ORCHIDEE
LAND SURFACE MODEL

The Global Land Surface Model ORCHIDEE

(ORganizing Carbon and Hydrology In Dynamic Ecosystems Environment)

Presented by Nicolas Viovy
LSCE/IPSL

Outline

- A brief history of ORCHIDEE & motivations
- Formalism
- Main processes
- Ongoing developments
- Configurations & Inputs requirements

Philosophy of the ORCHIDEE model

A generic tool:

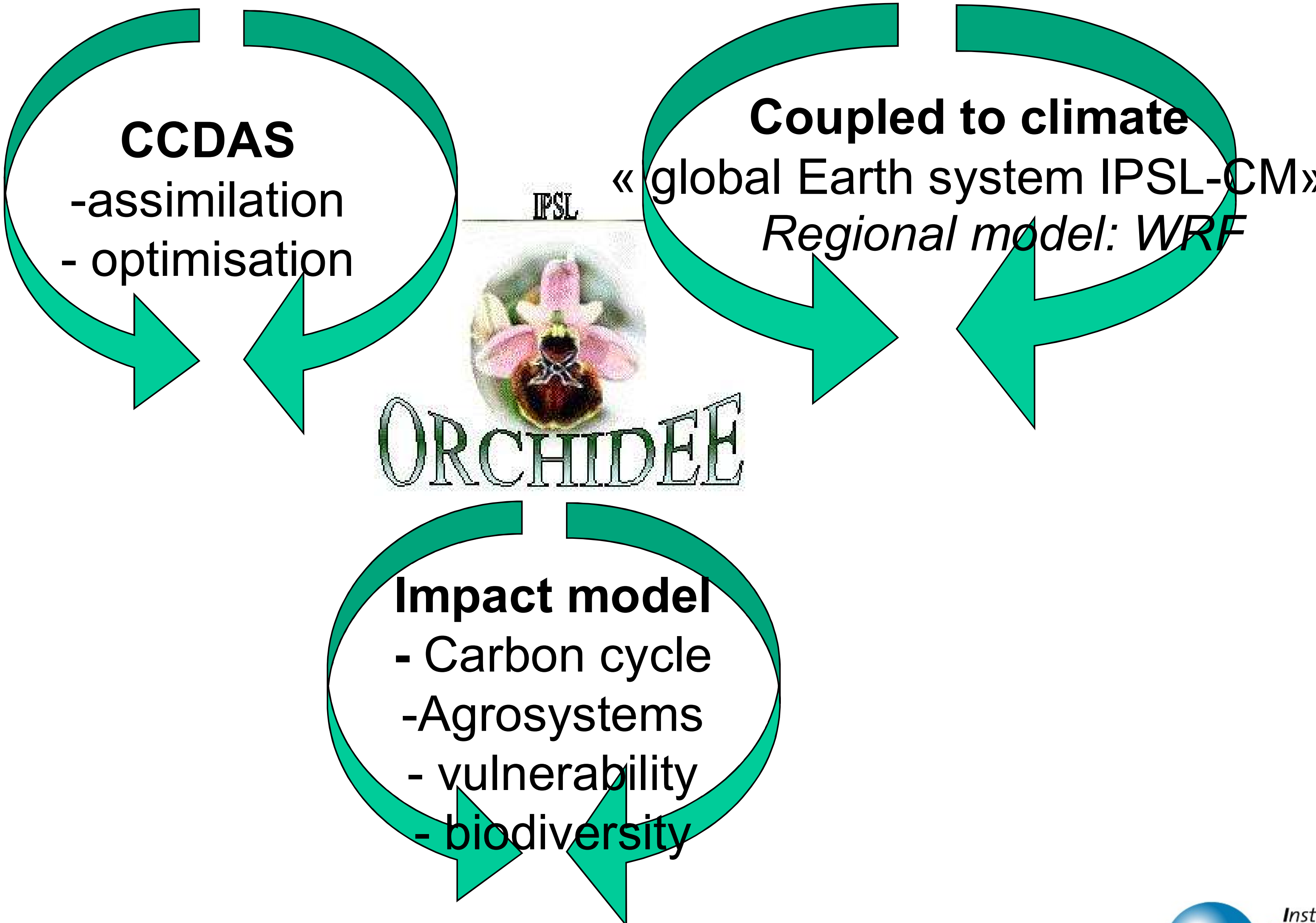
- For study of coupled carbon and water cycle

