NASA Biodiversity, Ecology, and Applied Science Workshop

Remote sensing of productivity, LUE, and stress

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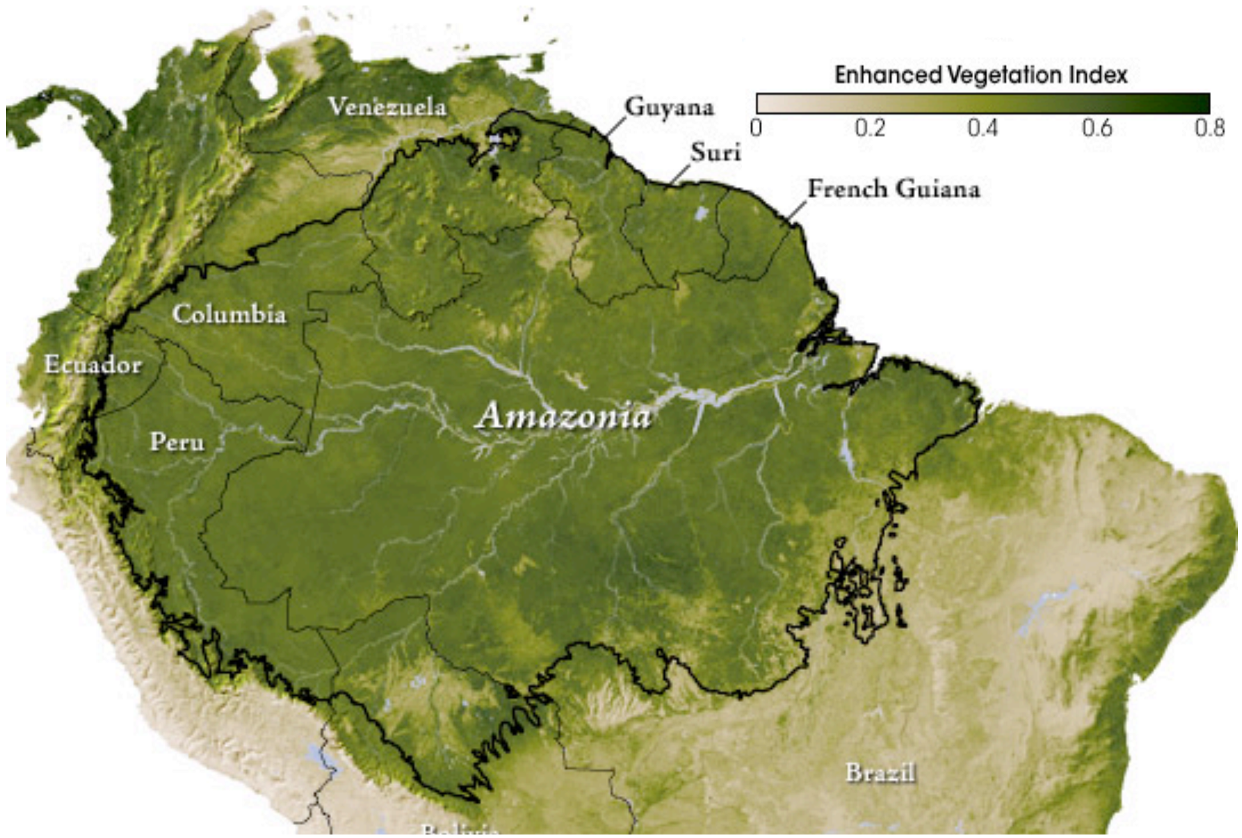
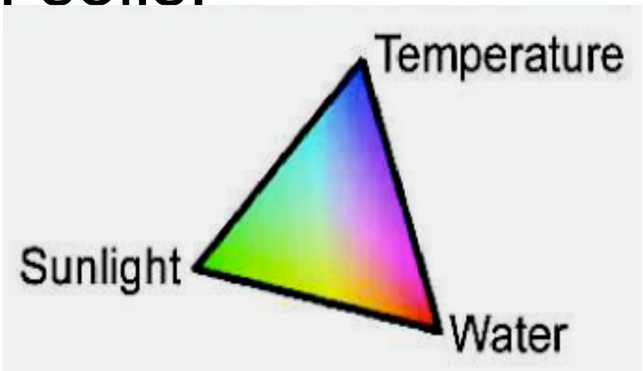


Robert Simmon, Earth Observatory

Controls on productivity (NPP/GPP)

- Fluxes of CO_2 and energy are strongly influenced by temperature; variations in cellular metabolism; and rates of supply of limiting resources (water, nutrients, light,..).
- Both biotic and abiotic factors regulate metabolic rates of individuals, which combine to determine ecosystem flux rates.
- Plant characteristics (roots, litter). soils. climate, and disturbance regime influence production.
- Resources and resource regulators



Nemani, *Science* 2003

Satellite-based Production Efficiency Models

Light use efficiency model:

GPP = $\boldsymbol{\varepsilon_g}$ x FPAR x PAR,

- where $\boldsymbol{\varepsilon_g}$ is the light-use efficiency (g C/mol PAR),
- FPAR is the fraction of PAR absorbed by the vegetation canopy,
- APAR = FPAR x PAR.

- *Light absorption process (chlorophyll absorbs PAR) and*
- *Carbon fixation process where absorbed energy is then used to combine water and CO2.*

Table 1. A comparison of maximum light use efficiency (ε_0, g C/mol PAR) used in different Production Efficiency Models for deciduous broadleaf forest. T – air temperature scalar; SM – soil moisture scalar; VPD – water vapor pressure deficit scalar; W – leaf water content scalar.

Model	$FPAR_{canopy}$ or $FPAR_{chl}$	ε_g	ε_0
TURC[2]	$FPAR_{canopy} = f(NDVI)$	$\varepsilon_g = \boldsymbol{\varepsilon_0}$	0.24
GLO-PEM[1]	$FPAR_{canopy} = f(NDVI)$	$\varepsilon_g = \boldsymbol{\varepsilon_0} \times T \times SM \times VPD$	0.146
PSN[3]	$FPAR_{canopy} = f(LAI)$ $FPAR_{canopy} = f(NDVI)$	$\varepsilon_g = \boldsymbol{\varepsilon_0} \times T \times VPD$	0.227
VPM[12]	$FPAR_{chl} = f(EVI)$	$\varepsilon_g = \boldsymbol{\varepsilon_0} \times T \times W$	0.528
CO_2 flux site[15]	NEE and PAR data from Harvard Forest	deciduous broadleaf forest	0.528

*LUE is difficult to characterize because it is affected by by both variations in climate, and by biological attributes (LC type, C3-C4,)

Xiao, 2006

Uncertainties

- Satellites can provide consistent measures of vegetation activity with spatial- and temporal-detail at the global scale, which can be linked to ecosystem health, productivity and carbon fluxes,
- There remains large uncertainties in estimating GPP at the canopy level associated with
  – Seasonal dynamics
  – Spatial variation due to climate, soils, and land use (disturbance, management,…)
- Uncertainties associated with coarse scale meteorology, remote sensing variables (LAI, FPAR, VI), and canopy biophysical attributes (land cover type, biome-specific, disturbance history)

Heinsch et al., 2006

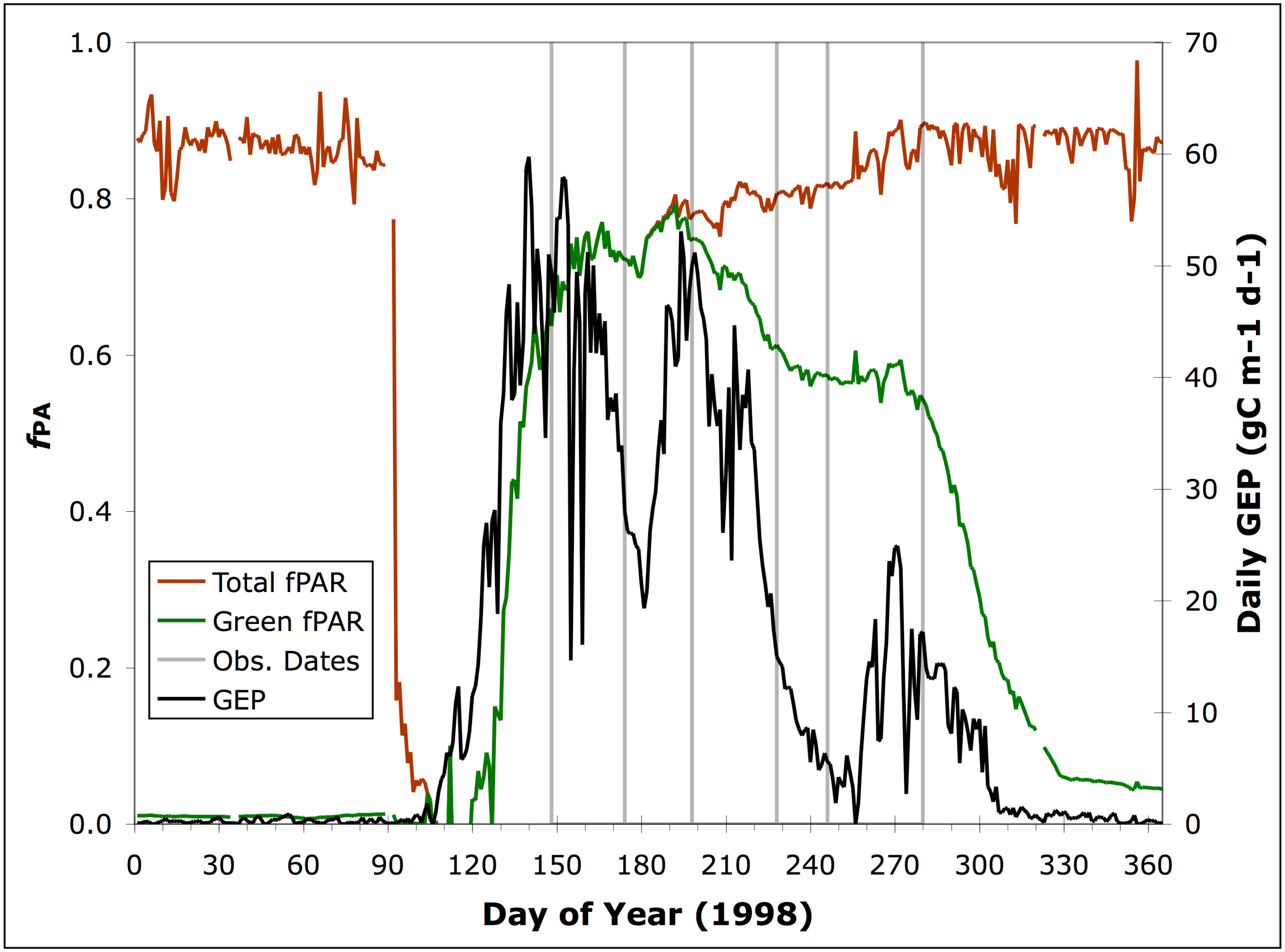
Conversion of VI to FPAR?

- Most common method to derive FPAR is through NDVI relationships
- Only PAR absorbed by chlorophyll is responsible for photosynthesis:
  - $FPAR_{canopy} = FPAR_{chl} + FPAR_{NPV}$

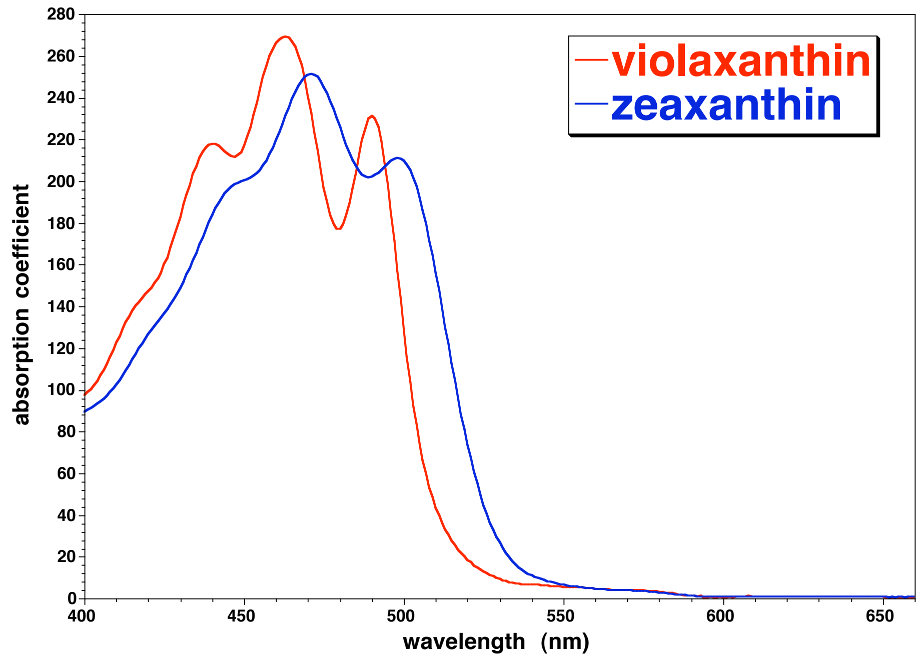
- Comparisons of $FPAR_{chl}$ and $FPAR_{canopy}$ would help define to what degree the PEM models are consistent with light absorption process of photosynthesis at the chlorophyll level.
  - Work by Gitelson on estimation of chlorophyll in crops with remote sensing chlorophyll indices
  - Work by Xiao in using EVI to estimate $FPAR_{chl}$ in different temperate/tropical forest types.
  - Non-photochemical dissipation mechanisms

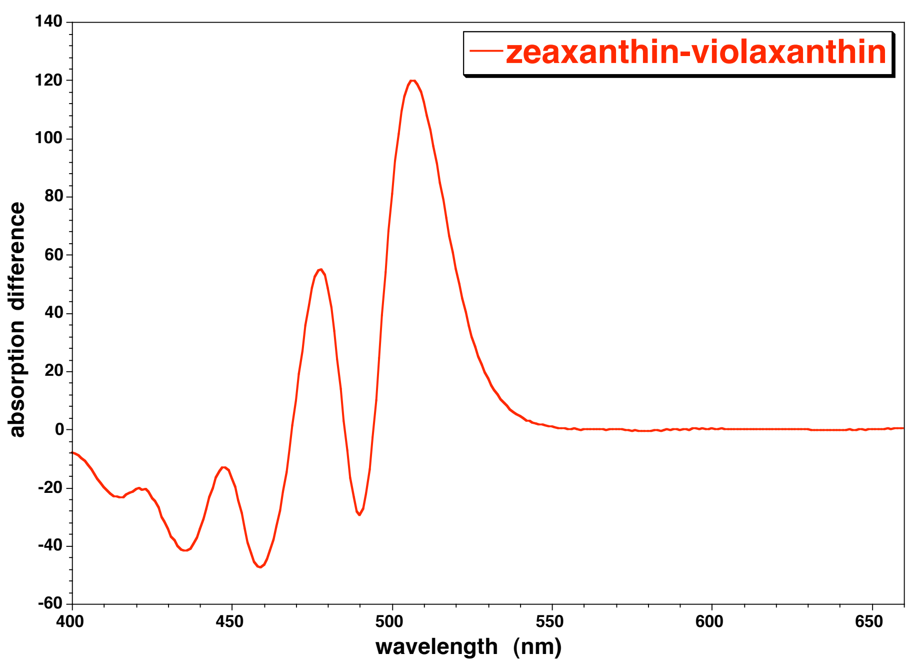
Seasonal Flux and FPAR

Prairie Shidler, Oklahoma, C4 Grassland



Huemmrich et al.



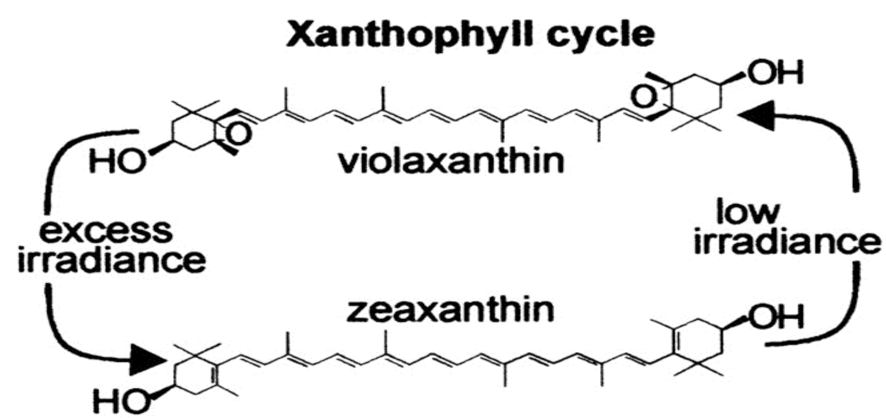


When leaves are stressed they can no longer photosynthesize at normal rates

They must dump excess energy

Xanthophyll cycle

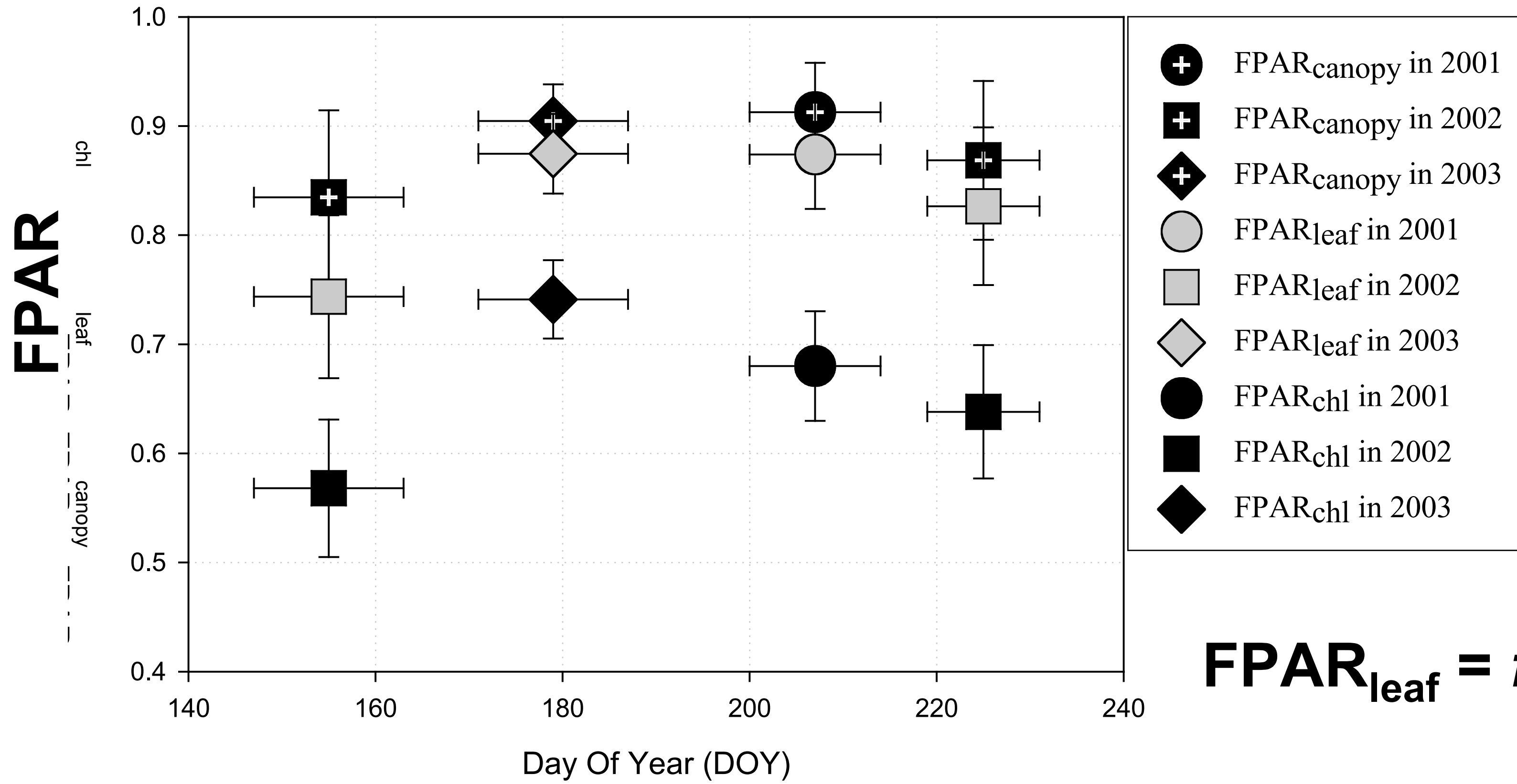
- **the de-epoxidation of violaxanthin to zeaxanthin**
- **a reversible reaction**
- **dissipates excess energy**
- **causes leaf reflectance change at 531 nm**



Middleton et al.

