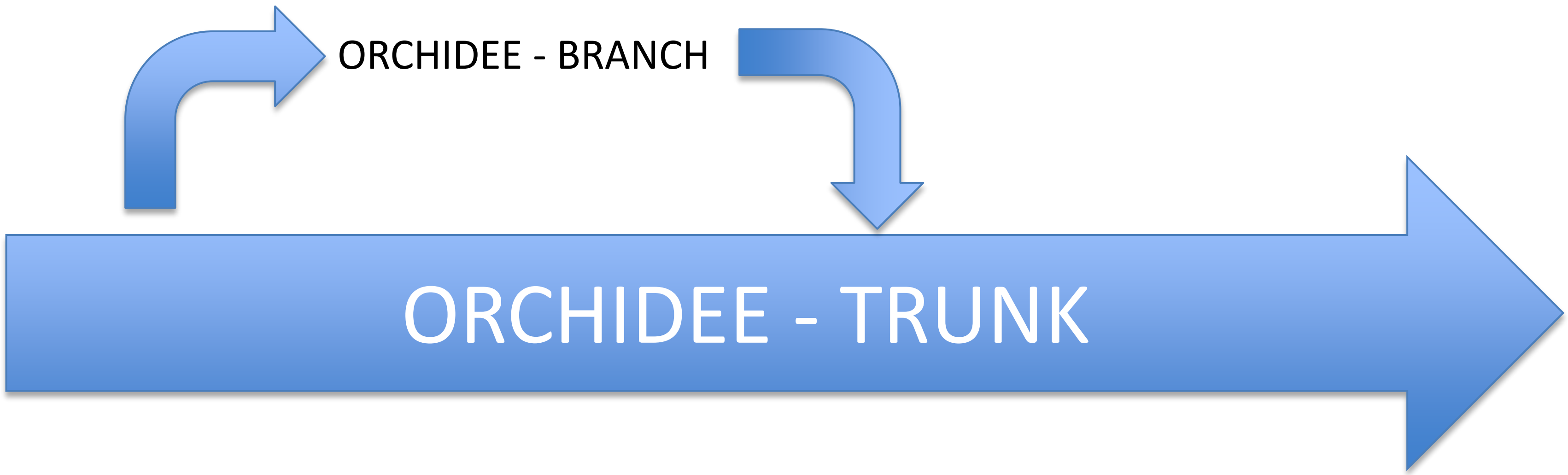
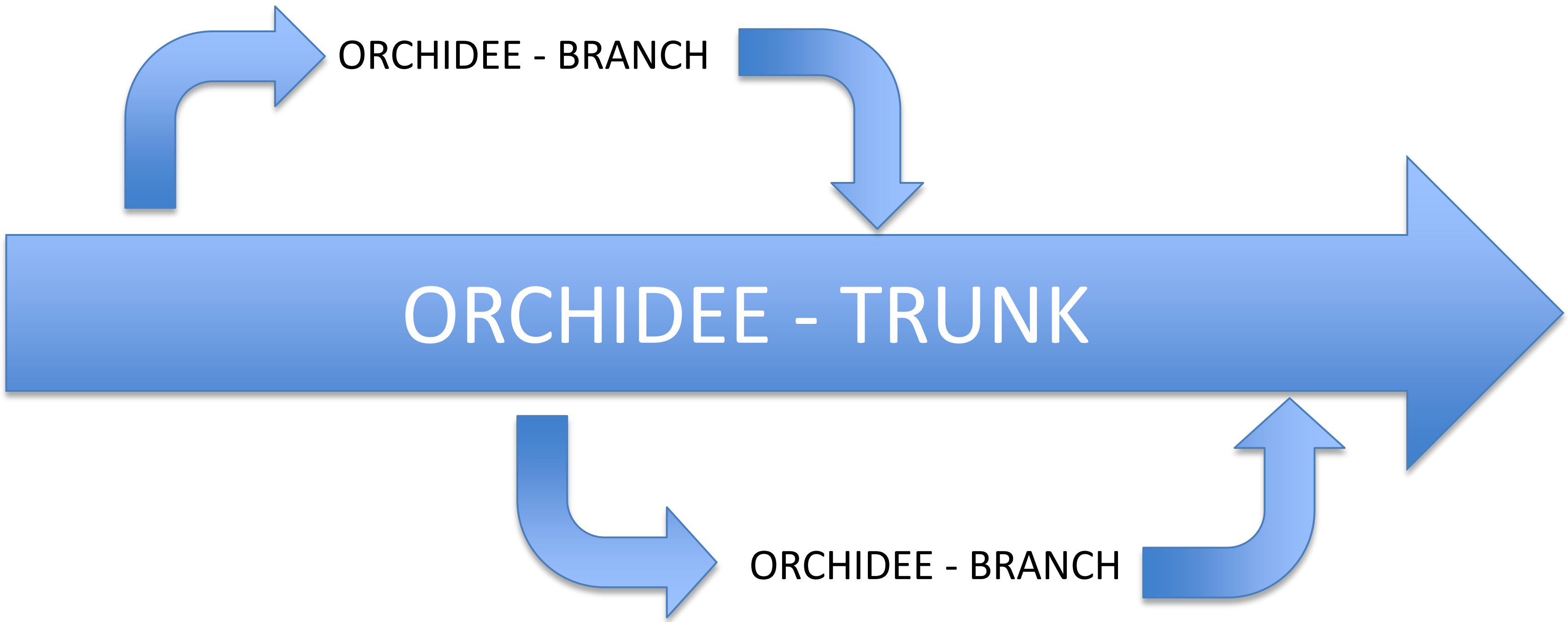
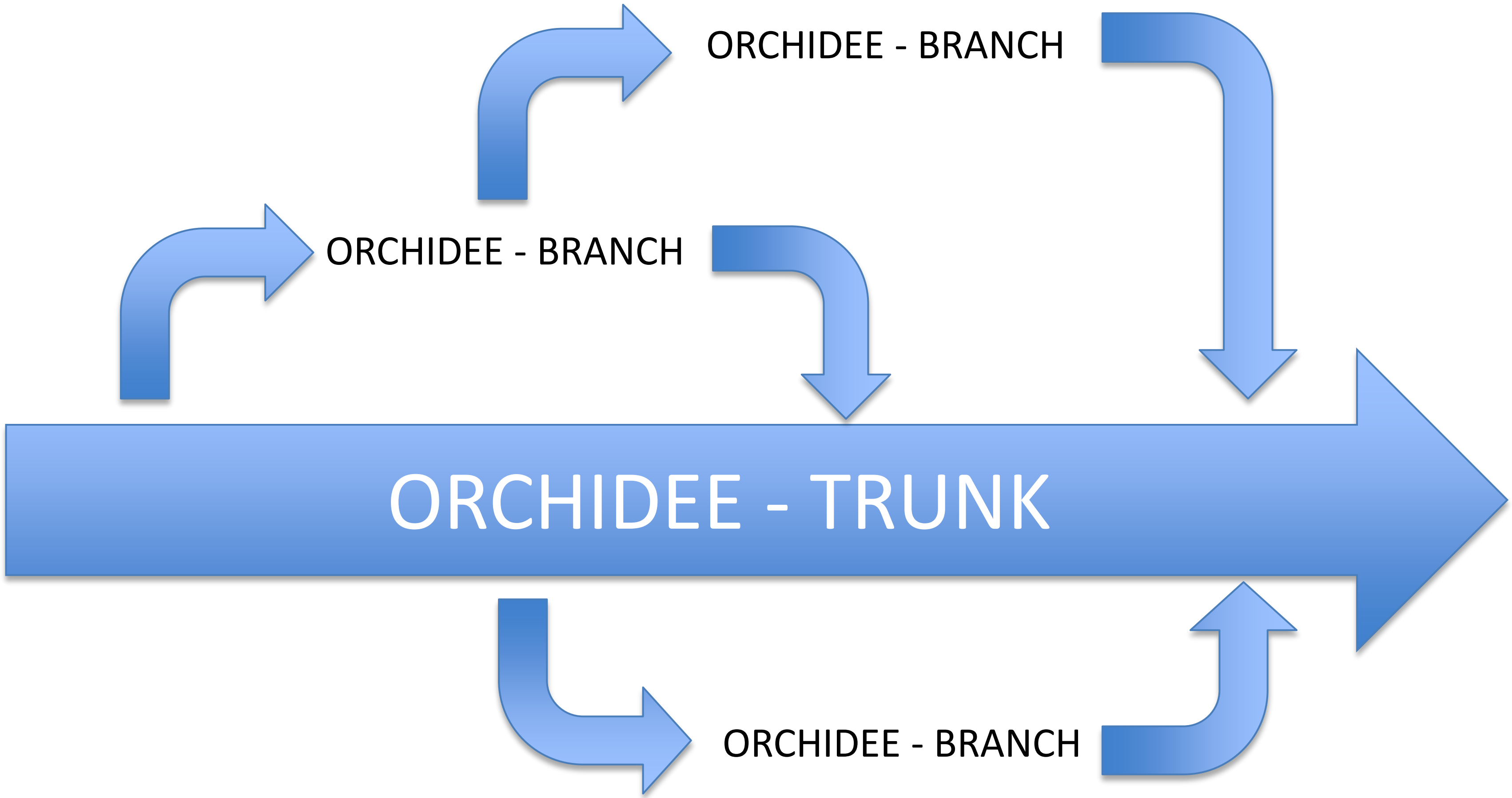
What do we need the photosynthesis module for?

