# A Framework for Global Mapping of Ecosystem Properties and Composition Using Biophysical/ Biochemical Leaf Traits

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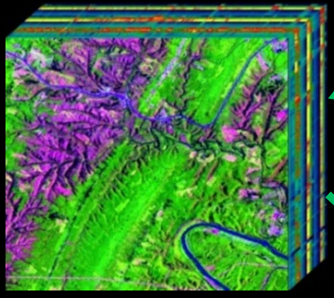
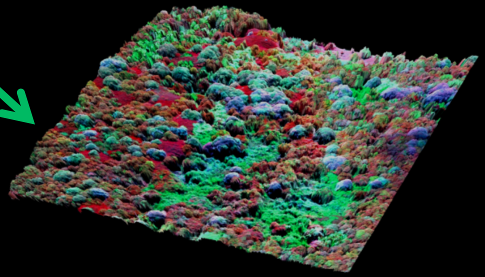


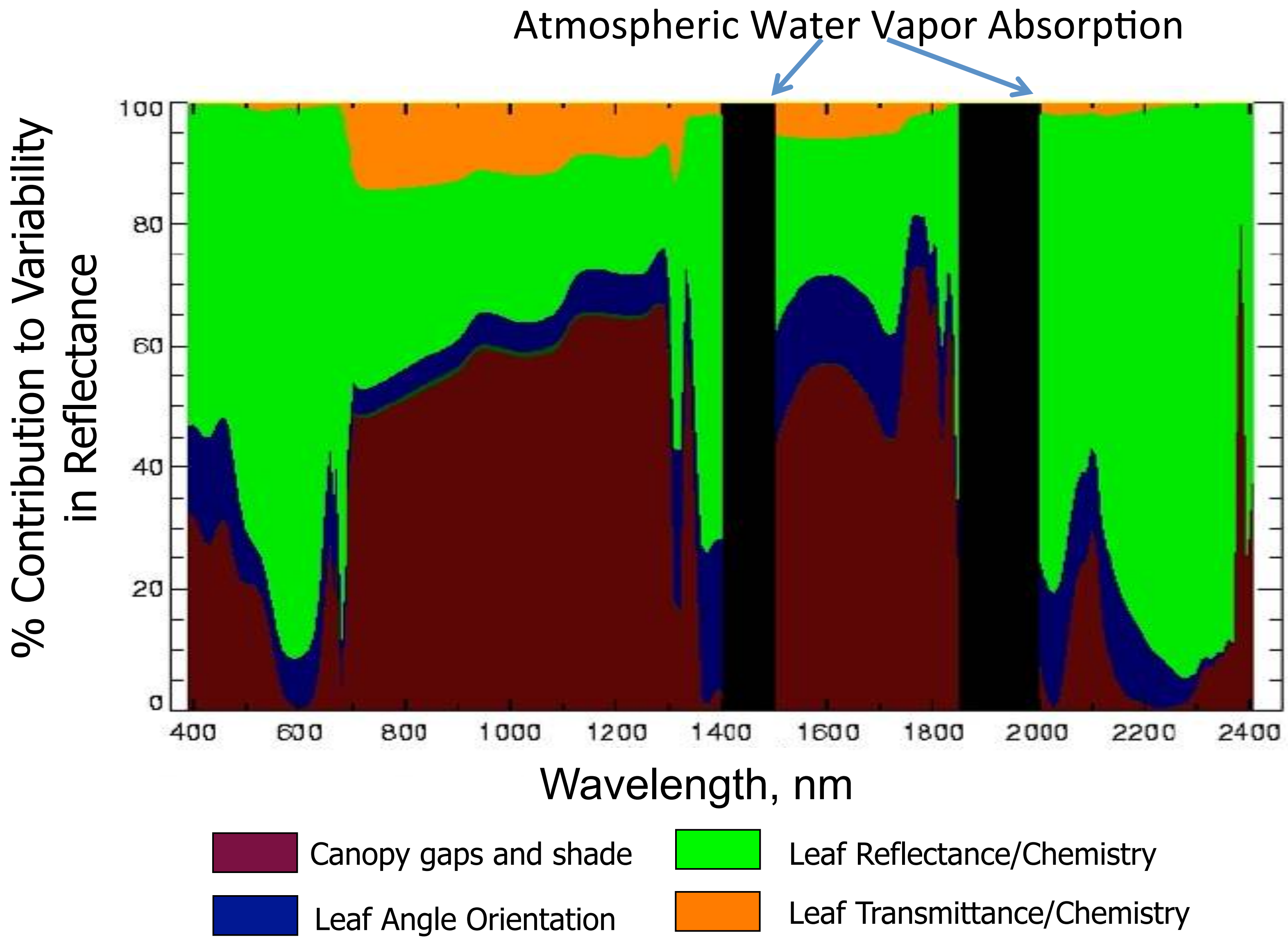


# Today's Ecosystem Models Are Over-reliant on Simple Vegetation Inputs

| Major Ecosystem Model Inputs | CASA-3D | SiB3 | ED-2 |
|---|---|---|---|
| | | | |
| Vegetation Type | General Land Cover | General Land Cover | Prescribed |
| Plant Functional Types | Prescribed | Prescribed | Prescribed |
| Fractional Carbon Cover | --- | --- | --- |
| Vegetation Greenness | NDVI | NDVI | NDVI |
| Fractional PAR Absorption | NDVI | NDVI | NDVI |
| Leaf Area Index (0-4 LAI units) | NDVI | NDVI | NDVI |
| Leaf Area Index (4-10 LAI units) | --- | --- | --- |
| Canopy Gap Frequency and Size | Prescribed | --- | Prescribed |
| Light-use Efficiency (leaf water, N) | Prescribed | Prescribed | Prescribed |
| | | | |
| Live vs. Senescent Biomass | --- | --- | Prescribed |
| Woody vs. Leaf Biomass | Prescribed | Prescribed | Prescribed |
| Canopy Allometry | Prescribed | Prescribed | Prescribed |
| | | | |
| Disturbance Type and Intensity | Landsat-SMA | --- | Prescribed |

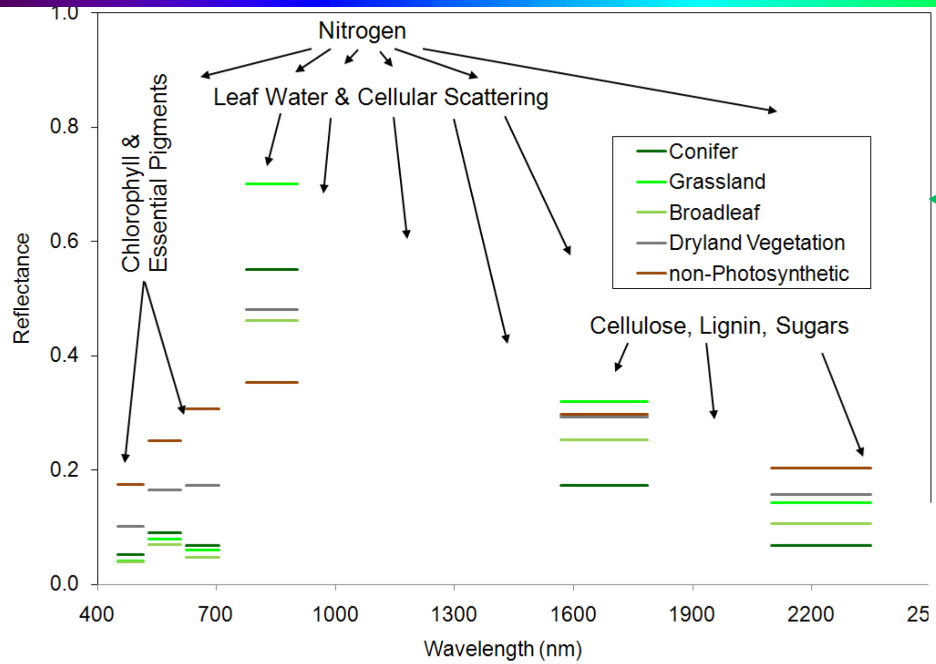
## Vegetation Inputs from Top 3 land models to GCMs

