Using MODIS optical reflectance observations to constrain canopy biophysics

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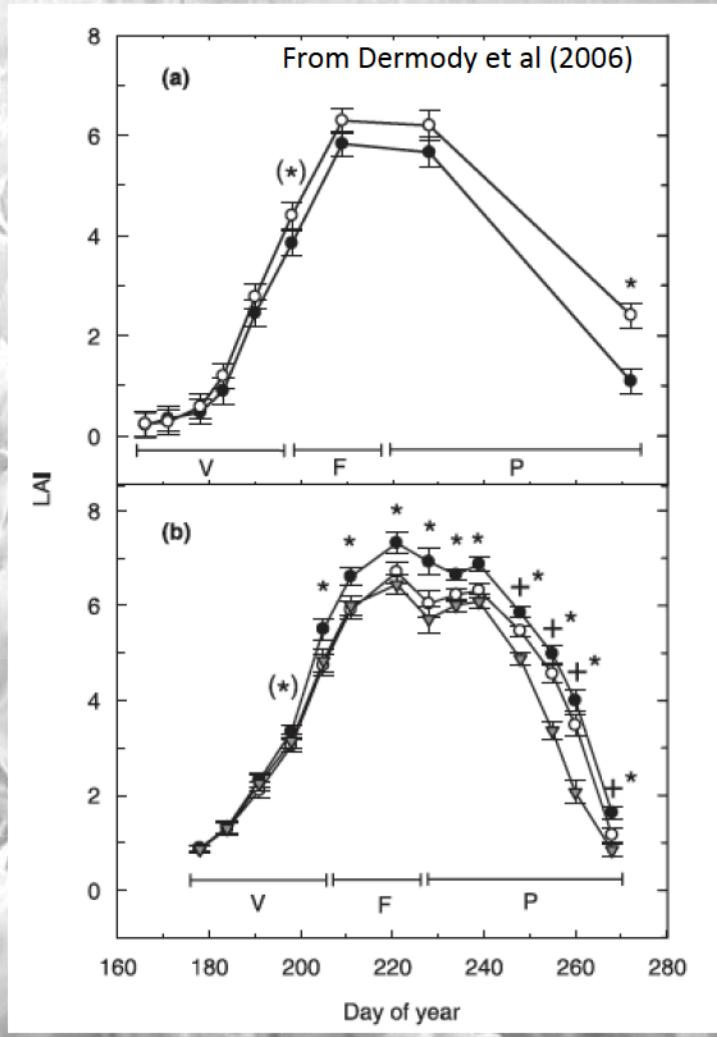
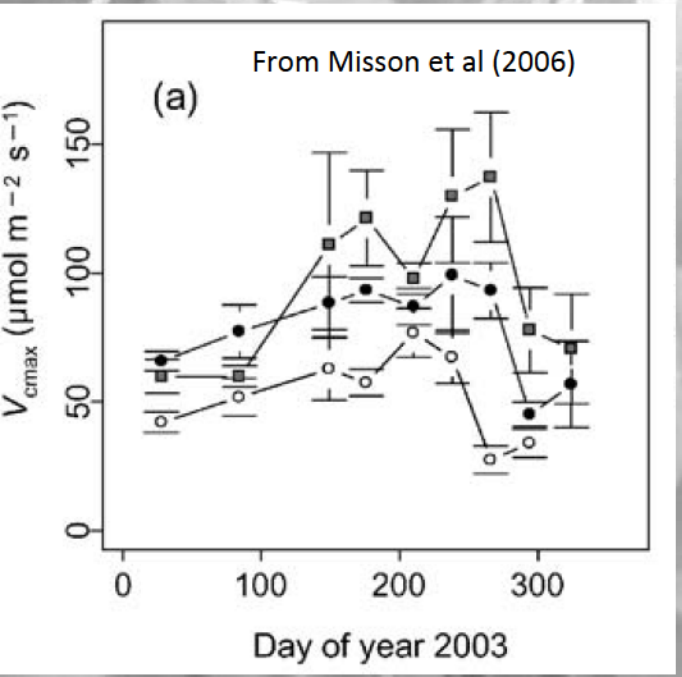
Overview

Seasonal variations in vegetation canopy structure, biochemical states and water status control terrestrial response to climate

- Canopy leaf area index (LAI) controls capture of photosynthetically active radiation (PAR) that drives photosynthesis





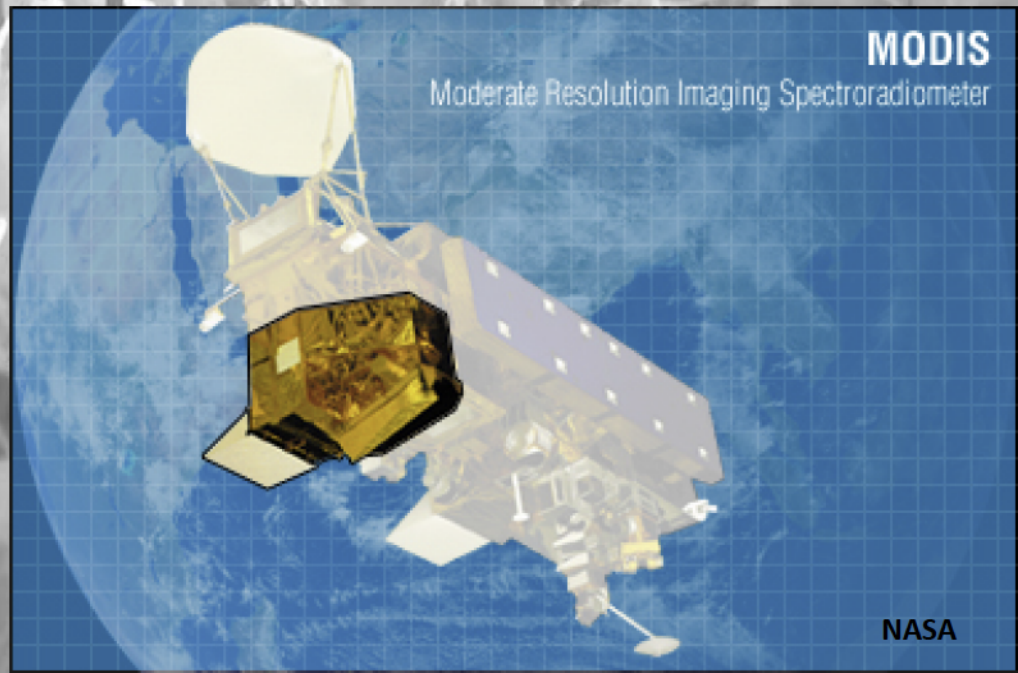
- Photosynthetic capacity of vegetation, related to N or chlorophyll (Chl) content of leaves, controls the efficiency that absorbed PAR is used to assimilate carbon

Overview

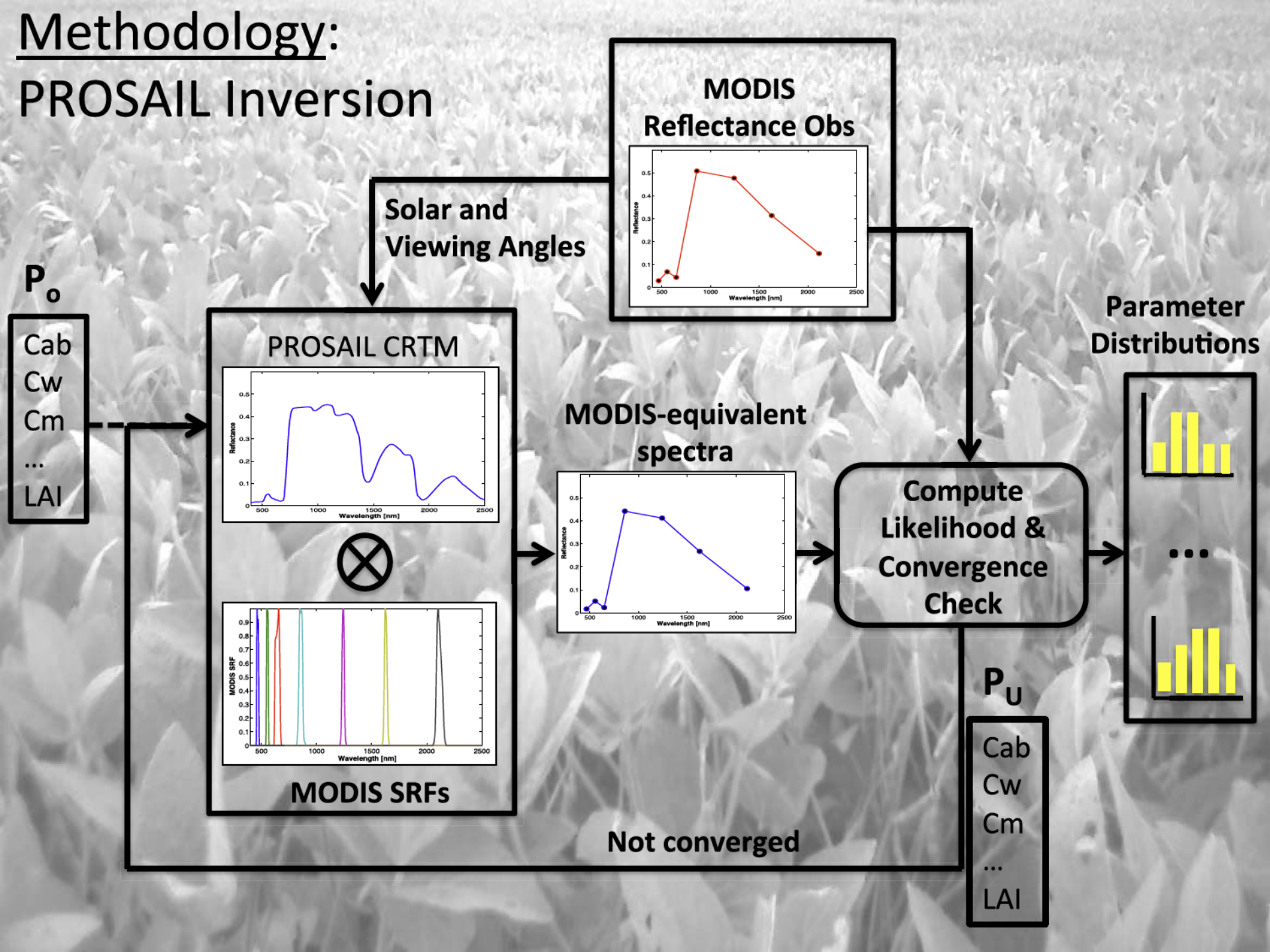
Capturing this seasonality in canopy structure and biochemical traits remains a significant challenge to accurate model-based estimation of canopy-atmosphere exchange of CO_2, water and energy

Moderate Resolution Imaging Spectro-radiometer (MODIS) observations are attractive due to:

- High frequency repeat cycle – view the Earth's surface every 1-2 days
- Onboard both Aqua and Terra – providing more observations at differing solar and viewing geometries
- Observes 7 spectral bands across optical spectrum at 250m and 500m resolution