- To be used coupled to an AGCM or forced by external climate forcing

- Developed in coherence with other models of IPSL (LMDZ/ORCA/INCA) to be include in a complete climate model

- High level of complexity to be used for application for regional to global scale

- High level of modularity to easy modules exchange


CCDAS
-assimilation
- optimisation
Coupled to climate
« global Earth system IPSL-CM»
Regional model: WRF
IPSL
ORCHIDEE
Impact model
- Carbon cycle
-Agrosystems
- vulnerability
- biodiversity

A brief history

Model

SECHIBA(

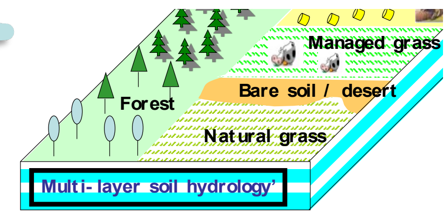
Carbon'Cycle' (STOMATE)'

Dynamic'Veg.'(LPJ)'

ORCHIDEE(

+ new hydrology
+ river routing
+ Forest management
+ Crops module
+ Permafrost
+ Nitrogen Cycle

Toward a single community tool



(Laval et al., 1981) *(Ducoudré et al., 1993)* *(Viovy et al., 1997)* *(Polcher et al., 1998)* *(Krinner et al., 2005)*

80s — 90s — 2000 — 2009

Project / Users

Few Scientists at LMD (3-4)

Small group btw LMD/LSCE (5-10)

Increasing number of developers & users (15-25)

LMD — organization LMD/LSCE — Specific "Project Group" across IPSL & few other labs.

Objective

- Simulate Energy, Water and Carbon fluxes at the land surface/atmosphere interface.
  - To be used for being the 'land surface' component of a Earth system model (IPSL-CM5).
    - Global => to represent the main vegetation cover.
    - Regional => to study feedback processes.
  - For past, present and future climates
    - Module of vegetation dynamic
    - Process-based modeling
- Conservation of mass and energy is a guiding principle for ORCHIDEE.

