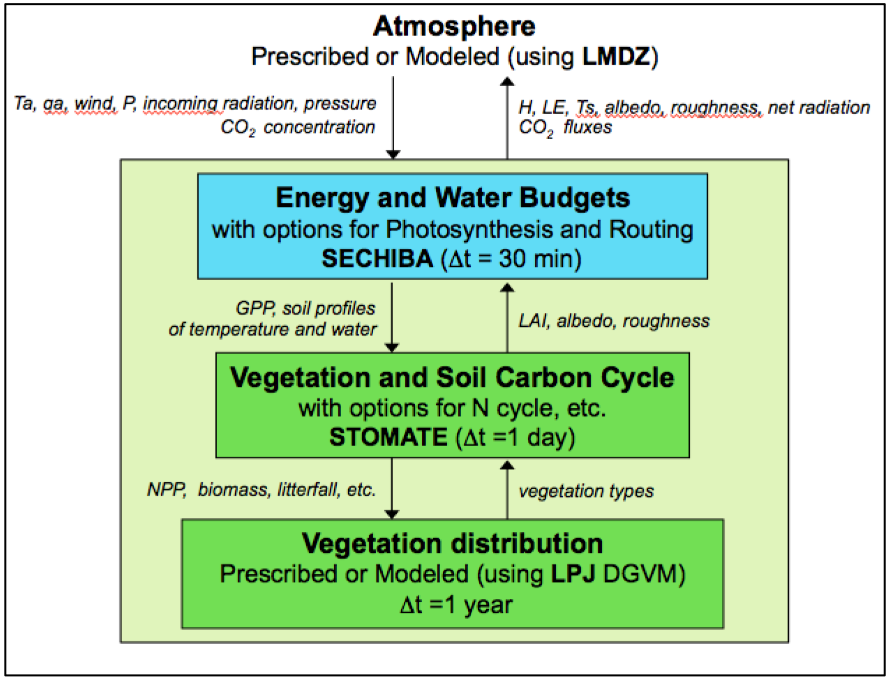
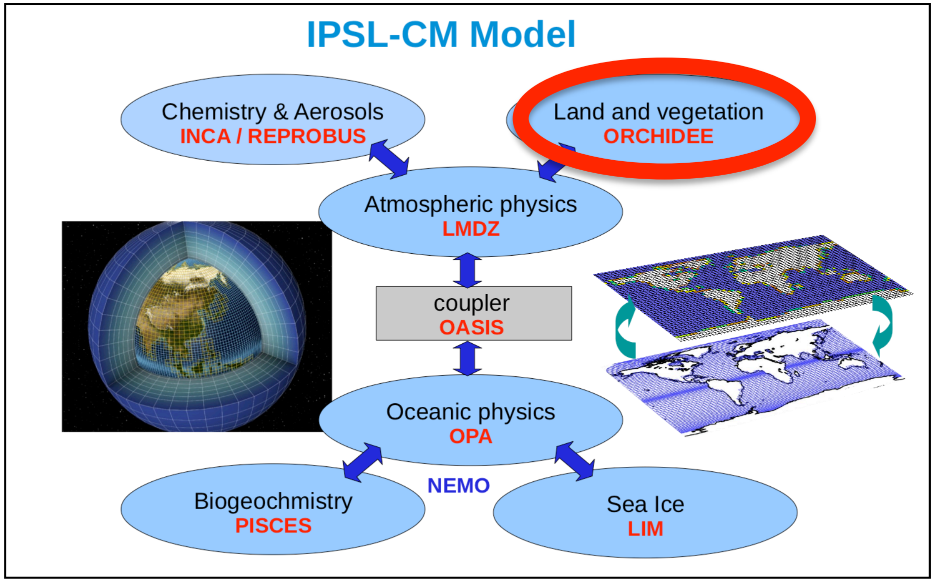
Le modèle ORCHIDEE:
récent & futur développements

Philippe Peylin *pour le groupe projet ORCHIDEE*





ORCHIDEE recent developments (for CMIP6)

Implemented: V1

Soon..: V1.5

Merging

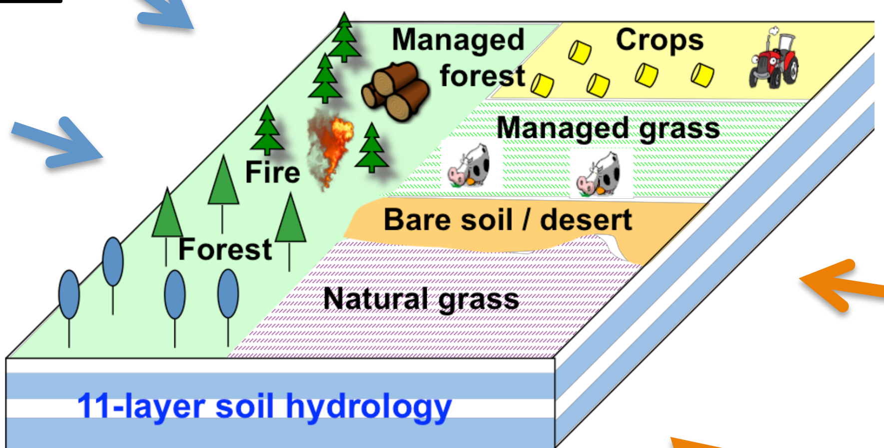
New Aerodynamic resistance

Nitrogen – carbon Coupled cycles

Optimized albedo (using MODIS)

Permafrost carbon

Land cover based on ESA-CCI



Forest management & forest structure

New 3 layers snow model

11-layer soil hydrology With soil freezing

SPITFIRE and Land use gross transitions

Improved Carbon cycle description

CH4 emissions (wetland and permafrost)

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Other Mature/Ongoing developments

Biophysical

Biogeochemical

Lake model (FLAKE)

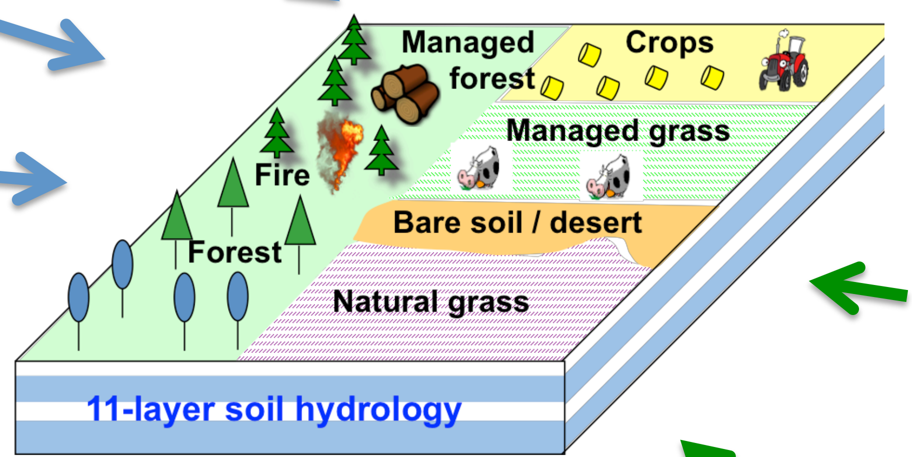
Nitrogen – Phosphorus - Carbon coupled cycles

Soil Carbon discretization

Irrigation

Termokarst lake

Crop model (wheat, corn, rice,…)



Grassland management

DOC – DIC transport by river

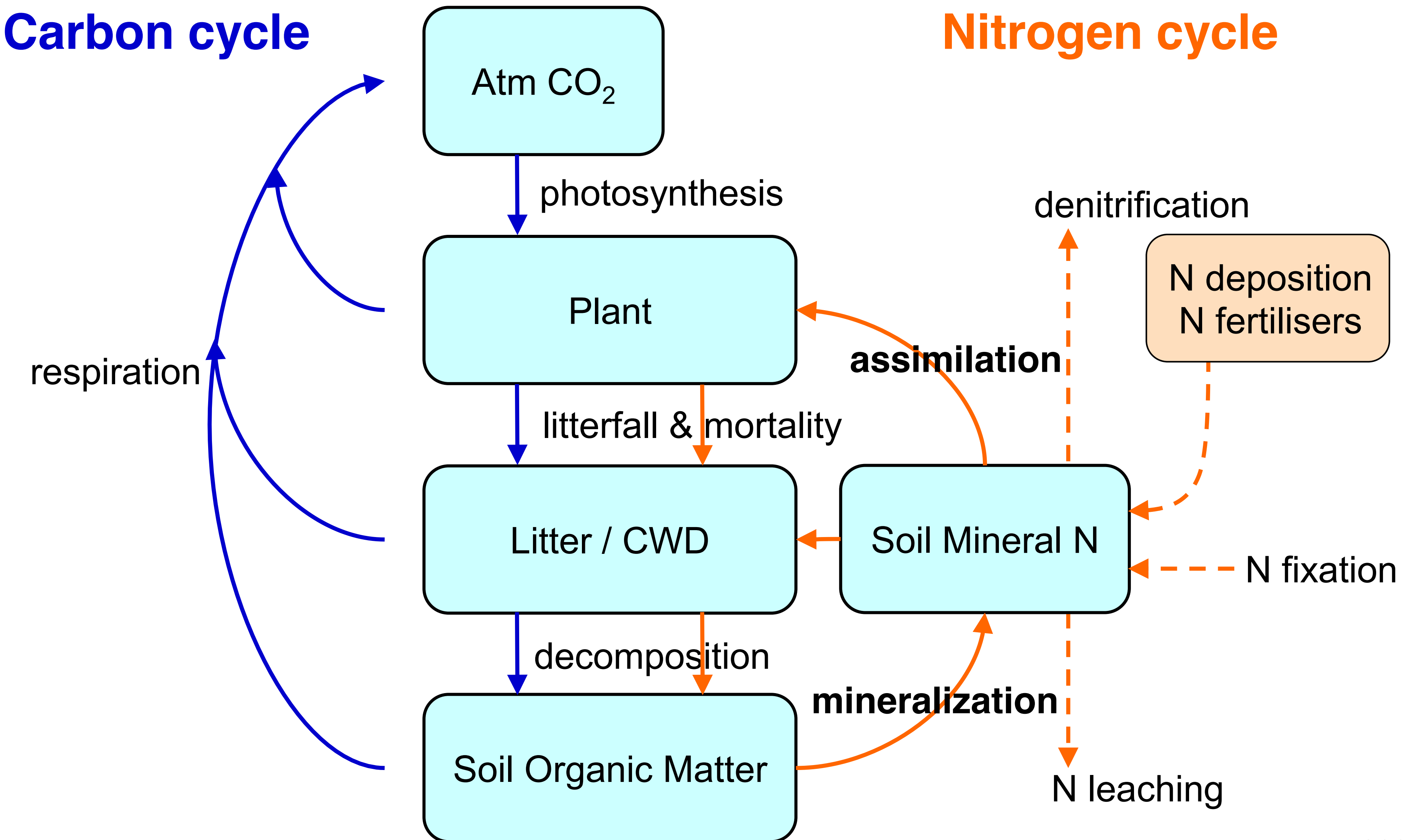
Peatland model (CH4)

Herbivory (large herbivore)

New boreal PFTs (Mosses, lichens, shrubs)

Plant Traits

C & N land interactions



From Thornton et al., 2009

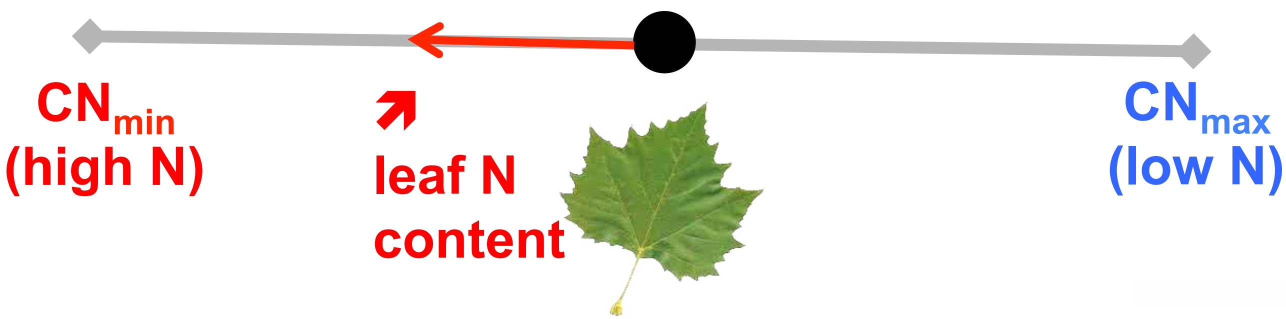
ORCHIDEE-CN version

- Inclusion of the features from OCN (Zaehle & Friend, 2010)
  - N cycle
  - C/N interactions
  - Allocation scheme with short- / long-term reserve pool

- ... Into the trunk version of ORCHIDEE (Peylin et al., in prep.)
  - New hydrological scheme : 11-layeer, 2m depth, accounts for deep drainage
  - New snow model and soil freezing process
  - New background albedo based on MODIS data
  - New parameterization of the roughness length

Leaf C/N ratio

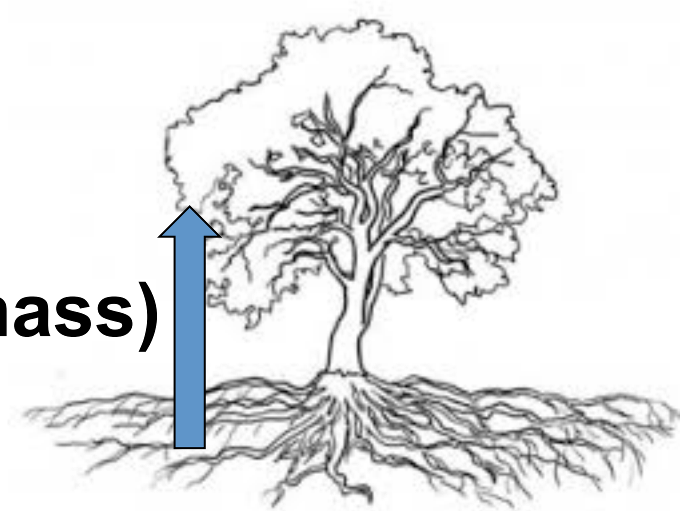
- A key variable of the N-version
- Varies across two constrained boundaries : $CN_{leaf,min}$ and $CN_{leaf,max}$
- C/N allocation



$N_{reserve} > N_{alloc}$ **needed for maintaining CN**

- Plant uptake

$$f(CN_{leaf}, N_{min}, \text{temp, root biomass})$$



Leaf C/N ratio

- A key variable of the N-version
- Varies across two constrained boundaries : $CN_{leaf,min}$ and $CN_{leaf,max}$
- C/N allocation

CN_{min} (high N)

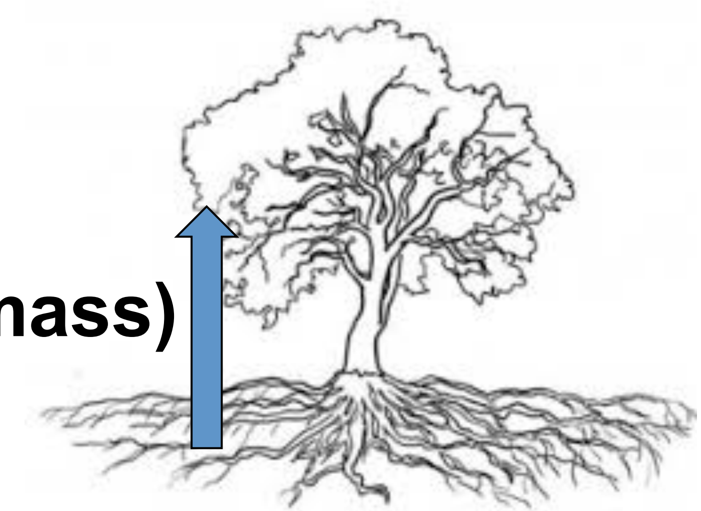
↘ leaf N content

CN_{max} (low N)

$N_{reserve} < N_{alloc}$ needed for maintaining CN

- Plant uptake

$f(CN_{leaf}, N_{min}, temp, root\ biomass)$



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Photosynthesis scheme

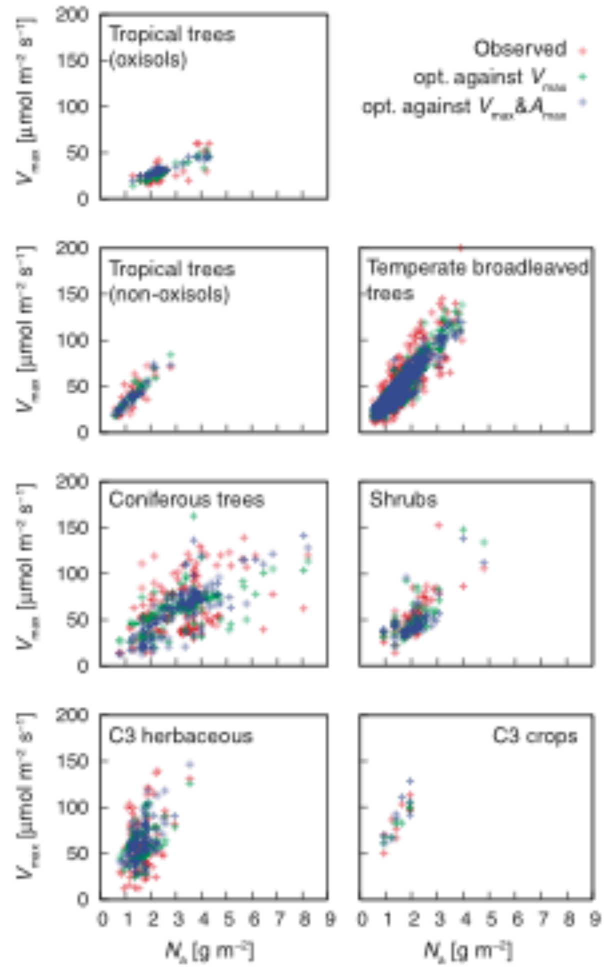
- Based on Farquahr model
- Vc_{max} : photosynthetic capacity (µmol CO_2 m^{-2} s^{-1})
- Modiified based on the work of Kattge et al. (2009)

$$Vc_{max} = NUE \times N_L$$

with *NUE* the Nitrogen Use Efficiency (PFT-dependant)

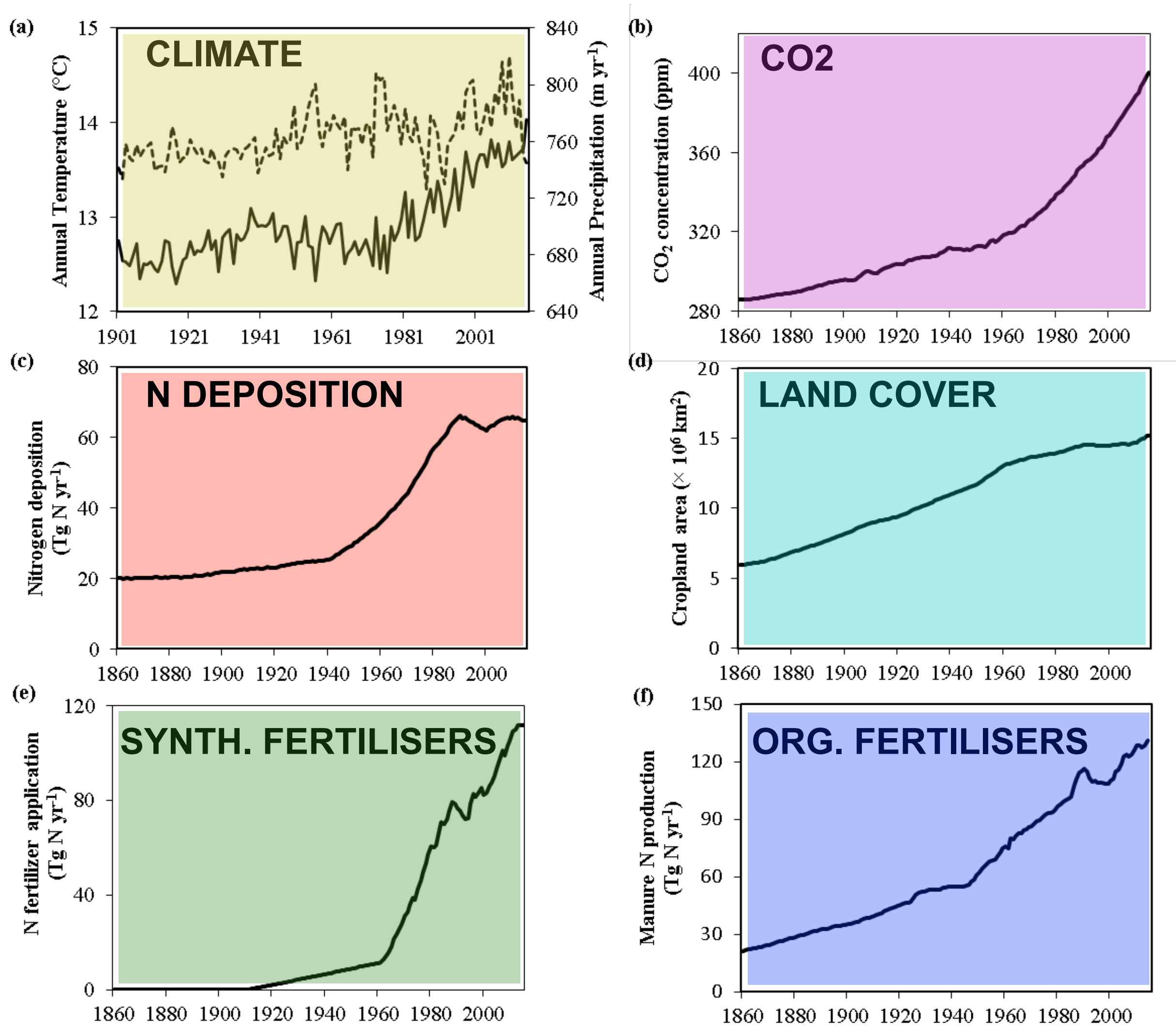
and N_L the leaf N content (gN $m^{-2}_{[leaf]}$)