$FPAR_{canopy}$, $FPAR_{leaf}$, and $FPAR_{chl}$

deciduous broadleaf forest (Harvard Forest)

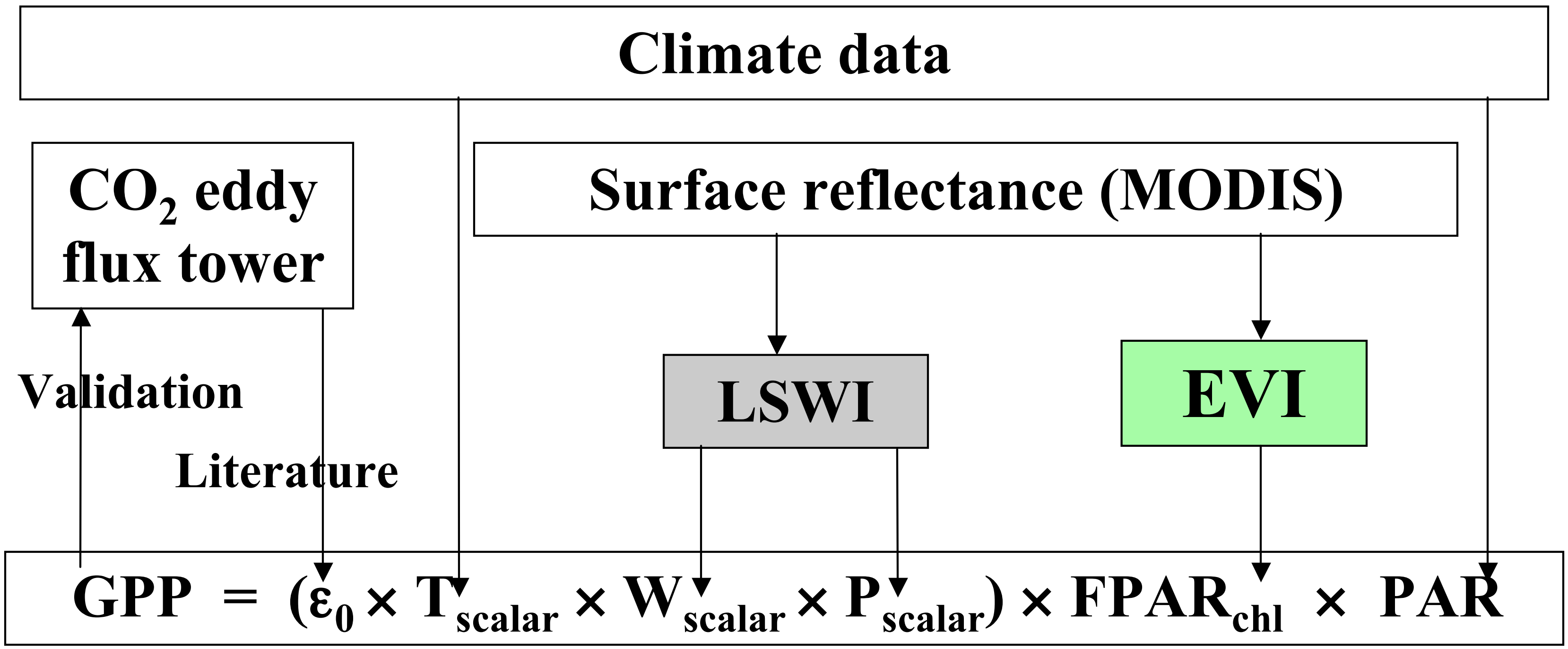


$FPAR_{leaf}$ = *f*(NDVI)

$FPAR_{chl}$ = *f*(EVI)

Zhang et al.,2005, using a radiative transfer model (PROSAIL2) & daily MODIS data

Satellite-based Vegetation Photosynthesis Model (VPM)



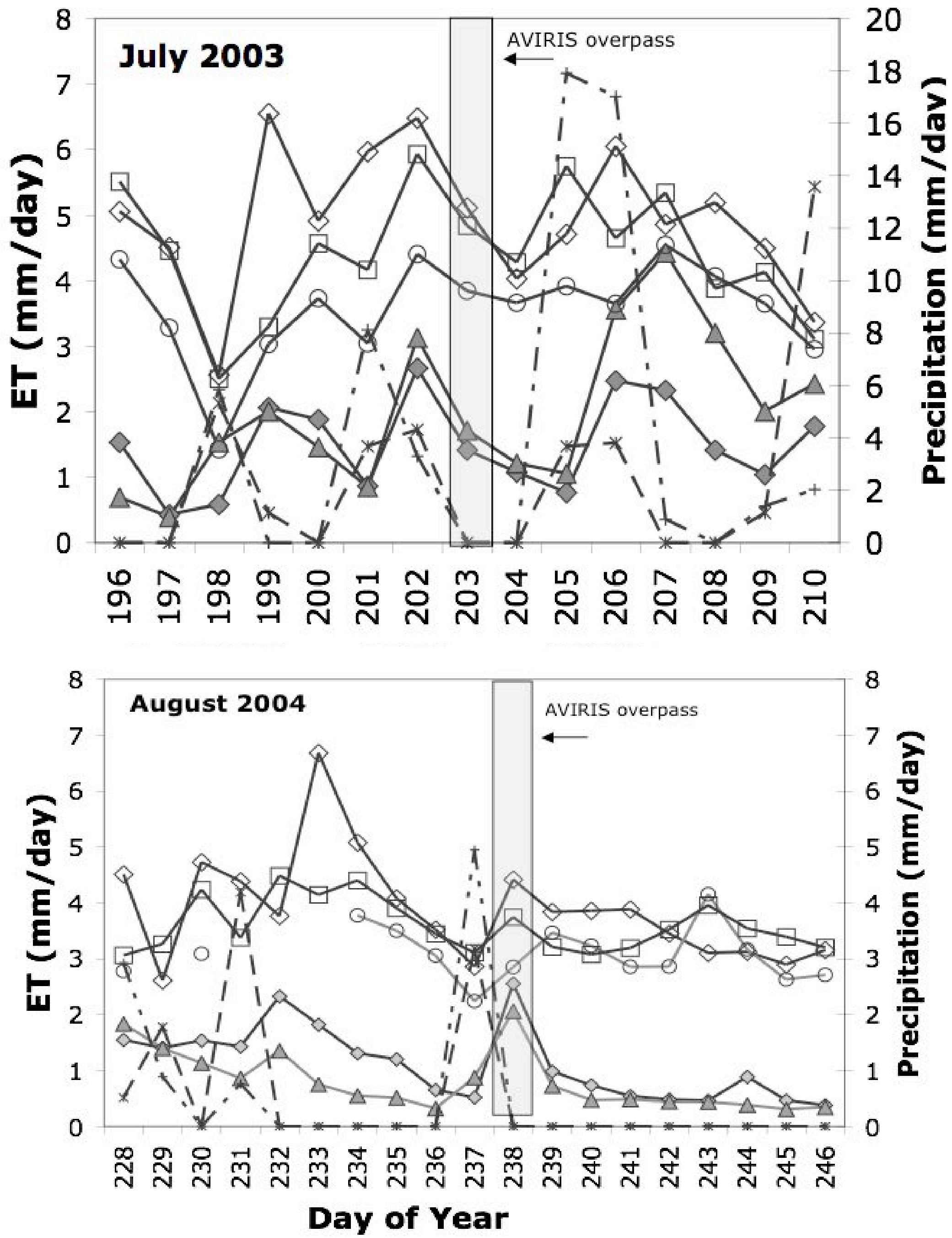
Input data for simulation of the VPM model

Air temperature, PAR, Vegetation indices (EVI, LSWI), Maximum light use efficiency (ε_0)

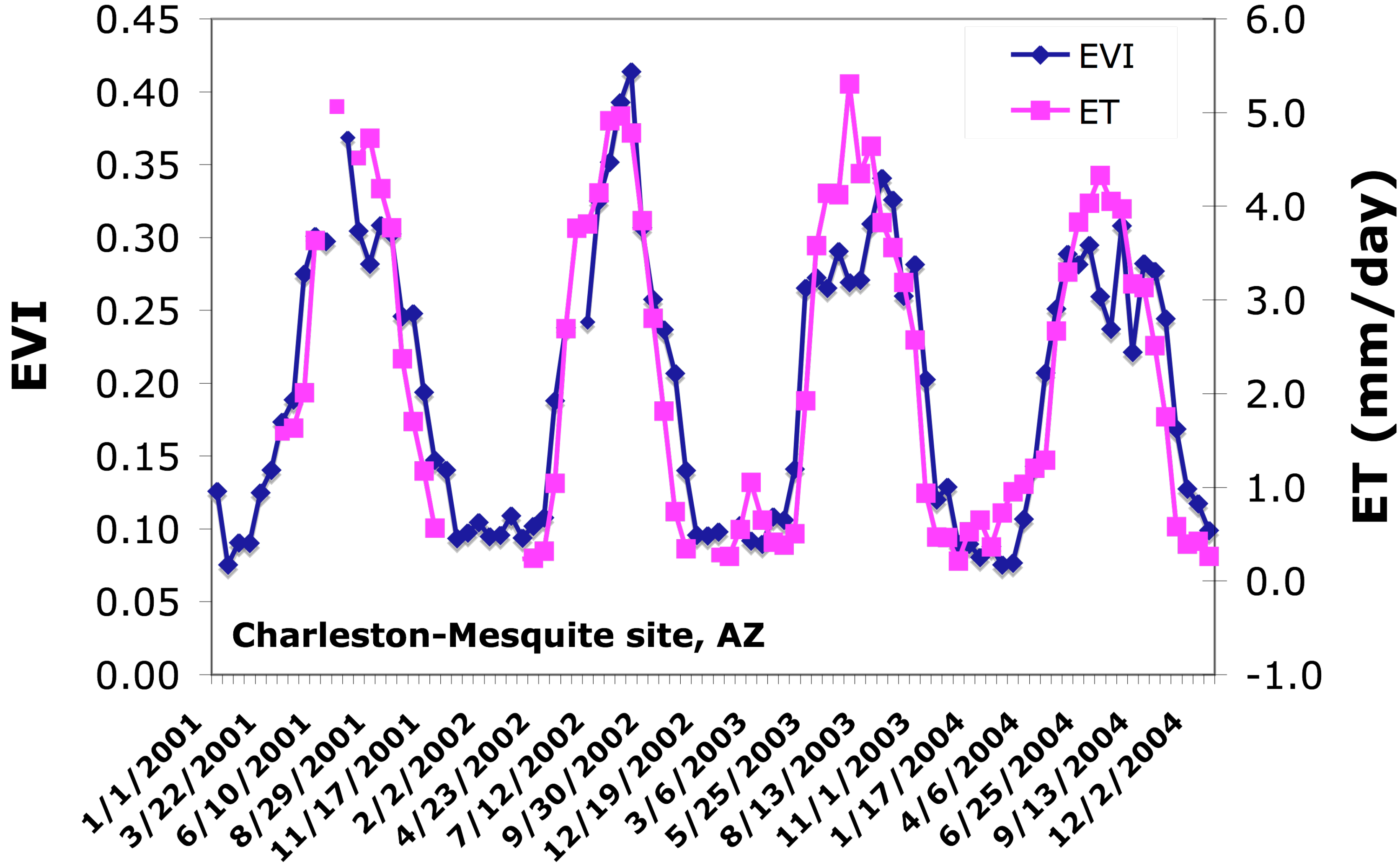
Xiao et al. 2004,2006,2006

Validation with Eddy-covariance flux towers

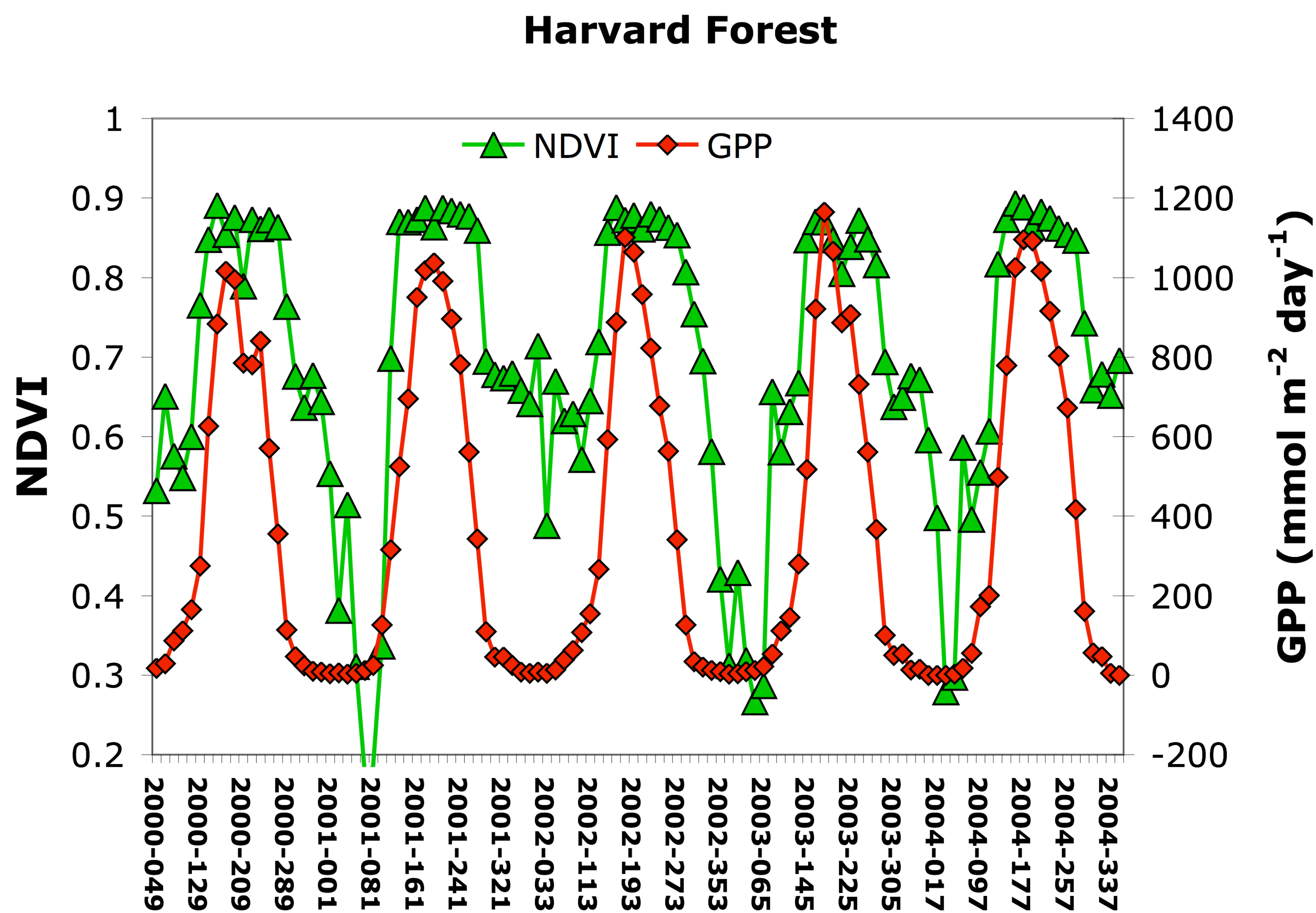
- They have measured fluxes (CO_2, H_2O, heat and momentum) continuously at many primary forest tower sites since 2001.
- These data are powerfully suited for vegetation dynamics and for deriving relationships between carbon fluxes and key driving variables.
- Can test model/remote-sensing estimates of carbon-exchange and seasonality.