Slides from: Fabienne, Cederic, Marc, Nicolas and Emilie

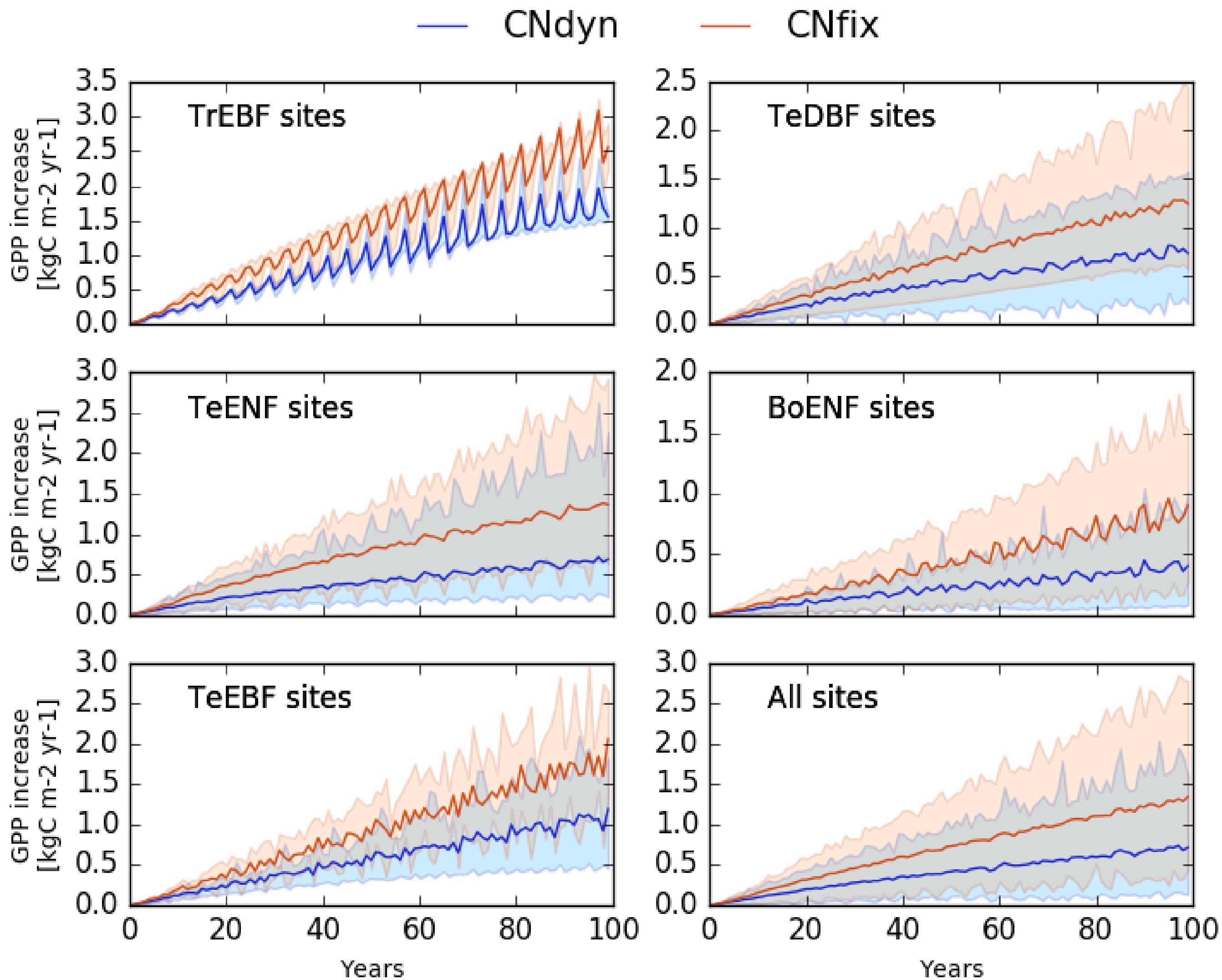
- Photosynthesis (prognostic)
- Transpiration (prognostic)
- Fluorescence (constraint)
- Coordination (unifying principles)