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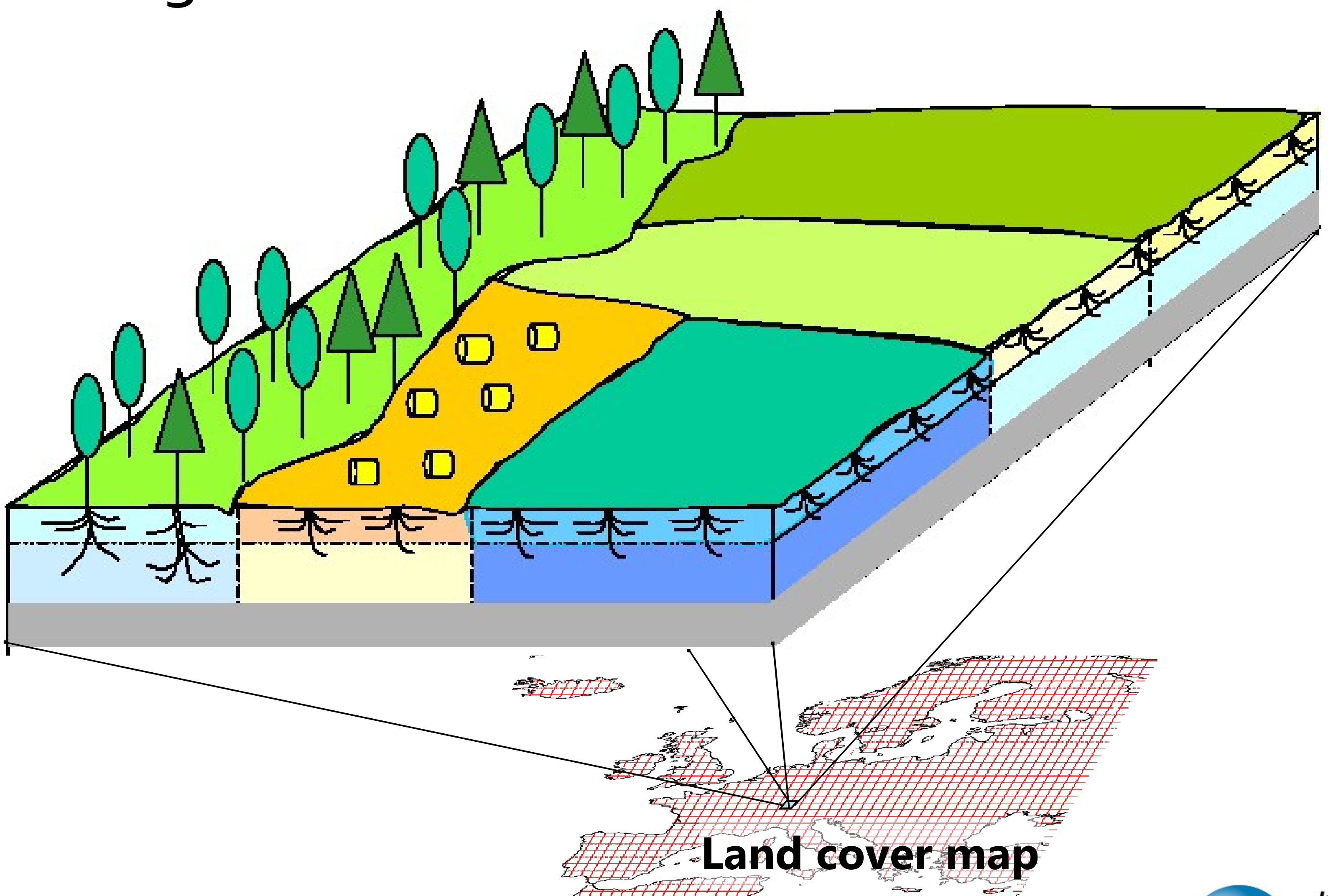
Surface variability representation ?

- A mosaïc of vegetation and soil moisture



Surface variability representation ?

- In each grid cell, we account for:
  - Bare soil
    - *veget_max(1)*
  - Vegetated lands
    - *veget_max(2:nvm)*
  - Other lands (so far, only the continental ice)
    - *frac_nobio*

$$\sum_{i=1}^{nvm}\left(veget\_\max_i\right) + frac\_nobio = 1$$

- One soil type per grid cell but different soil moisture profiles.

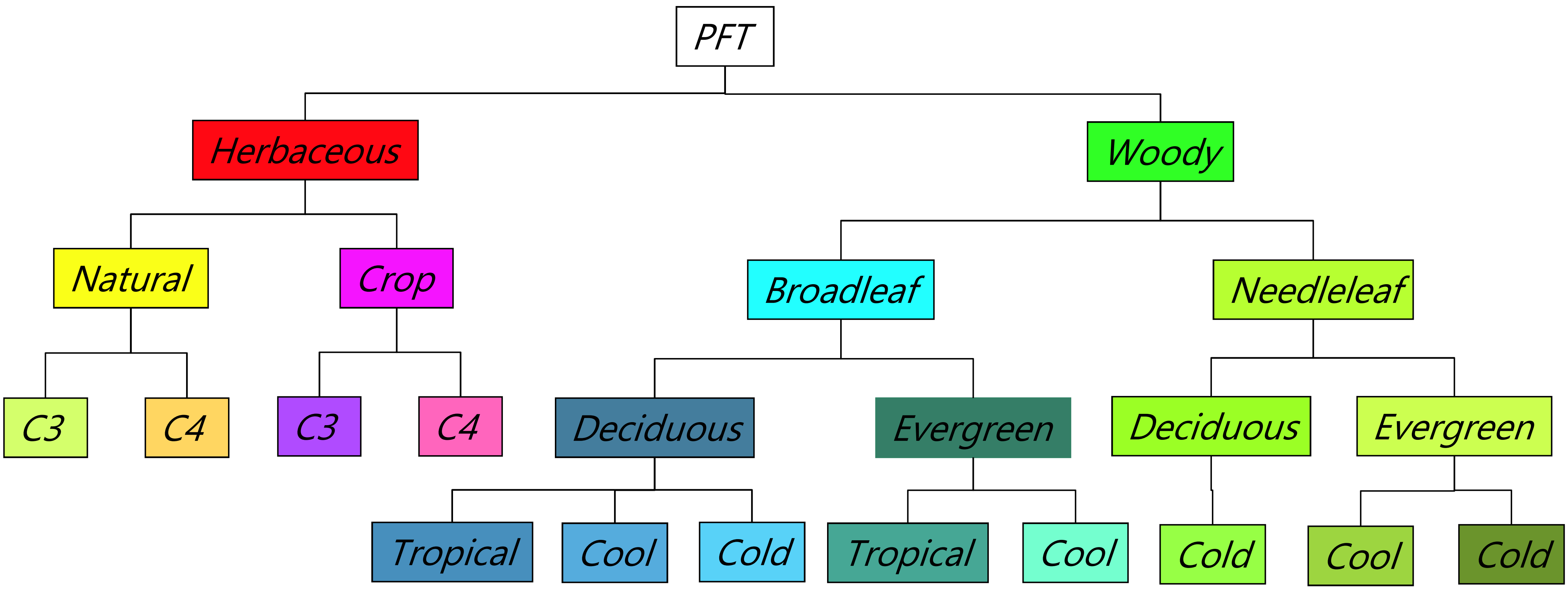
Sciences de l'environnement Institut Pierre Simon Laplace

