Ecological Context for Ebola Outbreaks in the African Rainforest using Hyperspectral Data

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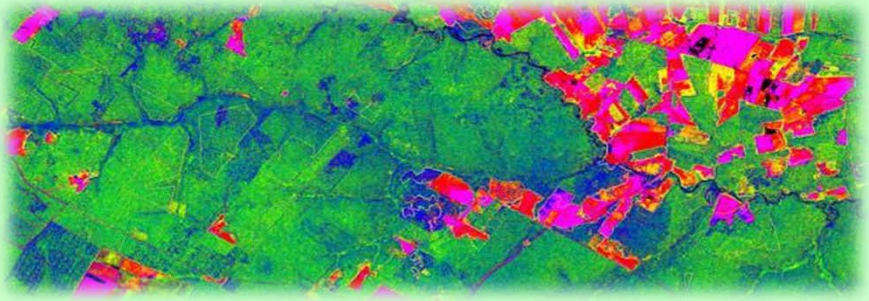
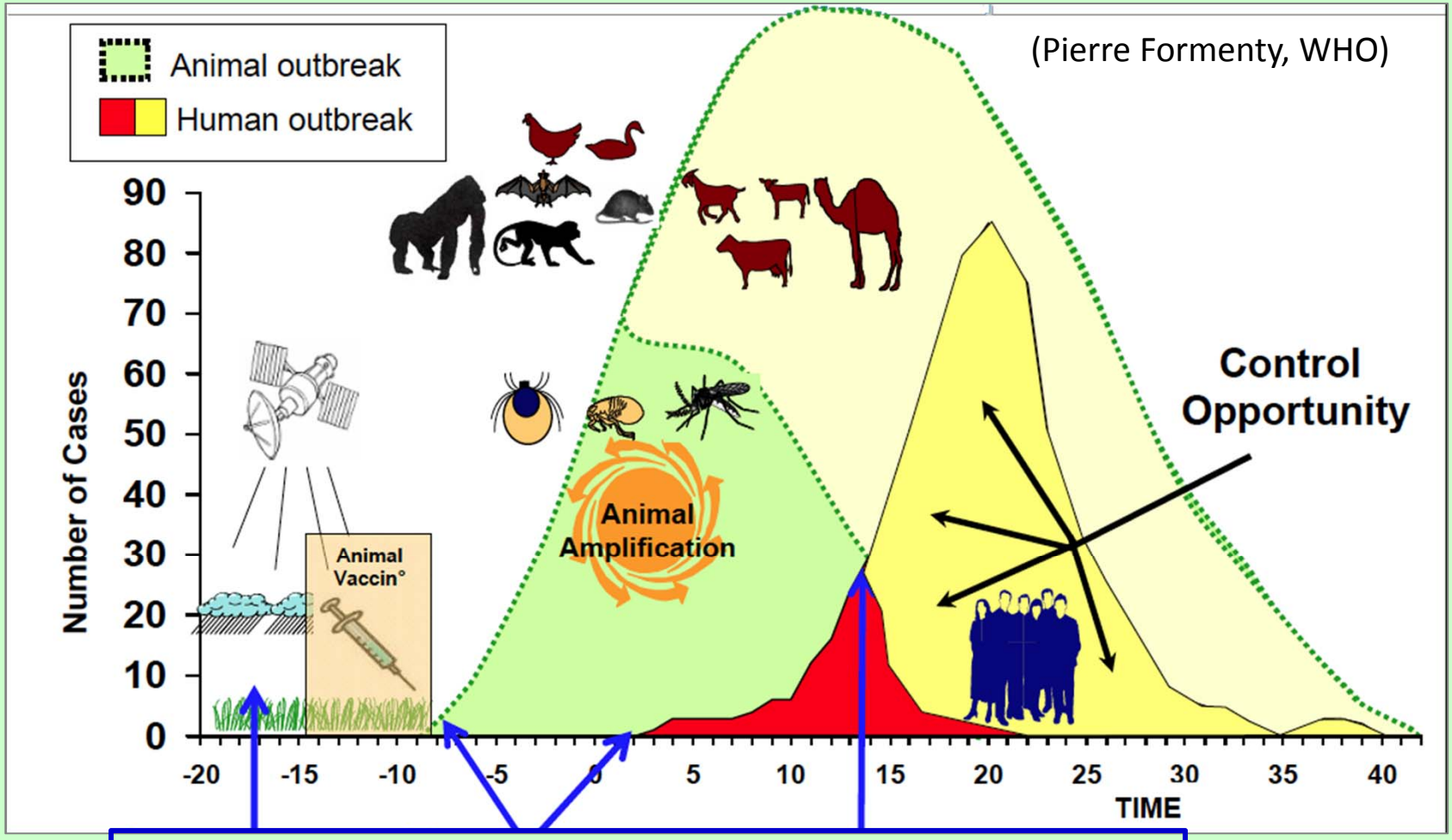


Background

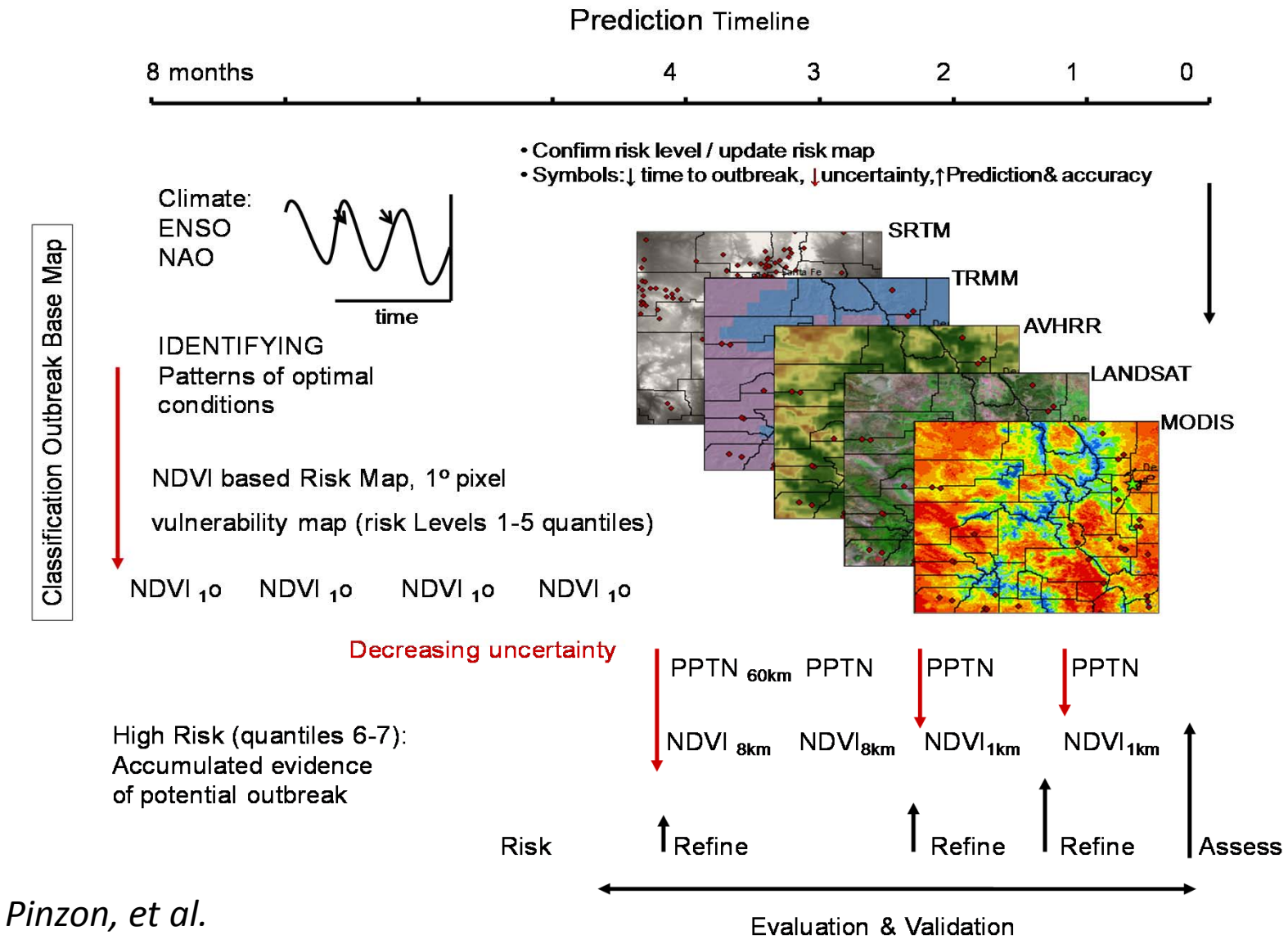
- Five genetic subtypes of Ebola virus have been reported: Zaire, Cote d'Ivoire, Sudan, Reston and Bundibugyo.
- Previous research based on environmental factors detected from satellite broadband sensors have established useful relationships among climate variability, vegetation and EHF disease patterns. The environmental trends provide an ecological context that contributes to our understanding of infectious diseases. In particular, the majority of documented EHF outbreaks occurred toward the end of the rainy seasons, when a sharply drier period was followed by a sudden return to very wet conditions in the tropical moist forest or gallery tropical forest in the Central African sub-region.
- **Despite extensive field investigations to define the natural history of the Ebola hemorrhagic fever (EHF) virus, the origin and mechanism of disease transmission, from reservoir to humans, remain unknown.**
- High spectral resolution measurements (≤10 nm, 400-2500 nm), providing a synoptic evaluation of many of the factors significantly affecting the local ecosystems, are an optimal tool to significantly improve the specificity of the disease parameters.

Strategy for Assessment Using Vegetation Type & Function



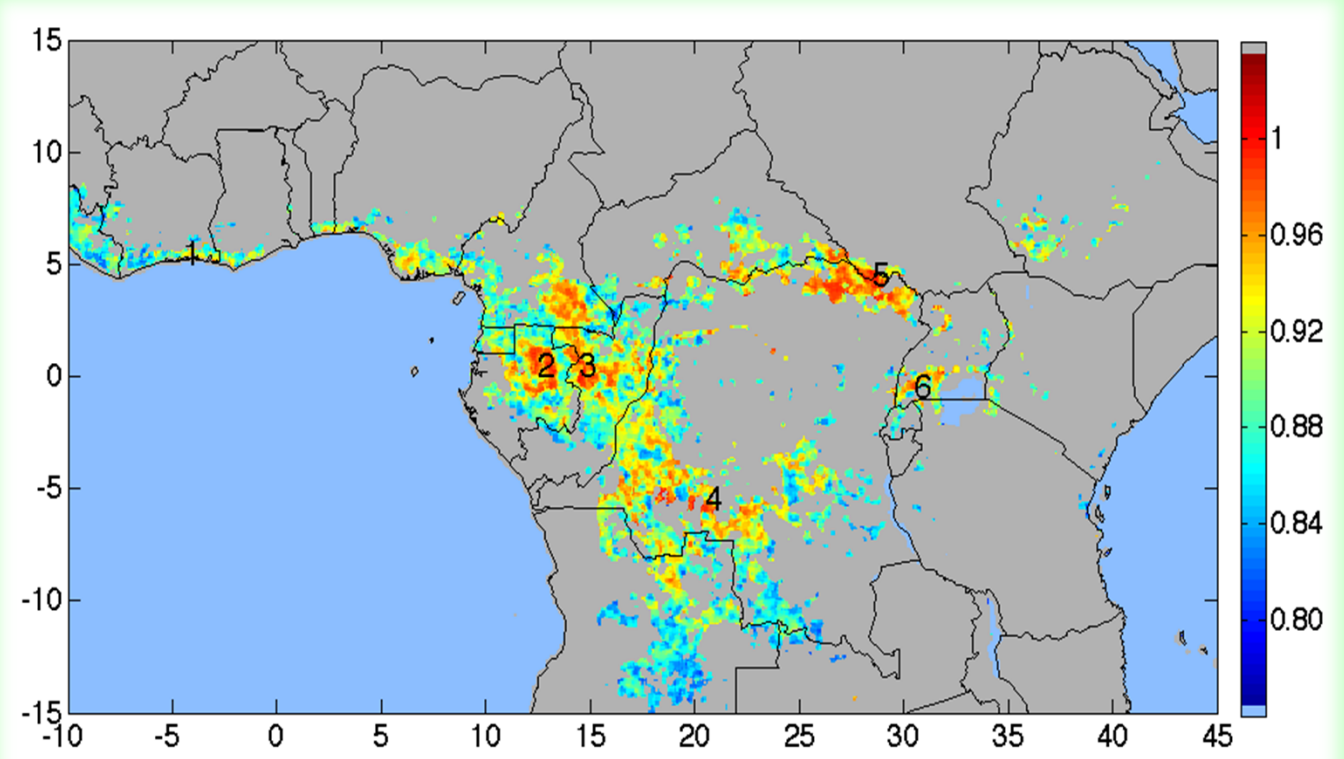
Early detection is critical
for triggering timely control activities

Model Prediction Framework - *Current*

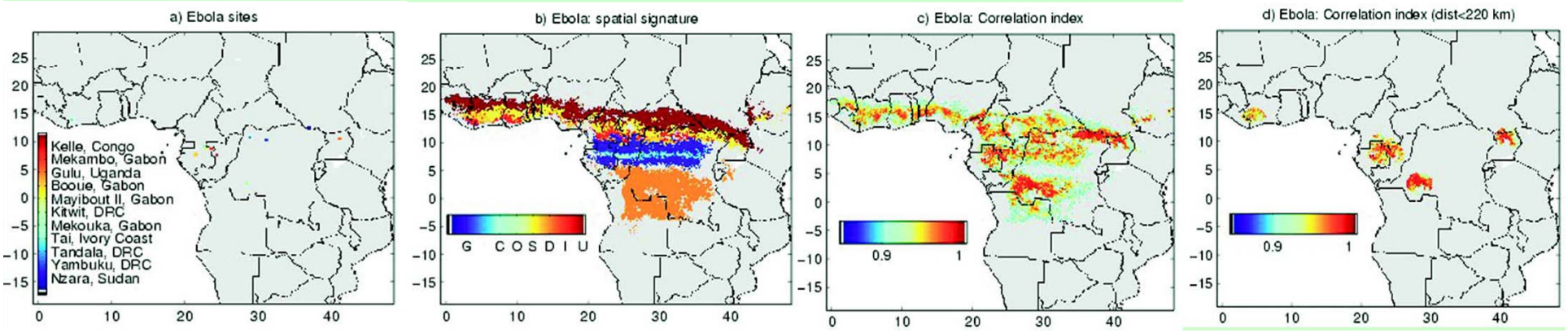


Pinzon, et al.