# Contribution of Leaf and Canopy Properties to Pixel Reflectance



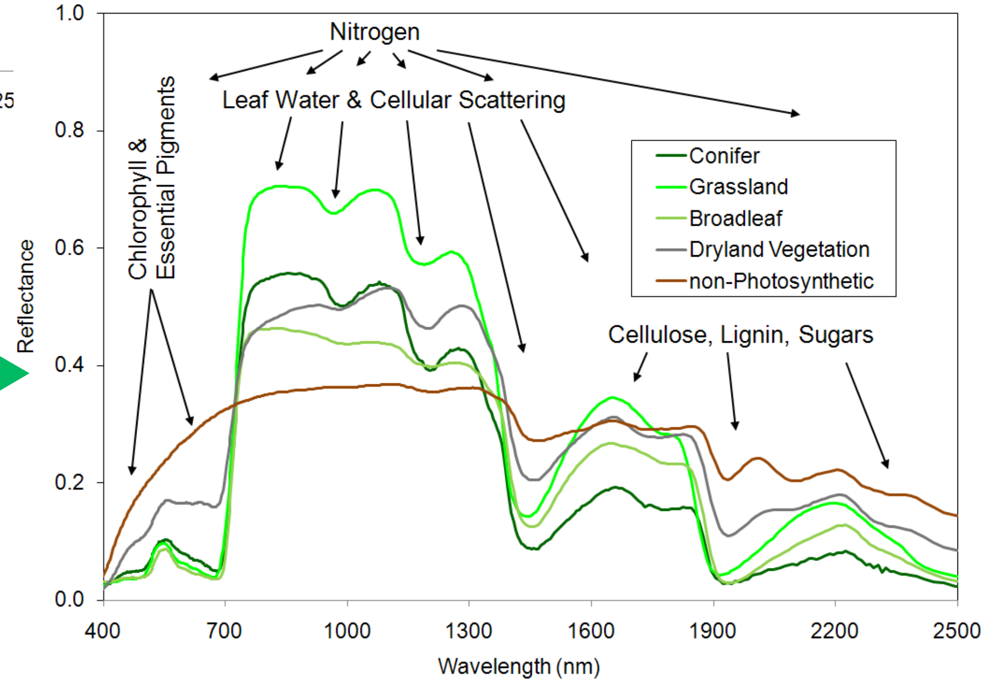

Greg Asner

# Measuring the Terrestrial Biosphere: An Underdetermined Problem

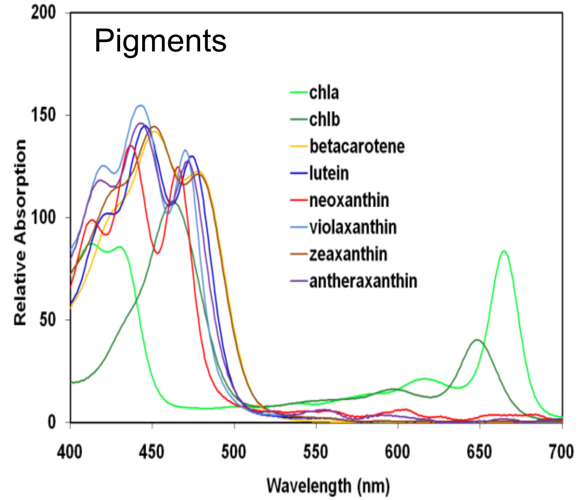


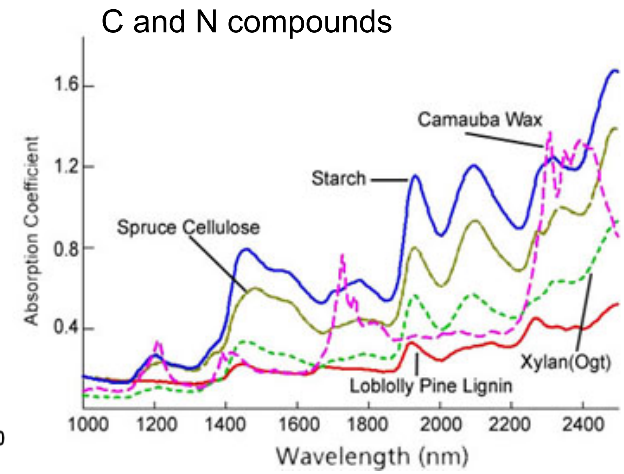

Multi-spectral imaging provides insufficient detail about plant functioning beyond “presence measures”

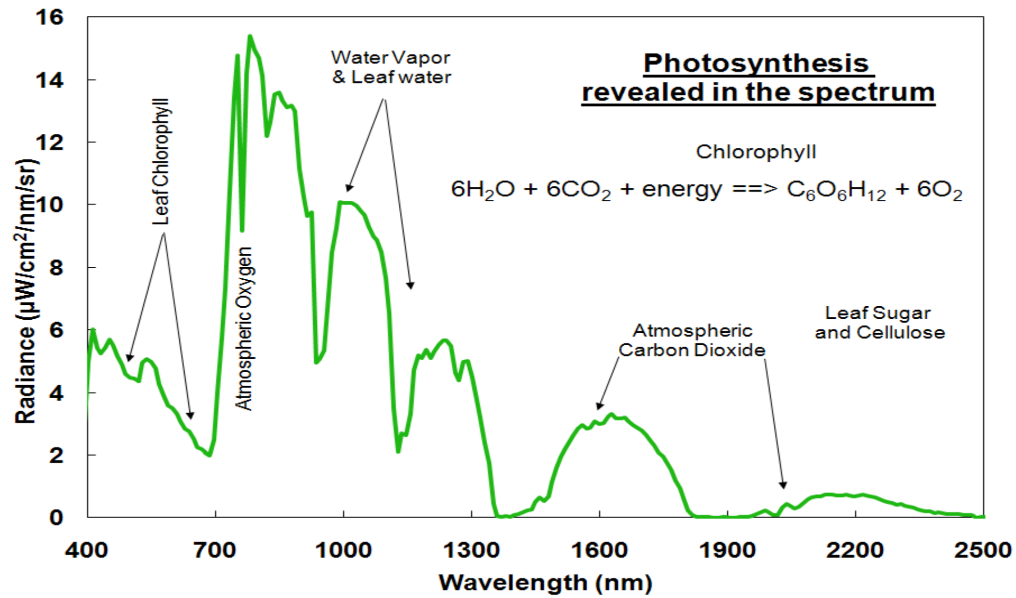
Imaging Spectroscopy is required to measure biophysical variables that directly relate to functioning of the terrestrial biosphere.



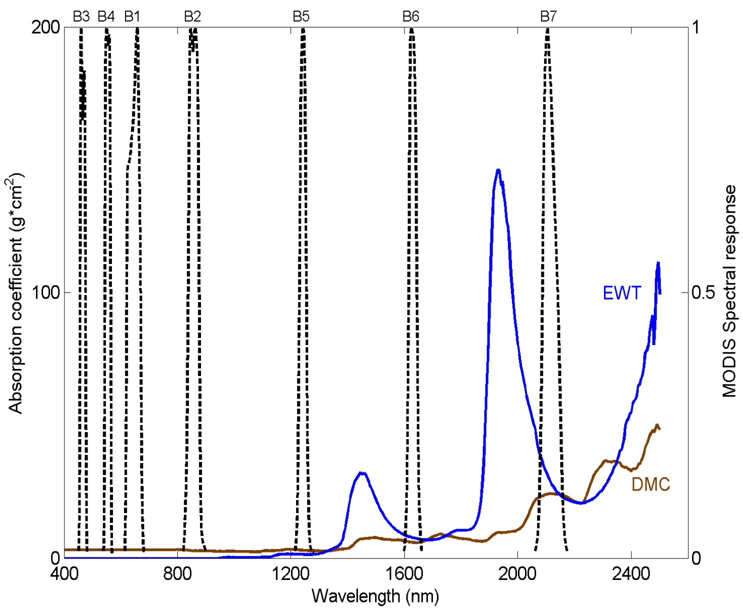
# The Spectroscopic Signal of Terrestrial Vegetation
# 380 to 2500 nm



