A simple data assimilation approach for constraining global scale modeled GPP using GOME2 SIF data

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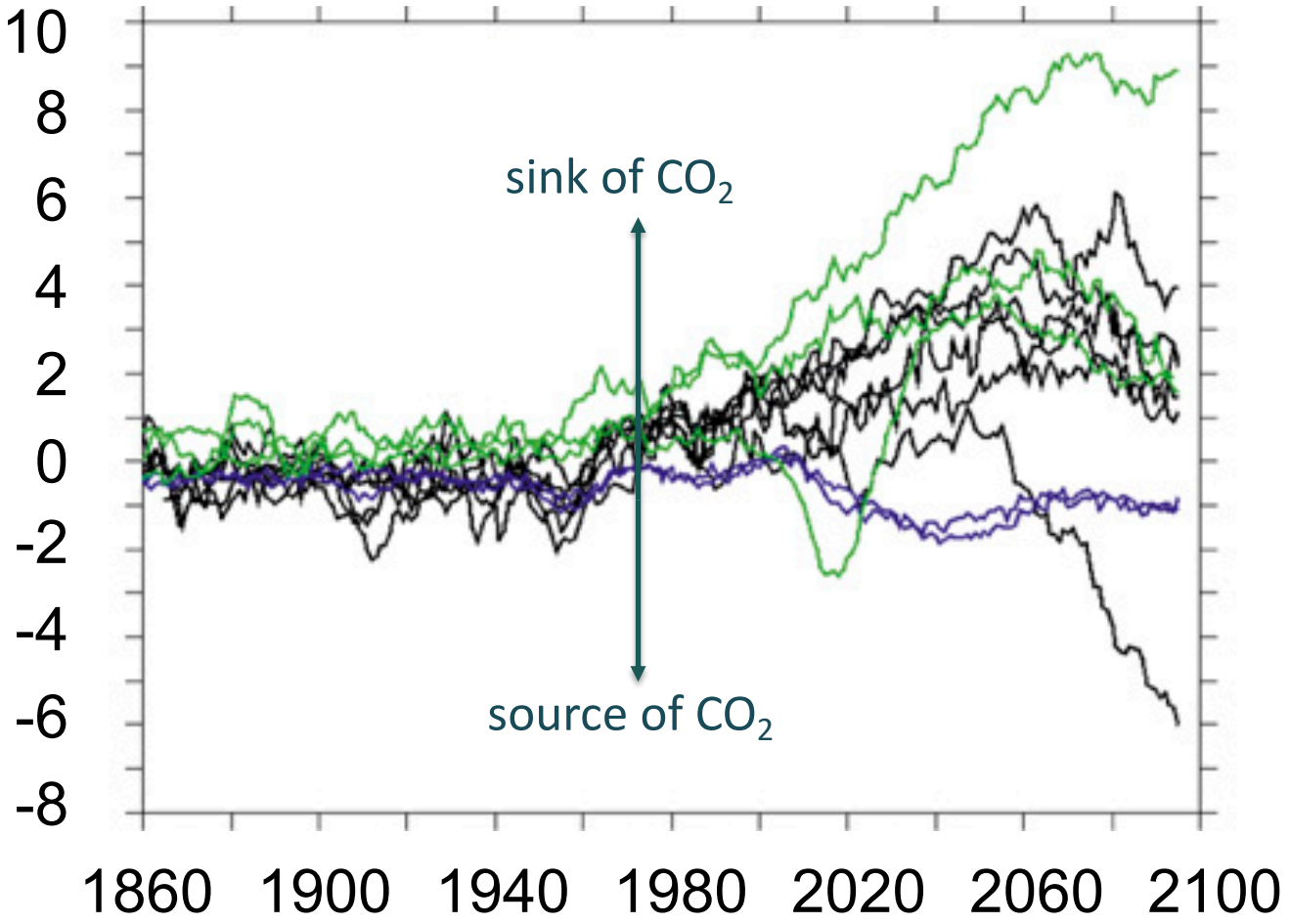
Outline

- Motivation for this research
- ORCHIDEE Data Assimilation System (ORCHIDAS) and past studies
- SIF DA set-up and results
- Perspectives and future directions…

Remaining uncertainty in terrestrial carbon sink

Global land-atmosphere net CO_2 flux ($PgCyr^{-1}$)

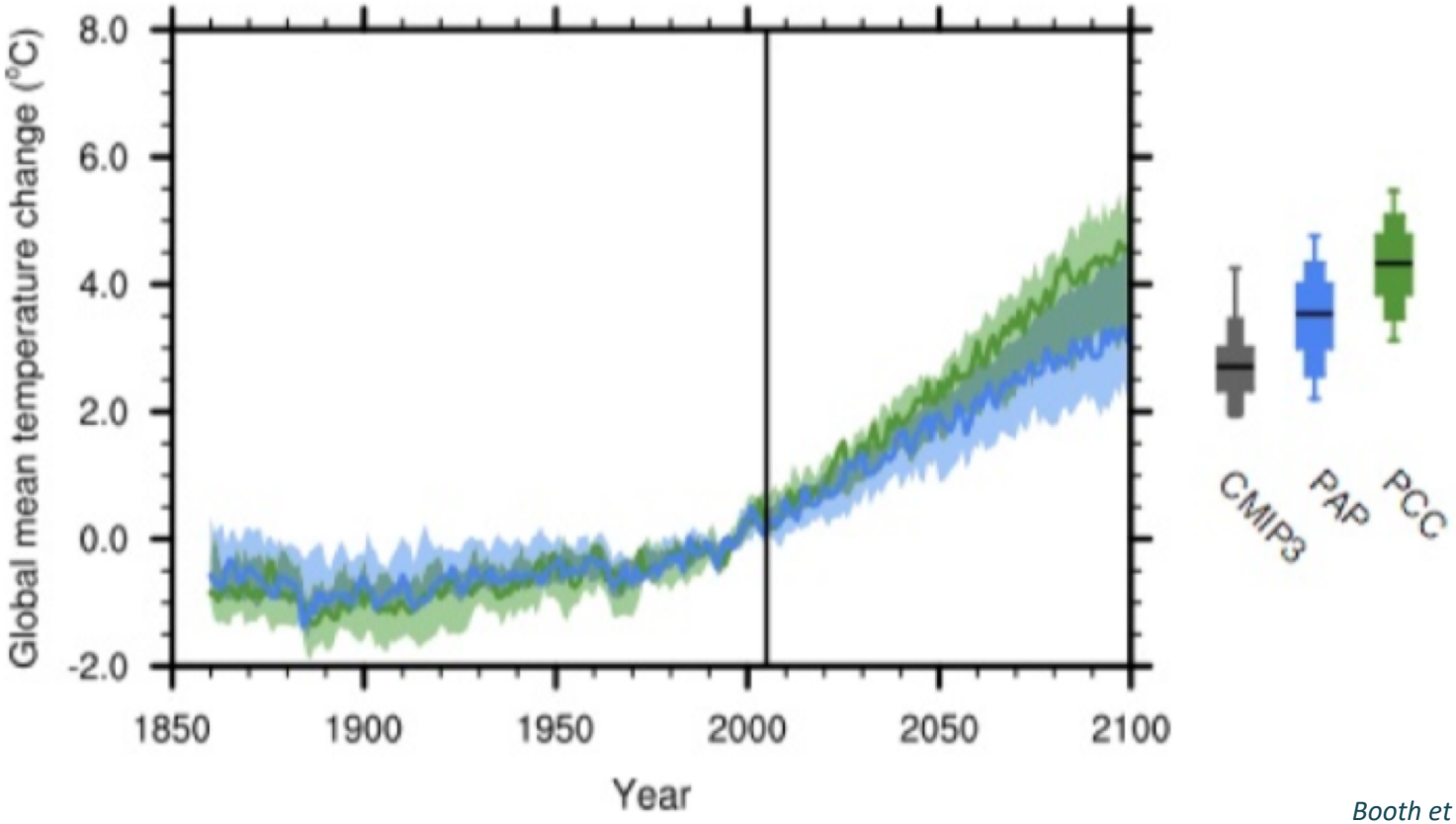
(RCP8.5)



Friedlingstein et al. (2014)

How important are carbon-climate feedbacks?

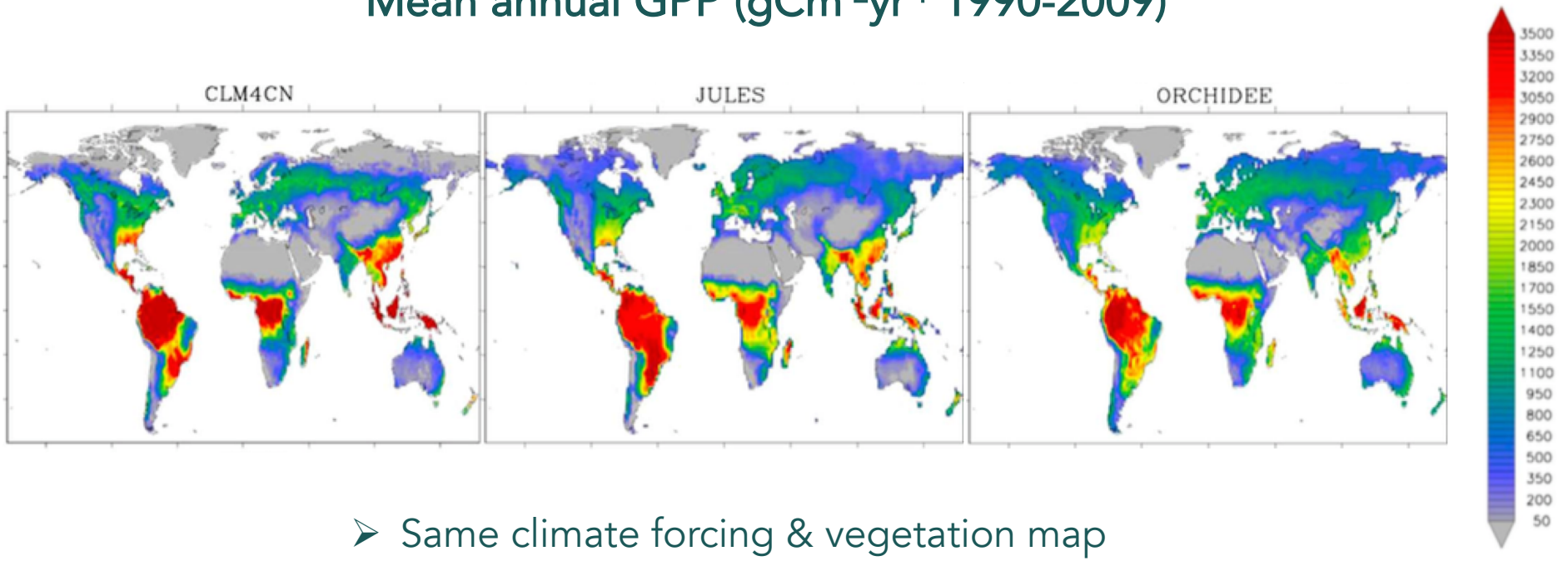
- Earth System Model (ESM) sensitivity analysis – 1 model & 1 scenario (HadCM3 – SRES-A1B)
- Altered **atmospheric physics parameters**
- Compared to **terrestrial carbon cycle parameters**



Booth et al. (2012)

Remaining uncertainty in current model estimates and future projections – *gross C uptake (GPP)*

Mean annual GPP ($gCm^{-2}yr^{-1}$ 1990-2009)



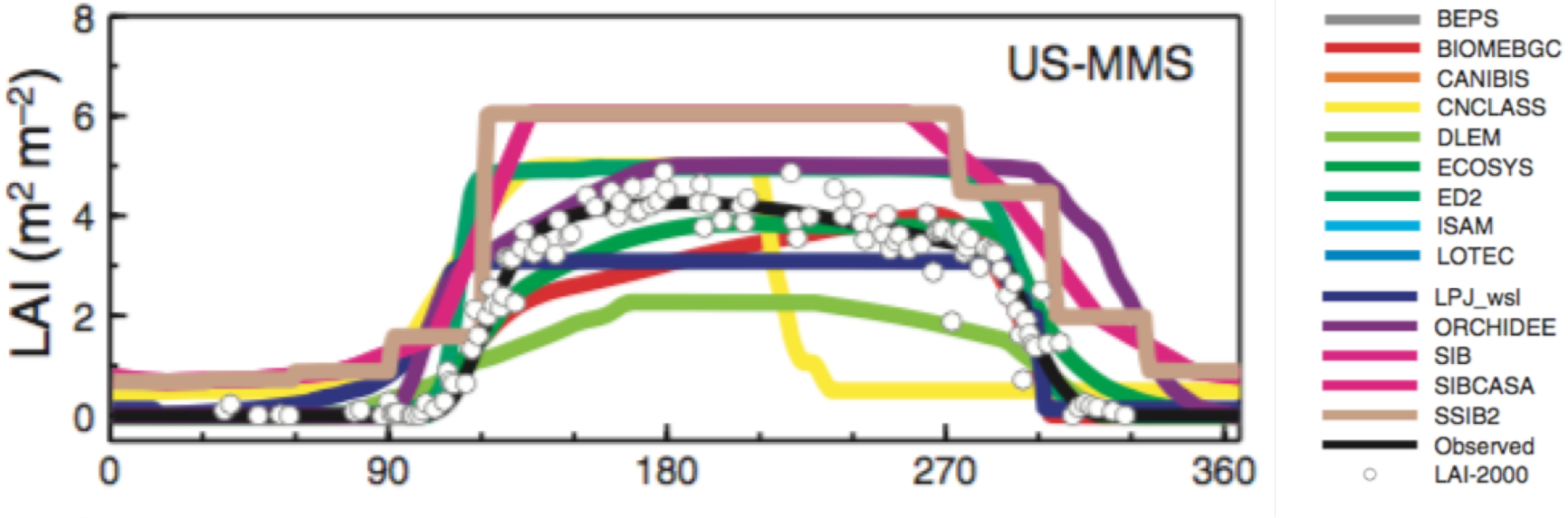
- Same climate forcing & vegetation map
- Different GPP spatial distribution
- Different GPP magnitude

= Uncertainty due to model processes/parameters

Anav et al. (2015)