Vmax vs. Leaf N content



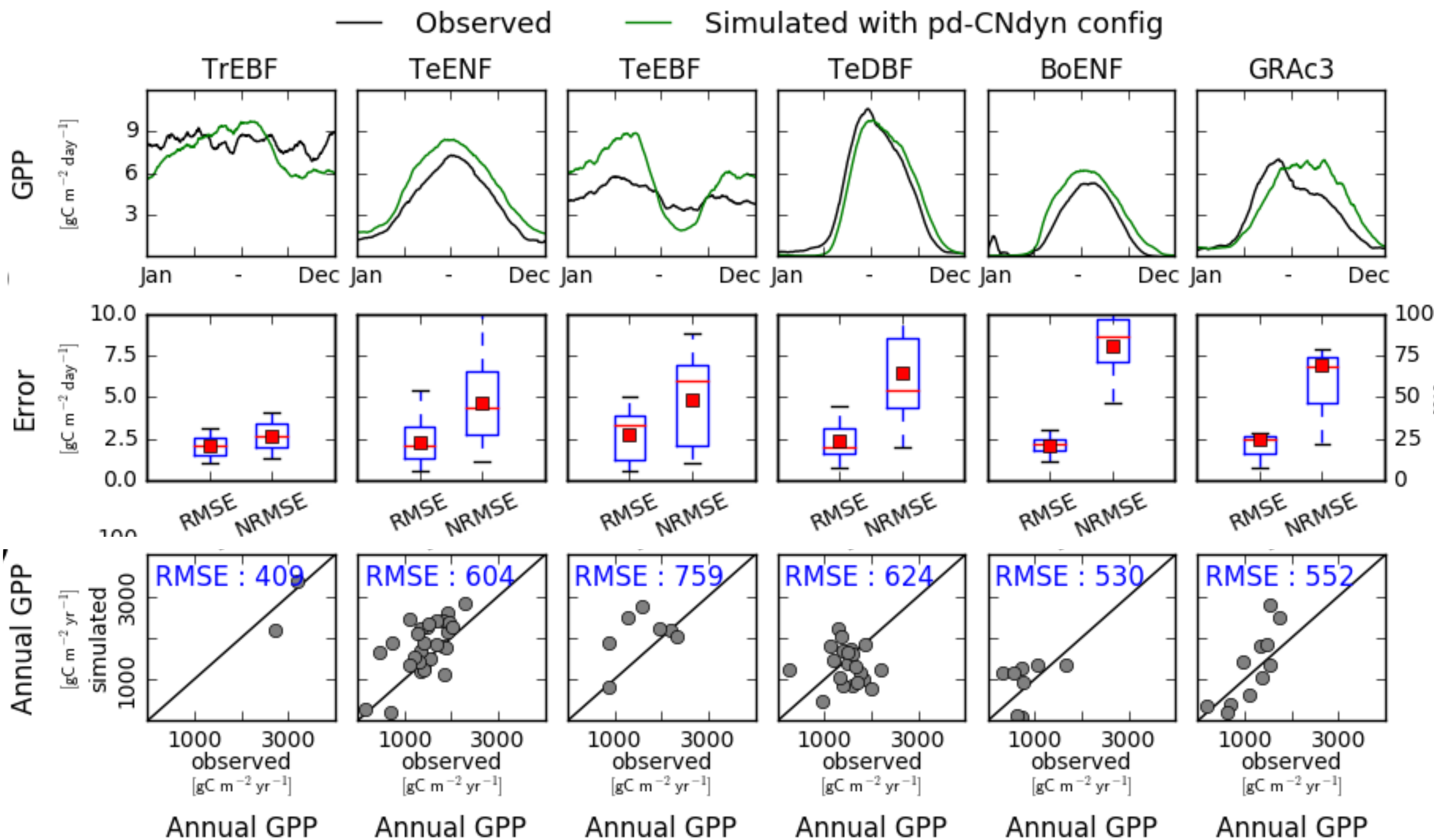
Global scale simulations

- Based on the NMIP protocol (N_2O Model Intercomparison Project)
- Account for all main drivers
  => S1-CNdyn simulation

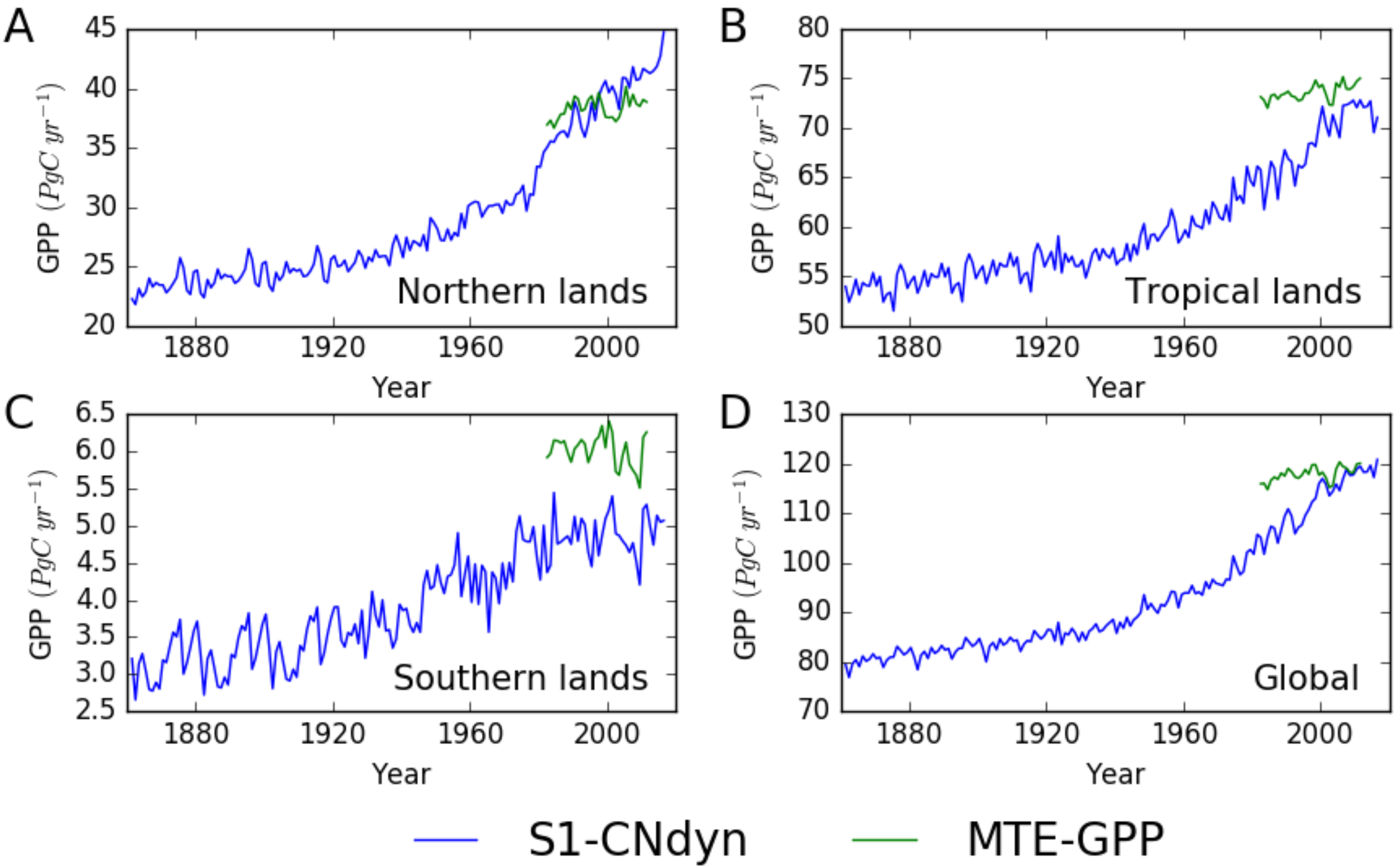


From Tian et al., 2018

Model evaluation @ fluxnet sites

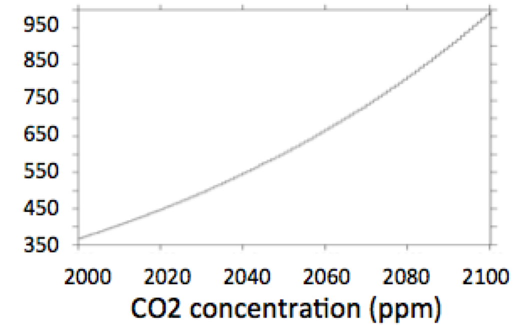


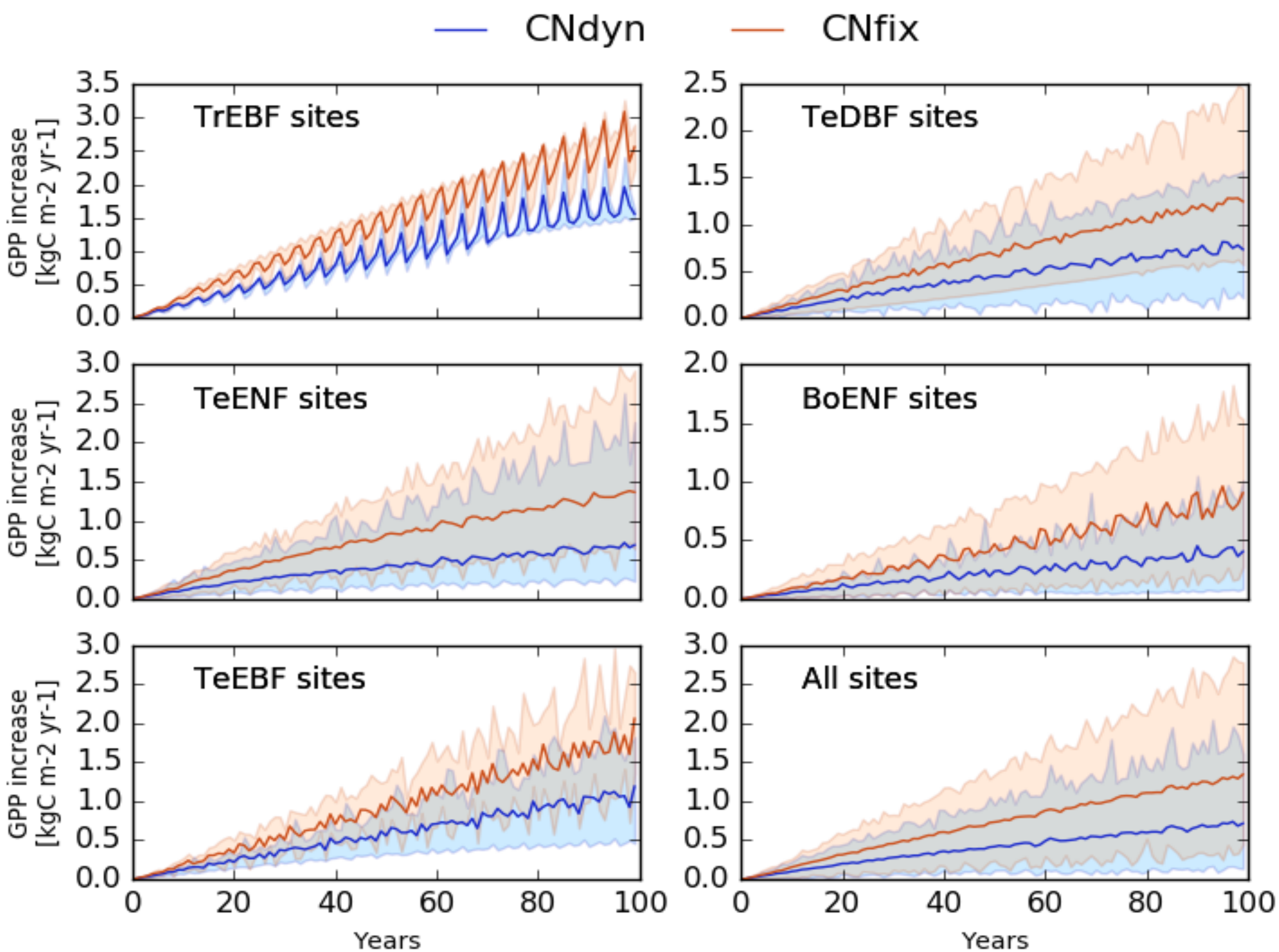
Model evaluation @ global scale



Adding the Nitrogen cycle: impact on the C cycle !

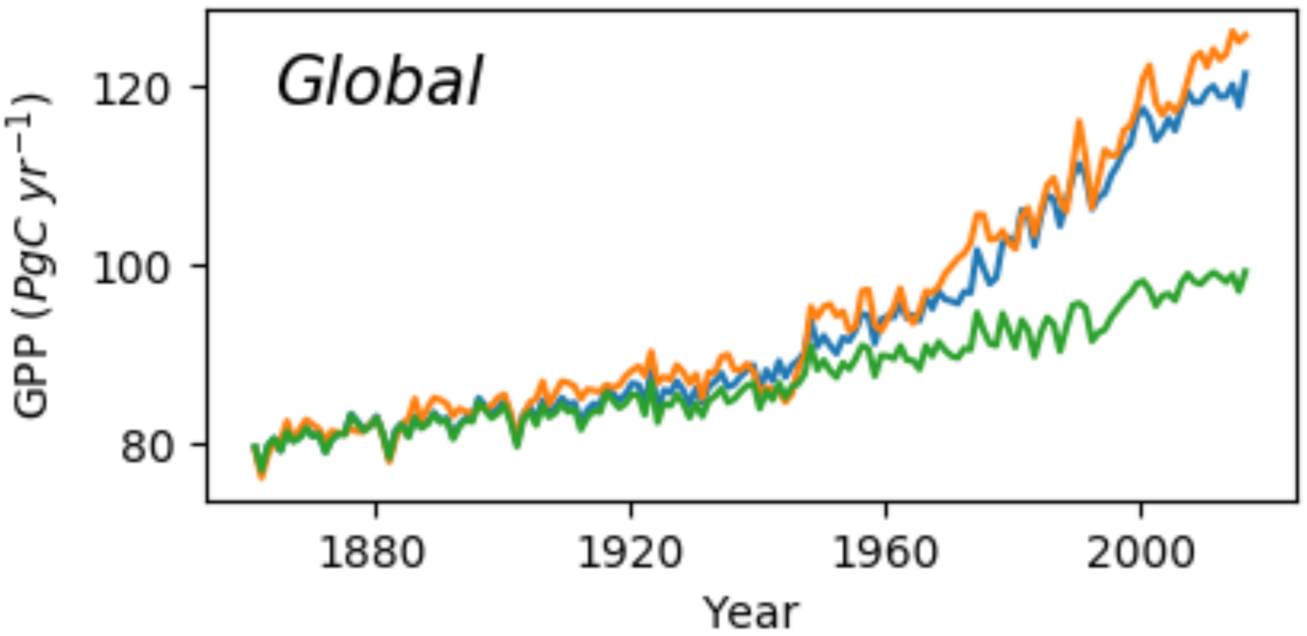
- Using ORCHIDEE-CN version – FluxNet sites
- 1% yr-1 CO_2 increase experiment





➔ Large reduction of the fertilisation effect at all sites (half the effect)

Role of the C/N interactions on GPP



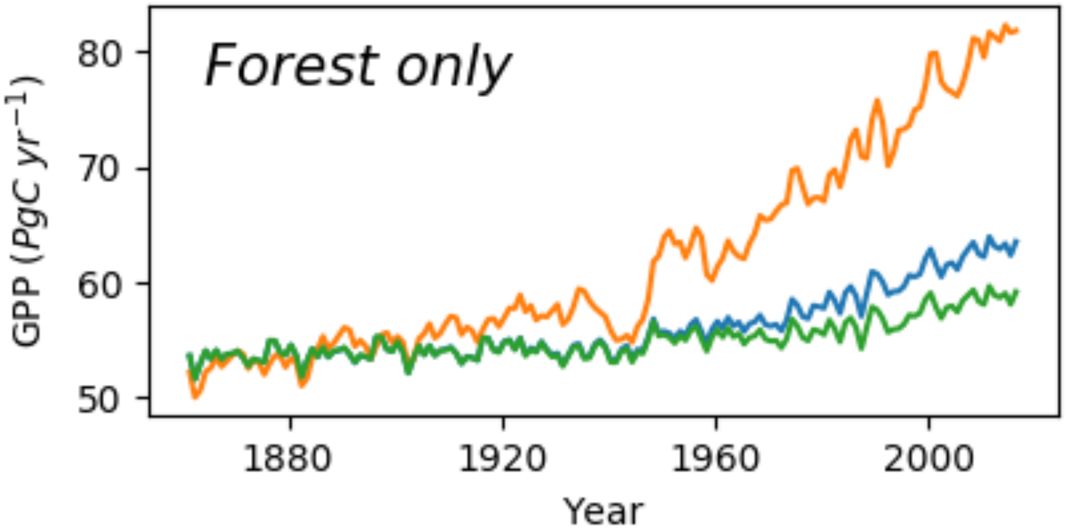
CN fix – 1850
Clim + LUC + CO2

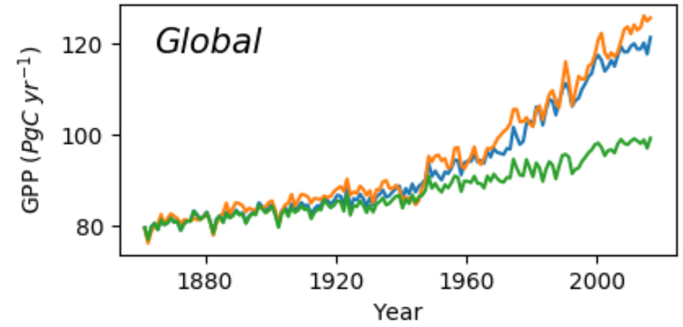
CN dyn
Clim + LUC + CO2 + N input

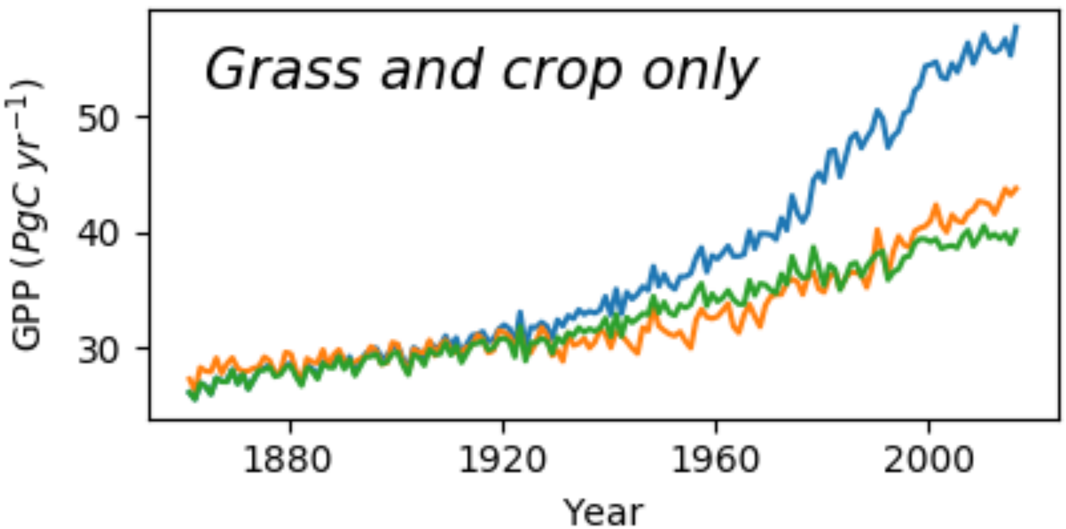
CN dyn
Clim + LUC + CO2

Mean increase compared to preindustrial era
~ 25% without N inputs increase, with C/N interactions
~ 50% with N inputs, with C/N interactions
~ 50% with CN fixed to pre-industrial values (= no C/N interactions)

Role of the C/N interactions on GPP







CN fix – 1850
Clim + LUC + CO2

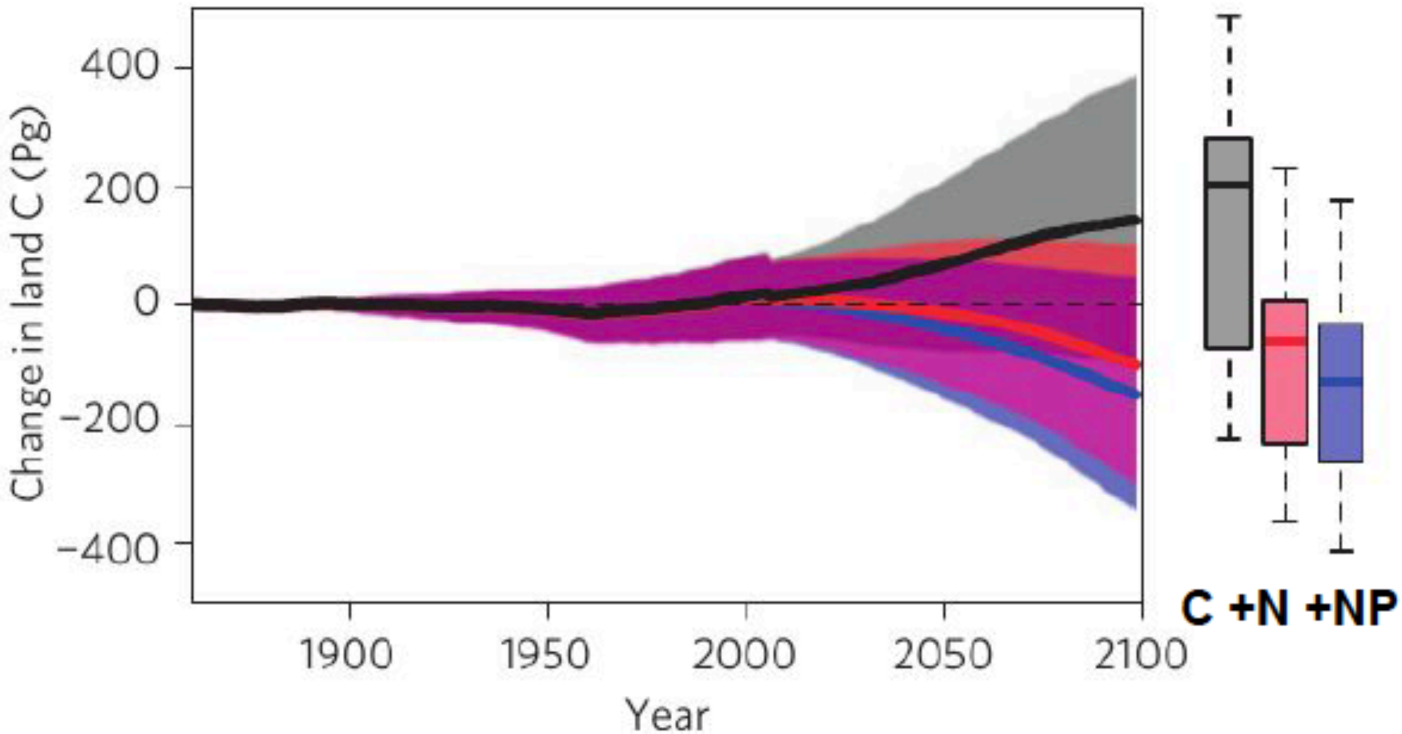
CN dyn
Clim + LUC + CO2 +
N input

CN dyn
Clim + LUC + CO2

Summary: N – C cycles

- Overall good performances at simulating GPP fluxes at site-level and globally
- Accounting for C/N interactions does not substantially improve the predictive skill of the model for present-day conditions
- The GPP response to elevated-CO2 is significantly different across model configurations (w and wo C/N)
- Over the historical period, N acted as a factor limiting GPP increase over forests, while it fostered the GPP increase over grass- and croplands

Adding the Phosphorus cycle



Wieder et al., Nat. Geosc., 2015

➔ Work done with ORCHIDEE-CNP version : Goll et al. 2017

ORCHIDEE-CAN

(known as ORCHIDEE-DOFOCO on svn)

