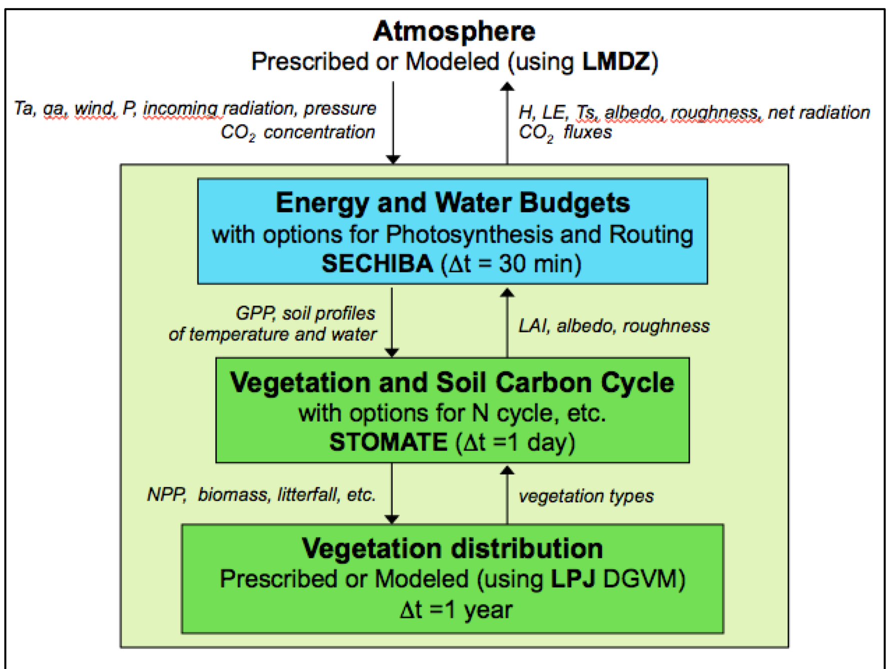
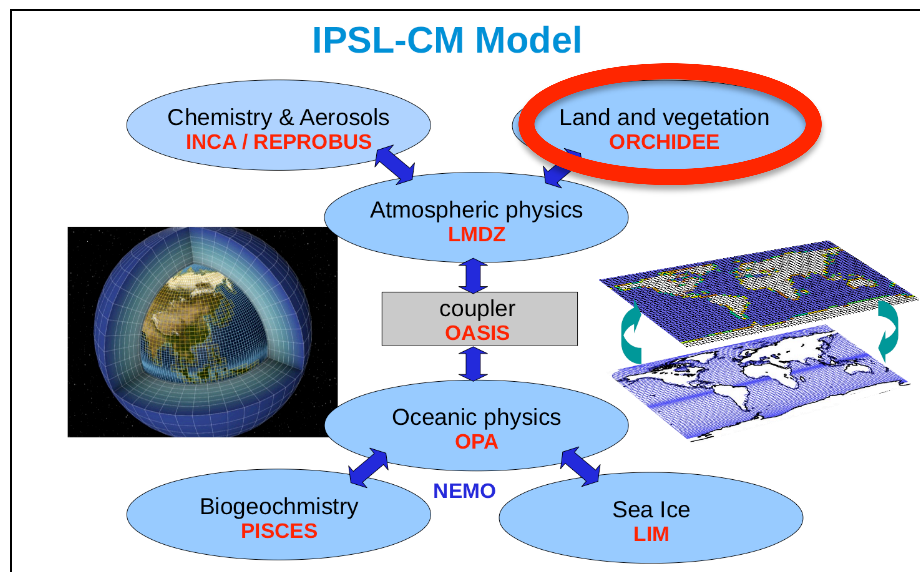
Le modèle ORCHIDEE: récent & futur développements

Philippe Peylin *pour le groupe projet ORCHIDEE*





ORCHIDEE recent developments (for CMIP6)

Implemented: V1

Soon..: V1.5

Merging

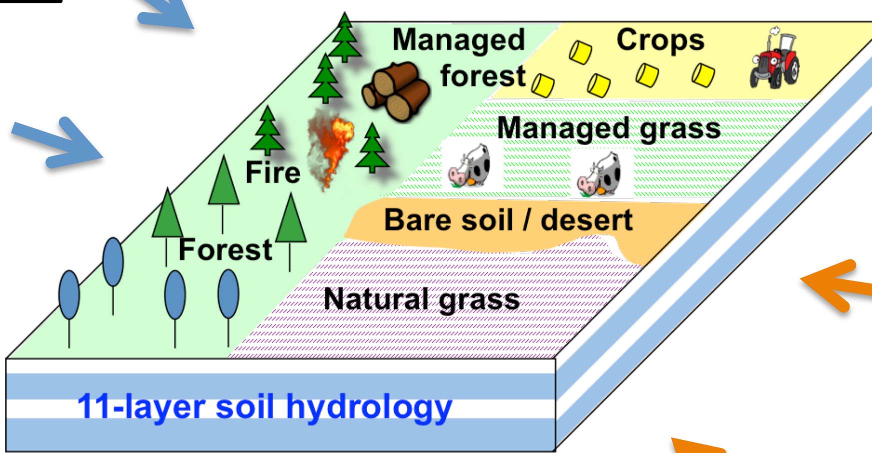
New Aerodynamic resistance

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)

Other Mature/Ongoing developments

Biophysical

Lake model (FLAKE)

Irrigation

Termokarst lake

DOC – DIC transport by river

New boreal PFTs (Mosses, lichens, shrubs)

Biogeochemical

Nitrogen – Phosphorus - Carbon coupled cycles

Soil Carbon discretization

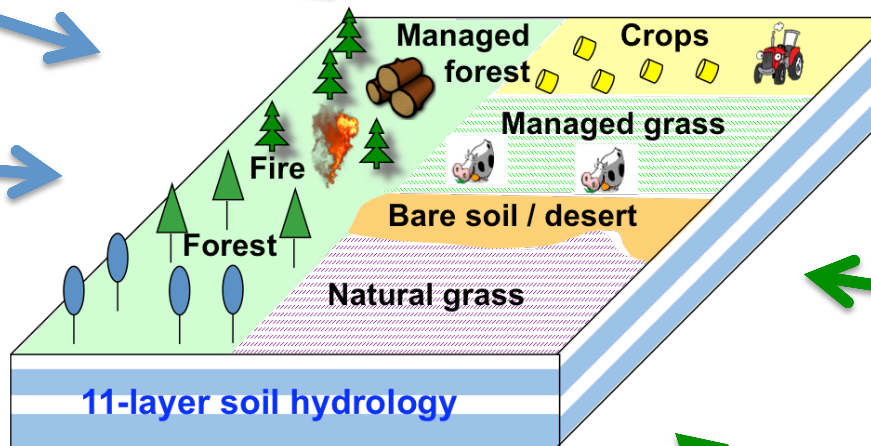
Crop model (wheat, corn, rice,…)

Grassland management

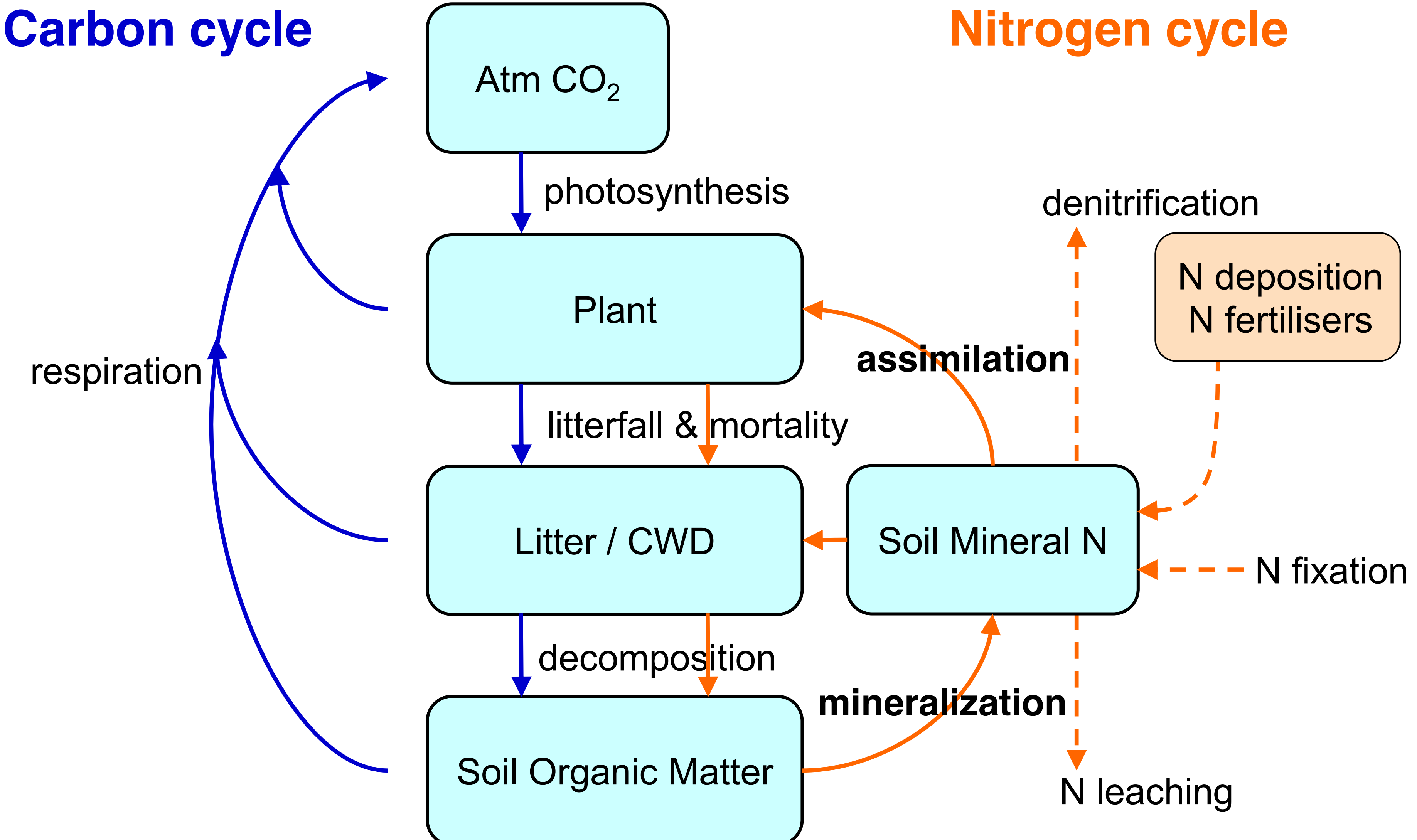
Peatland model (CH4)

Herbivory (large herbivore)

Plant Traits



C & N land interactions



From Thornton et al., 2009

TRUNK = include CN coupling

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

- Main description in Vuichard et al. (2019)

Photosynthesis scheme

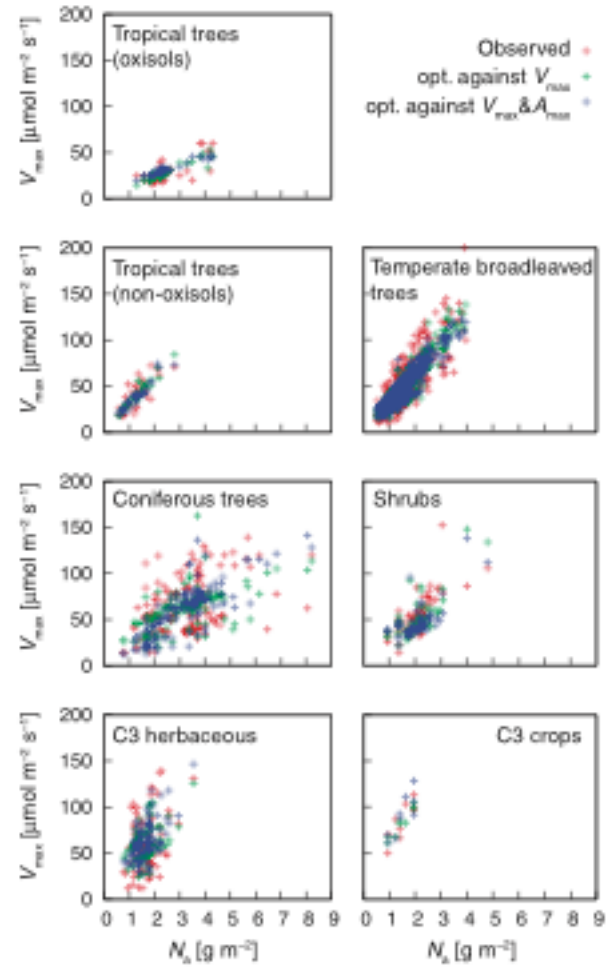
- Based on Farquahr model
- Vc_{max} : photosynthetic capacity (μmol CO_2 m^{-2} s^{-1})
- Modiified based on the work of Kattge et al. (2009)

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

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

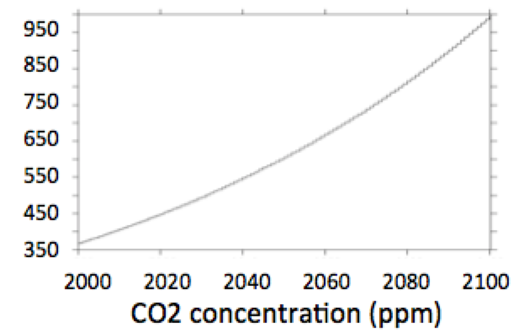
and N_L the leaf N content (gN $m^{-2}_{[leaf]}$)

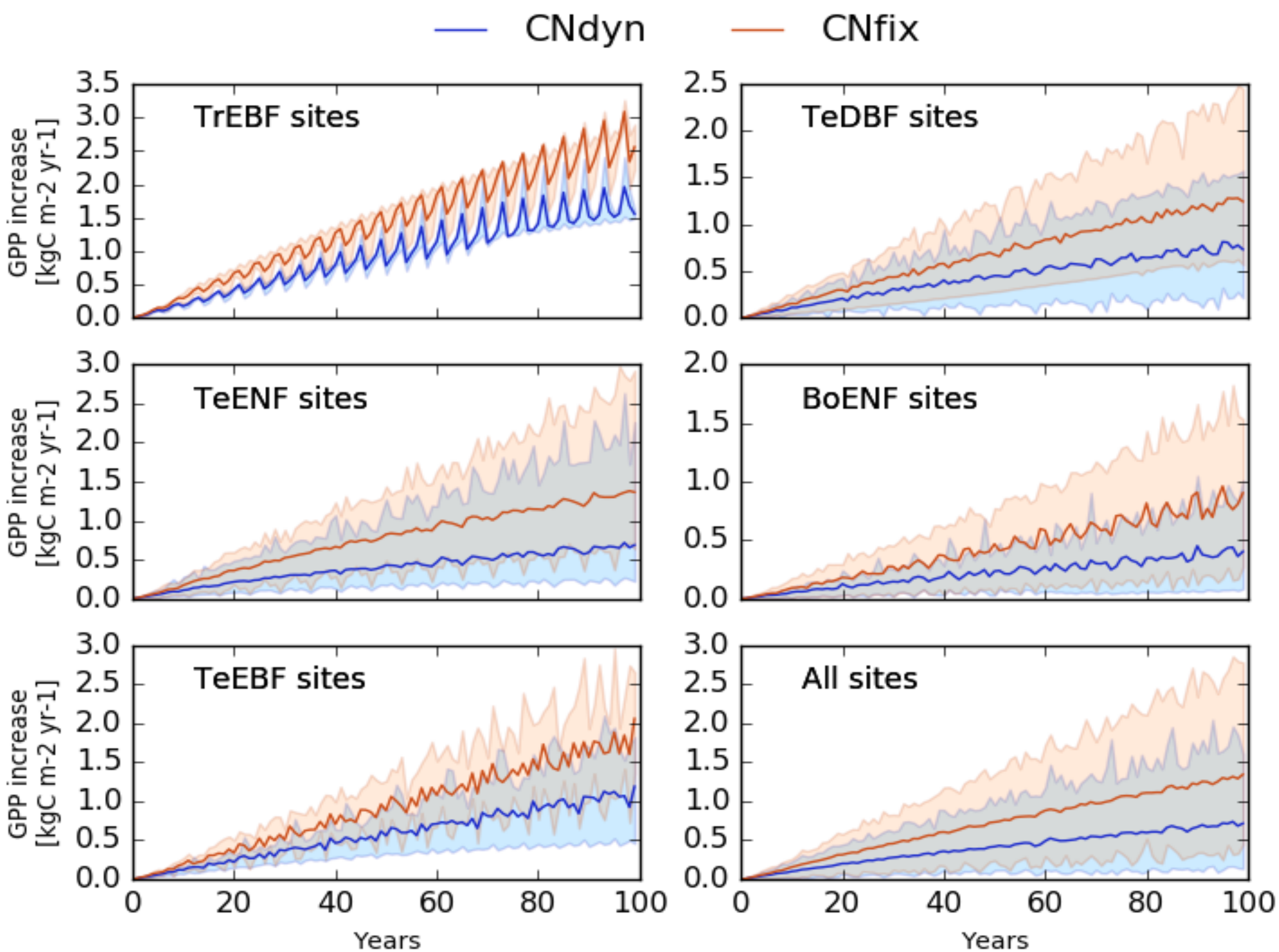
Vmax vs. Leaf N content



Adding the Nitrogen cycle: impact on the C cycle !

