Remote Sensing of Ecosystem Productivity Using MODIS

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Study Goals

Develop methods using only 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

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

The Photochemical Reflectance Index (PRI) is the normalized difference of reflectances at 531 nm (Band 11) 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)

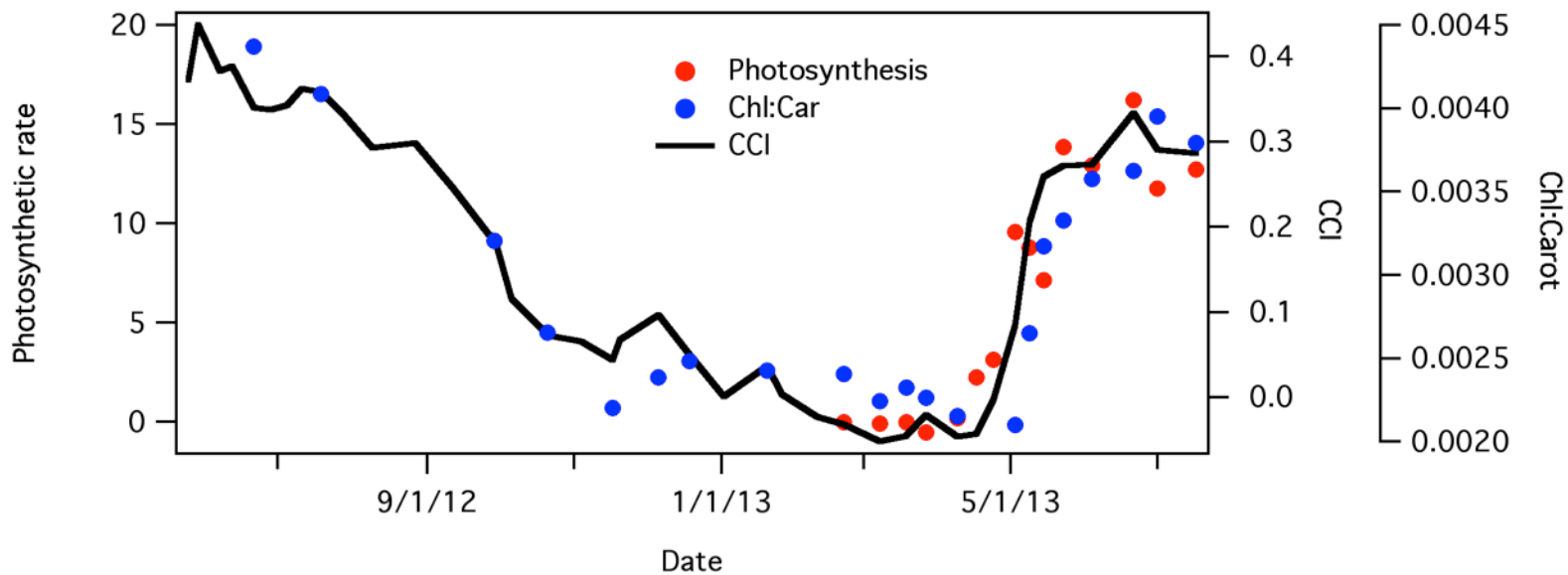
$$PRI = \frac{(R_{11} - R_{ref})}{(R_{11} + R_{ref})}$$

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

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

Wong and Gamon 2015

Methods

Examined 43 flux tower sites

- Chose sites based on visual evaluation that at least 1 km^2 around tower was uniform vegetation type

Used MAIAC reflectances from Aqua

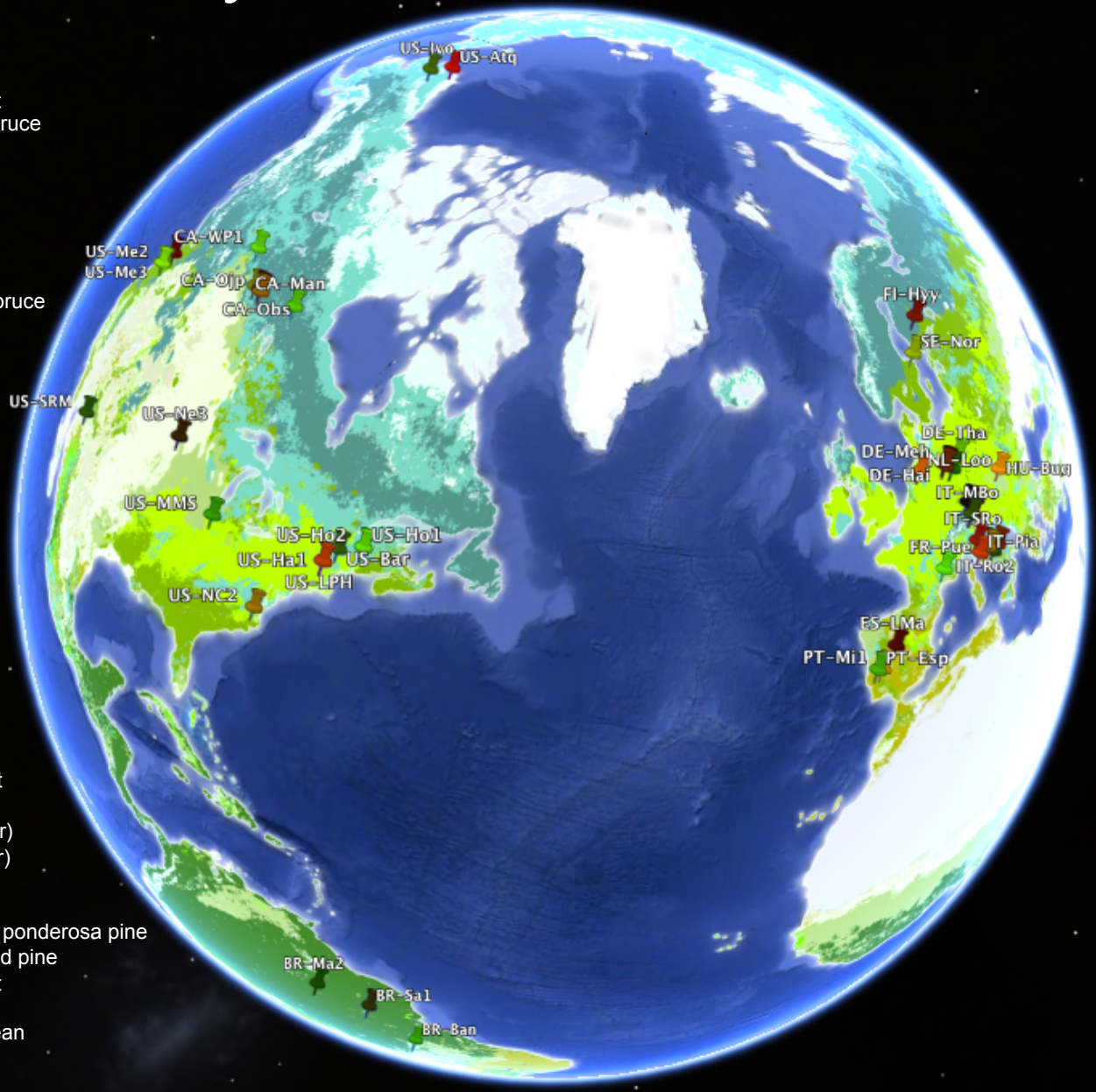
- –Clear observations during growing season
- –MODIS bands 1-12 (Land and Ocean bands)
- –VZA<45°
- –Filtered spikes and removed noisy winter data
- –At least two years of data for each site

