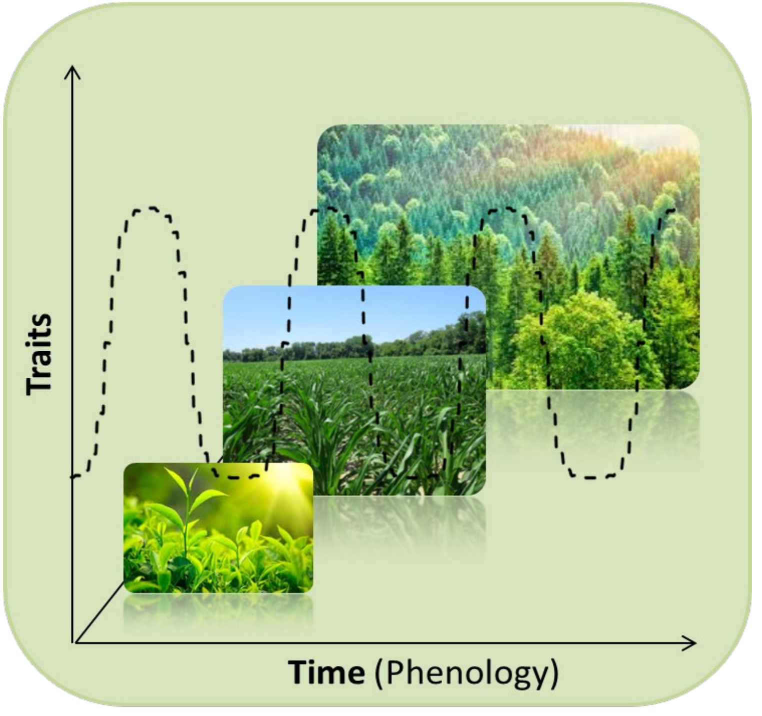
SPECTROSCOPY @ LEAF & CANOPY SCALES

Remote Sensing of Vegetation Function and Photosynthesis

Petya Campbell



GOFC-GOLD
Global Observation of Forest and Land Cover Dynamics

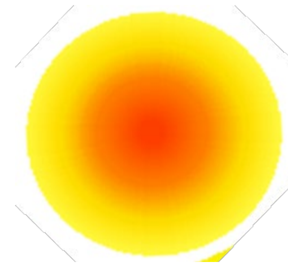
Land-Cover / Land-Use Change Program

[1] SCERIN; [2] UMBC & NASA/GSFC, Greenbelt, MD, USA

Outline

1. Background
2. Linking Vegetation Function & Remote Sensing Spectroscopy
3. Optical remote sensing tools and data for assessment of vegetation function
4. Synergy of Driving Factors -- > Data Synergies
5. Reflectance Time Series
6. Validation and Modeling Framework

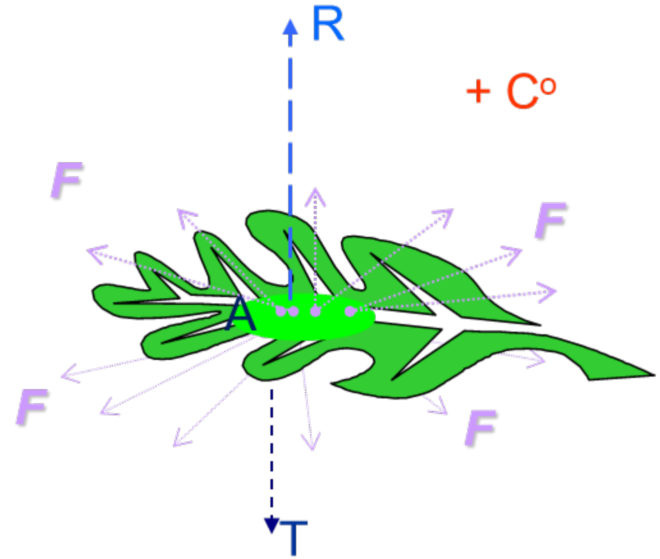
Sources of Energy

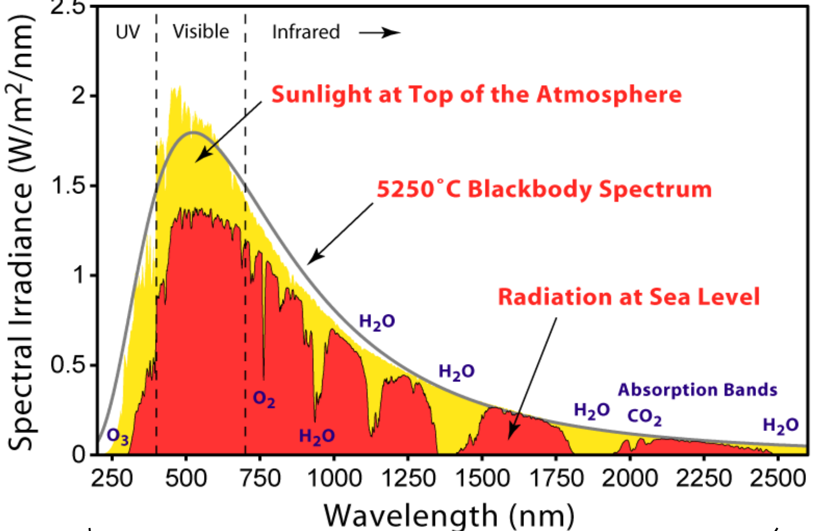


- The major source of Electromagnetic energy that earth receives is from the Sun
  . Nuclear reactions within the Sun produce a full range of electromagnetic radiation

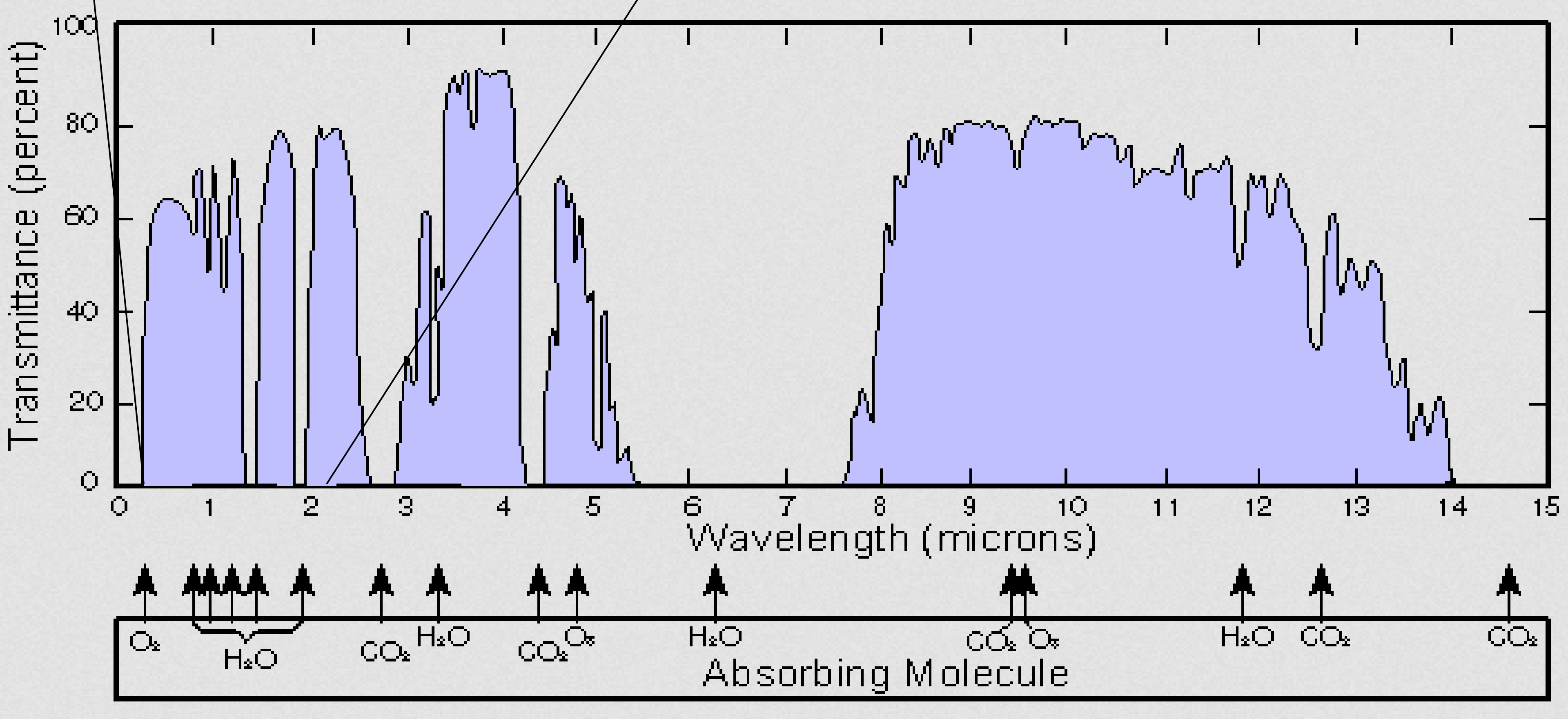
- Reflected electromagnetic energy
  Reflectance ($R\lambda = R_{incoming} / R_{Reflected}$)

- Emitted electromagnetic energy
  . Changes in the energy levels of electrons
  fluorescence and luminance
  . Thermal motion of atoms and molecules
  thermal emissions

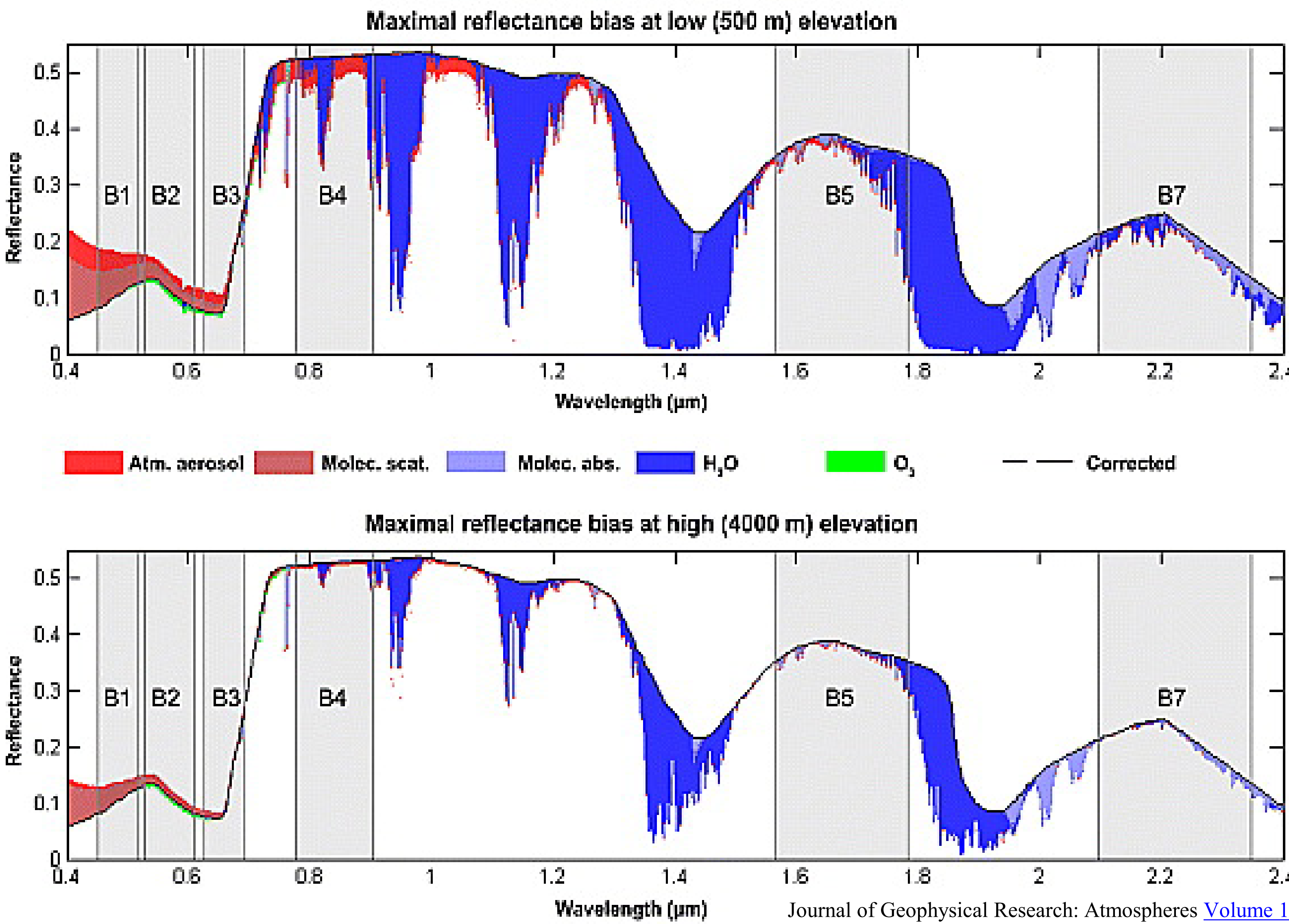




Earth's atmosphere is a continuously changing filter that modifies the sunlight that travels through it.



Atmospheric Effects on Satellite Vegetation Reflectance at Low and High Altitude



Journal of Geophysical Research: Atmospheres Volume 116, Issue D18, D18308, 30 SEP 2011 DOI: 10.1029/2010JD015488

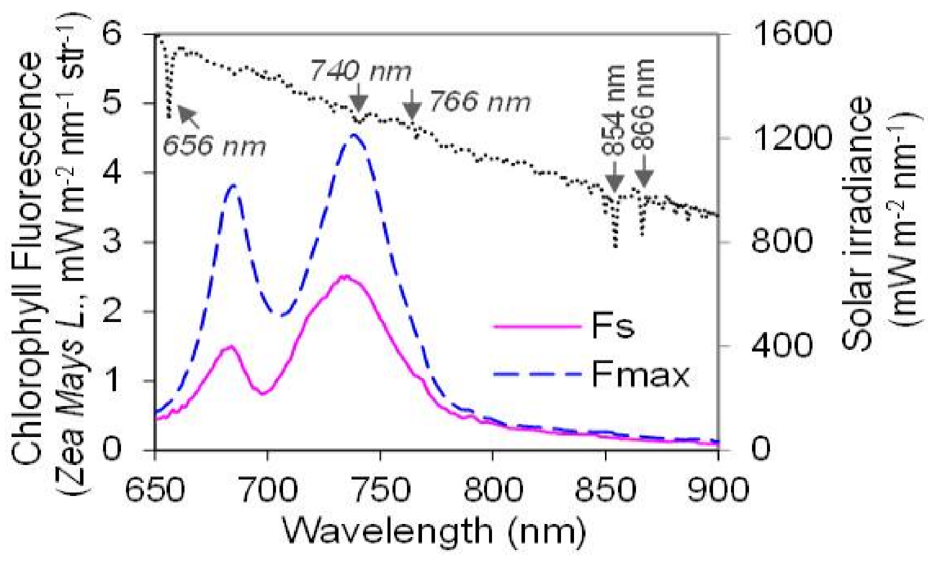
VNIR High Spectral Resolution Spectroscopy of fluorescence and photosynthesis

Fluorescence – can provide a measure of photosynthetic efficiency

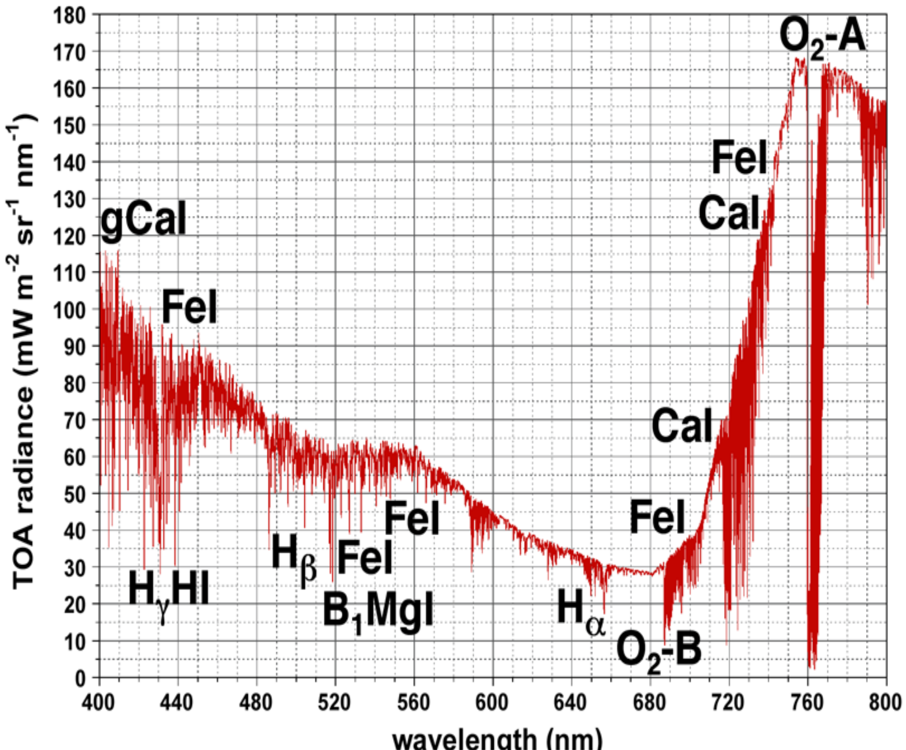
- fluorescence can be measured in the blue, green, red and far-red
- chlorophyll fluorescence (red (685 nm peak) and far-red (740 nm peak)
- actively induced (leaf, proximal)
- passive leaf and canopy requires 0.2 nm resolution - Solar Induced Fluorescence (SIF)

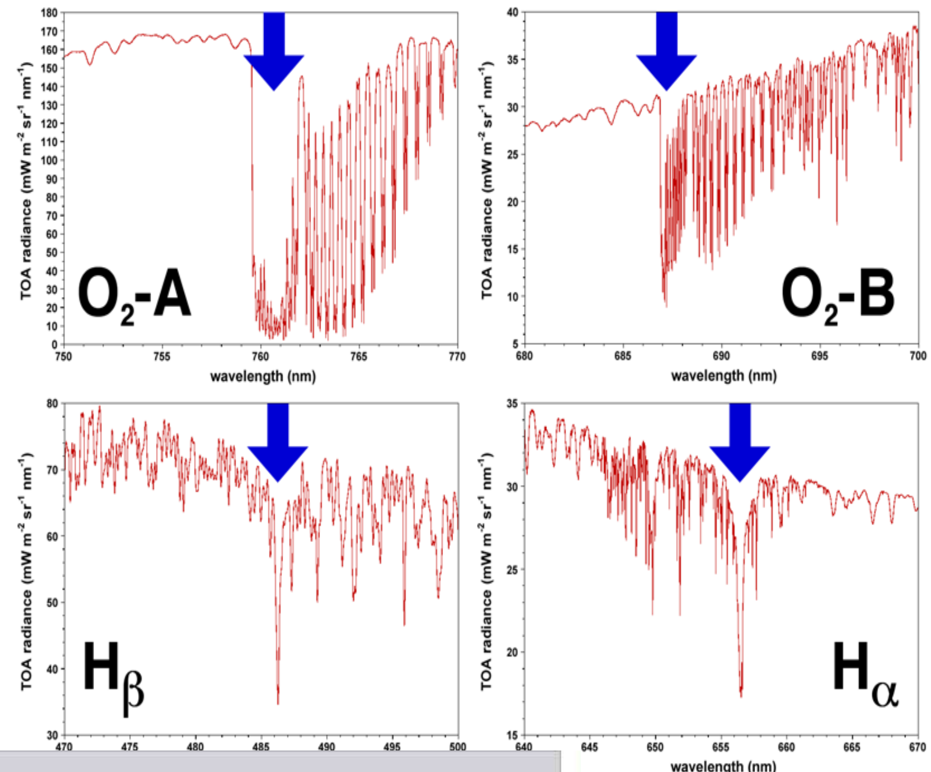
➢ At leaf level active chlorophyll fluorescence is inversely related to photosynthesis (same chlorophyll; varying light, temperature and water)

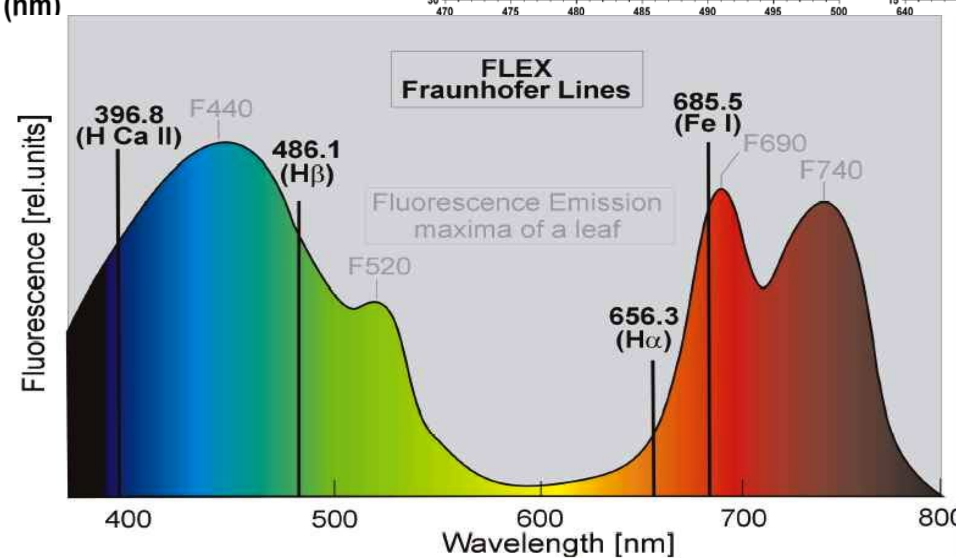
➢ At leaf and canopy level passive chlorophyll fluorescence (SIF) is related to chlorophyll content, light level (PAR), canopy structure, and photosynthesis



Fluorescence Explorer (FlEX, 2024), ESA





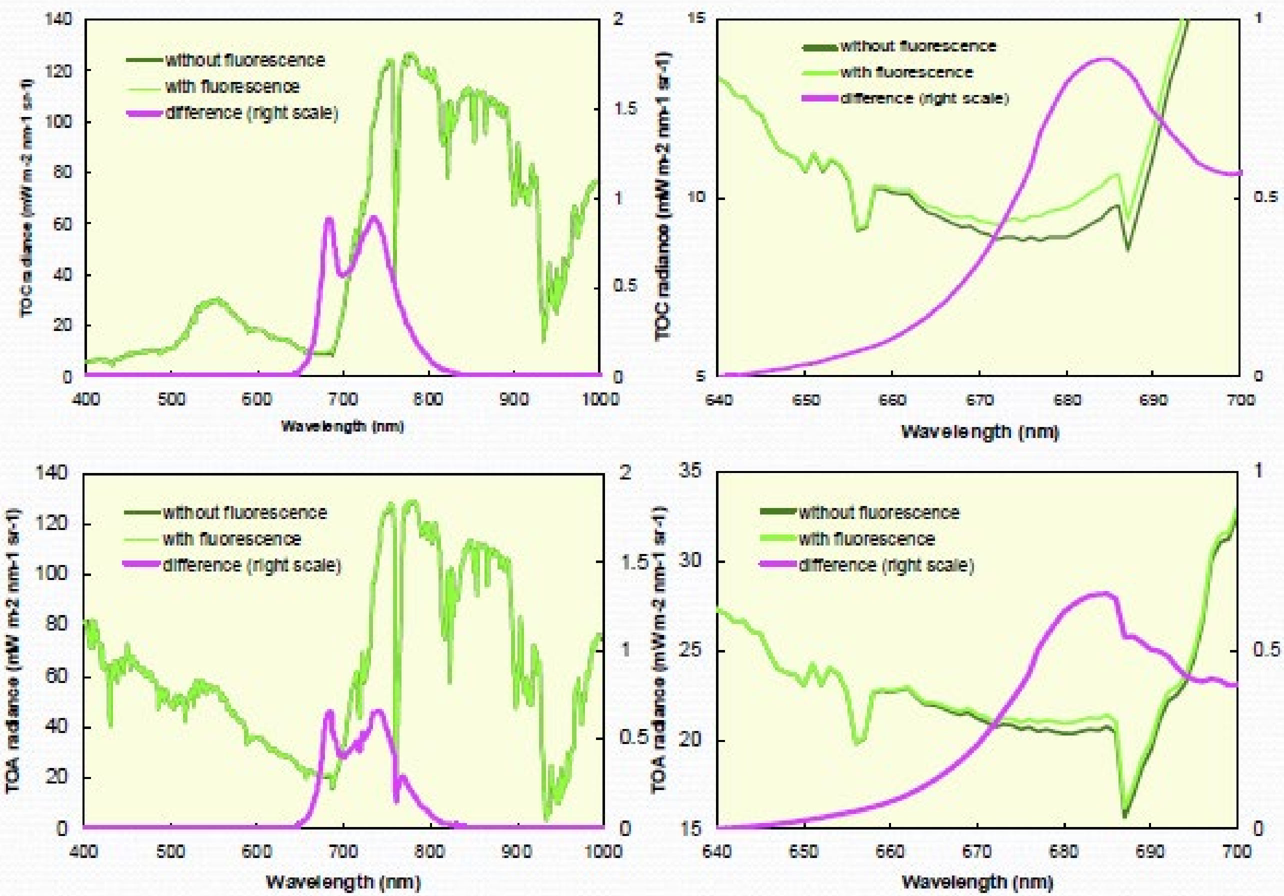


Chlorophyll Fluorescence Emissions and Solar Induced Fluorescence (SIF)

TOC and TOA radiance spectra

O_2-A

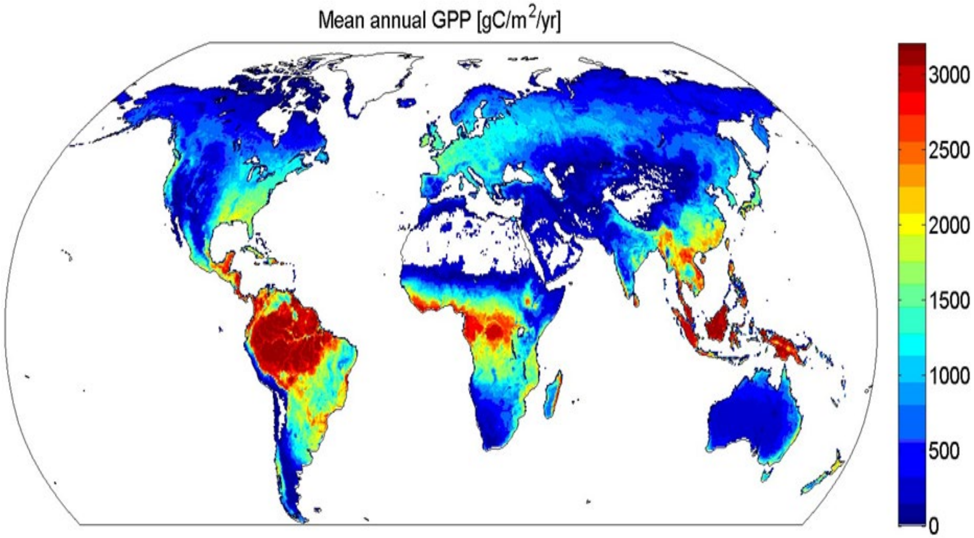
O_2-B



W. Verhoef Univ. of Twente - Faculty ITC 7th EARSeL Imaging Spectroscopy Workshop, Edinburgh, 11-13 April 2011

Linking Vegetation Function & Remote Sensing Spectroscopy

Small changes in photosynthesis (GPP) cause great variations and uncertainties in the carbon exchange and balance

