ORCHIDEE-CNP

Daniel S. Goll,
Y. Sun, J. Chang, Y. Huang, F. Maignan, A. Jornet, P. Ciais,
among many others

ORCHIDEE
LAND SURFACE MODEL

LSCE
LABORATOIRE DES SCIENCES DU CLIMAT
& DE L'ENVIRONNEMENT

UNIVERSITÉ DE VERSAILLES
ST-QUENTIN-EN-YVELINES

IMBALANCE P

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European Research Council
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Why would you want P in ORCHIDEE?

What processes are implemented?

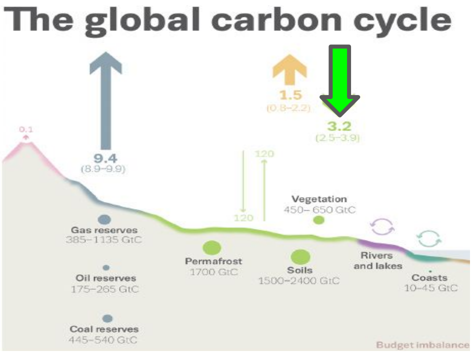
Does the model work?

What could a CNP model be used for?

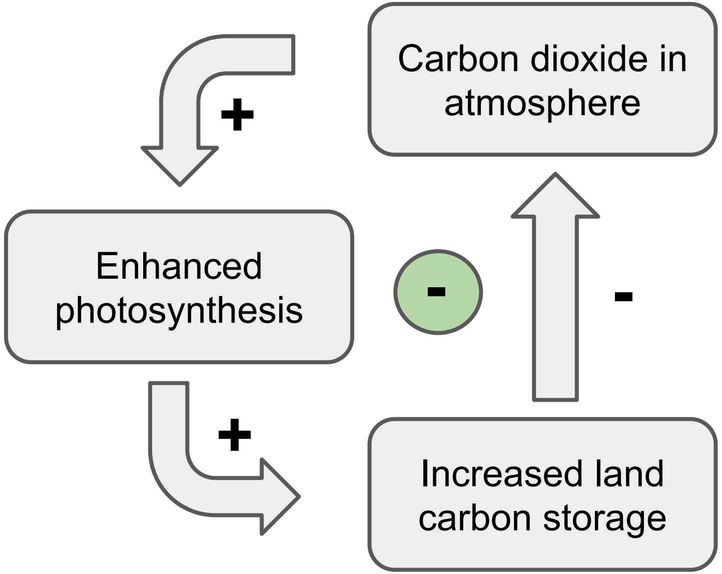
Technical aspects

Why would you want P in a land surface model?

CO_2 fertilization

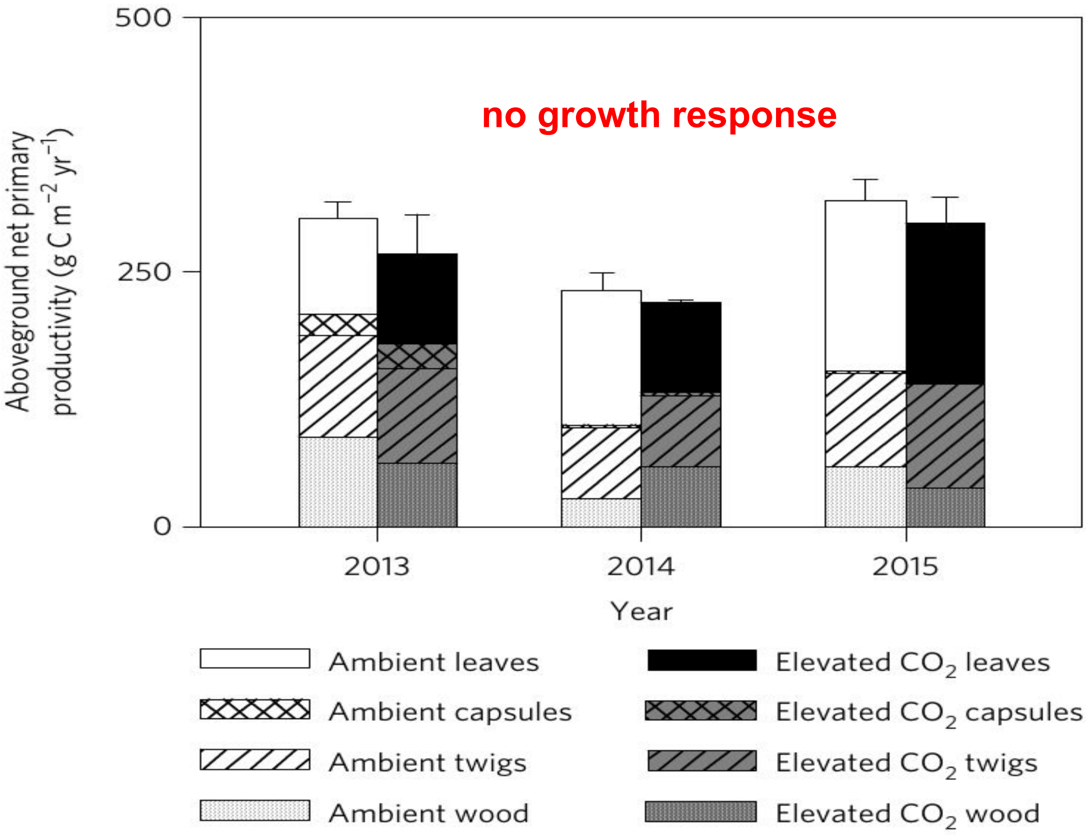


Negative feedback: dampening climate change



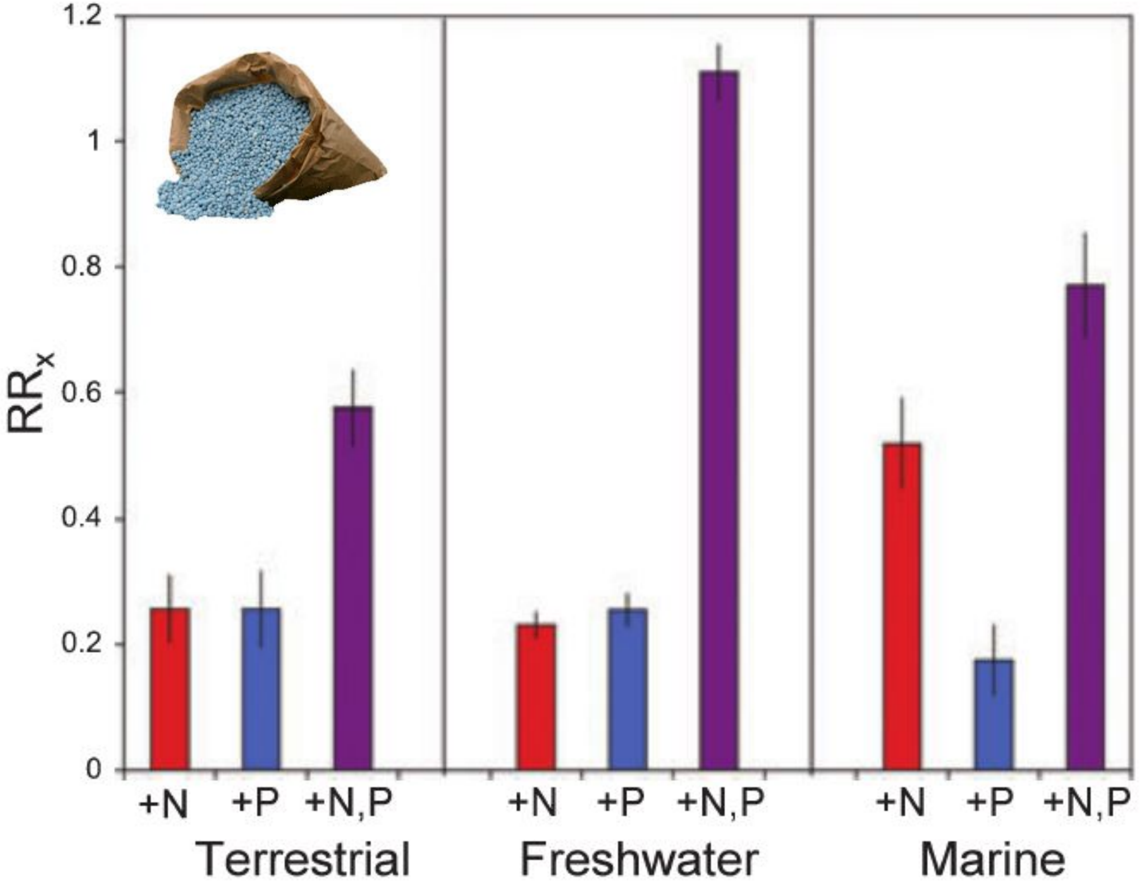
Ecosystem manipulation experiments

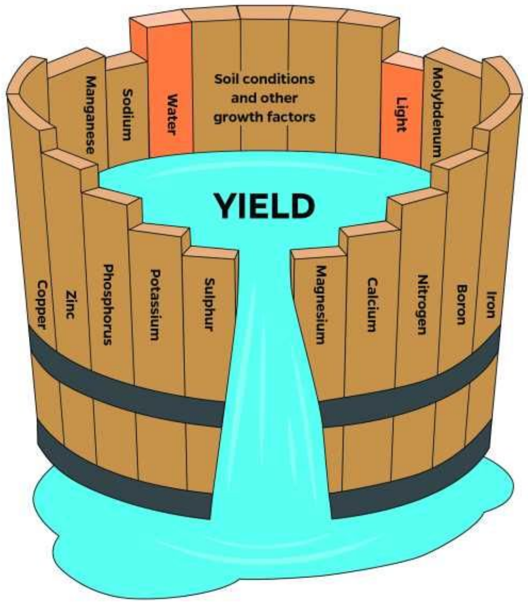
Free Air Carbon Enrichment Experiment (FACE)



Ellsworth et al. 2017

Nutrient limitation of growth is widespread





Elser et al. 2007

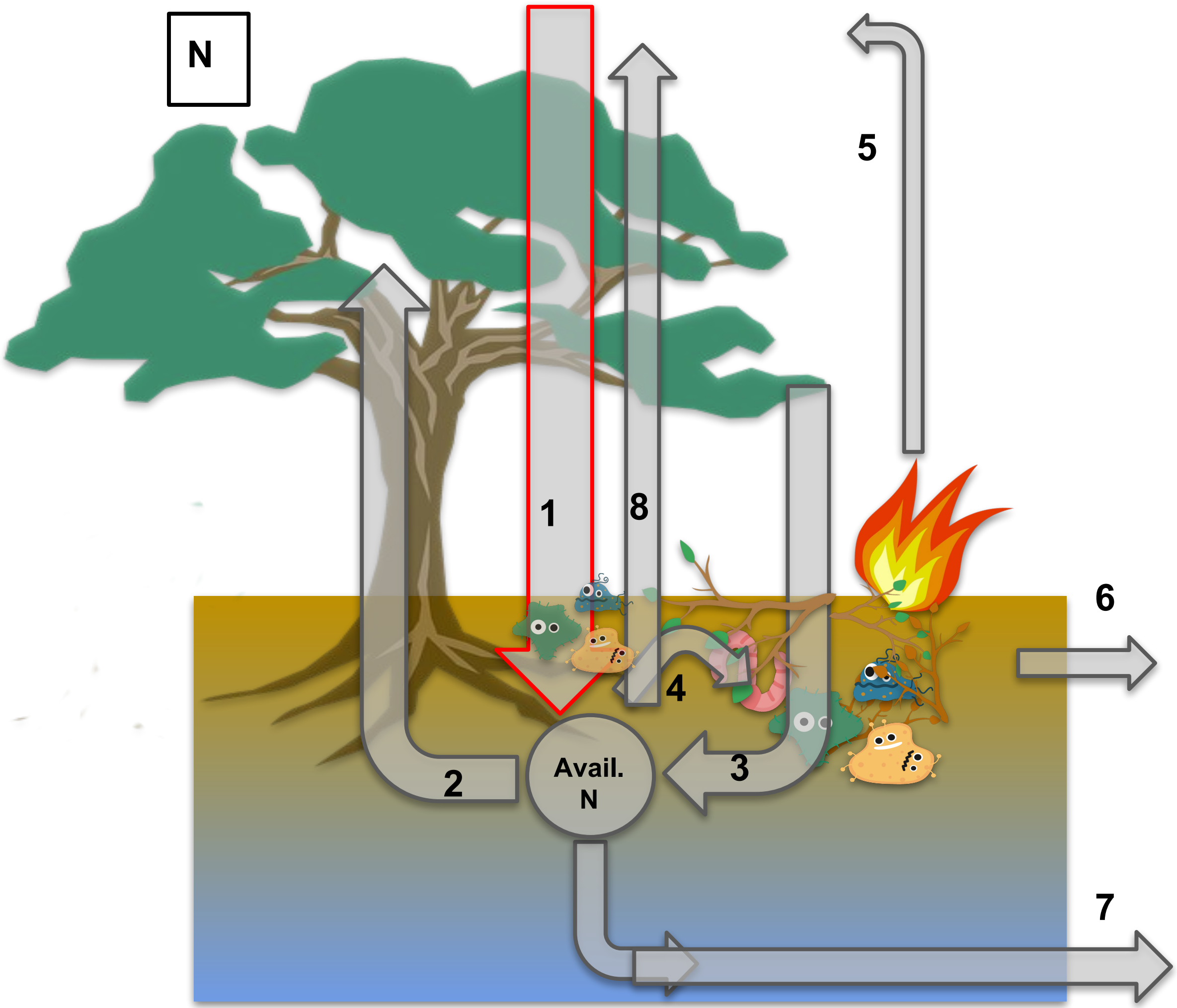
Nitrogen is increasingly included into models

	Bookkeeping models		DGVMs															
	H&N2017	BLUE	CABLE-POP	CLASS-CTEM	CLM5.0	DLEM	ISAM	JSBACH	JULES	LPJ-GUESS	LPJ	LPX-Bern	OCN	ORCHIDEE-CNP	ORCHIDEE-Trunk	SDGVM	SURFEX	VISIT
Processes relevant for E_{LUC}																		
Wood harvest and forest degradation[a]	Y	Y	Y	N	Y	Y	Y	Y	N	Y	Y	N[d]	Y	N	Y	N	N	Y
Shifting cultivation/sub-grid-scale transitions	N[b]	Y	Y	N	Y	N	N	Y	N	Y	Y	N[d]	N	N	N	N	N	Y
Cropland harvest (removed, r, or added to litter, l)	Y(r)[h]	Y(r)[h]	Y(r)	Y(l)	Y(r)	Y	Y	Y(r,l)	N	Y(r)	Y(l)	Y(r)	Y(r,l)	Y(r)	Y(r)	Y(r)	N	Y(r)
Peat fires	Y	Y	N	N	Y	N	N	N	N	N	N	N	N	N	N	N	N	N
Fire as a management tool	Y[h]	Y[h]	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
N fertilisation	Y[h]	Y[h]	N	N	Y	Y	Y	N	N	Y	N	Y	Y	Y	N	N	N	N
Tillage	Y[h]	Y[h]	Y	Y[e]	N	N	N	N	N	Y	N	N	N	N	Y[g]	N	N	N
Irrigation	Y[h]	Y[h]	N	N	Y	Y	Y	N	N	Y	N	N	N	N	N	N	Y[g]	N
Wetland drainage	Y[h]	Y[h]	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Erosion	Y[h]	Y[h]	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	Y
Southeast Asia peat drainage	Y	Y	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
Grazing and mowing harvest (removed, r, or added to litter, l)	Y(r)[h]	Y(r)[h]	Y(r)	N	N	N	Y(l)	Y(l)	N	Y(r)	Y(l)	N	Y(r,l)	N	N	N	N	N
Processes relevant also for S_{LAND}																		
Fire simulation	US only	N	N	Y	Y	Y	N	Y	N	Y	Y	Y	N	N	N	Y	Y	Y
Climate and variability	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
CO_2 fertilisation	N[f]	N[f]	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y[e]	Y	Y	Y
Carbon–nitrogen interactions, including N deposition	N[h]	N[h]	Y	N[d]	Y	Y	Y	Y	N	Y	N	Y	Y	Y	N	Y[c]	N[i]	N

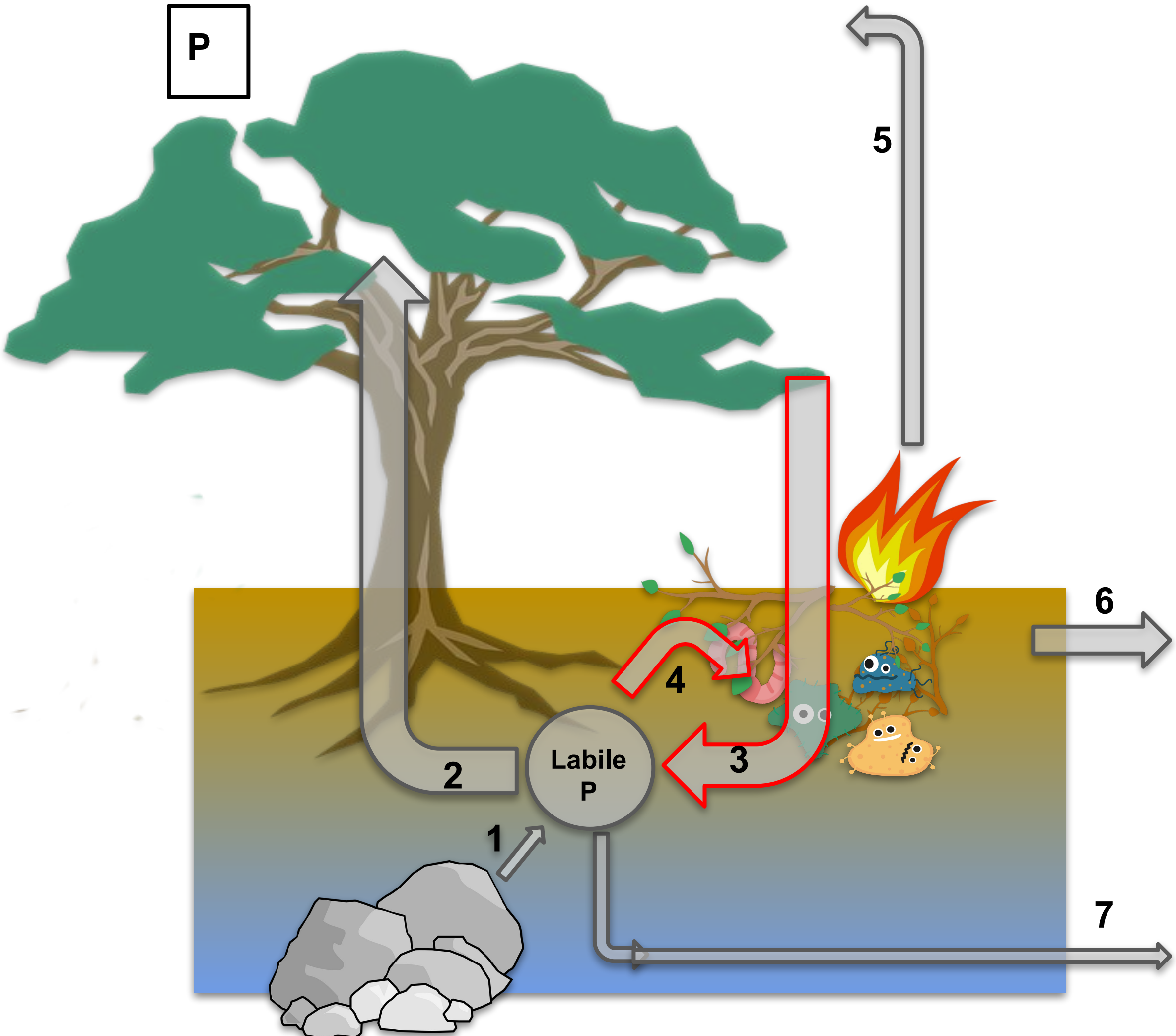
N fertilisation: 9 out of 18

Carbon–nitrogen interactions, including N deposition: 10 out of 18

Le Quere et al. 2018



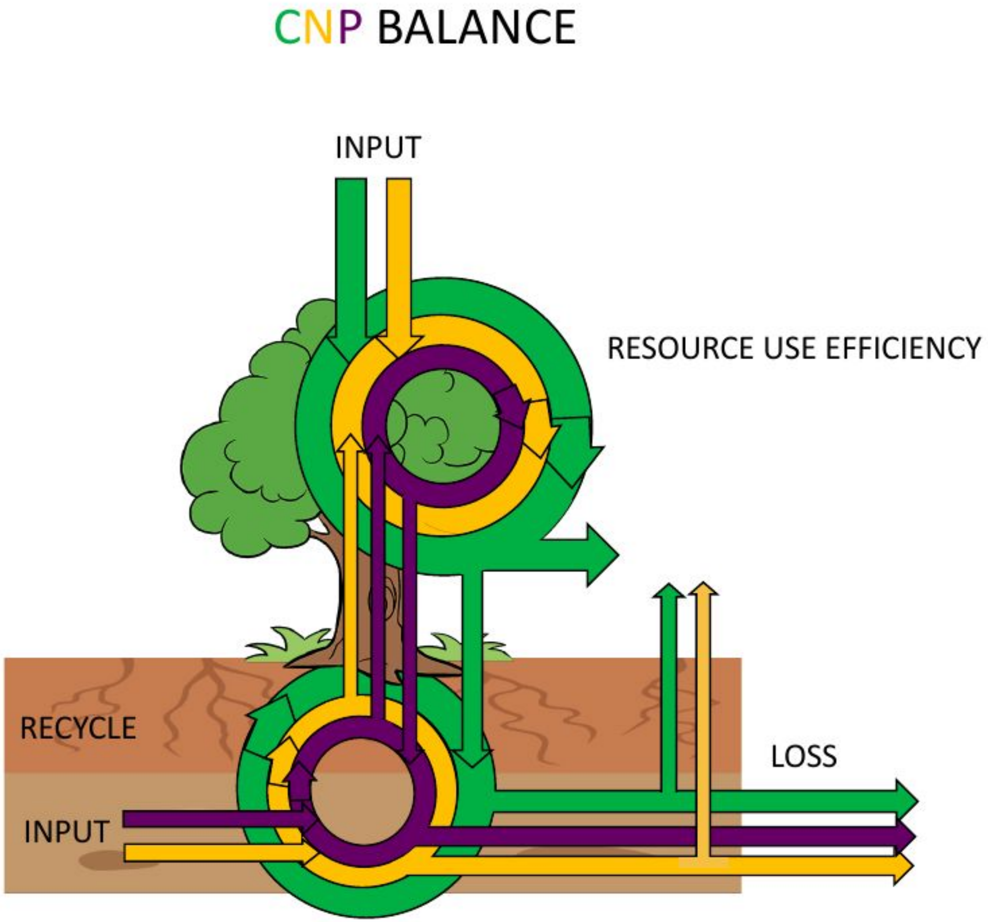
1 Biological nitrogen fixation
2 Plant uptake
3 Litter fall & mineralisation
4 Immobilisation
5 Fire emission
6 Erosion
7 Leaching
8 Denitrification



