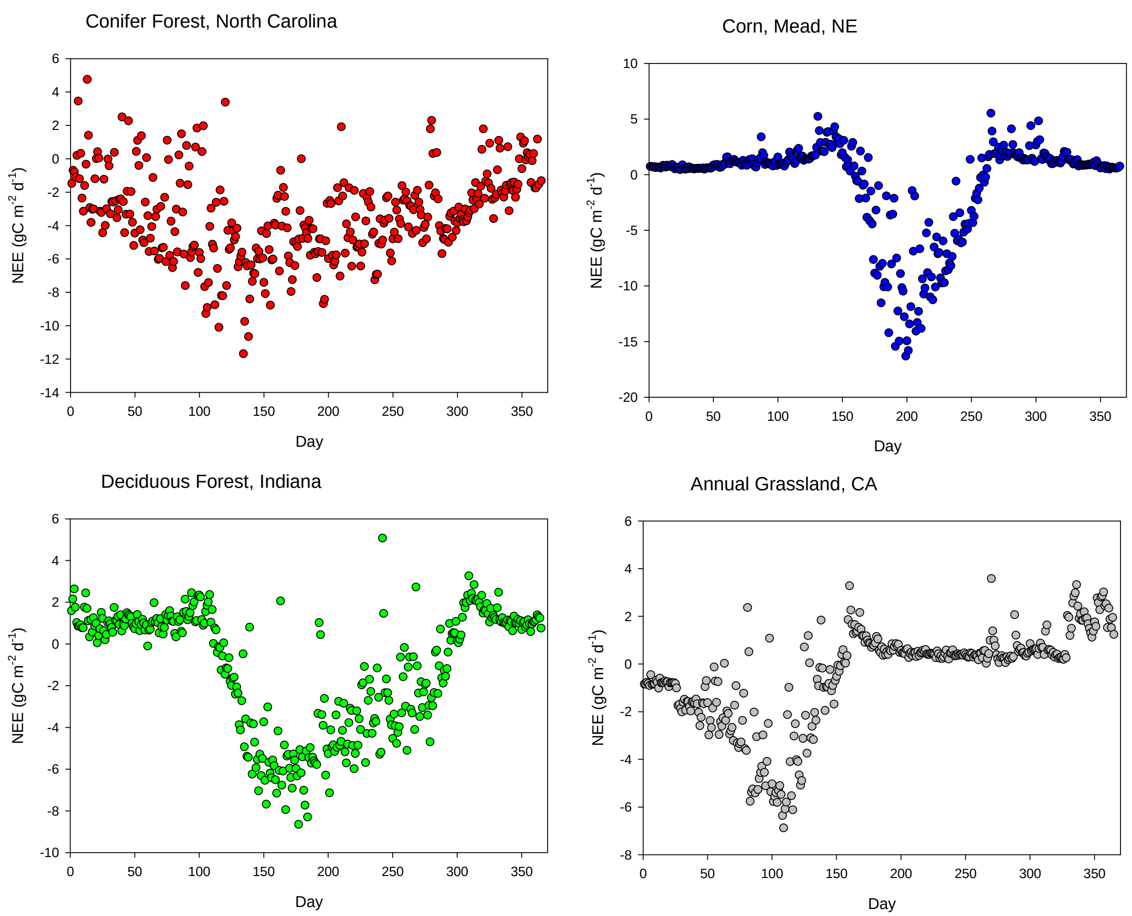
  

Shaking Hands between Eddy Fluxes and Remote Sensing

Dennis Baldocchi
University of California, Berkeley

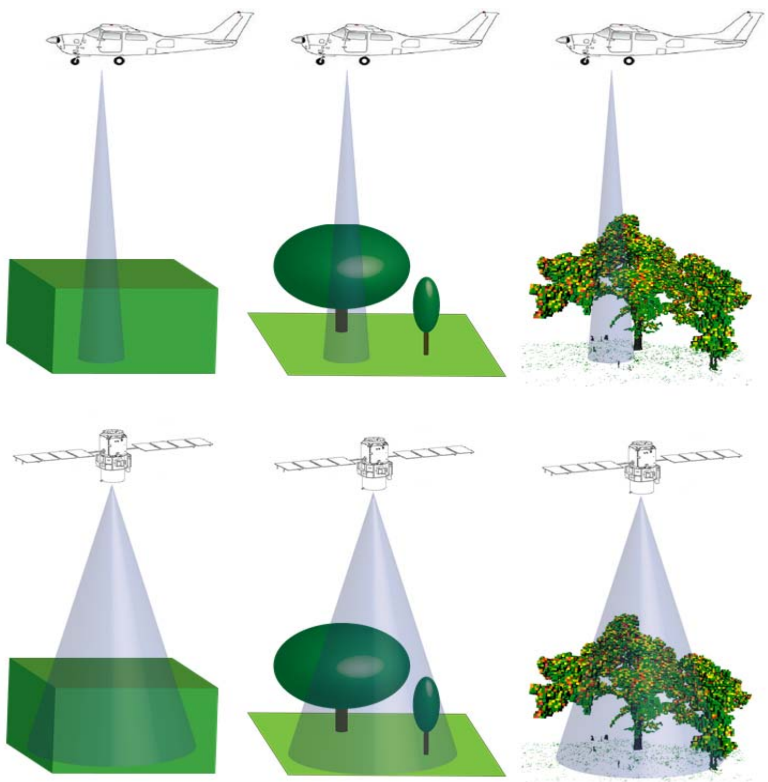
Eurospec Workshop,
Trento, Italy, Nov 7, 2013

To Understand the Temporal and Spatial Dynamics of Carbon Fluxes We must have Appropriate Site Meta Data



Contrasting Ecosystems Experience Different Seasonality in C fluxes

Remote Sensing is an Important Partner to Quantify Canopy Structure, Function and Phenology of Ecosystem Metabolism



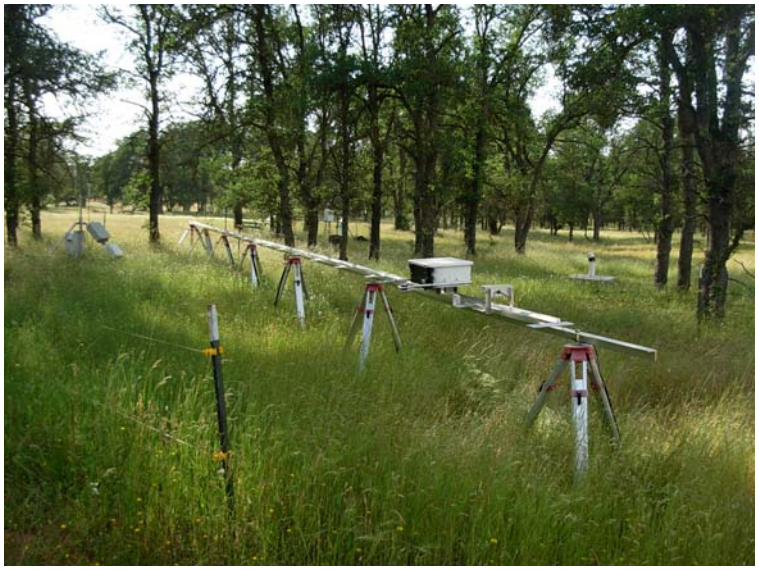
How we Interpret Reflected Light, from Space and Aircraft
To infer Canopy Structure Depends upon How we Abstract that Canopy

Topics

- Evaluating Site Meta Data
  - LAI and Phenology with Gap Fraction and Spectral Reflectance
  - Canopy Height with LIDAR and Turbulence
- Temporal/Spatial Upscaling and Modeling
  - Flux Correlations with Normalized Difference Spectral Indices, broad-band and narrow-band

In Heterogeneous Forests it is Necessary to deploy Sensors On a Roving Tram to Study Light transmission and Canopy Structure

Bill Reifsynder (1924-2006), Yale



Renaissance in Instrumentation to Monitor Surface Phenology with a Suite of Optical Sensors

LED NDVI Sensor

Flux Tower with Digital Camera

Hyper-spectral spectrometer

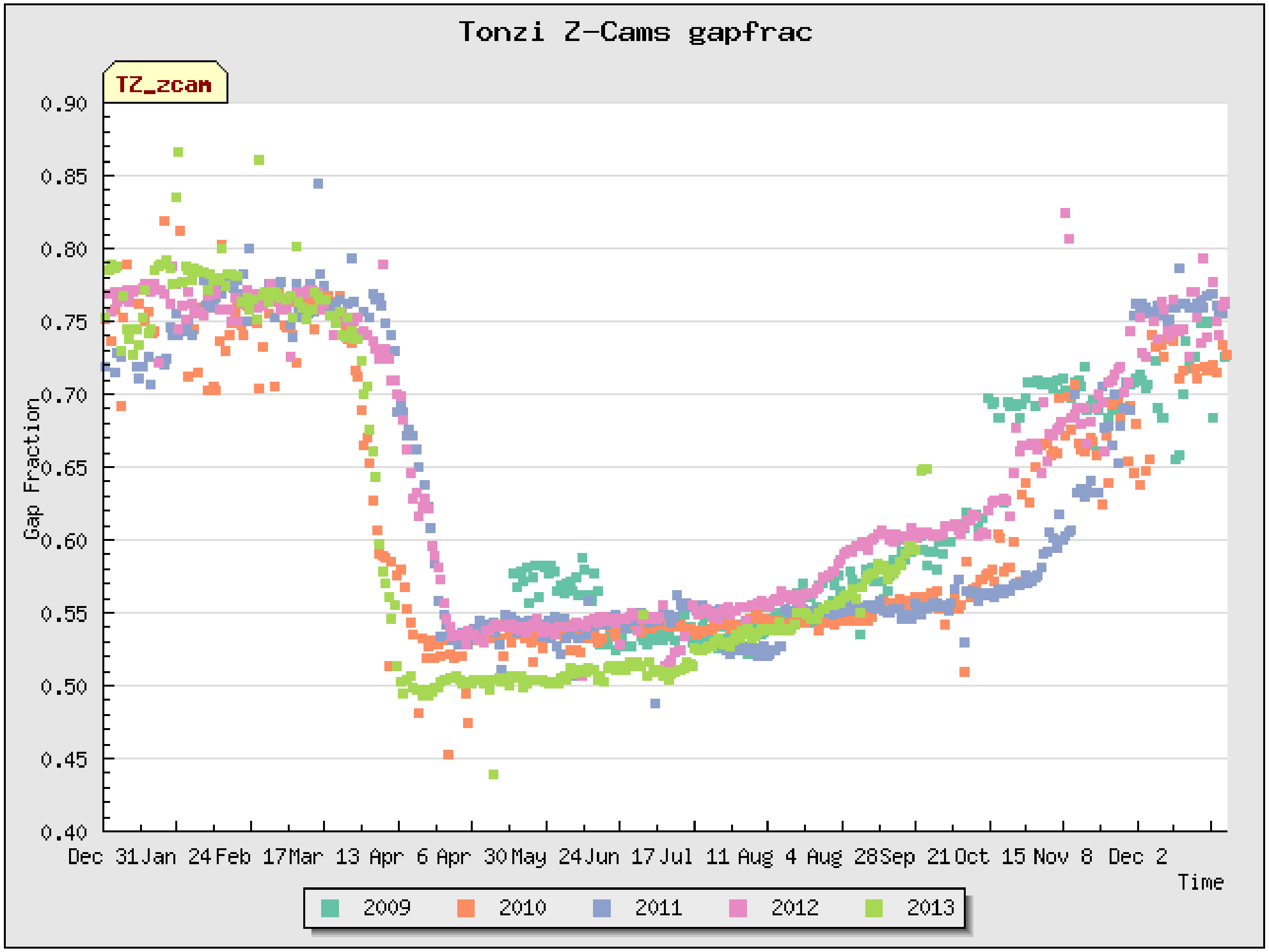
Upward Looking Camera

What New Optical Sensors can Do?

- Digital Cameras: P_0, Normalized Difference Vegetation Indices, e.g. greenness, phenology
- Radiation Trams: P_0, APAR
- LEDs: NDVI, phenology
- HyperSpectral Spectrometers: NDVIs
- Airborne LIDAR: canopy height, tree size and spacing, digital elevation maps, flux footprint
- Terrestrial LIDAR: 3D voxel geometry of trees

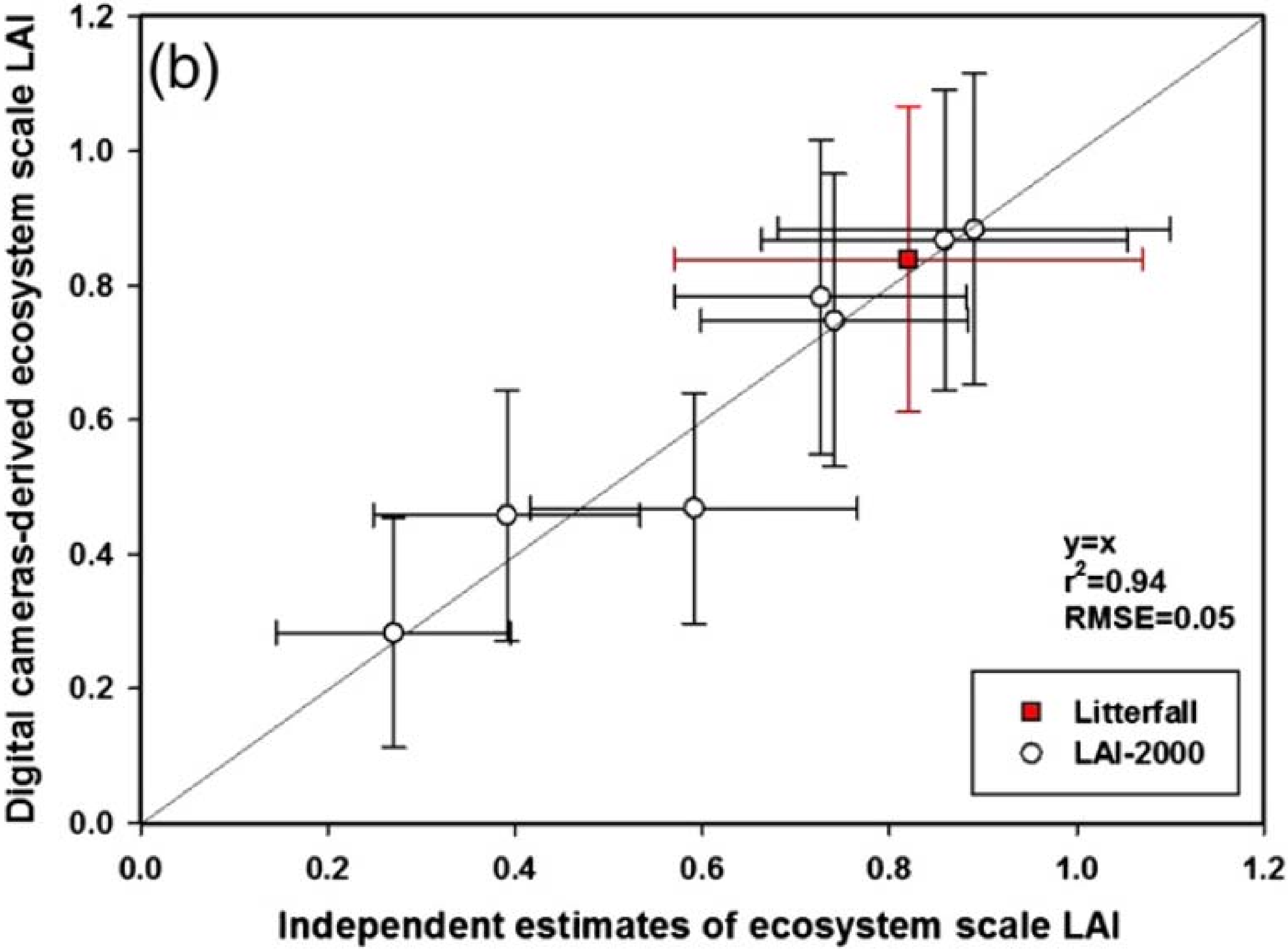
Monitor Seasonality of Gap Fraction of Forests with Upward Looking Camera

Gap Fraction Phenology with Upward Looking Cameras under Oak Savanna



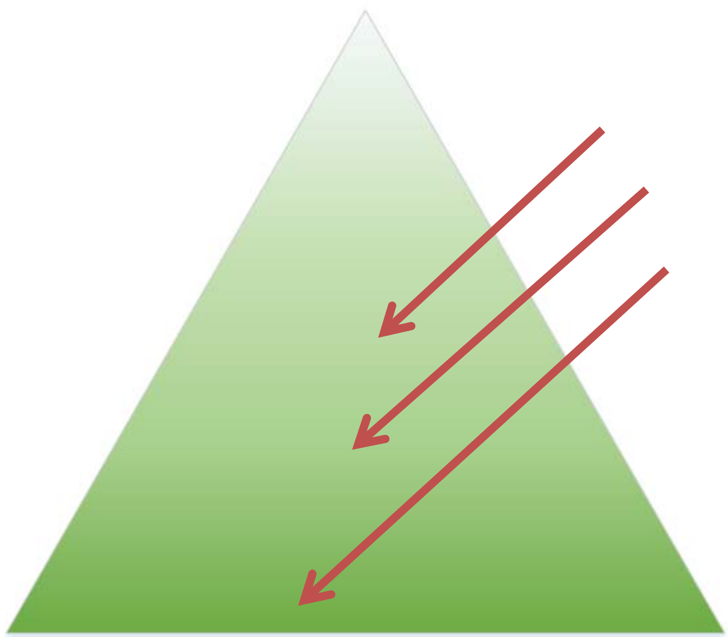
Can Detect Start and End of Growing Season with Precision

Upward Looking Cameras can Produce Accurate LAI estimates

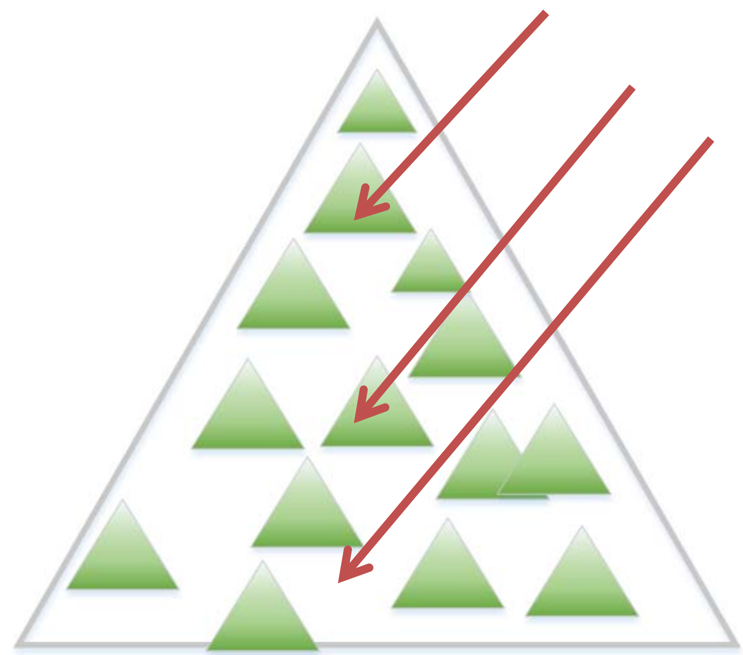


Ryu et al 2012 Remote Sensing Environment

Many Native Vegetation Stands are Clumped At Crown and Landscape Scales

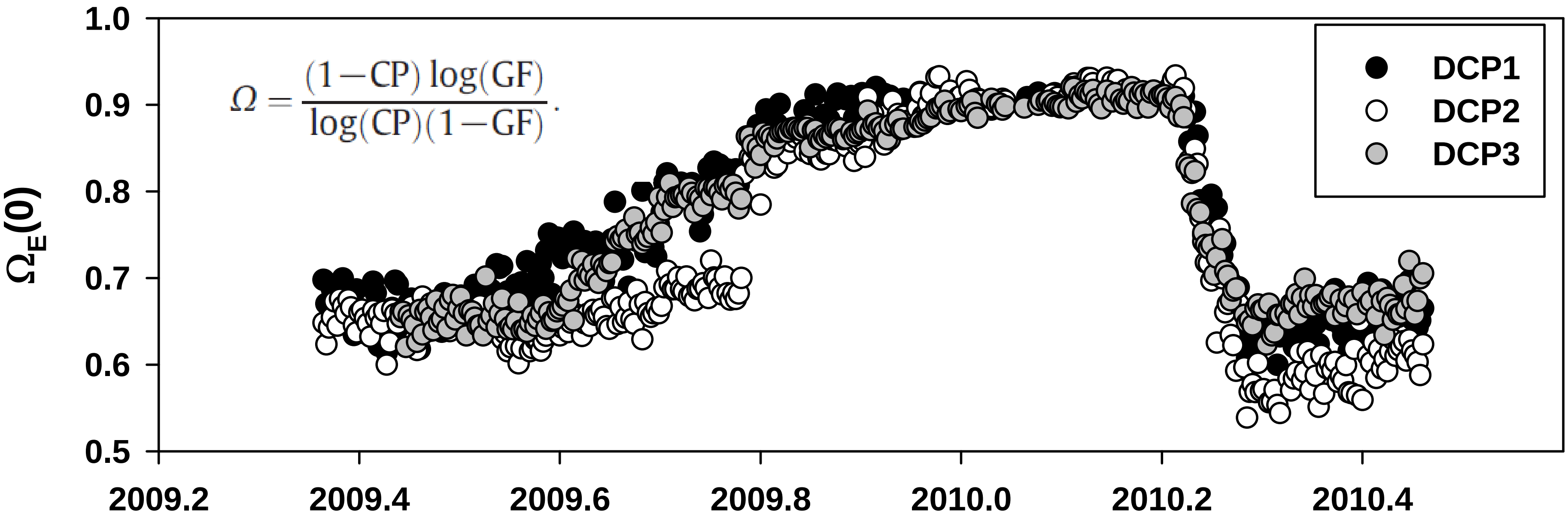


Canopy as a Turbid Medium
With Random Leaves



Canopy with Clumps of
Vegetation

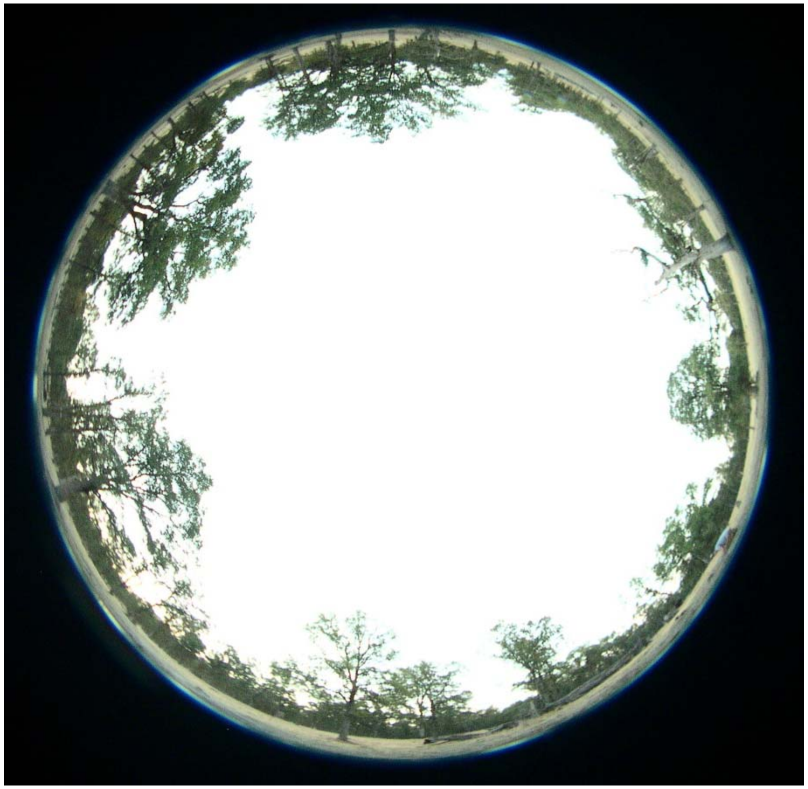
Seasonality of clumping index = f(Crown Porosity, Gap Fraction)



Ryu et al 2012 Remote Sensing Environment

Hemispherical Lens have Limitations in Open Savanna

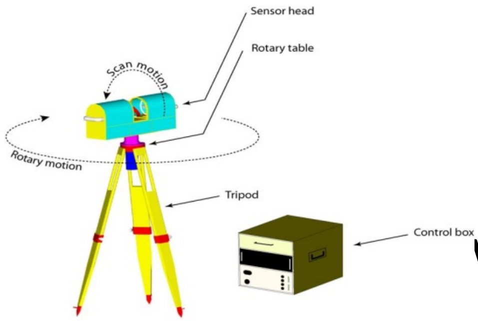
Hemispherical Camera



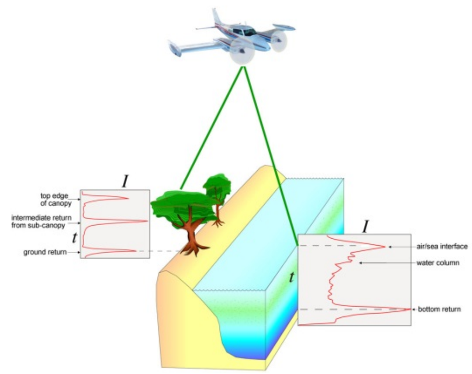
Upward Looking Camera

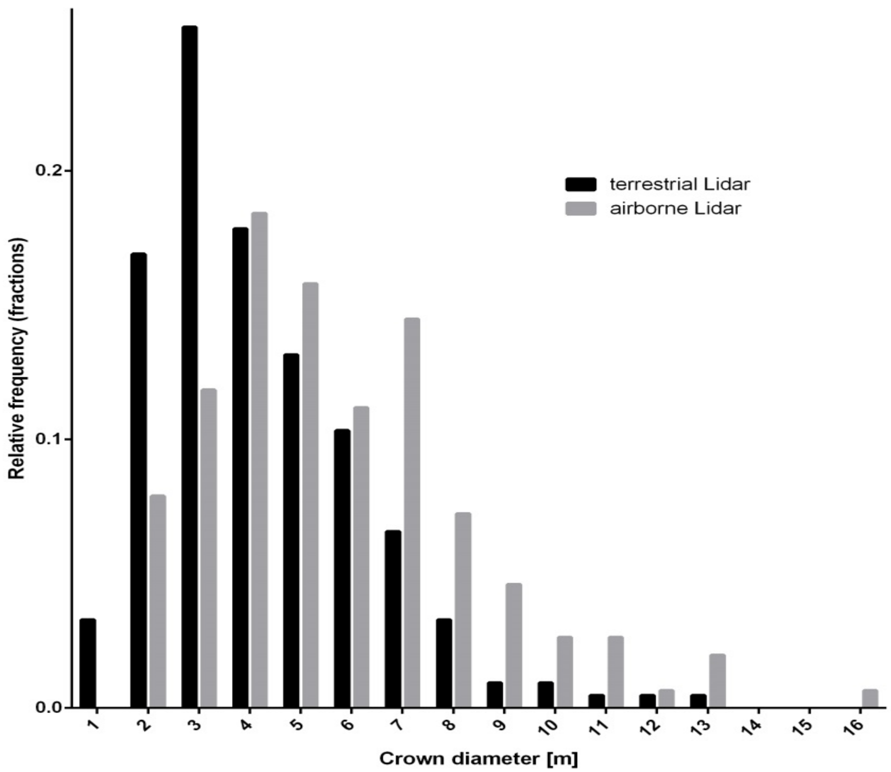
Terrestrial LIDAR Maps Canopy in High Fidelity To Better Evaluate Clumping and Upscaling of Leaves to Canopies

