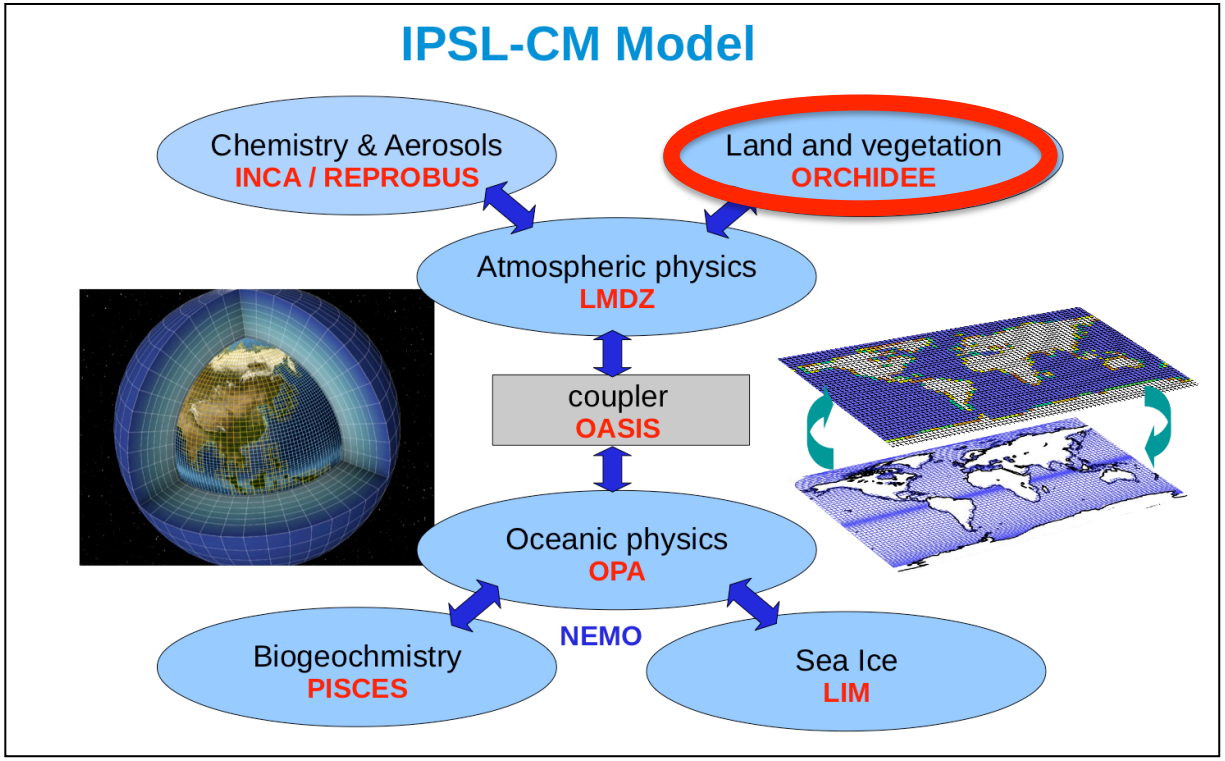
Lessons from the development of the ORCHIDEE LSM for CMIP6

*Philippe Peylin for the **ORCHIDEE project group***



Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
- Importance of sub-grid heterogeneity & processes
- Few challenges for future ESM improvements
- Needs for large spatial/temporal scales evaluation
- Recommendations including human dimension

ORCHIDEE developments for CMIP6

Implemented V1

Ongoing V2

Merging

New **Aerodynamic resistance**

Nitrogen – carbon Coupled cycles

Optimized **albedo** (using MODIS)

Permafrost carbon

Land cover based on ESA-CCI

Forest management & forest structure

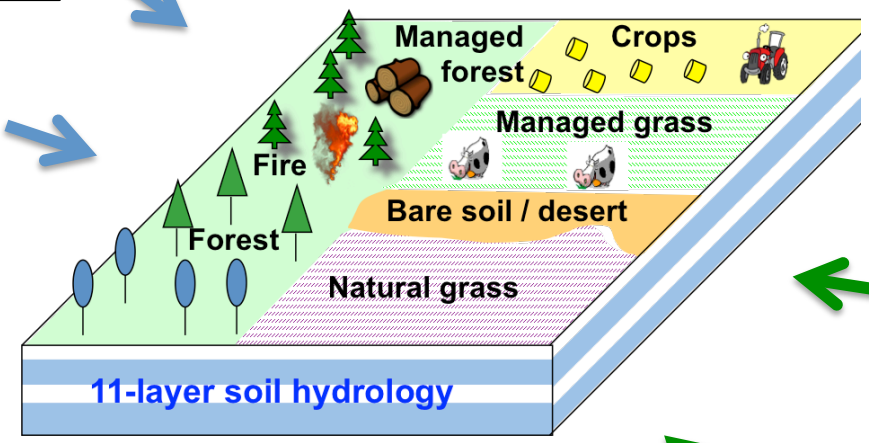
New 3 layers **snow** model

11-layer **soil hydrology** With soil **freezing**

SPITFIRE and Land use gross transitions

Optimized Carbon cycle **parameters**

CH4 emissions (wetland and permafrost)

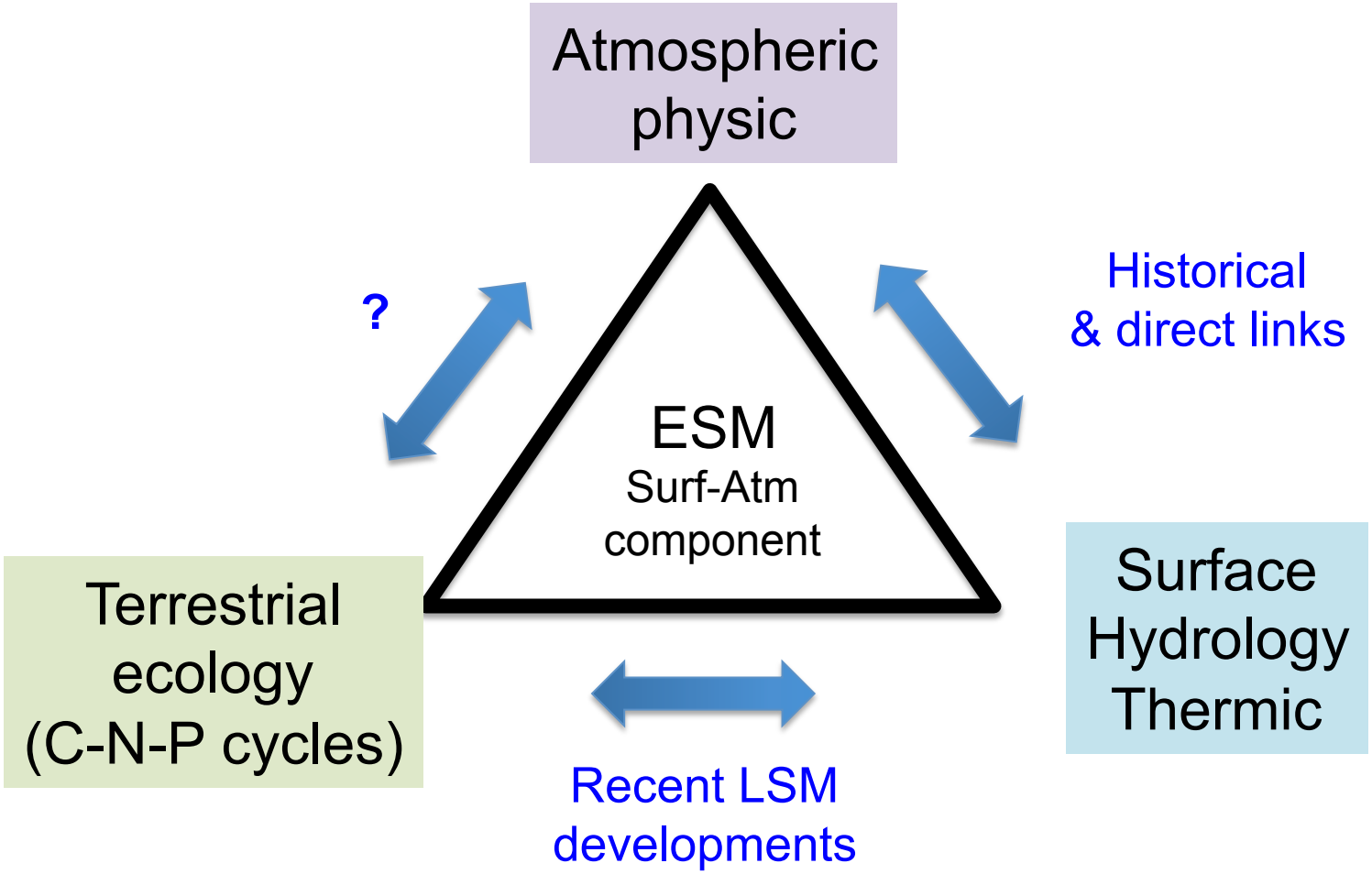


Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
  - Example: Soil physic – Biogeochemistry – Atmosphere

    (Soil freezing – Snow cover – Snow fall – Surf Temp.)
- Importance of sub-grid heterogeneity & processes
- Few challenges for future ESM improvements
- Needs for large spatial/temporal scales evaluation
- Recommendations including human dimension

Interactions between communities

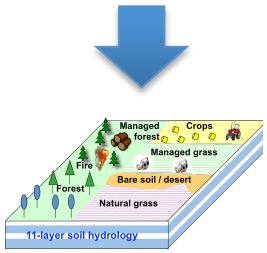


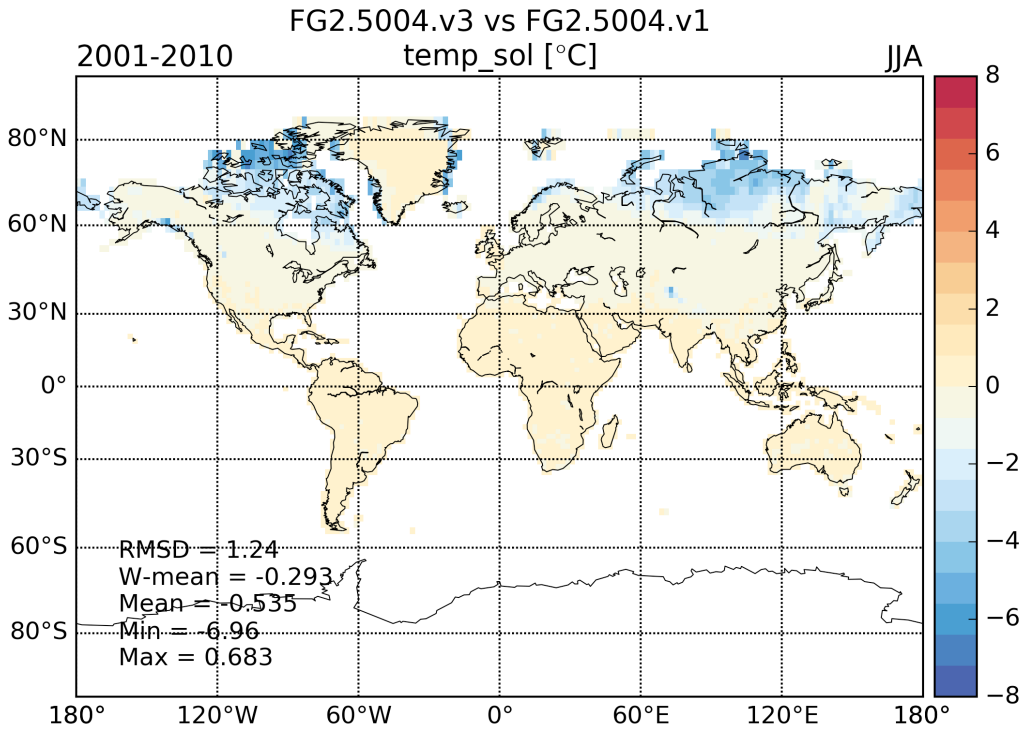
Soil freezing : **forced simulations**

Freezing ➔ Increase winter soil/air temp. (≈ 1°C)