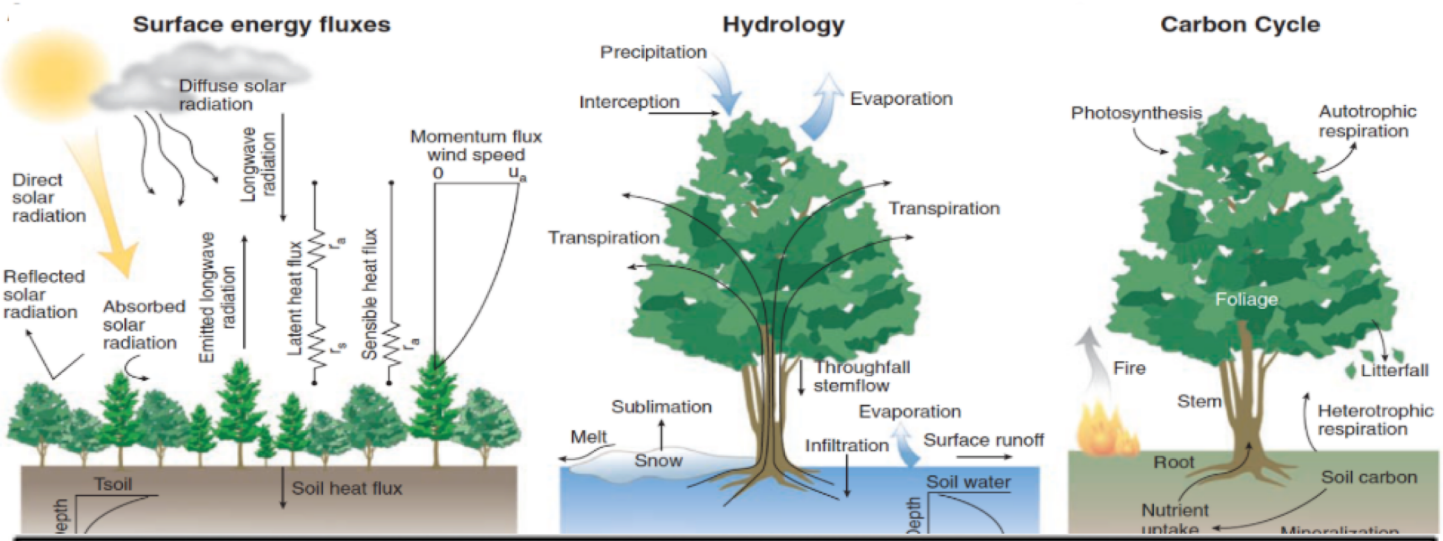
Remaining uncertainty in current model estimates and future projections – *leaf phenology*

Seasonal leaf dynamics (Leaf Area Index – LAI) at Morgan Monroe Forest



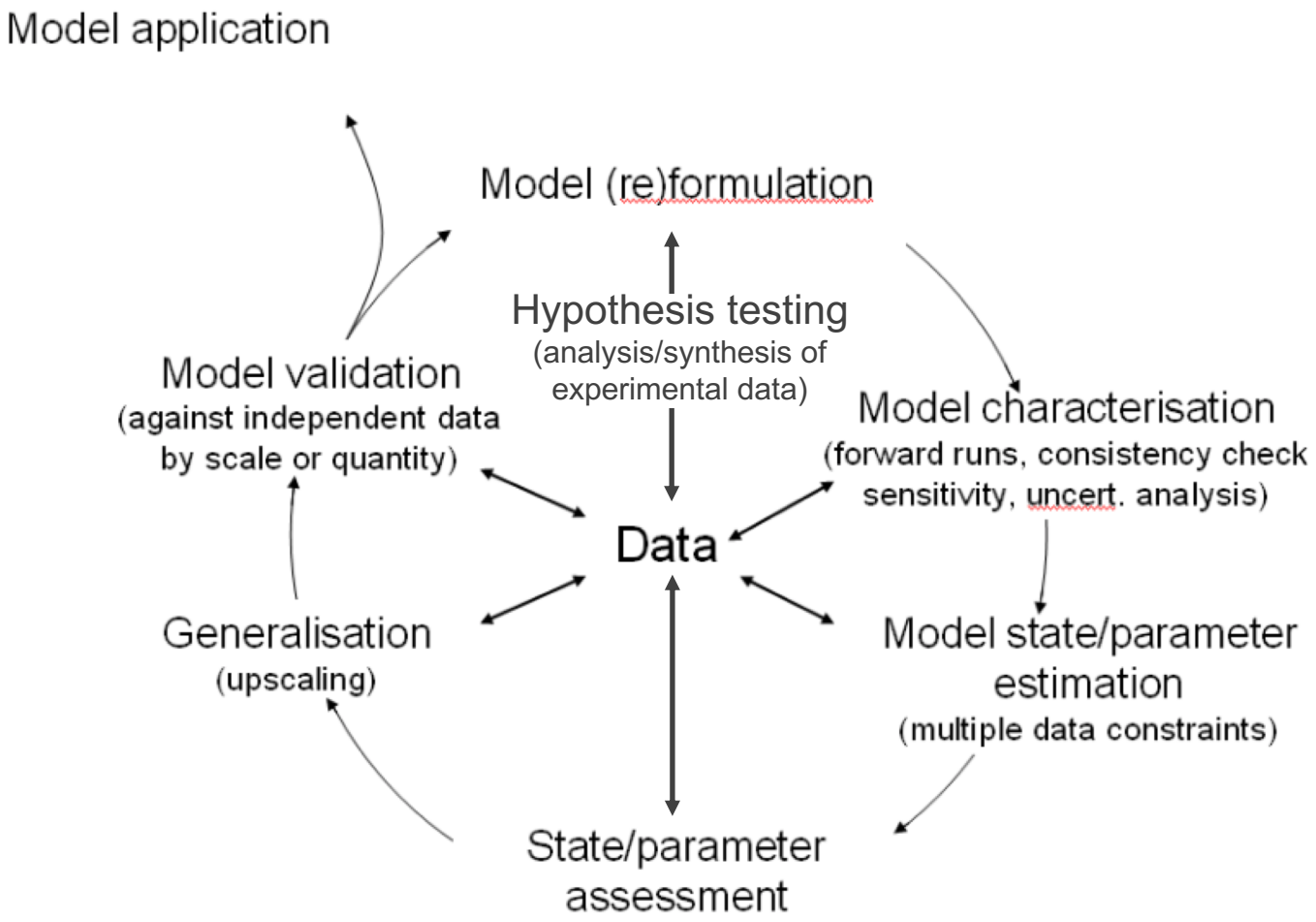
Richardson et al. (2012)

What is a land surface/terrestrial biosphere model?



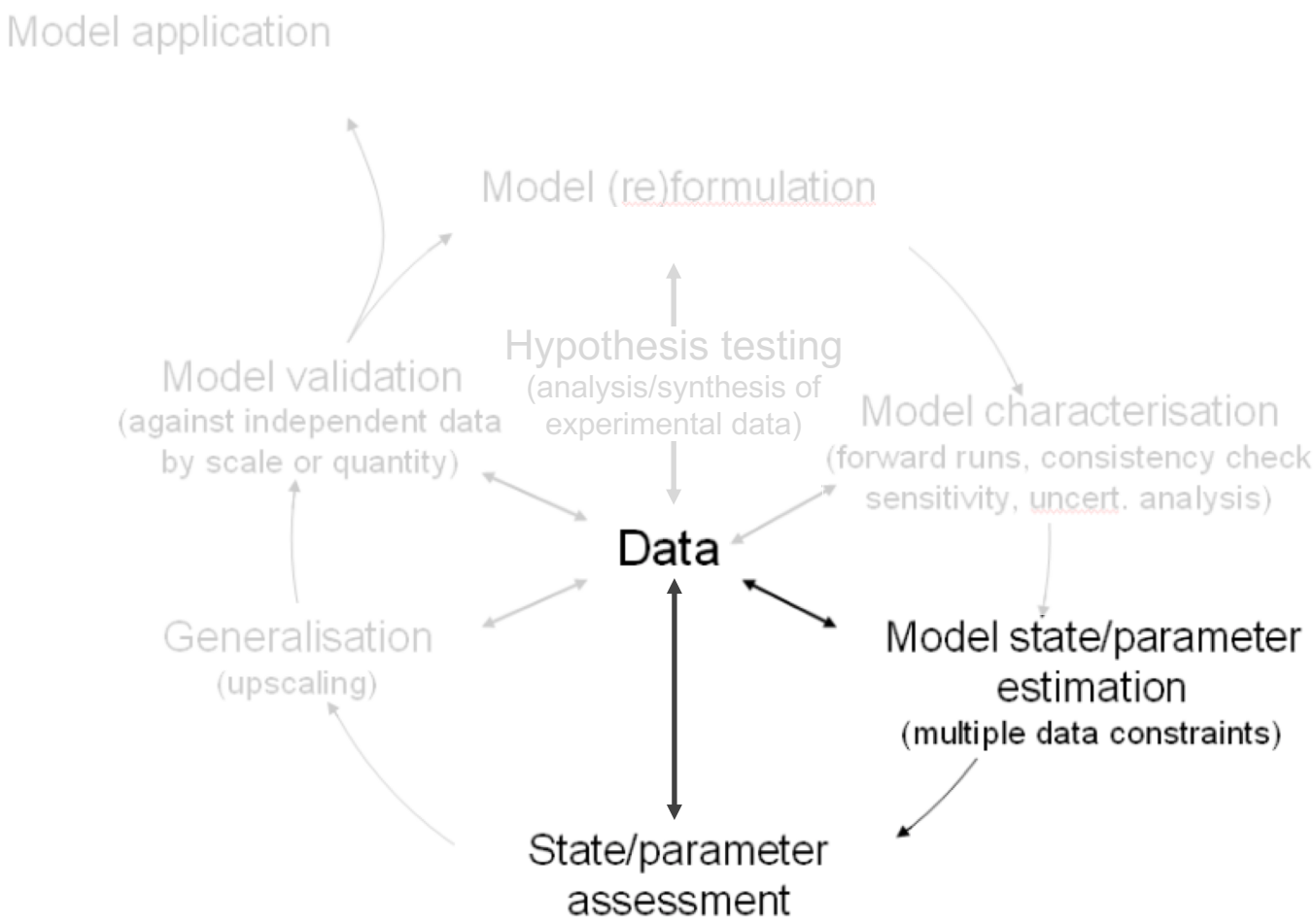
http://www.cesm.ucar.edu/models/clm/

Improving models | Reducing uncertainty → the model development cycle



Adapted from Williams et al. (2009)

Improving models | Reducing uncertainty → the model development cycle



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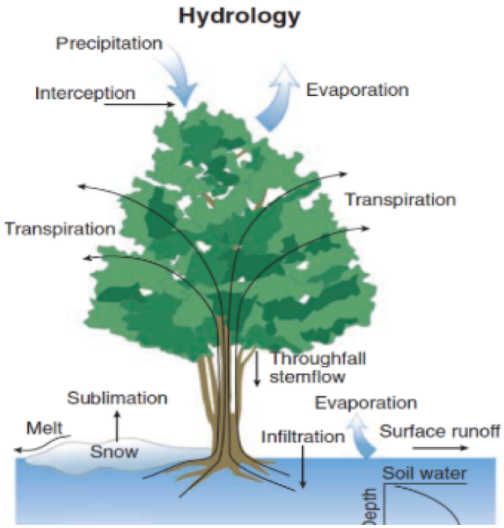
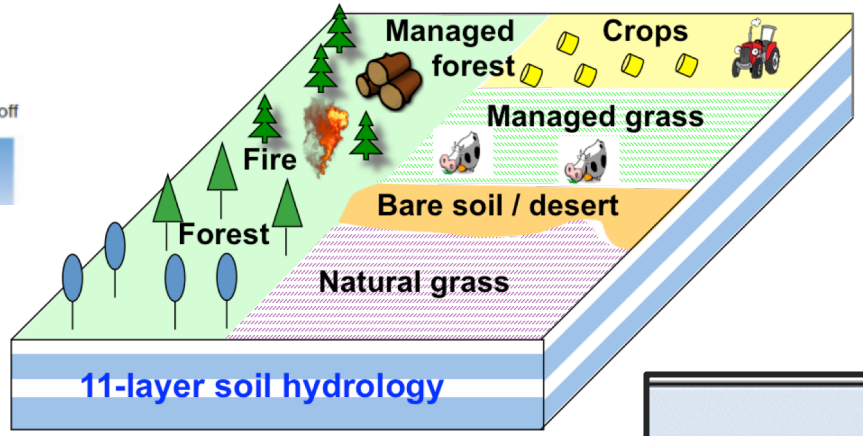
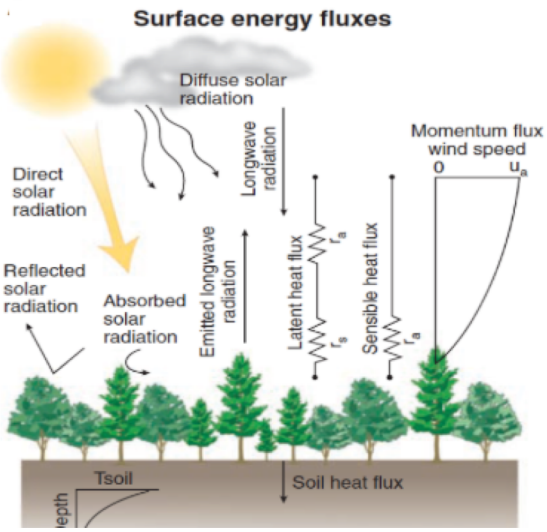
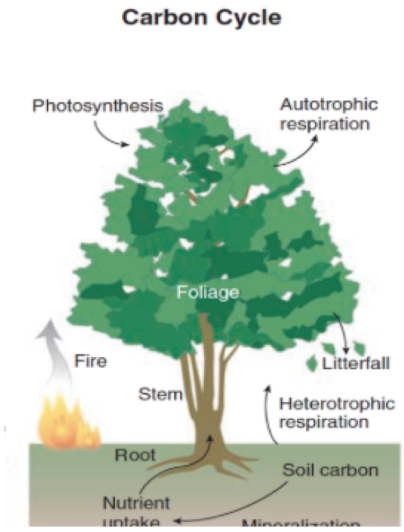
ORCHIDEE terrestrial biosphere models (TBMs)



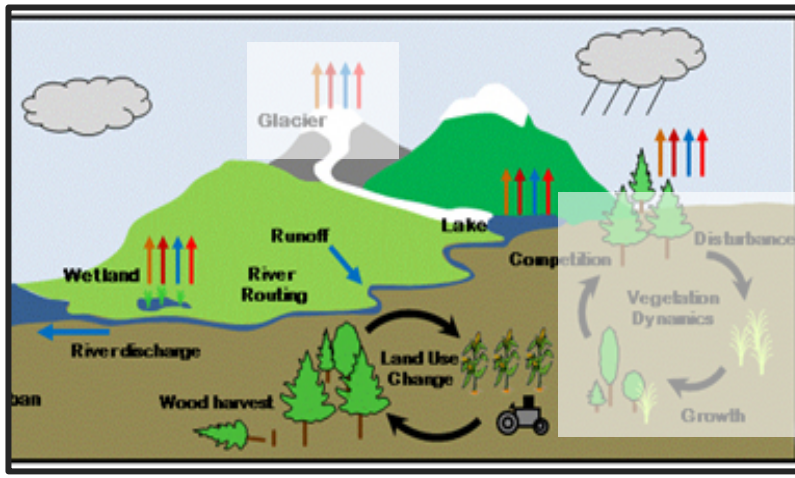
ORCHIDEE TBM/LSM





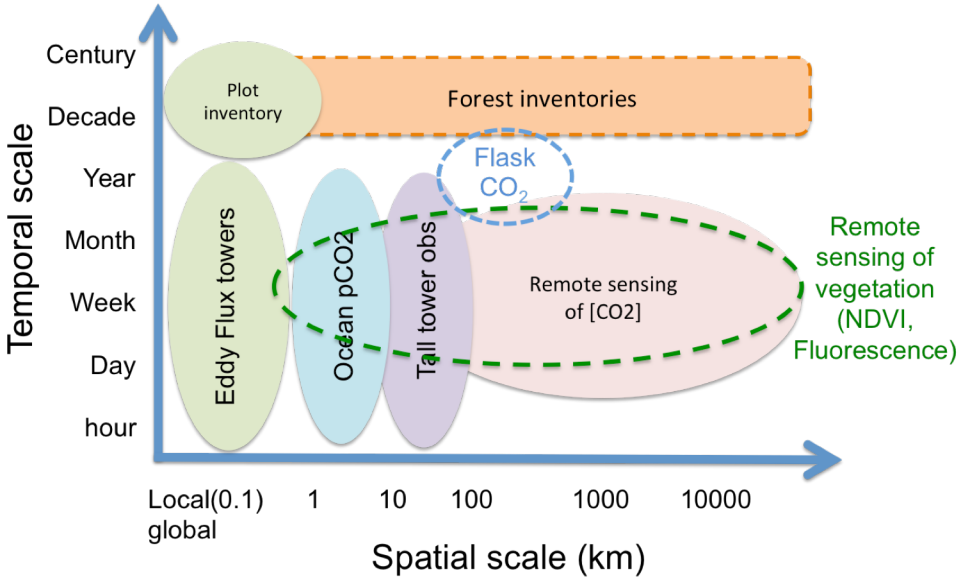


13 Plant Functional Types (PFTs)



Reducing uncertainty: the need for model – data integration

Available C-related data streams



Model
Parameters
Obs
Model-data mismatch

$$J(\mathrm{x}) = \tfrac{1}{2}(\mathbf{M}(\mathrm{x})-\mathrm{y})^{\mathrm{T}}\,\mathbf{R}^{-1}(\mathbf{M}(\mathrm{x})-\mathrm{y})$$