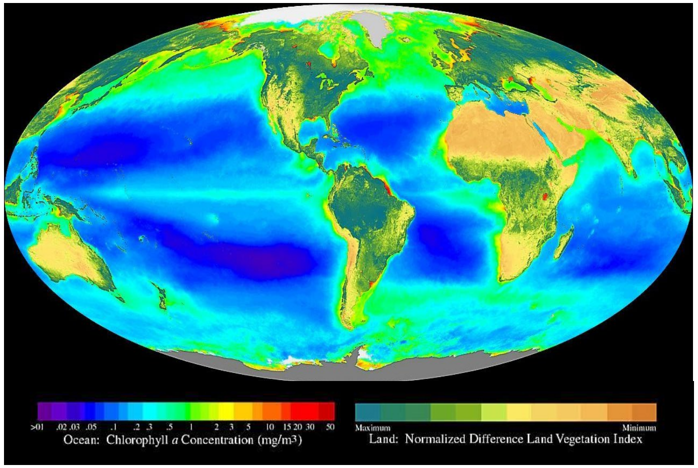


$$GPP = \varepsilon \times fAPAR \times PAR$$

LUE=GPP/APAR

ε = LUE *– light use efficiency, low LUE = low GPP*

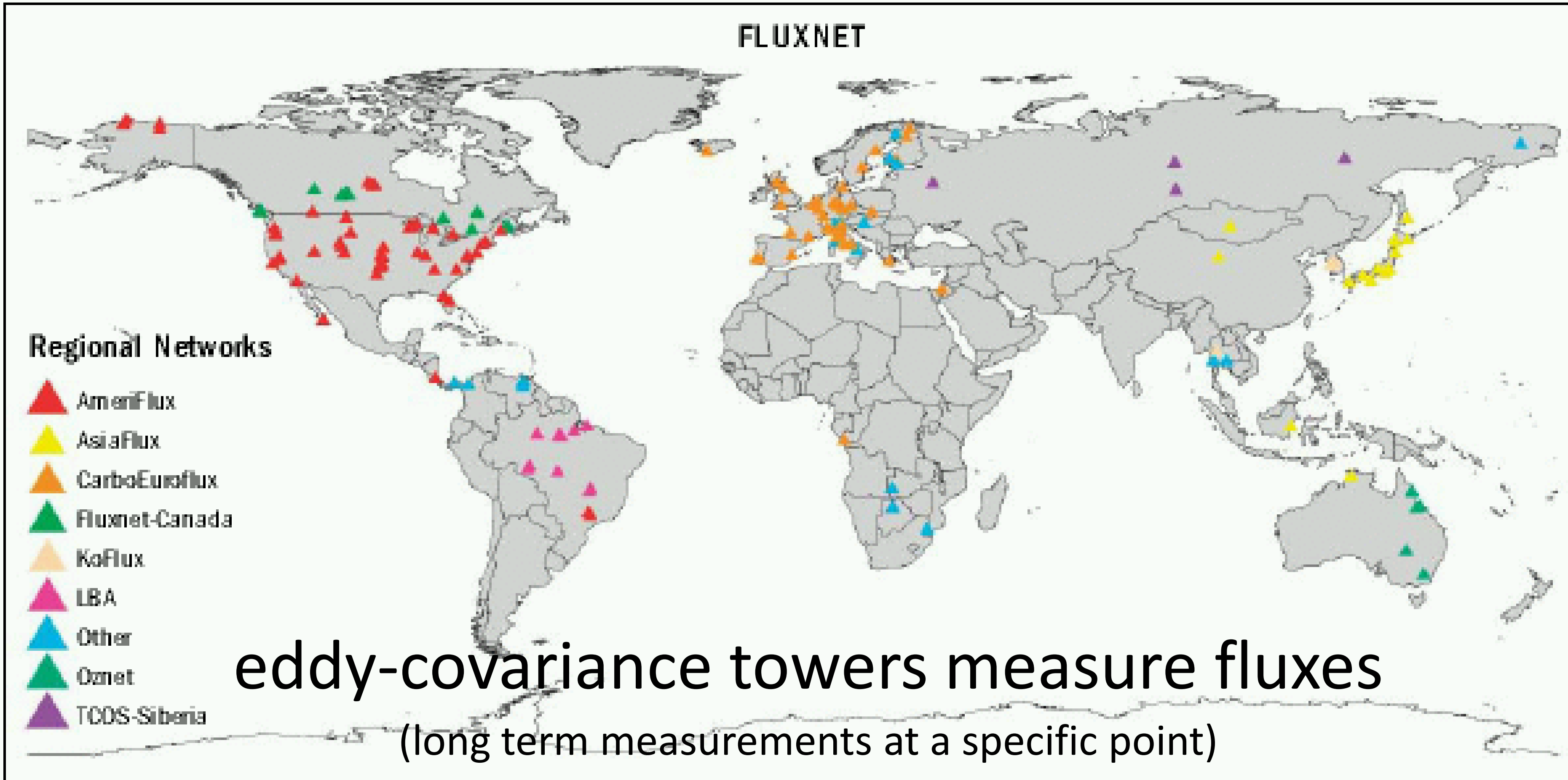
Terrestrial and Ocean Chlorophyll (terrestrial NDVI)



Key application:

- modeling and global and regional climate predictions
- local-regional scale management – sustainable agriculture, ecology, forestry

Canopy photosynthesis - how is it measured?

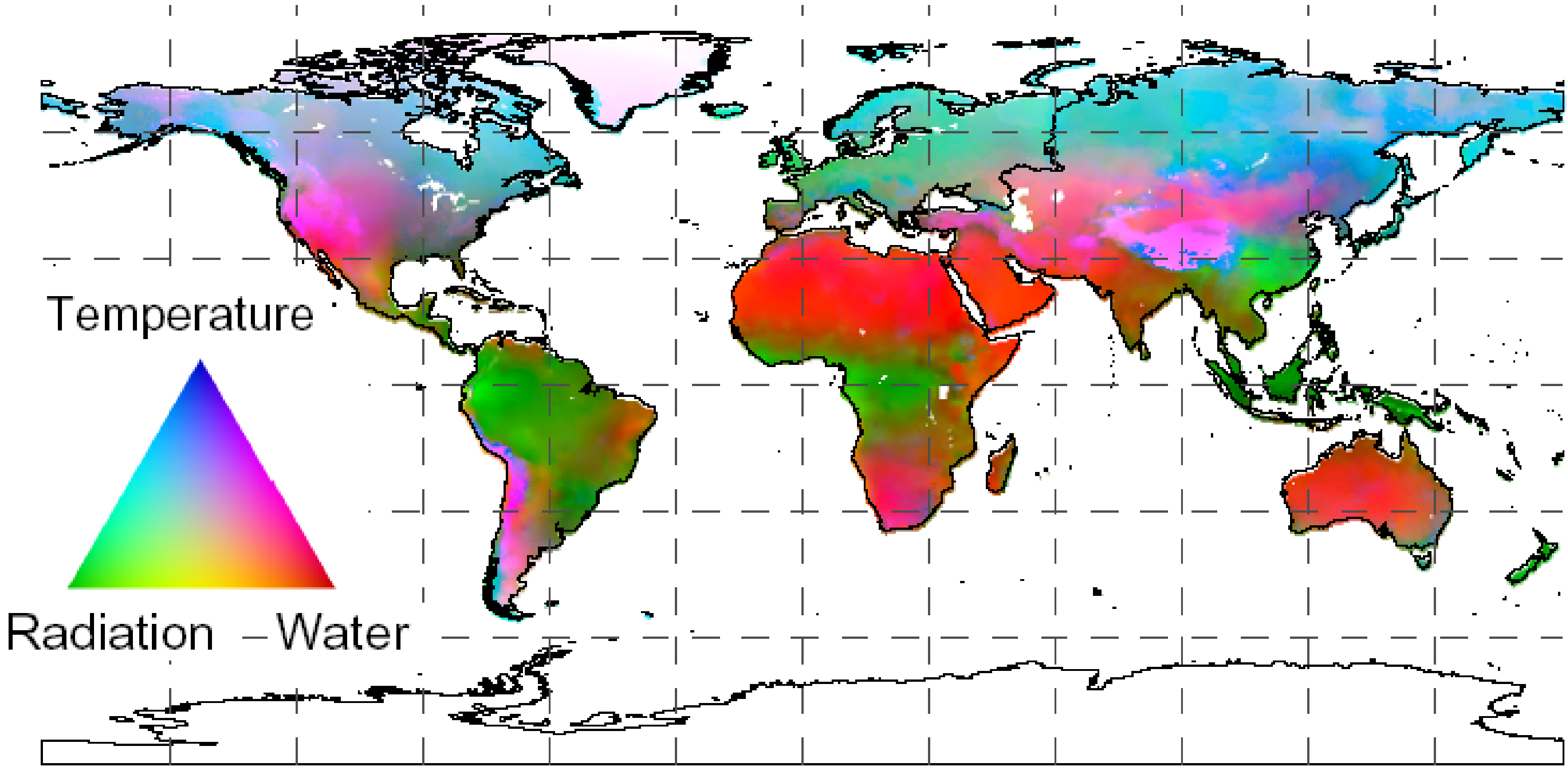


eddy-covariance towers measure fluxes

(long term measurements at a specific point)

- ***Challenge:*** lack of **comprehensive** information on the spatial and temporal variability of the critical biophysical traits and environmental parameters that drive photosynthesis (e.g., chlorophyll, APAR, LAI)

Limiting Factors of Vegetation Photosynthesis



Total vegetated area: 117 M km2

Dominant Controls

water availability 40%
temperature 33%
solar radiation 27%

Curtesy of: Dr. Mat Disney, www.geog.ucl.ac.uk/~mdisney

Linking Plant Physiology and Remote Sensing

What are we observing and when?

Vegetation traits and spectra (reflectance and SIF) have:

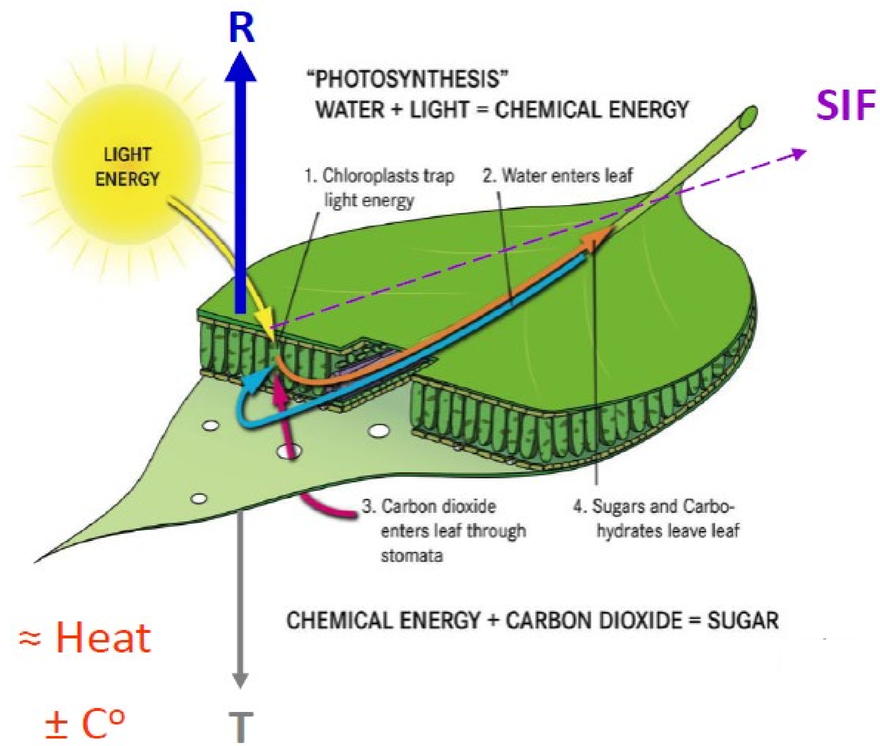
- *Diurnal cycle, and*
- *Seasonal cycle*

Vegetation function (*and states*)

- Photosynthetic function (GPP canopy) - water - stomatal conductance, N, leaf chlorophyll and structural compounds
- Canopy vigor (photosynthetic biomass)
  - Photosynthetic leaf area and biomass
  - Canopy structure (height, closure)

Environmental conditions

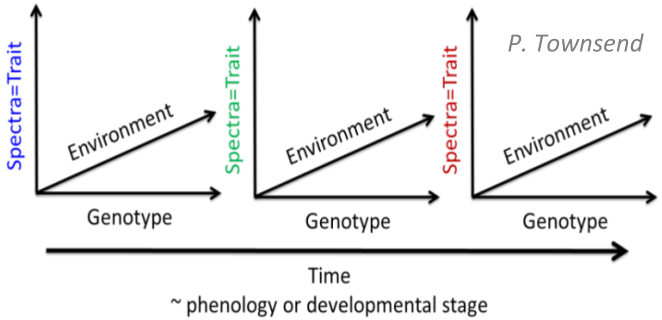
- Light level
- Water availability
- Temperature
- Nitrogen availability
- Stress factors (e.g., infestations, pollution)



"Photosynthesis" from ESA/FLEX final report, 2015. Modified adding reflectance, transmittance, heat and fluorescence (P. Campbell, 2015).

Why we need Hight Spectral Resolution Reflectance?

Using remote sensing spectroscopy the goal is to improve the monitoring of the interactions between surface climate and vegetation function, however this requires also measurements at different spatial and temporal scales.



Canopy processes, functional traits and structure vary at different rates

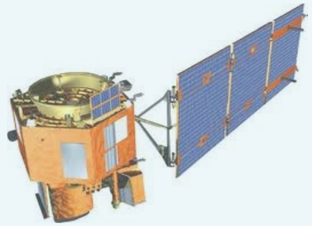
- Photosynthesis – diurnal and seasonal variations
- Canopy chlorophyll and photosynthetic biomass – seasonal changes

Objectives:

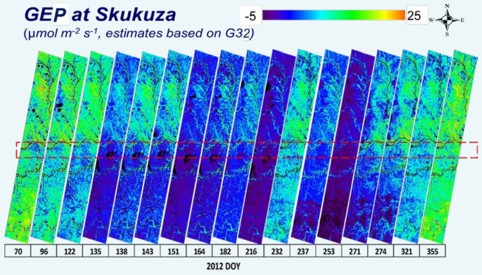
1: Identify optimal spectral resolution to characterize vegetation function and its diurnal and seasonal dynamics

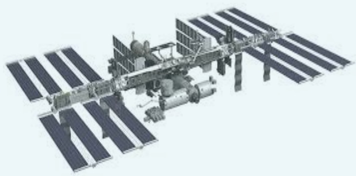
2: Determine the **'right'** time/frequency to remotely measure the key characteristics of vegetation function (e.g. photosynthetic pigments; LAI; leaf chemistry, mass, area; canopy structure)

3: Determine the optimal spatial scales to assess the variation in the functional traits, across vegetation types, disturbances, and a range of anthropogenic drivers.



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





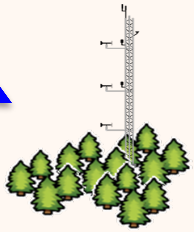
Space station(@ 400 km)

Spatial coverage, repeat

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

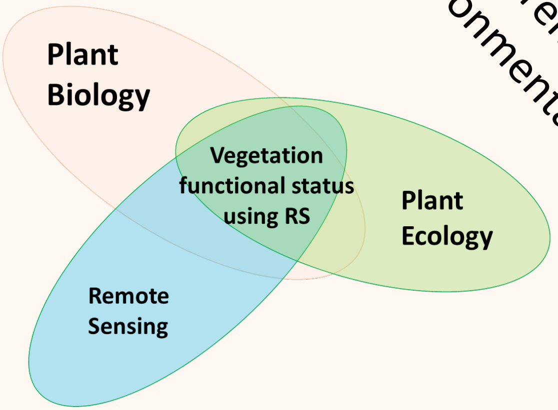
Consistent spectral measurements across ALL spatial scales and environmental conditions

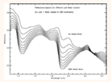
UAV (@ 10 – 120 m) Spatial coverage & TS site & region



Automated/Fixed Tower (@ 10 - 120 m)

canopy/site, TS





Leaf - canopy (@ ~ 10 m)

leaf – canopy – site consistent TS

Factors Determining the Reflectance of Vegetation Canopies in the Near Infrared (NIR)

. Leaf radiative properties – leaf type, shape and size

Broadleaf, needle leaf

Shiny, hard: American holy, tulip poplar, etc.

Shiny, soft: persimmon, glossy buckhorn, etc

Hairy: sagebrush,

Simple: elms, birches, aspens, beeches, maples, etc.

Compound: ashes, locusts, sumacs, walnuts, etc.

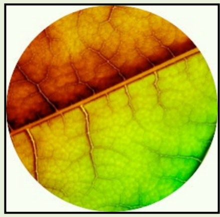
. Canopy structure and cover

Mature old growth: Fully developed canopy structure

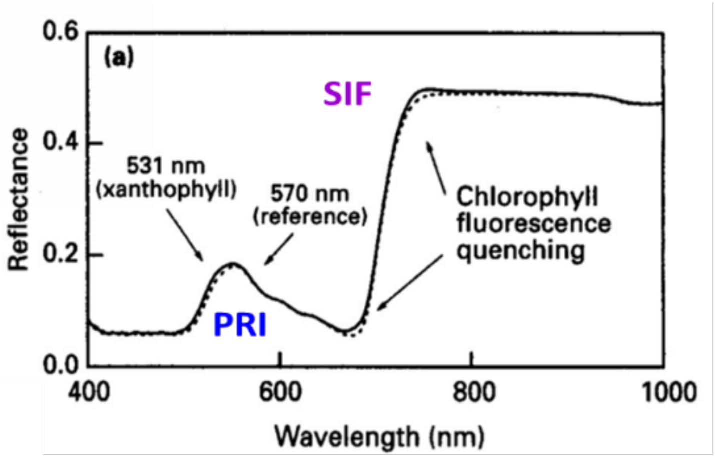
Intermediate secondary successional stage

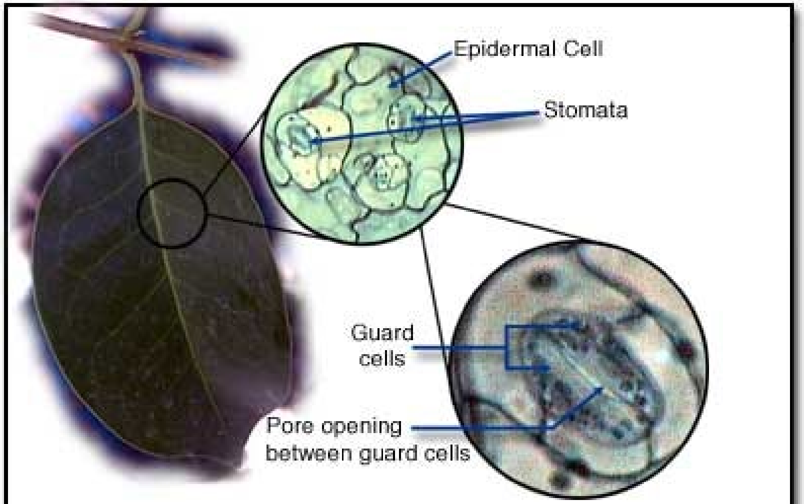
Initial secondary successional stage: Even aged young saplings

Vegetation trats, which can be monitored by VNIR Spectroscopy



- **chlorophyll (C_{ab})**
  - The most important photosynthetic pigments
  - Indicator of vegetation stress –chlorophyll content decrease, change of C_a/C_b
- **carotenoids (Car)**
  - Light-collecting, protective pigments – participation on light transfer
  - senescence (natural) x stress – increase of Car/C_{ab}
- **anthocyanins**
  - protection against UV radiation
  - In new leaves X part of senescence
- **nitrogen content**
- **water**
  - Stress condition, health, drougth, water intake…



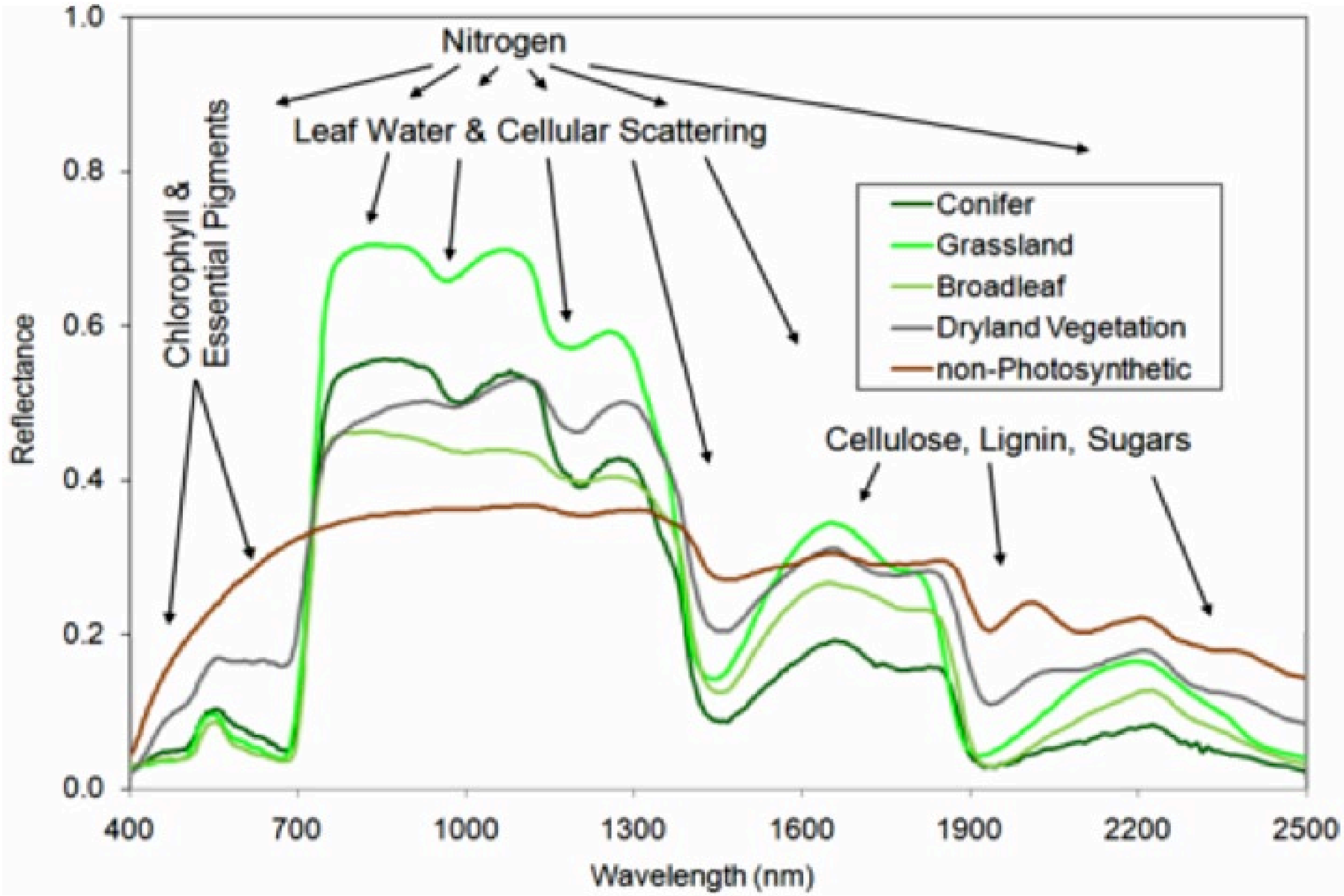


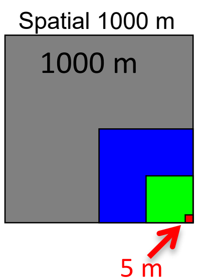
Leaf surface magnfied by 10x and 40x showing empidermal cells and guard cells of stomata, which allow for gas exchange for photosynthesis.