What is a PFT

A ‘Plant Functional Types’ (PFT) can be represented in the model by a set of parameters and parameterization

Vegetated lands

- Concept of 'Plant Functional Types' (PFT)
- Defined according to systematic, physiological, phenological, climatic conditions



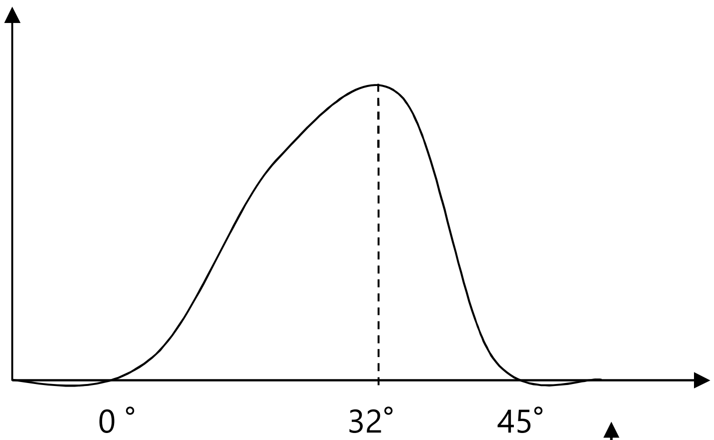
Plant Functional Types

- Mainly same set of equations governs PFT (but can differ in some cases eg. Phenology)
- But parameter values differ among PFT's

