Remote Sensing of Ecosystem Productivity Using MODIS

Fred Huemmrich, UMBC/GSFC
John Gamon, University of Alberta

Study Goals

We want to develop methods to use optical signals to estimate ecosystem carbon exchange

1) Examine the relationships between ecosystem production (GEP) and spectral reflectance
   - We have some physical understanding of the nature of these relationships but we do not have a good physical model relating leaf/canopy biochemistry, photosynthetic processes, and spectral reflectance
   - Use data from existing flux towers to empirically examine relationships for different vegetation types over multiple years
2) Define an algorithm for a potential MODIS product

Light Use Efficiency (LUE) Model

$$G = \varepsilon\, f_{APAR}\, Q_{in} = \varepsilon\ APAR$$

G is gross ecosystem production (GEP)

Qin is the incoming photosynthetically active radiation (PAR)

f_{APAR} is the fraction of PAR absorbed by green vegetation

APAR is the PAR absorbed by vegetation or f_{APAR} Qin,

ε is the light use efficiency (LUE)

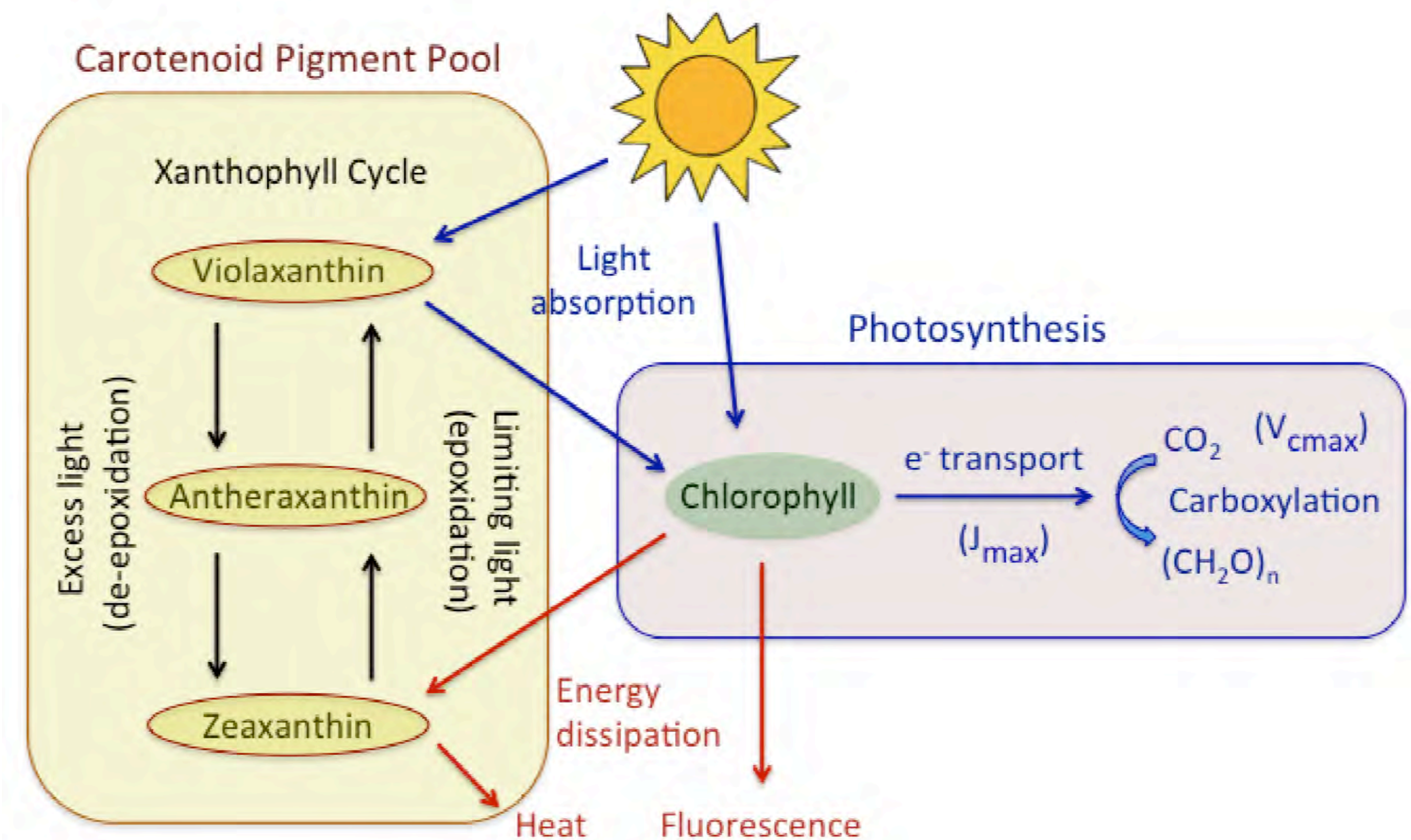
In MOD17 ε is calculated based on meteorological conditions and vegetation type

$$\varepsilon = f(T_{air})\, g(VPD)\, \varepsilon^*$$

ε* is the maximum LUE for the vegetation type

Can we determine GEP using only optical inputs?

Photosynthetic Energy Pathways



Radiation absorbed by a leaf can go to: productive photosynthesis (blue text and arrows), energy dissipation (red text and arrows), regulatory processes associated with the xanthophyll cycle (black text and arrows), and carotenoid and chlorophyll pigment pools, all of which can be assessed with optical sampling

Gamon 2015

Optical Signals

Leaf biochemistry responds to stresses over varying time scales

- Short term stress responses change relative amounts of Xanthophyll cycle pigments in leaves
- There are also longer term changes in the relative amounts of photosynthetic and photoprotective pigments (Chlorophylls and Carotenoids) in leaves

These biochemical changes produce detectable changes in leaf optical properties - we are trying to relate them to carbon fluxes

Using these optical signals as model inputs has an important effect on the interpretation of the model

- We go from trying to <u>predict</u> vegetation response to environmental variables (temperature and humidity)
- To an approach where we are <u>observing</u> the plant's responses to environmental conditions
  - even if we don't know exactly what those environmental forcings are

Optical Signals

Shifts in pigments affects the spectral region around 531 nm (MODIS band 11)

