SiB4: New Developments and Results

CMMAP Summer Team Meeting

Multi-Scale Land Surface Session

August 7, 2013

SiB4 Overview

- Combines three SiB3 models
  - Prognostic phenology: SiB-pp (Stockli et al., 2008; 2011)
  - Crop: SiB-crop (Lokupitiya et al., 2009; Corbin et al., 2010)
  - Carbon pool: SiB-CASA (Schaefer et al., 2008)
- 11 above/below ground pools
- 22 plant functional types (PFTs)
- Calculates photosynthesis every time-step using enzyme kinetics
- Releases carbon every time-step via autotrophic and heterotrophic respiration
  - Depends on carbon pool sizes
  - Uses prescribed turnover times and exchange coefficients
- Updates carbon pools daily
  - Calculates leaf area index (LAI) from the leaf pool
- Allocates carbon using environmental factors
  - Temperature, moisture, light, growing degree day
- Fully prognostic system

SiB4 Simulation

- 1997-2008
- MODIS 1-km PFT map (20 PFTs; Lawrence et al., 2007)
- 0.5-degree crop map
  (Ramankutty et al., 2008; Monfreda et al., 2008)
- 1-degree soil map downloaded from ORNL DAAC (Global Soil Data Task Group, 2000)
- MERRA driver data
  - Precipitation scaled to GPCP 1-degree data
- Initial carbon pool, soil moisture, and other prognostic variables set to generic PFT values
- Annual carbon fluxes balanced post simulation

Global Comparisons

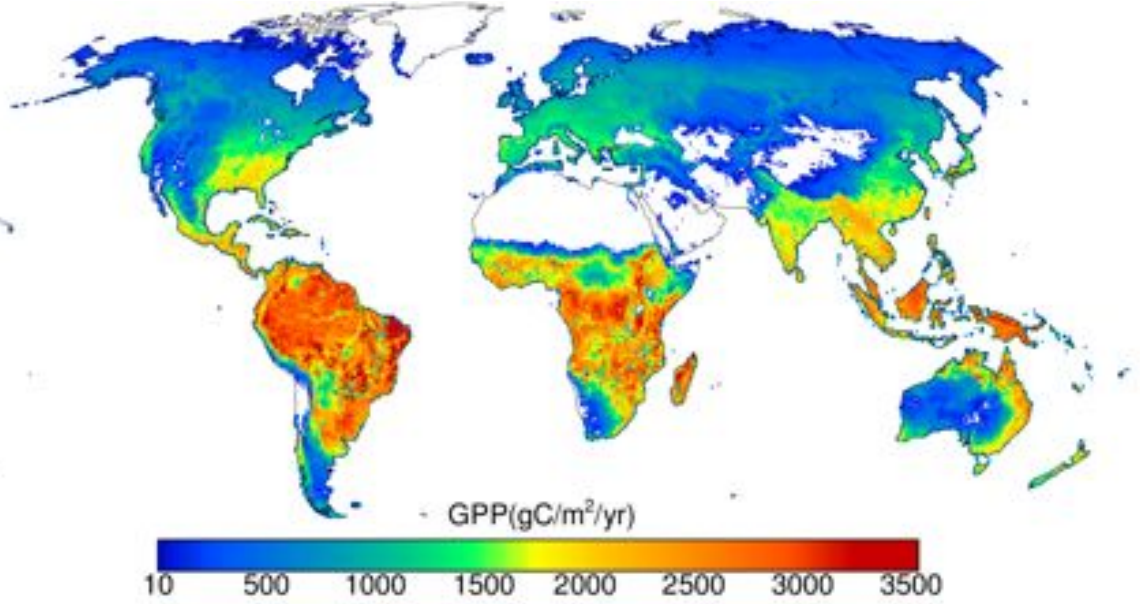
- Gross Primary Productivity (GPP)
  - Observational-based annual GPP from eddy covariance flux data and diagnostic models by Beer et al., 2010
  - Scaled-up eddy covariance flux data by Jung et al., 2011
- Above Ground Biomass (AGB)
  - Mapped biomass from satellite lidar by Saatchi et al., 2011
- Leaf Area Index (LAI)
  - MODIS/Terra monthly maps

Annual GPP

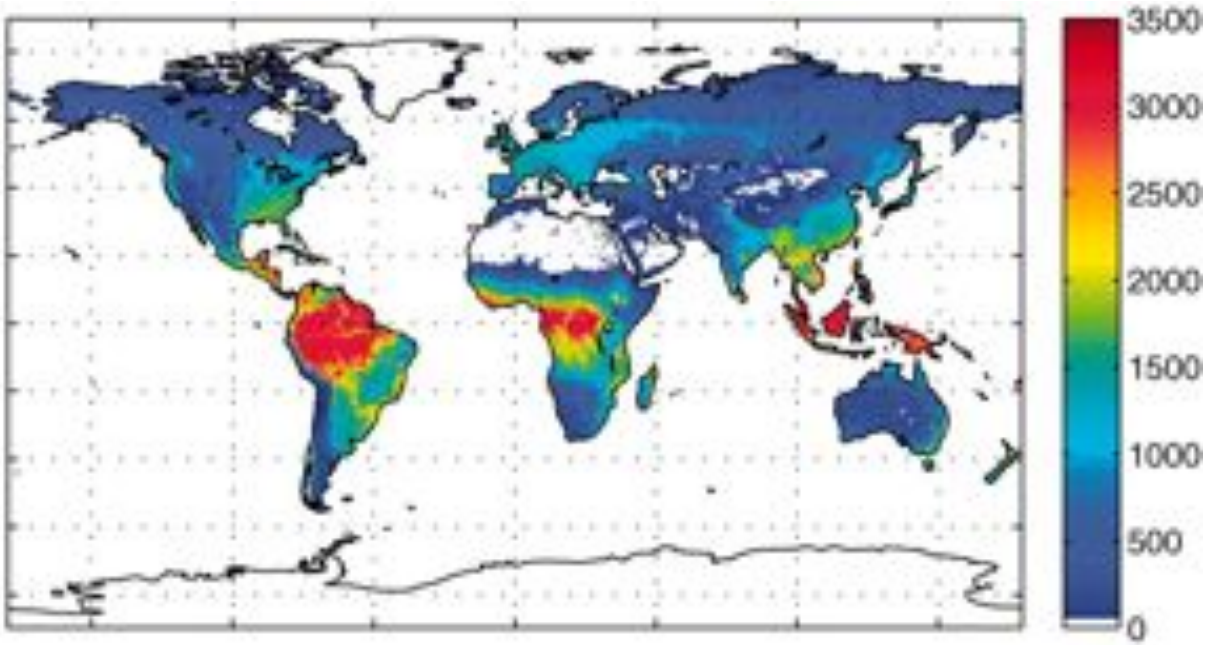
- Similar patterns / magnitudes
  - High GPP in the tropics, which decreases with latitude
  - High GPP over forested regions and croplands compared to grasslands

- SiB4 overestimates the GPP across broad regions
  - Extra-tropics, particularly in the southern hemisphere
  - Eastern North America, Europe and southeast Asia

SiB4



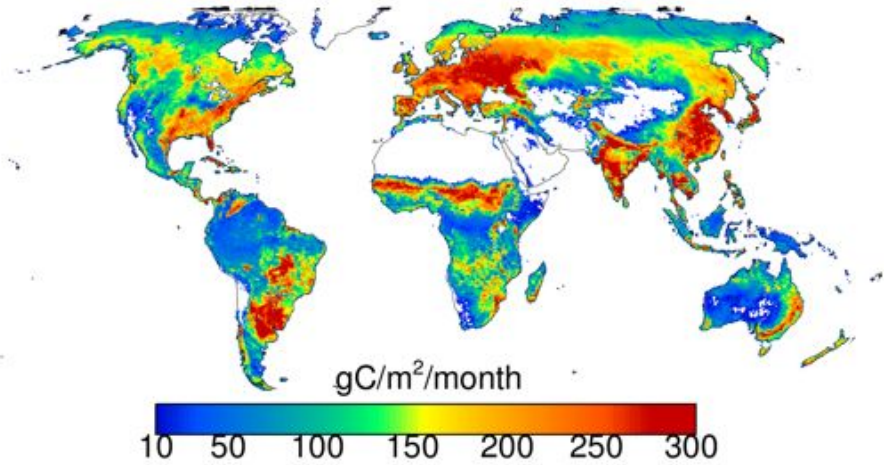
Beer et al. (2010)



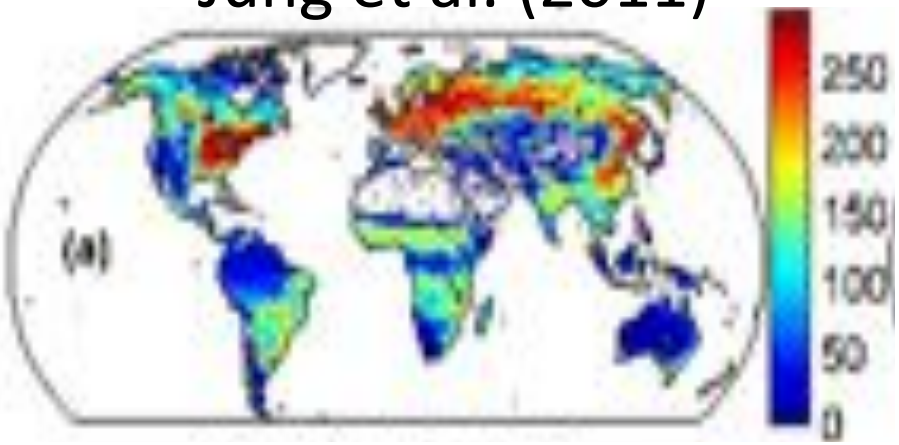
GPP Seasonal Cycle Amplitude

+ Largest seasonality in northern temperate forests
+ Minimal seasonality in tropical forests
+ SiB4 has larger seasonal cycles in the Sahel and the southern hemisphere

SiB4



Jung et al. (2011)



Annual GPP by Biome

Beer et al. (2010)			SiB4	
Biome	Area 10^{12} m^2	GPP (Pg C/yr)	GPP (Pg C/yr)	Area 10^{12} m^2
Tropical Forest	17.5	40.8	31.9	14.0
Temperate Forest	10.4	9.9	13.1	6.8
Boreal Forest	13.7	8.3	6.31	7.0
Tropical Savannah	27.6	31.3	44.0	14.5
Temperate Grassland	17.8	8.5	13.39	11.0
Desert	27.7	6.4	7.93	54.4
Tundra	5.6	1.6	6.77	14.5
Cropland	13.5	14.8	22.78	17.3
Total	**133.8**	**121.7**	**146.2**	**139.5**

- Per area, similar GPP in tropical forest, desert, tundra
- SiB4 GPP larger in savannah, temperate forest, grassland and cropland

→ Separating grasses and crops into climate zones

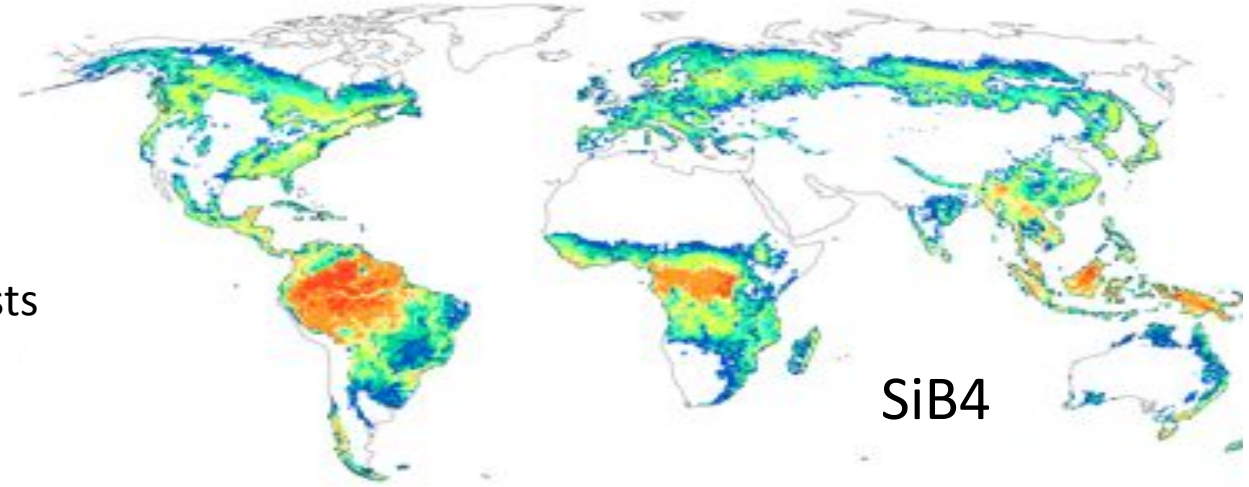
Above Ground Biomass

+ Similar spatial pattern and magnitude: high biomass in tropics, decreasing with latitude

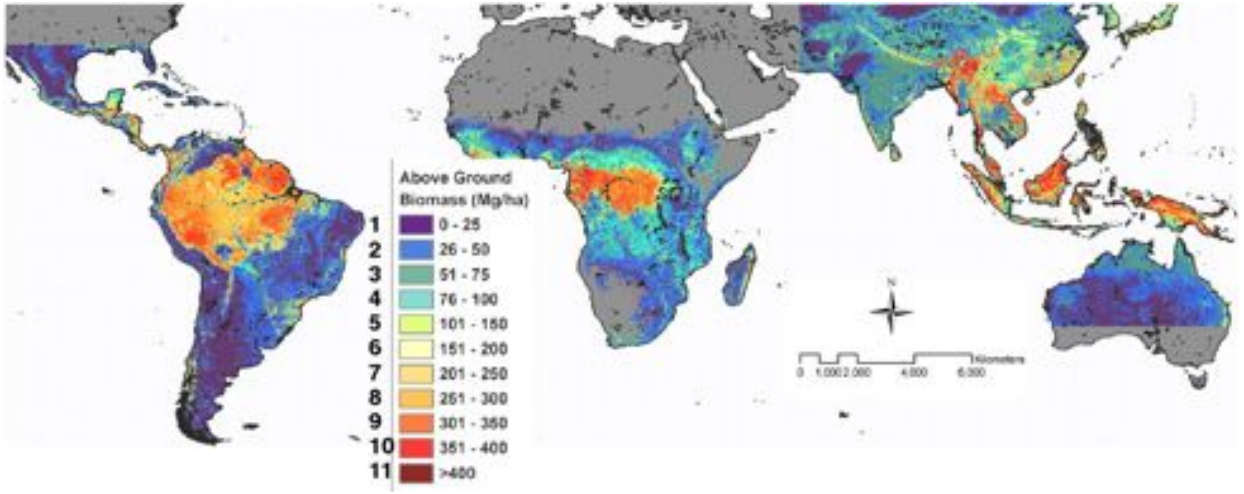
+ Asian and Indonesian forests have lower biomass in SiB4 compared to Saatchi et al.

+ Selected South American sites match site in situ and tower flux data

+ Extra-tropical regions have higher biomass simulated from SiB4
  - Due primarily to (semi) deciduous forests
  - Overestimation of LAI seasonality feeds back to increase carbon pools

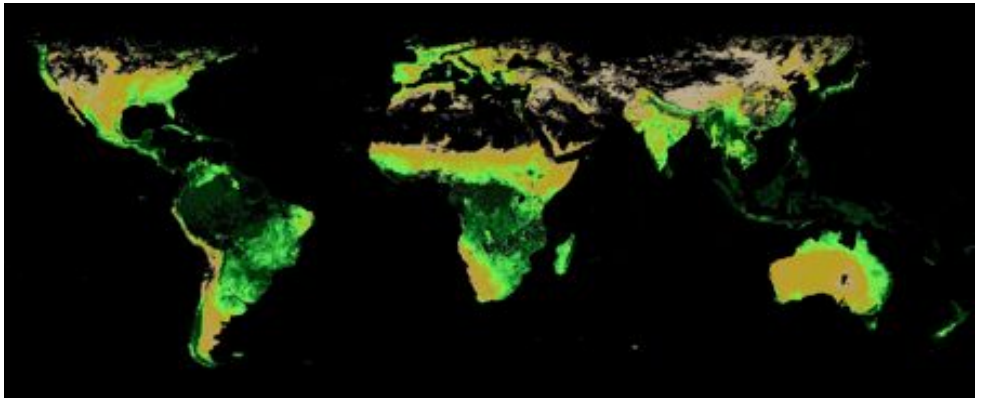


Saatchi et al. (2011)



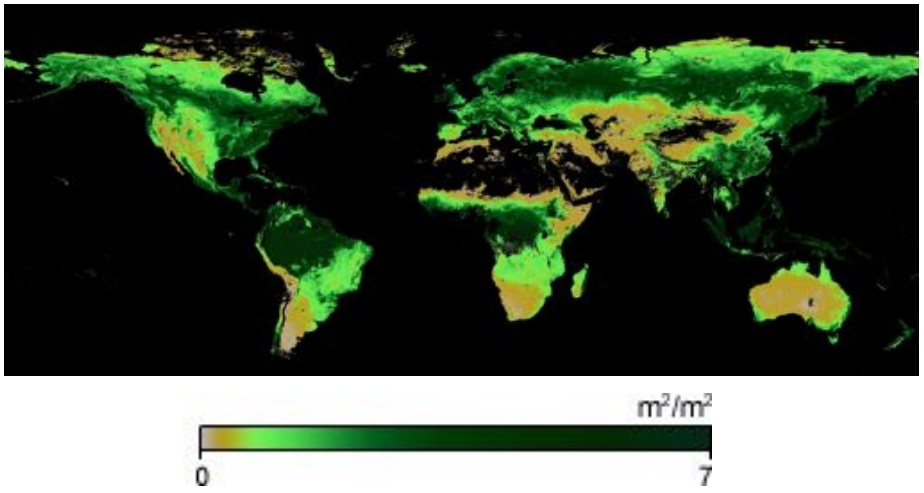
Leaf Area Index (LAI)