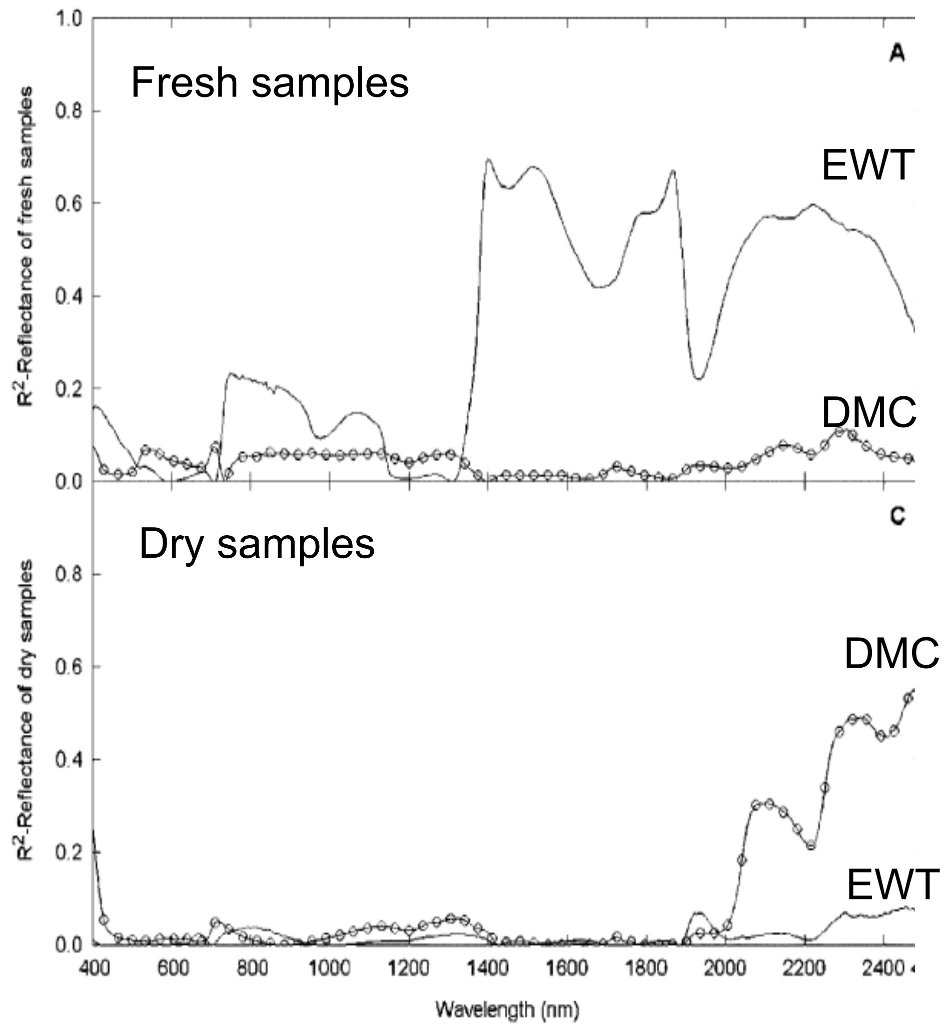



# Some Features are Masked by Strongly Absorbing Compounds




EWT = Equivalent water thickness
DMC = Dry Matter Content

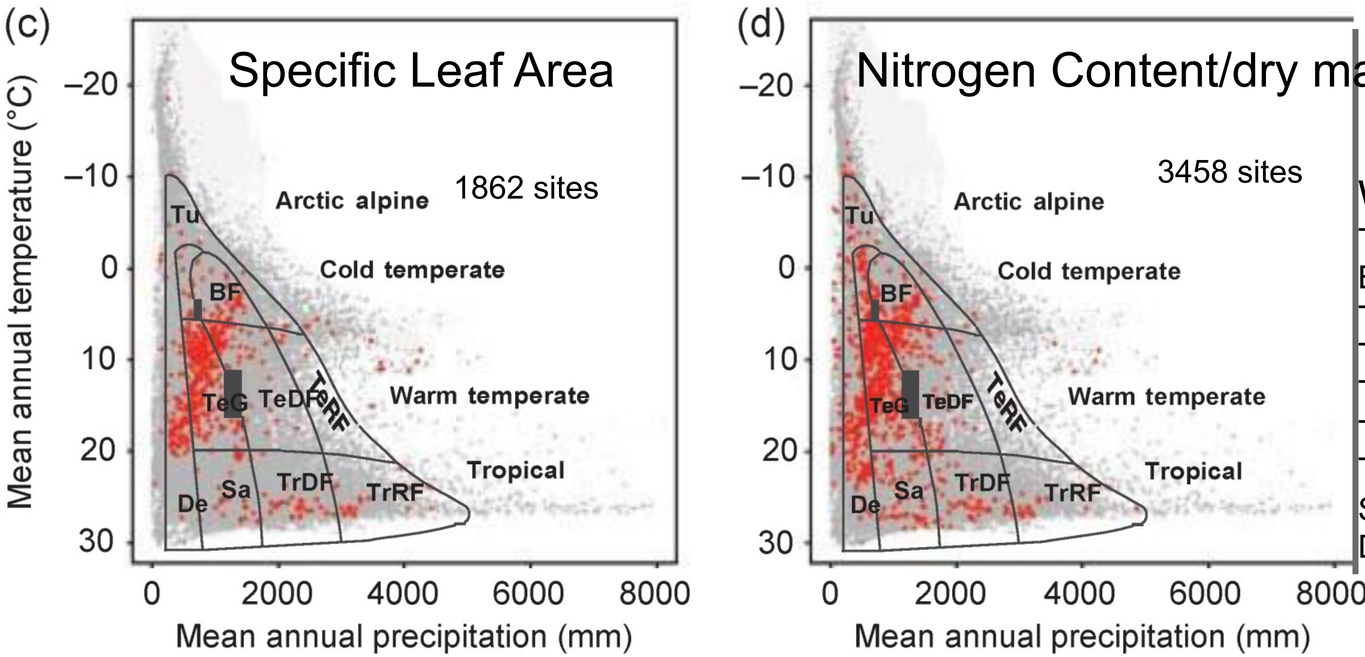



How to consistently retrieve small spectral signals?

- Coordinated multi-sensor acquisitions
  The “B Train” (Biological constellation)
- new statistical/signal processing methods?
- improved absorption coefficients?
- empirical/theoretical studies?

Riaño et al 2005, IEEE TGRS

# Continuous Relationships between Climate Space and Trait-based Variation



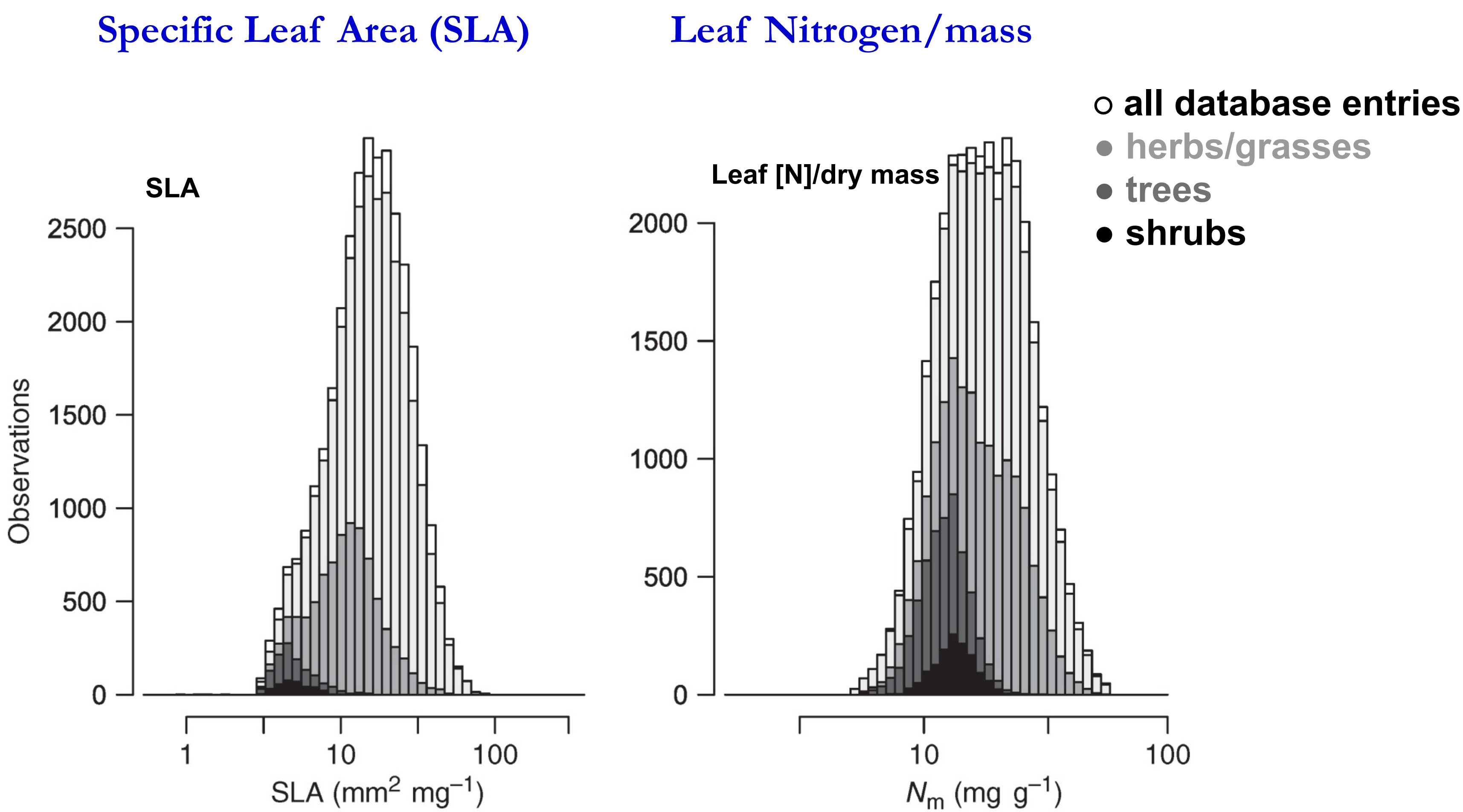

Whittaker Biome Types:
Tu: Tundra
BF: Boreal Forest
TeG: Temperate Grassland
TeDF: Temp. Deciduous Forest
TeRF: Temp. Rain Forest
TrDF: Tropical Deciduous Forest
TrRF: Tropical Rain Forest
Sa: Savanna
De: Desert

Note: SLA = 1/LMA

- Georeferenced in TRY Database (**69,296 species; 93 traits**)
- Global Biodiversity Information Facility Database

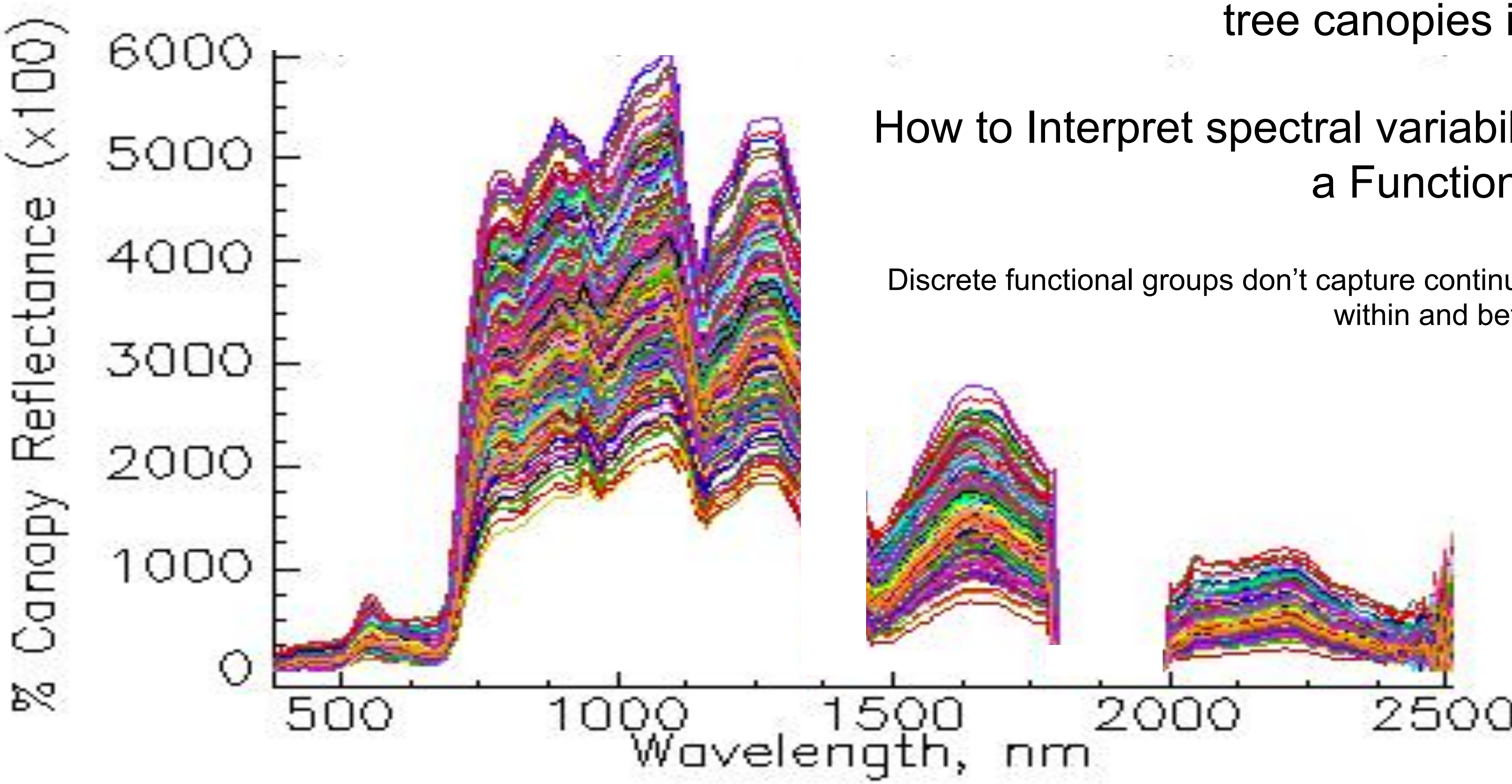
J . KATTGE & 134 others, 2011. TRY – A Global Database of Plant Traits. Global Change Biology (2011) 17, 2905–2935