Matched MODIS data with daily daily gross ecosystem productivity (GEP) from LaThuile fluxnet synthesis data

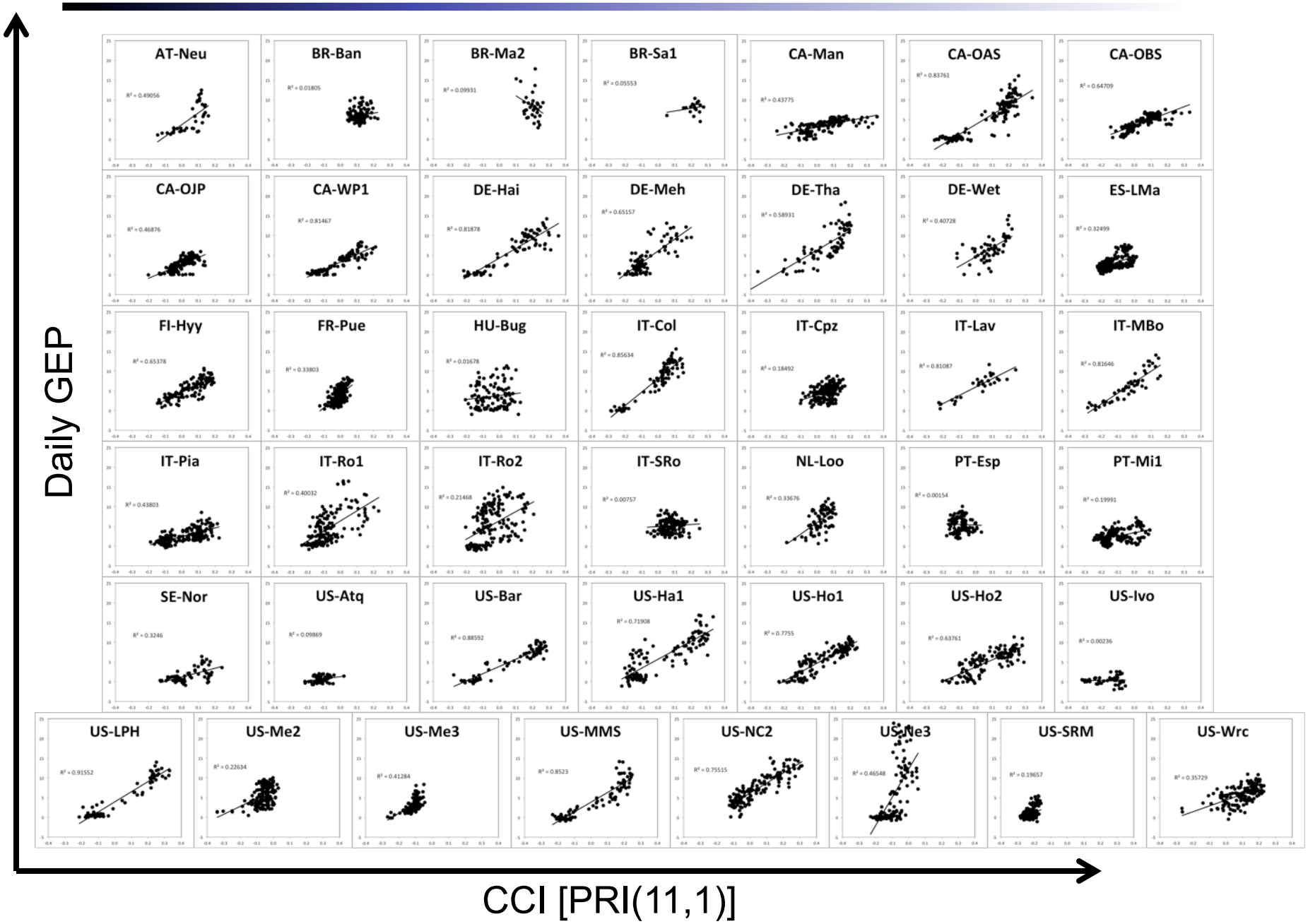
- –~4500 points total

Study Sites

Site	Site name
AT-Neu	Austria - Neustift/Stubai Valley
BR-Ban	Brazil - Ecotone Bananal Island
BR-Ma2	Brazil - Manaus - ZF2 K34
BR-Sa1	Brazil - Santarem-Km67-Primary Forest
CA-Man	Canada - BOREAS NSA - Old Black Spruce
CA-Oas	Canada - Sask.- SSA Old Aspen
CA-Obs	Canada - Sask.- SSA Old Black Spruce
CA-Ojp	Canada - Sask.- SSA Old Jack Pine
CA-WP1	Canada - Western Peatland- LaBiche
DE-Hai	Germany - Hainich
DE-Meh	Germany - Mehrstedt 1
DE-Tha	Germany - Anchor Station Tharandt - spruce
DE-Wet	Germany - Wetzstein
ES-LMa	Spain - Las Majadas del Tietar
FI-Hyy	Finland - Hyytiala
FR-Pue	France - Puechabon
HU-Bug	Hungary - Bugacpuszta
IT-Col	Italy - Collelongo- Selva Piana
IT-Cpz	Italy - Castelporziano
IT-Lav	Italy - Lavarone (after 3/2002)
IT-MBo	Italy - Monte Bondone
IT-Pia	Italy - Island of Pianosa
IT-Ro1	Italy - Roccarespampani 1
IT-Ro2	Italy - Roccarespampani 2
IT-SRo	Italy - San Rossore
NL-Loo	Netherlands - Loobos
PT-Esp	Portugal - Espirra
PT-Mi1	Portugal - Mitra (Evora)
SE-Nor	Sweden - Norunda
US-Atq	USA - AK - Atqasuk
US-Bar	USA - NH - Bartlett Experimental Forest
US-Ha1	USA - MA - Harvard Forest EMS Tower
US-Ho1	USA - ME - Howland Forest (main tower)
US-Ho2	USA - ME - Howland Forest (west tower)
US-Ivo	USA - AK - Ivotuk
US-LPH	USA - MA - Little Prospect Hill
US-Me2	USA - OR - Metolius-intermediate aged ponderosa pine
US-Me3	USA - OR - Metolius-second young aged pine
US-MMS	USA - IN - Morgan Monroe State Forest
US-NC2	USA - NC - NC_Loblolly Plantation
US-Ne3	USA - NE - Mead - rainfed maize-soybean
US-SRM	USA - AZ - Santa Rita Mesquite
US-Wrc	USA - WA - Wind River Crane Site



CCI vs. GEP – All Sites



Analysis Plan

Evaluate

- What is the best reference band for MODIS PRI?
- How do other vegetation indices perform?
- How does view angle affect relationships?
- How do relationships differ for different vegetation types?
- What is the expected accuracy in retrievals?