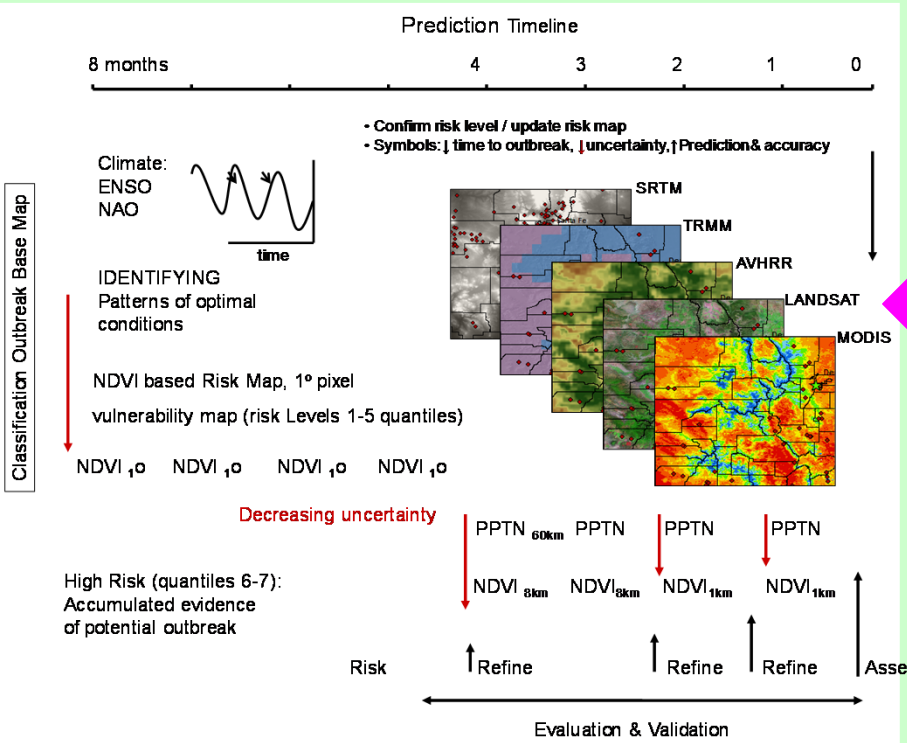
Current Ebola Risk Map

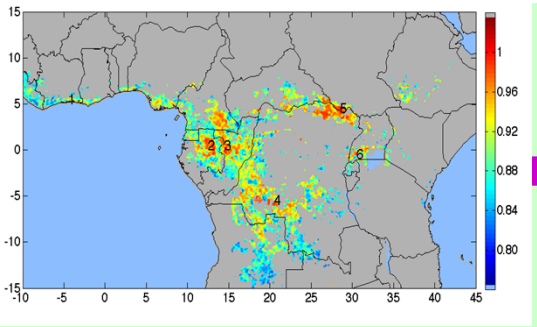


Pinzon, et al.



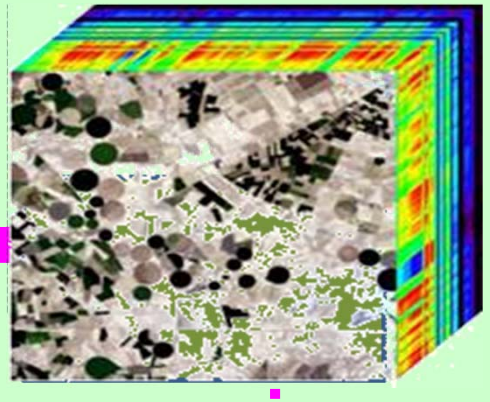
Ecological Context for Ebola Outbreaks - *Proposed*

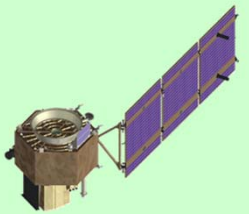




Current Ebola risk map

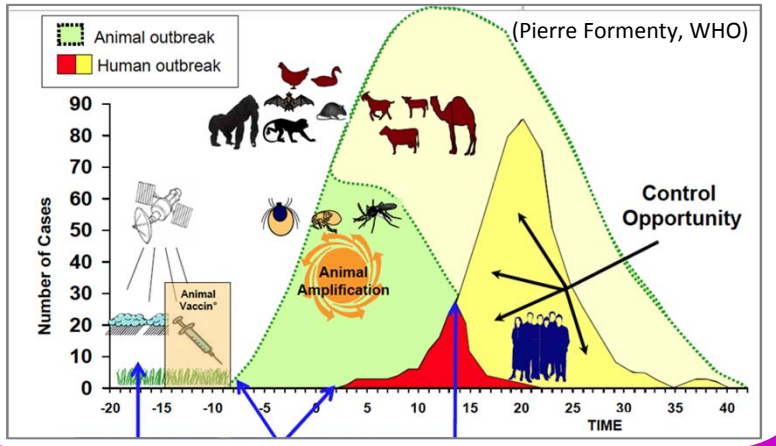
Hyperspectral (EO-1 Hyperion)





! Improving the specificity of disease parameters

Strategy for assessment using vegetation type & function



Earlier detection control activities

Research Objectives

Our goal is to test the ability of high spectral resolution data for providing ***higher detail in the habitat classification of complex rain forest vegetation***. Selected will be a number of different study sites, representative of the major vegetation associations and diversity in the region.

Our objectives are to:

- identify the spectral trends associated with the key environmental parameters, vegetation associations and function (e.g. variations in species composition, soil properties, moisture and humidity)
- characterize the ecosystem and functional diversity at the select sites, and determine the key differences from the surrounding environment
- establish if high spectral resolution data is able to provide sufficient species separation and generate detailed habitat maps
- determine the optimal spectral approach for tracing vegetation function at the sites (tracing changes in canopy fractions (PV/NPV), species, pigments, foliar chemistry)

Science Questions

- What are the spatial pattern of and diversity distribution of the ecosystems at risk?
- How do ecosystems at risk change over time in their composition and function/health?
- How do spectral properties of ecosystems at risk compare to the ecosystems at similar environmental conditions, not associated with the disease?
- Is there a common spectral approach to trace changes in vegetation diversity and function associated with higher risk of an outbreak?
- How can harmful consequences of ecosystem change (degradation) be reduced or prevented?

Why Hyperspectral?

- A complete knowledge of the spectral signature requires *contiguous* and large number of spectral channels

- In the cases of early detection it is more useful to know *the spectral signature,* than its very detailed geometrical property

- A better understanding of complex ecological systems, requires sensors not only with suitable spatial and temporal but also with *high spectral resolution*.

- The *large number of data-products obtained simultaneously* by hyperspectral sensors, both environmental and biological indicators, provides high potential in the field of Earth Observation for ecological and especially for health monitoring and prediction.

Exciting Future for Hyperspectral Sensing

Improvements in airborne HIS: much better ***spectral*** resolution (<5 nm); high ***spatial*** resolution (<4m)

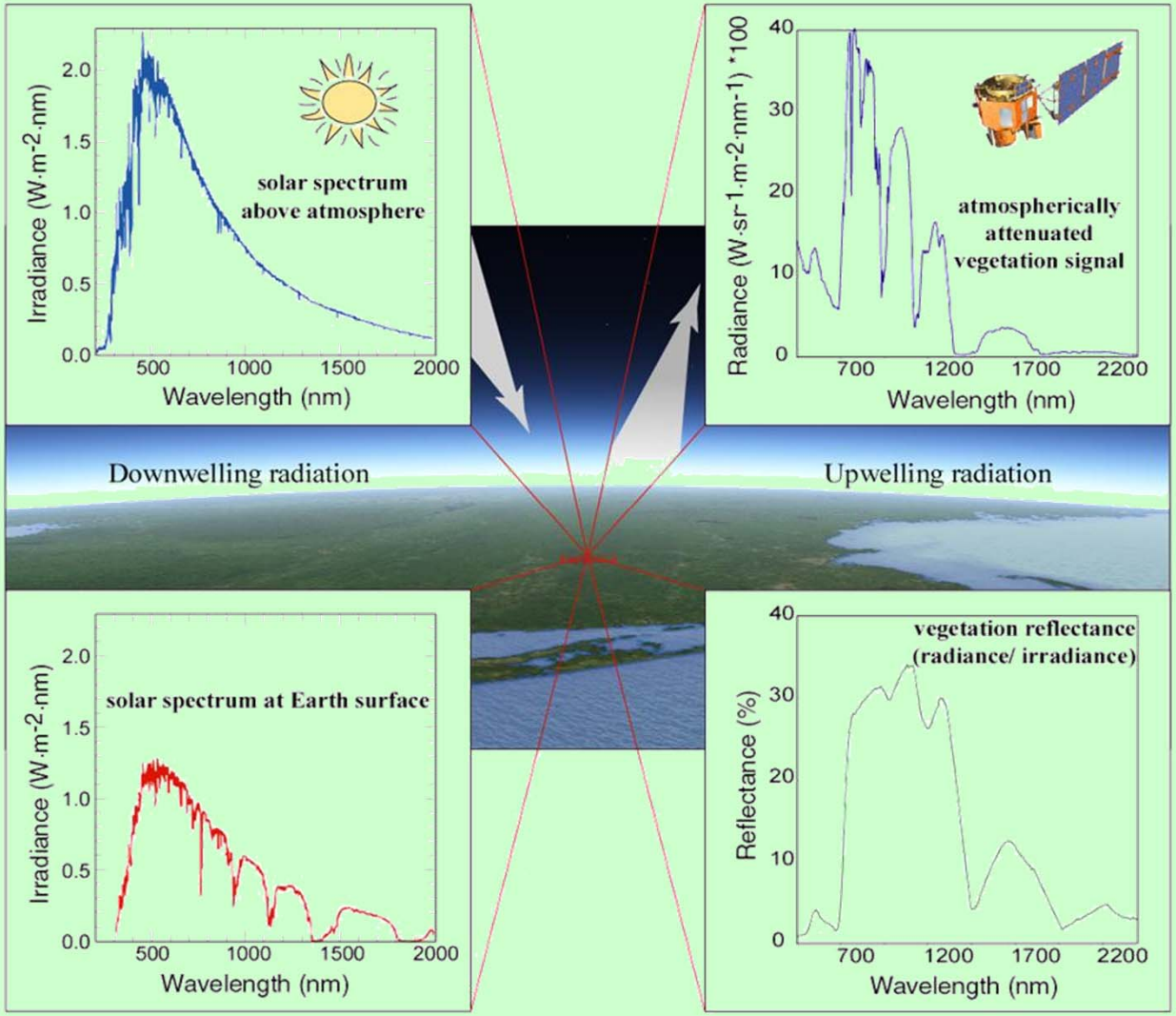
Satellite HIS:

- Goals: global coverage, large area mapping by species; sample mapping of vegetation health by species
- Up now: EO-1 Hyperion, CHRIS (PROBA)
- Coming: ENMAP (2014), PRISMA (2013), ALOS-3&4 (2015-16), HyspIRI (2020)

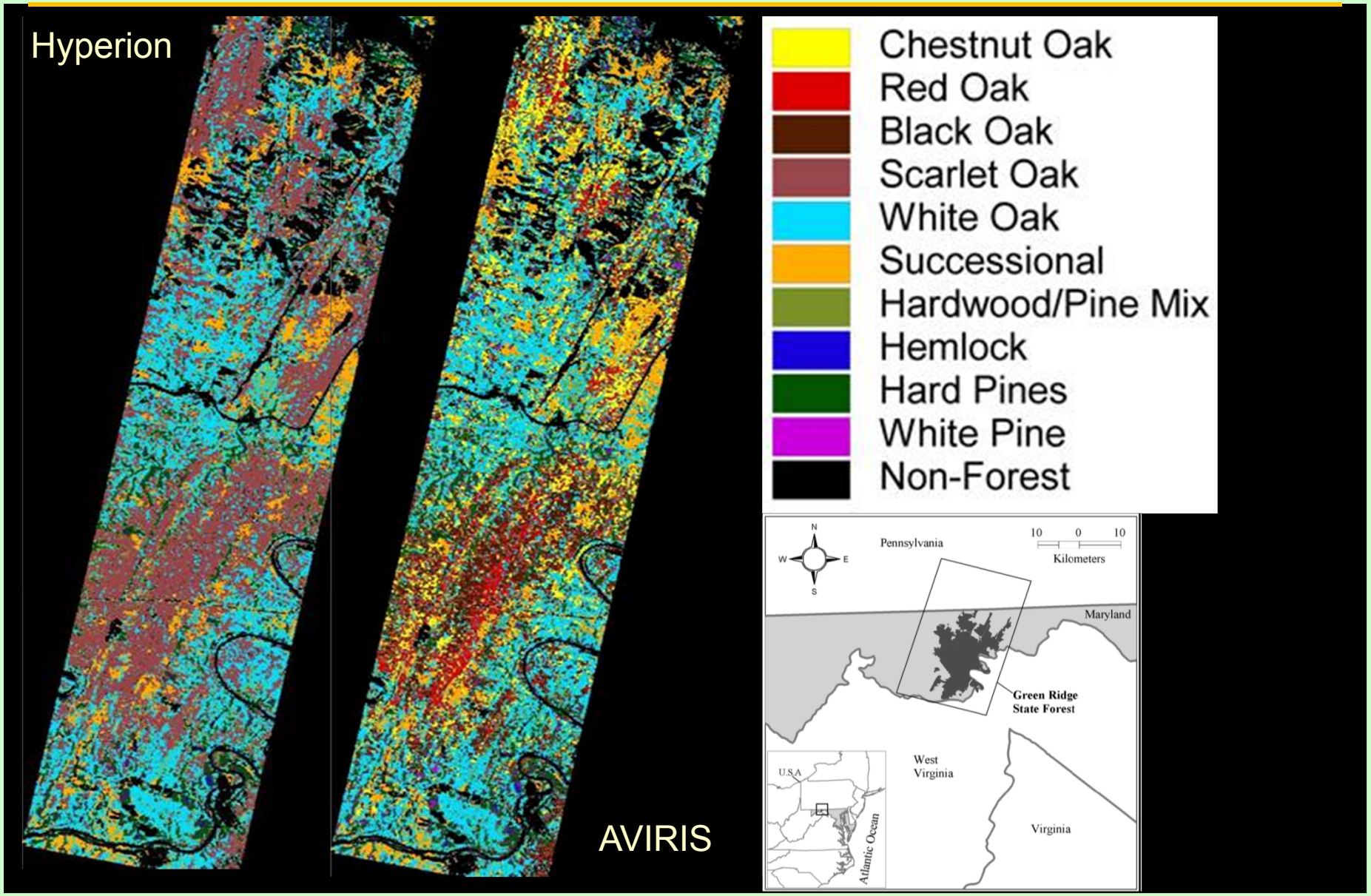
Hyperspectral Data & Processing

Radiometric corrections for hyperspectral data

- Molecular components of atmosphere absorb/scatter certain frequencies and transmit others (atmospheric windows)
- Sensors translate photon reception to voltage then digital number (DN)
- Radiometric calibration translates DN to radiance ($W \cdot sr^{-1} \cdot m^{-2} \cdot nm^{-1}$)
- Atmospheric correction translates radiance to apparent or surface reflectance (R%)
  - Radiative transfer code
  - Empirical line calibration
- Information is recorded in energy interaction with Earth surfaces
  - Spectral bio-indicators
  - Spectral analysis: un-mixing, classifications, PCA



