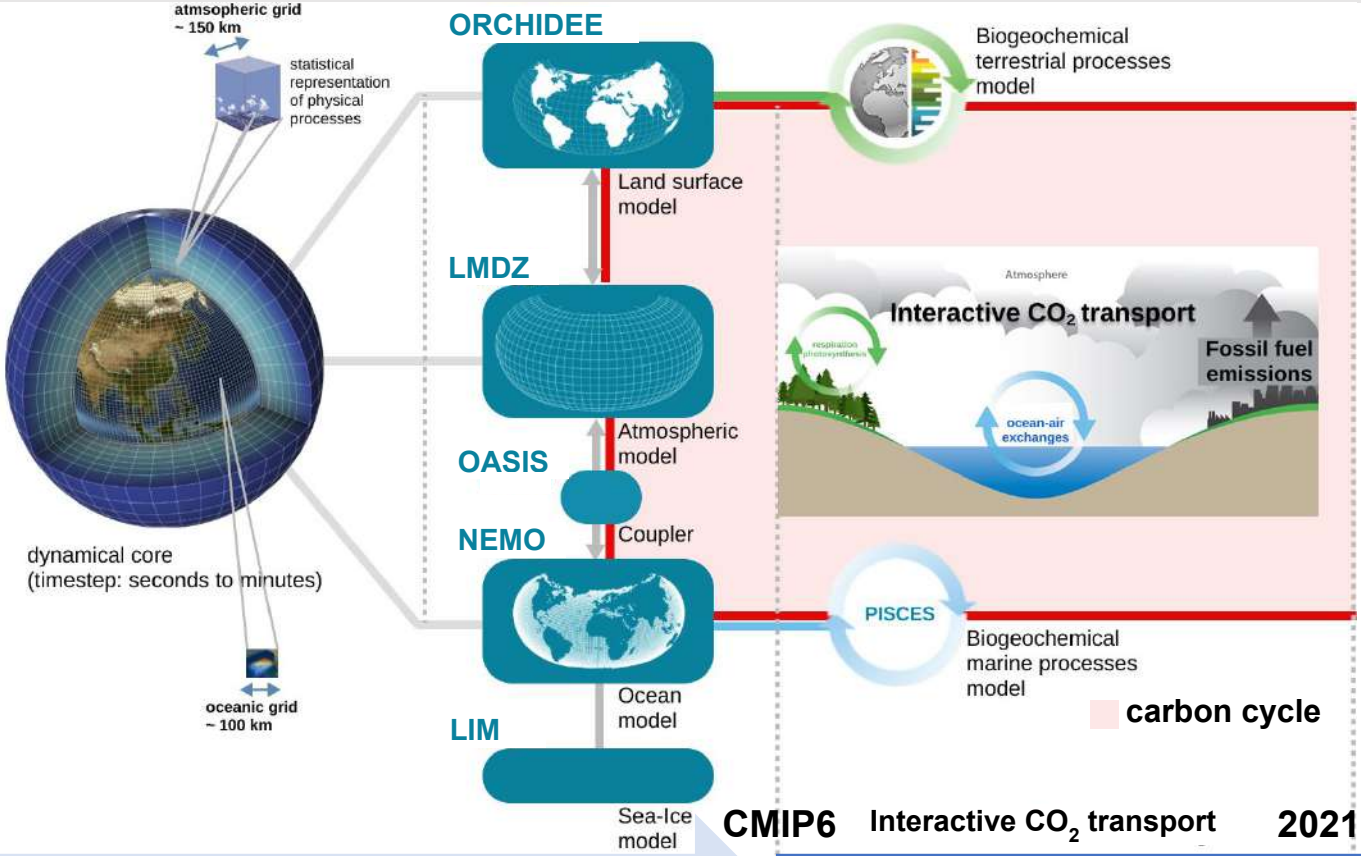
Centre de modélisation du climat de l'IPSL
Retraite des 17-18 novembre 2022 – Domaine Saint-Paul

Developments for the next ESM versions !

C / N / S / P cycles in the IPSL model…

- Interactive CO2 transport
- CH4 cycle in the ESM !
- Nitrogen compounds - interactions between components
- Phosphorus cycle
- Dust impacts
- Sulfur compounds..
- Water isotopes
- Lateral transfer of water, C/N/P elements and heat from land to ocean
- Stratosphere and aerosols

Interactive CO2 in the Earth System Model



CMIP6 Interactive CO_2 transport 2021 Integration of additional biogeochemical cycles

Climate model with carbon cycle only

Earth System Model development

Interactive CO_2 transport

without CO_2 transport

Cadule et al,

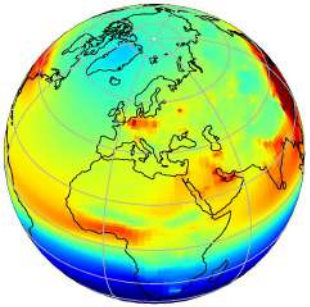
390 391 392 393 [ppm]

2009
first climate-carbon model

~2 months for 250 yr simulation
horizontal resolution of 200 km

atmospheric CO_2 concentration for present day period

with interactive CO_2 transport



Cadule et al, in

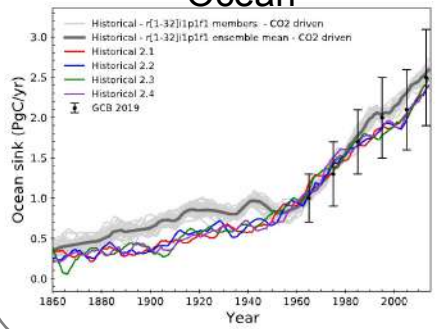
390 391 392 393 [ppm]

2021
4th generation climate-carbon model with interactive CO_2 transport

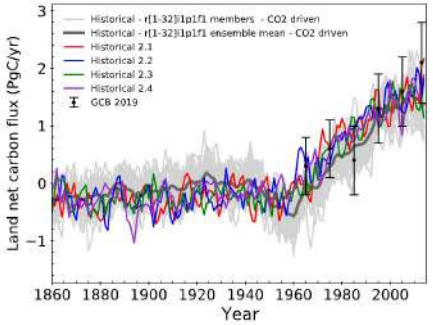
~15 days for 250 yr simulation
horizontal resolution of 100 km

Carbon Cycle

Ocean



Land



… still need to reduce uncertainties and improve processes modeling

P. CADULE,

CH4 cycle in the ESM !

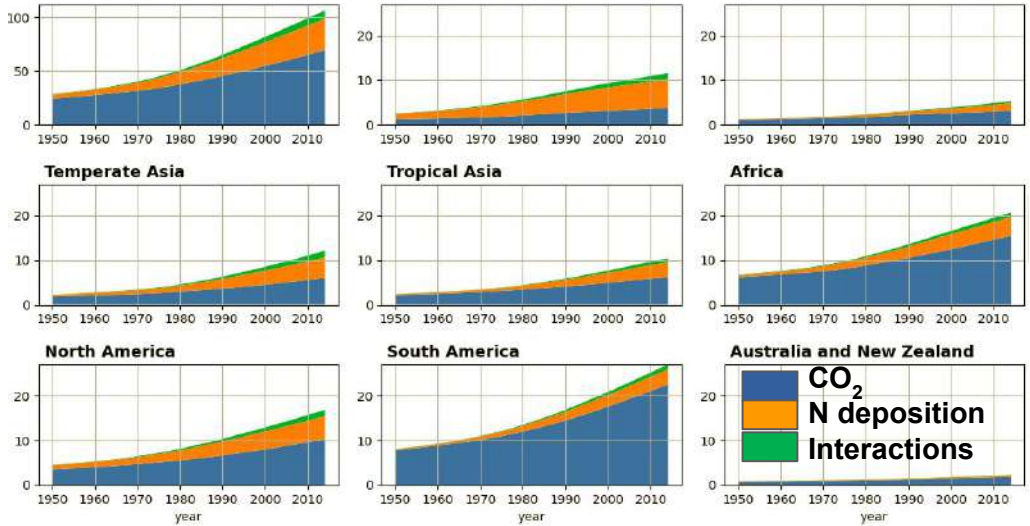
- LAND: Emission of CH4 by wetland and peatland
  - Exist in several “branches” (ORC_peat, …)
  - On-going effort to merge all CH4 emission modules into TRUNK !