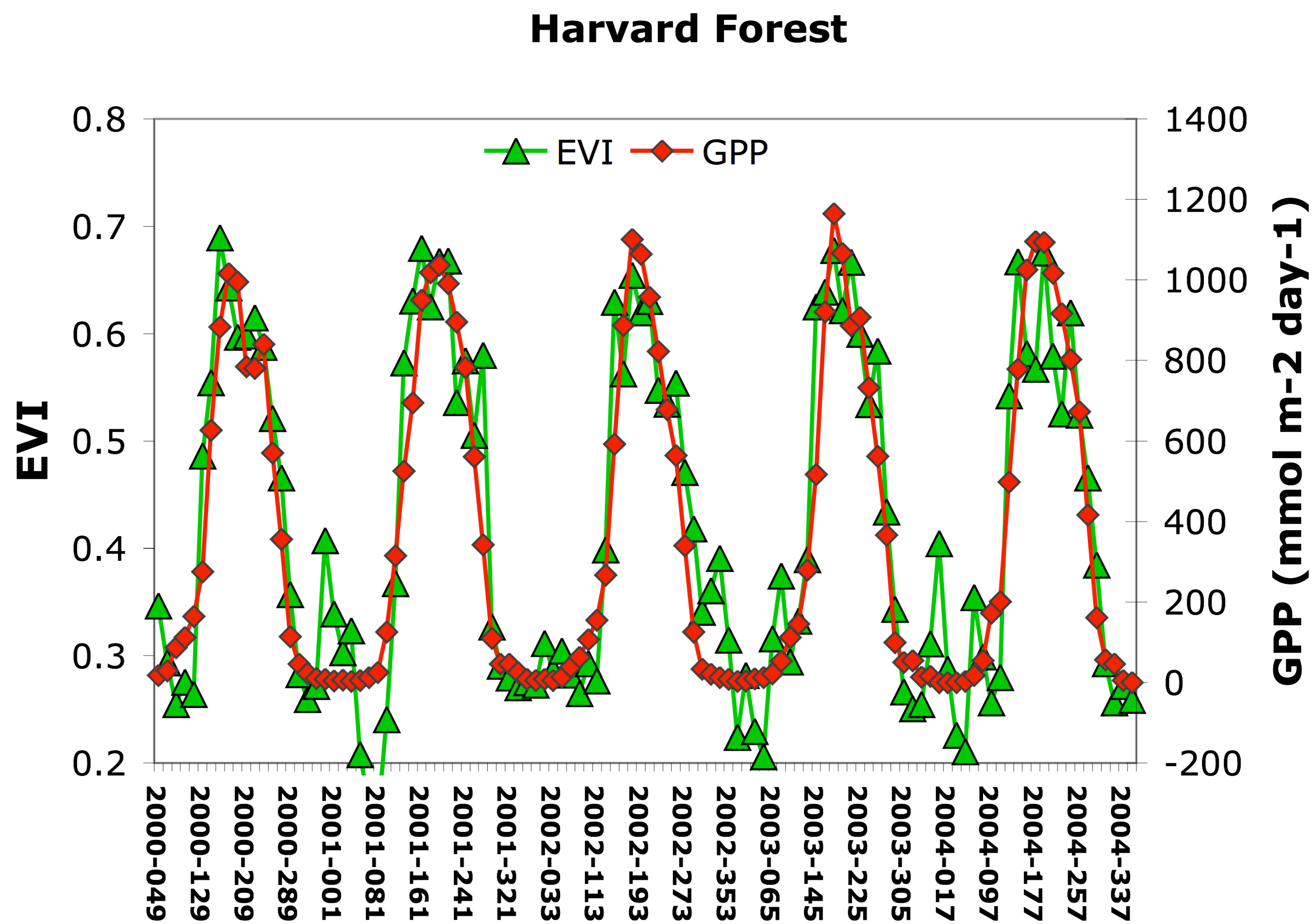
- At hour and daily time intervals, ecosystem variables (VI, FPAR, LAI) would not be expected to correlate well with ecosystem fluxes of carbon, water, & energy.



At weekly time scales, these same remote sensing variables become more highly correlated-

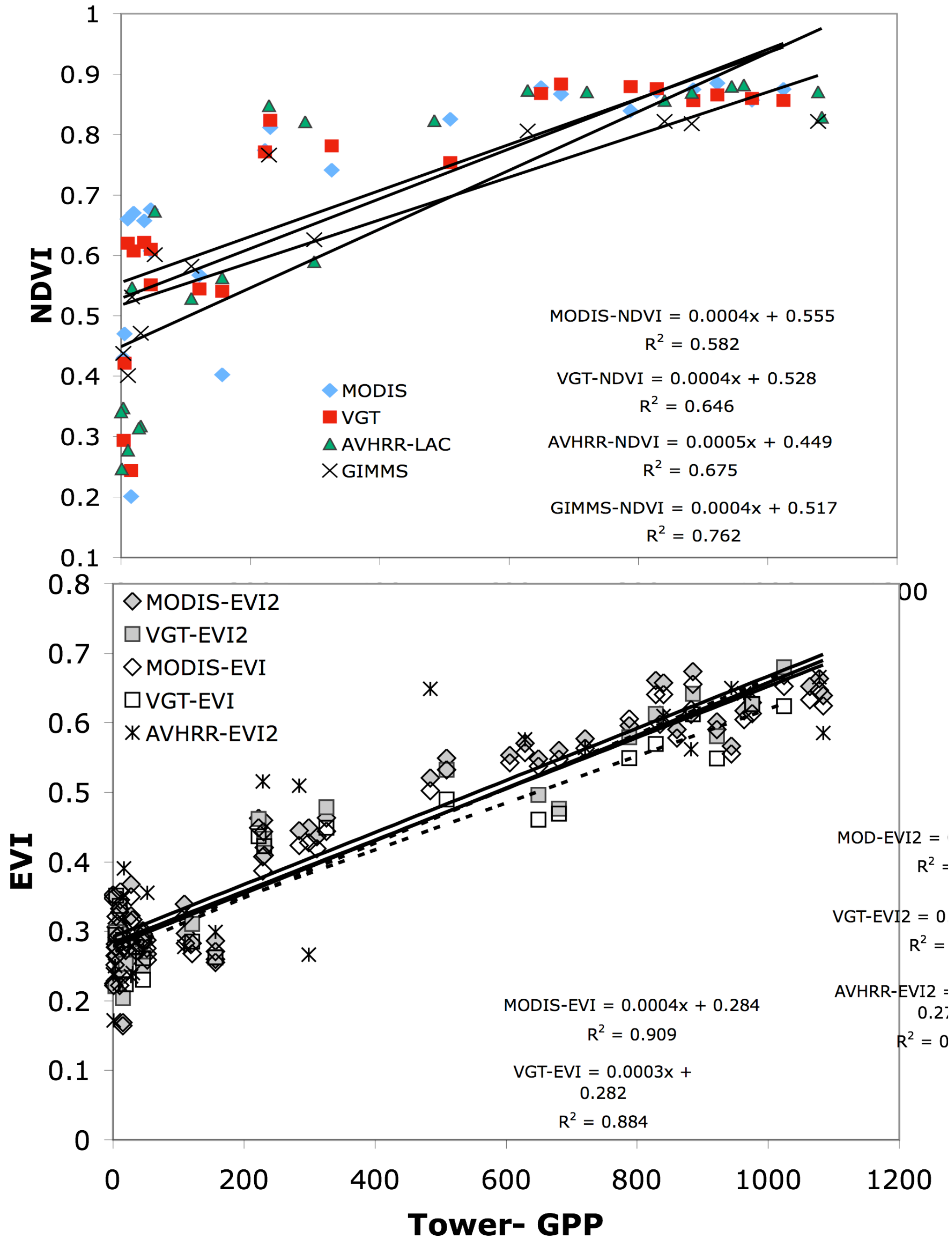


- 16-day MODIS NDVI with 16-day integrated GPP-
- NDVI and FPAR become insensitive to GPP at peak season



- 16-day MODIS EVI with 16-day integrated GPP-/ EVI remains sensitive to GPP at peak season

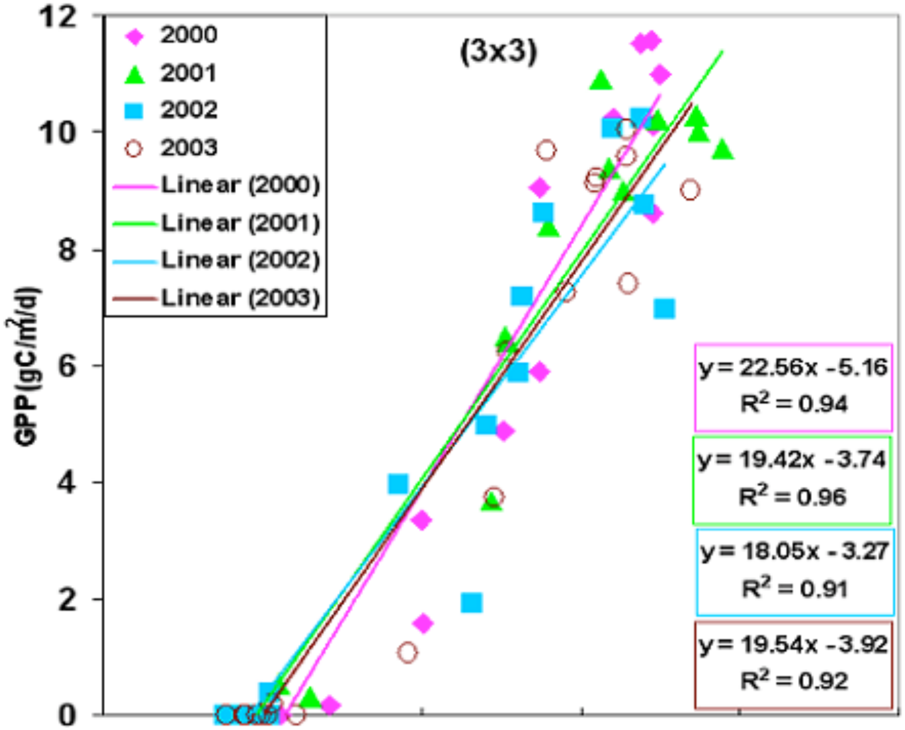
$$EVI = G \times \frac{\rho_{nir} - \rho_{red}}{\rho_{nir} + C_1 \times \rho_{red} - C_2 \times \rho_{blue} + L}$$



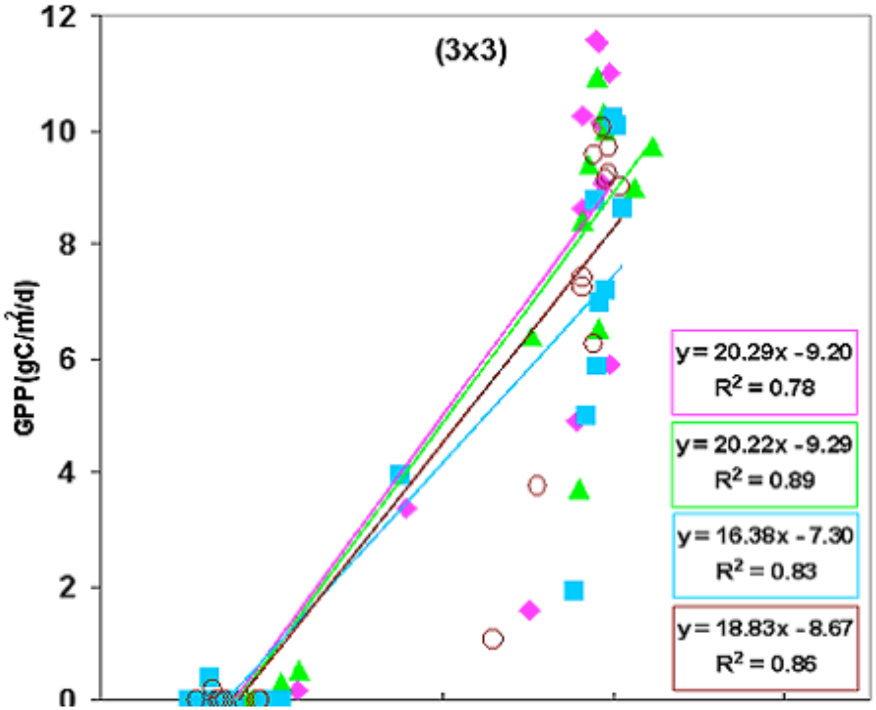
NDVI
MODIS
VGT
AVHRR-LAC
GIMMS
MODIS-NDVI = 0.0004x + 0.555
R2 = 0.582
VGT-NDVI = 0.0004x + 0.528
R2 = 0.646
AVHRR-NDVI = 0.0005x + 0.449
R2 = 0.675
GIMMS-NDVI = 0.0004x + 0.517
R2 = 0.762
EVI
MODIS-EVI2
VGT-EVI2
MODIS-EVI
VGT-EVI
AVHRR-EVI2
MOD-EVI2 =
VGT-EVI2 = 0.
AVHRR-EVI2 =
MODIS-EVI = 0.0004x + 0.284
R2 = 0.909
VGT-EVI = 0.0003x + 0.282
R2 = 0.884
Tower- GPP

LUE?

MMFS (Deciduous broadleaf forest)



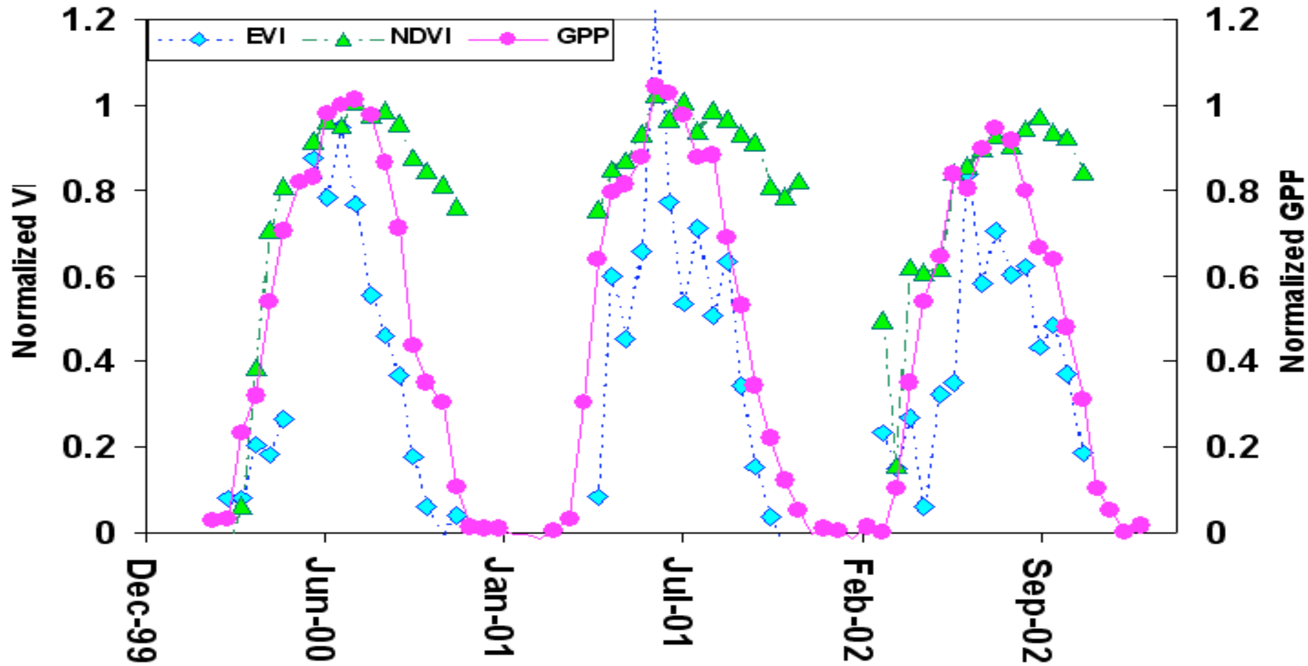
EVI

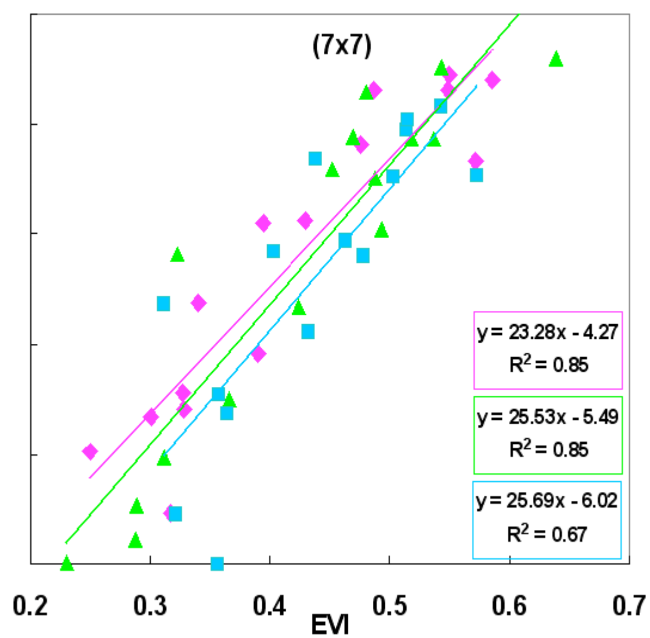


NDVI

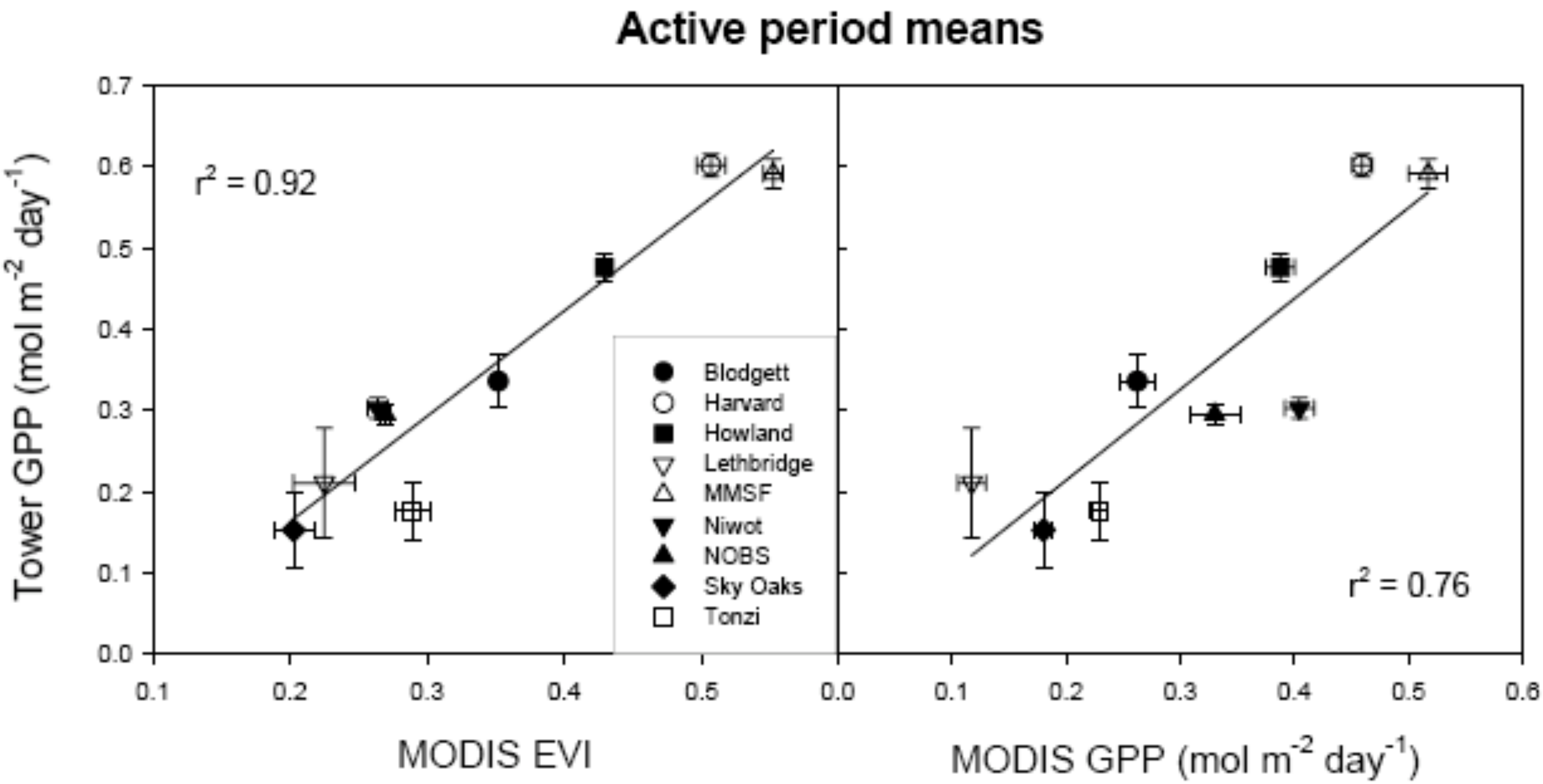
Sirikul et al 2006

HOWLAND (Evergreen coniferous forest)