➔ decrease summer soil/air temp. (≈1°-2°C)

CRU-NCEP





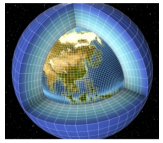
Delta Surface Temperature (summer, °K):

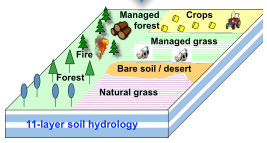
‘freezing’ minus ‘no freezing’

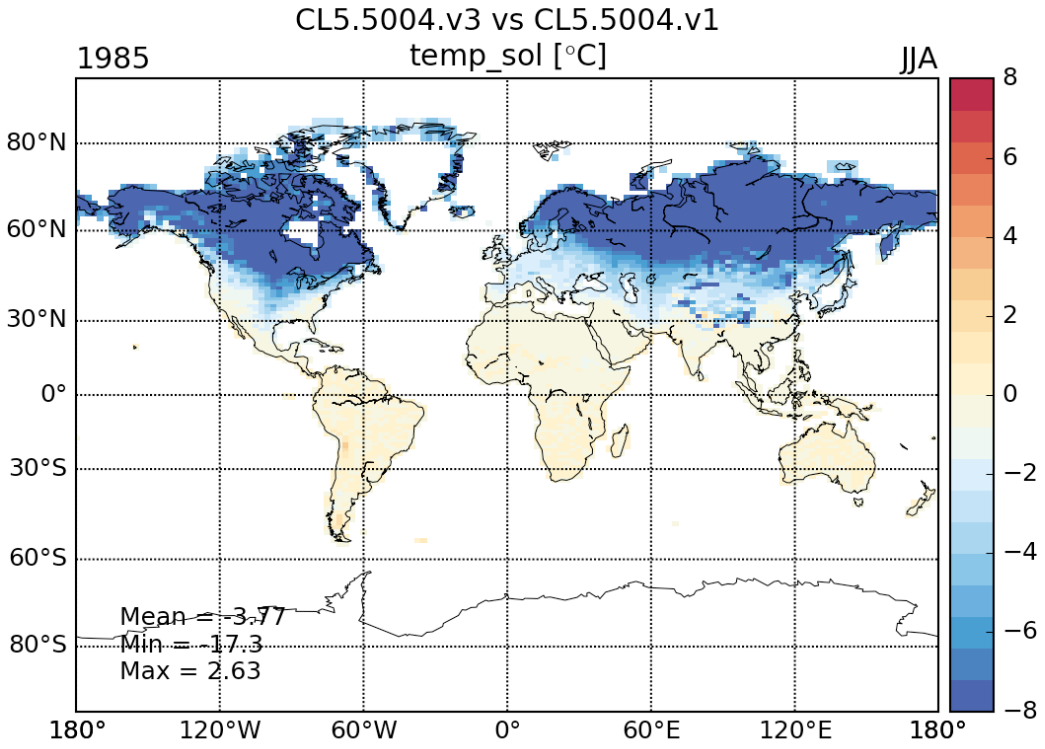
Soil freezing : **coupled simulations**

Freezing ➔ Increase winter soil/air temp. (≈ 1°C)

➔ decrease summer soil/air temp. (6°- 8°C)







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Soil freezing : **coupled simulations**

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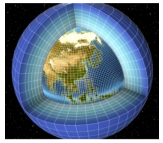
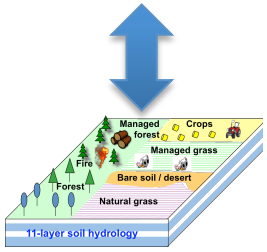
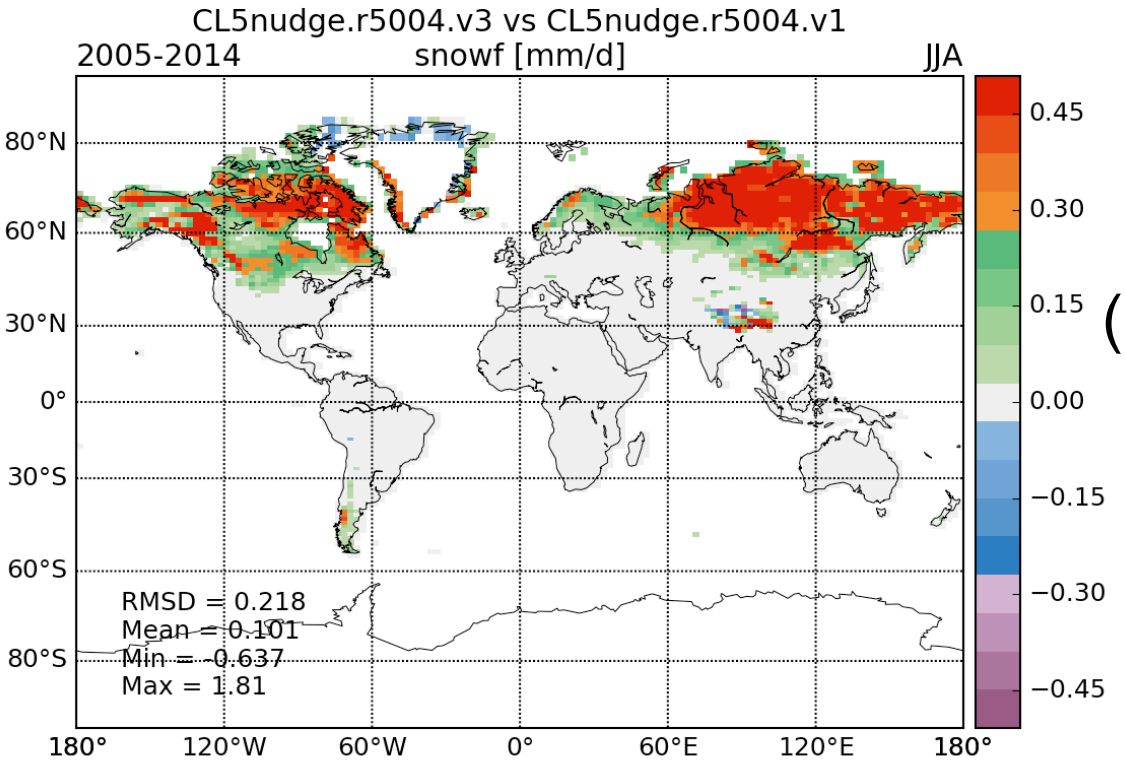
➔ decrease summer soil/air temp. (6°-8°C)

➔ increase snow fall







Delta
snow cover
(summer, mm/d)

'freezing'
minus
'no freezing'

Soil freezing : **coupled simulations**

Freezing ➔ Increase winter soil/air temp. (≈ 1°C)

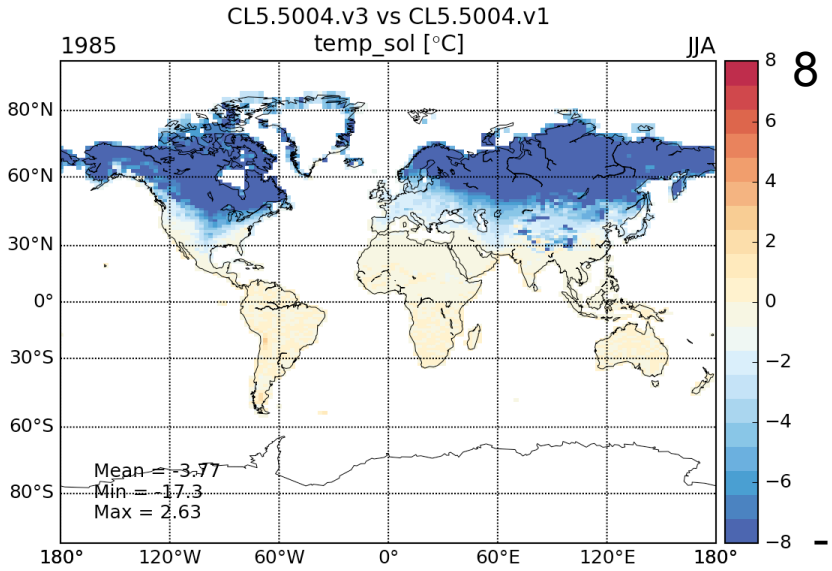
➔ decrease summer soil/air temp.

➔ increase snow fall

➔ Highly sensitive to surface heat conductivity

Standard soil conductivity

decrease conductivity
for upper 10 cm (to that of mosses)

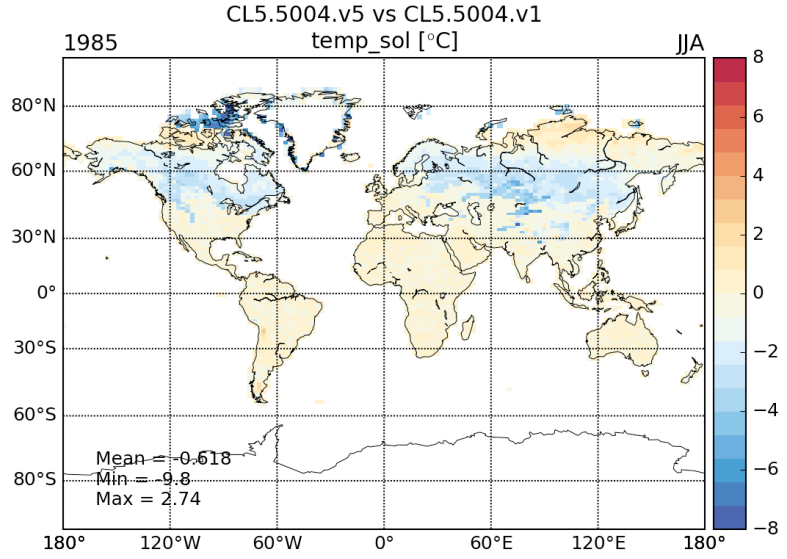


Delta Surface Temperature (summer, °K):

'freezing' minus 'no freezing'