1 Weathering
2 Plant uptake
3 Litter fall & decomposition
4 Immobilisation
5 Fire emission
6 Erosion
7 Leaching

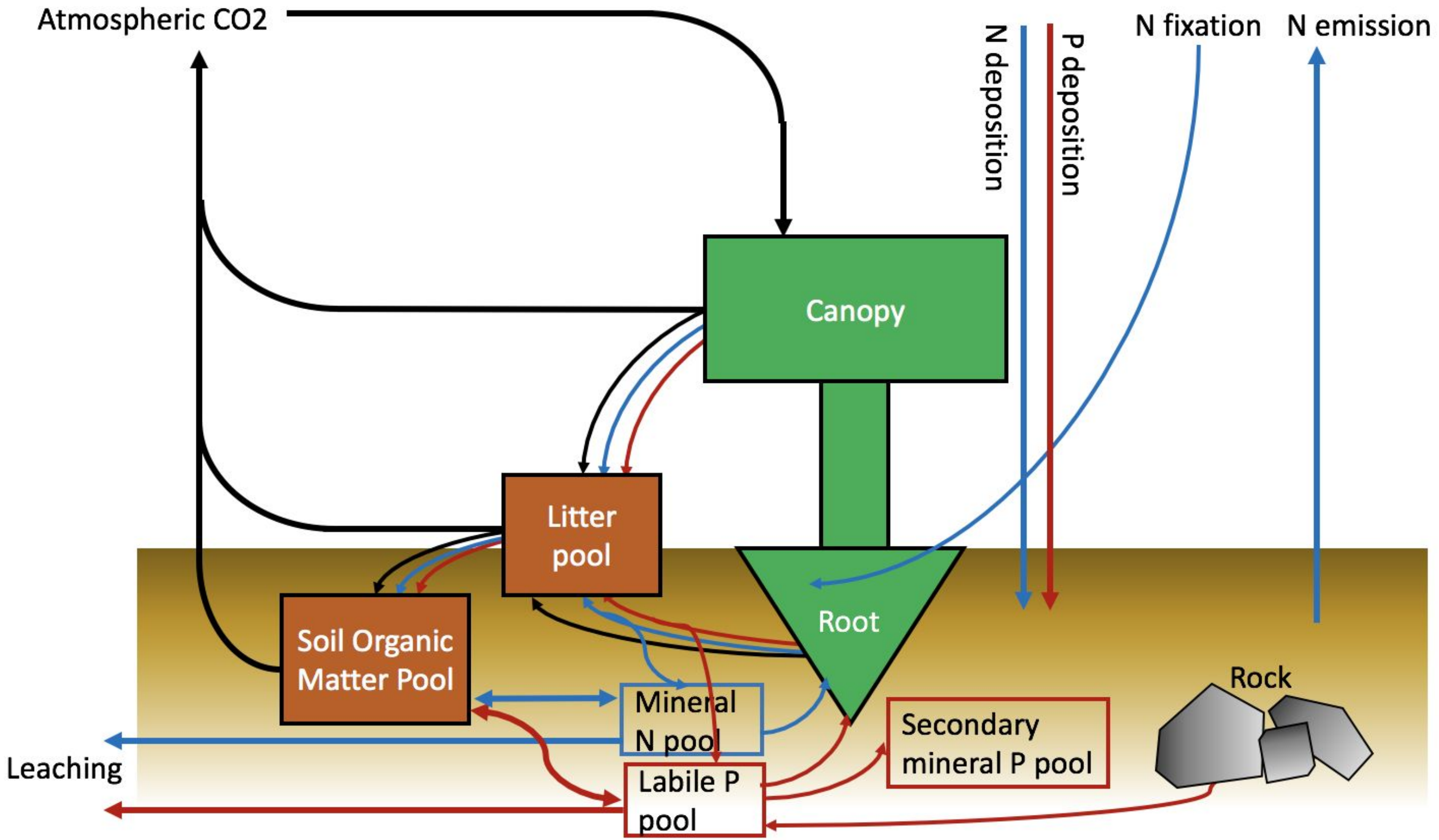
What processes are implemented?

ORCHIDEE-CNP (Goll et al. 2017b)

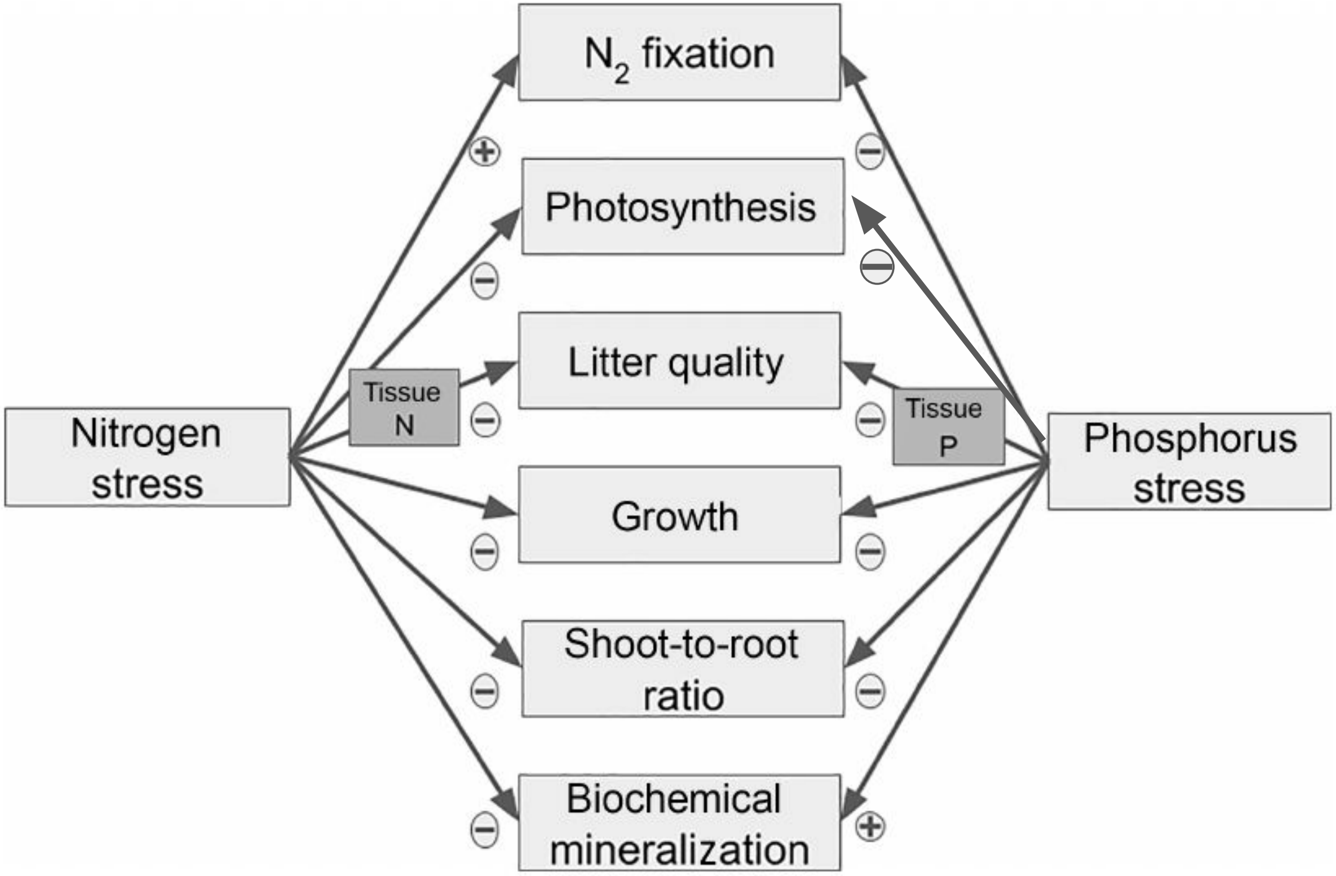


<u>Key paper:</u>
Krinner et al. 2005
Zaehle & Friend 2010
Goll et al. 2012
Naudts et al. 2015
Vuichard et al. in review
Goll et al. 2017b

ORCHIDEE-CNP (Goll et al. 2017b)



Major interactions



Goll et al. 2017

Ellsworth et al. in prep.

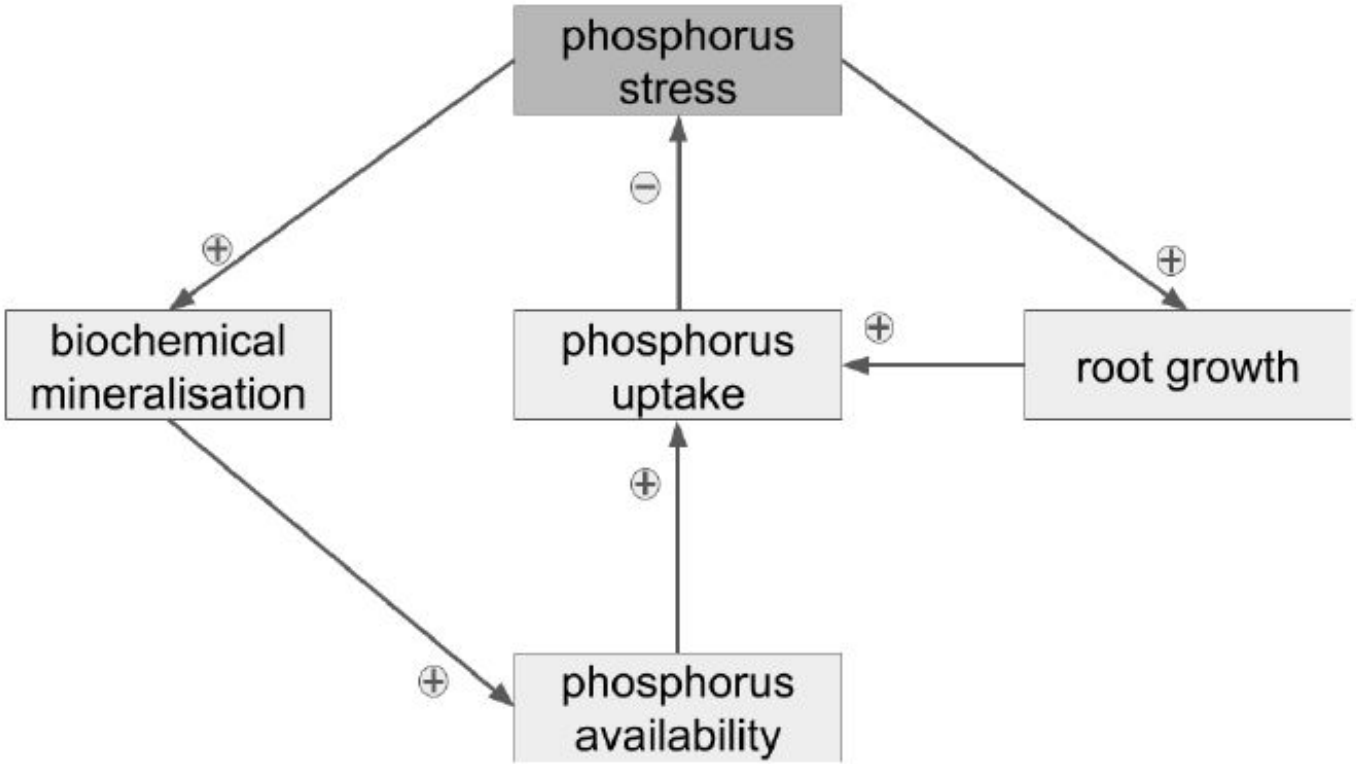
Zaehle & Friend, 2010

Zaehle & Friend, 2010

Zaehle & Friend, 2010

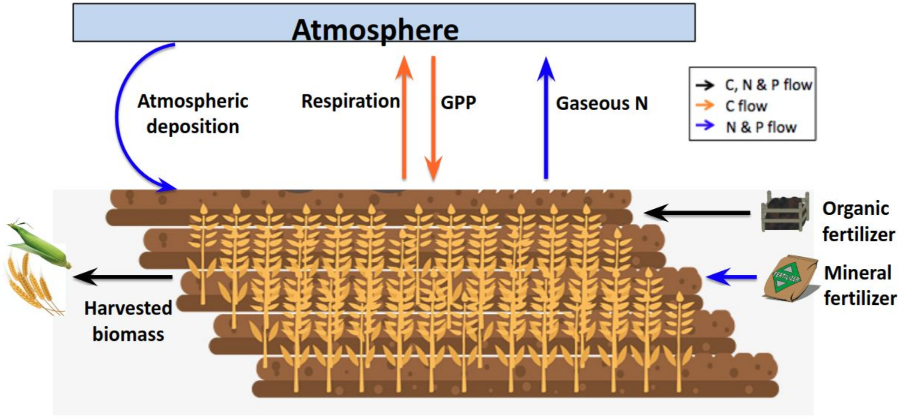
Goll et al. 2017

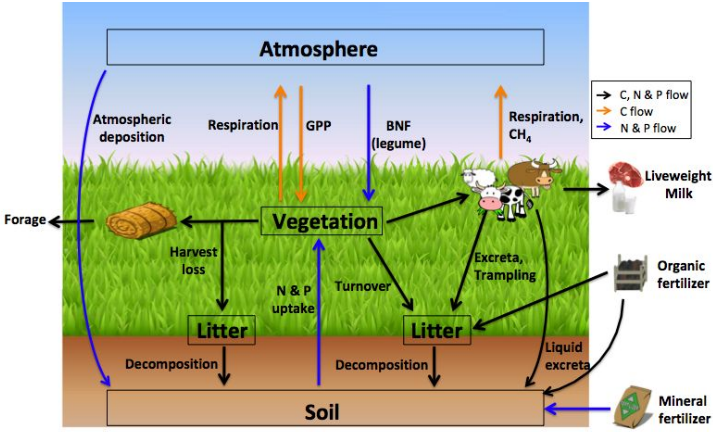
Feedbacks: e.g. ecosystem scale



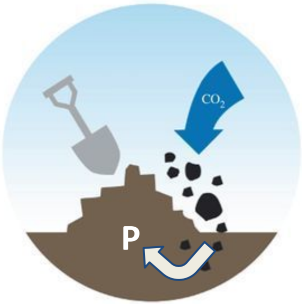
Land management / fire

1. Cropland (trunk) & grassland management (Chang et al. 2013, ...)



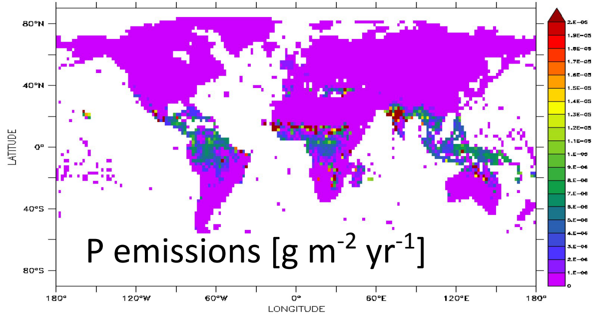


2. Negative emission technologies (Goll et al. in prep)



Enhanced weathering
Crushed minerals for direct carbon dioxide capture and improved soil fertility.
(Goll et al. in prep.)

3. Fire emission (trunk module)



publications / contributions

Model description: Goll et al. 2017b, Goll et al. 2018, Sun et al. in prep.
Evaluation, site-scale: Goll et al. 2017b, Goll et al. 2018, Huang et al. in prep., Combe et al. in prep.
Evaluation, global: Sun et al. in prep.
Resource-interactions and use efficiencies: Goll et al. 2018, Zhang et al. 2018, Sun et al. in prep., Cresto-Aleina et al. in prep.

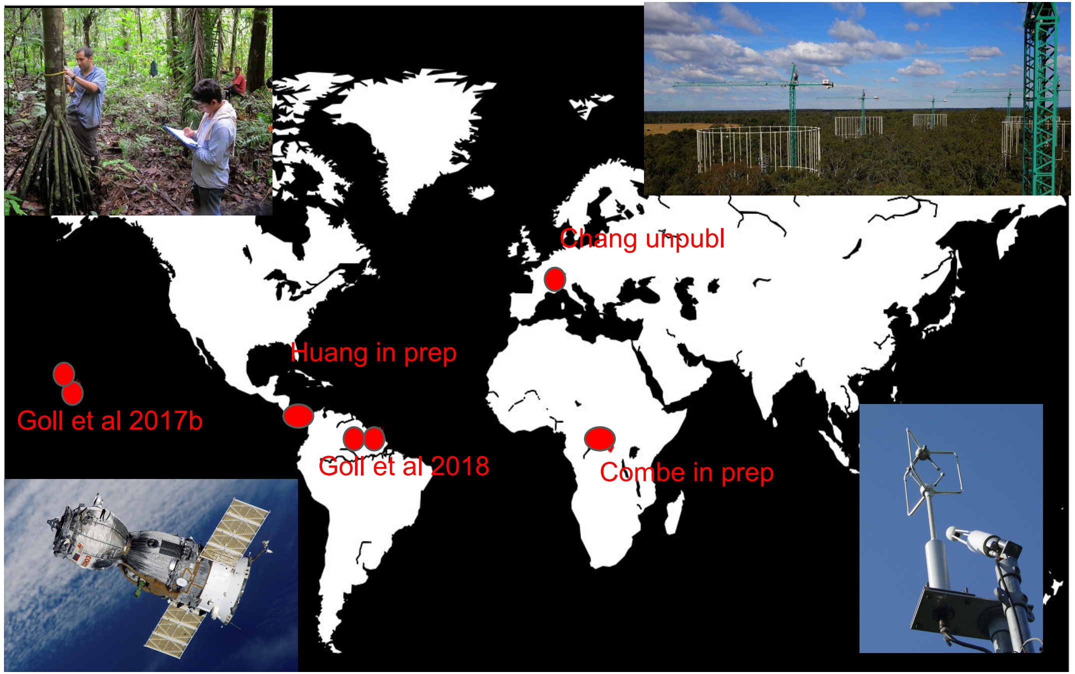
Model intercomparisons:
AmazonFACE (Fleischer et al, in revision)
INTERFACE2 - precipitation response (Fatichi et al, in prep.)
Global N_2O model intercomparison project (NMIP) (Tiang et al., 2018)
Global carbon budget 2018 (Le Quere et al., 2018)
GPP - leaf P relationship (Ellsworth et al, in prep.)

Does it work?