Previous studies have looked at these questions but only for a few sites

- Collection 6 processing made it possible to examine lots of sites

Evaluation of MODIS PRI Reference Bands

	Ref Bands		12	10	1	3	4
	Site	IGBP class	PRI (11,12)	PRI (11,10)	PRI (11,1)	PRI (11,3)	PRI (11,4)
Deciduous Broadleaf Forest	CA-Oas	DBF	0.03	0.58	0.84	0.49	0.21
	DE-Hai	DBF	0.16	0.20	0.82	0.61	0.01
	IT-Col	DBF	0.06	0.11	0.86	0.43	0.07
	IT-Ro1	DBF	0.05	0.26	0.40	0.39	0.00
	IT-Ro2	DBF	0.00	0.17	0.21	0.33	0.03
	US-Bar	DBF	0.10	0.56	0.89	0.70	0.00
	US-Ha1	DBF	0.03	0.43	0.72	0.55	0.00
	US-LPH	DBF	0.18	0.63	0.92	0.74	0.01
	US-MMS	DBF	0.20	0.55	0.85	0.76	0.08
Evergreen Broadleaf Forest	BR-Ban	EBF	0.01	0.00	0.02	0.00	0.03
	BR-Ma2	EBF	0.01	0.00	0.10	0.00	0.01
	BR-Sa1	EBF	0.00	0.08	0.06	0.19	0.12
	FR-Pue	EBF	0.18	0.00	0.34	0.26	0.20
	IT-Cpz	EBF	0.06	0.02	0.18	0.18	0.09
	PT-Esp	EBF	0.05	0.05	0.00	0.00	0.08
	PT-Mi1	EBF	0.10	0.17	0.20	0.23	0.04
Evergreen Needleleaf Forest	CA-Man	ENF	0.07	0.27	0.44	0.05	0.47
	CA-Obs	ENF	0.00	0.21	0.65	0.02	0.38
	CA-Ojp	ENF	0.11	0.17	0.47	0.00	0.44
	DE-Tha	ENF	0.27	0.05	0.59	0.35	0.25
	DE-Wet	ENF	0.32	0.17	0.41	0.16	0.37
	FI-Hyy	ENF	0.19	0.03	0.65	0.09	0.21
	IT-Lav	ENF	0.45	0.22	0.81	0.80	0.53
	IT-SRo	ENF	0.35	0.13	0.01	0.00	0.34
	NL-Loo	ENF	0.41	0.30	0.34	0.02	0.42
	SE-Nor	ENF	0.00	0.16	0.32	0.04	0.00
	US-Ho1	ENF	0.42	0.15	0.78	0.47	0.53
	US-Ho2	ENF	0.54	0.01	0.64	0.20	0.59
	US-Me2	ENF	0.31	0.19	0.23	0.02	0.34
	US-Me3	ENF	0.41	0.31	0.41	0.05	0.44
	US-NC2	ENF	0.00	0.58	0.76	0.73	0.09
	US-Wrc	ENF	0.21	0.00	0.36	0.07	0.26
Grassland	AT-Neu	GRA	0.16	0.00	0.49	0.31	0.41
	DE-Meh	GRA	0.05	0.35	0.65	0.57	0.01
	HU-Bug	GRA	0.16	0.15	0.02	0.01	0.21
	IT-MBo	GRA	0.00	0.16	0.82	0.54	0.12
Shrub/ Savanna	IT-Pia	OSH	0.25	0.29	0.44	0.39	0.17
	ES-LMa	SAV	0.01	0.19	0.32	0.25	0.01
	US-SRM	WSA	0.01	0.15	0.20	0.05	0.00
	US-Ne3	CRO	0.10	0.43	0.47	0.49	0.15
Wetlands	US-Atq	WET	0.08	0.10	0.10	0.12	0.05
	US-Ivo	WET	0.12	0.01	0.00	0.00	0.01
	CA-WP1	WET (MF)	0.05	0.68	0.81	0.54	0.34

Table shows R^2 with Daily GEP
Color coded as:

$R^2 \geq 0.5$ - Yellow

$R^2 \geq 0.7$ - Red

$$PRI(11, ref) = \frac{(R_{11} - R_{ref})}{(R_{11} + R_{ref})}$$

PRI(11,1) = Chlorophyll-Carotenoid Index (CCI)

Evaluation of Other MODIS Vegetation Indices

	Site	IGBP class	NDVI	EVI	Chl	NDWI	NDII	PRI (11,1)
Deciduous Broadleaf Forest	CA-Oas	DBF	0.78	0.80	0.75	0.42	0.57	0.84
	DE-Hai	DBF	0.83	0.88	0.73	0.78	0.11	0.82
	IT-Col	DBF	0.79	0.84	0.54	0.63	0.03	0.86
	IT-Ro1	DBF	0.58	0.72	0.60	0.61	0.01	0.40
	IT-Ro2	DBF	0.46	0.60	0.60	0.45	0.01	0.21
	US-Bar	DBF	0.84	0.89	0.45	0.82	0.53	0.89
	US-Ha1	DBF	0.58	0.68	0.46	0.69	0.56	0.72
	US-LPH	DBF	0.83	0.91	0.67	0.85	0.79	0.92
	US-MMS	DBF	0.78	0.87	0.74	0.85	0.77	0.85
Evergreen Broadleaf Forest	BR-Ban	EBF	0.00	0.05	0.00	0.00	0.00	0.02
	BR-Ma2	EBF	0.01	0.01	0.00	0.00	0.01	0.10
	BR-Sa1	EBF	0.01	0.20	0.03	0.15	0.04	0.06
	FR-Pue	EBF	0.00	0.32	0.04	0.01	0.00	0.34
	IT-Cpz	EBF	0.02	0.22	0.01	0.20	0.00	0.18
	PT-Esp	EBF	0.03	0.00	0.04	0.06	0.01	0.00
	PT-Mi1	EBF	0.24	0.33	0.27	0.31	0.03	0.20
Evergreen Needleleaf Forest	CA-Man	ENF	0.11	0.54	0.01	0.00	0.00	0.44
	CA-Obs	ENF	0.26	0.46	0.00	0.12	0.21	0.65
	CA-Ojp	ENF	0.08	0.06	0.23	0.14	0.00	0.47
	DE-Tha	ENF	0.48	0.58	0.15	0.19	0.01	0.59
	DE-Wet	ENF	0.07	0.36	0.00	0.20	0.00	0.41
	FI-Hyy	ENF	0.46	0.47	0.24	0.09	0.00	0.65
	IT-Lav	ENF	0.65	0.62	0.17	0.08	0.02	0.81
	IT-SRo	ENF	0.08	0.03	0.05	0.20	0.00	0.01
	NL-Loo	ENF	0.03	0.43	0.00	0.09	0.00	0.34
	SE-Nor	ENF	0.45	0.17	0.51	0.24	0.13	0.32
	US-Ho1	ENF	0.46	0.63	0.06	0.02	0.04	0.78
	US-Ho2	ENF	0.18	0.44	0.02	0.00	0.03	0.64
	US-Me2	ENF	0.38	0.01	0.38	0.34	0.09	0.23
	US-Me3	ENF	0.28	0.01	0.37	0.31	0.26	0.41
	US-NC2	ENF	0.64	0.76	0.48	0.72	0.65	0.76
	US-Wrc	ENF	0.06	0.15	0.05	0.10	0.06	0.36
Grassland	AT-Neu	GRA	0.41	0.41	0.24	0.52	0.00	0.49
	DE-Meh	GRA	0.71	0.74	0.69	0.73	0.06	0.65
	HU-Bug	GRA	0.09	0.03	0.14	0.05	0.04	0.02
	IT-MBo	GRA	0.76	0.79	0.52	0.72	0.05	0.82
Shrub/ Savanna	IT-Pia	OSH	0.45	0.44	0.38	0.44	0.02	0.44
	ES-LMa	SAV	0.32	0.46	0.30	0.32	0.03	0.32
	US-SRM	WSA	0.61	0.72	0.41	0.45	0.19	0.20
	US-Ne3	CRO	0.64	0.66	0.62	0.63	0.56	0.47
Wetlands	US-Atq	WET	0.24	0.10	0.17	0.04	0.07	0.10
	US-Ivo	WET	0.03	0.03	0.06	0.10	0.03	0.00
	CA-WP1	WET (MF)	0.47	0.78	0.01	0.28	0.18	0.81