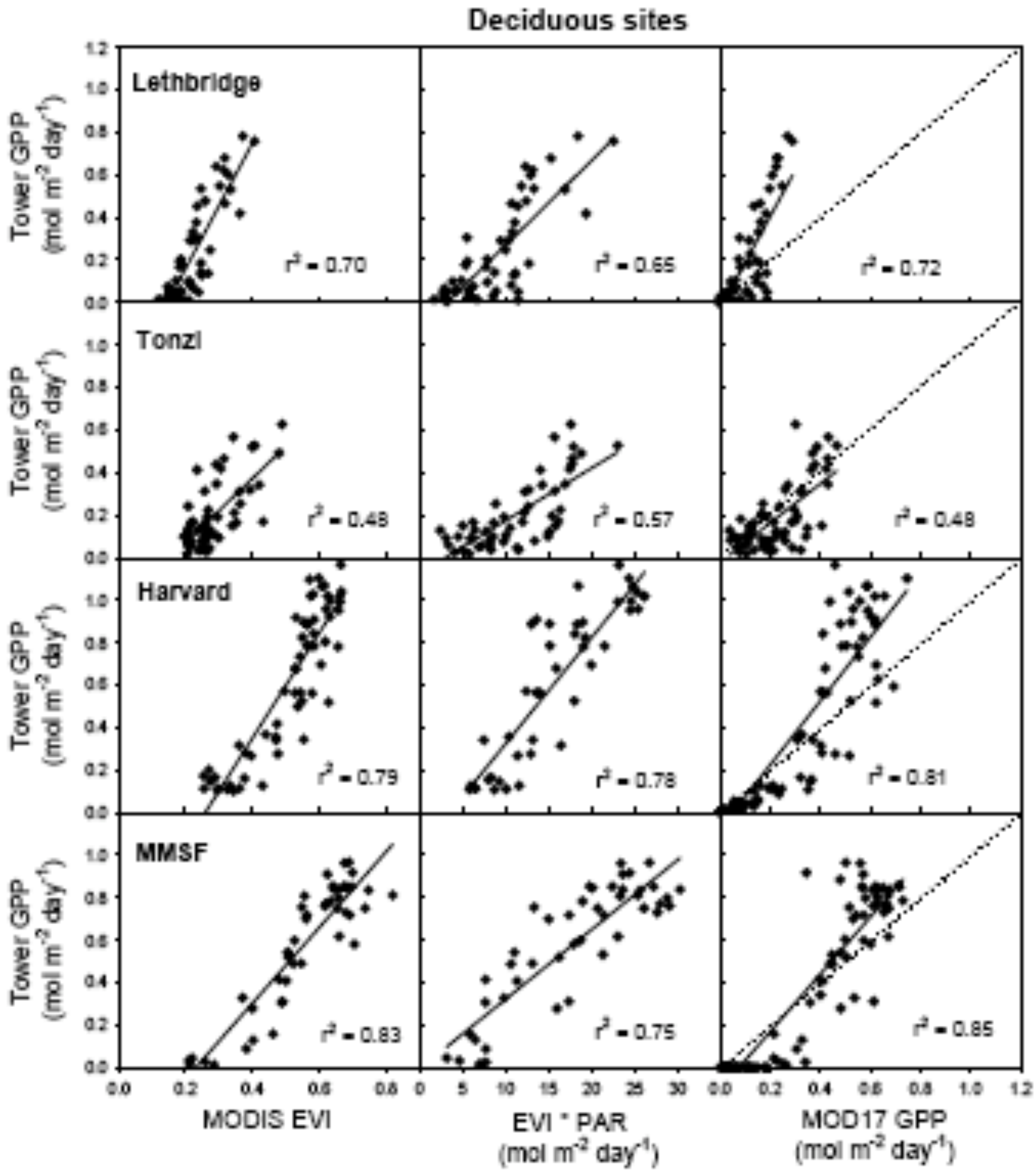




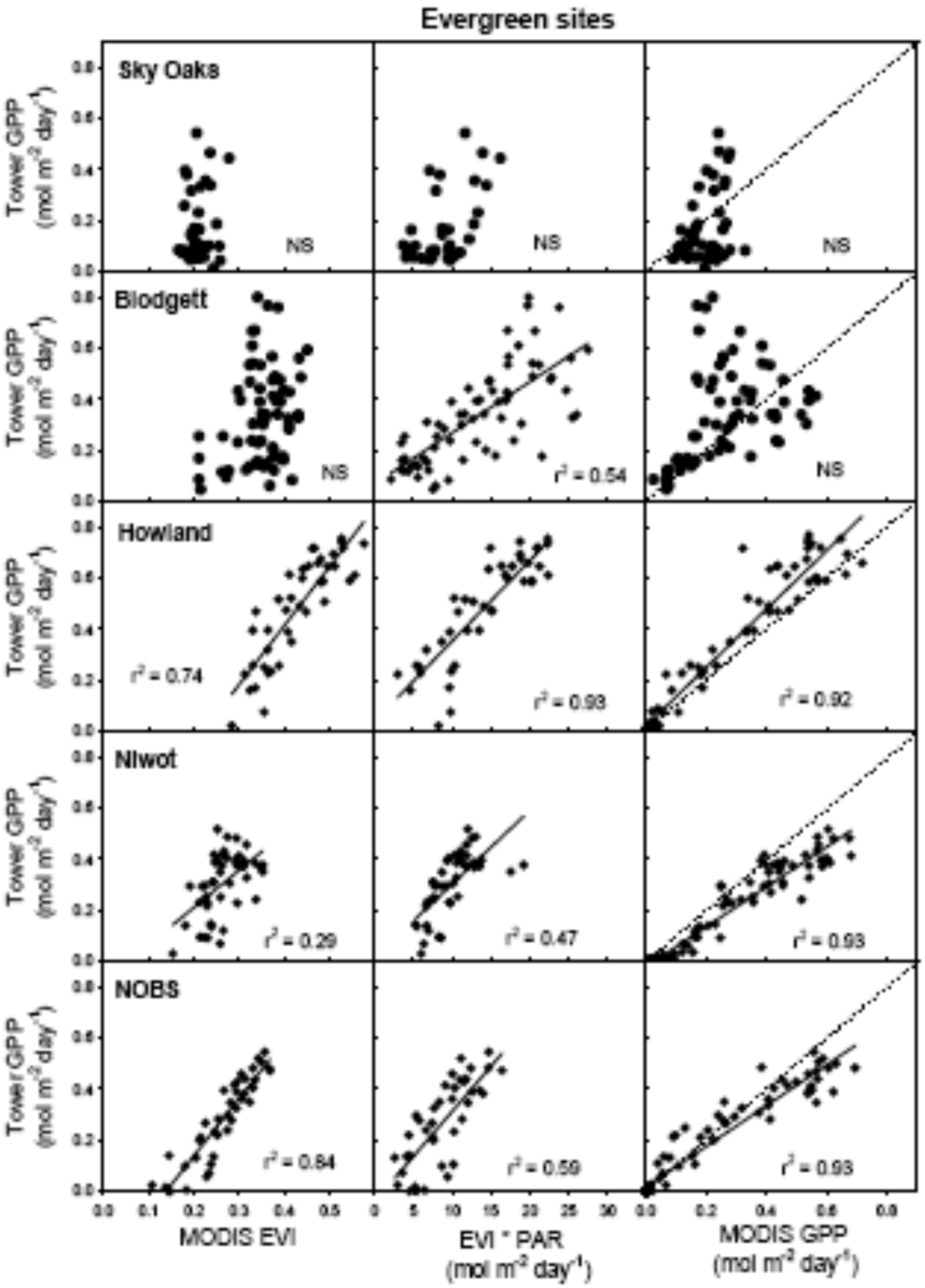
Sirikul et al 2006



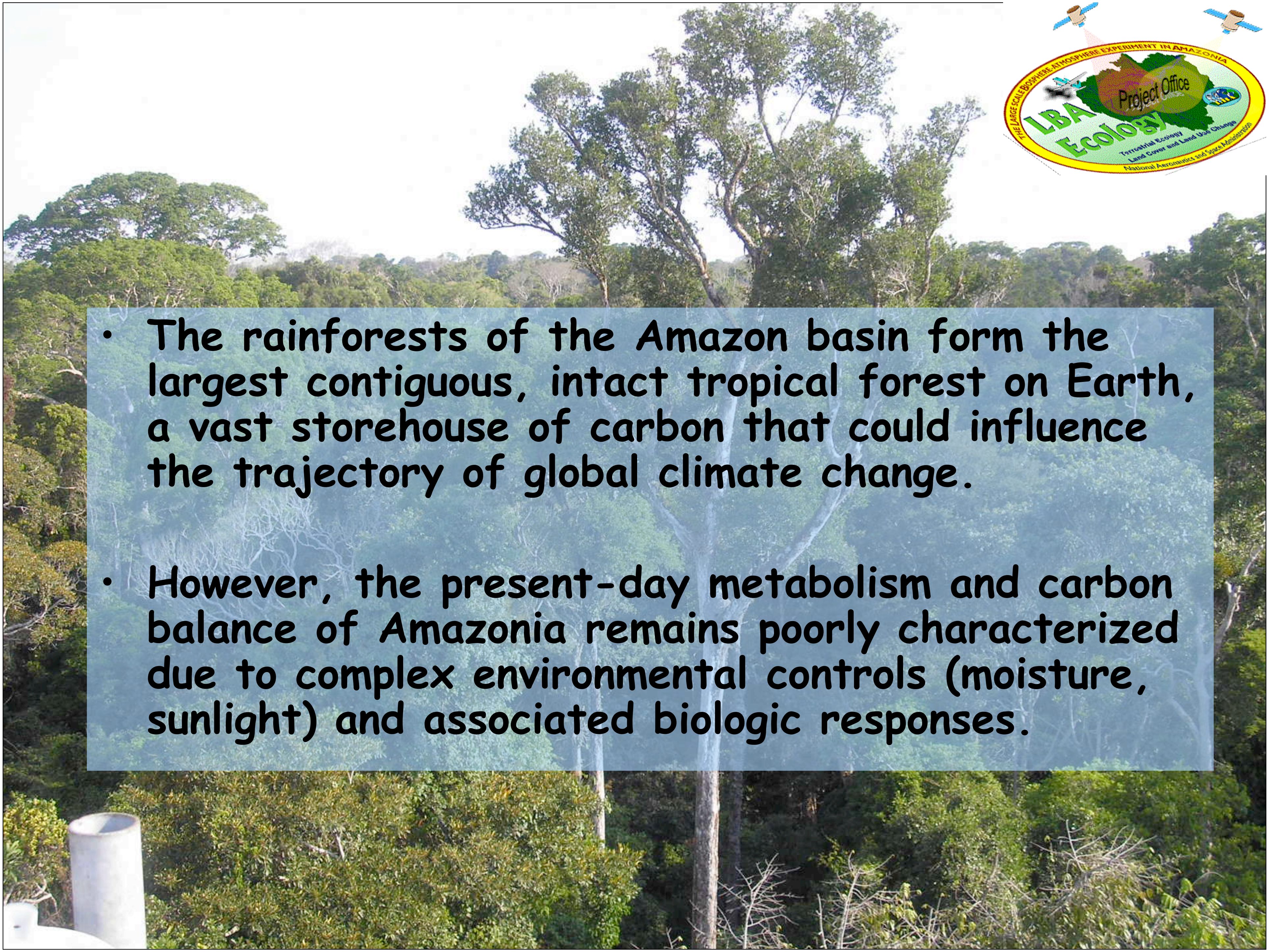
Rahman et al. 2005 (GRL); Sims et al. 2006 (JGR)



Sims et al. 2006



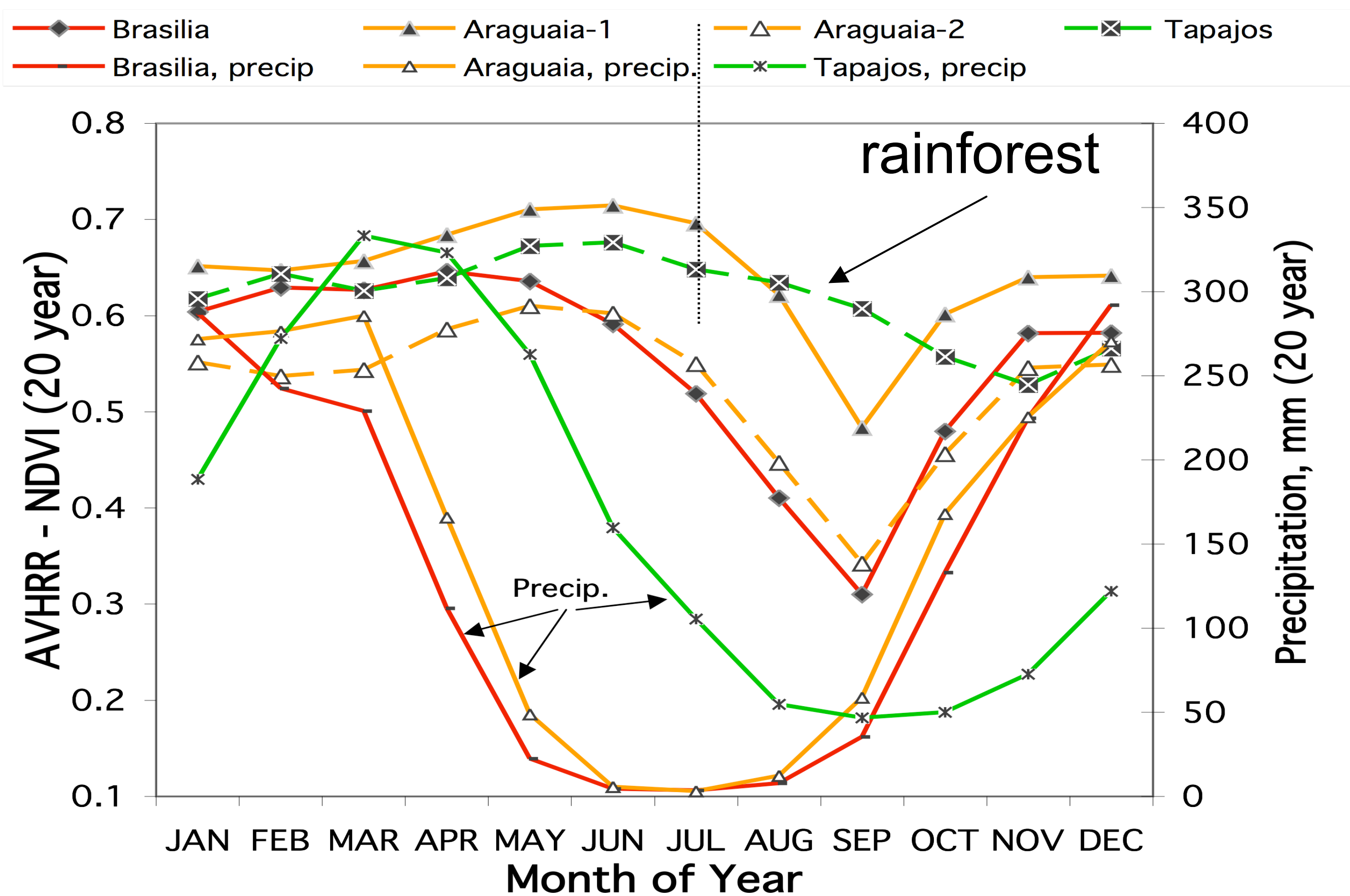
Sims et al. 2006



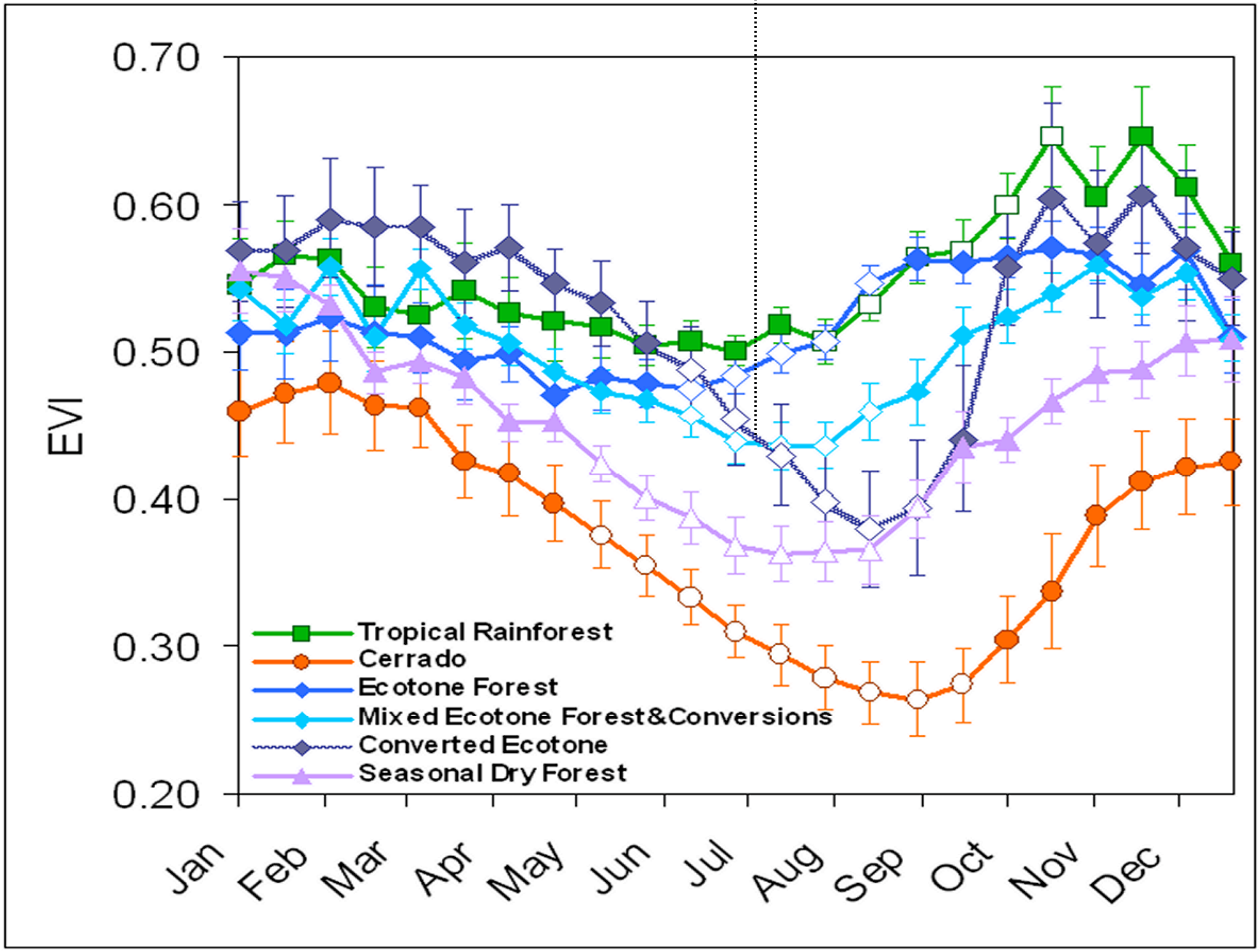
- The rainforests of the Amazon basin form the largest contiguous, intact tropical forest on Earth, a vast storehouse of carbon that could influence the trajectory of global climate change.