Observation term

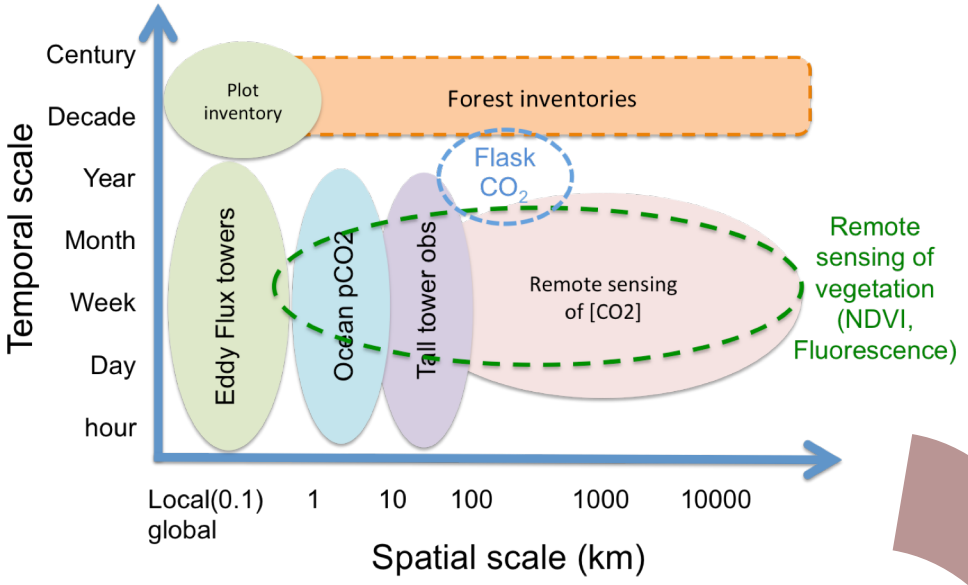
Prior parameters

$$+\ \tfrac{1}{2}(\mathrm{x}-\mathrm{x_b})^{\mathrm{T}}\,\mathbf{B}^{-1}(\mathrm{x}-\mathrm{x_b})$$

Prior parameter term

Reducing uncertainty: the need for model – data integration

Available C-related data streams



Model | Parameters | Obs | Model-data mismatch

$$J(\mathbf{x}) = \tfrac{1}{2}(\mathbf{M}(\mathbf{x})-\mathbf{y})^{T}\,\mathbf{R}^{-1}(\mathbf{M}(\mathbf{x})-\mathbf{y})$$

Observation term

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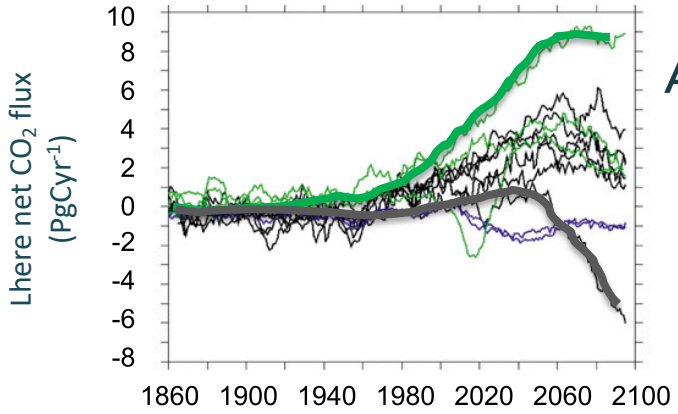
$$+\ \tfrac{1}{2}(\mathbf{x}-\mathbf{x}_b)^{T}\,\mathbf{B}^{-1}(\mathbf{x}-\mathbf{x}_b)$$

Prior parameter term



DATA ASSIMILATION

Improve:

- C land budget estimates
- Quantify & reduce uncertainty
- Future climate predictions
- Process understanding

Global Data Assimilation System – ORCHIDEE LSM

ASSIMILATION DATA

Vegetation greenness indices

Flux tower net CO_2 (NEE) and latent heat flux

Satellite Solar Induced Chl Fluorescence

Aboveground biomass

FORCING DATA

Meteo. data
Prior param. values

Land
ORCHIDEE LSM

LAND
DATA ASSIMILATION
SYSTEM

https://orchidas.lsce.ipsl.fr

Global Data Assimilation System – ORCHIDEE LSM

ASSIMILATION DATA

Vegetation greenness indices

Flux tower net CO_2 (NEE) and latent heat flux

Satellite Solar Induced Chl Fluorescence

Aboveground biomass

Atmos. CO_2 conc.

FORCING DATA

Meteo. data
Prior param. values

Fossil fuel and biomass burning fluxes

Land **ORCHIDEE LSM**

Ocean pCO_2 flux model

Atmosphere model

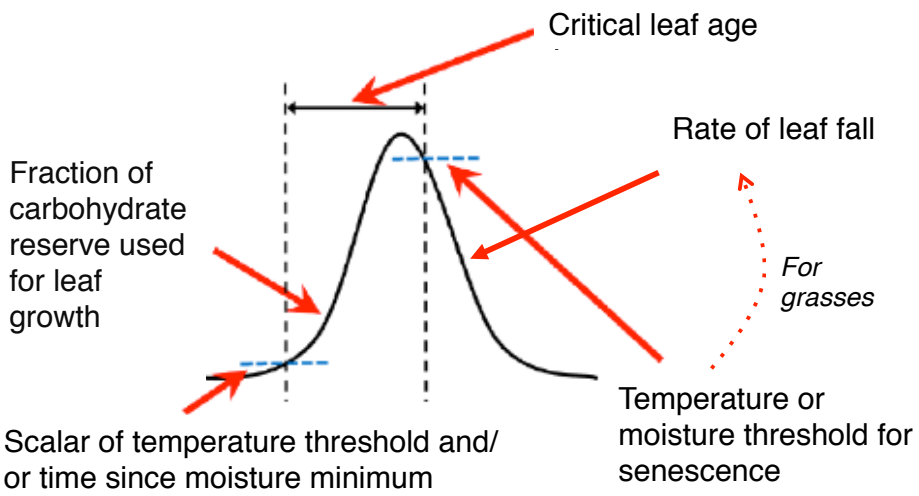
LAND DATA ASSIMILATION SYSTEM

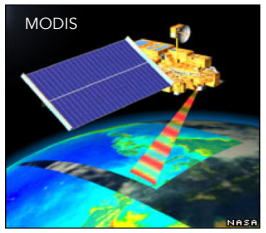
Validation with independent data

Optimized carbon stocks and fluxes (values plus uncertainties)

https://orchidas.lsce.ipsl.fr

Satellite NDVI to constrain leaf seasonal dynamics

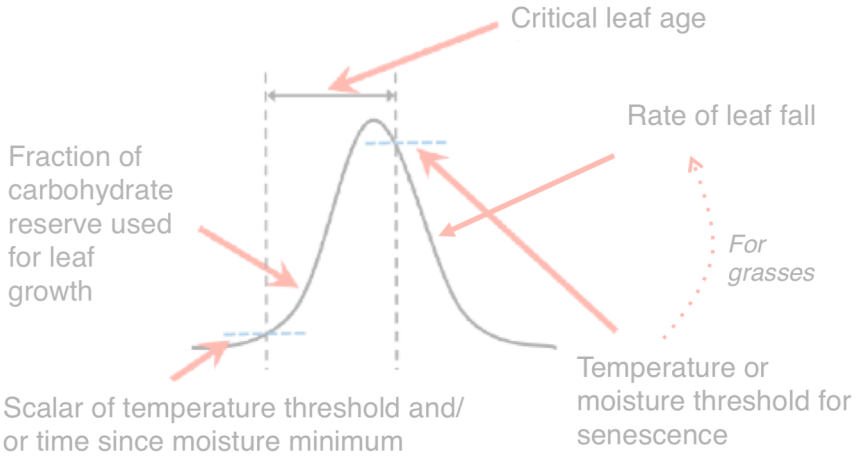


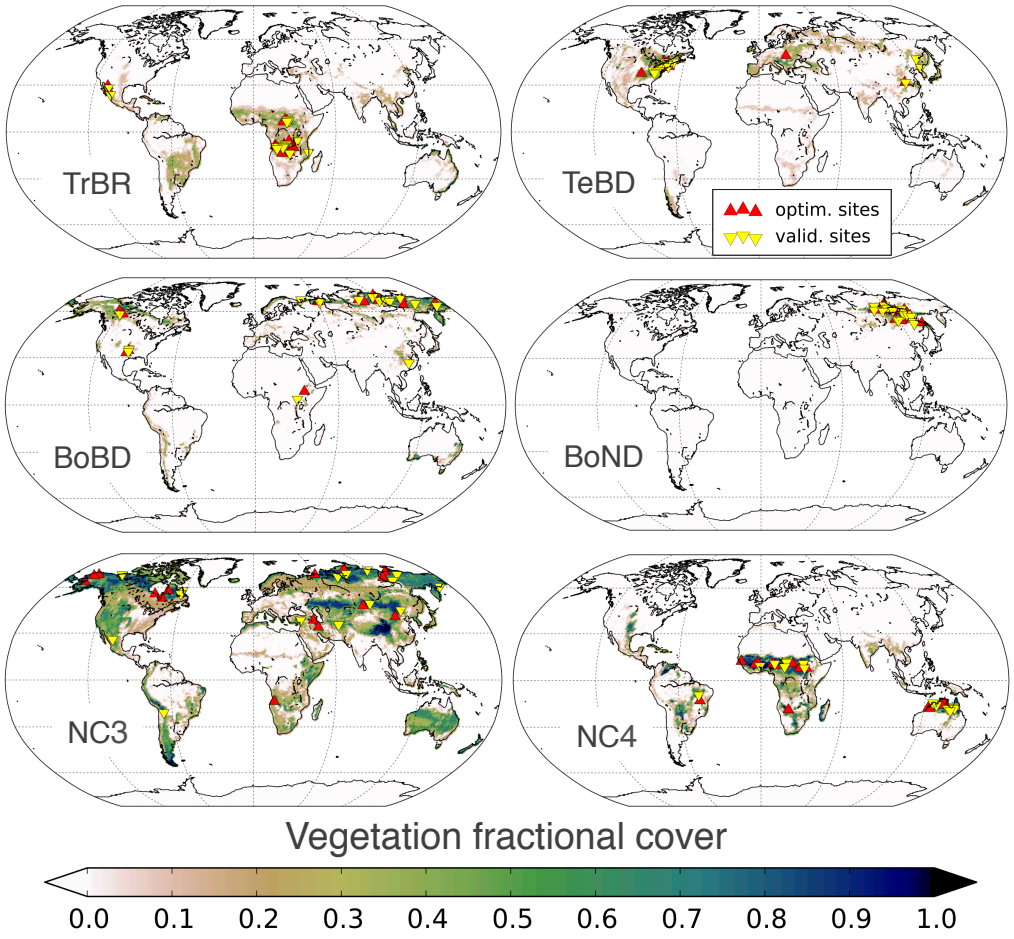


- Satellite NDVI compared to modeled fraction of absorbed photosynthetic radiation (FAPAR)
- FAPAR → LAI via Beer Lambert Law
- 4 – 6 parameters per plant functional type (PFT)

N. MacBean et al. (2015) Using satellite data to improve the leaf phenology of a global Terrestrial Biosphere Model, *Biogeosciences,* 12, 7185-7208

Satellite NDVI to constrain leaf seasonal dynamics

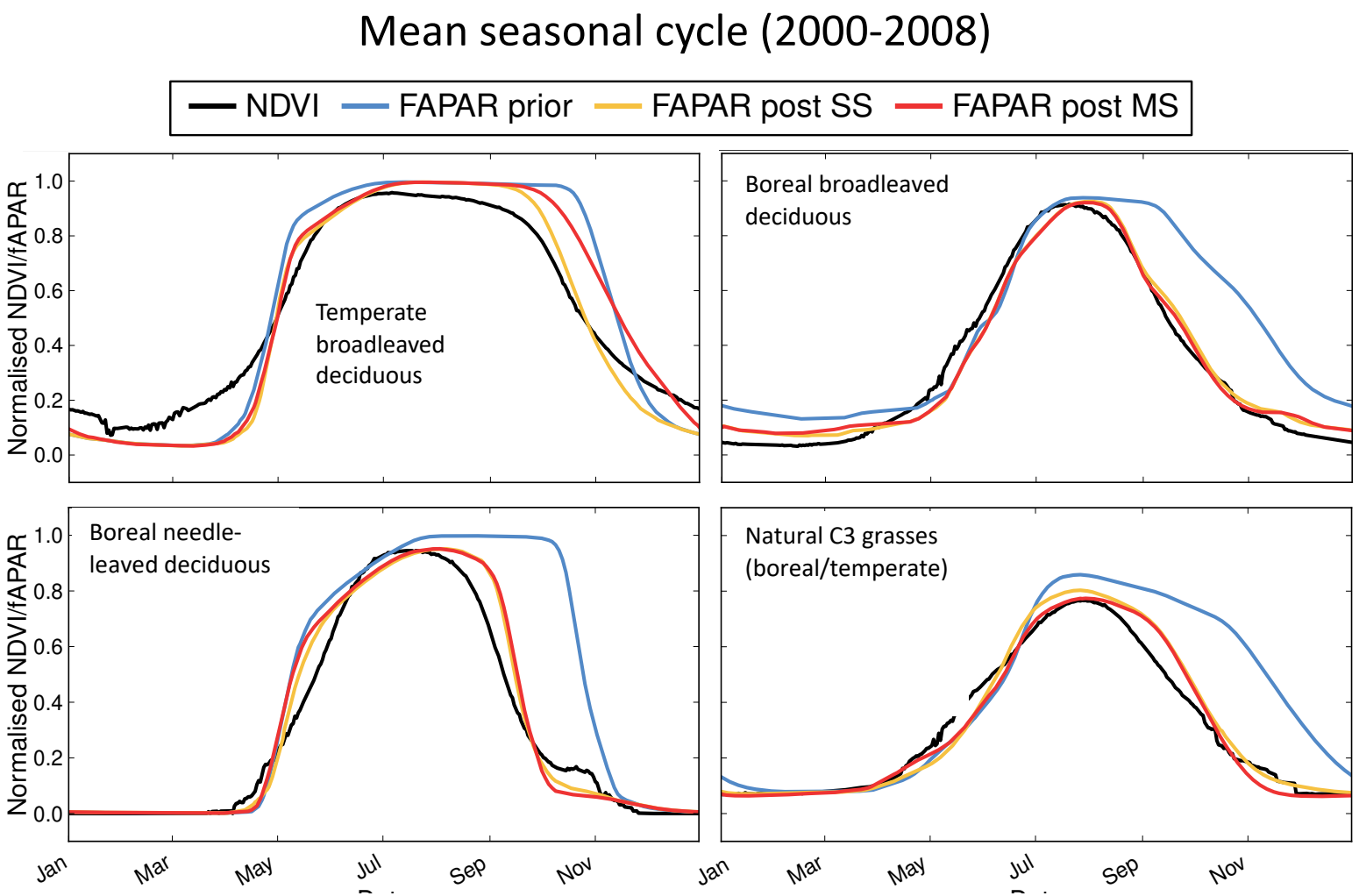




- Satellite NDVI compared to modeled fraction of absorbed photosynthetic radiation (FAPAR)
- FAPAR → LAI via Beer Lambert Law
- 4 – 6 parameters per plant functional type (PFT)
- 6 deciduous PFTs
- 15 random grid points per PFT