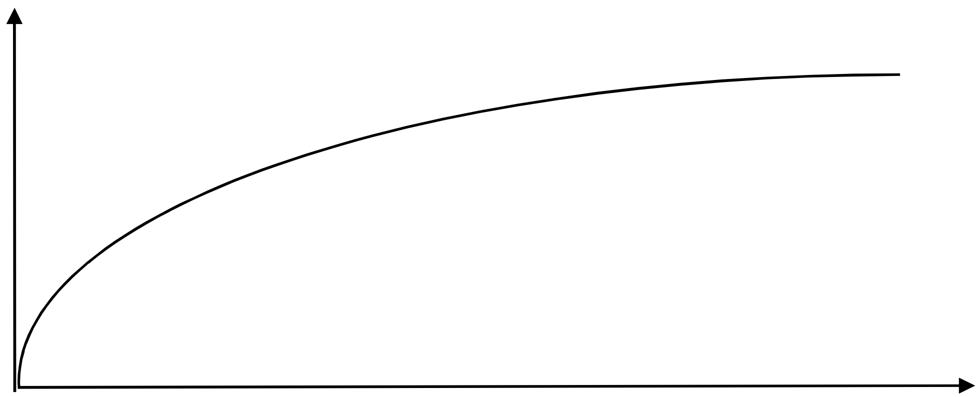
PFT	$V_{cmax,opt}$	T_{opt}	λ_{max}	z_{root}	α_{leaf}	h	A_c	T_s	H_s
TrBE	50	37	10	1.25	0.12	25	910	-	0.3
TrBR	60	37	10	1.25	0.14	25	180	-	0.3
TeNE	37.5	27	5	1.	0.14	15	910	-	-
TeBE	37.5	32	5	1.25	0.14	15	730	-	-
TeBS	37.5	28	5	1.25	0.14	15	180	12.5	-
BoNE	37.5	25	4.5	1.	0.14	10	910	-	-
BoBS	37.5	25	4.5	1.	0.14	10	180	5	-
BoNS	35	25	4	1.25	0.14	10	180	7	-
NC3	70	$27.5 + 0.25T_l$	2.5	0.25	0.20	0.2	120	4	0.2
NC4	70	36	2.5	0.25	0.20	0.2	120	5	0.2
AC3	90	$27.5 + 0.25T_l$	6	0.25	0.18	0.4	150	10	0.2
AC4	90	36	3	0.25	0.18	0.4	120	10	0.2

Response to environmental conditions

Temperature



Light



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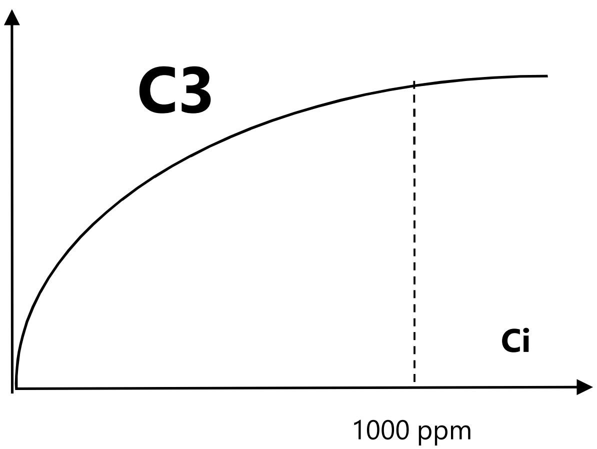

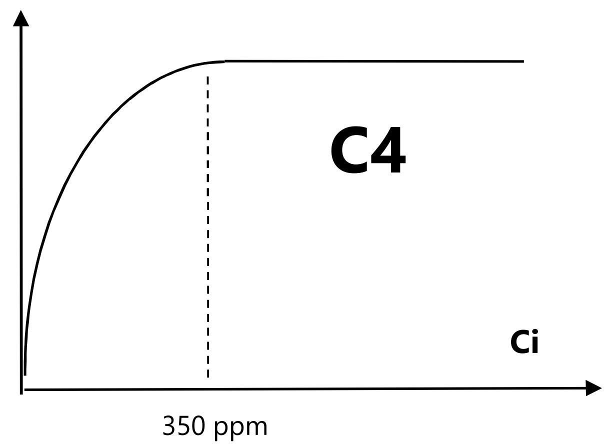

Concept of externalization

- By default 13 PFT's (named Metaclass) with pre-defined parameters setting
- Most of the parameters can be modified by the user (see http://forge.ipsl.jussieu.fr/orchidee/wiki/Documentation/OrchideeParameters or orchidee.default file in the config/PARAM directory)
- The number of PFT's can be extended
  - By setting the NVM parameter and PFT_TO_MTC (correspondance array linking a PFT to MTC)

