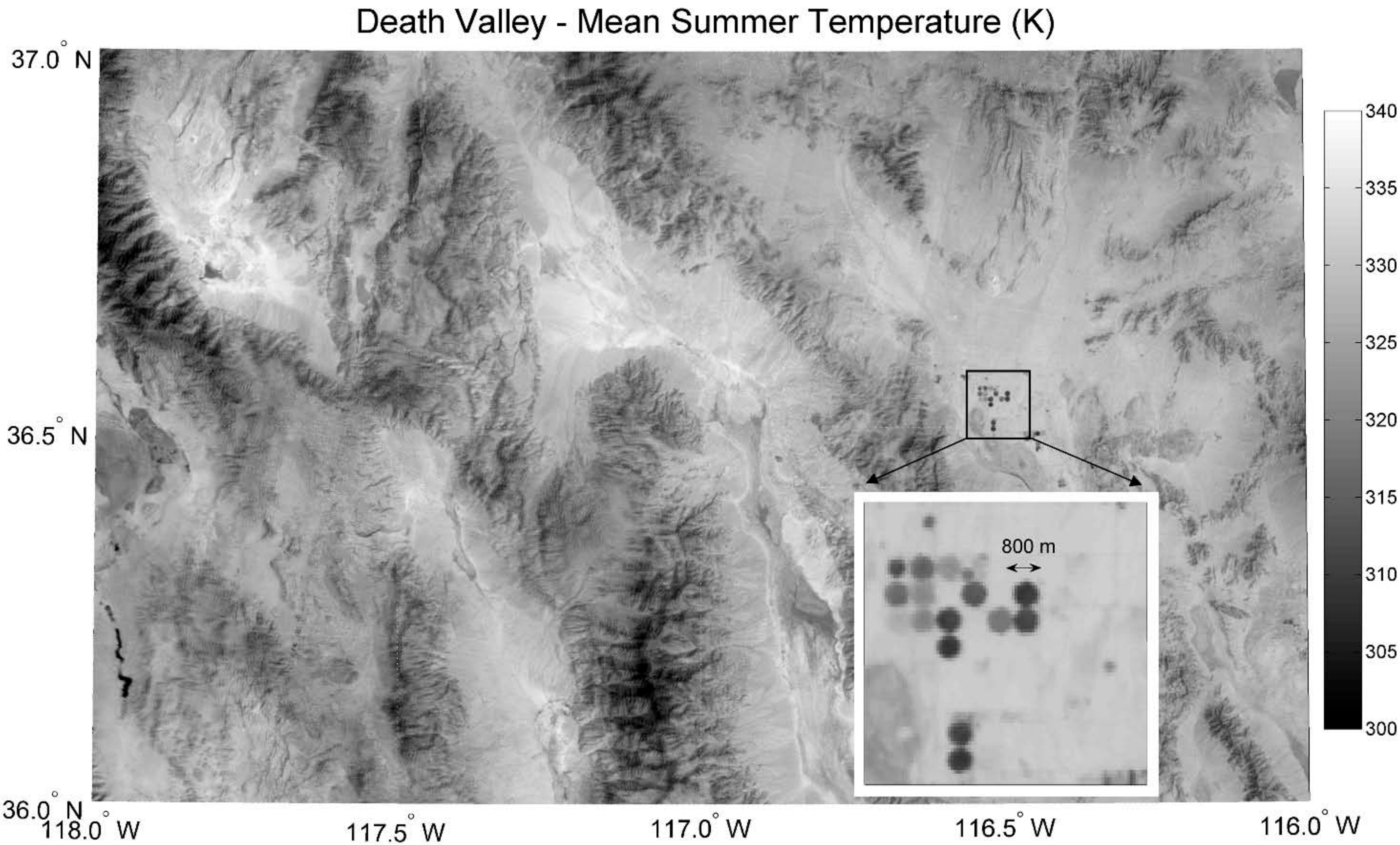
** Gaps plan to be filled during Jul-Sep 2009 ASTER acquisition

Hulley, G. C., & Hook, S. J., (2009),The North American ASTER Land Surface Emissivity Database (NAALSED) Version 2.0, *Remote Sensing of Environment*, doi:10.1016/j.rse.2009.05.005

Death Valley - Mean Summer Emissivity - Band 10 (8.3μm)

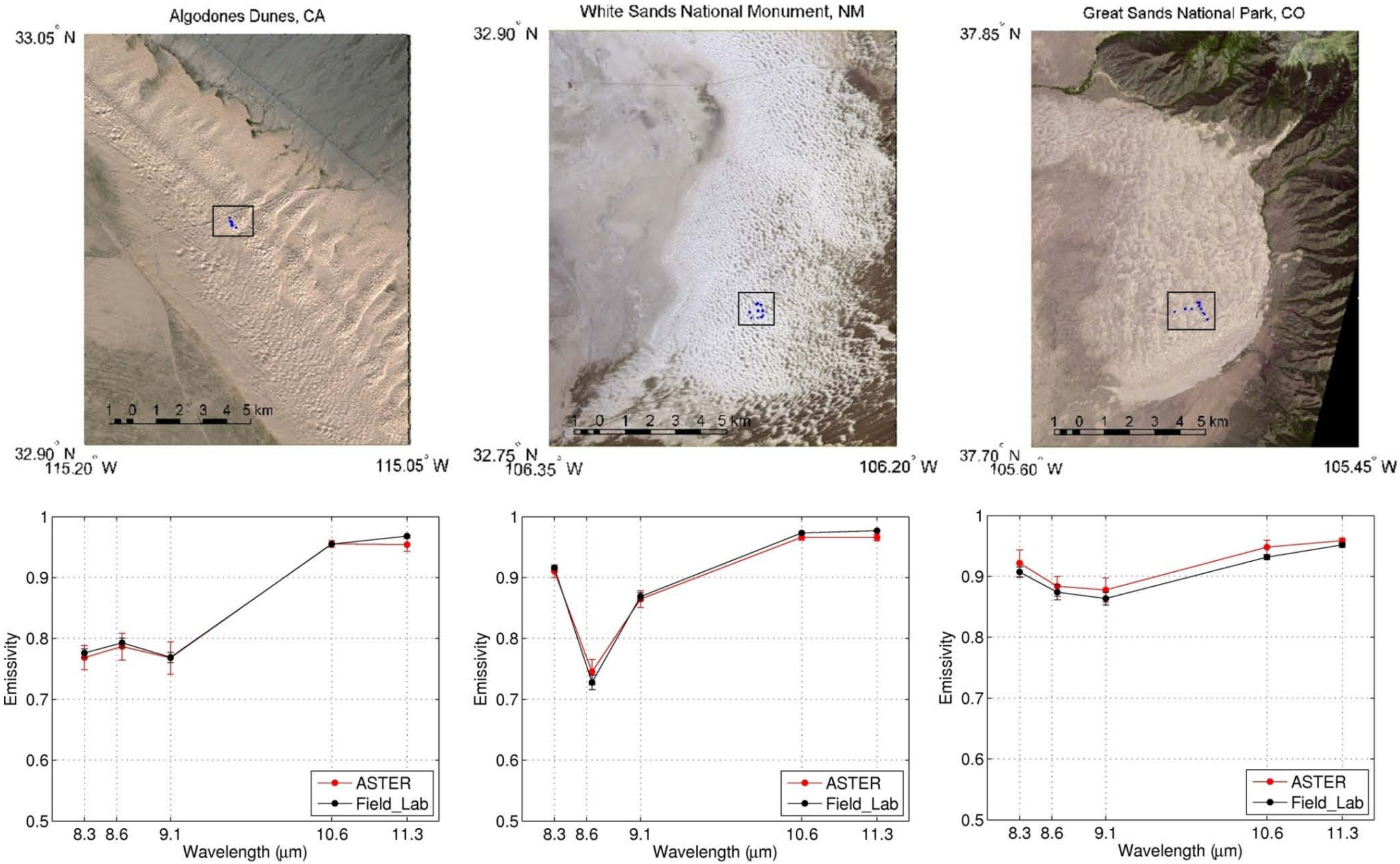


NAALSED LST at 100 m – ASTER Emissivity Database



Rice crop spatially well resolved, as well as temperature differences between them

Validation of North American ASTER Emissivity Database (NAALSED)



Hulley, G. C., Hook, S. J., and A.M. Baldridge, (2009), Validation of the North American ASTER Land Surface Emissivity Database (NAALSED) Version 2.0, *Remote Sensing of Environment*, 113, 2224-2233

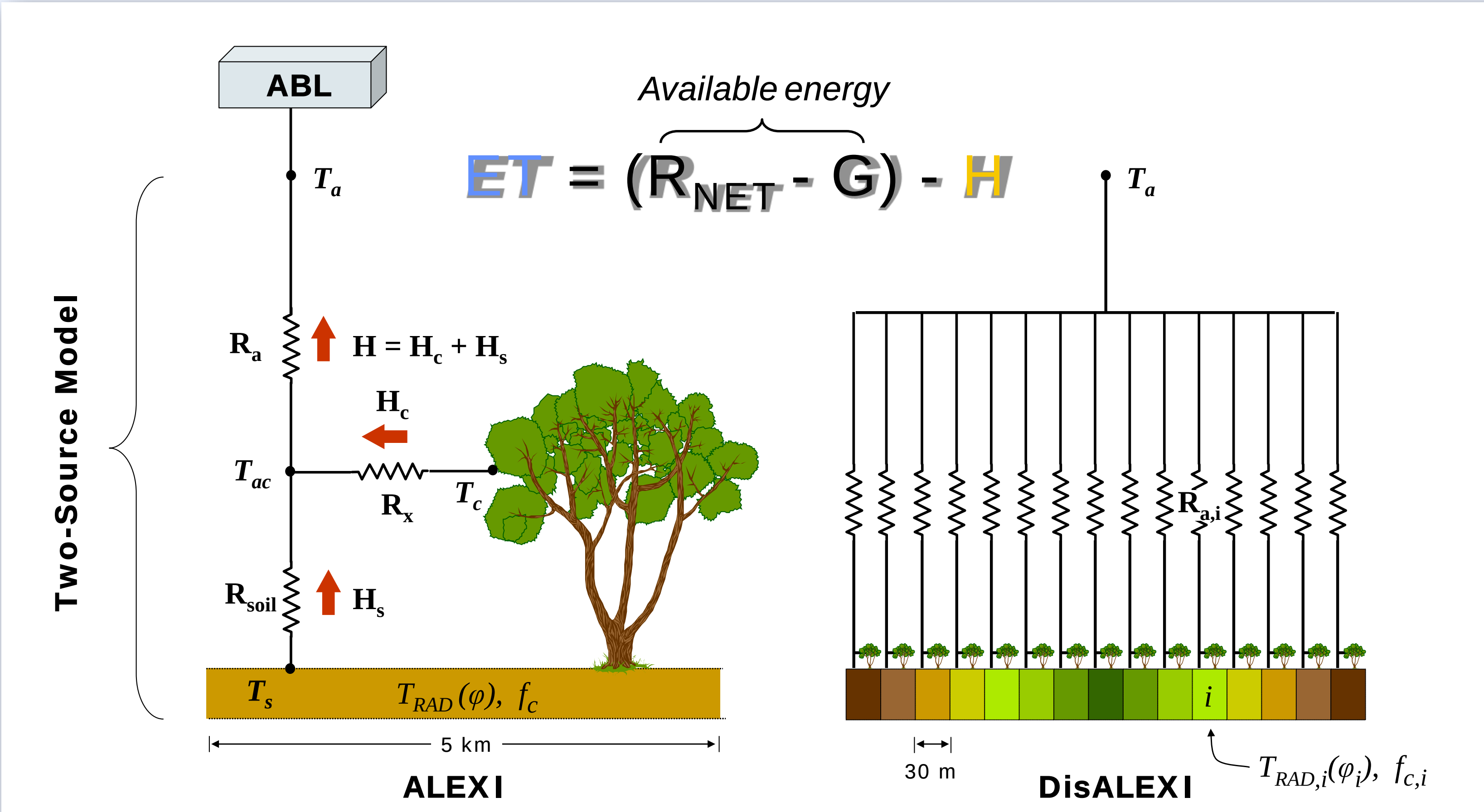
Conclusions

- Identified core L-2 Products
  - Surface Radiance
  - Land/water Surface Temperature
  - Land Surface Temperature
- Identified atmospheric correction scheme
  - MODTRAN 5*
  - Water-Vapor Scaling Atmospheric Correction
- Identified LST&E algorithm
  - Temperature Emissivity Separation (TES)
  - Investigate different calibration curves and atmospheric correction techniques (WVS)
- Core validation sites
  - Not discussed here but have started to identify sites.

High Spatiotemporal Resolution Maps of Evapotranspiration and Surface Moisture Availability

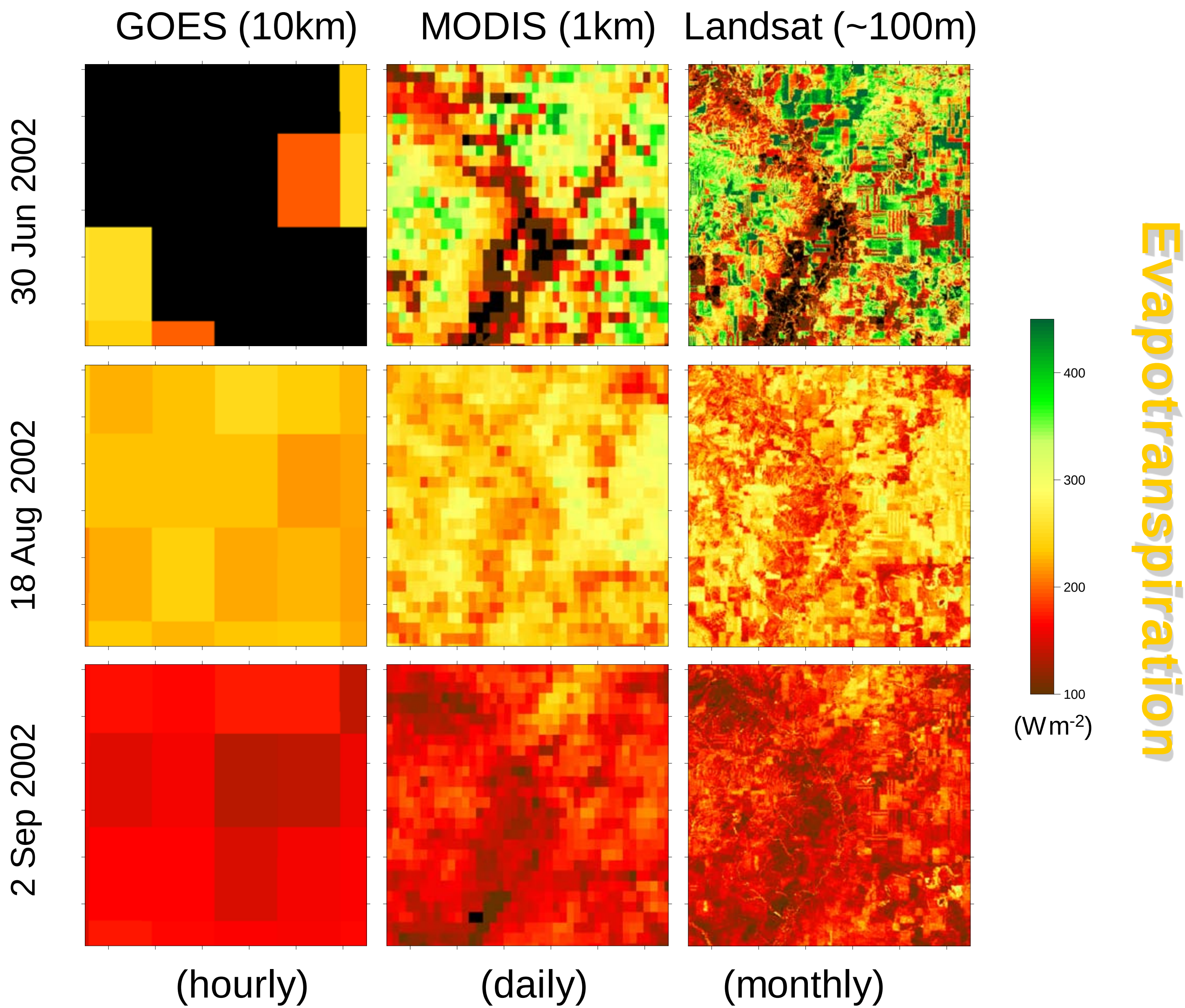
M.C. Anderson, W.P. Kustas
USDA-ARS, Hydrology and Remote Sensing Laboratory

Atmosphere-Land Exchange Inverse (ALEXI)

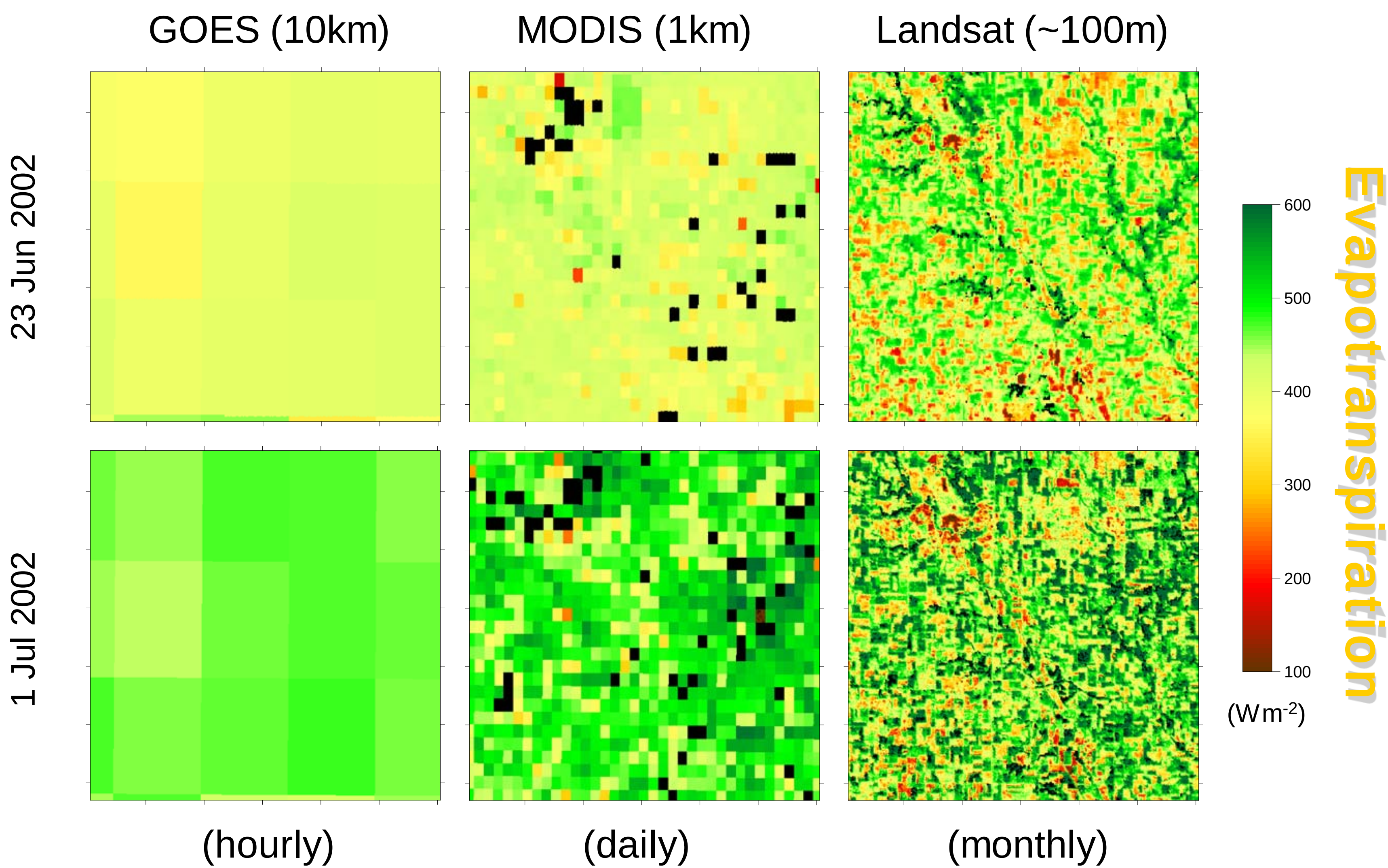


	Regional scale		Landscape scale	
Surface temp:	ΔT_{RAD}	- GOES	T_{RAD}	- TM, MODIS, HyspIRI
Air temp:	T_a	- ABL model	T_a	- ALEXI

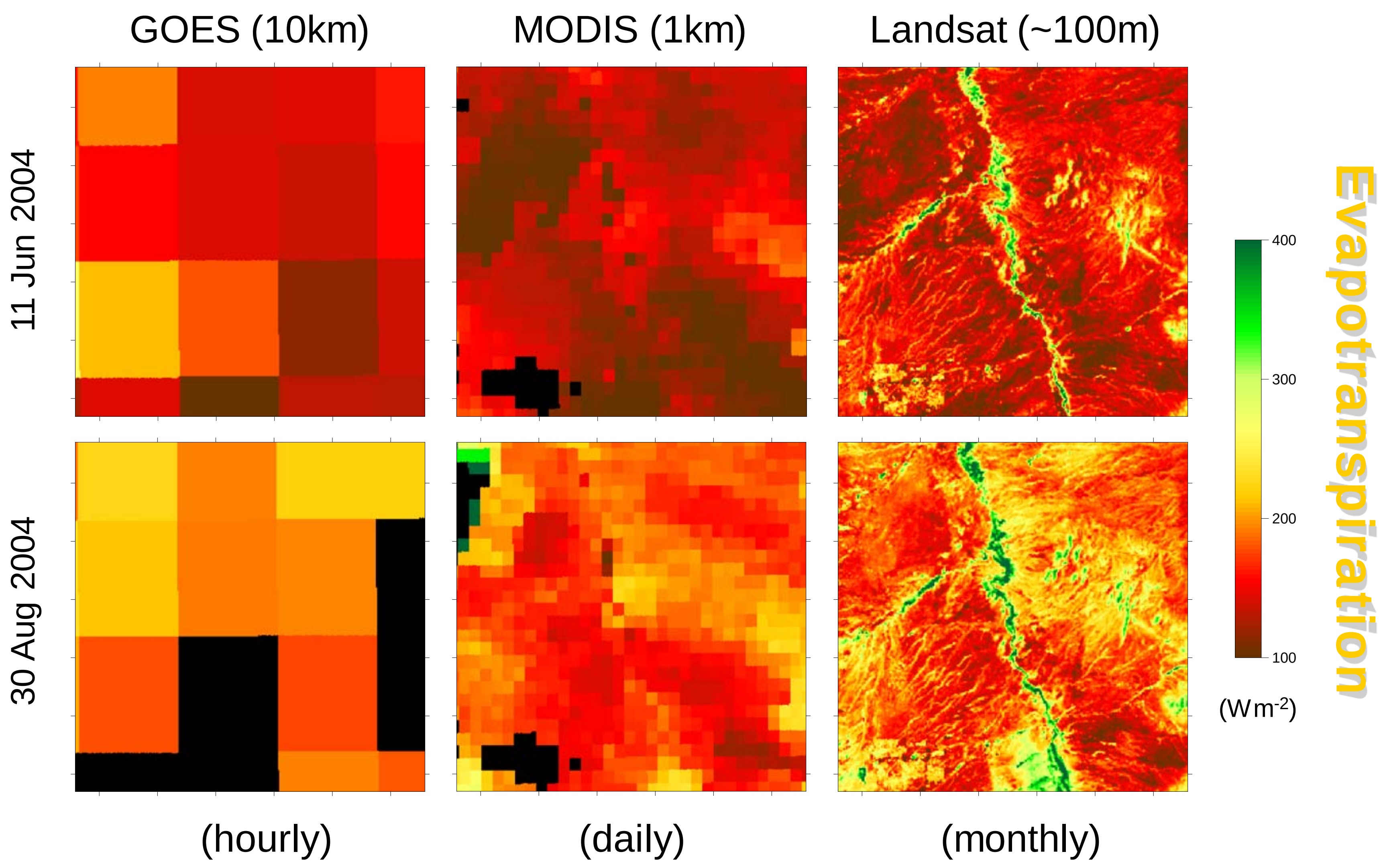
FORT PECK, MONTANA



AMES, IOWA

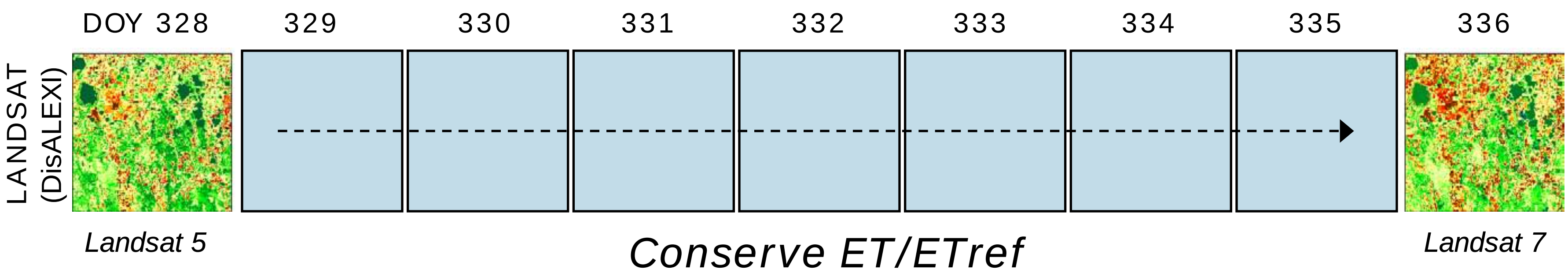

GOES (10km)
MODIS (1km)
Landsat (~100m)
23 Jun 2002
1 Jul 2002
600
500
400
300
200
100
(Wm-2)
Evapotranspiration
(hourly)
(daily)
(monthly)

SAN PEDRO RIVER, ARIZONA

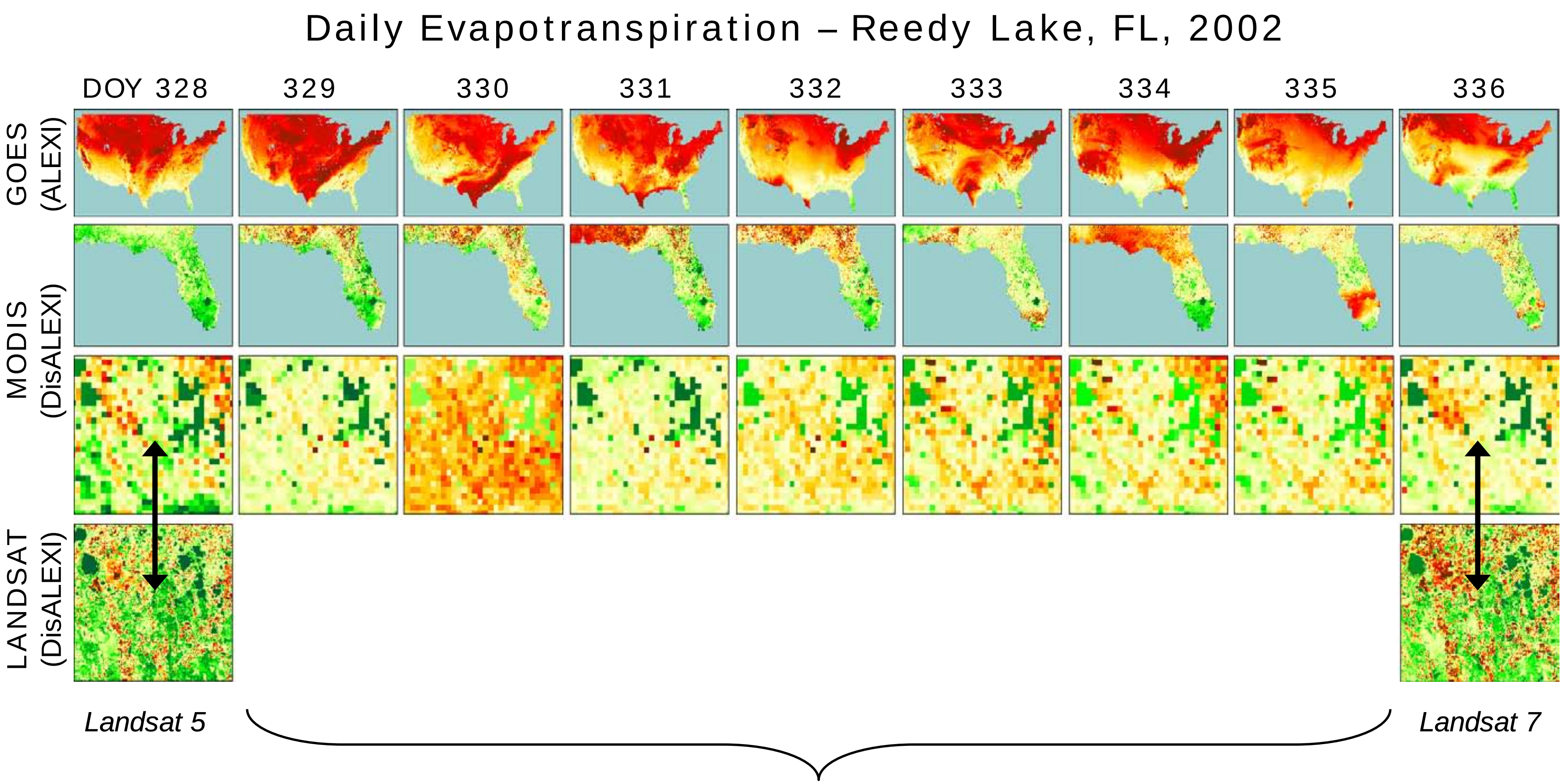


HIGH-RESOLUTION INTERPOLATION

Daily Evapotranspiration – Reedy Lake, FL, 2002

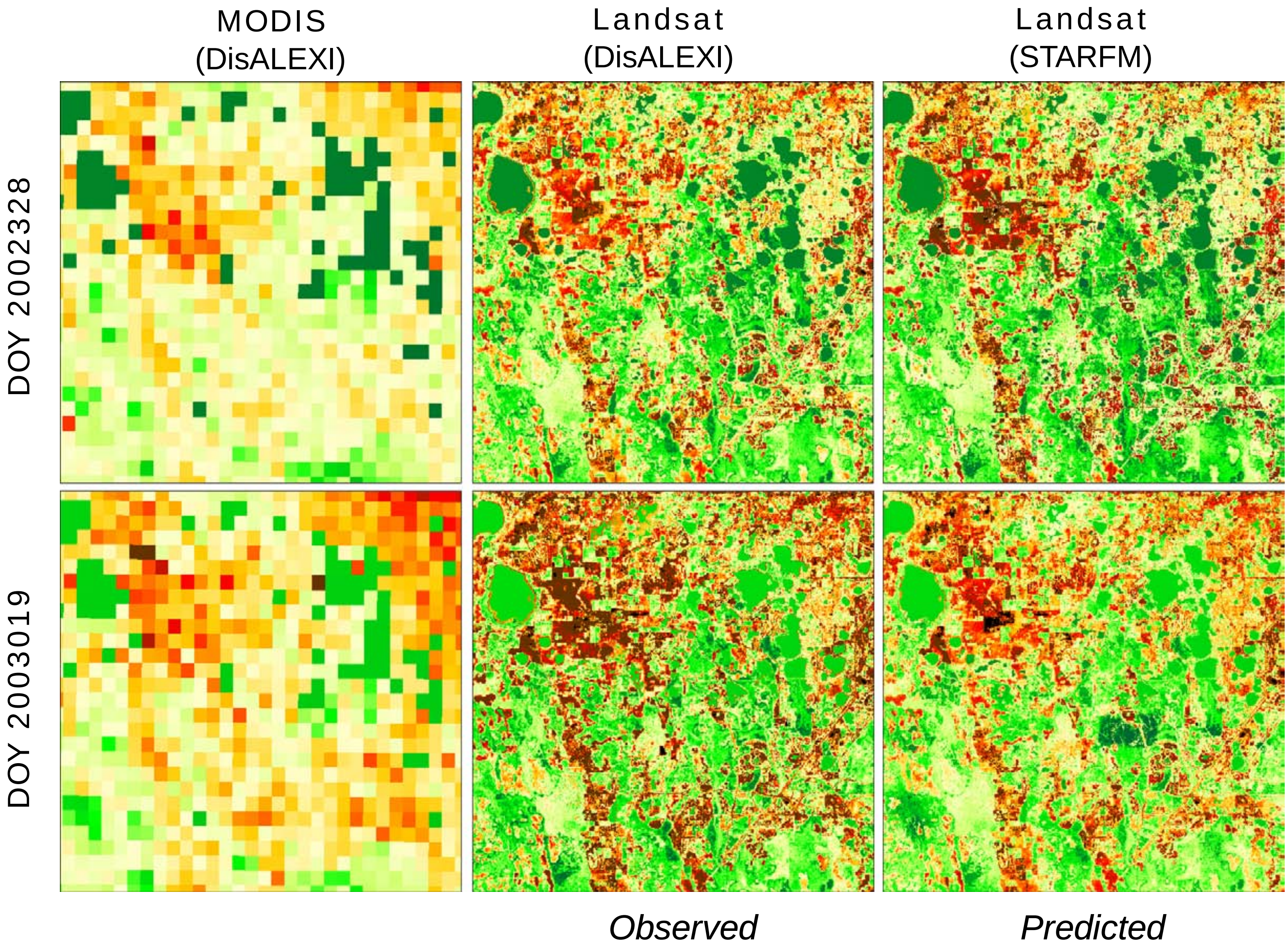


GOES/MODIS/Landsat FUSION



Spatial Temporal Adaptive Reflectance Fusion Model (STARFM) *(Gao et al, 2006)*

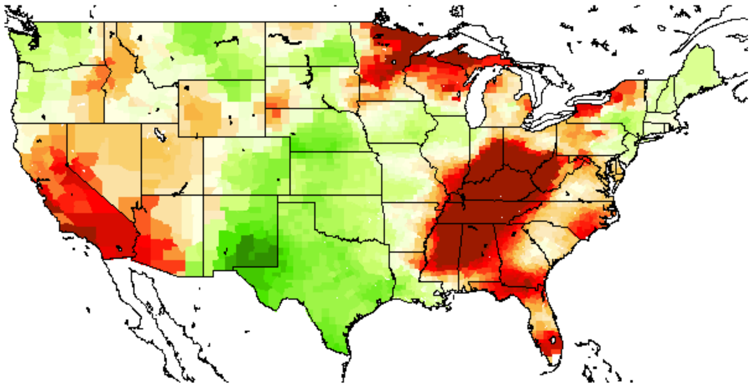
EVALUATION OF PREDICTED FIELDS



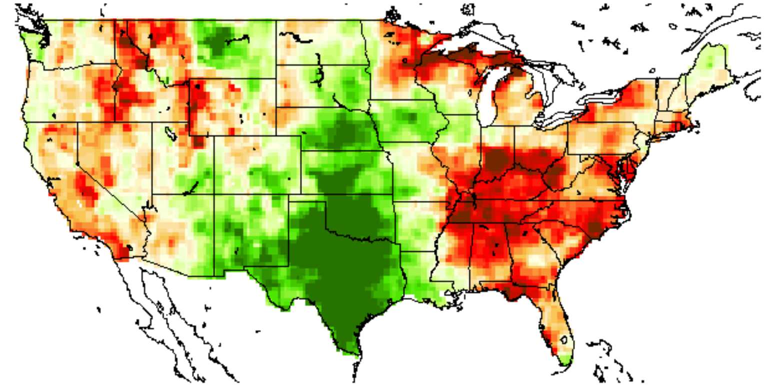

APPLICATIONS
... monitoring ecosystem health
Anomalies in $\frac{AET}{PET}$
Evaporative Stress Index

2007 GROWING SEASON ANOMALIES

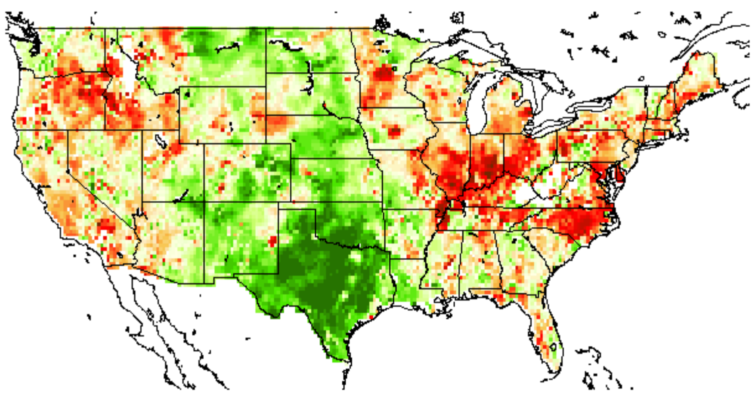
US DROUGHT MONITOR



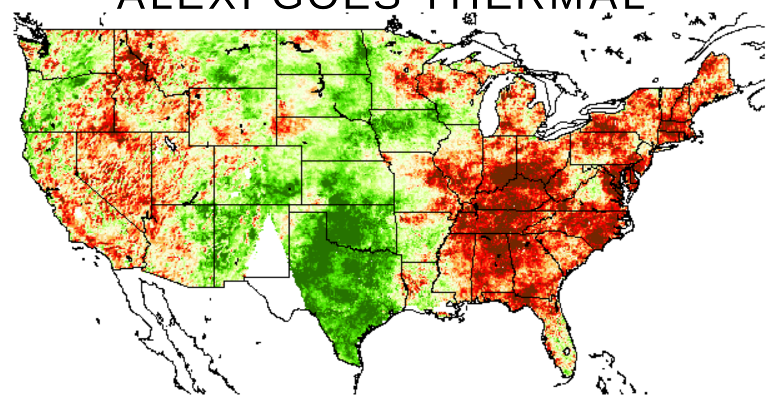
LIS - NOAH



USDA AMSR-E MICROWAVE



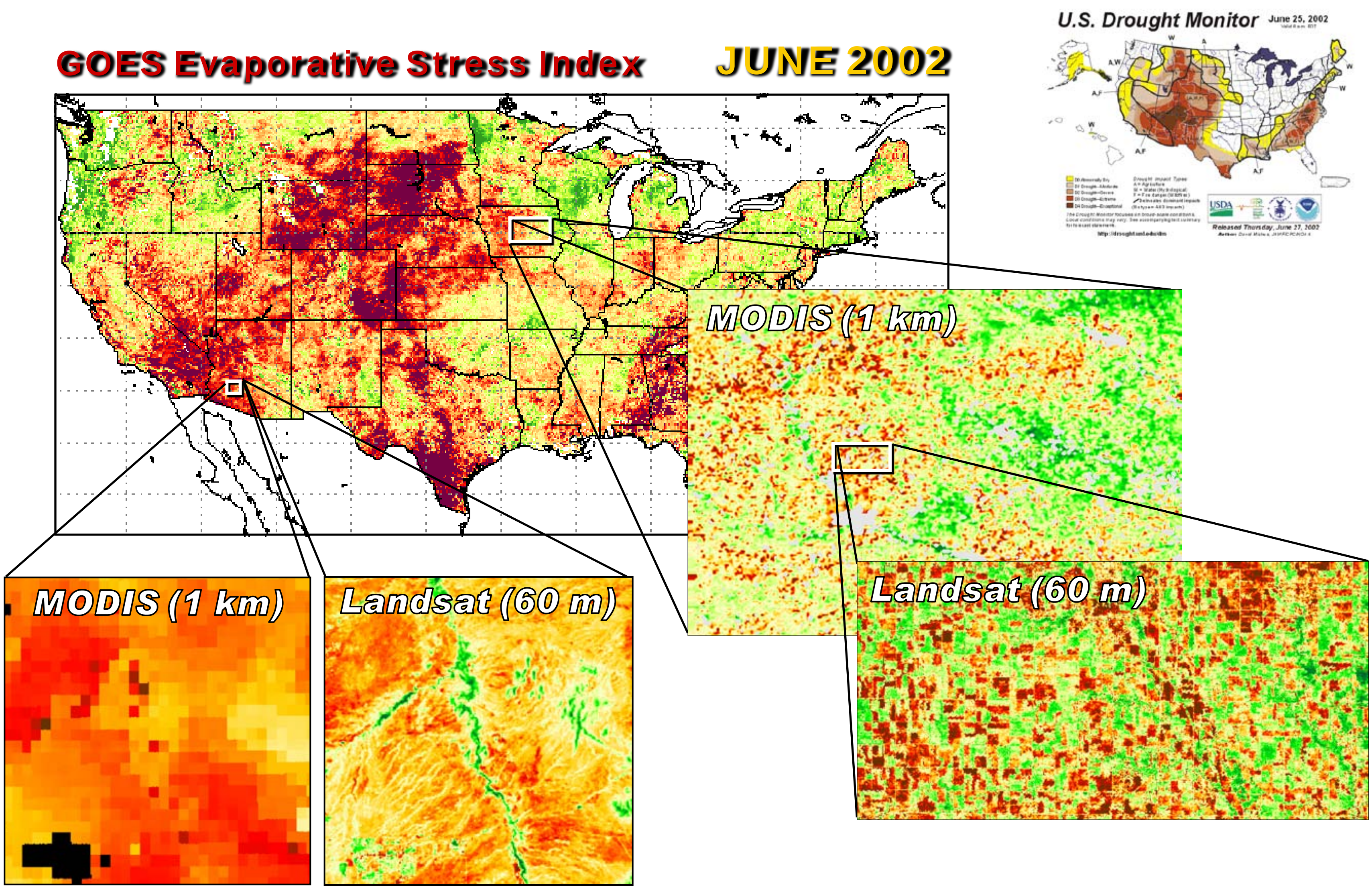
ALEXI GOES THERMAL

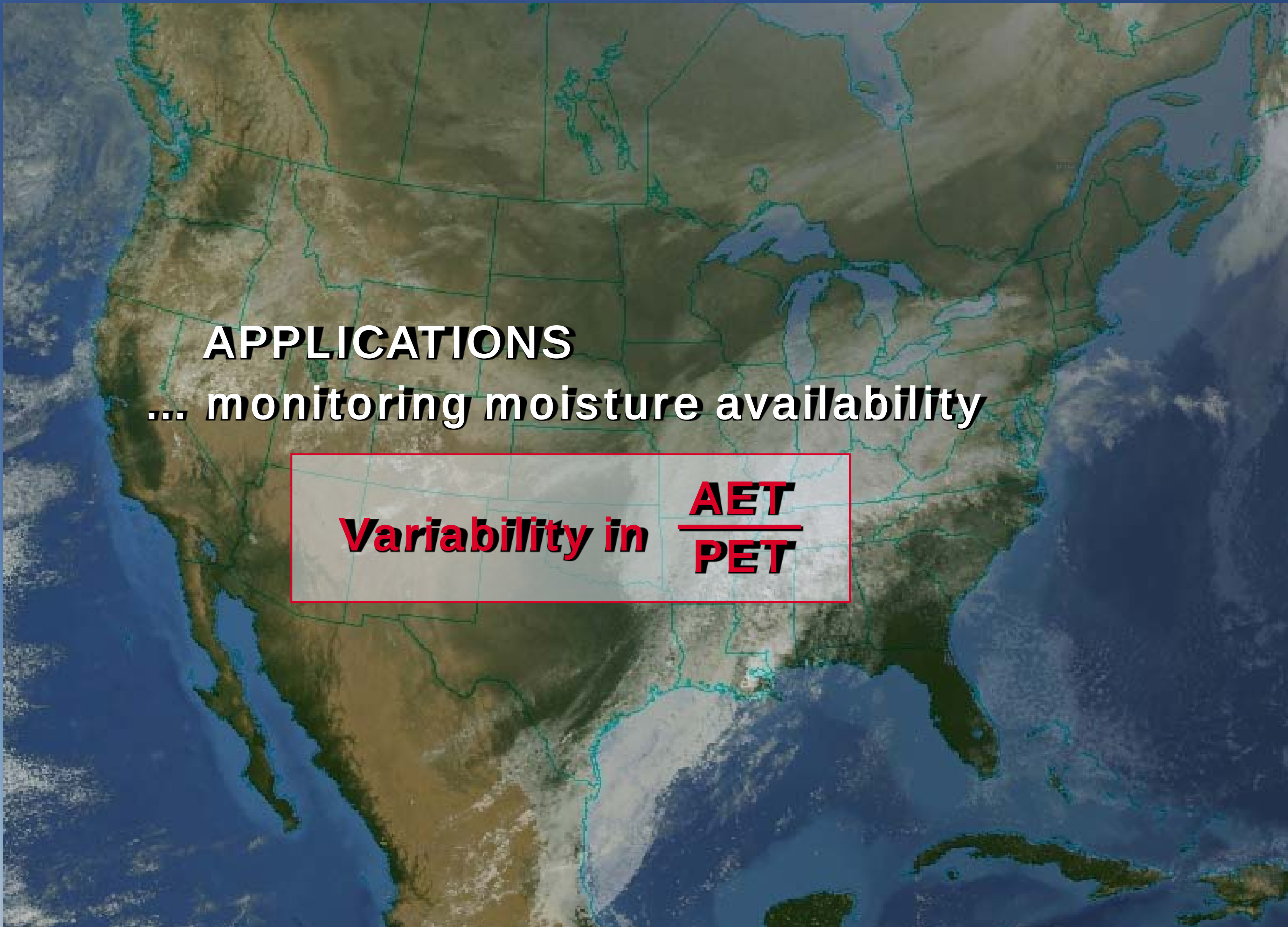


- samples 5cm layer
- 50km pixels (AMSR)
- ~2-day coverage
- light vegetation cover

- samples ~1-2m layer
- 60m - 5km pixels (L7, GOES)
- ~15-day coverage (90%)
- low to high vegetation cover

Multi-scale Drought Monitoring

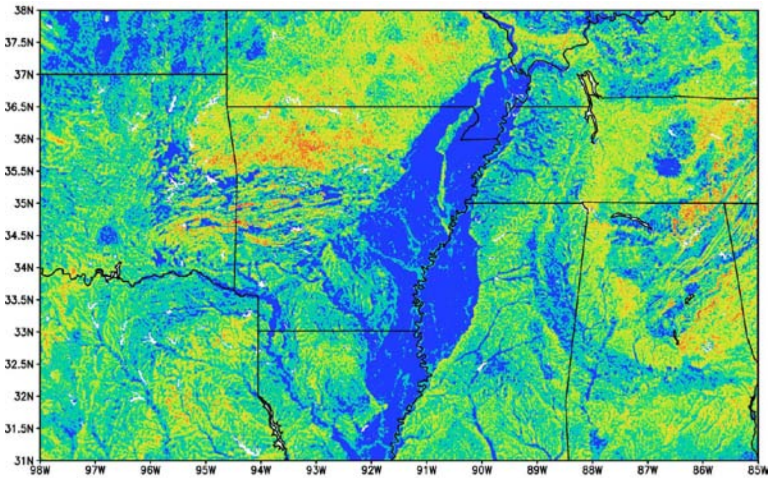


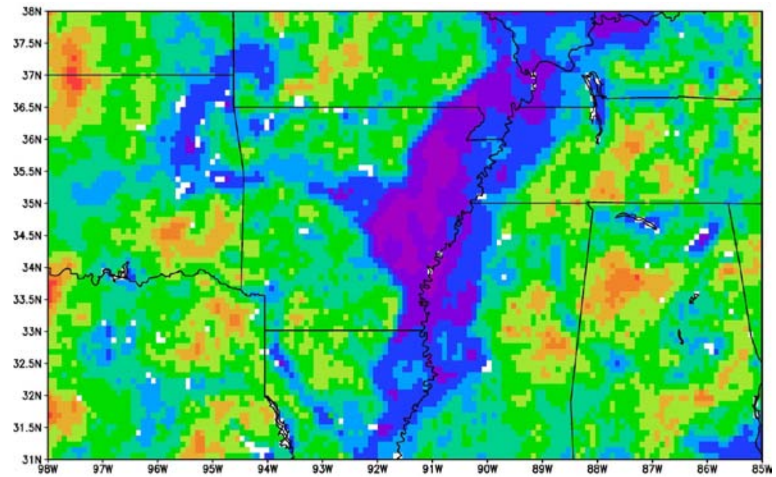

APPLICATIONS
... monitoring moisture availability
Variability in $\frac{AET}{PET}$

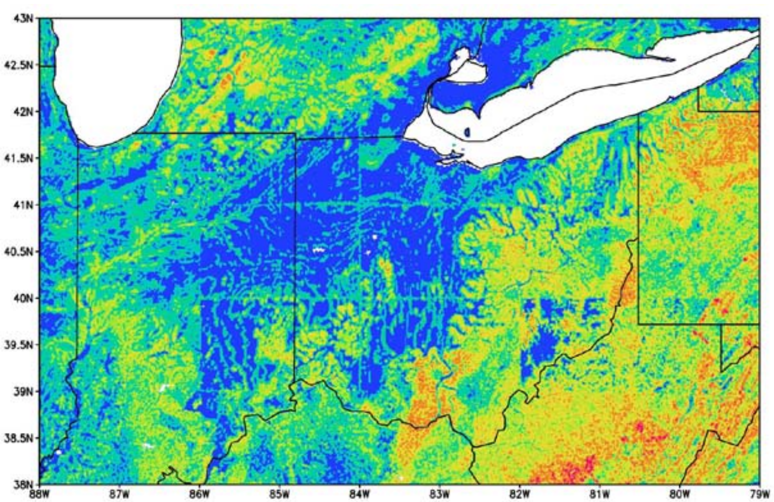
Sensitivity to shallow water tables

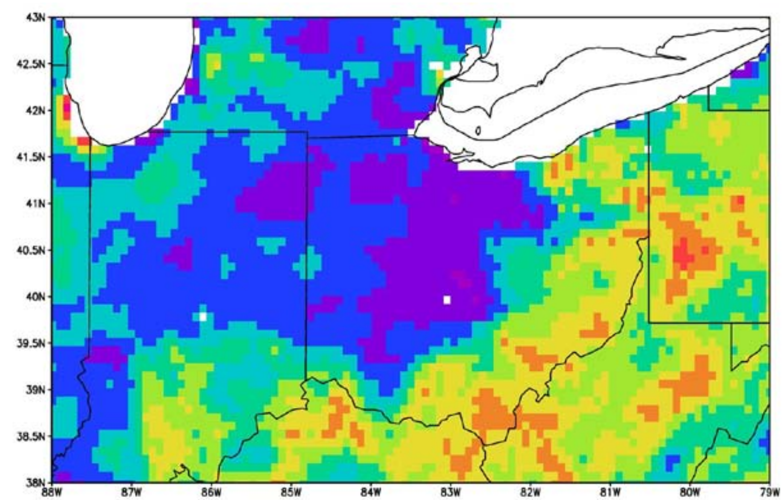
Simulated climatological water table*

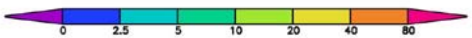
Temporal variability in ET/PET



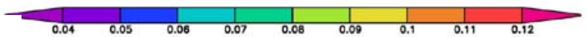








shallow deep



low high

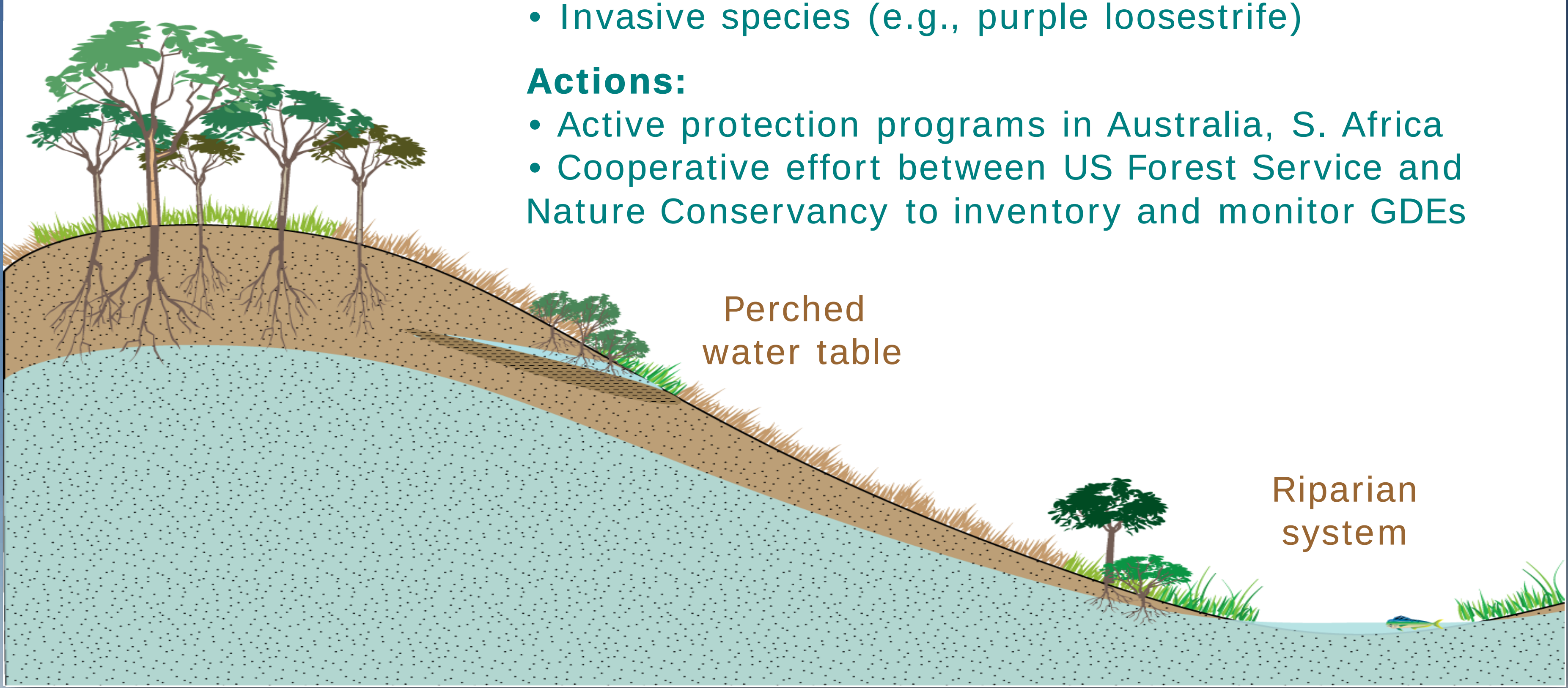
* Miquez-Macho et al, BAMS, 90, 663-672

Groundwater Dependent Ecosystems (GDE)

Services:
- Rich in biodiversity, especially in semiarid climates
- Habitat for birds, amphibians, endemic fish

Threats:
- Declining water tables due to over-extraction and climate change
- Invasive species (e.g., purple loosestrife)

Actions:
- Active protection programs in Australia, S. Africa
- Cooperative effort between US Forest Service and Nature Conservancy to inventory and monitor GDEs



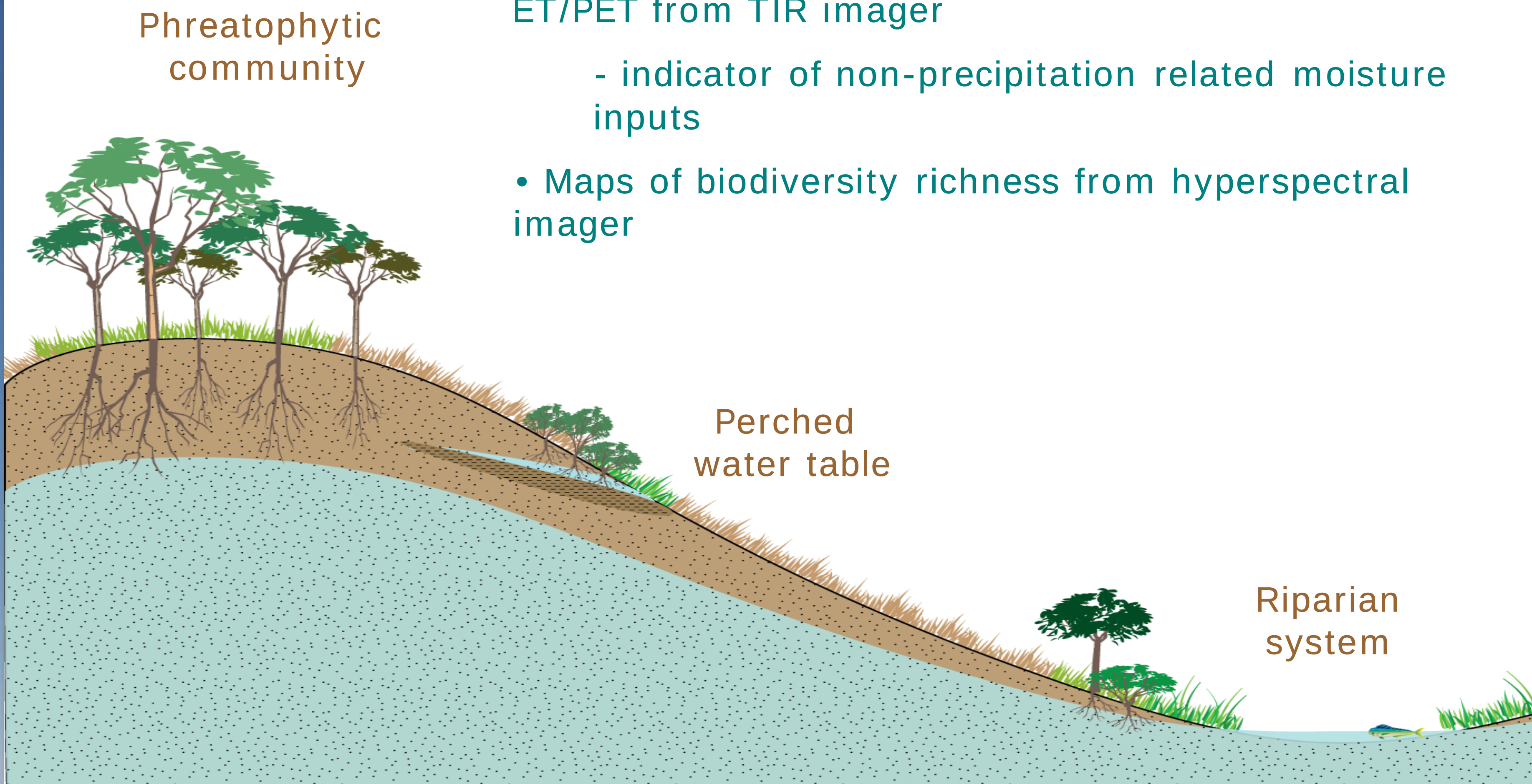
Groundwater Dependent Ecosystems (GDE)

HyspIRI data layers for GDE identification:

• High resolution maps of temporal variability in ET/PET from TIR imager

- indicator of non-precipitation related moisture inputs

• Maps of biodiversity richness from hyperspectral imager



PRODUCTS

- *60m maps of daily ET*

  ... monitoring water use

- *60m maps of daily ET/PET*

  ... monitoring moisture availability

HYSPIRI WILL ADD VALUE
TO EXISTING TIR PRODUCTS

Martha.Anderson@ars.usda.gov

HyspIRI VNIR and TIR Data Products
Susan Ustin

Ready and Near Ready Products

Atmospheric calibration for phases of water (vapor, liquid, solid)
Narrow band Indexes (e.g., PRI)
Red edge detection

Linear Mixture models (green vegetation, dry vegetation (NPV), soil, water, impervious surfaces

Multiple endmember spectral mixture analysis (MESMA)

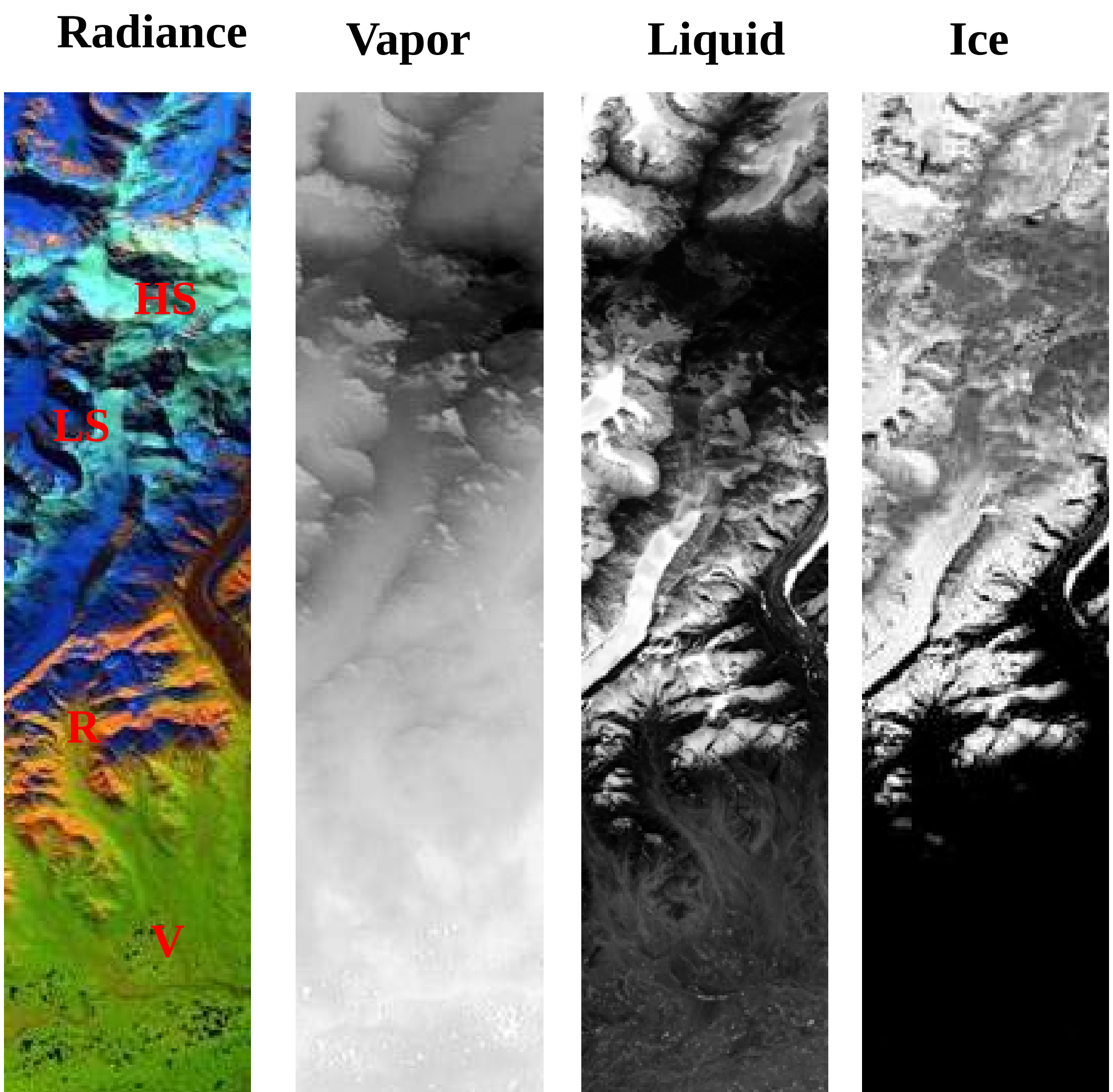
Leaf Area Index

Quantified Chemistry (inversion of PROSPECT models)
Total pigments, carotenoids, chlorophylls,
Equivalent water thickness, canopy water content

Tested but needs more validation on wider range of ecosystems

Steady State Fluorescence
Canopy nitrogen content; other elements: P, K, etc. (see Asner)
Anthocyanin (Gitleson method)
Fuel Moisture Content (PROSPECT inversion)

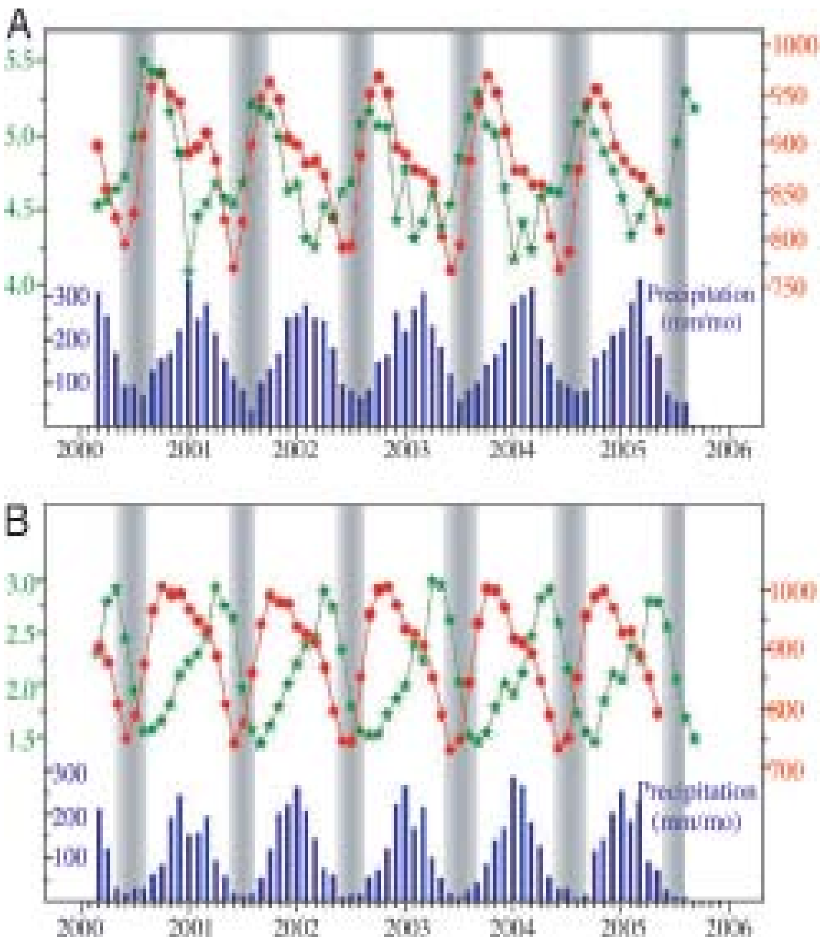
Retrieval of Quantified Water in Different Phases from Atmospheric RT Model

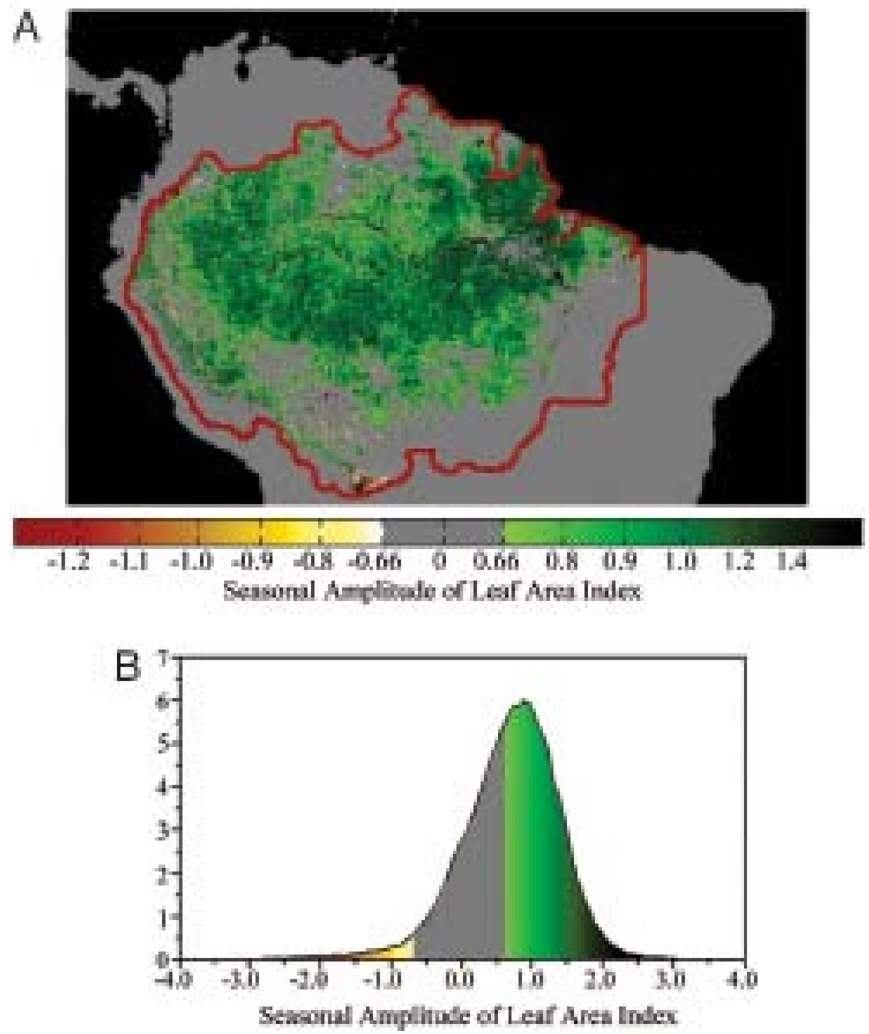


- **Water vapor** 0.51 to12.7mm precipitable water per pixel
- **Liquid water** 0 to 7.4 mm equivalent path transmittance
- **Ice** 0 to 27.9 mm equivalent path transmittance

Robert O. Green

Leaf Area Index is a Critical Variable for Physiological Status and Fluxes

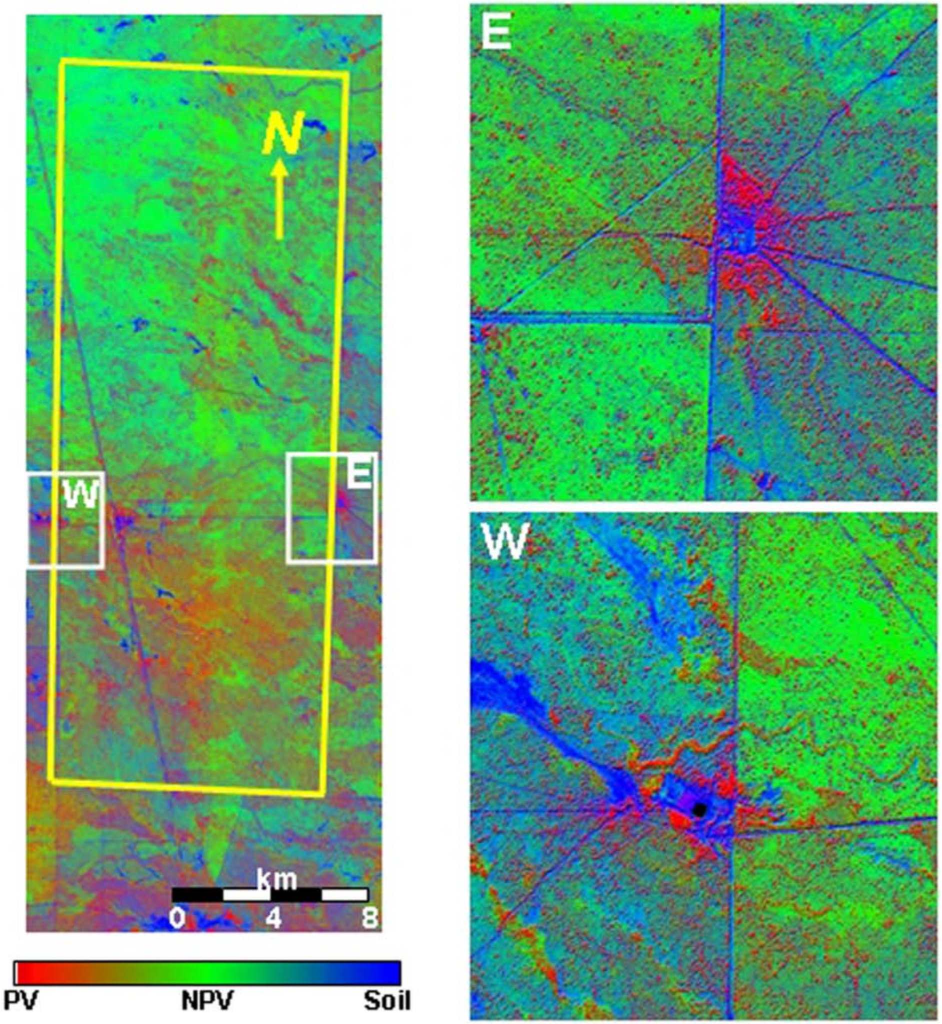




●LAI ● Radiation Budget

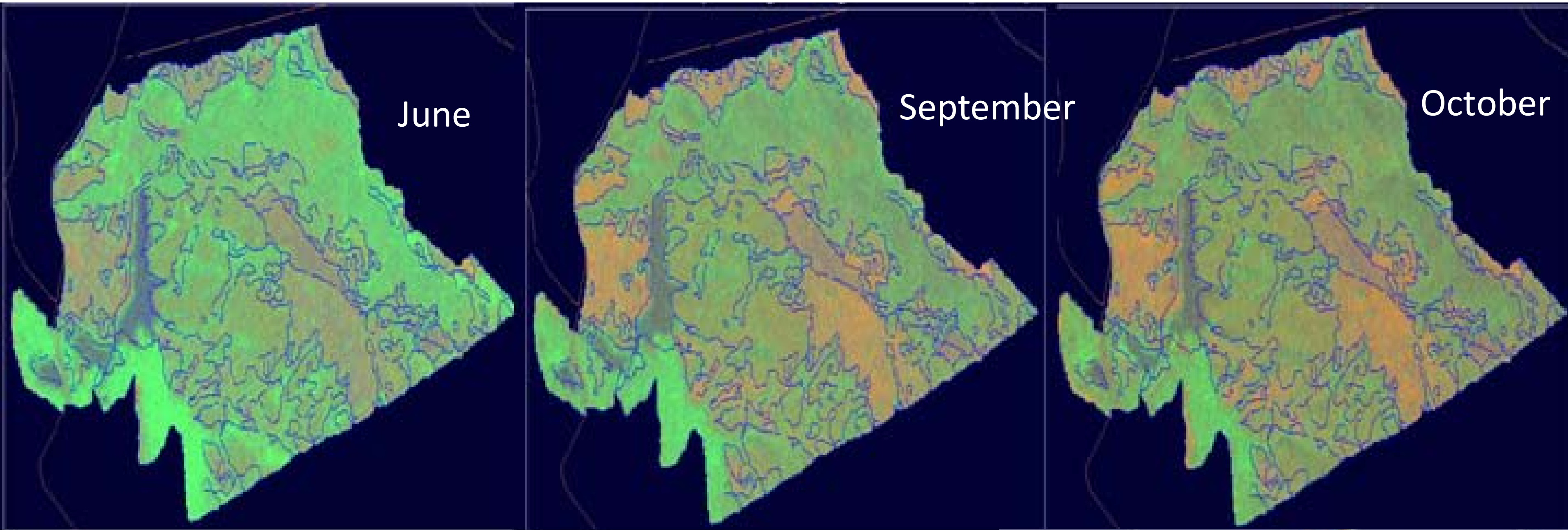
Ranga Myneni et al. 2007. Large seasonal swings in leaf area of Amazon rainforests. NPAS.

Linear Spectral Mixture Analysis for 3 Endmembers



Asner GP, Green RO. 2001. Imaging spectroscopy measures desertification in the Southwest U.S. and Argentina. EOS Transactions. 82(49):601-606.

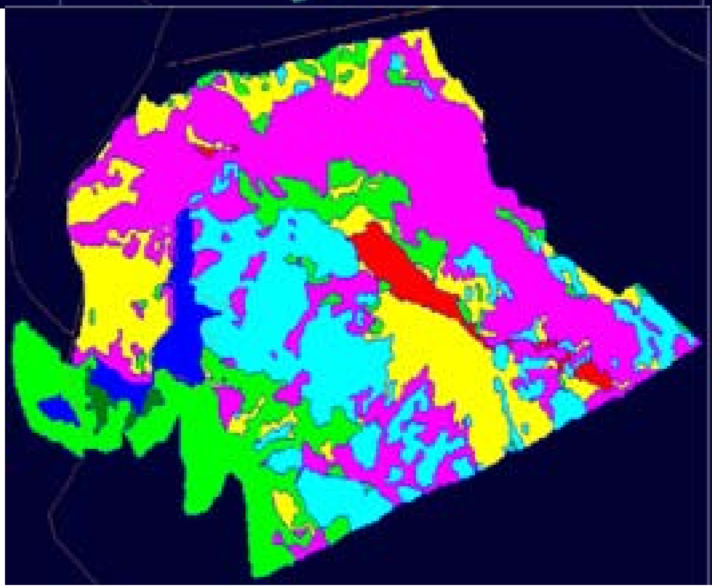
SMA Endmember Fraction Map Tracks Phenological Changes



Endmembers:
Green vegetation
Dry vegetation
Soil

Independent Vegetation Map

Deciduous Forest
Mixed Evergreen Forest
Chaparral
Greenstone Grassland
Serpentine Grassland
Wetland
Lake



Ustin et al., 1999

SMA: Monitoring Disturbance History, Forest Composition & Structure

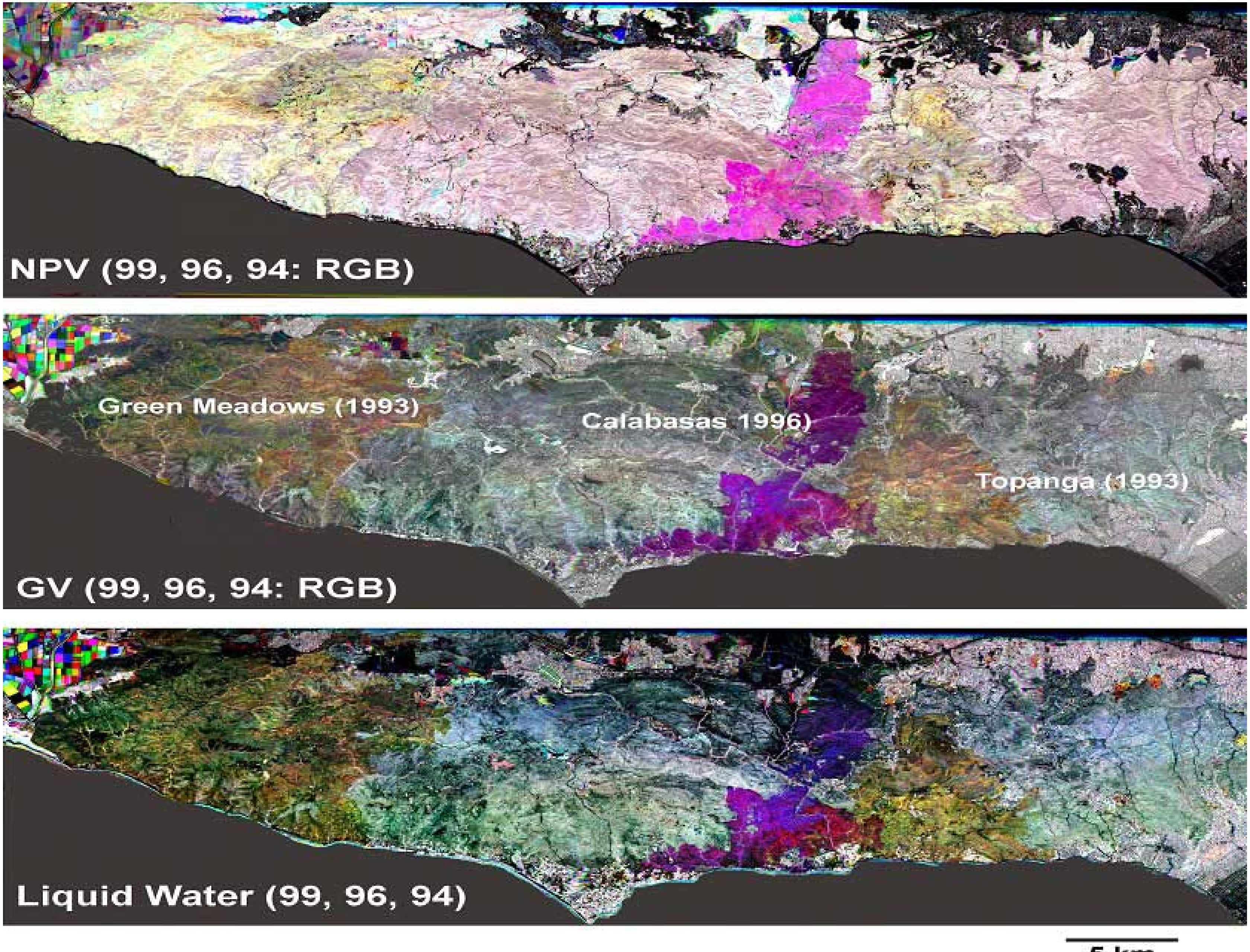
Endmembers:
Soil
Green Vegetation
Shade

What you can see:

- Riparian Hardwood Forest
- Old Growth Forest
- Soil in Clear Cut Forest
- Regrowing conifer forest
- Meadow/agriculture

Wind River Experimental Forest within the Gifford Pinchot National Forest

July, 3 Years of Change in NPV, GV, and EWT

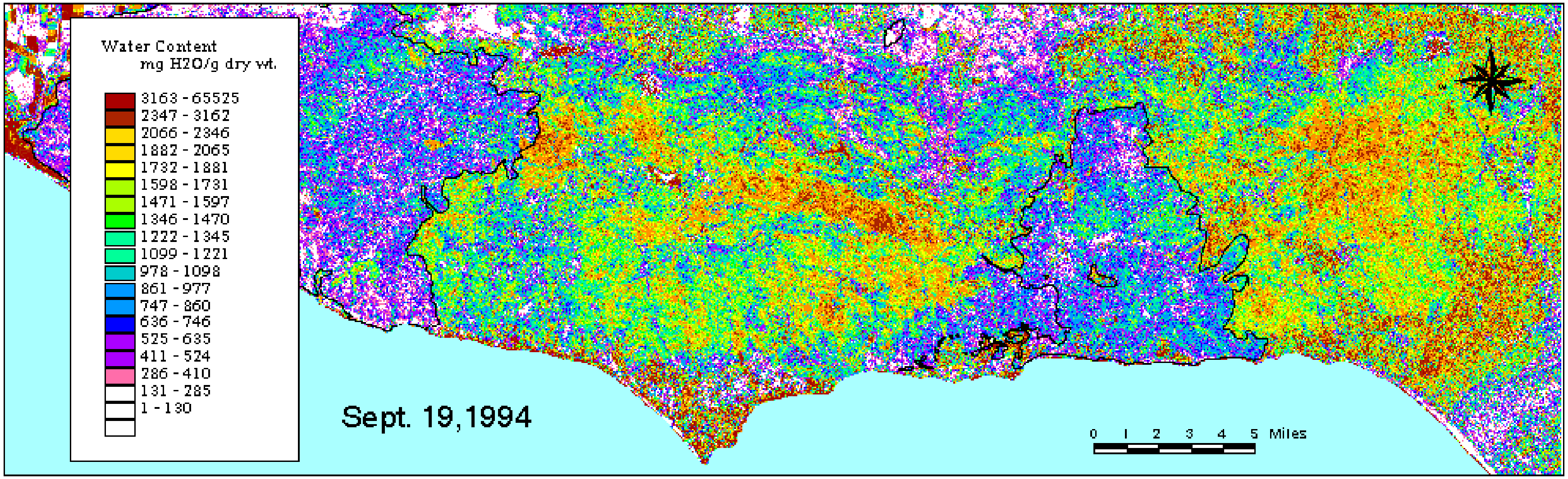


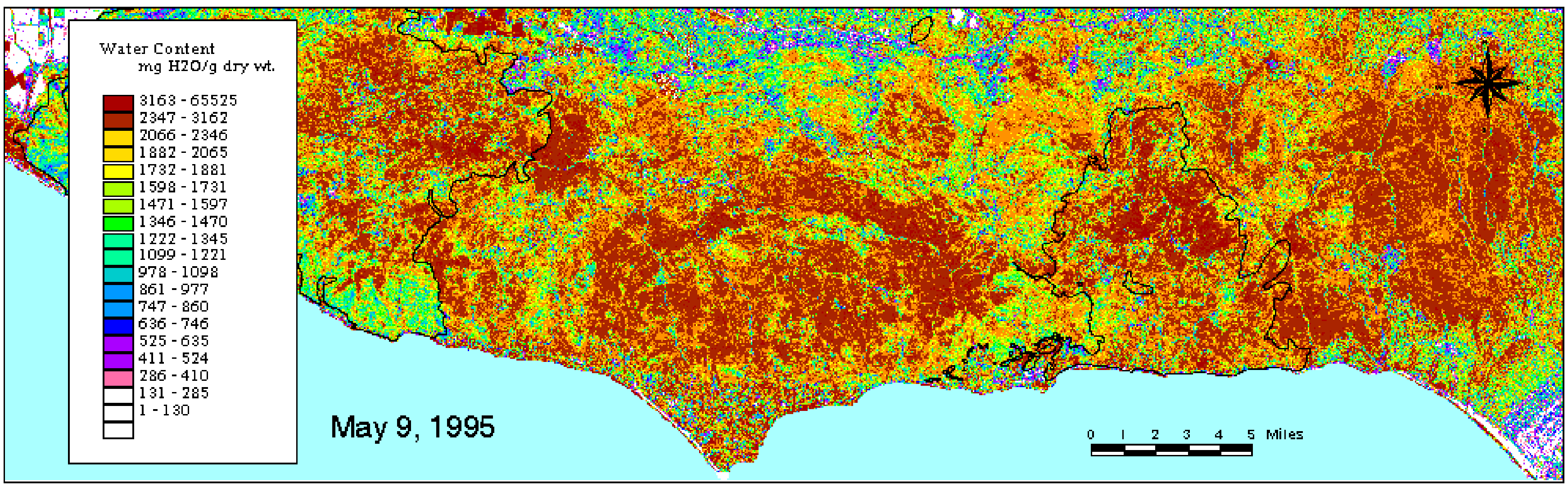
Semi Arid Chaparral, Santa Monica Mountains, southern California

D. Roberts

Canopy Water Content: Seasonal changes

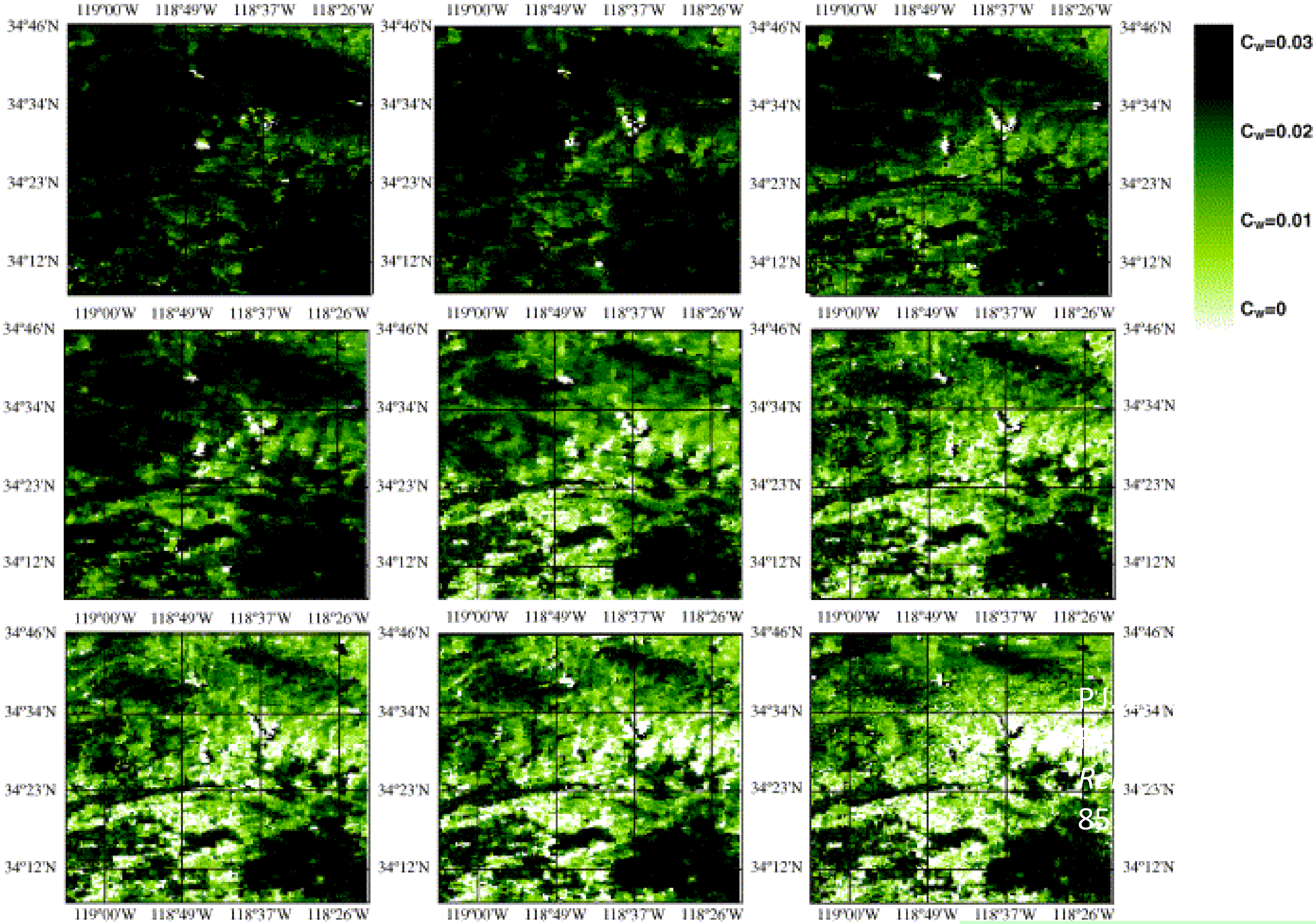
Santa Monica Mtns: Canopy Water Content





S.L. Ustin 1998, *Remote Sens. Environ.*, 65:280-291.

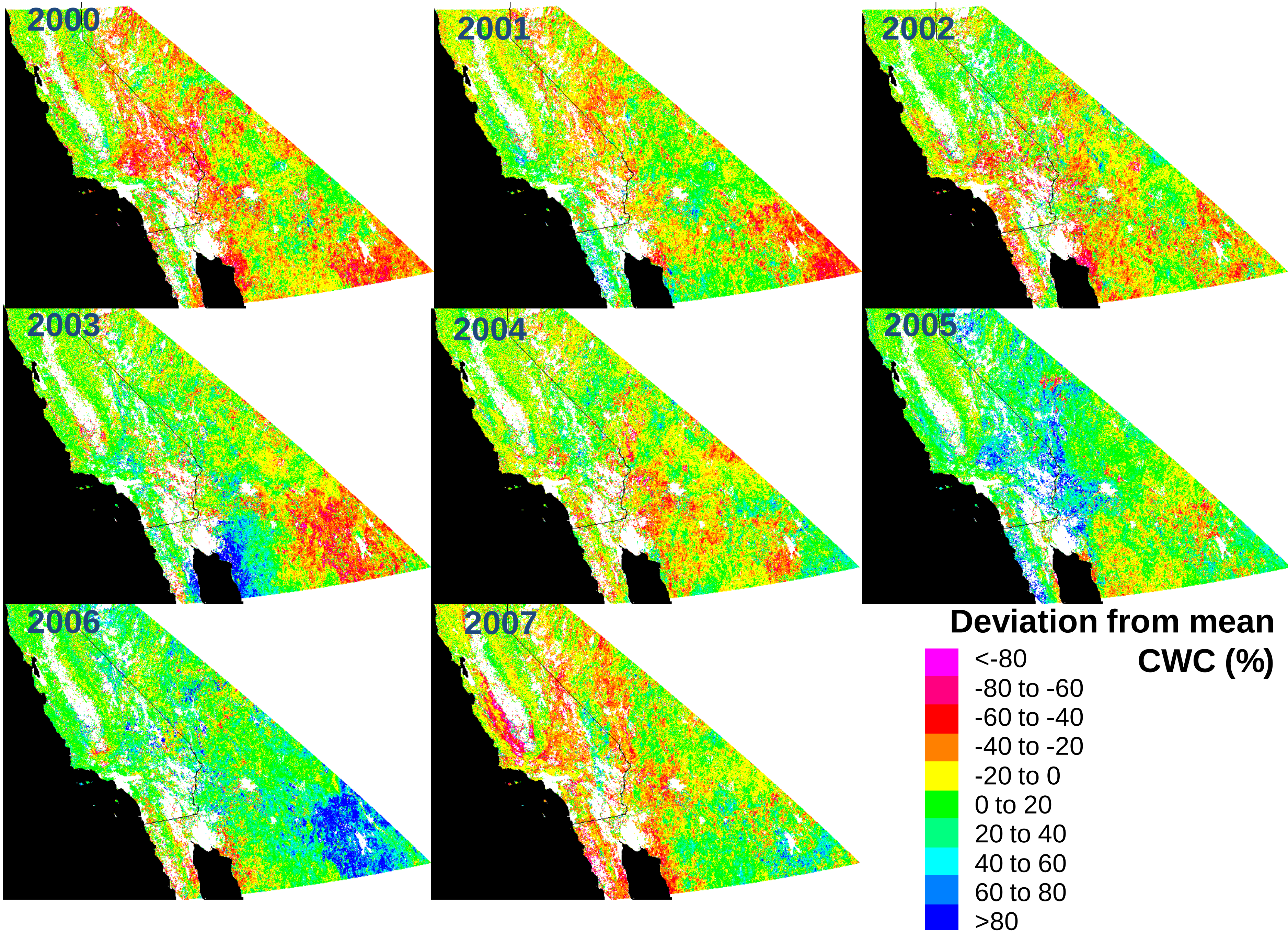
Weekly Retrieval of Water Content at the Canopy Scale



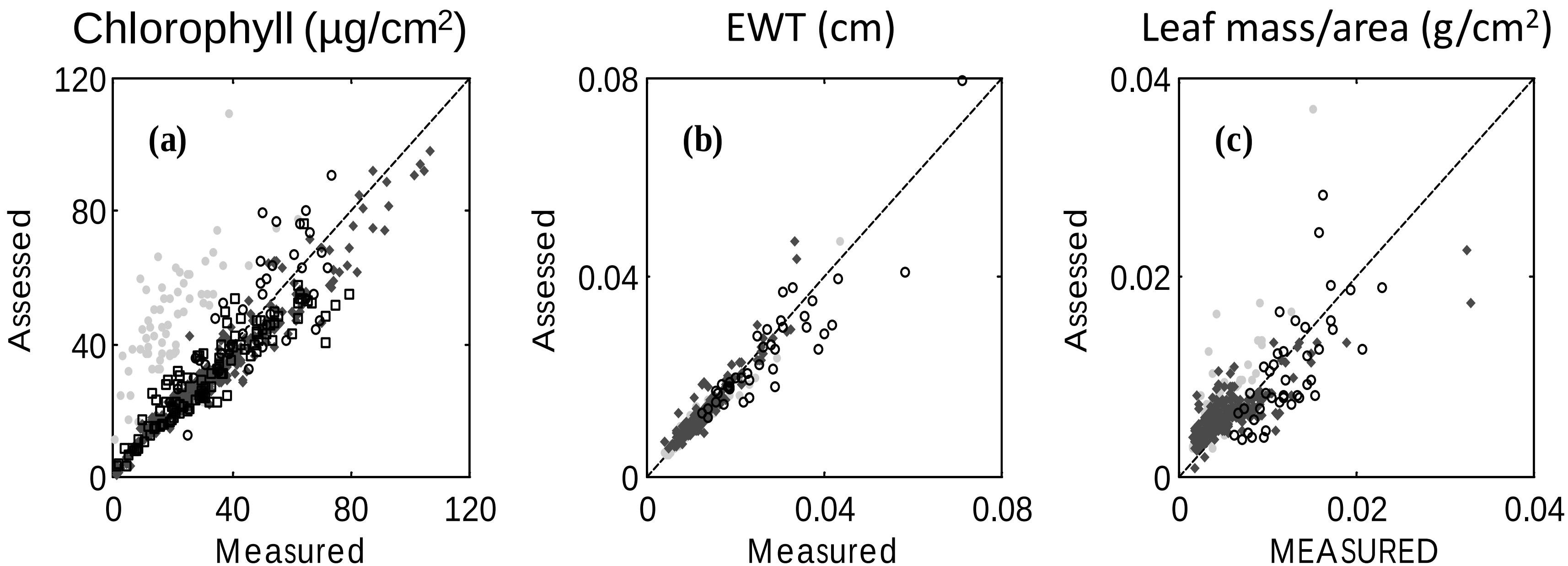
P. Zarco-Tejada et al., RSE 2003

$$\chi^2 = \sum_{i=1}^{n} \left\{ R_i - R_{\text{mod}}\left(\Theta, \lambda\right) \right\}^2$$

Interannual September CWC for Southwestern US & Mexico



PROSPECT 4: Data sets ● LOPEX □ CALMIT ◆ ANGERS ○ HAWAII

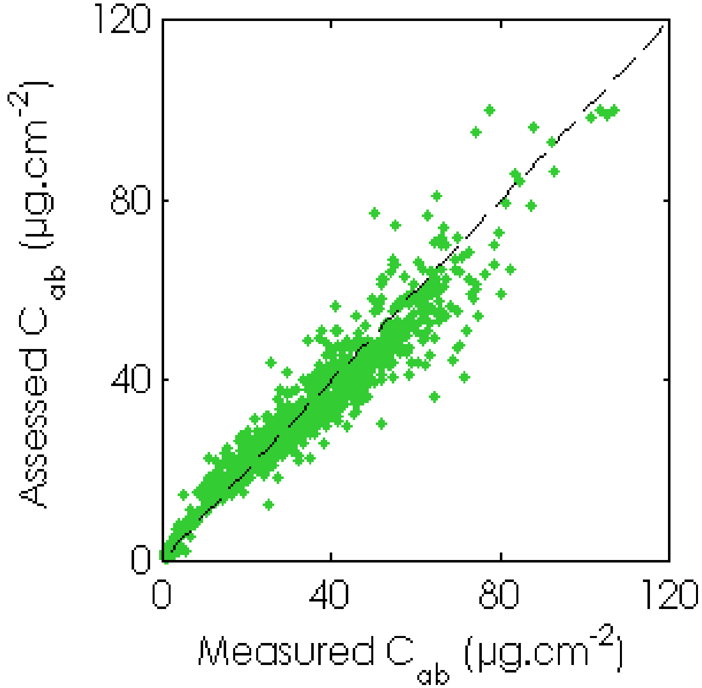


Feret, J-B., François, C. Asner, GP, Gitelson, AA, Martin, RE, Bidel, L.P.R., Ustin, S.L., le Maire, G., and Jacquemoud, S. 2008. PROSPECT-4 and -5: Advances in the Leaf Optical Properties Model Separating Photosynthetic Pigments. Remote Sensing of Environment 112: 3030-3043.

PROSPECT 4, 5: Assessment of Leaf Pigment Content

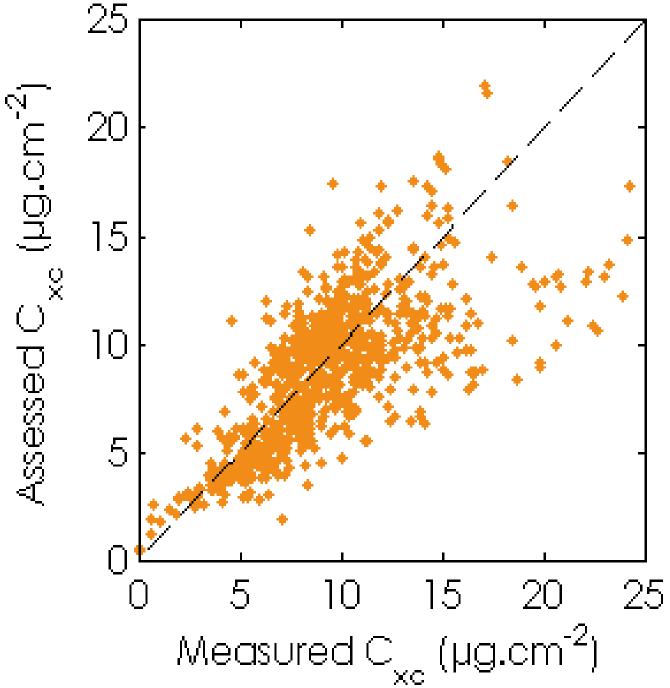
Chlorophyll

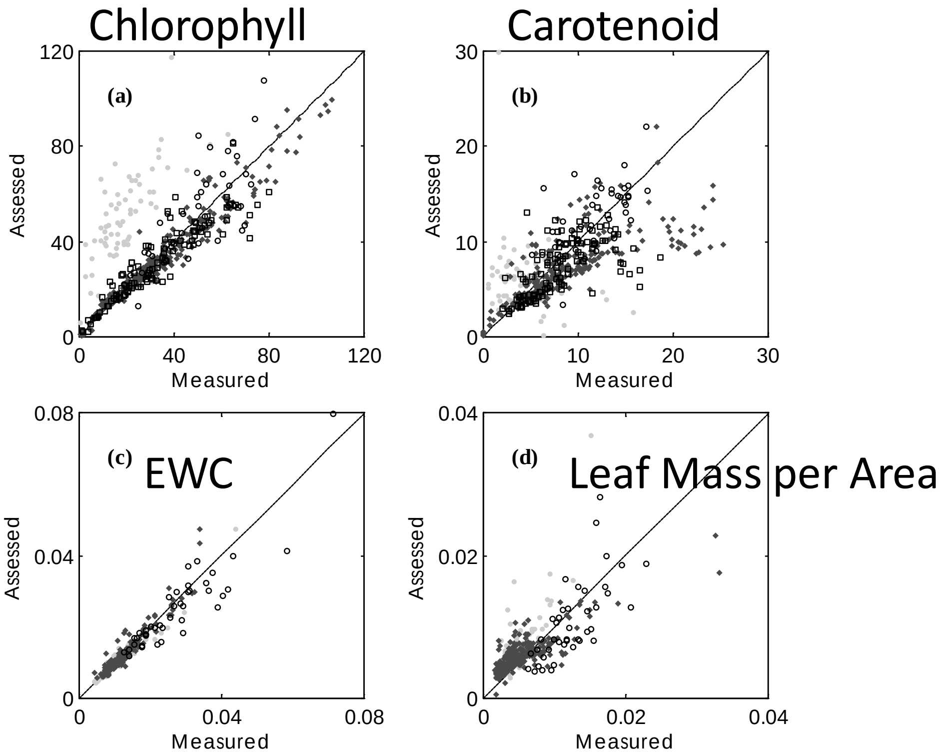
RMSE = 6.0 µg.cm^{-2}



Carotenoids

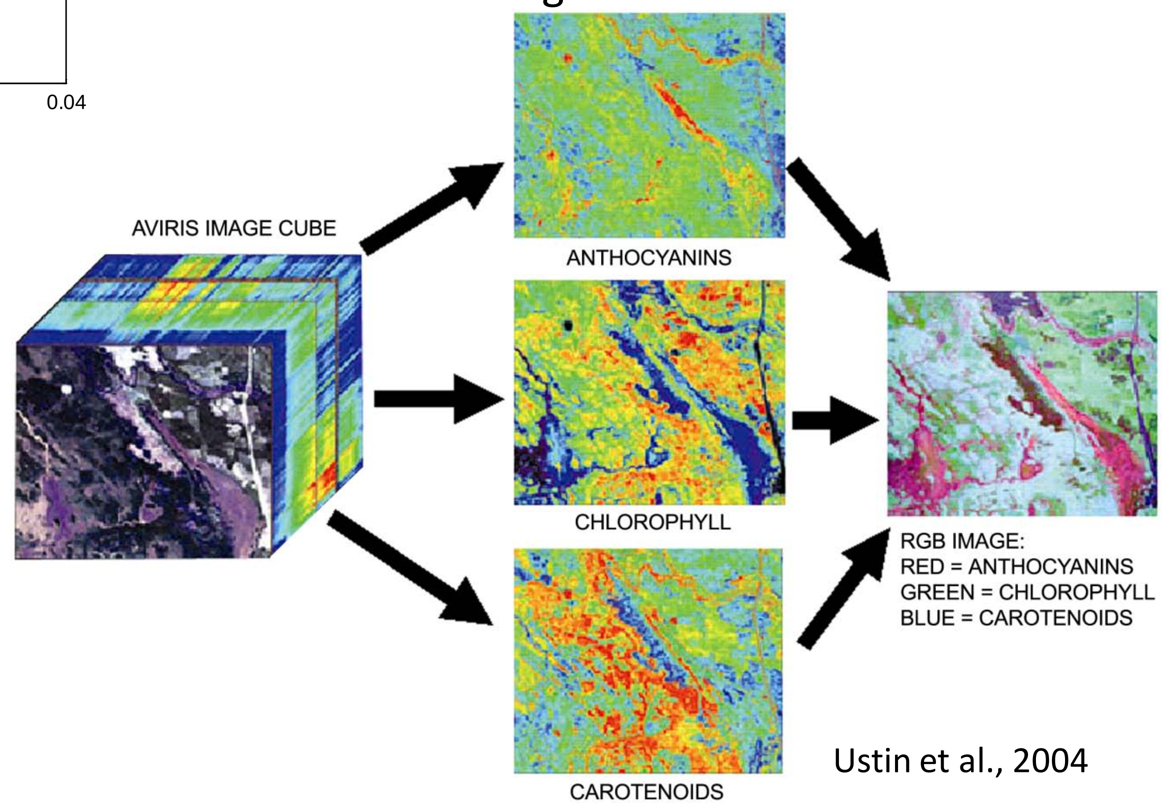
RMSE = 2.8 µg.cm^{-2}





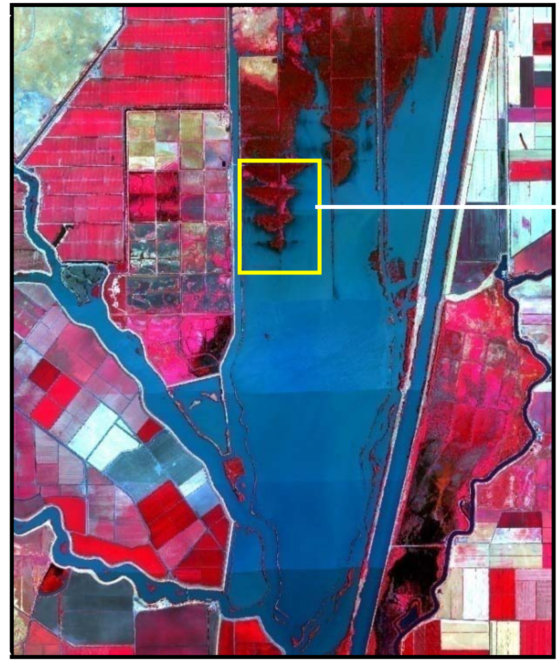
Feret et al. 2009. Remote Sensing of Environment 112: 3030-3043.

Following Fuentes et al. 2001

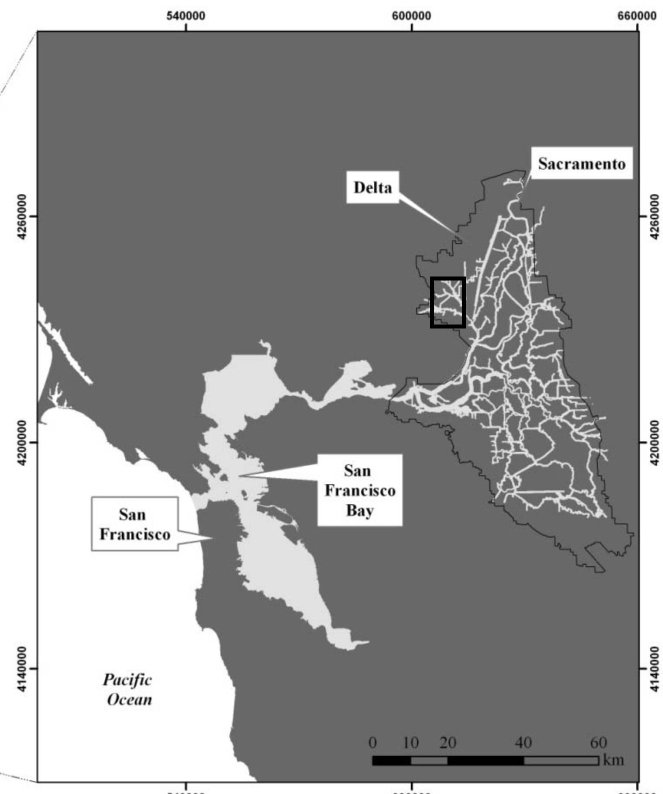


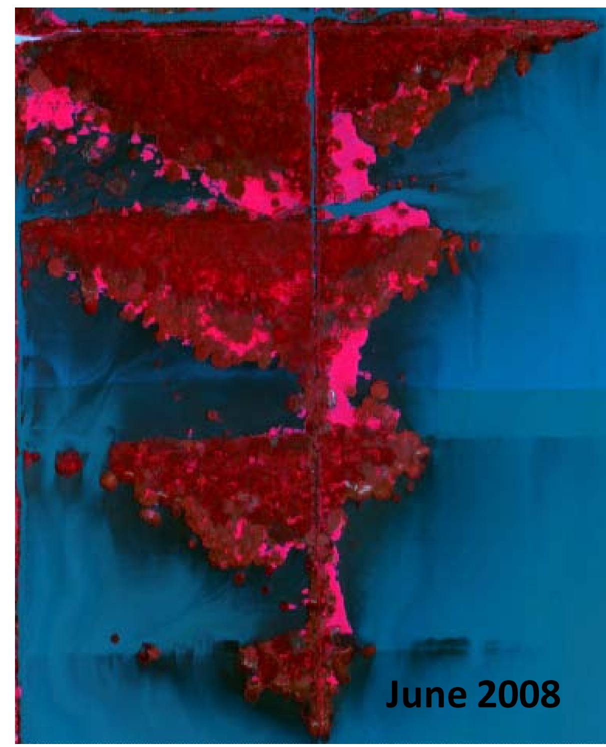
Ustin et al., 2004

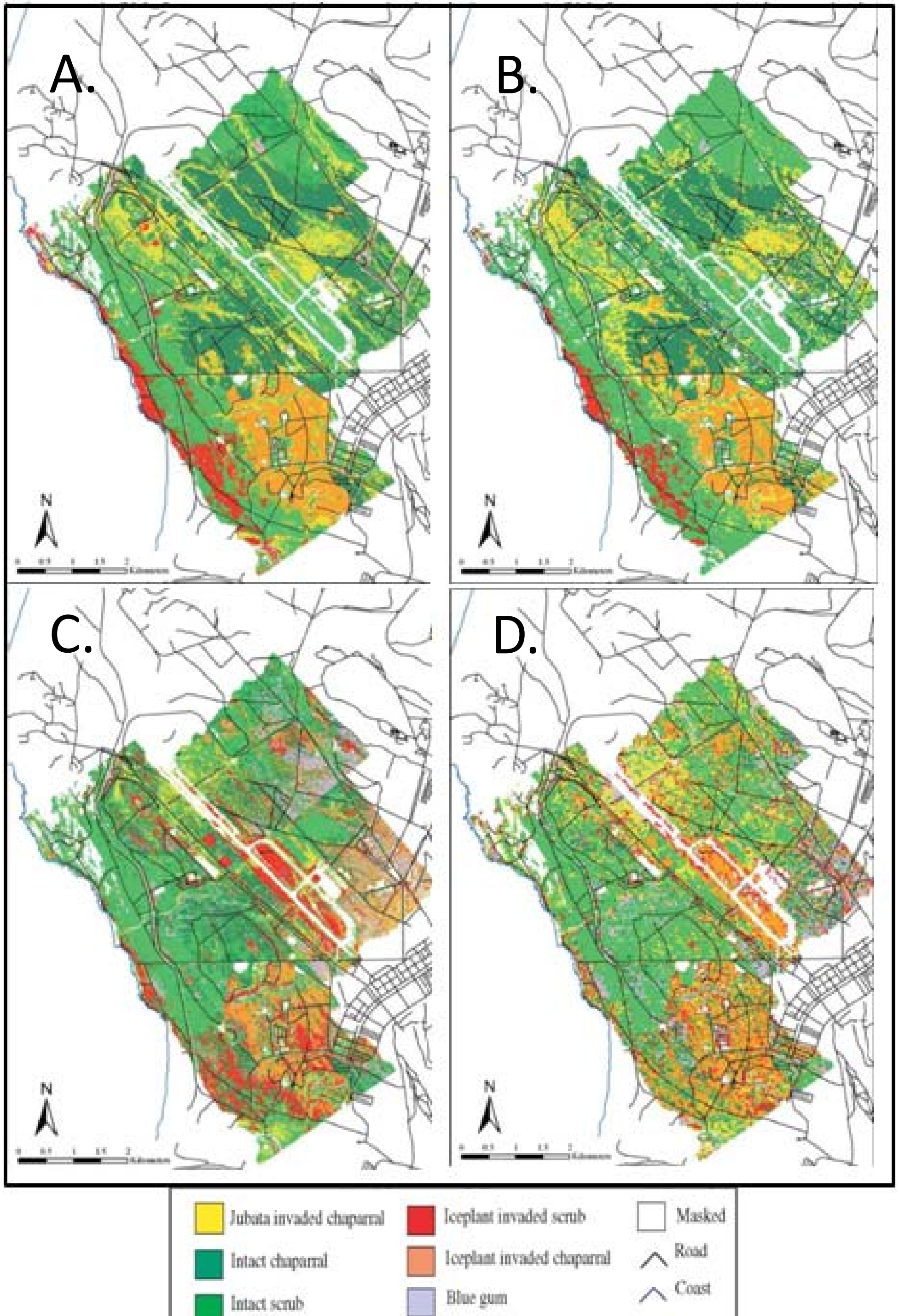
Expansion of Native Tule Marsh into flooded Liberty Island in four years



Liberty Island (flooded, former agricultural land)







Spatial Resolution is Less Important for Species/Community Mapping than Spectral Resolution

A. Full AVIRIS spectral resolution, 3m IFOV
B. Full AVIRIS spectral resolution, 30m IFOV
C. Landsat TM bands, 3m IFOV
D. Landsat TM bands, 30m IFOV

Underwood, E. S.L. Ustin and C. Ramirez. 2006. A comparison of spatial and spectral image resolution for mapping invasive plants in coastal California, Ecological Management, 39 (1): 63-83.

Fire Risk Maps of Roof and Building Composition, Impervious Surfaces and Vegetation

A: Red tile roof
B: Wood shingle roof
C: Grey composite shingle roof

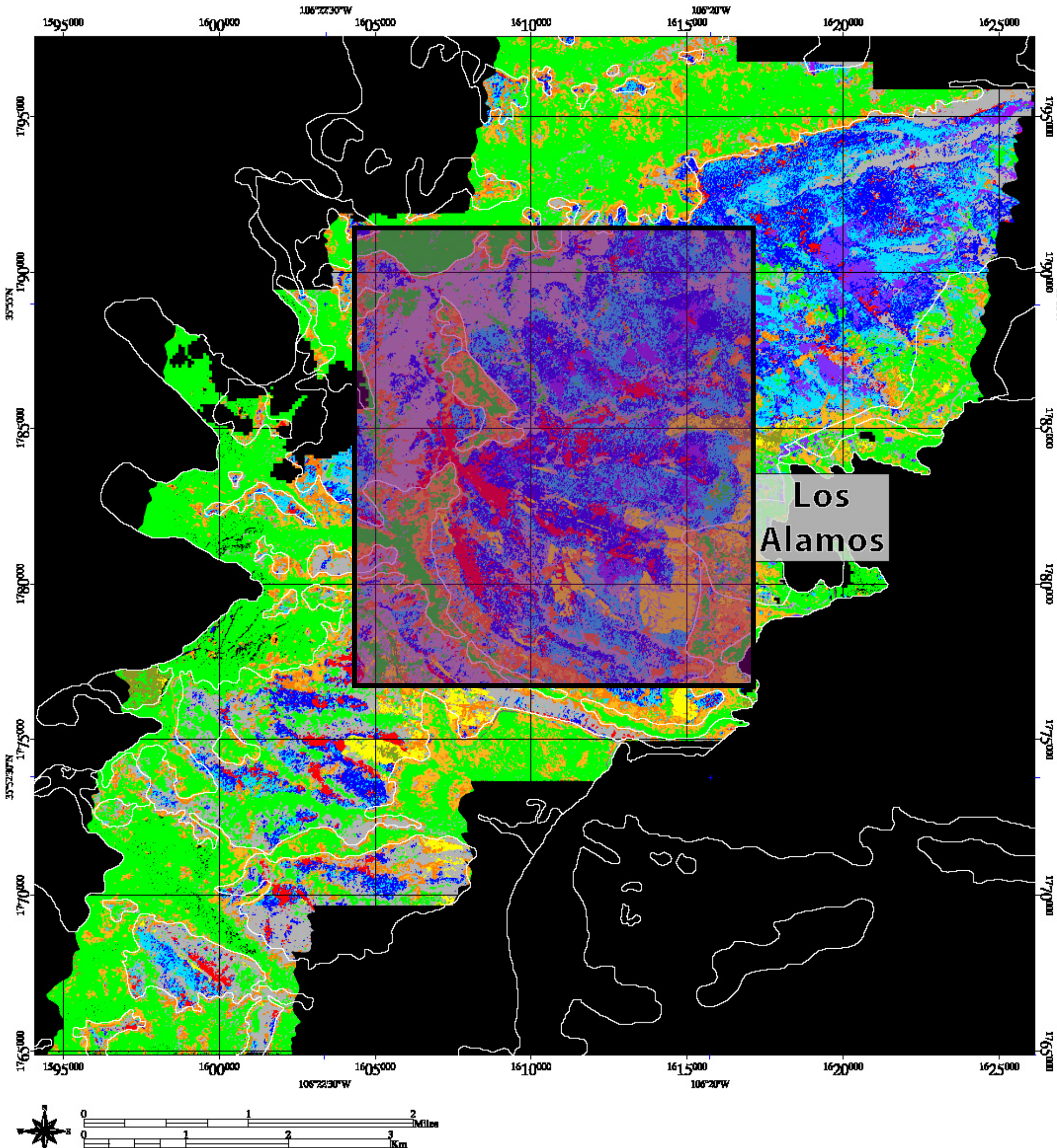
D: Concrete road
E: Asphalt road
F: Parking lot

G: Green vegetation
H: Non-photosynthetic vegetation
I: Bare soil

High resolution AVIRIS image
RGB: 2338nm/846nm/438nm
Goleta, CA, June 2000

Dar Roberts lab

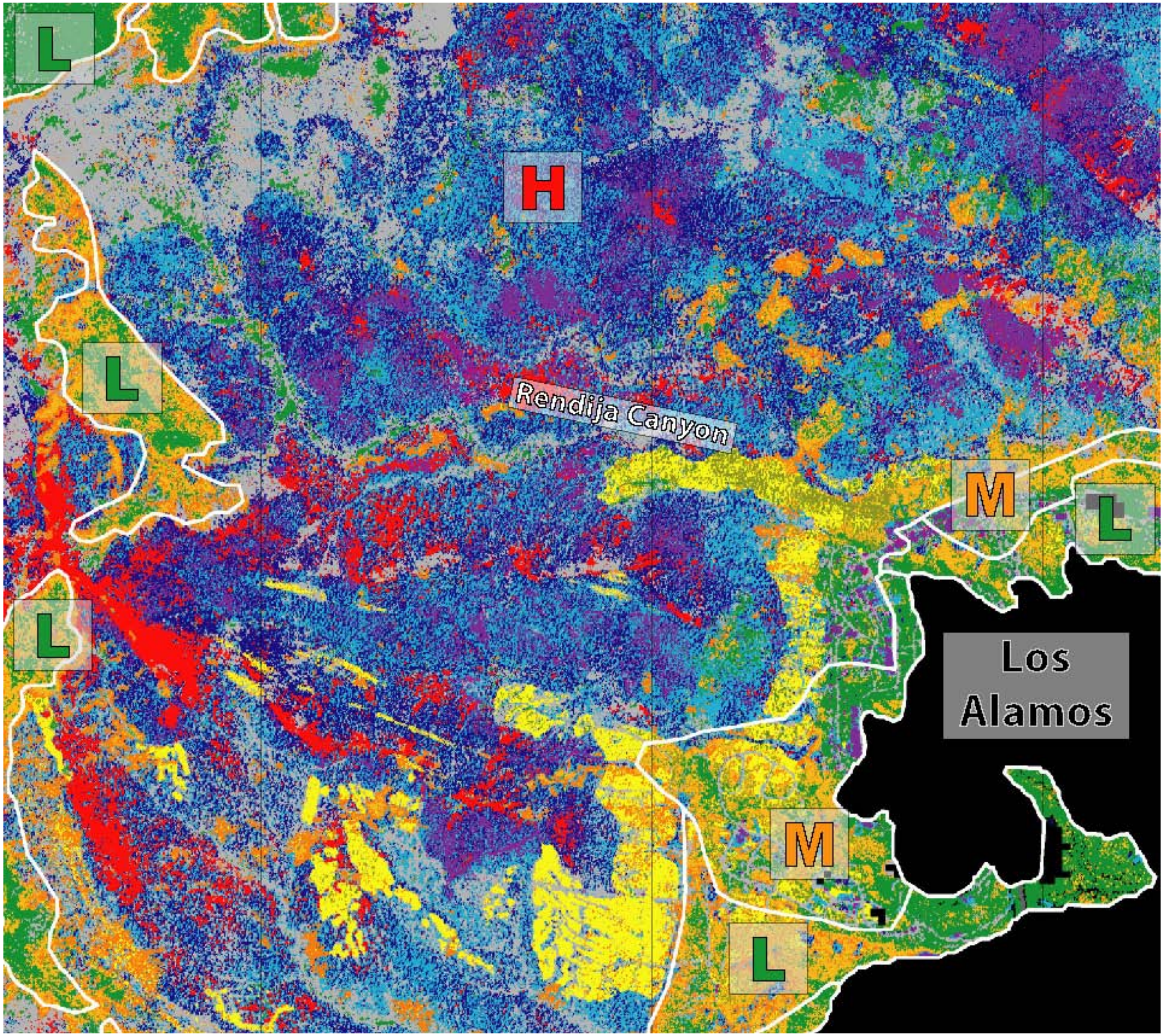
AVIRIS Maps of Wildfire Disturbance: Burned and Unburned Land Cover within Burn Scar Area



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

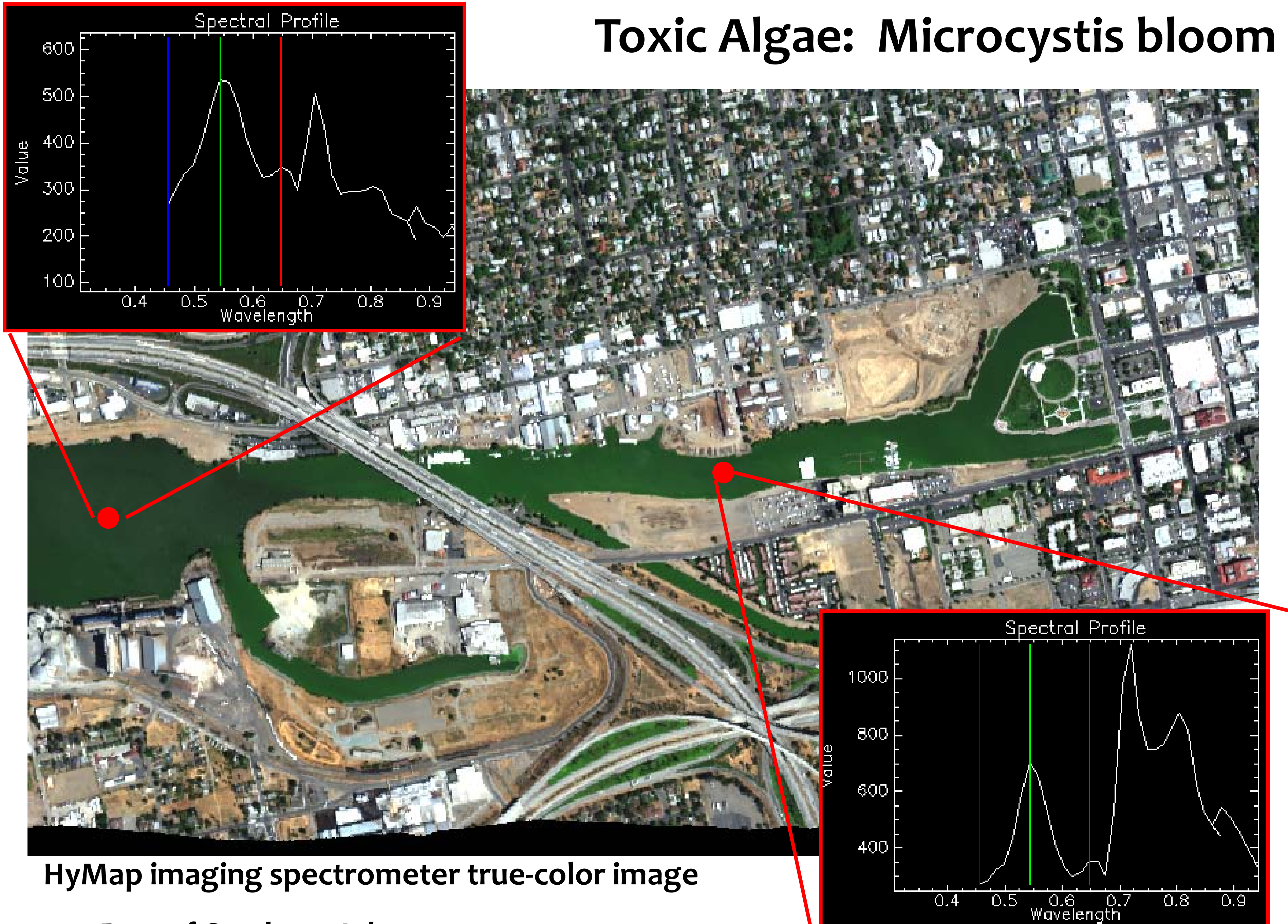
Kokaly et al., Remote Sensing of Environment, 2007

Recovery and Revegetation Depend on Survival Patterns



Kokaly et al., Remote Sensing of Environment, 2007

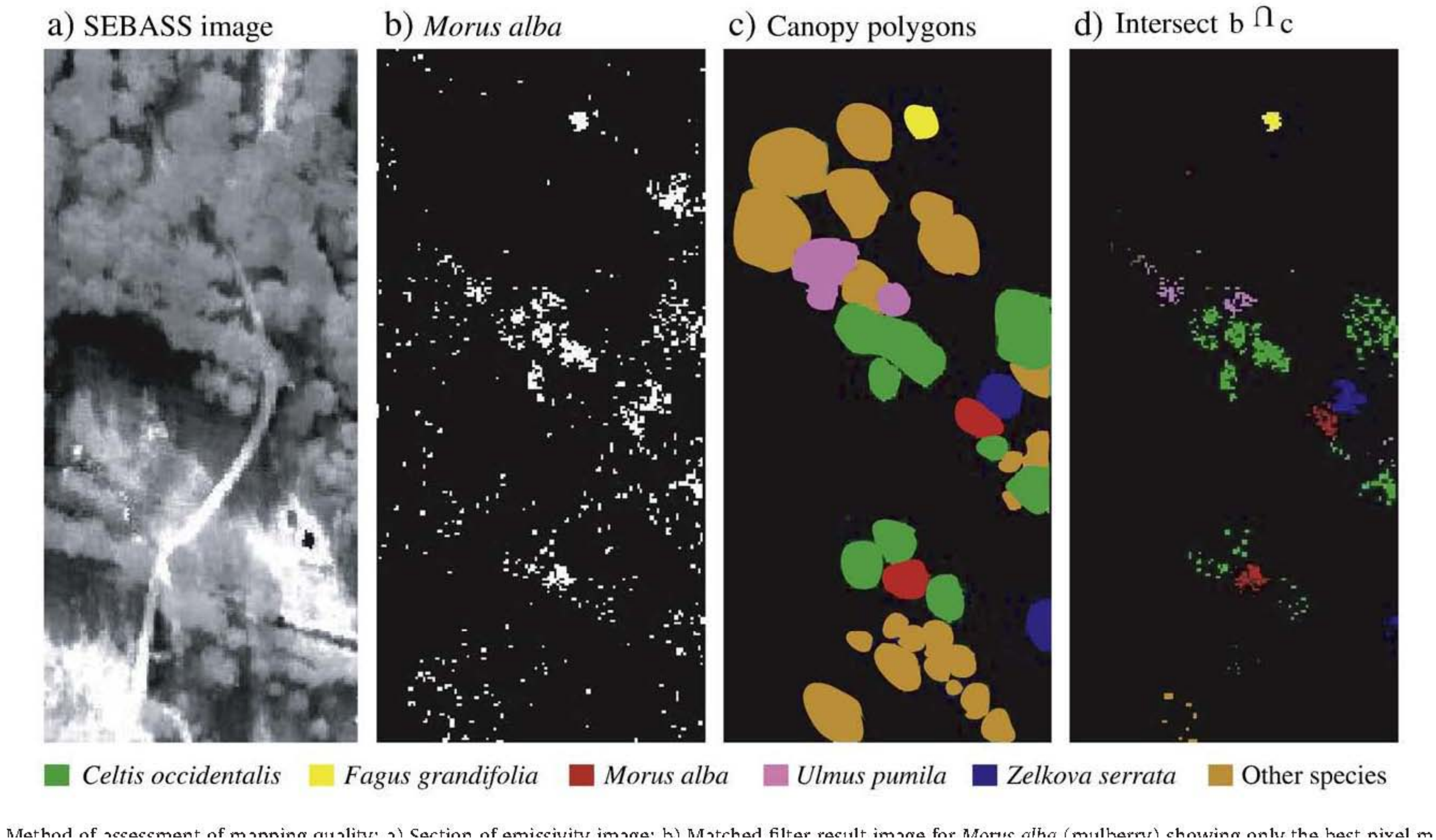
Toxic Algae: Microcystis bloom



HyMap imaging spectrometer true-color image

Port of Stockton July 2, 2004

Vegetation Mapping is Improved using Multiband and Hyperspectral TIR Imagery



Identification of plant species by using high spatial and spectral resolution thermal infrared (8.0–13.5 μm) imagery
Beatriz Ribeiro da Luz , James K. Crowley, RSE 2010

Atmospheric Correction Algorithms for Remote Sensing of Land and Water Surfaces

Bo-Cai Gao[1]

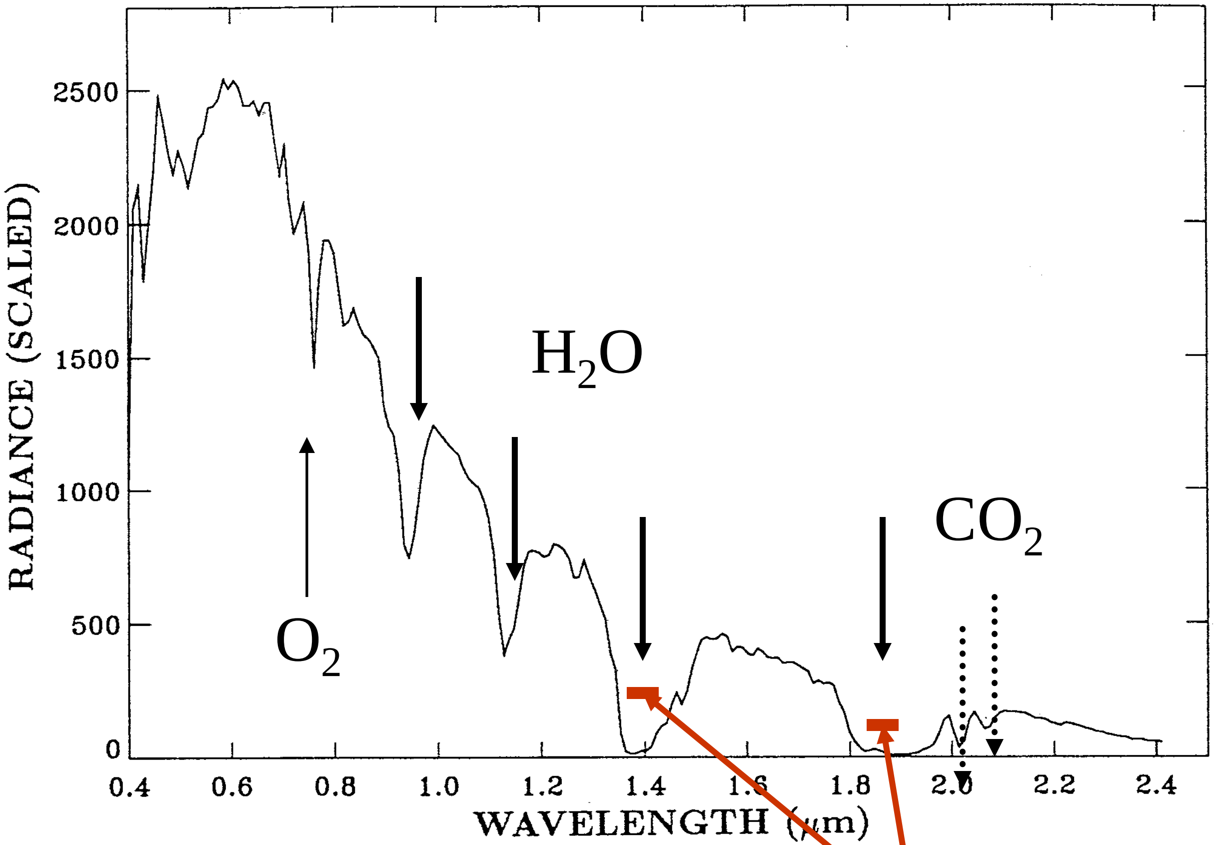
[1]Remote Sensing Division,
Naval Research Laboratory, Washington, DC USA

OUTLINE

- Atmospheric corrections over land
- Atmospheric corrections over water
- Discussions and summary

Atmospheric Correction Over Land

An AVIRIS Spectrum



The AVIRIS spectrum is affected by atmospheric absorption and scattering effects. In order to obtain the surface reflectance spectrum, the atmospheric effects need to be removed.