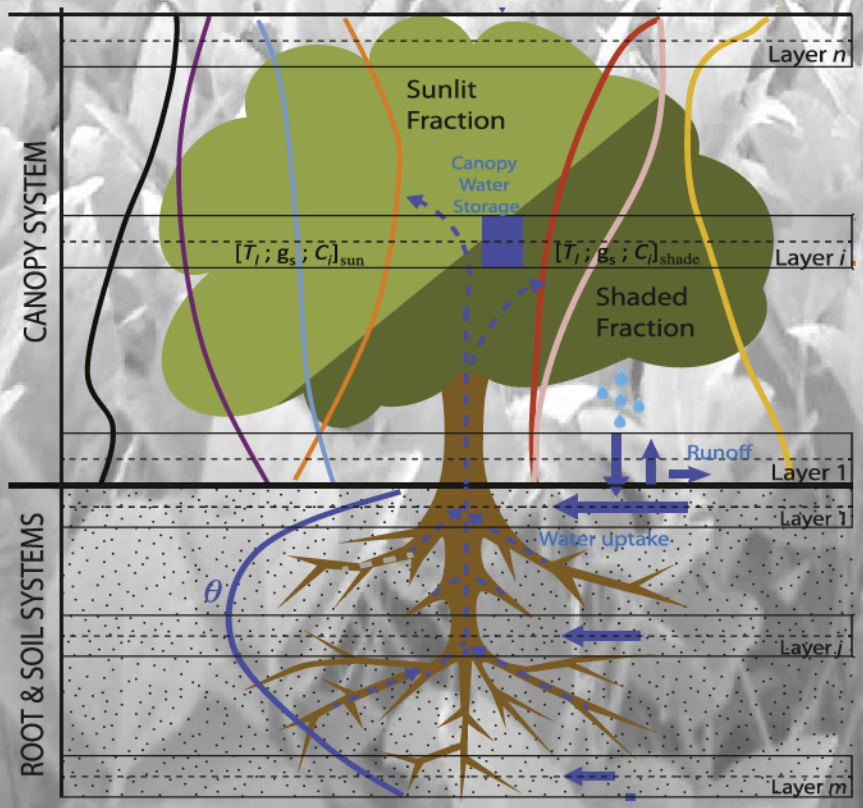
Methodology:
PROSAIL Inversion



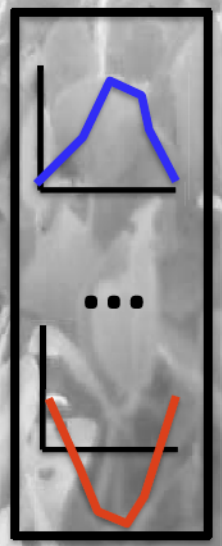
Methodology:
Forward Model Update and Uncertainty

Parameter Distributions

MLCan Forward Model



Canopy-Atmosphere Exchange Estimates / Uncertainty



PROSAIL Overview

PROSAIL = PROSPECT + SAIL

PROSPECT-5: model of leaf optical properties

- Requires the specification of leaf biochemical properties:
  - chlorophyll concentration (C_{ab})
  - carotenoid concentration (C_{ar})
  - brown pigment content (C_{brown})
- and leaf physical properties:
  - equivalent water thickness (C_w)
  - dry matter content (C_m)
  - leaf (mesophyll) structure parameter (N)

Jacquemoud and Baret (1990) *Remote Sensing of Environment*
Féret et al (2008) *Remote Sensing of Environment*

PROSAIL Overview

PROSAIL = PROSPECT + SAIL

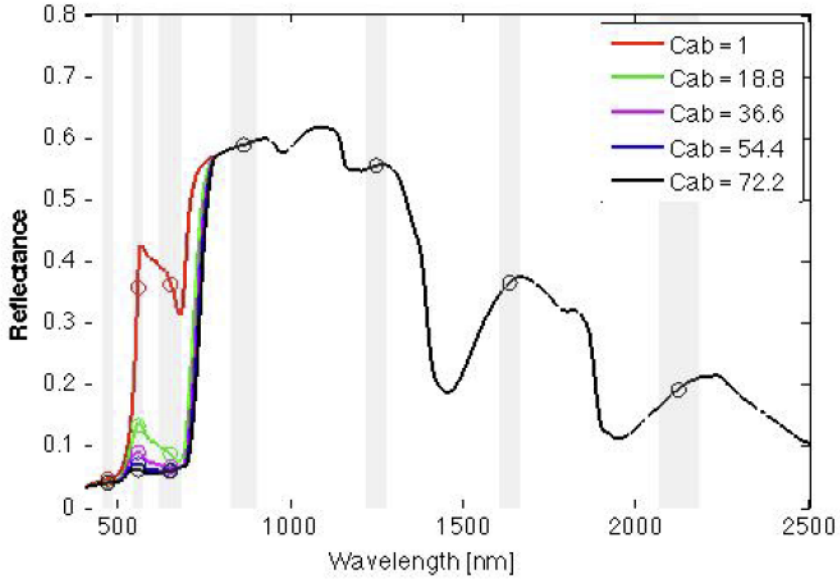
SAIL: canopy bidirectional reflectance model

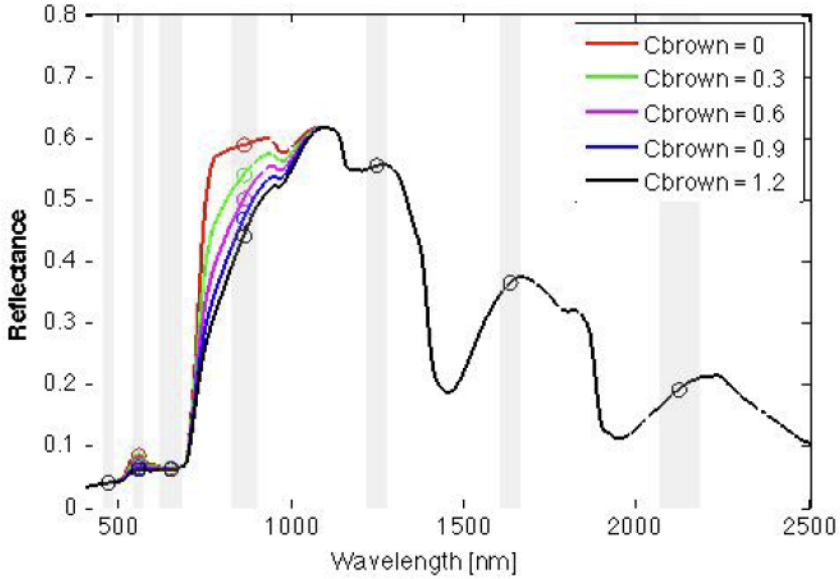
- Requires the specification of canopy structural properties:
  - Leaf angle distribution
  - Leaf area index (LAI)
- Solar and viewer angles
- Soil reflectance

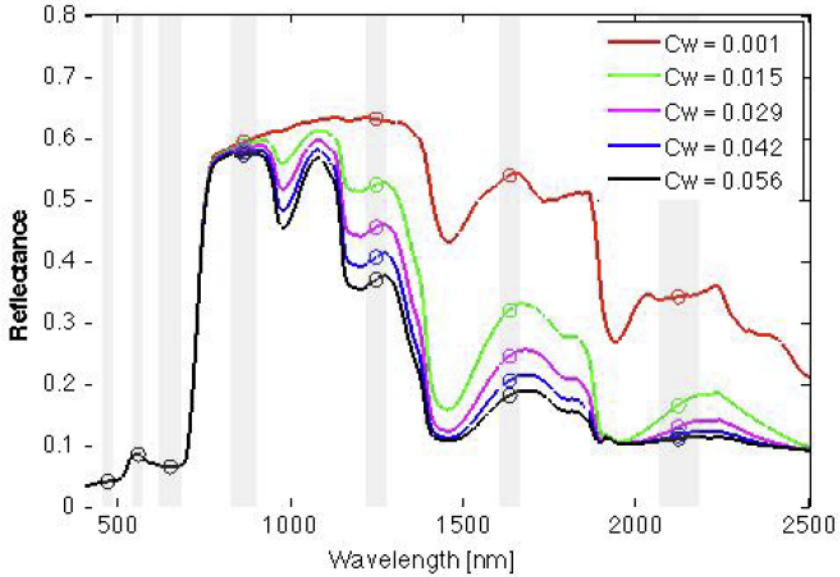
Together PROSAIL solves for TOC reflectance as a function of leaf biochemical and physical properties, canopy structure, soil influences and geometry

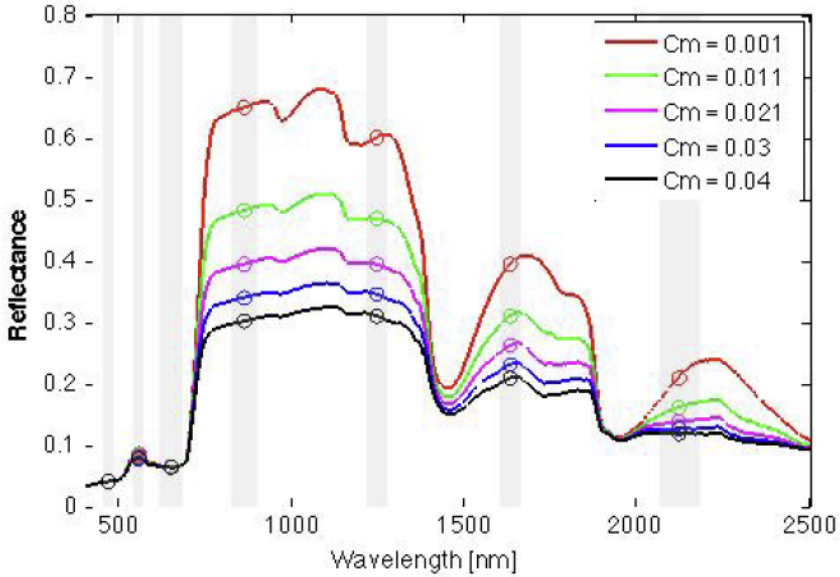
Verhoef (1984, 1985) *Remote Sensing of Environment*