Table shows R^2 with Daily GEP

Color coded as:

$R^2 \geq 0.5$ - Yellow

$R^2 \geq 0.7$ - Red

$$NDVI = \frac{(R_2 - R_1)}{(R_2 + R_1)}$$

$$EVI = \frac{2.5 * (R_2 - R_1)}{(R_2 + 6 * R_1 + 7.5 * R_3 + 1)}$$

$$Chl = \left[\frac{1}{R_1} - \frac{1}{R_2}\right] * R_2$$

$$NDWI = \frac{(R_2 - R_5)}{(R_2 + R_5)}$$

$$NDII = \frac{(R_2 - R_6)}{(R_2 + R_6)}$$

$$PRI(11,1) = \frac{(R_{11} - R_1)}{(R_{11} + R_1)}$$

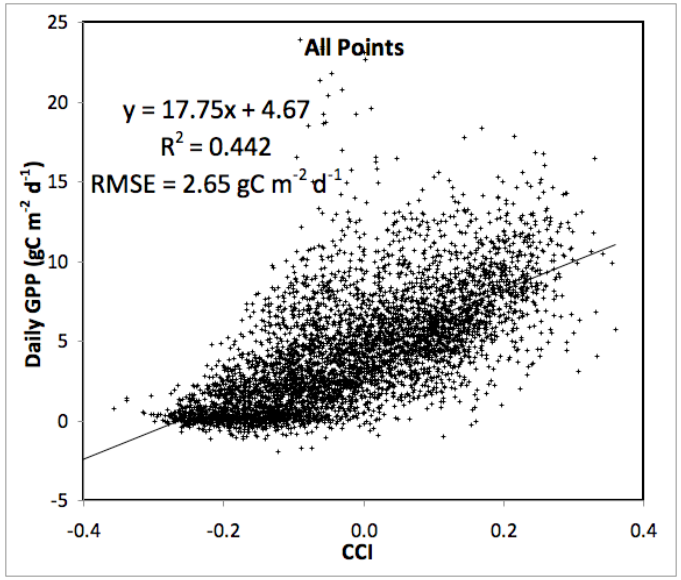
View Angle Effect on CCI

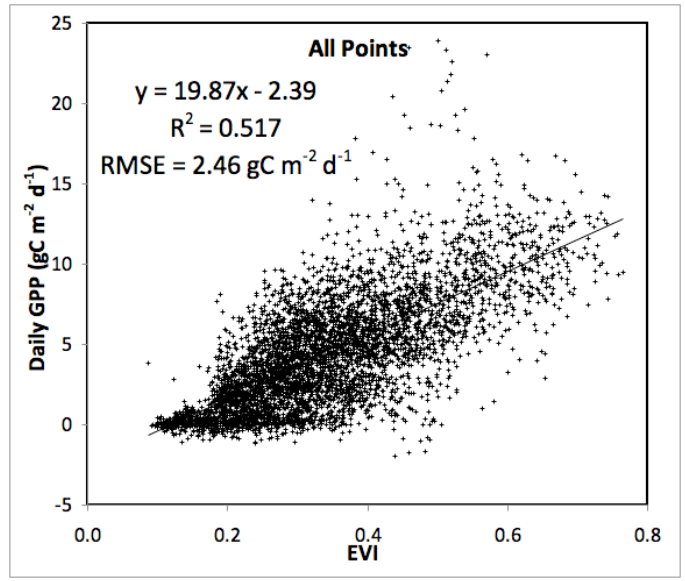
	Site ID	IGBP class	All Pts. R2 CCI	Forward R2 CCI (F)	Back R2 CCI (B)	Nadir R2 CCI (N)
Deciduous Broadleaf Forest	CA-Oas	DBF	0.84	0.87	0.85	0.79
	DE-Hai	DBF	0.82	0.78	0.80	0.89
	IT-Col	DBF	0.86	0.82	0.89	0.90
	IT-Ro1	DBF	0.40	0.29	0.38	0.55
	IT-Ro2	DBF	0.21	0.13	0.21	0.38
	US-Bar	DBF	0.89	0.93	0.90	0.85
	US-Ha1	DBF	0.72	0.71	0.75	0.74
	US-LPH	DBF	0.92	0.91	0.94	0.91
	US-MMS	DBF	0.85	0.82	0.84	0.94
Evergreen Broadleaf Forest	BR-Ban	EBF	0.02	0.03	0.01	0.02
	BR-Ma2	EBF	0.10	0.26	0.03	0.03
	BR-Sa1	EBF	0.06	0.03	0.00	0.22
	FR-Pue	EBF	0.34	0.51	0.26	0.40
	IT-Cpz	EBF	0.18	0.21	0.24	0.26
	PT-Esp	EBF	0.00	0.01	0.09	0.00
	PT-Mi1	EBF	0.20	0.26	0.14	0.21
Evergreen Needleleaf Forest	CA-Man	ENF	0.44	0.47	0.53	0.24
	CA-Obs	ENF	0.65	0.65	0.64	0.70
	CA-Ojp	ENF	0.47	0.53	0.48	0.36
	DE-Tha	ENF	0.59	0.62	0.69	0.67
	DE-Wet	ENF	0.41	0.55	0.52	0.78
	FI-Hyy	ENF	0.65	0.80	0.73	0.61
	IT-Lav	ENF	0.81	0.88	0.89	0.76
	IT-SRo	ENF	0.01	0.10	0.02	0.01
	NL-Loo	ENF	0.34	0.57	0.12	0.44
	SE-Nor	ENF	0.32	0.54	0.33	0.07
	US-Ho1	ENF	0.78	0.83	0.82	0.76
	US-Ho2	ENF	0.64	0.71	0.75	0.57
	US-Me2	ENF	0.23	0.34	0.27	0.34
	US-Me3	ENF	0.41	0.56	0.46	0.52
	US-NC2	ENF	0.76	0.77	0.76	0.79
	US-Wrc	ENF	0.36	0.48	0.54	0.41
Grassland	AT-Neu	GRA	0.49	0.46	0.54	0.62
	DE-Meh	GRA	0.65	0.67	0.78	0.59
	HU-Bug	GRA	0.02	0.06	0.07	0.00
	IT-MBo	GRA	0.82	0.89	0.81	0.78
Shrub/ Savanna	IT-Pia	OSH	0.44	0.45	0.57	0.37
	ES-LMa	SAV	0.32	0.40	0.25	0.38
	US-SRM	WSA	0.20	0.29	0.26	0.14
	US-Ne3	CRO	0.47	0.48	0.47	0.49
Wetlands	CA-WP1	WET	0.81	0.82	0.89	0.76
	US-Atq	WET	0.10	0.33	0.06	0.17
	US-Ivo	WET	0.00	0.01	0.00	0.01