- The Photochemical Reflectance Index (PRI) is the normalized difference of reflectances at 531 nm and a reference band at 570 nm (which we don't have on MODIS)
  - it was developed to detect Xanthophyll pigments
- PRI is also affected by the overall size of the the Chlorophyll and Carotenoid pools in leaves
  - we are calling the index for this the Chlorophyll-Carotenoid Index (CCI), the normalized difference of bands 11 and 1 (red band)

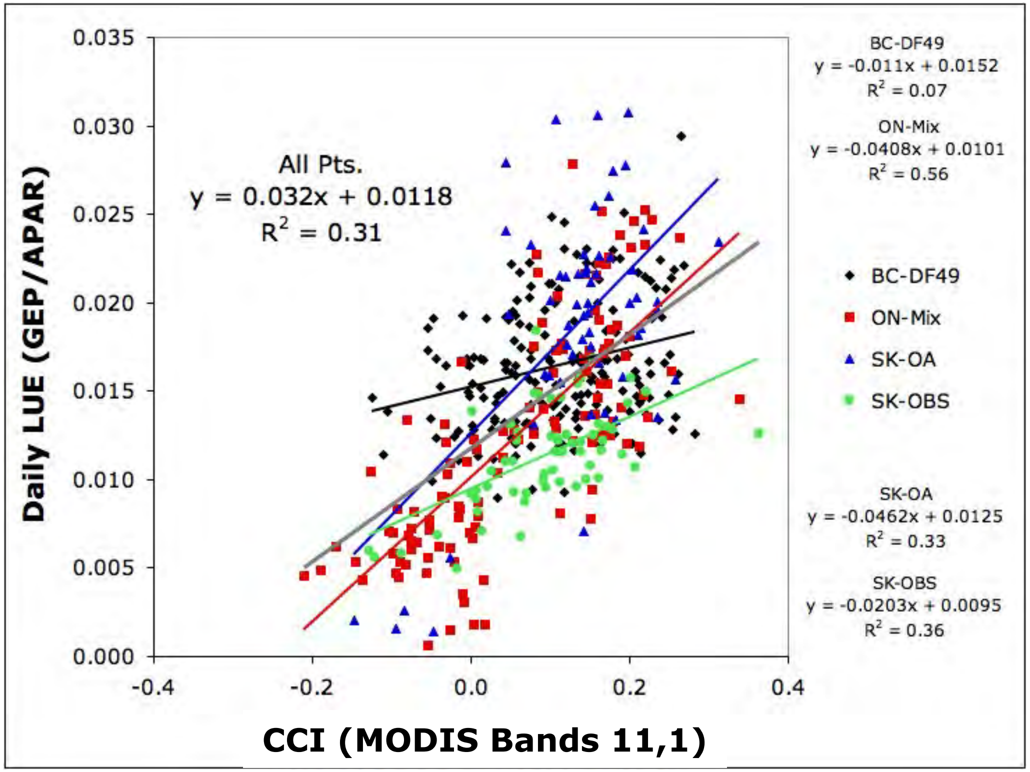
MODIS CCI and LUE

Look at four different Canadian flux tower sites

- Summertime observations only, little change in LAI or NDVI
- LUE from flux tower data

CCI calculated using MODIS bands 11 (an ocean band) and 1 (red band)

Different relationship for each forest type, consistent across years

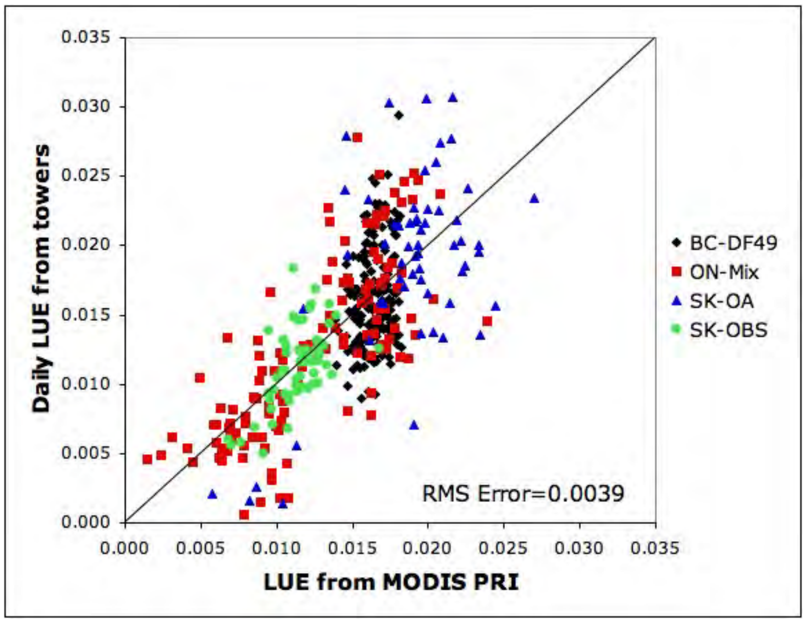


BC-DF49 = British Columbia, Douglas fir site; ON-Mix = Ontario, mixed forest; SK-OA = Saskatchewan, Old Aspen; SK-OBS = Saskatchewan, Old Black Spruce

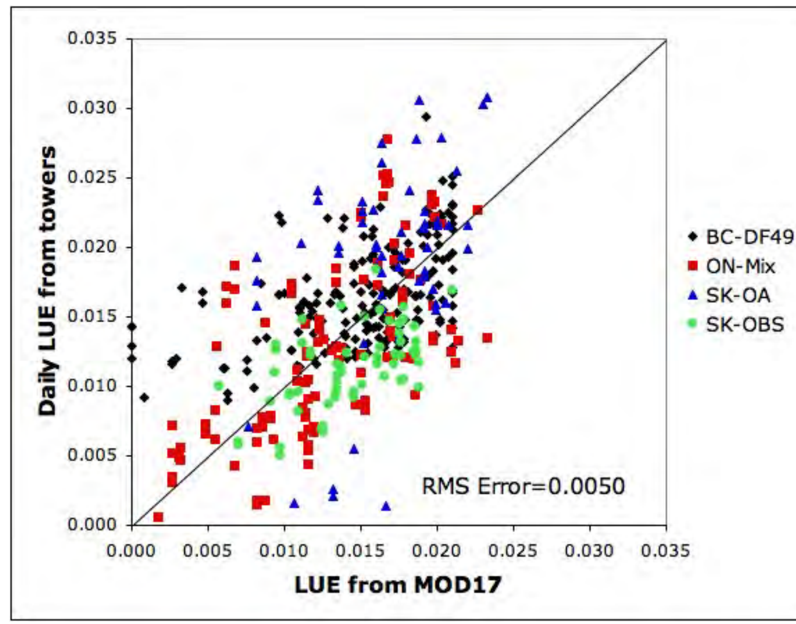
LUE Uncertainties

Comparing LUE from CCI to LUE from MOD17 algorithm

- For these sites CCI does a better job than the existing MODIS GPP model (MOD17) using the tower meteorological observations