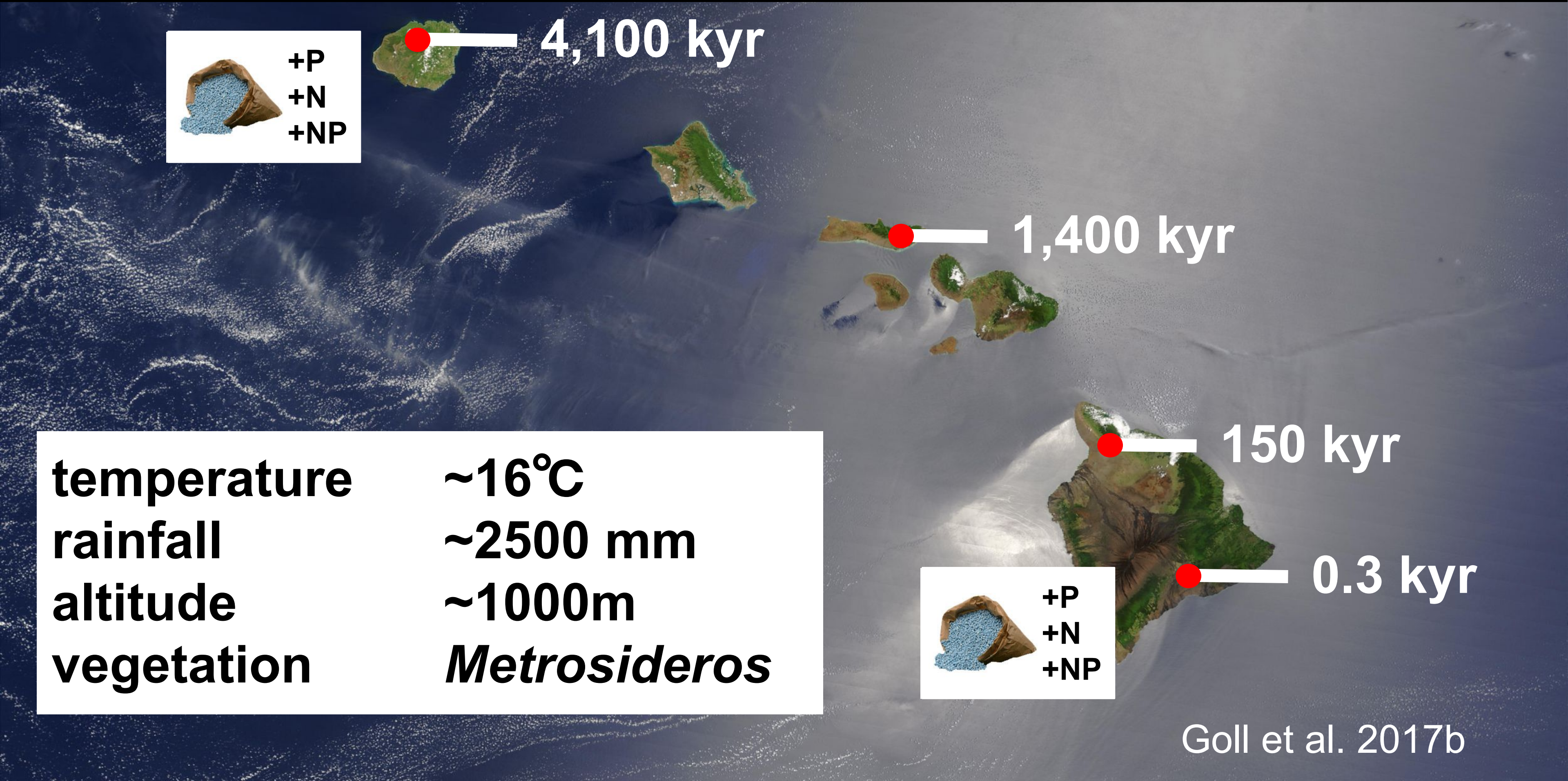
“Although it seems reasonable to expect that a model including a larger subset of processes that are known to be important should be more realistic than a simpler model, increases in ***reliability and robustness*** *are by no means automatic.” (Prentice et al. 2015).*

Evaluation

spatial extent: local, regional to global
data: forest inventories, eddy covariance towers, satellite products, river discharge ...
ecosystem manipulation experiments: free air carbon enrichment, fertilization, throughfall exclusion, ...



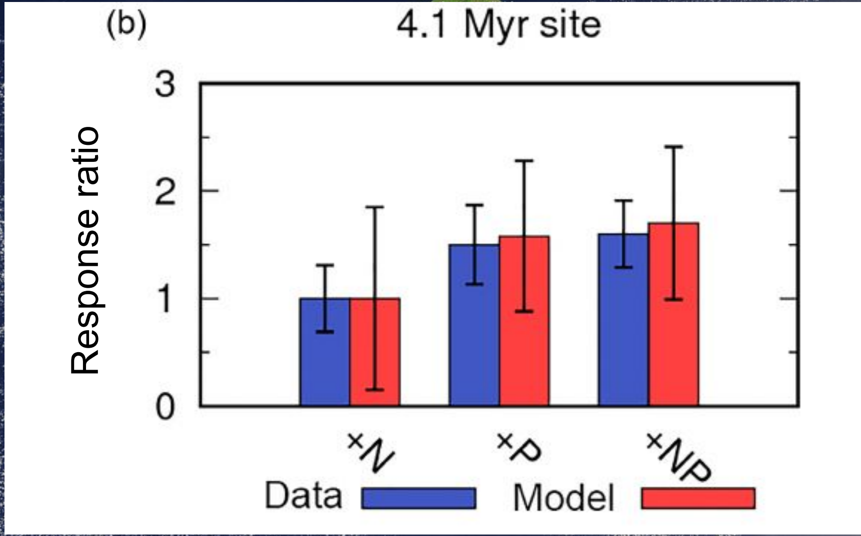
Hawaii: fertilization experiments

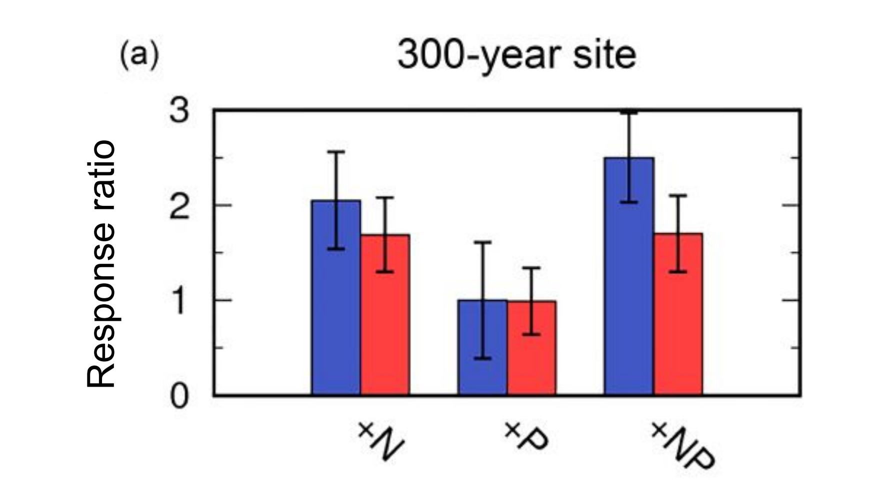


temperature	~16℃
rainfall	~2500 mm
altitude	~1000m
vegetation	*Metrosideros*

Goll et al. 2017b

Hawaii: fertilization experiments

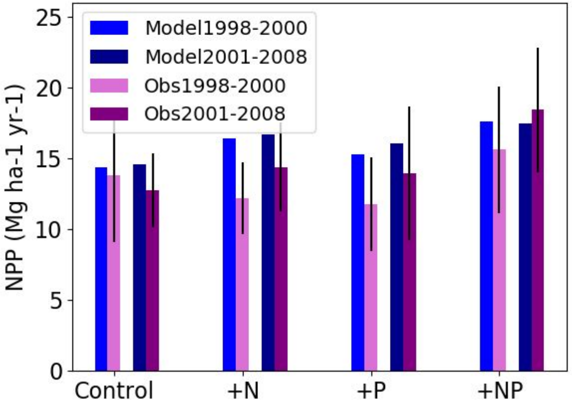




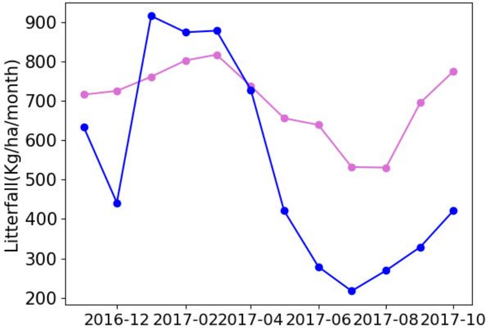
Goll et al. 2017b

Model evaluation: S-America

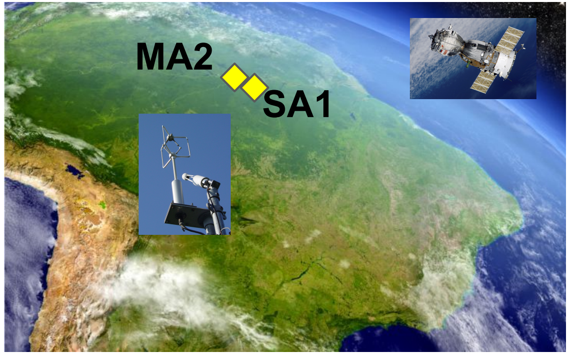
Growth response

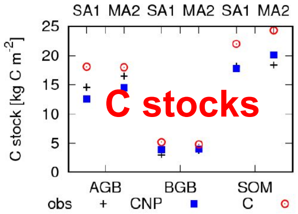


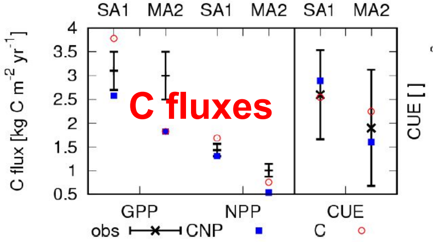
Identification of major issues



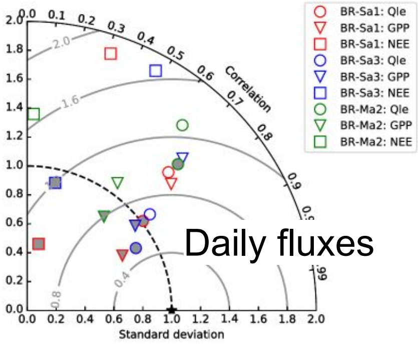
Huang et al. in prep







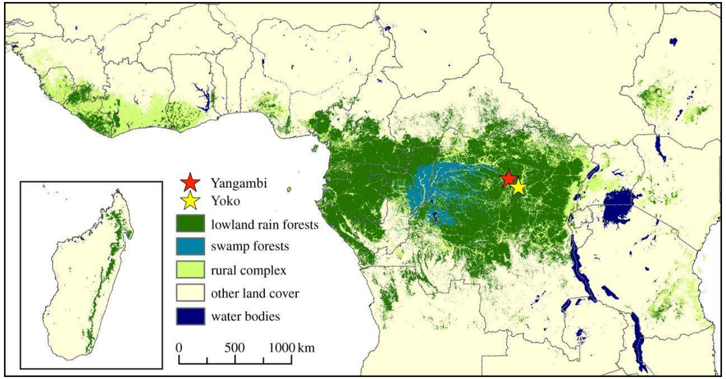
Site	EC	NIR_t	NIR_v	C model	CNP model
BR-MA2	0.195	0.211	0.242	0.402	0.143
BR-Sa1	0.104	0.189	0.236	0.408	0.267
BR-Sa3	0.165	0.176	0.225	0.482	0.224