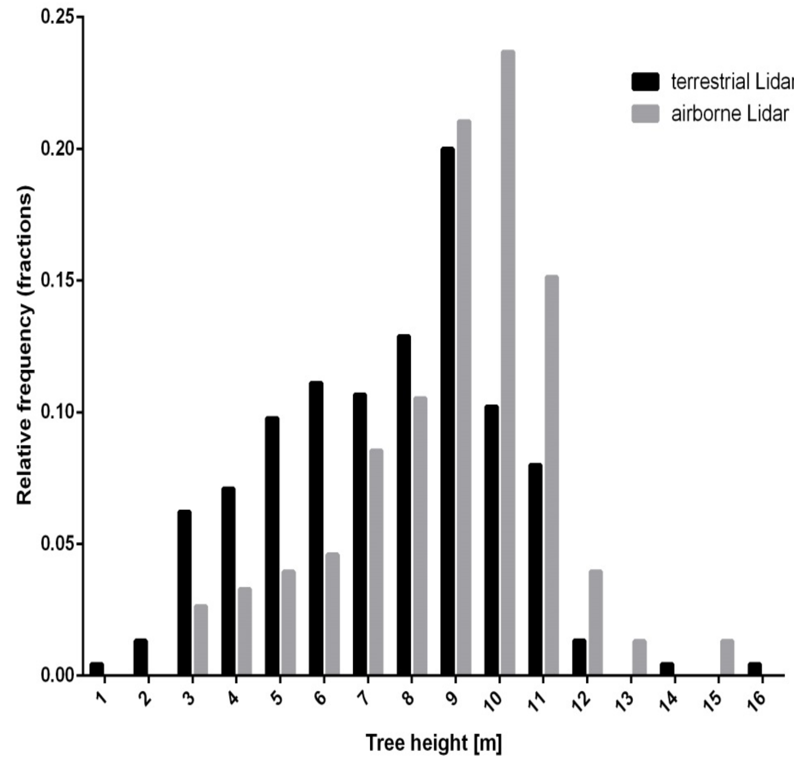
Slide of M. Beland



Type of LIDAR Matters: Comparison of Tree Characteristics with Terrestrial and Airborne LIDAR







Beland, Natake, Baldocchi, unpublished

Measuring Light Transmission and Clumping

Volume: 30 cm * 30cm * 30cm

Grid: 14 *14 (2cm each)

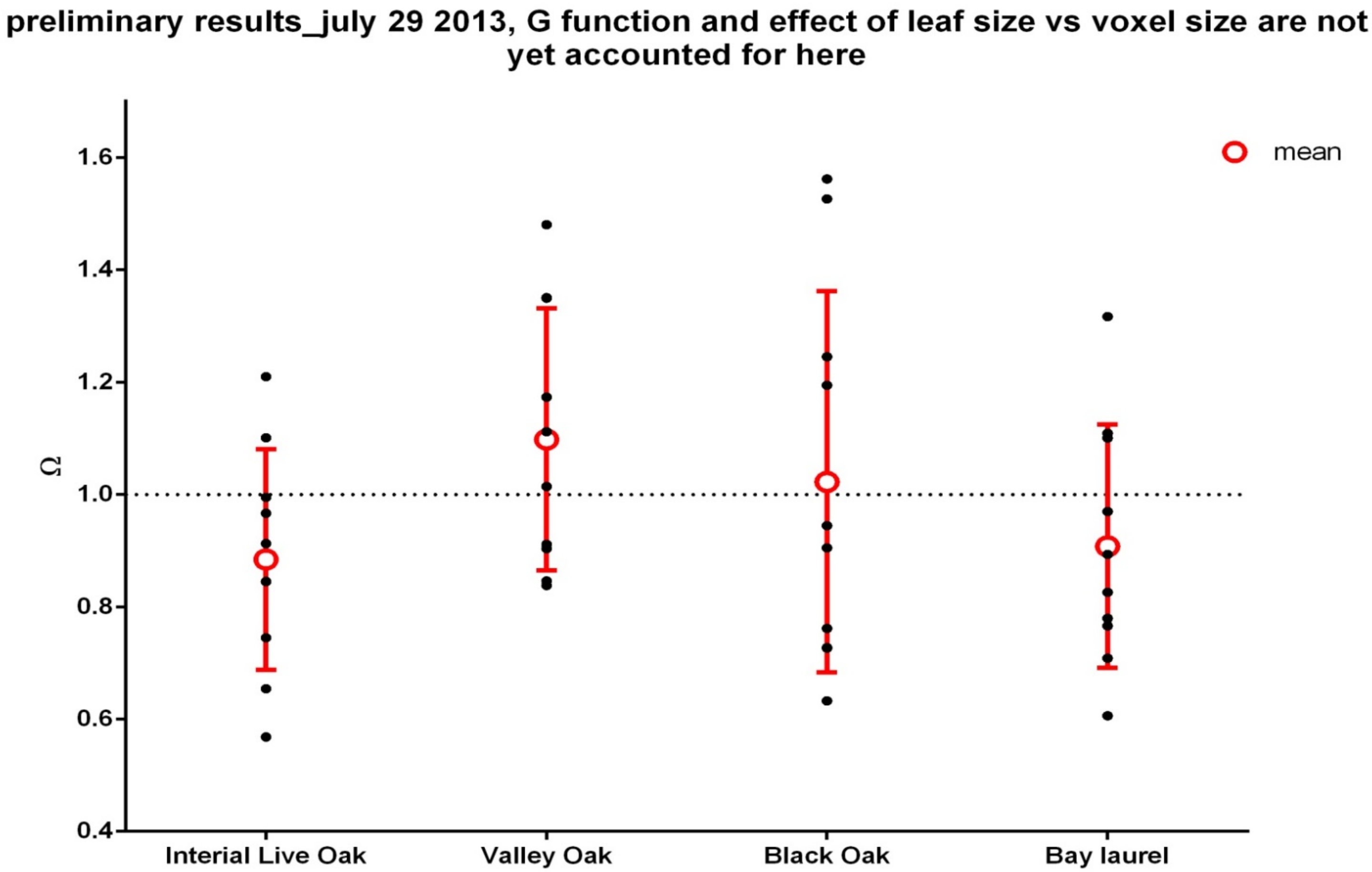
0	0	0	0	0	0	0	2	0	0	1	0	0	0
0	0	0	0	0	0	2	2	1	1	0	0	0	0
0	0	0	0	0	1	0	2	0	0	0	0	0	0
0	0	0	0	0	1	1	0	0	0	0	0	0	0
0	0	0	1	3	0	0	0	0	0	0	0	0	0
0	0	0	2	0	0	0	0	0	0	0	0	0	0
1	3	3	2	2	0	0	0	0	2	2	0	1	3
0	0	2	1	1	0	0	0	3	3	1	1	2	4
1	2	0	2	2	0	1	1	1	1	2	3	2	0
0	1	1	1	1	3	1	1	1	1	1	1	0	0
1	0	2	2	1	2	1	2	1	0	0	1	0	0
1	2	2	1	1	2	1	3	1	1	0	0	0	0
1	0	0	0	1	3	1	2	2	0	0	0	0	0
0	0	0	0	2	1	1	1	1	1	1	0	0	0

Numbers: The number of contacts the needle made with leaves

Ω = 2 / (σ^2 / Mx +1)
σ^2 = variance
Mx = mean of numbers

Beland, Nakate, Baldocchi, unpublished

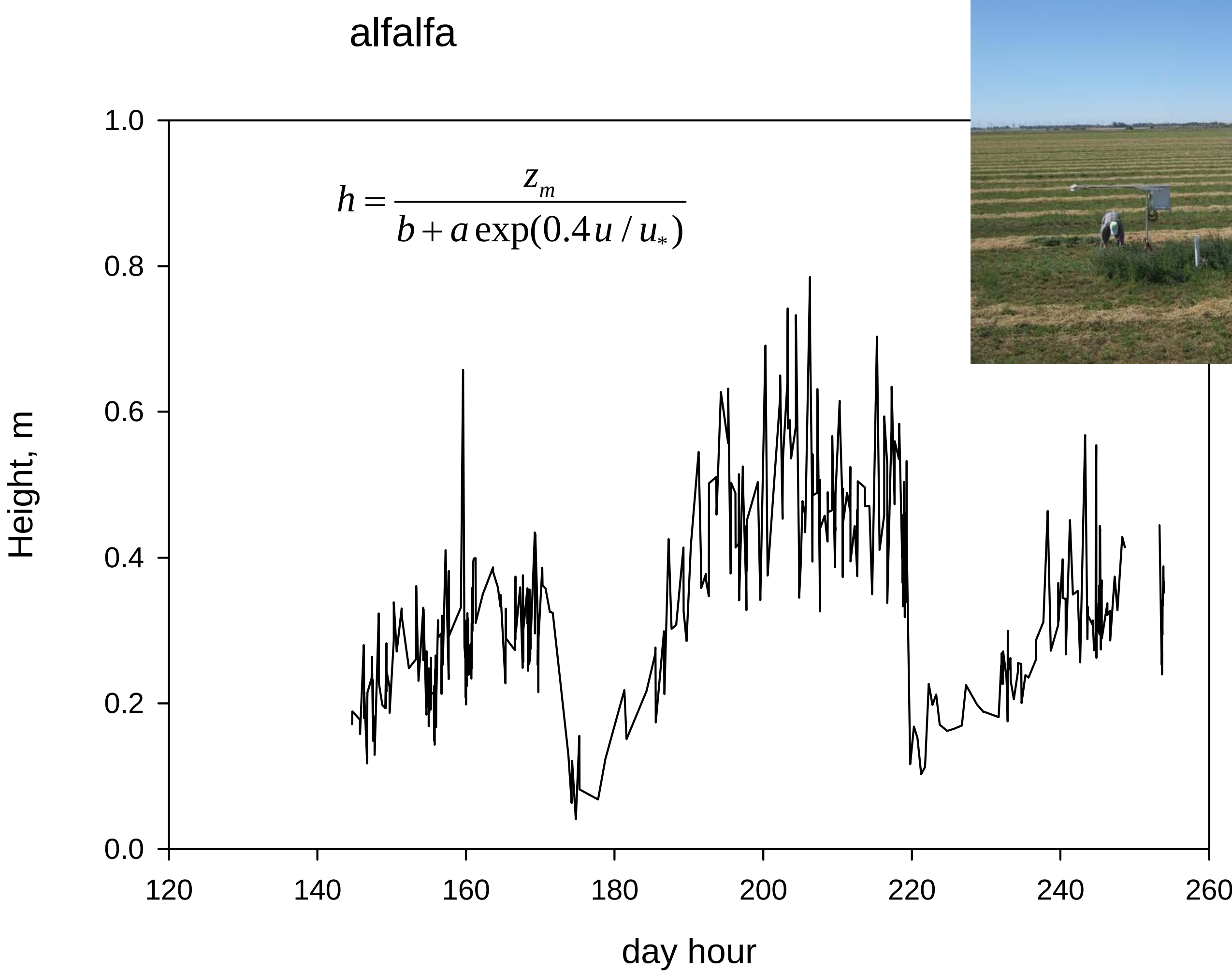
Clumping within Foliage Voxels of Broadleaved Trees seems to be Nil, but Variable



High variability of clumping within a species

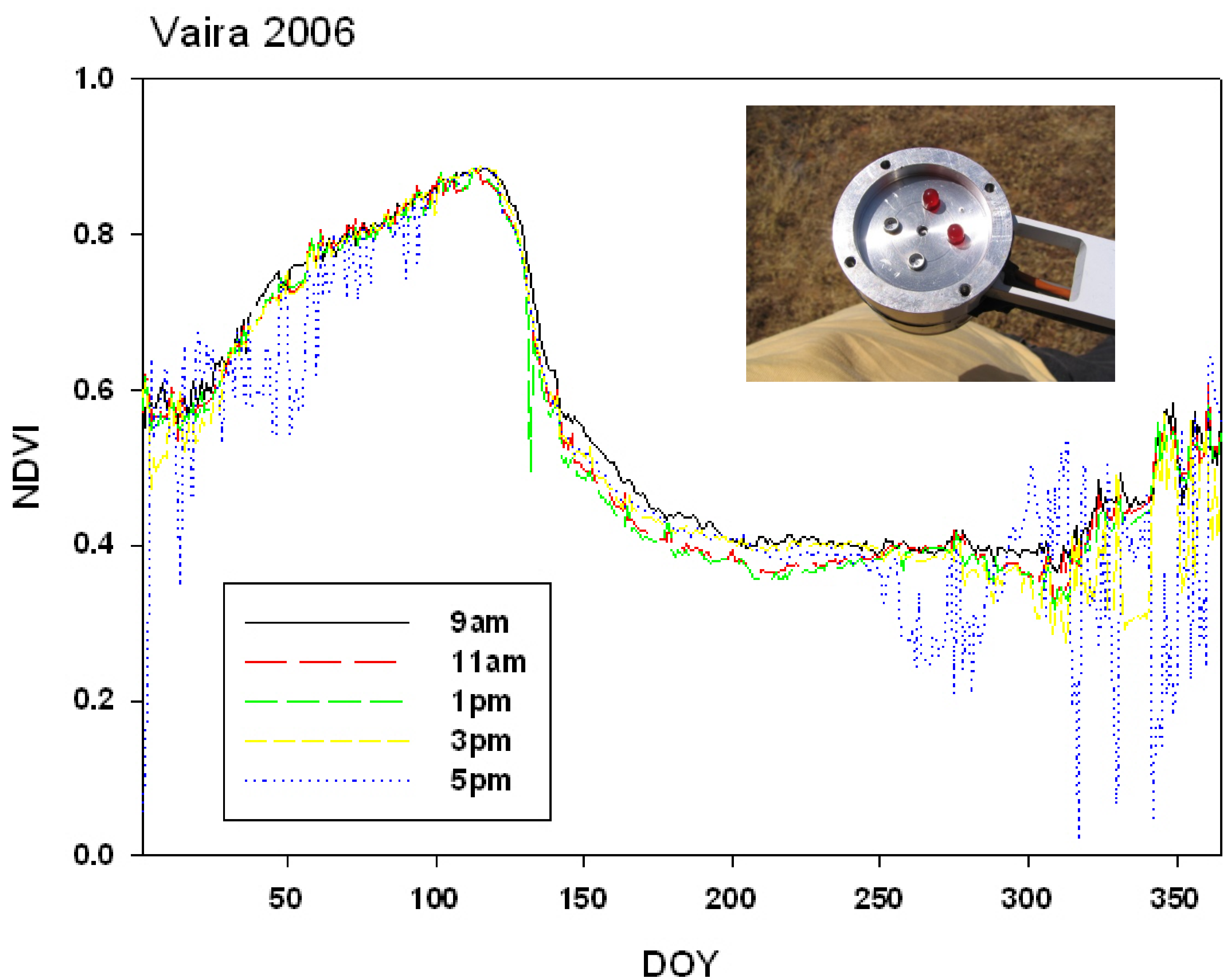
Samples: 10 each = 40 total

New Opportunity to Deduce Canopy Height from Log Wind Law: Cheaper and Can Produce Time Series

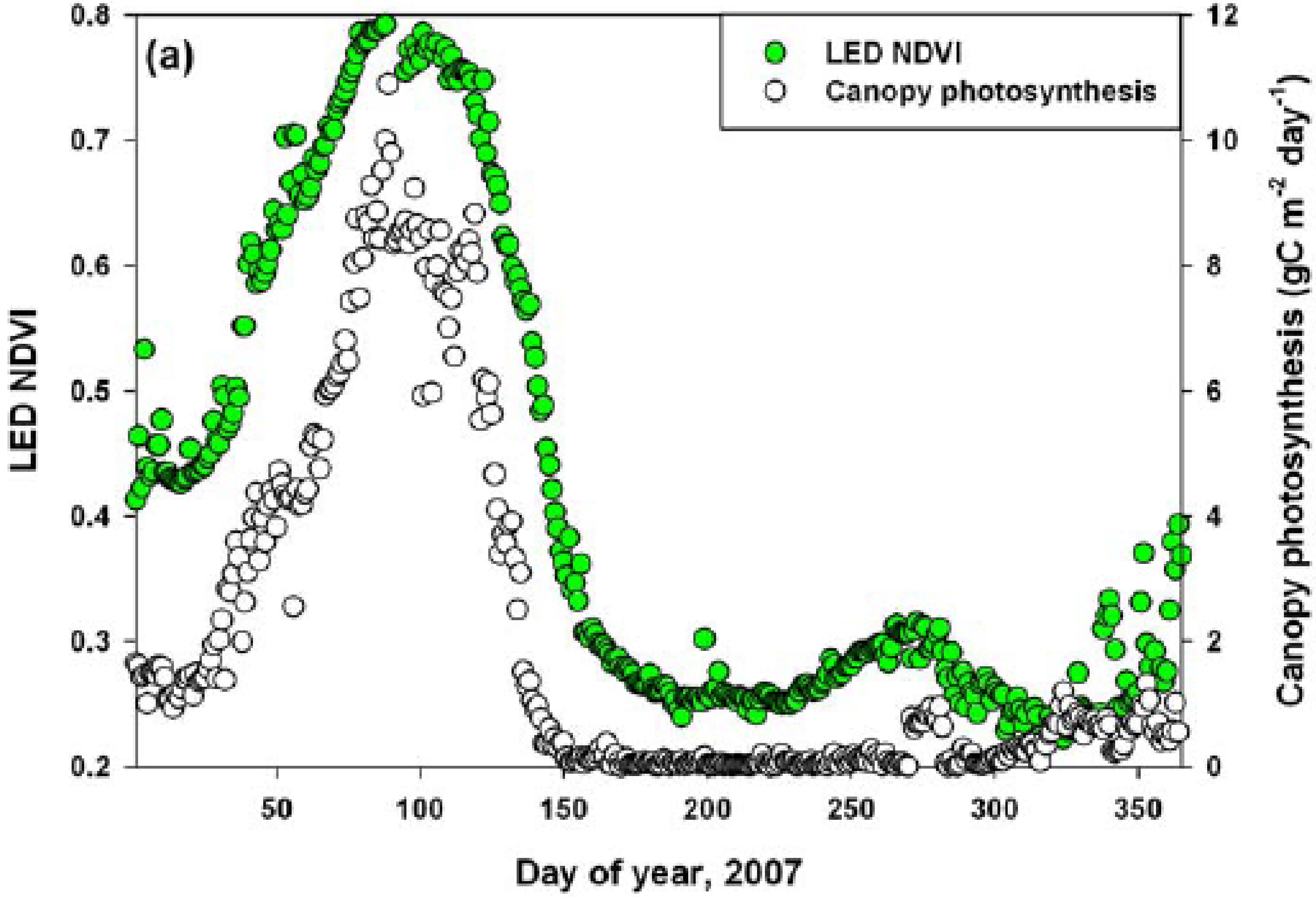


Baldocchi, Sturtevant, Knox, Koteen, Pennypacker, Verfaillie, unpublished

LED NDVI over Annual Grassland

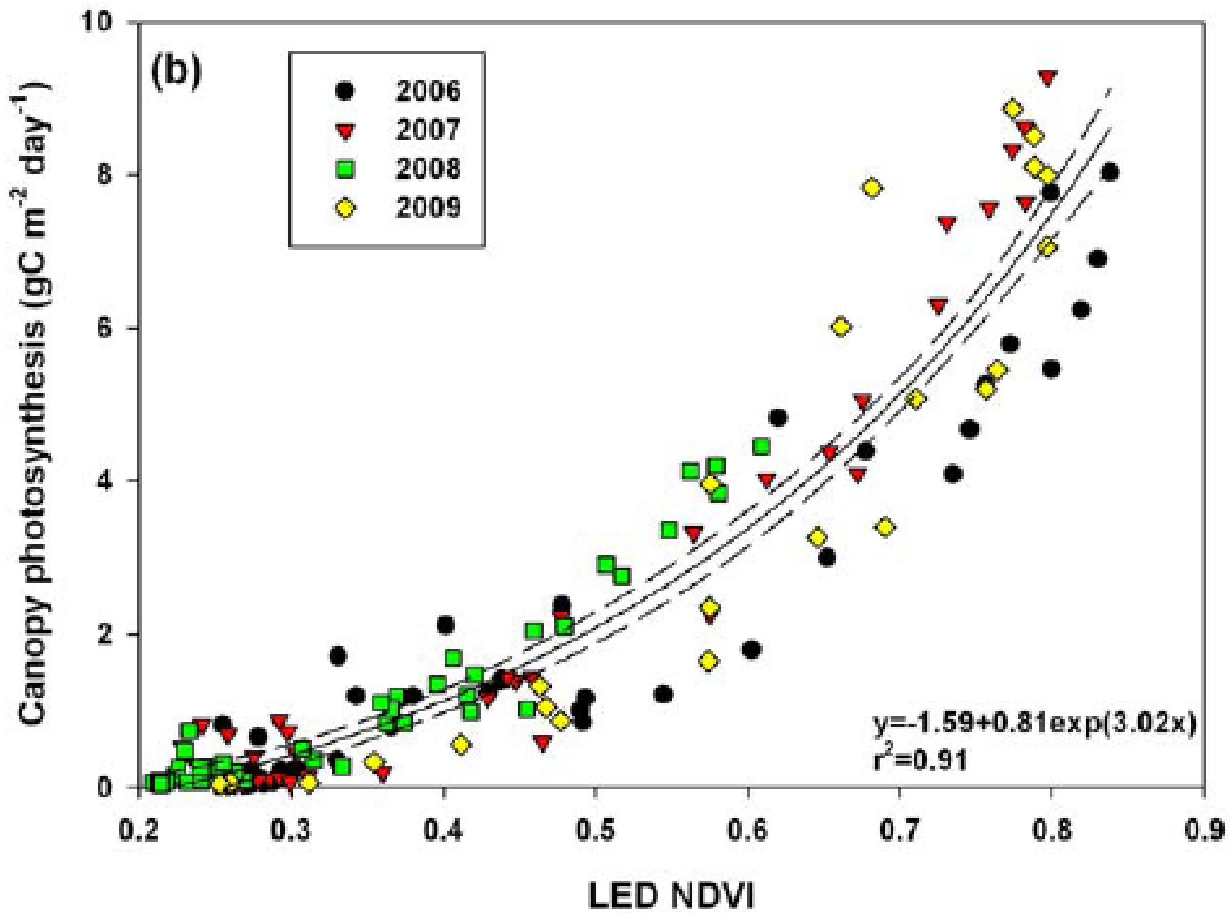


Canopy Photosynthesis vs Vegetation Index, Annual Grassland



Ryu et al. 2010 AgForMet

Good Fit over Multiple Years, but Non-Linear and May be Site Specific



Ryu et al 2010 AgForMet

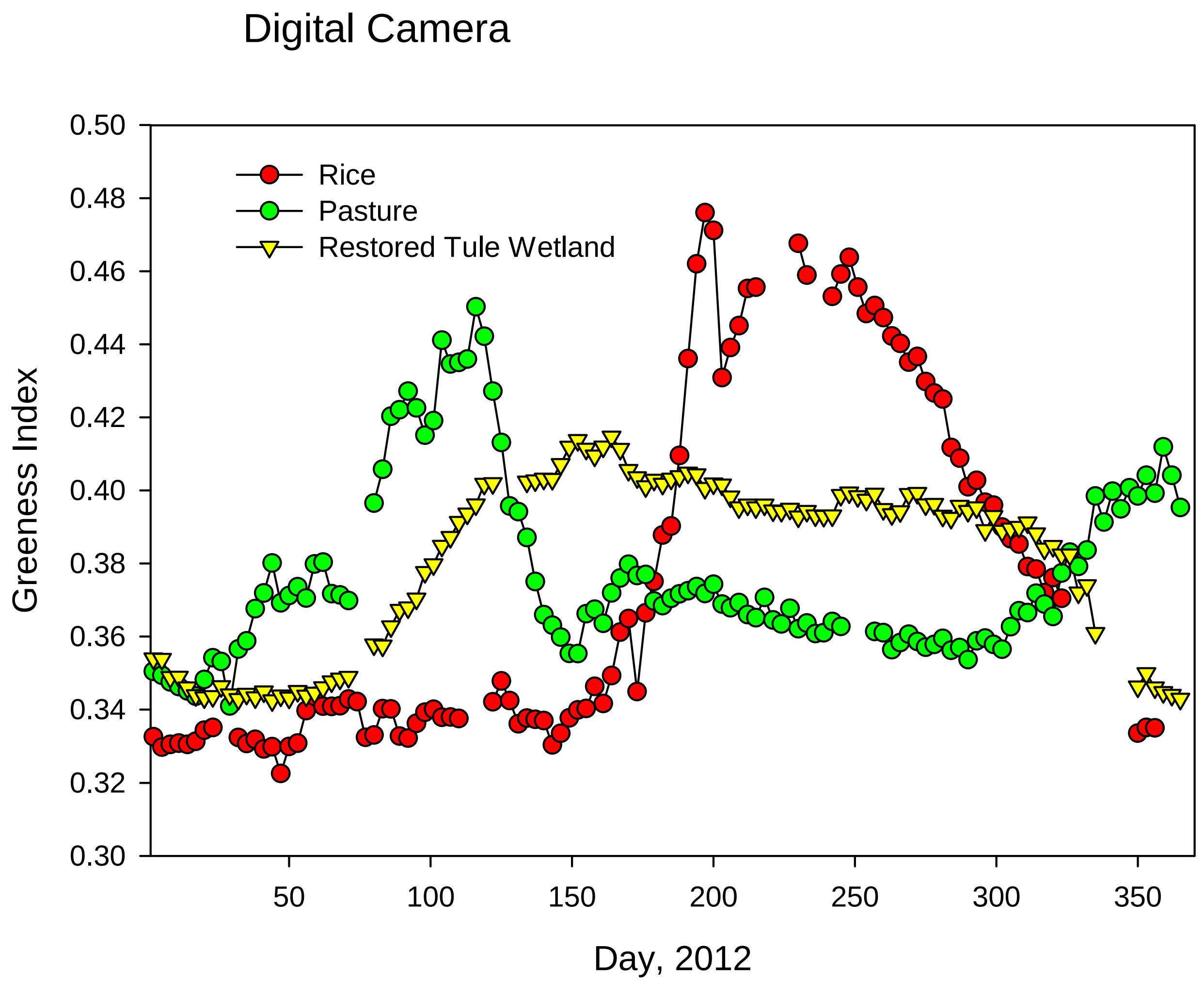
Phenology of Flowering and Seeding Plants Complicates interpretation of Greenness Indices