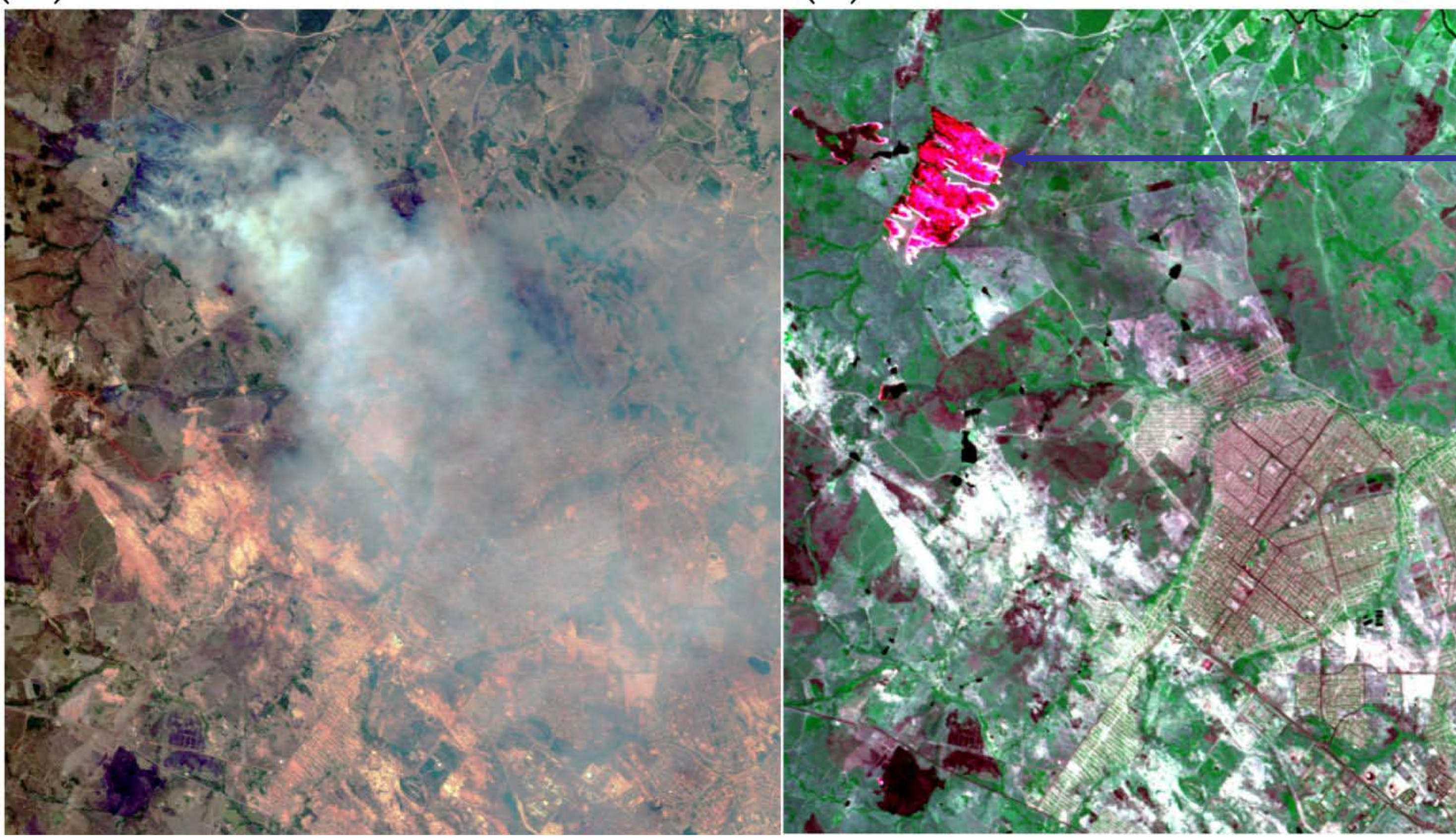
Strong water vapor bands are located near 1.38 and 1.88 micron. No signals are detected under clear sky conditions.

Aerosol Scattering Effects

True Color Image
(R: 0.66, G: 0.55, B: 0.47 μm)

False Color Image
(R: 2.13, G: 1.24, B: 1.64 μm)

(A) (B)



Smoke is seen in visible channel images, but disappears in the near-IR channel images. Smoke particle size is ~0.1 – 0.2 μm.

Equations For Atmospheric Correction Over Land

The measured radiance at the satellite level can be expressed as:

$$L_{obs} = L_a + L_{sun}\, t\, \rho \qquad (1)$$

L_a: path radiance;
ρ : surface reflectance;
L_{sun}: solar radiance above the atmosphere;
t: *2-way transmittance for the Sun-surface-sensor path*

Define the satellite apparent reflectance as

$$\rho^*_{obs} = \pi\, L_{obs} / (\mu_0\, E_0) \qquad (2)$$

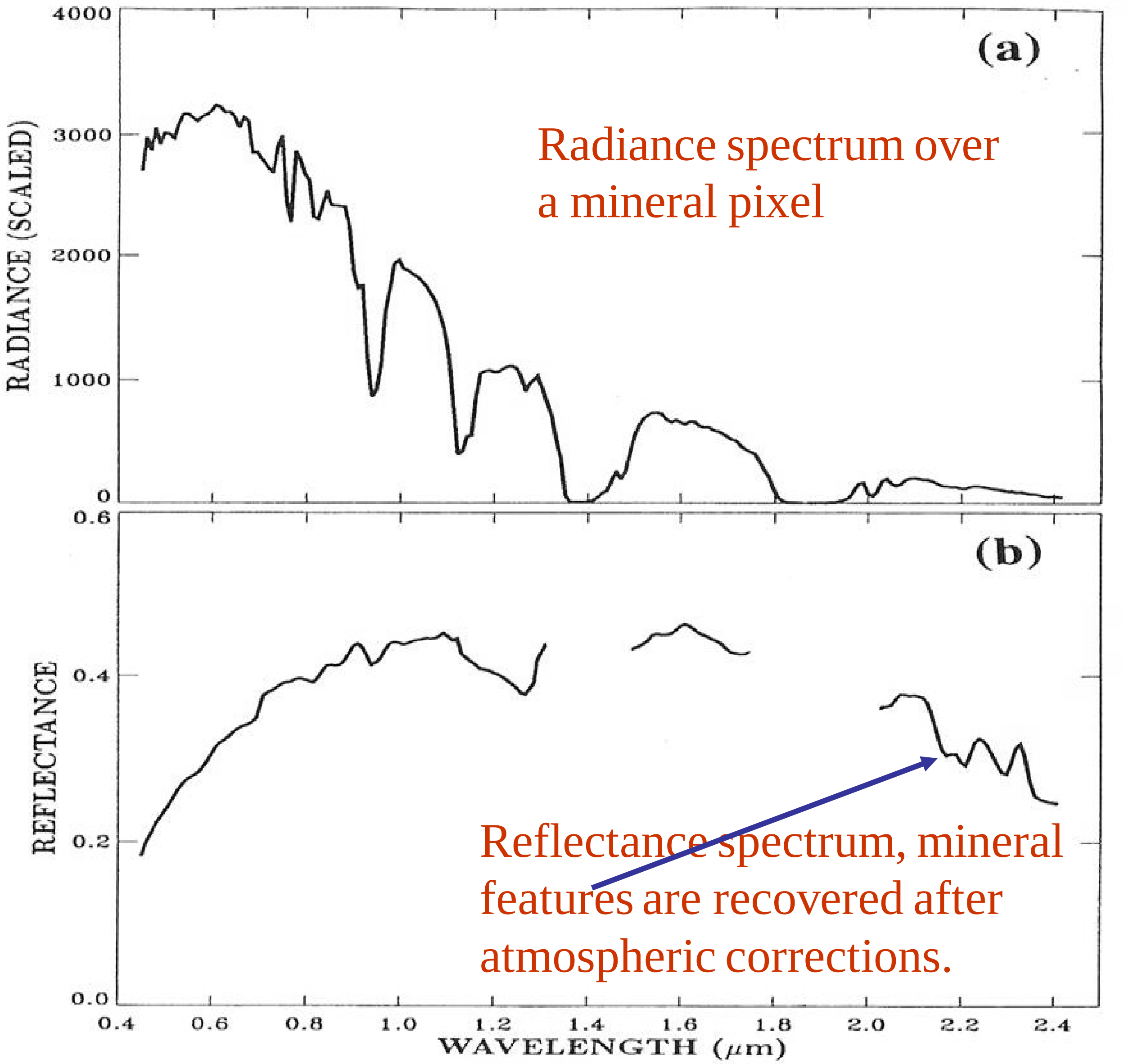
$$\rho^*_{obs} = T_g\, [\, \rho_a + t\, \rho / (1 - \rho\, s)\,] \qquad (3)$$

By inverting Eq. (3) for ρ, we get:

$$\rho = (\rho^*_{obs}/T_g - \rho^*_a) / [t + s\, (\rho^*_{obs}/T_g - \rho^*_a)\,] \qquad (4)$$

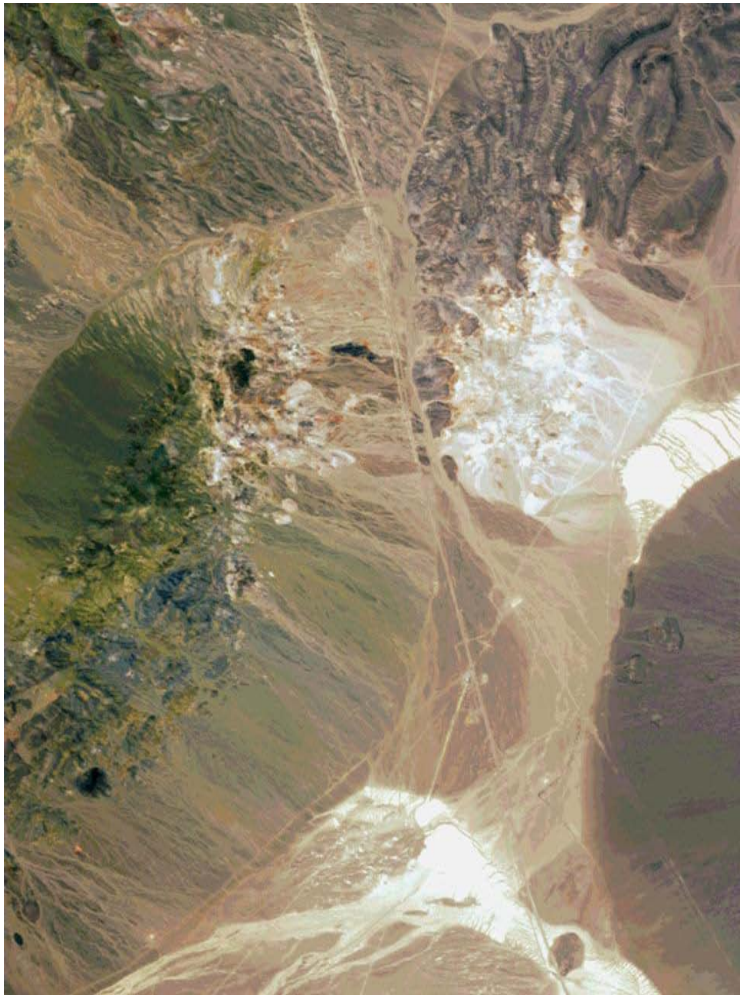
Gao, B.-C., K. H. Heidebrecht, and A. F. H. Goetz, Derivation of scaled surface reflectances from AVIRIS data, *Remote Sens. Env., 44*, 165-178, 1993.

SAMPLE REFLECTANCE RETRIEVALS OVER MINERAL

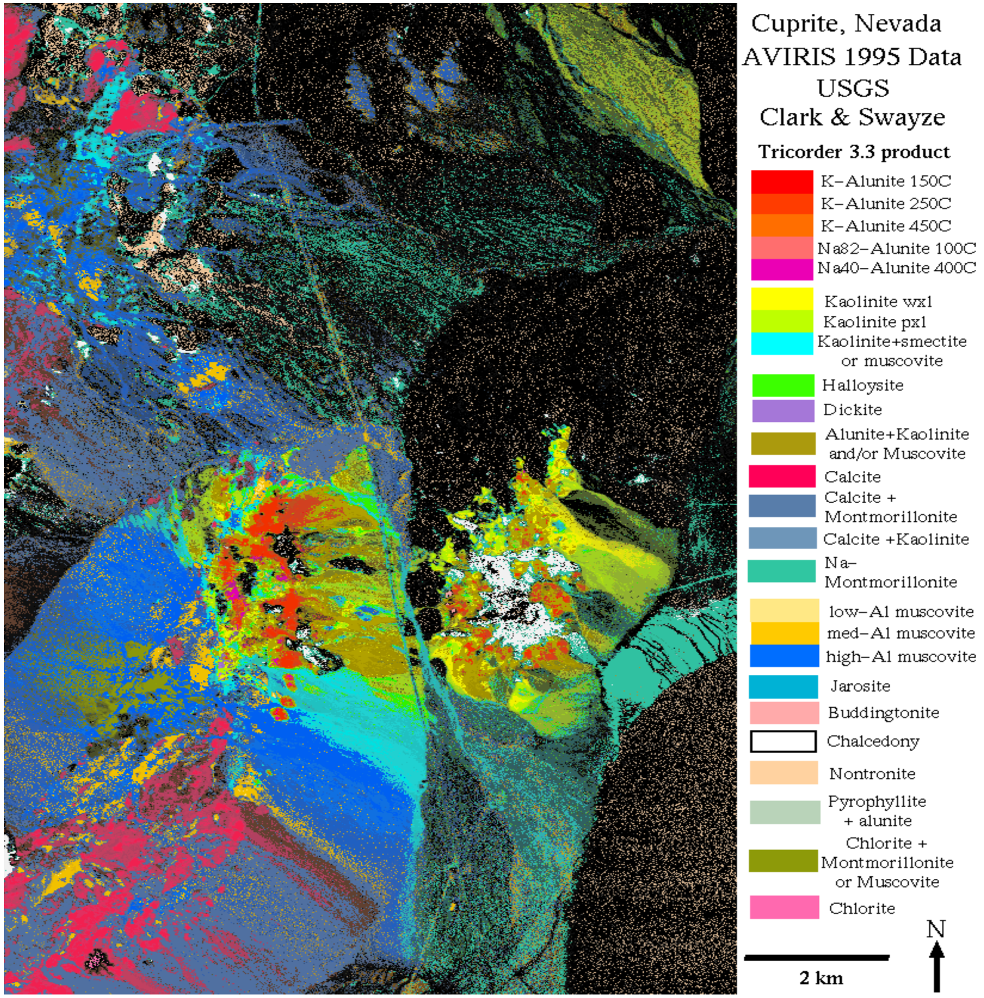


MINERAL MAPPING USING ATREM OUTPUT
by Scientists at USGS in Denver, Colorado

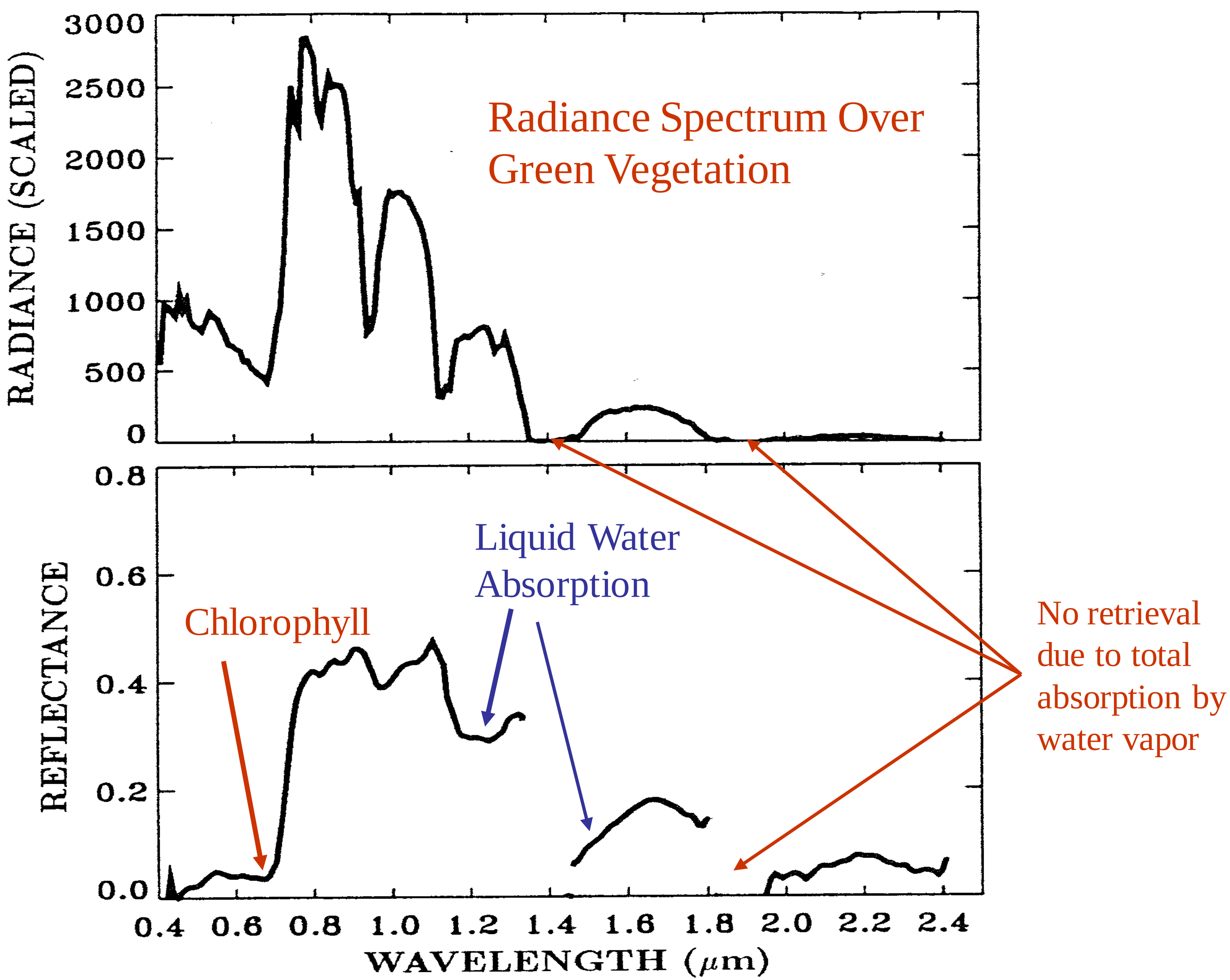
RGB Image (Cuprite, NV)



USGS Mineral Map, ~11x18 km

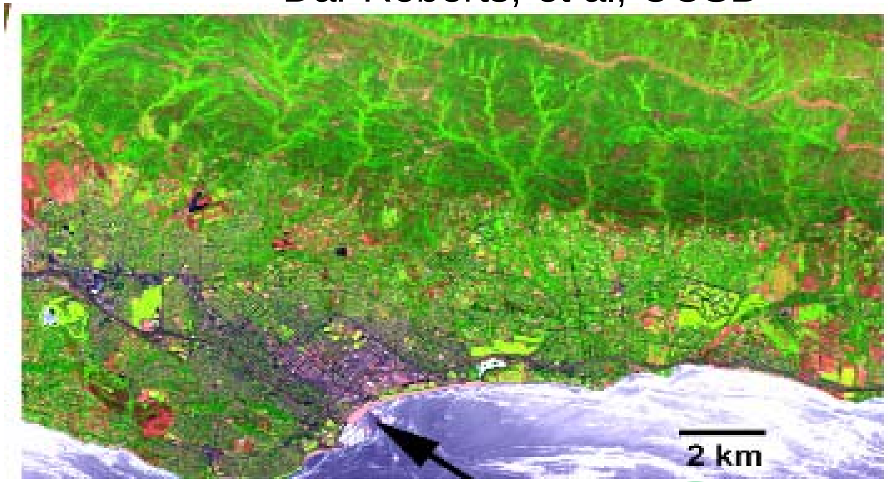


SAMPLE REFLECTANCE RETRIEVALS WITH ATREM

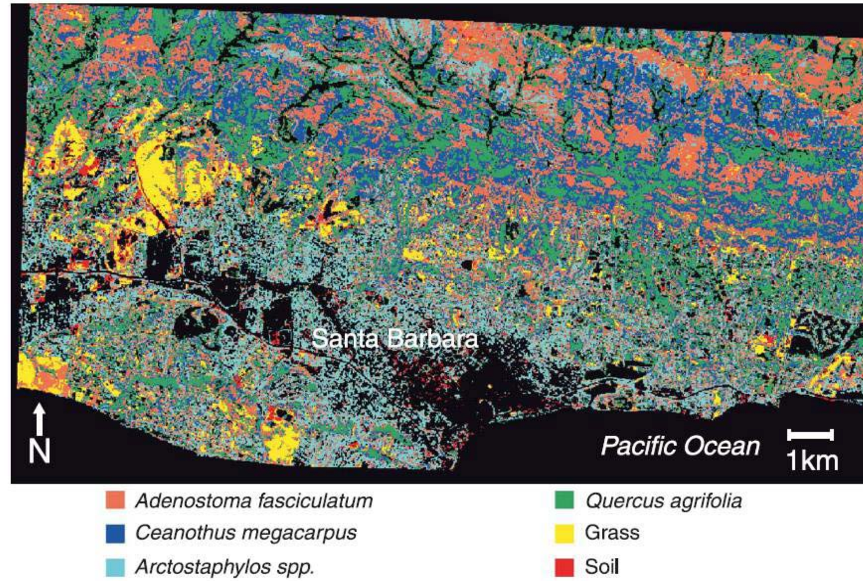


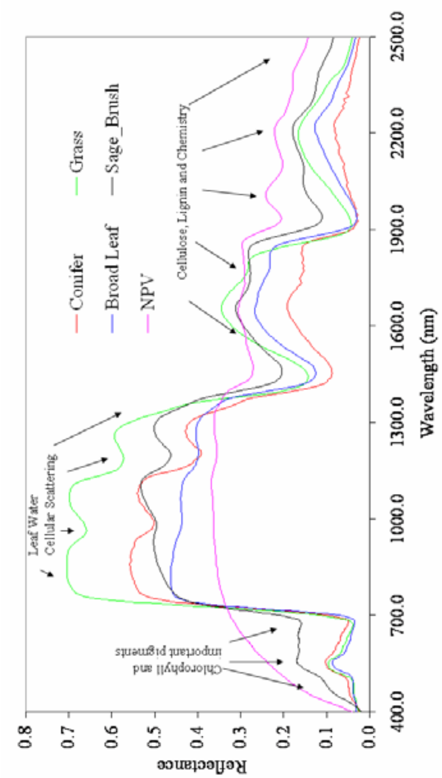
Vegetation Functional Type Analysis, Santa Barbara, CA

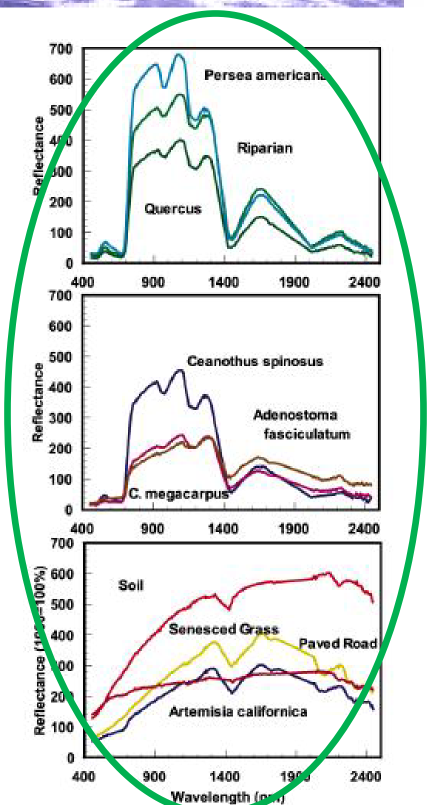
Dar Roberts, et al, UCSB



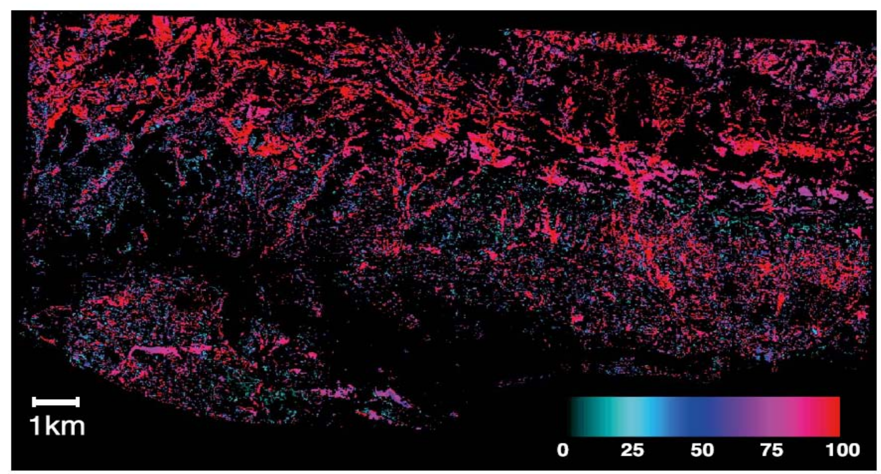
MESMA Species Type 90% accurate





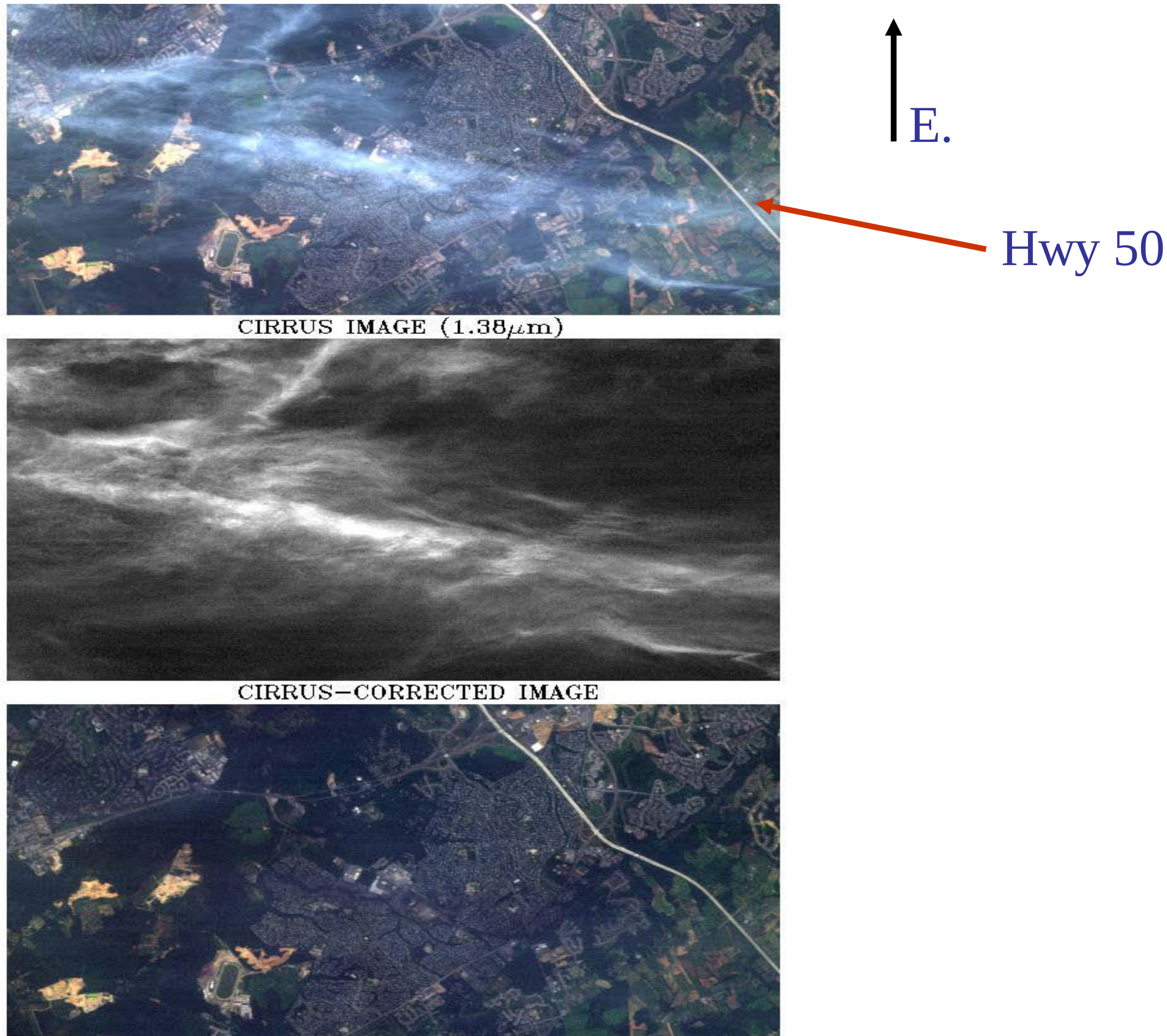


Species Fractional Cover

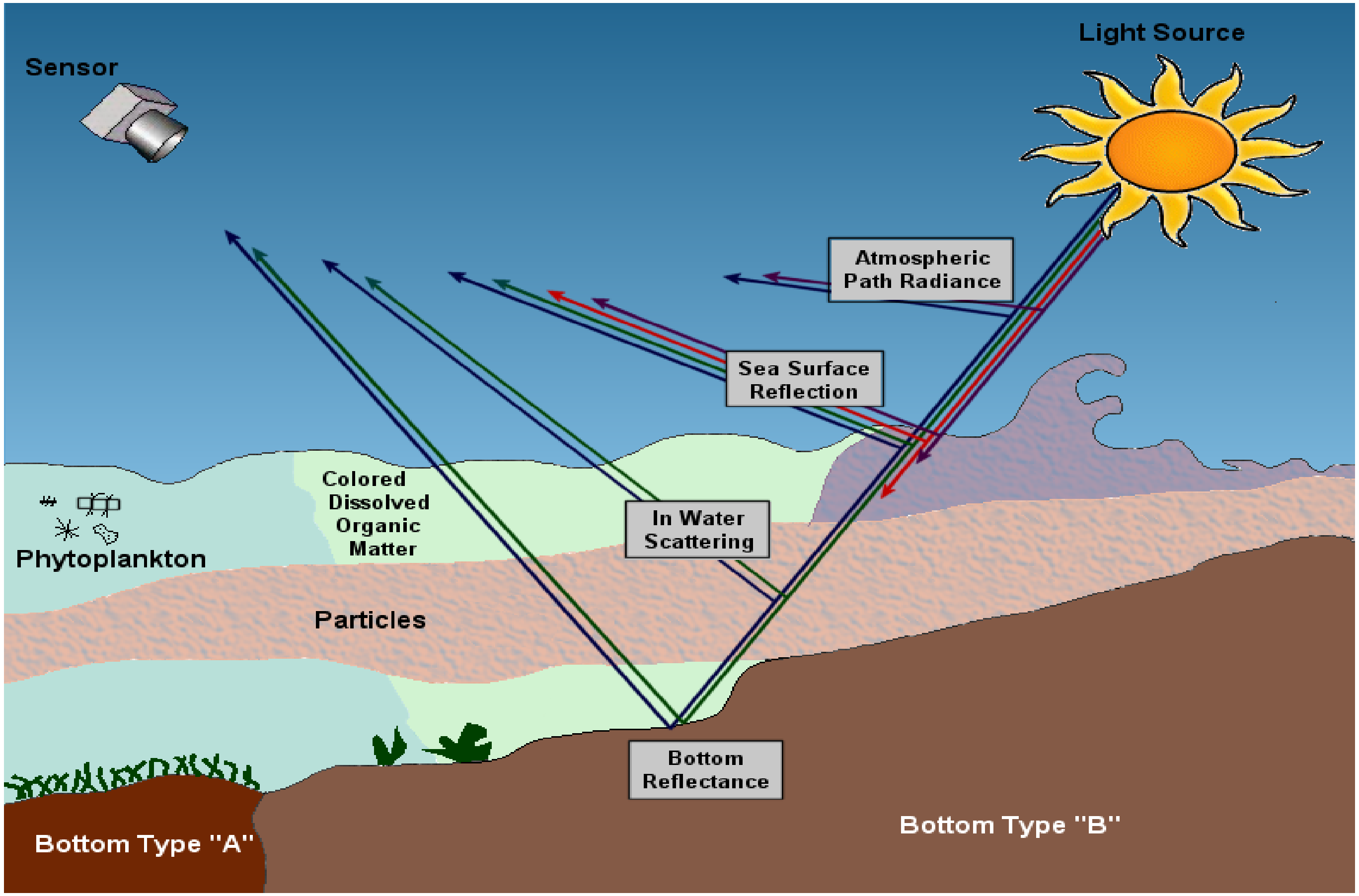


Examples of Cirrus Detection & Corrections

AVIRIS data acquired over Bowie, MD in summer 1997

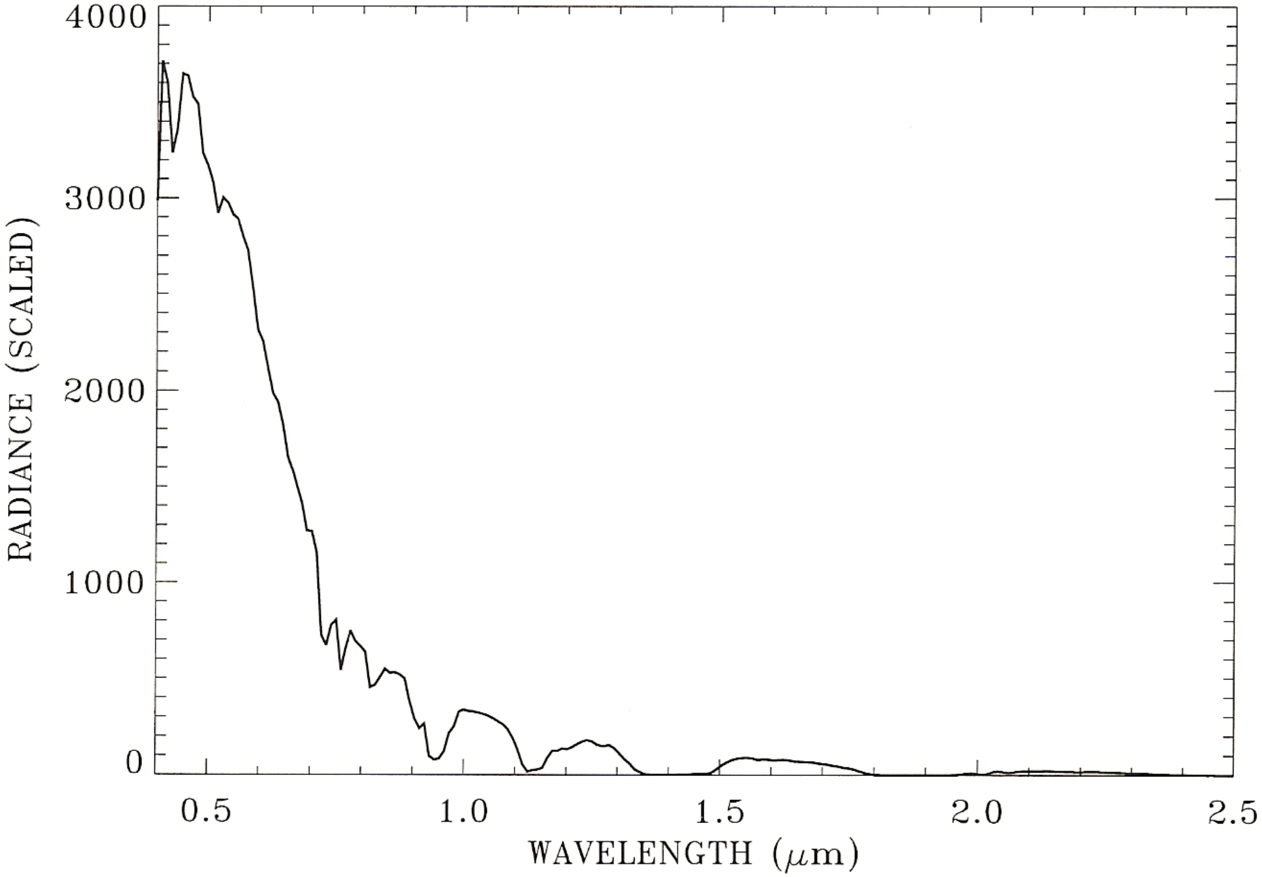


Atmospheric Correction Over Water



Over the dark water surfaces, ~90% of satellite radiances come from the atmosphere, and ~10% come from water. Very accurate atmospheric corrections are required in order to derive the useful water leaving reflectances. The specular reflection at the air/water interface introduces additional complications for modeling.

An AVIRIS Spectrum Over A Water Pixel



The radiances above one micron are very small.

Relevant Equations and Definitions

In the absence of gas absorption, the radiance at the satellite level is:

$$L_{obs} = L_0 + L_{sfc}\, t'_u + L_w\, t_u, \qquad (1)$$

L_0: path radiance; L_w: water leaving radiance;

L_{sfc}: radiance reflected at water surface; t_u: *upward transmittance*

Define $$L_{atm+sfc} = L_0 + L_{sfc}\, t'_u \qquad (2)$$

Eq. (1) becomes: $$L_{obs} = L_{atm+sfc} + L_w\, t_u \qquad (3)$$

Multiply Eq. (3) by π and divide by $(\mu_0 E_0)$, Eq. (3) becomes:

$$\pi L_{obs} / (\mu_0 E_0) = \pi L_{atm+sfc} / (\mu_0 E_0) + \pi L_w\, t_d\, t_u / (\mu_0 E_0\, t_d) \qquad (4)$$

Several reflectances are defined as:

Satellite apparent reflectance: $$\rho^*_{obs} = \pi L_{obs} / (\mu_0 E_0), \qquad (5)$$

$$\rho^*_{atm+sfc} = \pi L_{atm+sfc} / (\mu_0 E_0), \qquad (6)$$

Water leaving reflectance: $$\boldsymbol{\rho_w = \pi L_w / (\mu_0 E_0\, t_d) = \pi L_w / E_d} \qquad (7)$$

Remote sensing reflectance: $$\mathbf{R_{rs}} \boldsymbol{= \rho_w / \pi = L_w / E_d} \qquad (7')$$

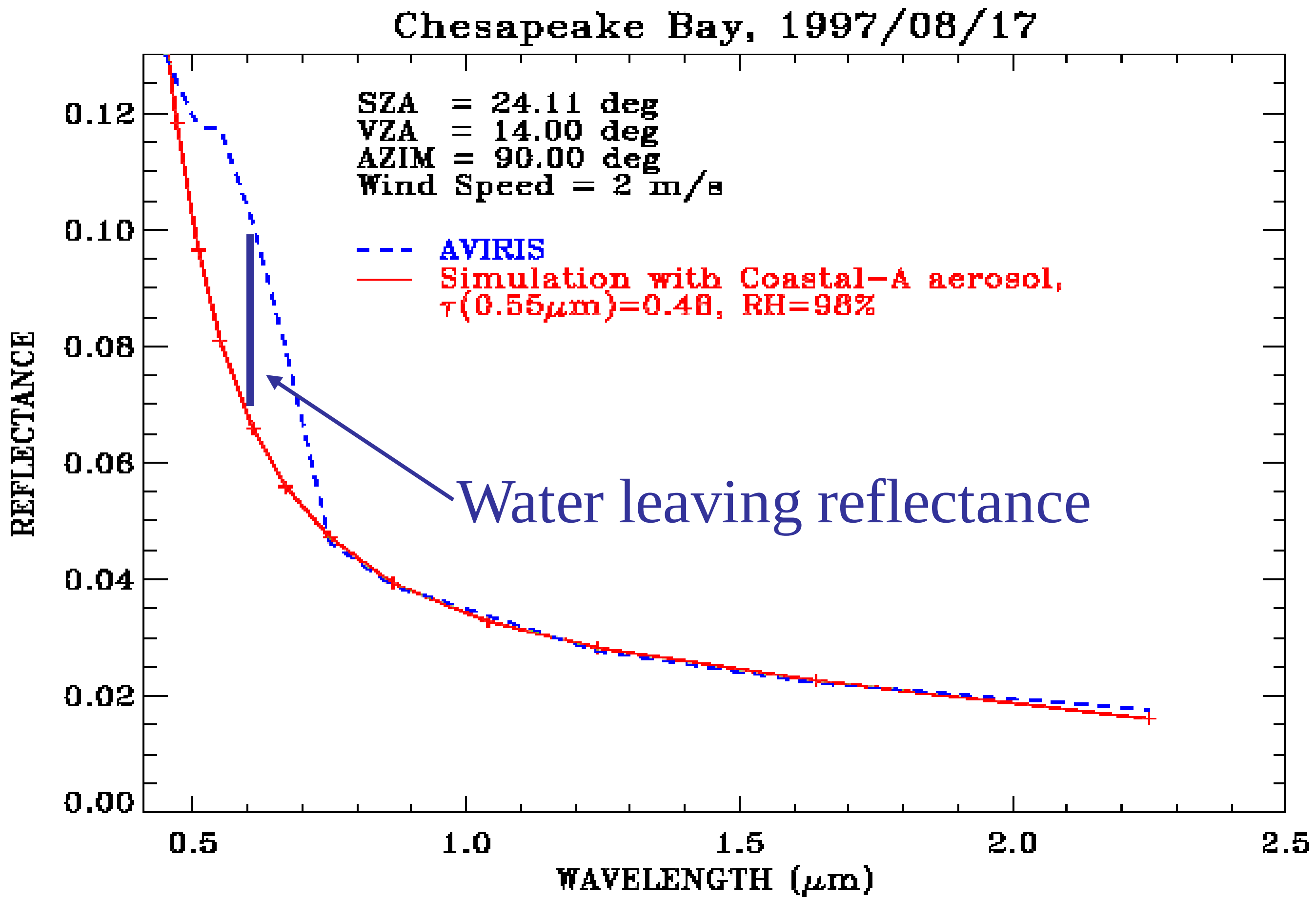
Substitute Eqs (5) – (7) into Eq. (4): $$\rho^*_{obs} = \rho^*_{atm+sfc} + \rho_w\, t_d\, t_u \qquad (8)$$

After consideration of gas absorption and multiple reflection between the atmosphere and surface and with further manipulation, we can get:

$$\rho_w = (\rho^*_{obs}/T_g - \rho^*_{atm+sfc}) / [t_d\, t_u + s\,(\rho^*_{obs}/T_g - \rho^*_{atm+sfc})] \qquad (11)$$

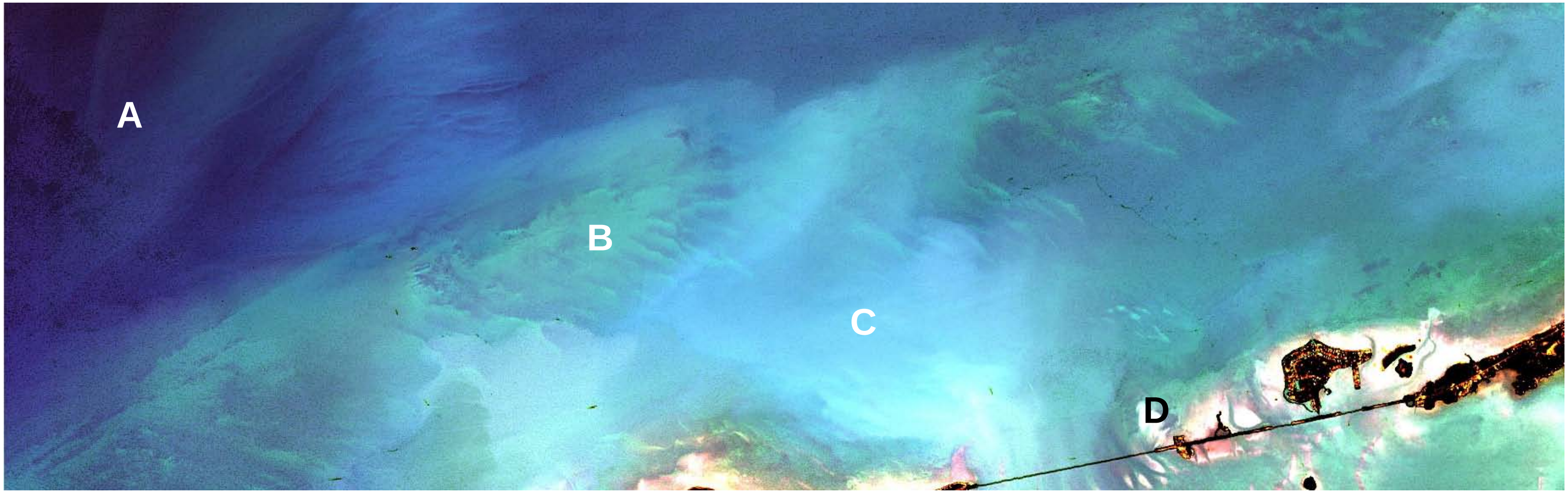
Gao, B.-C., M. J. Montes, Z. Ahmad, and C. O. Davis, Atmospheric correction algorithm for hyperspectral remote sensing of ocean color from space, Appl. Opt., 39, 887-896, February 2000.

Atmospheric Correction for Water Surfaces

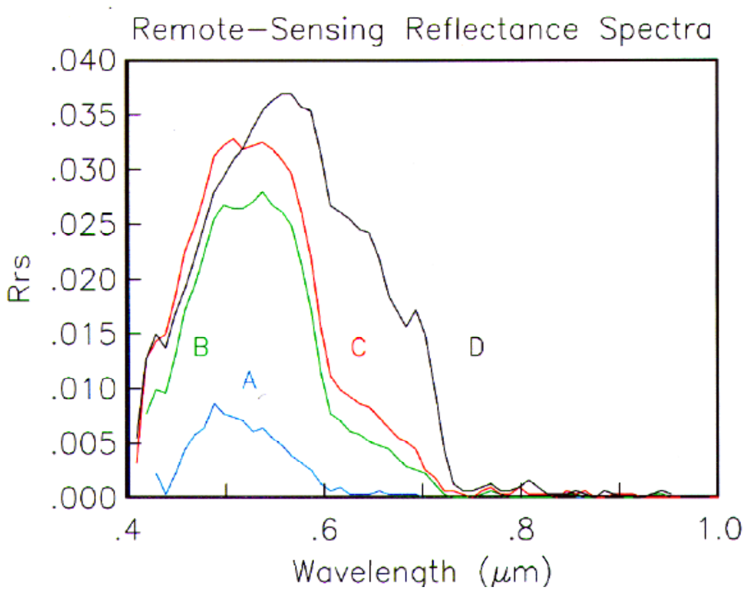


Channels at 0.86 and longer wavelengths are used to estimate atmospheric effects, and then extrapolate to the visible region. The differences between the two curves above are proportional to water leaving reflectances.

An Example of Ocean Atmospheric Correction Including Surface Glint Correction

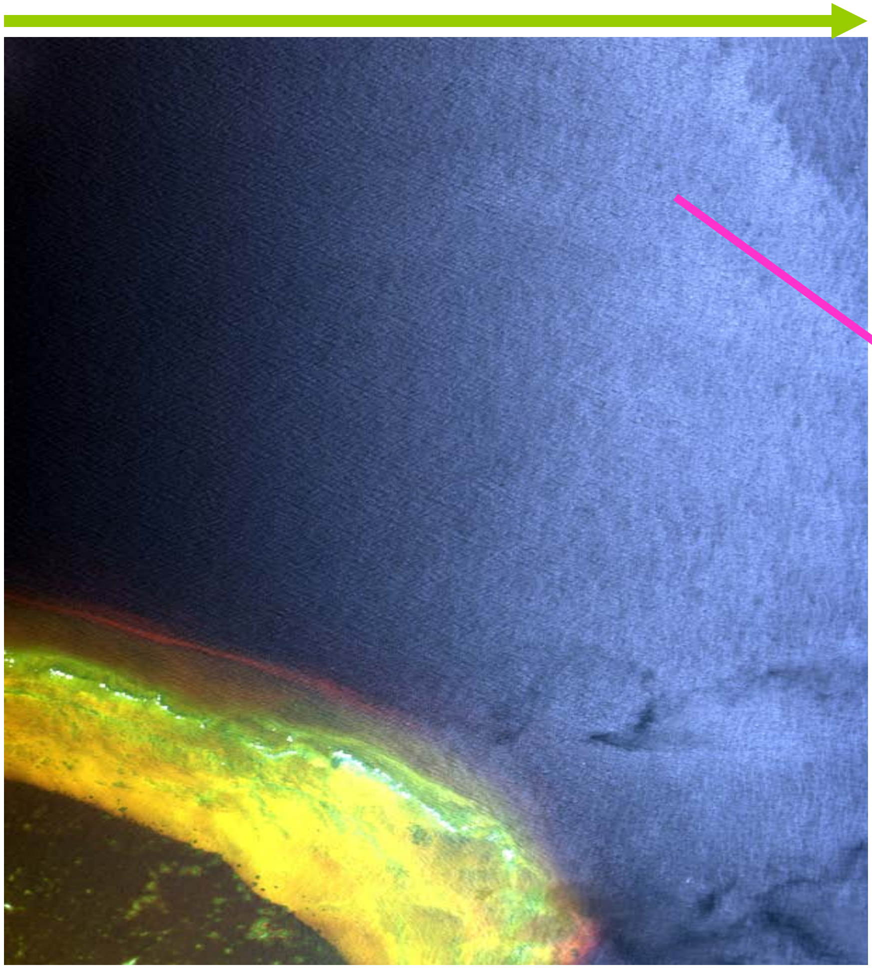


AVIRIS data were atmospherically corrected for ocean scenes. The data are corrected for skylight reflected off the sea surface. It is assumed that the water leaving radiance is 0 for wavelengths greater than 1.0 micron. Note how all of the spectra are 0 past 0.82 micron. (B.-C. Gao, M. J. Montes, Z. Ahmad, and C. O. Davis, *Appl. Opt.* 39, 887-896, 2000.)

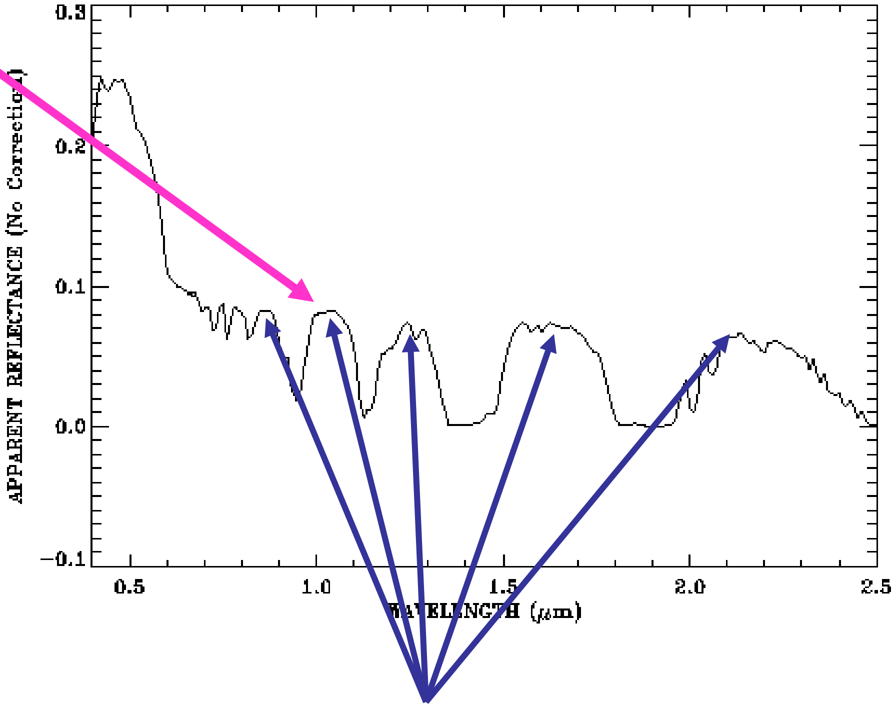


Sunglint Effect Removal With An Empirical Technique

Sunglint effect becomes stronger from left to right in an AVIRIS image. Individual wave facets are observed in the high spatial resolution AVIRIS image (20 m). It is not possible to use Cox & Munk model to predict sun glint effects in this case.



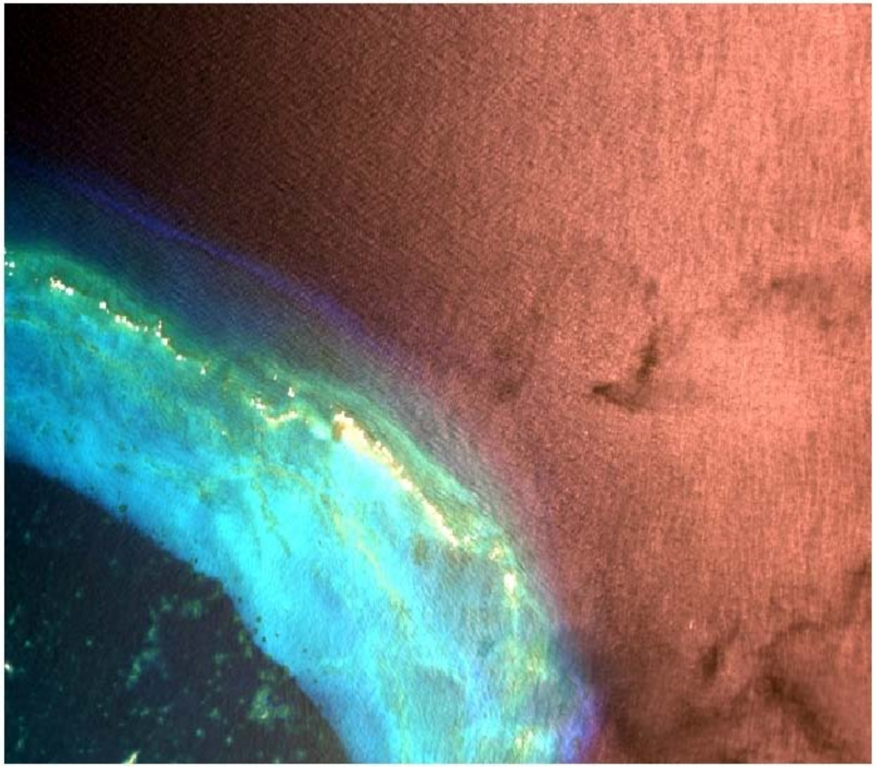
A sample sunglint apparent reflectance spectrum



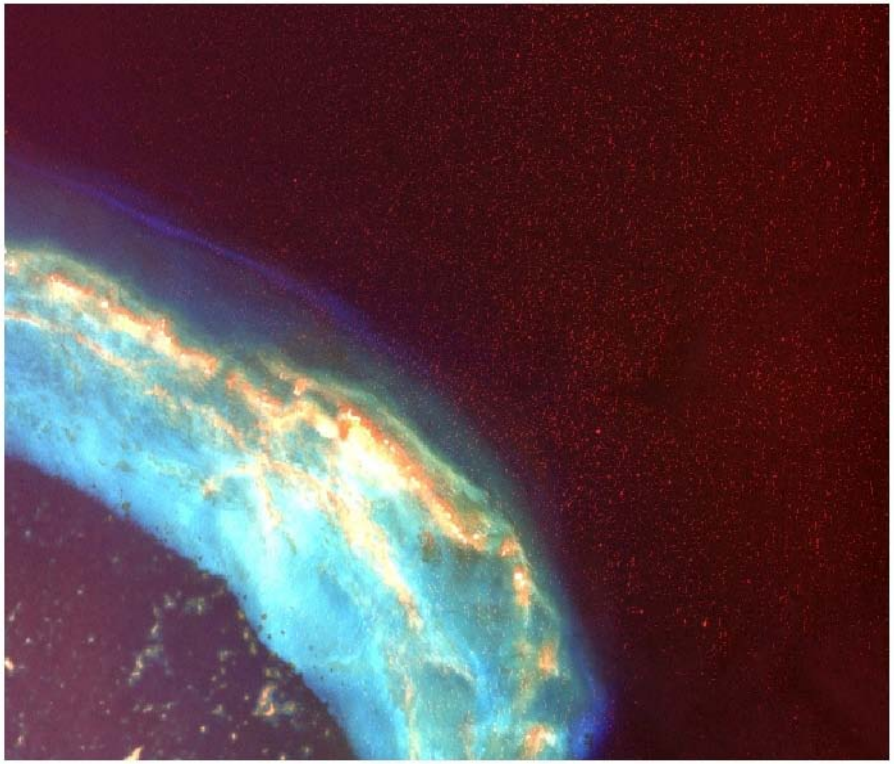
The sunglint reflectances for atmospheric window channels above 0.8 micron are almost constant. The empirical technique = ATREM (Land) reflectance minus 1.04 micron reflectance value on the pixel by pixel basis.

Images Before and After The Empirical Sunglint Correction

Before



After



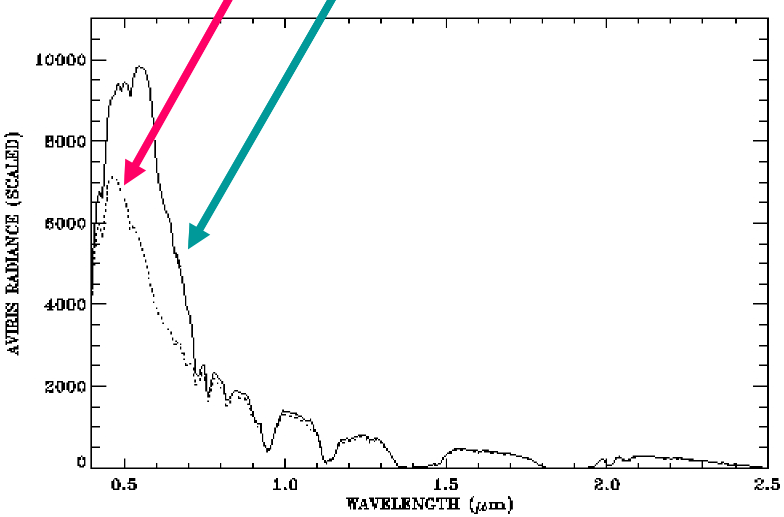
The image at right demonstrates that, after the empirical correction, the sunglint effects are mostly removed. The “contiguous” spatial features in the middle bottom portions of the image are seen much better. However, minor noise effects are seen in areas without bottom reflection.

Second Case of Glint Removal Using AVIRIS Data Over Kaneohe Bay, HI

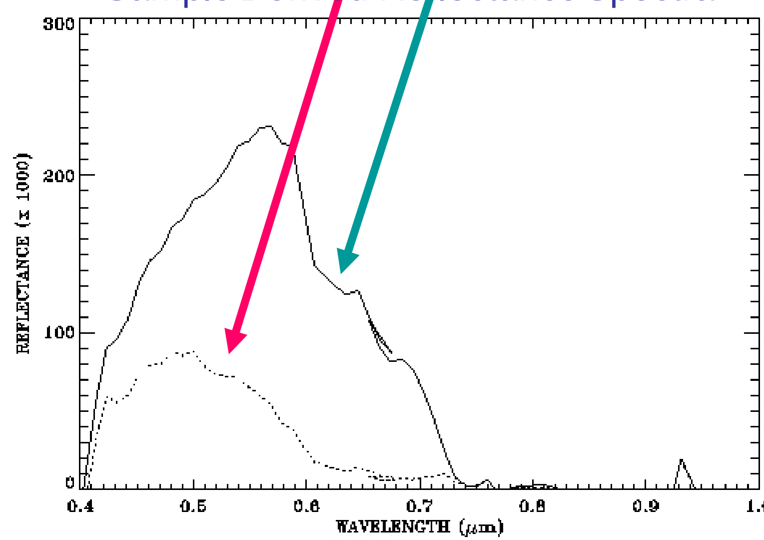
Before

After

Sample Radiance Spectra



Sample Derived Reflectance Spectra



Earth Surface Images from HICO

Images are about 43 km wide and 190 km long

Orientations are given below

Cape Town, South Africa, Oct. 3, 2009. Orientation is from NW at top to SE at bottom.

Lower Chesapeake Bay, Oct. 7, 2009. Orientation is from NW at top to SE at bottom.

Coast of South China Sea, near Hong Kong, China, Oct. 2, 2009. Orientation is from SW at bottom to NE at top.

Part of the Grand Canyon, Sept. 27, 2009. The center of the image is at 35° 50' N, 111° 23' W and the orientation is from SW at bottom to NE at top.

Florida Keys, over Key Largo, Sept. 27, 2009. Orientation is from SW at bottom to NE at top.

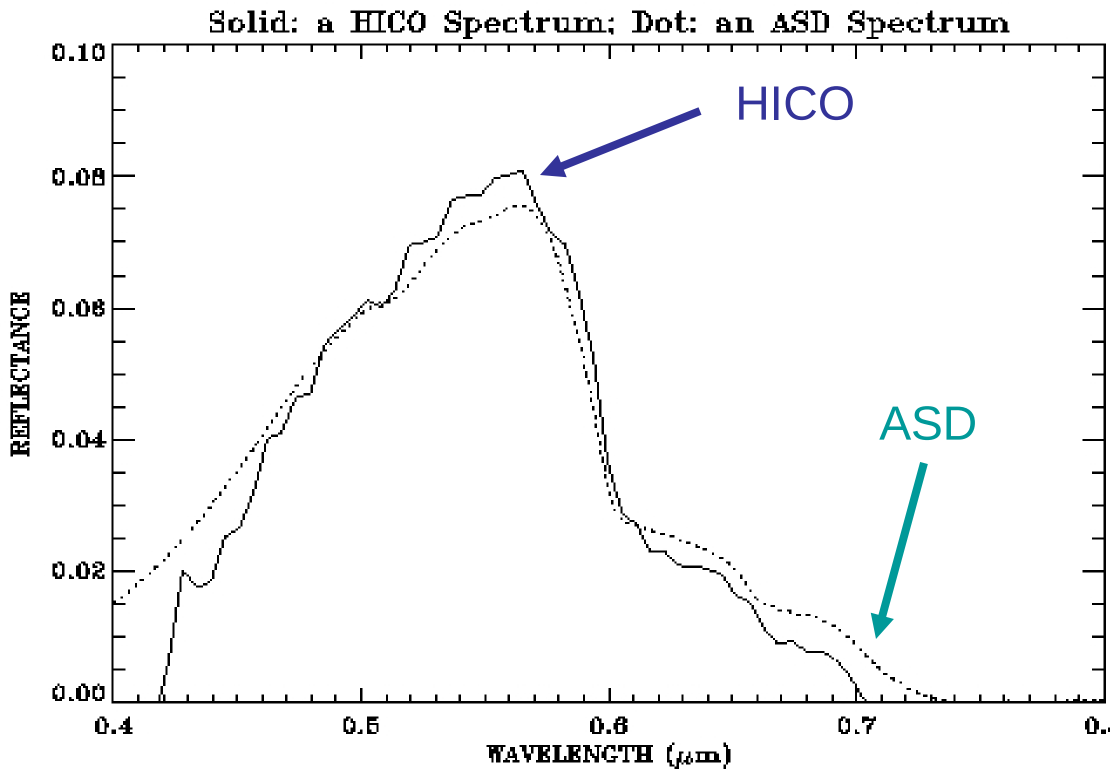
Sahara Desert over Egypt, Sept. 27, 2009. Orientation is from SW at bottom to NE at top.

Taken over the Bahamas, Oct. 2, 2009. Orientation is from NW at top to SE at bottom.

Gem of the Pacific. Midway Island, Sept. 27, 2009. Orientation is from NW at top to SE at bottom.

HICO RGB Image & Sample Spectra of Florida Keys

Examples of an ASD Spectrum and a Water Leaving Reflectance Spectrum Retrieved From HICO Data Over Florida Keys



Please note that the shapes of the two spectra in the 0.45 – 0.8 micron wavelength Interval are very similar. The two spectra are not measured over the same time, nor over the same spatial location.

Summary

- At present, both the land and ocean version of the algorithms work well under typical atmospheric conditions.

- In the presence of absorbing aerosols, the model tends to overestimate the atmospheric contribution to the upwelling radiance, resulting in inferred surface reflectances which are biased low in the blue region of the spectrum.

- Upgrades to the atmospheric correction algorithms are planned, particularly in view of major advances in aerosol models. Specific upgrades include:
    - Incorporation of absorbing aerosol models
    - Incorporation of UV channels (380 nm, 400 nm)

- An algorithm theoretical basis document for HyspIRI Level 2 at surface reflectance (land) and remote sensing reflectance (shallow water) is under development.

HypsIRI On-Board Science Data Processing

HyspIRI Symposium
May 4, 2010

Tom Flatley – Branch Head
NASA/GSFC Science Data Processing Branch

On-Board Science Data Processing

HypsIRI On-Board Processing

- Data Volume Reduction
- Compression
- Calibration / Correction
- Classification
- Product Generation
- Autonomy
- Event / Feature Detection
- Real-time / Direct Broadcast

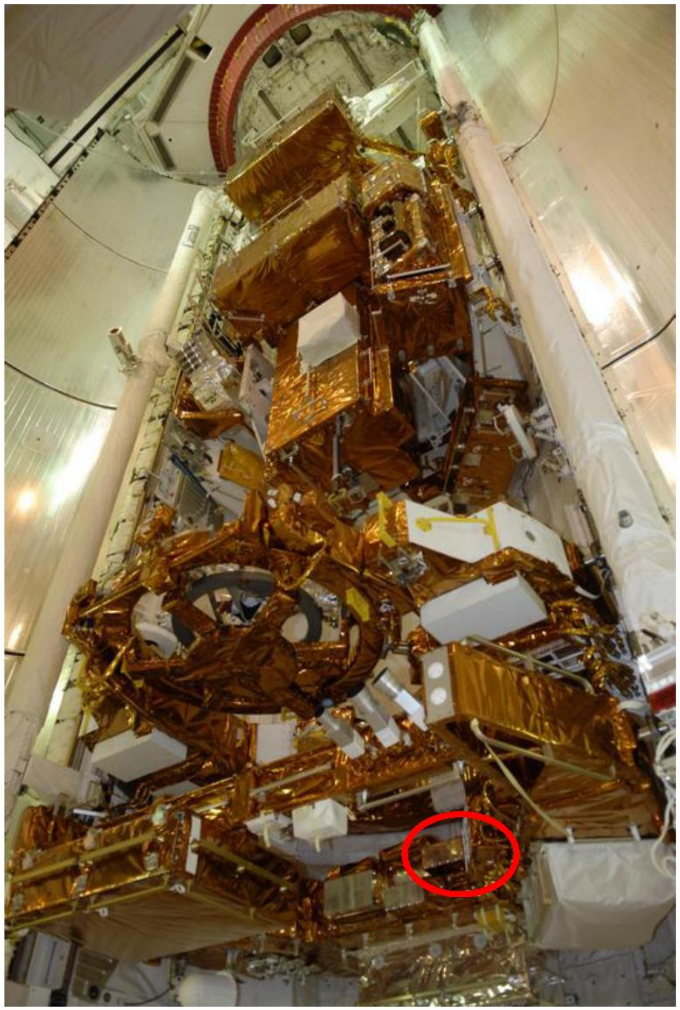
Hybrid Science Data Processing

- CPU
- FPGA
- DSP

GSFC SpaceCube On-Board Processor

- 10x-100x computing performance
- Lower power (MIPS/watt)
- Lower cost (commercial parts)
- Radiation tolerant (not hardened)
- Software upset mitigation

On-Board Image Processing

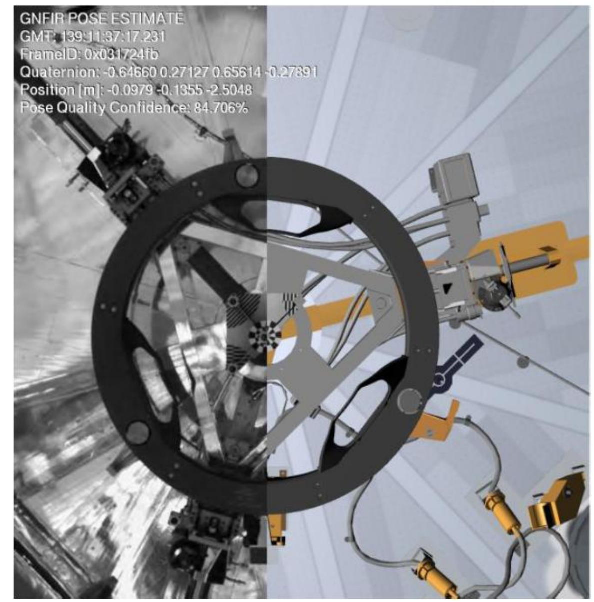


STS-125 Payload Bay

Long Range Camera on Rendezvous

Flight Image RNS Tracking Solution

Short Range Camera on Deploy



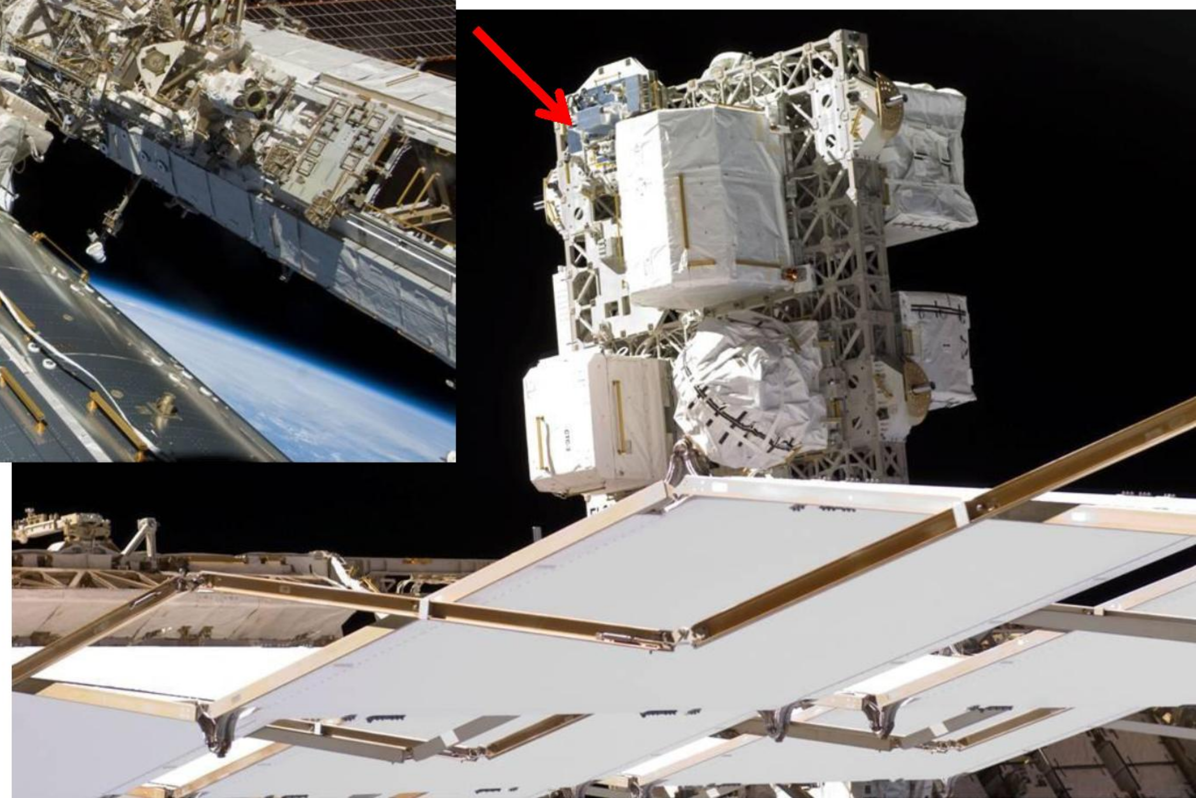
Flight Image RNS Tracking Solution

GSFC SpaceCube 1.0a - Hubble SM 4 (May 2009):

- Autonomous Rendezvous and Docking Experiment
- Hosted camera AGC and two Pose algorithms

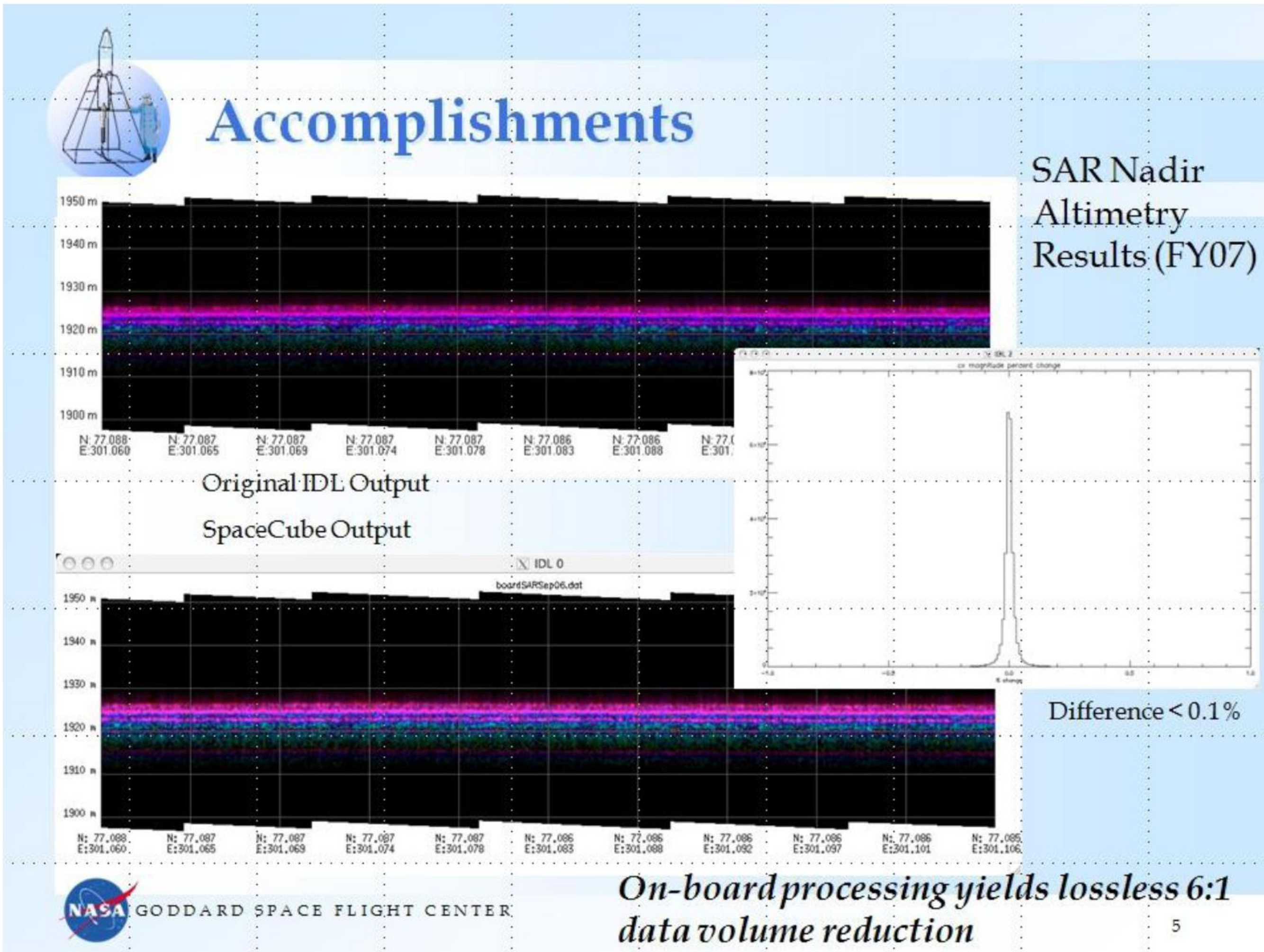
Software Upset Mitigation

GSFC SpaceCube 1.0b (Nov 2009):
- "Radiation Hardened by Software" Experiment
- Autonomous Landing Application
- Collaboration with NRL

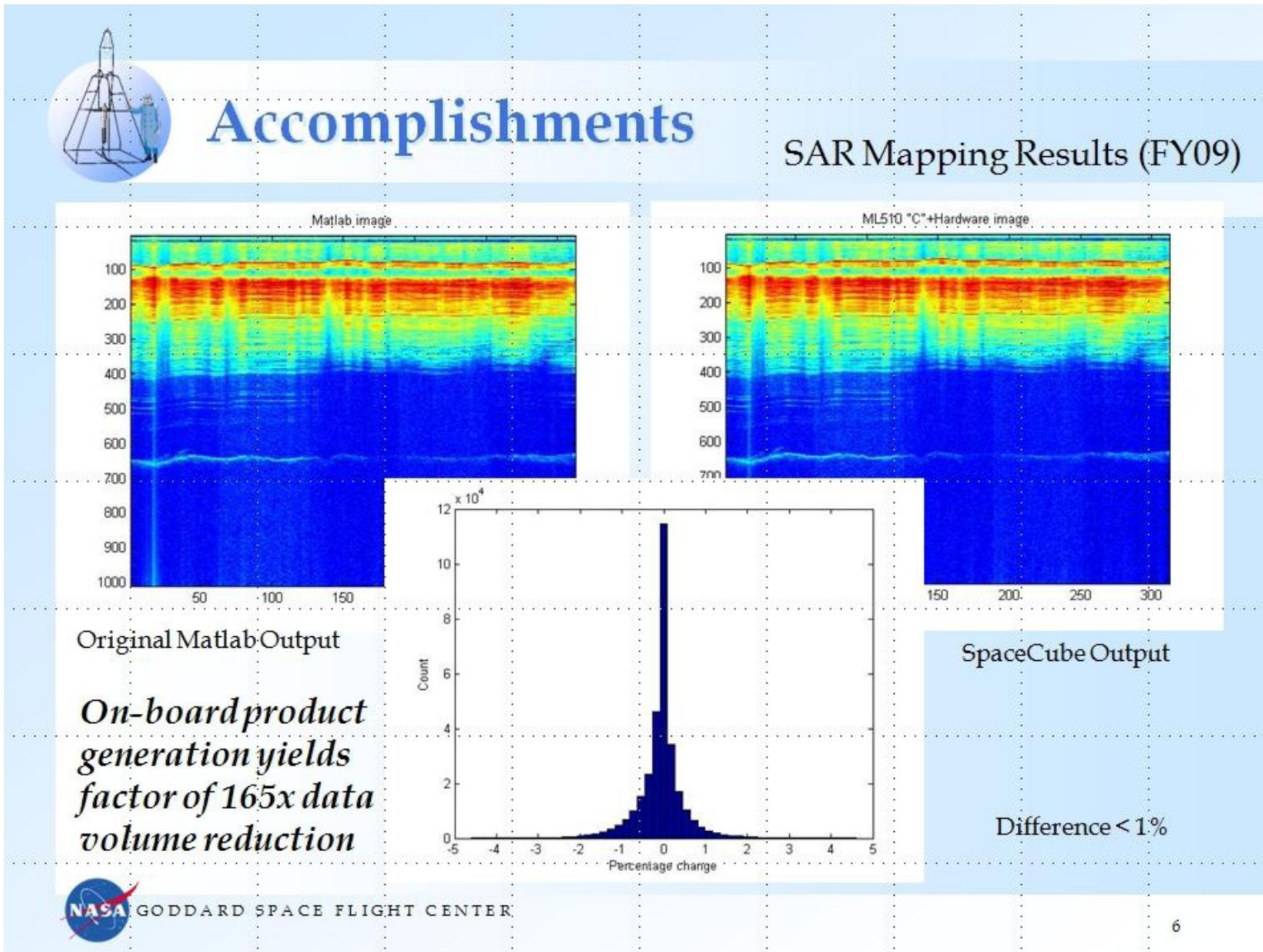


ISS Orbit	
Days Up	**157 days 2 hours**
Total SEUs	**56.00**
Avg SEUs/FPGA	**14.00**
Avg SEUs/FPGA/Day	**0.09**
Avg SEUs/FPGA/Week	**0.62**
Avg SEUs/FPGA/Year	**32.55**

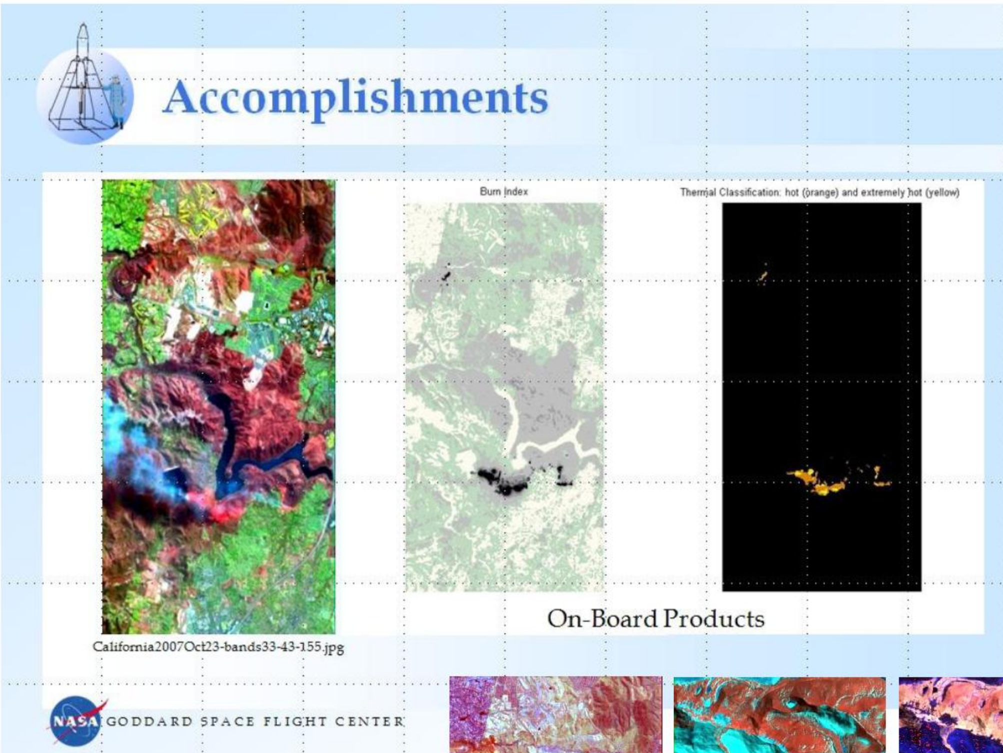
On-Board Data Reduction

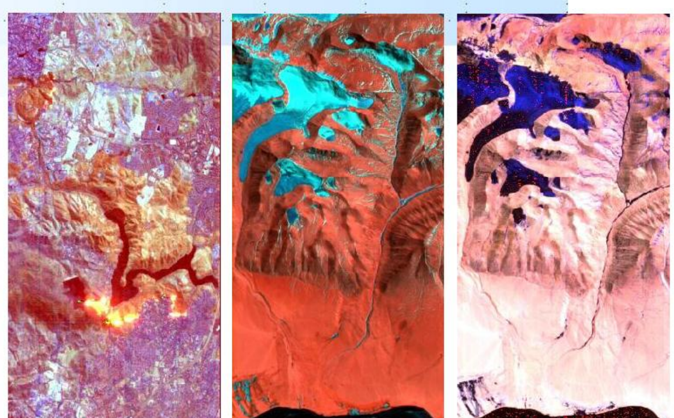


On-Board Data Reduction

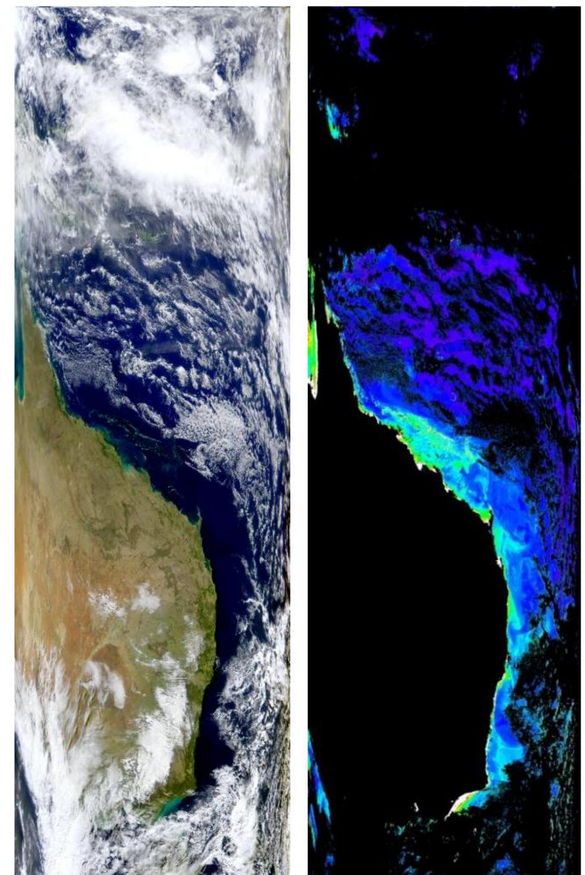


On-Board “VSWIR” Products



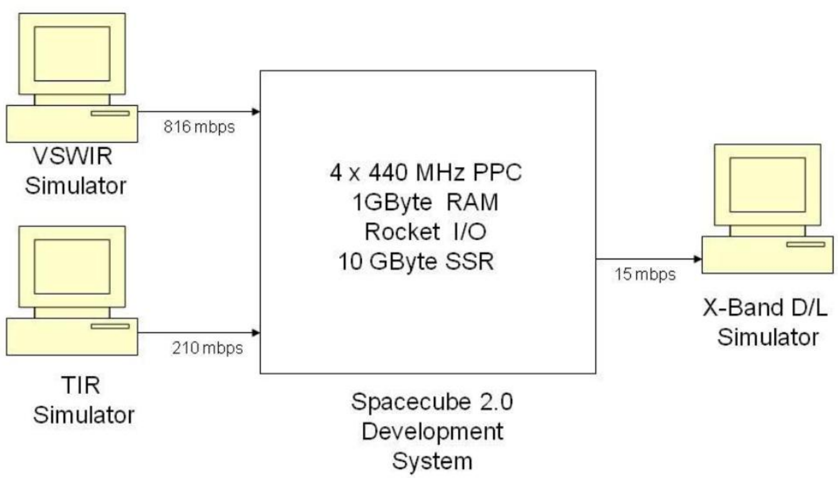


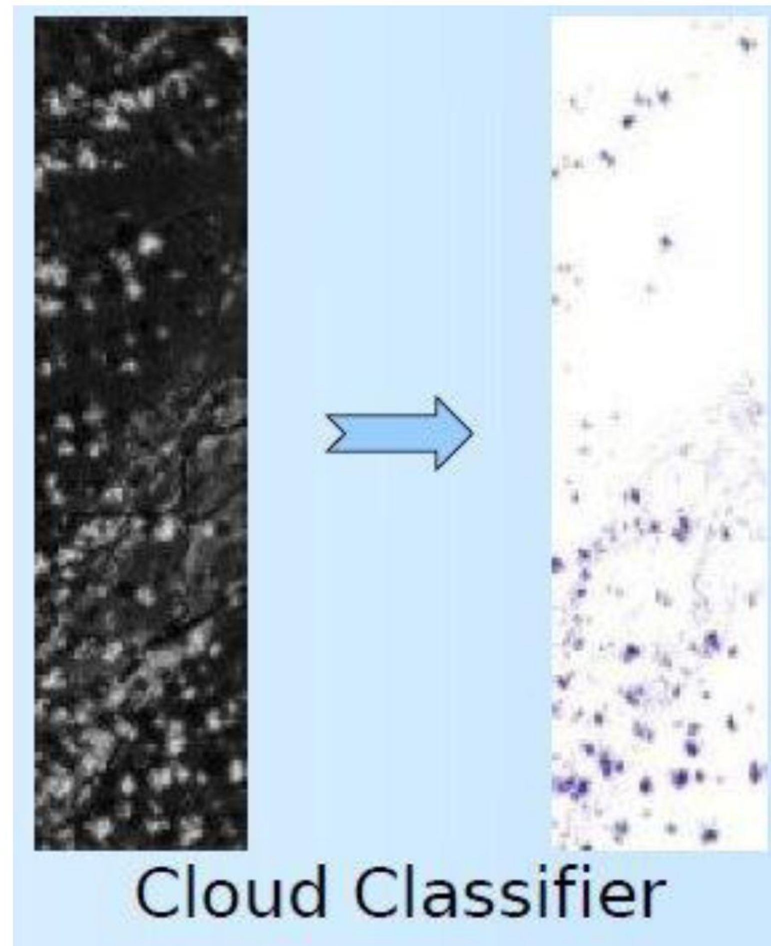
- Classification
- Product Generation
- Event Detection



HyspIRI Demonstration Testbed

HyspIRI SpaceCube IPM Testbed





Processor Comparison

	MIPS	Power	MIPS/ W
MIL-STD-1750A	3	15W	0.2
RAD6000	35	10-20W	2.33[1]
RAD750	300	10-20W	20[2]
SPARC V8	86	1W[3]	86[3]
LEON 3FT	60	3-5W[3]	15[3]
GSFC SpaceCube 1.0	3000	5-15W	400[4]
GSFC SpaceCube 2.0	5000	10-20W	500[5]

Notes:

1 – typical, 35 MIPS at 15 watts

2 – typical, 300 MIPS at 15 watts

3 – processor device only ... total board power TBD

4 – 3000 MIPS at 7.5 watts (measured)

5 – 5000 MIPS at 10 watts (calculated)

HyspIRI Intelligent Payload Module(IPM) and Benchmarking Algorithms for Upload

Dan Mandl/GSFC

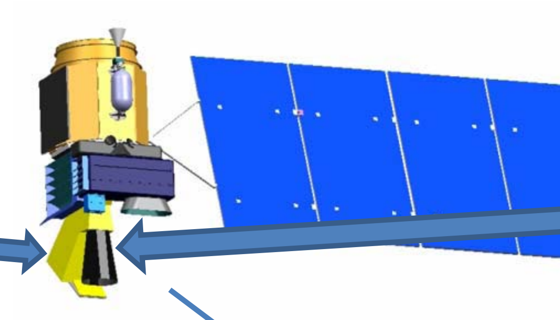
5-4-10

HyspIRI Science Symposium on

Ecosystem Data Products

HyspIRI Low Latency Data Production Concept

130.2 Mbps
Multispectral
Thermal InfraRed
(TIR) Scanner

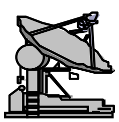


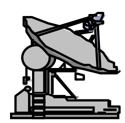
804 Mbps
Hyperspectral Visible
ShortWave InfraRed
(VSWIR) Imaging
Spectrometer

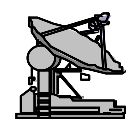
Spectral
Bands (8) 3.98 µm, 7.35 µm, 8.28 µm, 8.63 µm, 9.07 µm, 10.53 µm, 11.33 µm, 12.05
Spatial
IFOV 60 m
Range 600 km (25.3 at 626 km)

Direct
Broadcast

Spectral
Range 380 to 2500 nm
10 nm bands
Spatial
Range ~146 km
(13.2 deg. at 626km)
Cross-Track Samples >2560
Sampling 60 m



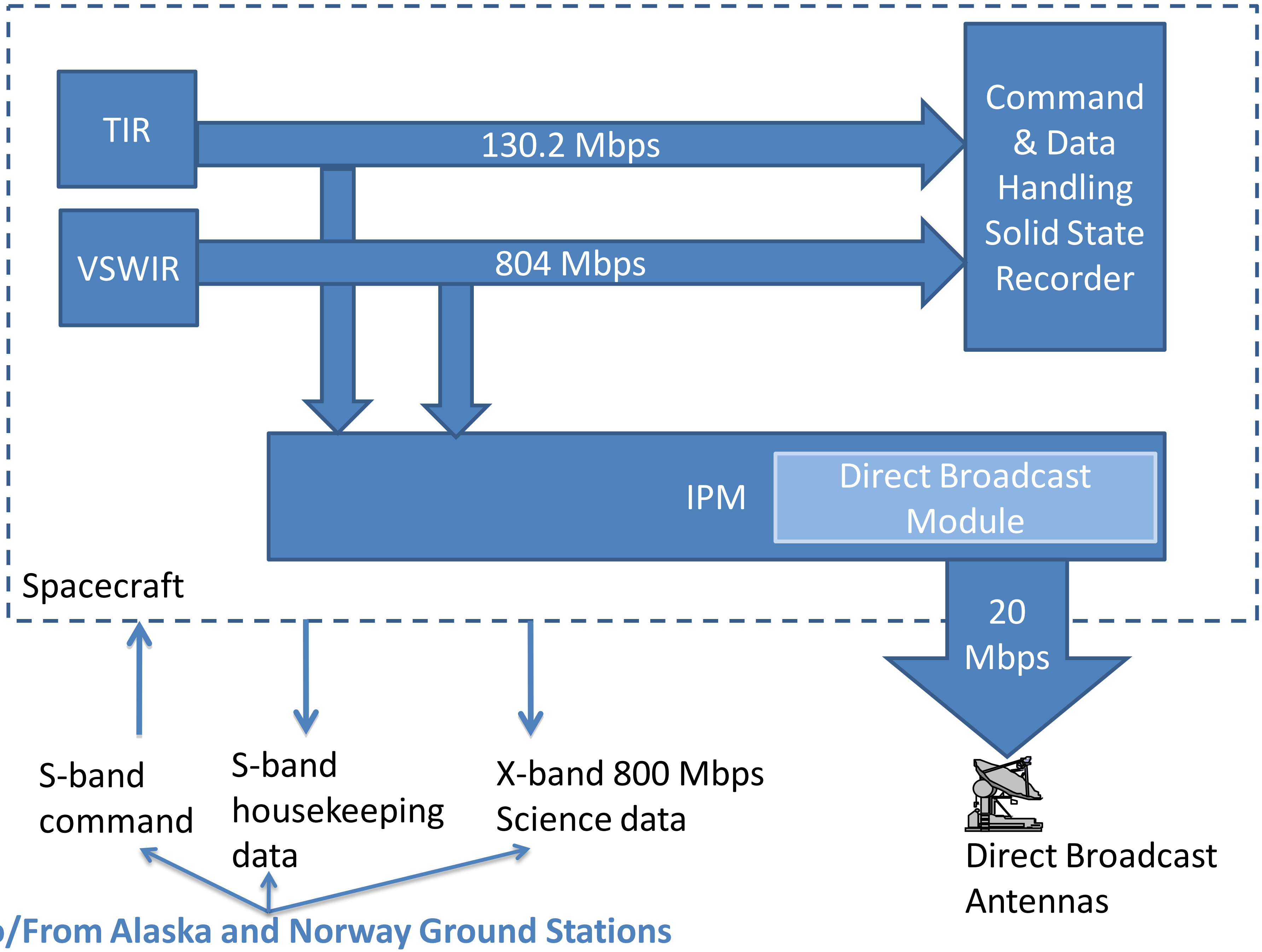




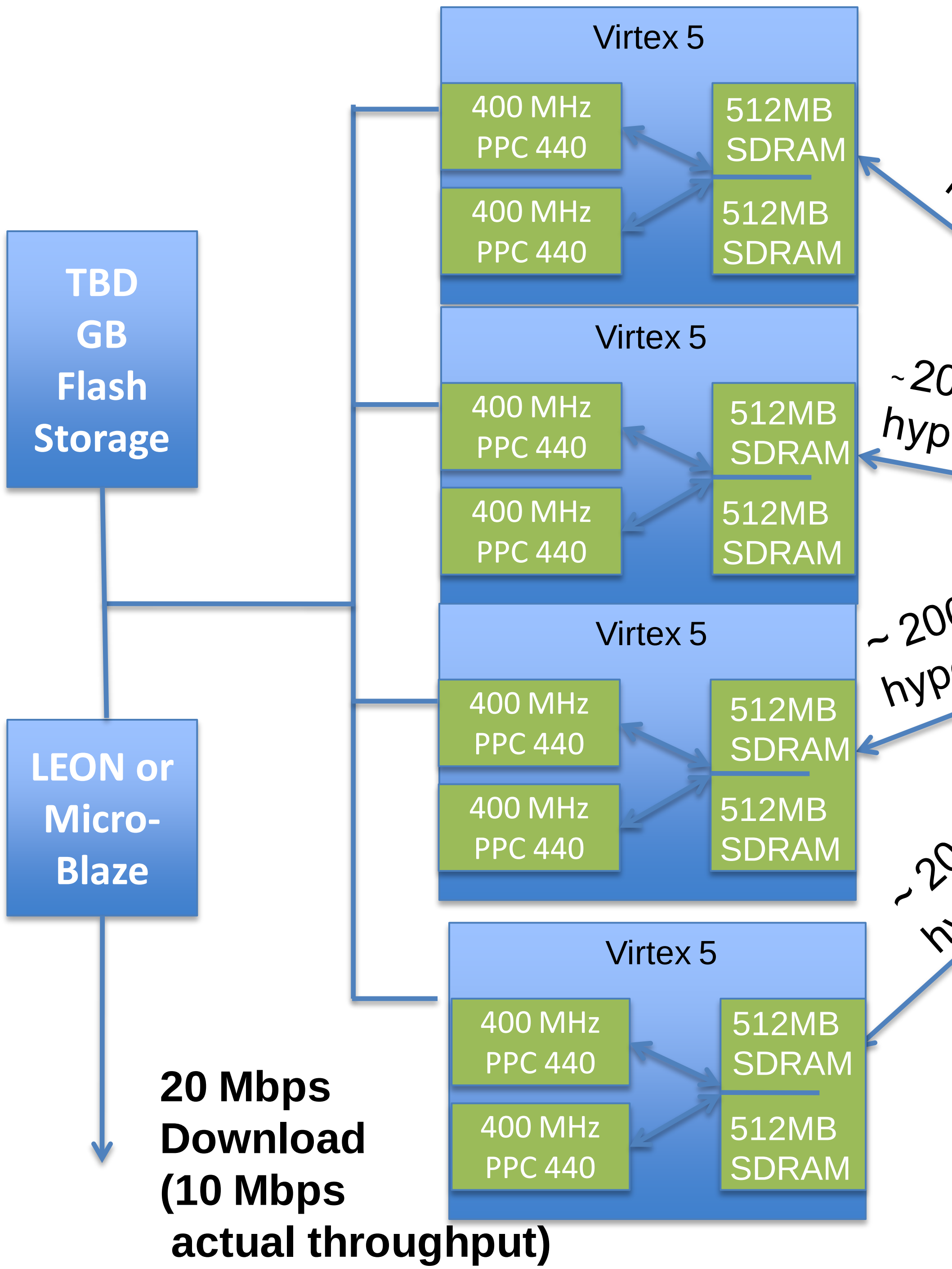
20 MBPS Direct Broadcast
(Net downlink throughput – 10 Mbps)
Downlink:
- Select Spectral Bands
- Select L-2 Products

Continuous Earth-view Broadcast

HyspIRI Data Flow



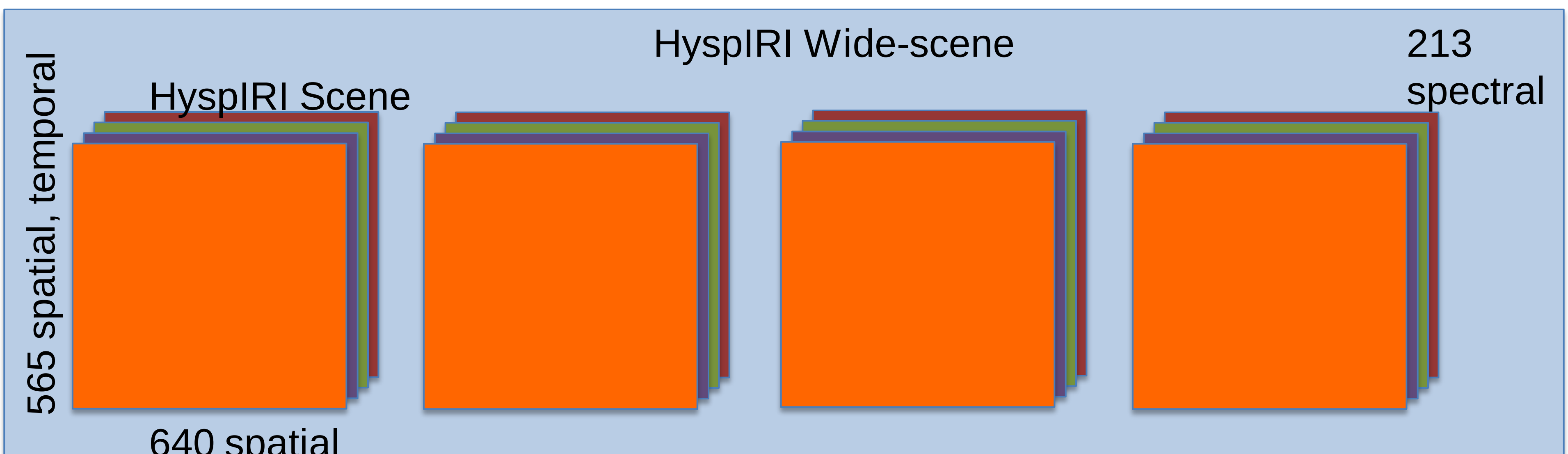
HyspIRI VSWIR Data Processing Architecture Only



- Each data stream has ¼ swath (~36km) all spectral bands
- PPC = Power PC
- LEON and MicroBlaze are types of flight processors
    - Orchestrate PPC activity augmented by Field Programmable Arrays (FPGA)

Testbed Approach for HyspIRI IPM VSWIR Processing

- 5 seconds of HyspIRI data captured at a time by PPC processors - 38 km x 34 km (640 pixels x 565 pixels x 213 bands)
  - Flight software will process 4 quarter swath HyspIRI Scenes in parallel
  - Migrate band stripping to FPGA's later
  - Each PPC processor will ping pong HyspIRI scenes, processing one scene while the next is flowing into memory
- Each 5 second scene will require 616 MB memory
- Scenes will be stored in memory in band sequential order in an array of words



Low Fidelity HyspIRI IPM Testbed

Features

- Hardware
  - Xilinx Virtex-5 (SpaceCube 2)
  - 2 x 400MHz PPC
  - 100MHz Bus
  - 2 x 512MB SDRAM
  - Dual Gigabit Ethernet
- Support Linux kernel 2.6.31 (gcc version 4.2.2)
- Support software running in standalone mode for better performance
- Can stream raw data up to 800 Mbps
- Ready for operations

Software Application Examples

- Band-stripping
- Algorithms: cloud, sulfur, flood, thermal, SWIL, NDVI, NDWI, SIWI, oil spills, algae blooms, etc.
- Corrections: geometric, radiometric, atmospheric
- Core Flight System / dynamic software bus
- CCSDS File Delivery Protocol
- Delay Tolerant Network
- CASPER / onboard planning
- Fault monitoring / recovery software
- S/C command and telemetry software
- Data compression
- Sensor Web for Autonomous Mission Operations

Low Fidelity HyspIRI IPM Testbed

Data Generator Workstation

- Generates test data and streams it to the board at rate up to 800Mbps.

NETGEAR Gigabit Switch

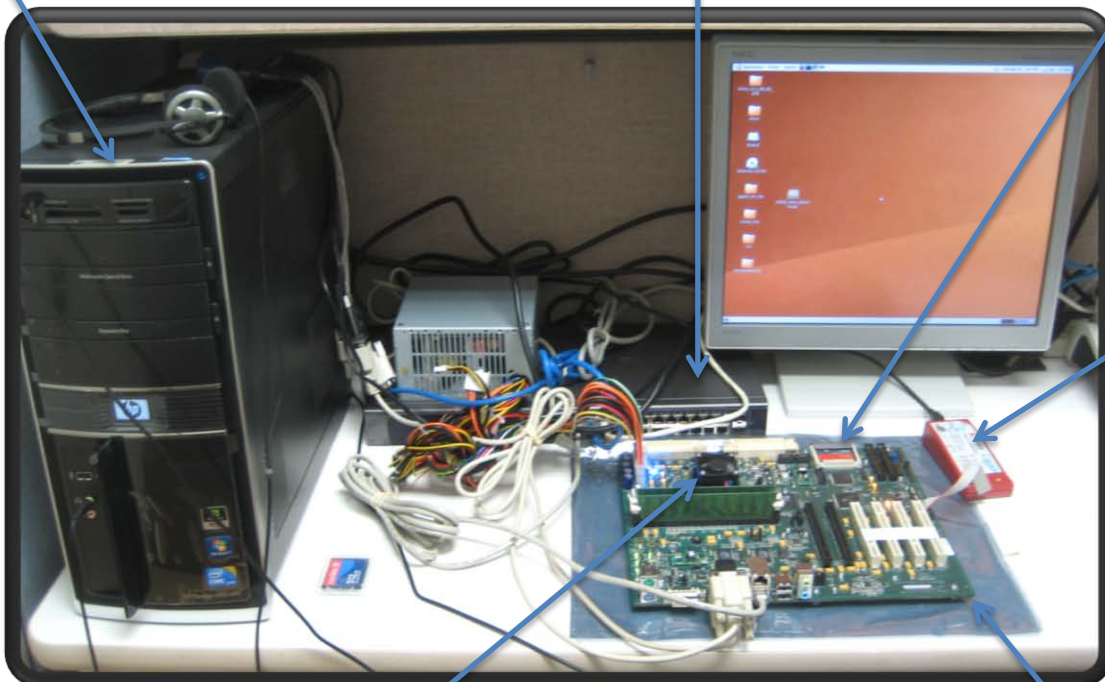
- Allows the board and the data generator workstation to connect at Gigabit speed.

Compact Flash

- Ext3 formatted file system with Linux libraries and tools

Platform Cable USB

- Provides an easy method for debugging software running on the board



Virtex-5 FPGA

- SpaceCube 2 core FPGA
- Configured as dual 400MHz PPC design
- Capable of running with Linux or in a standalone mode

Xilinx ML510 Development Board

- Enables the development team to verify the Virtex-5 while the SpaceCube 2 is finalizing the design

Initial Benchmark Results

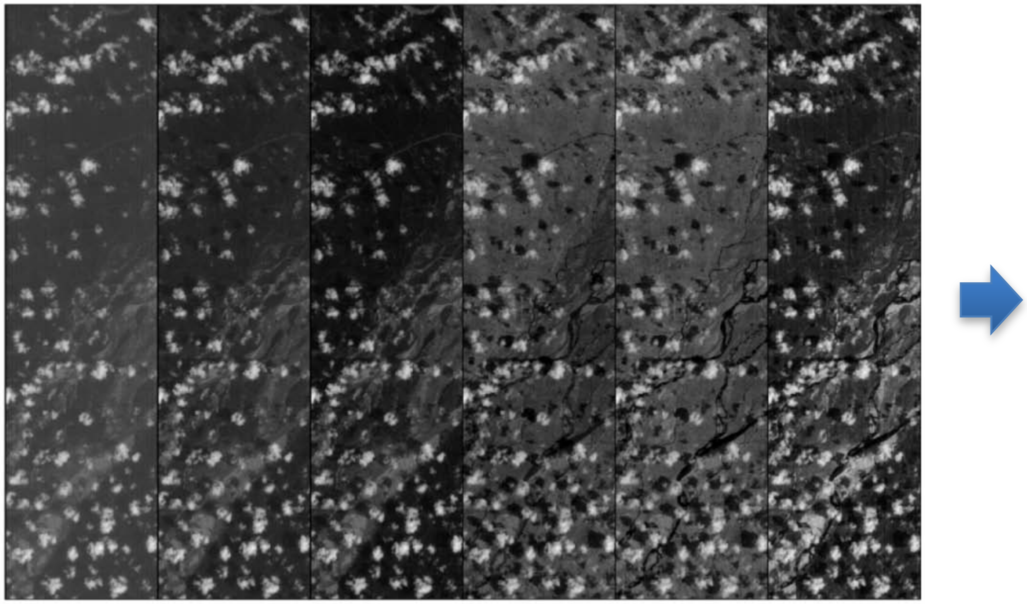
32-bit Memory Test	Write (ms)	Read + Verify (ms)
128MB	711	1179
256MB	1564	2365
512MB	2942	4731
1024MB	6673	10670

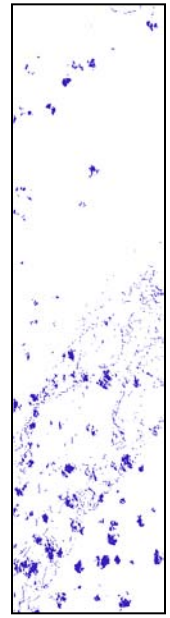
Not Optimized!
FPGA not leveraged

Algorithms	Linux (ms)	Standalone (ms)	Linux (ms)	Standalone (ms)
	EO1 scene (256 x 1000 pixels)		HyspIRI ¼ swath (640 x 565 pixels)	
Cloud	1791	431	2170	589
Flood	3024	937	3782	1311
SWIL	7350	2872	10226	4058
Sulfur	116362	29515	164978	42026
Thermal	1103	304	1475	431
SIWI	580	44	823	62
NDVI	630	44	904	62
NDWI	589	44	836	62

Disclaimer: Code not optimized. Performance based on a 400MHz PPC design.

Other CPU IPM Processor Benchmarks





Cloud benchmark
pixels detected
as a cloud in blue

bands (21, 31, 51, 110, 123, 150 }

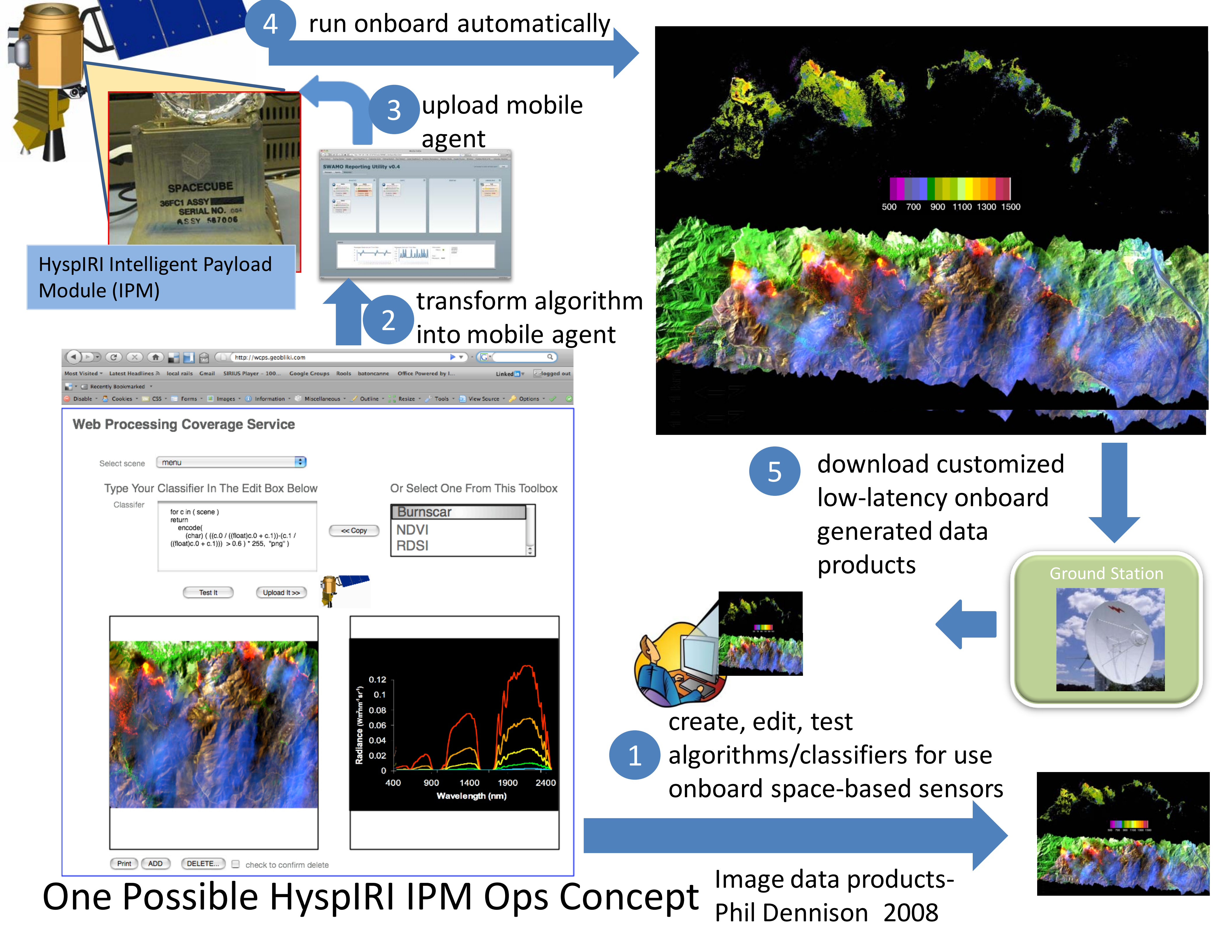
GSFC Benchmark	MHz	Thermal CPU%	Cloud CPU%
Aeroflex LEON3	75	80	110
BAE RAD750	133	50	80
Xilinx PPC 440	440	20	30

JPL Benchmark	MHz	Thermal CPU%	Cloud CPU%	Flood CPU%	SWIL SVM CPU%	SULPHUR SVM CPU%
Mongoose V	12	tbd				
Atmel LEON2	100	597	684	823	1784	14935
RAD750	200	294	383	441	1030	4856
GESPEC	150	166	190	230	520	2202
PPC 440	440	156	181	299	966	23223
GESPEC	500	120	156	180	421	1985

- Benchmark numbers need reconciliation to understand differences
- More sophisticated algorithms will clearly require FPGA acceleration

Vision for Development of IPM Process Chain

Processes	Ground	Flight
Level 0	Yes	-
Level 1R	Yes	-
Atmospheric Correction	Automation in progress	-
Dynamic Algorithms	JPL WCPS/SWAMO	In Testbed
Geometric Correction	L1G	-
Compression	CCSDS	Card Available
Downlink	N/A	-


4 run onboard automatically
3 upload mobile agent
HyspIRI Intelligent Payload Module (IPM)
SPACECUBE
2 transform algorithm into mobile agent
500 700 900 1100 1300 1500
Web Processing Coverage Service
Select scene
menu
Type Your Classifier In The Edit Box Below
Or Select One From This Toolbox
Classifer
for c in (scene)
return
encode(
(char) (((c.0 / ((float)c.0 + c.1))-(c.1 / ((float)c.0 + c.1))) > 0.6) * 255, "png")
<< Copy
Burnscar
NDVI
RDSI
Test It
Upload It >>
Radiance (W/m²/nm¹sr¹)
Wavelength (nm)
Print
ADD
DELETE...
check to confirm delete
5 download customized low-latency onboard generated data products
Ground Station
1 create, edit, test algorithms/classifiers for use onboard space-based sensors
One Possible HyspIRI IPM Ops Concept
Image data products-
Phil Dennison 2008

Low Latency Data/IPM Operations Concept and Applications

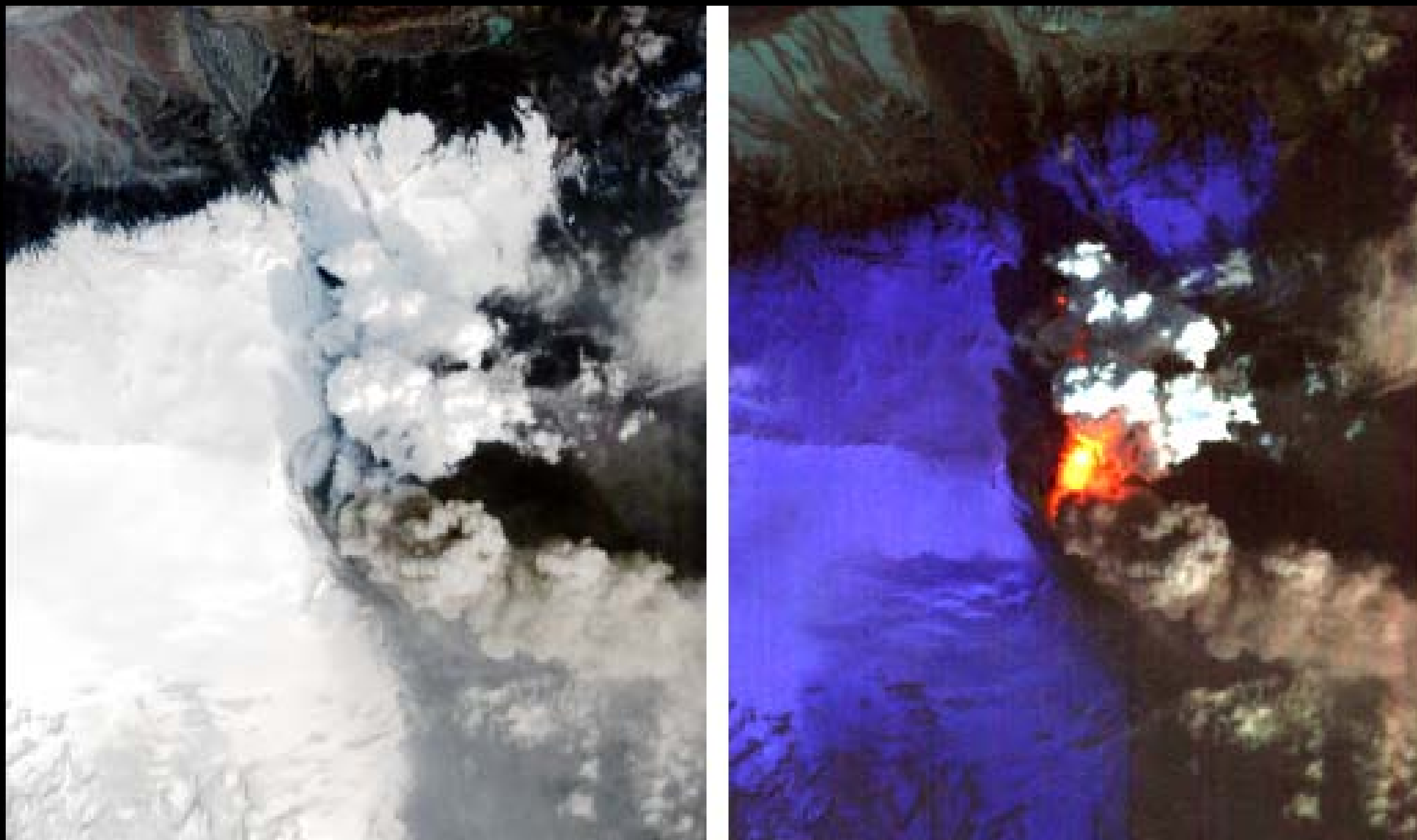
Steve Chien, Dorothy Silverman, David Mclaren, Gregg Rabideau
Jet Propulsion Laboratory, California Institute of Technology

Daniel Mandl, Goddard Space Flight Center

Jerry Hengemihle, Microtel LLC

Rapid Data delivery:

02 May 2010 Hyperion Imagery



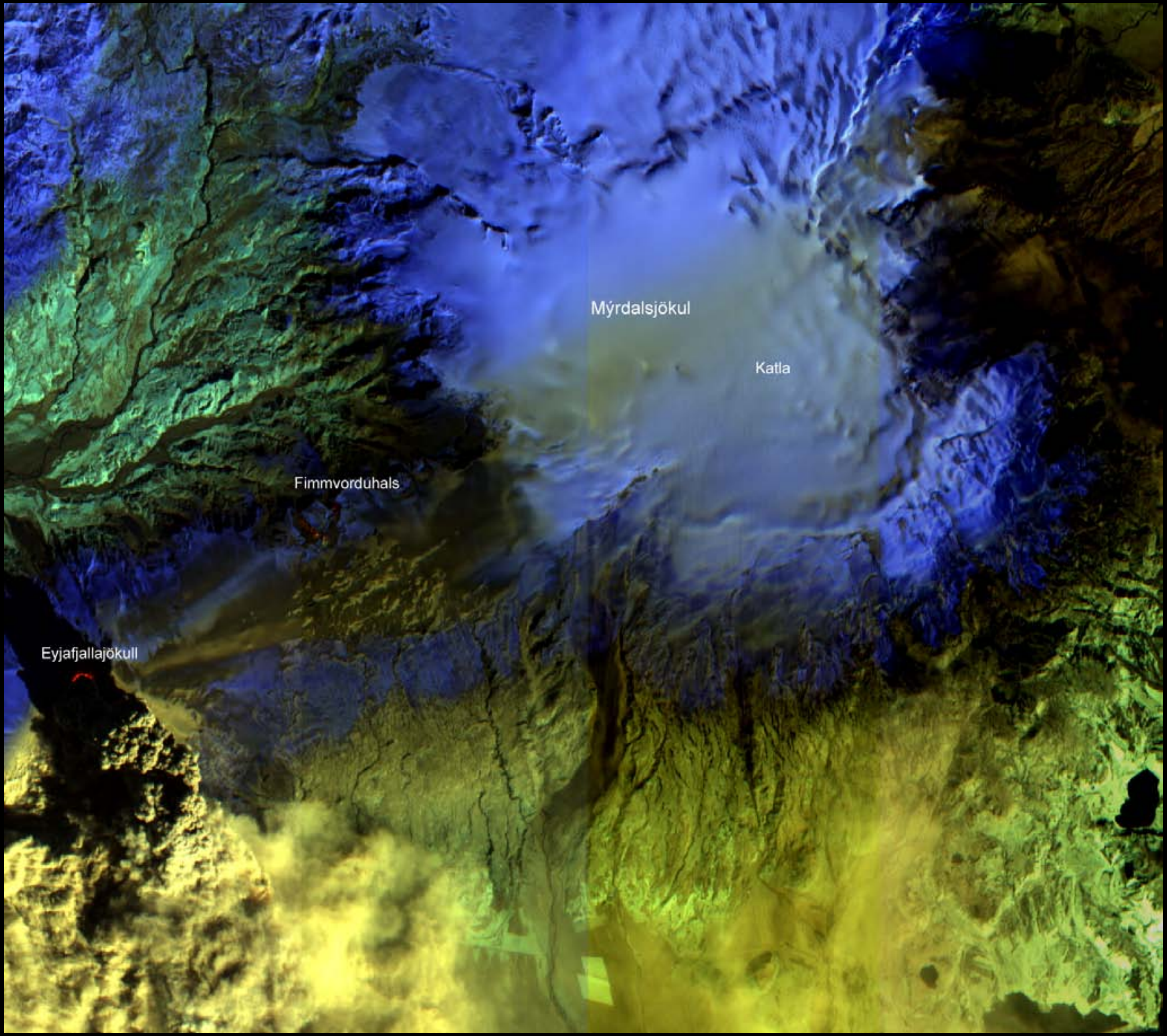
Left – True color   Right - thermal false color

Image courtesy EO-1 Mission/GSFC, Volcano Sensorweb/JPLA. Davies

Recent: Iceland Volcano

False color Advanced Land Imager (ALI) from EO-1 acquired 17 April 2010

Image courtesy EO-1 mission NASA GSFC & Volcano Sensorweb Courtesy JPL/A. Davies

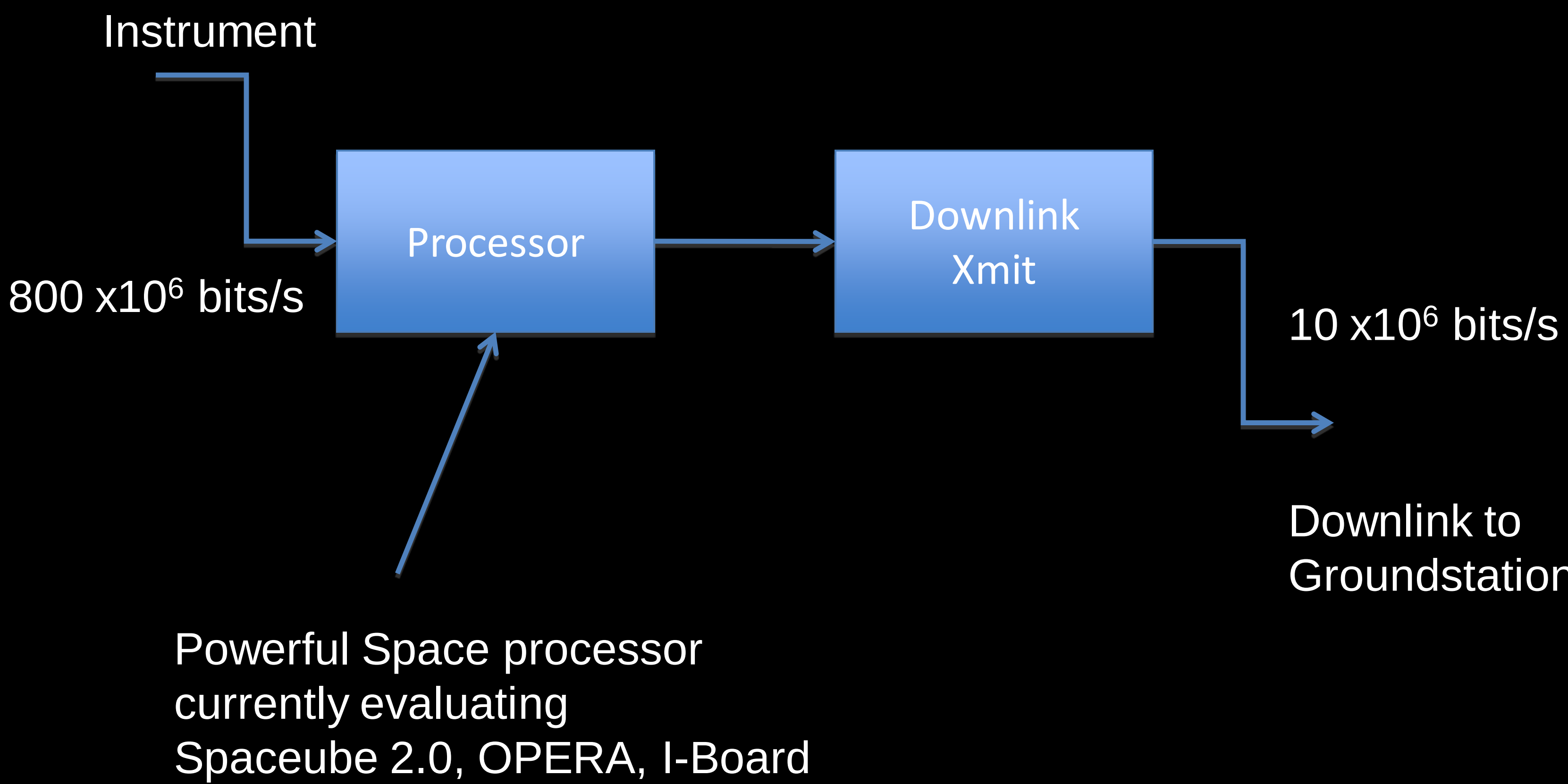


HyspIRI Direct Broadcast

- HyspIRI TIR + VSWIR will produce 800 x 10^6 bits per second (raw uncompressed)

- In order to use heritage technology groundstations HyspIRI DB will have an effective rate of 10 x 10^6 bits per second (uncompressed)
  - Even assuming 4:1 compression we have a 20x oversubscription

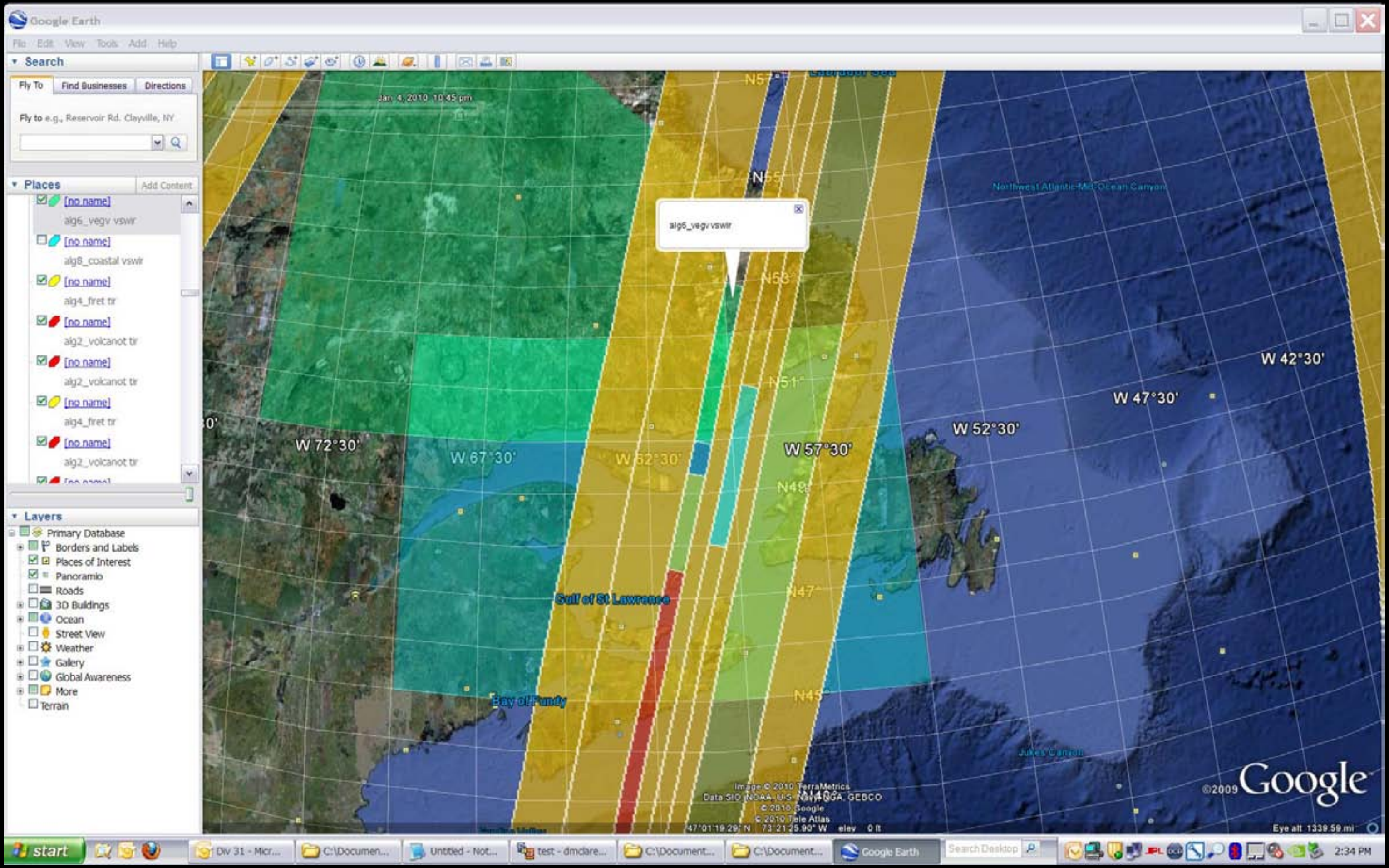
HyspIRI DB Concept



Operations for HyspIRI DB

- Users specify "areas of interest" which are
  - geographical regions (polygon on surface of Earth)
  - product, (e.g. normalized burn index)
  - priority, (e.g. 50 on 1-100 scale)
  - Constraint (sun must be at least 20 degrees above horizon)
- In generic tool (e.g. Google Earth)
- DB can also be used to rapidly downlink "scenes"