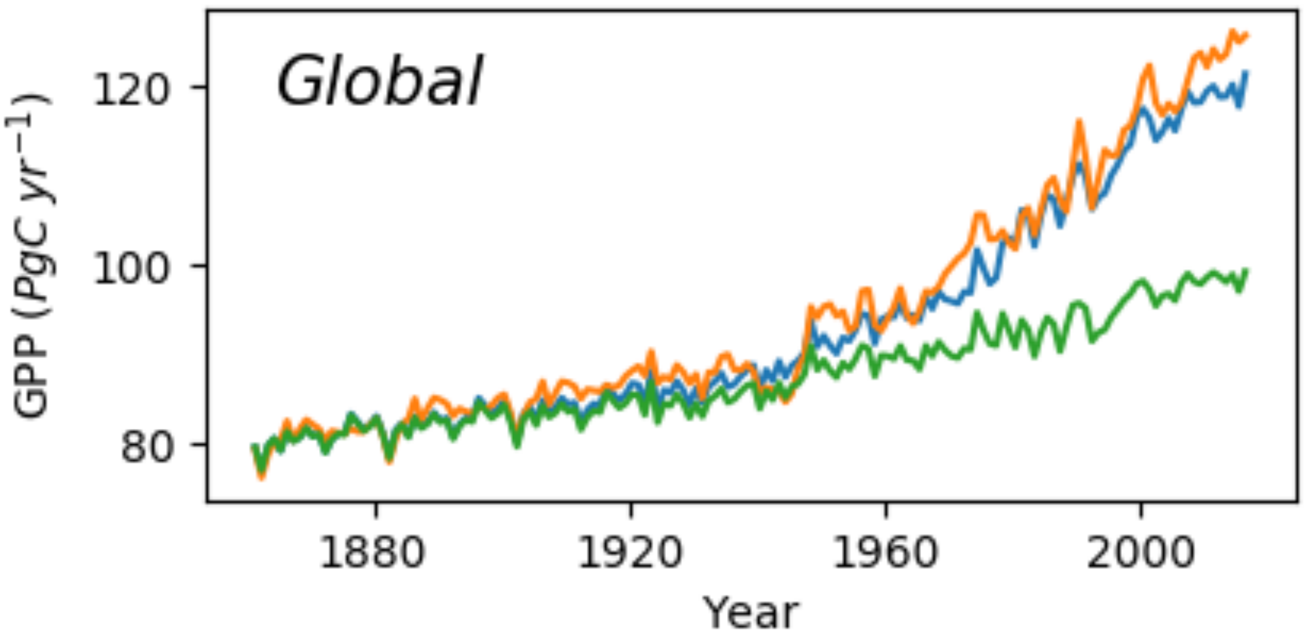
- Using ORCHIDEE-CN version – FluxNet sites
- 1% yr-1 CO2 increase experiment





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

Role of the C/N interactions on GPP



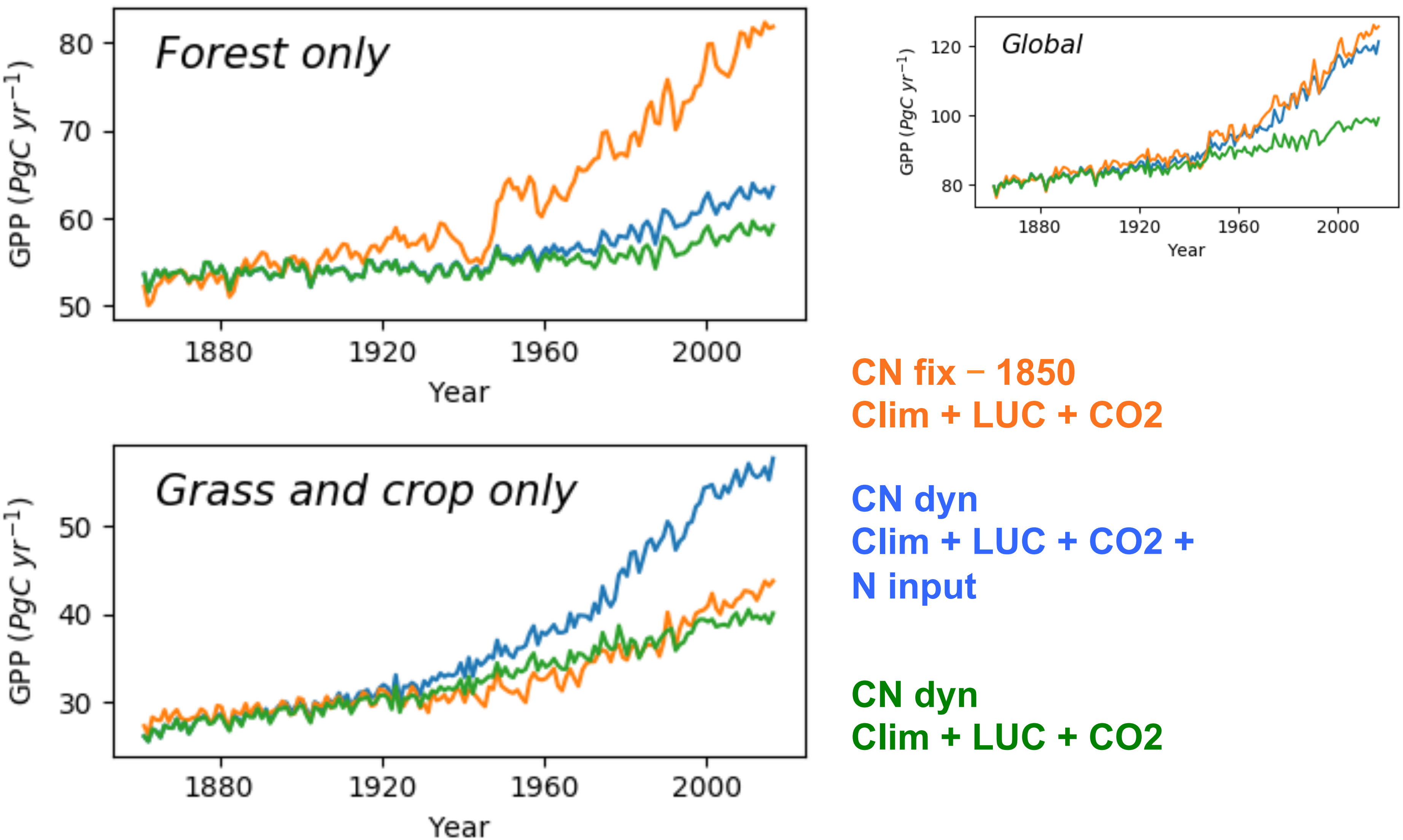
CN fix – 1850
Clim + LUC + CO2

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

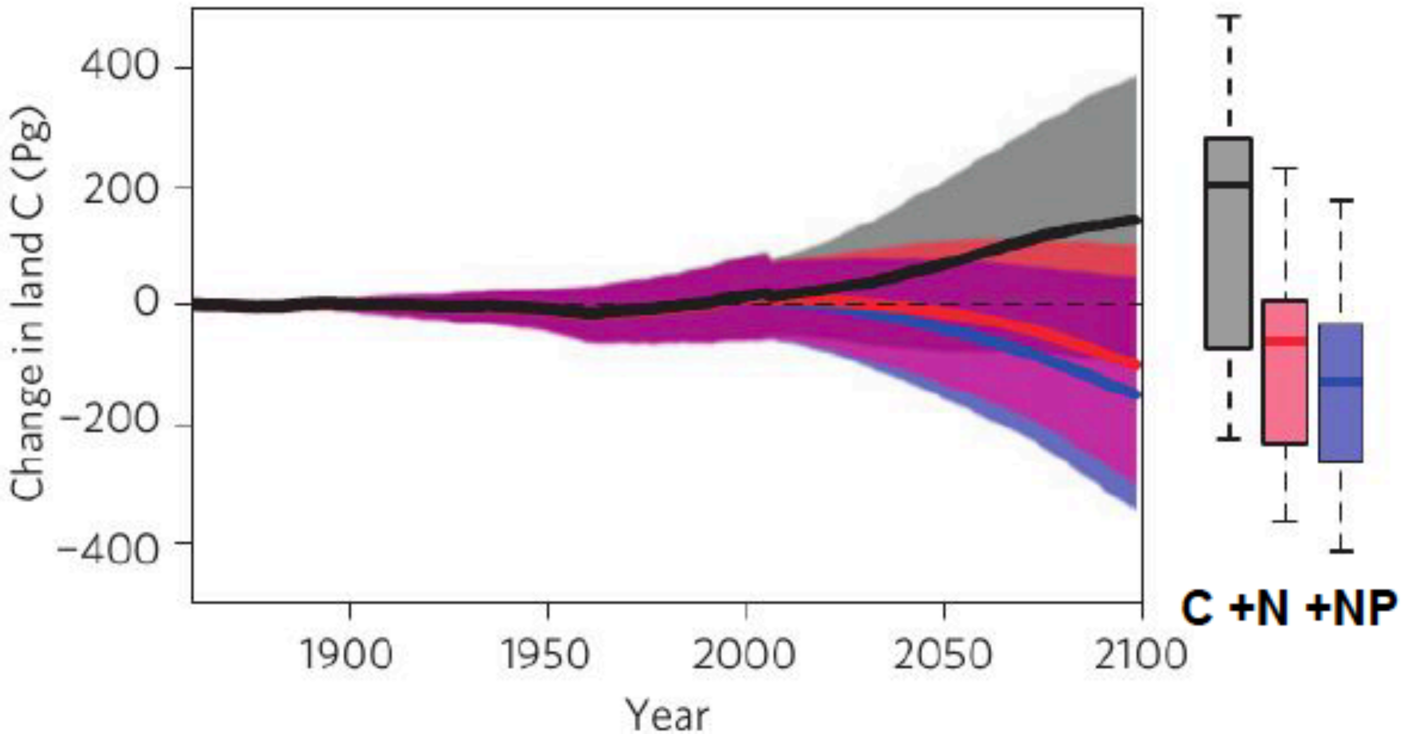


CN fix – 1850
Clim + LUC + CO2

CN dyn
Clim + LUC + CO2 + N input

CN dyn
Clim + LUC + CO2

Adding the Phosphorus cycle

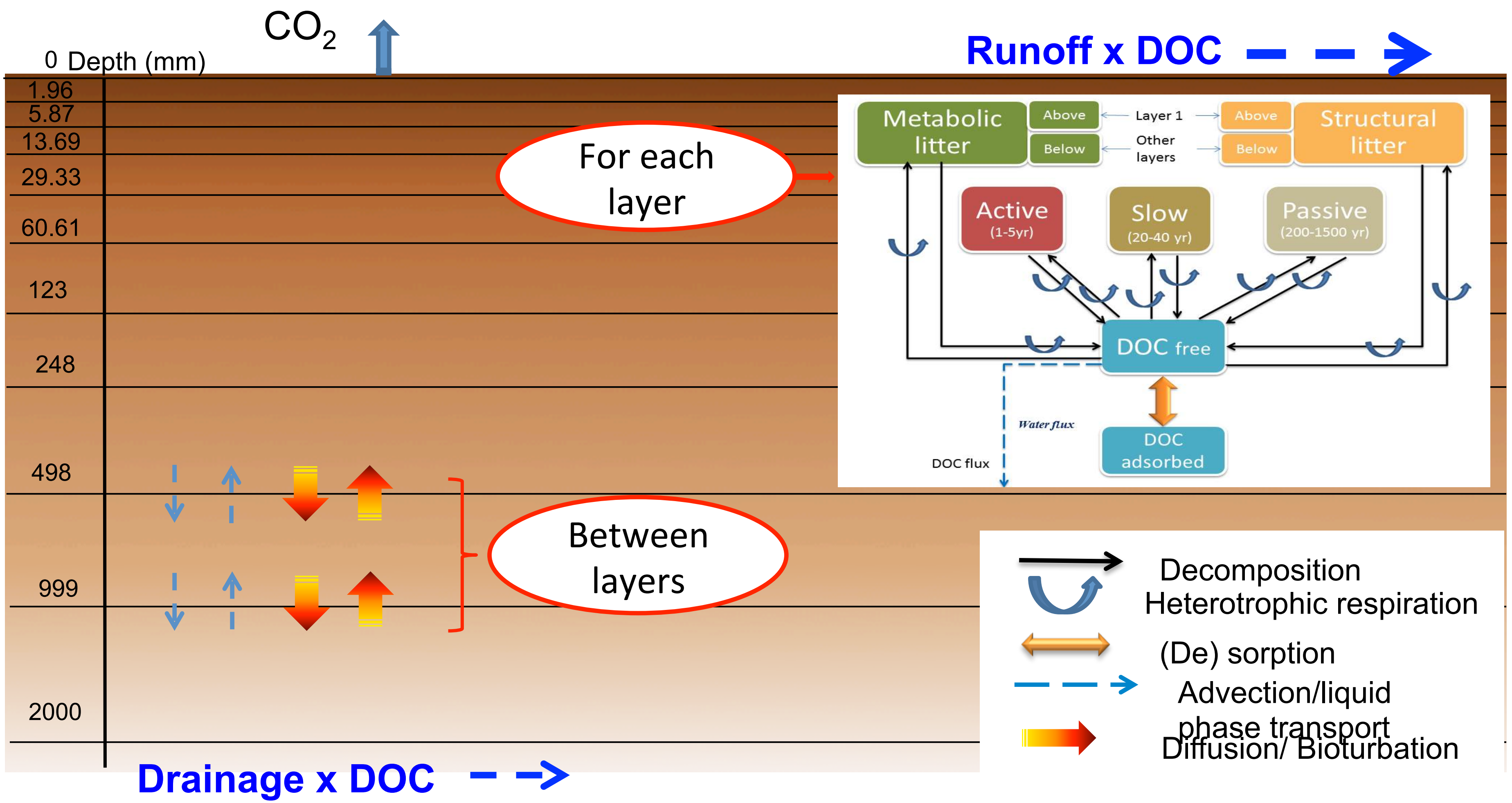


Wieder et al., Nat. Geosc., 2015

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

A new soil carbon model..