- However, the present-day metabolism and carbon balance of Amazonia remains poorly characterized due to complex environmental controls (moisture, sunlight) and associated biologic responses.

NOAA- Advanced Very High Resolution Radiometer (AVHRR) in the Amazon

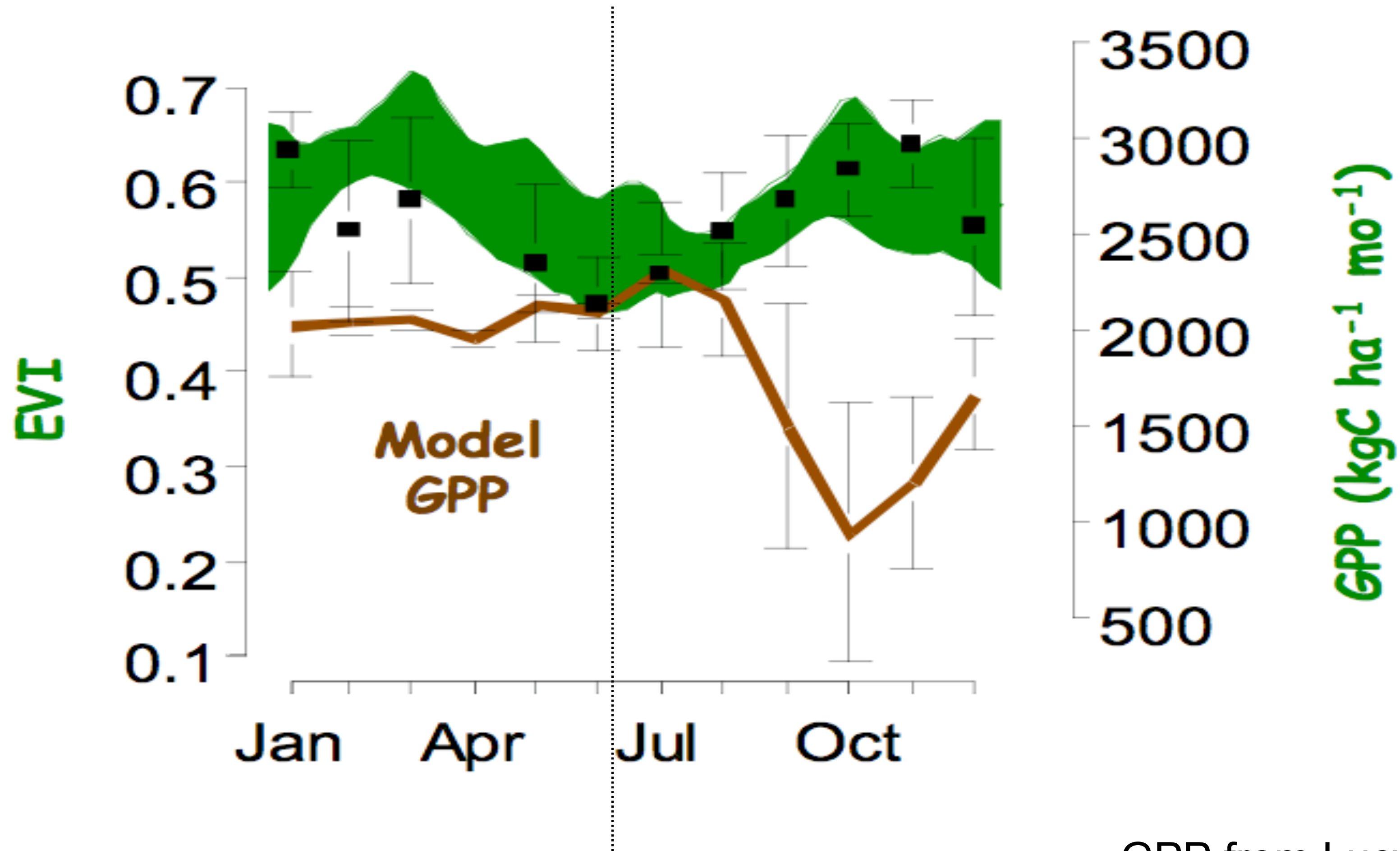


MODIS EVI transects
Cerrado to Rainforest



Ratana et al. 2006

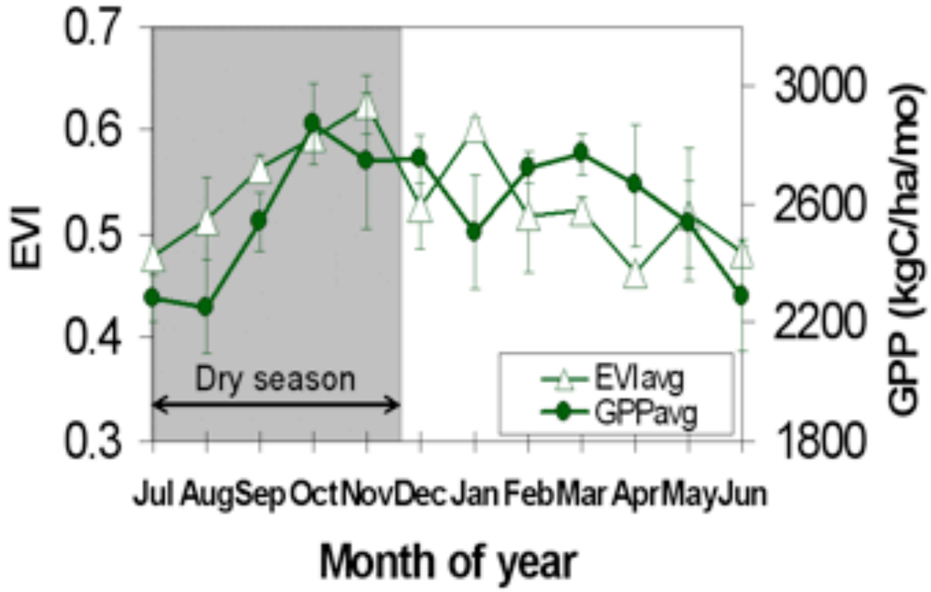
Rainforest GPP & EVI with modeled GPP (IBIS) at Tapajós

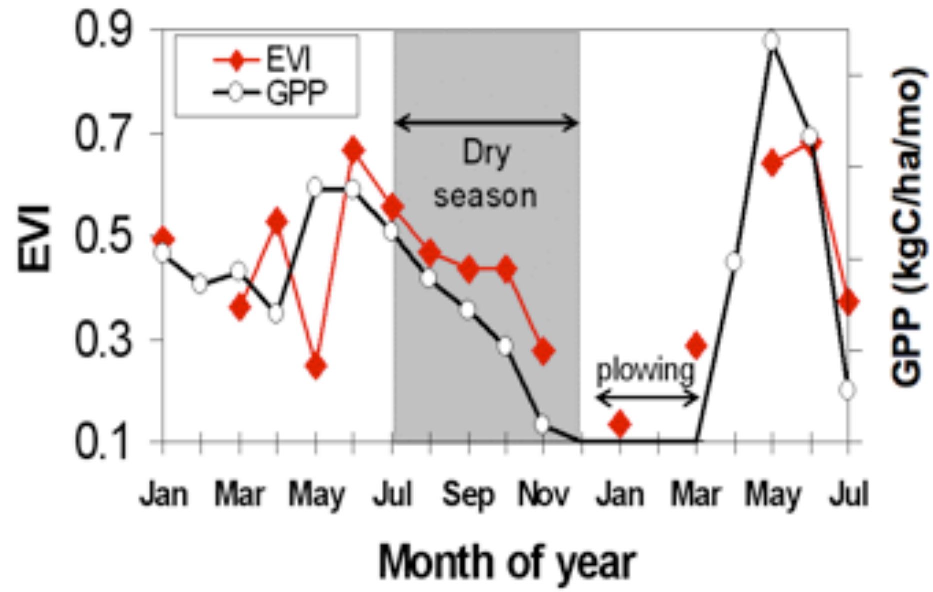


GPP from Lucy Hutyra
(Harvard Univ)

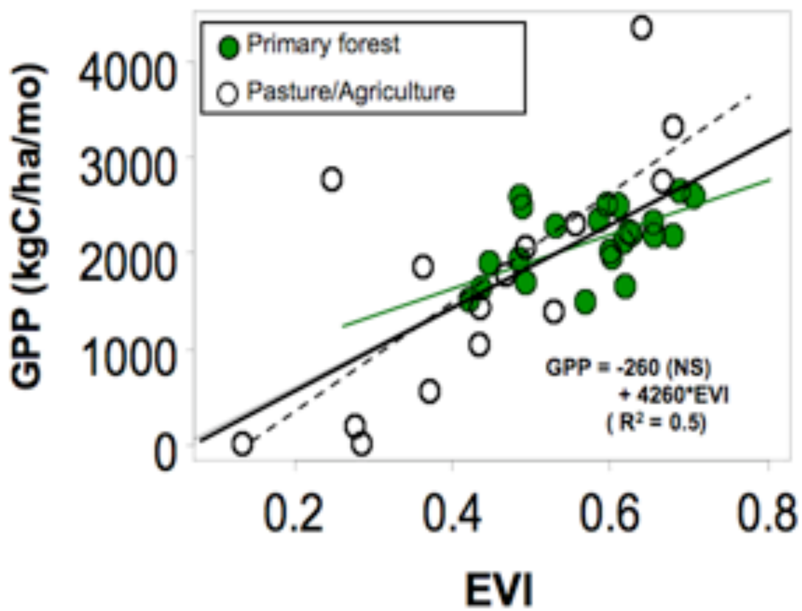
This raises a question about model predictions

- The same model constructs affect both short-term (seasonal) and long-term variations of C and water exchange,
- but the performance of models at short time-scales (where they can now be tested with data) is problematic, hence affecting confidence in reliability of their long-term predictions?

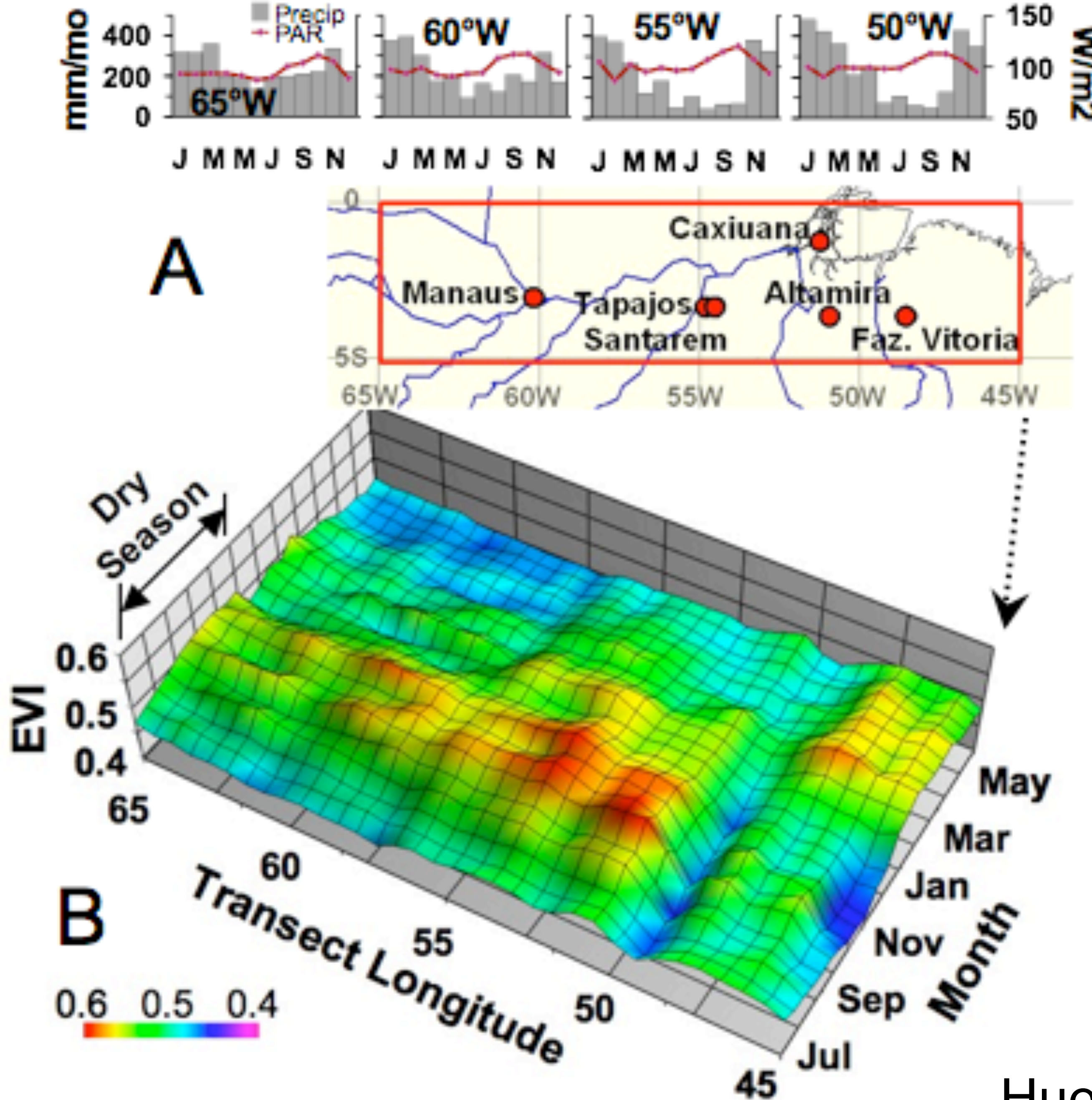




Tapajos Forest



Santarem Pasture

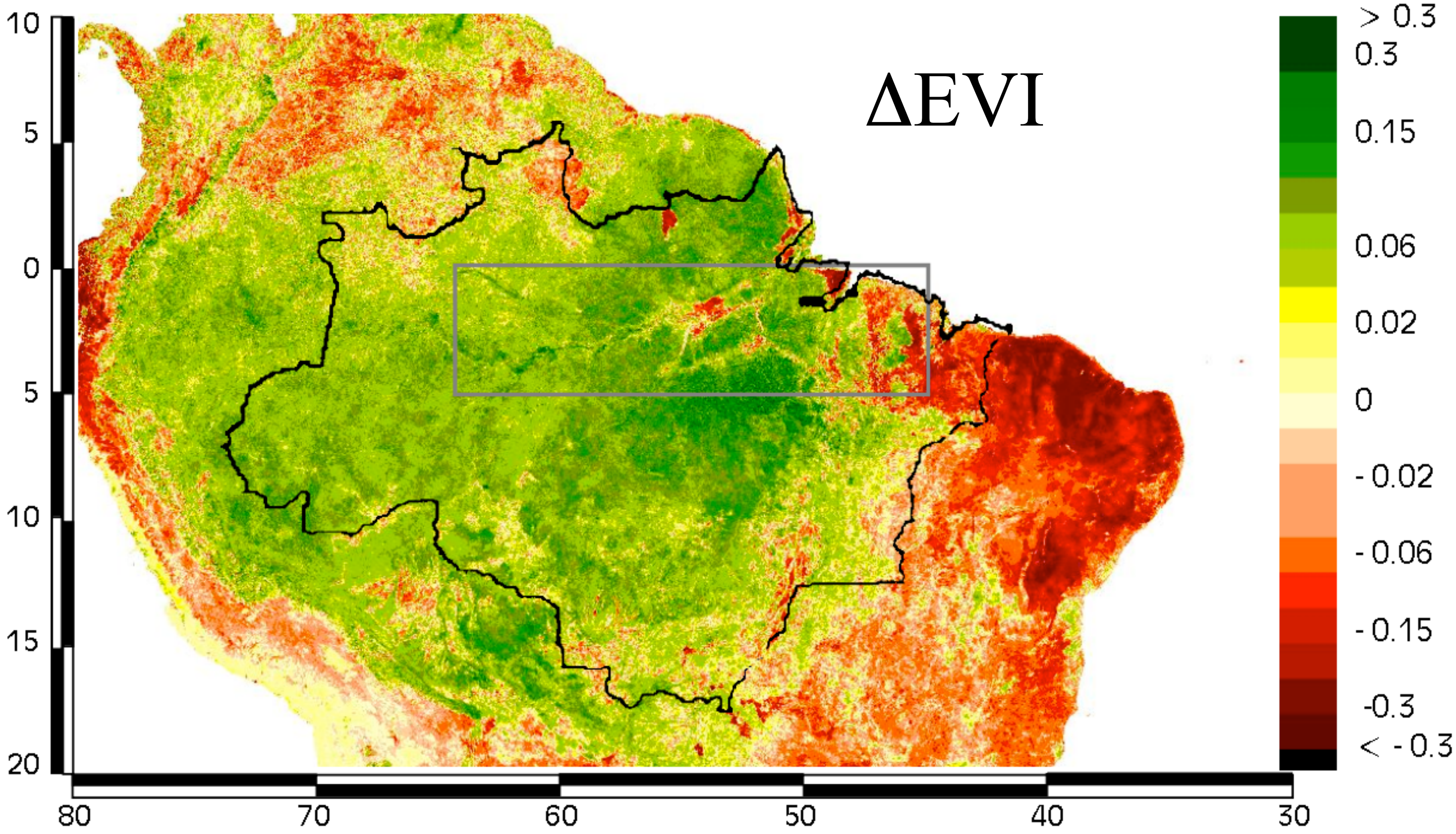


Precip
PAR
mm/mo
400
200
0
65°W
60°W
55°W
50°W
150
100
50
W/m2
J M M J S N
0
5S
65W
60W
55W
50W
45W
Caxiuana
Manaus
Tapajos
Santarem
Altamira
Faz. Vitoria
A
Dry Season
EVI
0.6
0.5
0.4
65
60
55
50
45
Transect Longitude
May
Mar
Jan
Nov
Sep
Jul
Month
B
0.6 0.5 0.4