Instrument Swaths

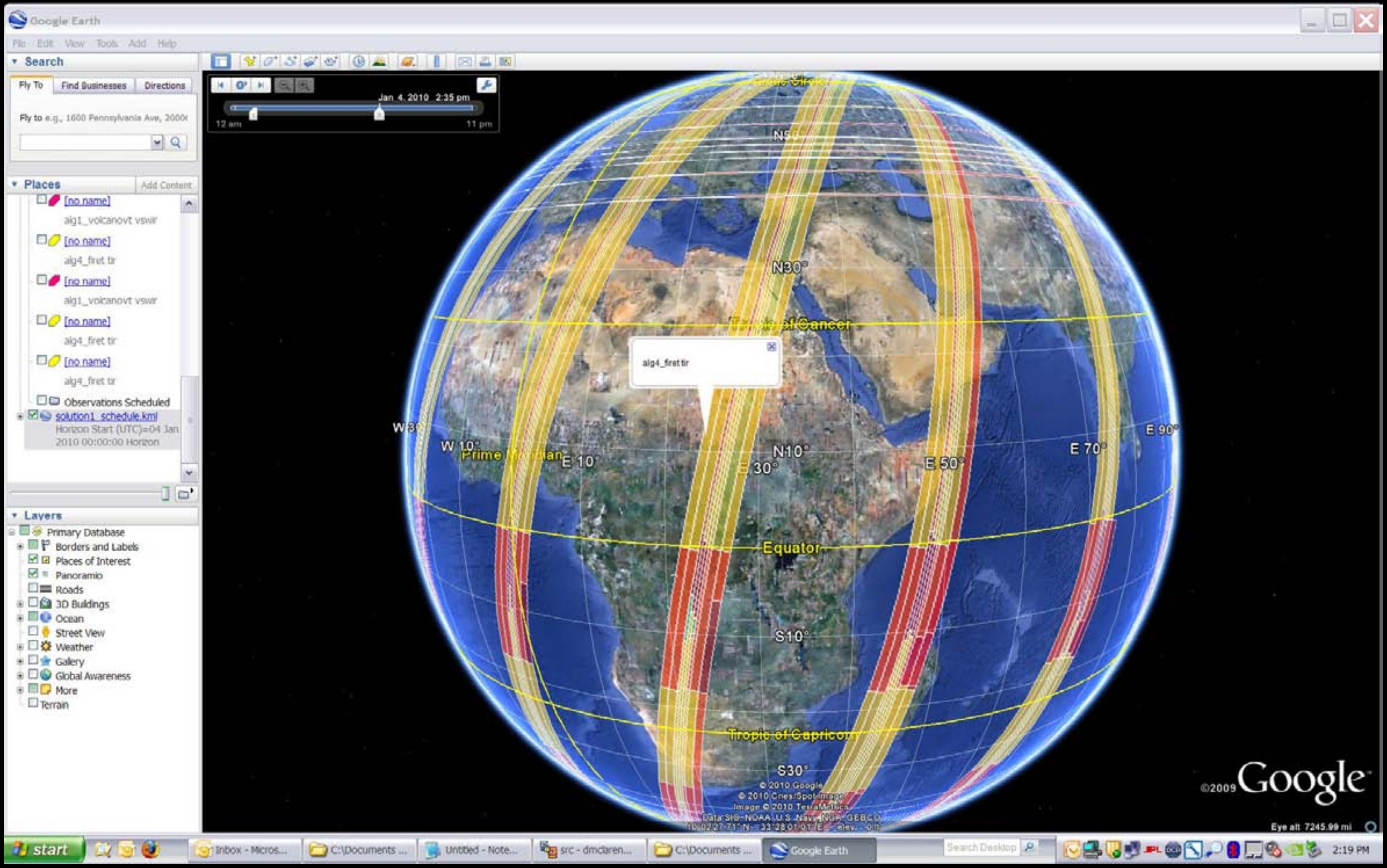


Automated Operations Planning

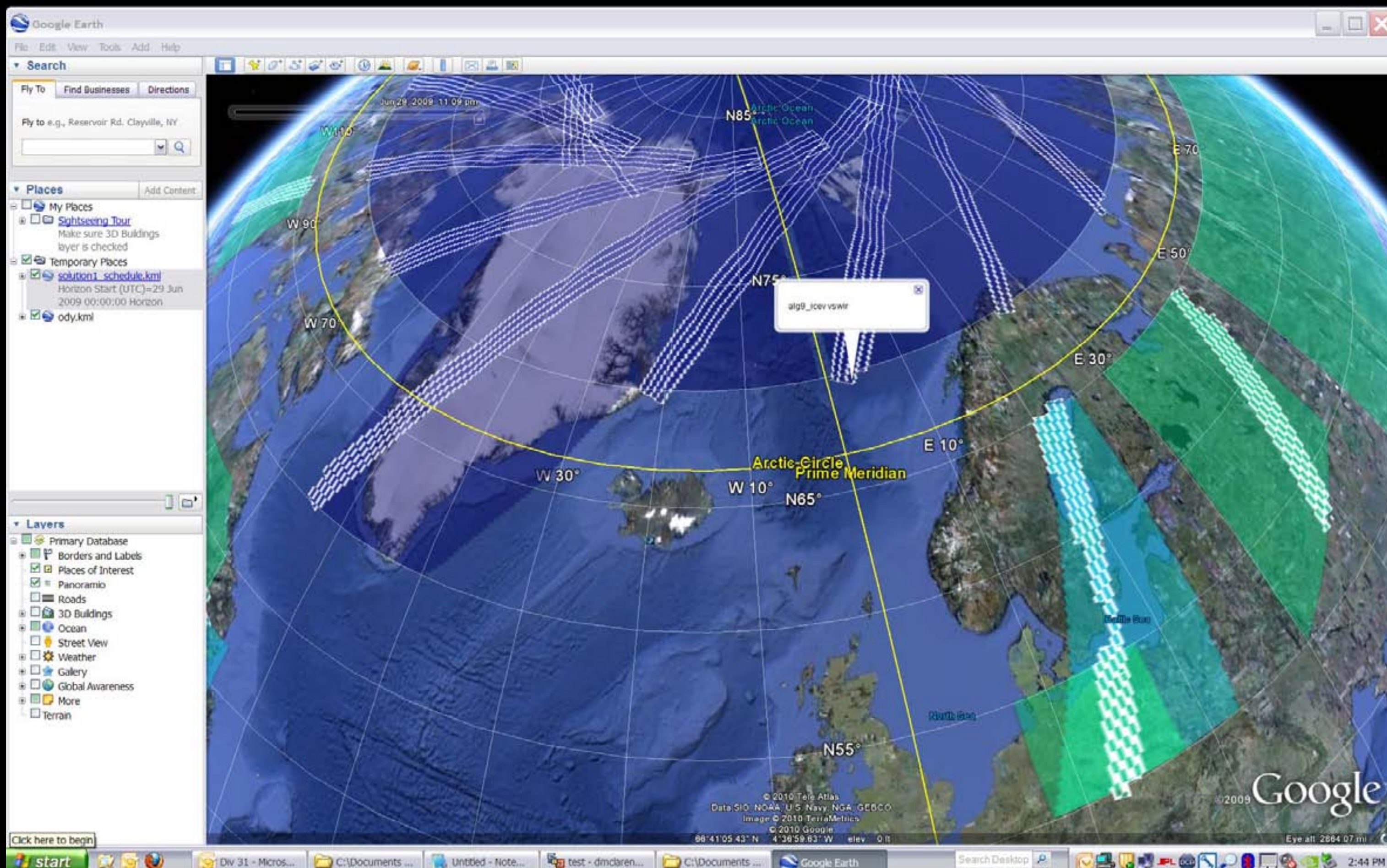
- Automated Planning tool selects highest priority products while respecting
  - Visibility (instrument swaths)
  - Onboard CPU limits
  - Downlink data limits

- Result is a time ordered sequence of commands to process instrument data from each of 8 instrument swaths

Sample Plans



More Plans

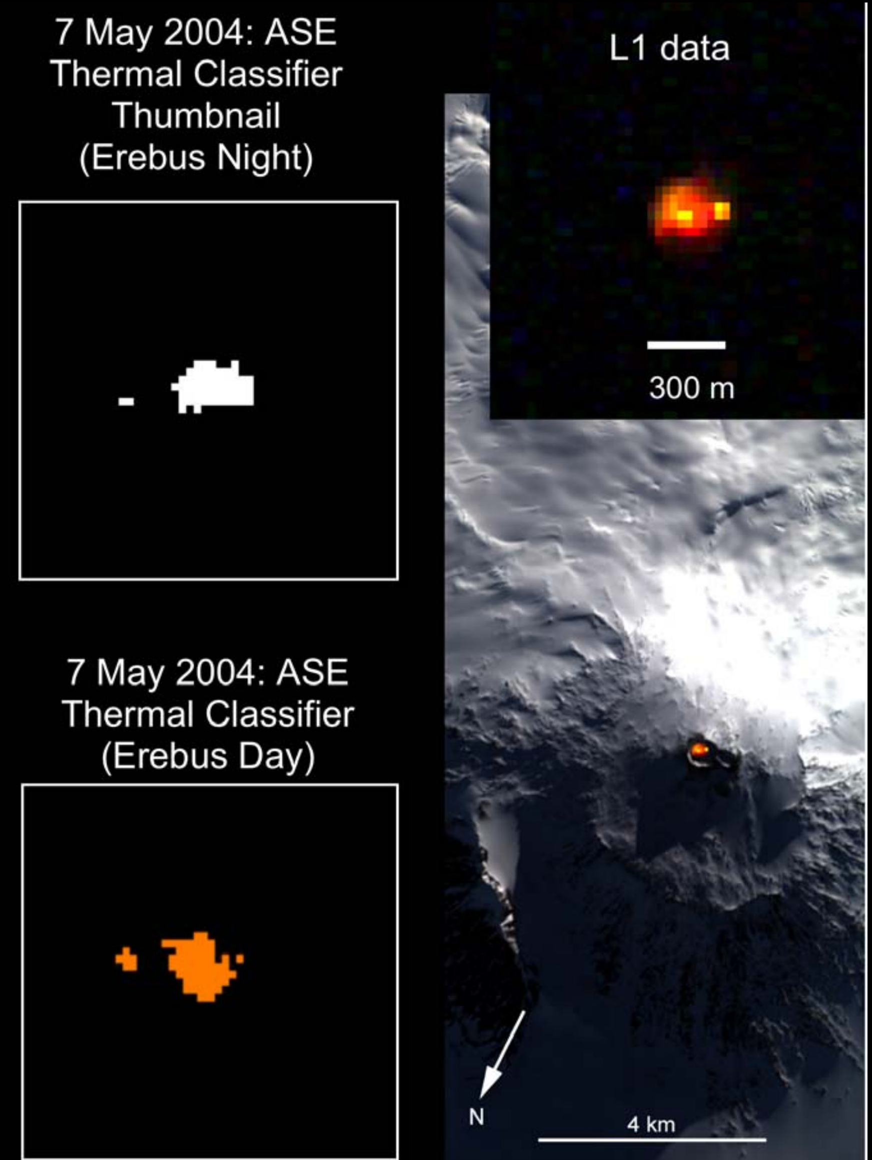

Google Earth
File Edit View Tools Add Help
Search
Fly To
Find Businesses
Directions
Places
My Places
Sightseeing Tour
Temporary Places
solution1_schedule.kml
ody.kml
Layers
Primary Database
Borders and Labels
Places of Interest
Panoramio
Roads
3D Buildings
Ocean
Street View
Weather
Gallery
Global Awareness
More
Terrain
Arctic Circle
Prime Meridian
N85°
N75°
N65°
N55°
W 90°
W 70°
W 30°
W 10°
E 70°
E 50°
E 30°
E 10°
Google
start
2:44 PM

HyspIRI DB Applications

- Volcanos
- Fires
- Flooding
- Cryosphere
- Ocean

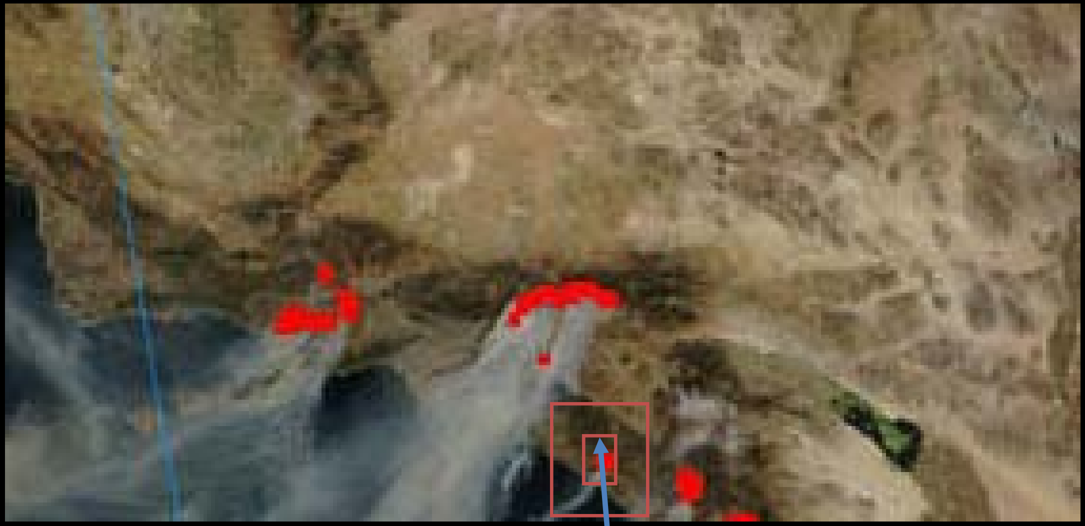
Heritage (onboard) – EO-1/ASE Thermal Detection

- EO-1
  - Onboard thermal event detection in use since 2004 based on onboard Hyperion spectral signature
  - Uses spectral slope in 1.65-2.28μ
  - Onboard event detection can trigger:
    - Subsequent imaging
    - Alert Notices
    - Generation of thermal summary and quicklook context images
    - Ground-based automatic data product generation and distribution



Courtesy [Davies et al. 2006]

Heritage – ground-based MODIS Active Fire Detection



Looks for areas significantly hotter than surrounding area (requires 6 surrounding pixels cloud, water, fire free → 21x21)

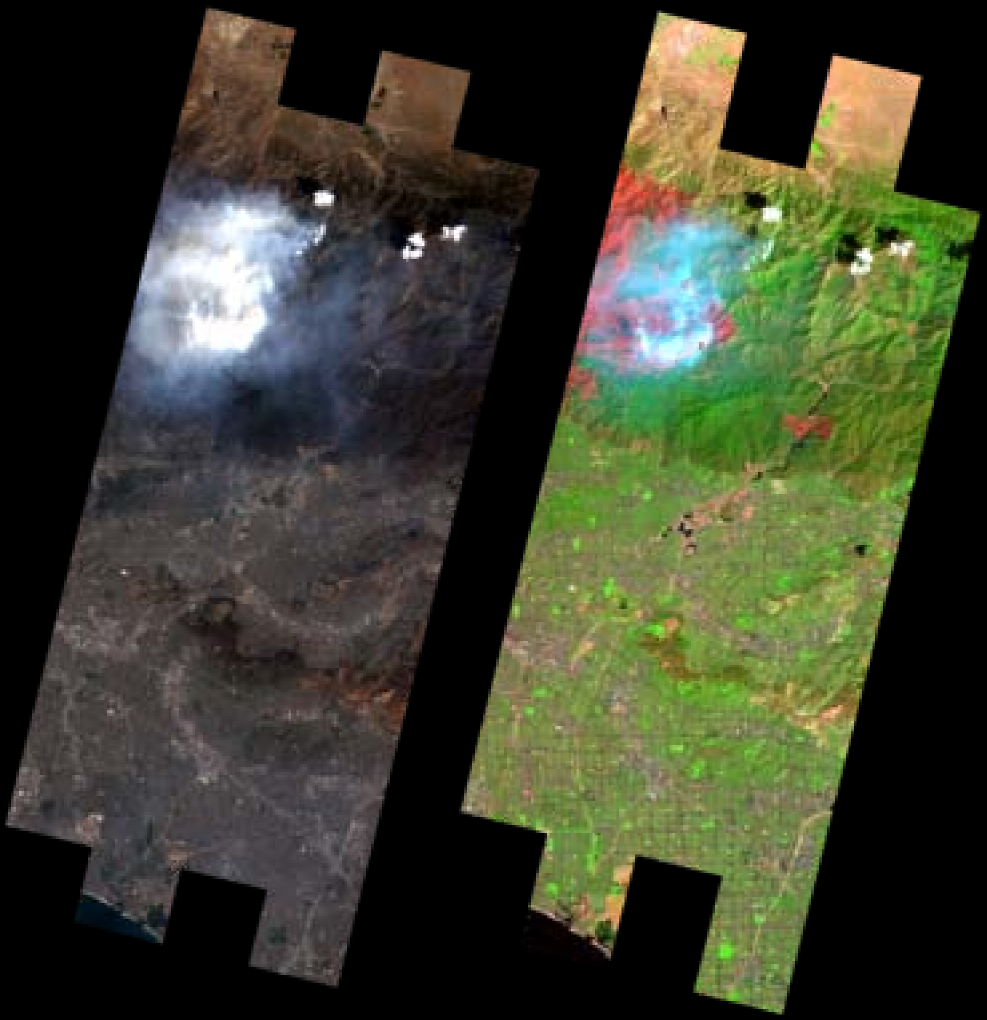
- Detects hotspots using
  - absolute threshold
    - T_4>360K, 330K(night) or
    - T_4>330K, 315K(night) and T_4-T_{11}>25K(10K @ night)
  - and relative threshold
    - $T_4 > \text{mean}(T_4) + 3\text{stddev}(T_4)$ and $T_4 - T_{11} > \text{median}(T_4-T_{11}) + 3\text{stddev}(T_4-T_{11})$

C. Justice et al.

Fires – Burn Scar

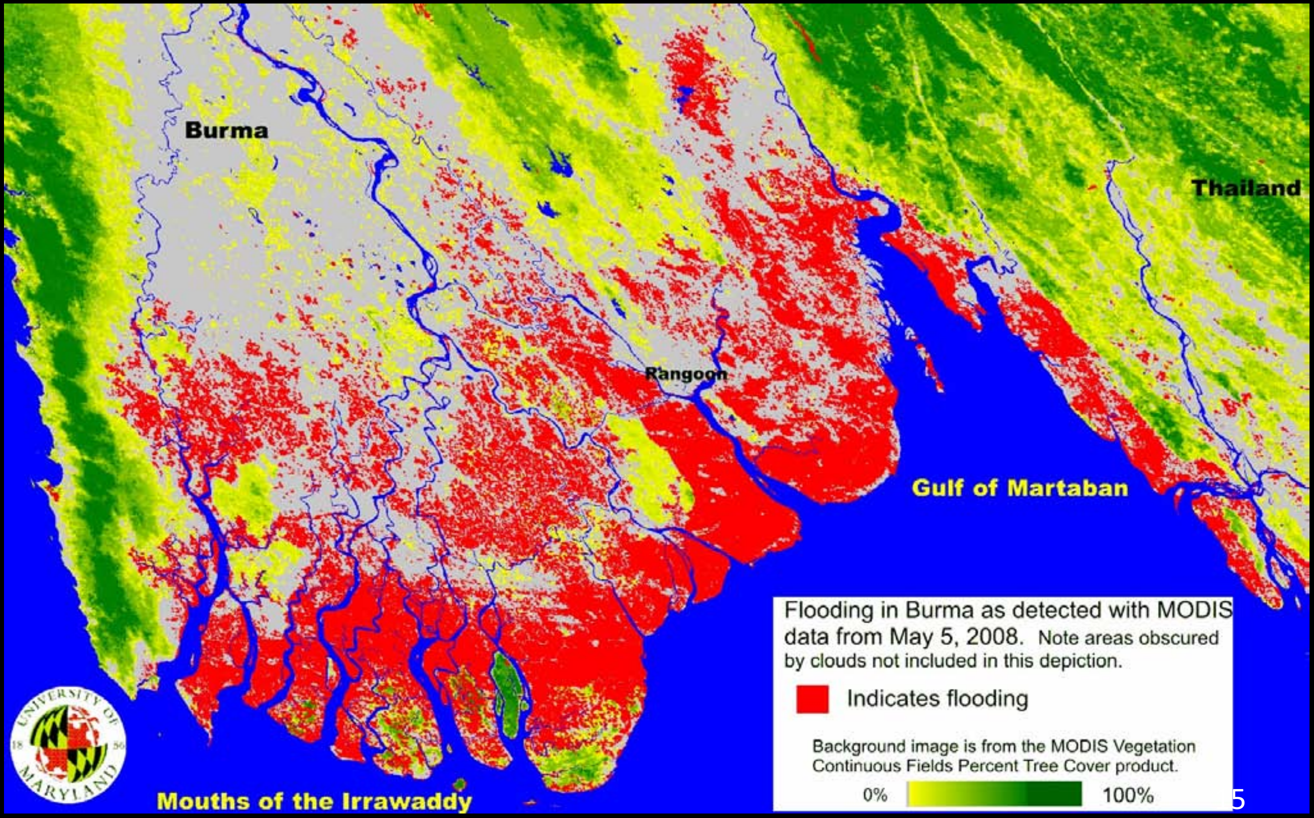
Visible and burn scar enhanced images from ALI instrument on EO-1 of Station Fire near Los Angeles 03 September 2009

Images courtesy EO-1 Mission NASA GSFC



Flooding – Heritage (Ground) MODIS/UMD

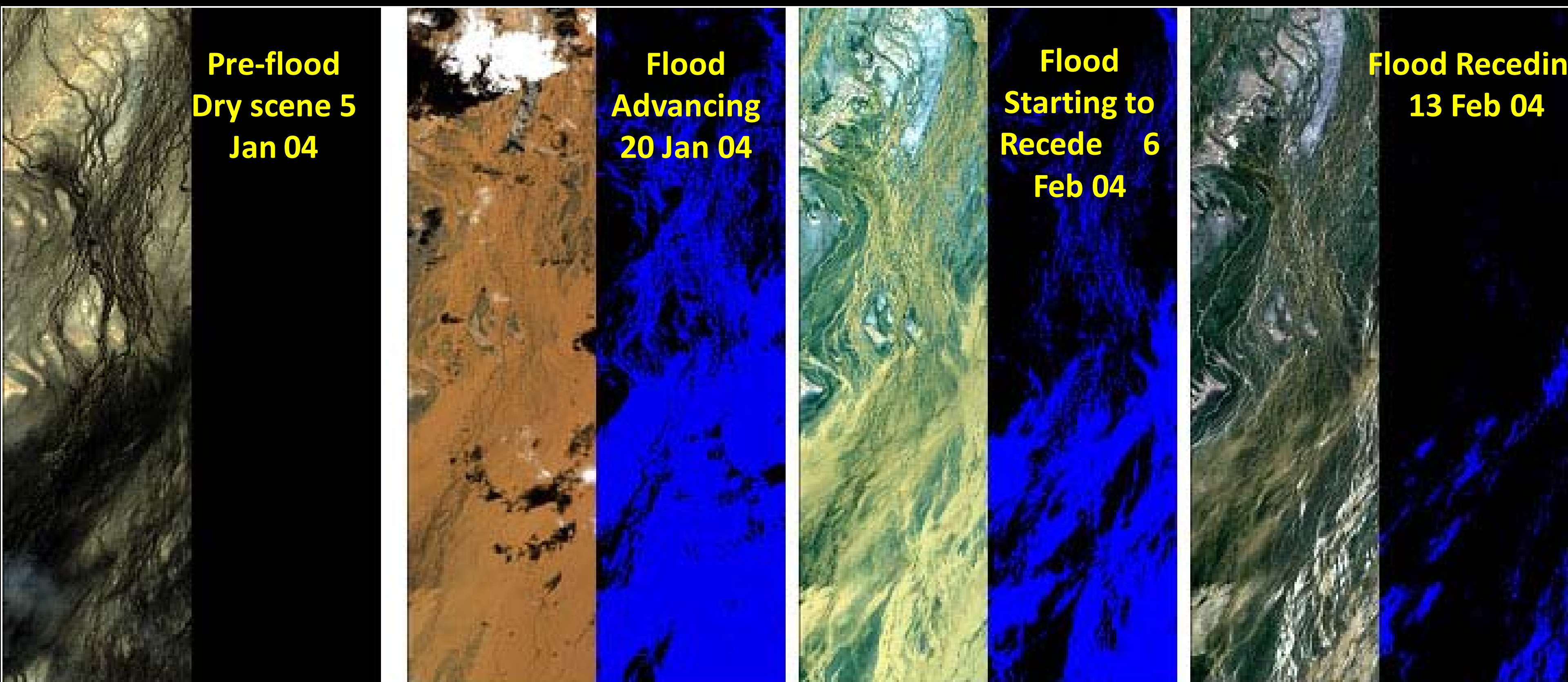
- UMD Flood tracking of Myanmar using MODIS bands 1,2,5,7 (620-2155 nm)



M. Carroll et al.

Flooding - Heritage (Flight) – EO-1/ASE

Onboard Detection of a Rare Major Flood on Australia's Diamantina River



Cause of flooding: Monsoonal rain

EO-1 Hyperion. Wavelengths used: 0.86 µm and 0.99 µm

F. Ip, V. Baker, et al., University of Arizona

Cryosphere (Ground)

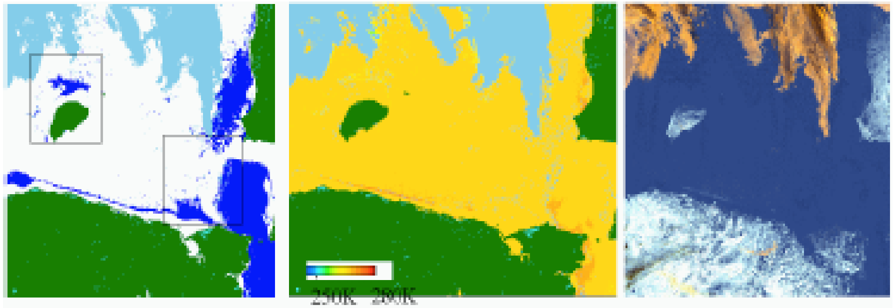


Figure 4: MODIS sea ice product by NDSI method (left), IST method calculated temperatures (center), and a composite image made from MODIS Bands 20 (3.7μm), 22 (3.9μm) and 23 (4.0μm) to highlight clouds (right).

Image courtesy of [Scharfen and Kalsa 2003]

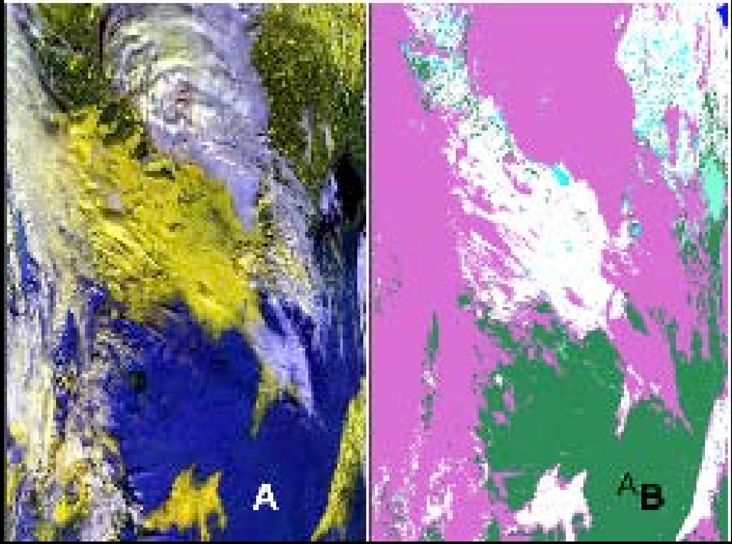
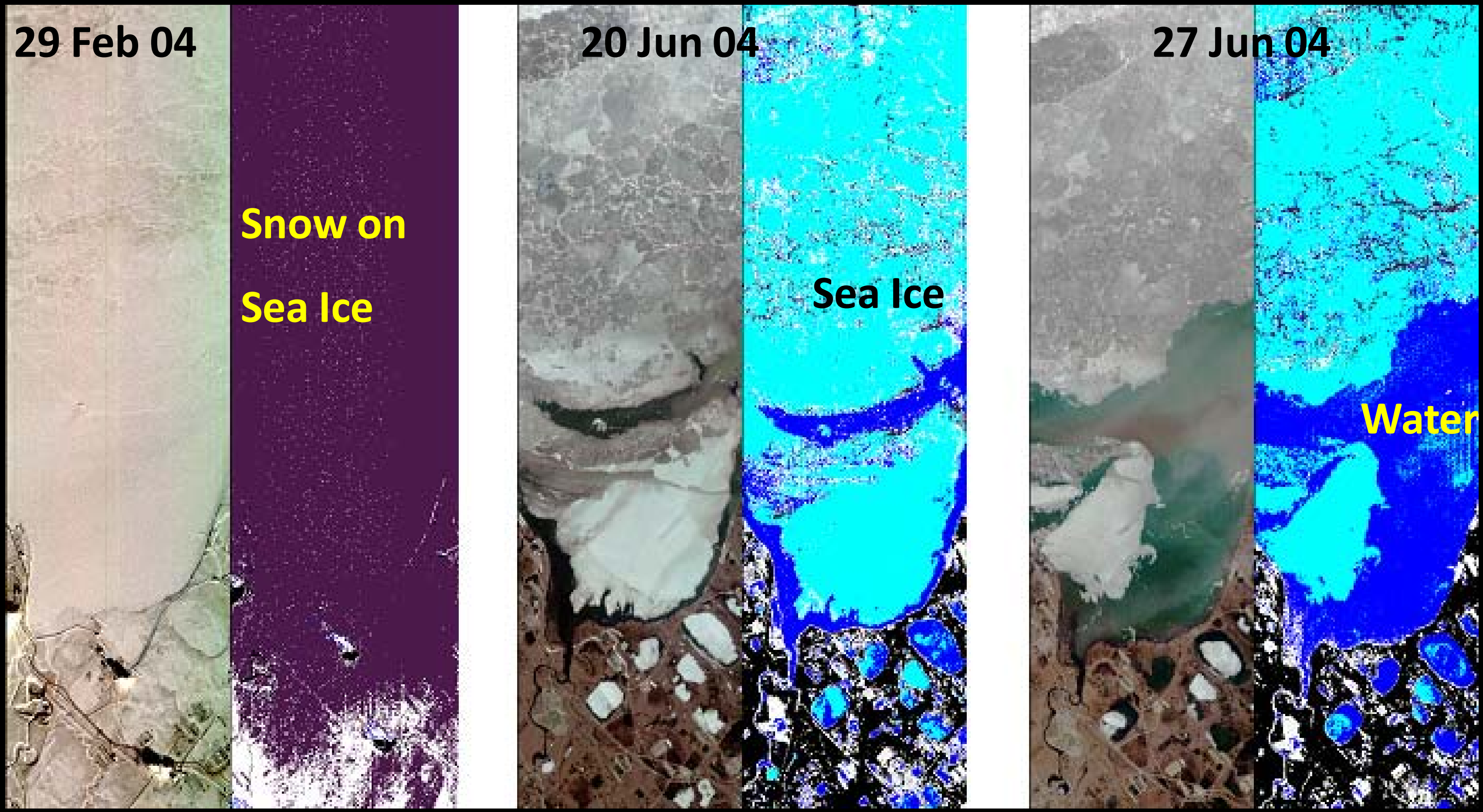


Figure 1 MODIS at-satellite reflectance image from swath of MOD02HKM for 3 January 2003 (A). Snow cover appears as yellow in this display of bands 1, 4 and 6. Snow cover map of the swath (B) and the snow cover map in sinusoidal projection (C).

Courtesy of *MODIS Snow Products User Guide*

Heritage (onboard) EO-1/ASE Hyperion Cryosphere Classifier

Deadhorse (Prudhoe Bay), Alaska

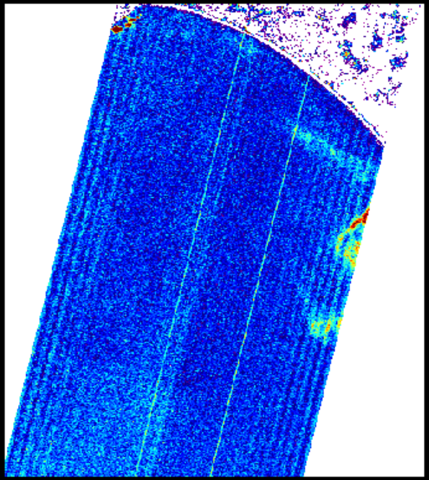


- Snow
- Water
- Ice
- Land
- Unclassified

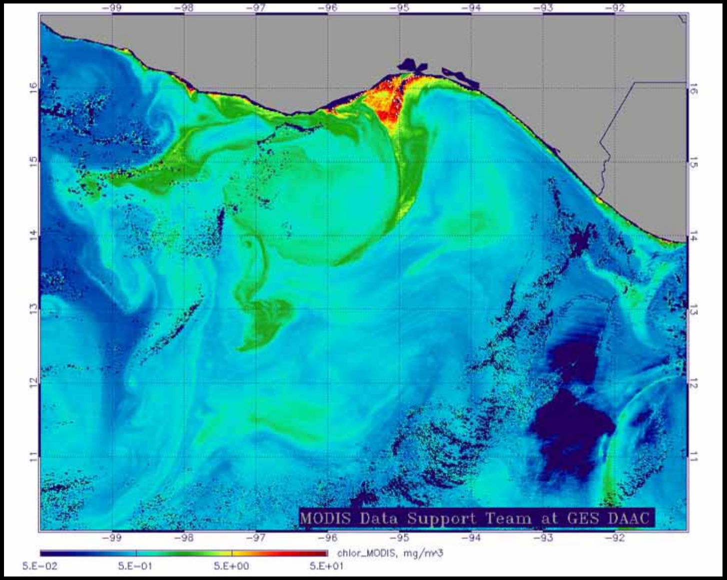
EO1/Hyperion data
Wavelengths used in classifier:
0.43, 0.56, 0.66, 0.86 and 1.65 µm

Arizona State University
Planetary Geology Group

Coastal



Maximum Chlorophyll Index derived from Hyperion imagery acquired 21 October 2008 of Monterey Bay [Chien et al. 2009] using 660, 681, 711, 752, nm. (ack J. Ryan/MBARI)



Uses 490nm/555nm or 490nm/565 nm MODIS reflectance data Courtesy GSFC DAAC

Dust

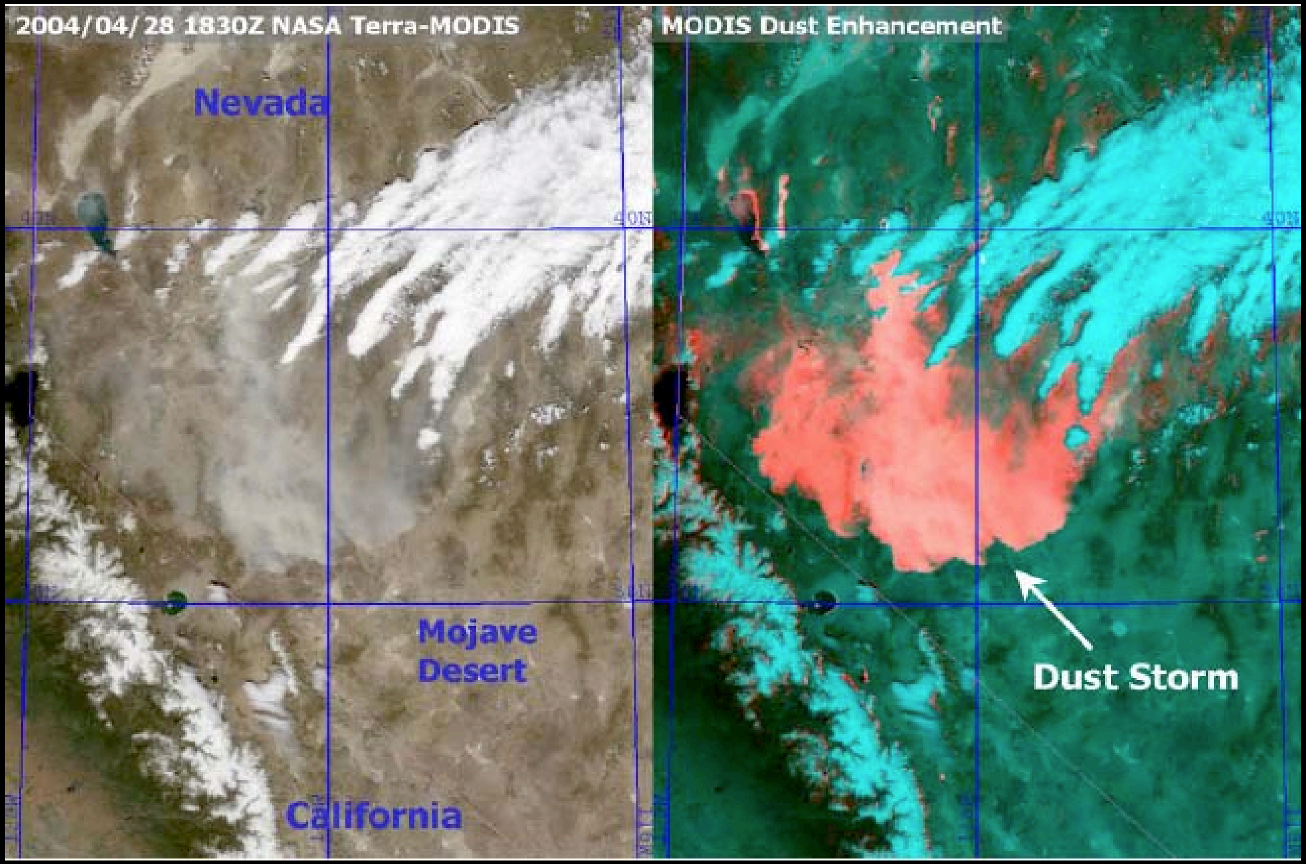


Image (processed MODIS) courtesy of *Satellite Product Tutorials: Desert Dust Storms, S. Miller et al.*

Vegetation

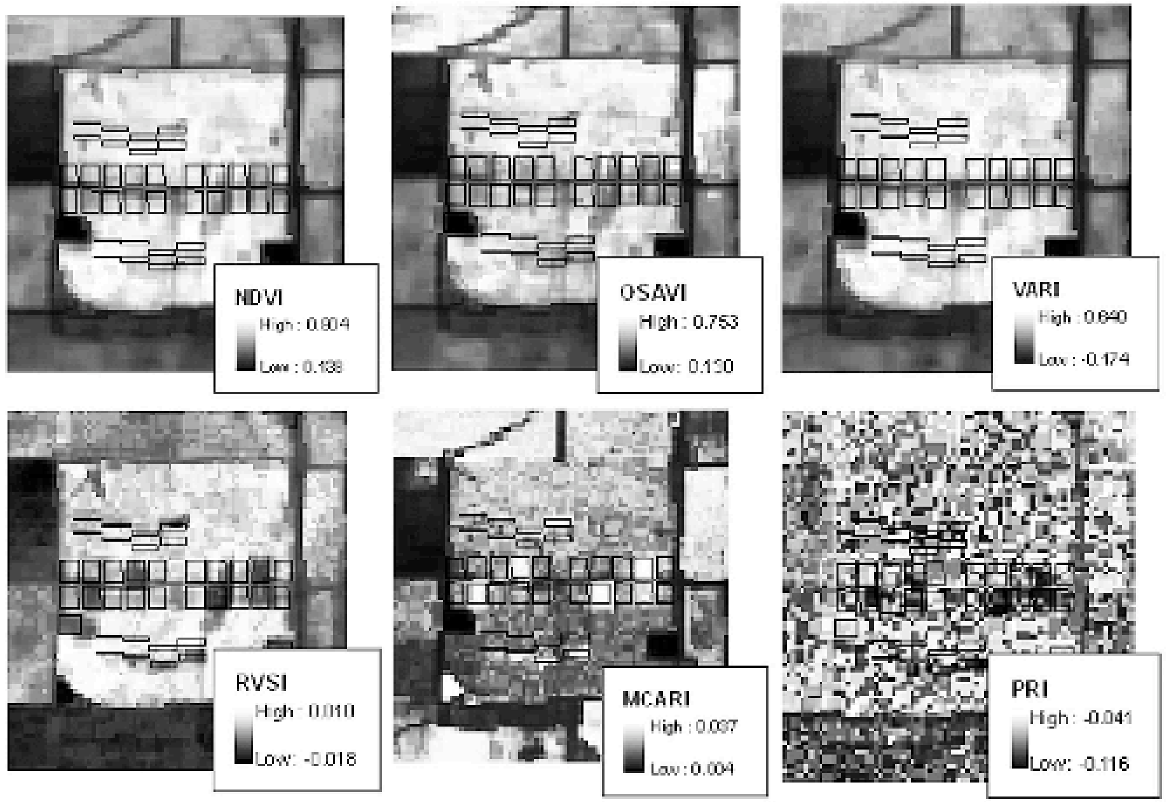


Fig. 3. Comparison of selected indices derived from 6 July Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) imagery (18-m spatial resolution) with locations of N trial plots and subpixel plots shown. The corresponding classification accuracies are shown in Table 7. Note the differences between the appearance of the subpixel areas and the classification accuracies. For example, the subpixel stressed areas for the Normalized Difference Vegetation Index (NDVI) and the Modified Chlorophyll Absorption in Reflectance Index (MCARI) are quite apparent, although the classification accuracies (Table 7) for the Photochemical Reflectance Index (PRI) are generally higher.

Aviris measurement of plant stress using NDVI, MCARI, and PRI [Perry & Roberts 2008]

Conclusions

- Direct broadcast can provide key data at low latency
- Onboard computing can address issues to downselect data to fit within reduced downlink
- Operations can be simple and automated

To Facilitate the Use of HyspIRI Data

Tools for On-line Products and Analysis

Petya Campbell[1,2] and Betsy Middleton[2]

[1]JCET/UMBC and [2]NASA/GSFC

Product Levels

Level 0: Digital Numbers

Level 1: 1A - Level 0 reconstructed, time-referenced and annotated with ancillary information;
1B - TOA radiance, Cloud screened images.

Level 2: *Description* - Swath data. *Products*: surface reflectance (%), Land Surface Temperature (LST, day or night); Surface Spectral Emissivity (day or night)

===

Level 3: *Description* - Swath *and* Gridded data, Terrain corrected products.

Level 4: *Description* – Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types (e.g., ET, Fire fuel & fuel moisture)

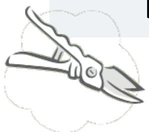
- ***Regional Scale (60m-1km)***: *For specific sites, watersheds, geographical units or global samples of ecosystems*
- ***Global Scale (gridded, ¼-1 deg+)***: *For modeling ecosystems/general cover categories*

HyspIRI Products (Summary)

Products	VSWIR Sensor	TIR Sensor	Combined
L1A	TOA radiance spectra	TOA radiance bands	
L2 Swath Local/Regional	Surface Reflectance (%)	Land Surface Temperature (LST) Surface Emissivity	?
L3 Scene/Region, Global, Terrain corrected	End-member abundance, Fractional vegetation cover Canopy constituents (CCs, pigments, water, nitrogen) Land cover classifications Albedo	LST, Surface Emissivity, Fire detection	New indicators of ecosystem function, disturbance, diversity
L4 Time series Data fusion Model outputs	Fractional land cover, FVC, LAI, End-members, CCs Plant functional types (PFT), LUE, GPP, NEP	LST and emissions by LC, Evapotranspiration (ET)	Day/night, seasonal LST & emissivity differences by LC & FVC, Damage and fire suscept.

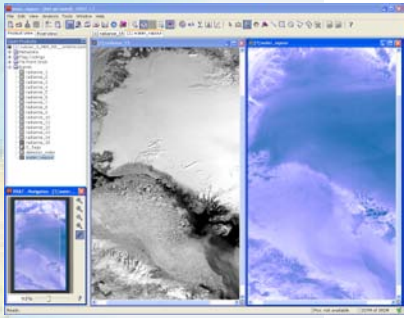
Currently Existing Tools and Databases

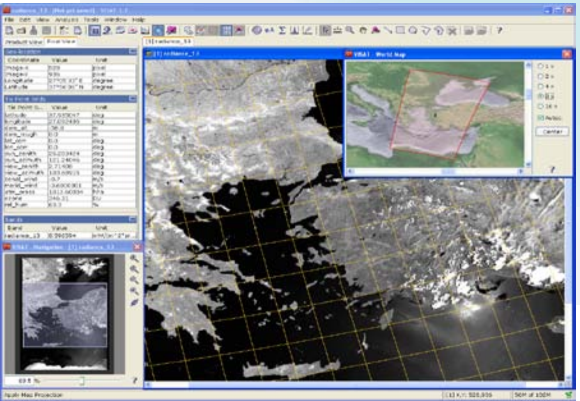
- Data and sensor co-location tools
- Conversion of L1A to L2 at local to regional scale
- Cloud prediction and detection
- Download of swaths or scenes of data
- Spectral libraries for major cover types, vegetation species
- Tools for spectral analysis and assessments: propriety and non-propriety
- Tools for land cover analysis and determinations: propriety and non-propriety

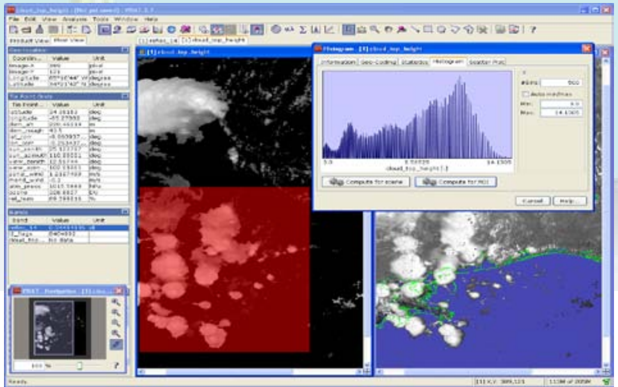


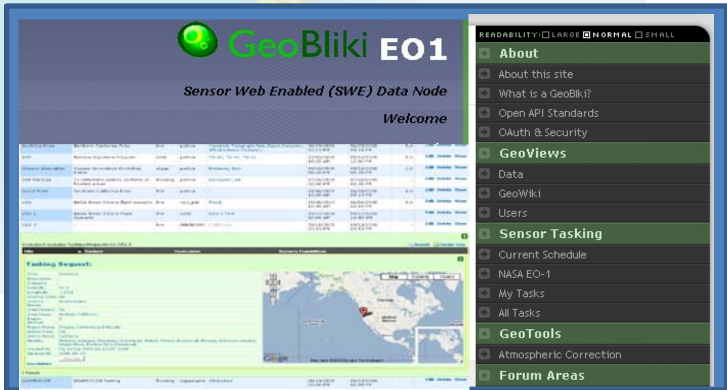
Current Tools - *Examples*

- Visualization and Image Processing of Environmental Resources (VIPER) - Advanced Spectral Mixture Analysis (UCSB, Roberts et al.)
- WINVICAR (JPL, Hook et al.) – work with thermal emissivity data from ASTER, MASTER, other EOS data as well
- Processing Routines in IDL for Spectroscopic Measurements (PRISM, USGS, Kokaly et al.)
- BEAM (C. Brockman/ESA) – data management, viewing and pre-processing for Envisat, PRISM, CHRIS/Proba, AVNIR, MODIS, MERIS, etc.
- Open Source Software Image Map (OSSIM, OSGeo)
- ENVI, ERDAS Imagine, PCI Geomatica, other …
- EO-1 tools for tasking, data management and prototyping



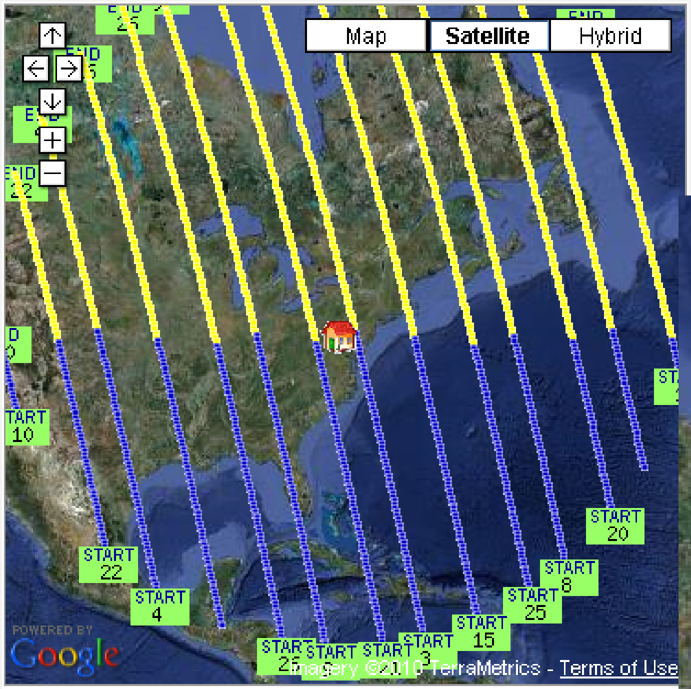






Real Time Satellite Tracking

s up in the sky? FAQ Links Send feedback



#	Day	Mag	Start		Max			End		Map
			LOCAL	Az	LOCAL	Az	El	LOCAL	Az	
2	Apr 29	9.3	20:53:35	102	20:58:10	60	7.64	21:02:45	17	Draw »
3	Apr 29	6.8	22:28:00	162	22:34:45	78	77.77	22:41:30	349	Draw »
4	Apr 30	9.2	00:07:40	223	00:12:40	270	9.15	00:17:40	319	Draw »
8	Apr 30	8.5	21:29:30	128	21:35:25	67	19.23	21:41:20	5	Draw »
9	Apr 30	7.6	23:05:55	184	23:12:35	262	40.75	23:19:10	339	Draw »
10	May 1	9.9	00:50:05	269	00:50:55	276	0.25	00:51:55	285	Draw »
14	May 1	9.7	20:33:30	84	20:36:40	55	3.17	20:39:50	27	Draw »
15	May 1	7.3	22:06:20	150	22:12:55	73	44.87	22:19:30	355	Draw »
16	May 1	8.7	23:44:40	207	23:50:30	266	16.58	23:56:25	328	Draw »
20	May 2	9.0	21:08:35	113	21:13:45	63	11.71	21:19:00	11	Draw »
21	May 2	6.8	22:43:50	171	22:50:35	254	71.54	22:57:25	345	Draw »
22	May 3	9.5	00:24:45	236	00:28:40	272	4.99	00:32:45	310	Draw »
25	May 3	8.1	21:44:50	137	21:51:10	69	27.11	21:57:25	1	Draw »
26	May 3	8.1	23:22:05	193	23:28:30	264	27.81	23:34:55	335	Draw »

Co-locating of HyspIRI data, co-locating with other sensors

http://www.n2yo.com (April 29, 2010)

Earth Observing 1 (EO-1) Campaign Manager on-line Tool

NorthCal Fires	Northern California Fires	fire	patrice	Yosemite Telegraph Fire, Basin Complex, Whiskeytown Complex, ...	06/29/2008 02:13 PM	06/29/2008 09:18 PM	0.4	Edit Delete Show
NSP	Nationa Signature Program	intel	patrice	TA-03, TA-02, TA-01	03/03/2008 10:25 AM	05/16/2008 12:42 PM	0.2	Edit Delete Show
Oceans Innovation	Oceans Innovation Workshop Demo	algae	patrice	Monterey Bay	09/10/2008 06:18 PM	09/16/2008 06:38 PM	1.0	Edit Delete Show
Salt Marshes	To determine salinity contents of flooded areas	flooding	patrice	Lancaster, VA	07/26/2008 02:36 PM	07/26/2008 02:36 PM	-	Edit Delete Show
SoCal Fires	Southern California Fires	fire	patrice	-	09/06/2007 12:00 AM	06/28/2008 09:23 PM	0.0	Edit Delete Show
UAV	NASA Ames Ihkana flight scenario	fire	veri_pat	Flood	09/06/2007 12:00 AM	06/04/2008 02:00 PM	0.0	Edit Delete Show
UAV 2	NASA Ames Ihkana Flight Scenario	fire	scott	UAV 2 Test	09/17/2008 12:40 AM	09/17/2008 12:40 AM	-	Edit Delete Show
UAV 3	-	fire	UNKNOWN	California	09/18/2008 03:53 PM	09/18/2008 03:53 PM	-	Edit Delete Show

http://geobpms.geobliki.com/

Scenario/Campaign Tasking Requests for UAV 3

Search Create New

Title	Content	Geolocation	Scenario Feasibilities

Tasking Request:

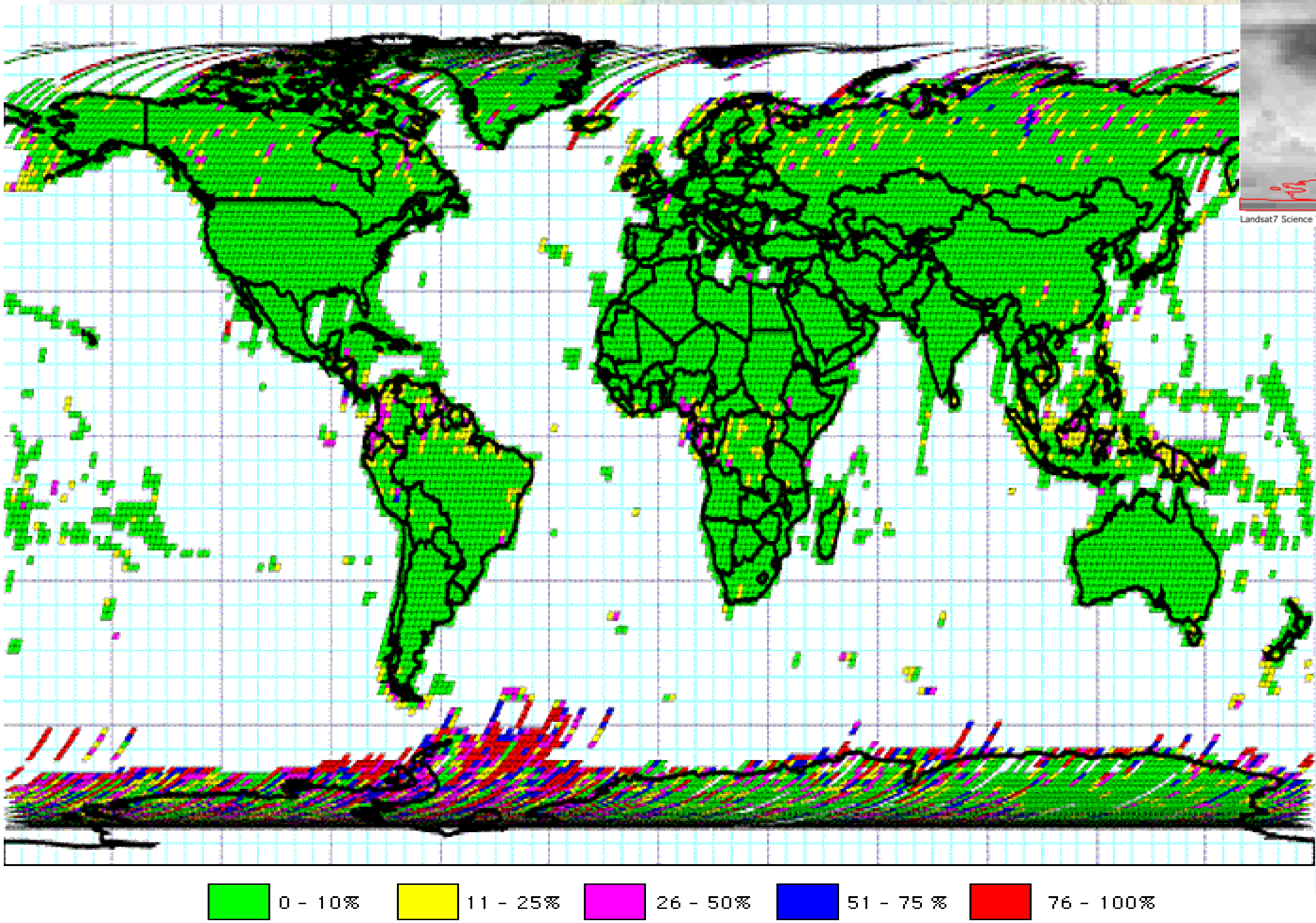
Title:	California
Description:	
Category:	
Latitude:	41.3
Longitude:	-123.8
Country Code:	US
Country Name:	United States
Zone Number:	36
Zone Name:	Northern California
Region Number:	3
Region Name:	Oregon, California and Nevada
Admin Code:	CA
Admin Name:	California
Nearby:	Notchko, Surgone, Shregegon (historical), Mettah, Pekwan (historical), Pecwan, Johnsons, Waseck, Wright Place, Martins Ferry (historical)
Created At:	Fri, 19 Sep 2008 02:32:22 -0000
Updated At:	2008-09-19
	Show Map
Feasibilities	

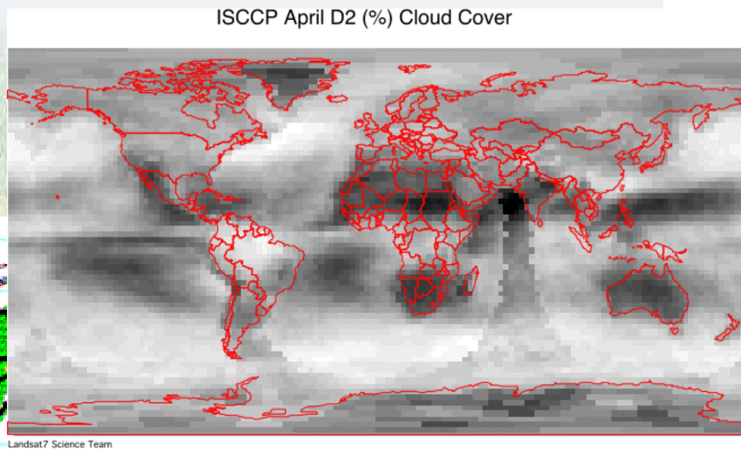
1 Found

USAFRICOM	USAFRICOM Testing	flooding	cappelaere	Zimbabwe	06/19/2008 02:58 PM	06/19/2008 02:58 PM	-	Edit Delete Show

Cloud Prediction, utilizing historic data and weather satellites

Landsat 7 Lowest cloud level for acquisitions during the first year





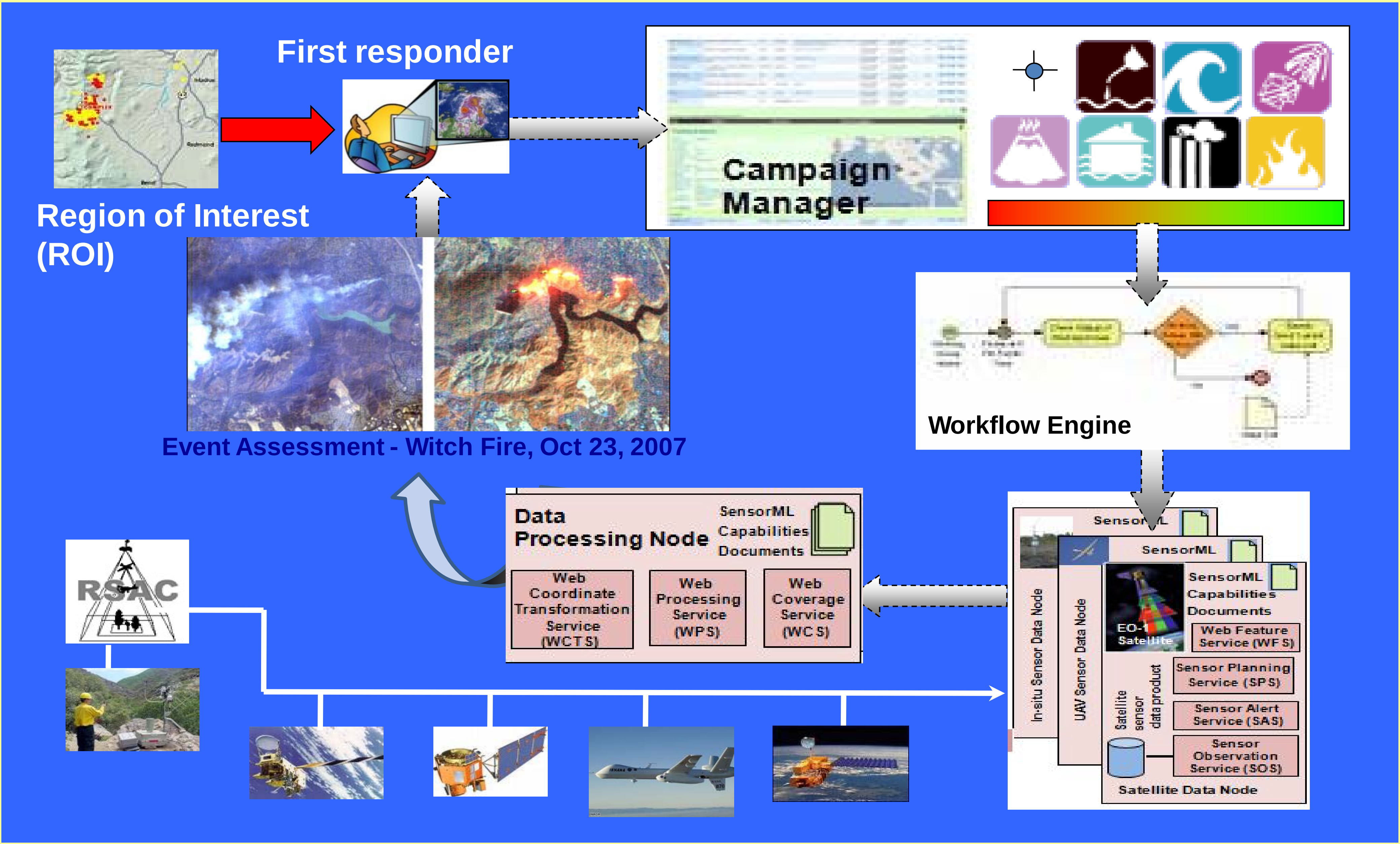
International Satellite Cloud Climatology Project (Rossow et al. 1989)

Hyperion Cloud Cover (HCC)

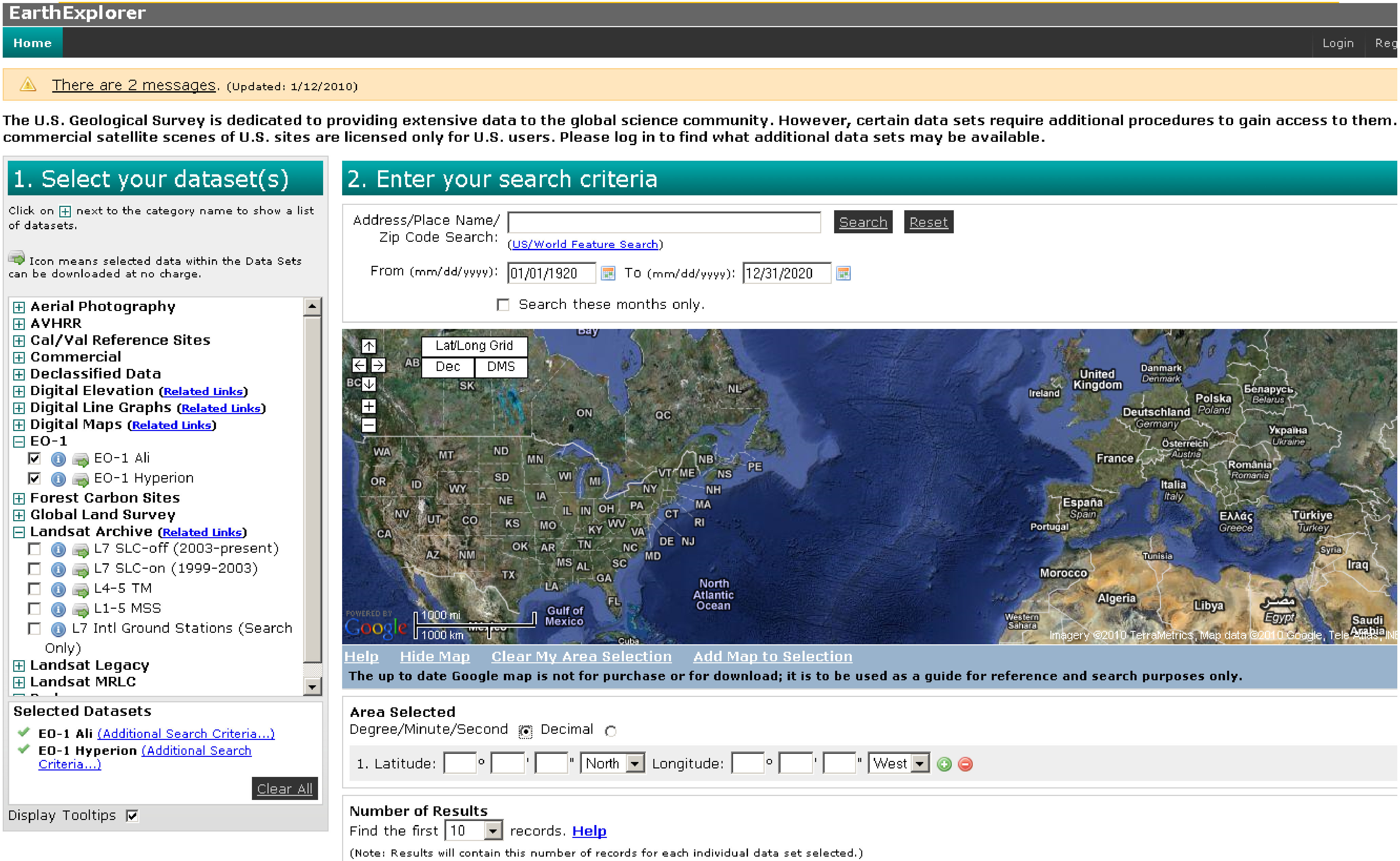
Band (µm)	Usage
0.55	Snow/ice/cloud test
0.66	Red reflectance test Vegetation ratio test
0.86	Vegetation ratio test Desert/sand test
1.25	Snow/ice/cloud test Desert/sand test
1.38	High cloud test Ice/low cloud test
1.65	Snow/ice/cloud test Desert/sand test

Mandl, Griffin et al. 2003
Gao et al. 1995, 1998

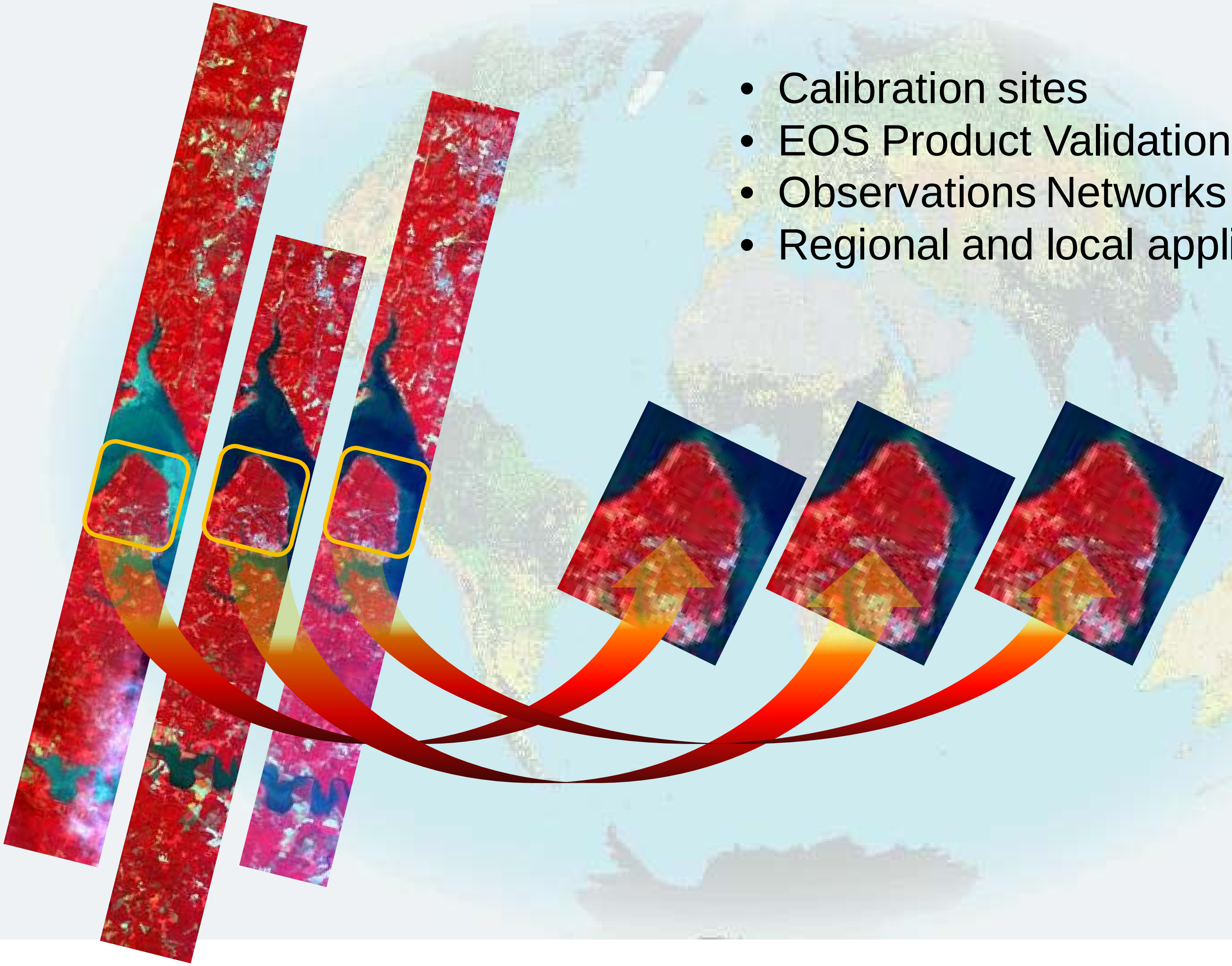
EO-1 SensorWebs serve as a Pathfinder for Event Assessments and Enabling of Rapid Response Remote Sensing



Downloading Whole Scenes



Tools to Download Regions of Interest

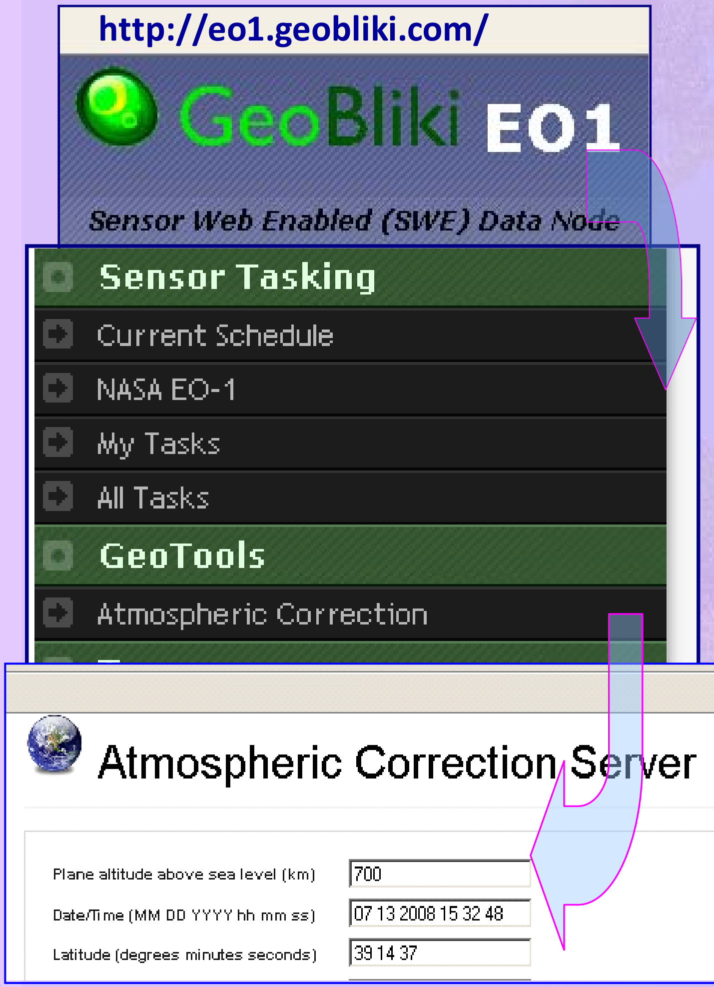


- Calibration sites
- EOS Product Validation sites
- Observations Networks
- Regional and local applications

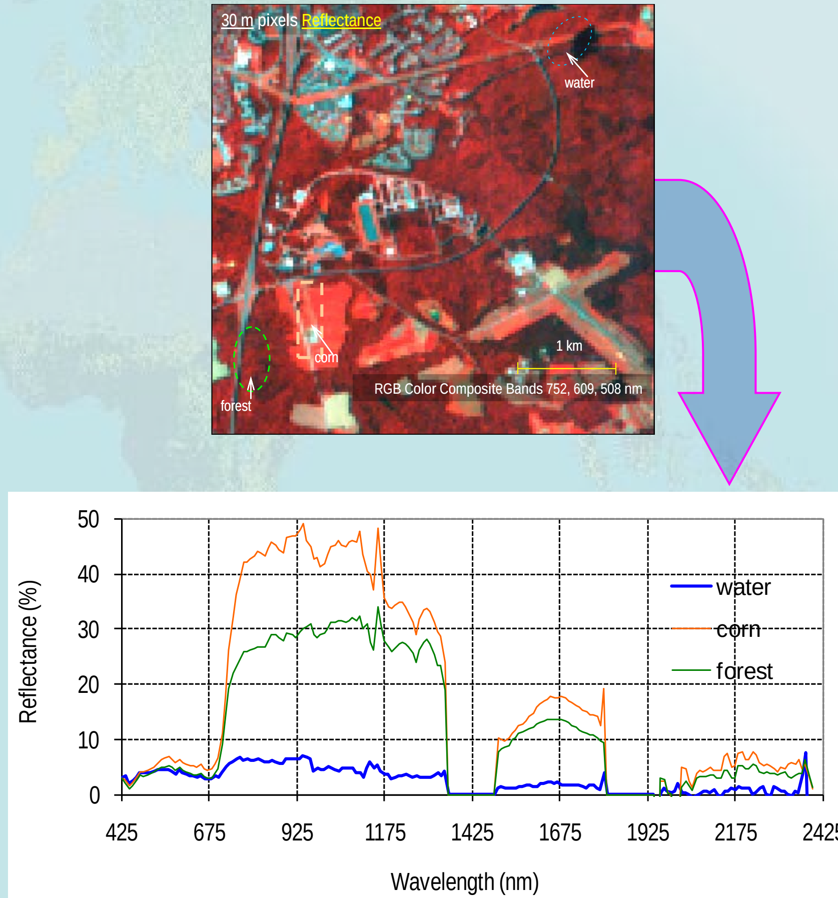
Tools and Prototype Reflectance Product Algorithms

albedo; fAPAR; LAI; spectrum derivatives; chlorophyll, N, water content…..

EO-1 Toolkit



EO-1 Product Prototypes



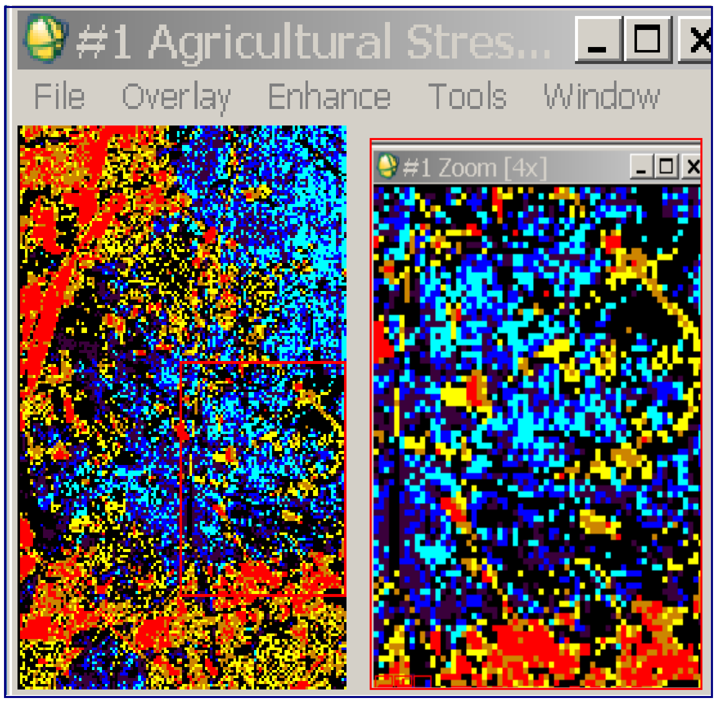
Developing Higher level EO-1 Hyperion Science Products

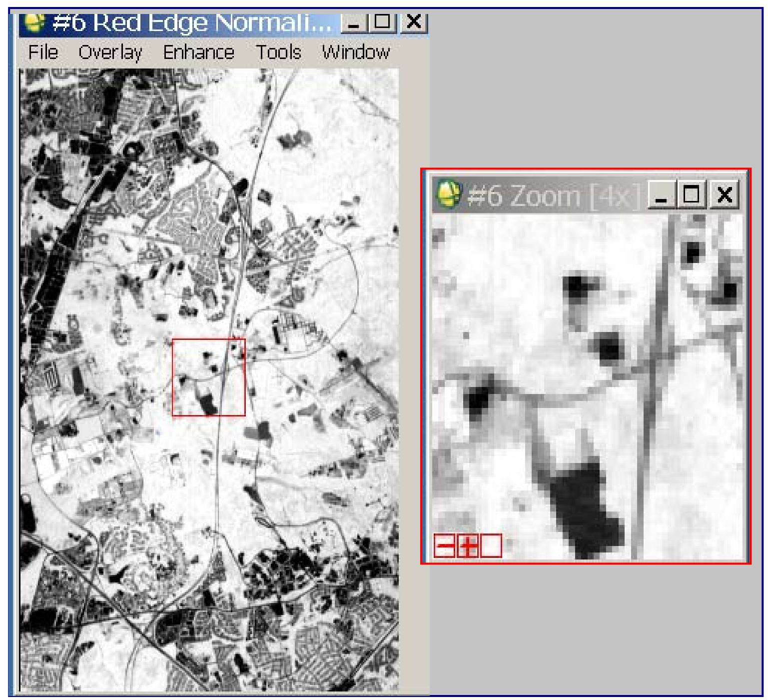
Vegetation Indices and Albedo for major Crops and Land Cover Types (example for Greenbelt, MD)

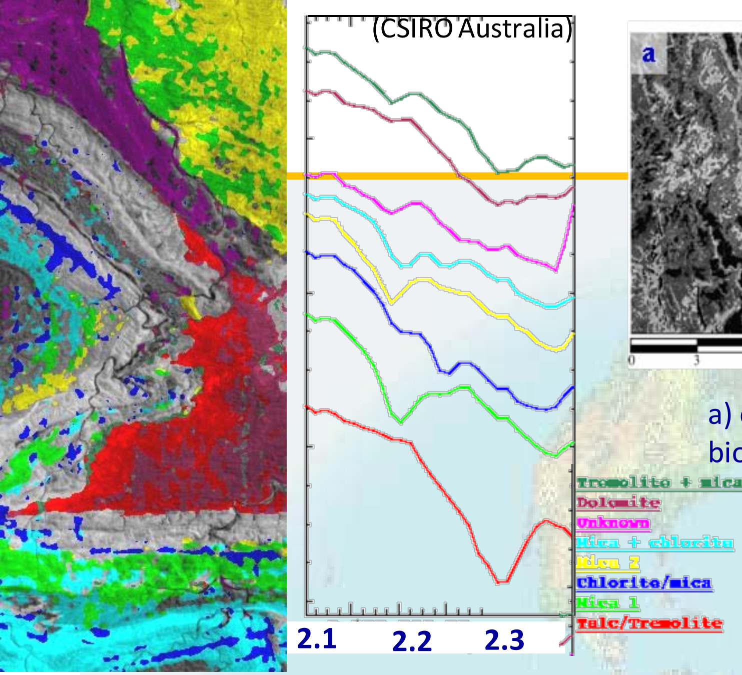
Pixel size	Vegetation Indices*						Albedo		
	V1	PRI	REIP	Dmax	NDWI	NDVI	water	corn	forest
30 m	1.81	-0.14	721	0.749	0.14	0.81	0.03	0.20	0.14
60 m	1.88	-0.15	721	0.748	0.15	0.82	0.04	0.20	0.13

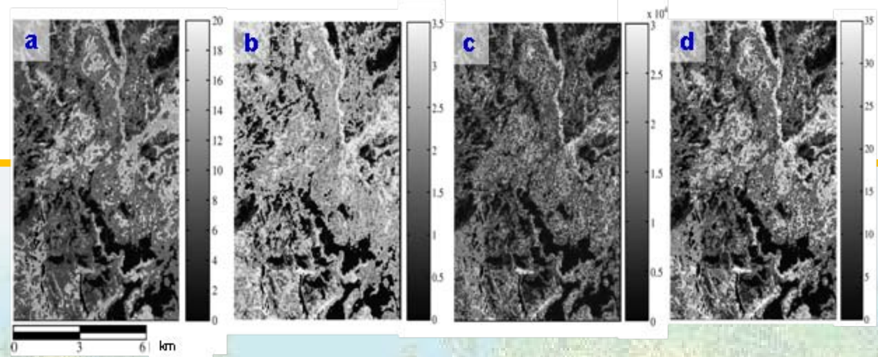
* Reported means, no statistically significant differences established

- **Enabling conventional users to conduct their own assessments, using software such as ENVI (Agricultural stress and Red edge Greenbelt, MD)**

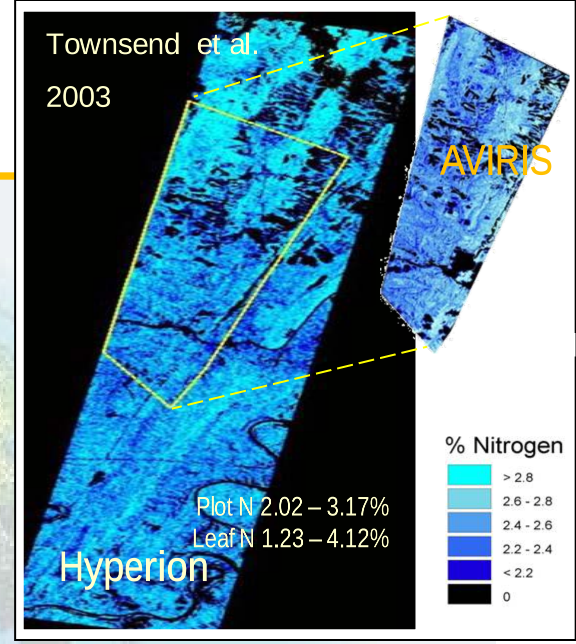






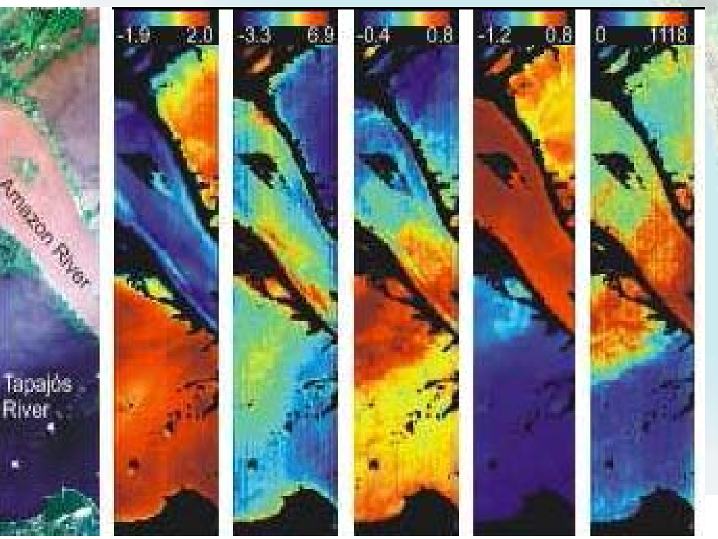


a) canopy height (m); b) Shannon species richness; c) biomass (kg/0.1 ha); d) basal area (m2/ha)
(Kalacska et al. 2007)

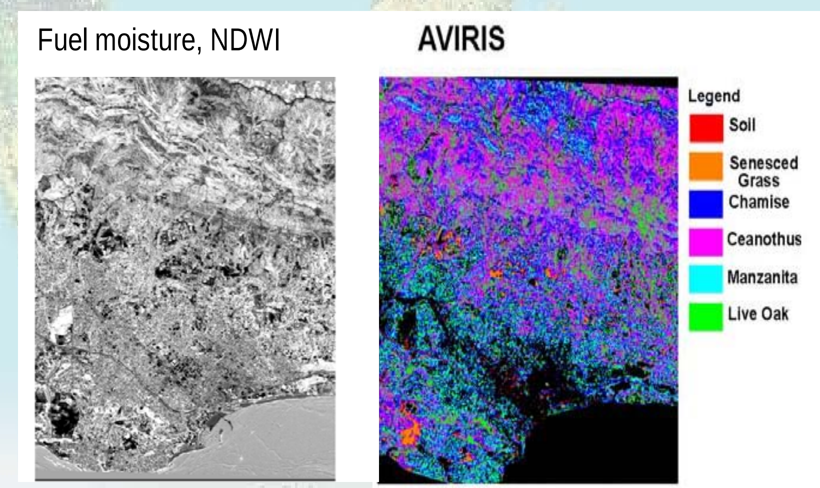


10/23/07
EO-1 Hyperion
Witch Wildfire

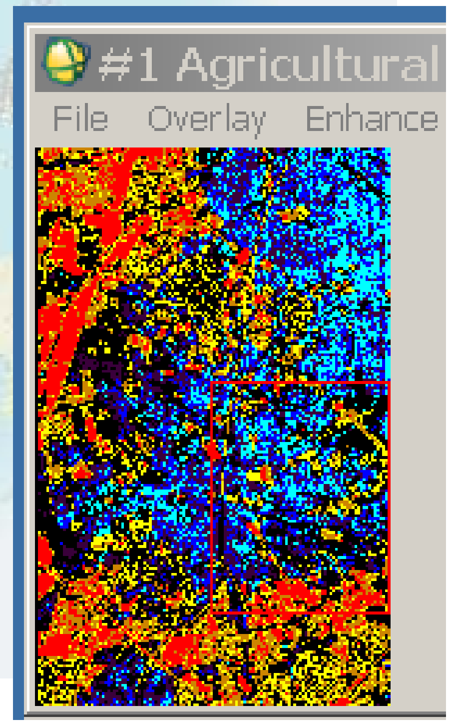
(a) (RGB: 640; 549; 457nm). Hyperion fractional end-member abundance results presented as color images: (b) *f*clear-water; (c) *f*DOM; (d) *f*phytoplankton; (e) *f*SIM; (f) RMS error.



(a) (b) (c) (d) (e) (f)



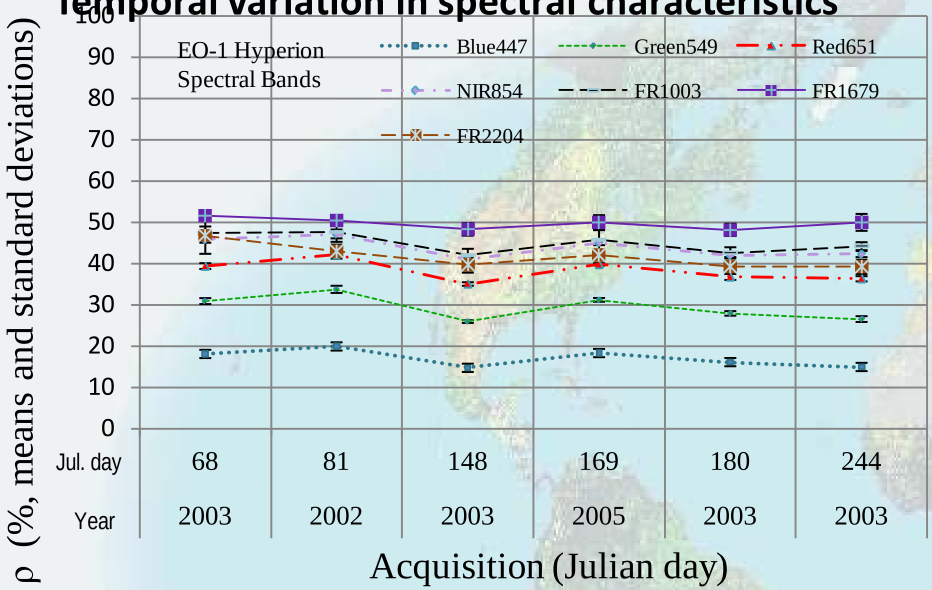
Roberts et al.



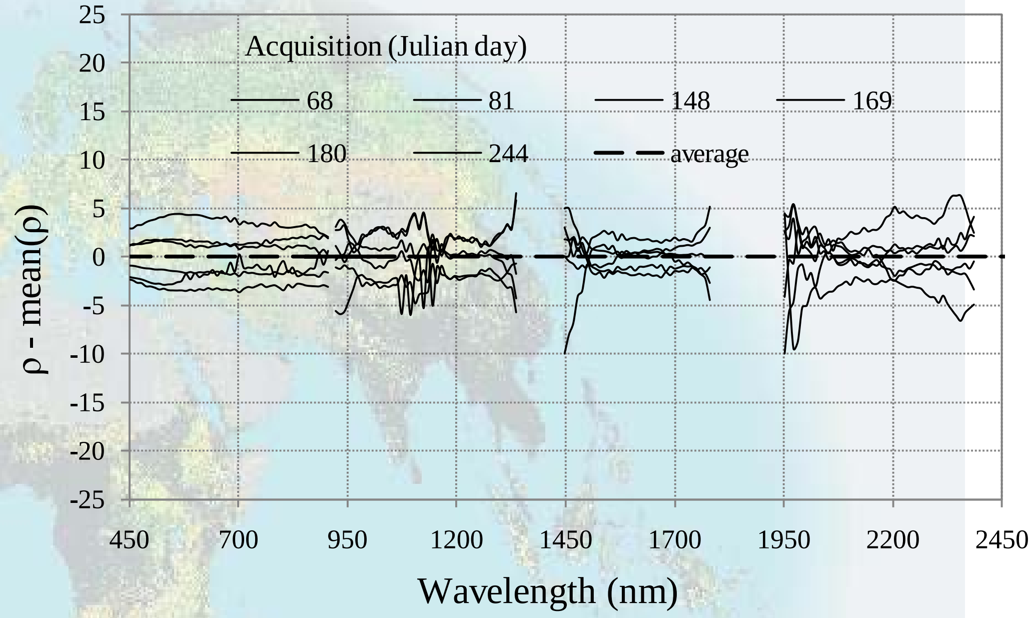
(ENVI/ Asner)

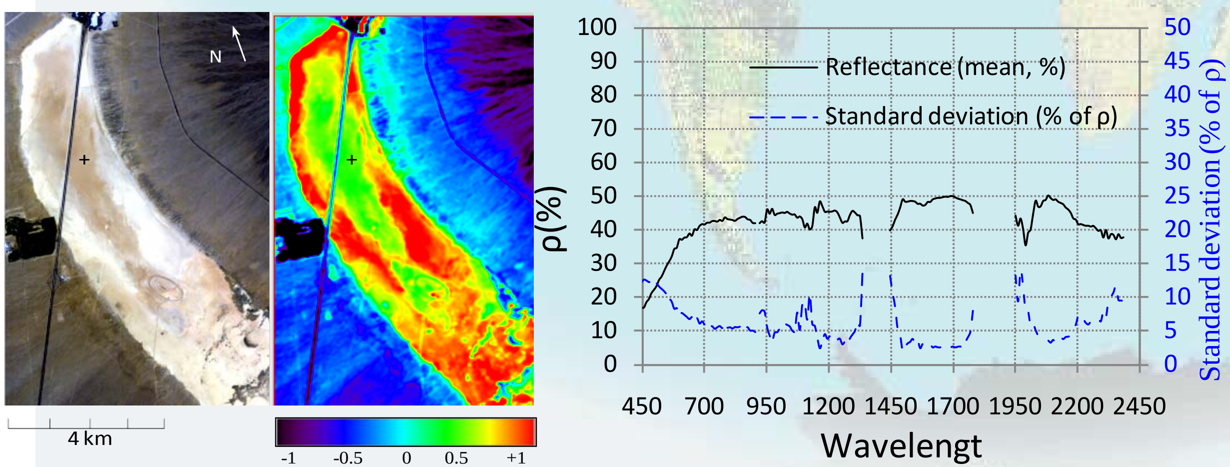
Time Series for CEOS Cal/Val Sites

Temporal variation in spectral characteristics



Reflectance differences

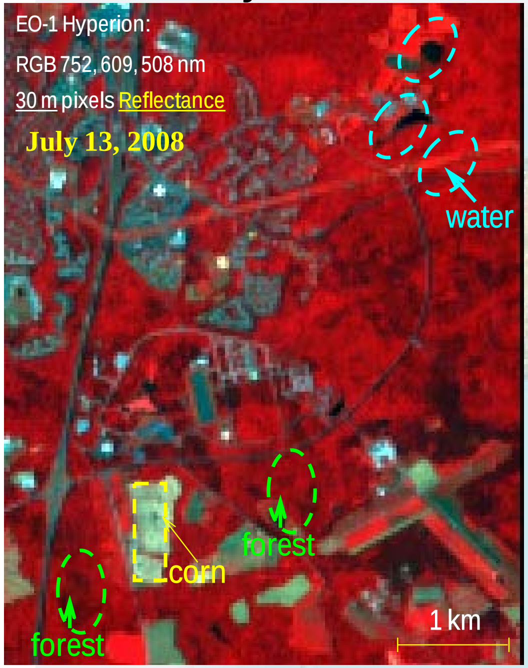


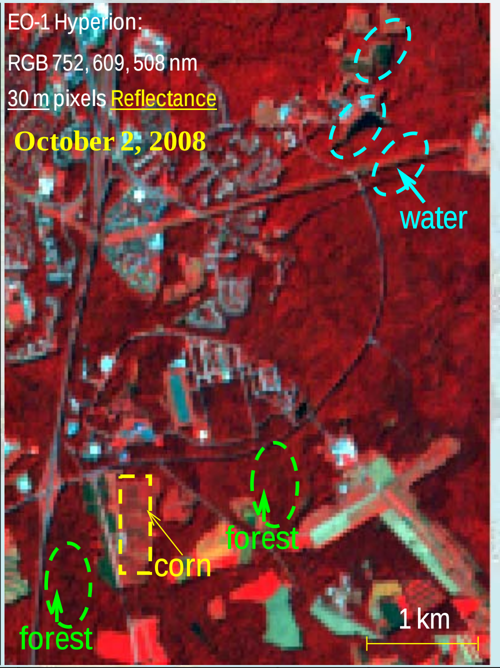


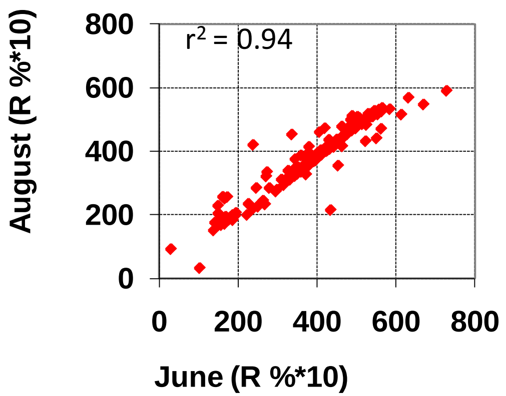
Example from Ivanpah playa: Natural color composite (RGB: 651, 549, 447), Getis Gi* statistics (band 549), Reflectance Mean and Standard Deviation

Time Series Composites for EOS Vegetative Sites

Seasonal Dynamics of Major Land Cover Types, USDA ARC, Greenbelt, MD



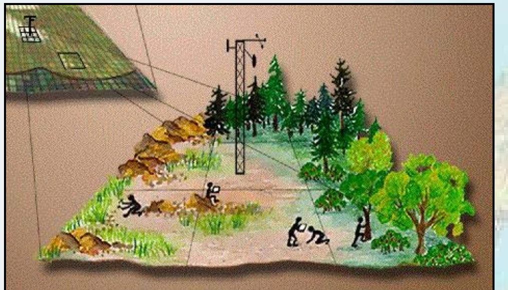




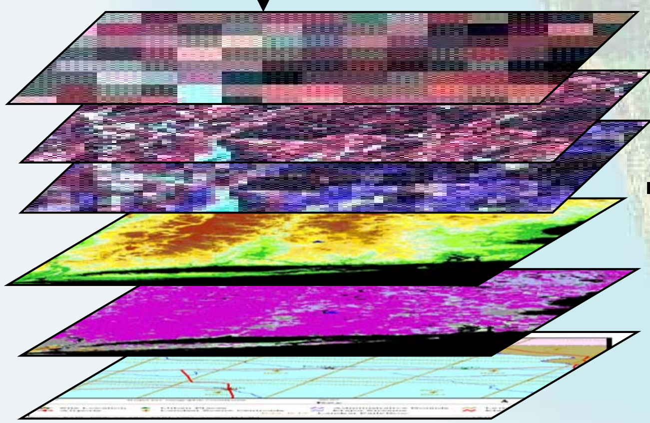
Cover Type	Hyperion, 2008	V1	PRI	REIP	Dmax	WBI	Albedo
Corn	13-Jun	1.03	-0.04	712	0.36	0.96	0.461
	18-Aug	1.81	-0.06	722	0.75	1.09	0.197
	3-Oct	1.15	0.04	721	0.51	0.98	0.155
Forest	13-Jun	1.12	-0.06	712	0.89	1.00	0.257
	18-Aug	1.56	-0.03	722	0.51	1.01	0.140
	3-Oct	1.61	-0.10	712	0.42	0.94	0.127
Water	13-Jun	0.15	0.01	712	0.16	1.23	0.058
	18-Aug	0.52	0.02	712	0.10	1.46	0.031
	3-Oct	0.62	-0.07	712	0.08	0.93	0.036

Calibration and Validation Tools

Goal: Uncertainty assessment of high spectral and spatial resolution products, Confirmation/validation of high temporal resolution multi-spectral GLCPs and trends



Calibration & Validation of HyspIRI products to field/tower data



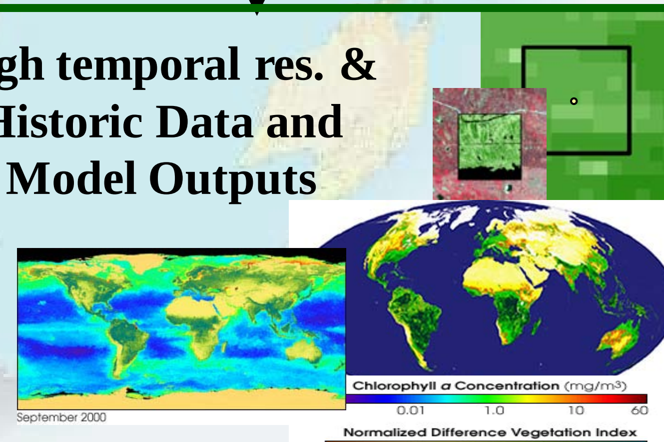
Simulation of Data and Products from Other Sensors

Multi-Spectral
- AVHRR
- Landsat
- MODIS
- VIIRS

High Spectral Res.
- EnMAP, DLR
- PRISMA, ASI
- CHRIS - Proba

Correlate **Provide Context**

High temporal res. & Historic Data and Model Outputs



After CEOS WGCV/LPV (LCP Simulation and inter-comparison, Morrisette et al. 2006; and Shunlin Liang, UMD)

Tools/Products to be Developed

- Tools combining the use of TIR and High Spectral Resolution Data
- Different tools for local & regional and for continental & global scale L1A to L2, analysis and detection
- Work with time series - download of composites at regions of interest, on-line evaluation of spectra at ROI
- Change Event Delineation and Characterization - incl. clouds, fires, volcanoes, water properties
- Cal/Val tools – at select sites time series collection, simulation of other sensors, simulation of global products
- Spectral database/libraries for major FLC, FVC and PFT types

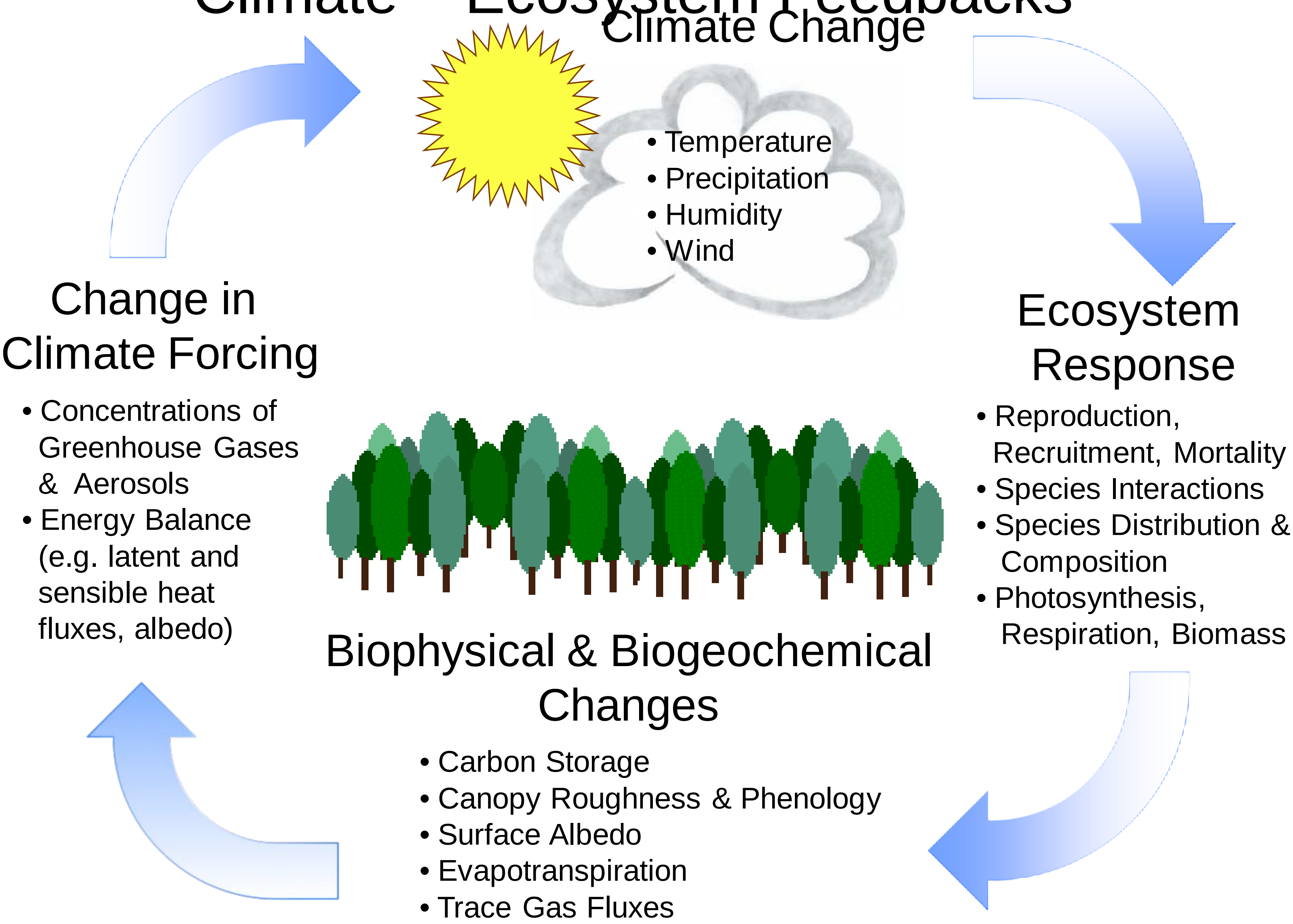
WE NEED YOUR INPUT !

Petya.Campbell@nasa.gov

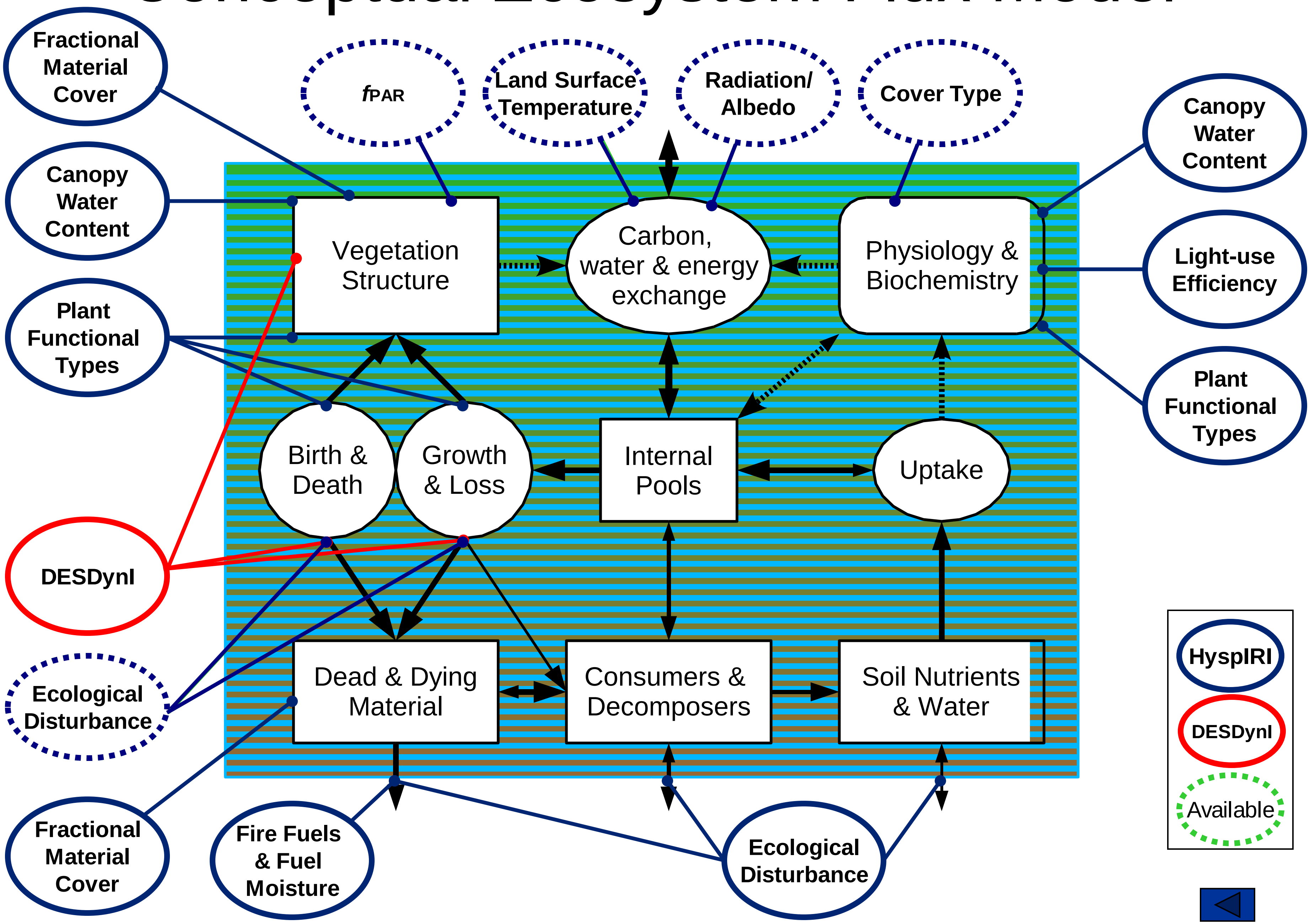
HyspIRI Input to Models

K. Fred Huemmrich
GSFC HyspIRI Symposium on Ecosystem Data Products
May 4, 2010

Climate – Ecosystem Feedbacks



Conceptual Ecosystem Flux Model



Modeling Approaches

- Diagnostic models
  - Describes fluxes, e.g. Light Use Efficiency models

  - Inputs from HyspIRI include
    - PRI
    - Chlorophyll concentrations
    - Canopy water content
    - fPAR
    - Albedo
    - Radiometric surface temperature

Diagnostic models

- Diagnostic models and HyspIRI
  - Mission too short to directly observe climate change effects
  - VSWIR will not provide a dense time series
    - Merge with temporally frequent broadband data to improve temporal resolution
  - Output at spatial scale appropriate for land management
  - Provides validation data sets for prognostic models
  - Use to develop and test algorithms that can feed into prognostic models
    - e.g. examining effect of foliage N content on photosynthetic stress responses in different plant functional types

Modeling Approaches

- Prognostic models
  - Can be utilized to provide predictions and projections
- HyspIRI produced input data fields
  - New types of data for inputs, e.g. better descriptions of Plant Functional Types
  - Provide seasonally changing input values
  - Higher spatial resolution and improved classification provide better understanding of mixtures

HyspIRI Model Inputs

- Leaf nitrogen
  - photosynthetic rates
- Disturbances
  - Thinning and diffuse disturbances
  - May have important effects on carbon and water fluxes
- Species distributions (functional biodiversity)
- Biomass in low stature ecosystems (grasslands, shrublands, etc.)
  - Cover types with the largest areas
  - May be significant biomass changes with increased shrubs

Plant Functional Types

- PFT often defined based on landcover classification
  - HyspIRI will produce improved landcover classifications
- PFT can be defined by direct measurement of a suite of variables such as:
  - Green/nongreen fractions
  - Maximum photosynthetic rate
  - Photosynthetic efficiency
  - Green leaf area
  - Foliage Nitrogen
  - Leaf water content
  - Pigment concentrations
  - Albedo
  - Sensitivity to climate change (e.g., inferring rooting depth from stress responses)

Conclusions/Issues

- Model improvements occur through
  - Improved algorithms
  - Utilization of new types of information
  - Improved accuracy of input data fields
  - More and better data for validation
- How do we facilitate using HyspIRI data to improve models?
  - Development of ways to organize and manage the huge data volumes from HyspIRI
    - Ability to extract level 2+ data for study sites
    - Standardized gridding of global products
      - Cloud-free composites
    - Tools to make it easy to link HyspIRI data with other data products

Extending EOS and CEOS WGCV Land Product Validation Sub-group activities to the HyspIRI era

Joanne Nightingale, Jaime Nickeson (Sigma Space Corporation)
Petya Campbell (UMBC)
Rob Green (JPL)

Outline

- LPV sub-group
  - Structure
  - Goals and objectives
- HyspIRI products
- Importance of scaling
- Examples HyspIRI products <--> validation
  - Biophysical
  - Land cover
  - Fire
- Test validation activities
- Things to consider…

Land Product Validation Sub-group

CEOS *(Committee on Earth Observing Satellites)*

WGCV *(Working Group on Calibration and Validation)*

Chair: Joanne Nightingale (NASA GSFC)

Vice-Chair: Gabriela Shaepman-Strub (University of Zurich)

NASA EOS Validation: Joanne Nightingale / Jaime Nickeson

6 Land Product Focus Groups

- Established in June 2009
- 2 co-leads per group
- ~3-year terms

LPV Focus Groups

Focus Group	North America	Europe / Other
Land Cover	Mark Friedl (Boston University)	Martin Herold (Wageningen University, NL, GOFC/GOLD)
Fire (Active/Burned Area)	Luigi Boschetti (University of Maryland)	Kevin Tansey (University of Leicester, UK)
Biophysical (LAI, *f*APAR)	Richard Fernandes (NR Canada)	Stephen Plummer (ESA, IT)
Surface Radiation (Reflectance, BRDF, Albedo)	Crystal Schaaf (Boston University)	Gabriela Schaepman (University of Zurich, SW)
Land Surface Temperature	Simon Hook (JPL)	Jose Sobrino (University of Valencia, SP)
Soil Moisture	Tom Jackson (USDA)	Wolfgang Wagner (Vienna University of Technology, AT)
Land Surface Phenology	Jeff Morisette (USGS)	TBD

LPV Objectives

To foster **quantitative validation** of *higher level global land products* derived from remotely sensed data, in a traceable way, and relay results so they are relevant to users

- To increase the quality and efficiency of global satellite product validation by developing and promoting international standards and protocols for:
    - Field sampling
    - Scaling techniques
    - Accuracy reporting
    - Data / information exchange
- To provide feedback to international structures (GEOSS) for:
    - Requirements on product accuracy and quality assurance (QA4EO)
    - Terrestrial ECV measurement standards
    - Requirements for future missions

HyspIRI Products

Existing Val Methods

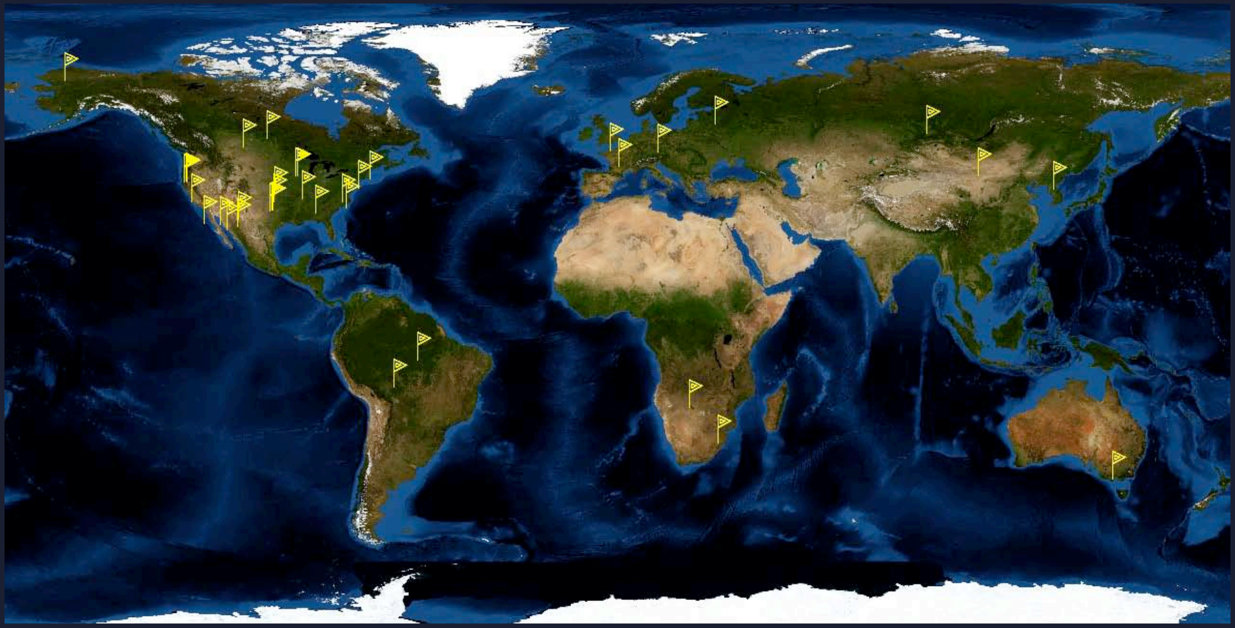
Research Required

LPV Focus Group / Product	VSWIR L 2/ 3	VSWIR L4	VSWIR Global	TIR L4	SWIR / TIR
LAND COVER					
Fractional land cover / veg cover					
Disturbance, PFT, hazard susceptibility					
SURFACE RADIATION					
Surface Reflectance					
Albedo					
BIOPHYSICAL					
Gross / Net Primary Production					
fPAR					
LAI					
Water content, LUE, Pigments					
FIRE					
Detection of Fire events					
Fire fuel loads					
LAND SURFACE TEMPERATURE					
LST					
Emissivity					
Evapotranspiration					

HyspIRI product ⟷ Validation

- Methods and structures in place for validation of most land products (field sampling, sites, networks etc)
- Current validation activities lack:

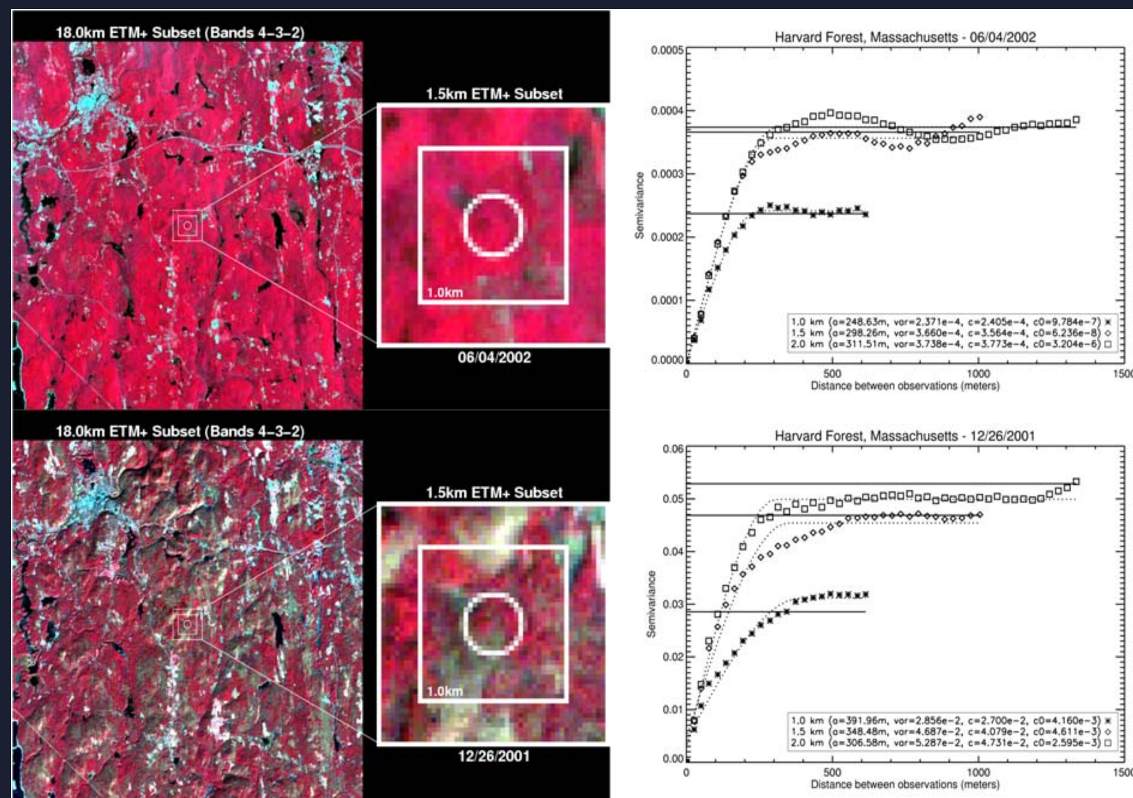
1. A consistent temporal component
   - A lot of high resolution image capture is opportunistic
2. Spatial coverage (global)



EOS Land Validation Core Sites

Importance of Scaling

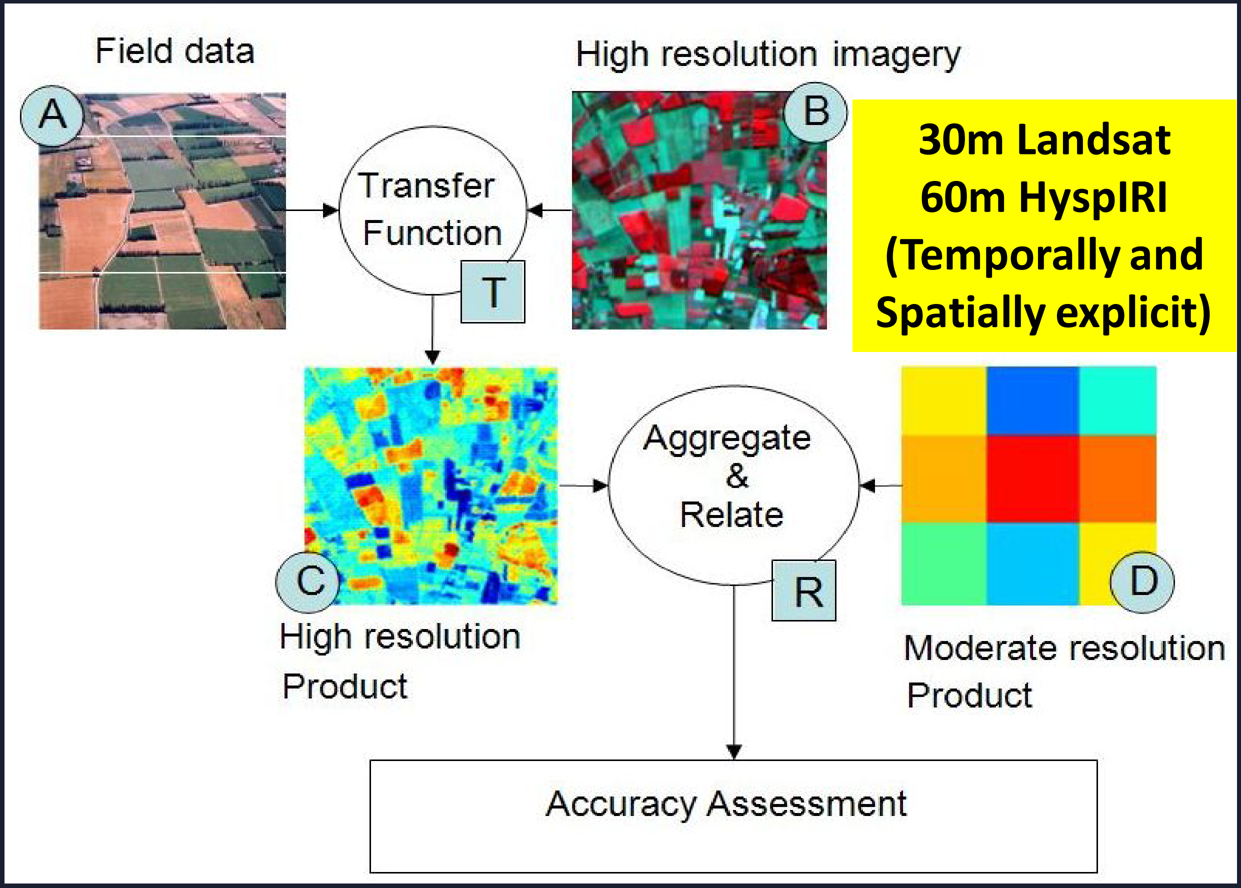
- Point to Pixel validation is unacceptable
- Site characterization using Landsat ETM - representativeness, homogeneity and seasonal consistency for validation
  - HyspIRI will provide enhanced spatial / temporal capabilities for assessing validation sites



Roman et al. 2010

Scaling of Biophysical Products

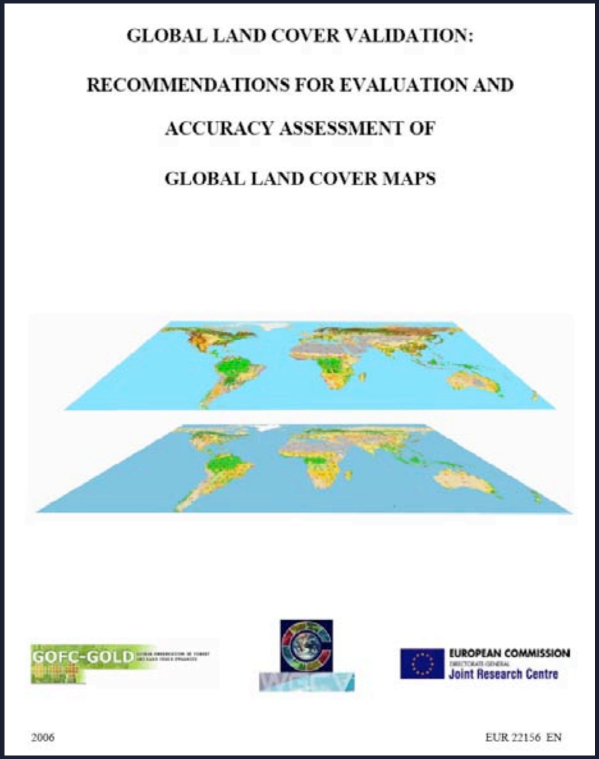
- LAI, fPAR, GPP, NPP, Albedo
- Protocol for ground sampling, scaling and validation of LAI, fPAR and albedo products in preparation



- HyspIRI will provide enhanced spatial / temporal capabilities for scaling activities (bridge 30m – 250m/1km+ gap)

Enhanced Land Cover

- EOS, GOFC-GOLD, LPV, FCT
- Land cover validation protocol from 2006 being updated
- Global land cover validation exercise in progress
- HyspIRI will bring enhanced land cover classification accuracy
- Better land/water boundary maps
- Definition of functional types which will improve biophysical models used to generate GPP/NPP products



GLOBAL LAND COVER VALIDATION:

RECOMMENDATIONS FOR EVALUATION AND

ACCURACY ASSESSMENT OF

GLOBAL LAND COVER MAPS

GOFC-GOLD

EUROPEAN COMMISSION

Joint Research Centre

2006 EUR 22156 EN

CEOS WORKING GROUP ON CALIBRATION & VALIDATION

Fire

- EOS, LPV, GOFC-GOLD Fire
- Protocol for Burned Area product validation in preparation
- Current methodology uses 2 sequential Landsat ETM+ images retrieved within the persistence time of the burned area
- Limited spatial and temporal capability of Landsat acquisitions
- Will provide improved validation data for coarse resolution fire products

Image 1: 3 Sept 2001

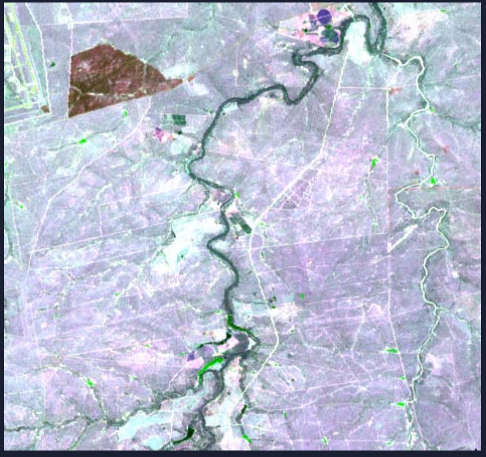
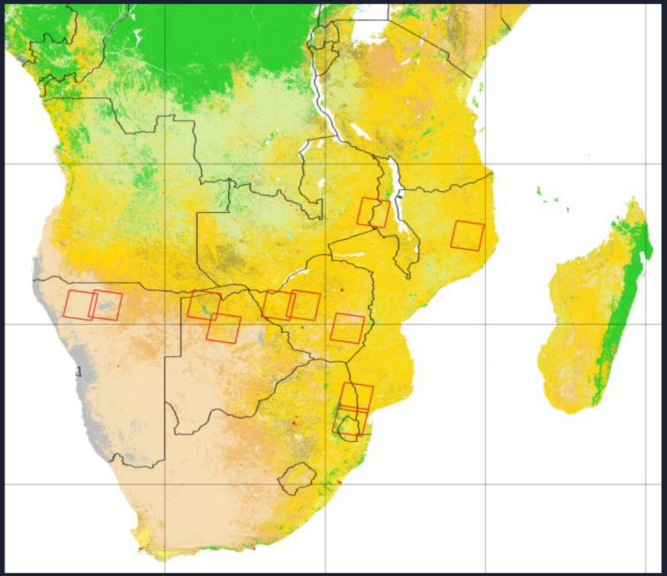
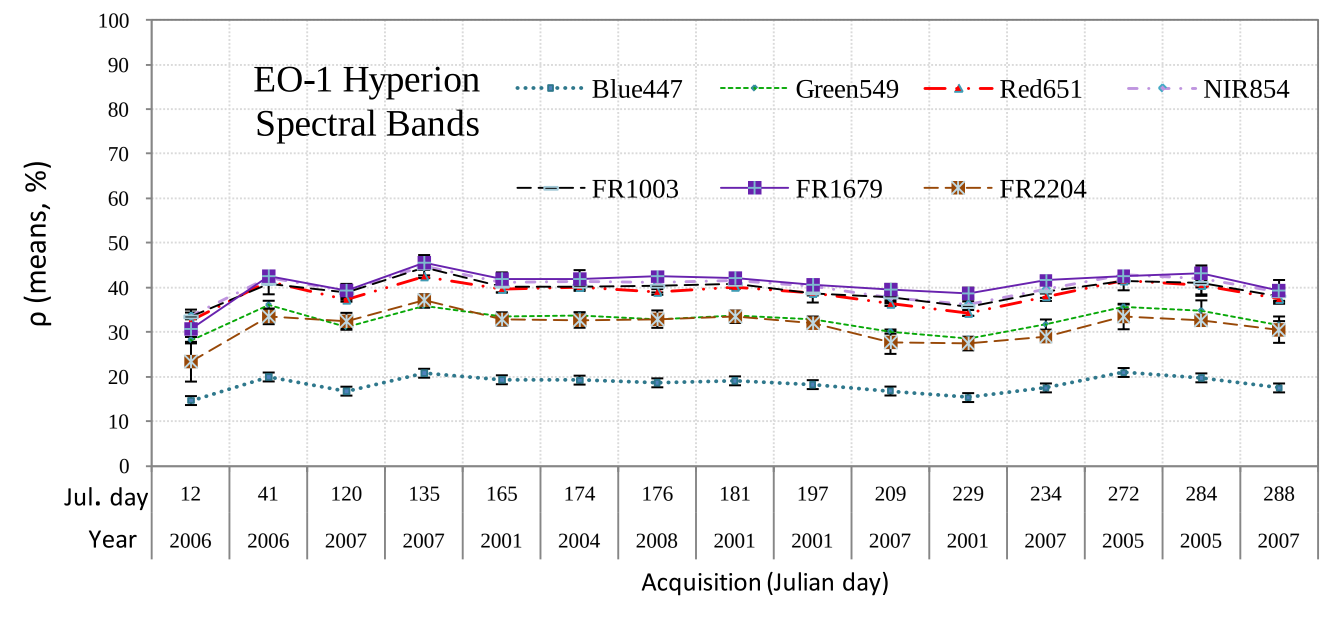


Image 2: 5 Oct 2001



Test Validation Activities

- Use of Hyperion for validation approach testing
  - Hyperion archive being collected at Core Sites



Temporal variation in spectral characteristics, Railroad Valley, NV

Similar datasets are being assembled at other CEOS Cal/Val and LPV sites

- Airborne measurements for validation and scaling
  - AVIRIS, AVIRISng, MASTER, HyTES, etc
- North America through the seasons
- International campaigns

Things to Consider….