- Discretized soil carbon (11 layers) + new pools introduced (DOC)
- New decomposition scheme (priming): $\frac{\partial SOC}{\partial t} = I - k_{SOC} \times SOC \times (1 - e^{-c \times FOC}) \times \theta \times \tau$



ORCHIDEE-CAN

(known as ORCHIDEE-DOFOCO on svn)

+

ORCHIDEE-CN

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

=

ORCHIDEE-CN-CAN

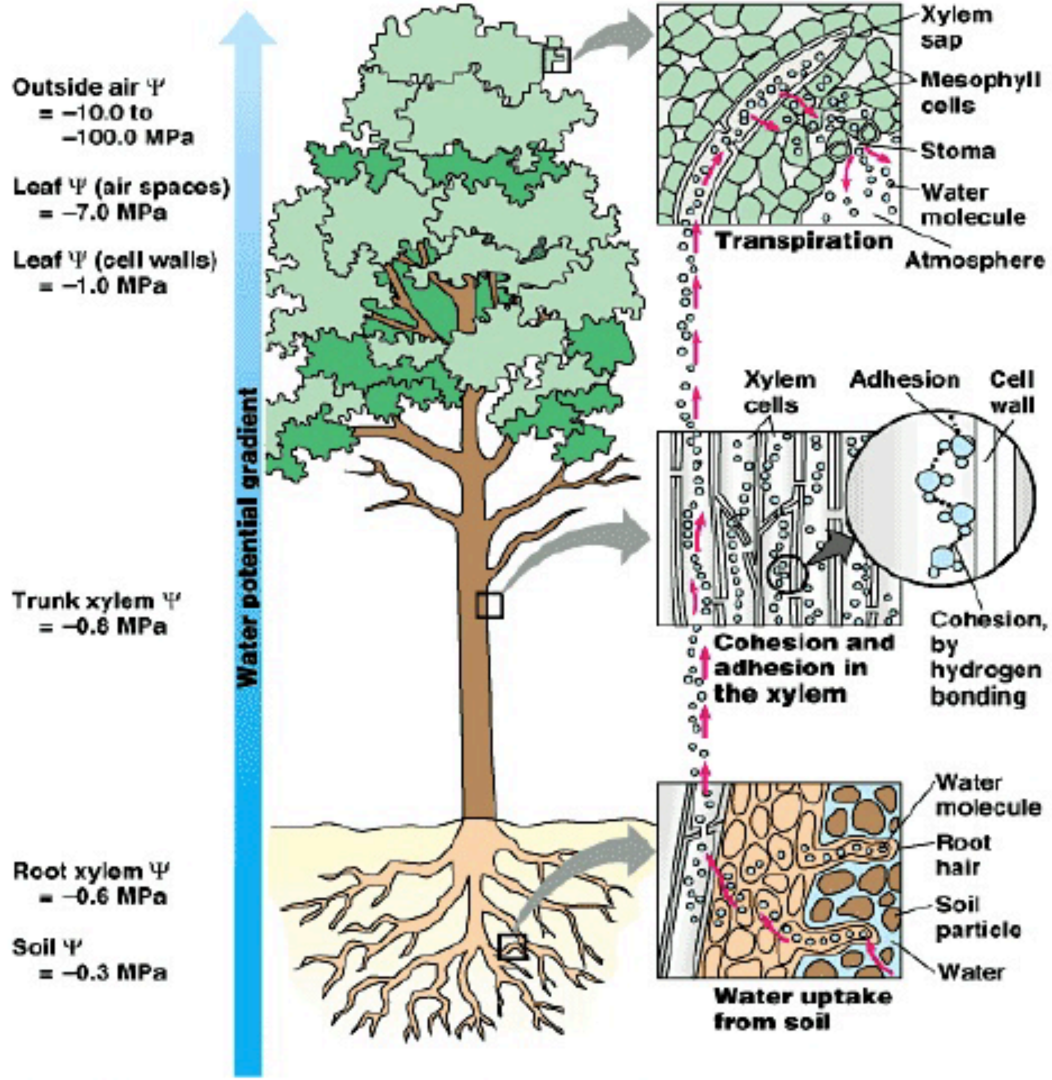
Simulating the canopy

Pipe model theory

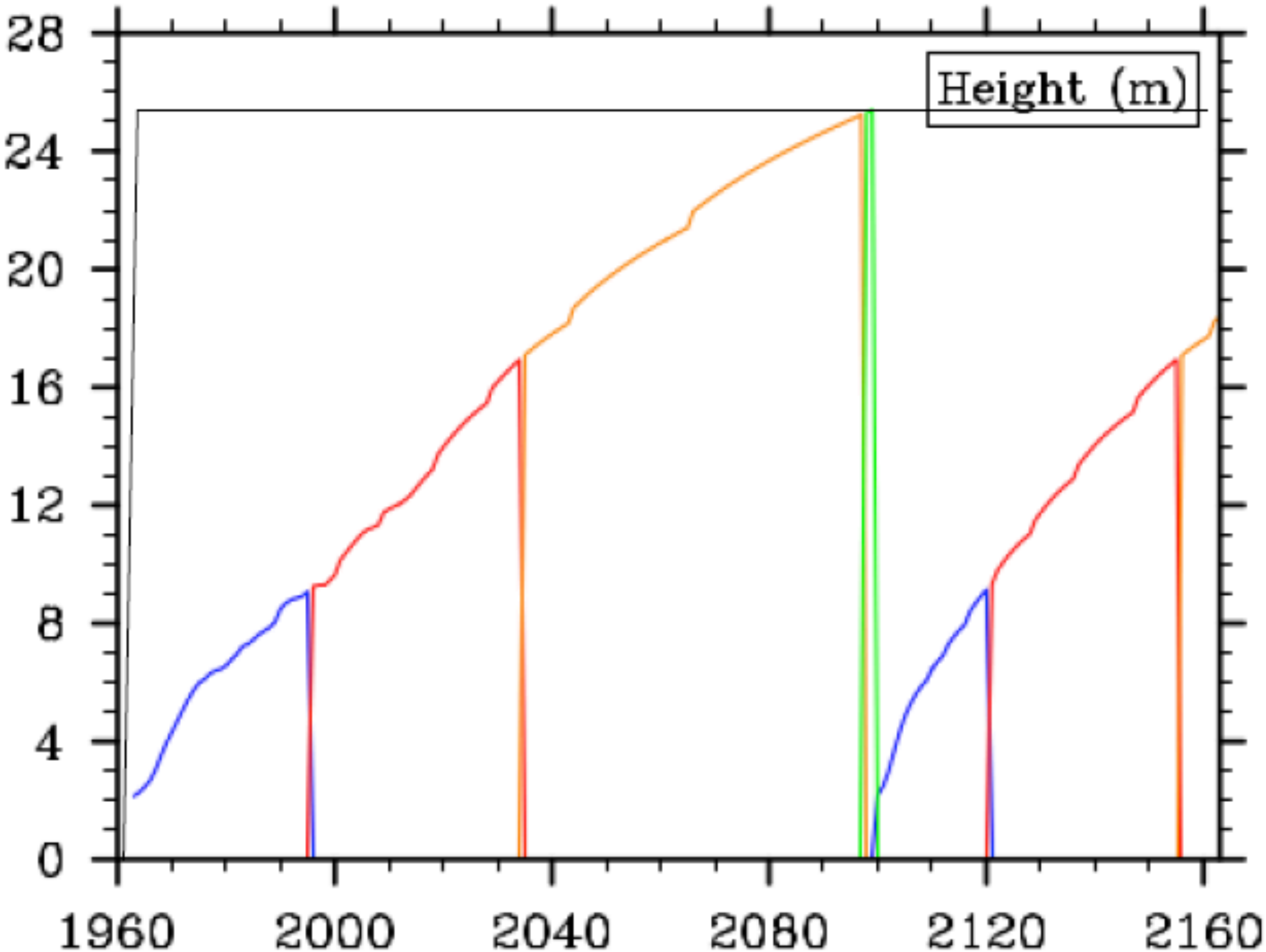
- Recognize how stomata is hydrological connected to the roots and the need to invest carbon in building roots and stem
- Allometric relationships, leaf to sapwood area ratio, relationship between diameter and height

Water stress

- Hydraulic architecture

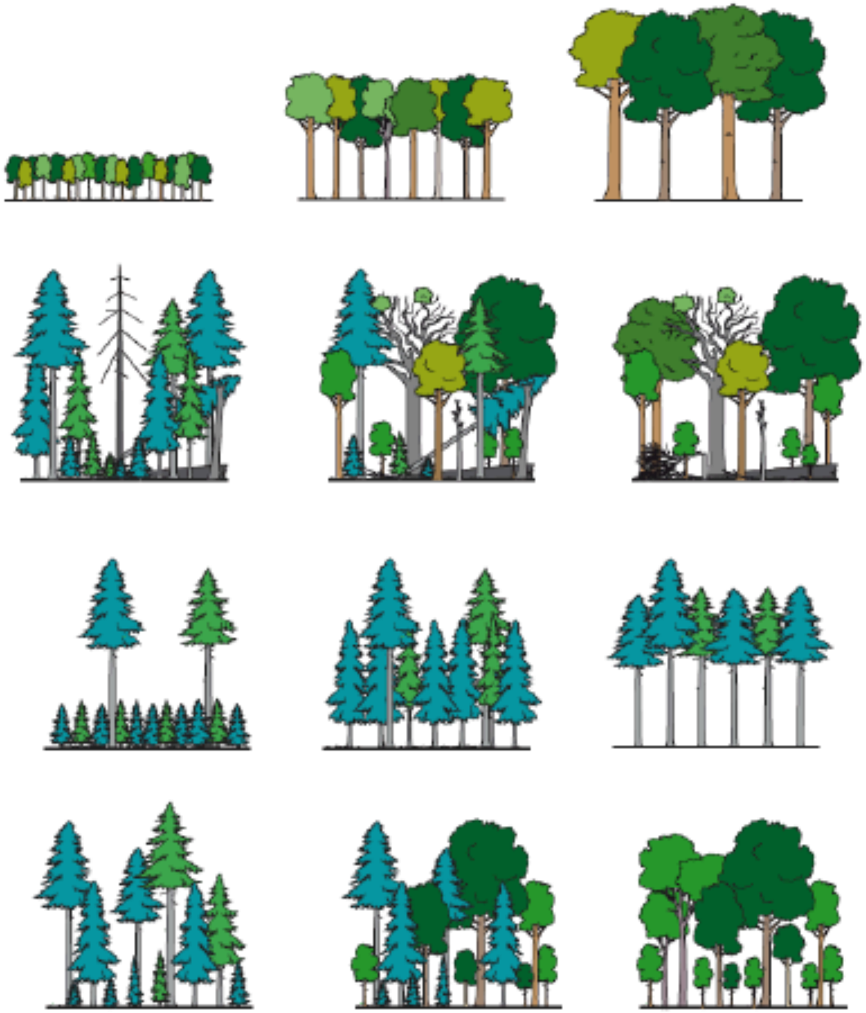


Simulating the canopy

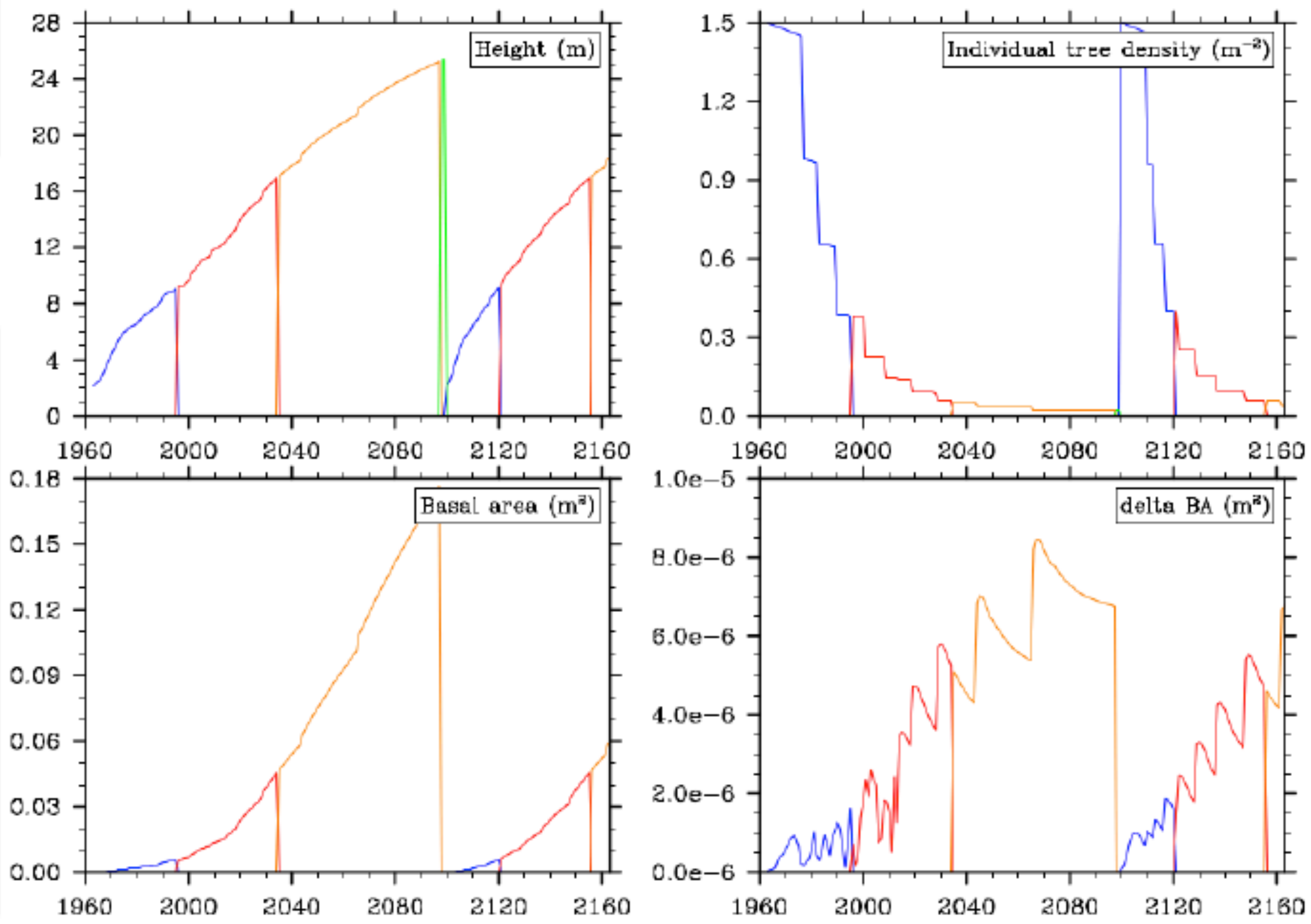


Simulating the canopy

- 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



Ecosystem dynamics



Gross land use change

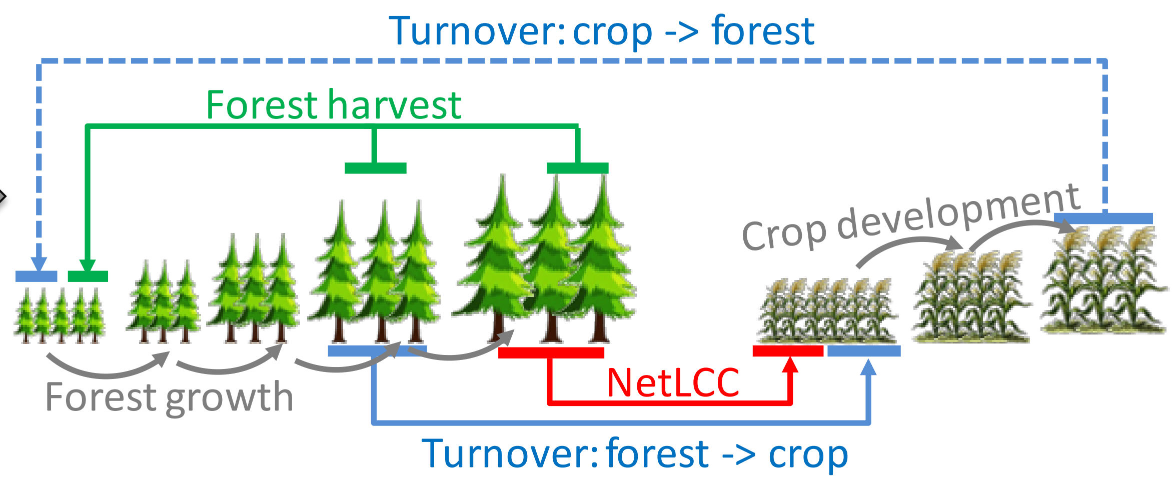

Deforestation


Shifting cultivation


Shifting cultivation


Wood harvest

Gross land use change with age cohorts



Factorial simulations

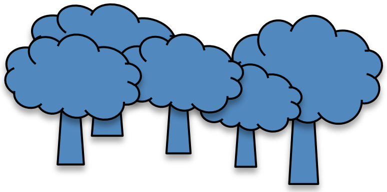
Simulations	Net LCC	Turnover	Harvest
S0 (S'0)			
S1 (S'1)	✔		
S2 (S'2)	✔	✔	
S3 (S'3)	✔	✔	✔

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

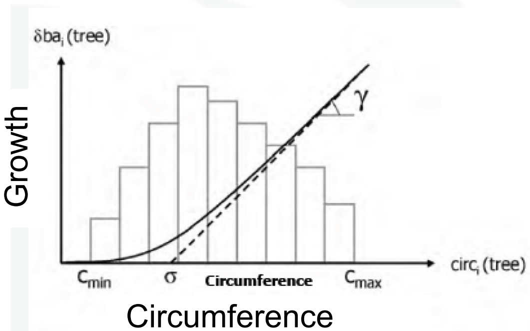
Chao Yue et al.