8

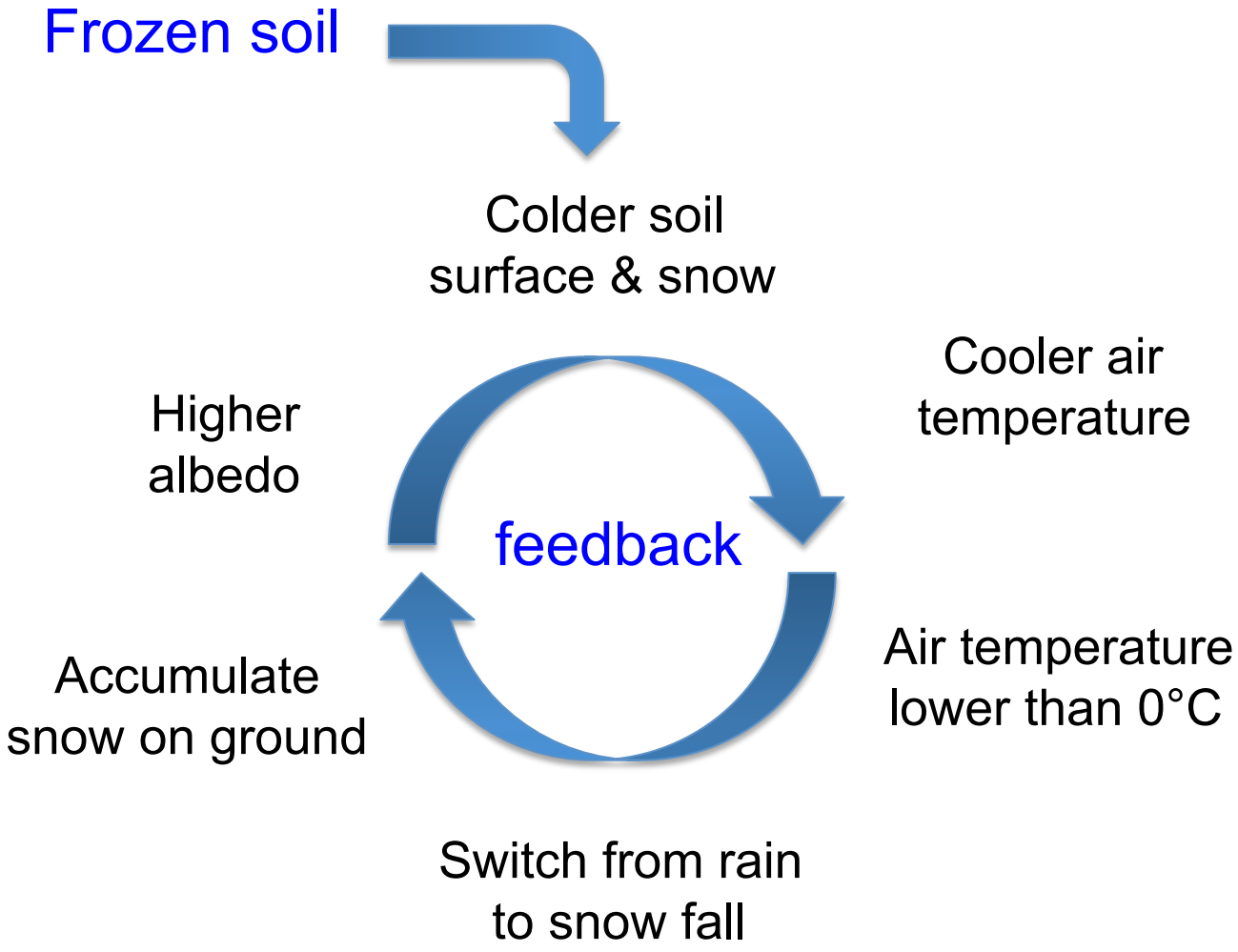
- 8



Soil freezing : **coupled simulations**

➔ Large feedback loop during spring/summer time

Spring & Summer



Soil freezing : **coupled simulations**

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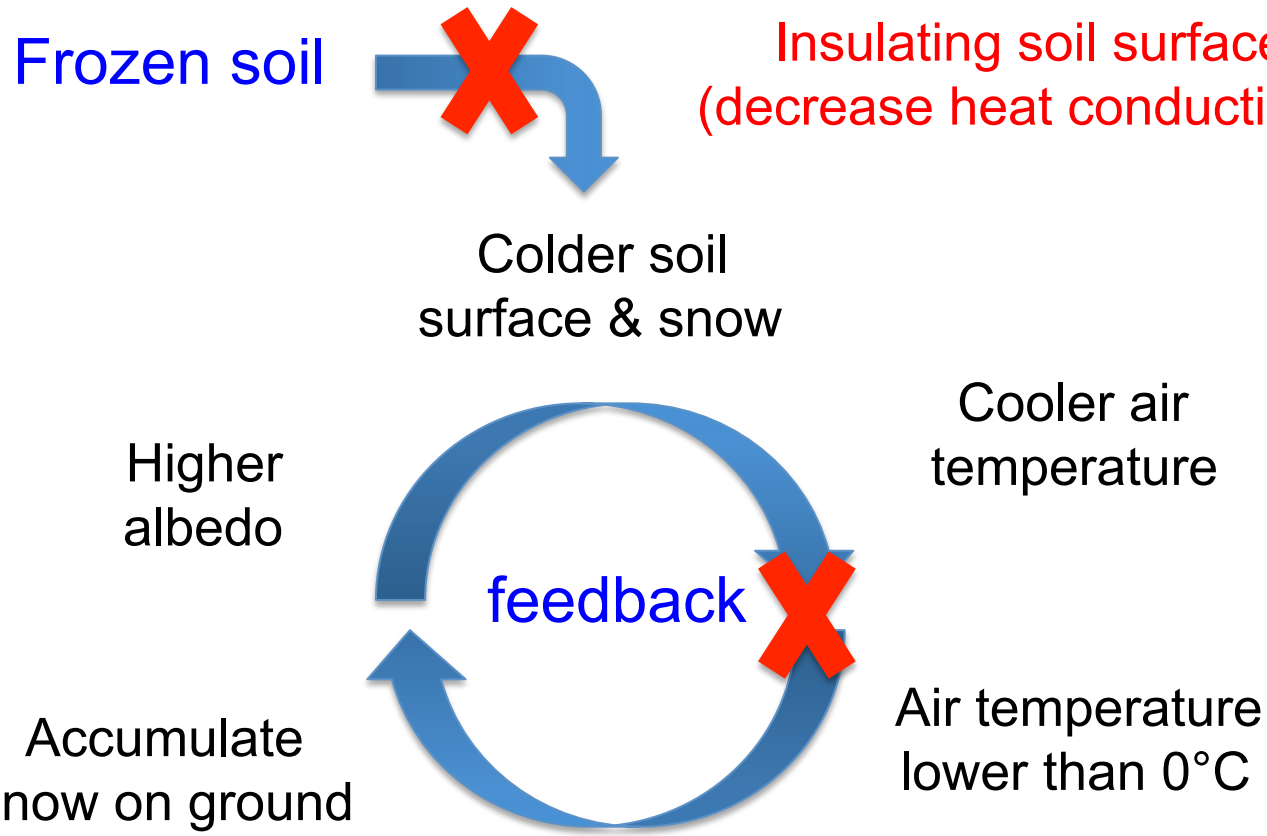
Spring & Summer



Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
- Importance of sub-grid heterogeneity & processes
  - Example: Soil water infiltration – summer plant stress
- Few challenges for future ESM improvements
- Needs for large spatial/temporal scales evaluation
- Recommendations including human dimension

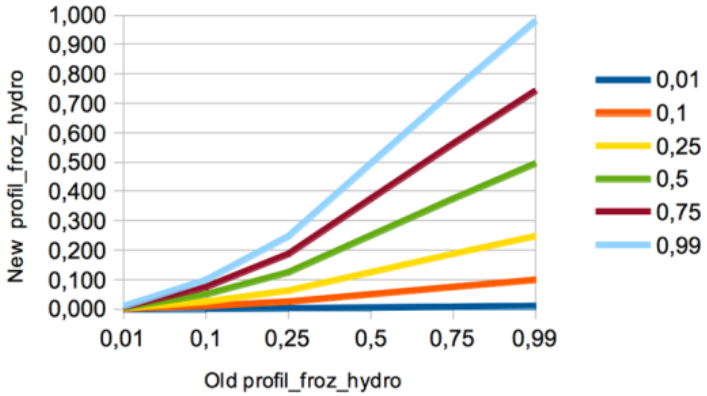
Soil freezing impact on hydrology

Freezing → ↘ Infiltration → ↘ summer W availability

1) No sub-grid scale accounting → Veg. water stress in Siberia → Surf. warming → Plant Mortality (low LAI)

Strong feedback

2) Sub-grid processes f (intensity , θ)



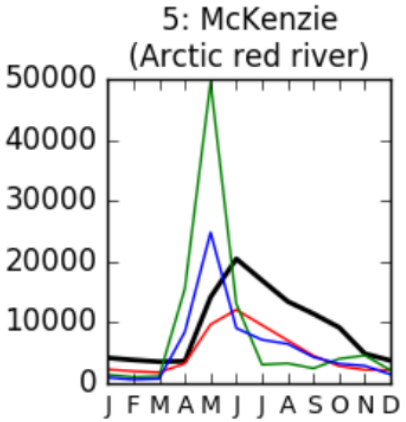
→ Large C/W/E improvements

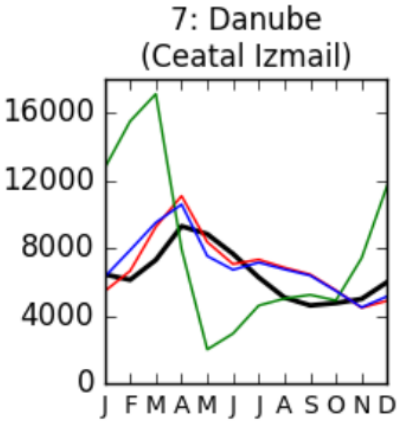
Soil freezing impact on hydrology

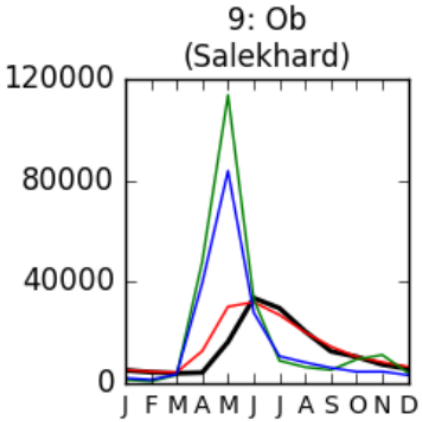
Freezing ➡ ↘ Infiltration ➡ ↘ summer W availability

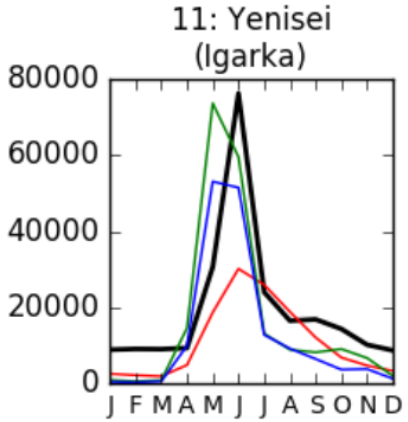
➔ River discharge (m^3/ s)

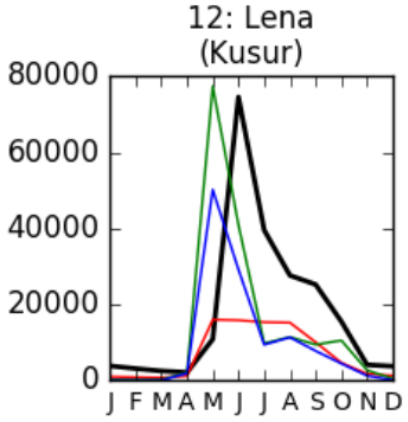
OBS (GRDC)
ORC STD
ORC Freeze std
ORC freeze optim

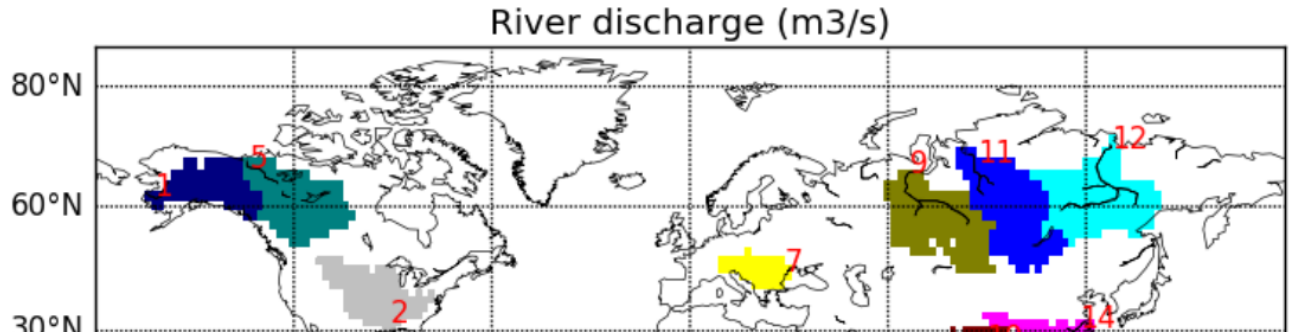












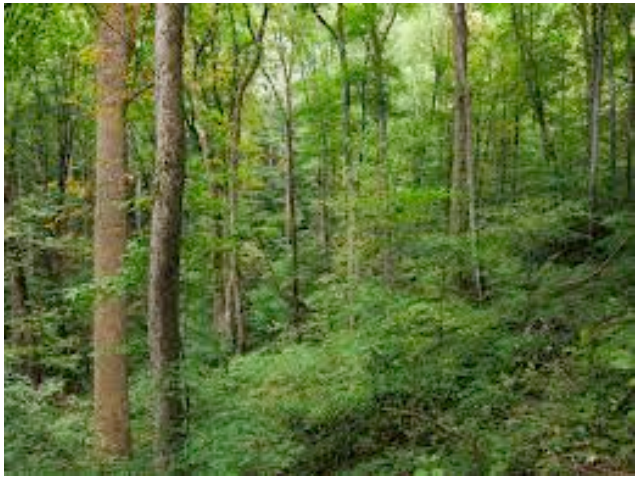
Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
- Importance of sub-grid heterogeneity & processes
- Few challenges for future ESM improvements
  - Surf-atm coupling : Multi-layer energy budget
  - Accounting for sub-grid scale landscape
  - Ecosystem management
  - Ecosystem dynamic
- Needs for large spatial/temporal scales evaluation
- Recommendations including human dimension

A multi-layer energy balance scheme

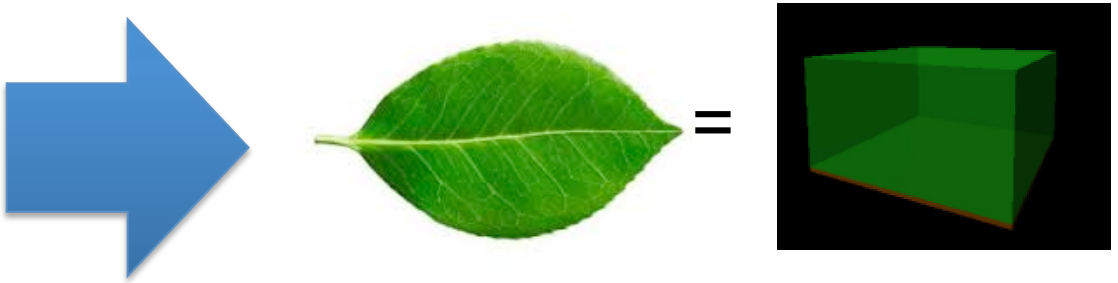
- Why a multi-layer energy canopy scheme ?