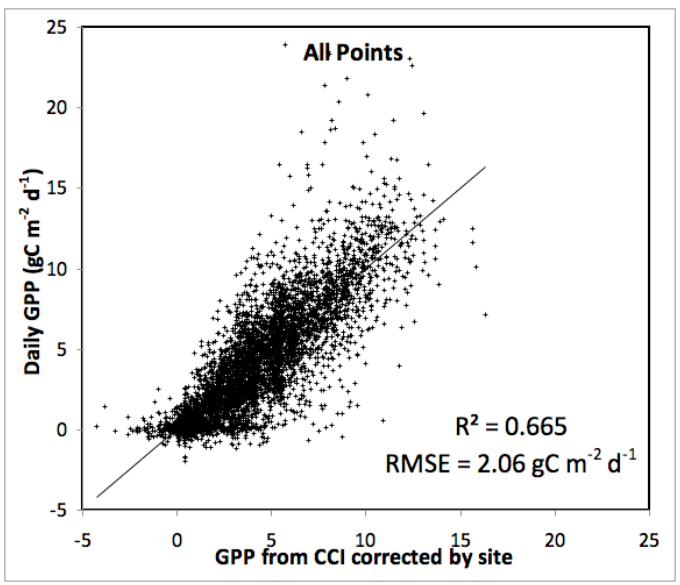
Table shows R^2 with Daily GEP
- Nadir - All VAZ when VZA<15°

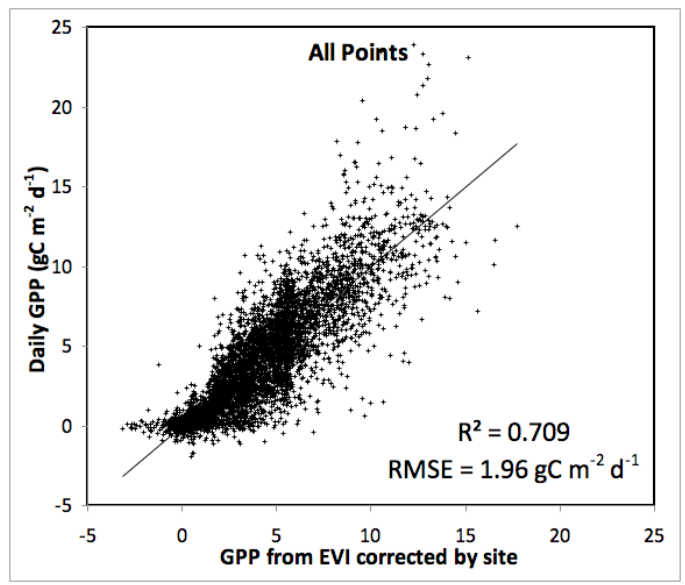
Highlighted cell has highest R^2
- Red means difference between max and min R^2 >0.15