MODIS Jan 2008

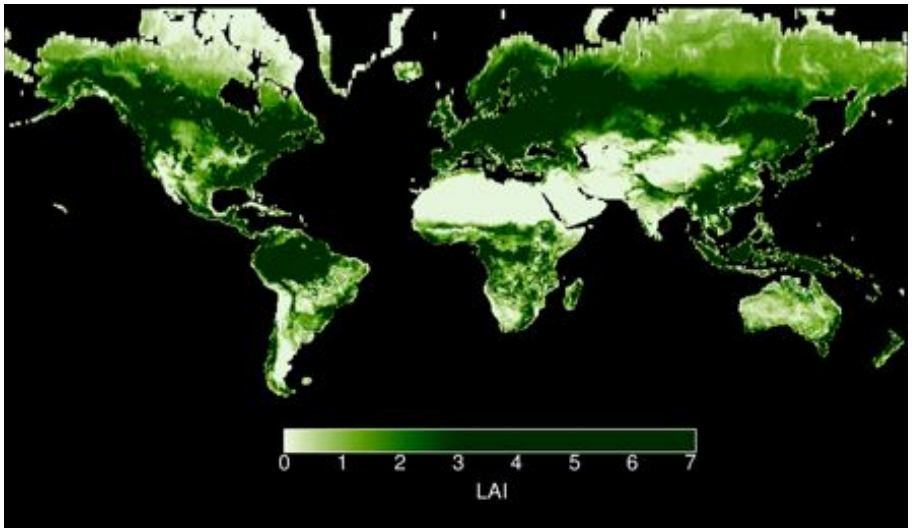


SiB4 Jan 2008

MODIS Jul 2008



SiB4 Jul 2008



Plant Functional Type (PFT) Comparisons

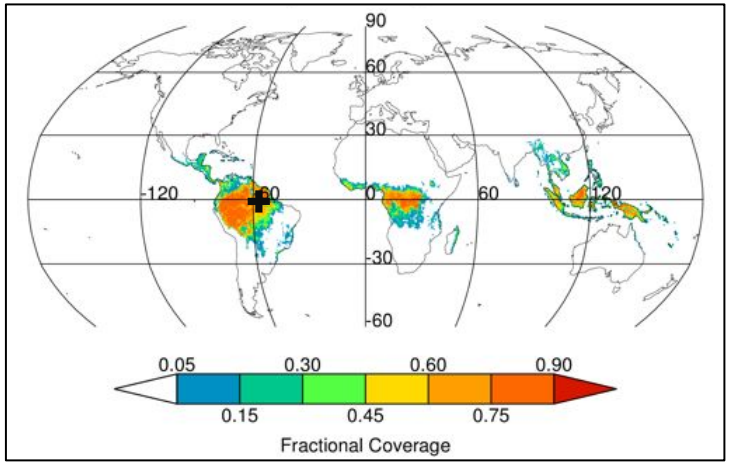
20 PFTs

- Forests
  - Temperate evergreen needle-leaf (enf-tem)
  - Boreal evergreen needle-leaf (enf-bor)
  - Boreal deciduous needle-leaf (dnf-bor)
  - Tropical evergreen broadleaf (ebf-tro)
  - Temperate evergreen broadleaf (ebf-tem)
  - Tropical deciduous broadleaf (dbf-tro)
  - Temperate deciduous broadleaf (dbf-tem)
  - Boreal deciduous broadleaf (dbf-bor)
- Shrubs
  - Evergreen broadleaf (ebs-all)
  - Temperate deciduous broadleaf (dbs-tem)
  - Boreal deciduous broadleaf (dbs-bor)
- Grasslands
  - C3 arctic (c3g-arc)
  - C3 non-arctic (c3g-nar)
  - C4 (c4g-all)
- Crops
  - General (cro-all)
  - Maize (cro-mze)
  - Soybean (cro-soy)
  - Winter wheat (cro-wwt)
  - Spring wheat (cro-swt)
- Bare Ground (non-veg)

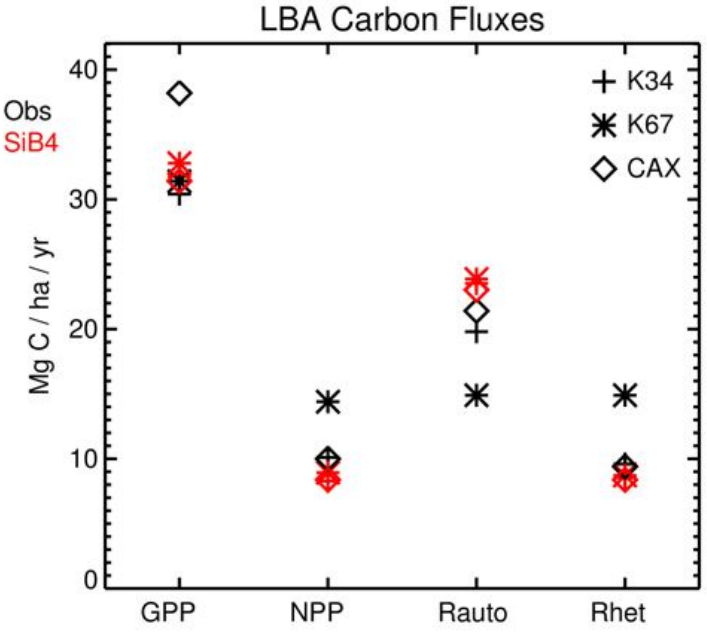
All PFT comparisons are single point comparisons with carbon pools spun up to equilibrium.

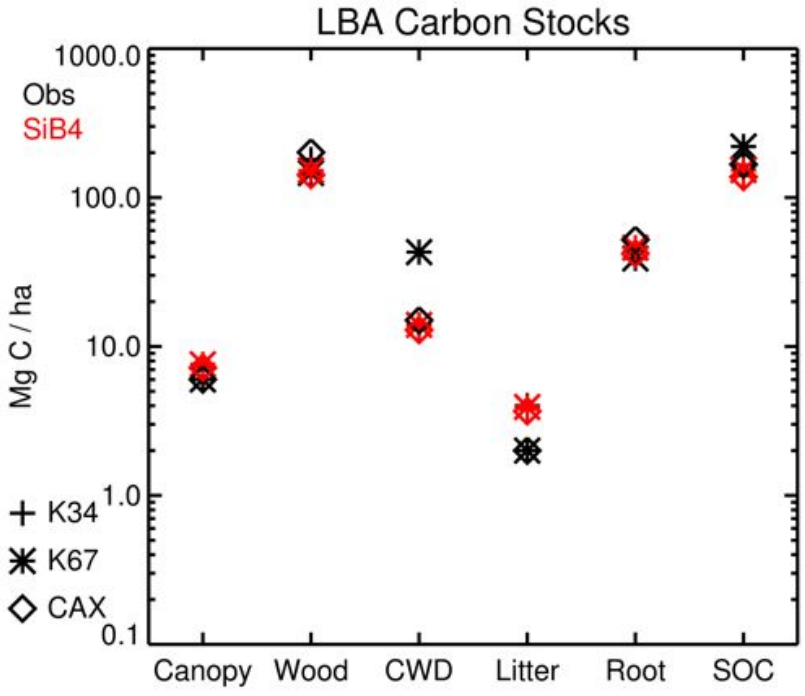
PFT Comparisons: Forests

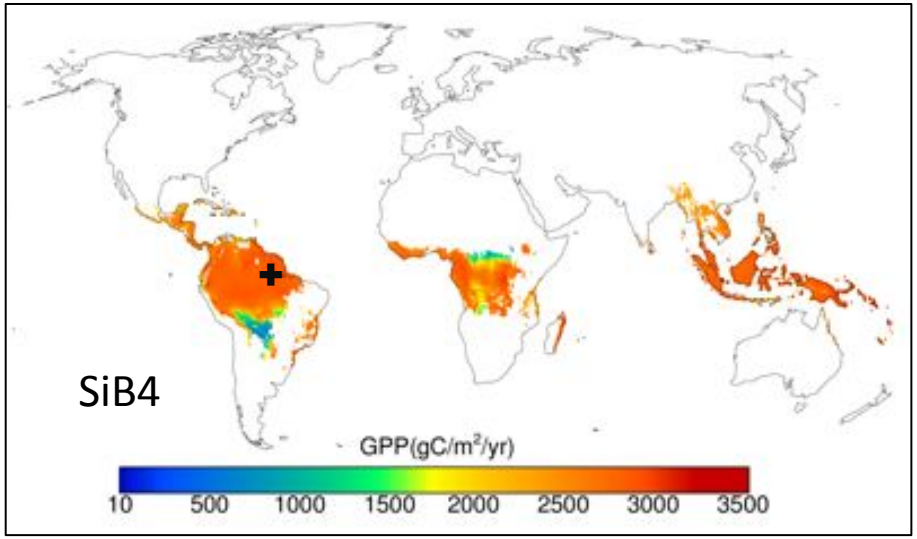
Tropical Broadleaf Evergreen

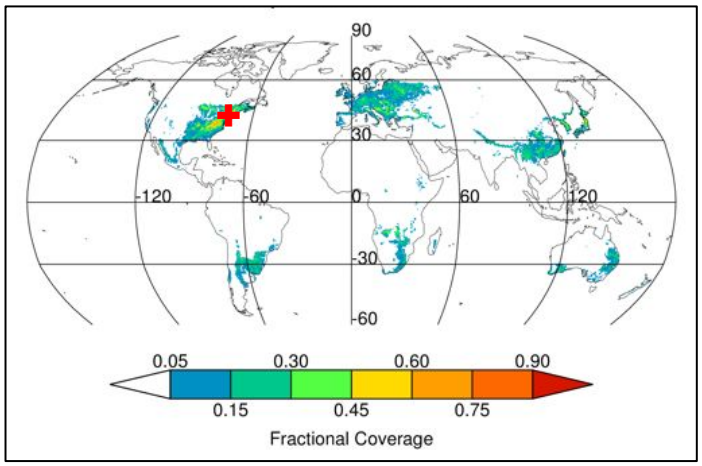


Comparisons of carbon pools and fluxes at three sites in the Amazon (Malhi et al., 2009).





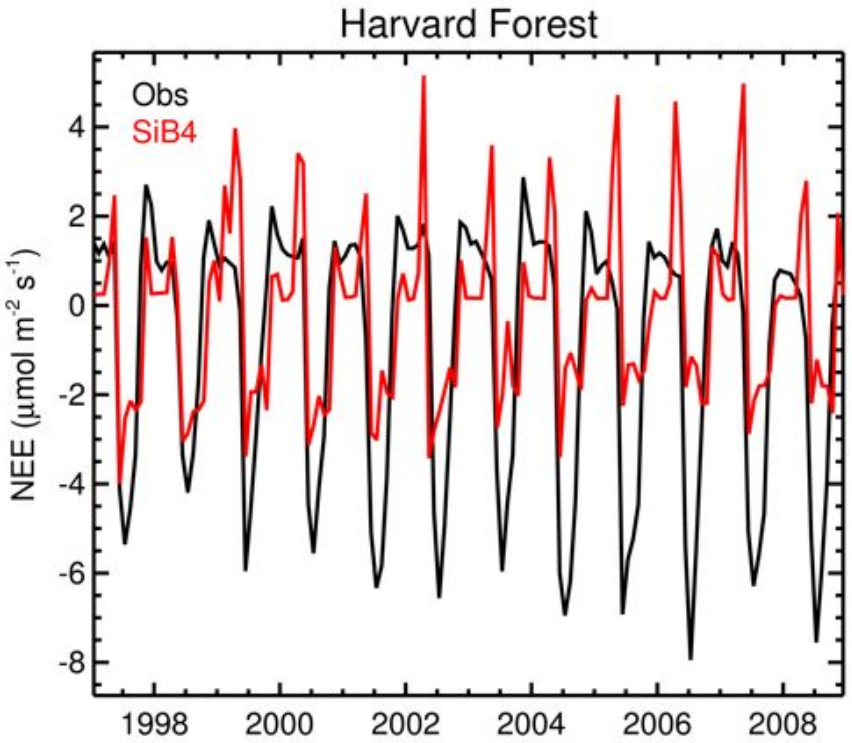


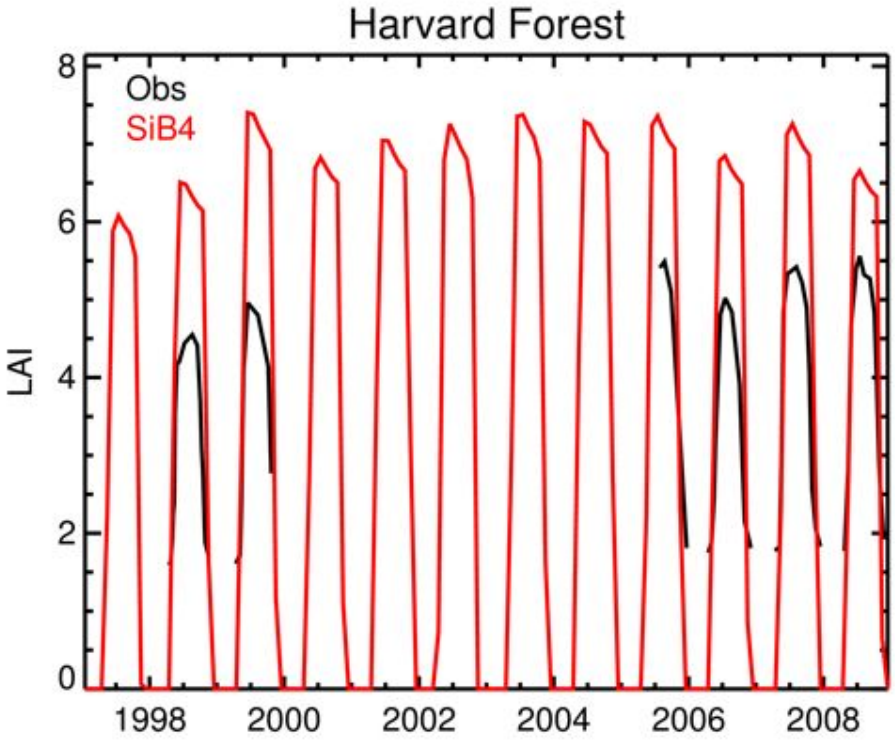


PFT Comparisons: Forests

Temperate Broadleaf Deciduous

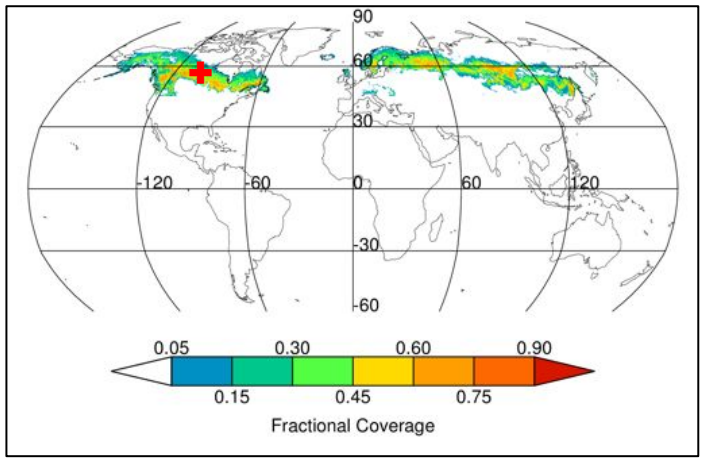
Monthly net ecosystem exchange (NEE; left) and leaf area index (LAI; right) at Harvard Forest. Data from the AmeriFlux database: http://ameriflux.ornl.gov.



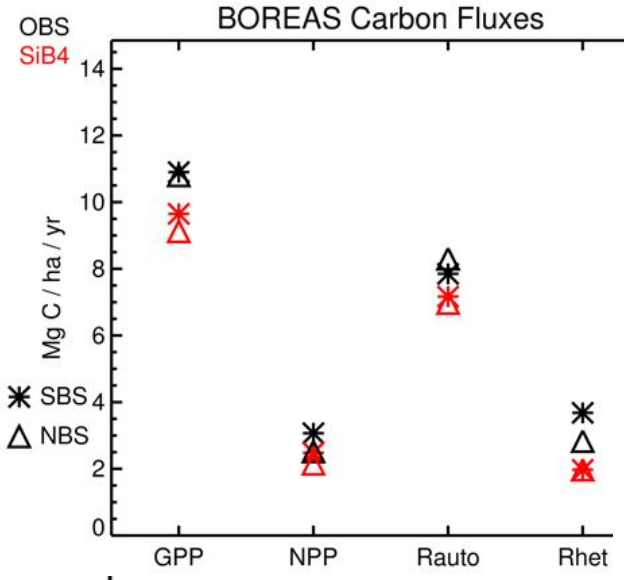


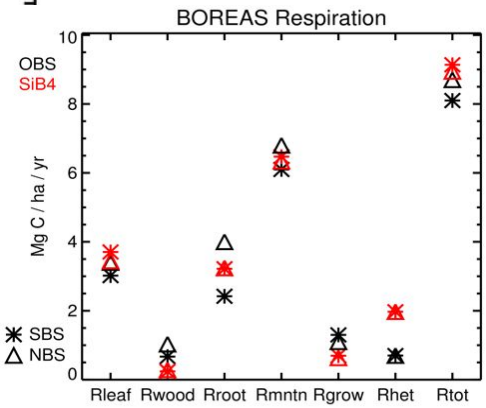
PFT Comparisons: Forests

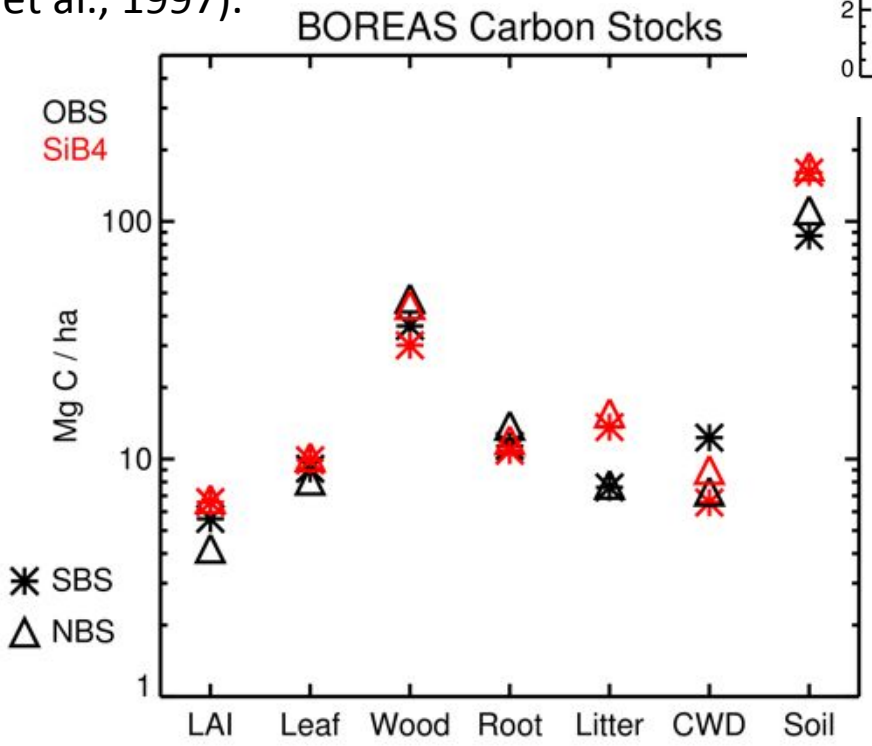
Boreal Evergreen Needle-leaf

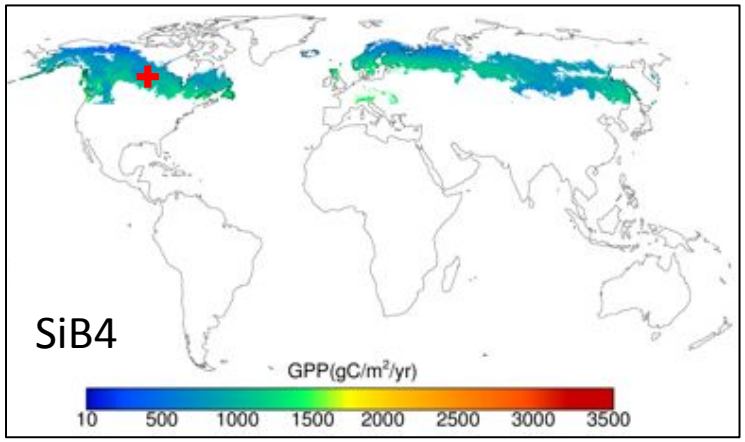


Comparisons at 2 tower sites in the BOREAS field campaign (Gower et al., 1997; Kimball et al., 1997; Ryan et al., 1997).