# Trait Frequency Distributions by Functional Groups:




**J . KATTGE & 134 others, 2011. TRY – A Global Database of Plant Traits.**
Global Change Biology (2011) 17, 2905–2935

# How to Address Biological Complexity in Spectral Properties?




Species from a local area: 583 individual tree canopies in 100 ha

How to Interpret spectral variability within a Functional Type?

Discrete functional groups don't capture continuous variation within and between groups

Unpublished data courtesy of Greg Asner

Measured by CAO-2 Imaging Spectrometer at 100 ha site in the lowland Amazon.
Data controlled for shade and minimum 0.5 NDVI

# Peter Reich: Key Canopy Traits Drive Forest Productivity

*Proc. R. Soc. B,* 2012. **279**: 2128-2134

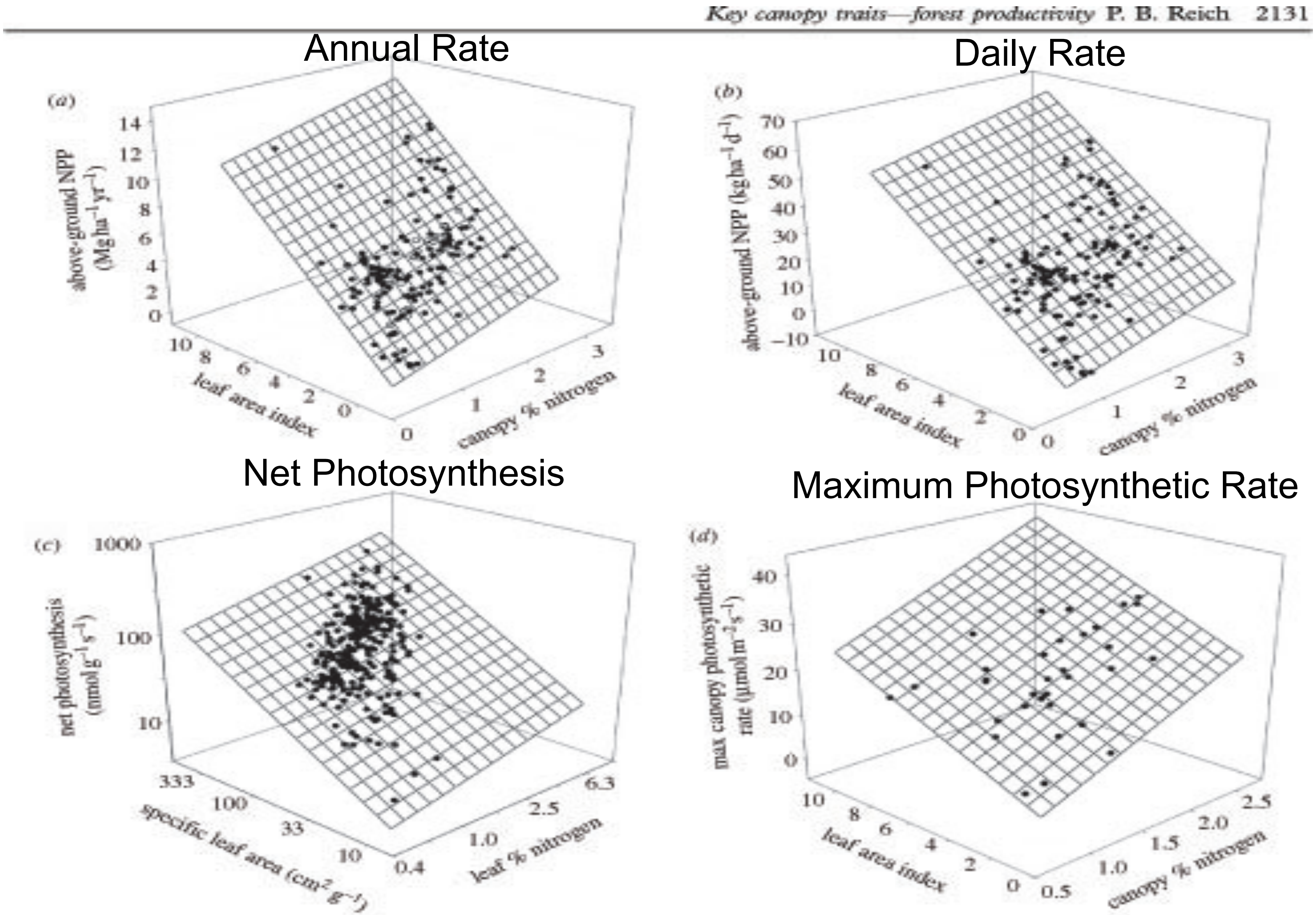
"Stand-scale productivity is a function of the **Capacity To Harvest Light** (leaf area index, **LAI**) and to **Biochemically Fix Carbon** (canopy nitrogen concentration, **%N**)"

- LAI + % canopy N explain >75% variation in above-ground NPP among temperate and boreal forests, per year or per day of growing season.

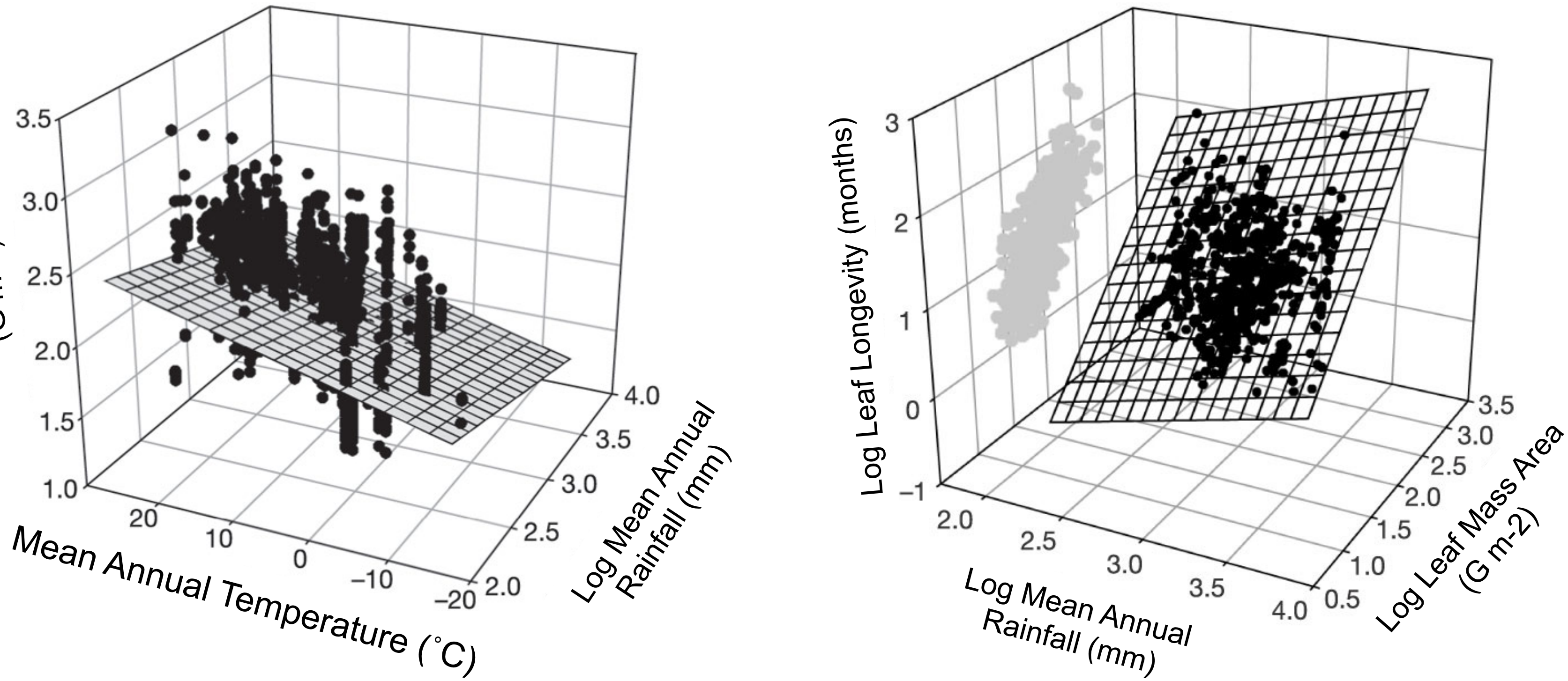
- Including **Growing Season Length** and **Climate** effects explains **90% variation**

* Eddy flux measures show similar dependence of photosynthetic rates on LAI and N.