CCI and EVI vs. Daily GEP for all sites combined



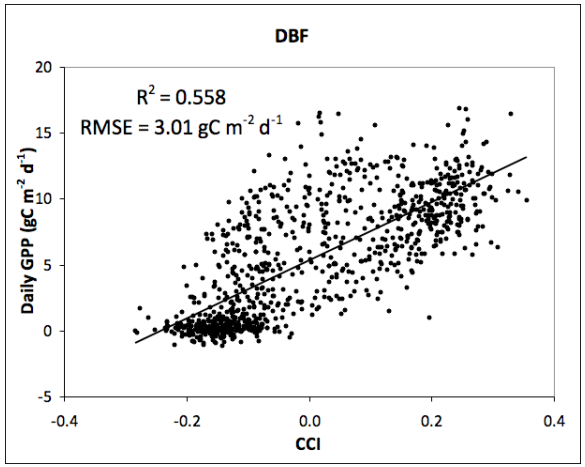




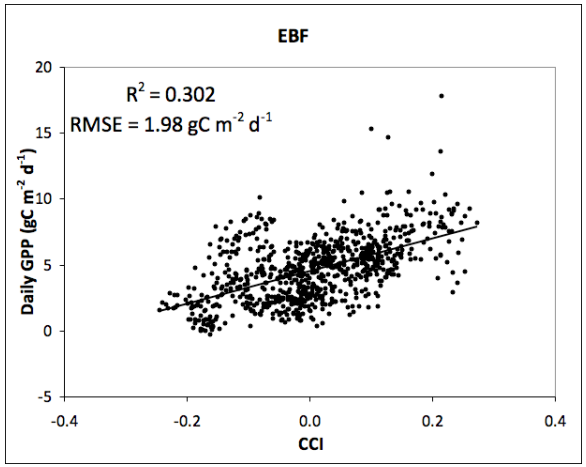


CCI vs. Daily GEP – Grouped by IGBP Class

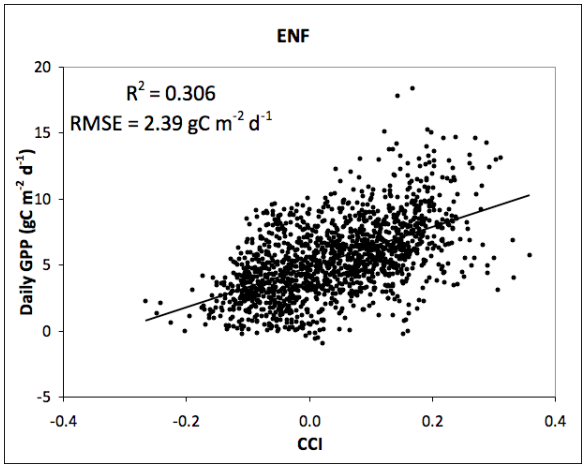
DBF



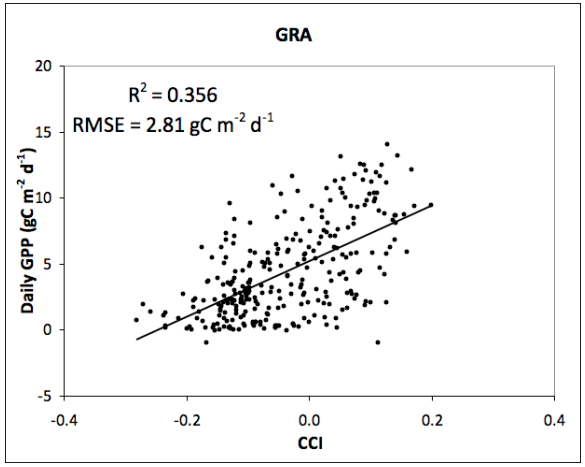
EBF



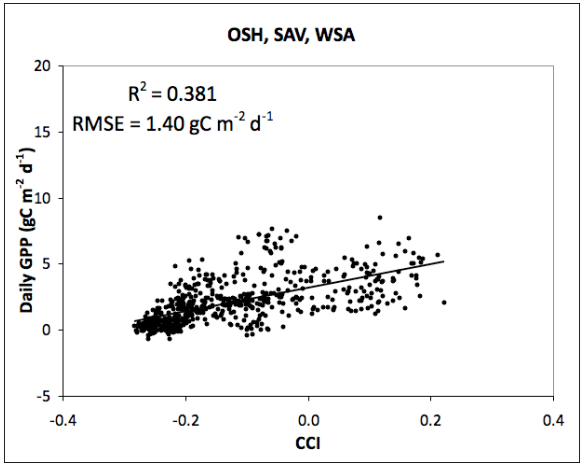
ENF



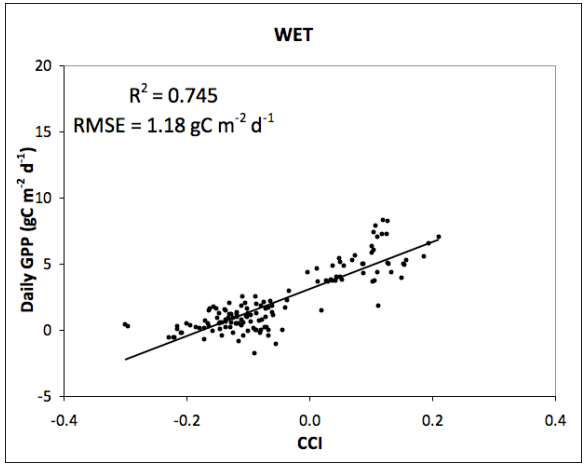
GRA



OSH, SAV, WSA

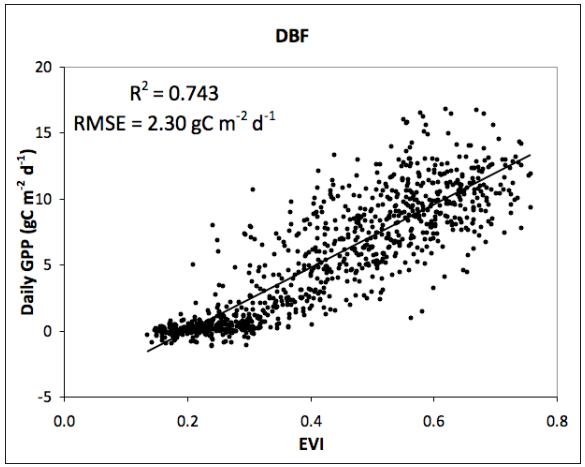


WET

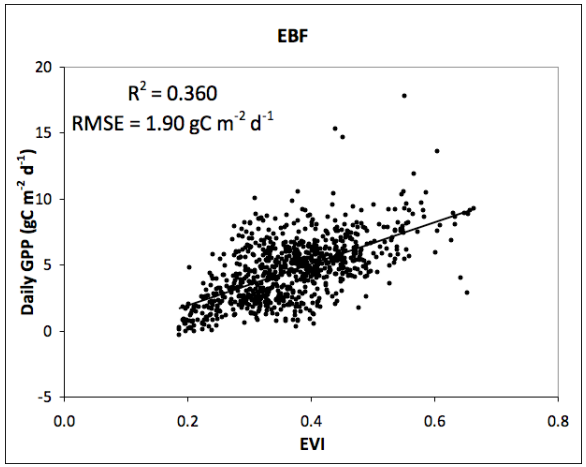


EVI vs. Daily GPP – Grouped by IGBP Class

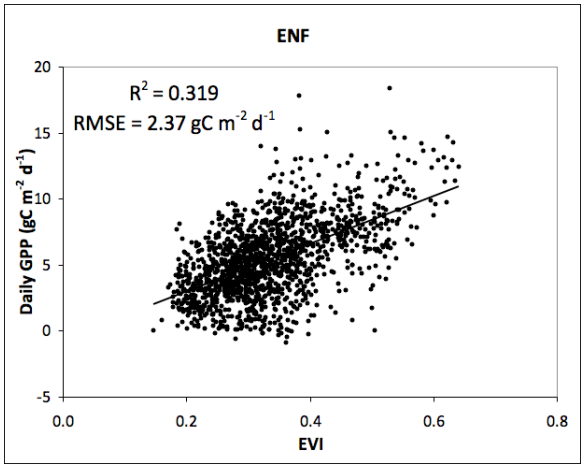
DBF



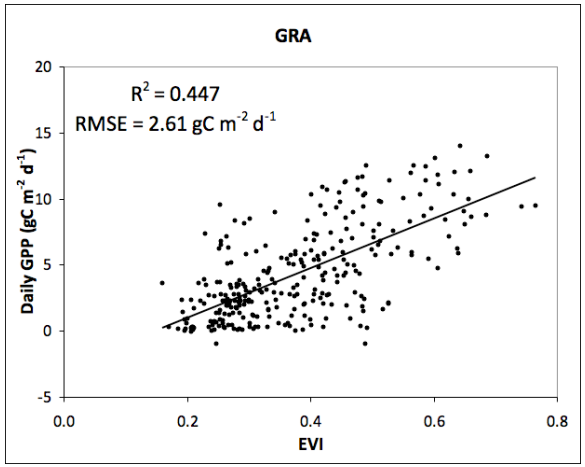
EBF