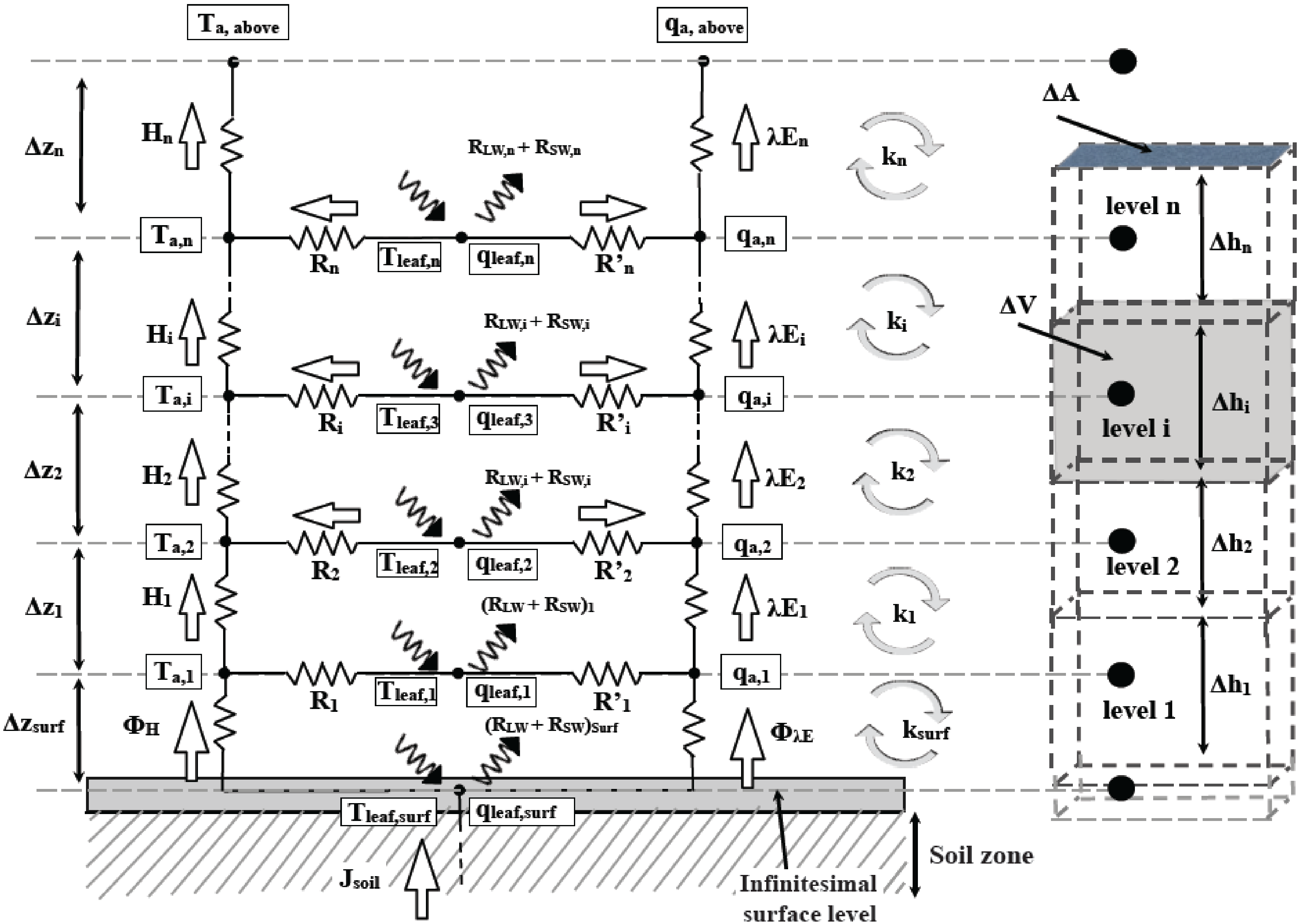

ORCHIDEE - BRANCH
ORCHIDEE - TRUNK


ORCHIDEE - BRANCH
ORCHIDEE - TRUNK
ORCHIDEE - BRANCH


ORCHIDEE - BRANCH
ORCHIDEE - BRANCH
ORCHIDEE - TRUNK
ORCHIDEE - BRANCH

- Photosynthesis (prognostic)
- Transpiration (prognostic)
- Fluorescence (constraint)
- Coordination (unifying principles)


CNdyn
CNfix
TrEBF sites
TeDBF sites
TeENF sites
BoENF sites
TeEBF sites
All sites
GPP increase
[kgC m-2 yr-1]
Years


Ta, above
qa, above
ΔA
Δzn
Hn
λEn
kn
RLW,n + RSW,n
level n
Δhn
Ta,n
Rn
Tleaf,n
qleaf,n
R'n
qa,n
Δzi
Hi
λEi
ki
ΔV
RLW,i + RSW,i
Ta,i
Ri
Tleaf,3
qleaf,3
R'i
qa,i
level i
Δhi
Δz2
H2
λE2
k2
RLW,i + RSW,i
Ta,2
R2
Tleaf,2
qleaf,2
R'2
qa,2
level 2
Δh2
Δz1
H1
λE1
k1
(RLW + RSW)1
Ta,1
R1
Tleaf,1
qleaf,1
R'1
qa,1
level 1
Δh1
Δzsurf
ΦH
(RLW + RSW)Surf
ΦλE
ksurf
Tleaf,surf
qleaf,surf
Jsoil
Infinitesimal surface level
Soil zone

