Advancing Techniques for Informing Terrestrial Ecosystem Models with Leaf and Imaging Spectroscopy to Improve the Representation and Prediction of Vegetation Dynamics and Carbon Cycling

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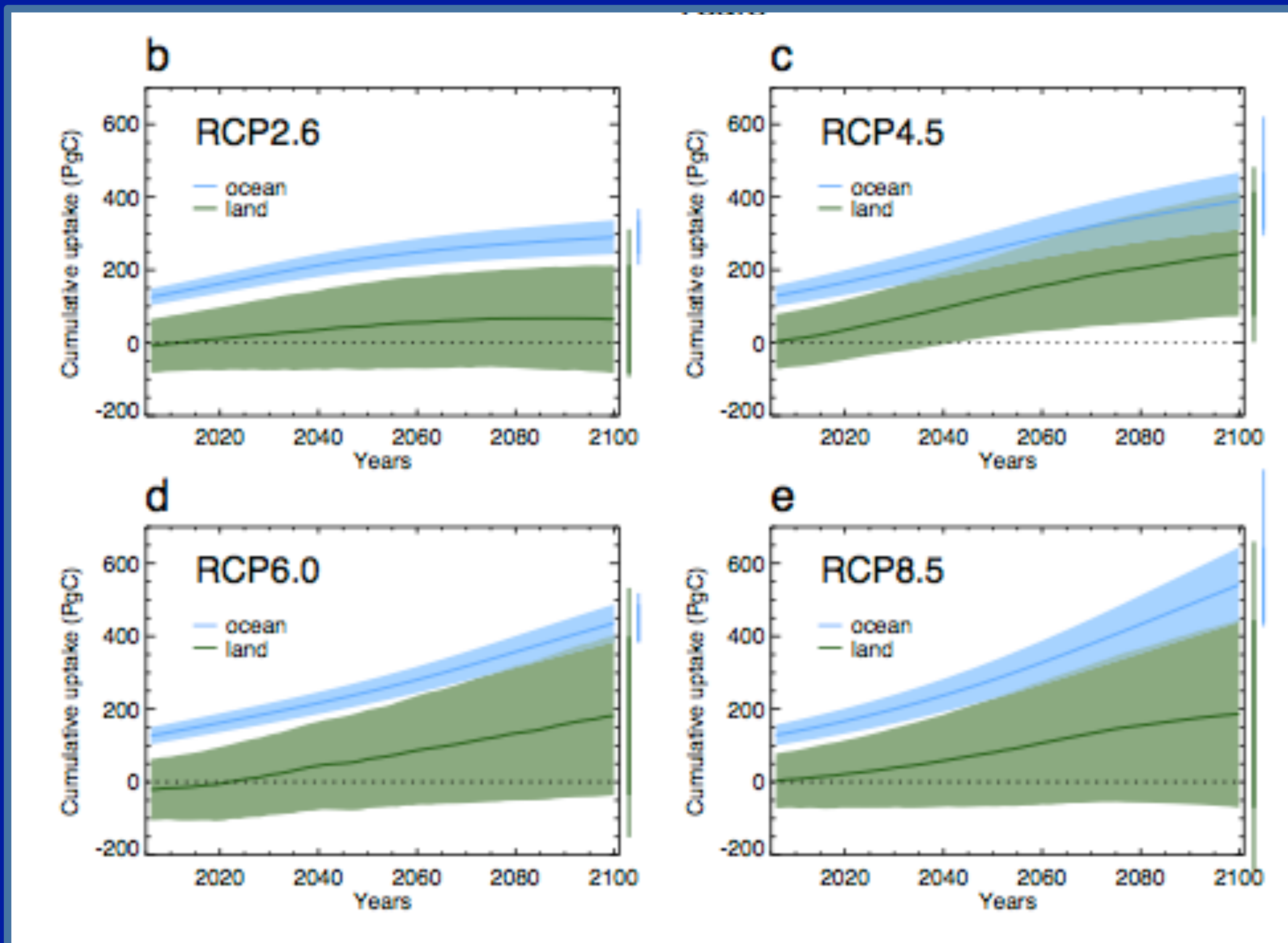
#EuroSpec2013 Final Conference, Nov 6-8 2013, Trento, Italy

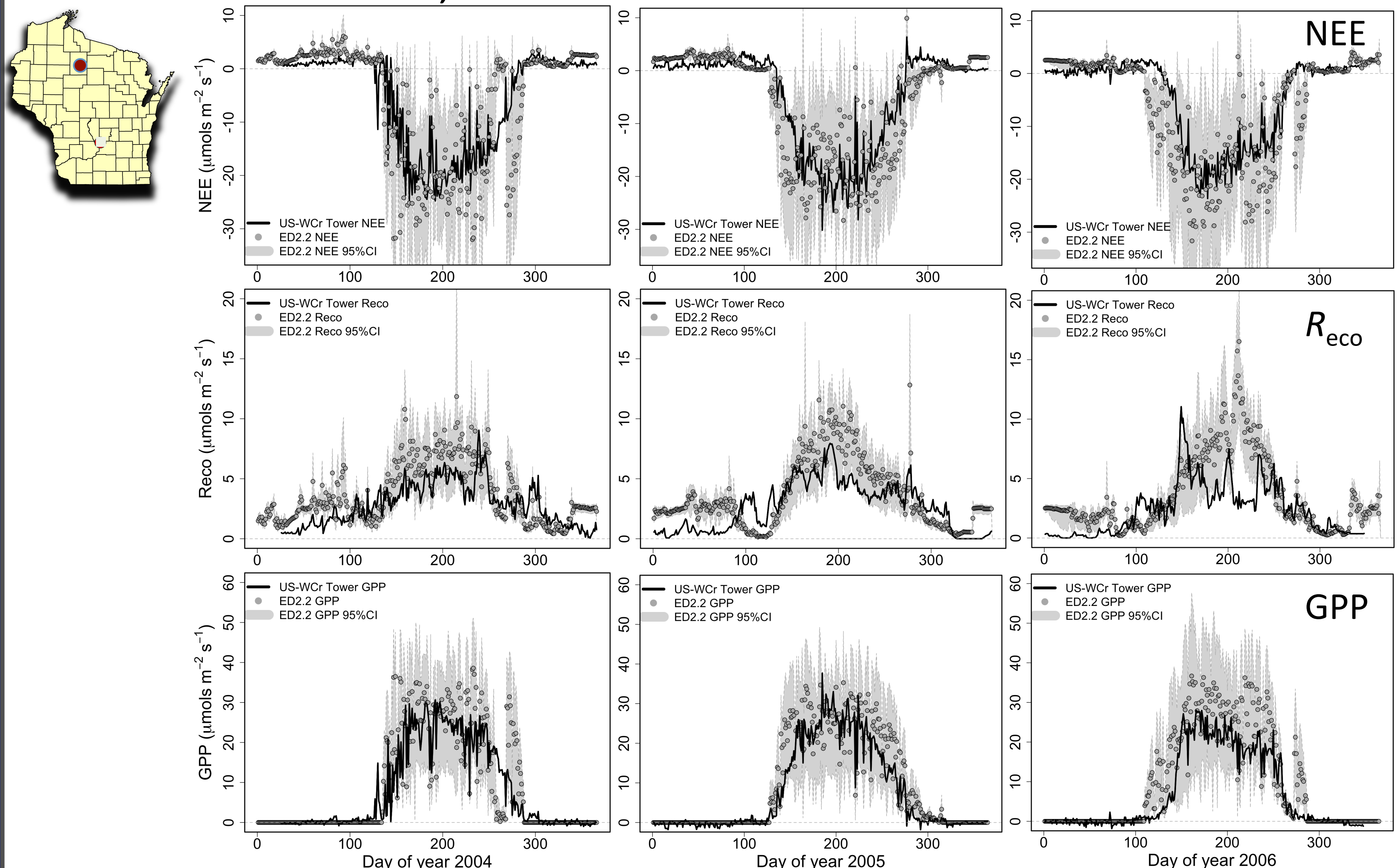
Terrestrial carbon cycle feedback is a leading order uncertainty for climate simulation



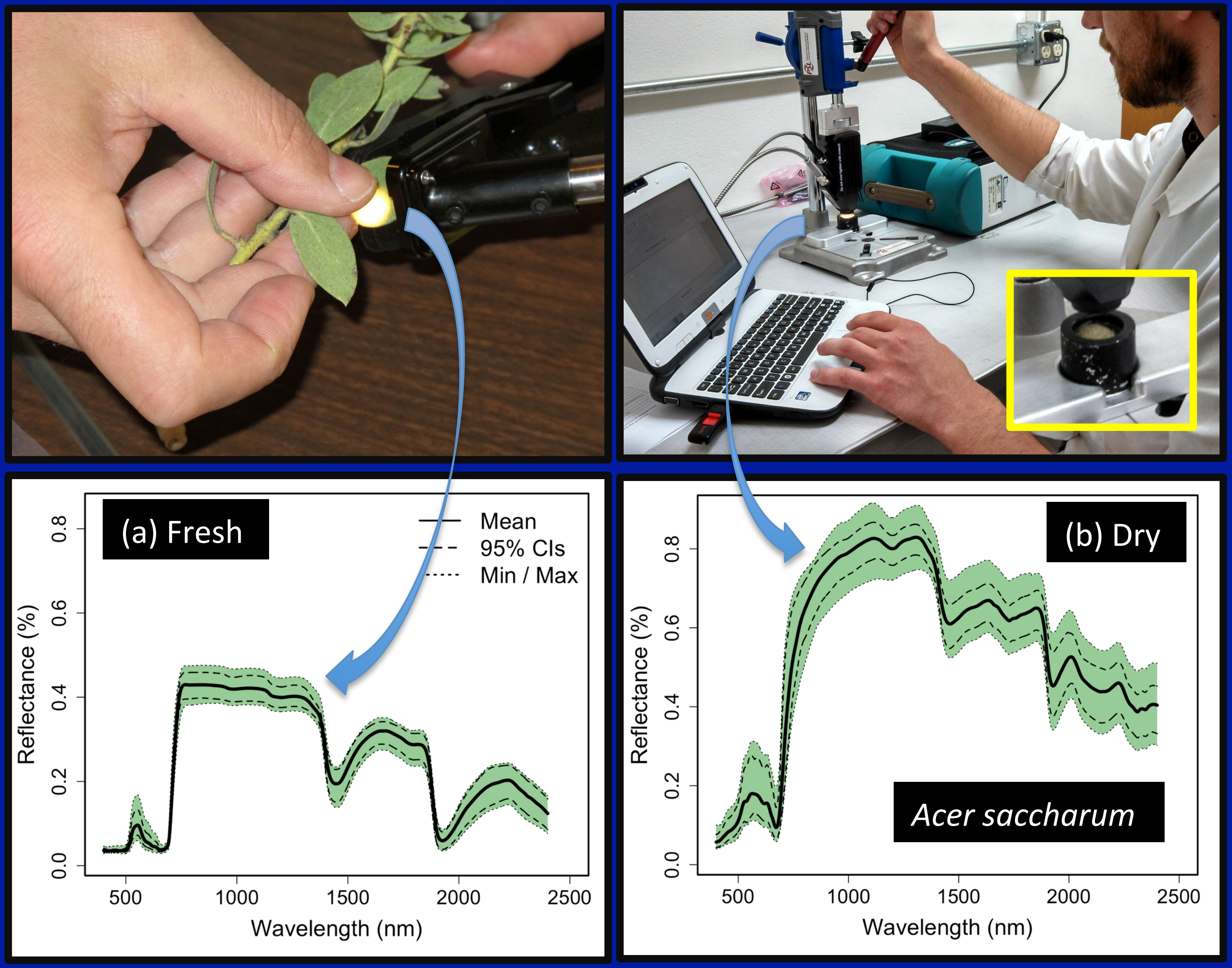
IPCC AR5 WG1 CH6 (draft)

This is true at the site level, too!

