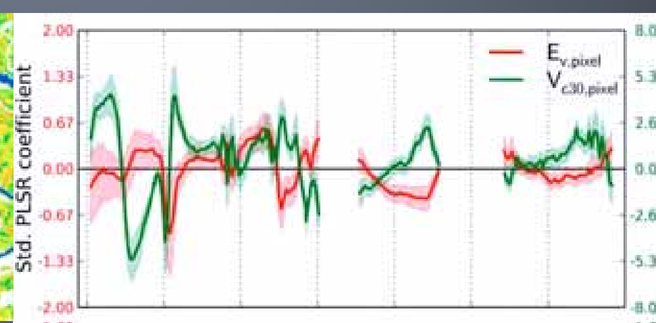
Hypertemporal and Hyperspectral Remote Sensing Applications for Regional Water Quality Assessments

Aditya Singh
Department of Agricultural and Biological Engineering
University of Florida, Gainesville



UF | IFAS
UNIVERSITY of FLORIDA

EcoDyn
The Ecosystem Dynamics Laboratory, University of Florida - Gainesville

Background

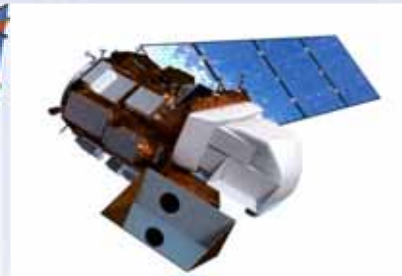
Pressing issues:

- Biodiversity loss, anthropogenic disturbances, climate change etc…
- Increasing pressures on ecosystem service provisioning

- Remote sensing an important tool historically
- Allows regional assessments extrapolations from field-based studies
- Synoptic, repeatable measurements

- Continuing need for new tools and techniques for the most pressing issues

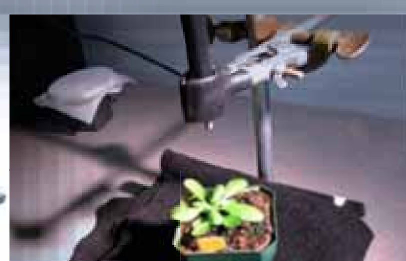
Optical remote sensing: tradeoffs in scale/resolution

Multispectral space-borne:
Landscape scale
Composition, disturbance, phenology …
$

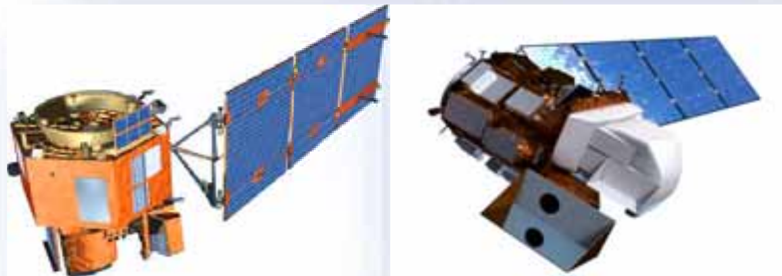

Hyperspectral airborne:
Landscape, field, plot scale
Composition, biochemistry, function, disturbance
$$$$


Hyperspectral UAS, mobile:
Plot, canopy
Plant, canopy biochemistry, function
$$ -$$$

Hyperspectral contact:
Leaf/plant scale
Leaf biochemistry, function
$$-$$$

Organization



Methodological developments in satellite remote sensing

- Landscape-scale nutrient cycling, crop production

Imaging spectroscopy

- Mapping foliar biochemical, morphological and metabolic traits and their uncertainties.

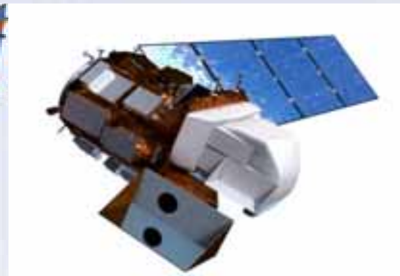
Filling gaps, ongoing research

- Desktop spectroscopy, mobile and airborne remote sensing platforms

Contact spectroscopy

- Deriving foliar biochemical and morphological traits

Organization

Methodological developments in satellite remote sensing

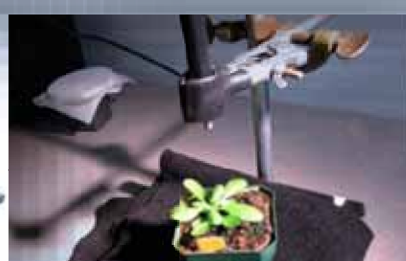
- Landscape-scale nutrient cycling, crop production


Imaging spectroscopy

- Mapping foliar biochemical, morphological and metabolic traits and their uncertainties.


Filling gaps, ongoing research

- Desktop spectroscopy, mobile and airborne remote sensing platforms

Contact spectroscopy

- Deriving foliar biochemical and morphological traits

Landscape dynamics, satellite imagery, and water quality

Remote Sensing of Environment 128 (2013) 74–86

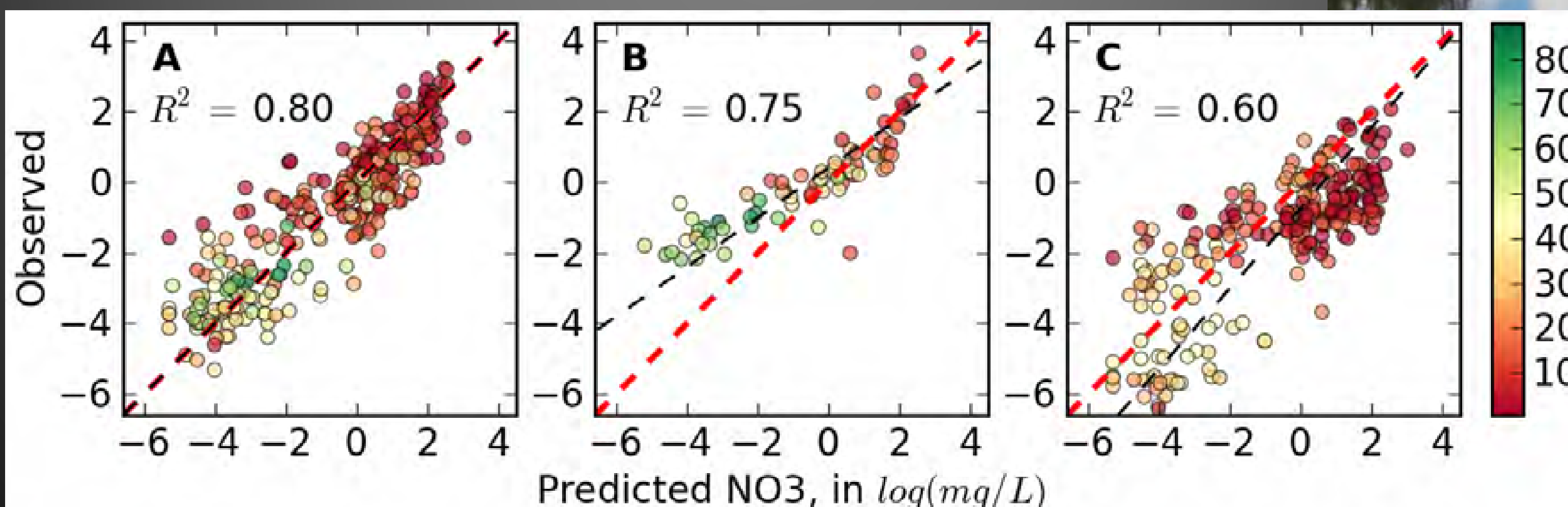
Contents lists available at SciVerse ScienceDirect

Remote Sensing of Environment

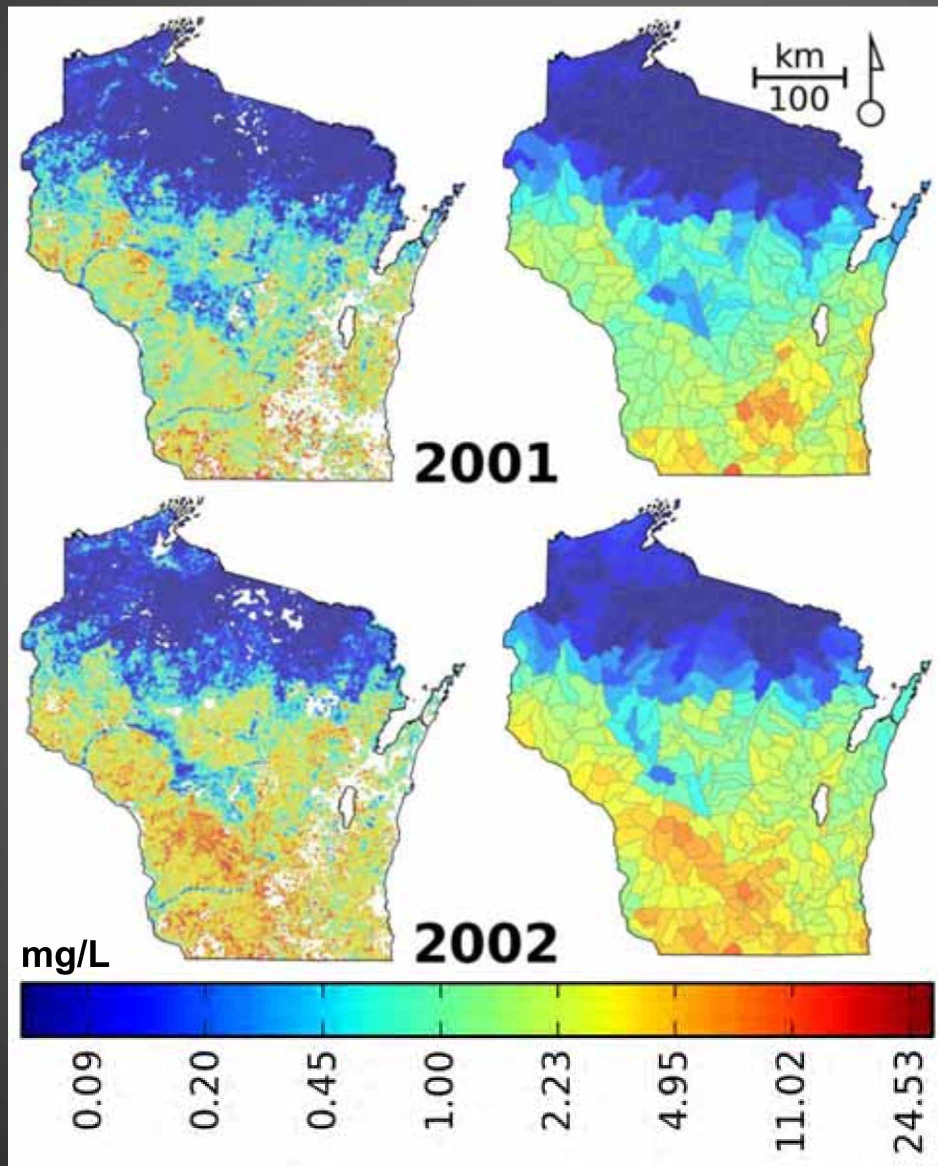
journal homepage: www.elsevier.com/locate/rse

A MODIS approach to predicting stream water quality in Wisconsin

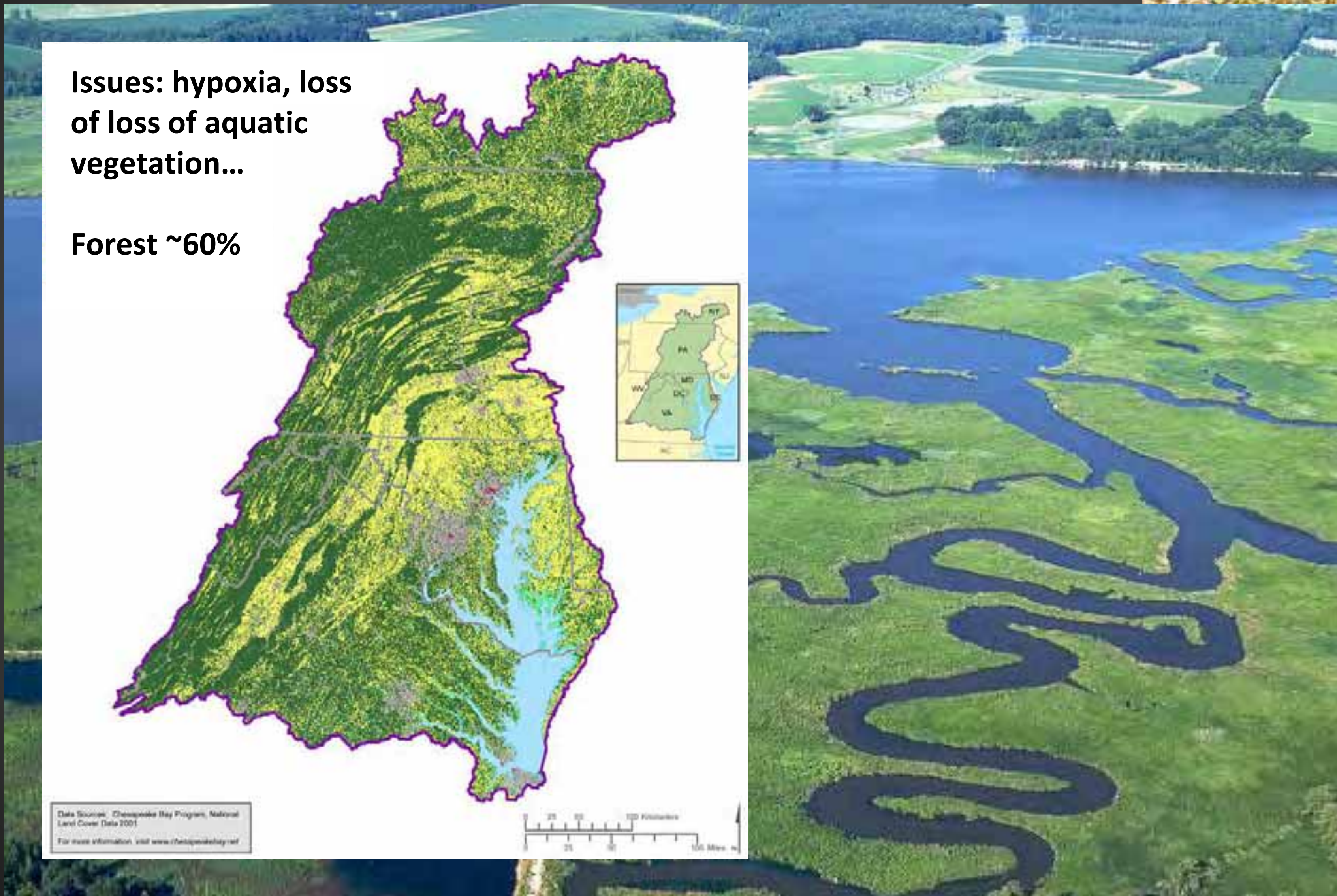
Aditya Singh [a,*], Andrew R. Jakubowski [b,1], Ian Chidister [c,2], Philip A. Townsend [a,3]