- Methods and structure in place for validation of most land products
- Require more! / improvement boosted by validation campaigns for new sensors / products
- Important to understand products and ways of validating now, approach networks (Fluxnet, NEON etc), design field campaigns, leverage existing data sources
  - How will we validate new products / What do we need??
- Ensure validation protocols written by LPV sub-group are relevant to HyspIRI (coordination and collaboration)

For more information

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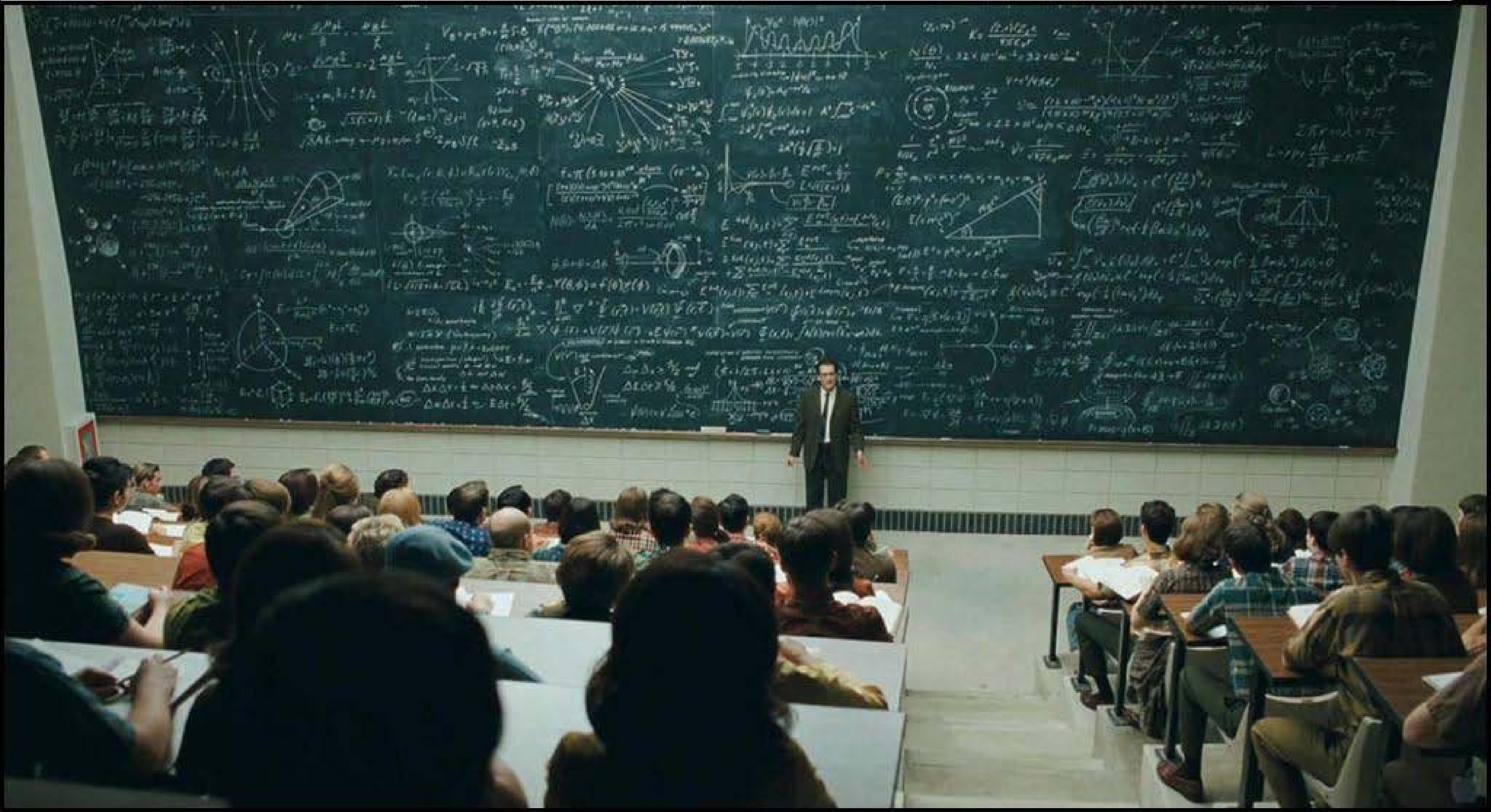
Jaime.E.Nickeson@nasa.gov

Or visit:

http://lpvs.gsfc.nasa.gov/

All you need to know about spectral/spatial alignment impact on derived-parameter uncertainty *in 10 minutes*

Steve Ungar – NASA/GSFC Scientist Emeritus
HyspIRI Science Symposium – NASA GSFC – May 4, 2010



Spectral/Spatial Alignment Impact

Multi-Spectral

Band-to-band misalignment limits parameter estimation accuracies at pixel, regional and global scales *which can<u>not</u> be "corrected" by re-sampling (e.g. Bilinear interpolation).*

Even perfectly aligned observing systems provide pixel and regional scale measurements sensitive to spatial sampling *which can<u>not</u> be adequately "adjusted" through re-sampling.*

Spectral/Spatial Alignment Impact

Why is this important?

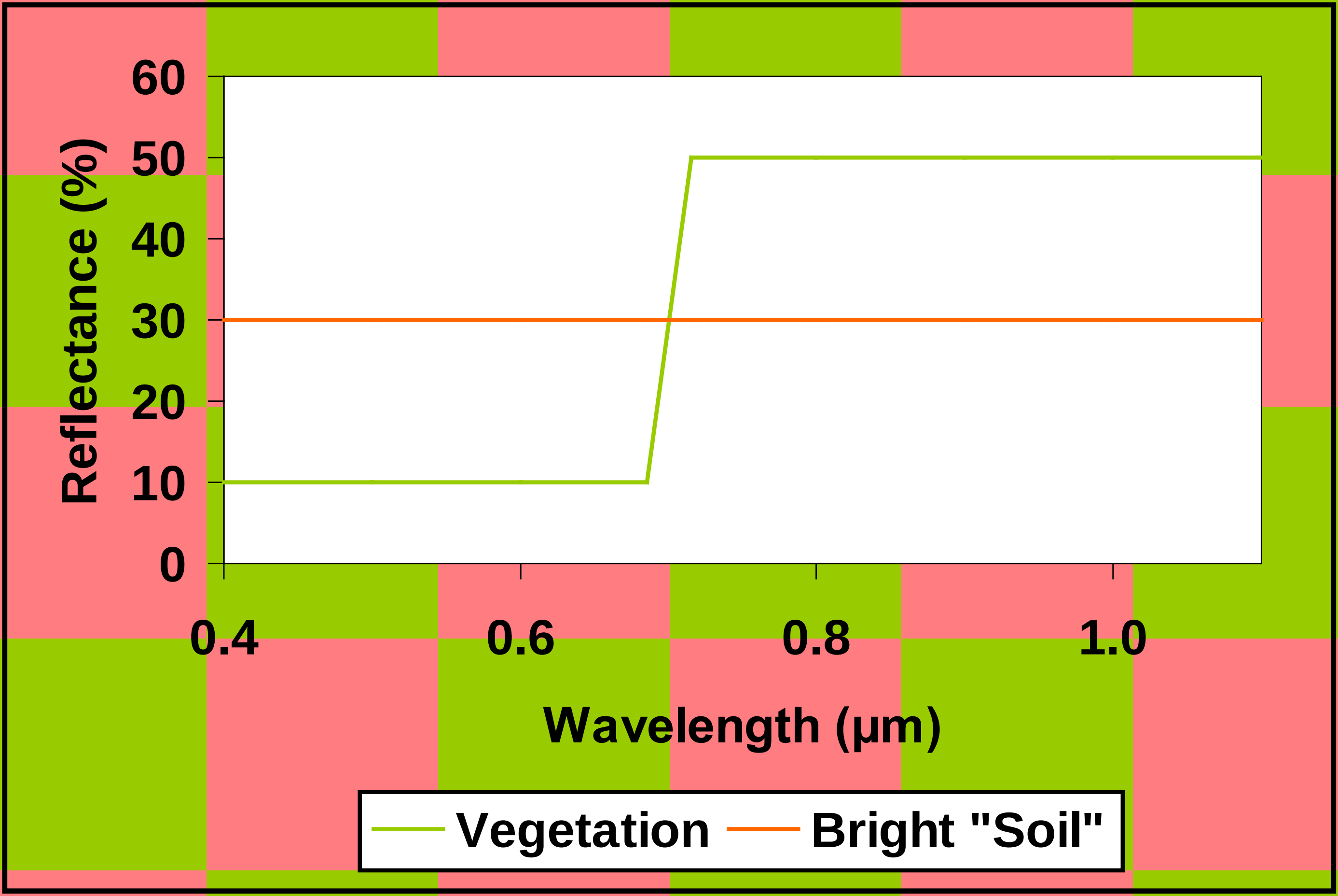
Biophysical parameters are derived by using combinations of spectral band reflectance values (e.g. band ratios) at the pixel level.

Continuously Spectral

Properly designed imaging spectrometers possess Inherent spectral/spatial integrity.

Spectral content can be used to mitigate the impact of temporal sampling offsets.

Synthetic Scene Composition



Landscape Reflectance Values
Synthetic Scene Scenario

.3	.1	.3	.1
.1	.3	.1	.3
.3	.1	.3	.1
.1	.3	.1	.3

VIS Reflectance

.3	.5	.3	.5
.5	.3	.5	.3
.3	.5	.3	.5
.5	.3	.5	.3

NIR Reflectance

Landscape Reflectance Ratios
Synthetic Scene Scenario

NIR Reflectance

.3	.5	.3	.5
.5	.3	.5	.3
.3	.5	.3	.5
.5	.3	.5	.3

VIS Reflectance

.3	.1	.3	.1
.1	.3	.1	.3
.3	.1	.3	.1
.1	.3	.1	.3

=

1	5	1	5
5	1	5	1
1	5	1	5
5	1	5	1

$$\frac{\textbf{NIR-Reflectance}}{\textbf{VIS-Reflectance}} = \textbf{VI}$$

“Scene” Reflectance Ratio Synthetic Scene Scenario

NIR Reflectance

.3	.5	.3	.5
.5	.3	.5	.3
.3	.5	.3	.5
.5	.3	.5	.3

―――――――

VIS Reflectance

.3	.1	.3	.1
.1	.3	.1	.3
.3	.1	.3	.1
.1	.3	.1	.3

=

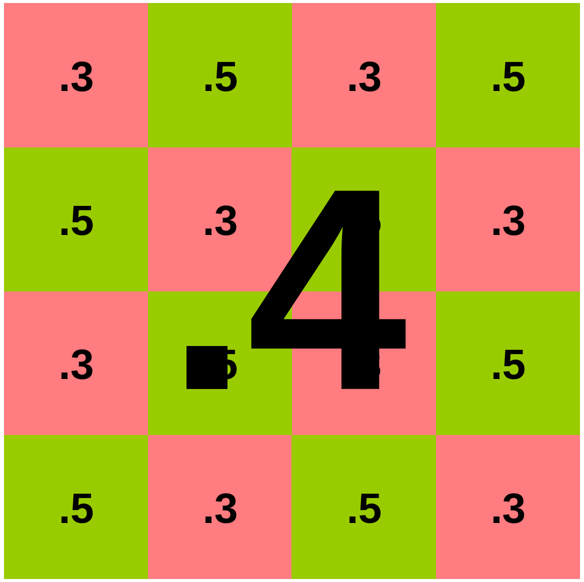
1	5	1	5
5	1	5	1
1	5	1	5
5	1	5	1

3

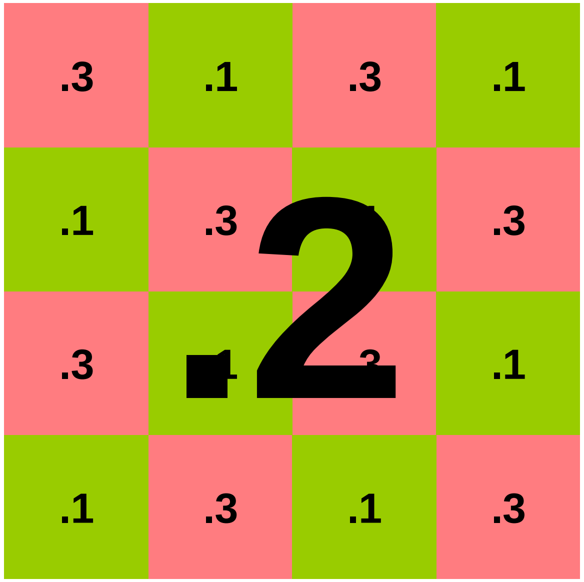
$$\frac{\text{NIR-Reflectance}}{\text{VIS-Reflectance}} = \text{VI}$$

Ratio of Scene Reflectance
Synthetic Scene Scenario

NIR Reflectance



VIS Reflectance



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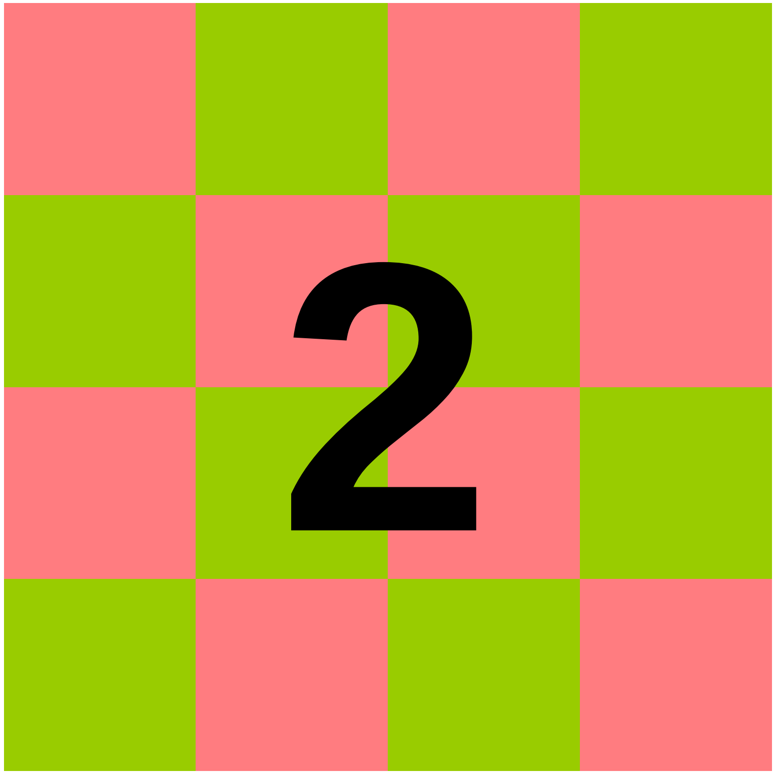
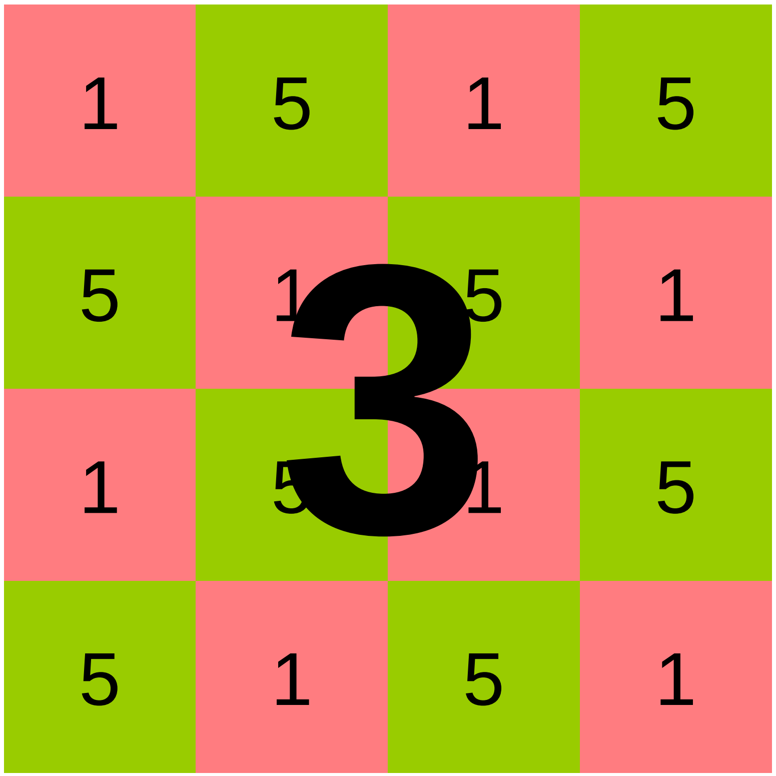


$$\frac{\text{NIR-Reflectance}}{\text{VIS-Reflectance}} = \text{VI}$$

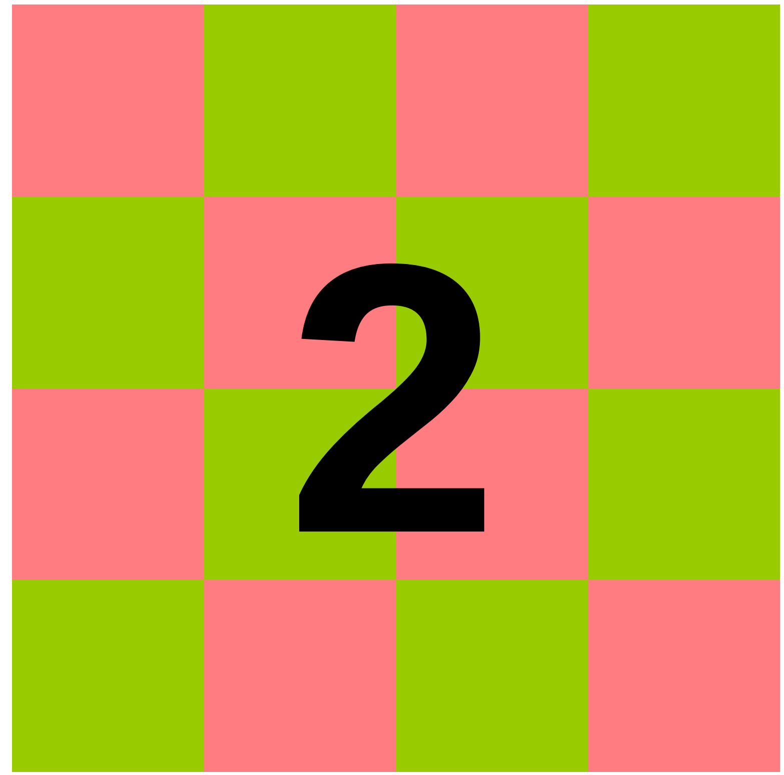
Synthetic Scene Scenario

"Scene" Reflectance-Ratio



$$\left\langle \frac{\text{NIR-Reflectance}}{\text{VIS-Reflectance}} \right\rangle$$

Ratio of Scene Reflectances



$$\frac{\langle \text{NIR-Reflectance} \rangle}{\langle \text{VIS-Reflectance} \rangle}$$

Pixel Reflectance Values
Aligned Bands Scenario

.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3

Nominal Position VIS Band

.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3

Nominal Position NIR Band

Pixel Reflectance Values
Misaligned Bands Scenario 1

.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2

"Half-pixel" Shift VIS Band

.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3

Nominal Position NIR Band

Pixel Reflectance Values
Misaligned Bands Scenario 2

.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3

Nominal Position VIS Band

.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4

"Half-pixel" Shift NIR Band

Nominal Position NIR Band

.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3

=

Nominal Position VIS Band

.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.3	.3	.3	.1	.1	.1	.3	.3	.3	.1	.1	.1
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3
.1	.1	.1	.3	.3	.3	.1	.1	.1	.3	.3	.3

Study Basis

bands perfectly aligned

1	1	1	5	5	5	1	1	1	5	5	5
1	1	1	5	5	5	1	1	1	5	5	5
1	1	1	5	5	5	1	1	1	5	5	5
5	5	5	1	1	1	5	5	5	1	1	1
5	5	5	1	1	1	5	5	5	1	1	1
5	5	5	1	1	1	5	5	5	1	1	1
1	1	1	5	5	5	1	1	1	5	5	5
1	1	1	5	5	5	1	1	1	5	5	5
1	1	1	5	5	5	1	1	1	5	5	5
5	5	5	1	1	1	5	5	5	1	1	1
5	5	5	1	1	1	5	5	5	1	1	1
5	5	5	1	1	1	5	5	5	1	1	1

$$\frac{\textbf{NIR-Reflectance}}{\textbf{VIS-Reflectance}} = \textbf{VI}$$

Study Scenario 1

Nominal Position NIR Band

.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3

"Half-pixel" Shift VIS Band

.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2

=

1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5
1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
1	1	1.5	5	5	2.5	1	1	1.5	5	5	2.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5
5	5	2.5	1	1	1.5	5	5	2.5	1	1	1.5

$$\frac{\text{NIR-Reflectance}}{\text{VIS-Reflectance}} = \text{VI}$$

Study Scenario 1

misalignment "corrected"

Nominal Position NIR Band

.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	..5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.3	.3	.3	.5	.5	.5	.3	.3	.3	.5	.5	.5
.5	..5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3
.5	.5	.5	.3	.3	.3	.5	.5	.5	.3	.3	.3

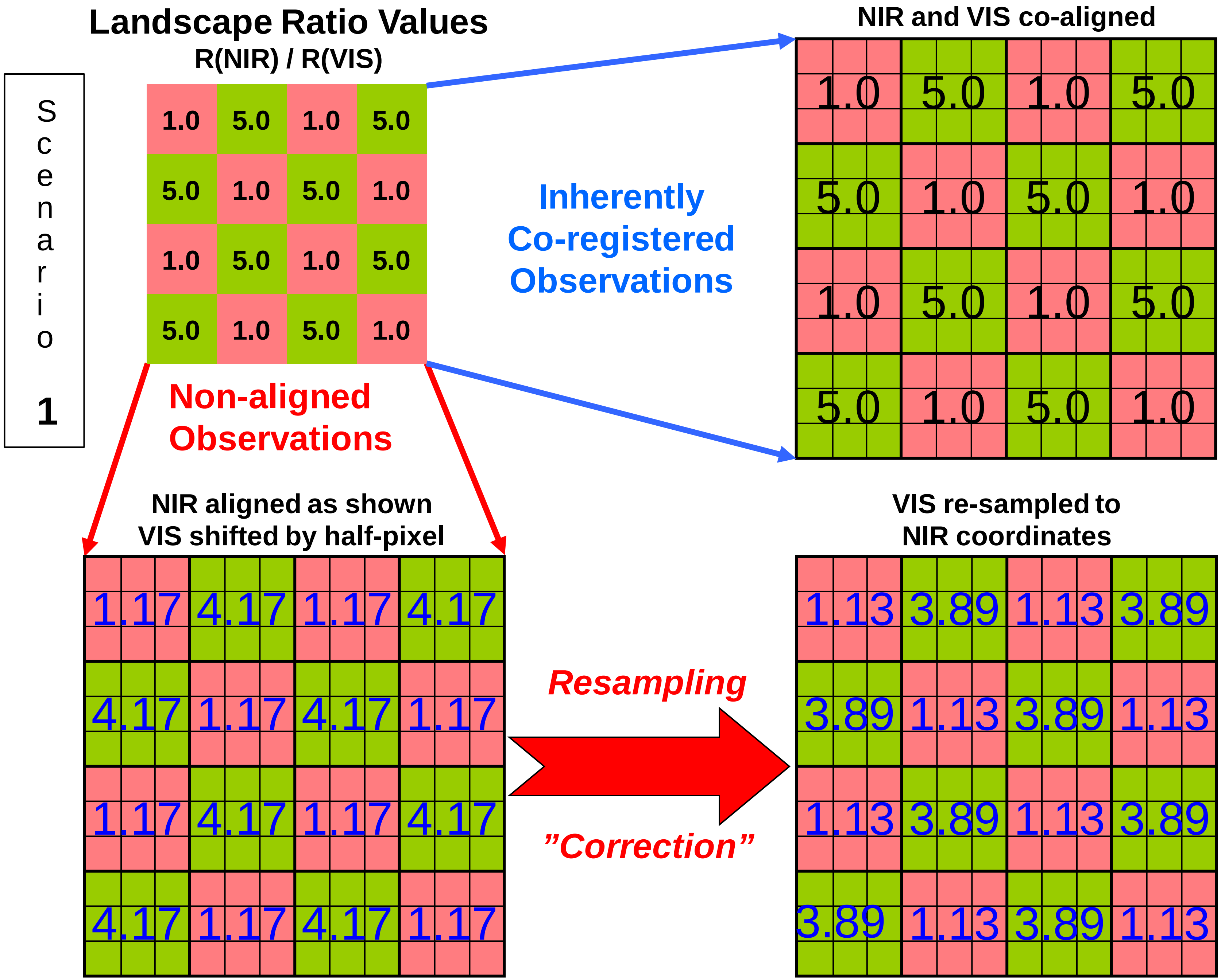
"Half-pixel" Resampled VIS Band

.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25

=

1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2
1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
1.2	1	1.2	3.3	5	3.3	1.2	1	1.2	3.3	5	3.3
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2
3.3	5	3.3	1.2	1	1.2	3.3	5	3.3	1.2	1	1.2

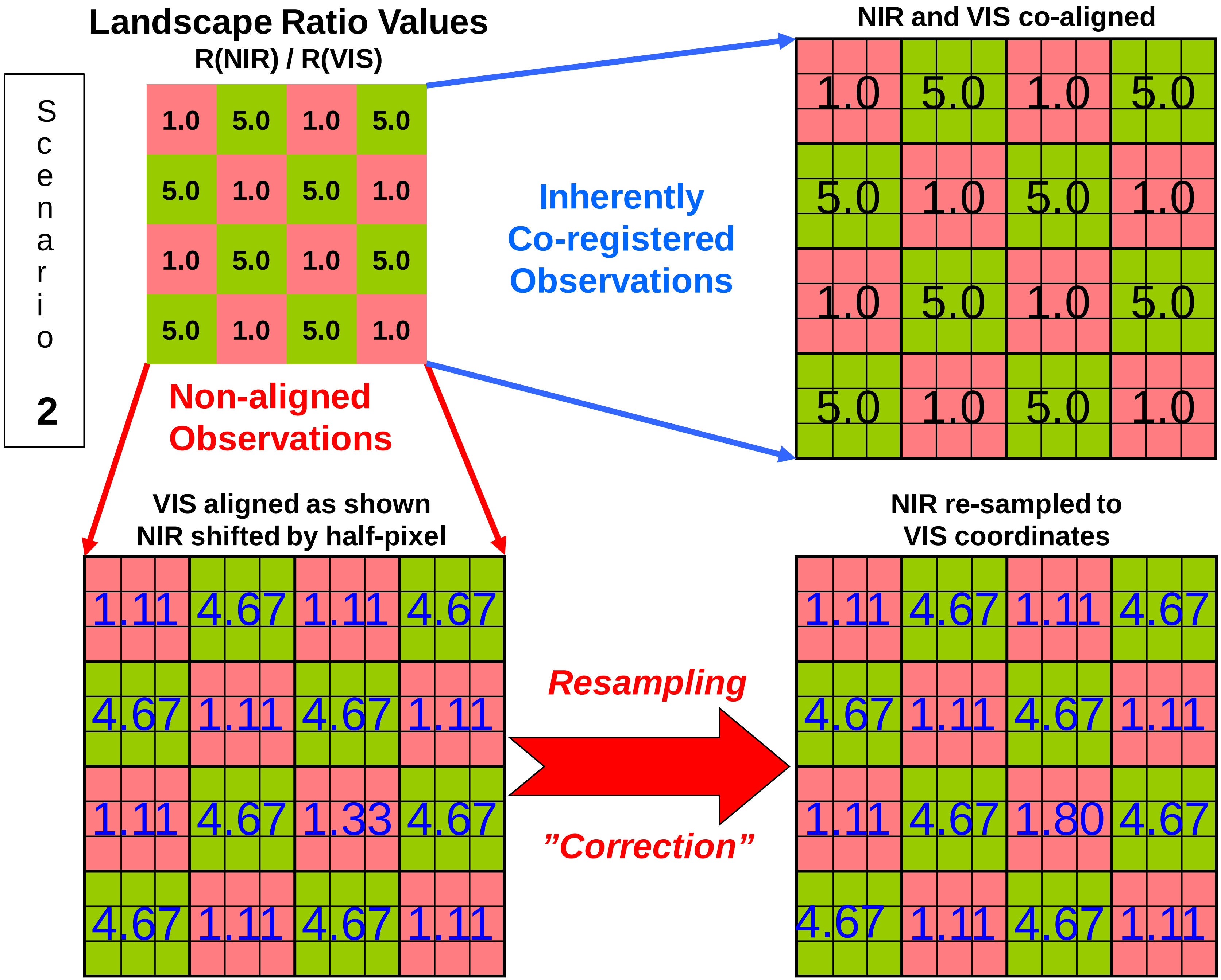
$$\frac{\text{NIR-Reflectance}}{\text{VIS-Reflectance}} = \text{VI}$$



Scenario 1
Landscape Ratio Values
R(NIR) / R(VIS)
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Inherently Co-registered Observations
NIR and VIS co-aligned
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Non-aligned Observations
NIR aligned as shown
VIS shifted by half-pixel
1.17 4.17 1.17 4.17
4.17 1.17 4.17 1.17
1.17 4.17 1.17 4.17
4.17 1.17 4.17 1.17
Resampling
"Correction"
VIS re-sampled to
NIR coordinates
1.13 3.89 1.13 3.89
3.89 1.13 3.89 1.13
1.13 3.89 1.13 3.89
3.89 1.13 3.89 1.13

Results of half pixel misalignment and correction through linear re-sampling

Scenario 1	Category 1 Ratio Value	Category 1 Discrepancy	Category 2 Ratio Value	Category 2 Discrepancy
VIS and NIR co-aligned	1.00	0%	5.00	0%
VIS and NIR misaligned	1.17	+17%	4.17	-17%
VIS realigned by resampling	1.13	+13%	3.89	-22%


Landscape Ratio Values
R(NIR) / R(VIS)
Scenario 2
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Inherently Co-registered Observations
NIR and VIS co-aligned
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Non-aligned Observations
VIS aligned as shown
NIR shifted by half-pixel
1.11 4.67 1.11 4.67
4.67 1.11 4.67 1.11
1.11 4.67 1.33 4.67
4.67 1.11 4.67 1.11
Resampling
"Correction"
NIR re-sampled to
VIS coordinates
1.11 4.67 1.11 4.67
4.67 1.11 4.67 1.11
1.11 4.67 1.80 4.67
4.67 1.11 4.67 1.11

Results of half pixel misalignment and correction through linear re-sampling

Scenario 2	Category 1 Ratio Value	Category 1 Discrepancy	Category 2 Ratio Value	Category 2 Discrepancy
VIS and NIR co-aligned	1.00	0%	5.00	0%
VIS and NIR misaligned	1.11	+11%	4.67	-7%
NIR realigned by resampling	1.11	+11%	4.67	-7%

Can we expect perfect observing systems to agree with each other?

NO! For multi-spectral *(i.e. <u>hypo</u>-spectral)* observing systems.

YES! For full spectral *(i.e. <u>hyper</u>-spectral)* observing systems.

Thank you Joe Boardman!

Why don't perfect multi-spectral systems agree with each other?

Most landscapes of interest, observed at *"moderate"* resolution, are comprised of a large number of *"mixed"* pixels.

There usually is insufficient information to find a *<u>unique</u>* *"unmixed" solution.*

Multi-Spectral systems are under determined!

"Half-pixel" Shift NIR Band

.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4

"Half-pixel" Shift VIS Band

.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2

=

Shifted Scenario

1	1	2	5	5	2	1	1	2	5	5	2
1	1	2	5	5	2	1	1	2	5	5	2
1	1	2	5	5	2	1	1	2	5	5	2
5	5	2	1	1	2	5	5	2	1	1	2
5	5	2	1	1	2	5	5	2	1	1	2
5	5	2	1	1	2	5	5	2	1	1	2
1	1	2	5	5	2	1	1	2	5	5	2
1	1	2	5	5	2	1	1	2	5	5	2
1	1	2	5	5	2	1	1	2	5	5	2
5	5	2	1	1	2	5	5	2	1	1	2
5	5	2	1	1	2	5	5	2	1	1	2
5	5	2	1	1	2	5	5	2	1	1	2

$$\frac{\textbf{NIR-Reflectance}}{\textbf{VIS-Reflectance}} = \textbf{VI}$$

“Half-pixel” Resampled NIR Band

.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35
.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.35	.3	.35	.45	.5	.45	.35	.3	.35	.45	.5	.45
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35
.45	.5	.45	.35	.3	.35	.45	.5	.45	.35	.3	.35

=

“Half-pixel” Resampled VIS Band

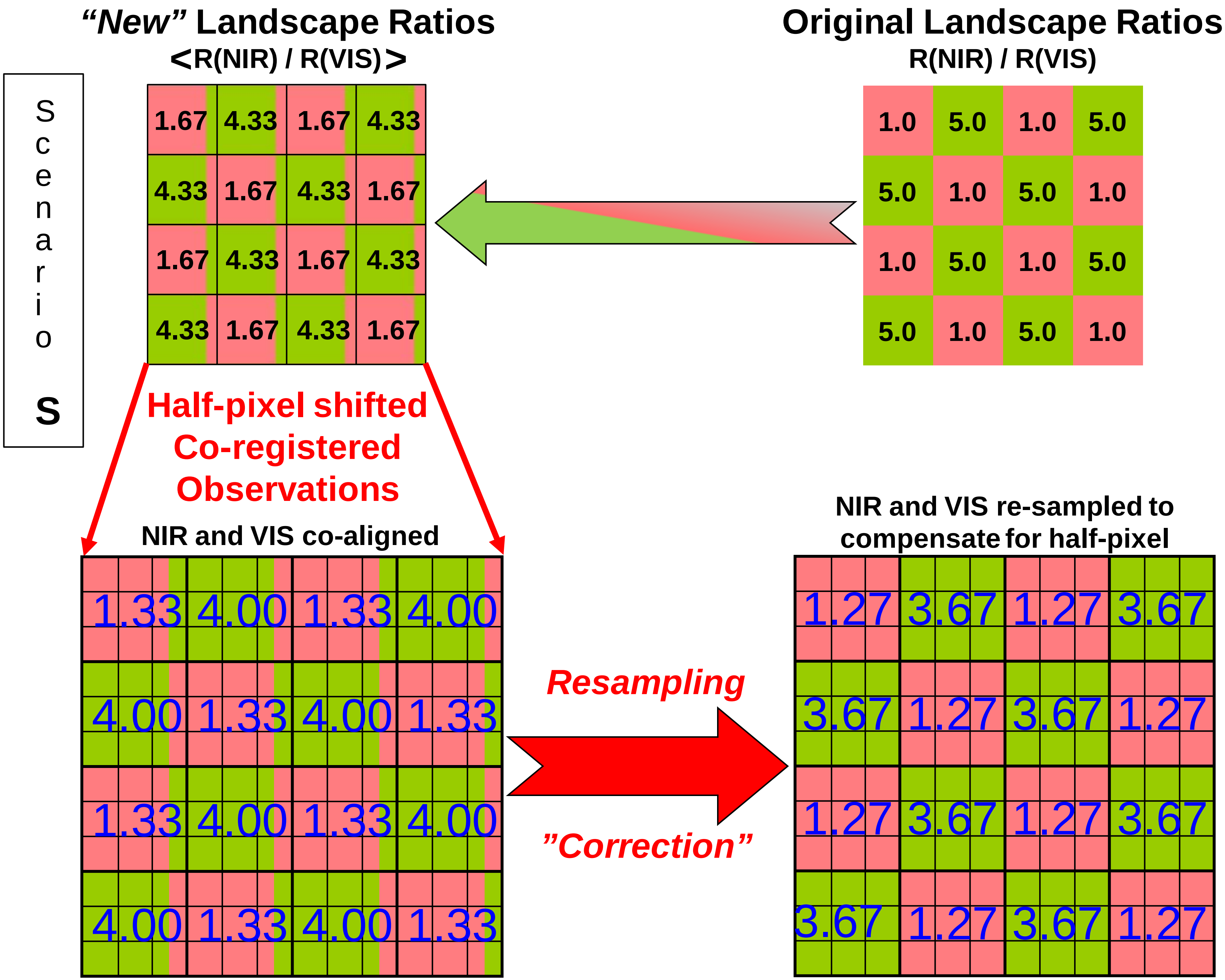
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.3	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.3	.3	.25	.15	.1	.15	.25	.3	.25
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.25	.3	.25	.15	.1	.15	.25	.3	.25	.15	.1	.15
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25
.15	.1	.15	.25	.3	.25	.15	.1	.15	.25	.3	.25

Shifted Scenario

misalignment “corrected”

1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4
1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
1.4	1	1.4	3	5	3	1.4	1	1.4	3	5	3
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4
3	5	3	1.4	1	1.4	3	5	3	1.4	1	1.4

$$\frac{\textbf{NIR-Reflectance}}{\textbf{VIS-Reflectance}} = \textbf{VI}$$


"New" Landscape Ratios
<R(NIR) / R(VIS)>
Original Landscape Ratios
R(NIR) / R(VIS)
Scenario S
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Half-pixel shifted
Co-registered
Observations
NIR and VIS co-aligned
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
Resampling
"Correction"
NIR and VIS re-sampled to
compensate for half-pixel
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27

"New" Landscape Ratios

$\langle R(NIR) / R(VIS) \rangle$

1.67	4.33	1.67	4.33
4.33	1.67	4.33	1.67
1.67	4.33	1.67	4.33
4.33	1.67	4.33	1.67

Original Landscape Ratios

R(NIR) / R(VIS)

1.0	5.0	1.0	5.0
5.0	1.0	5.0	1.0
1.0	5.0	1.0	5.0
5.0	1.0	5.0	1.0

S c e n a r i o **S**

The landscape ratios shown in each of the gridded regions represents the areal weighted average of actual landscape component ratios.

$$\left\langle \frac{R_{NIR}}{R_{VIS}} \right\rangle \neq \frac{\langle R_{NIR} \rangle}{\langle R_{VIS} \rangle}$$

Half-pixel shifted Co-registered Observations

NIR and VIS co-aligned

1.33	4.00	1.33	4.00
4.00	1.33	4.00	1.33
1.33	4.00	1.33	4.00
4.00	1.33	4.00	1.33

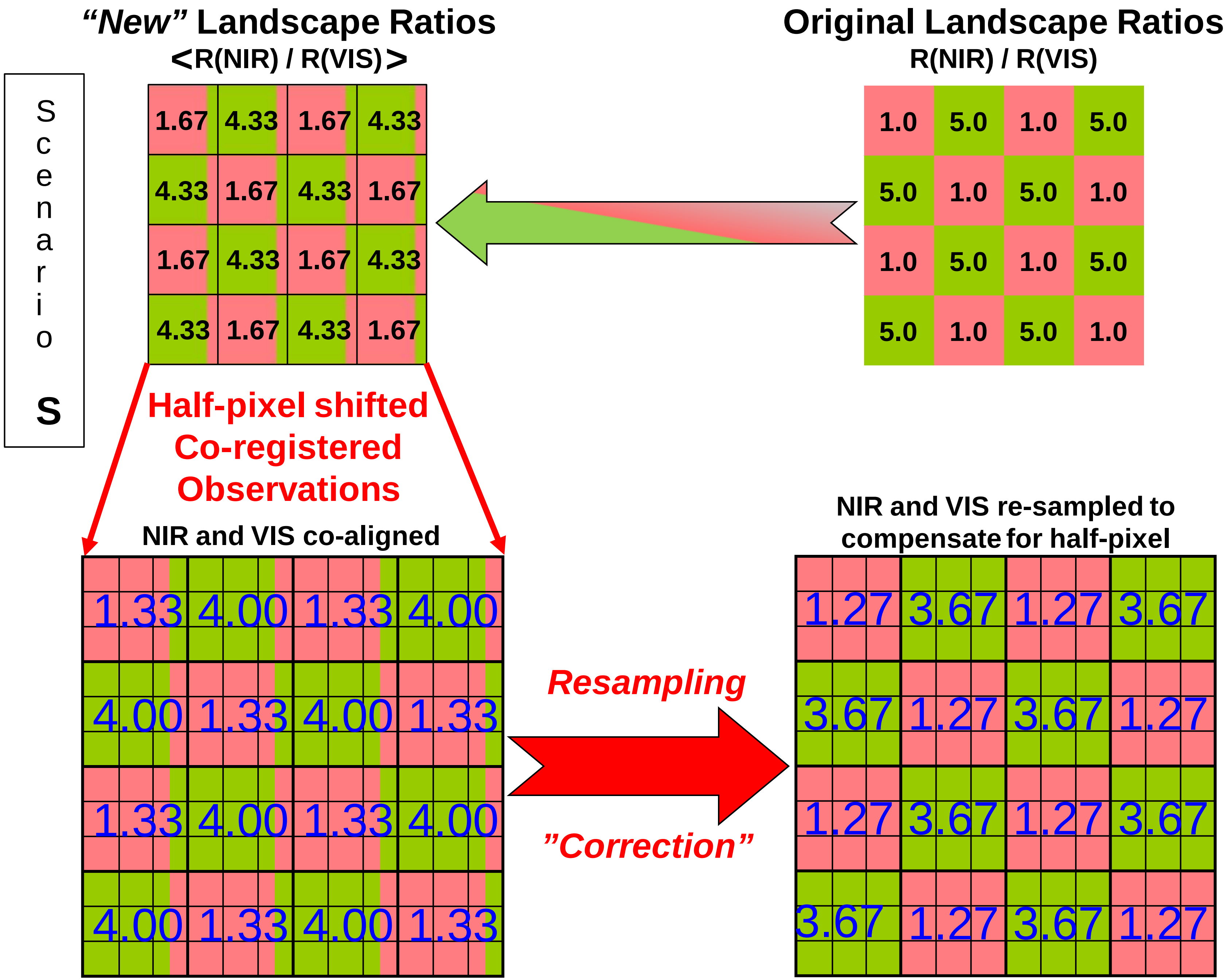
Resampling

"Correction"

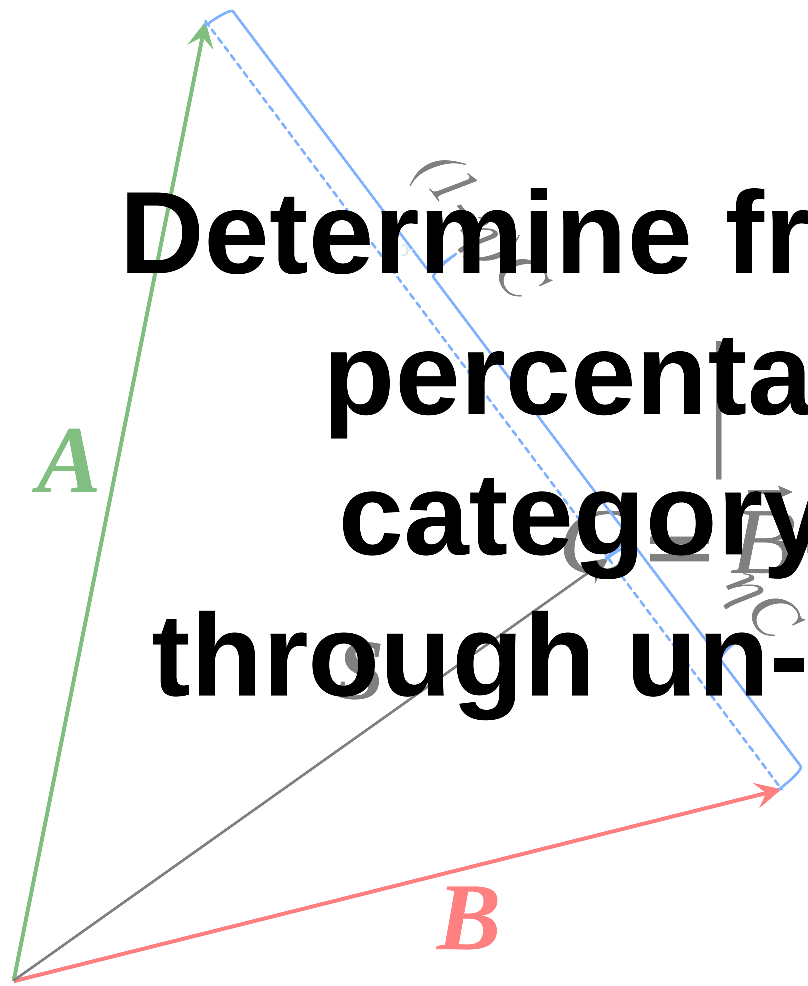
NIR and VIS re-sampled to compensate for half-pixel

1.27	3.67	1.27	3.67
3.67	1.27	3.67	1.27
1.27	3.67	1.27	3.67
3.67	1.27	3.67	1.27

The ratios shown in each of the gridded regions represents the average of the individual pixel ratio values.


"New" Landscape Ratios
<R(NIR) / R(VIS)>
Original Landscape Ratios
R(NIR) / R(VIS)
Scenario S
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
1.0 5.0 1.0 5.0
5.0 1.0 5.0 1.0
Half-pixel shifted
Co-registered
Observations
NIR and VIS co-aligned
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
Resampling
"Correction"
NIR and VIS re-sampled to
compensate for half-pixel
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27

Determine fractional cover percentage of each category (η and 1- η) through un-mixing model



$$\vec{C} = \vec{B} - \vec{A}$$

$$\vec{S} = \eta\vec{A} + (1-\eta)\vec{B}$$

where: $0 \le \eta \le 1$

$$S_3 = \eta A_3 + (1-\eta)B_3$$

$$S_4 = \eta A_4 + (1-\eta)B_4$$

$$\eta = \frac{S_3 B_4 - S_4 B_3}{A_3 B_4 - A_4 B_3}$$

Ungar et al - 1970!

“Half-pixel” Shift NIR Band

.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.3	.3	.4	.5	.5	.4	.3	.3	.4	.5	.5	.4
.5	.5	.4	.3	.3	.4	.5	..5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4
.5	.5	.4	.3	.3	.4	.5	.5	.4	.3	.3	.4

=

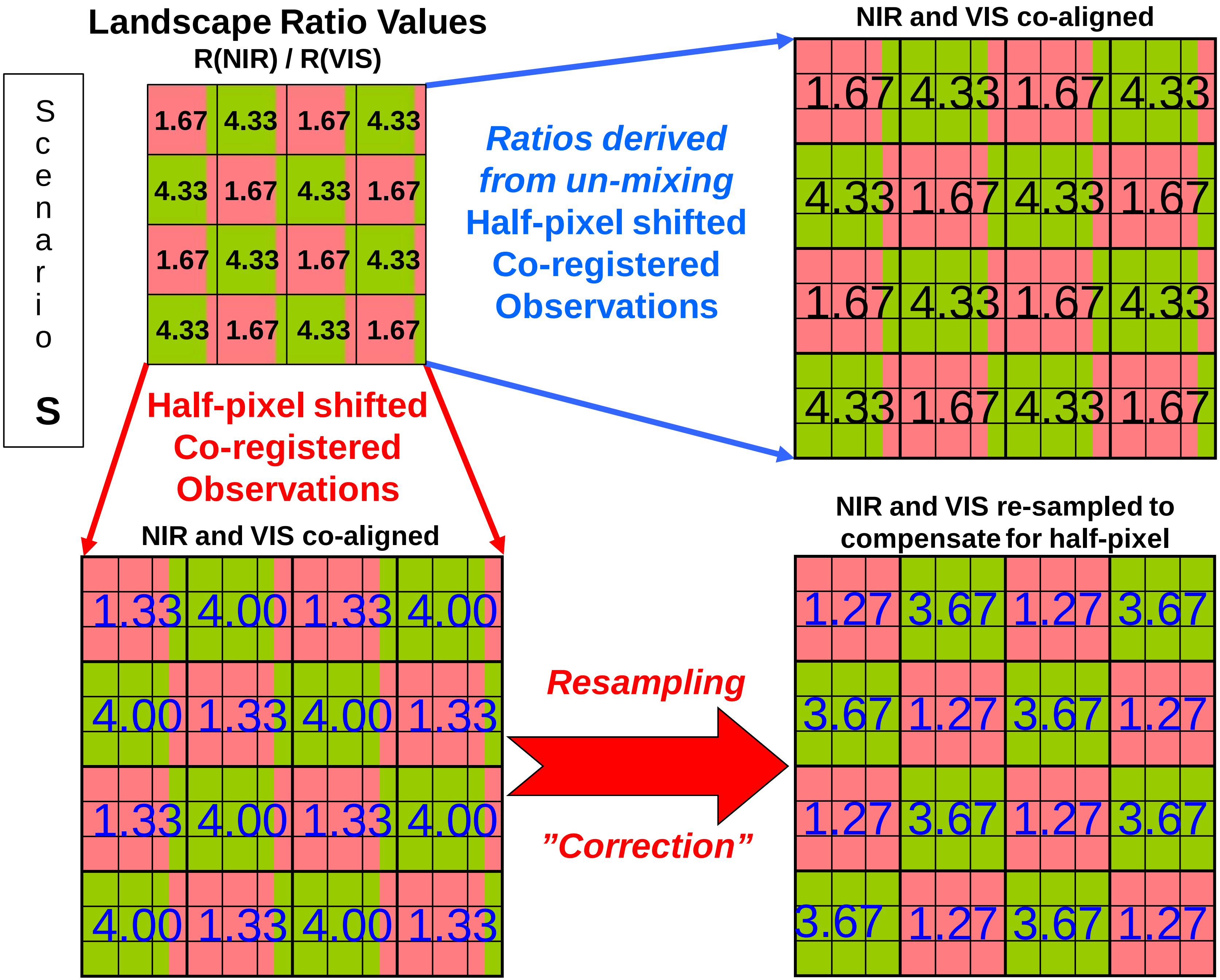
“Half-pixel” Shift VIS Band

.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.3	.3	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.3	.3	.2	.1	.1	.2	.1	.1	.2	.1	.1	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2
.1	.1	.2	.3	.3	.2	.1	.1	.2	.3	.3	.2

Shifted Scenario

1	1	3	5	5	3	1	1	3	5	5	3
1	1	3	5	5	3	1	1	3	5	5	3
1	1	3	5	5	3	1	1	3	5	5	3
5	5	3	1	1	3	5	5	3	1	1	3
5	5	3	1	1	3	5	5	3	1	1	3
5	5	3	1	1	3	5	5	3	1	1	3
1	1	3	5	5	3	1	1	3	5	5	3
1	1	3	5	5	3	1	1	3	5	5	3
1	1	3	5	5	3	1	1	3	5	5	3
5	5	3	1	1	3	5	5	3	1	1	3
5	5	3	1	1	3	5	5	3	1	1	3
5	5	3	1	1	3	5	5	3	1	1	3

Mixture Model $\left\langle \frac{R_{NIR}}{R_{VIS}} \right\rangle = VI$


Landscape Ratio Values
R(NIR) / R(VIS)
Scenario
S
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
Ratios derived from un-mixing
Half-pixel shifted Co-registered Observations
NIR and VIS co-aligned
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
1.67 4.33 1.67 4.33
4.33 1.67 4.33 1.67
Half-pixel shifted Co-registered Observations
NIR and VIS co-aligned
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
1.33 4.00 1.33 4.00
4.00 1.33 4.00 1.33
Resampling
"Correction"
NIR and VIS re-sampled to compensate for half-pixel
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27
1.27 3.67 1.27 3.67
3.67 1.27 3.67 1.27

Results of half pixel misalignment and *"correction"* through linear re-sampling

Pixel Shift Scenario	Category 1 Ratio Value	Category 1 Discrepancy	Category 2 Ratio Value	Category 2 Discrepancy
VIS and NIR ½ pixel shift	*1.33*	*+33%*	*4.00*	*-20%*
VIS and NIR resampled	1.27	+27%	3.67	-26%
VIS and NIR unmixed	1.00	0%	5.00	0%

Pixel-shift/Band-misalignment Study Results

Averaged Scene Ratios	Ratio Value	Discrepancy	Ratio Value	Discrepancy
VIS and NIR co-aligned	3.00	0%		
VIS and NIR misaligned	*Scenario 1* 2.67	*Scenario 1* -11%	*Scenario 2* 2.89	*Scenario 2* -4%
realigned by re-sampling	*Scenario 1* 2.50	*Scenario 1* -17%	*Scenario 2* 2.89	*Scenario 2* -4%
VIS and NIR both shifted	2.67	-11%		
Shifted pixels re-sampled	2.47	-18%		
Shifted pixels unmixed	3.00	0%		

Inherent spectral/spatial integrity, required for HyspIRI, allows for substantially more accurate parameter determination than is possible with *currently planned* sequentially sampled pushbroom multispectral systems.

Unlike these multispectral systems, the rich spectral content offered by HyspIRI has the potential to mitigate the impact of temporal sampling offsets as well as to address mixed pixels.

Band-to-Band Registration
The Bottom Line

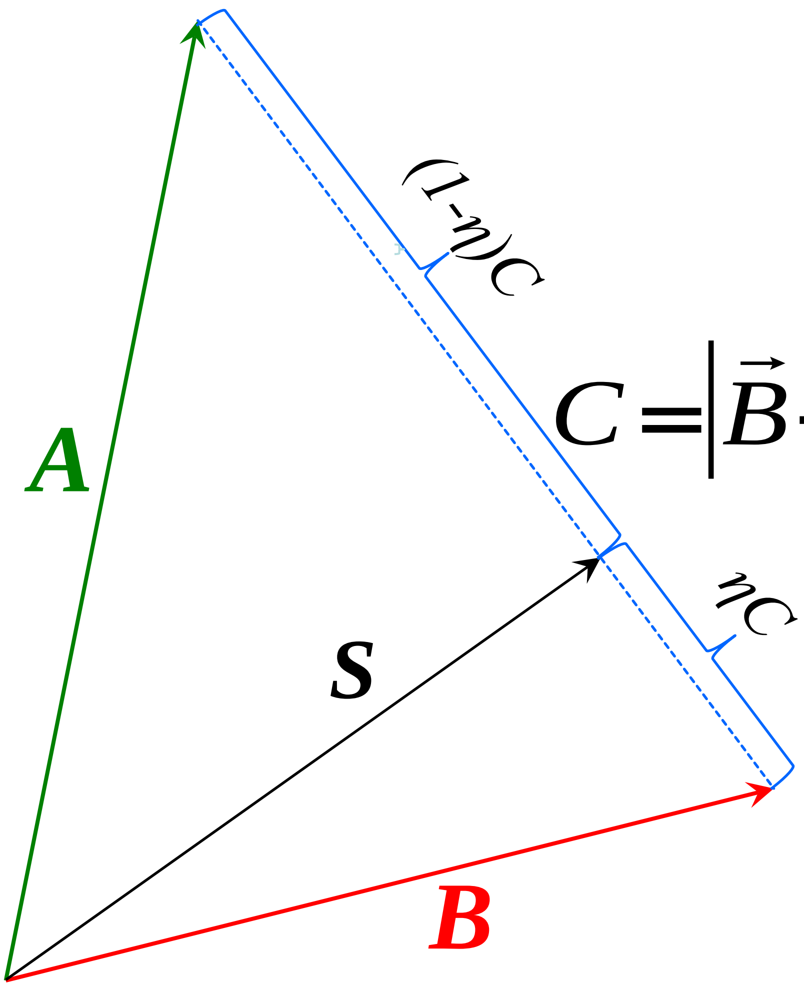
$$\left\langle \frac{R_{NIR}}{R_{VIS}} \right\rangle \neq \frac{\langle R_{NIR} \rangle}{\langle R_{VIS} \rangle}$$

Band-to-Band Registration

However ....

$$\frac{64}{16} = \frac{\cancel{6}4}{1\cancel{6}} = \frac{4}{1} \equiv 4$$

Determine fractional cover percentage of each category (η and 1- η) through un-mixing model



$$C = \left|\vec{B} - \vec{A}\right|$$

$$\vec{S} = \eta\vec{A} + (1-\eta)\vec{B}$$

$$\text{where:} \quad 0 \le \eta \le 1$$

$$S_3 = \eta A_3 + (1-\eta)B_3$$

$$S_4 = \eta A_4 + (1-\eta)B_4$$

$$\eta = \frac{S_3 B_4 - S_4 B_3}{A_3 B_4 - A_4 B_3}$$

Combined VSWIR/TIR Products Overview: Issues & Examples

Robert G. Knox, for the HyspIRI concept study team

NASA's Goddard Space Flight Center,

Biospheric Sciences Branch, Code 614.4

Greenbelt, MD

HyspIRI Science Symposium on Ecosystem Data Products

May 4, 2010

Introduction

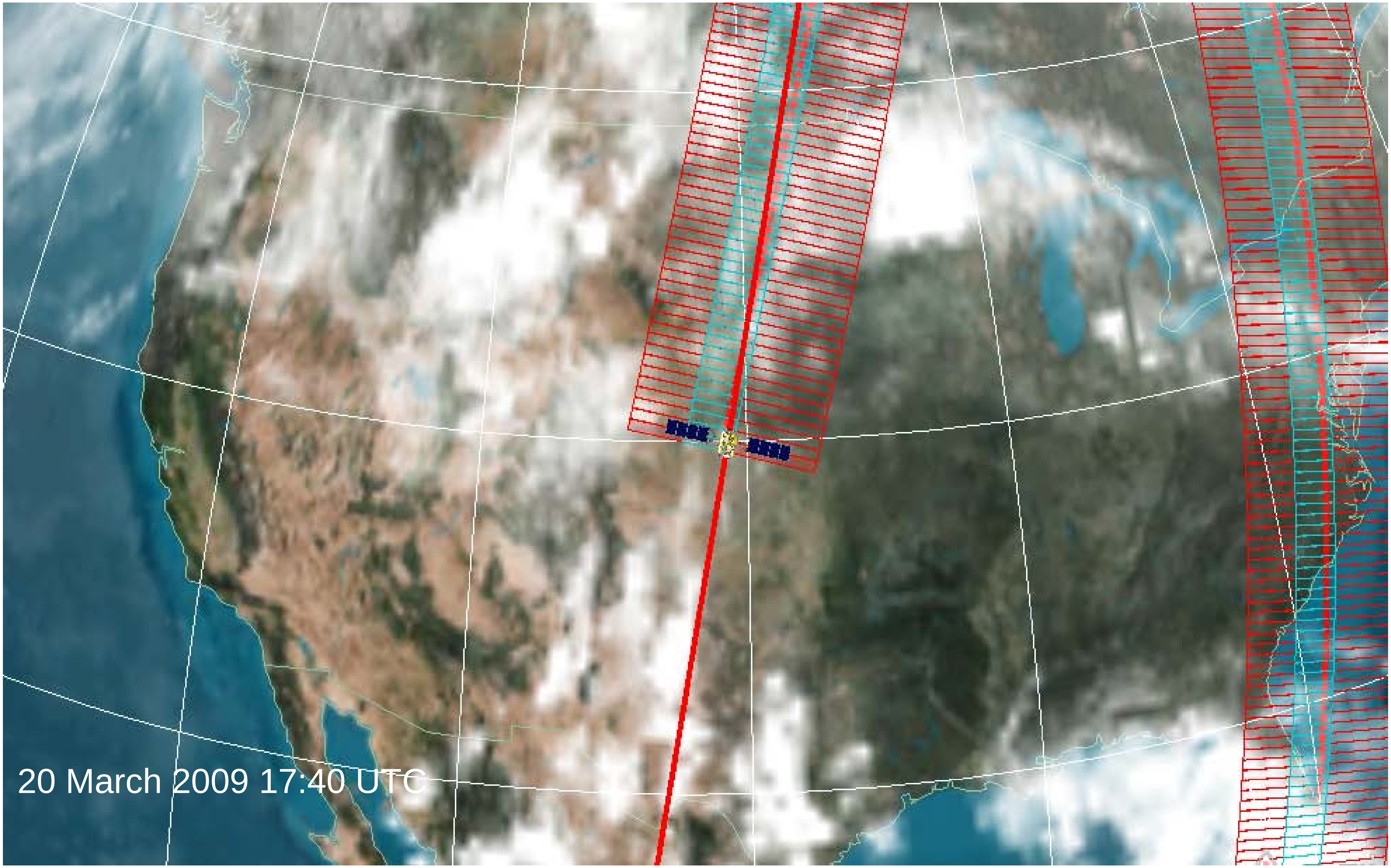
Context

- VSWIR data collected at 19-day intervals for most areas.
- TIR data collected day & night on a 5-day cycle (more frequent at higher latitudes).
- TIR swath is 4X as wide as VSWIR (∴ wider range of view angles).
- 5-day orbit repeat is approximate (∴ same locations viewed from different angles and different GSD).

Outline

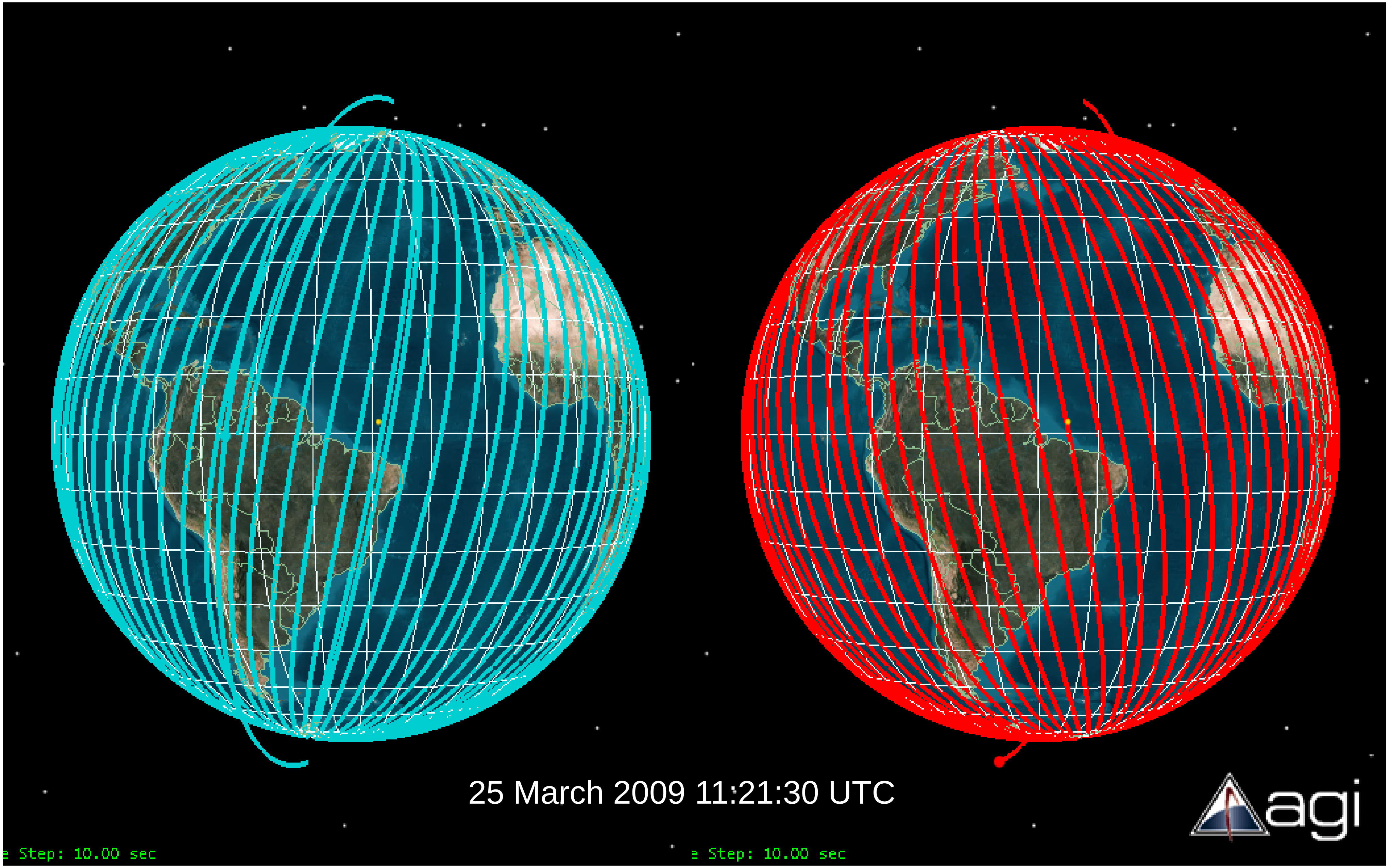
- Nested swath geometry for reference point design.
- Coverage simulations for example FLUXNET tower sites
  - Re-visit frequency varies with latitude
  - Overpass times vary with latitude
  - Between VSWIR collects, TIR overlap geometry and timing varies with latitude (broadly) and location.

HyspIRI observatory crossing 40 N in the central U.S.

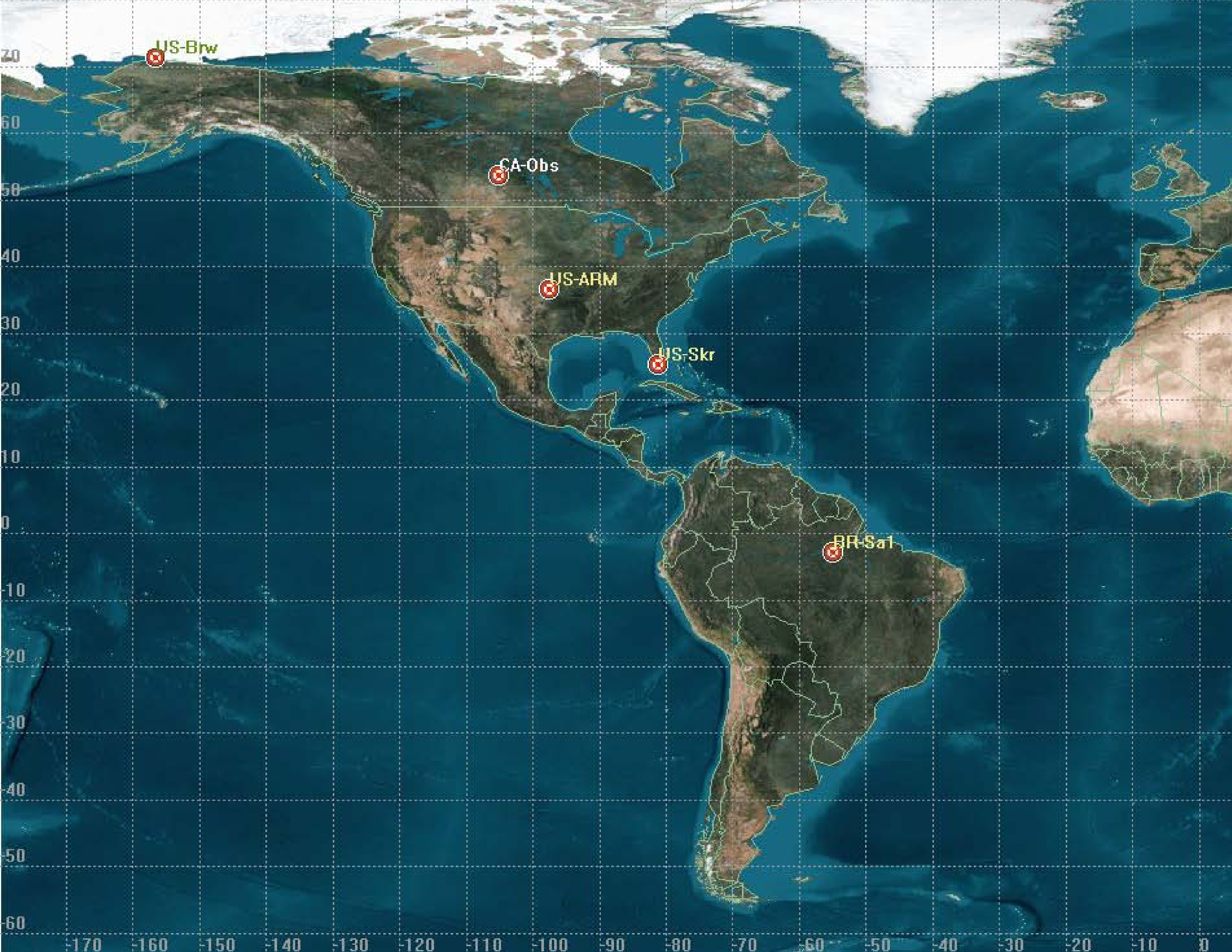


VSWIR swath (light blue) is nested within TIR swath (red), with a swath center offset west of the satellite's ground track. (Cross-track rectangles drawn for simulated 5 s time-steps.) 20 March 2009, 17:40:10 UTC

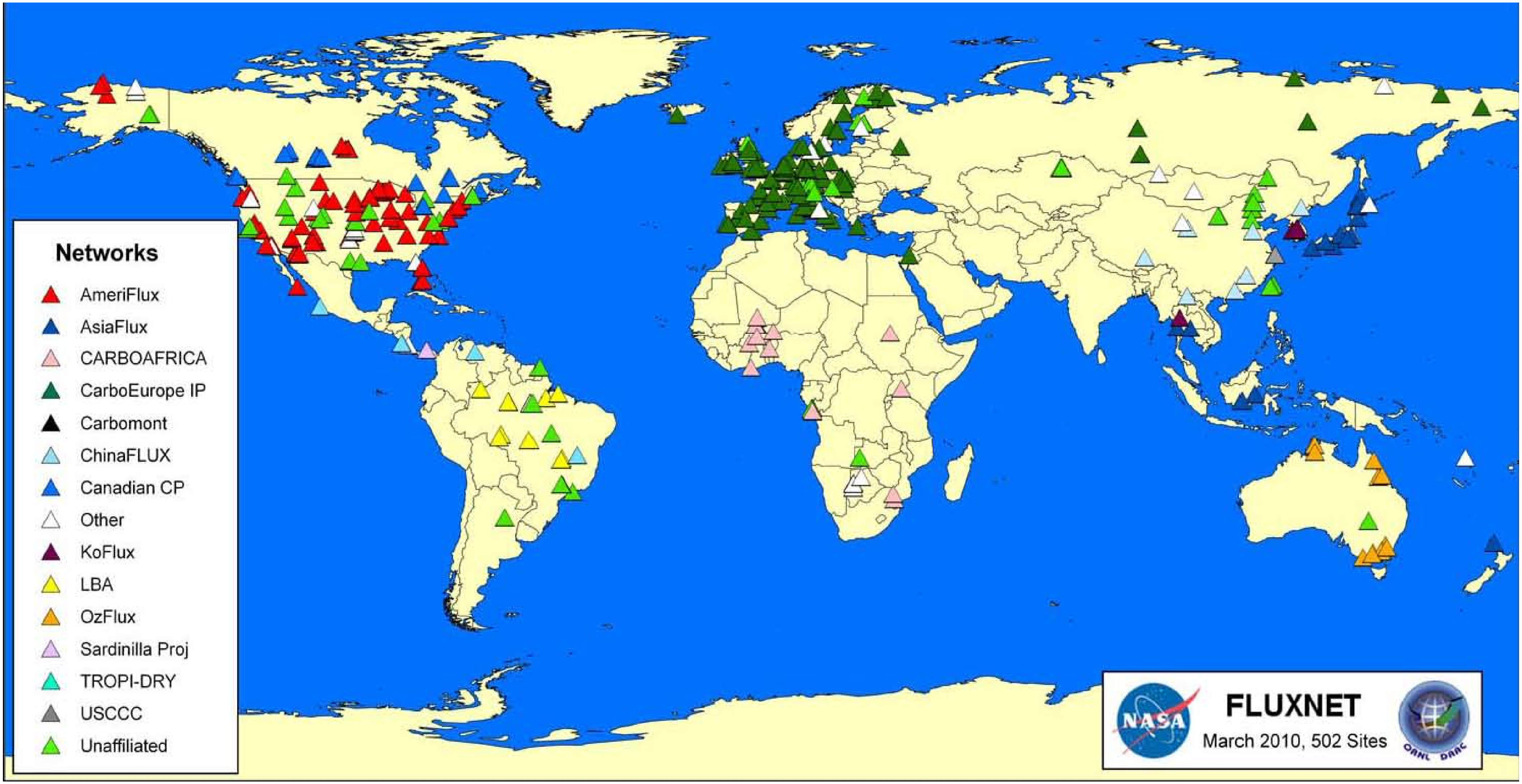
HyspIRI ground tracks shortly after completing a 5-day near repeat pattern:
(a) blue – descending (day) passes and orbit track;
(b) red – ascending (night) passes and orbit track.



R.G. Knox simulation with STK v8.1.3. Orbit: alt. 626.8 km, inclination: 97.8°. Earth graphics courtesy of Analytical Graphics Inc.

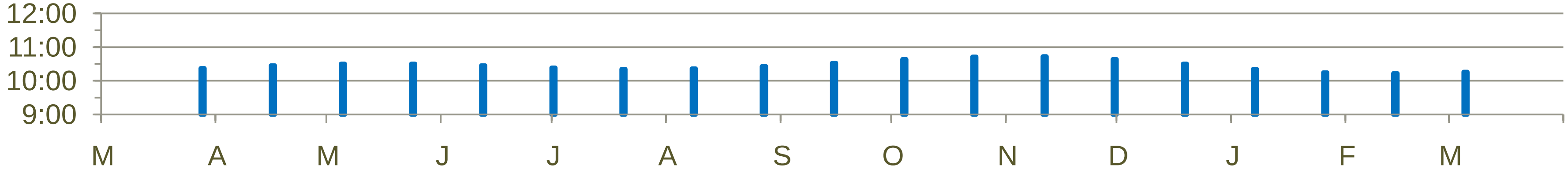

US-Brw
CA-Obs
US-ARM
US-Skr
BR-Sa1
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
-170
-160
-150
-140
-130
-120
-110
-100
-90
-80
-70
-60
-50
-40
-30
-20
-10
0

What is FLUXNET?

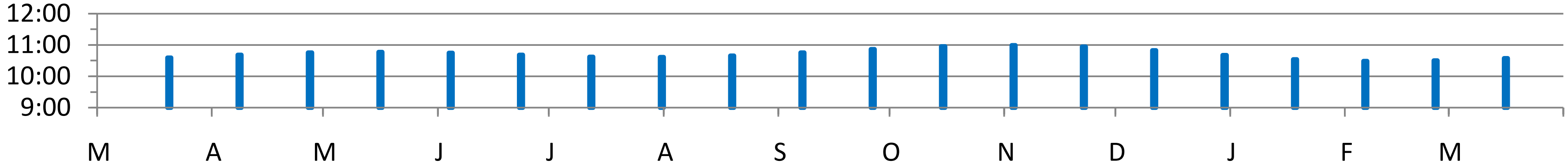


VSWIR accesses for 1 simulated year

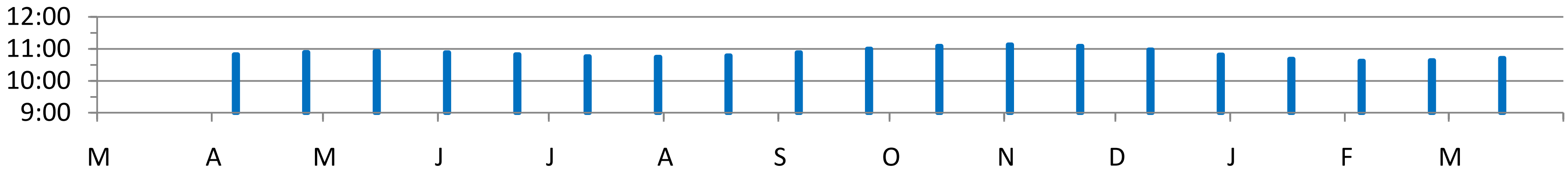
Brazil - Santarem km 67 (LBA), Primary Forest (2.86 S)



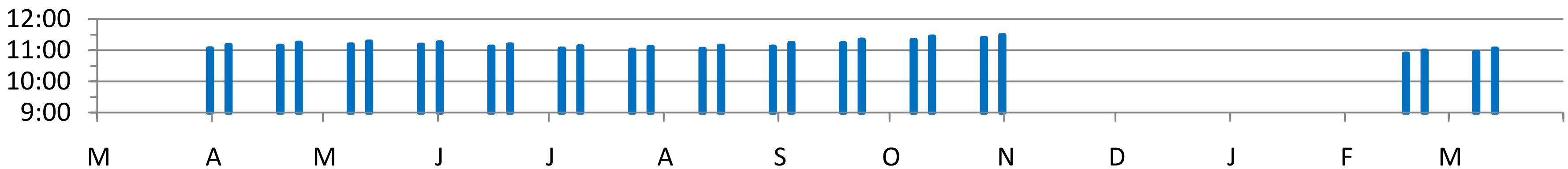
US - Florida Everglades, Shark River Slough, Mangrove Forest (25.36 N)



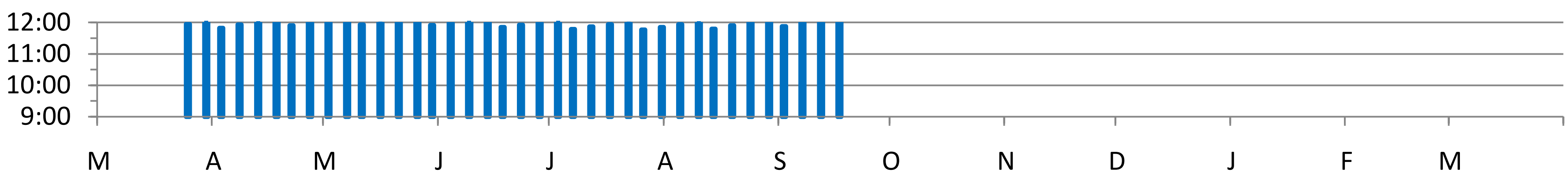
US - ARM Southern Great Plains, Main Tower, Croplands (36.6 N)



Canada - Saskatchewan - (BOREAS) SSA Old Black Spruce (53.99 N)



US - Barrow, Alaska, Moist Tundra (71.32 N)



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

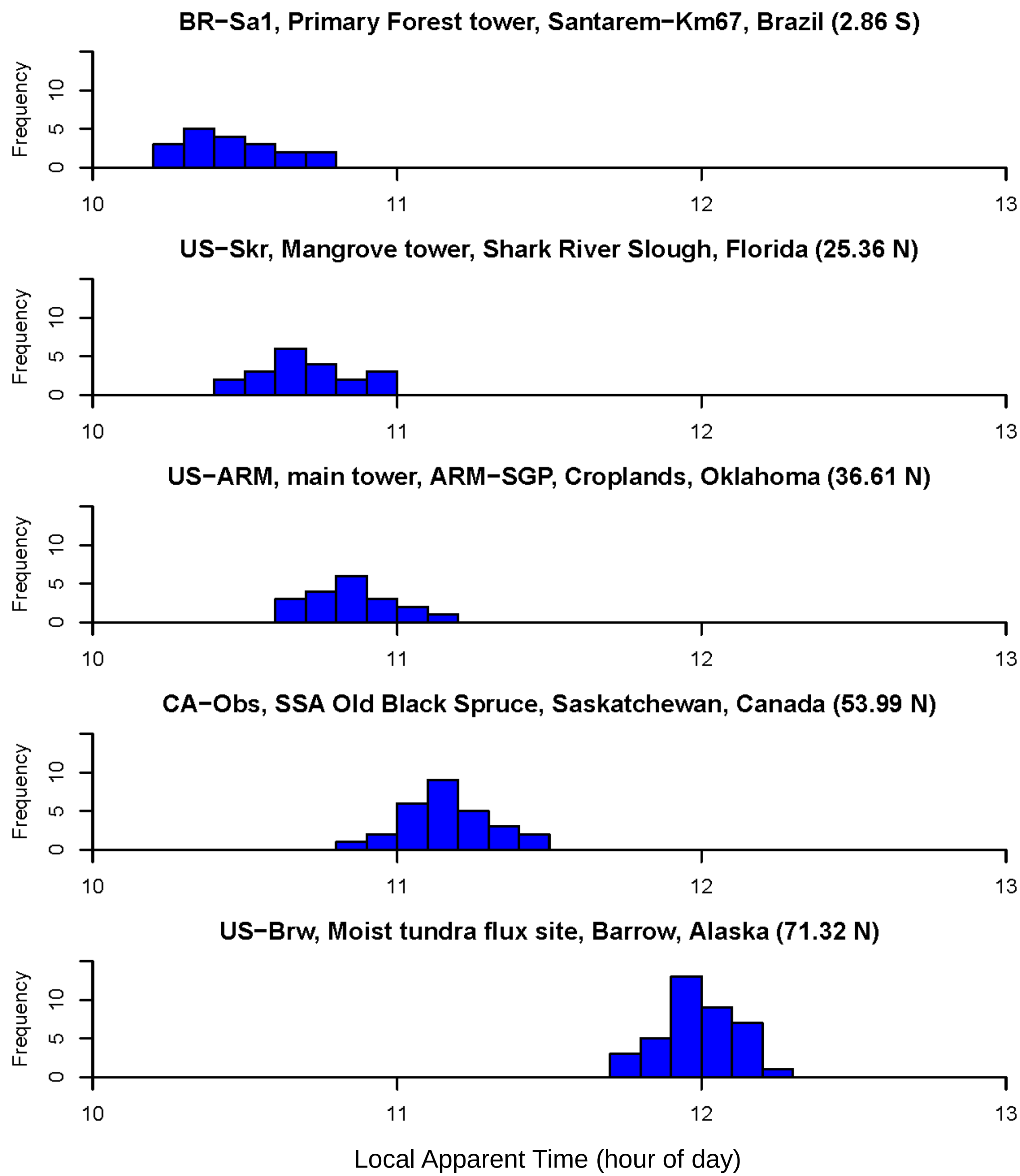
Local time of VSWIR overpasses of 5 FLUXNET sites, simulated for 1 year

Local apparent time, for a fixed mean local time, varies with the Earth's orbit.

As the N latitude of the site increases, the local apparent time of potential VSWIR accesses also increase.

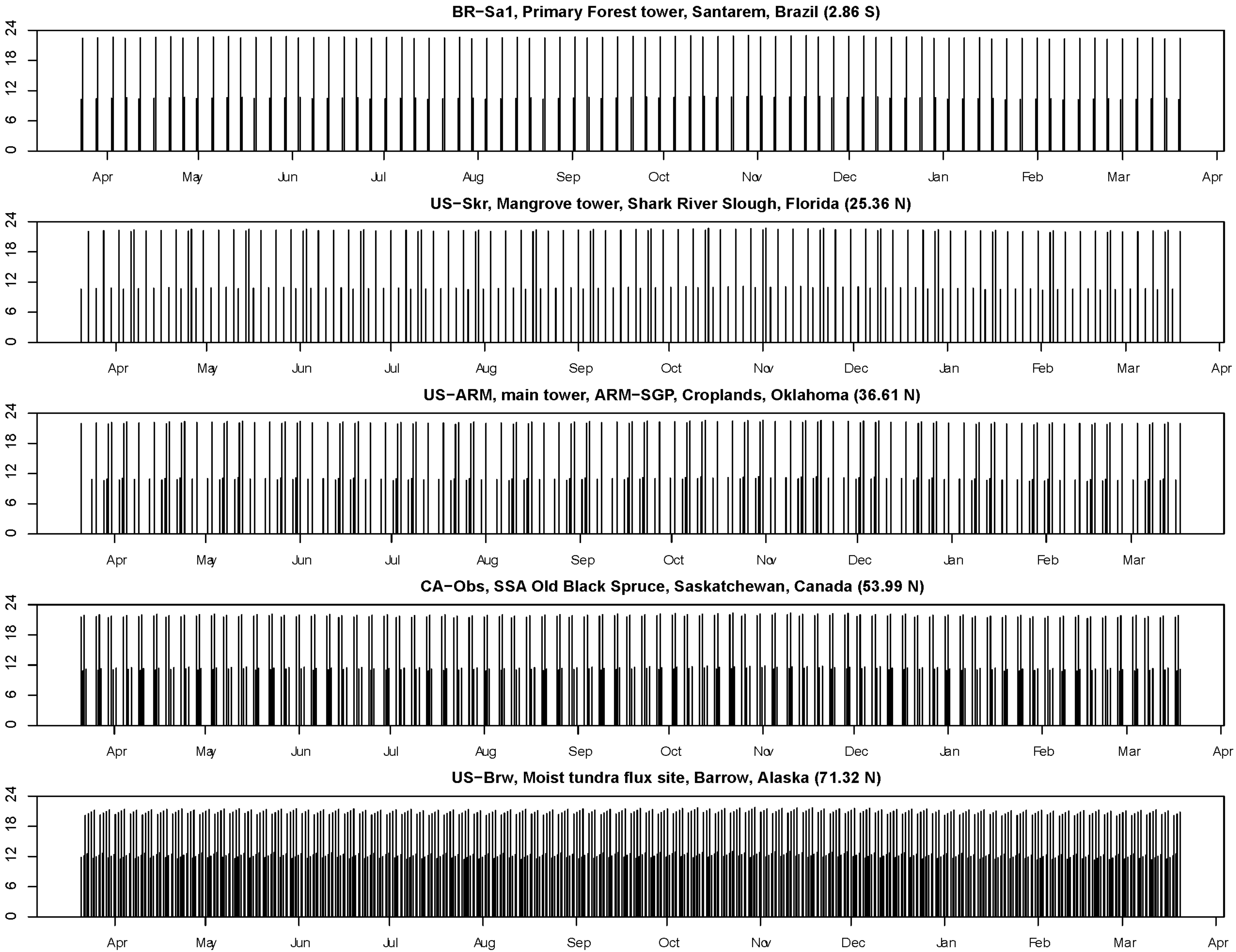
Near the north orbit pole (82.1 N) the local time of potential accesses may be nearly 6 hours later than when crossing the equator (not shown).

Moving toward the south orbit pole local times are progressively earlier in the morning (not shown).



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

TIR accesses for 1 simulated year

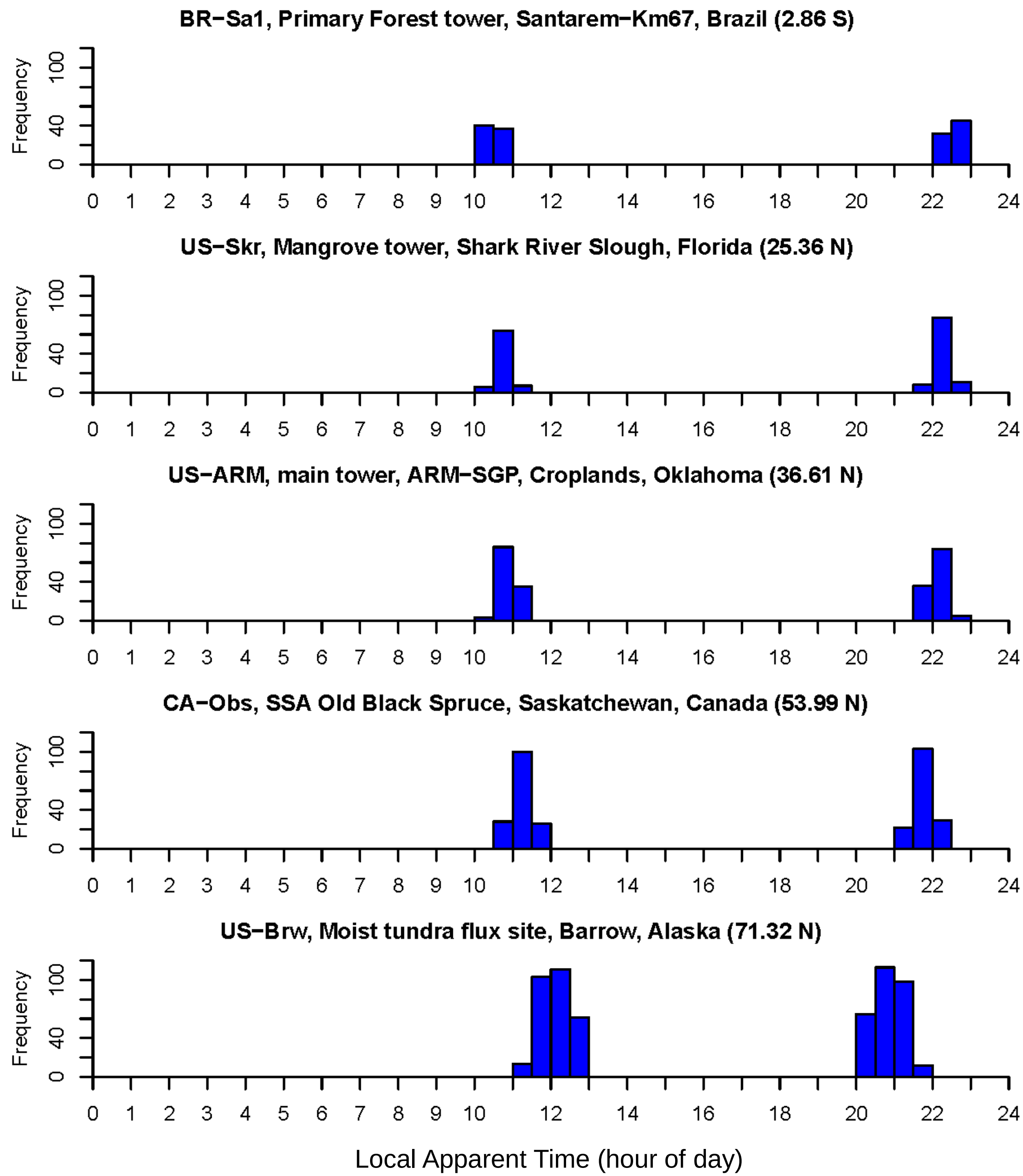


Local time of TIR overpasses of 5 FLUXNET sites, simulated for 1 year

Near the equator, overpass times are separated by 12 hours, on average.

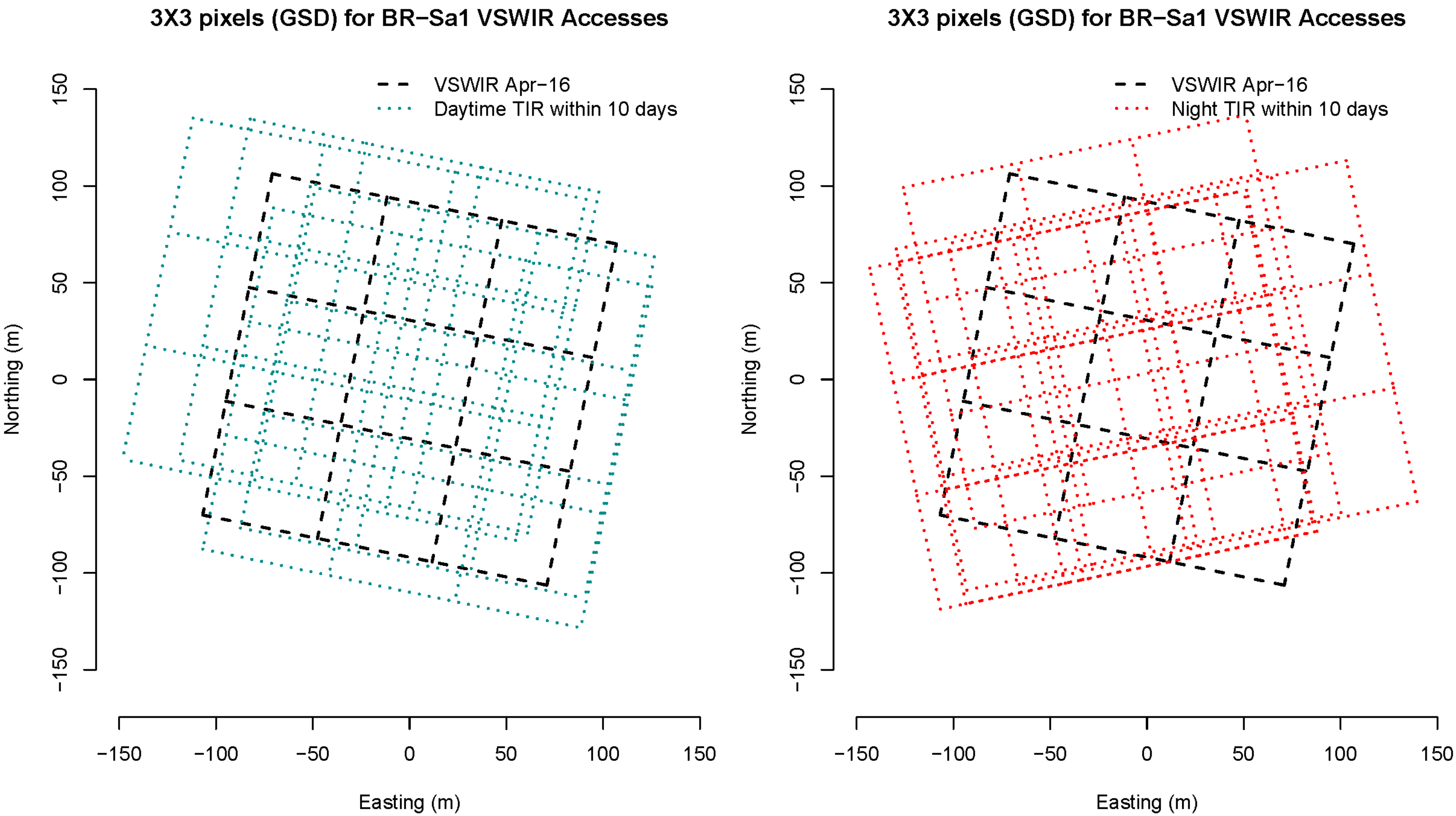
As the N latitude of the site increases, potential TIR collects are more frequent and less tightly clustered in local time.

Also, moving toward the north orbit pole (82.1 N) daytime collects are later and night collects earlier, whereas moving south the reverse is true (not shown).



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

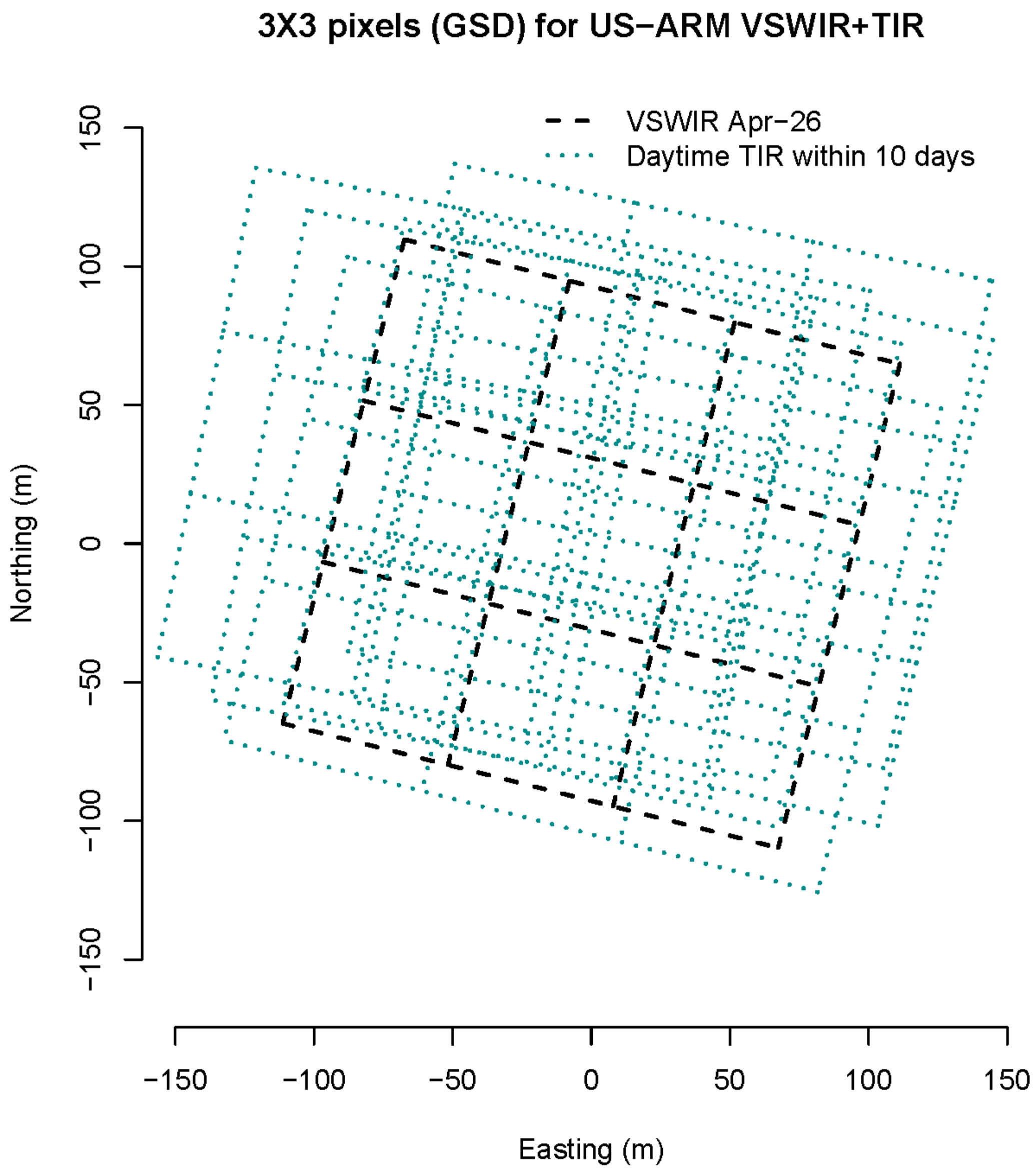
Example of potential HyspIRI TIR data within 10 days of VSWIR coverage, for a near-equatorial study site in Brazil

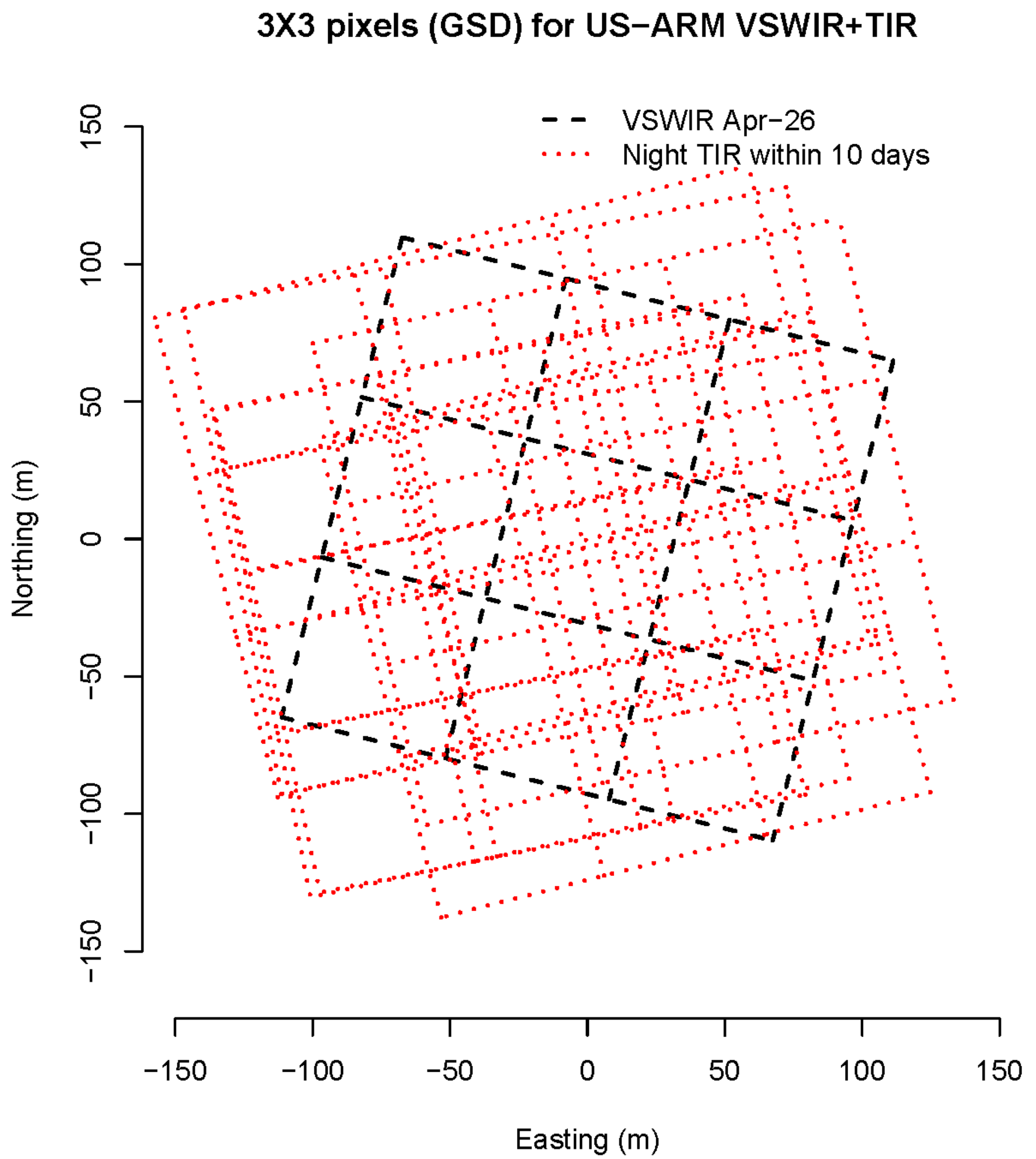


Daylight accesses (cyan) include 1 coincident with the SWIR coverage and 3 other dates.
Potential night data (red) include 5 overpasses, 1 within 13 hours of the SWIR coverage.

R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Example of potential HyspIRI TIR data within 10 days of VSWIR coverage, for a mid-latitude study site in Oklahoma

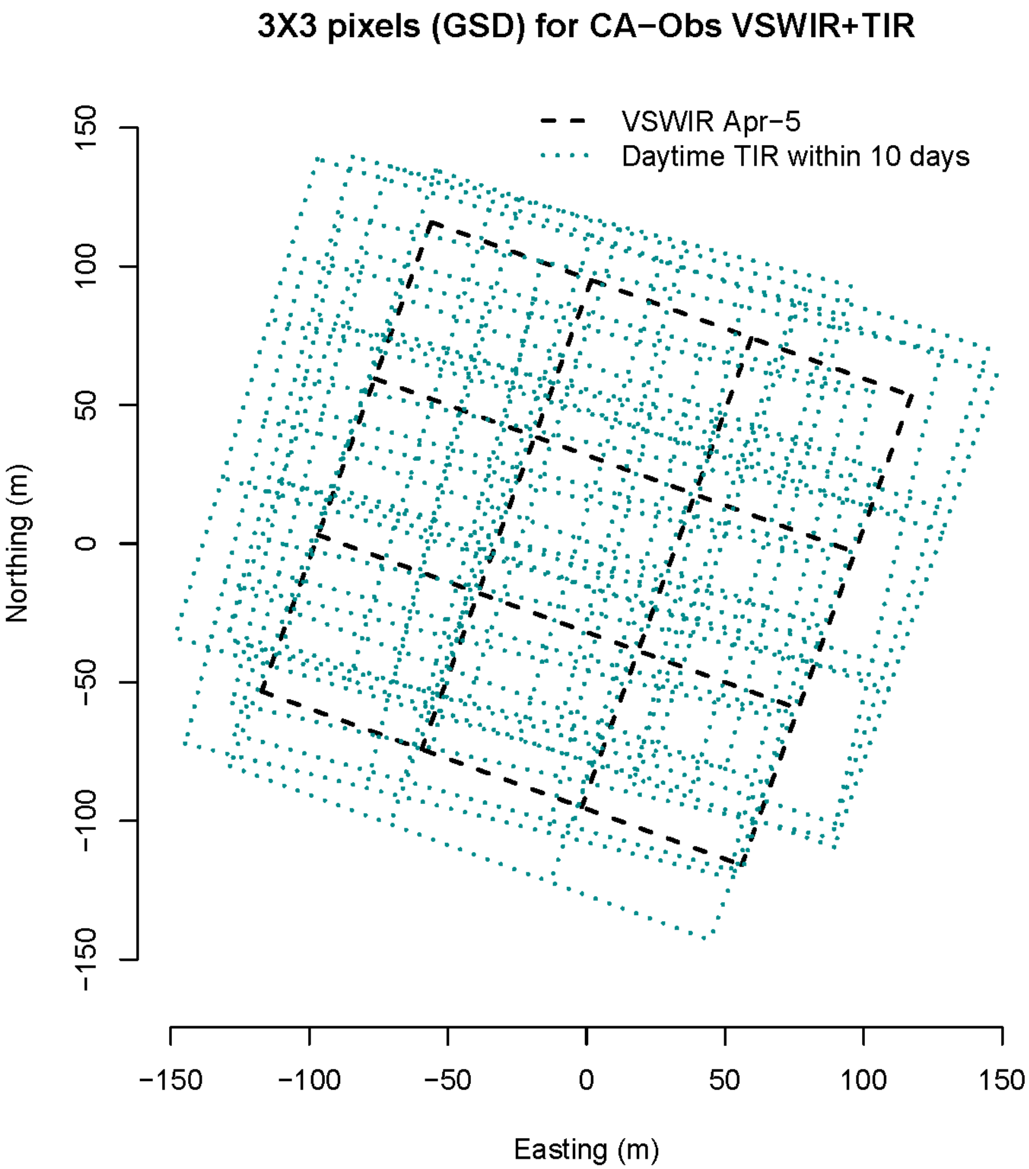


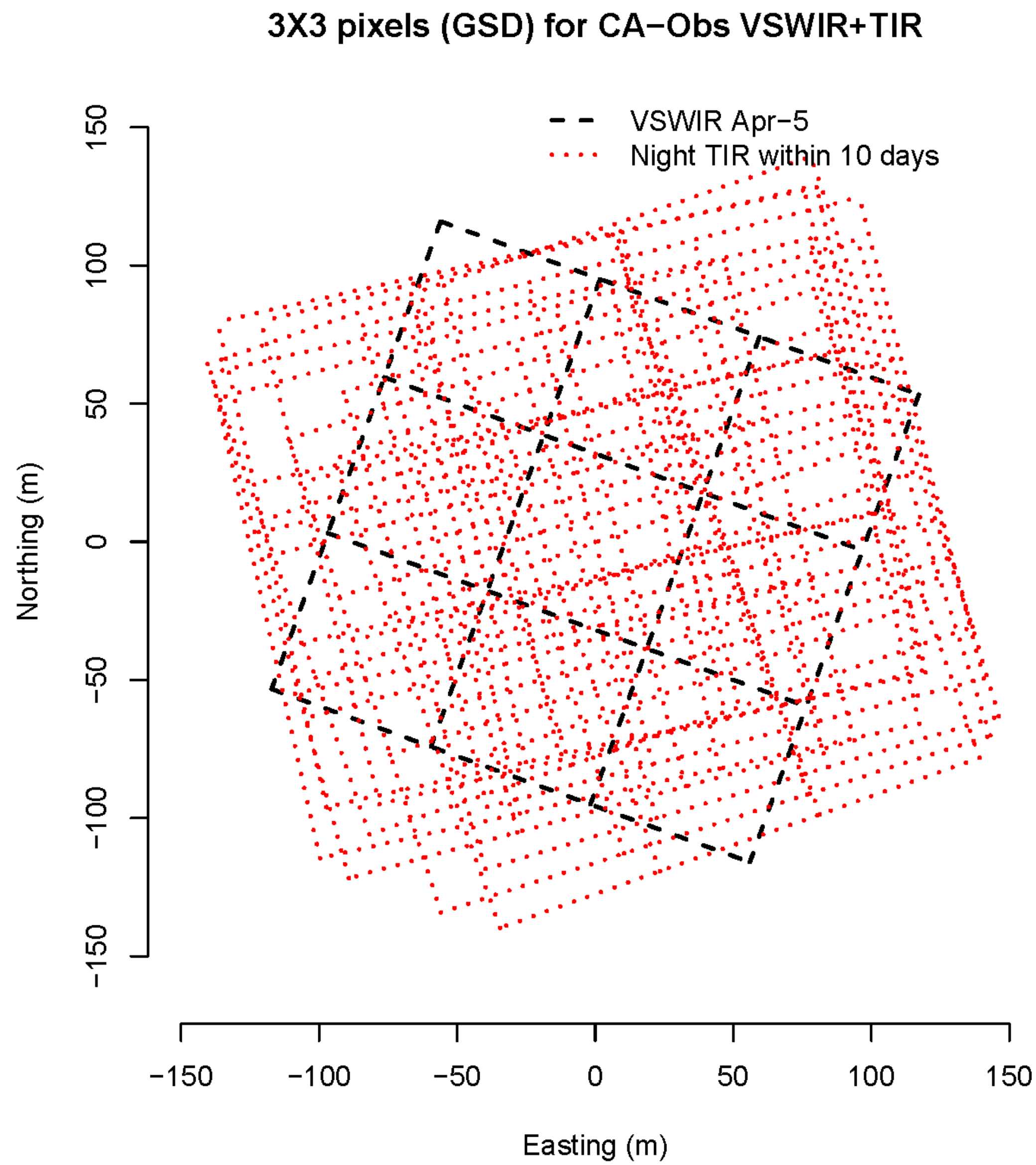


Daylight accesses (cyan) include 1 coincident with the SWIR coverage and 5 other dates.
Potential night data (red) include 6 overpasses.

R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Example of potential HyspIRI TIR data within 10 days of VSWIR coverage, for a boreal study site in Saskatchewan





Daylight accesses (cyan) include 1 coincident with the SWIR coverage and 7 other dates.
Potential night data (red) include 9 overpasses.

R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Some issues & options: Combined VSWIR & TIR data

- Level 2 pixels are geolocated but not re-sampled.
- Single-instrument level 3/4 data products might already be spatially re-sampled or composited across multiple overpasses.
- Providers of **global** combined data products may need to handle data volumes equivalent to both level 2 data streams.

- Questions:
  - *How might combined data products be affected by the overpass time-of-day differences or variation in view azimuths shown in these simulations?*
  - *Will HyspIRI need standard grids for multi-temporal data products?*
  - *What options for producing and distributing level 2/3/4 data products will be viable in 5+ years?*

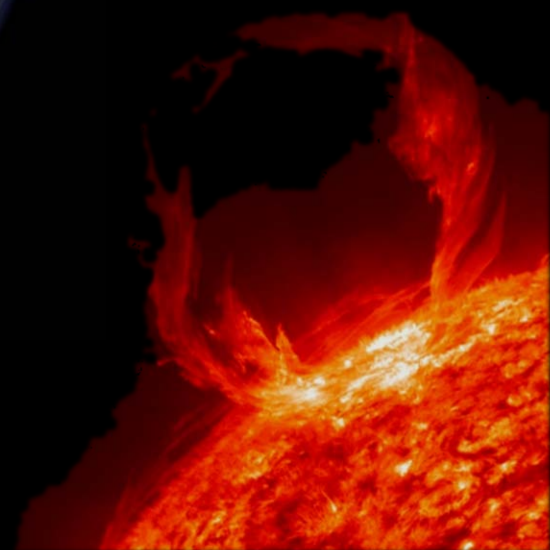
  Regional processing & re-distribution nodes? Release code to run at central, regional, or end-user sites? Peer-to-peer distribution of high interest data?

NASA

USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

Combining observations in the reflective solar and thermal infrared domains to improve carbon, water and energy flux estimation

Rasmus Houborg and Martha Anderson



HyspIRI Science Symposium on Ecosystem Data Products (NASA GSFC May 4, 2010)

Menu

1. Product introduction
2. Why do we need HyspIRI?
3. Relevance

★★★

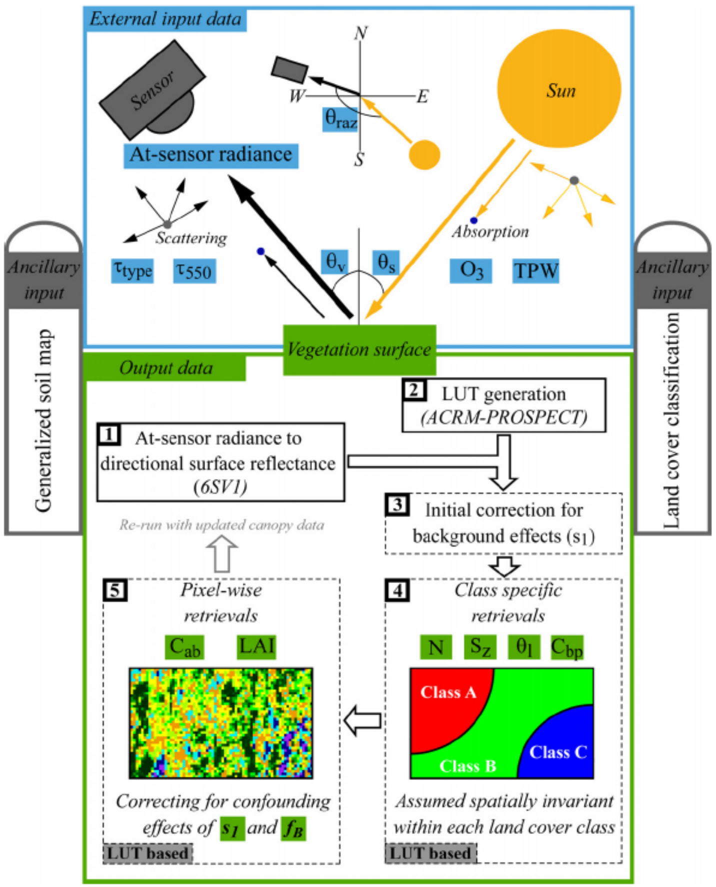
4. Mapping vegetation parameters
5. LUE – leaf chlorophyll inter-correlation

★★★

6. Thermal-based flux mapping and evaluation

Product description

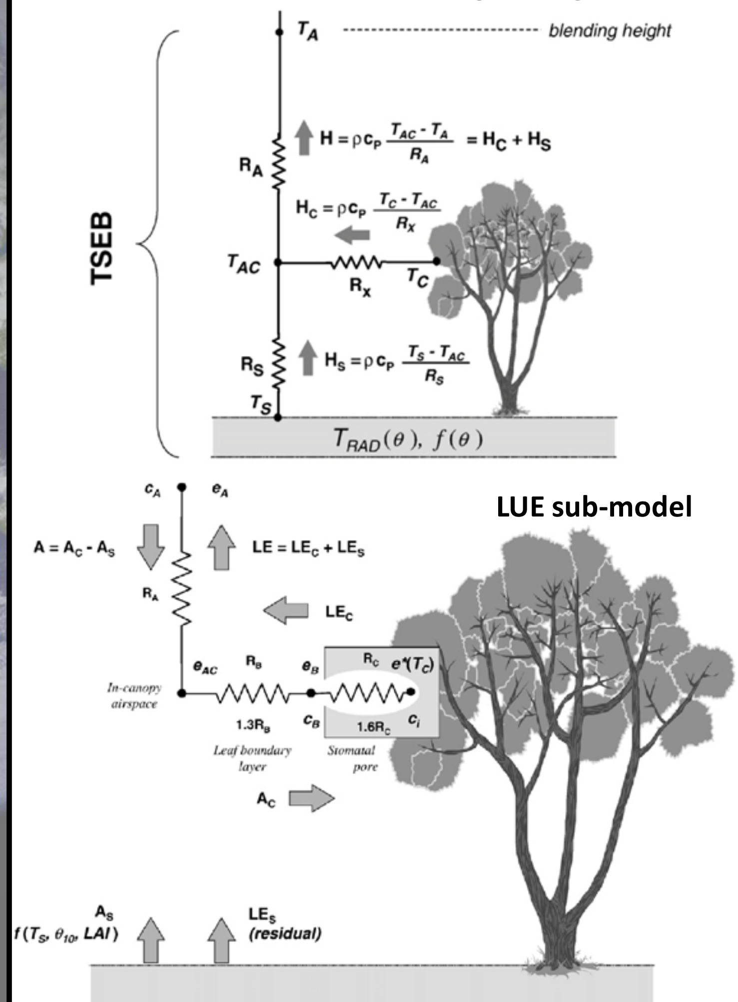
REGFLEC (VNIR)



$\rightarrow$ **LAI, C_{ab}, f_B**

$LUE_n = f(C_{ab})$

TSEB-LUE (TIR)



Why do we need HyspIRI?

- Only HyspIRI will have the capability to simultaneously acquire observations in the reflective solar and thermal regions of the spectrum required as input to REGFLEC – TSEB-LUE

- HyspIRI will allow us to efficiently exploit the synergy between TIR and shortwave reflective wavebands for producing valuable remote sensing data for monitoring of carbon and water fluxes

- The integration of hyperspectral reflective measurements is likely to expand the utility of REGFLEC for high fidelity LAI and Cab retrievals, as the HyspIRI data will allow identification of shortwave bands and indices with optimized sensitivity to changes in leaf chlorophyll (e.g. PRI)

Relevance

- Accurate means for mapping surface fluxes at fine spatial scales (<100m) are critically important to local water resource and agricultural management

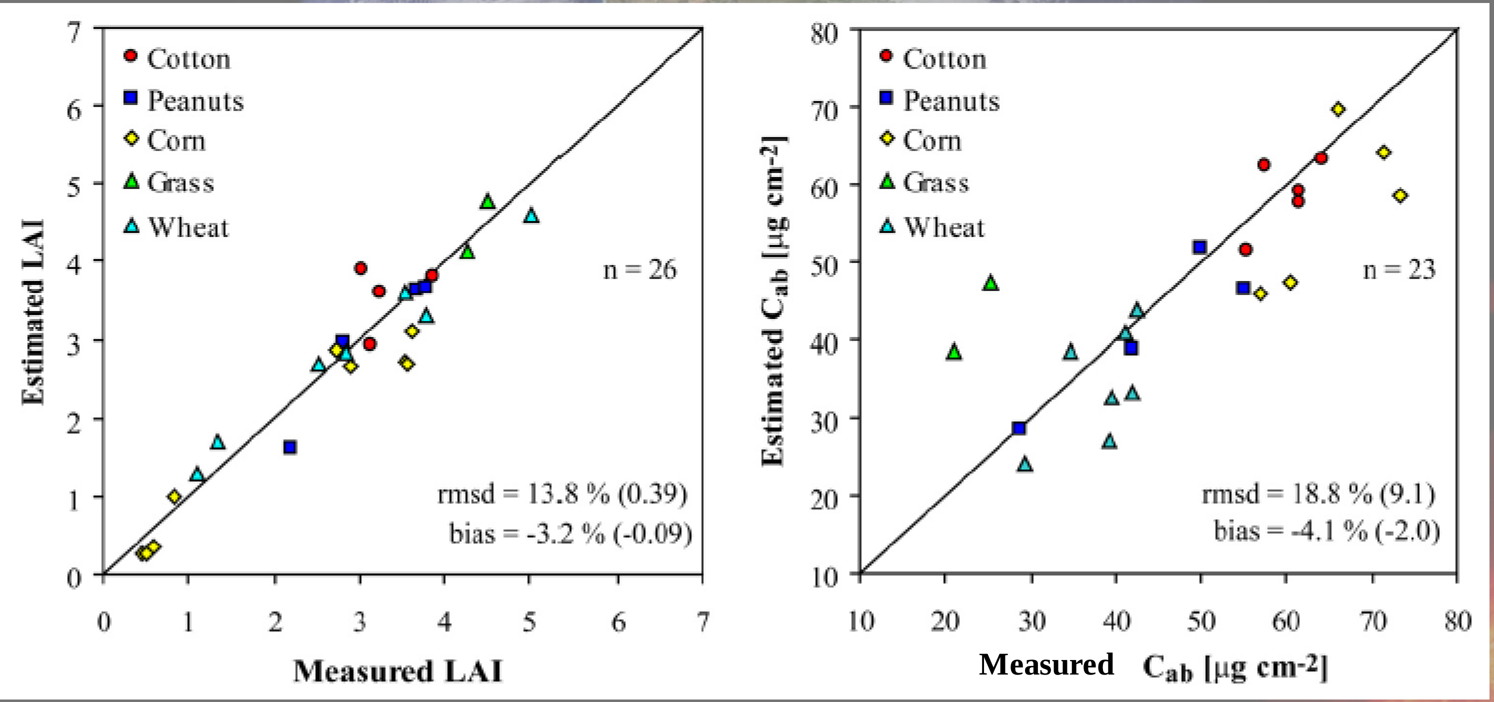
- Carbon fluxes are particularly valuable for monitoring vegetation productivity and for studying carbon cycle functioning in response to changes in environmental and physiological controls and a changing climate

- Leaf chlorophyll is being increasingly recognized as a key for quantifying photosynthetic efficiency and gross primary production of terrestrial vegetation

- Thermal-based LSMs are well suited for mapping instantaneous fluxes down to 1 m resolution, as TIR data provide valuable information about the sub-surface moisture status, obviating the need for precipitation input and prognostic modeling of soil transport processes.