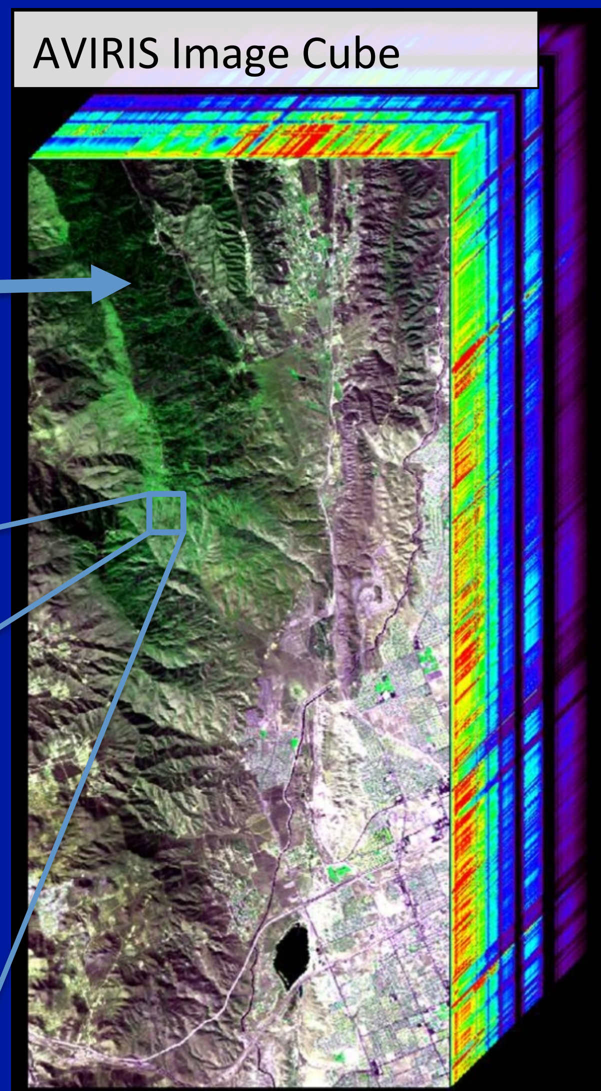
Willow Creek EC Tower Site, Wisconsin

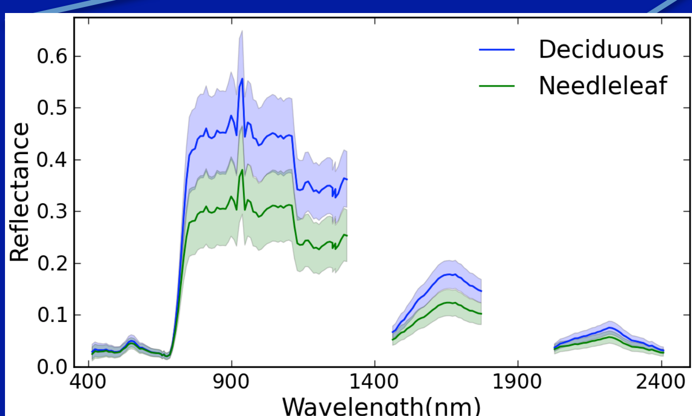


Leaf and canopy high-spatial and spectral resolution spectroscopy to the rescue?

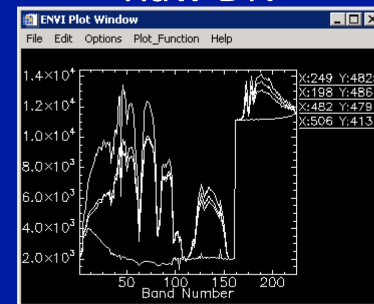


Imaging spectroscopy has a wealth of underutilized observations for ecosystem models!