Results: Nitrate-N



Advancing to continuous-time models: The Chesapeake Bay



Issues: hypoxia, loss of loss of aquatic vegetation…

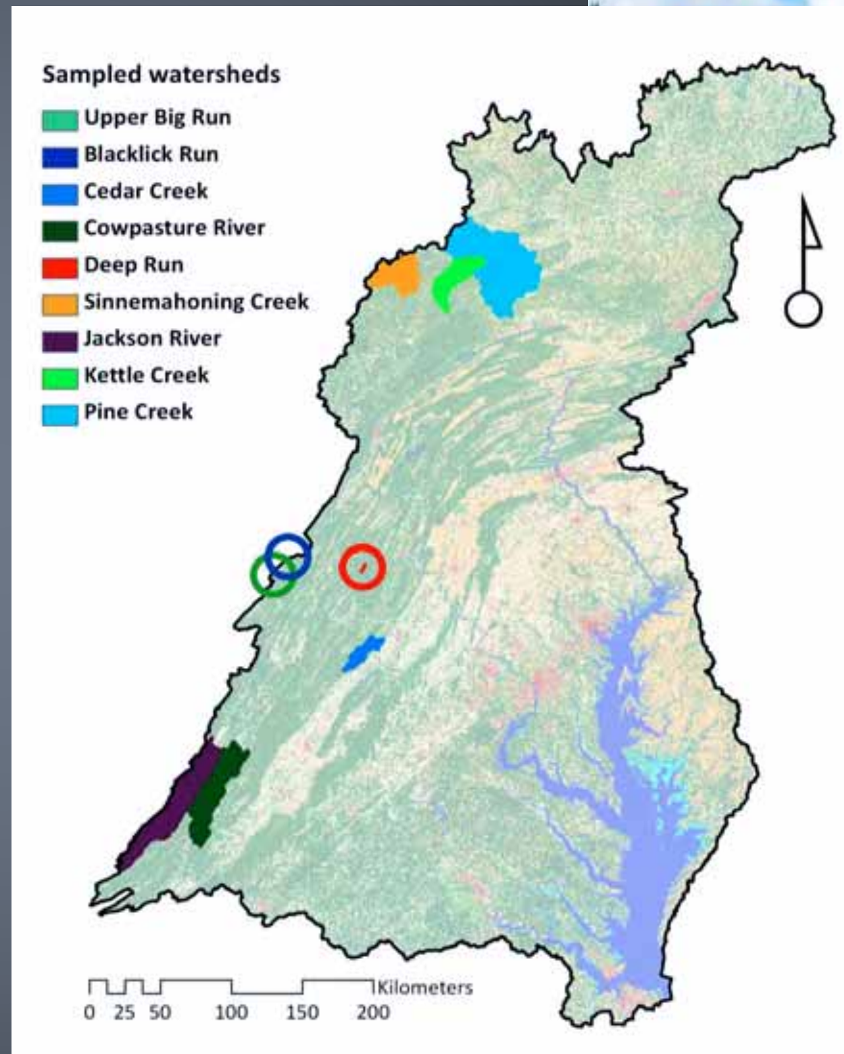
Forest ~60%

Study area: Chesapeake Bay watershed

10 Years, 9 Watersheds, Monthly Nitrate-N loads

Determine:

- ***what* influences water quality and *where?***
- ***when* are those influences most strong?**

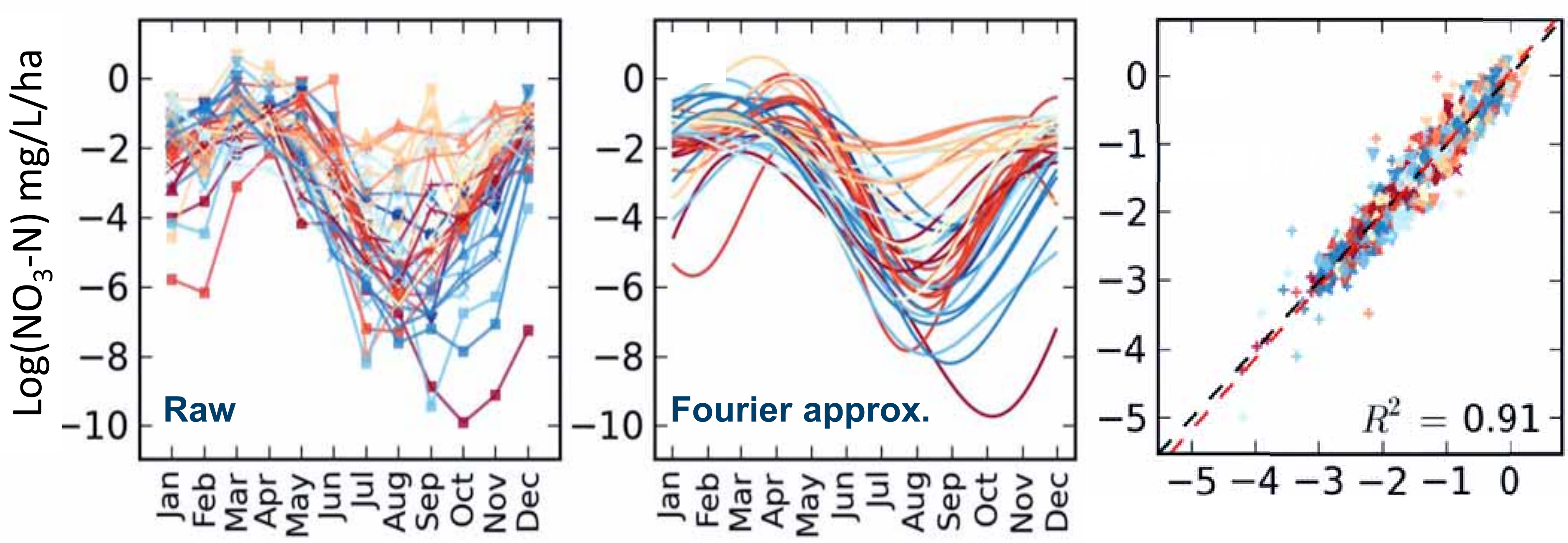


Method: Functional Linear Models (FLMs)

- **Functional models:**
  - Relate observations to *functions* of (…classically, time-varying) predictors:

$$y_i = \beta_0 + \sum_{j=1}^{k} \beta_j x_{ij} + \varepsilon_i \qquad\qquad y_i = \beta_0 + \int \beta_t x_{it} dt + \varepsilon_i$$

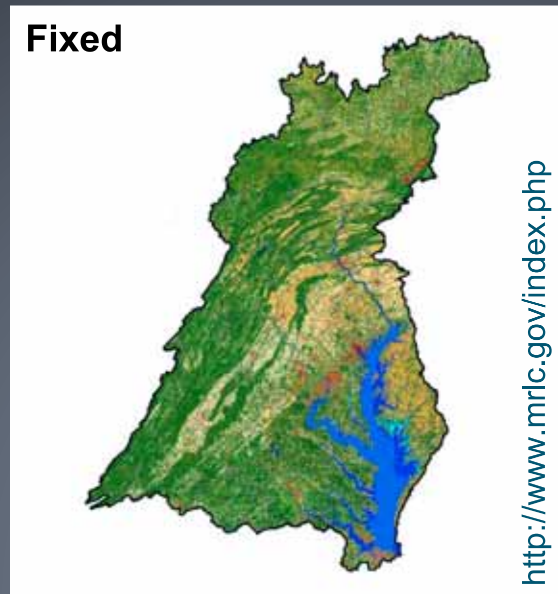
  - Flexible: responses can also be functions (FL *concurrent* models).



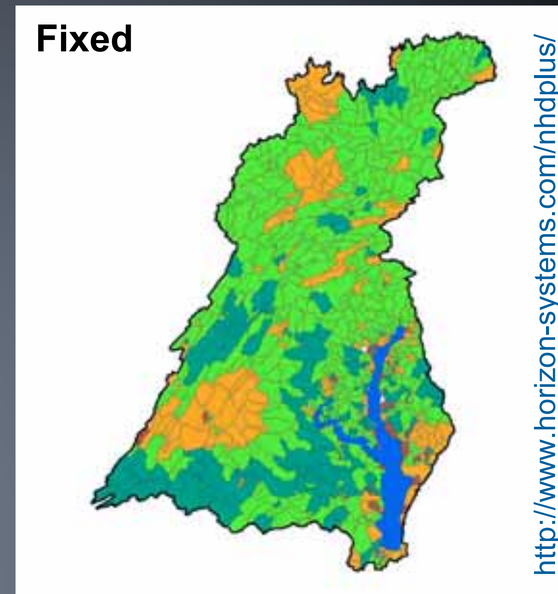
Spatial variables:

- Landcover
- Ws characteristics
- N. Deposition
- Precipitation
- NDVI
- Disturbance

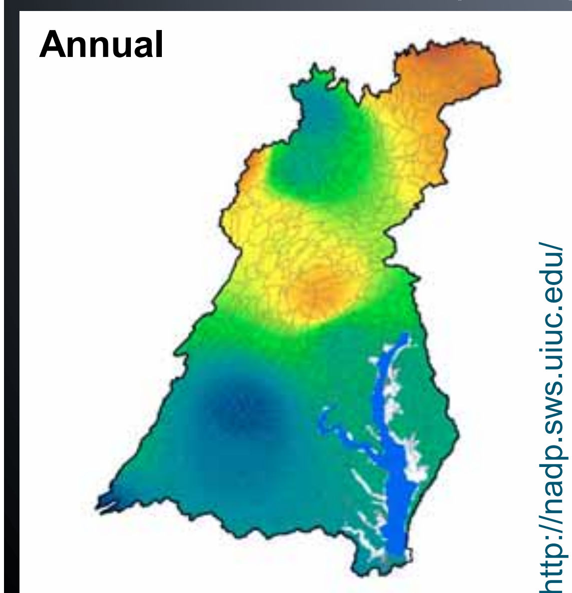
Landcover (NLCD 2006)



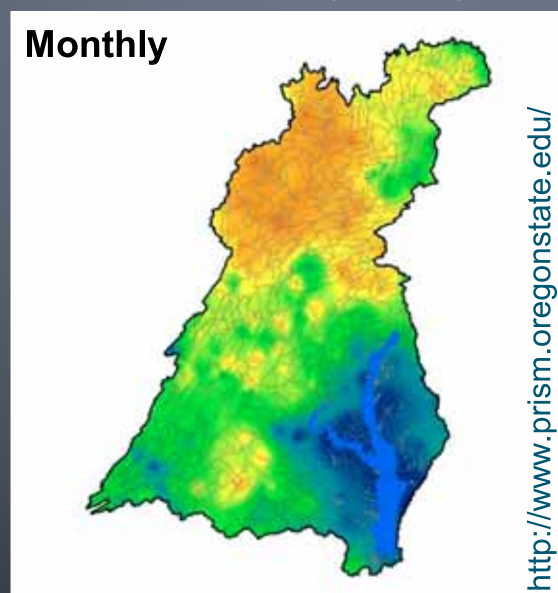
Watershed characteristics



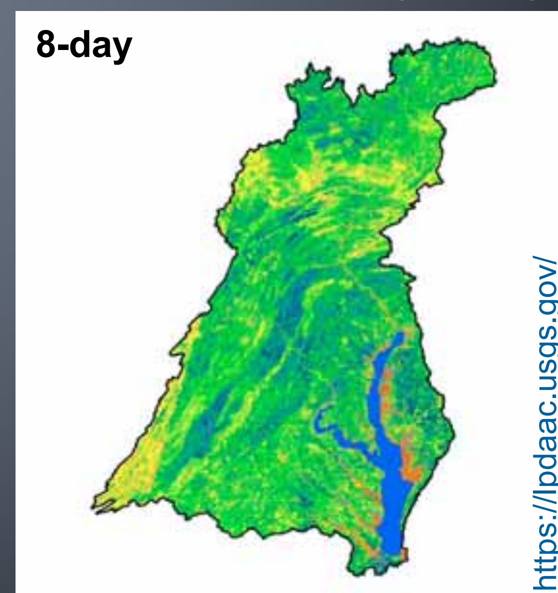
Total Atm. N deposition (NADP)



