SPECTROSCOPY @ LEAF & CANOPY SCALES

Remote Sensing of Vegetation Function and Photosynthesis

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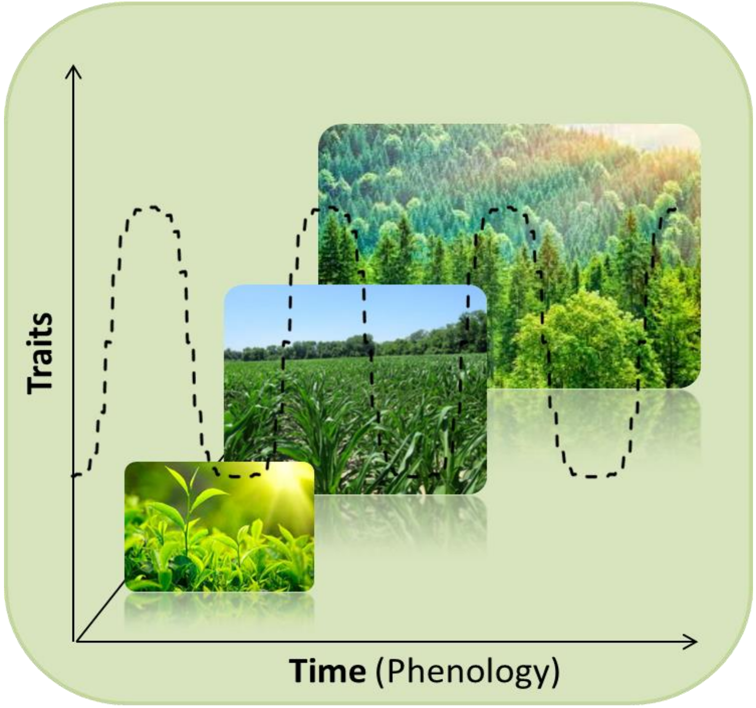

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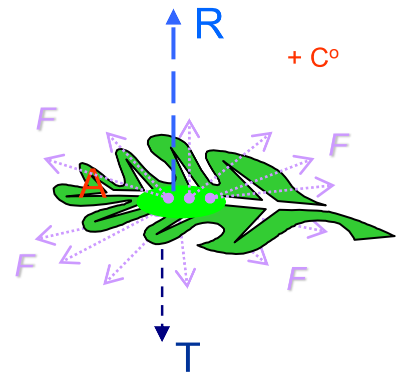
Outline

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

- Electromagnetic energy emissions are generated by several mechanisms
  . Changes in the energy levels of electrons
  . Acceleration of electrical charges
  . Decay of radioactive substances
  . Thermal motion of atoms and molecules



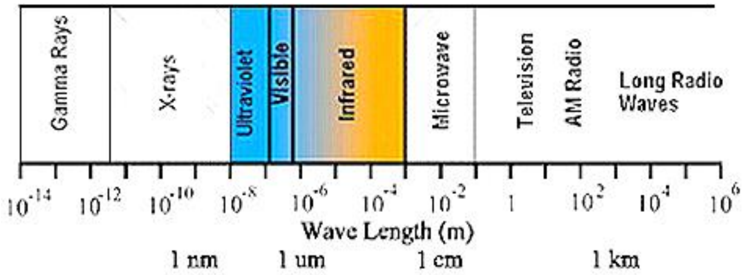
Major Regions of the Electromagnetic Spectrum

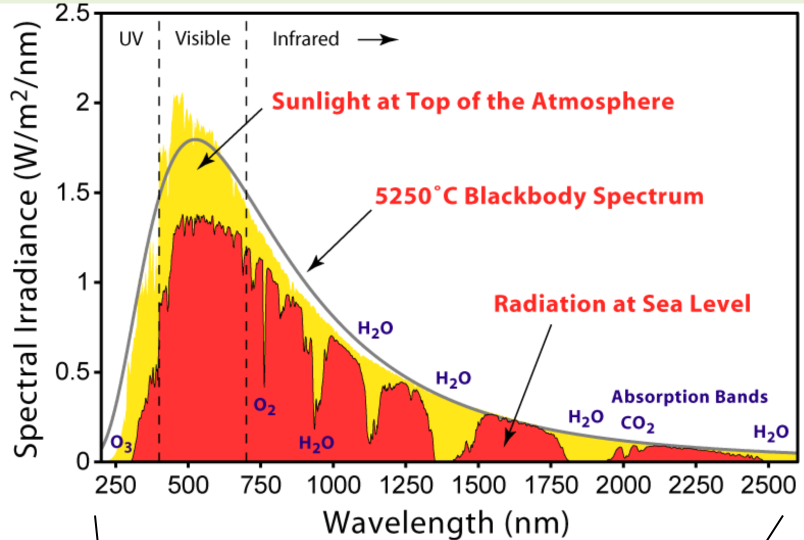
High Energy Light	
Gamma Rays (γ)	<0.03 nm
X-Ray	0.03 – 300 nm
Ultra Violet (UV)	300 – 380 nm

Infrared *	
Near (NIR)	0.72 – 1.30 µm
Shortwave (SWIR)	1.30 – 3.00 µm
Far, Longwave or TIR	4.00 – 1000 µm

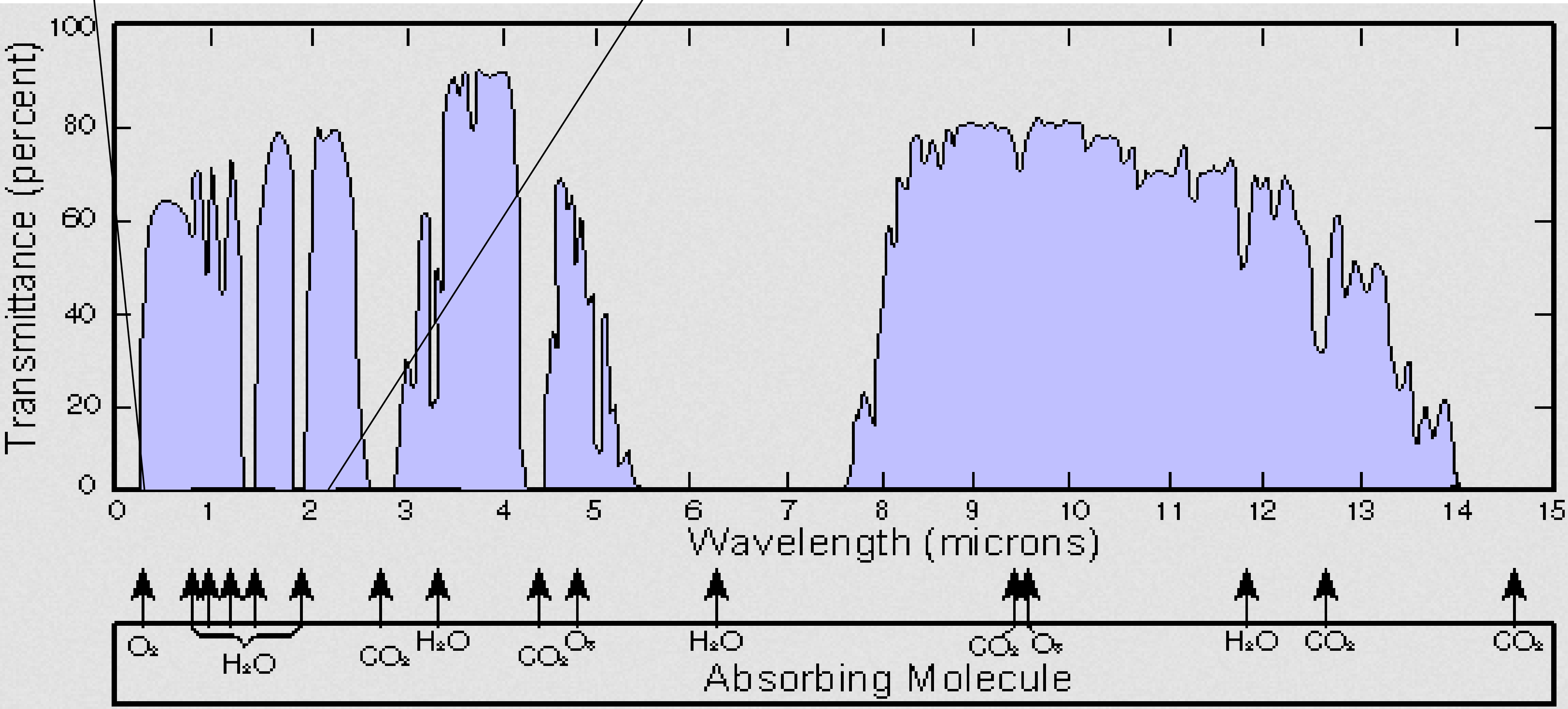
Visible Light *	
Blue	380 – 500 nm
Green	500 – 600 nm
Red	600 – 720 nm

Low Energy Light	
Microwave	1000 – 300,000 µm (1mm- 300 mm)
Radio	> 3,000,000 µm





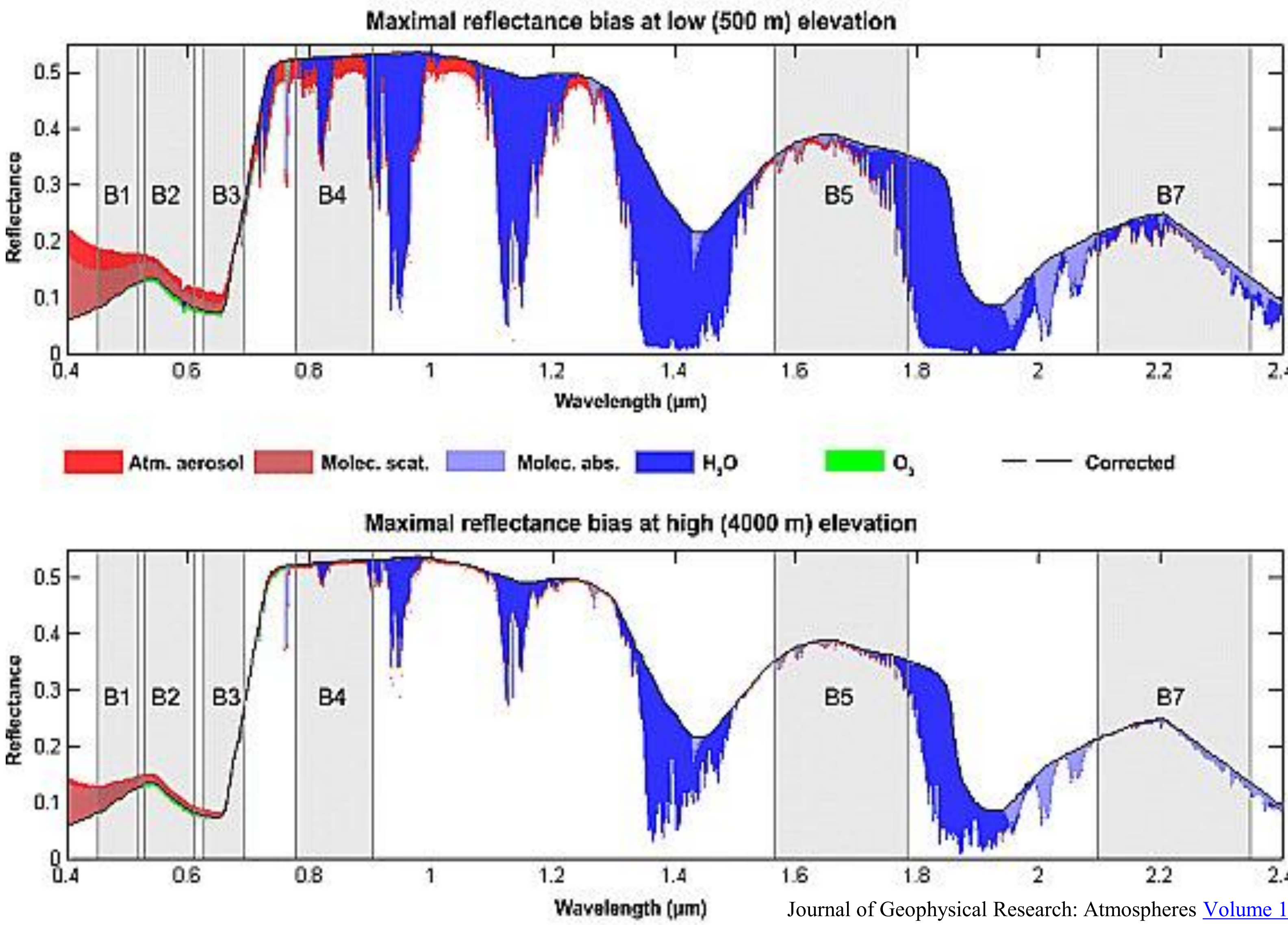
Earth's atmosphere is a continuously changing filter that modifies the sunlight that travels through it.



Types of Remote Sensing

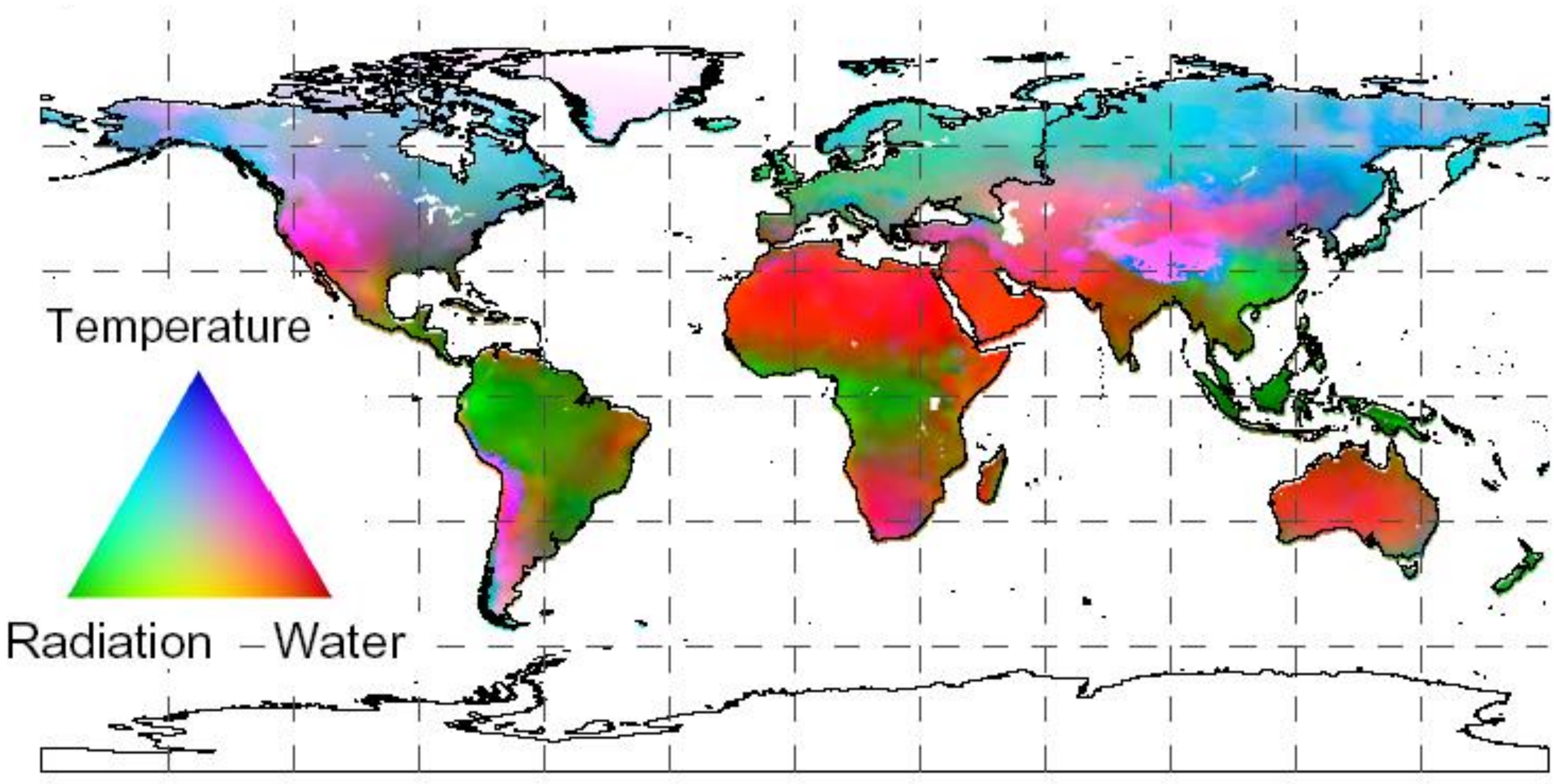
Electromagnetic Wavelength (μm)		Passive Systems	Active Systems
0.1 - 0.4	Ultraviolet (UV)		
0.4 – 0.7	Visible	**Airborne Cameras**	LIDAR
0.7 – 1.4 1.4 – 3.0	Near-Infrared Shortwave Infrared	**Radiometers** **Spectrometers**	
3.0 – 1,000	Infrared		
1,000-300,000	Microwave		Radar (SAR)

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

Limiting Factors of Vegetation Photosynthesis

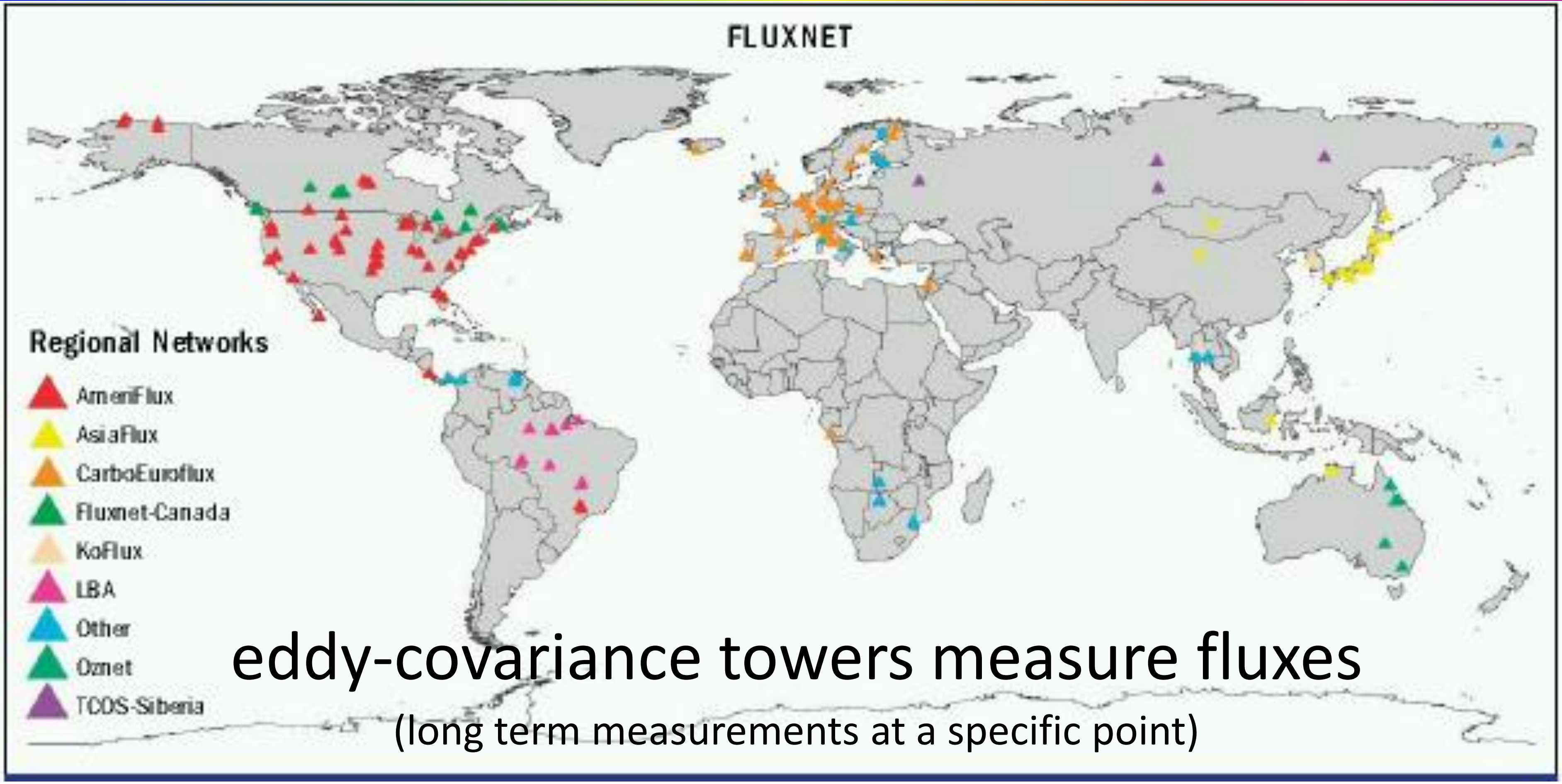


Total vegetated area: 117 M km2

Dominant Controls
water availability 40%
temperature 33%
solar radiation 27%

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

Canopy photosynthesis - how is it measured?

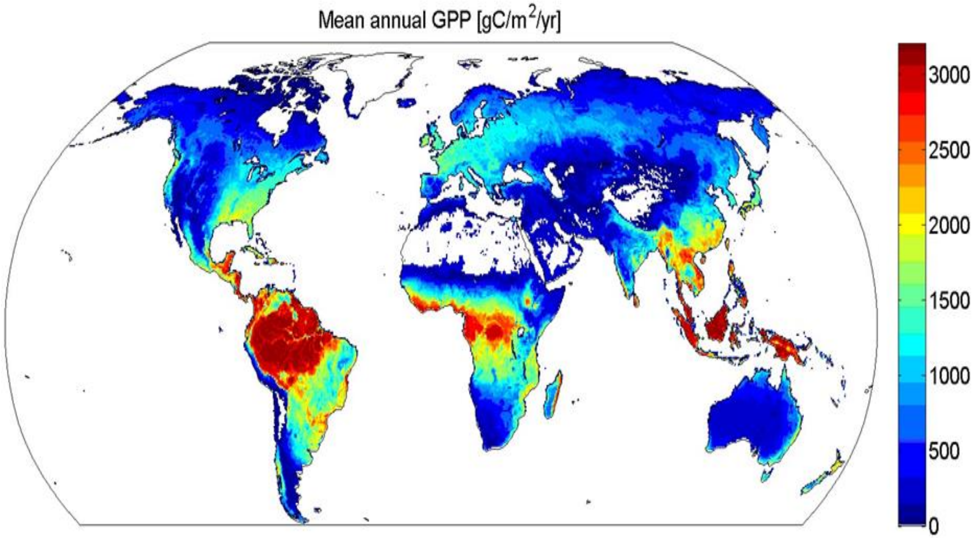


eddy-covariance towers measure fluxes

(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)

Linking Vegetation Function & Remote Sensing Spectroscopy



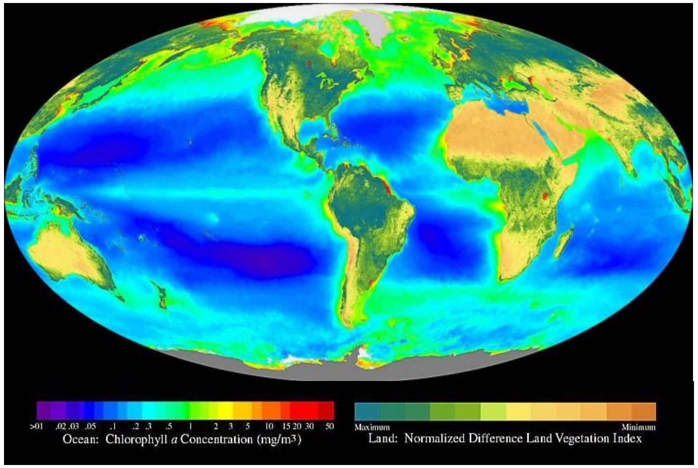
Small changes in photosynthesis (GPP) cause great variations and uncertainties in the carbon exchange and balance

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

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

Linking Plant Physiology and Remote Sensing

What are we observing and when?