Courtesy of:
Dr. L. Kupkova and Jana Albrechova, Charles Univ. Prague

Spectral Measurements Required for Global Ecosystem Function Assessments

21st Century Spectroscopic Measurements

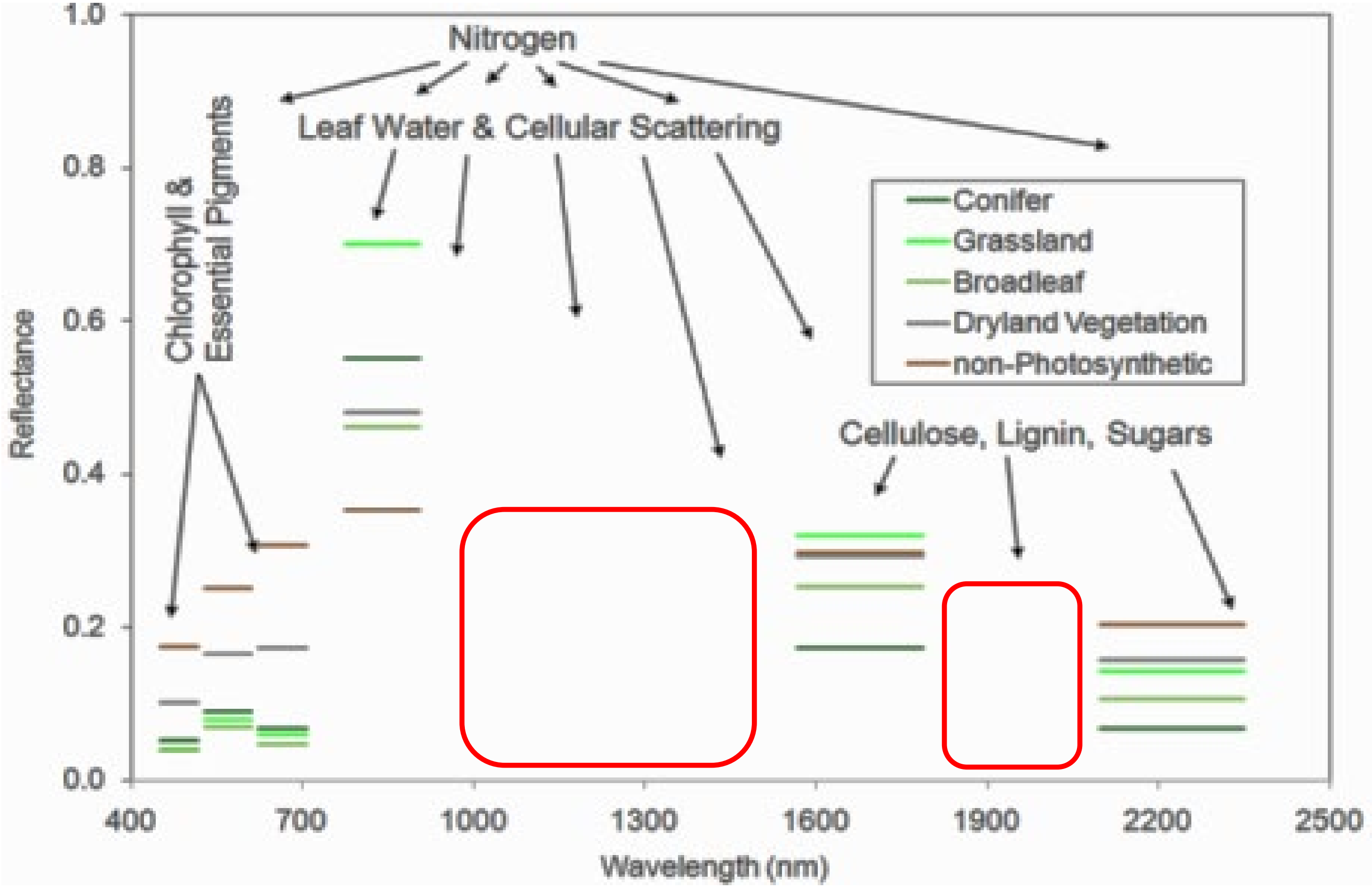




Full range imaging spectroscopy is required to measure composition, chemistry, health and change of ecosystems.

Differences between multispectral and hyperspectral RS data

Multispectral Measurements



Multi-spectral imaging is insufficient to accurately derive the required terrestrial surface compositional parameters.

Green et al. 2011

Deriving Canopy Traits with Continuous Reflectance – *VNIR Examples*

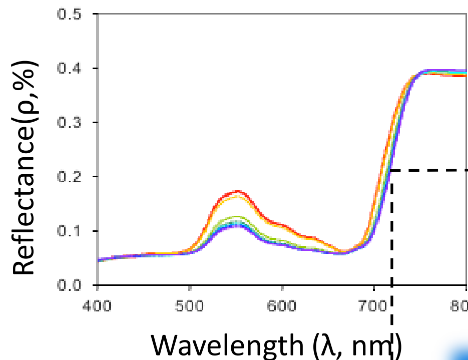
No prior knowledge

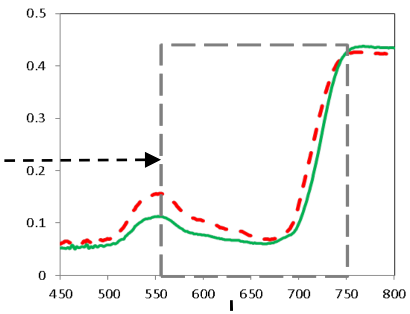
- Continuous spectra
  - reflectance
  - Fluorescence (SIF)
  - derivatives, derivative VIs
- Spectral features (e.g., PRISM)
  - continuum removal

https://pubs.usgs.gov/of/2011/1155/

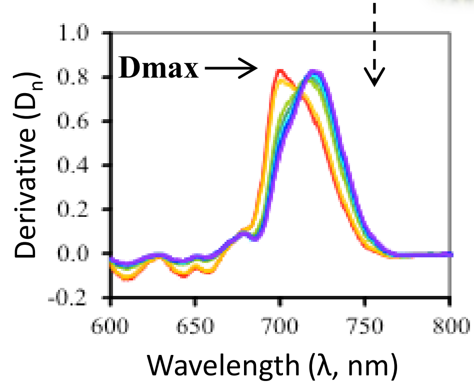
Some prior knowledge

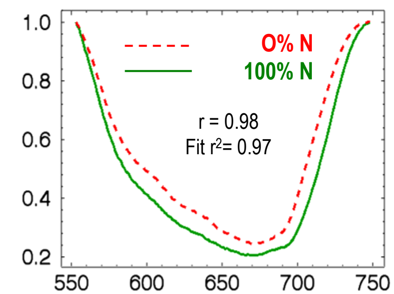
- Discrete Vegetation indices (VIs)
- Temperature estimates
- Models - PLSR, RTMo





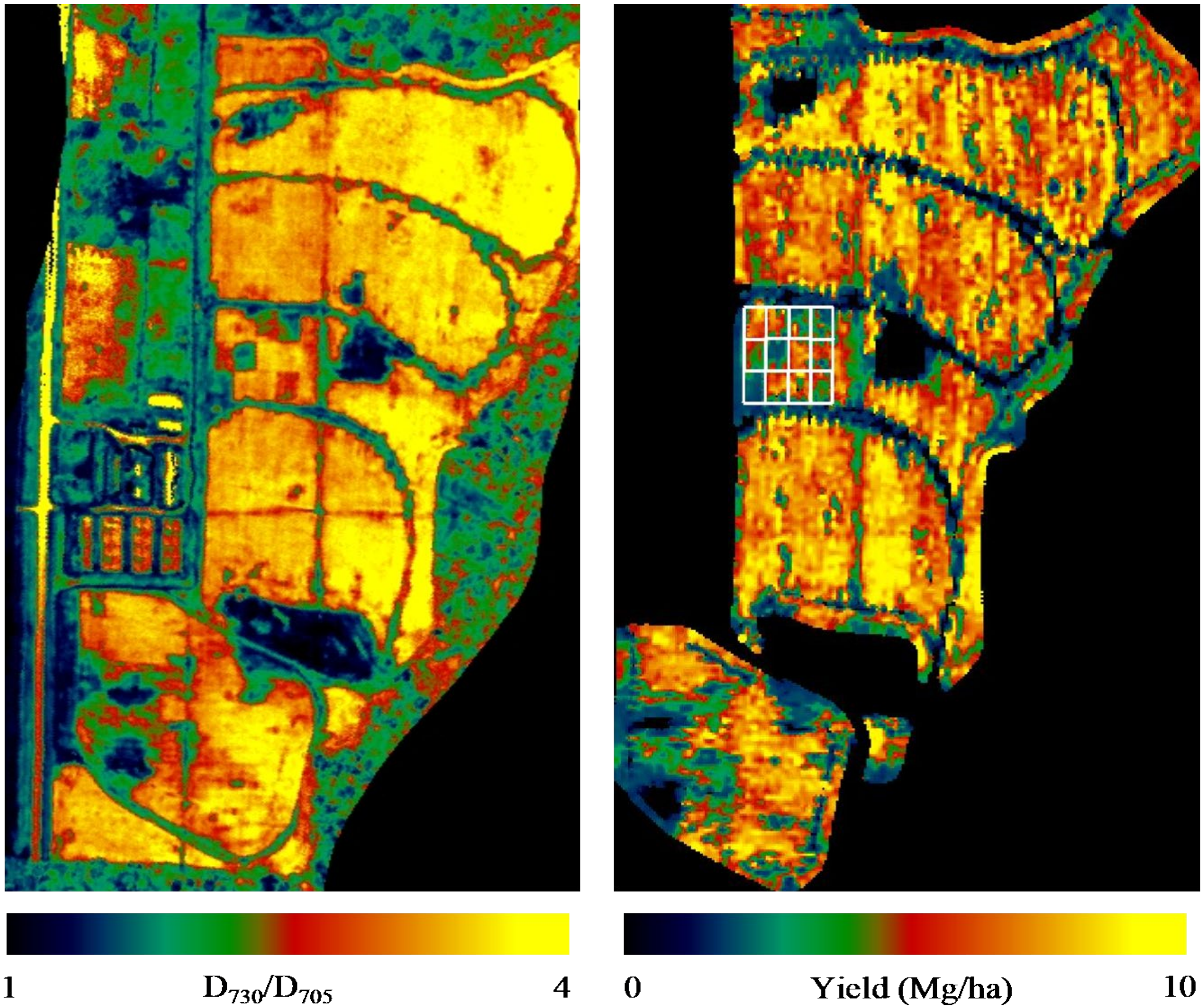
$$D_n = \frac{\rho_{n-1} - \rho_{n+1}}{\lambda_{n-1} - \lambda_{n+1}}$$





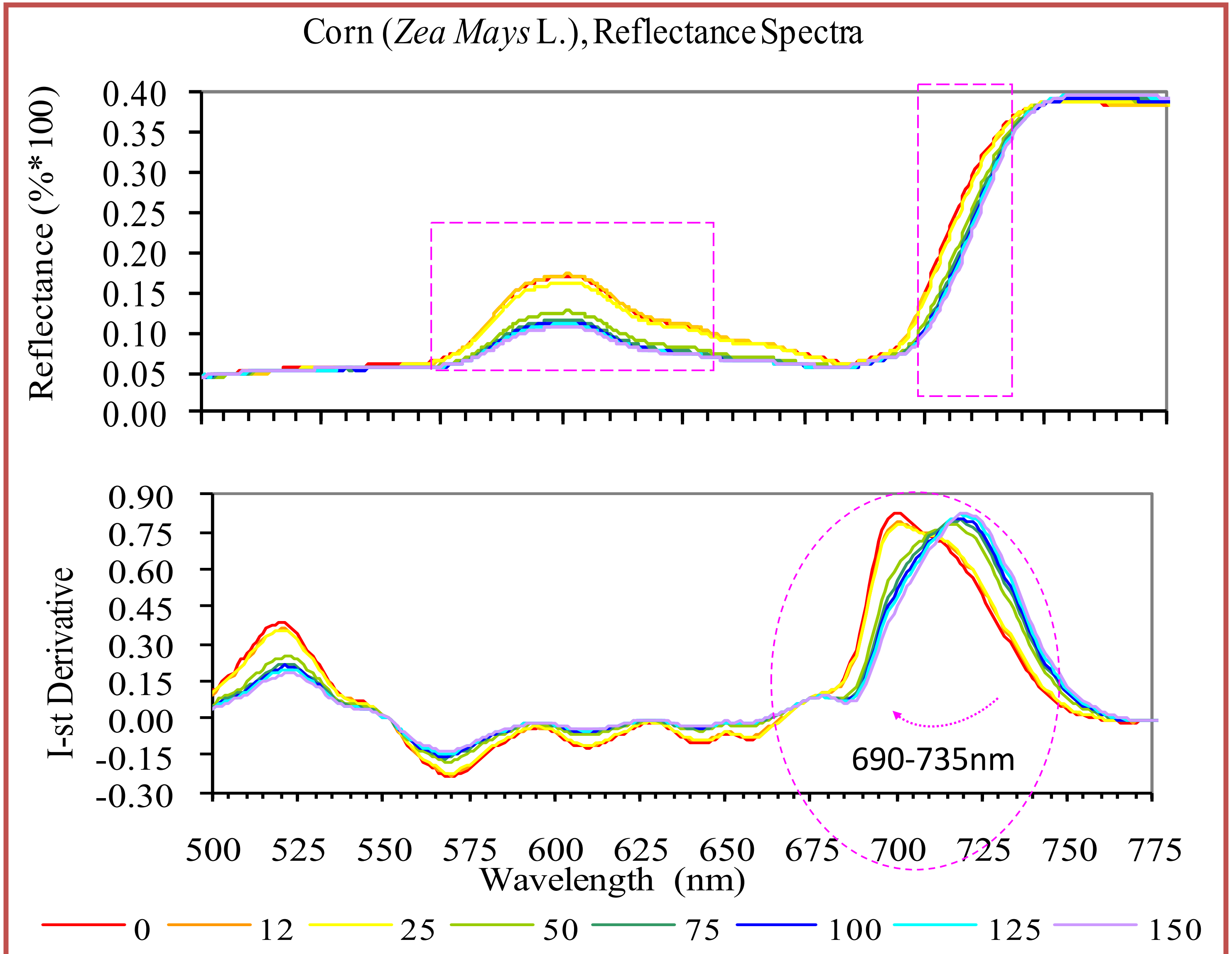
0% N, feature FWHM = 129.33, Area = 93829
100% N, feature FWHM = 141.92, Area = 102911

Canopy Reflectance
Differences Associated with N Availability

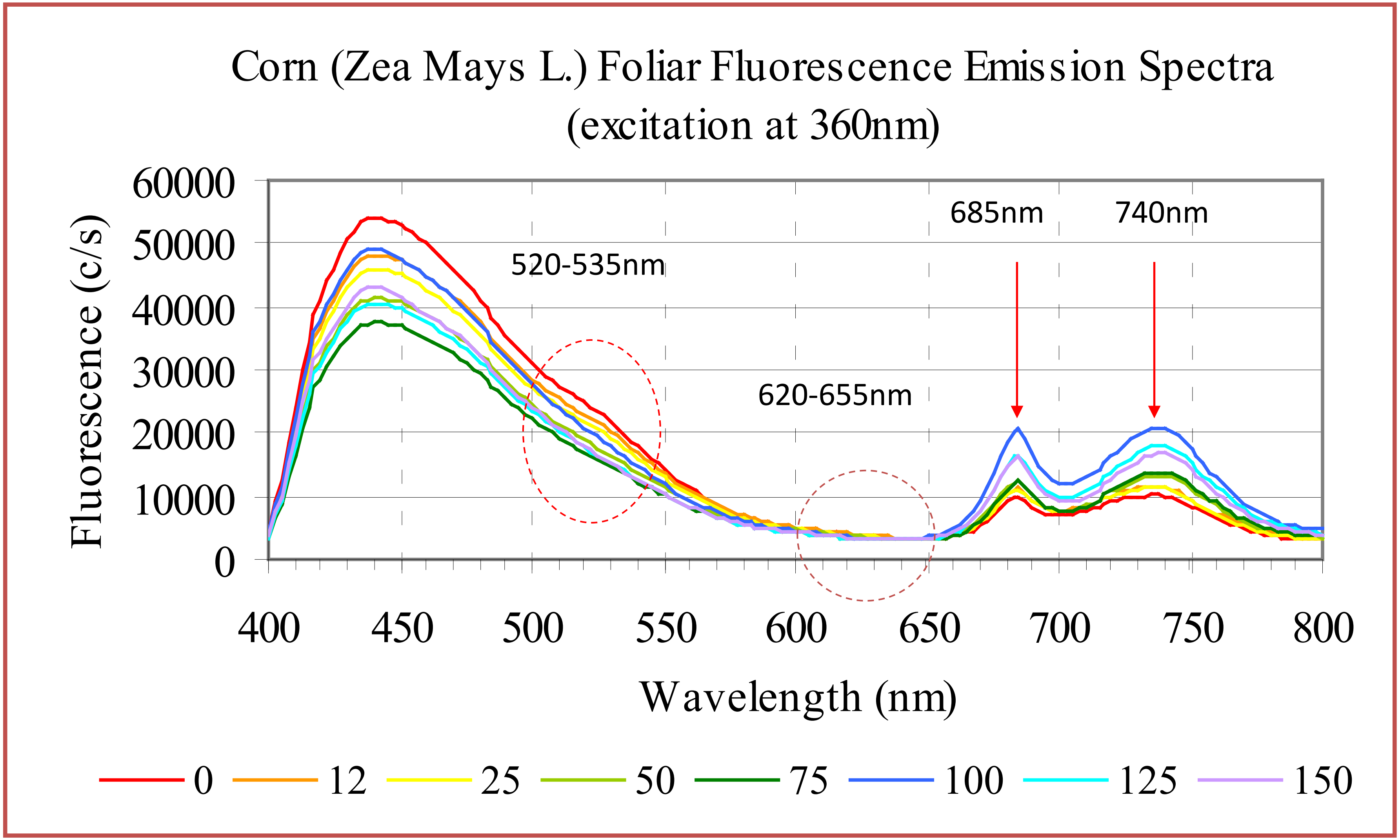


Reflectance derivative ratio (left) along with yield monitor data (right) over the OPE field site from AISA imagery

Changes in Foliar Reflectance Associated with N Availability



Leaf Level Changes in Fluorescence Associated with N Availability

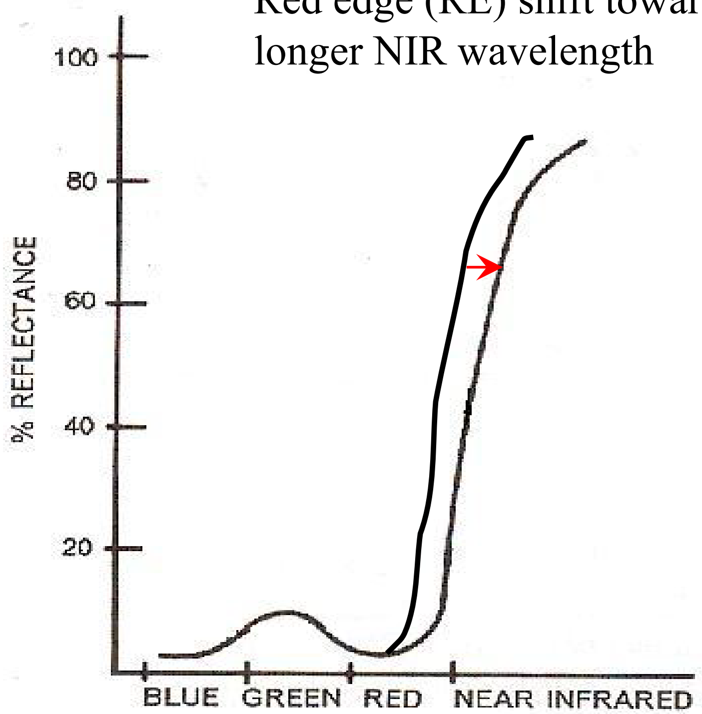


Red and Blue Shift of the Chlorophyll Absorption Edge

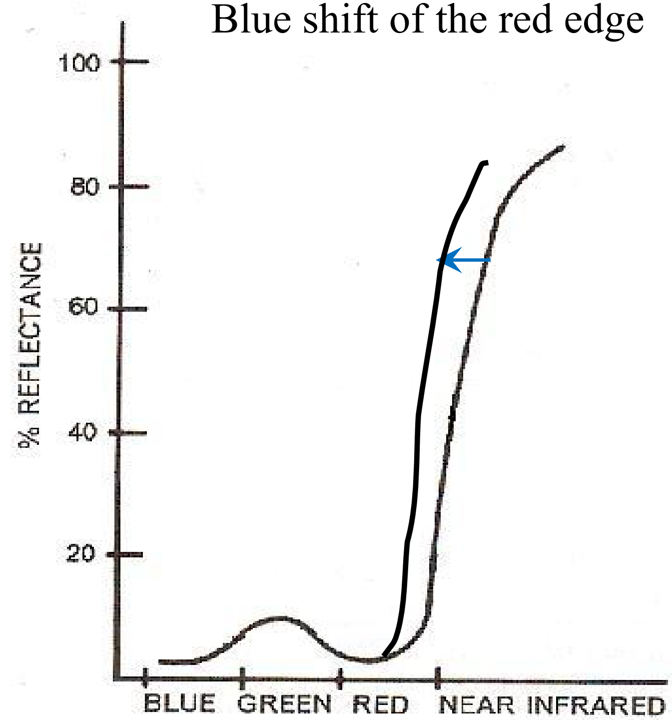
- As leaves mature, the amount of chlorophyll in the foliage increases and the absorption edge of the chlorophyll shifts towards longer NIR wavelength
- As plant stress in plant tissue increases, the absorption edge shifts toward shorter wavelength

Utilized in stress mapping (esp. geo-chemical stress) mapping of vegetation

Red edge (RE) shift toward longer NIR wavelength

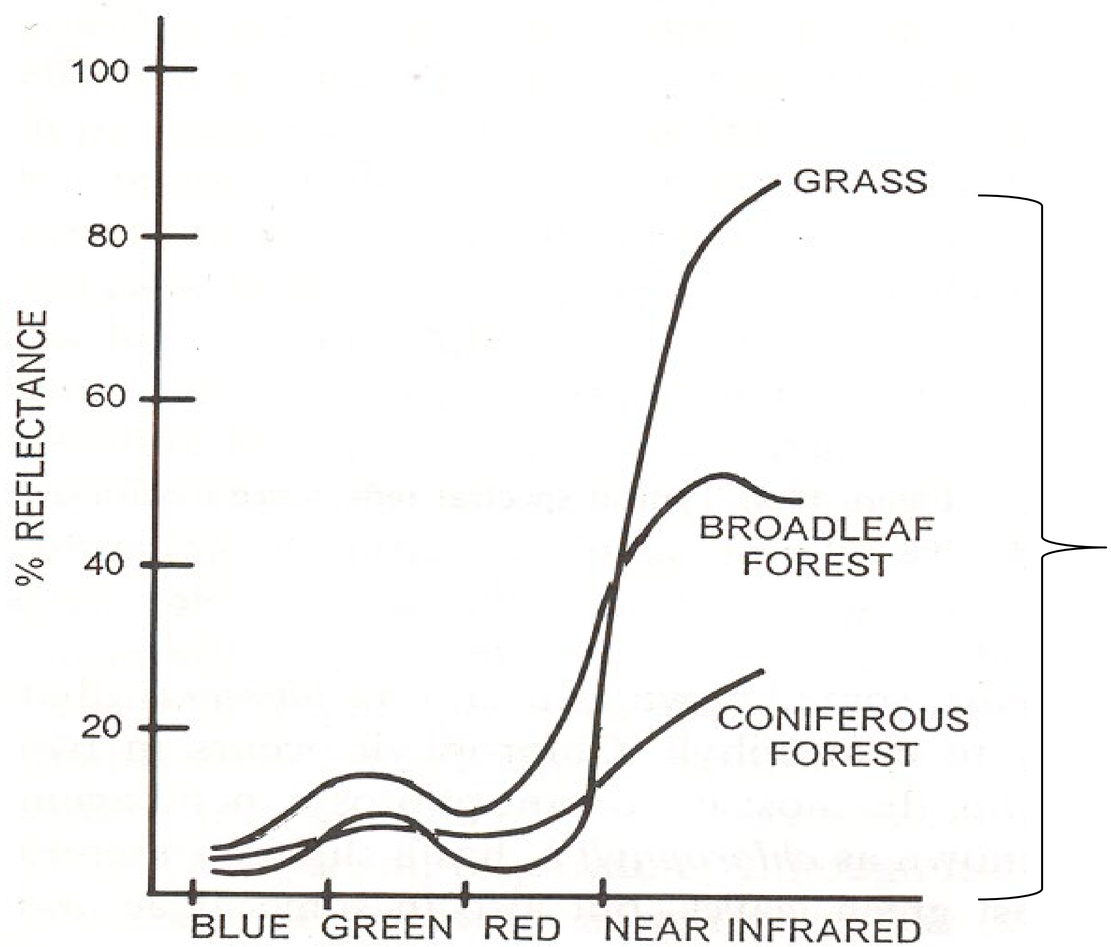


Blue shift of the red edge



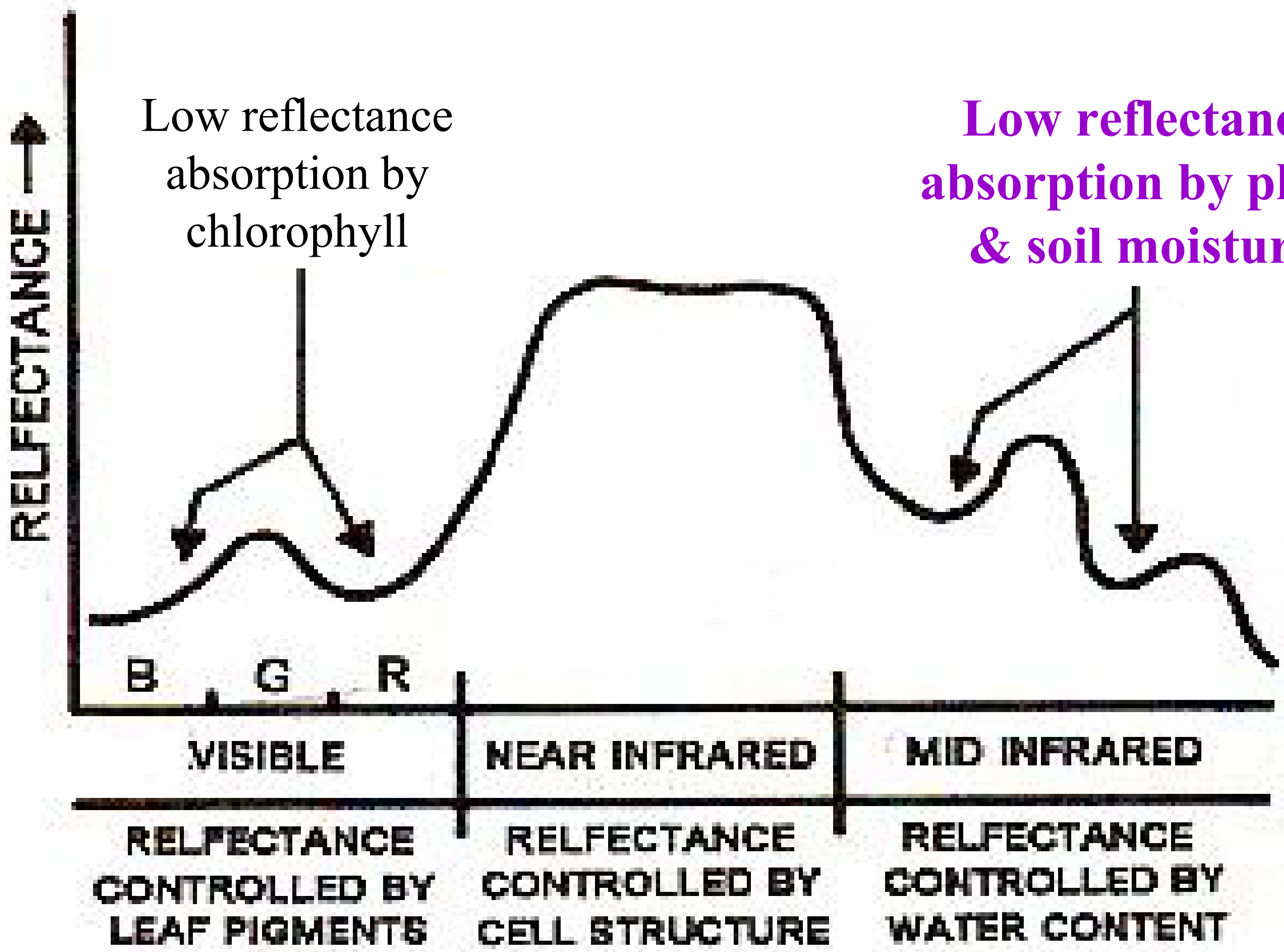
Near IR Grass > Broadleaf > Coniferous

High Reflection due to Spongy Mesophyll Tissues



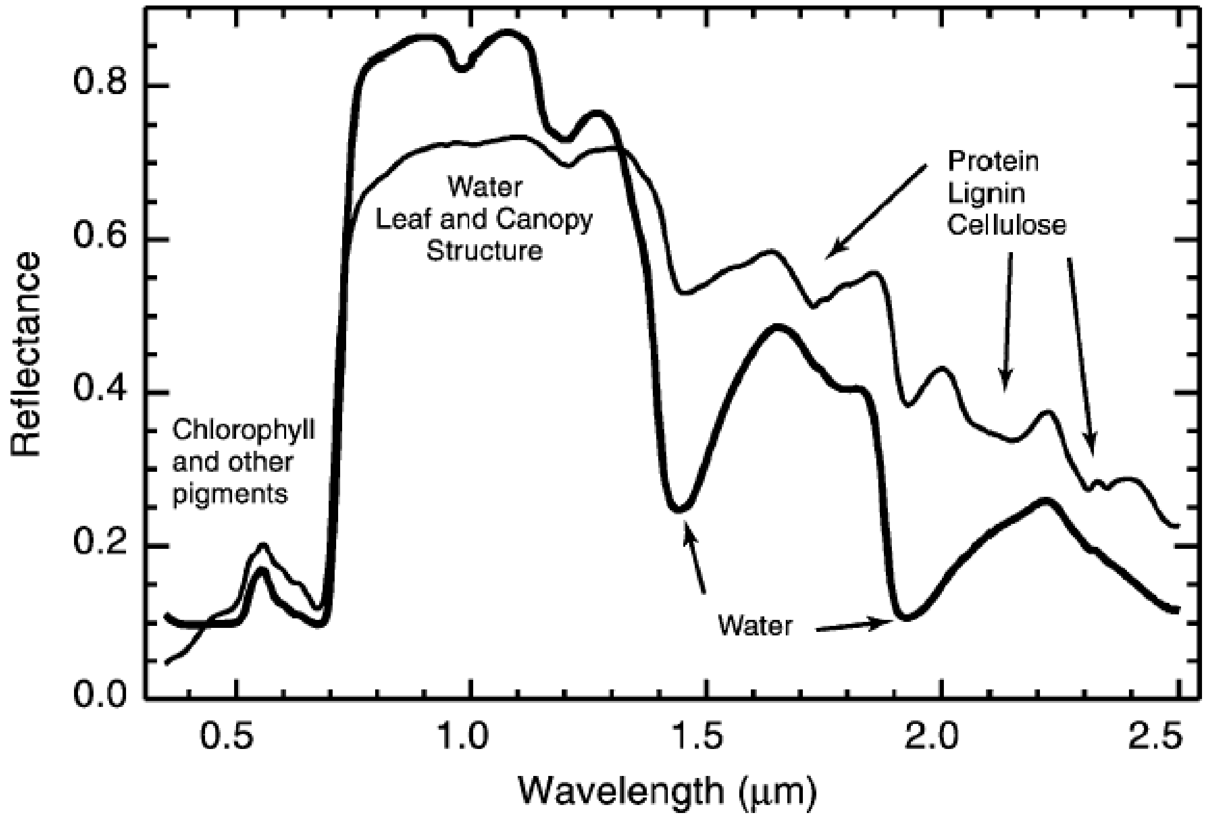
High Reflection due to Spongy Mesophyll Tissues