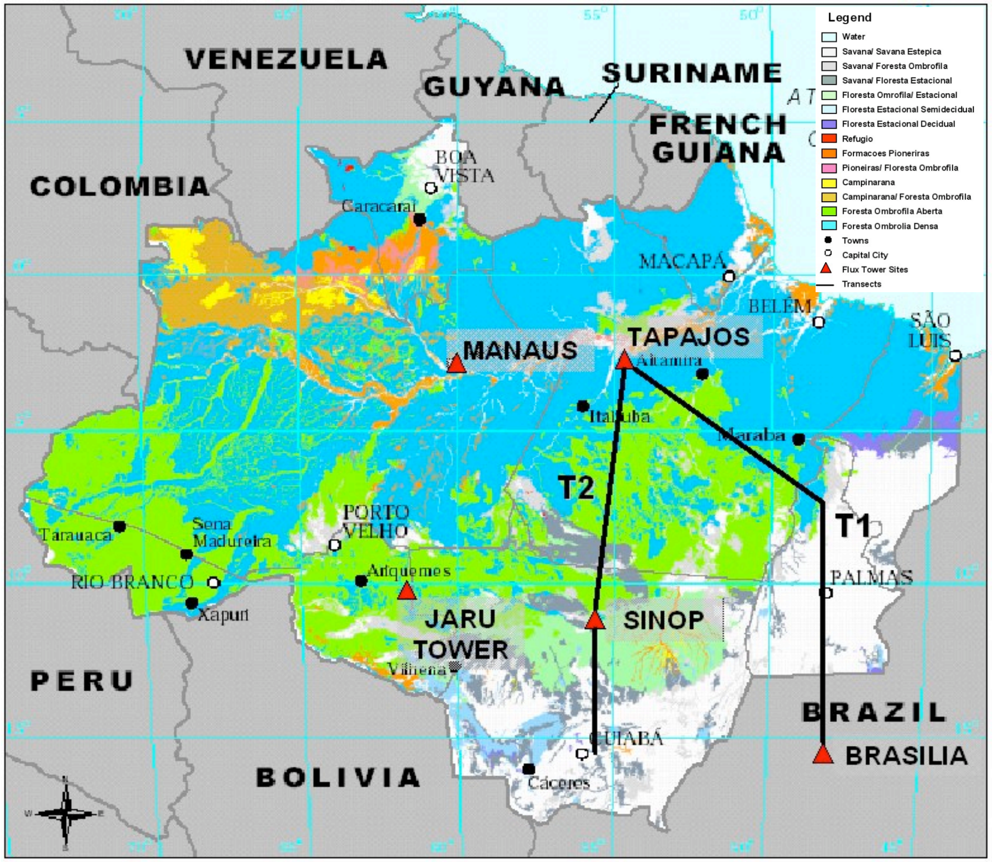
Huete, A

Basin-wide greening in dry season

October EVI (dry season) minus June EVI (wet season)



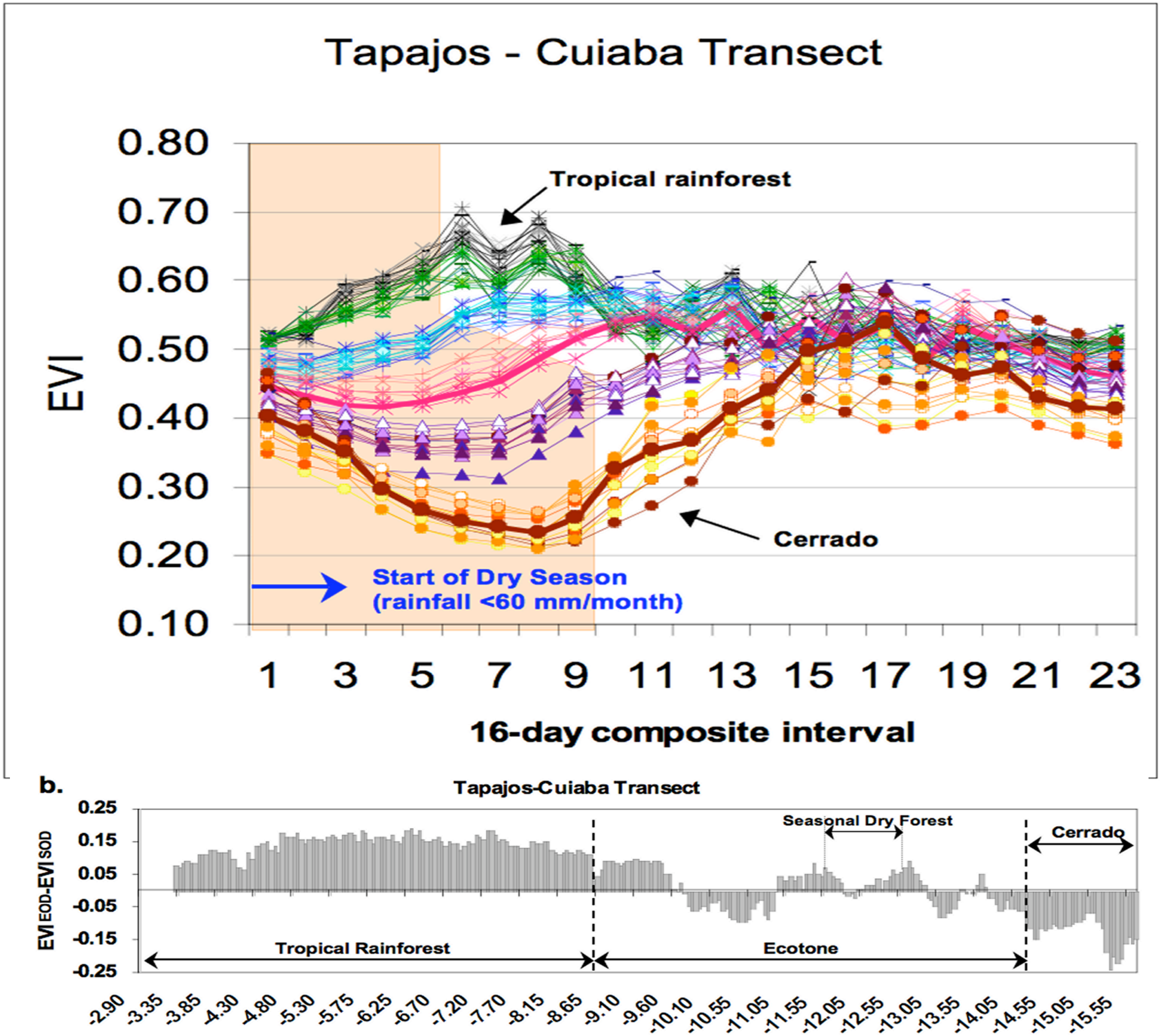
Huete, A



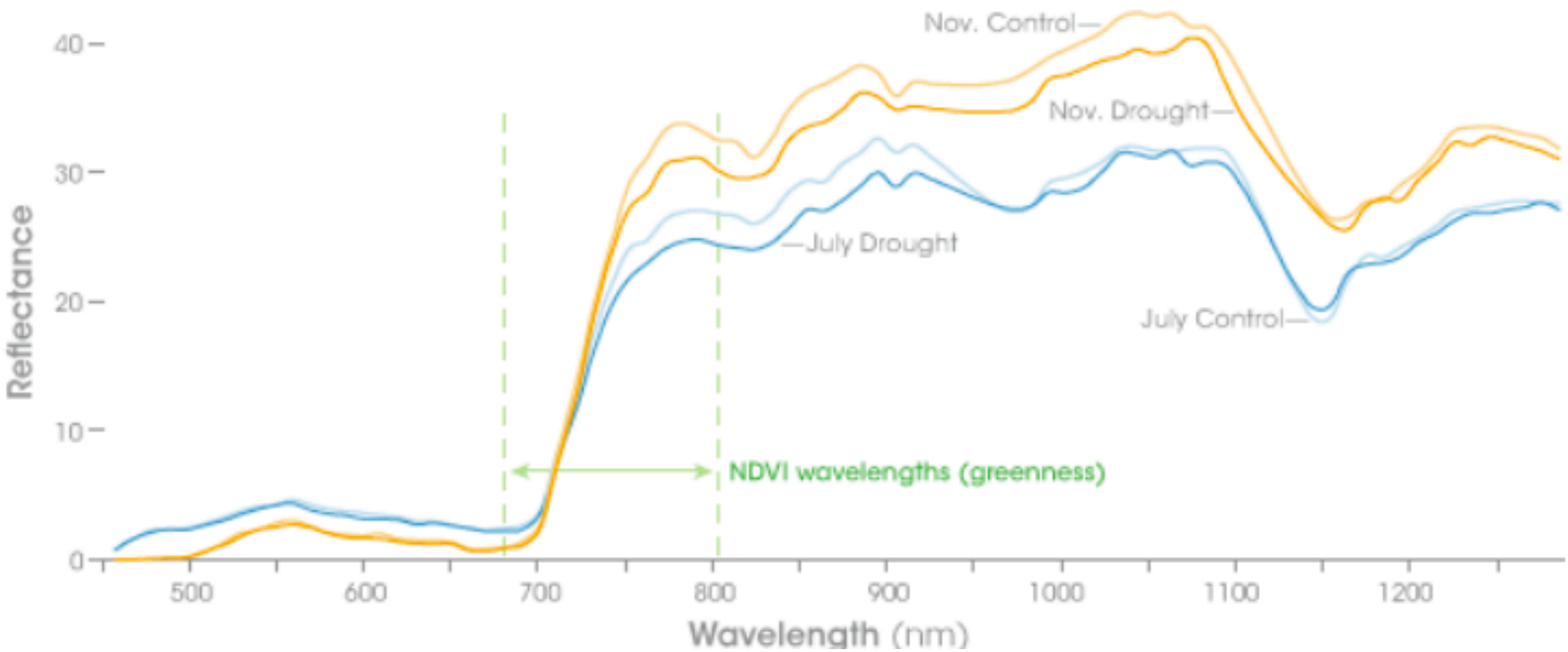
Ecotone Rainforests
(Transitional)

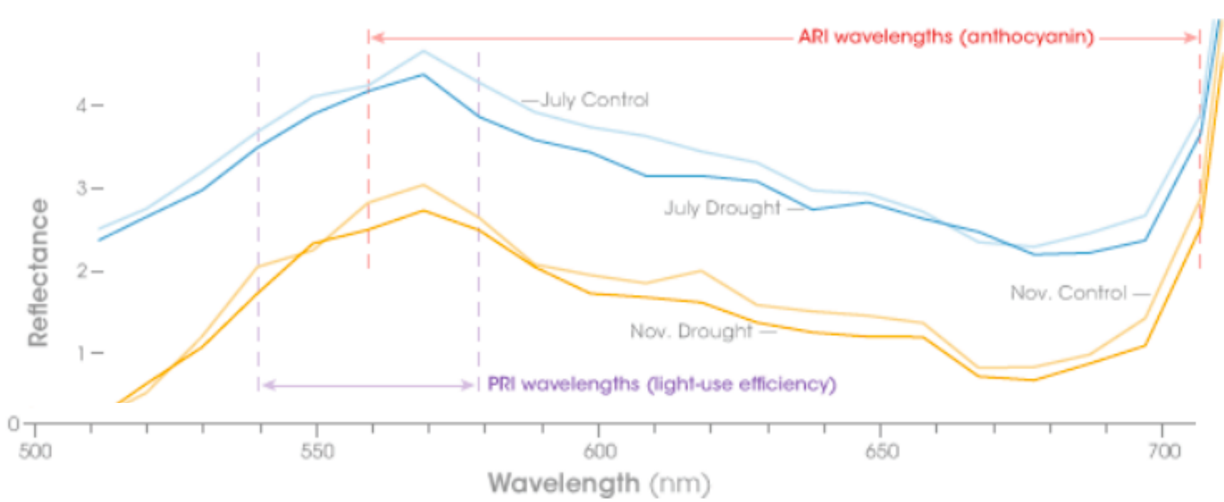
- Both light and moisture controls on ecosystem metabolism and productivity

Ratana, P


Tapajos - Cuiaba Transect
Tropical rainforest
Cerrado
Start of Dry Season
(rainfall <60 mm/month)
EVI
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
1 3 5 7 9 11 13 15 17 19 21 23
16-day composite interval
b.
Tapajos-Cuiaba Transect
Seasonal Dry Forest
Cerrado
Tropical Rainforest
Ecotone
EVI EOD-EVI SOD
0.25
0.15
0.05
-0.05
-0.15
-0.25
-2.90 -3.35 -3.85 -4.30 -4.80 -5.30 -5.75 -6.25 -6.70 -7.20 -7.70 -8.15 -8.65 -9.10 -9.60 -10.10 -10.55 -11.05 -11.55 -12.05 -12.55 -13.05 -13.55 -14.05 -14.55 -15.05 -15.55

Ratana, P





Hyperion data, Asner

Spectral Measurements of Ecosystem Light Use Efficiency

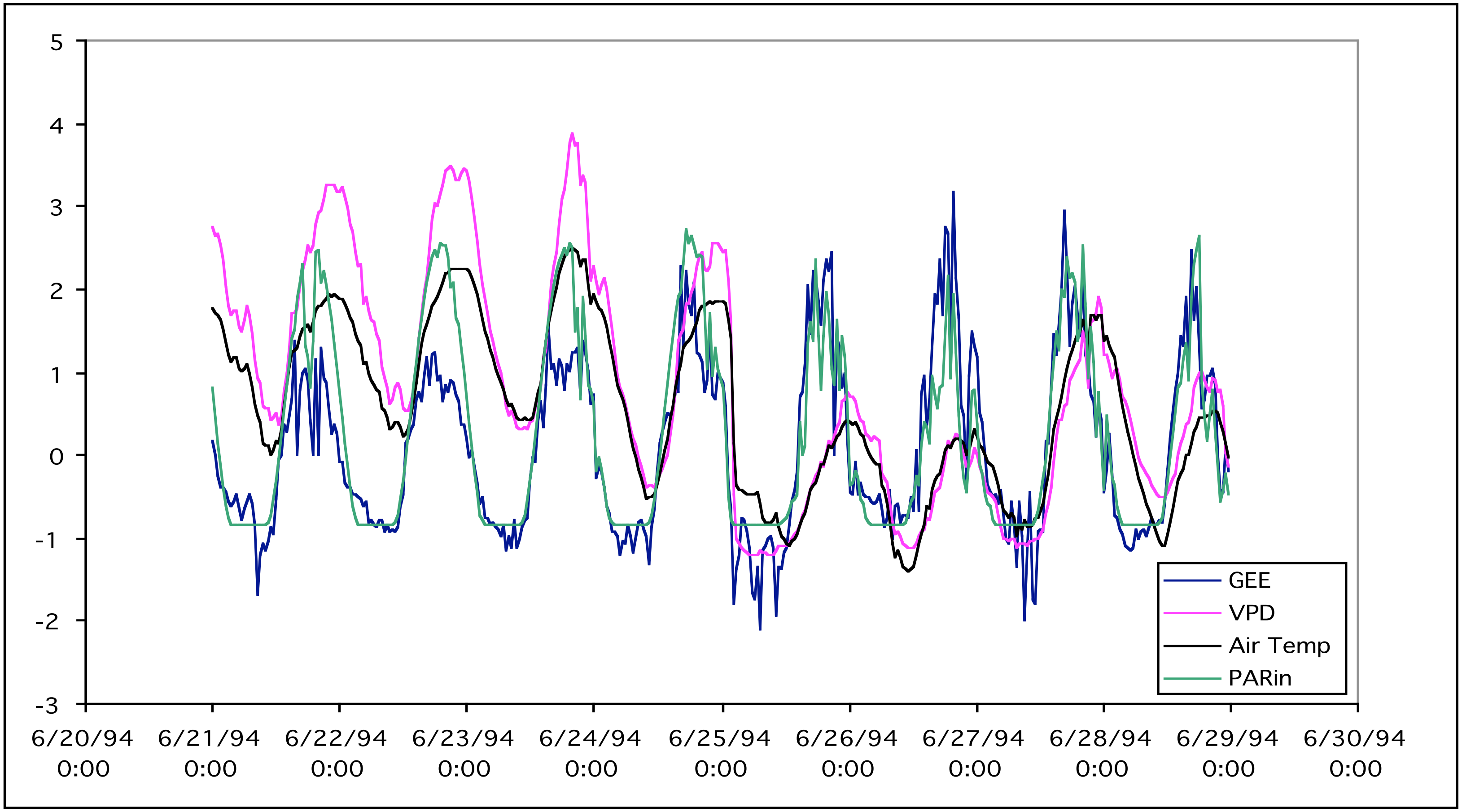
E.M. Middleton & K.F. Huemmrich

$$GPP = \int \varepsilon(t)\, f\mathrm{PAR}(t)\, \mathrm{PAR}_{in}(t)$$

We want to find ε, the light use efficiency, through remote sensing,

Determining LUE from remote sensing requires both hyperspectral and hypertemporal time series data to observe transient and sustained physiological stress effects on plants.