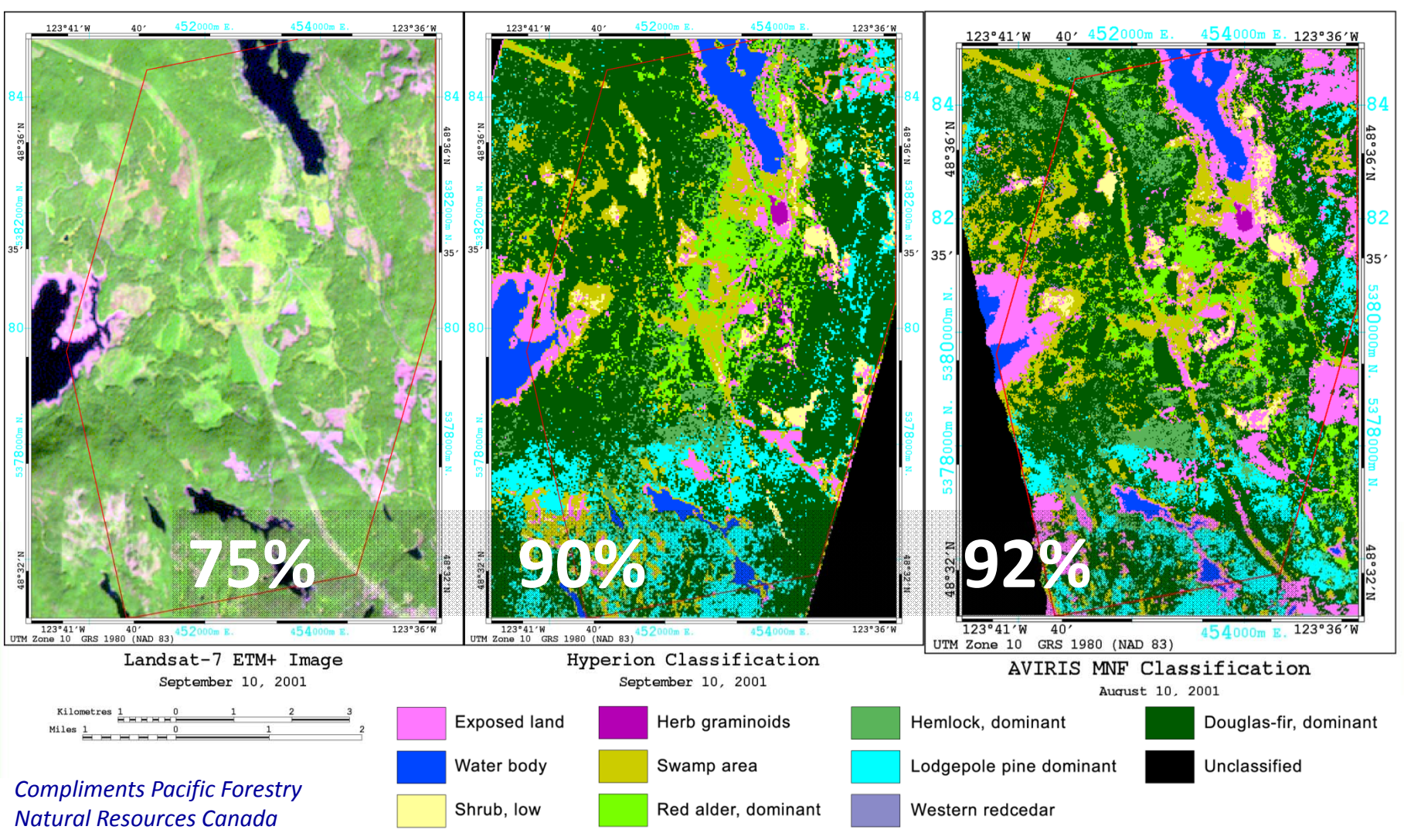
Species Mapping with EO-1 Hyperion



Townsend et al. (2003)

Species Recognition

Landsat 7 Hyperion AVIRIS



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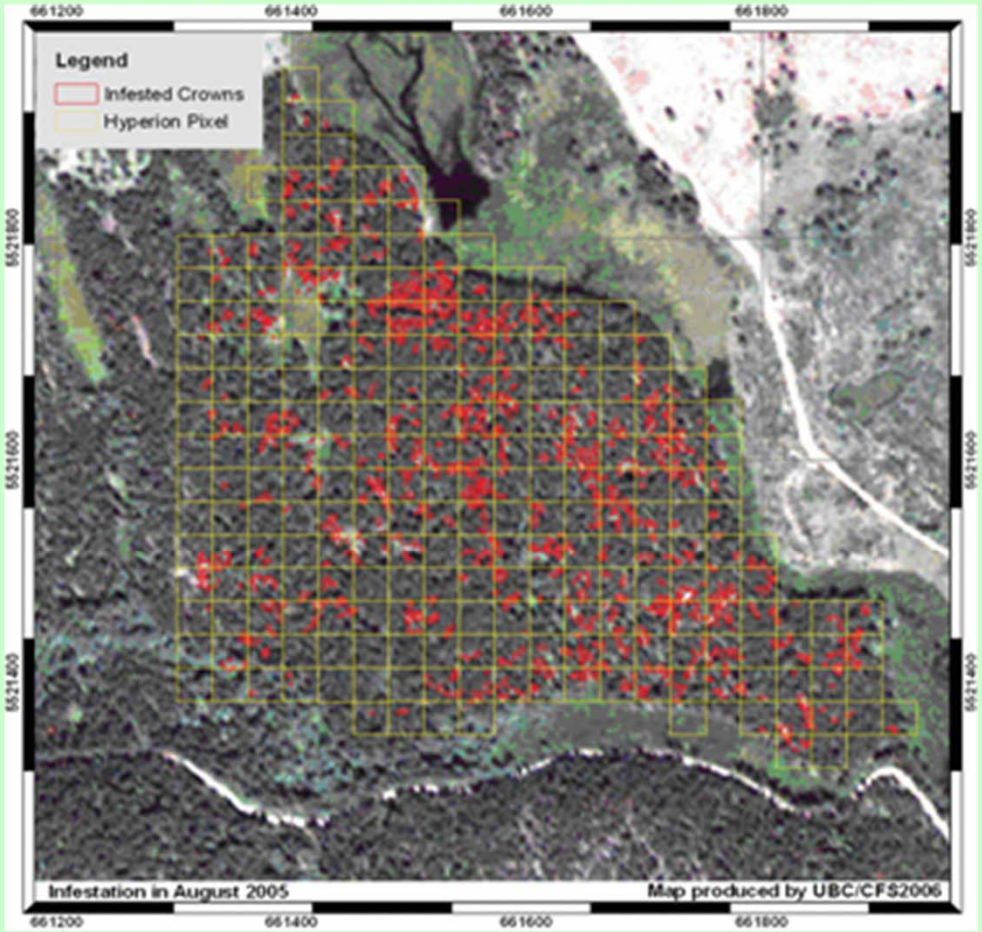
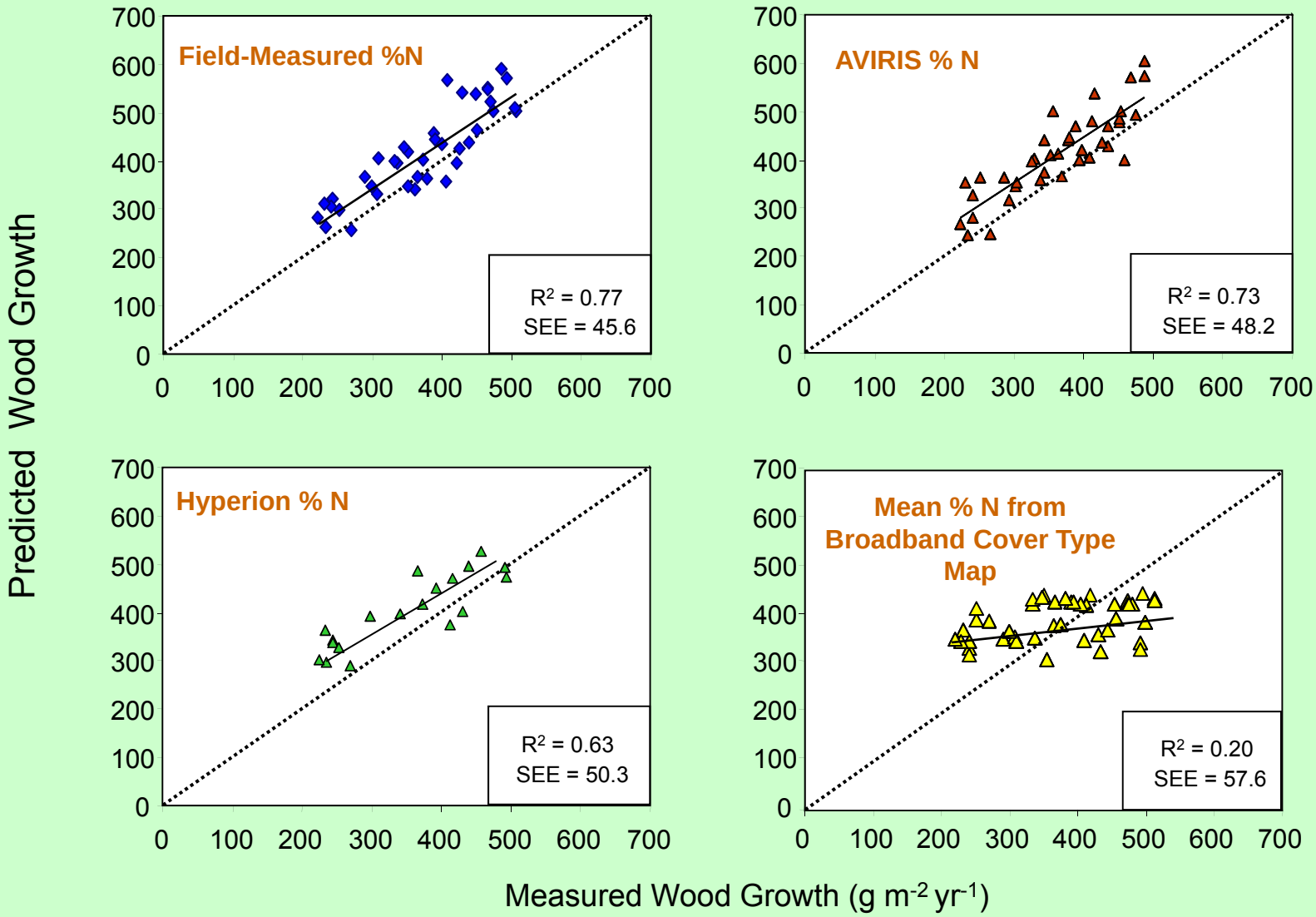
Detection of mountain pine beetle red attack damage, using Hyperion moisture stress indices (MSI)



Individual tree crowns with mountain pine beetle red attack damage (delineated in red) were identified using the Hyperion spectra & then overlaid on a QuickBird image.

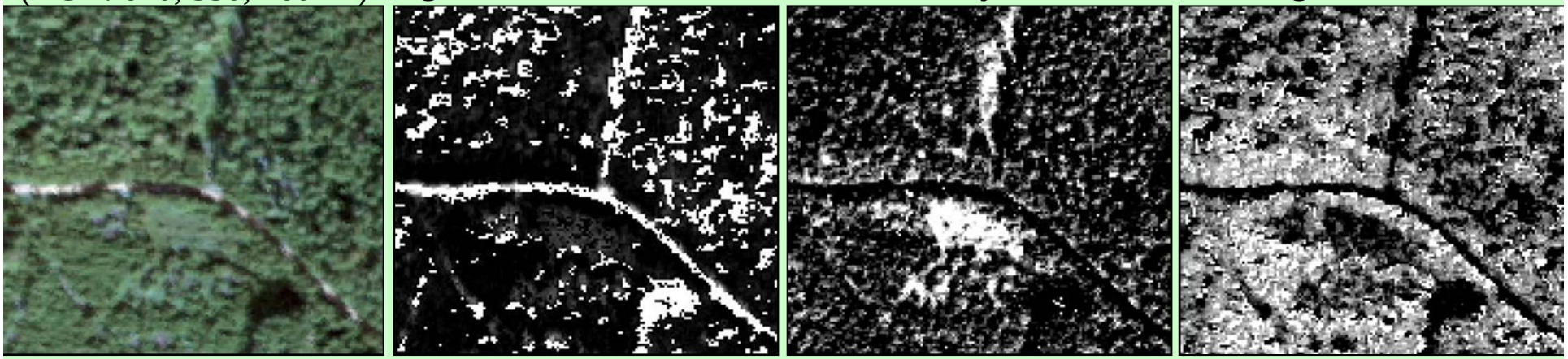
White et al. (2007)

Predicting Forest Growth from Canopy Nitrogen
Bartlett Experimental Forest, NH



Ollinger et al.

Classification of Forest Endmember Fractions



- Fully constrained (Σ=1, fractions>0) least squares based linear unmixing procedure applied in hyperspectral image analysis
- Highest endmember contribution to road spectra is made by exposed ground and is not significantly effected by shade
- Low signal in forest spectra however, may confound unmixing (bottom right)

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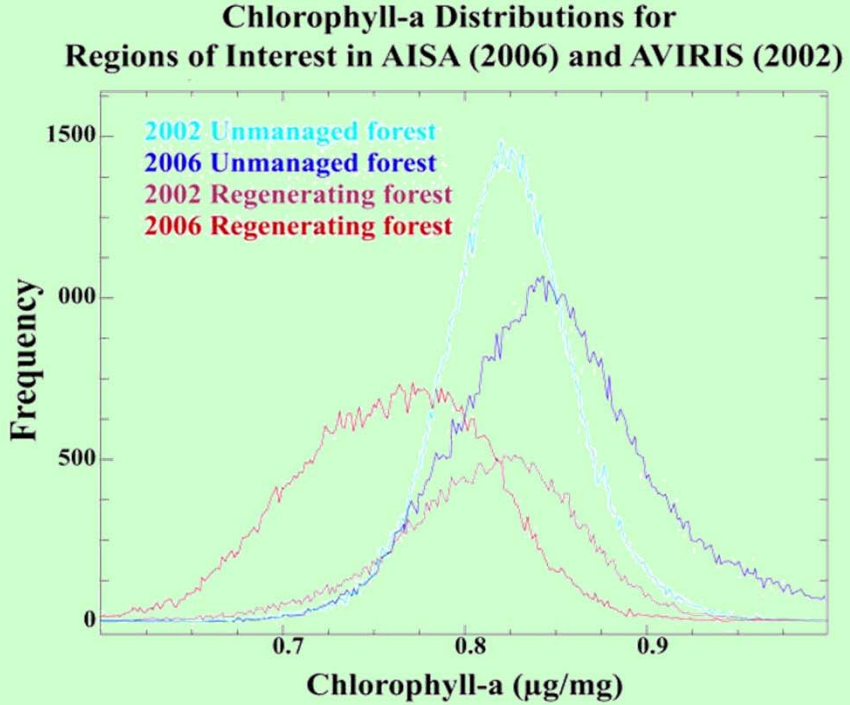
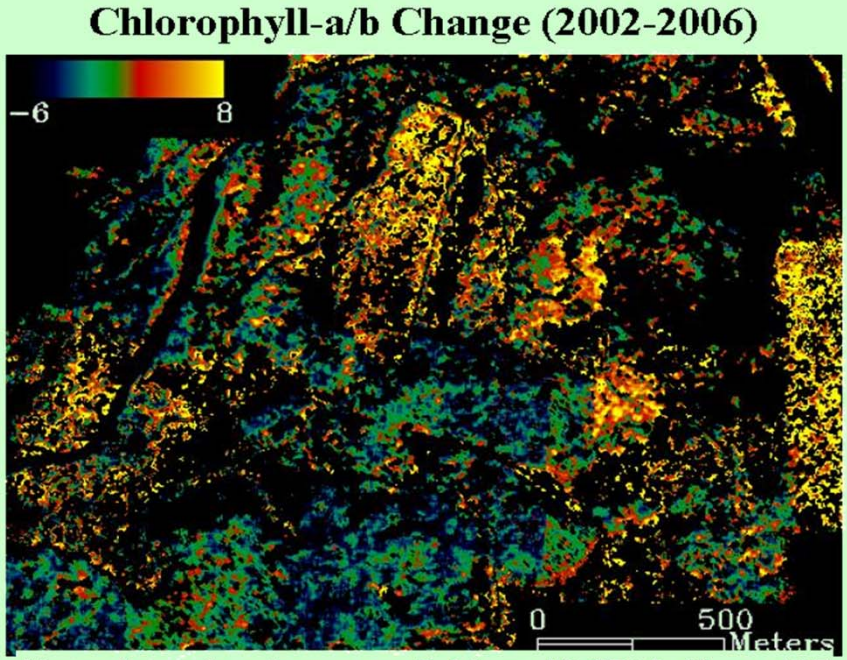
Vegetation Health

Forest health through chemistry and change detection

- **Decreased foliar pigments** is a general physiological response to stress
- The **ratio chlorophyll-a/b** has been considered as a sensitive indicator of stress
- Multi-temporal analysis can indicate **rate of foliar chemistry change**

In regenerating stands chlorophyll-a & a/b decreased between 2002 and 2006, the inverse found for stands free to grow.