+

ORCHIDEE-CN

N-version of ORCHIDEE updated with the trunk, June 2017

=

ORCHIDEE-CN-CAN

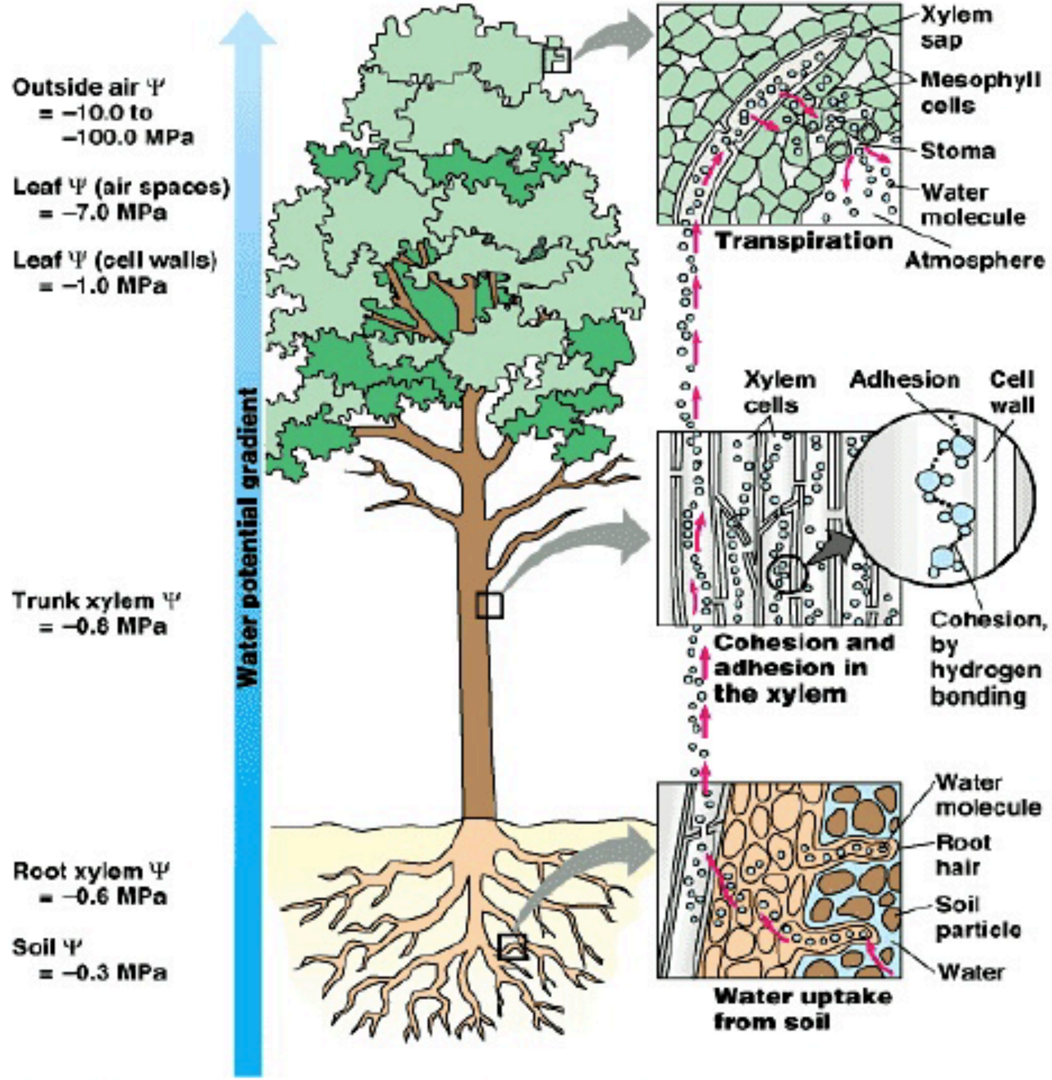
Simulating the canopy

Pipe model theory

- Recognize how stomata is hydrological connected to the roots and the need to invest carbon in building roots and stem
- Allometric relationships, leaf to sapwood area ratio, relationship between diameter and height

Water stress

- Hydraulic architecture



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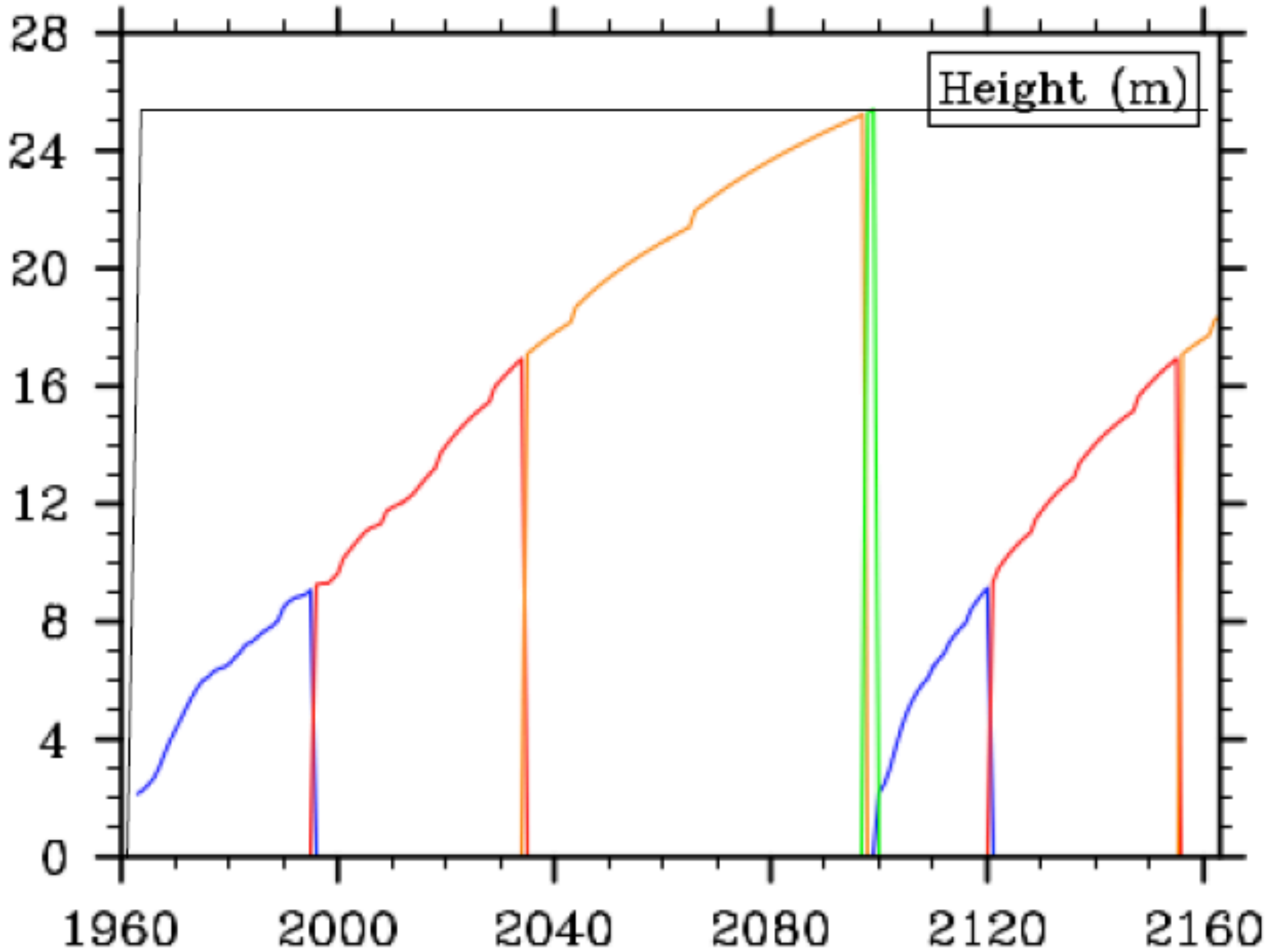
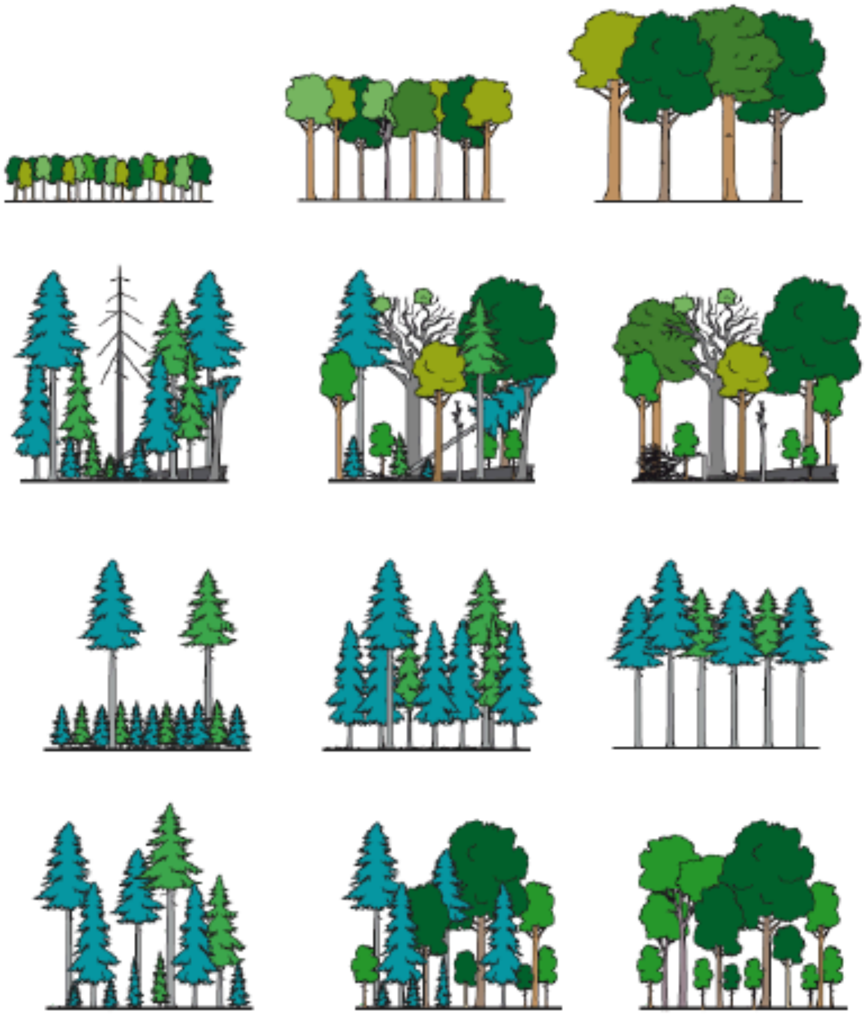
Simulating the canopy

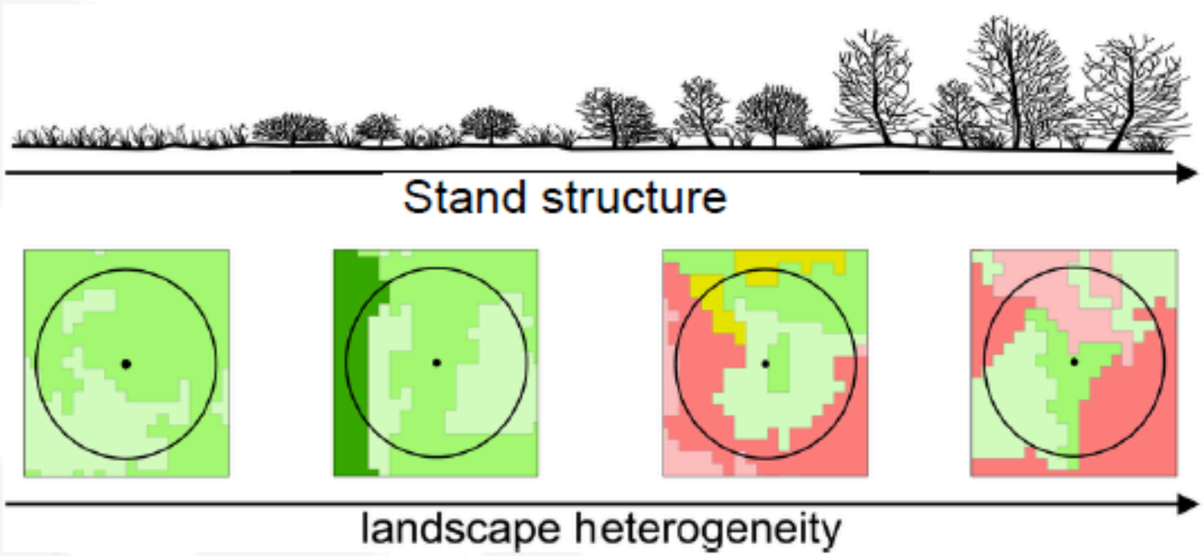


Simulating the canopy

- Diameter classes and age classes are introduced
- Number of PFTs depend on number of age classes
- Each PFT has x numbers of diameter class
- Each diameter class has x number of trees depending on basal area - self-thinning rule



Simulating the canopy



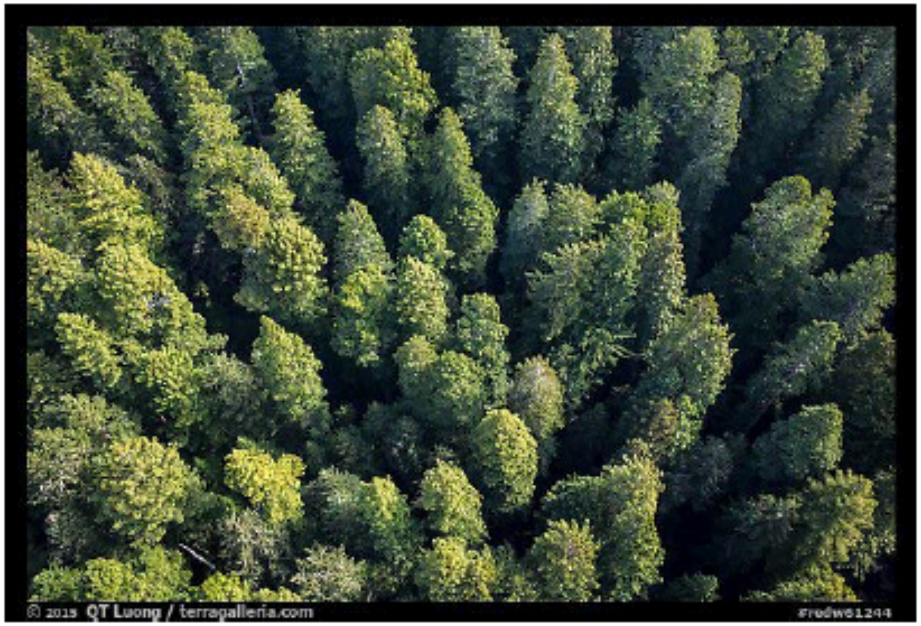
Illustrations from Moreira et al 2015 PLoS One

Allocation + Diameter classes + recruitment → Stand structure

Age classes → Landscape heterogeneity

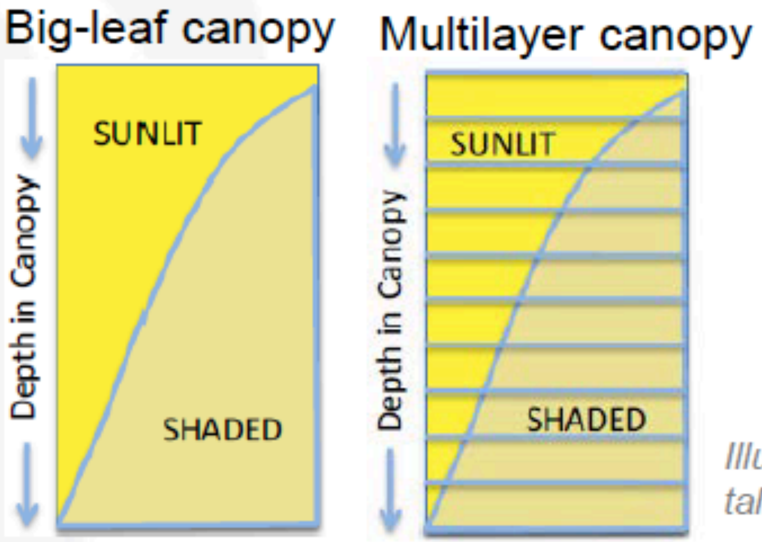
Simulating the canopy

- The trees are horizontally distributed following a Poisson distribution
- The structured canopy allows for calculations of light penetration within the canopy.
- Statistic approach to reduce memory allocation