# Relationships between Leaf Area Index and % Canopy Nitrogen with Measures of Productivity



# A Global Universal Spectrum of Leaf Economics: Key Co-Varying Structural and Physiological Properties

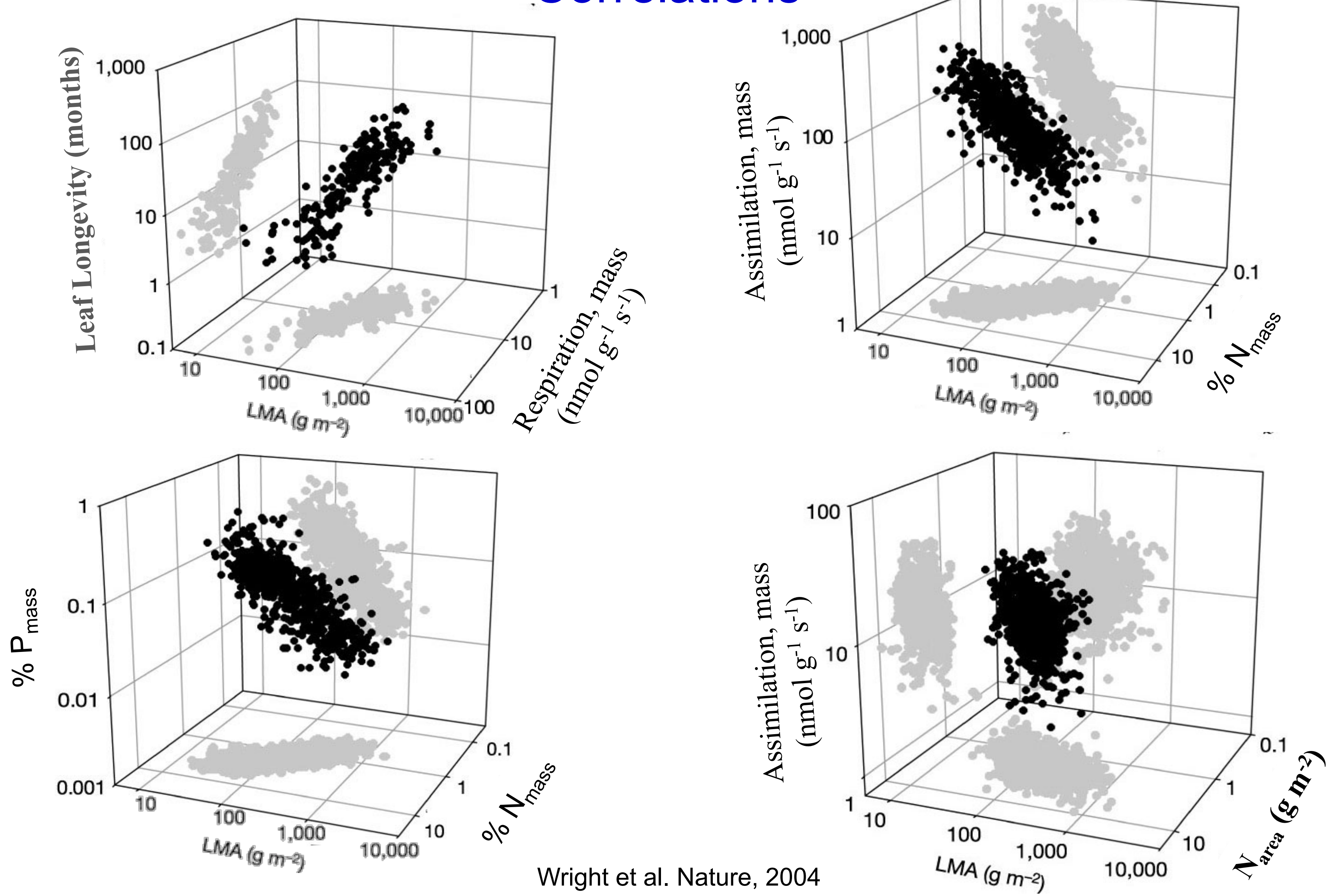



Traits vary from fast to slow return on investments in nutrients and dry mass in leaves, and operate largely independently of growth form, PFT or biome

>2500 species from 175 global sites

Wright et al. Nature, 2004

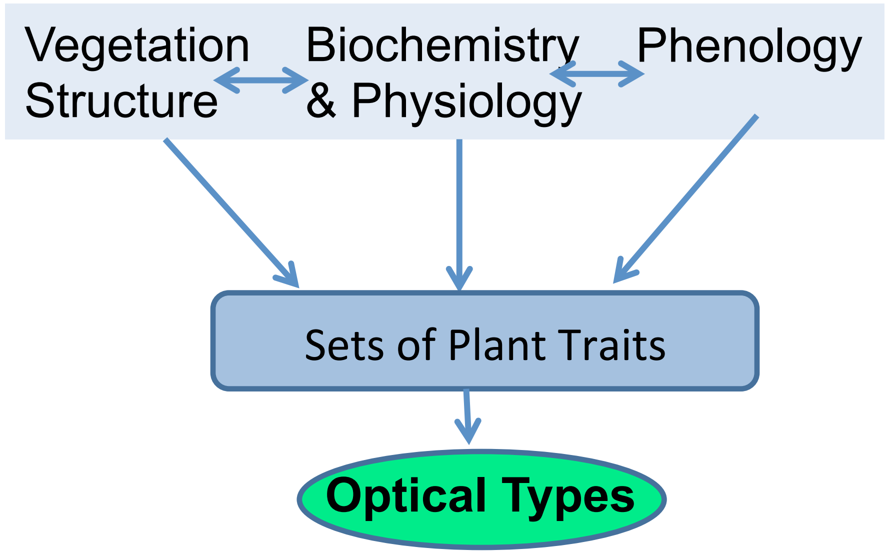
# Leaf Investment Strategies are Largely Arrayed Along A Single Spectrum, With a Globally Consistent Pattern of Trait Correlations




Wright et al. Nature, 2004

# The Concept of Leaf Optical Types: An Alternative to Mapping Functional Types

- Based on Theory of Functional Convergence
- Limited Range of Leaf Functional Strategies

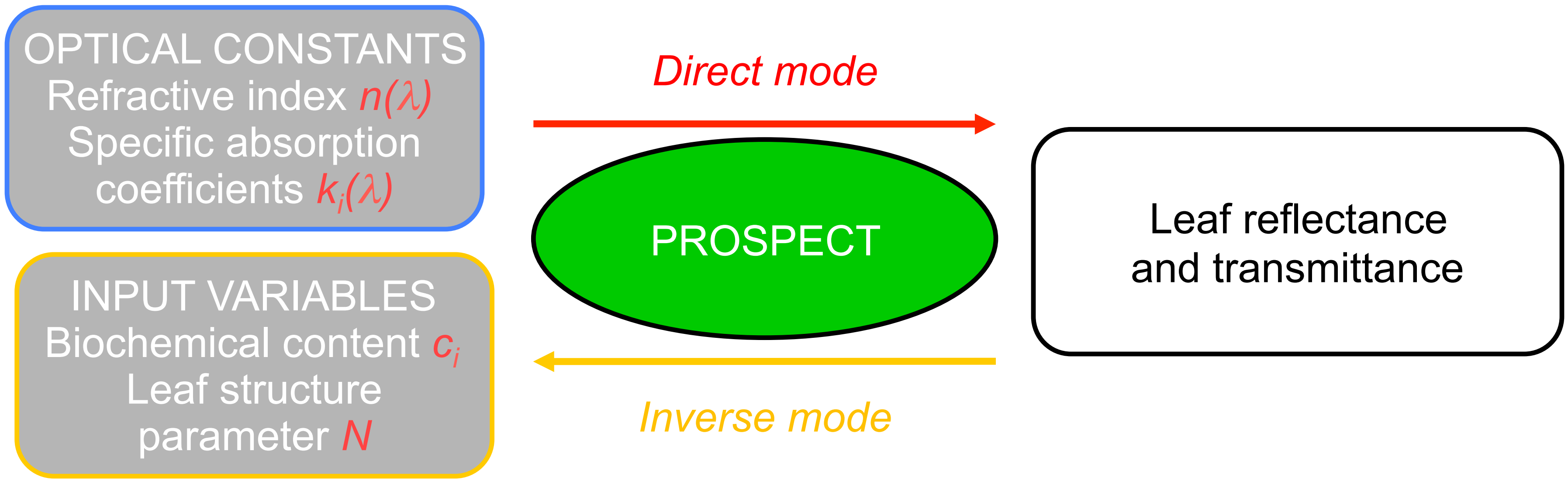


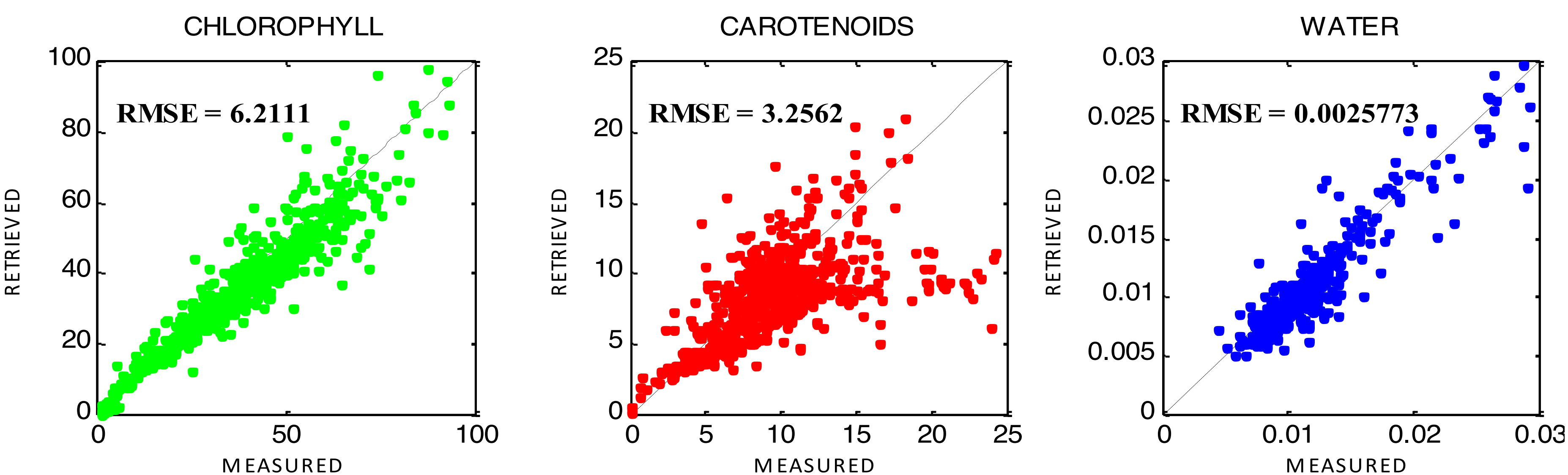

Ustin and Gamon: New Phytologist 186: 795-816

*A few key leaf traits ("trait syndromes") regulate the fluxes of carbon and water in terrestrial ecosystems*