Purple Flowering Alfalfa

White and Yellow flowers on Pepperweed

Rice in Seed Stage

Greenness Index over Crop, Wetland and Pasture



Saenz, Knox, Sturtevant, Koteen, Verfaillie, Baldocchi, unpublished

Cameras Monitor Management and Phenology of Crops, Rice 2013

Disced, pre-planting

Flooding, seedlings

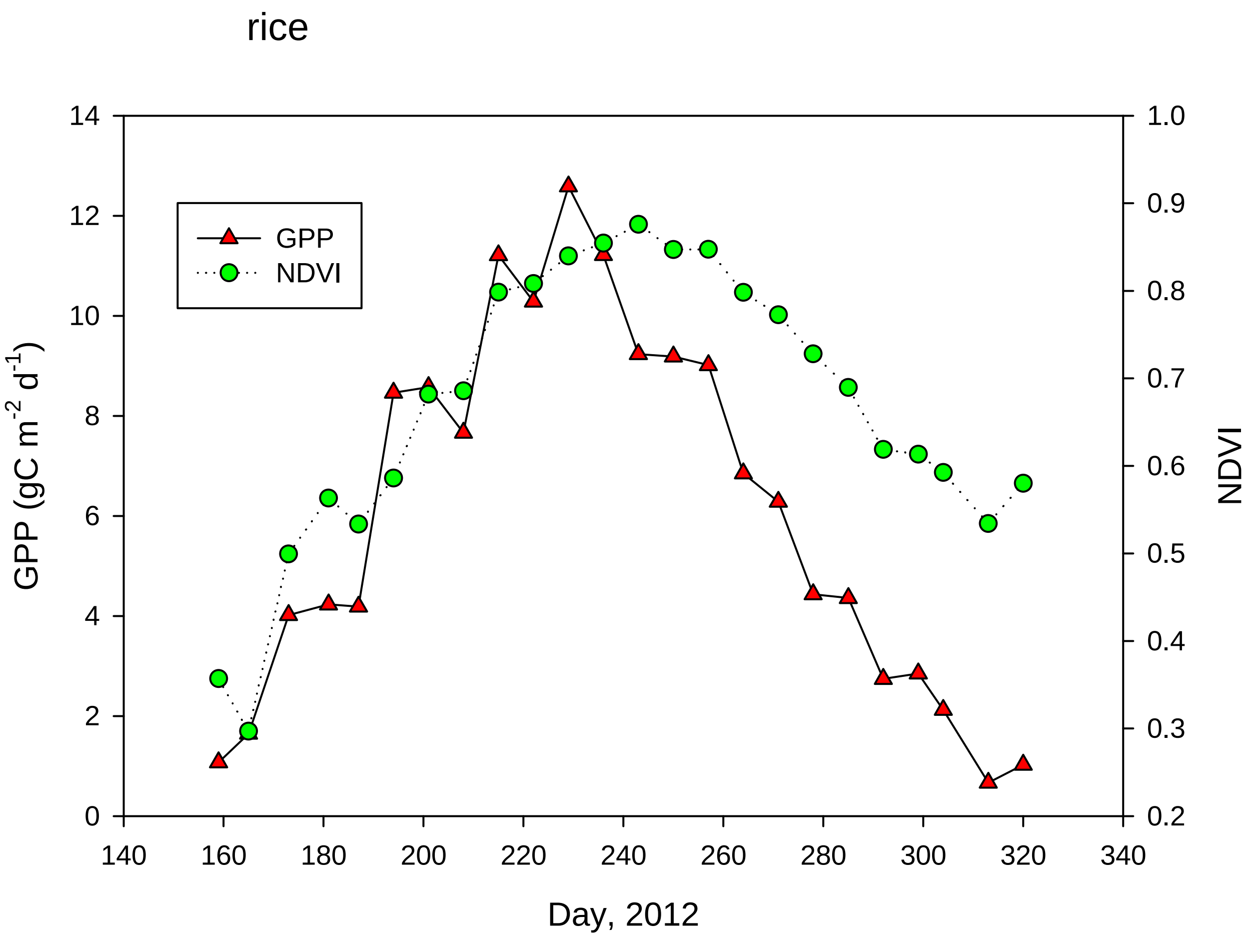
Full canopy, vegetated

Seed Filling

Harvesting

Chopped Straw

Canopy Photosynthesis vs Vegetation Index, Rice



Restored Wetland

Fall 2010

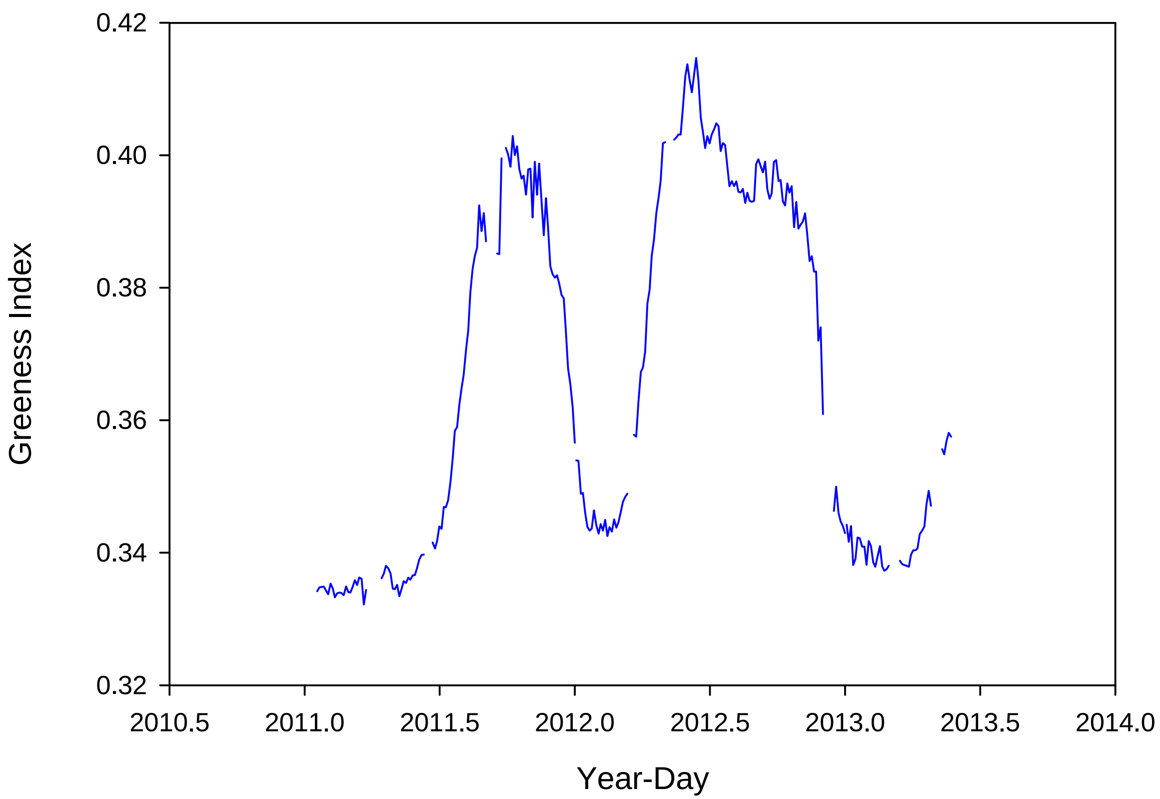
Summer, 2012

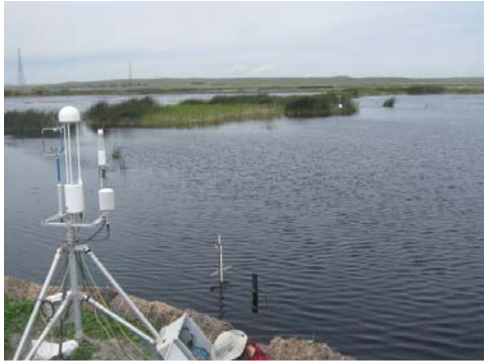
Winter, 2013

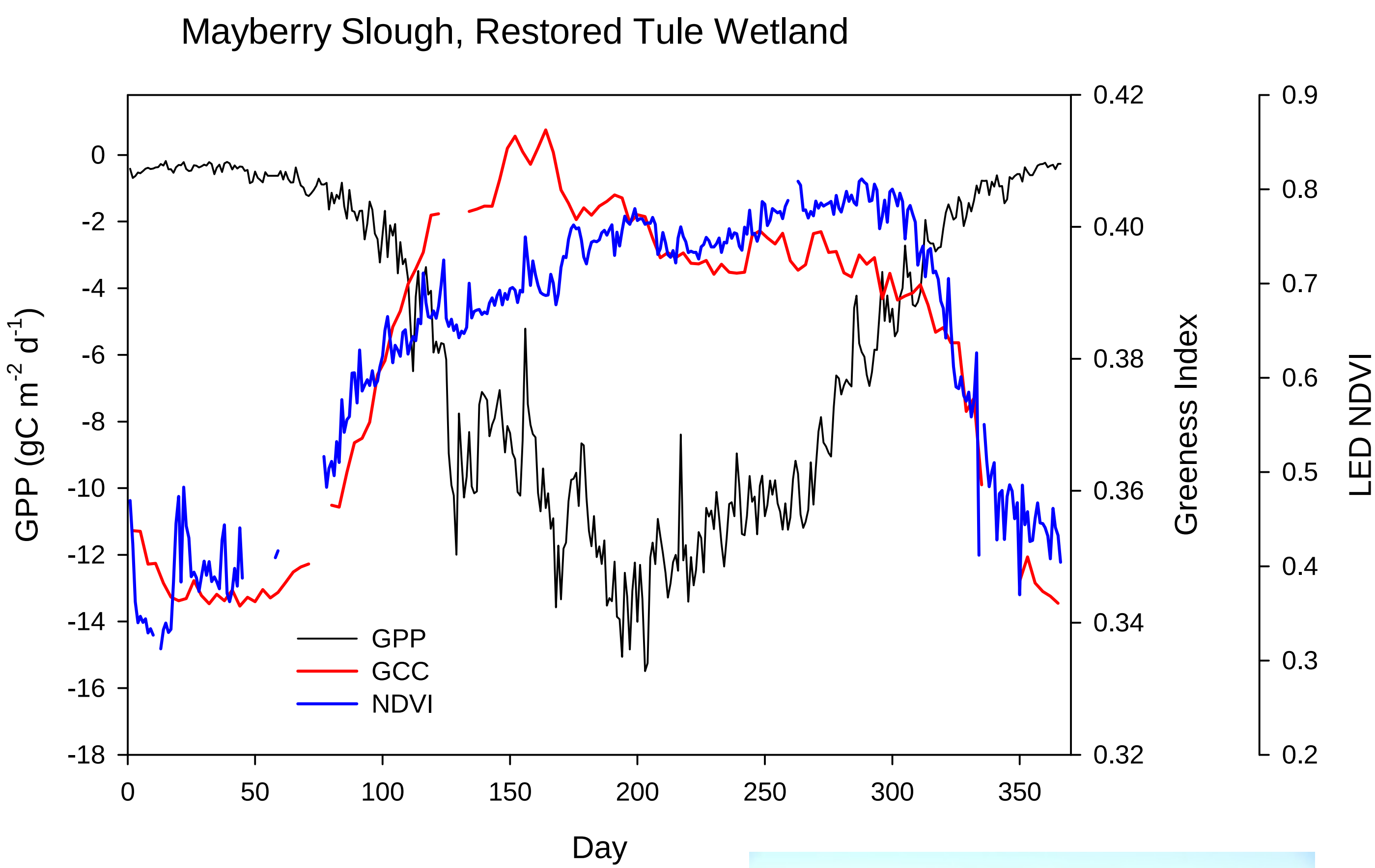
Summer, 2013

Digital Cameras Produce Cheap Long Term Records of Phenology

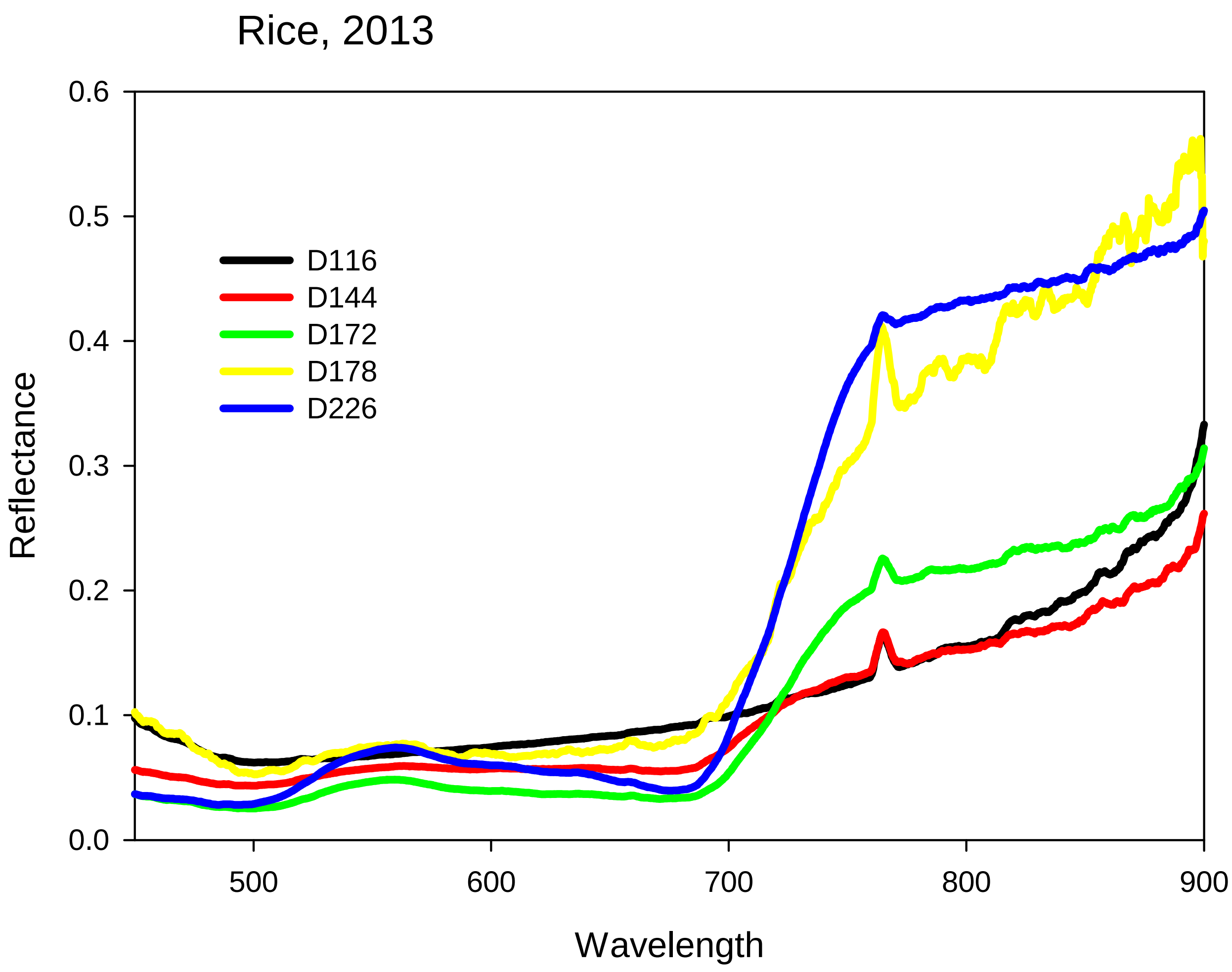
Mayberry Restored Tule Wetland



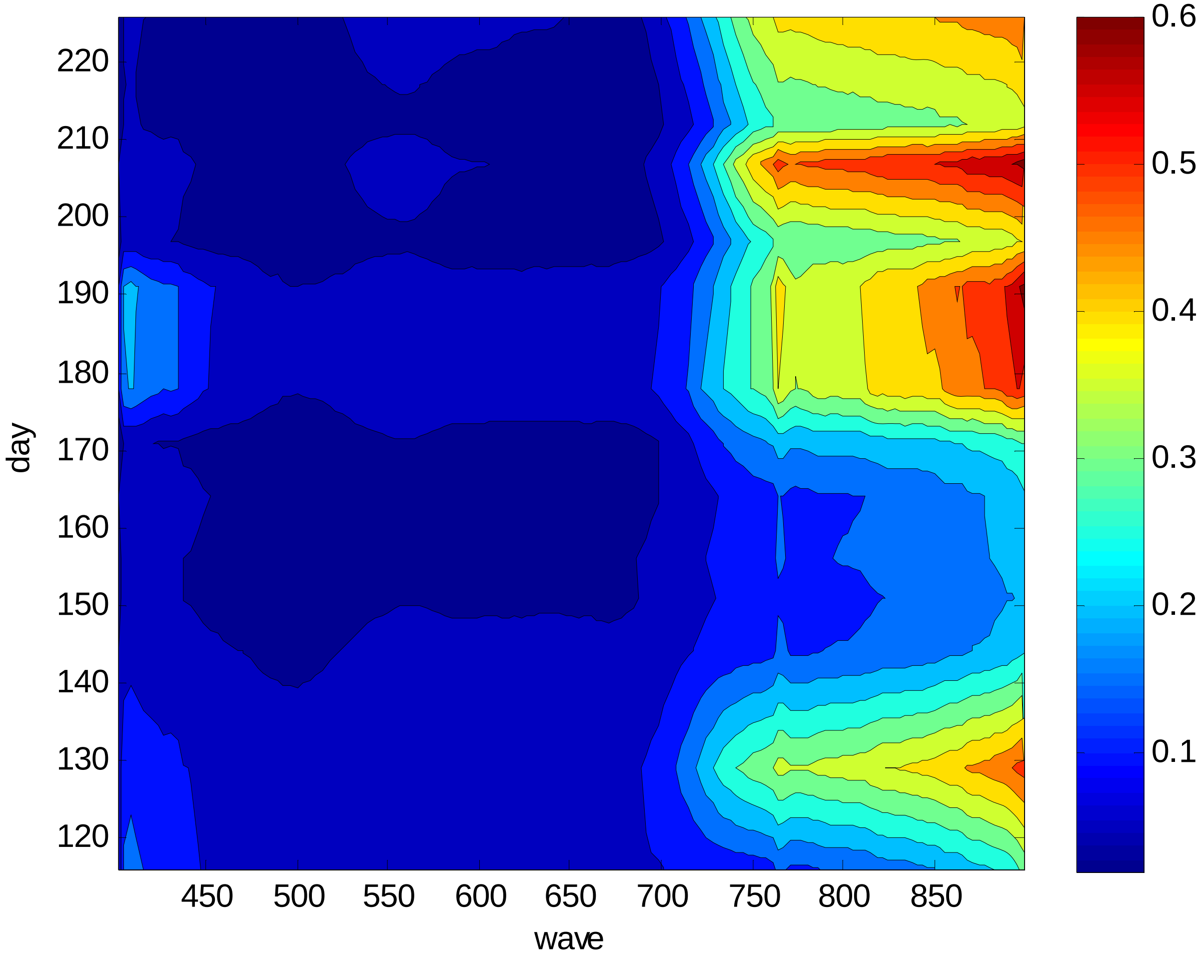


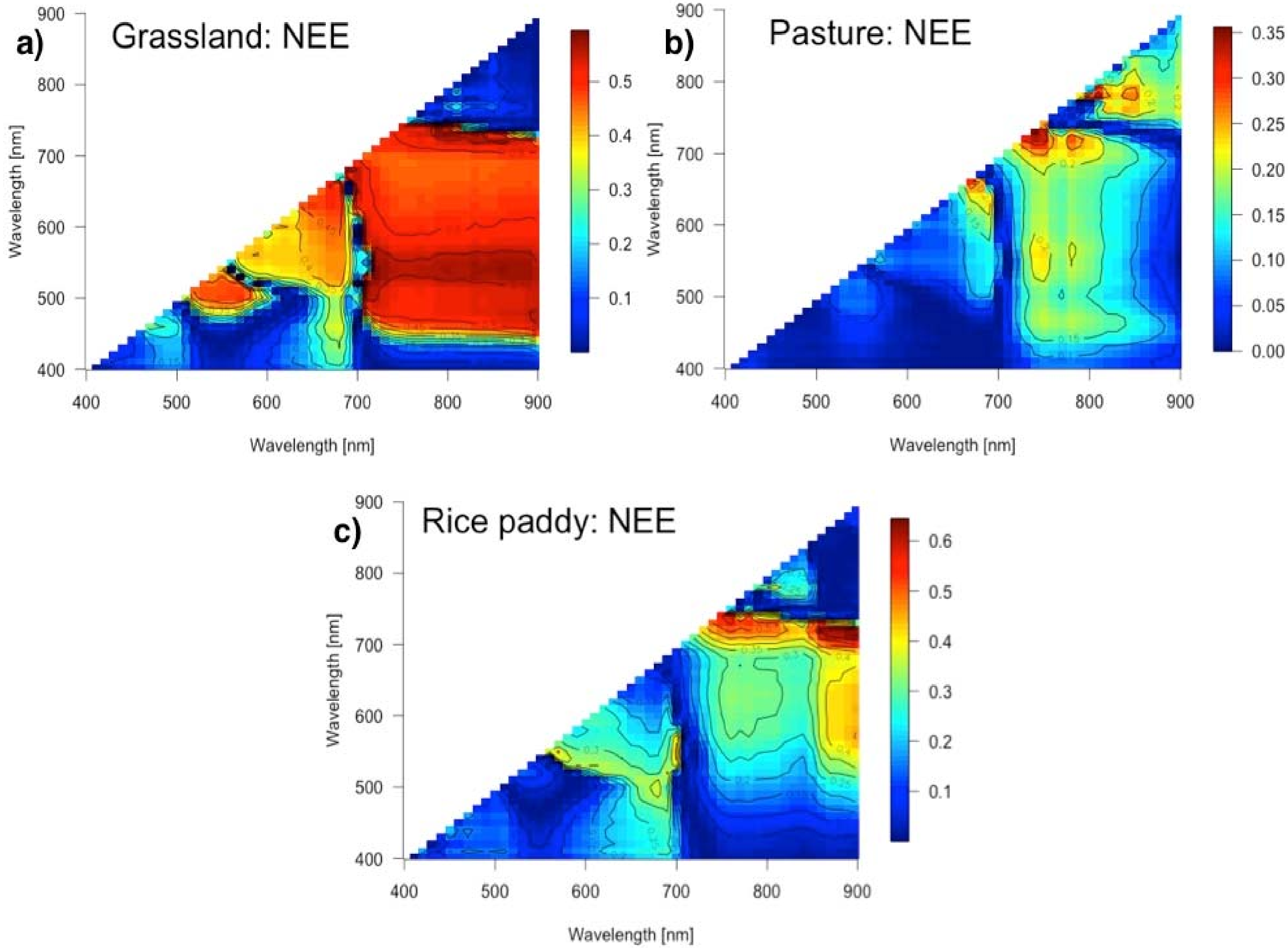

Mayberry Slough, Restored Tule Wetland
GPP (gC m-2 d-1)
Greeness Index
LED NDVI
Day
GPP
GCC
NDVI
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
0.42
0.40
0.38
0.36
0.34
0.32
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0
50
100
150
200
250
300
350

Time Series of Hyperspectral Reflectance



3D time Series of Hyperspectral Reflectance, Rice



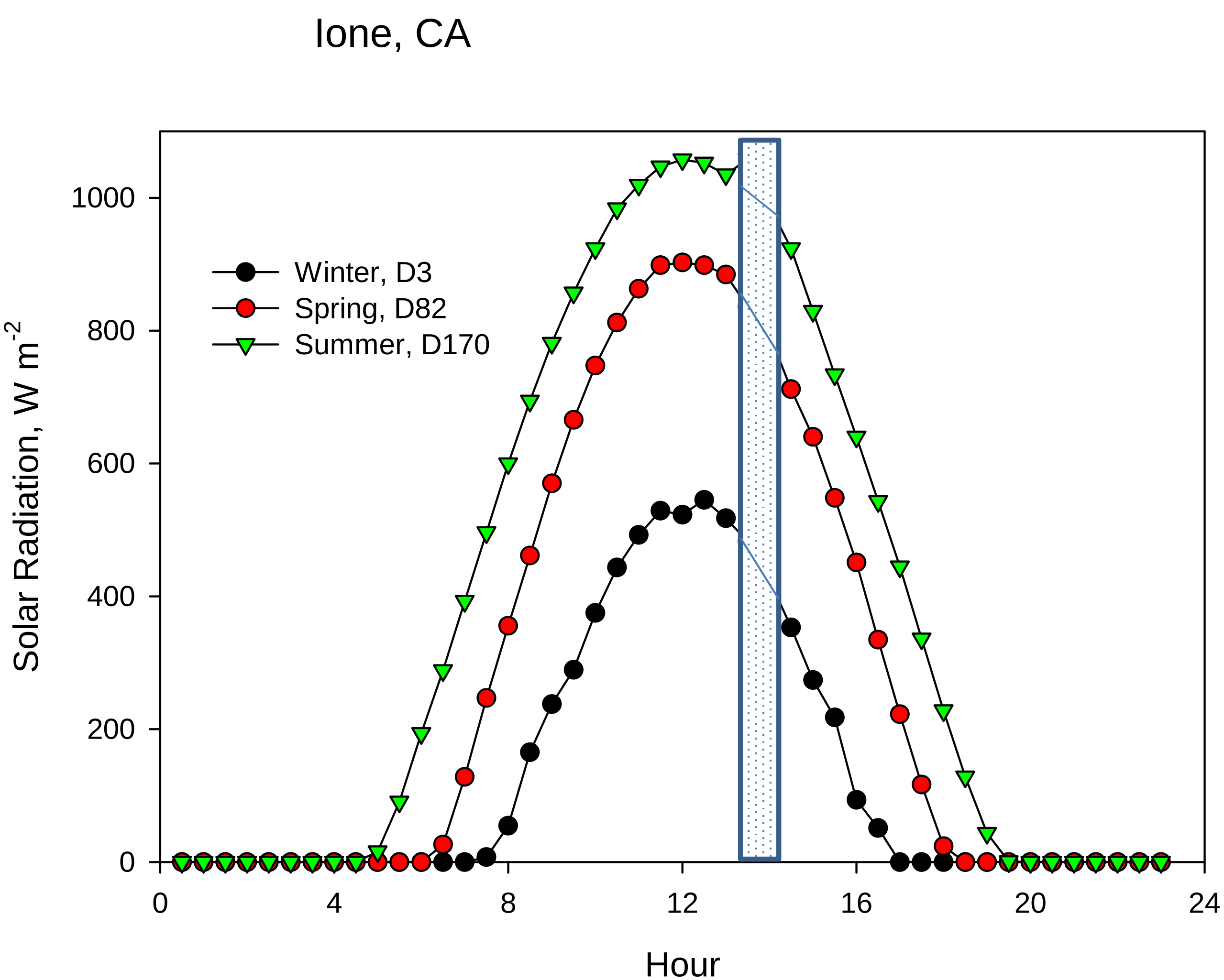


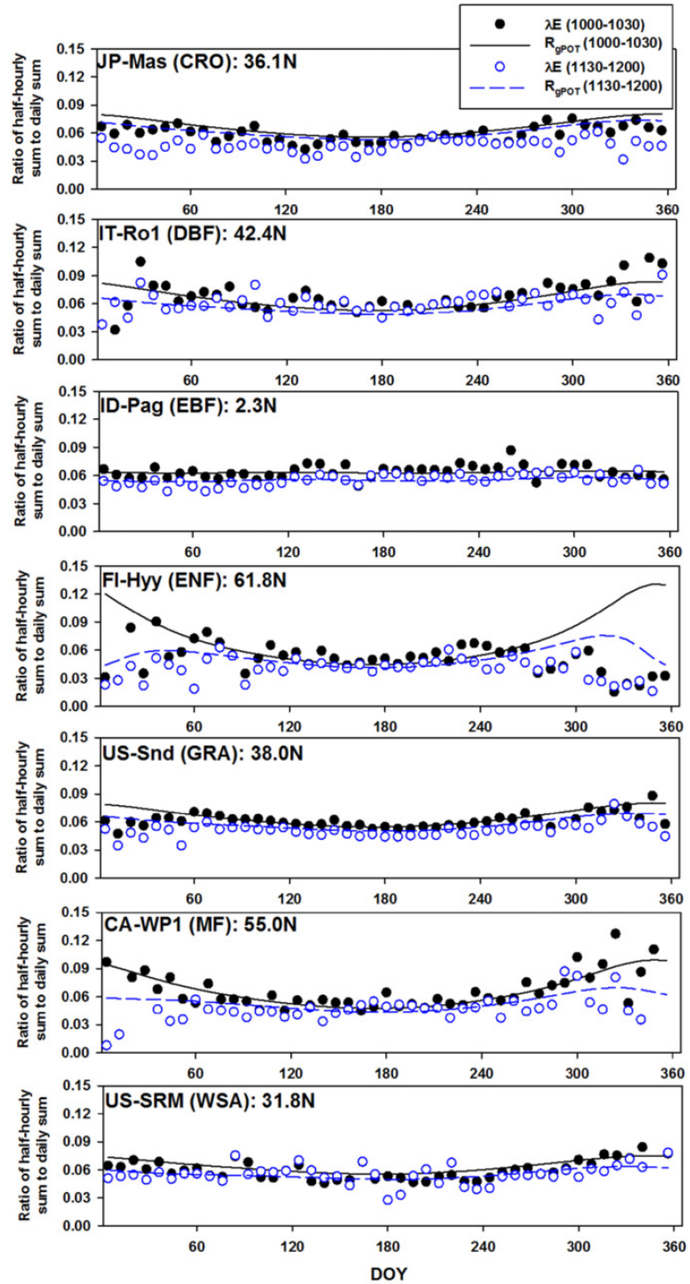
Jaclyn Hatala, PhD dissertation

Big Picture Goal :