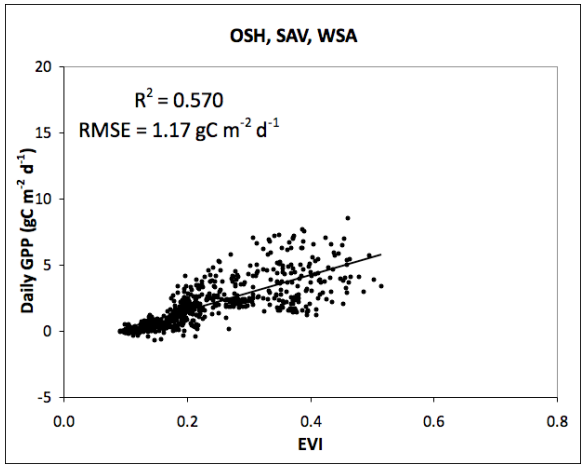
ENF



GRA



OSH, SAV, WSA



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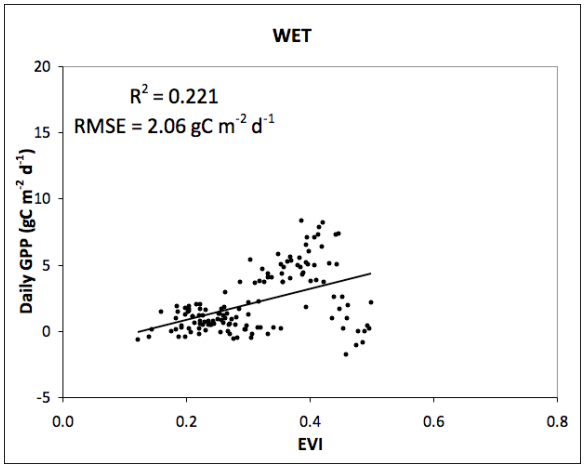
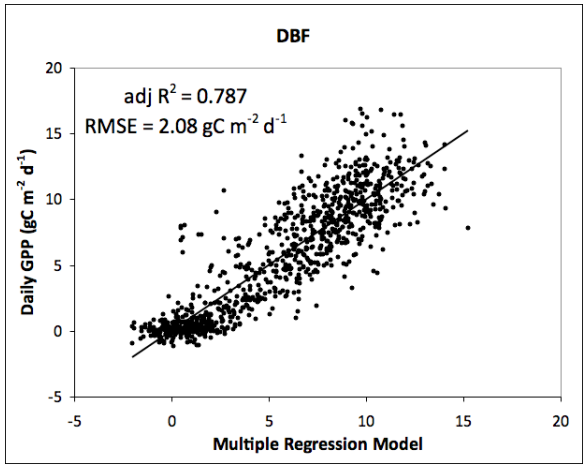


Multiple Regression of MODIS Bands on Daily GEP

DBF



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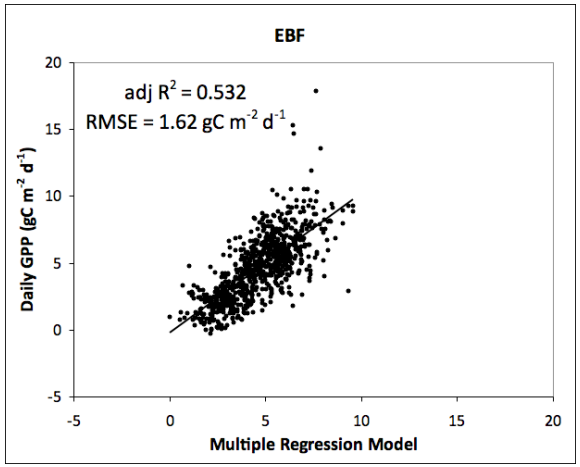

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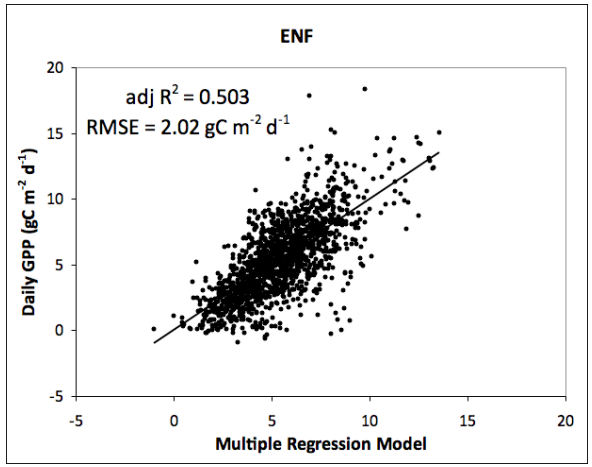

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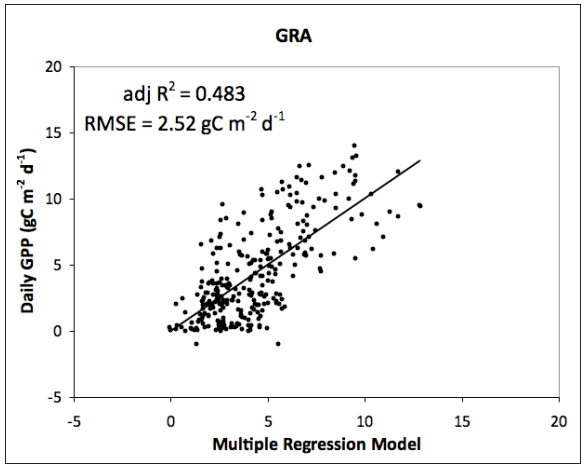

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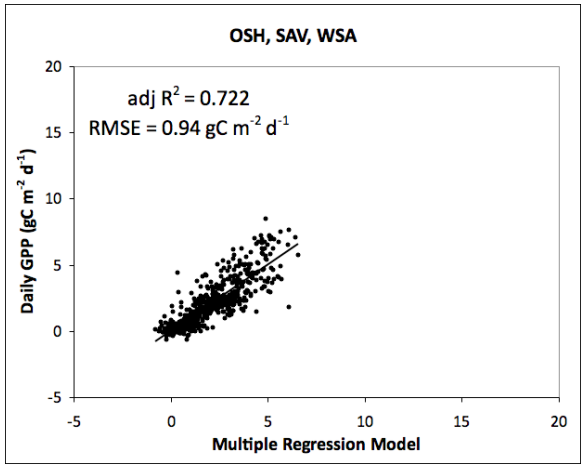