Precipitation (PRISM)



Disturbance, NDVI (MODIS)



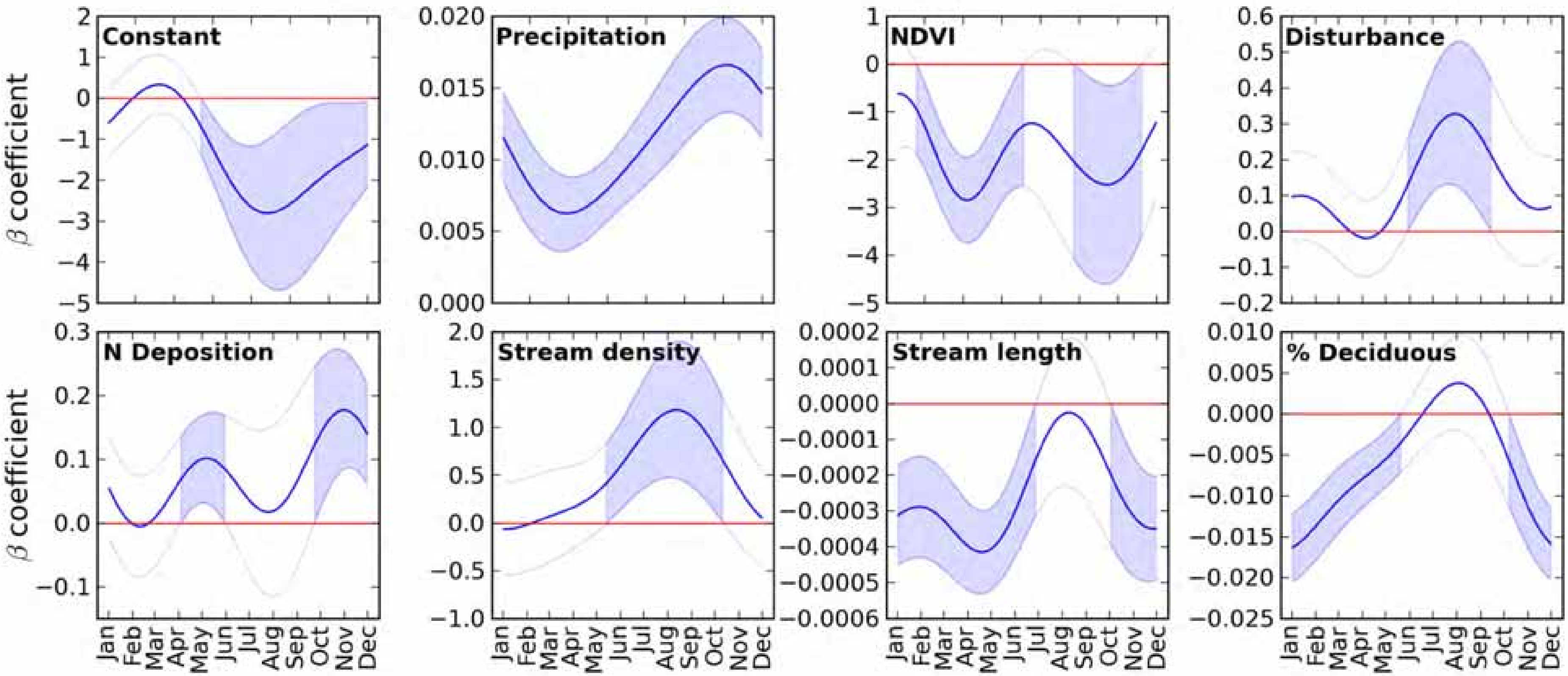
Results:

Intercept

Summer flushing

Spring uptake

Summer flushing



Direct inputs

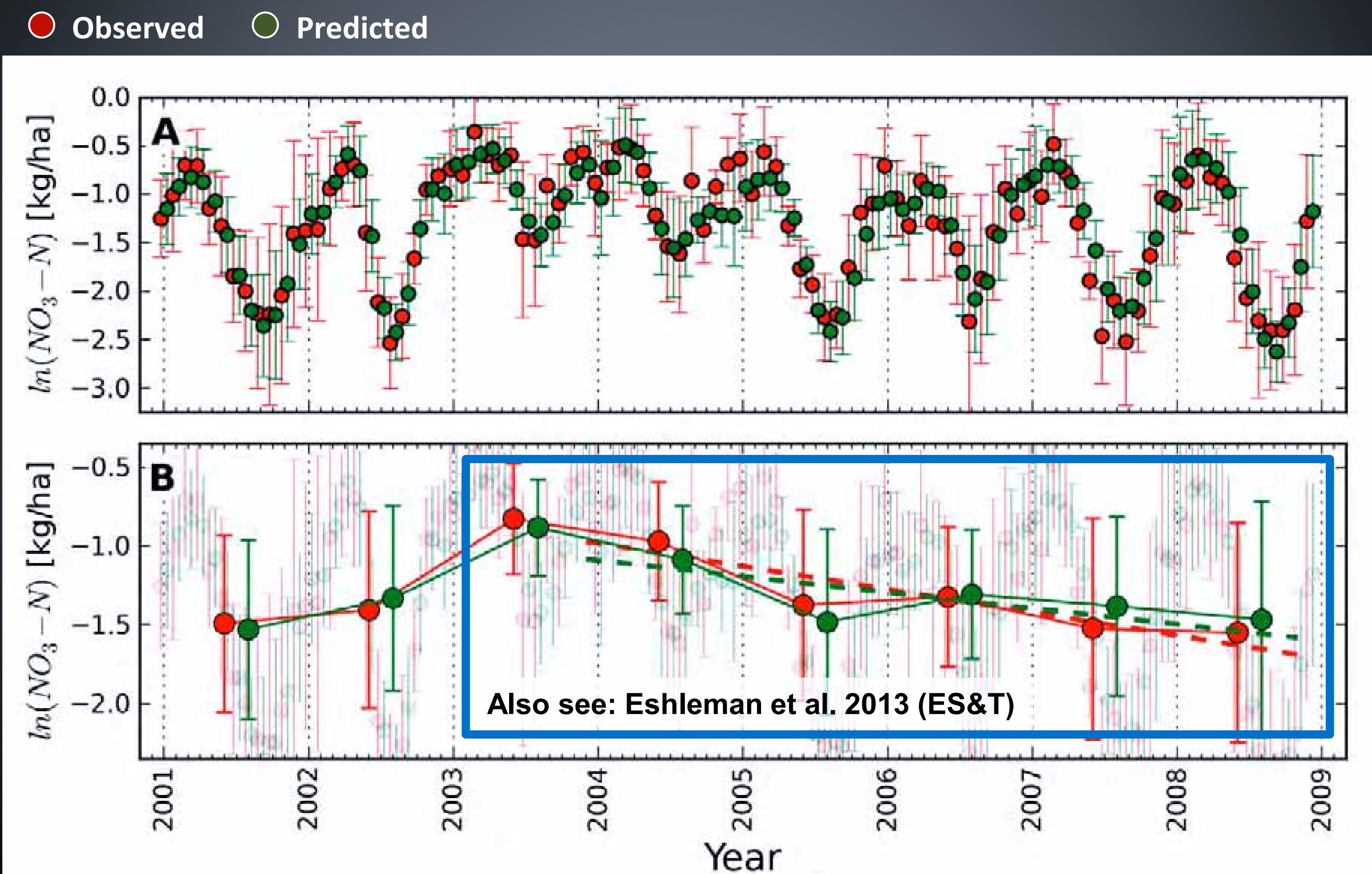
Shorter flowpath

In-stream processing

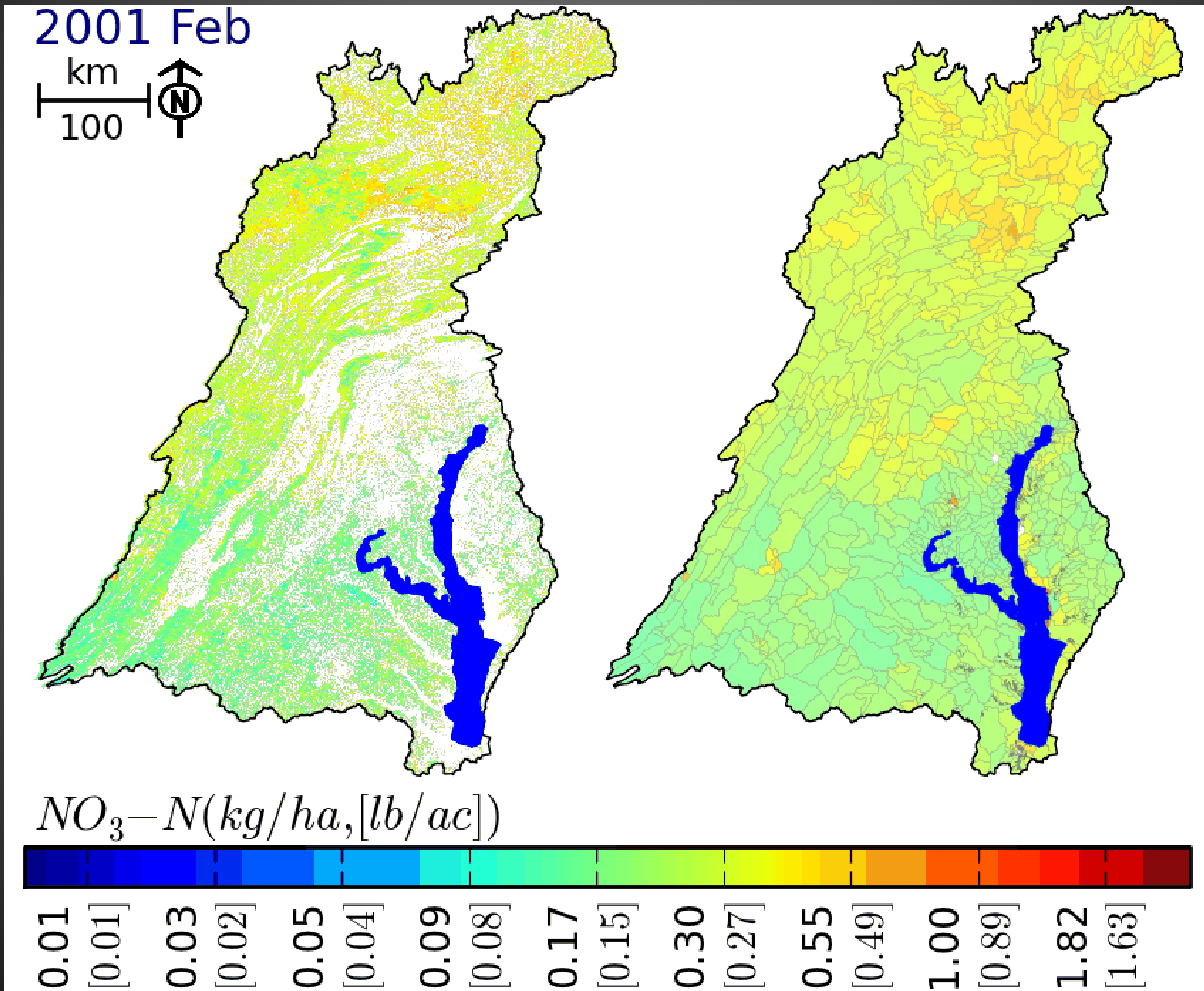
Forest functional type

Results:

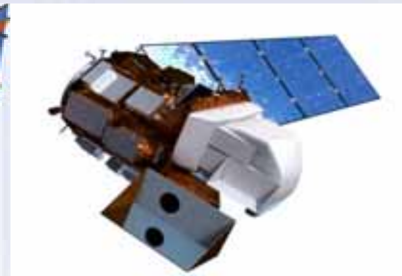
Model matches both intra- and inter-annual variations well



Results: Pixel-wise / watershed averaged predictions:



Optical remote sensing: Issues of scale and resolution

Methodological developments in satellite remote sensing

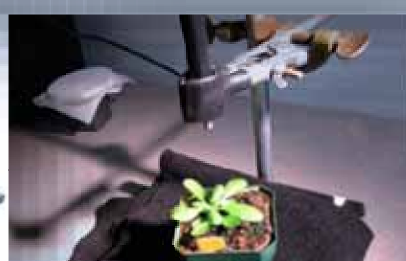
- Landscape-scale nutrient cycling, crop production


Imaging spectroscopy

- Mapping foliar biochemical, morphological and metabolic traits and their uncertainties.


