EO-1 Hyperion globally distributed spectral time series for assessment of the seasonal changes in vegetation function and productivity

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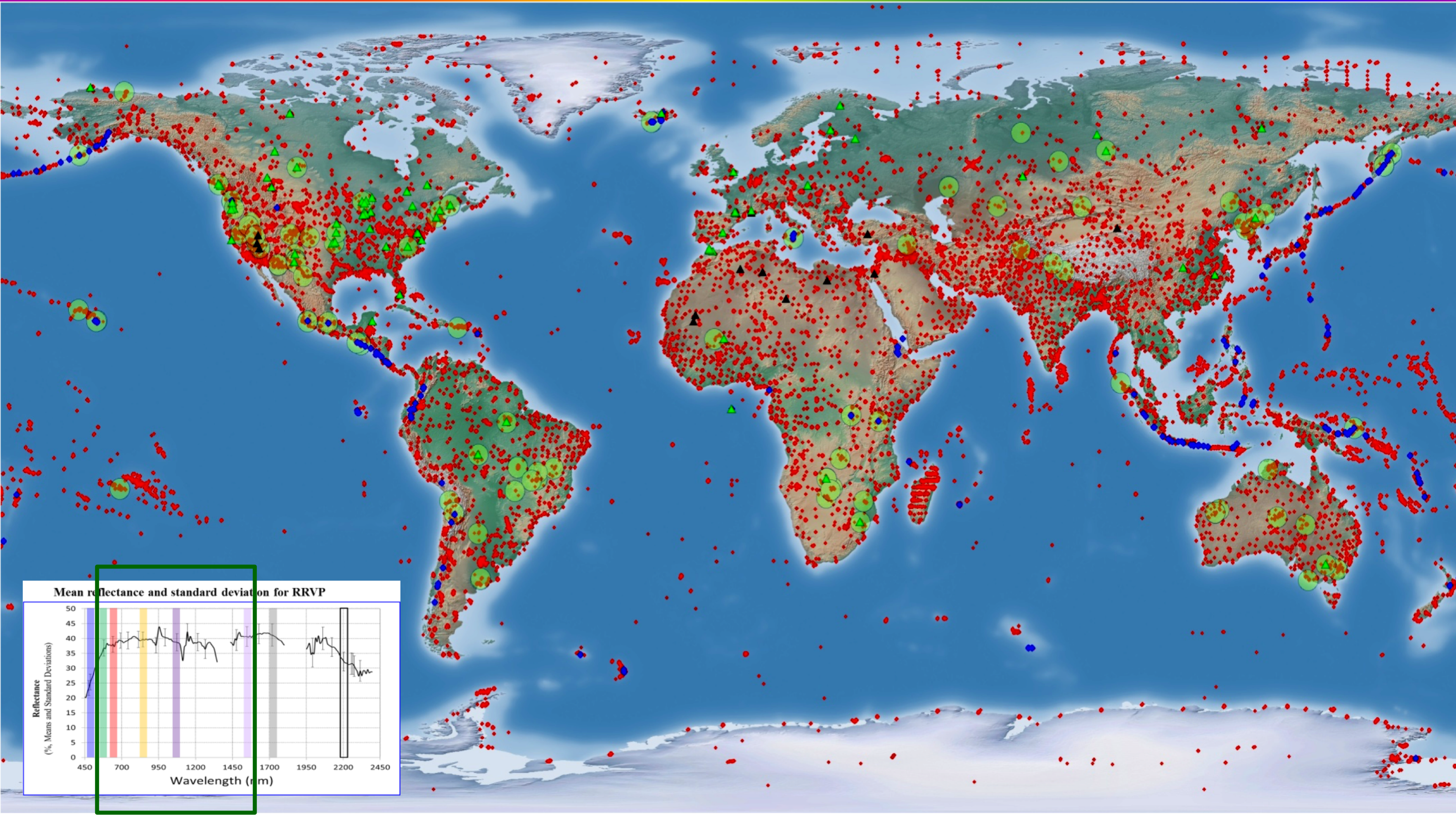
The EO-1 Image Archive

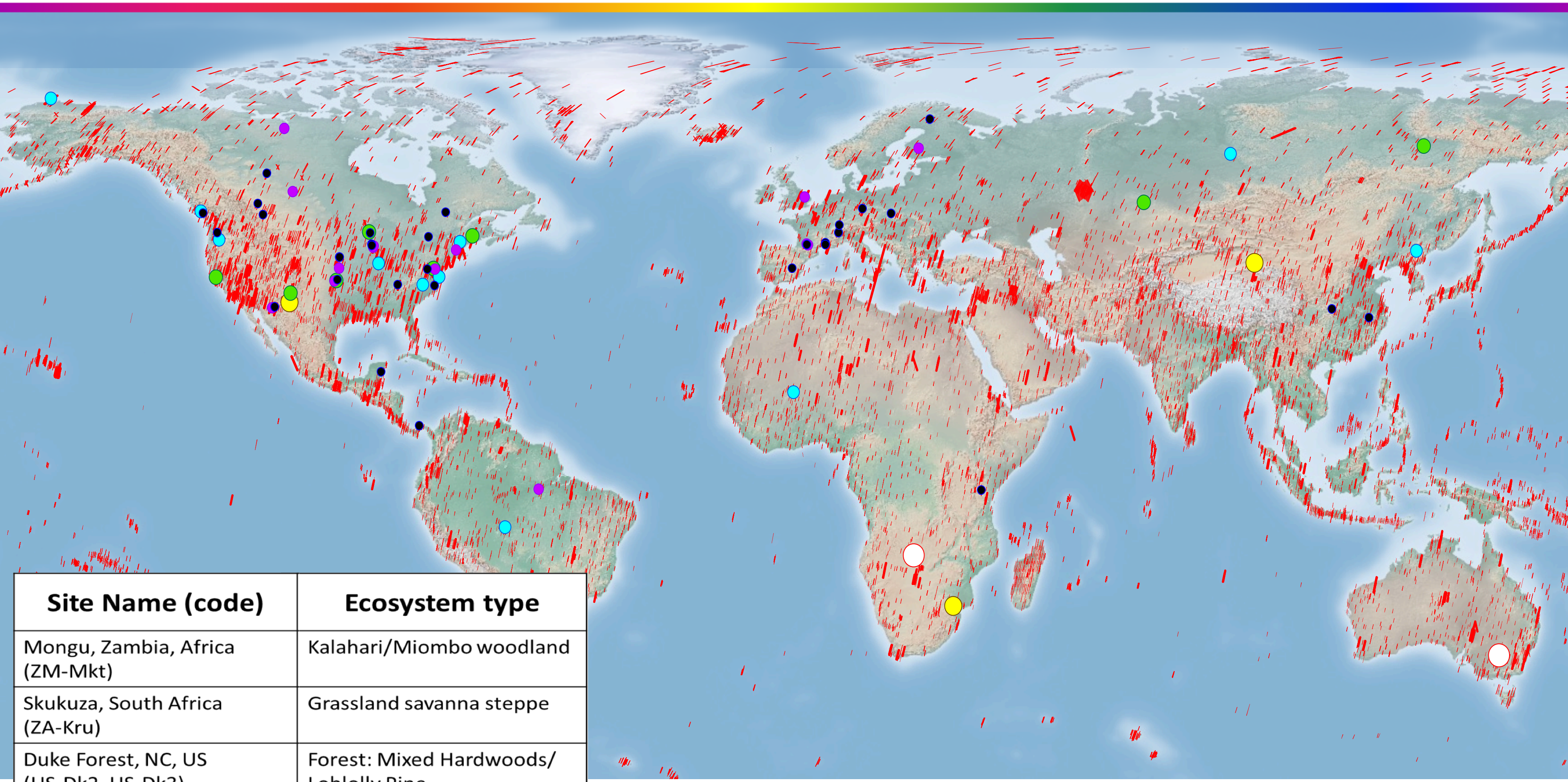
EO-1 Hyperion collected 90,995 scenes



EO-1 Observations • MSO Sites ▲ CEOS Sites ▲ Volcanoes ◆ > 10 Observations ●

Distribution of Hyperion Scenes by FLUX Site

> 9,600 Hyperion scenes have been collected over FLUX sites



Site Name (code)	Ecosystem type
Mongu, Zambia, Africa (ZM-Mkt)	Kalahari/Miombo woodland
Skukuza, South Africa (ZA-Kru)	Grassland savanna steppe
Duke Forest, NC, US (US-Dk2, US-Dk3)	Forest: Mixed Hardwoods/ Loblolly Pine
Park Falls, Wisconsin, US (US-Pfa)	Mixed Deciduous Broadleaf
Konza Prairie , KS, US (US-KFB, US-Kon)	Grassland/ C4 tall grass prairie
Greenbelt, MD, USA (USDA/BARC)	Corn, C4
Howland, ME, US (US- Ho1)	Evergreen: Black spruce

7 PFTs
300+ images

Goal and Science Questions

Goal: to monitor and compare vegetation function and productivity for different functional types.

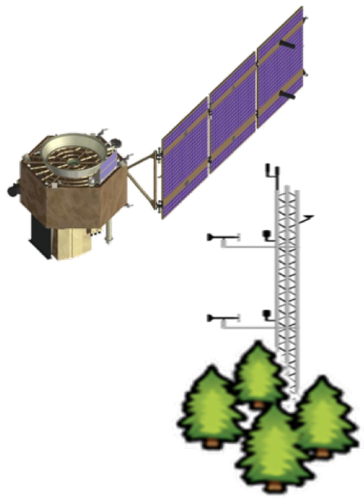
Q1. What are the seasonal changes in vegetation reflectance associated with changes in function and CO_2 sequestration ability?