- Photosynthesis (prognostic)
- Transpiration (prognostic)
- Fluorescence (constraint)
- Coordination (unifying principles)

Hydraulic architecture in ORCHIDEE-CAN

Based on Hickler et al. 2006, implemented, tested & validated in Naudts et al., 2015 (European forests) => **Computes the plant water supply**. If > than Transpiration, reduction on g_s(by iteration)

$$F_{trs} = \text{pdelta} \;/\; (R_{froot} + R_{sap} + R_{leaf})$$

sum resistances

$$\text{pdelta} = \Psi\text{rootzone} - \Psi l_{MIN} - dh \times k\rho w \times kg$$

Loss of water potential (gravity)

Minimum leaf water pot. (PFT specific parameter)

$$\Psi\text{rootzone} = \sum(l)\,[p_{\psi s} \times d_{rd}] + m_{\psi}$$

Tuning factor (PFT specific parameter)

Soil water potential per layer (Van Genuchten)

Root profile

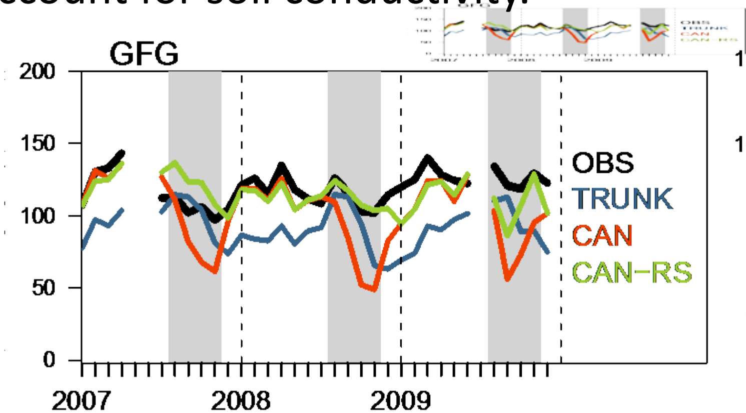
Account for cavitation (s-shape vulnerability curve) increase in Rsap (PFT specific calibration)
Derived by Ψrootzone

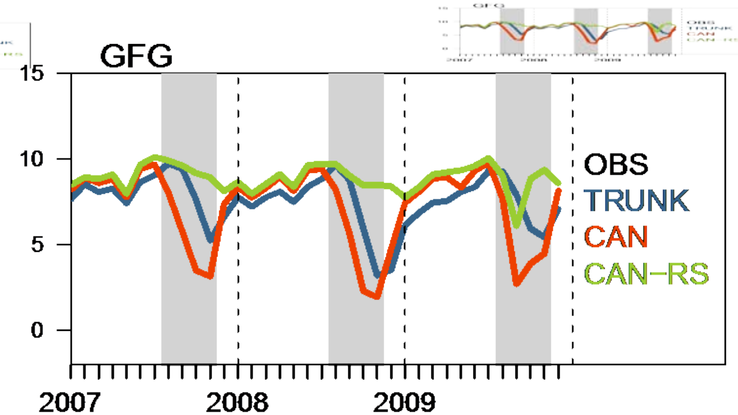
$$R_{sap} = \frac{d_h}{(d_s \times k_{scon})}, \quad k_{scon} = k_{scon} \times e^{(-p_{\psi rs}/k_{\psi 50})^{k_c}}$$

Proposed modifications for tropical forests

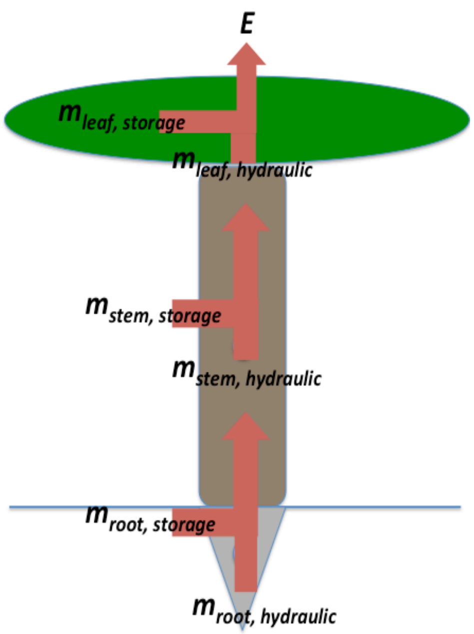
L. Sack, M. Bartlett, F. Maignan, J. Chave, P.Ciais, B. Poulter

1. From Ψsoil to Ψrootzone (Joetzjer et al., in prep) based on Williams et al., 2001 (CAN-RS). Account for soil conductivity.





2. From Ψrootzone to Ψleaf (in dev – tested against throughfall exclusion experiment at CAX)



- Root, stem and leaf water storage (dependant of tree size)
- Conductivity gradient (based on vulnerability curves)
- Hydraulic potential gradient
- Gravity taking in account

- Stomatal conductance depends on psi_leaf

⇒ Downregulation of the hydraulic on GPP and transpiration

- Threshold : when stem cavitation is > 88% we consider the tree dead (Not implemented yet)

Hydraulic coordination (started 01/01/2018)
- Trait-trait relationships
- Trait-environment relationships