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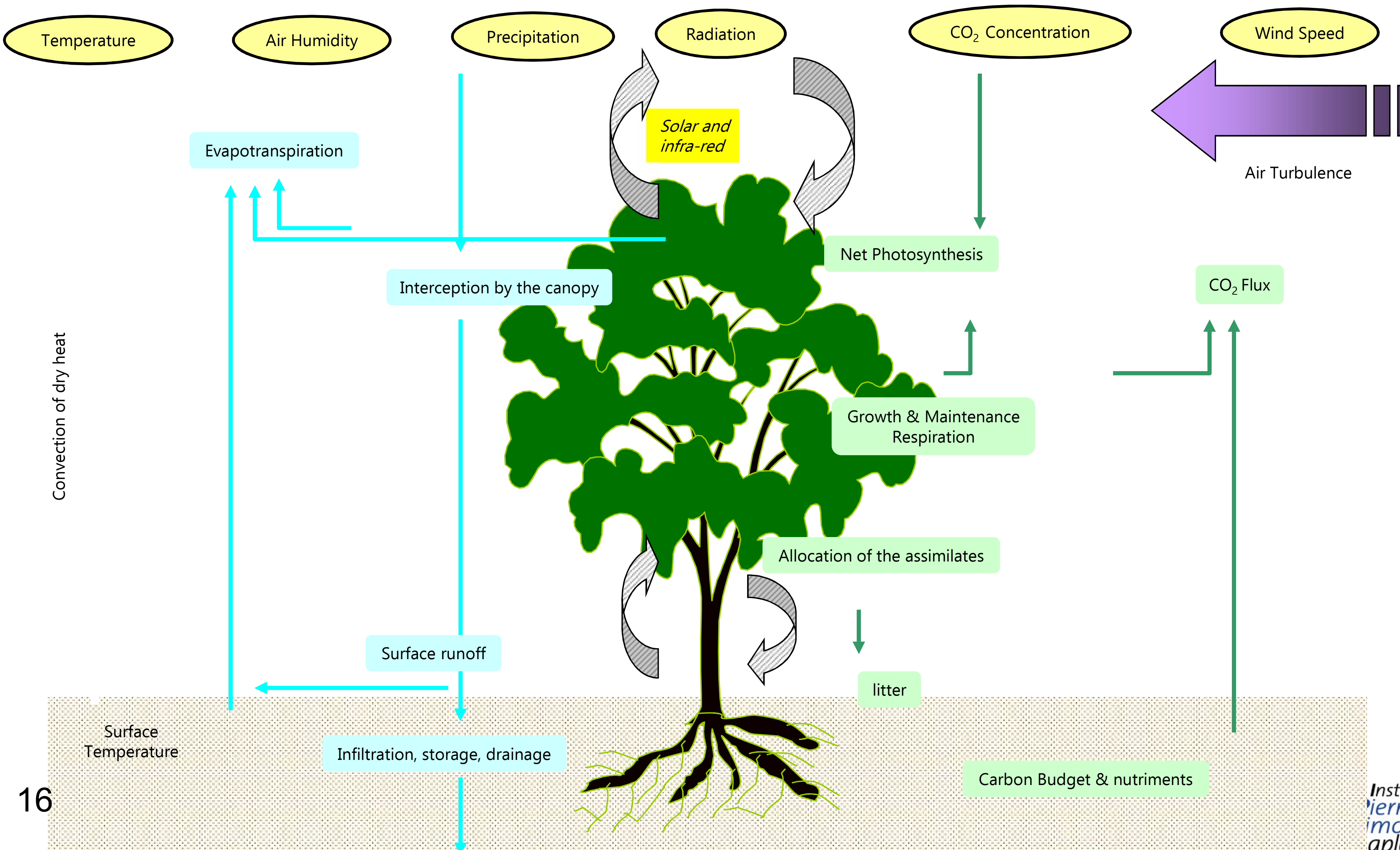
Main processes



Energy budget & Resistance terms

enerbil module

- Calculation of :
  - Sensible heat flux
  - Latent heat flux
    - Transpiration
    - Evaporation of bare soil and leaf water
    - Sublimation
  - Net radiation
  - Soil and surface temp.
  - GPP calculation
- *One calculation per grid cell*
- *No vertical discretization*

diffuco module

- vbeta1 : sublimation
- vbeta2 : interception loss
- vbeta3 : transpiration
- vbeta4 : bare soil evaporation
- vbeta5 : flood plains