- Atmosphere
  - Degradation by OH already in INCA !!

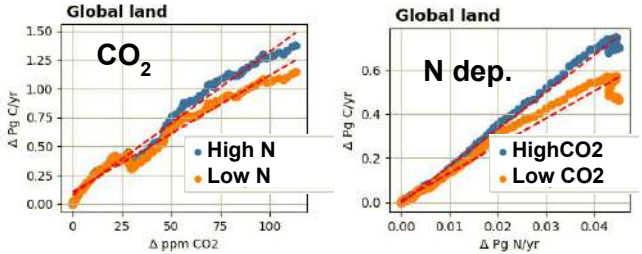
⇒ Coupling land emission with INCA in the ESM should become effective !

Nitrogen cycle: Impact on the land C uptake !

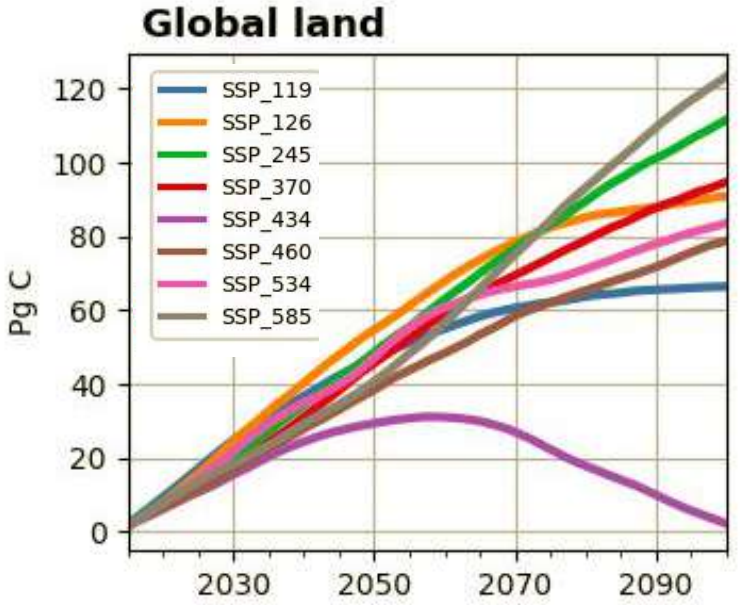
Change in Land Carbon store due to CO2 and N deposition since 1850 (GtC)



Net land C flux as a function of



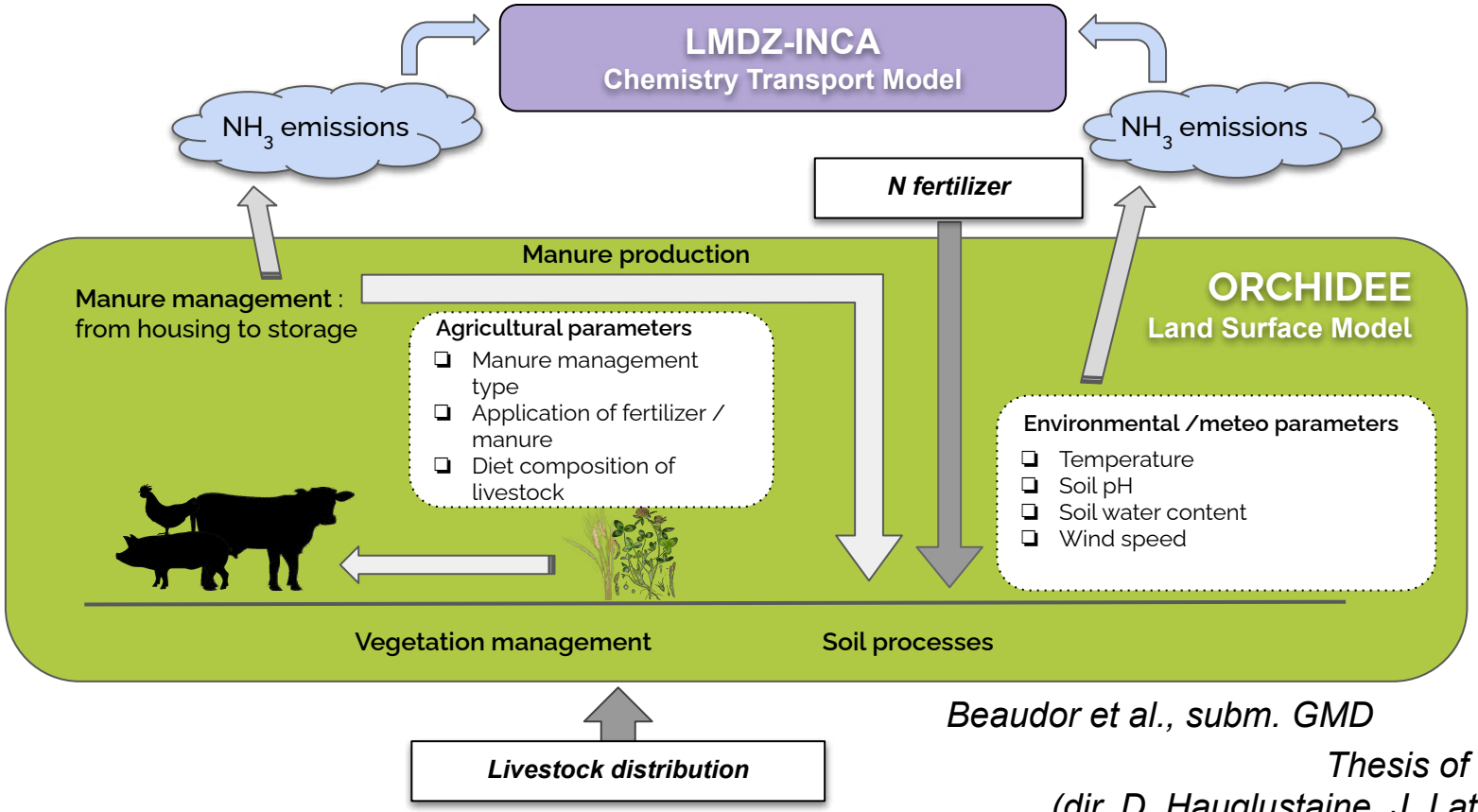
Change in Land Carbon store since 2014 (GtC)



=> ~60 GtC less than with ORC-2 for any SSP

Thesis of Jaime Riano Sanchez (dir. N. Vuichard, P. Peylin)