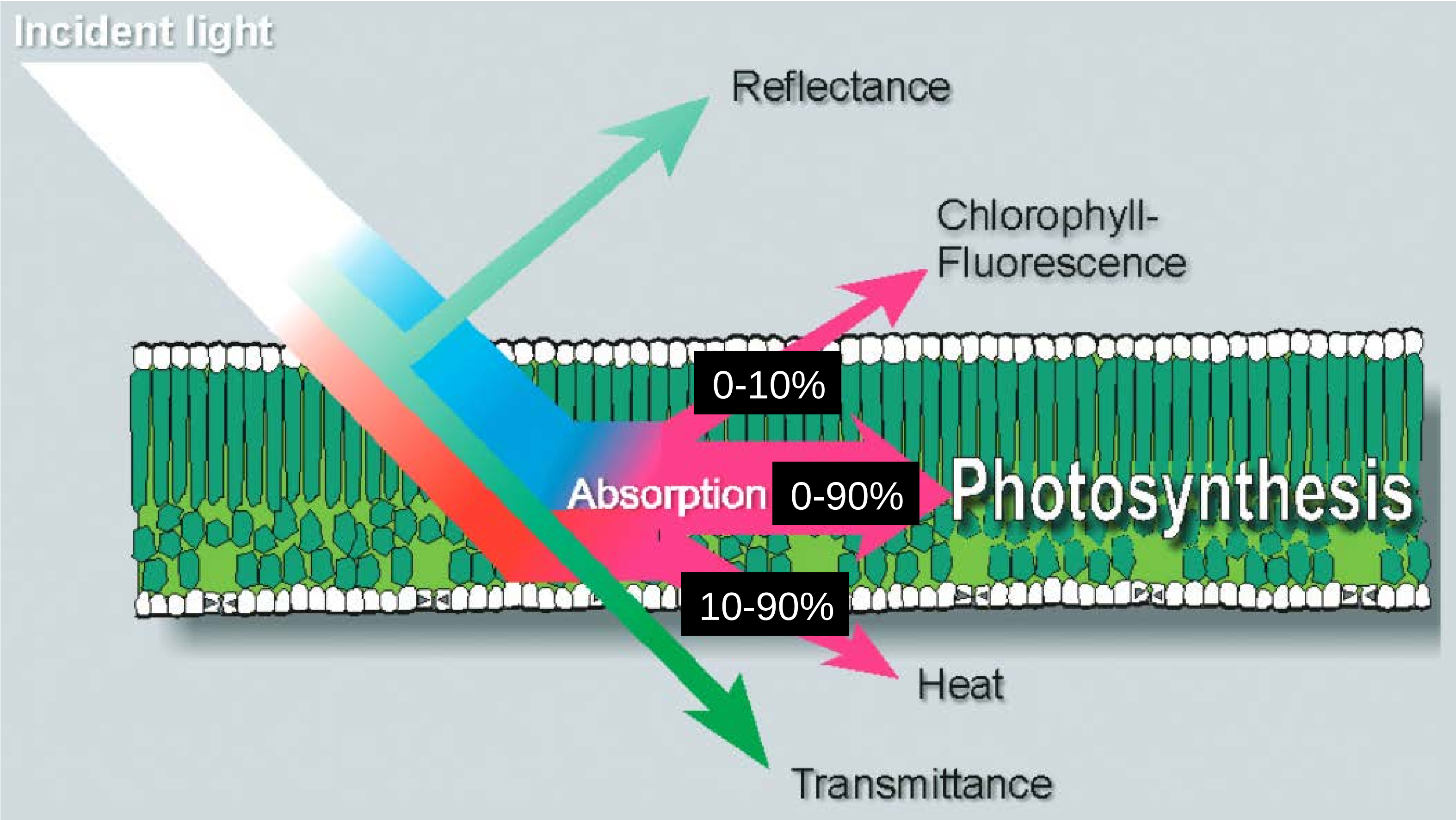
Adding water transport in phloem (R-project)

- Photosynthesis (prognostic)
- Transpiration (prognostic)
- Fluorescence (constraint)
- Coordination (unifying principles)

Assimilation of fluorescence products to constrain gross primary production in the ORCHIDEE land surface model

F. Maignan[1], C. Bacour[2], N. MacBean[1,3] , P. Peylin[1], V. Bastrikov[1], …
[1] Laboratoire des Sciences du Climat et de l'Environnement (LSCE), France
[2] NOVELTIS, 153 rue du Lac, 31670 Labège, France
[3] University of Arizona, School of Natural Resources and Environment, Tucson, AZ, USA

3 processes in the leaves competing for light energy



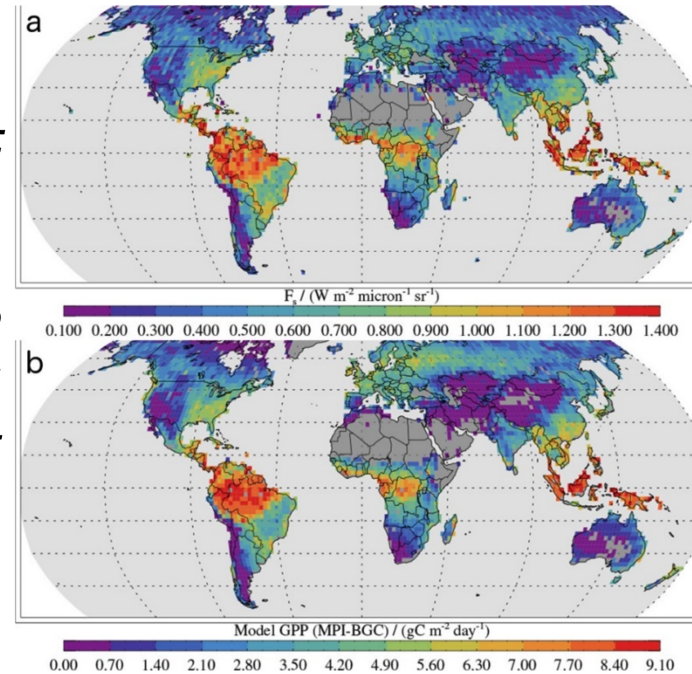
A remote-sensed proxy for Gross Primary Production?

Solar Induced Fluorescence (SIF)
Measurable from space: GOSAT, GOME-2, SCIAMACHY, OCO-2 + FLEX (2022)

R^2(SIF, GPP)=0.8

GOSAT-SIF

MTE-GPP extrapolated from FLUXNET measurements (Jung et al., 2011)



© Frankenberg et al. (2011)

Land Surface Model
ORCHIDEE

Canopy

Leaves

Fluorescence NEW!

Photosynthesis

How to improve the simulated GPP ?