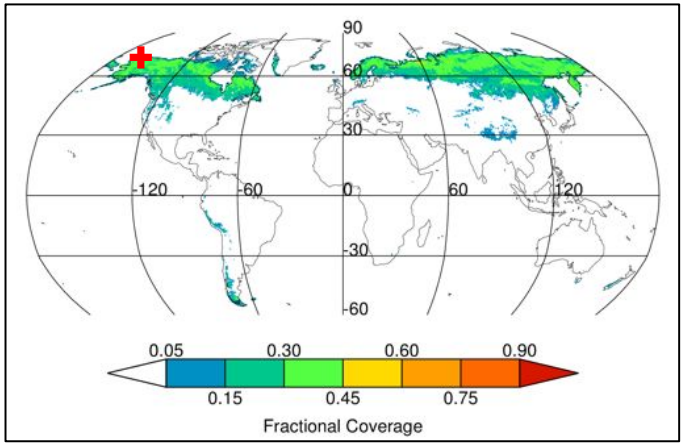




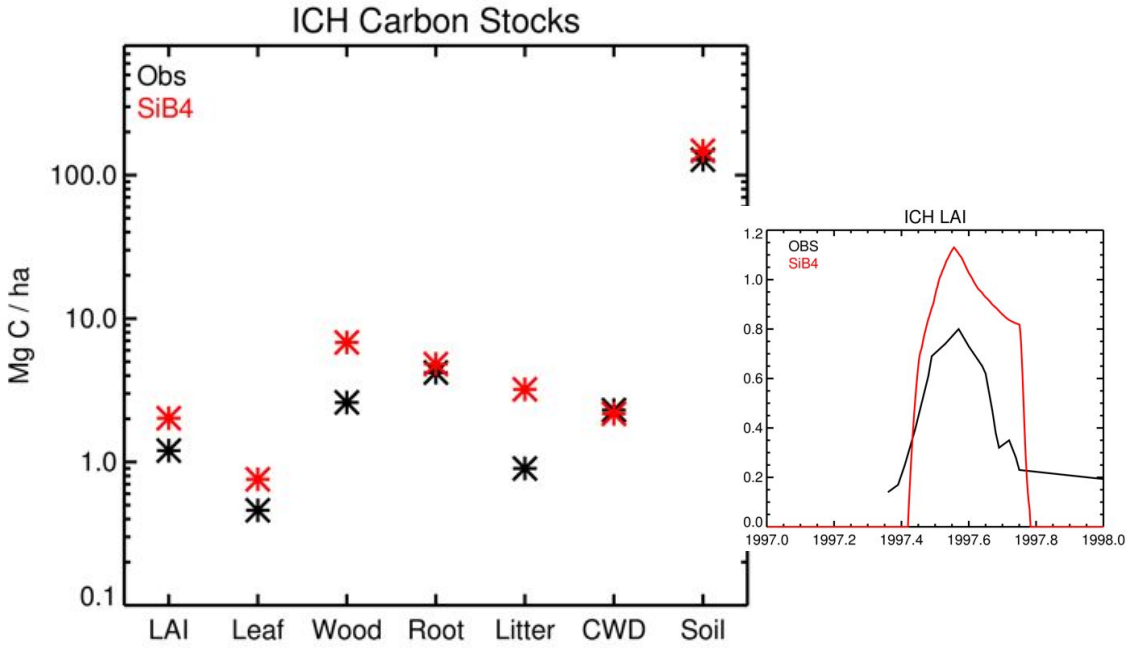


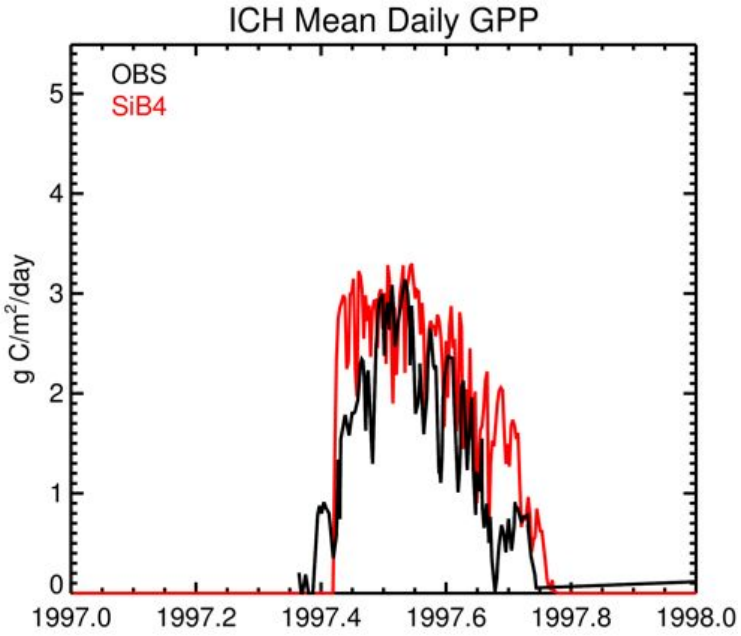
PFT Comparisons: Shrubs

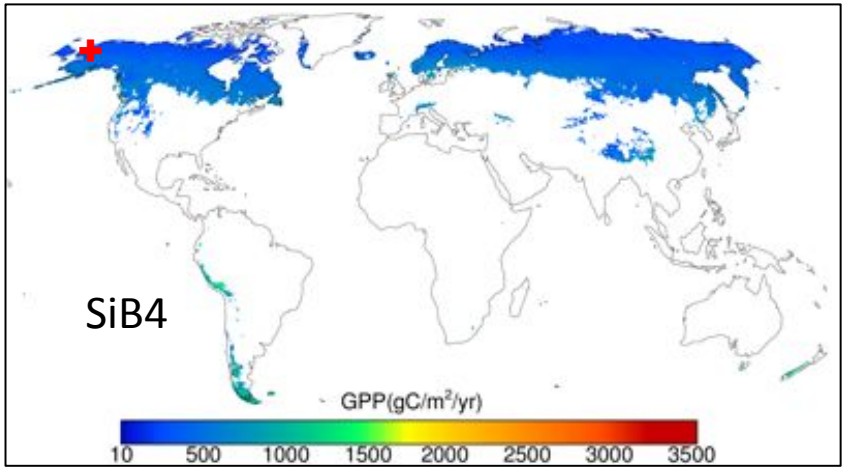
Boreal Deciduous Broadleaf (Tundra)



Annual carbon stocks (right; Shaver, 1986 and Shaver and Chapin, 1991), daily GPP (lower left), and LAI (mid) (Williams et al., 2001) at an AmeriFlux tundra site, ICH.

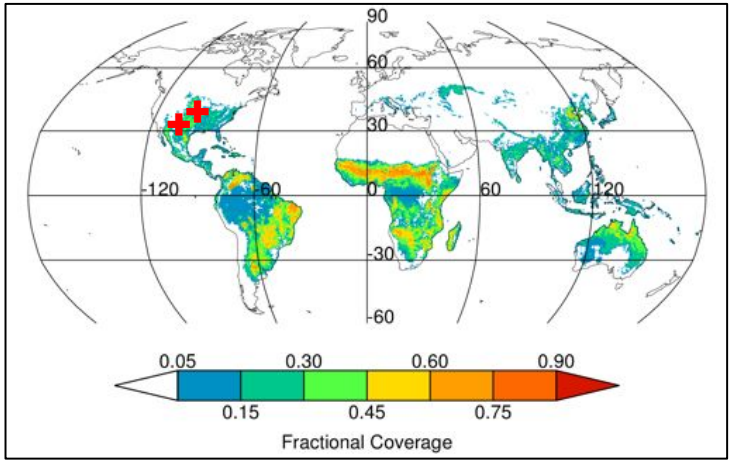




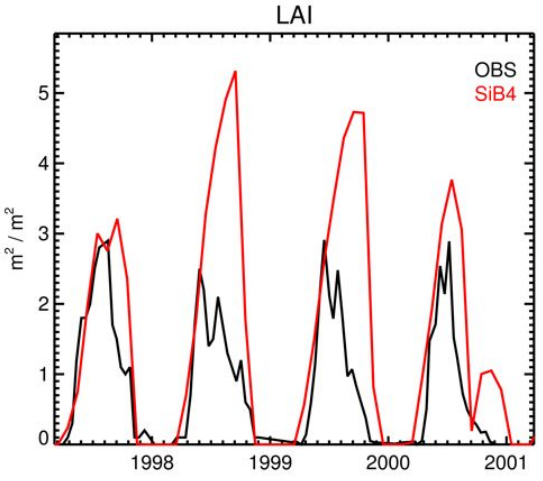


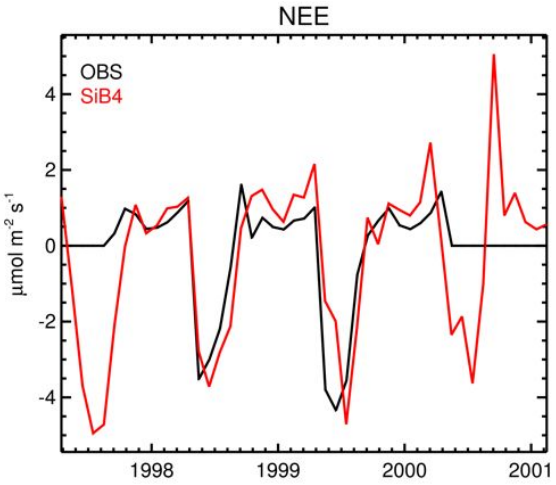
PFT Comparisons: Grass

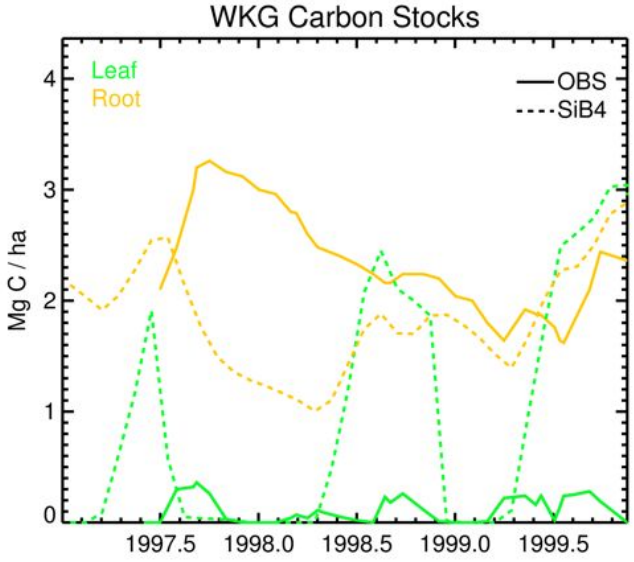
C4 All

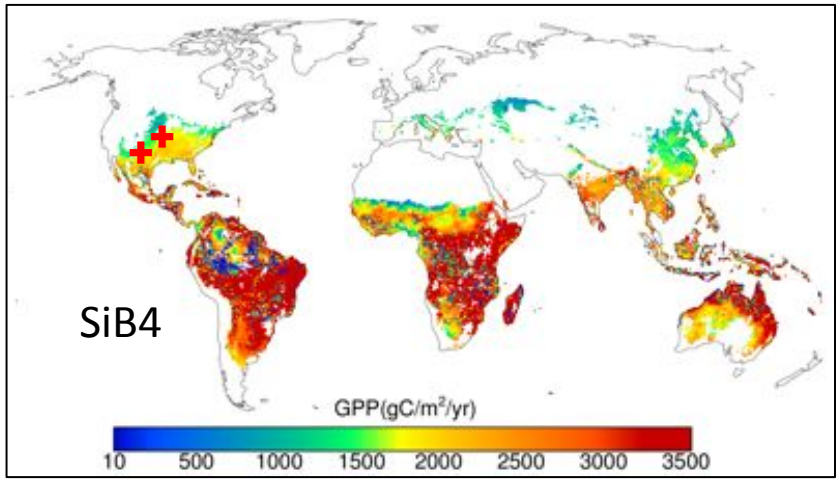


Below) Leaf and root pools at an AmeriFlux site in Arizona, WKG (Emmerich, 2003). Right) LAI and NEE at a tall grass AmeriFlux site in Oklahoma, SHD (http:ameriflux.ornl.gov).



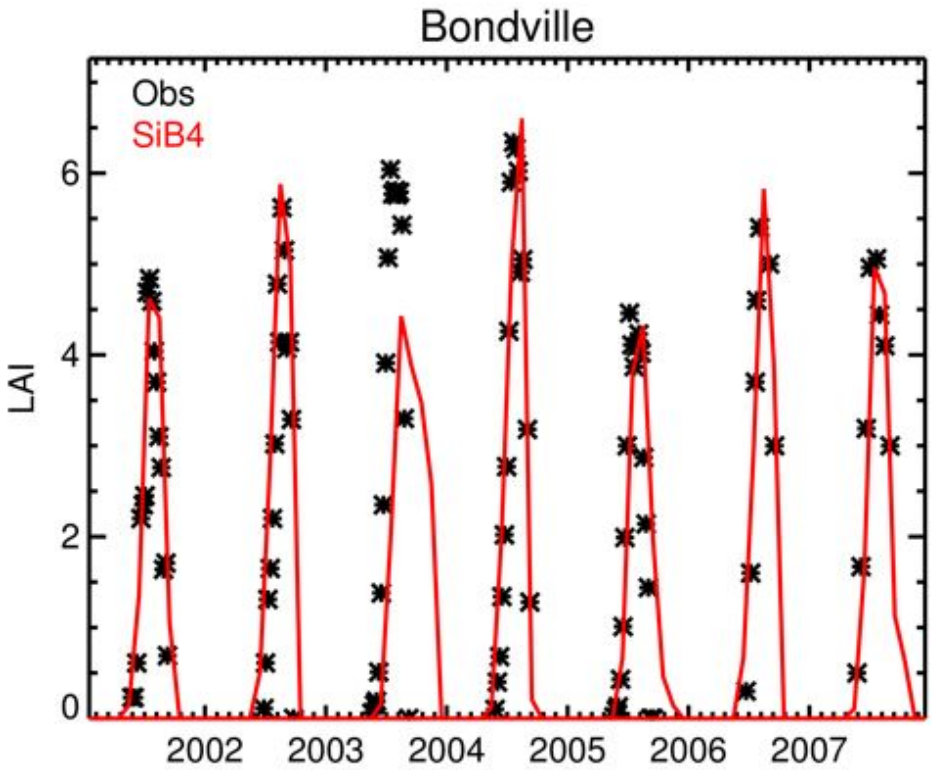


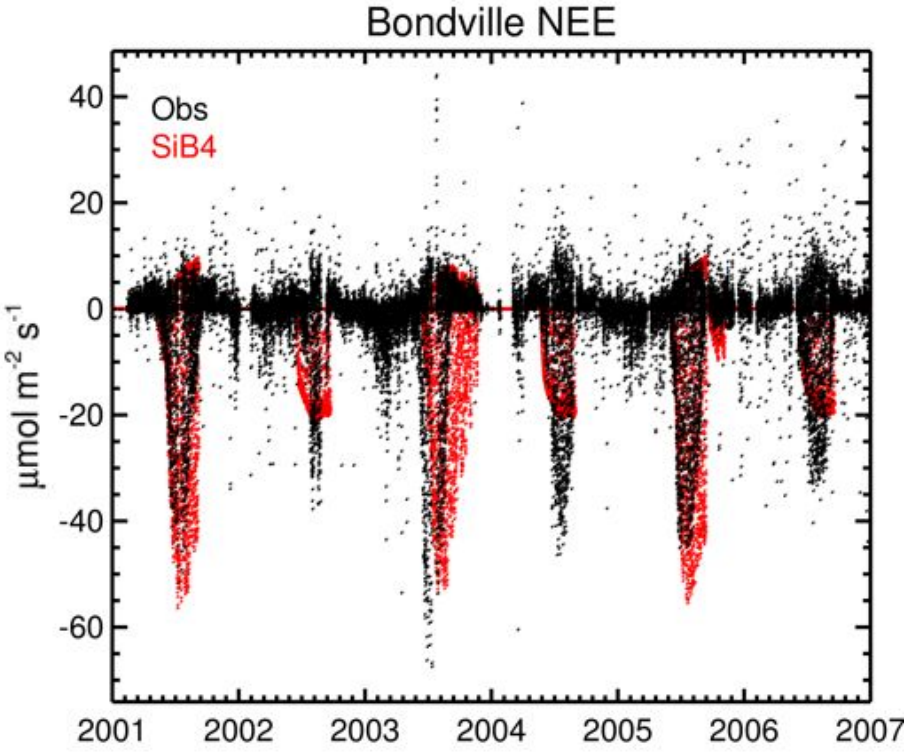




PFT Comparisons: Crops

Maize and Soybean





Maize and soybean at a rotation site in AmeriFlux, BO1.
Odd years are maize, even years are soybean.
Data are from http://ameriflux.ornl.gov.
Left) Monthly LAI. Right) Hourly NEE.