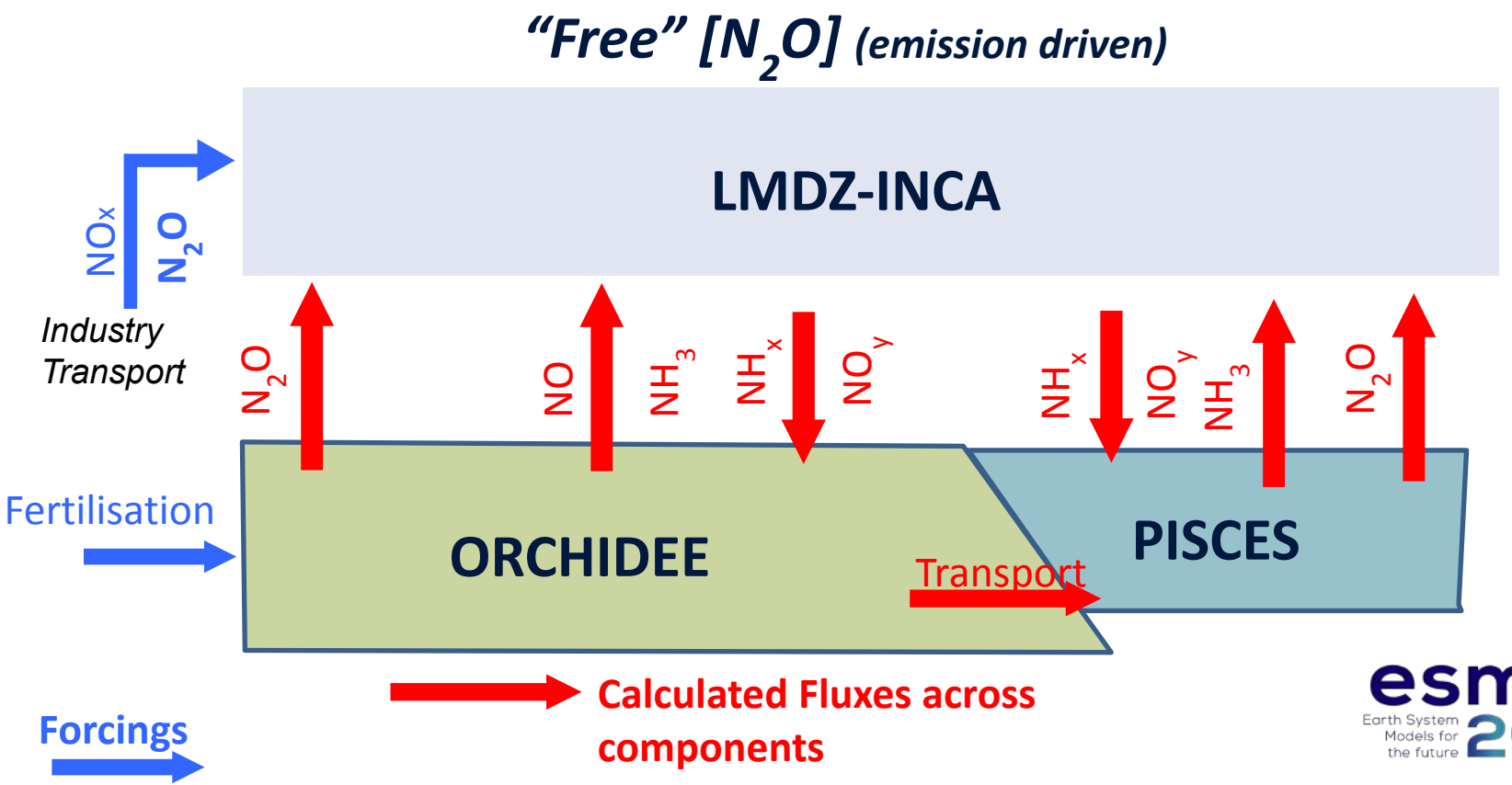
Modeling Nitrogen fluxes within land-housing-soil continuum



Beaudor et al., subm. GMD

Thesis of Maureen Beaudor
(dir. D. Hauglustaine, J. Lathière,N. Vuichard)

Cycle interactif de l'azote



esm 2025 Earth System Models for the future

CDD Ingénieur Karine Laurent

Couplages INCA-ORCHIDEE dans le cadre de ESM2025

ESM2025: Development of the **IPSL CM6** with focus on land-atmosphere exchange of chemical species (coupling between **INCA** and **ORCHIDEE** soil-vegetation model):

- **BVOC** emission scheme extended in order to include biogenic emissions of DMS (3.2 Tg/yr) and H_2S (0.8 Tg/yr) from vegetation.
- **Ammonia** (NH_3) emissions from agricultural soils and livestock. Present-day emissions and model result evaluation (Beaudor et al., 2022a). Future NH3 emissions based on several SSP scenarios for livestock evolution up to 2100 (Beaudor et al., 2022b). Impact on atmospheric chemistry and N deposition (Beaudor et al., 2022c). In link WP 5-6.
- **Nitrous oxide** (N_2O) interactive cycle including soil emissions from ORCHIDEE, oceanic emissions (PISCES) provided by Météo-France, anthropogenic emissions reconstruction and atmospheric chemistry. Long-term (1850-Present) simulations in preparation. In link with WP5-6.
- Coupled version including BVOC (and S) emissions and nitrogen cycle (NH3, N2O, NO soil emissions) tested and should be ready soon

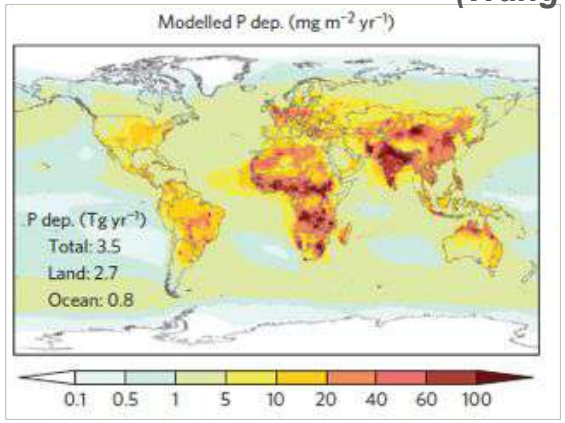
Cycle du Phosphore dans l'ESM

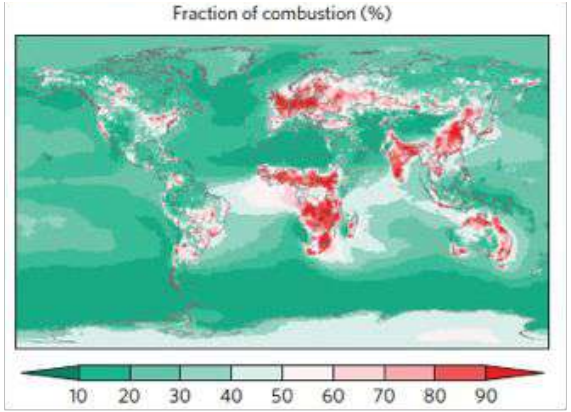
⇒ **Atmospheric deposition of P & N from 1750 to 2021 !**

(Wang et al. 2015)

ORCHIDEE - LAND :

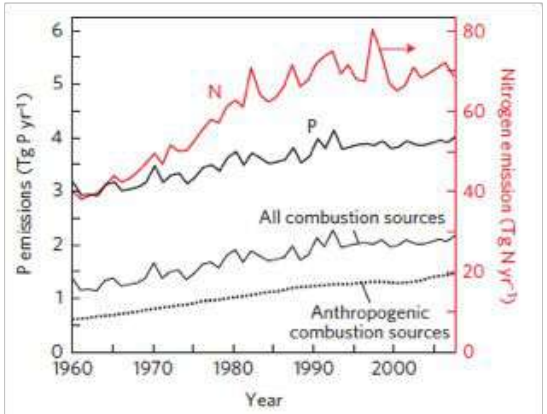
- **A version (C-N-P) exist**
- **Integration in the Trunk is under investigation**