Note: Sample a/b range: 5-30, $\bar{x}$: 12.57±3.43, n: 497

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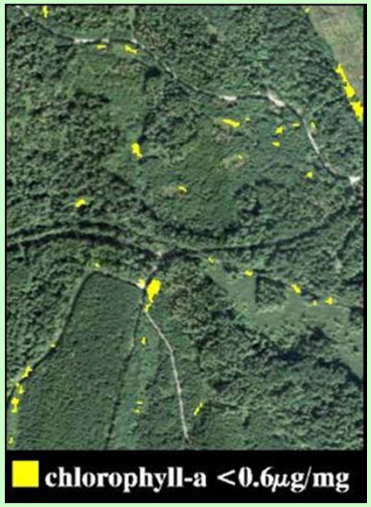
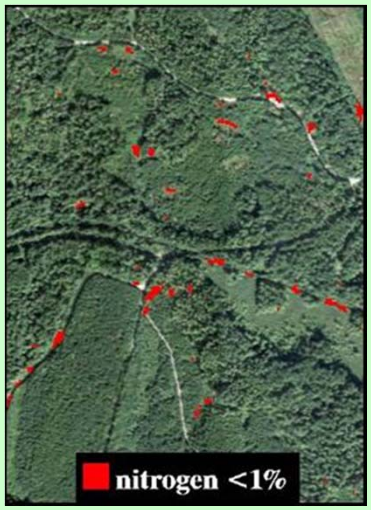
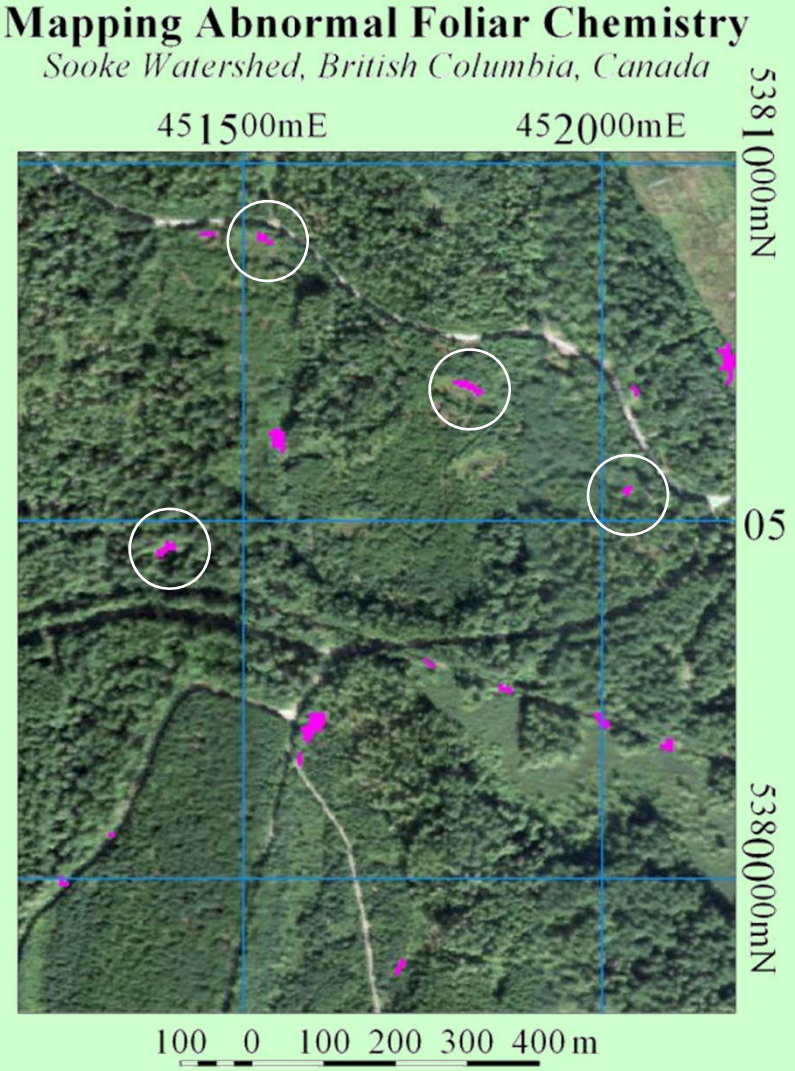
Normal Forest Chemistry

Locating significant departures from normal chemistry

- NIR spectroscopy and wet chemistry determined that chlorophyll-a of stressed Douglas-fir was <0.6 µg/mg, and nitrogen distribution corresponded with ~1% foliar nitrogen content
- The union of the two chemistry thresholds identify **regions of abnormal chemistry** 3 ha out of 2,528 ha or <1% of mature forest by area.
- **Potential root disease** sites are detected as abnormally low chemistry occurring at the fringes of canopy gaps







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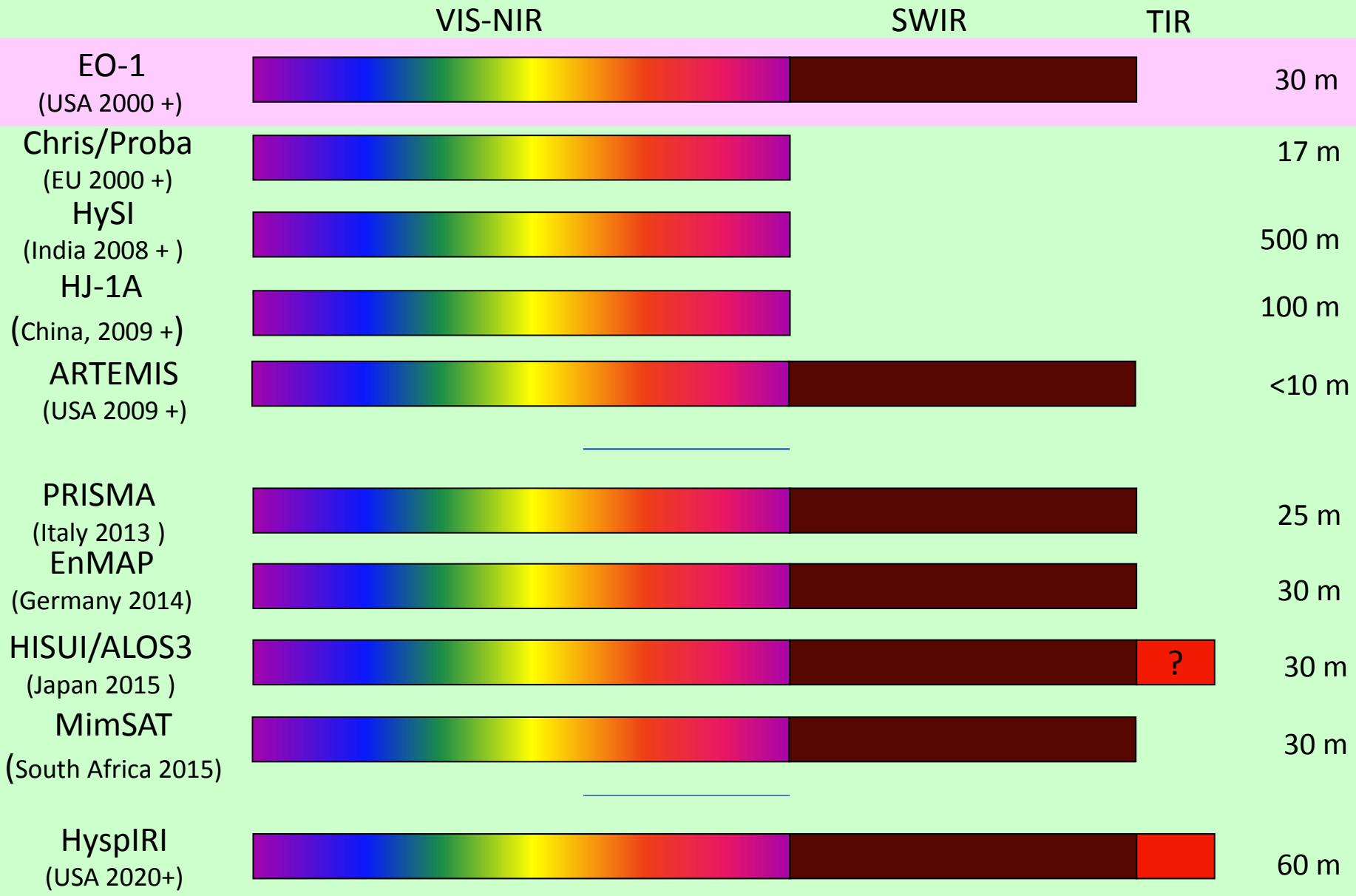
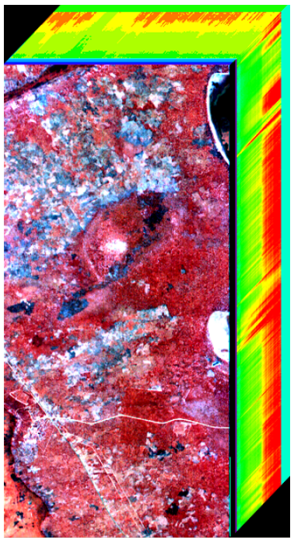
Satellite Missions *(updated August 2011)*

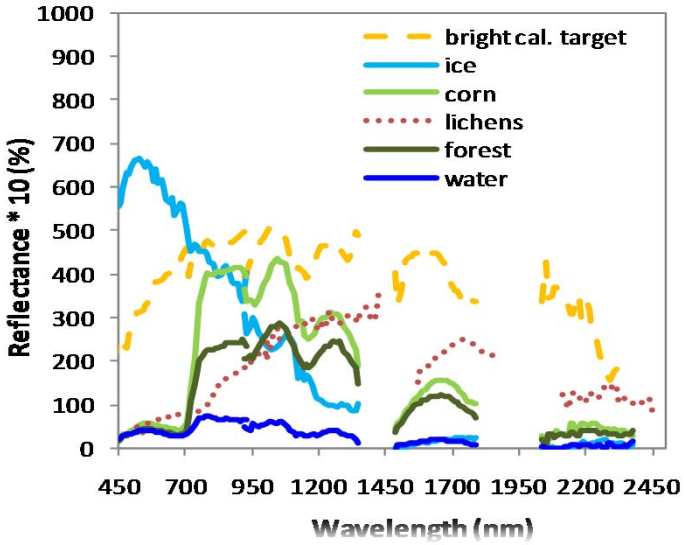


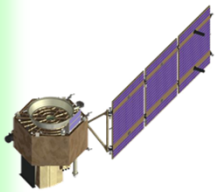
Hyperion Description

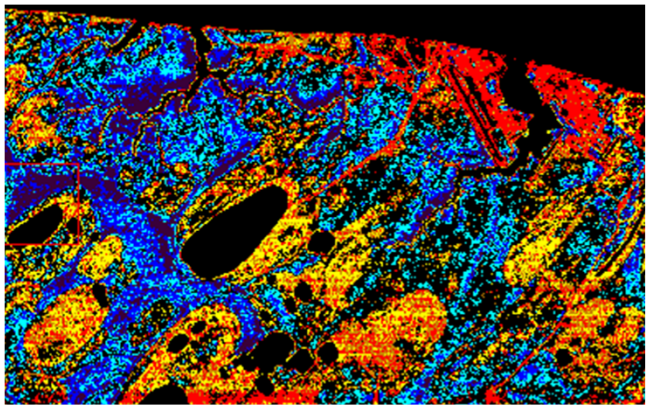
Nominal Data Specification	
Spatial Resolution	30 m..
Swath Width	7.5 km
Spectral Range	400 - 2400 nm
Spectral Resolution	10 nm

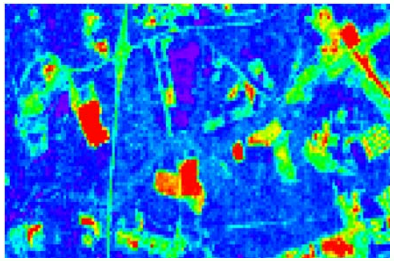
Fully Calibrated Spectral Bands		
	Band #	**Wavelength** (nm)
VNIR	8 - 55	426 - 895
	56 - 57	*913 - 926*
SWIR	*77 - 78*	*912 - 923*
	79 - 224	933 - 2396