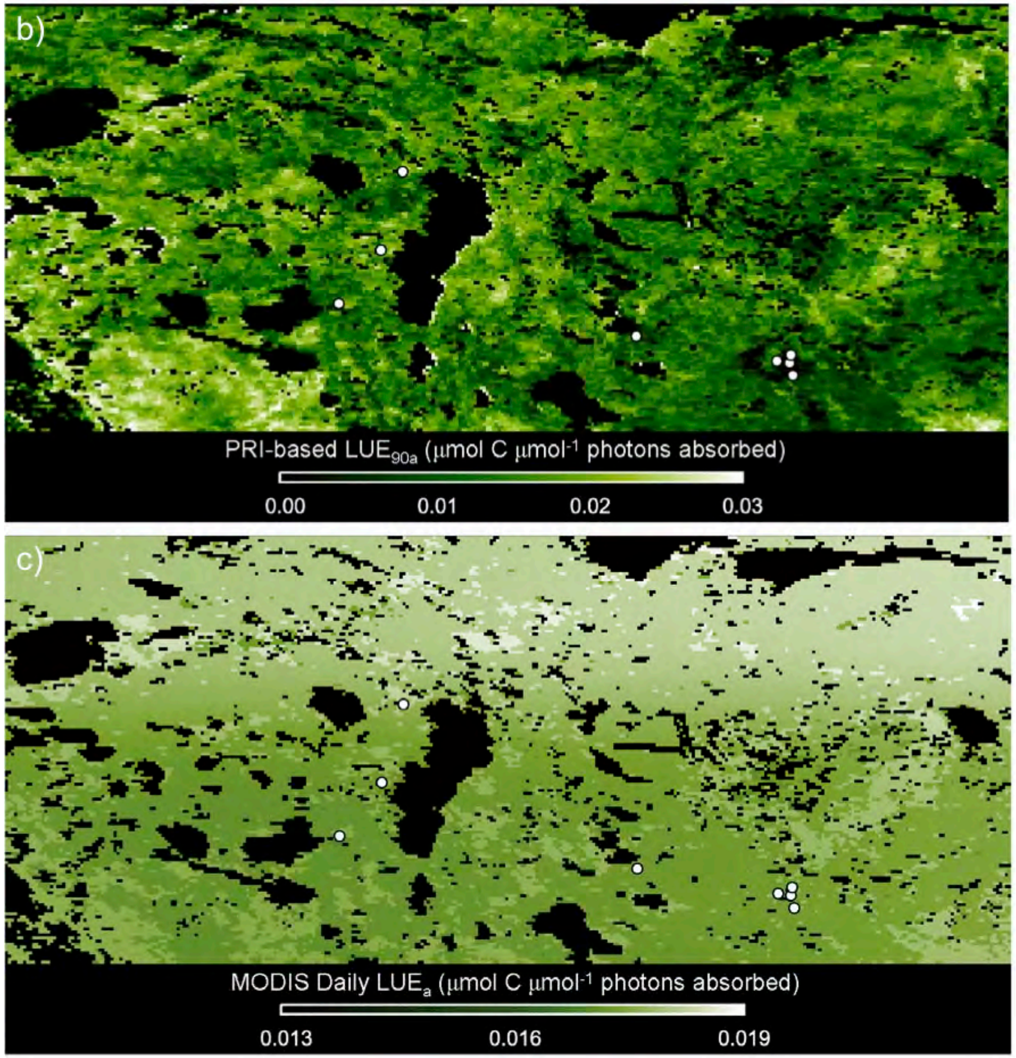
From MODIS observations



Modeled using Met Data

BC-DF49 = British Columbia, Douglas fir site; ON-Mix = Ontario, mixed forest;
SK-OA = Saskatchewan, Old Aspen; SK-OBS = Saskatchewan, Old Black Spruce

Optical Approaches and Landscape Heterogeneity



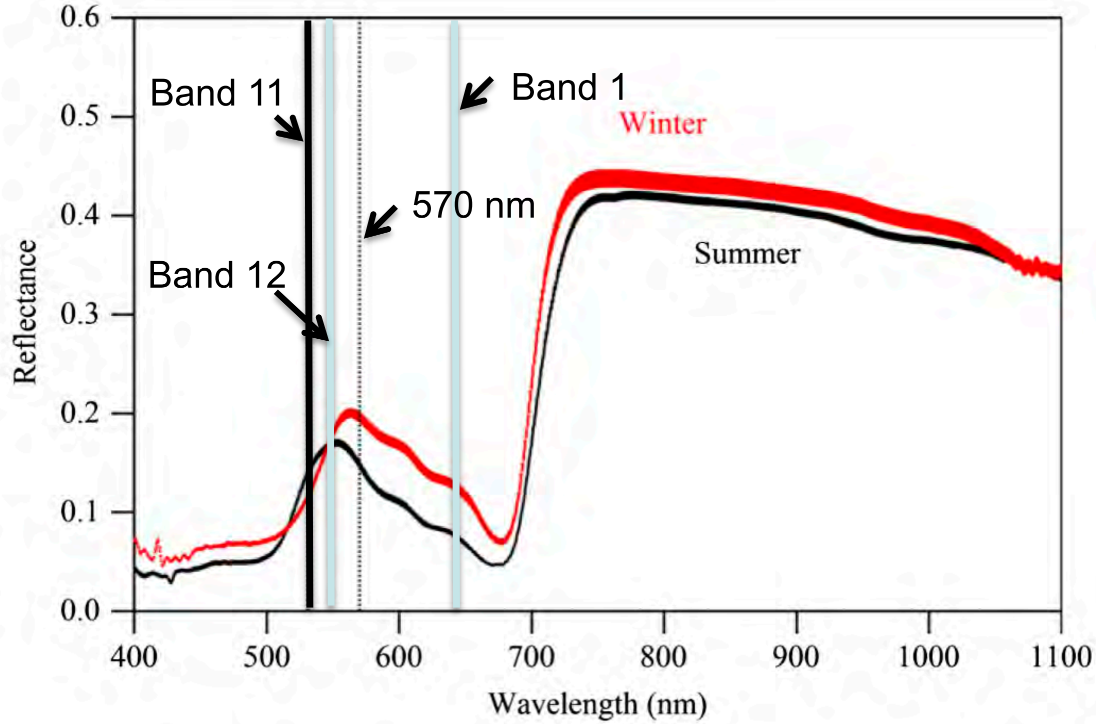
Upper figure: LUE from MODIS reflectances