Vegetation traits and spectra (reflectance and SIF) have:

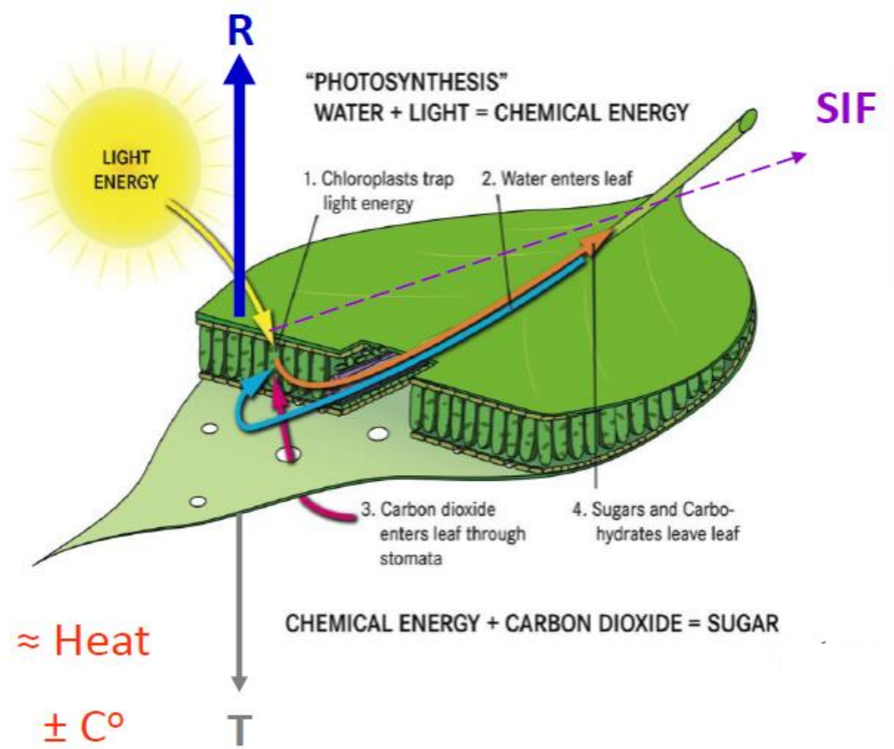
- *Diurnal cycle, and*
- *Seasonal cycle*

Vegetation function (*gradient of 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)

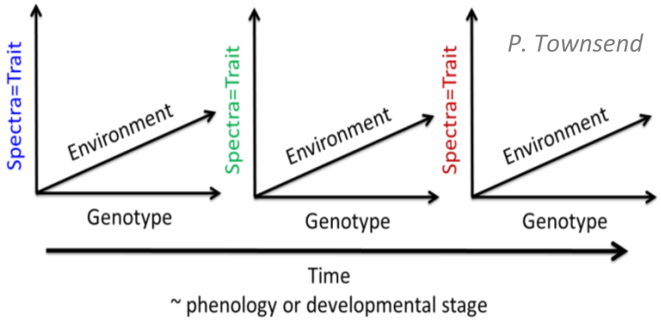


"Photosynthesis" from ESA/FLEX final report, 2015. Modified adding reflectance, transmittance, heat and fluorescence (P. Campbell, 2015).

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



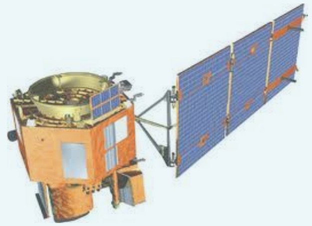
- Photosynthesis – diurnal and seasonal variations
- Canopy chlorophyll and photosynthetic biomass – seasonal changes

Objectives:

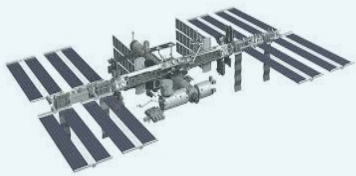
1: Identify optimal spectral resolution to characterize vegetation function and its diurnal and seasonal dynamics

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.

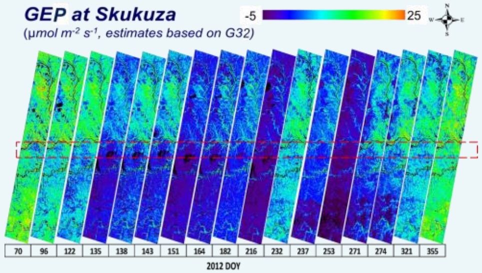


Orbital (@ ~ 700 km) Global spatial extend, **systematic** repeat for time series (TS)



Space station(@ 400 km)

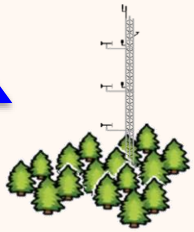
Spatial coverage, repeat



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

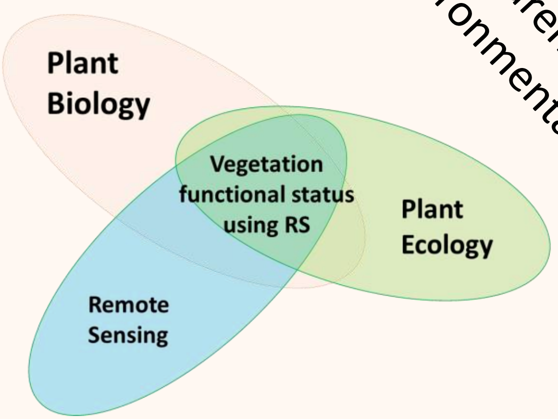
Consistent spectral measurements across ALL spatial scales and environmental conditions

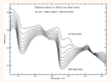
UAV (@ 10 – 120 m) Spatial coverage & TS site & region



Automated/Fixed Tower (@ 10 - 120 m)

canopy/site, TS

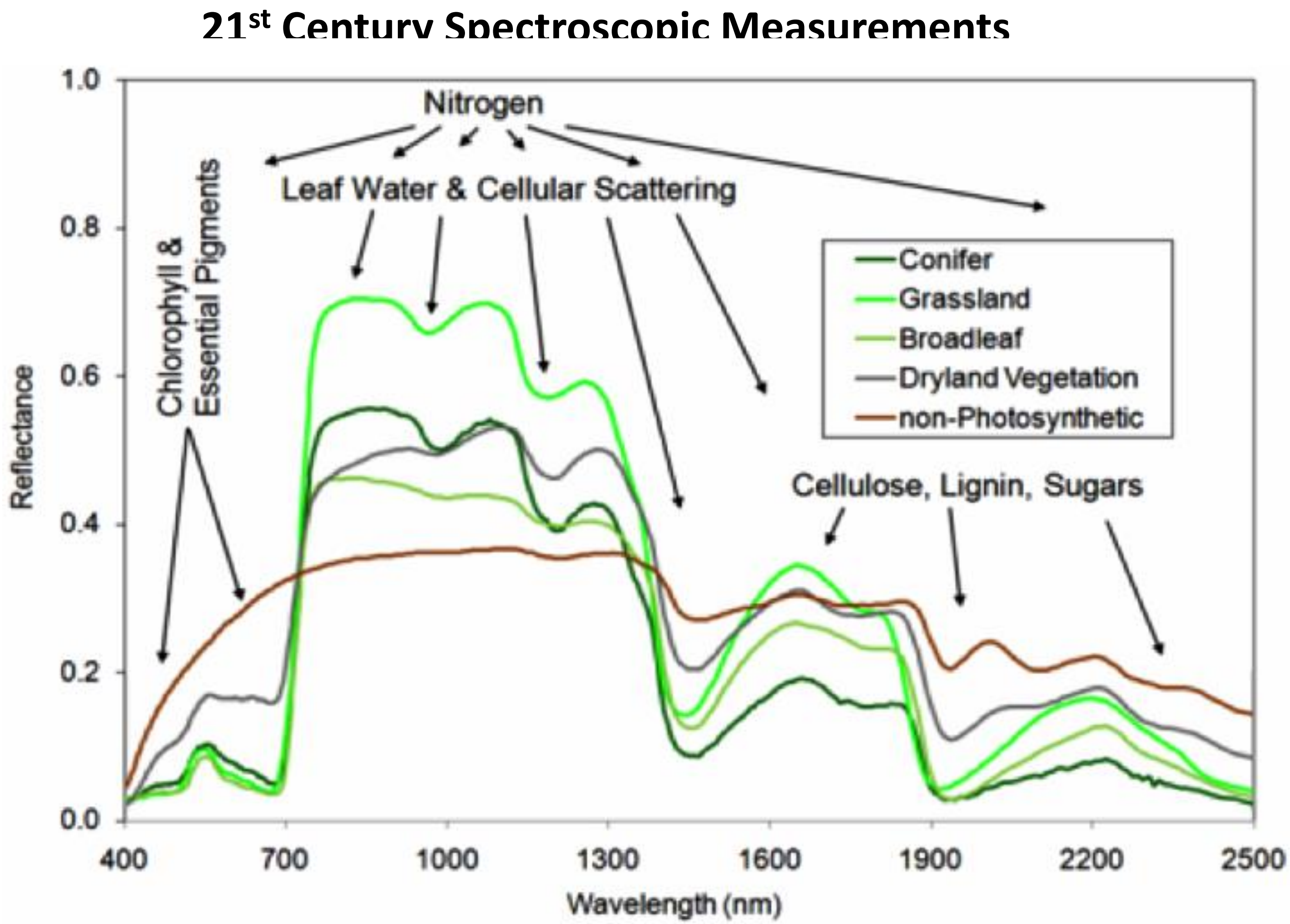


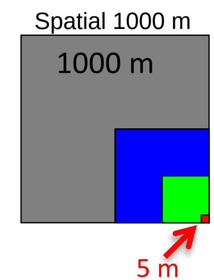


Leaf - canopy (@ ~ 10 m)

leaf – canopy – site consistent TS

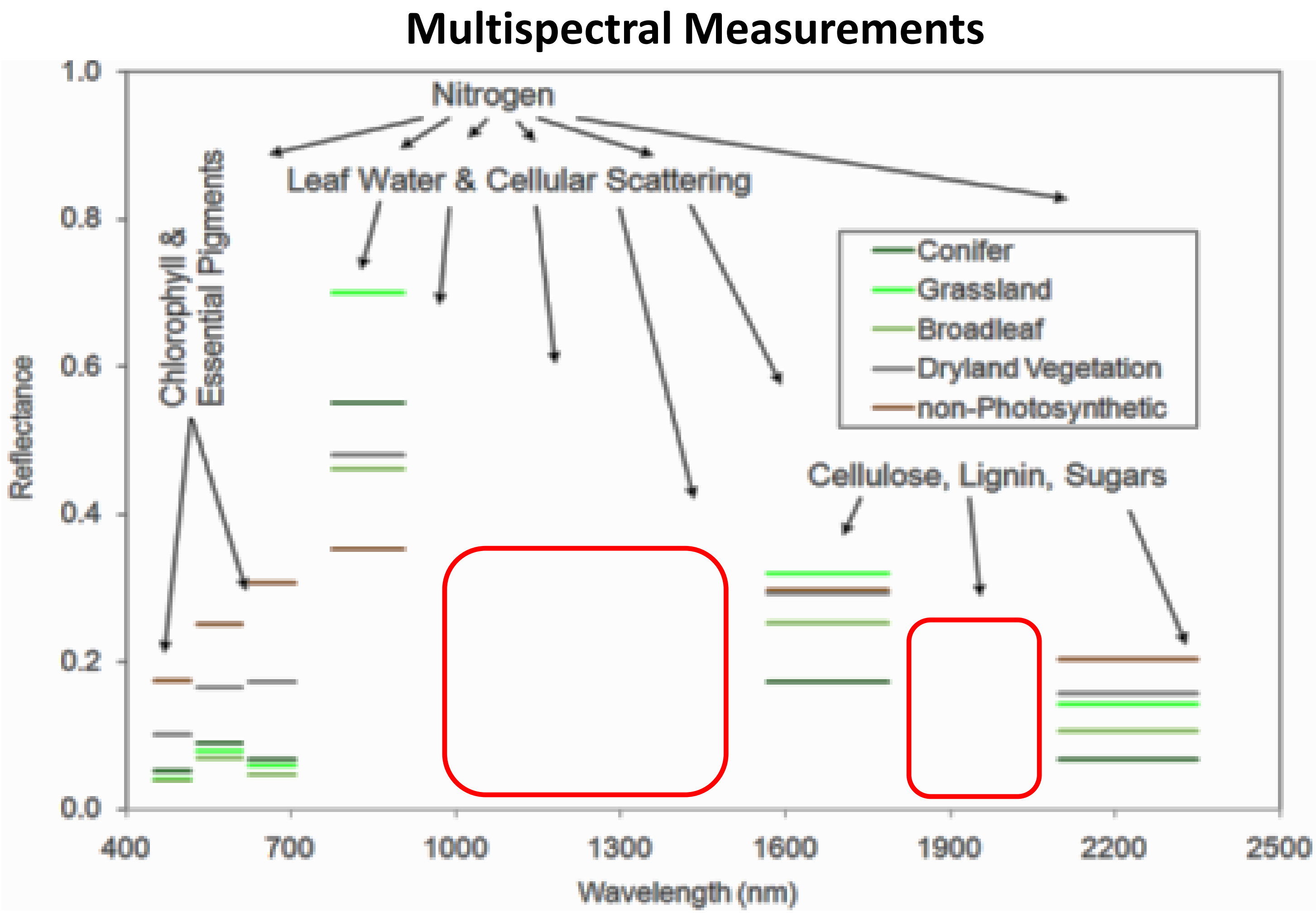
Spectral Measurements Required for Global Ecosystem Function Assessments





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

Differences between multispectral and hyperspectral RS data



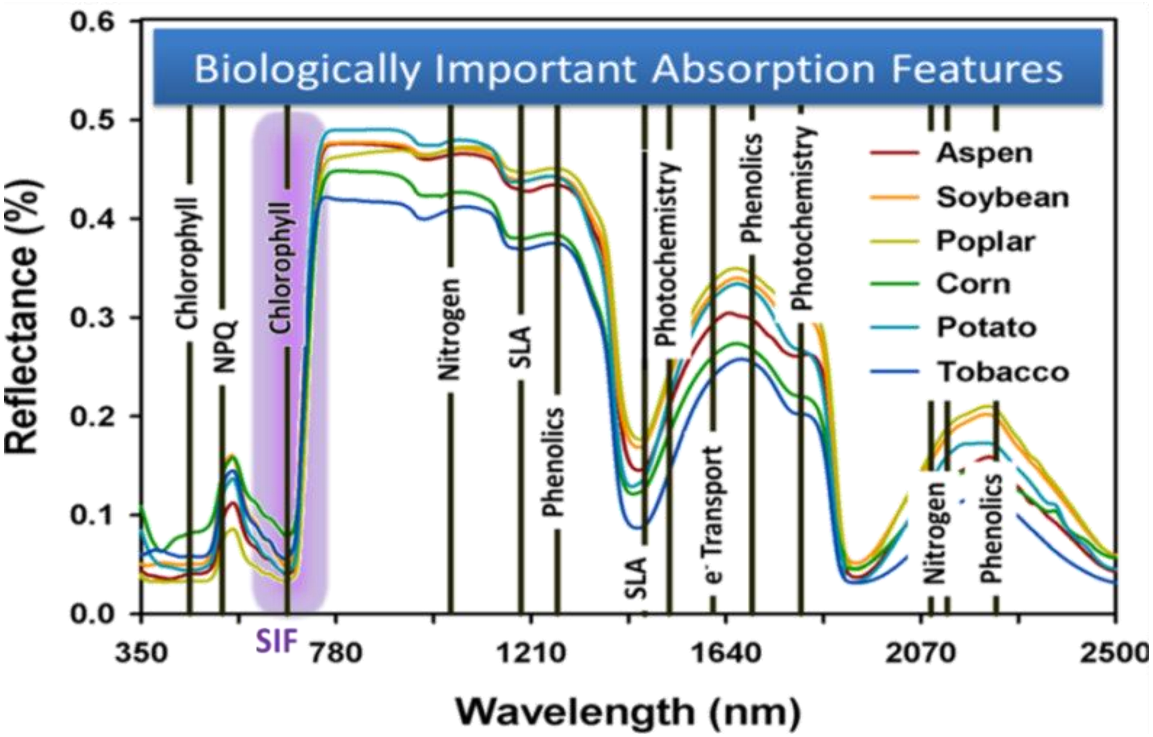
Multi-spectral imaging is insufficient to accurately derive the required terrestrial surface compositional parameters.

Green et al. 2011

Spectroscopy Use for Vegetation Function

VSWIR Reflectance Spectroscopy (R, %; feature analysis and indices/VIs):

- VNIR: chlorophyll and nitrogen content (red edge; PLSR)
- NIR: water content, specific leaf area (SLA) (NDWI)
- SWIR: lignin, cellulose, N, Phenolics
- VSWIR: photosynthetic function (PRI, PLSR), water content (liquid water), canopy vigor and structure (features, derivatives D705/D714



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

Deriving Canopy Traits with Continuous Reflectance – *VNIR Examples*

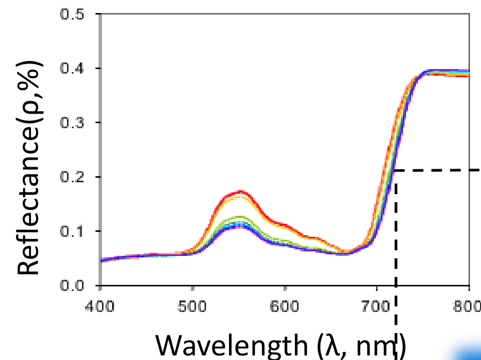
No prior knowledge

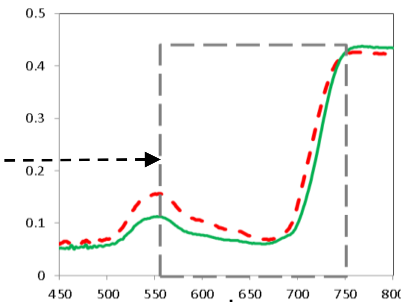
- Continuous spectra
  - reflectance
  - Fluorescence (SIF)
  - derivatives, derivative VIs
- Spectral features (e.g., PRISM)
  - continuum removal

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

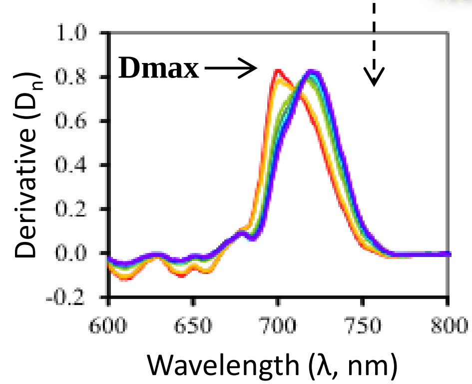
Some prior knowledge

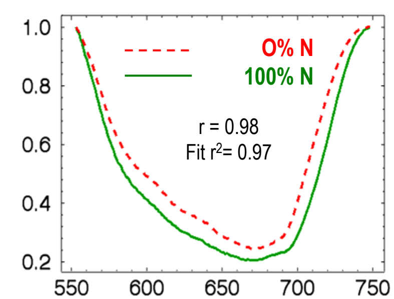
- Discrete Vegetation indices (VIs)
- Temperature estimates
- Models - PLSR, RTMo





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



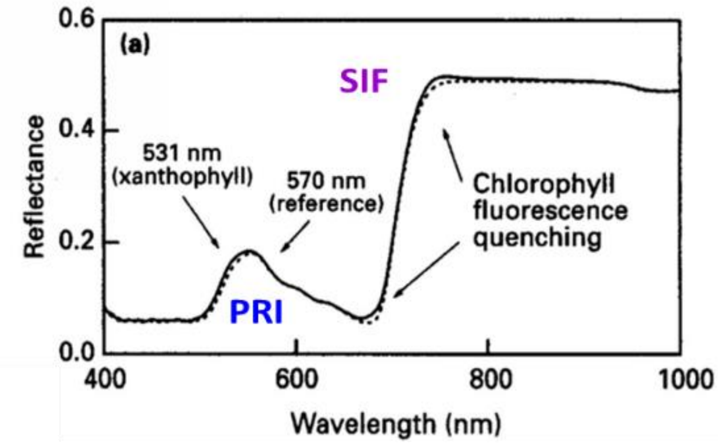


0% N, feature FWHM = 129.33, Area = 93829
100% N, feature FWHM = 141.92, Area = 102911

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}

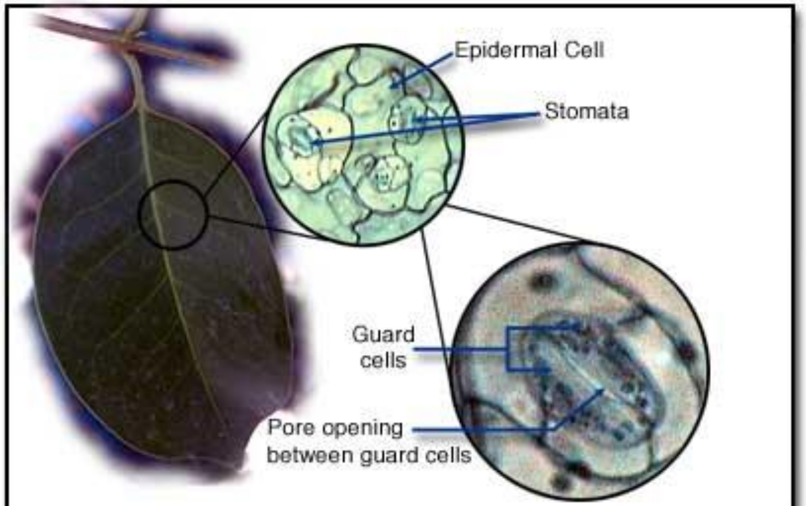
• anthocyanins

- 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:

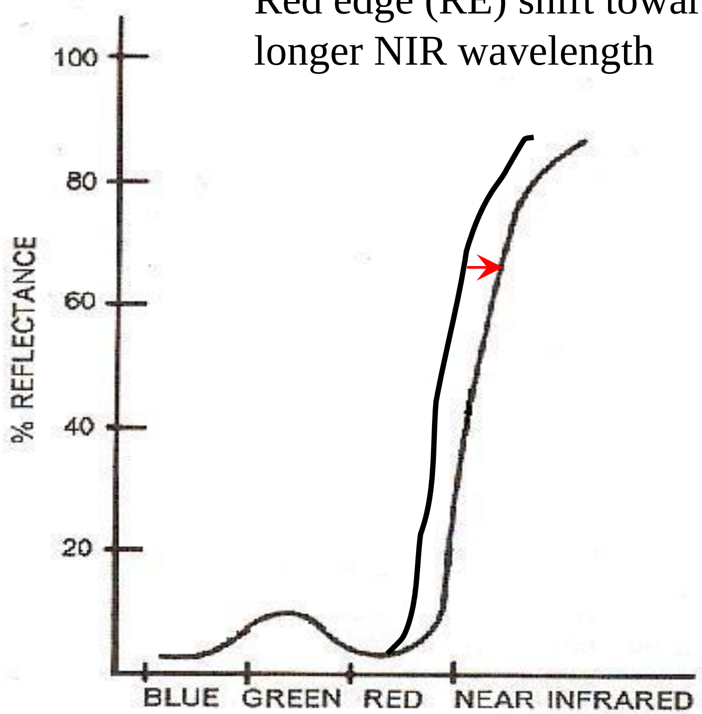
Dr. L. Kupkova and Jana Albrechova, Charles Univ. Prague

Red and Blue Shift of the Chlorophyll Absorption Edge

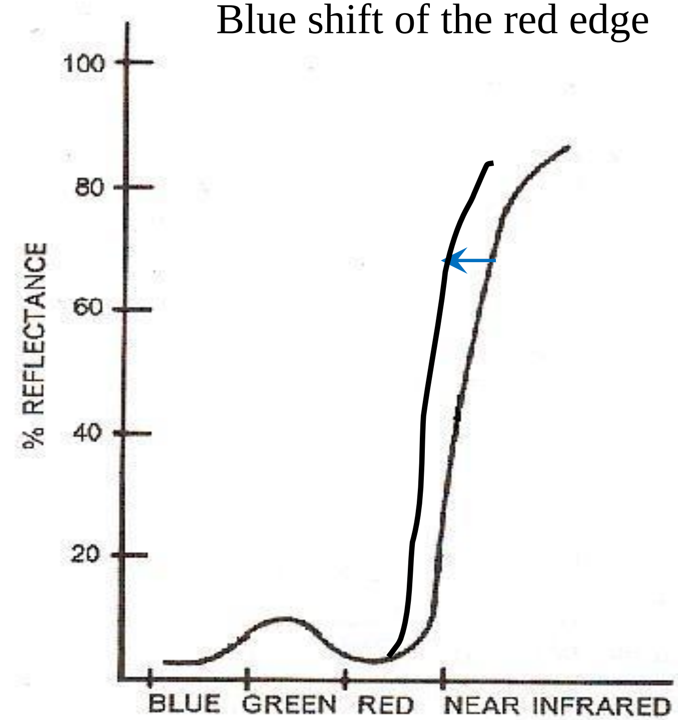
- As leaves mature, the amount of chlorophyll in the foliage increases and the absorption edge of the chlorophyll shifts towards longer NIR wavelength
- As plant stress in plant tissue increases, the absorption edge shifts toward shorter wavelength

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

Red edge (RE) shift toward longer NIR wavelength

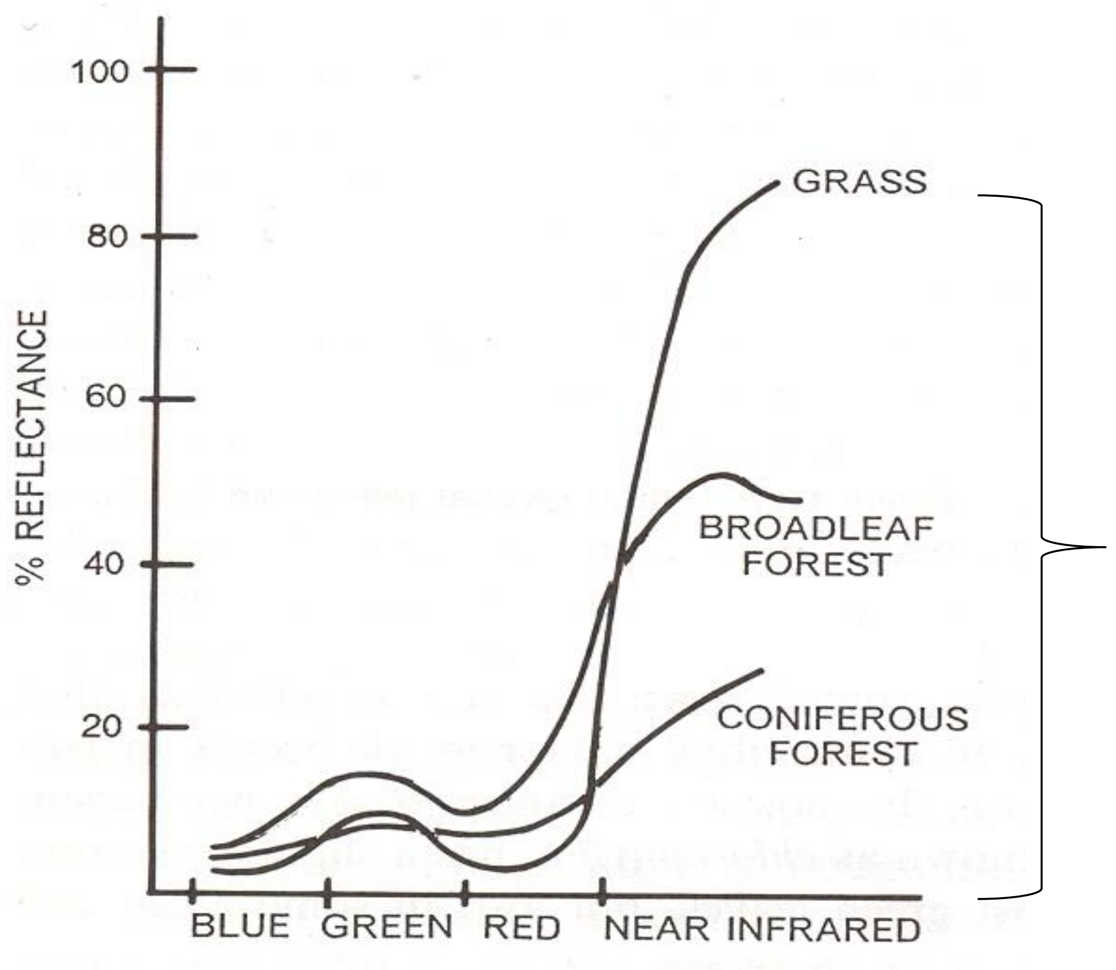


Blue shift of the red edge



Near IR Grass > Broadleaf > Coniferous

High Reflection due to Spongy Mesophyll Tissues



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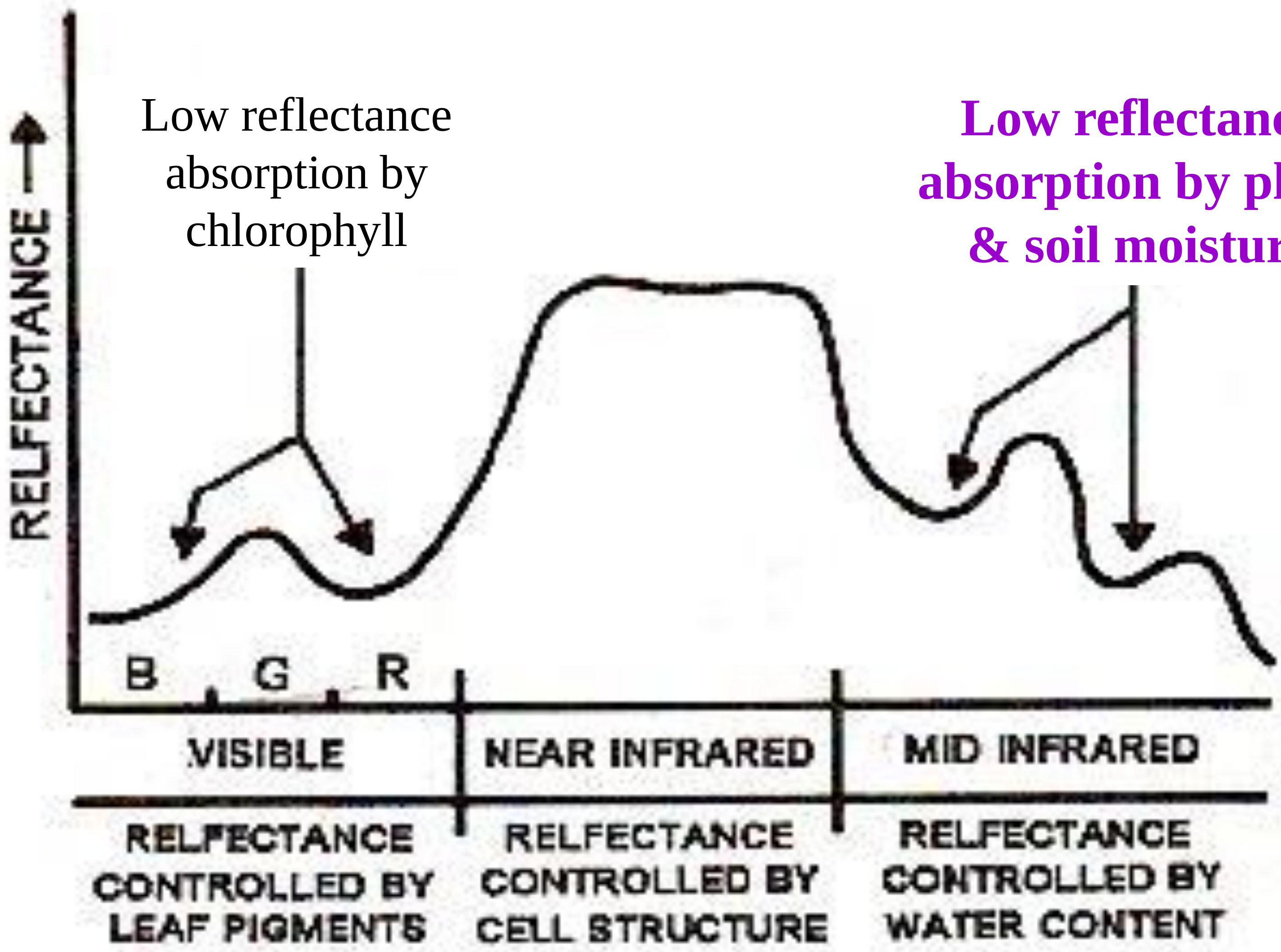
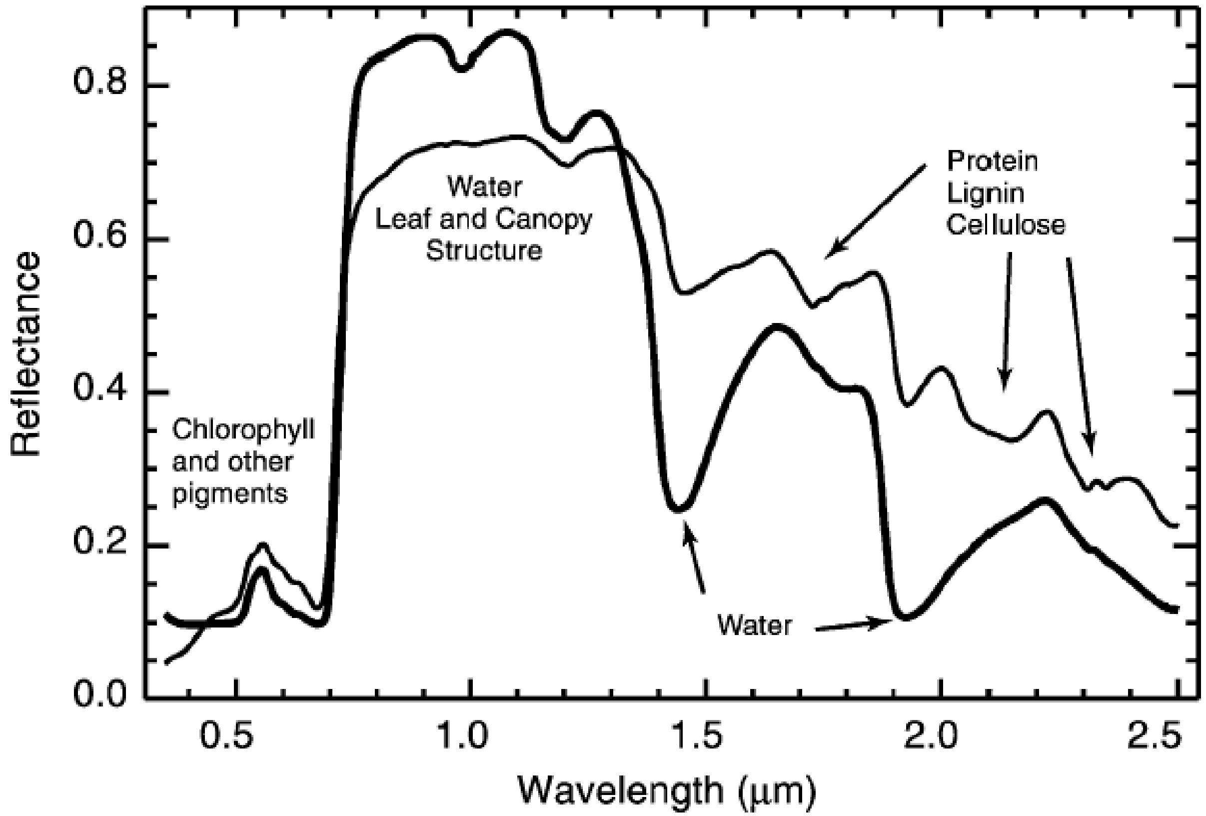
Mid IR (band 5,7 of Landsat)



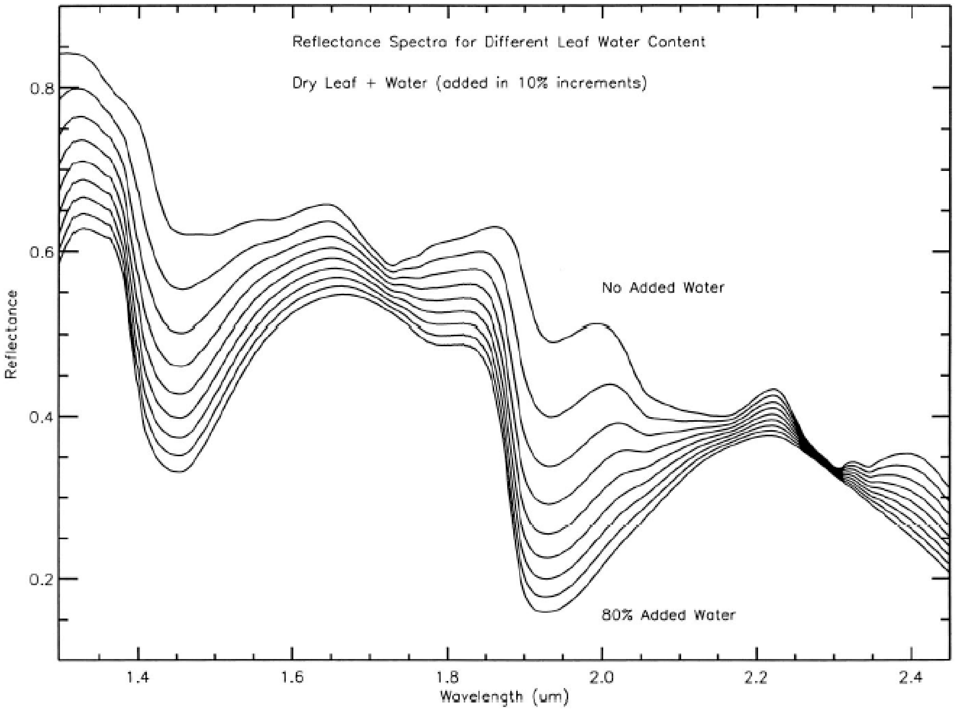
NSWIR Spectroscopy of Vegetation biochemical composition

- 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

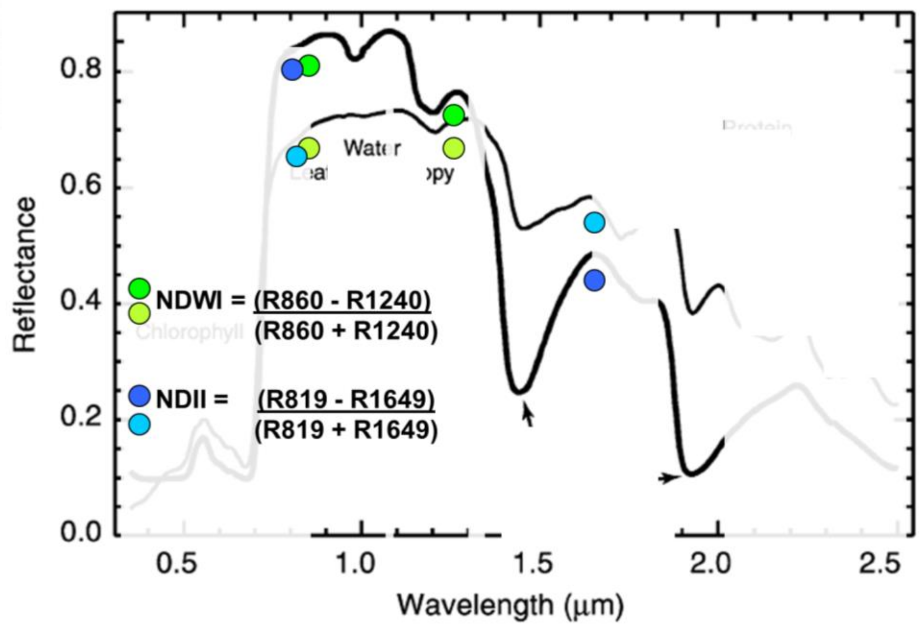


Features sensitive to Vegetation Water Content:

- R1240
- R1649

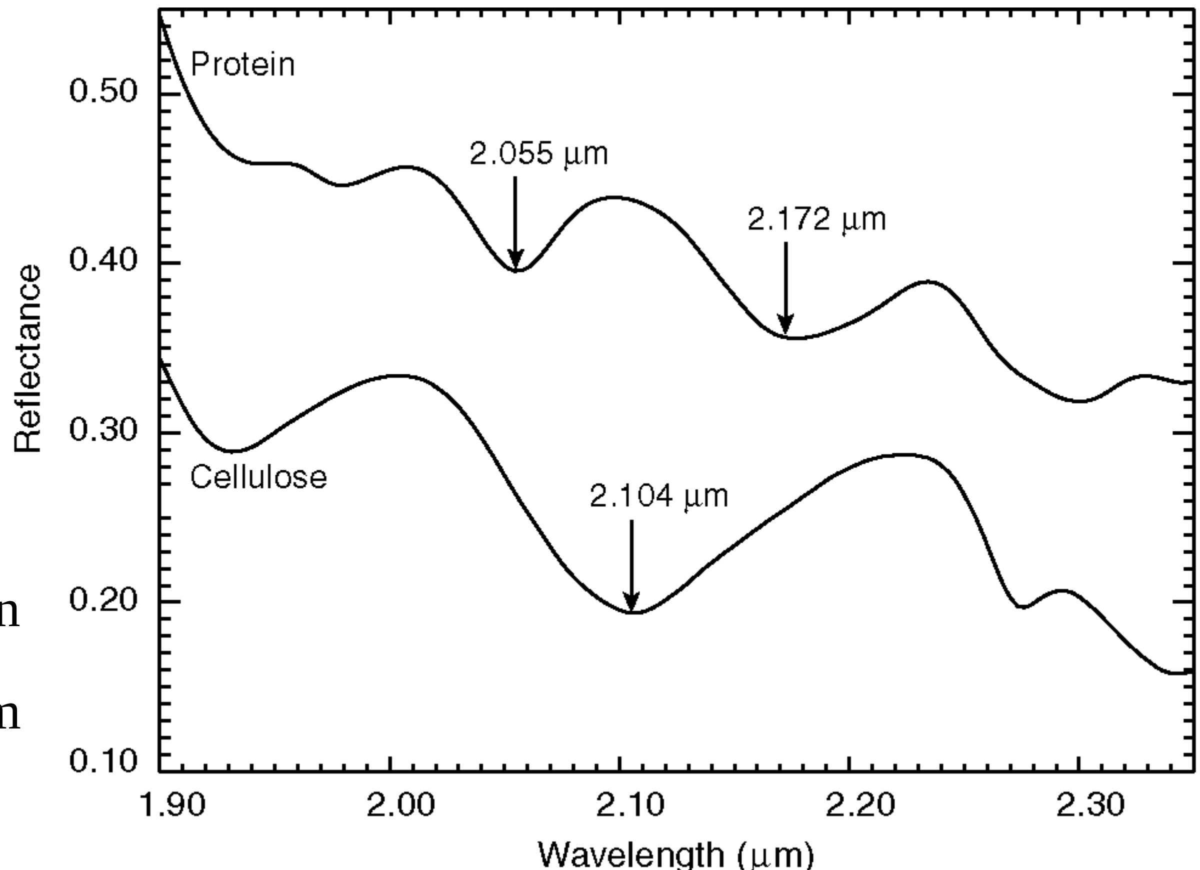
In-sensitive bands: 860 nm and 819 nm

- 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

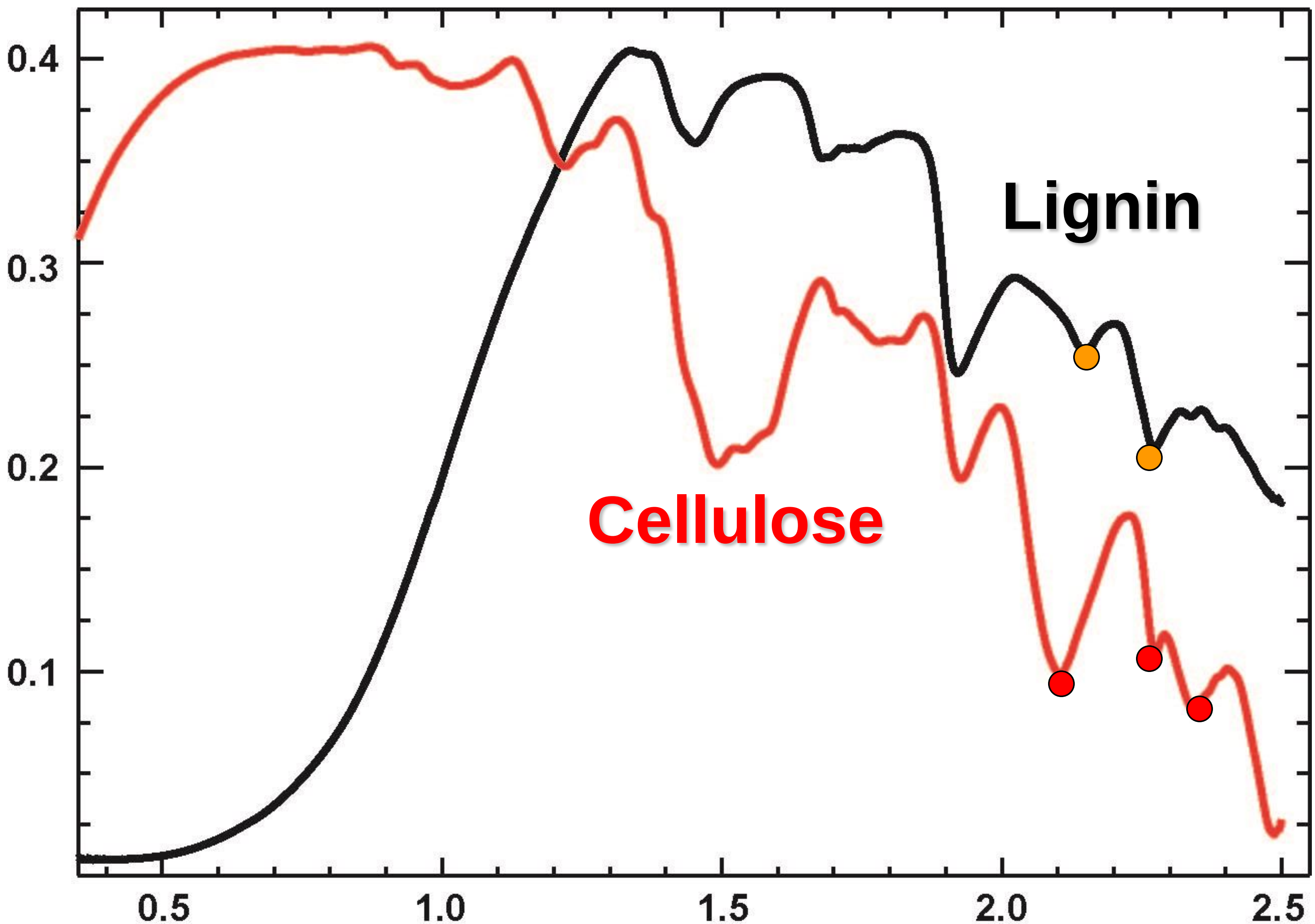


Structural Biochemical Compounds

- **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



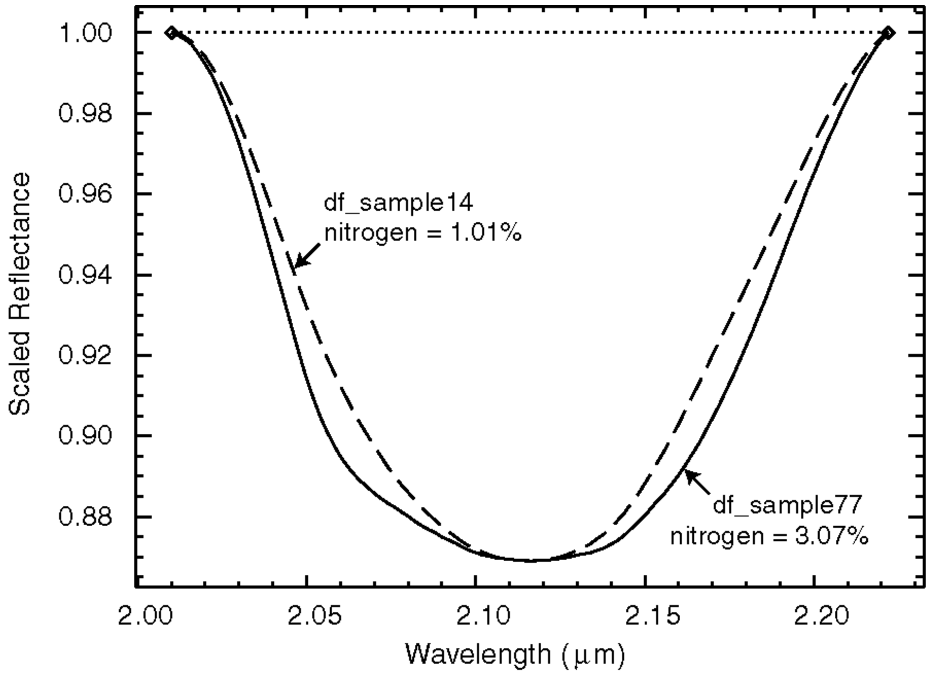
Kokaly, REMOTE SENS. ENVIRON. 75:153–161 (2001)



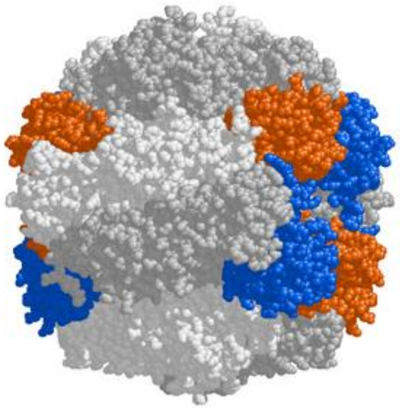
0.4
0.3
0.2
0.1
0.5
1.0
1.5
2.0
2.5
Lignin
Cellulose

Nitrogen

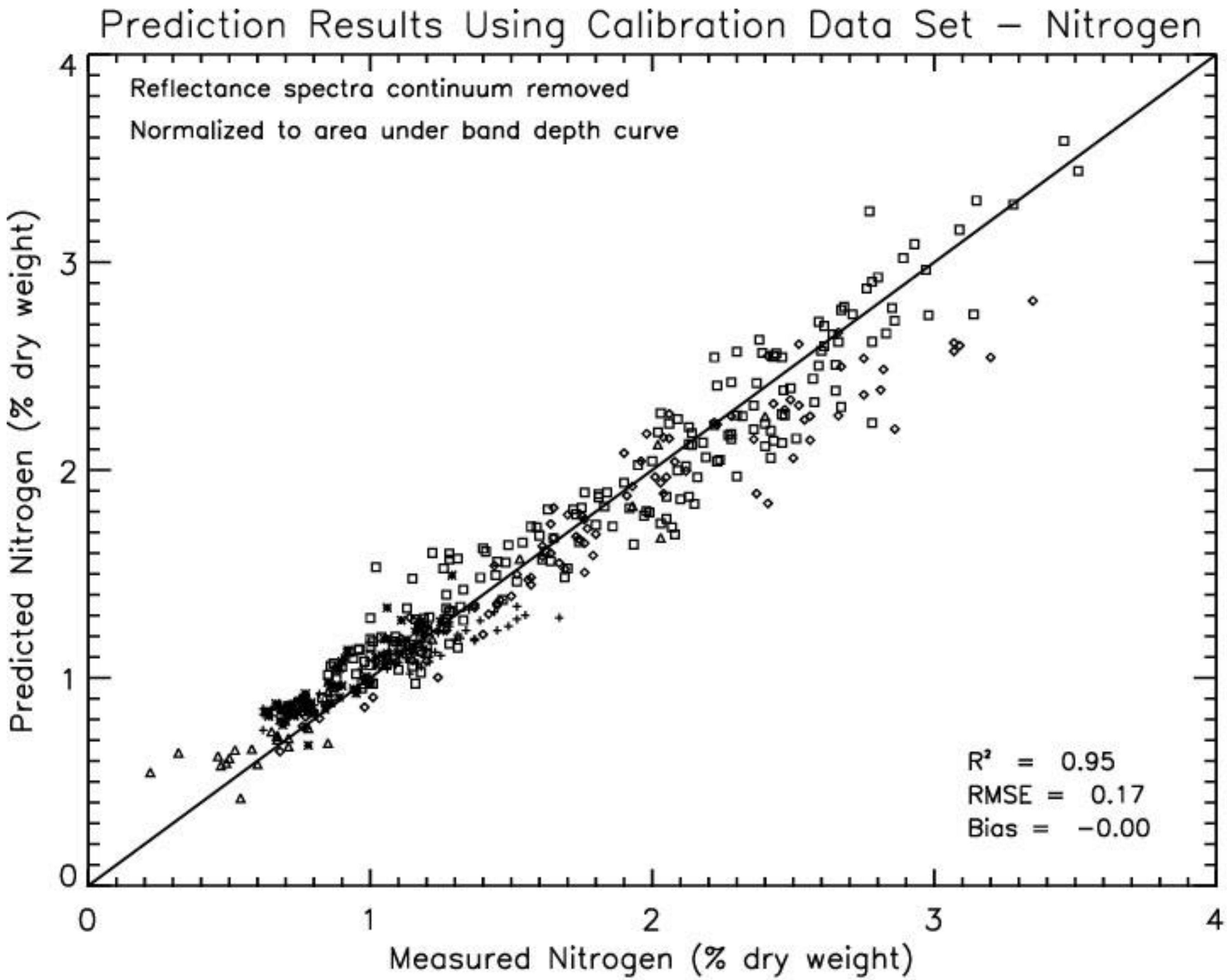
- By dry weight, very low abundance in leaves, only 0.5-4%
- Present in important biochemical constituents of plants
  - Chlorophyll
  - Protein
- Linked by field studies to rates of ecosystem functioning (carbon fixation) and widely used in ecosystem models



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

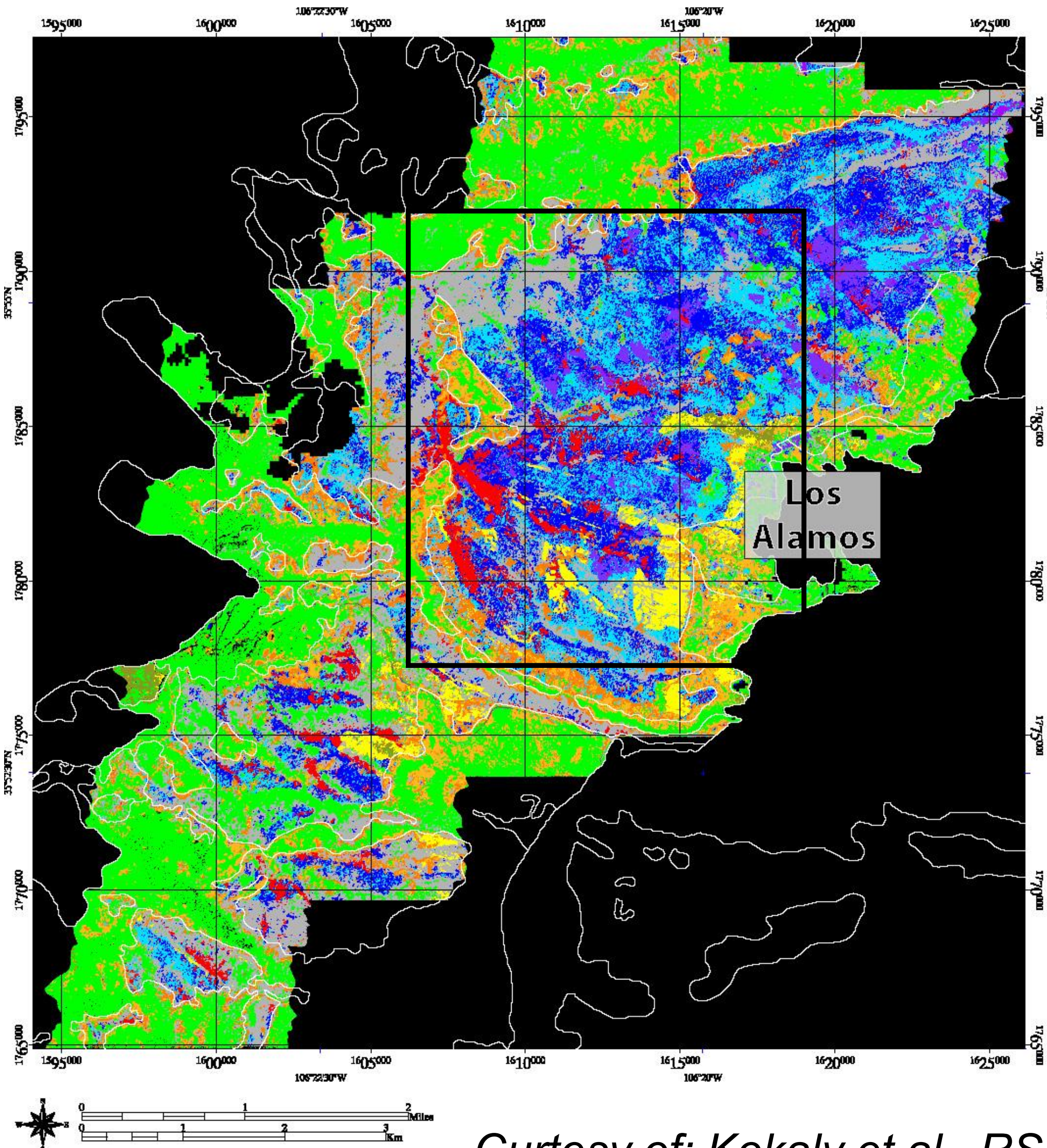


Ribulose-1,5-bisphosphate carboxylase/oxygenase, catalyzes the first major step of carbon fixation.
RuBisCO is the most abundant protein in leaves (maybe the most abundant on Earth).



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

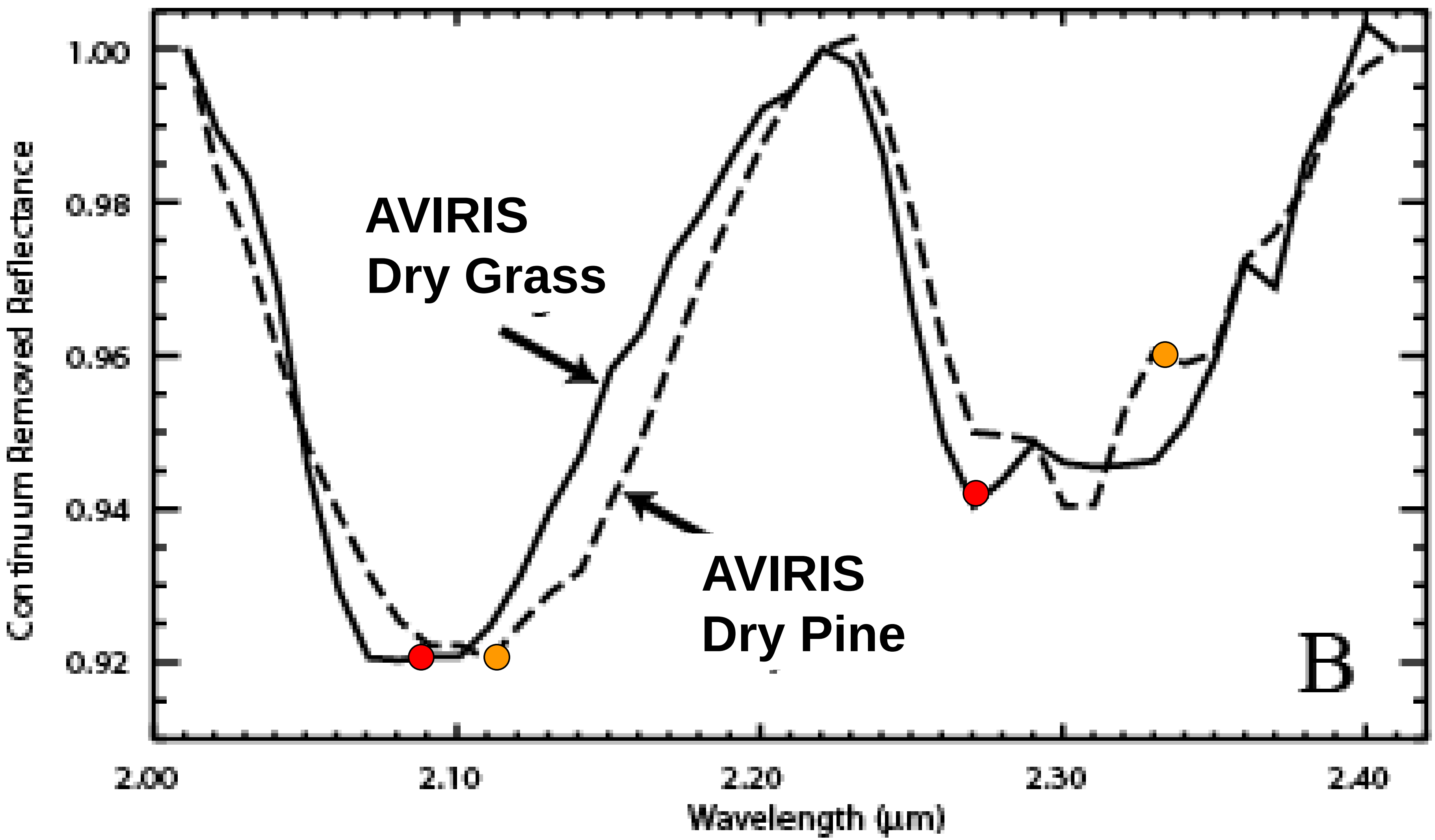
Results: AVIRIS Maps



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

Curtesy of: Kokaly et al., RSE

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



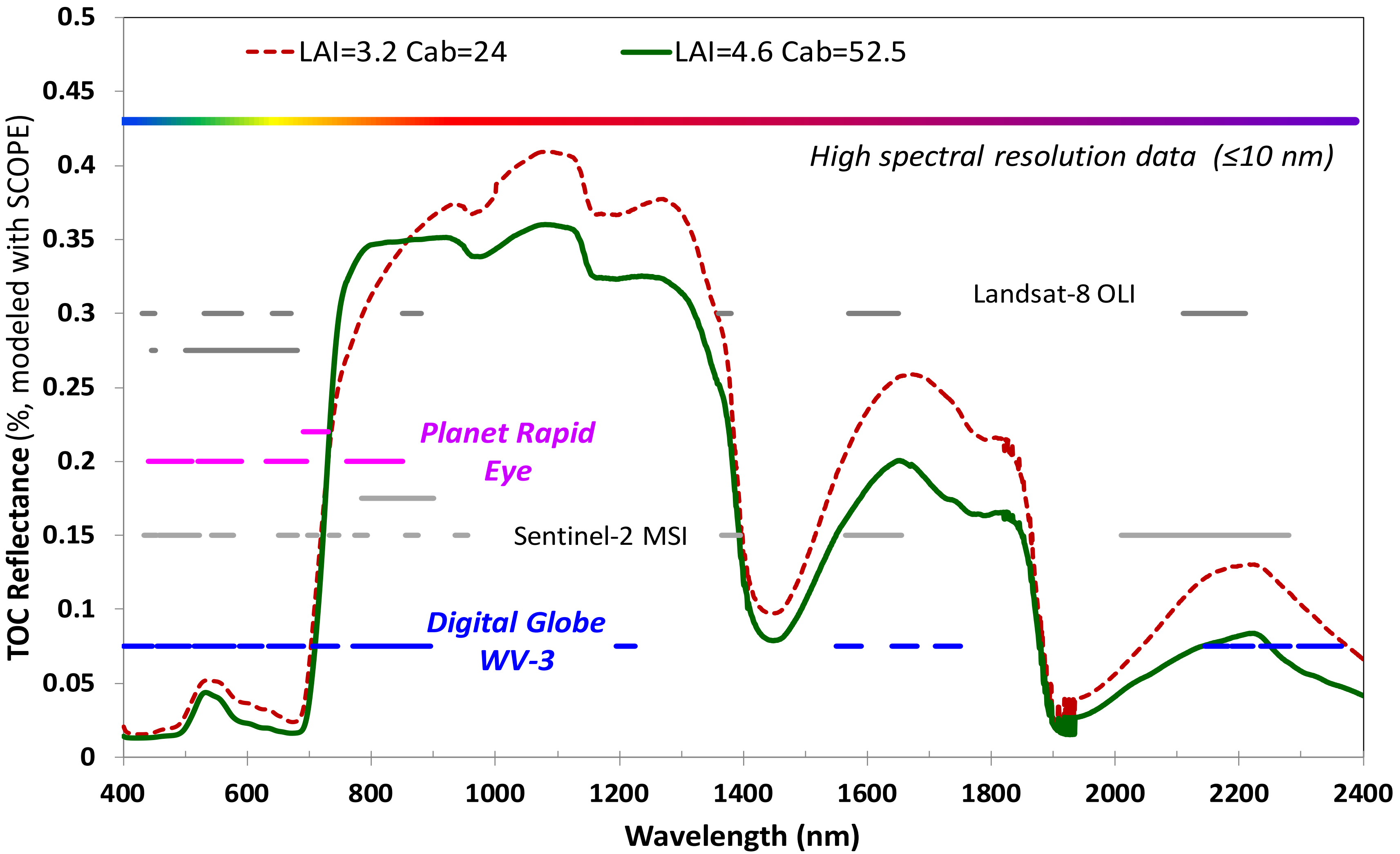
Kokaly et al., Remote Sensing of Environment

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

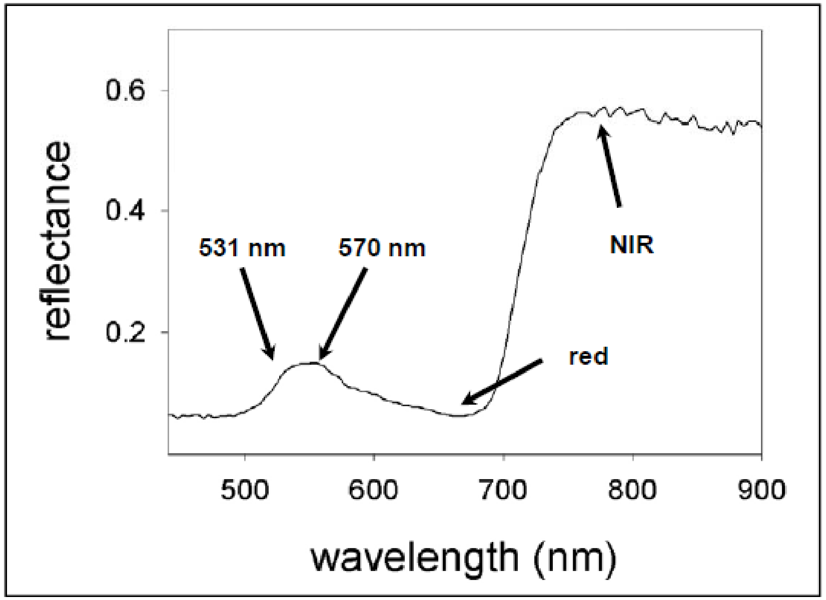
- SR (Simple ratio): correlation with chlorophyll content or leaf area index
- NDVI: correlation with chlorophyll content or leaf area index
- PRI (Photochemical Reflectance Index): correlation with photosynthetic efficiency

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

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

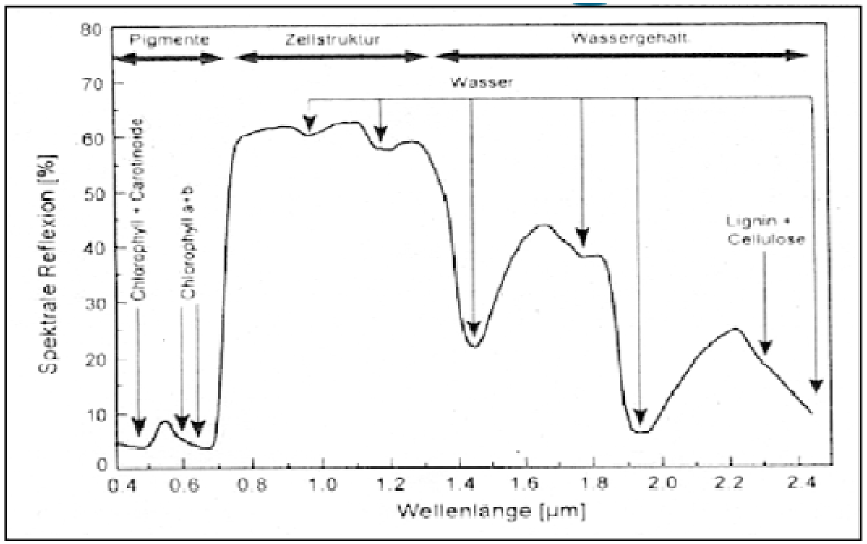
$$NDVI = \frac{R_{780} - R_{670}}{R_{780} + R_{670}}$$