Ecosystem structure



Model representation

Big leaf model

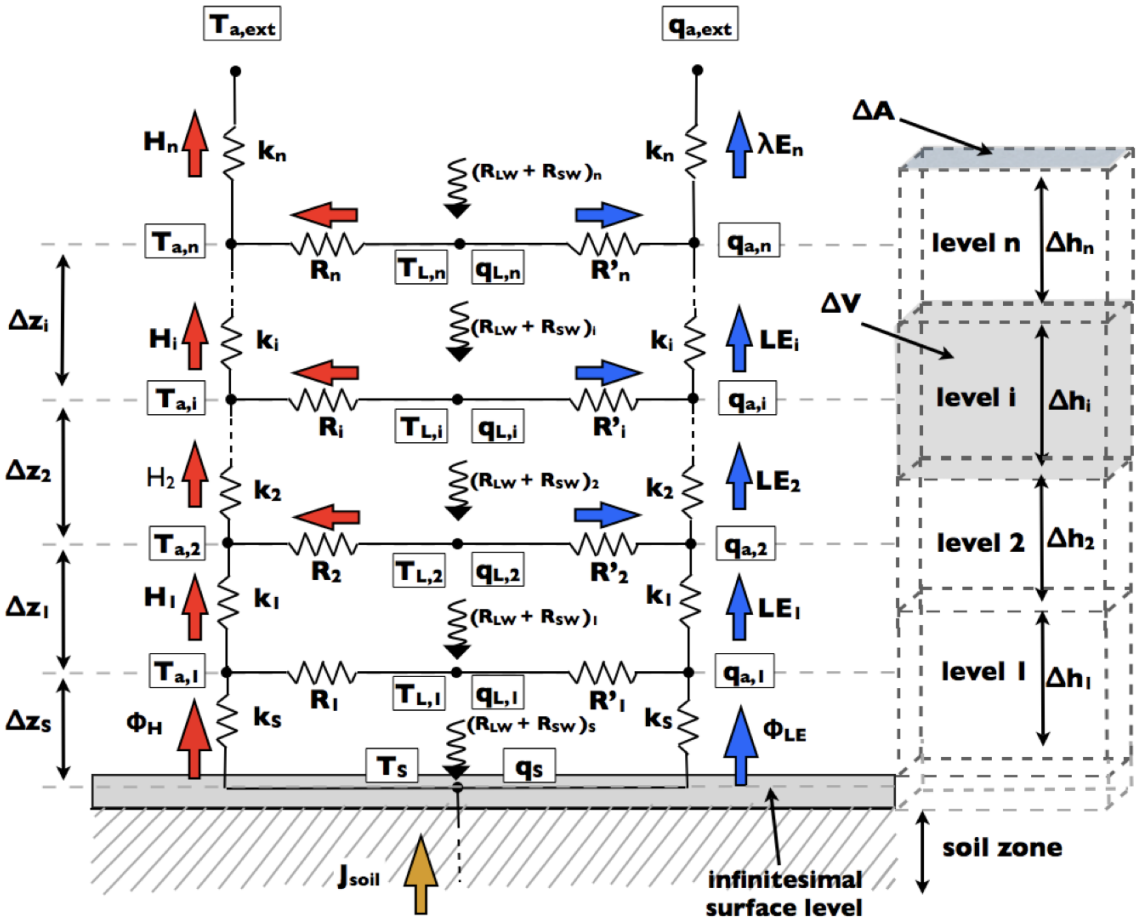


- DGVM still poorly represent site-level heat fluxes
- Canopy space and Trunk crown have different behaviours
- Under-storey vs over-storey representation ?
- Link to ecosystem services: forest canopy climate

Multi-layer energy budget

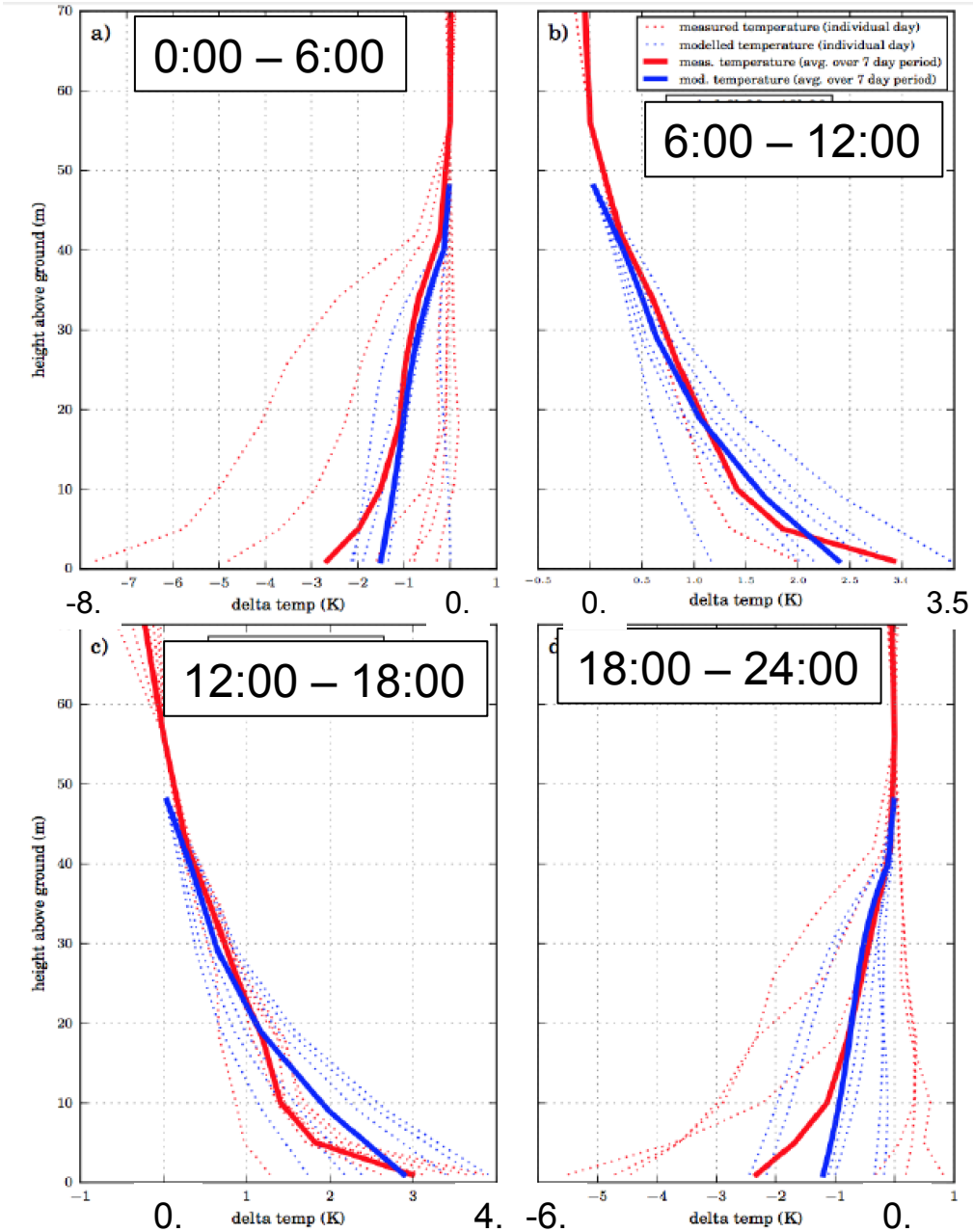
Ryder et al., 2015

- 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



Daily temperature

Temperature profile at Tumbarumba site

Observations

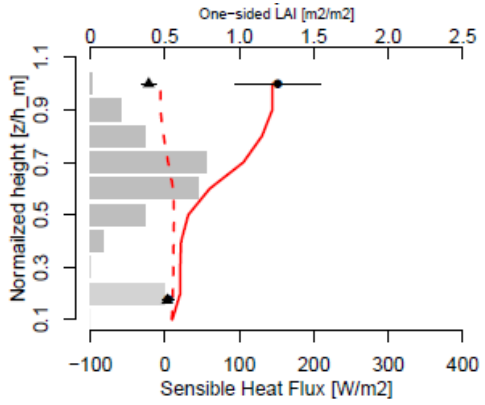
Model

Ryder et al., 2015

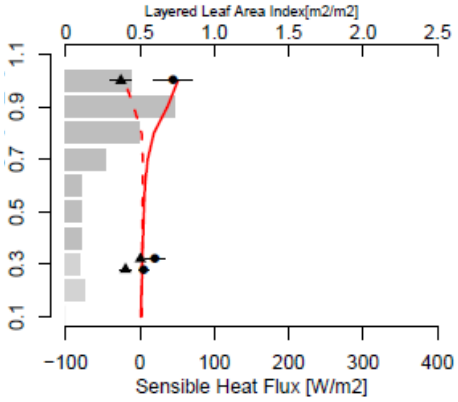
Sensible heat flux with multi-layers scheme