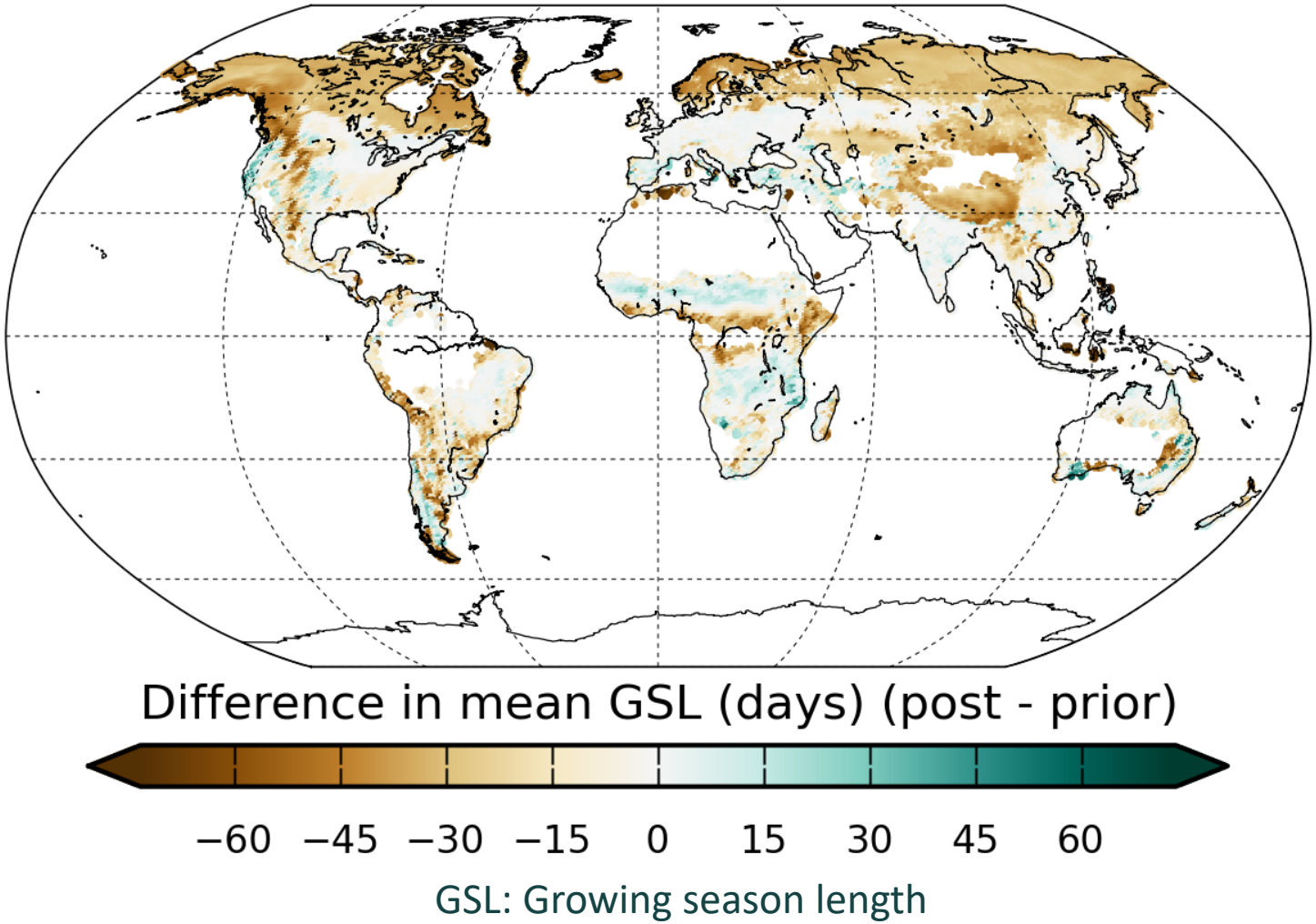
N. MacBean et al. (2015) Using satellite data to improve the leaf phenology of a global Terrestrial Biosphere Model, *Biogeosciences,* 12, 7185-7208

Improvement in modeled leaf senescence…



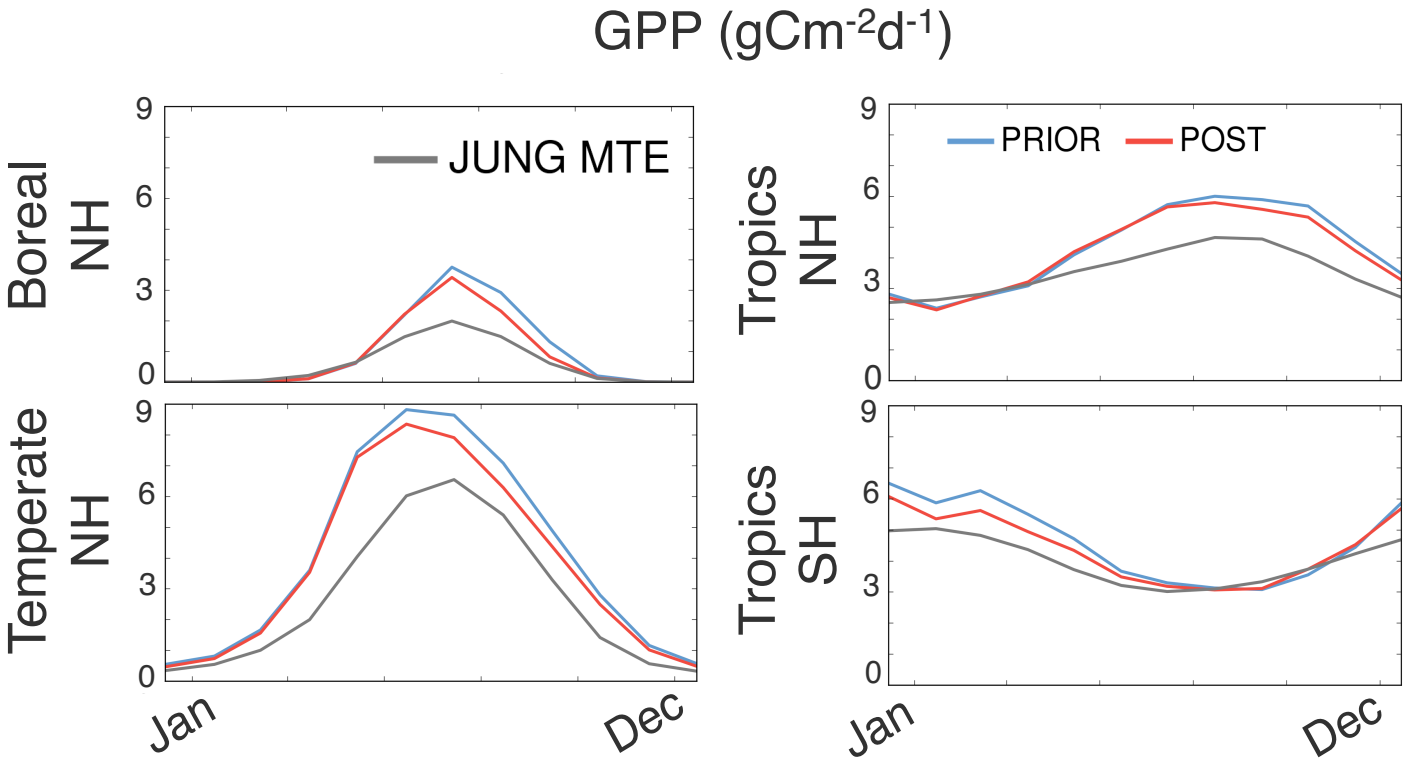
N. MacBean et al. (2015) Using satellite data to improve the leaf phenology of a global Terrestrial Biosphere Model, *Biogeosciences,* 12, 7185-7208

Dramatic reduction in growing season length

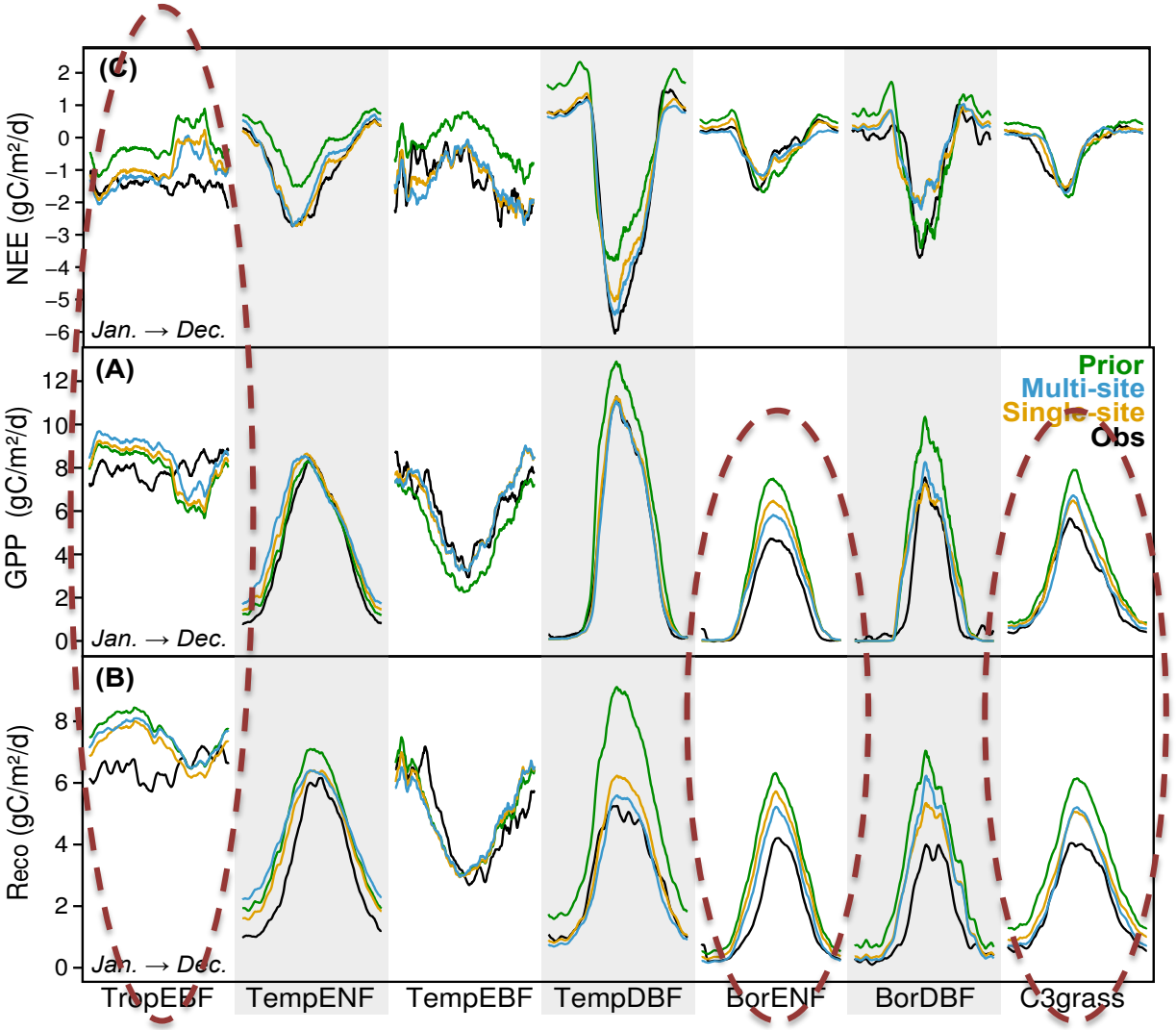


N. MacBean et al. (2015) Using satellite data to improve the leaf phenology of a global Terrestrial Biosphere Model, *Biogeosciences,* 12, 7185-7208

But not much change in GPP magnitude…



Constraining "fast" processes using FLUXNET data



- NEE (and LE) → *not gross C fluxes*
- optimized "fast" C-related parameters (photosynthesis, respiration), phenology, water stress & some energy balance
- ~60 sites overall
- Improved fit to mean seasonal cycle

Kuppel et al. (2014) Model–data fusion across ecosystems: from multi-site optimizations to global simulations, *Geosci. Model Dev.*, 7, 2581-2597