The Generalized Leaf Trait literature, developed over the past decade, provides a framework to translate changes in spectral properties into measurements of ecosystem function

# Retrieving Leaf Chemistry from Reflectance: PROSPECT




J.B. Féret, C. François, G.P. Asner, A.A. Gitelson, R.E. Martin, L.P.R. Bidel, S.L. Ustin, G. le Maire & S. Jacquemoud, 2008, PROSPECT-4 and 5: Advances in the leaf optical properties model separating photosynthetic pigments, *Remote Sensing of Environment*, 112:3030-3043.

# Detectable Optical Properties Using Imaging Spectrosco

Leaf area index
Leaf Mass Area (=1/SLA)
Chlorophyll and Carotenoid Pigments
Canopy Water Content

Xanthophyll pigments
Leaf Longevity
Leaf Nitrogen
Ligno-cellulose

Do plants optimize light harvesting, water & nutrient resources for given climate conditions?

These Optical Properties are consistent with Generalized Leaf Trait literature developed over the past decade.

# Finding Universal Features for Spectral Traits

1. Plant Trait Databases (spectral libraries)
2. Using models to identify better band placements for retrievals

Most vegetation indexes are based on the available bands not the best wavelengths

Leaf Mass Area:

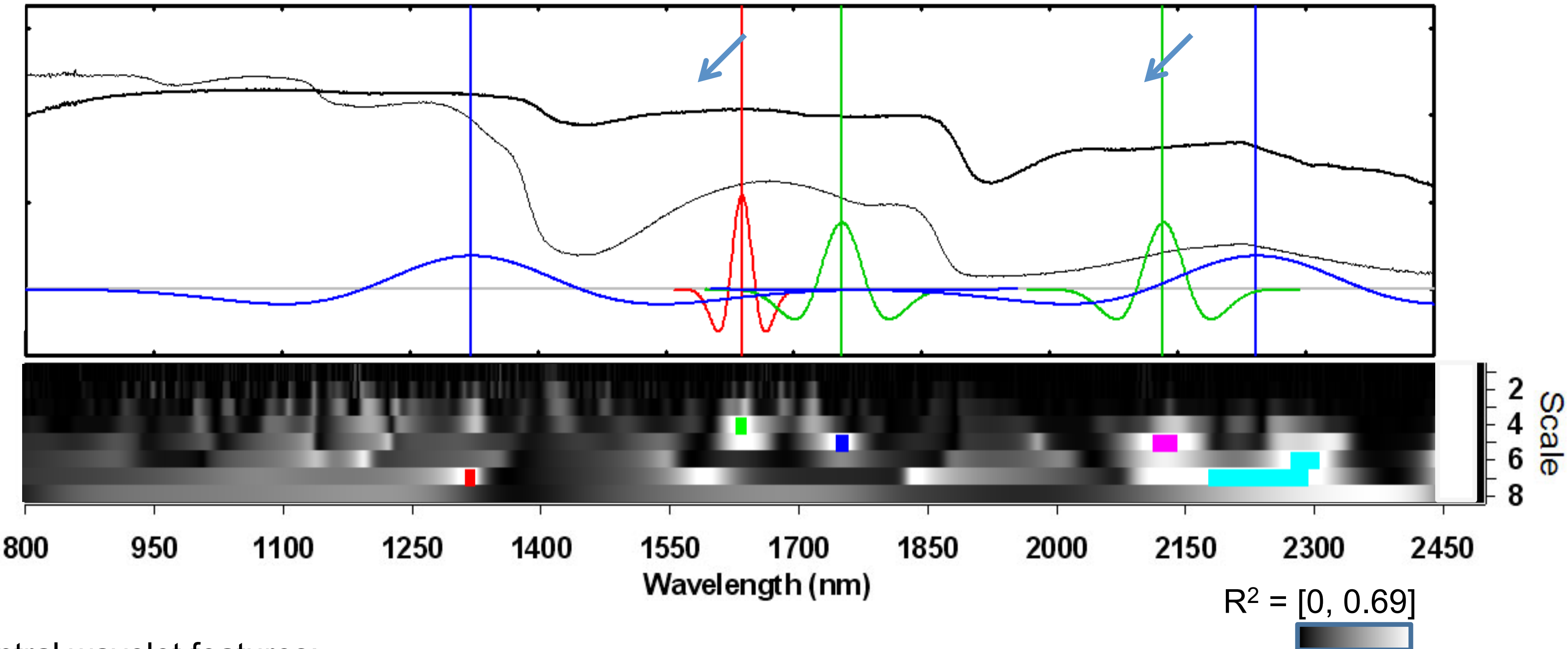
$$ND_{LMA} = R_{1368} - R_{1722} / R_{1368} + R_{1722}$$

(Feret et al., 2011)

$$NDMI = R_{1649} - R_{1722} / R_{1649} + R_{1722}$$

(Wang et al., 2011)

# Finding Universal Features for Spectral Traits: Wavelet Analysis



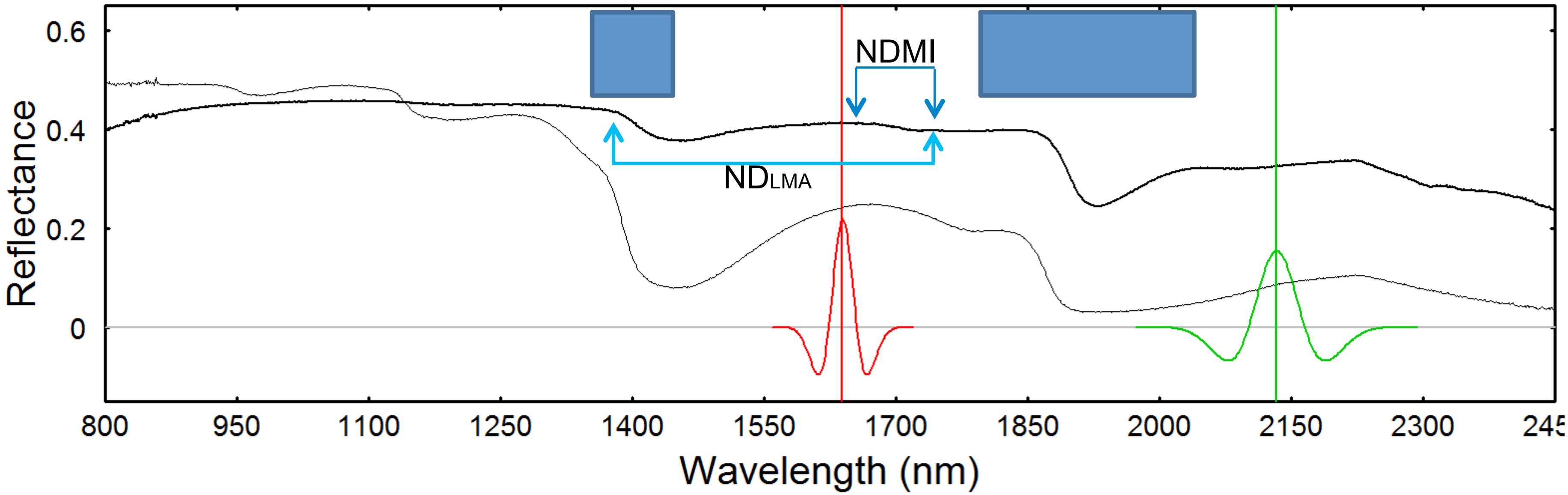

Central wavelet features:

- (1322 nm, scale 7): broad absorption by water @ 1200 nm and 1430 nm
- (1639 nm, scale 4): absorption by starch and sugar @ 1580 nm and lignin @ 1690 nm
- (1756 nm, scale 5): absorption by lignin @ 1690 nm, absorption by cellulose @ 1780 nm
- (2133 nm, scale 5): absorption by starch @2100 nm, absorption by protein and nitrogen @ 2180 nm
- (2242 nm, scale 7): overlapping absorptions by dry matter constituents starch, cellulose, protein, nitrogen and oil

Most robust features for transferring a regression model from simulated data to measured data:

- (1639 nm, scale 4)
- (2133 nm, scale 5)

# Sensitivity of Indexes to Atmospheric Water Absorption




Effect of removing two strong atmospheric absorption regions: 1340-1450 nm and 1790-2030 nm:

- The feature (1639 nm, scale 4) is not affected. The influence on the feature (2133 nm, scale 5) is minimal.