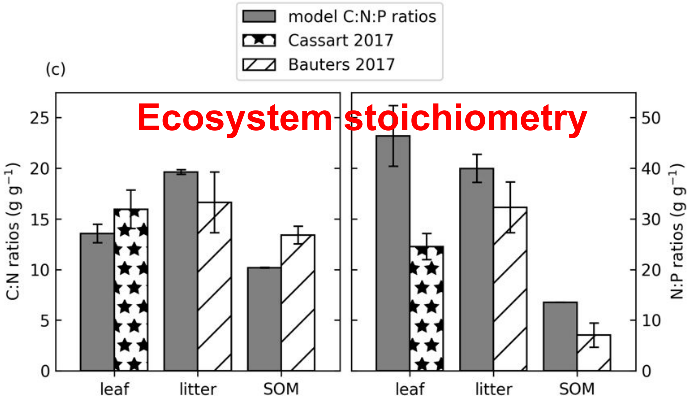
Variability in C fluxes

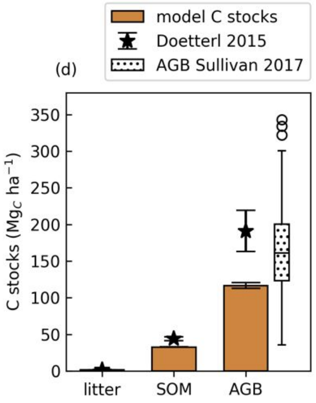
Goll et al. 2018

Model evaluation: Africa

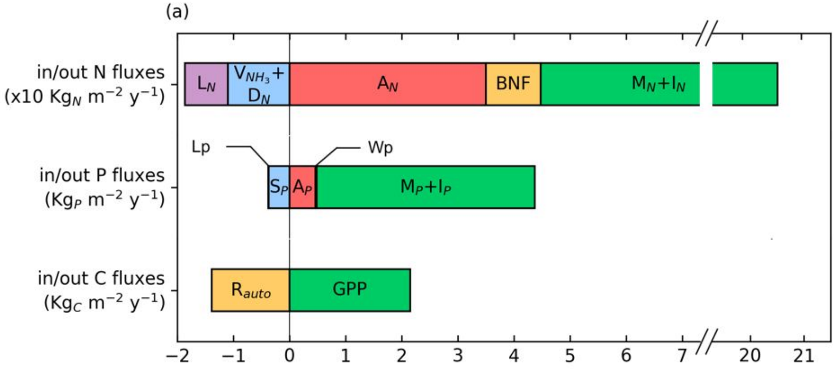


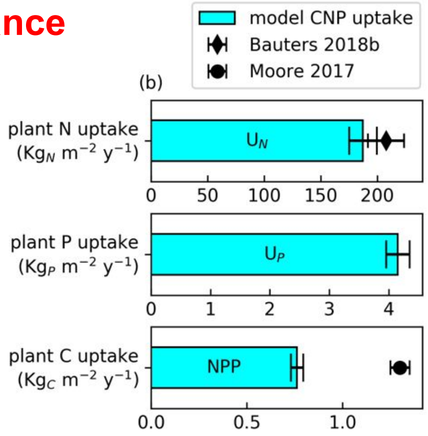
Ecosystem stoichiometry





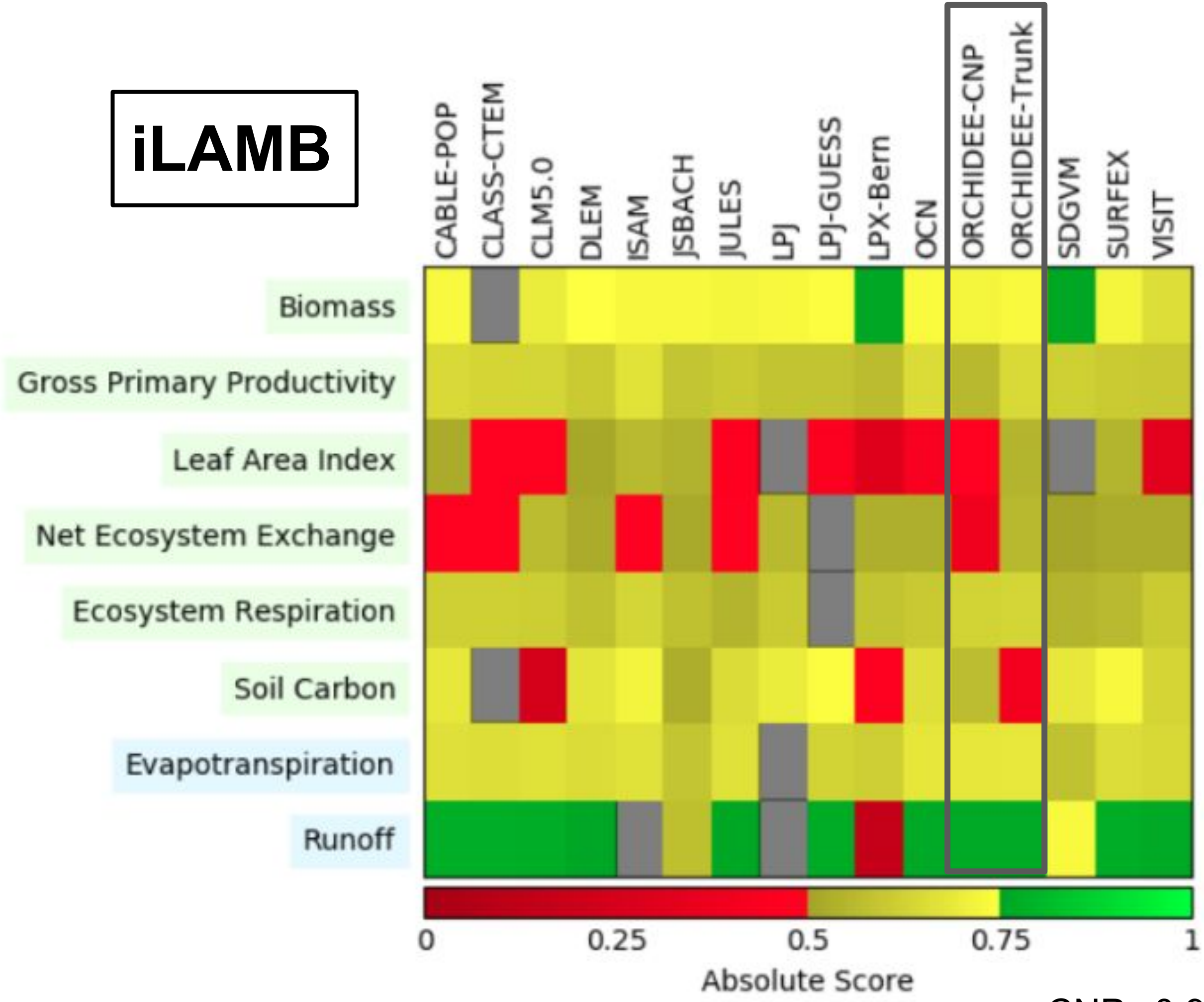
nutrient balance





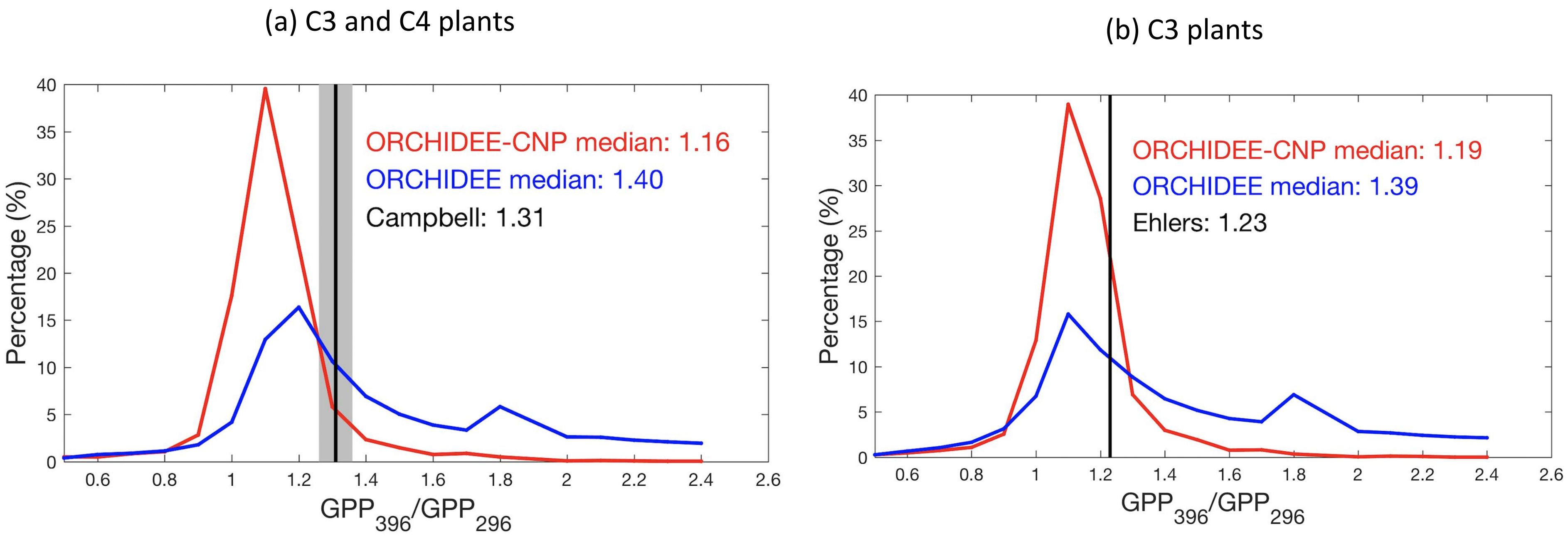
Combe et al. in prep

iLAMB



CNP v0.9

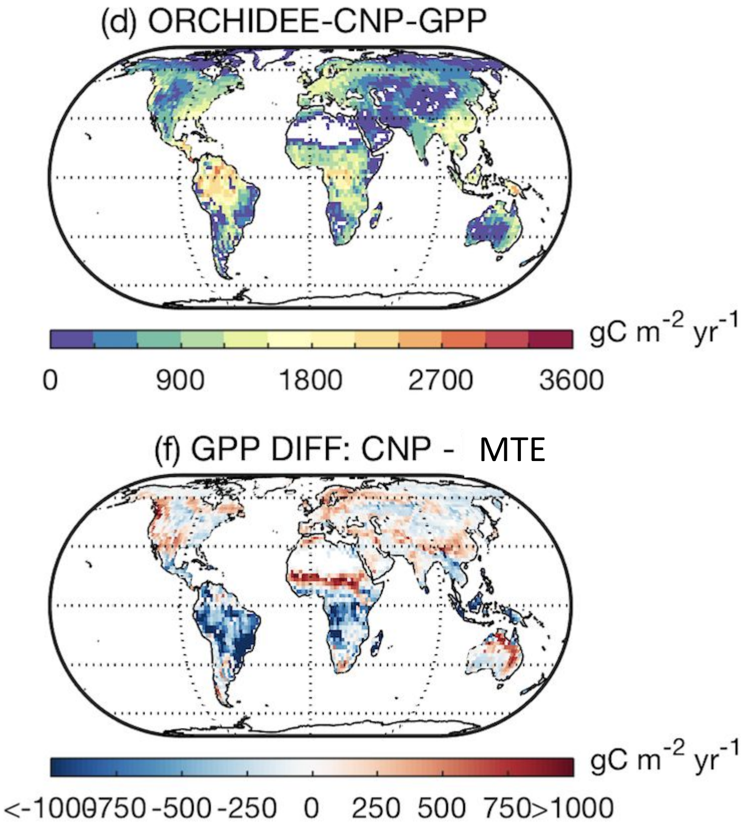
CO_2 fertilization effect of GPP

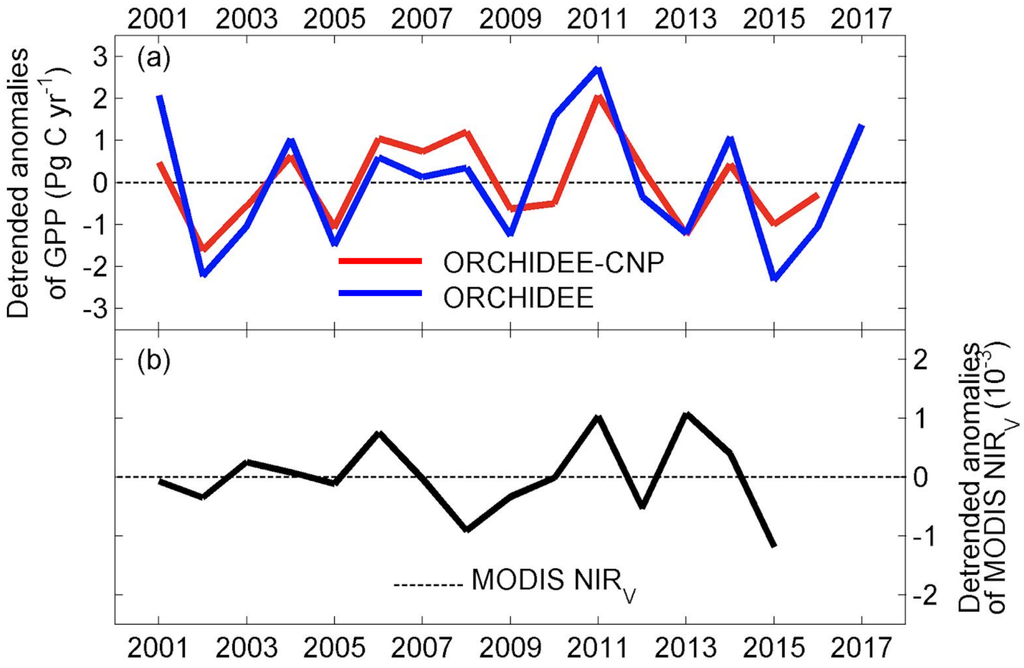


ORCHIDEE: uses an empirical down-regulation of CO2 fertilization based on short-term FACE experiments

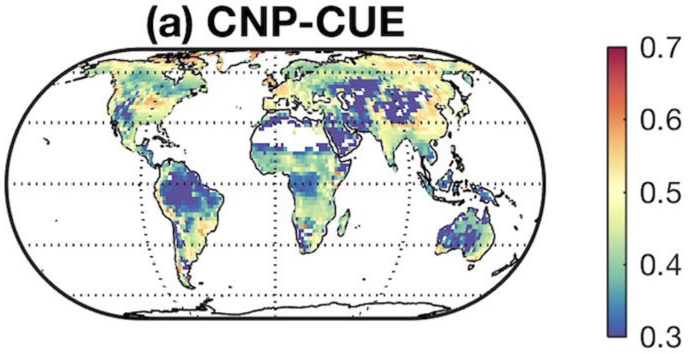
GPP in space in time

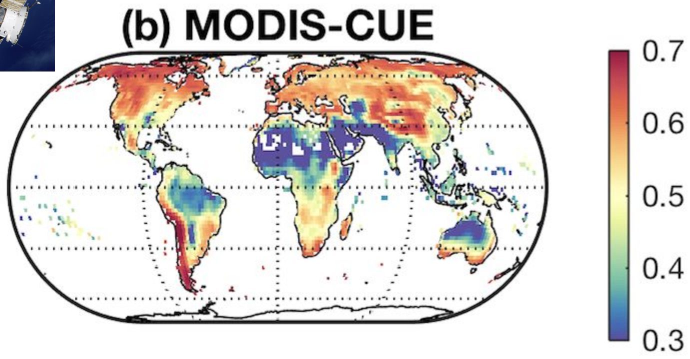
CNP v1.0, v1.1

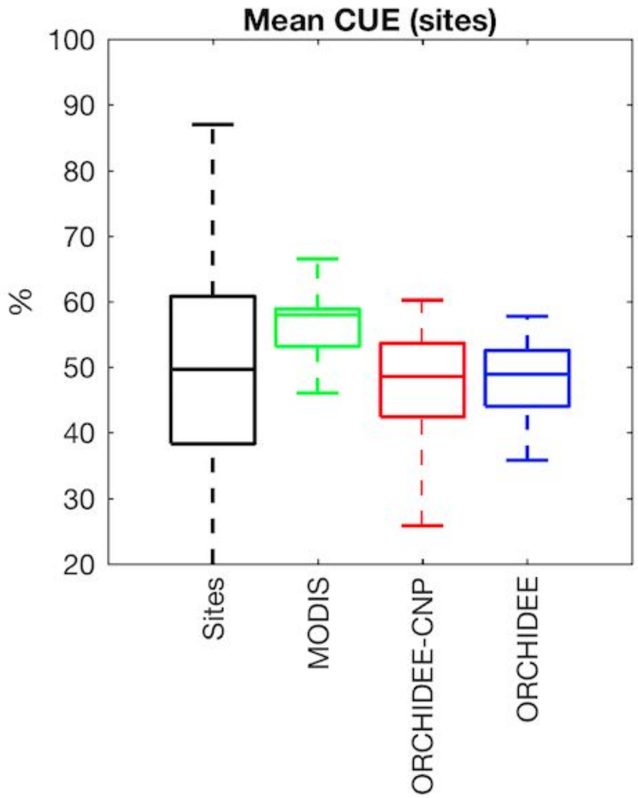




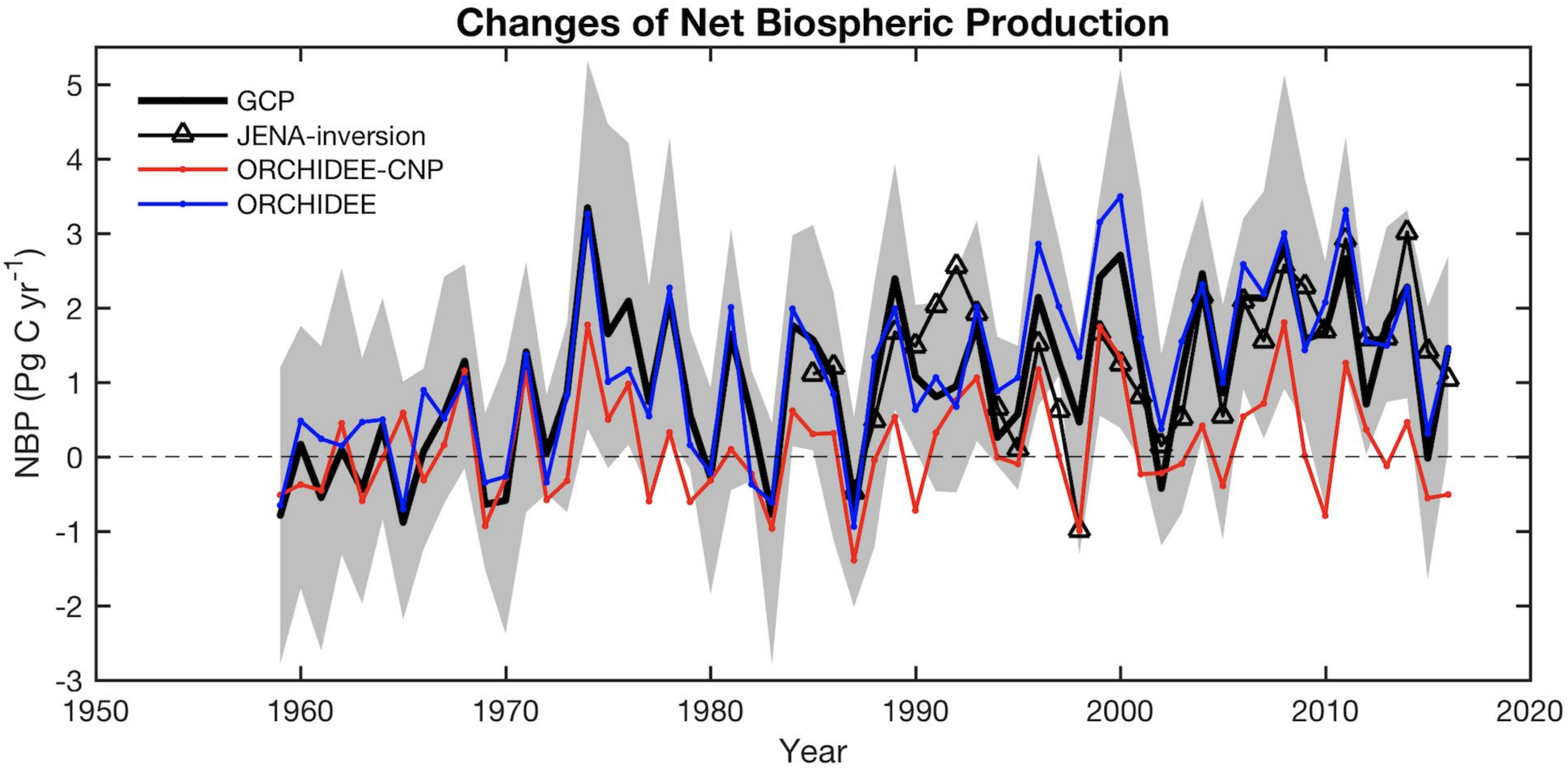
Carbon use efficiencies







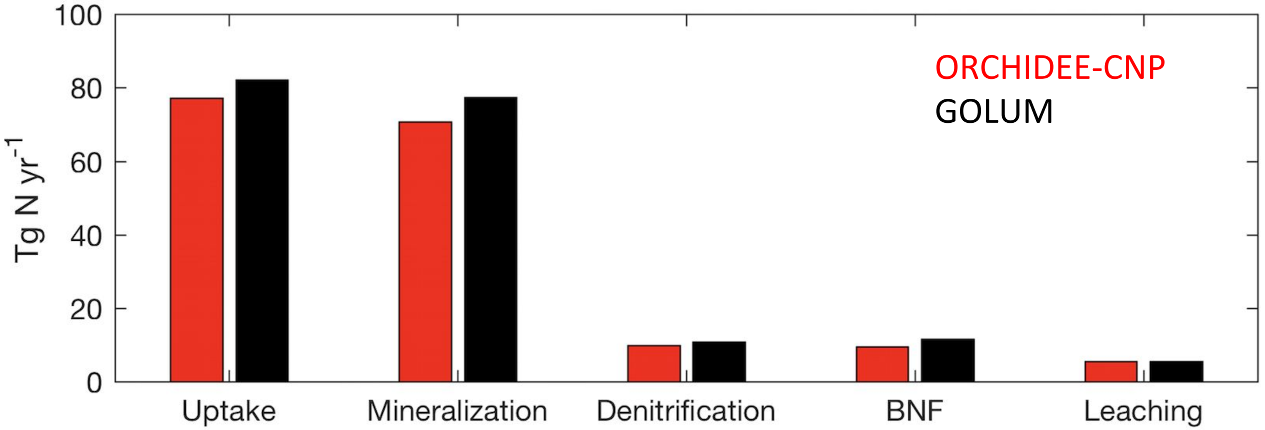
C sink: too low



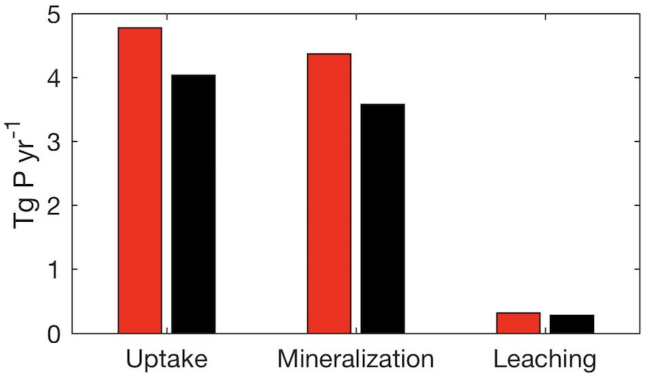
CNP v1.1

N and P fluxes: e.g. global fluxes

N fluxes

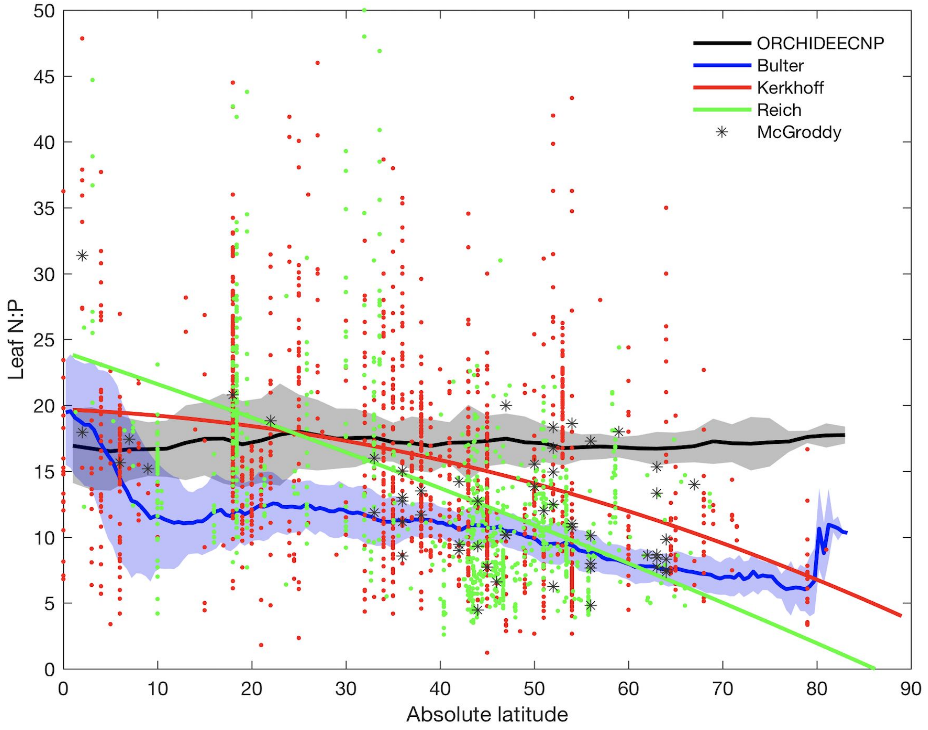


P fluxes



GOLUM-CNP v1.0: a data-driven modeling of carbon, nitrogen and phosphorus cycles in major terrestrial biomes (Wang, 2018, GMD)

Leaf N:P ratio for model evaluation



Is a well observed property of ecosystems

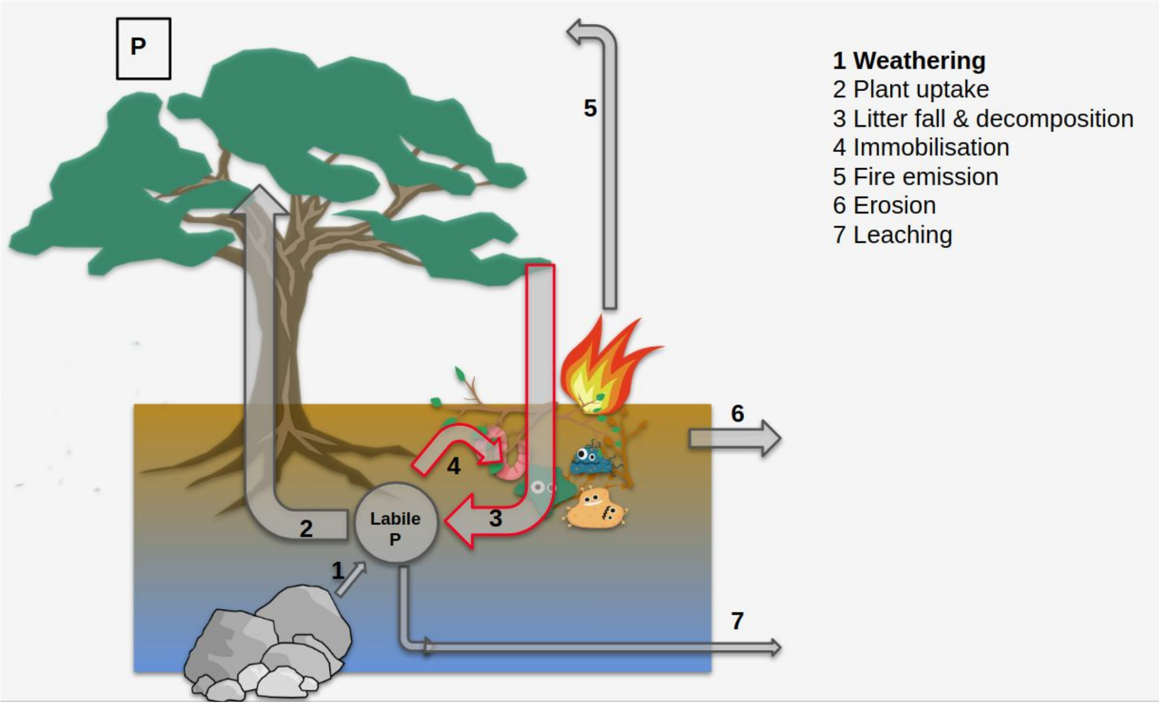
ORCHIDEE:

- Dynamically computed in ORCHIDEE as function of availability and demand of nutrients
- Global uniform range parameterization / other models prescribe narrow PFT-specific range (see table)