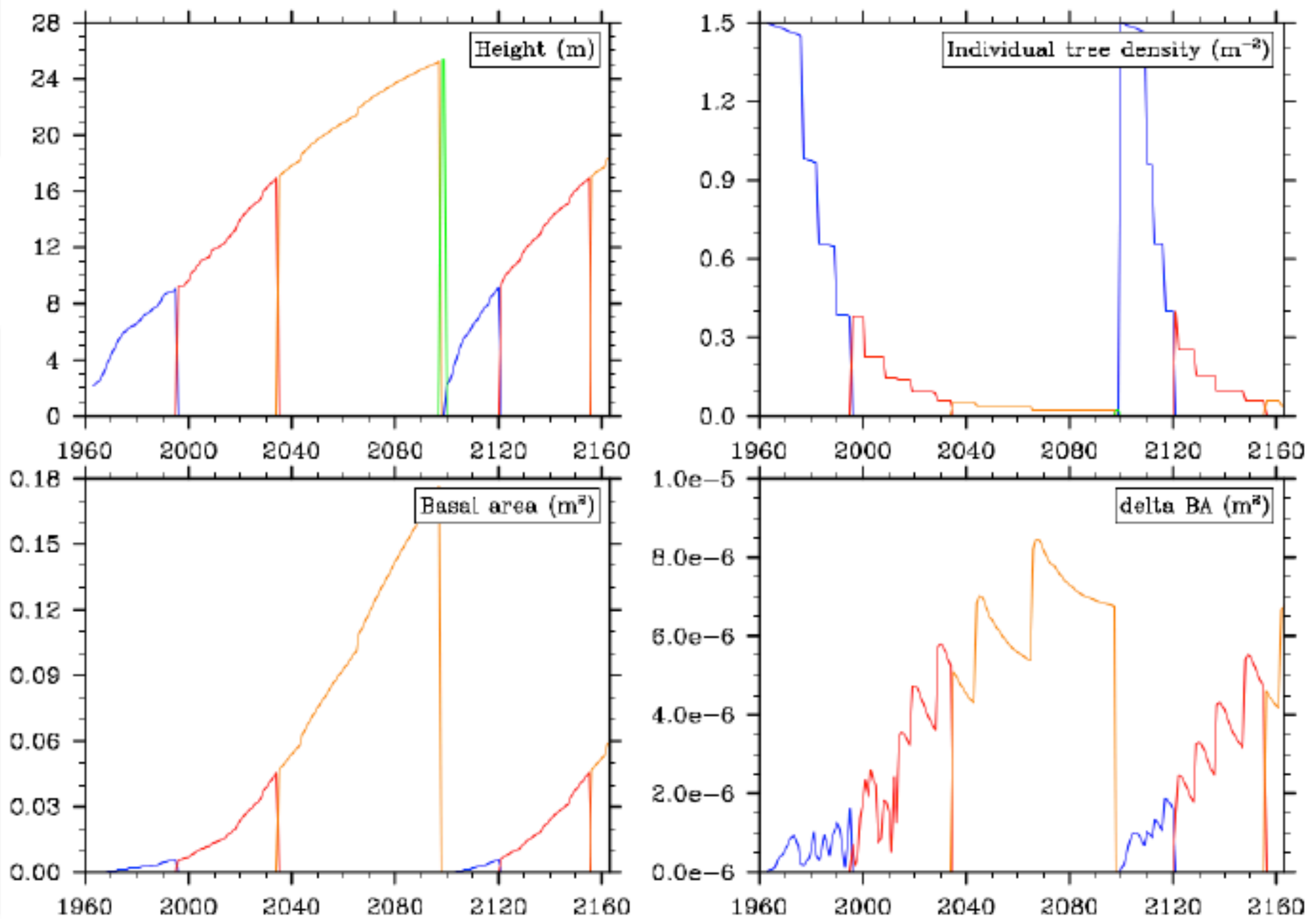
Using the canopy

Changing the formalization of the canopy

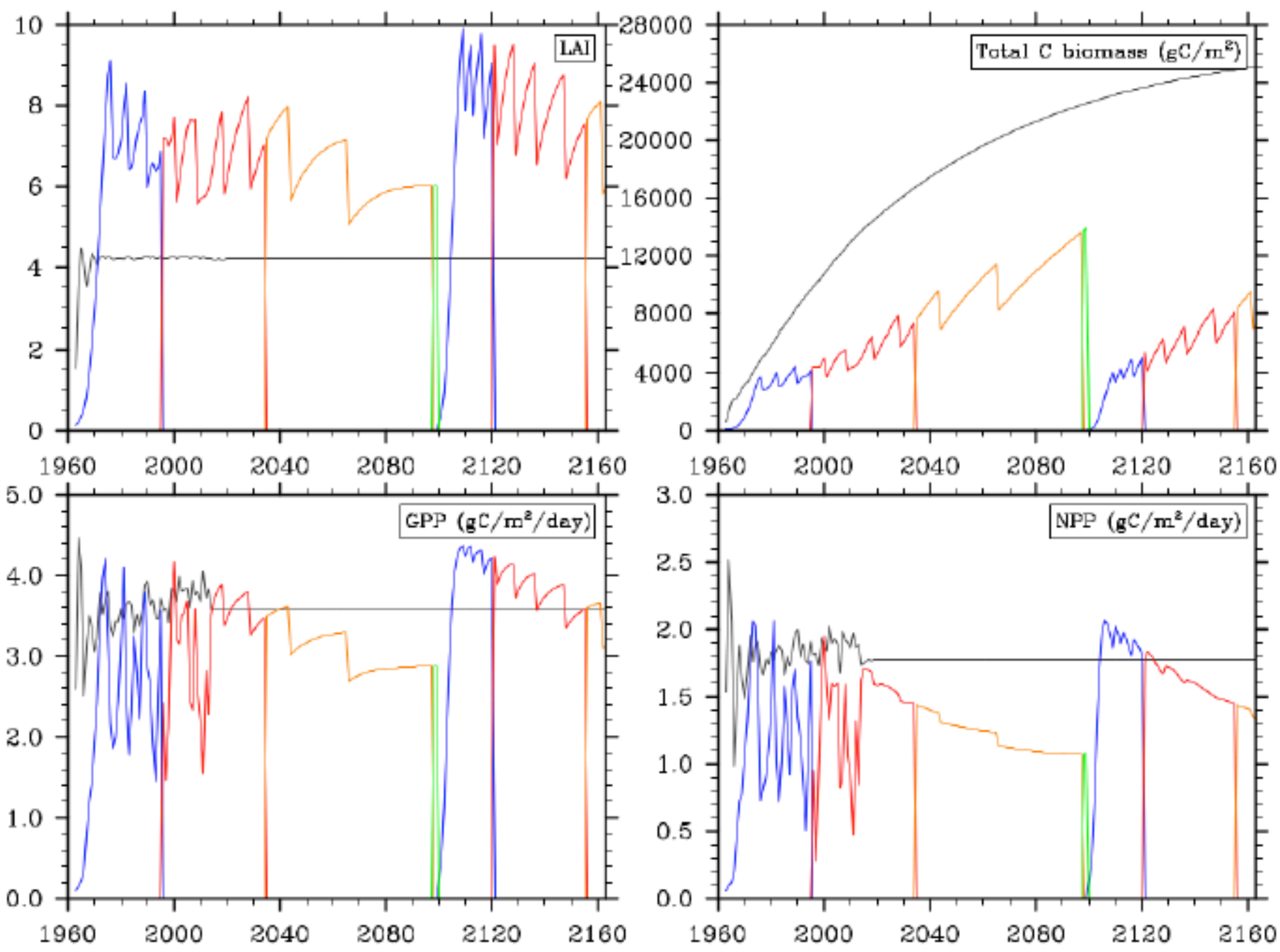


Illustrations from Gordon Bonan, talk 2016, CMMAP meating

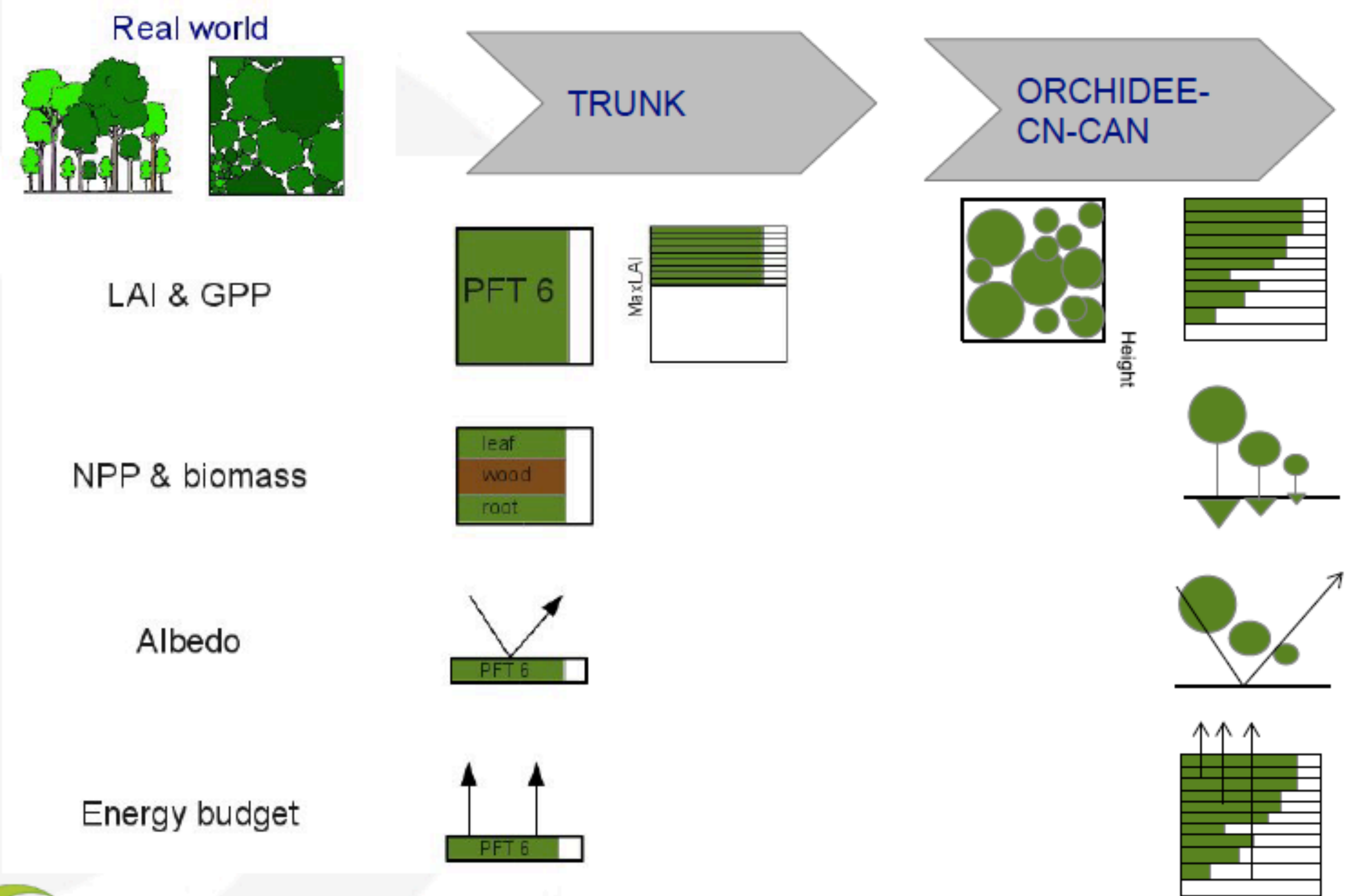
Ecosystem dynamics



Ecosystem dynamics



Summary sheet of CAN



Gross land use change

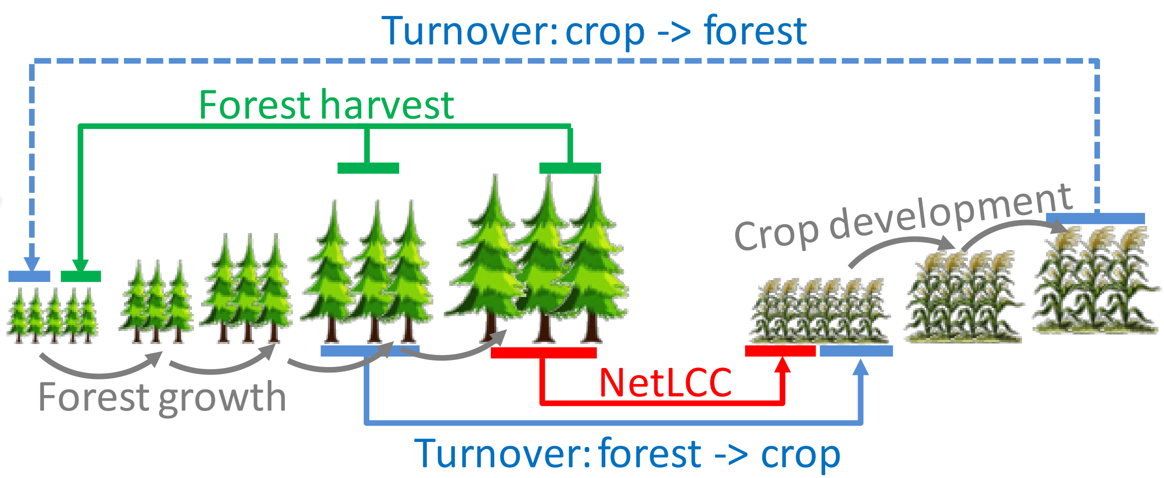

Deforestation


Shifting cultivation


Shifting cultivation


Wood harvest

Gross land use change with age cohorts



Factorial simulations

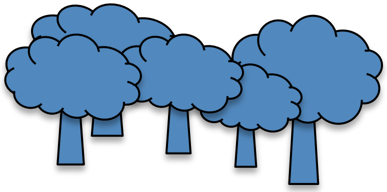
Simulations	Net LCC	Turnover	Harvest
S0 (S'0)			
S1 (S'1)	✔		
S2 (S'2)	✔	✔	
S3 (S'3)	✔	✔	✔

→ allow to quantify the contributions of different land use change processes (net change, land turnover or shifting cultivation and wood harvest).

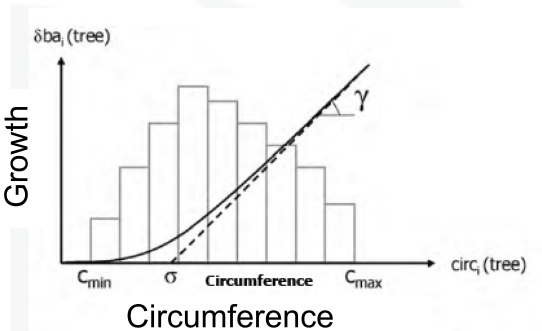
Chao Yue et al.

Forest management and stand description

Include diameter & age classes



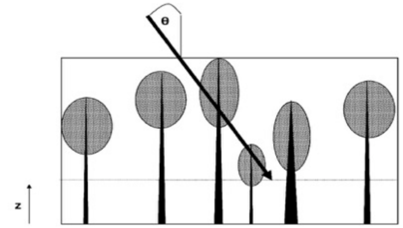
Allocation : “big get bigger”



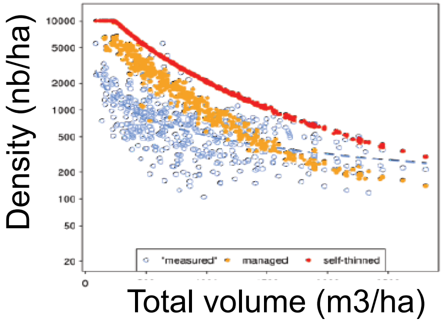
ORCHIDEE - CAN

(Naudts et al., 2015)

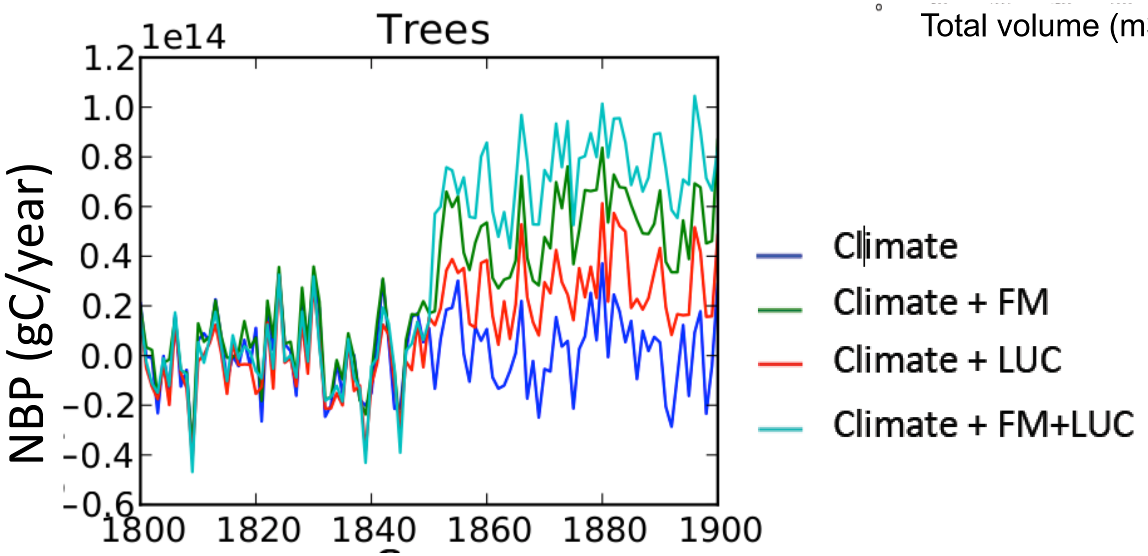
Accounts for gaps (PGAP)



Mortality from self-thinning



➔ Impact of climate, Forest management, Land Use Change on European NBP



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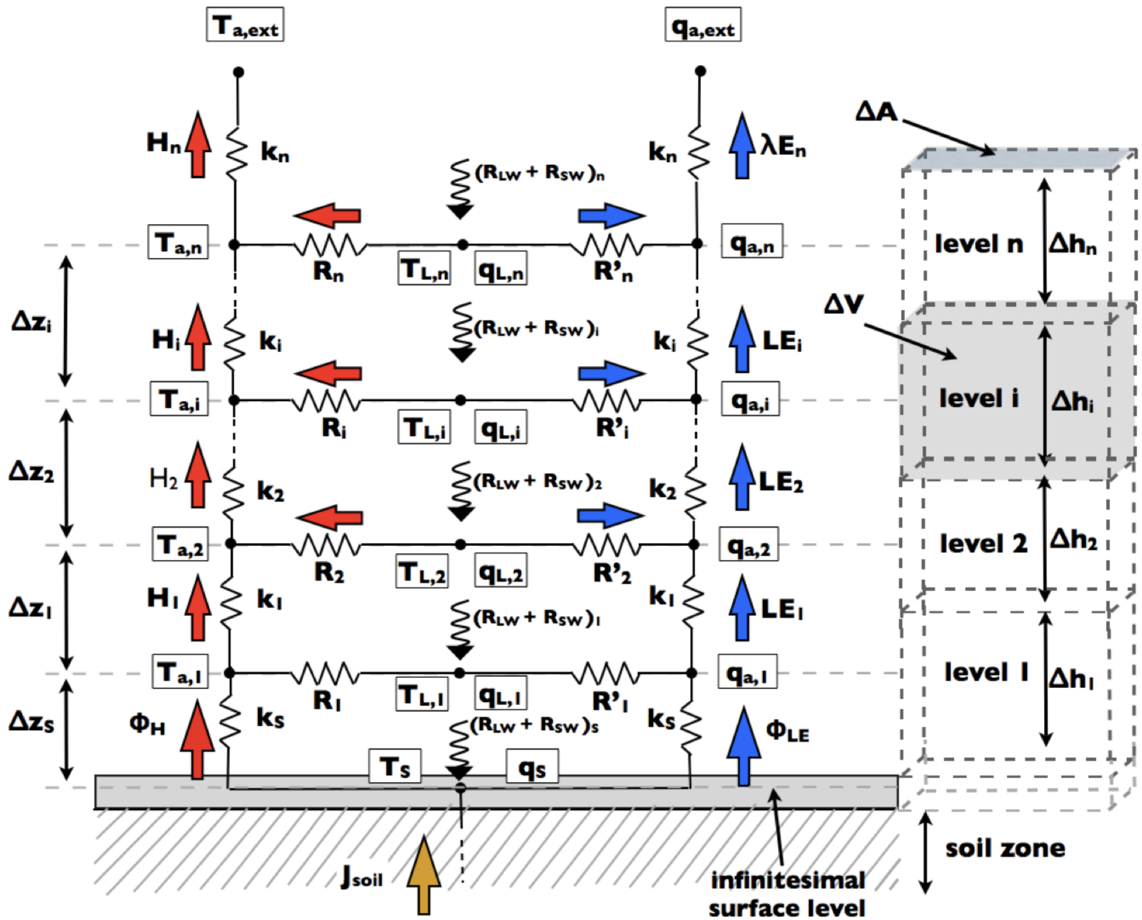
Vertical multi-layers scheme..

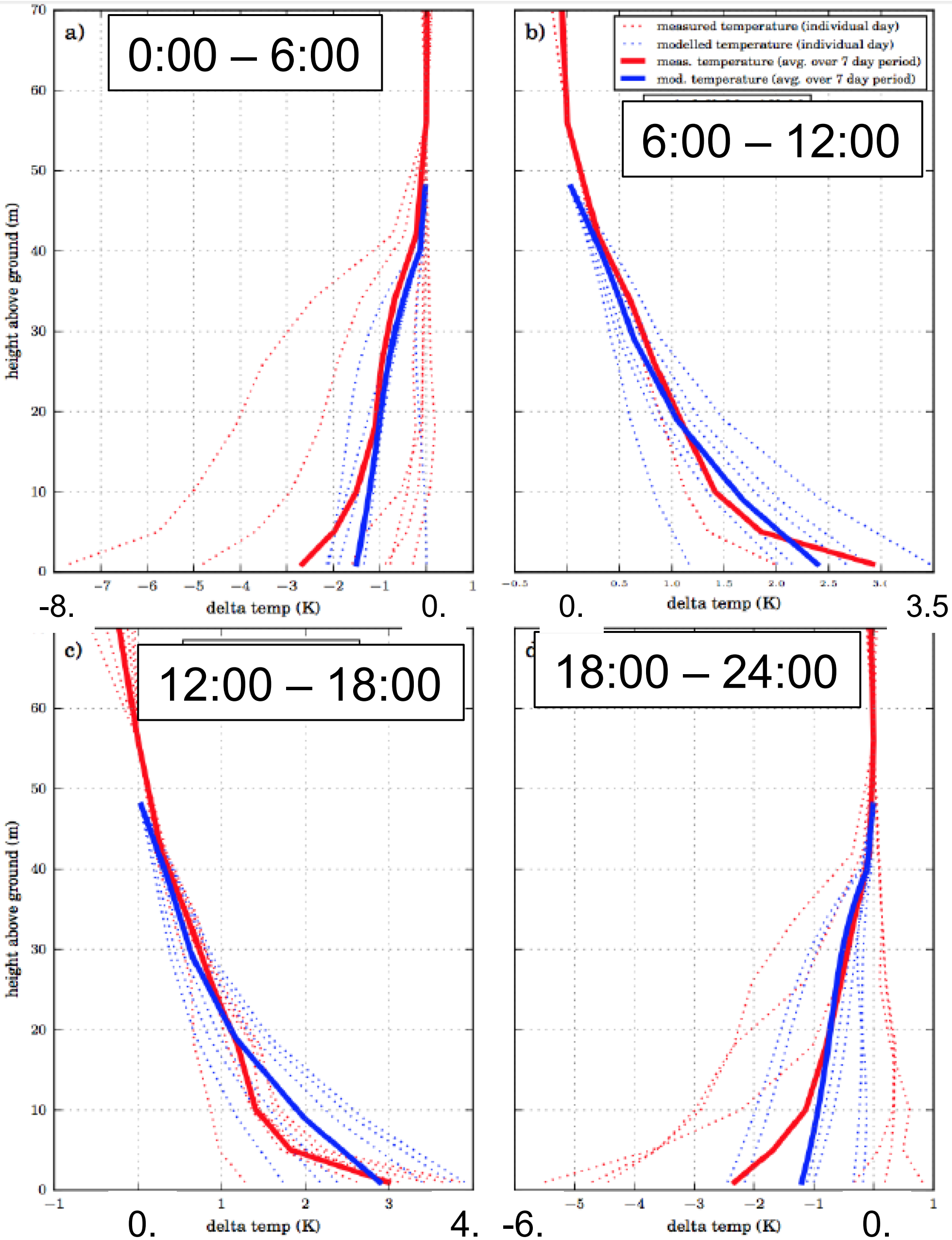
- Free number of layers
- E / W / C exchange at each level
- Turbulance mixing within air canopy
- Light penetration following Pgap model



Implementation constraints :

- Coupling with plant growth / harvesting module (variable plant height)
- Implicit coupling with Atmospheric model (30' step)
- Parametrisation of intra-canopy turbulence

Temperature profile at Tumbarumba site



Daily temperature

Observations

Model

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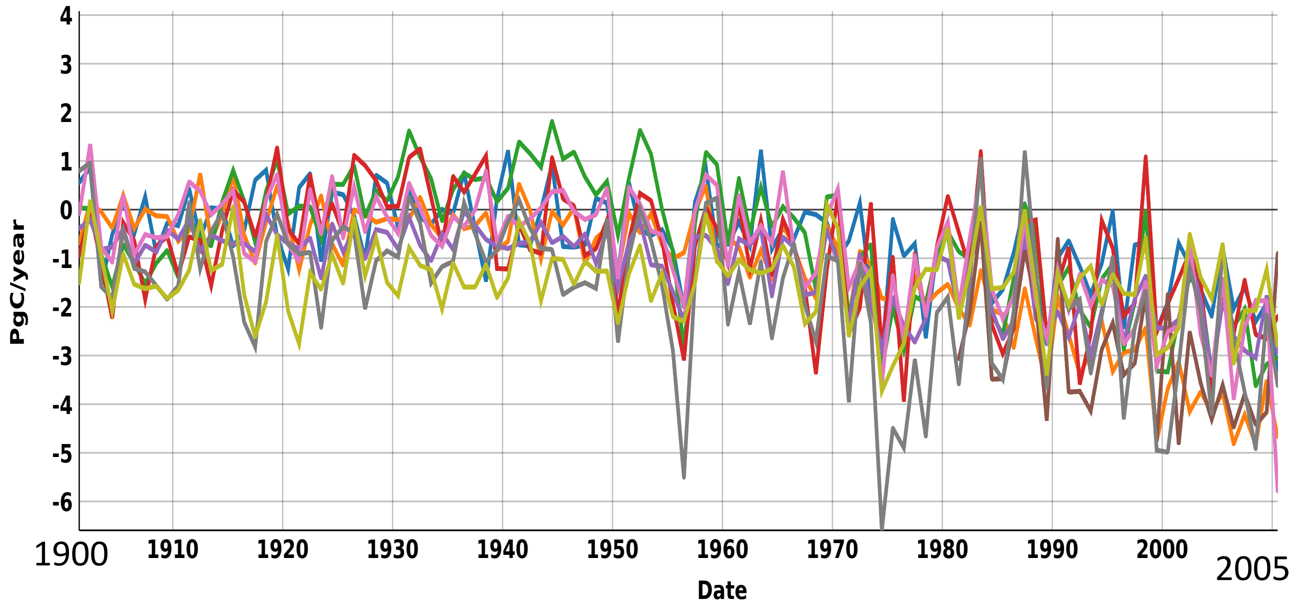
Data assimilation with ORCHIDEE

Philippe Peylin, Cédric Bacour, Natasha MacBean, Vladislav Bastrikov, Nina Raoult, Catherine Ottle, Pascal Maugis, Fabienne Maignan and the ORCHIDEE project team

Large spread in model net C fluxes !