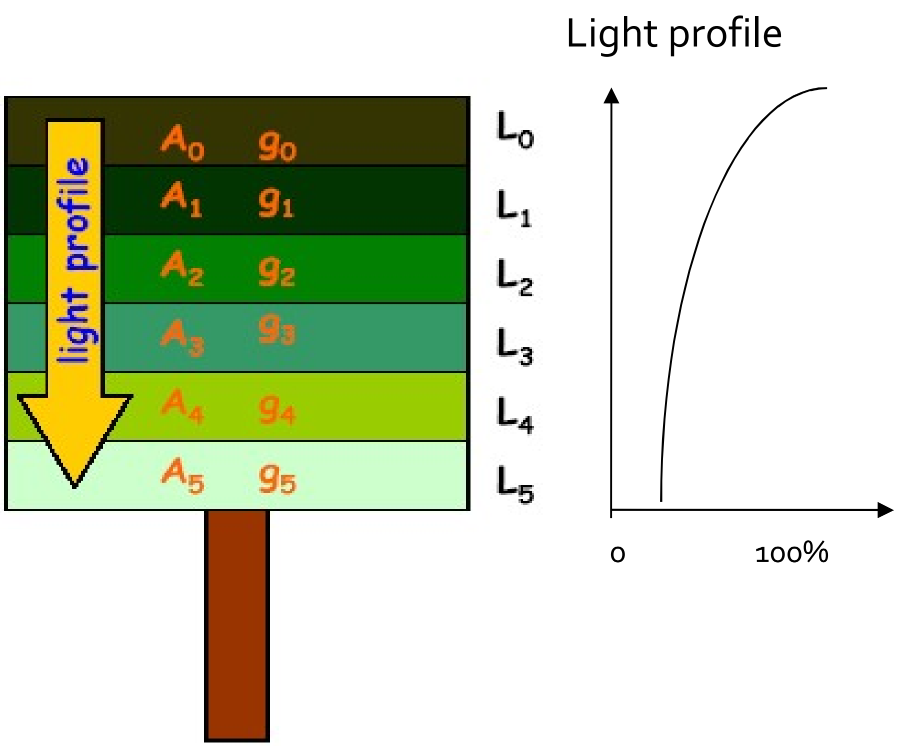
C assimilation/stomatal conductance

diffuco module

diffuco_trans_co2 routine

- A and G_s are calculated at each LAI level:
- Beer-Lambert decrease of light in the canopy
- Exponential decrease of Vmax (but limited to 30%) to mimic nitrogen decrease
- The others parameters (e.g g CO_2, rel hum..) are held constants.