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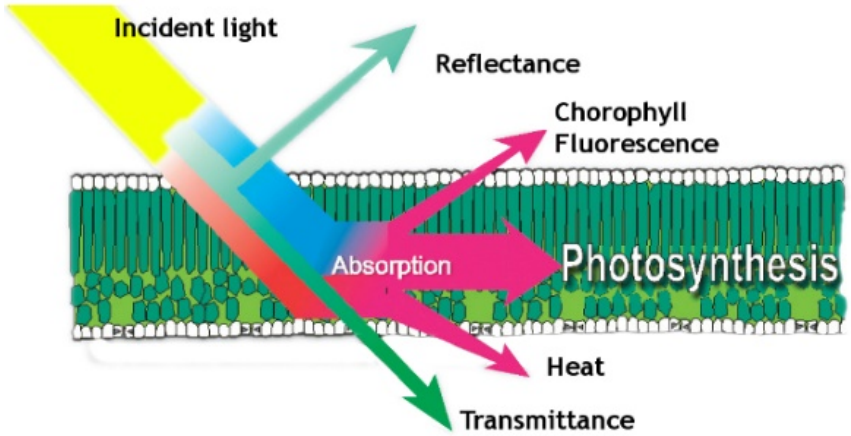
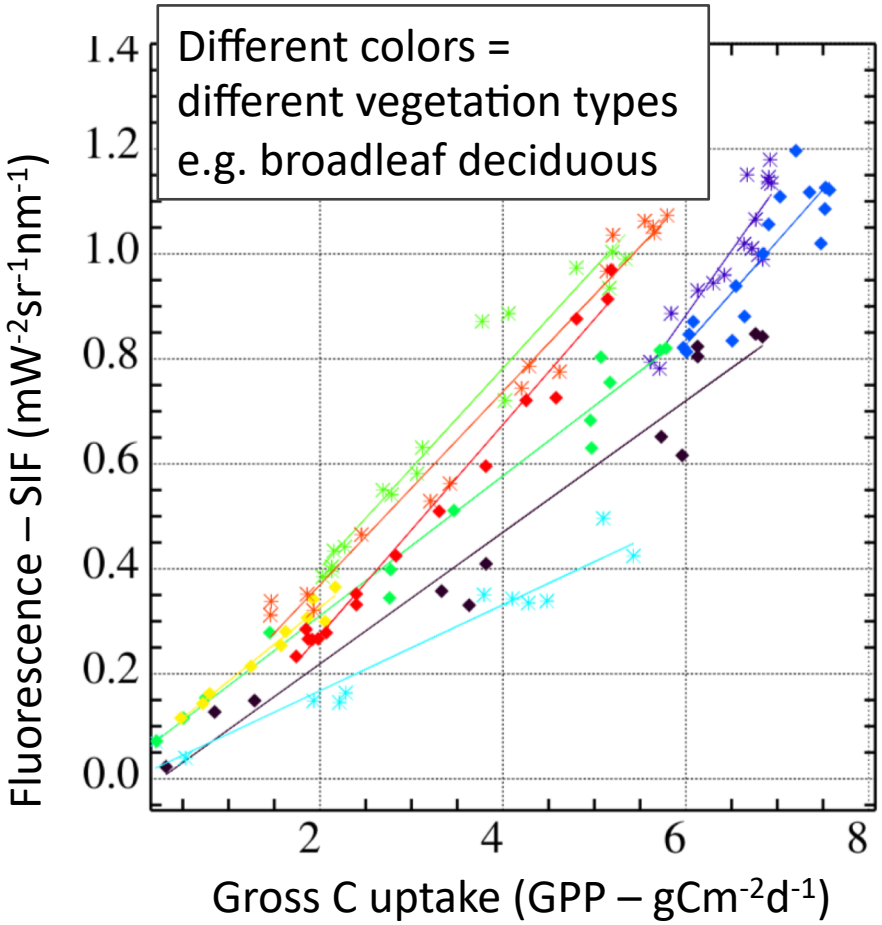
New data streams! Solar-induced chlorophyll fluorescence (SIF)



- Appears to be a linear relationship between SIF and GPP at large spatial (>0.5°) & temporal (~monthly) scales
- Slope dependent on vegetation type/structure
- Damm et al. (2015); Zhang et al. (2016); Goulas et al., (2017); Verma et al. (2017); Wood et al. (2017)



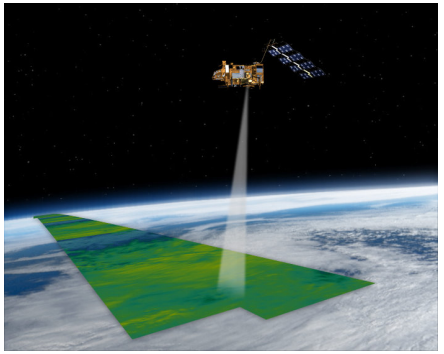
Guanter et al. (2012)

Optimization set-up

- Assume simple empirical linear relationship between GPP and SIF:

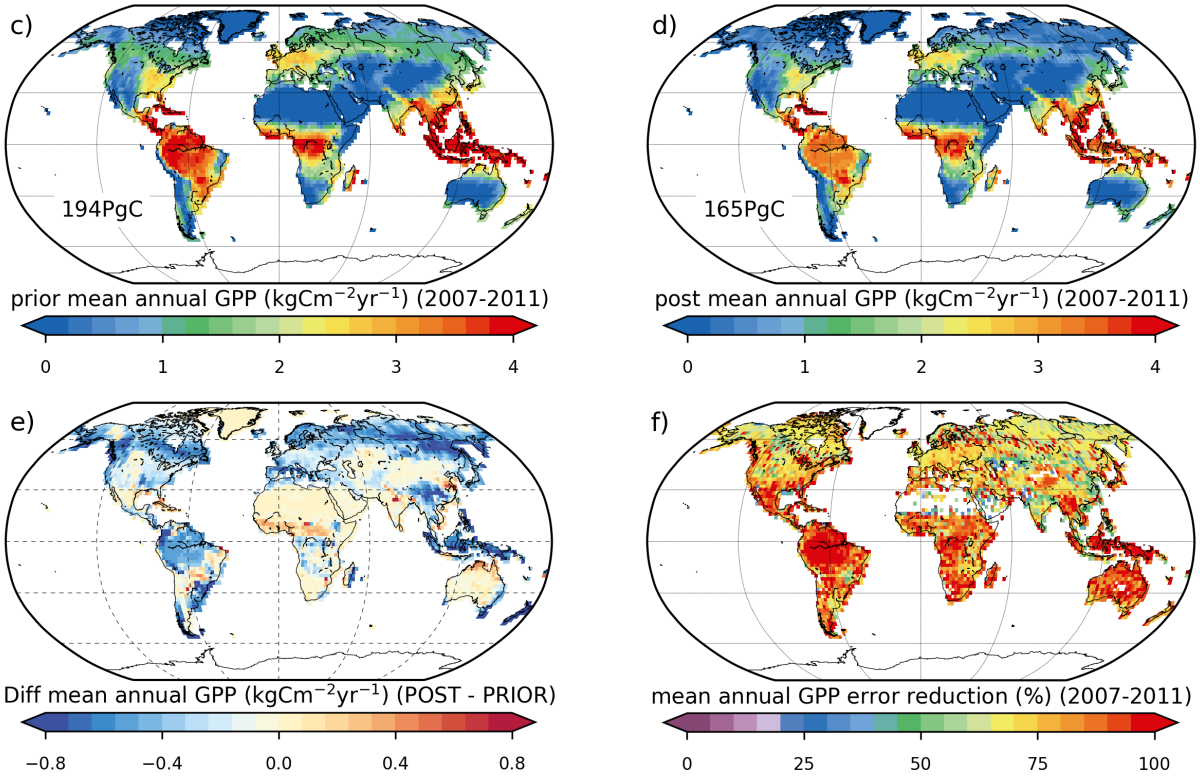
$$SIF = a\,GPP + b$$

- **Use GOME2 SIF data (Köhler et al., 2015)**
  - **monthly aggregated SIF, 0.5x0.5° resolution, 2007-2011**
- Constrain 'a' and 'b' (slope and offset) parameters of linear GPP – SIF relationship – **in addition to 6 photosynthesis and 9 phenology parameters for ALL vegetated PFTs**
- 15 grid cells chosen randomly per PFT (where obs available) (fractional cover > 0.6) → all 12 vegetated PFTs = total 180 sites
- 12-16 parameters per PFT
- Multi-site optimization performed for each PFT
- Prior obs uncertainty ($\mathbf{R}$) set to RMSE between model & data
- Parameter uncertainty (**B**) 40% of range



- **Impact at global scale → global simulations following standard protocol (spinup + transient). Cf Jung et al. MTE-GPP**

SIF data constraint reduces GPP magnitude

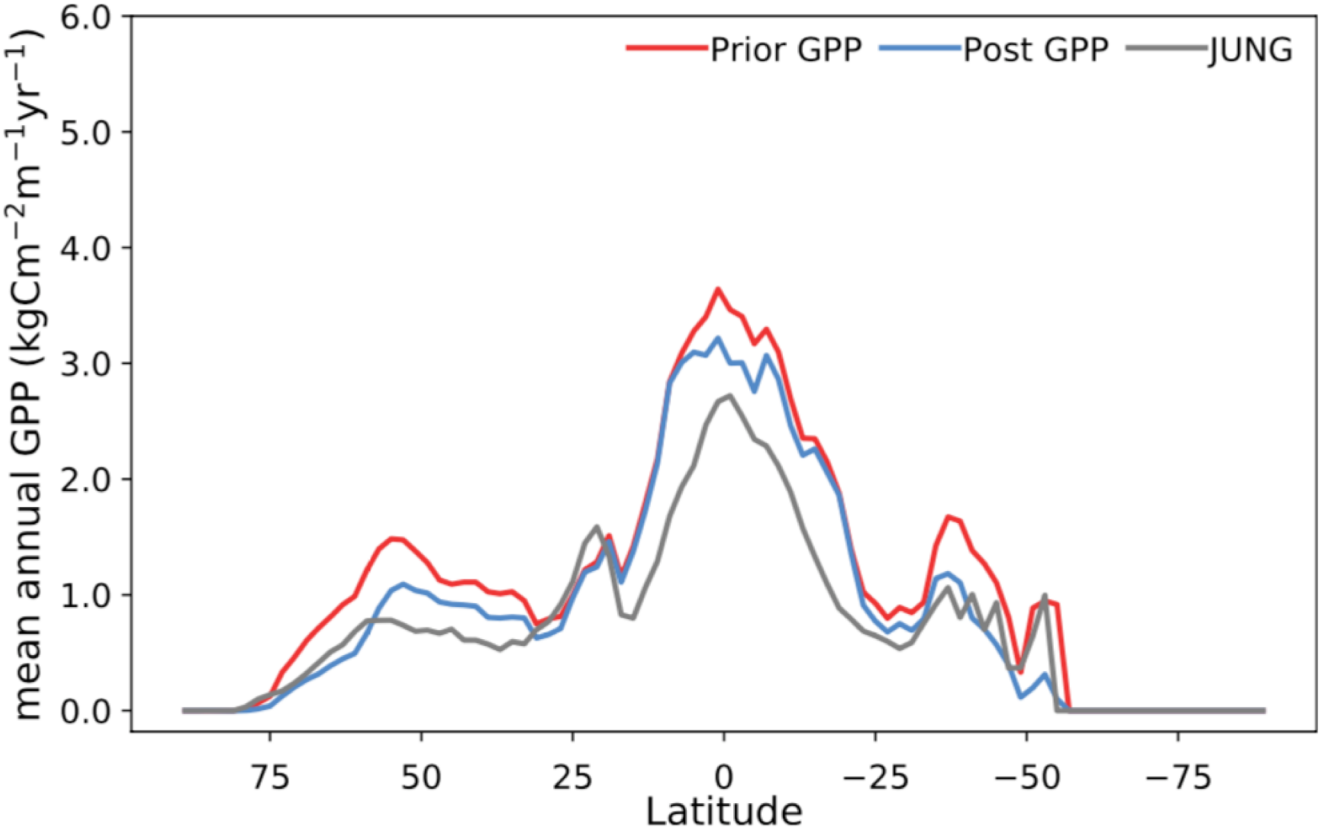


- Decrease in global GPP magnitude for all PFTs
- …except for moisture-driven PFTs
- Highest decrease in NH extra tropics → shift in global GPP distribution
- Strong reduction in uncertainty (~83%)

Region/PFT	Prior mean annual GPP (PgC)	Posterior mean annual GPP (PgC)	Reduction in annual GPP uncertainty (%)
Global	194.4	165.6	82.8
Temperate + boreal KG biome	88.6	67.1	67
Tropical KG biome	92.2	86.1	93.4
Arid KG biome	13.6	12.4	88.9

MacBean, N. et al. (2018), Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data, *Scientific Reports*, 8, 1973.

Shifts in spatial distribution (important for global C sink)



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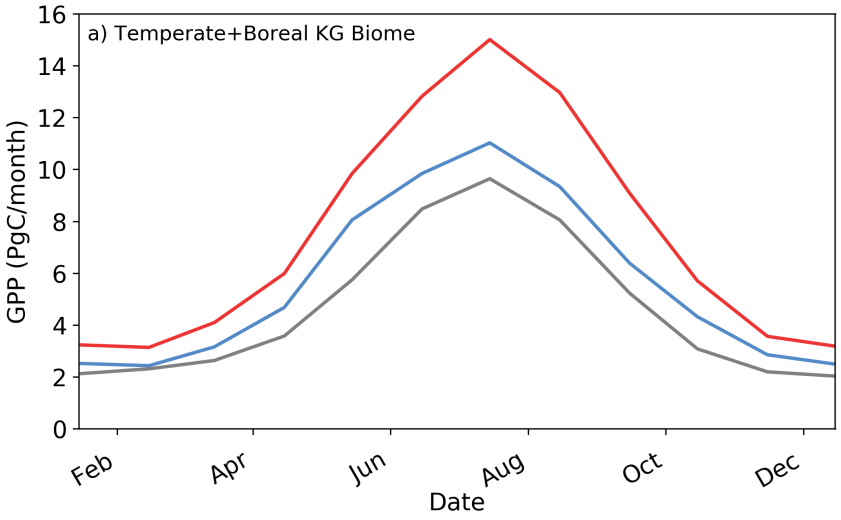
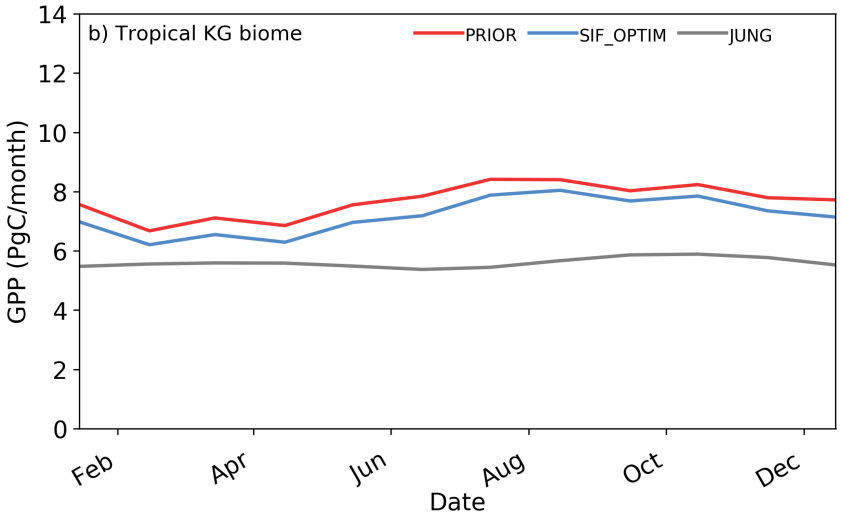
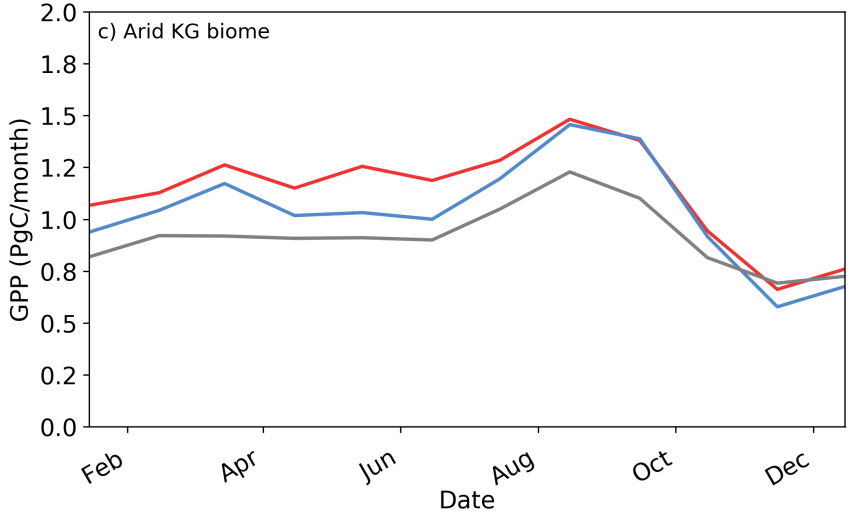
SIF data assimilation *does* reduce GPP magnitude