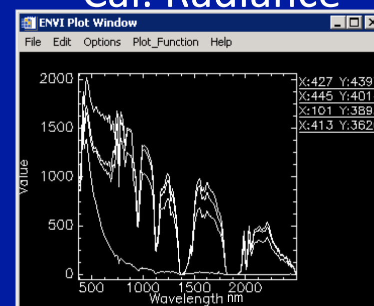




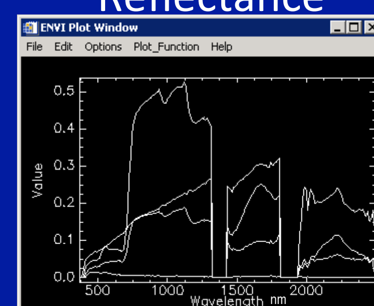
Raw DN



Cal. Radiance



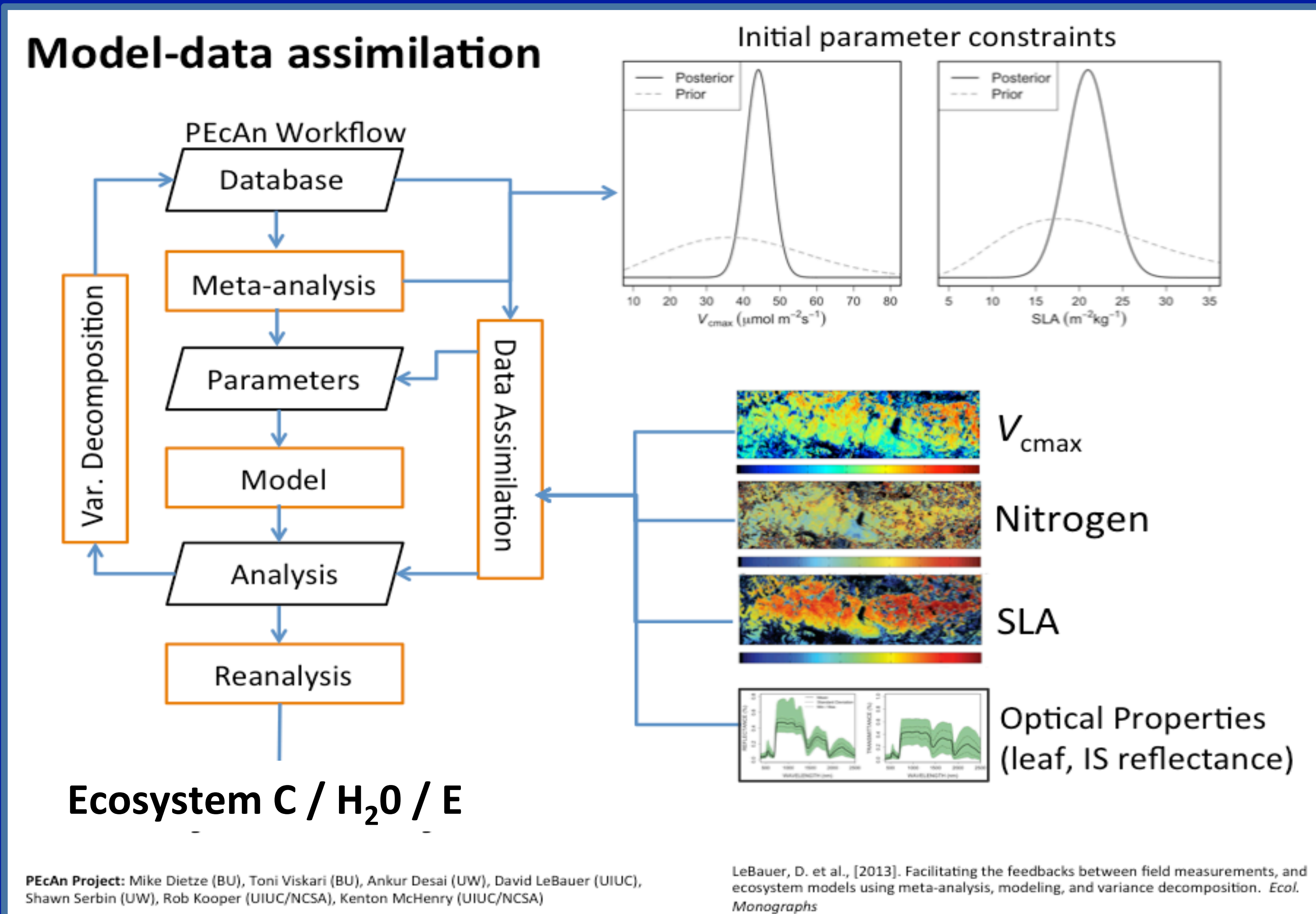
Reflectance



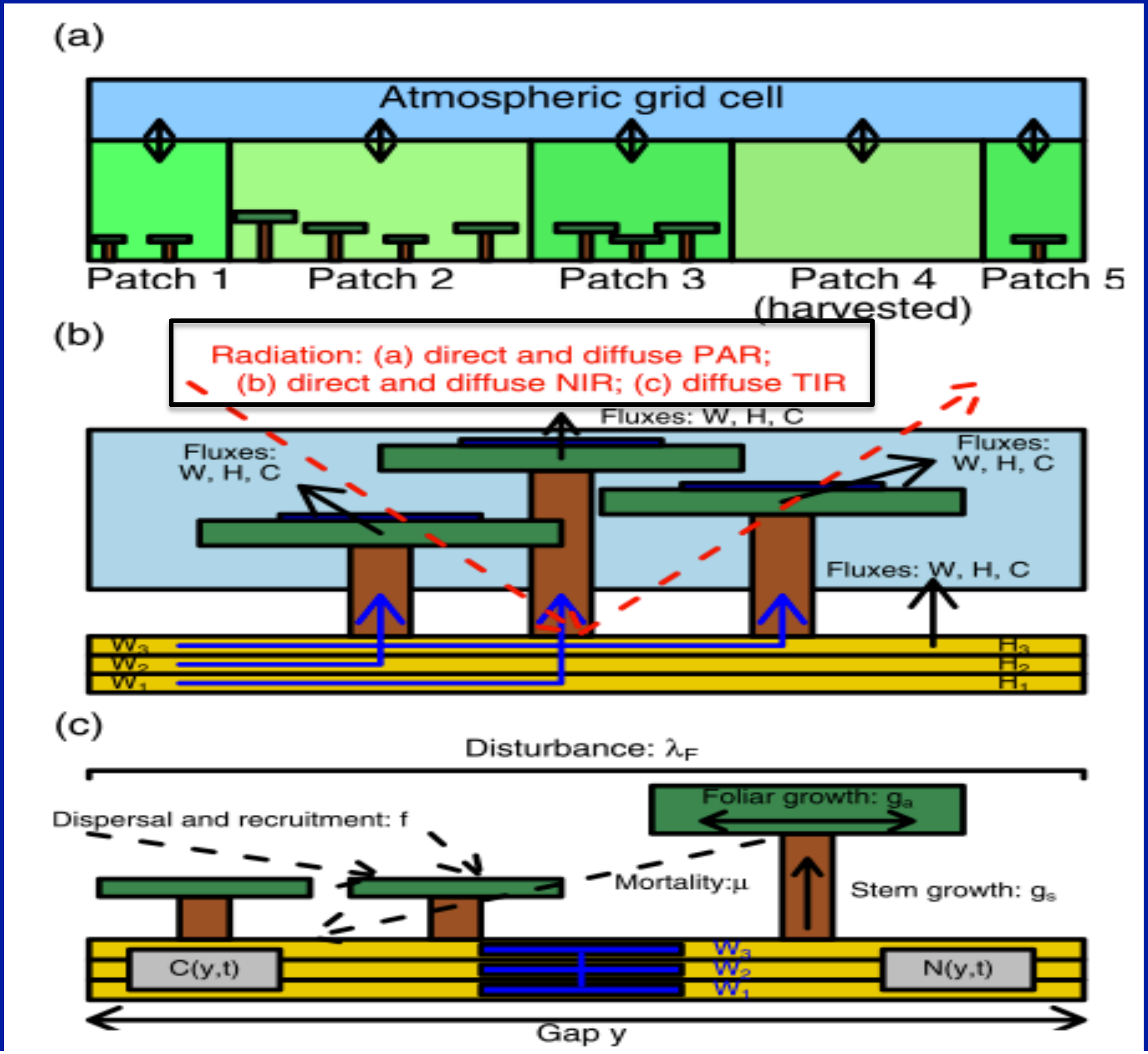
il menu del giorno

- Two possible pathways:
  - Data products assimilation
  - Direct optical properties assimilation
- Based on results from two field projects:
  - ChEAS Ameriflux Cluster
  - NASA HyspIRI prep mission
- With one assimilation system / model:
  - PEcAn with ED2

PEcAn: Predictive Ecosystem Analayzer is a workflow for model-data assimilation

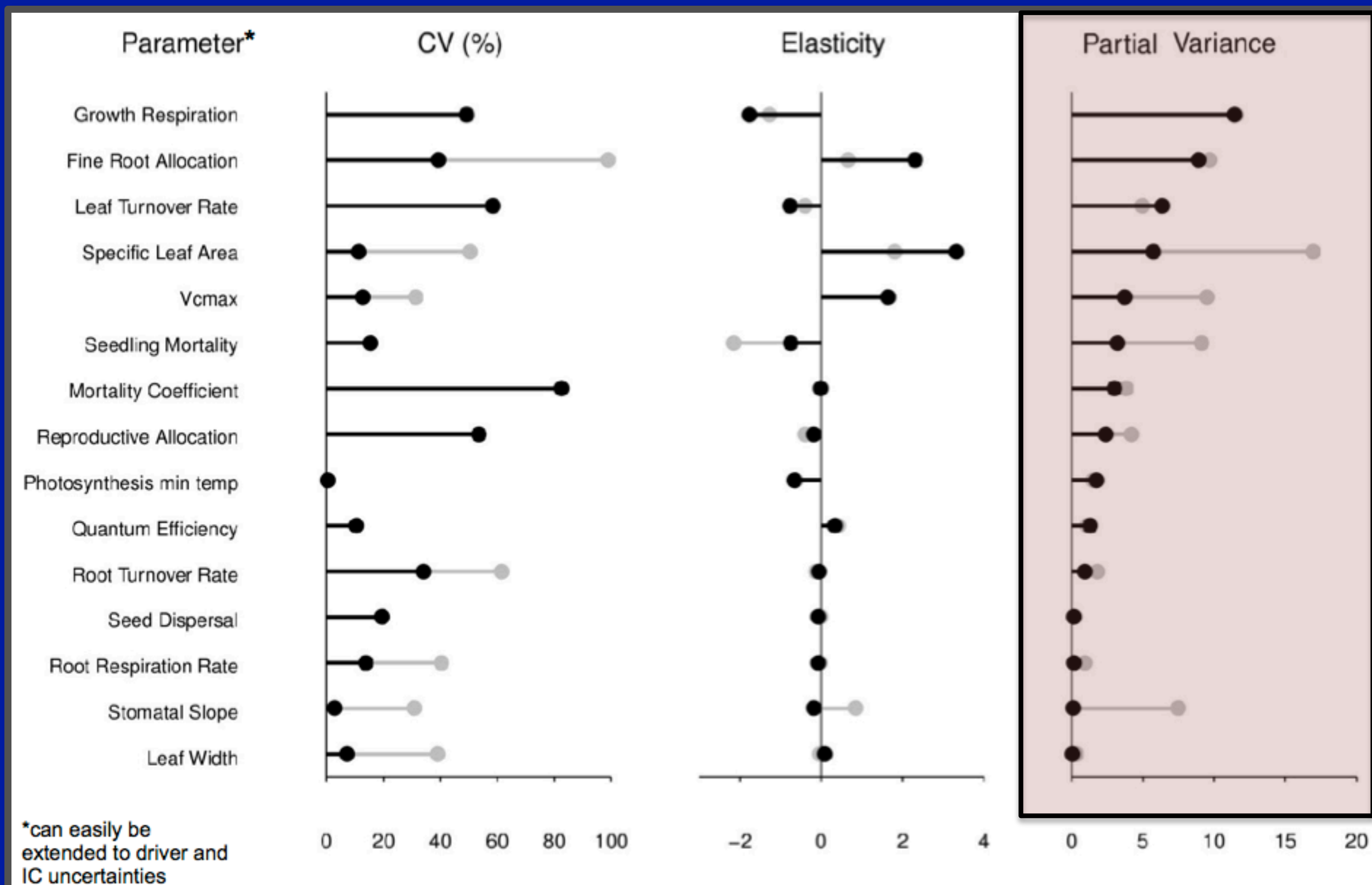


ED2 is a dynamic ecosystem model and already includes broadband radiative transfer



Medvigy et al 2009

PEcAn variance decomposition provides information on sensitivity of a model output variable (e.g., NPP) to uncertainty in input data (CV), model sensitivity (elasticity), and joint variance