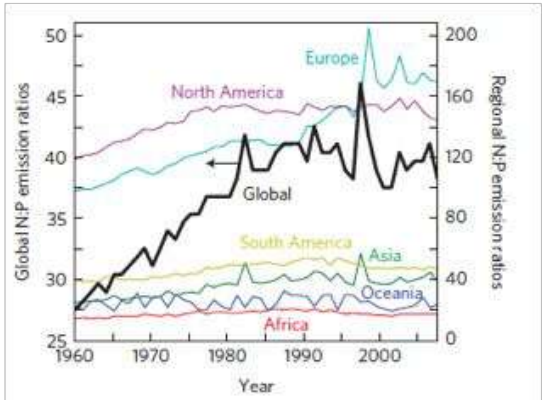




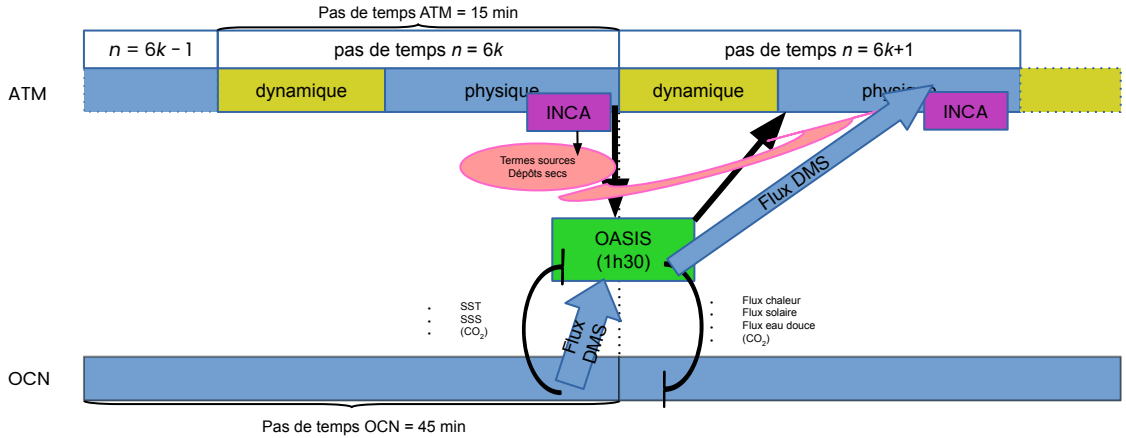
OCEAN :

- **P deposition Integrated in PISCES**

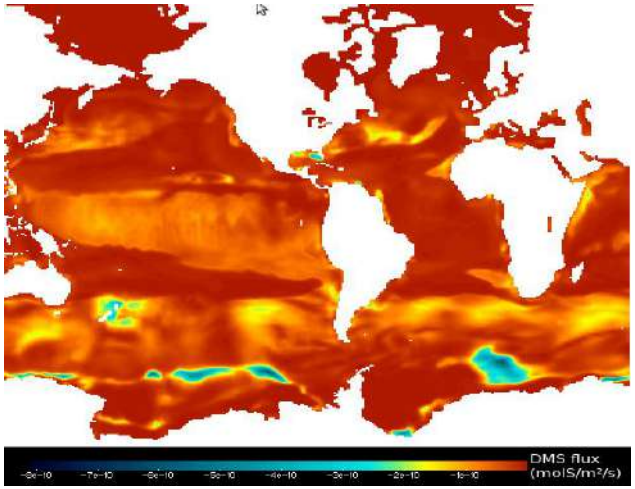




DMS coupling between the different components



L'objectif du codage est de transmettre les flux océaniques de l'espèce DMS (issus du module océanique PISCES) directement au module de chimie troposphérique INCA, sans passer par l'intermédiaire du module atmosphérique LMDZ.



Carte de flux de DMS en sortie de PISCES

T. Lurton, IPSL

Water isotopes in the IPSL model

Aim: perennially implement water isotopes in every component of the ISPL ESM

- Initiated by the funding provided by IPSL on a proposition of the PALEO « theme » of IPSL
- Implies working with the latest releases of the ESM (means no backward compatibility with e.g. IPSLCM5A2)

Different levels of implementation:

- **LMDZ6**:
  - Fully implemented and already in the TRUNK!
  - On-going work to improve perennity (Sébastien Nguyen, David Cugnet, Camille Risi)

- **ORCHIDEE**:
  - Requires implementation in the new 11-layer soil physics as well as in the vegetation
  - Aya Bahi (finishing her PhD at INRAE) will start mid-February for 18 months

- **NEMO-OPA (dynamical ocean):**
  - Requires porting the isotope code from NEMO-v3.6 to the latest release of NEMO (currently NEMO-v4.2)
  - Mohamed Ayache (currently postdoc at LSCE) will start in January for 18 months

- **NEMO-SI3 (sea ice):**
  - No action from IPSL at the moment but Louise Sime's group at BAS may hire someone to implement water isotopes in SI3 and we are in contact to avoid duplicating the work

- **Coupling between components:**
  - Mohamed and/or Aya may start working on this depending on their progress

River routing of matter & energy

⇒ Three versions of the water routing scheme still co-exist !

- **Standard (CMIP6)**:
  - Low resolution
  - within the ORCHIDEE code

- **Externalised scheme at high resolution (Yan M.)**:
  - External to ORCHIDEE (on a different grid);
  - Need interpolation of Runoff and Drainage
  - Easily parallelised !

- **New High resolution scheme within ORC (Jan P.)**
  - ORC grid sub-divided into different Hydrological Transfer Units (HTU)
  - No interpolation needed and possibly easier to combine with floodplain / energy budget per HTU / ….
  - But difficult to parallelise

Routing of organic / inorganic compounds

- In a “Branch” of ORCHIDEE we can now transport DOC, DIC, POC
- It changes significantly the C balance of land ecosystems
- Ongoing merge with the peat and mangroves ecosystems
- Plan to be merged with the ORCHIDEE N version also (V3).
- A direct coupling with the NEMO-PISCES seems possible.

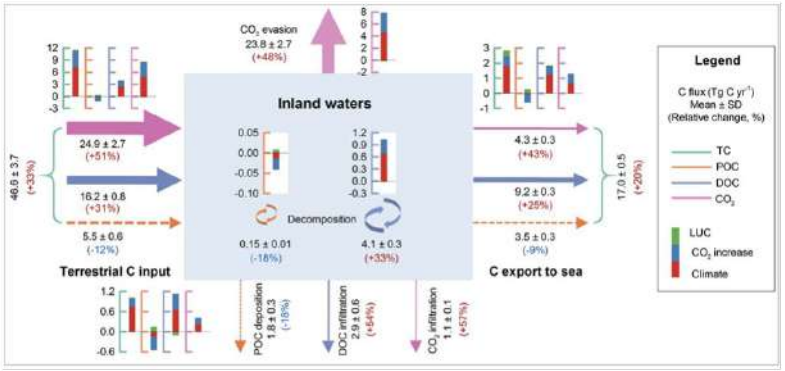
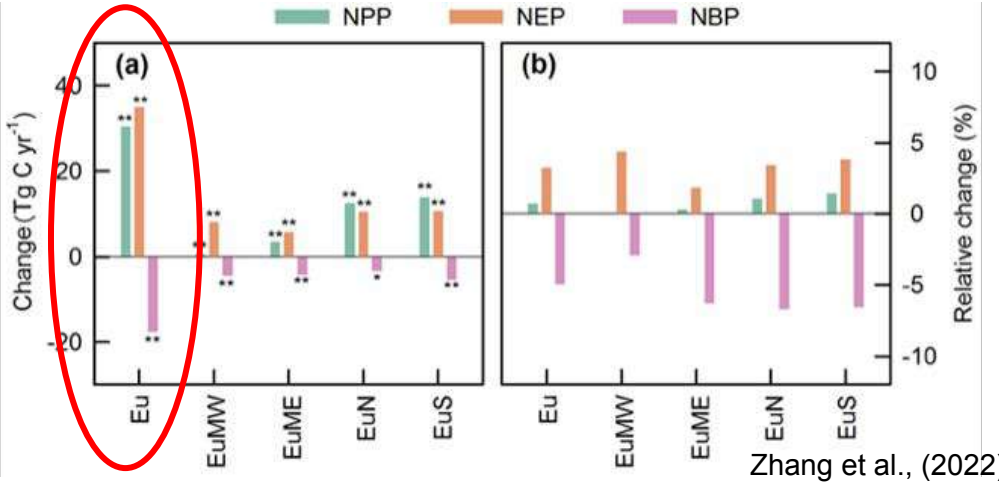


Fig. 1 Present-day (2005–2014) lateral carbon fluxes in Europe and their relative changes from the reference period 1901–1910 to 2005–2014. POC particulate organic carbon (C), DOC dissolved organic C, CO_2 dissolved C dioxide, TC total C flux which is the sum of POC, DOC and CO_2. Percentages in the brackets are the relative changes in C fluxes from the reference period 1901–1910 to present-day (2005–2014), with dashed arrows and percentages in blue representing the decrease and solid arrows and percentages in red representing the increase. Bar charts show the respective contributions of climate change, atmospheric CO_2 increase and land use change (LUC) to the changes in lateral C fluxes from 1901–1910 to 2005–2014.