The Effect of VPD on GEE



- **Very high VPDs occurred on the afternoons of June 22-24, causing PARin and GEE to separate.**
- **When VPD drops for the last few days of this period,GEE and PARin again track each other.**

The Approach:

Leaves have multiple responses to stress, including

1. Xanthophyll cycle pigments (531nm)
2. Solar Induced Fluorescence (690, and 735nm)
3. and, over a longer period, reducing the amount of photosynthetic machinery, decreasing chlorophyll concentration (multiple wavelengths)

All of these responses have specific effects on leaf spectral reflectance

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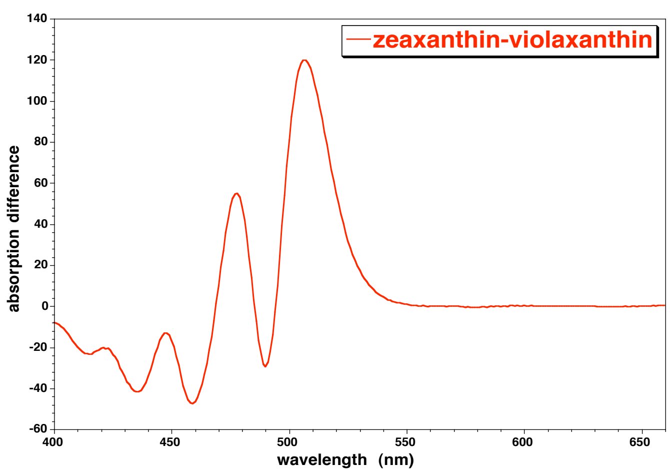
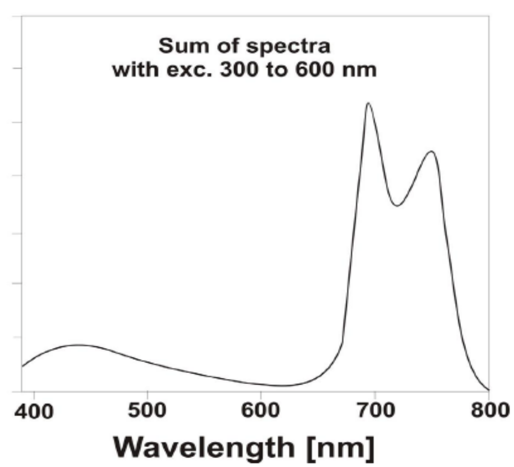
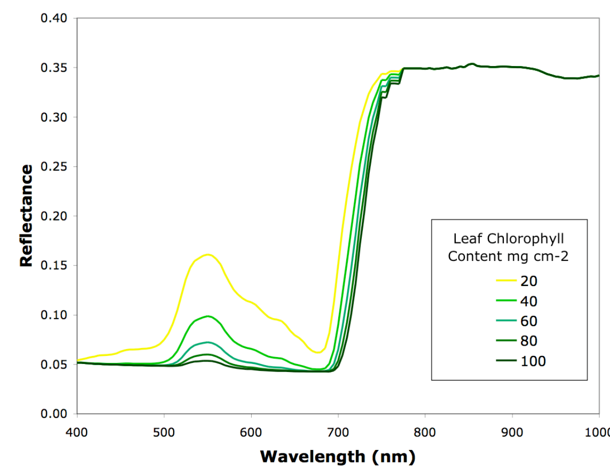
Xanthophyll



Fluorescence



Chlorophyll



Photochemical Reflectance Index (PRI)

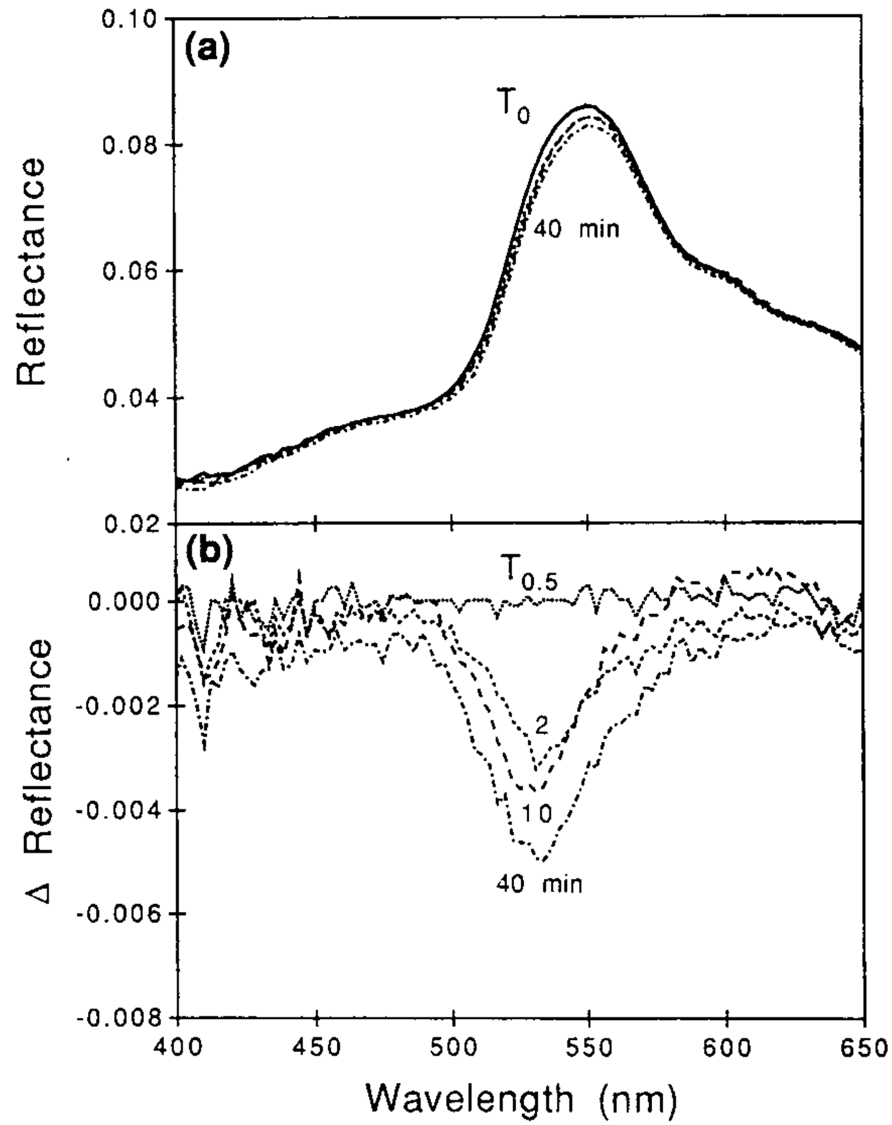
PRI uses the narrow-band reflectance at 531 nm and a second reference band to detect changes in the xanthophyll cycle

$$PRI = \frac{\rho(531nm) - \rho(570nm)}{\rho(531nm) + \rho(570nm)}$$

- Scaled PRI (sPRI)

Makes all values positive

sPRI = (1+PRI)/2



Moisture Stress Creates Changes in Leaf Biochemistry and Leaf Reflectance

- Absorbed Photosynthetically Active Radiation Cannot Be Utilized When Stomata Close.
- As a protective mechanism, leaf xanthophyll cycle responds to dissipate excess energy.
- This process can be detected in leaves through a change in the reflectance at 531 nm.

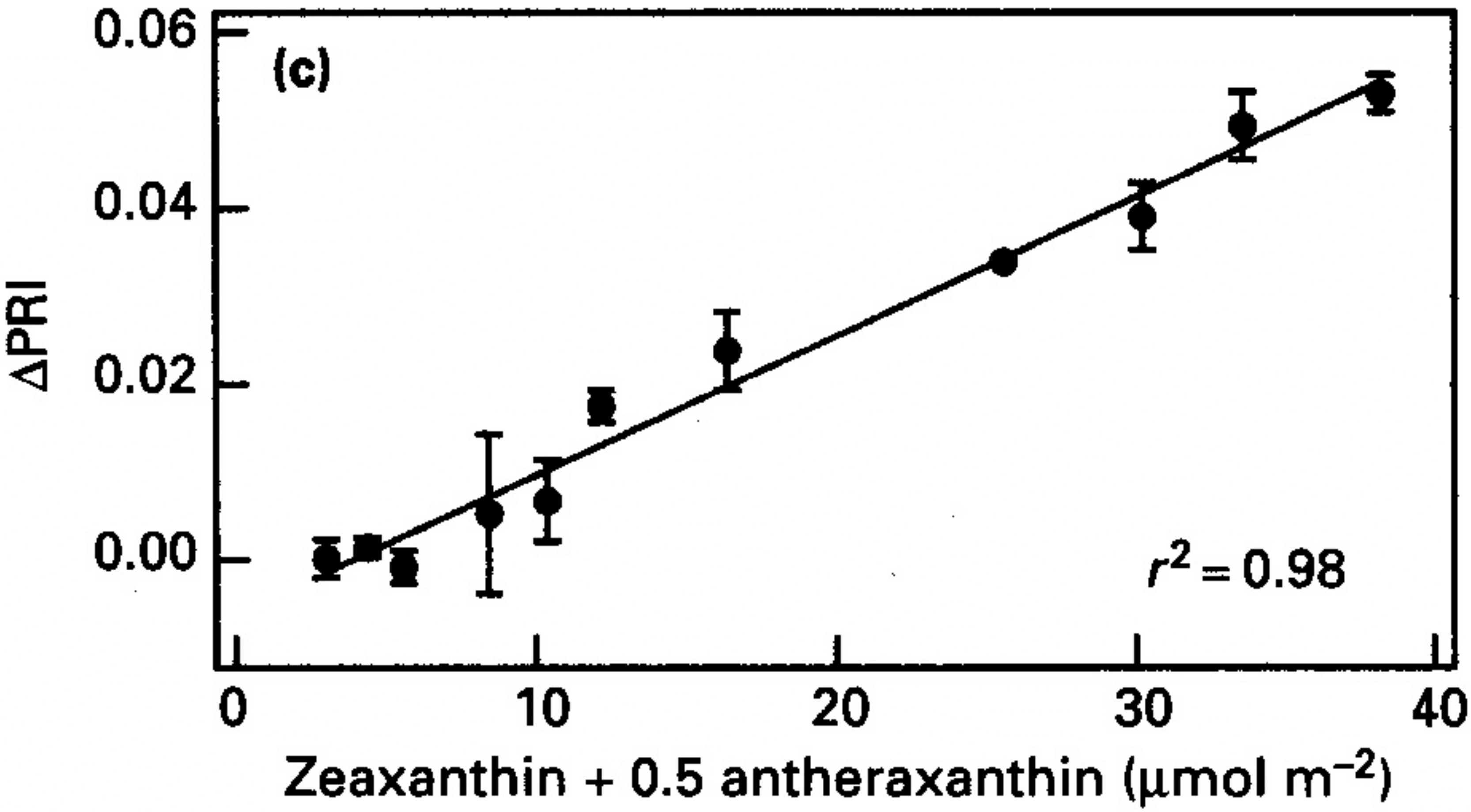
$g_c = Ah/C$

ENVIRONMENTAL STRESS
Reduces g_c
(h, T, M, N)

→ **Decreasing g_c reduces ρ_{531}**

g_c = stomatal conductance
A (T, M, N) = assimilation rate
h = humidity
C = CO_2 concentration

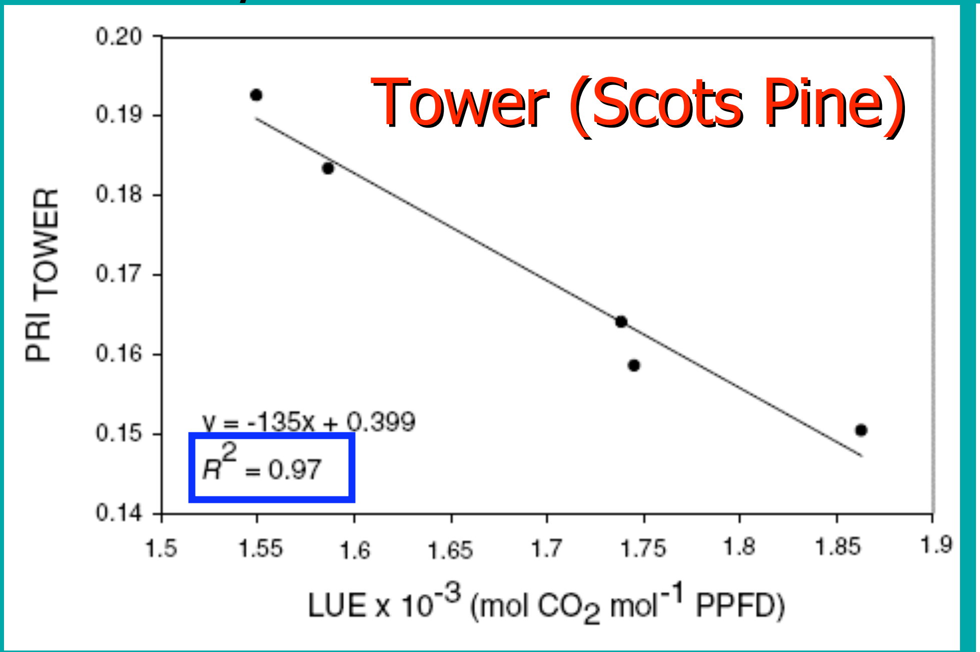
Changes in PRI are closely linked to xanthophyll cycle pigments



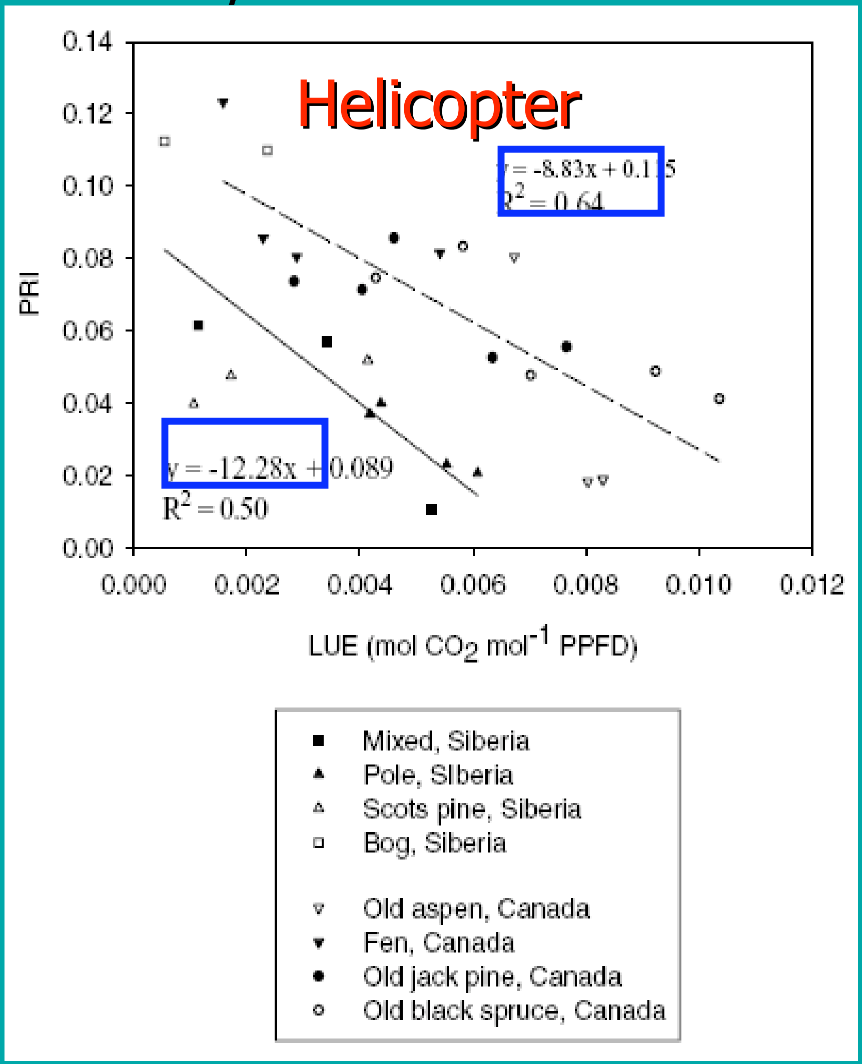
Gamon and Surfus 1999

Stand-level PRI

Diurnal variations in LUE/PRI



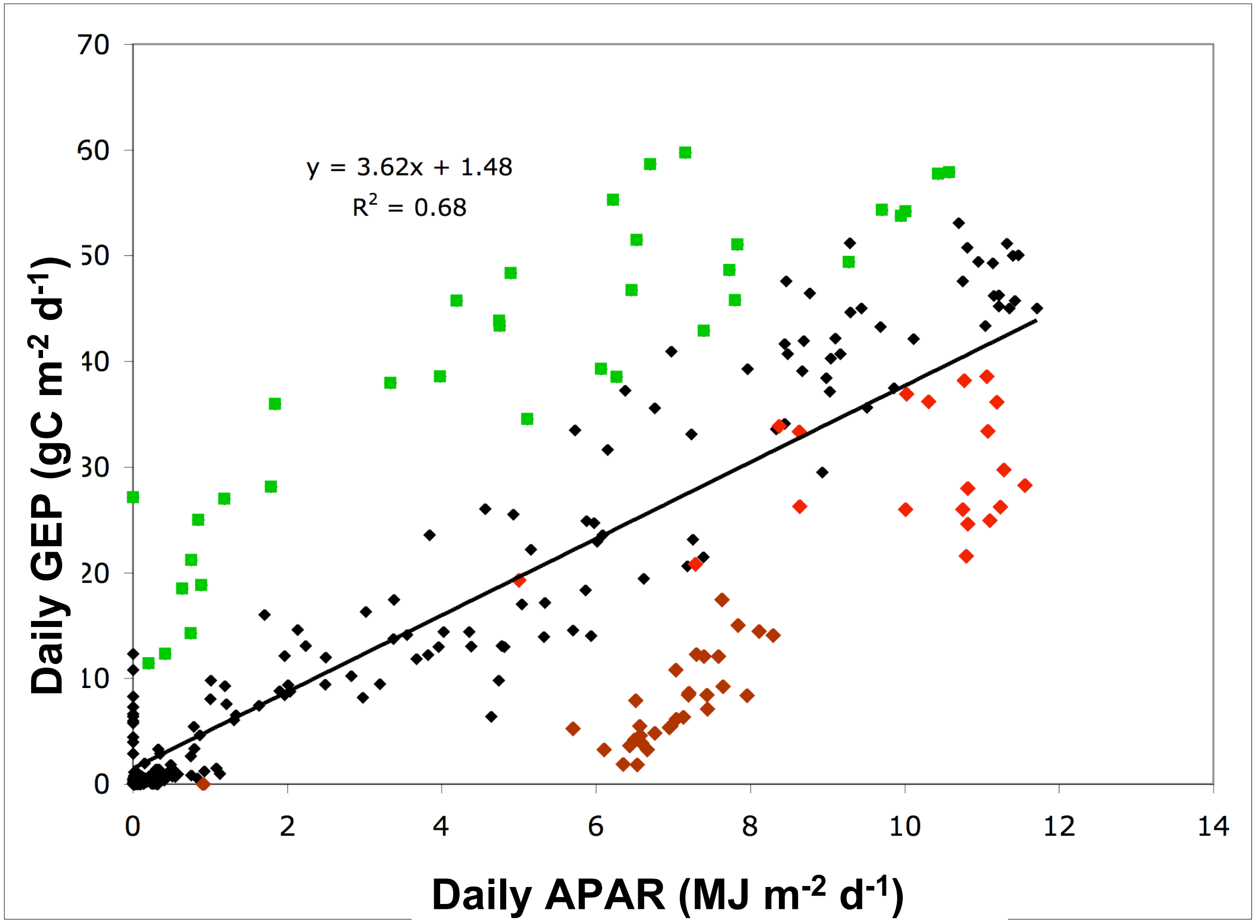
Seasonal variations in LUE/PRI



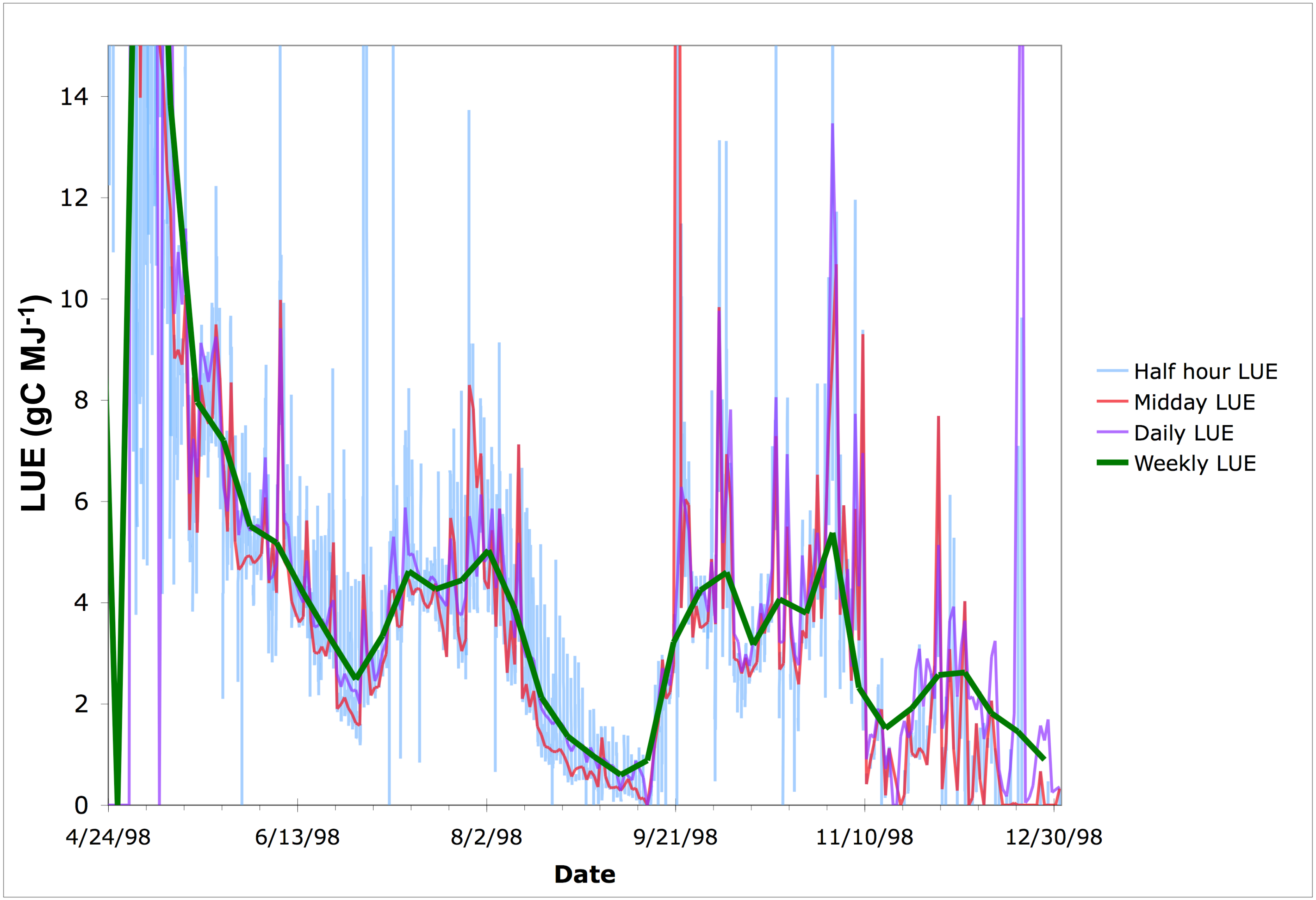
(Nichol et al., 2002)