Forest management and stand description

Include diameter & age classes



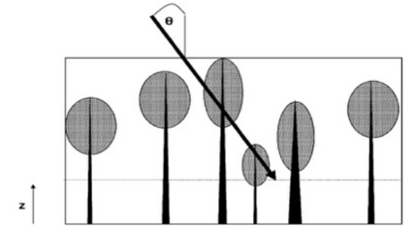
Allocation : "big get bigger"



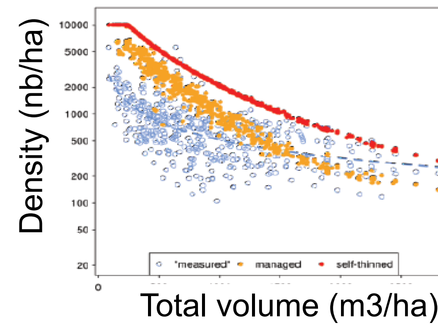
ORCHIDEE - CAN

(Naudts et al., 2015)

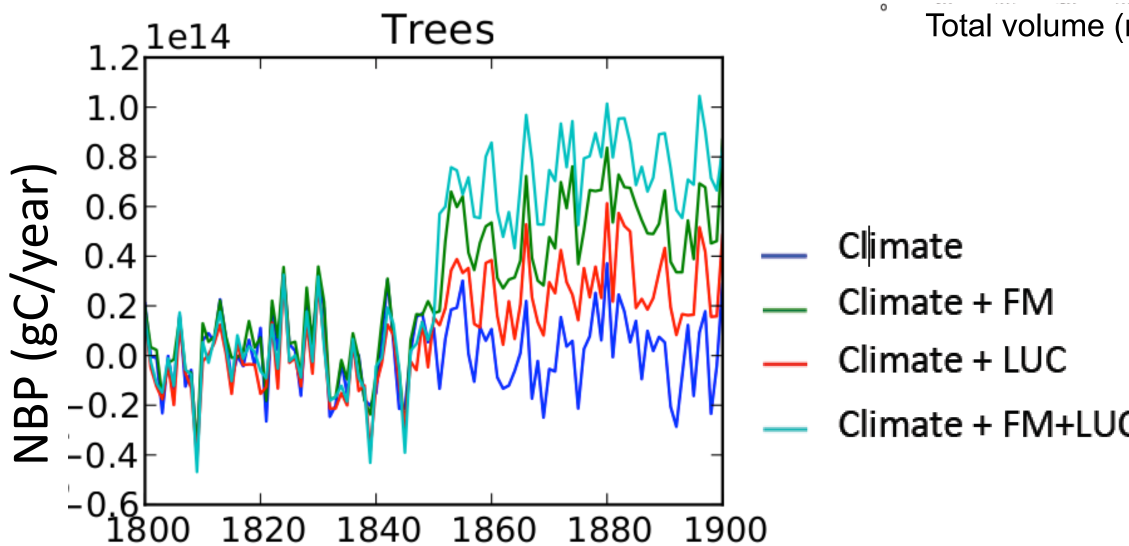
Accounts for gaps (PGAP)



Mortality from self-thinning



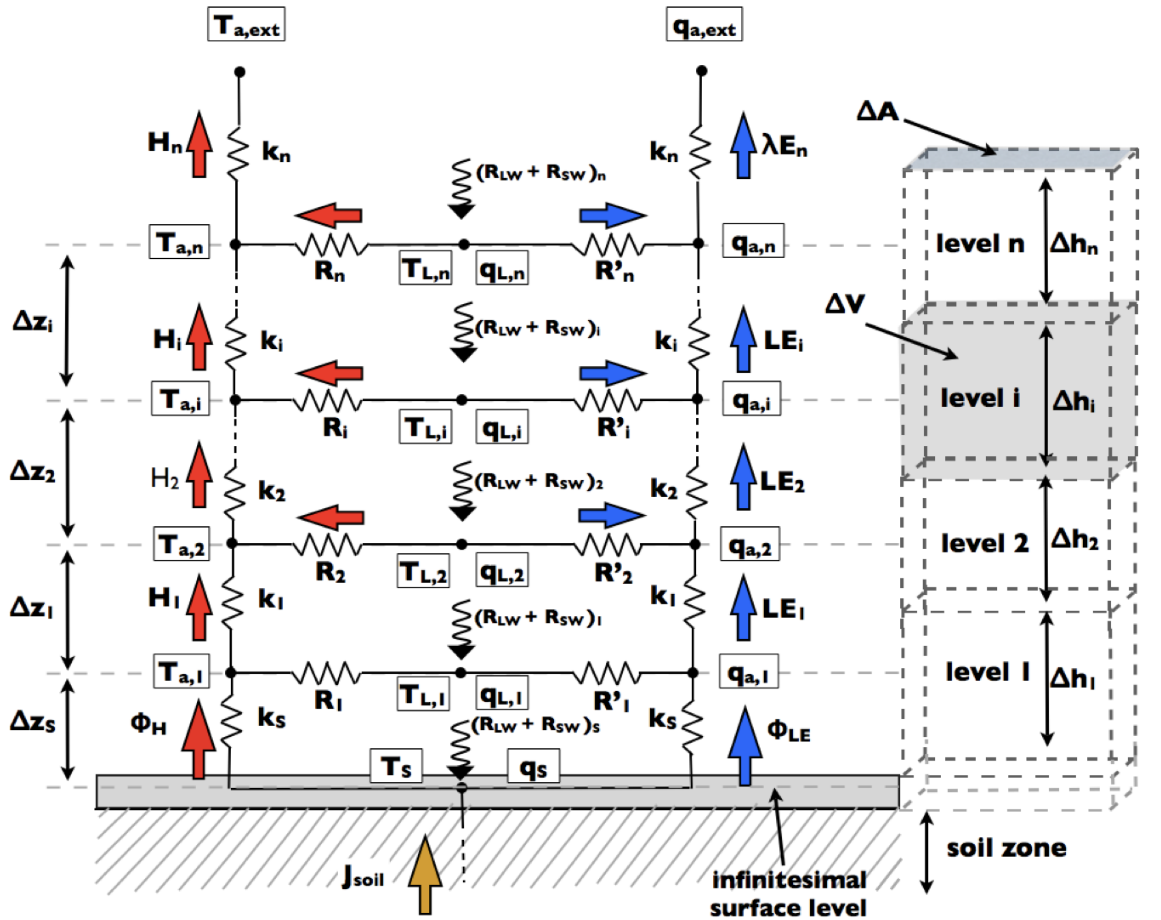
➔ Impact of climate, Forest management, Land Use Change on European NBP



Institut Pierre Simon Laplace
Sciences de l'environnement

Vertical multi-layers scheme..

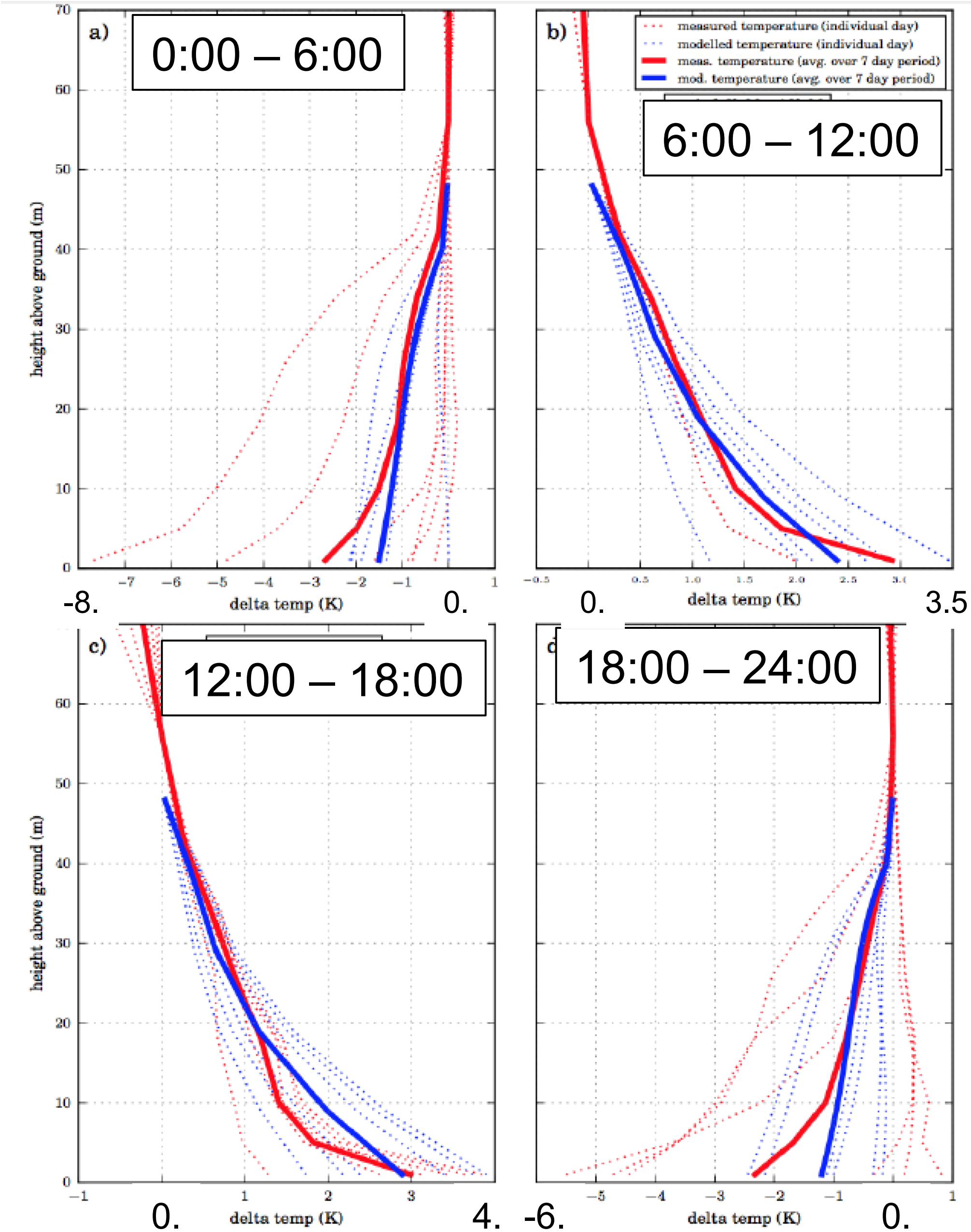
- Free number of layers
- E / W / C exchange at each level
- Turbulance mixing within air canopy
- Light penetration following Pgap model