Q2. What are the key environmental factors driving the changes?

Q3. What are the observations needed to monitor vegetation function?

DS07: VQ2, VQ4 and CQ4 → *DS17: **E-1a**, E-2 and E-3*

Workflow



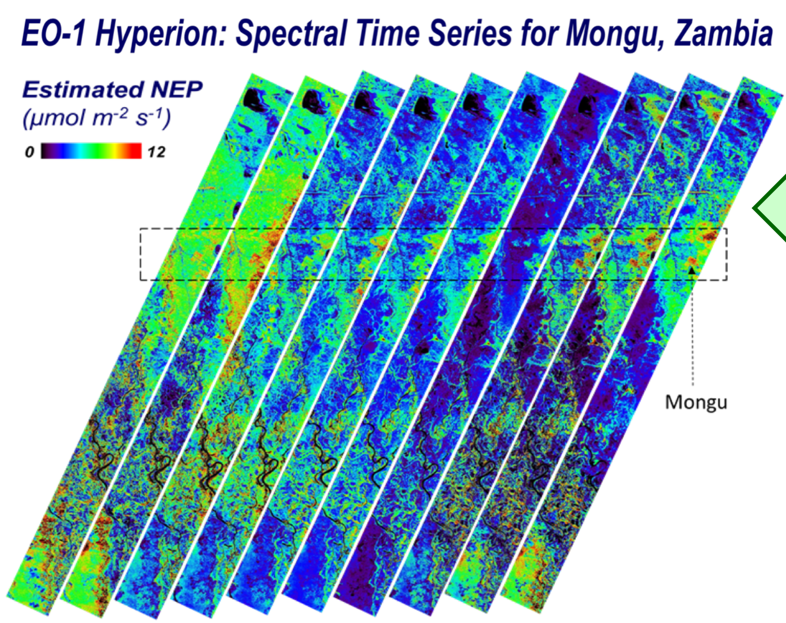
EO-1 Hyperion seasonal time series (TOA rad)

Atmospheric correction, Pre-processing (TOC reflectance)

Reflectance continuous (D, CR/FD) discrete (VIs) (SBIs)

FLUX tower measurements (CO_2 flux, µmol m^{-2} s^{-1})

CO_2 FLUX parameters (**NEP**, GEE, etc.)



Relationship between CO_2 FLUX parameters & Hyperion SBIs

MODELS

Statistical (PLSR)

Bio-physical (RTMo - SCOPE)

Parameters Capturing the Seasonal Dynamics of Ecosystem Productivity and Function

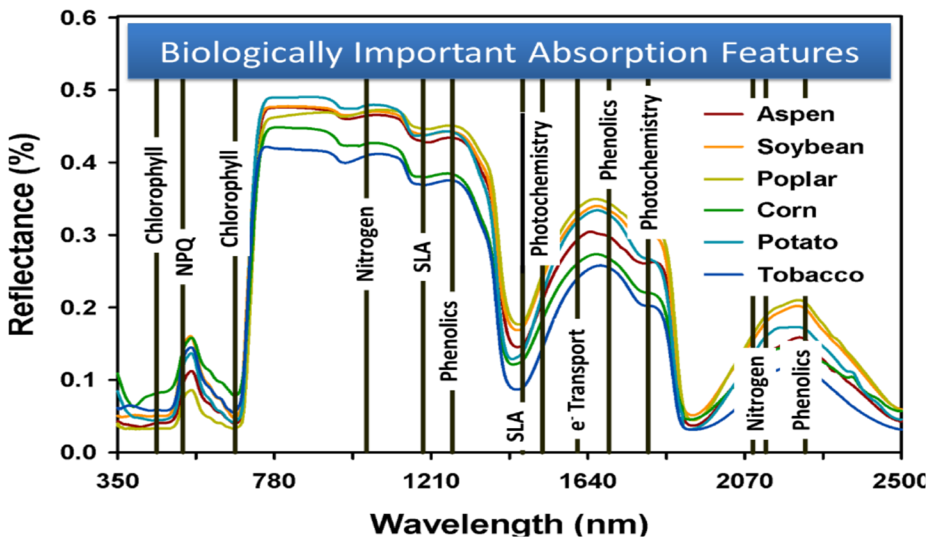
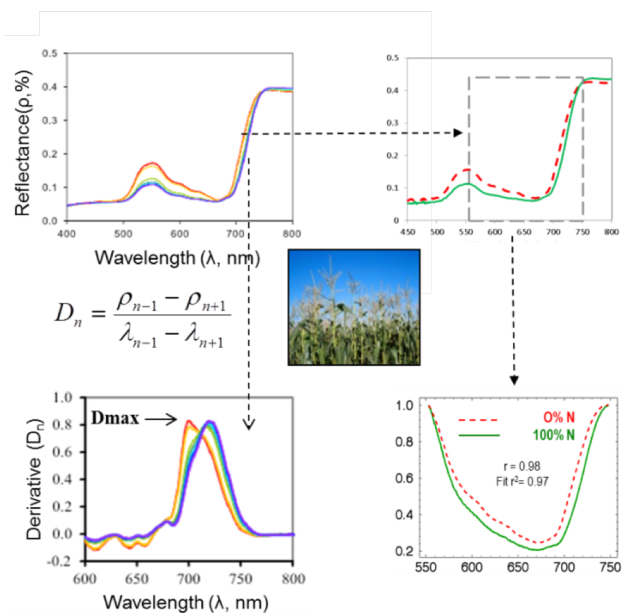


Figure by P. Townsend and J. Couture, use only with attribution.



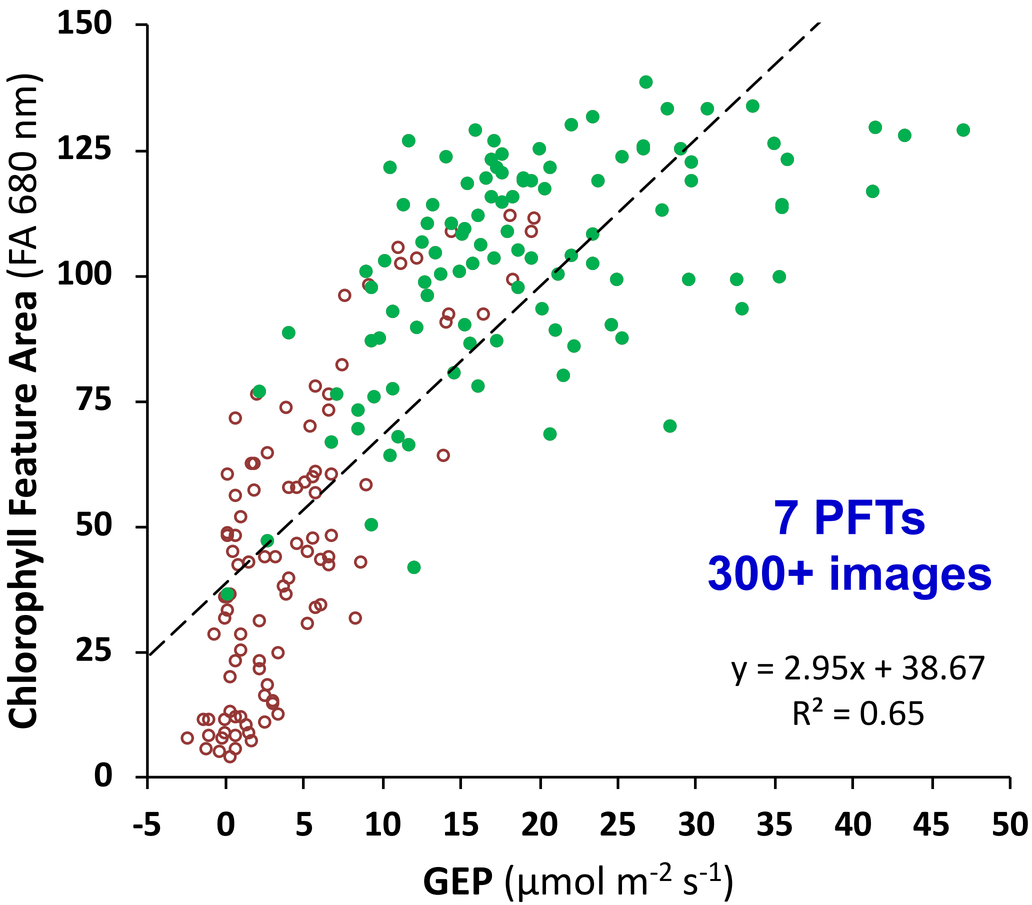
Objective: observe the change in a suite of spectral parameters or features

Tools:

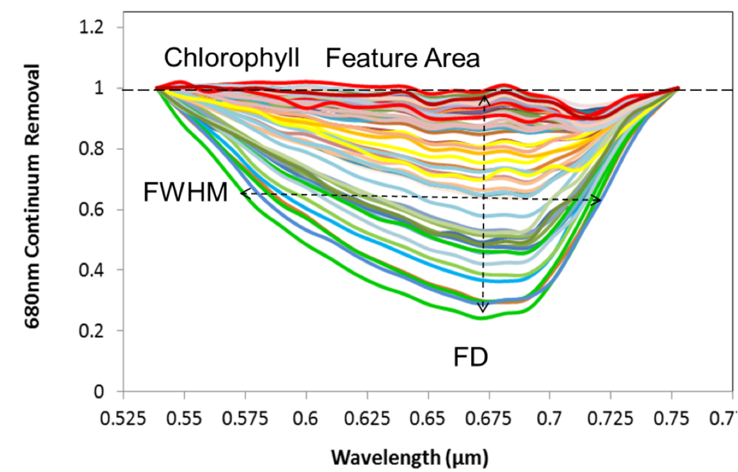
- Reflectance and derivatives
- Continuum removal and spectral feature analysis
- Vegetation indices (VIs)
- Models – statistical & bio-physical

0% N, feature FWHM = 129.33, Area = 93829
100% N, feature FWHM = 141.92, Area = 102911

Reflectance Time Series Capturing the Range in Photosynthetic Function (7 PFTs, 267 images)



Chlorophyll Feature Area (FA)

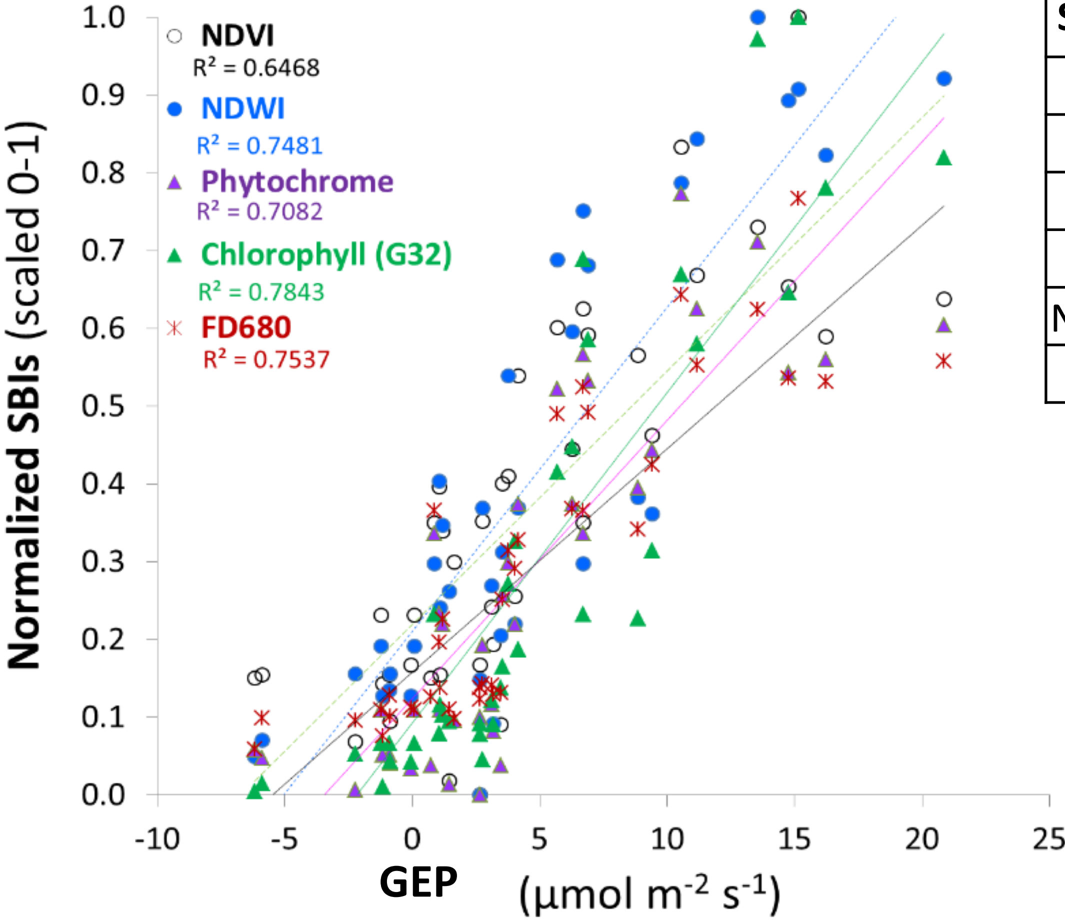


Skukuza (ZA-Kru)

Feature depths and areas were derived using the USGS PRISM tools (Kokaly et all. 2011) https://pubs.usgs.gov/of/2011/1155/

- ✓ The 680 nm feature area (FA) is associated with canopy chlorophyll and GEP for all 7 PFTs.
- ✓ Time series are required to capture the dynamics in GEP across the season.

VIs Associated with GPP are Related to a Suite of Different Bio-physical Parameters



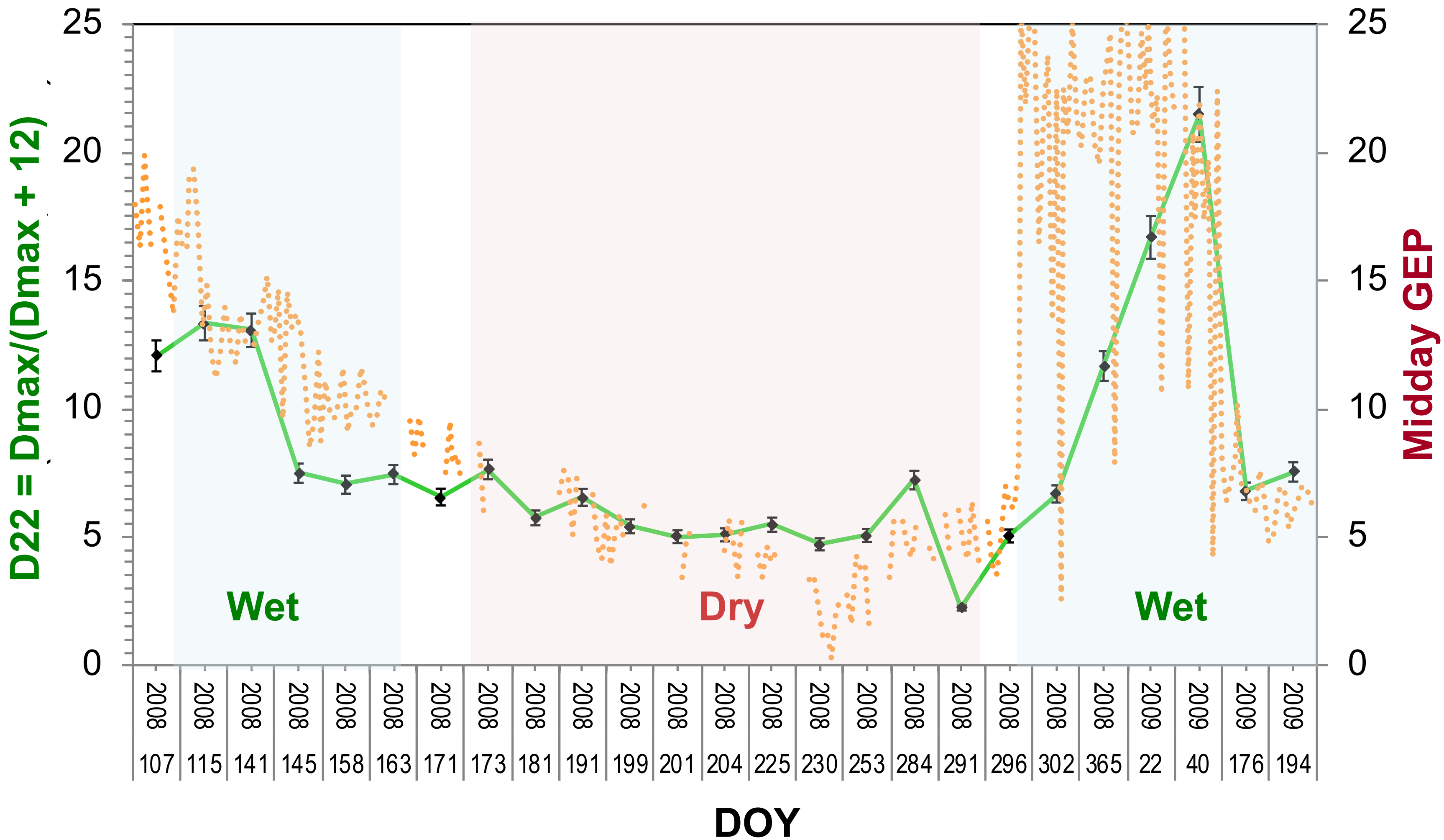
Spectral Parameters	R^2 to GEP
FD680 (PRISM)	0.75 *
FA680 (PRISM)	**0.82 ***
Phyt=(R724-R654)/(R724+R654)	0.71
G32=(R750-R445)/(R700-R445)	**0.78 ***
NDWI=(R819-R1649)/(R819+R1649)	0.74
NDVI=(TM4-TM3)/(TM4+TM3)	0.65

Key bio-physical parameters

- canopy chlorophyll
- water content
- but also phytochrome, lignin and cellulose

Example from Skukuza (ZA-Kru)