Mapping vegetation parameters

Sensor	Vegetation	N LAI	N Cab	LAI RMSD	LAI Bias	Cab RMSD	Cab Bias
SPOT 20m *(OK, U.S.)*	Cotton/peanuts/corn/grass/wheat	26	23	14% (0.39)	-3.2% (-0.09)	19% (9.1)	-4.1% (-2.0)
SPOT 10m *(MD, US)*	Soybean/grass/corn/alfalfa	47	41	13% (0.40)	-0.9% (-0.03)	11% (4.9)	-0.1% (-0.02)
Aircraft 1m *(MD, US)*	Corn	31	31	10% (0.25)	0.5% (0.01)	10% (4.4)	-2.2% (-0.9)
SPOT 20m *(Denmark)*	Maize/barley/wheat	19	26	19% (0.74)	-9.0% (-0.40)	10% (5.3)	-0.2% (-0.08)
MODIS 250m *(DK)*	Barley/wheat	48	-	20% (0.54)	9.0% (0.24)	-	-
	Forest	19	-	18% (0.63)	-15% (-0.52)	-	-



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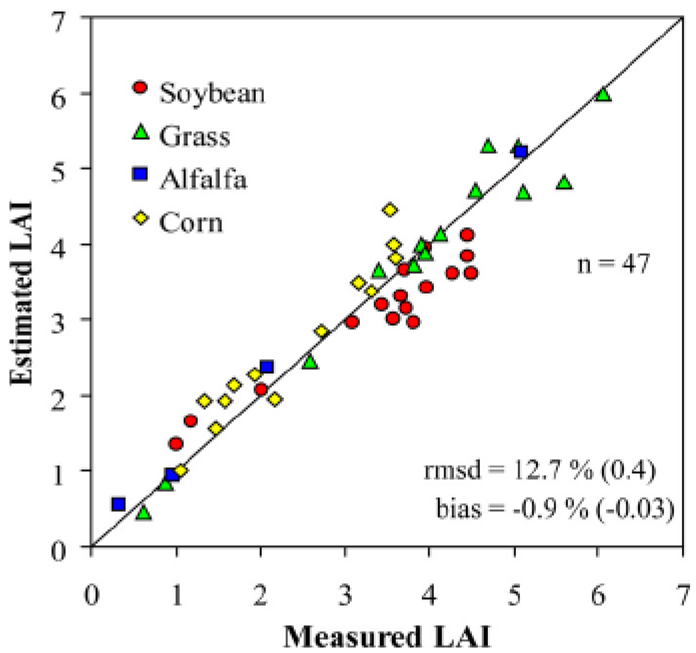

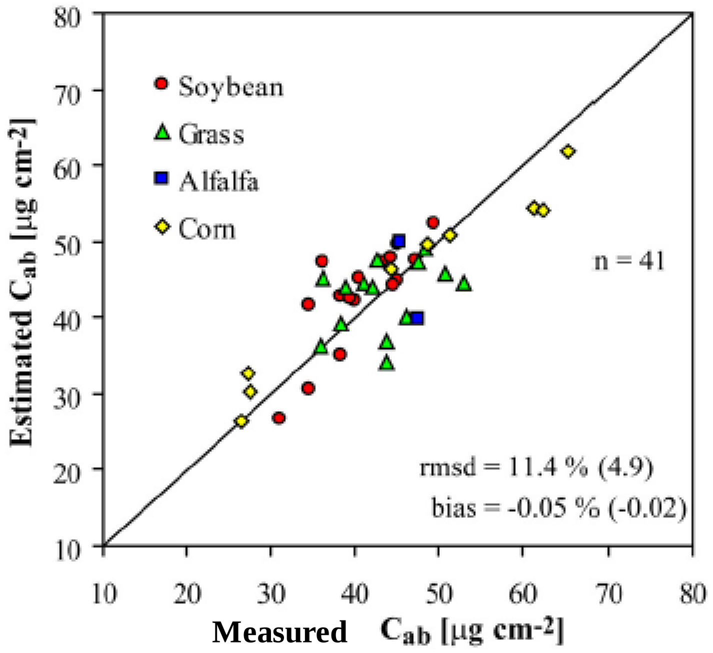

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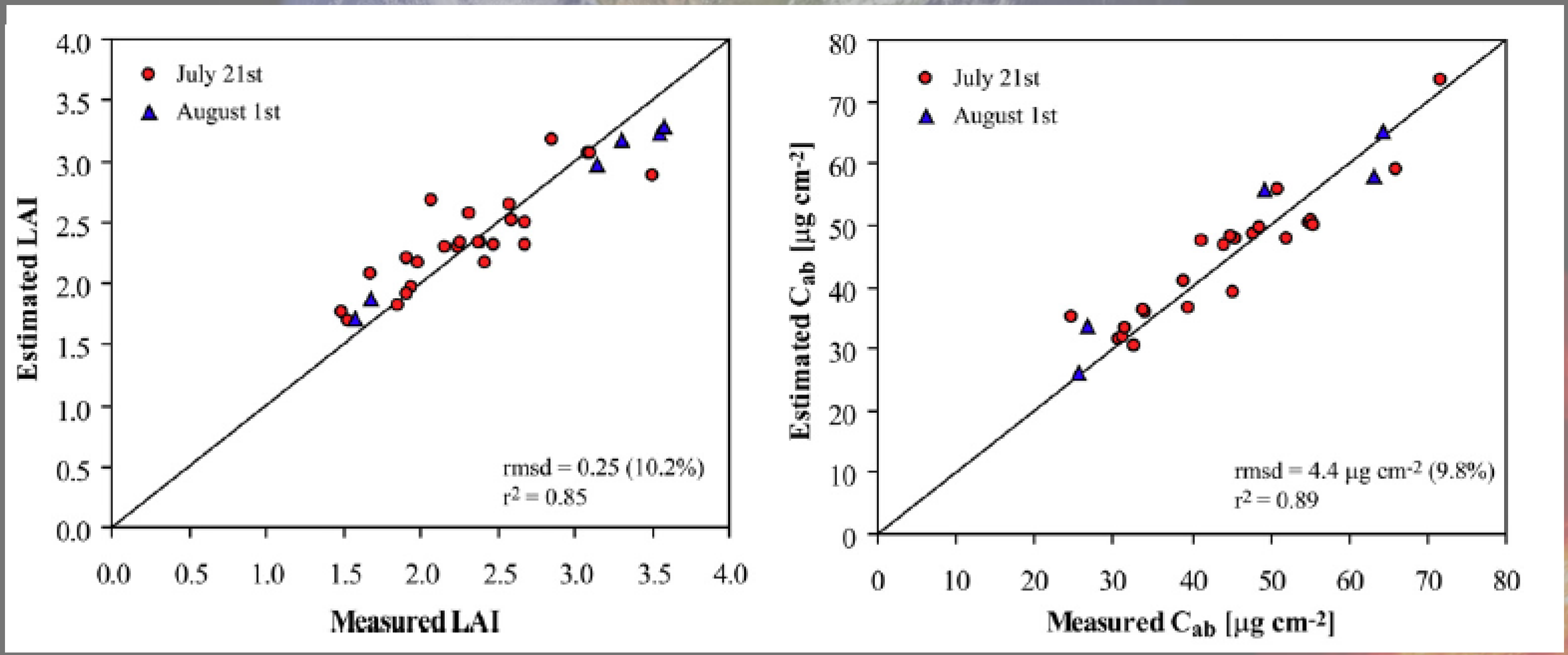

HyspIRI Science Symposium on Ecosystem Data Products (NASA GSFC May 4, 2010)

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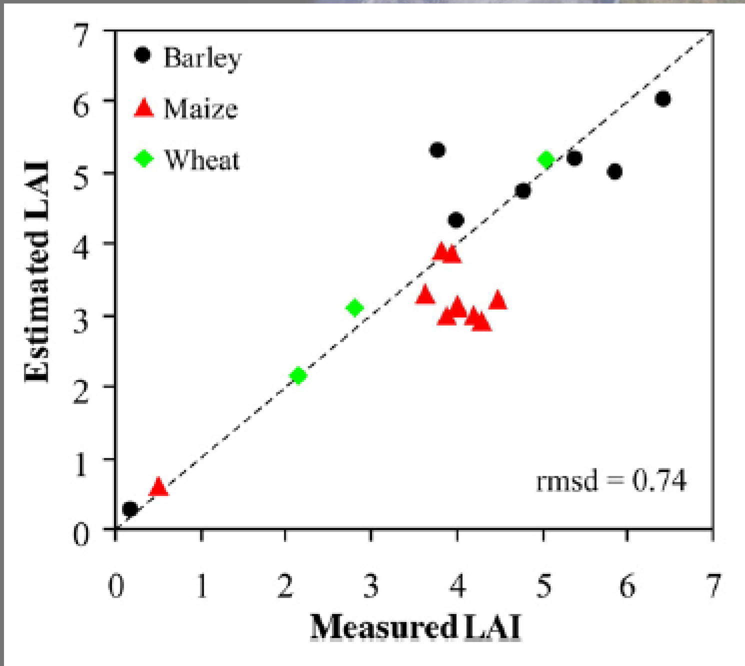

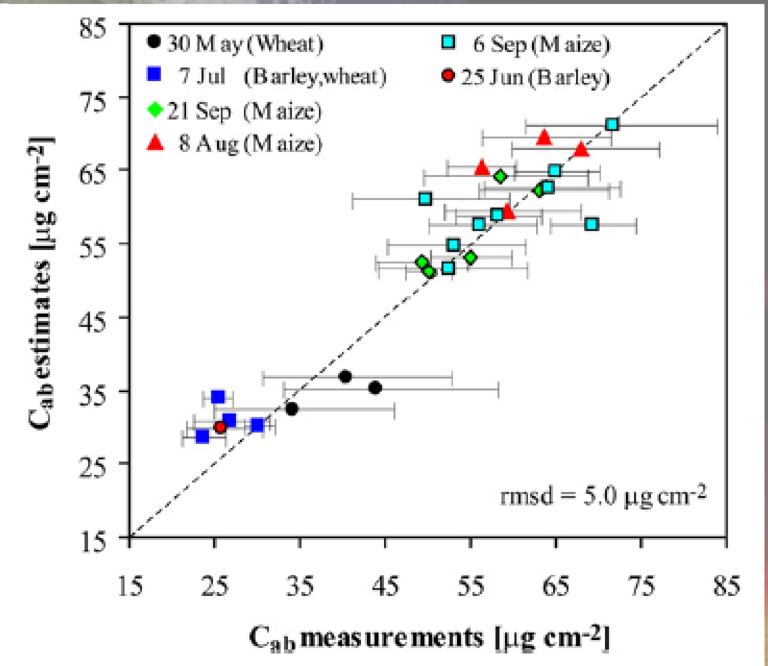

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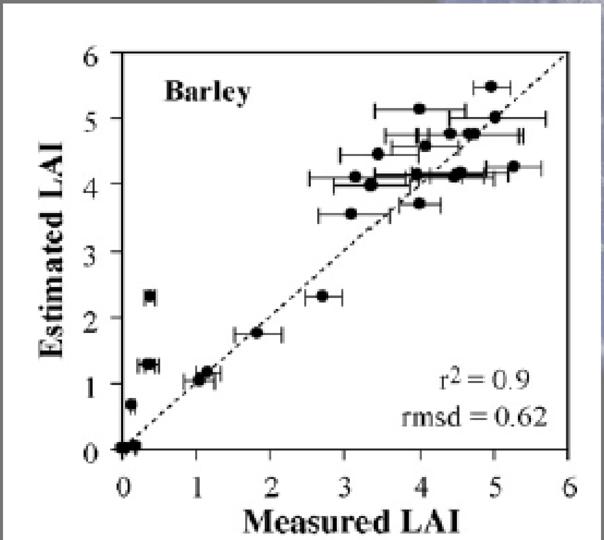
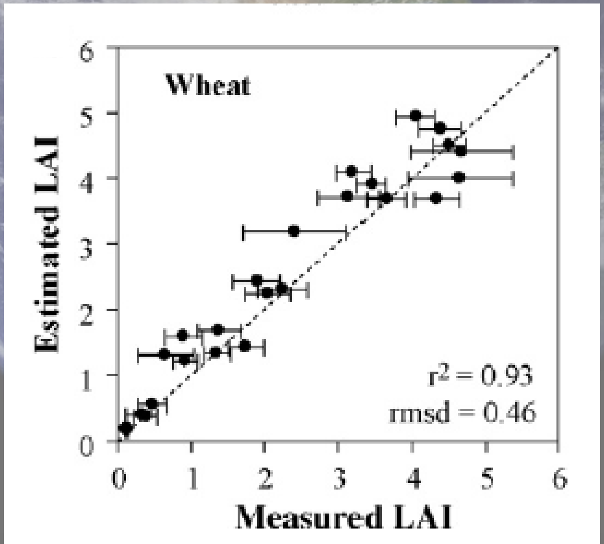
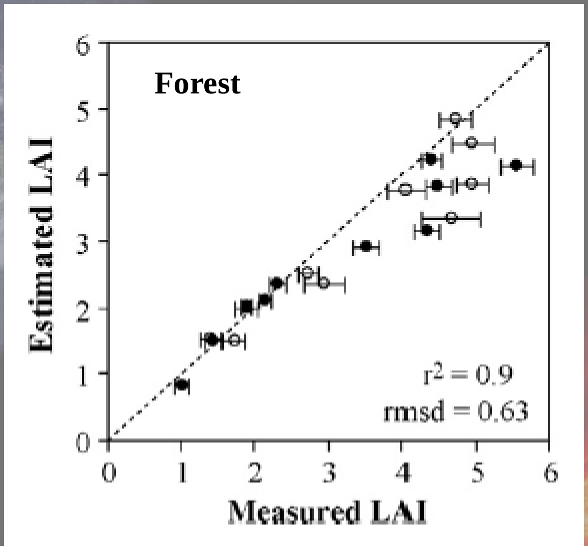
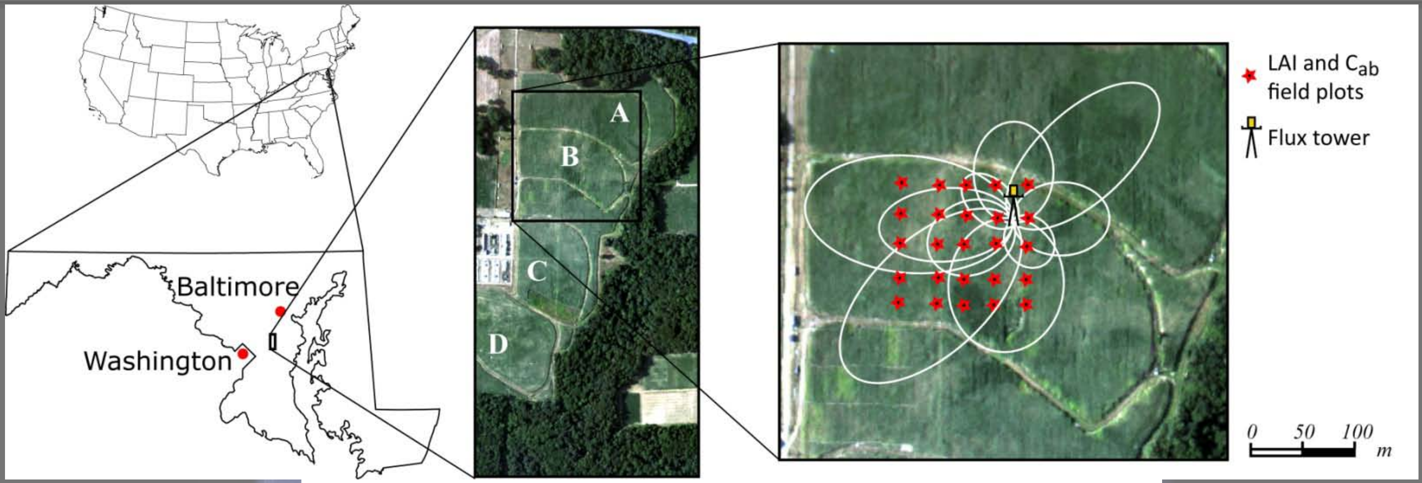
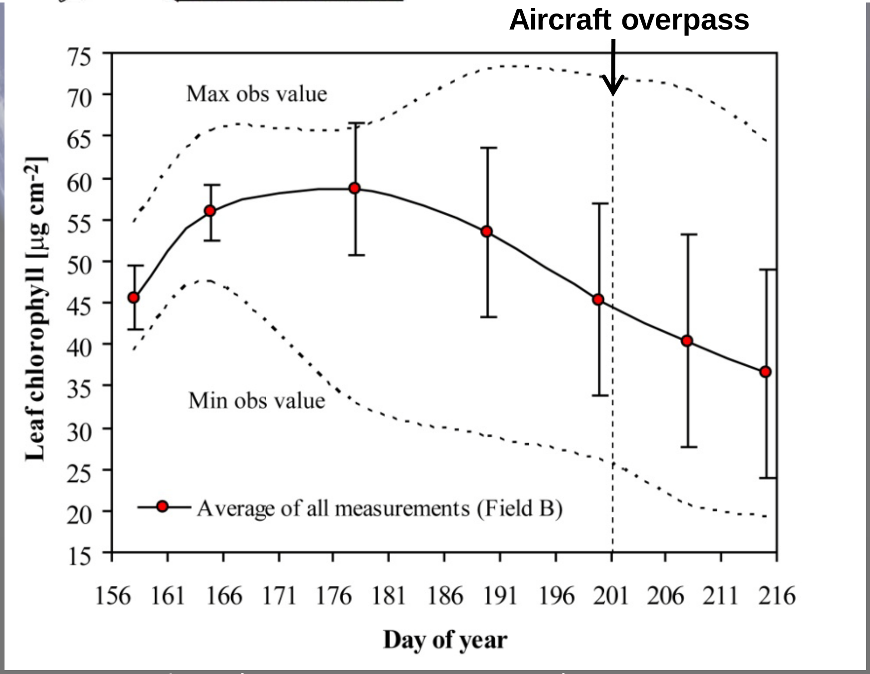






LUE – Leaf chlorophyll inter-correlation





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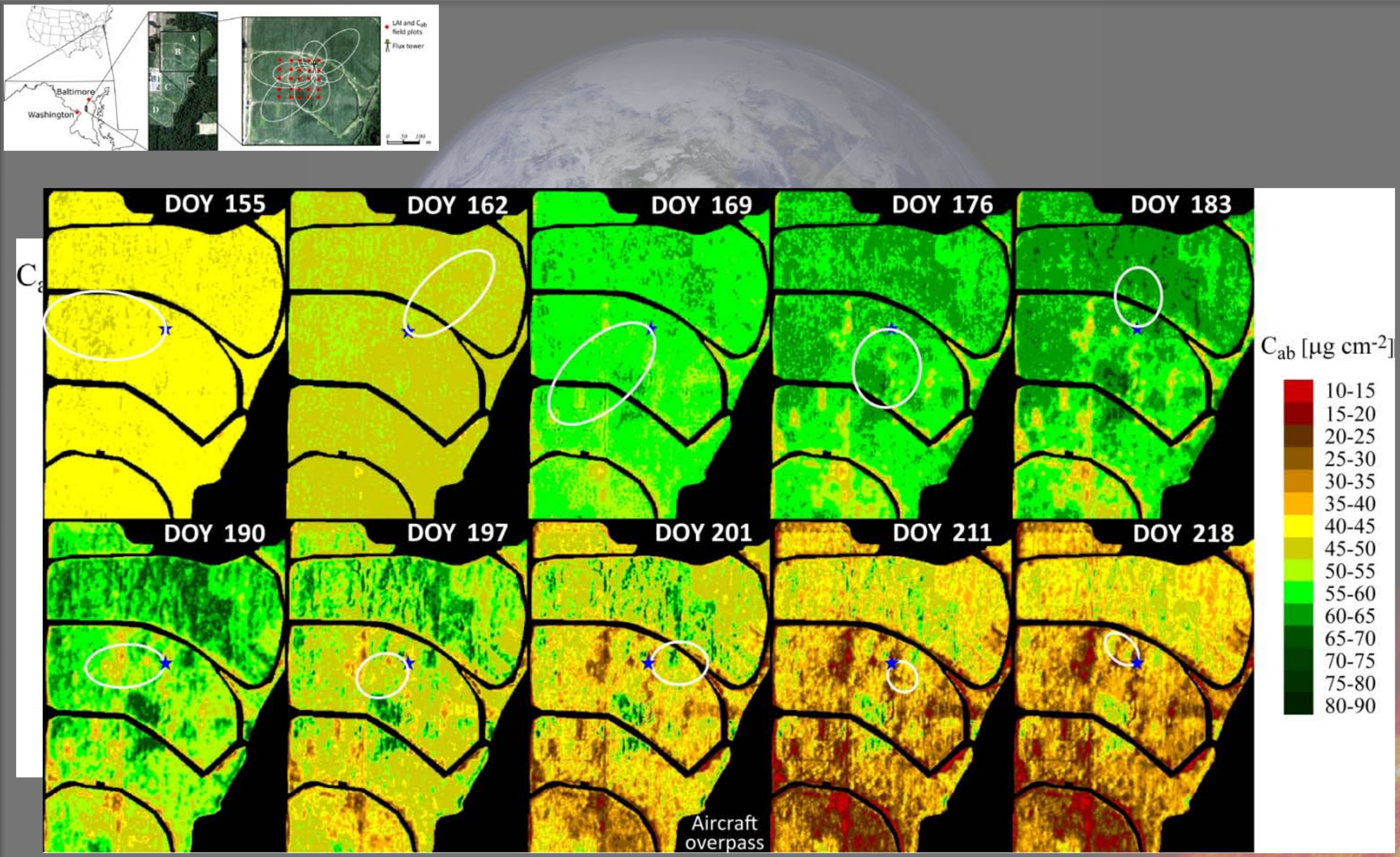

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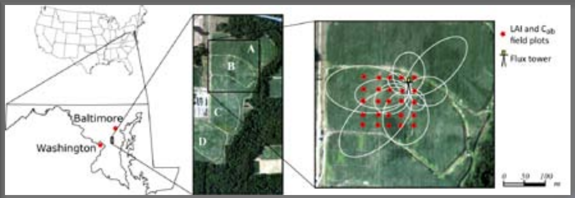
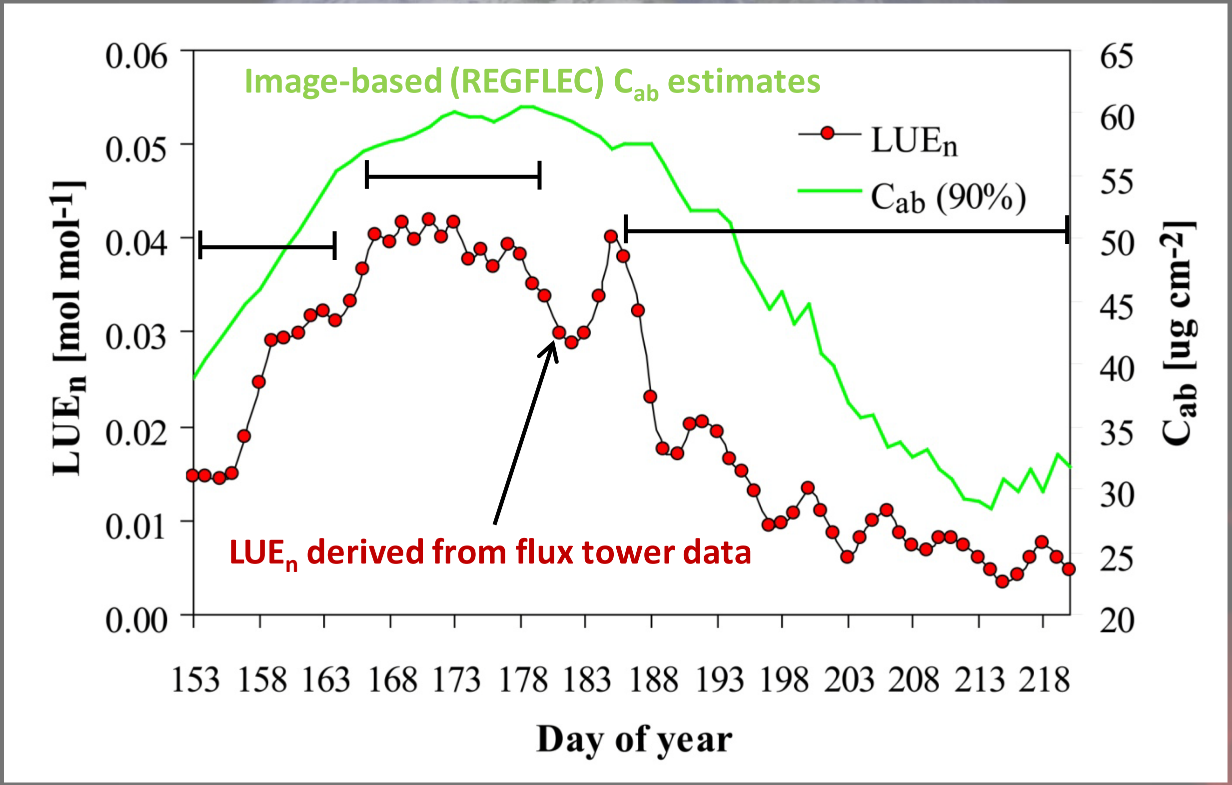
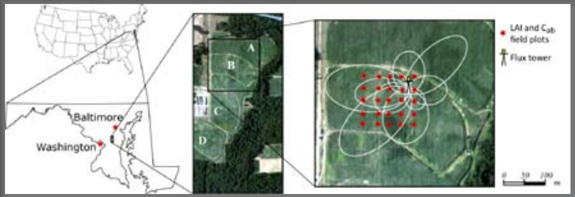
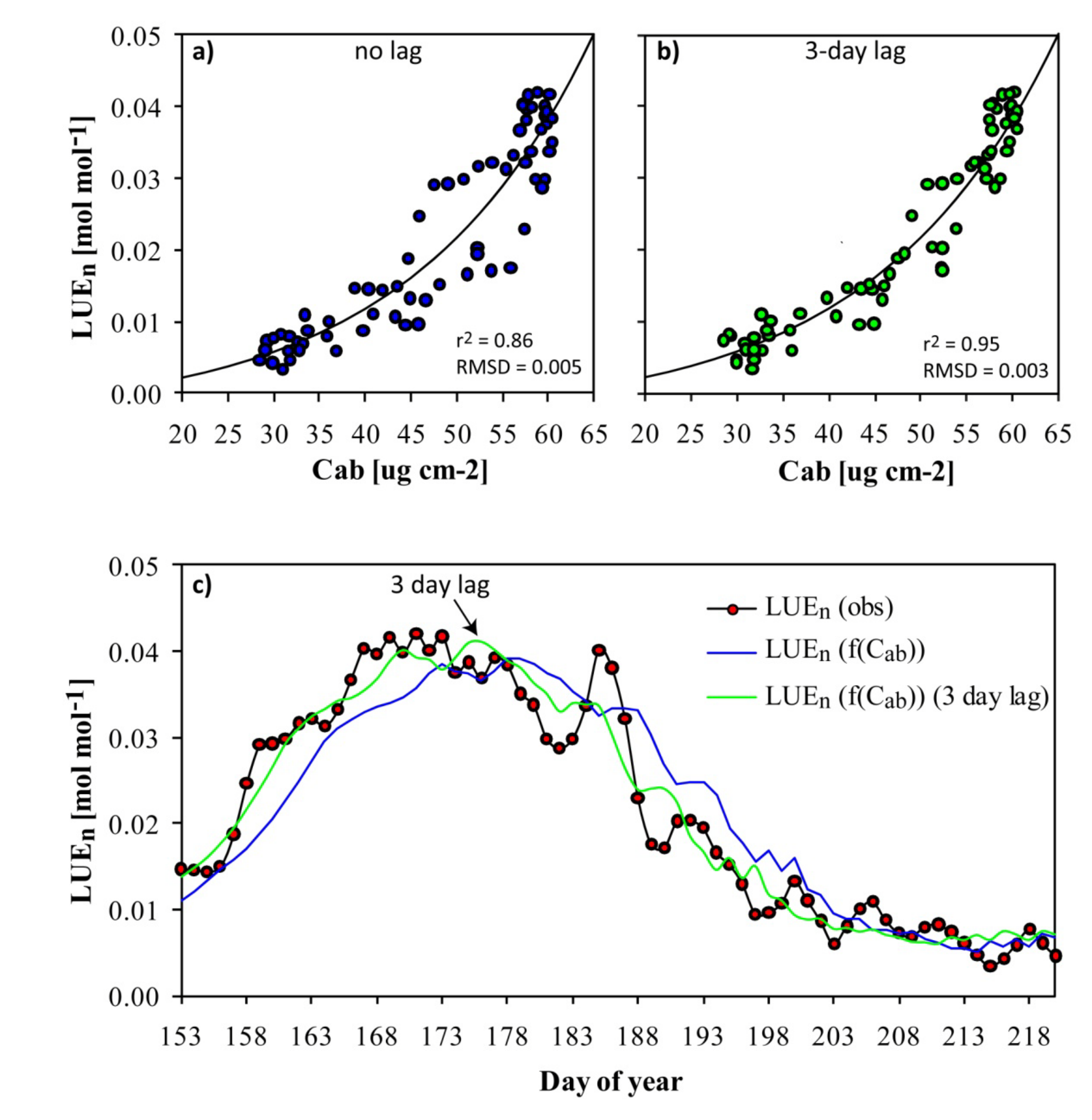
LUE – Leaf chlorophyll inter-correlation





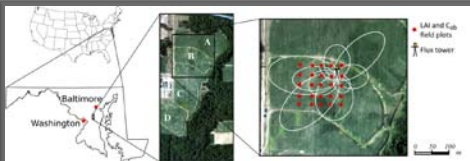
LUE – Leaf chlorophyll inter-correlation

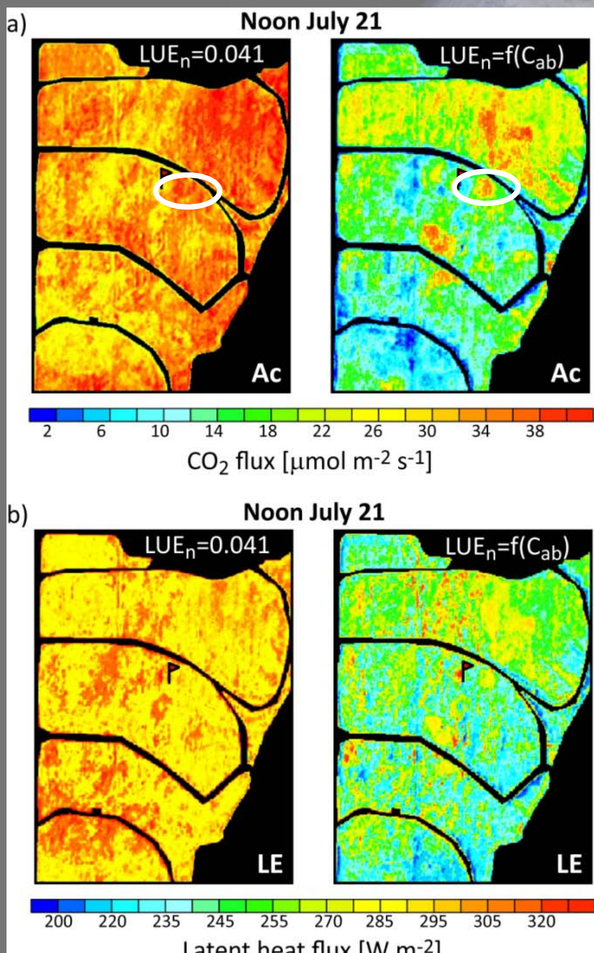


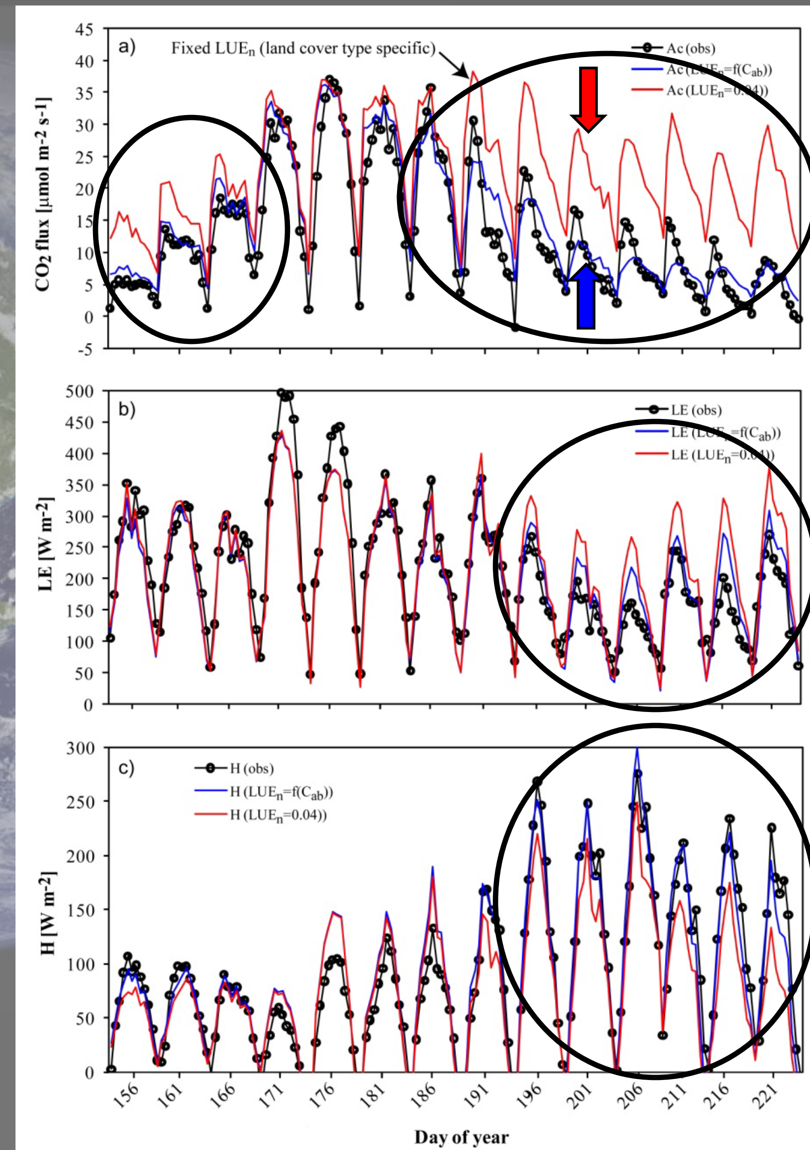


HyspIRI Science Symposium on Ecosystem Data Products (NASA GSFC May 4, 2010)

Thermal-based flux mapping

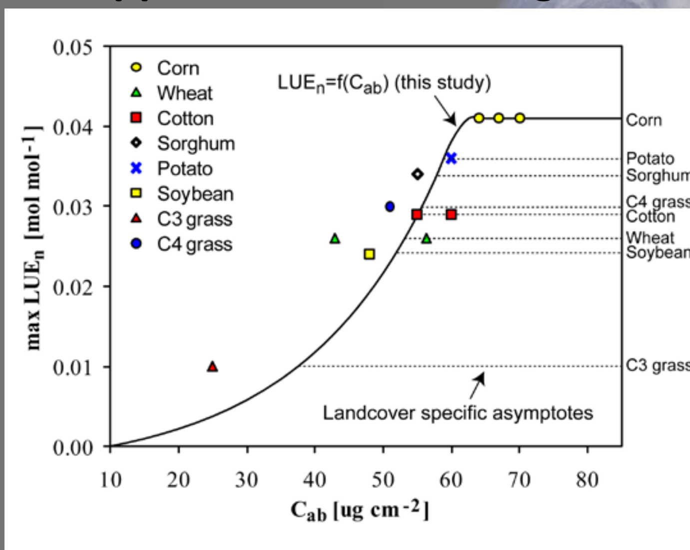


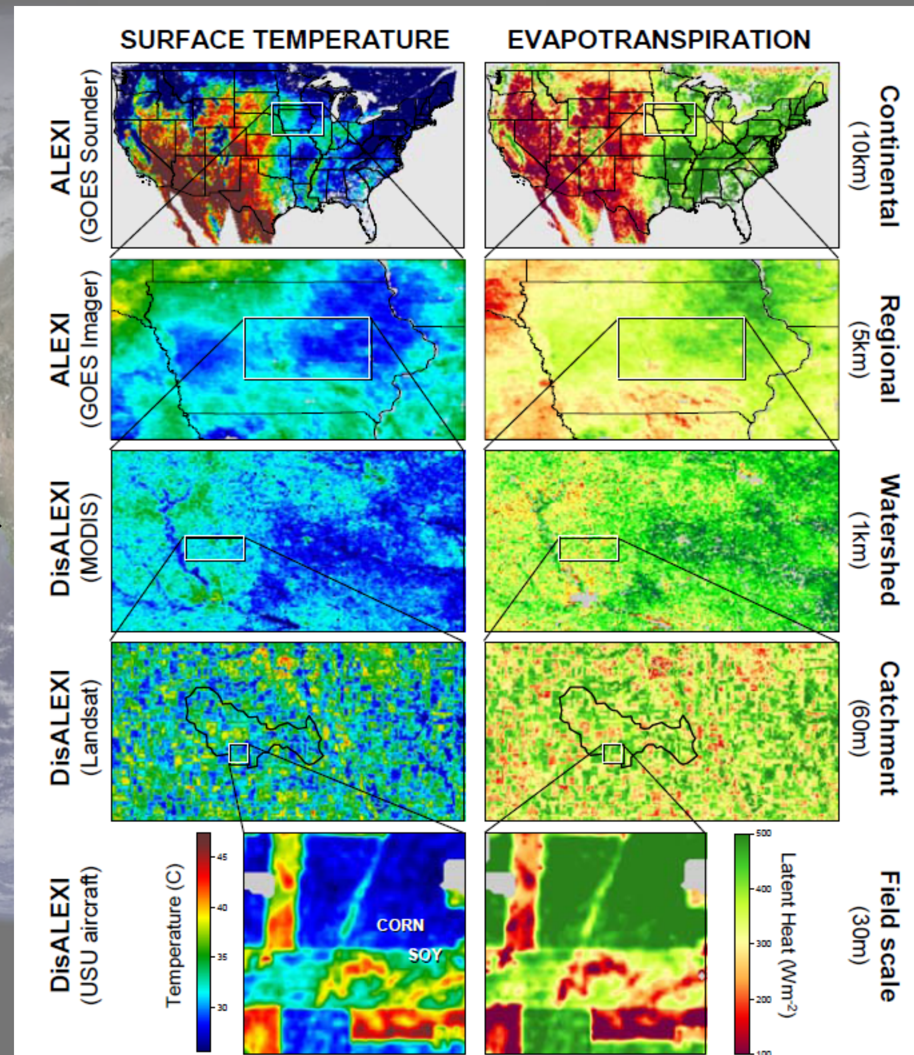




Thermal-based flux mapping

Application to other regions





USDA-ARS HRSL
Hydrology & Remote Sensing Lab
Beltsville, Maryland, USA

Combining observations in the reflective solar and thermal domains for improved carbon and energy flux estimation

Rasmus Houborg[1,3], Martha Anderson[2], W. P. Kustas[2]

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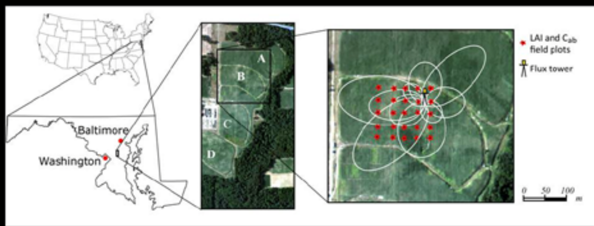
[3] Hydrological Sciences Branch, NASA Goddard Space Flight Center, Greenbelt, MD (contact: rasmus.houborg@nasa.gov)

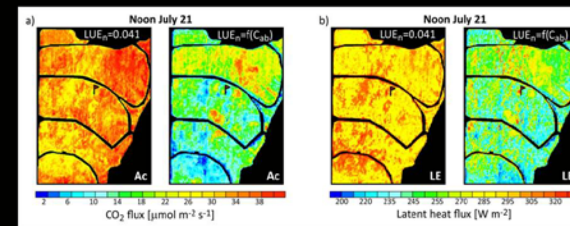
Chlorophylls absorb photosynthetically active radiation and thus function as vital pigments for photosynthesis, which makes leaf chlorophyll content (C_{ab}) useful for monitoring vegetation productivity and an important indicator of the overall plant physiological condition. This study investigates the utility of integrating remotely sensed estimates of C_{ab} into a thermal-based Two-Source Energy Balance (TSEB) model that estimates land-surface CO2 and energy fluxes using an analytical, light-use-efficiency (LUE) based model of canopy resistance. The LUE model component incorporates LUE modifications from a nominal (species-dependent) value (LUE_n) in response to short-term variations in environmental conditions. However LUE_n may need adjustment on a daily timescale to accommodate changes in physiological condition and nutrient status. Day to day variations in LUE_n were assessed for a heterogeneous corn crop field in Maryland, U.S.A. through model calibration with eddy covariance CO_2 flux tower observations. The optimized daily LUE_n values were then compared to estimates of C_{ab} integrated from gridded maps of chlorophyll content weighted over the tower flux source area. The time-continuous maps of daily C_{ab} over the study field were generated by fusing in-situ measurements with retrievals generated with an integrated radiative transfer modeling tool (accurate to within ±10%) using at-sensor radiances in green, red and near-infrared wavelengths acquired with an aircraft imaging system. The resultant daily changes in C_{ab} within the tower flux source area generally correlated well with corresponding changes in daily calibrated LUE_n values derived from the tower flux data, and hourly water, energy and carbon flux estimation accuracies from TSEB were significantly improved when using C_{ab} for delineating spatio-temporal variations in LUE_n. The results demonstrate the synergy between thermal infrared and shortwave reflective wavebands in producing valuable remote sensing data for operational monitoring of carbon and water fluxes.

STUDY SITE



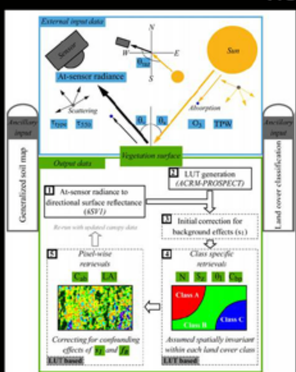
Natural color aircraft imagery mosaic (1 m resolution) of the OPE3 corn field (labeled B) study site in Maryland with a blowup of the area in immediate vicinity of the flux tower. Locations of LAI and leaf chlorophyll (C_{ab}) sampling sites are indicated by the red stars. 90% source areas of the flux tower CO2 fluxes at the time of midday are depicted for a collection of days.

FLUX MAPPING

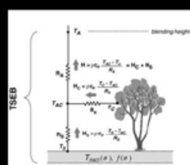


Maps of CO_2 flux (a) and latent heat flux (b) at the time of the aircraft overpass comparing TSEB_LUE (Two-Source Energy Balance model implementing a Light-Use-Efficiency based model of canopy resistance) output from runs using nominal LUE parameterized as a function of remotely sensed leaf chlorophyll (C_{ab}) (right panels) and runs assuming a fixed value for the entire field (left panels). Evidently, the use of spatially variable values of LUE_n, retrieved from remote sensing estimates of C_{ab}, has a pronounced effect on simulated fluxes.

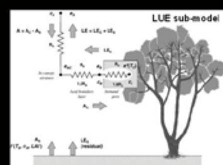
MODELS



Schematic diagram of the coupled 6SV1 - ACRM - PROSPECT REGularized canopy reFLECtance (REGFLEC) modeling tool. REGFLEC is an automatic and image-based methodology that facilitates direct use of at-sensor radiance observations in green, red and near-infrared wavebands for the retrieval of vegetation parameters. Input requirements are sparse and the integrated modeling system requires no calibration and may be run for any locality with availability of standard atmospheric state data, a land cover classification and soil map



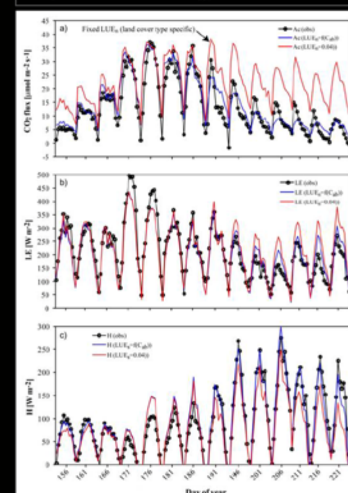
Thermal-based Two-Source Energy Balance (TSEB) modeling scheme. The thermal data (T_{rad}) provide valuable information about the sub-surface moisture status, obviating the need for precipitation input data and prognostic modeling of the soil water balance.



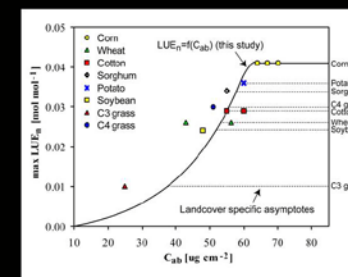
LUE-based canopy resistance method for computing coupled carbon and water fluxes within the TSEB framework. LUE is modified from a nominal value (LUE_n) in response to variations in humidity, CO_2 concentration, temperature, wind speed, and fraction of diffuse radiation.

FLUX VALIDATION

Comparison of hourly eddy covariance flux observations with model estimates of CO_2 (a), latent heat (b) and sensible heat (c) fluxes generated with the TSEB_LUE using a fixed LUE_n and a LUE_n that varied seasonally as a function of leaf chlorophyll. Each diurnal segment represents flux data averaged by hour over 5-day intervals. Consideration of temporal changes in LUE_n (as dictated by variations in C_{ab}) improves the accuracy of simulations of carbon uptake by the corn field, particularly during leaf expansion and development (doy 156 - 171) and late stages of leaf maturity and leaf senescence (> doy 191), where observed fluxes otherwise would be vastly overestimated. While performance improvements are less pronounced for latent and sensible heat fluxes, the results do promote photosynthetic capacity (i.e. LUE_n) as a key control on also water and energy fluxes.

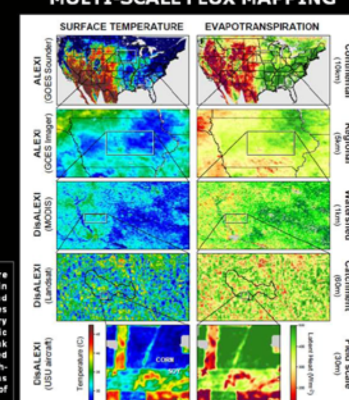


APPLICATION TO OTHER REGIONS



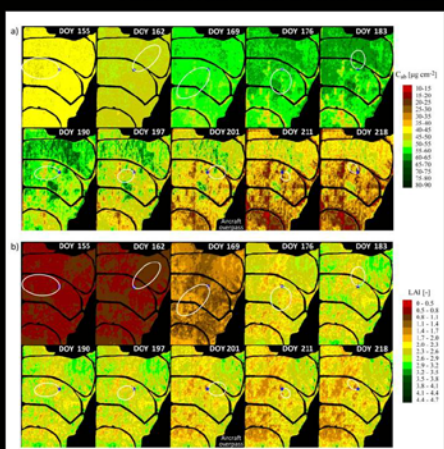
In-situ measurements of maximum leaf chlorophyll (C_{ab}) from various land cover types plotted against land cover specific maximum nominal LUE (LUE_n) compiled from a survey of literature values. The exponential LUE_n - C_{ab} relationship for corn derived in this study is shown with an asymptotic behavior above the max LUE_n (0.041). Points representative of other land cover types tend to fall in close proximity to this relationship that may be valid for these cover types also as long as the upper asymptote is adjusted to correspond to the maximum LUE_n for the given land cover type (dashed lines).

MULTI-SCALE FLUX MAPPING

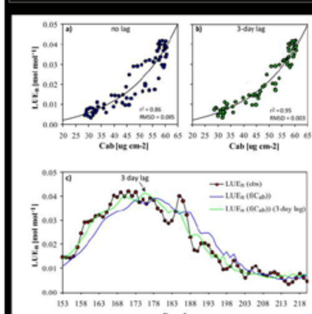


The coupled REGFLEC – TSEB_LUE modeling system described here demonstrates the synergy between TIR and shortwave reflective wavebands in producing valuable remote sensing data for operational monitoring of carbon and water fluxes. The ALEXI/DisALEXI modeling suite (based on TSEB) facilitates scalable flux mapping using thermal imagery from a combination of geostationary and polar orbiting satellites, zooming in from the national scale to sites of specific interest. We are currently working toward a full integration of the functional link between LUE and leaf chlorophyll within ALEXI/DisALEXI to improve thermal-based flux mapping activities at field to regional scales. New missions with high-resolution (sub-field scale, <100m) TIR and shortwave imaging capabilities, such as LDCM (Landsat Data Continuity Mission) and HyspIRI, will enable a continuation of these flux mapping activities at field to regional scales.

VEGETATION MAPS AND LUE-Cab INTERCORRELATION



Weekly maps of leaf chlorophyll (C_{ab}) (a) and LAI (b) generated by fusing in-situ measurements in vicinity of the flux tower with image-based (REGFLEC) retrievals derived using reflectances acquired from aircraft on doy 201. The fusion approach assumes that (1) the relative temporal evolution of LAI and C_{ab} at any point within the field follows the temporal characteristic at one of the in-situ sampling sites, and (2) spatial pattern anomalies of LAI and C_{ab} present during the aircraft acquisition are preserved. Daily averaged source areas (90%) of the flux tower CO_2 fluxes are overlain.



Scatter plots of model calibrated LUE_n and footprint averaged leaf chlorophyll content and associated exponential fits with (a) and without (b) a 3-day lag applied to the leaf chlorophyll timeseries record. c) Timeseries intercomparison plot of model calibrated LUE_n and LUE_n estimated as exponential functions of C_{ab}. The improved agreement with the lagged C_{ab} estimates suggest that short-term environmental stresses are not immediately manifested in the C_{ab} record.

CONCLUSIONS

➢ An integrated radiative transfer modeling tool (REGFLEC) facilitated accurate retrieval of leaf chlorophyll (C_{ab}) and LAI from remote spectral observations in the visible domain

➢ The spatio-temporal C_{ab} record was highly correlated with variations in nominal light-use-efficiency, and thus proved useful for optimizing flux estimates by a thermal-based Two-Source Energy Balance (TSEB) model that implements a LUE-based model of canopy resistance

➢ The symphony of LUE_n (that varied seasonally as a function of C_{ab}) and thermal input data provided accurate flux retrievals for a 'difficult' site characterized by highly variable degrees of plant stress

➢ The results demonstrate utility in combining observations in the reflective solar and thermal domains for estimating carbon, water and heat fluxes within a coupled framework

Combined VSWIR-TIR Data Products

Dar A. Roberts (others)

Product List

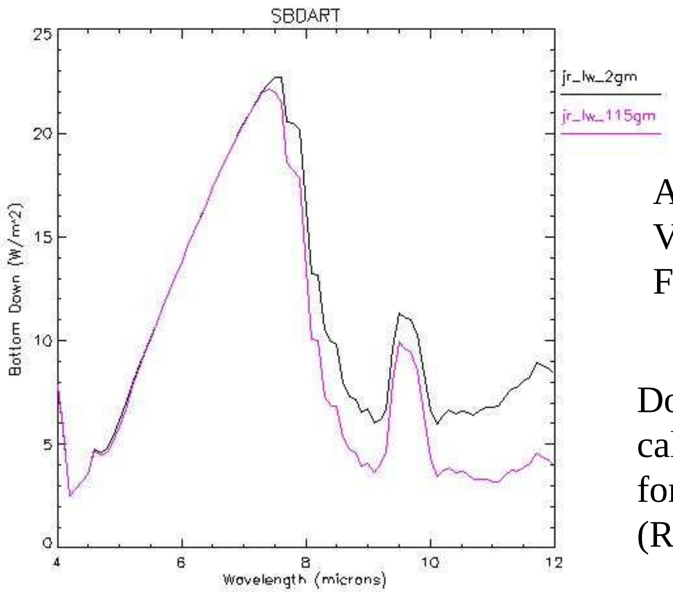
- **Improved Temperature Emissivity Separation**
- **Combined VNIR-SWIR Physiological/Thermal Stress Measures**
- **Combined Species/PFT and Thermal Stress Measures**
- **Combined Sub-pixel Fractions (GV, NPV, Soil, Shade) and Canopy/Soil Temperatures**
  - **Sub-pixel canopy temperature (experimental)**
  - **Sub-pixel soil temperature (experimental)**
- **Improved Sub-pixel Vegetation/Impervious/Soil fraction**
- **Urban Albedo/Temperature Product**

Improved Temperature Emissivity Separation

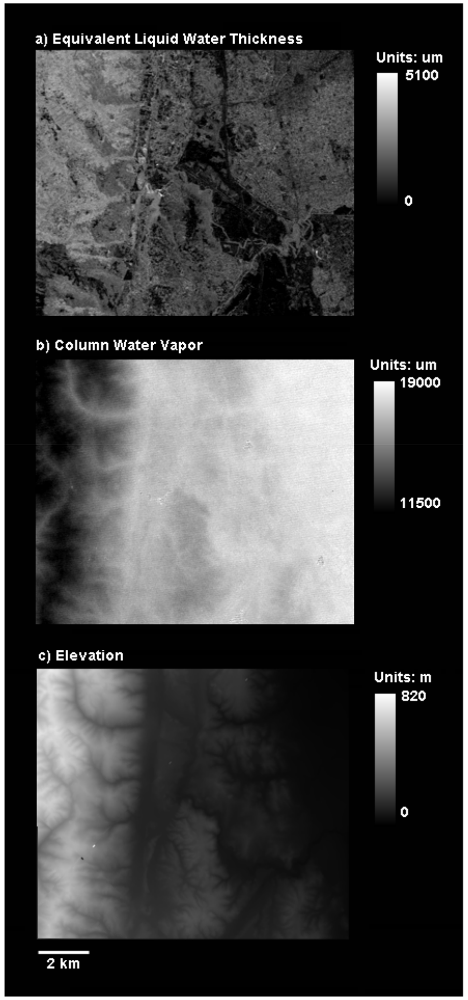
- **Product description:**
  - Improved pixel-based estimate of Temperature and Emissivity
- **Justification:**
  - The largest error source in TES for ASTER is estimated atmospheric downwelling radiance and attenuation
- **Unique Hyspiri Contribution**
  - Hyspiri provides pixel scale column water vapor, significantly improving upon climatology, radiosonde or MODIS
  - Emissivity should be slowly varying, thus improved emissivity at 19 days should improve temperature estimates at 5 day intervals
- **Climate Continuity Relevance**
  - Temperature impacts numerous hydrological and biological processes including rates of ET, photosynthesis and respiration
  - HyspIRI provides a mechanistic understanding of temperature variability seasonally and across ecosystems

Improved Temperature Emissivity Separation

- **Column water vapor is estimated using forward inversion as it varies spatially and with elevation**
- **Column water vapor is used to calculated downwelling radiance as a first step for emissivity estimation**



Downwelling longwave calculated using SBDART for 1.15 and 2 g/m^2 water vapor (Richiazzi et al.)



AVIRIS EWT, Column Water Vapor, and a DEM From Roberts et al., 1997

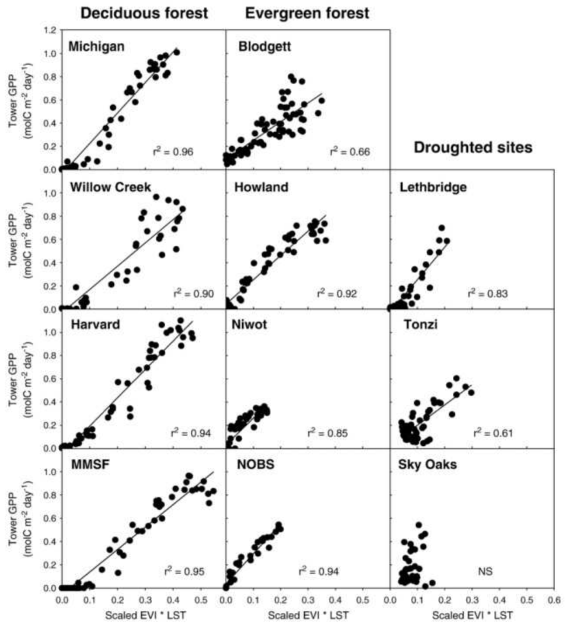
Production: Standard ASTER TES Algorithm modified to include 60 m Column water vapor and surface elevation. Other synergies are likely

Combined VNIR-SWIR Physiological/Thermal Stress Measures

- **Product description:**
  - **Fused VNIR-SWIR indices and canopy temperature**
- **Justification:**
  - **Plants respond to stress either biochemically, such as a change in plant chemistry or biophysically, such as through leaf drop or elevated canopy temperatures**
- **Unique Hyspiri Contribution**
  - **Hyspiri can generate a suite of standard hyperspectral stress indices such as PRI, MCARI, EWT, red-edge measures that cannot be generated with other sensors**
  - **Improved measures of canopy emissivity & temperature. Relationships established at a 19 day repeat can be interpolated using TIR at 5 day intervals**
  - **60 m spatial resolution can improve upon current 1 km products from MODIS**
- **Climate Continuity Relevance**
  - **Models for calculating GPP currently prescribe many physiologically significant variables such as LUE or WUE based on biome and thus fail to capture important interactions between vegetation, temperature and available moisture**
  - **Improved model performance should provide a better mechanistic understanding of how changes in temperature and moisture impact GPP**

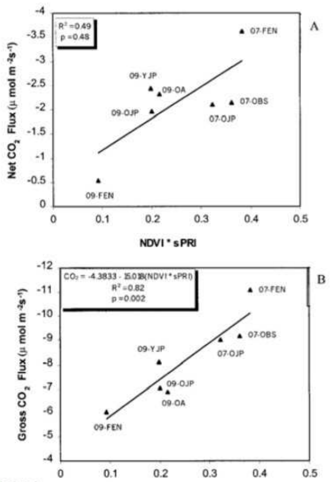
Combined VNIR-SWIR Physiological/Thermal Stress Measures

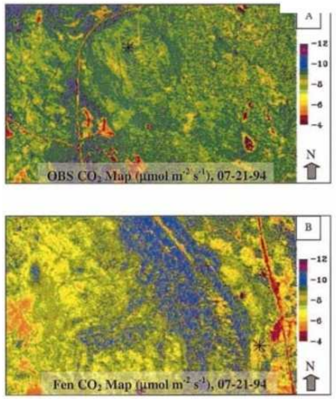
- **The ability to improve estimates of carbon uptake using PRI has been established using flux data and AVIRIS**
- **MODIS estimates of carbon uptake can be improved using LST and a vegetation index. What is the potential at 60 m with better indices?**



Plot of scaled EVI*LST compared to carbon uptake from flux towers.
Example derived from MODIS
From Sims et al., 2008

Plots of net and gross carbon dioxide flux measured at 7 Boreas flux tower sites compared to estimates of FPAR (NDVI) and quantum efficiency (PRI) from AVIRIS. From Rahman et al., 2001





Maps of carbon dioxide uptake estimated from scaled PRI and NDVI, calibrated to eddy flux data. From Rahman et al., 2001.

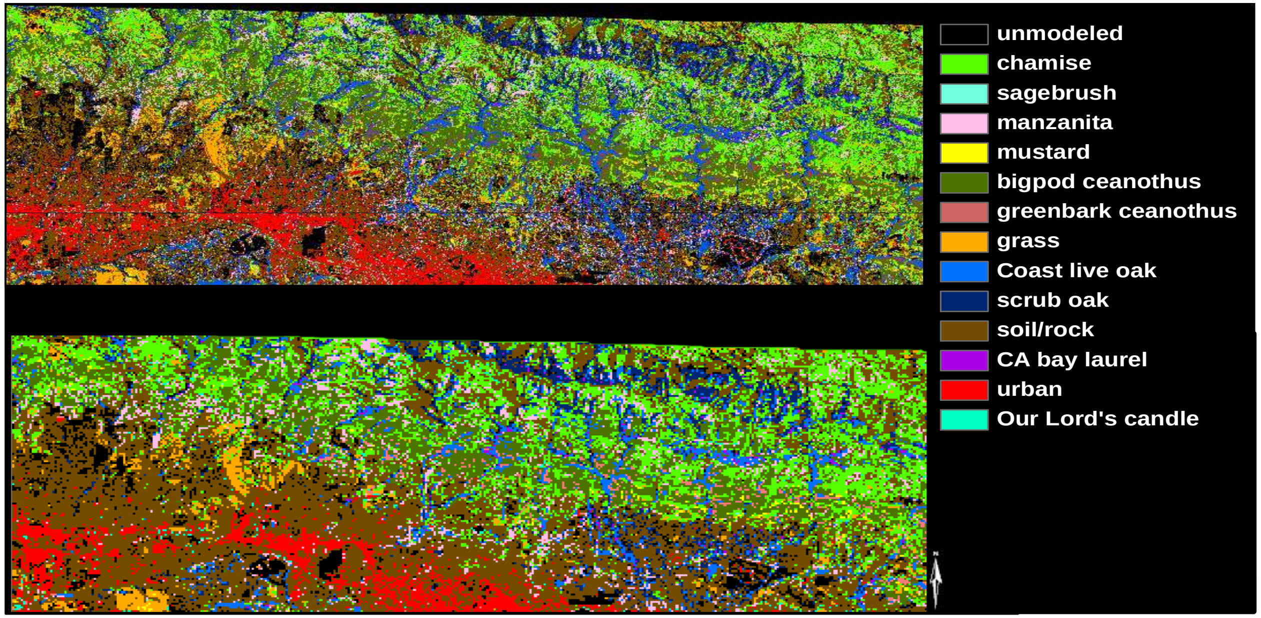
Production: Improved ASTER-TES algorithm and suites of standard hyperspectral indices from reflectance

Combined Species/PFT composition and Thermal Stress Measures

- **Product description:**
  - **Temperature estimates for HyspIRI-mapped plant species and PFTs**
- **Justification:**
  - **Physiological and compositional differences between plant species and PFTs are likely to impact surface temperatures**
- **Unique Hyspiri Contribution**
  - **Hyspiri can provide species-PFT level discrimination and surface temperature**
  - **Five day thermal repeat provides measures of how PFT/species change physiologically in response to environmental variation (PFT/Species are unlikely to change in distribution over such as short time scale).**
- **Climate Continuity Relevance**
  - **Temperature impacts numerous hydrological and biological processes including rates of ET, photosynthesis and respiration**
  - **HyspIRI provides a measure of how seasonal changes in the environment (moisture, air temperature) modify plant physiological functioning within distinct species-PFTS**

Combined Species/PFT composition and Thermal Stress Measures

- **Species/PFT responses to environmental variation, expressed in LST are likely to be lost at coarse spatial scales where they are mixed**



AVIRIS species map at 16 and 64 m spatial resolution. Accuracy actually increased as spatial resolution became coarser

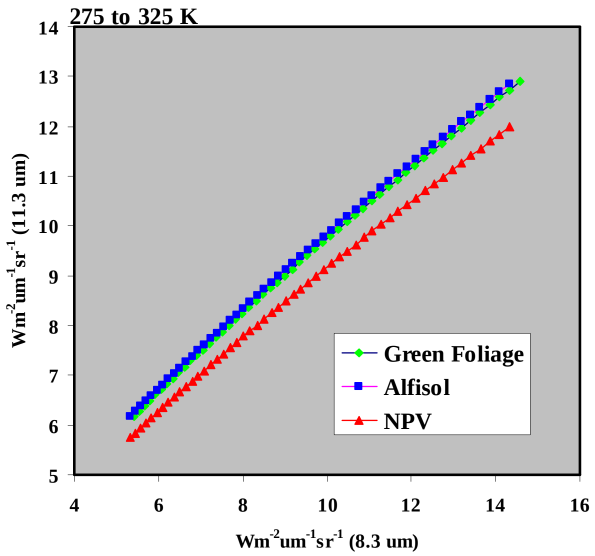
Production: Standard ASTER TES Algorithm modified to include 60 m Column water vapor and surface elevation combined with PFT/Species product

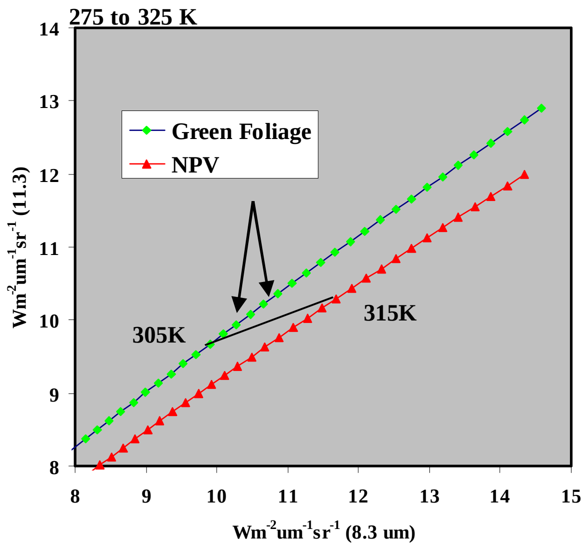
Combined Sub-pixel Fractions (GV, NPV, Soil, Shade) and Canopy/Soil Temperatures

- **Product description (Experimental):**
  - **Sub-pixel green leaf, NPV, soil temperatures**
- **Justification:**
  - **ASTER TES provides an aggregate measure of temperature and emissivity and thus does not provide sub-pixel estimates of LST for each component.**
- **Unique Hyspiri Contribution**
  - **Hyspiri VNIR-SWIR can provide highly accurate sub-pixel measures of GV, NPV and Soil Fractions**
  - **Simultaneous TIR spectra provide aggregate measures of emissivity and temperature**
- **Climate Continuity Relevance**
  - **The ratio of ET to PET can be estimated from canopy temperatures, provides measures of how hydrology and surface energy balance varies locally and with environmental change**

Combined Sub-pixel Fractions (GV, NPV, Soil, Shade) and Canopy/Soil Temperatures

- **Example**
  - Emission spectra over a range in temperatures for three materials show minor (GV-Alfisol) to significant (GV-NPV) spectral contrast
  - Mixing lines between a 315K NPV and 305 K GV
- **Production: Experimental**
  - VNIR-SWIR establishes composition and fractional cover
  - Emissivities assigned to endmembers from above
  - Temperatures estimated by intersection of mixing lines with pure temperature-radiance lines
    - Requires gradients in cover, assumes uniform temperatures within a cover type
    - Multiple wavelengths in TIR improve estimates of temperatures through greater emissivity contrasts





Climate Change and Examples of Combined HyspIRI VSWIR/TIR Advanced Level Products for Urban Ecosystems Analysis

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Earth Science Office

Marshall Space Flight Center

Huntsville, AL

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- The 21st century is the first urban century in the history of humankind

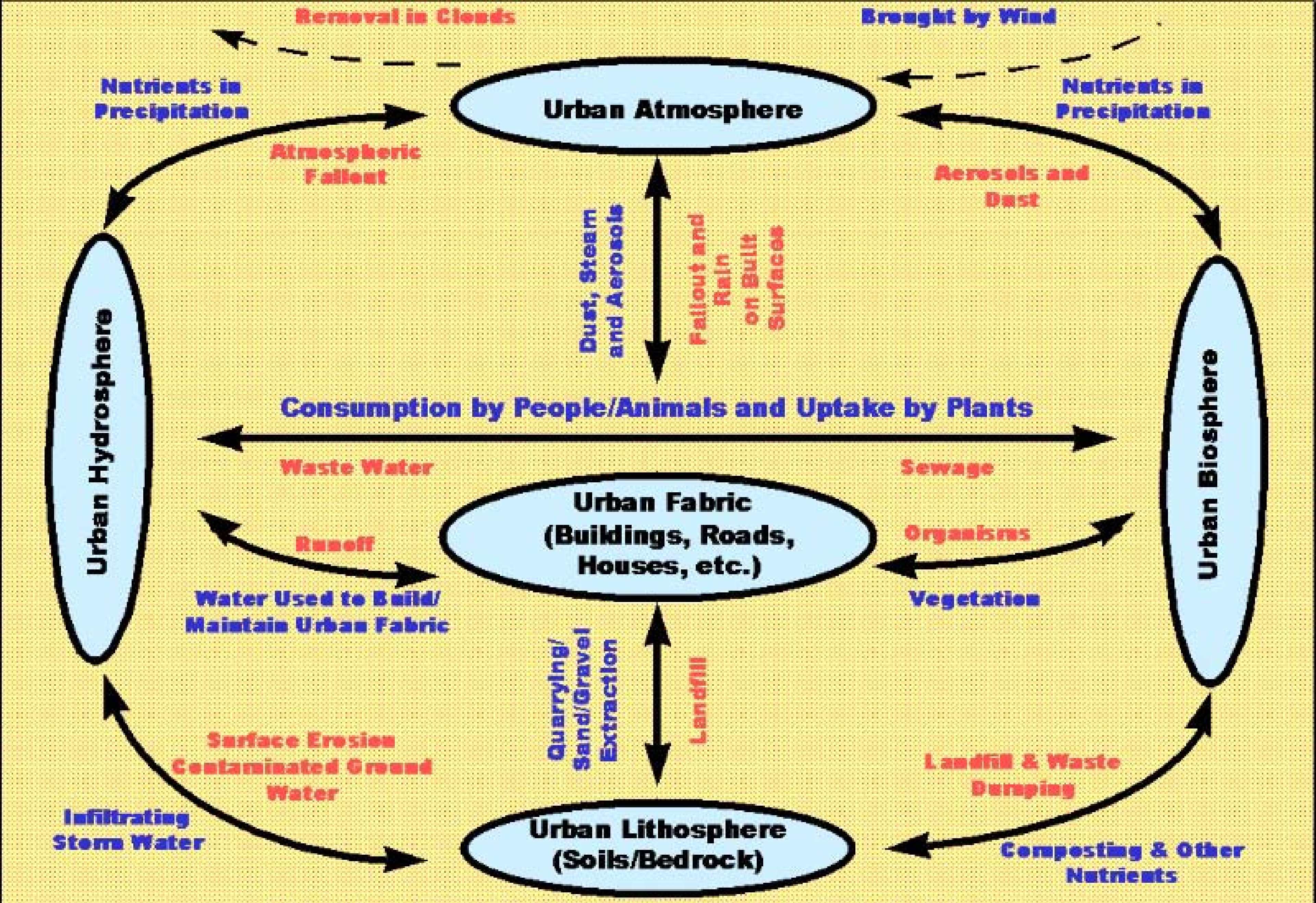
- Current projections are suggest that 60-80% of the world population will live in urban settlements by the end of this century

- Across the globe, more than 411 cities have more than one million inhabitants

- In the 1970's the United Nations defined cities of 10 milliion or more residents as "megacities"

- In 1975 there were five megacities around the world

- Today there are 19+, and by 2015 the number of megacities is expected to grow to 23



URBAN ECOSYSTEM CYCLES

(Revised from Douglas, 1983, P. 68)

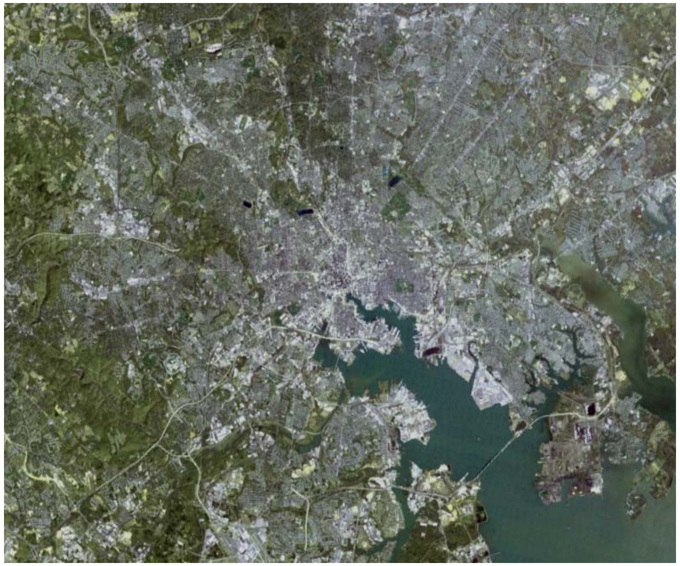
- Because urbanization is growing so rapidly around the world, the total urban ecosystem is changing dramatically

- The urban ecosystem is extremely complex and consists of a number of intertwined and interacting systems

- Because of their complexity, the processes and flows into and out of the urban ecosystem are best studied as separate entities

- **Remote sensing in conjunction with ancillary or *in situ* data can be used to observe, monitor, measure, and model many of the components that comprise urban ecosystems cycles**

- **In particular, remote sensing can be used to observe, quantify and model changes in land surface characteristics within the city (e.g., land covers, NDVI, surface thermal radiance)**



Landsat

ASTER

MODIS

- The satellites that have been principally used to date, to provide data on urban ecosystems, however, have limited capabilities

- Some general limitations are:

- MODIS – 250m-1km spatial resolution
- ASTER – 90m spatial resolution in TIR; data acquisition must be tasked
- Landsat – Non-hyperspectral; revisit time not optimal, especially for TIR data collection over urban areas
- EO-1 – very small swath width

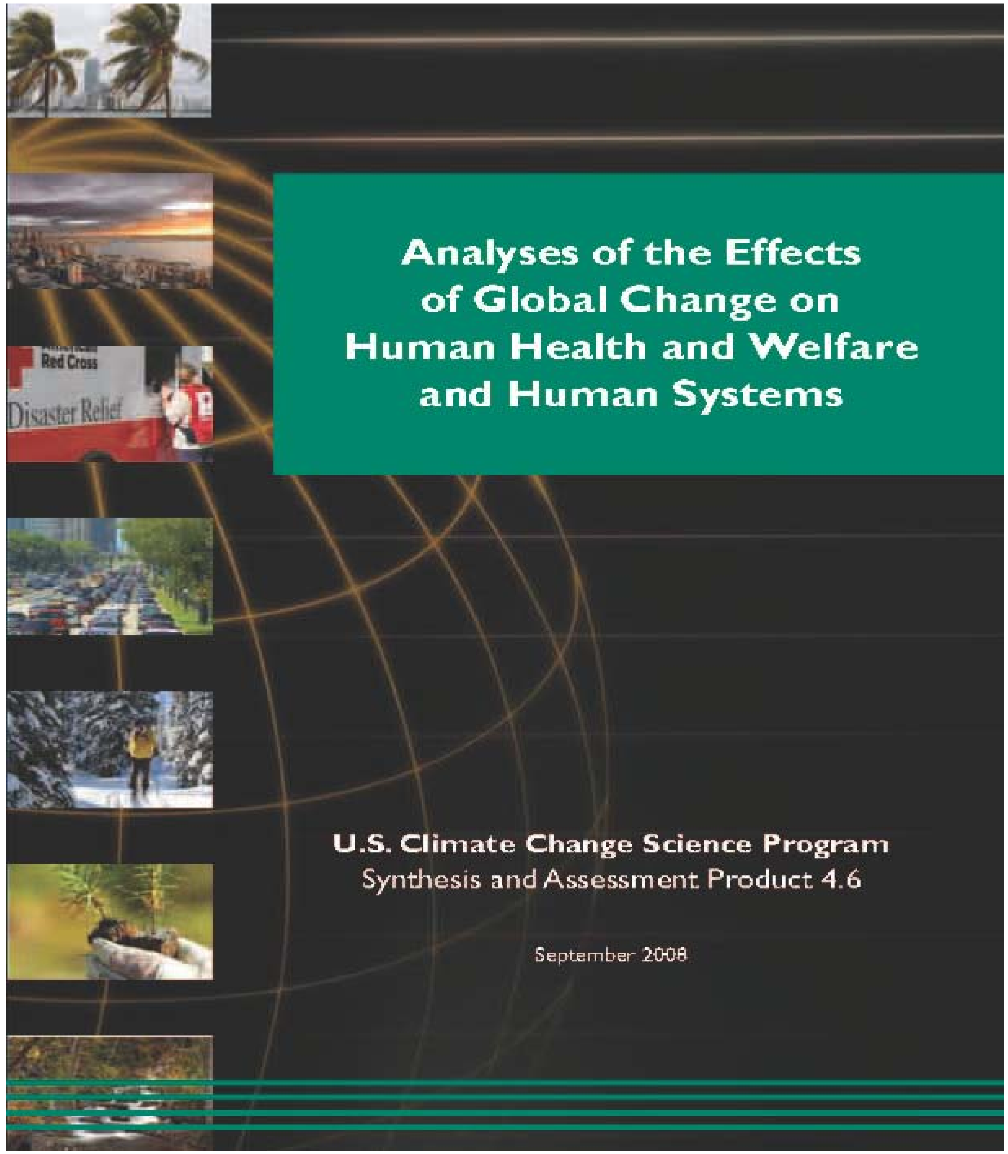
- None of these sensors is “truly” hyperspectral in the same ‘vain’ as AVIRIS for example

- HyspIRI's spectral, spatial and orbit characteristics will make HyspIRI very attractive for producing advanced image/data products that can provide more precise and accurate data on various aspects of the urban ecosystem for use in analysis and modeling by scientists and decision makers

Decadal Survey – Chapter 6 – Human Health and Security

(Concerns about the use of Landsat and ASTER and their deficiencies in regard to measuring the urban heat island effect as a cycle within the urban ecosystem)

“They allow surface vegetation and temperature to be mapped down to the scale of cities, towns, and agricultural fields and forest patches (i.e., 1km), revealing important relationships between heat and land use. Unfortunately, these satellite/sensor systems have poor return times, typically 18 days or more, limiting their usefulness for monitoring”…”Heat stress (on biophysical systems and humans) may begin to climb within just a few days after the start of extreme conditions”


Analyses of the Effects
of Global Change on
Human Health and Welfare
and Human Systems
U.S. Climate Change Science Program
Synthesis and Assessment Product 4.6
September 2008
Red Cross
Disaster Relief

Climate Change Impacts on Urban Ecosystems

(From U.S. Climate Change Science Program, Synthesis and Assessment Product 4.6 - “Analysis of the Effects of Global Change on Human Health and Welfare and Human Systems”)

Effects on Urban Metabolism:

•Climate change will impact a host of inputs, transformations, and outputs such as heat, and energy and many other inputs and outputs from the urban ecosystem

•An example is the Urban Heat Island (UHI) effect that is expected to greatly increase over cities as a function of urban growth and increased solar radiation and warmer surface temperatures

IN EFFECT, CLIMATE CHANGE WILL BASICALLY IMPACT THE ENTIRE URBAN ECOSYSTEM

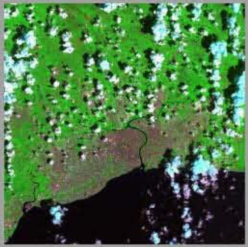
Inter-Urban Variability

1999 - 2001 Landsat ETM+

30 x 30 km

Small, 2002

Shanghai



Santo Domingo

St. Petersburg

Taipei

Tianjin

Vancouver

Vienna

New York

Port au Prince

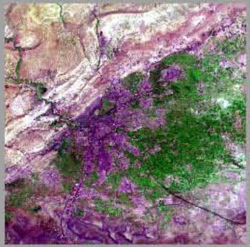
Pyongyang

Quito

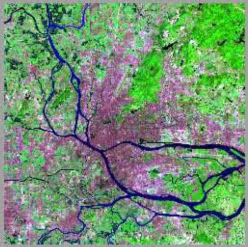
San Salvador

Sao Paulo

San Francisco

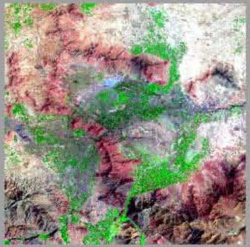


Damascus

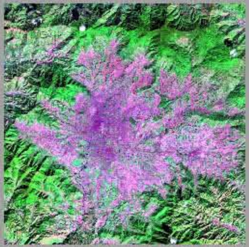


Guangzhou

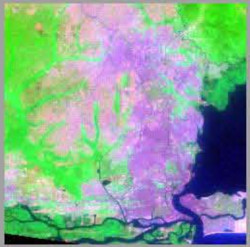
Hanoi



Kabul



Kathmandu



Lagos

Miami

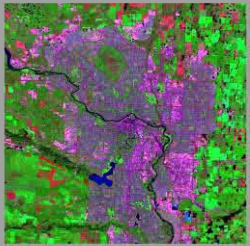
Bangalore

Beirut

Budapest

Cairo

Calcutta



Calgary

Chicago

Reflectance Spectra

Manmade materials

Diverse w/ characteristic absorbtions

Highly variable albedo

Rarely areally extensive

Concrete

Areally extensive

Few characteristic absorbtions

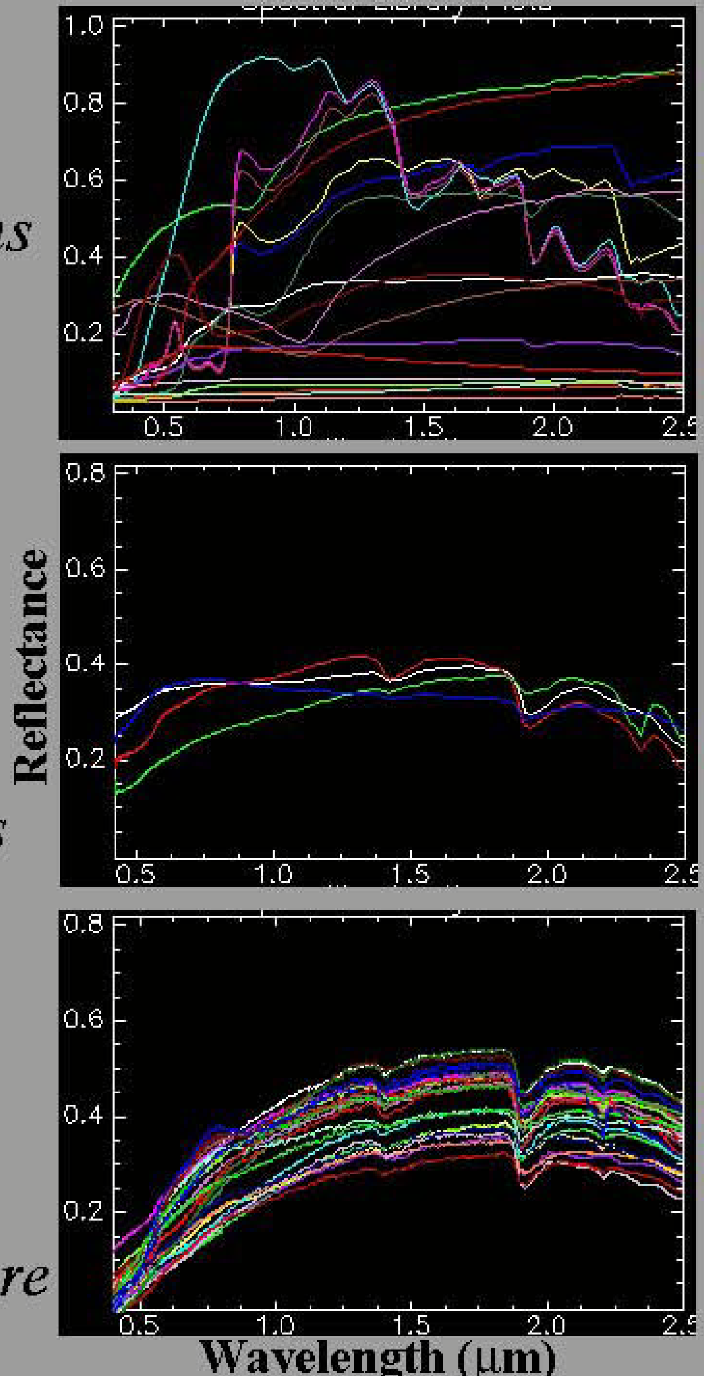
Compositionally similar to some soils

Soils

Subtle absorbtions

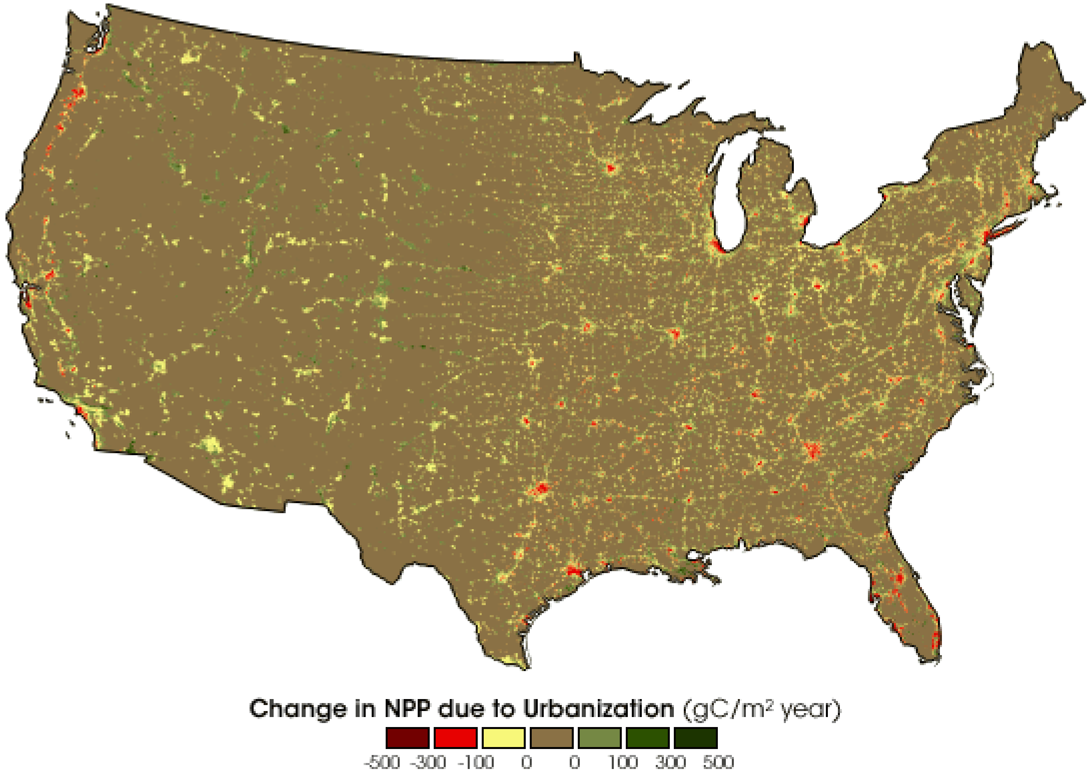
Similar shape w/ variable albedo

Albedo strongly dependent on moisture



Small, 2002

U.S. Urbanization



•Total Impervious Surface Area of Continental U.S. is 112,610 km^2 (Slightly smaller than the state of Ohio)

Source: *EOS*, June 2004

The V-I-S Model

Proposed by Ridd (1995)

A vegetation-impervious surface-soil model

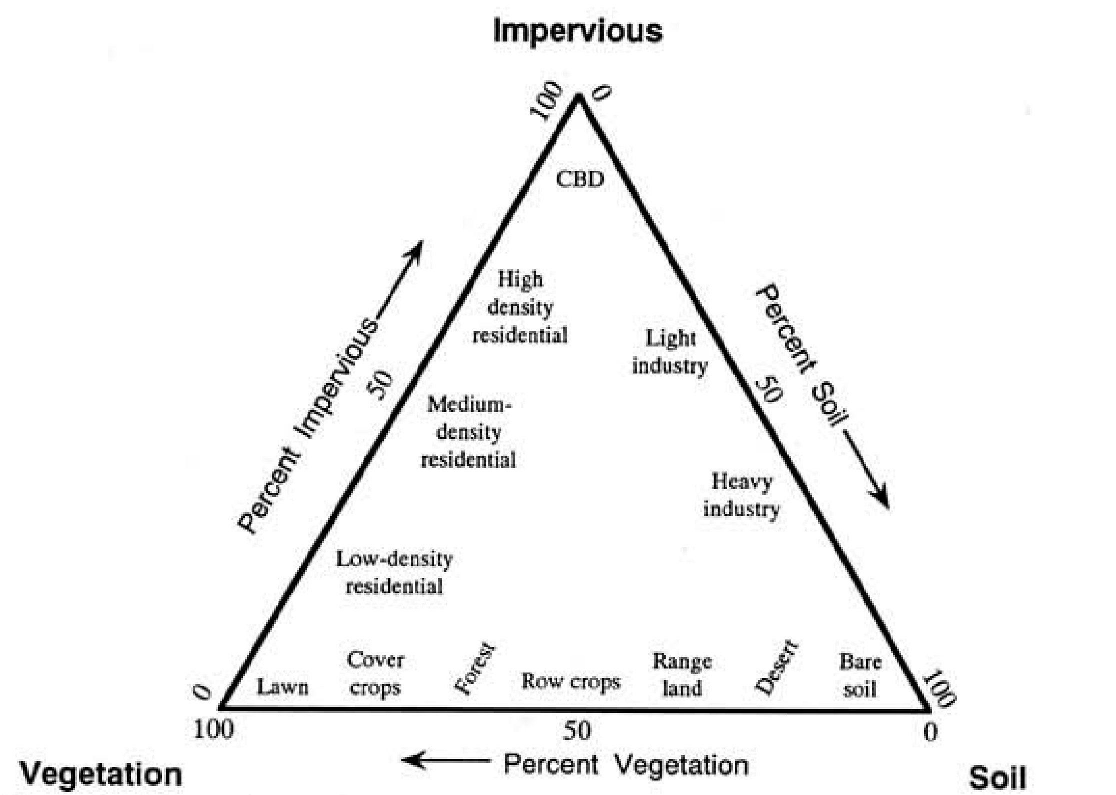


Figure 6. Some urban and near-urban features placed in the ternary V-I-S model.

Small, 2002

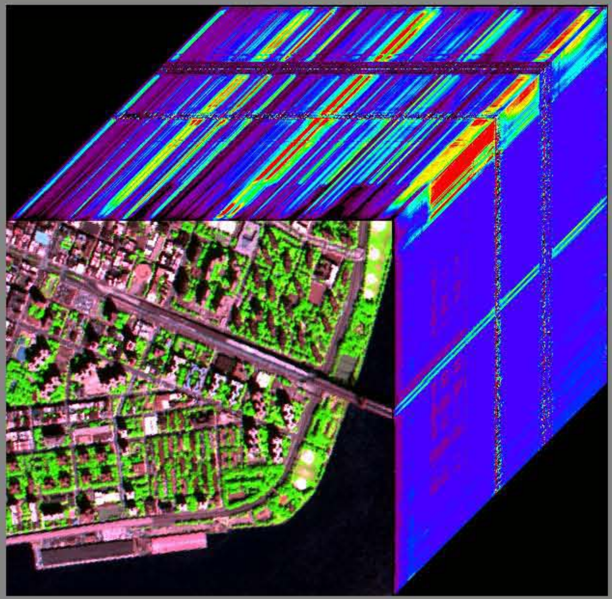
- Using the VIS model for classification of optical imagery is problematic because **Impervious surfaces and Soils often have indistinguishable reflectances**.
- A variety of approaches (*Unsupervised, Maximum Likelihood, Decision Tree, Expert System classifications, Spectral Mixture Analysis*) result in wide range of accuracies (44% to 94%).
- Highest accuracies are associated with moderate sized settlements in densely vegetated areas.

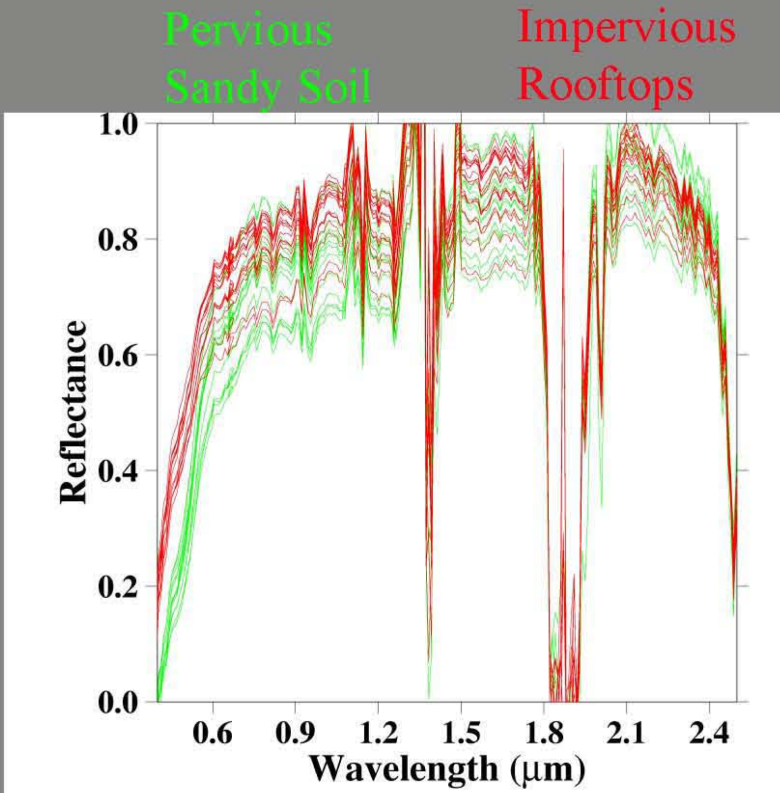
Spectral Resolution

Many pervious and impervious surfaces are compositionally similar and therefore have similar spectral properties.

Even with high spatial and spectral resolution, considerable spectral ambiguity still exists.

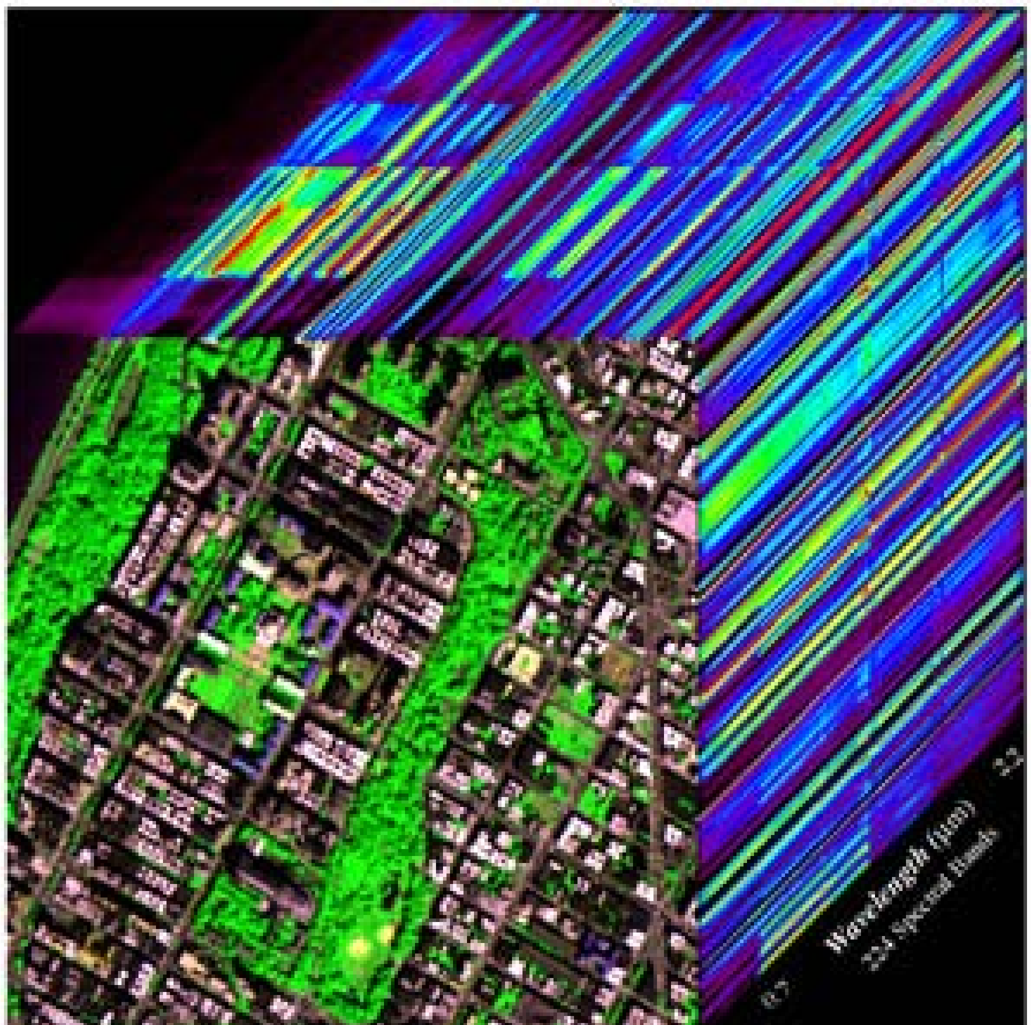
AVIRIS NYC 9/16/2001 4m

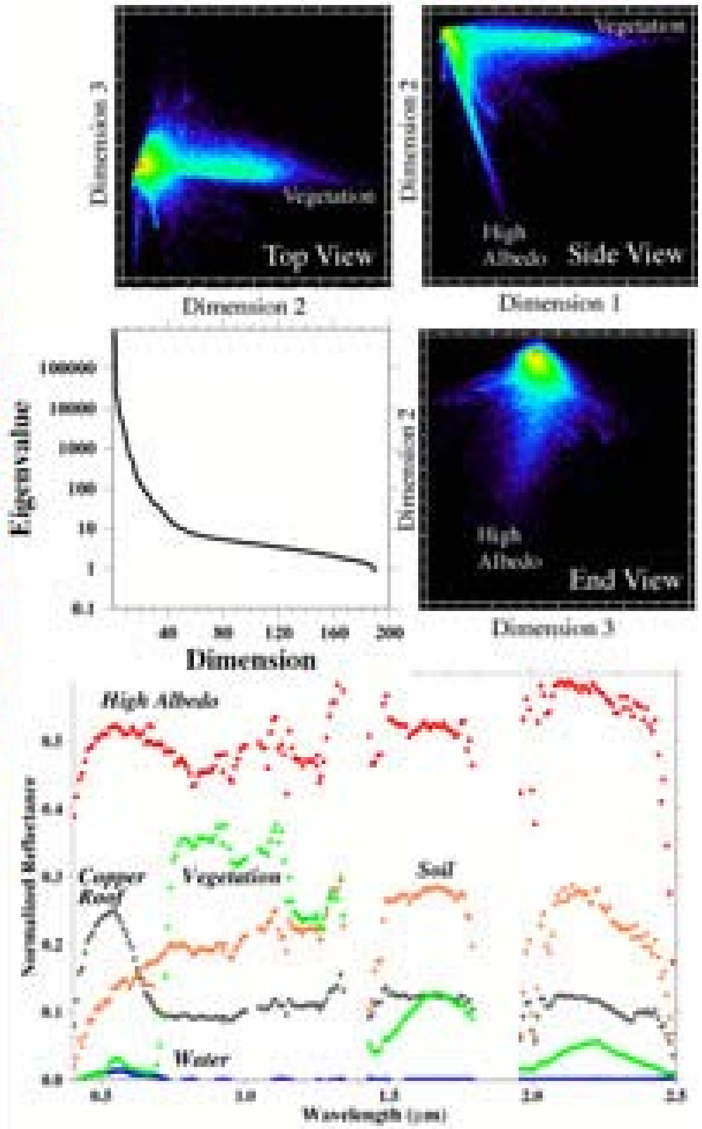




Small, 2002

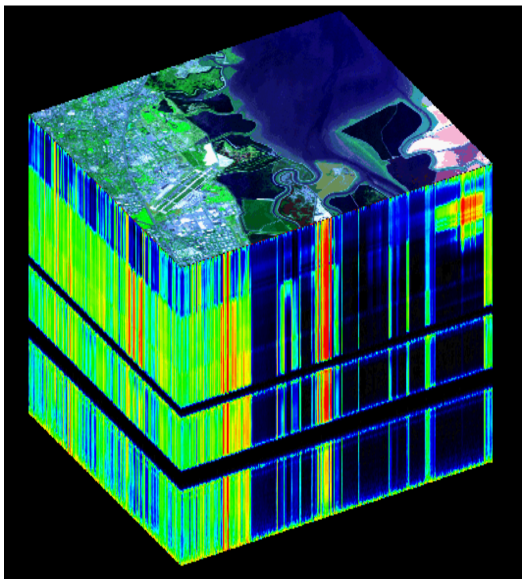
AVIRIS 4 meter Manhattan 16 September, 2001





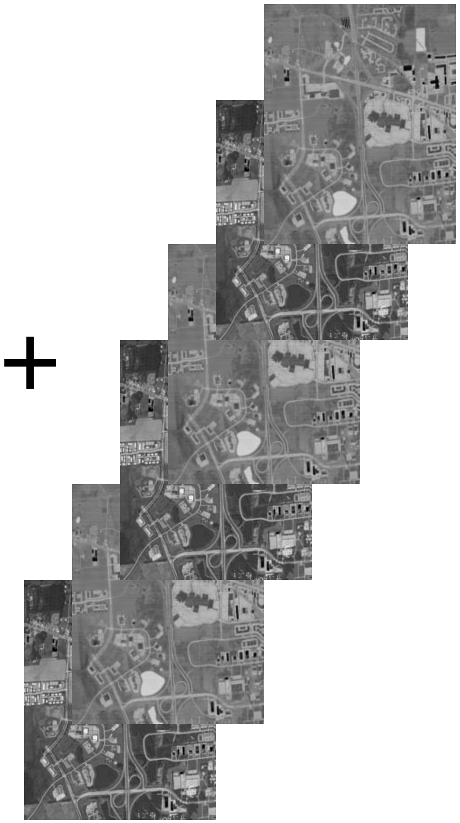
Small, 2002

HyspIRI Combined Composite Data Set Advanced Product for Urban Ecosystems Analysis



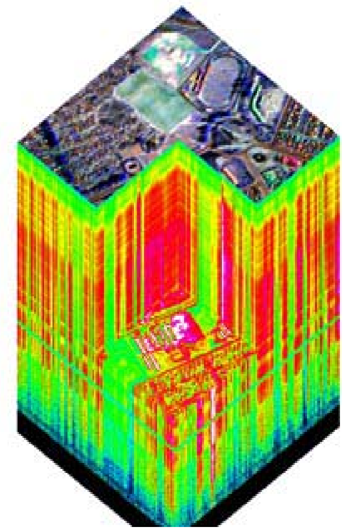
HyspIRI Hyperspectral VSWIR Level II Product
(NDVI, fPAR, surface reflectance characteristics)

+



HyspIRI TIR multispectral Level II product (8 TIR Bands)
(surface temperature, radiance, [day/night], emissivity)

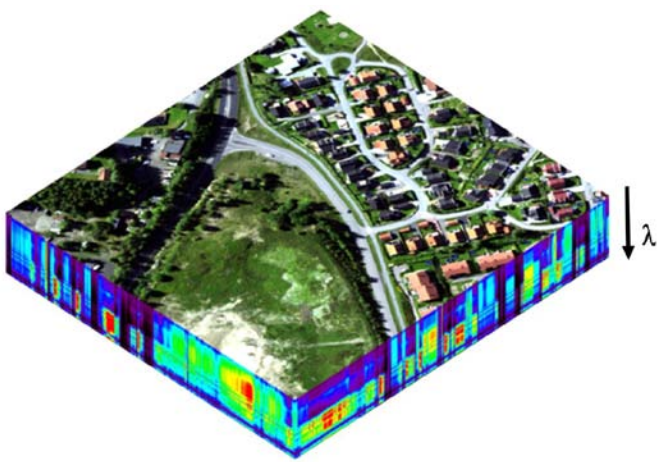
=



HyspIRI VSWIR/TIR composite data set
(quantitative integrative measurement of urban surface reflectances, temperatures, and emissivity across the urban ecosystem)

HyspIRI Combined Composite Land Use Change Advanced Product for Urban Ecosystems Analysis

Through Time



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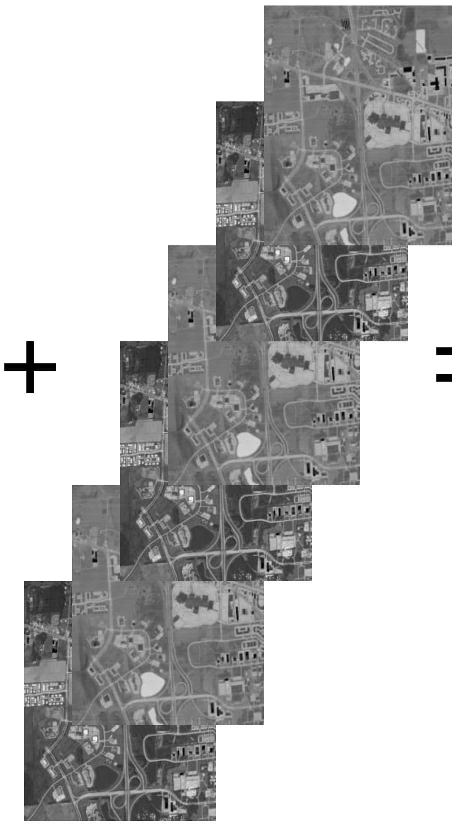

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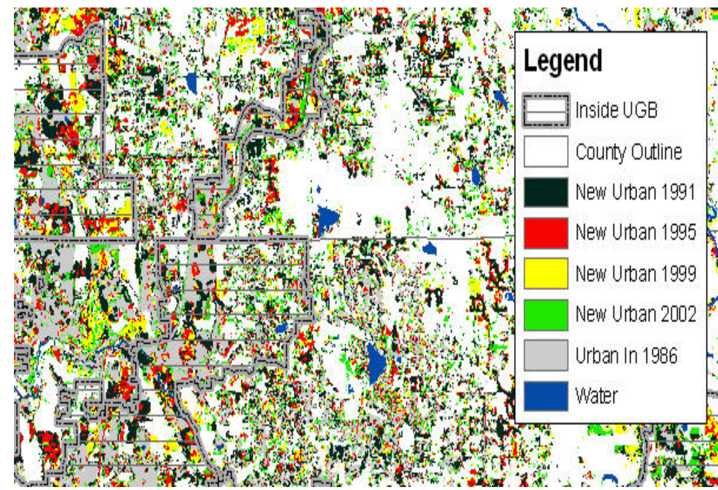


HyspIRI Hyperspectral VSWIR Level II Product

(NDVI, fPAR, surface reflectance characteristics)

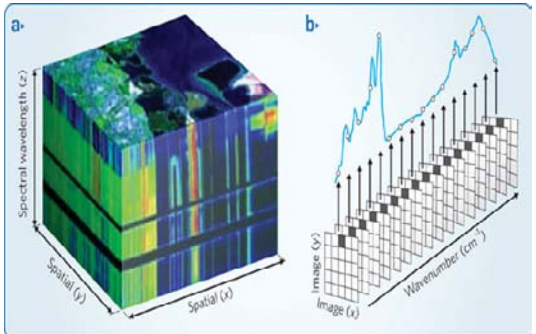
HyspIRI TIR multispectral Level II product (8 TIR Bands)

(surface temperature, radiance, [day/night], emissivity)

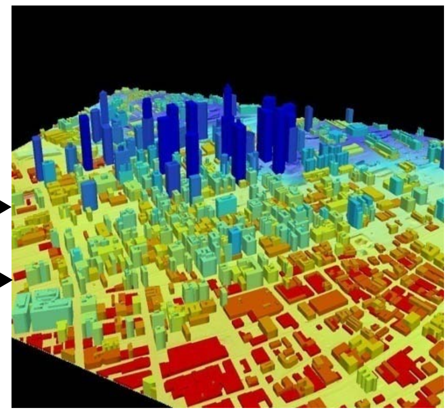
HyspIRI VSWIR/TIR composite land cover change data set

(quantitative integrative measurement of urban surface reflectances, temperatures, and emissivity across the urban ecosystem as they change through time)

HyspIRI Combined "Integrated" Advanced Product for Urban Ecosystems Analysis



HyspIRI Hyperspectral VSWIR Level II Product
(NDVI, fPAR, surface reflectance characteristics)



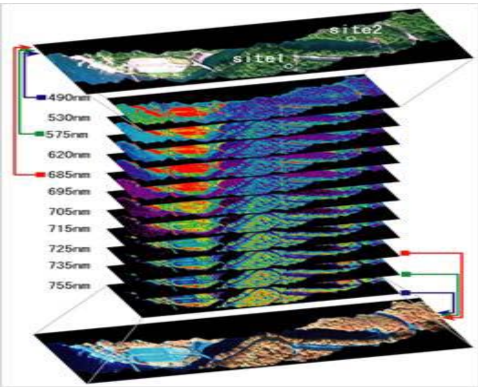
Lidar Data

=

HyspIRI VSWIR/TIR and Lidar composite data set
(X, y, z surface reflectance/thermal interactions of urban ecosystem processes)

HyspIRI TIR multispectral Level II product (8 TIR Bands)
(surface temperature, radiance, [day/night], emissivity)

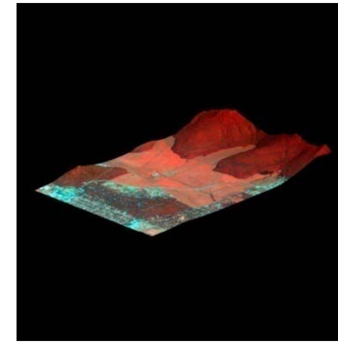
HyspIRI Combined "Integrated" Topographic Advanced Product for Urban Ecosystems Analysis

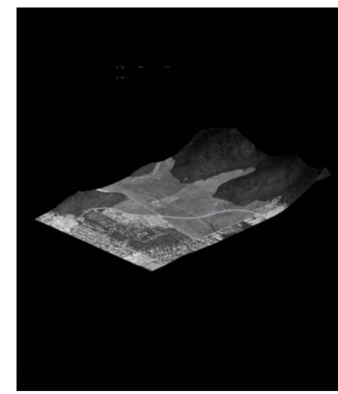


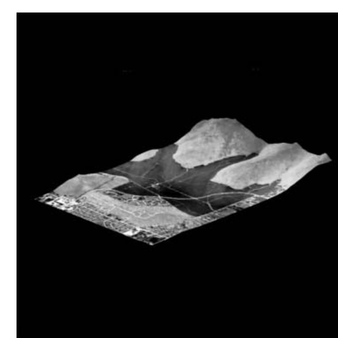
Hyperspectral VSWIR Level II Product (NDVI, fPAR, surface reflectance characteristics)

Digital Topographic Data (DEM)

=







HyspIRI VSWIR/TIR and DEM composite data set

(hyperspctral/day/night TIR digital elevation model data sets))

HyspIRI TIR multispectral Level II product (8 TIR Bands) (surface temperature, radiance, [day/night], emissivity)

Mapping Plant Functional Types with Synergistic Use of Spectrometer and Thermal Imagery

Yen-Ben Cheng

Elizabeth M. Middleton

Bruce D. Cook

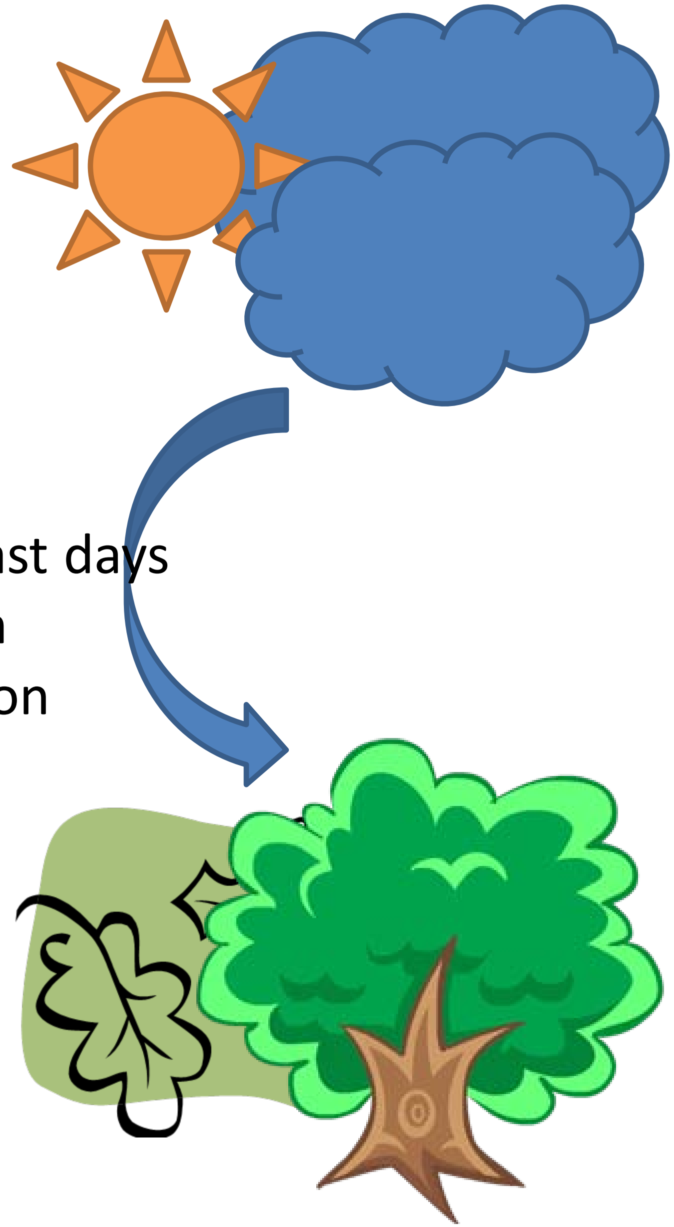
Qingyuan Zhang

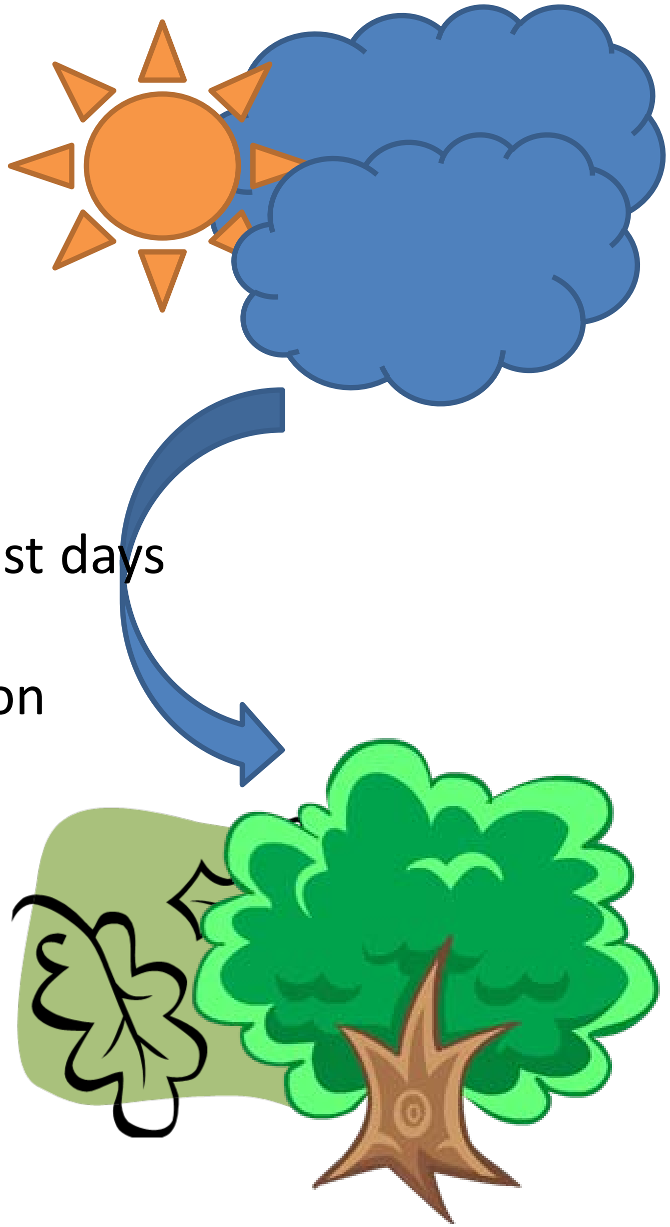
HyspIRI Science Symposium on Ecosystem Data Products

NASA Goddard Space Flight Center, May 4&5, 2010

Changes in :

- Air temperature
- Precipitation
- # sunny vs. overcast days
- CO_2 concentration
- Nitrogen deposition





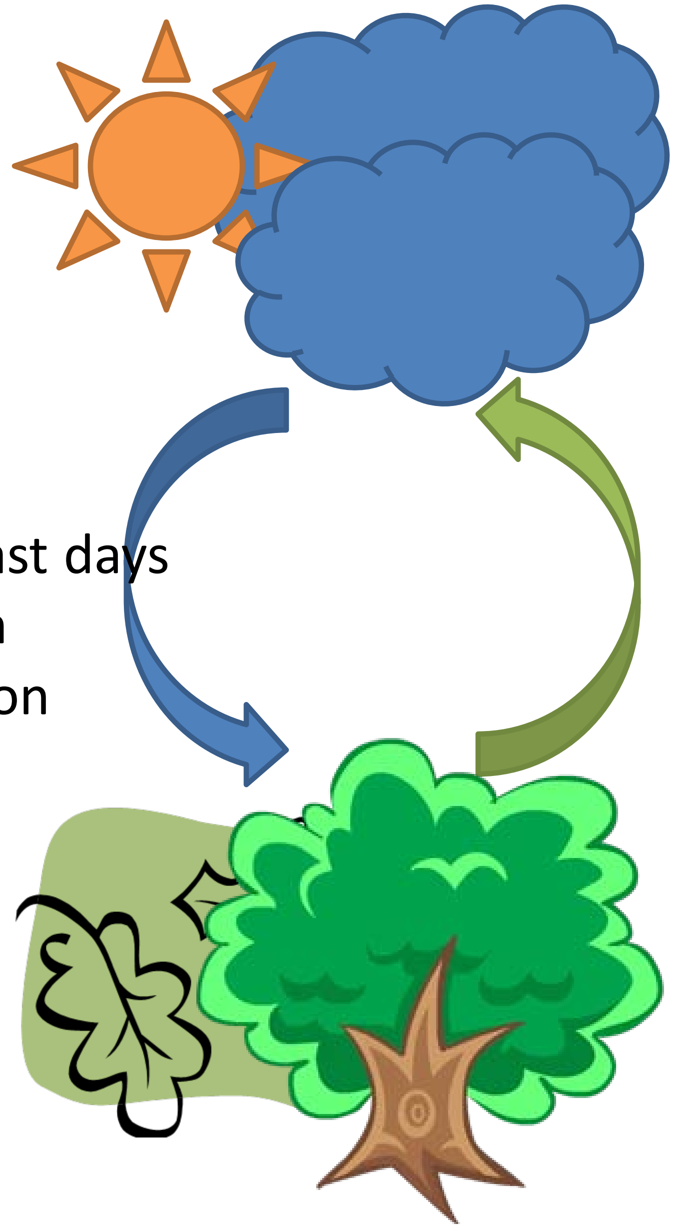
Changes in :

- Air temperature
- Precipitation
- # sunny vs. overcast days
- CO_2 concentration
- Nitrogen deposition

Changes in:

- Timing of greening
- Length of growing season
- Stomatal closure
- Balance among species
- PFTs, spatial & temporal

Changes in :
- Air temperature
- Precipitation
- # sunny vs. overcast days
- CO_2 concentration
- Nitrogen deposition

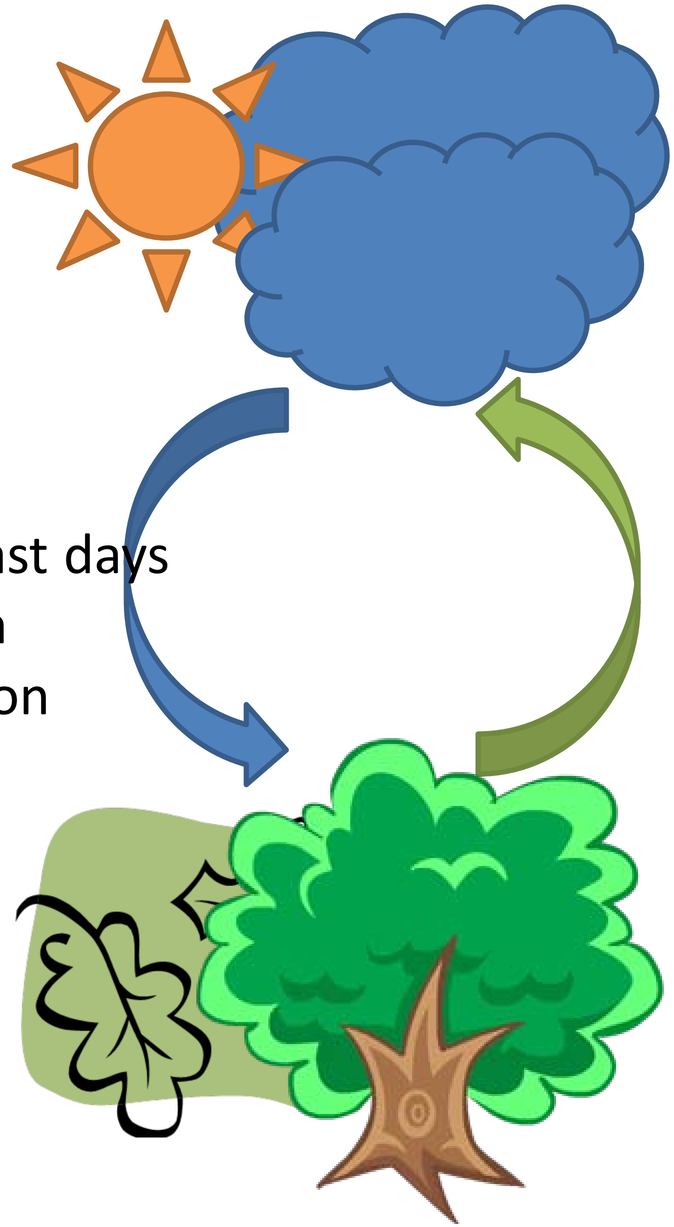


Changes in:
- Albedo
- Evapotranspiration
- Soil moisture
- Surface temperature

Changes in:
- Timing of greening
- Length of growing season
- Stomatal closure
- Balance among species
- PFTs, spatial & temporal

Changes in :

- Air temperature
- Precipitation
- # sunny vs. overcast days
- CO_2 concentration
- Nitrogen deposition



It’s not only ***that*** the climate is changing.

It’s also ***what*** the climate is changing.

Why do we study PFTs ??

- Plant functional types (**PFTs**) bridge the gap between plant physiology and community and ecosystem processes, <u>thus providing a powerful tool in climate change research</u>.
- **PFTs** are a necessary device for reducing the complex and often uncharted characteristics of species diversity for function and structure attributes, when attempting to model and/or predict ecosystems in future environmental and climate scenarios.
- **PFTs** serves as the bridge that connects climate and ecosystem models. Accurate assessment of PFTs coverage has become more important since modeling effort, land surface modeling.

Woodard & Wolfgang, 1996; Díaz & Marcelo, 1997; Bonan et al., 2002

PFTs link to:

- VQ1. Pattern and spatial distribution and ecosystems and their components [DS 195]
- VQ2. Ecosystem Function, Physiology and Seasonal Activity [DS 191,195,203]
- VQ3. Biogeochemical Cycles
- CQ4. Ecosystem Function and Diversity [DS 194, 195, 203]

HyspIRI and mapping PFTs (theory)

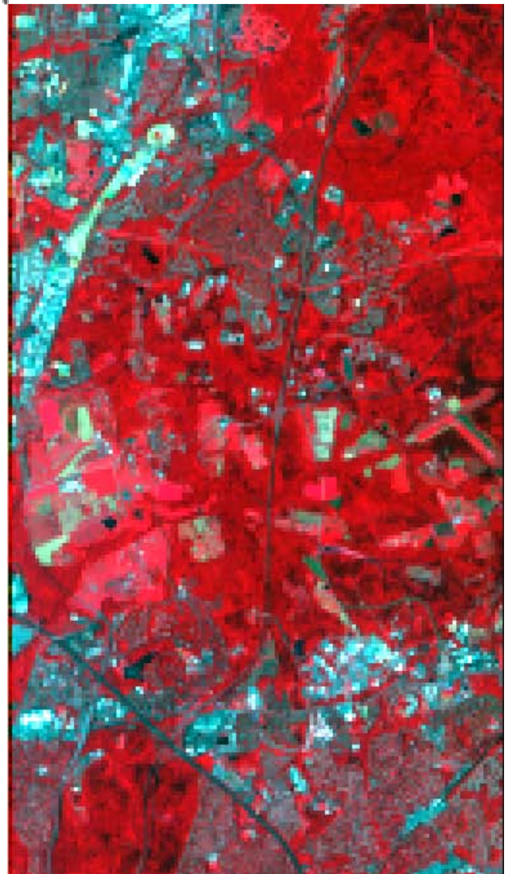
- HyspIRI measures continuous VSWIR spectral feature and even more frequent TIR characteristics to provide ecosystem physiology and energy balance information.

- The value of using TIR in vegetation classification has been recognized, especially for land surface processes modeling purposes at global scale, because of the correlation with ET and LST.

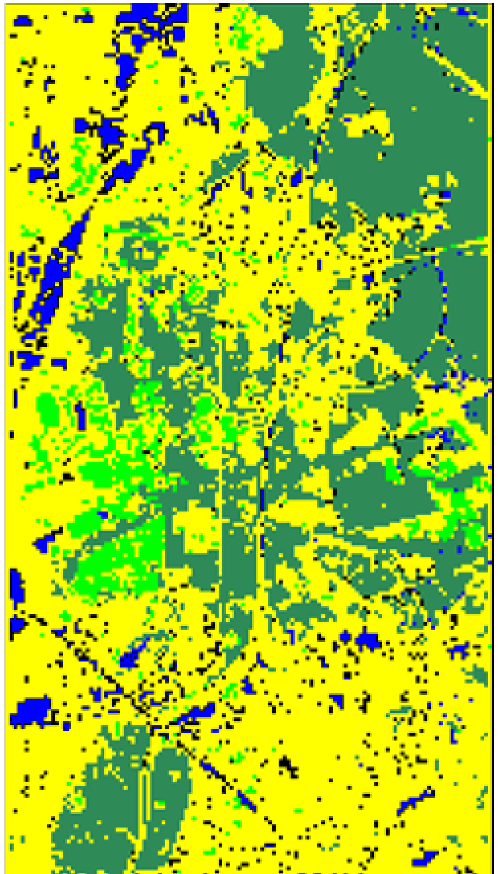
Bonan et al. 2002a,b; Hansen et al. 2000, 2003

HyspIRI and mapping PFTs (tech)

- Utilize cutting edge classifiers to take advantage of BOTH VSWIR and TIR observations
- Spectral features vs. spatial distribution
- Pixel based spectral discrimination vs. Object based segmentation analysis



EO-1 Hyperion VSWIR



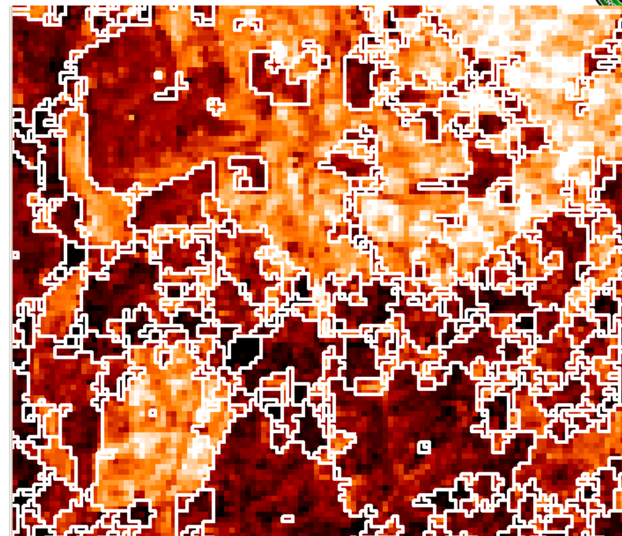
Greenbelt, MD

Mixed Forest

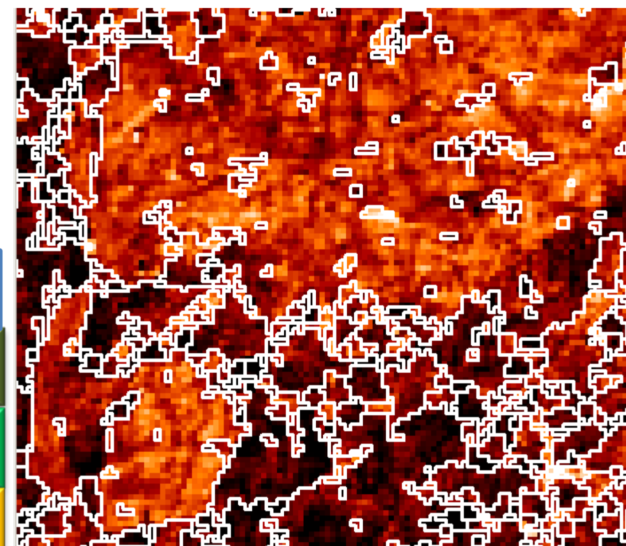
Crops

Residential / Grassland

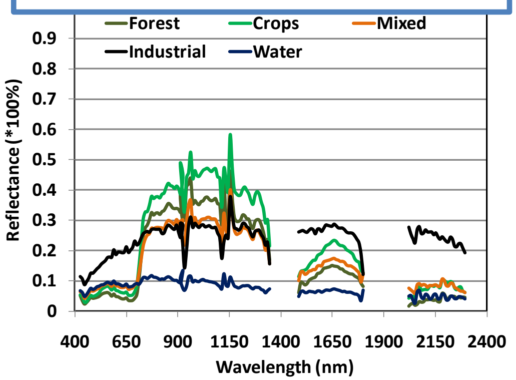
Business / Industrial



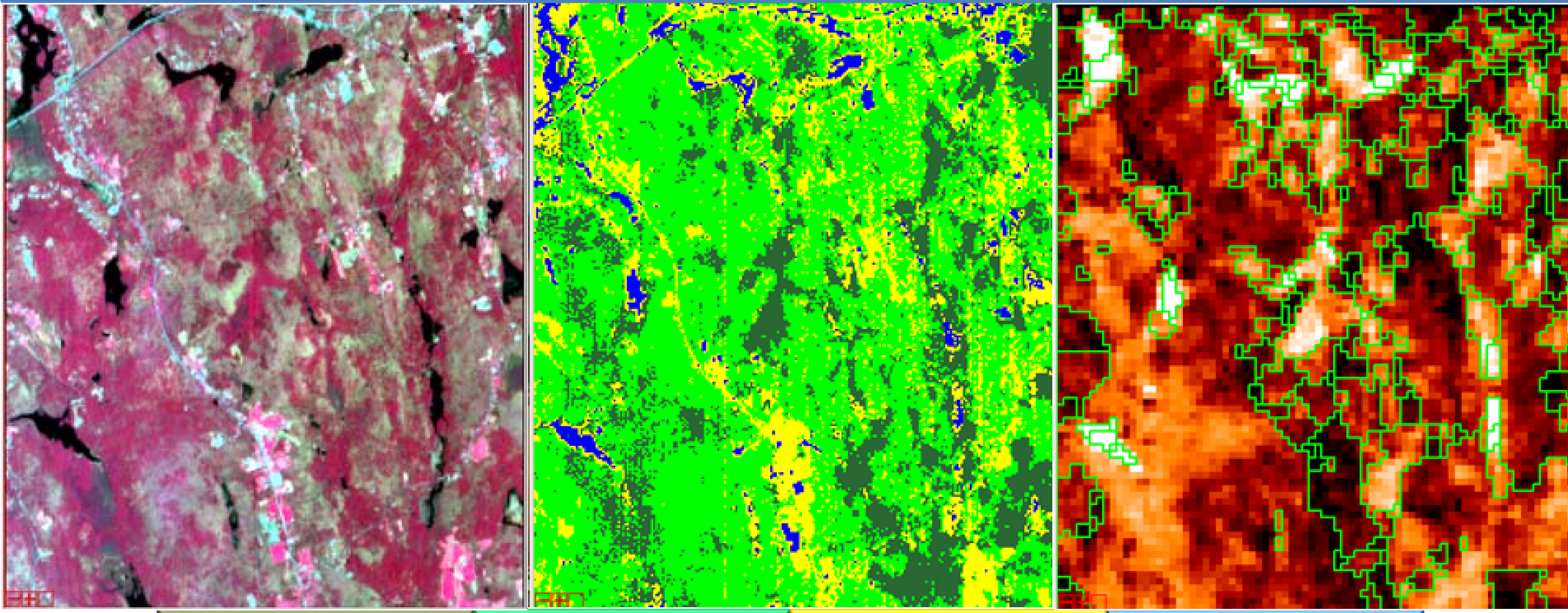
ASTER TIR 04/18/2009



ASTER TIR 11/28/2009



EO-1 Hyperion VSWIR	Harvard Forest, MA	ASTER TIR



Evergreen Needle Leaf

Deciduous Hardwood

Grassland

Water / Road

Accurate assessment of spatial and temporal distribution of PFTs will help us to:

- understand the effects of climate change to terrestrial ecosystems.
- assess feedbacks from ecosystems to the atmosphere.
- provide input parameters essential to land surface and climate modeling.

Thank you!!

Spectroscopic Remote Sensing of Invasive Plants

VSWIR/TIR Detection of Biochemical Signatures and Evaluation of Ecosytem Impacts

Presented by
Raymond F. Kokaly
USGS Spectroscopy Laboratory
Denver, Colorado

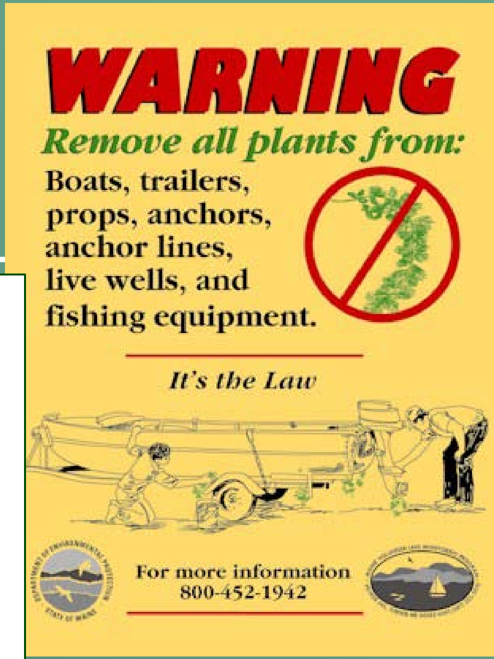
Jeffrey Morrisette, USGS, CO
Pamela Nagler, USGS, AZ
Aaryn Olssen, UA, AZ
Craig Daughtry, USDA-ARS, MD

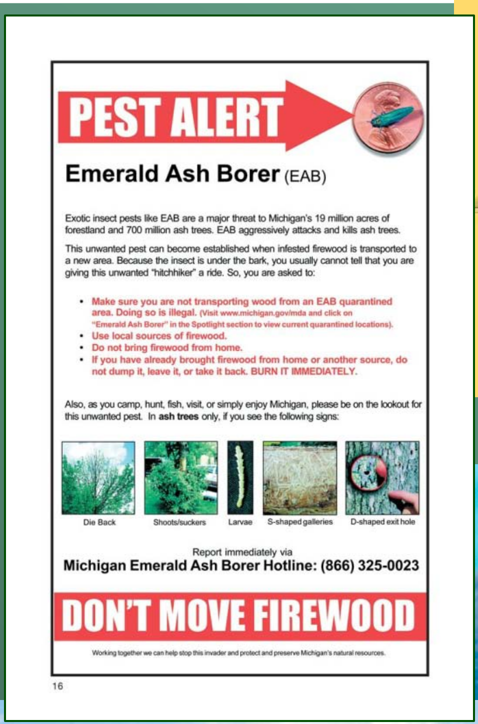
Presented at
HyspIRI Science Symposium on Ecosystem Data Products
May 4-5, 2010

Invasive Species

A Top Environmental Issue of the 21st Century …

- **Economic Costs:**
  - ***$137+ Billion / Yr***
    (Pimentel, et al. 1999; NISRC Management Plan, 2001)
- **Environmental Costs:**
  - ***Decreased biodiversity, ecological services, etc.***
- **Human-Health Costs:**
  - ***West Nile Virus, Malaria, etc.***
- **Agricultural Costs:**
  - ***Crop pathogens, hoof-and-mouth, mad cow disease***





PEST ALERT

Emerald Ash Borer (EAB)

Exotic insect pests like EAB are a major threat to Michigan's 19 million acres of forestland and 700 million ash trees. EAB aggressively attacks and kills ash trees.

This unwanted pest can become established when infested firewood is transported to a new area. Because the insect is under the bark, you usually cannot tell that you are giving this unwanted "hitchhiker" a ride. So, you are asked to:

- Make sure you are not transporting wood from an EAB quarantined area. Doing so is illegal. (Visit www.michigan.gov/mda and click on "Emerald Ash Borer" in the Spotlight section to view current quarantined locations).
- Use local sources of firewood.
- Do not bring firewood from home.
- If you have already brought firewood from home or another source, do not dump it, leave it, or take it back. BURN IT IMMEDIATELY.

Also, as you camp, hunt, fish, visit, or simply enjoy Michigan, please be on the lookout for this unwanted pest. In **ash trees** only, if you see the following signs:

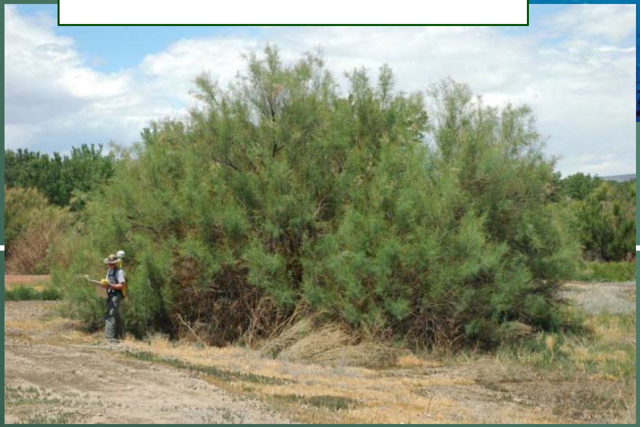
Die Back | Shoots/suckers | Larvae | S-shaped galleries | D-shaped exit hole

Report immediately via
Michigan Emerald Ash Borer Hotline: (866) 325-0023

DON'T MOVE FIREWOOD

Working together we can help stop this invader and protect and preserve Michigan's natural resources.