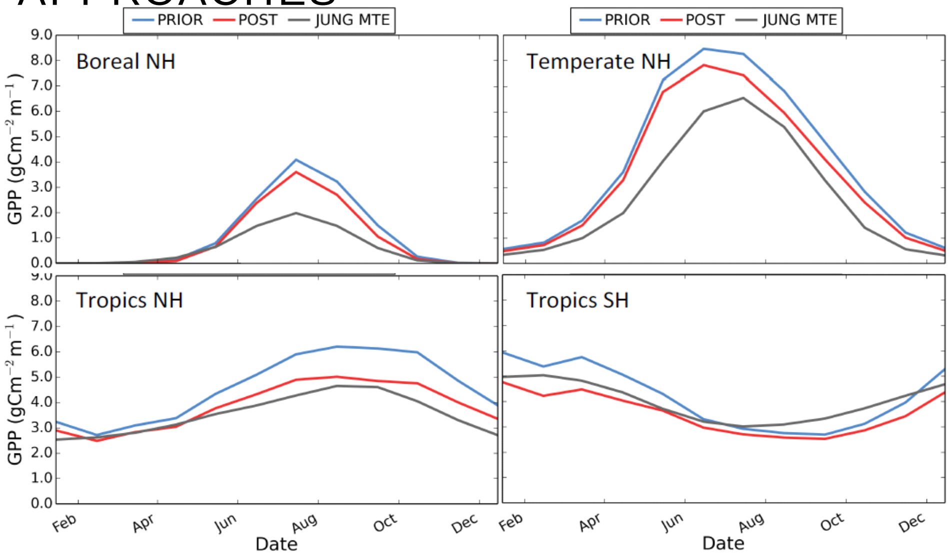
Gross Primary Production (GPP)
Amount of atmospheric carbon fixed by plants through photosynthesis

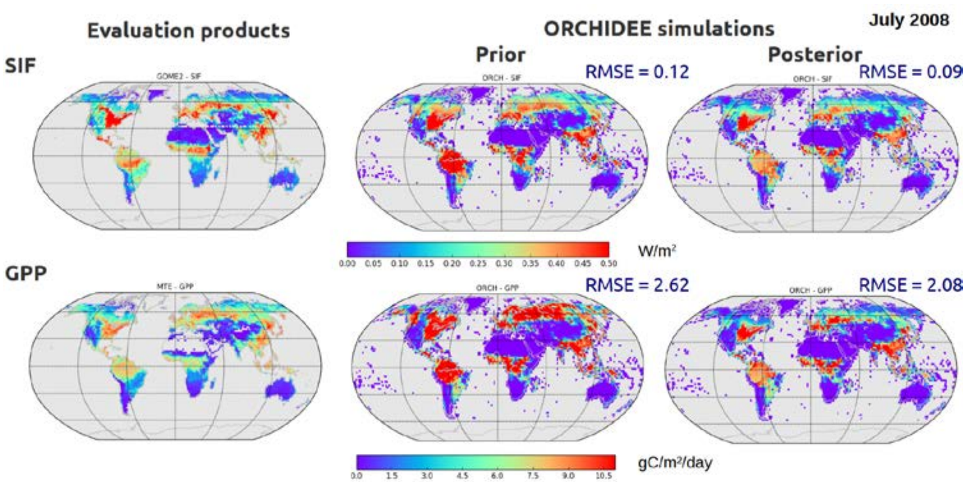
Assimilation of SIF data to optimize model parameters

Modeling Approaches

- Approach 1: Linear model SIF = aGPP + b at a monthly time-scale
- Approach 2: Mechanistic representation of processes at leaf level and upscale at the canopy level using a parametric model

Results: Global GPP improvement (phase, amplitude) for both approaches





Improved temporal agreement with the global Jung et al. (2010) GPP product after assimilation (MacBean et al., 2018, *Scientific Reports*)

Improvement of the simulated spatial patterns / gradients for both SIF and GPP (Bacour et al., *in prep*.)

Next steps

Intercomparison of SIF products / Complementary with other products (NDVI, FLUXNET, CO_2 atmospheric concentrations) / Impact on evapotranspiration / …

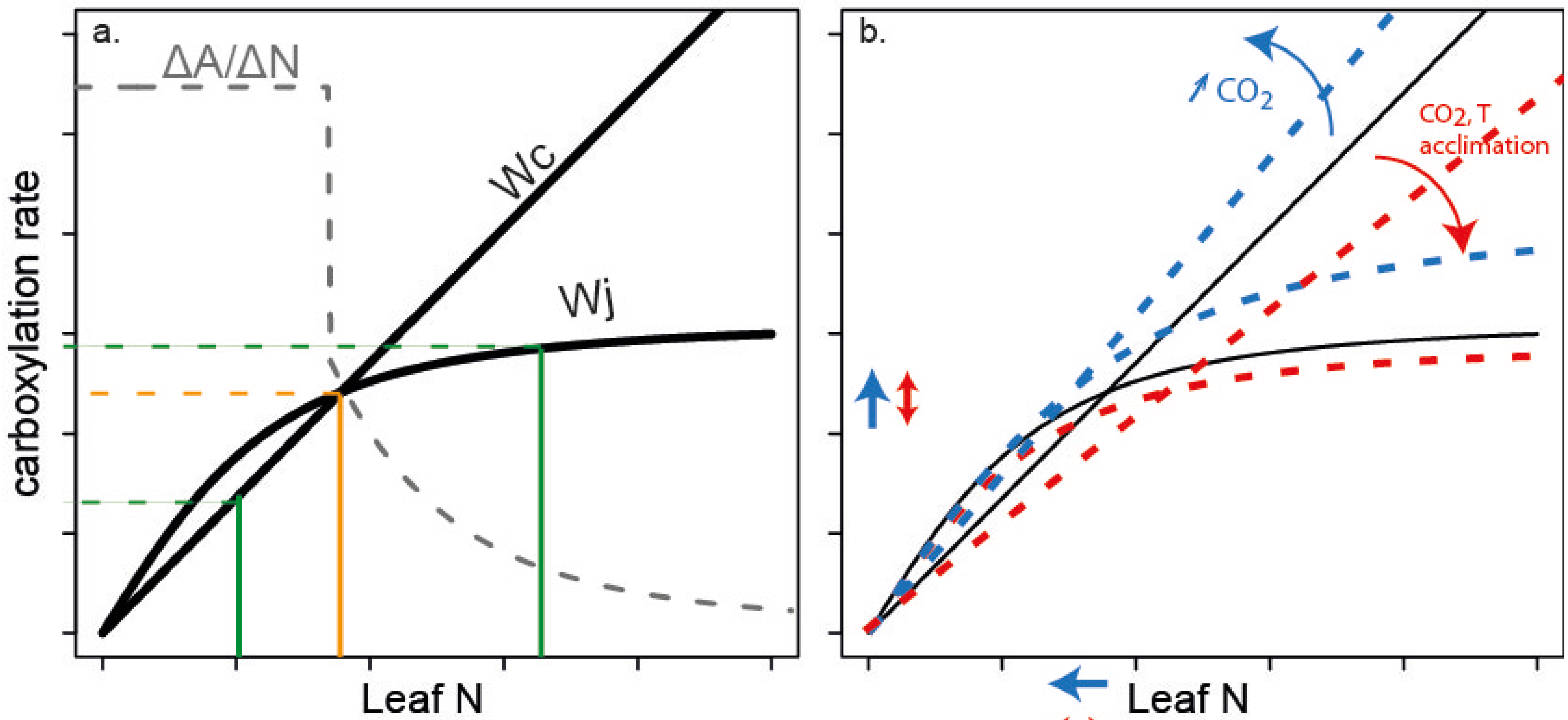
- Photosynthesis (prognostic)
- Transpiration (prognostic)
- Fluorescence (constraint)
- Coordination (unifying principles)