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

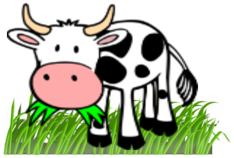
Model

Accounting for management

Crop management

Wang et al., 2017

Grassland management

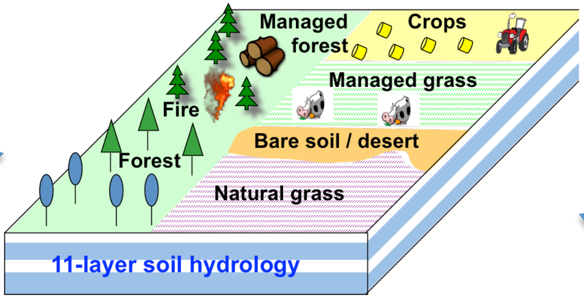


CO_2
CH_4
N_2O

Climate mitigation potential

Chang et al. 2015, 2016

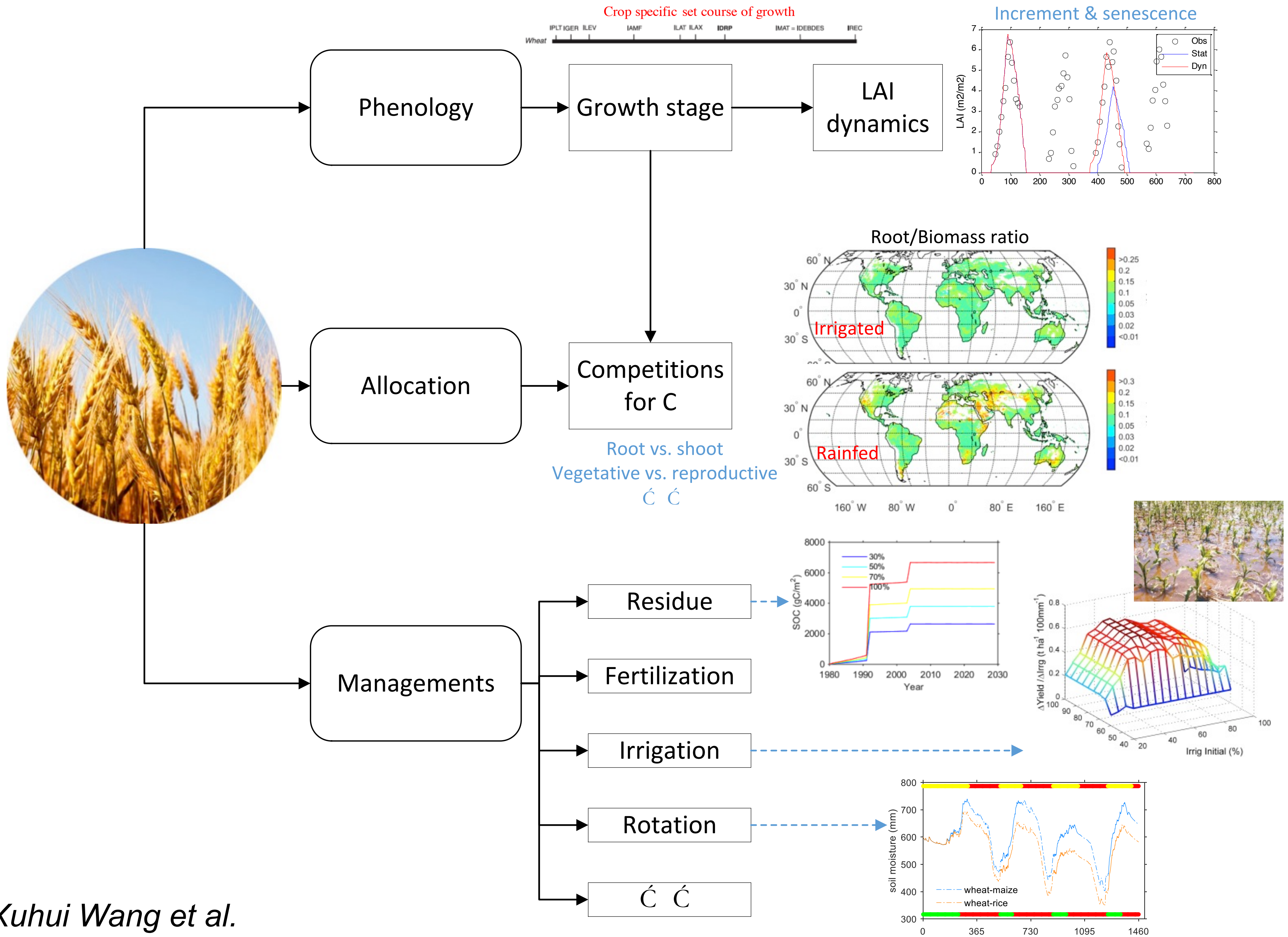
Forest management



Irrigation

Naudts et al., 2015, 2016
MacGraph et al, 2015

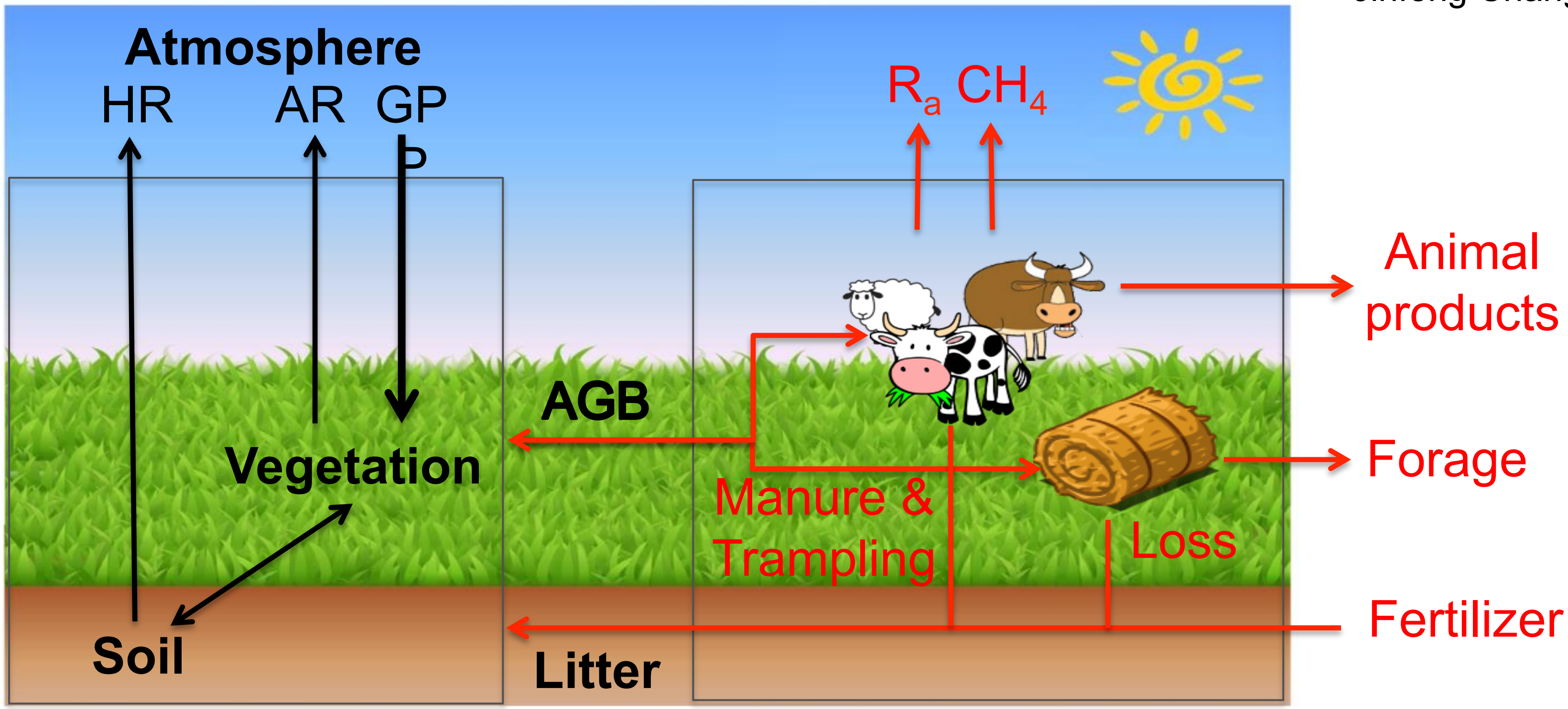
Cultivated ecosystems : major crops



Xuhui Wang et al.

Grassland: from intensive pasture to rangeland

Jinfeng Chang et al.



ORCHIDEE

Management module from PaSim
(Graux et al., 2012 ; Vuichard et al.,2007)

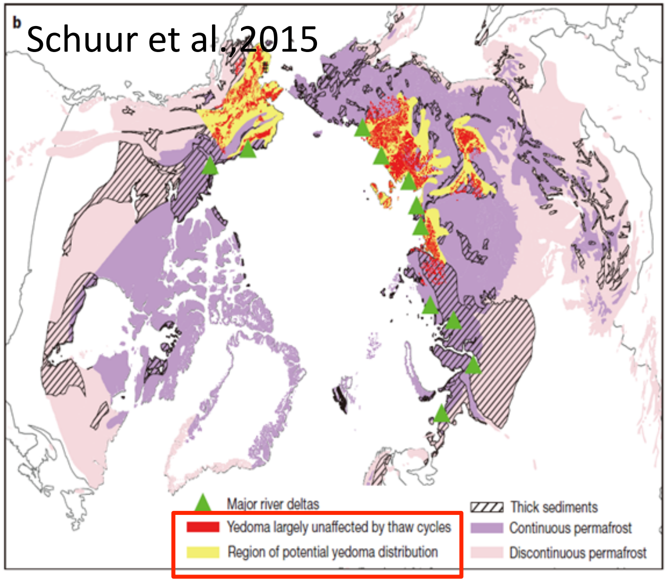
Applications:

- Grassland management optimization/adaptation (simulating potential productivity)
- Reconstruction of historical management intensity
- Long-term carbon and GHG balance of grassland ecosystem and livestock farm.
- Milk production simulation and projection.

Permafrost : Modeling Yedoma organic carbon

Dan Zhu et al.

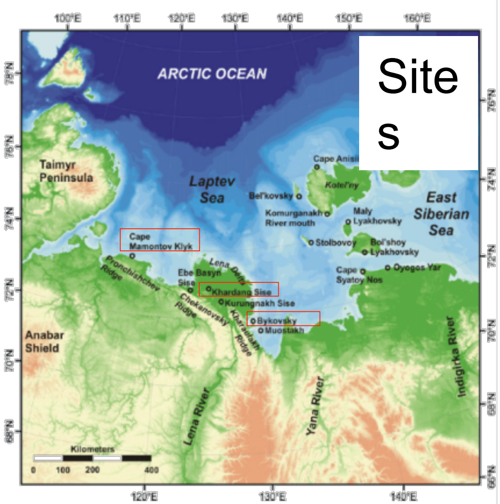
Yedoma: organic-rich, ice-rich, thick deposits in permafrost region

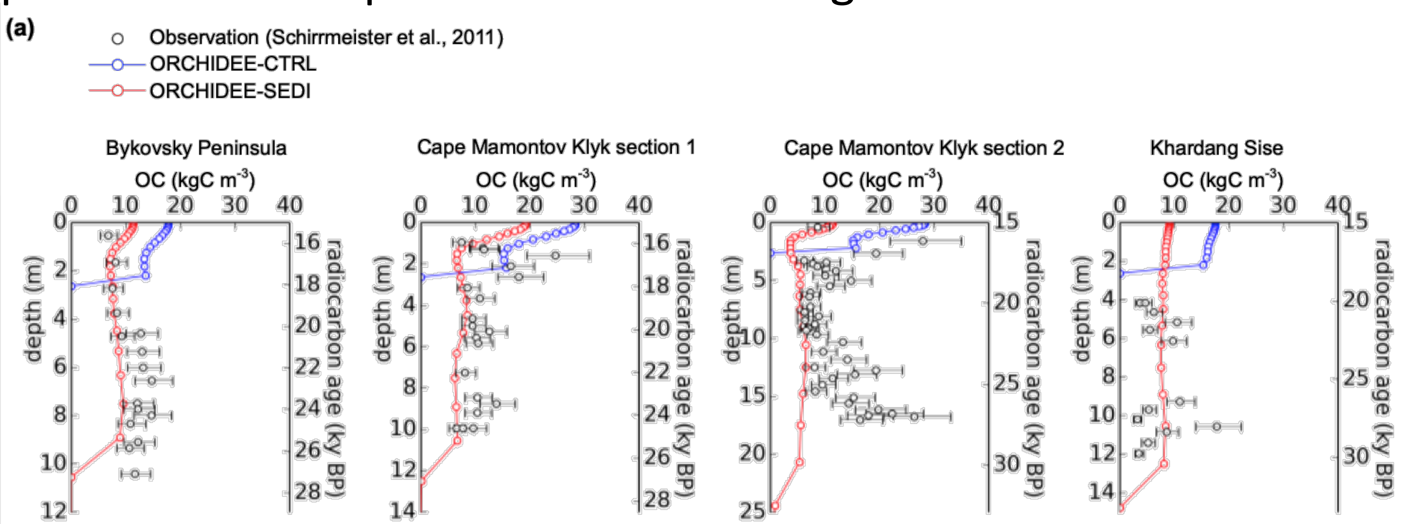


Area: ~1.3 million km^2
C stock: 300-550 PgC

- **Large ice content: 50-80 vol%**
- **Ancient carbon: accumulated during last ice age (~60-15 kyr)**
- **Depth 5-50m, C contents ~2%**
- **Formation condition: sedimentation**

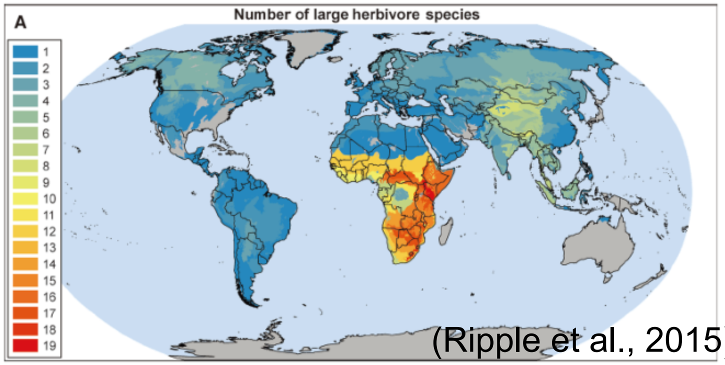
The new model can reproduce vertical profiles of Yedoma organic carbon





Representing wild large herbivores

Large herbivores today



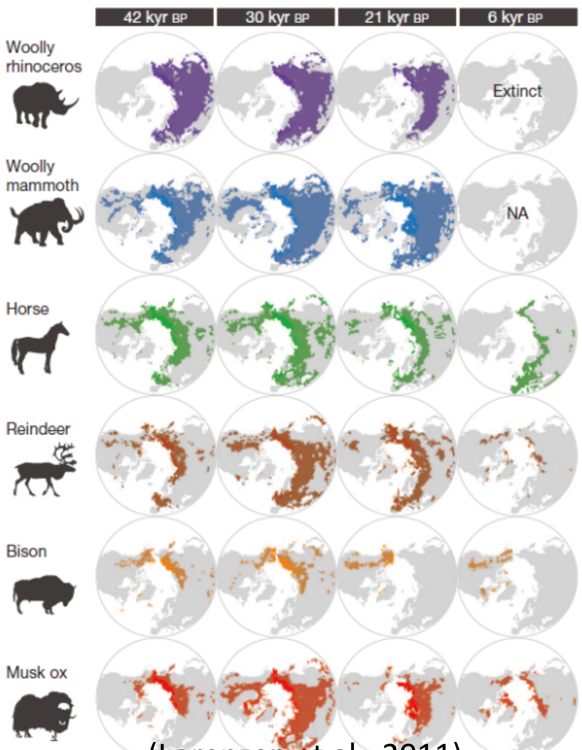
(Ripple et al., 2015)

Bones preserved in yedoma deposits (Zimov et al., 2012)

Herbivore biomass in the Arctic during 40~15 kyr BP: ~**9000** kg/km^2

➔ **comparable to today's African savannah**

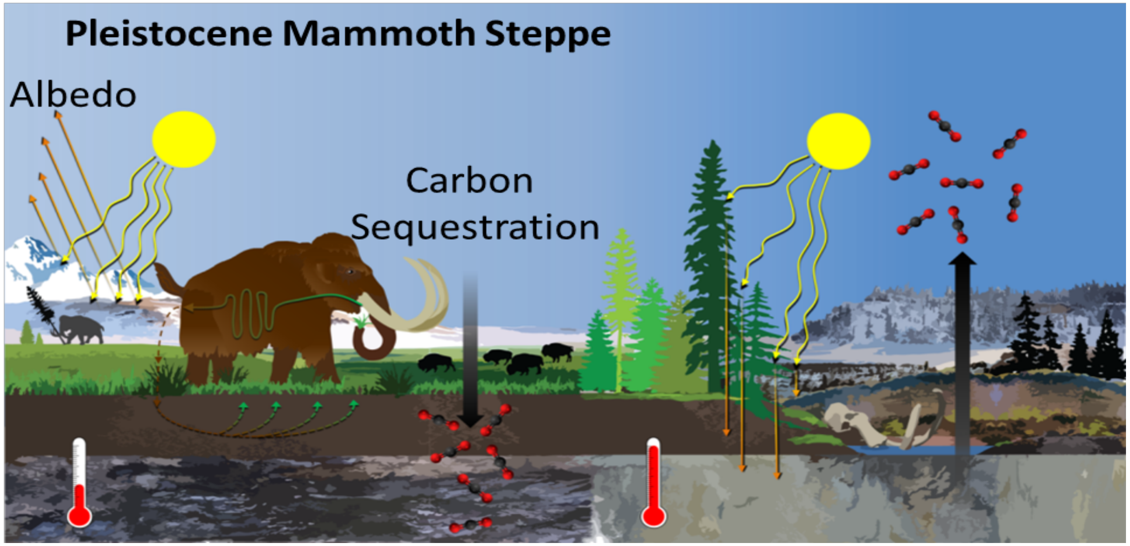
Large herbivores during late-Pleistocene



(Lorenzen et al., 2011)

"keystone herbivore" hypothesis

(Owen-Smith, 1987; Zimov et al., 1995)



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

Ozone

Aerosols

Lifetime

Oxidizing capacity

Isoprene

Alcohols

Acids

Monoterpenes

NO

NO_2

Volatile Organic Compounds (1000 TgC/yr)

80% of global emissions

Methane

30% of global emissions

Nitrogen oxides

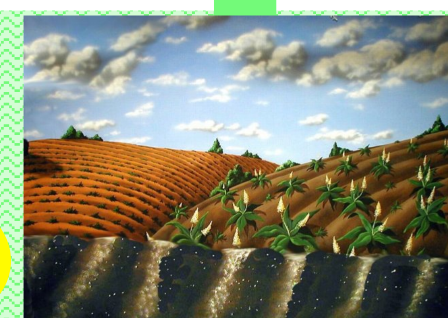
10% of global emissions

O_3

NO_x

Isop.