- $ND_{LMA}$ **IS** affected. The 1368 nm band must be shifted to shorter wavelengths for satellite data.
- NDMI is not affected.

$$ND_{LMA} = R_{1368} - R_{1722} / R_{1368} + R_{1722}$$

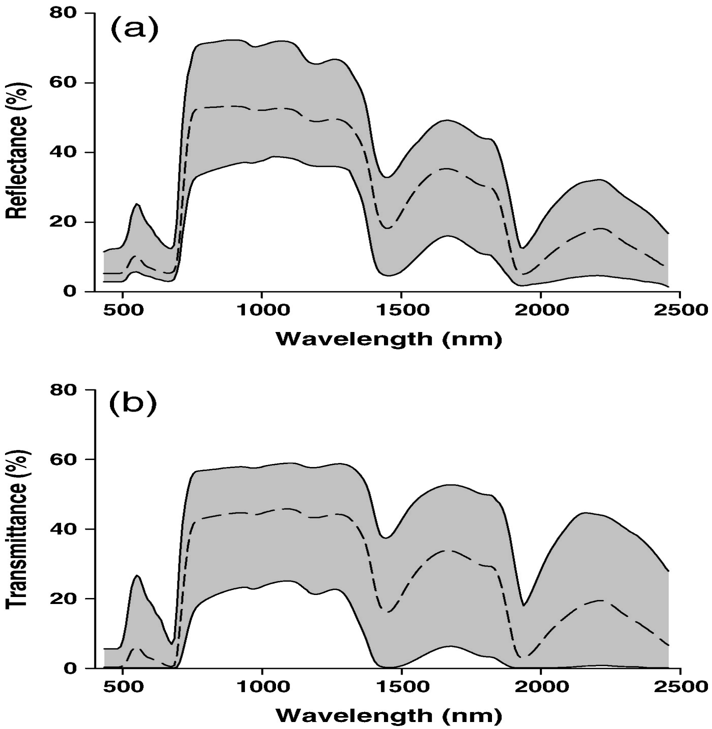
(Feret et al., 2011)

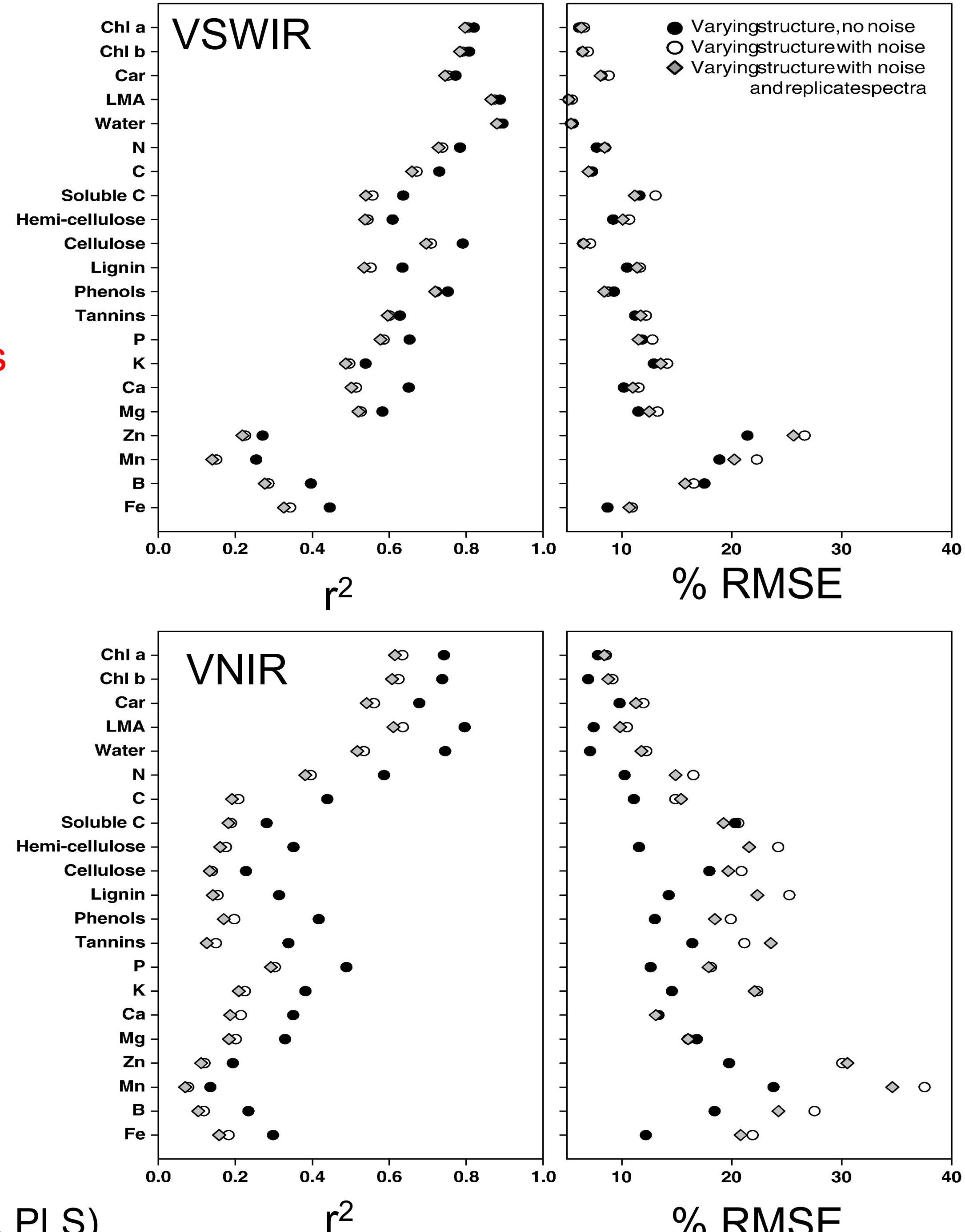
$$NDMI = R_{1649} - R_{1722} / R_{1649} + R_{1722}$$

(Wang et al., 2011)