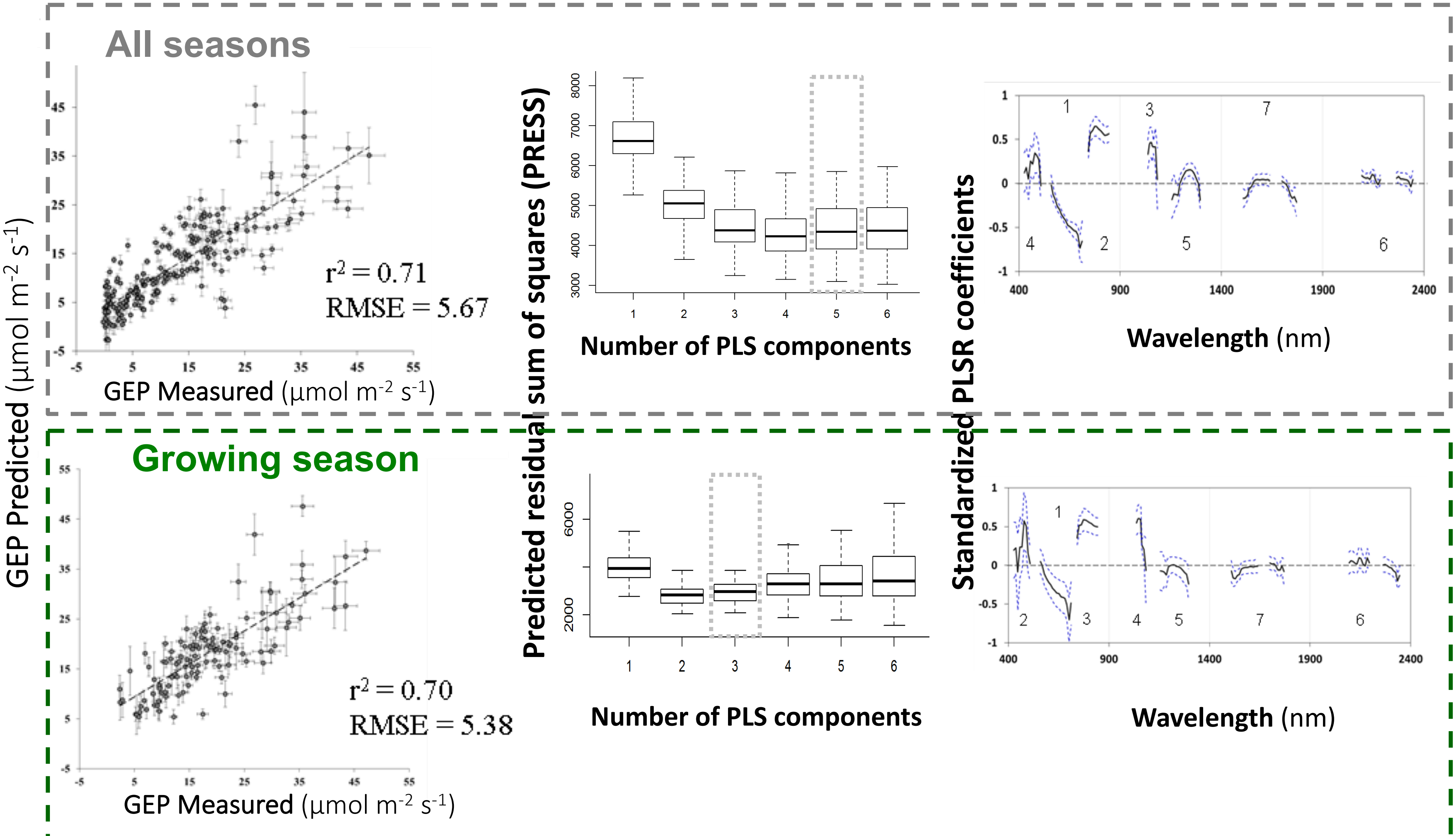
Hyperion Derivative Indices and GEP



The derivative index D22 associated with chlorophyll content (green line) captured the CO_2 dynamics related to vegetation phenology at Mongu

PLSR Models - Use with Reflectance Time Series

Predicted vs. Observed Canopy GEP



7 PFTs 300+ images

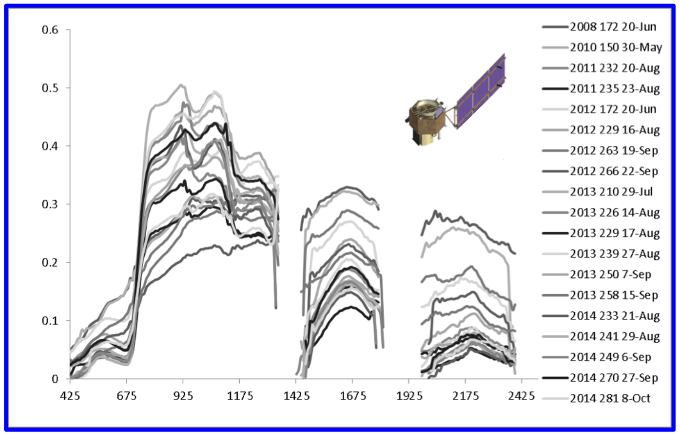
PLSR models were derived and evaluated using the methods and tools developed by the group of P. Townsend (Singh et al. 2015)

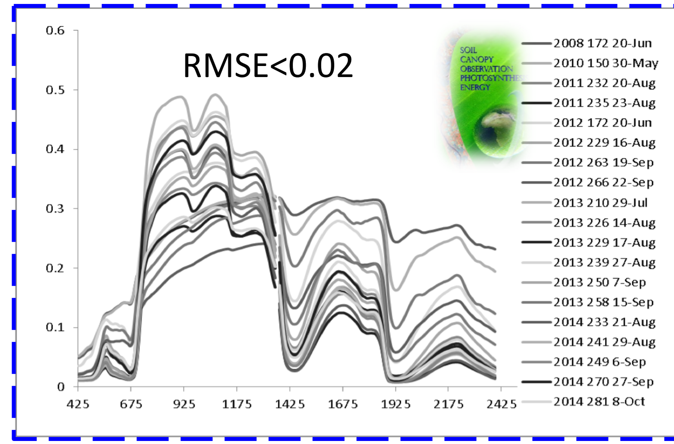
Bio-physical Model - Use with Reflectance Time Series

Reflectance time series
→ RTMo
→ Simulated reflectance + canopy bio-physical parameters
→ SCOPE
→ **GEP** predicted

Measured - - - - - - - - → **Simulated**

EO-1 Hyperion reflectance | **SCOPE, RTMo**





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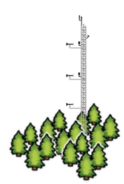


GEP measured

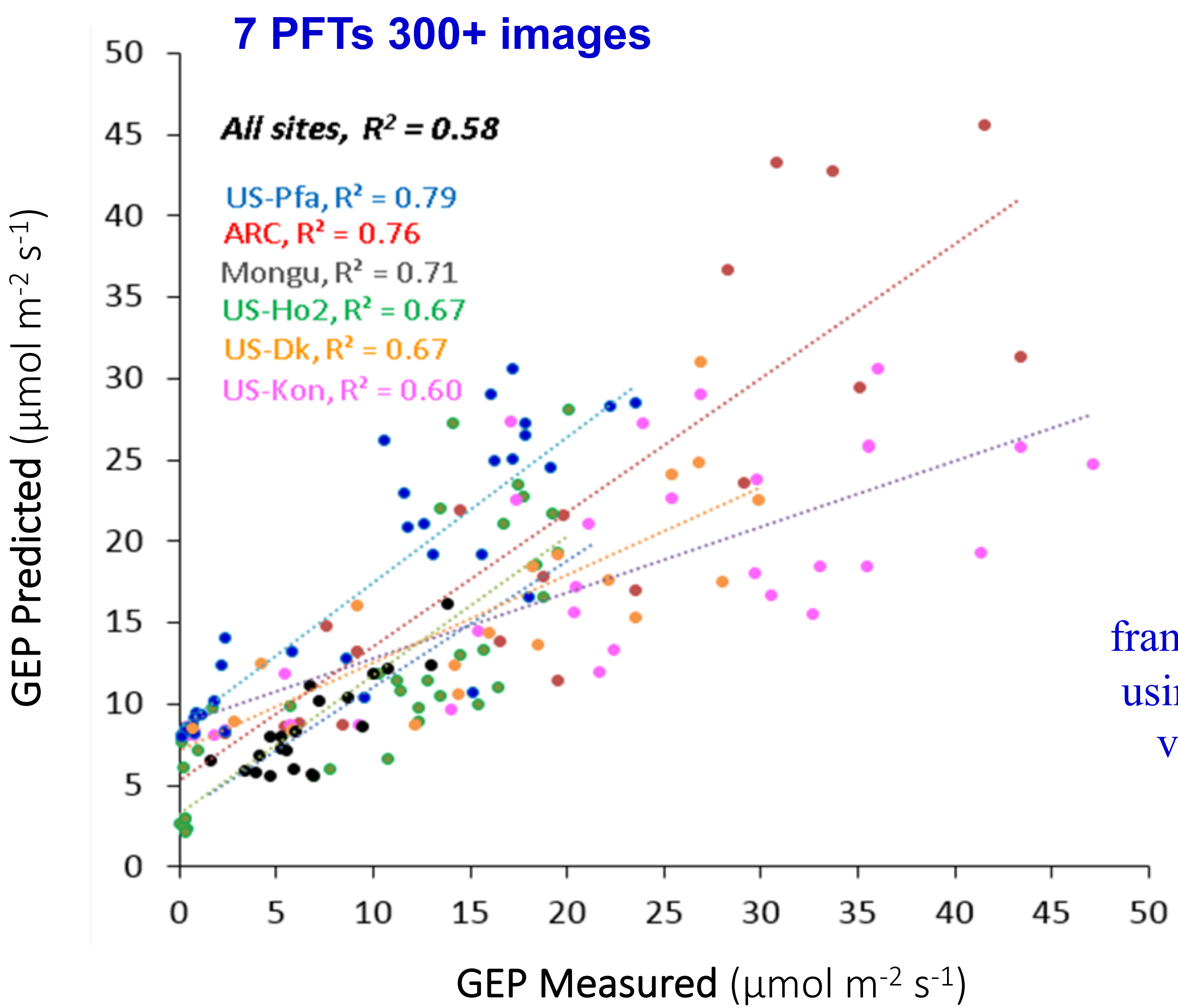
RTMo is a part of SCOPE, including:

- 4SAIL – canopy radiative transfer
- Fluspect/PROSPECT5 - leaf optical
- GSV - soil reflectance

The SCOPE modeling framework provides the ability to
*- identify the **driving factors, and***
- validate/confirm the findings
against field and eddy covariance measurements.