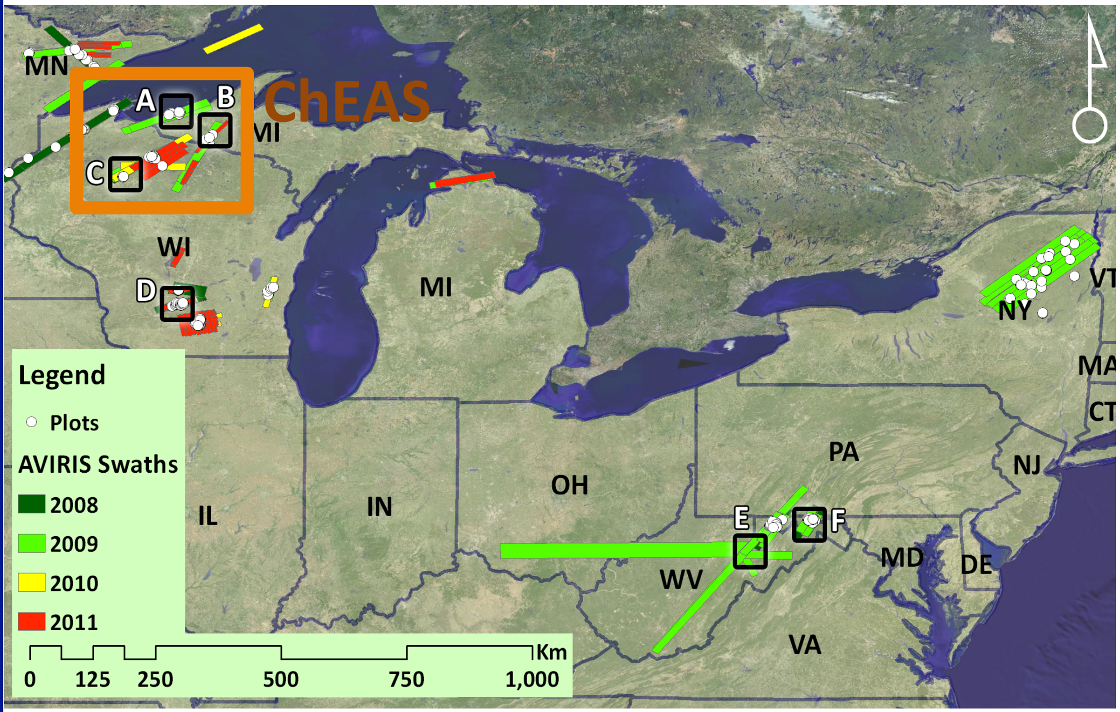


Two study regions in US

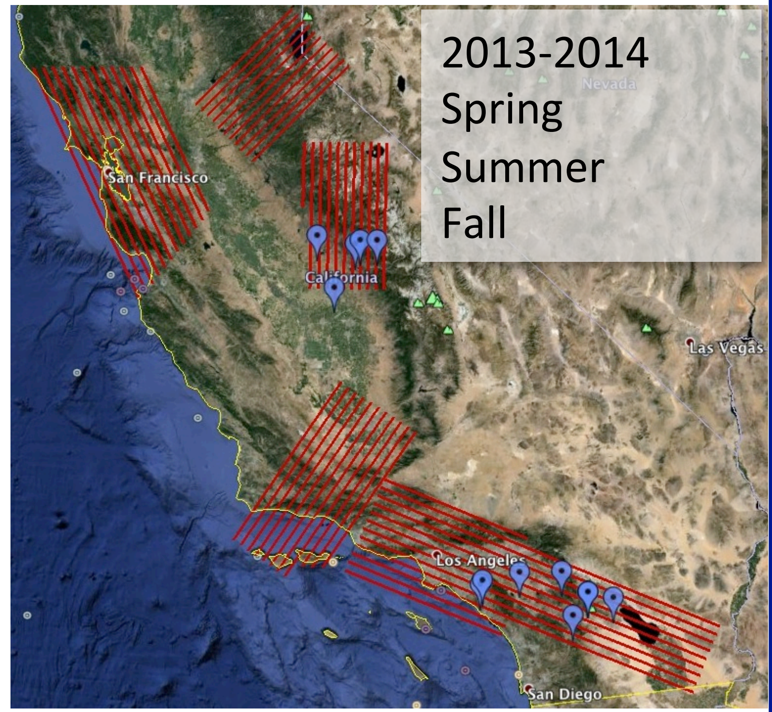
ChEAS: AVIRIS over 4 Ameriflux sites

165 Plots 120+ AVIRIS Scenes

NASA FFT Project



NASA HyspIRI Campaign



Singh, Serbin, McNeil, Townsend. (in prep) *Eco. Apps.*

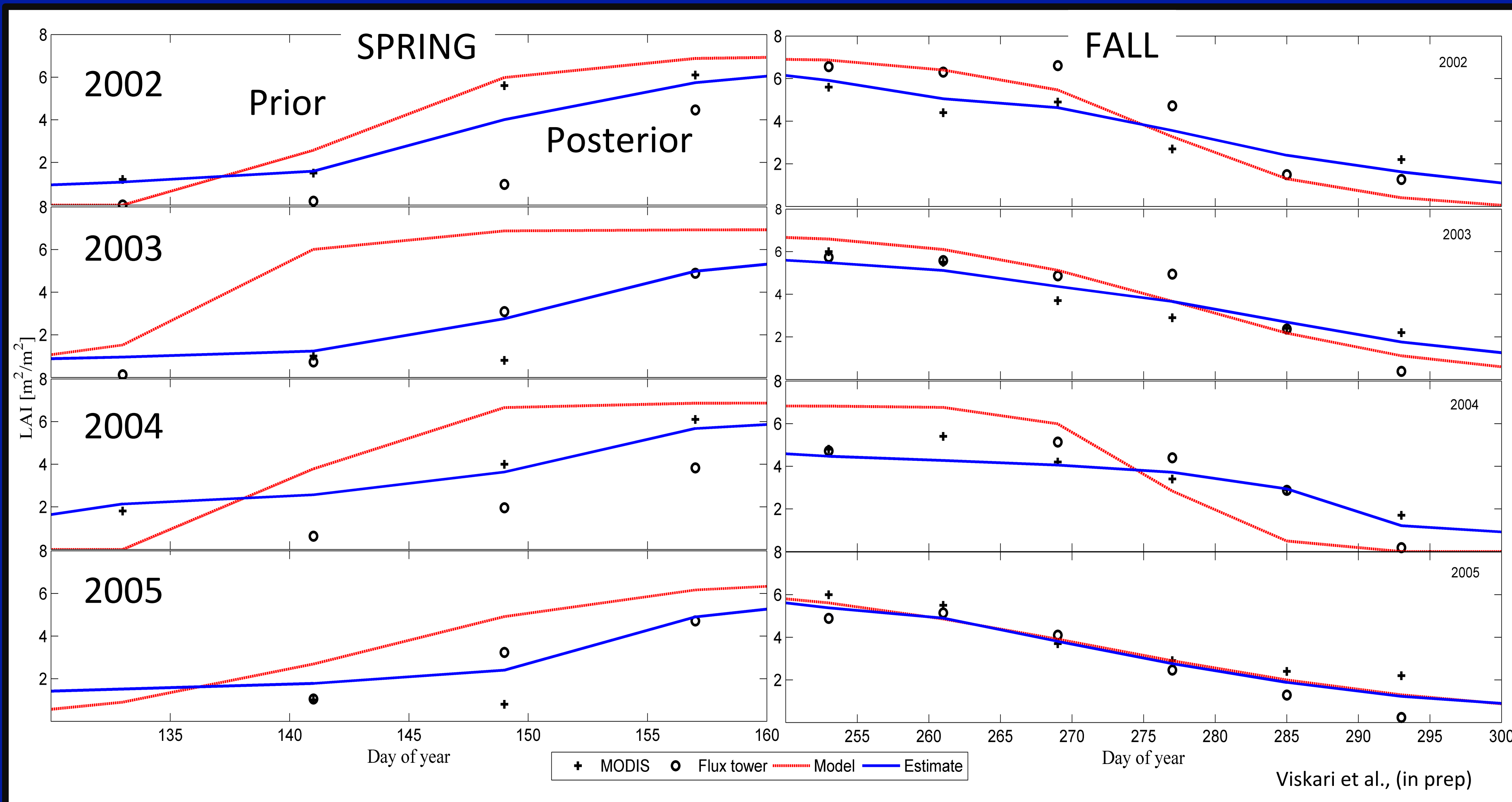
Of a total of 145 scenes, 26 in ChEAS:
All midsummer (July/August) images
7.0m - 16.8m resolution (low/high alt. ER-2)

AVIRIS
Airborne Visible / Infrared Imaging Spectrometer

DATA PRODUCT ASSIMILATION

MODIS LAI + Flux tower vertical PAR profile tames model phenology

Filled dot = MODIS LAI, open dot = LAI from flux tower profile FaPAR



AVIRIS products generated with PLSR technique and leaf-level spectroscopy calibration

Serbin et al.,
2012 J Exp Botany

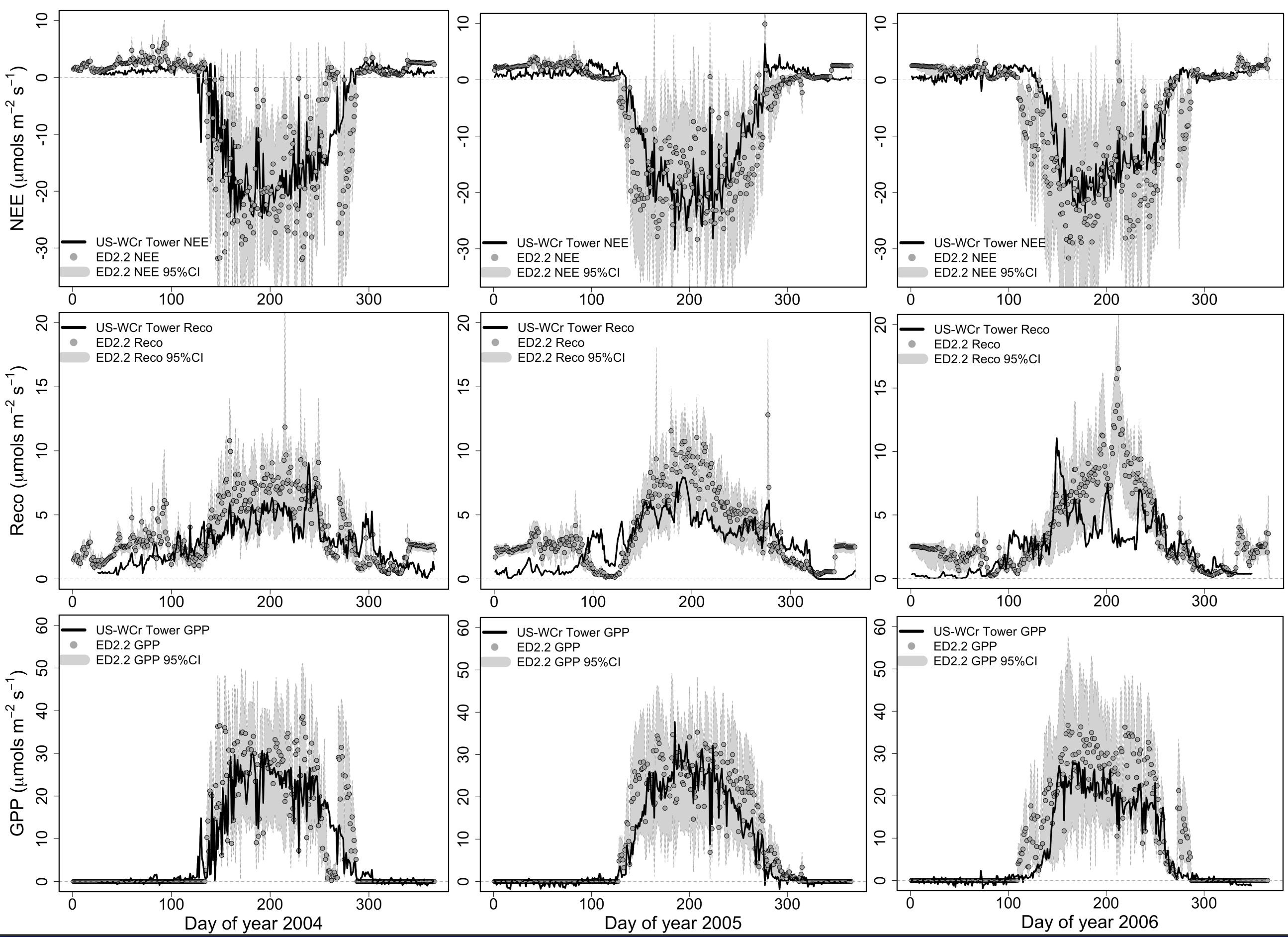
Where we are today:

Standardized algorithms to predict foliar constituents (%C,%N,LMA,…) using spectroscopy across diverse forest types w/ uncertainty estiamtes.