Global flux (PgC/yr)

Fixed climate
(TRENDY_v1)

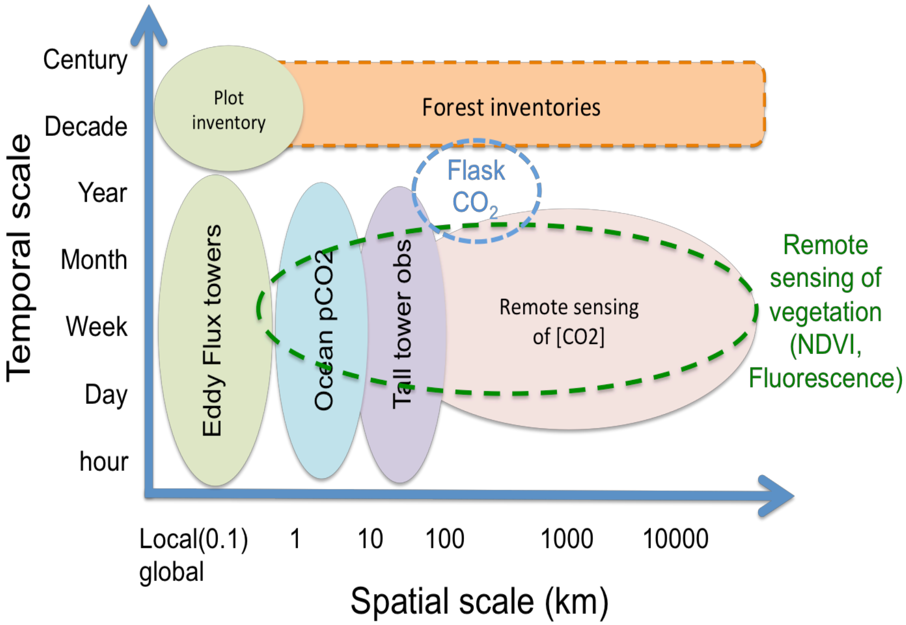


➔ Part of the spread due to “poorly” calibrated parameters

➔ Large impact of the C-dynamic on the Water fluxes
through changes in Leaf Area Index and thus Evapotranspiration

Reducing uncertainties with model – data integration

Available C-related data streams



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

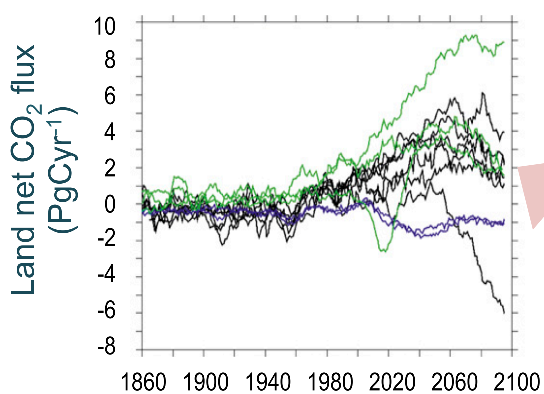
Observation term

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

Prior parameter term

X: model params to optimize

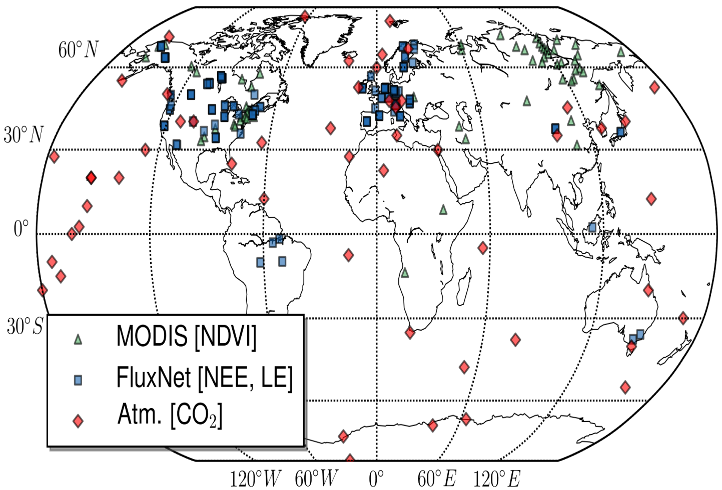
DATA ASSIMILATION

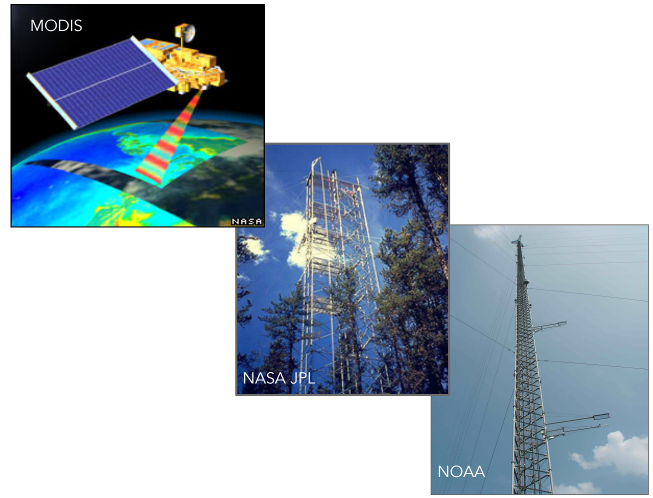


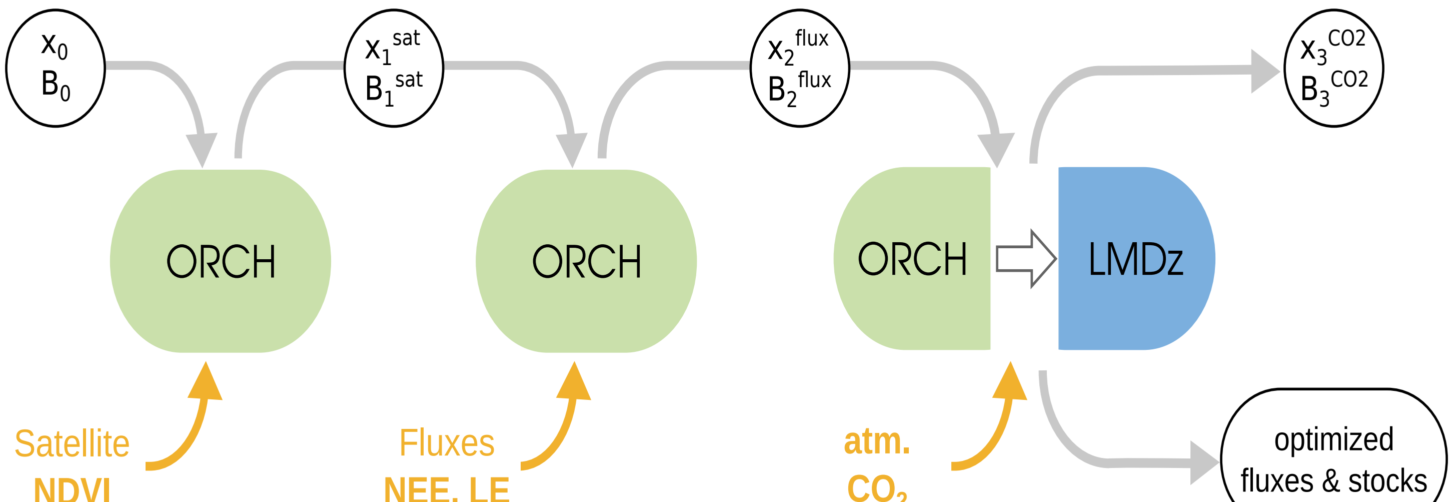
Improve:

- C budget estimates
- Quantify uncertainty
- Future climate predictions
- Process understanding

Stepwise approach: Multiple constraint on C fluxes







MacBean et al. (2015)

40 params

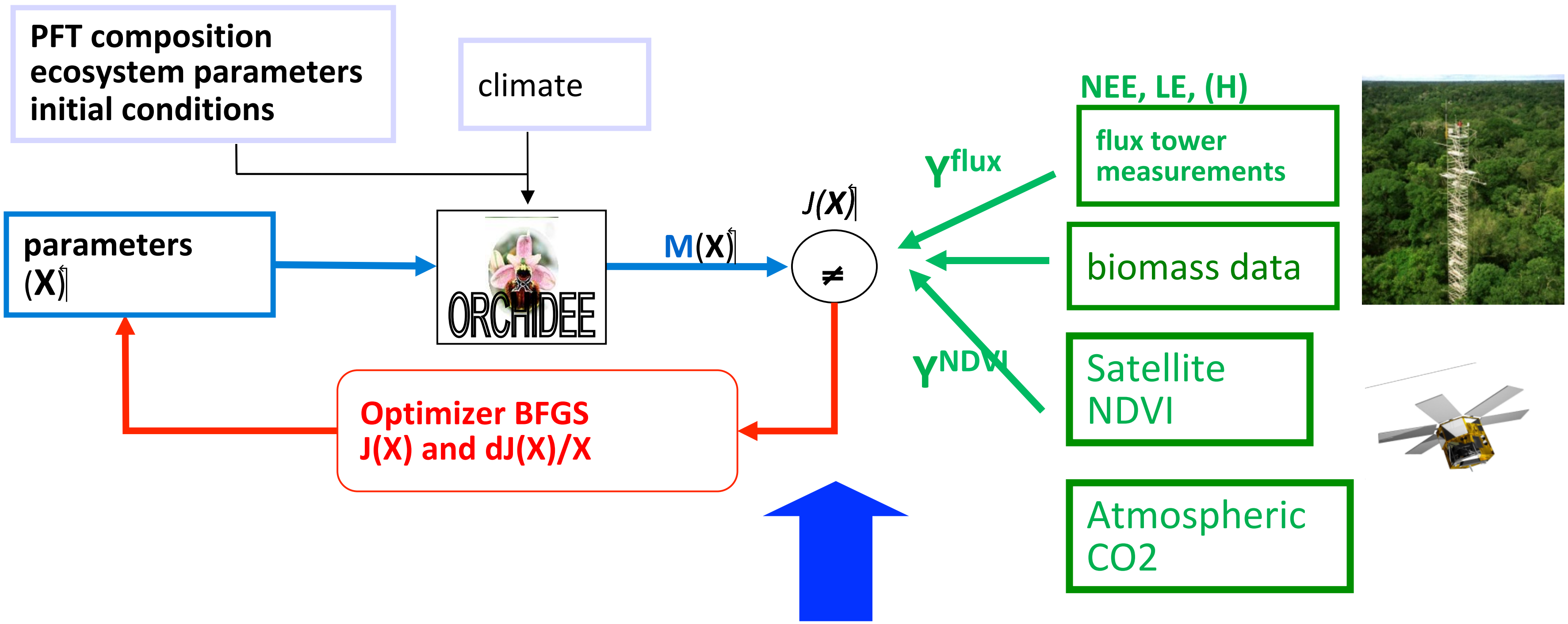
Kuppel et al. (2014)

≈ 100 params

Peylin et al. (2016)

≈ 80 params

Optimization of the C-cycle parameters..

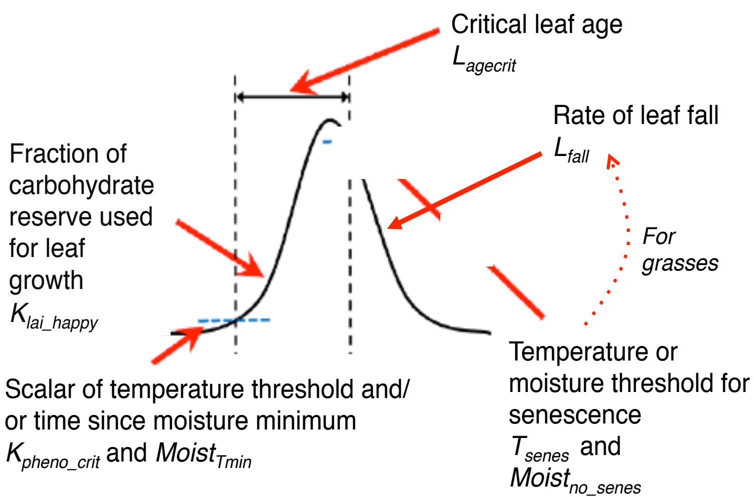


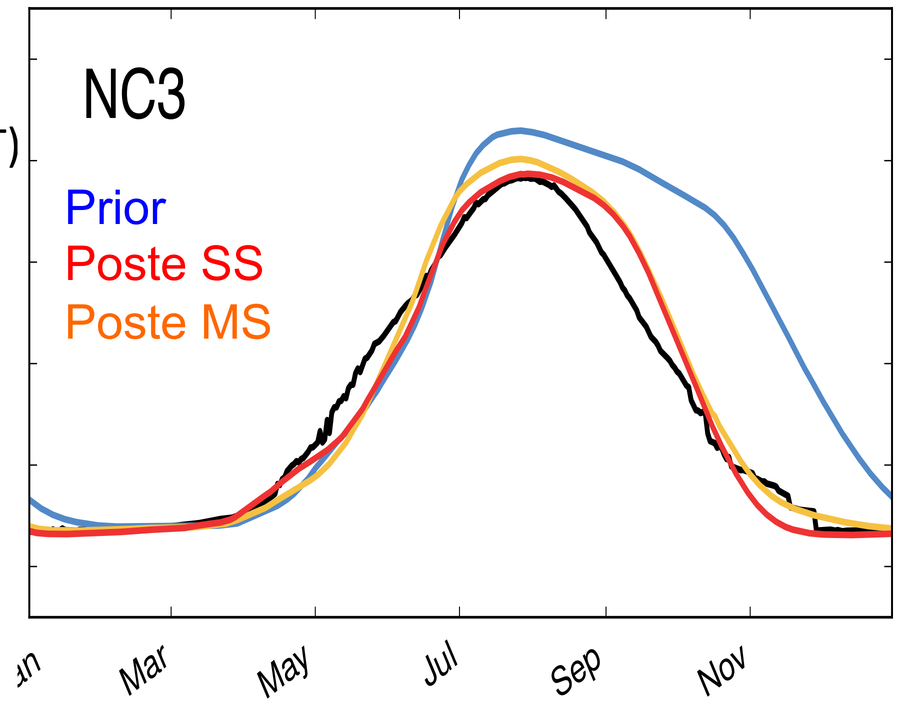
- **Cost function:** $$J(x)=\frac{1}{2}\left[\left(y-M(x)\right)^{t}R^{-1}\left(y-M(x)\right)+(x-x_b)^{t}P_b^{-1}(x-x_b)\right]$$

- **Iterative minimization using either:**
  - **Variational approach (with Tangent Linear model for DJ/dx)**
  - **Monte Carlo approach (Genetic Algorithm)**

Step1: satellite-derived "vegetation greenness" index constrains seasonal leaf dynamics

- MODIS - NDVI compared to model fAPAR
- 4 – 6 parameters per plant functional type (PFT)





- 15 random grid points per PFT

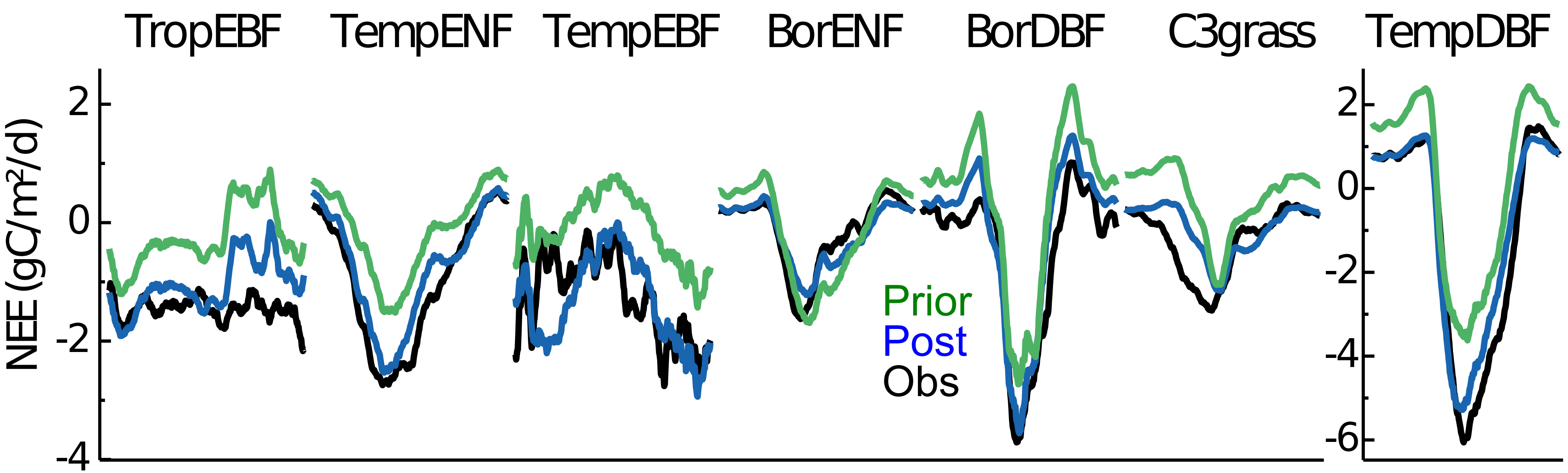
N. MacBean et al. (2015)

Step2: Net CO_2 fluxes constrains flux seasonal cycle

75 fluxnet data (NEE, LE)

≈ 20 parameters per PFT

NEE mean seasonal cycle: PFT average



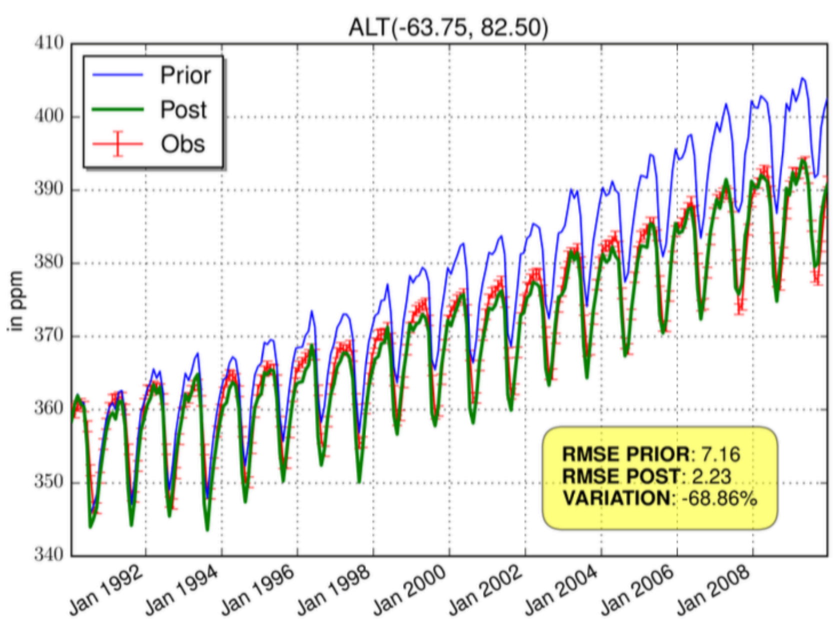
➔ Improvement of amplitude and phase

➔ Highlight model deficiencies

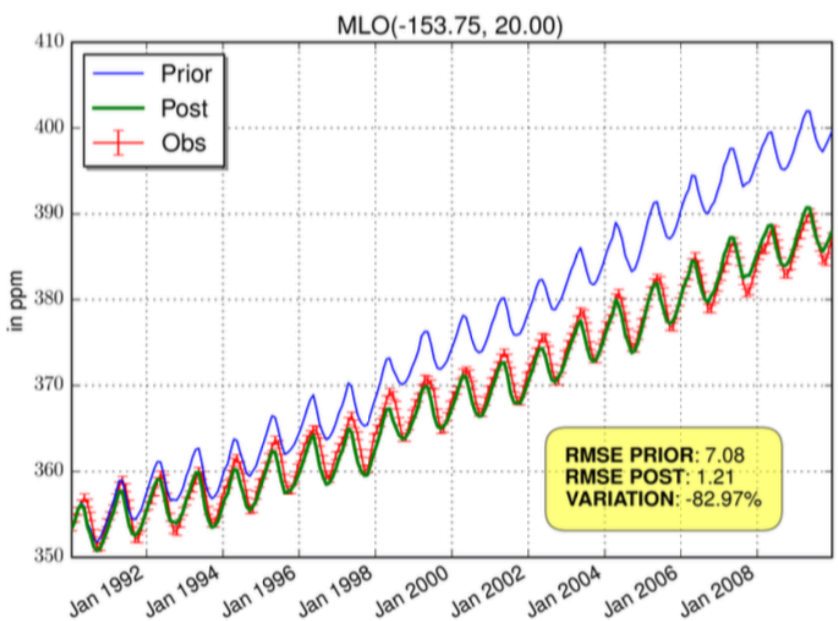
Kuppel et al. (2012)

Step 3: Atmospheric CO_2 constrains trend in the net C sink

- Optimization at 77 sites
- Fit to long-term $[CO_2]$ trend & improve seasonal amplitude with
  - reduced total soil carbon content
  - changed soil respiration parameters



Prior
Post
Obs

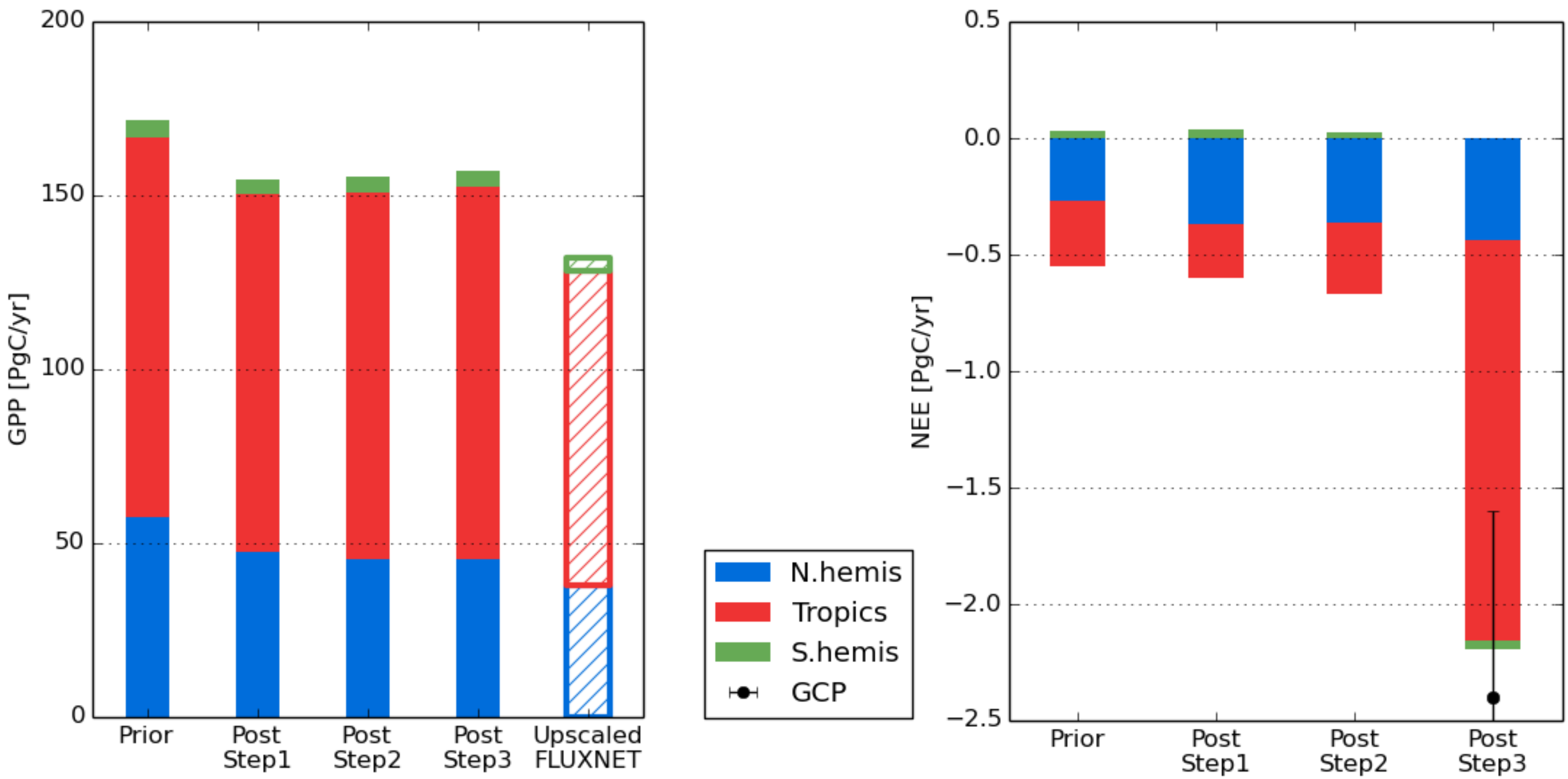


Impact on net and gross C budgets:

Gross Primary Productivity
→ (C uptake)

mean annual total
(1990-2010)

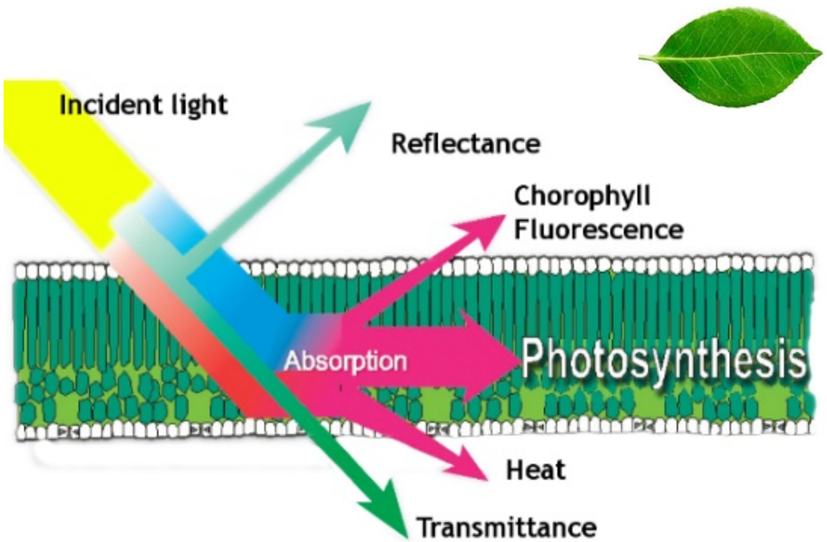
Net Ecosystem Exchange
→ (net CO_2 flux)



Peylin, P., et al., 2016.