Lower figure: LUE estimated using meteorological inputs in MOD17 model

From Drolet et al. 2008

Boreal Conifer Needle Reflectance

MODIS bands 11 and 1 can detect seasonal change in needle reflectance



Leaf spectra of *Pinus contorta* showing the seasonal changes between summer- (black line) and winter-adapted (red line) leaves. Vertical lines indicate bands used for Chlorophyll:Carotenoid Indices (CCIs), including MODIS bands 1 (645 nm, a terrestrial band), 11 (531 nm, an ocean band), and 12 (551 nm, an ocean band), and the standard PRI reference band (570 nm, unavailable from MODIS).

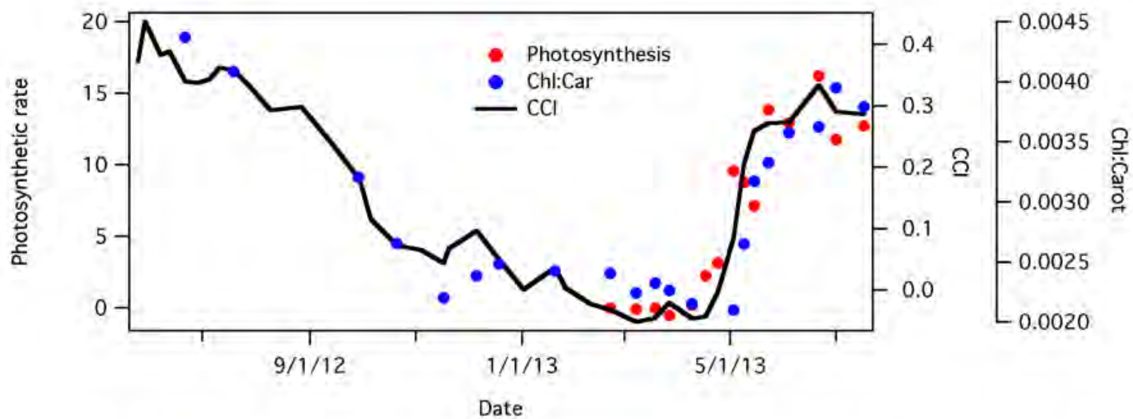
Wong and Gamon 2015

Seasonal Change in Boreal Conifer Needles

Time trends for *Pinus contorta* leaves exposed to a boreal climate

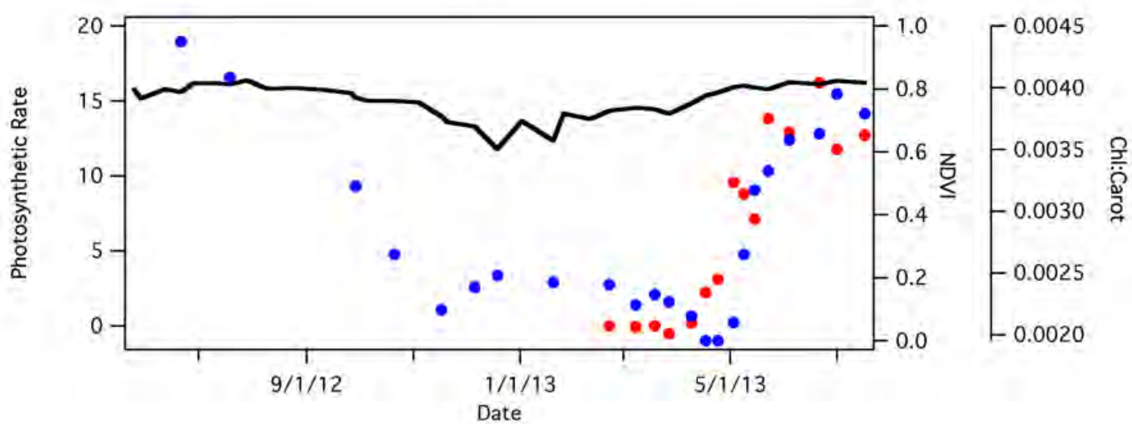
Red points - needle photosynthesis

Blue points - chlorophyll:carotenoid ratio



Black line:
Chlorophyll-Carotenoid Index

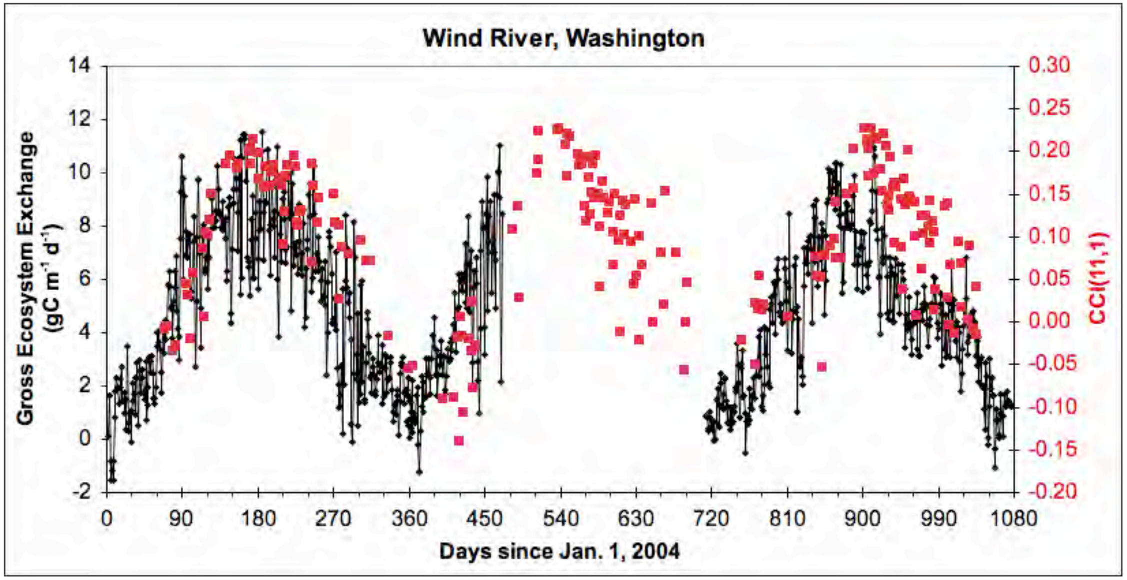
$$CCI = \frac{(R_{11} - R_1)}{(R_{11} + R_1)}$$