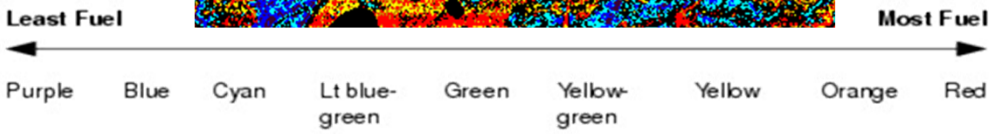






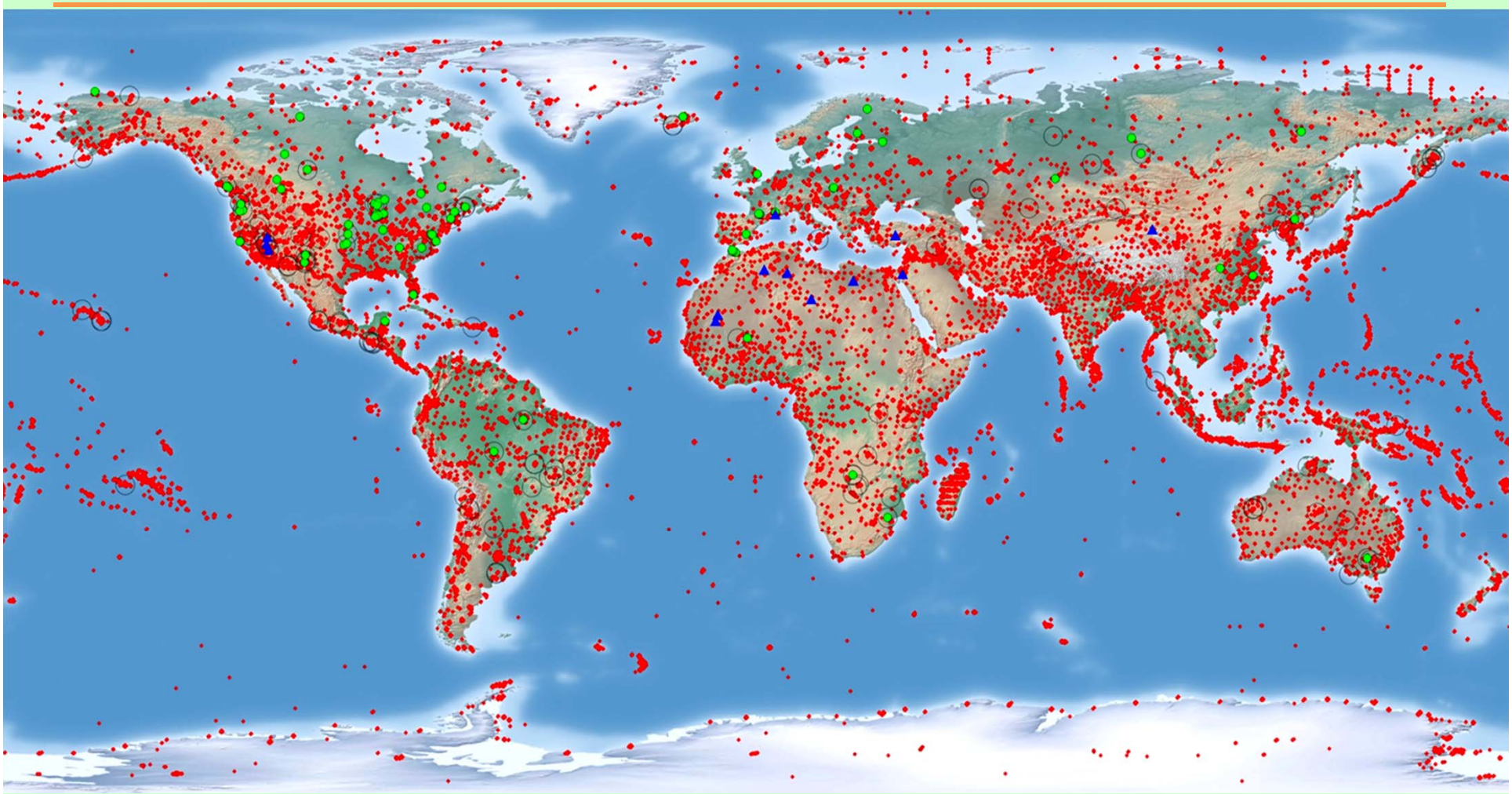


$$MSI = \frac{\rho_{1599}}{\rho_{819}}$$



EO-1 Acquisitions

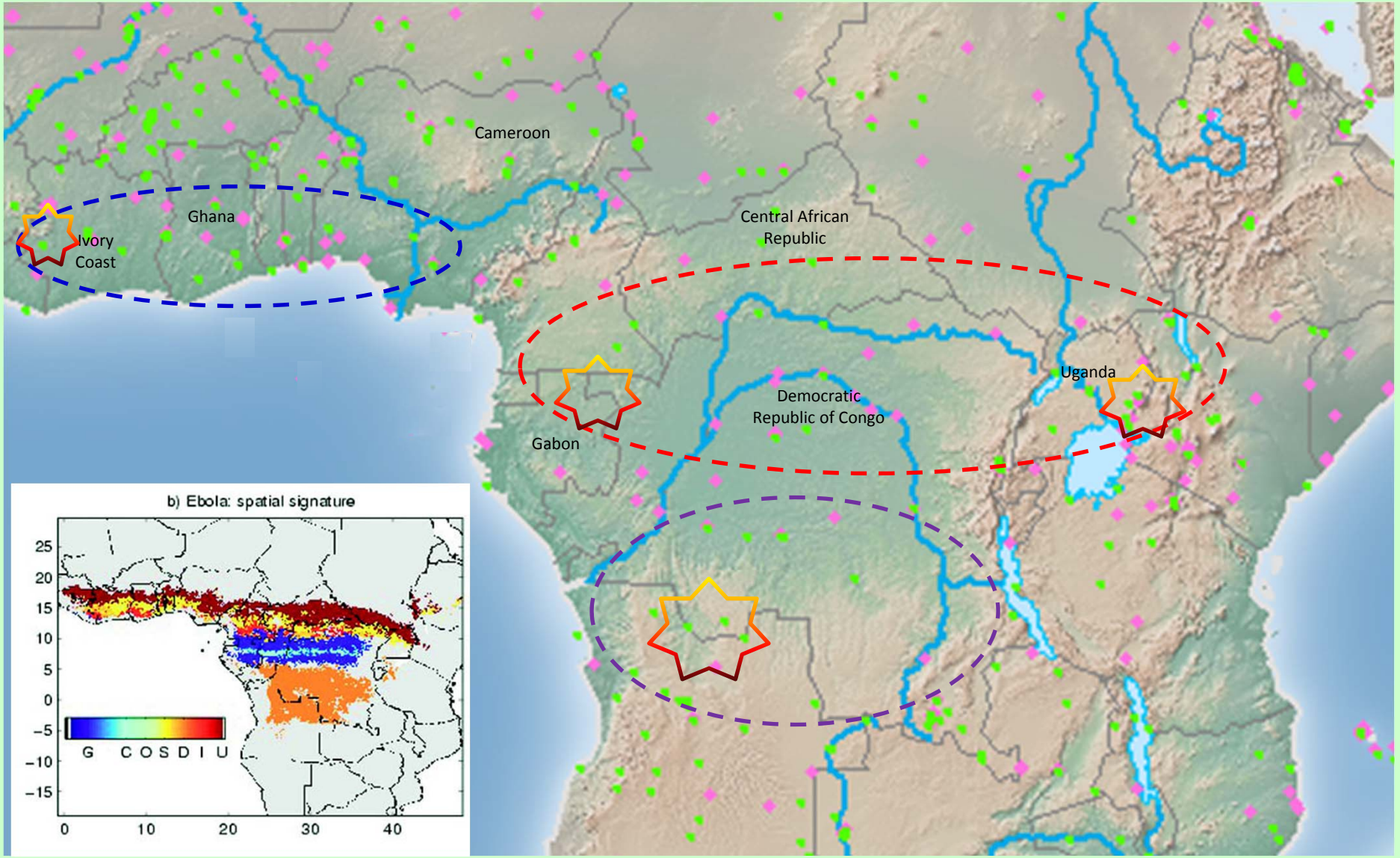
> 55000 Hyperion scenes have been collected (August 2011)

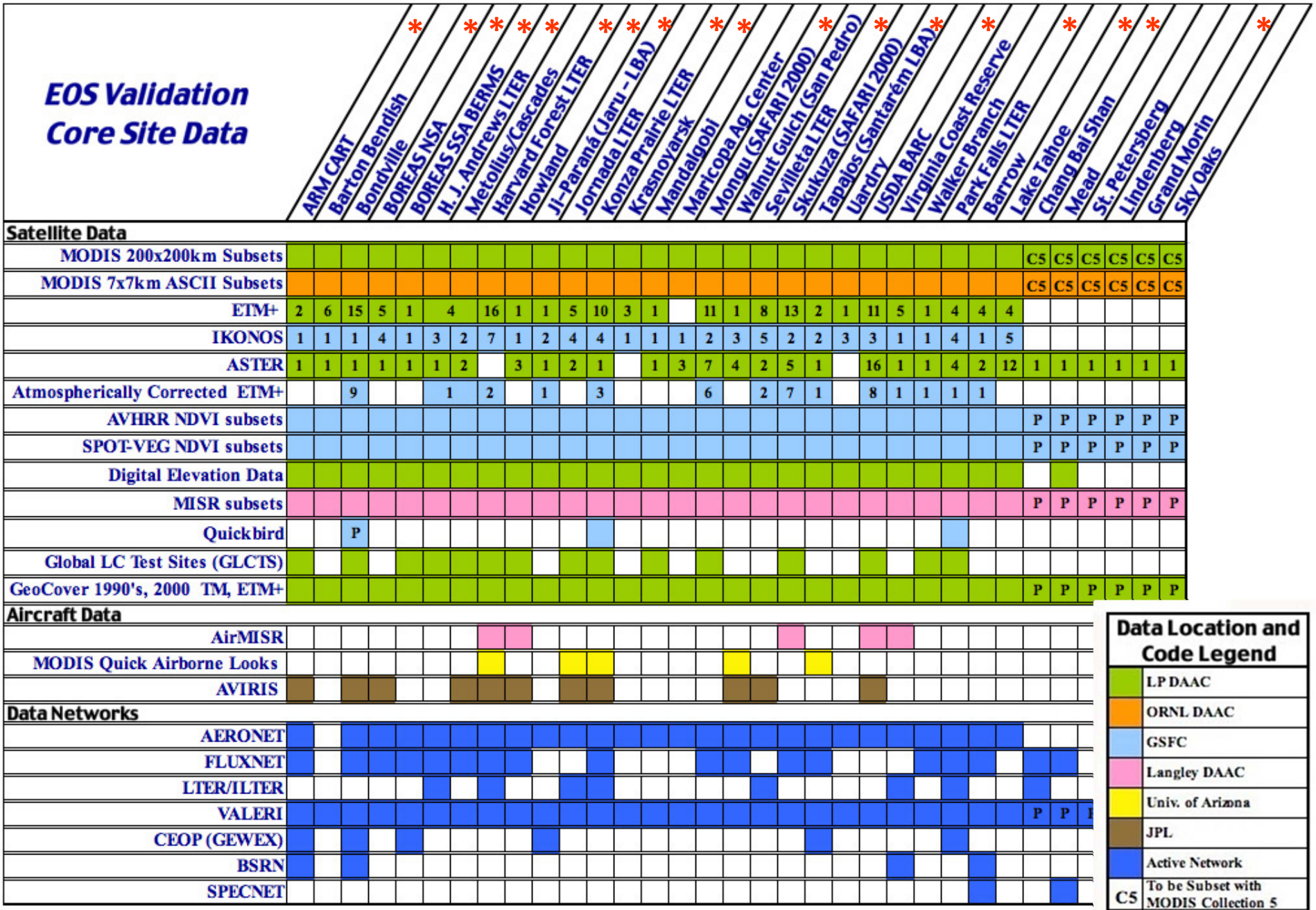


EO-1 Observations •
> 10 Observations ○

EO-1 Time Series: Vegetative Sites ●
Cal/Val Targets ▲

EO-1 Hyperion Acquisitions in Areas at Risk of Ebola



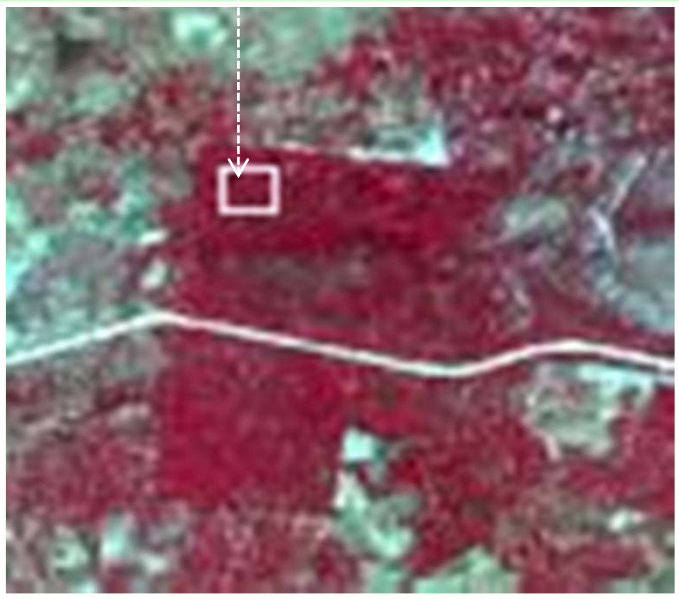


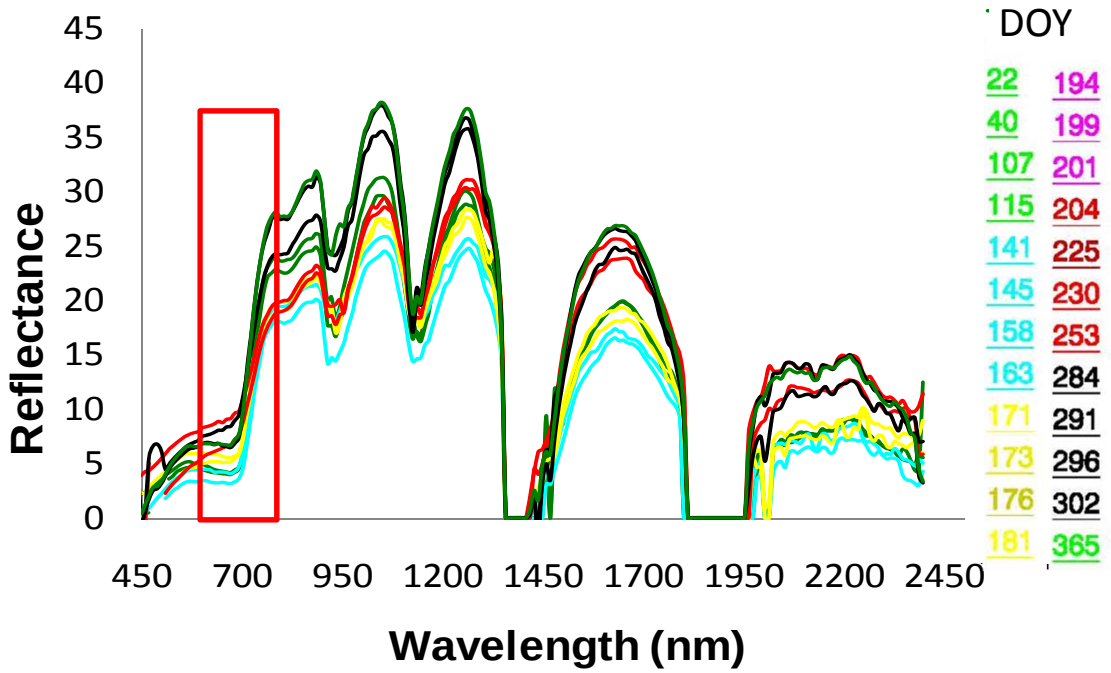
Nickeson, J., J. Morisette, J. Privette, C. Justice, D. Wickland, 2007. Coordinating Earth Observing System Land Validation, *EOS Transactions*, 88(7)81-82.