Solar Induce Fluorescence data

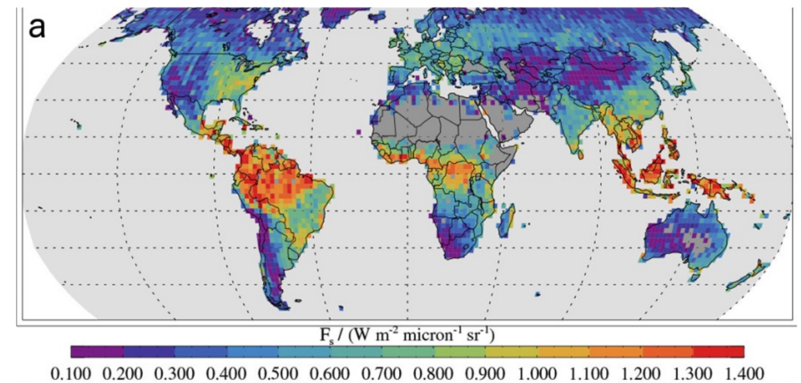
Solar Fluorescence (SIF)



SIF = function (GPP, T,…)

→ Use SIF satellite data
(GOME-2 from Köhler et al., 2015)

GOME-2 SIF



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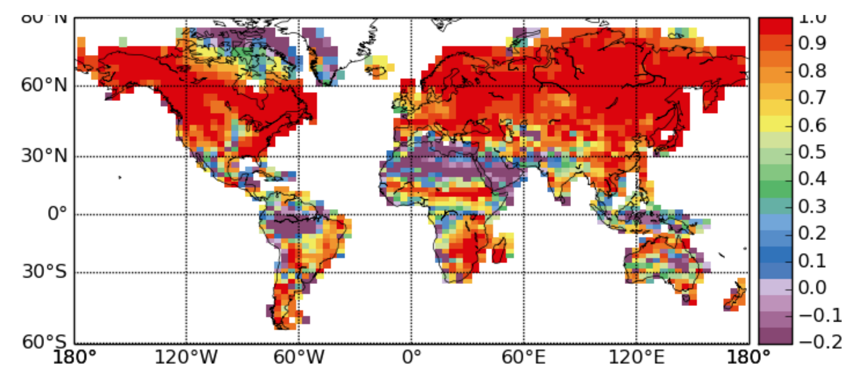
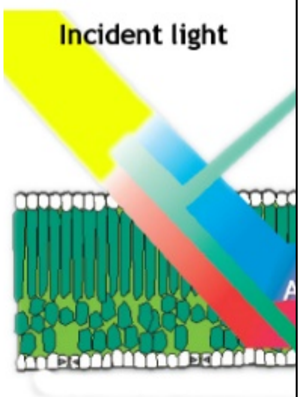
Correlation: ORCHIDEE-GPP vs SIF



➔ Regional scale information for phase (& synoptic events)

Solar Induce Fluorescence data

Solar Flu



SIF = fun

→ Use S
(GOME-2 fr

RESEARCH | REMOTE SENSING

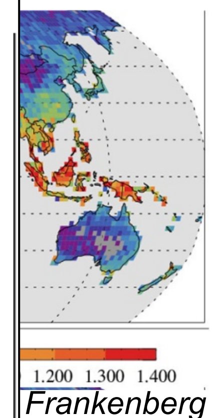
RESEARCH ARTICLE

CARBON CYCLE

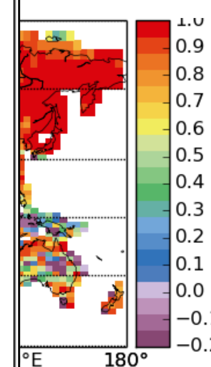
Contrasting carbon cycle responses of the tropical continents to the 2015–2016 El Niño

Junjie Liu,[1*] Kevin W. Bowman,[1] David S. Schimel,[1] Nicolas C. Parazoo,[1] Zhe Jiang,[2] Meemong Lee,[1] A. Anthony Bloom,[1] Debra Wunch,[3] Christian Frankenberg,[1,4] Ying Sun,[1†] Christopher W. O'Dell,[5] Kevin R. Gurney,[6] Dimitris Menemenlis,[1] Michelle Gierach,[1] David Crisp,[1] Annmarie Eldering[1]

The 2015–2016 El Niño led to historically high temperatures and low precipitation over the tropics, while the growth rate of atmospheric carbon dioxide (CO_2) was the largest on record. Here we quantify the response of tropical net biosphere exchange, gross primary production, biomass burning, and respiration to these climate anomalies by assimilating column CO_2, solar-induced chlorophyll fluorescence, and carbon monoxide observations from multiple satellites. Relative to the 2011 La Niña, the pantropical biosphere released 2.5 ± 0.34 gigatons more carbon into the atmosphere in 2015, consisting of approximately even contributions from three tropical continents but dominated by diverse carbon exchange processes. The heterogeneity of the carbon-exchange processes indicated here challenges previous studies that suggested that a single dominant process determines carbon cycle interannual variability.



vs SIF



nation
vents)

Optimisation set-up

- Simple linear relationship between GPP and SIF:

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

- Constrain 'a' and 'b' (slope and offset) parameters in addition to photosynthesis and phenology parameters for ALL vegetated PFTs

- Use GOME2 SIF data (Köhler et al., 2015)
- 15 grid cells chosen randomly per PFT
- 12-16 parameters per PFT
- Multi-site optimisation performed for each PFT
- 4D – variational/finite difference data assimilation system

MacBean et al. submitted

Optimisation set-up

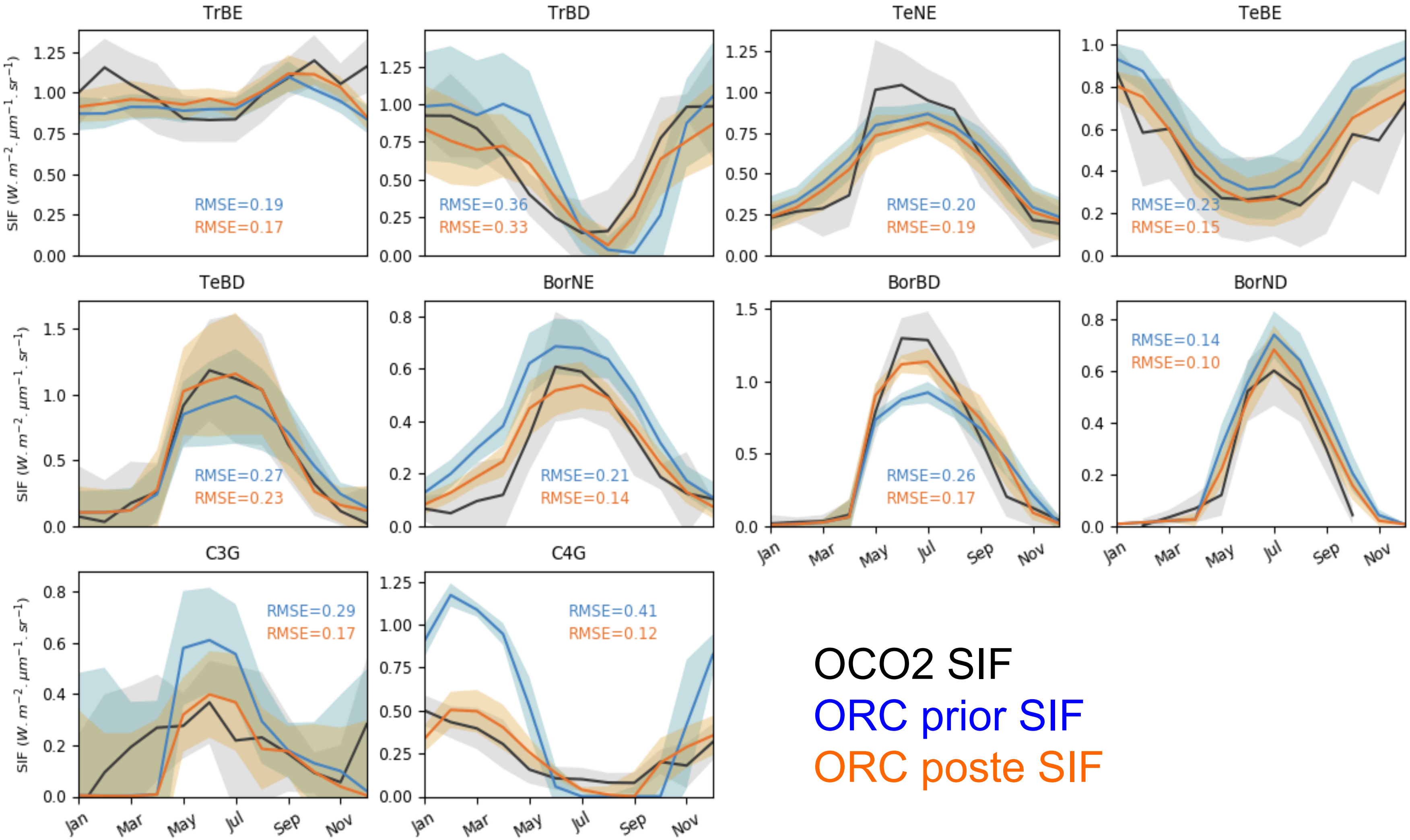
- New mechanistic GPP – SIF relationship:

  SCOPE model f(GPP, Temp, Vcmax,…)

- Constrain several parameters of SCOPE and the photosynthesis & phenology model for ALL vegetated PFTs

- Use OCO2 SIF data
- 15 grid cells chosen randomly per PFT
- 12-16 parameters per PFT
- Multi-site optimisation performed for each PFT
- 4D – variational/finite difference data assimilation system

OCO2 fluorescence assimilation



OCO2 SIF
ORC prior SIF
ORC poste SIF

Bacour et al. In prep

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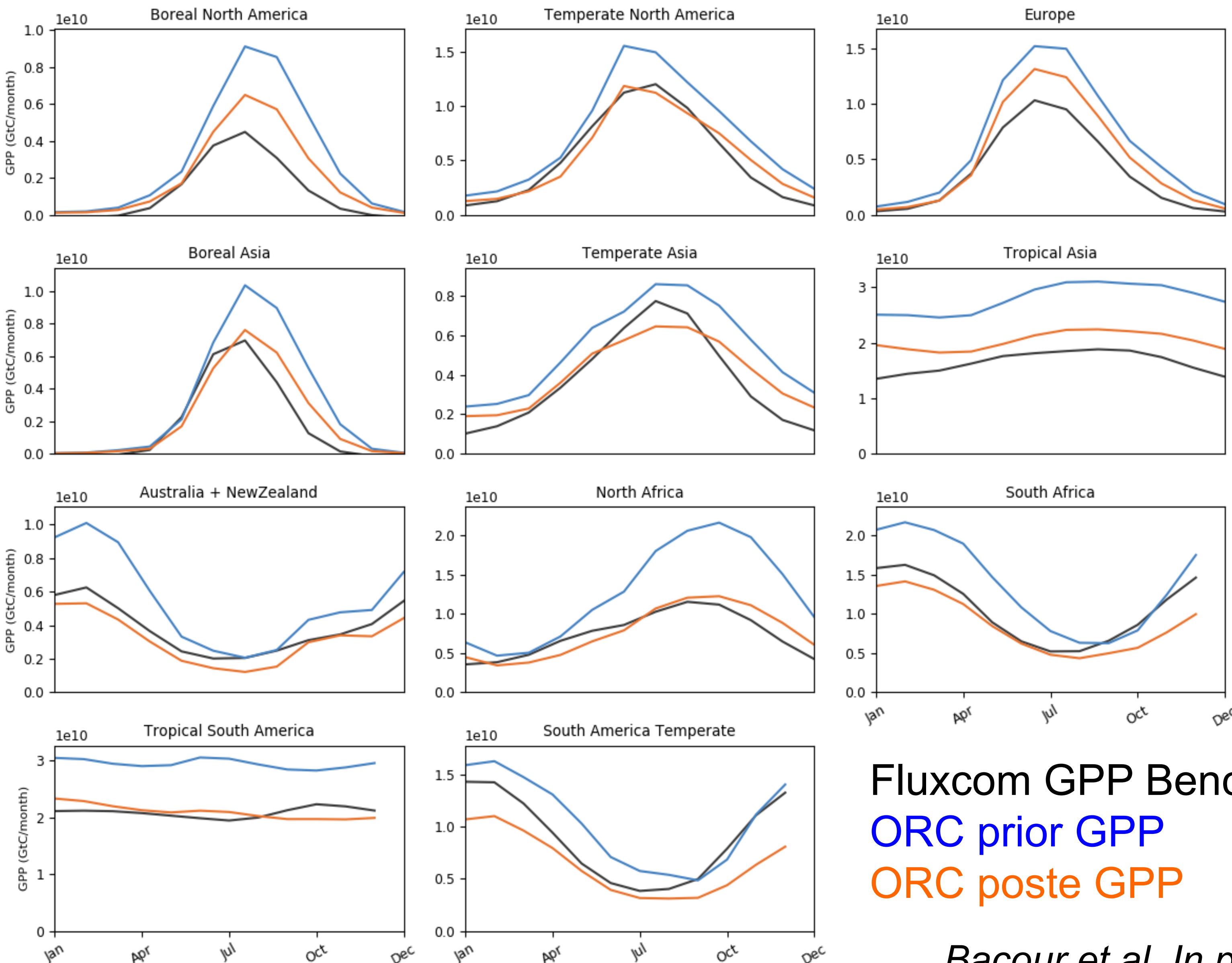
OCO2 fluorescence assimilation



Fluxcom GPP Benchmark
ORC prior GPP
ORC poste GPP

Bacour et al. In prep

Experiences gained with ORCHIDEE and challenges

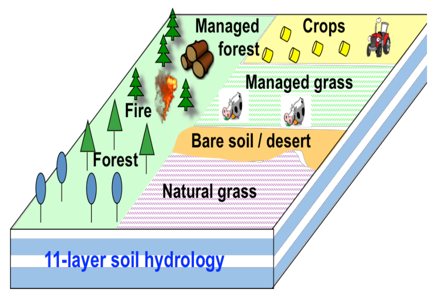
Site scale
Optimization

Chen et al., 2016
Santaren et al. 2014
Verbeeck et al., 2011
Santaren et al. 2007

Multi-site or
Multi-data stream
optimization

Kuppel et al., 2014
Peng et al., 201
Thum et al. 2016
Bacour et al., 2015

Model
development



Forest management
N-P cycles
Permafrost C
…

Technical DA
improvement

Kuppel et al. 2013
MacBean et al., 2016
Bastrikov et al., in prep

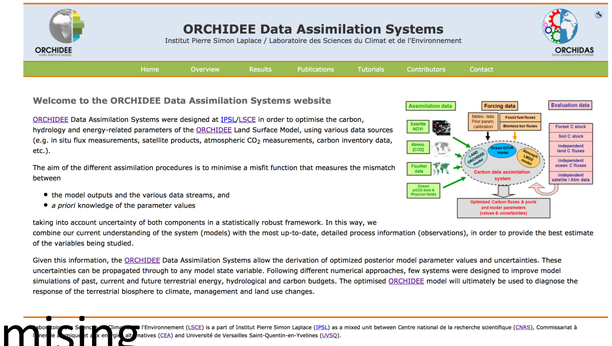
Global – Scale
Multi data stream
optimization

MacBean et al. 2015
Peylin et al., 2016

http://orchidas.lsce.ipsl.fr

In summary….

- Need to combine model developments AND parameter optimization !
- Results with ORCHIDEE are summarized under a web site: http://orchidas.lsce.ipsl.fr


ORCHIDEE Data Assimilation Systems
Institut Pierre Simon Laplace / Laboratoire des Sciences du Climat et de l'Environnement

Home | Overview | Results | Publications | Tutorials | Contributors | Contact

Welcome to the ORCHIDEE Data Assimilation Systems website

ORCHIDEE Data Assimilation Systems were designed at IPSL/LSCE in order to optimise the carbon, hydrology and energy-related parameters of the ORCHIDEE Land Surface Model, using various data sources (e.g. in situ flux measurements, satellite products, atmospheric CO_2 measurements, carbon inventory data, etc.).

The aim of the different assimilation procedures is to minimise a misfit function that measures the mismatch between

- the model outputs and the various data streams, and
- *a priori* knowledge of the parameter values

taking into account uncertainty of both components in a statistically robust framework. In this way, we combine our current understanding of the system (models) with the most up-to-date, detailed process information (observations), in order to provide the best estimate of the variables being studied.

Given this information, the ORCHIDEE Data Assimilation Systems allow the derivation of optimized posterior model parameter values and uncertainties. These uncertainties can be propagated through to any model state variable. Following different numerical approaches, few systems were designed to improve model simulations of past, current and future terrestrial energy, hydrological and carbon budgets. The optimised ORCHIDEE model will ultimately be used to diagnose the response of the terrestrial biosphere to climate, management and land use changes.

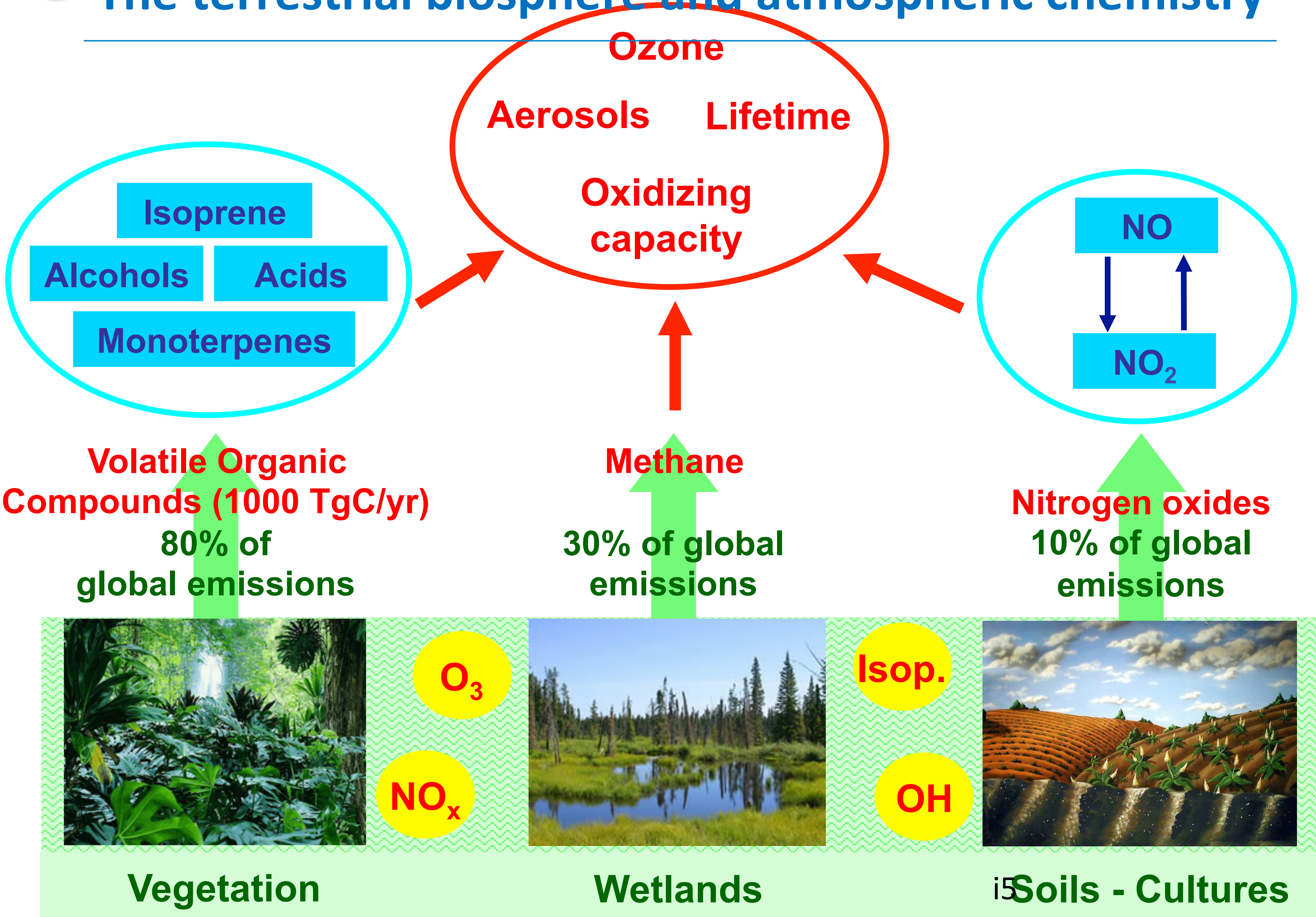
- DA should become a standard for all LSM !
- Assimilating Water and Carbon observations is promising
  - ✓ Constraint on plant water use efficiency
  - ✓ Phenology in dry ecosystem is still poorly modeled
- New set of observations still largely under-used
  - ✓ Carbon stock data (above ground biomass)
  - ✓ Manipulative experiments *(CO2, rain, temperature,…)*

A taste of atmospheric chemistry in ORCHIDEE: Importance of the terrestrial biosphere for surface-atmosphere chemical interactions.