PROSAIL Sensitivity



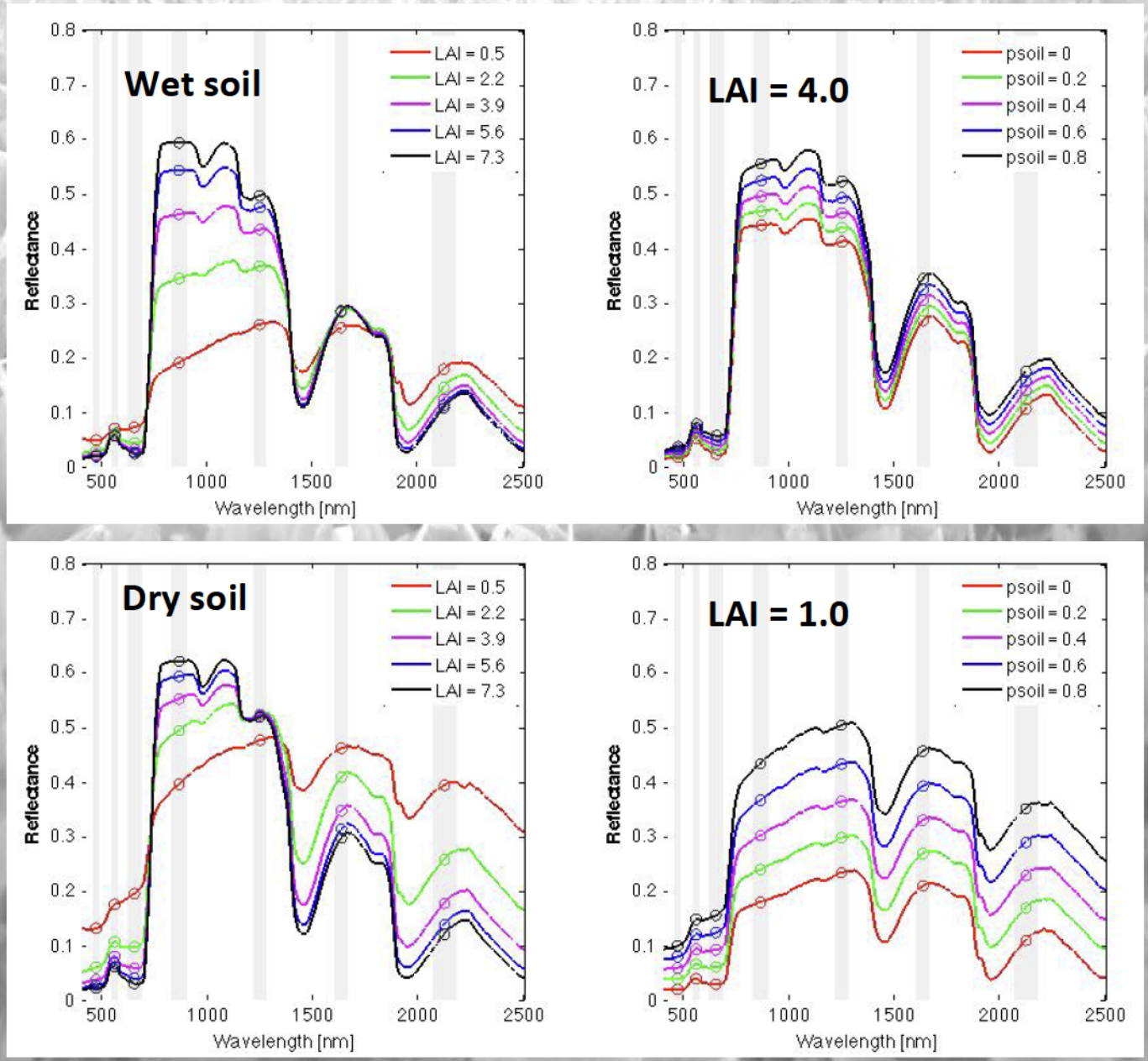






PROSAIL Sensitivity

Vertical grey bands denote MODIS bands



PROSAIL Inversion Approach

DREAM_ZS algorithm (Vrugt et al, 2008, 2009)

- Markov Chain Monte Carlo (MCMC) simulation
- Efficient generation of trial moves
- Allows for the characterization of posterior parameter distributions

- Use uniform priors across the parameter ranges described below
- 5 chains, 50,000 iterations, retained the last 25% to characterize parameter distributions
- Sum of squared error likelihood function
- [Zhang et al, 2005] used similar method to constrain PROSAIL for deciduous forest

PROSAIL 6 Parameters Varied and Ranges:

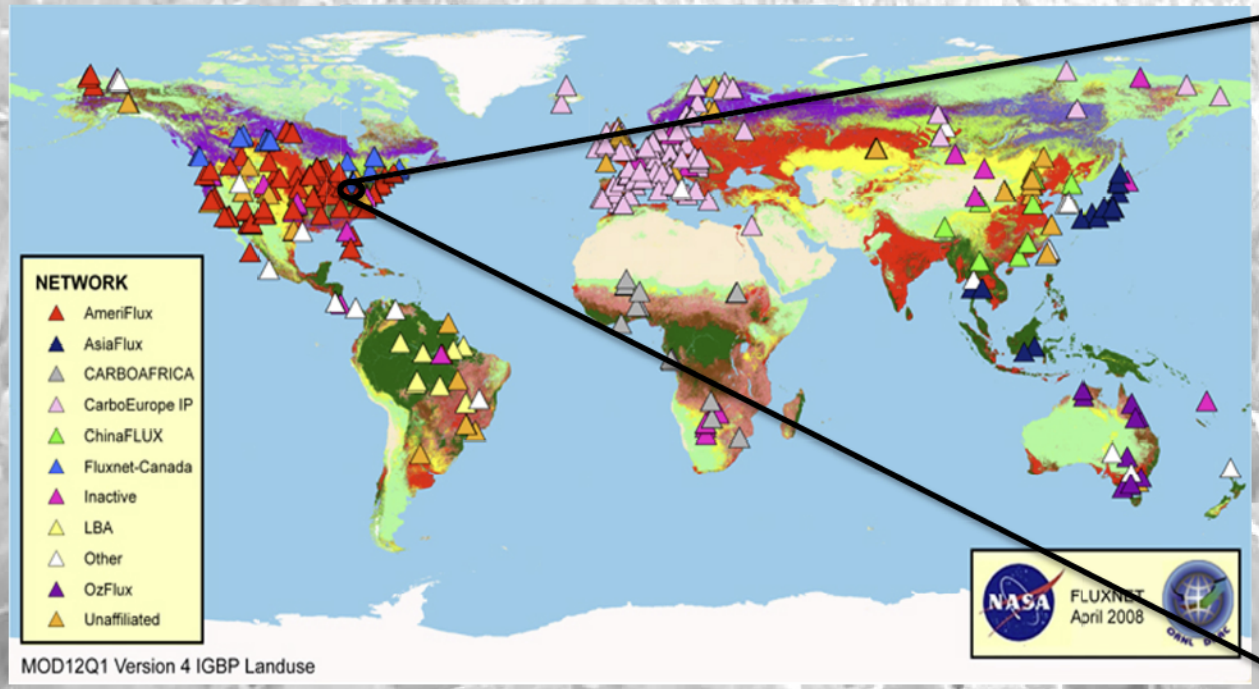
C_{ab} -> [1…110];	C_{brown} -> [0.0001…8];	C_w -> [0.001…0.07]
C_m -> [0.001…0.05];	LAI -> [0…8];	psoil -> [0…1]

Parameters held fixed:

leaf structure parameter (N) - Fixed for both crops from LOPEX93 data

leaf angle distribution - Fixed for maize (erectophile) and soybean (spherical)

Study Site: Bondville Ameriflux



Eddy covariance fluxes:

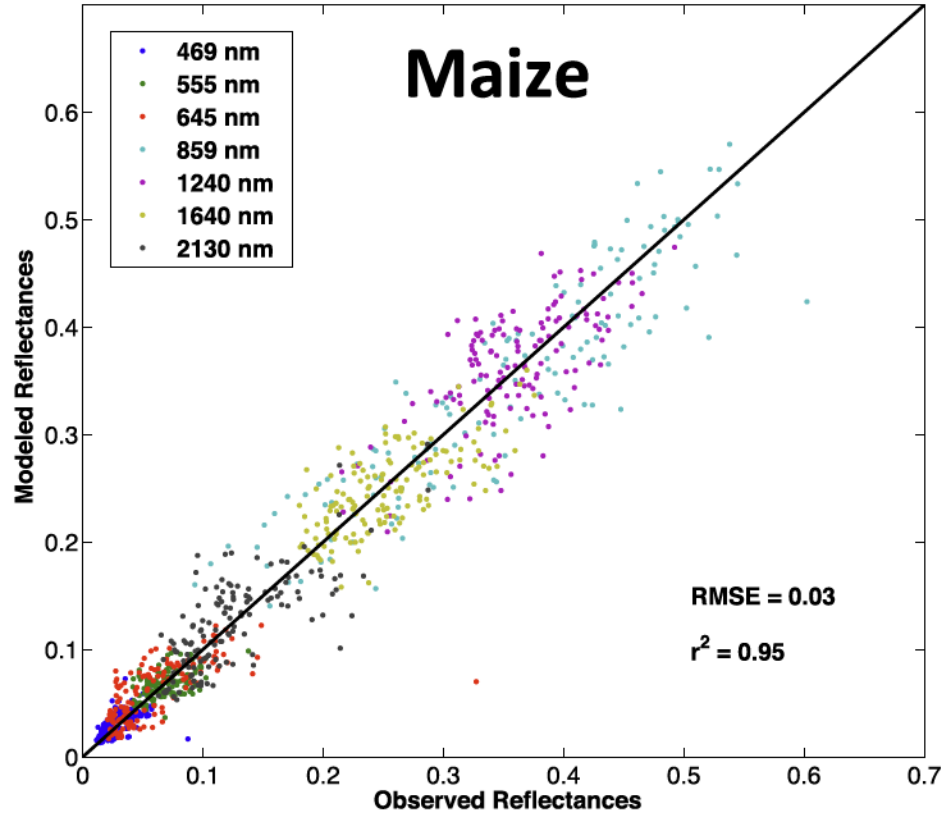
- Net CO_2 (F_c, A_n)
- Latent energy (LE)
- Sensible heat (H)
- ~6200 (maize) and 7500 (soybean) data points

Ambient meteorological conditions:

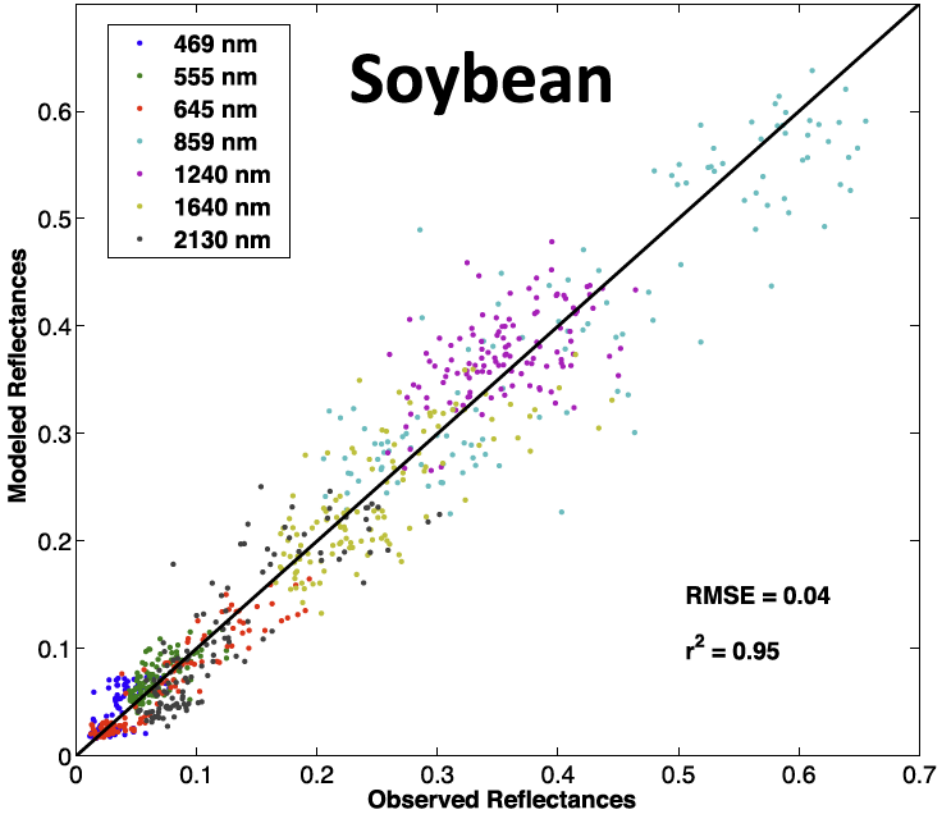
- PAR, NIR, LW
- U, T_a, e_a

Annual Rotation between soybean (2004, 2006) and maize (2003, 2005)