Predicted vs. Observed Canopy GEP

Bio-physical model: RTMo + SCOPE

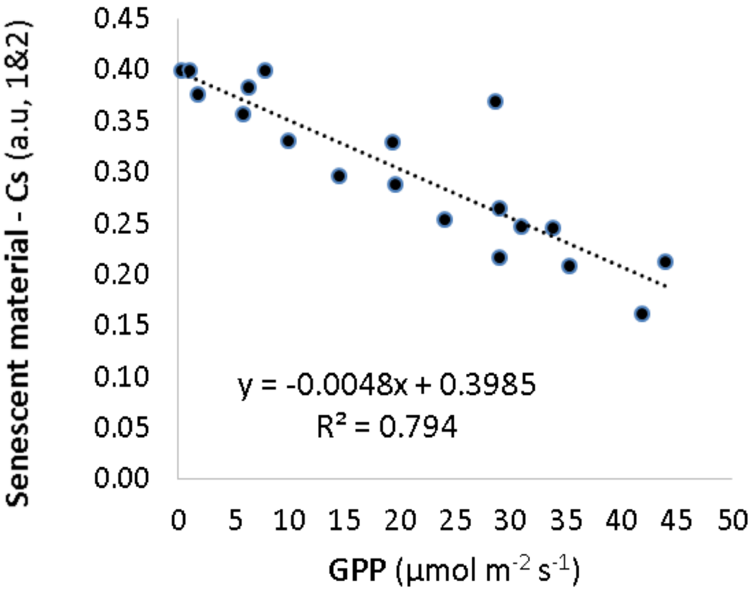


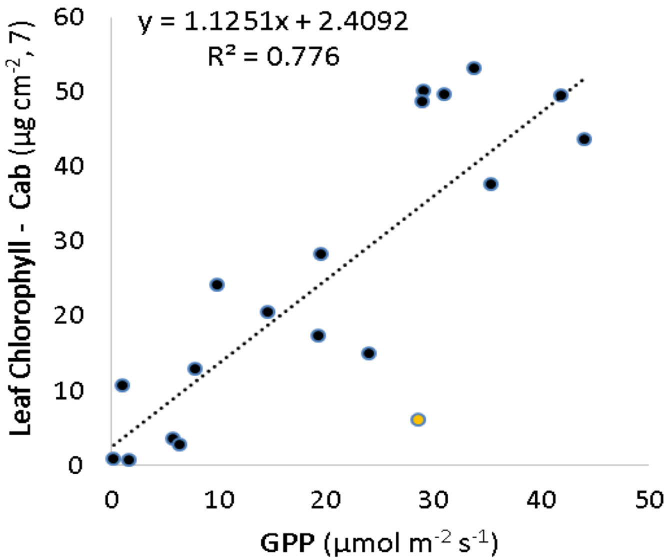
The SCOPE model framework was implemented using tools developed by C. van der Tol et al. (2009, 2014, 2016)

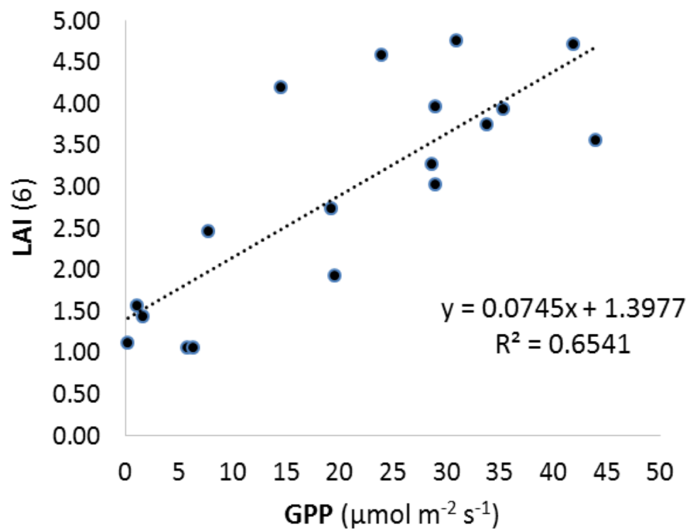
Bio-physical Parameters Associated with GPP

EO-1 Hyperion; Example for Corn, OPE3, USDA/ARC

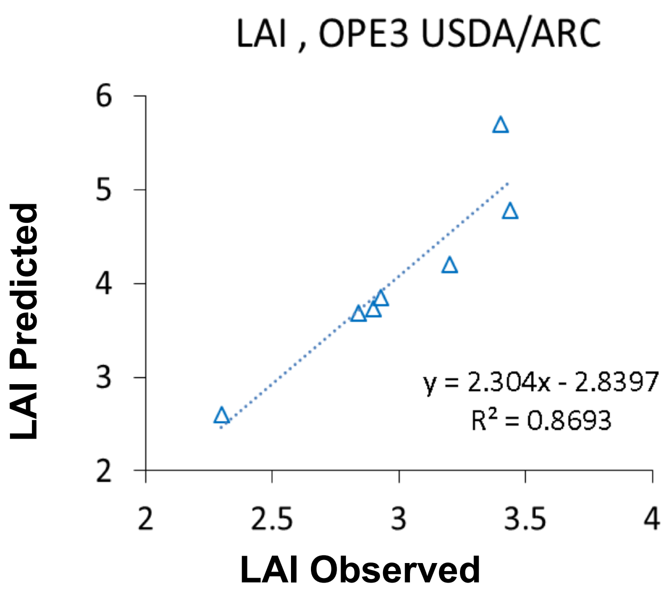
Bio-physical parameters *(in order of importance)*
Senescent material - Cs (a.u, 1&2)
Total Chlorophyll - Cab (µg cm^{-2}, 3)
Dry mater - Cdm (g cm^{-2}, 4)
Leaf inclination - LIDF (5)
Canopy water content - Cw (g cm^{-2}, 6)
Leaf Area Index - LAI (7)