Mid IR (band 5,7 of Landsat)



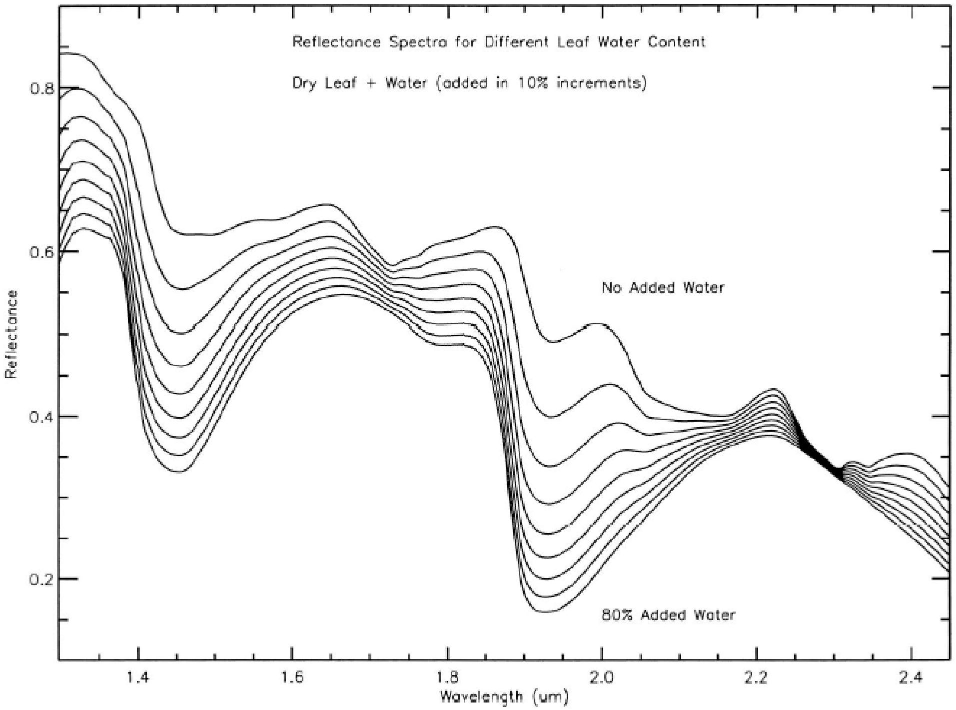
NSWIR Spectroscopy of Vegetation biochemical composition

- Water
- Nitrogen (in chlorophylls and proteins)
- Lignin and Cellulose
- Non-Photosynthetic Vegetation



Kokaly, REMOTE SENS. ENVIRON. 84:437-456 (2003)

Spectroscopic Estimates of Leaf/Canopy Water

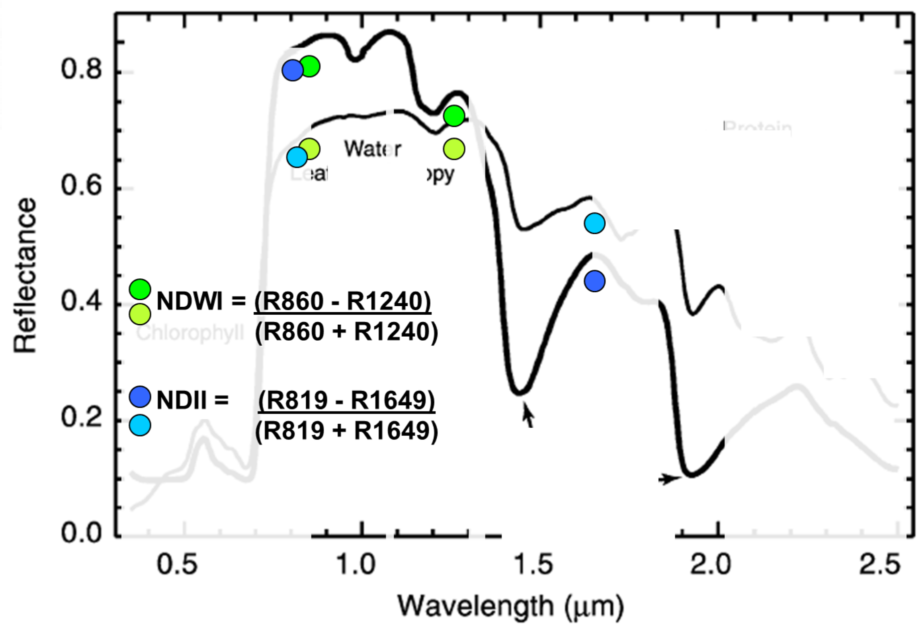


Features sensitive to Vegetation Water Content:

- R1240
- R1649

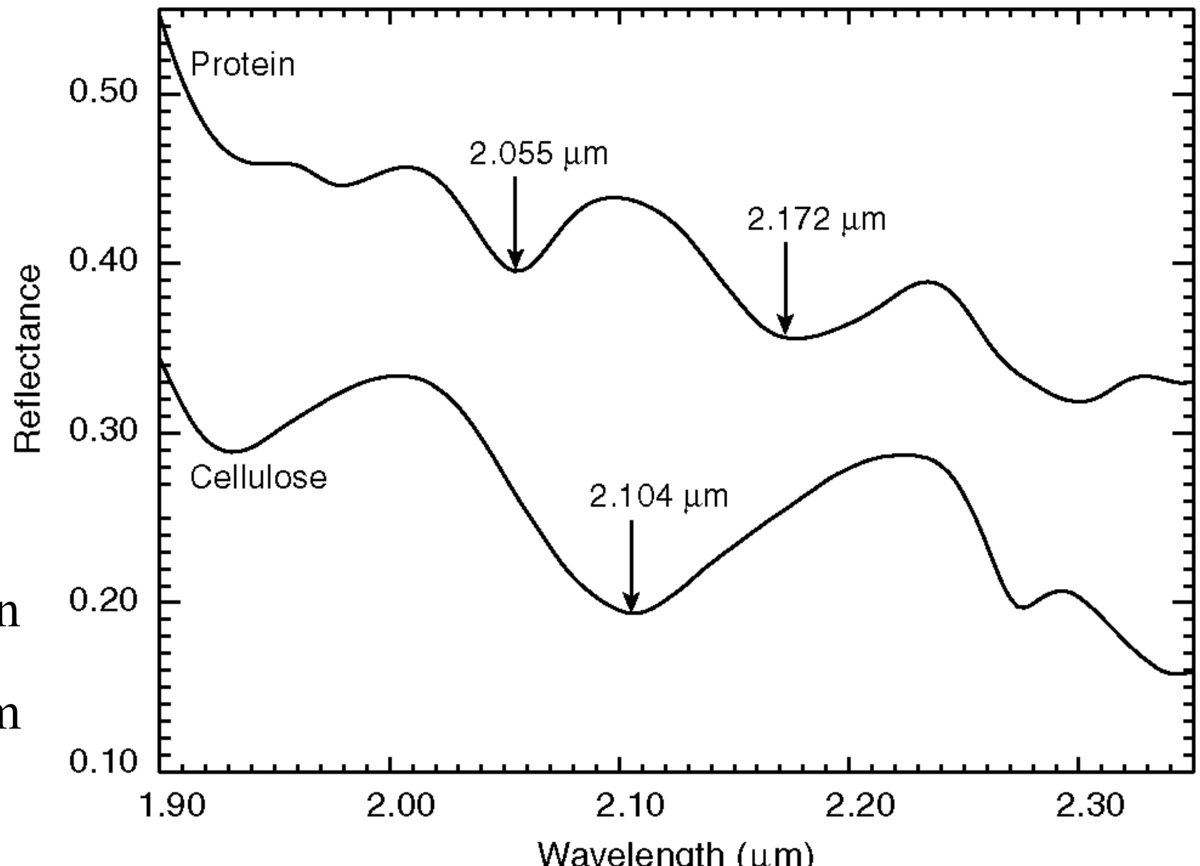
In-sensitive bands: 860 nm and 819 nm

- Leaf/Canopy Liquid Water Thickness
  - Gao & Goetz, 1994
- Canopy Equivalent Water Thickness
  - Green et al., 1991 & Roberts et al. 1997
- Canopy Relative Water Content
  - Serrano et al. 2000
- Foliar Water Potential
  - Stimson et al. 2005

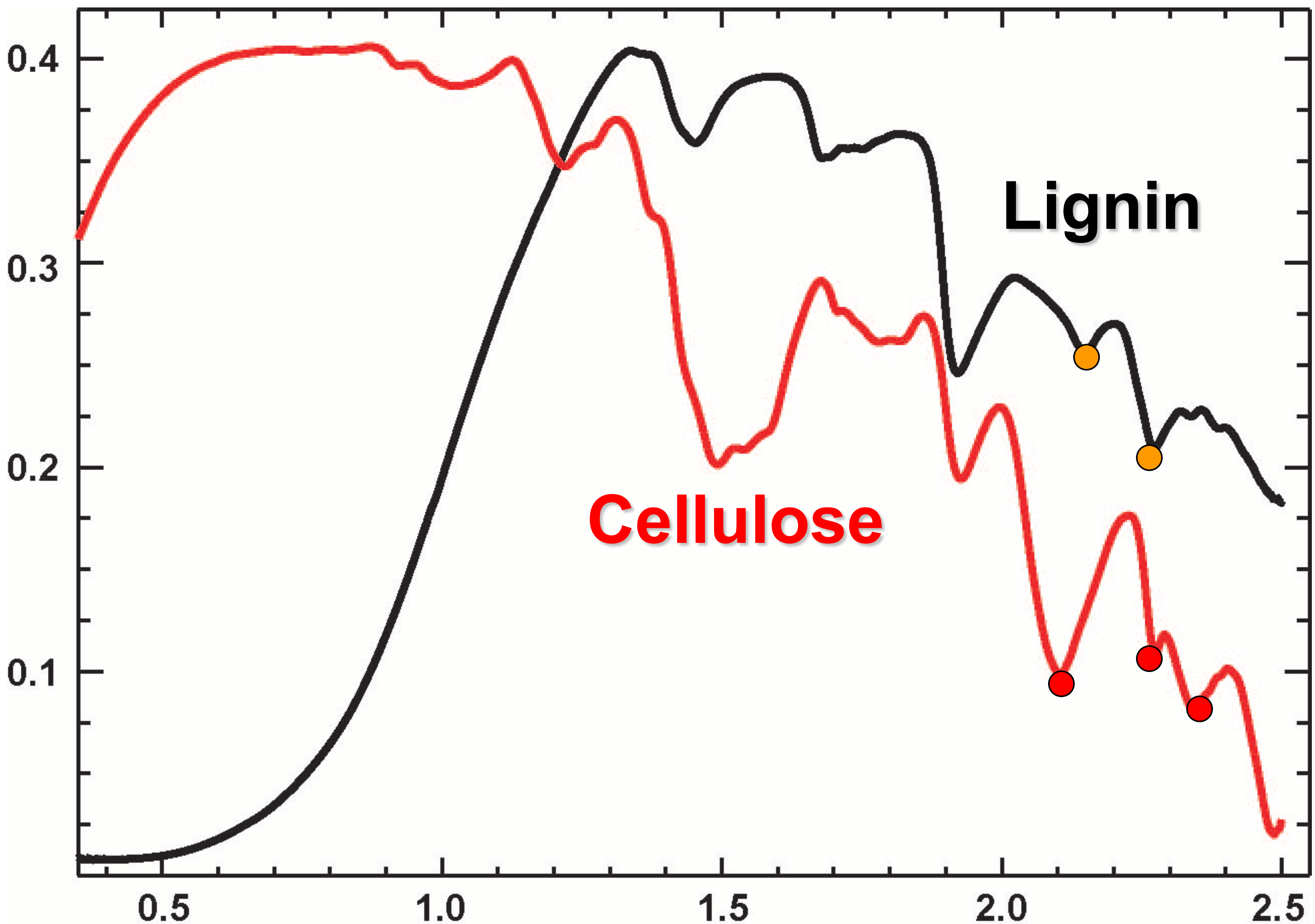


Structural Biochemical Compounds

- **Cellulose**
  - Cellulose is a common material in plant cell walls
  - Cellulose is the most abundant form of living terrestrial biomass (R.L. Crawford 1981).
- **Lignin**
  - 10% to 40% by dry weight
  - Lignin is a large macromolecule with molecular mass in excess of 10,000 amu.
  - Structural component of plant cell walls
  - Lignin concentration in litter has strong influence on ecosystem processes



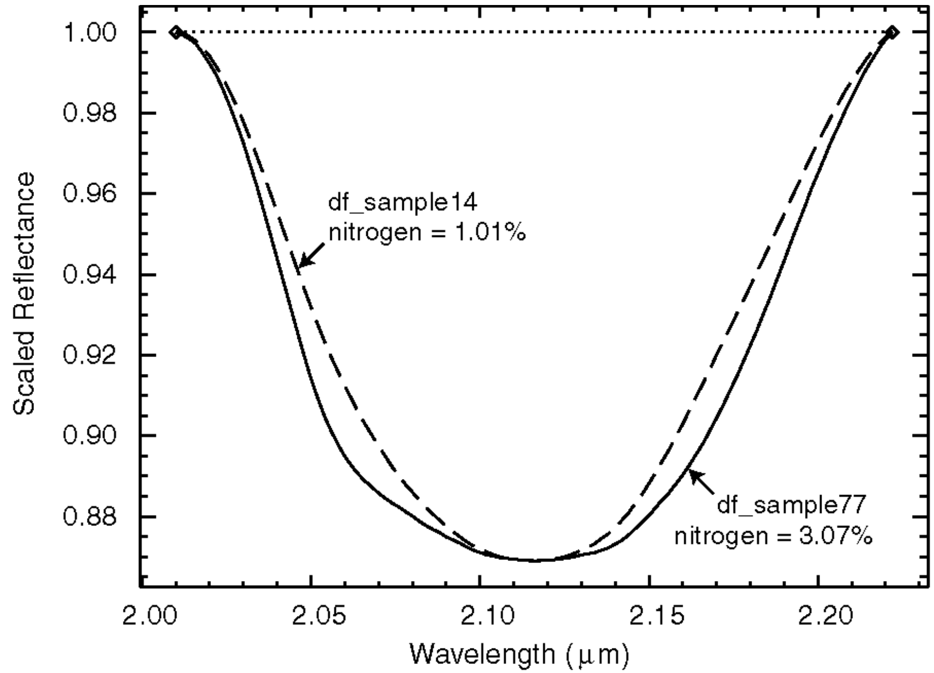
Kokaly, REMOTE SENS. ENVIRON. 75:153–161 (2001)



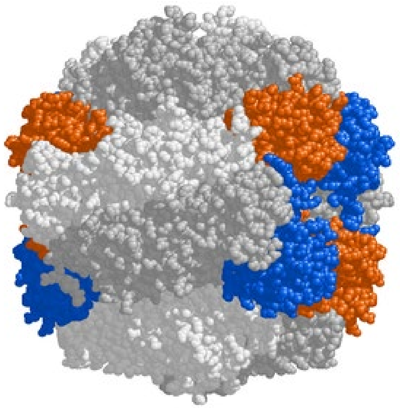
0.4
0.3
0.2
0.1
0.5
1.0
1.5
2.0
2.5
Lignin
Cellulose

Nitrogen

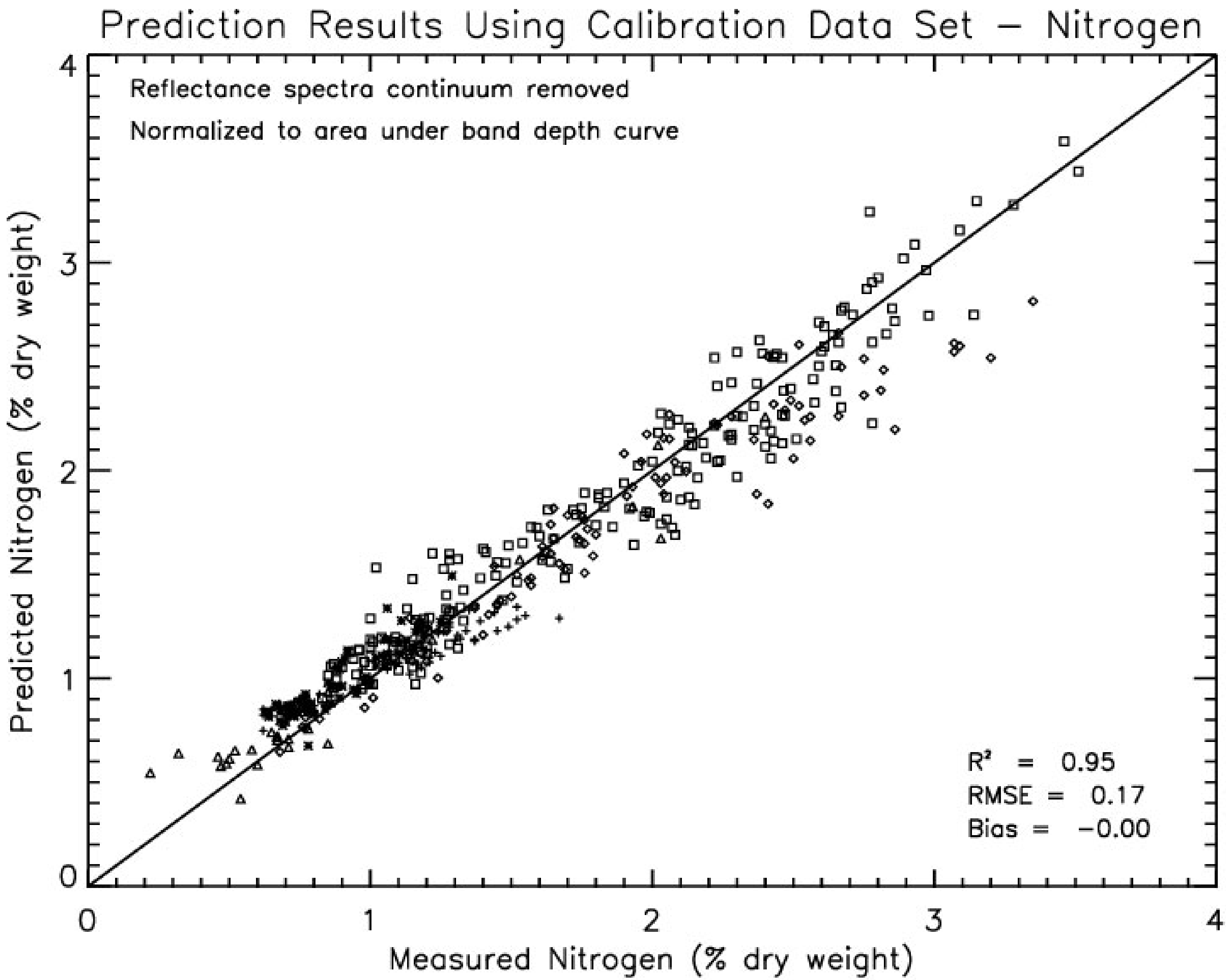
- By dry weight, very low abundance in leaves, only 0.5-4%
- Present in important biochemical constituents of plants
  - Chlorophyll
  - Protein
- Linked by field studies to rates of ecosystem functioning (carbon fixation) and widely used in ecosystem models



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

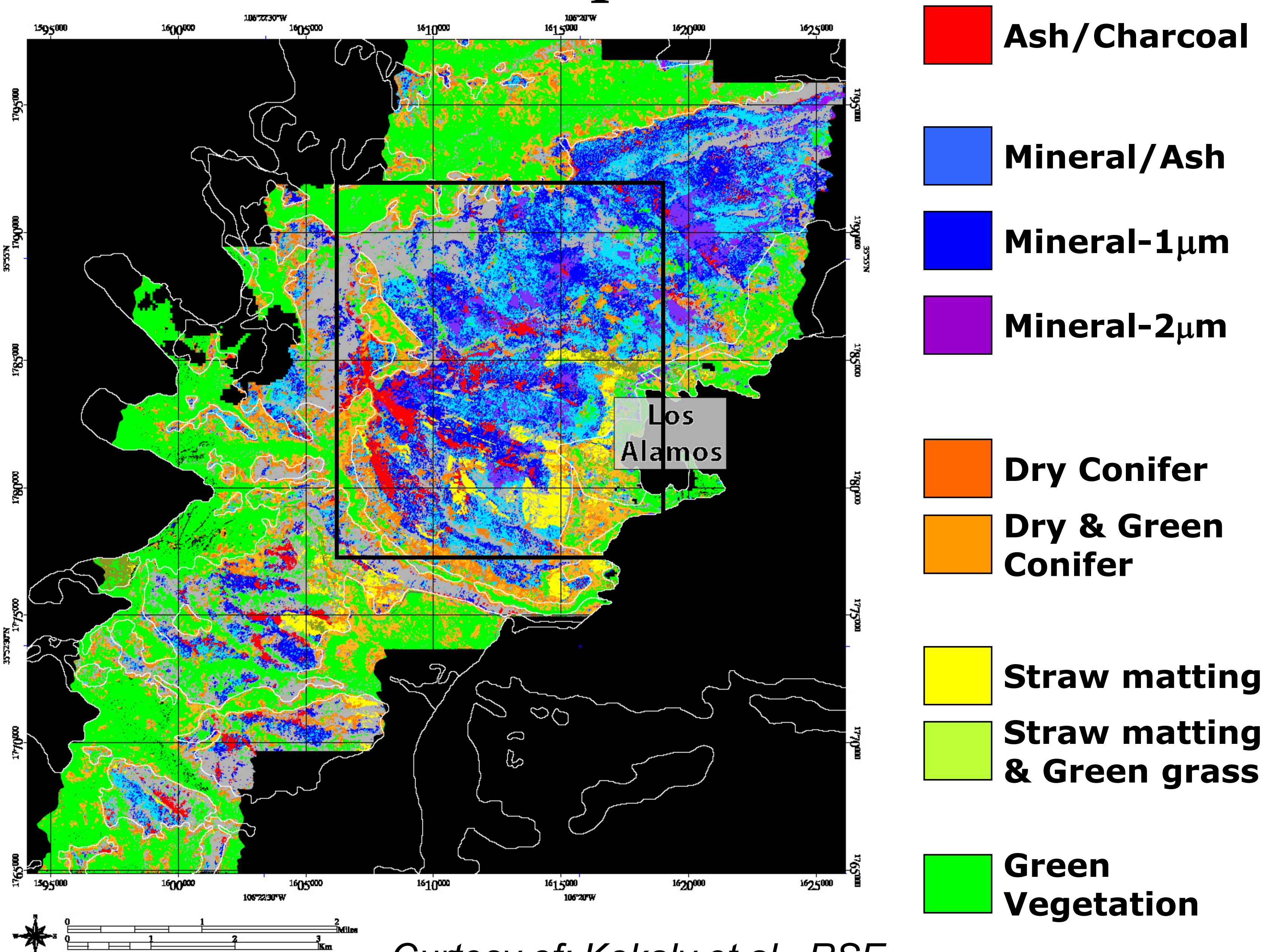


Ribulose-1,5-bisphosphate carboxylase/oxygenase, catalyzes the first major step of carbon fixation.
RuBisCO is the most abundant protein in leaves (maybe the most abundant on Earth).