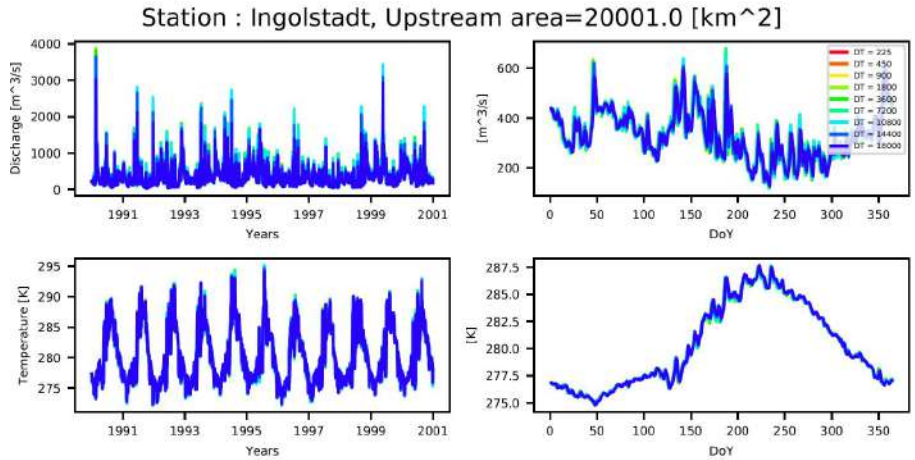
Zhang et al., (2022)

Towards predicting river temperatures in IPSL-CM

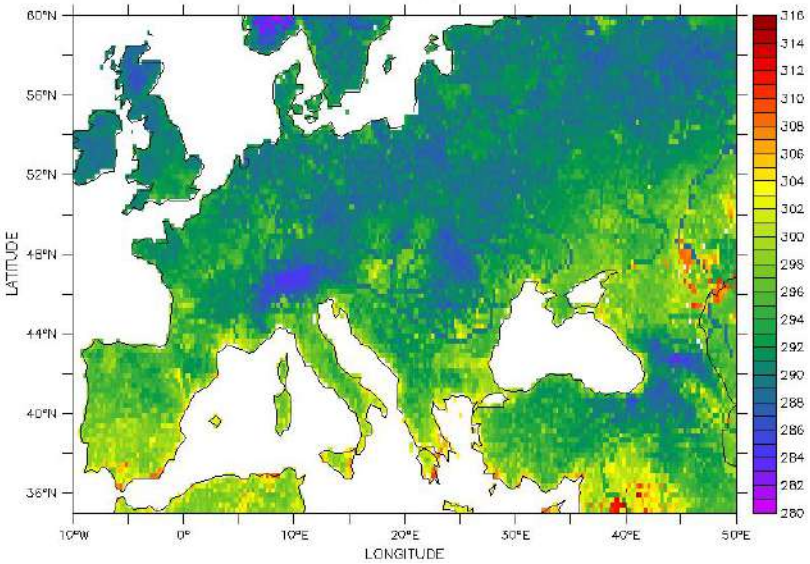
$$T^{t+1}_{i,stream} = \frac{W^{t}_{i,stream}}{W^{t+1}_{i,stream}} T^{t}_{i,stream} + \frac{\Delta t}{W^{t+1}_{i,stream}} \cdot \sum_{j \in \{i-1\}} \left(Q^{t}_{j,slow} T^{t}_{j,slow} + Q^{t}_{j,fast} T^{t}_{j,fast} + Q^{t}_{j,stream} T^{t}_{j,stream}\right) - \frac{\Delta t}{W^{t+1}_{i,stream}} \cdot Q^{t}_{i,stream} T^{t}_{i,stream}$$

Predicting river temperatures is beneficial for

- coupling to the ocean model (fully coupled mode)
- the ORCHIDEE model when used offline
- future climate services



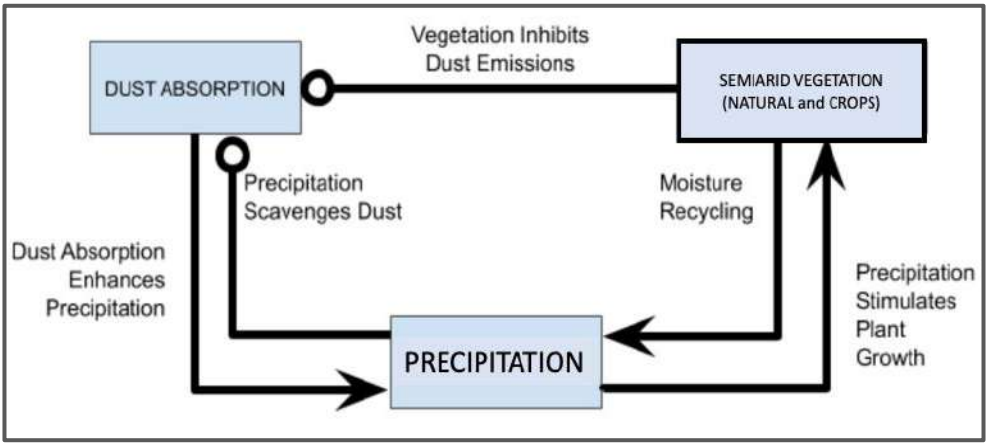
Average river temperature (in K) in 1980 over all hydrological transfer units in gridbox



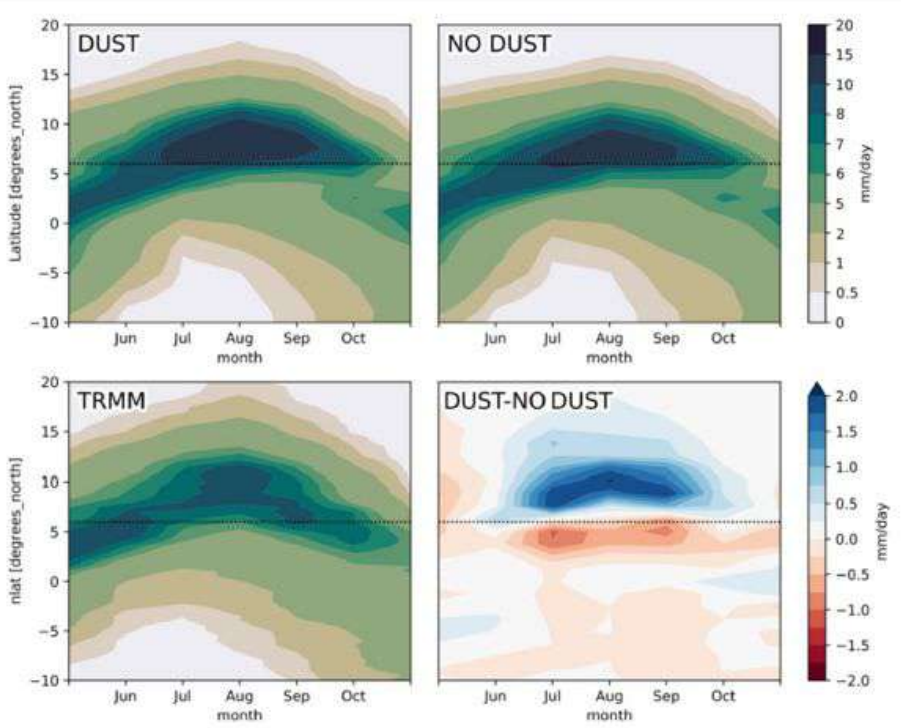
E. Dupont & J. Polcher, IPSL, 2021

Aerosol - impact on climate

⇒ On-going effort to better account for DUST - VEGETATION - CLIMATE interactions
(See Y. Balkansky)



⇒ More precipitation with dust over the Sahelian region !