Filling gaps, ongoing research

- Desktop spectroscopy, mobile and airborne remote sensing platforms

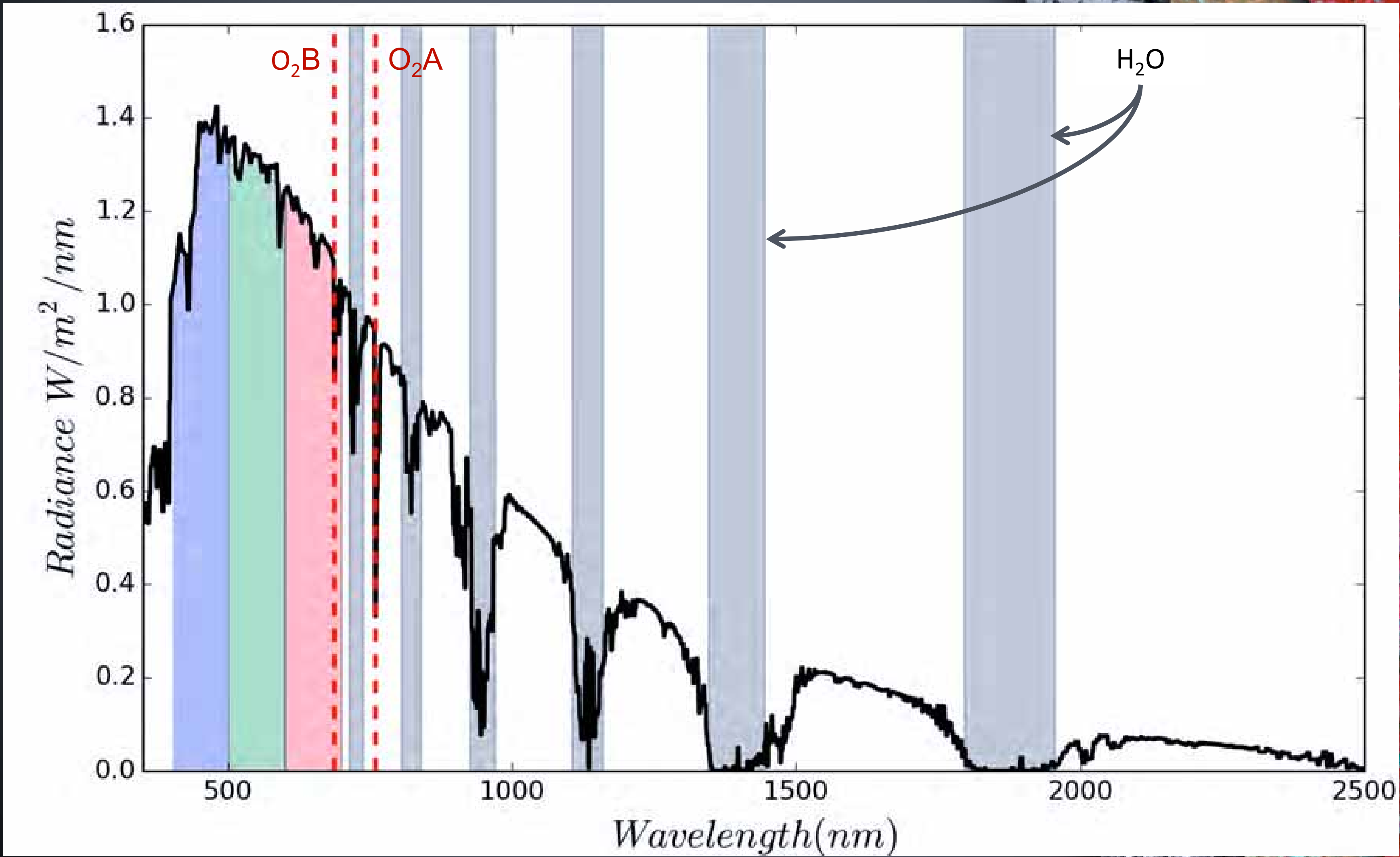



Contact spectroscopy

- Deriving foliar biochemical and morphological traits

Optical remote sensing: Issues of spectral resolution

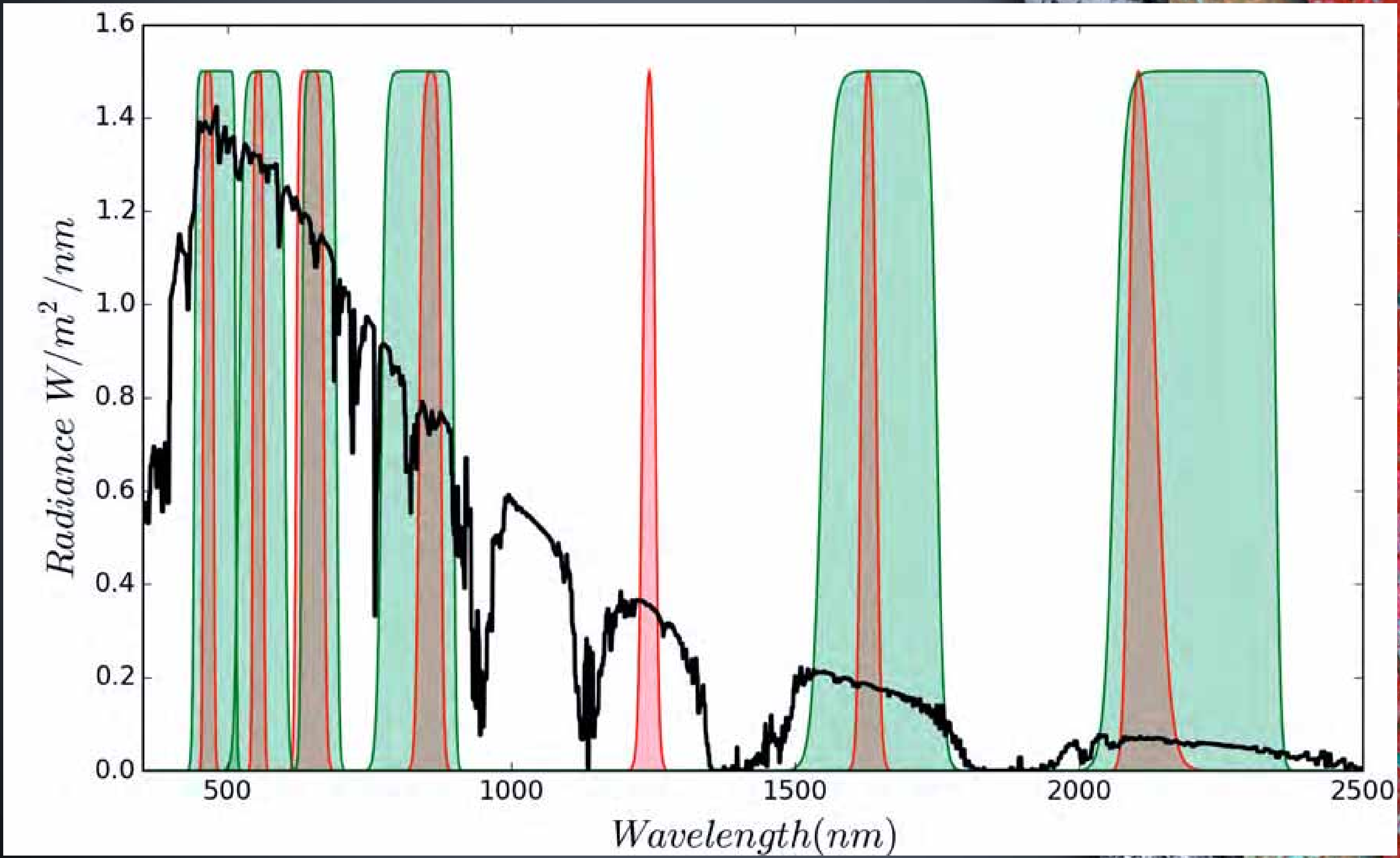
Solar spectral irradiance at sea level



Optical remote sensing: Issues of spectral resolution

Spectral sampling: Multispectral sensors

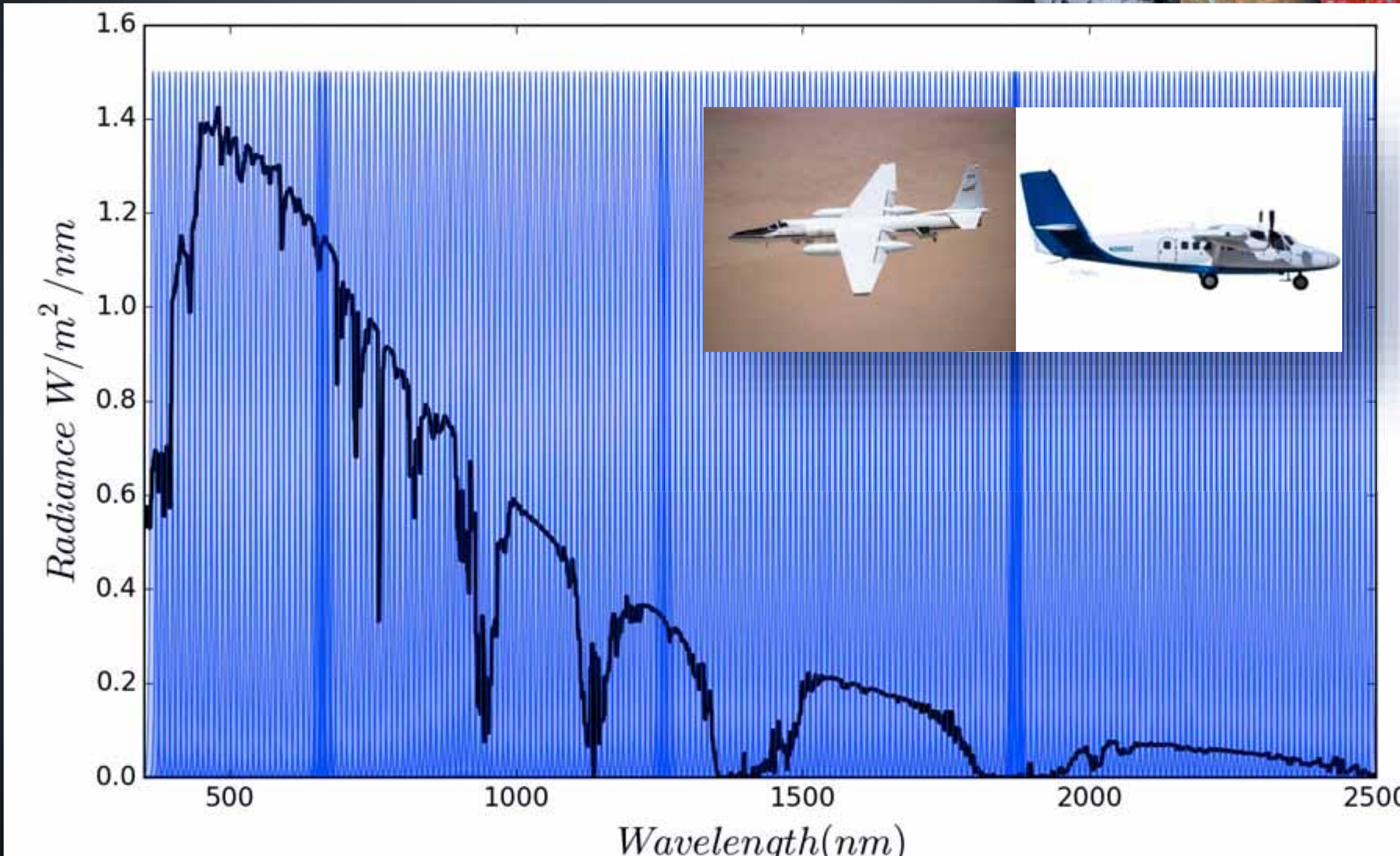
MODIS Terra, Landsat 7



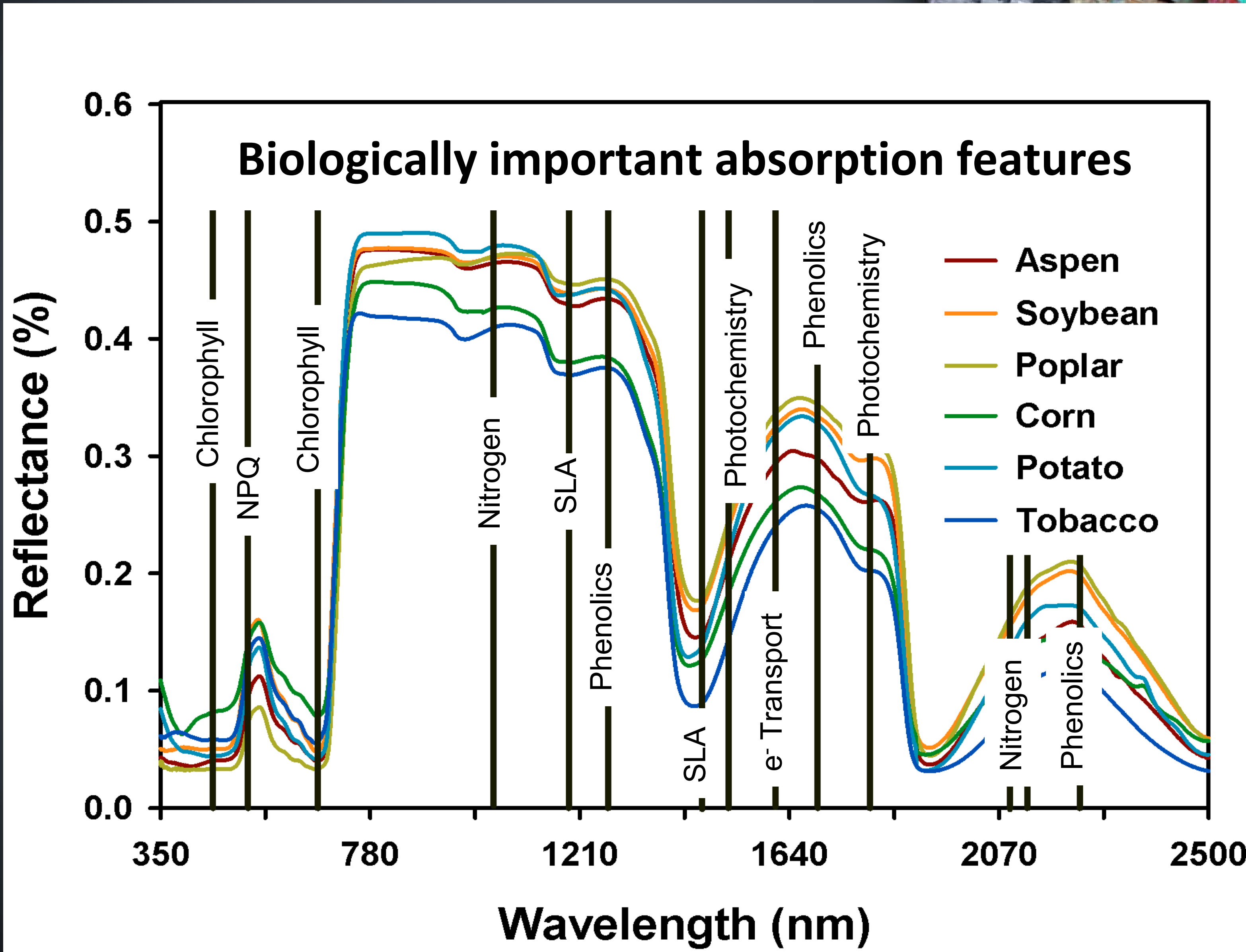
Optical remote sensing: Issues of spectral resolution