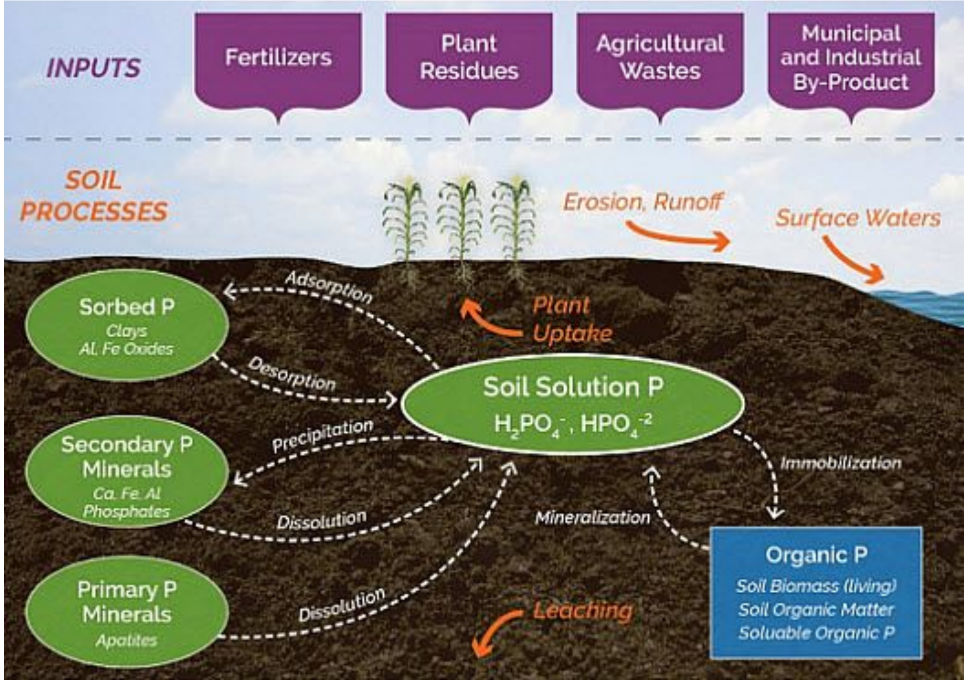
Parameter	unit	1	2	3	4	5	7	8	9	10	12	16
leaf N:P	gN/gP	9.8 (2.9)	19.2 (1.2)	8.1 (1.3)	16.0 (4.7)	10.1 (2.4)	8.8 (0.8)	17.0 (4.5)	23.6 (4.5)	20.0 (7.0)	16.0 (3.4)	10.0 (1.5)

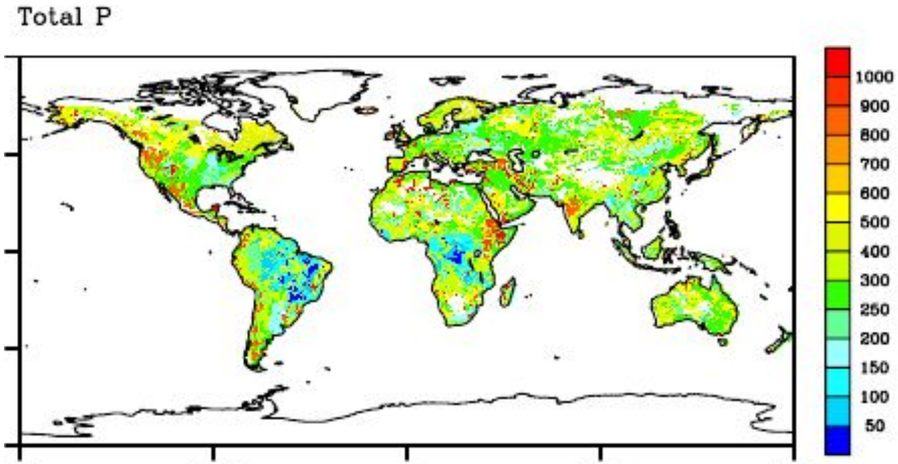
PFT 1-16 in CABLE-CNP (Wang et al 2010)

Improving critical processes



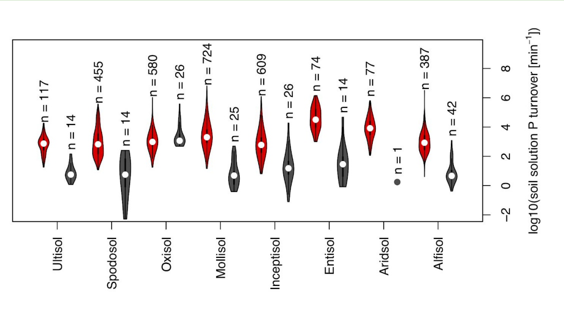
How much P is in the soils?





Yang et al. 2013

Constraining inorganic P turnover

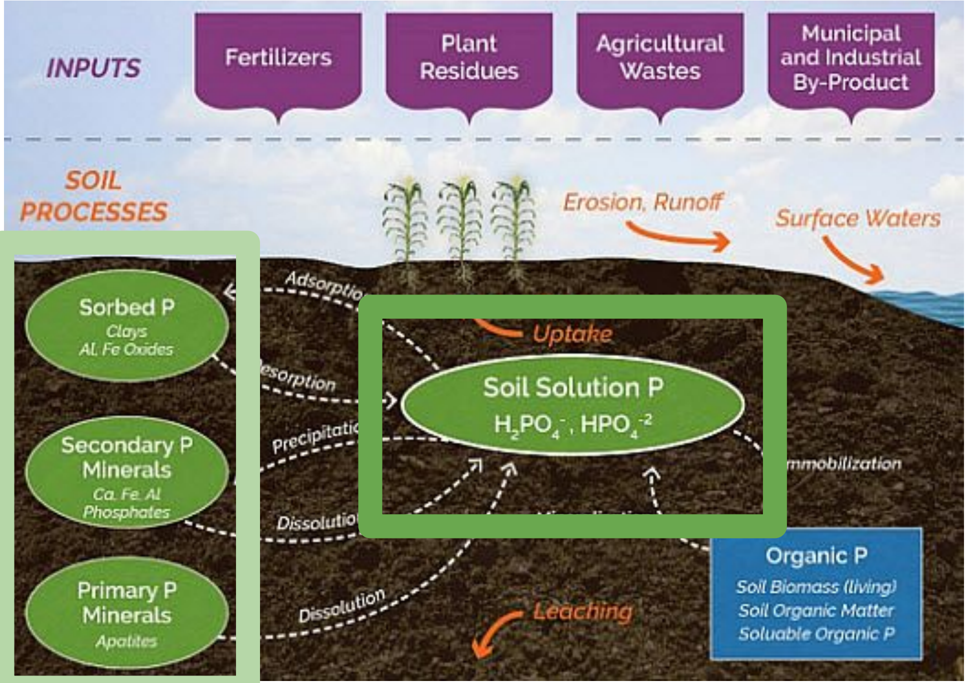


Estimates of ~~mean~~ residence times of P in commonly-considered inorganic soil phosphorus pools

Julian Helfenstein[1]*, Chiara Pistocchi[2]*, Astrid Oberson[1], Federica Tamburini[1], Daniel Goll[3], Emmanuel Frossard[1]

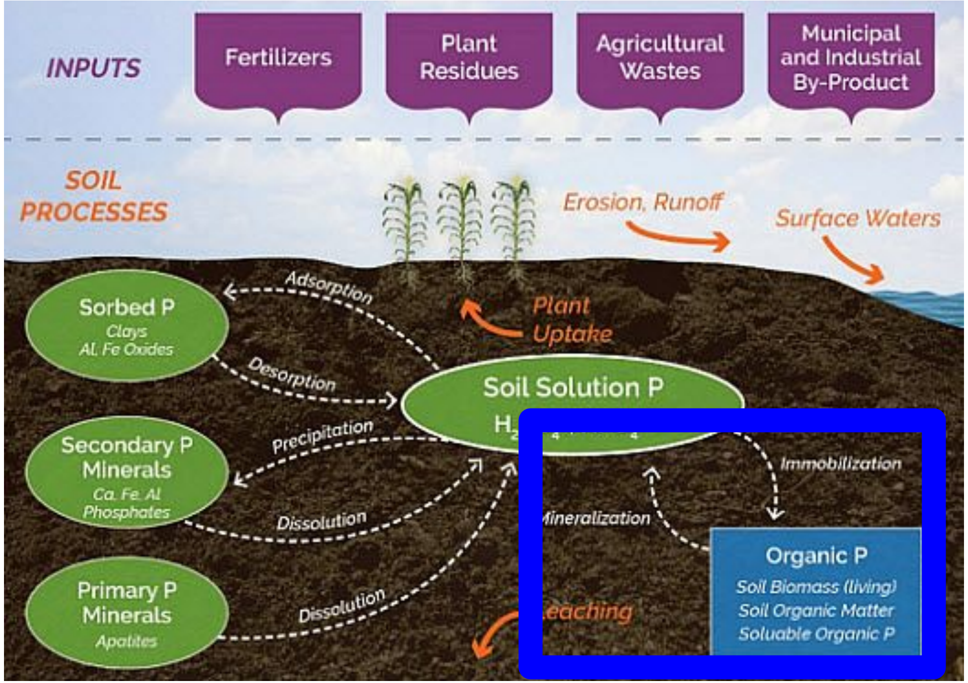
[1]Institute of Agricultural Sciences, ETH Zurich, Lindau, 8315, Switzerland
[2]Eco&Sols, Montpellier SupAgro, University of Montpellier, CIRAD, INRA, IRD, 34060 Montpellier, France
[3]Le Laboratoire des Sciences du Climat et de l'Environnement, IPSL-LSCE CEA/CNRS/UVSQ Saclay, Gif-sur-Yvette, France

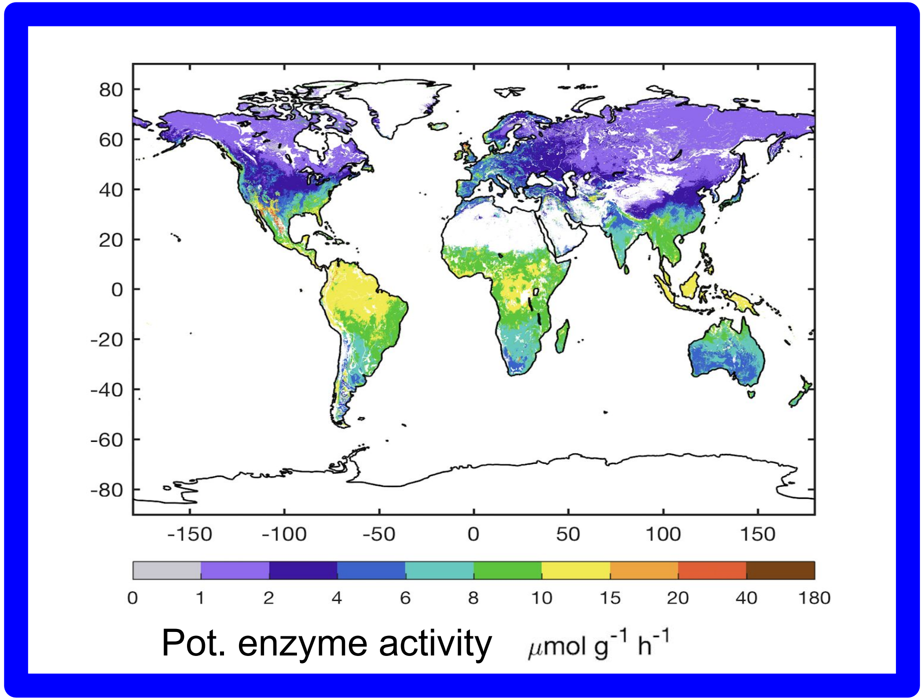
Next: SNSF early-post doc mobility grant to integrate data into ORCHIDEE



Helfenstein et al. 2018, in prep.

Constraining organic P turnover

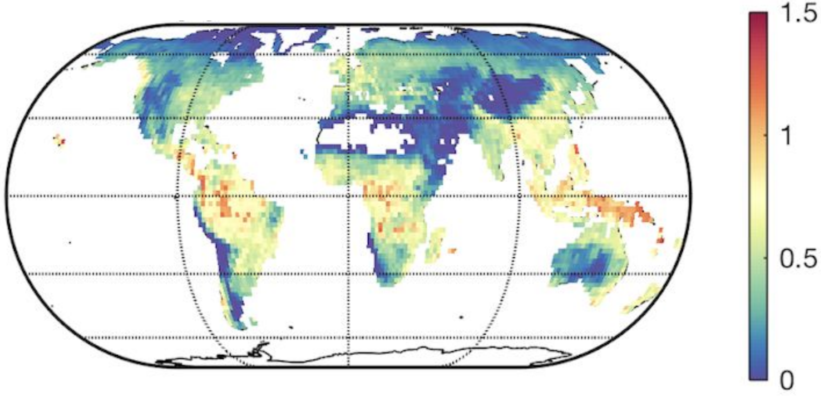




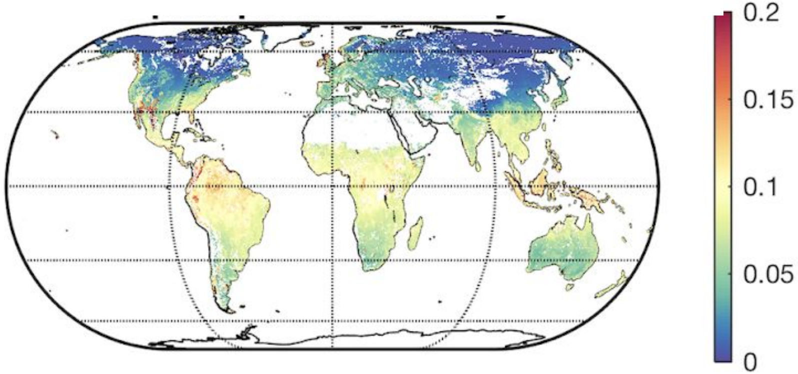
Sun et al. in prep.

Phosphatases

ORCHIDEE mineralisation flux (normalized)

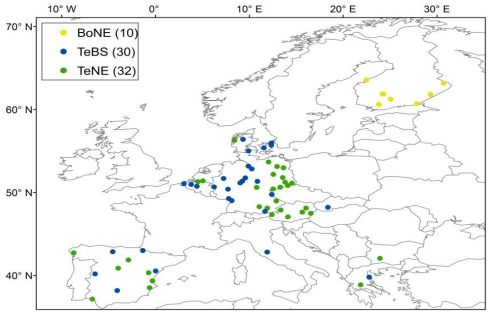


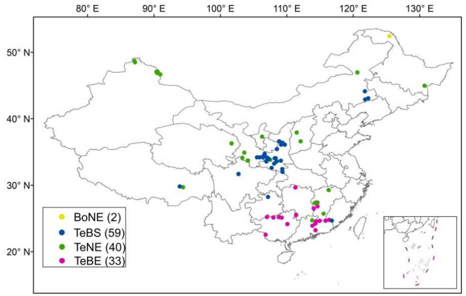
Potential enzyme activity (normalized)

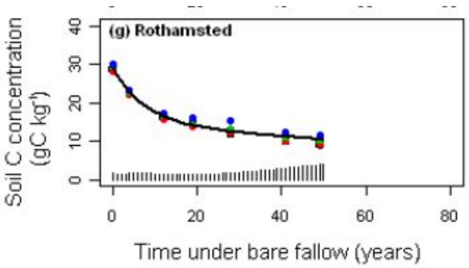


Sun et al. in prep

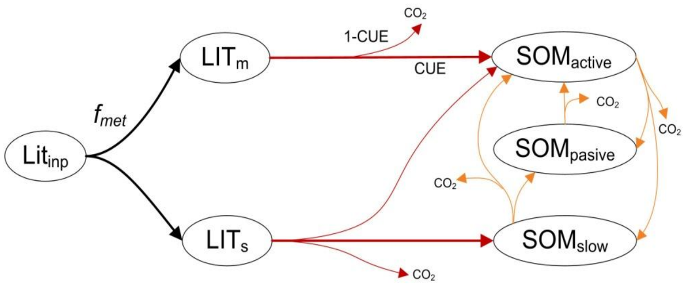
Soil organic matter decomposition model

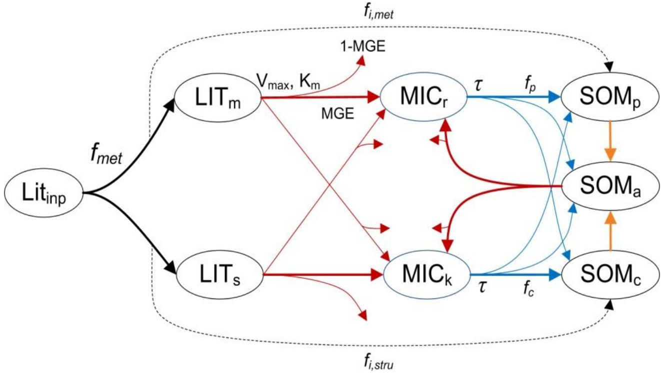


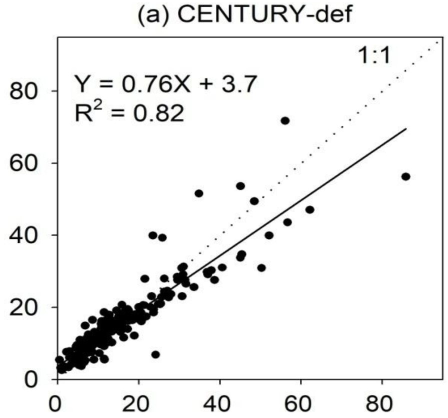


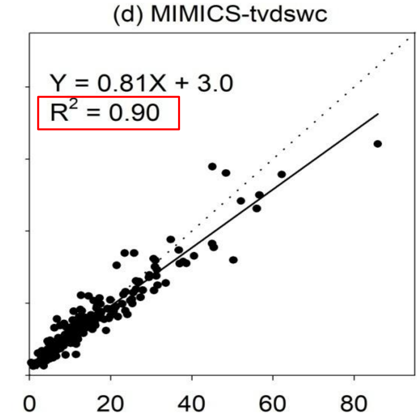


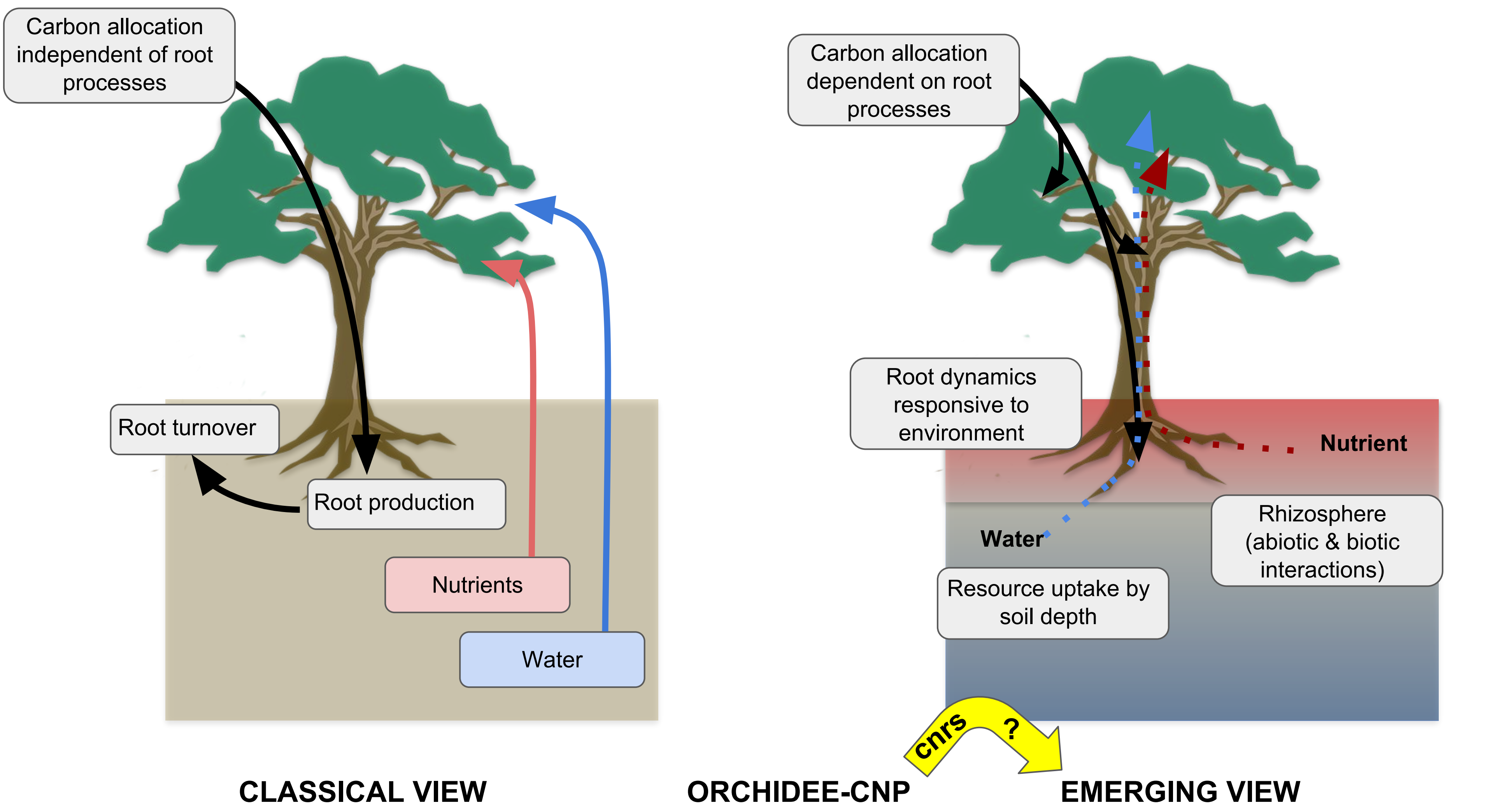
Haicheng Zhang, Ying-Ping Wang, Pierre Barre