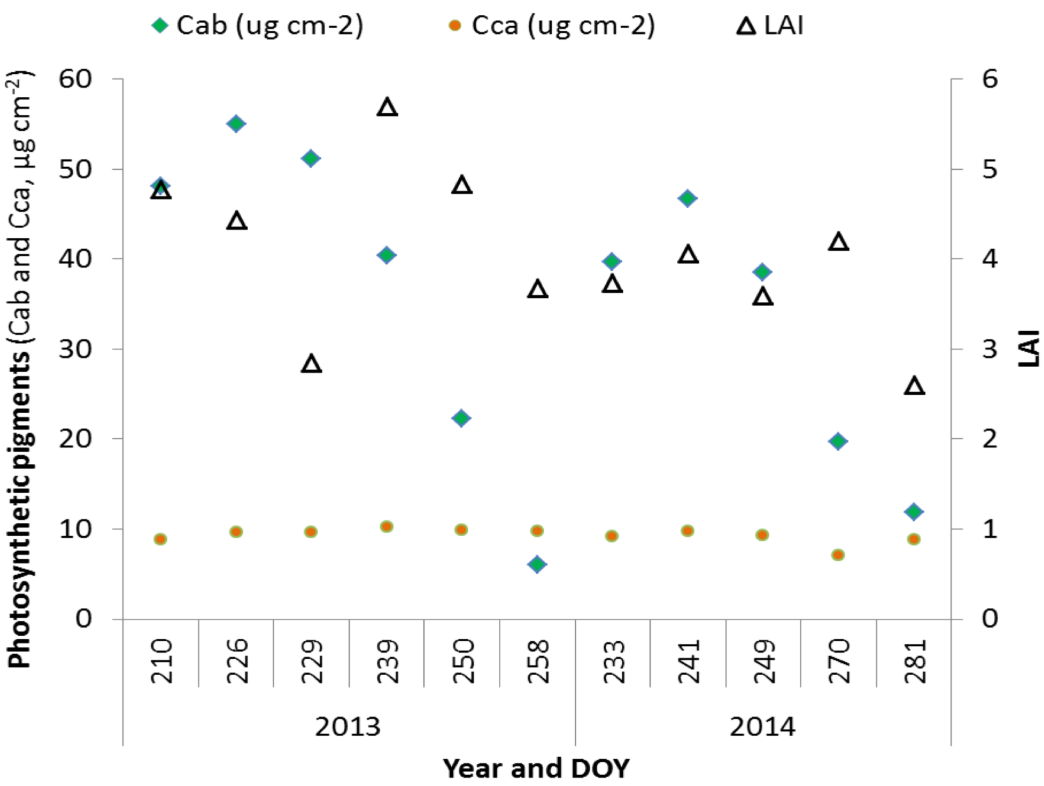




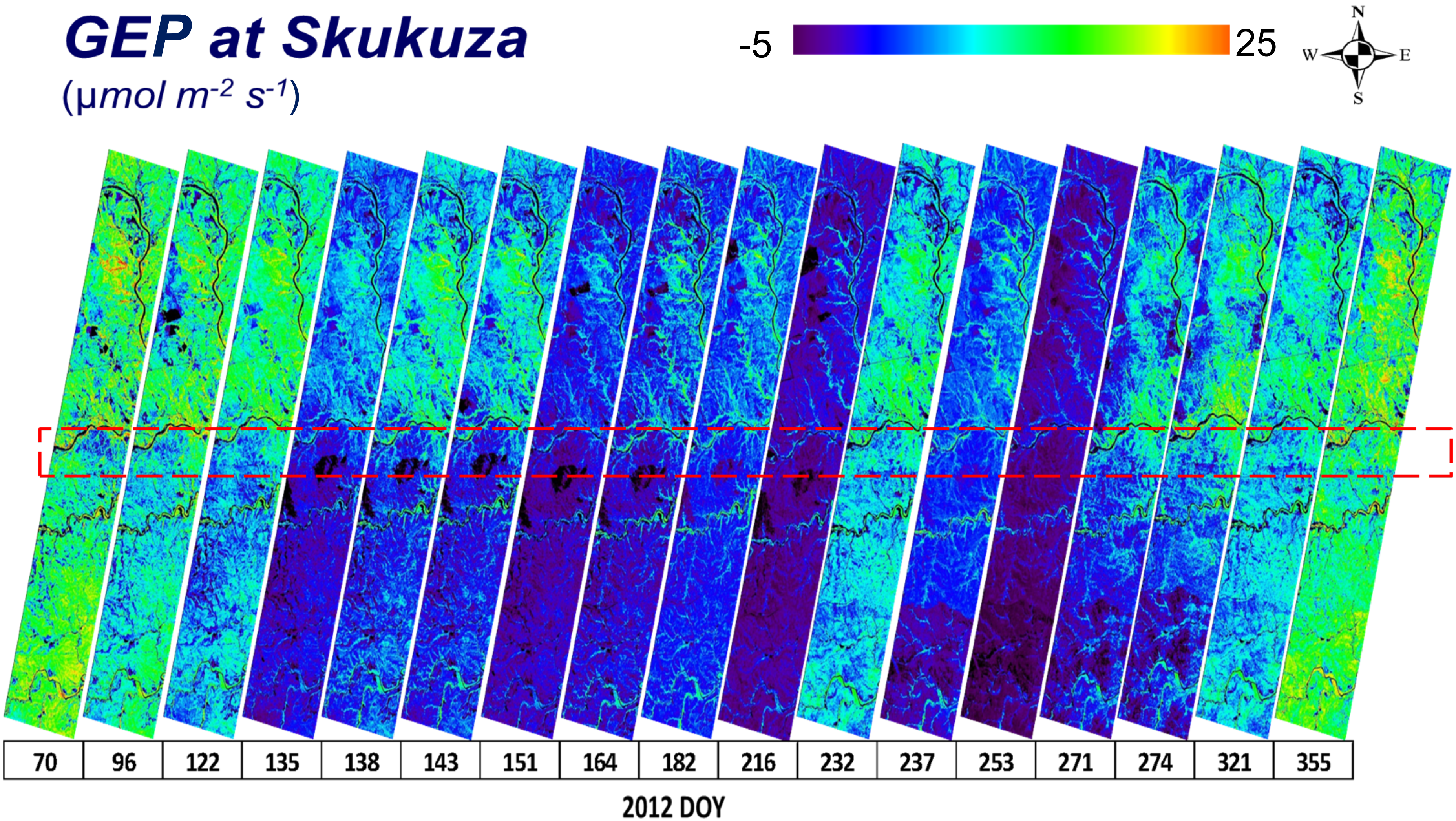


Confirmation and Dynamics of the Bio-physical Parameters at OPE3

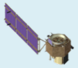




Hyperion Spatial Distribution Maps, Capturing the Seasonal Range of CO_2 Absorbed by the Vegetation



Combined Modeling and Observation of Bio-physical Parameters and Productivity (GEP)



EO-1 Hyperion reflectance time series
(TOA radiance)

↓

Atmospheric correction
Pre-processing
(TOC reflectance)

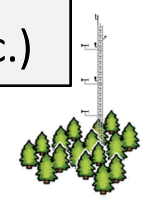
↓

Canopy Reflectance
Spectral features
Derivative spectra
Vegetation indices

FLUX tower measurements
(CO_2 flux, µmol m^{-2} s^{-1})

↓

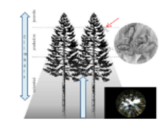
Canopy Function and Productivity
(NEP, GEP, LUE etc.)



Field Measurements

<u>**Leaf**</u> Chlorophyll
Water, Nitrogen

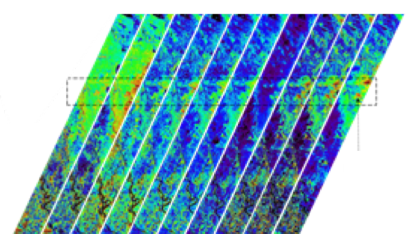
<u>**Canopy**</u> LAI,
Photosynthetic vs non-photosynthetic component



Models
Statistical (R, PLSR) + Biophysical (RTMo)

calibration and validation of observables

spatial and temporal extend



-2 15
GEP at Mongu (µmol m^{-2} s^{-1})

Observables: time series of canopy chlorophyll and water

Use: vegetation function and GEP

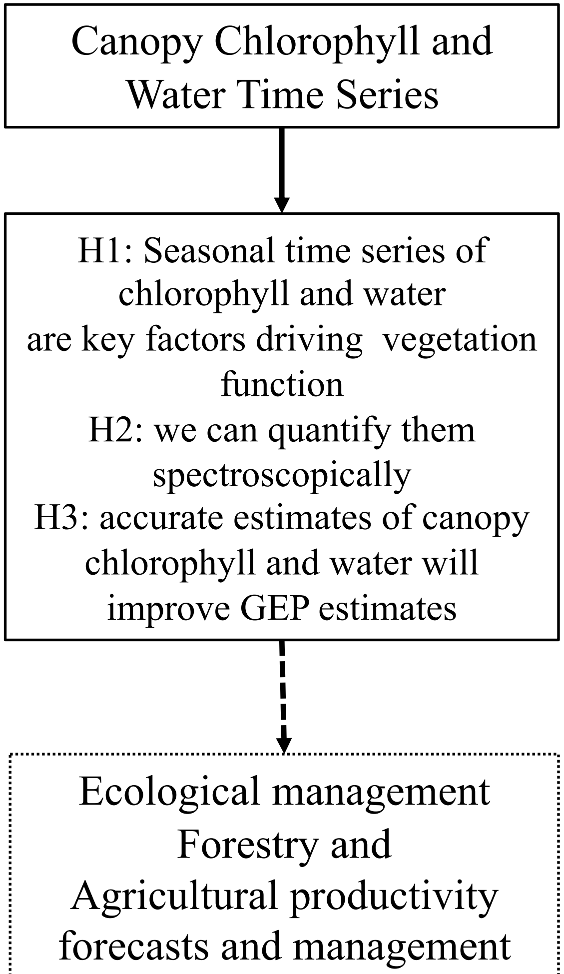
Summary

- The parameters with strongest relationships to GPP were derived using continuous spectra, and were associated with canopy water, chlorophyll content and senescent material
- PLSR models provided highly transferable equations across the 7 PFTs. SCOPE performed well across seasons for each PFT and provided indication of the key bio-physical parameters, which can be validated against field measurements. The complimentary use of both is beneficial for monitoring of vegetation function and GEP.
- Common (global) spectral approaches to compare vegetation function across PFTs and estimate GEP would require:
  - reflectance capturing simultaneously the parameters indicative of vegetation function – chlorophyll, water + others for GEP
  - a diverse spectral coverage, representative of the major ecosystem types
  - spectral time series, to cover the phenological dynamics within a cover type

Future direction: increased PFT diversity, higher frequency time series (TS of spectra + VI), TS including more complete suite of traits (AVIRIS NG), Field validation

Canopy Chlorophyll and Water Content

Preliminary Science Traceability matrix



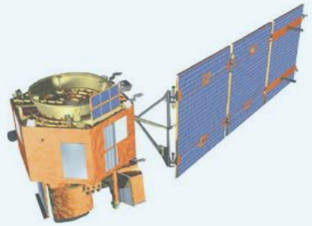
1. Characteristics of proposed information product(s):
   - Products: vegetation canopy chlorophyll and water content
   - Frequency: weekly/monthly/seasonal
   - Spatial: 30 to 60 m
   - Units: g m^{-2}
   - Geographic domain: terrestrial ecosystems and agriculture

2. Currently – high frequency VI time series are used to determine the length of the growing season, and detect stress and limitations in function and productivity. The information is used in precision agriculture, carbon modeling, productivity forecasts; and for efficient and timely response to stress and planning of resources (recovery from nitrogen and water deficiency, forest air-pollution damage mitigation).