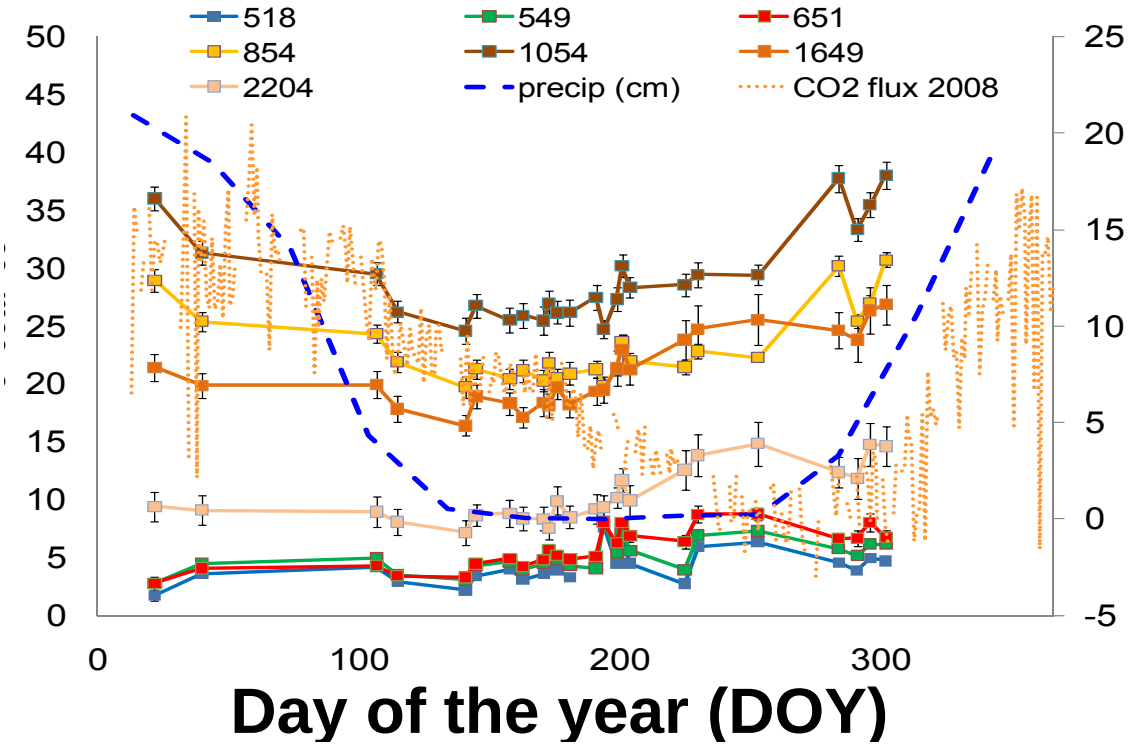
Vegetative Study Sites (FLUXNET)

FLUX Site Name	Location	Climate	Vegetation
1. Mongu lat: -15.4377778 lon: 23.252778	Zambia, Africa	Tropical/ dry vs. wet seasons/ hot	Kalahari/ Miombo woodland
2. Duke Loblolly Pine lat: 35.977130 lon: -79.095240	North Carolina, US	Temperate/ no dry season/ hot summer	Mixed forest/ Hardwoods/ Evergreen
3. Konza Prairie lat: 39.0823925 lon: -96.560277	Kansas, US	Continental/ cold winter/ hot summer	Grassland/ C4 tall grass prairie
4. Bartlett lat: 44.0664 lon: -71.288077	White Mountains NH, US	Temperate, Continental	Northern Hardwoods (C3)
5. Skukuza lat: 25.02 lon: 31.497	Kruger Nat. Park, South Africa	Subtropical/ dry vs. wet seasons/ hot	Woody Savannah
6. DF49, BC lat: 49.539333 lon: -124.901749	Vancouver, British Columbia	Temperate, Cool	Douglas Fir, Coniferous Rain forest

Mongu, Zambia

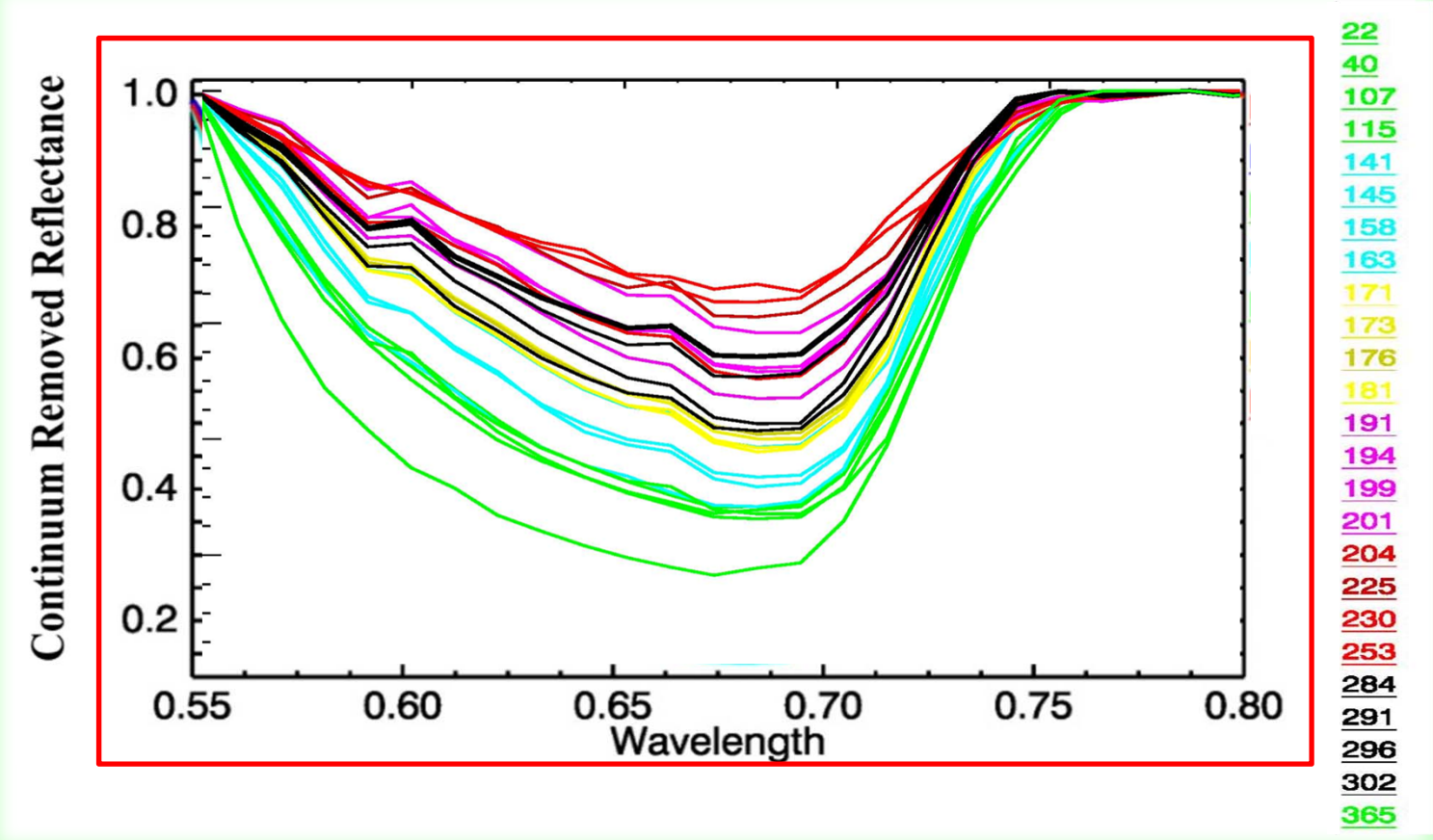






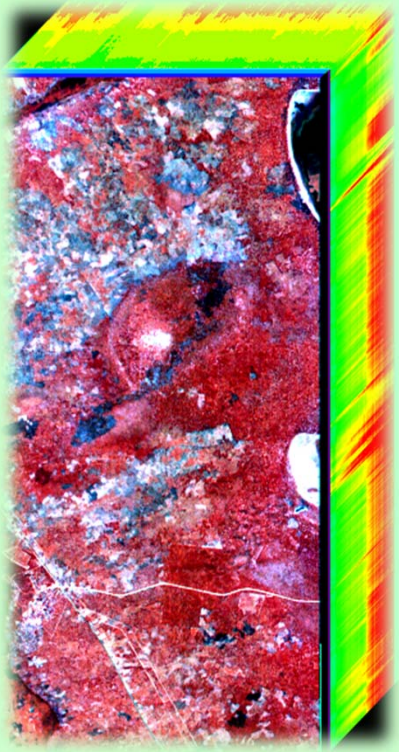
Vegetation Health

detailed changes in pigment absorption provide reliable health condition classes



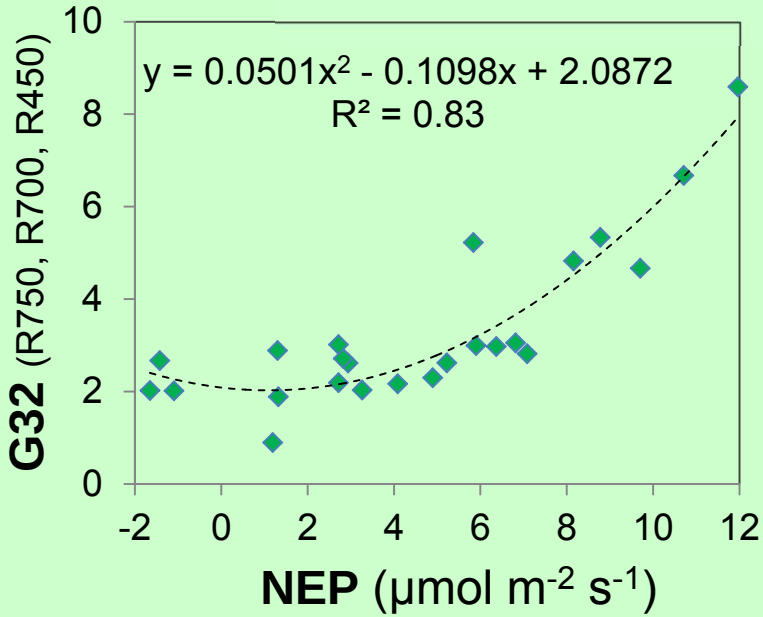
- Target spectral feature centered at 680nm known to be significantly modified by composition and concentration of leaf pigments
- Continuum removal analysis of laboratory reflectance characterized spectral deformations associated with changing chlorophyll concentrations
- Agents of vegetation stress manifest changes in pigments

Bio-indicator	Bands (nm)	R^2 [NEP (GEP)]
G32	R750, 700, 450	0.83 (0.81) NL
Dmax	D max (650…750 nm)	0.77 (0.87) NL
Dmax / D704	D(690-730)	0.79 (0.80) NL
mND705	R750, 704, 450	0.75 (0.79) NL
RE1	Av. R 675…705	0.71 (0.56) NL
EVI	R (NIR, Red, Blue)	0.73 (0.88) L
NDVI	Av. R760-900, R620-690	0.52 (0.60) NL



G32, Associated with *Chlorophyll*

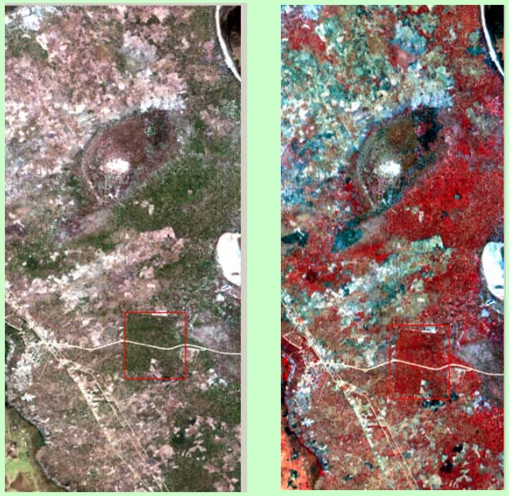
(Gitelson et al. 2003)

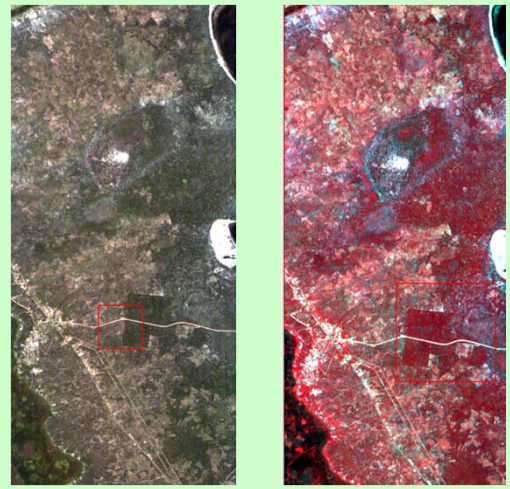


Mongu: Seasonal change in G32 *& NEP*

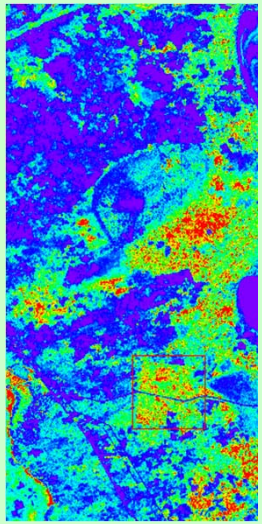
A. Dry season (DOY 214)

B. Wet season (DOY 22)





G32



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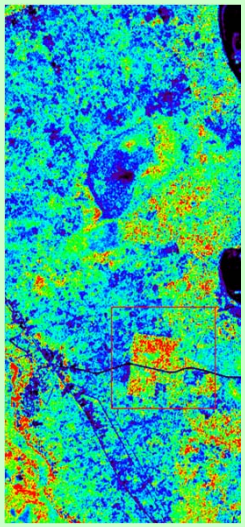
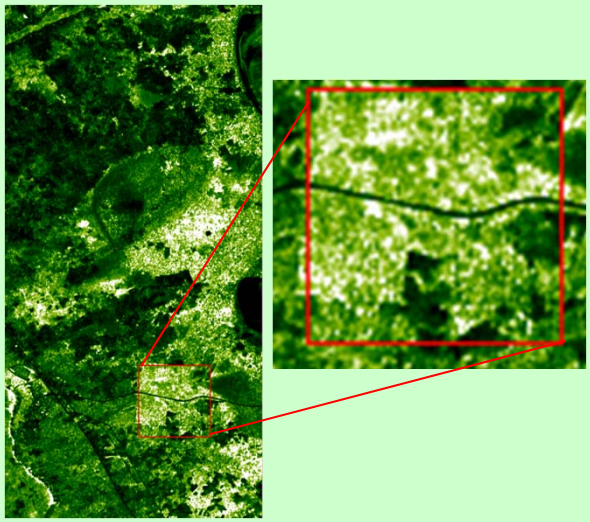