▲ ● Obs — — 22:00 ——— 14:00

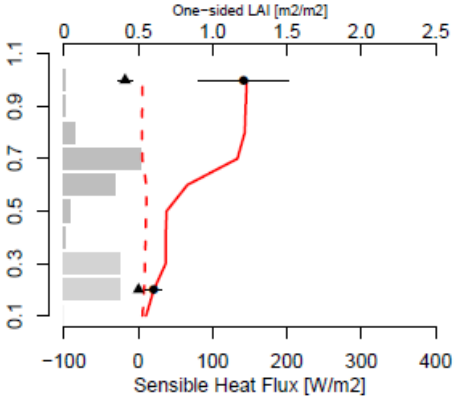
FI-Hyy



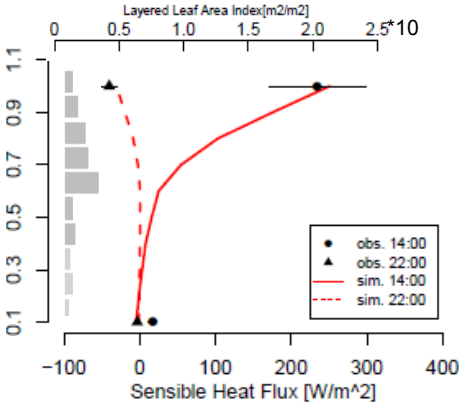
FR-LBr

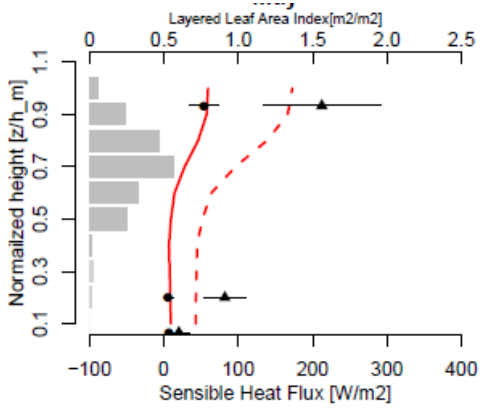


NL-Loo

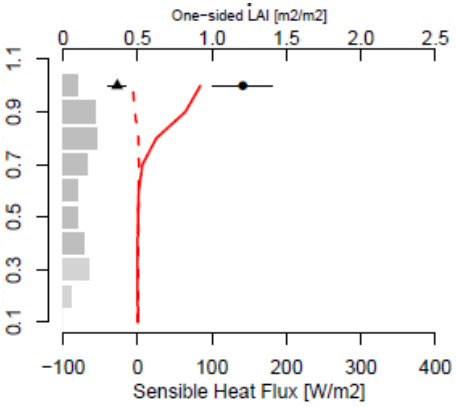


DE-Bay

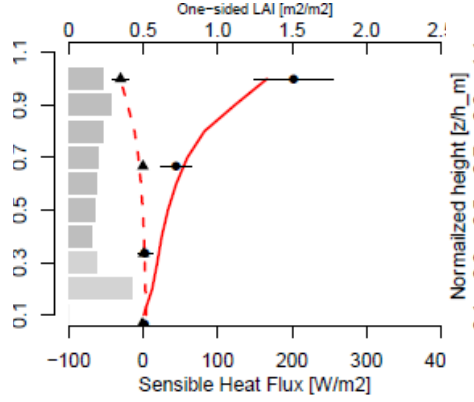




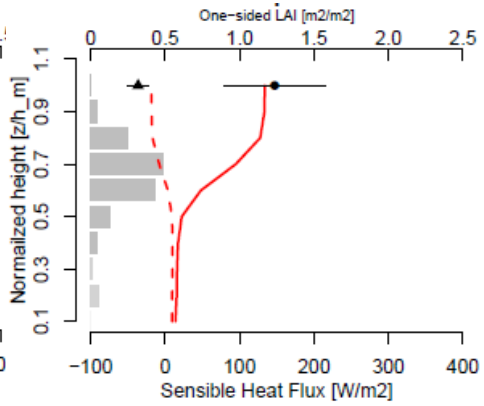
CA-Oas



AU-Tum



DE-Hai



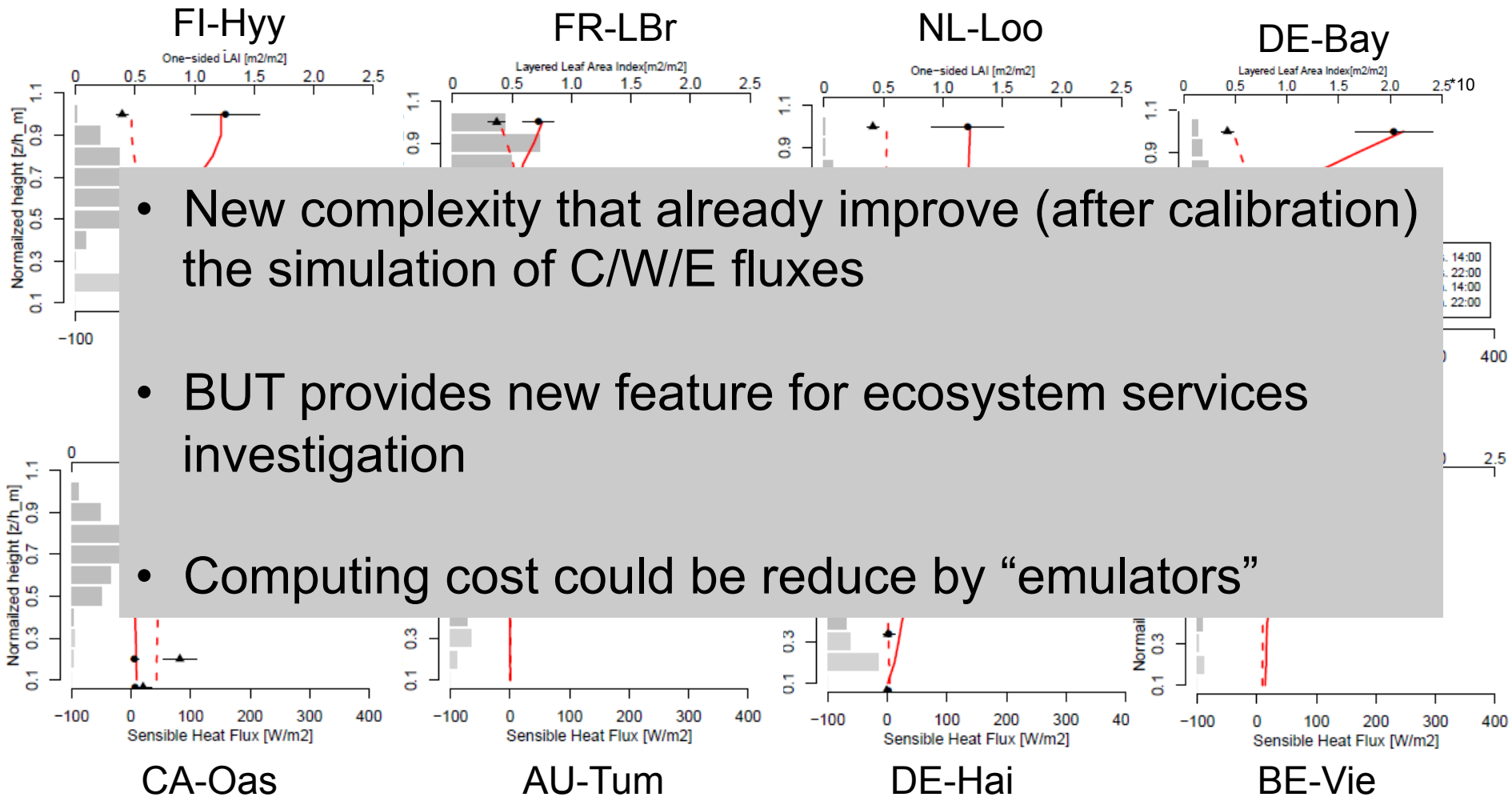
BE-Vie

Chen et al., 2016

Monthly average flux (months of each site are random selected)

Sensible heat flux with multi-layers scheme

▲ ● Obs — — 22:00 ——— 14:00



- New complexity that already improve (after calibration) the simulation of C/W/E fluxes
- BUT provides new feature for ecosystem services investigation
- Computing cost could be reduce by “emulators”

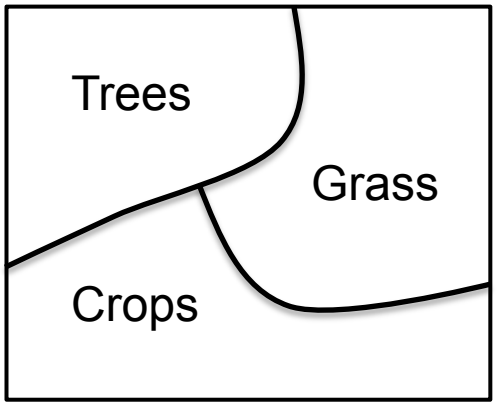
Chen et al., 2016

Monthly average flux (months of each site are random selected)

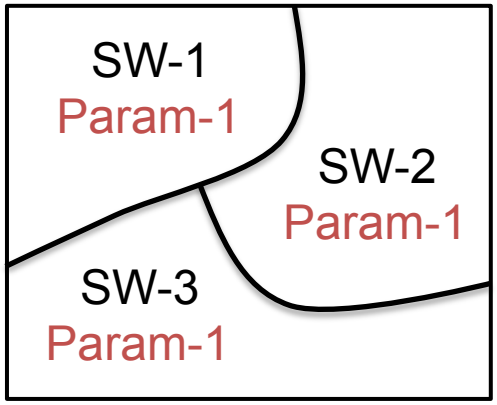
Landscape heterogeneity & organisation

Models

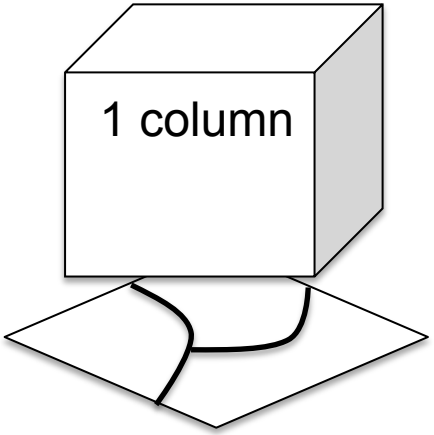
Surface Vegetation



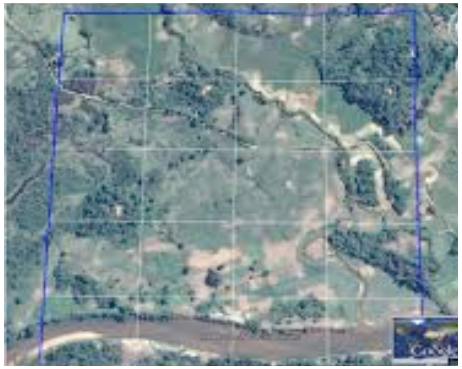
Ground Hydrology



Atmospheric coupling



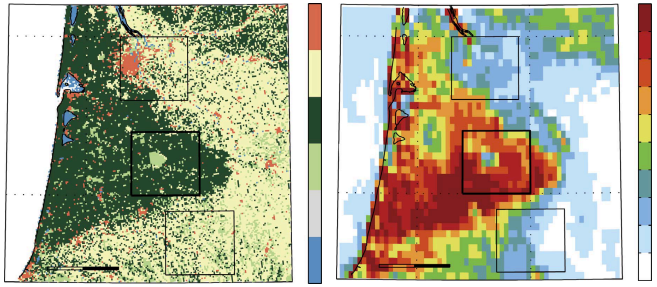
Reality



Satellite product ≈10 m

Soil properties
- topography

Forest cover ➔ more cloud



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

Accounting for sub-grid heterogeneity ?

➔ Existing new products of HR (10m) land cover opens new possibilities

➔ Plant types/species – topography – soil properties (water, nutrients) are not random within grid cells of 20 – 50 km !