OH



Vegetation

Wetlands

Soils - Cultures

Chemistry-vegetation retroactions

Atmospheric chemical composition

CO_2

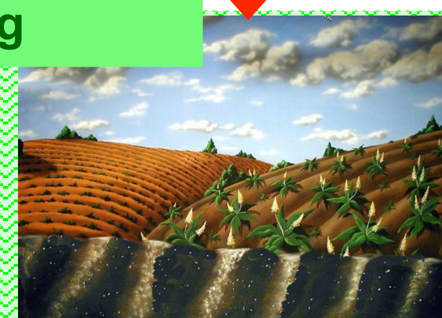
Pollution: O_3, NOx, SO_2 and particles

Deposition

Deposition

Deposition

→ Growth, Distribution, Functioning

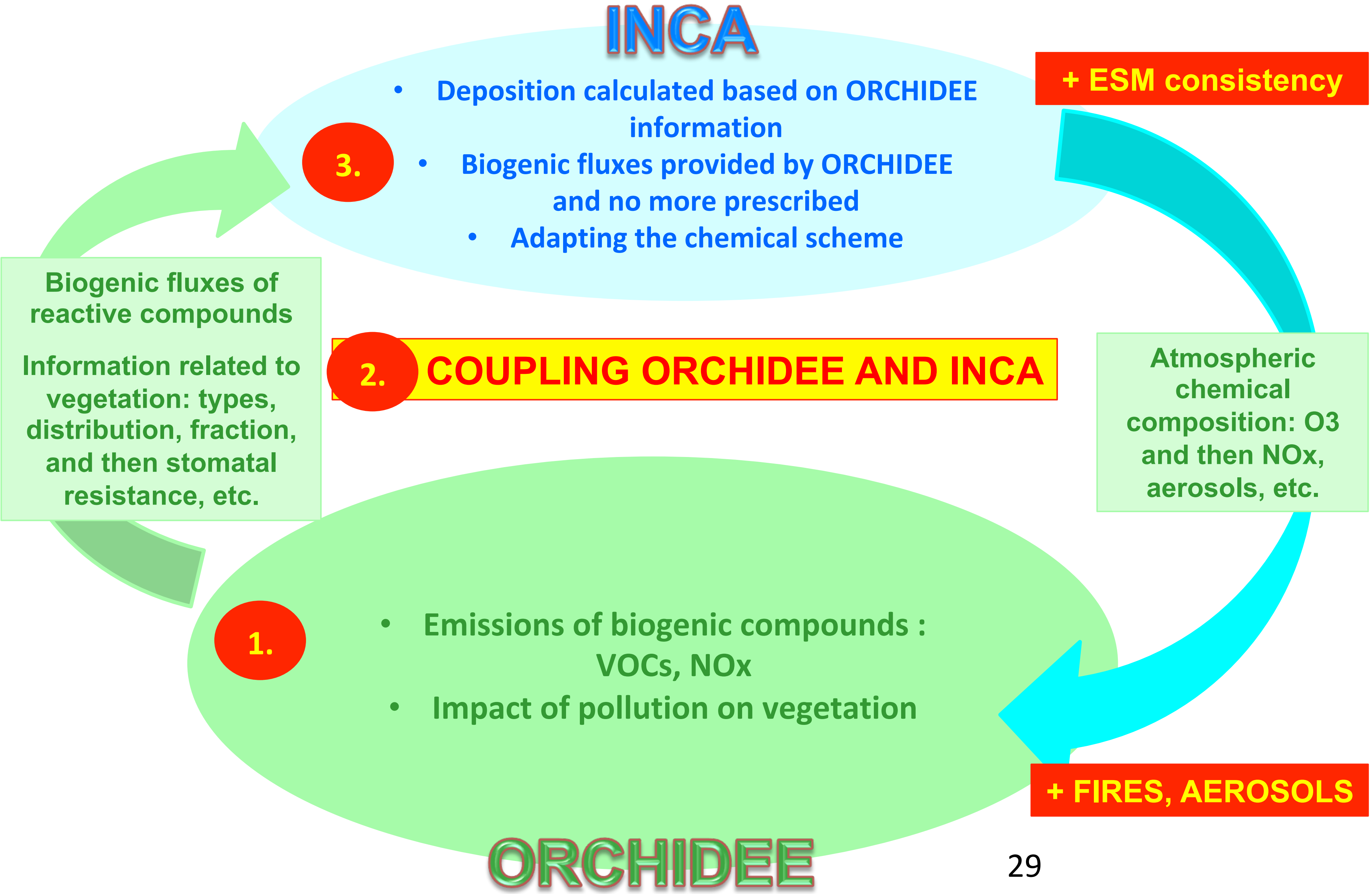


Vegetation

Wetlands

Soils - Cultures

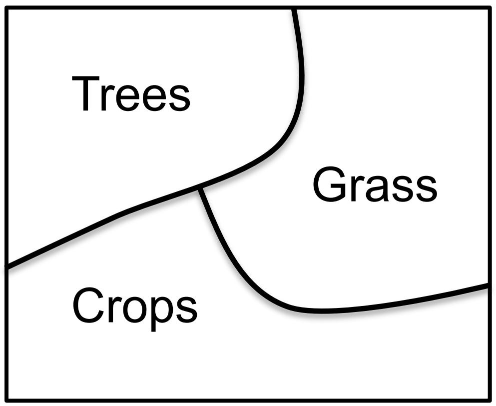
Interactions between the terrestrial biosphere and the atmospheric chemical composition - Coupling INCA and ORCHIDEE



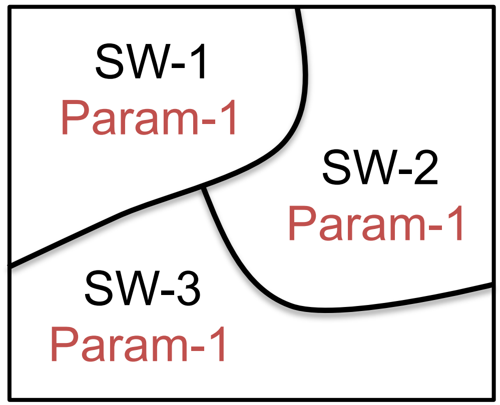
Landscape heterogeneity & organisation

Models

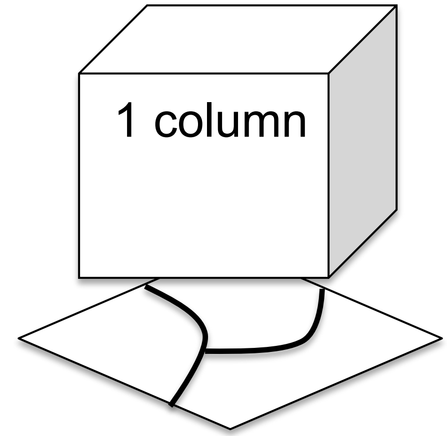
Surface Vegetation



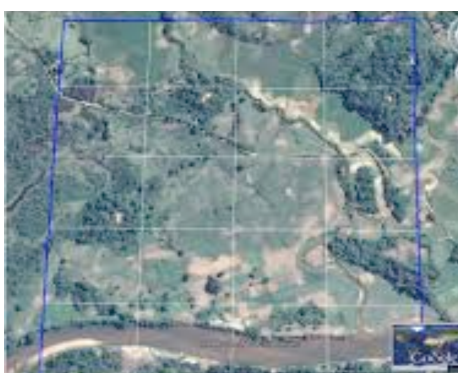
Ground Hydrology



Atmospheric coupling



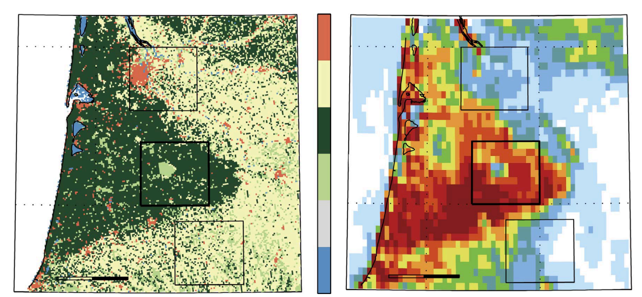
Reality



Satellite product ≈10 m

Soil properties - topography

Forest cover ➔ more cloud



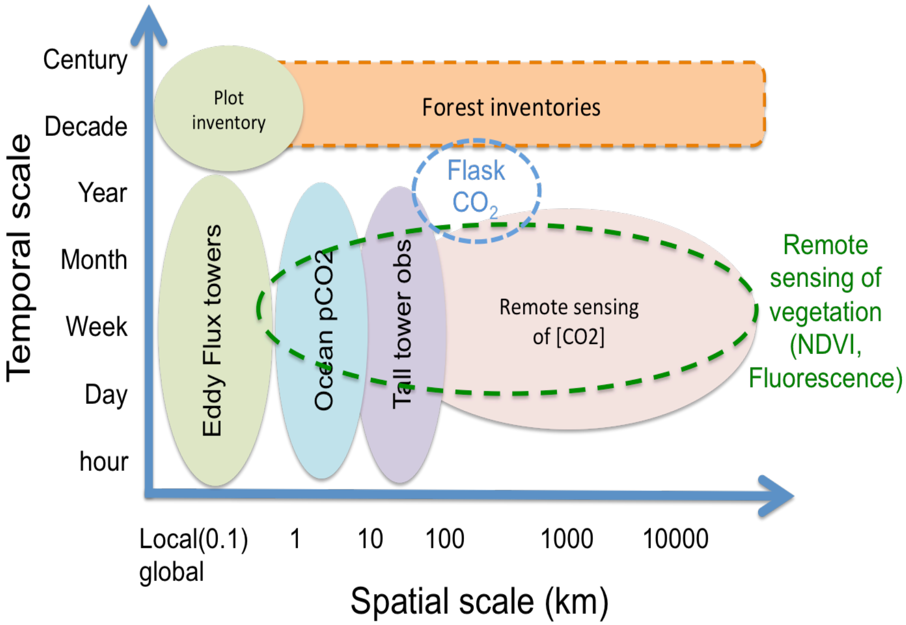
Ex: Landes forest - France (Teuling et al. 2017)

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

Reducing uncertainties with model – data integration

Available C-related data streams



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

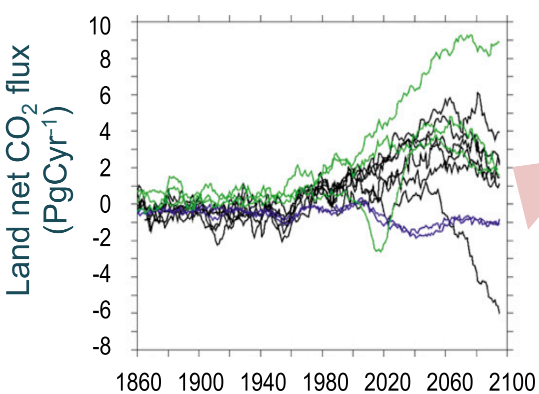
Observation term

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

Prior parameter term

X: model params to optimize

DATA ASSIMILATION

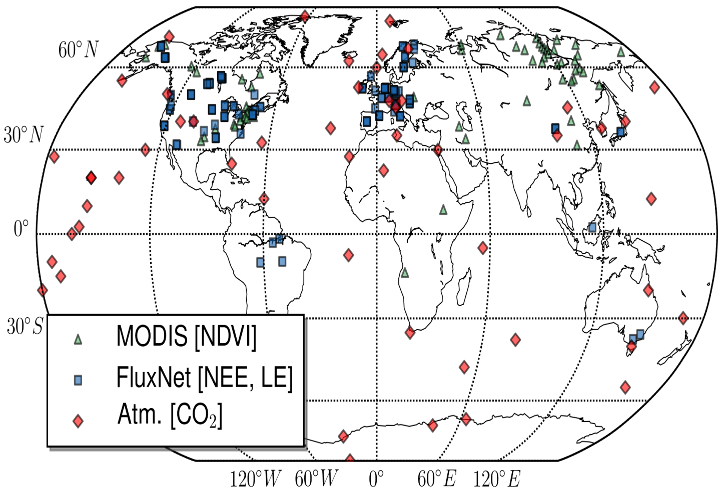


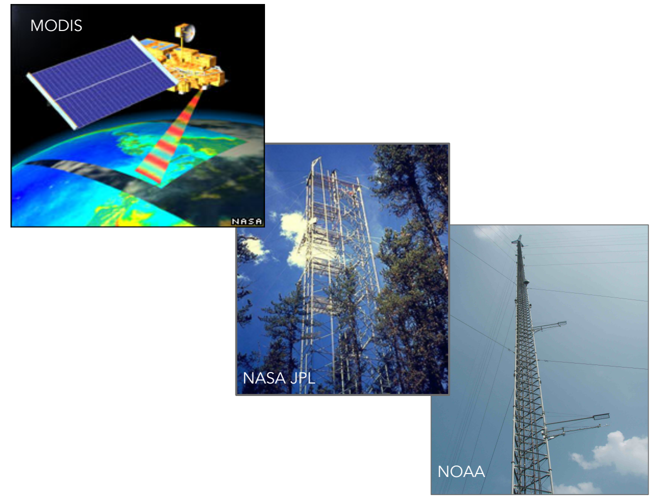
Improve:

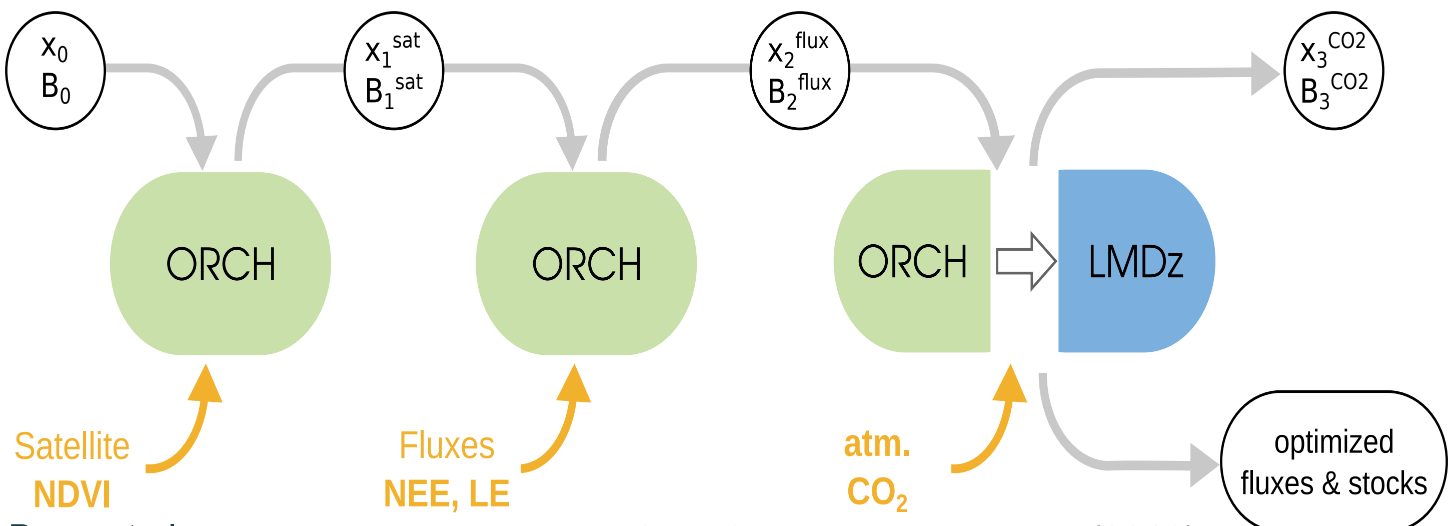
- C budget estimates
- Quantify uncertainty
- Future climate predictions
- Process understanding

Sciences de l'environnement Institut Pierre Simon Laplace

Stepwise approach: Multiple constraint on C fluxes







MacBean et al. (2015)