- Our scaling methods propagate the uncertainties at the leaf-level through the canopy PLSR modeling to produce estimates of foliar traits (i.e. trait maps) with an estimate of the associated retrieval uncertainty (pixel by pixel).
- Thus, we can utilize these products in a model DA framework given that we have quantified uncertainty in retrievals.

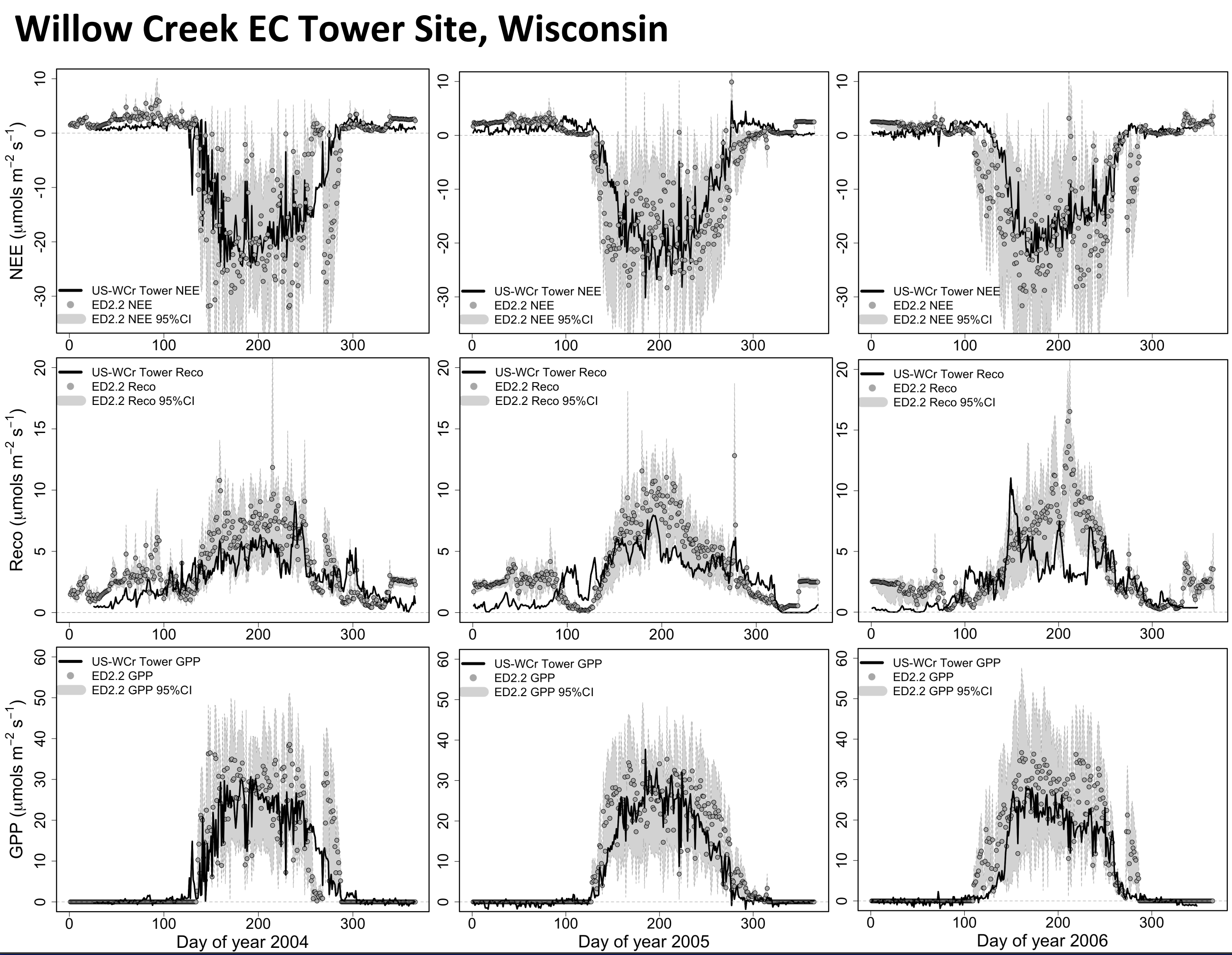
Model-data Assimilation: AVIRIS

Willow Creek EC Tower Site, Wisconsin



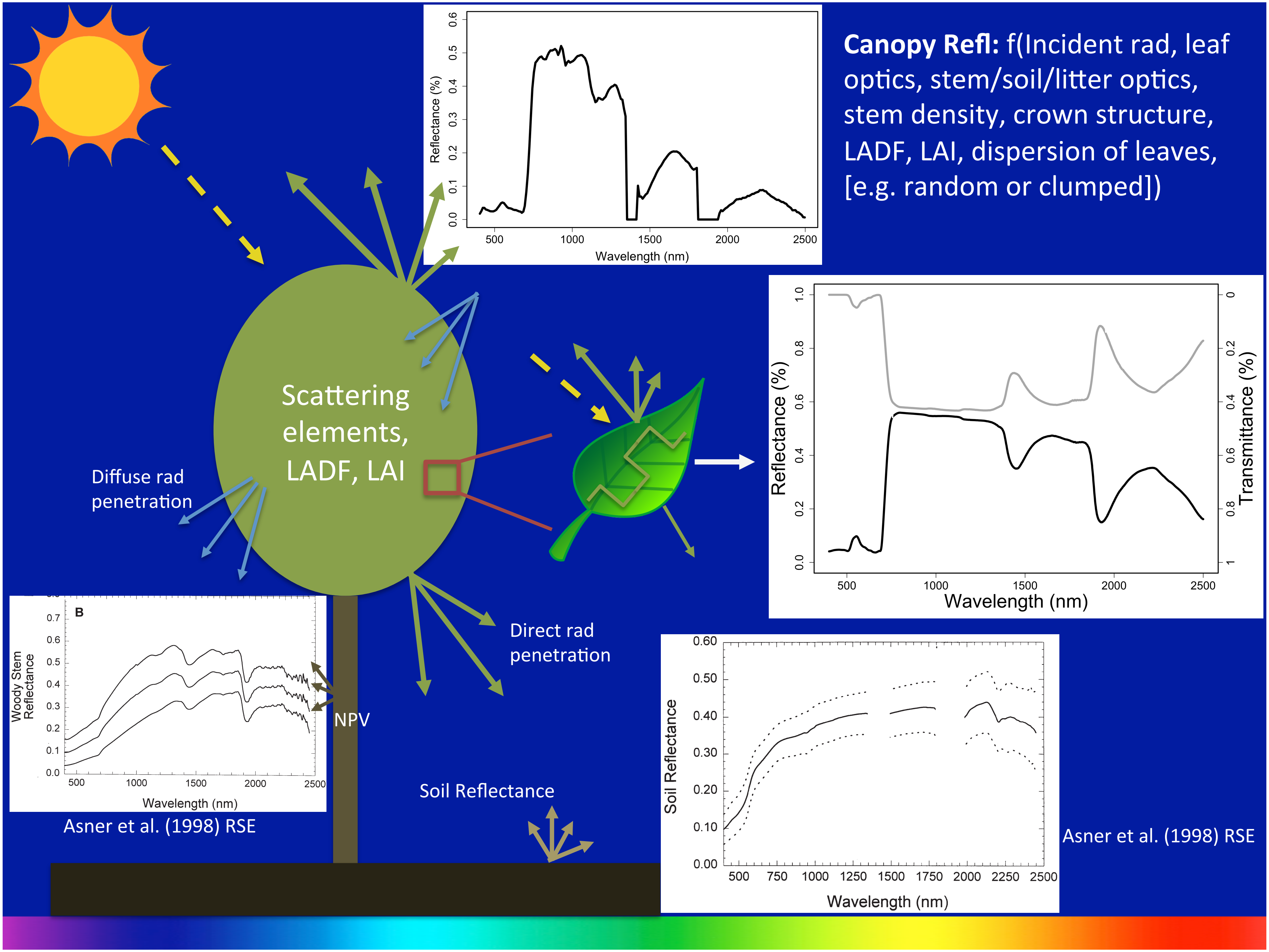
Working toward the assimilation of AVIRIS-derived products. These include foliar chemistry (e.g. N, C, CN, lignin) and morphology (SLA).