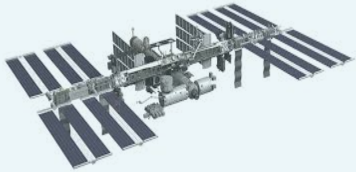
3. Determine utility of time series of canopy chlorophyll and water content, derived trough combined spectroscopy and models, and evaluate/calibrate the standard VIs and single-model approaches for improving the assessment of vegetation function and productivity.
Canopy chlorophyll and water can be derived spectroscopically and validated, their accuracy quantified and improved, to improve GEP prediction.

4. Science Question and Objective – see slide 4

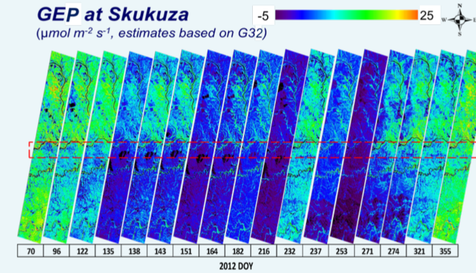
5. Future research – *to document observables and their requirements and make the case that they can be used to address the hypotheses/objectives*.



Orbital (@ ~ 700 km) Global spatial extend, **systematic** repeat for time series (TS)

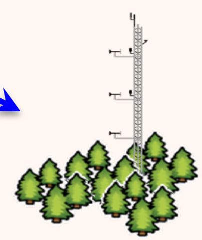


Space station(@ 400 km)
Spatial coverage, repeat

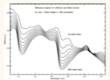


Low - Mid - High Altitude (@ 500 m – 5 km) Spatial coverage

UAV (@ 10 – 120 m) Spatial coverage & TS
site & region



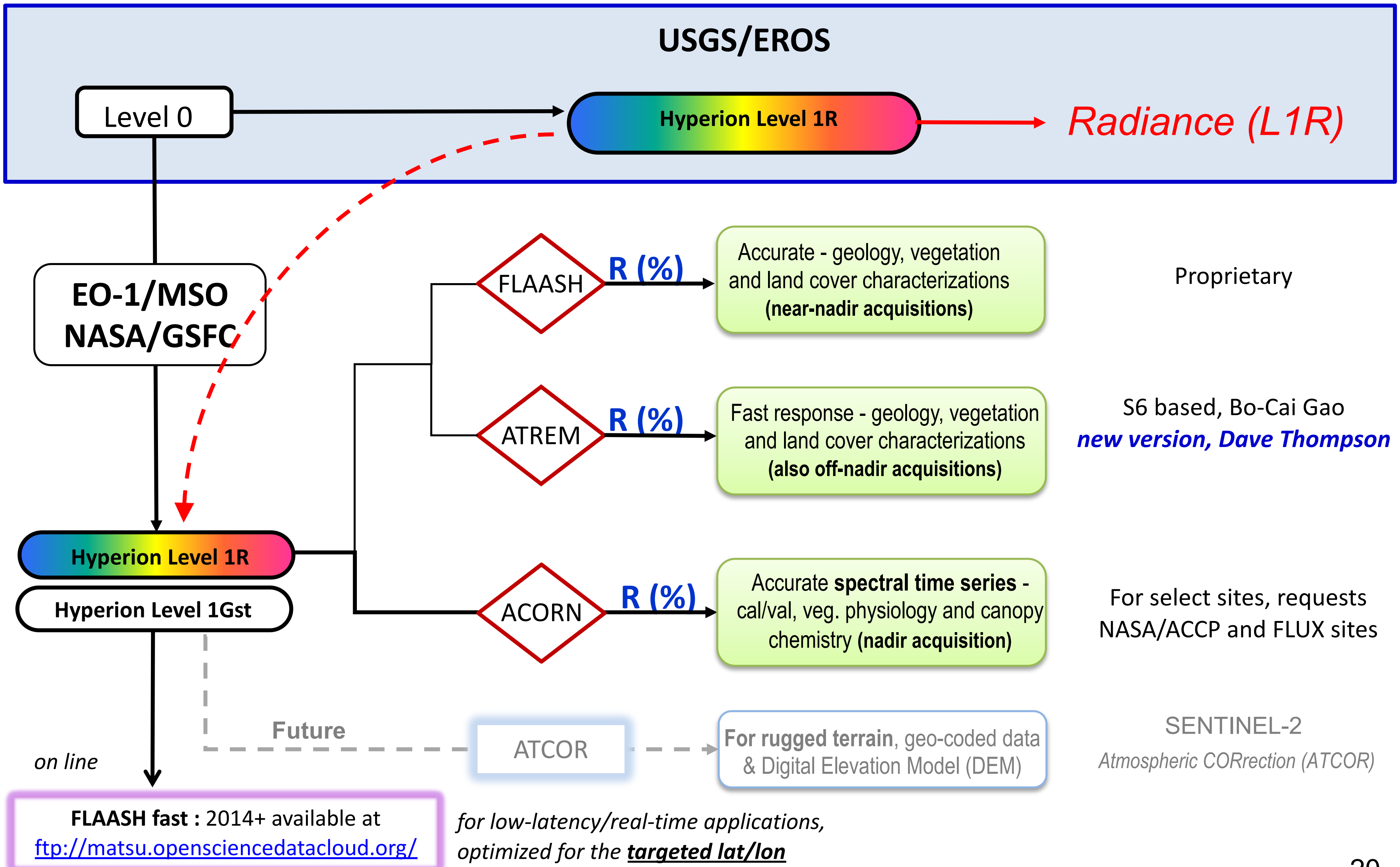
Automated/Fixed Tower (@ 10 - 120 m)
canopy/site, TS



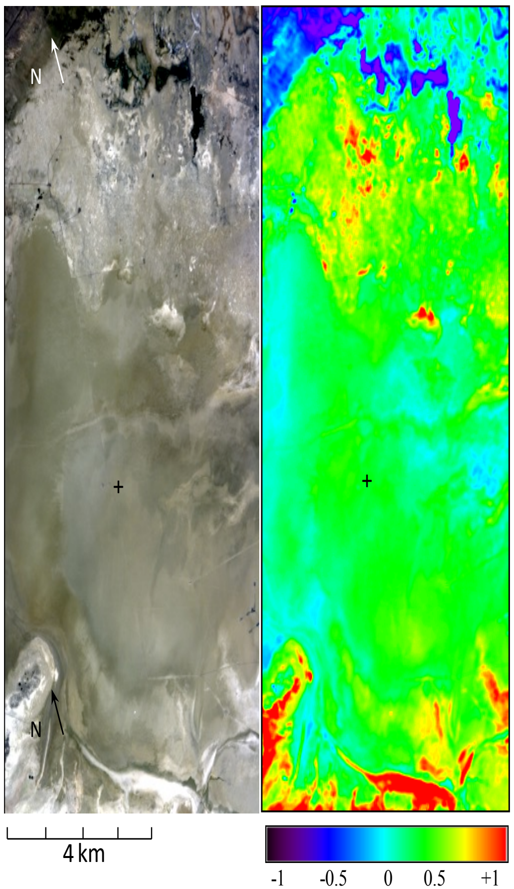
Leaf - canopy (@ ~ 10 m)
leaf – canopy – site
consistent TS

Consistent spectral measurements across ALL spatial scales and environmental conditions