Conclusions

- SiB4 has developed into a fully prognostic model that realistically simulates twenty-two different plant functional types (PFTs) globally with minimal input data
- SiB4 has the capability to simulate high resolution carbon fluxes and long term carbon pools
- Since SiB4 predicts both pools and fluxes, various data metrics can be used for evaluation, which leads to improvement in the model and further understanding of the carbon cycle
  + Predicting the leaf pool from environmental factors combined with carbon uptake captures plant phenology well across a wide range of PFTs
  + Capturing the timing of LAI leads to more realistic carbon fluxes
  + Including specific crops alters the timing of GPP due to the short, intense growing season
- Evaluating all PFTs highlights future work
  + Complete spin-up to equilibrium
  + Reduce the LAI and productivity of certain PFTs
    - Grasslands
    - Generic Crops
    - Temperate forests

Acknowledgements

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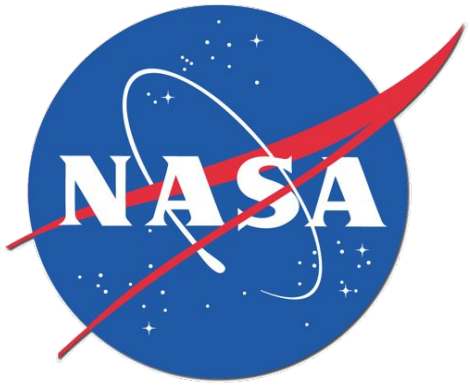
We sincerely thank the principal investigators (Pis) at all the Fluxnet sites, including AmeriFlux, Fluxnet Canada, and AsiaFlux.

Colorado State University

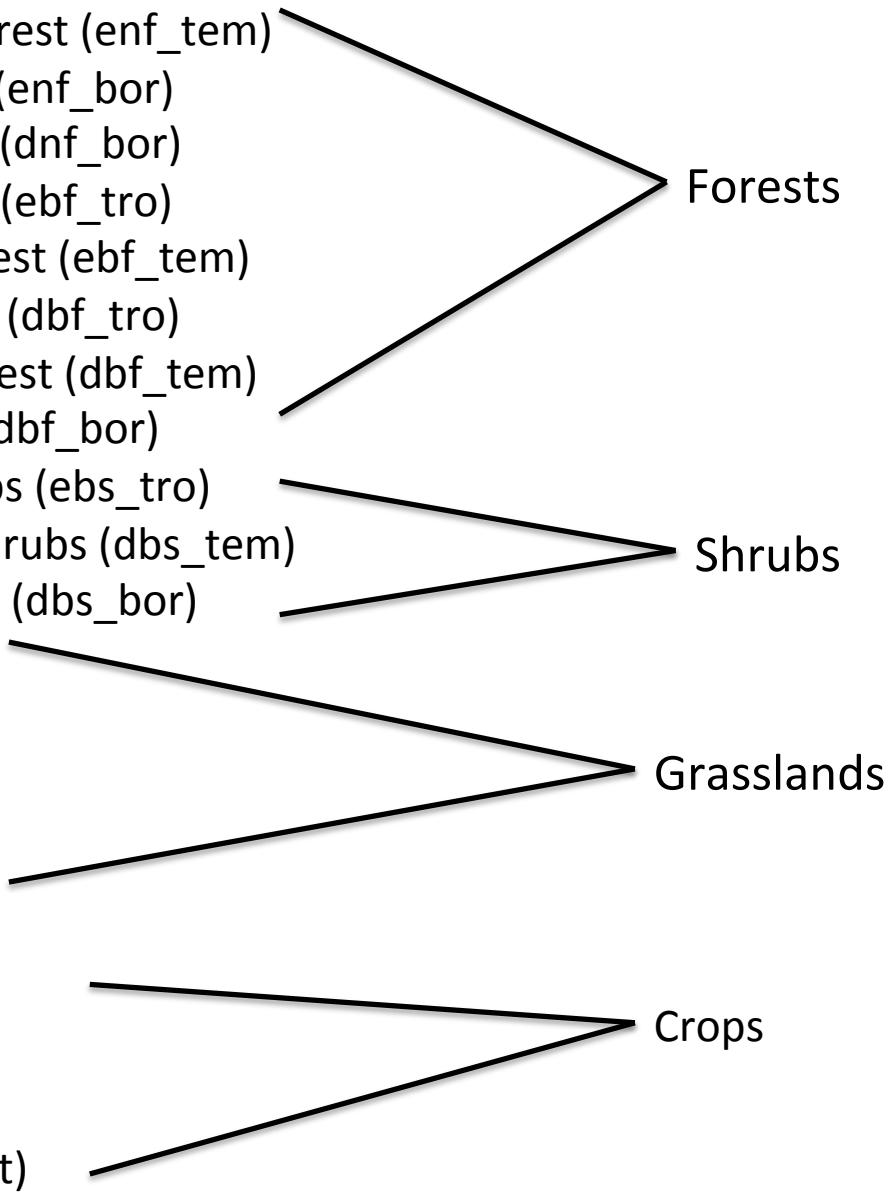


SiB4 Carbon Pools

1= Storage
2 = Leaf
3 = Root
4 = Wood
5 = Product
6 = Coarse Woody Debris (CWD)
7 = Litter Metabolic
8 = Litter Structural
9 = Soil Litter
10 = Slow
11 = Armoredß

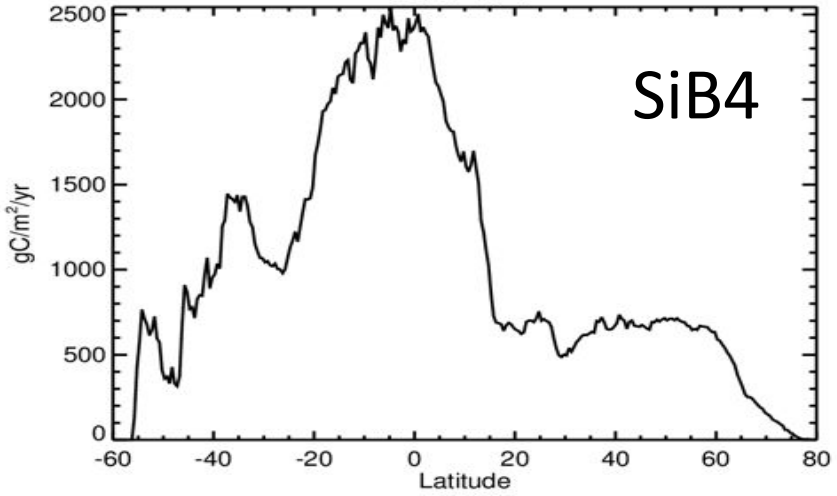
SiB4 Plant Functional Types (PFTs)

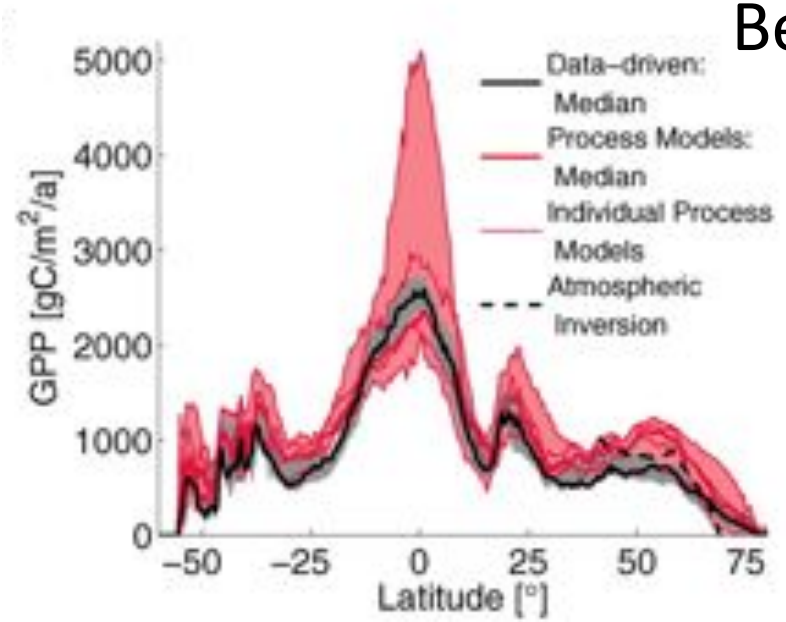
1=Bare Ground
2=Temperate Evergreen Needleleaf Forest (enf_tem)
3=Boreal Evergreen Needleleaf Forest (enf_bor)
4=Boreal Deciduous Needleleaf Forest (dnf_bor)
5=Tropical Evergreen Broadleaf Forest (ebf_tro)
6=Temperate Evergreen Broadleaf Forest (ebf_tem)
7=Tropical Deciduous Broadleaf Forest (dbf_tro)
8=Temperate Deciduous Broadleaf Forest (dbf_tem)
9=Boreal Deciduous Broadleaf Forest (dbf_bor)
10=Tropical Evergreen Broadleaf Shrubs (ebs_tro)
11=Temperate Deciduous Broadleaf Shrubs (dbs_tem)
12=Boreal Deciduous Broadleaf Shrubs (dbs_bor)
13=Tropical C3 Grass (c3g_tro)
14=Temperate C3 Grass (c3g_tem)
15=Boreal C3 Grass (c3g_bor)
16=Tropical C4 Grass (c4g_tro)
17=Temperate C4 Grass (c4g_tem)
18=Tropical Crops (cro_tro)
19=Temperate Crops (cro_tem)
20=Temperate Maize (cro_mze)
21=Temperate Soybean (cro_soy)
22=Temperate Winter Wheat (cro_wwt)



Latitudinal Annual GPP

- Similar distribution and magnitude
- SiB4 tropical peak broader than Beer et al.
- SiB4 GPP in southern hemisphere higher

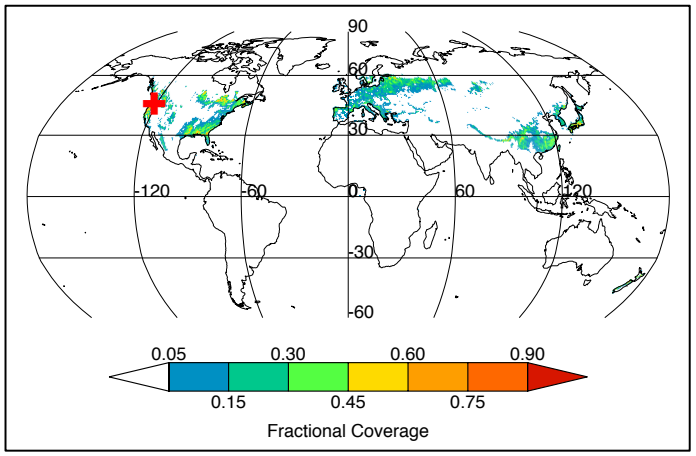




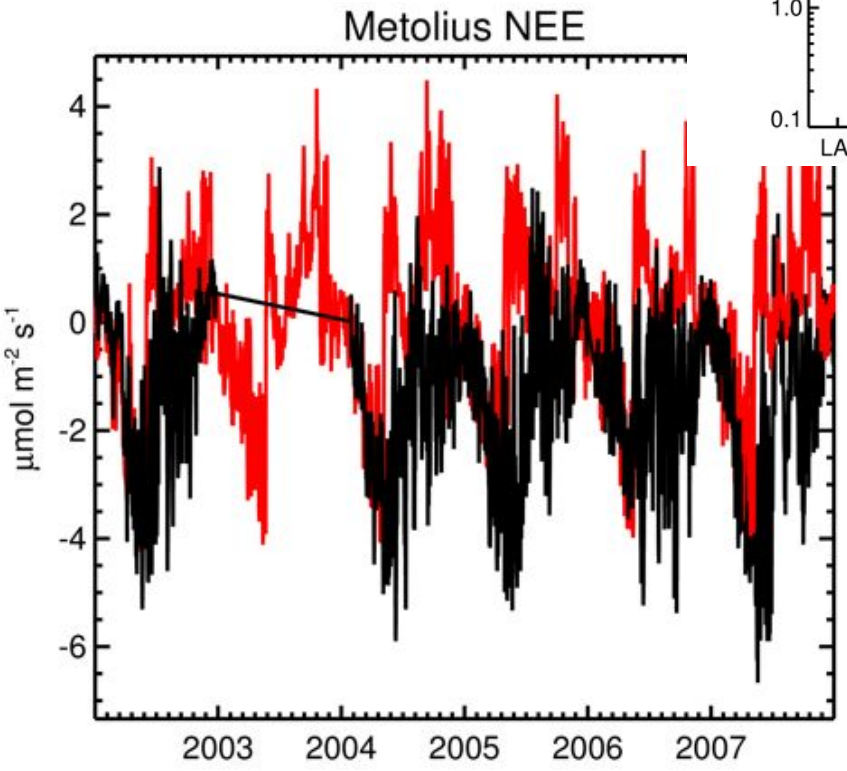
Beer et al. (2010)

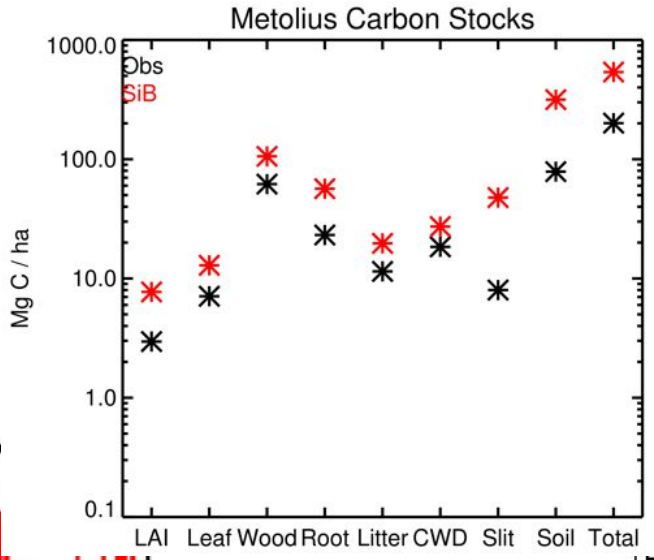
PFT Comparisons: Forests

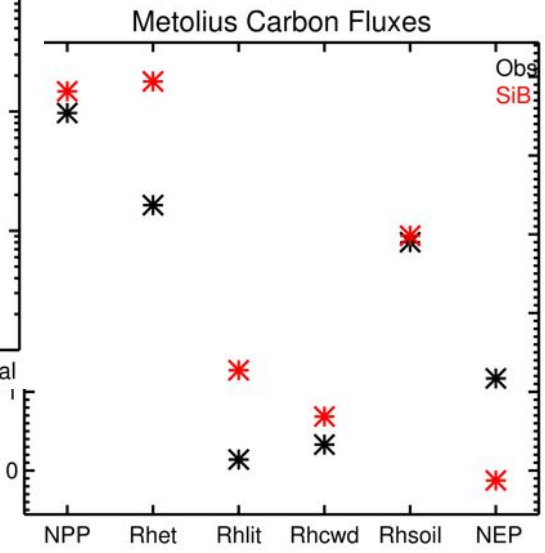
Temperate Evergreen Needle-leaf



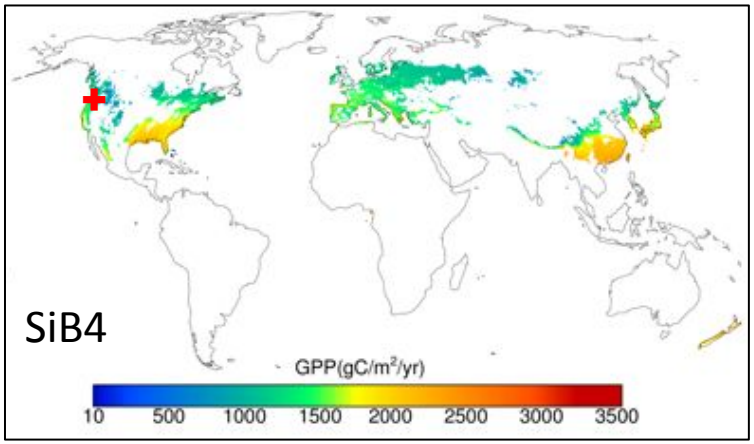
NEE data from the AmeriFlux database http://ameriflux.ornl.gov





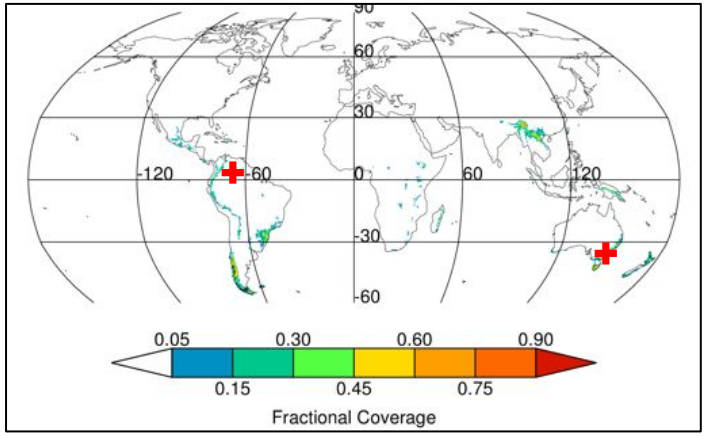


Carbon stock and flux data from Law et al. (2003).