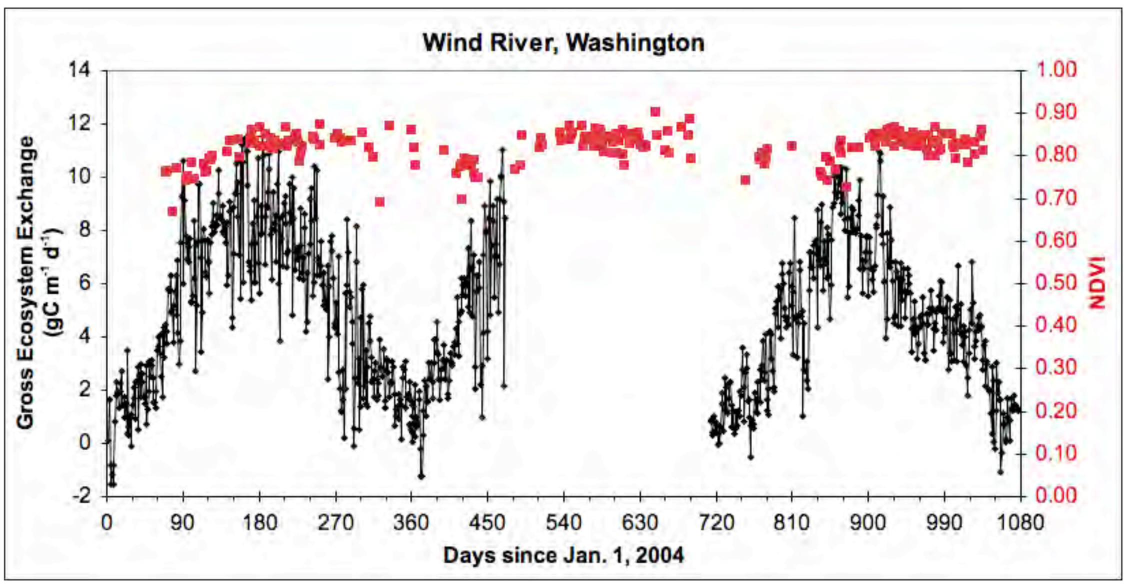


Black line: NDVI

Wong and Gamon 2015

Seasonal Change in Evergreen Conifer Stands





Wind River, WA

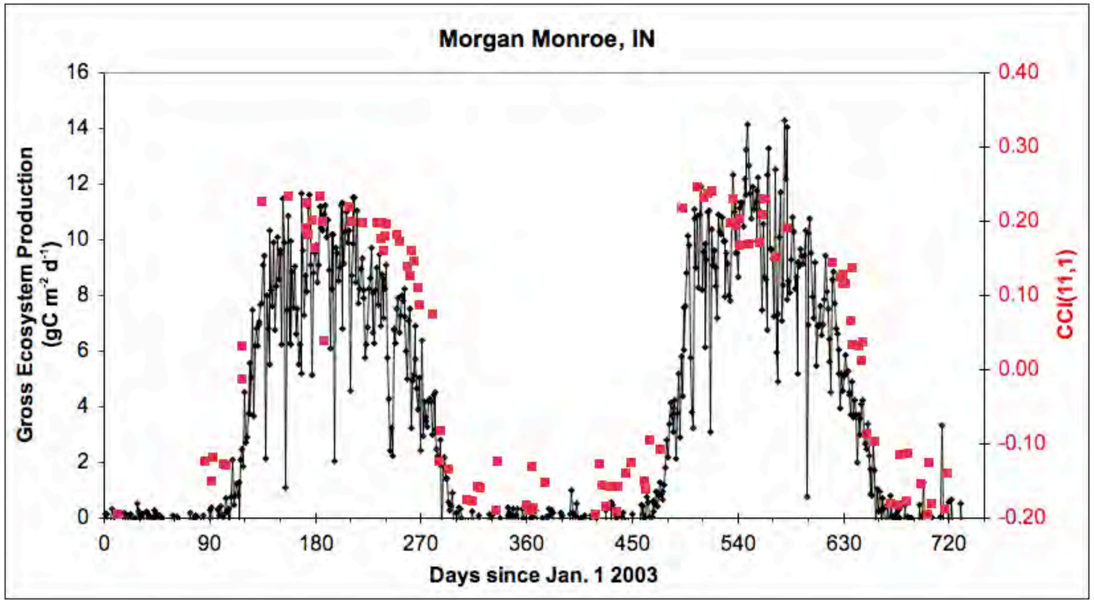
CCI from Aqua MODIS

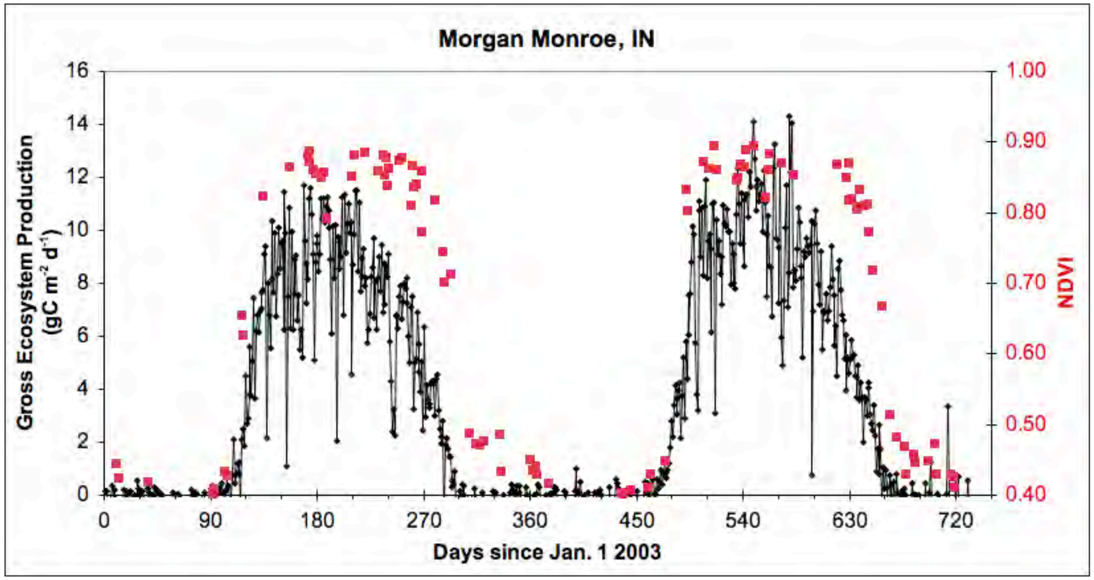
NDVI from Aqua MODIS

Black lines: Daily GEP from flux tower

Flux data from Fluxnet Synthesis

Seasonal Change in Deciduous Forest Stands