➔ Impact on :

- ✓ Plant physiology
- ✓ Vegetation clumping (stand scale) for radiative transfert
- ✓ Roughness properties (depending on wind conditions)
- ✓ Water availability/competition per PFTs
- ✓ Water transfer

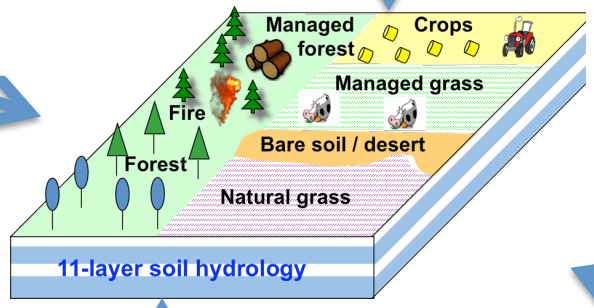
Accounting for management / fauna

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

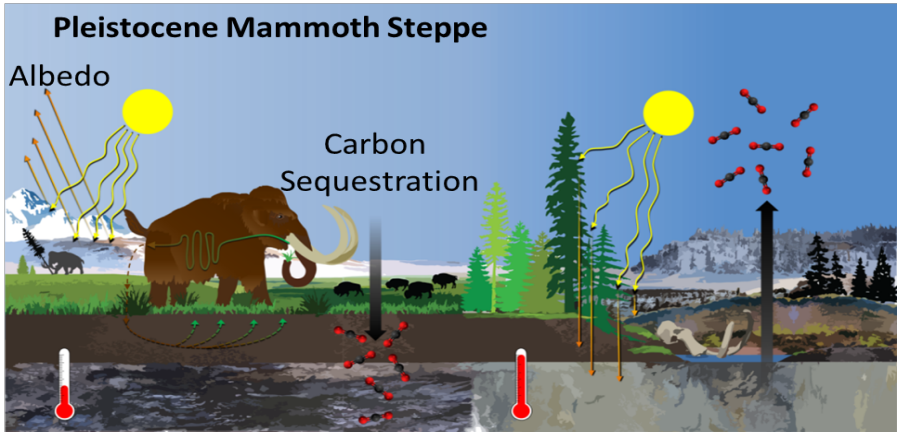
Chang et al. 2015, 2016

"keystone herbivore" hypothesis

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

Representing large wild herbivores

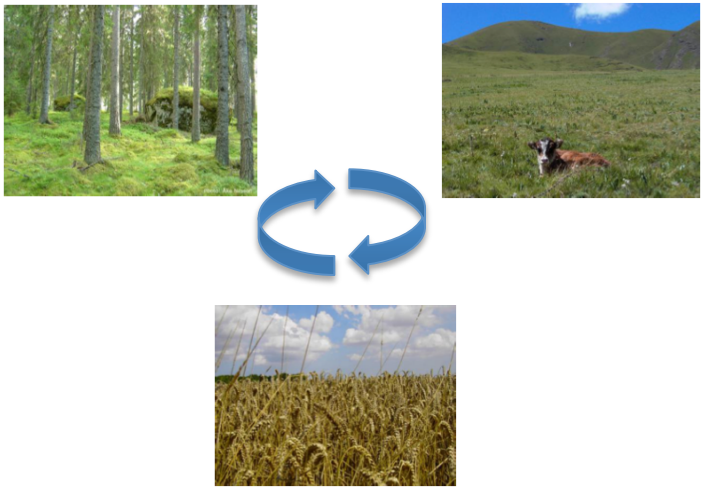
Zu et al., 2018



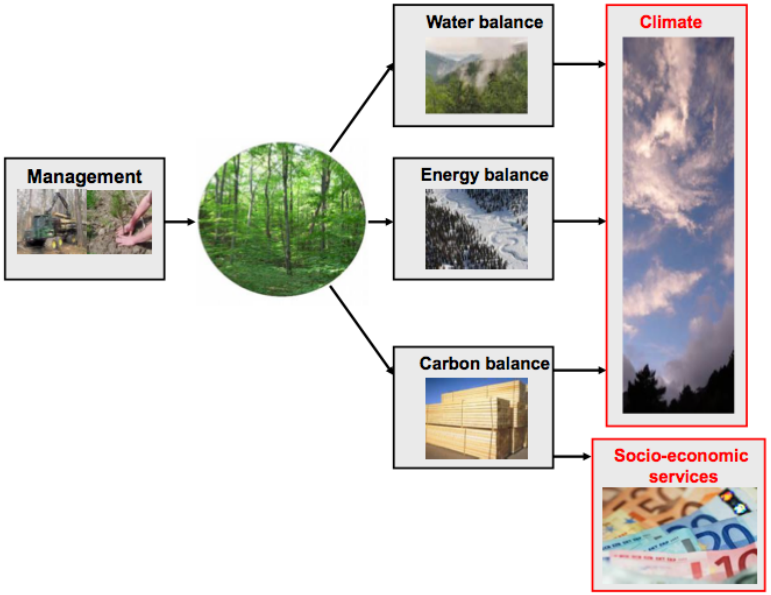
Irrigation

Potential of joint C/W/E assimilation

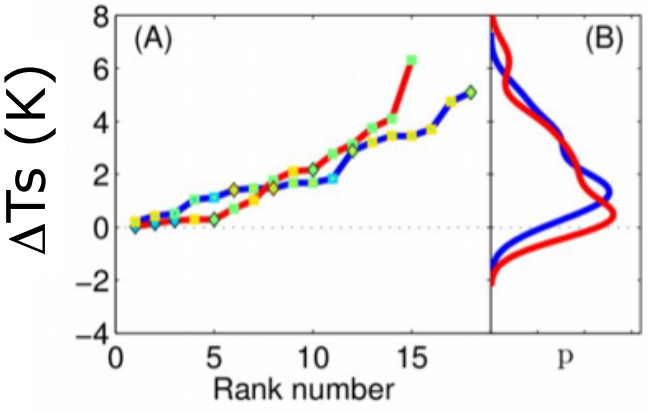
Land cover changes



Land cover management



Effect on surface climate (Analysis from nearby FluxNet sites)



Luyssaert et al. 2014

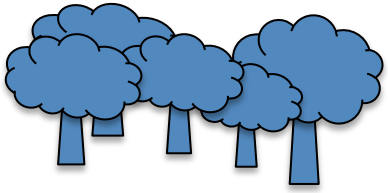
Land cover effect

Land management effect

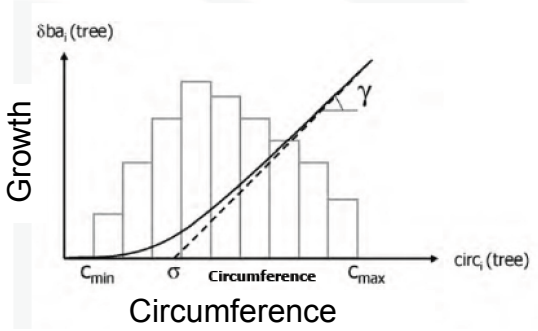
➔ link betw biogeochemical and biophysical cycles

Forest management and C cycle

Include diameter & age classes



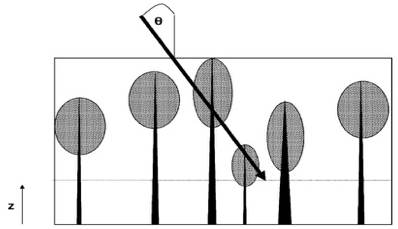
Allocation : "big get bigger"



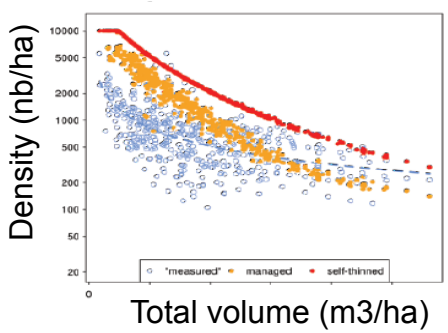
ORCHIDEE - CAN

(Naudts et al., 2015)

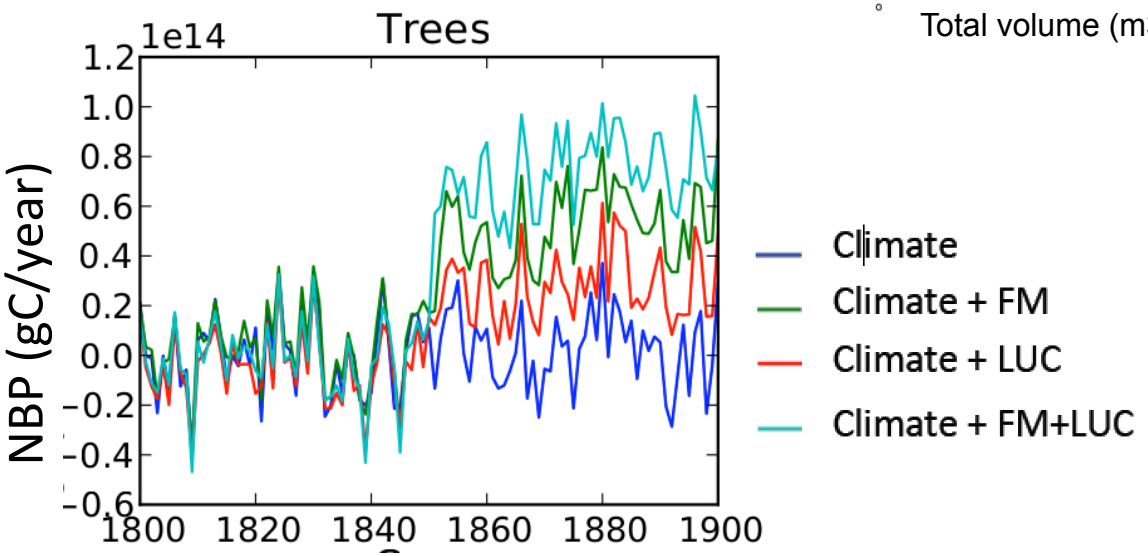
Accounts for gaps (PGAP)



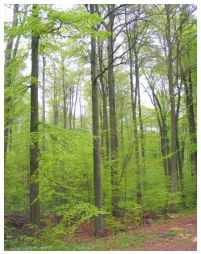
Mortality from self-thinning

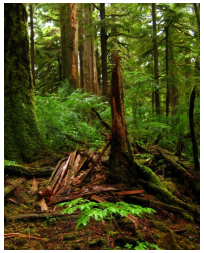


➔ Impact of climate Forest management Land Use Change on European NBP



Climate effects of 250-years of forest management in Europe

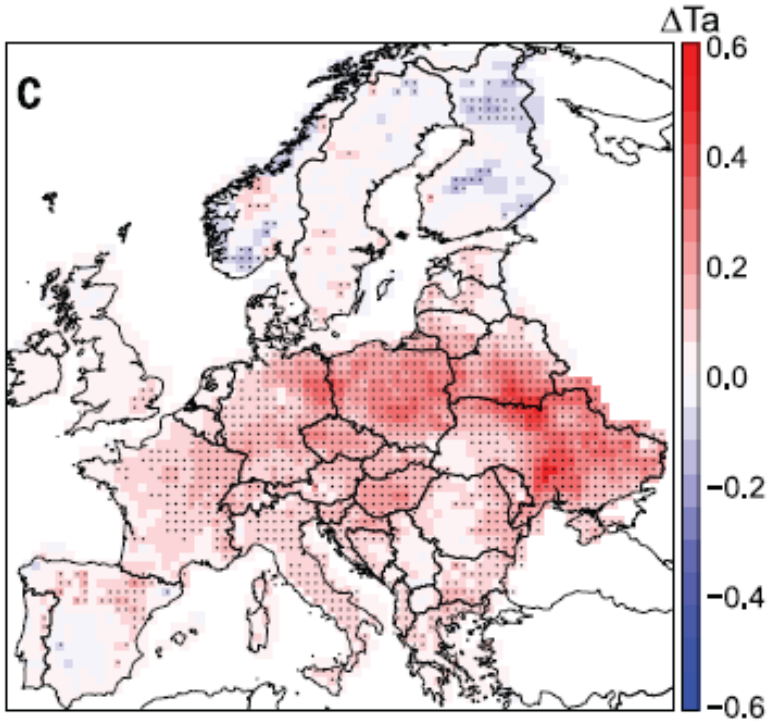




- Large afforestation in Europe since 1850
- Large species changes braodleaf → Needleaf
- Litter raking was important in the past

➔ Need to account for all effects (biophysical and biogeochemical)

Delta surface air temperature
Today – 1750
from species conversion



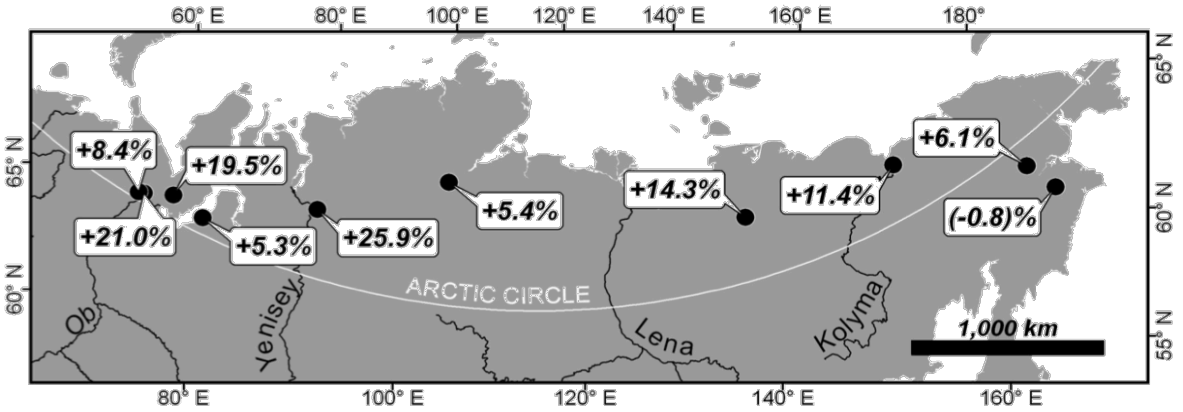
Naudts et al. 2016

Change in vegetation with climate !