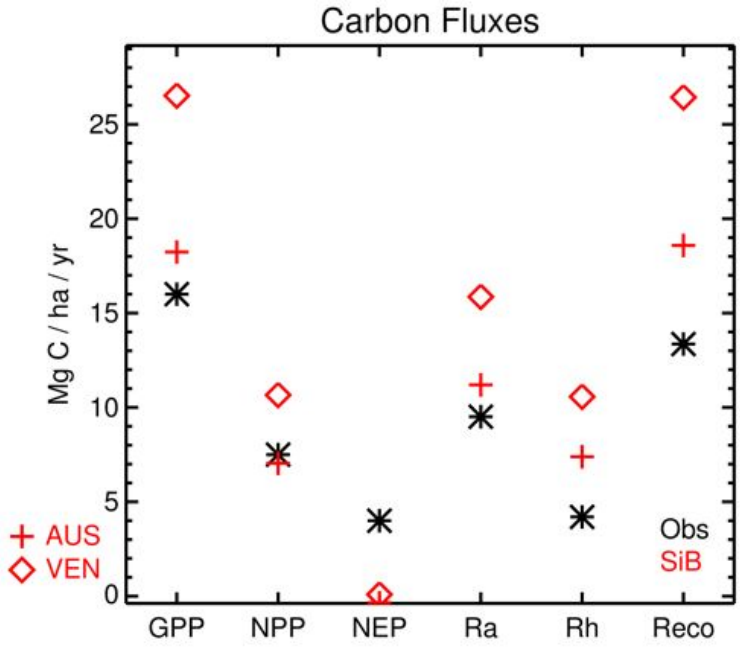


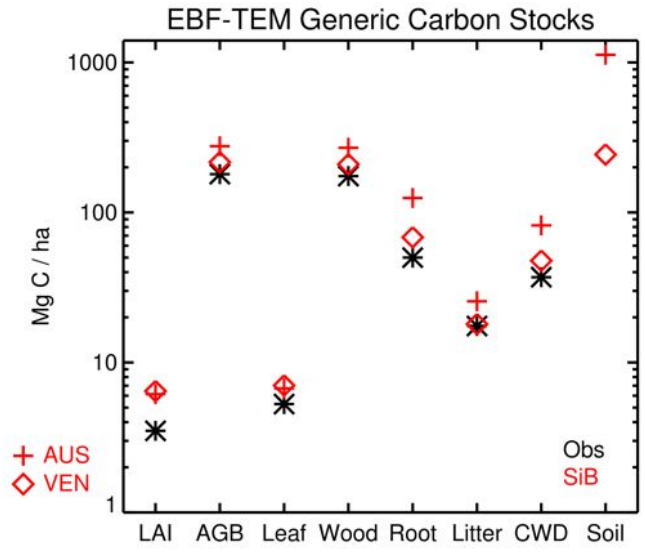
PFT Comparisons: Forests

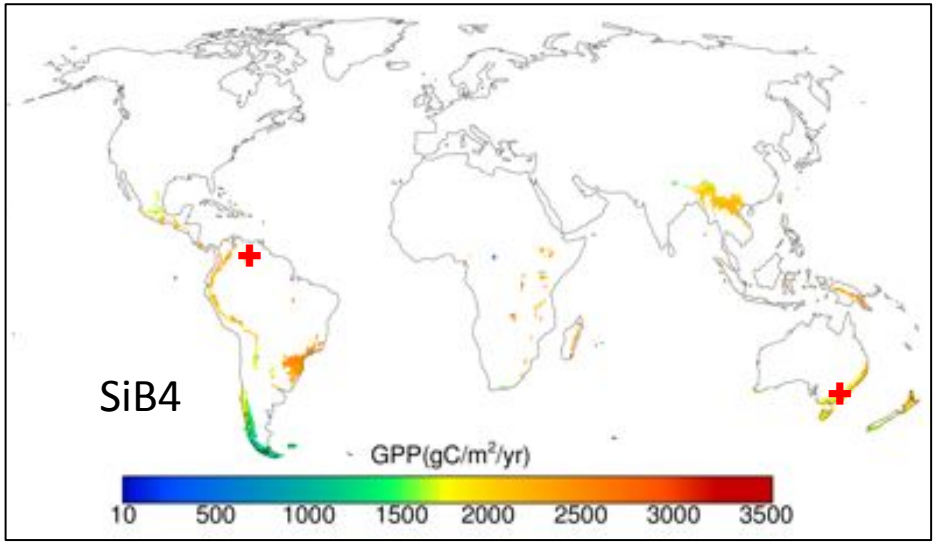
Temperate Broadleaf Evergreen



Comparisons of generic temperate broadleaf pools and fluxes at two sites (Box et al., 1989; Luyssaert et al., 2007; Matthews et al., 1997; Mokany et al., 2006).

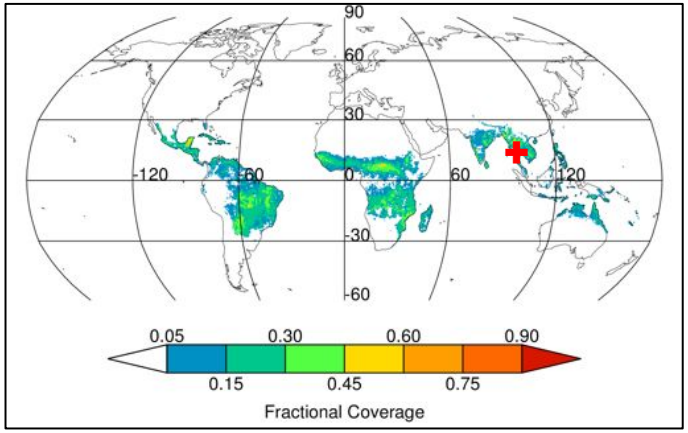




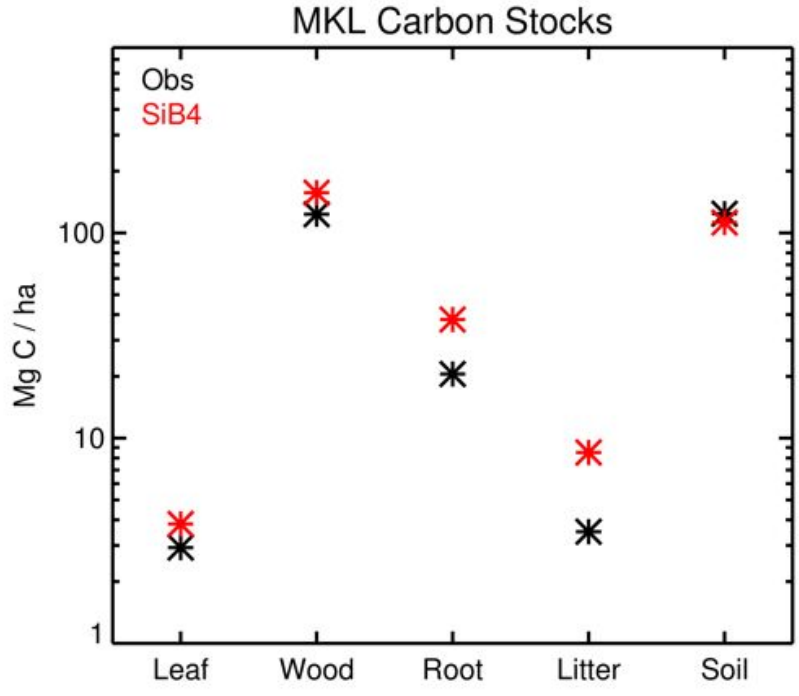


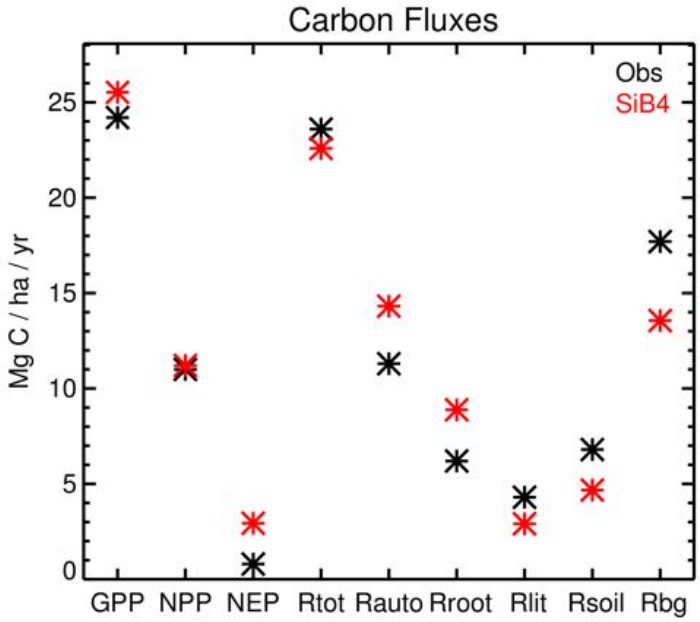
PFT Comparisons: Forests

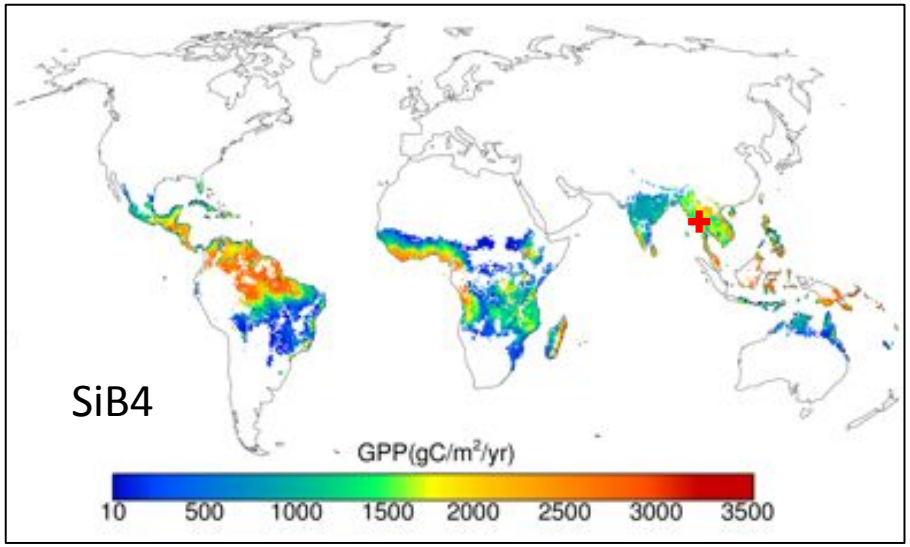
Tropical Broadleaf Deciduous (I)



Comparisons for an AsiaFlux site, MKL (Takahashi et al., 2012; Huete et al., 2008; AsiaFlux Database).

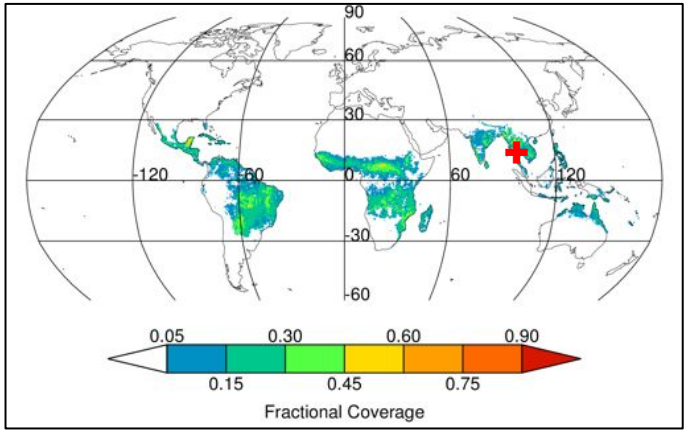




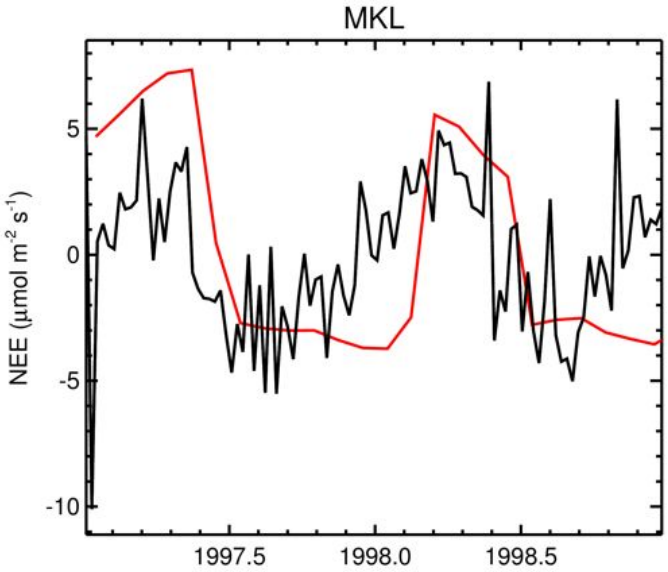


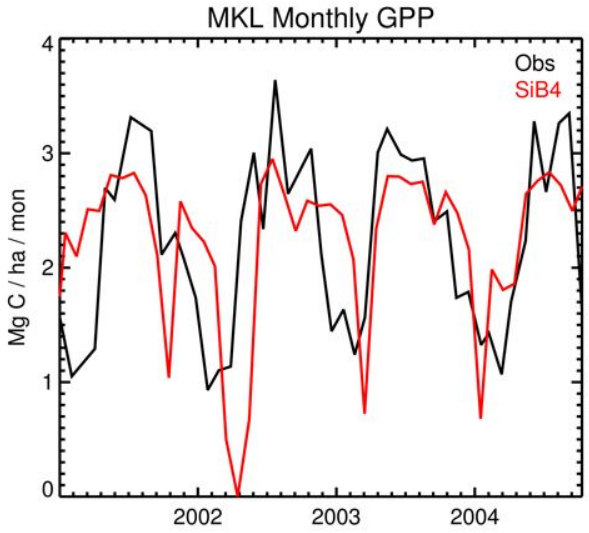
PFT Comparisons: Forests

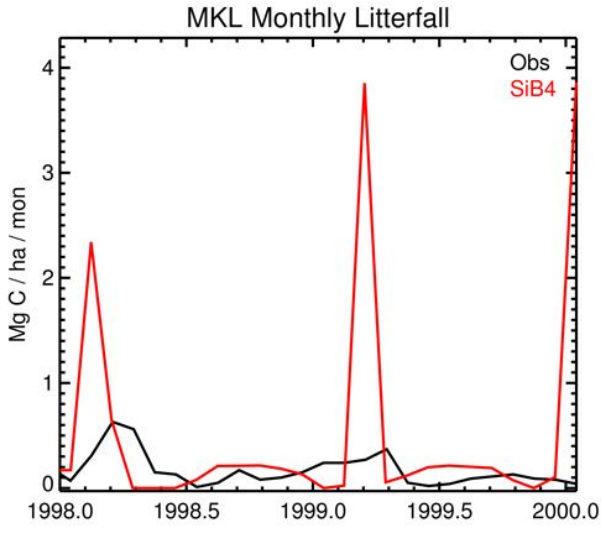
Tropical Broadleaf Deciduous (II)

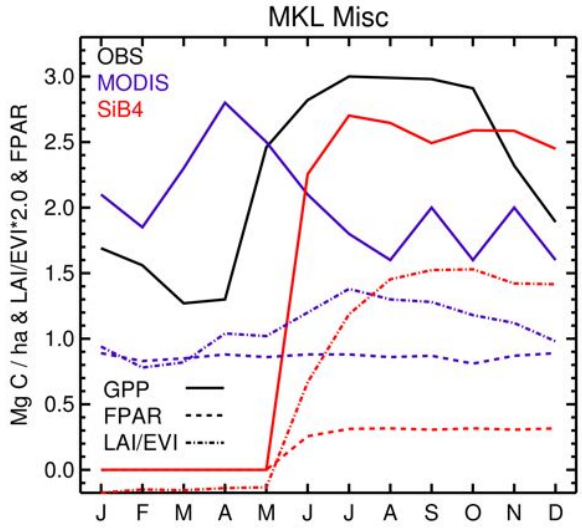


Comparisons for an AsiaFlux site, MKL. Right) NEE from the AsiaFlux Database. Below left) Seasonal GPP from Huete et al., 2008. Below mid) Litterfall from Takahashi et al., 2012. Below right) Seasonal GPP, FPAR, and EVI from Huete et al. (2008). EVI compared to SiB4 LAI.