Juliette Lathière and coworkers.

juliette.lathiere@lsce.ipsl.fr - CNRS Researcher LSCE

The terrestrial biosphere and atmospheric chemistry



Chemistry-vegetation retroactions

Atmospheric chemical composition

CO_2

Pollution: O_3, NOx, SO_2 and particles

Deposition | Deposition | Deposition

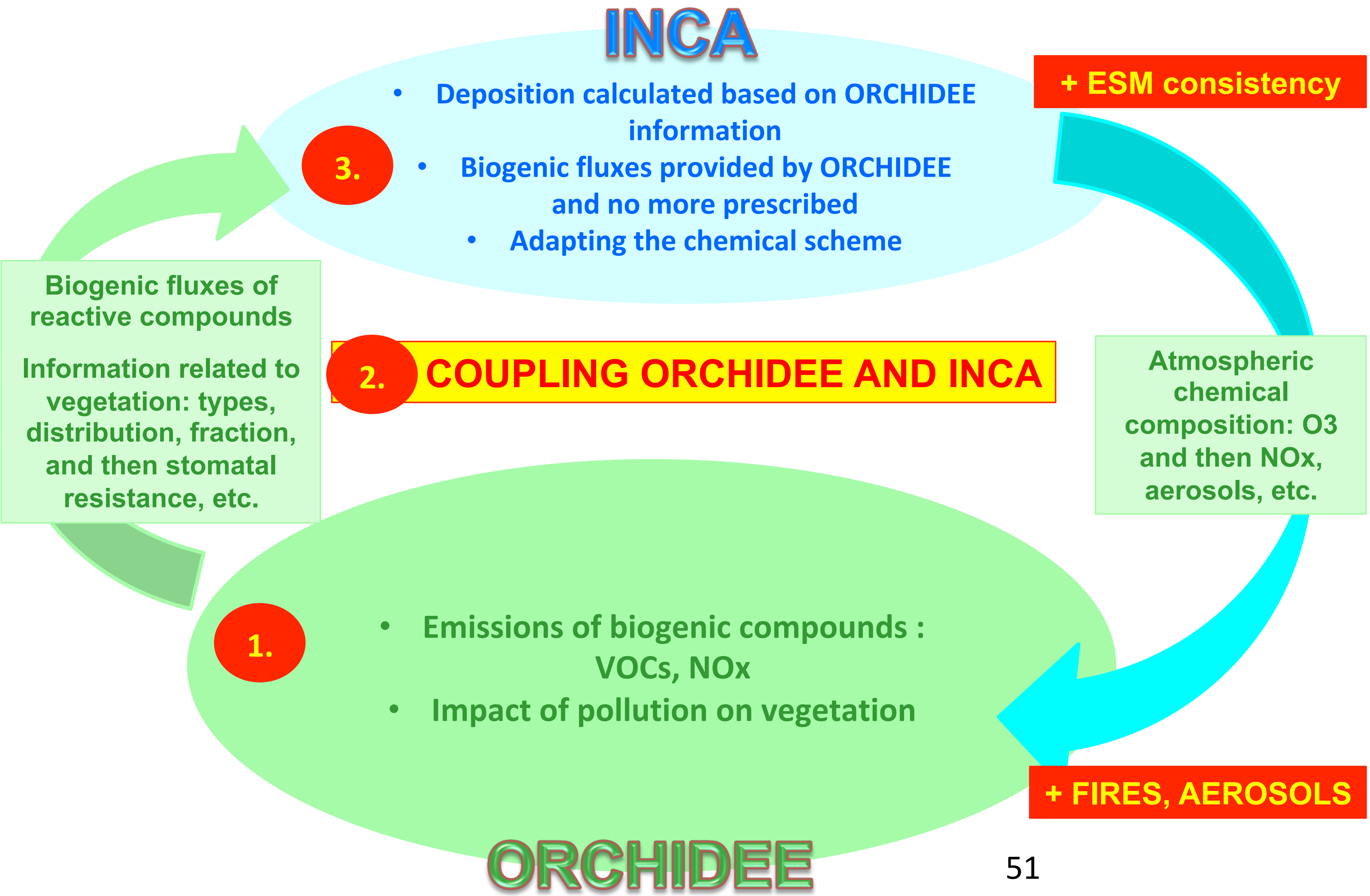
→ Growth, Distribution, Functioning

Vegetation

Wetlands

Soils - Cultures

Interactions between the terrestrial biosphere and the atmospheric chemical composition - Coupling INCA and ORCHIDEE



Evaluation of model simulations

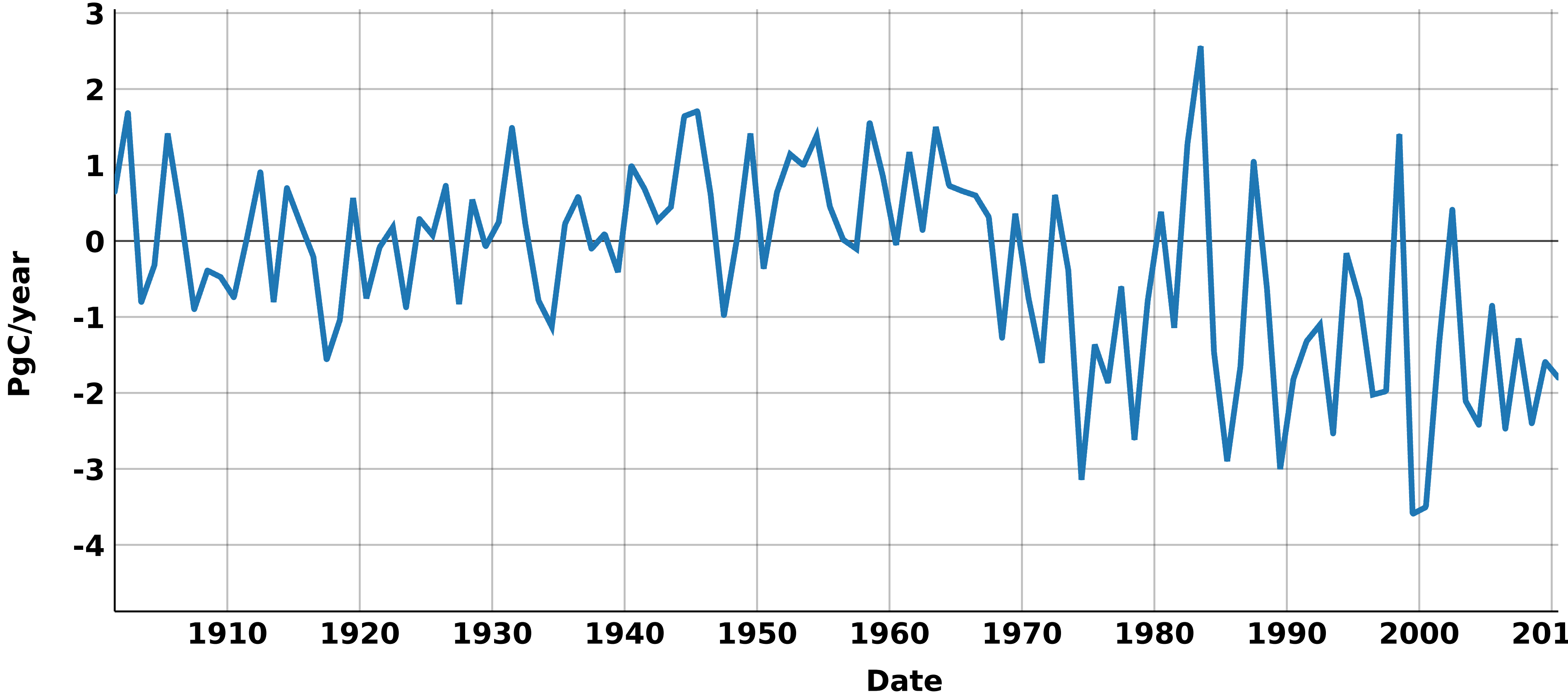
- https://orchidas.lsce.ipsl.fr/mapper/maps.php (evaluation of standard model simulations)

- http://eraclim.globalcarbonatlas.org/rc/woodpecker/

(comparison of simulation with different forcing;

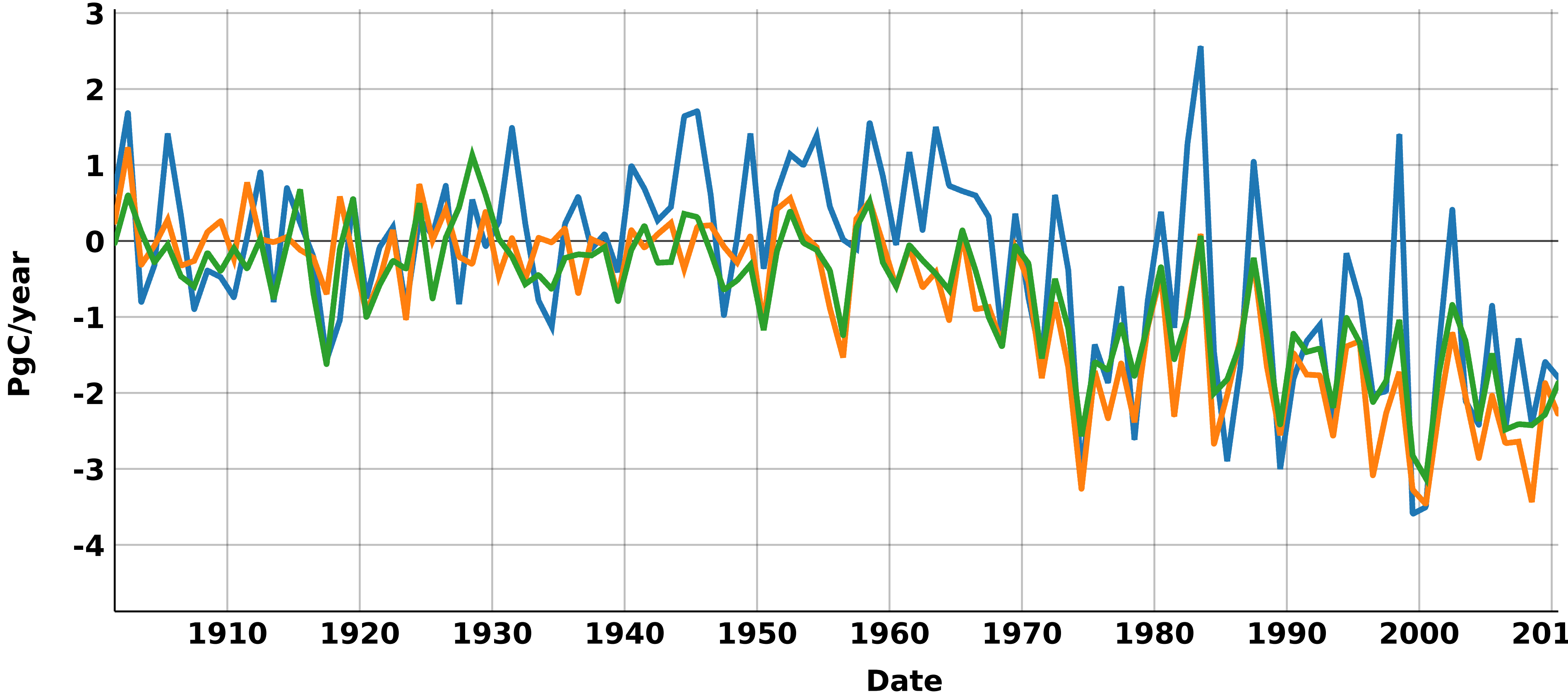
User/Passwd: eraclim / eraclim2017

Net CO_2 flux – Meteorological forcings



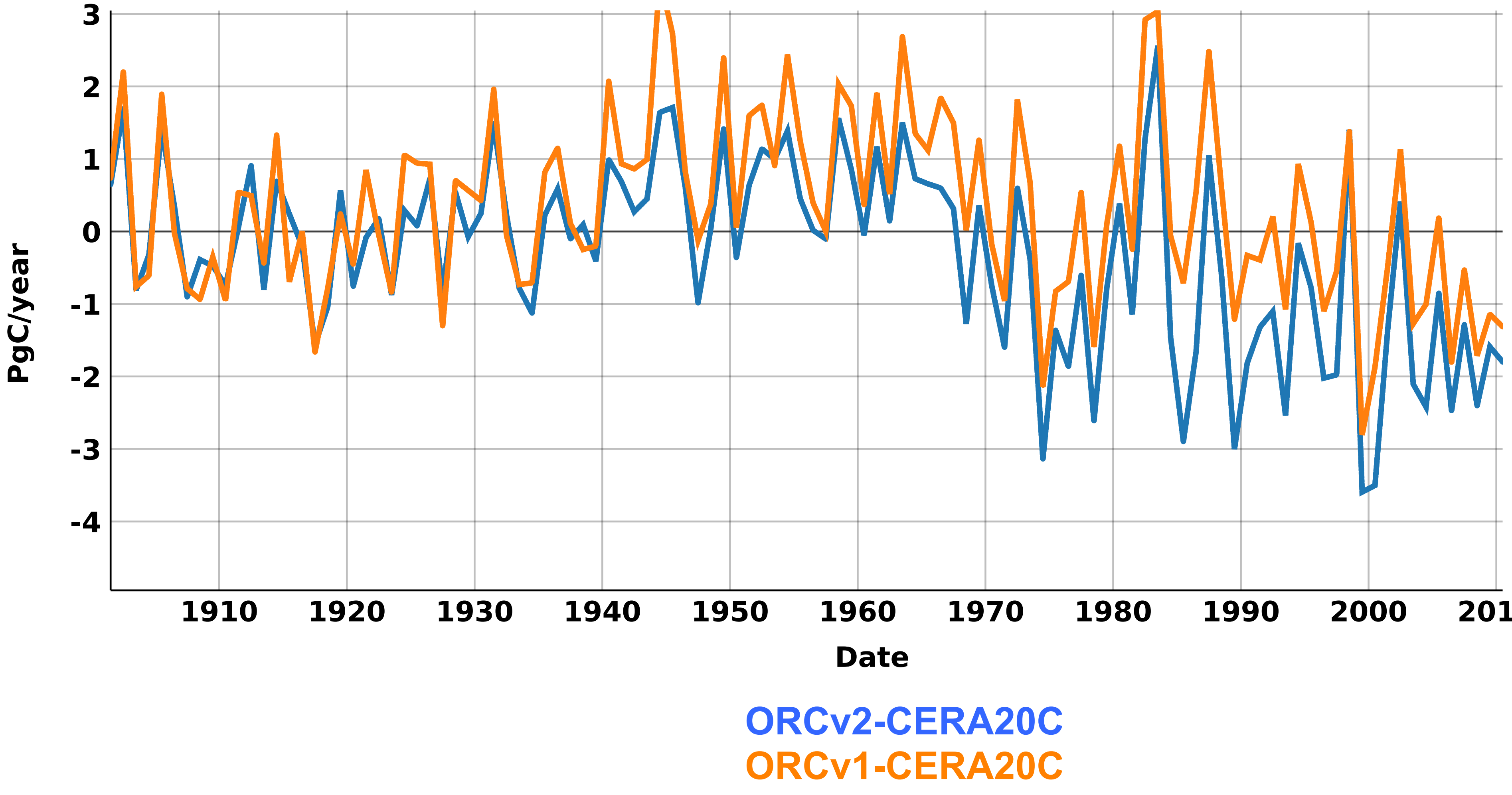
CERA20C

Net CO_2 flux – Meteorological forcings



CERA20C
CRUNCEP
GSWP3

Net CO_2 flux – Different versions



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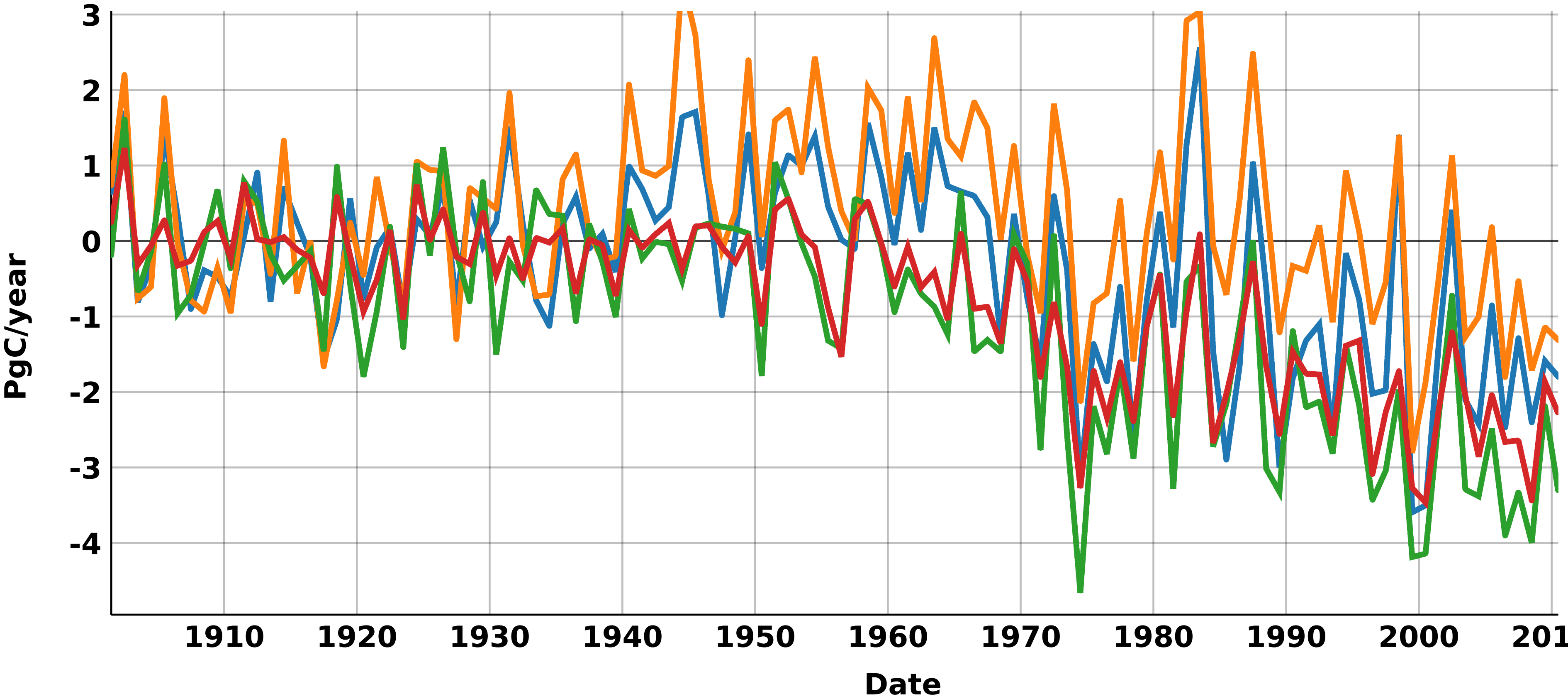
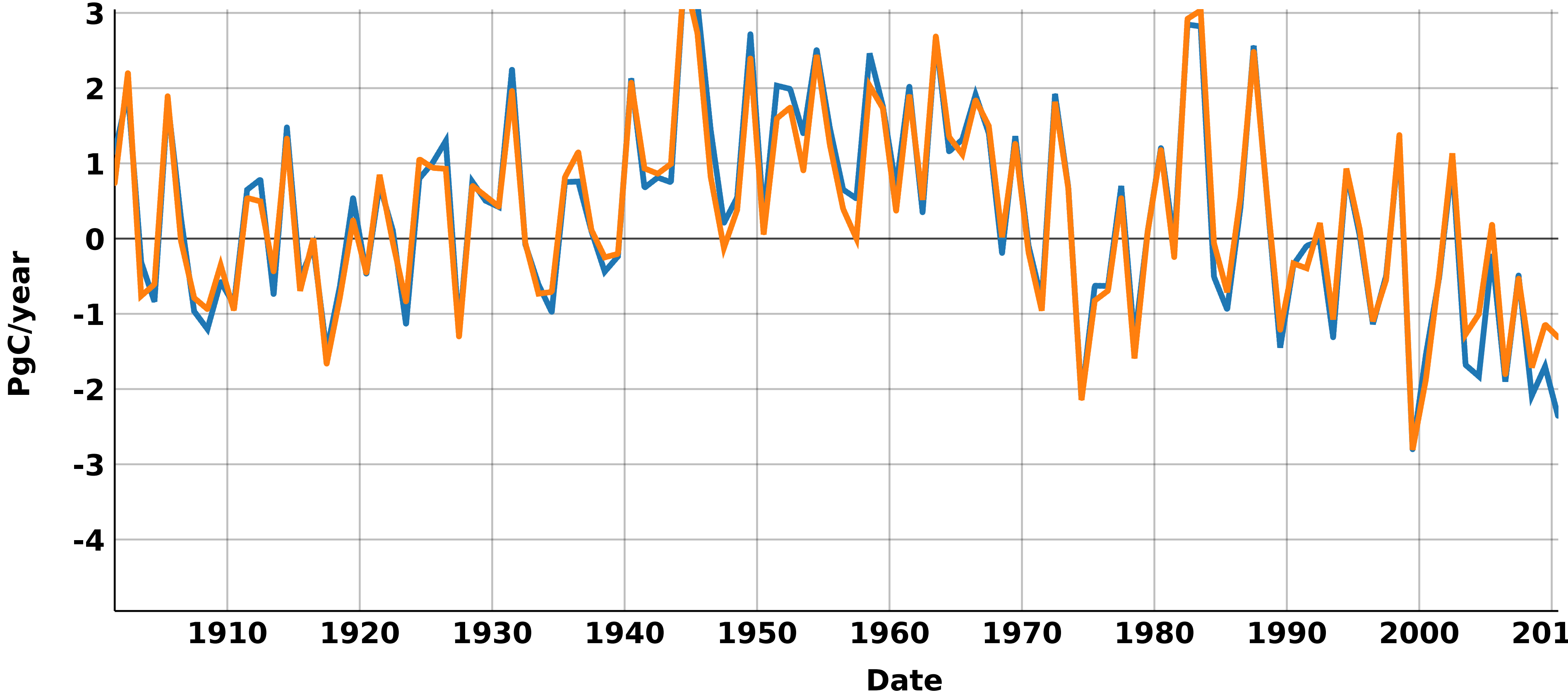
Net CO_2 flux – Different versions