40 params

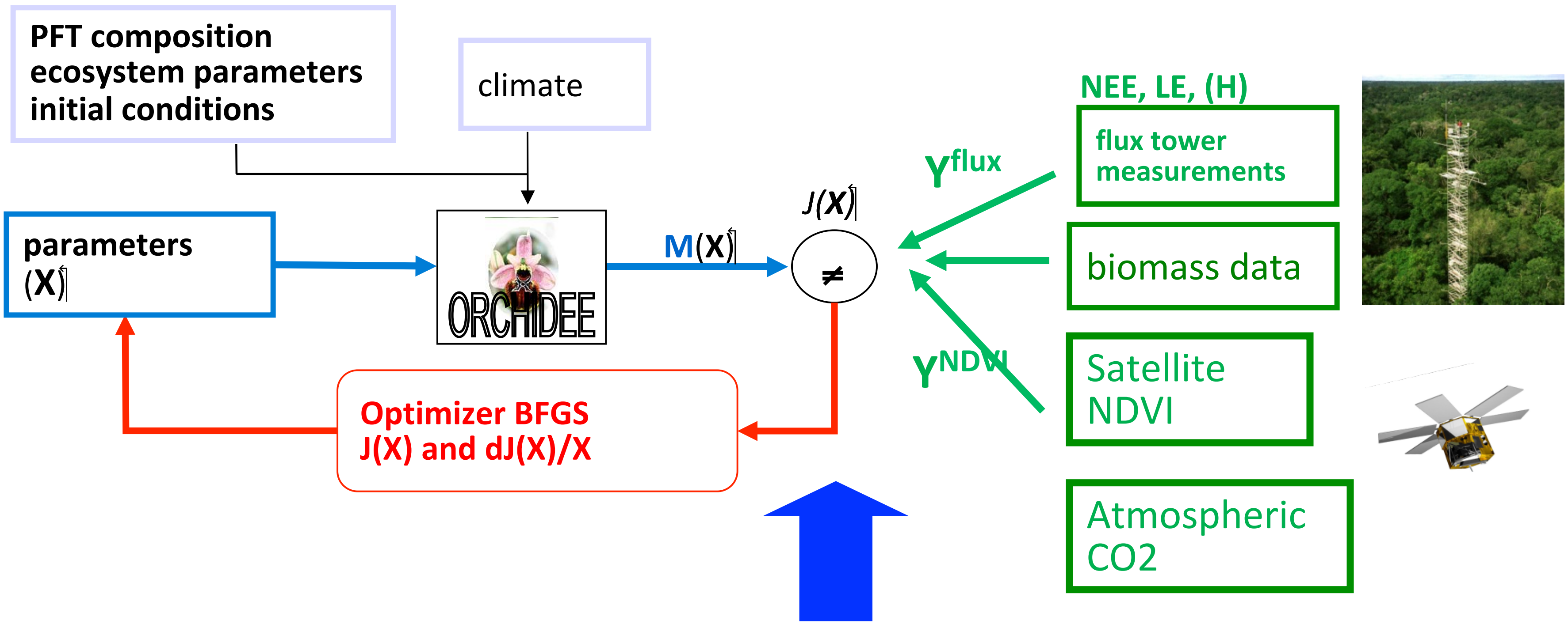
Kuppel et al. (2014)

≈ 100 params

Peylin et al. (2016)

≈ 80 params

Optimization of the C-cycle parameters..



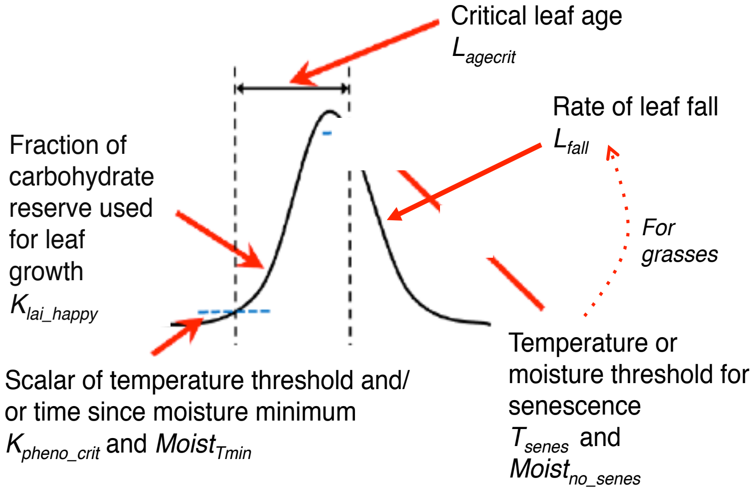
- **Cost function:**

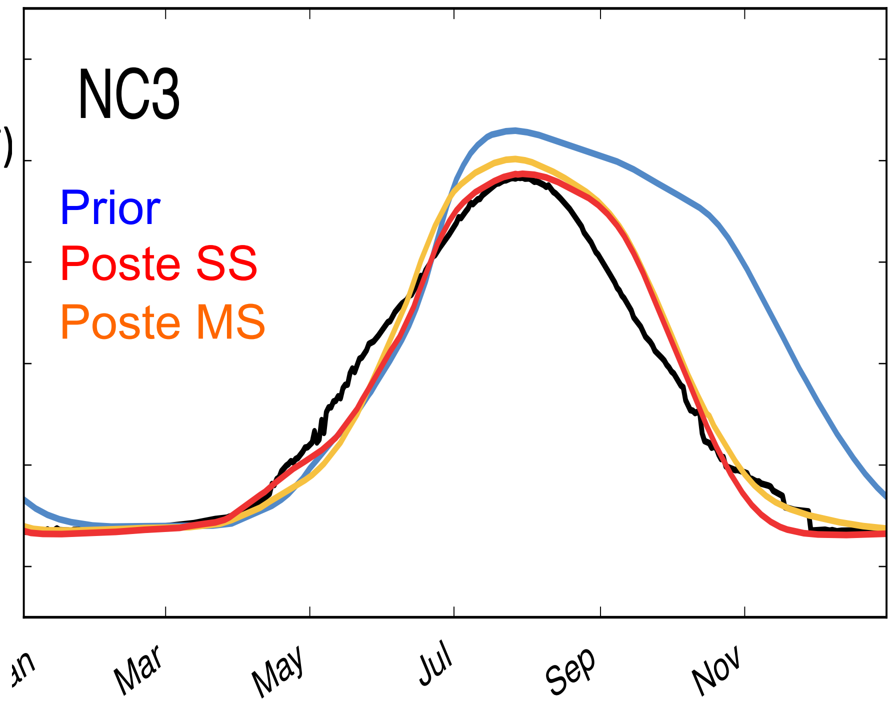
$$J(x) = \frac{1}{2}\left[\left(y - M(x)\right)^t R^{-1}\left(y - M(x)\right) + (x - x_b)^t P_b^{-1}(x - x_b)\right]$$

- **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

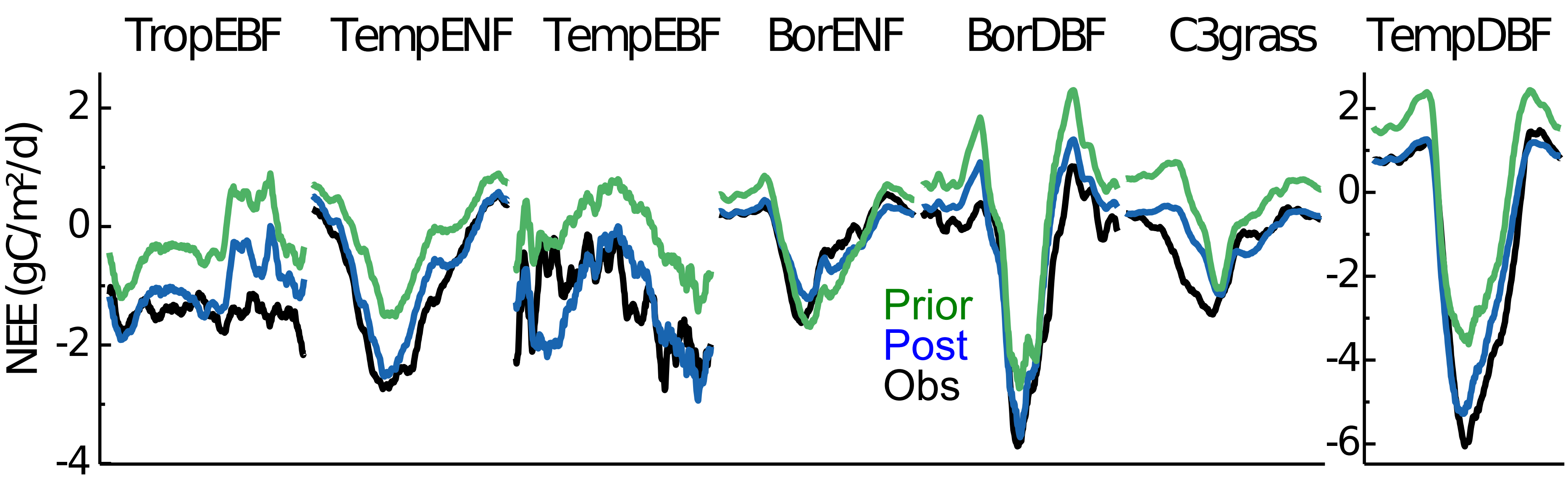
N. MacBean et al. (2015)

Step2: Net CO_2 fluxes constrains flux seasonal cycle

75 fluxnet data (NEE, LE)

≈ 20 parameters per PFT

NEE mean seasonal cycle: PFT average



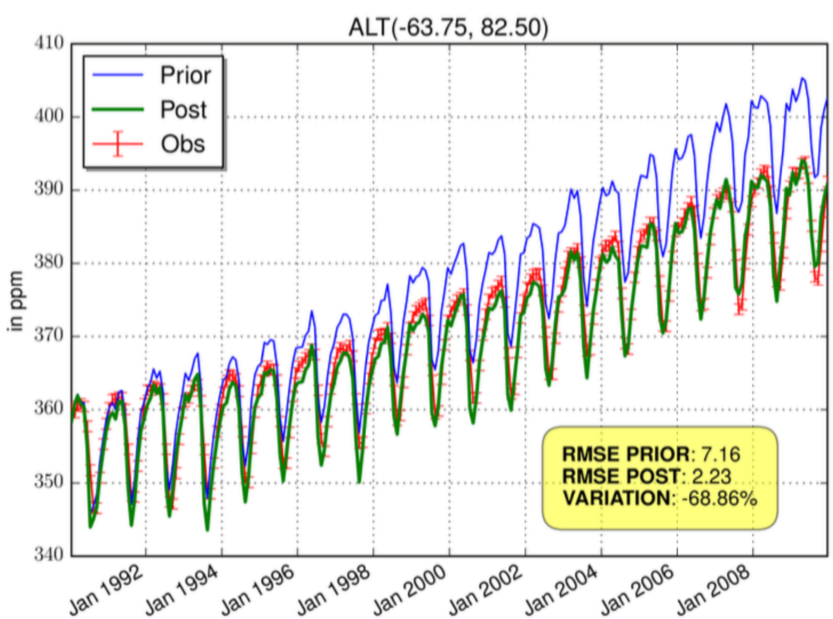
➔ Improvement of amplitude and phase

➔ Highlight model deficiencies

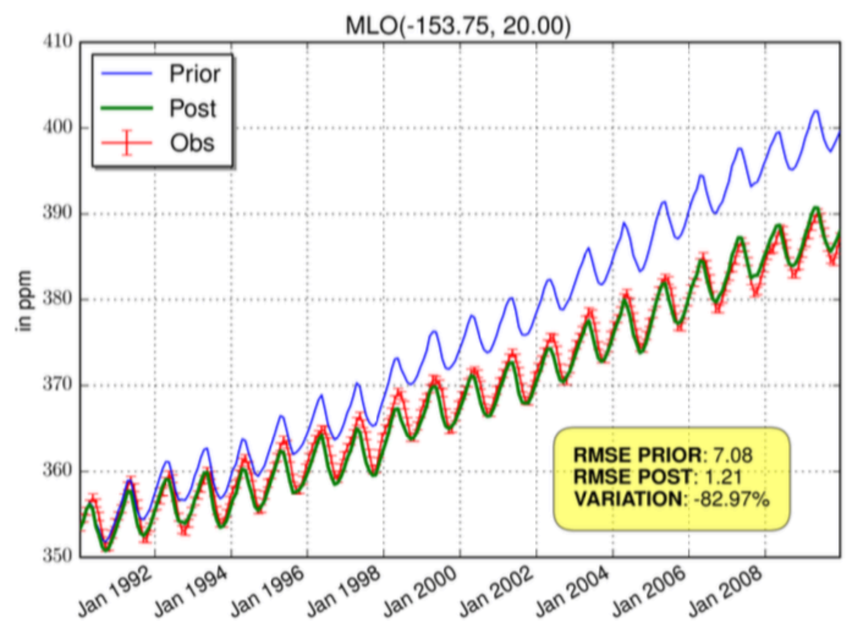
Kuppel et al. (2012)

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

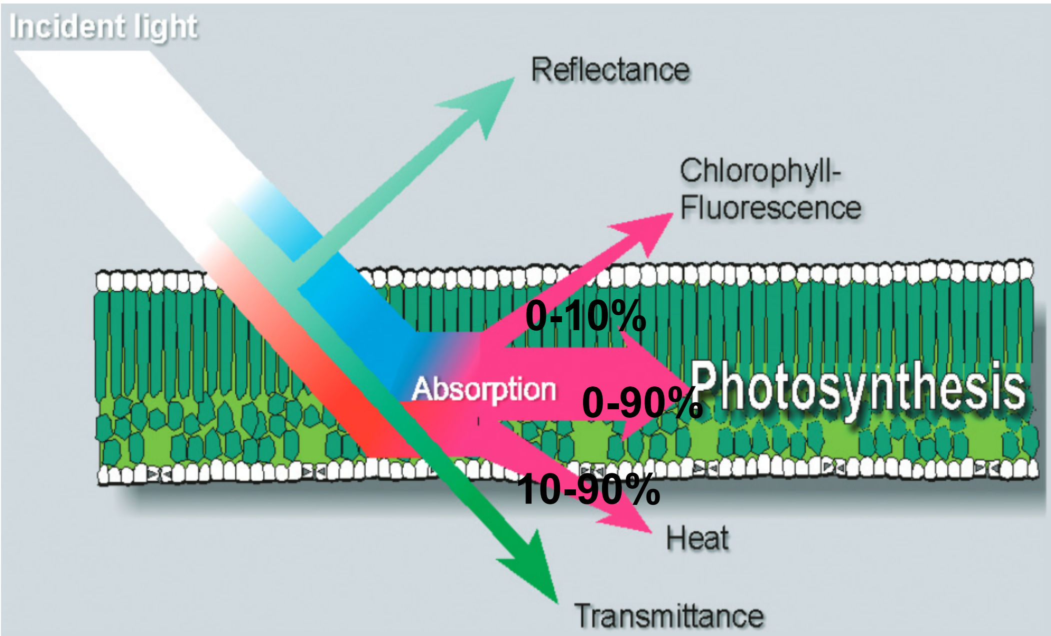


Prior
Post
Obs

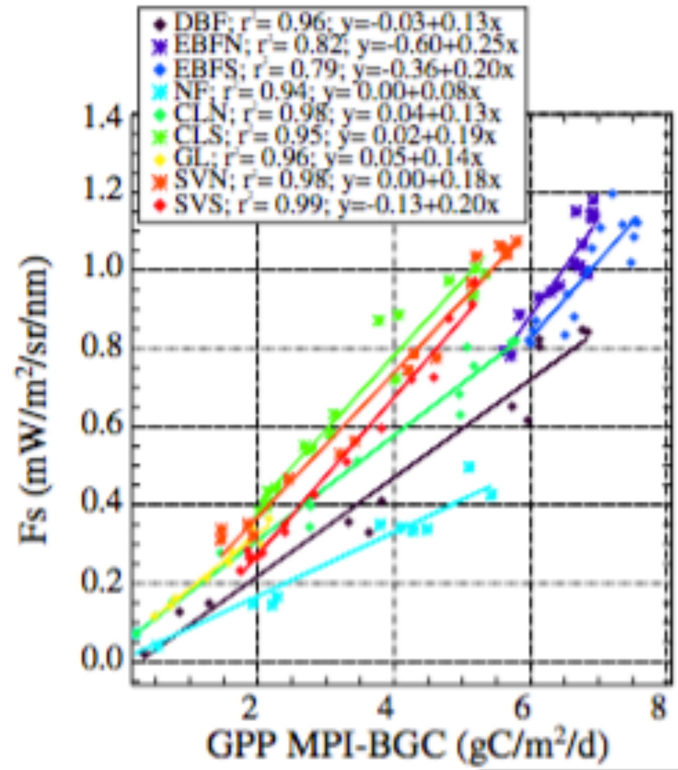


Plant physiology: use of new tracers (fluorescence)

3 competing processes in the leaves



Solar induce fluorescence correlate with GPP



➔ Work leaded at LSCE by Fabienne M.