PROSAIL Inversion Against MODIS

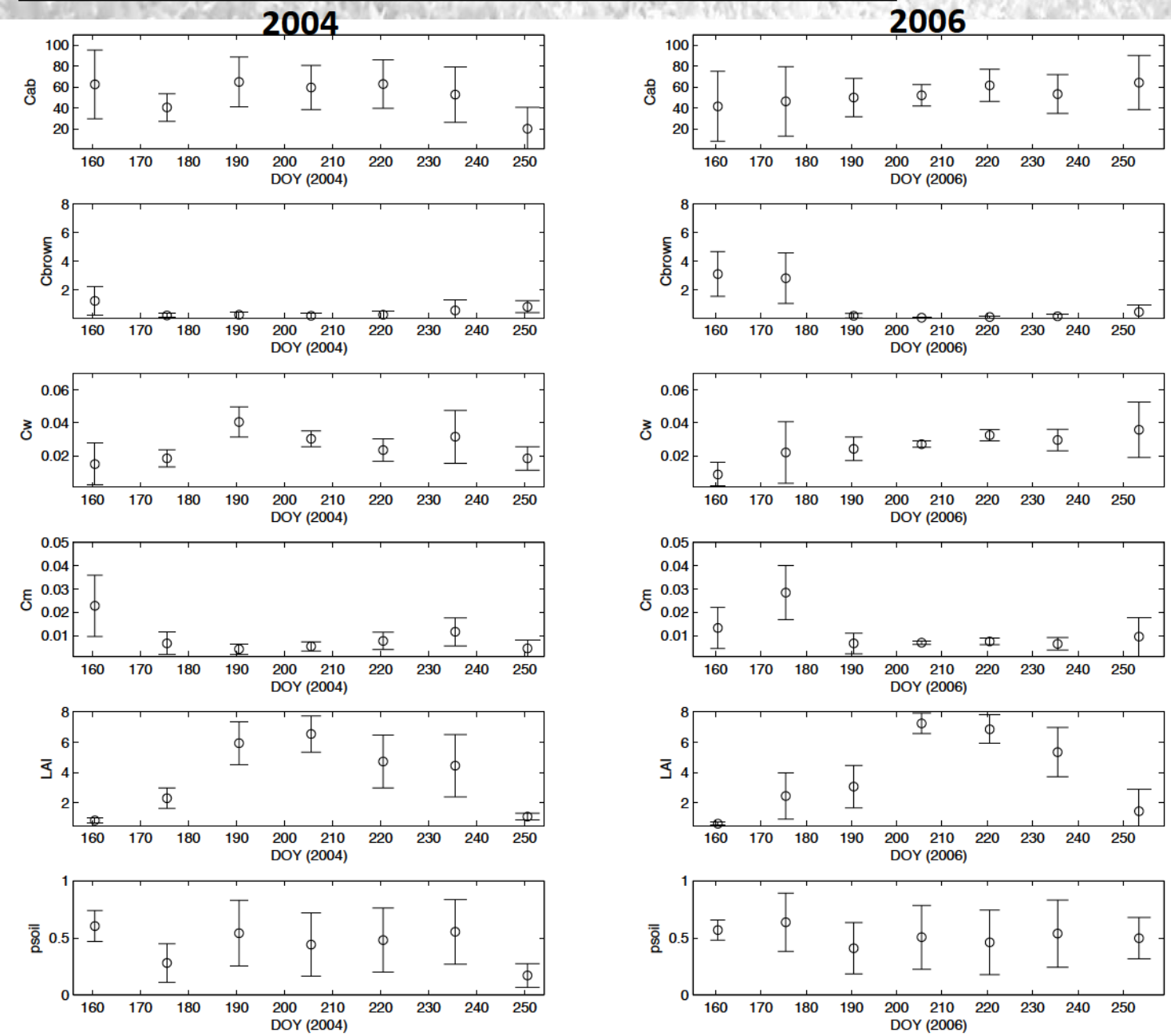


Maize: 2003, 2005
140 spectra



Soybean: 2004, 2006
167 spectra

Parameter Timeseries: Soybean



Chlorophyll content

Brown pigment content

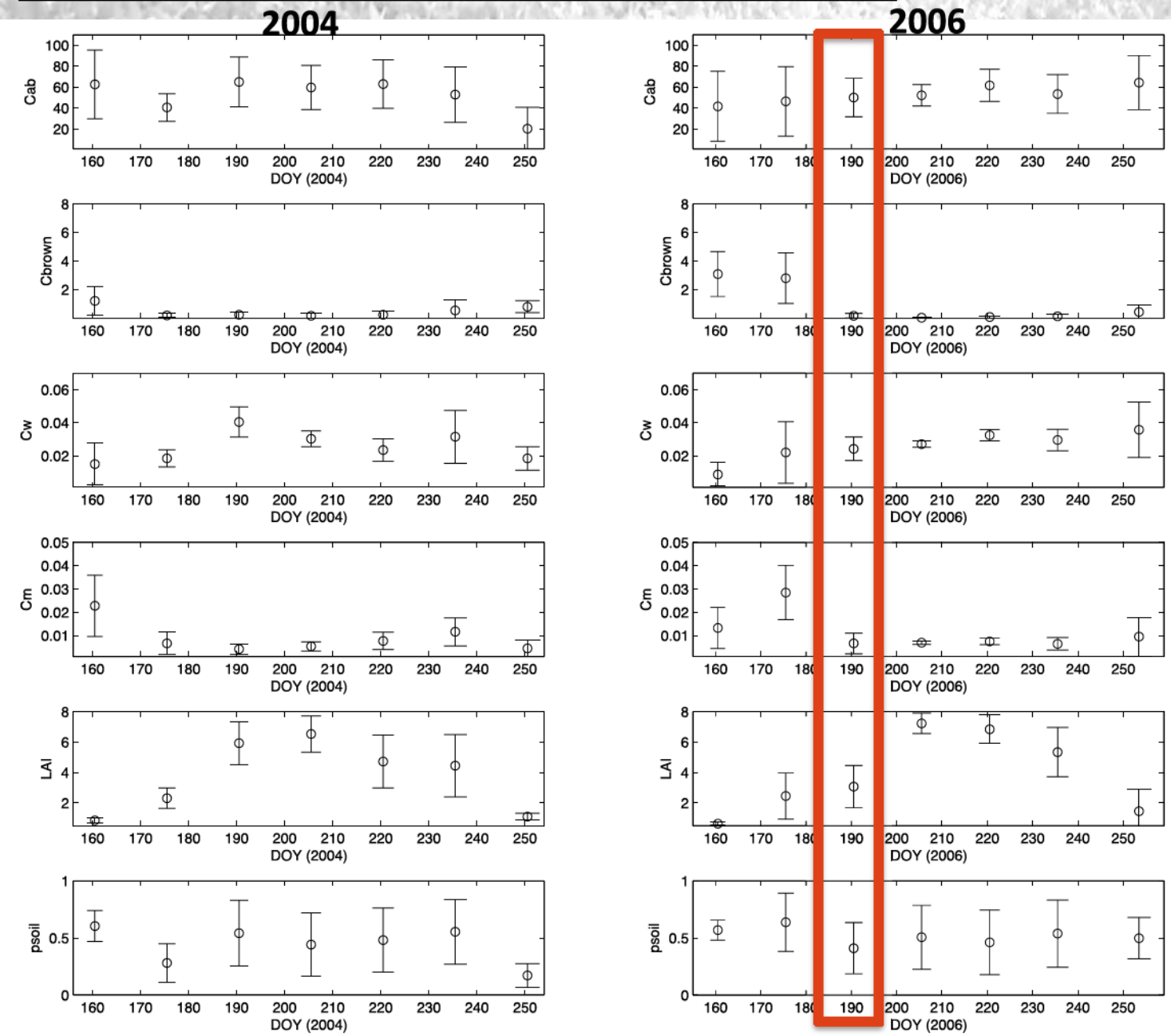
Equiv. water thickness

Dry matter content

LAI

Soil surface wetness

Parameter Timeseries: Soybean



Chlorophyll content

Brown pigment content

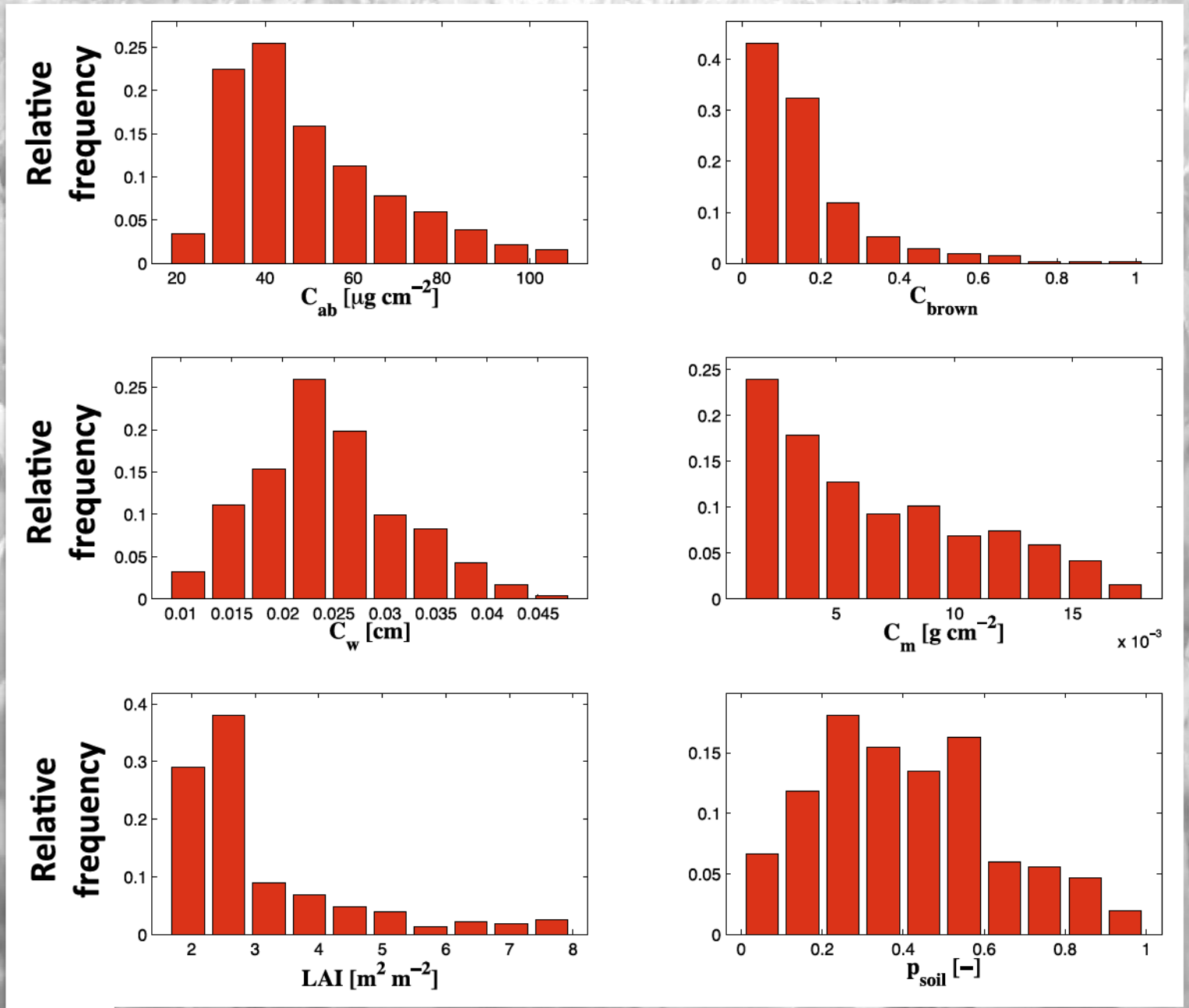
Equiv. water thickness