16



USGS

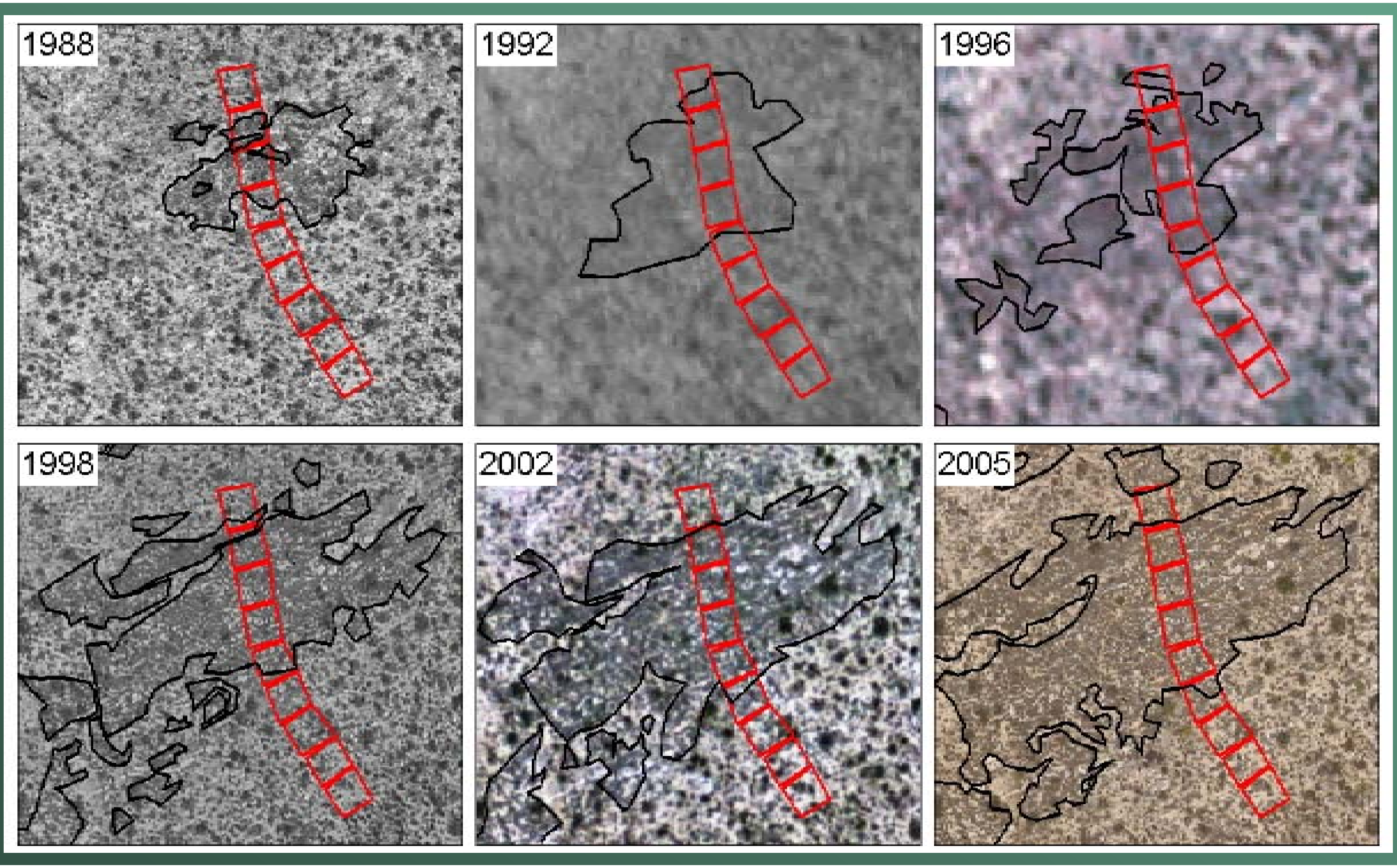
Invasive species

- Where is it now?
  (locating)
- Where can it survive?
  (habitat modeling)
- What are the ecological and economic impacts?
  (impacts)
- How does it spread?
  (dispersal/vectors)
- How can we control it?
  (efficacy)

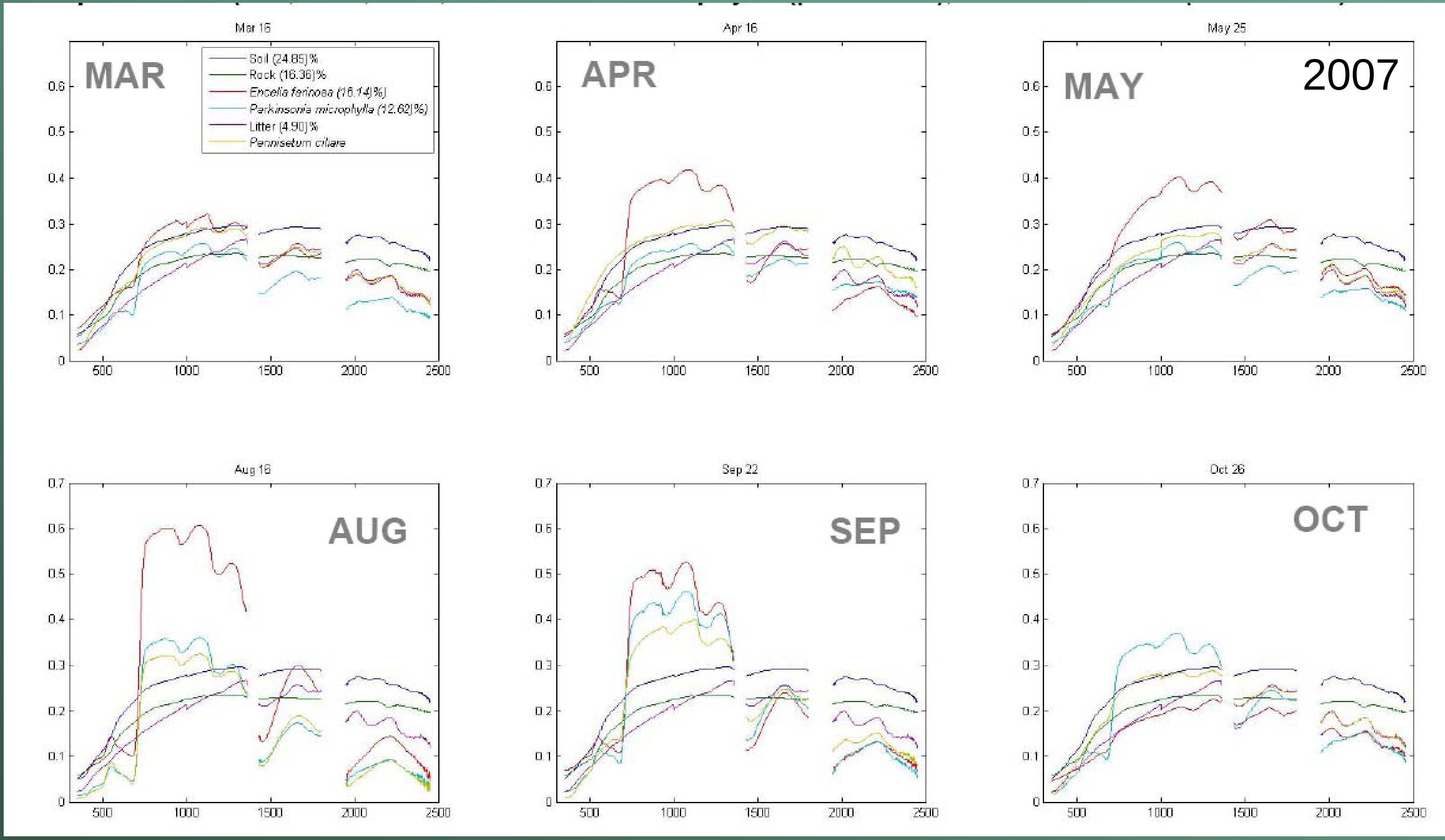
USGS

Buffelgrass (*Pennisetum ciliare*)

Field Spectroscopy at plots near Tucson, AZ



USGS



Earlier senescence of buffelgrass (SEPT) compared to dominant natives

Spectroscopic Remote Sensing

- VSWIR: Detect patterns of pigment, water and cellulose/lignin content consistent with invasive plant and divergent from native plants
- TIR: Calculate land surface temperature, model evapotranspiration, compare to air temperature to reveal temporal patterns divergent from native plants

Thermal Infrared

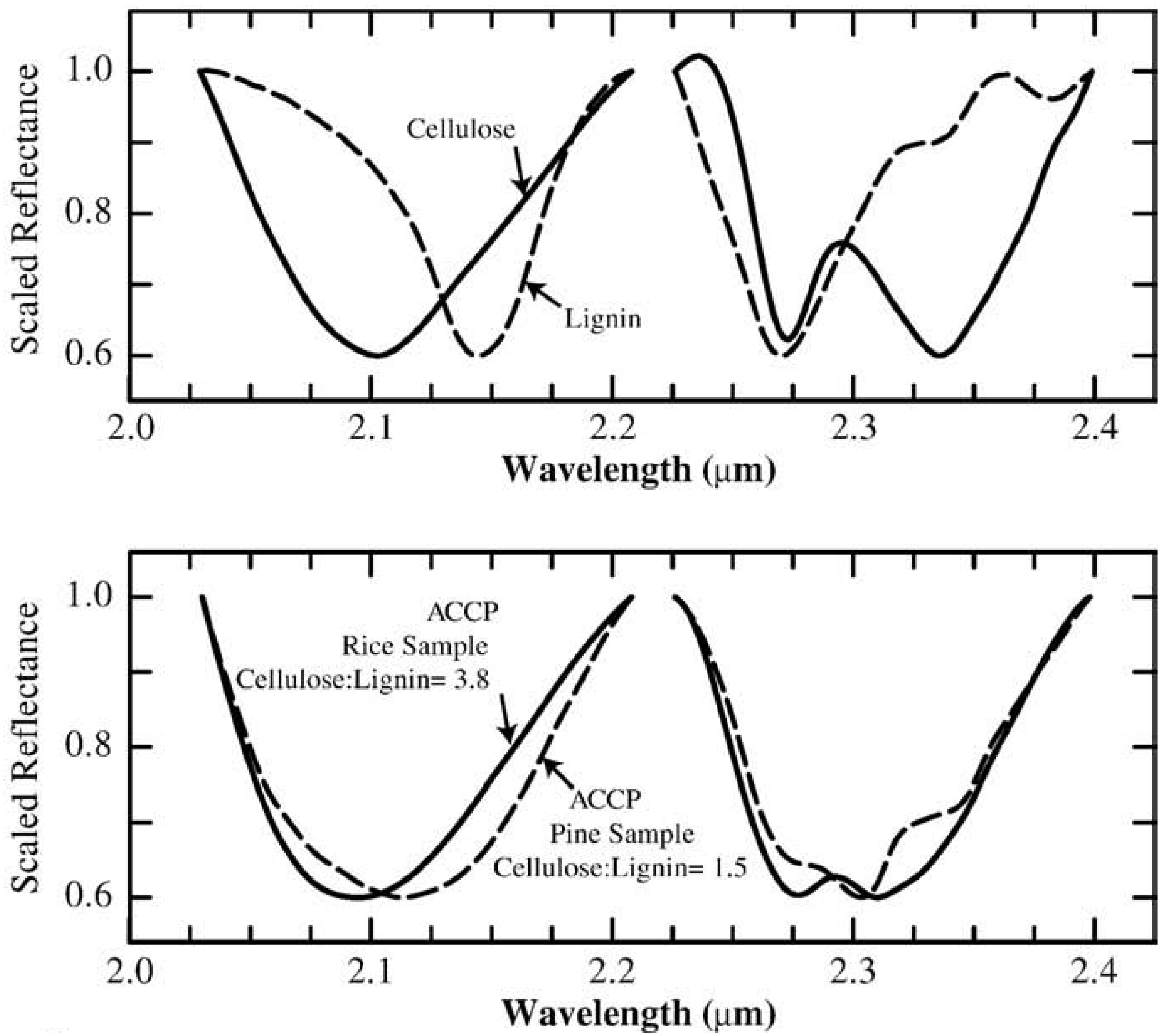
Thermal-band detection of land surface temperatures (LST) minus the air temperature (Ta), will aid in distinguishing BG invasions in the summer monsoon period (August) versus the rest of the year

	Uninvaded Desert	Invaded Desert
Most of Year	Low CAI Low NDVI Bare soil w/high LST - Ta	High CAI Low NDVI Dormant BG w/ low LST - Ta
Summer Monsoons	Low CAI High NDVI Bare soil w/high LST - Ta	Low CAI Highest NDVI Green BG w/very low LST - Ta

USGS

VSWIR

A change in plant composition to grass dominated system leads to cellulose dominated absorption features in reflectance spectrum



USGS

Application of Results

- Land management (treatment and evaluation)
- Shifts in plant composition (to non-woody)
- Soil composition (formation of caliche)
- Fire promotion (post-fire soil impact)
- Predictive modeling of expansion
- Climate change
- Identification of areas at risk for invasion

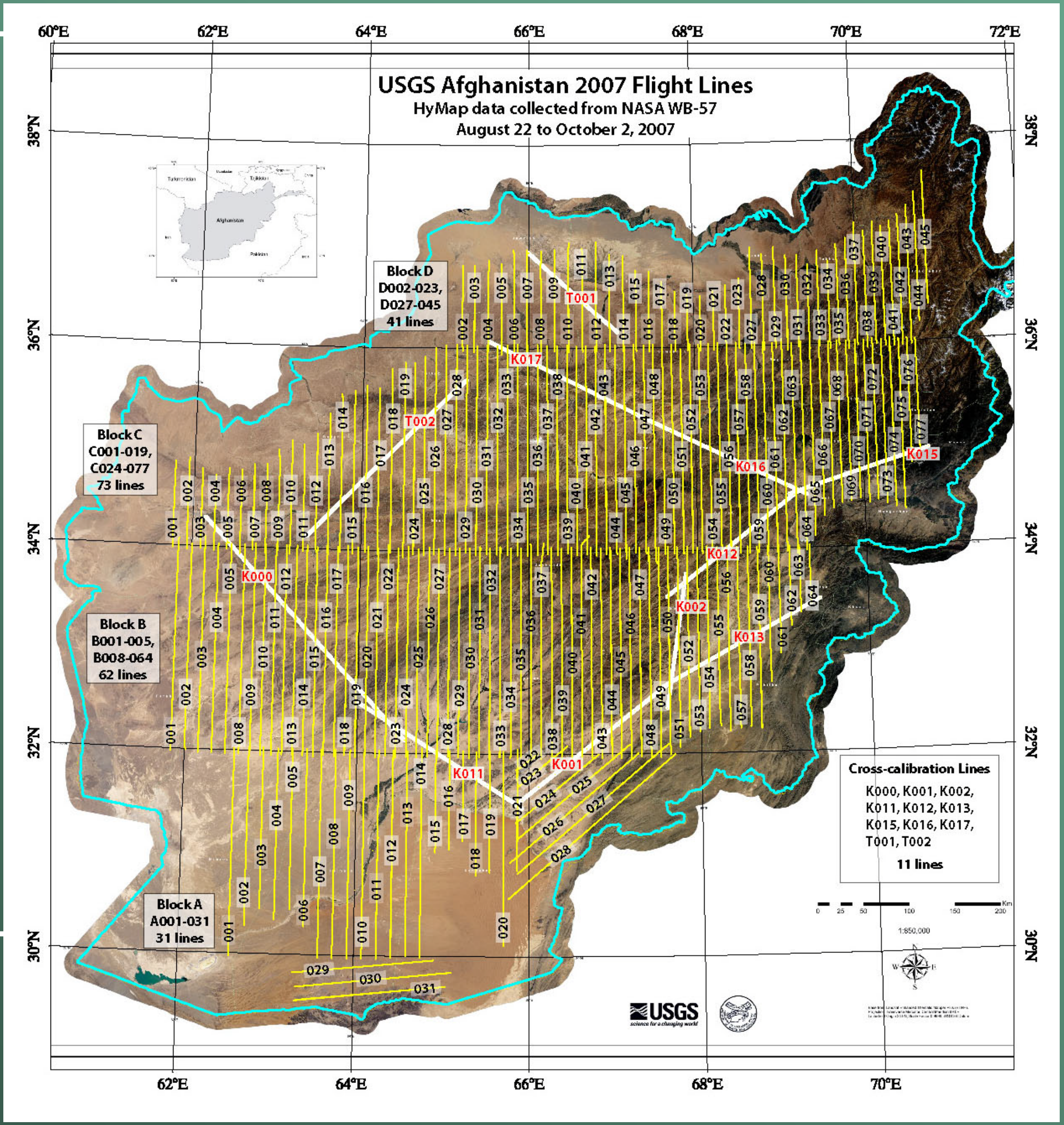
National-level detection, monitoring and early warning system for invasive plant species

USGS

Large Area Coverage

Large area coverage by VSWIR + TIR

- needed for current land management
- significant for HyspIRI calibration, product development
- largest, continuous imaging spectrometer data coverage was done in 2007 in Afghanistan, no TIR



Opportunities and Challenges

- Arid and semi-arid ecosystems
  - Low percent cover by plants
  - Effects of soil and hydrologic changes
  - Soil mineral composition detectable
- Invasive plant species
  - Detection of small infestations
  - Broad areas need to be covered
  - Temporal trends in expansion

National-level detection, monitoring and early warning system for invasive plant species

Land Surface Classification Opportunities

Craig Daughtry, Martha Anderson, Bill Kustas, Paul Doraiswamy, Ray Hunt

USDA-ARS Hydrology and Remote Sensing Lab, Beltsville, MD

Jerry Hatfield

USDA-ARS National Laboratory for Agriculture and the Environment, Ames, IA

Melba Crawford

Agronomy Dept., Purdue University, West Lafayette, IN

Introduction

- Reliable estimates of surface heat fluxes require accurate classification of land surfaces.
- In agricultural regions, land surfaces are dynamic.
  - Bare soil, Green vegetation, Senesced vegetation
  - All classes present, but proportions change with time and space.
- HyspIRI will provide opportunities to improve surface classification by simultaneously acquiring VSWIR and thermal IR.

What is crop residue?

The portion of a crop that is left in the field after harvest.

- Crop residues on the soil surface:
  - Decrease soil erosion
  - Increase soil organic matter
  - Alter surface energy balance
    - Albedo and emissivity
- Soil tillage and biomass harvesting
  - Reduce residue cover

Current Methods of Measuring Crop Residue Cover

Line Point Transect

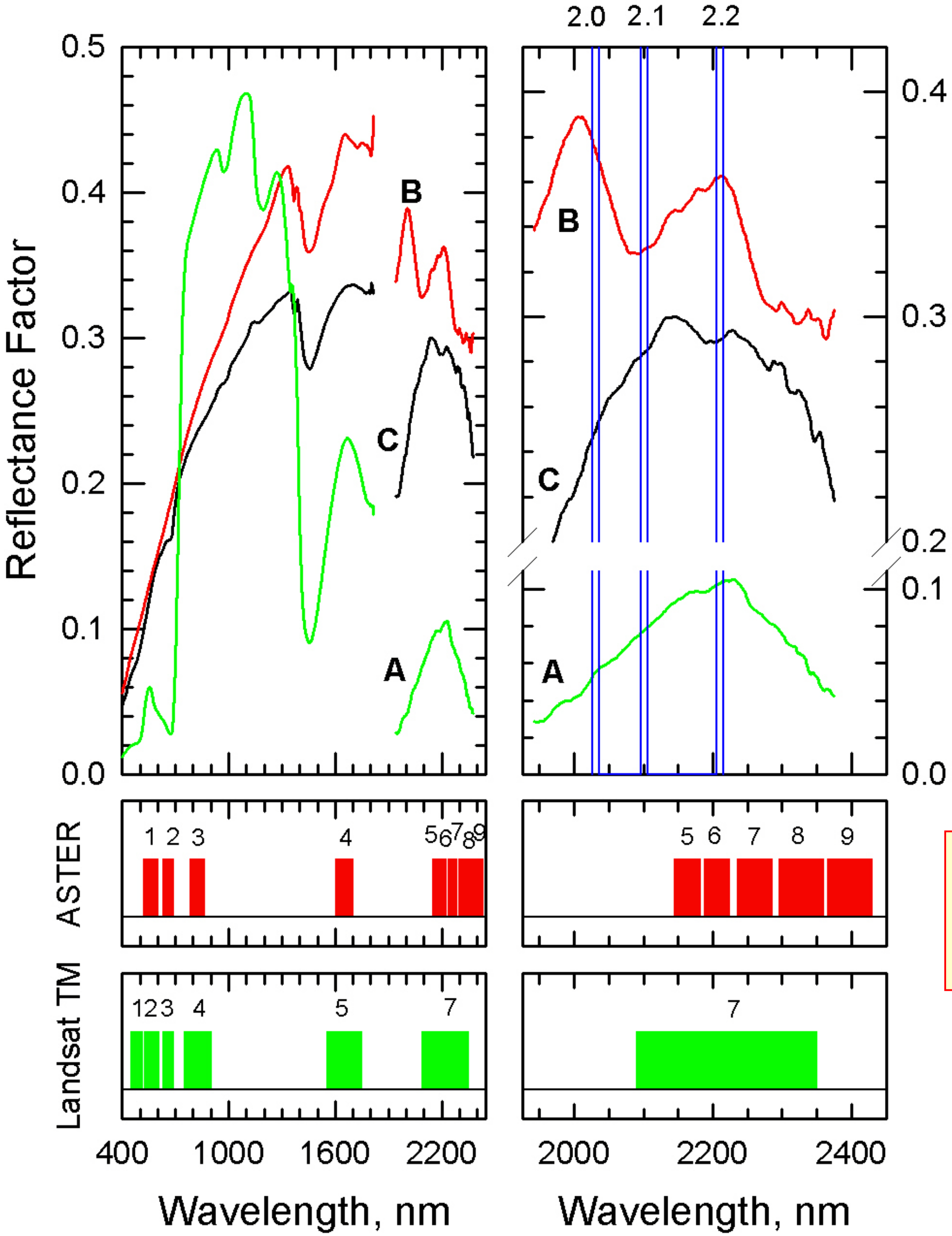
- Stretch Line-Point Transect across rows and count the number of markers that intersect residue.
- Accuracy depends on length of line, number of points, and size of residue pieces.

Windshield Survey

- Trained observers stop at intervals along a fixed route and assess fields on both sides of road.
- Errors due to subjective interpretation and limited observation of field conditions near the road.

Traditional methods of measuring crop residue cover are inadequate for many fields and large areas.

Reflectance Spectra



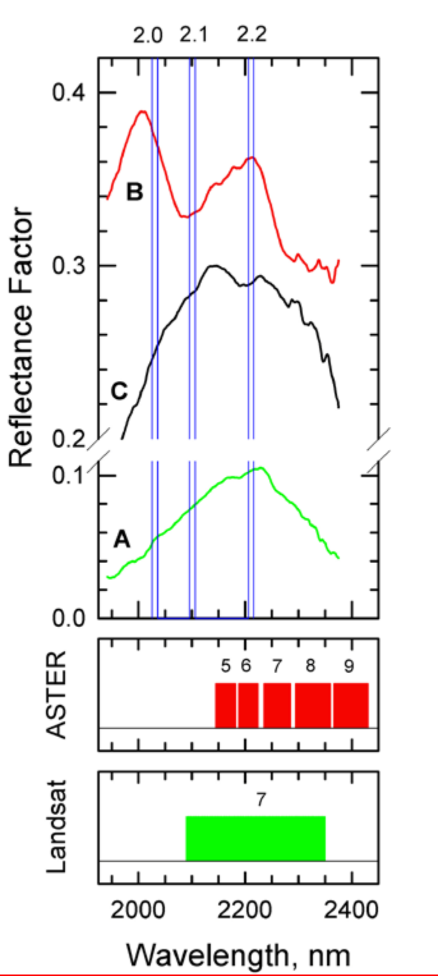
Corn residue

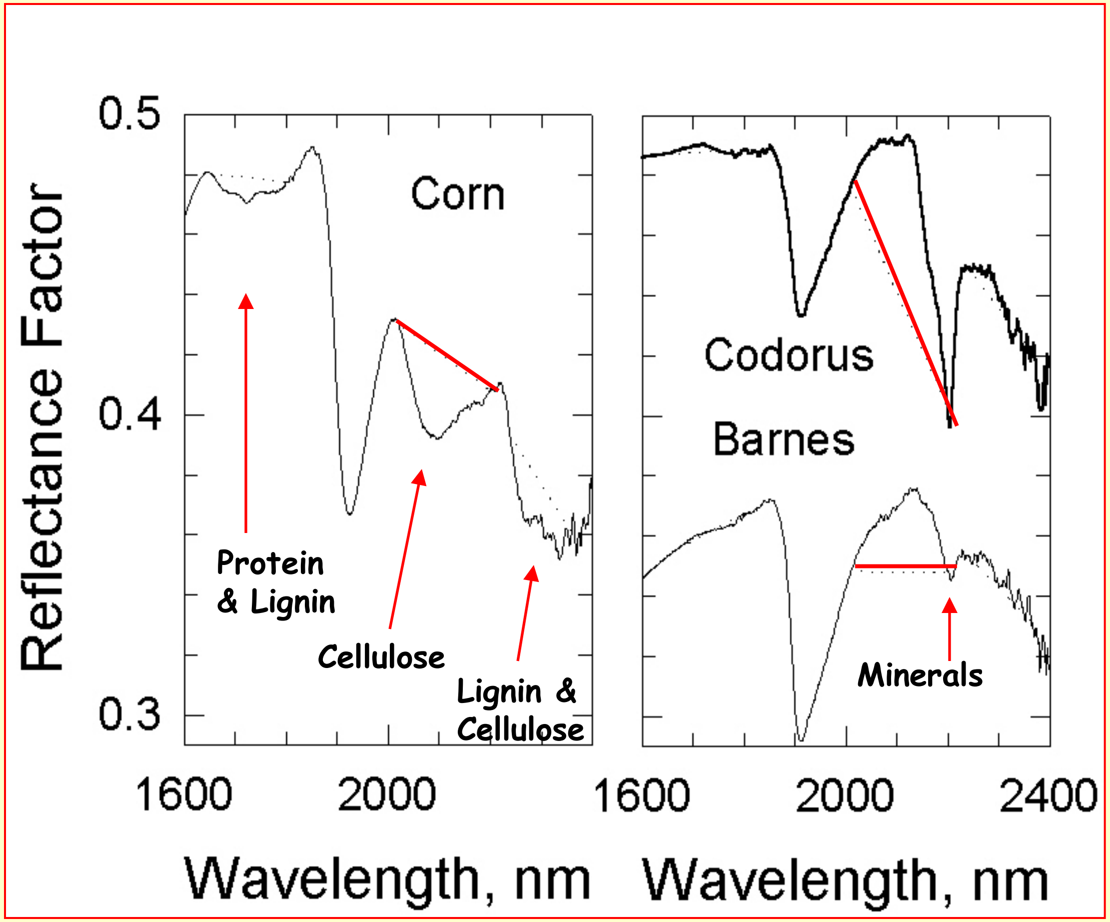
Bare soil

Green vegetation

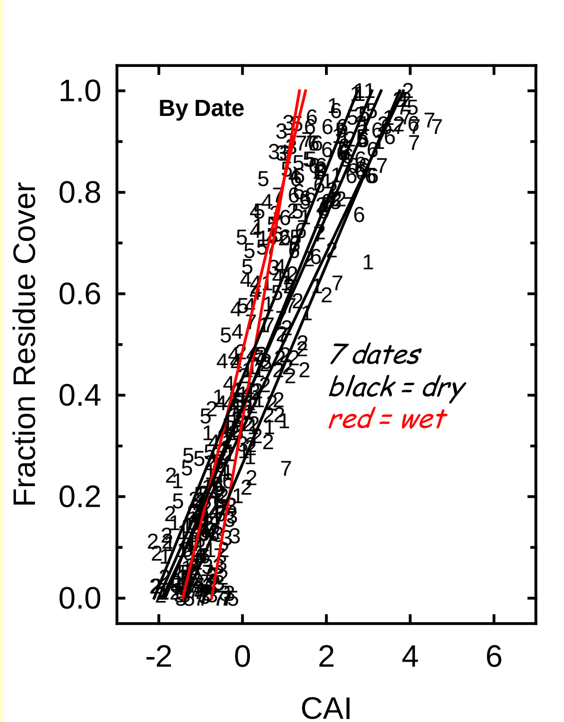
- Crop residues and soils have very similar spectral signatures in the 400-1100 nm wavelength region.

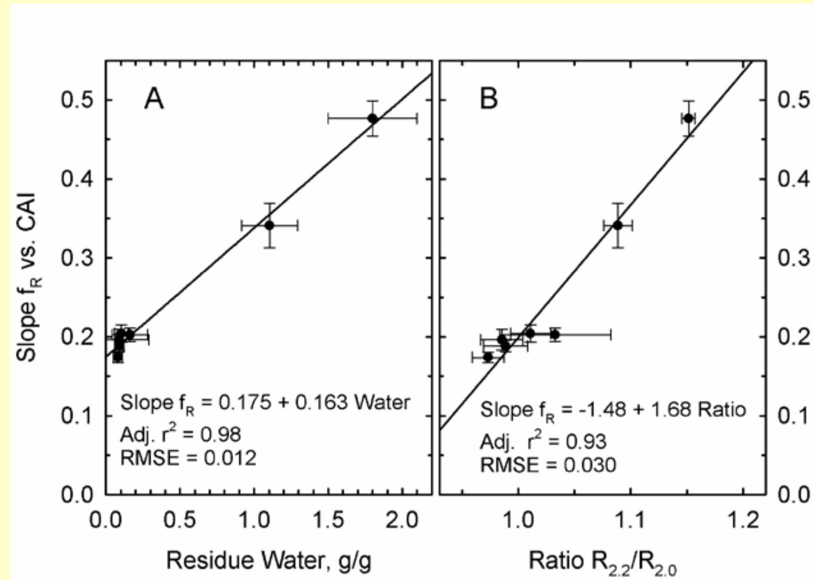
- Cellulose Absorption Index (CAI) is a measure of the relative depth of the absorption feature near 2100 nm.
- Other features are associated with protein, lignin, and minerals.





Basic Research: Lab & Field Reflectance Spectra





Cellulose Absorption Index

- CAI = 100 [0.5 (R_{2030} + R_{2210}) – R_{2100}]
- CAI measures the relative intensity of the absorption feature at 2100 nm.
- Crop residue cover is linearly related to CAI, but water in the scene attenuates the reflectance signal and changes the slope of relationship.
- A ratio index measured relative scene moisture and improved estimates of crop residue cover.

Daughtry and Hunt 2008. Remote Sensing Environment 112:1647-1657.

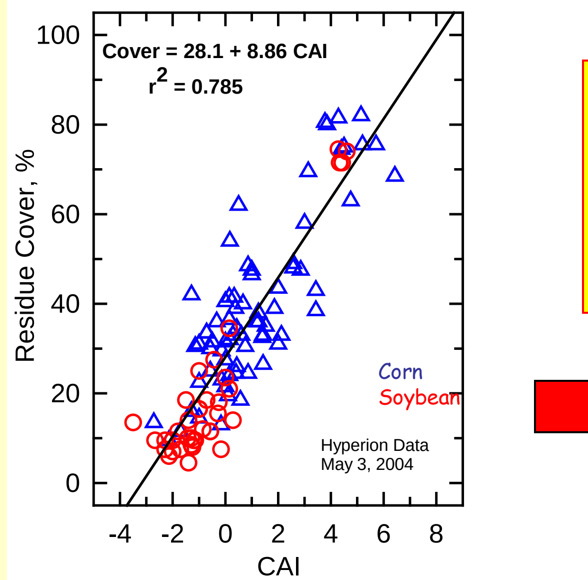
Scaling-up: Airborne & Satellite Imaging Spectrometer Data

EO-1 Hyperion
- 400-2500 nm
- ~10 nm bands
- 30 m pixels;

AVIRIS (NASA)
- 400-2450 nm
- ~10 nm bands
- 20 m pixels;

AISA Sensor (SpecTIR)
- 400-2450 nm
- ~5-10 nm bands
- 0.5 to 4 m pixels

Iowa 2004

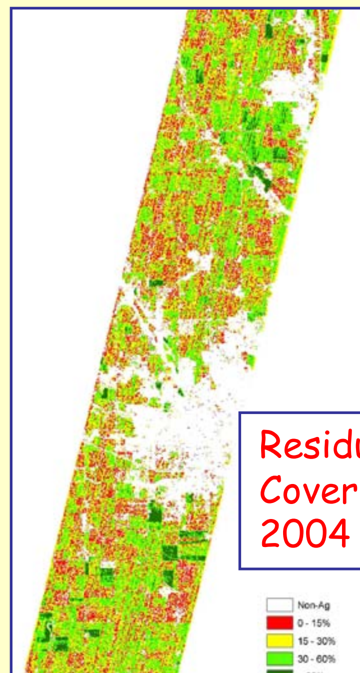


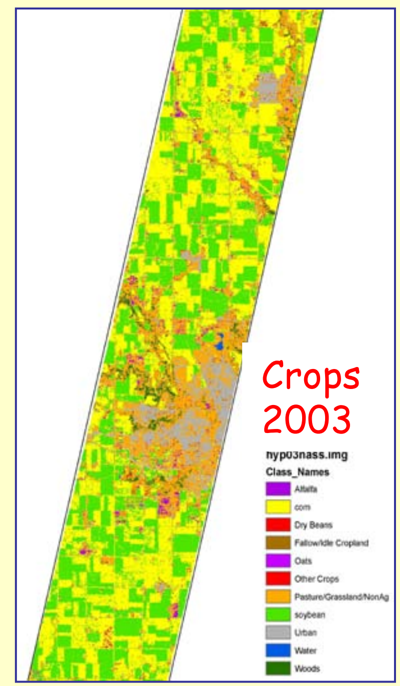
Slope of line is similar to ground-based (ASD) and aircraft (AVIRIS & AISA) data in MD, IN, and IA.

Residue cover was measured: May 10-12

Planting progress for May 9
(Iowa Crop & Weather, 2004)
Corn:
93% planted;39% emerged
Soybeans:
54% planted; 4% emerged

Hyperion Imagery was acquired: May 3





Residue Cover Category

Tillage Class = Intensive Reduced Conservation

	<15%	15-30%	>30%	Area
2003 Crop	**%**	**%**	**%**	**ha**
Corn	18	36	46	27,286
Soybean	35	40	25	20,832
Overall	**25**	**38**	**37**	**48,118**

May 3, 2004

Crop residue cover classes derived from Hyperion data using CAI, were combined with the Cropland Data Layer product from NASS.

	<15%	15-30%	>30%	Area
2004 Crop	**%**	**%**	**%**	**ha**
Corn	7	38	55	35,034
Soybean	3	21	76	25,261
Overall	**5**	**31**	**64**	**60,295**

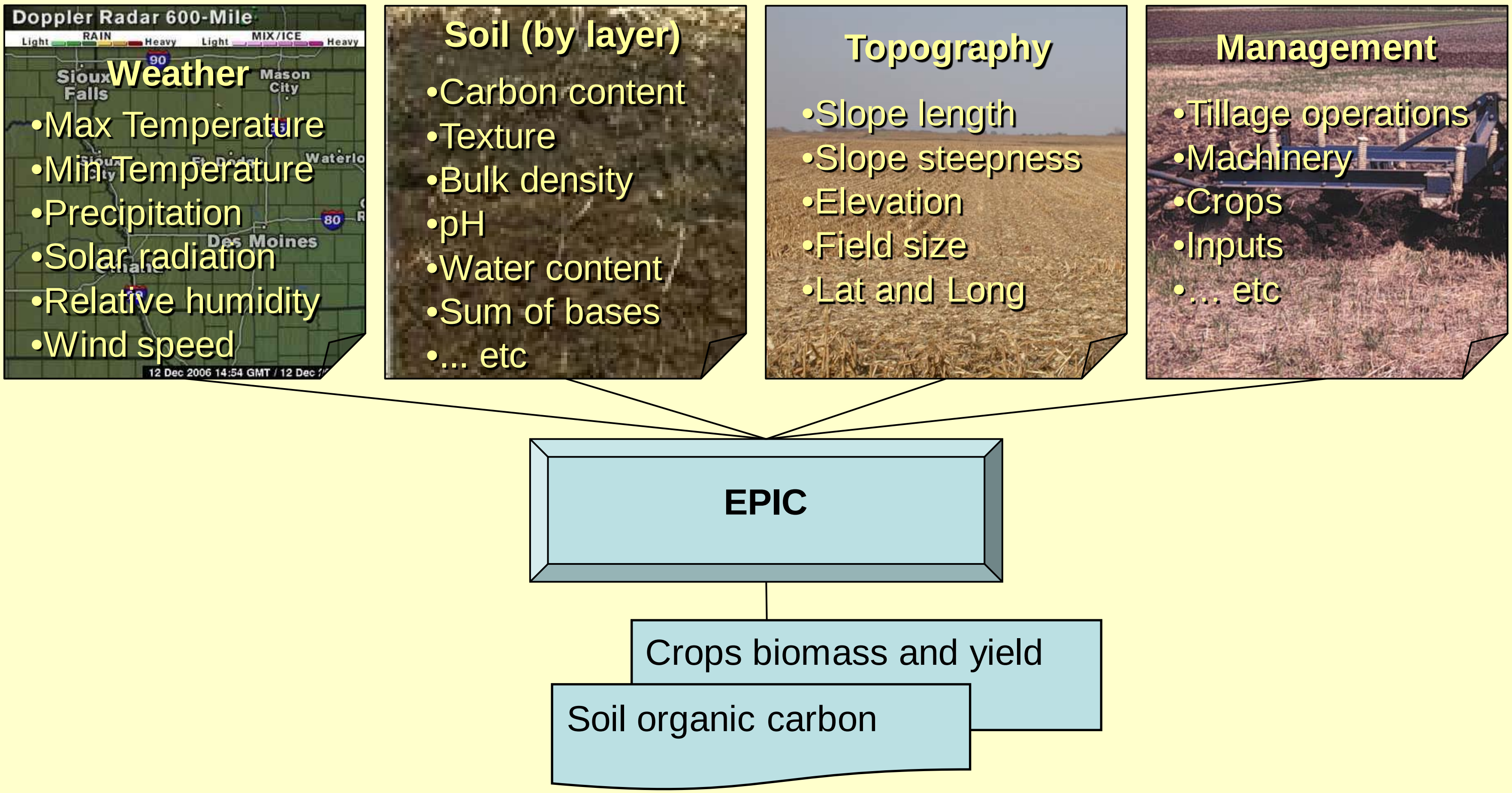
May 22, 2005

- Previous crop and its biomass (yield) determine the potential (maximum) crop residue cover.
- Tillage practices (intensity) and/or biomass harvesting determine the actual crop residue cover.

- Weather at planting influences tillage intensity.
    - 2004: warm, dry = more intense tillage
    - 2005: cool, wet = less intense tillage

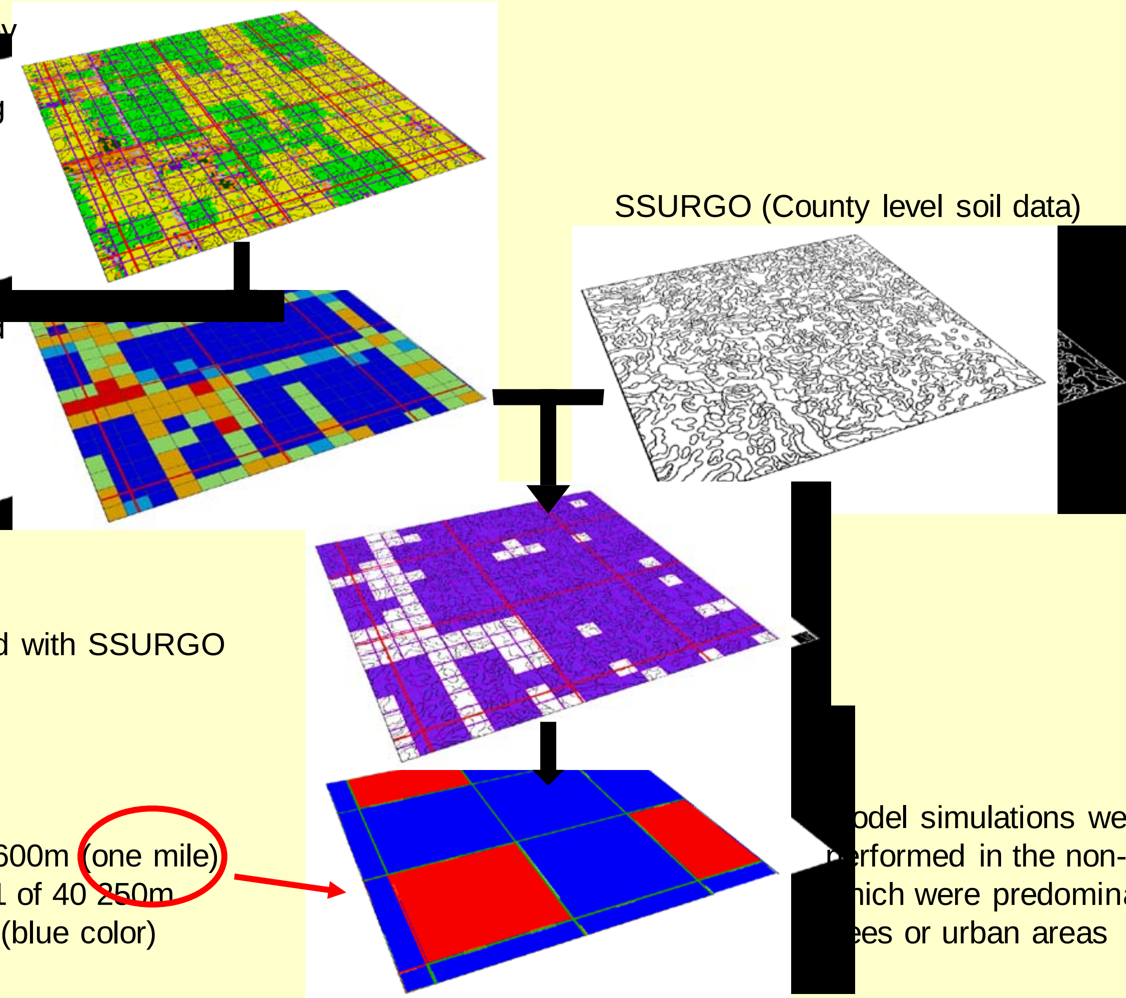
The Environmental Policy Integrated Climate (EPIC) model was used to predict the long-term impacts of management practices on crop yields and soil organic carbon (SOC) across the US Corn Belt.

http://www.public.iastate.edu/~tdc/i_epic_main.html



Preparation of the Database

Crop classification developed by the USDA-Nation[redacted]ultural Statistics Service (NASS) using 30m pixels Lansa[redacted]TM imagery



NASS crop class[redacted]n aggregated to 250m pixels, and those with >90% co[redacted]-soybean masked (blue color)

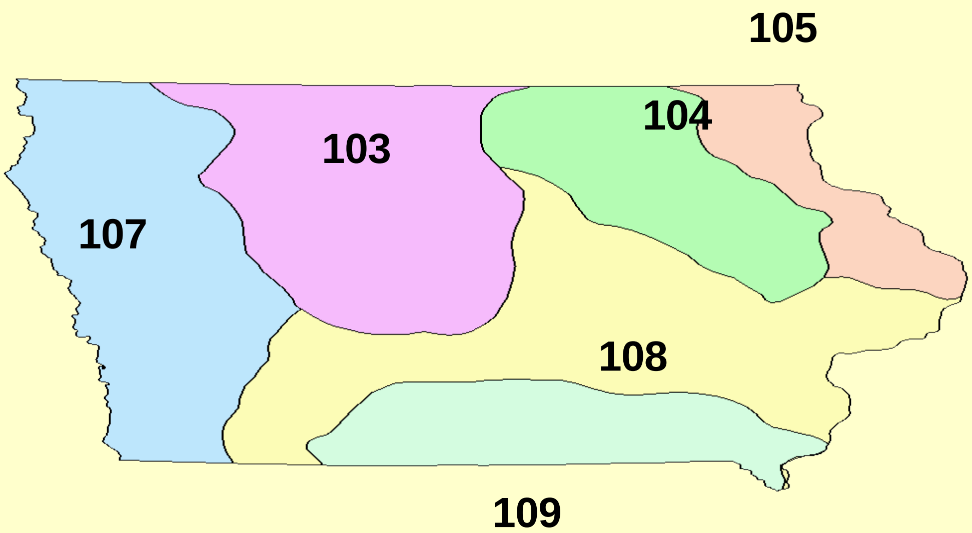
Corn-soybean mask intercepted with SSURGO

Statistics were performed on 1600m (one mile) pixels that contained at least 21 of 40 250m corn-soybean/SSURGO pixels (blue color)

[redacted]odel simulations were not [redacted]erformed in the non-crop areas, [redacted]hich were predominantly grass, [redacted]ees or urban areas

Paul C. Doraiswamy, USDA-ARS
HRSL, Beltsville, MD

Simulated Changes in Soil Organic C (1980-2019)



- Climate, physiography, soil, and tillage practices affects the magnitude of change in SOC.

Simulated Changes in Soil Organic C (1980-2019)

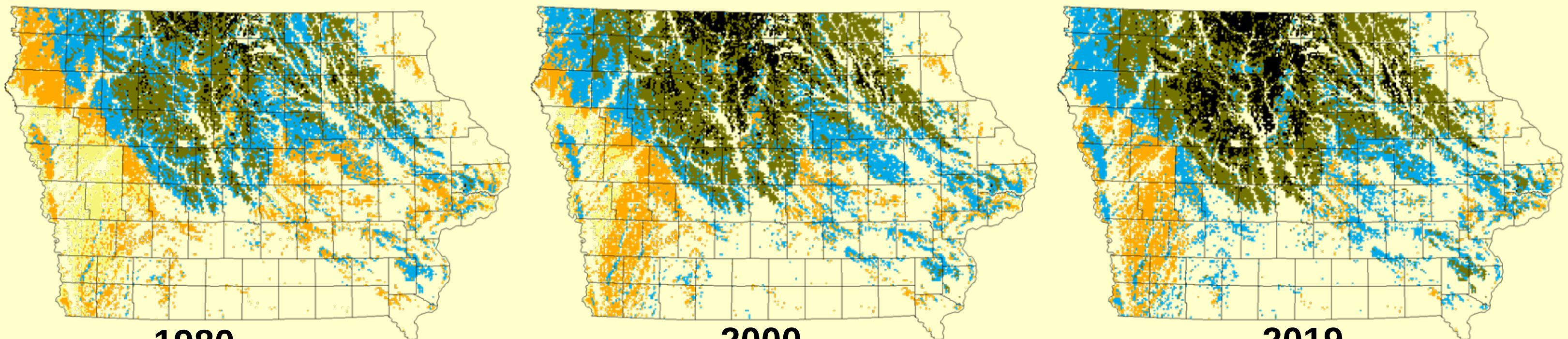
Major Land Resource Area	Tillage System		
	Conventional	Reduced	No Till
	-- Simulated SOC Changes (Mg ha^{-1}) --		
103 Central Iowa and Minnesota Till Prairies	-7.35	-0.79	14.79
104 Eastern Iowa and Minnesota Till Prairies	-8.48	-2.42	11.66
105 Northern Mississippi Valley Loess Hills	-8.49	0.08	14.33
107 Iowa and Missouri Deep Loess Hills	-4.67	3.52	18.35
108 Illinois and Iowa Deep Loess and Drift	-5.74	1.06	15.88
109 Iowa and Missouri Heavy Till Plain	-6.37	0.02	14.37

Causarano, H.J., P.C. Doraiswamy, G.W. McCarty, J.L. Hatfield, S. Milak, and A.J. Stern. 2008. EPIC modeling of soil organic carbon sequestration in croplands of Iowa. . J. Environmental Quality, 37: 1345-1353.

Temporal Changes in Soil Organic C Stocks

SOC (Mg/ha) in the top 20 cm

18.4 38.7 56.1 73.5 90.8 108.0



1980 | 2000 | 2019

1980	2000	2019
100% Conventional Tillage	14% Conventional Tillage	3% Conventional Tillage
	25% Reduced Tillage	19% Reduced Tillage
	61% No Tillage	78% No Tillage
451 Tg C	**501 Tg C**	**539 Tg C**
		+88 Tg

Simulations conducted at 2.56 km^2 resolution in the crop areas for a 50-year period.
Model was initiated in 1970 when the NRCS STATSGO data were developed.

Causarano, H.J., P.C. Doraiswamy, G.W. McCarty, J.L. Hatfield, S. Milak, and A.J. Stern. 2008. EPIC modeling of soil organic carbon sequestration in croplands of Iowa. . J. Environmental Quality, 37: 1345-1353.

Conclusions

- Relationships developed with ground-based spectroradiometers (ASD) are extendable to airborne (AISA & AVIRIS) and space-borne (Hyperion & ASTER) sensors.

- Maps and inventories of crop residue cover and soil tillage practices across agricultural landscapes are possible.

- Estimates of surface energy balance can be improved by better characterization of the surface.

Special Opportunities for Highly Sampled Areas

Robert G. Knox, for the HyspIRI concept study team

NASA's Goddard Space Flight Center,

Biospheric Sciences Branch, Code 614.4

Greenbelt, MD

HyspIRI Science Symposium on Ecosystem Data Products

May 4, 2010

Introduction

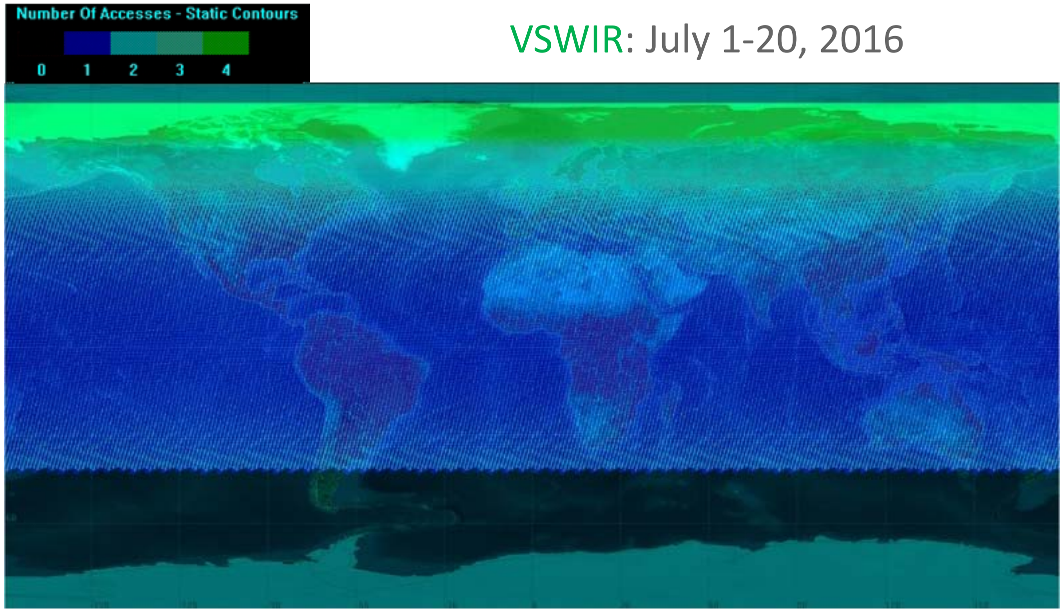
Context

- Some HyspIRI process questions can be addressed with samples, in lieu of full global maps.
- Some VSWIR questions will be difficult to answer without some information at intervals < 19 days.
- Some areas may have repeat TIR data over short intervals (e.g., day-night pairs).

Outline

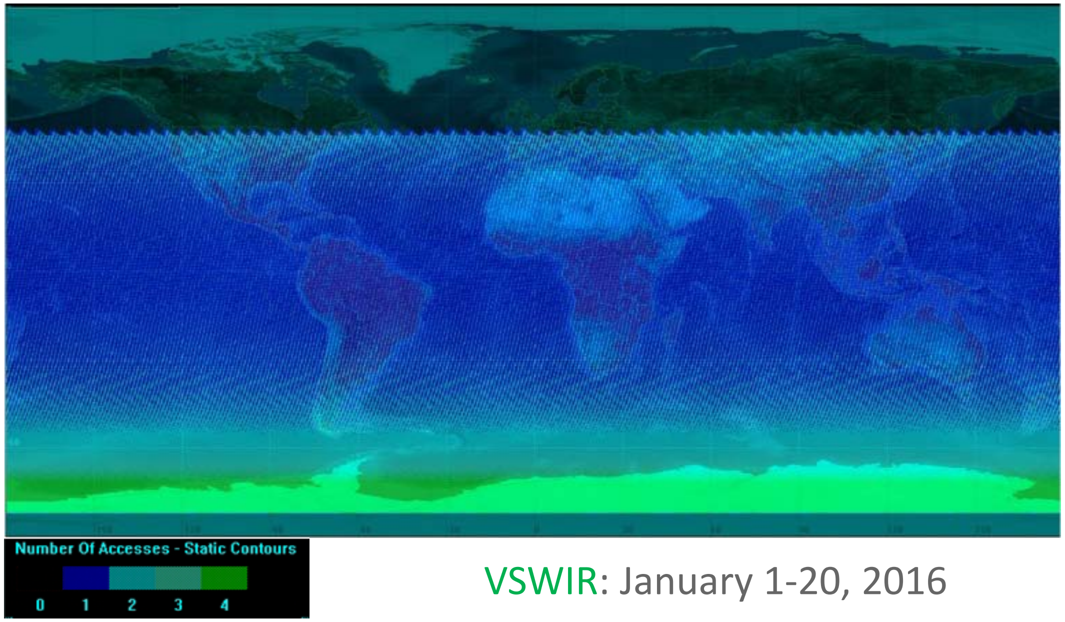
- VSWIR Coverage simulations
  - Global coverage grids
  - Example FLUXNET tower sites
- TIR coverage simulations
  - Global coverage grids
  - Example FLUXNET tower sites
- Minimum TIR revisit intervals and opportunities to measure diurnal variation.

VSWIR coverage frequency varies seasonally



VSWIR: July 1-20, 2016

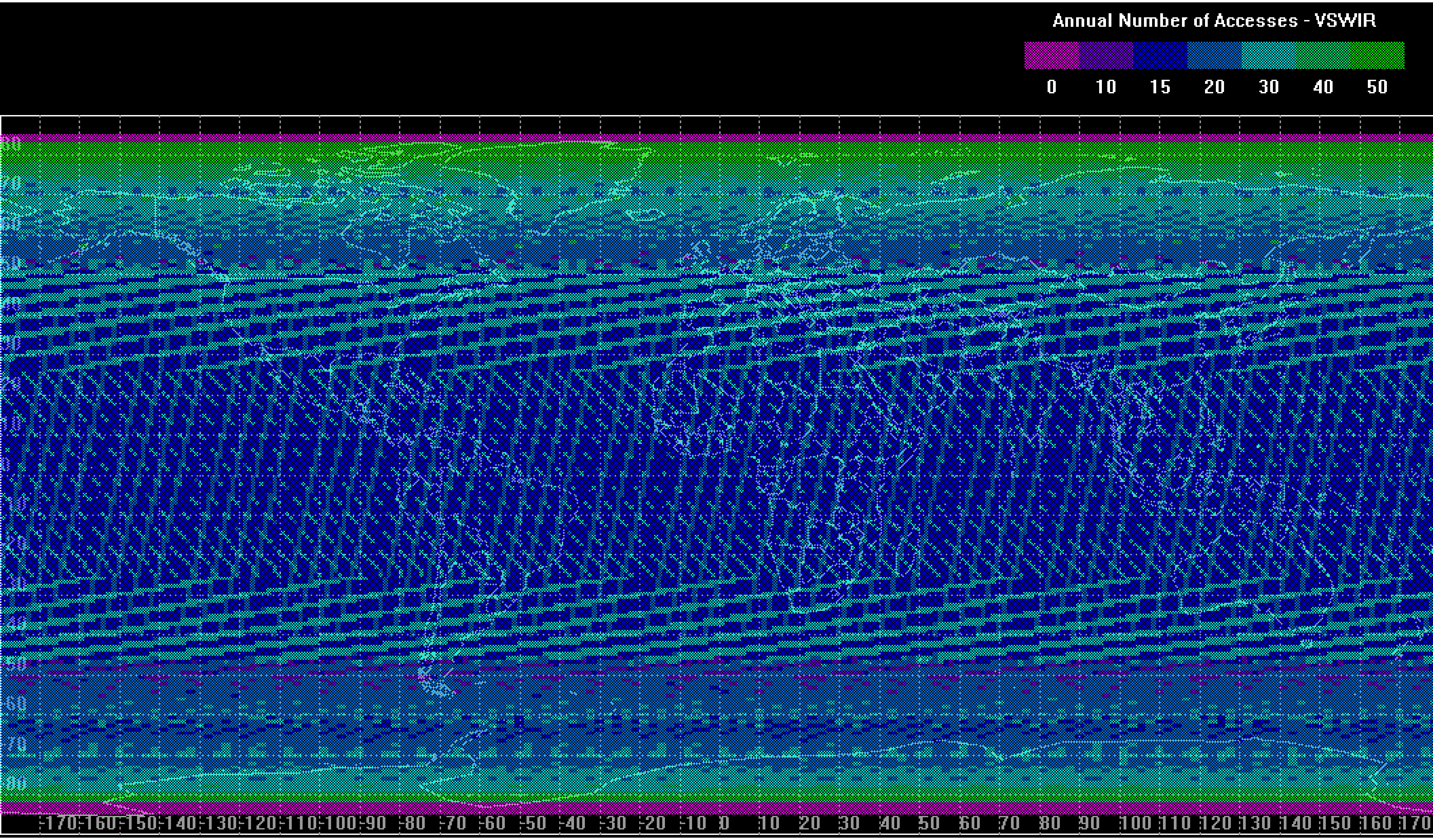
VSWIR coverage is limited by constraint: minimum 20 deg. Sun elevation angle.



VSWIR: January 1-20, 2016

Simulated by Michael Mercury, JPL, figures from HyspIRI customer presentation to Team X, JPL, 3/23/2010

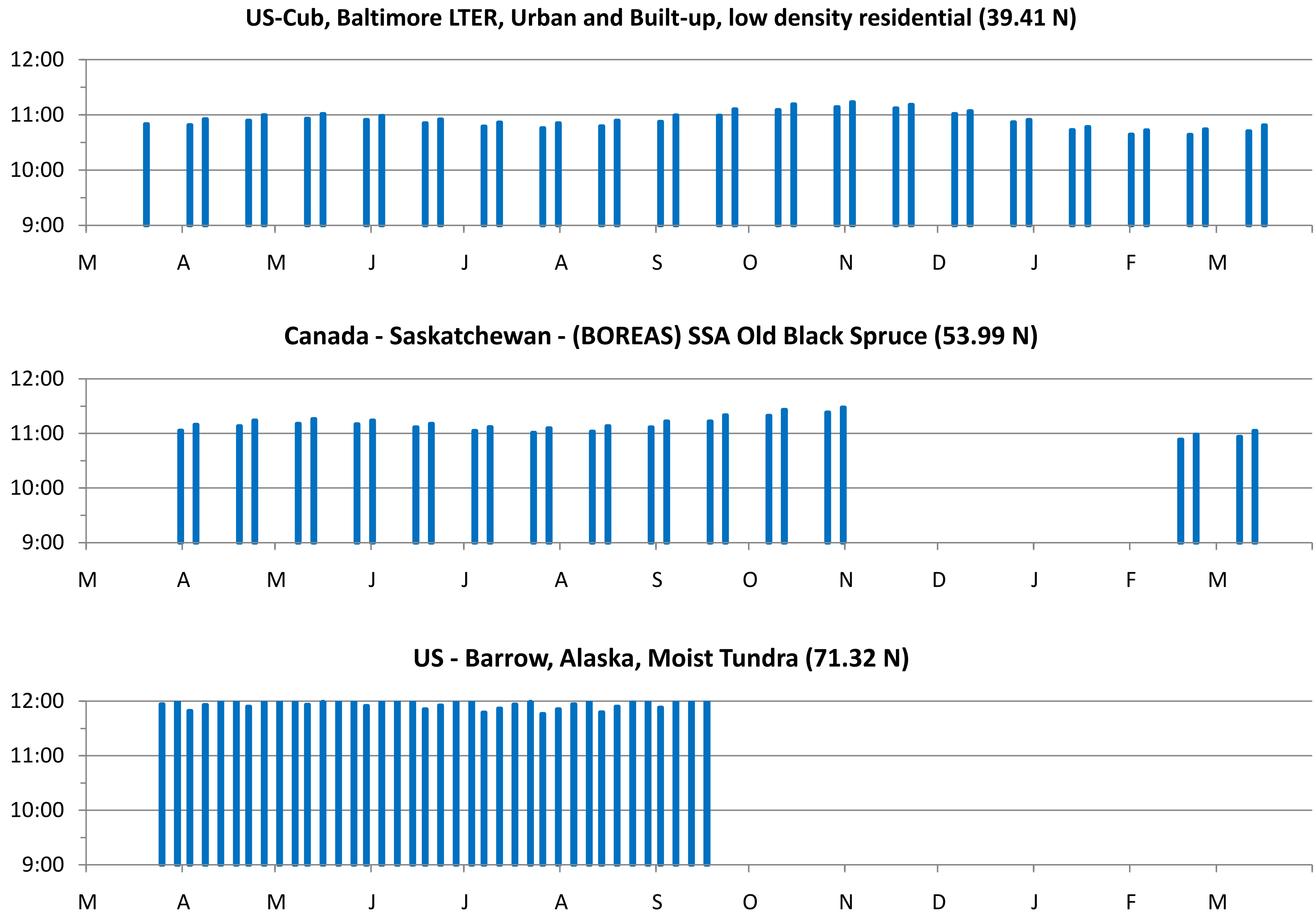
Annual VSWIR imaging opportunities in a 19-day repeating orbit, 1 yr. simulation, with a minimum solar elevation of 20°



Nominal orbit: av. alt. 626.8 km, incl. 97.8°. VSWIR spectrometer FOV: 2.8° E, 10.8° W (60 m pixel GSD at nadir, 2480 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010. Note aliasing with sample grid.

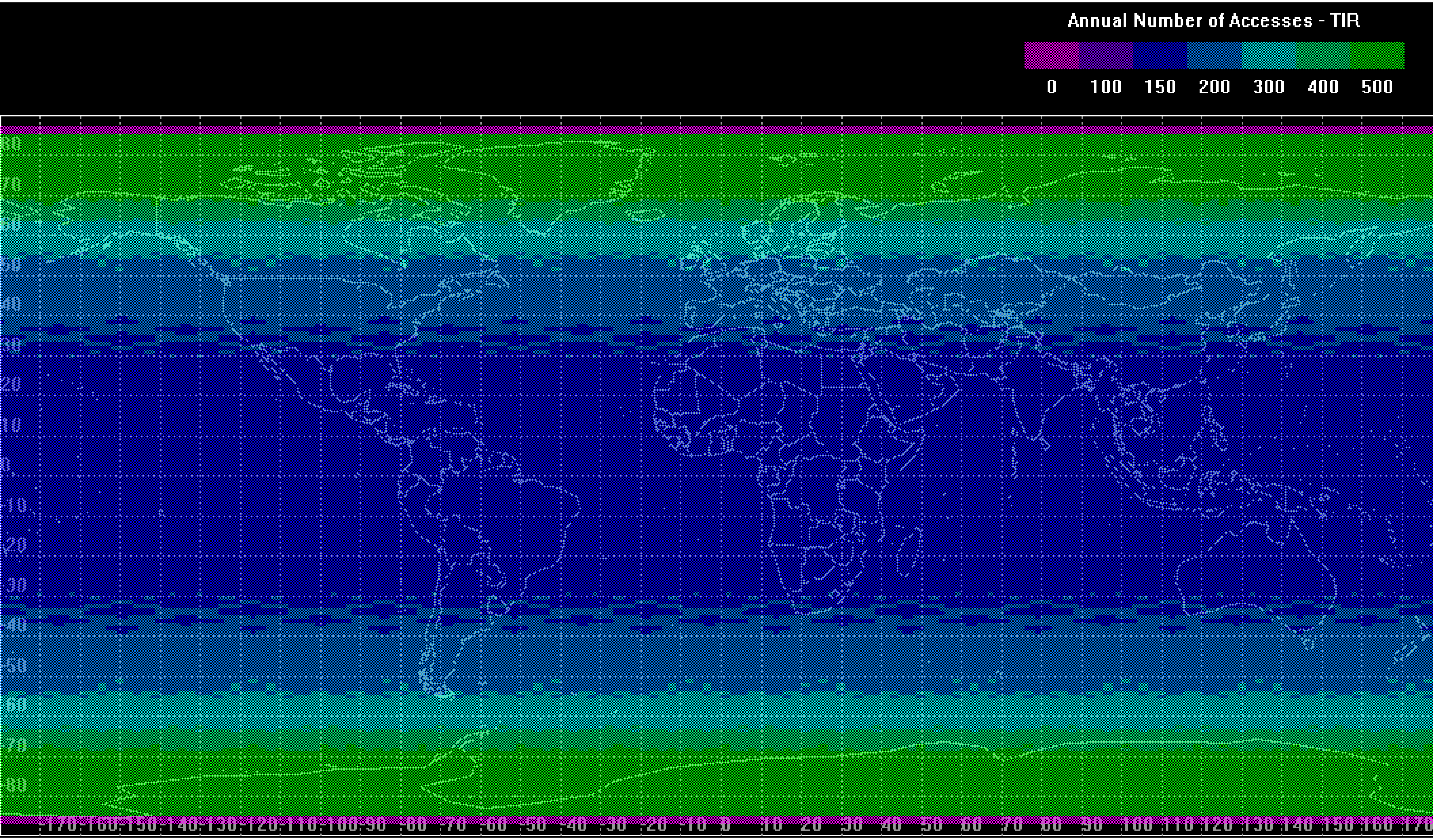
80
70
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
US-Brw
CA-Obs
US-Cub
US-ARM
US-Skr
BR-Sa1

Examples of more frequent potential VSWIR accesses (swath overlap zones, high latitudes)



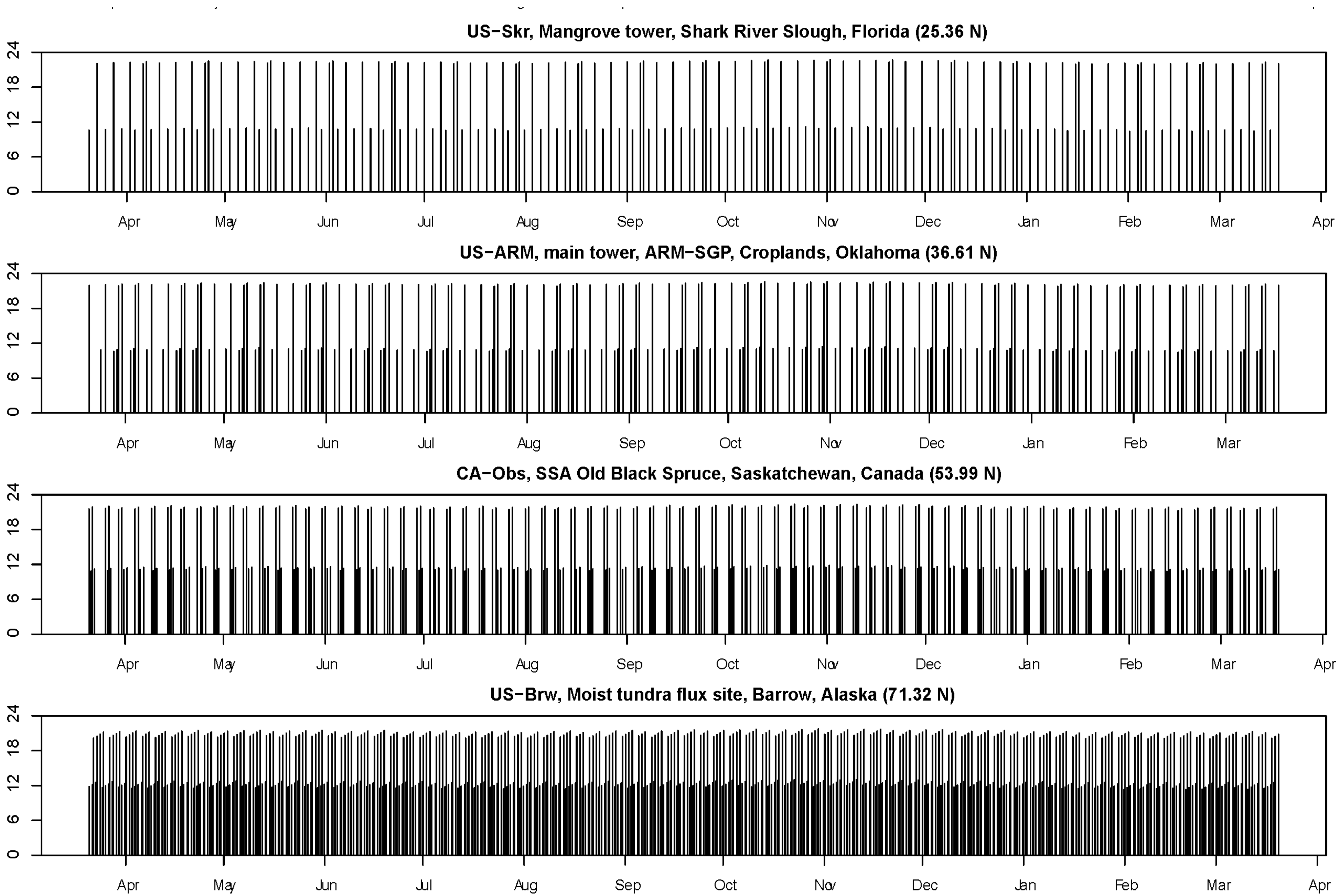
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

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



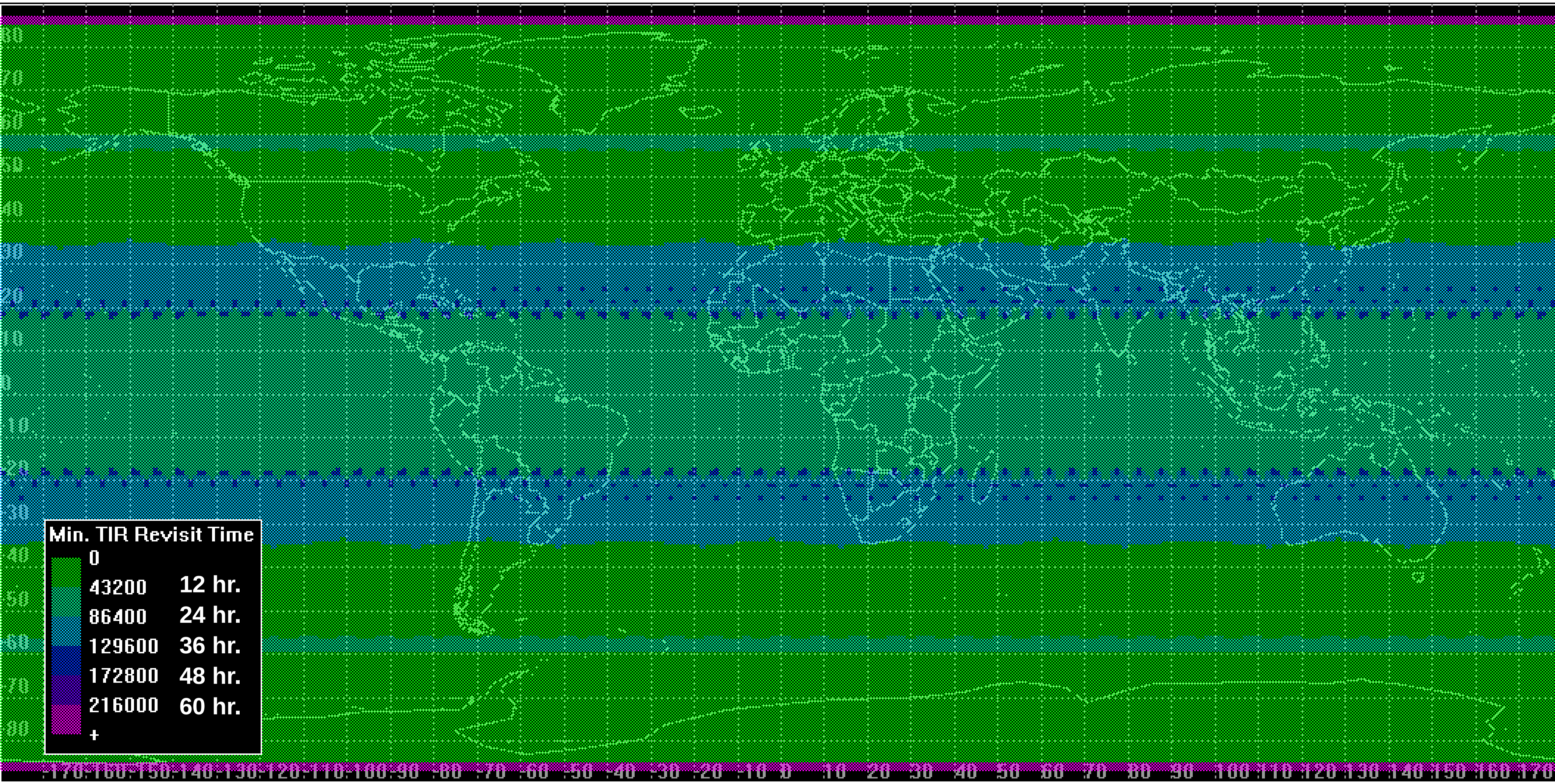
Nominal orbit: average alt. 626.8 km, inclination 97.8°. TIR imager FOV: +/- 25.46° (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 7, 2010. Plotted May 3, 2010.

Frequent TIR coverage occurs at mid-latitudes and higher



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Minimum times between Multispectral Thermal (TIR) Imager accesses
Potential accesses simulated for 1 year, sampled over a 1 by 1 deg. grid



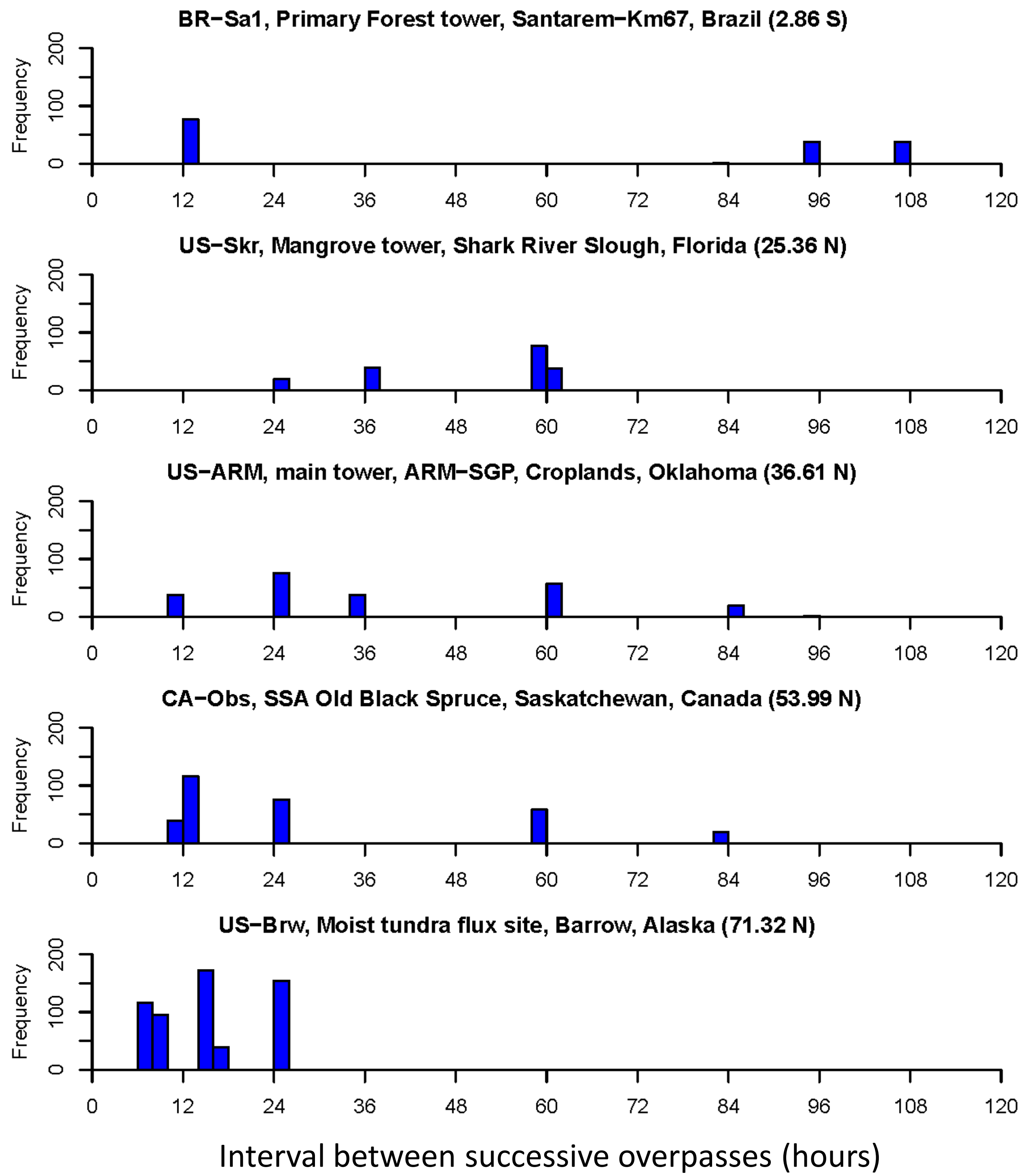
Nominal orbit: alt. 626.8 km, incl.: 97.8. TIR sensor FOV: +/- 25.46 (60 m pixel GSD at nadir, 9272 cross-track pixels).
R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3, March 20, 2010. Plotted May 3, 2010.

Frequency Distributions of Intervals between Potential Coverage with the TIR Instrument

Equatorial sites have frequent day-night pairs, separated by 4 days or 4.5 days.

High latitudes are characterized by revisit intervals that are daily or shorter.

A subset of subtropical locations have most overpasses separated by 2.5 days (the worst case in a 5-day repeat with both daytime and night data).



R.G. Knox, NASA GSFC, Biospheric Sciences Branch, Code 614.4. Simulated with STK v8.1.3

Some conclusions & questions: Highly sampled areas

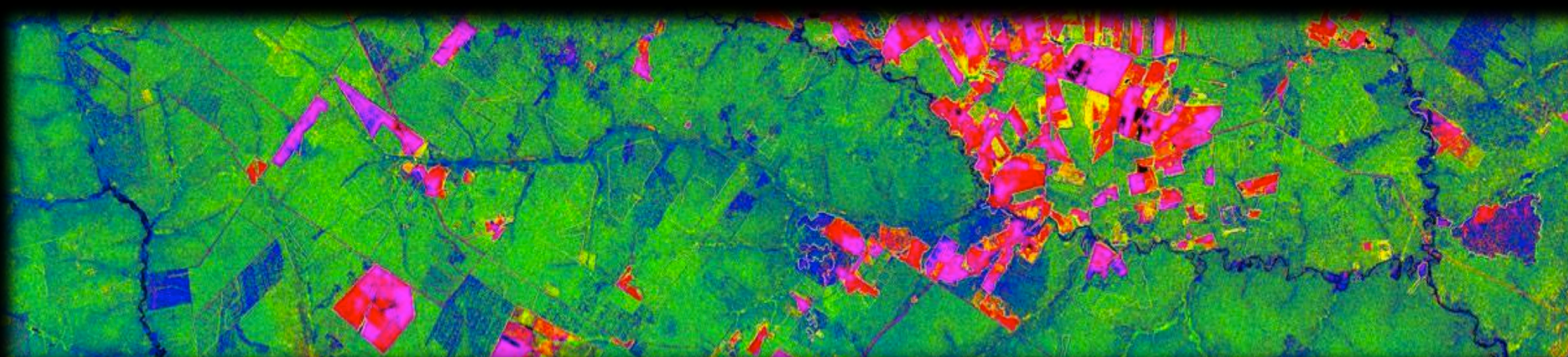
- A feasible design to meet 5-day and < 20 day requirements (the reference orbit and instrument concepts) also provides highly sampled areas: e.g., high latitudes, overlapping swaths.
- The reference orbit and TIR instrument swath provides day-night pairs—within 24 hours at many locations (was not a mission requirement).
- Questions:
  - *What science questions could best be addressed in highly sampled areas? With what level 3 or 4 data products?*
  - *Will VSWIR swath overlap zones vary over course of the mission? (orbit nodes drift away from fixed longitudes) How would that change data products?*
  - *Does the complicated pattern of time intervals between TIR re-visits, notable in some regions, present difficulties for deriving a consistent sets of products using, for example, diurnal temperature differences?*

NASA

Synergy of VSWIR and LiDAR for Ecosystem Structure, Biomass, and Canopy Diversity

Bruce D. Cook
NASA-GSFC

Gregory P. Asner
Carnegie Institution



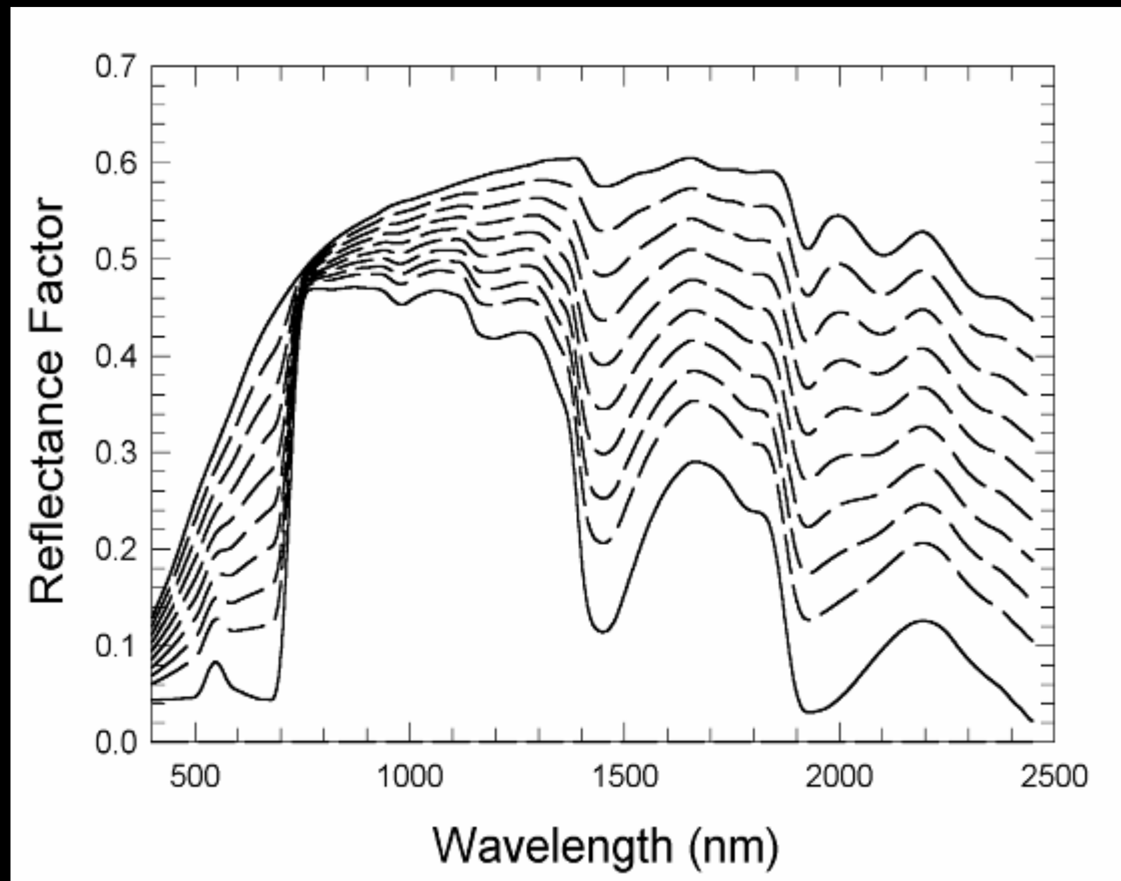
HyspIRI Science Questions

VQ1. What is the global ***spatial pattern of ecosystem and diversity distributions*** and how do ecosystems differ in their composition or biodiversity?

VQ2. What are the ***seasonal expressions*** and cycles for terrestrial and aquatic ecosystems, ***functional groups***, and diagnostic species?

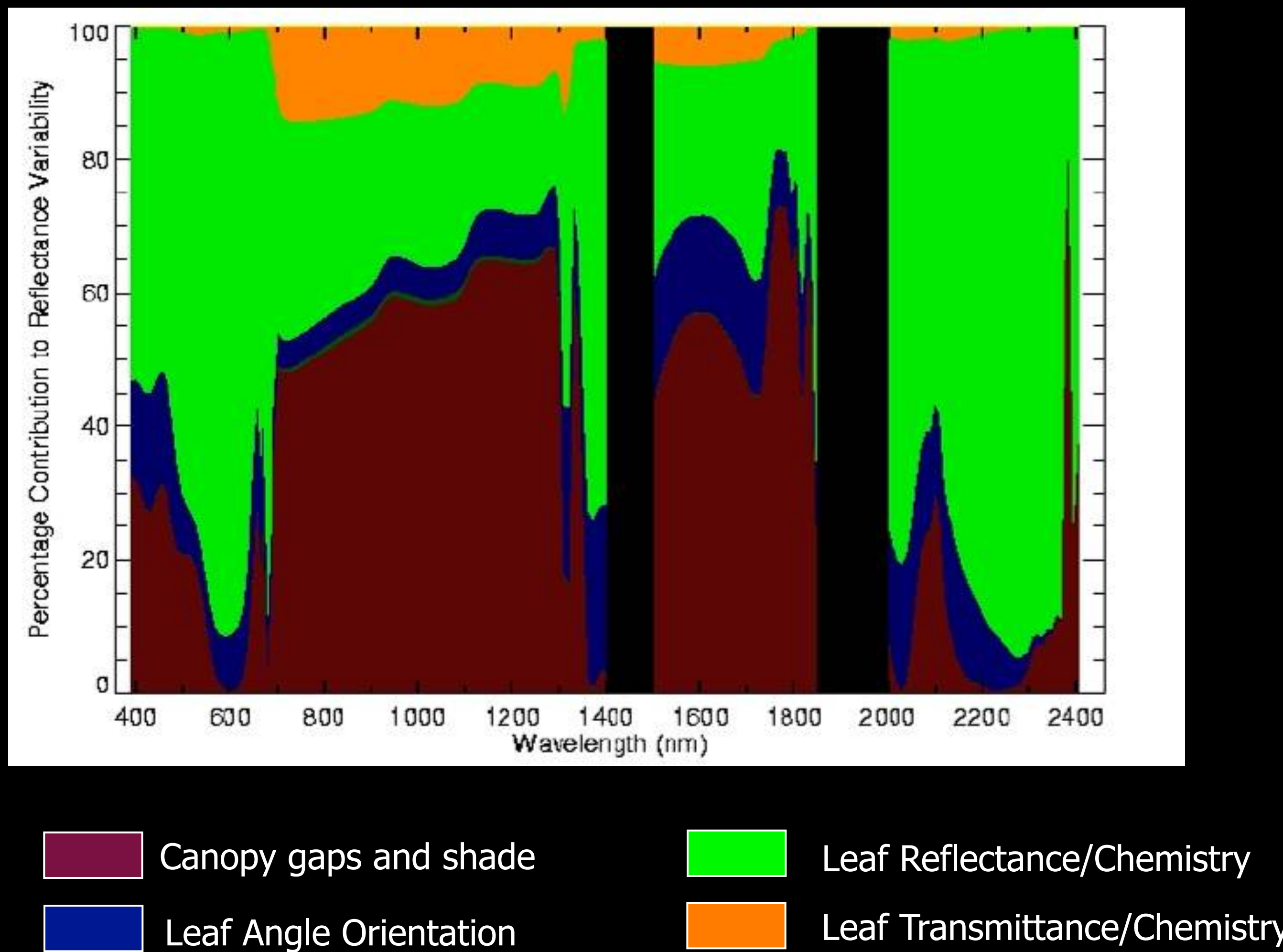
VQ3. How are the ***biogeochemical cycles*** that sustain life on Earth being altered/ disrupted by ***natural and human-induced environmental change***?

Challenges to Imaging Spectroscopy



Plant chemical signatures are influenced by canopy structure and shadows

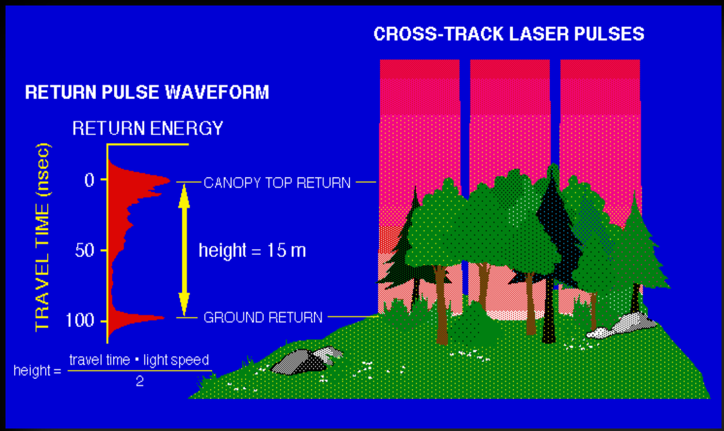
Spectral Dependence of Leaf and Canopy Properties



Carnegie Airborne Observatory (CAO)

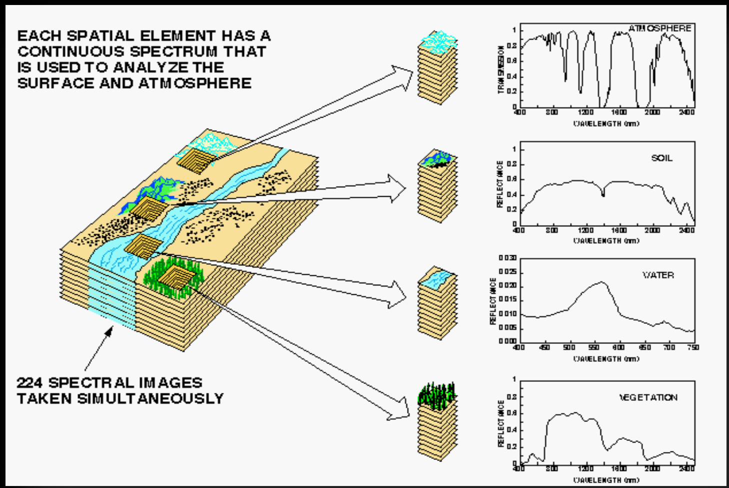
3-D functional imaging of ecosystems

LiDAR for topography, canopy structure, LAI, etc.



+

Hyperspectral for species, chemistry, etc.



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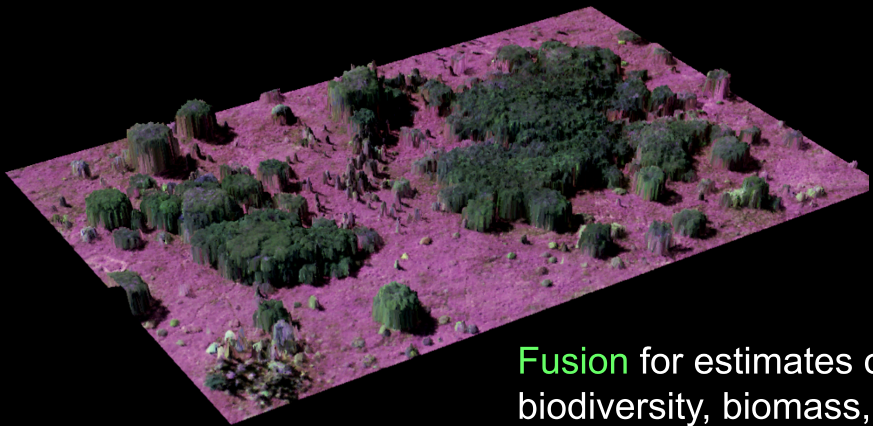
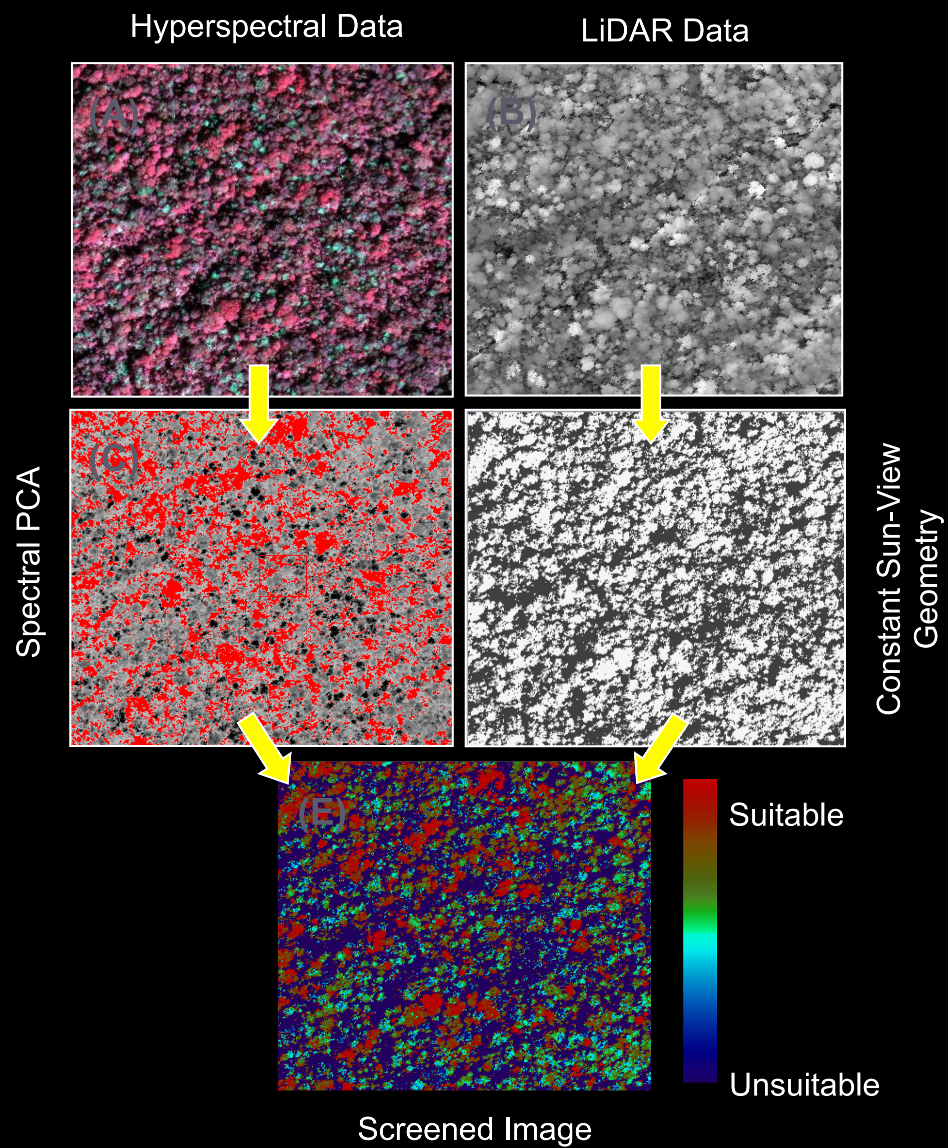
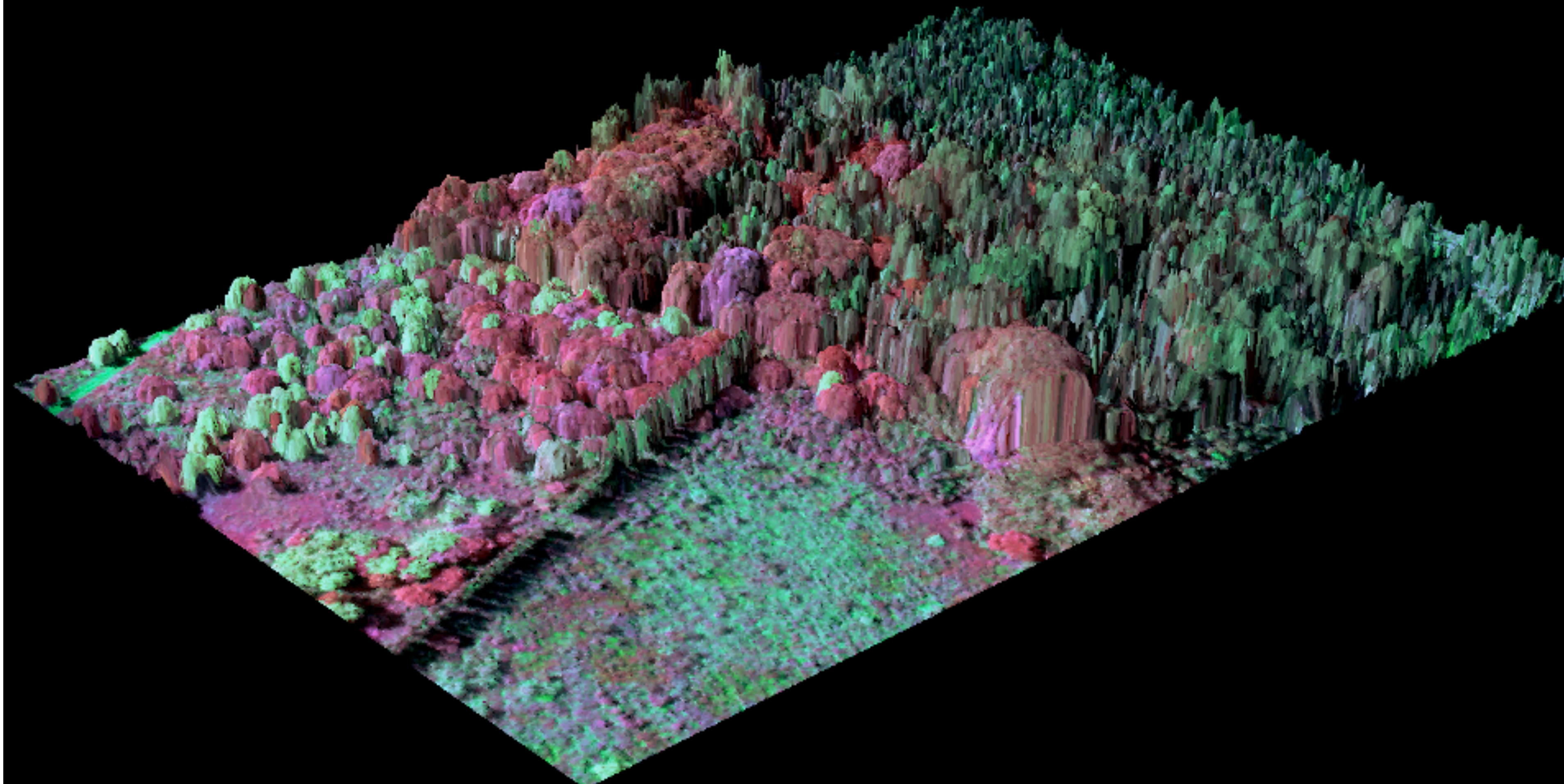


Fusion for estimates of biodiversity, biomass, sun/shade fraction, habitat suitability, etc.

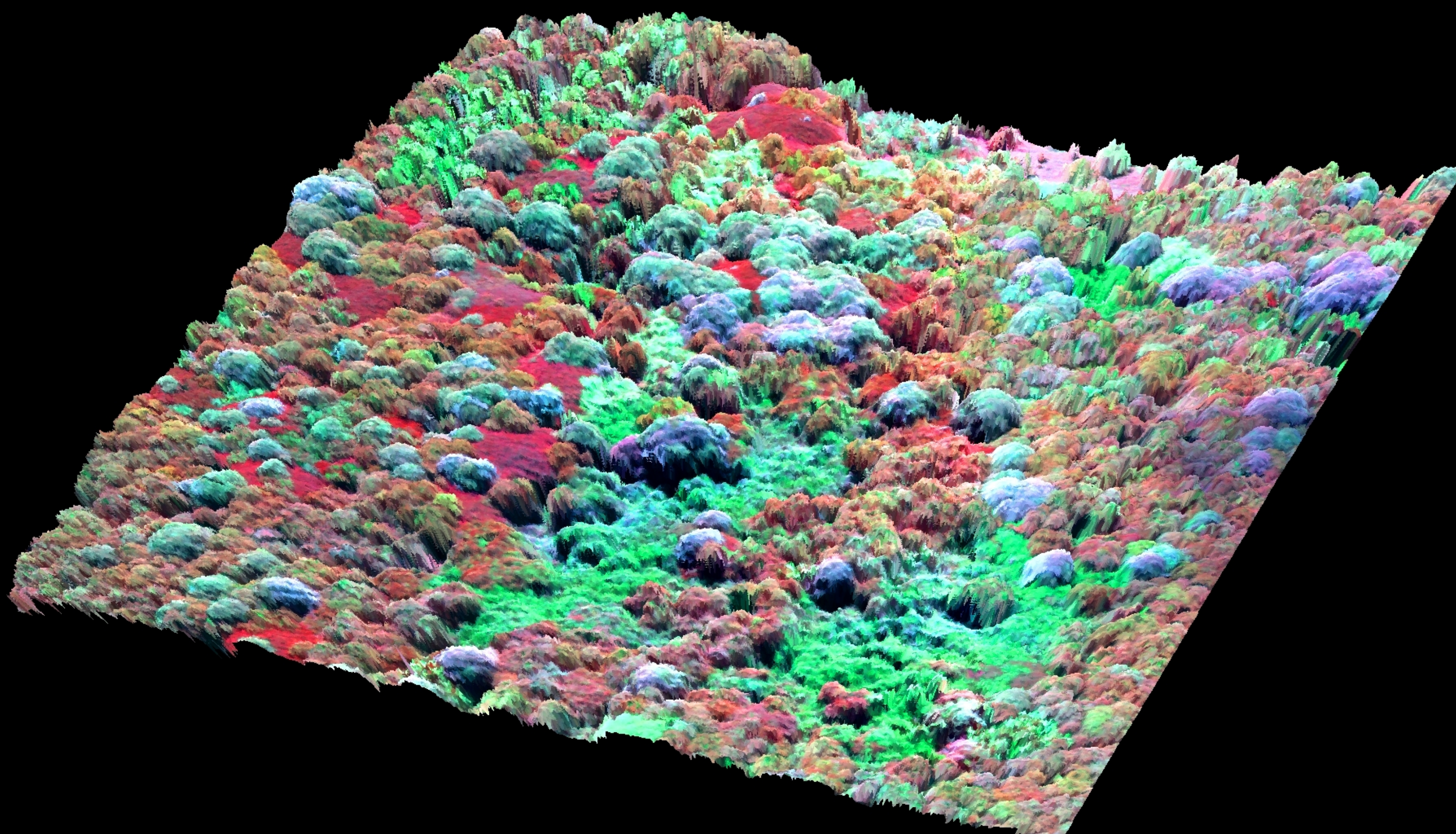
Carnegie Data Processing Stream



Biological Invasion Fronts



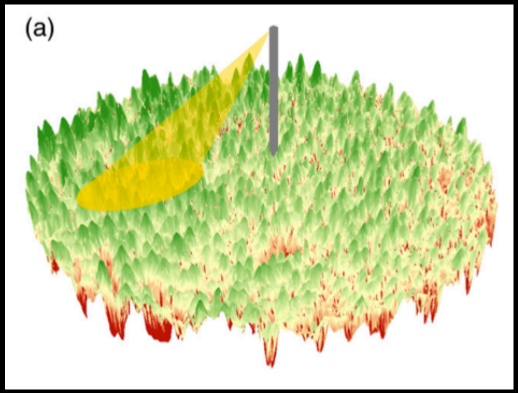
Canopy chemistry and biodiversity in tropical forest canopies



High-Temporal Tower-Based Studies

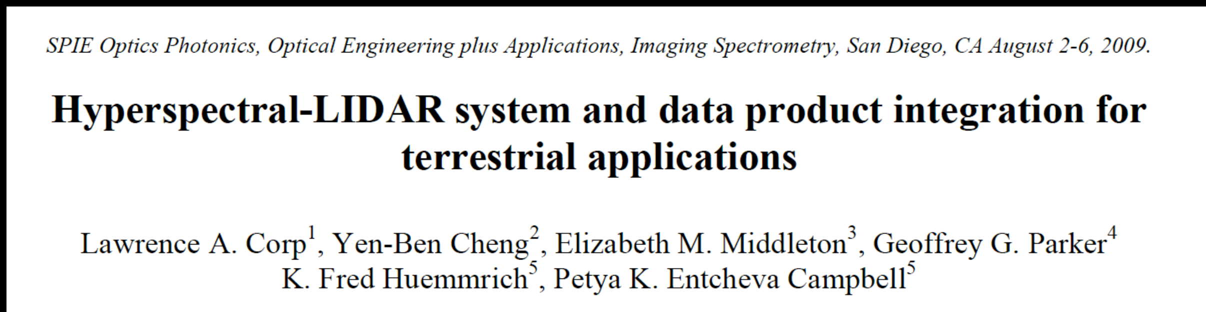
1) Thermal + LiDAR/Hyperspectral

2) Correcting hyperspectral observations for shadow fraction



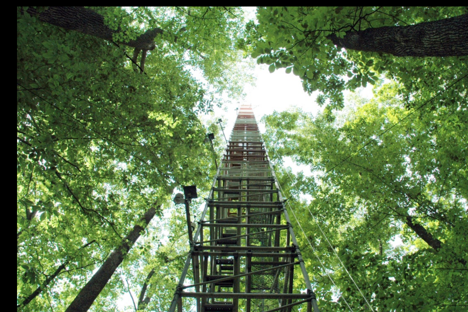
Thermal + LiDAR/Hyperspectral

(Middleton, Cook, Corp, *et al.*, NASA-GSFC)


SPIE Optics Photonics, Optical Engineering plus Applications, Imaging Spectrometry, San Diego, CA August 2-6, 2009.

Hyperspectral-LIDAR system and data product integration for terrestrial applications

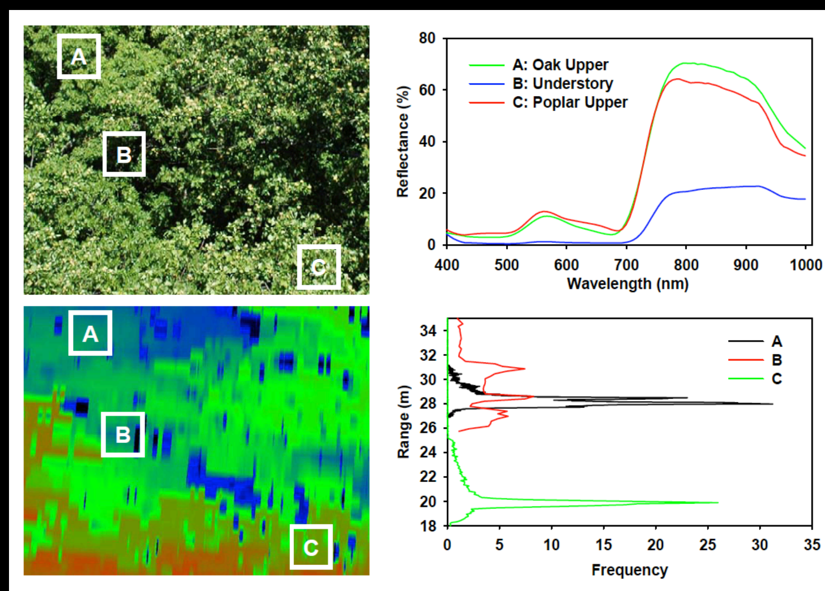
Lawrence A. Corp[1], Yen-Ben Cheng[2], Elizabeth M. Middleton[3], Geoffrey G. Parker[4]
K. Fred Huemmrich[5], Petya K. Entcheva Campbell[5]

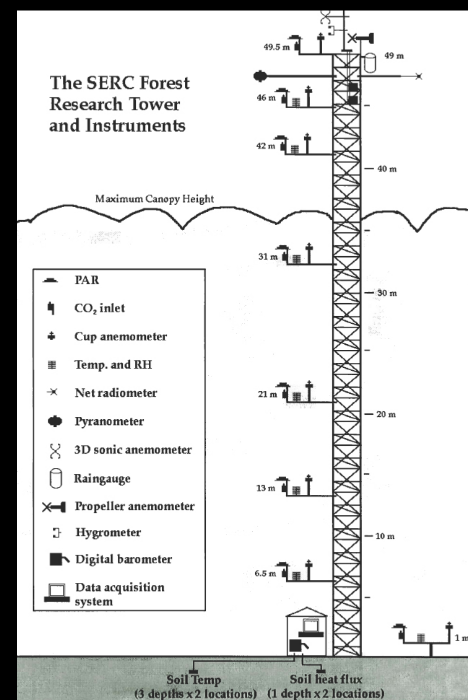



Pan-tilt mount

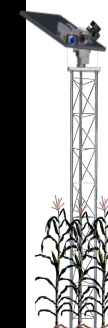

Thermal imager (NEW!)

Continuous Sun/Shade Measurements





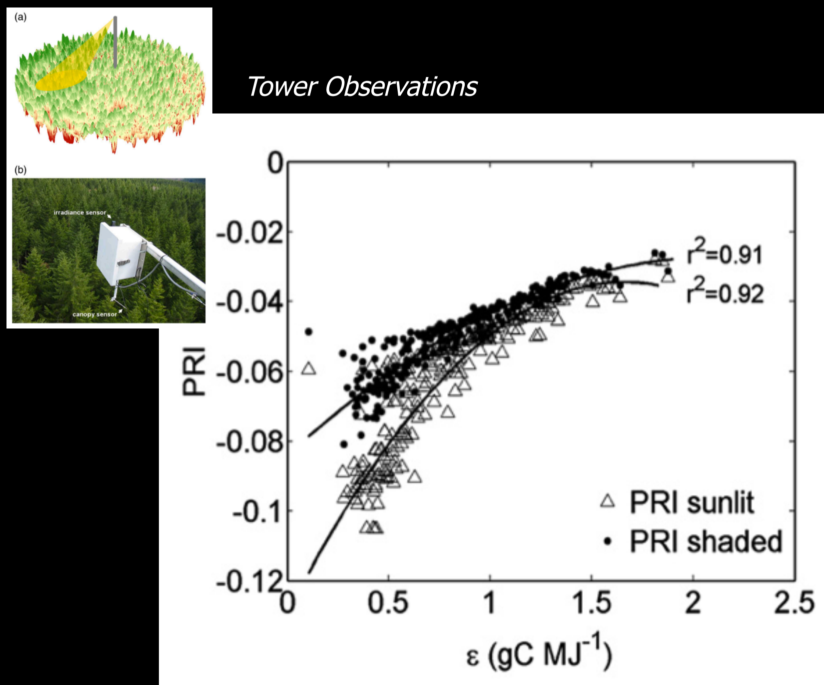
SERC Flux Tower



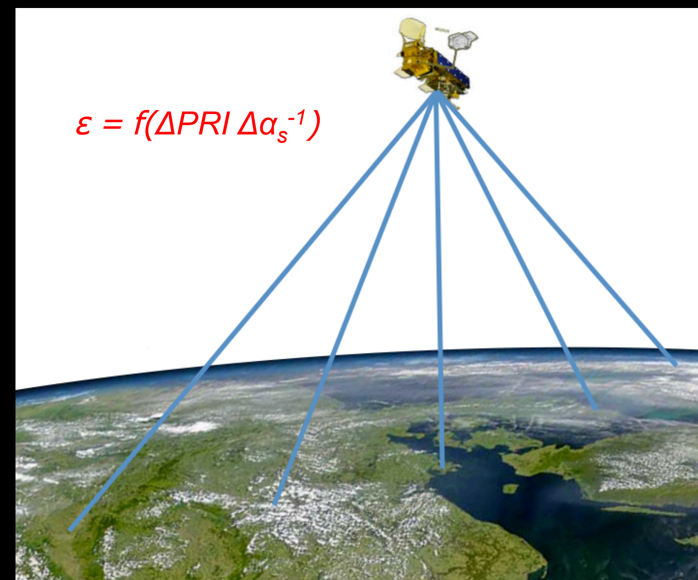
View Angle/Shadow Fraction Correction

(Hilker and Hall, *et al.*; Univ. British Columbia, UMBC/NASA-GSFC)

Tower Observations



Space-Based Observations



PRI = Photochemical Reflectance Index

ε = photosynthetic light-use efficiency

Photosynthetic light-use efficiency (ε) from multiple angles can be related to:

1) *direct measurements of PRI; and*
2) *shadow fraction (α_s) derived from LiDAR or mixture decomposition.*

Conclusions

Biophysical information from LiDAR and *biochemical* information from hyperspectral remote sensing provides complementary data for:

1) describing *spatial patterns of vegetation and biodiversity*;

2) characterizing relationships between *ecosystem form and function*; and

3) Detecting natural/human-induced change that affects *biogeochemical cycles*.

[redacted]

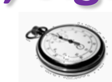
HyspIRI Science Symposium on Ecosystem Data Products

NASA/GSFC, May 4 and 5, 2010
Building 33, Room H114

GSFC EO-1/HyspIRI Team

Betsy Middleton, NASA
Bob Knox, NASA
Steve Ungar, UMBC

Petya Campbell, UMBC
Qingyuan Zhang, UMBC
Fred Huemmrich, UMBC
Ben Cheng, ERT
Larry Corp, Sigma Space



Other Assistants for Symposium:
Hank Margolis, Laval University [TIMEKEEPER]
Sandi Bussard, Jacob Gude, Sheila Humke & Carla Evans
Sigma Space

look for flags on their name tags

List of Attendees

	First	Last	Affiliation	E-mail		First	Last	Affiliation	E-mail
1	Steve	Ambrose	NASA/GSFC	sambrose@nasa.gov	35	Bill	Kustas	BARC/USDA	Bill.Kustas@ARS.USDA.GOV
2	Martha	Anderson	BARC/USDA	Martha.Anderson@ars.usda.gov	36	John	LaBrecque	NASA/HQ	John.LaBrecque@nasa.gov
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4	John	Bolton	NASA/GSFC	jfbolton@fullspectralimaging.net	38	Alex	Lyapustin	NASA/GSFC	alexei.i.lyapustin@nasa.gov
5	Chris	Brehany		cbrehany@aol.com	39	Tom	Maiersperger	USGS	tmaiersperger@usgs.gov
6	Molly	Brown	NASA/GSFC	molly.e.brown@nasa.gov	40	Dan	Mandl	NASA/GSFC	daniel.j.mandl@nasa.gov
7	Carl	Bruce	NASA/JPL	carl.f.bruce@jpl.nasa.gov	41	Antonio	Mannino	NASA/GSFC	Antonio.Mannino-1@nasa.gov
8	Petya	Campbell	NASA/GSFC	petya.campbell@nasa.gov	42	Hank	Margolis	UMBC-GEST	hank.a.margolis@nasa.gov
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10	Ben	Cheng	NASA/GSFC	Yen-Ben.Cheng@nasa.gov	44	Jeff	Masek	NASA/GSFC	Jeffrey.G.Masek@nasa.gov
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12	John	Cipar	HANSCOM/MIL	John.Cipar@hanscom.af.mil	46	Mark	Matsumura	NASA/GSFC	mark.m.matsumura@nasa.gov
13	Bruce	Cook	NASA/GSFC	bruce.cook@nasa.gov	47	Michael	Mercury	NASA/JPL	Michael.Mercury@nasa.gov
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17	Craig	Daughtry	BARC/USDA	Craig.Daughtry@ARS.USDA.GOV	51	Joanne	Nightingale	NASA/GSFC	joanne.m.nightingale@nasa.gov
18	Richard	Driver	Headwall Photonics	rdriver@headwallphotonics.com	52	C. Doug	Norton	NASA/JPL	Charles.D.Norton@jpl.nasa.gov
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27	Rob	Green	NASA/JPL	robert.o.green@jpl.nasa.gov	61	James	Tilton	NASA	James.C.Tilton@nasa.gov
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30	Simon	Hook	NASA/JPL	simon.j.hook@jpl.nasa.gov	64	Steve	Ungar	NASA/GSFC	stephen.g.ungar@nasa.gov
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33	Bob	Knox	NASA/GSFC	Robert.G.Knox@nasa.gov	67	Diane	Wickland	NASA/HQ	Diane.E.Wickland@nasa.gov
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HyspIRI Science Symposium on Ecosystem Data Products

Sponsor: NASA/Goddard Space Flight Center

May 4 & 5, 2010

Building 33, Conference Room H114 (and H118, H120)

Focus: Identifying Potential Higher Level Products for Climate/Carbon End Users

Objectives:

Identify science/application data products to be derived from HyspIRI measurements *by users*;

Discover/Discuss issues underlying data product processing/integration/fusion;

Prioritize the development of product prototypes.

Science Discipline Areas to be addressed: Terrestrial Ecosystems, Agriculture

Science Questions for the HyspIRI Mission (http://hyspIRI.jpl.nasa.gov)

HyspIRI has three top-level science questions [identified in the NRC Decadal Survey] related to:

1) Ecosystem function and composition,

What is the global distribution and status of terrestrial and coastal-aquatic ecosystems and how are they changing?

2) Volcanoes and natural hazards,

How do volcanoes, fires and other natural hazards behave and do they provide precursor signals that can be used to predict future activity?

3) Surface composition and the sustainable management of natural resources.

What is the composition of the land surface and coastal shallow water regions and how can they be managed to support natural and human-induced change?

VSWIR Questions: 6 over-arching questions. VQ1-6 (with 35 sub-questions)

TIR Questions: 5 over-arching questions, TQ1-5 (with 23 sub-questions)

Combined VSWIR and TIR Questions: 6 over-arching questions, CQ1-6 (with 32 sub-questions)

Terrestrial Ecosystems: *HyspIRI Science Questions for Symposium*

VQ1: Ecosystem Pattern, Spatial Distribution and Components

What is the global spatial pattern of ecosystem and diversity distributions and how do ecosystems differ in their composition or biodiversity?

VQ2: Ecosystem Function, Physiology and Seasonal Activity

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 disturbance?

VQ3: Biogeochemical Cycles

How are the biogeochemical cycles that sustain life on Earth being altered/disrupted by natural and human-induced environmental change? How do these changes affect the composition and health of ecosystems and what are the feedbacks with other components of the Earth system?

VQ4: Disturbance Regimes

How are disturbance regimes changing and how do these changes affect the ecosystem processes that support life on Earth?

TQ2 and CQ2: Wildfires

TQ2: What is the impact of global biomass burning on the terrestrial biosphere and atmosphere, and how is this impact changing over time? CQ2: How are fires and vegetation composition coupled?

TQ3. Water Use and Availability:

How is consumptive use of global freshwater supplies responding to climate changes and demand, and what are the implications for sustainable management of water resources?

CQ4: Ecosystem Function and Diversity

How do species, functional type, and biodiversity composition within ecosystems influence the energy, water and biogeochemical cycles under varying climatic conditions?

VSWIR Spectrometer (212 contiguous channels)

Level 0: Digital Numbers

Level 1: 1A - Level 0 reconstructed, time-referenced and annotated with ancillary information, 1B : surface radiance spectra & water leaving radiance spectra at TOA. Cloud screened images.

Level 2: *Description* - Swath data. ***Products*** - TOA and Surface Reflectance (%) Spectra.

==

Level 3: *Description* - Swath *and* Gridded data, Terrain corrected products.

Products: Albedo, Land cover classifications, Composites (seasonal, regional and global composites), Spectral indices for vegetation function/health, Spectral indicators for canopy contents (pigments, nitrogen, water, Maps of end-member abundance.

Level 4: *Description* – Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types (e.g., ET, Fire fuel & fuel moisture).

Products – Regional Scale (60m-1km)*: For specific sites, watersheds, geographical units or global samples of ecosystems, but potentially for global maps:* Gross Primary or Ecosystem Production (GPP, GEP); Net Primary or Ecosystem Production (NPP, NEP); Fractional land cover; Fractional vegetation cover (FVC), based on: photosynthetic vegetation (PV) and non-photosynthetic vegetation (NPV), Soil, Water, Snow, Ice; Fractional PAR absorption (*f*APAR); Leaf area index (LAI); Water Content; Plant functional types (PFT); Fractional vegetation cover by PFT(FVC); Light-use efficiency (LUE); Canopy stress and Physiology (combining PFT, LAI, canopy water, nutrients, pigments); Ecological disturbance (>10% change); Susceptibility to fires (fire fuels & fuel moisture, FVC, canopy water); Susceptibility to hazards (e.g., landslides).

Products -Global Scale (gridded, ¼-1 deg+)*: For modeling ecosystems/general cover categories:* GPP, GEP; NPP, NEP; Fractional land cover (Veg., Soil, Water, Snow, Ice); *f*APAR; LAI; Water Content; Disturbance (>10% change).

TIR Multiband Sensor (8 discrete bands)

Level 0: Digital Numbers
Level 1: 1A - Level 0, reconstructed, time-referenced and annotated with ancillary information; 1B – surface band radiances at TOA, Cloud screened images. ***Products*** – Brightness temperature.

Level 2: *Description* - Swath data. ***Products*** – Land Surface Temperature, LST (day or night); Surface Spectral Emissivity (day or night); Detection of fire events.

==

Level 3: *Description* – Day or night swath and gridded data, Terrain corrected, Day or Night Composites (seasonal, regional and global).

Products – Distribution and variation in land surface temperature, surface spectral emissivity maps, Water stress indicators; Fire severity, directions and associated risks.

Level 4: *Description* - Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types.

Products - Regional (60m-1km): *For specific sites, watersheds, geographical units, agricultural fields, or global samples of ecosystems, but potentially for global maps:* LST (from temperature/emissivity separation) by functional groups and ecosystem types, LST urban/sub-urban, Evapotranspiration (ET).

Products - Global (gridded, ¼-1 deg+): *For modeling ecosystems/general cover categories:* LST and emissions by Fractional land cover (Vegetation, Soil, Water, Snow, Ice), ET, Increase in sensible heat due to Urban Heat Islands (anthropogenic heat).

Synergy between TIR Day & Night and VSWIR & TIR

Level 4 Products: Time series, Model outputs, Multi-sensor data fusion, Assimilation with other data types.

TIR, day and night - ***Products - Regional (60m-1km)* & *Global (1-5 deg. grids)*:**

Bi-weekly, monthly and/or seasonal averages for day-night temperature & emissivity differences per geographic study unit (watershed, etc.).

VSWIR and TIR – ***Products - Regional (60m-1km) & Global (1-5 deg. grids)*:**

- Day-night temperature & emissivity differences according to vegetation/ecosystem type,
- LST (from day/night pairs) by functional groups and ecosystem types,
- Water/land boundaries defined,
- Ecosystem & Agricultural Crop Classifications, using both VSWIR & TIR,
- ET per ecosystem or agricultural type, using both VSWIR & TIR,
- Assess fire severity and available fuel by vegetation type,
- Develop spectral Reflectance & Emission libraries by land cover types and/or vegetation functional groups (at regional and global scales),
- Develop *high spectral resolution indicators of ecosystem/crop health,* by combining VSWIR indices and TIR indices; Construct spectral indicators of ecosystem function, disturbance, diversity, maturity to improve modeled predictions.
- Compare high spectral resolution indicators to currently used broadband indicators of ecosystem/crop function.

Expected Outcomes of Symposium

Goal: To Identify and Evaluate Potential Higher Level Products for Climate/Carbon End Users, in Terrestrial Ecosystem & Agriculture Science/Applications.

Objectives/Outcomes:

1] Identify science/application data products that could be derived from HyspIRI measurements ***by users***;

2] Prioritize the development of product prototypes.

3] Discover issues underlying data product processing and related to data integration/fusion.

4] Address the case for relevance of HyspIRI to climate change studies.

5] Develop a report on the community consensus for **1-4** above.

DAY 1 (May 4): Morning Agenda

I. Establish Background

8:30 am: Welcome-- HQ on the HyspIRI mission concept and Decadal Survey status [**Woody Turner**]

8:45 am: Objectives and Outline of the Symposium & Expected Results [**Betsy Middleton**]

8:55 am: Overview of the Mission: Description of the VSWIR and TIR instruments [**Rob Green & Simon Hook**]

9:15 am: Relevance of HyspIRI to Carbon and Climate [**Susan Ustin**]

9:30 am: Orbit & Platform Information, update from Team X [**Bogdan Oaida**]

9:45 am: Description and Examples of Typical VSWIR and TIR Image Collections [**Bob Knox**]

10:00 am: **Questions/Answers** (10 minutes)

10:10 -10:30 am: Coffee Break & Posters

II. Science & Application Products from the User Community: VSWIR & TIR

10:30 am –noon: Proposed VSWIR and TIR High Level Products [7 speakers, 10 min each] [**Phil Townsend, John Gamon, Anatoly Gitelson, Mary Martin, Ben Cheng, Simon Hook, Martha Anderson, Susan Ustin**]

Noon - 1:00 pm: Lunch and Poster Session (Sandwiches/Drinks in conference serving area)

DAY 1 (May 4): Afternoon Agenda

III. Factors Affecting Product Integrity and Availability **1:00 – 2:30 pm (10 min each)**

* Atmospheric Correction [**Rob Green**]
* Data volume/compression, SpaceCube [**Tom Flatley**]
* Intelligent Payload Module (IPM) & algorithms for upload [**Vuong Ly/Dan Mandl**]
* Low-latency Applications, Science, and Operations for HyspIRI [**Steve Chien**]
* On-line tools to facilitate HyspIRI products and analysis [**Petya Campbell**]
* Hyperspectral Input to models [**Fred Huemmrich**]
* Calibration/Validation & CEOS/GEO [**Joanne Nightingale**]
* Impact of Spectral-Spatial Misalignment on Measurement Accuracy [**Steve Ungar**]

IV. Science & Application Products from the User Community: Combined VSWIR & TIR

2:30 -2:50 pm: Combined VSWIR/TIR Products Overview: Issues & Examples [**Betsy Middleton/Bob Knox**]

2:50-3:00 pm: **Questions/Answers** (10 minutes)

3:00-3:20 pm – Coffee Break & Posters

3:20- 4:30 pm: Proposed Combined Products (7 speakers, 10 min each)

[**Rasmus Houborg, Louis Giglio, Dar Roberts, Dale Quattrochi, Ben Cheng, Ray Kokaly, Craig Daughtry**]

The Break-Out Group Discussions

[Topics for consideration]

How important is HyspIRI to the User Community, for TE and climate?

What are the most important Products for Terrestrial Ecology?

What are the Tools needed to produce these Products?

What are the road-blocks to having Products that users want?

DAY 1 (May 4): Afternoon Agenda Con't

V. Special & Potential Observation Capabilities

4:30-4:40 pm: Special Opportunities for Highly Sampled Areas
(orbit overlaps, high latitudes etc.) [**Bob Knox**]

4:40-4:50 pm: Synergy of VSWIR and Lidar for Ecosystem Biodiversity
[**Bruce Cook/Greg Asner**]

VI. Break-Out Discussions (Guidelines, **Betsy)**

4:55 -6:15 pm: Three Simultaneous Break-Out Discussions
(H114, H118, H120)
VSWIR Products [**Phil Townsend/John Gamon**]
TIR Products [**Simon Hook/Kurt Thome**]
Combined Products [**Dar Roberts/Susan Ustin**]

6:20 pm – Adjourn, Dinner at Chevy's Restaurant, Carpools Organized

The Break-Out Group Discussions:

About 30 of the Symposium attendees participated in three discussion groups on these topics related to Higher Level Ecosystem Products:
VSWIR Products, TIR Products, and Combined VSWIR/TIR Products.

The results of those discussions are summarized in the following two charts.

Mature & Ready: *Proposed HyspIRI Terrestrial Ecology Products*

(* = Climate Variable; ** = Essential Climate Variables defined by CEOS/GEO)

(Green text items show significant enhancement over existing multi-spectral observations)

VSWIR Imaging Spectrometer ALONE

Level 4 Biophysical & Physiological Products

1 **Directional Canopy Albedo [**]**
2 Fractional Cover: Snow, Water and Ice [**]
3 Leaf Area Index, LAI [**]
4 Canopy fAPAR (PAR absorbed by vegetation) [**]
5 Canopy fAPARchl (PAR absorbed by chlorophyll-containing canopy only) [*]
6 **Total Canopy Chlorophyll Content [*]**
7 **Fractional Cover: Green Vegetation, Non-Photosynthetic Vegetation, impervious surfaces, soil [*]**
8 **Fractional Cover for Vegetation Classes: Coniferous, Deciduous, and Mixed Forests; Grasslands; Wetlands; Crops [*]**

Multi-Spectral TIR Imagery ALONE

Level 2 & 3 Products [Day or Night swath & gridded data] (Terrain corrected; Day/Night Seasonal Composites)

1 Soil Moisture [**]
2 Fire Severity & Direction & Fire Radiative Power [**]
3 Distribution and variation in land surface temperature [*]
4 Water Stress Indicators [*]
5 Emissivity-Based Land Surface Classification (e.g., pervious vs. impervious) [*]
6 Cloud Mask [*]

VSWIR + TIR Combined

Level 4 Combined Products

1 Biomass for Grasslands [**]
2 Diversity, Coastal Habitats [**]
3 Evapotransporation (ET) by Land Cover Type [*]
4 Functional Types/Species Composition [*]
5 Ecological Disturbance Area (logging, natural disasters, etc.) [*]
6 Drought Index (PET/AET) by Land Cover Type [*]

Proposed Terrestrial Ecology Products from HyspIRI

Potential Products Needing Further Validation (* = Climate Variable; ** = ECV defined by CEOS)

(Green text items show significant enhancement over existing multi-spectral observations)

VSWIR Imaging Spectrometer ALONE

Level 4 Biophysical & Physiological Products

1. **Photosynthetic Parameters (LUE, Jmax, Vcmax) [*]**
2. **Environmental Stress Measurements (response variables) [*]**
3. **Canopy N content (mass/area) [*]**
4. **Canopy Water Content [*]**
5. **Vegetation Pigment Content (Chl a, Chl b, Carotenoids, Anthocyanins)**
6. **Canopy Lignin and Cellulose**

Multi-Spectral TIR Imagery ALONE

L3 Products [Day or Night swath & gridded data]

1. Burn Area (experimental as TIR only)
2. Burn Severity (experimental as TIR only)

VSWIR + TIR Combined

L4 Products – Regional

1. **Surface Energy Flux [**]**
2. **Combusted Biomass [**]**
3. **Sensible Heat due to Urban Heat Islands (Anthropogenic Heat) [*]**
4. **LST: Day/Night Differences for Ecosystems & Urban Areas [*]**
5. **LST Urban/Suburban [*]**
6. **LST by Functional Groups and Ecosystem Types [*]**
7. **Surface Topographic Temperature Mapping [*]**

L4 Products – Global

1. **LST & Emissions by Fractional Land Cover (Vegetation, Soil, Water, Snow, Ice, etc.) [**]**
2. **Ecosystem/Crop Phenology with Fusion Approaches [*]**

AGENDA – DAY 2 (May 5)

8:00 - 8:20 am: Coffee and donuts, Posters

8:30 -8:40 am: Review of Day 1 [**Betsy**]

VII. Related Activities to HyspIRI Mission

8:40 – 9:00 am: 2 Presentations on 2009 Funded HyspIRI Preparatory Studies
[**Petya Campbell, Phil Townsend**]

9:00 – 9:15 am: International collaborations, ISIS & WGCV [**Rob Green**]

9:15 – 9:35 am: A Mission Calibration Plan to support Products
[**Kurt Thome/Rob Green/Simon Hook**]

9:35 – 10:10 am: Synthesis of the Three Break-out Group Inputs (10 min each)
[**Phil/John, Simon/Kurt, Dar/Susan**]

10:10 -10:30 am: Coffee Break & Posters

Assessment of ecosystem diversity and urban boundaries:

Combining surface reflectance and emissivity

Petya K. E. Campbell*, ** and Kurtis J. Thome**

* Joint Center for Earth Systems Technology (JCET), University of Maryland Baltimore County
** NASA Goddard Space Flight Center

Project Collaborators

- *Dr. Nicholas Coops (UBC, Vancouver, CA)*
- *Dr. Nona R. Chiariello (Stanford University, CA)*
- *Professor Goodenough (CFS Victoria, BC)*
- *Dr. Tony Trofymow (CFB Esquimalt, BC)*
- *Dr. Elizabeth Middleton (NASA/GSFC)*

The project will also provide research experience for graduate and undergraduate students. They will participate through established programs with GSFC, UMBC and FIU, Miami, providing support to process and organize data, and assisting with preparation of reports.

Background

Problem: With the increase in the population density and the ever expanding conversion of land from rural to urban, the urban heat island (UHI) effect has become a problem of critical importance. *Land cover type and land surface temperature (LST) in urban and rural areas display significant differences, such as higher LST and lower moisture content, with increasing urbanization.*

Hypotheses: The distribution, and spectral and spatial characteristics of optical and thermal data co-vary, in significantly different way in natural and anthropogenic environments; The combination of high spectral resolution optical and thermal infrared imagery will provide a powerful capability for more precise land cover type discrimination and ecosystem monitoring than possible using current satellite systems.

Science Questions

- How do natural and anthropogenic ecosystem compositions compare with regard to land cover types, diversity, function, and spectral properties?
- How do environmental characteristics, associated with natural factors and effects of urban pressure and UHI, affect vegetation composition and function, and ecosystem health?
- How do species, functional type, and ecosystems biodiversity composition differ spectrally, in relation to gradients of anthropogenic and non-anthropogenic stressors?
- How do natural ecosystems respond to impinging environmental changes, particularly to urban growth and land cover change and the associated impacts of urbanization?

Goals

1. Using together VSWIR and TIR measurements, to assess the differences in natural and anthropogenic ecosystem composition and their vegetation bio-physical parameters.

2. Provide data that can elucidate how urbanization impacts the environment. Seeking common spectral trends associated with vegetation function, induced by natural and anthropogenic factors such as effects of urbanization and UHI, we would contribute toward improving the current capabilities for vegetation assessments.

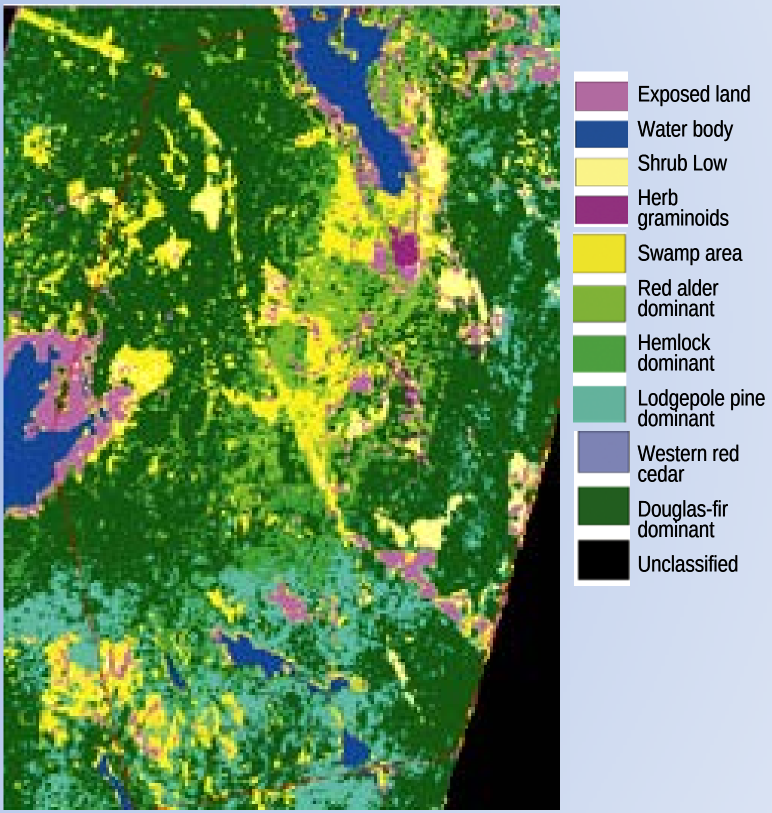
3. Generate HyspIRI-like datasets and tools for work with the data.