Model-data Assimilation: AVIRIS

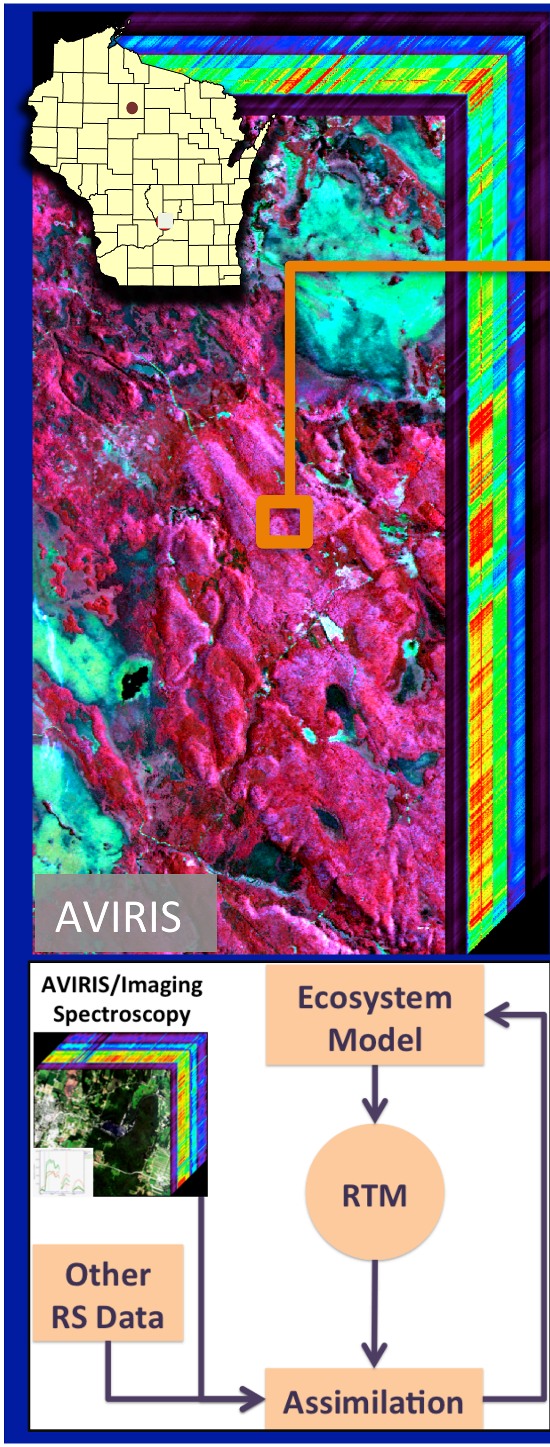


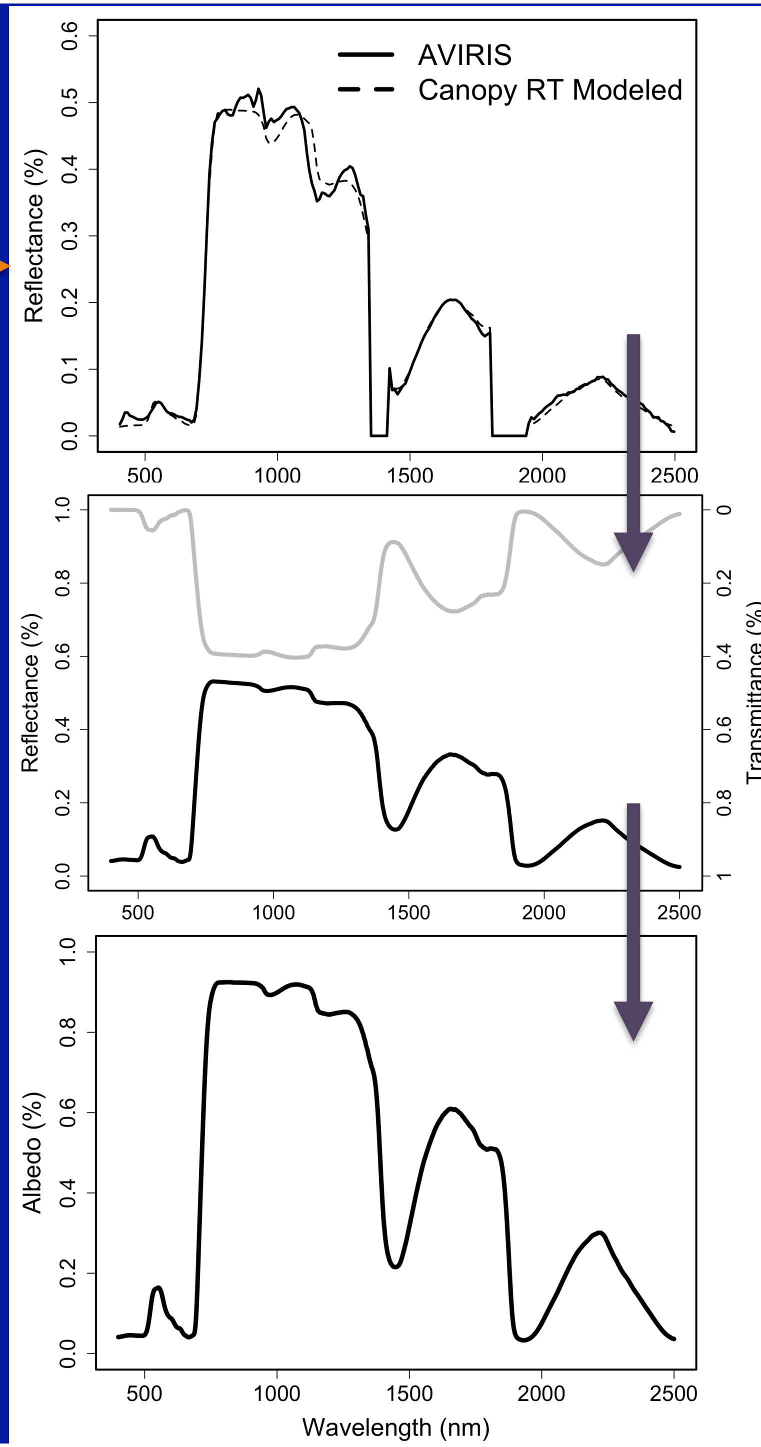
- Of course this requires uncertainty for proper DA. Otherwise too much weight given to the RS estimates causing overconfidence. Therefore, our methods utilize the generation of AVIRIS retrieval uncertainty to properly assimilate datasets!

DIRECT OPTICAL ASSIMILATION



Canopy Refl: f(Incident rad, leaf optics, stem/soil/litter optics, stem density, crown structure, LADF, LAI, dispersion of leaves, [e.g. random or clumped])
Scattering elements, LADF, LAI
Diffuse rad penetration
Direct rad penetration
NPV
Soil Reflectance
Asner et al. (1998) RSE
Asner et al. (1998) RSE
Reflectance (%)
Wavelength (nm)
Transmittance (%)
Woody Stem Reflectance
Soil Reflectance





Canopy RTM Inversion

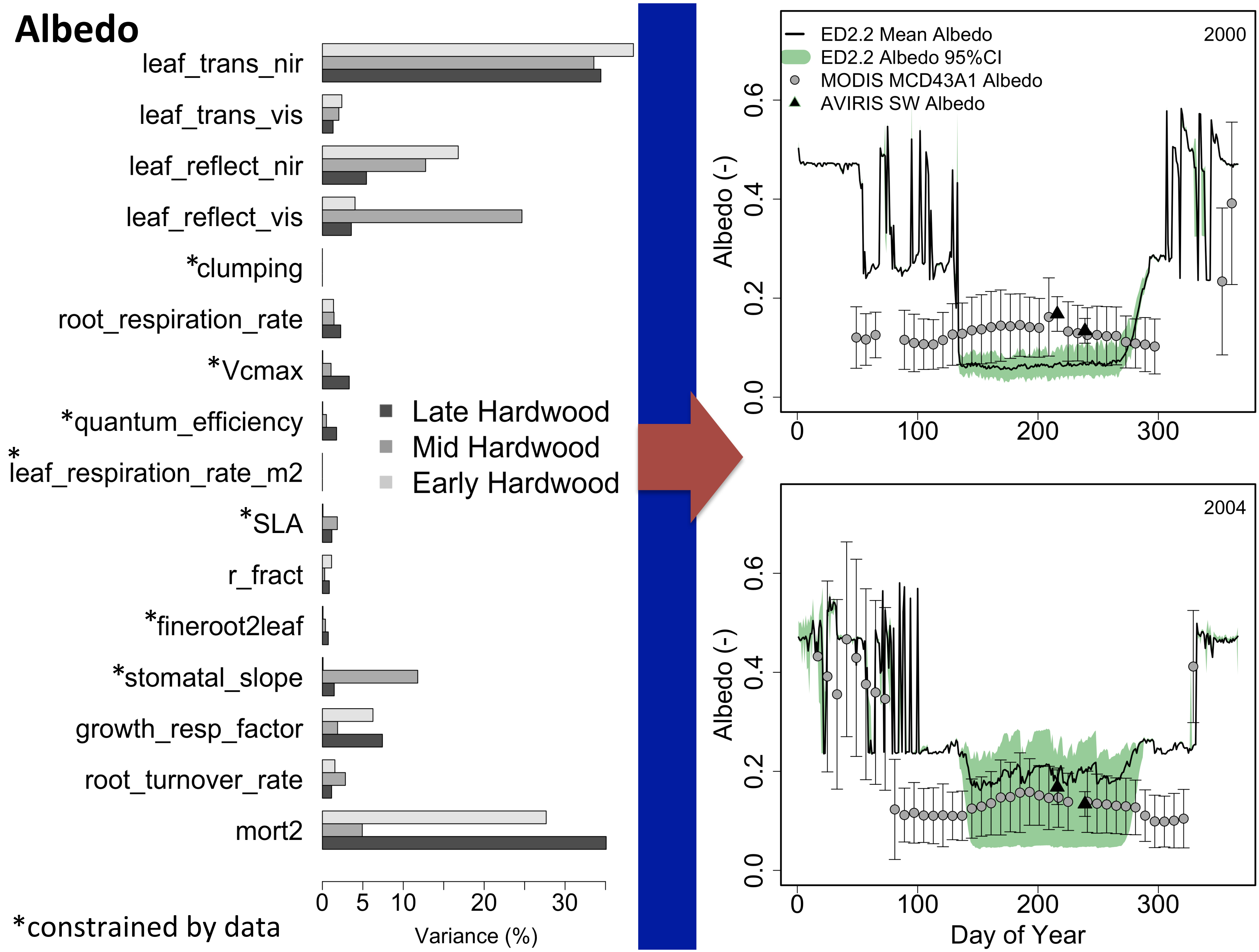
RMSE = 0.015
LAI = 4.89

PROSPECT Inversion (Modeled Optics)