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



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)

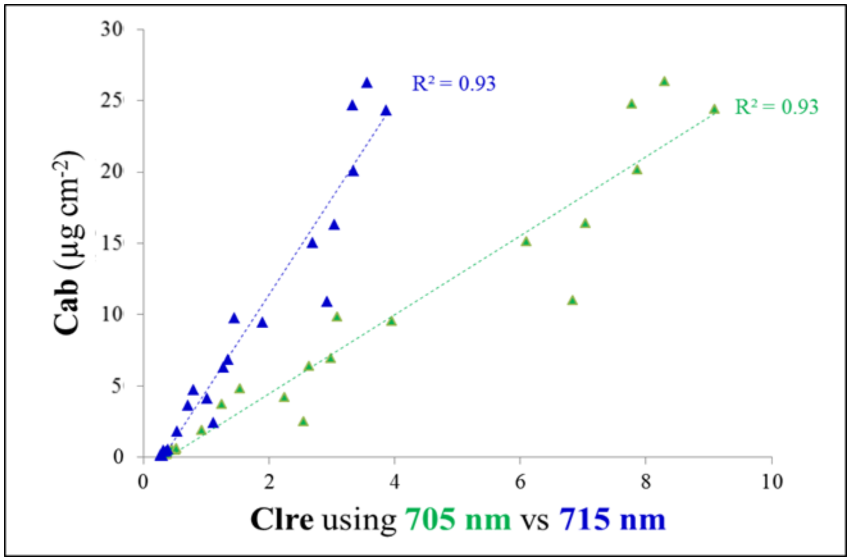
ARI1 / ARI2: Anthocyanin Reflectance Index (yellow and red spectral region, correlates with anthocyanin / chlorophyll ratio)

NDWI: Normalized Difference Water Index (canopy water content)

Importance of RE Bands for Chl Detection with VIs

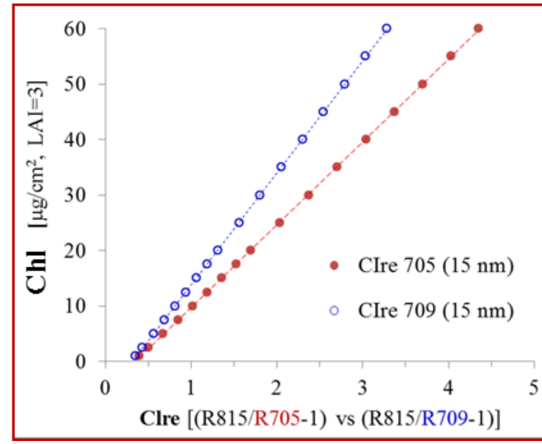
EO-1 Hyperion, OPE3

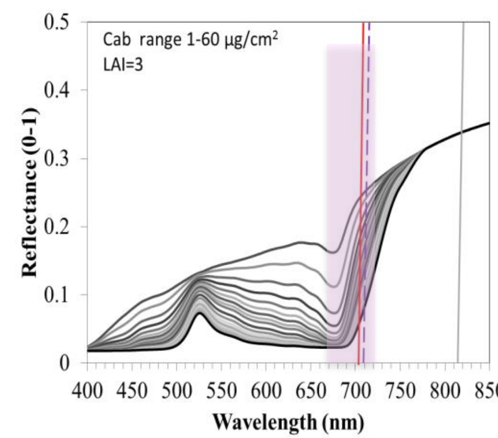
Cl_{re} = (R815/R705 - 1)



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.**

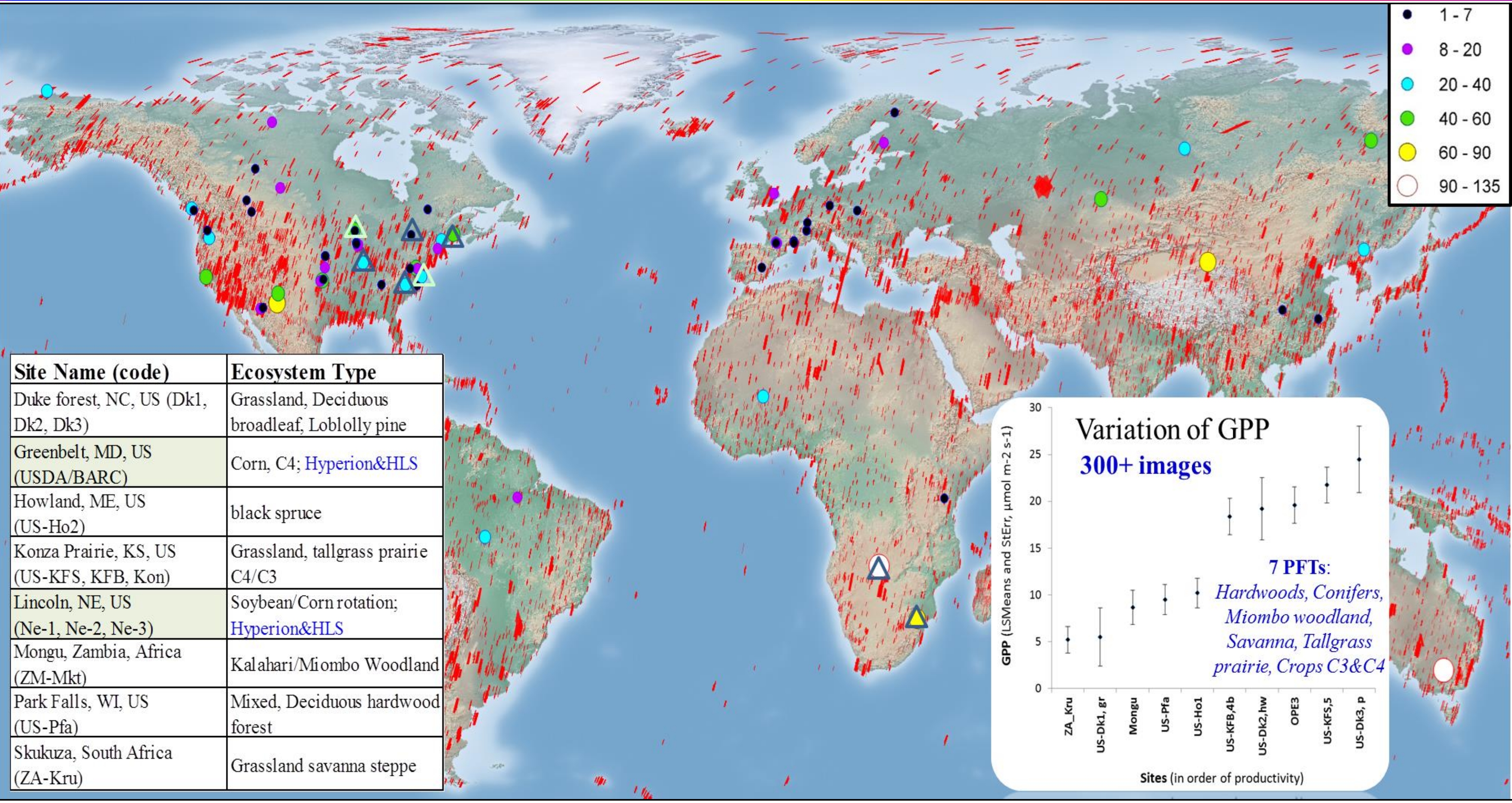
Space borne - Satellite and ISS Hyperspectral Reflectance Time Series

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



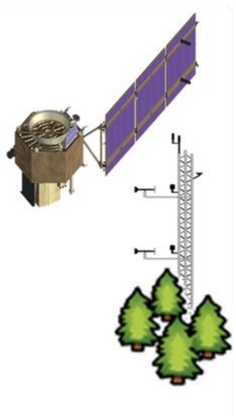
Site Name (code)	Ecosystem Type
Duke forest, NC, US (Dk1, Dk2, Dk3)	Grassland, Deciduous broadleaf, Loblolly pine
Greenbelt, MD, US (USDA/BARC)	Corn, C4; Hyperion&HLS
Howland, ME, US (US-Ho2)	black spruce
Konza Prairie, KS, US (US-KFS, KFB, Kon)	Grassland, tallgrass prairie C4/C3
Lincoln, NE, US (Ne-1, 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

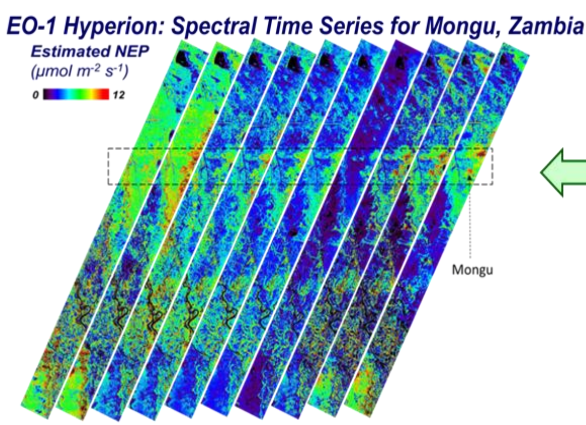


Seasonal time series (Hyperion and HLS) → **Canopy reflectance** (R, 0-1) → **Hyperion** Spectral features & VIs, **HLS** VIs

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



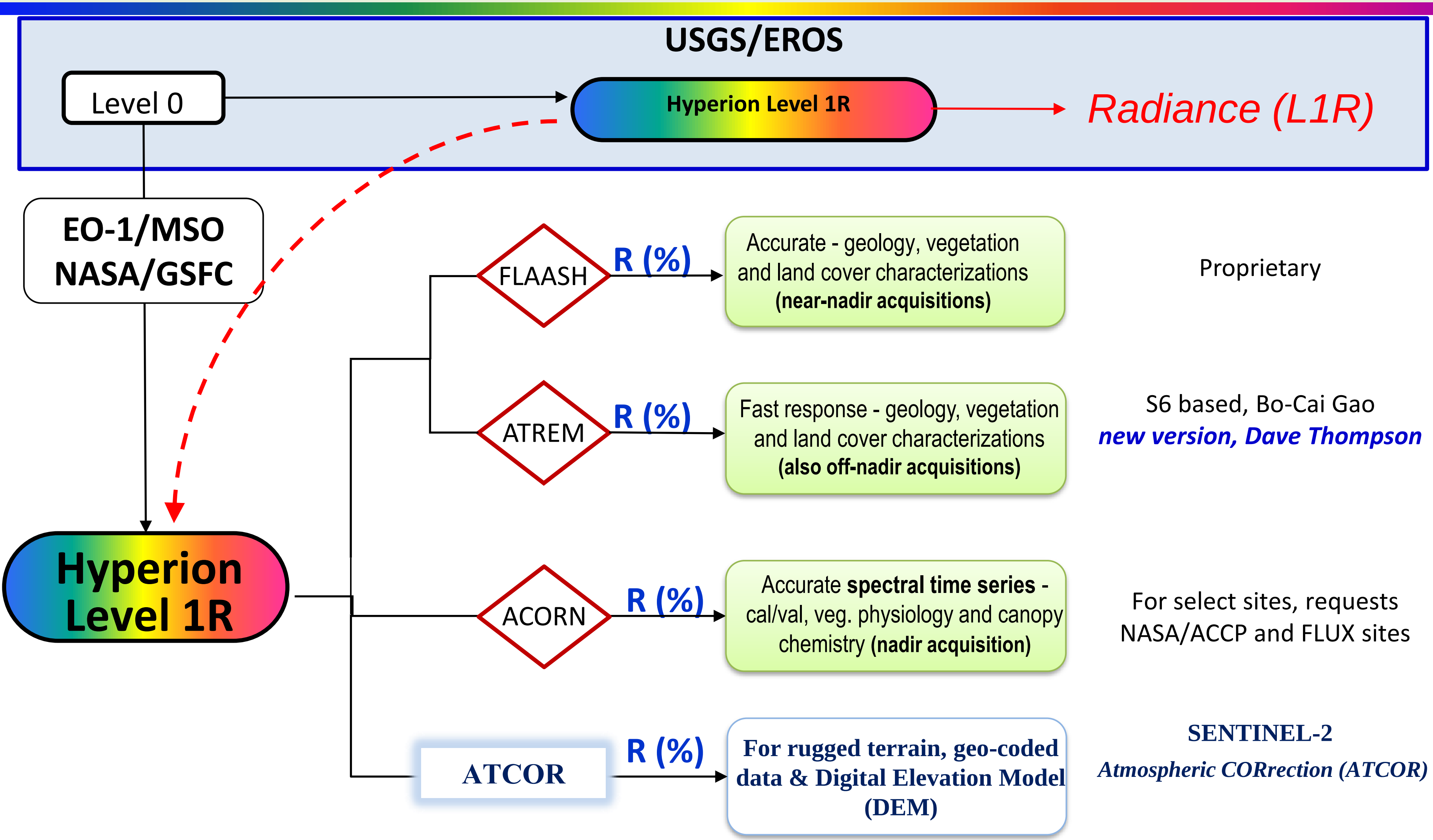
Relationships between flux GPP or field Cab & spectra (Fs and VIs)

MODELS
Statistical (PLSR)
Bio-physical (SCOPE)

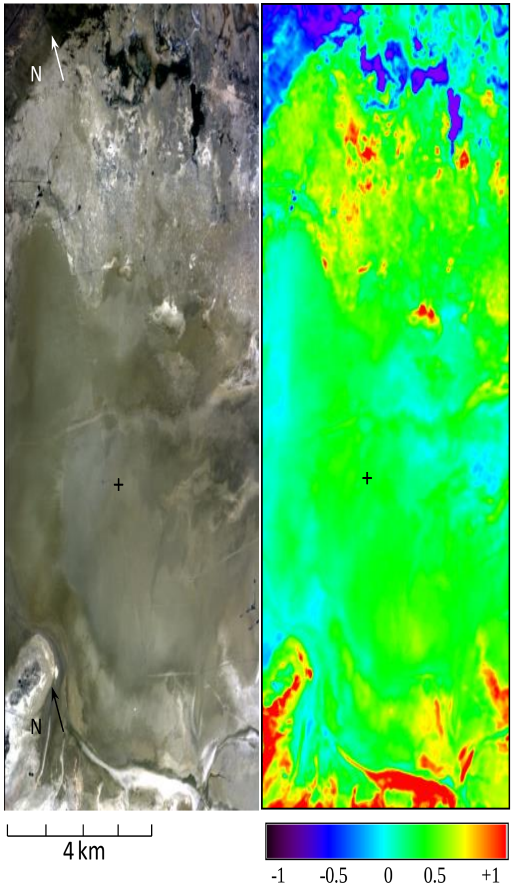
Empirical and biophysical models

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

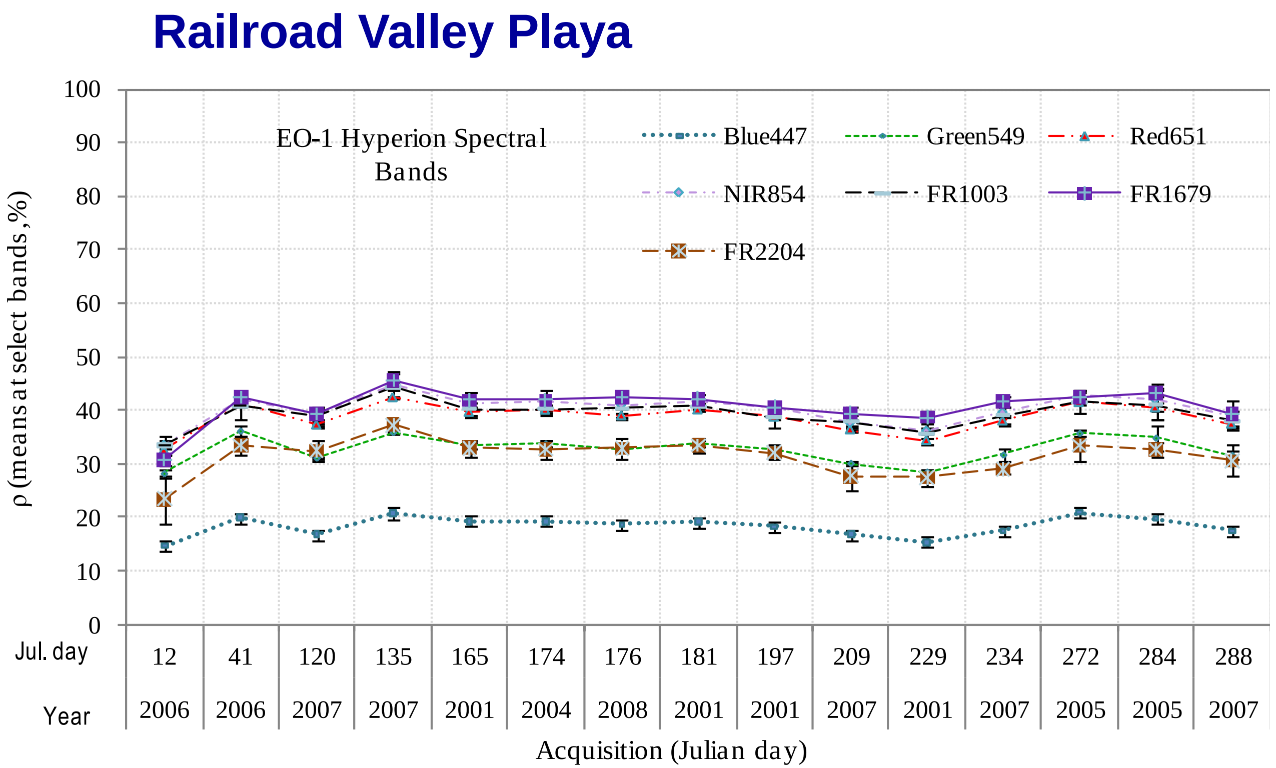
EO-1 Hyperion Level-2 Surface Reflectance



EO-1 Hyperion Reflectance Time Series at Calibration Sites

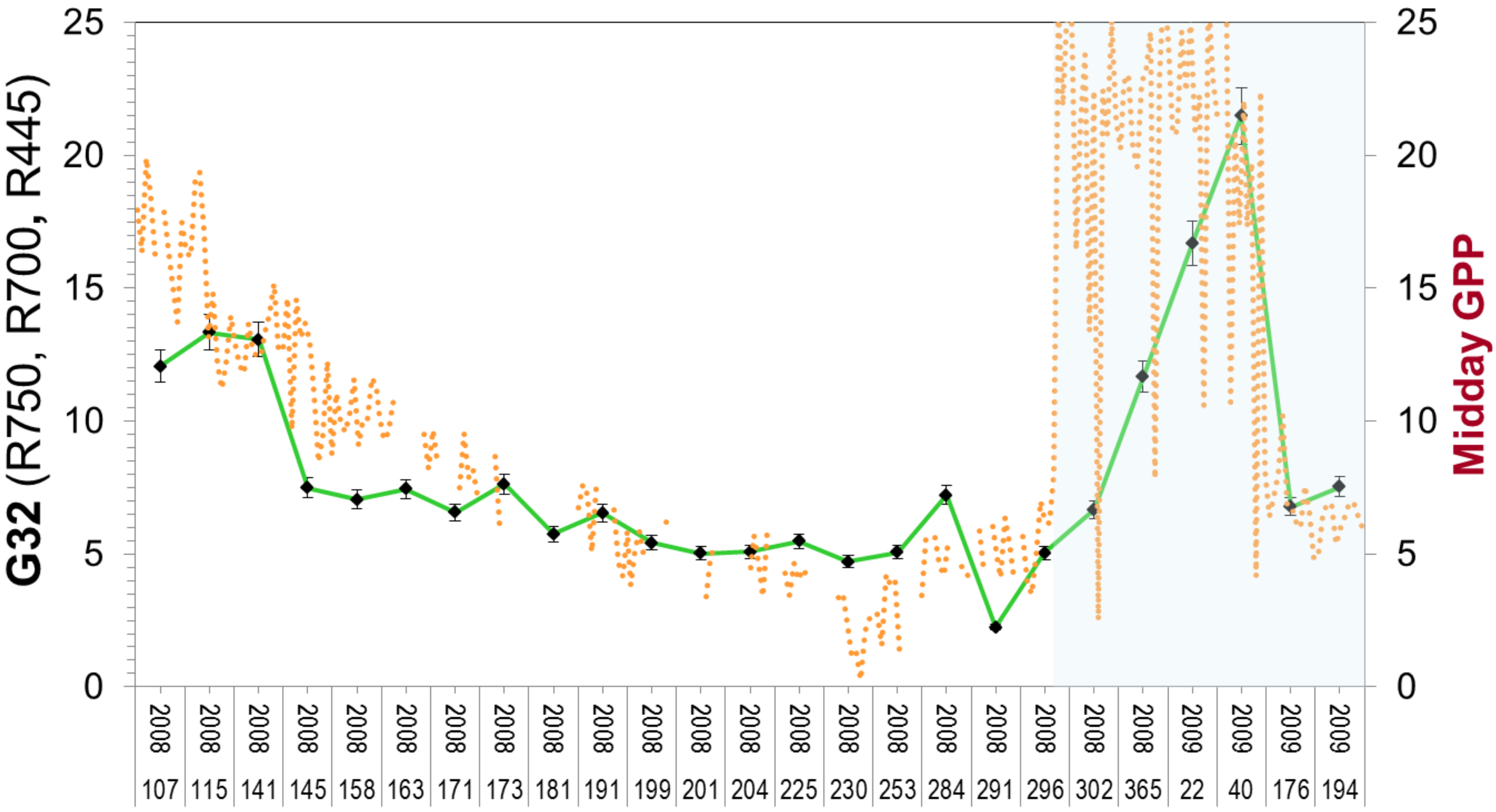


Evaluating the consistency/stability of derived reflectance from Hyperion



Hyperion Chlorophyll Indices and GPP

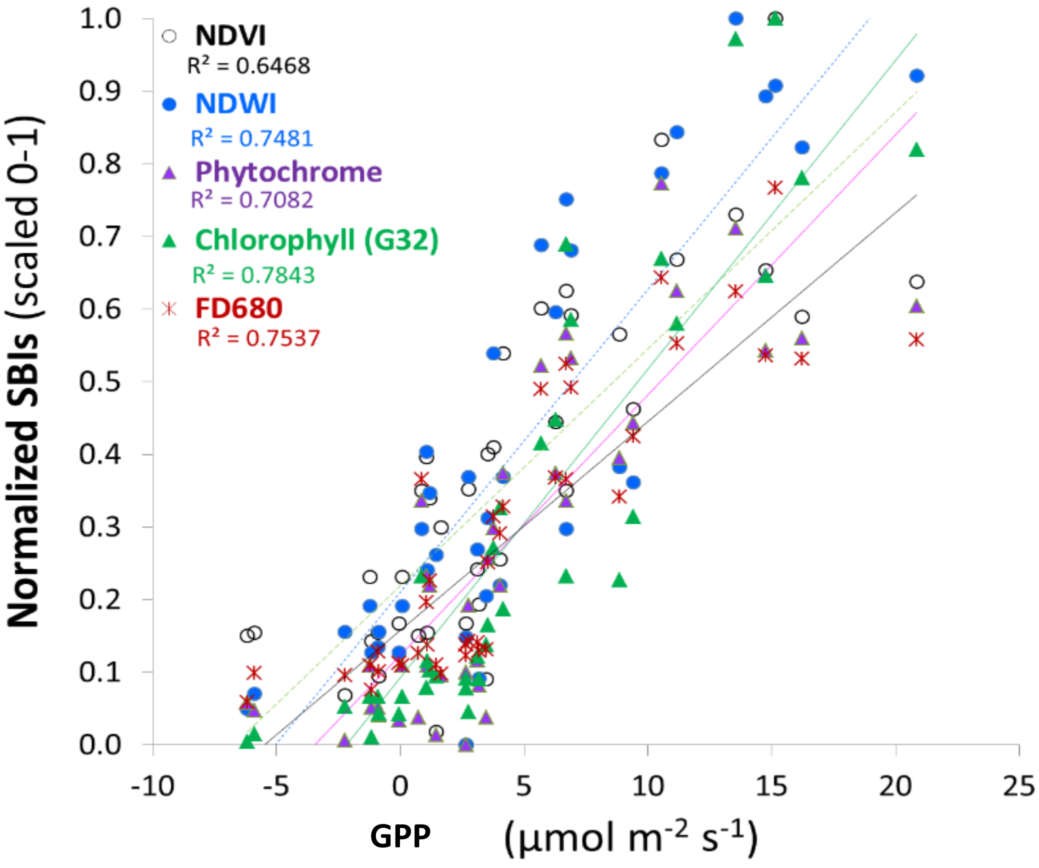
Campbell et al. 2013



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)