LMDZ-StratAer model

Presentation

This is a sectional approach for stratospheric sulfate aerosol including microphysic processes.

History

- First version done with LMDZ5 (Kleinschmitt, 2017)
- Adapted for IPSLCM6-LR model to produce geoMIP run
- Used for an inter-model comparison in VolMIP-Tambora context (Clyne, 2020)
- Actually available in LMDZ trunk using CPP key

Future works

- Add new process to increase the model behavior (OH reduce, H2SO4 photolysis)
- Use methan oxydation to get better water representation in stratosphere
- Multi-injections routines (ex: sulfur and H2O)
- Coupling with REPROBUS

N. Lebas, S. Bekki, M. Marchand, M. Khodri, D. Cugnet, L. Falletti

LMDz-REPROBUS model

Presentation

Chemistry Climate model : coupling between LMDz and chemical scheme of REPROBUS

History

- Adapted for IPSLCM6-LR model : historical + future simulations
- Used for an inter-model comparison (CCMVal, CCMI, CMIP6)
- Actually available in LMDZ trunk using CPP key

Future works

- Test LMDZ-Reprobus Nemo configuration
- Add new chemistry Solver (ASIS) , already implemented in Mars and Venus atmosphere (F. Lefèvre)
- Add Multi-injections routines of chemical species (H2O, halogen, NOx) in case of volcanic eruption, constant emissions, rockets
- Add isotopes of sulfur
- Coupling with StratAer

N. Lebas, S. Bekki, M. Marchand, M. Khodri, D. Cugnet, L. Falletti

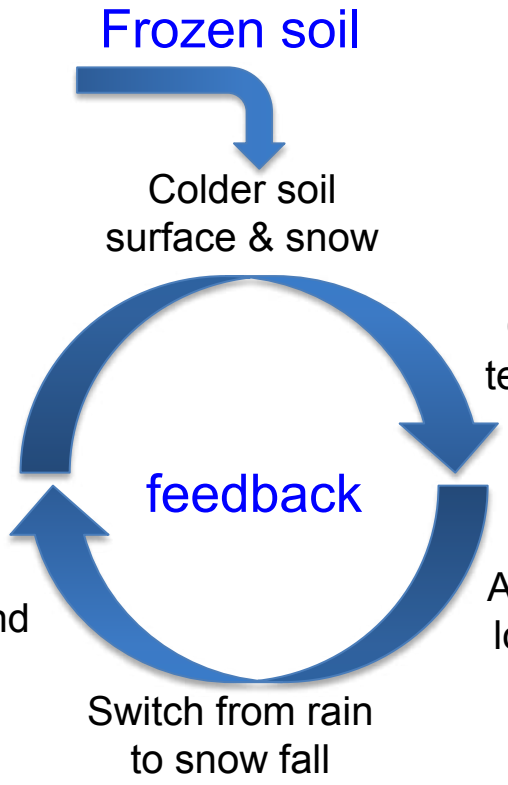
ORCHIDEE upcoming features compared to CMIP6 (the ORCHIDEE team)

- Nitrogen cycle (see above)
- Soil freezing and Permafrost
- Multi-tiling energy budget !
- Forest dynamic & forest management + new C allocation + new RT (current Trunk of ORCHIDEE; under optimization)
- Accounting for Irrigation & flood plain & Lakes & Ground Water !
- Inclusion of fire (SPITFIRE)
- Improved representation of Agrosystems:
  Crop specific module & Grassland management

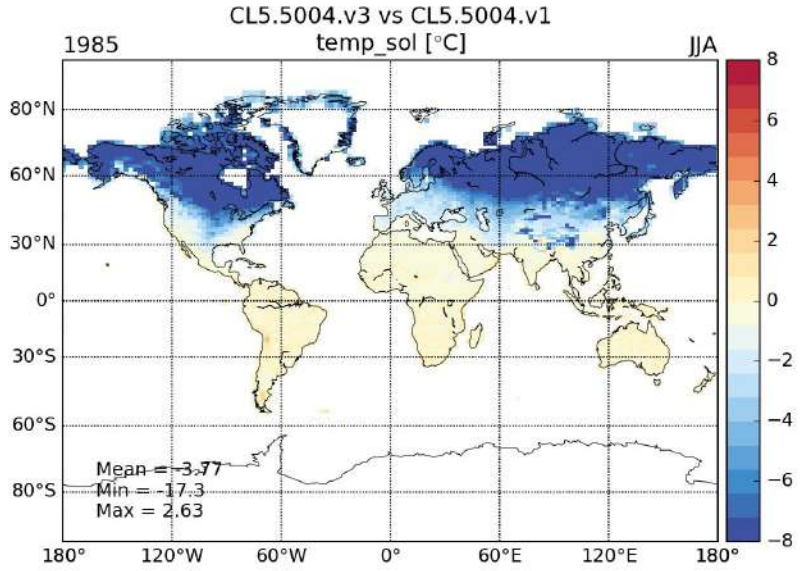
Permafrost

⇒ Large feedback loop during spring/summer time

Spring & Summer



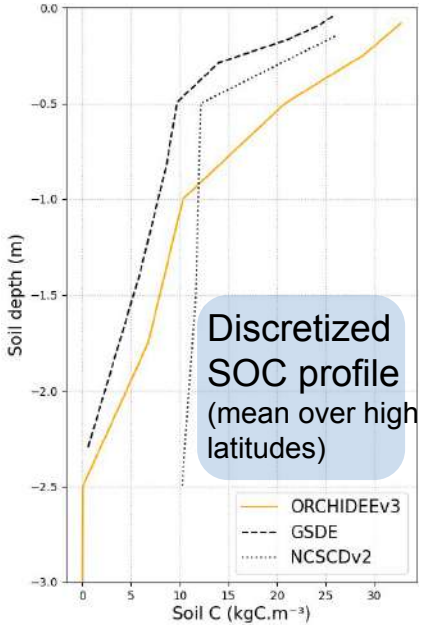
Delta Surface Temperature (summer, °K):
'freezing' minus 'no freezing'

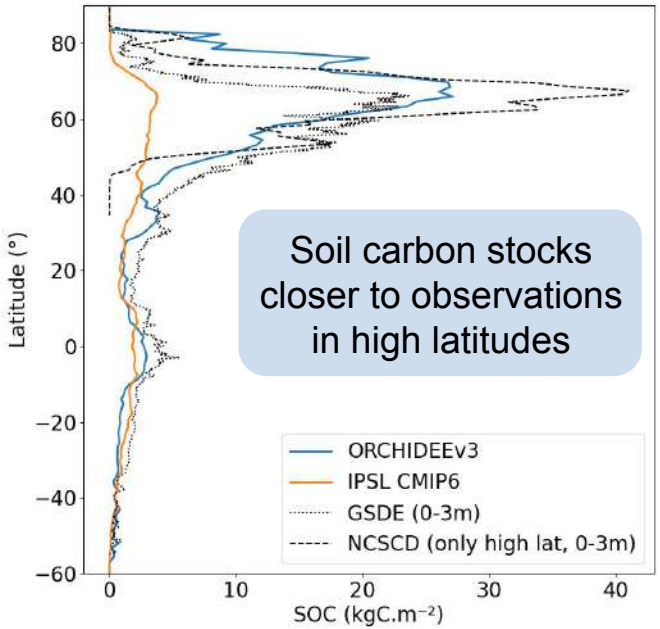


Permafrost

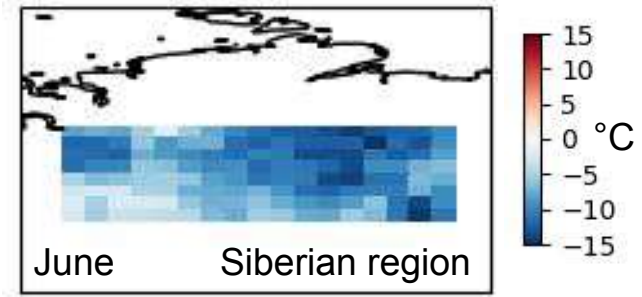
Implementation **of soil carbon discretization** allows for the representation of **vertically resolved processes** : soil carbon (SOC) decomposition, exchanges between soil layers, SOC insulation, cryoturbation…