Dry matter content

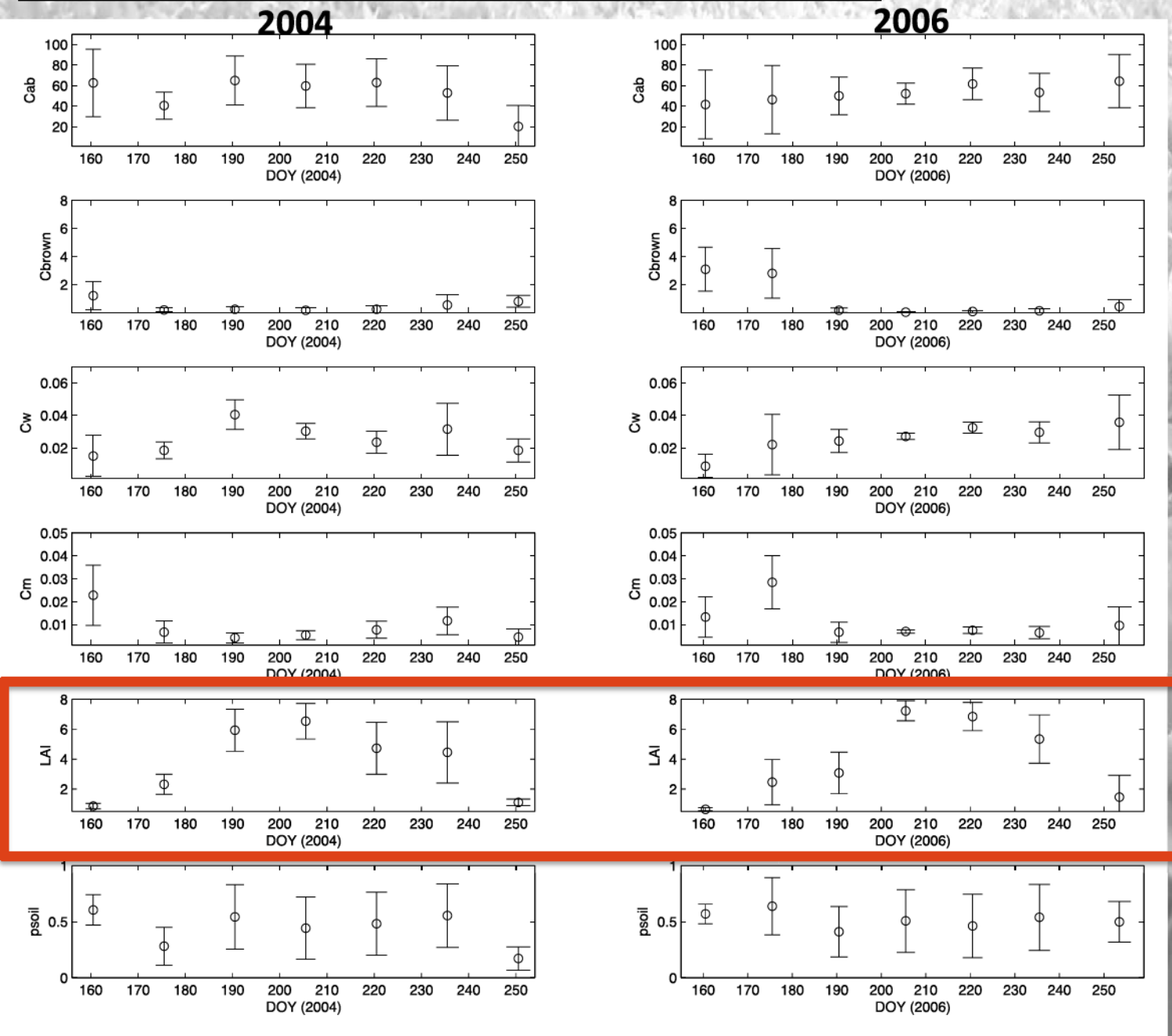
LAI

Soil surface wetness

PROSAIL Inversion Parameter Constraint



Parameter Timeseries: Soybean



Chlorophyll content

Brown pigment content

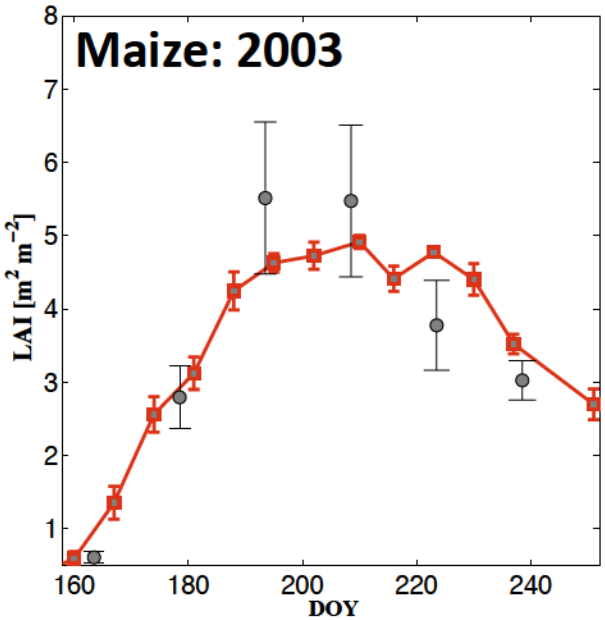
Equiv. water thickness

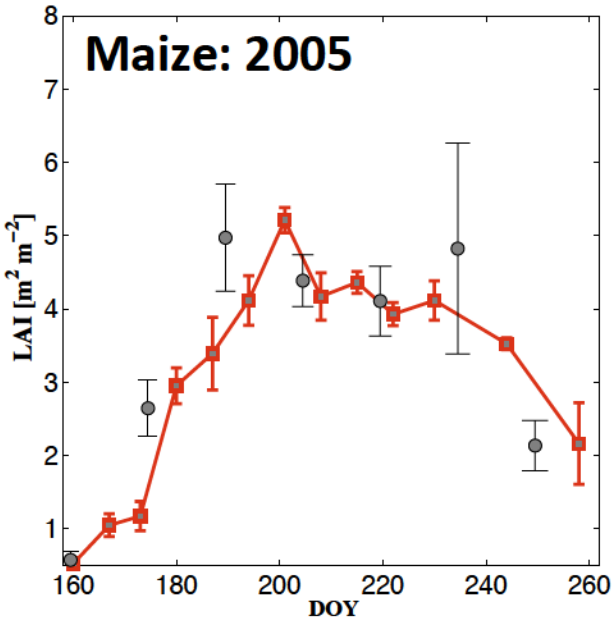
Dry matter content

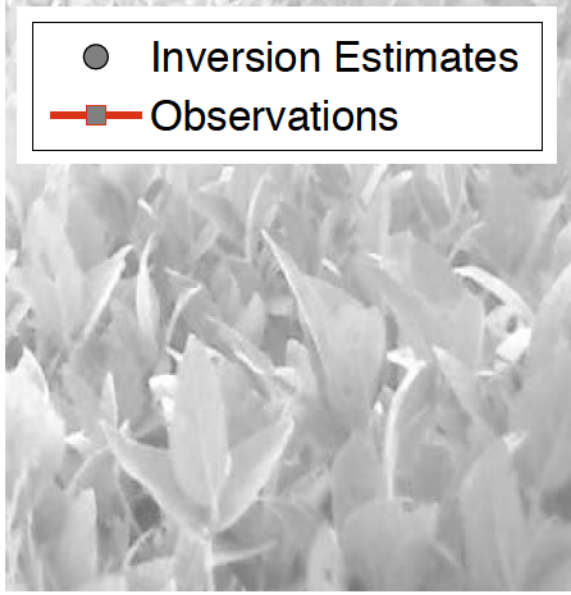
LAI

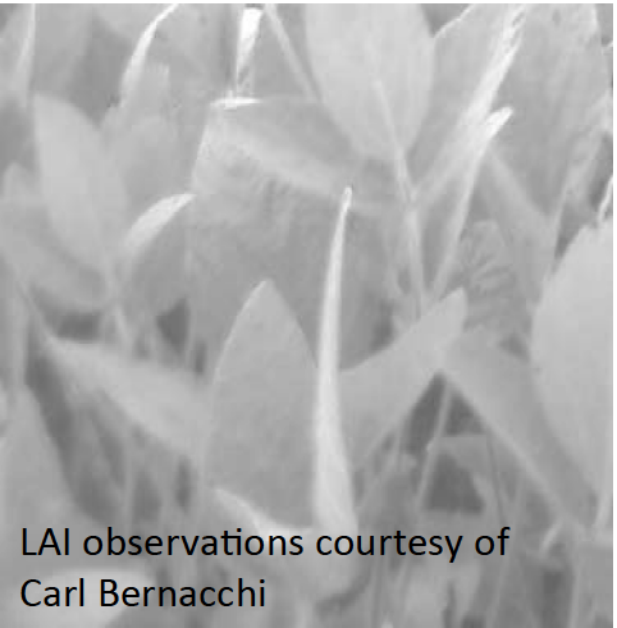
Soil surface wetness

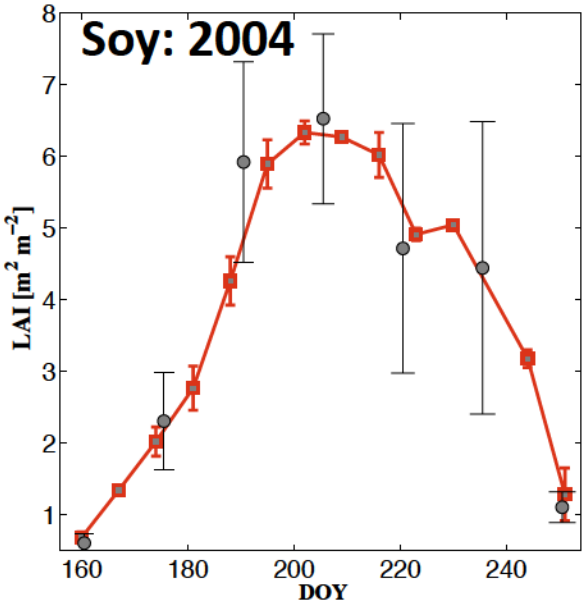