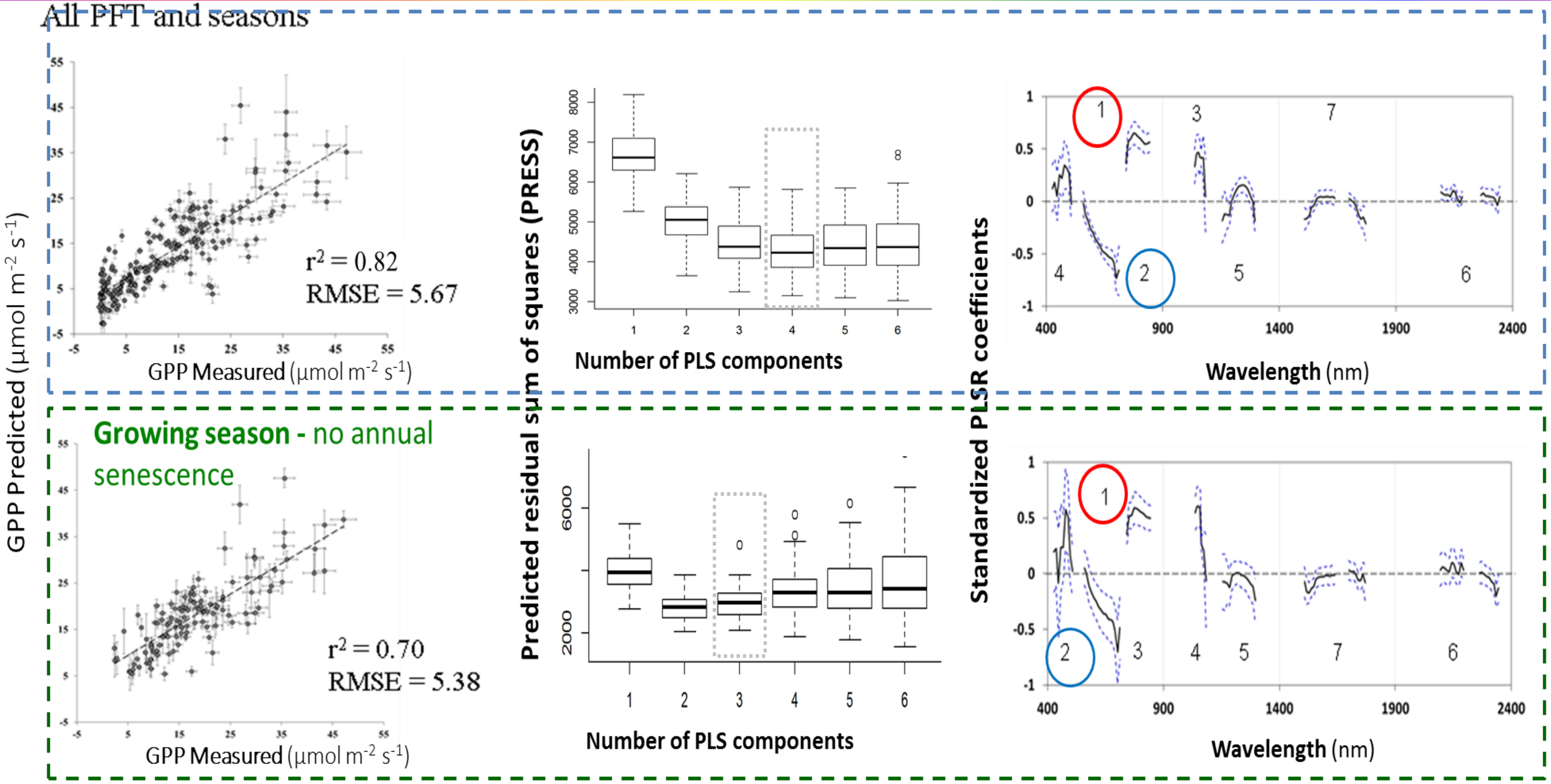
Spectral Parameters	R^2 to GEP
FA680 (PRISM)	**0.82 ***
G32=(R750-R445)/(R700-R445)	**0.78 ***
FD680 (PRISM)	0.75 *
NDWI=(R819-R1649)/(R819+R1649)	0.74
Phyt=(R724-R654)/(R724+R654)	0.71
NDVI = (TM4-TM3)/(TM4+TM3)	0.65

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)

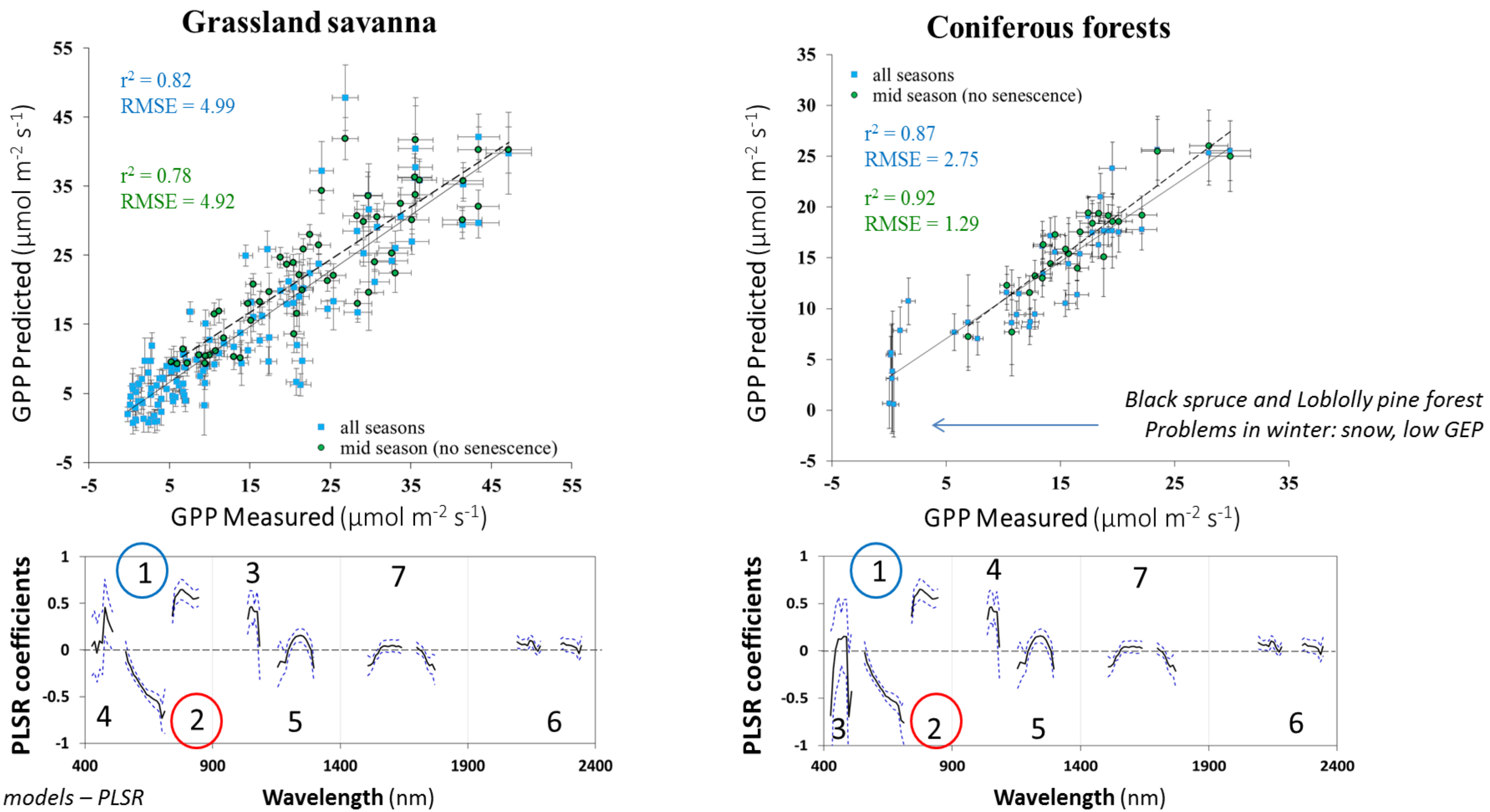
Midday GPP estimated using a partial least squares regression (PLSR) model with Hyperion seasonal time-series, for eight globally distributed sites



Empirical models – PLSR, 7 PFTs

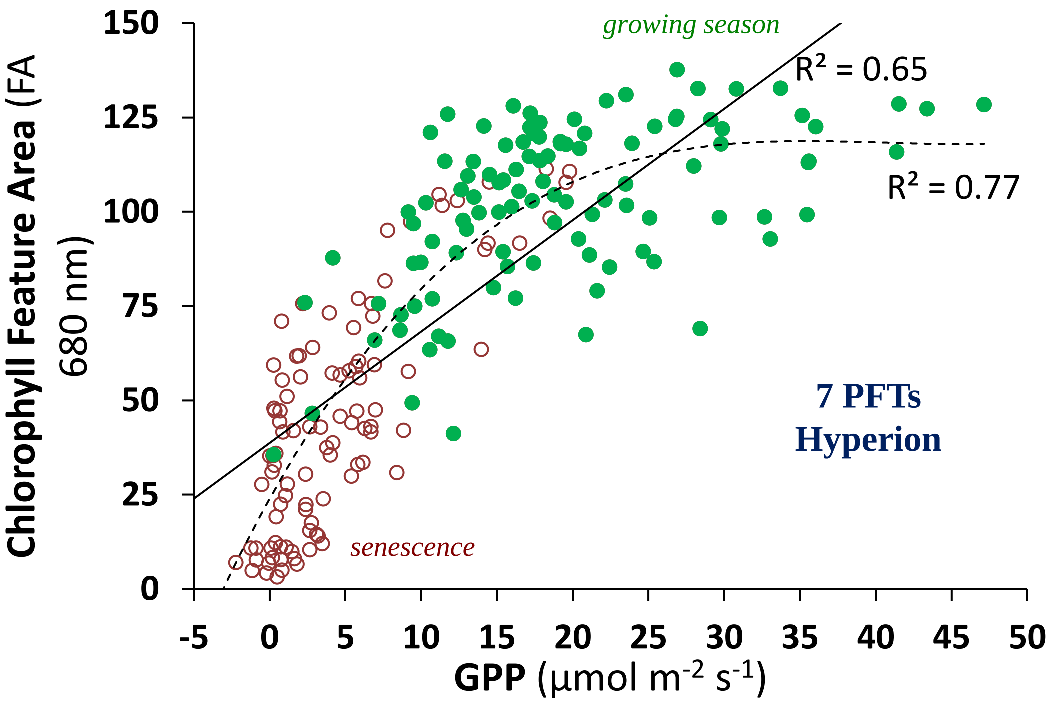
R tools for PLSR models Singh et al. 2015

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

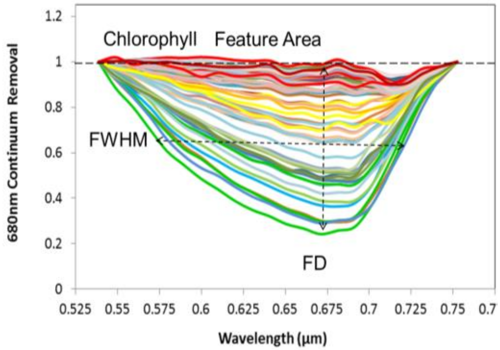


cal models – PLSR

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



Chlorophyll Feature Area (FA)



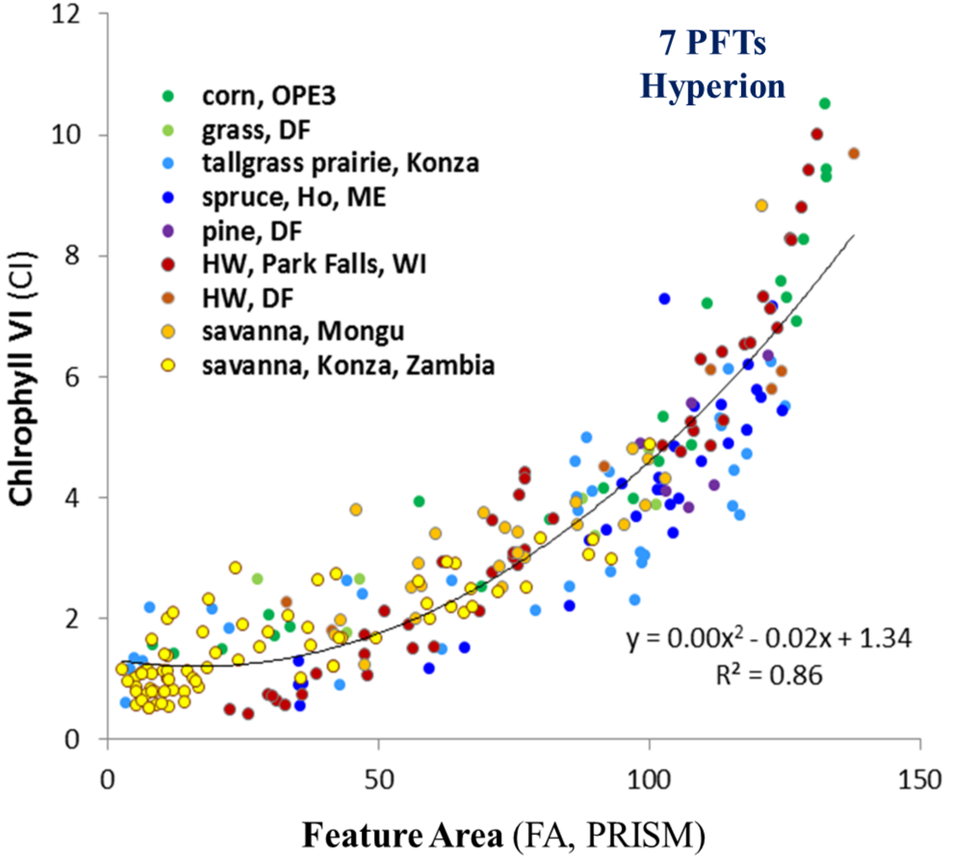
Skukuza (ZA-Kru)

- ✓ 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/

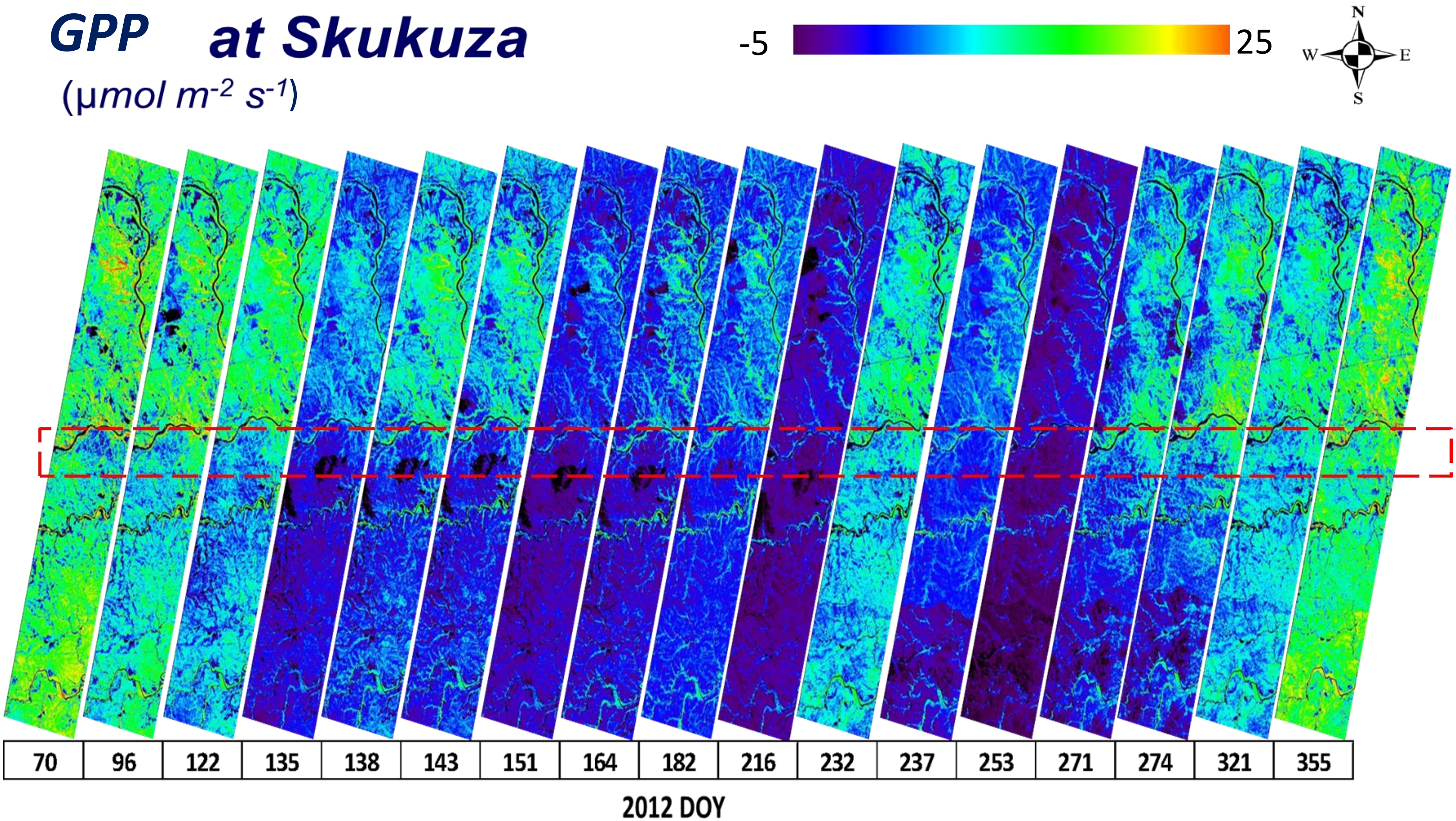
Relationship Between Chl Feature Area and Cl_{re} VI



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

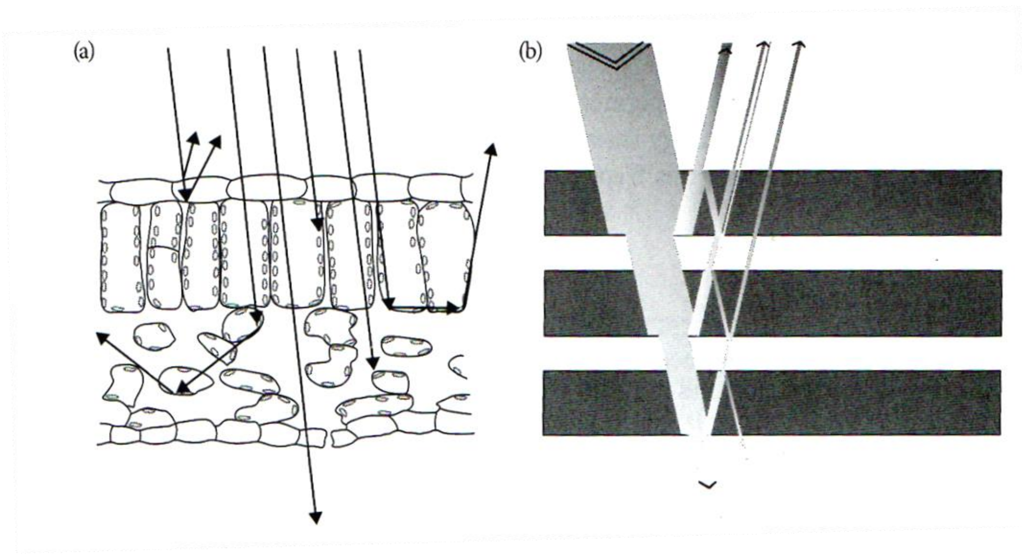
PROSPECT Model

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



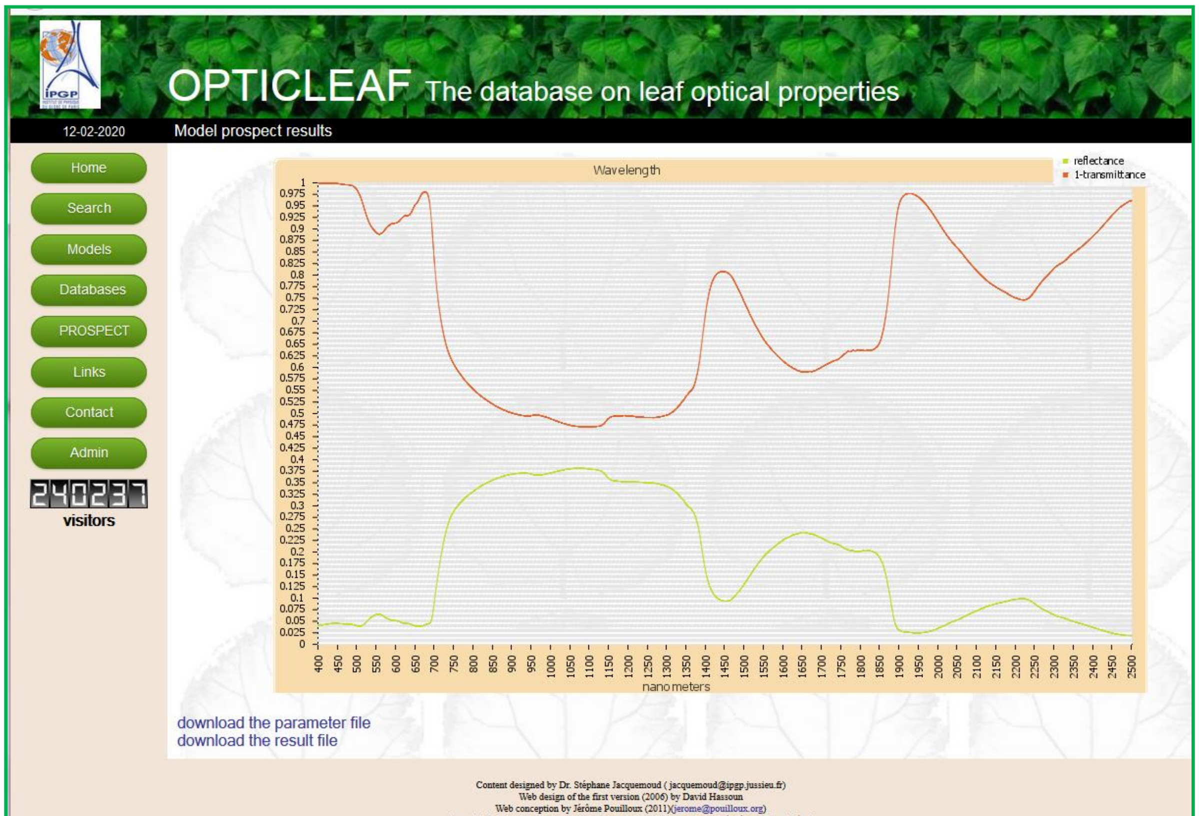
Jones and Vaughn 2010

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](http://photobiology.info/Jacq_Ustin.html)

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



Factors Affecting Leaf Reflectance / Absorption

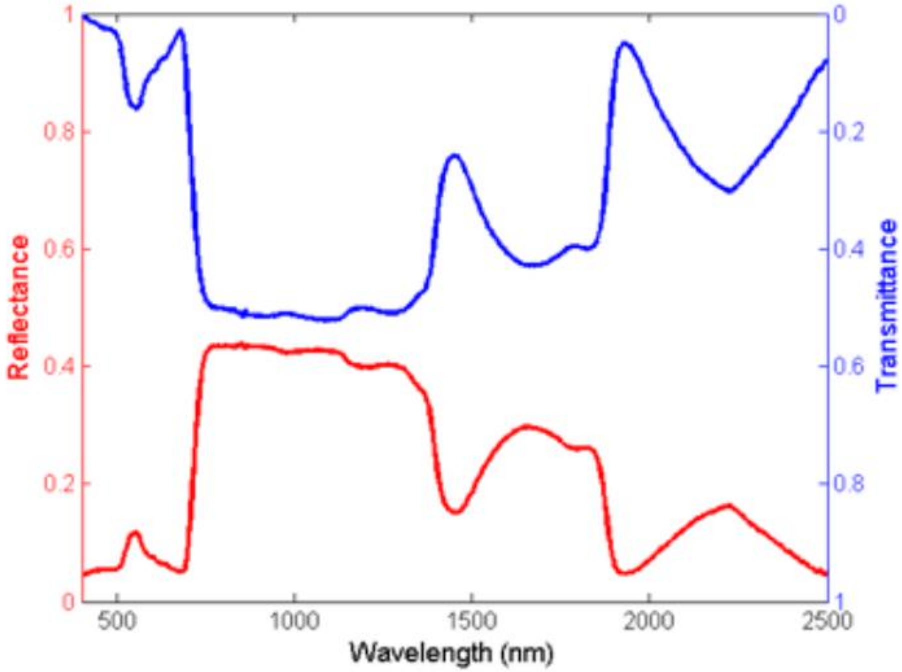


Figure 1. Reflectance (red) and transmittance (blue) spectra of a fresh Carolina poplar (*Populus canadensis*) leaf.