$y = -0.214x^2 + 3.78x - 5.07$, $R^2 = 0.67$

Estimated NEP (µmol m^{-2} s^{-1})



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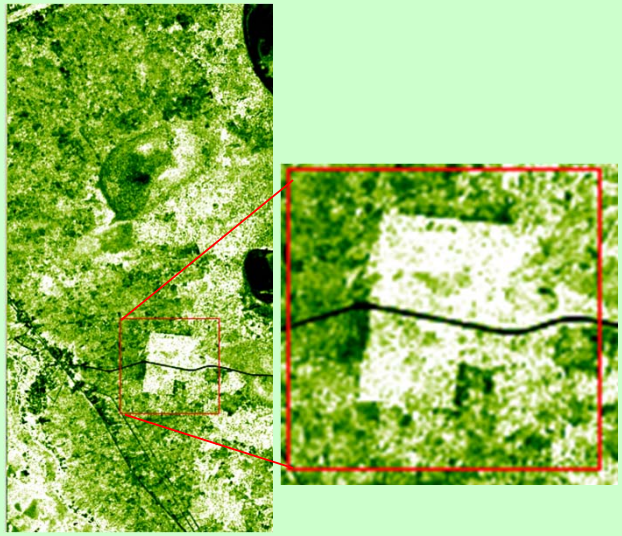
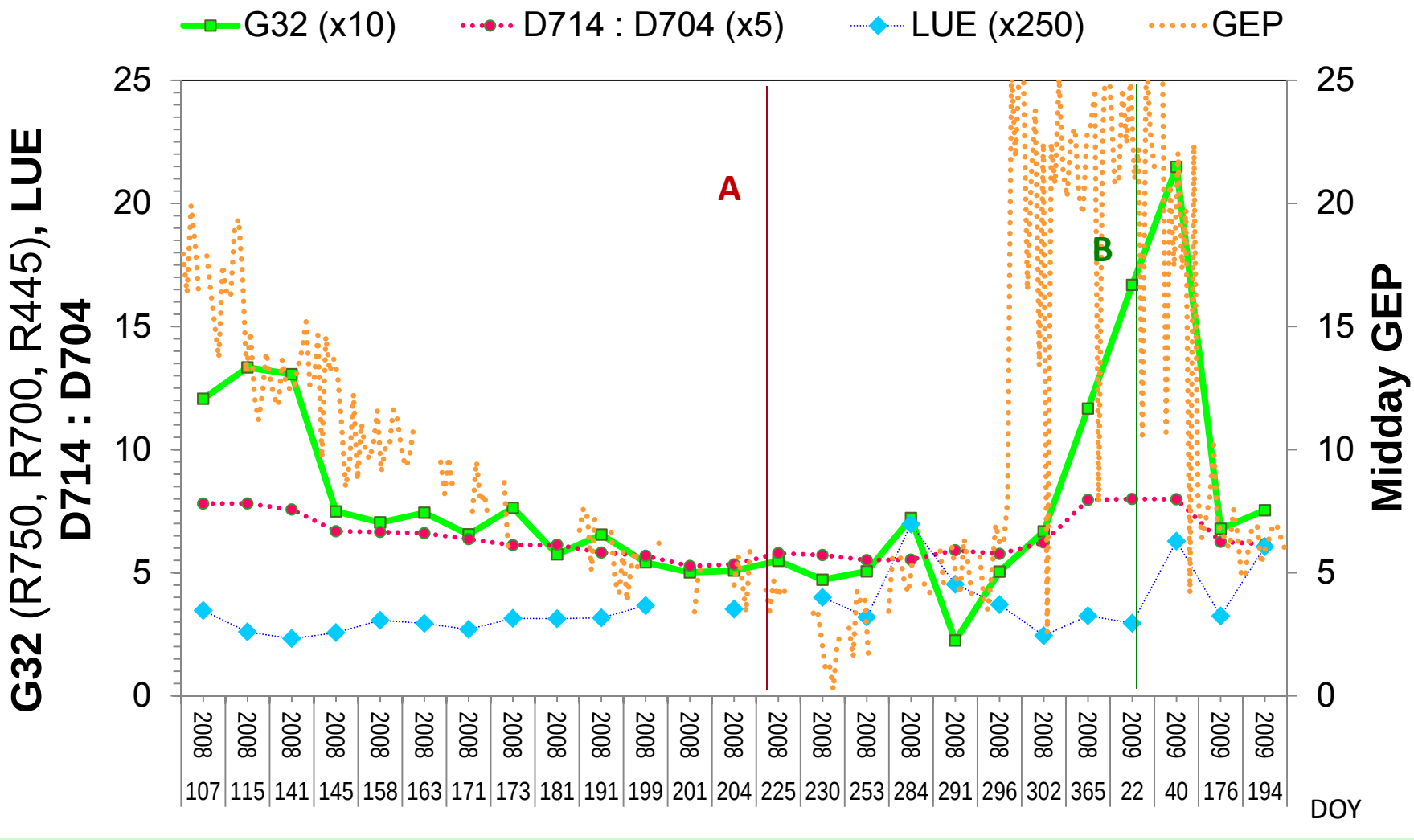


Hyperion Spectral Indices and GEP at Mongu



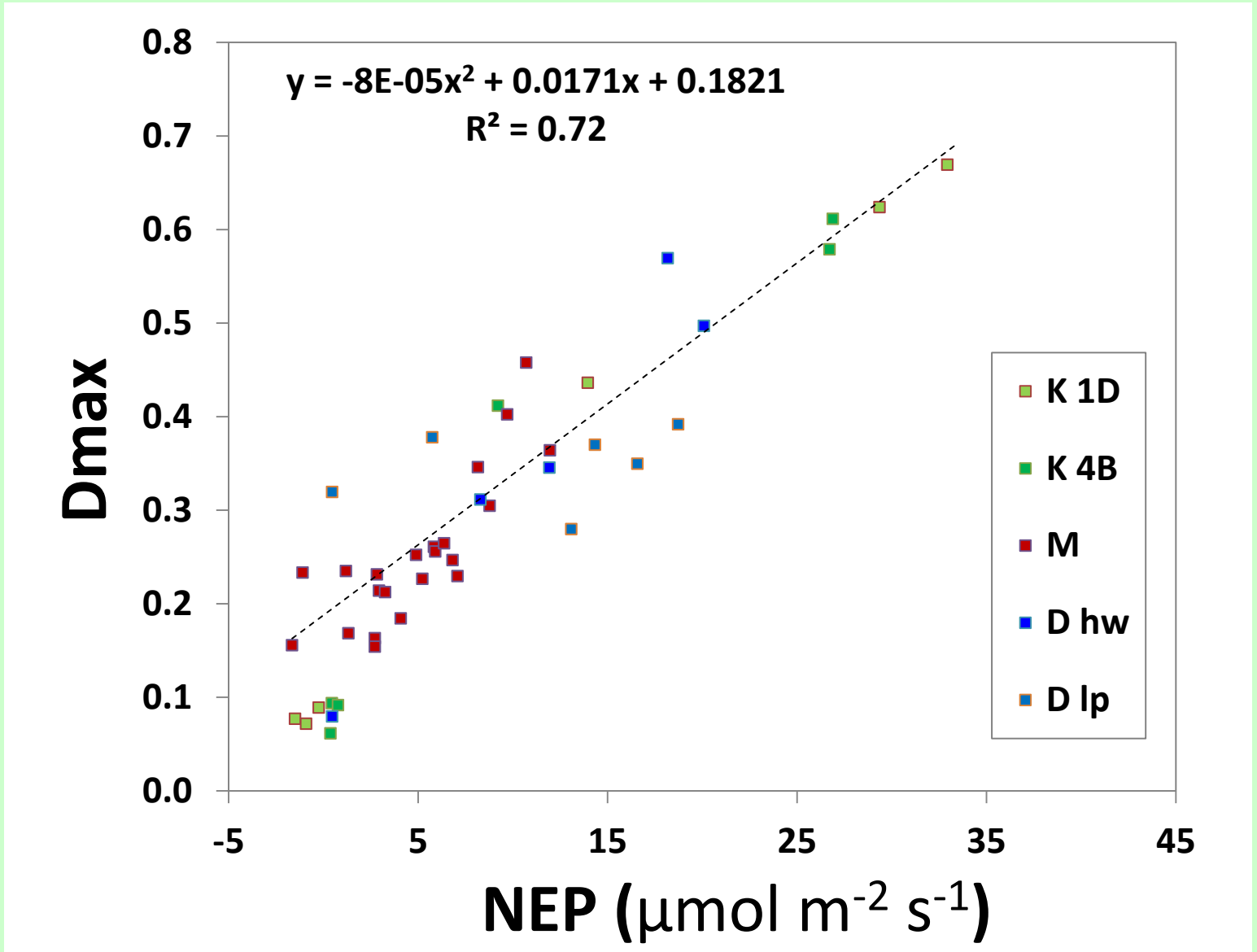
The temporal profile of a spectral bio-indicator associated with chlorophyll content (G32, green line) captured the dynamics in vegetation phenology at the flux site Mongu, Zambia.

All Flux Sites -- Regression Coefficients for the Top Performing Spectral Bio-indicators (R^2 values)

Spectral indicator	Formula	NEP	GEP	LUE
Dmax	Max D in the 650-750 nm	**0.73 L+**	**0.77** L+	0.75 L+
DP22	Dmax/D(max + 12)	0.65 L+	0.74 NL+	0.71 L+
NDWI	R(870-1240)/R(870-1240)	**0.74** NL +	0.67 NL+	0.63 L+
MCARIa	Chlorophyll, R bands at 700, 670, and 550	0.41 L+	0.75 L+	**0.77** L+
PRI4	(R531-R670)/(R531-R670)	0.66 NL+	0.62 NL+	0.49 NL+
NDVI	(NIR-R)/(NIR+R) NIR= Av. 760..900, R=Av. 620..690	0.56 NL+	0.59 NL+	0.44 NL+

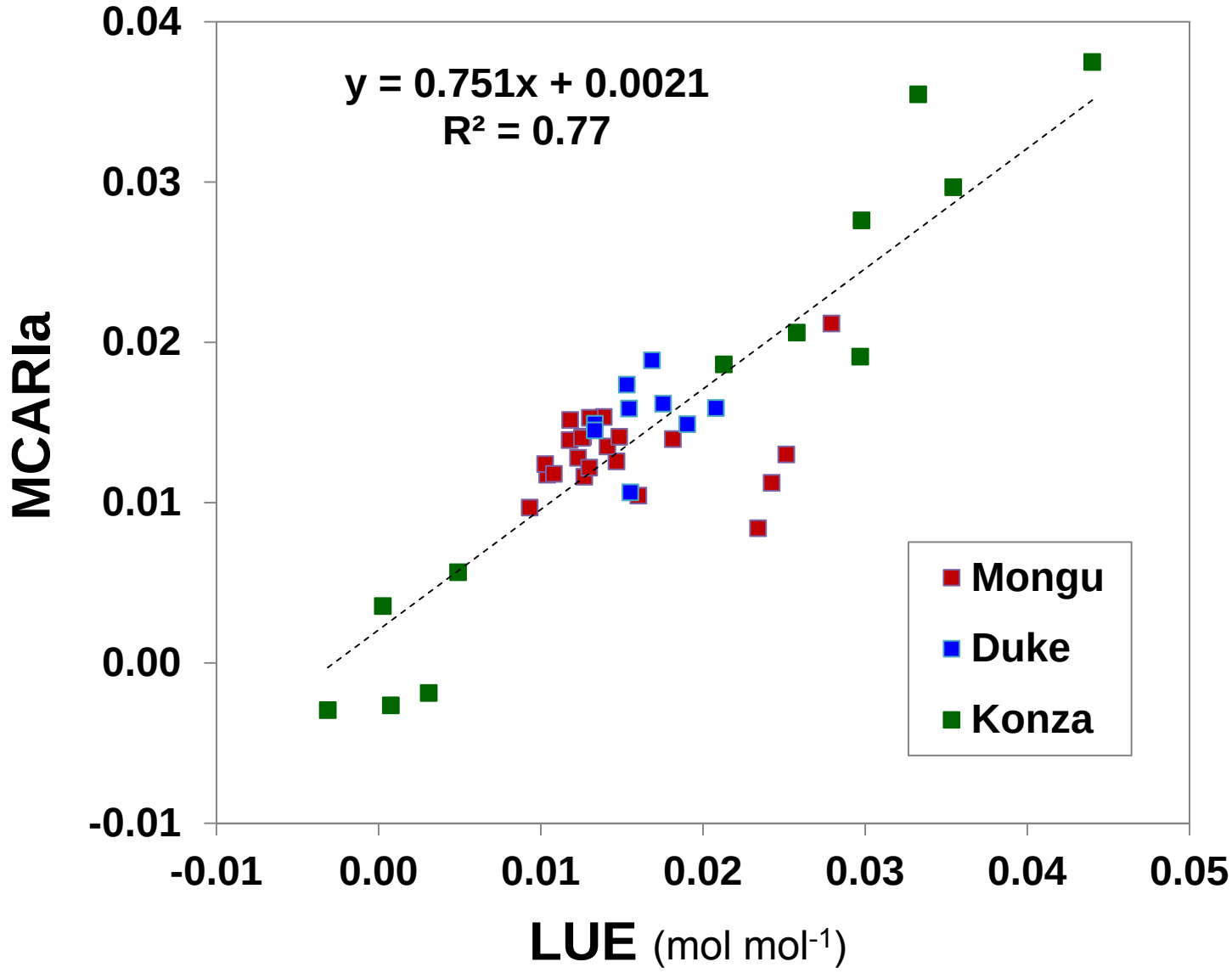
Derivative Maximum

Konza (K), Mongu (M), Duke (D)