ORCv2-CRUNCEP
ORCv1-CRUNCEP
ORCv2-CERA20C
ORCv1-CERA20C

Net CO_2 flux – Different Land-use maps



ORCv1-CMIP6
ORCv1-CMIP5

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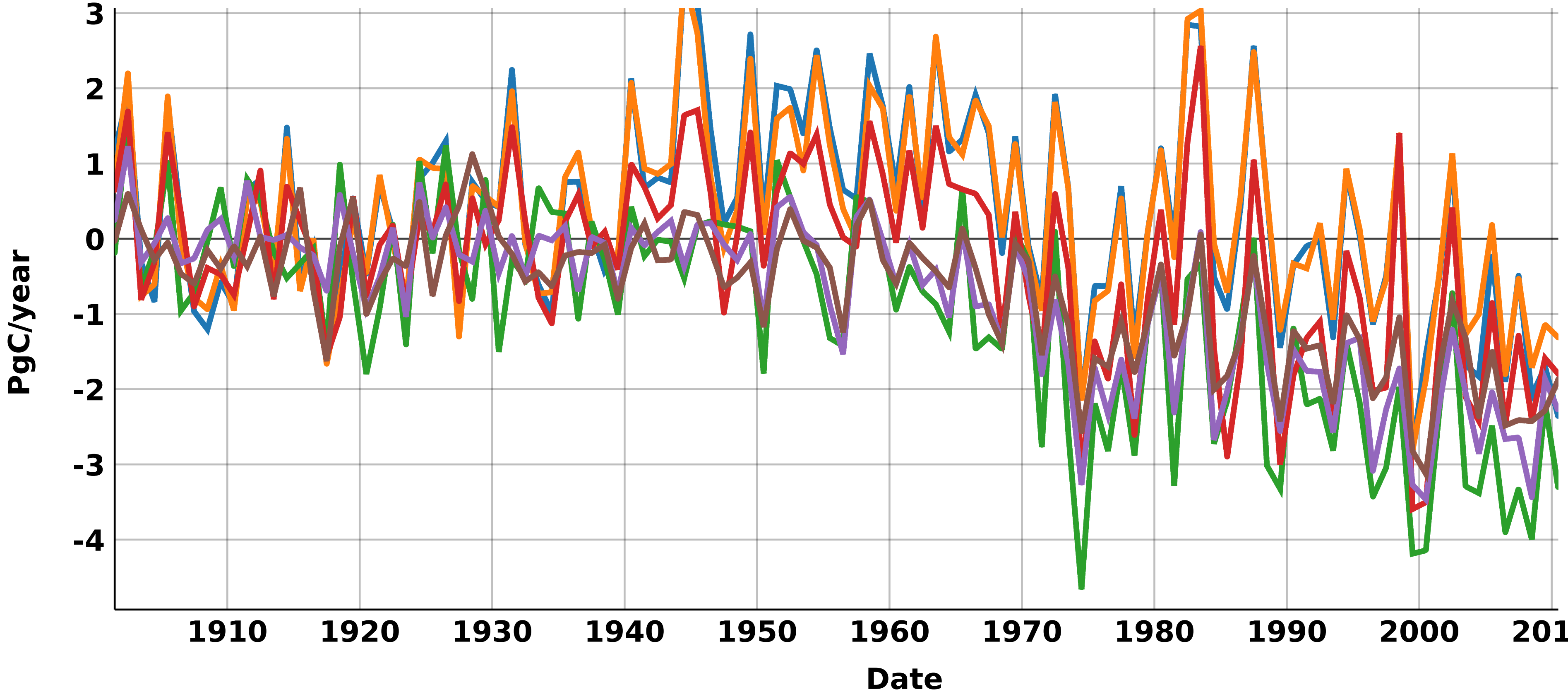
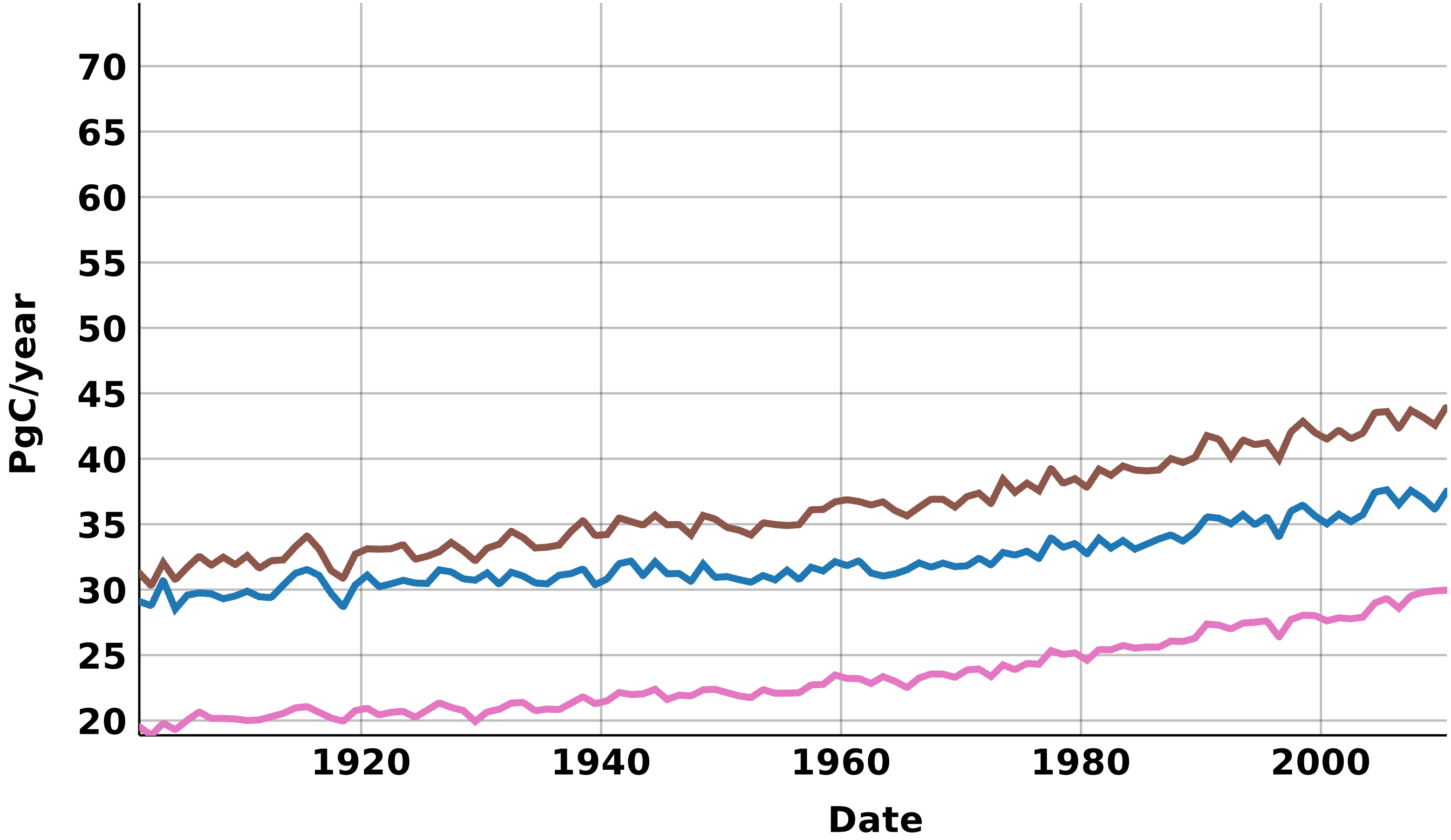
Net CO_2 flux – All uncertainties

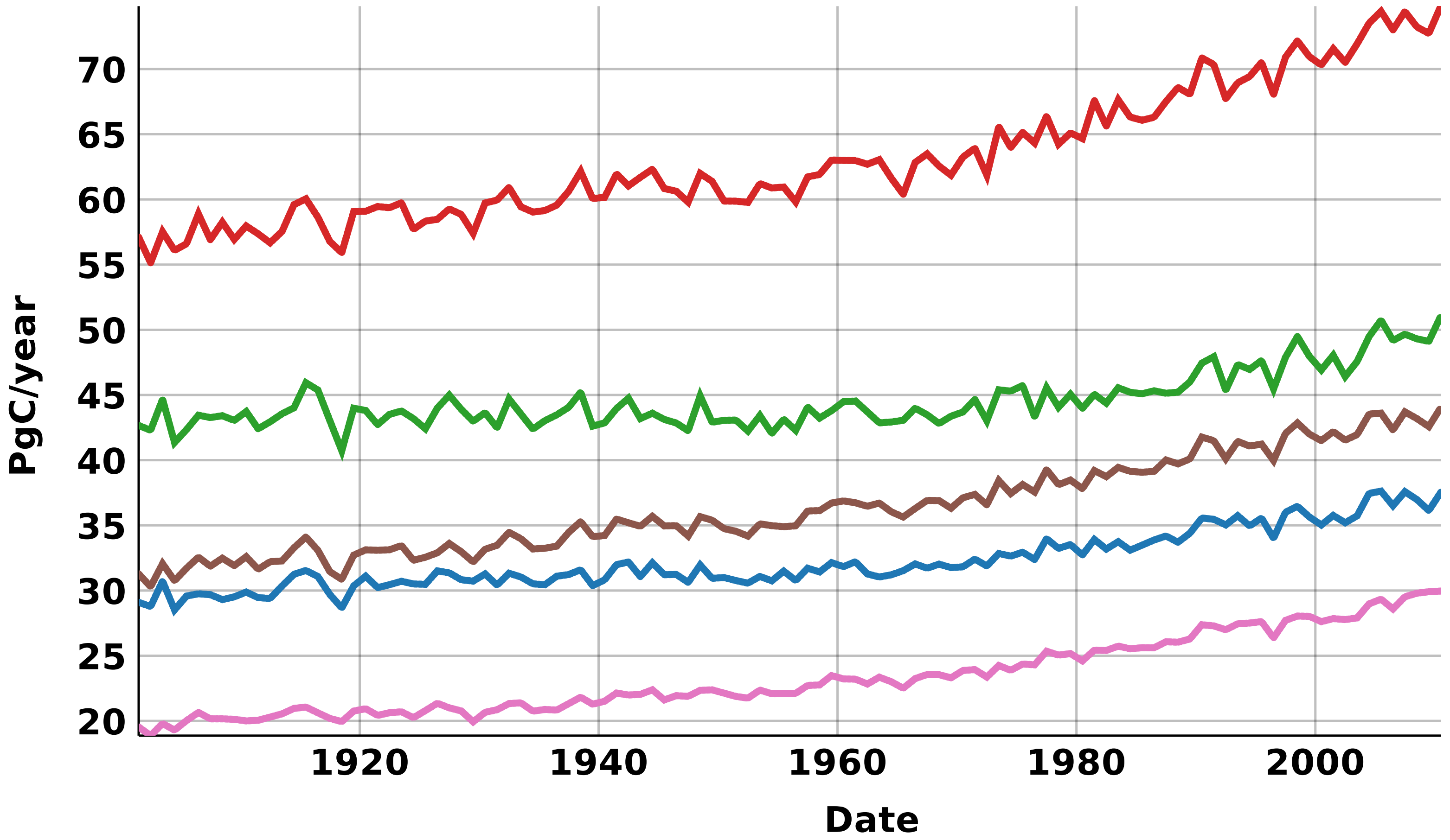


GPP flux (Photosynthesis) – Northern lands



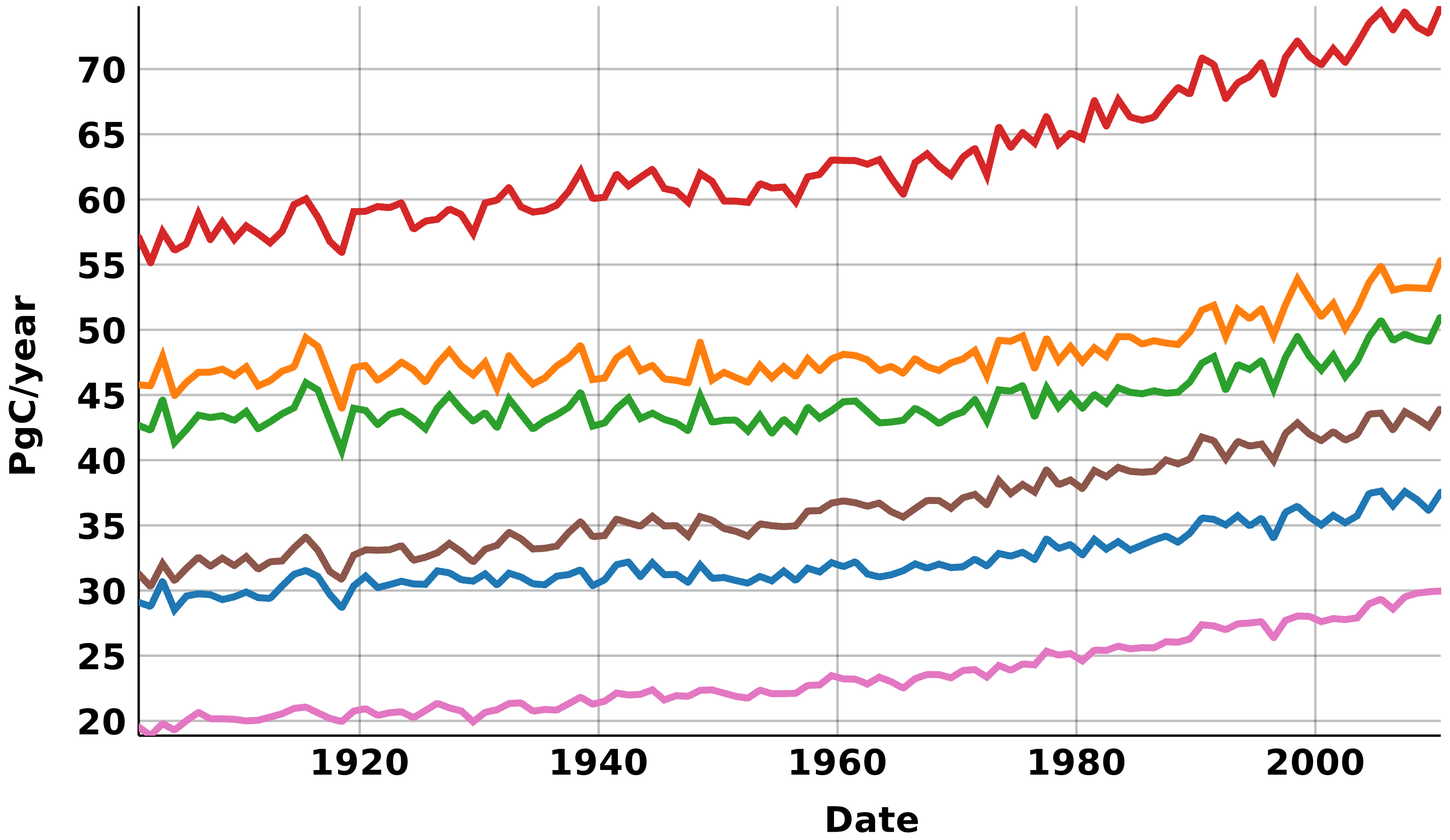
Meteorological forcings

GPP flux – Northern lands



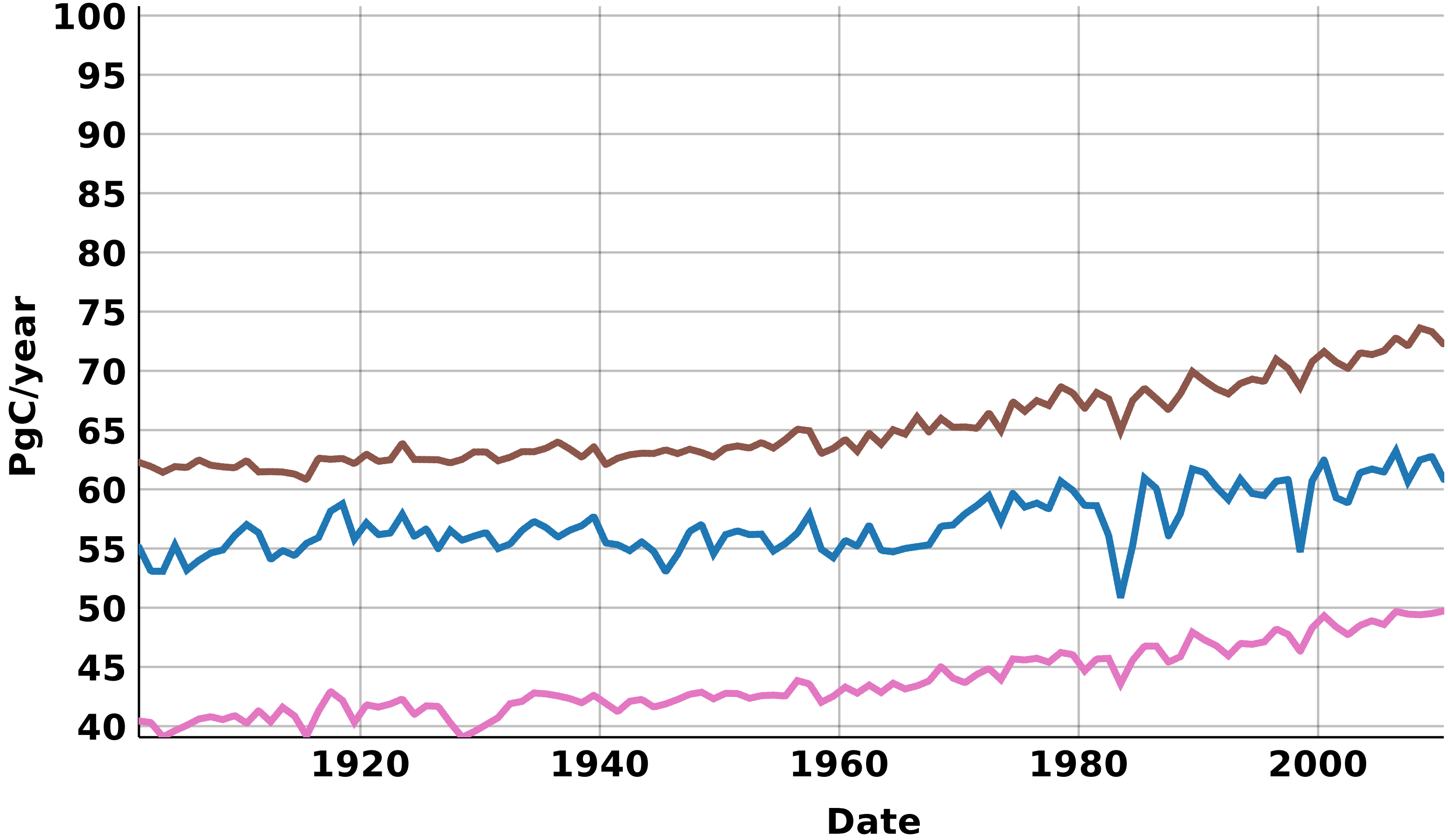
Meteorological forcings + Model version

GPP flux – Northern lands



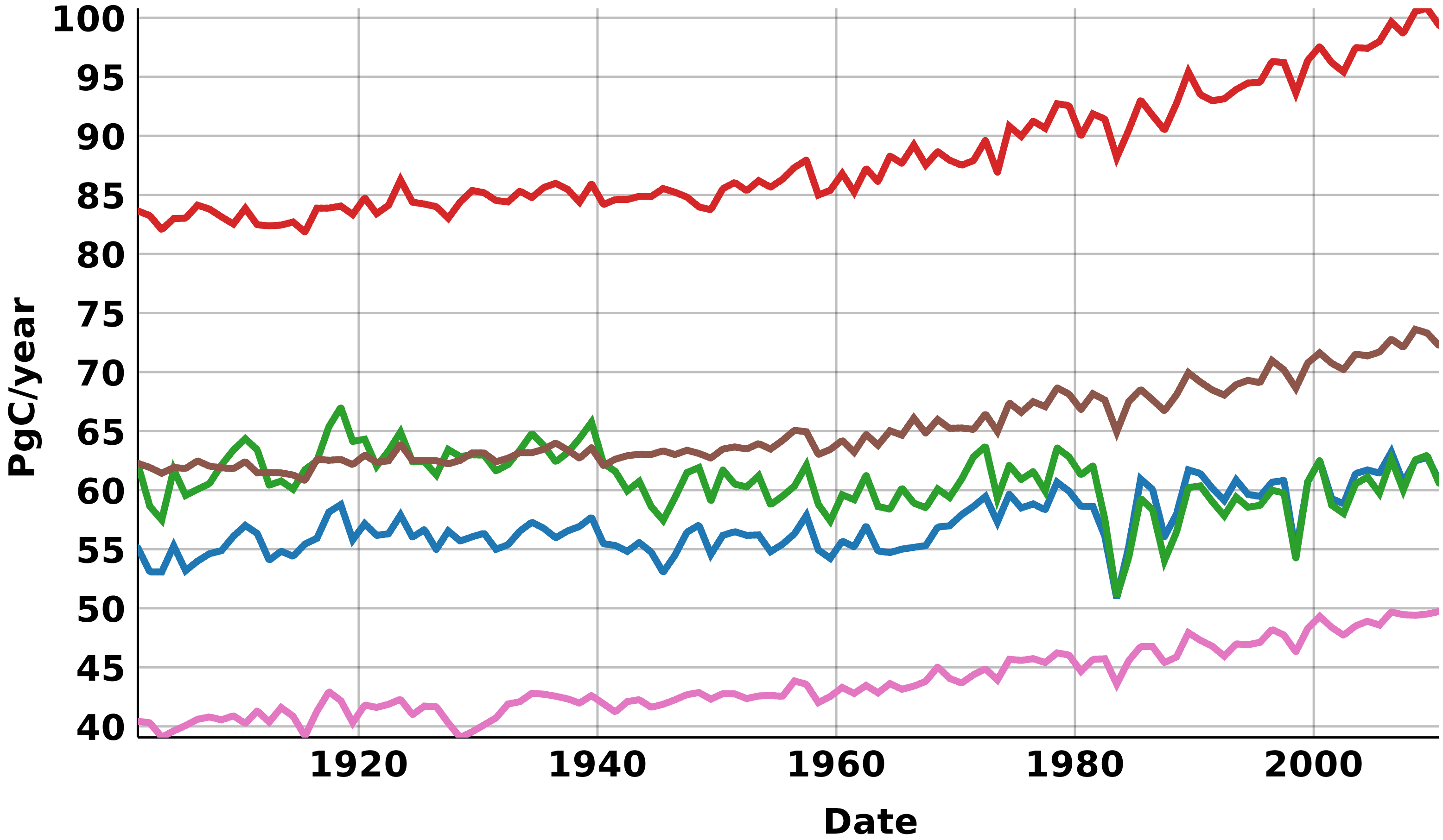
Meteorological forcings + Model version + Land-use

GPP flux – Tropical lands



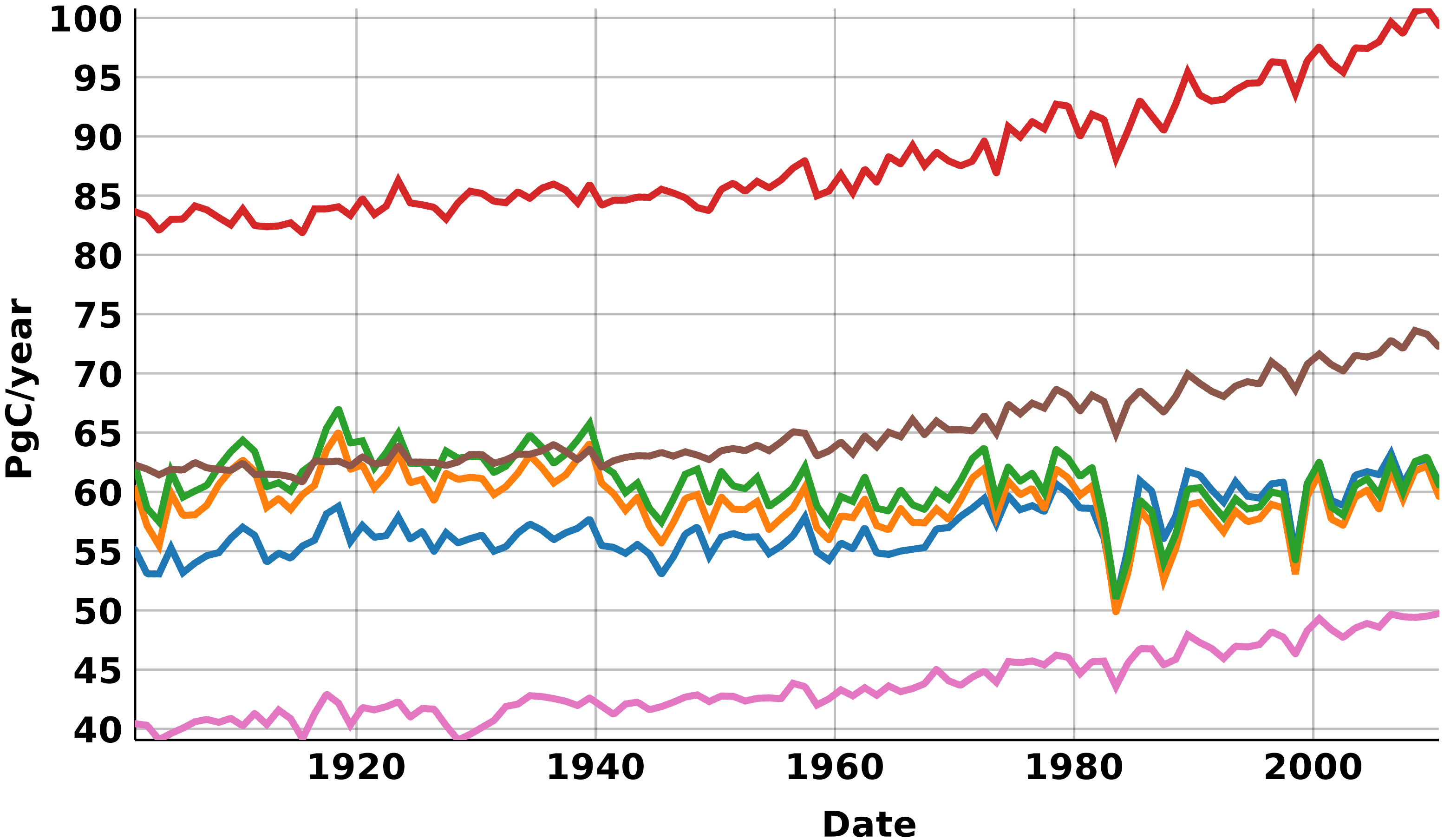
Meteorological forcings

GPP flux – Tropical lands



Meteorological forcings + Model version

GPP flux – Tropical lands



Meteorological forcings + Model version + Land-use