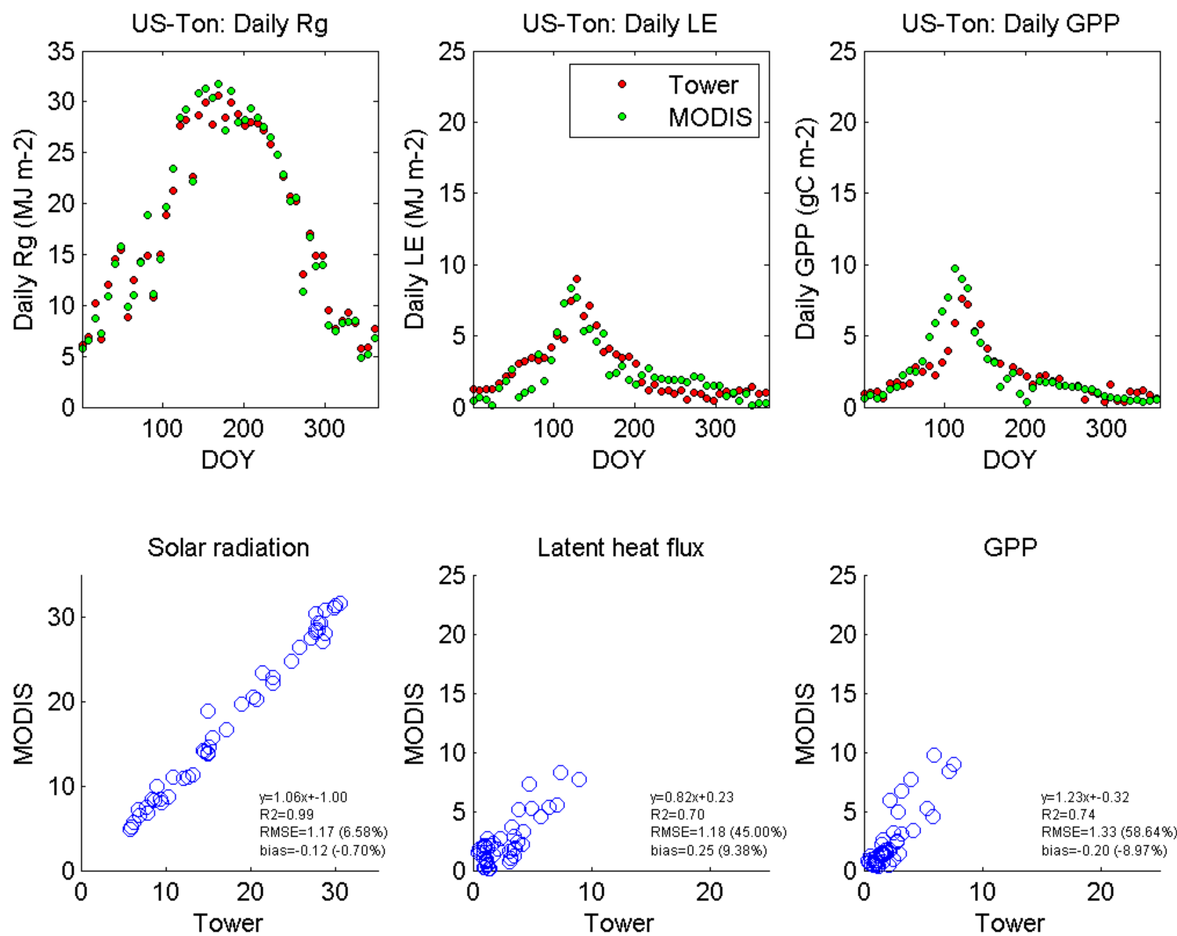
- **How can We Evaluate Carbon Fluxes ‘Everywhere, All the Time?’**

Scale Satellite Snap-Shot with Daily Integral of Energy Fluxes



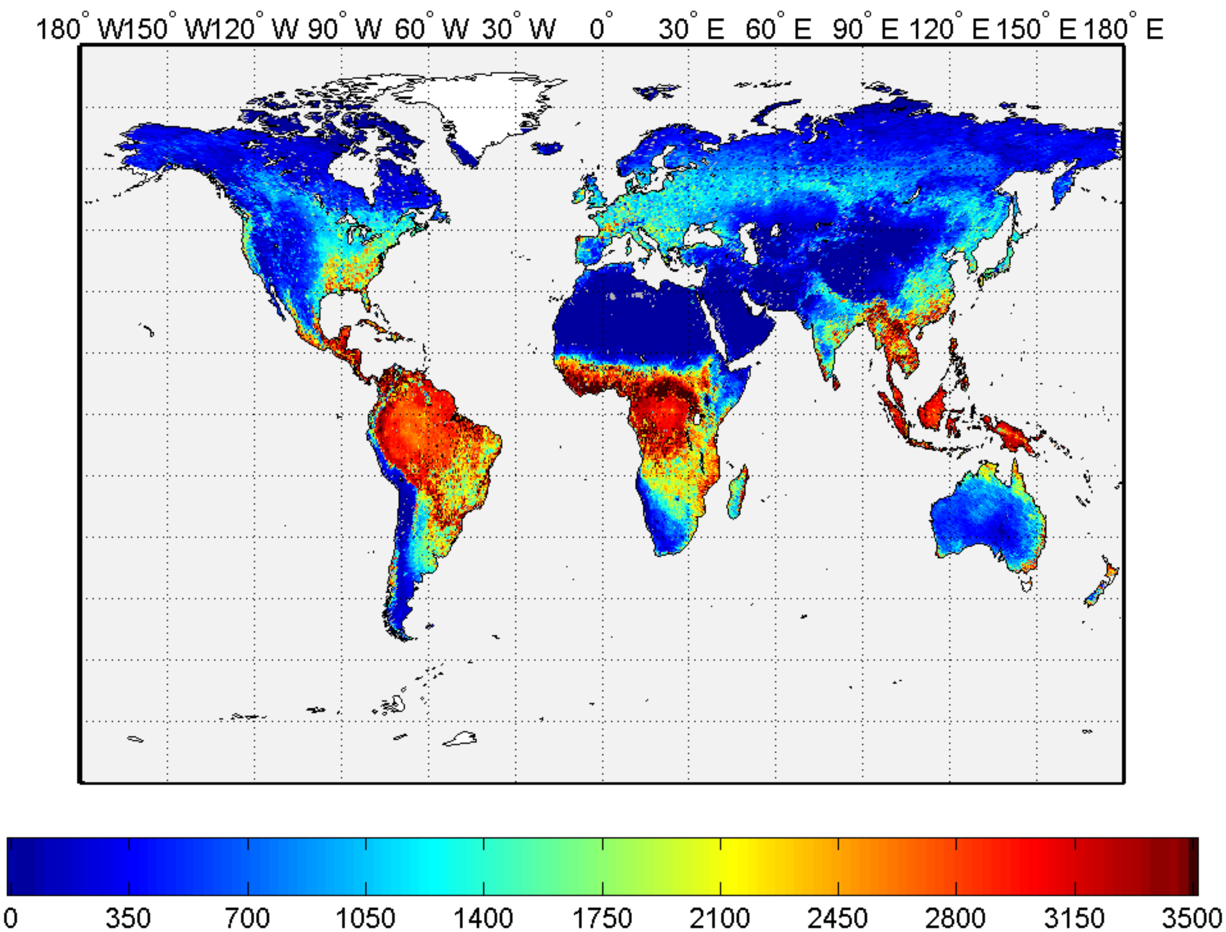

λE (1000-1030)
R_{gPOT} (1000-1030)
λE (1130-1200)
R_{gPOT} (1130-1200)
JP-Mas (CRO): 36.1N
IT-Ro1 (DBF): 42.4N
ID-Pag (EBF): 2.3N
FI-Hyy (ENF): 61.8N
US-Snd (GRA): 38.0N
CA-WP1 (MF): 55.0N
US-SRM (WSA): 31.8N
Ratio of half-hourly sum to daily sum
DOY

Validate Model Across FLUXNET

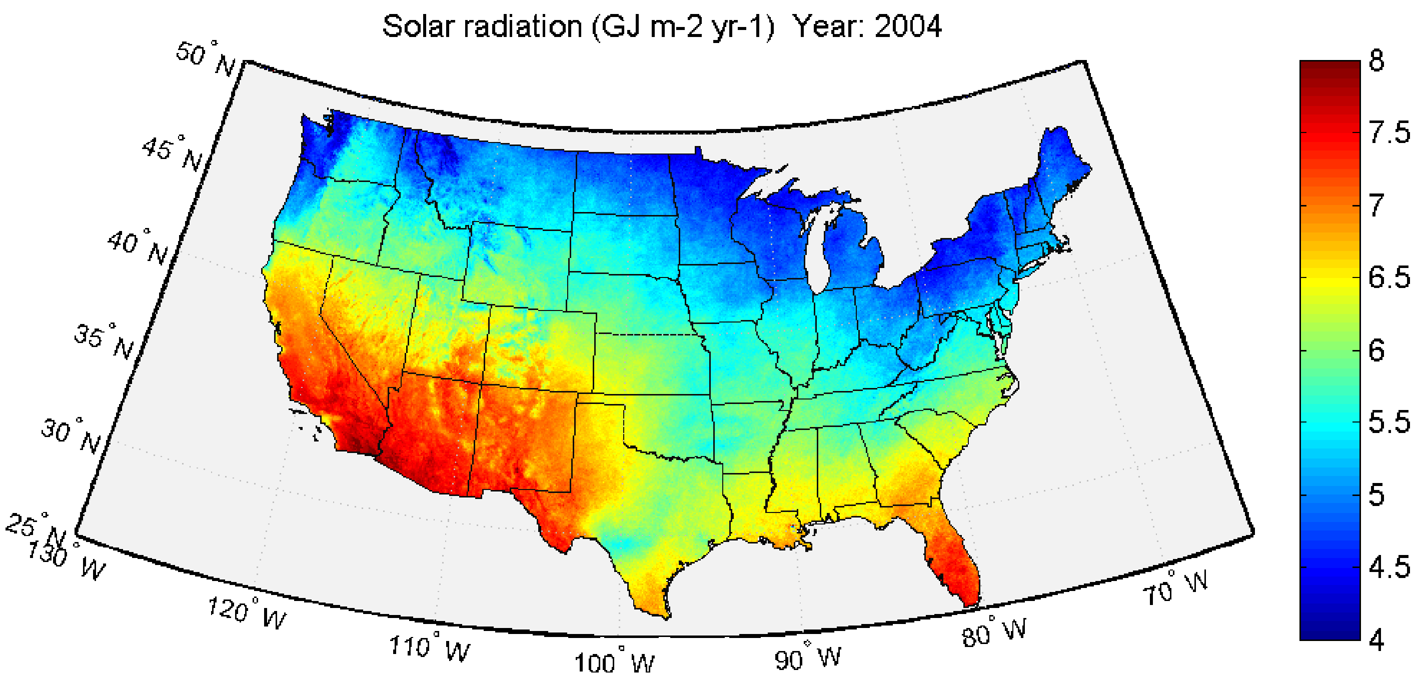


Ryu et al. 2012 Global Biogeochemical Cycles

GPP (gC m-2 yr-1) Year: 2003



Ryu et al. 2012 Global Biogeochemical Cycles


Solar radiation (GJ m-2 yr-1) Year: 2004
50° N
45° N
40° N
35° N
30° N
25° N
130° W
120° W
110° W
100° W
90° W
80° W
70° W
8
7.5
7
6.5
6
5.5
5
4.5
4

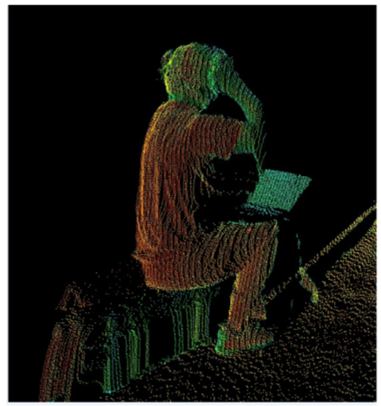
Concluding Remarks

- Links between Eddy Flux Measurements and Digital Information from Cameras, LED sensors and Hyperspectral Spectrometers has potential for Inexpensive landscape upscaling of carbon fluxes
  - May have potential for assessing Carbon Exchange for Carbon markets and other Applications

Acknowledgments: The Biomet Lab

Acknowledgment to Biomet Lab

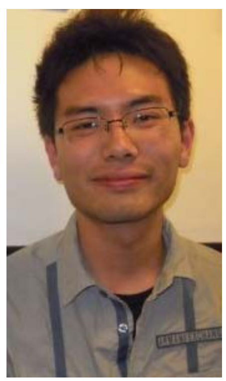
Joe Verfaillie



Martin Beland

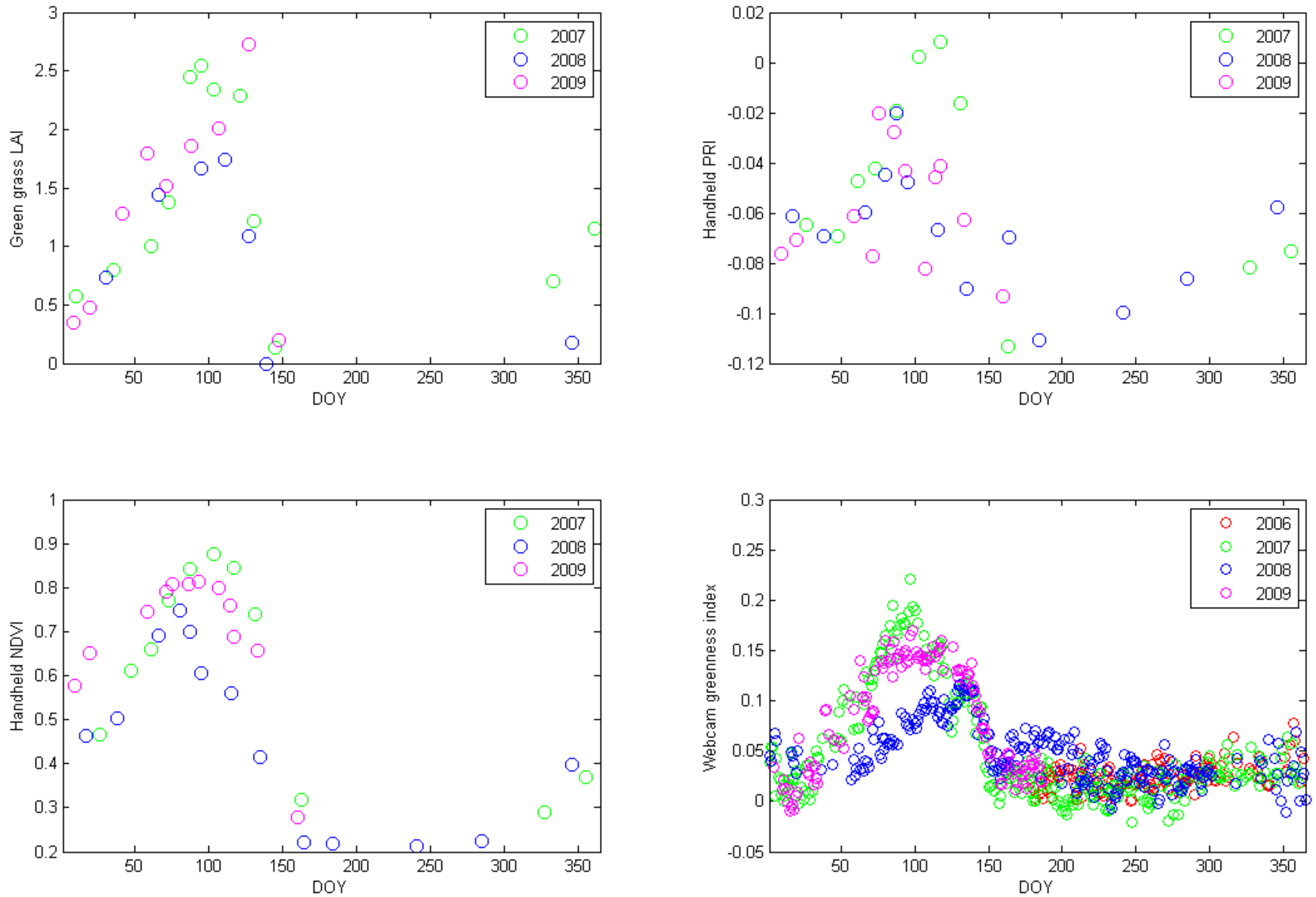
Jaclyn Hatala

Youngryel Ryu

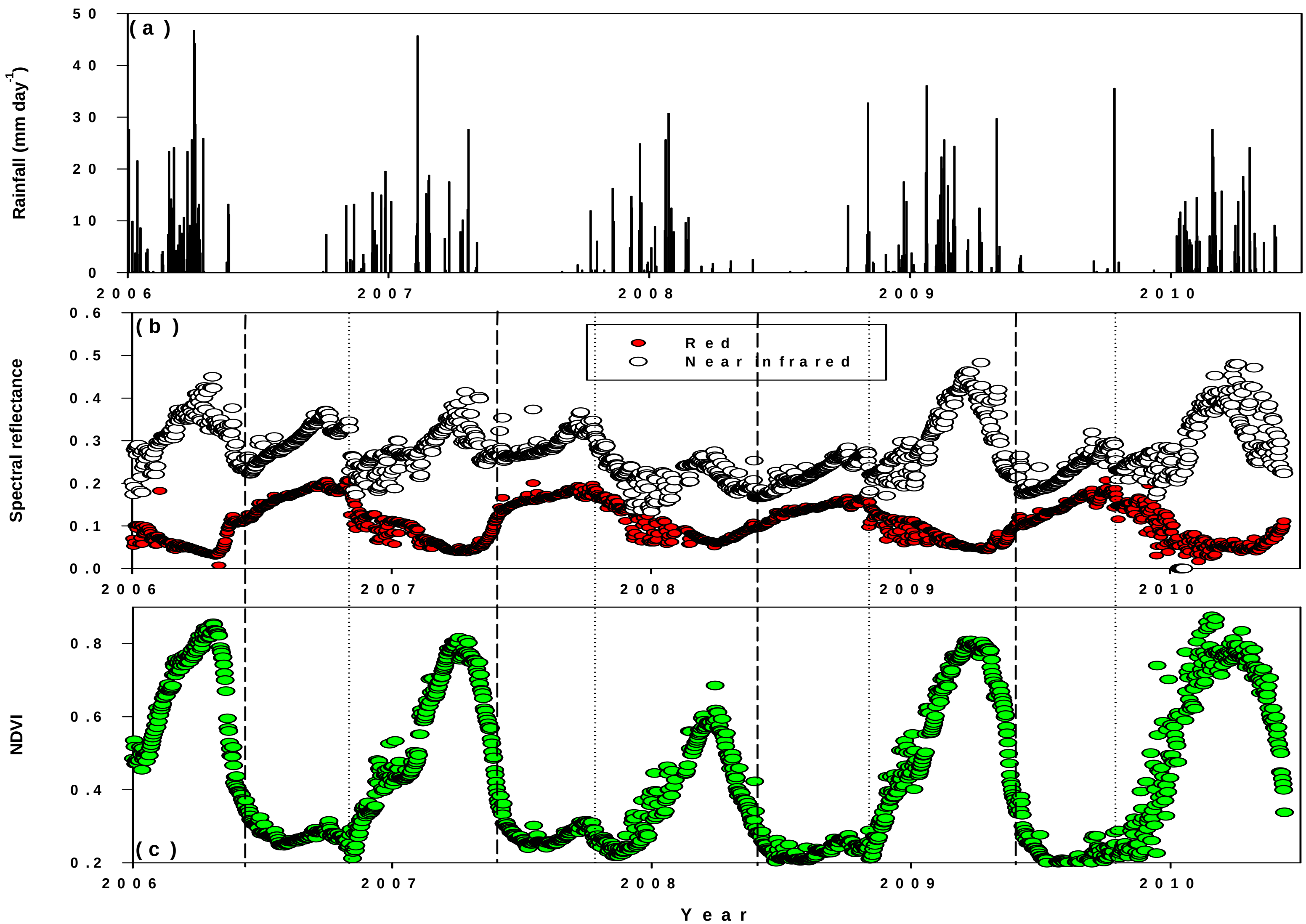


Taichi Natake

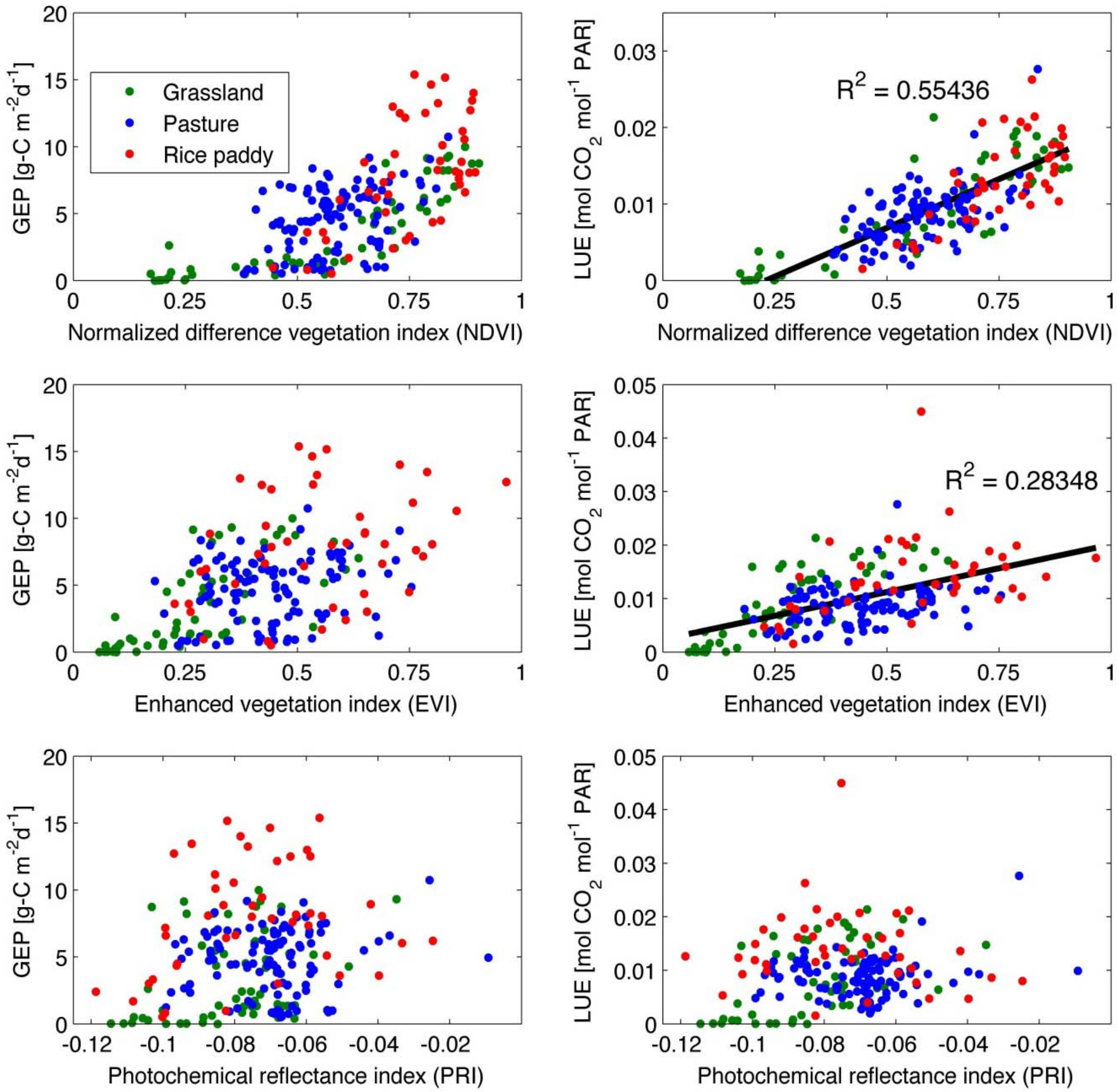
Seasonality of Remote Sensing Indices, annual grassland



Interannual Variability

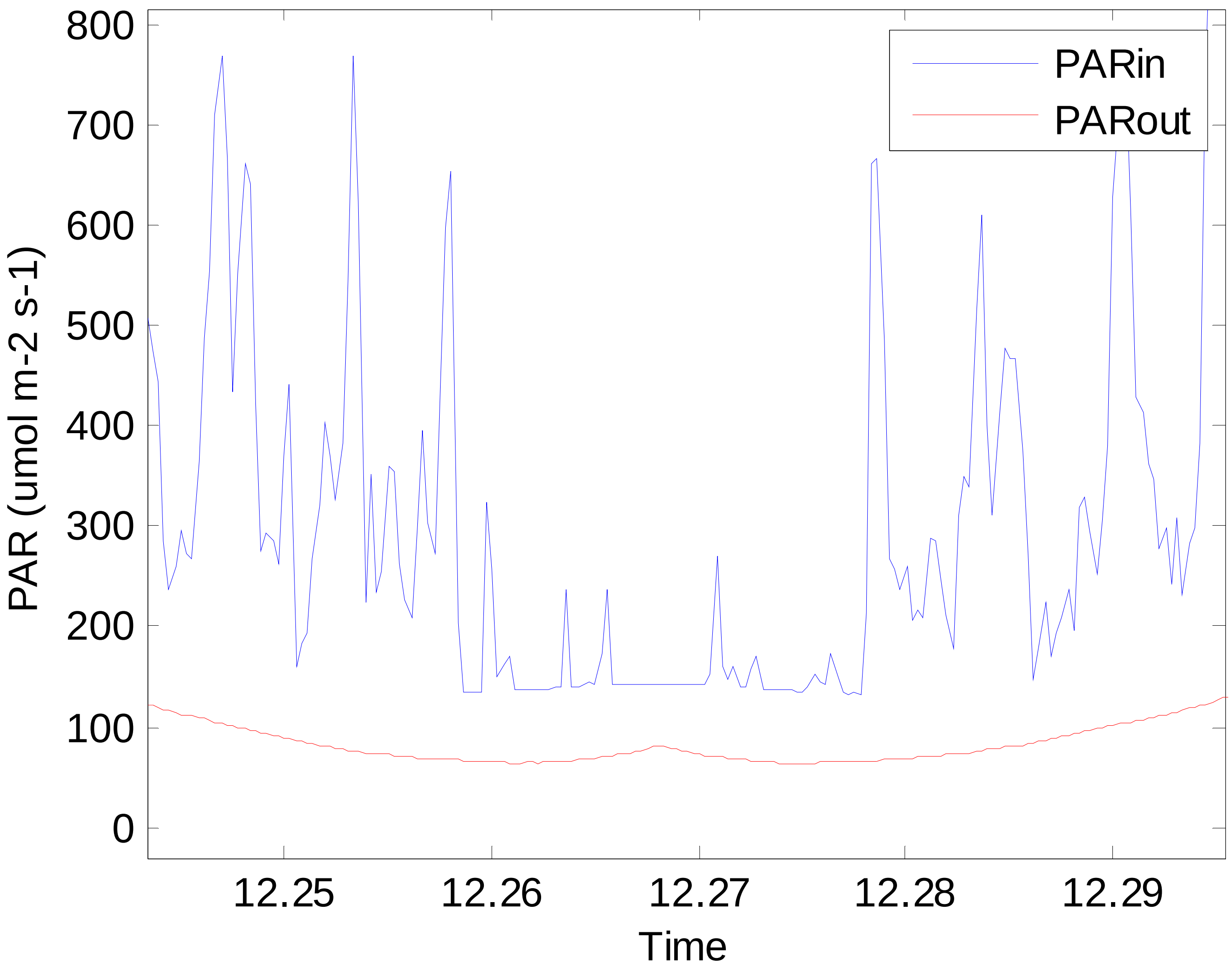


Ryu et al.