Kokaly and Clark, REMOTE SENS. ENVIRON. 67:267–287 (1999)

Results: AVIRIS Maps



Curtesy of: Kokaly et al., RSE

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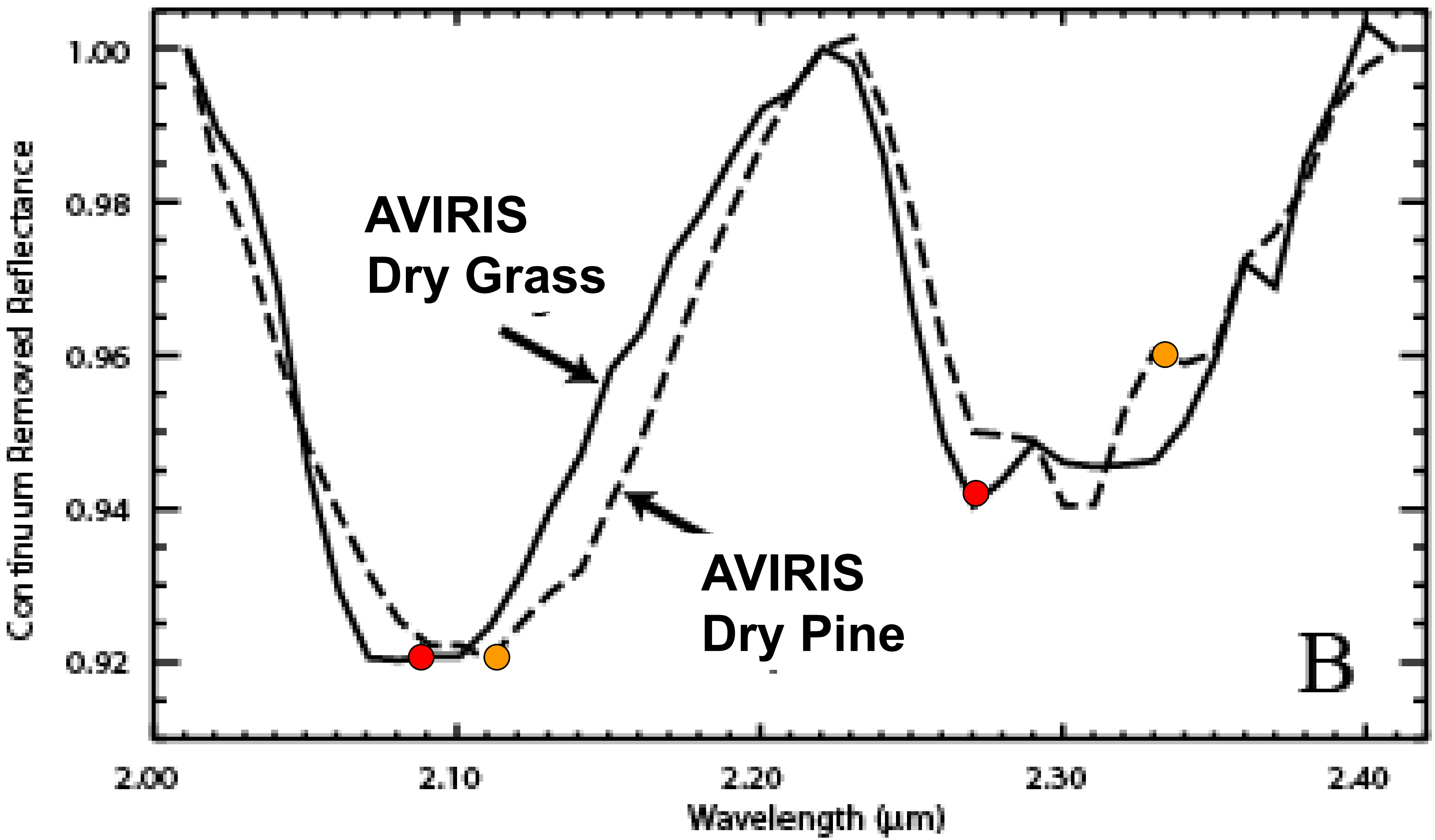


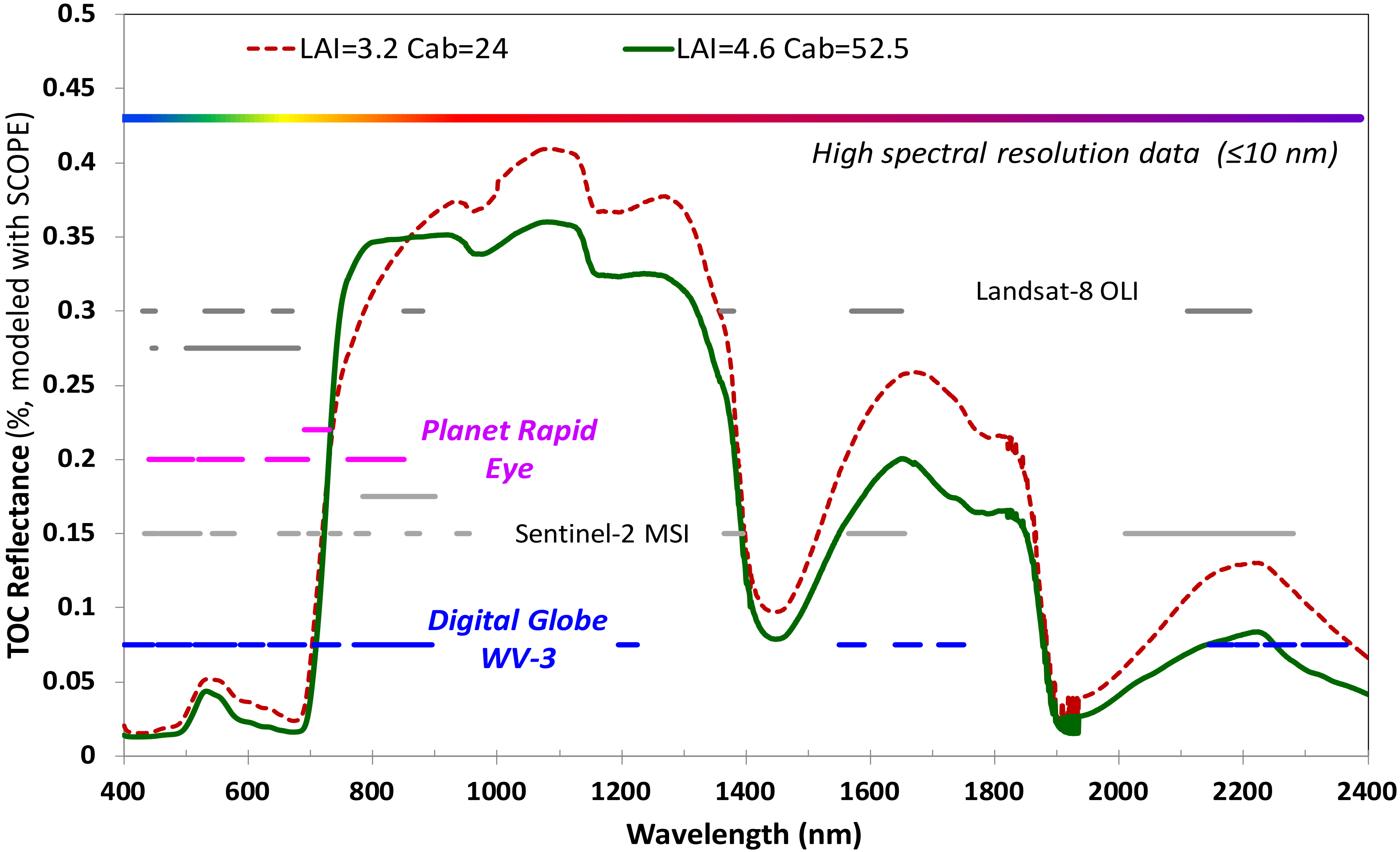
Kokaly et al., Remote Sensing of Environment

Analysis of spectral shape (full spectrum and/or absorption features) for vegetation characterization

- *Absorption feature analysis, Tetracorder:*
  - *Clark, et al. (2003) . J. Geophys. Research 108 (E12): 5-1 to 5-44*
  - *PRISM/USGS, Kokaly 2011*
- *Multiple Endmember Spectral Mixture Models:*
  - *Roberts, et al. (1998) Remote Sens. Environ. 65:267–279*
- *Monte Carlo spectral unmixing model:*
  - *Asner and Heidebrecht (2002) Int. J. Remote sensing 23: 3939–3958*

Synergy between Multispectral and Hyperspectral Reflectance, MS Vis

(https://www.indexdatabase.de/db/i.php)



Vegetation Indices (VIs) Provide Tool to Compare the Functional Status of Vegetation

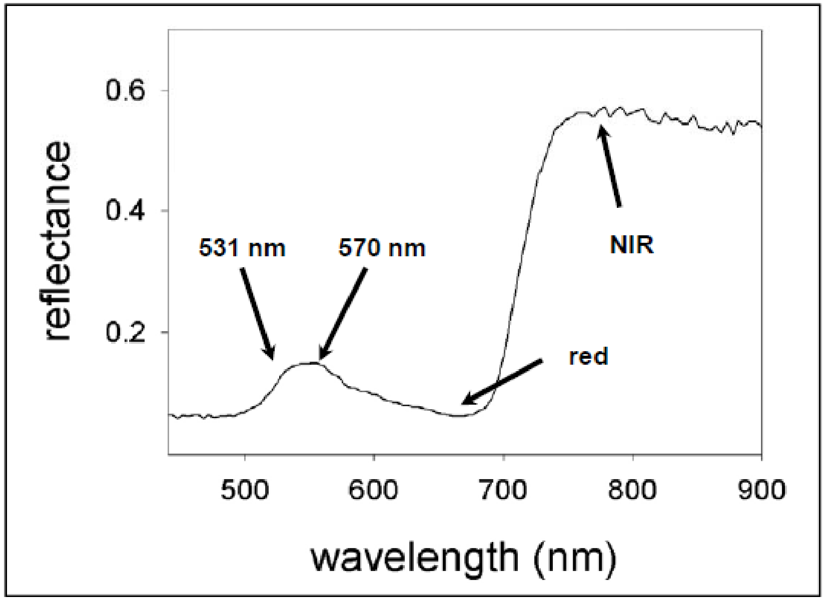
- SR (Simple ratio): correlation with chlorophyll content or leaf area index
- NDVI: correlation with chlorophyll content or leaf area index
- PRI (Photochemical Reflectance Index): correlation with photosynthetic efficiency

$$SR = \frac{R_{NIR}}{R_{red}}$$

$$NDVI = \frac{R_{NIR} - R_{red}}{R_{NIR} + R_{red}}$$

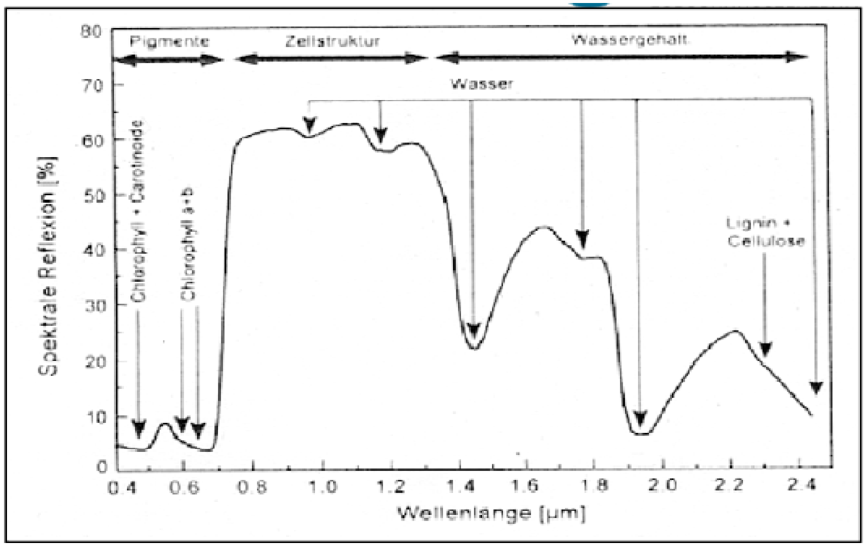
$$NDVI = \frac{R_{780} - R_{670}}{R_{780} + R_{670}}$$

$$PRI = \frac{R_{570} - R_{531}}{R_{570} + R_{531}}$$



Credit to Uwe Rascher

VIs Require Prior Knowledge of the Limiting Factors and the Related Vegetation Traits



EVI: Enhanced Vegetation Index (similar to NDVI including blue reflectance)

Red Edge Indices (quantify the slope of red absorption)

NDNI: Normalized Difference Nitrogen Index (Nitrogen absorption at 1510 nm)

NDLI: Normalized Difference Lignin Index (Lignin absorption at 1754 nm)

CAI: Cellulose Absorption Index (cellulose absorption at 2000 – 2200 nm)

PSRI: Plant Senscence Index (correlates with senescence and fruit ripening)

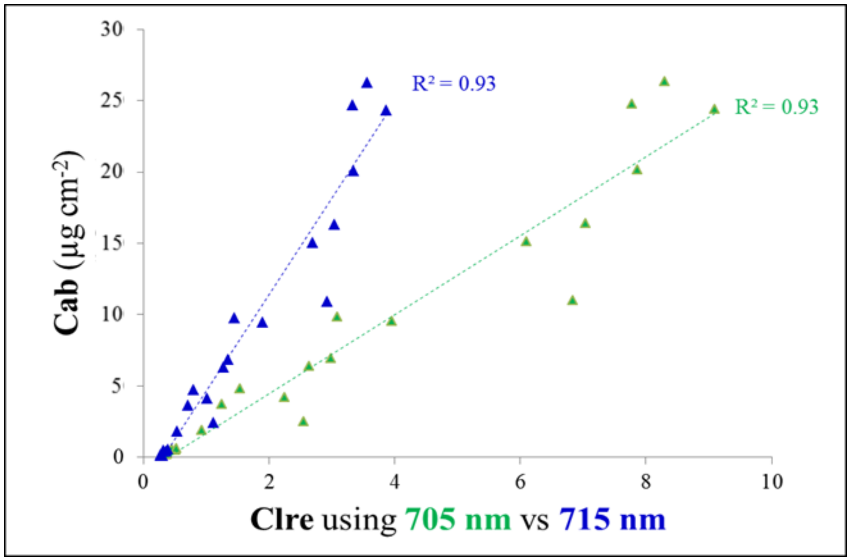
CRI1 / CRI2: Carotenoid Reflectance Index (yellow spectral region, correlates with carotinoid / chlorophyll ratio)

ARI1 / ARI2: Anthocyanin Reflectance Index (yellow and red spectral region, correlates with anthocyanin / chlorophyll ratio)

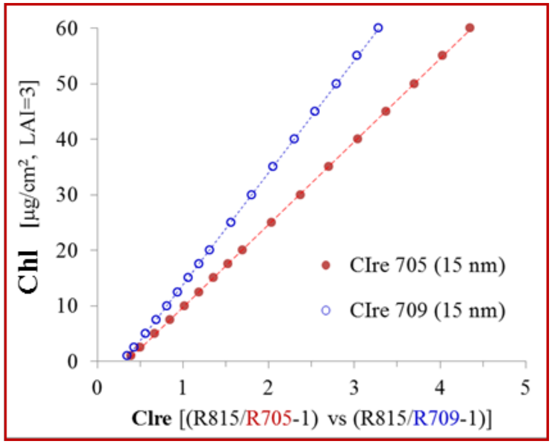
NDWI: Normalized Difference Water Index (canopy water content)

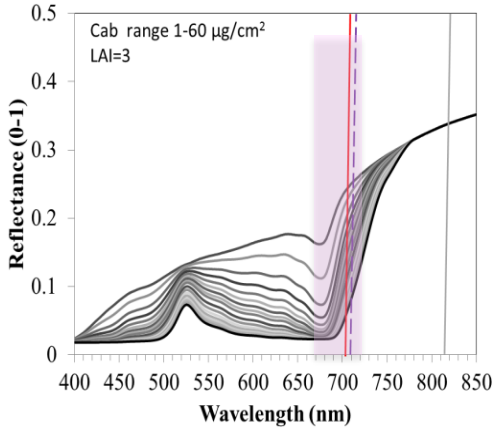
Importance of RE Bands for Chl Detection with VIs

EO-1 Hyperion, OPE3
Cl_{re} = (R815/R705 - 1)



SCOPE Reflectance
Chl 1-60 µmol/cm², LAI = 3





- Using R715 nm instead of R705nm reduces the sensitivity the chlorophyll VI, which is most pronounced at high chlorophyll levels. The result is reduced ability to detect the changes during initial senescence, when chlorophyll level is high.

The dynamic range of a VI is important **– using a red-edge band higher on the RE shoulder** (695-720 nm) **reduces the sensitivity of the VI.**

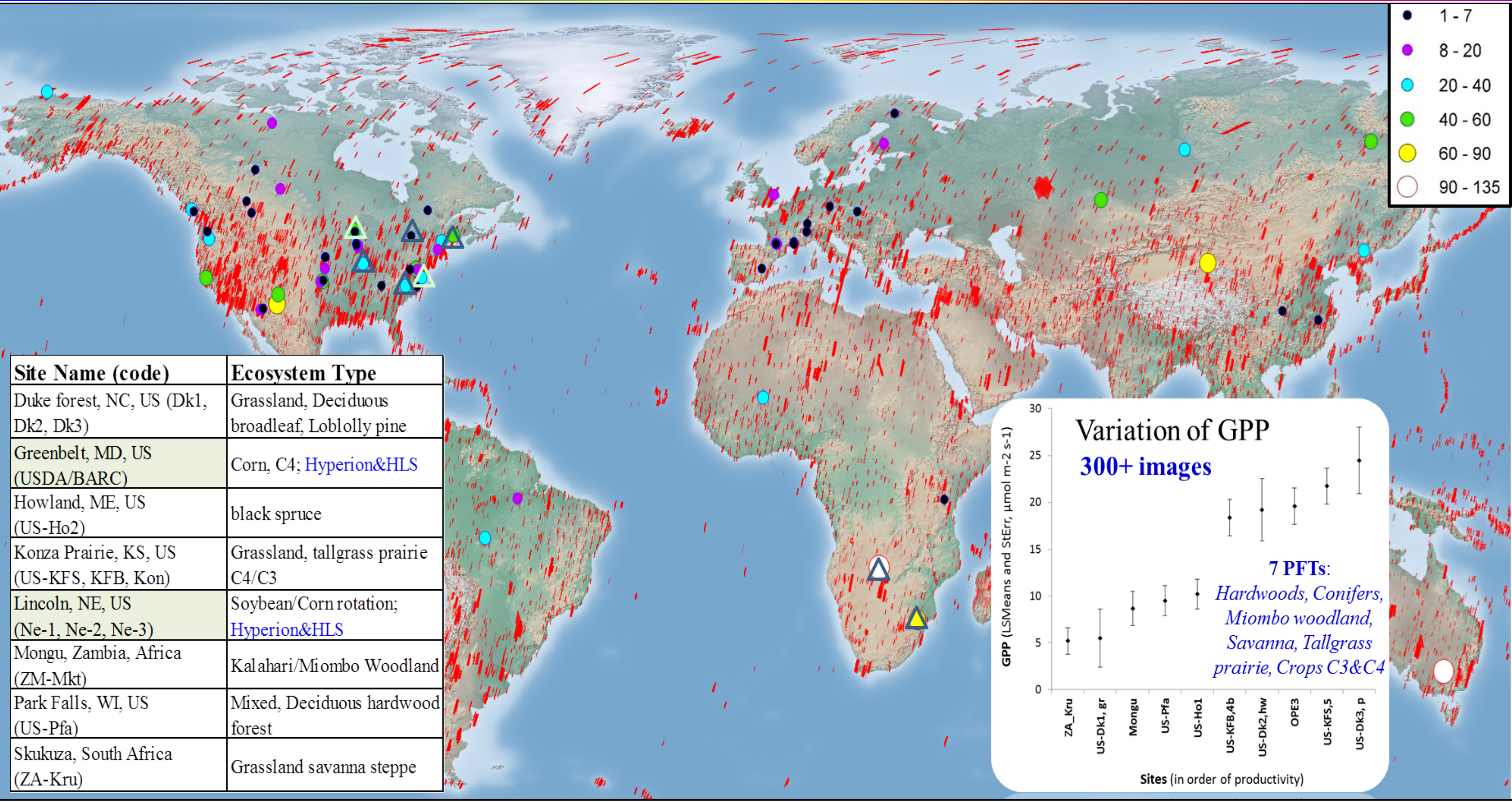
Space borne - Satellite and ISS Hyperspectral Reflectance Time Series

EO-1 Hyperion & DESIS: Using hyperspectral remote sensing to compare vegetation function (i.e., GPP and Cab) between species and across the seasons, for sites representing diverse functional types

- Evaluation of stability of the spectral time series
  - Calibration sites */ deserts
  - Vegetation – Key field data (e. g. flux sites, instrumented, *in situ* field collections)
- Characterization of canopy function
  - Using established bio-indicators: VIs, features, spectral sensitivity analysis to derive empirical models to map productivity
  - Using integrated leaf- canopy models with the spectra to derive canopy bio-physical and bio-chemistry parameters and estimate productivity

* *CEOS REFERENCE SITES for Validation of Reflectance and Evaluation of Vegetation Products (super sites)*
https://lpvs.gsfc.nasa.gov/LPV_Supersites/LPVsites.htm

EO-1 Hyperion Scenes and Selected FLUX Sites



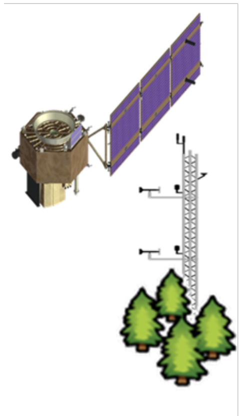
Site Name (code)	Ecosystem Type
Duke forest, NC, US (Dk1, Dk2, Dk3)	Grassland, Deciduous broadleaf, Loblolly pine
Greenbelt, MD, US (USDA/BARC)	Corn, C4; Hyperion&HLS
Howland, ME, US (US-Ho2)	black spruce
Konza Prairie, KS, US (US-KFS, KFB, Kon)	Grassland, tallgrass prairie C4/C3
Lincoln, NE, US (Ne-1, Ne-2, Ne-3)	Soybean/Corn rotation; Hyperion&HLS
Mongu, Zambia, Africa (ZM-Mkt)	Kalahari/Miombo Woodland
Park Falls, WI, US (US-Pfa)	Mixed, Deciduous hardwood forest
Skukuza, South Africa (ZA-Kru)	Grassland savanna steppe

> 9,500 Hyperion scenes have been collected over FLUX sites

Workflow for Processing and Analysis

Using reflectance time-series to capture the seasonal variability in GPP

spectral consistency
+
repeated coverage

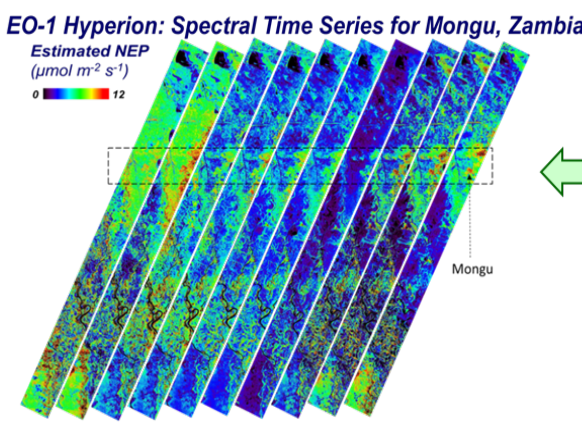


Seasonal time series (Hyperion and HLS) → **Canopy reflectance** (R, 0-1) → **Hyperion** Spectral features & VIs, **HLS** VIs

- Spectral features (SF)
- Vegetation indices (NDVI, TVI, SR and Cl_{705})

FLUX tower measurements
Field leaf & canopy traits → Canopy **GPP** (NEP, T°C, etc.) **Cab**, LAI, Cw, Cdm

- NEP - Net Ecosystem Production (μmol m^{-2} s^{-1})
- **GPP**- Gross Primary Production (μmol m^{-2} s^{-1})



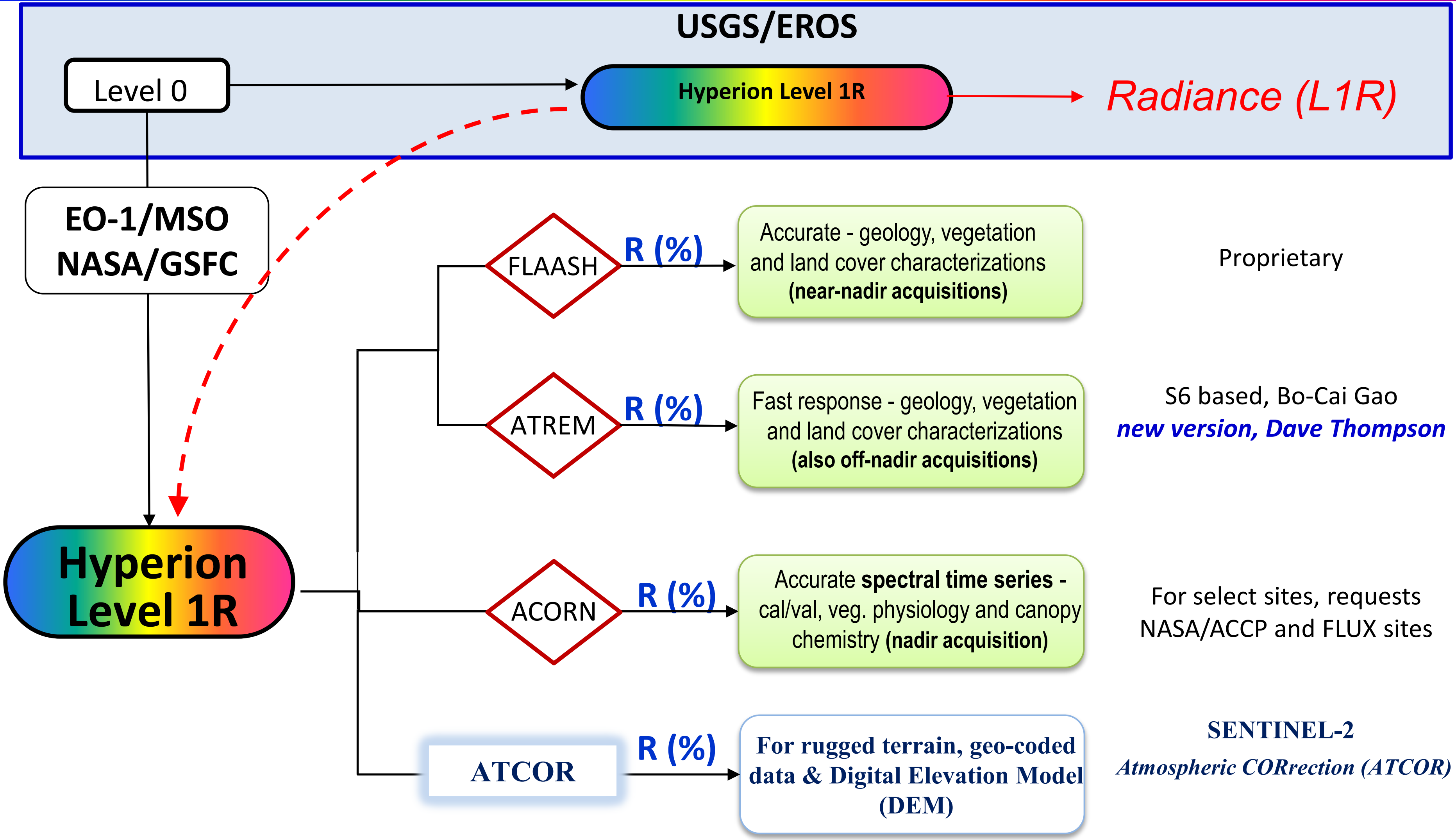
Relationships between flux GPP or field Cab & spectra (Fs and VIs)