# Detailed Chemistry Retrieval from Canopy Reflectance

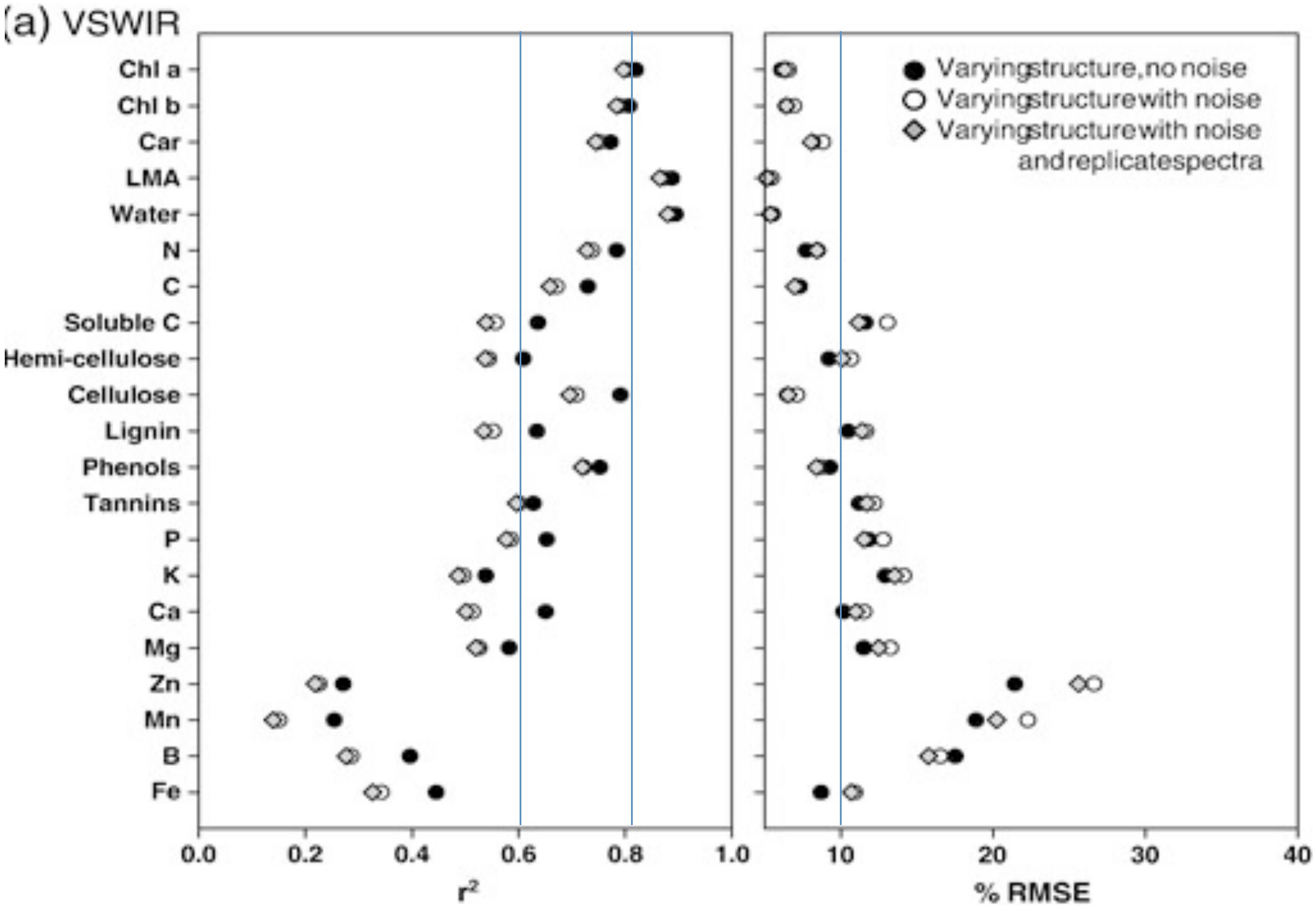
6136 Humid Tropical Forest Canopies



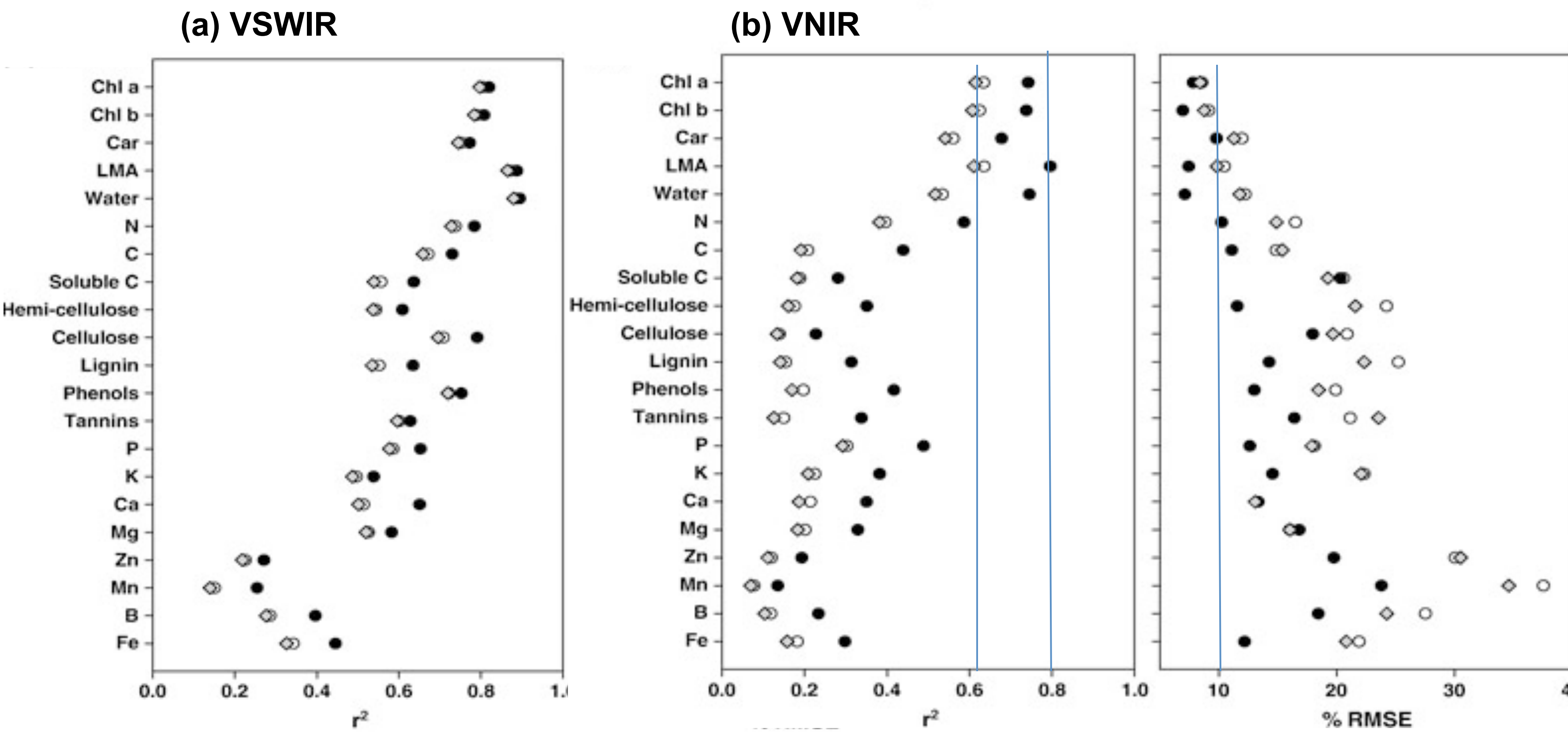

Asner et al. 2011 RSE (PROSPECT, RTM, PLS)

# Detailed Chemistry Retrieval from Canopy Reflectance




Asner et al. 2011 RSE

# Detailed Chemistry Retrieval from Canopy Reflectance



# New & Improved IS Products for Monitoring Ecosystem Functioning

1) **Ecosystem chemistry and physiological condition**

- **Leaf mass area (LMA)*, Leaf Longevity***
- **Water***
- **Ligno-cellulose***
- **Foliar pigments (*chlorophyll**, *carotenoids*‡, *anthocyanins* ‡)**
- **Nitrogen†**, *Phosphorous*†

2) **Ecosystem health**

- ***Canopy structure (improved LAI*, gap distribution*)***
- ***Species Composition (fractional composition‡)***
- ***Other Canopy Chemistry †***
- ***General stress indicators (e.g., PRI ‡, red edge ‡)***

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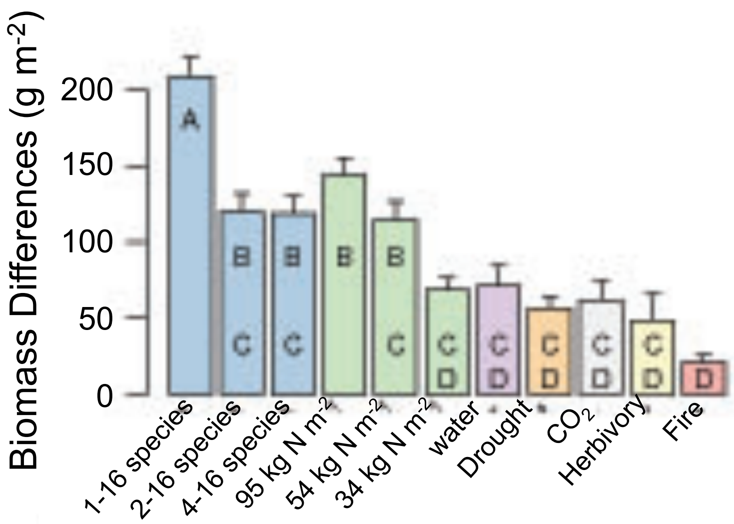
**application ready ‡advanced †researched*

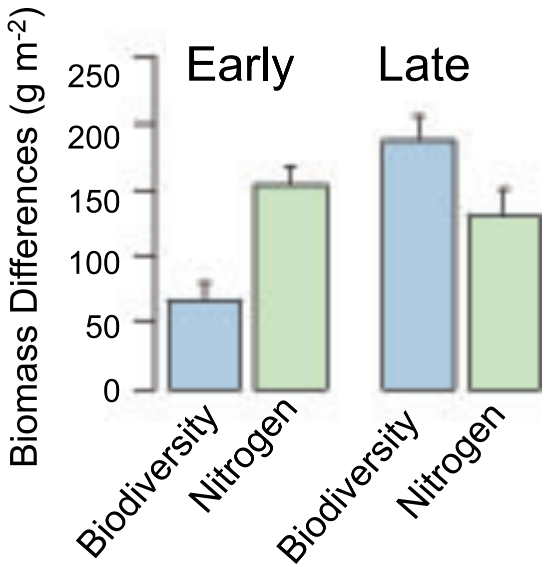
# What is the Impact of Biodiversity on Ecosystem Productivity?

Tillman and Reich (2012) studied effects of biodiversity on NPP compared to:

- Added nitrogen: 0, 34, 54 or 95 kg N·ha$^{-1}$·y$^{-1}$
- Water: ~50% increase or decrease
- Elevated $CO_2$, 560 ppm
- Annual fire
- Herbivory (Deer exclosures)

11 experiments manipulated one or more factors over a period of 5 to 28 yr




Tillman and Reich, 2012. PNAS 109: 10394-10397.

Impact of biodiversity increases with time

# Improvements in Monitoring Ecosystem Multifunctionalitywith Imaging Spectroscopy (+LiDAR and TIR)

| Major Model Inputs | CASA | SiB3 | Ecosystem Demography |
|---|---|---|---|
| | | | |
| Vegetation Distributions | IS | IS | IS |
| Multifunctional Plant Distributions | IS+LiDAR+TIR | IS+Lidar+TIR | IS+Lidar+TIR |
| Fractional Carbon Cover | IS | IS | IS |
| Vegetation Greenness | IS | IS | IS |
| Fractional PAR Absorption | IS | IS | IS |
| Leaf Area Index (0-4 LAI units) | IS | IS | IS |
| Leaf Area Index (4-10 LAI units) | IS | IS | IS |
| Canopy Gap Frequency and Size | LiDAR +IS | LiDAR +IS | LiDAR +IS |
| Light-use Efficiency (leaf water, N) | IS | IS | IS |
| | | | |
| Live vs. Senescent Biomass | IS/LiDAR | IS/LiDAR | IS/LiDAR |
| Woody vs. Leaf Biomass | LiDAR | LiDAR | LiDAR |
| Canopy Allometry | Prescribed | Prescribed | Prescribed |
| | | | |
| Disturbance Type and Intensity | IS | IS | IS |

*based on assumption that IS has capability of HyspIRI like instrument

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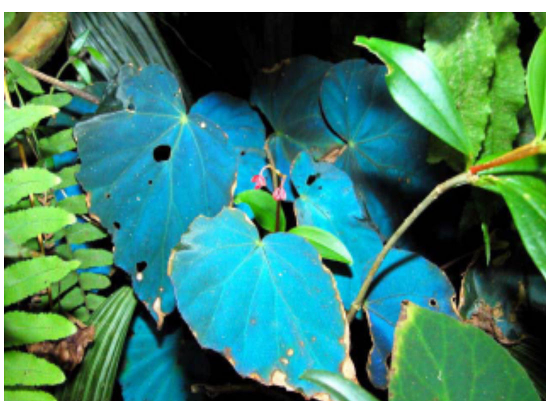
John Gamon, U Alberta

NASA TE, Hydrology, Biodiversity and HyspIRI programs!



# Questions?

Model of Proposed HyspIRI Satellite