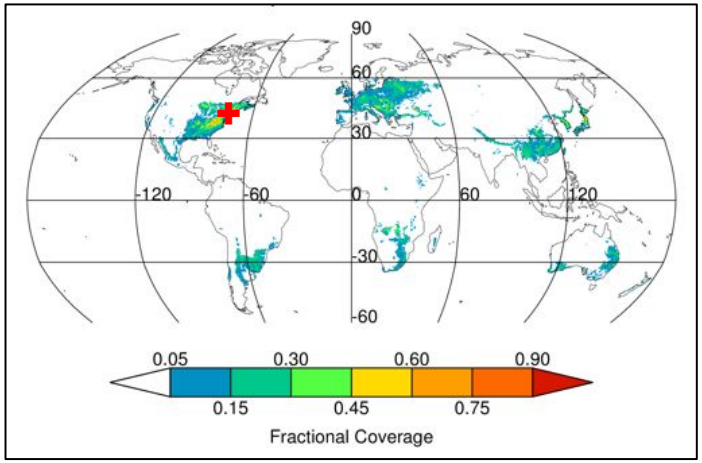




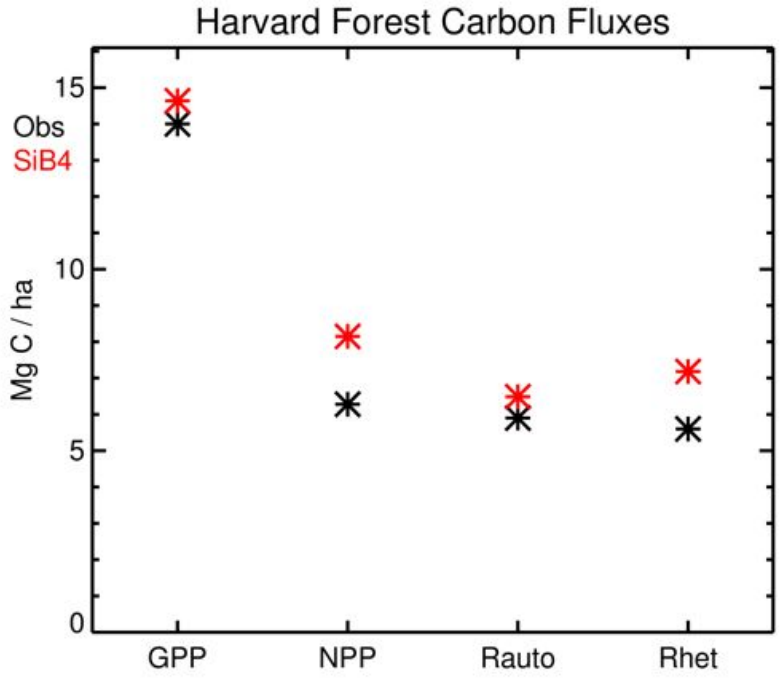


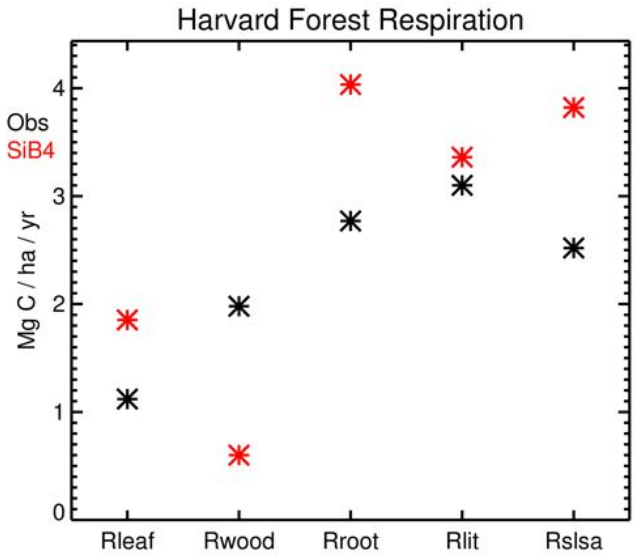
PFT Comparisons: Forests

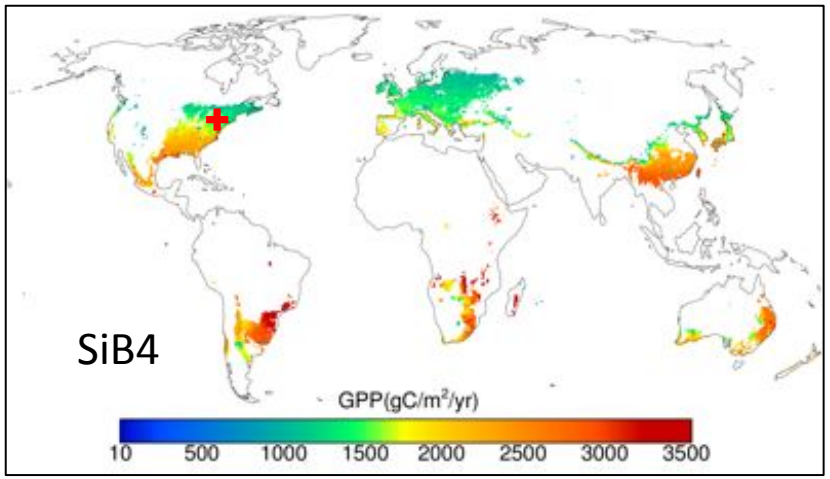
Temperate Broadleaf Deciduous (I)



Carbon fluxes and respiration components at Harvard Forest (Munger, 1999; Xiao et al., 2004; Urbanski et al., 2007; Law et al., 2002; Bahn et al., 2010; Bowden et al., 1993; Melillo et al, 2011; Compton and Boone, 2000; Gaudinski et al., 2000).

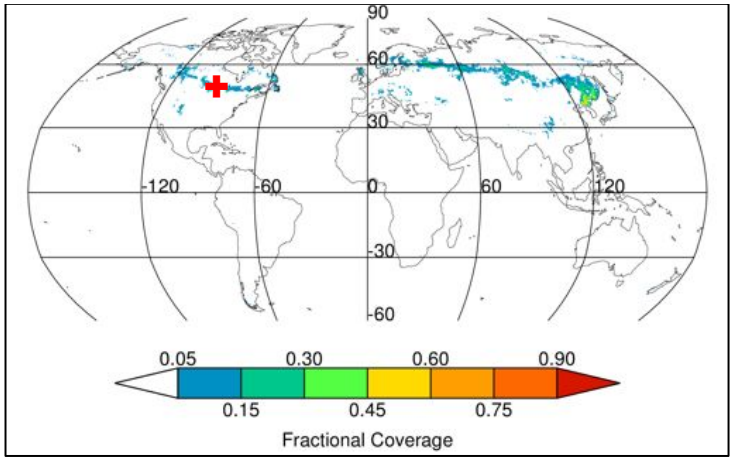




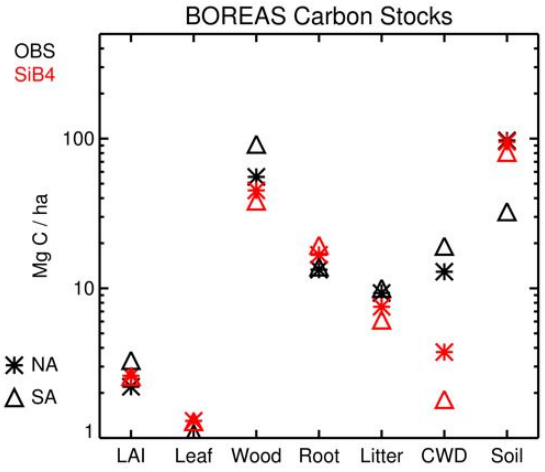


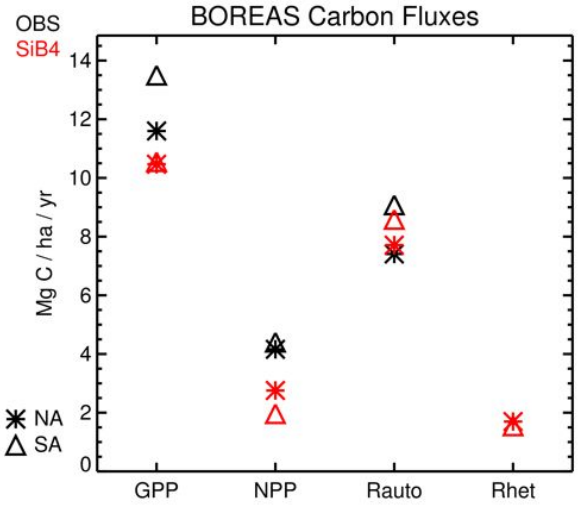
PFT Comparisons: Forests

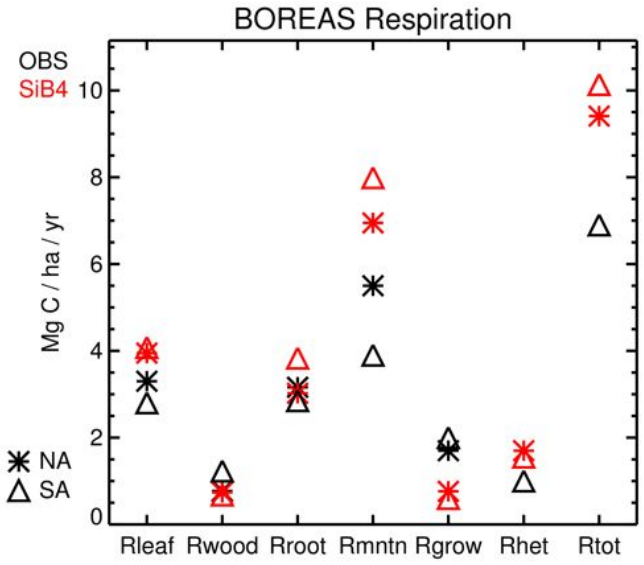
Boreal Broadleaf Deciduous

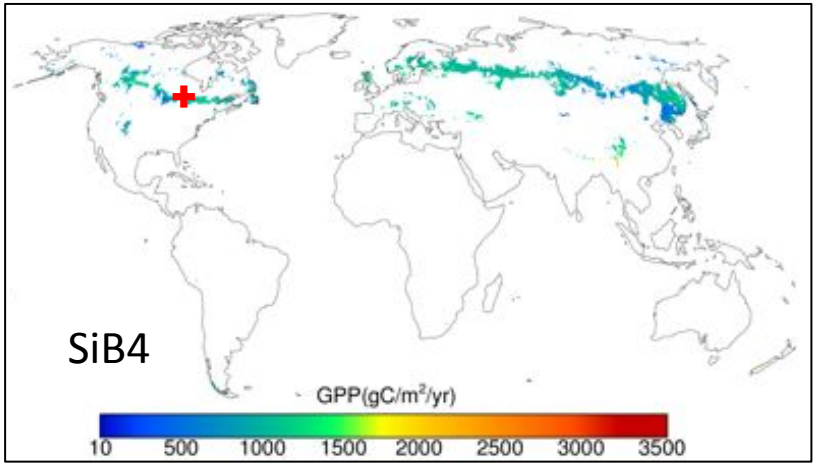


Comparisons at two tower sites in the BOREAS field campaign (Gower et al., 1997; Kimball et al., 1997; Ryan et al., 1997).



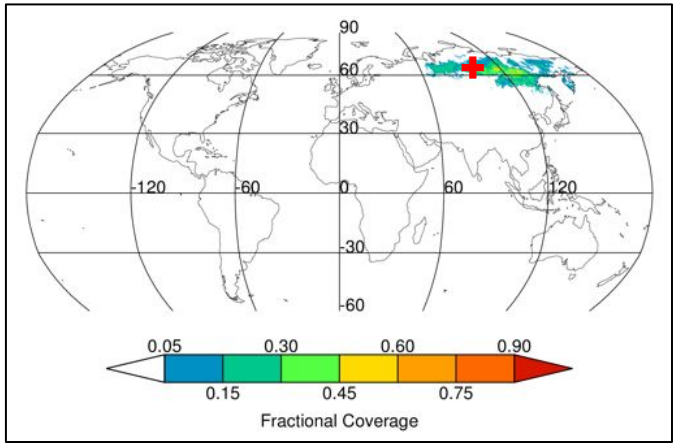




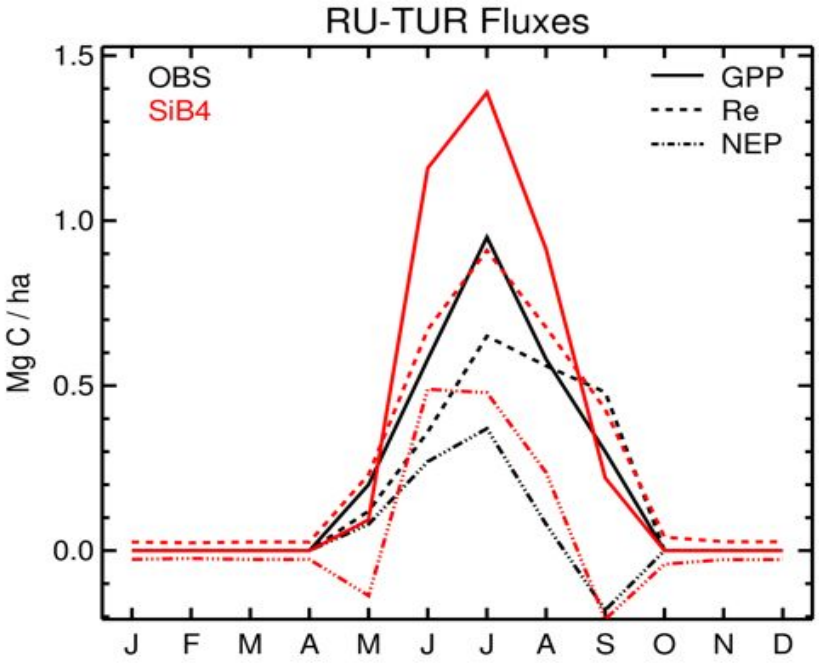


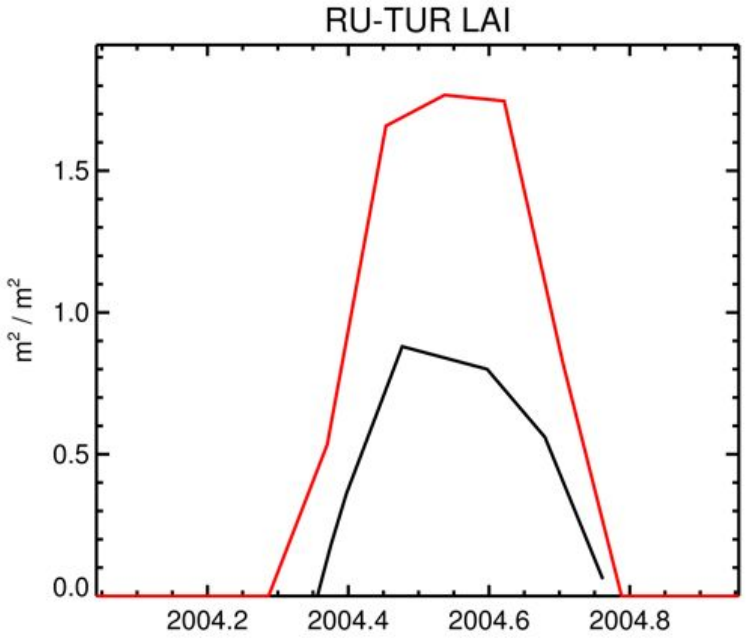
PFT Comparisons: Forests

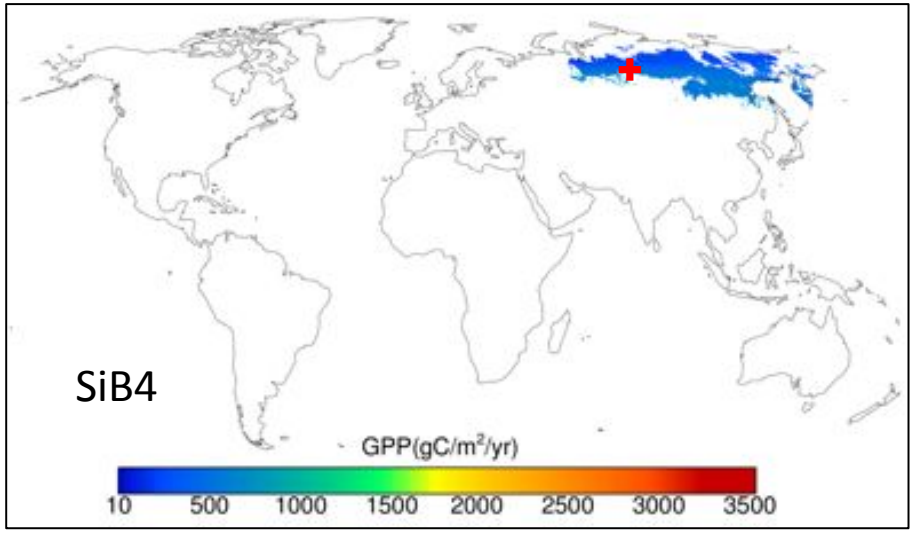
Boreal Deciduous Needle-leaf



Comparisons for an AsiaFlux site, RU-TUR (Saigusa et al., 2008; Ueyama et al., 2009; Kobayashi et al., 2007).