Spectral sampling: Hyperspectral sensors

AVIRIS-C

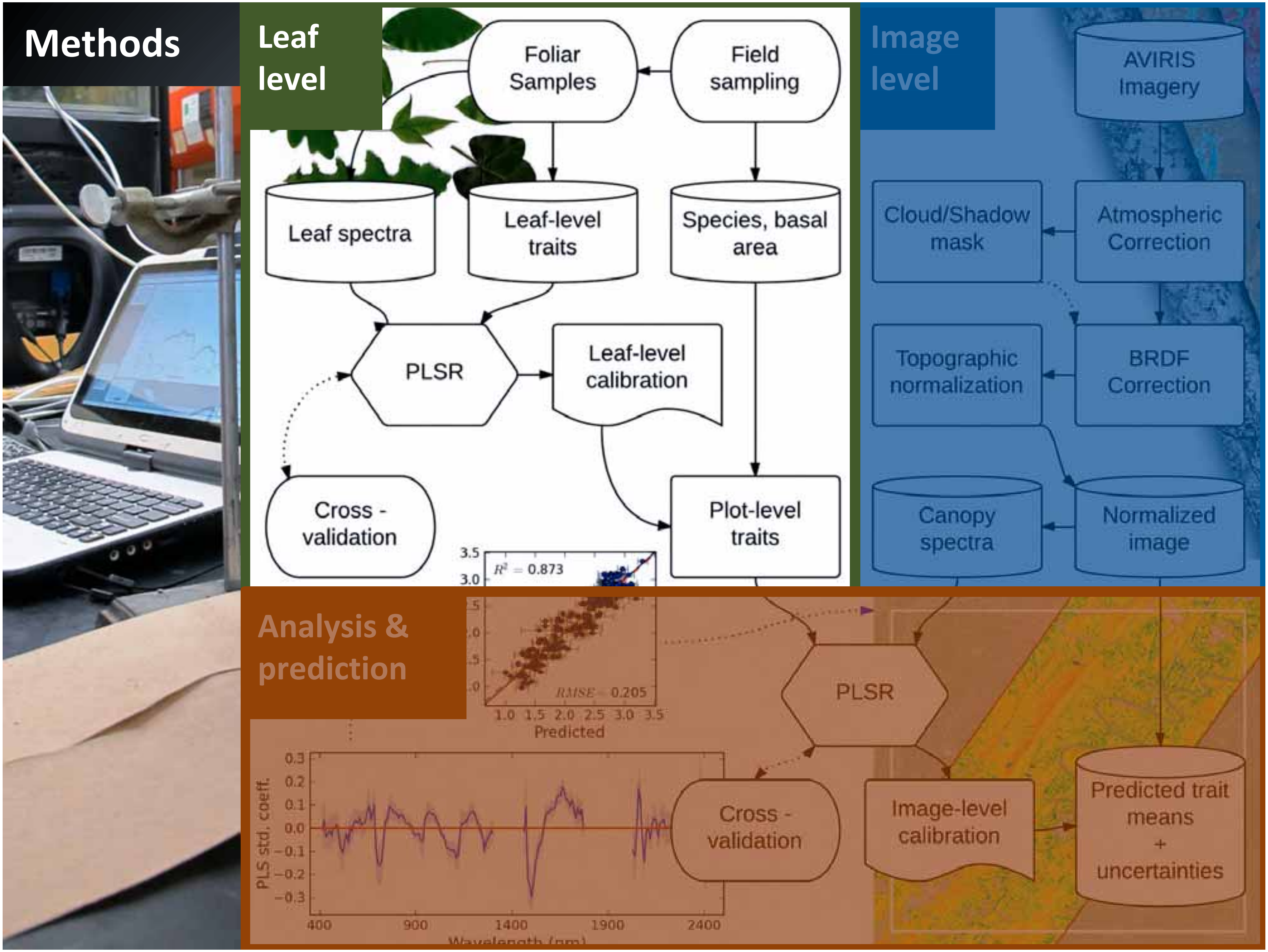


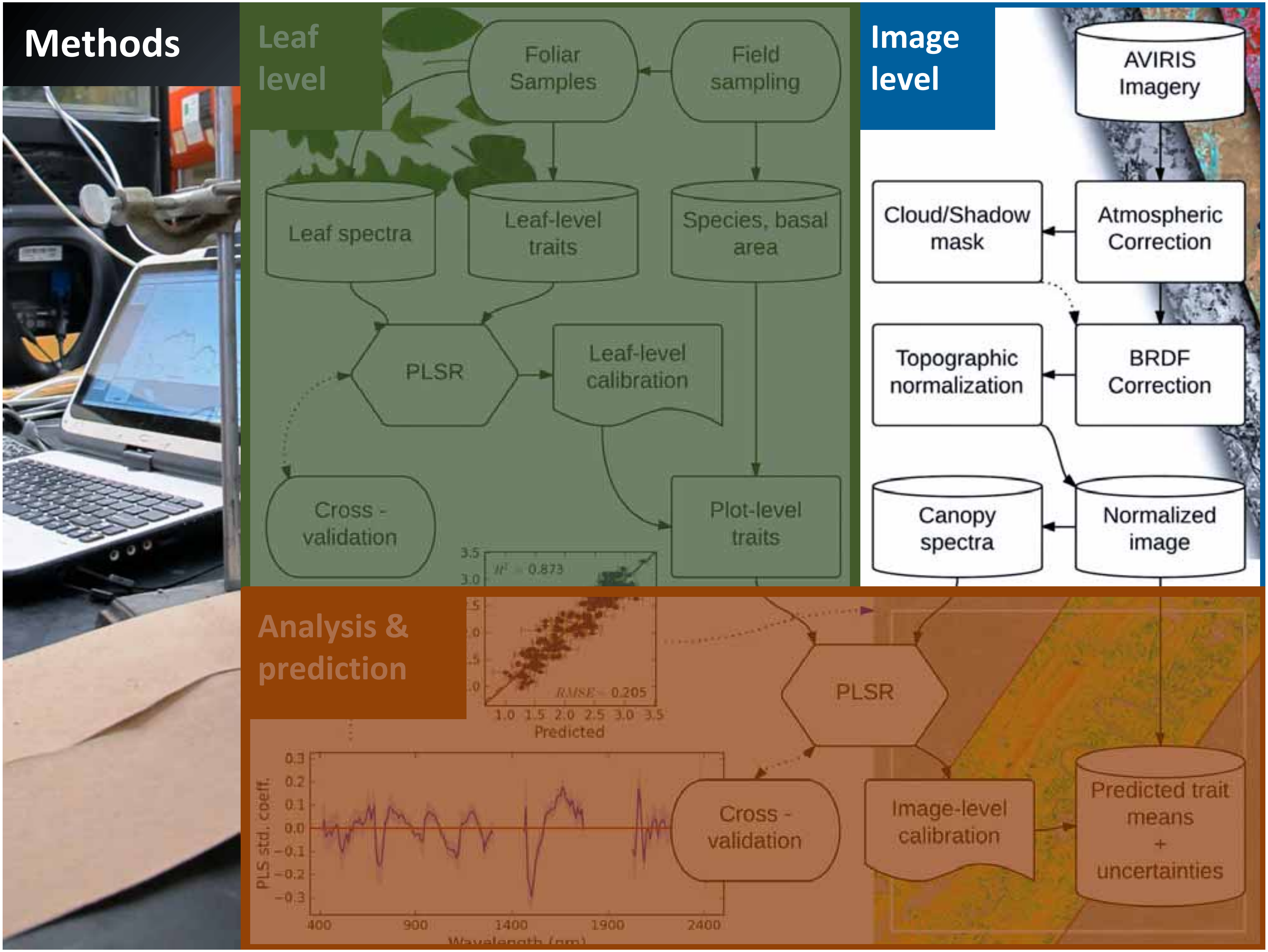
Spectroscopy



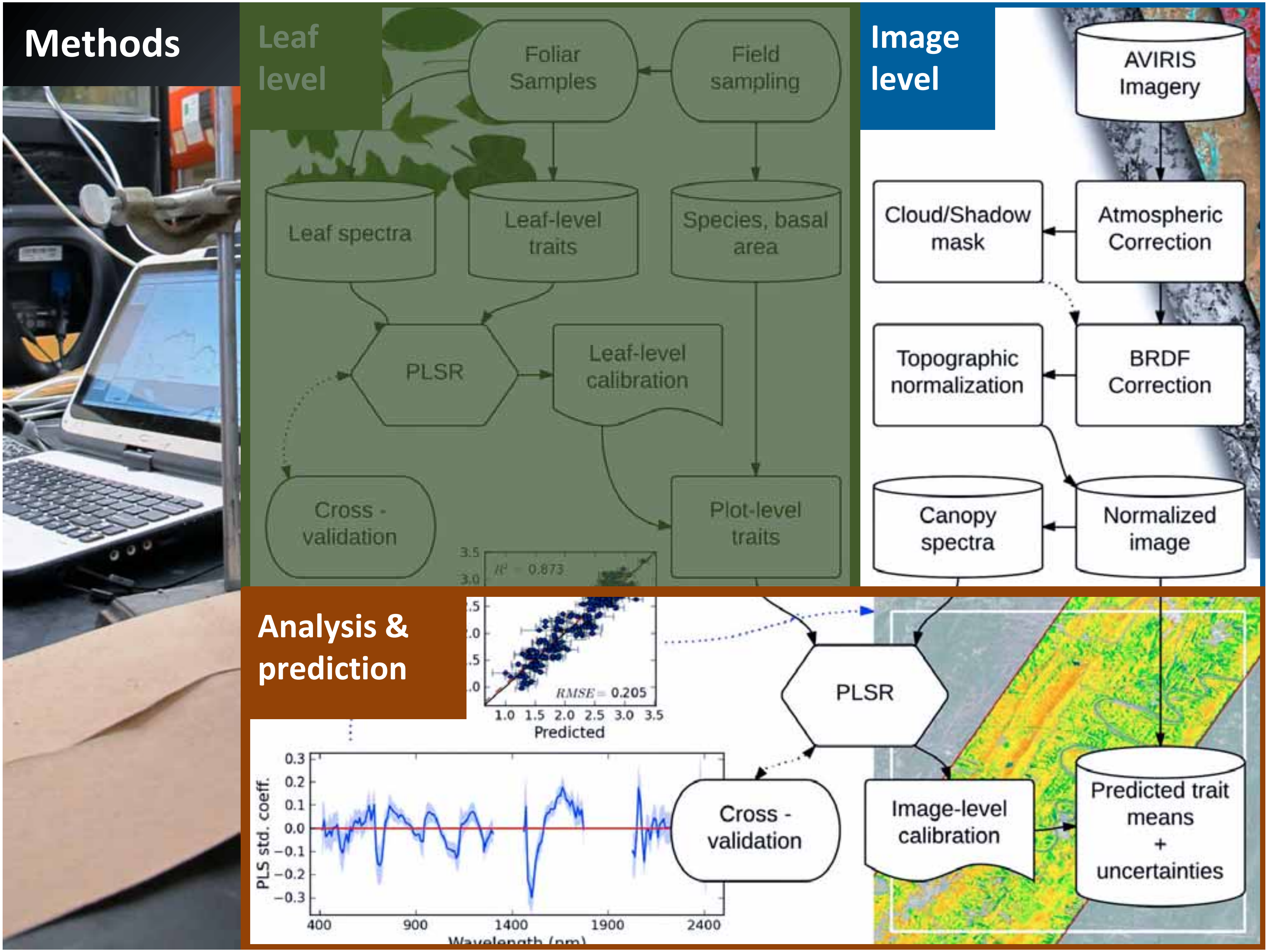
Foliar biochemistry from spectroscopy

4 years (2008-2011), 237 plots, 6 states, 36 species, 7 Traits (N%, LMA, C%, Lignin%, Cellulose% , Fiber%, δ^{15}N)