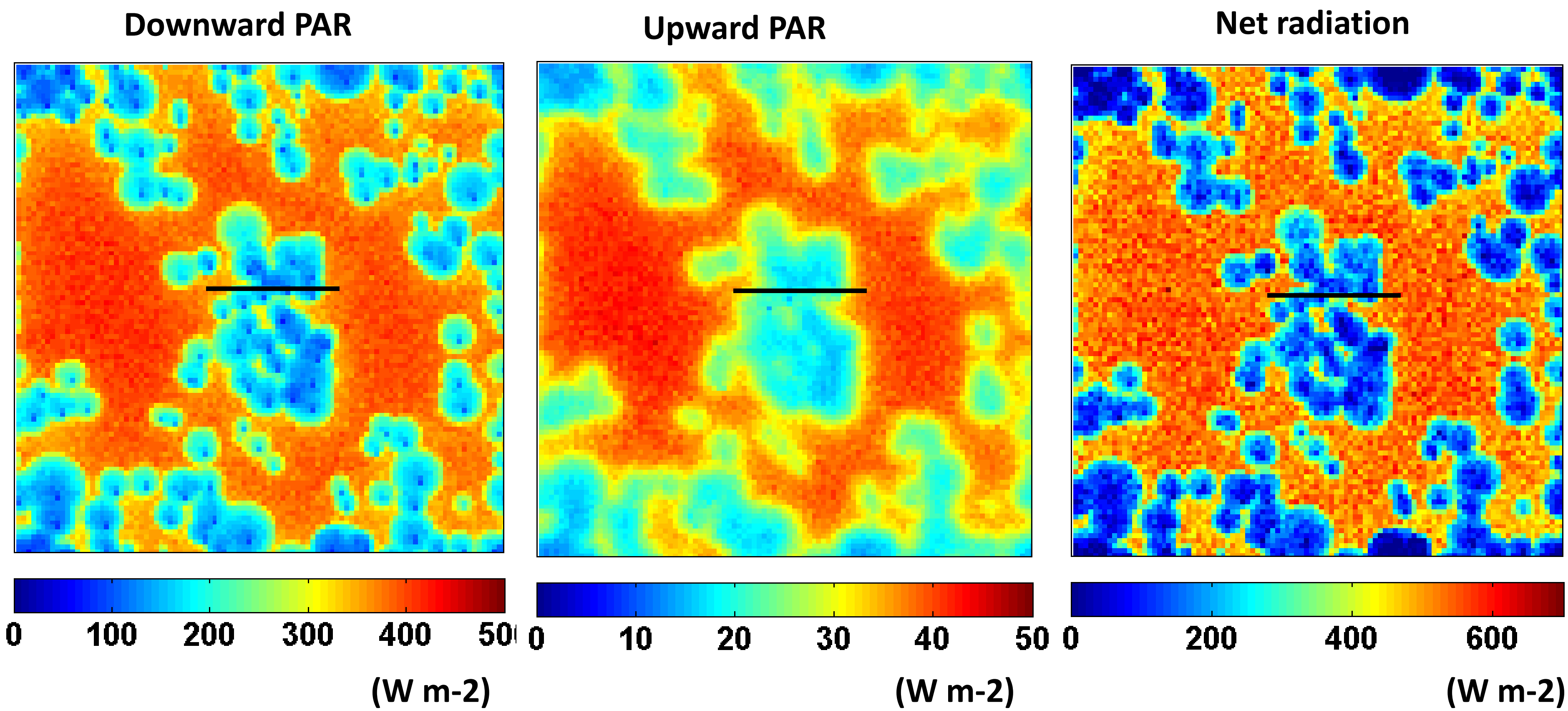


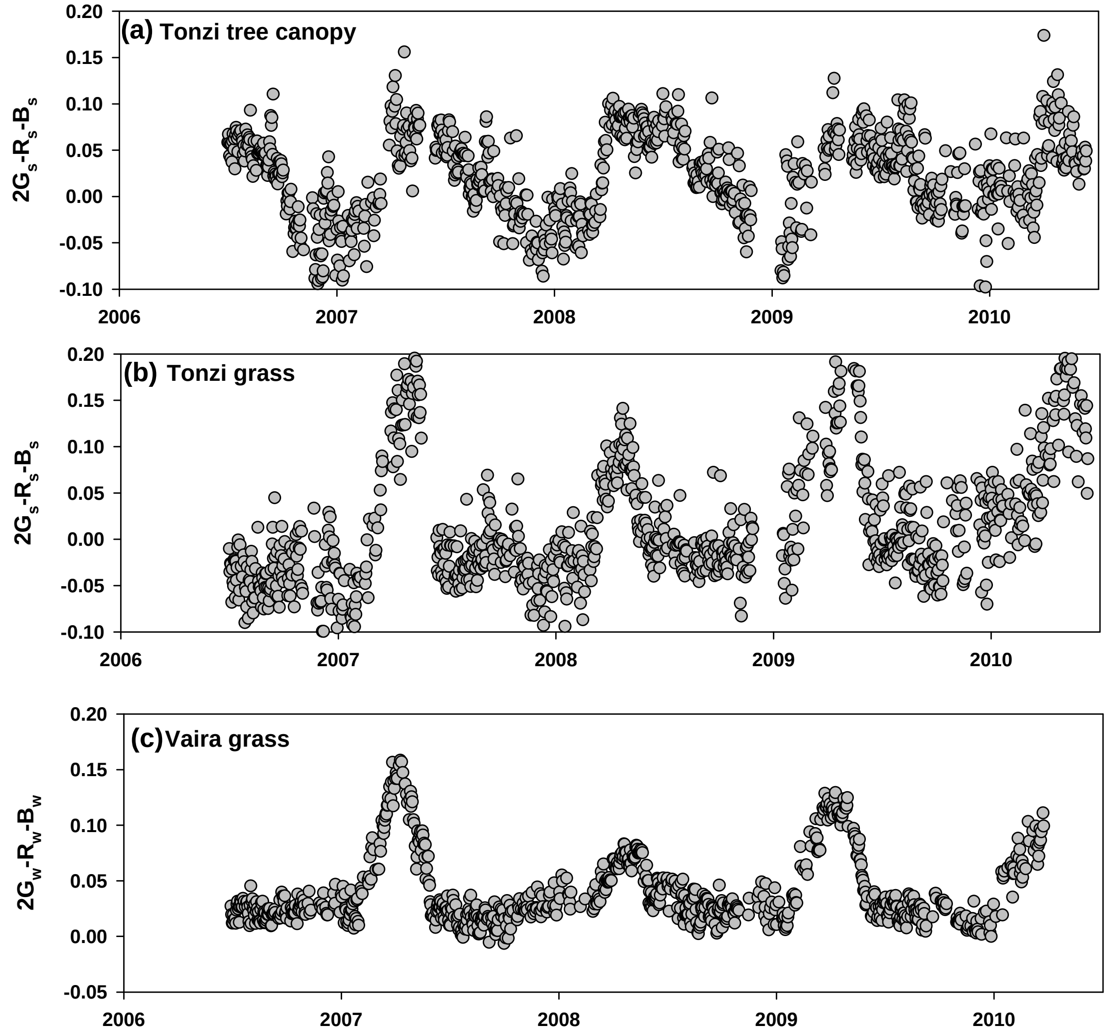
Jaclyn Hatala, PhD dissertation

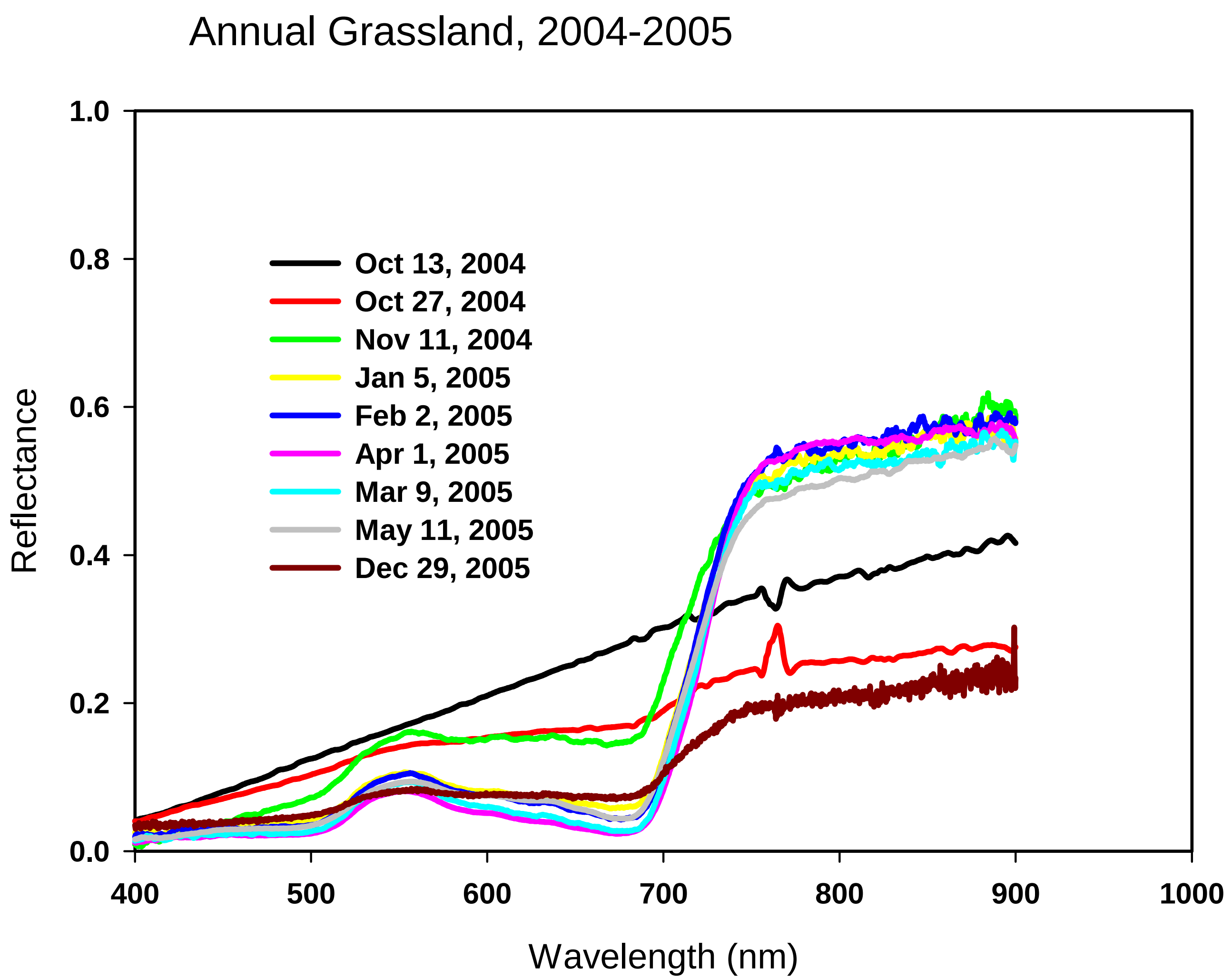
Tram Transect

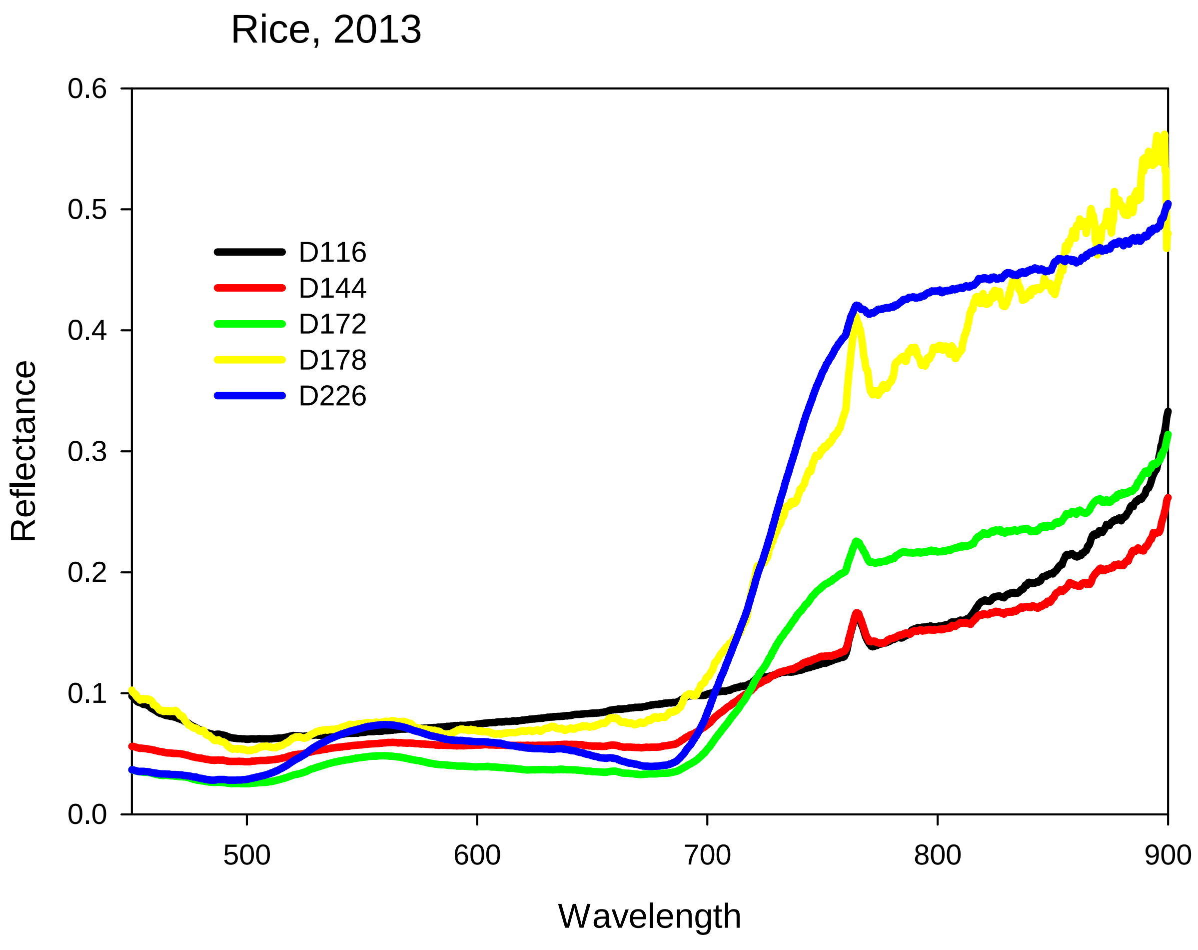


Simulated understory (1m above the ground) radiations near the tram site



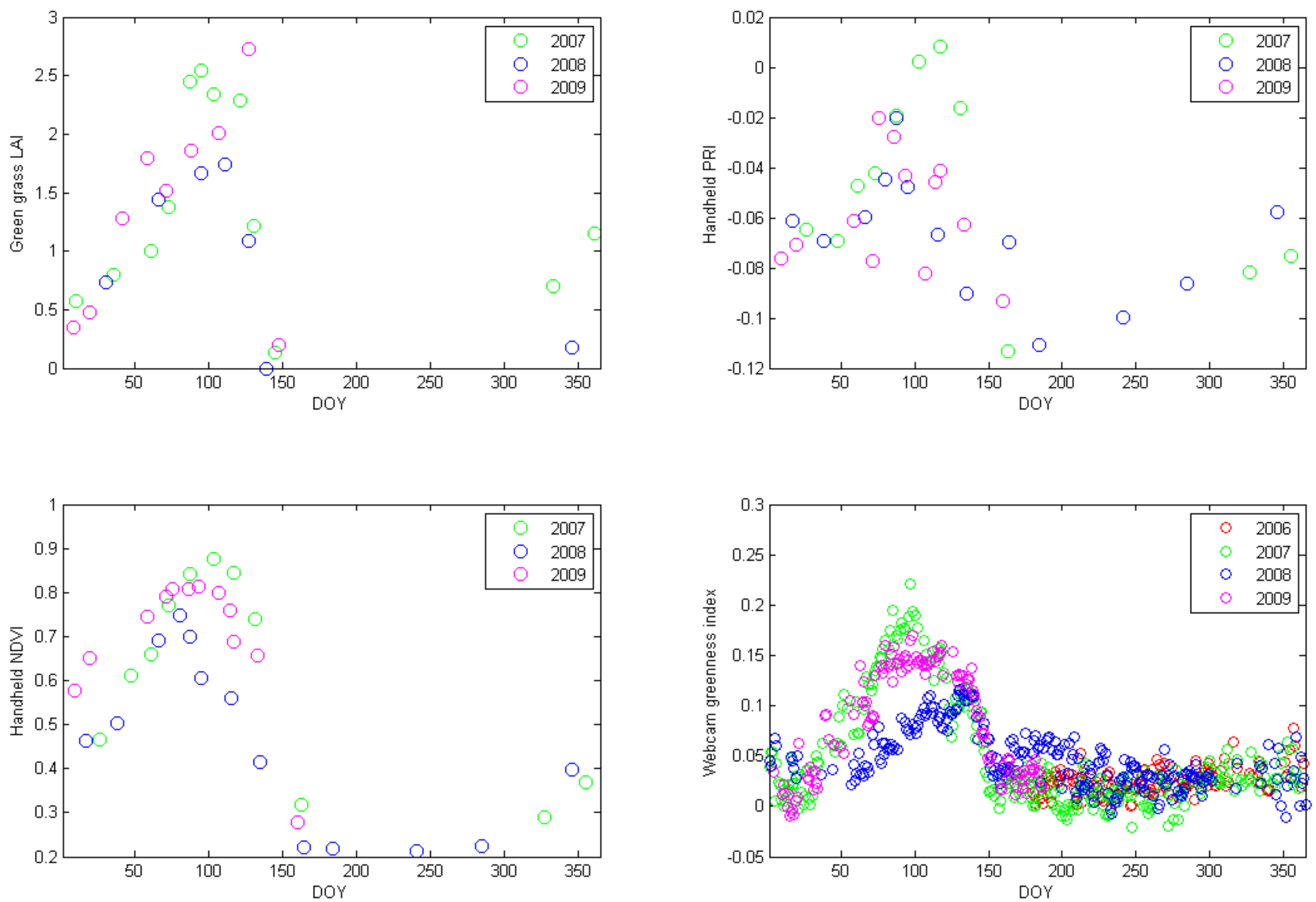

(a) Tonzi tree canopy
$2G_s-R_s-B_s$
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
2006
2007
2008
2009
2010
(b) Tonzi grass
$2G_s-R_s-B_s$
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
2006
2007
2008
2009
2010
(c) Vaira grass
$2G_w-R_w-B_w$
0.20
0.15
0.10
0.05
0.00
-0.05
2006
2007
2008
2009
2010


Annual Grassland, 2004-2005
Reflectance
Wavelength (nm)
0.0
0.2
0.4
0.6
0.8
1.0
400
500
600
700
800
900
1000
Oct 13, 2004
Oct 27, 2004
Nov 11, 2004
Jan 5, 2005
Feb 2, 2005
Apr 1, 2005
Mar 9, 2005
May 11, 2005
Dec 29, 2005

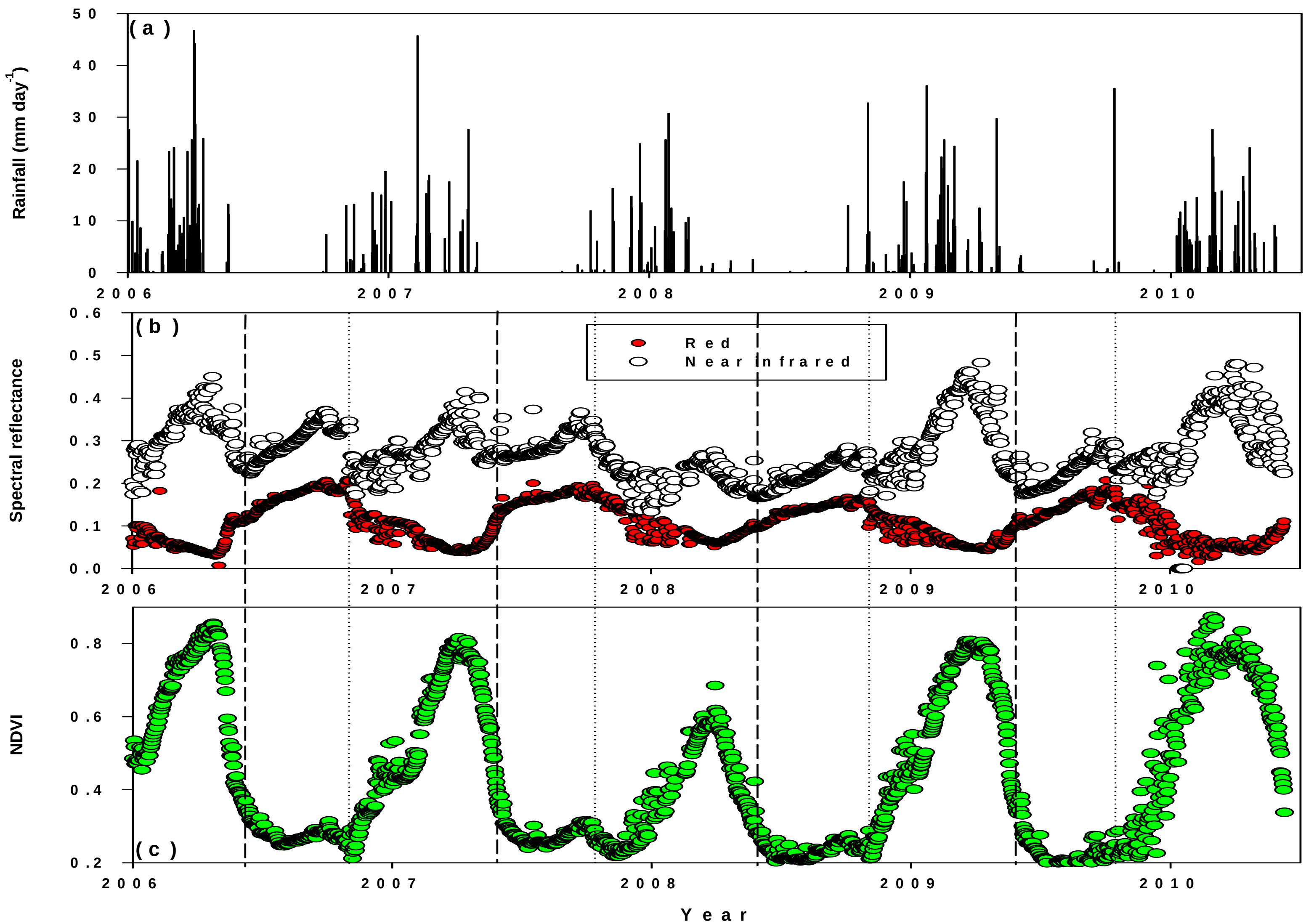


Rice, 2013
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Reflectance
500
600
700
800
900
Wavelength
D116
D144
D172
D178
D226

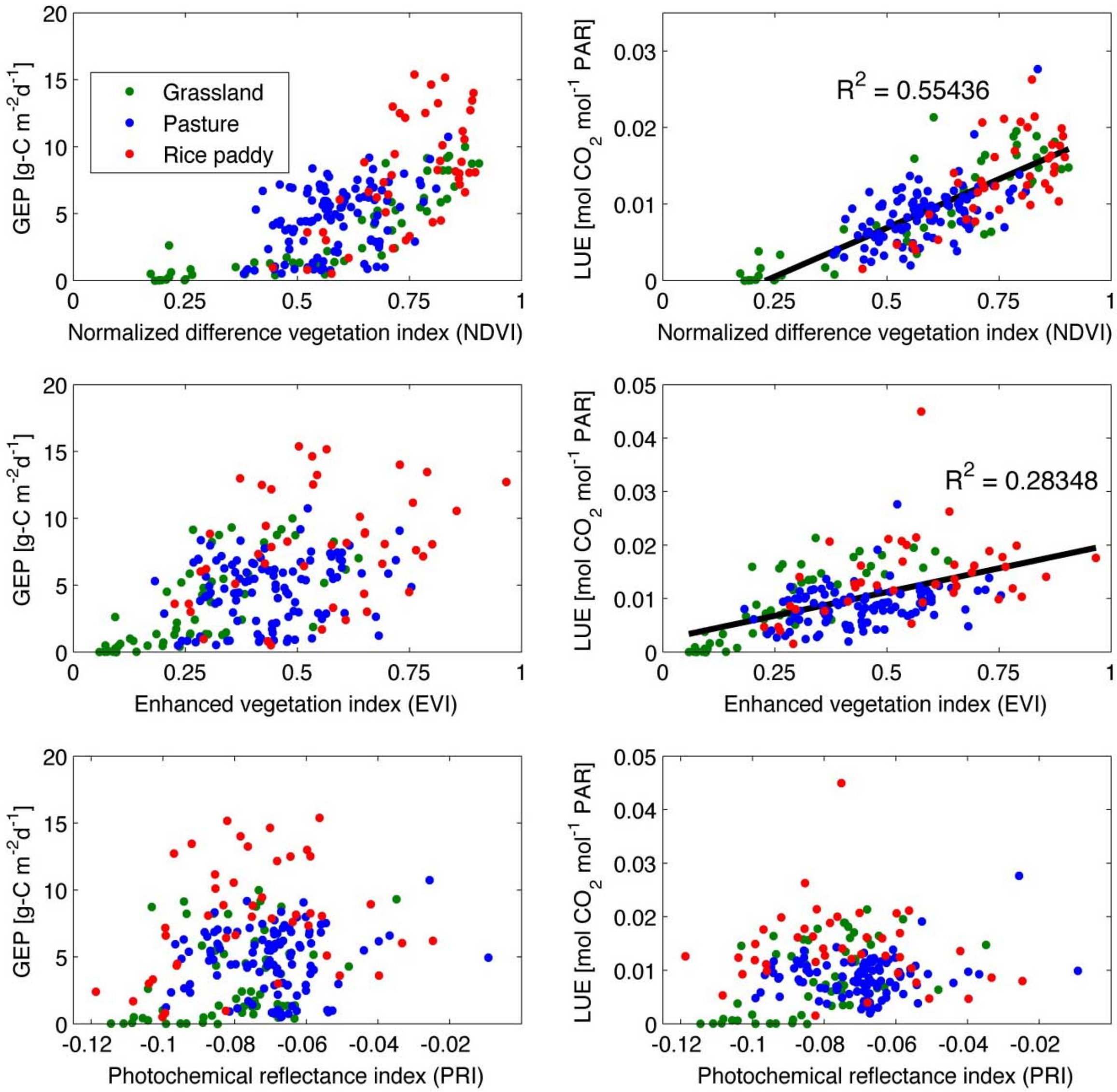
Seasonality of Remote Sensing Indices, annual grassland