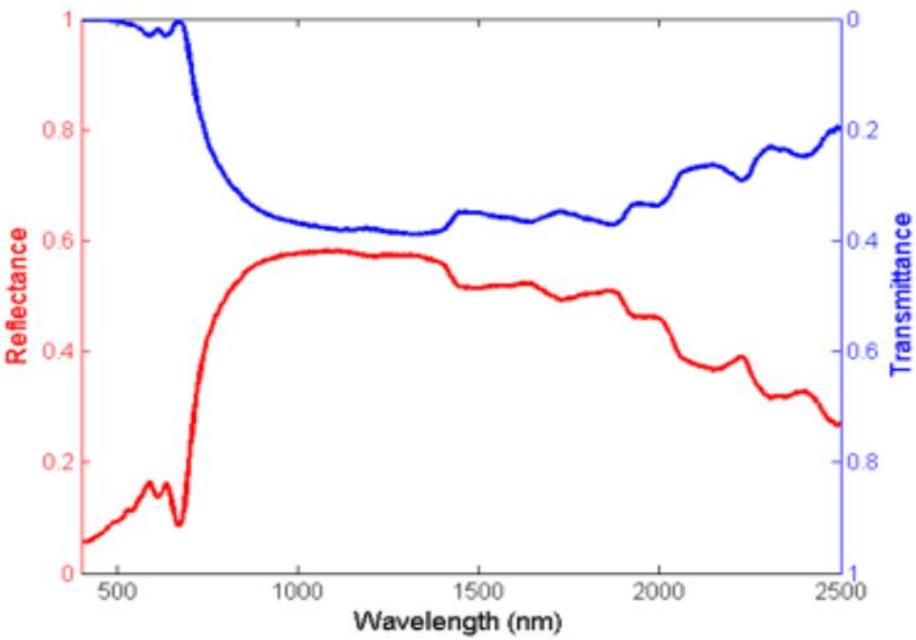


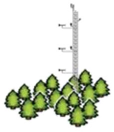
Figure 2. Reflectance (red) and transmittance (blue) spectra of a dry Carolina poplar (*Populus canadensis*) leaf.

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

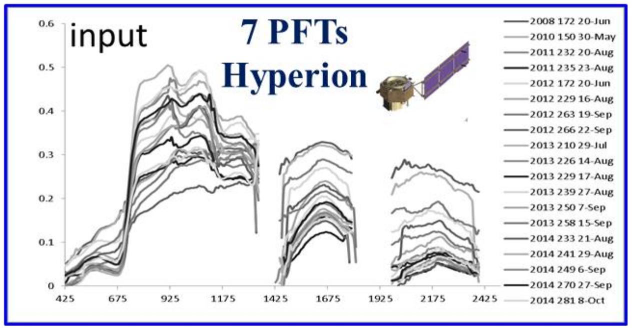
Campbell et al. 2021 in preparation

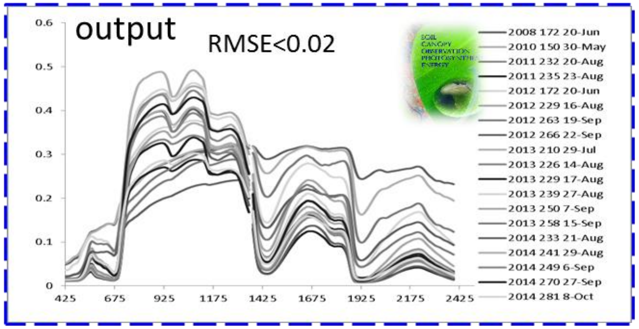
Reflectance time series
↓
RTMo
↓
Simulated reflectance + canopy bio-physical parameters
↓
SCOPE
↓
GPP predicted ? ≈ **GPP** measured



Measured - - - - - → **Simulated**

Reflectance (EO-1 Hyperion, DESIS, SBG) | SCOPE, RTMo



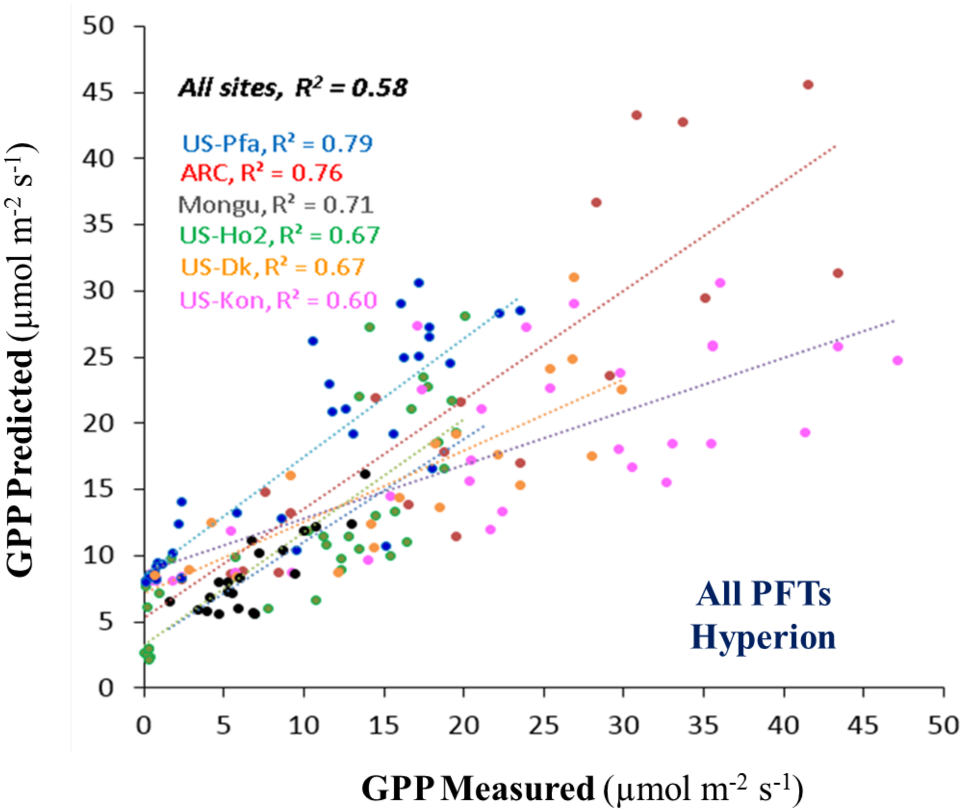


Leaf and canopy RTMs are a part of SCOPE, including:

- 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

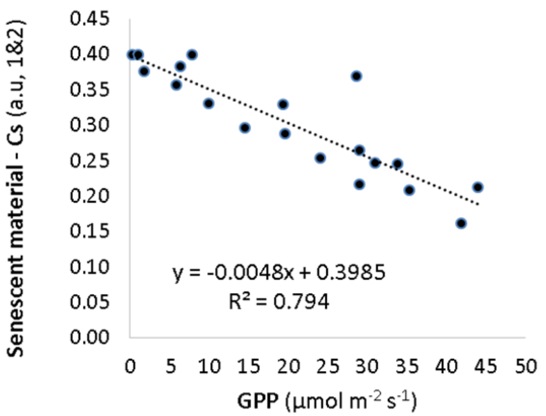


Campbell et al. 2021, in preparation

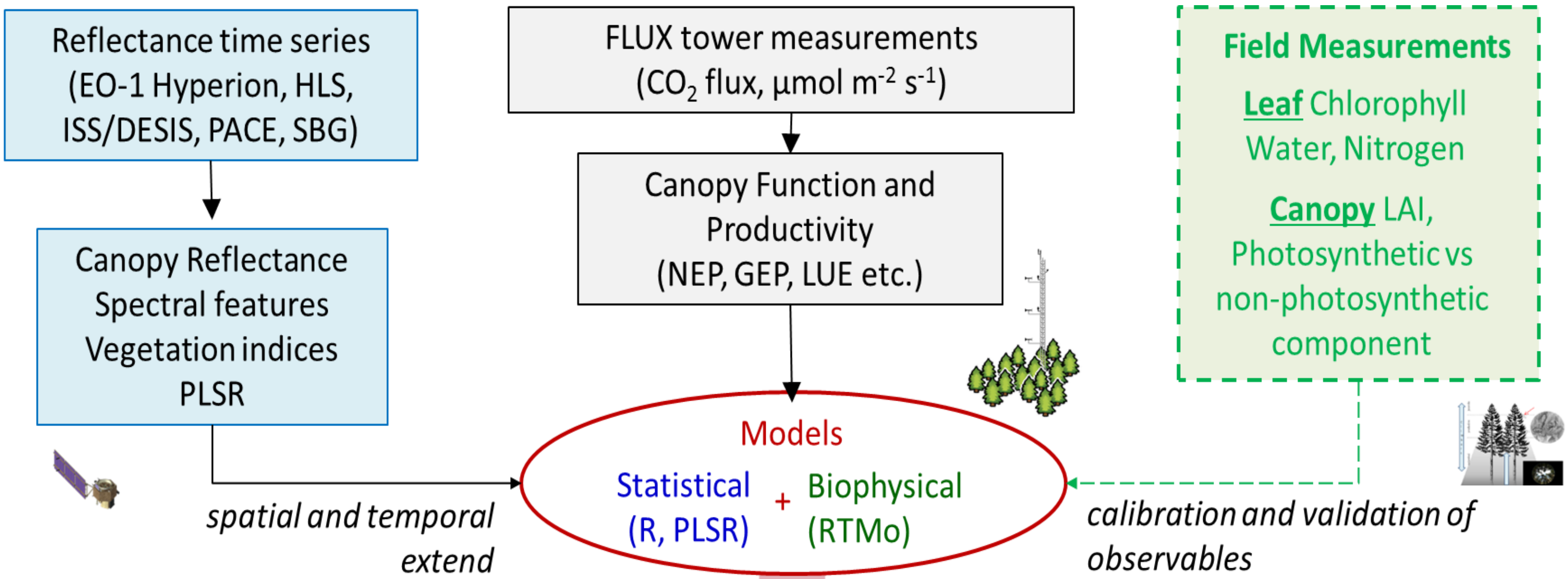
Bio-physical parameters
(in order of importance)

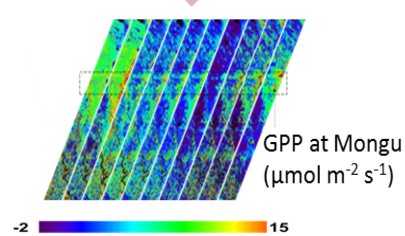
Senescent material - Cs (1)
Total Chlorophyll - Cab (µg cm^{-2}, 2)
Dry mater - Cdm (g cm^{-2}, 3)
Leaf inclination - LIDF (4)
Canopy water content - Cw (g cm^{-2}, 5)
Leaf Area Index - LAI (6)

GPP vs. Cs, Corn, ARC Corn



Combined Strategy for Monitoring Vegetation Function





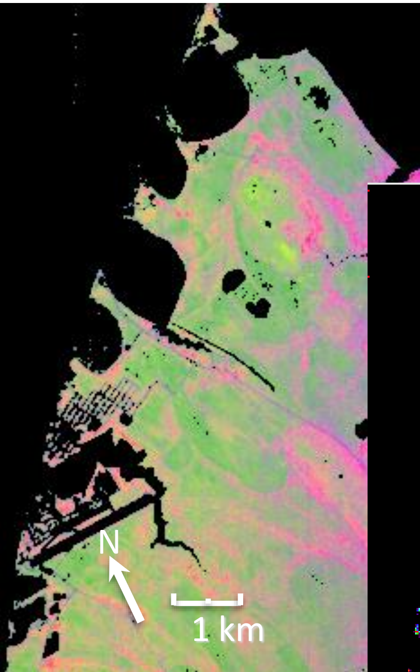
Observables: time series of canopy GPP, chlorophyll and water

Use: vegetation function

Hyperion and PLSR Mapping Tundra Ecosystem Diversity and Function

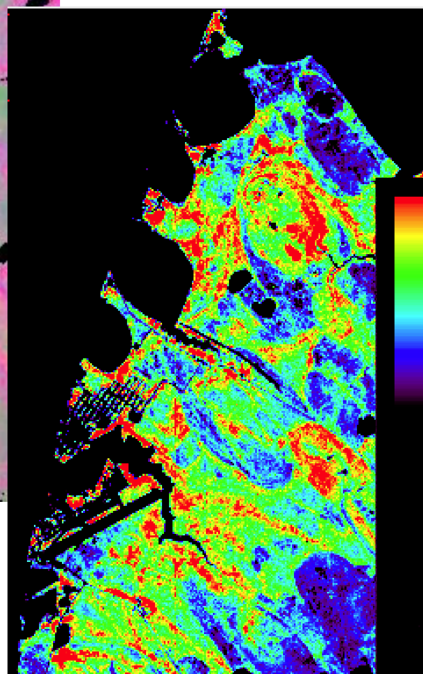
Addressing questions of terrestrial ecosystem diversity, biochemistry and function

Biodiversity



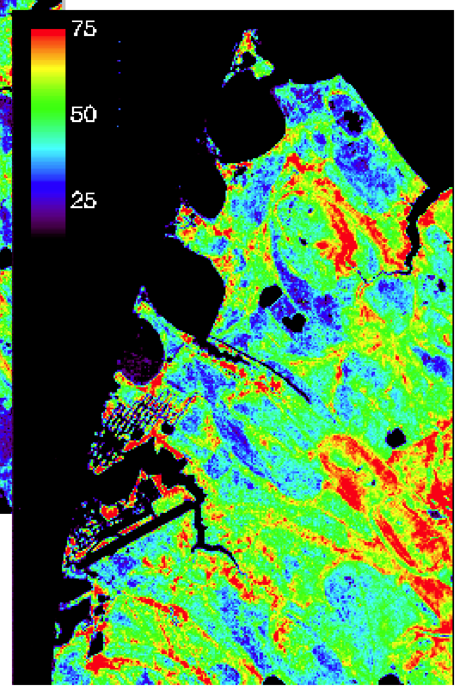
Tundra plant type cover fractions
R-Vascular Plants
G-Moss
B-Lichen

Biochemistry



Chlorophyll Index

Ecosystem Function

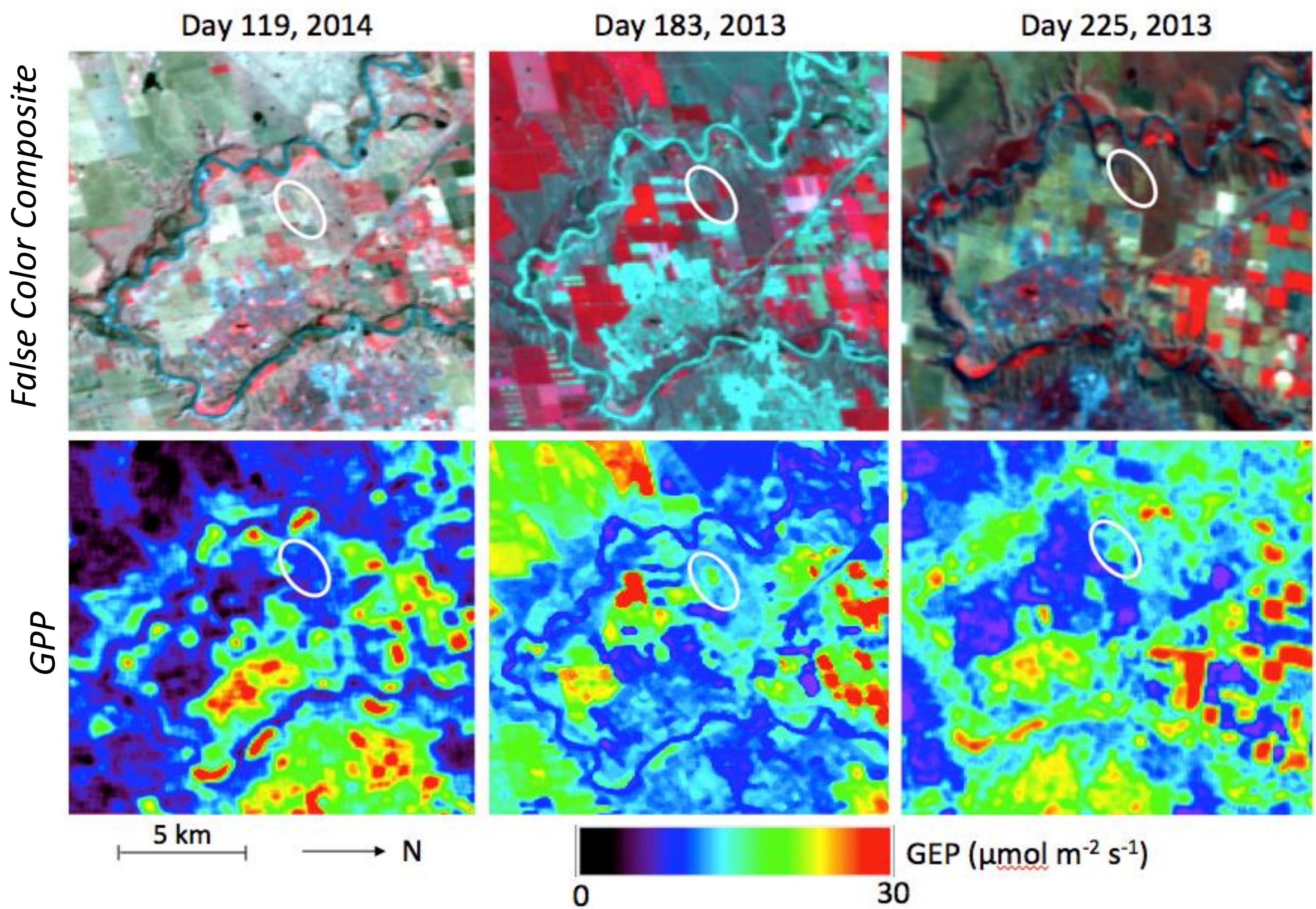


Photosynthetic light use efficiency (mol C mol^{-1} absorbed quanta X 1000)

Hyperion image of tundra near Barrow, AK, USA, July 20, 2009
Huemmrich et al. JSTARS 2013

- Plant type distribution affects ecosystem processes and response to climate change
- Biochemistry is diagnostic of responses to environmental conditions, e.g. soil nutrients, water availability
- Ecosystem function shows the spatial patterns in productivity over an area considered a single vegetation type in models

Repeated Observations of GPP from the ISS
HICO Images and PLSR, Lethbridge, CA



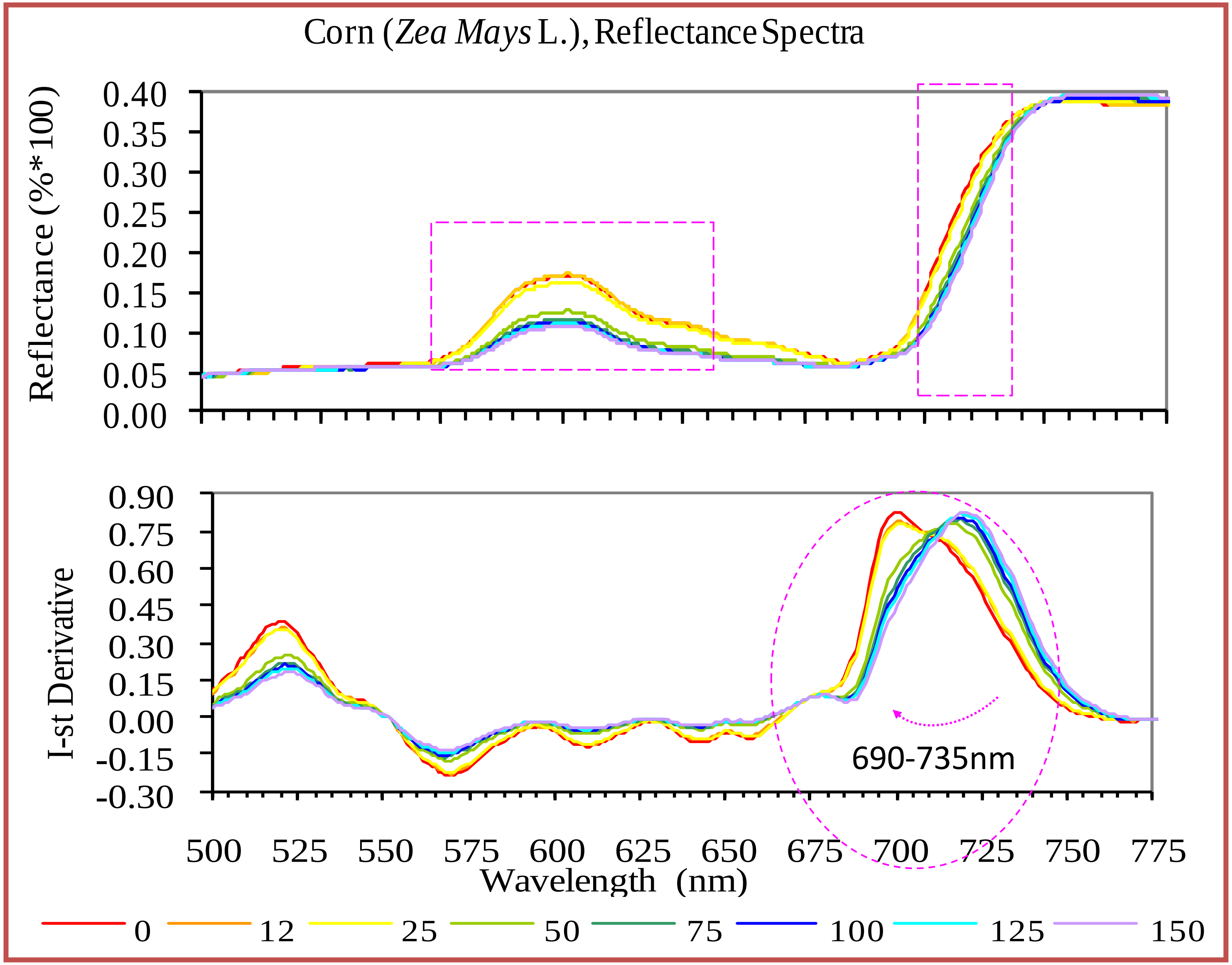
ULTRA high Spectral Measurements (0.3 nm)