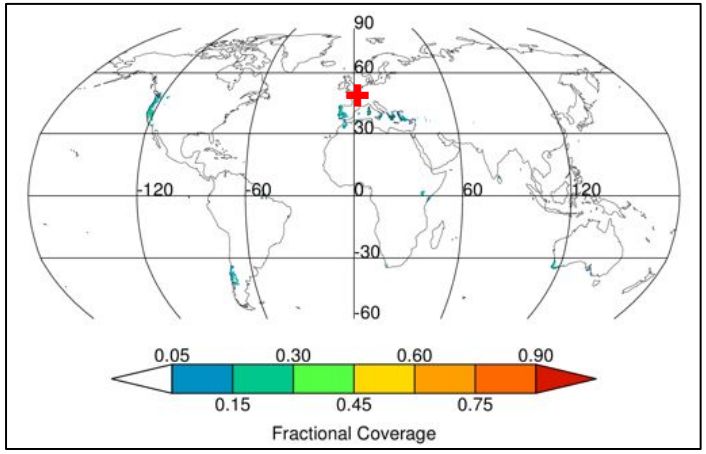




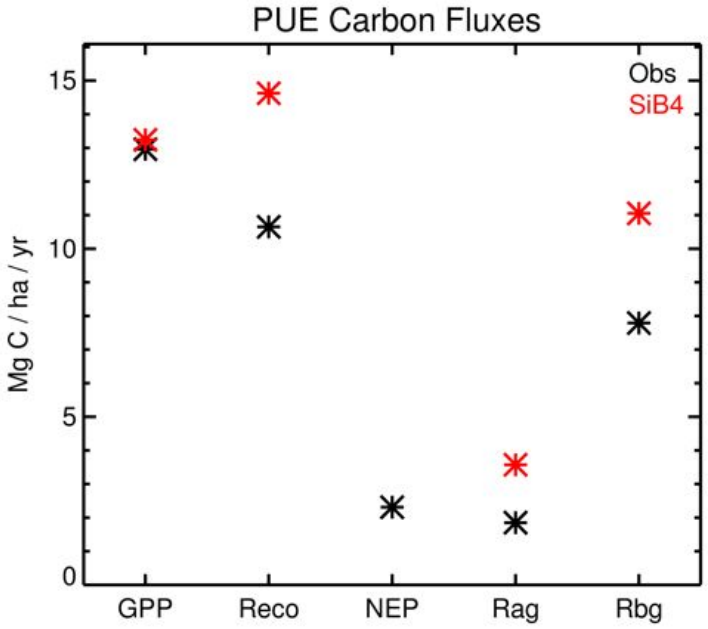


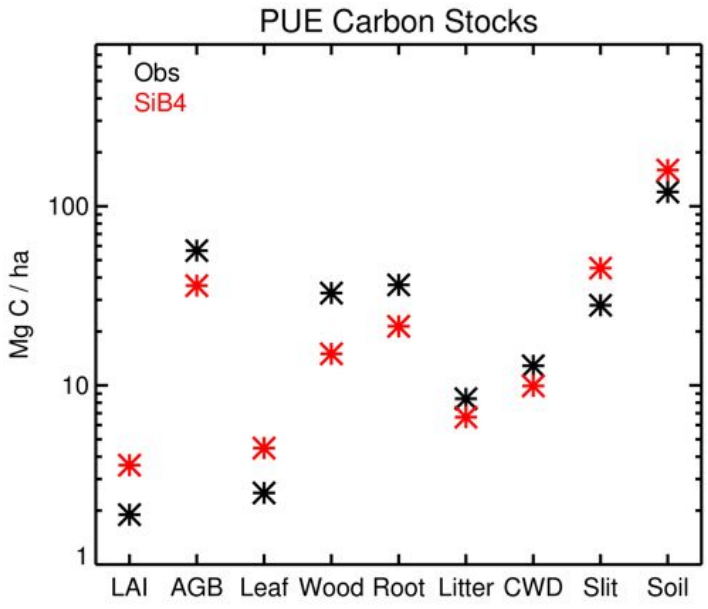
PFT Comparisons: Shrubs

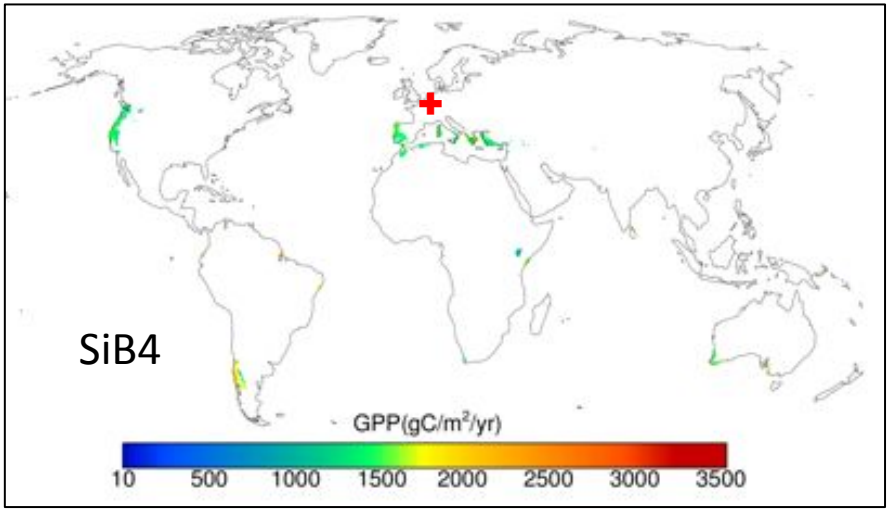
Evergreen Broadleaf (I)



Carbon pool and flux comparisons at the CarboEurope site FR-PUE (Allard et al., 2008; Misson et al., 2010; Rambal et al., 2004; Hoff et al., 2002; Baldocchi et al., 2010).

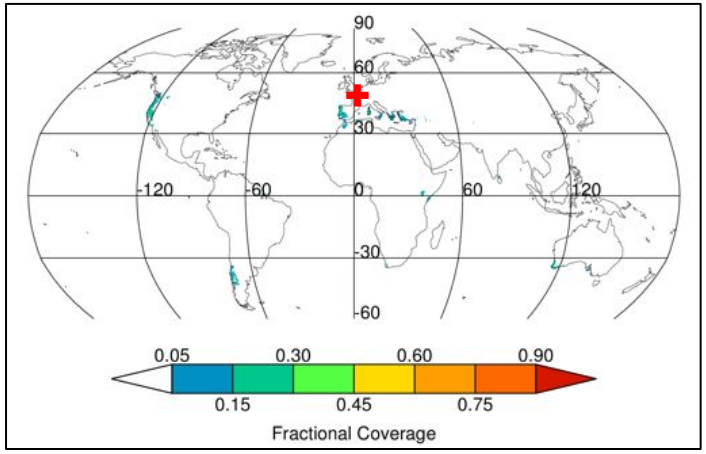


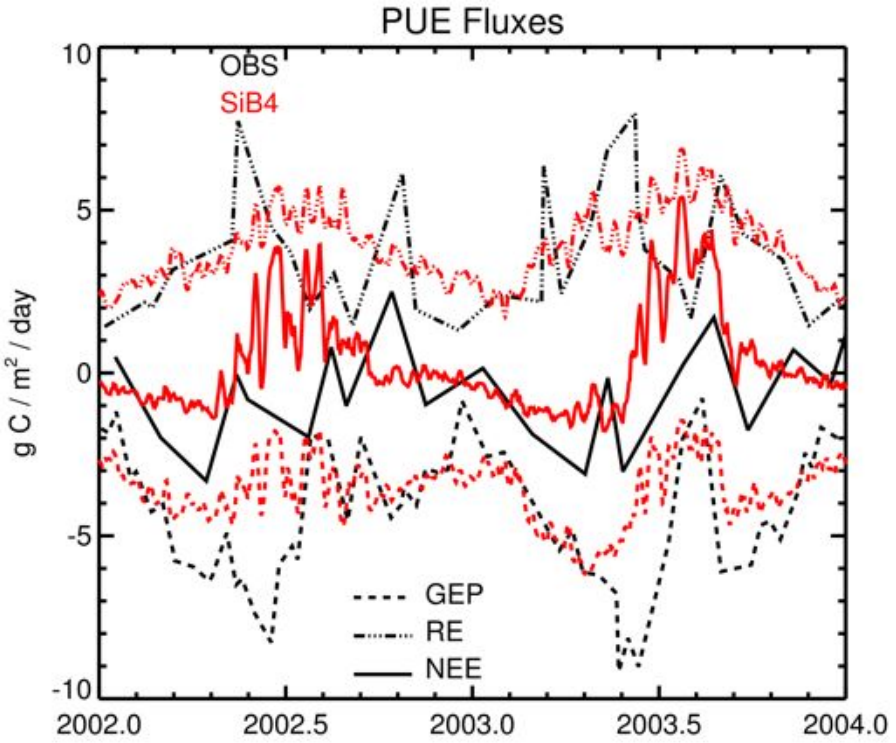


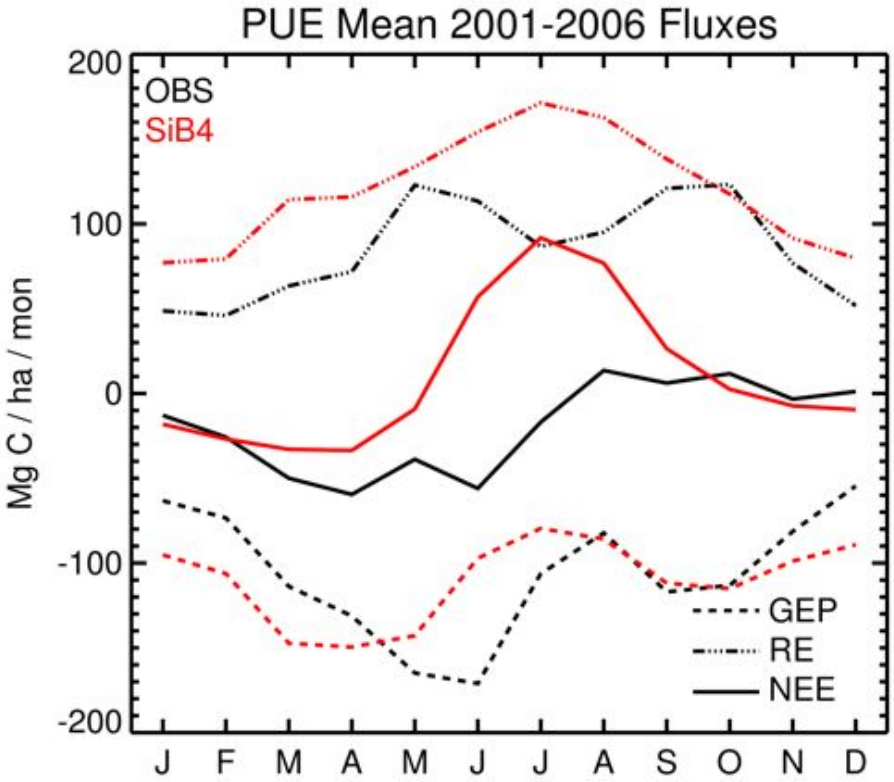


PFT Comparisons: Shrubs

Evergreen Broadleaf (II)



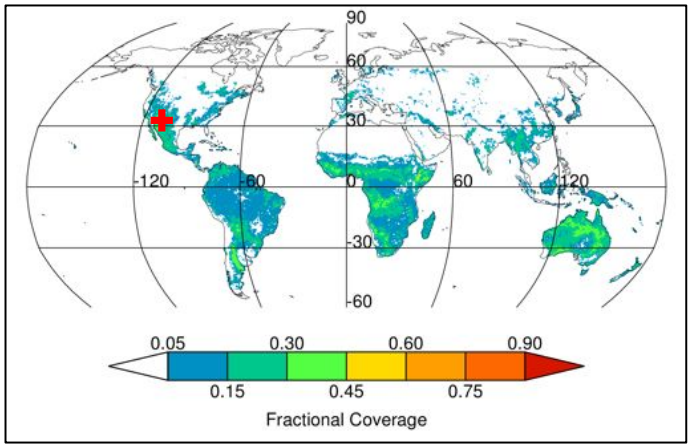




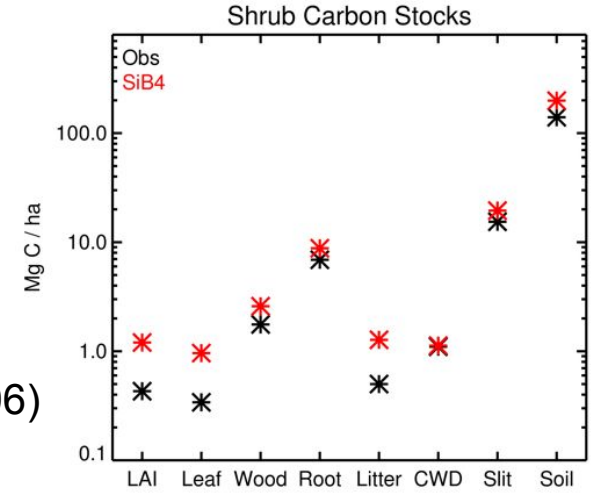
Daily carbon fluxes (above, Keenan et al., 2007) and mean monthly carbon fluxes (left, Allard et al., 2008) at the CarboEurope site FR-PUE.

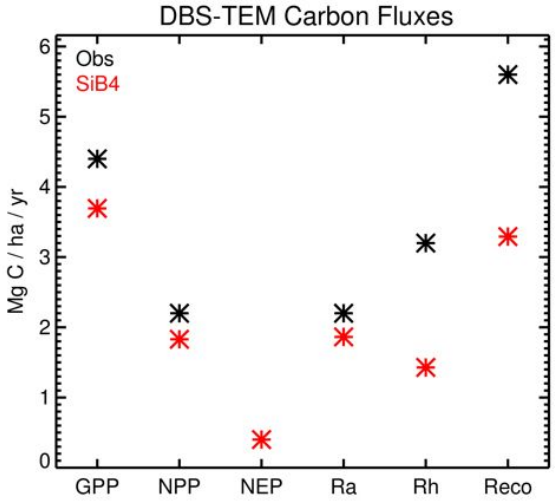
PFT Comparisons: Shrubs

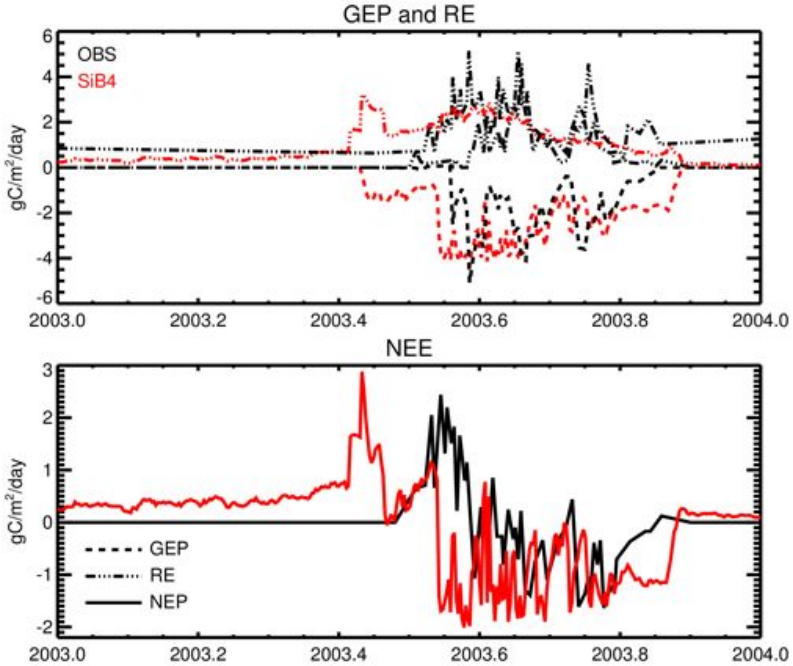
Temperate Deciduous Broadleaf

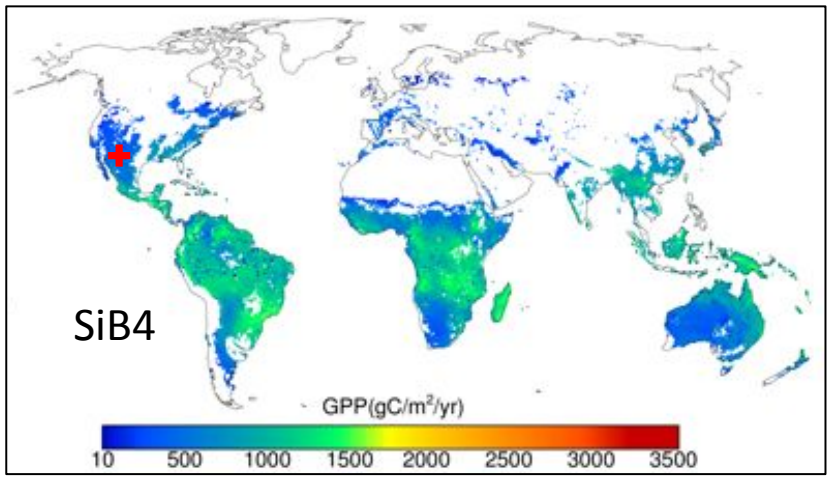


Annual carbon stocks and fluxes (right; Emmerich et al. 2003) and daily fluxes (below; Scott et al., 2006) at an AmeriFlux shrub site, WHS.



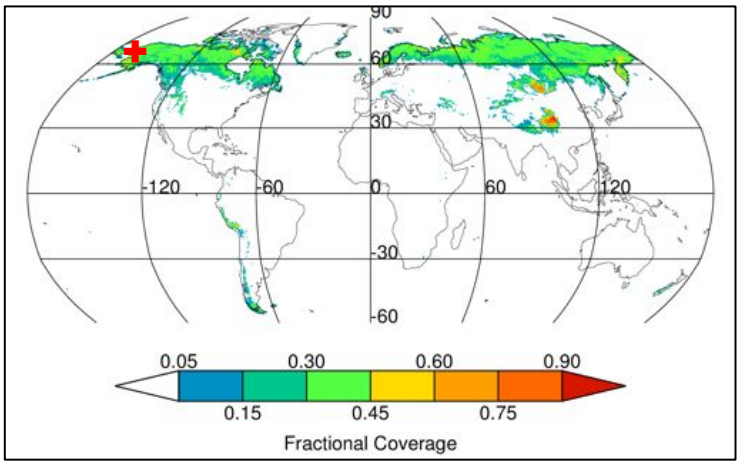




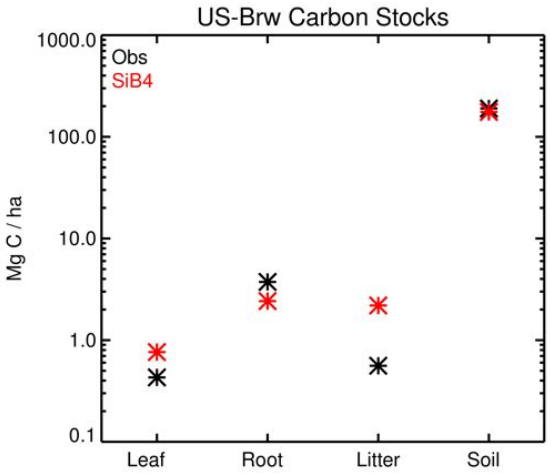


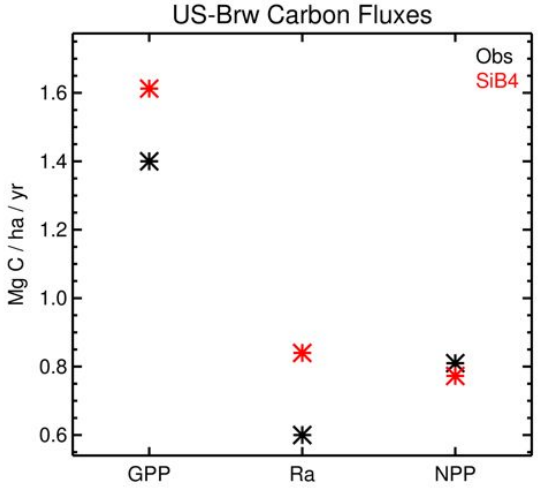
PFT Comparisons: Grass

C3 Arctic (Tundra)

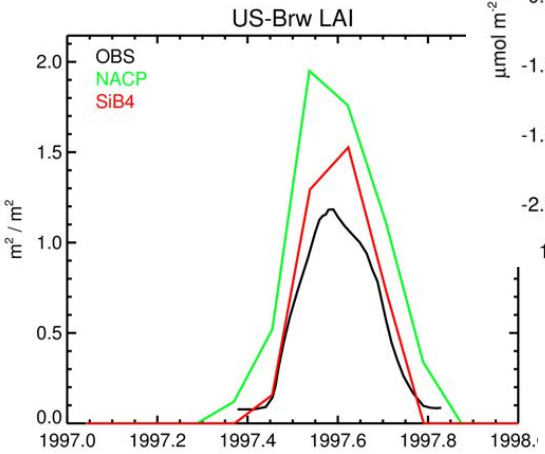


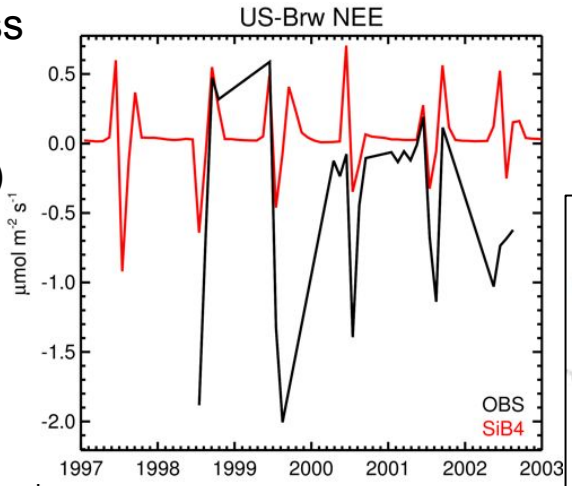
Annual carbon stocks (mid right; Billings, 1987) and carbon fluxes (far right; Grant et al., 2003) at an AmeriFlux tundra site, BRW.