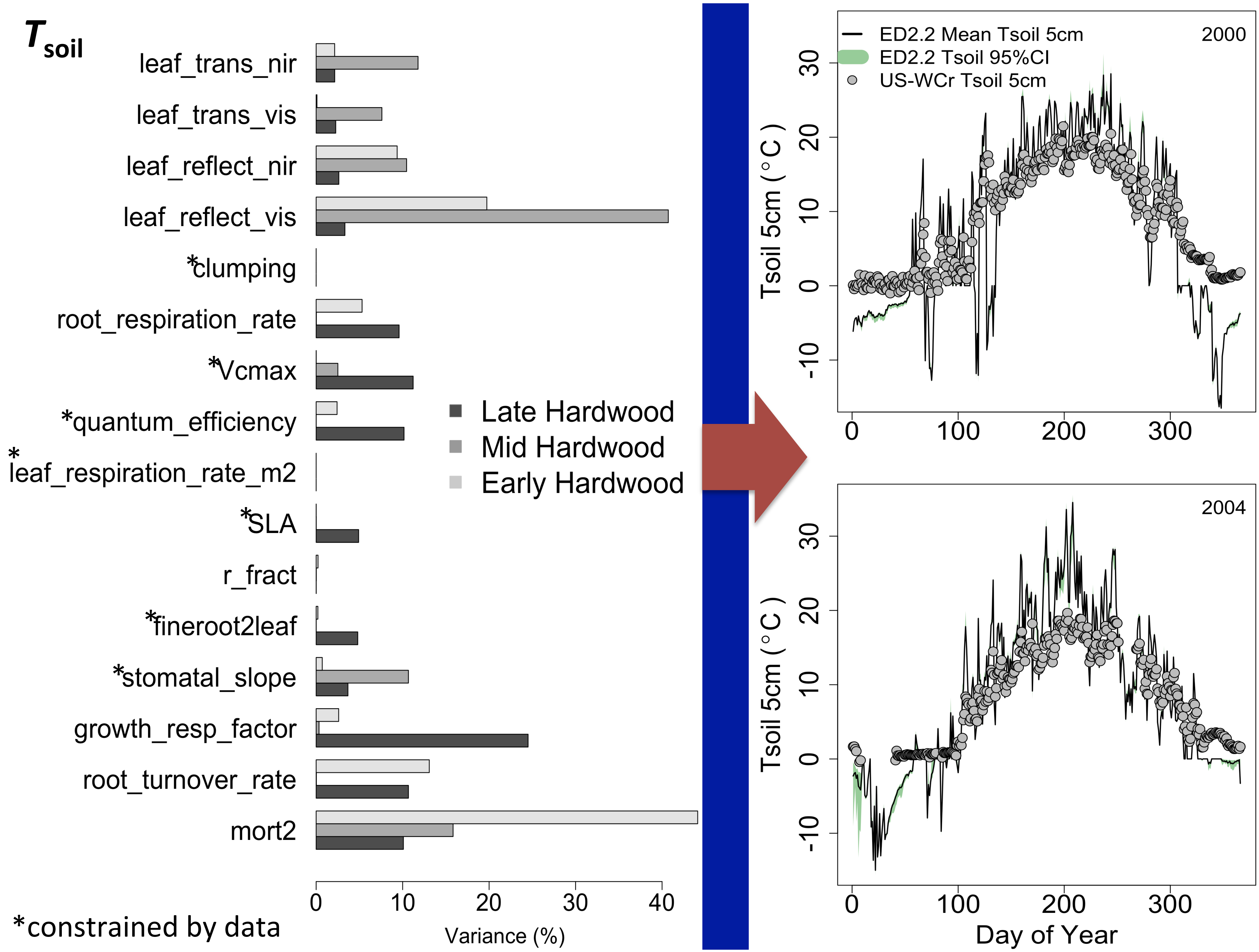
Cab = 58.3
EWT = 0.020 cm
SLA = 18.4 m2 / kgC

Single Scattering Albedo

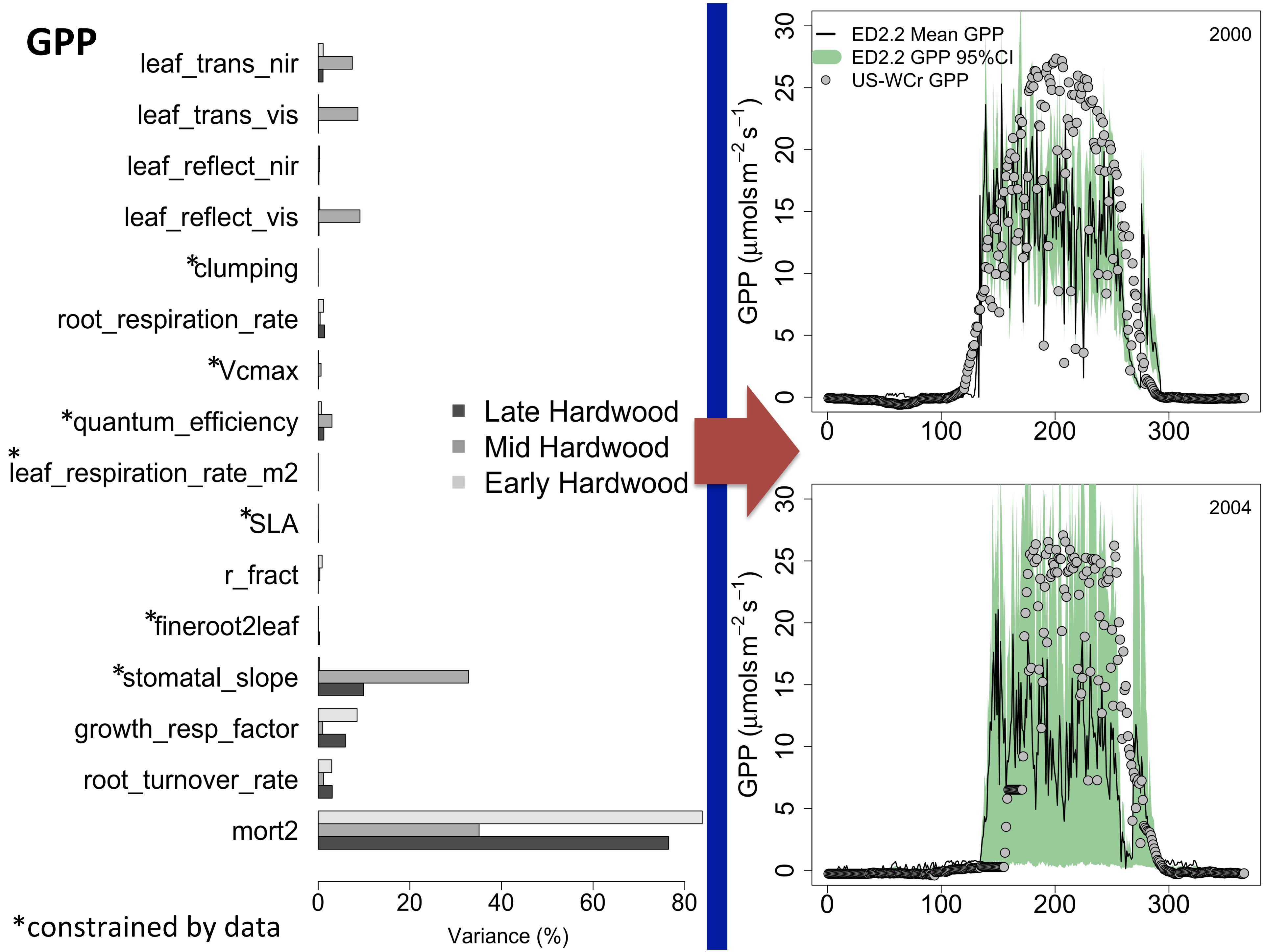
Update Eco. Model leaf optics (refl. / trans)



Albedo
leaf_trans_nir
leaf_trans_vis
leaf_reflect_nir
leaf_reflect_vis
*clumping
root_respiration_rate
*Vcmax
*quantum_efficiency
*leaf_respiration_rate_m2
*SLA
r_fract
*fineroot2leaf
*stomatal_slope
growth_resp_factor
root_turnover_rate
mort2
Late Hardwood
Mid Hardwood
Early Hardwood
0 5 10 20 30
Variance (%)
*constrained by data
ED2.2 Mean Albedo
ED2.2 Albedo 95%CI
MODIS MCD43A1 Albedo
AVIRIS SW Albedo
2000
2004
Albedo (-)
0.0 0.2 0.4 0.6
0 100 200 300
Day of Year



T_{soil}
leaf_trans_nir
leaf_trans_vis
leaf_reflect_nir
leaf_reflect_vis
*clumping
root_respiration_rate
*Vcmax
*quantum_efficiency
*leaf_respiration_rate_m2
*SLA
r_fract
*fineroot2leaf
*stomatal_slope
growth_resp_factor
root_turnover_rate
mort2
Late Hardwood
Mid Hardwood
Early Hardwood
0
10
20
30
40
Variance (%)
*constrained by data
ED2.2 Mean Tsoil 5cm
ED2.2 Tsoil 95%CI
US-WCr Tsoil 5cm
2000
2004
Tsoil 5cm (°C)
Day of Year


GPP
leaf_trans_nir
leaf_trans_vis
leaf_reflect_nir
leaf_reflect_vis
*clumping
root_respiration_rate
*Vcmax
*quantum_efficiency
*leaf_respiration_rate_m2
*SLA
r_fract
*fineroot2leaf
*stomatal_slope
growth_resp_factor
root_turnover_rate
mort2
0
20
40
60
80
Variance (%)
*constrained by data
Late Hardwood
Mid Hardwood
Early Hardwood
ED2.2 Mean GPP
ED2.2 GPP 95%CI
US-WCr GPP
2000
2004
GPP (µmols m⁻² s⁻¹)
0
5
10
15
20
25
30
0
100
200
300

Pros and Cons: Product assimilation

- Product assimilation typically requires less modification of most ecosystem models
  - Tradeoff is uncertainty of product directly propagates into uncertainty in model
  - Model and product make different assumption about canopy architecture – bias is likely if the two are fundamentally different (also scale dependent)
  - Computational cost for radiative transfer based parameter inversion is done at product stage instead of during model execution
  - Characterizing product uncertainty as important as actual value for data assimilation approaches

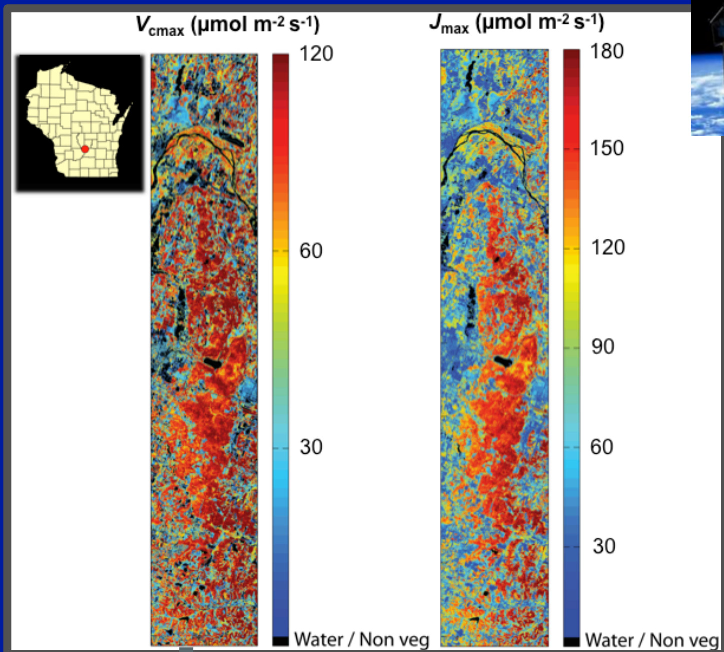
Pros and Cons: Direct optical assimilation