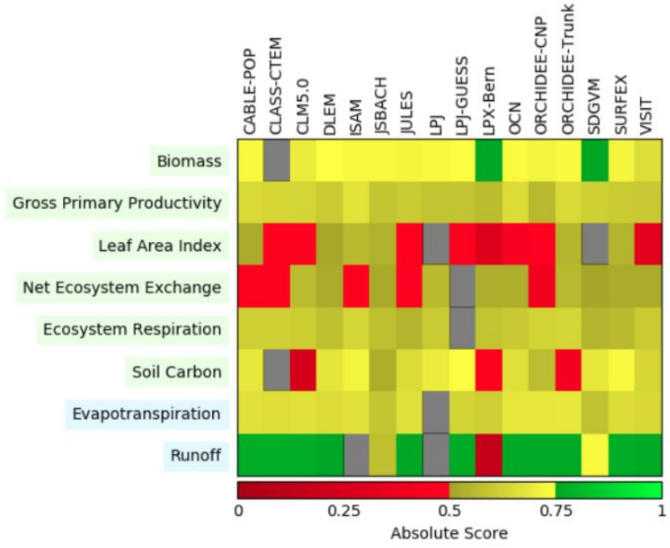




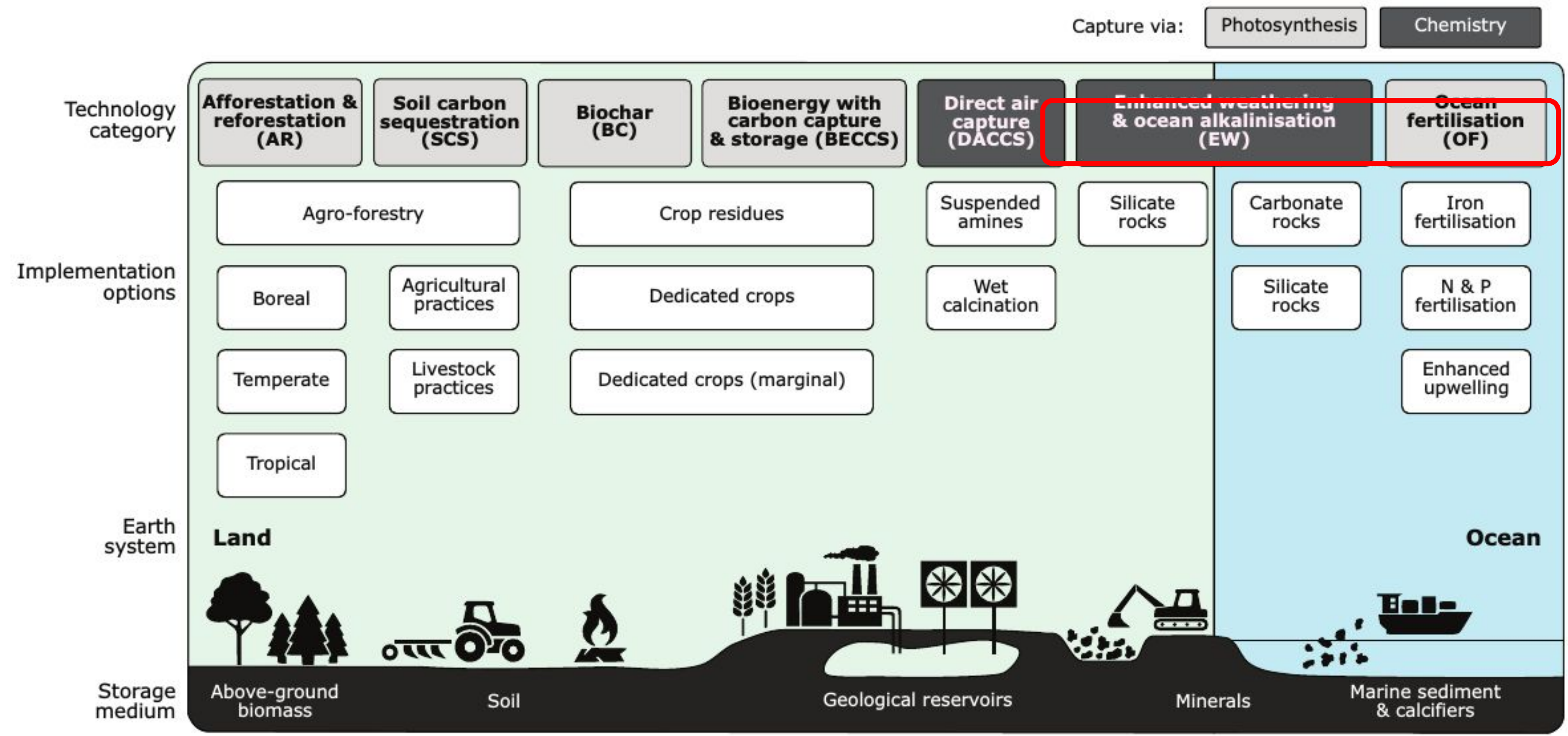


Carbon allocation independent of root processes
Root turnover
Root production
Nutrients
Water
Carbon allocation dependent on root processes
Root dynamics responsive to environment
Nutrient
Water
Rhizosphere (abiotic & biotic interactions)
Resource uptake by soil depth
cnrs
?
CLASSICAL VIEW
ORCHIDEE-CNP
EMERGING VIEW

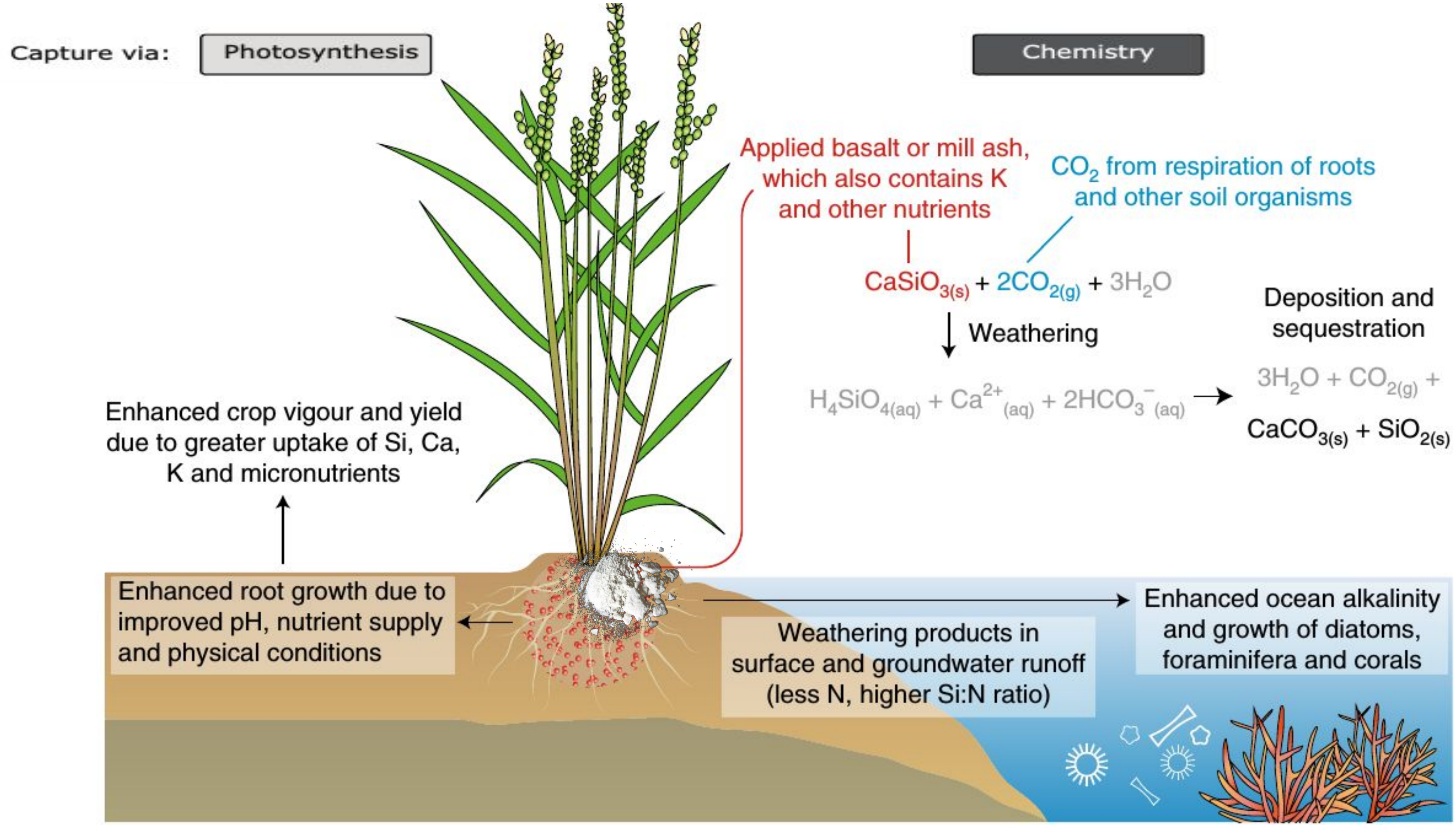
What could a CNP model be used for?



Negative emission technologies (NETs)

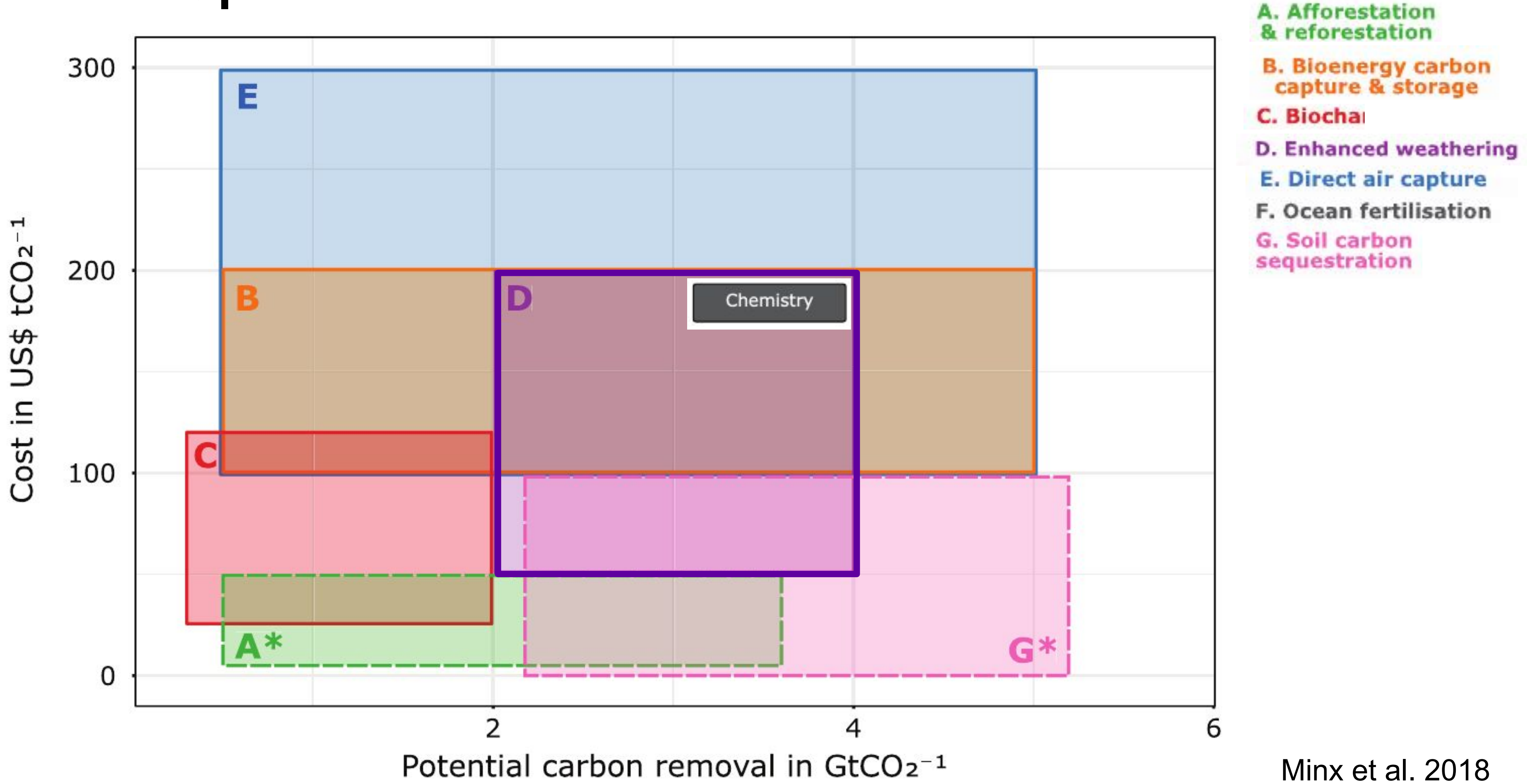


Minx et al. 2018



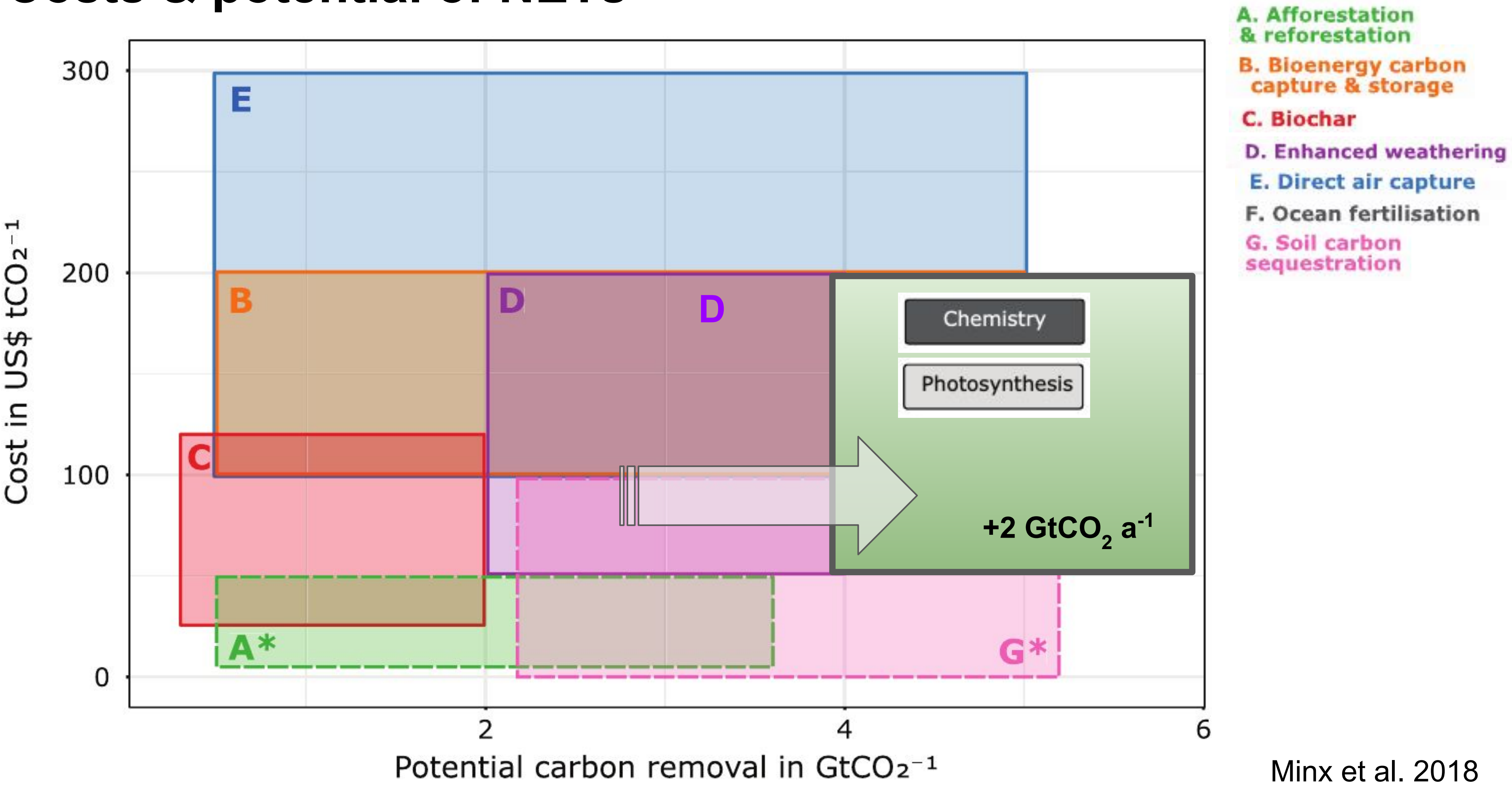
Capture via:
Photosynthesis
Chemistry
Applied basalt or mill ash, which also contains K and other nutrients
CO_2 from respiration of roots and other soil organisms
$CaSiO_{3(s)} + 2CO_{2(g)} + 3H_2O$
Weathering
$H_4SiO_{4(aq)} + Ca^{2+}_{(aq)} + 2HCO_3^-{}_{(aq)}$
Deposition and sequestration
$3H_2O + CO_{2(g)} + CaCO_{3(s)} + SiO_{2(s)}$
Enhanced crop vigour and yield due to greater uptake of Si, Ca, K and micronutrients
Enhanced root growth due to improved pH, nutrient supply and physical conditions
Weathering products in surface and groundwater runoff (less N, higher Si:N ratio)
Enhanced ocean alkalinity and growth of diatoms, foraminifera and corals

Costs & potential of NETs



Minx et al. 2018

Costs & potential of NETs



Minx et al. 2018

Technical aspects

Coding

- **17,198 lines more than trunk** (incl. CAN allocation & N cycle, grassland management)
- all files/subroutines were modified which handle organic matter/biomass, as well as routine(s) for photosynthesis.
- **P-only processes:** all combined in stomate_phosphorus.f90
- N-only processes: remain in stomate_som.f90

coding standards:

- (nearly) all parameters are externalized
- avoidance of redundant code via new subroutines (e.g. root uptake kinetics, stoichiometric scaling functions, etc.)
- mass conservation and stoichiometry is ensured (at time step , within a single routine and among all routines of stomate)
- Added/revised/cleaned comments in code
- Runs stable with executable with “debug compilation”

Additional boundary conditions

1. Soil order map (to derive soil type specific parameters) - potential conflicts with hydrological parameter
2. Lithological map
3. Nutrient boundary conditions (mineral fertilizer, manure and atmospheric deposition; annual fluxes)

input reading is parallel (not sequent. Like trunk)

coding issues solved: mass conservation

```
!DSG mass conservation ========================================
mass_before(:,:,:) = SUM(biomass(:,:,:,:),DIM=3)

CALL prescribe (npts, &
     veget_cov_max, dt_days, PFTpresent, everywhere, when_growthinit, &
     biomass, leaf_frac, ind, co2_to_bm,n_to_bm,p_to_bm, &
     KF,senescence,age,npp_longterm,&
     lm_lastyearmax,k_latosa_adapt)

IF(dsg_debug) THEN
   !DSG mass conservation ========================================
   CALL  check_mass(npts,biomass(:,:,:,:),'lpj: after prescribe')

   mass_after(:,:,:) = SUM(biomass(:,:,:,:),DIM=3)
   mass_change(:,:,icarbon)     = co2_to_bm
   mass_change(:,:,initrogen)   = n_to_bm
   mass_change(:,:,iphosphorus) = p_to_bm

   CALL cons_mass( mass_before(:,:,:),                &  ! mass before
        mass_after,                                   &  ! mass after
        mass_change(:,:,:),                           &  ! net of fluxes
        'lpj: after prescribe' )
ENDIF
```

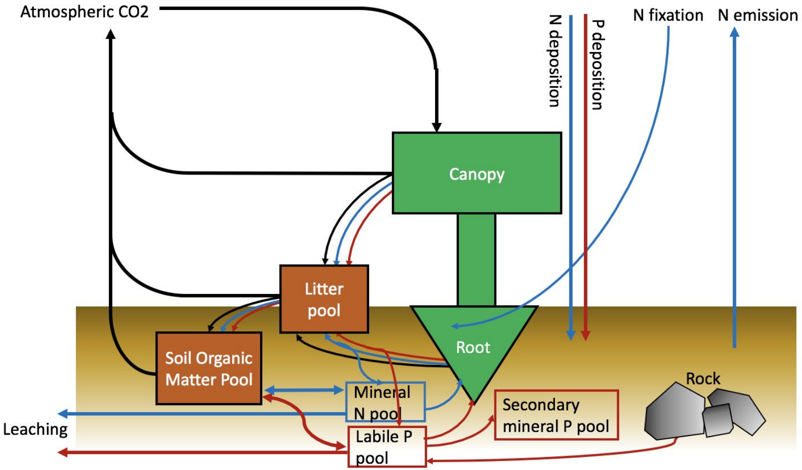
coding issues (partly) solved: low precision