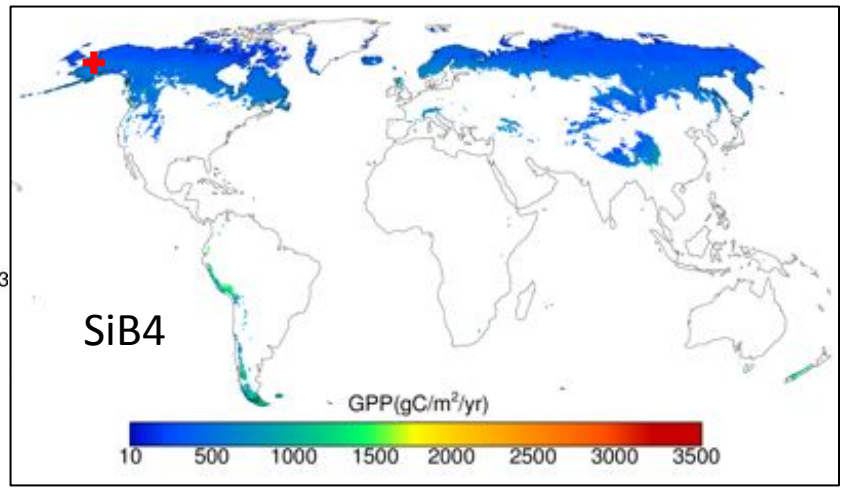




Leaf area index (LAI; Bliss et al., 1981) and NEE (Ameriflux database: http://ameriflux.ornl.gov)

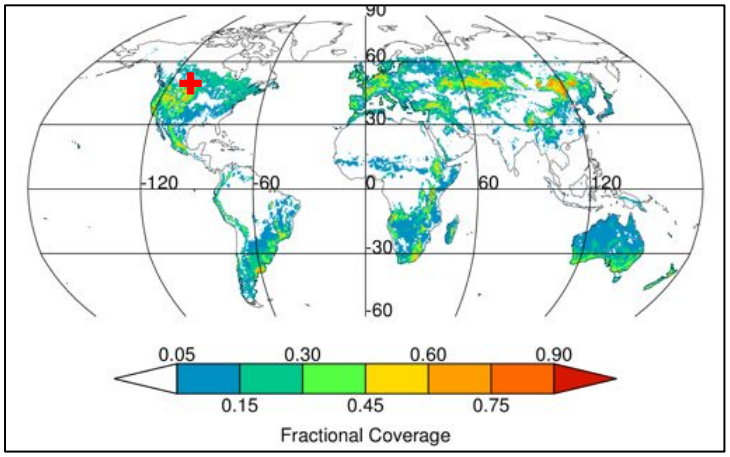




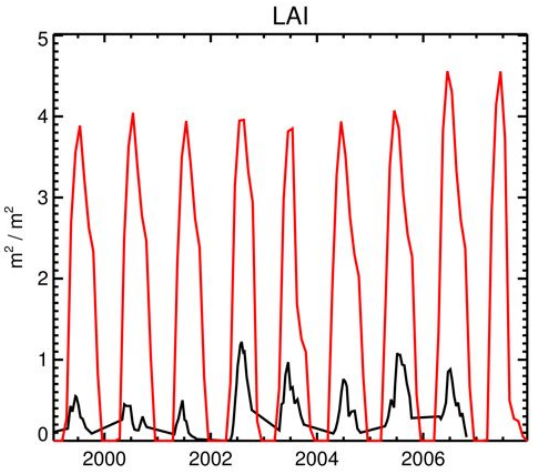


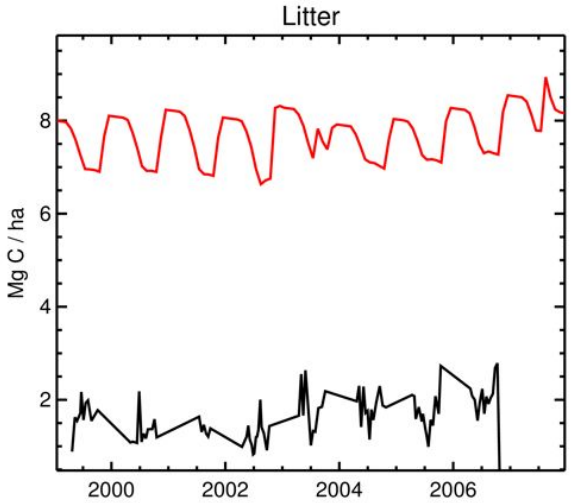
PFT Comparisons: Grass

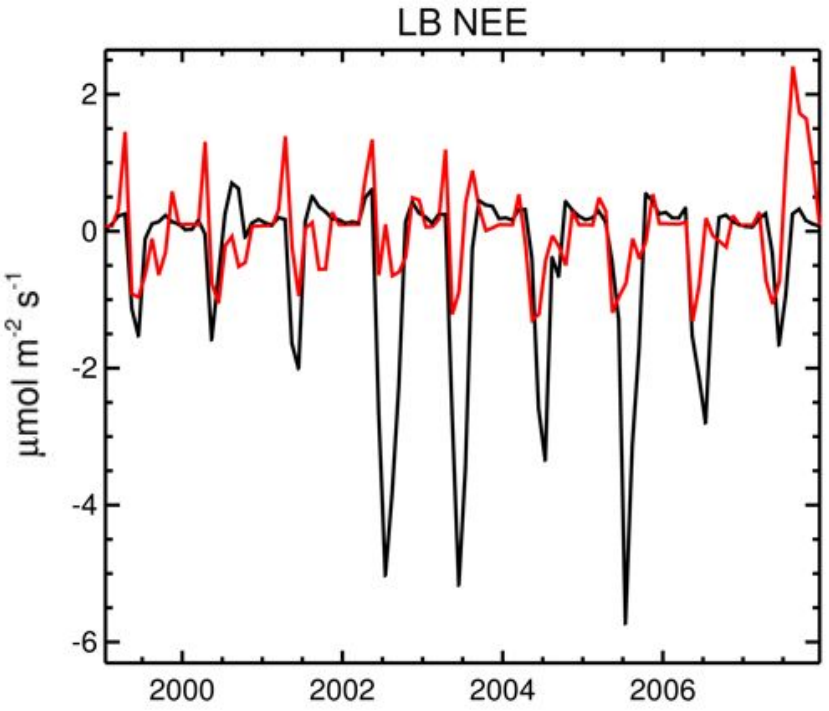
C3 Non-Arctic

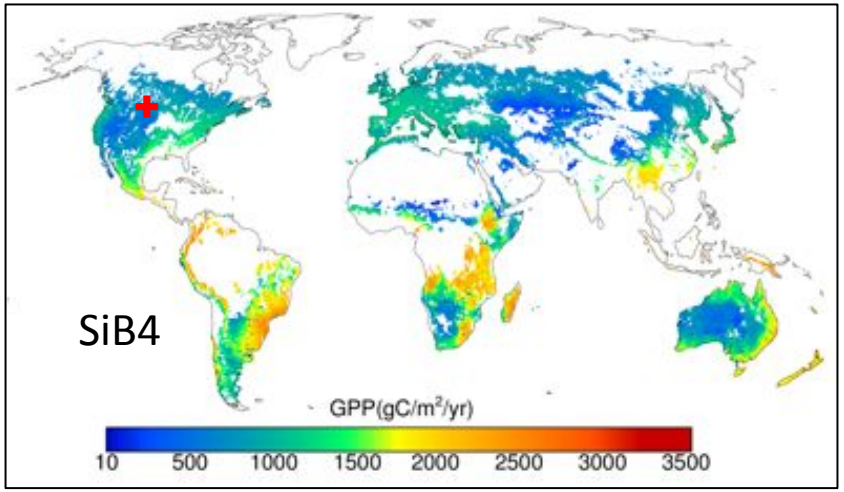


LAI, litter pool, and monthly mean NEE comparisons at a short prairie, AB-LB, in Canada Fluxnet (http://fluxnet.ccrp.ec.gc.ca).



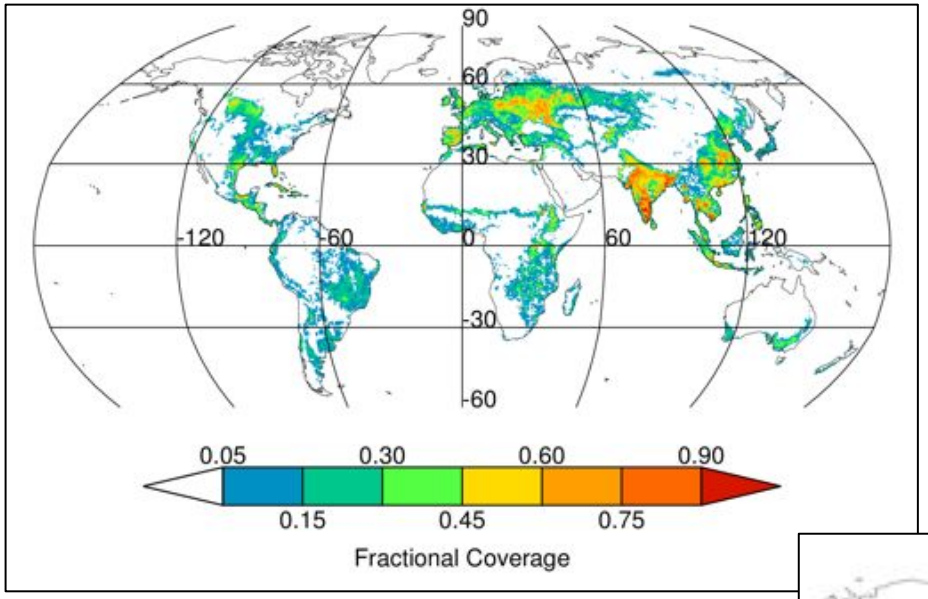


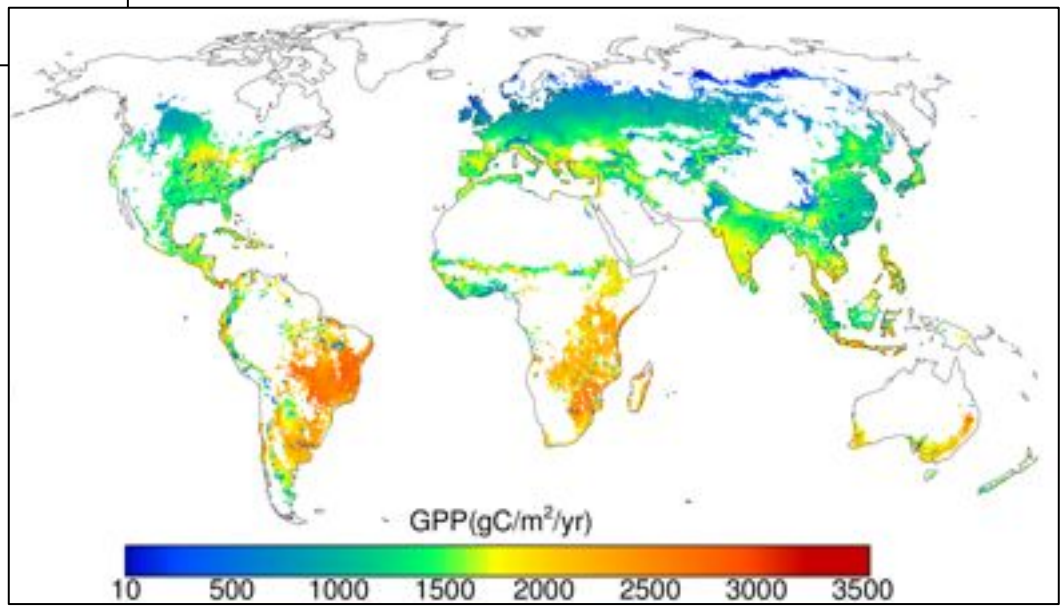




PFT Comparisons: Crops

Generic



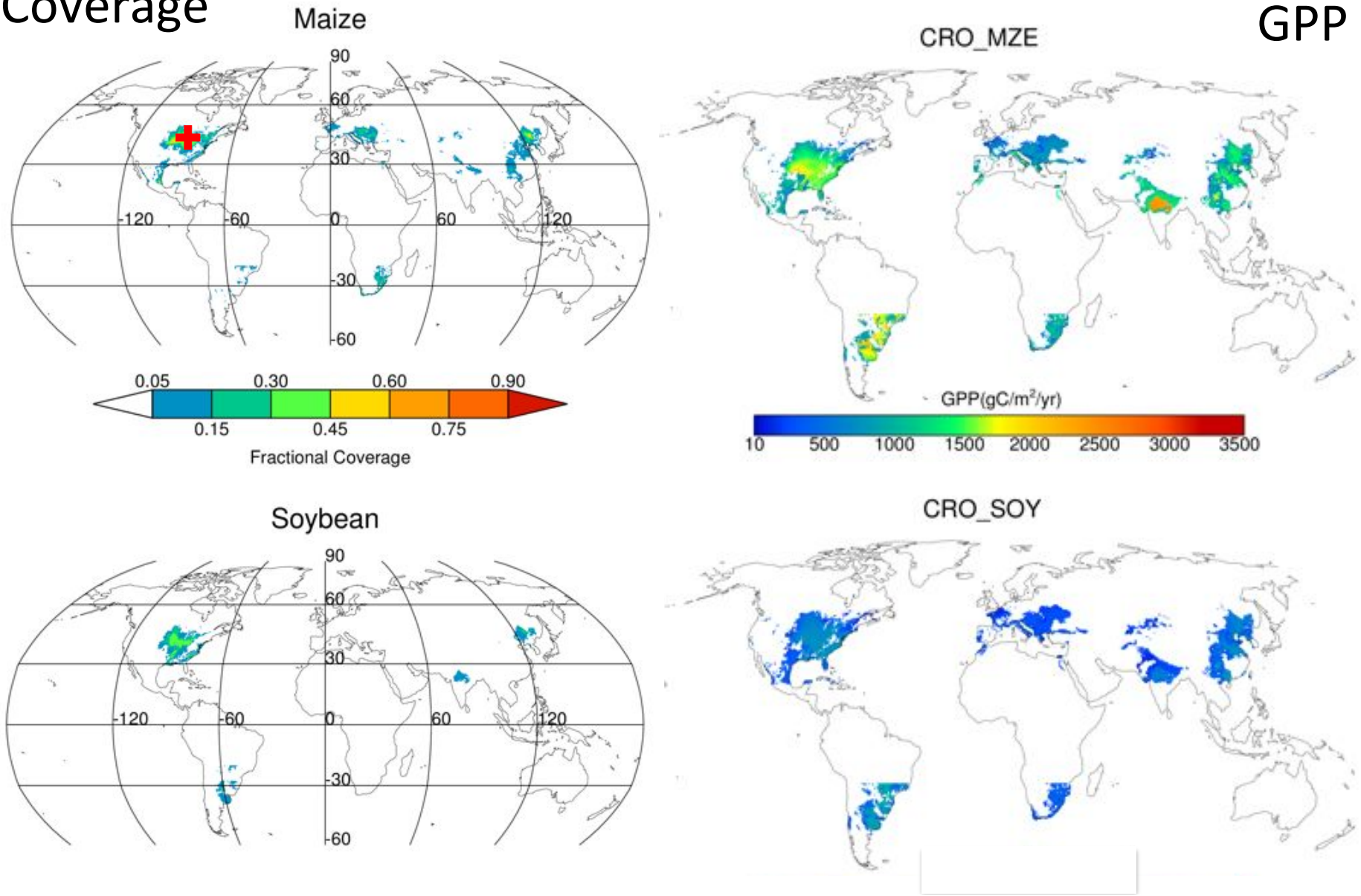


PFT Comparisons: Crops

Maize and Soybean (I)

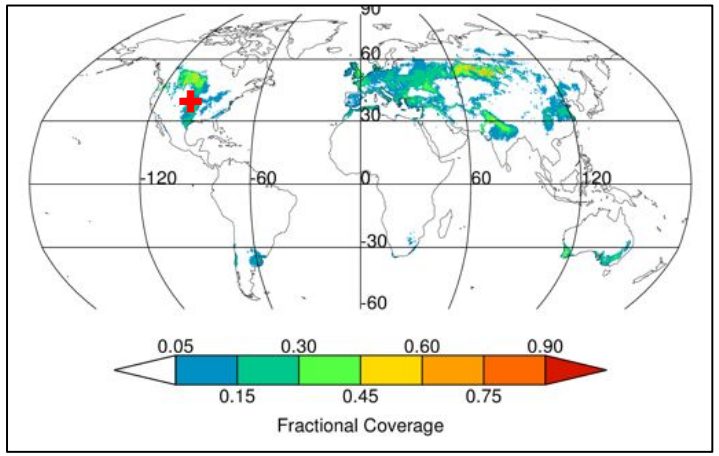
Areal Coverage

GPP



PFT Comparisons: Crops

Winter Wheat



LAI and NEE at a winter wheat location in the AmeriFlux network. Data are from http://ameriflux.ornl.gov.