EO-1 Hyperion Level-2 Surface Radiance and Reflectance

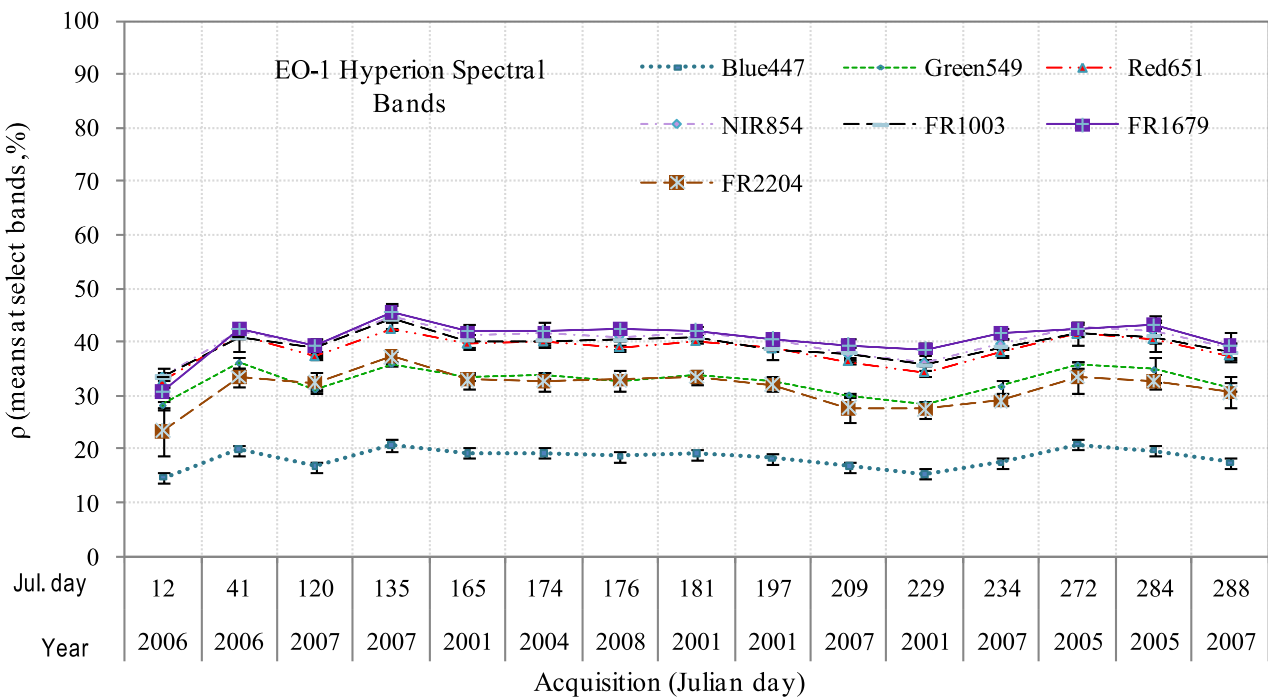


HyspIRI Reflectance Time Series at Calibration Sites



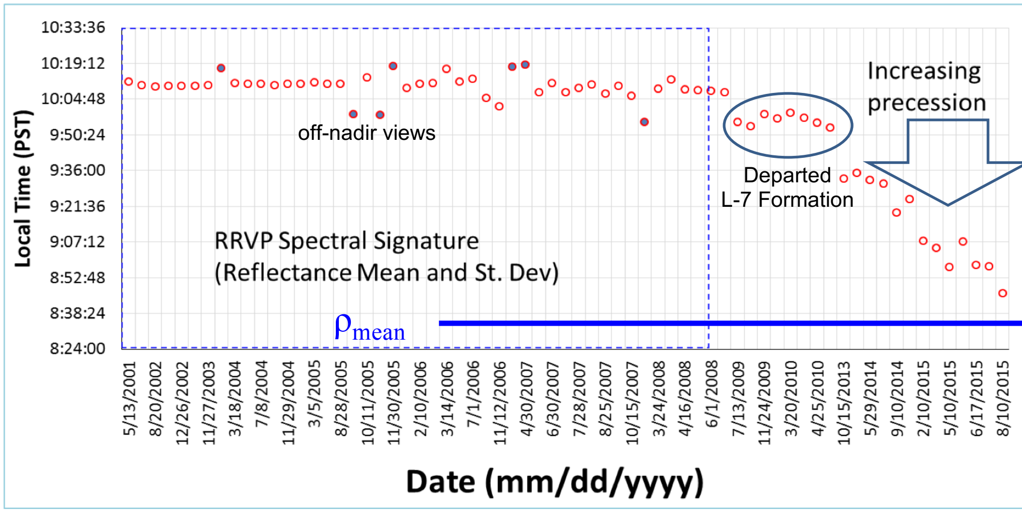
Evaluating the consistency/stability of derived reflectance from Hyperion

Railroad Valley Playa

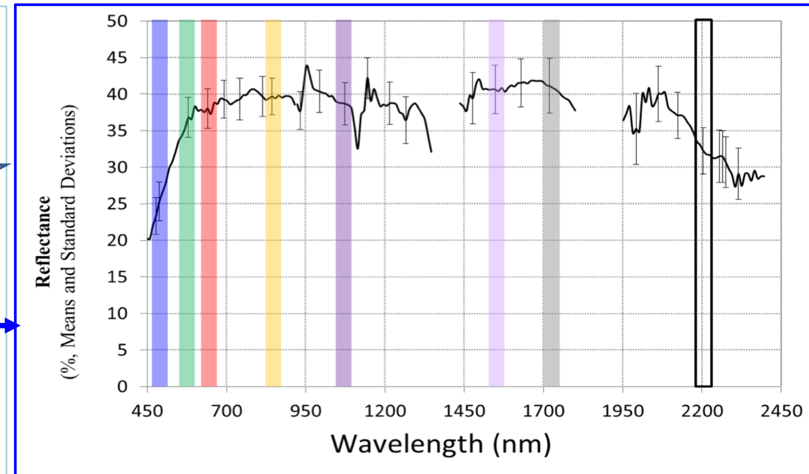


EO-1 Hyperion Reflectance Stability During Increased Precession at Railroad Valley Playa (RRVP)

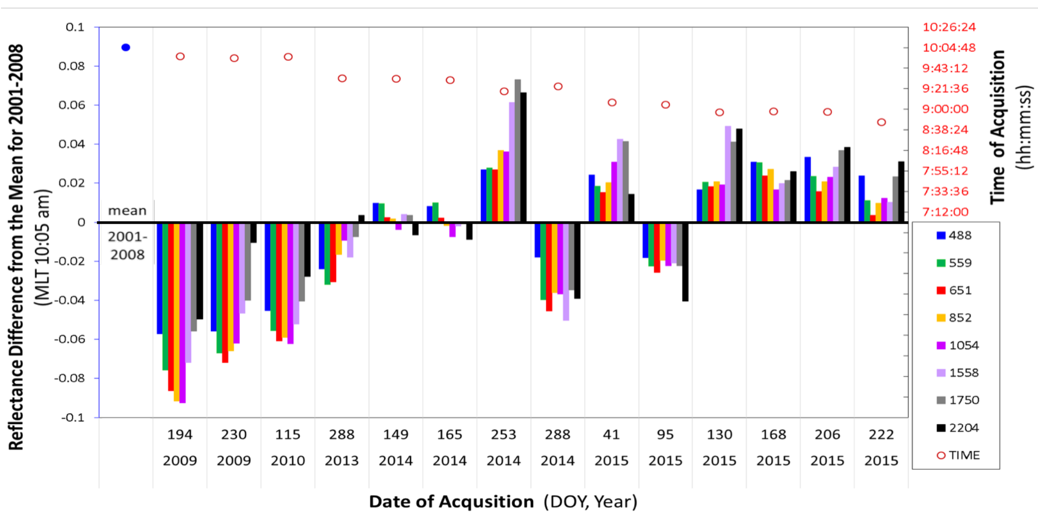
EO-1 increased precession started in 2011. Acquisition time at RRVP declined from 10:05 to 8:40, approximately.



Mean reflectance and standard deviation for RRVP (2001-2008 data, n=15, ~10:05 am MLT acquisition)



Change in reflectance anomaly (Δρ) at select wavelengths at RRVP



The difference in reflectance continues to be within ± 5-9% of the mean prior to Δ precession.

The regions of highest spectral stability (e.g. green, red edge, NIR) remain the same.

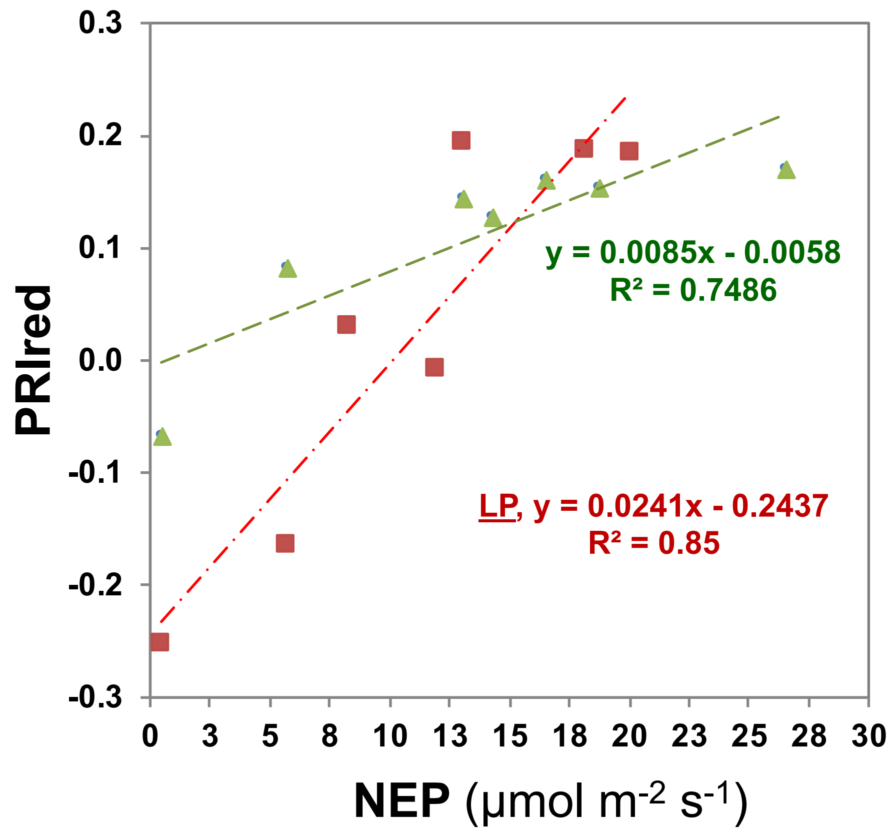
Bio- indicators of *Photosynthetic Function*

Loblolly Pine (LP)

Index	Bands (nm)	R^2 [NEP (GPP) *LUE*]
PRI1	531, 570	0.84 (0.73) L
PRI4	531, 670	0.75 (0.63) *0.73* L
DPI	D 680, 710, 690	0.91 (0.44) NL
NDVI	NIR, Red	0.19 (0.48) L

Hardwoods (HW)

Index	Bands (nm)	R^2 [NEP (GPP) *LUE*]
PRI4	531, 670	0.84 (0.48) NL
Dmax	D max (650…750 nm)	0.83 (0.40) NL
EVI	NIR, Red, Blue	0.84 (0.41) L
NDVI	NIR, Red	0.63 (0.19) L



Duke Forest – PRI & NEP