Simulation of increasing shrub cover in the Arctic ?

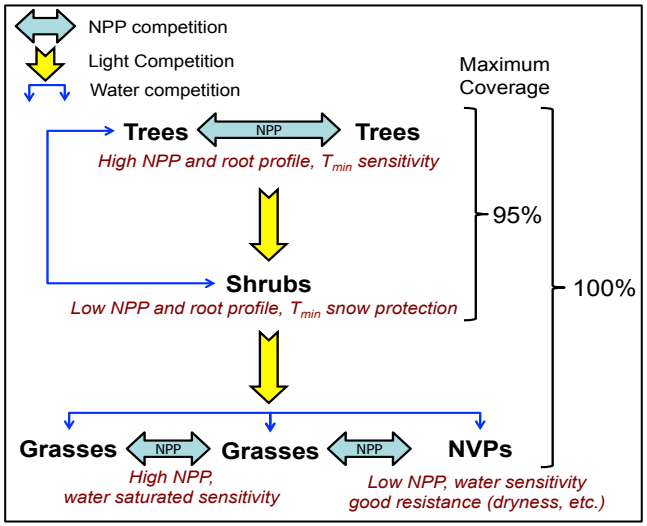
Observational evidence !

Frost and Epstein, 2014

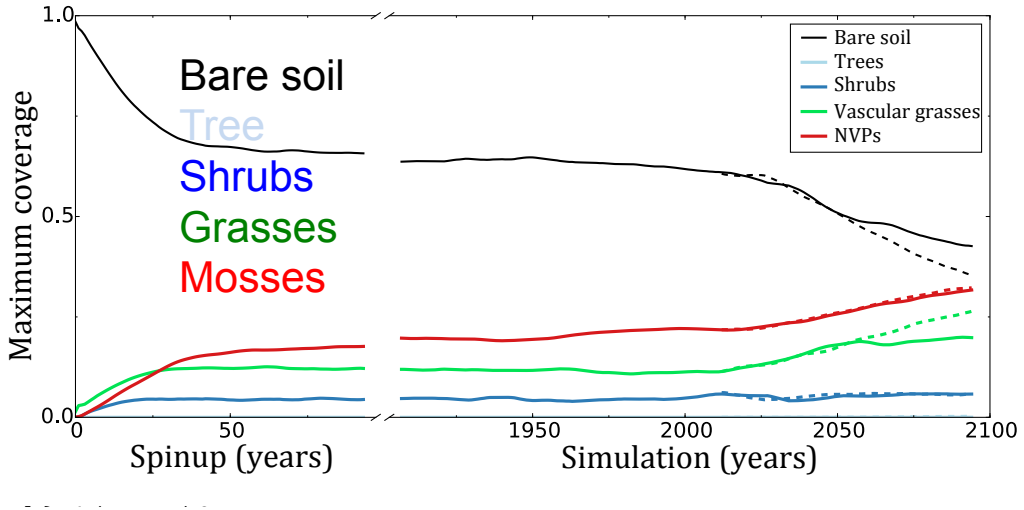


ORCHIDEE

DGVM principles



➔ No shrubs increase



Druel et al., in prep

Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
- Importance of sub-grid heterogeneity & processes
- Few challenges for future ESM improvements
- Needs for large spatial/temporal scales evaluation
  - How to evaluate the LSM in an ESM context ?
  - [COS] a new tracer of regional GPP
  - Tree ring as new historical benchmark
- The human dimension with LSM developments

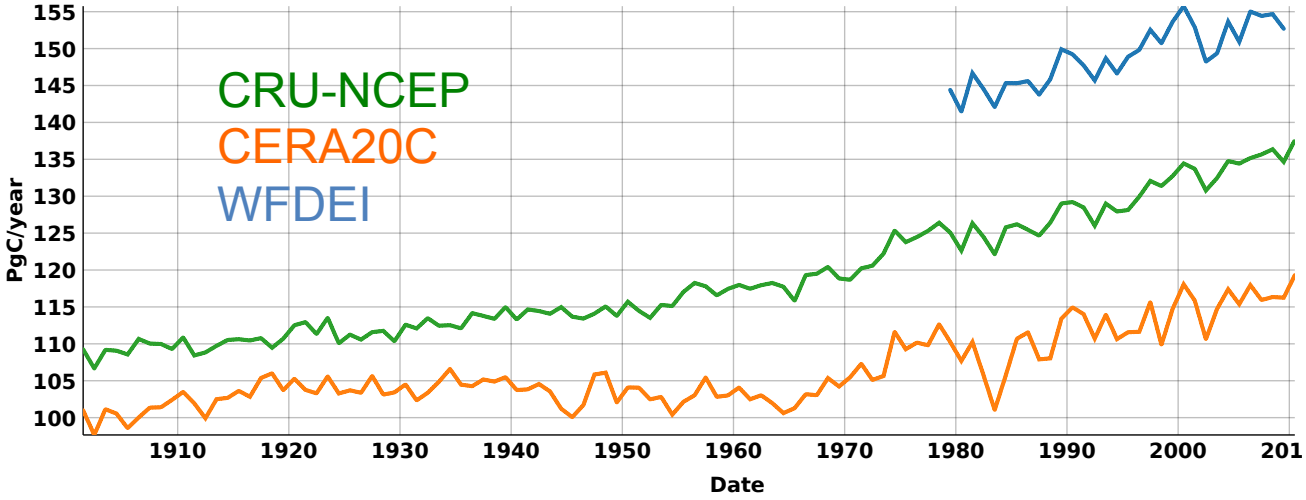
How to validate LSM for ESM application?

Should we evaluate LSM mainly in forced mode or
in coupled Atmospher-Surface mode for ESM applications ?

- Coupled mode:
  - Error compensation → may degrade future predictions
  - Depend on the questions and time frame targeted

- Forced mode: Be careful when choosing a climate forcing !

ORCHIDEE
Global
GPP
(PgC/yr)



- Forced mode: precipitation distribution over sub forcing-time step is crucial

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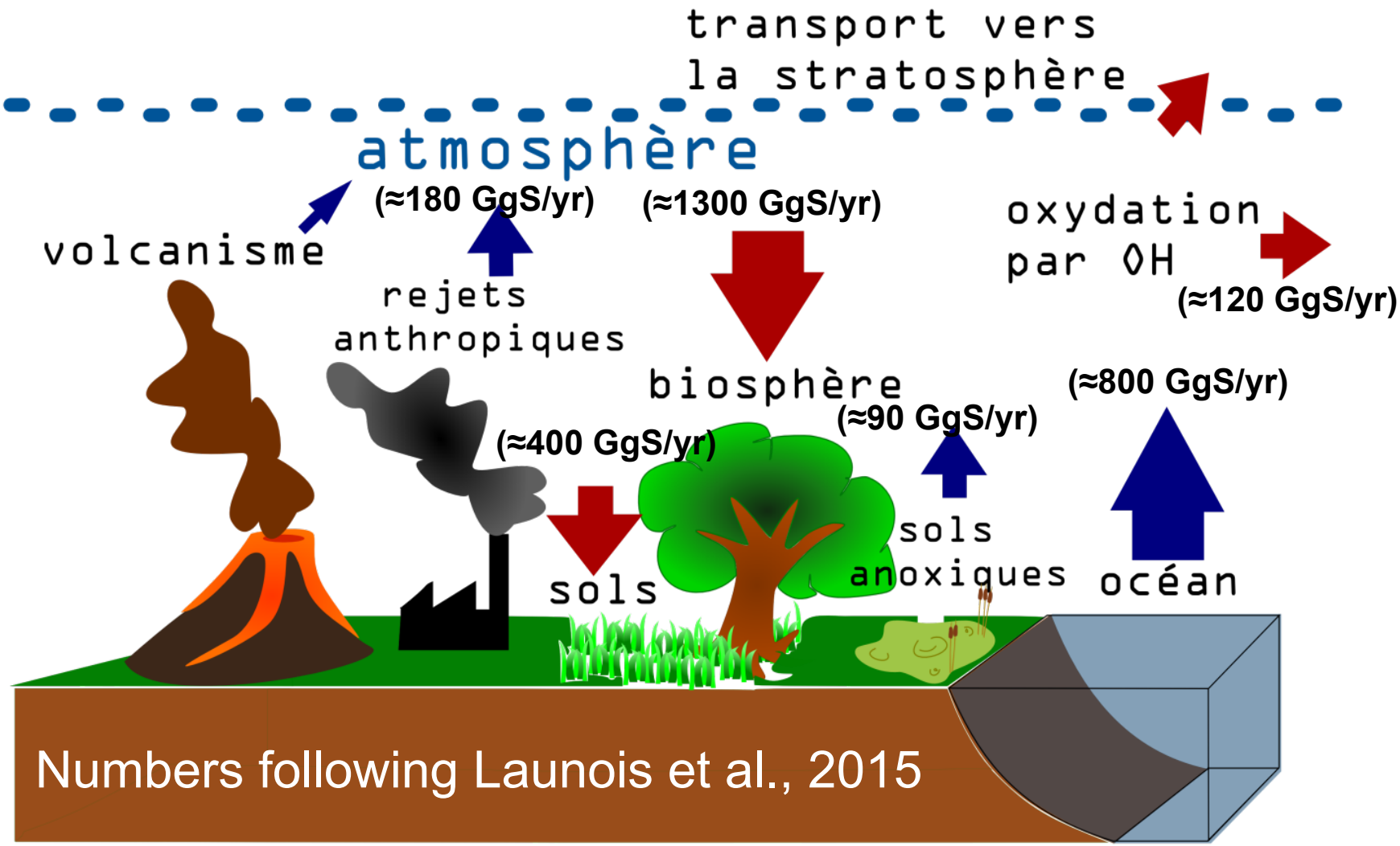
The need for large spatial scale

and long temporal scale

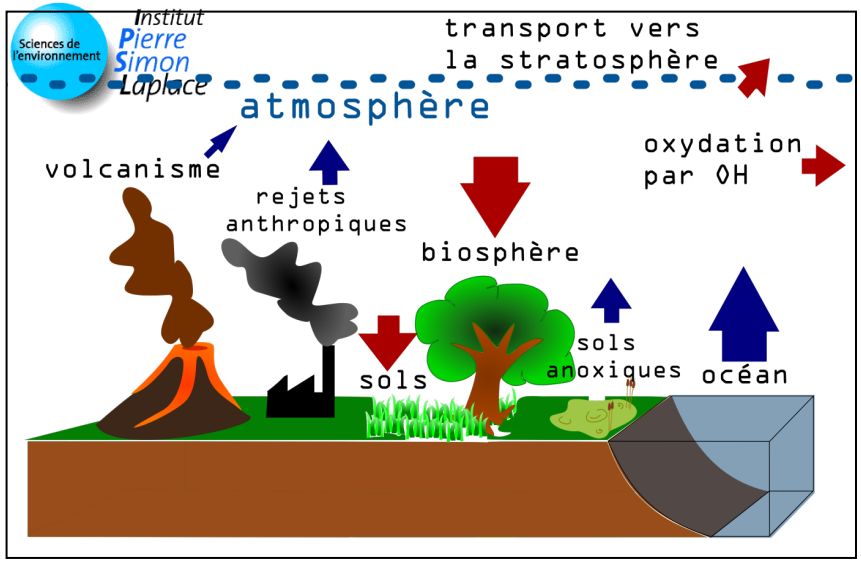
model evaluation !