The coordination of leaf photosynthesis

→ → Equilibrium between CO2 limited (Wc) and light limited (Wj) carboxylation rate

Maximize the cost-benefit difference of N allocation to photosynthesis

- → Continuous estimation of *Vcmax* et *Jmax* from **Light, temperature and CO_2**
- → Allows to estimate the “optimal” N content of leaves such as Wc == Wj
- → Takes into account Temperature and CO_2 acclimation



Coordination: A ~ Wc=Wj

Constant traits: A ~ min{Wc,Wj}

Traits of interest

❼ Coupled to the « *Leaf Economic Spectrum* » theory : Estimation of SLA and LL from leaf N

- Wc=Wj
- f(*Vcmax*)=f(*Jmax*)

With Jmax = **Jfac***Vcmax

And N_{area} = N_{pac} + N_s (Maire et al.2012)

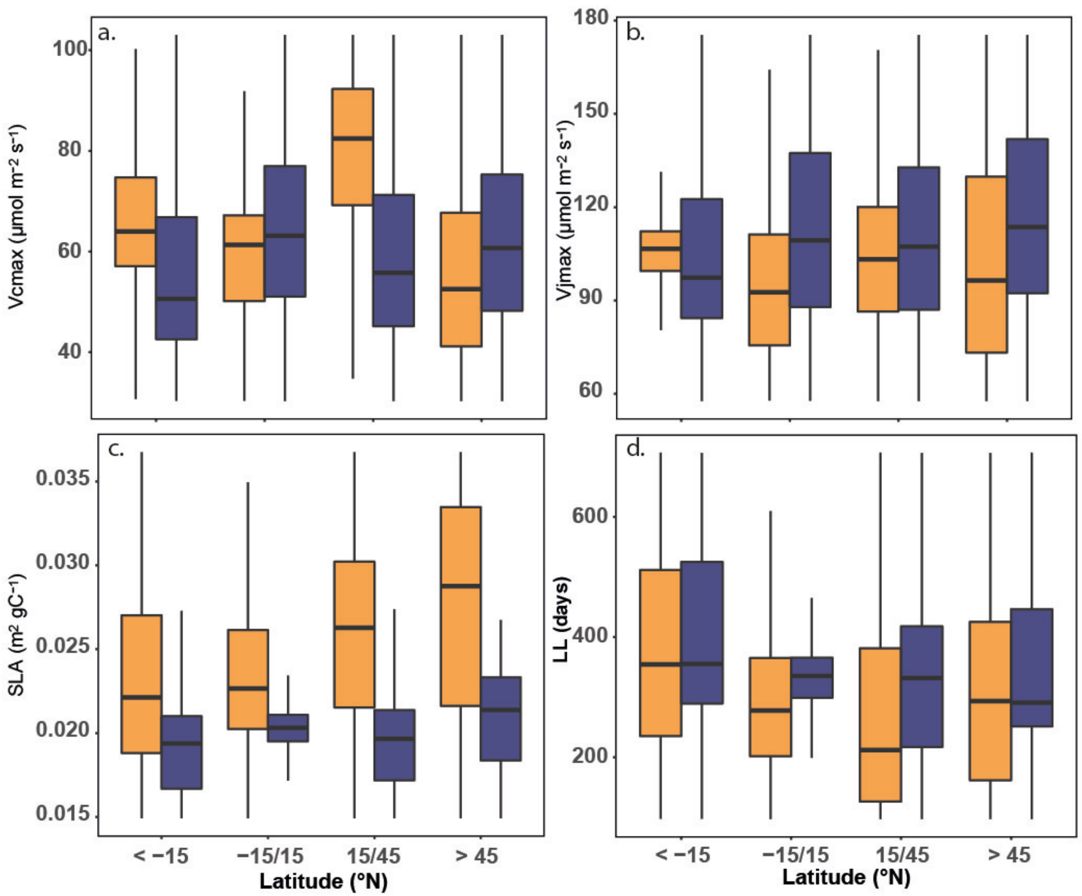
= Vcmax/**k3** + **f_{ns}**/SLA

$$Np_{ac} = \frac{4 \cdot 1 \alpha \cdot PPFD}{k_3^{ac}} \cdot \left(\left(\frac{C_i + k_2}{(4 \cdot C_i + 8 \cdot \Gamma^*) \cdot \Phi_{V_{cmax}}} \right)^2 - \left(\frac{1}{J_{fac}^{atc} \cdot \Phi_{J_{max}}} \right)^2 \right)^{1/2}$$

Jfac, k3 and SLA are PFT-dependent calibrated with TRY

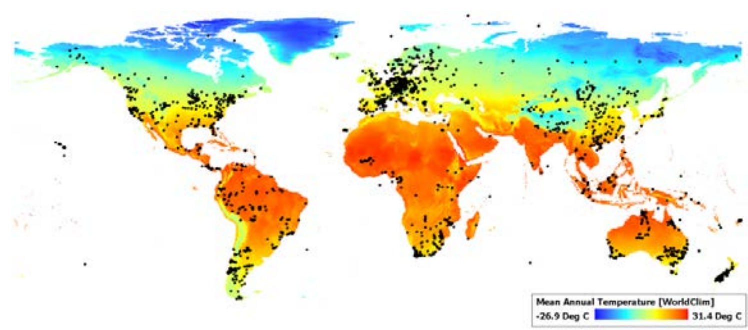
→Implemented in ORCHIDEE TRUNK v.1.9.6 (**no N nor P cycles**)
→Vcmax and Jmax updated every 10 days
→SLA and LL every year
→Historical simulations (1901-2016 CRU-NCEP)
→Future simulations (2016-2100, RCP8.5 IPSL)