LAI Seasonal Estimates

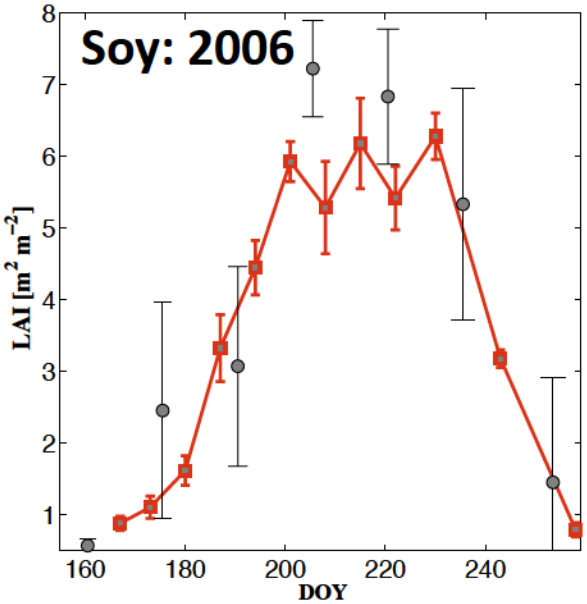




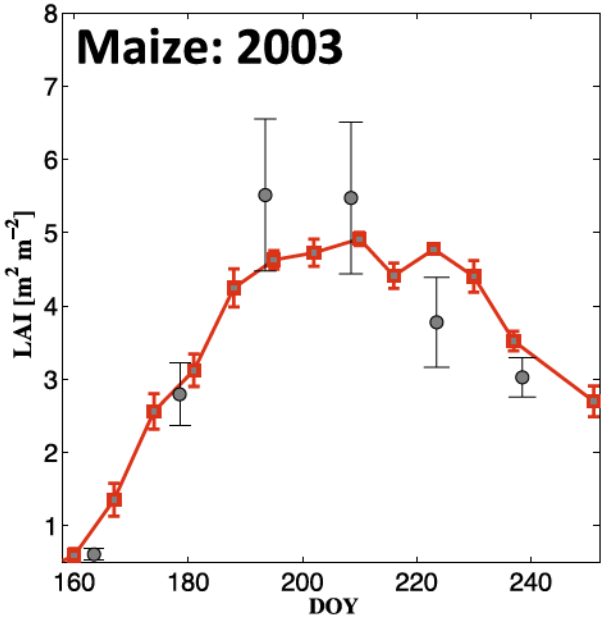


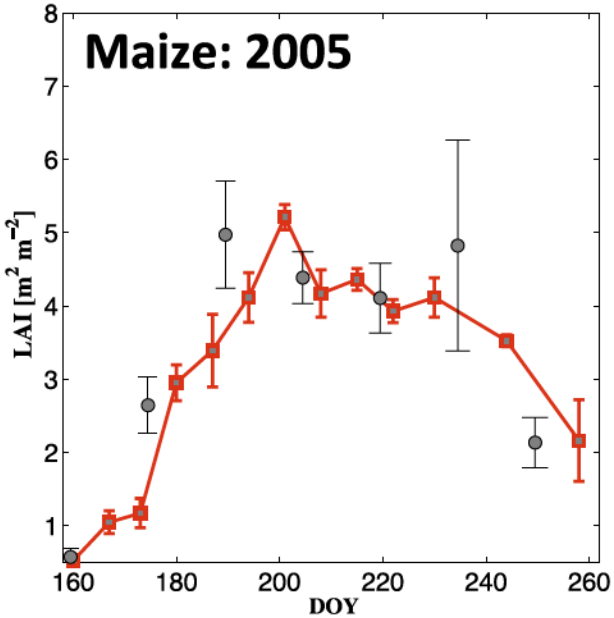


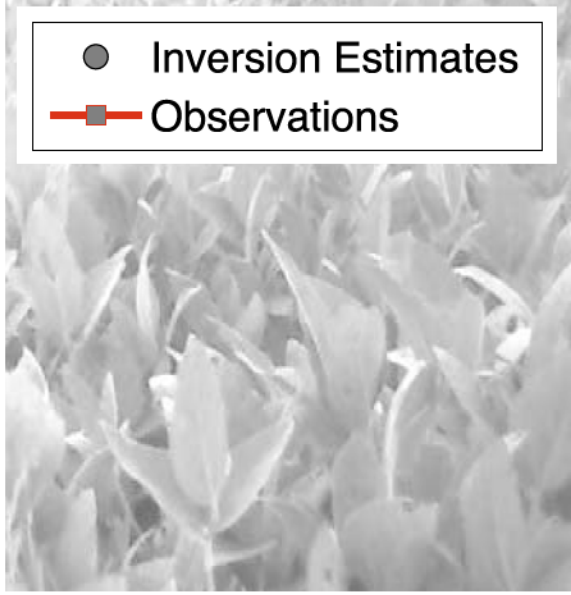


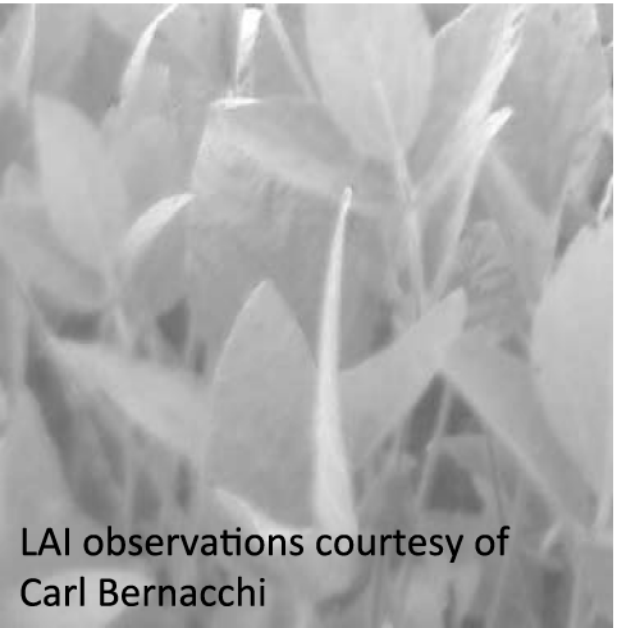


LAI Seasonal Estimates

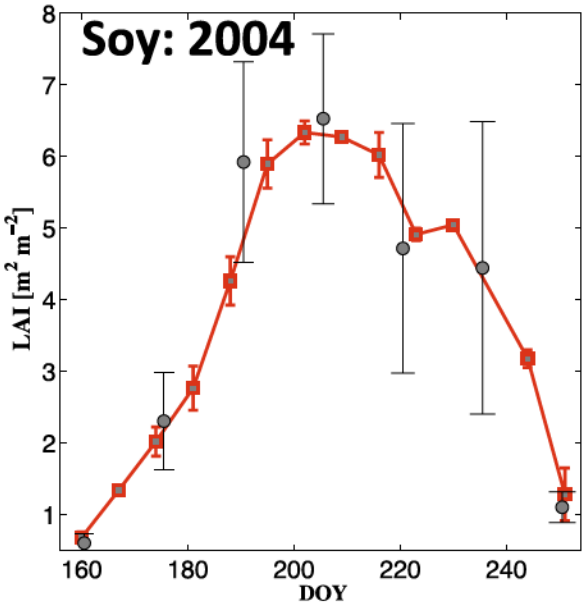


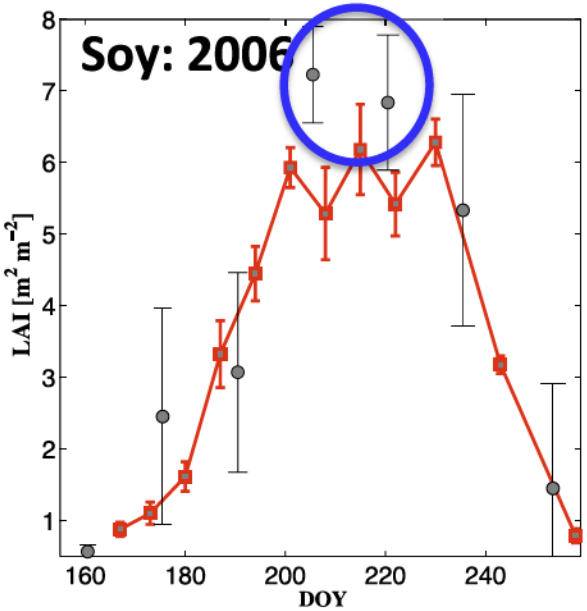




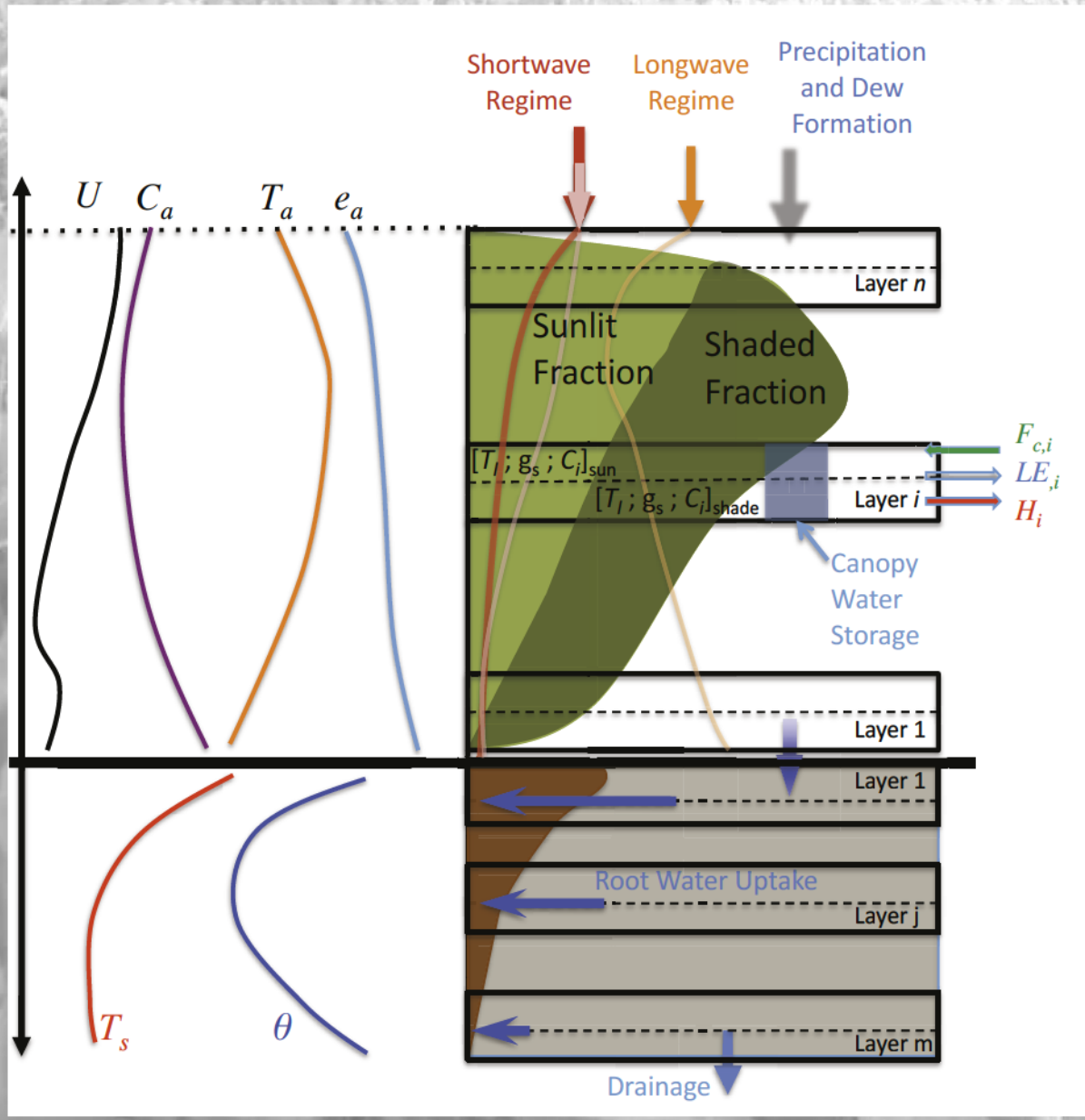


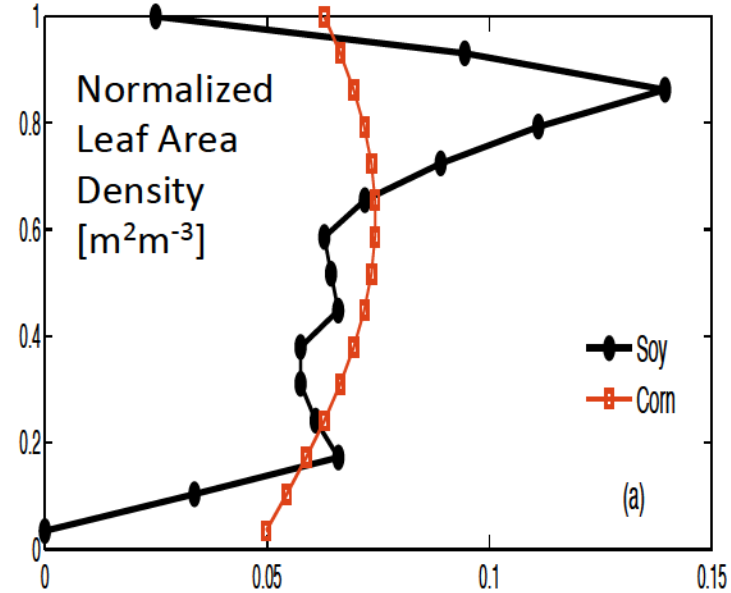
LAI observations courtesy of Carl Bernacchi