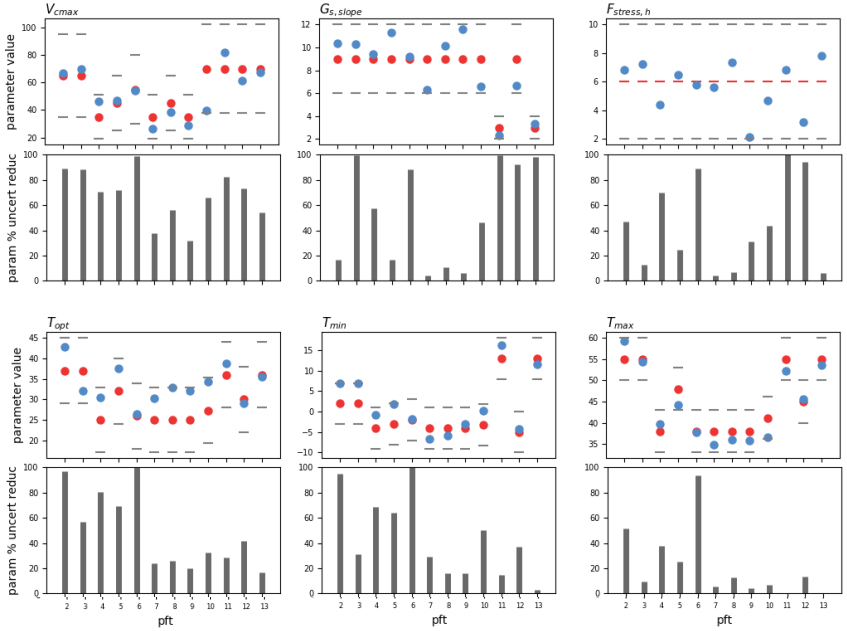


Region/PFT	Prior mean monthly SIF-GPP correlation	Posterior mean monthly SIF-GPP correlation
Global	0.72	0.74
Temperate + boreal KG biome	0.77	0.77
Tropical KG biome	0.5	0.5
Arid KG biome	0.59	0.61

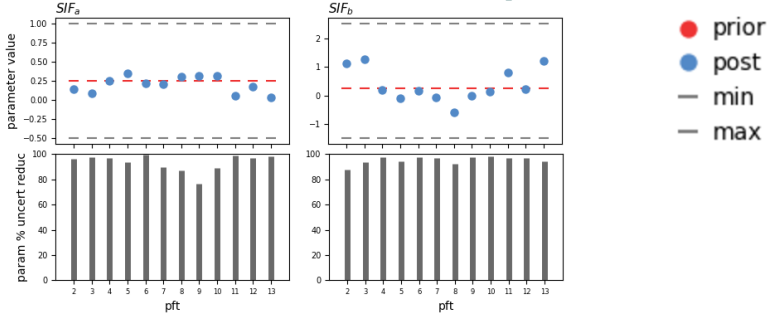
MacBean, N. et al. (2018), Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data, *Scientific Reports*, 8, 1973.

Parameter constraint

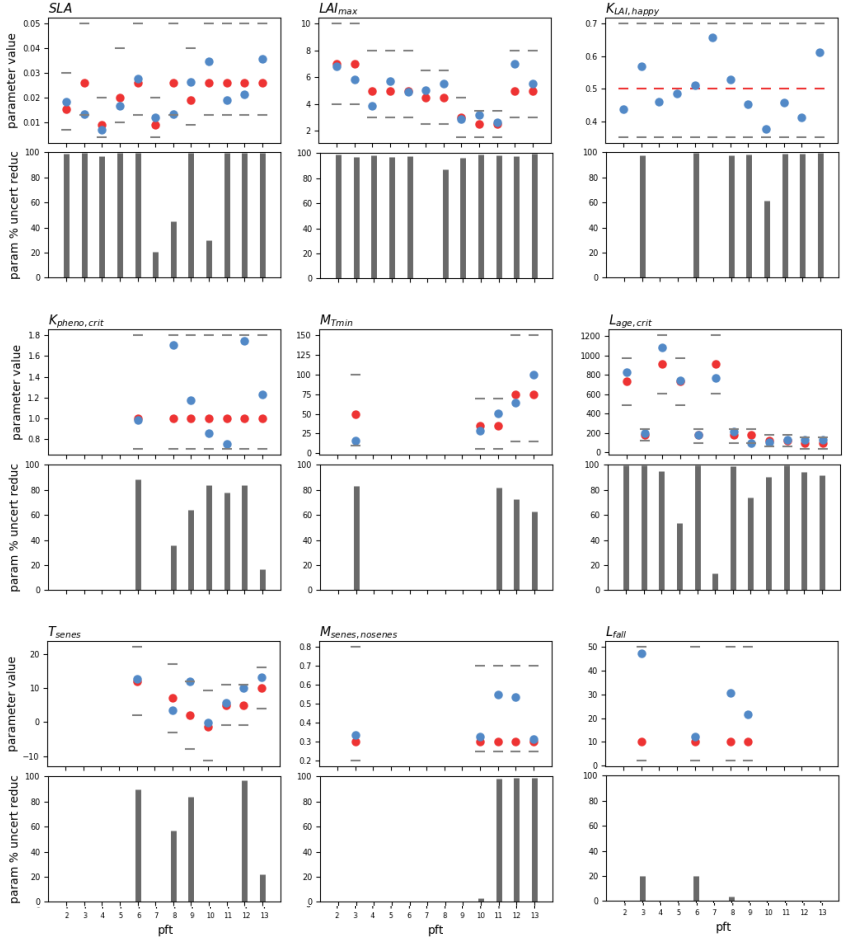
Photosynthesis



Linear SIF-GPP reln parameters



Phenology



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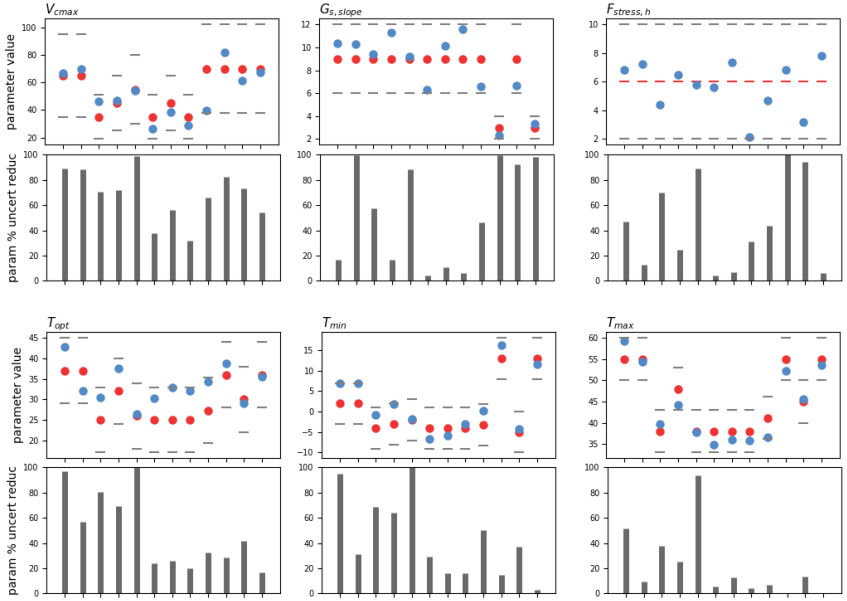
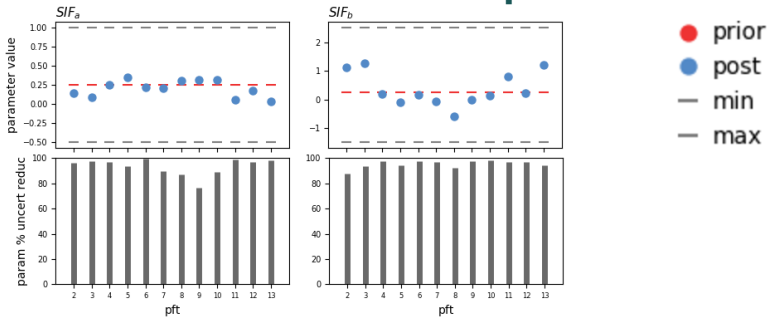
Parameter constraint

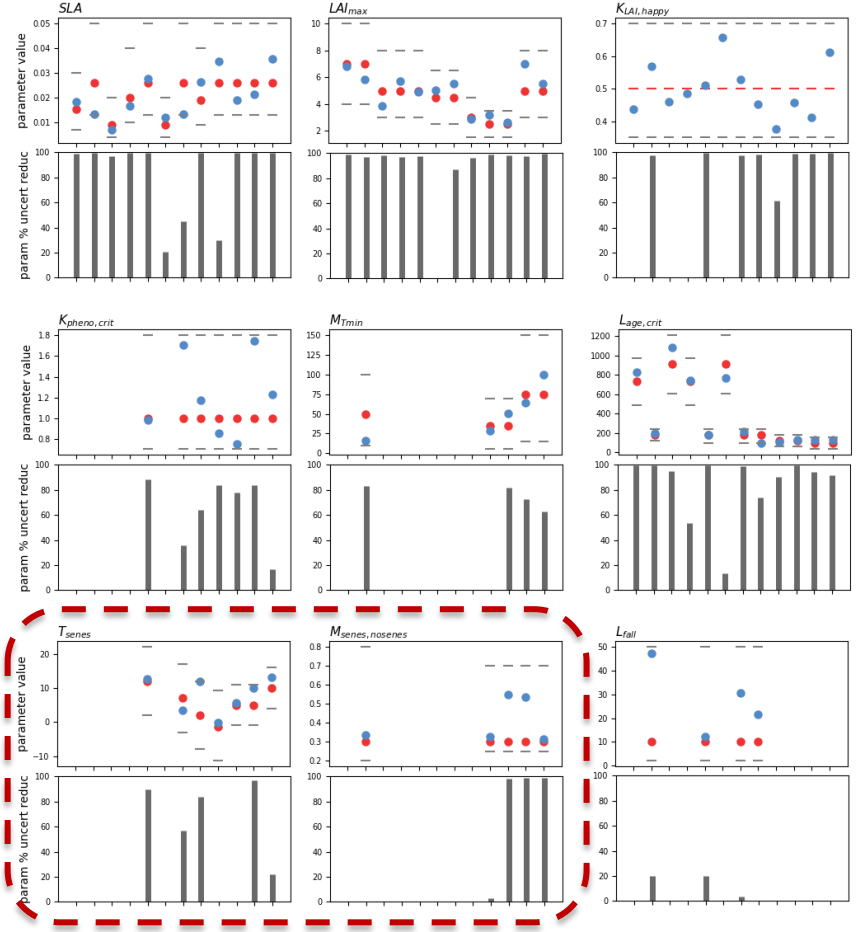
Photosynthesis



Linear SIF-GPP reln parameters



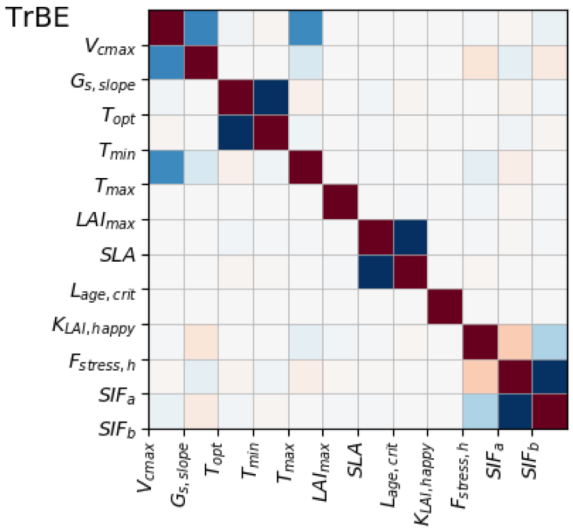
Phenology



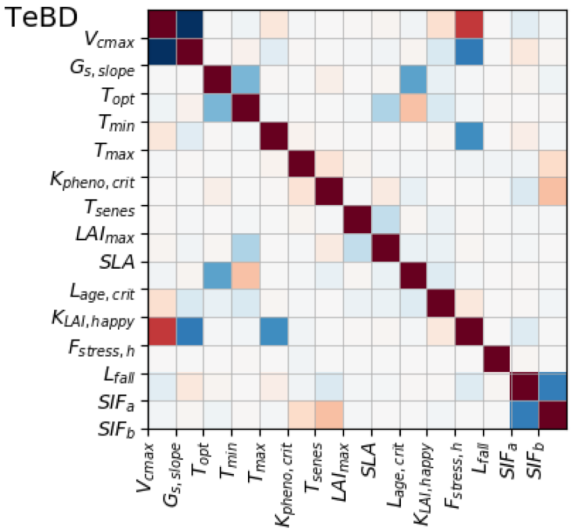
MacBean, N. et al. (2018), Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data, *Scientific Reports*, 8, 1973.