Study Sites

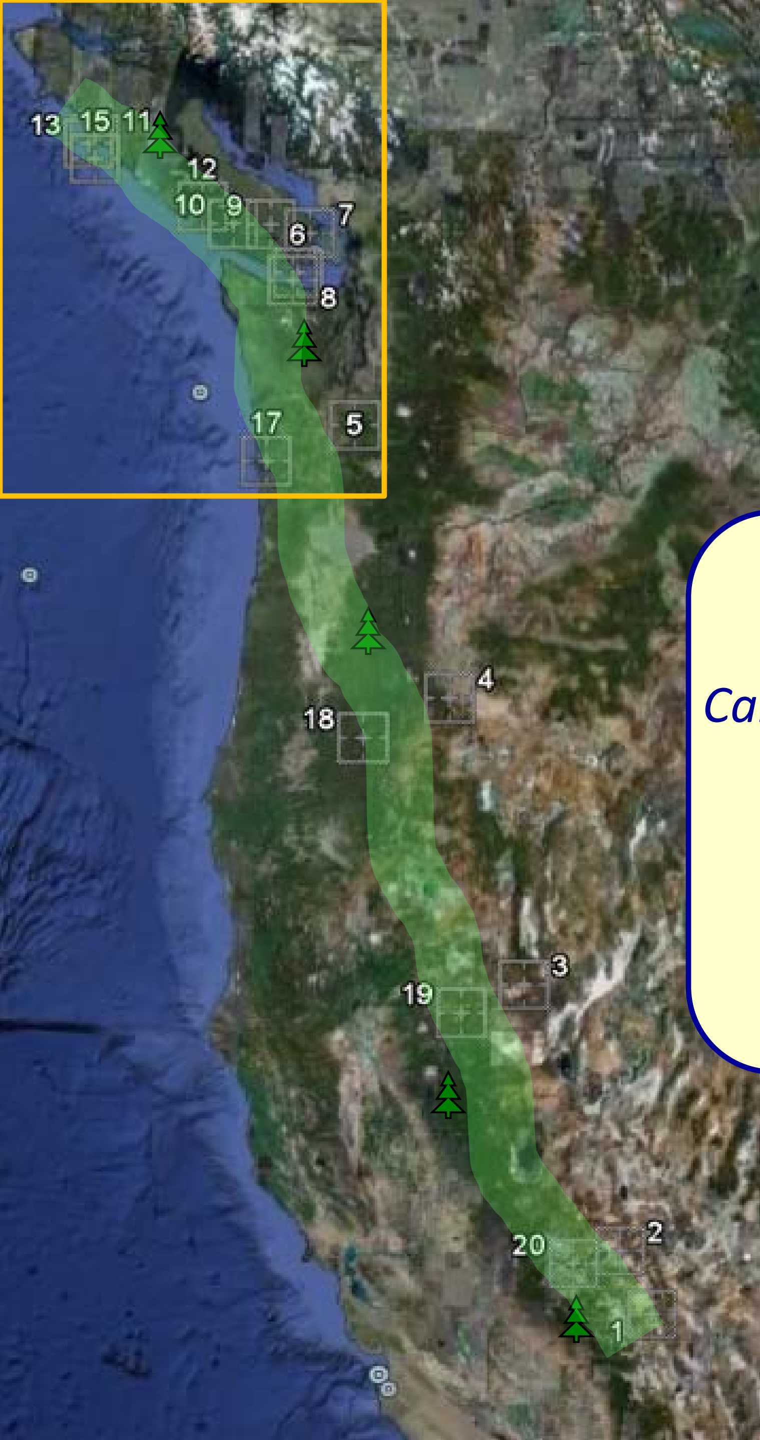
The study includes two independent locations with different regional climate and ecosystem types. Data aggregated to higher and lower spatial scales will be compared for the same locations.

Vancouver Island, Canada/Hoquiam, WA: includes portions of unique natural ecosystems such as the Olympic National Park, WA and the Great Victoria Watershed (GVWD) test site on Vancouver Island, BC and rural, sub-urban and urban environment associated with the city of Victoria, BC.

Jasper Ridge Biological Preserve (JRBP), CA: provides Mediterranean-type climate, with five major vegetation types: evergreen forest, deciduous forest, chaparral shrublands, herbaceous perennial wetlands, and annual grasslands



Hyperion land cover classification of the Greater Victoria Watershed (GVWD) test site on Vancouver Island (September 10 2001, Goodenough et al. 2003).



Area 1:

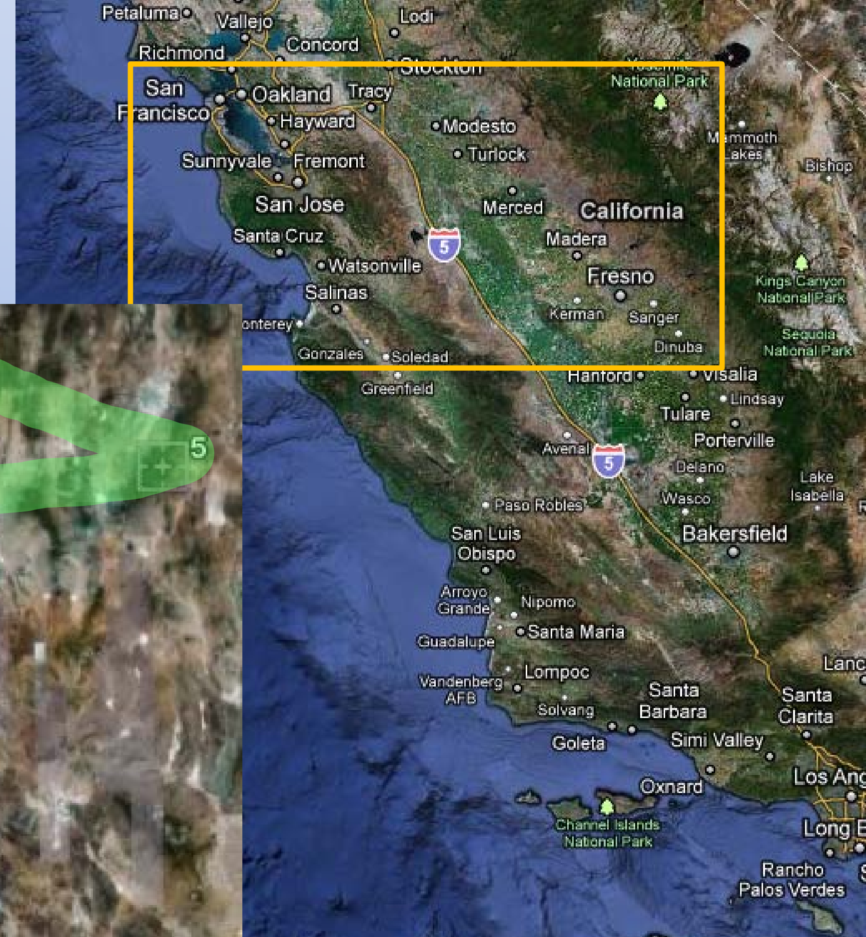
Vancouver Island
Canada/Hoquiam, WA

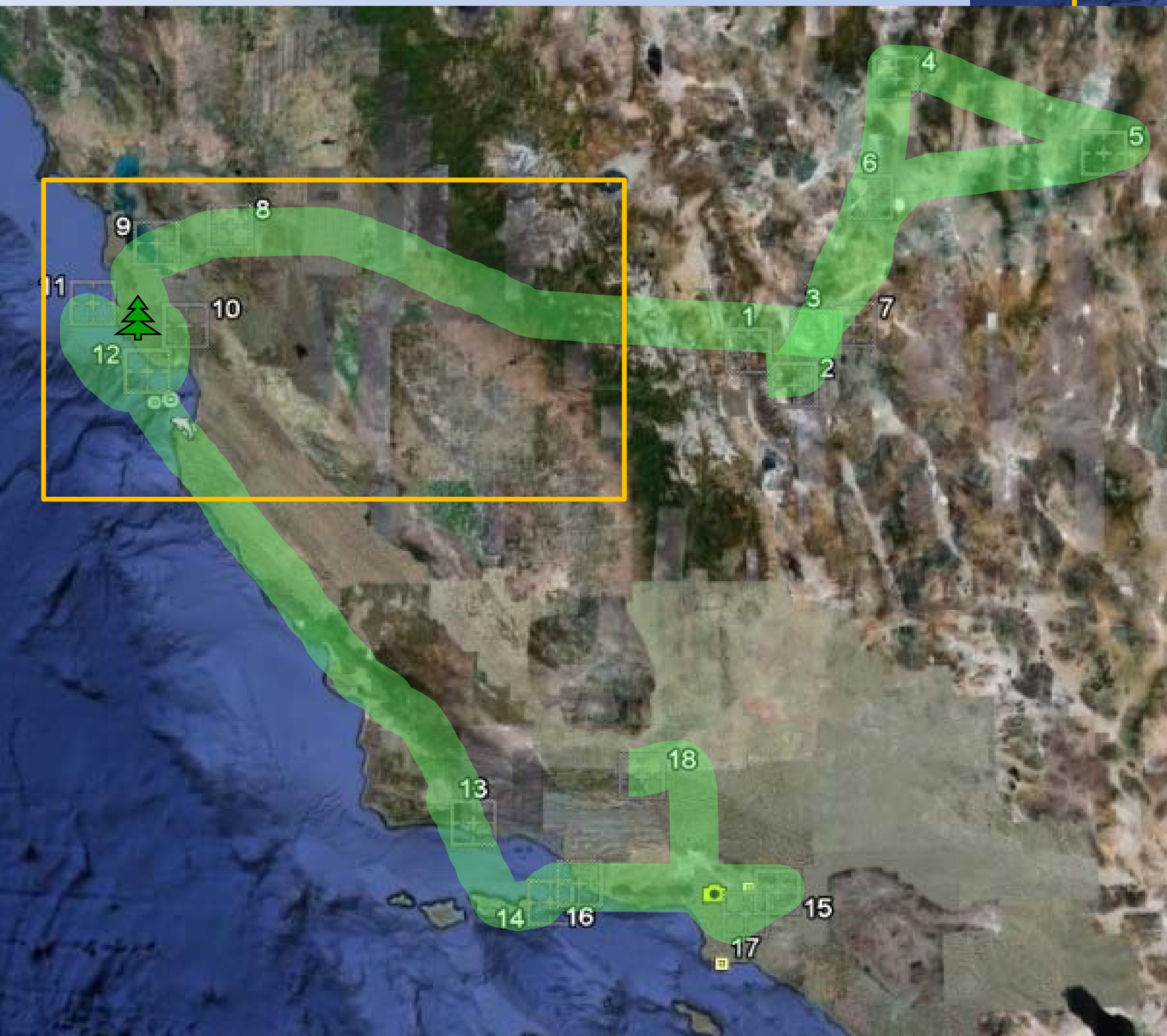
Data:

MASTER & AVIRIS
ASTER
EO-1 Hyperion

Area 2:

Jasper Ridge Biological Preserve (JRBP), CA





Data:

MASTER & AVIRIS

Calibration of TIR and VISWIR data

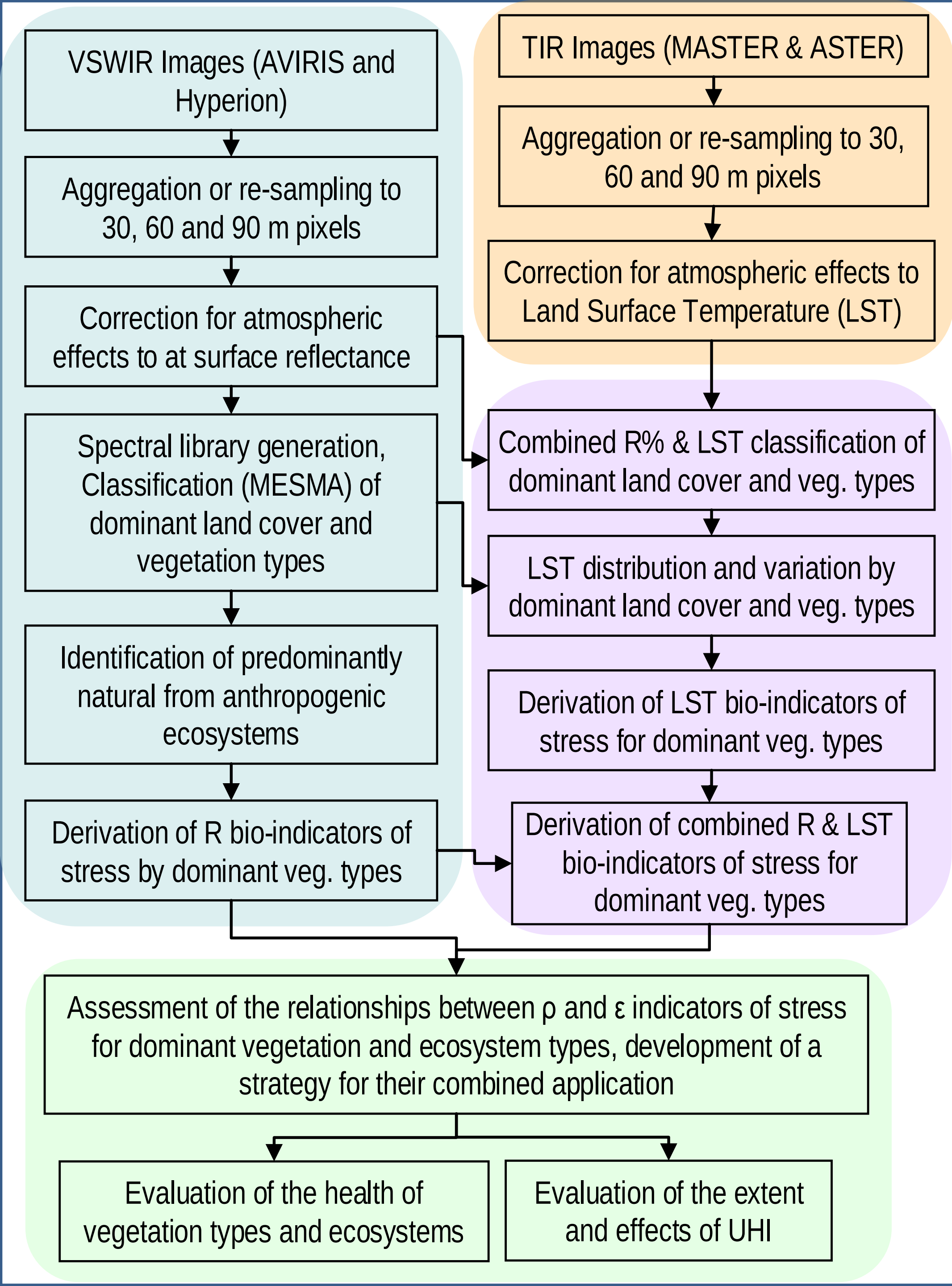
[*Lake Tahoe*] is a high-altitude, large-sized lake on the California-Nevada border near Reno, Nevada.

The [*Ivanpah Playa*] test site is approximately 3 km by 7 km in size with excellent spatial uniformity, hence its use for the vicarious calibration of reflective bands.

Sample MASTER imagery from the Ivanpah test site, reflectance (left), vegetation in green; thermal (right) side.

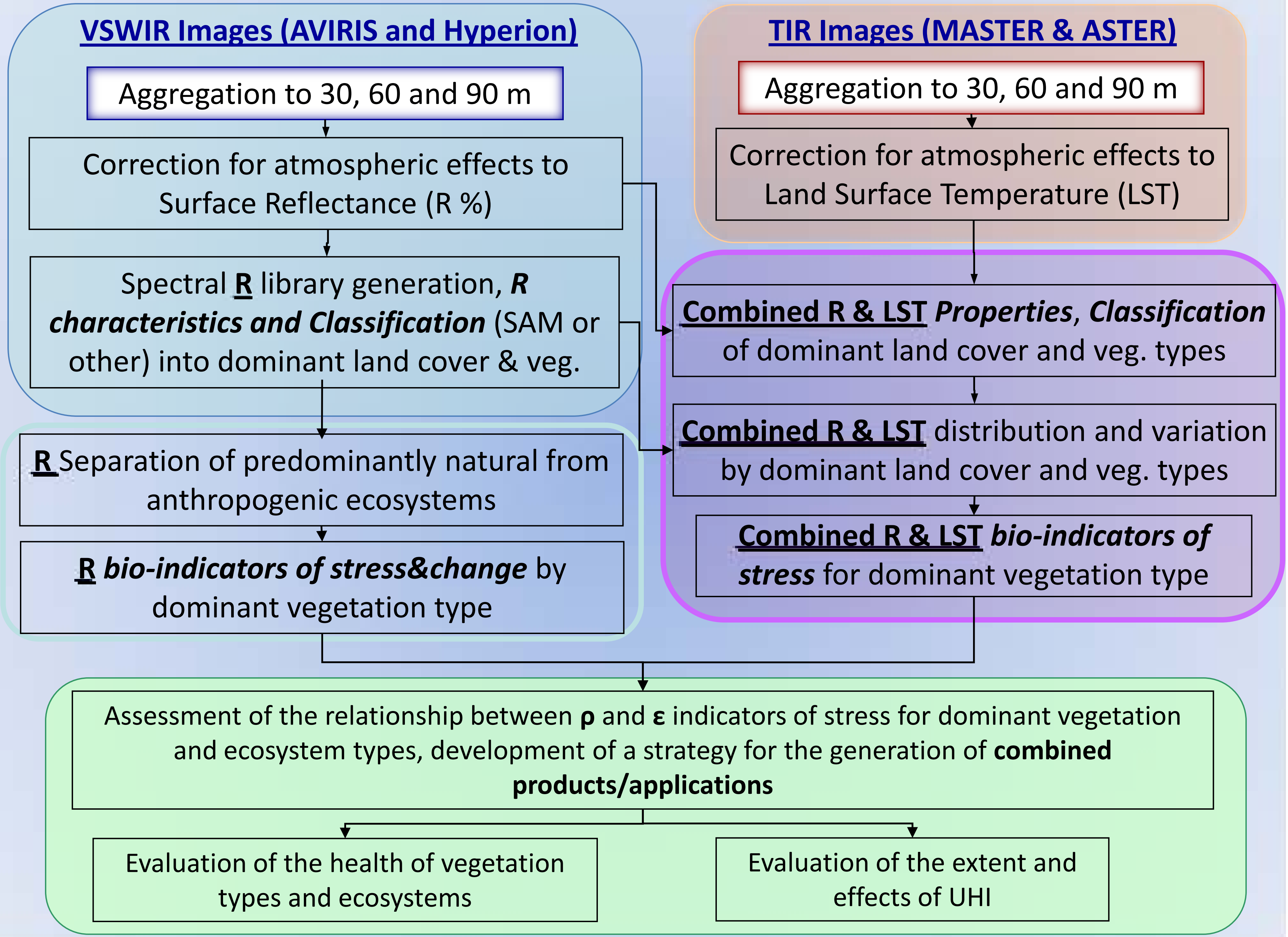
Data

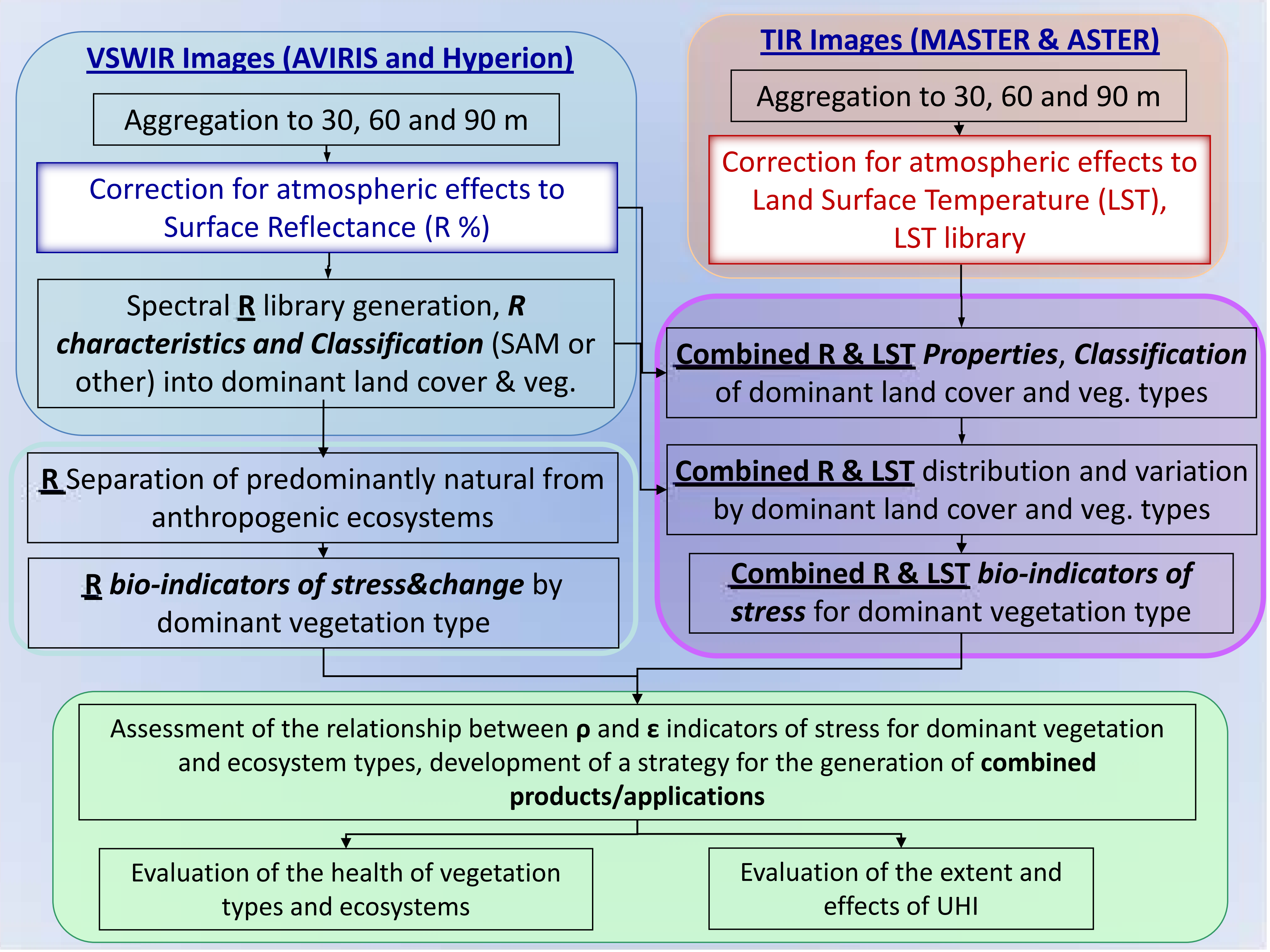
Parameters	*HyspIRI VSWIR*	AVIRIS	EO-1 Hyperion
Spectral range	*0.38 - 2.5 µm*	0.4 - 2.5 µm	0.4 - 2.5 µm
Band width	*10 nm*	10 nm	10 nm
number of bands	*~ 220*	224	220 (196 calibrated)
Spectral Coverage	*contiguous*	contiguous	contiguous
Spatial resolution	*60 m*	20 m	30 m
Swath width	*145 km*	11 km	7 km
Thermal infrared emission instruments and data characteristics (summary/overview)			
HyspIRI TIR	**Number of bands**	**Spectral bands (discrete)**	**Spatial resolution**
TIR channel centers	*8*	*3.98, 7.35, 8.28, 8.63, 9.07, 10.53, 11.33, 12.05 µm*	*60 m*
Swath width	*600 km*		
ASTER	**Number of bands**	**Spectral bands (discrete)**	**Spatial resolution**
Spectral range 0.5 - 12 µm	14		vary
VNIR channel centers	4	0.54, 0.66, 0.81, 1.65 µm	15 m
SWIR channel centers	5	2.17, 2.21, 2.26, 2.33, 2.40 µm	30 m
TIR channel centers	5	8.30, 8.65, 9.10, 10.60, 11.30 µm	90 m
Swath width	60 km		
MASTER	**Number of bands**	**Spectral bands (discrete)**	**Spatial resolution**
Spectral range 0.4 - 13 µm	50		5-25 m (B200) 10-30 m (DC-8) 50 m (ER-2)
0.45-2.39 µm	25	0.05 µm a part	
3.15-5.27 µm	15	0.15 µm a part	
7.75-12.87 µm	10	0.40-0.80 µm a part	
Total field of view	85.92°		



Capability of HyspIRI data for assessments of vegetation type and function

The analysis will be conducted using the native data resolution (~ 30 m), and aggregated to 60 and 90 m images, comparing the results.


VSWIR Images (AVIRIS and Hyperion)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Surface Reflectance (R %)
Spectral R library generation, R characteristics and Classification (SAM or other) into dominant land cover & veg.
R Separation of predominantly natural from anthropogenic ecosystems
R bio-indicators of stress&change by dominant vegetation type
TIR Images (MASTER & ASTER)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Land Surface Temperature (LST)
Combined R & LST Properties, Classification of dominant land cover and veg. types
Combined R & LST distribution and variation by dominant land cover and veg. types
Combined R & LST bio-indicators of stress for dominant vegetation type
Assessment of the relationship between ρ and ε indicators of stress for dominant vegetation and ecosystem types, development of a strategy for the generation of combined products/applications
Evaluation of the health of vegetation types and ecosystems
Evaluation of the extent and effects of UHI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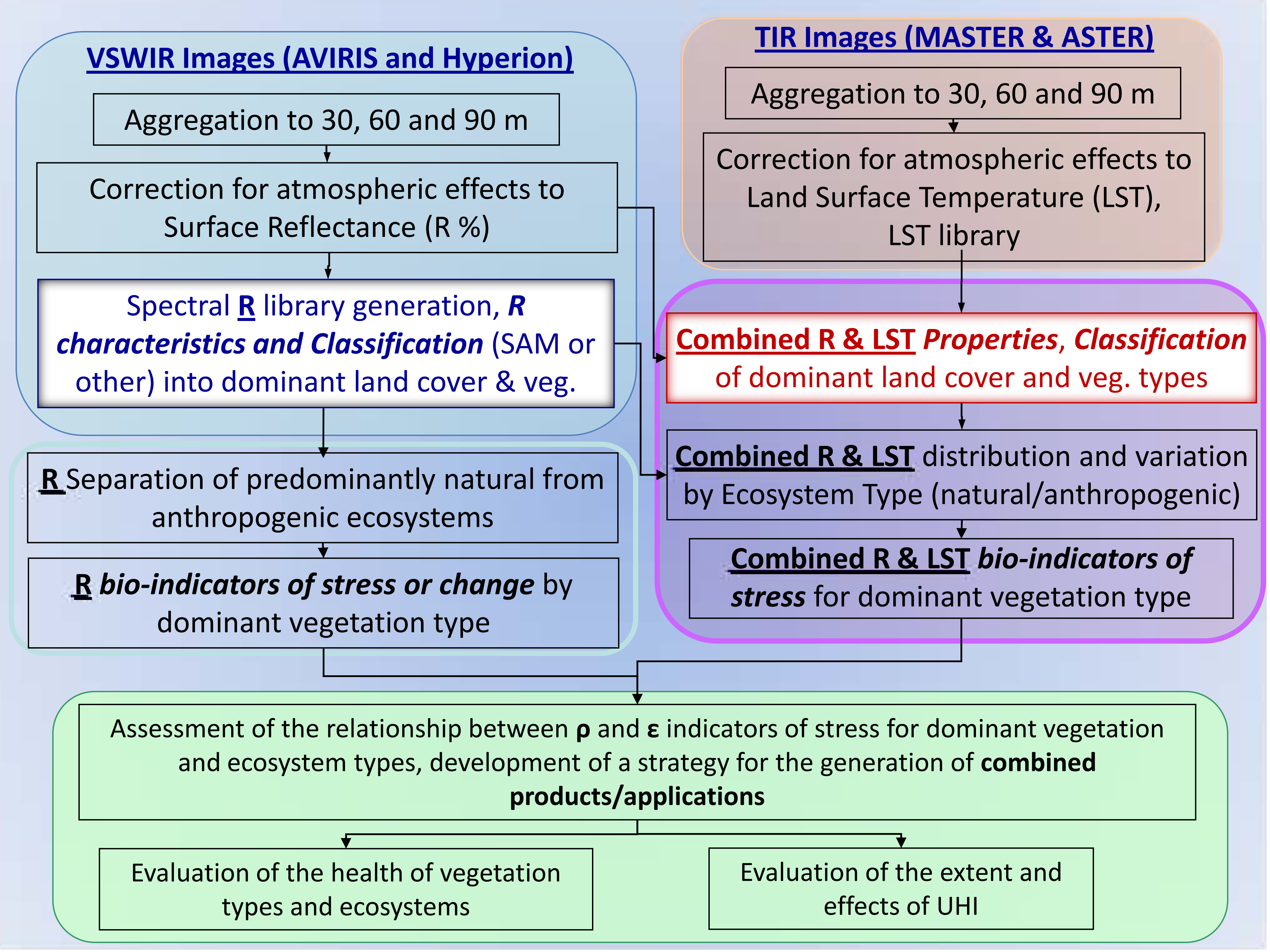
R Separation of predominantly natural from anthropogenic ecosystems
R bio-indicators of stress&change by dominant vegetation type
TIR Images (MASTER & ASTER)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Land Surface Temperature (LST), LST library
Combined R & LST Properties, Classification of dominant land cover and veg. types
Combined R & LST distribution and variation by dominant land cover and veg. types
Combined R & LST bio-indicators of stress for dominant vegetation type
Assessment of the relationship between ρ and ε indicators of stress for dominant vegetation and ecosystem types, development of a strategy for the generation of combined products/applications
Evaluation of the health of vegetation types and ecosystems
Evaluation of the extent and effects of UHI


VSWIR Images (AVIRIS and Hyperion)
Aggregation to 30, 60 and 90 m
Correction for atmospheric effects to Surface Reflectance (R %)
Spectral R library generation, R characteristics and Classification (SAM or other) into dominant land cover & veg.
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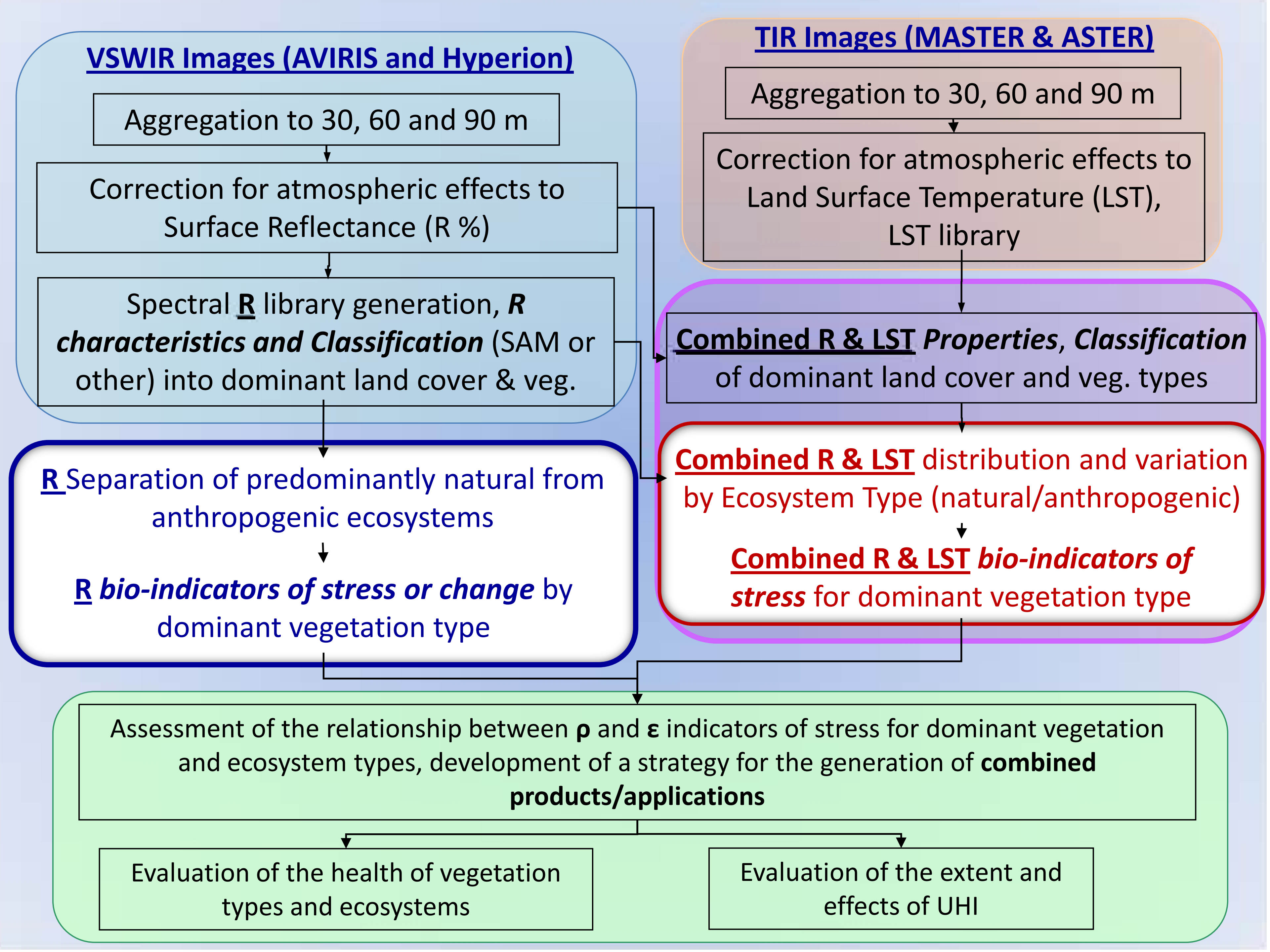
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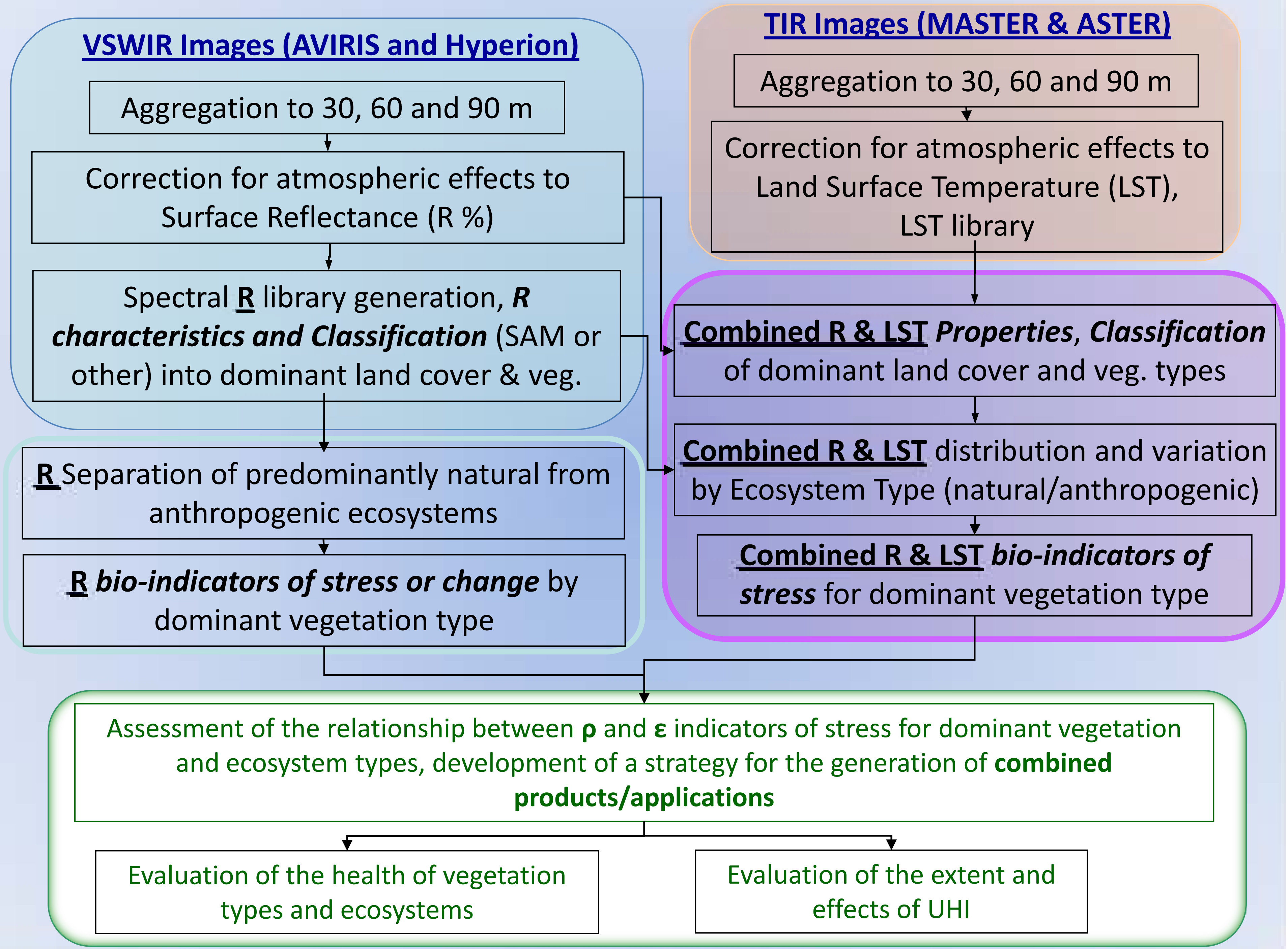
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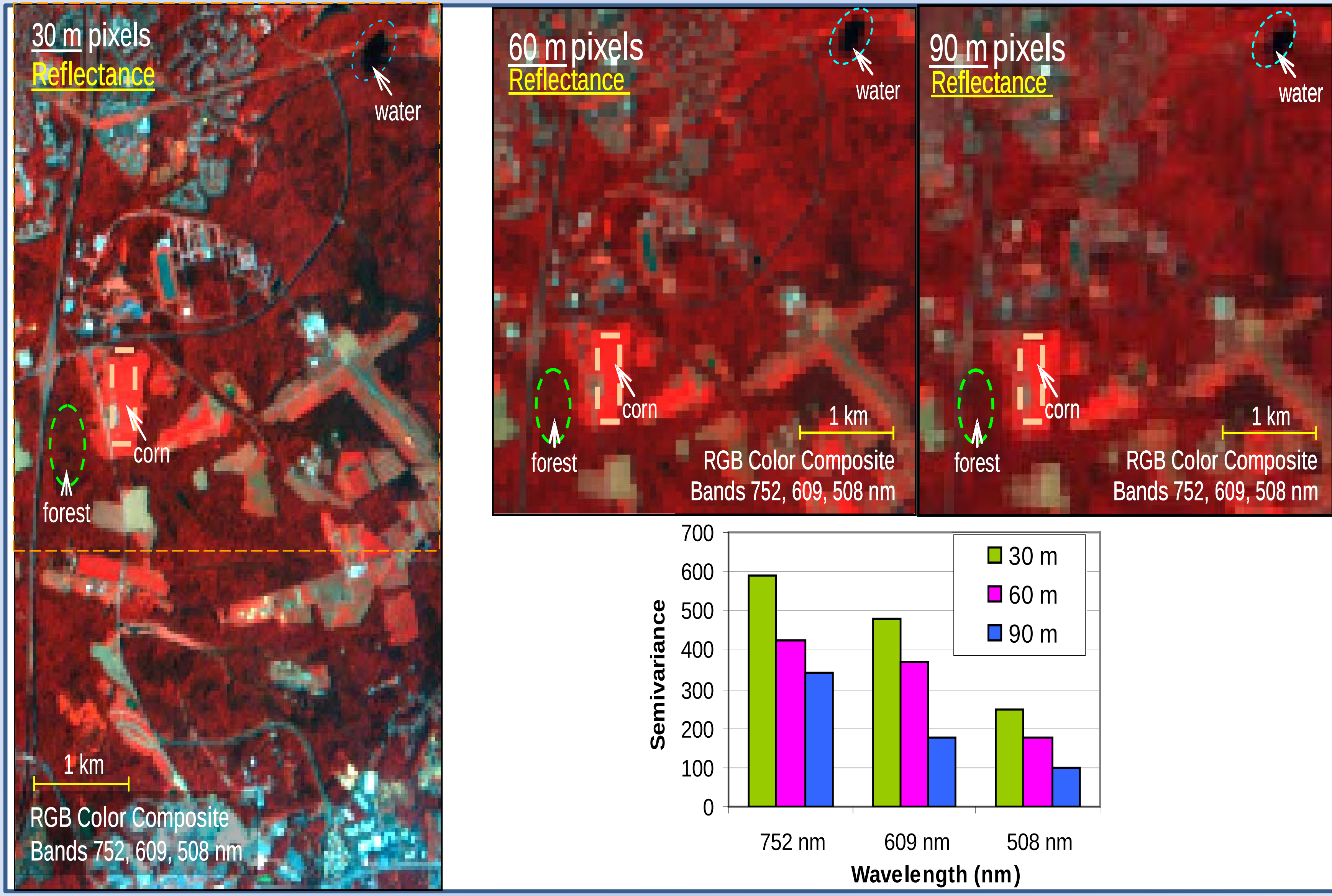
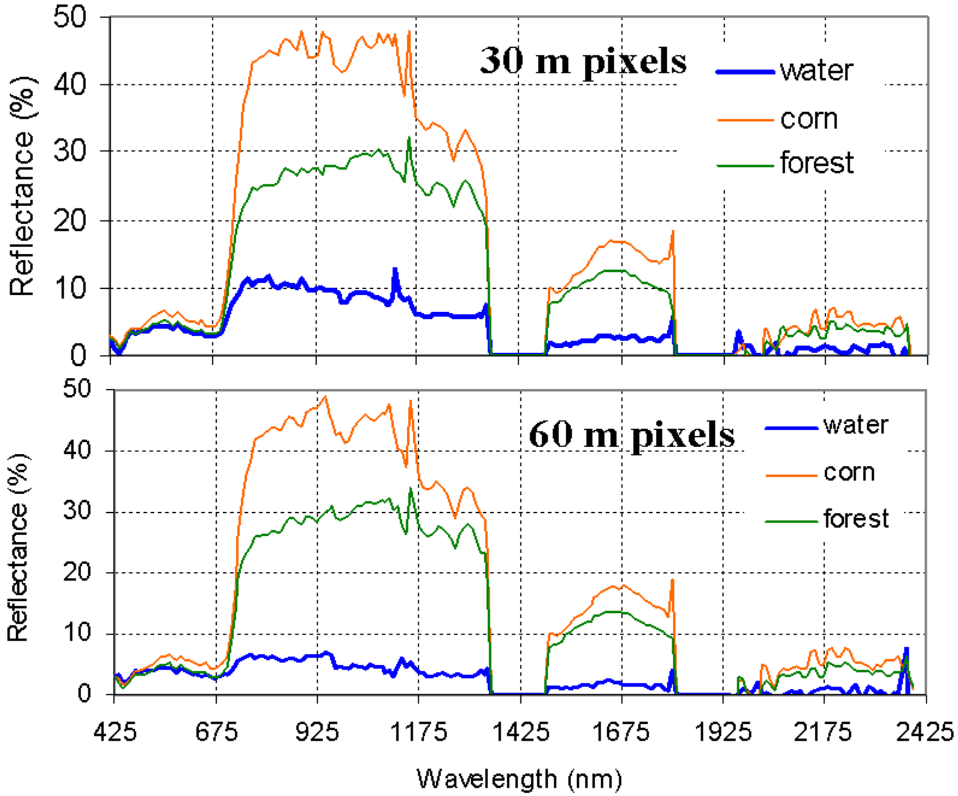
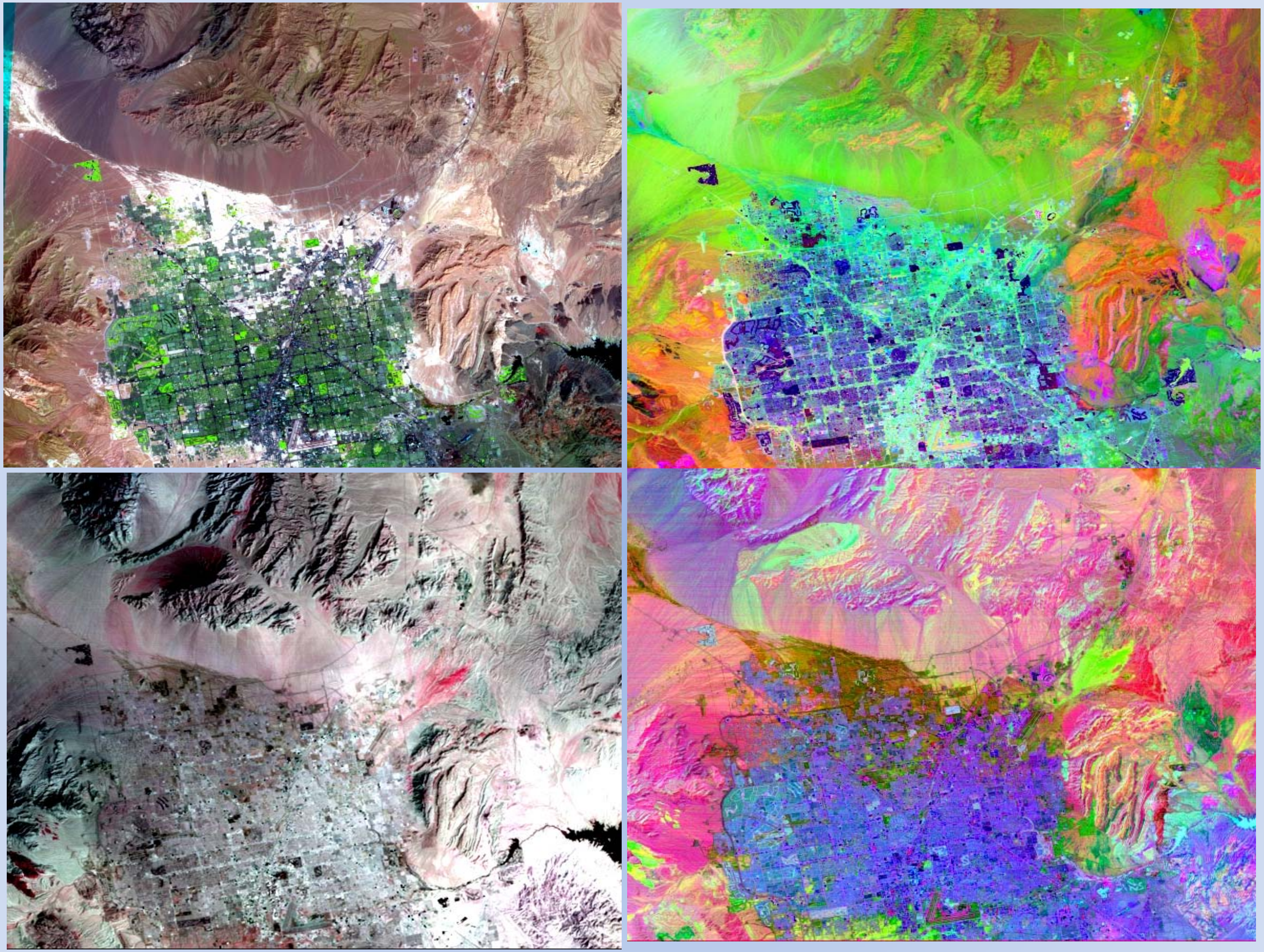


Examples of Hyperion reflectance image (30 m pixels) and the re-sampled to 60 and 90 m subset, demonstrate the spatial differences between HyspIRI-like data (60 m) and 30 and 90 m data.



Pixel	Vegetation Indices:						Albedo		
size	V1	PRI	REIP	Dmax	NDWI	NDVI	water	corn	forest
30 m	1.81	-0.14	721	0.749	0.14	0.81	0.03	0.20	0.14
60 m	1.88	-0.15	721	0.748	0.15	0.82	0.04	0.20	0.13

While there were significant differences in the spatial variability between the original 30 m and the aggregated to 60 and 90 m data, the spectral properties of the major land cover types did not significantly differ.



ASTER imagery, Las Vegas area: VSWIR aggregated to 90 m (upper left, vegetation in green) and TIR bands (lower left), principle components of reflective bands (upper right) and all VSWIR and TIR (lower right).

Bio-physical parameter	Spectral bio-indicators *(examples)*	References
VSWIR indicators		
Chlorophyll in crops	$(R_{NIR}/ R^{-1}_{720\text{-}730}) - 1$	Gitelson et al., 2005
Canopy greenness	$EVI = G * \frac{R_{NIR} - R_{red}}{R_{NIR} + C_1 R_{red} - C_2 R_{blue} + L}$	Huete et al. 2002
Chlorophyll concentration estimation	$TCARI / OSAVI = \frac{3*[(R_{700} - R_{670}) - 0.2*(R_{700} - R_{550})*(R_{700} / R_{670})]}{(1+0.16)*(R_{800} - R_{700})/(R_{800} + R_{670} + 0.16)}$	Haboudane et al. 2002, Zarco-Tejada et al. 2004
Efficiency of photosynthesis	PRI=(R570-R531)/(R570+R531)	Gamon et al., 1992, Suarez et al. 2008
Canopy foliar water content	$NDWI = \frac{R_{NIR} - R_{1240}}{R_{NIR} + R_{1240}}$	Gao, 1996
Canopy foliar water content	$SIWI = \frac{R_{NIR} - R_{1640}}{R_{NIR} + R_{1640}}$	Fensholt and Sandholt, 2003
Vegetation stress	Average (R675…. R705)	Vogelman, 1993
Veg. structure and foliar biomass	NDVI = (R800-R670)/(R800+R670)	Deering, 1978
Stress/Chlorophyll	D714/D705, where D is product of first derivative transformation of R	Entcheva, 2004
Stress/ Chlorophyll	Dmax/D705, where Dmax is the maximum of D in the 670-730nm region	Entcheva, 2004

Bio-physical parameter	Spectral bio-indicators *(examples)*	References
<u>TIR indicators</u>		
Water stress (100% vegetative cover)	CWSI = (ΔTcanopy – ΔTnws)/(ΔTmax – ΔTnws), where Tmax for non-transpiring and Tnws is “non-water-stressed” baseline temperature. 0 = no stress, 1 = maximal stress, Δ = (Tsurface - Tair)	Idso et al. 1981, Jackson, 1981
Irrigated vs. non-irrigated (100% veg.)	IG = (Tmax – Tcanopy)/(Tcanopy – Tnws),	Jones 1999
Increase in sensible heat due to UHI	Rn = G + LE + H, Rn + A = G + LE + H; where Rn is net radiation, G ground heat, LE latent heat, H sensible heat, A anthropogenic heat	Kato and Yamaguchi, 2005
<u>Combined VSWIR & TIR indicators</u>		
Relative water status (Veg. cover < 100%)	WDI trapezoid, defined by the fractional vegetation cover and Δ = (surface - air temperature); 0.0 well-watered (latent heat flux is limited only by atmospheric demand), 1.0 no available water	Moran et al. 1994
Water supply	WSVI=NDVI/Ts, where Ts is the brightness temperature at ~11 µm, the smaller this index is, the more severe the drought is	Hatfield et al. 2008
Temperature–vegetation dryness index	TVDI = (*T*s – *T*s_min)/(*a* + *b*NDVI – *T*s_min), where *T*s_min is the minimum temperature in the triangle; and *a* and *b* are the interception and slope of the dry edge, respectively	Wand et al. 2004
After WSVI and TDVI	Like WSVI and TVDI, but using VSWIR parameters sensitive to water stress, such as NDWI or SIWI.	New, to test

Deliverables and Milestones

- Best estimates of atmospheric properties needed to atmospherically correct the two HyspIRI-like data sets;
- Radiometric calibration coefficients for the sensors used to create the HyspIRI-like data sets;
- Algorithm to spatially convolve the airborne or spaceborne imager data sets to 30, 60, and 90 m spatial resolution;
- Classifications of HyspIRI-like data for a broad range of natural and anthropogenic ecosystems and vegetation functional types;
- Development of HyspIRI-like spectral bio-indicators of ecosystem health; and
- Presentation materials for the HyspIRI workshop and final report delivered one month prior to the completion of the project.

Expected Results

- Through the combined use of reflective and emissive data, the proposed work will evaluate the suitability of HyspIRI for delineating ecosystem functional types and tracking the conversion of land from rural to urban.
- The research will produce two HyspIRI-like data sets combining reflectance and thermal data, which will be used to assess the potential of HyspIRI data for delineating land cover and vegetation types, discriminating natural versus urban ecosystems, and assessing ecosystems diversity and health.
- In addition, the work will produce methods and tools for work with the HyspIRI data.

Thank You

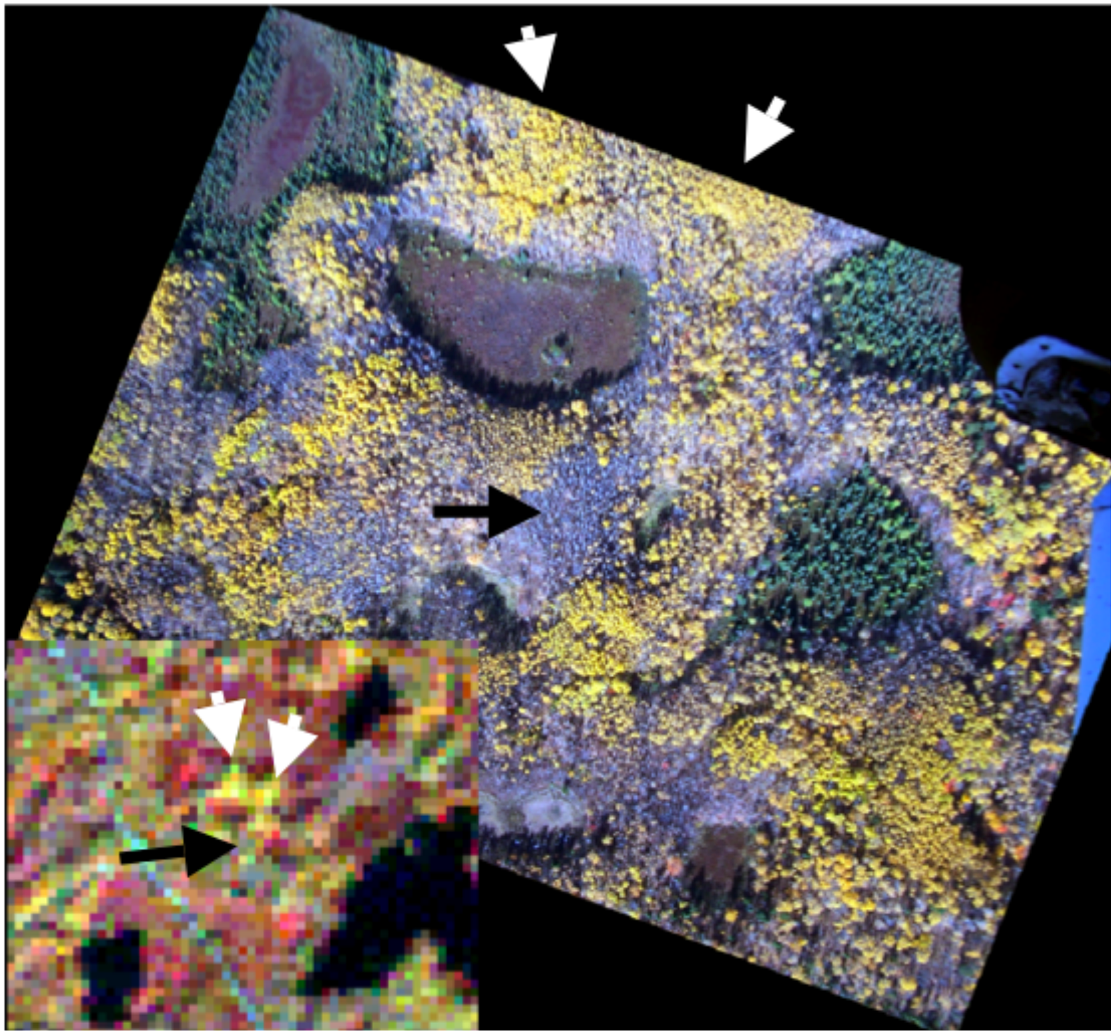
HyspIRI Research: Photosynthesis and Genetics of Aspen

Phil Townsend, Shawn Serbin, Dylan Dillaway, Eric Kruger, Mike Madritch

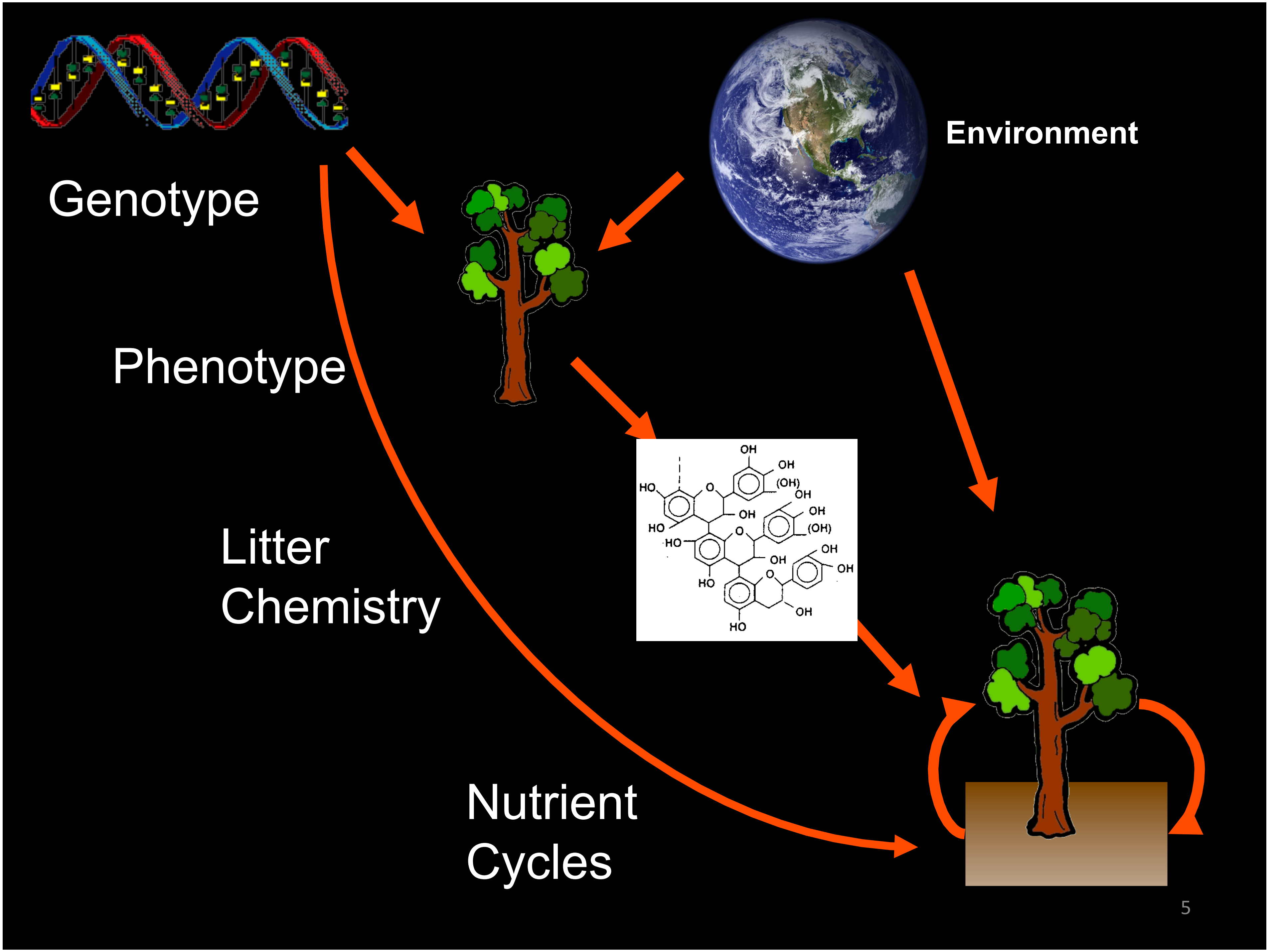
Quaking aspen (*Populus tremuloides*) as a model system

- Most widely distributed native tree species in North America
- Important timber species
- Early-successional
- Large, monospecific stands of genetic clones
- Genetically diverse
- Wide phenotypic variation

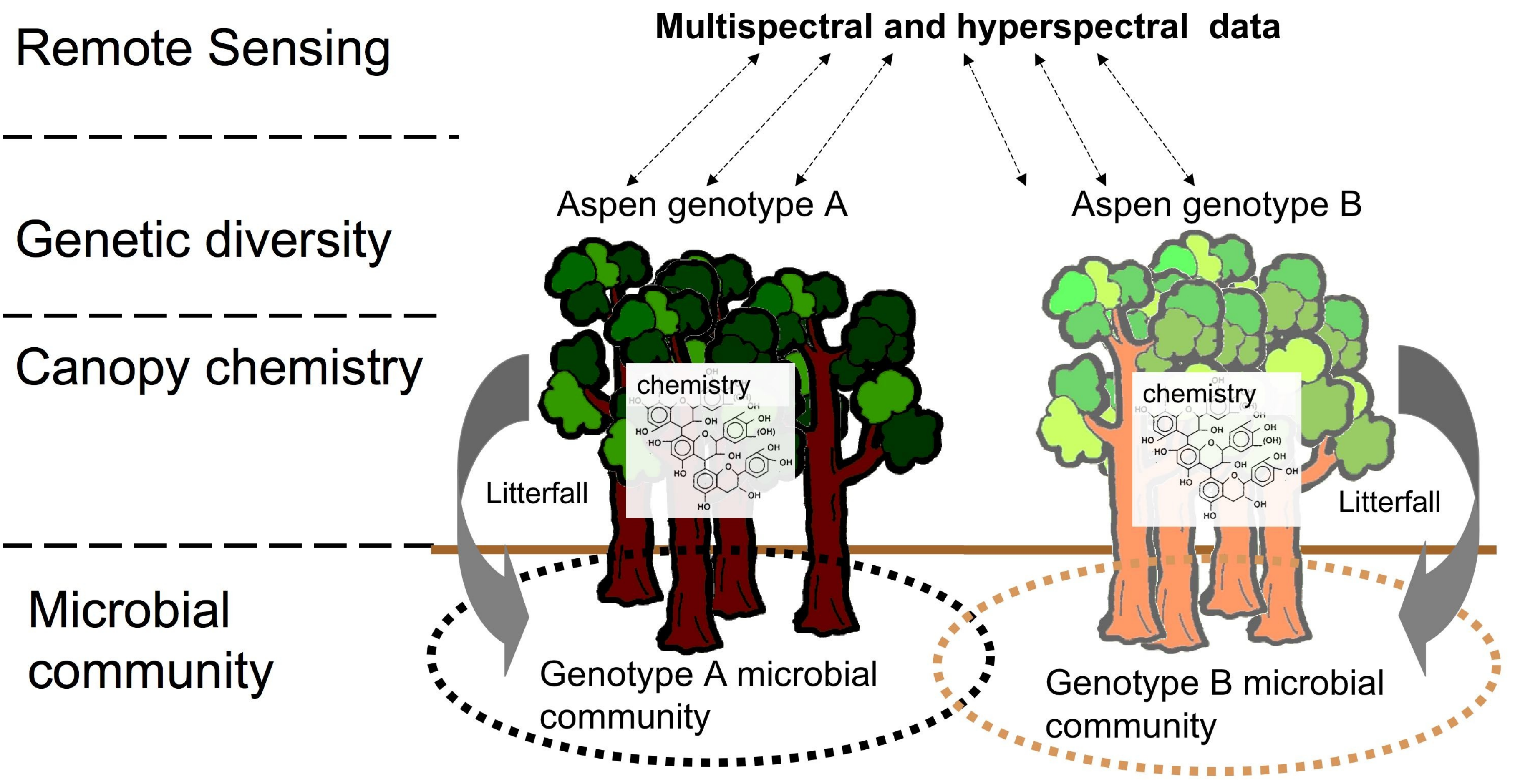
Remote sensing of genetic diversity in aspen



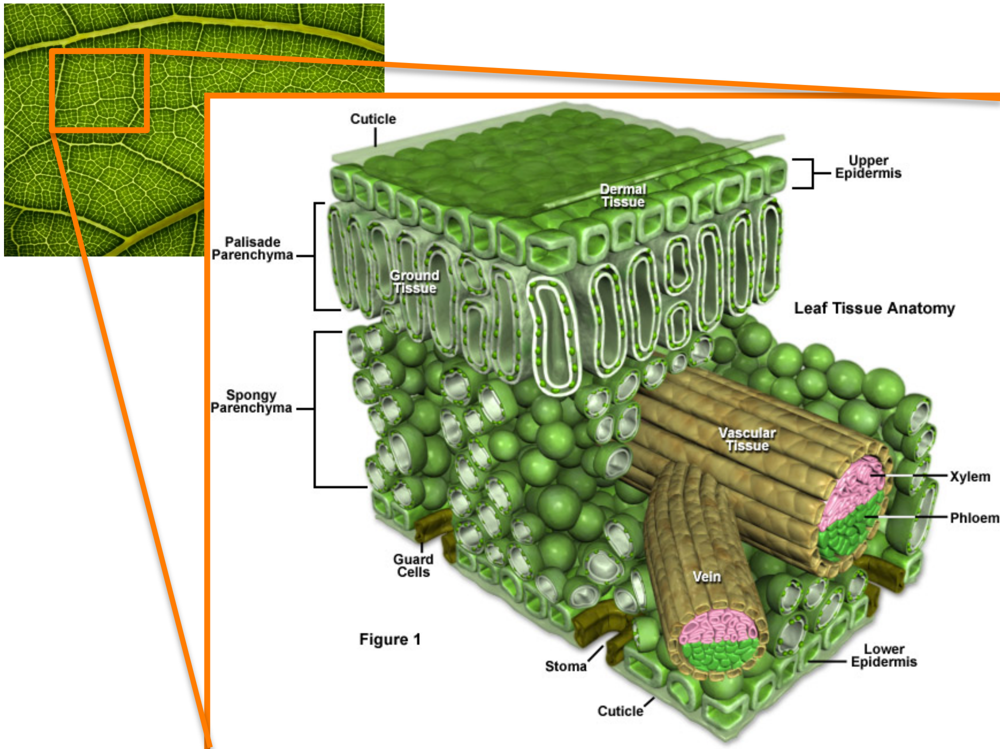
Early October Landsat and true color aerial photo
Differing senescence among genotypes

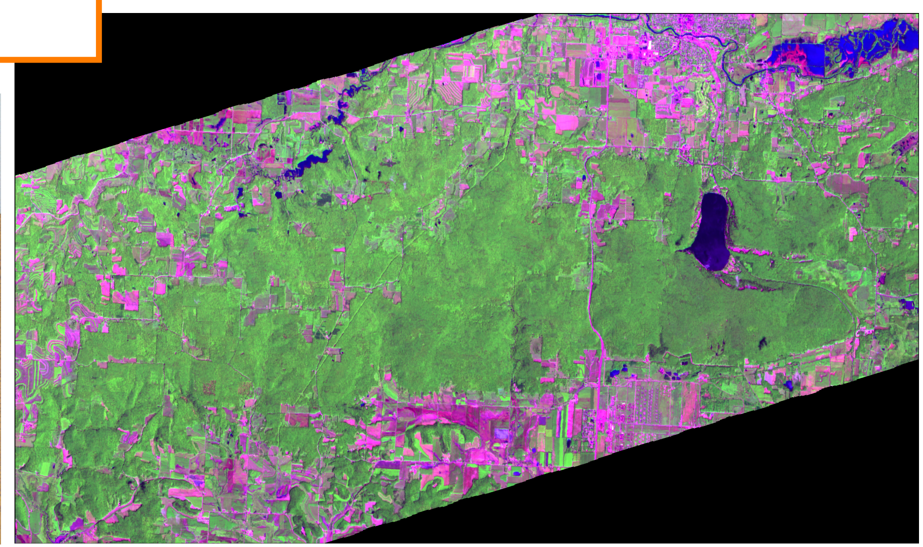

Environment
Genotype
Phenotype
Litter
Chemistry
Nutrient
Cycles

Remote sensing of genetic diversity in aspen

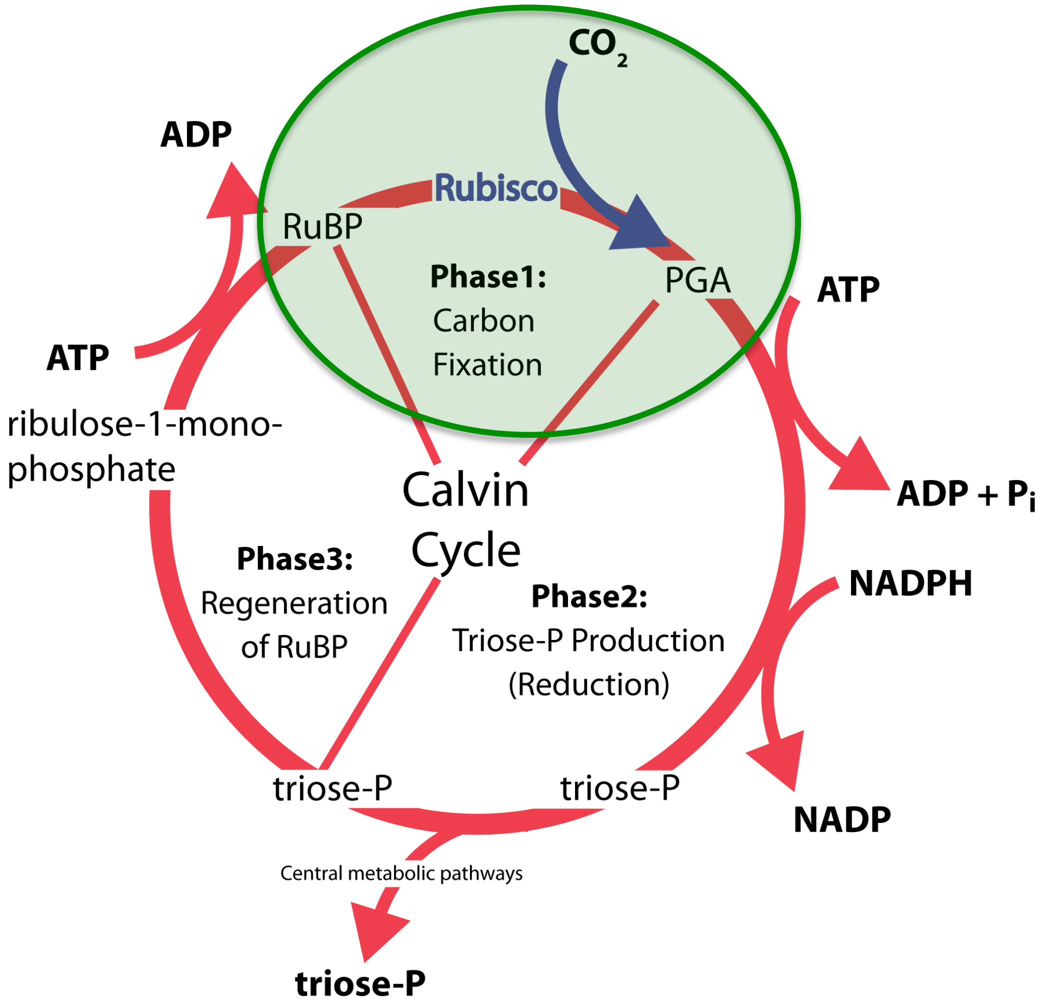


Detection of leaf metabolic rates using spectroscopy





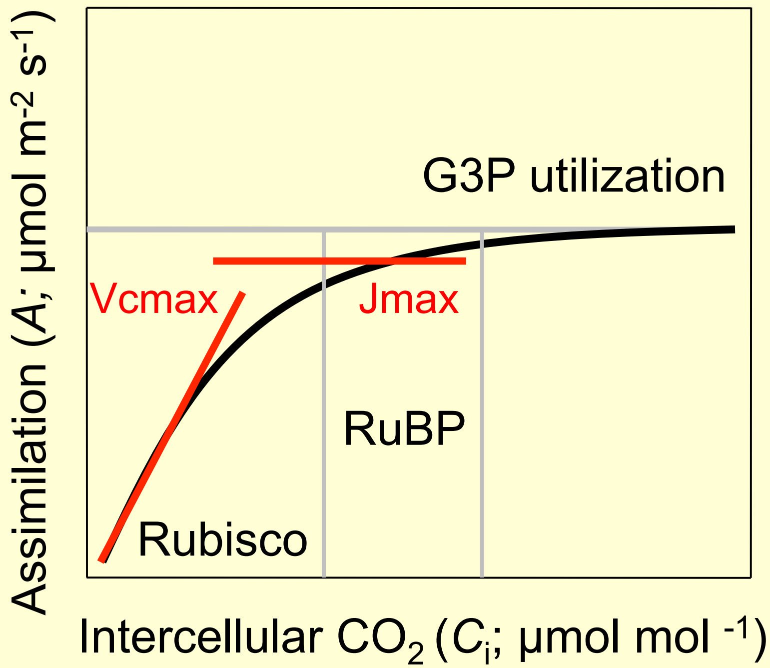
V(c)max – maximum rate of carboxylation



Carboxylation – initial addition of CO_2 to RuBP (catalyzed by RuBisCO). Energy from ATP and NADPH → triose phosphate

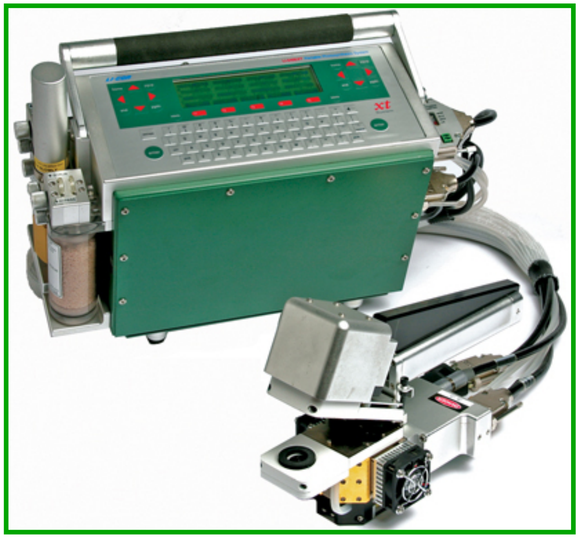
Biochemical modeling of photosynthesis

$$A_n = \min(A_c, A_j, A_p) - R_d$$



- Limited by
  - Rubisco
  - RuBP regeneration
  - triose phosphate utilization (G3P)
- Determine key metabolic variables
  - **Vcmax**: Rubisco activity
  - **Jmax**: Electron transport

Physiological data in glasshouse study

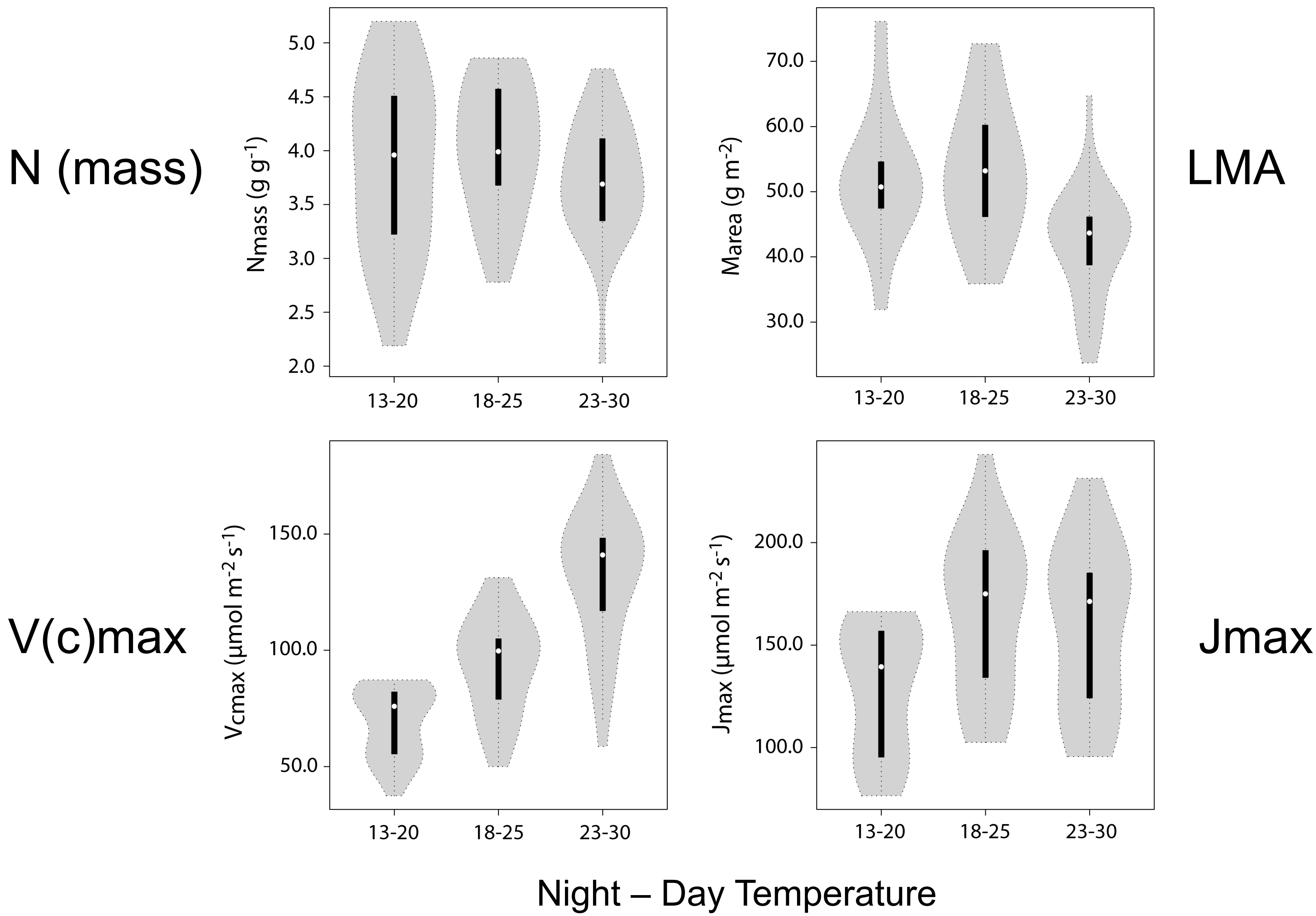


- Three temperature regimes
  - 13/20 °C, 18/25 °C, 23/30 °C
- Leaf gas exchange
  - Vcmax, Jmax, A_{mass}, A_{area}
- Structure and chemistry
  - SLA, Leaf N
- Leaf optical properties (350-2500 nm)

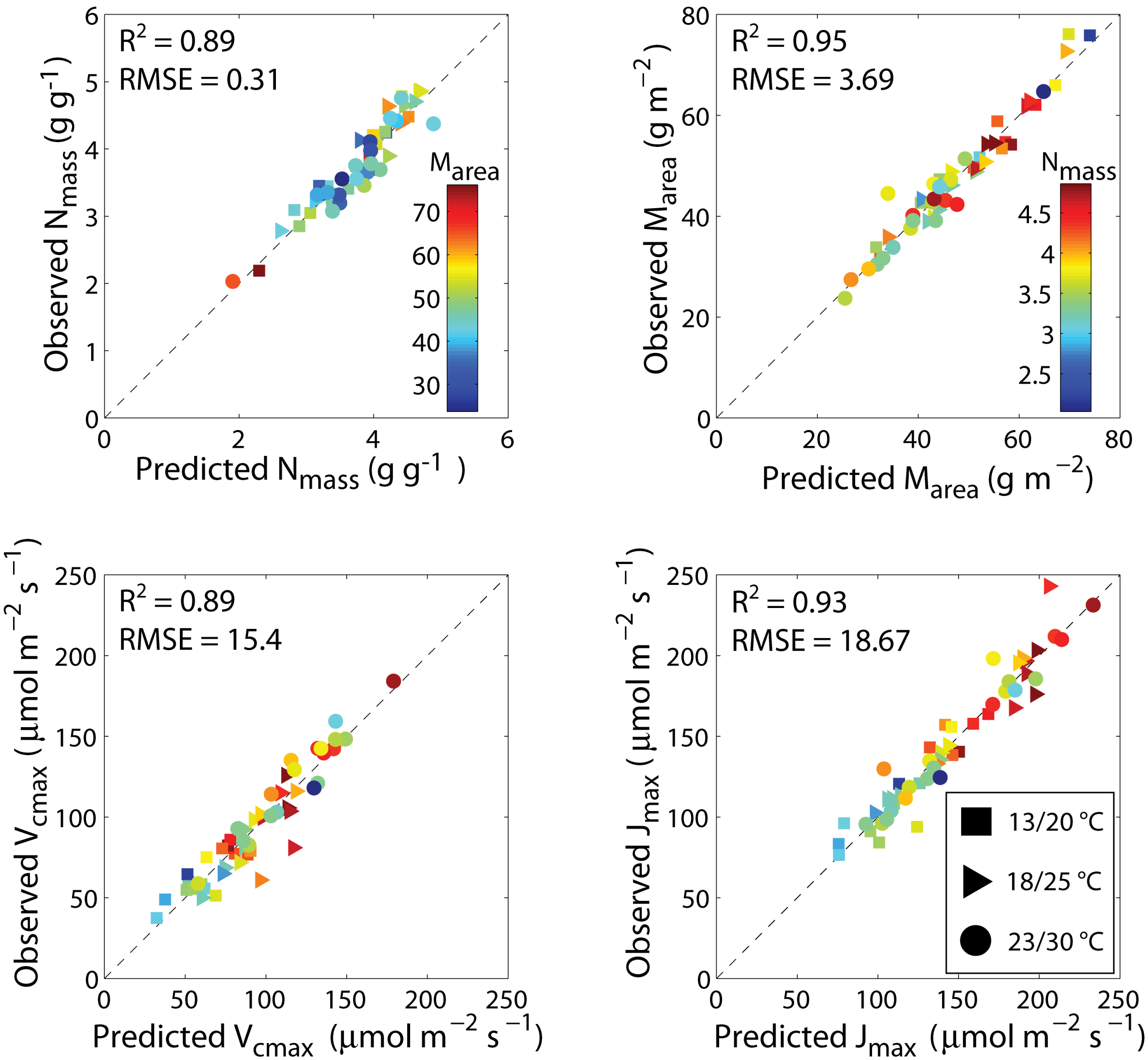
FERST

FOREST ECOSYSTEM REMOTE SENSING TEAM
DEPARTMENT OF FOREST AND WILDLIFE ECOLOGY
UNIVERSITY OF WISCONSIN - MADISON

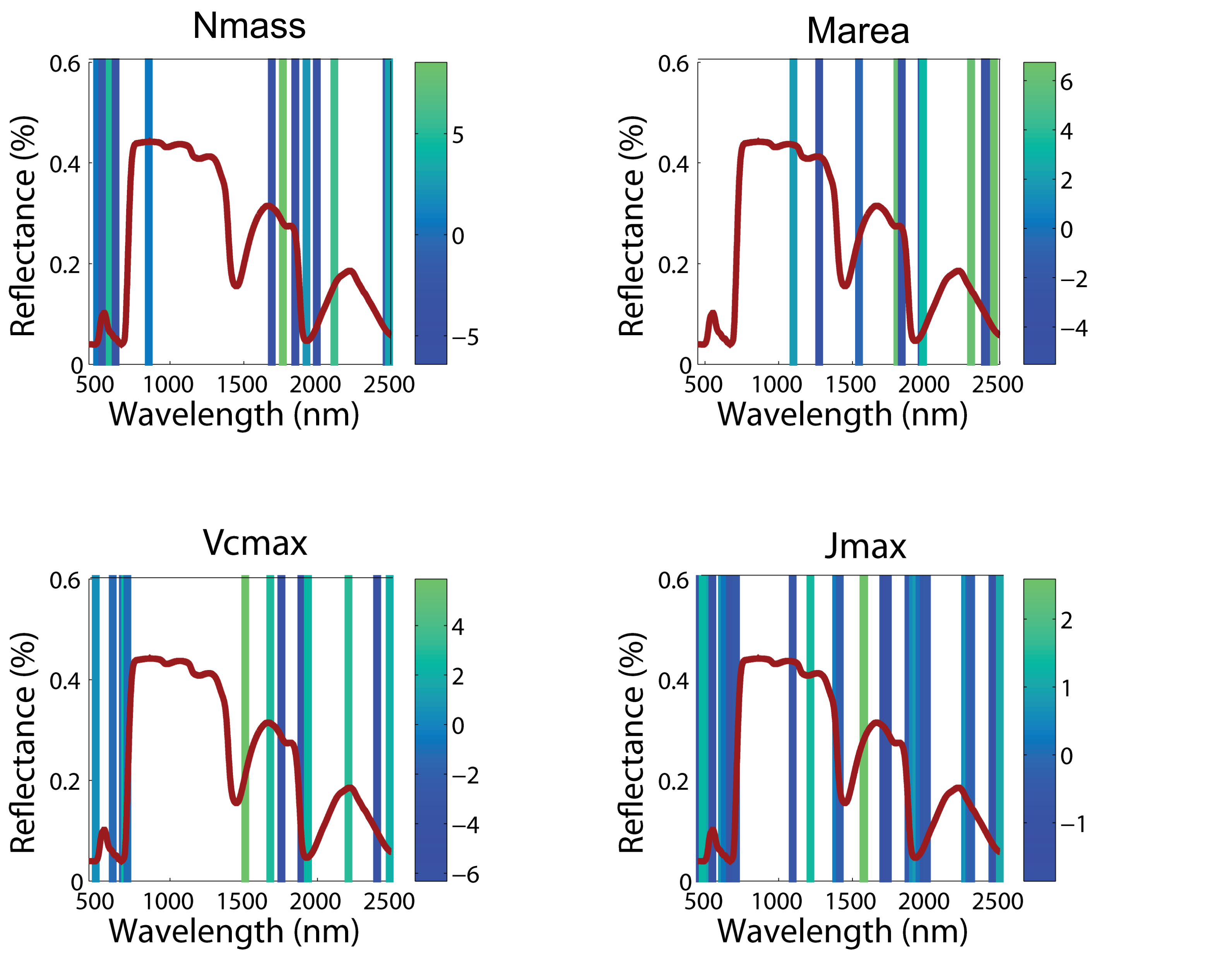
Physiological measurements across temperature regimes



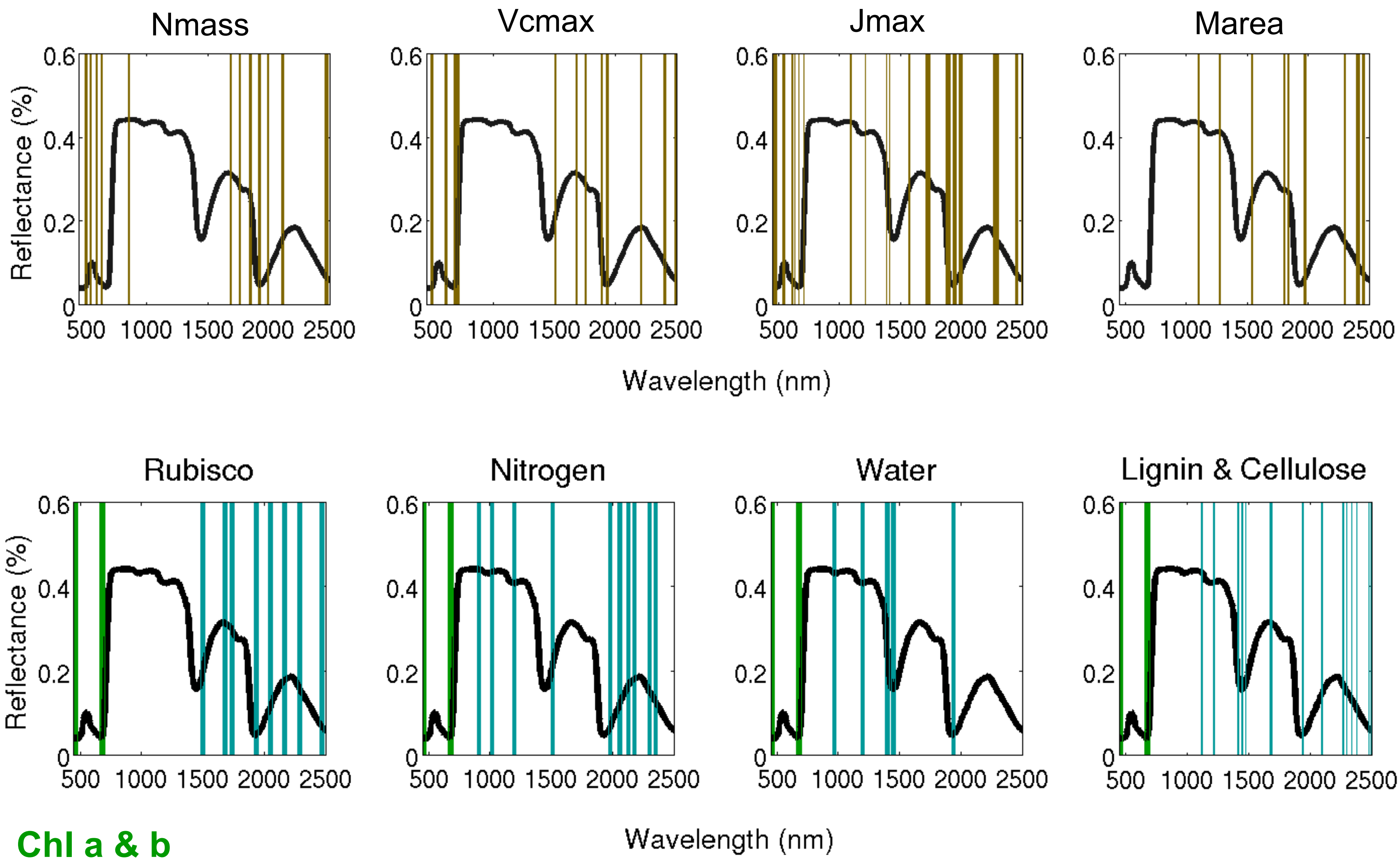
Predictions using leaf spectra and PLSR



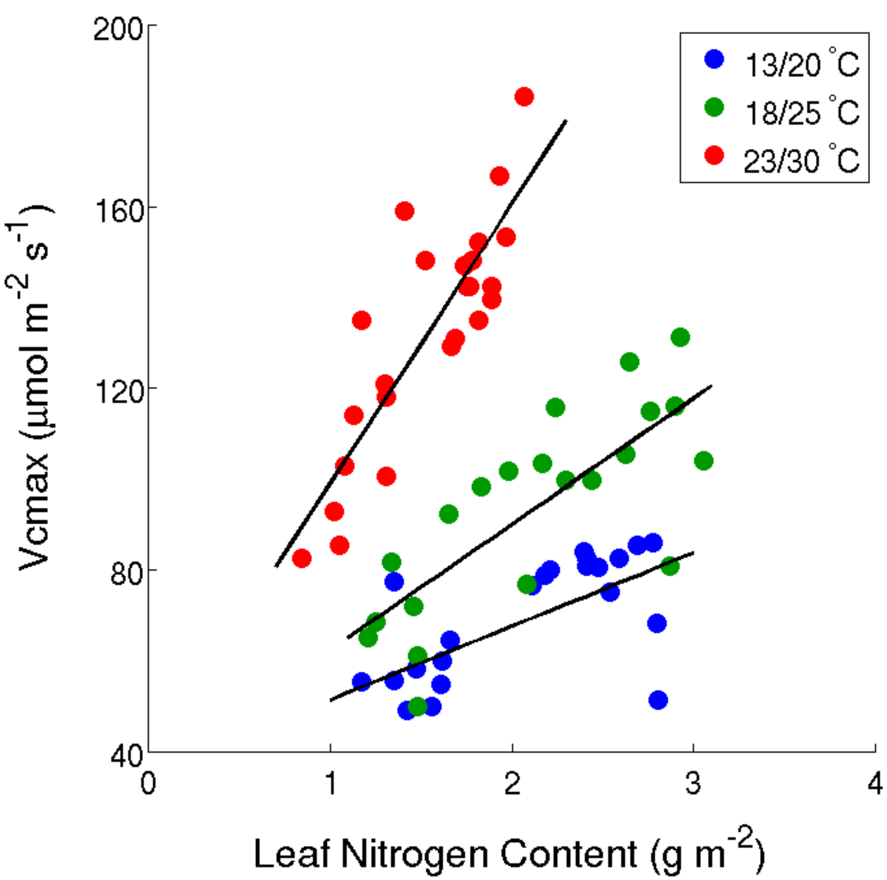
PLSR waveband selection



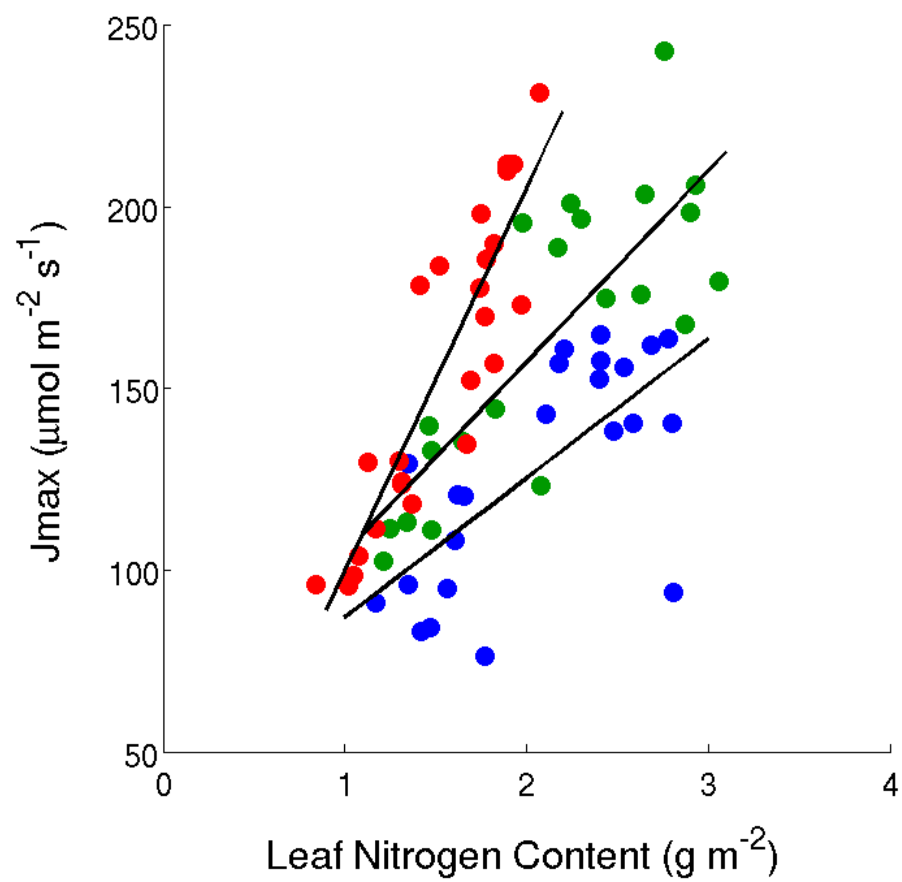
PLSR waveband selection and the state of knowledge



Biotron measurements show thermal effects on leaf metabolism



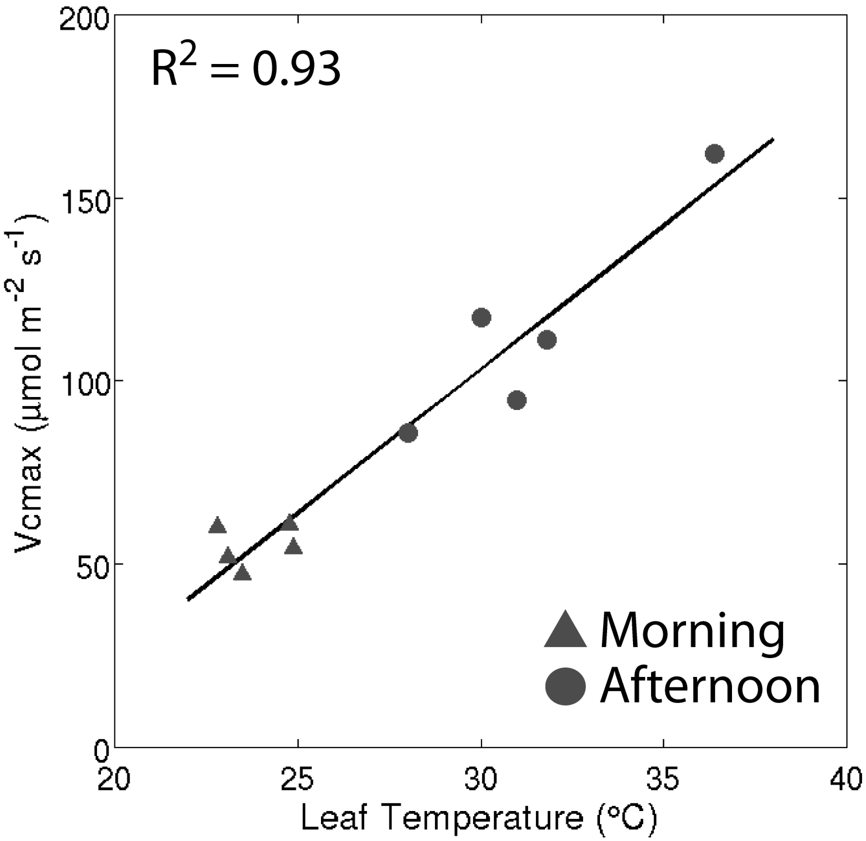
$R^2 = 0.003$

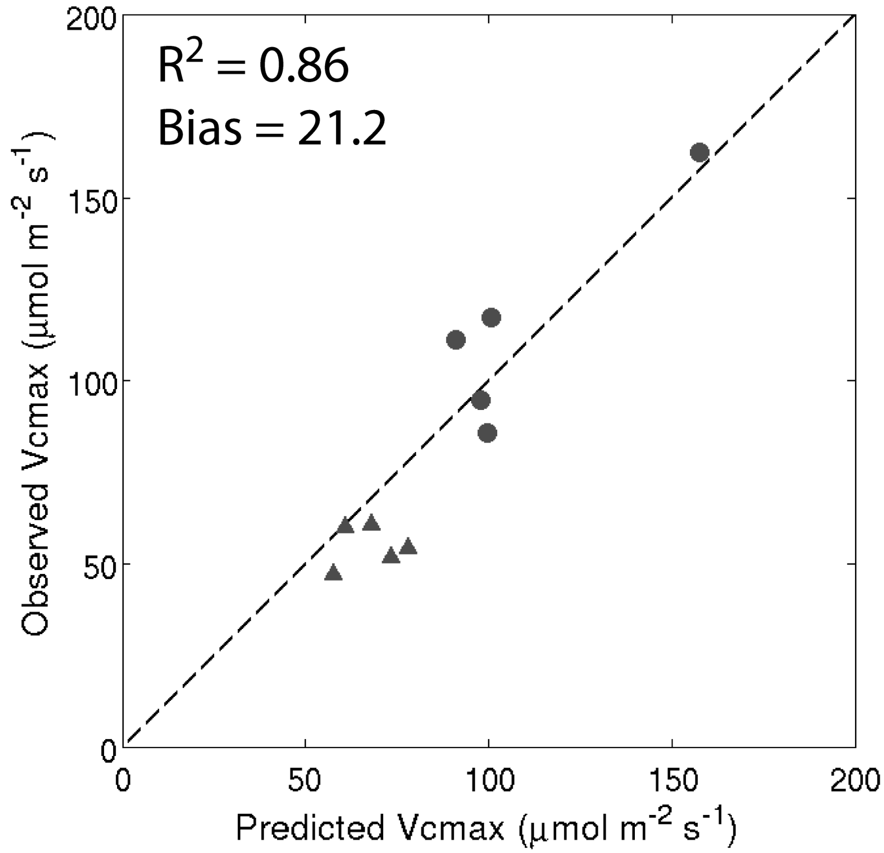


$R^2 = 0.33$

Pooled R^2 between spectra-predicted V(c)max/Jmax and leaf N

Spectra are responsive to temp.-driven variations in metabolism

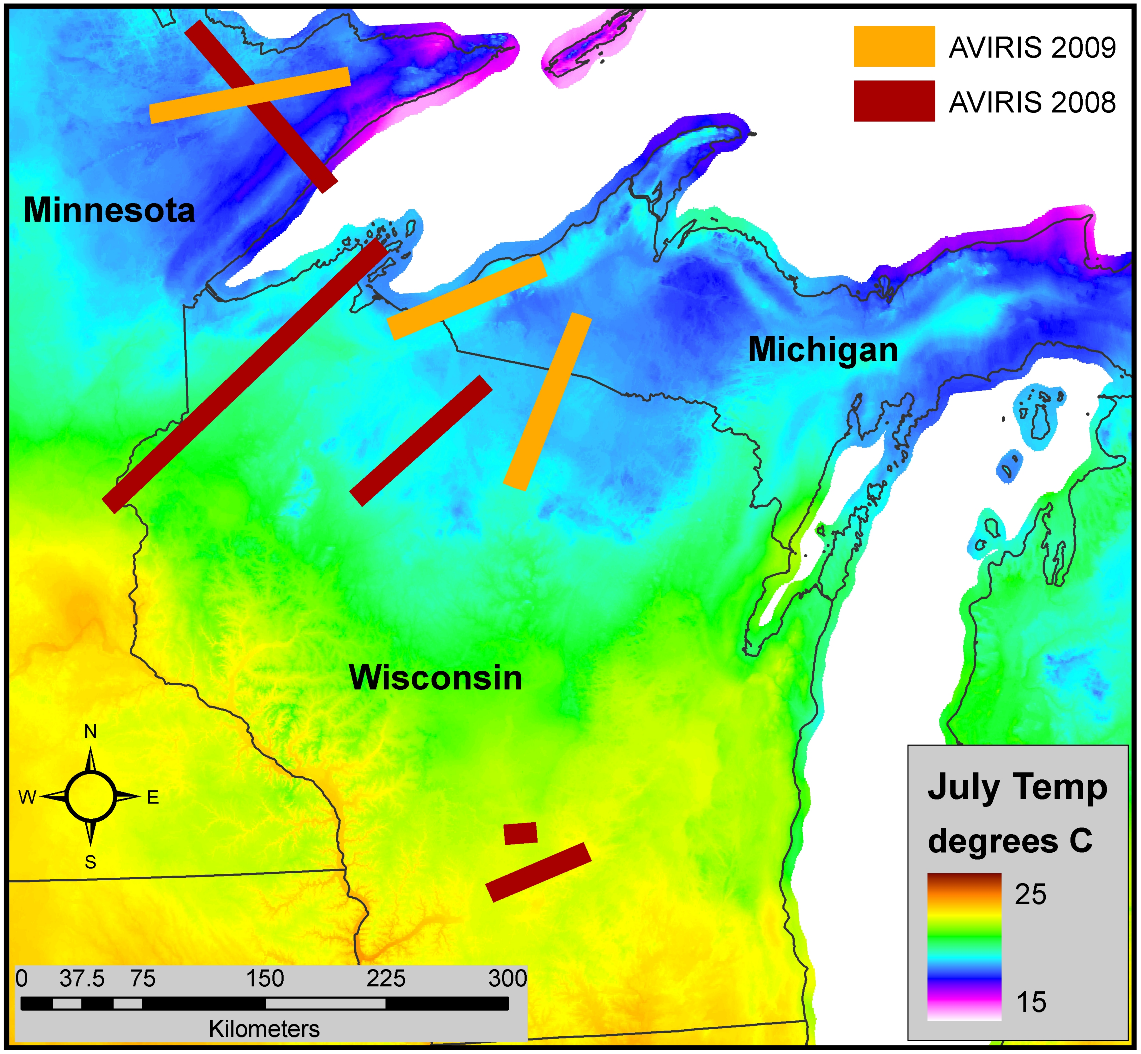




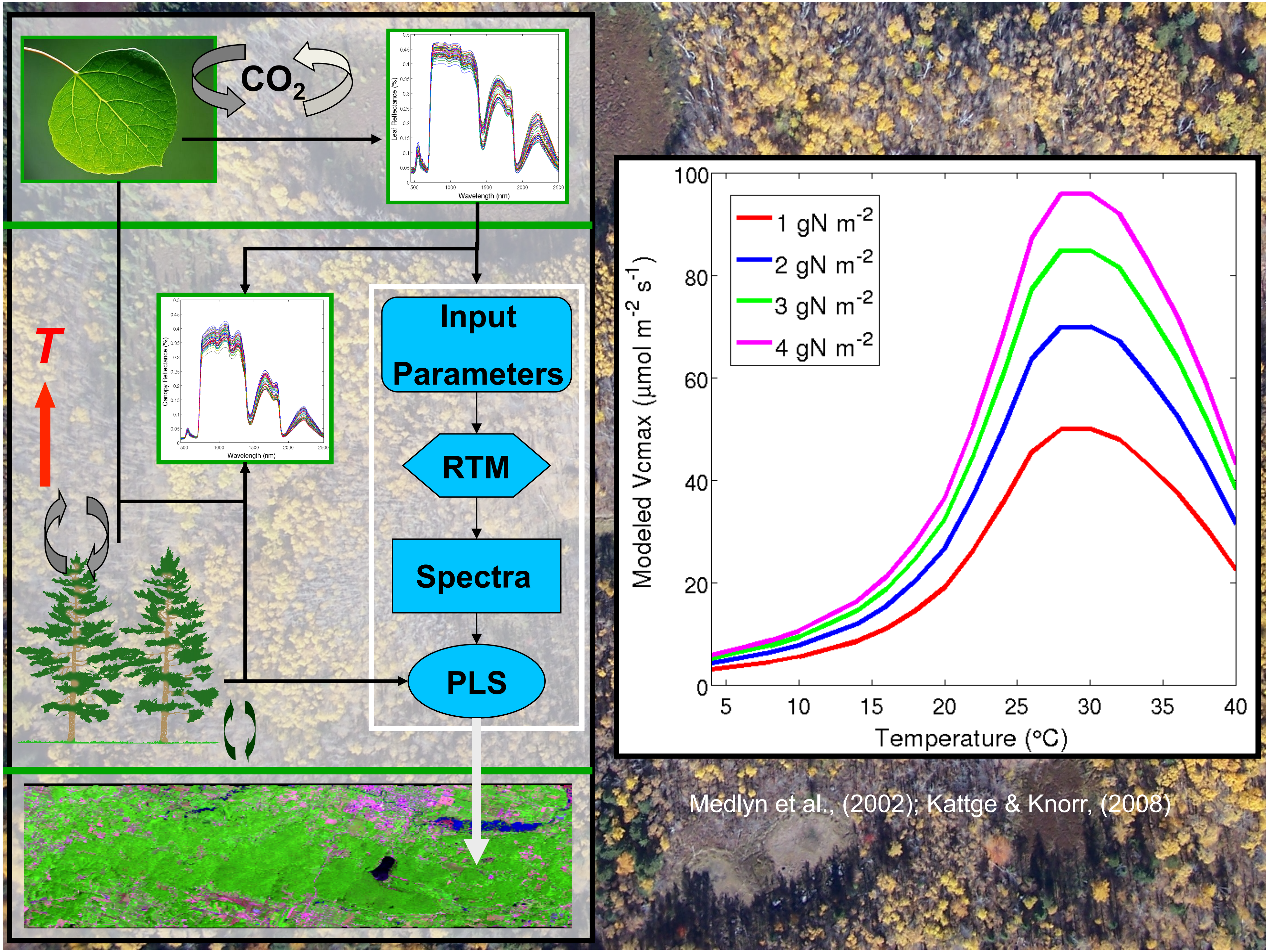
Time	Tleaf (°C)	$Vcmax^{25}$
Morning	23.8	54.8
Afternoon	31.4	114.3

How will climate change affect composition and metabolism?

- Hyperspectral imagery
- Field collection
  - Gas exchange
  - Spectra
  - Canopy temperature
- Examine regional trends
  - Lat/Long variation



PRISM Data: http://www.prism.oregonstate.edu/


CO2
Leaf Reflectance (%)
Wavelength (nm)
Canopy Reflectance (%)
Wavelength (nm)
T
Input Parameters
RTM
Spectra
PLS
1 gN m-2
2 gN m-2
3 gN m-2
4 gN m-2
Modeled Vcmax (µmol m-2 s-1)
Temperature (°C)
0
20
40
60
80
100
5
10
15
20
25
30
35
40
Medlyn et al., (2002); Kattge & Knorr, (2008)

Acknowledgments

- Terrestrial Ecology Program
- Earth & Space Science Fellowship
- HyspIRI Preparatory Activities (forthcoming)

NASA

JPL
Jet Propulsion Laboratory
California Institute of Technology

AVIRIS

FERST
Forest Ecosystem Remote Sensing Team
Department of Forest and Wildlife Ecology
University of Wisconsin - Madison

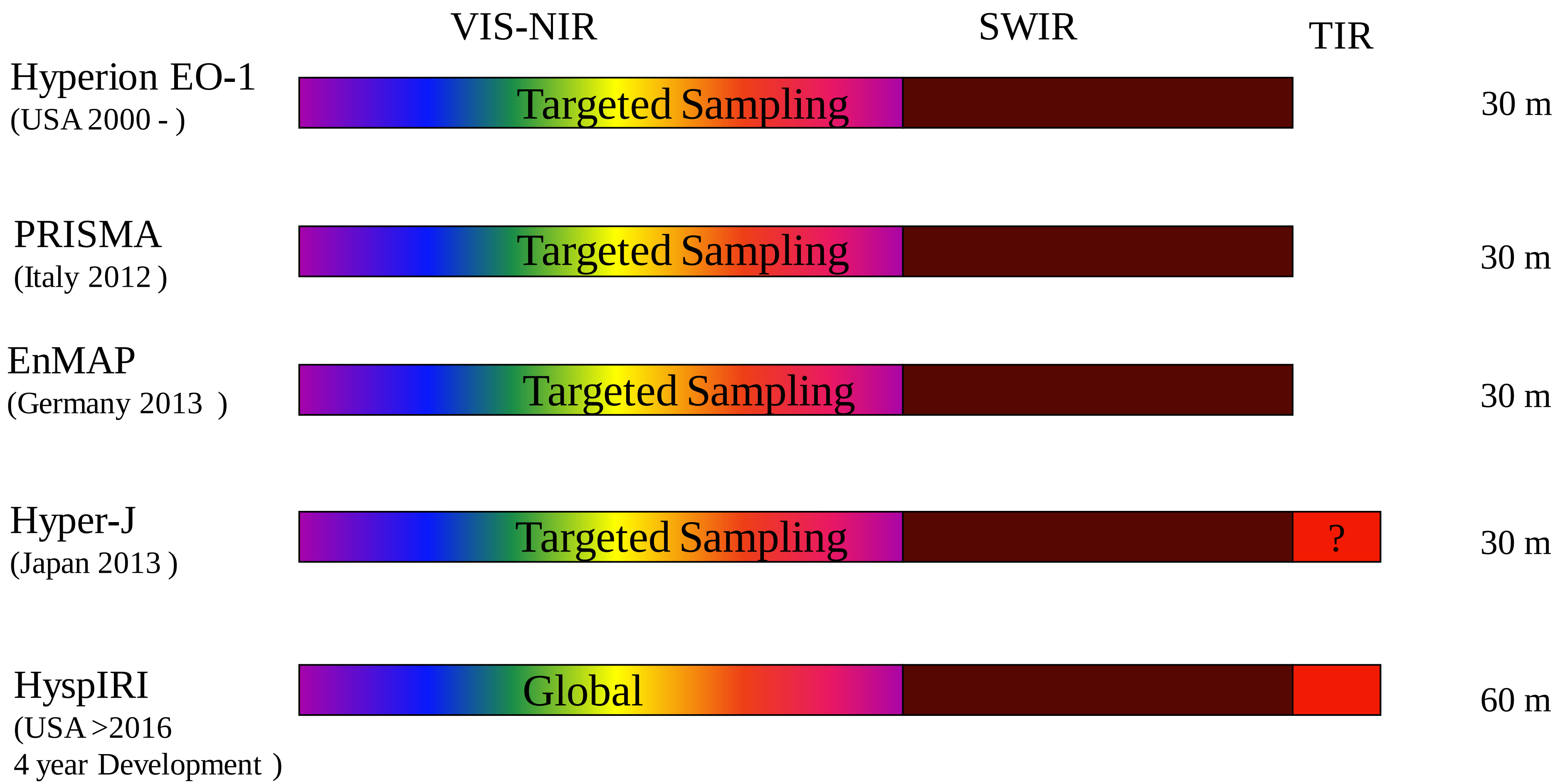
HyspIRI

International Activities and Connections

NASA Earth Science and Applications Decadal Survey

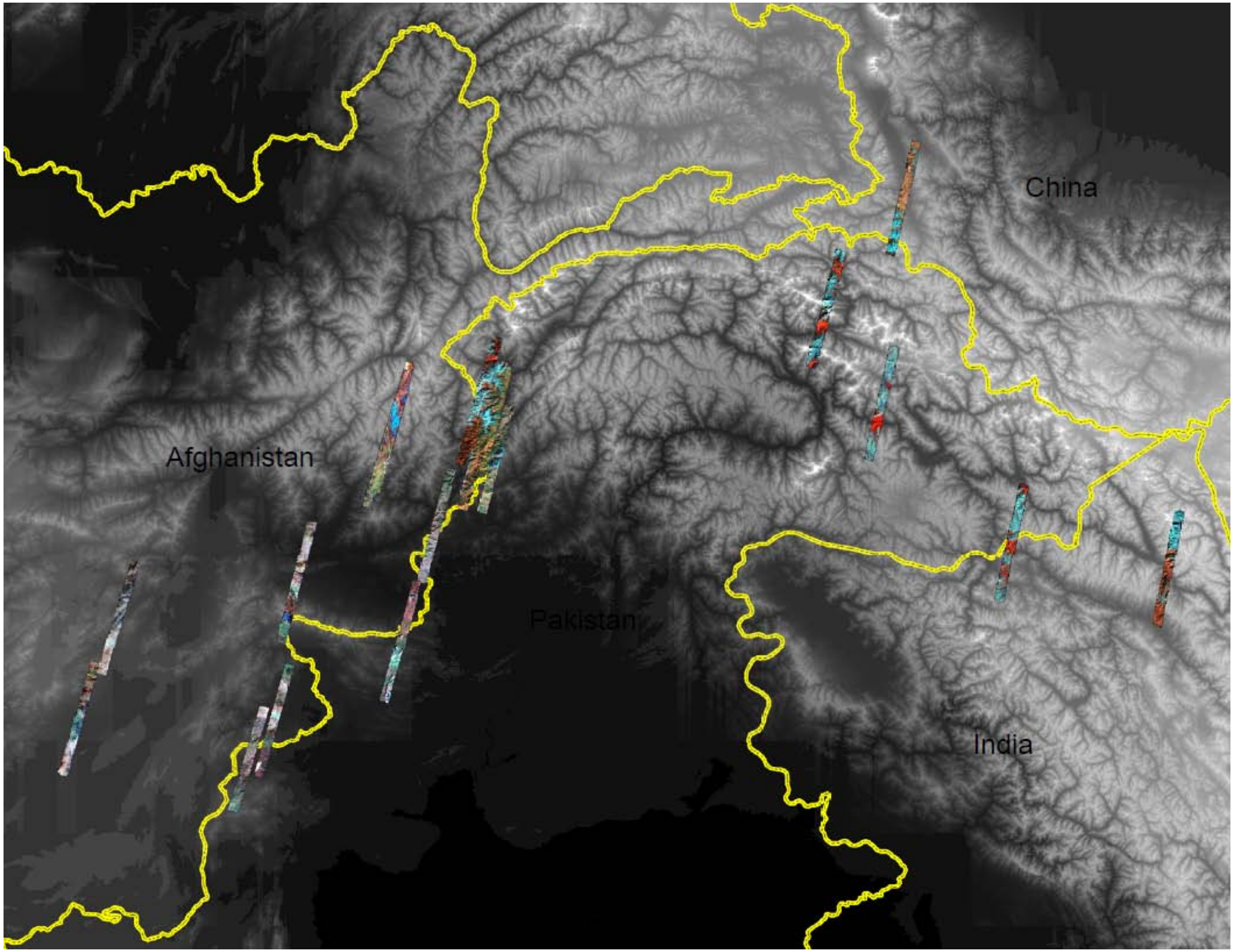
Robert O. Green and HyspIRI Team

Planned Civilian Satellite Missions



EO1-Hyperion Coverage for Himalaya Study

- Example of study for snow and ice science in the Himalaya with EO1-Hyperion
  - Coverage is a severe limitation of regional and global **climate** investigations.



- **<u>HyspIRI would measure the full area every 19 days returning all the data</u>**

HyspIRI compared with possible International Imaging Spectroscopy Missions

Only HyspIRI provides the full spectrum of data required to address climate-carbon cycle feedbacks articulated in the NRC Decadal Survey

HyspIRI Provides Seasonal and Annual Global Coverage that Uniquely Addresses Critical Gaps in Climate Research and Ecosystem Understanding.

>100 years for international mission to equal 1 year of HyspIRI

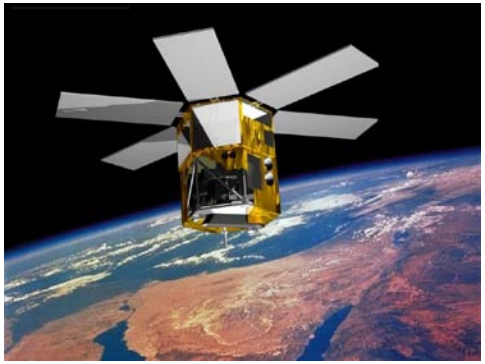
Country	Instrument	Swath km	Pixel Size, m	Terrestrial Coverage in 19 days	Repeat interval, days	TIR capability
USA	**HyspIRI**	**150**	**60**	**100%**	**19**	**8 TIR bands**
Germany	EnMAP	30	30	<1%	--	NO
Italy	PRISMA	30-60	20-30	<1%	--	NO
Japan?	ALOS3	30	30	<1%	--	NO
India?	IMS Resource Sat-3	25	25	<1%	--	1 TIR band

US, HyspIRI: a full spectral range (380 to 2500 at 10 nm), high SNR, uniform, 60m spatial with 150 km swath imaging spectrometer and multiband thermal imager (8 band thermal imager from 3-12 μm).

Other countries are occasionally mentioned (China, South Africa, South Korea, etc.). All are proposing first generation visible-only, small sample process/application missions with scattered terrestrial coverage and no TIR imager

International Satellite Imaging Spectroscopy – ISIS Technical Committee

Co-Chairs: Alex Held, CSIRO - Australia
Karl Staenz - University of Lethbridge - Canada



Background

- The ISIS TC provides a forum for technical and programmatic discussion and consultation among national space agencies, research institutions and other.

- Main goals of the ISIS are to share information on current and future spaceborne imaging spectroscopy missions, and to seek opportunities for new international partnerships to the benefit of the global user community.

- An initial “ISIS Working Group” was established in November 2007, realising the large number of countries planning imaging spectroscopy satellite missions with little mutual understanding and coordination.

- Meetings of the WG have been held in Hawaii (2007), Boston (IGARSS 2008) and Tel Aviv (EARSeL 2009).

- Next meeting IGARSS 2010

Inaugural Meeting of ISIS WG

Hilo, Hawaii, November 2007

Bryan Bailey (USGS), Greg Asner (Carnegie), Bruce Quick (USGS), Andreas Muller (DLR), Joe Boardman (AIG), Karl Staenz (ATIC), Hermann Kaufmann (GFZ), Benoit Rivard (Univ Alberta), Steve Ungar (NASA), Jan van Aardt (CSIR), Hiroji Tsu (ERSDAC), DeWayne Cecil (NASA/USGS), Rob Green (JPL), Alex Held (CSIRO), Duke Takahashi (WSI), Stephen Ward (Symbios Communications), Nagamitsu Ohgi (JAROS),

Key Drivers/Arguments for Imaging Spectroscopy Missions

Science — Management Support/Policy

Science Questions
Eg. HyspIRI

- VQ1 - Pattern and Spatial Distribution of Ecosystems
- VQ2 - Ecosystem Function, Physiology and Seasonal Activity
- VQ3 - Biogeochemical Cycles
- VQ4 - Ecosystem Response to Disturbance
- VQ5 - Ecosystems and Human Well-being
- VQ6 - Surface and Shallow-Water Bottom Composition
- TQ1 - Volcanoes and Earthquakes
- TQ2 - Wildfires
- TQ3 - Water Use and Availability
- TQ4 - Human Health and Urbanization
- TQ5 - Earth Surface Composition and Change
- CQ1 - Coastal, Ocean, and Inland-Aquatic Environments
- CQ2 – Wildfires
- CQ3 - Volcanoes
- CQ4 - Ecosystem Function and Diversity
- CQ5 - Land Surface Composition and Change
- CQ6 - Human Health and Urbanization

Standard Level 2, 3 Global Products

?

Commercial ????

GEO 'Societal Benefit Areas':
Energy
Health
Agriculture
Water
Disasters
Etc.

National Priorities
Food Security
Water Security
National Security
Etc.

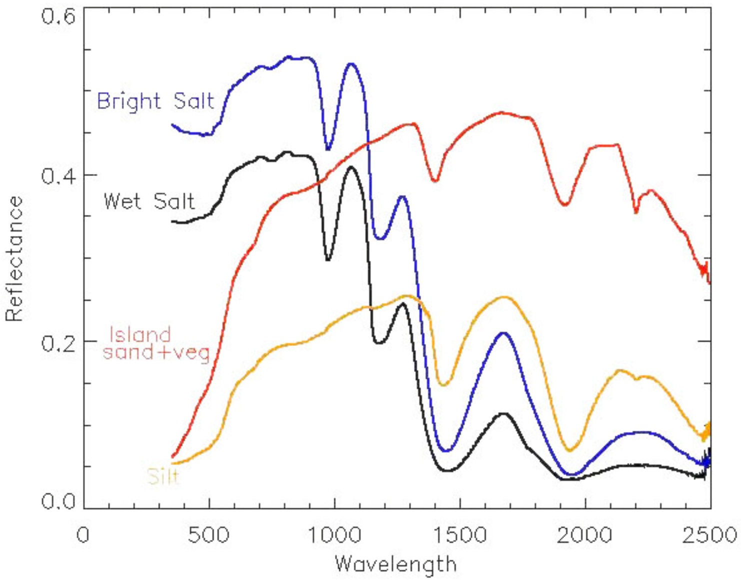
Policy-relevant Issues
Climate Convention
Desertification Convention
Etc.

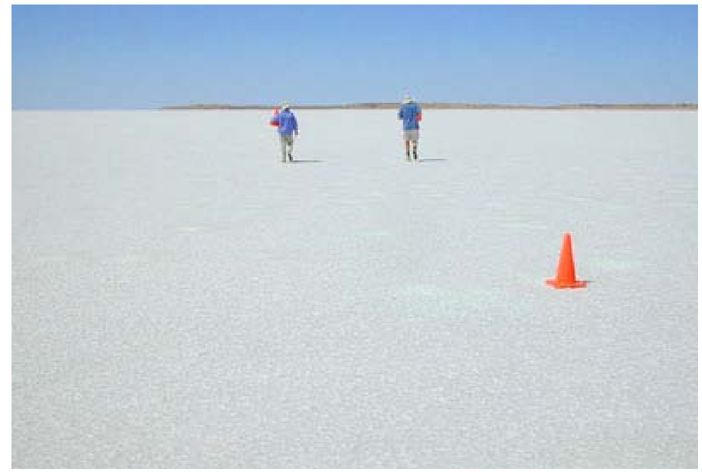
Main Topics for GRSS ISIS TC

- Primarily about multiple satellite mission planning, and data interoperability aspects [Not about hyperspectral science and applications development -this is well covered elsewhere].

- Specific coordination of:
  - interoperability among missions,
  - 'best practice' mission implementation,
  - **data management challenges,**
  - **establishment of global reference cal/val sites and regular field campaigns and**
  - 'Global' imaging spectroscopy products.

Establishment of Key Post-launch Spectroscopy Instrument Calibration & Validation Sites





International Interaction for Calibration and Validation (Level 1 and Level 2)

- Australia
  - Calibration-validation, Carbon, Coastal Ocean GBR
  - Data Processing
- Canada
  - Product validation, Forestry,
  - Data Processing
- Israel
  - Calibration-validation
- Europe
  - EnMap, PRISMA, Product validation
  - Data Processing
- Brazil
  - Product validation
- Argentina
  - Calibration-validation, Product validation
- India
  - Agriculture, Himalaya, Product validation

Next Meeting

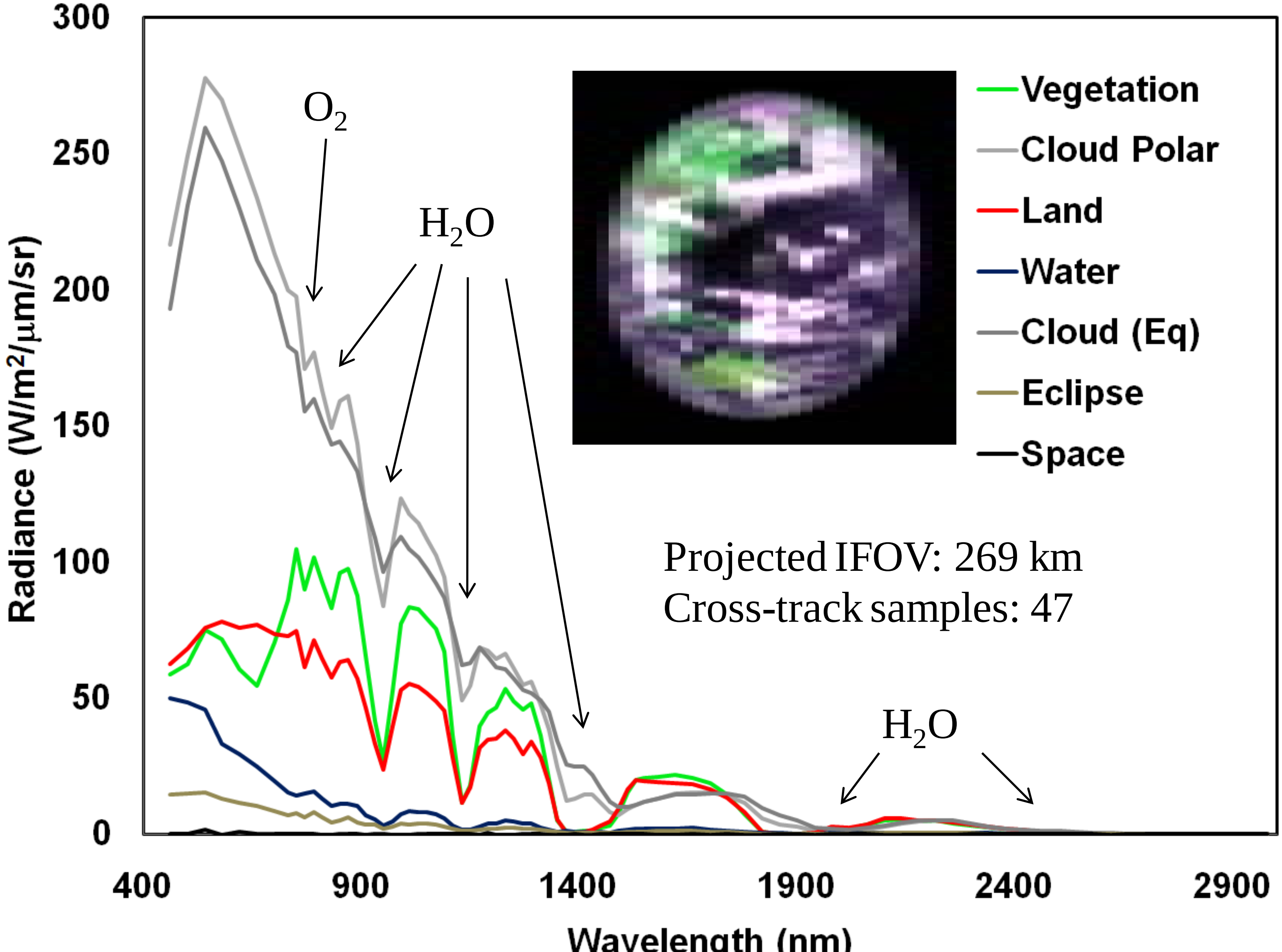
ISIS Meeting planned for IGARSS 2010
July 26-30, Honolulu, Hawaii, USA

http://www.grss-ieee.org/Resources/TechCommittees

Also plans for ISRSE 2011 in Sydney

Image of Earth from the Moon acquired by the NASA Discovery Moon Mineralogy Mapper (M3) that is a guest instrument onboard the ISRO Chandrayaan-1 Mission to the Moon. Australia is visible in the lower center of the image. The image is presented as a false color composite with oceans dark blue, clouds white, and vegetation enhanced green. The data were acquired on the 22nd of July 2009.