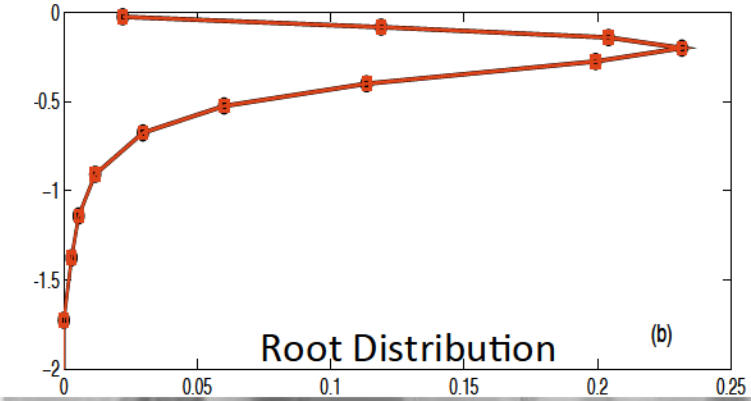




MLCan Biophysical Canopy Model

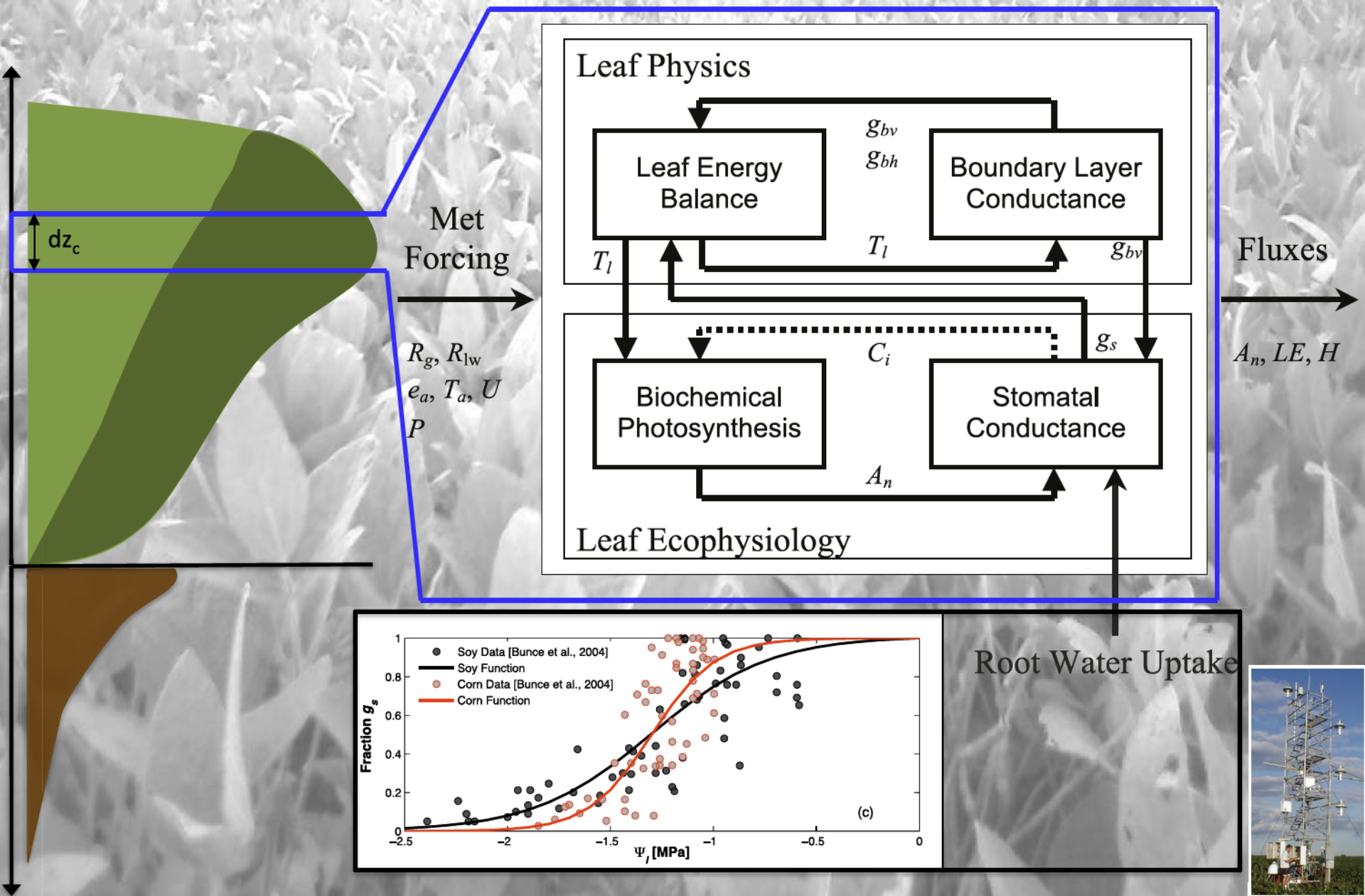






Drewry et al (2010a,b) *Journal of Geophysical Research - Biogeosciences*

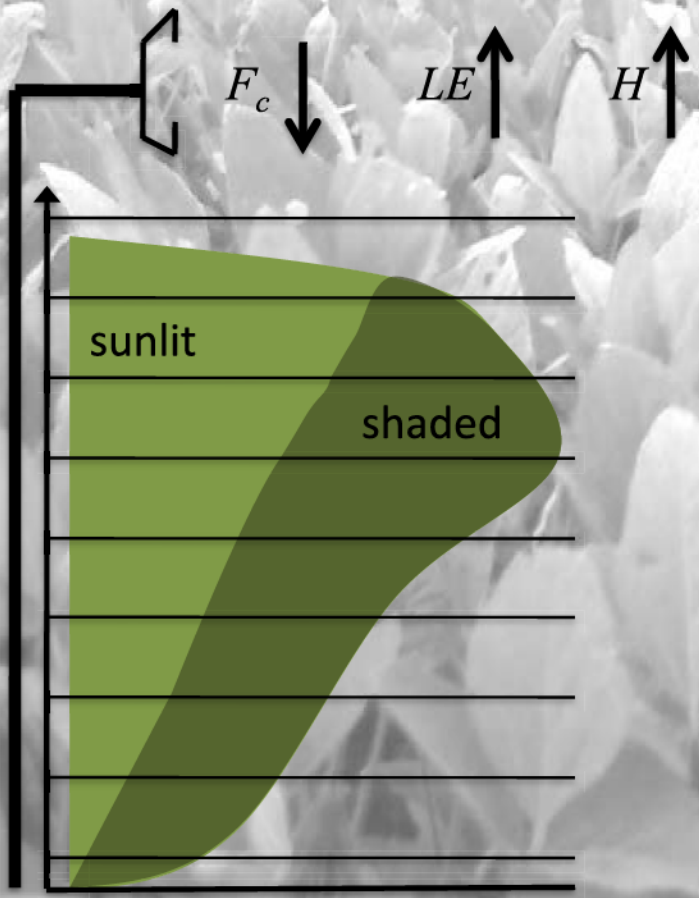
Leaf-level energy balance - ecophysiology coupling



Canopy Scaling

Model *validation data*:

F_c, LE, H --> Eddy covariance: vertical integral of sources/sinks



$$F_c = \int_0^h \left(S_{c,sun}(z) + S_{c,shade}(z) \right) dz$$

$$LE = \int_0^h \left(S_{v,sun}(z) + S_{v,shade}(z) + S_{v,wet}(z) \right) dz$$

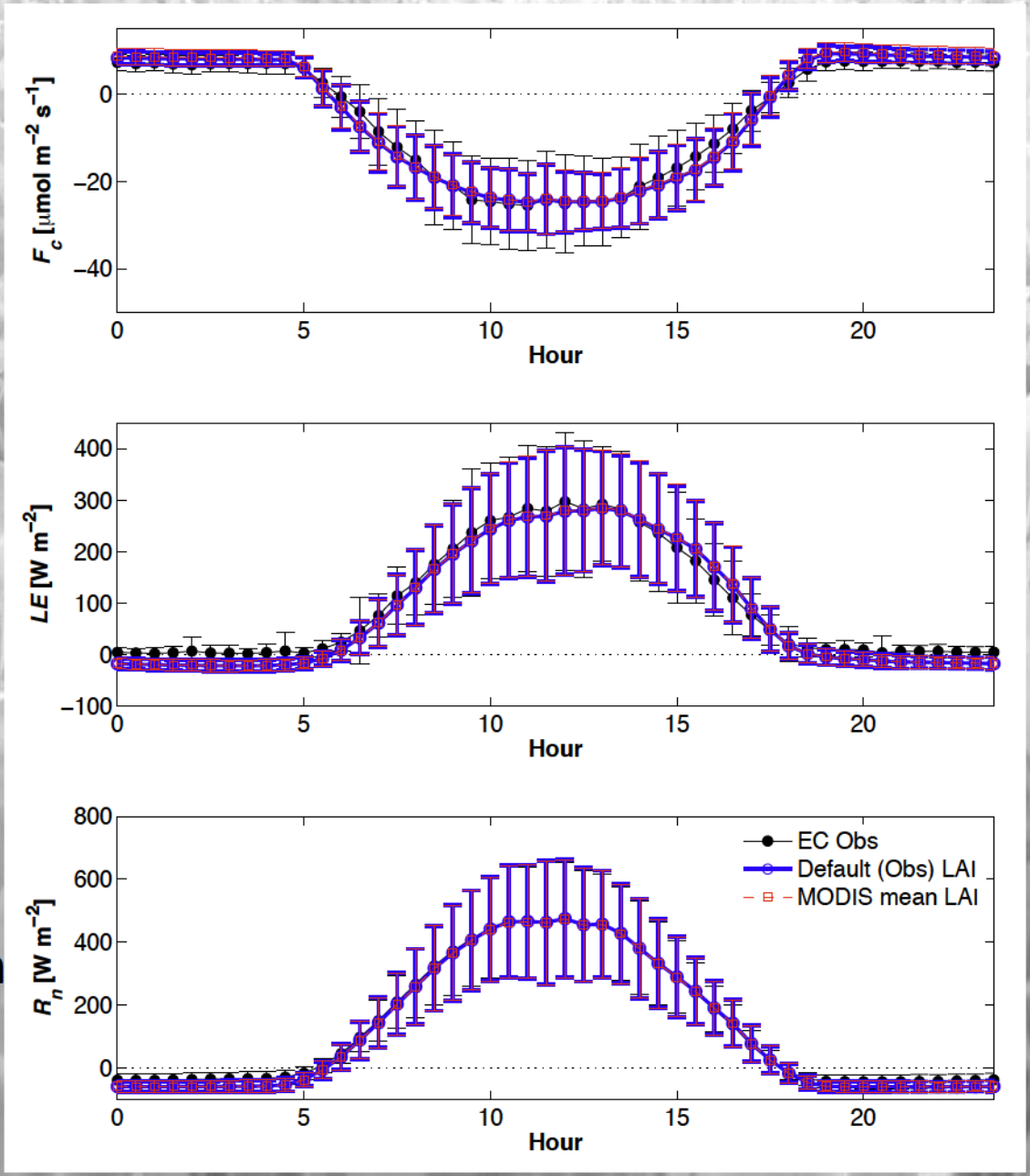
$$H = \int_0^h \left(S_{h,sun}(z) + S_{h,shade}(z) \right) dz$$