COS: A new tracer for photosynthesis



Numbers following Launois et al., 2015

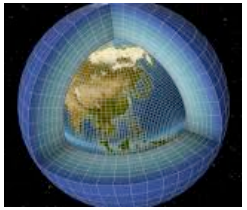
Combining COS and CO_2 Atmospheric data



COS flux scenarios

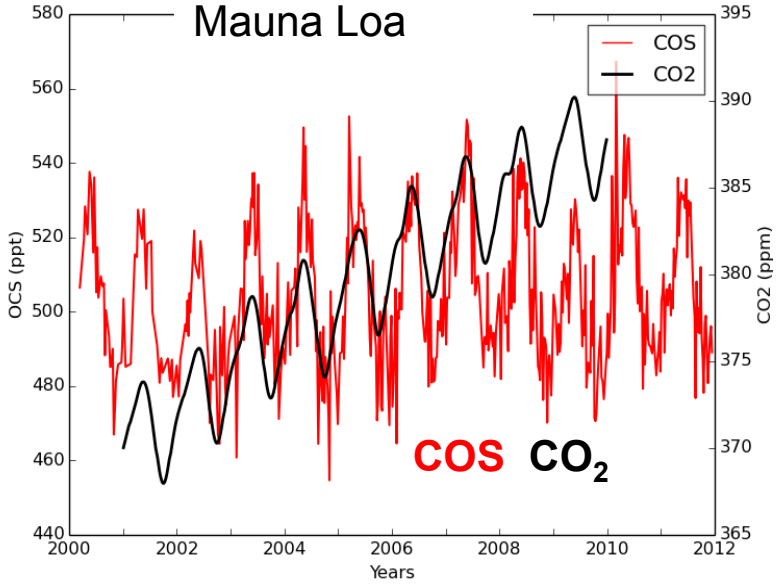
- Fbio = f(model GPP)

LMDz transport model



CO2 flux scenarios

- Model NEE
- Ocean flux from Takahashi
- Fossil fuel + biomass burning



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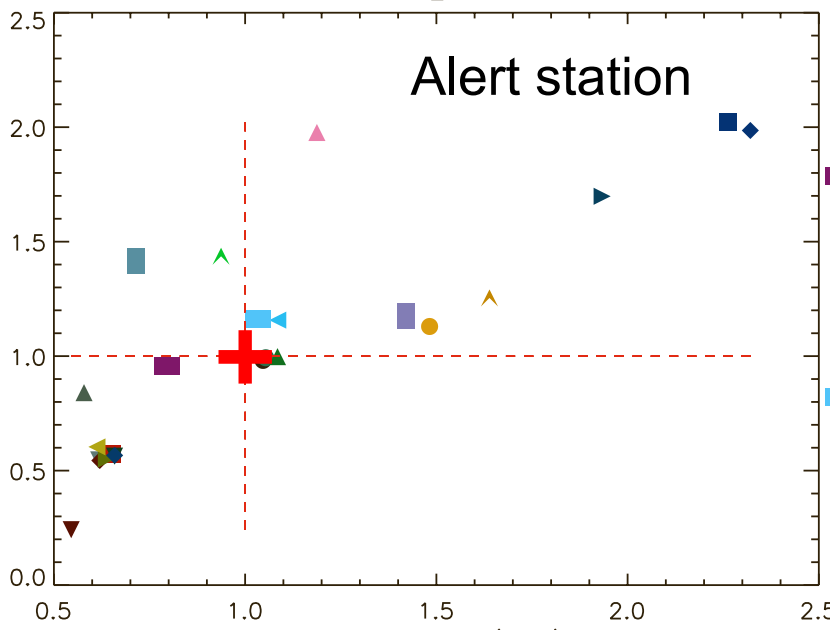
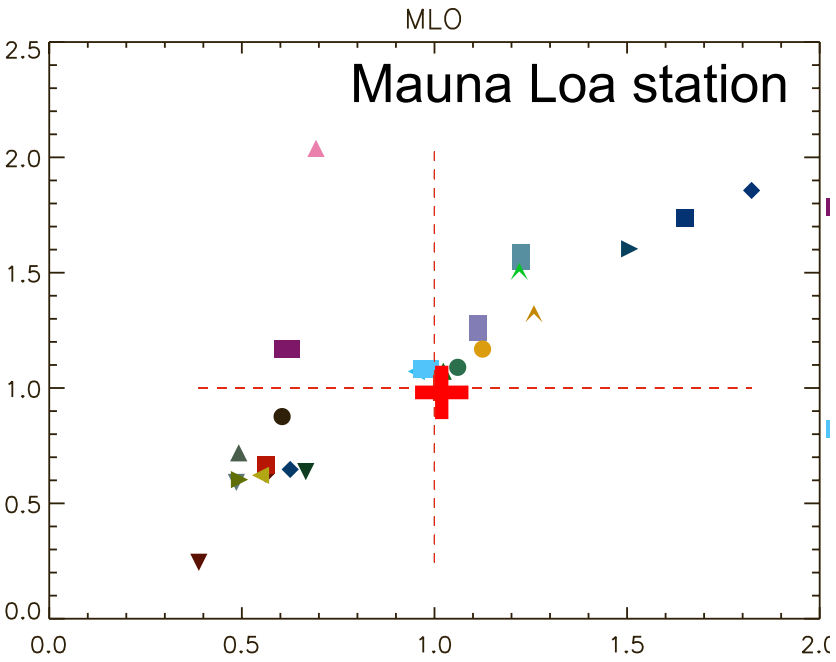
Amplitude of CMIP5 model seasonal cycles





COS amplitude scaled by the OBS

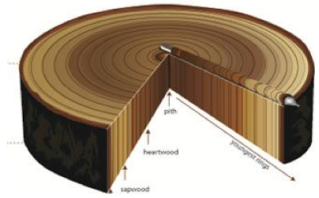
CO2 amplitude scaled by the OBS

- BNU−ESM
- CanESM2
- CCSM4
- CESM1−BGC
- CESM1−CAM5
- CESM1−FASTCHEM
- CESM1−WACCM
- CNRM−ESM1
- GFDL−ESM2G
- GFDL−ESM2M
- HadGEM2−CC
- HadGEM2−ES
- inmcm4
- IPSL−CM5A−LR
- IPSL−CM5A−MR
- IPSL−CM5B−LR
- MIROC−ESM−CHEM
- MIROC−ESM
- MPI−ESM−LR
- MPI−ESM−MR
- MPI−ESM−P
- MRI−ESM1
- NorESM1−ME
- NorESM1−M

+ OBS target

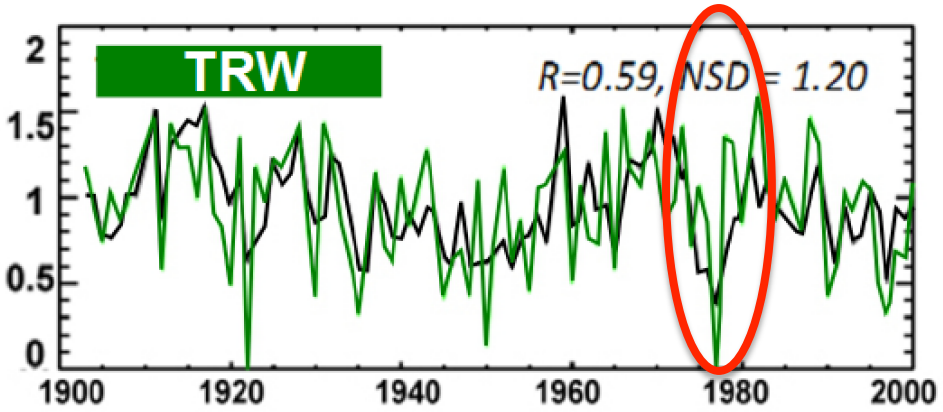
Using Tree Ring data to optimize LSM

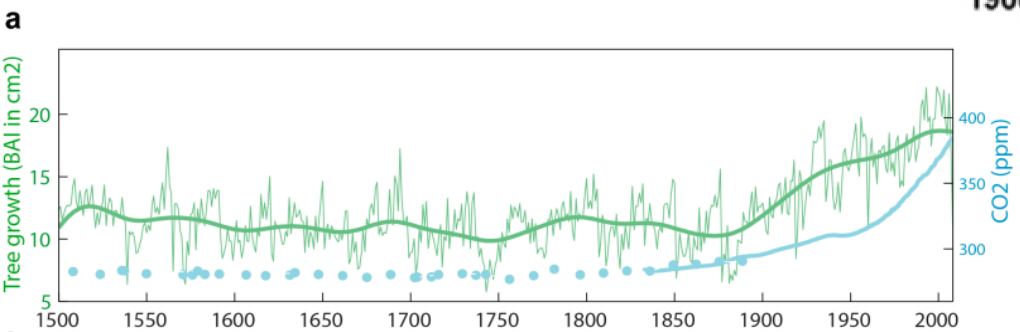
Tree ring
(width, isotopes)

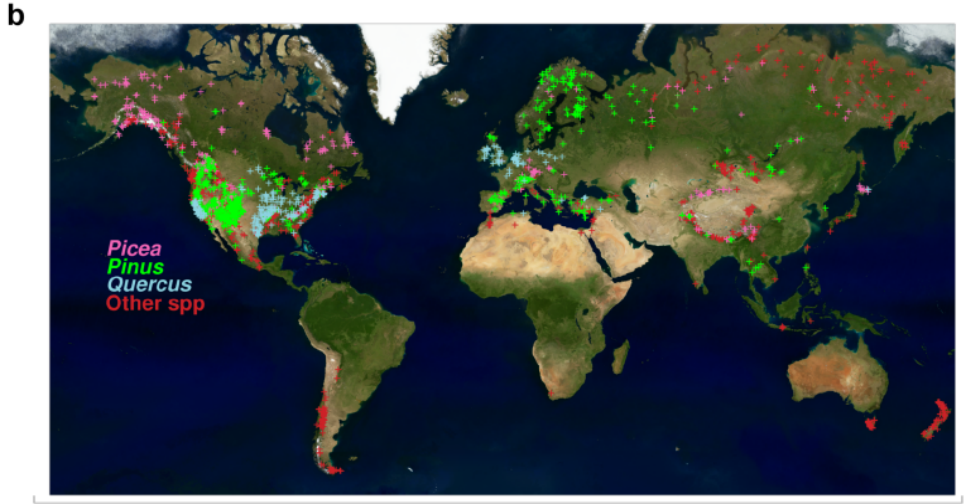


Ex: Oak forest
(France)

ORCHIDEE







- Existance of a large data base including ^{13}C ^{18}O
- Covering century long periods
- Still poorly used for LSM calibration !
- Covering many ecosystems

Outline

- Recent history of ORCHIDEE development (CMIP6)
- Surface – atmosphere coupling and feedbacks
- Importance of sub-grid heterogeneity & processes
- Few challenges for future ESM improvements
- Needs for large spatial/temporal scales evaluation
- Recommendations including “human dimension”

Additional thoughts for furture LSM

- ✓ Keep balance btw biophysics – biogeochemistry
- ✓ Integrate Data Assimilation needs at the core of model structure (possibly Tangent Linear & Adjoint model)
- ✓ Use more “statistical emulators” : to speed computation time and to compute uncertainties
- ✓ Define “standard” interface between module: to facilitate exchanges btw groups and to enlarge the ‘developing community’
- ✓ Share through WEB automated “diagnostic” of LSM outputs (ILAMB,…)

Human dimension of collective work

➔Coordination of efforts should not be neglected

- ✓ Integration of developments into main version may take longer than the development itself !!
- ✓ Divergent view on what is crucial and how to move forward
  conservative approach ←→ exploratory approach
- ✓ Level of details: Process-based ←→ Empirical formulations
- ✓ Open code is optimal but same time need to avoid internal competition !! Not always easy
- ✓ Need to put more energy on model developments than model inter-comparisons…

Conclusion

- Model diversity is beneficial but when it is real diversity !

- Target comprehensive model that can tackle various scientific questions (climate, ecosystem services,….)

Thanks to: Vladislav Bastrikov, Sauveur Belviso, Patricia Cadule, Yiyin Chen, Frederique Cheruy, Philippe Ciais, Agnes Ducharne, Arsene Druel, Josefine Ghataz, Bertrand Guenet, Matthieu Guimberteau, Gerhard Krinner, Thomas Launois, Sebastiaan Luyssaert, Fabienne Maignan, Natasha MacBean, Catherine Ottle, Jan Polcher, James Ryder, Nicolas Viovy, Nicolas vuichard, Dan Zhu

ORCHIDEE yesterday