(Cedric, Natasha, Phililppe P,..)

➔ Growing number of measurements

(In situ and satellite)

Evaluation of model simulations

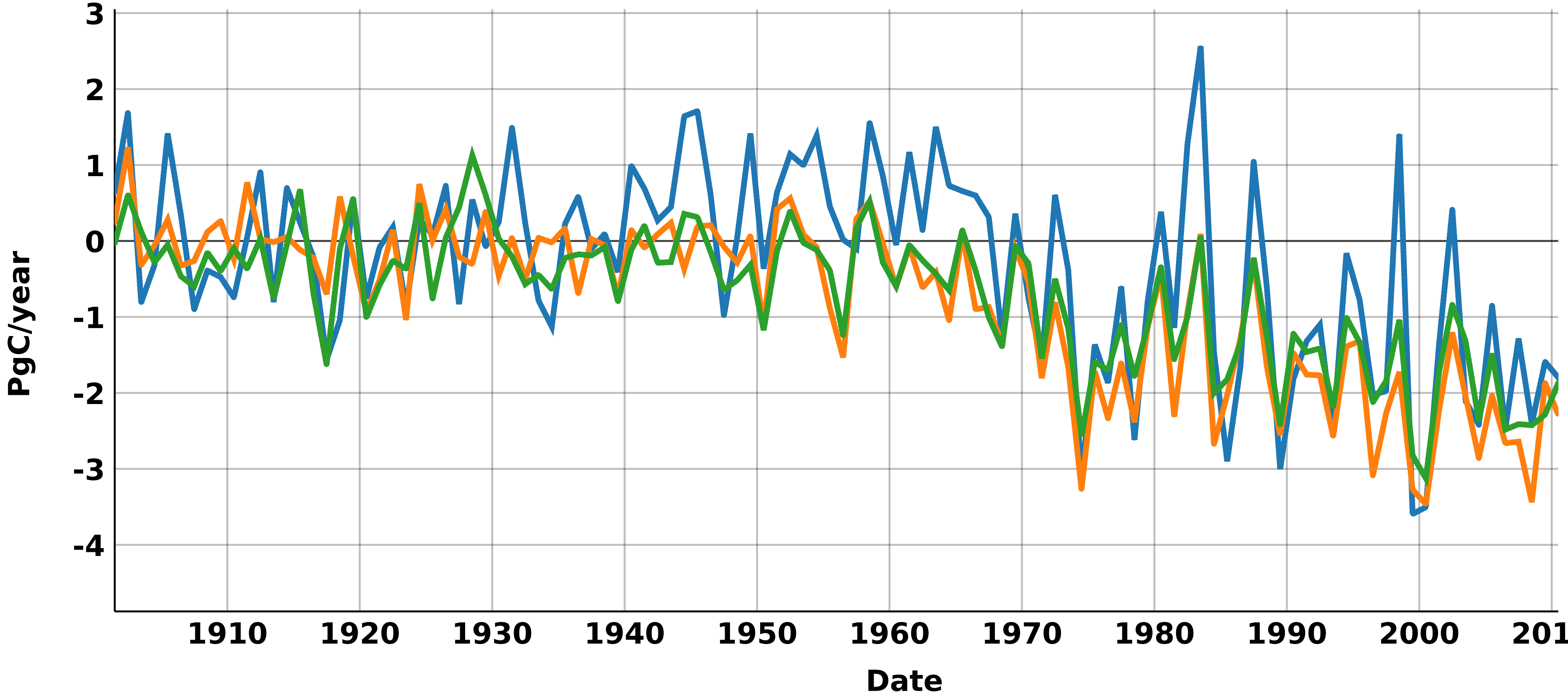
- https://orchidas.lsce.ipsl.fr/mapper/maps.php (evaluation of standard model simulations)

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

(comparison of simulation with different forcing;

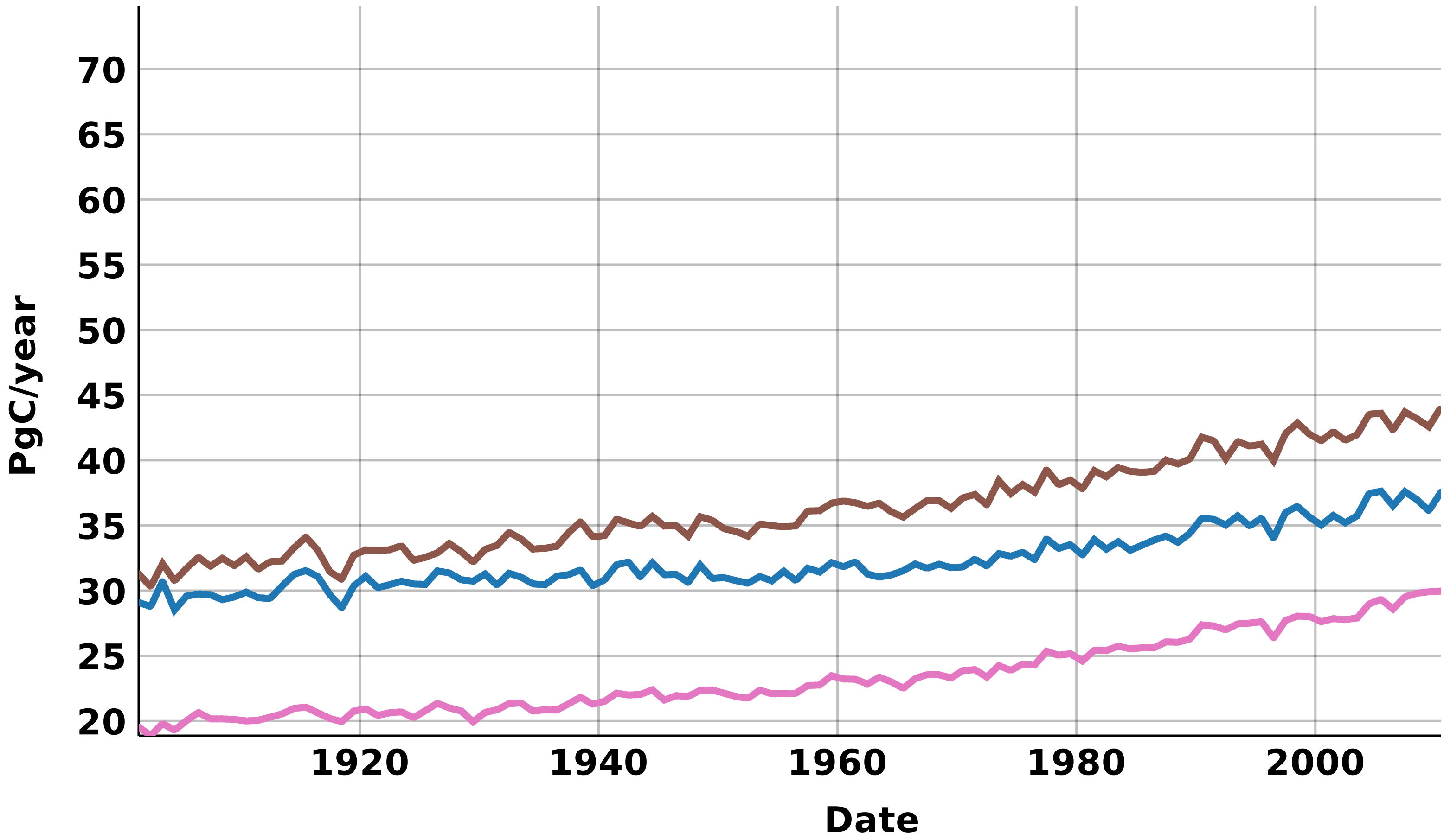
User/Passwd: eraclim / eraclim2017

Net CO_2 flux – Meteorological forcings



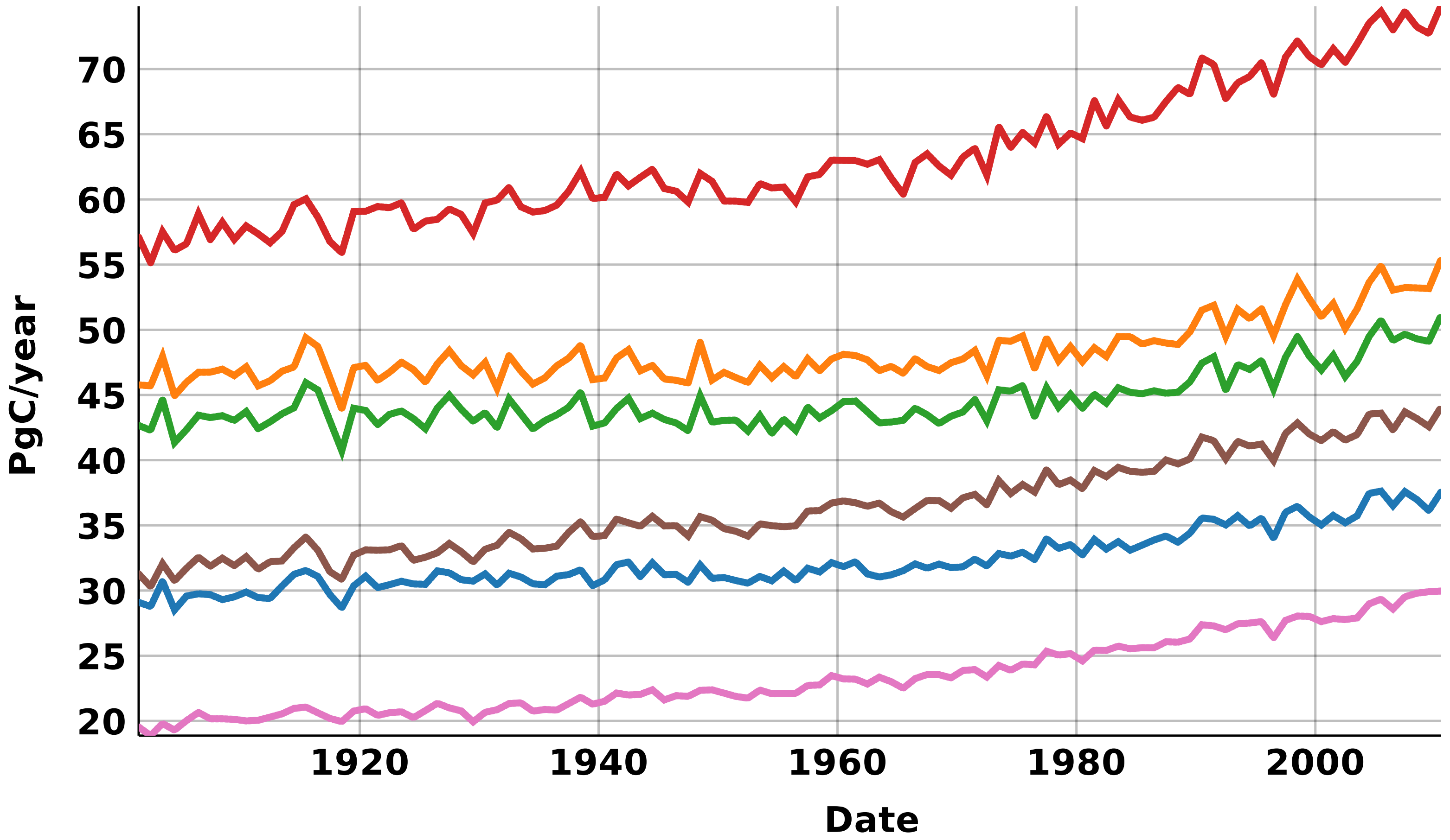
CERA20C
CRUNCEP
GSWP3

GPP flux (Photosynthesis) – Northern lands



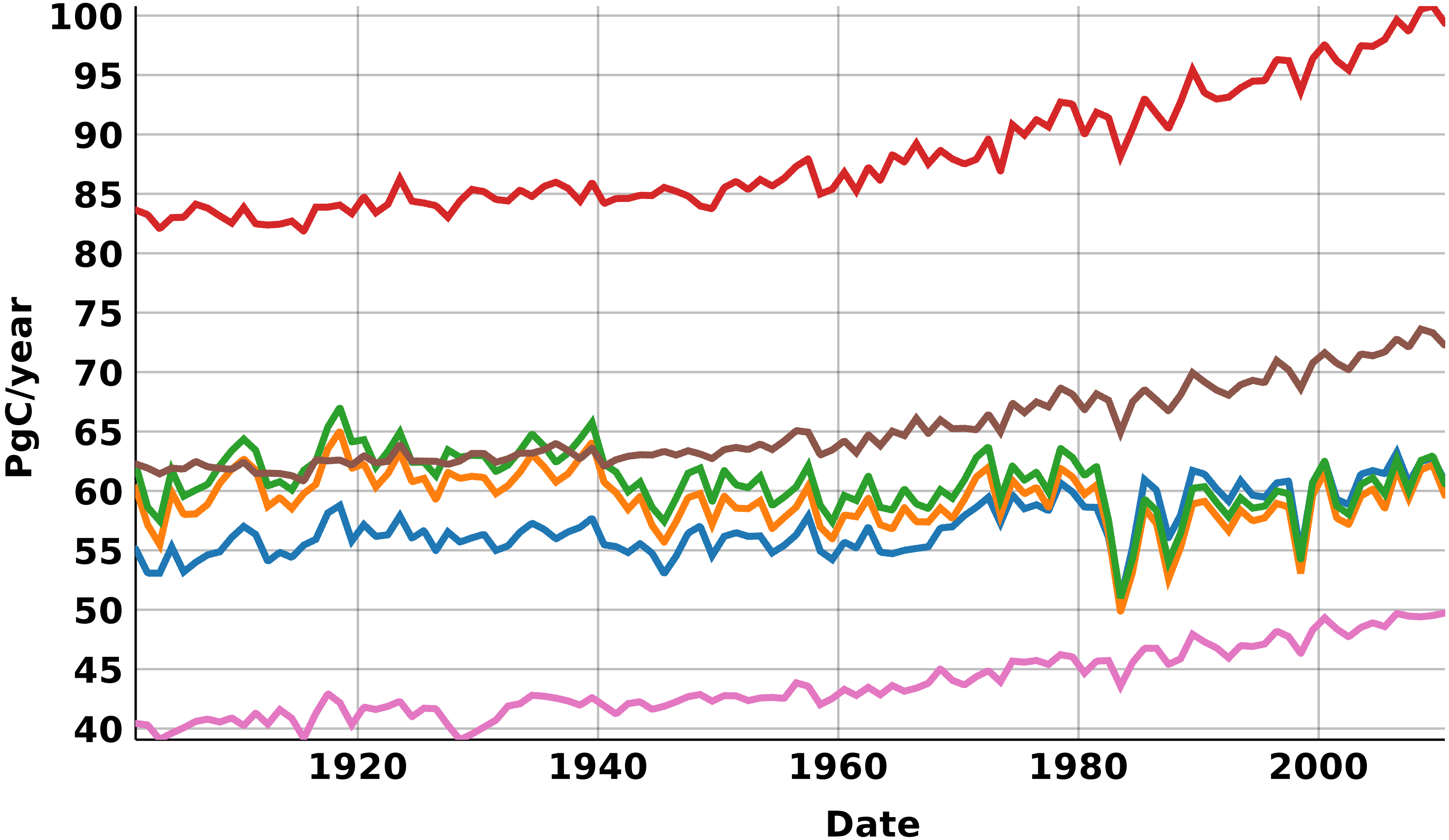
Meteorological forcings

GPP flux – Northern lands



Meteorological forcings + Model version + Land-use

GPP flux – Tropical lands



Meteorological forcings + Model version + Land-use