MODELS
Statistical (PLSR)
Bio-physical (SCOPE)

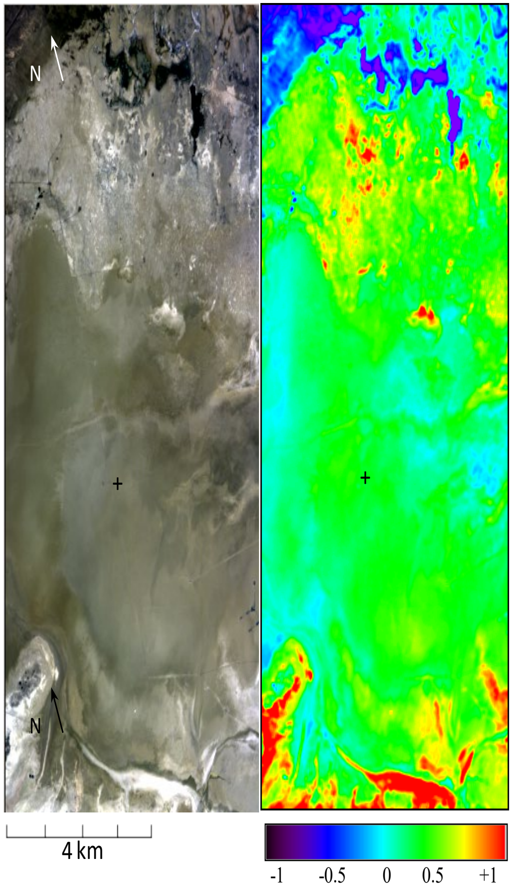
Empirical and biophysical models

1) **PLSR** - Partial Least Squares Regressions
2) **Regression** models with Feature area (FA) and VIs
3) **Biophysical,** integrated leaf+canopy model SCOPE

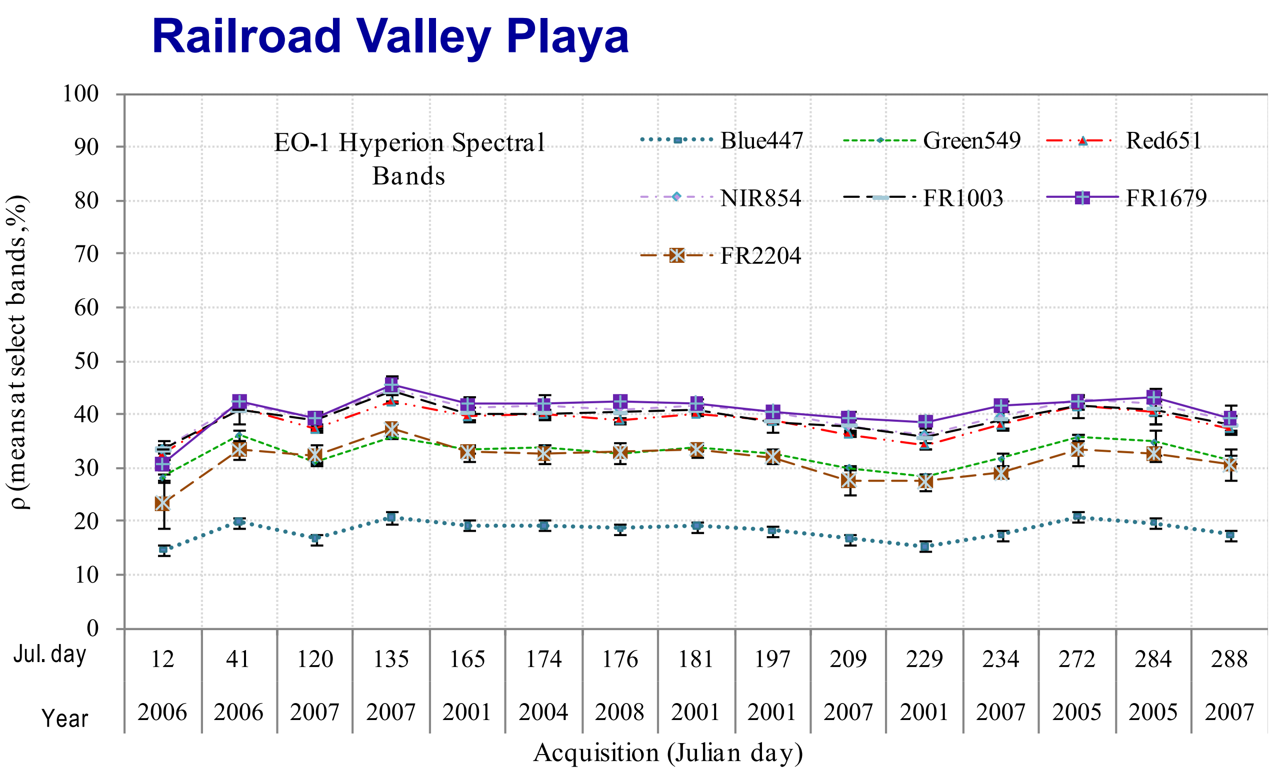
EO-1 Hyperion Level-2 Surface Reflectance



EO-1 Hyperion Reflectance
Time Series at Calibration Sites

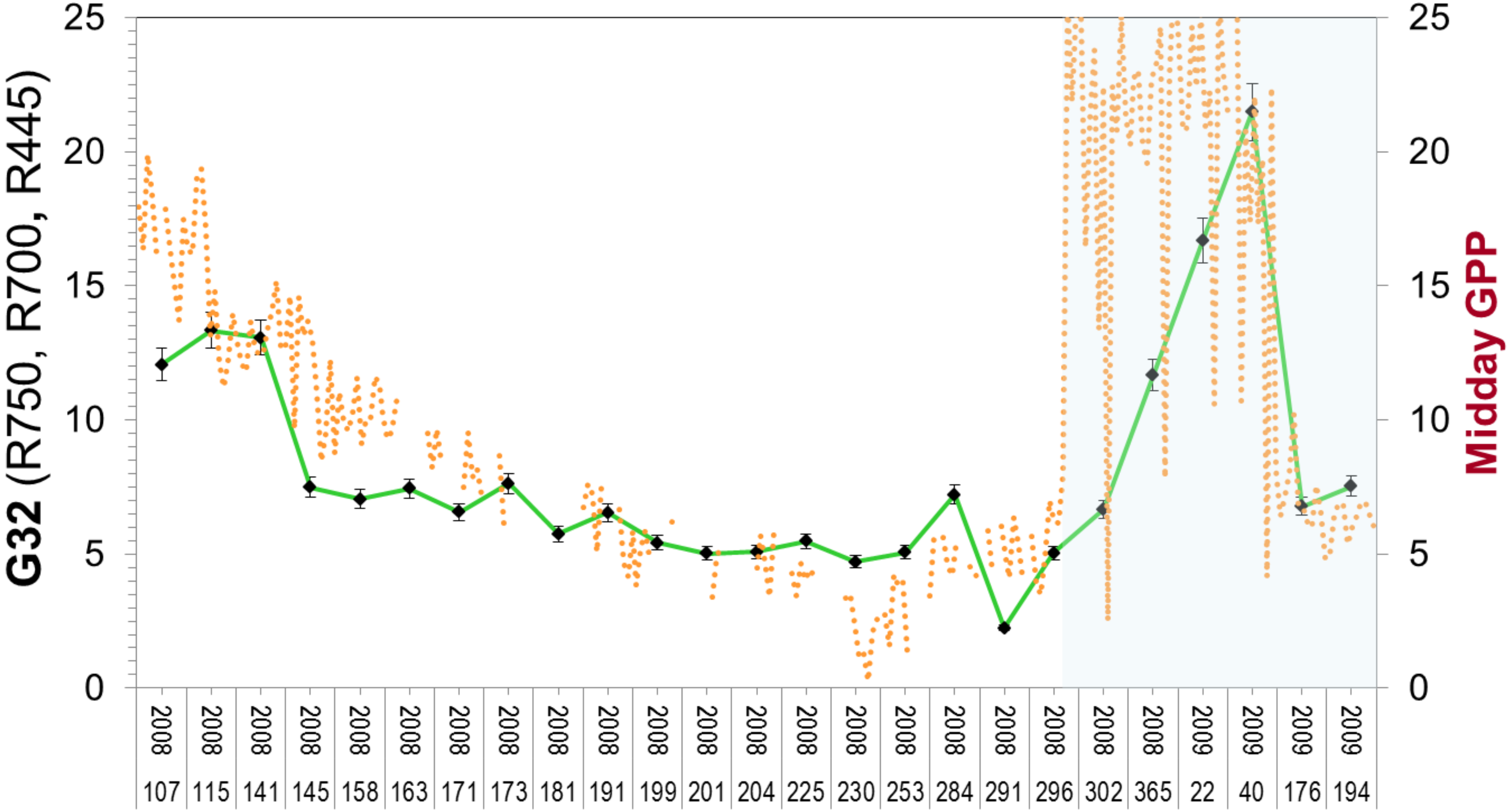


Evaluating the consistency/stability of derived reflectance from Hyperion



Hyperion Chlorophyll Indices and GPP

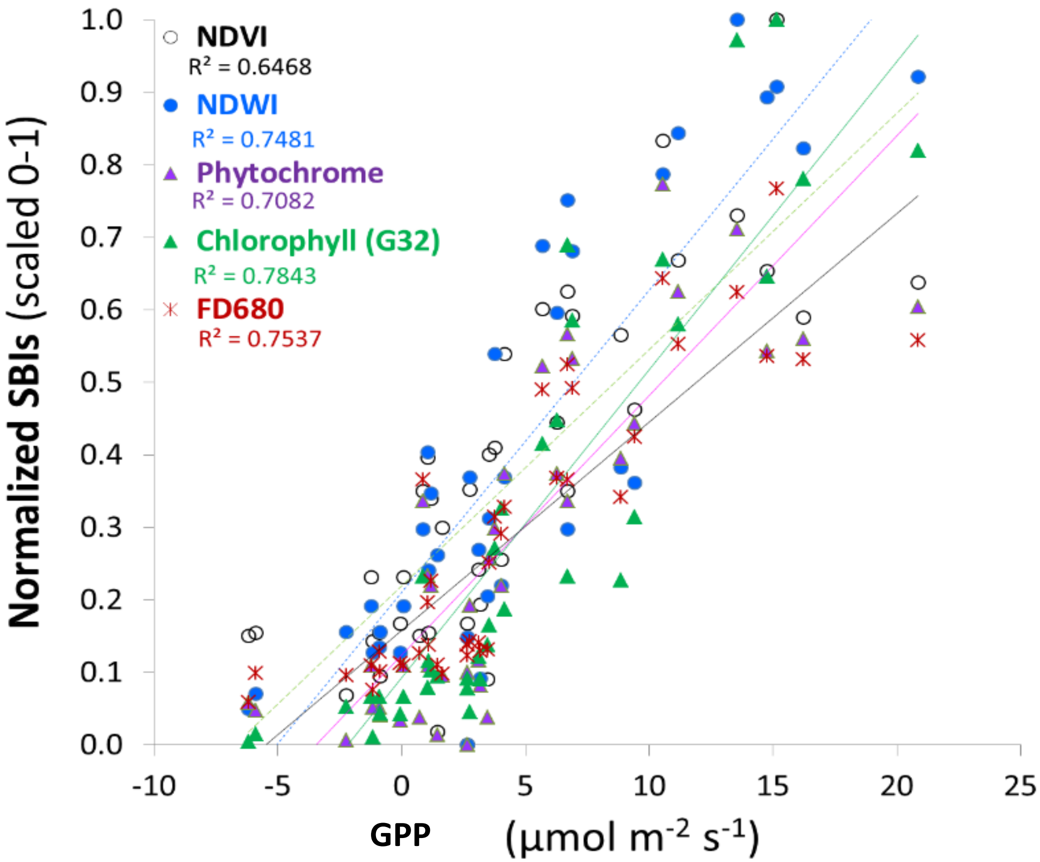
Campbell et al. 2013



The G32 index, associated with chlorophyll content (green line) captured the CO_2 dynamics related to vegetation phenology at Mongu

The Hyperion VIs, Normalized 0-1, Associated with GPP are Related to a Suite of Bio-physical Traits

Example from Skukuza (ZA-Kru)



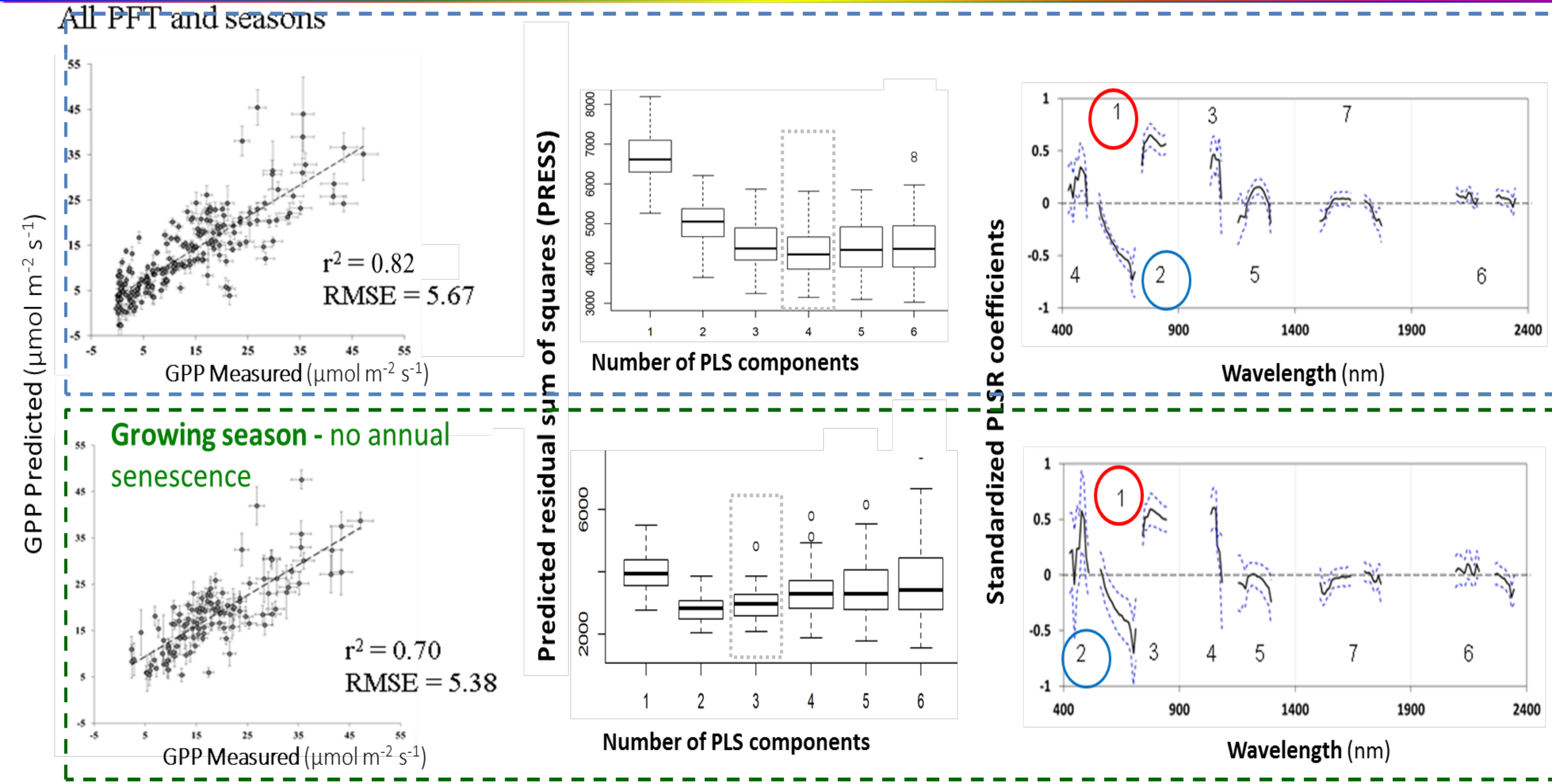
Spectral Parameters	R^2 to GEP
FA680 (PRISM)	**0.82 ***
G32=(R750-R445)/(R700-R445)	**0.78 ***
FD680 (PRISM)	0.75 *
NDWI=(R819-R1649)/(R819+R1649)	0.74
Phyt=(R724-R654)/(R724+R654)	0.71
NDVI = (TM4-TM3)/(TM4+TM3)	0.65

Key bio-physical parameters

1. canopy chlorophyll
2. water content
3. but also phytochrome, lignin and cellulose

Empirical models – Simple regressions, normalized VIs (0-1)

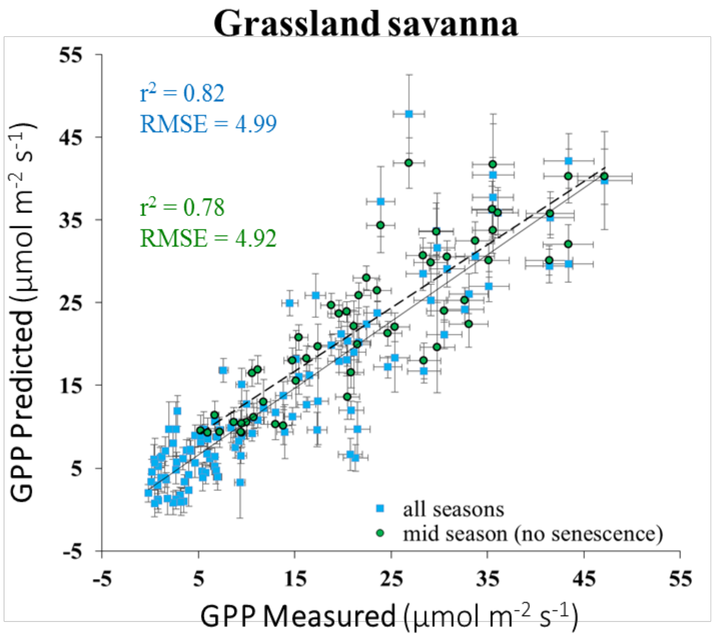
Midday GPP estimated using a partial least squares regression (PLSR) model with Hyperion seasonal time-series, for eight globally distributed sites

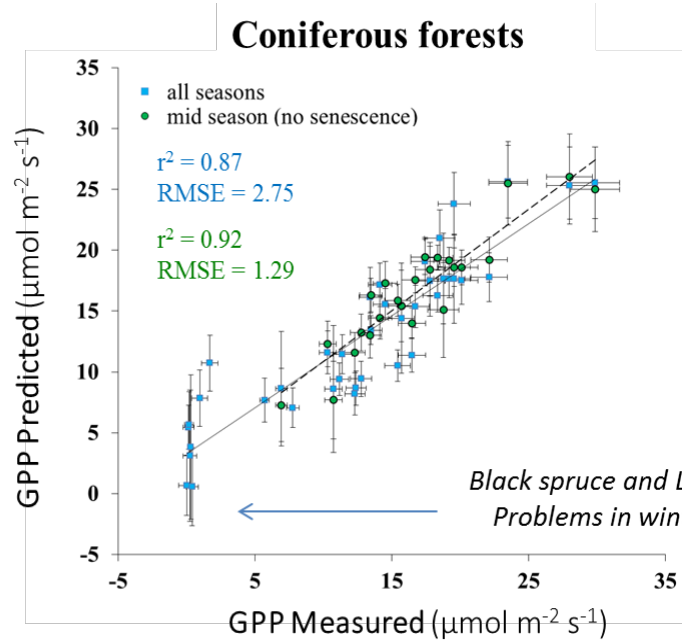


Empirical models – PLSR, 7 PFTs

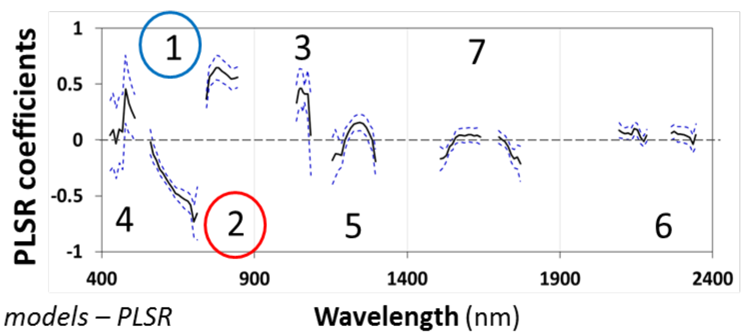
R tools for PLSR models Singh et al. 2015

Midday GPP estimated using a partial least squares regression (PLSR) model with Hyperion seasonal time-series, for individual PFTs

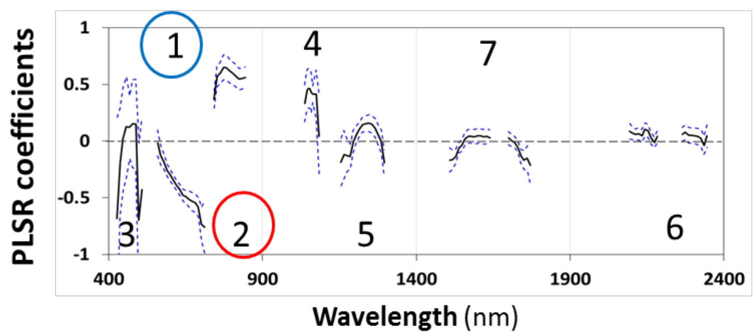




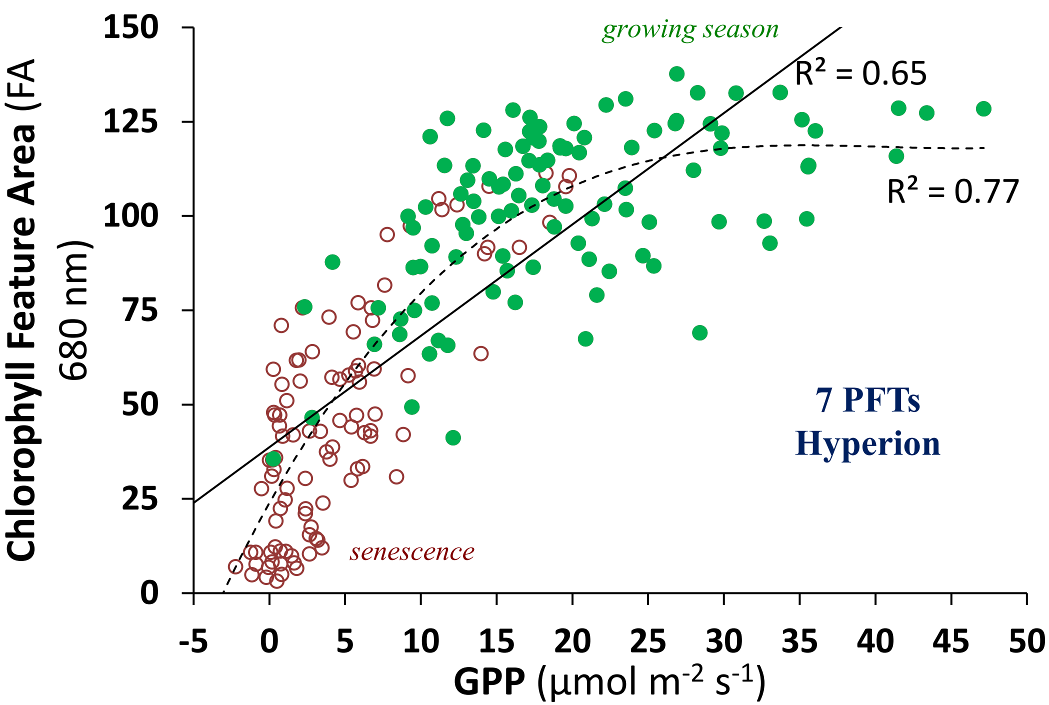
Black spruce and Loblolly pine forest
Problems in winter: snow, low GEP

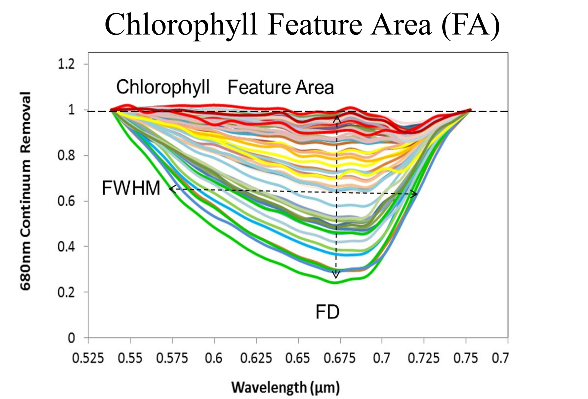


cal models – PLSR



Chlorophyll feature area (FA) capturing the dynamics in photosynthesis (e.g., canopy chlorophyll, Chl = Cab)