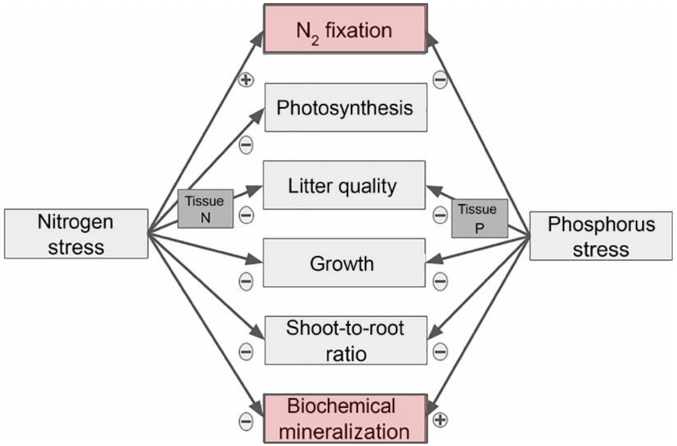
- Extensive use of thresholds, with rather large thresholds (1e-6)
- Can now be reduced to 1e-9 (for now LULCC calculations)

```
 WHERE ((ind(:,:).GT.min_stomate))
    woodmass_ind(:,:) = &
         ((biomass(:,:,isapabove,icarbon) + biomass(:,:,isapbelow,icarbon) &
         + biomass(:,:,iheartabove,icarbon) + biomass(:,:,iheartbelow,icarbon))*veget_cov_max(:,:))/ind(:,:)
 ENDWHERE
SE
 WHERE ((ind(:,:).GT.min_stomate))
    woodmass_ind(:,:) =(biomass(:,:,isapabove,icarbon) + biomass(:,:,isapbelow,icarbon) &
         + biomass(:,:,iheartabove,icarbon) + biomass(:,:,iheartbelow,icarbon))/ind(:,:)
 ENDWHERE
```

Spinup issue: not resolved

5-8 kyr needed to reach equilibrium in N and P cycle





- Analytical spinup: no time improvement
- RK4: marginal acceleration, discontinued development
- libIGCM: much time (up to 25%) is spent to copy files of large forcing files (N&P boundary conditions) - Albert is working on making libIGCM more efficient

Documentation

Secure | https://forge.ipsl.jussieu.fr/orchidee/wiki/DevelopmentActivities/ORCHIDEE-CNP

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ORCHIDEE LAND SURFACE MODEL

Overview

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wiki: DevelopmentActivities / ORCHIDEE-CNP

ORCHIDEE-CN-P (former branch ORCHIDEE-CNP)

This page describes the phosphorus cycle in ORCHIDEE-CN-P. It is based or as well as bugs.

The phosphorus cycle and the model evaluation at two sites along a soil form

1. Conceptual modifications to the nitrogen cycle

1.1 soil mineral N concentration in soil solution

Following Smith et al (2014), I introduced the use of the maximum water holdi soil water when soil water is very low. As we do not account for the inhibition

1.2 soil mineral N dynamics

ORCHIDEE-CN performs poorly in respect to soil mineral N dynamics. This is modifications in ORCHIDEE-CN I assume are not tested, as most of the envir

I step by step replaced all modification by using the formulation in Zaehle et a

Final mineral N dynamics The mineral N dynamics in ORCHIDEE-CN-P are of more soil layers (11 layers).

The mineral N stocks of the test sites are all in realistic ranges. Pattern correl

2. Re-calibration of the carbon cycle

The calibration of ORCHIDEE-CAN of the carbon cycle in combination with th turnover, we manipulated parameters of the pipe model (TAU_SAP, KLATOSA

The main issue with the previous calibration (Naudts et al GMD) is, that FLUX stocks. Even the biomass stocks estimates which exclude managed forest are

The range of K_LATOSA prescribed makes things tricky as total biomass is ve

I derived a set of parameters which result in kind of okay LAI, total biomass, b

ISSUE with my calibration: To facilitate the calibration I derive maintenance re even more constraints on K_LATOSA for example hydrological constraints (lik

3. New input files

You can find information on the new input files needed for the P cycle here:

4. unresolved issues (ideas for future developments)

There are still yet unresolved issue with the model. They are listed here: htt

5. Howto install, compile & run the model

Secure | https://forge.ipsl.jussieu.fr/orchidee/wiki/DevelopmentActivities/ORCHIDEE-CNP/howtoUse

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ORCHIDEE LAND SURFACE MODEL

How to install/run

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Up | Start Page | Index | History

HOWTO install/compile/run ORCHIDEE-CN-P for offline use with libIGCM.

This howto is based on the information which can be found in the ORCHIDEE wiki regarding the tru

See attachment for the file get_ORCNP.ksh for a script which does some(!, please check as I dont u

WARNING: the following assumes you run on obelix or curie

If you want to run on ada, please see the additional modification needed on the MICT wiki https://

For other machines, we currently have no support available.

1. install libIGCM & ORCHIDEE-CN-P

1.1 where to install

You should install the model NOT in the home directory; it is even too small to handle diagnostics lik

```
/ccc/work/cont003/dsm/<userID>
```

or project storage; here example for the IMBALANCE-P project on obelix:

```
/home/surface3/dgoll
```

1.2 install libIGCM & trunk ORCHIDEE

I use revision 2728 of libIGCM on obelix and curie (revision 2961 does not work):

```
svn -r2728 co http://forge.ipsl.jussieu.fr/igcmg/svn/modipsl/trunk mod
cd modipsl/util
./model ORCHIDEE_trunk
```

REMARK: When you are running on ada, you need to install revision 3609. For ada additional modif

1.3 Exchange the trunk ORCHIDEE with ORCHIDEE-CN-P

```
cd ../modeles
rm -fr ORCHIDEE
svn co svn://forge.ipsl.jussieu.fr/orchidee/branches/ORCHIDEE-CN-P/ORC
cd ../util ; ./ins_make
```

1.4 Exchange the XIOS with the XIOS2

Secure | https://forge.ipsl.jussieu.fr/orchidee/wiki/DevelopmentActivities/ORCHIDEE-CNP/newInput

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ORCHIDEE LAND SURFACE MODEL

Documentation: e.g. new input fils

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wiki: DevelopmentActivities / ORCHIDEE-CNP / newInput

Up | Start Page

The input files can be found on curie: /ccc/cont003/home/dsm/p529goll/ORC-CNP_input/

and here for deposition: /ccc/work/cont003/dsm/p529goll/NP_deposition/final/

4.0 soils_param.nc (including soilpH and bulk soil density)

To run the N cycle you need additional information on soil pH and bulk density in the soils_param.nc. Currently, only the "zobler file" for the old hydrological scheme is in the directory sepcified above. I generated but not yet tested a file for the 11-layer hydrological scheme. (please write me an email if you wa

4.1 USDA soil orders

We use the USDA soil order map of Sun et al. (in revision) with the dominant soil order per pixel. The gap filling of the missing values was done like this (see script /home/users/dgoll/ORC_data/USDA_soilorders/try_2_fill/fill_deserts.ksh):

We use the soiltext class 6 for cold desert from the input file "soils_param.nc" to fill missing values in these region with Gelisols (5). After we set cold desert, we use the level 1 of the maxvegetfrac in the input file "PFTmap.nc" to fill missing values of the remaining desert to Aridisols (2). Hereby, we use a thre for identifying deserts in maxvegetfrac.

In case of the remaining missing points, mostly coast line points, ORCHIDEE will assign the value of the nearest neighbour in the routine "get_soil_orders" in src_stomate_io.f90.

USDA soil order

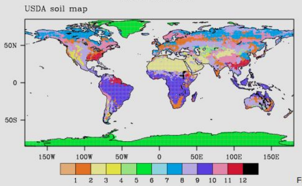


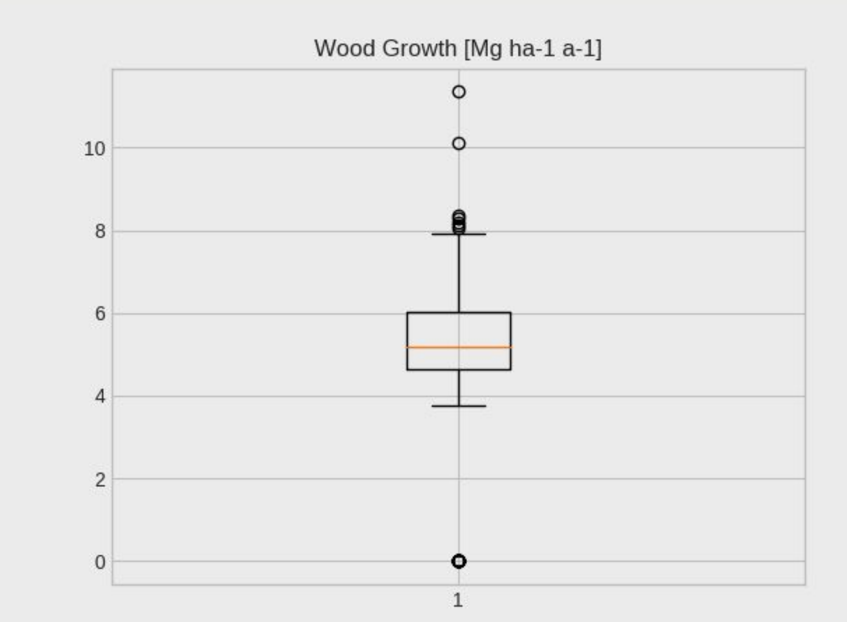
Figure 1: USDA soil orders: Alfisols(1), Andisols(2), Aridisols(3), Entisols(4), Gelisols(5), Histosols(6), Inceptisols(7), Mollisols(8), Oxisols(9), Spodosols(10),Ultisols(11), Vertisols(12)

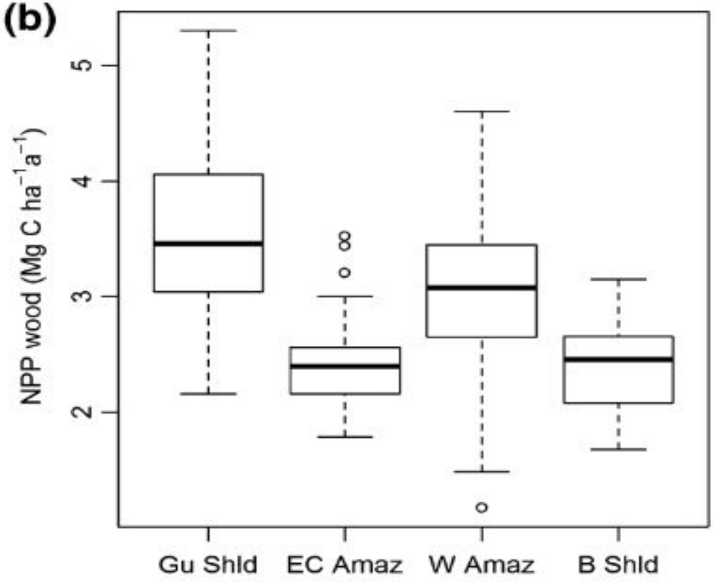
4.2 GliM lithology

Calibration of C cycle: partly resolved

1. Several parameter values were adjusted (allocation,allometry, SOM turnover) to better match <u>large scale</u> fluxes & stocks

ORCHIDEE-CNP (v1.0)

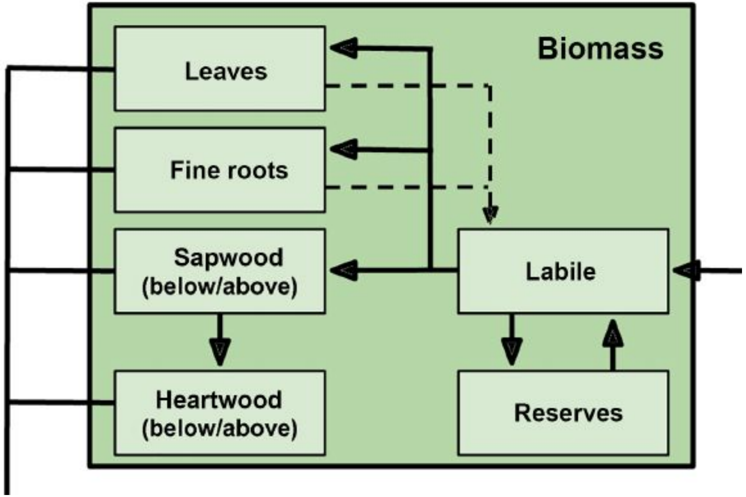


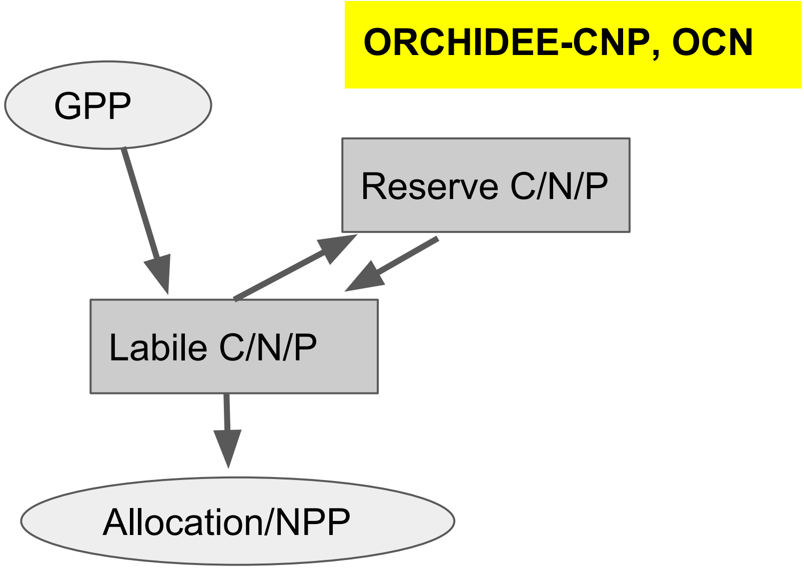


Structural changes to C and N cycle: examples

Major modifications to existing parts

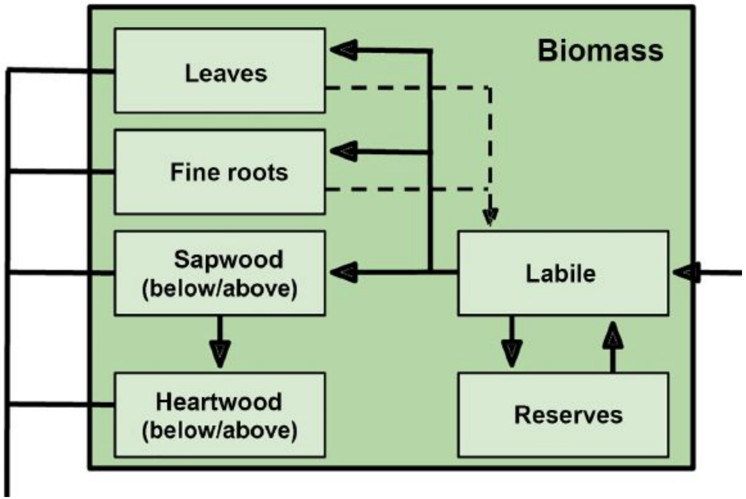
1. Simplification of non-structural carbohydrate dynamics



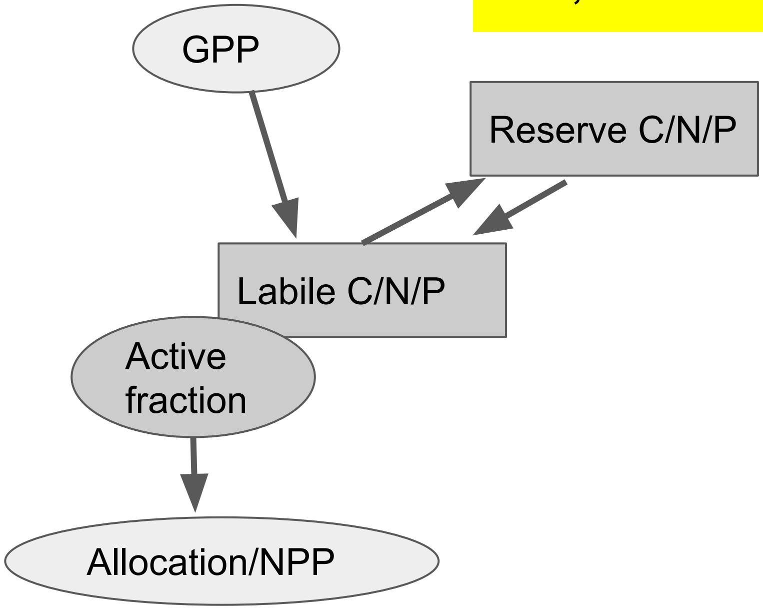


Major modifications to existing parts

1. Simplification of non-structural carbohydrate dynamics



CAN, ORCHIDEE-CN



Major modifications to existing parts

2. Simplification maintenance respiration

ORCHIDEE-CNP

$$Resp_{maint} = f(T, N_{leaf}) = f(T)\ k_{calibrated}\ N_{leaf}$$

CAN-CN

$$Resp_{maint} = f(T, N_{leaf}, N_{root}, N_{fruit}, N_{sapwood}, N_{labile}, CN_{leaf}, CN_{leaf,threshold})$$

$$Resp_{plant} = Resp_{maint} + Resp_{grwoth}$$

$$Resp_{grwoth} = 0.28\ {}^{*}GPP$$

Based on LPJ (Sitch et al.)

Major modifications to existing parts

3. Simplification of Vcmax/Jmax controls

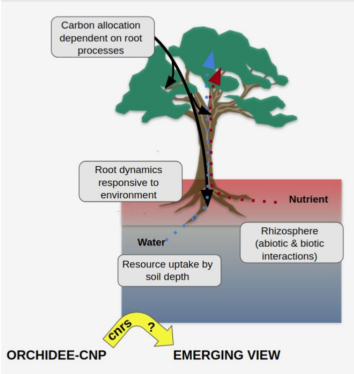
a) Decline of Vcmax with leaf age: disabled. As it is conflict with the lack of evergreen phenology. Ongoing model development will address this issues: Peaucelle (extra-tropics) & Chen (tropics))

b) Temperature acclimation of Vcmax: disabled. As pot. inconsistent with leaf nutrient - Vcmax relationships (Kattge et al 2009, Ellsworth et al in prep) as leaf N co-varies with temperature. More data analysis needed.