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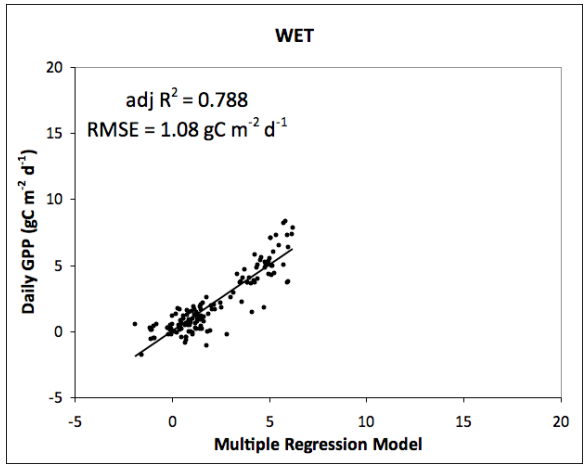
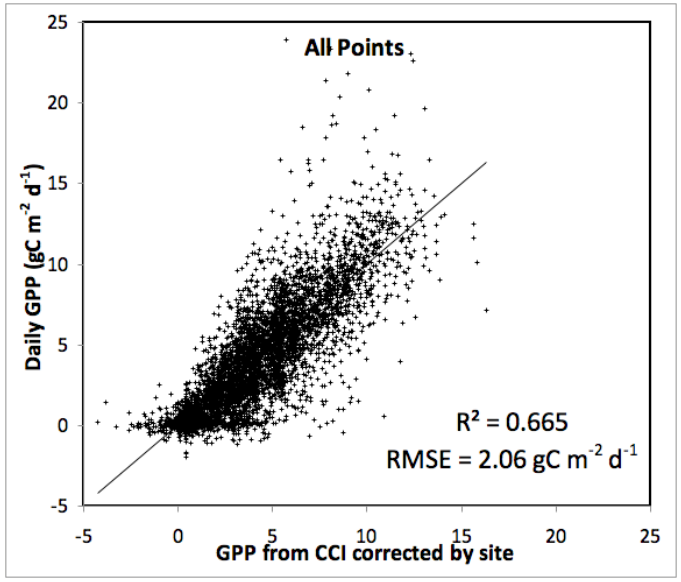
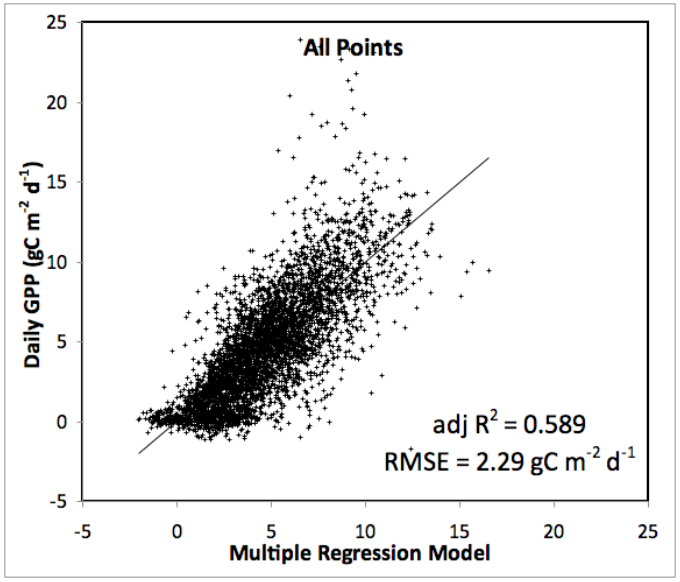


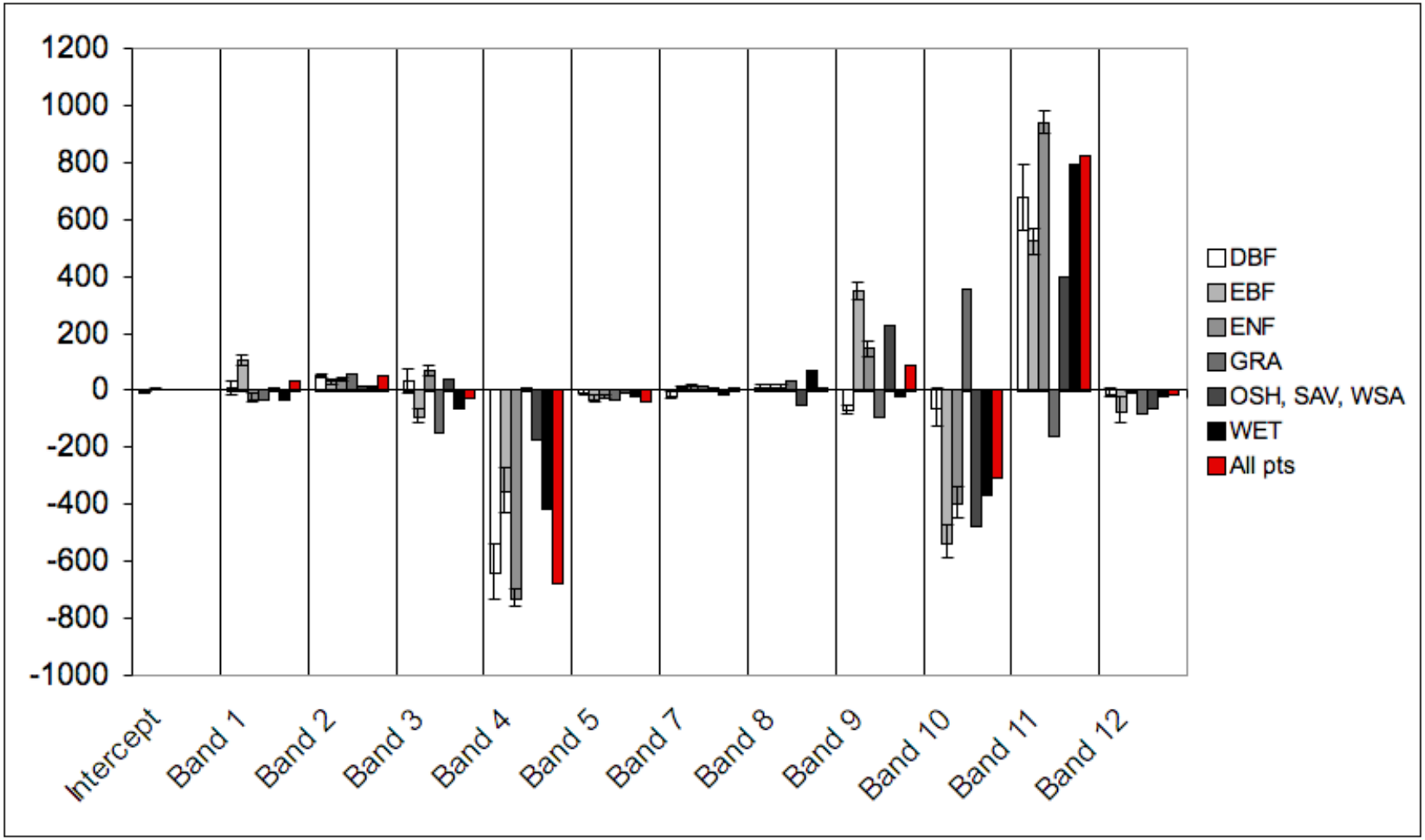
Used all bands except band 6

CCI and Multiple Regression vs. Daily GEP for all sites combined





Multiple Regression Coefficients



Conclusions

- Although not designed for this purpose, MODIS reflectances combining land and ocean bands can be used to derive GEP
  - Need more training data to develop robust algorithm
  - Often hard to find tower sites with uniform vegetation covering a large enough area, particularly for some vegetation types (e.g. crops)
- CCI and EVI appear to be the most promising vegetation indices
  - Multiple regressions using all bands works even better
- Effects of view angle can be significant, but presently cannot predict effect
  - variations may be more related to spatial distribution of vegetation
- RMSE of retrievals of daily GEP on the order of ~2 gC m^{-2} d^{-1}
- There are different relationships at different sites
  - Stratifying by vegetation type can help some

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