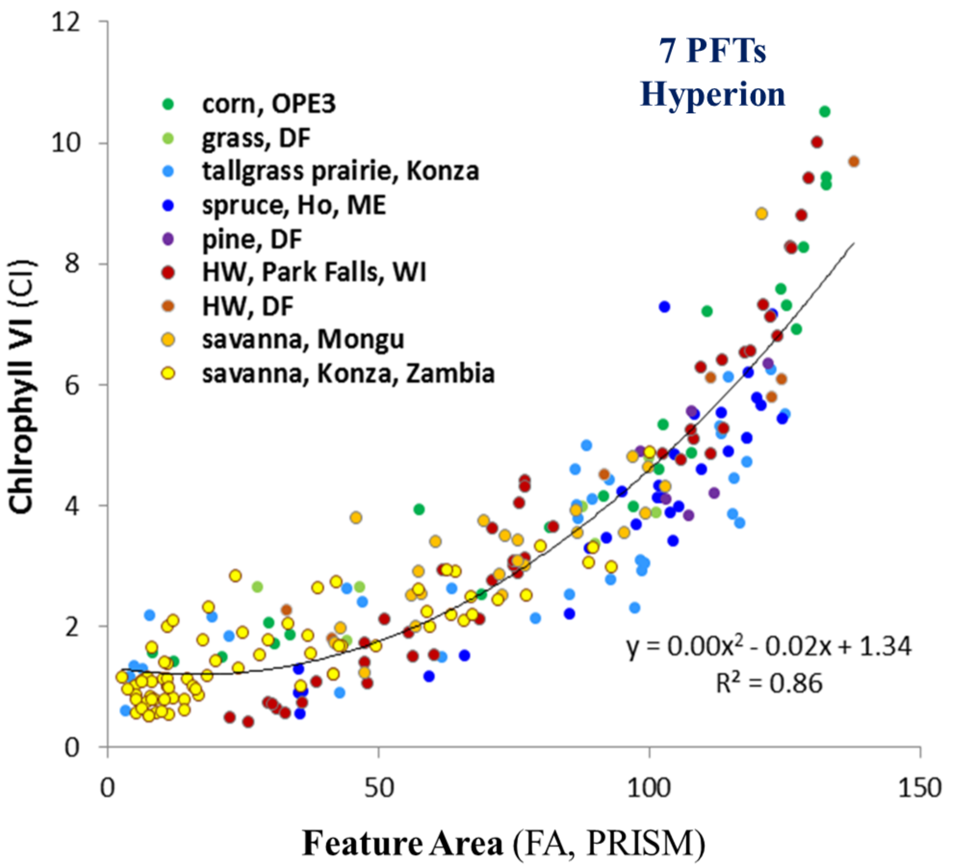
Skukuza (ZA-Kru)

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

Empirical models – Simple regressions

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

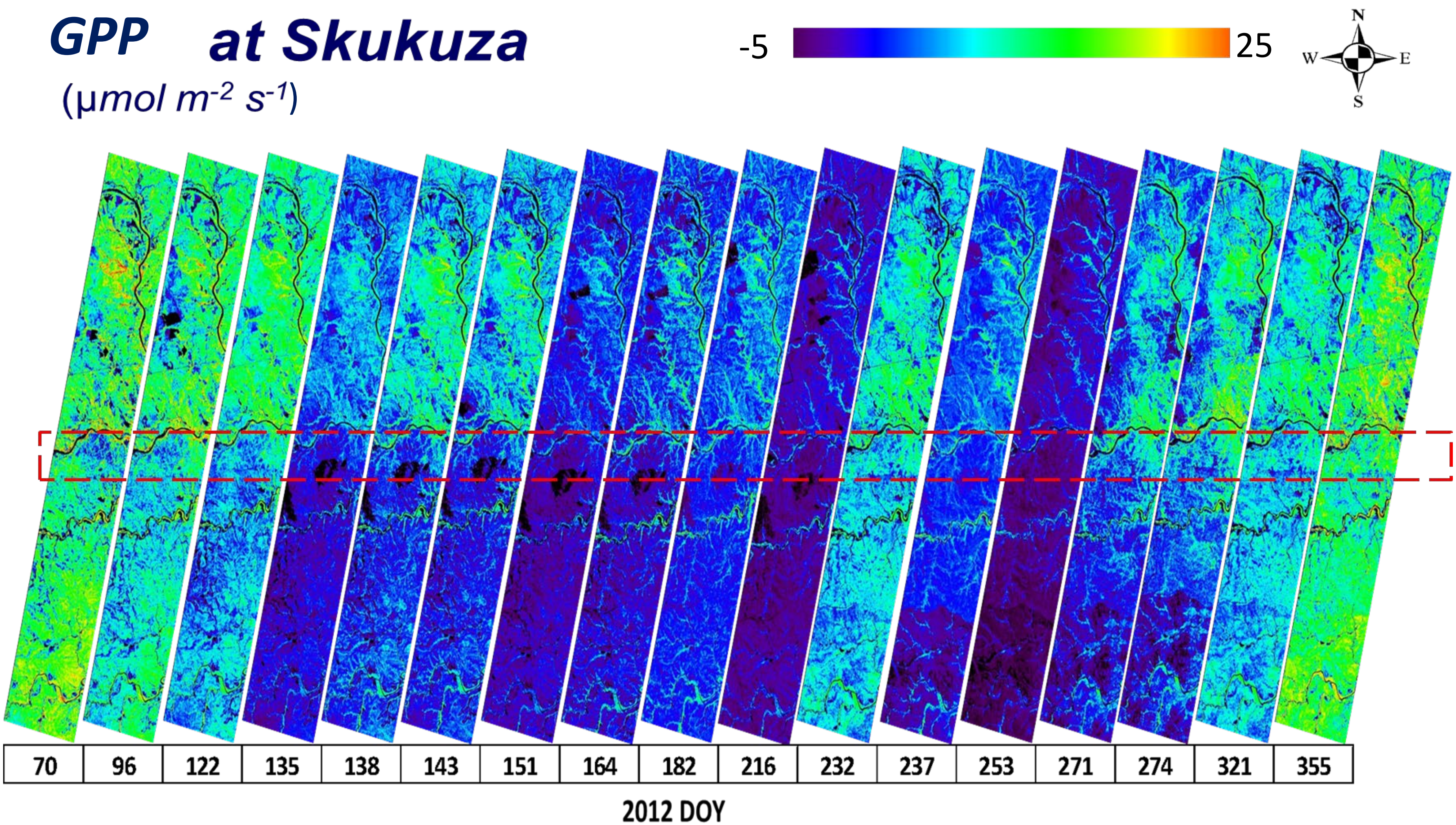
Relationship Between Chl Feature Area and Cl_{re} VI



Species	R^2
corn	0.96
grass + tallgrass prairie	0.87
spruce, ME	0.76
pine, DF	0.55
HW, DF and Park Falls	0.95
grassland savanna	0.88
wooded savanna	0.81

$CL_{RE} = (R_{nir}/R_{re} - 1)$

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



Upscaling from Leaf to Canopy with RS Models

1. Empirical models - direct canopy-integrated, relating RS to field data

- Statistical analyses to establish a relationship between the targeted biochemical parameter and a spectral parameter (e.g., **spectral indices, derivatives**).
- Multiplying the leaf content by the corresponding canopy biophysical parameter (e.g., LAI or biomass)

2. Physical (RTMo) and integrated bio-physical models (e.g., ProSAIL, SCOPE)

- employ inverted **radiative transfer models** (RTMo, e.g., PROSPECT, LEAFMOD, SAIL) to estimate the biochemical content at the leaf level.
- RT modeling simulates the transfer of radiation in the canopy by computing the interaction between a plant and solar radiation.
- Integrated bio-physical models – combine modules simulating the biochemistry and RTMo, leaf and canopy

Empirical models:

+ In general simple

+ Using of a good index leads to the elimination of surface geometry influence, of terrain reflection direction etc.

+ Take in account specific conditions from the data acquisition date

– **Always „site specific“** (model derived for one locality data – not possible to use for another locality – for both localities must be special field campaign with samples collection)

Bio-physical and RTMo models

+ In the case of a good parametrization universal use (possible to use for multiple areas)

– Have to run the simulations separately for the different canopies, slopes orientation and inclination

– Very difficult computationally

– Generalized model of radiation spreading need not always describe sharply the specific conditions that were locally in the time of the data acquisition

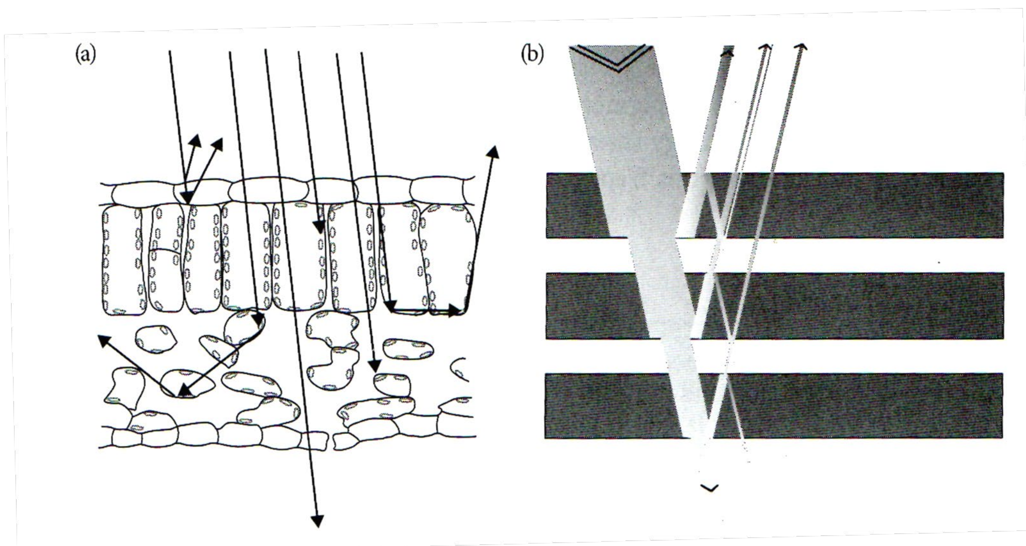
PROSPECT Model

PROSPECT is a radiative transfer model describing leaf level reflectance and transmittance based on leaf structure and light absorption characteristics of the leaf biochemical content

- It is frequently used to provide leaf reflectance and transmittance inputs to SAIL (PROSAIL)

PROSPECT describes describes leaves as a number of plates separated by air spaces

- The number of plates (N) is the number of compact layers representing the average number of air/cell wall interfaces within the mesophyll



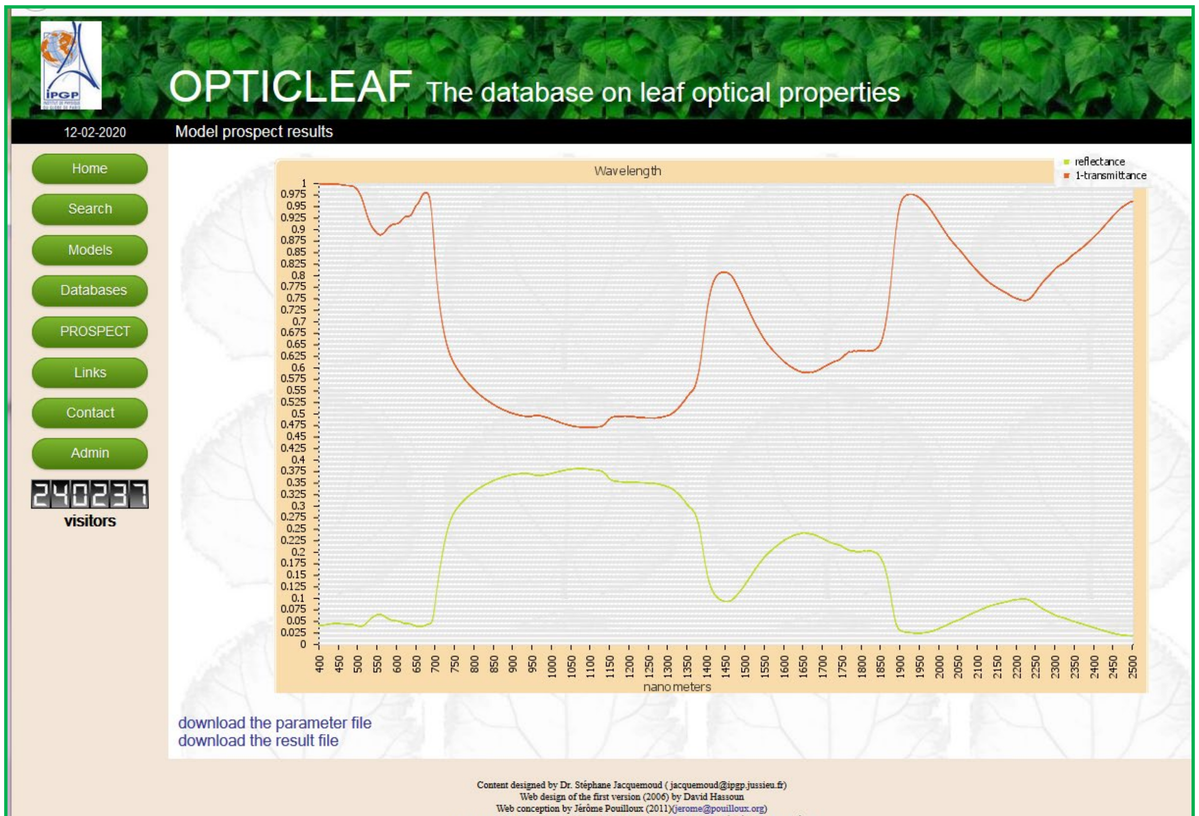
Jones and Vaughn 2010

PROSPECT: A model of leaf optical properties spectra

Radiative transfer model based of a generalized "plate model" that represents the optical properties of plant leaves from 400 nm to 2500 nm. Scattering is described by a spectral refractive index (n) and a parameter characterizing the leaf mesophyll structure (N). Absorption is modeled using pigment concentration (C_{a+b}), water content (C_w), and the corresponding specific spectral absorption coefficients (K_{a+b} and K_w). The parameters n, K_{a+b}, and K_w have been fitted using experimental data corresponding to a wide range of plant types and status.

Modeling of leaf optical properties: http://photobiology.info/Jacq_Ustin.html

PROSPECT: http://opticleaf.ipgp.fr/index.php?page=prospect (from http://photobiology.info/)



Factors Affecting Leaf Reflectance / Absorption

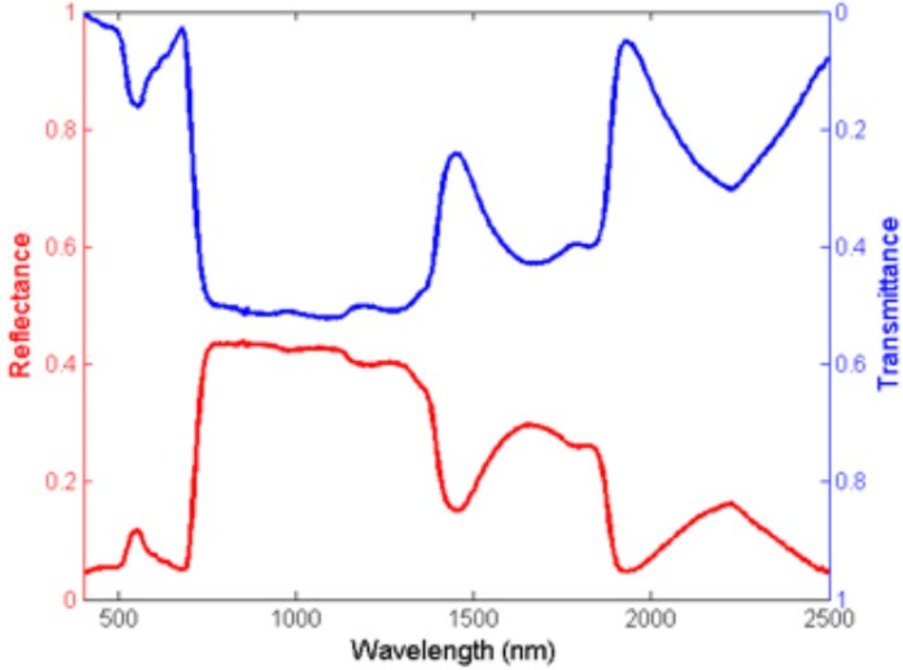


Figure 1. Reflectance (red) and transmittance (blue) spectra of a fresh Carolina poplar (*Populus canadensis*) leaf.

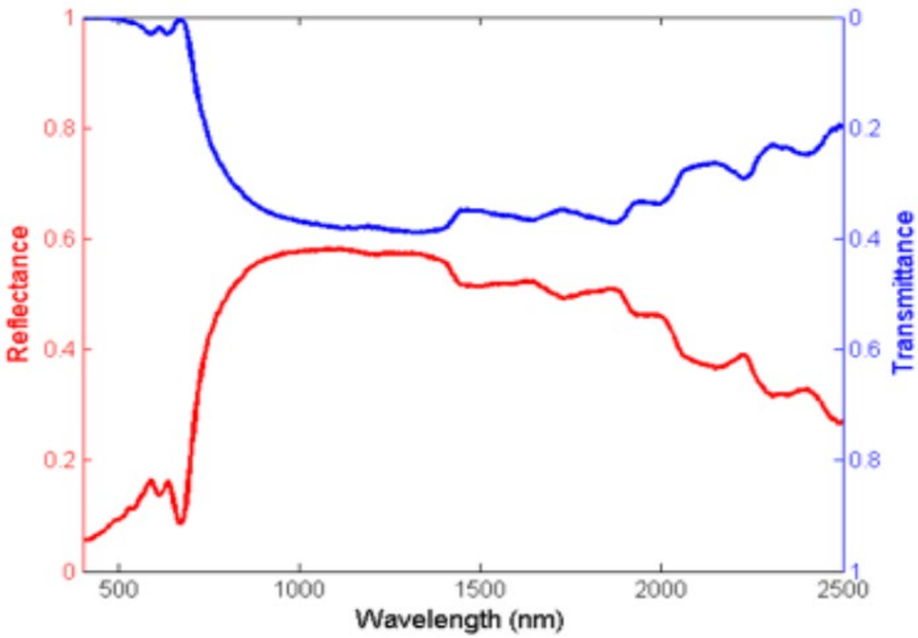


Figure 2. Reflectance (red) and transmittance (blue) spectra of a dry Carolina poplar (*Populus canadensis*) leaf.

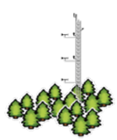
Deriving GPP and Chl using Hyperion Reflectance with the SCOPE Bio-physical Model

'Soil-Canopy-Observation of Photosynthesis and the Energy balance' SCOPE:
4SAIL - radiative transfer, Fluspect - leaf optical, GSV - soil reflectance,
Biochemical - leaf photosynthesis, reflectance and fluorescence

Campbell et al. 2021 in preparation

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

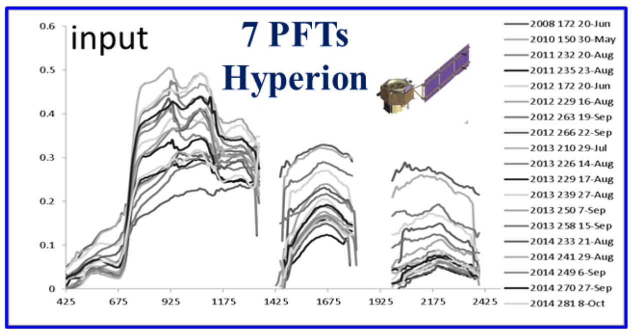
? ≈ GPP measured

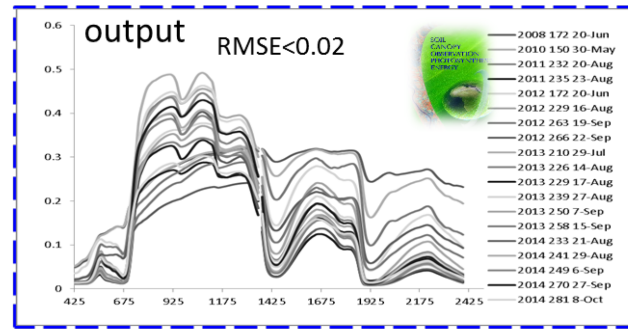


Measured → **Simulated**

Reflectance (EO-1 Hyperion, DESIS, SBG)

SCOPE, RTMo



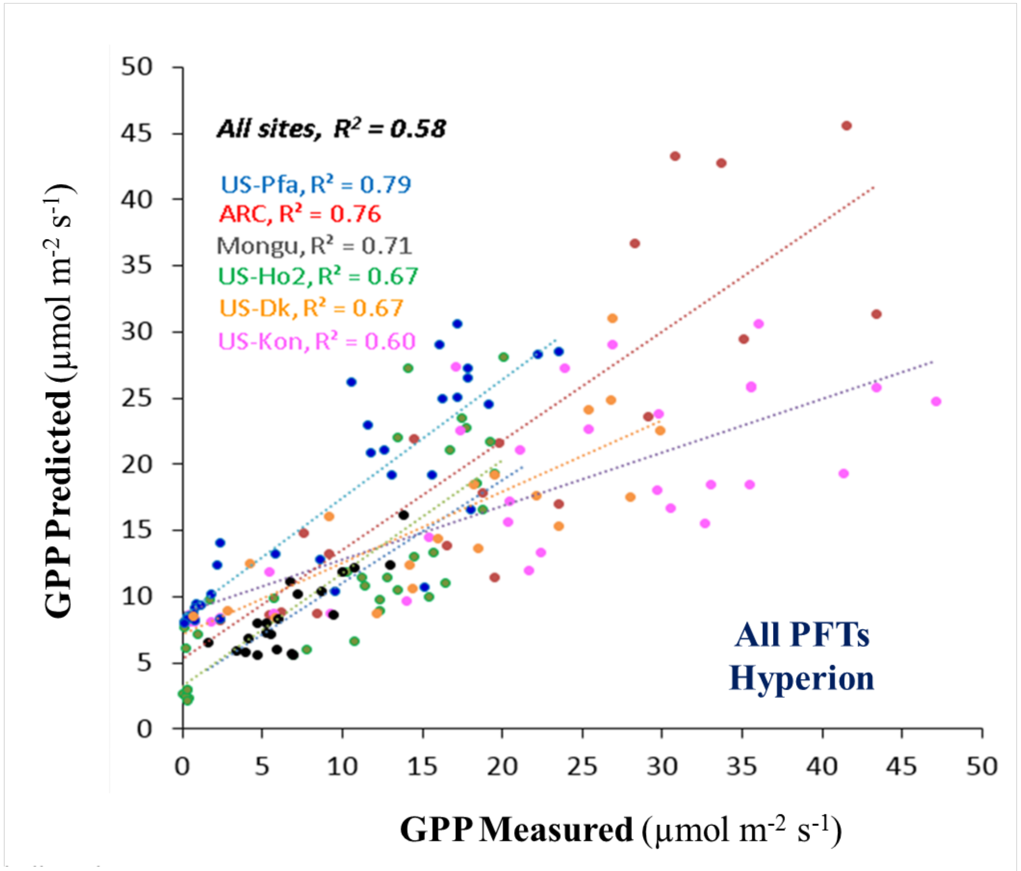


Leaf and canopy RTMs are a part of SCOPE, including:

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

The SCOPE model provides the ability and framework to:
*- identify the **driving factors,***
*- gap fill and forecast, for missing observational scenarios, **and***
- validate/confirm the findings against field and eddy covariance measurements

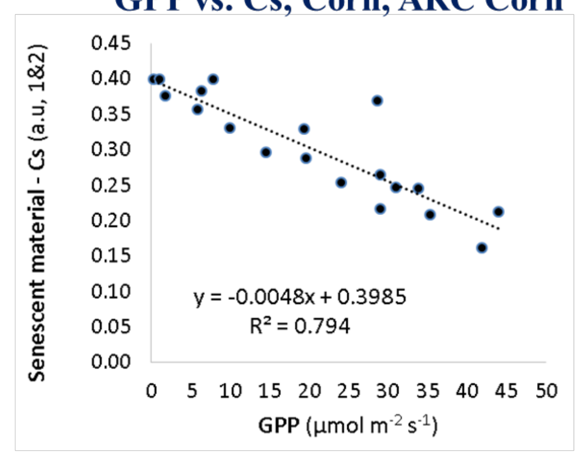
GPP and Functional Traits, SCOPE + Hyperion