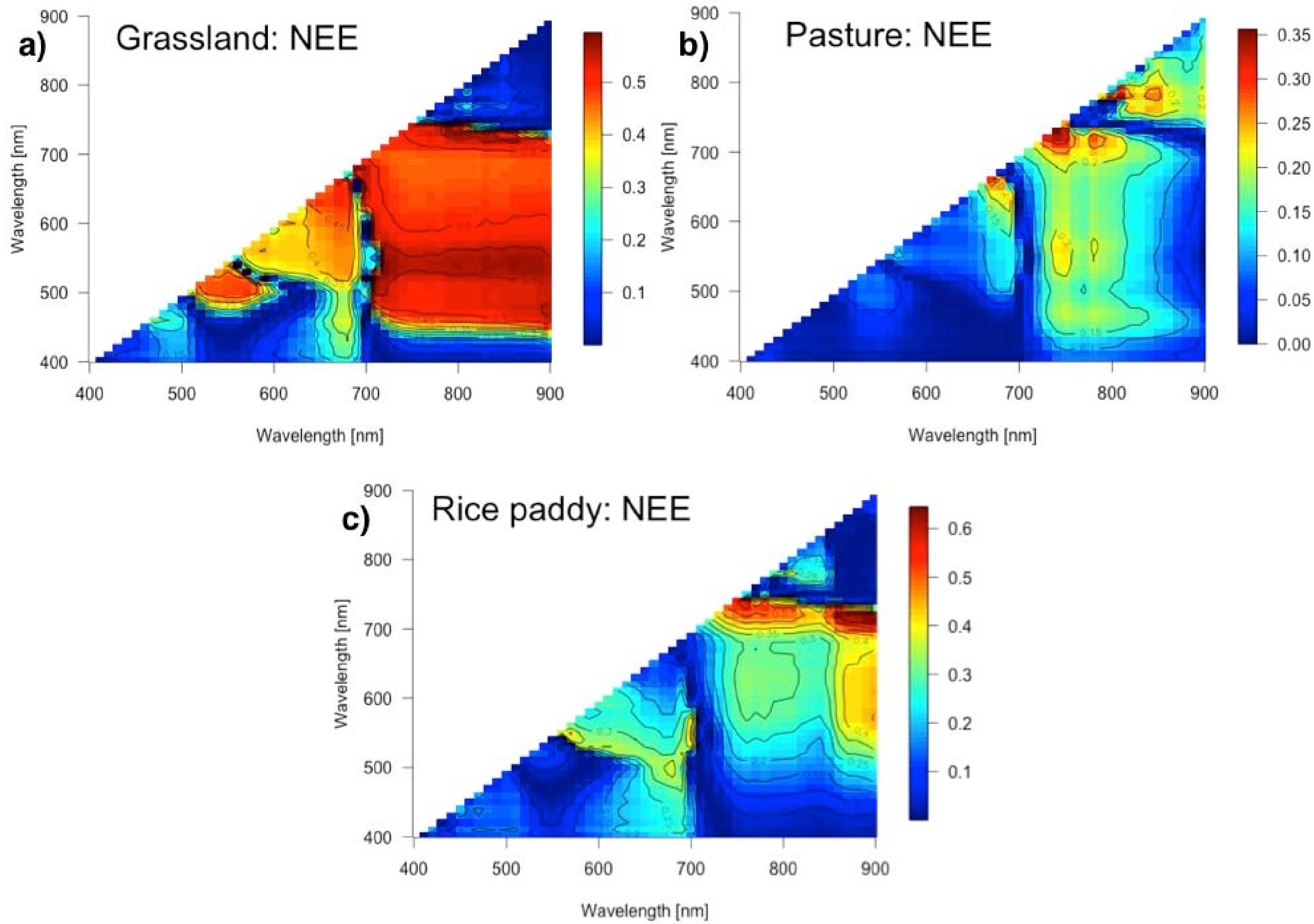
Interannual Variability



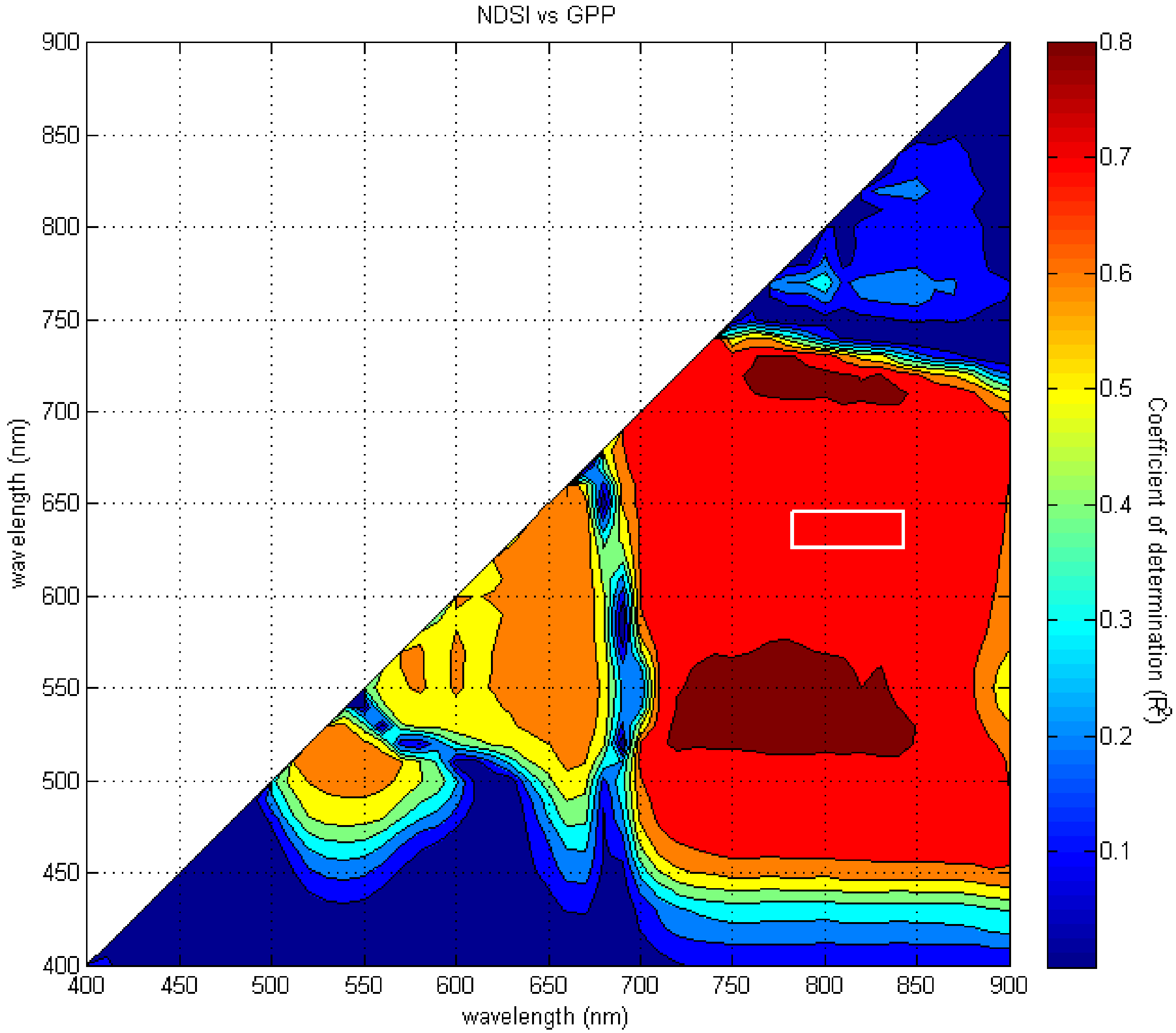
Ryu et al.

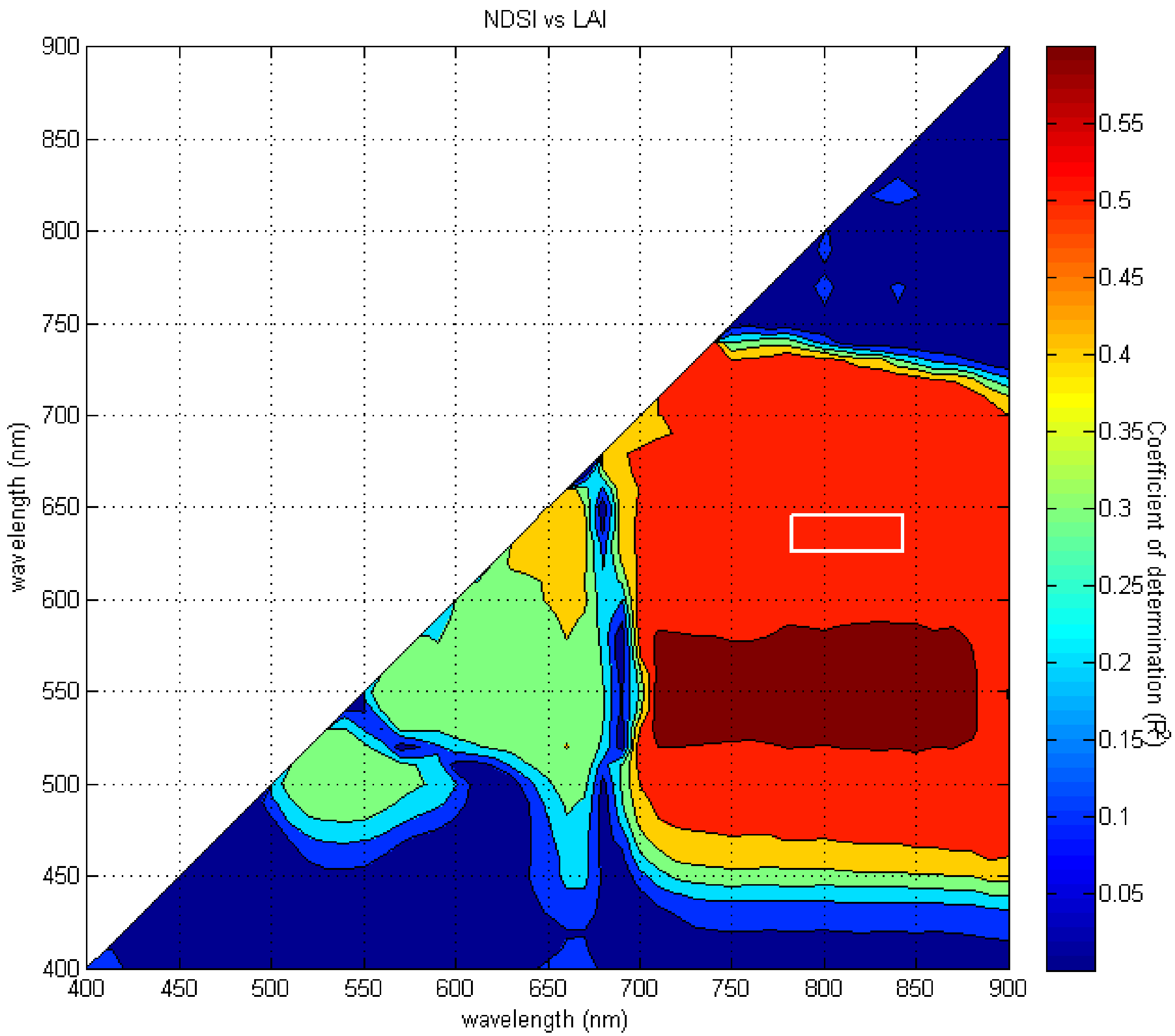


Jaclyn Hatala, PhD dissertation

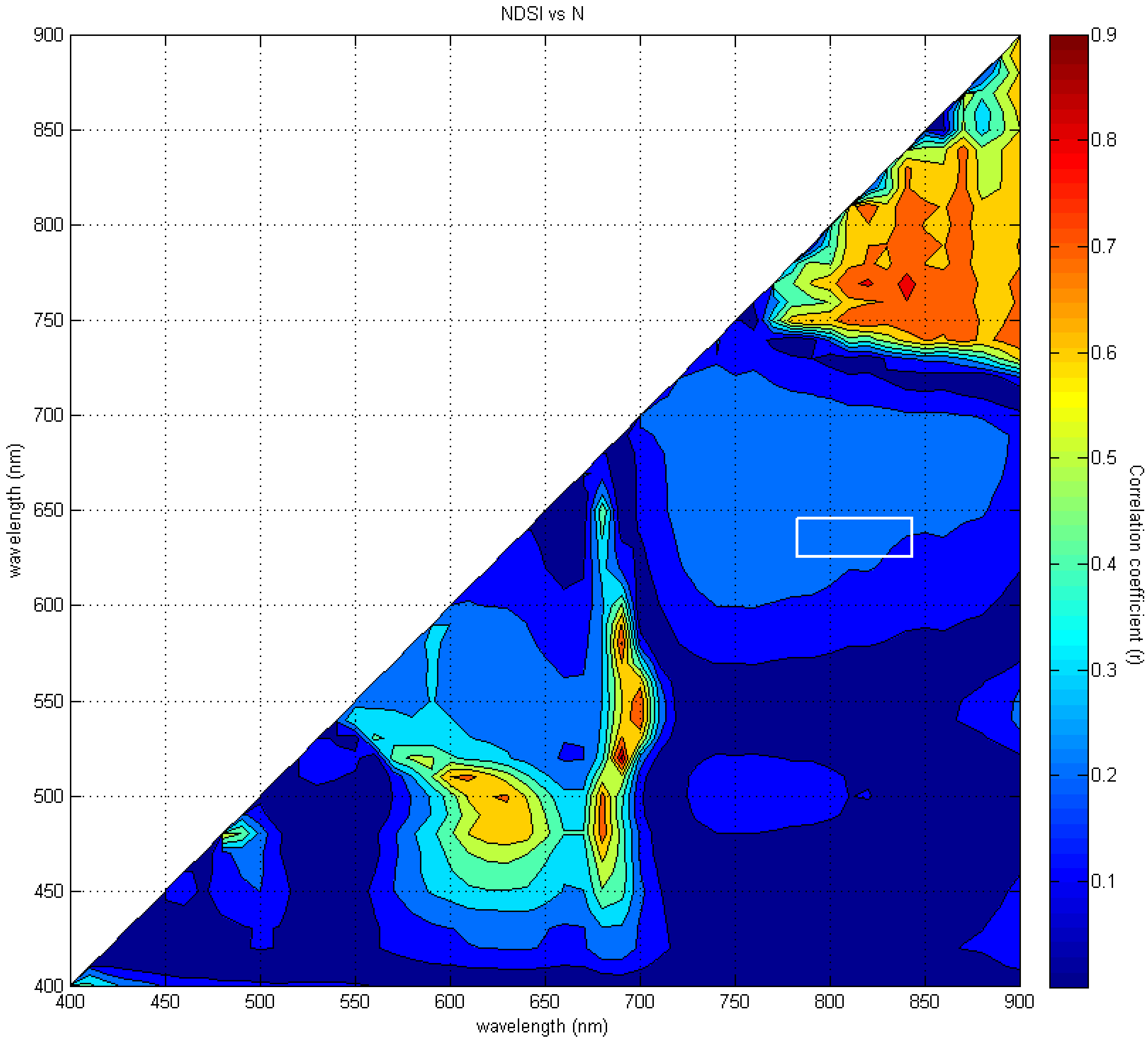


Jaclyn Hatala, PhD dissertation


NDSI vs GPP
900
850
800
750
700
650
600
550
500
450
400
wavelength (nm)
400 450 500 550 600 650 700 750 800 850 900
wavelength (nm)
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Coefficient of determination (R^2)

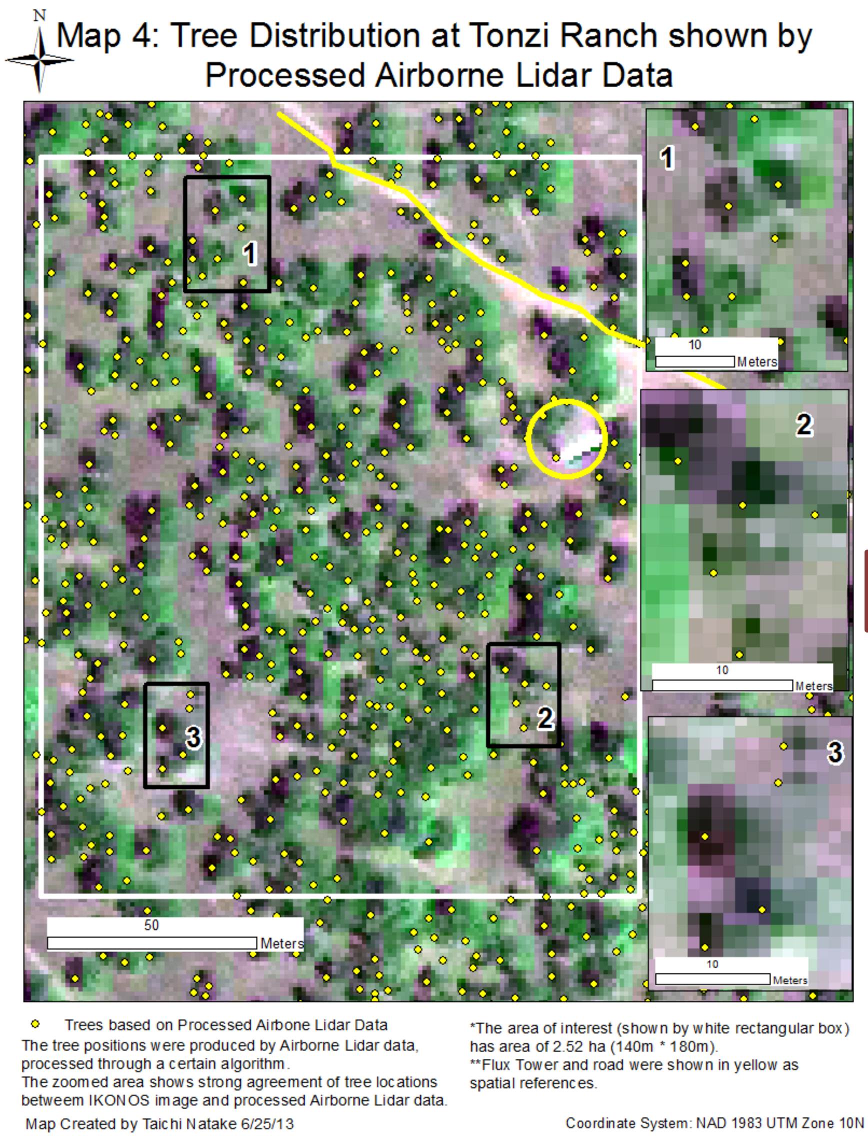


NDSI vs LAI
900
850
800
750
700
650
600
550
500
450
400
wavelength (nm)
400 450 500 550 600 650 700 750 800 850 900
wavelength (nm)
0.55
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
Coefficient of determination (R²)

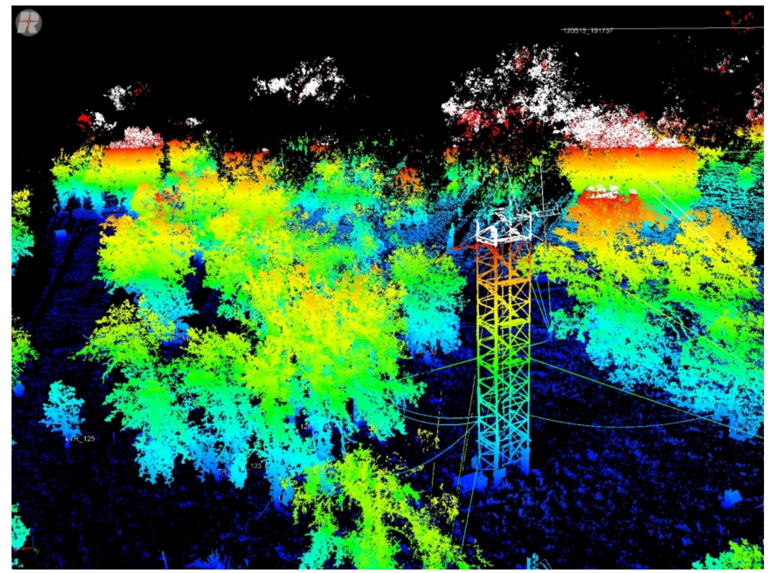


NDSI vs N
900
850
800
750
700
650
600
550
500
450
400
wavelength (nm)
400
450
500
550
600
650
700
750
800
850
900
wavelength (nm)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Correlation coefficient (r)

Method: Comparing Tree Location, Height and Crown Size



V.S.

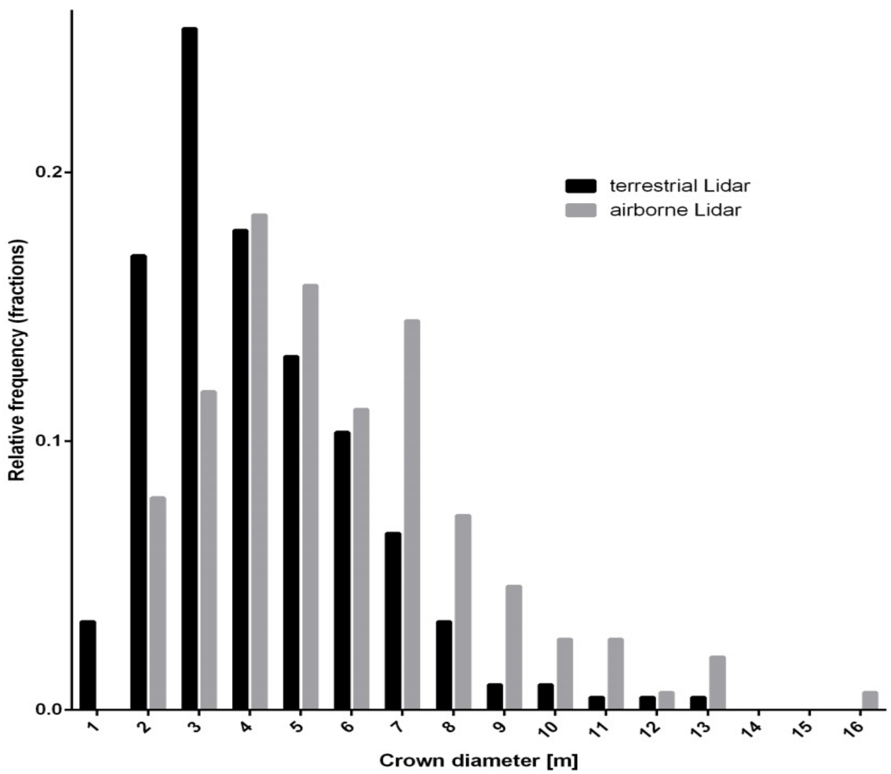


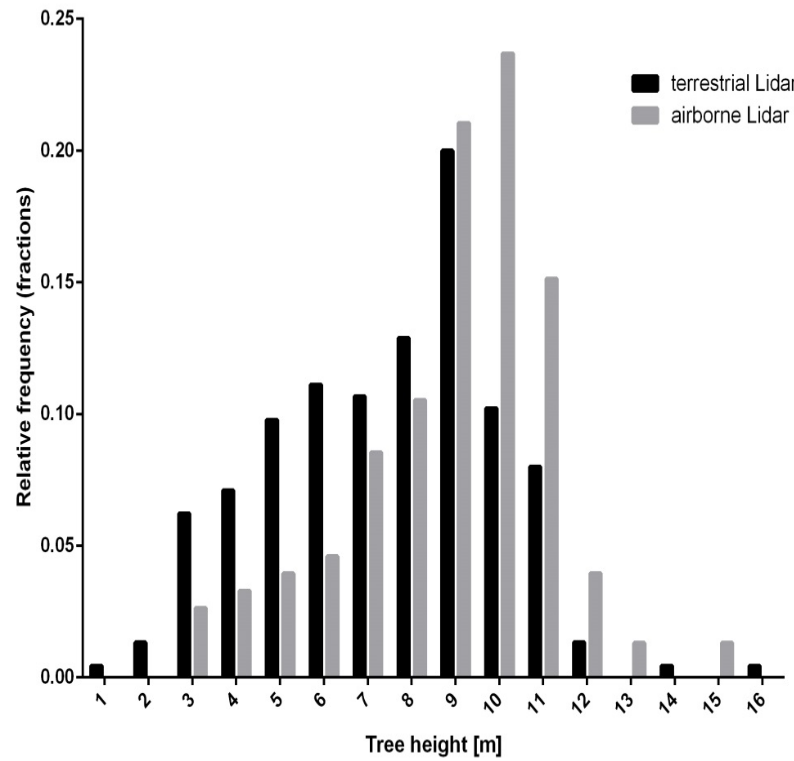
Processing Demo:

[Demo_Files\Terrest_Tree_Demo.mp4]

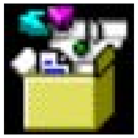
Airborne data was processed by Chen et al. 2006

Result2: Comparison of Tree Characteristics



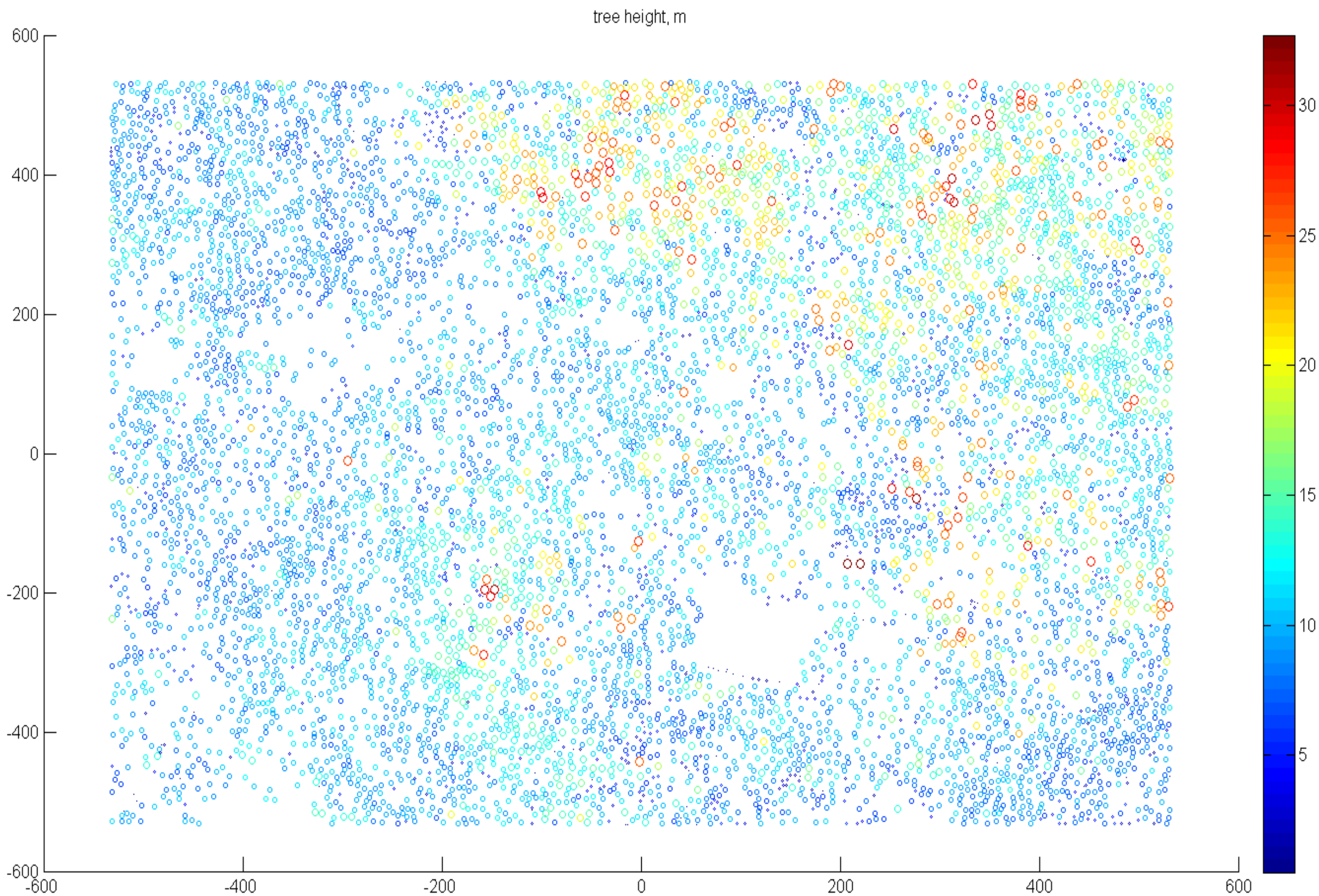


Differences between Airborne and Terrestrial LIDAR data might be significant to Radiative Transfer Model