Mean Diurnal Flux Comparison

Net CO_2 flux

Net latent heat flux

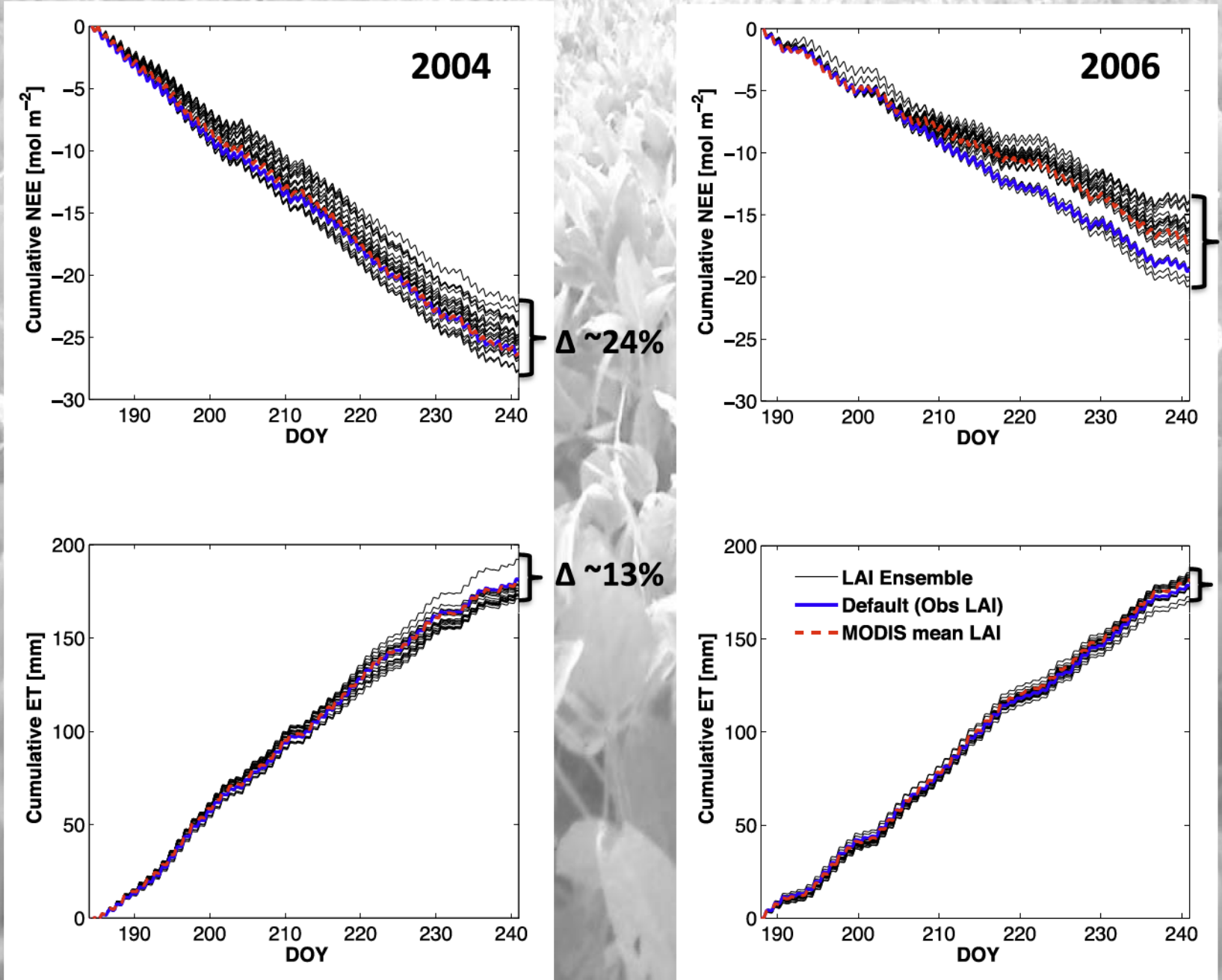
Net radiation flux



Mean diurnal fluxes for soybean for 2004 & 2006.

Only *extremely* small differences between simulations using observed LAI and using mean LAI determined from MODIS inversions

Cumulative NEE and ET: Soybean



Conclusions

MODIS reflectance obs present an opportunity to constrain seasonality in canopy structure and biochemistry in canopy biophysics models

- frequent repeat cycle
- 7 bands across optical spectrum at 250m (2) or 500m (5)

Inversions of PROSAIL against MODIS data resulted in excellent agreement of LAI seasonality relative to field obs

Uncertainty in LAI, however, resulted in large spread in NEE predictions using a validated canopy biophysical model

→ Characterizing the uncertainty in parameter values is critical for proper estimation of uncertainty in forward model predictions

Need to examine Chlorophyll (Houborg, Gitelson) and leaf H_2O, as well as additional constraints on the set of unknown parameters

Acknowledgements

DREAM-ZS code: Jasper Vrugt

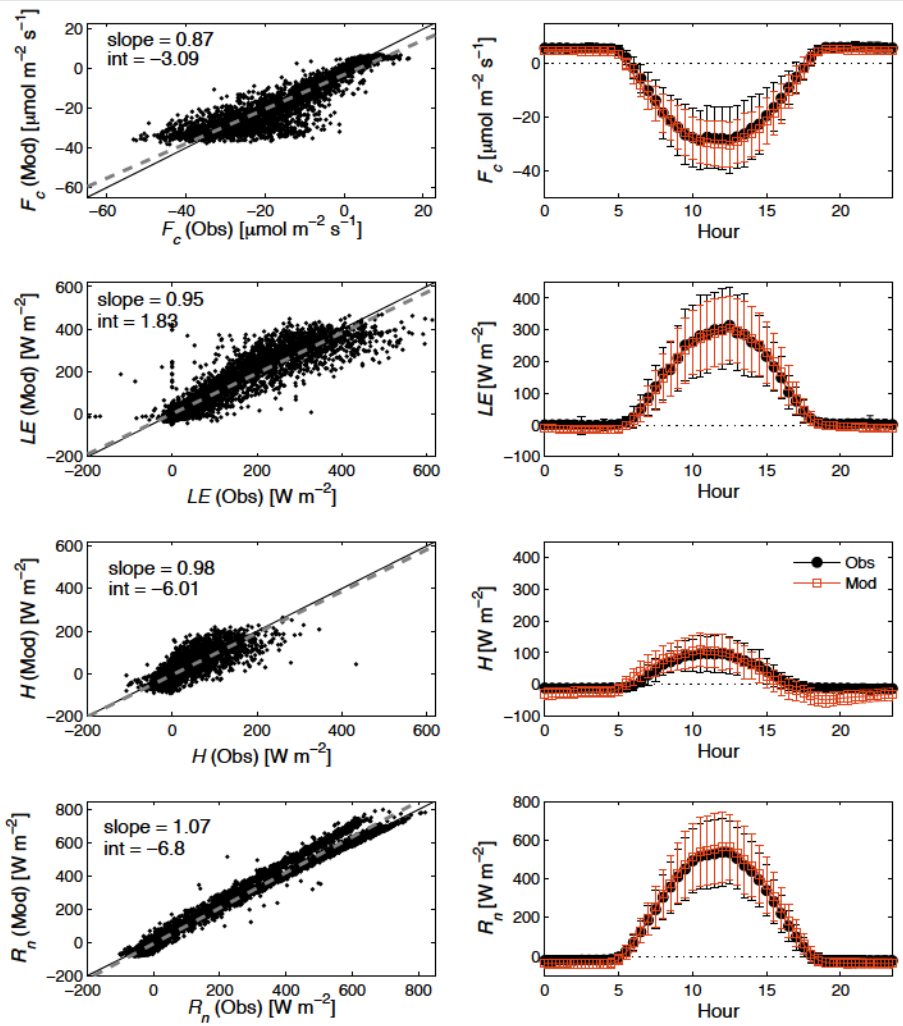
PROSAIL code: Stéphane Jacquemoud,
Jean-Baptiste Feret
Christophe Francois
Eben Broadbent

Bondville LAI data: Carl Bernacchi

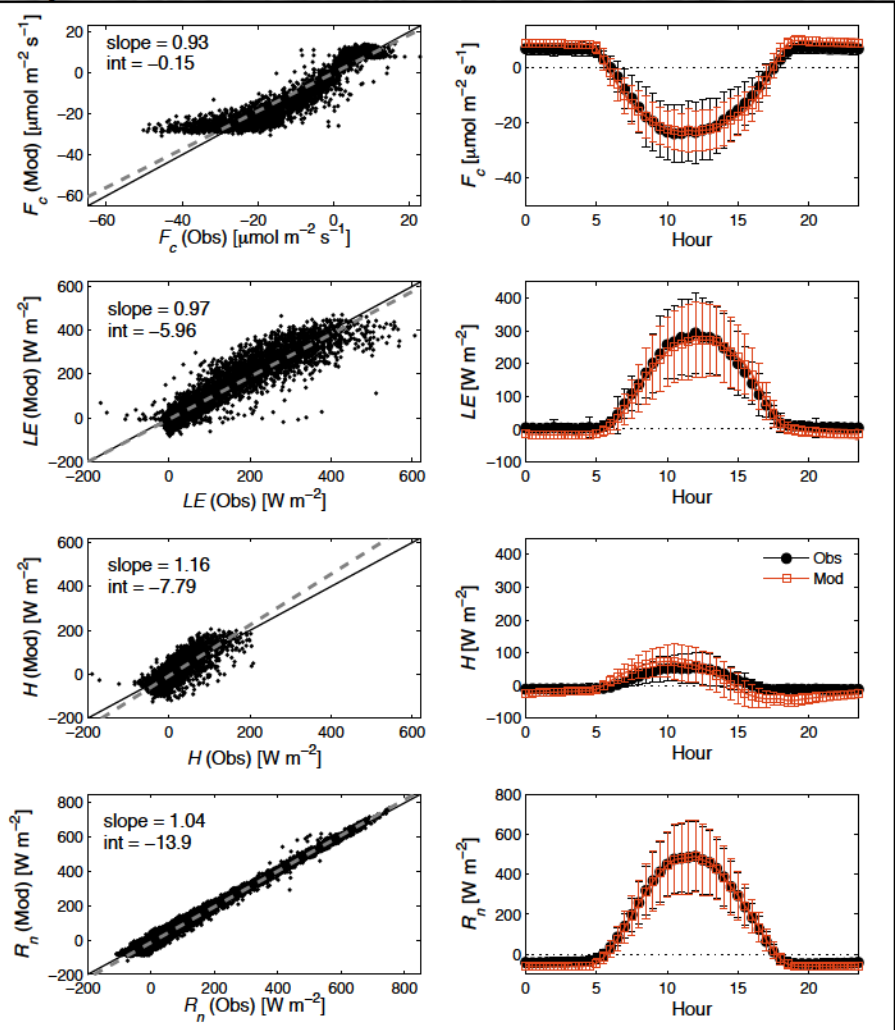
Funding: NASA

MLCan Eddy Flux Validation (Bondville)

Maize:



Soybean:



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