Parameter covariance

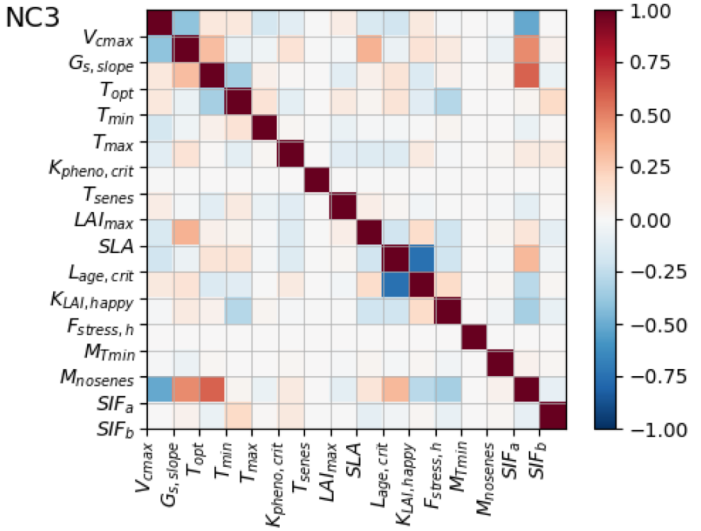
Tropical Broadleaved Evergreen



Temperate Broadleaved Deciduous



Natural C3 grass



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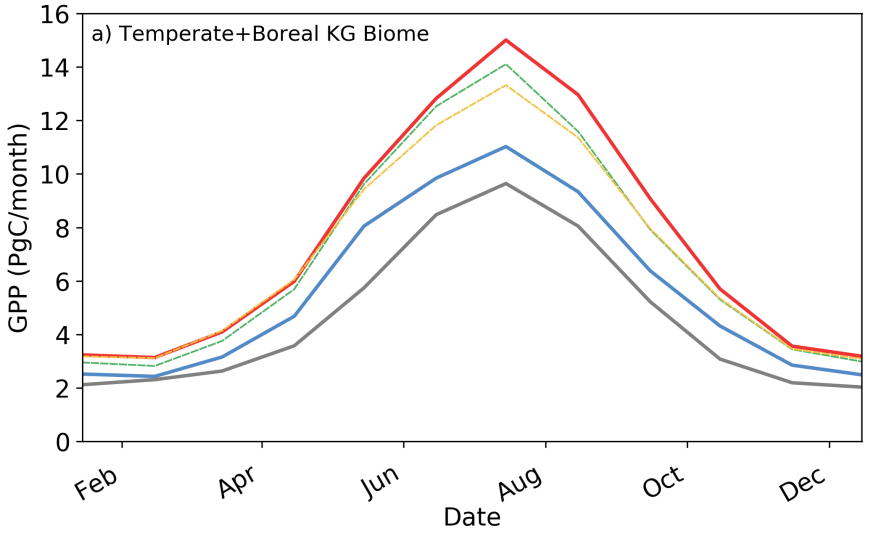
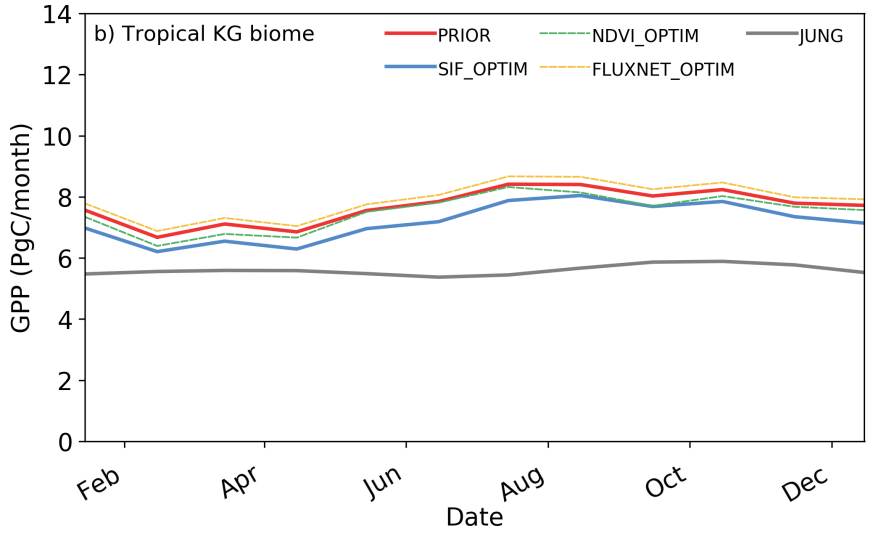
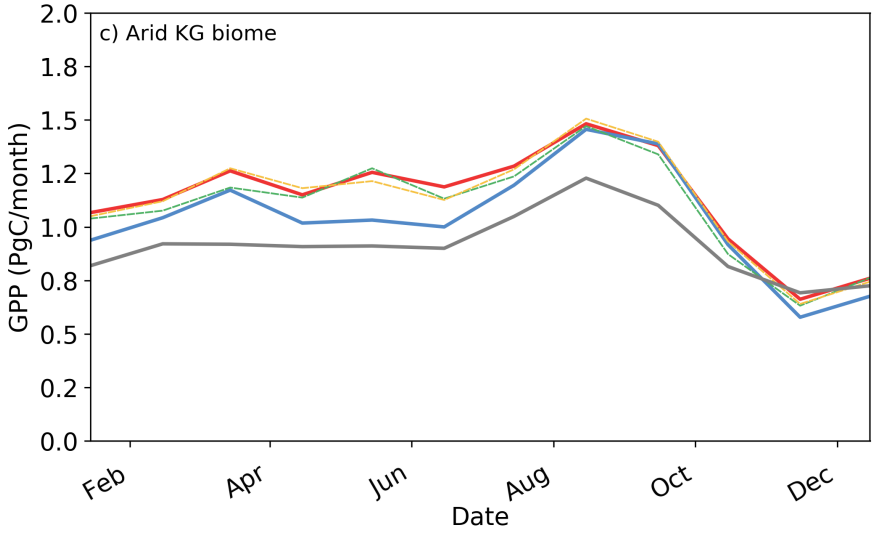
Comparison to NDVI and FLUXNET NEE

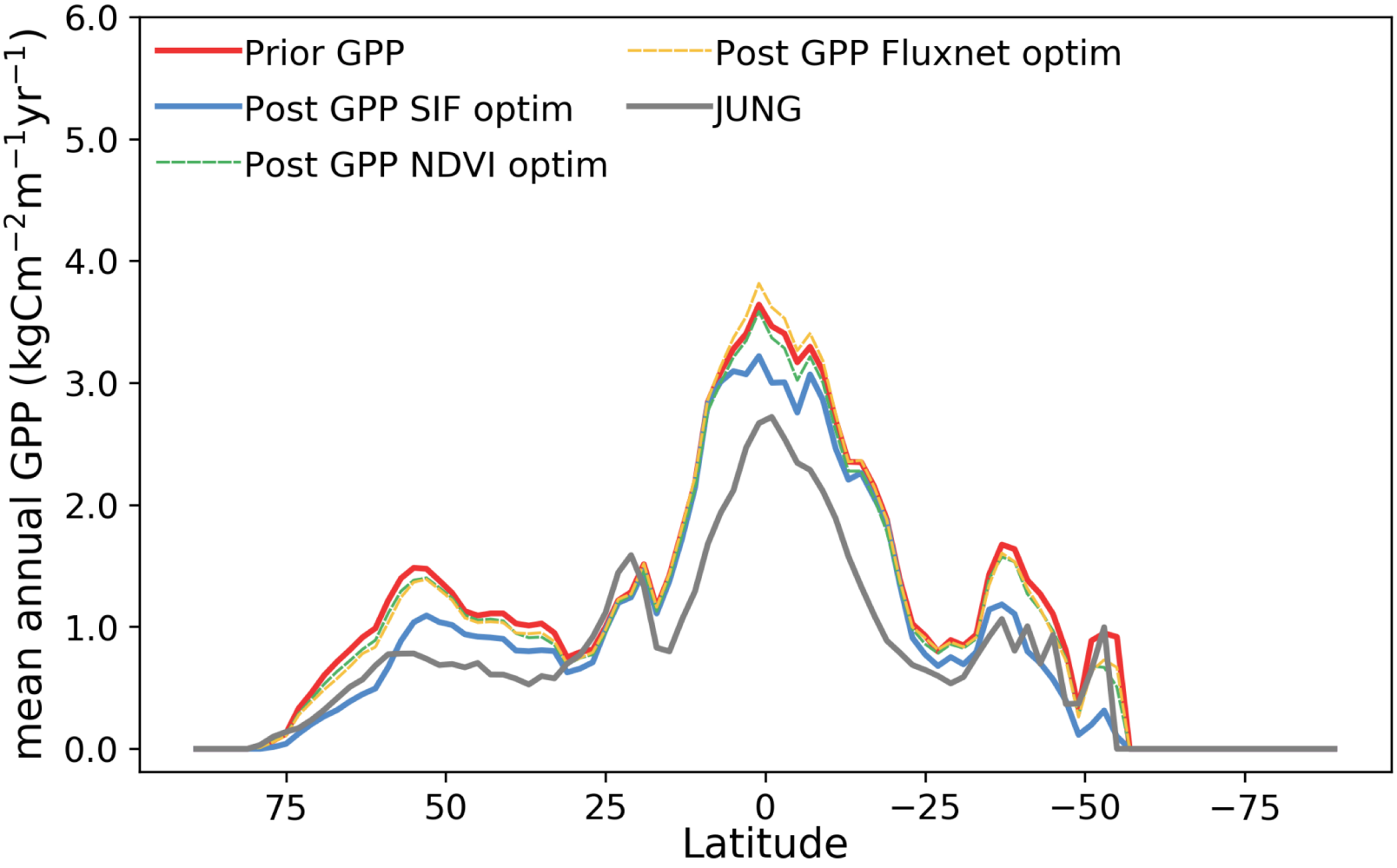






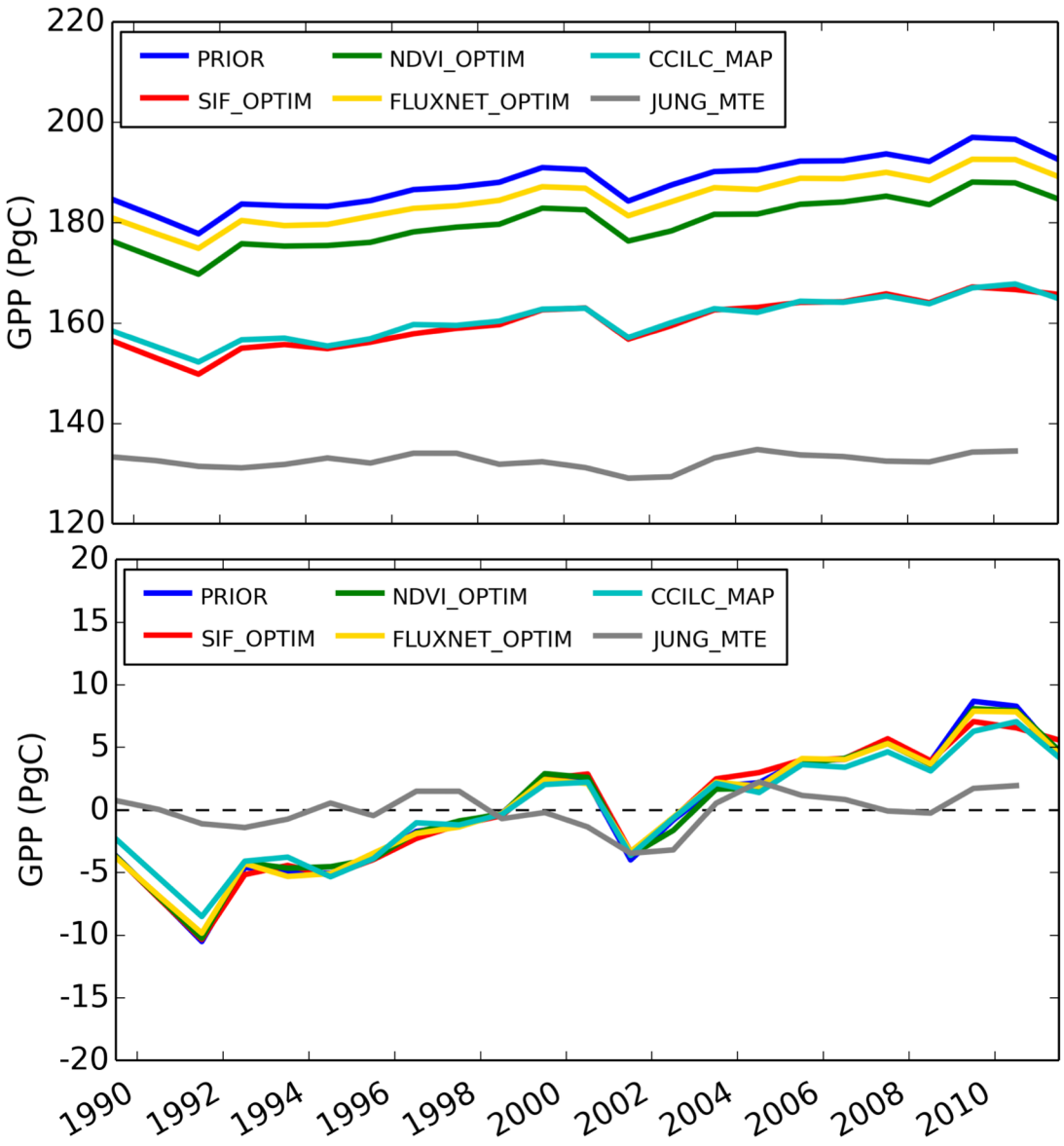
MacBean, N. et al. (2018), Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data, *Scientific Reports*, 8, 1973.

Comparison to NDVI and FLUXNET NEE

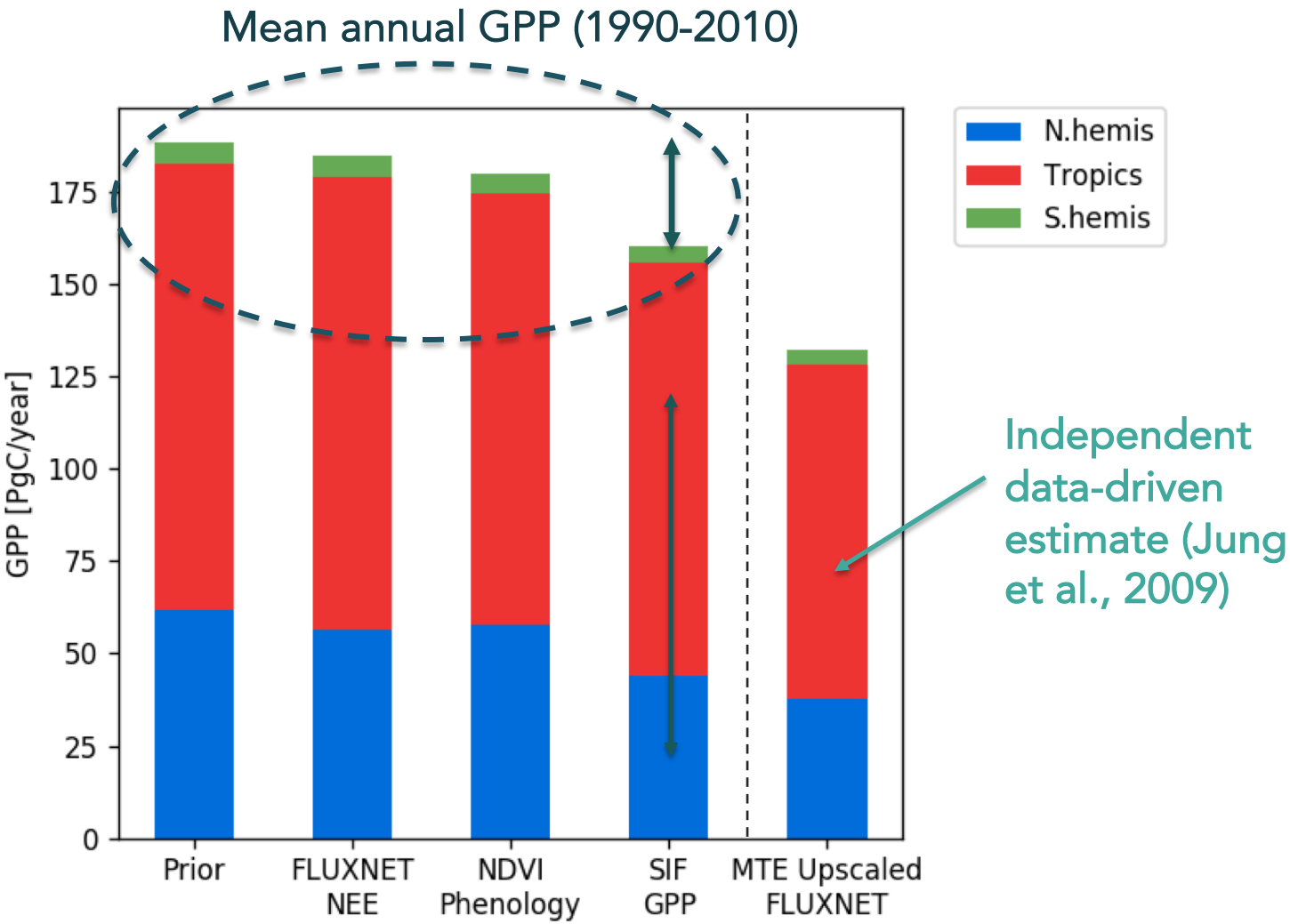


MacBean, N. et al. (2018), Strong constraint on modelled global carbon uptake using solar-induced chlorophyll fluorescence data, *Scientific Reports*, 8, 1973.