- **+ mosses thermal effect**
- **+ latent heat in energy budget**
- \+ explicit Nitrogen cycle since ORCHIDEE v3





ΔsurfaceT (no insulation - insulation by SOC + moss)

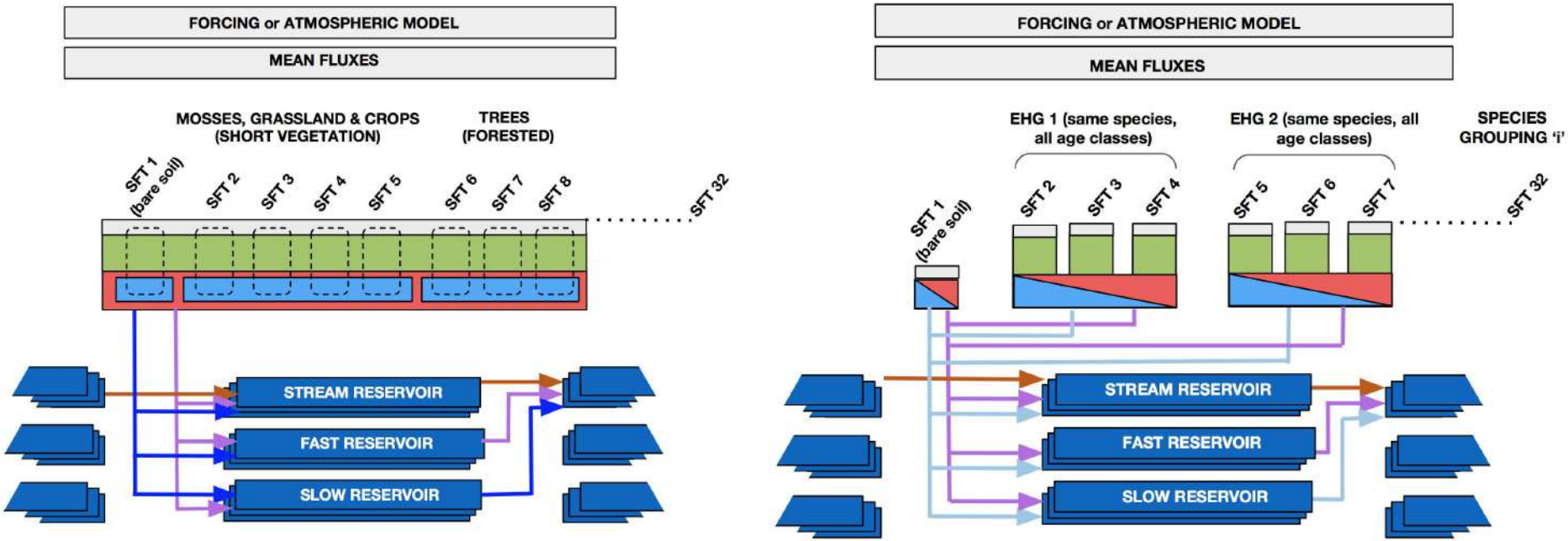


R. GAILLARD, ENS

Multi - energy budget (multi-tiling)

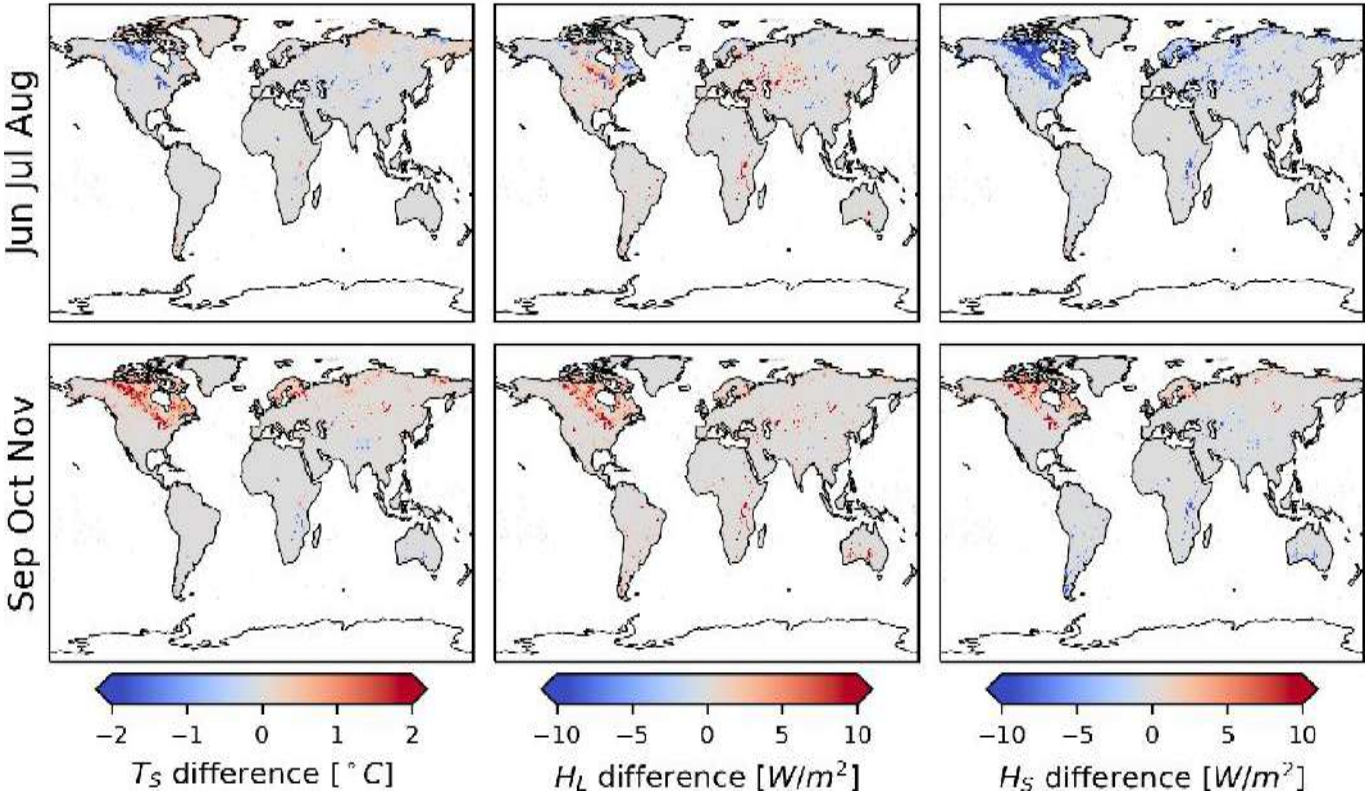
Current scheme
1 energy budget
3 water budget
Npft carbon budget

New scheme
Ngroups energy budget
Ngroups water budget
Npft carbon budget



Accounting for lakes

Implementation of **a lake model in ORCHIDEE** to asssess the impact of lakes on surface temperatures and turbulent fluxes (A. Bernus's PhD, Bernus and Ottlé, GMD, 2022)



ORCHIDEE Surface temperature (Ts) and fluxes (LE and Hs) differences (With lakes – No lakes)
Averaged over (2000 – 2016)

Surface temperatures differences at 0.5° resolution up to 2 K and fluxes up to 10 W/m2

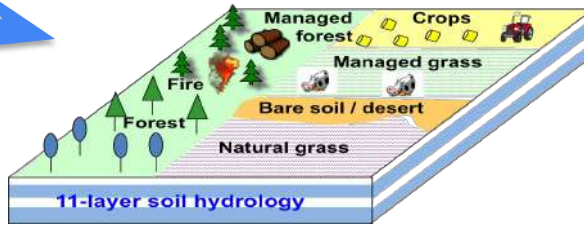
Accounting for land management !