➢Canopy Fluorescence (SIF) and Reflectance

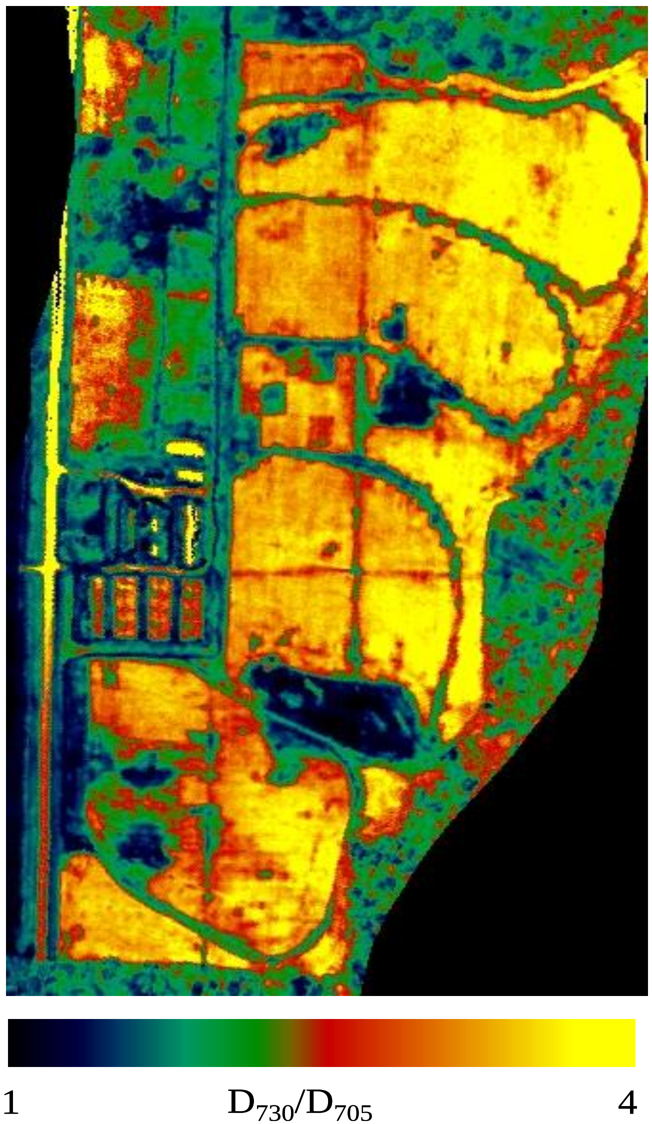
- Fluorescence Emissions were measured using Ocean Optics filed spectrometer and FUSSION (ultra high resolution imaging spectrometer), and applying the Fraunhofer Line Depth Technique.

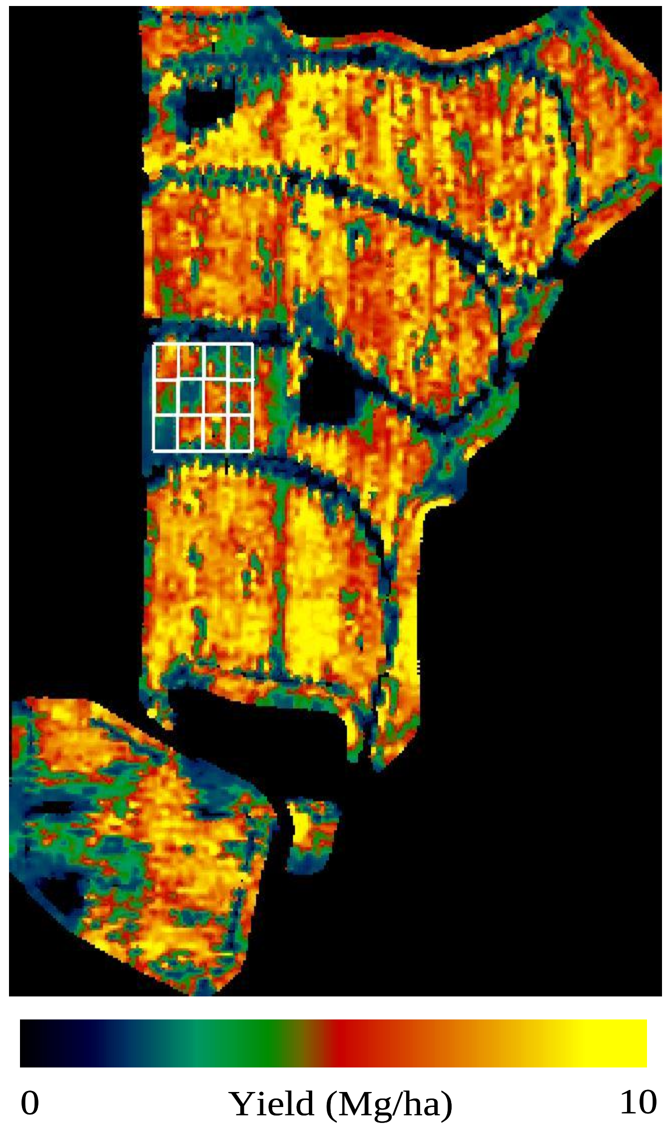
- Canopy Reflectance was measured using an ASD FieldSpec-Pro radiometer, at 1 m above plant canopies with a 22^{o} field of view and a 0^{o} nadir view zenith angle. The radiometer has 3 nm Full-Width at Half Maximum (FWHM) spectral resolution at a 1 nm sampling resolution

Changes in Foliar Reflectance Associated with N Availability



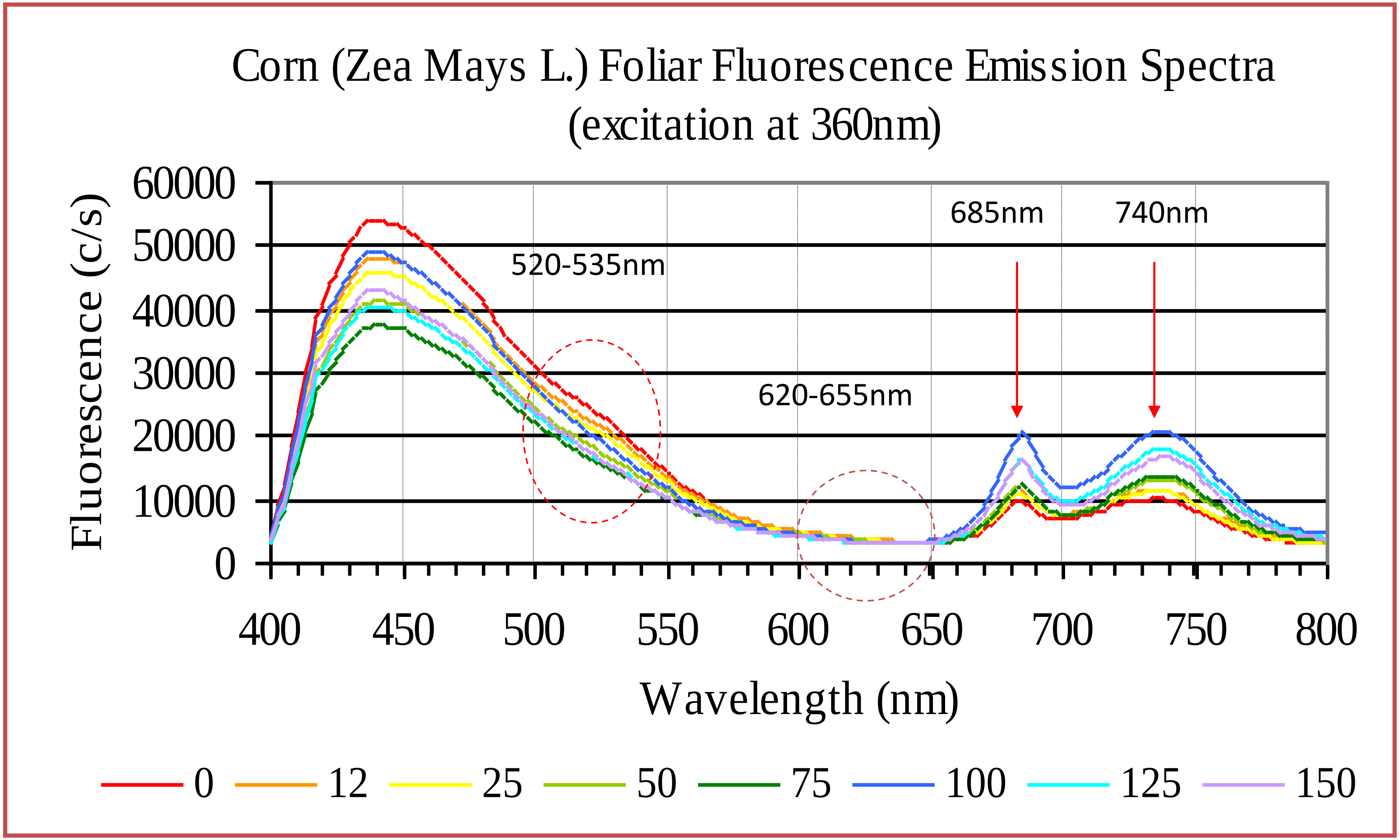
Canopy Reflectance Differences Associated with N Availability





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

Leaf Level Changes in Fluorescence Associated with N Availability



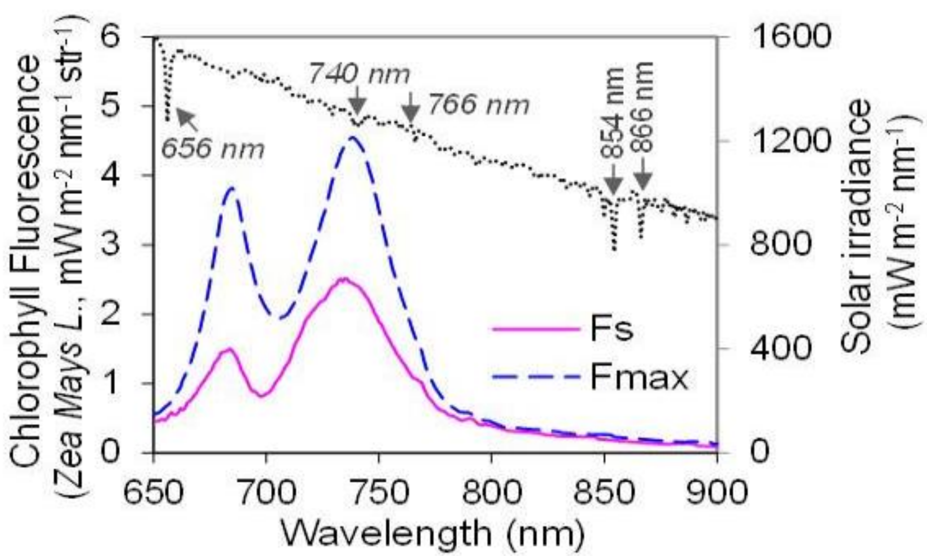
VNIR High Spectral Resolution Spectroscopy of fluorescence and photosynthesis

Fluorescence – can provide a measure of photosynthetic efficiency

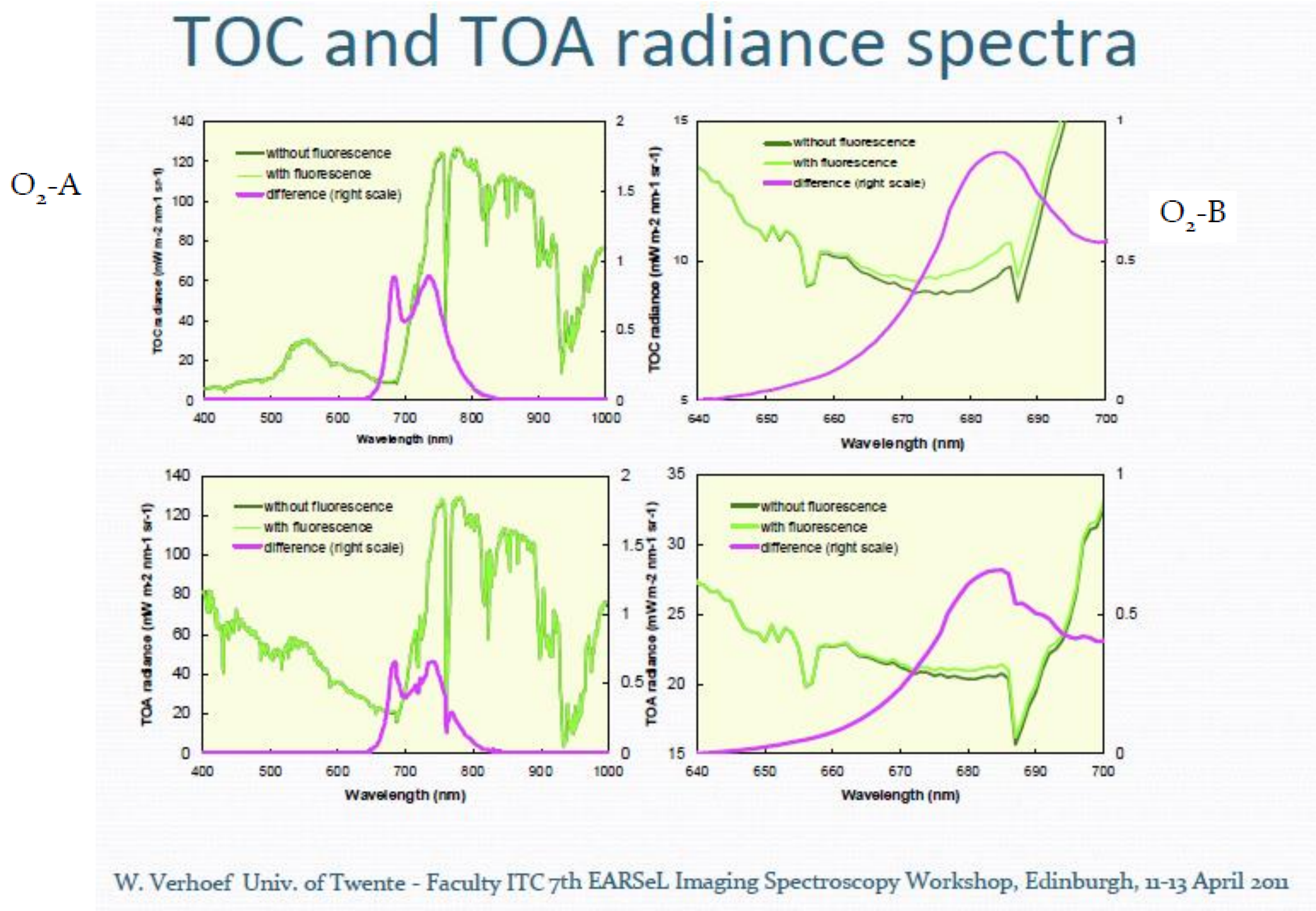
- fluorescence can be measured in the blue, green, red and far-red
- chlorophyll fluorescence (red (685 nm peak) and far-red (740 nm peak)
- actively induced (leaf, proximal)
- passive leaf and canopy requires 0.2 nm resolution - Solar Induced Fluorescence (SIF)

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

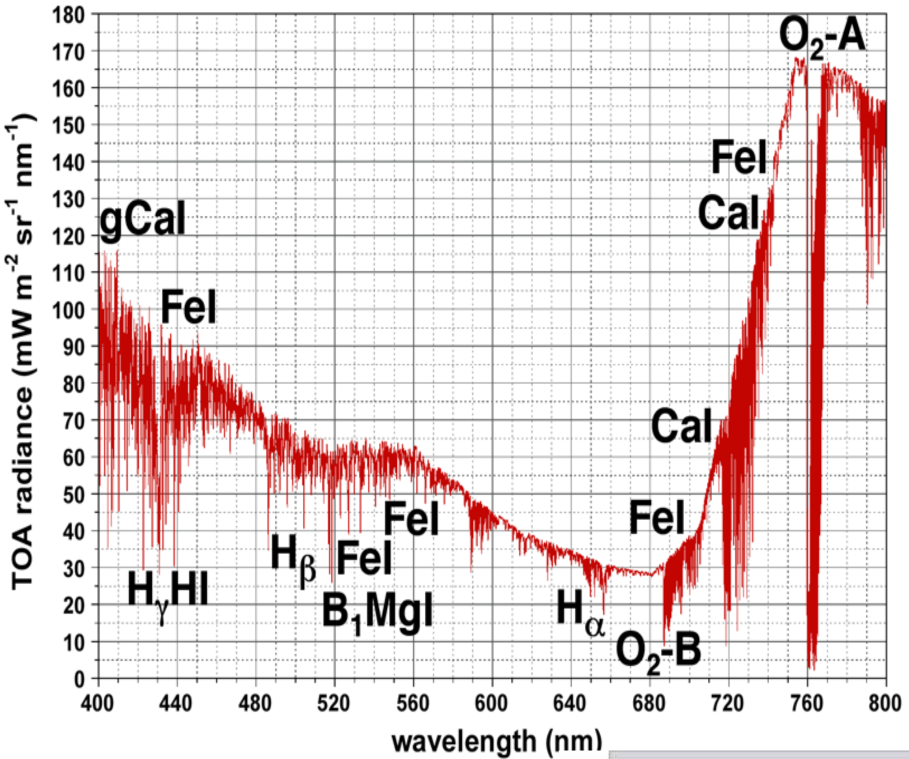
➢ At leaf and canopy level passive chlorophyll fluorescence (SIF) is related to chlorophyll content, light level (PAR), canopy structure, and photosynthesis

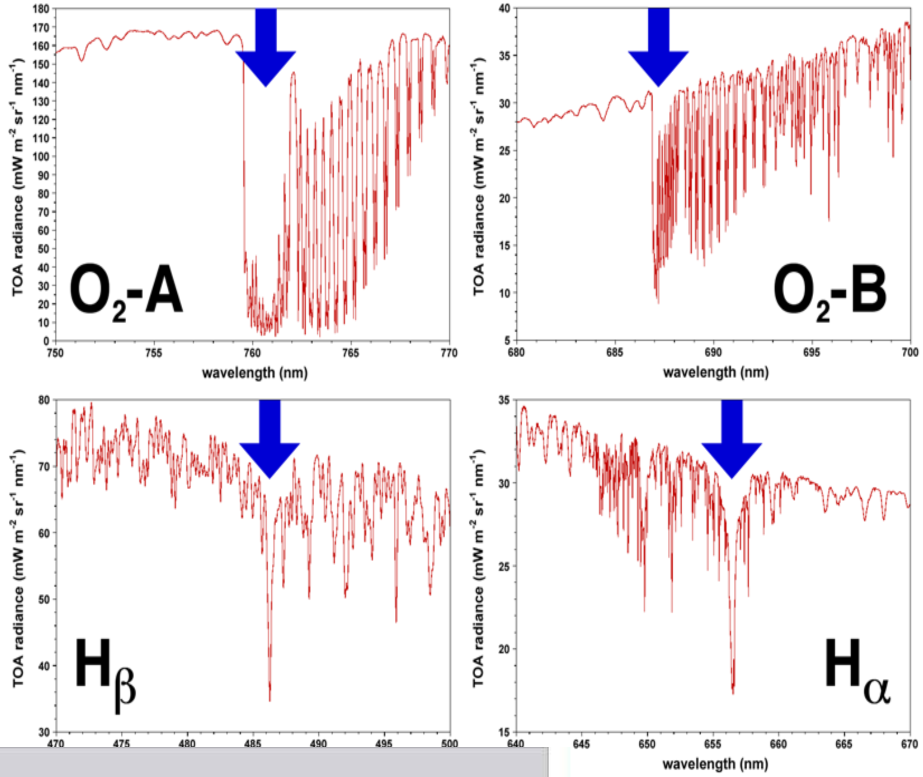


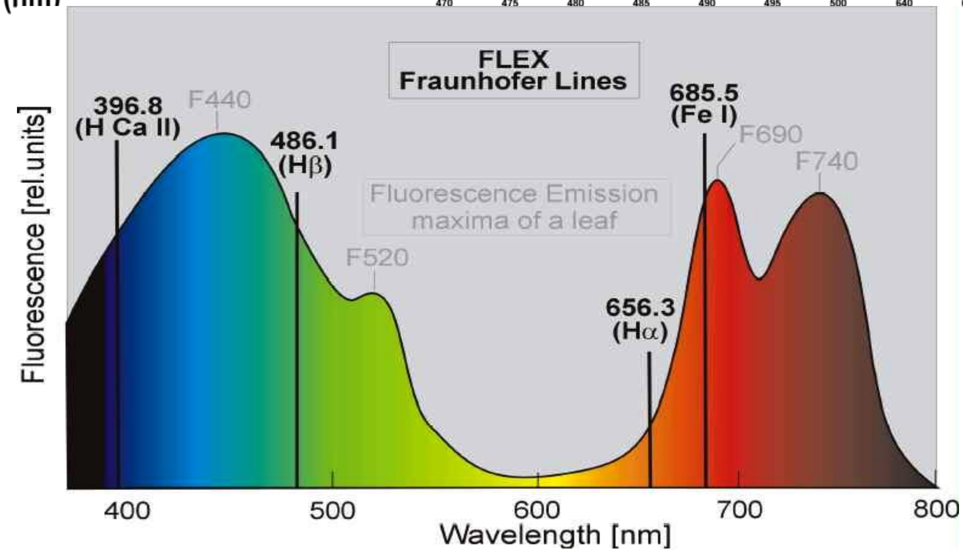
Chlorophyll Fluorescence Emissions and Solar Induced Fluorescence (SIF)



Fluorescence Explorer (FlEX, 2024), ESA







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)

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

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

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