Daily APAR and GEP

Prairie Shidler, Oklahoma, C4 Grassland

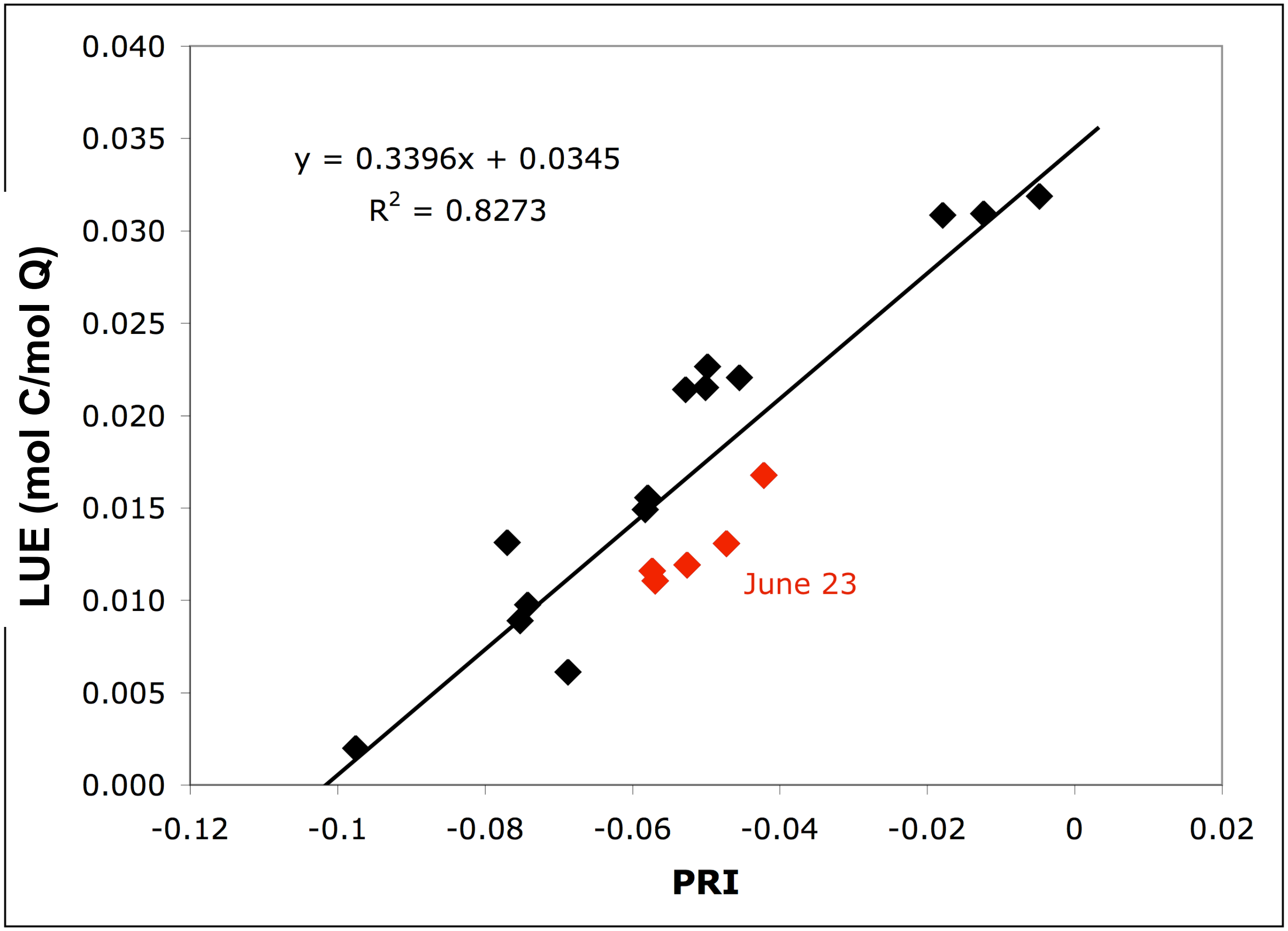


Temporal Variability of LUE

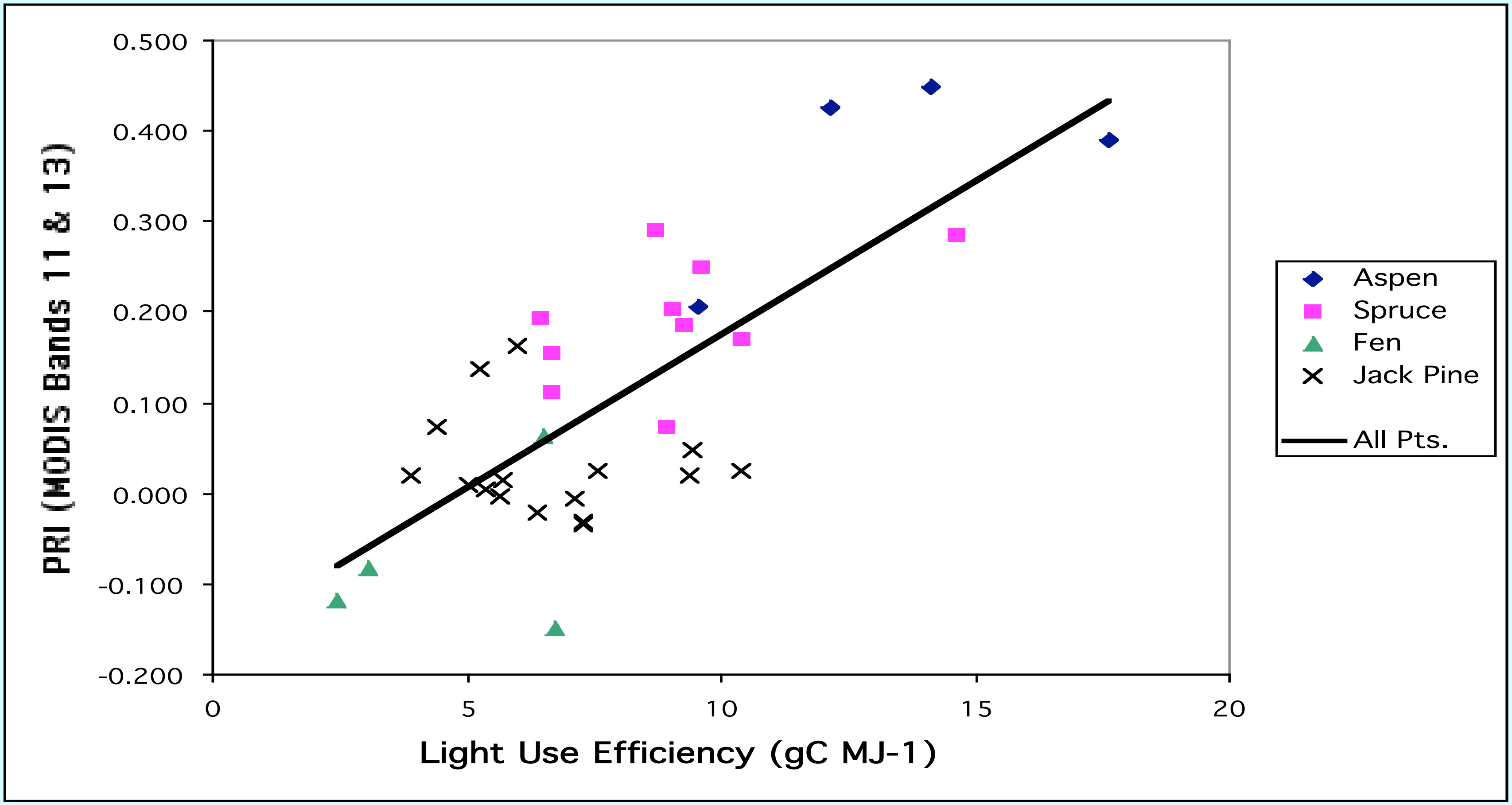


Spectral Indexes

- Match reflectance and flux measurements in time
- Look at relationships within days and over season
- PRI related to changes in Xanthophyll pigments



BOREAS Sites

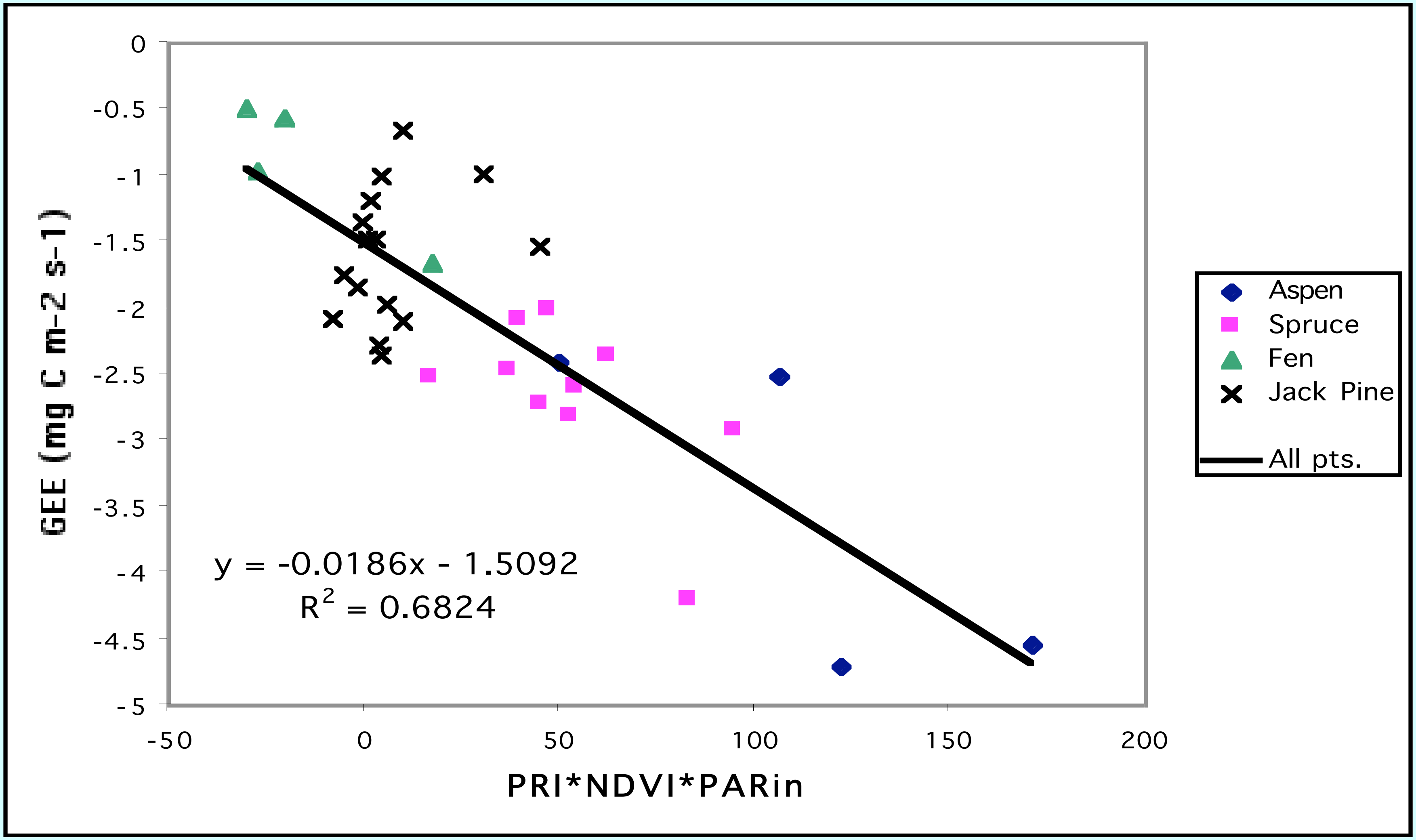


LUE calculated from flux tower data and PRI from helicopter hyperspectral reflectances averaged to MODIS bands 11 and 13 are correlated (r = 0.75).

LUE = GEE / *f*PAR Qin

Data from BOREAS, acquired throughout the 1994 growing season in four boreal ecosystems.

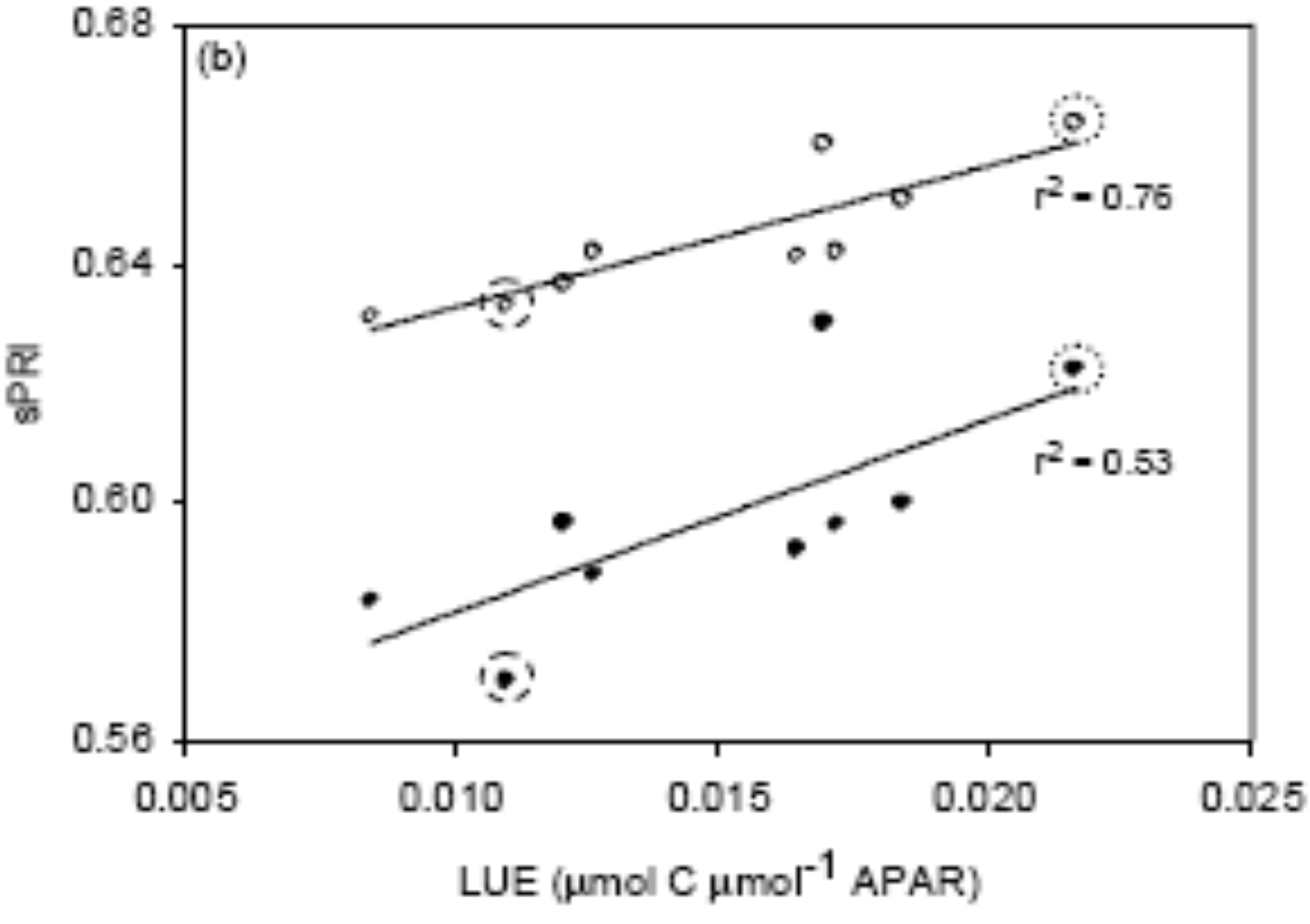
BOREAS Sites



We replaced the weekly ground-measured Fpar with NDVI from the helicopter, collected at the same time as GEE.

MODIS PRI and Aspen LUE

Data from summers of 2001, 2002, and 2003
Backscatter observations only



Summary

1. The "LAI – $FPAR_{canopy}$ – NDVI" paradigm is likely to continue to play a role in modeling of biogeochemical cycles and climate system.
2. The "Leaf chlorophyll – $FPAR_{chl}$ – EVI" framework , a biochemical perspective of vegetation canopy, opens new doors for improving GPP modeling, reducing uncertainty in modeling of terrestrial carbon cycle, and better characterizing leaf phenology.
3. The PRI offers much potential in pixel-based assessments of LUE and canopy stress at near real-time time scales,
4. Land surface and vegetation water indices are sensitive to changes in leaf water content/ soil moisture, useful in LUE derivations.
5. LST provides information useful in constraining C-fluxes (GPP and Respiration)