Forest management

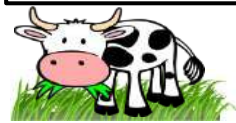
Naudts et al., 2015, 2016
MacGraph et al, 2015

Crop management

Wang et al., 2017



Grassland management



CO_2
CH_4
N_2O

Climate mitigation potential

Chang et al. 2015, 2016

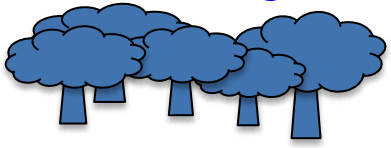
Irrigation

⇒ Planned effort to integrate past developments into the TRUNK

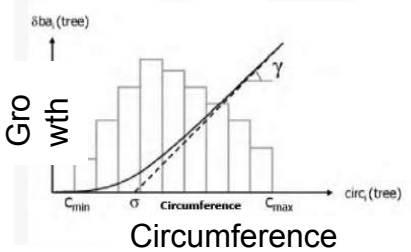
- Grassland management
- Cropland specificities (phenology, C allocation,...)
- Irrigation

Forest dynamics & management

Include diameter & age classes



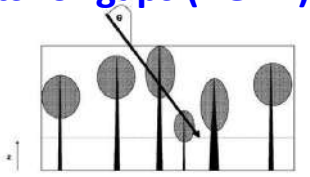
Allocation : "big get bigger"



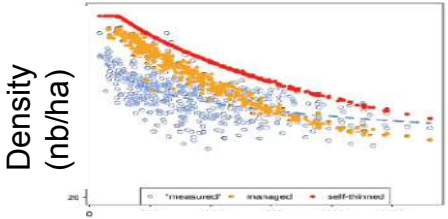
ORCHIDEE - TRUNK

(Naudts et al., 2015)

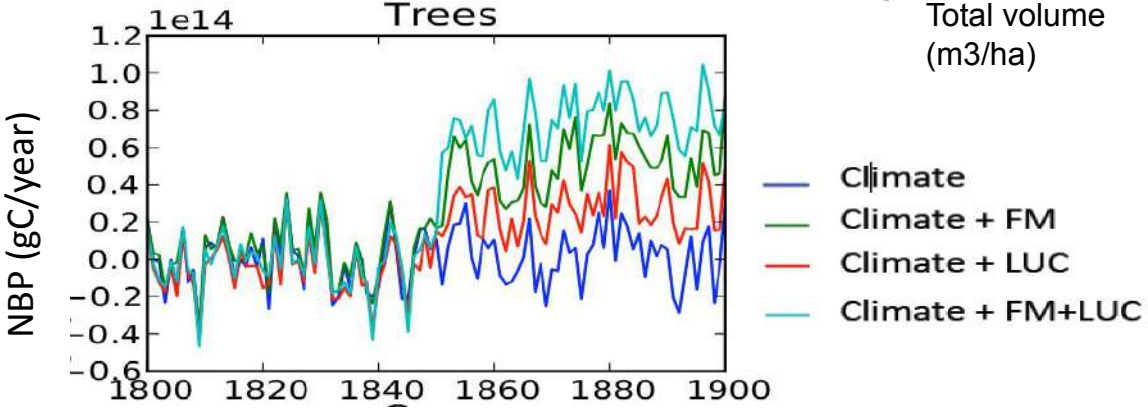
Accounts for gaps (PGAP)



Mortality from self-thinning



⇒Impact of climate
Forest management
Land Use Change
on European NBP



NEMO-PISCES on the route to IPSL-CM7

1). Better organized….

(https://www.pisces-community.org/)

The PISCES Community

- Led by O. Aumont
  User group, Steering Committe
  & 14 Partners

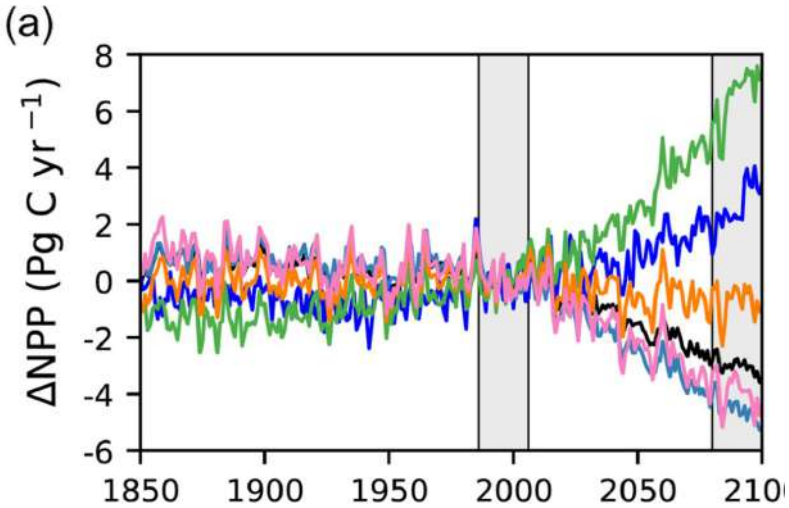
- Regular User Meeting,
  Training Sessions

- **PISCES-gas** which models the cycle of additional compounds emitted to the atmosphere such as N_2O, DMS and CO (Conte et al., 2019 ; Séférian et al., 2020 ; Conte et al. 2020).
- **PISCES-iso** which represents ^{13}C and ^{15}N (Buchanan et al., 2021).
- **PISCES-Byonic** which in addition to Fe, describes the cycles of the trace metals Co, Zn and Cu (Tagliabue et al., 2018 ; Weber et al., 2018 ; Richon and Tagliabue, 2019).

NEMO-PISCES on the route to IPSL-CM7

1). Better organized….

2). New versions tested offline with IPSL projections output



Bopp et al. 2022 :

Diazotrophy as a key driver of the response of marine net primary productivity to climate change

For IPSL-CM7 :

- PISCES-v2 to **PISCES-v2+** with new schemes for diazotrophy, DOM / POM lability, …
- PISCES-v2 to **PISCES-quota** : 24 to 42 tracers… [flexible C:N:P ratios, diurnal cycle, …]

NEMO-PISCES on the route to IPSL-CM7

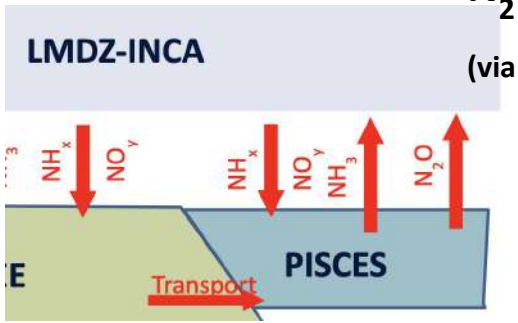
1). Better organized….

2). New versions tested offline with IPSL projections output

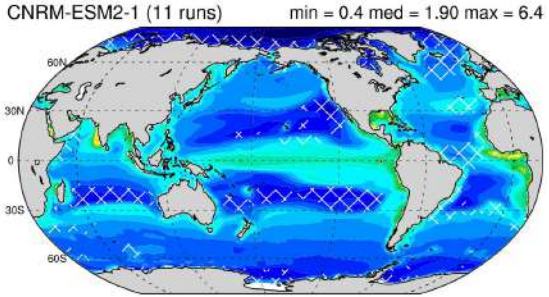
3). New opportunities for coupling with INCA / ORCHIDEE

N_2O, NH_3

(via ESM2025)



DMS (here in CNRM-PISCES)



But also BVOCS (isoprene, CO, …)

And coupling with river inputs of C,N,P & Explicit Sediment model

Merci !!