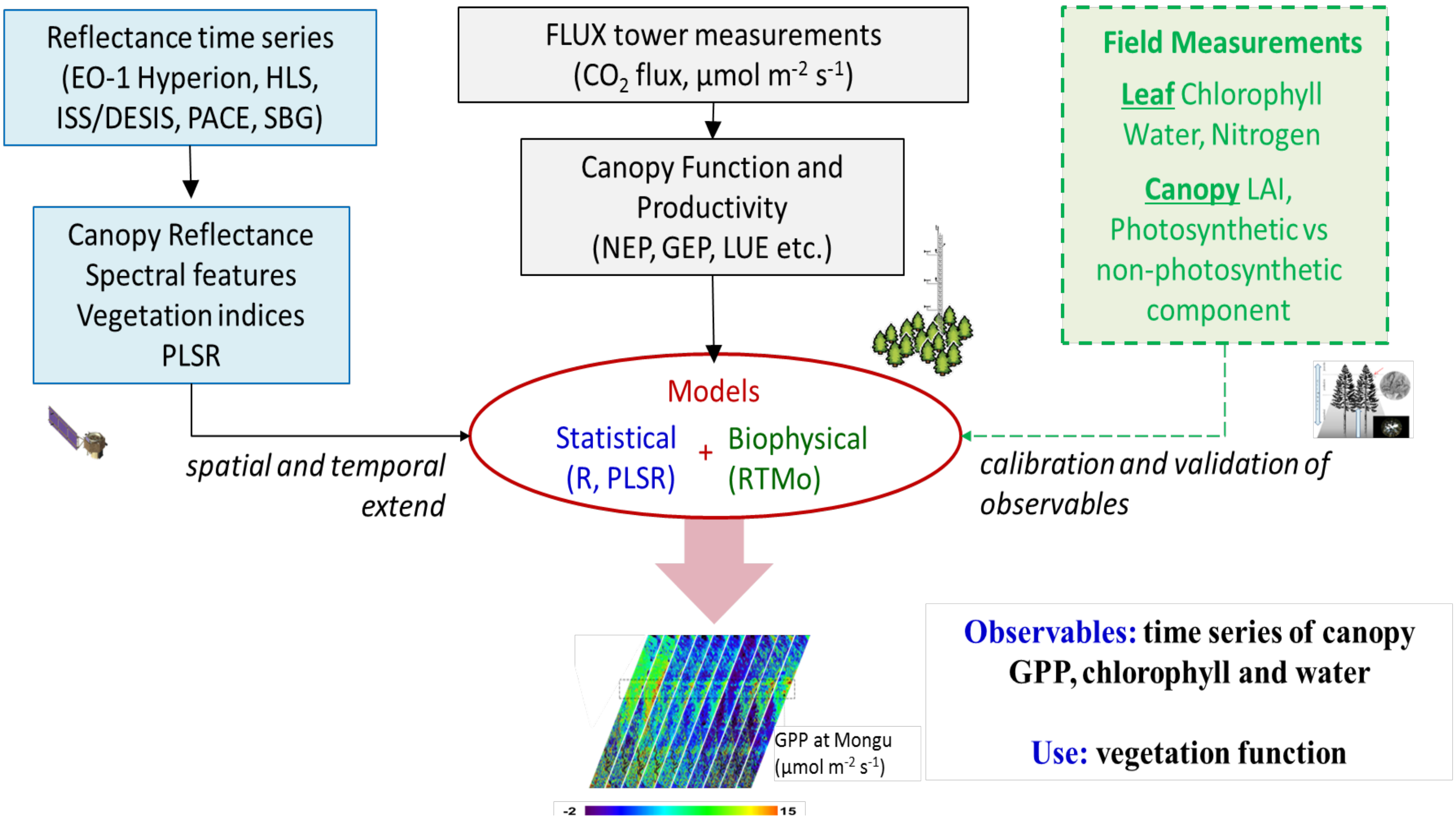
Campbell et al. 2021, in preparation

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

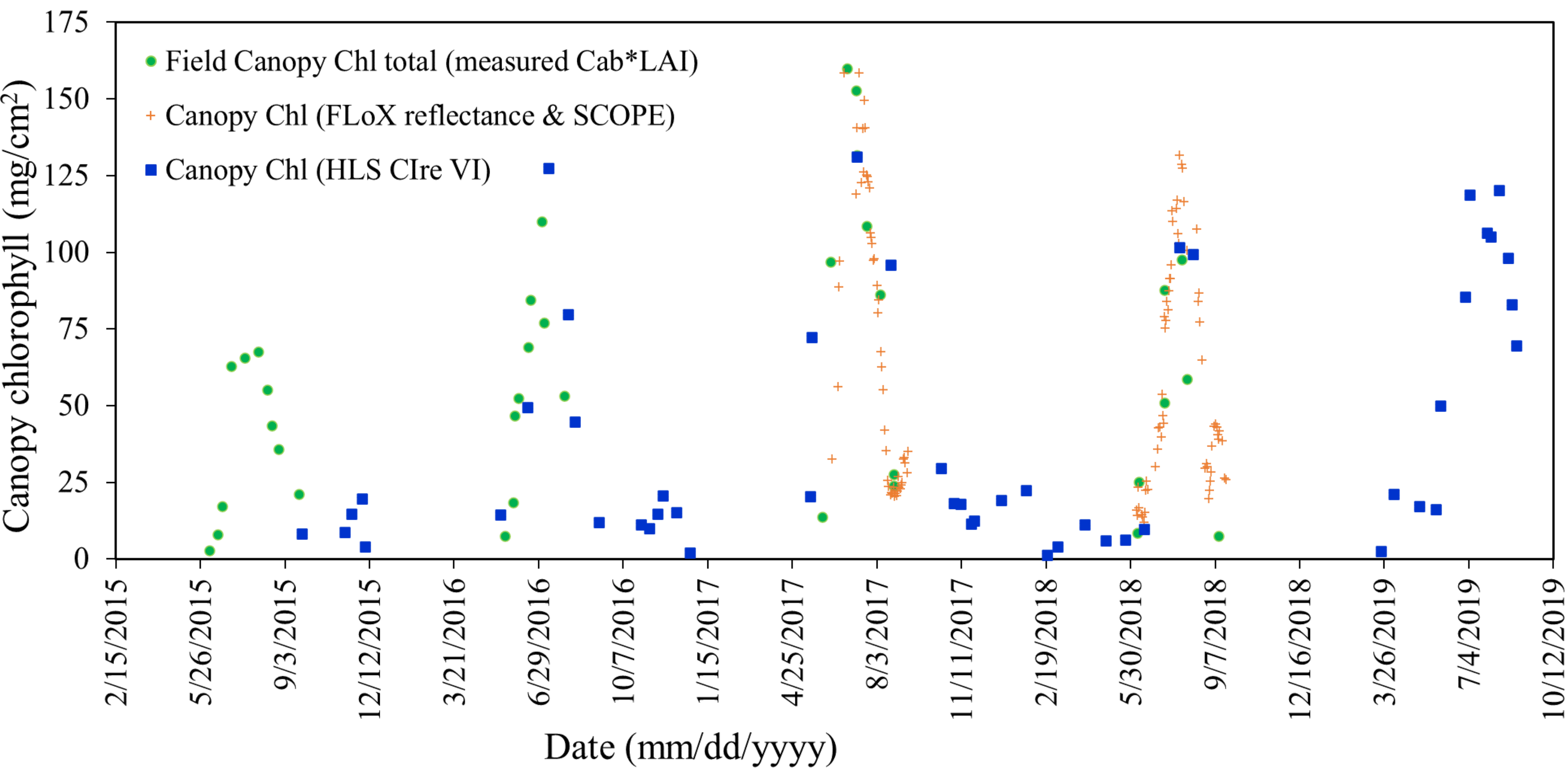
GPP vs. Cs, Corn, ARC Corn



Combined Strategy for Monitoring Vegetation Function

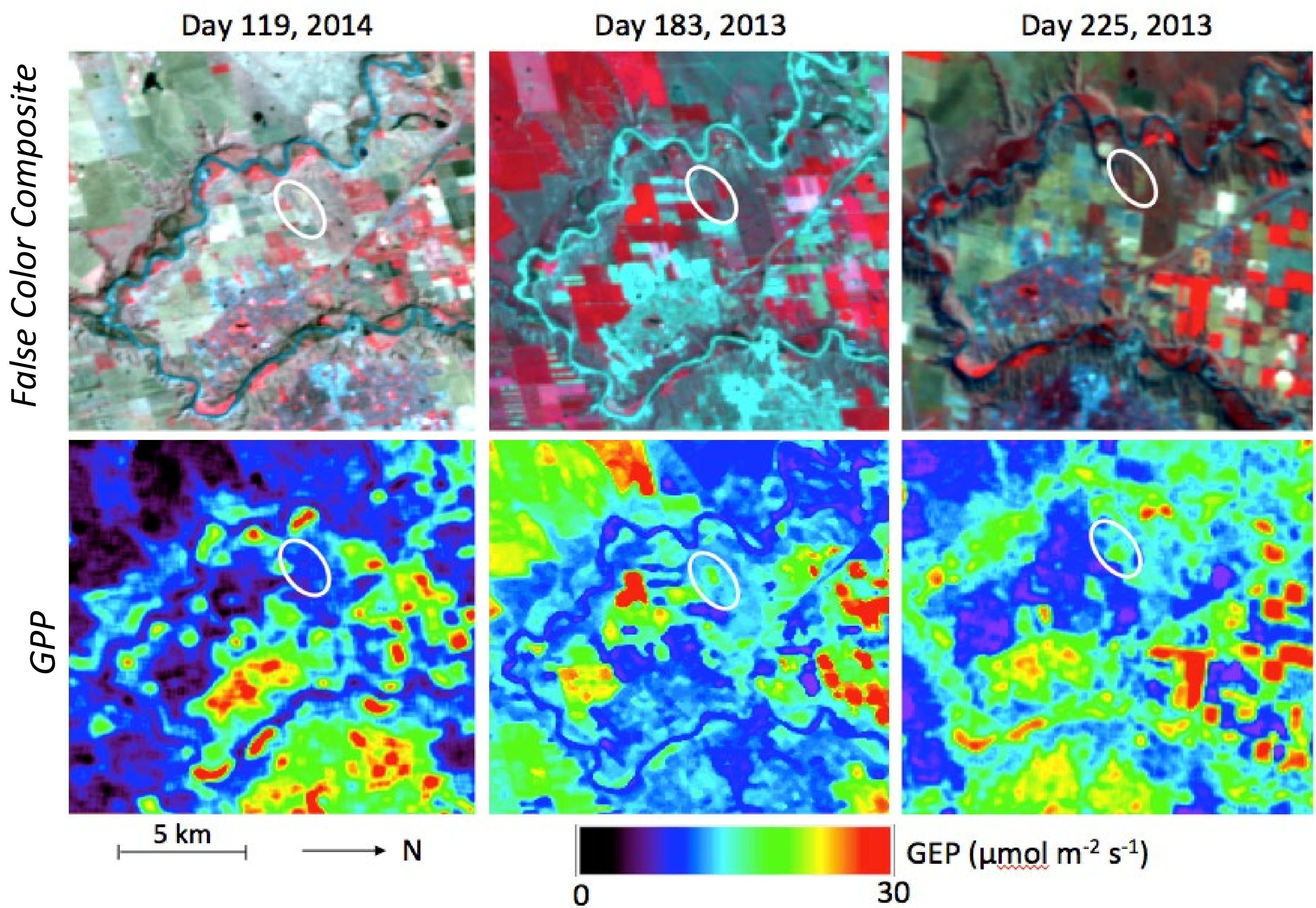


Combined Strategy Using Hyperspectral and Multispectral for Monitoring Vegetation Function



Repeated Observations of GPP from the ISS

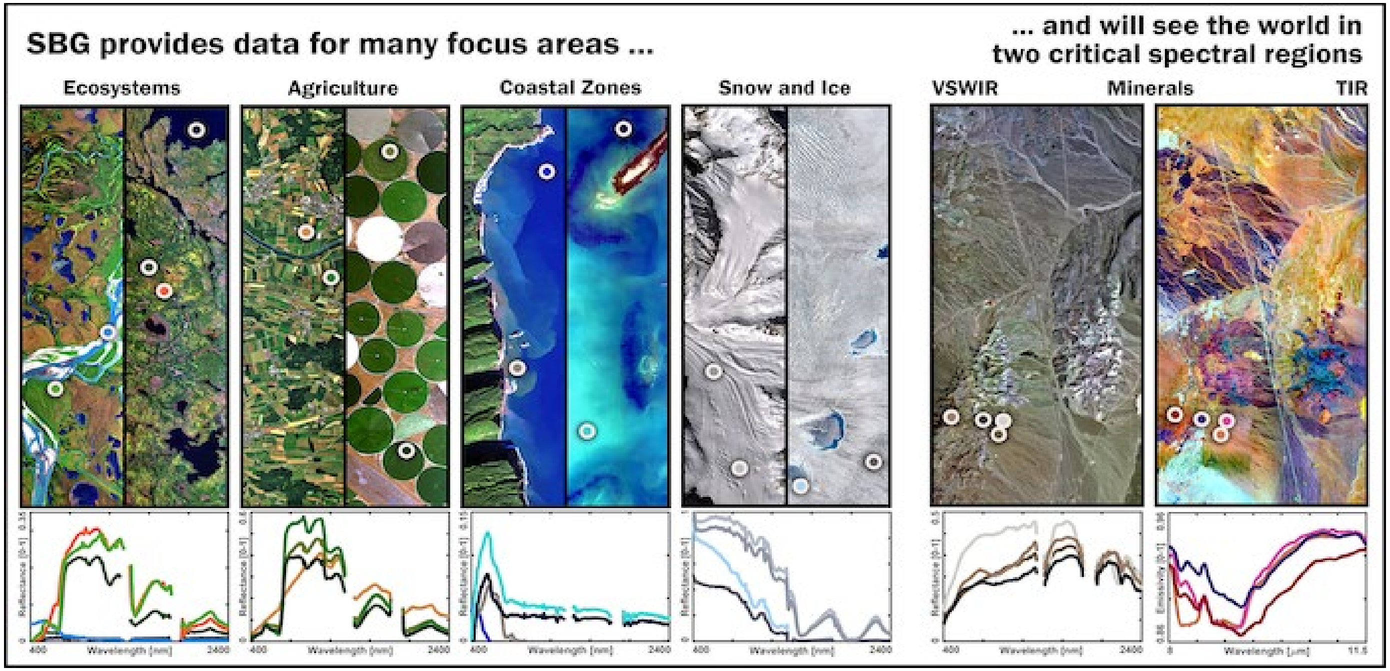
HICO Images and PLSR, Lethbridge, CA



Remaining Challenges and Future Directions

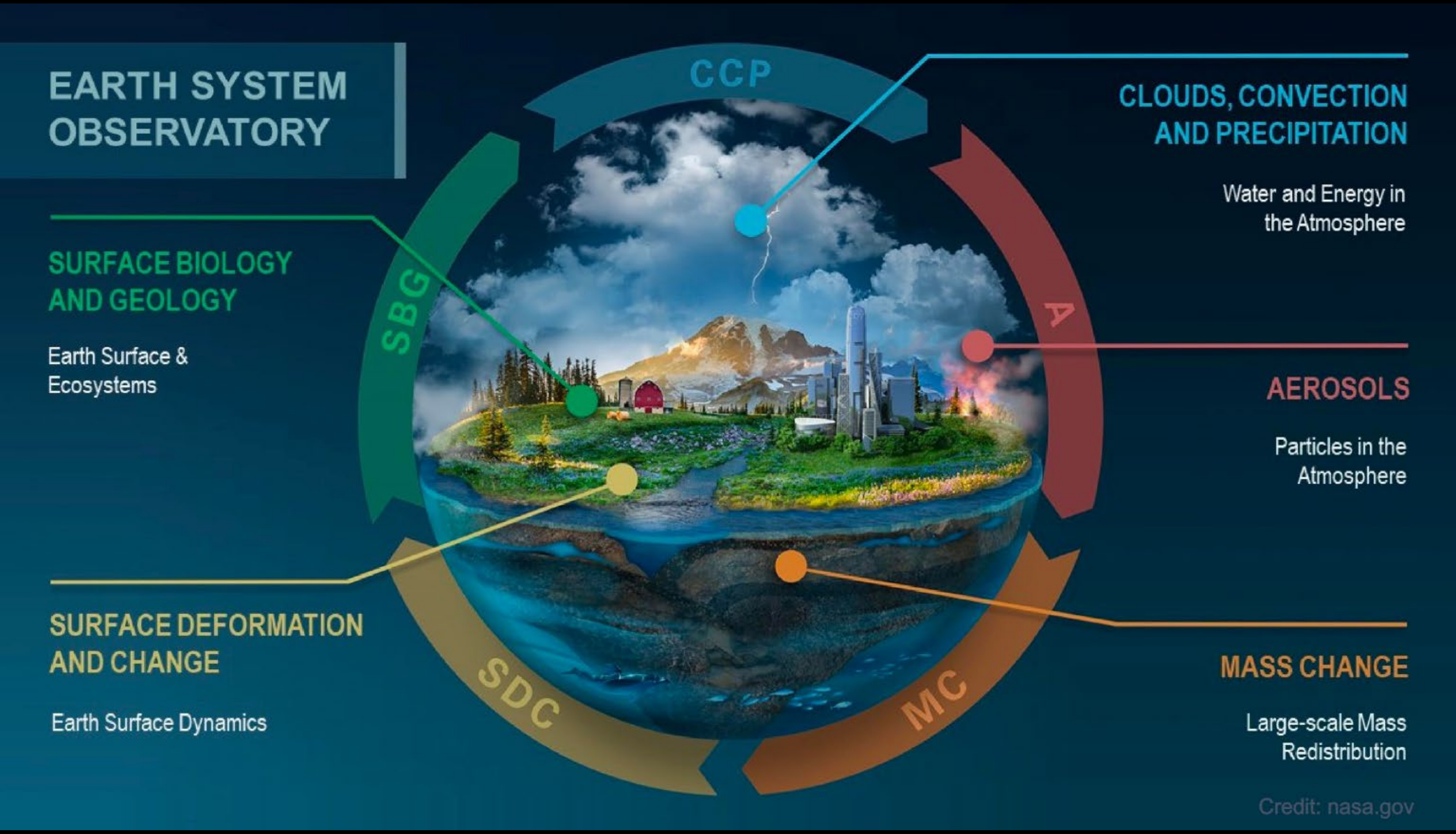
- Overlapping of biochemical absorption features
  - Leaf water masking effect
  - Understanding protein/lignin/cellulose changes which all affect the 2.1 and 2.3 μm features
- Quantification of other biochemicals (starch, tannin, hemi-cellulose, phosphorous)
- Independent-site/Multi-site validation
- Atmospheric correction needs improvements, to enable the us of one approach globally, and to lessen impact of residual features

NASAs Surface Biology and Geology (SBG) status and applications



SBG Carbon Cycle and Ecosystems Science Lead, David Schimel

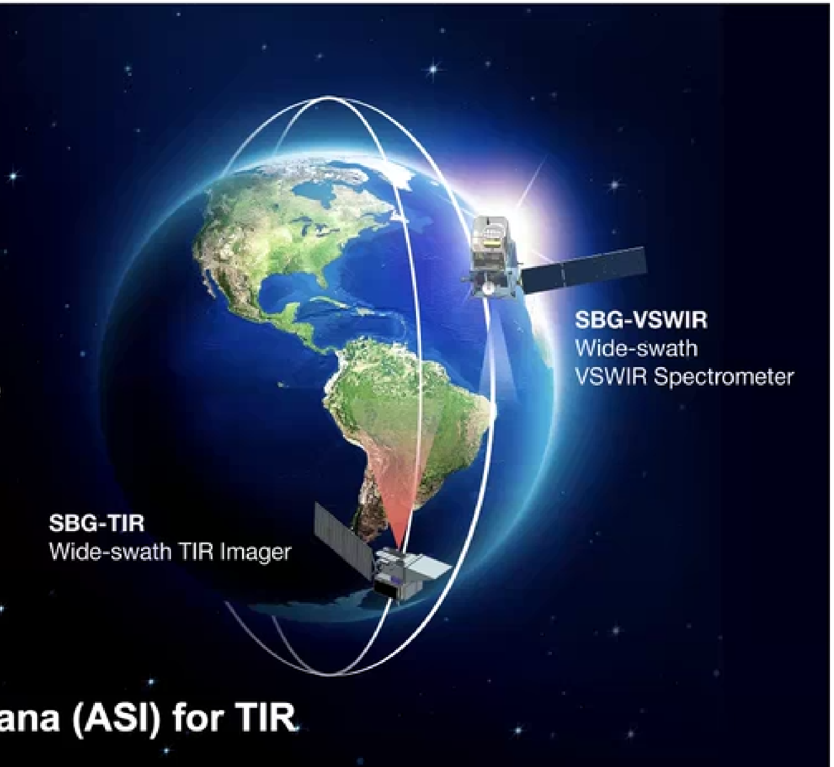
Applications WG, co-lead Christine Lee (christine.m.lee@jpl.nasa.gov). **Algorithms W**G, co-lead Kerry Cawse-Nicholson (kcawseni@jpl.nasa.gov). **Modeling WG**, co-lead Ben Poulter (benjamin.poulter@nasa.gov). **Cal/Val WG**, co-lead Kevin Turpie (kturpie@umbc.edu).


EARTH SYSTEM OBSERVATORY
CCP
CLOUDS, CONVECTION AND PRECIPITATION
Water and Energy in the Atmosphere
SBG
SURFACE BIOLOGY AND GEOLOGY
Earth Surface & Ecosystems
A
AEROSOLS
Particles in the Atmosphere
SDC
SURFACE DEFORMATION AND CHANGE
Earth Surface Dynamics
MC
MASS CHANGE
Large-scale Mass Redistribution
Credit: nasa.gov

NASA Surface Biology and Geology

Two-Platform SBG Mission Concept

- **Wide-swath Thermal Infrared (TIR) Imager platform**
- **Wide-Swath Visible and Short-Wave Infrared (VSWIR) Spectrometer platform**
- **Launches in the second half of the decade**
- **Each with a three-year prime mission**
- **Lead and other NASA Centers: JPL with ARC, GSFC, KSC, LaRC, and MSFC**
- **Partnership with the Agenzia Spaziale Italiana (ASI) for TIR**



NASA Surface Biology and Geology

Key requirements meets research and applications objectives

	Mission & Instrument Parameters	Threshold (11/28 observables fully met)	Baseline (16/28 observables fully met)	International Collaboration Shortens Revisit (26/28 observables fully met)
VSWIR	Spatial Resolution	40 m	30 m	30 m
	Temporal Resolution	22 days*	16 days	8 days*
	Spectral Resolution	20 nm	10 nm	10 nm
	Wavelength Range	400-2500	380-2500	380-2500
	Sensitivity (SnR)	300 (VNIR) / 200 (SWIR)	400 (VNIR) / 250 (SWIR)	400 (VNIR) / 250 (SWIR)
TIR	Spatial Resolution	100 m	60 m	60 m
	Temporal Resolution	5 days	3 days	~1 day
	Spectral Range	3 Bands + 1 MWIR	5 Bands+ 2 MWIR+ 1 VNIR	5 Bands+ 2 MWIR+ 1 VNIR
	Sensitivity (NedT)	0.4 K	0.2 K	0.2 K

Parts of some Decadal Survey Objectives require revisit more frequently than can be met within the cost cap.

International Synergies

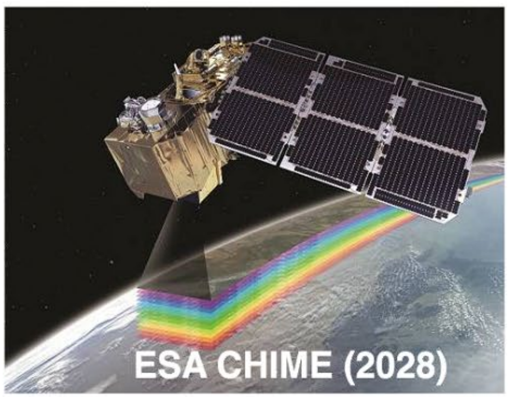
Objective: Interoperable data across the VSWIR and TIR from complementary missions

- No specific instructions in *Decadal Survey* but of interest to all agencies
- Informal coordination to create virtual constellations

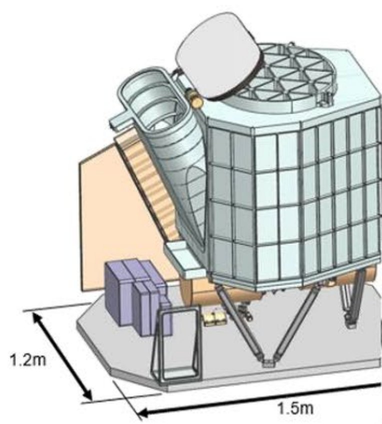
- SBG Lead: Chip Miller, JPL
- Crossover with Algorithms, Cal/Val, Modeling Working Groups, as well as SISTER and MEET-SBG Pathfinder activities

International Collaboration

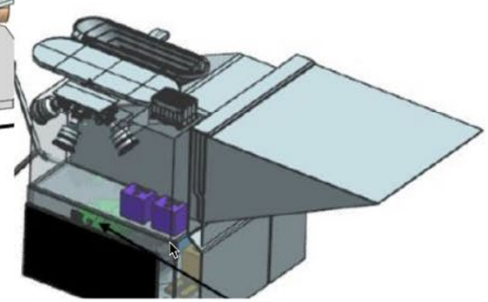
Improving 3 and 16 day revisit
Enhanced revisit by international data sharing



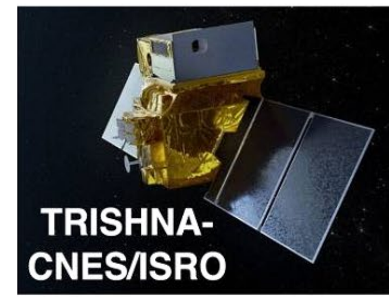
SBG VSWIR concept



SBG VSWIR + CHIME could achieve 8 to 11 day revisit or better



SBG TIR concept



SBG-TIR + LSTM + TRISHNA could achieve 1 to 1.5 day revisit or better

Field Campaign WG

- Goals: support mission concept development by scoping and executing SBG-led field campaigns and coordinating with other relevant field activities
- SBG High Frequency Timeseries
- Tracking/coordinating with ABoVE, BioSCape, SnowEX, HyTES Europe, ARCSIX, NEON AOP, CarbonMapper, etc
- Scoping potential campaigns to address/support:
  - Algorithm development/testing
  - Applications Early Adopters
  - Cal/Val prototyping and cross-calibration
  - Issues of scale
  - Synergies with other ESO missions




SBG Opportunities for Involvement

- In-person SBG community workshop in 2022 (Oct 12-14, DC area)
- Internship programs at JPL and other NASA centers:
  - Dave Schimel (dschimel@jpl.nasa.gov)
  - Ben Poulter (Benjamin.poulter@nasa.gov)
- SBG working groups: ongoing, regular meetings and seminars
  - Algorithms (kcawseni@jpl.nasa.gov)
  - Modeling (benjamin.poulter@nasa.gov)
  - Calibration/Validation (kturpie@umbc.edu)
  - Applications (christine.m.lee@jpl.nasa.gov
  - SHIFT (katherine.d.chadwick@jpl.nasa.gov)
- Email us (seriously we want to hear from you): sbg@jpl.nasa.gov
- Join the conversation at the SBG Community Slack

Future EO data and Remote Sensing of Vegetation Function

- EOS era (MODIS etc.) coming to an end
- **Global capability of Landsat and Sentinel 2 products at mid-resolution** (VISWIR + TIR 10m<30m<60<90m)
- Current and forthcoming NASA, ESA, DLR, ASI and other Hyperspectral missions **DESIS/ISS, PRISMA, SBG, CHIME, EnMAP**
  - Estimate vegetation cover (LAI) and/or chlorophyll content (Cab)
  - Dynamics (seasonal phenology, land use change etc.)
  - Productivity (NPP)
  - Disturbance (from drastic to gradual change detection)
- What does LAI or Cab at 5≤30 m mean?
  - Heterogeneity/mixed pixels
  - New abilities to validate the RS estimates
  - Combine multi-scale measurements – fine scale in some places, scale up across wider areas….

Děkuji ☺ !

This hands-on practical on *Spectroscopy for vegetation function* and the lab data and tools are available at the link below:
https://drive.google.com/drive/folders/13J33JnHM78eXiGnLL9iu_tHQ4UBwluL9?usp=sharing

1) Reflectance of leaves (ASD probe) and canopies (AVIRIS NG)
2) Vegetation index calculator
3) Sensor response function (SRF) calculator

E-mail with questions

petya@umbc.edu

Workflow for RS of Vegetation Function and Stress Detection

- Acquire sufficiently high spectral resolution VSWIR Time Series
- Atmospheric Corrections
- Canopy vegetation fraction, BRDF, sun/shade - normalization
- Derive and apply relationships to retrieve TOC Chl and Water, Lignin, Cellulose, N
- Diurnal & Seasonal Characterizations – according to dynamics

Using reflectance – seasonal trends in pigments and chemistry

- Estimate Photosynthetic Efficiency & GPP
  - Validation against ground measurements
- Retrieve SIF in O_2-A, O_2-B, and other solar or telluric lines, evaluation against ground measurements. *SIF at high-PAR – use to compare trends in photosynthetic efficiency and detect stress.*
- Retrieve LST (TIR, ET-modeling)