Morgan Monroe, IN

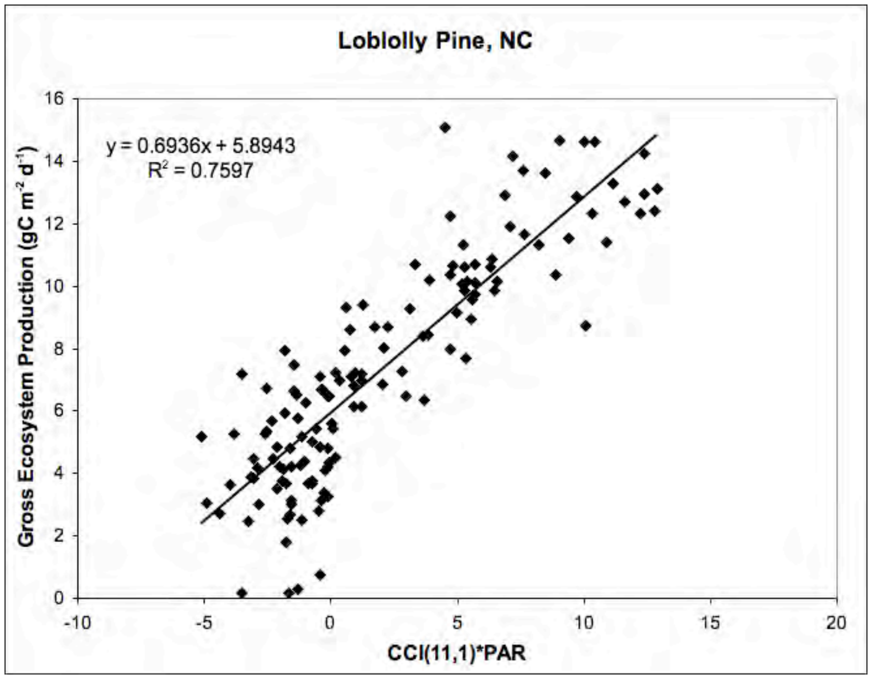
CCI from Aqua MODIS

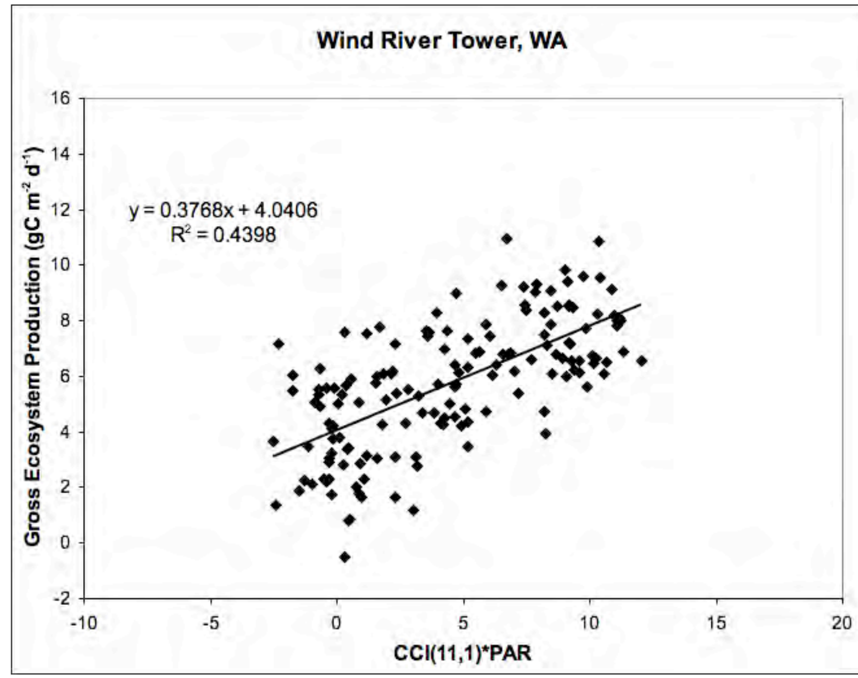
NDVI from Aqua MODIS

Black lines: Daily GEP from flux tower

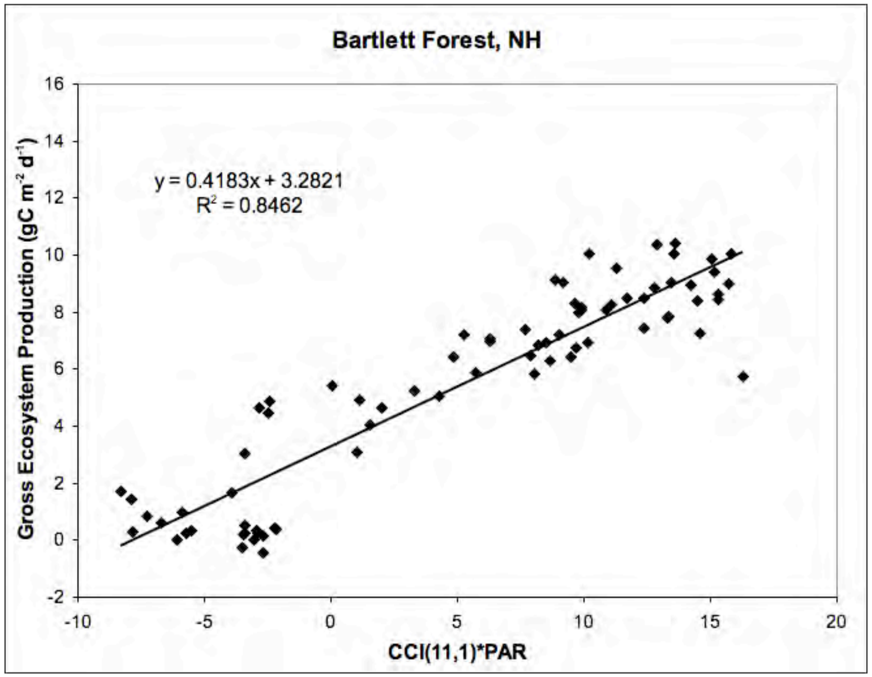
Flux data from Fluxnet Synthesis

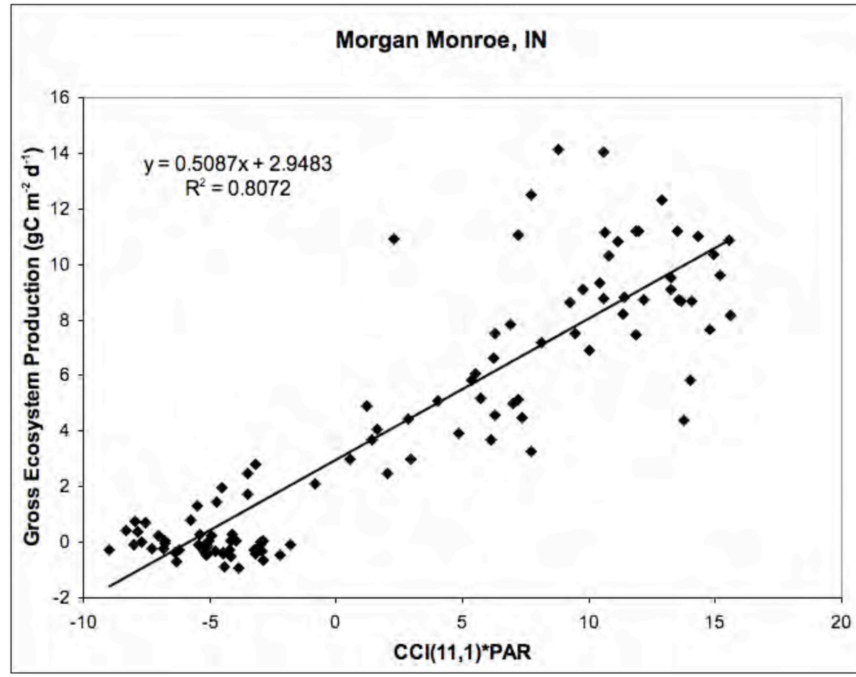
MODIS CCI and Gross Ecosystem Production (Conifers)