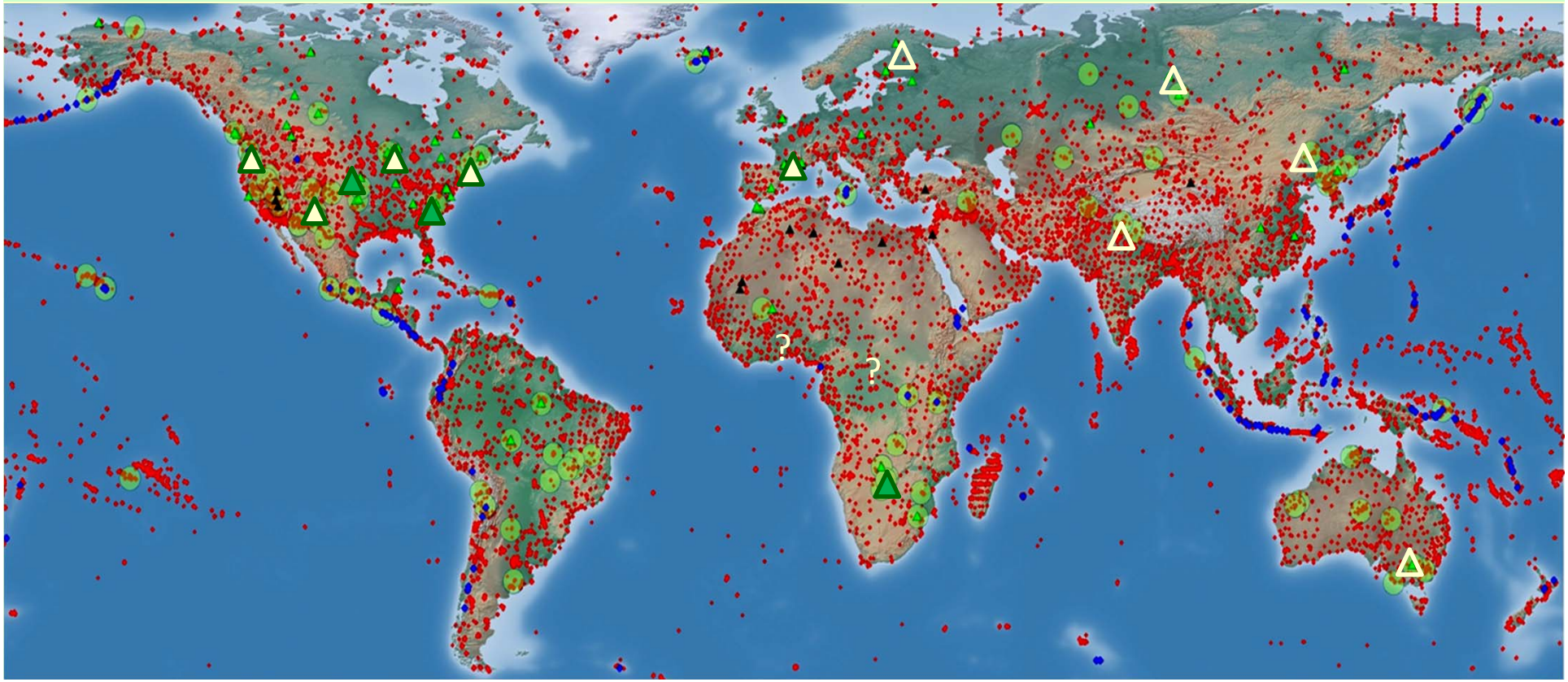
Multiple Flux Sites

Konza (K), Mongu (M), Duke (D)



Future Directions

- Expand the spectral collection over the risk areas, if possible develop time series to the rain forests of Africa
- Establish/confirm the approach for spectral analysis in the areas at risk of Ebola
- Produce new Ebola risk maps, providing improved ecological context



Anticipated Outcome

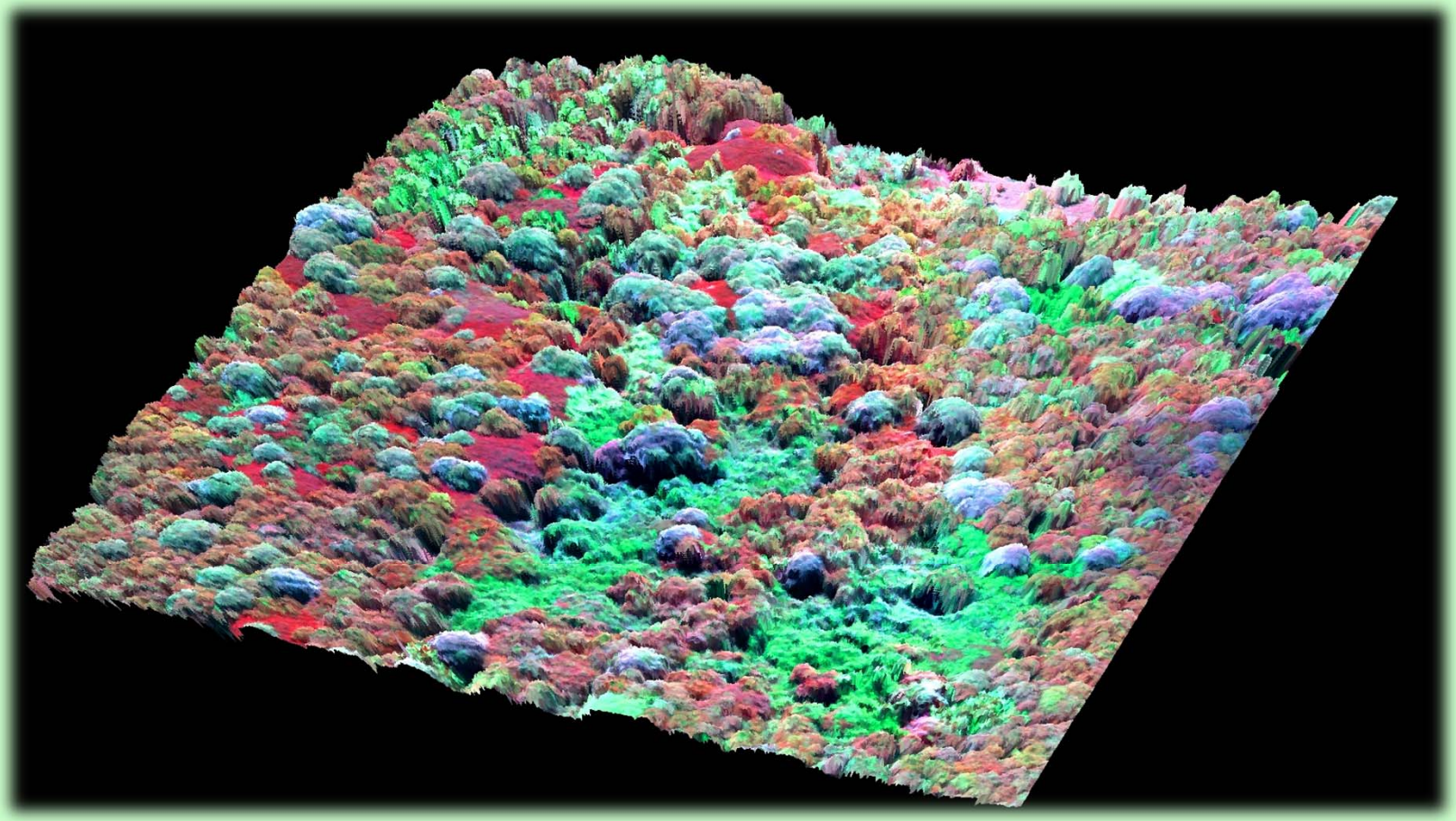
We anticipate that better characterization of vegetation type and function in the endemic regions of risk for Ebola outbreaks will improve the prediction ability of the current models and will result in timely generation of improved Ebola risk maps.

In anticipation of the forthcoming NASA/HyspIRI, continuous spectra at sufficient for ecological assessment high spatial resolution is becoming available with the launch of the new foreign spectral missions.

Requirement

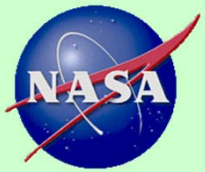
International collaboration to assemble **spectral time series** and **validation datasets** for key EOS sites, monitoring the changes in environmental and vegetation properties (e.g. chlorophyll content dynamics, canopy moisture, and structural foliar compounds) before, during and after the outbreak, to improve our understanding of the environmental factors in the regions at risk.

Canopy chemistry and biodiversity in tropical forest canopies



Asner, Amazon drought research
NATURE, Vol 466 (22) July 2010,
and *New Phytologist (3)*

Thank you for your attention!



Goddard
SPACE FLIGHT CENTER

Product Maturity Curve

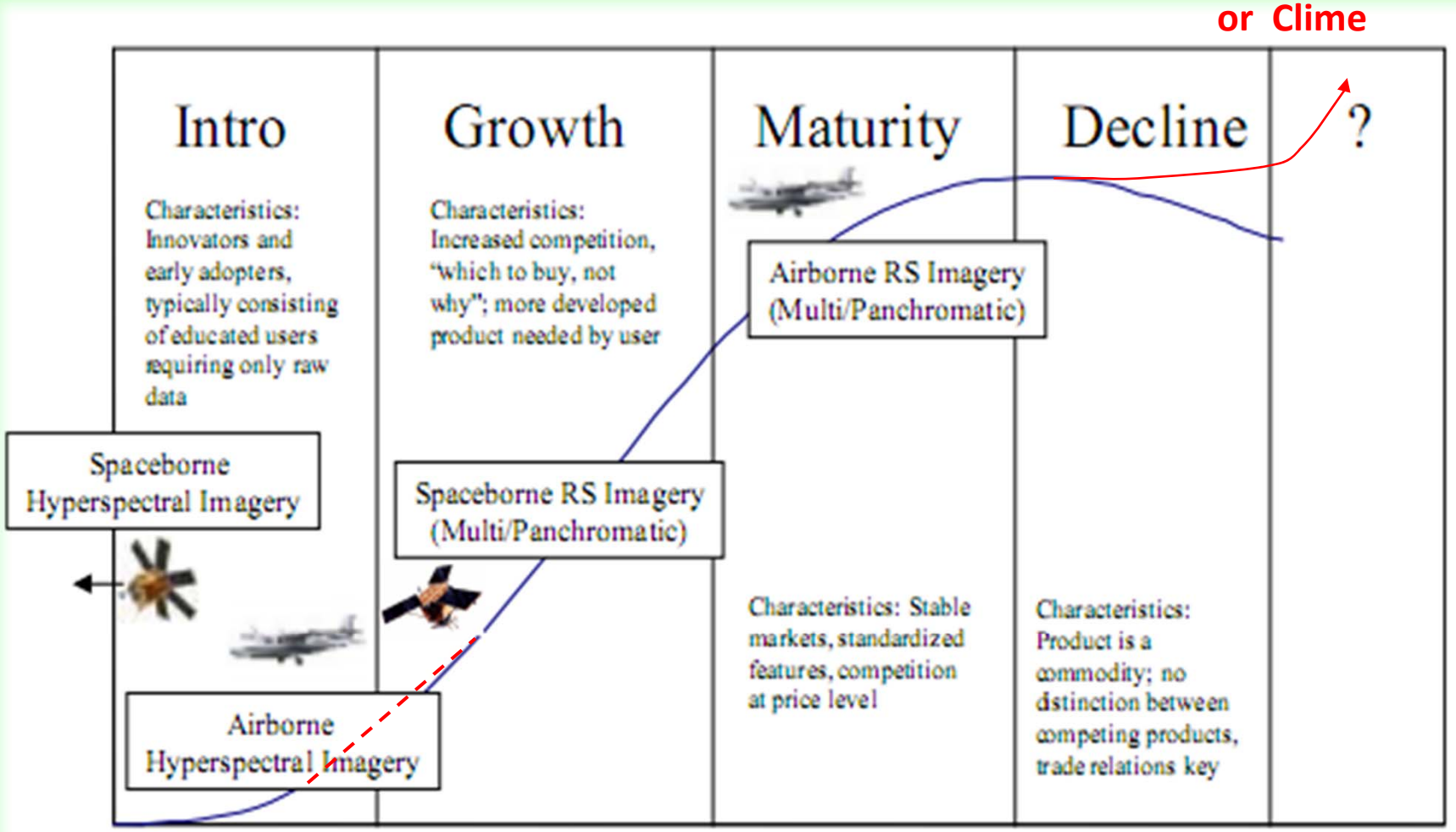
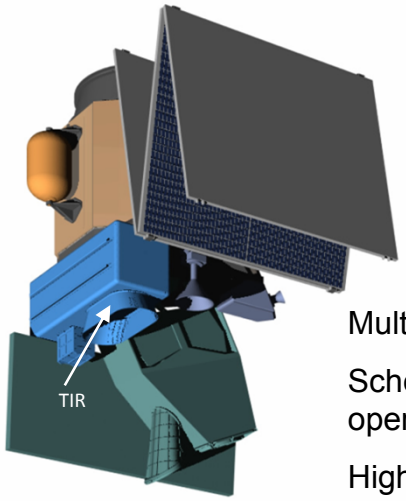
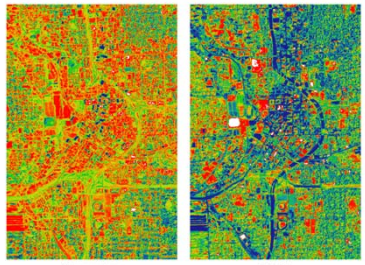


Figure 5-1. Product Maturity Curve.

Bendor, 2010

HyspIRI Thermal Infrared Multispectral (TIR) Science Measurements





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)

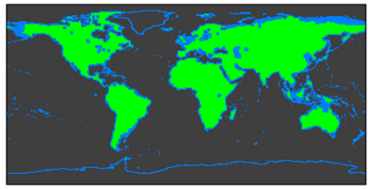
– How does urbanization affect the local, regional and global environment? Can we characterize this effect to help mitigate its impact on human health and welfare?

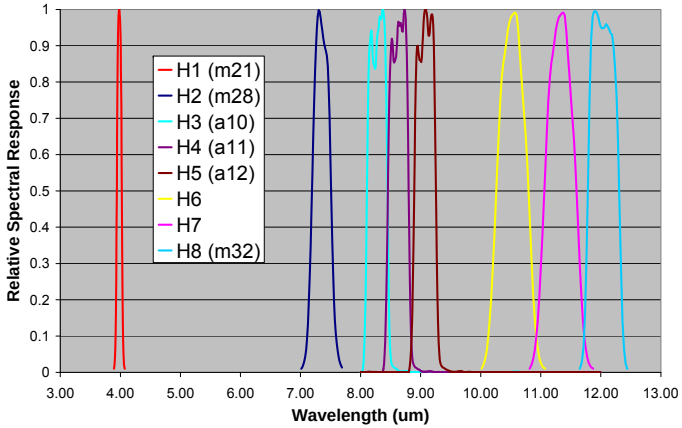
• TQ5. Earth surface composition and change, (AP,JC)

– 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?

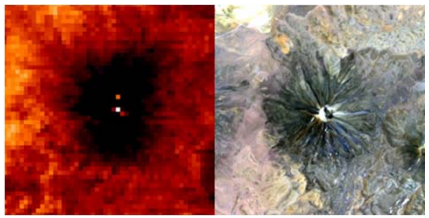
Measurement:

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

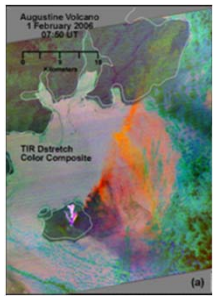




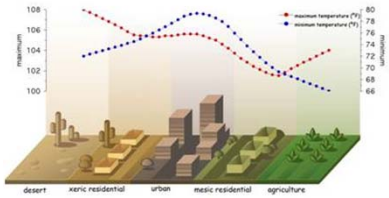
Andean volcano heats up



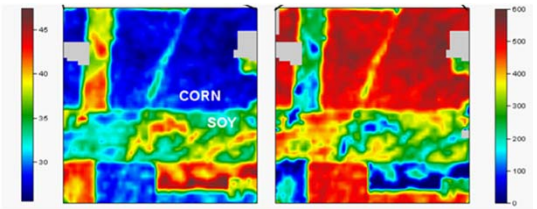
Volcanoes



Urbanization



Water Use and Availability



Surface Temperature

Evapotranspiration

HyspIRI VSWIR
Key Science Measurements Characteristics