Major structural issues: not solved

Specific issues with ORCHIDEE

(1) Growth / Allocation:
- Calibration issues: over-parameterization, large biases in allocation (wood growth of natural vegetation unrealistic)
- Implementation issues
- Dynamics: allometry "jumps" between different states (see also work by E. Joetzjer)



(2) Regrowth of vegetation from "air":
- substantial amounts of P are generated when trees

Summary

1. **ORCHIDEE-CNP**
   a. goes beyond the state of the art global P cycle models
   b. overall performance is average (iLAMB)
   c. well accepted by the community (H2020 proposal, NERC Large Grant, …)

2. Major issues are
   a. primarily the same as for the trunk (evergr. phenology, allocation, som decomposition)
   b. long spinup time
   c. being addressed by ongoing and starting work

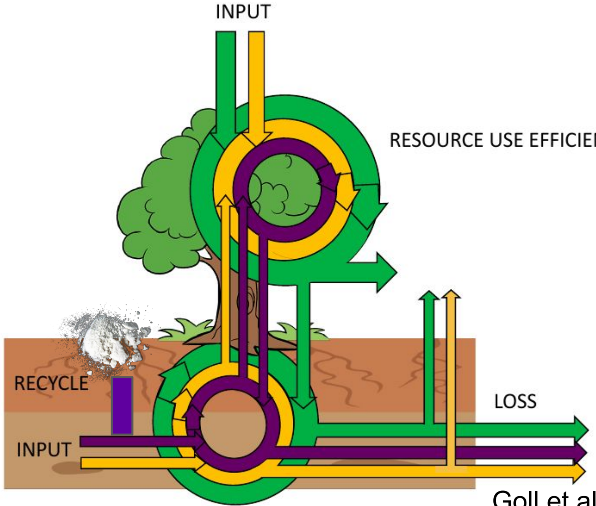
3. Comes with improvements in technical aspects
   a. higher computation precision
   b. detailed mass conservation diagnostics
   c. among others (parallel input reading, etc)

dsgoll123@gmail.com

Appendix

Model experiment: large-scale application of basalt

Land surface Model (ORCHIDEE-CNP)



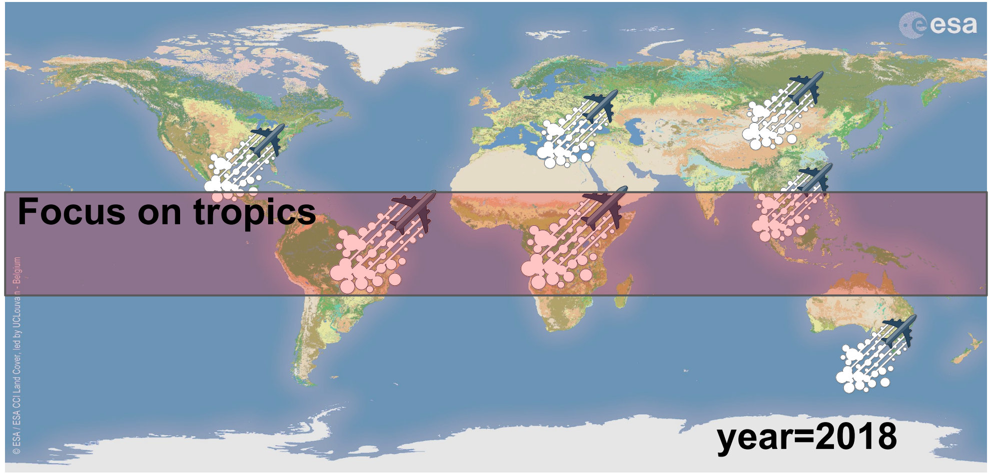
Goll et al. 2017b, 2018

Enhanced weathering model

dissolution rate = f(T, q, d_M, M)

T = temperature
q = runoff
d_M = diameter of mineral grain
M = type of mineral

Strefler et al. 2018



<u>One-time application:</u>

3 kg(*) m^{-2} (~ 1 mm high layer)
d_M = 20 µm particles (cost-efficient size)
1.51 ‰P content (global average)

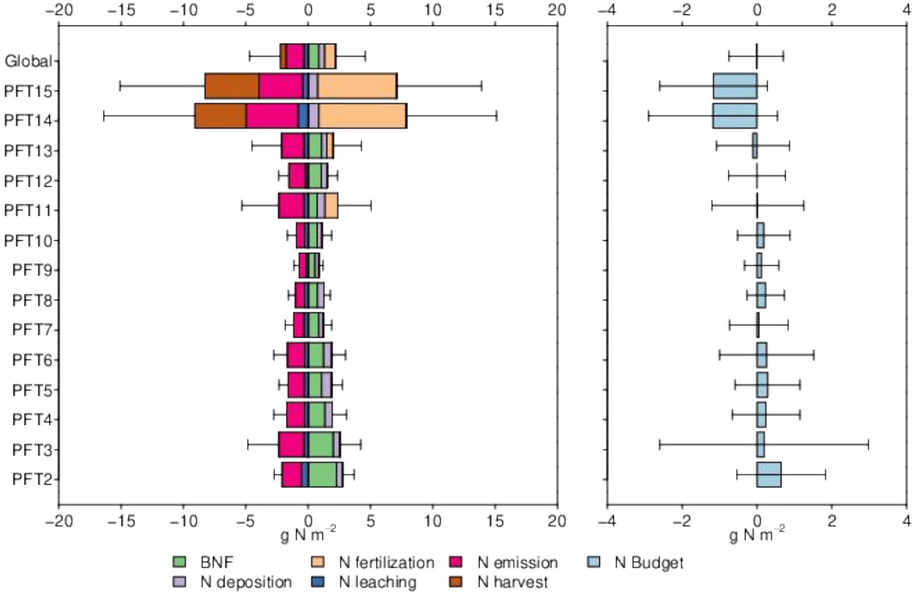
(*)application as slurry to avoid fine dust issues

<u>Boundary conditions (climate, CO_2, land cover etc):</u>

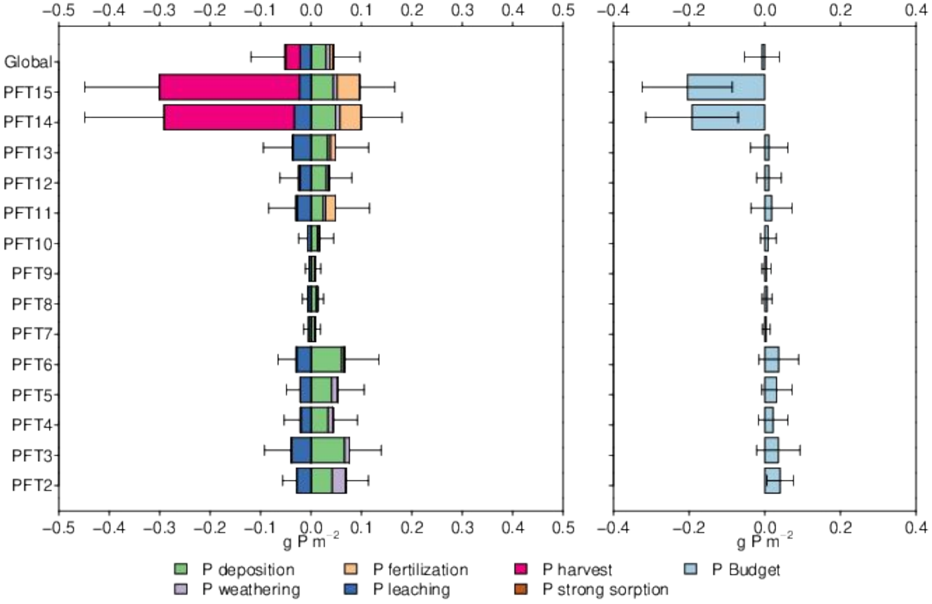
fixed to period: 2008 - 2017

1.2 N and P budgets and components

1.2.2 N and P budgets and components for each PFT

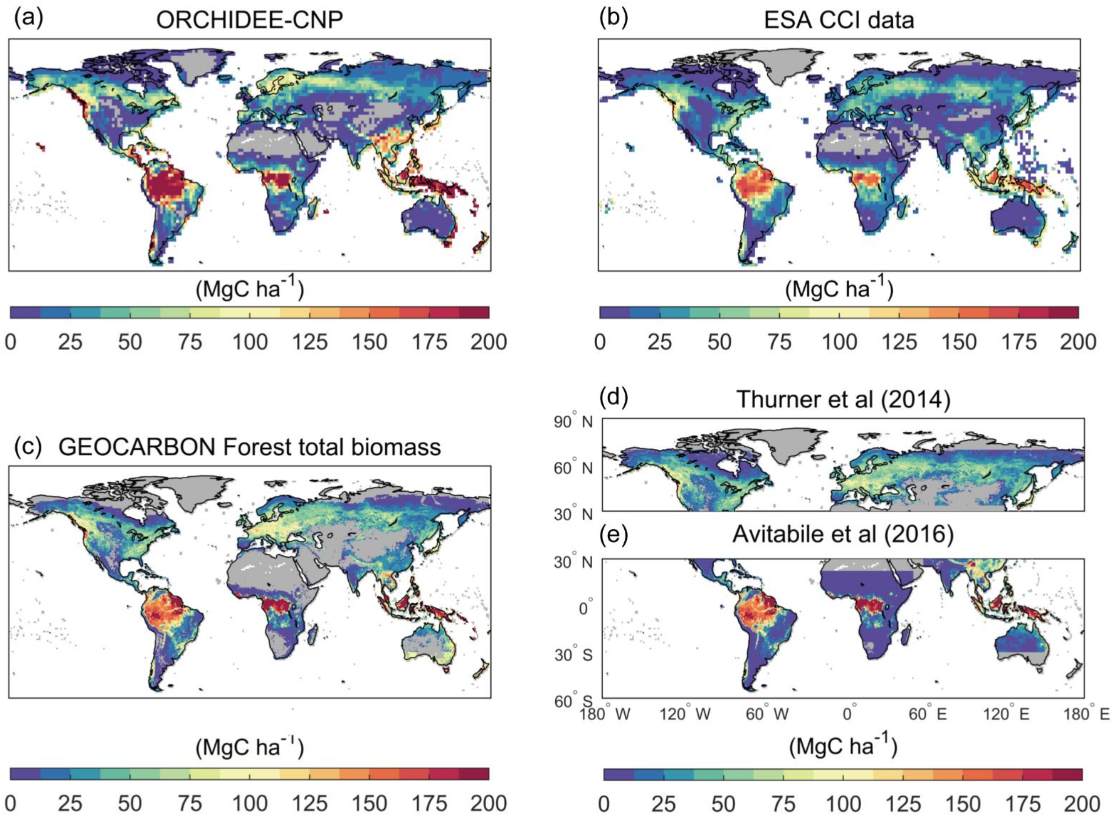


N budgets (2002-2010)



P budgets (2002-2010)

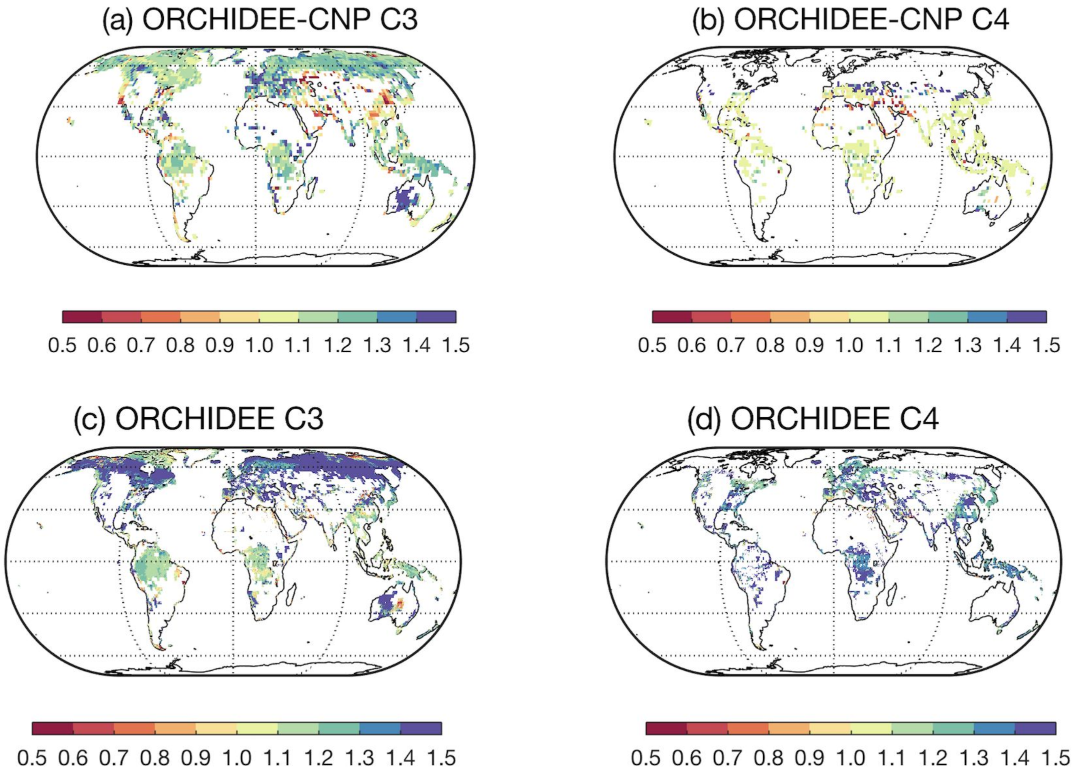
Biomass



(a) ORCHIDEE-CNP
(b) ESA CCI data
(c) GEOCARBON Forest total biomass
(d) Thurner et al (2014)
(e) Avitabile et al (2016)
(MgC ha^{-1})
0 25 50 75 100 125 150 175 200
90° N
60° N
30° N
0°
30° S
60° S
180° W 120° W 60° W 0° 60° E 120° E 180° E

CO_2 fertilization effect

GPP increase ratio from atm_CO_2 296ppm to 396ppm for natural C3 and C4 plants



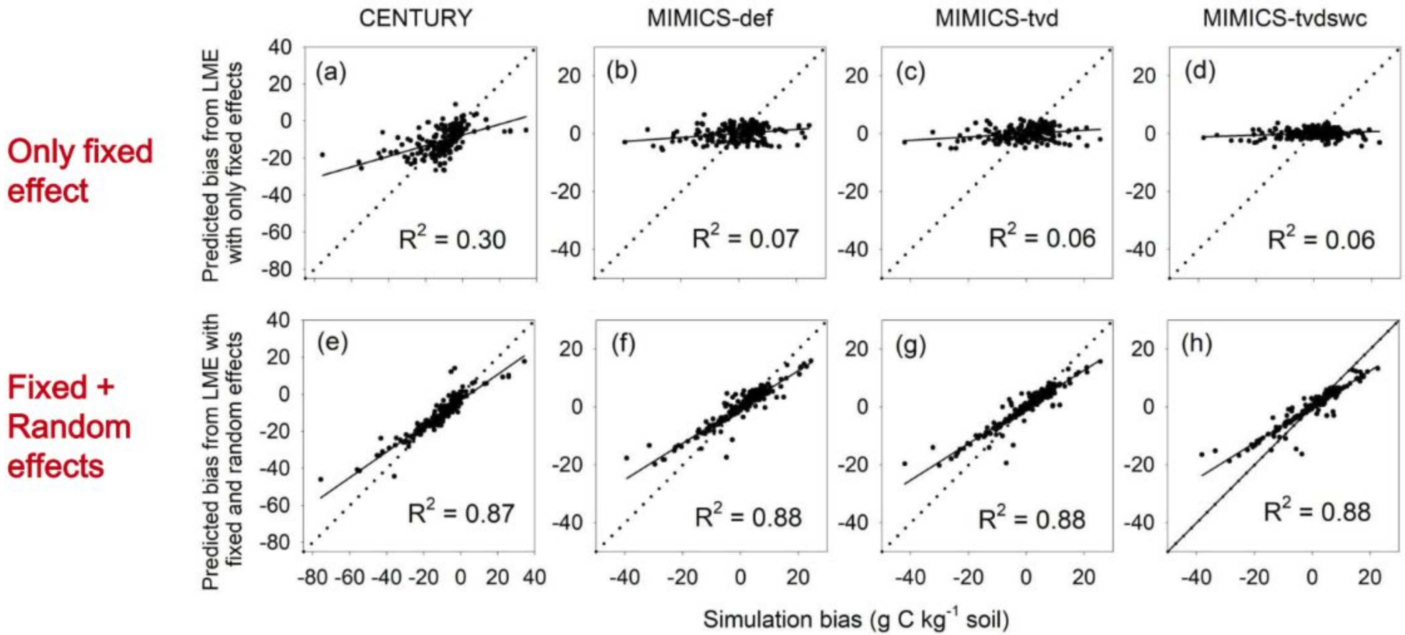
Linear Mixed-Effects model (LME)

LME with **only fixed** effects (= multi-variable linear regression):

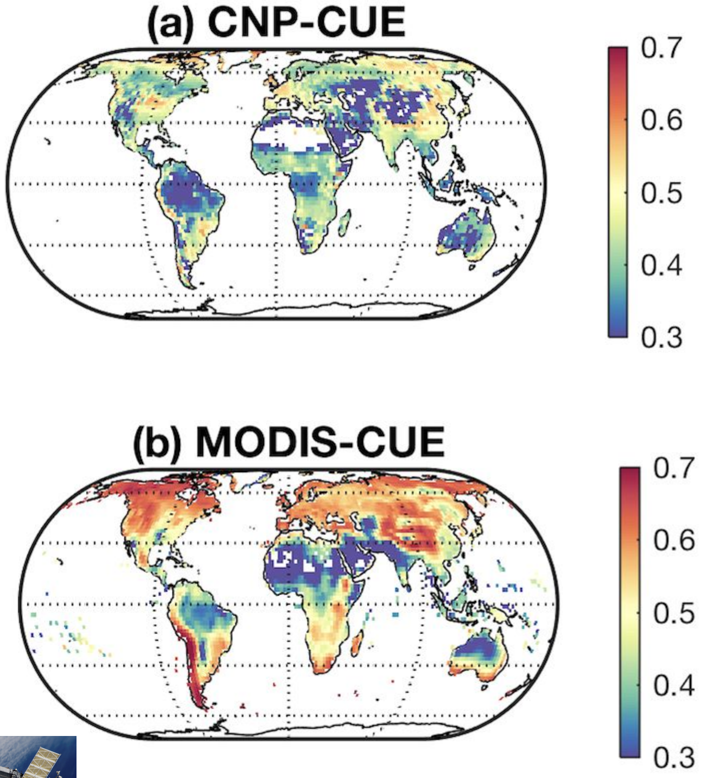
$$\text{Bias} = \underbrace{c_1 + b_1{*}\text{MAT} + b_2{*}\text{SWC} + b_3{*}\text{clay} + \ldots + b_n{*}\text{litterfall}}_{\text{Fixed effect}}$$

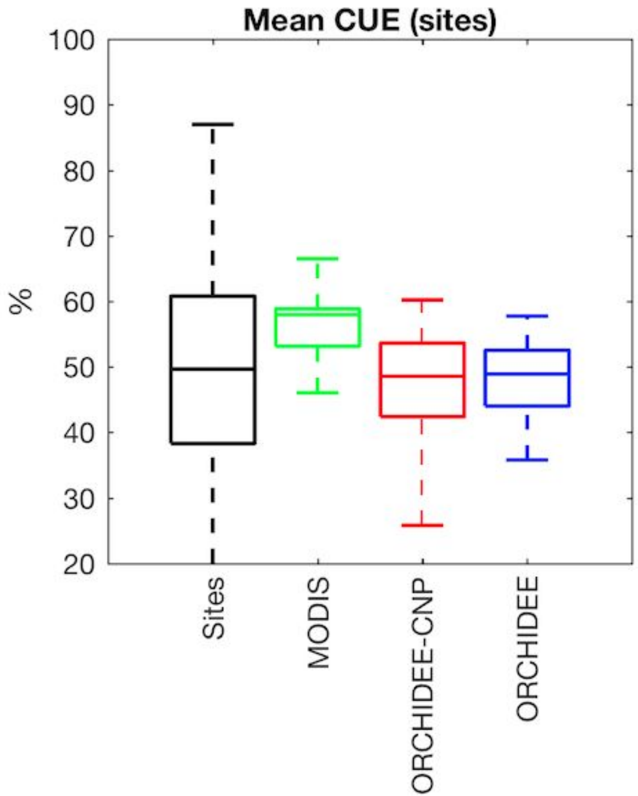
LME with **fixed & random** effects:

$$\text{Bias} = c_1 + b_1{*}\text{MAT} + b_2{*}\text{SWC} + b_3{*}\text{clay} + \ldots + b_n{*}\text{litterfall} + \text{RandomEffect (Site)}$$

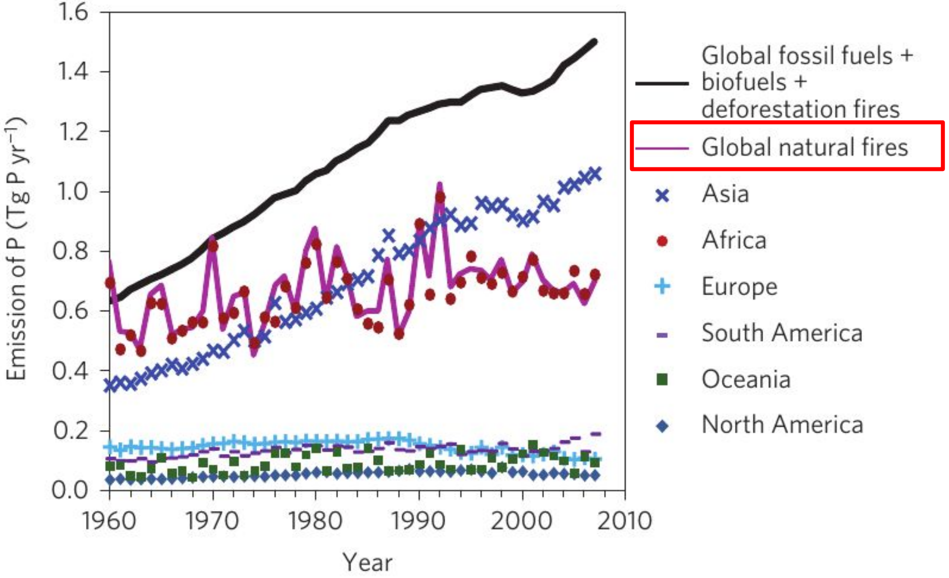


Carbon use efficiencies





Wildfires are important contributor to P deposition



Wang et al. 2015