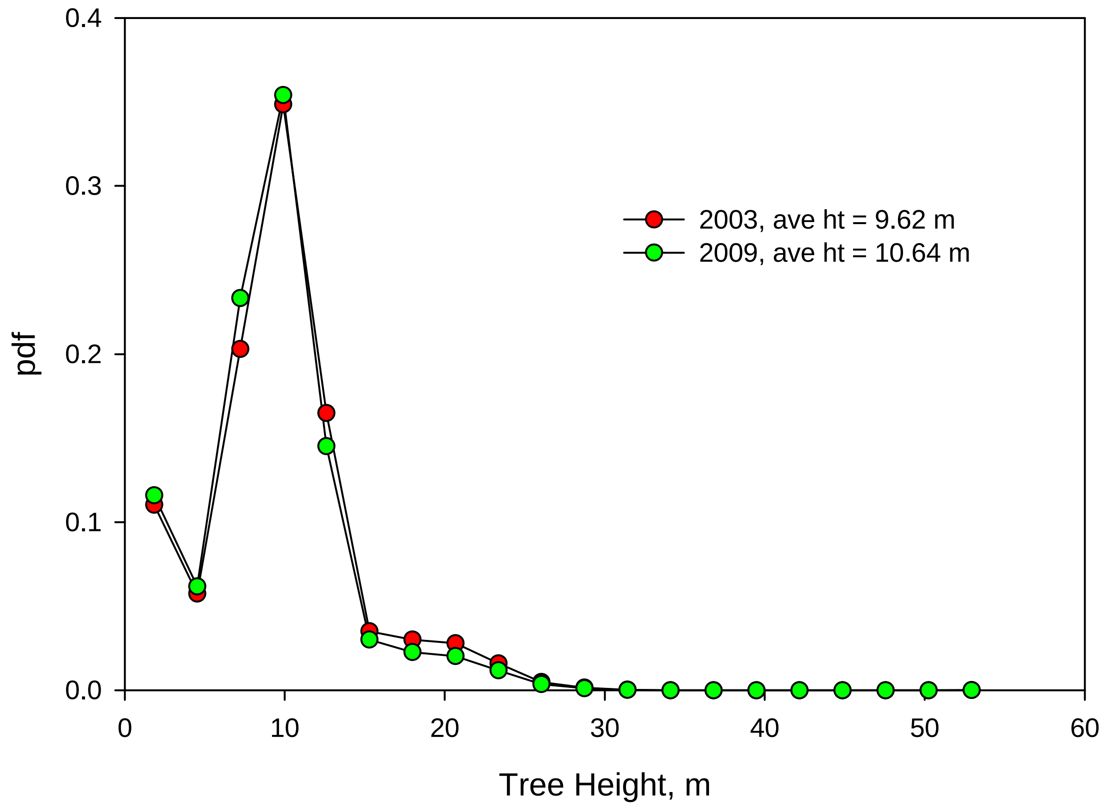


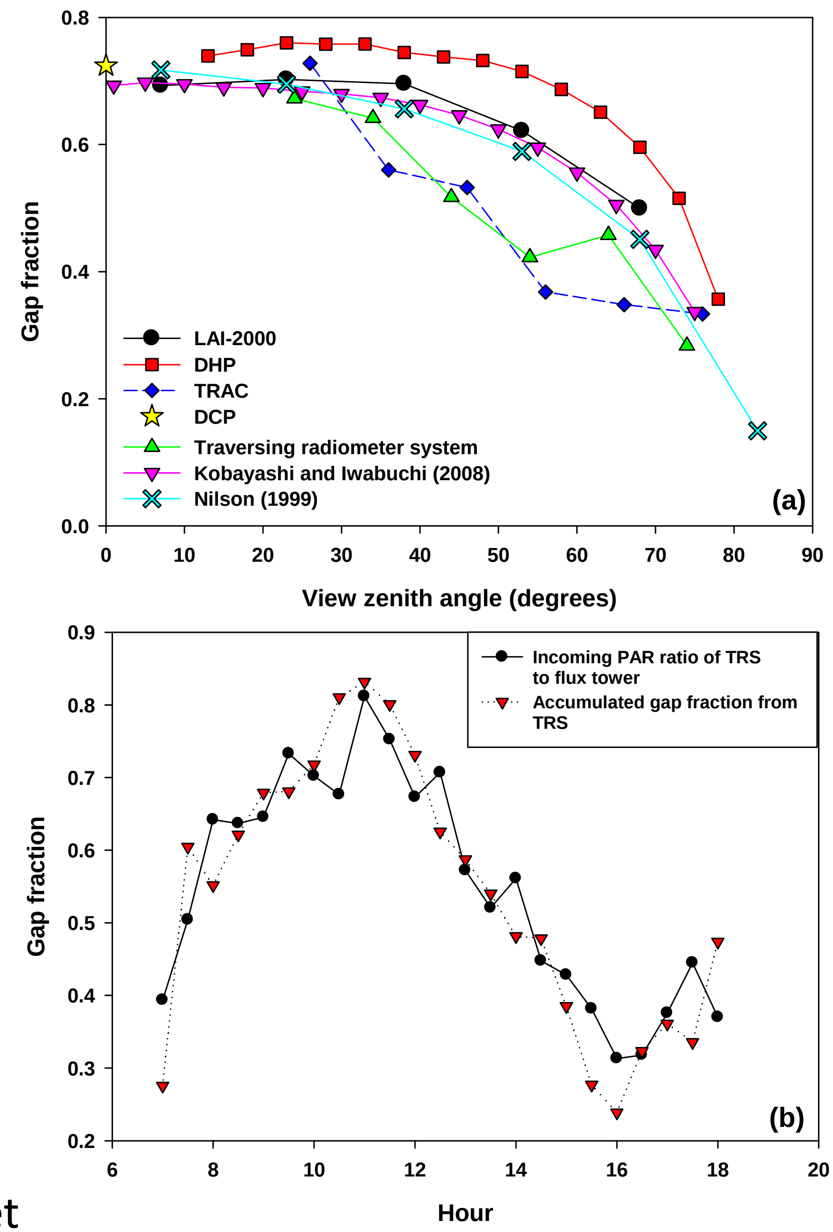
(.avi)

LIDAR derived map of Tree location and Height

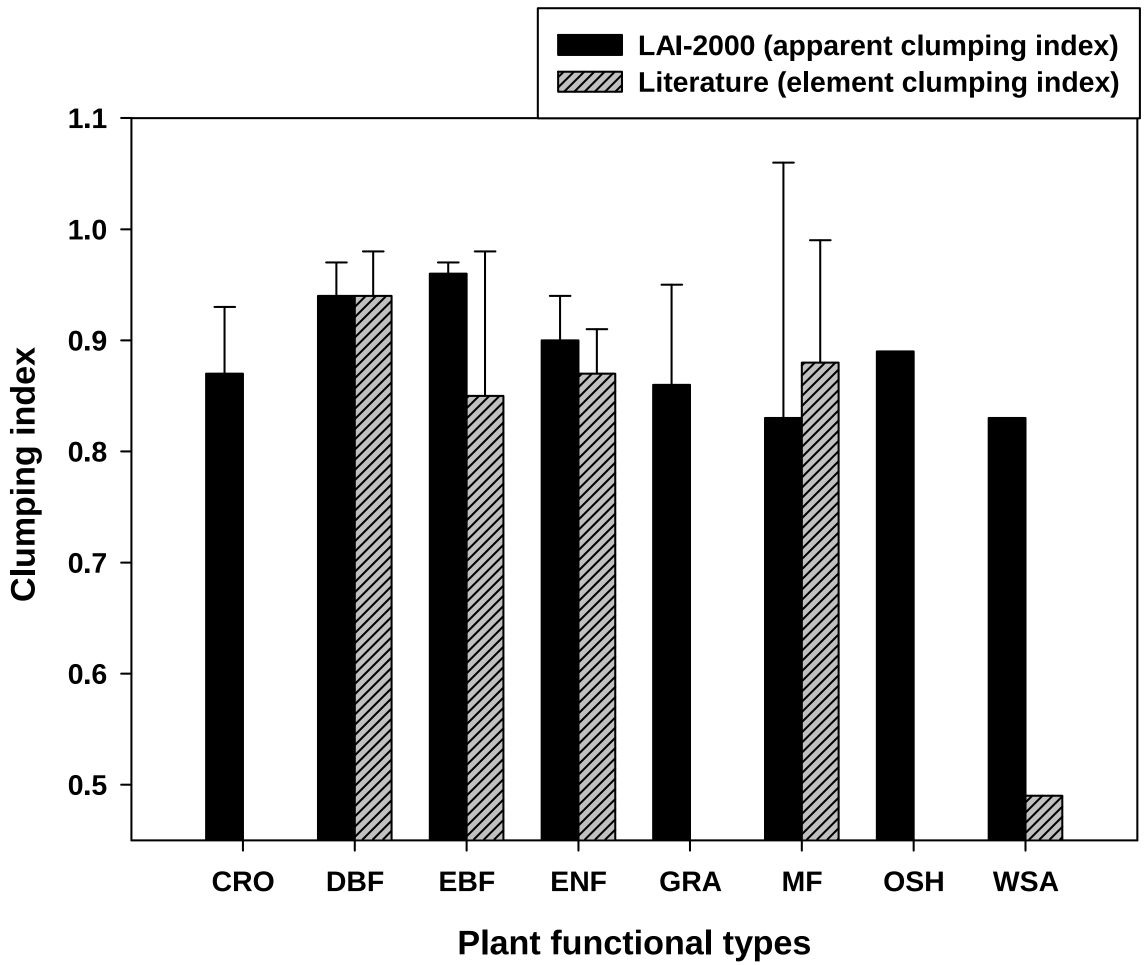


LIDAR Measurements of Tree Height
Oak Savanna, Ione, CA

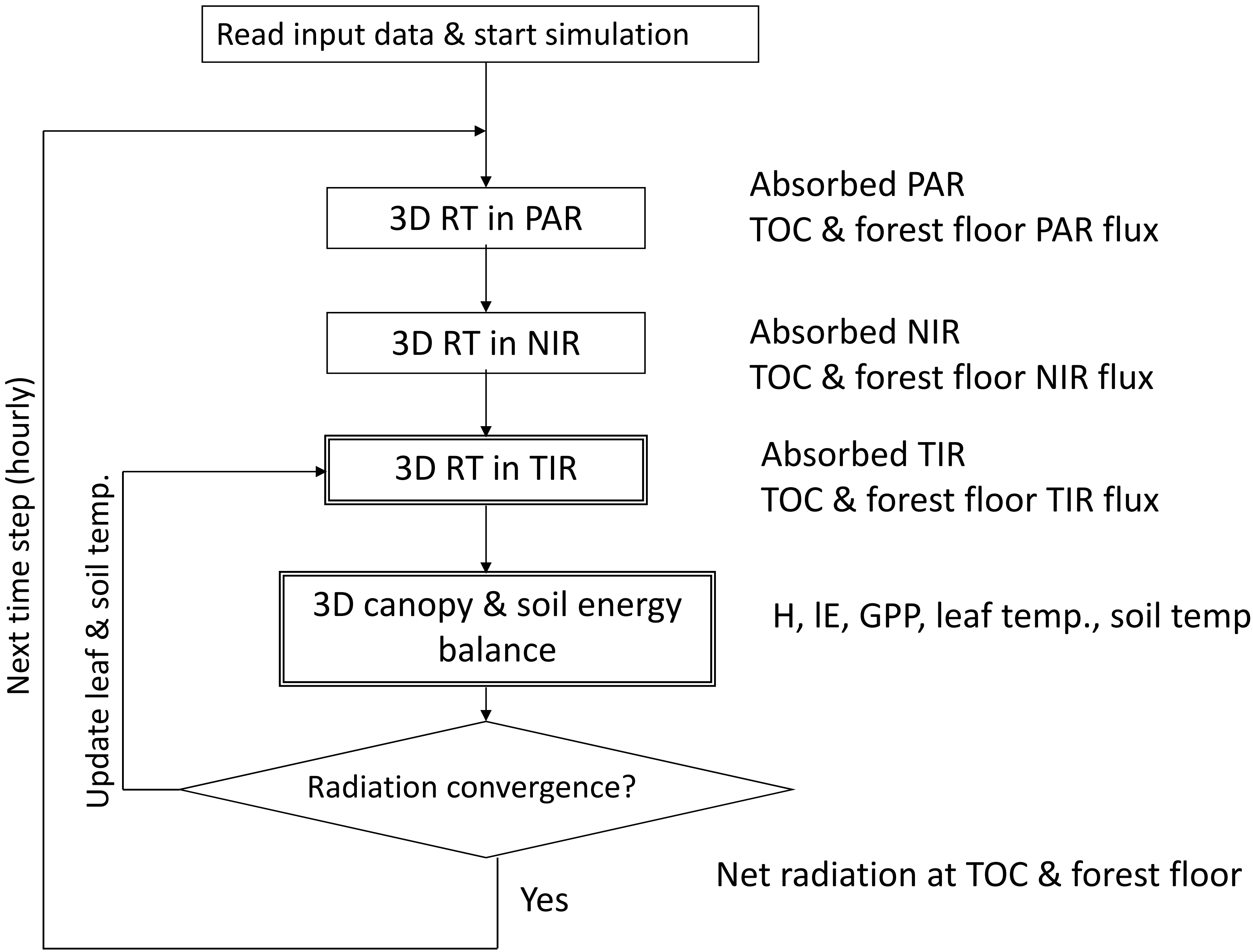




Ryu et al 2010 AgForMet

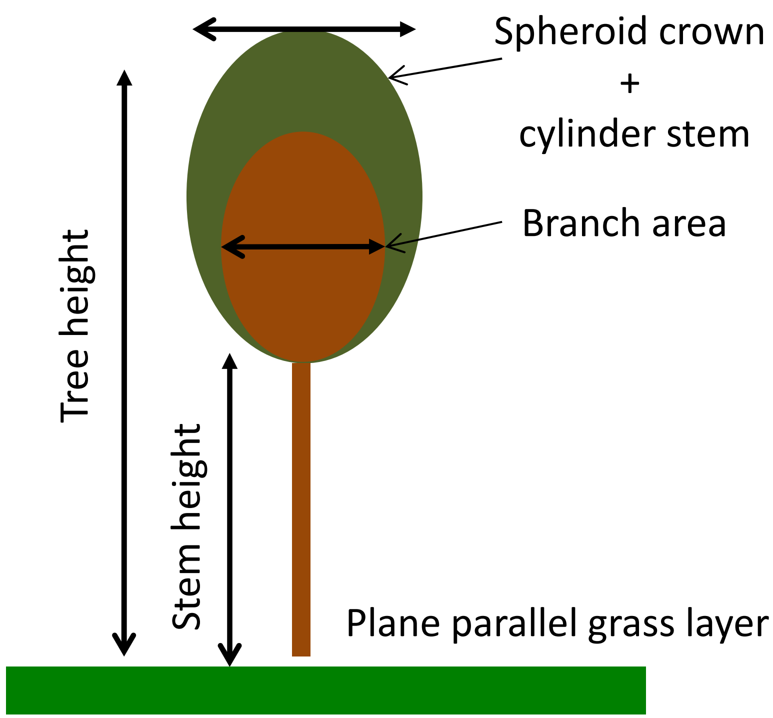


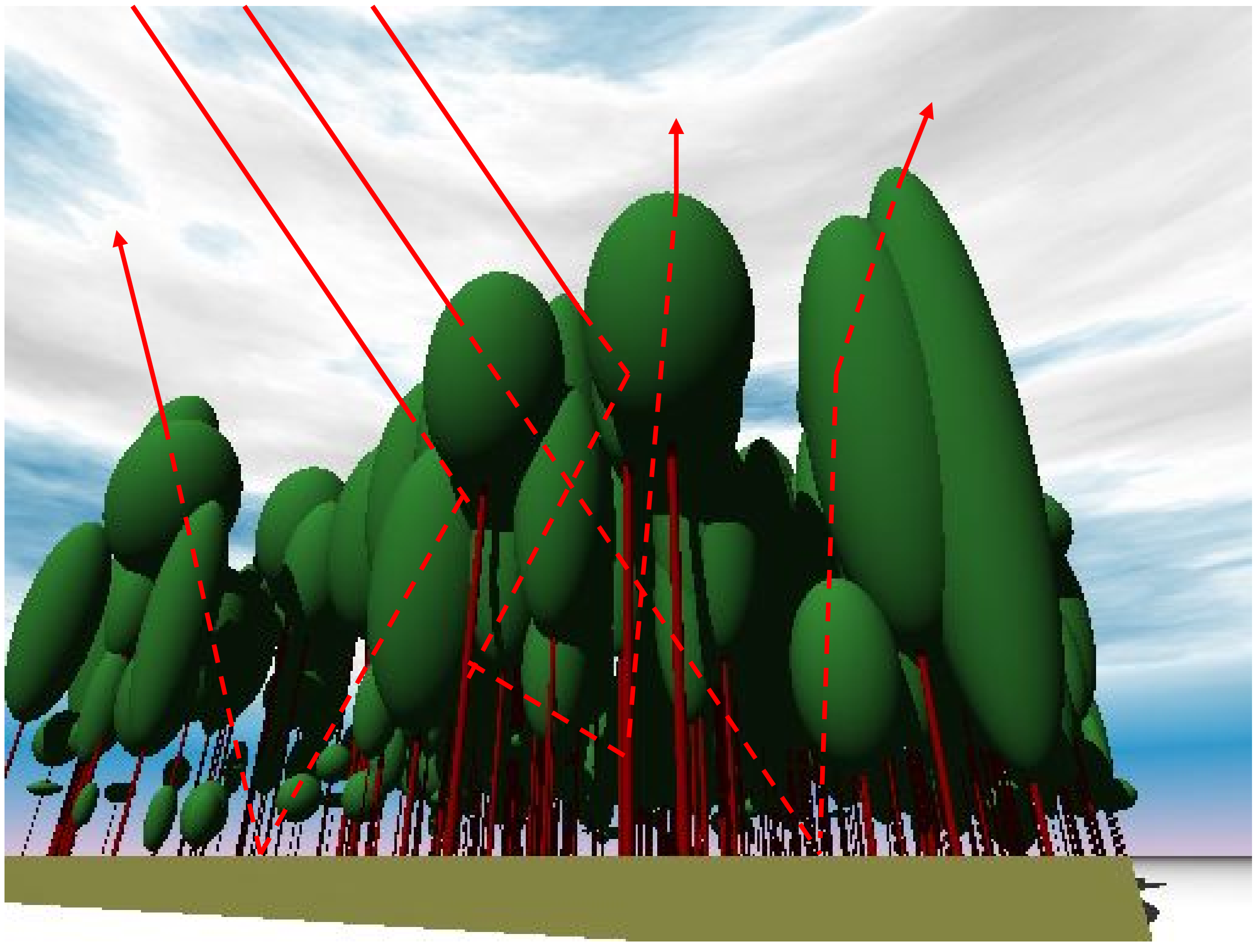
Ryu et al 2010 AgForMet



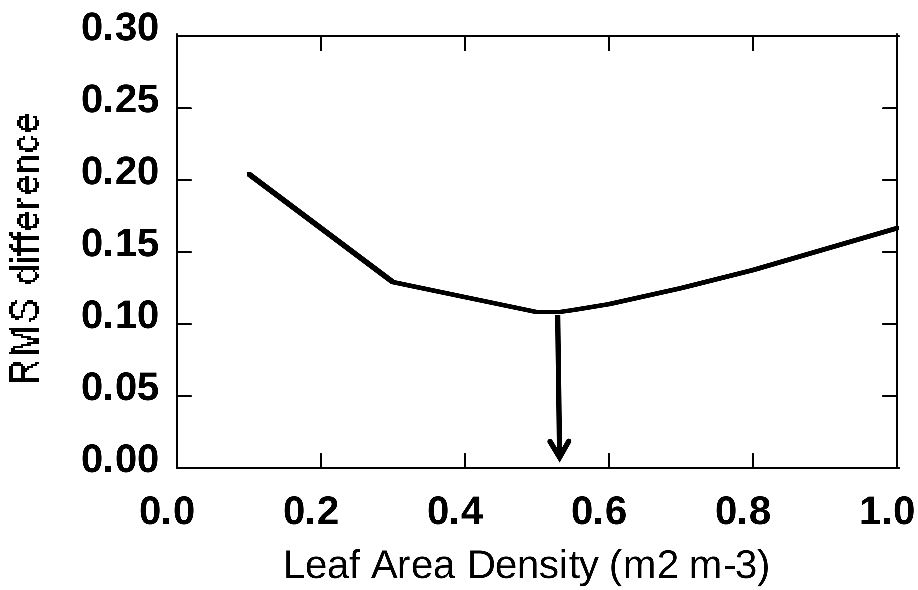
Read input data & start simulation
3D RT in PAR
Absorbed PAR
TOC & forest floor PAR flux
3D RT in NIR
Absorbed NIR
TOC & forest floor NIR flux
3D RT in TIR
Absorbed TIR
TOC & forest floor TIR flux
3D canopy & soil energy balance
H, lE, GPP, leaf temp., soil temp.
Radiation convergence?
Update leaf & soil temp.
Next time step (hourly)
Yes
Net radiation at TOC & forest floor

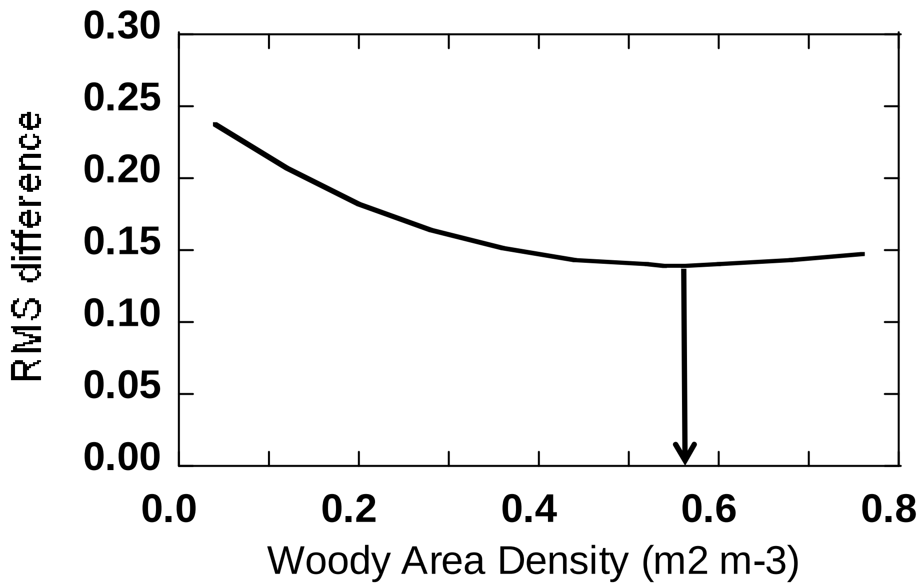
Model assumption of canopy shape





Comparison of simulated and observed gap fraction (RMS error)

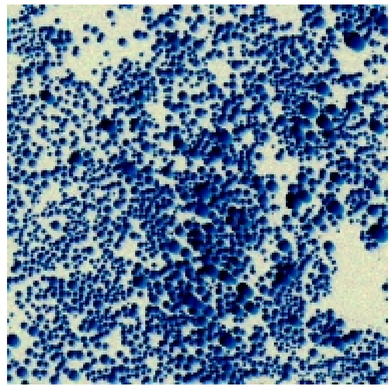




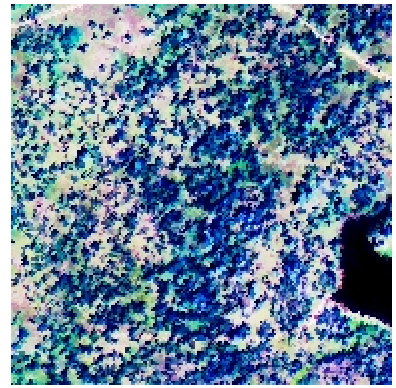
Simulated images (RGB composite)