Annual time series and anomalies



SIF helps us constrain GPP global magnitude and spatial distribution

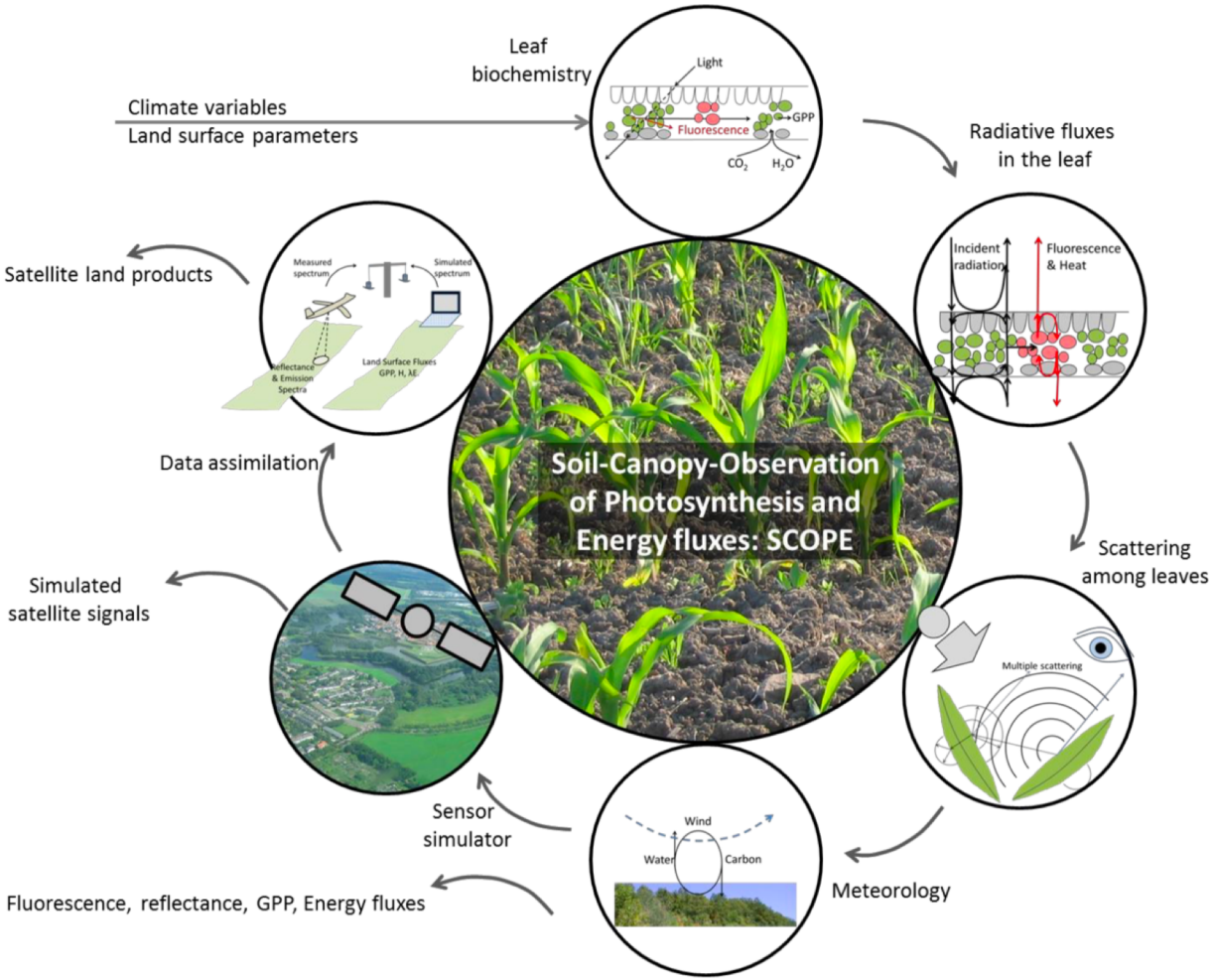


MacBean et al. (2015) – NDVI vs **MacBean et al. (2018)** – SIF.

Outline

- Motivation for this research
- ORCHIDEE Data Assimilation System (ORCHIDAS) and past studies
- SIF DA set-up and results
- Perspectives and future directions…

Future work in the ORCHIDAS group…
Implementation of SCOPE (*and a note on model complexity*)



Upcoming paper by Bacour et al.

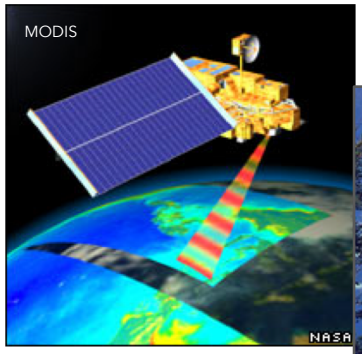
van der Tol et al.

Challenges and progress in using multiple datasets to constrain models

Agricultural and Forest Meteorology

The potential benefit of using forest biomass data in addition to carbon and water flux measurements to constrain ecosystem model parameters: Case studies at two temperate forest sites

T. Thum[a,*], N. MacBean[b], P. Peylin[b], C. Bacour[c], D. Santaren[b], B. Longdoz[d], D. Loustau[e], P. Ciais[b]



Journal of Geophysical Research: Biogeosciences

Joint assimilation of eddy covariance flux measurements and FAPAR products over temperate forests within a process-oriented biosphere model

C. Bacour[1,2], P. Peylin[2], N. MacBean[2], P. J. Rayner[2,3], F. Delage[2,4], F. Chevallier[2], M. Weiss[5], J. Demarty[5,6], D. Santaren[7,8], F. Baret[5], D. Berveiller[9], E. Dufrêne[9], and P. Prunet[1]

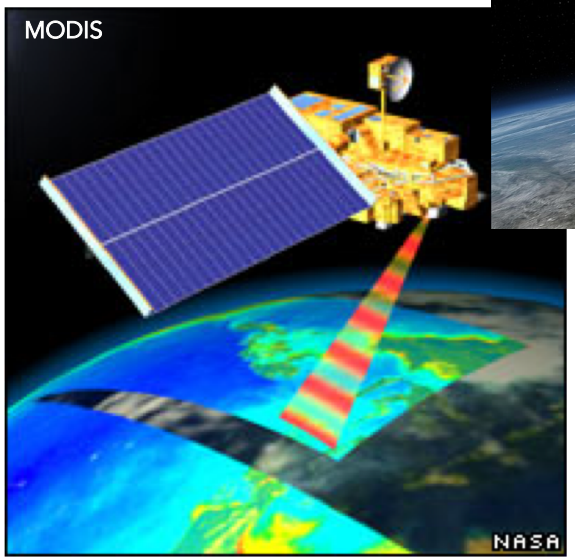
Geosci. Model Dev., 9, 3569–3588, 2016

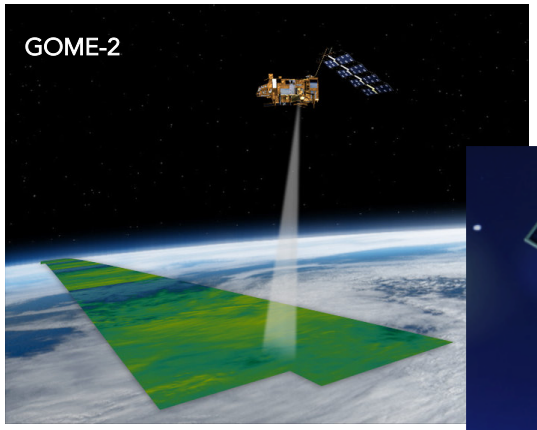
Consistent assimilation of multiple data streams in a carbon cycle data assimilation system

Natasha MacBean[1], Philippe Peylin[1], Frédéric Chevallier[1], Marko Scholze[2], and Gregor Schürmann[3]

Future work in the ORCHIDAS group… OCO-2 & TROPOMI?

SIF + NDVI? SIF + LAI? SIF + PRI? SIF + COS? SIF + NEE?





Resolve any inconsistencies between SIF datasets and between SIF and other data

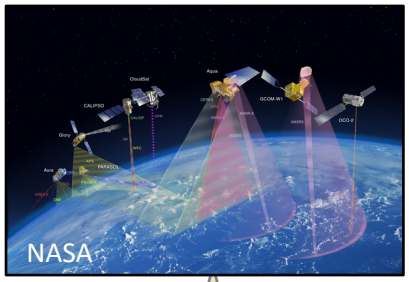
…and crucially -- with model !

See upcoming paper by Bacour et al.

Different relationships across scales?

→ If so, how do we account for that in a process-based model and DA system?

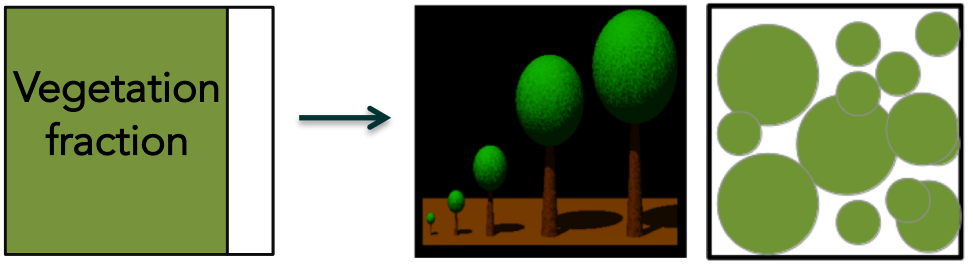
Relationships across scales



Global scale questions also relevant at local scales

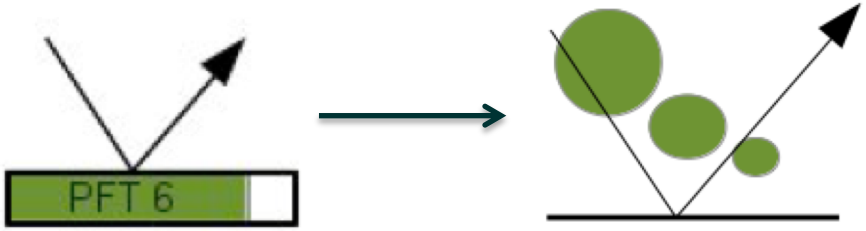
Ecosystem-level processes important for larger scales

Ongoing/future work using SIF in the ORCHIDEE group



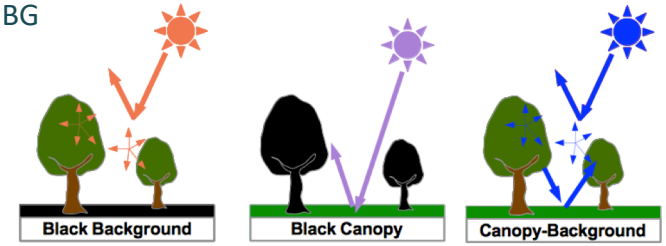
➢ New "gap fraction" model

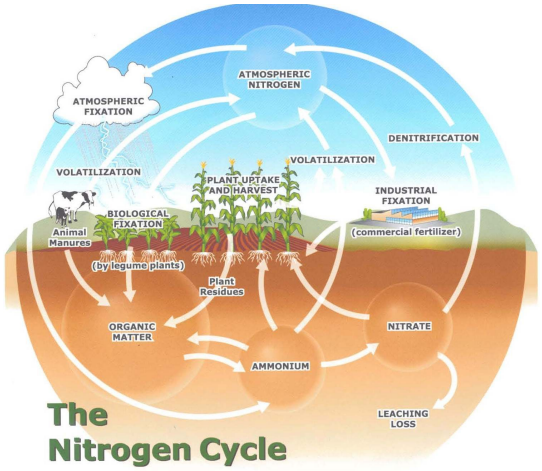
ORCHIDEE-CAN: Naudts et al. (2015)
Geosci. Model. Dev., 8, 2035-2065ß



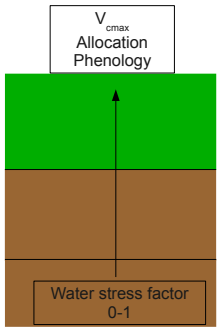
➢ New radiative transfer/albedo scheme

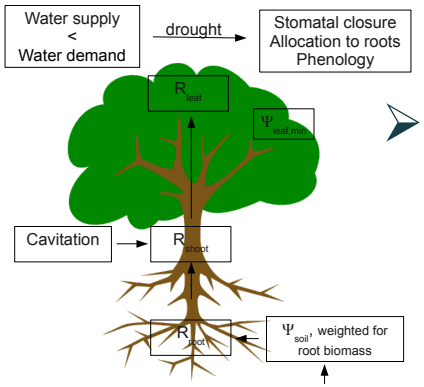
Otto et al. (2014) BG





Vuichard et al. ORCHIDEE-CN, *submitted*





➢ New plant hydraulic architecture

Summary

- Revised simulated global GPP budget *consistent* with ORCHIDEE structure (by optimising parameters as well as SIF – GPP relationship)
- SIF appears to provide stronger (parameter) constraint on GPP than NDVI or FLUXNET
- Most constraint on magnitude (peak) and shorter GSL in NH → change in global GPP distribution
- No considerable change in trends on IAV
- Lots of work still to be done, especially regarding consistencies between datasets.

Thank you for listening! Any questions?

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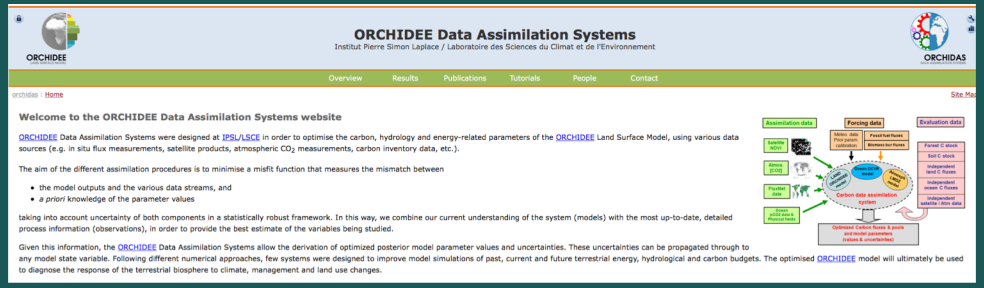

http://orchidas.lsce.ipsl.fr/