- Optical assimilation requires identification of proper canopy radiative transfer model
  - Increases parameters, but possibly allows for optics to directly guide model improvement without *a priori* assumptions of what spectral signatures mean
  - Similarly, no bias from difference in assumption of canopy architecture
  - Easily extendable to many remote sensing platforms
  - Initial model investment is high and model canopy may not be well suited for radiative transfer

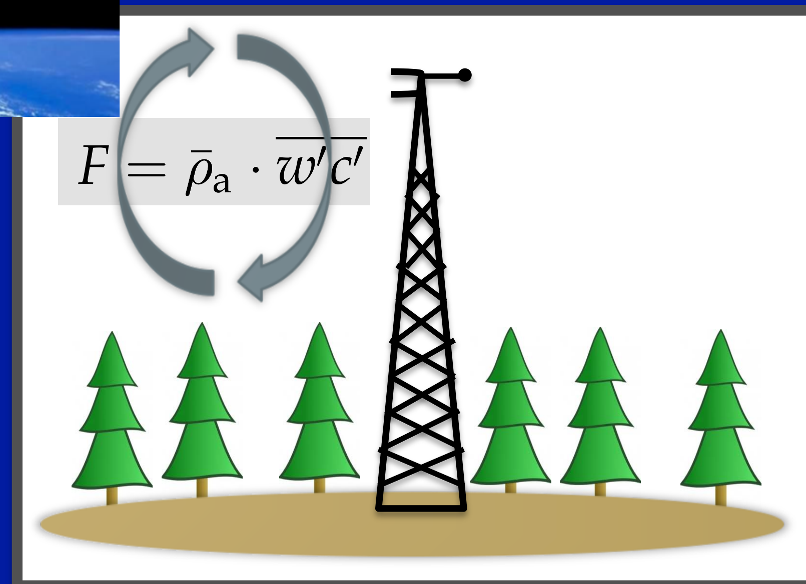
A look forward

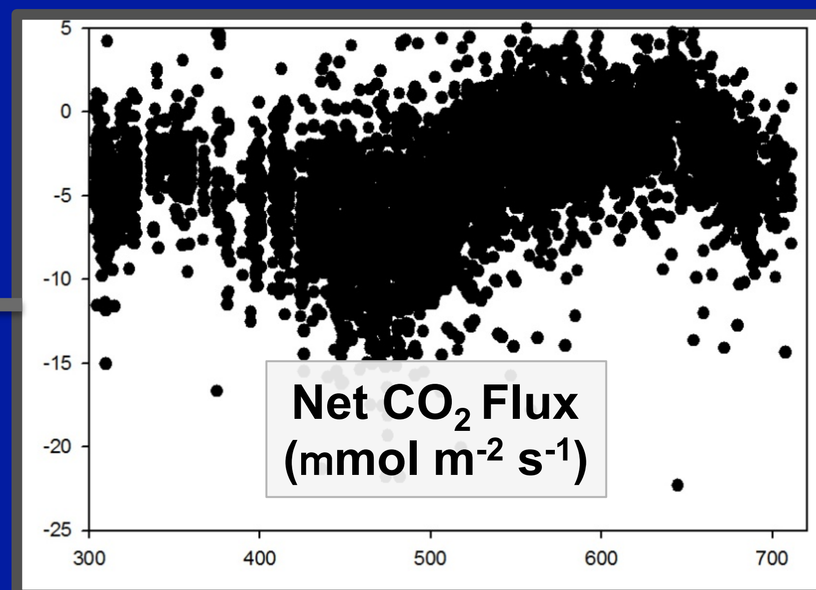
- HyspIRI (http://hyspiri.jpl.nasa.gov/) or similar future satellites (EnMAP; http://www.enmap.org/) along with continuous canopy spectral measurements (SpecNet) will dramatically increase the volume of spectral information in Visible, near IR, and thermal wavelengths
- We can do more than just make pretty pictures and poorly validated "products" - need to move away from exclusively using vegetation indices
- The need to reduce terrestrial carbon cycle model parameters is urgent and methods to assimilate spectral information directly into models is limited to date
- Spectral databases (e.g. EcoSIS, SPECCHIO) can be mined for key PFT-level information useful for constraining model projections

NASA HyspIRI California Campaign



Eddy Covariance





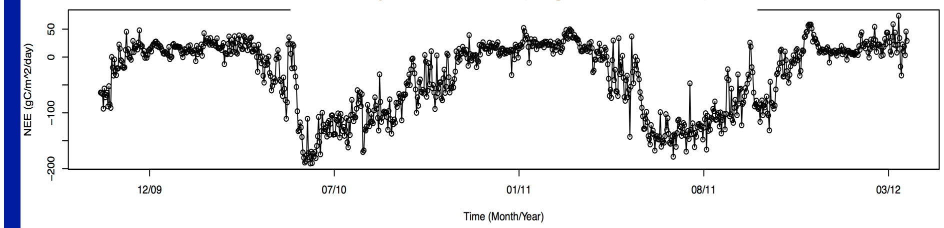
Evaluation

Param Est.

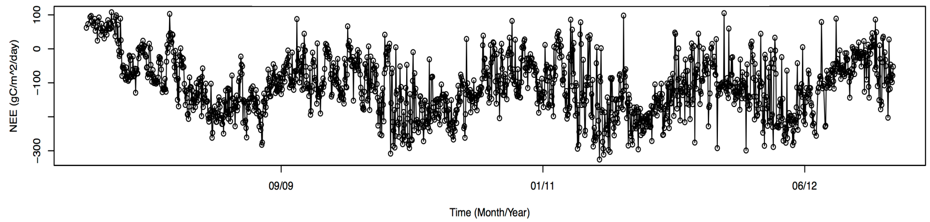
Estimates of V_{cmax} and J_{max} derived from imaging spectroscopy will be compared with those inverted from flux tower data at each site using a coupled 2-layer (sunlit-shaded canopy) FvCB ecosystem model. Uncertainty will be assessed using Bayesian parameter inversion.

HyspIRI overflies a range of Mediterranean and Western Pine ecosystem flux tower sites

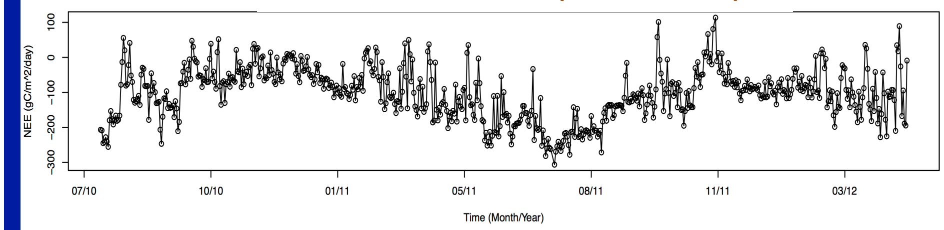
Subalpine Forest (high elevation)



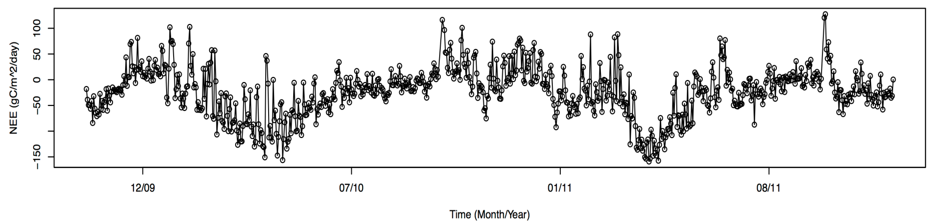
Mixed Conifer Forest (high elevation)



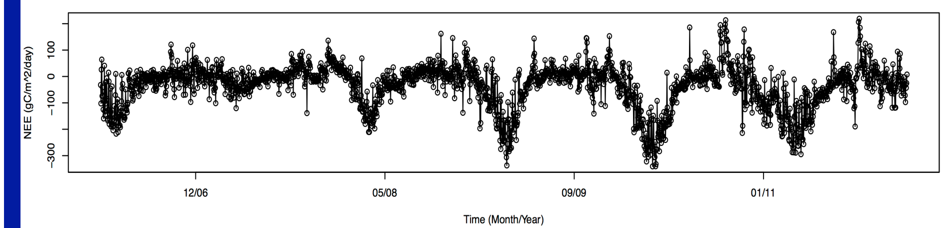
Ponderosa Pine Forest (mid elevation)



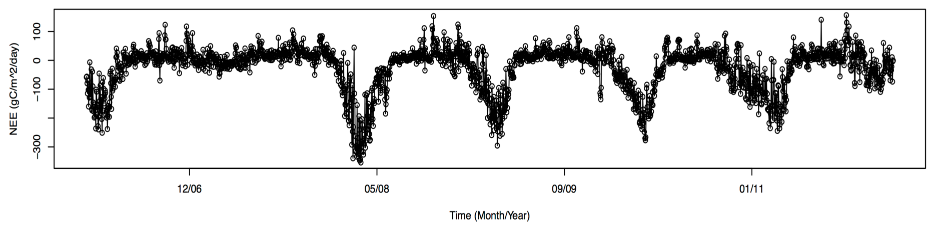
Oak-pine Woodland (low elevation)



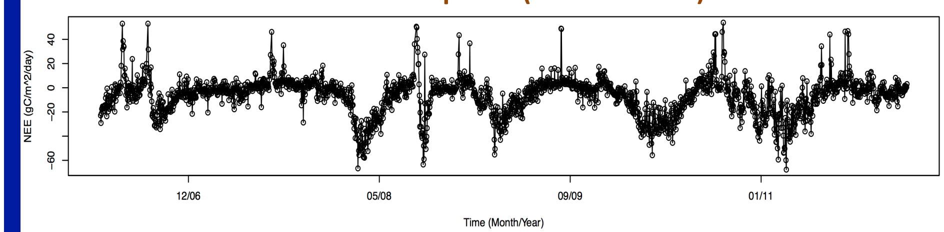
Coastal Sage (low elevation)



Coastal Grassland (low elevation)



Desert Chaparral (low elevation)



- Climatic & topographic variation in fluxes
- Water availability is key

Thank you

- Many collaborators in the field in Wisconsin and California, ED2 model developers, PEcAn data assimilation crew, NASA AVIRIS team
- More: http://pecanproject.org/
- Funding: NASA ROSES Hyspiri Preparatory NNX12AQ28G, NSF Advances in Biological Informatics DBI-1062204.