Results
Comparison with trait observations



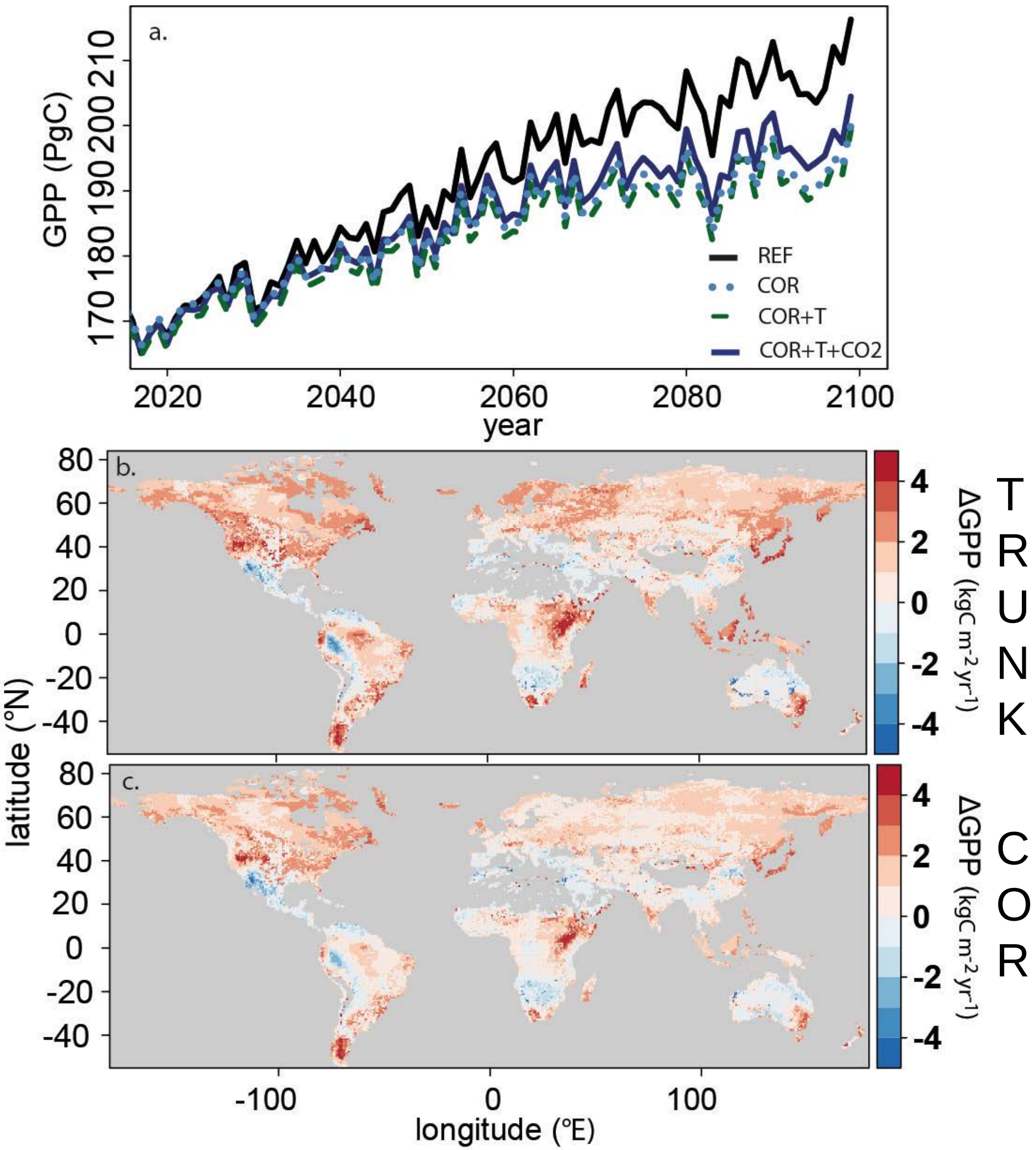
Interpolation of observations (TRY) following Verheijen et al. 2015

Trait simulated with the coordination (2000-2010)



(Kattge *et al.* ,2011)

Results
Slowdown of the CO_2 fertilization effect

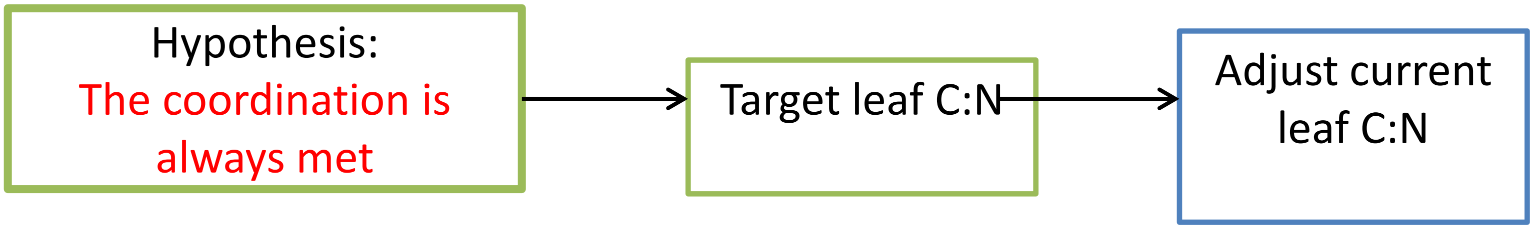


→Strong impact on projected GPP (12 PgC y^{-1} (28%) to 17.6PgC y^{-1} (37%) compared to REF in 2100)

→Similar to projected effects of N and P limitations (between 25 and 74%;Thornton et al., 2007; Zaehle et al, 2010; Goll et al., 2012)

Current developments

❼ Linking the coordination with the N cycle in ORCHIDEE-CNP



→ Including P in the coordination

- Can we predict leaf P from the coordination?
- How to simulate the effect of P deficiency on photosynthesis

❼ ⌖♒♋♦ ♎◻ ⬥♏ ■♏♏♎ ♓■ ⚐☼☝✋👎☜☜✍

1) The link between coordination and water transport/ optimal stomatal conductance

2) A way to estimate spatial and temporal optimal distributions of SLA from environment and within the canopy profile (especially the 'structural' part, the 'metabolic' part being estimated from the coordination)