Methods
Leaf level
Foliar Samples
Field sampling
Leaf spectra
Leaf-level traits
Species, basal area
PLSR
Leaf-level calibration
Cross - validation
Plot-level traits
Image level
AVIRIS Imagery
Cloud/Shadow mask
Atmospheric Correction
Topographic normalization
BRDF Correction
Canopy spectra
Normalized image
Analysis & prediction
$R^2 = 0.873$
$RMSE = 0.205$
Predicted
PLS std. coeff.
Wavelength (nm)
PLSR
Cross - validation
Image-level calibration
Predicted trait means
+
uncertainties



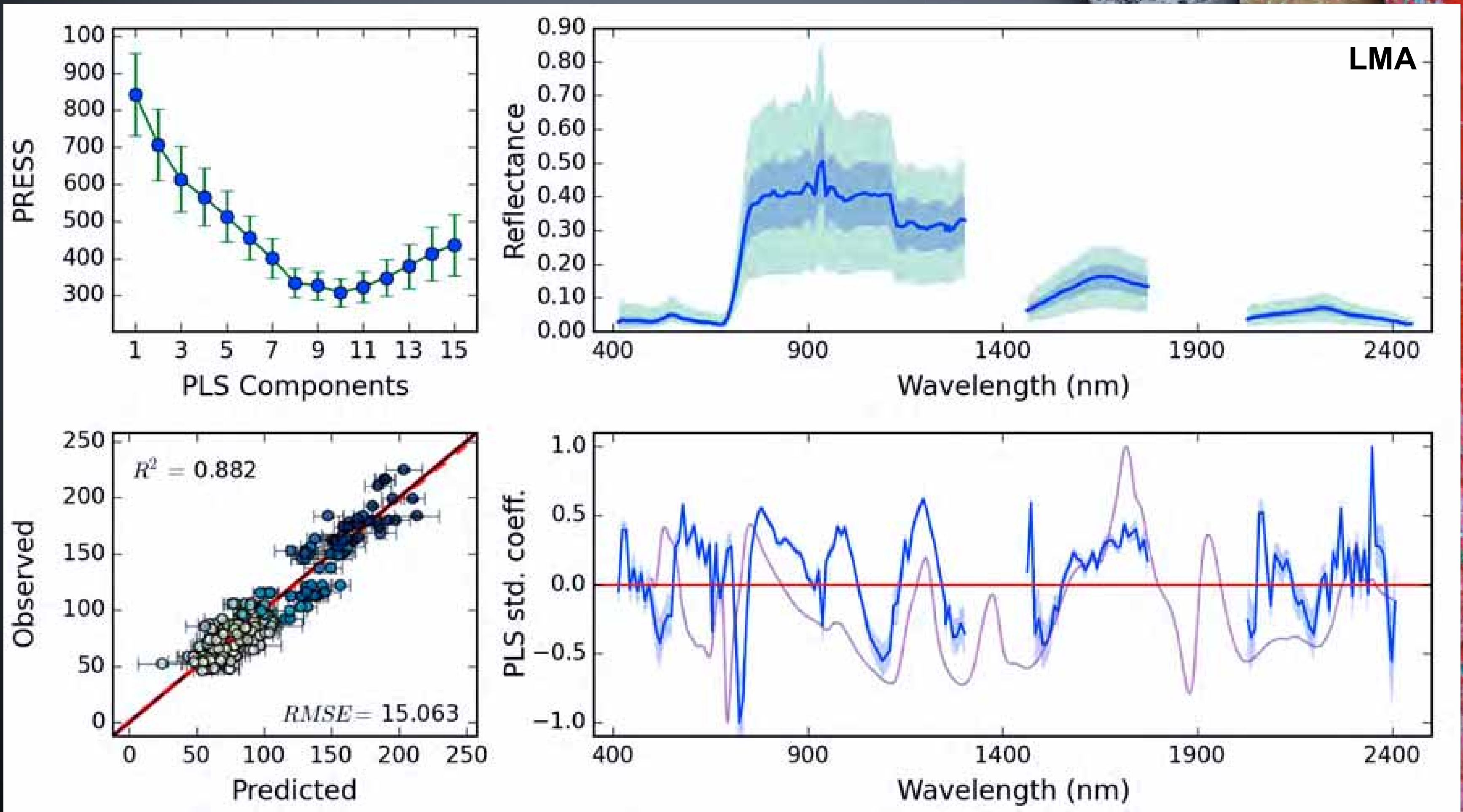
Methods
Leaf level
Foliar Samples
Field sampling
Leaf spectra
Leaf-level traits
Species, basal area
PLSR
Leaf-level calibration
Cross - validation
Plot-level traits
Image level
AVIRIS Imagery
Cloud/Shadow mask
Atmospheric Correction
Topographic normalization
BRDF Correction
Canopy spectra
Normalized image
Analysis & prediction
PLSR
Cross - validation
Image-level calibration
Predicted trait means + uncertainties
RMSE = 0.205
Predicted
PLS std. coeff.
Wavelength (nm)


Methods
Leaf level
Foliar Samples
Field sampling
Leaf spectra
Leaf-level traits
Species, basal area
PLSR
Leaf-level calibration
Cross - validation
Plot-level traits
Image level
AVIRIS Imagery
Cloud/Shadow mask
Atmospheric Correction
Topographic normalization
BRDF Correction
Canopy spectra
Normalized image
Analysis & prediction
RMSE = 0.205
Predicted
PLS std. coeff.
Wavelength (nm)
PLSR
Cross - validation
Image-level calibration
Predicted trait means + uncertainties

Foliar traits from imaging spectroscopy

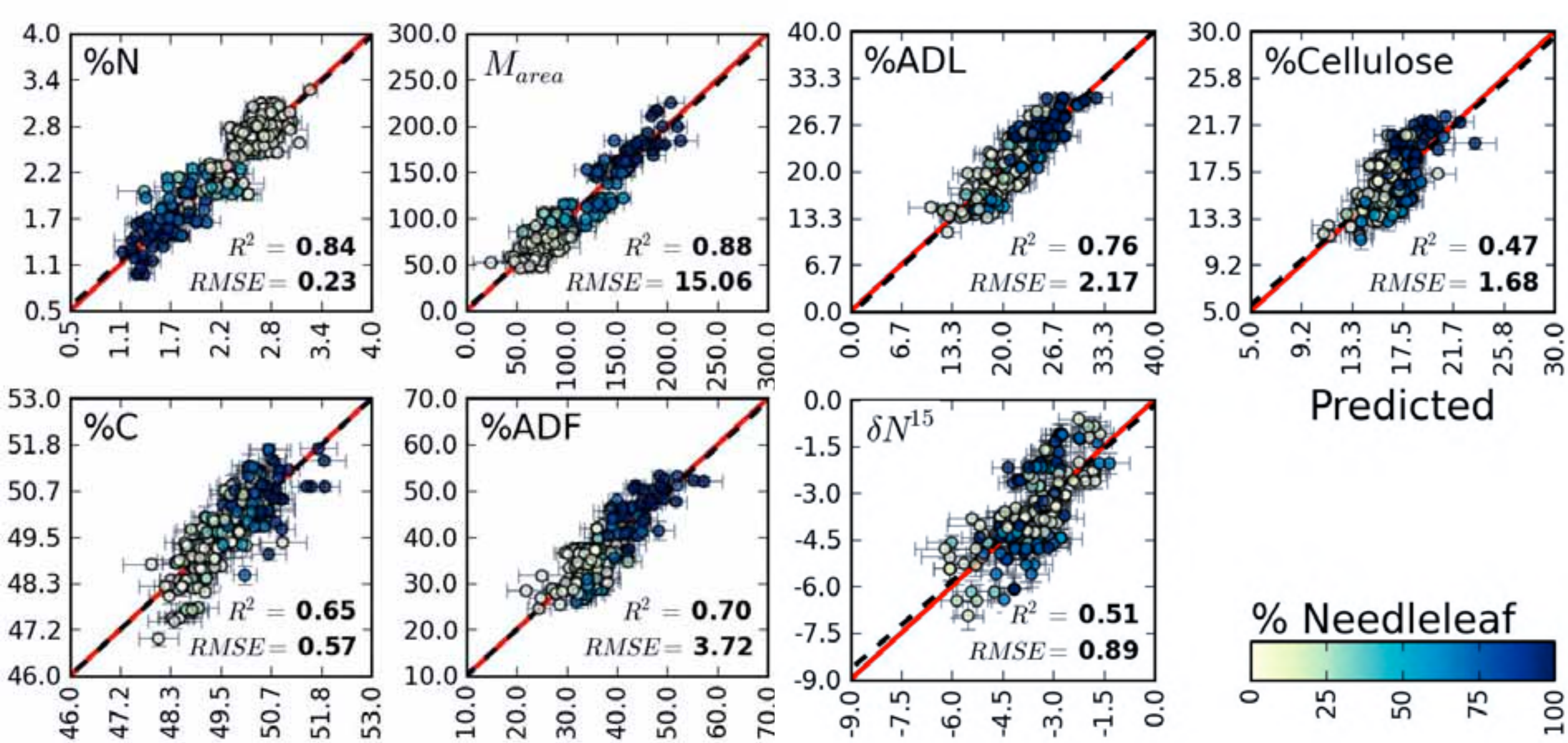
Partial least squares regression

- Chemometric method designed to handle high-dimensional, multicollinear data
- 50/50 Jackknife to get model uncertainties