5/12/2006

Simulation

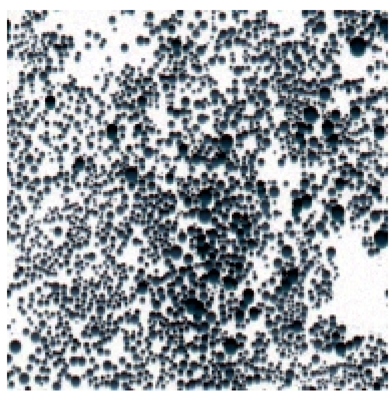


AVIRIS

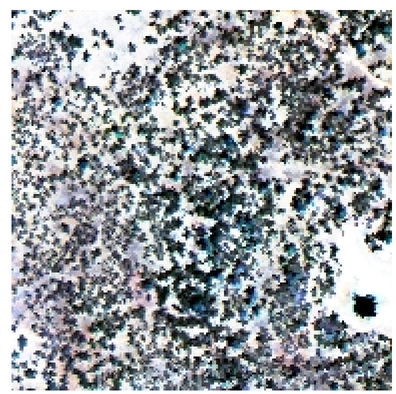


8/5/2007

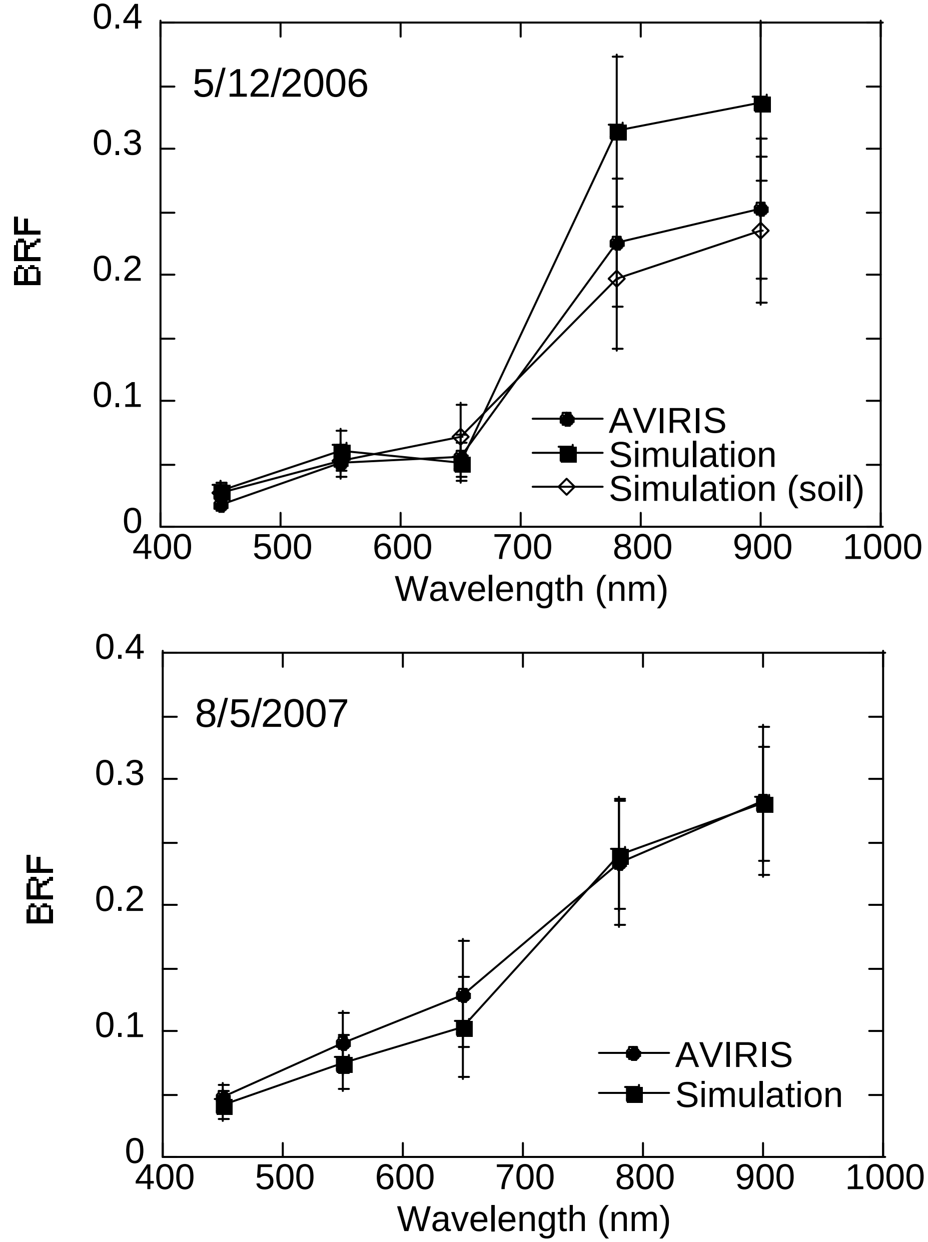
Simulation



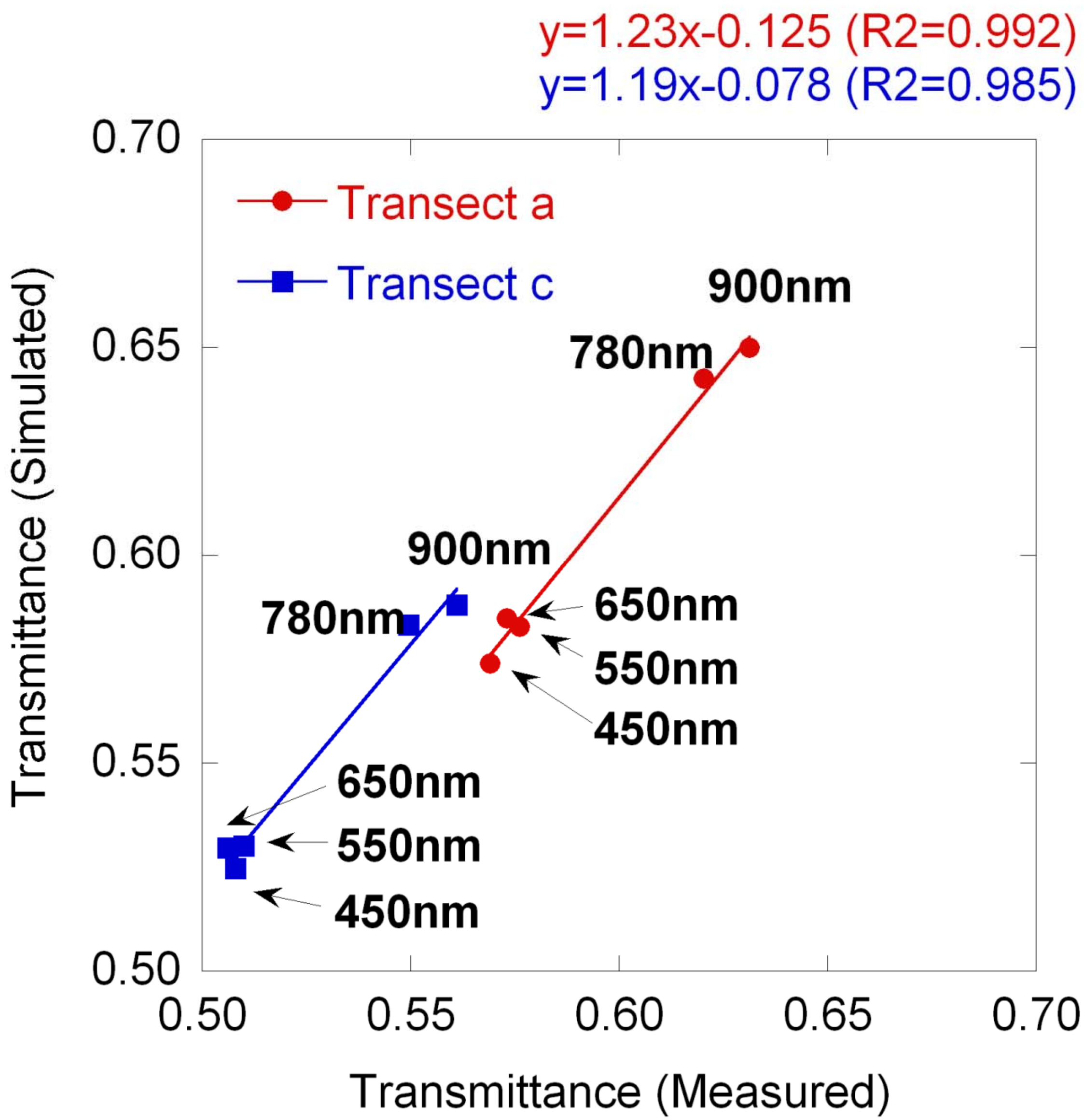
AVIRIS



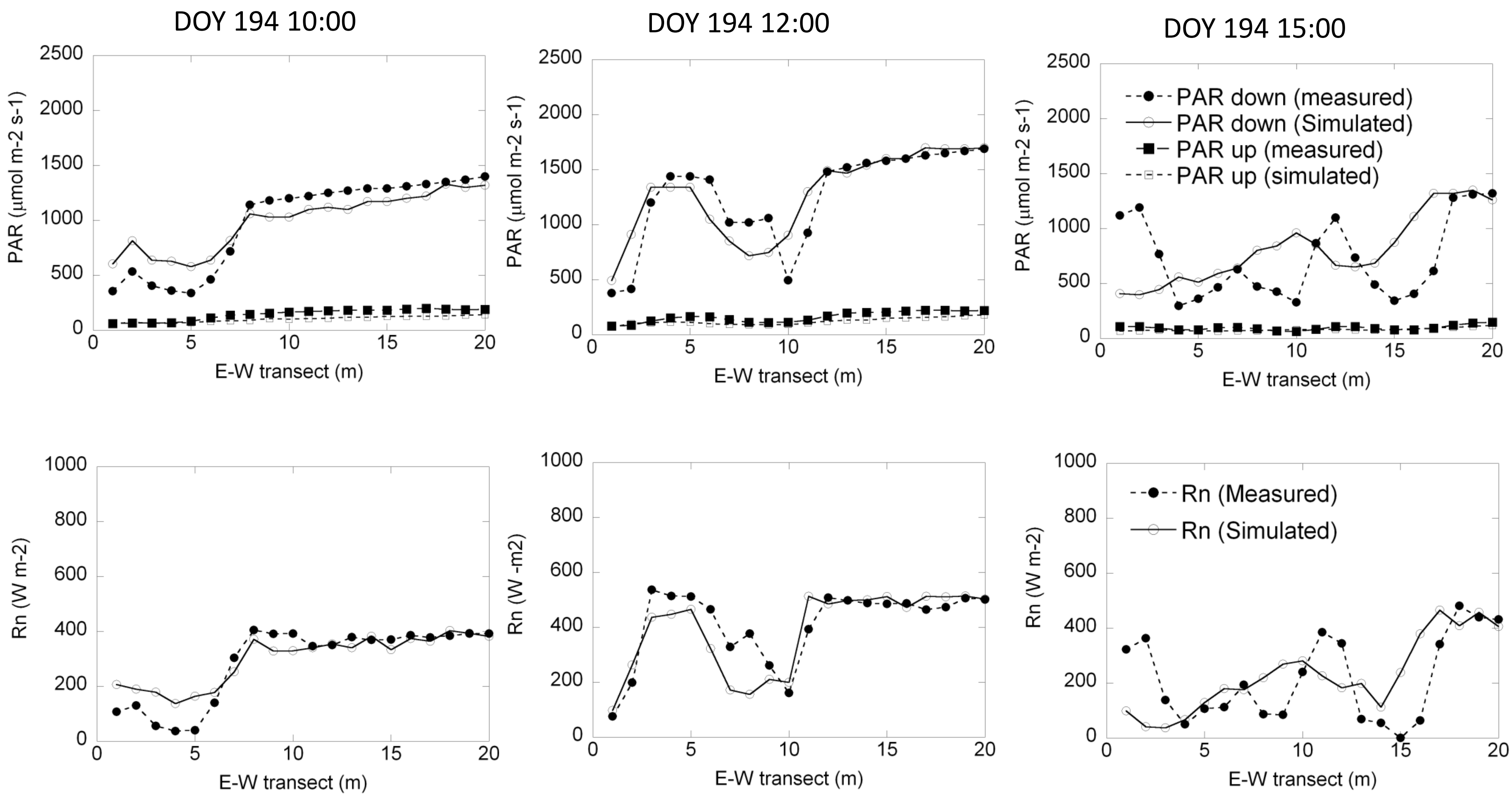
Comparisons of landscape average simulated and AVIRS reflectance



Comparisons of simulated and measured spectral transmittance

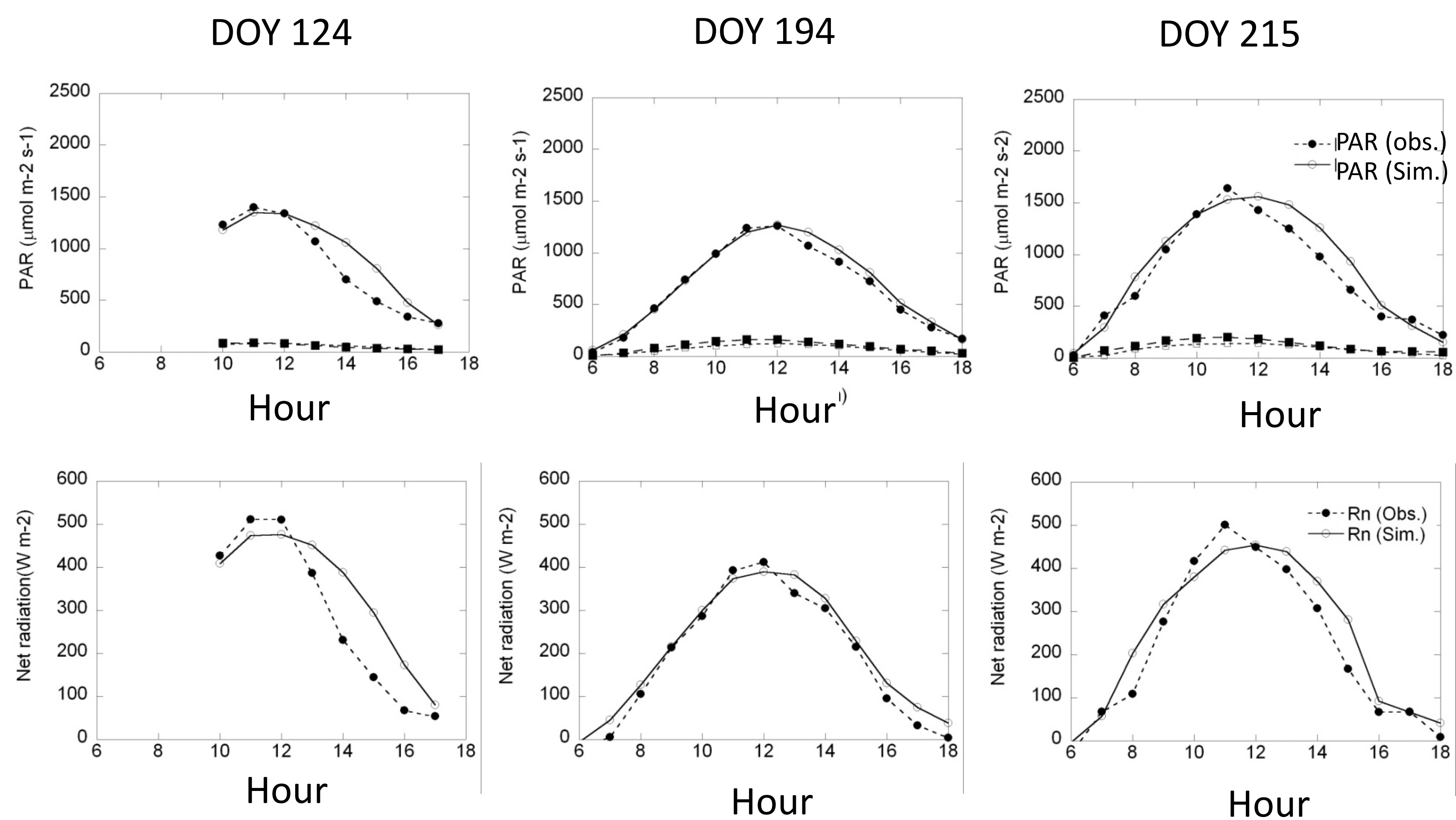


Simulated and measured understory radiations along the 20m transect

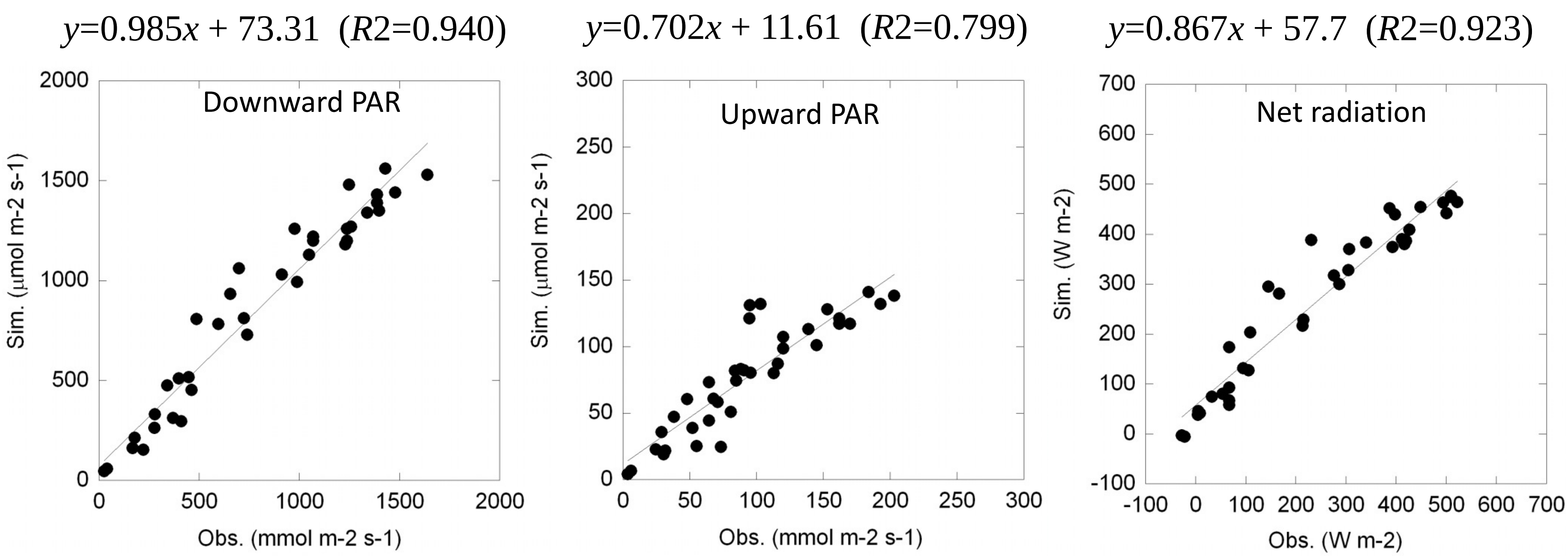


Comparison of simulated and tram-measured PAR and net radiation

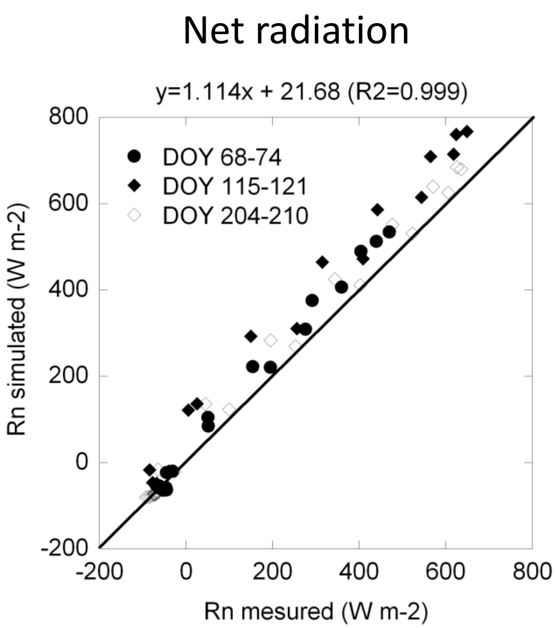
Each point is an average of 20m tram transect

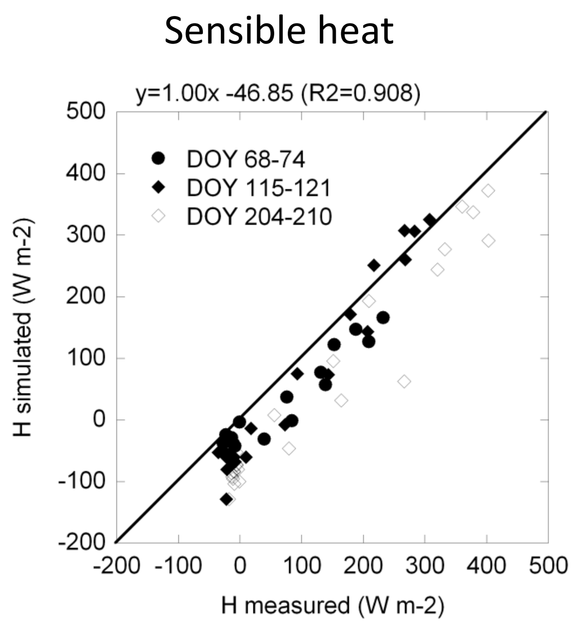


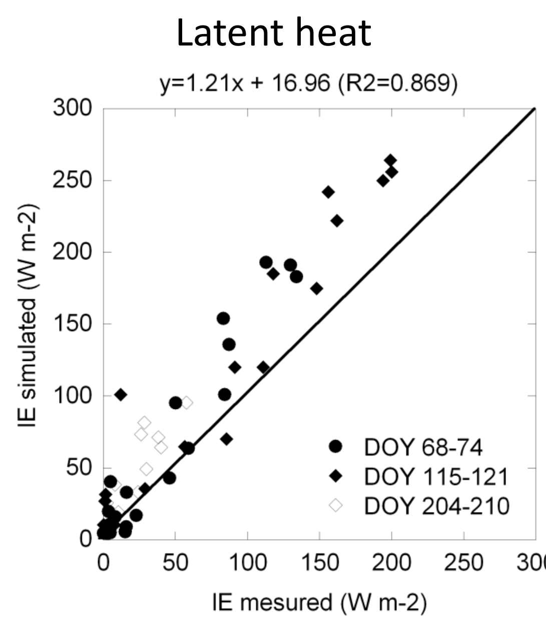
Comparison of simulated and tram based radiation measurements



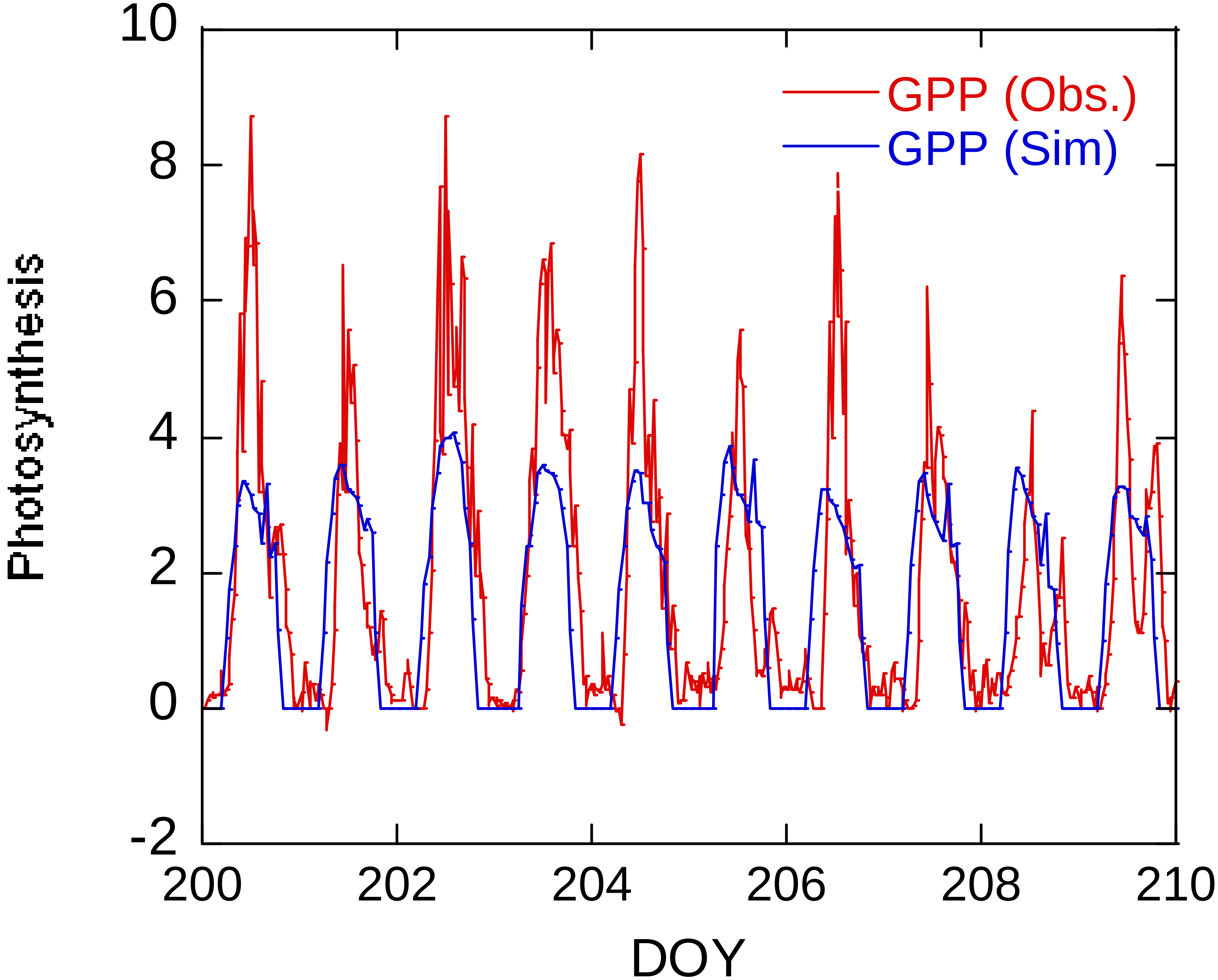
Comparison of top of the tower net radiation, sensible heat and latent heat





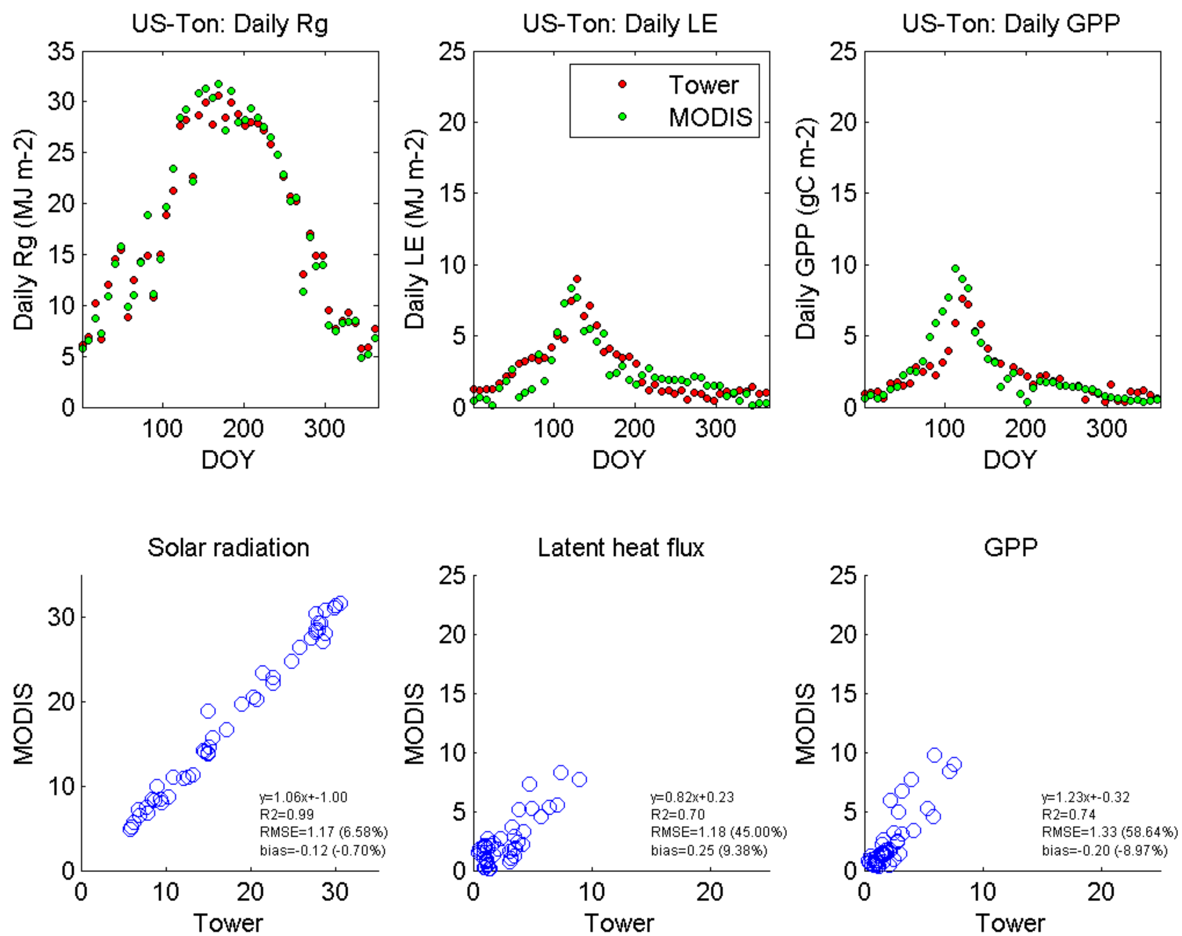


2008

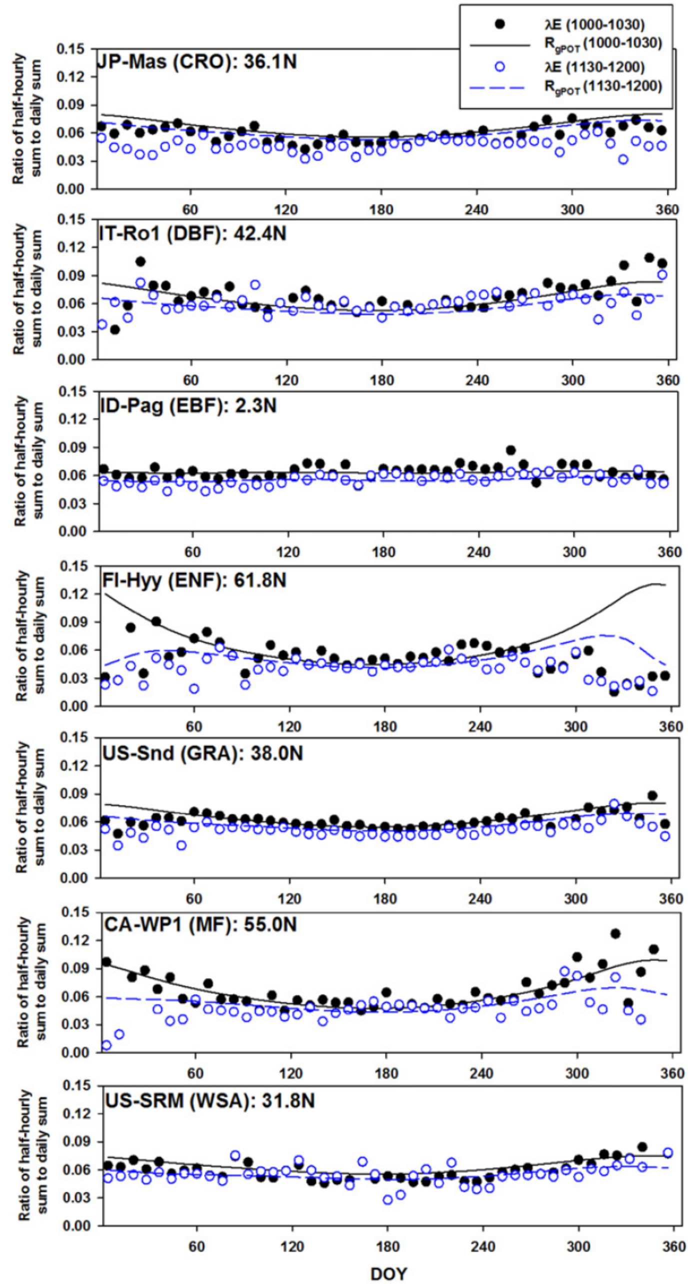


GPP (Obs.)
GPP (Sim)
Photosynthesis
10
8
6
4
2
0
-2
200
202
204
206
208
210
DOY

Validate Model Across FLUXNET



Ryu et al. 2012 Global Biogeochemical Cycles


λE (1000-1030)
R_{gPOT} (1000-1030)
λE (1130-1200)
R_{gPOT} (1130-1200)
JP-Mas (CRO): 36.1N
IT-Ro1 (DBF): 42.4N
ID-Pag (EBF): 2.3N
FI-Hyy (ENF): 61.8N
US-Snd (GRA): 38.0N
CA-WP1 (MF): 55.0N
US-SRM (WSA): 31.8N
Ratio of half-hourly sum to daily sum
DOY