M^3 On-Orbit Spectral



A Mission Calibration Plan to Support Products

K. Thome
Goddard Space Flight Center

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Introduction

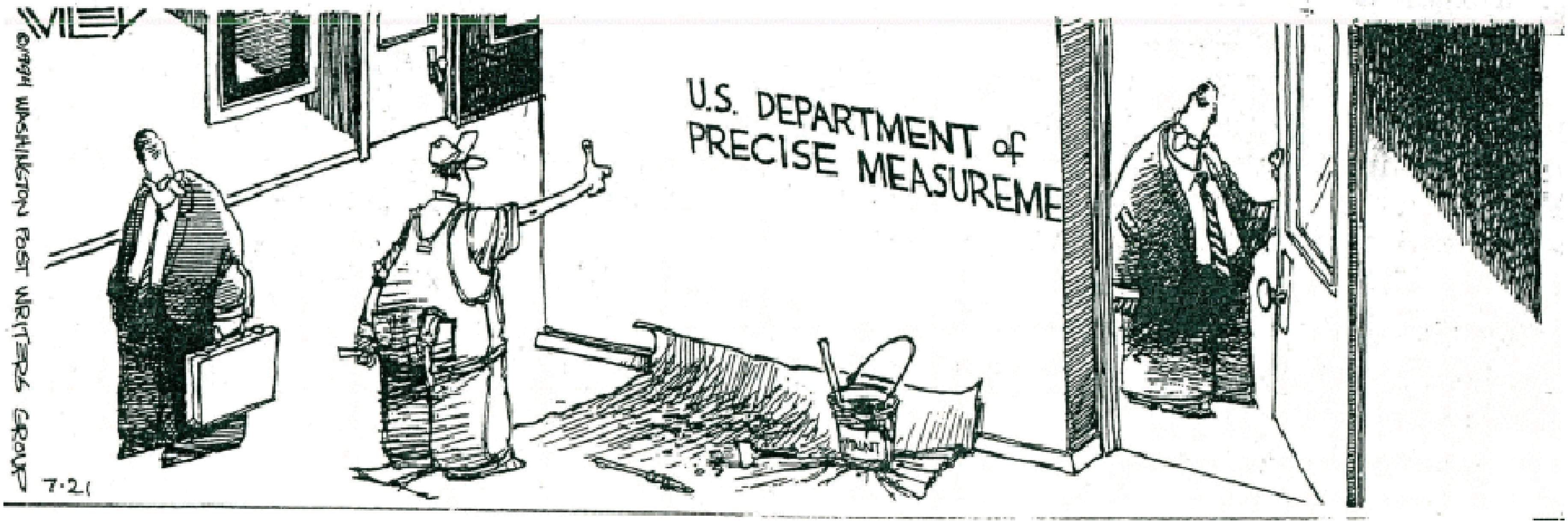
Calibration and validation of HyspIRI plays a key role in the success of the mission

- Present an overview of general approaches for prelaunch and inflight characterization/calibration applicable to HyspIRI sensors
- Discuss both reflective and emissive bands
- Talk overview
  - NIST and SI traceability
  - General calibration philosophy
  - Prelaunch approaches
    - Transfer radiometers
  - Inflight
    - Calibration
    - Validation

Accuracy

Terms accuracy and precision can be sources of contention in discussions

- Accuracy is essentially how well the results agree to the actual value
- Precision is how well individual measurements agree with each other
- Repeatability is used interchangeably with precision



Traceability

NIST and SI traceability are playing a larger role to ensure climate quality data sets

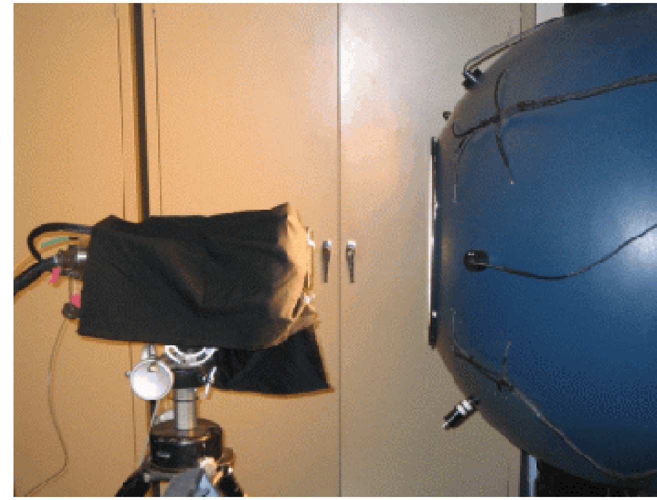
- SI Traceability requires the establishment of an unbroken chain of comparisons to stated references – NIST Website
  - "Unbroken chain of comparisons" means:

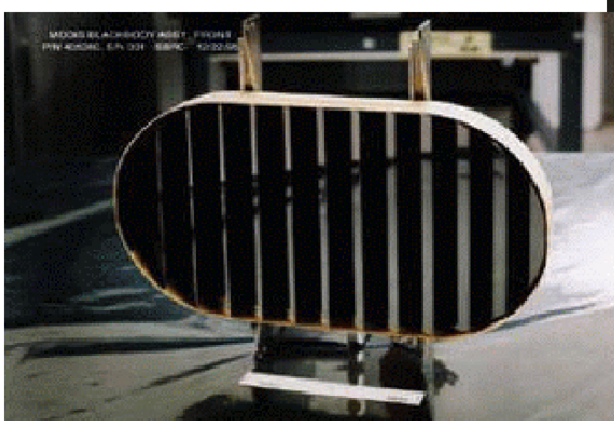
    "the complete, explicitly described, and documented series of comparisons that successively link the value and uncertainty of a result of measurement with the values and uncertainties of each of the intermediate reference standards and the highest reference standard to which traceability for the result of [the] measurement is claimed."
- NIST traceability is maintained through adherence to a documented set of protocols developed by NIST
  - Done properly, should lead to SI traceability
  - Can still lead to biases between laboratories operating under protocols of different national measurement institutes

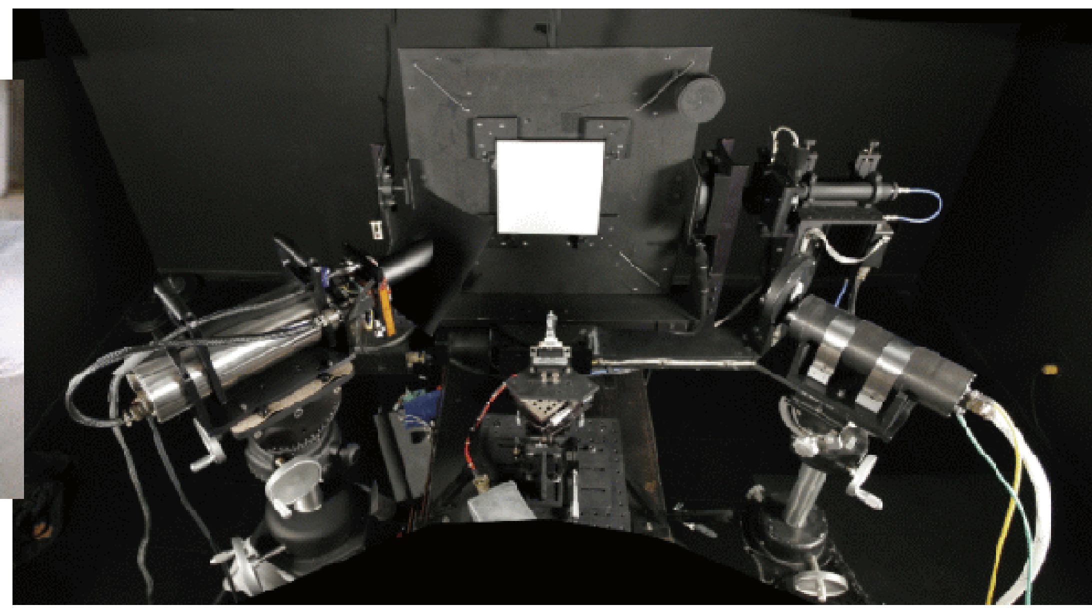
Source-based calibration

Preflight and inflight calibration require sources of known output

- Blackbodies in the thermal emissive
- Lamps and sphere sources in reflective
- Cross-calibration requires moving the sources from place to place



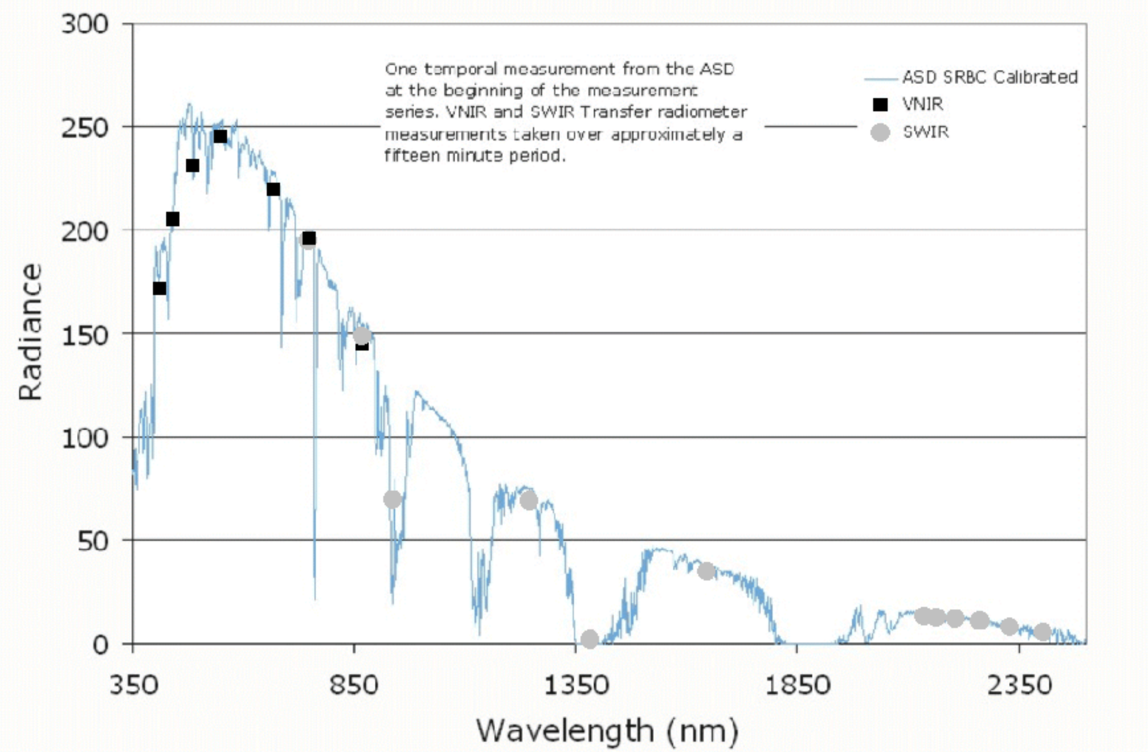




ARTEMIS solar-based example

Solar-based calibration approach was used for the preflight calibration of ARTEMIS

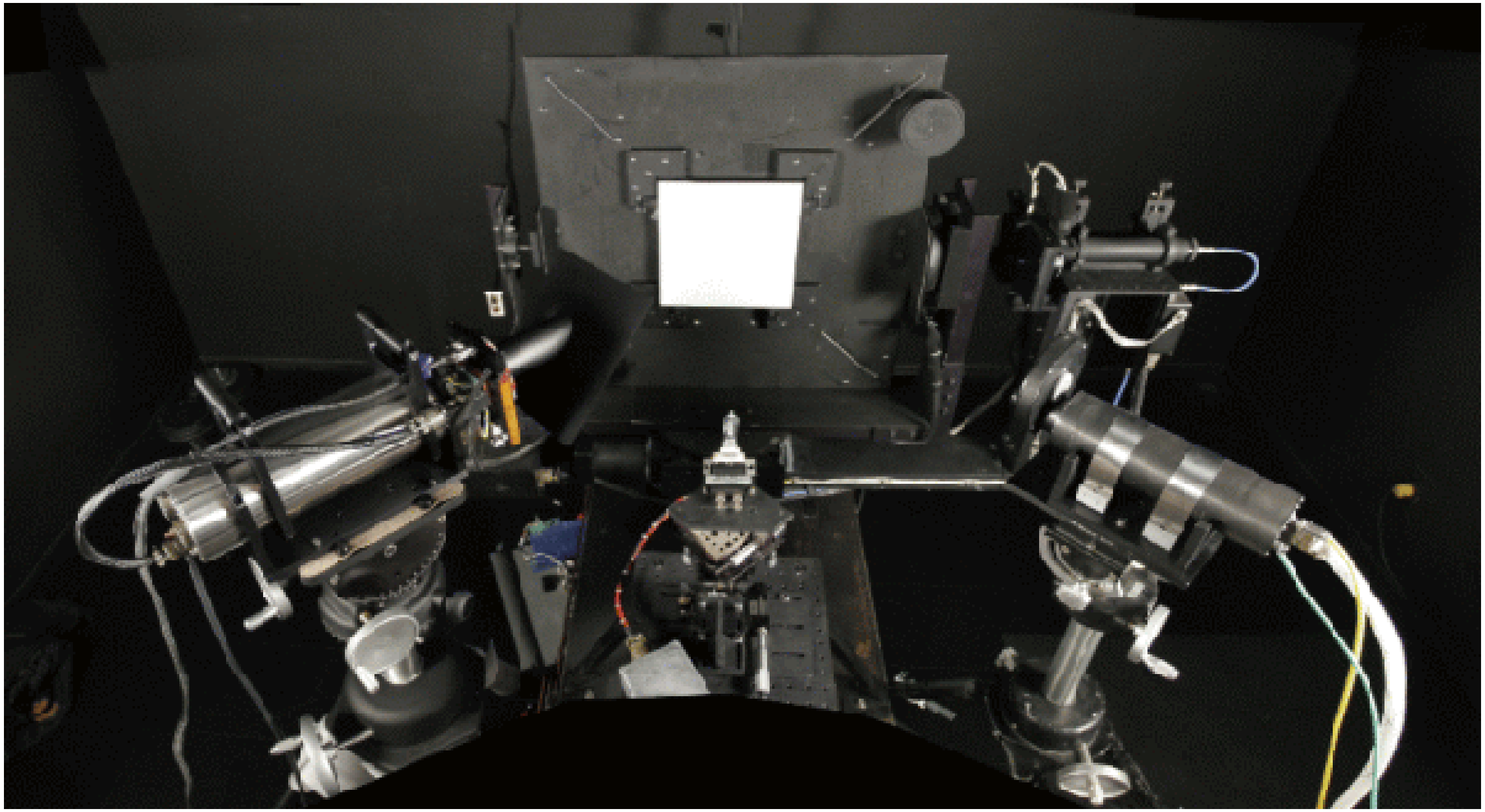
- Sensor viewed a large Spectralon panel
- Output radiance from the panel measured by transfer radiometers



Detector-based approaches

Detector-based approaches assume that radiometers can be used to assess a given source

- Detectors tend to degrade more slowly than lamp sources
- Radiometers more robust and portable than some sources



Inflight calibration

Vicarious approaches are useful for inflight cailbration since they do not degrade with time

- Approaches suggested for HyspIRI are
  - Deep space views
  - Lunar approaches have been successful for several sensors
  - Invariant scenes
  - Predictable scenes
  - In situ measurement approaches
  - Cross calibration
- Methods have been shown to work well in the past
  - Reflective and emissive bands
  - Multispectral and hyperspectral
- Approaches can be used for spectral, radiometric, and geometric calibration

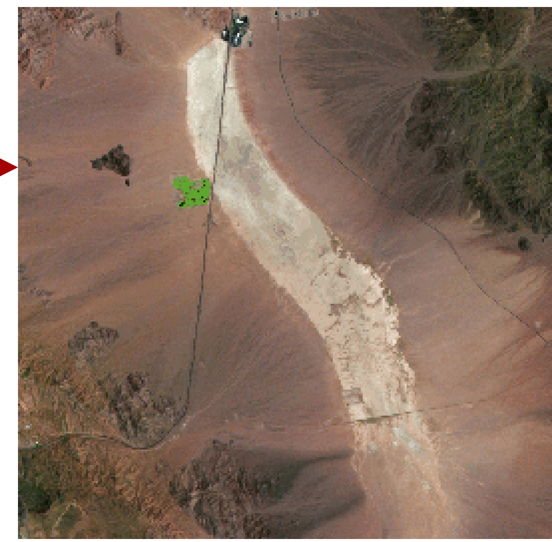
Inflight - vicarious

Measurements of surface reflectance of a homogeneous test site

Measurements of atmospheric conditions

RTC Code

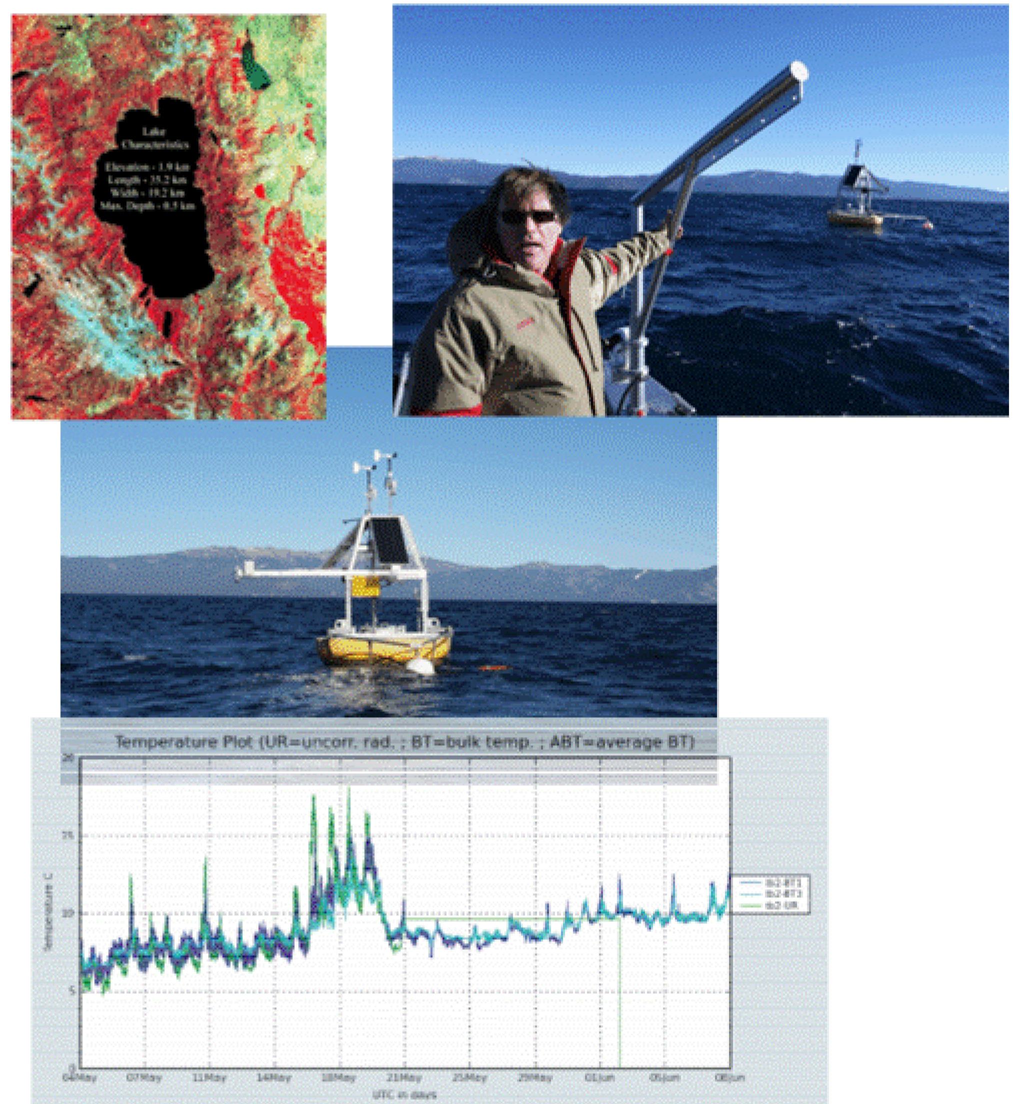
Predict at-sensor radiance for a selected area of the site and compare to imagery



Instrumented sites

Tahoe site is an excellent example of a ground measurement site

- Measure water leaving radiance
- Measure bulk temperature
- Characterize the atmosphere
- Predict at-sensor radiance
- Similar work in Great Lakes



Spectral and Geometric calibration

Spectral and geometric calibration takes place prelaunch and on orbit as well

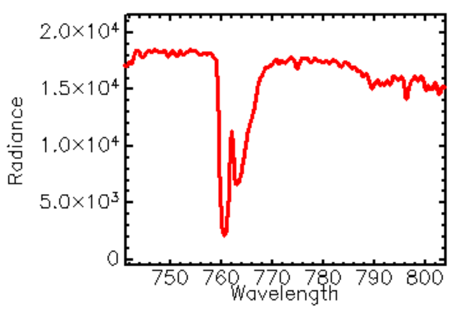
- Alignment between emissive and reflective bands
- Center wavelength and band shapes

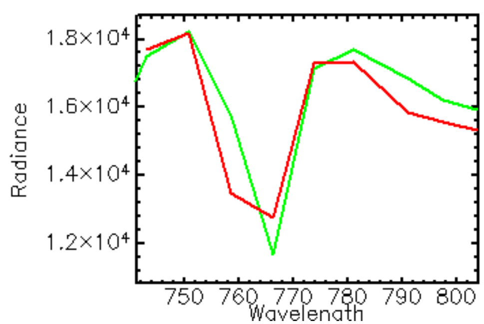
1. **Convolve SRF with High Resolution MODTRAN™ Model**

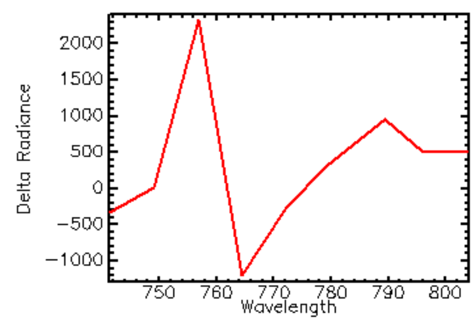
2. **Normalize Data (Green) to Model (Red)**

3. **Subtract Data from Model Fit Straight Line Compute Statistics**

4. **Shift Band Centers Repeat Steps 1-4**







Product validation

An important part of the sensor calibration will be to use product validation

- Validation of the data products permits further understanding of the sensor's behavior
  - More realistic scenes
  - Inter-band and inter-sensor differences
  - Expansion of areas for in situ collections
- MODIS provides a good example
  - NDVI used to cross-compare between sensors
  - Ocean products have found polarization sensitivities
- Should not permit product validation to be used as a substitute for sensor calibration
  - Separate sensor effects from algorithmic effects
  - Traceability is more difficult

Summary

Products should be used to determine the required calibration accuracy and precision

- Requirements will determine specific types of calibration needed
  - 0.5 K accuracy is currently being achieved on regular basis
  - 2-3% in reflectance in bands without strong atmospheric absorption
  - Better accuracy will require new approaches to laboratory and onboard calibrators
- Specific sensor design will determine the specific tests
  - Onboard calibrator approaches
  - Focal plane designs
- Calibration plan should include methods that allow comparisons to later sensors

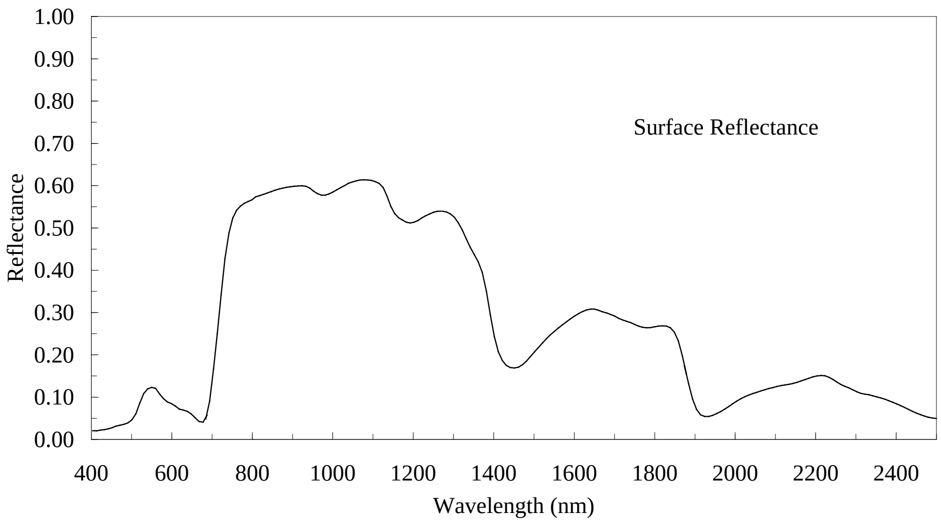
HyspIRI

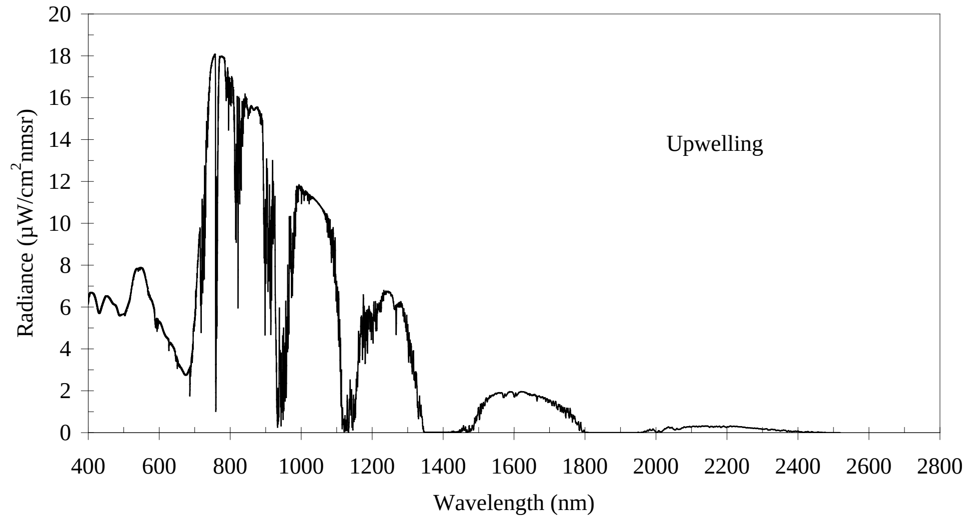
VSWIR Calibration and Validation

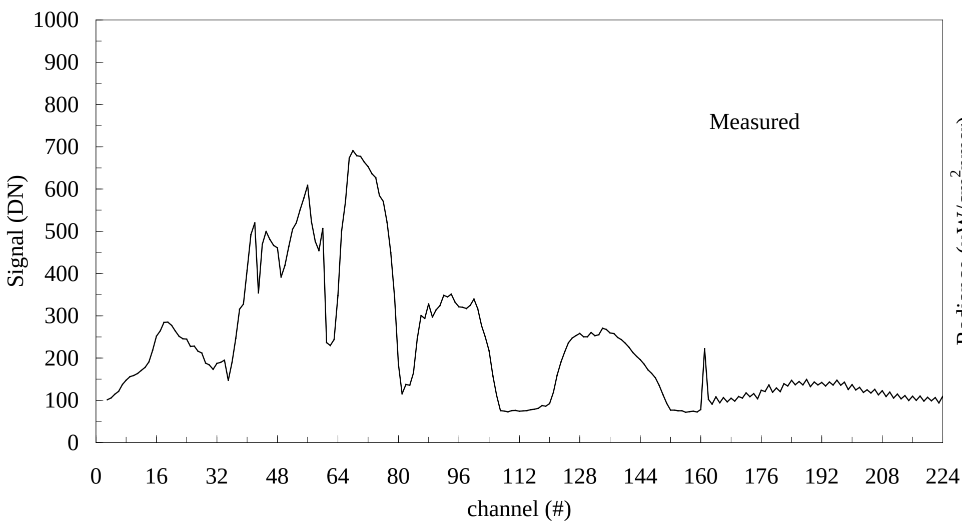
NASA Earth Science and Applications Decadal Survey

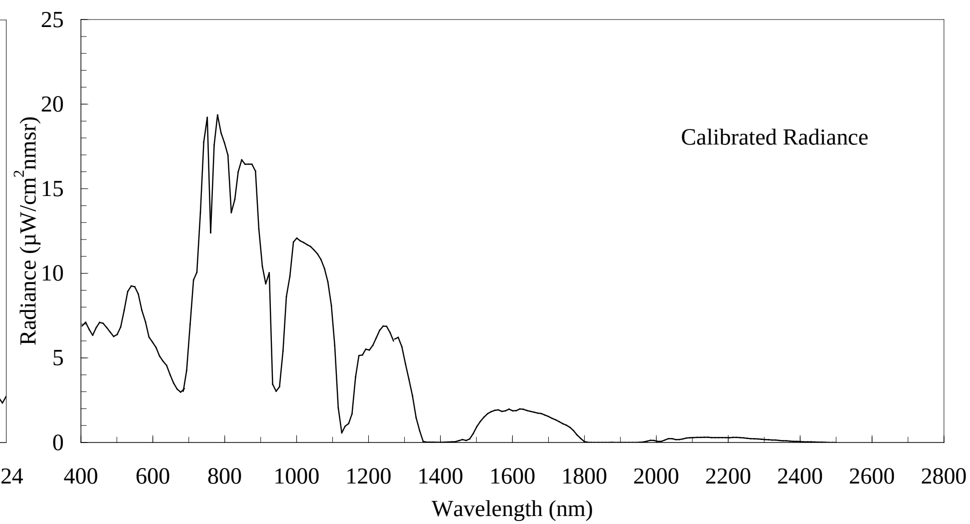
Robert Green and HyspIRI Team

Calibration and the Signal



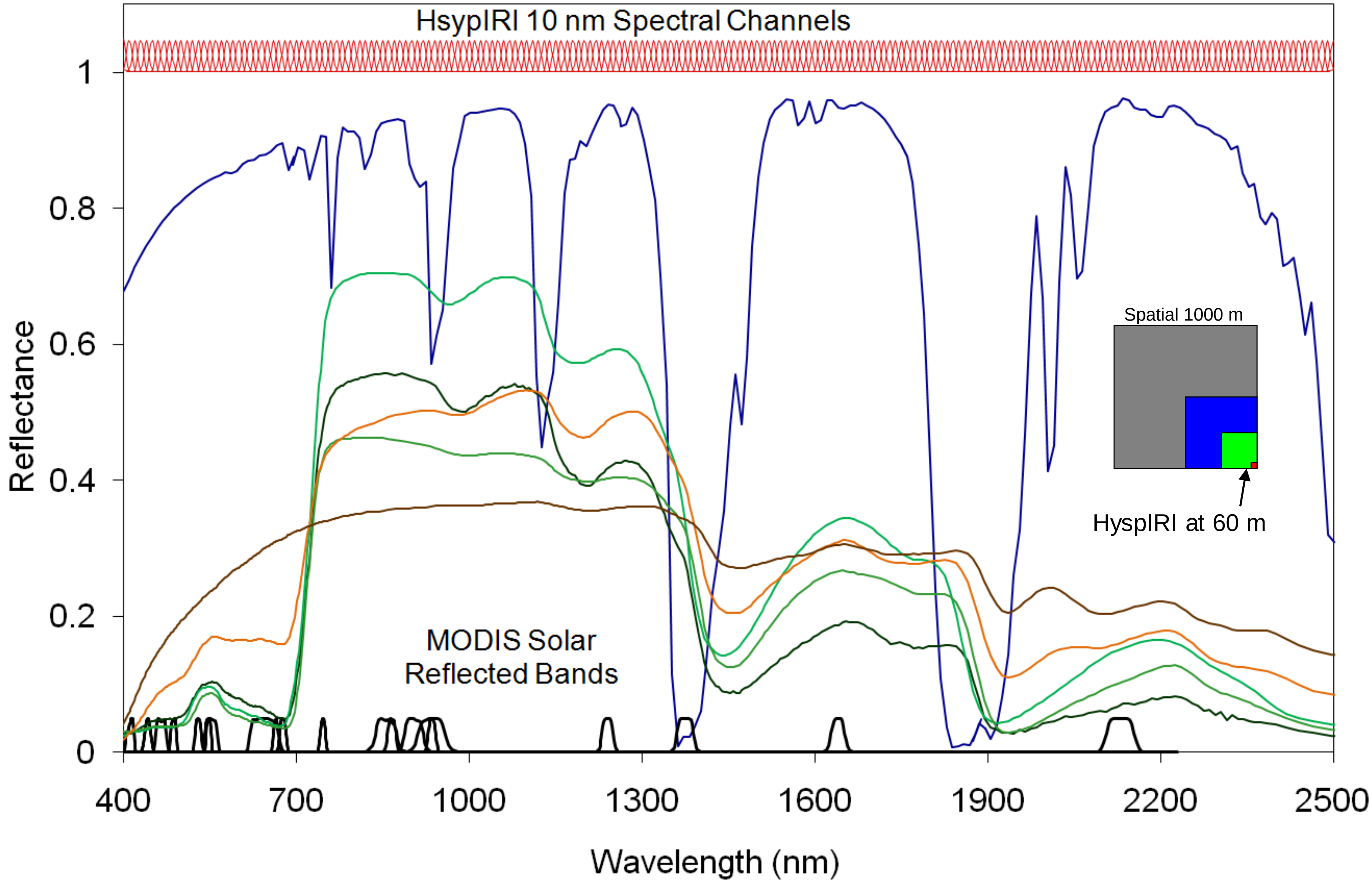






HyspIRI VSWIR
Imaging Spectrometer
Measurement Characteristics

HyspIRI VSWIR Key Science Measurements Characteristics

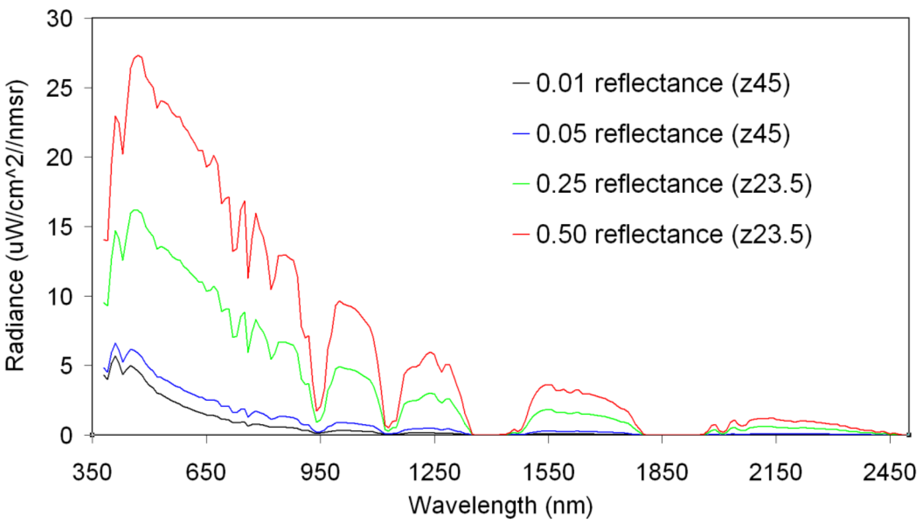


HyspIRI VSWIR
Science Measurement Characteristics

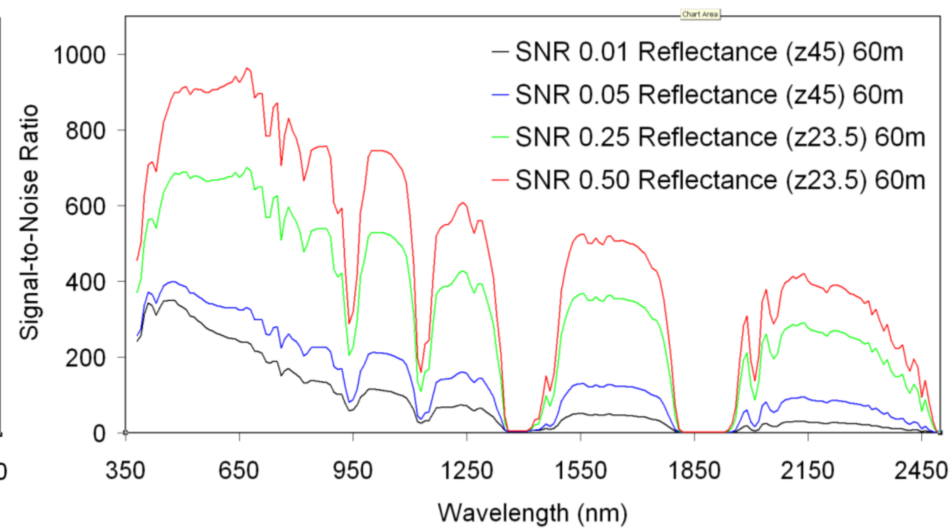
Spectral	
Range	380 to 2500 nm in the solar reflected spectrum
Sampling	<= 10 nm {uniform over range}
Response	<= 1.2 X sampling (FWHM) {uniform over range}
Accuracy	<0.5 nm
Radiometric	
Range & Sampling	0 to 1.5 X max benchmark radiance, 14 bits measured
Accuracy	>95% absolute radiometric, 98% on-orbit reflectance, 99.5% stability
Precision (SNR)	See spectral plots at benchmark radiances
Linearity	>99% characterized to 0.1 %
Polarization	<2% sensitivity, characterized to 0.5 %
Scattered Light	<1:200 characterized to 0.1%
Spatial	
Range	>150 km
Cross-Track Samples	>2500
Sampling	<=60 m
Response	<=1.2 X sampling (FWHM)
Uniformity	
Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}

HyspIRI VSWIR Science Measurements Key SNR and Uniformity Requirements

Benchmark Radiances

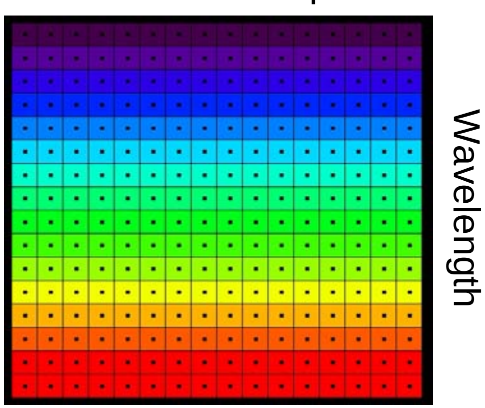


Required SNR



Uniformity Requirement

Cross Track Sample



Depiction

-Grids are the detectors

-dots are the IFOV centers

-Colors are the wavelengths

Requirement

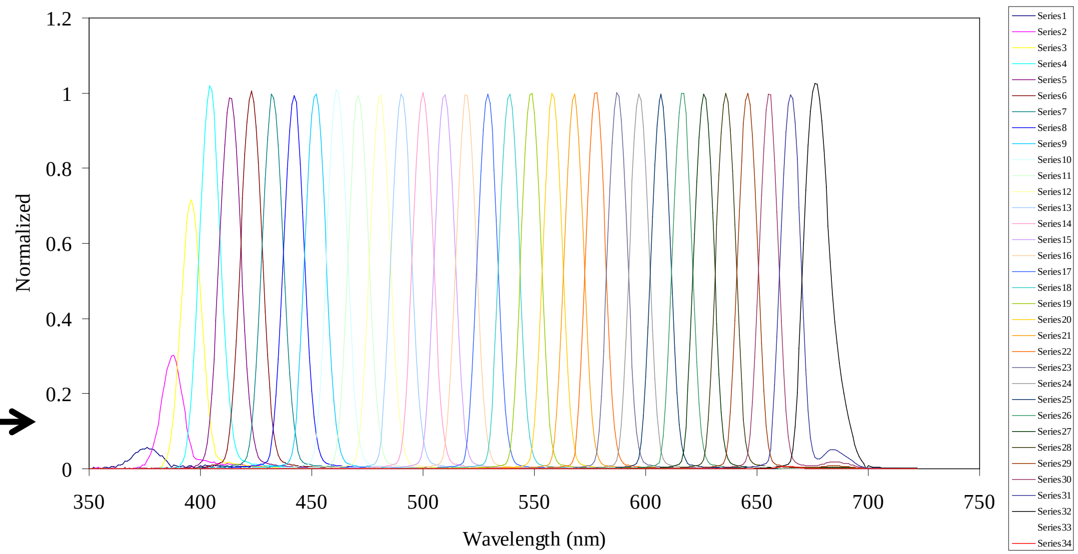
Spectral Cross-Track	>95% cross-track uniformity {<0.5 nm min-max over swath}
Spectral-IFOV-Variation	>95% spectral IFOV uniformity {<5% variation over spectral range}

Laboratory Calibration

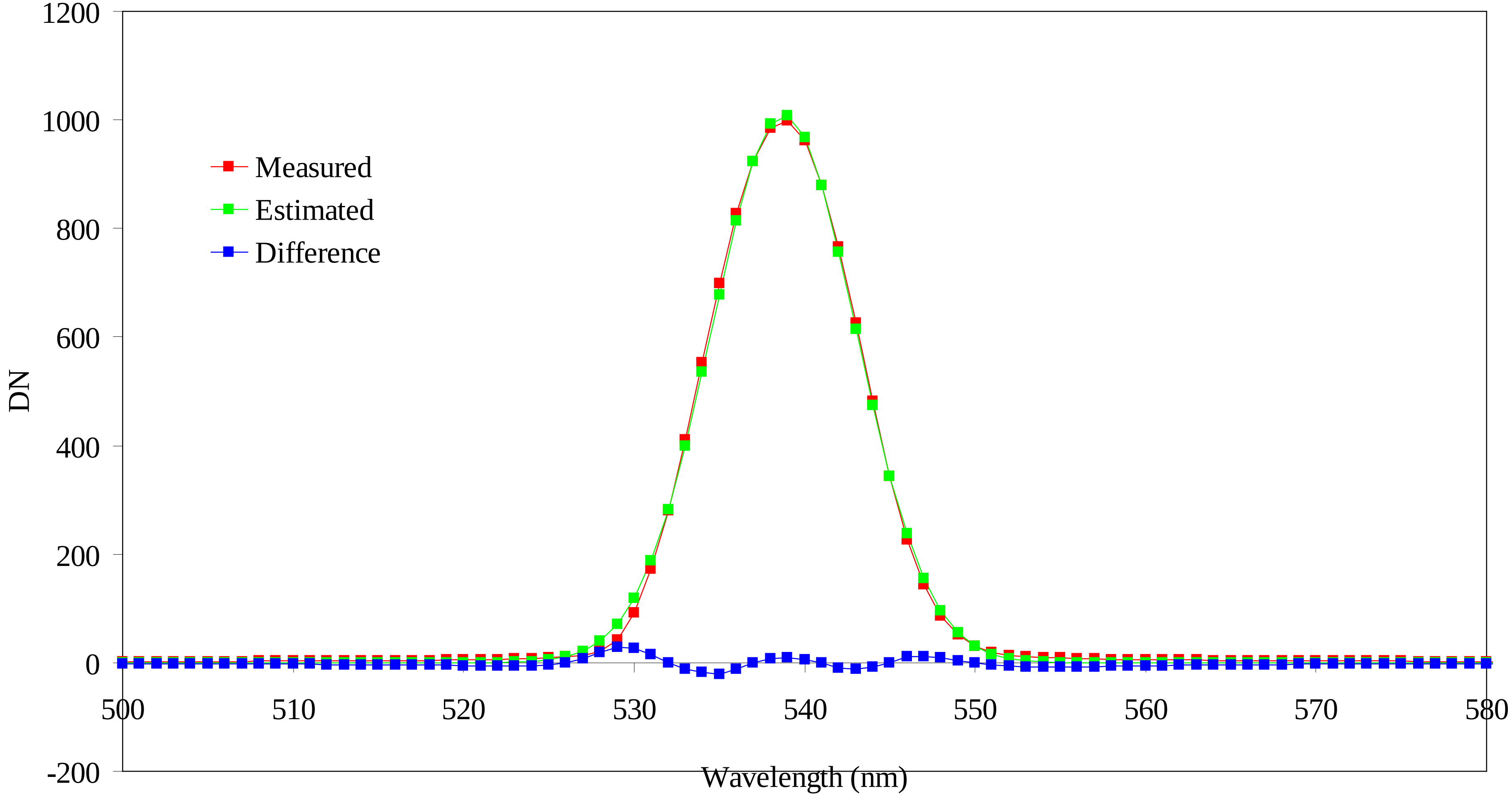
- Imaging Spectrometers have unique spectral, radiometric, and spatial characteristics
- Each calibration characteristic has response, range, and corresponding uncertainty factors
- With 100s of spectral channels and 100,000s of detector elements, imaging spectrometers present special challenges for calibration
  - HyspIRI 532,500 detector elements

Spectral Calibration

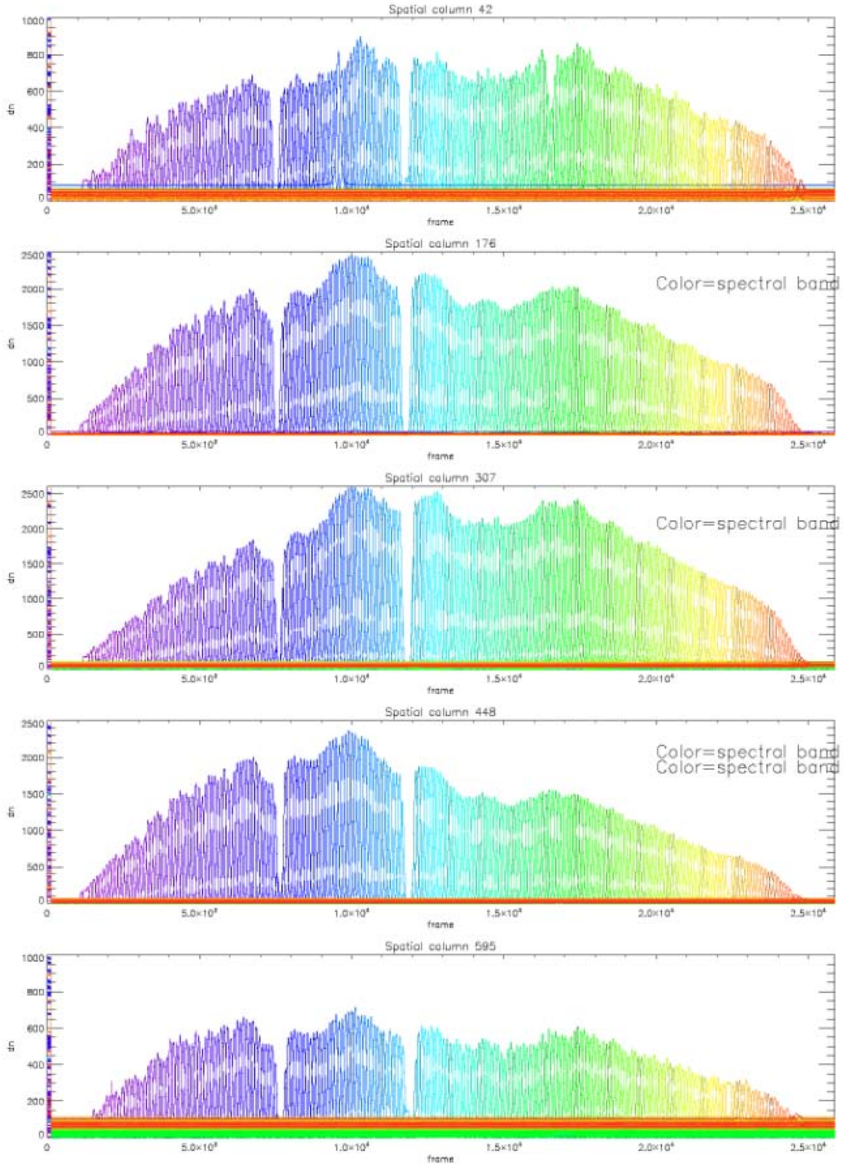
- Standards
  - Emission lamps, lasers and rare-earth target
- Approach
  - Collimator fed by scanned monochromator
  - Laser fed integrating sphere
  - Illuminated neodymium panel
- Calibration Analysis Output
  - 2D spectral calibration file with uncertainties for Global and Target modes
- Example
  - AVIRIS Spectral Response Functions (from ~2001)



Spectral Fit for Determination of Best Gaussian Function

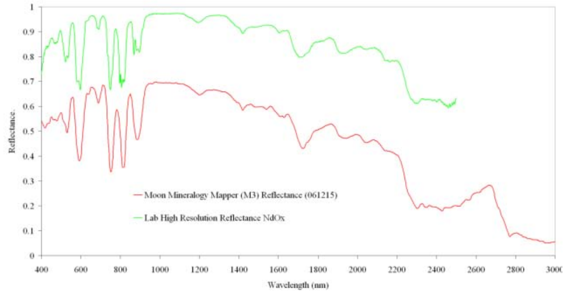


2010 Spectral Response Function Measurements



Spectral Equipment

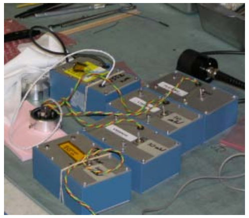
Illuminated Nd Panel



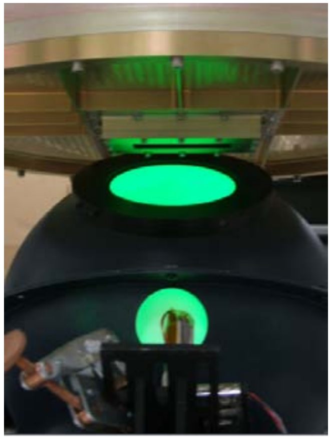
Custom Scanning Monochromator with Collimator

Laser-fed Integrating Sphere

407 nm
532 nm
632 nm
780 nm
830 nm
1064 nm
1a550 nm
2050 nm

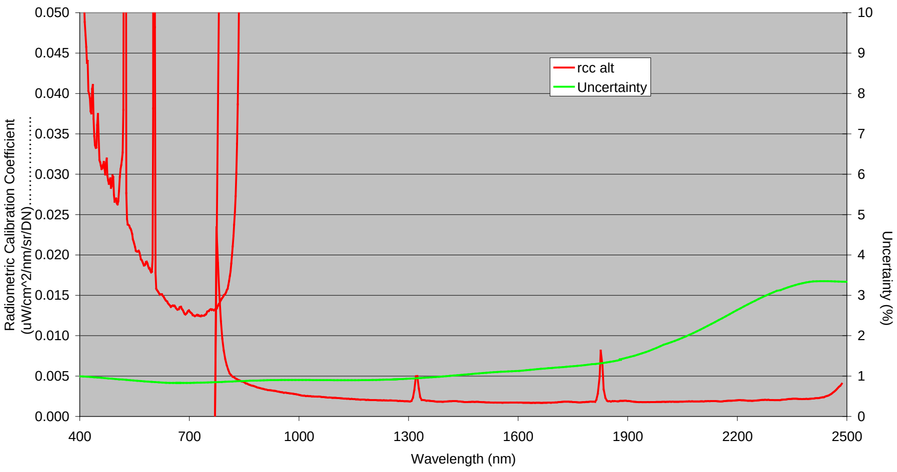


Sphere In Use



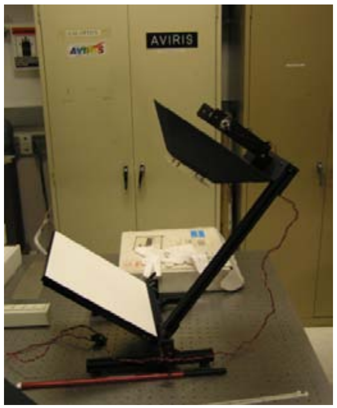
Radiometric Calibration

- Standards
  - NIST traced lamp panel 400 to 2500 nm
  - Blackbody (BB) 1500 to 3000 nm
  - Stable integrating sphere
- Approach
  - Direct view of NIST lamp panel, integrating sphere, and BB
- Calibration Analysis Output
  - 2D radiometric calibration coefficients and uncertainties
- Example
  - Airborne-IS : 321000 radiometric calibration coefficients and uncertainty

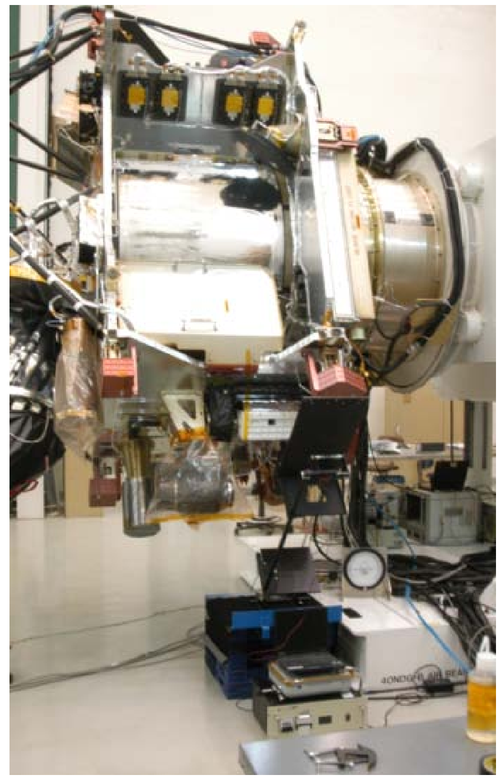


Radiometric Equipment

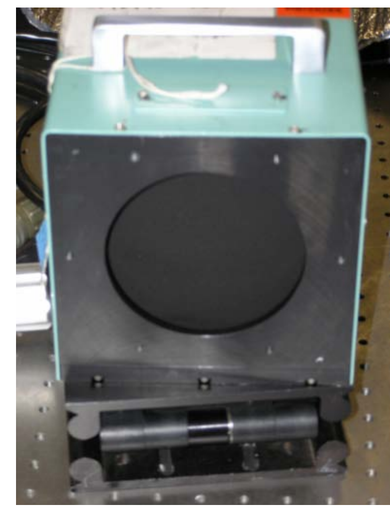
NIST Traced Lamp-Panel
400 to 2500 nm



NIST Traced Lamp-Panel
used for CRISM Check



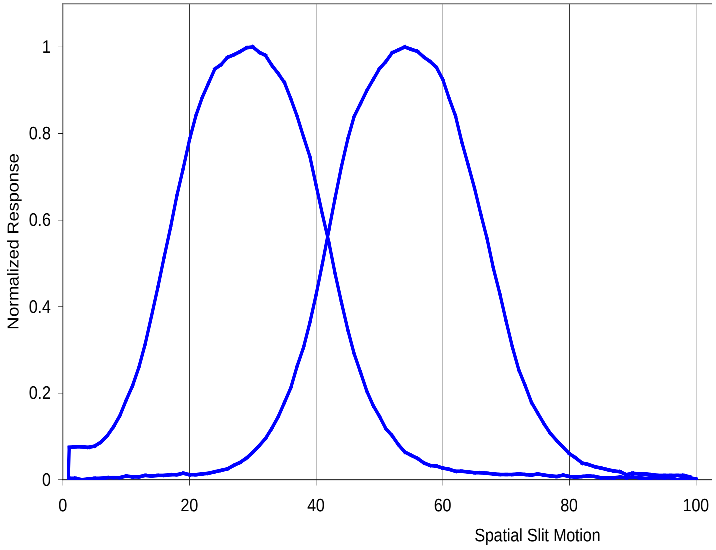
Extended Area Blackbody
1500 to 3000 nm



White-light Integrating Sphere
for Vignetting and Flat Field

Spatial Calibration

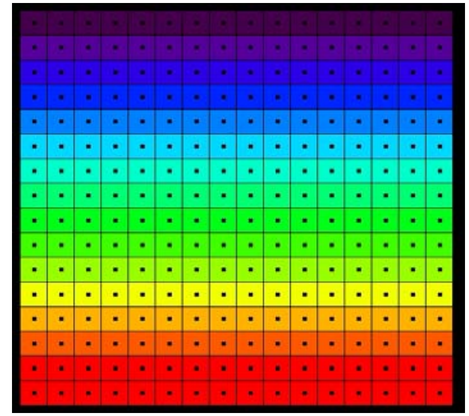
- Standards
  - White light illuminated slit
- Approach
  - Collimator fed by scanned white light slit
- Calibration Analysis Output
  - 2D spatial response functions
    and uncertainties
- Example
  - Airborne-IS spatial response functions



Geometric Calibration

- Standards
  - Spatial targets plus validated optical design
- Approach
  - Use optical design plus selected lab collimator fed spatial targets
  - Theodolite measurements of telescope projected slit
- Calibration Analysis Output
  - Camera model cosines
- Example
  - Airborne-IS georectification

HyspIRI Uniformity Calibration



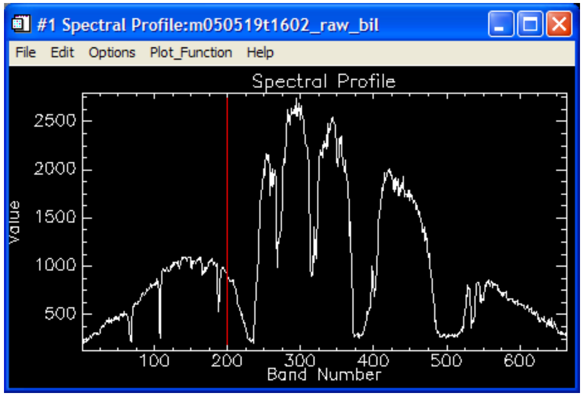
- Standards
  - Laser-fed integrating sphere
  - Neodymium panel
  - Scanning monochromator
  - Scanning white light slit
- Approach
  - Use optical design plus selected collimator-fed spatial targets
  - Use Laser-fed integrating sphere to cover FOV
- Calibration Analysis Output
  - Spectral cross-track uniformity
  - Spectral IFOV uniformity
- Example
  - M3 cross-track uniformity

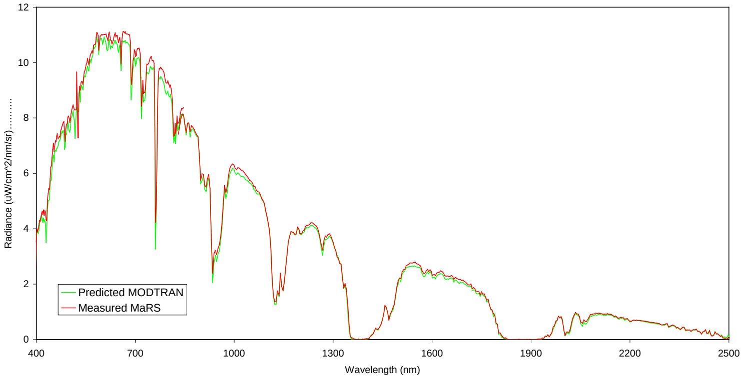
HyspIRI Example from Airborne-IS 2005

- Airborne-IS example from Ivanpah Playa
- Solar reflected spectrum
- Offner spectrometer
- TCM6604a detector array
- HyspIRI calibration standards and approach

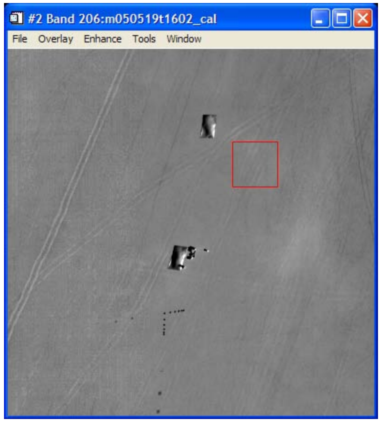
Level 0

DN versus Band

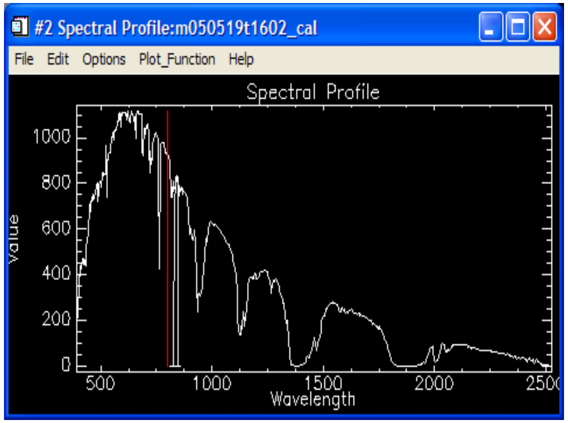




Level 1

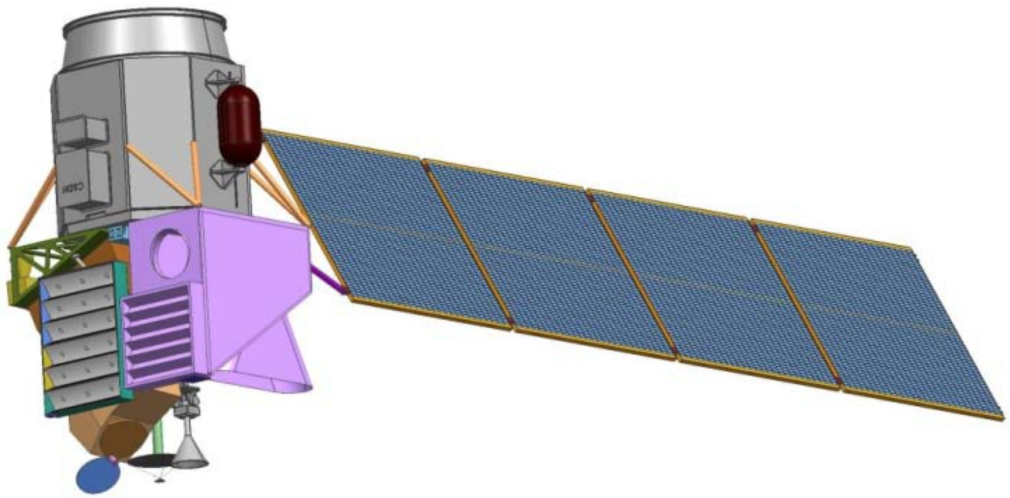


Radiance versus Wavelength

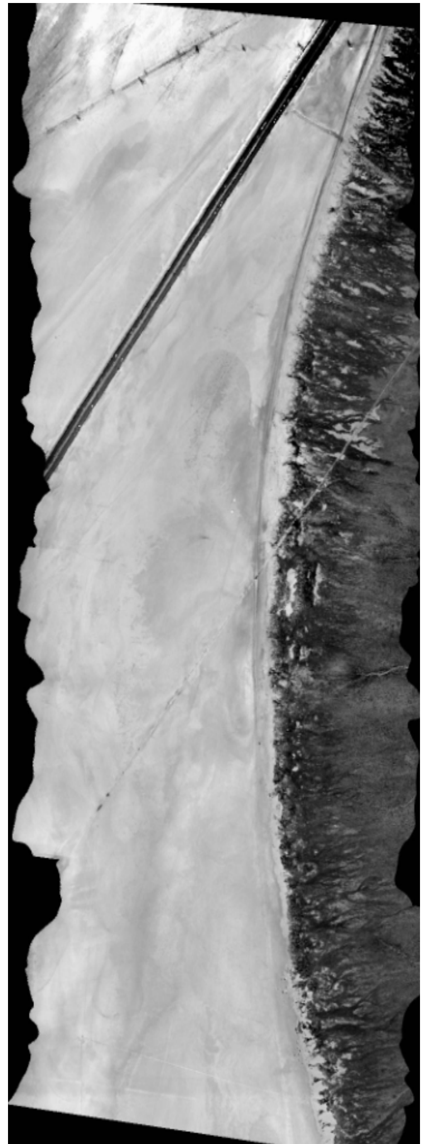


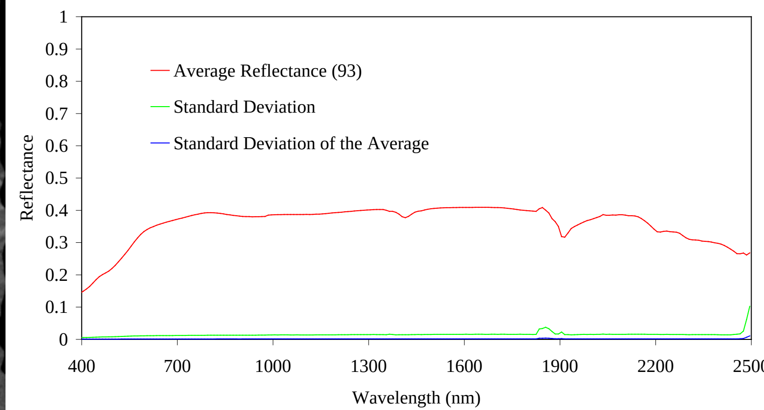
HyspIRI VSWIR Science Measurements On-Orbit Calibration Baseline

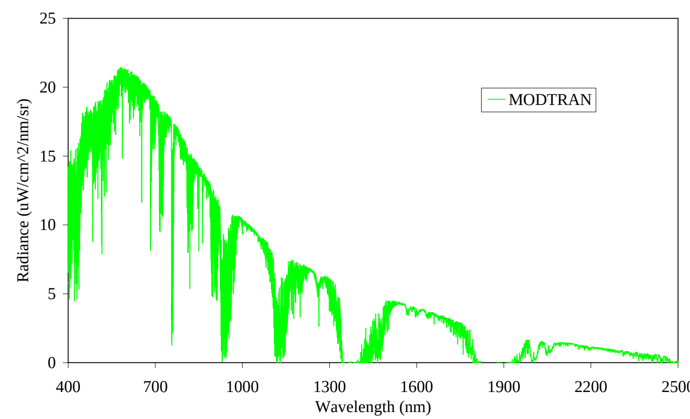
On-Orbit Calibration	
Lunar View	1 per month {radiometric}
Solar Cover Views	1 per day {radiometric}
Dark signal measurements	1 per orbit and edge detector tracking
Surface Cal Experiments	>3 per year {spectral & radiometric}



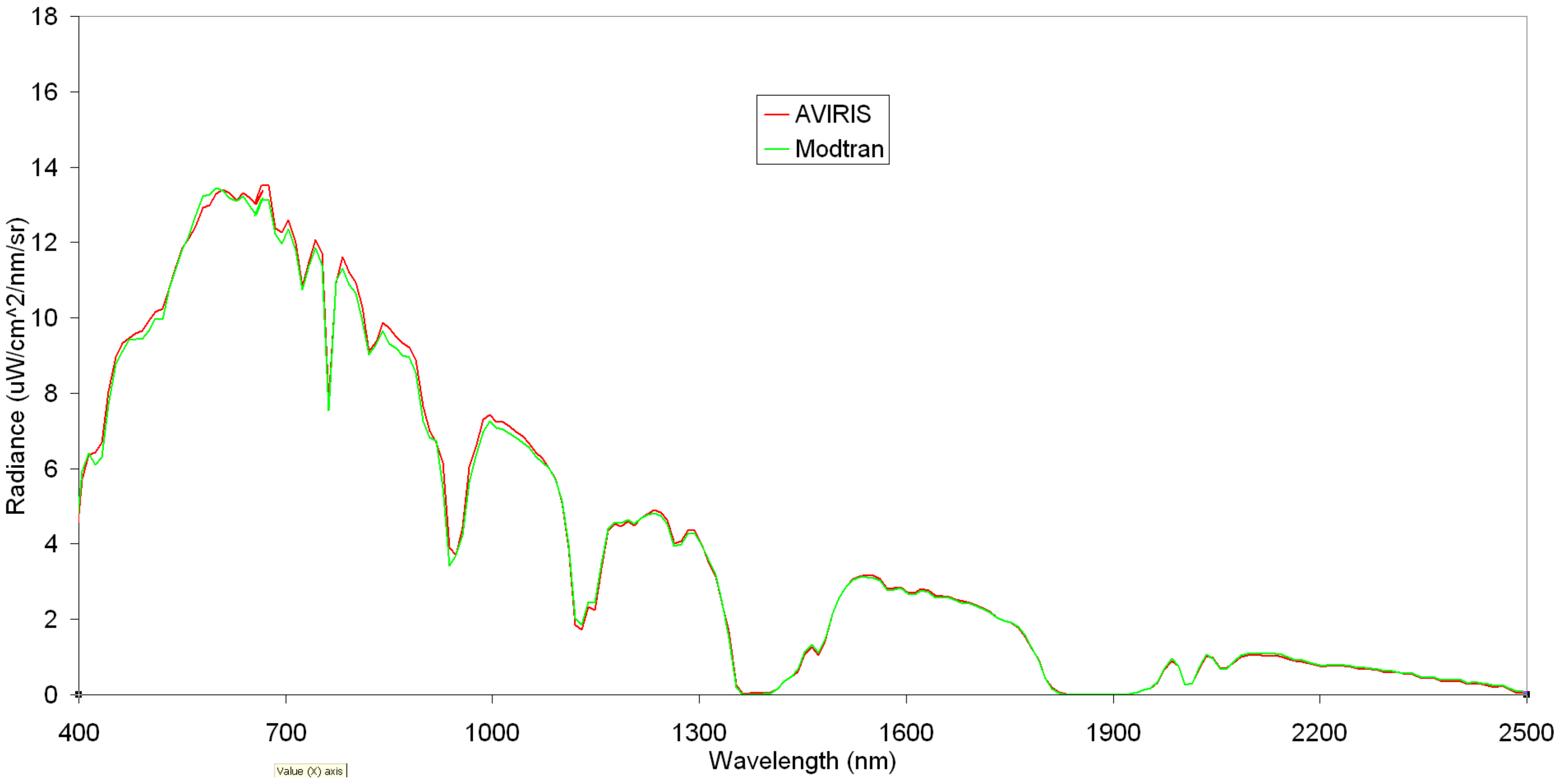
Inflight Calibration Validation Experiment



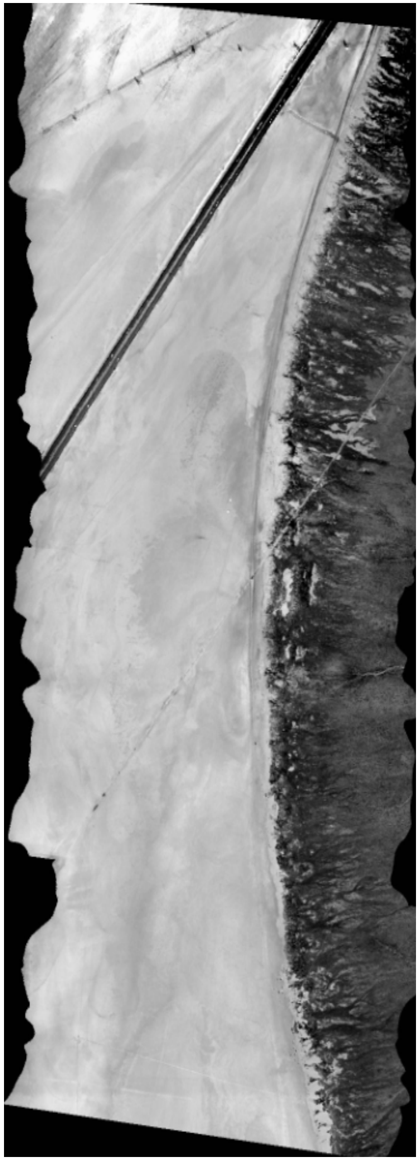


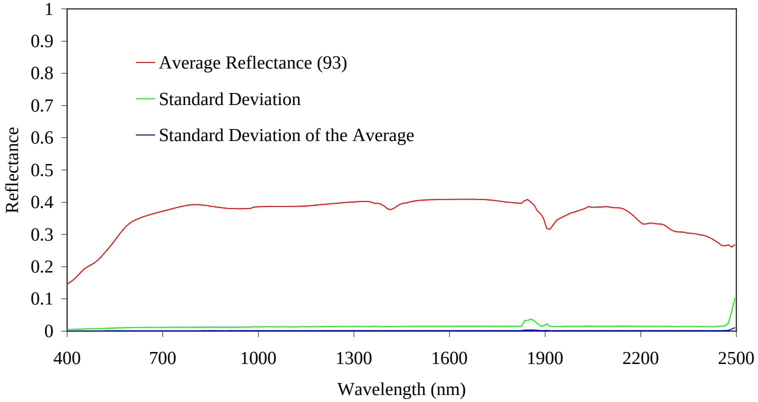


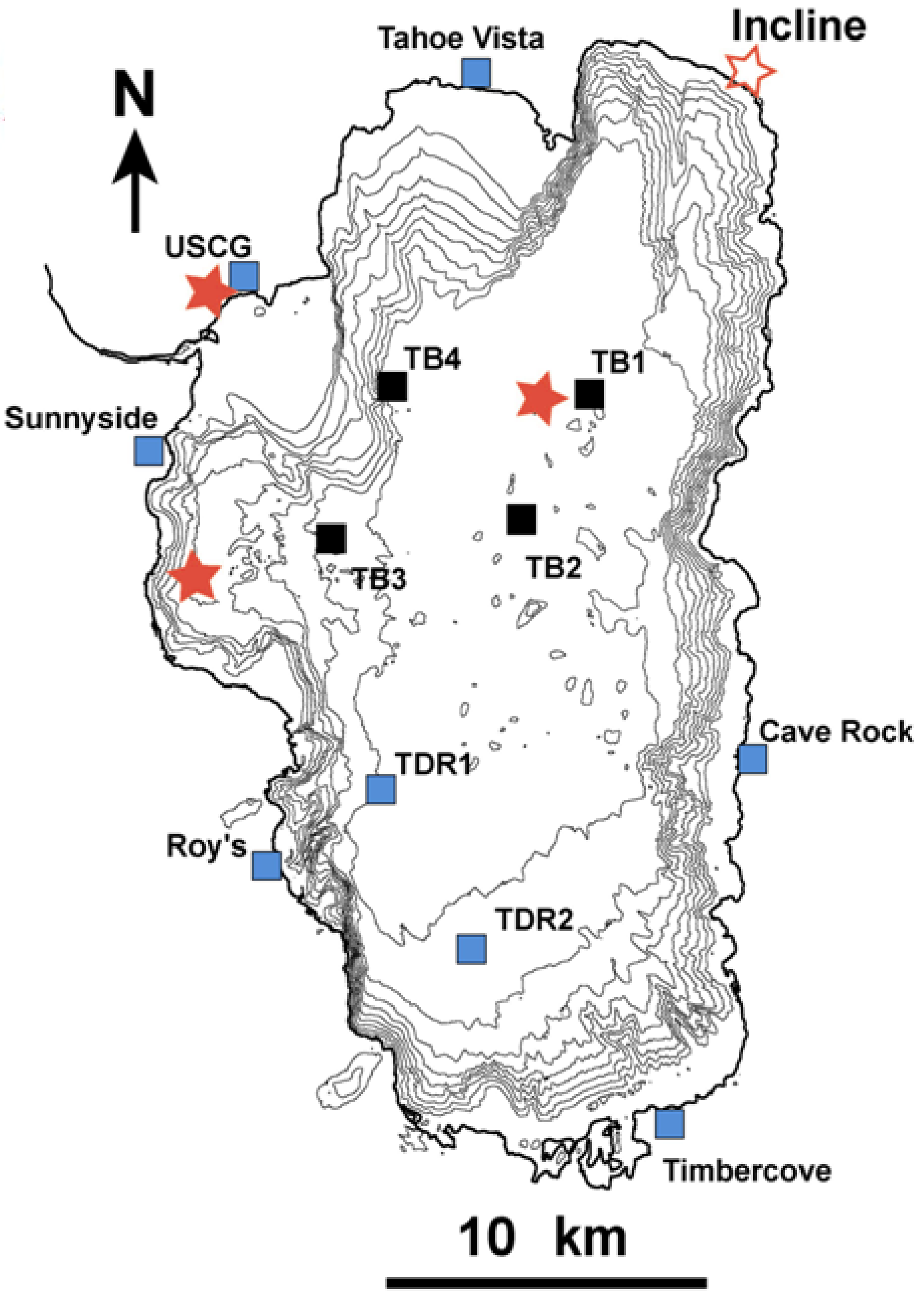
AVIRIS Calibration Experiment
060506



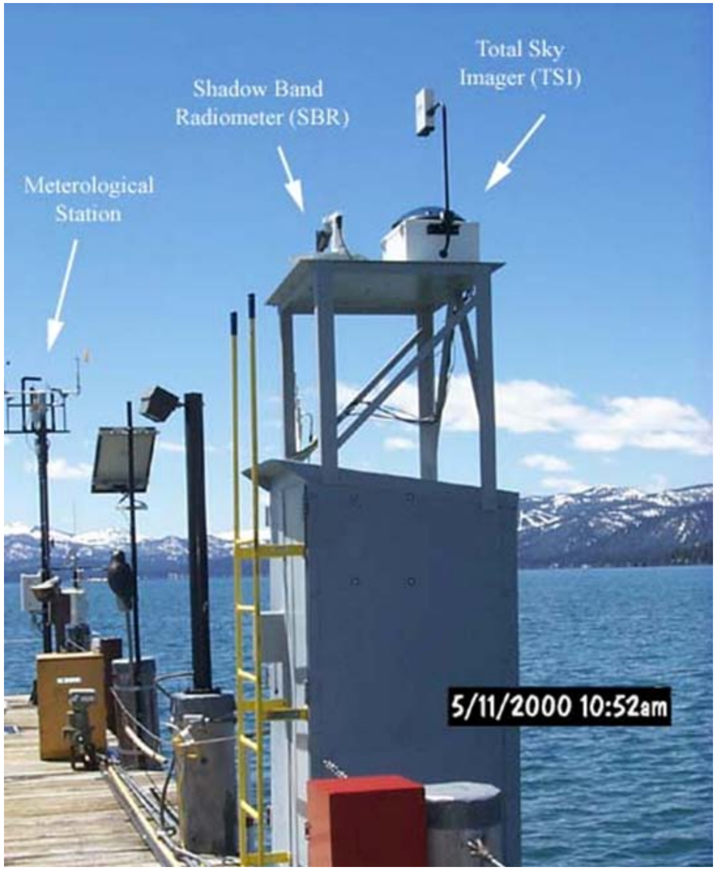
Level 2 Reflectance Validation

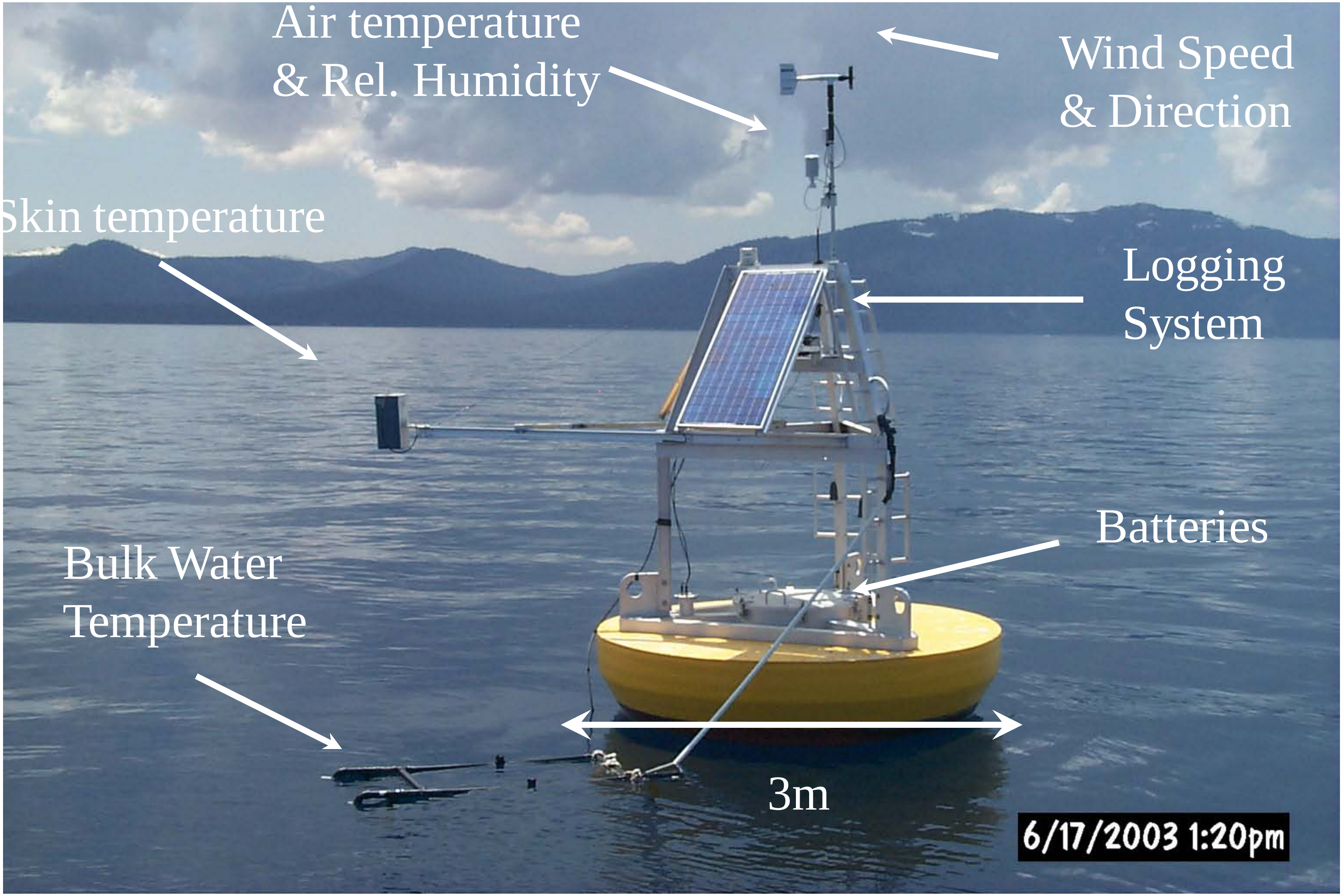






Candidate Dark Target Validation Site




Air temperature
& Rel. Humidity
Wind Speed
& Direction
Skin temperature
Logging
System
Batteries
Bulk Water
Temperature
3m
6/17/2003 1:20pm

International Interaction for Calibration and Validation

- Australia
  - **Calibration Validation**, Carbon, Coastal Ocean GBR
  - Data Processing
- Canada
  - Product validation, Forestry,
  - Data Processing
- Israel
  - **Calibration Validation**
- Europe
  - EnMap, PRISMA, Product validation
  - Data Processing
- Brazil
  - Product validation
- Argentina
  - **Calibration Validation**, Product validation
- India
  - Agriculture, Himalaya, Product validation

HyspIRI Calibration Summary

- The HsypIRI calibration requirements are well understood.

- The imaging spectrometer calibration history for HyspIRI is strong.
  - AVIRIS, WarFighter, Hyperion, CRISM, Airborne-IS, M3, etc.

- Detail ground calibration procedures and practices are in understood

- The HyspIRI VSWIR instrument includes a solar calibration panel (Hyperion derivative), Monthly lunar views, and ground calibration validation.

- On-Orbit Calibration experiments are core to the baseline mission

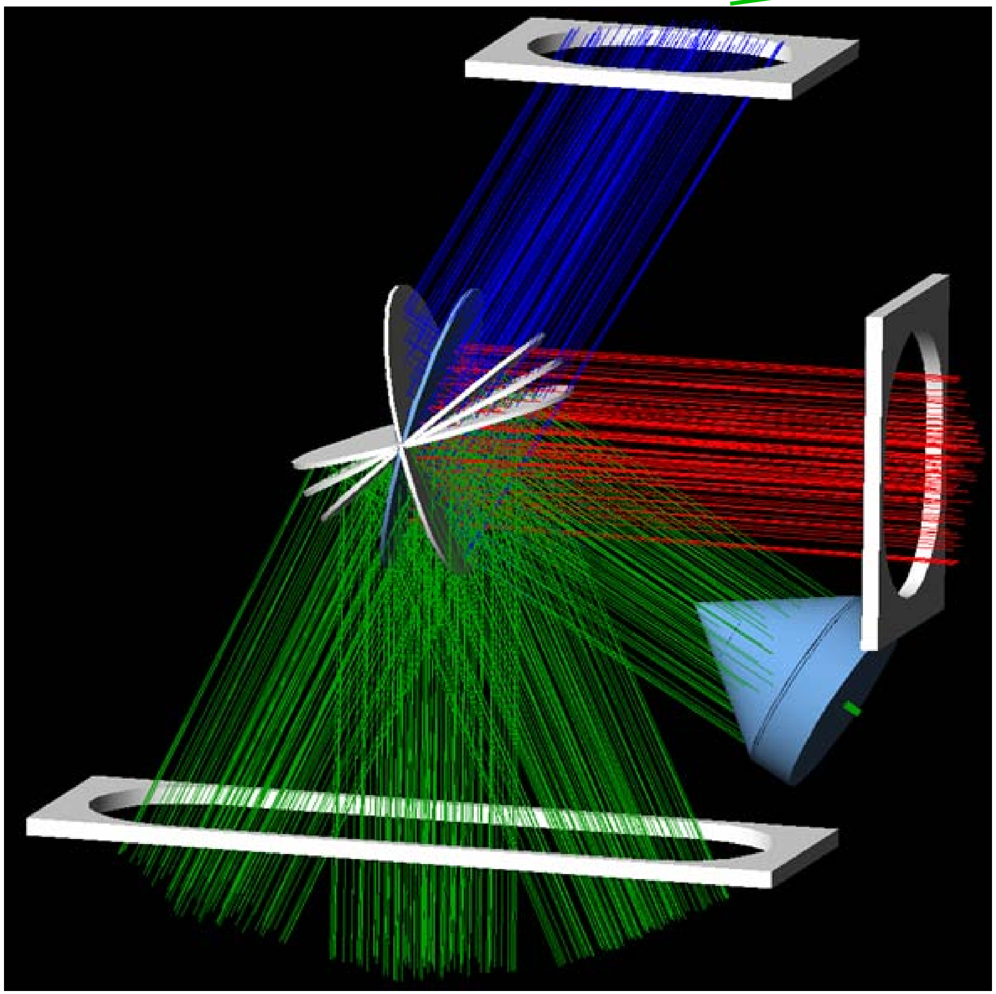
- Level 2 product validation will be performed for a range of surface types from bright to dark.

- Extensive international collaboration is planned for calibration and validation of level 1 and level 2 products

HyspIRI-TIR
Cal/Val Approach

Simon J. Hook, Marc C. Foote, Glynn Hulley, William R. Johnson

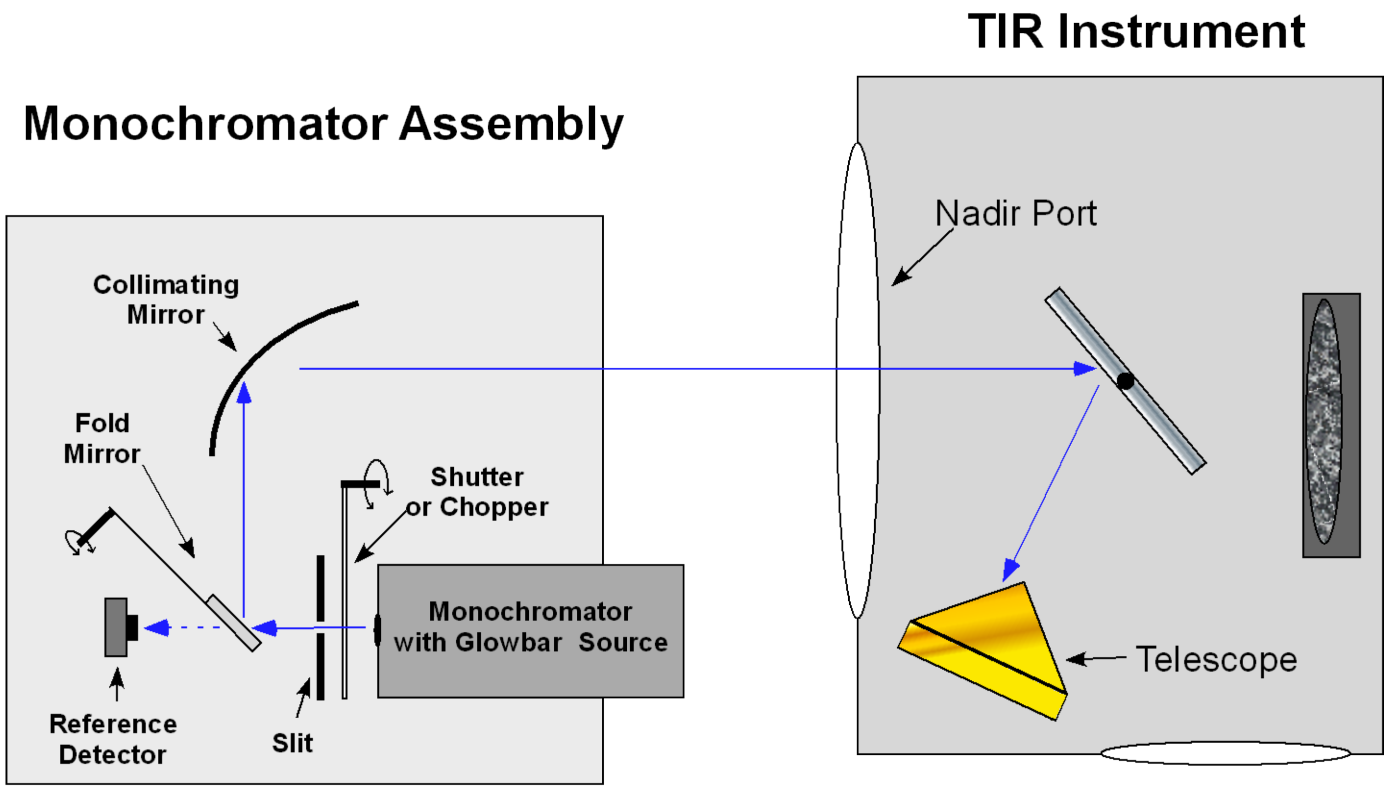
TIR Concept



Calibration Overview

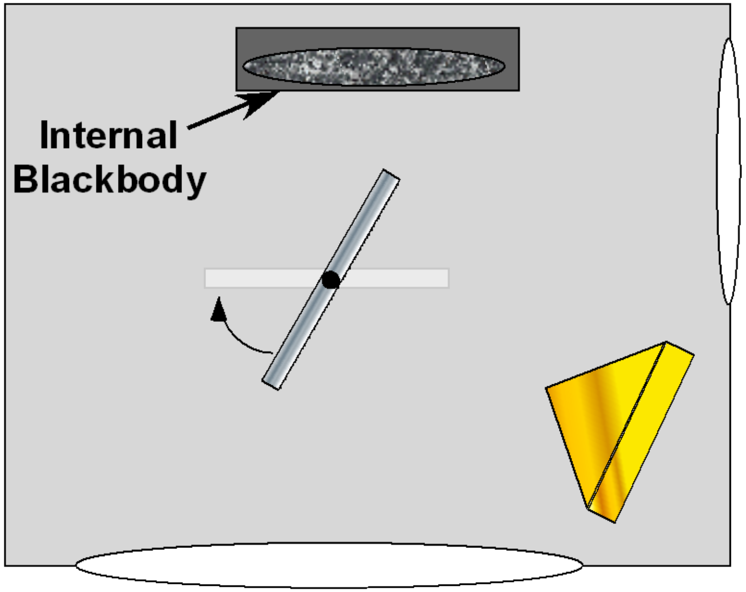
- Spectral Calibration
- Radiometric Calibration
- Spatial Calibration
- On-Orbit Calibration

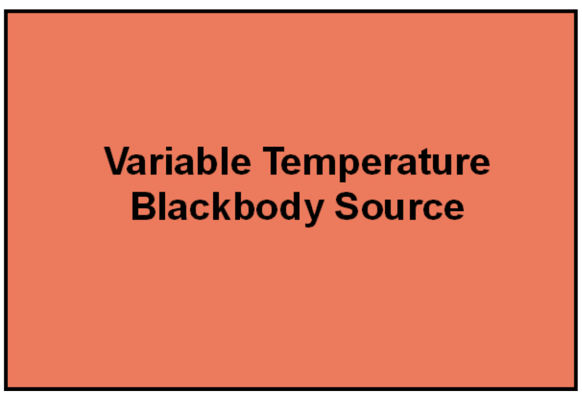
Spectral Calibration with Monochromator



- Heritage (JPL) – PMIRR, TES, MCS, Diviner
- Straightforward approach with reliable results.
- Only a small number of pixels are measured at once. Very time intensive to measure all pixels over full spectral range.

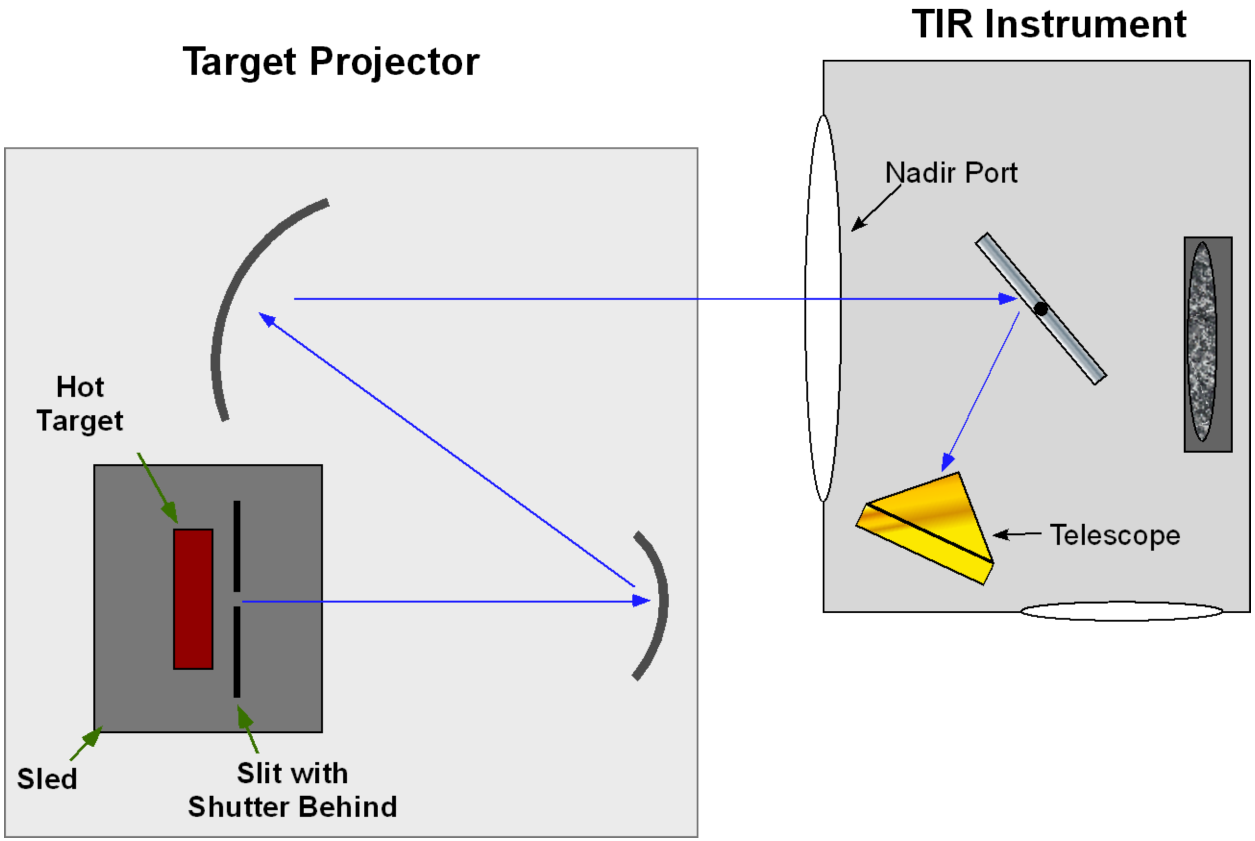
Radiometric Calibration





- Performed in vacuum to prevent condensation on cold blackbody surfaces.
- Scan mirror rotates to scan between internal blackbody, cold blackbody, and variable temperature blackbody.
- Variable temperature blackbody is stepped over entire scene temperature range.
- System nonlinearities can be determined using measured spectral response and blackbody response.
- NETD determined by temperature response and noise level.

Spatial (FOV) Calibration



- For cross-scan FOV measurements (slit out of page), TIR scan mirror will sweep slit across focal plane.
- For along-scan FOV measurements (slit vertical on page), slit will be scanned in perpendicular direction (perpendicular to page) to map out focal-plane FOV.

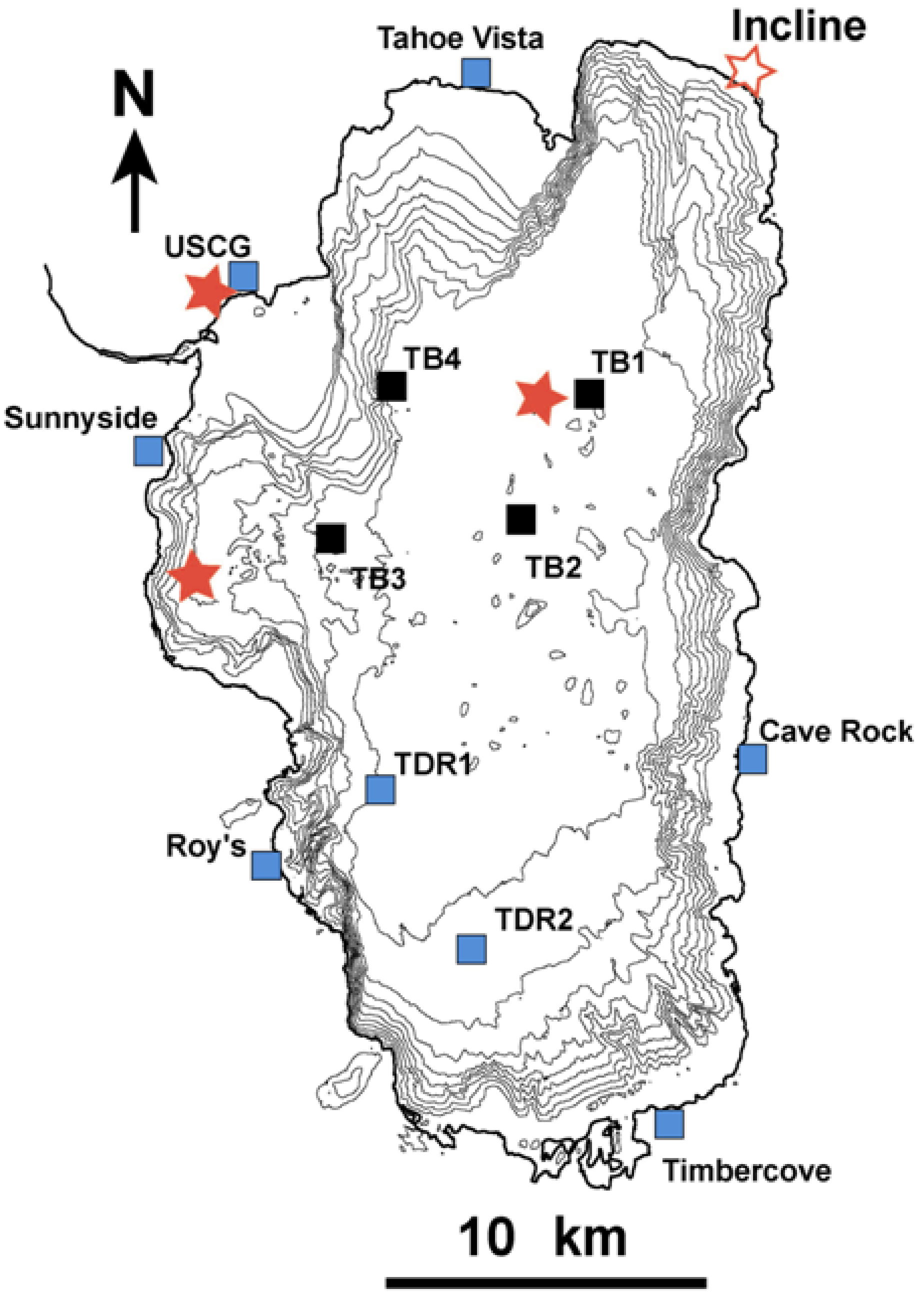
Validation Framework

- Multi-Component Approach
- Monitoring of instrument outputs (BB performance etc)
- Cross comparison of HyspIRI radiance with other instruments (airborne and spaceborne, emphasize HyTES)
- Validation against in situ targets (Tahoe and Salton Sea)

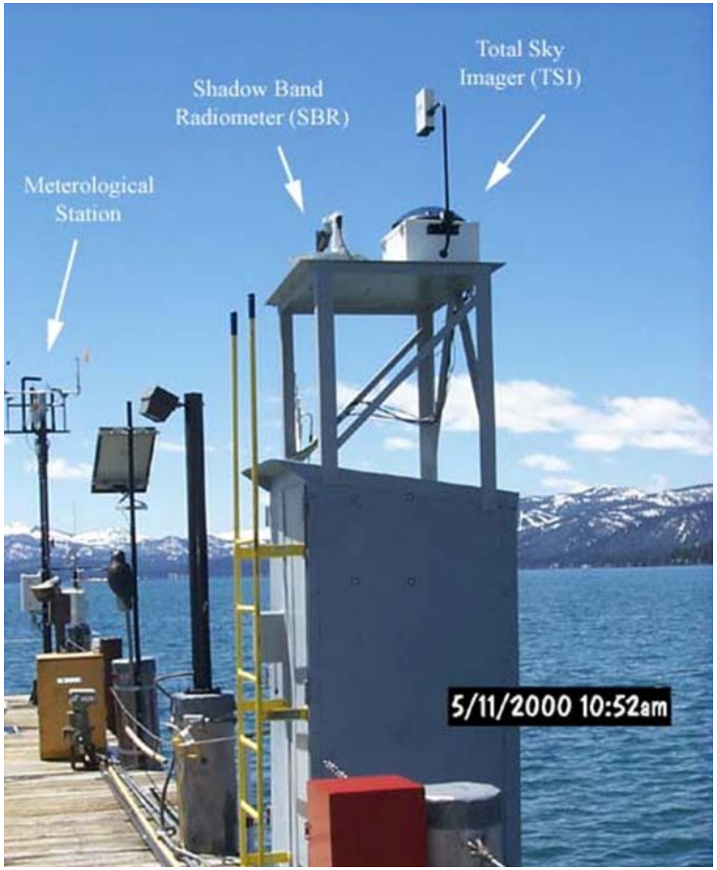
On-Orbit CalVal

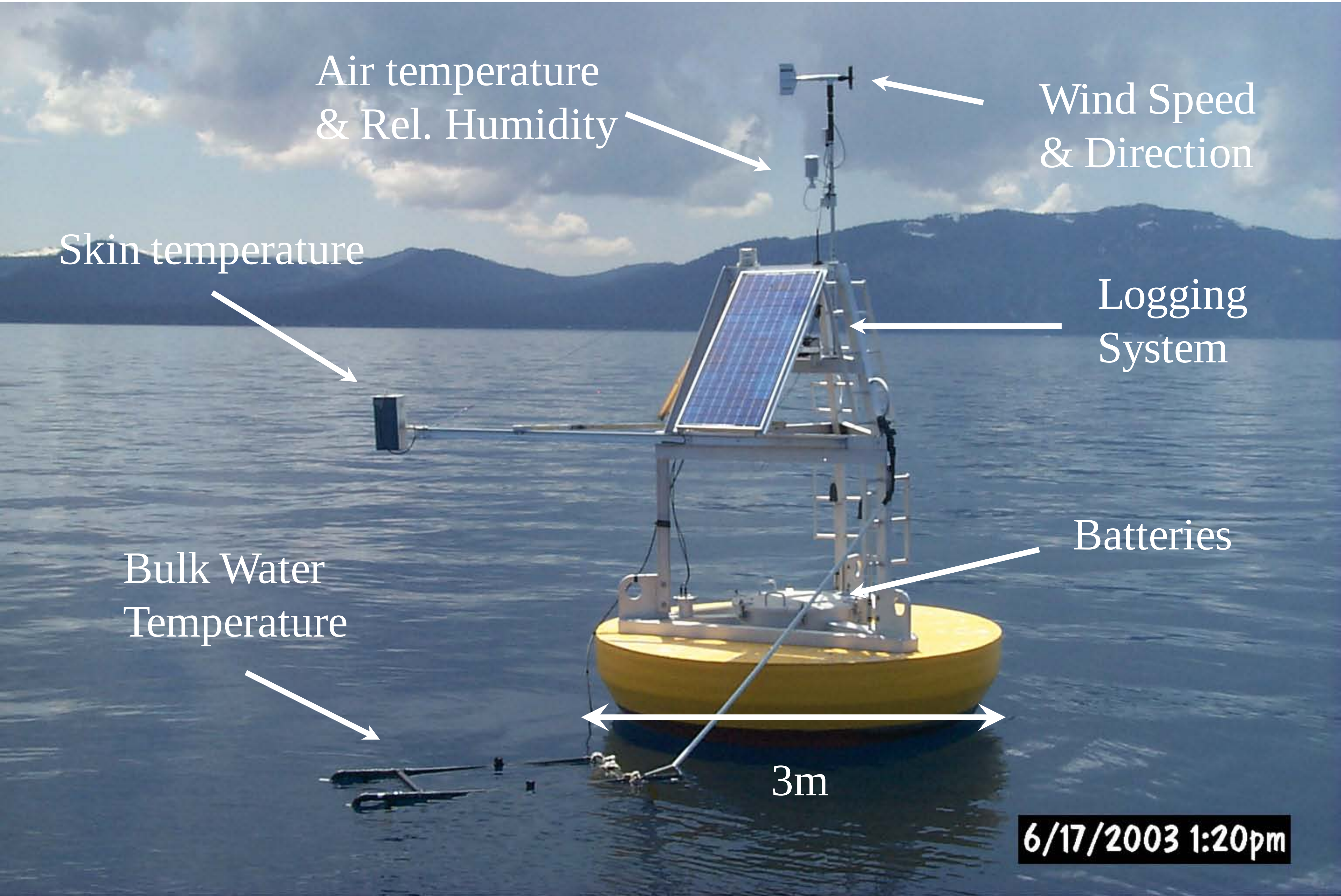
Lunar View	1 per month {radiometric}
Blackbody Views	1 per scan {radiometric}
Deep Space Views	1 per scan {radiometric}
Surface Cal Experiments	2 (d/n) every 5 days {radiometric}
Spectral Surface Cal Experiments	1 per year

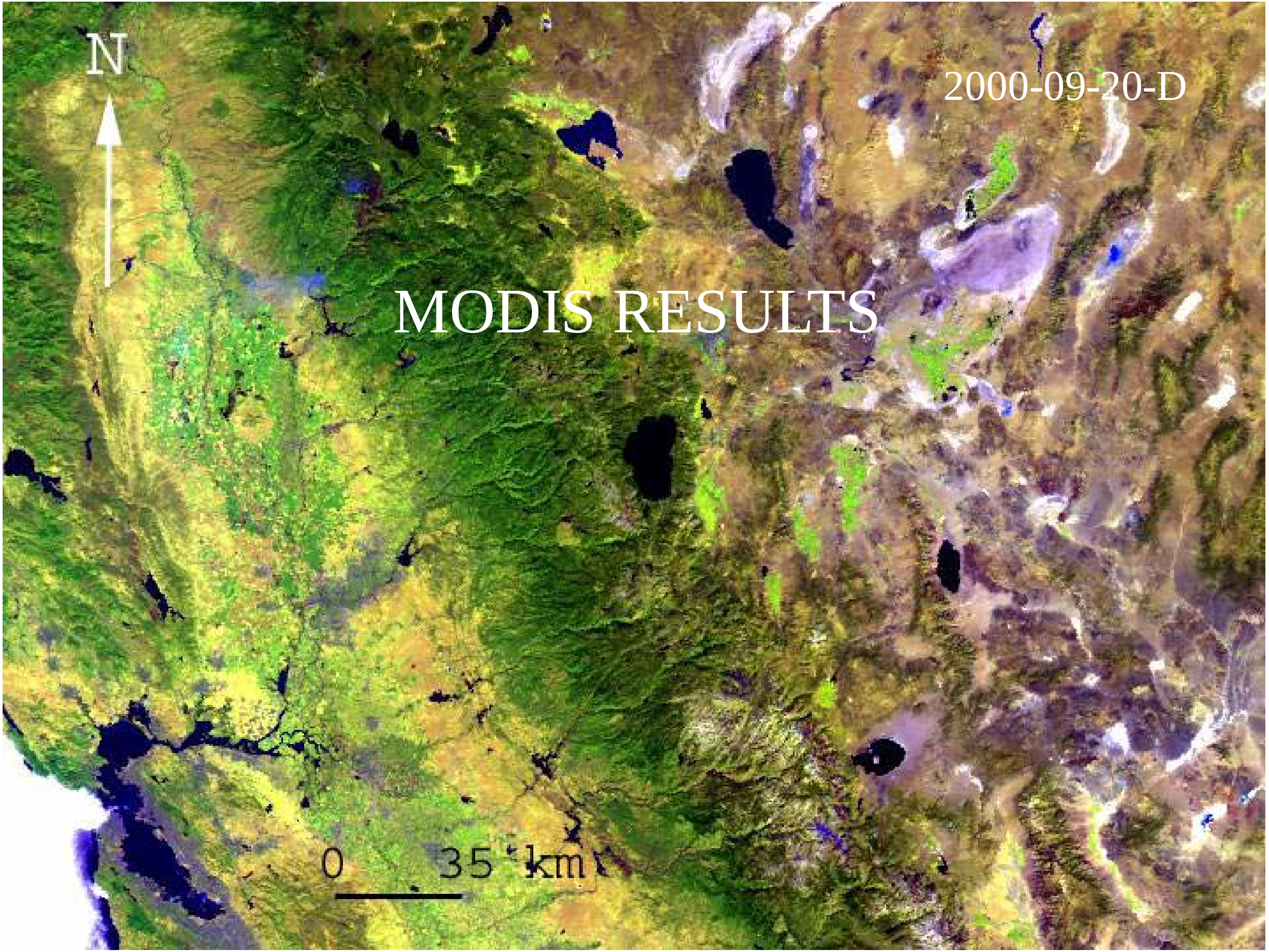
- Two-point calibration, using space and an ambient temperature blackbody, will be performed every 2.1 seconds.
- Detector specs limit 1/f noise over 2.1 second period. Optics/baffle design limits thermal drifts over 2.1 seconds.
- Data stream will include averaged values of space and blackbody readings for each pixel.
- Nonlinearities measured during ground calibration will be incorporated into calibration algorithm (performed on ground).

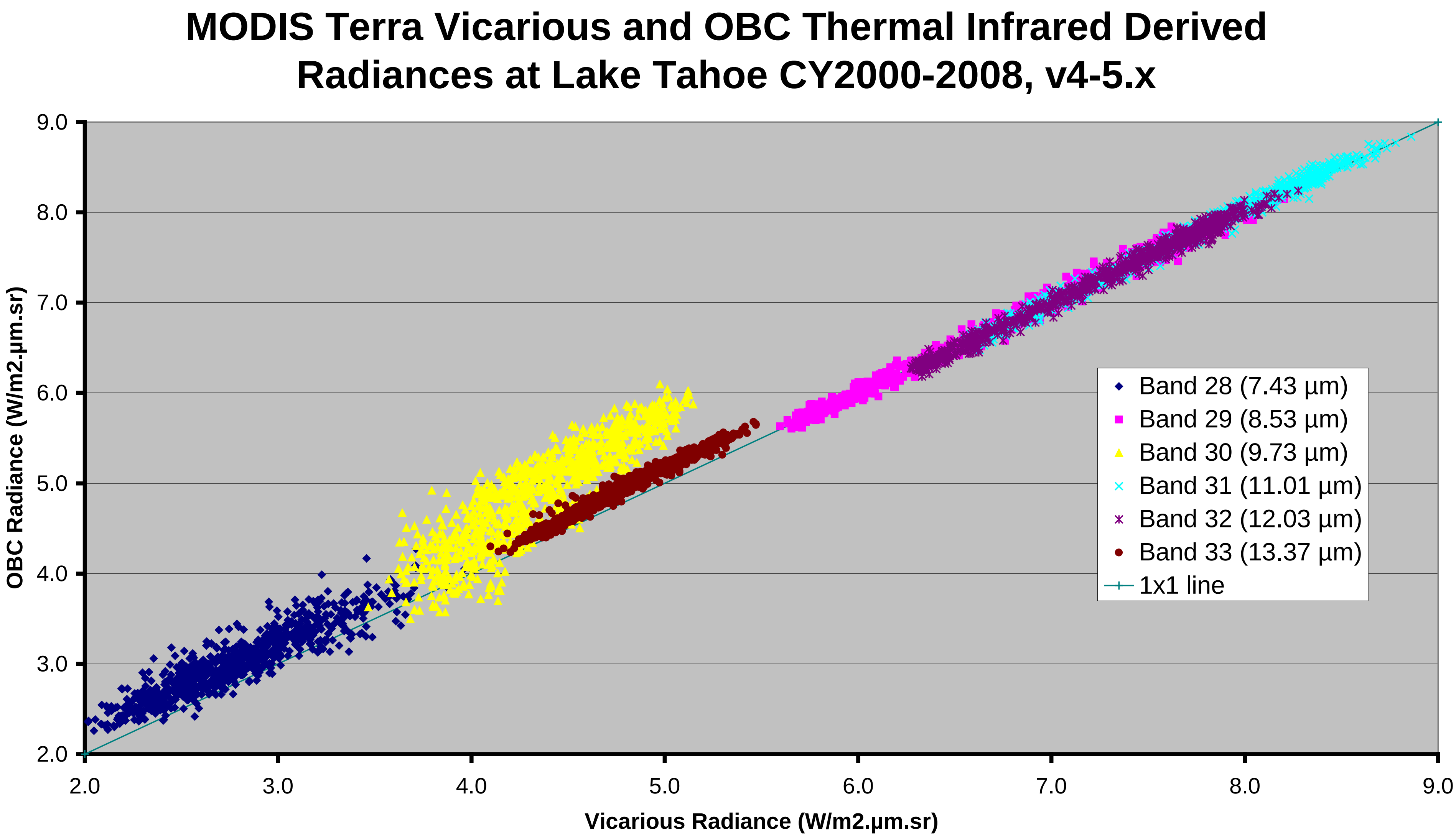


Site Layout and Measurement Stations

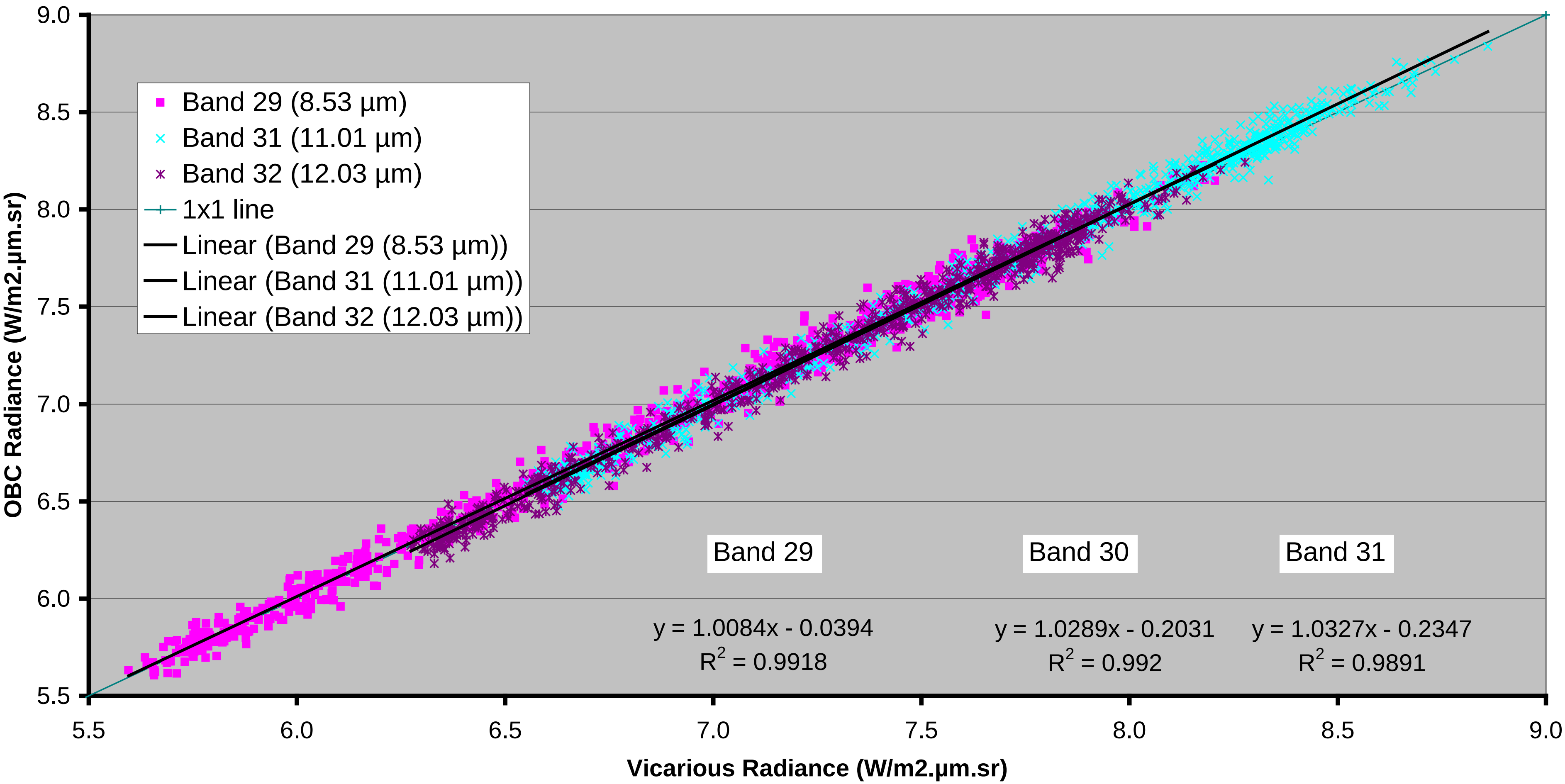


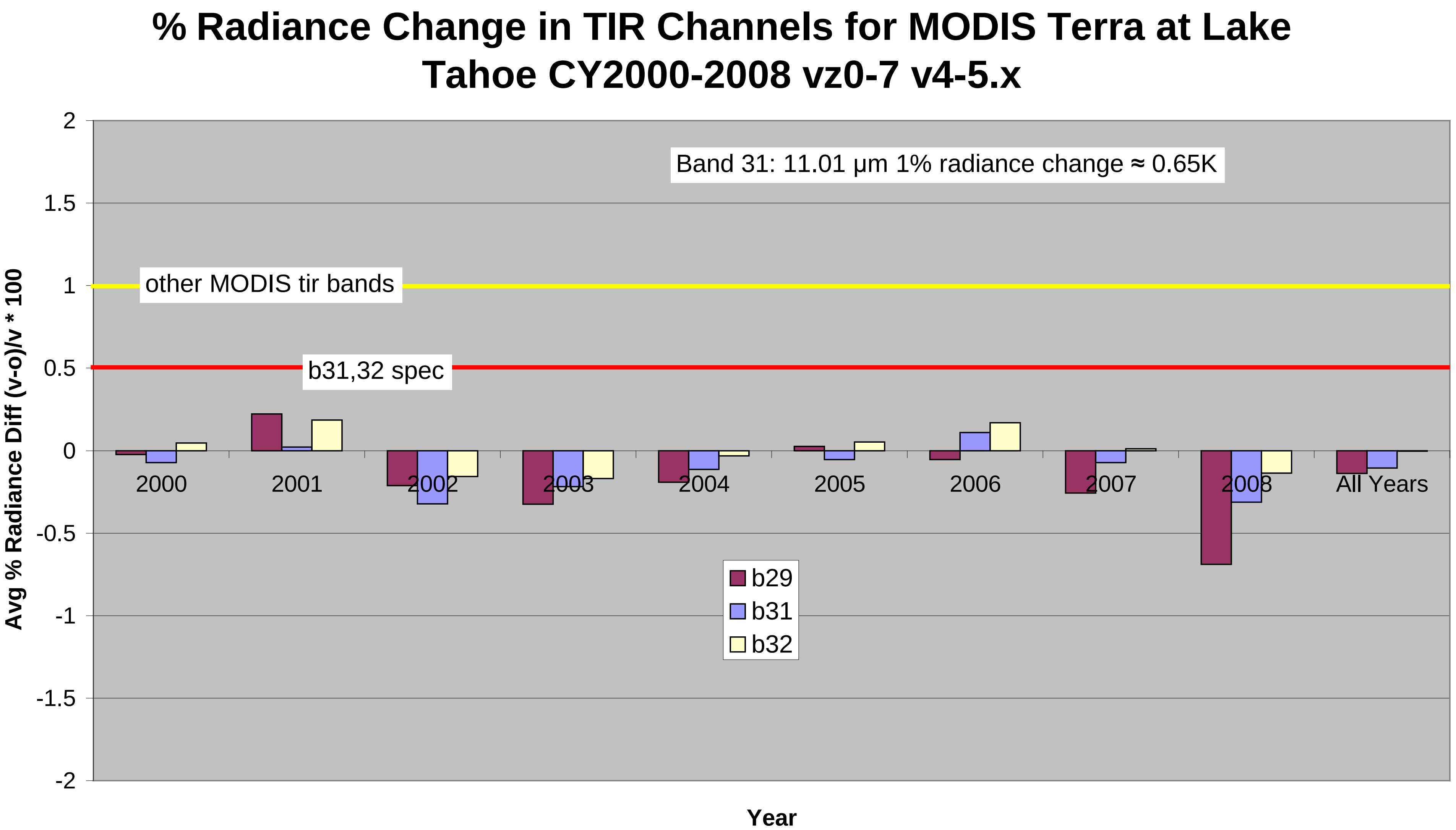

Air temperature
& Rel. Humidity
Wind Speed
& Direction
Skin temperature
Logging
System
Batteries
Bulk Water
Temperature
3m
6/17/2003 1:20pm


N
2000-09-20-D
MODIS RESULTS
0 35 km


MODIS Terra Vicarious and OBC Thermal Infrared Derived Radiances at Lake Tahoe CY2000-2008, v4-5.x
OBC Radiance (W/m2.µm.sr)
Vicarious Radiance (W/m2.µm.sr)
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
Band 28 (7.43 µm)
Band 29 (8.53 µm)
Band 30 (9.73 µm)
Band 31 (11.01 µm)
Band 32 (12.03 µm)
Band 33 (13.37 µm)
1x1 line

MODIS Terra Vicarious and OBC Thermal Infrared Derived Radiances at Lake Tahoe CY2000-2008, v4-5.x





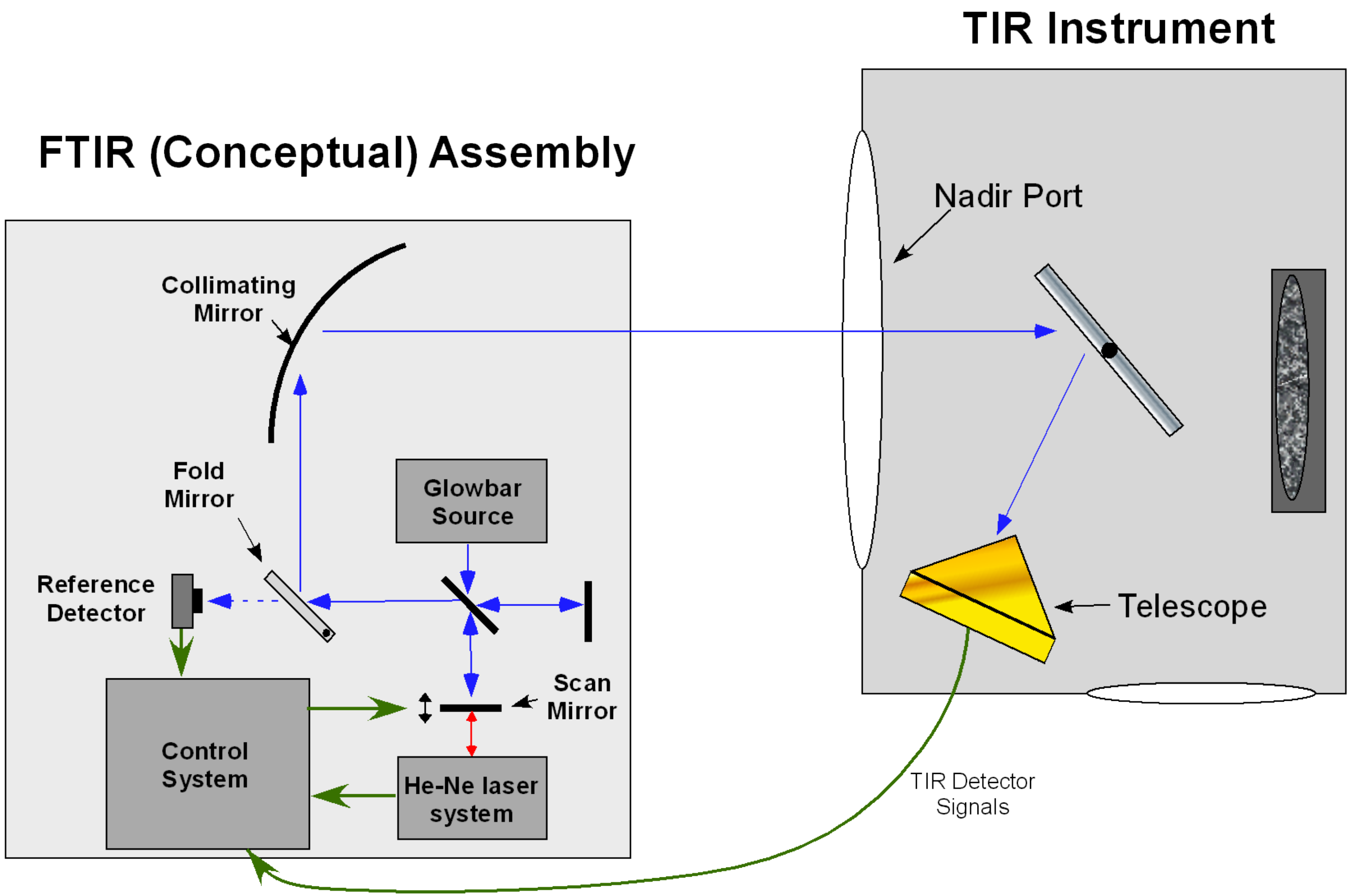
In previous presentations only showed nadir data (461 match ups as above) due to manual processing, now have more automated system allowing all clear data to be processed (5219 match ups)

Summary and Conclusions

- Pre-flight
  - Spectral calibration
  - Radiometric calibration
  - Spatial calibration
- In-flight
  - Radiometric: 2 point (blackbody and space view)
  - Radiometric: lunar
  - Radiometric: ground sites, e.g. L. Tahoe

Backup

Spectral Calibration with FTIR



FTIR Spectral Calibration

Heritage:
- AIRS
- OCO

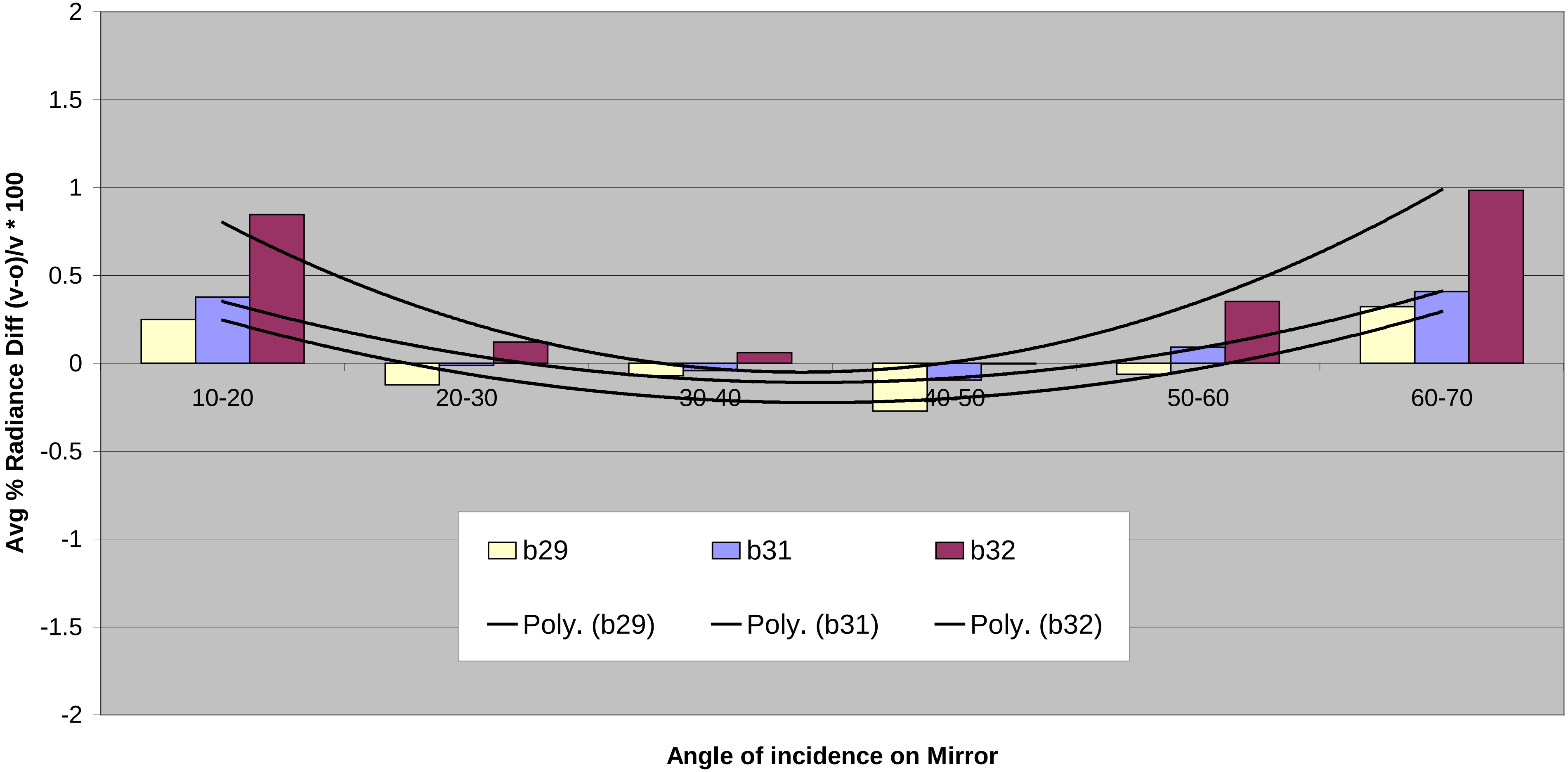
Advantages:
- All pixels and wavelengths measured simultaneously
- Automatic spectral calibration to Helium Neon laser standard wavelength (632.8nm)

Disadvantages:
- Requires stepping of FTS to be synchronized with sampling of TIR detectors, or cumbersome post analysis.

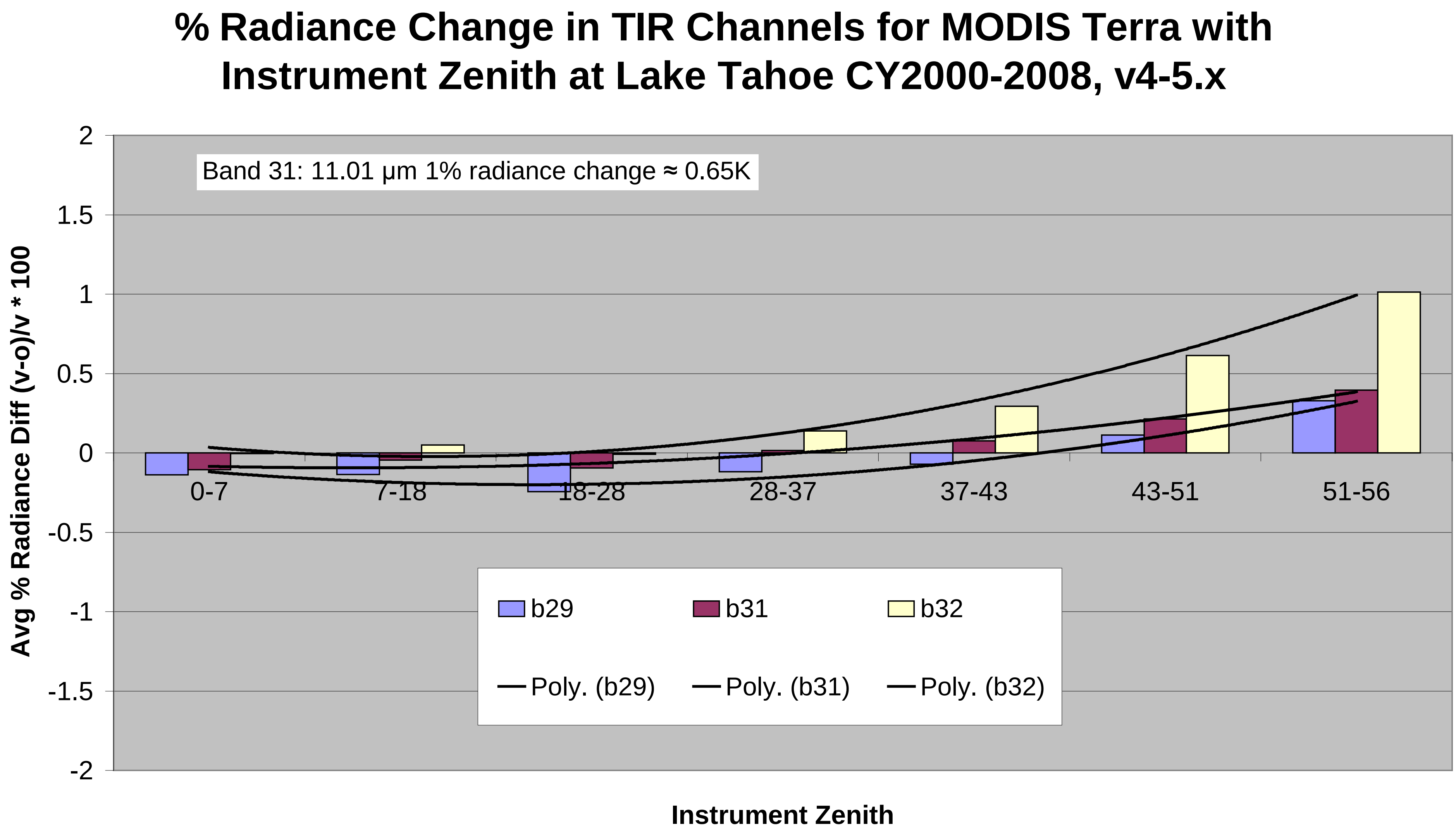
Calibration of Blackbody Source

- Cavity temperature will be determined using NIST-traceable sensors.
- NIST Thermal Infrared Transfer Radiometer (TXR) may be used to compare blackbody to NIST standard blackbody.

% Radiance Change in TIR Channels for MODIS Terra with Mirror AOI at Lake Tahoe CY2000-2008 v4-5.x



Low and high angle of incidences correspond to low and high viewing zeniths



Error increases with view angle. Most likely cause is change in emissivity with viewing zenith. Note increased path length in atmospheric correction was corrected.