Foliar traits from imaging spectroscopy

PLSR model results, 25/75 Cal/Val, 500× randomized Jackknife, 237 plots



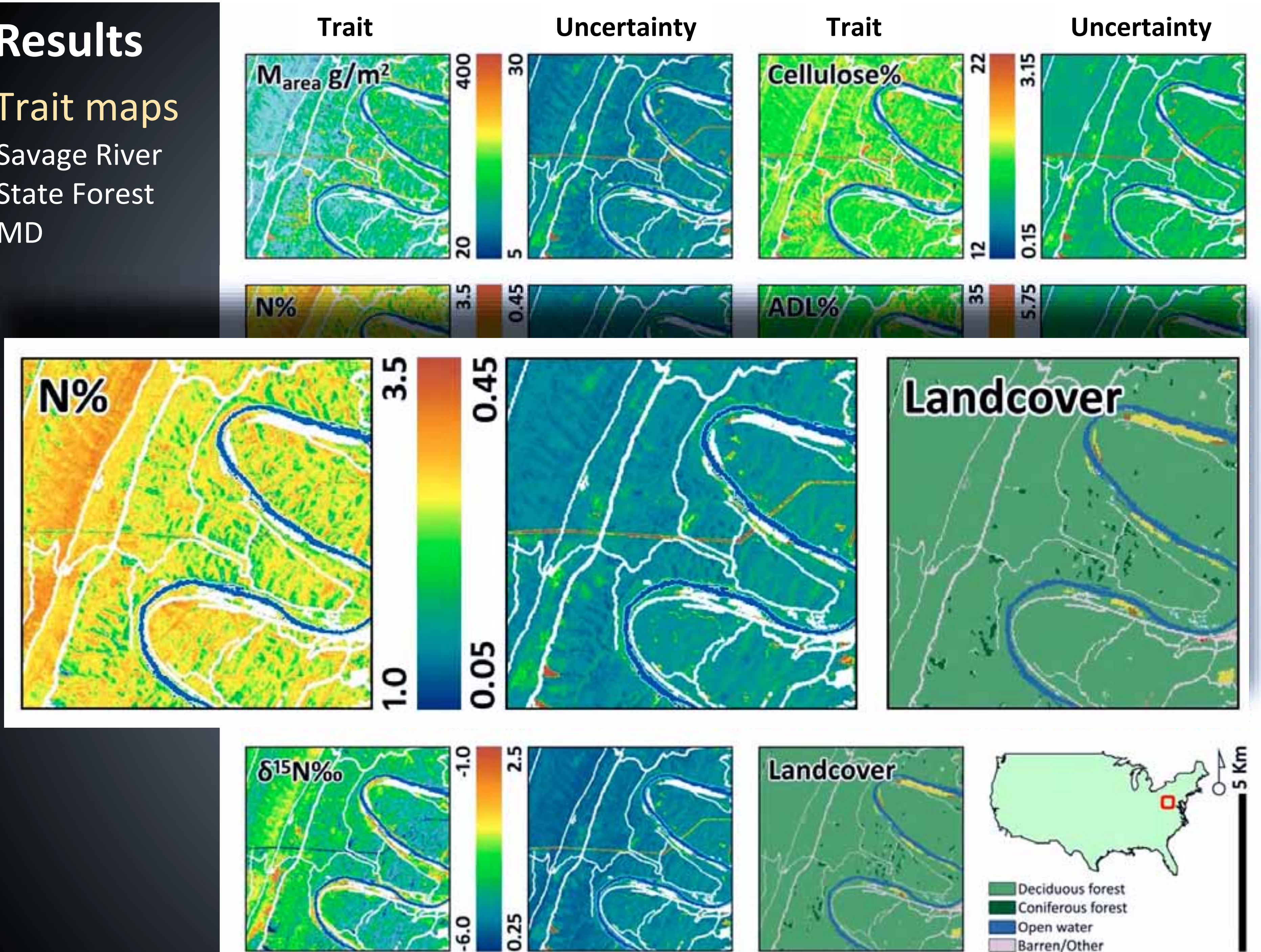
Predicted

Singh et al. (2015) Ecological Applications

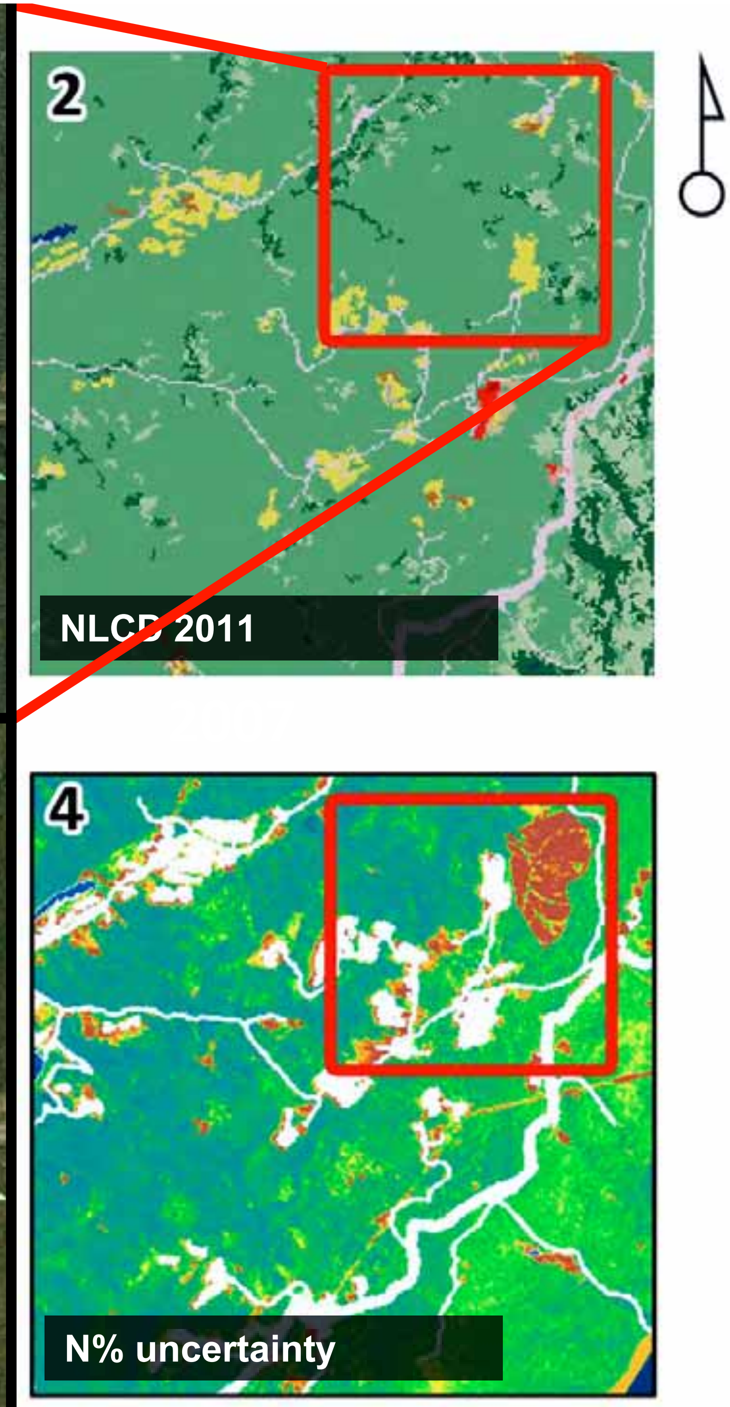
Results

Trait maps

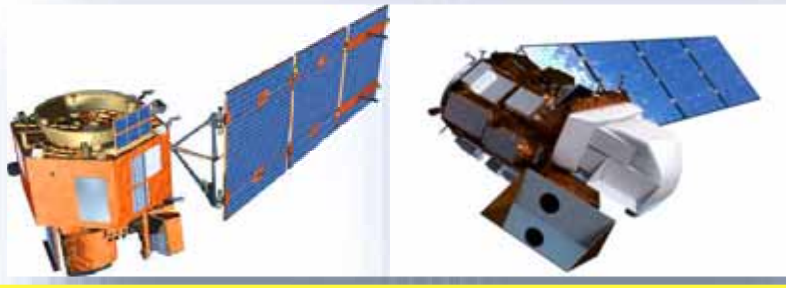
Savage River State Forest MD



Emergent patterns



What can we use maps of foliar biochemistry for?



Methodological developments in satellite remote sensing

- Landscape-scale nutrient cycling, crop production

Imaging spectroscopy

- Mapping foliar biochemical, morphological and metabolic traits and their uncertainties.

Filling gaps, ongoing research

- Desktop spectroscopy, mobile and airborne remote sensing platforms

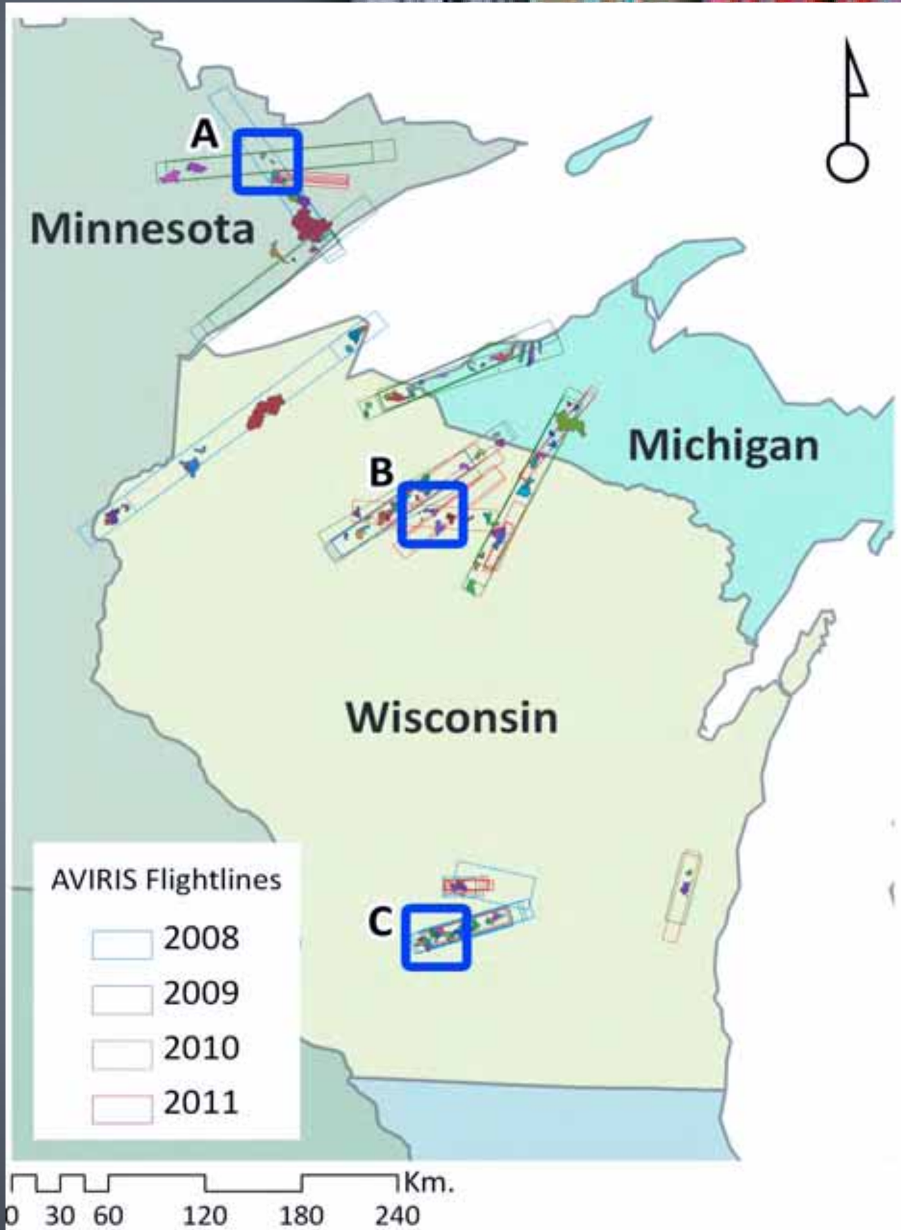
Contact spectroscopy

- Deriving foliar biochemical and morphological traits

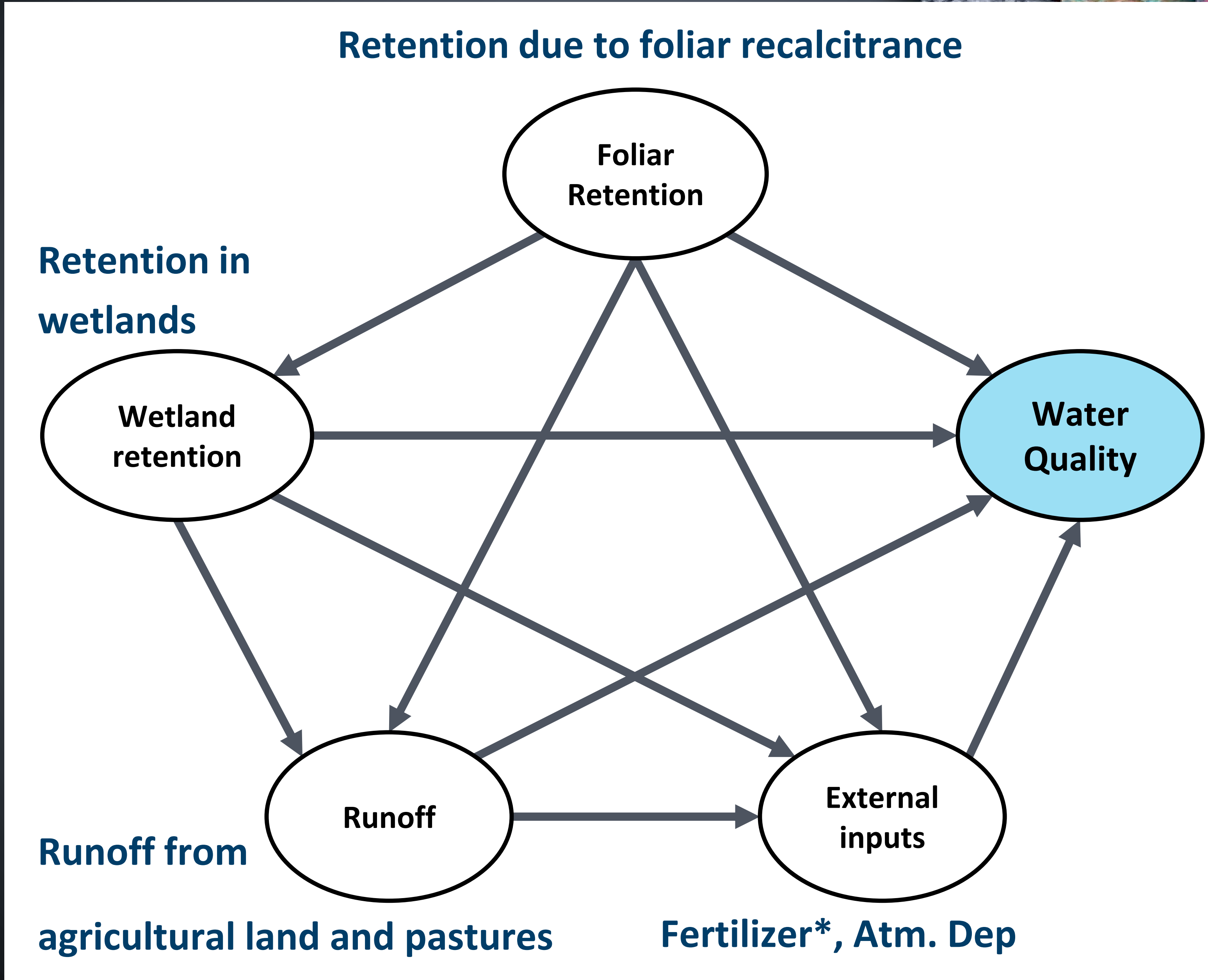
Water quality as a function of foliar traits