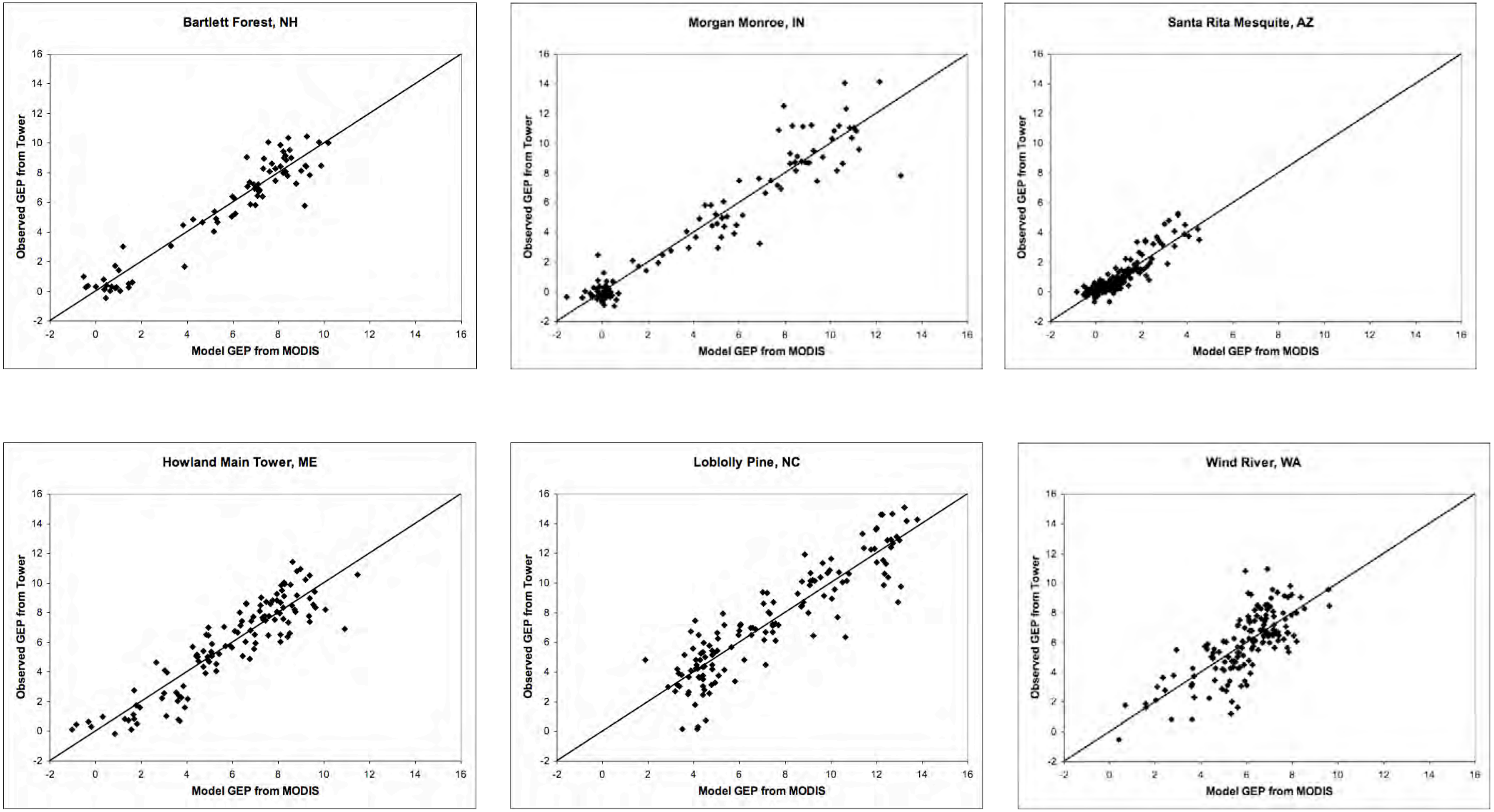


MODIS CCI and Gross Ecosystem Production (Deciduous)



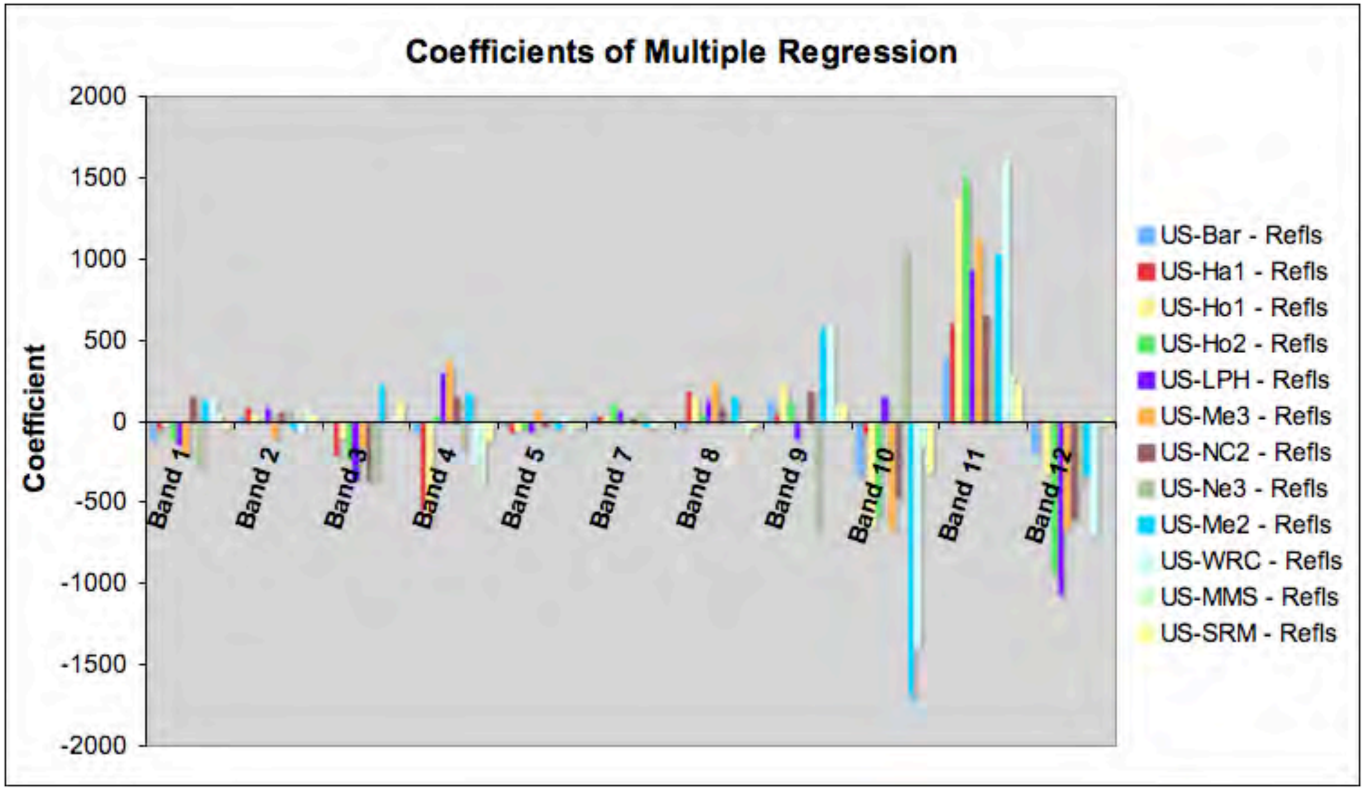


Multiple Linear Regressions of MODIS Band Reflectances



- Separate regression calculated for each site
- Used bands 1-12, except band 6

Multiple Linear Regressions of MODIS Band Reflectances



Coefficient weights suggest that the ocean bands 10 (498-493 nm),11(526-536 mn), 12 (546-556 nm) contain significant information on GEP for multiple sites

Conclusions

- Although not designed for this purpose, MODIS reflectances combining land and ocean bands may be able to derive GEP
- Optical signals from MODIS may give a direct observation of vegetation biochemistry
  - A change from trying to predict responses to observing responses to environmental conditions
  - Providing more spatial detail in GEP than modeling approaches
  - Can provide an independent estimate of fluxes
- There are different relationships for different vegetation types
  - Need to understand variability for GEP algorithm development
  - Could be used to define vegetation functional types (biodiversity)

Future Work

- Evaluate MODIS data for more flux tower sites
  - Convergence of new Fluxnet synthesis data and MODIS C6 data becoming available
- Define processing algorithms for future MODIS products
  - Effects of view and sun angles
  - How do relationships differ for different vegetation types?
  - How do relationships change with season?
  - What are the effects of spatial heterogeneity on relationships?
  - What are the expected errors in retrievals?