- 250 Watersheds across Wisconsin
- NO3-N , SRP
- Data from MODIS, AVIRIS, NLCD

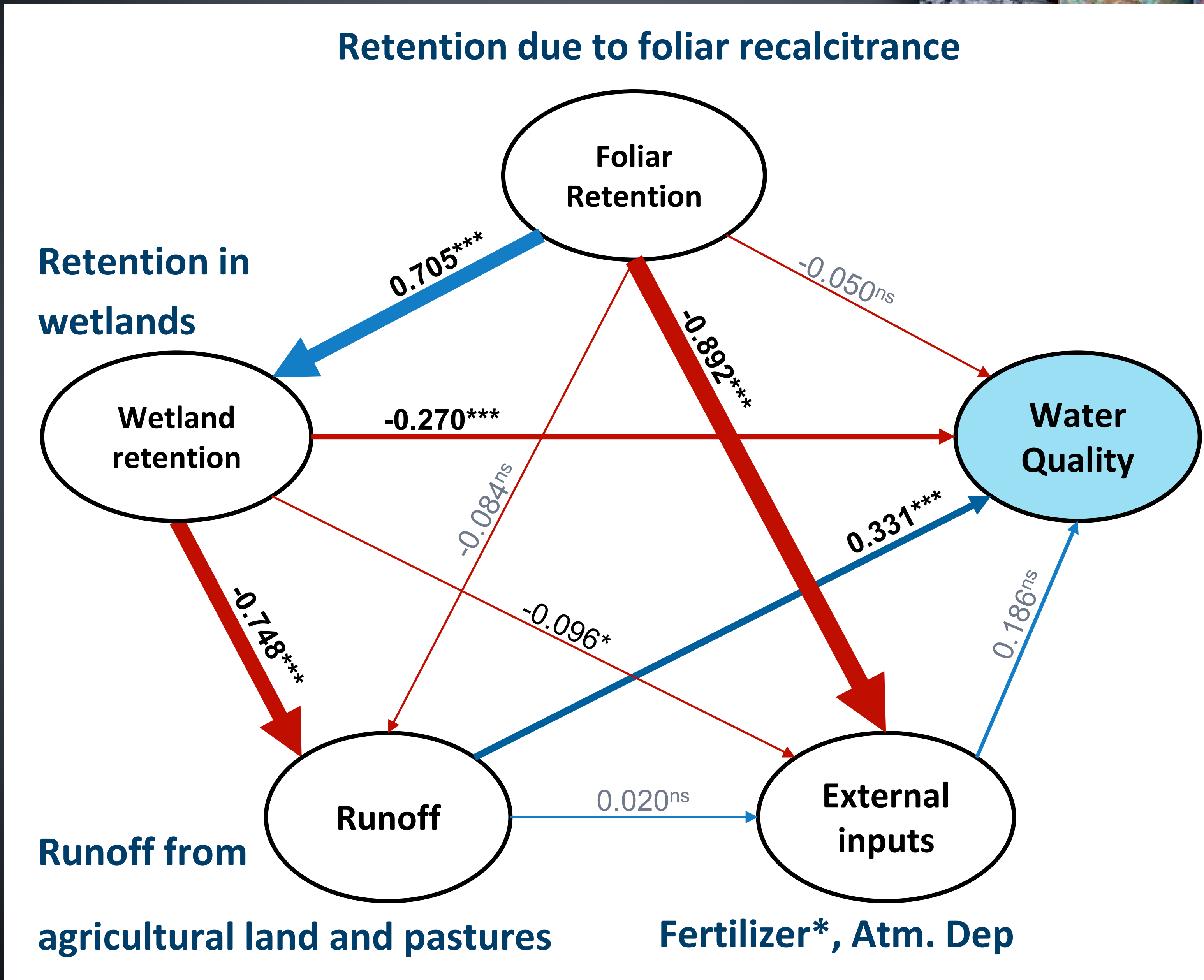
Latent variable	Manifest variable	Source
Foliar retention↓	C : N	**AVIRIS**
	Lignin : N	**AVIRIS**
Wetland retention ↓	TC Wetness index	MODIS
	% Water	NLCD
Runoff from	% Agriculture	NLCD
ag/pasture↑	% Pasture	NLCD
External inputs ↑	Foliar N %	**AVIRIS**
	Atm. Nitrogen dep.	N. Dep
Water quality	$\log(NO_3\text{-}N)$	Field



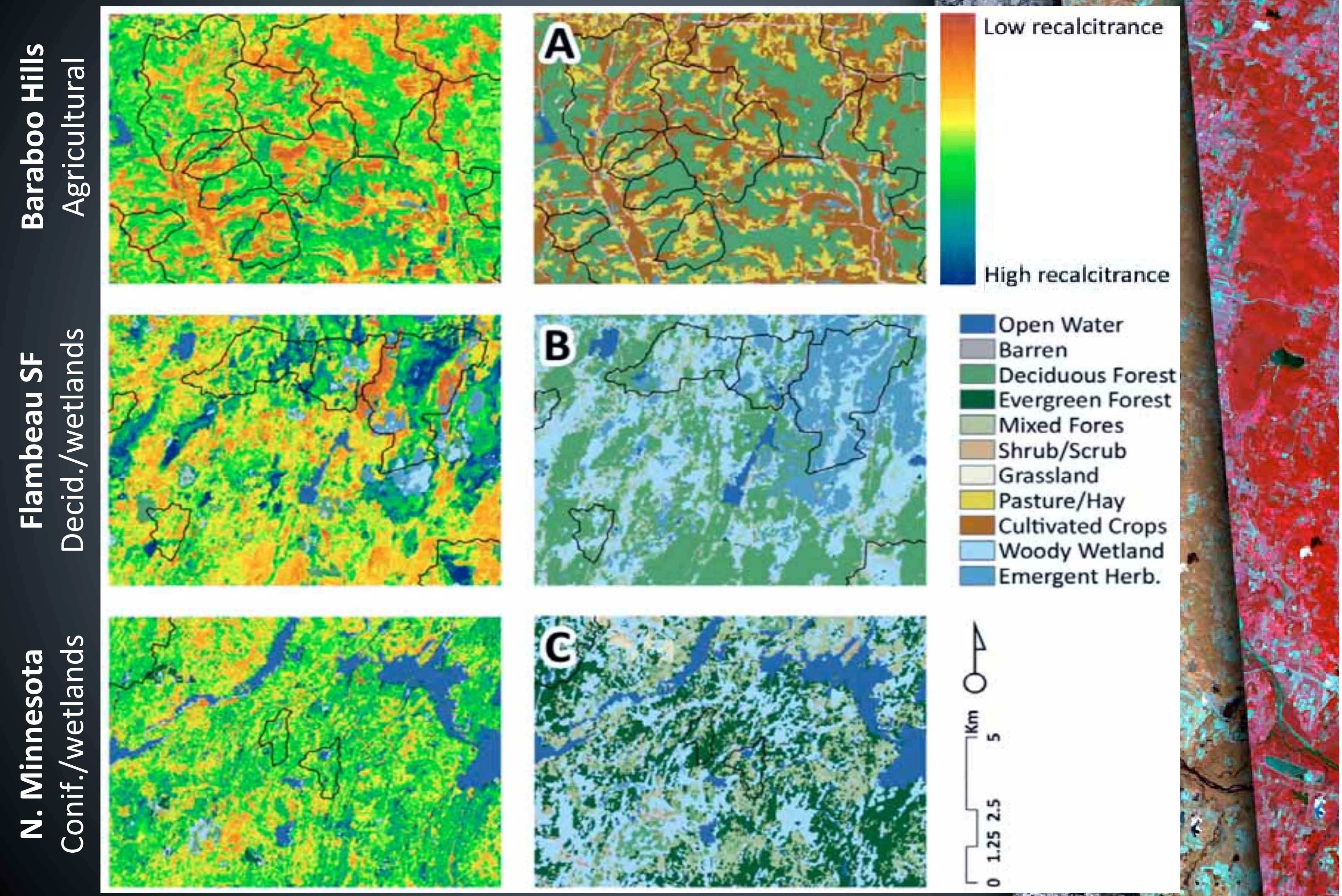
Method: Proposed PLS-path model



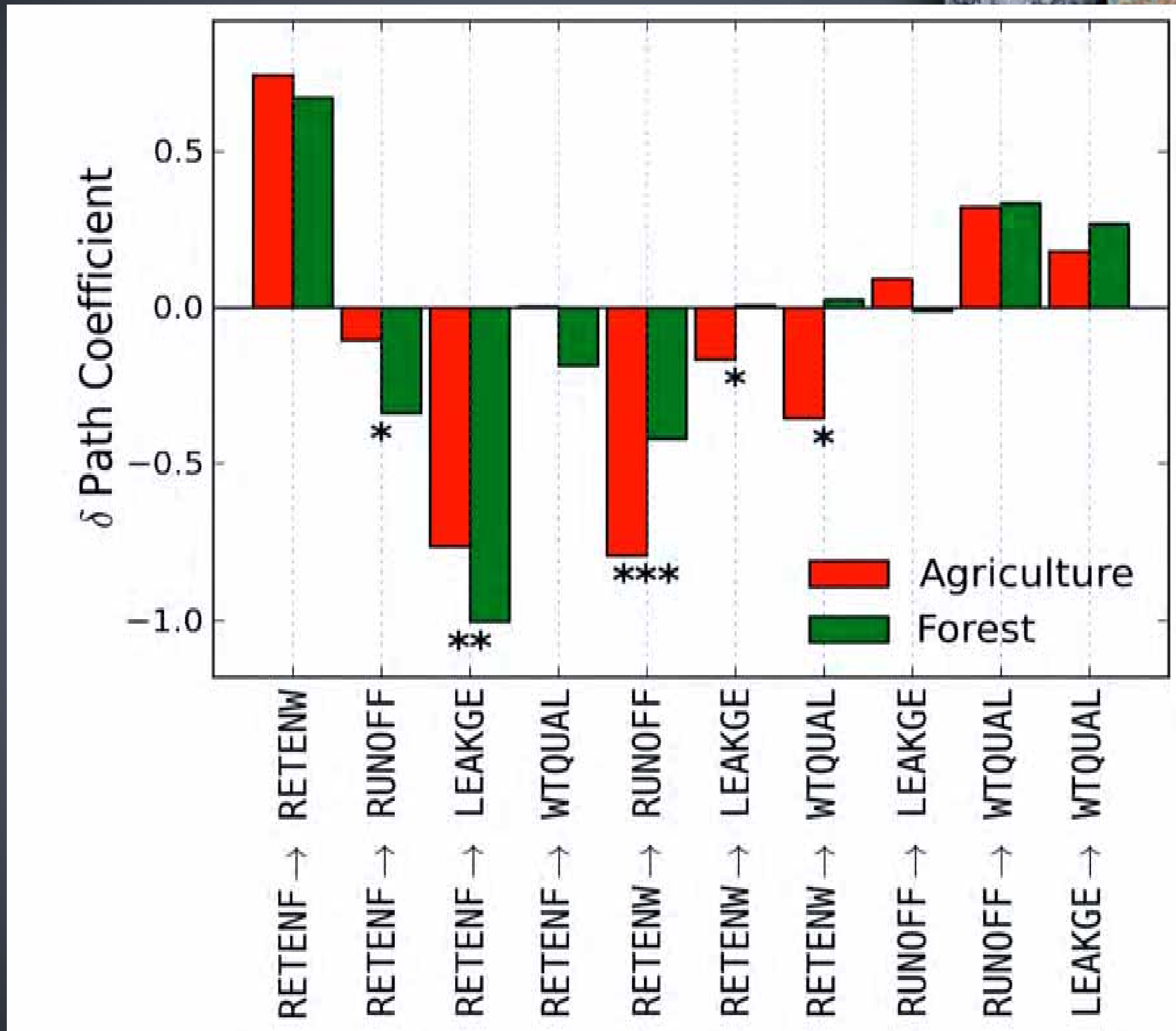
Results: Fitted path model



Path model: Mapping the 'foliar recalcitrance' latent variable

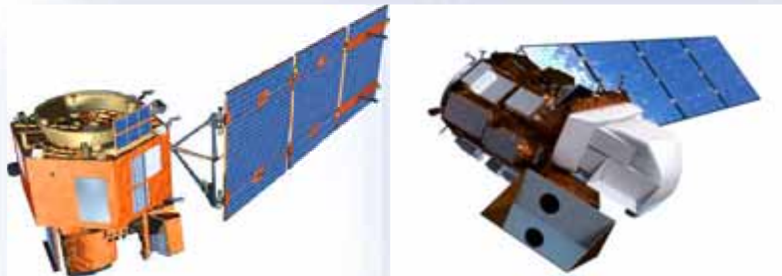


Path model: Results, Comparing forests and agriculture



→ Significant differences between mechanisms

Ongoing and future research



Methodological developments in satellite remote sensing

- Landscape-scale nutrient cycling, crop production

Imaging spectroscopy

- Mapping foliar biochemical, morphological and metabolic traits and their uncertainties.

Filling gaps, ongoing research

- Desktop spectroscopy, mobile and airborne remote sensing platforms

Contact spectroscopy

- Deriving foliar biochemical and morphological traits

Research in progress: UAS spectroscopy

- Parallel system being built at UF
- Headwall Photonics NanoHyperspec (400-1000nm) imaging spectrometer, Thermal
- Will be used to estimate ET at the canopy scale

Conclusion

- Remote sensing and spectroscopy powerful tools for assessing ecological responses to stress, at multiple scales.
- Combined with coordinated field surveys and analysis techniques, can help answer basic and applied questions in ecosystem sciences.
- In combination with process-based models, spatial estimates of ecosystem attributes can help inform responses to environmental change.
- Field-scale instrumentation and UASs can enable better characterization of entire ecosystems across space and time.

Thank you! questions?

Acknowledgements:

Collaborators IFAS: Jasmeet Judge, Reza Ehsani, Kati Migliaccio, Chris Martinez, Lincoln Zotarelli, Jim Fletcher, Kelly Morgan, John Robbins, Jorge Barrera, Adam Watson, Celina Gomez-Vargas, Damian Adams, Jason Vogel, Jiri Hulcr, Paloma Carton, Stephanie Bohlmann, Christopher Vincent, Michael Dukes, Ian Small, Davie Kadyampakeni, …many more!

Collaborators UW: Phil Townsend, John Couture, Shawn Conley, Keith Eshleman, Claudio Gratton, Eric Kruger, Chris Kucharik, Angelica Gutierrez-Magness, Brenden McNeil, Shawn Serbin, Clayton Kingdon

NASA

University of Maryland CENTER FOR ENVIRONMENTAL SCIENCE

Chesapeake Bay Program
A Watershed Partnership

WISCONSIN
UNIVERSITY OF WISCONSIN-MADISON

USDA NIFA
United States Department of Agriculture
National Institute of Food and Agriculture

UF | IFAS
UNIVERSITY of FLORIDA