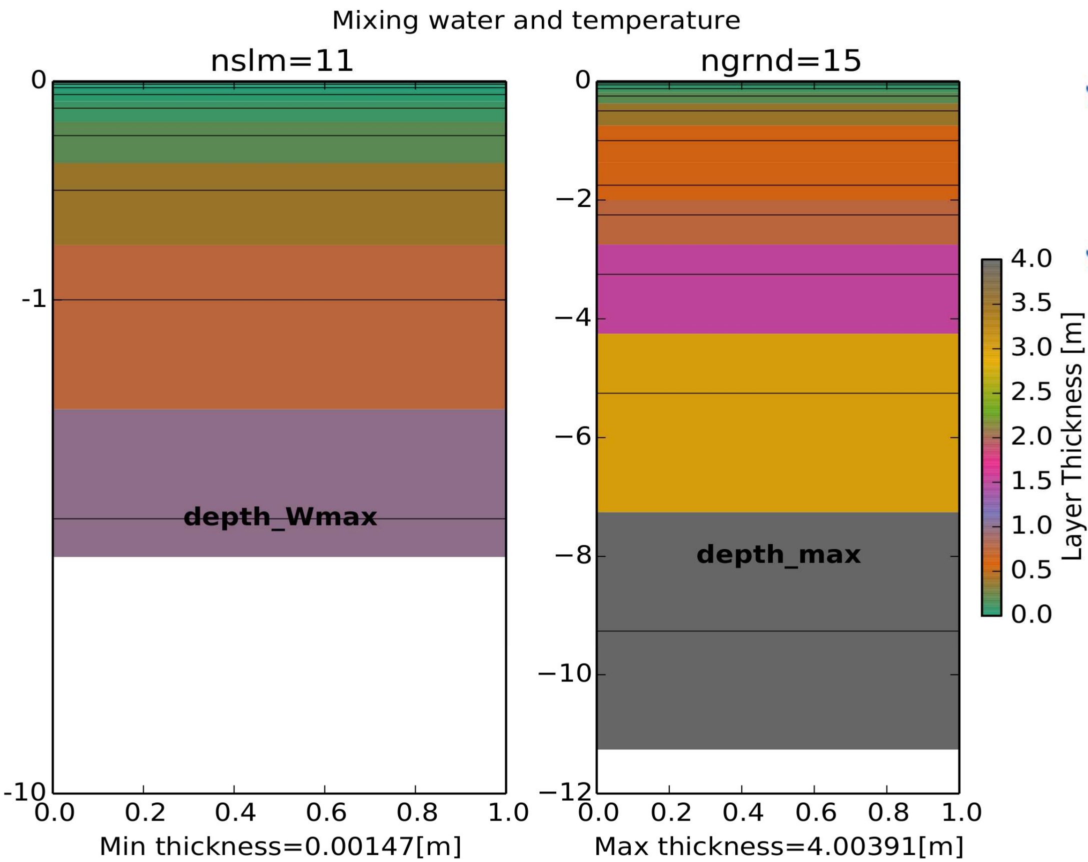
From the leaf to canopy



Vertical discretization in the soils

ORCHIDEE used to have different vertical discretizations for moisture and temperature. The physics require different numerical choices !

This was not tenable any more with soil freezing processes, permafrost and complex snow schemes.



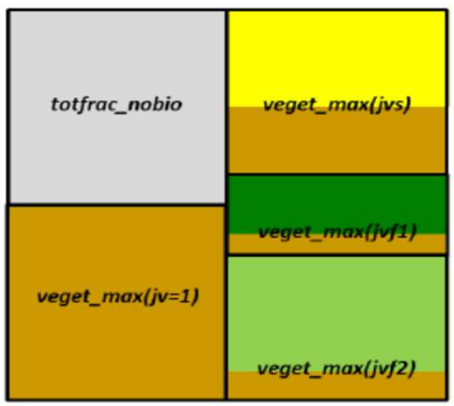
- The higher vertical resolution does not deteriorate the thermal diffusion (CFL criteria !)
- Users are now provided with a set of parameters to configure the soils.
  - zmax_t (DEPTH_MAX_T = 10)
  - zmax_h (DEPTH_MAX_H = 2)
  - depth_topthickness (~1 mm)
  - refinebottom
  - ratio_geom_below

Soils Tiles

Interactions with the vegetation/LC

1. Horizontally, PFTs define soil tiles with independent water budget (below ground tiling)

« Nobio » and PFTs



Each PFT with

Effective vegetation fraction

veget = veget_max (1 - exp(- LAI))

Bare soil fraction

*frac_bare = veget_max * exp(- LAI)*

→ **In each PFT j:**

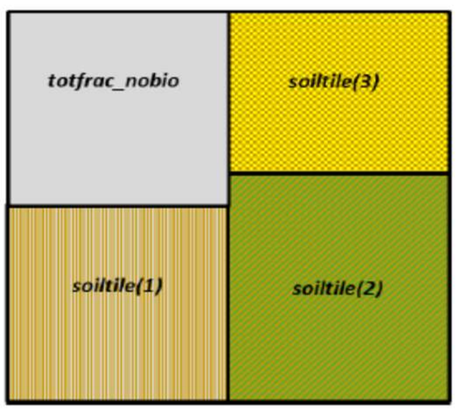
Us and β_3

Grid-cell scale:

$Tr = (\Sigma_j\ veget_j\ \beta_3)\ E_{pot}$

SUM(vbeta3)

Soil columns



Each soil tile with

frac_bare_ns

→ **In each soiltile c:**

β_4 calculation

Independant water budget

Grid-cell scale:

$E_{soil} = (\Sigma_c\ frac\_bare\_ns_c\ \beta_g)\ E_{pot}$

vbeta4

Interactions with the vegetation/LC

2. Vertically, ORCHIDEE defines a root density profile

In each PFT j — $R_j(z) = \exp(-c_j\, z)$

In each soil layer i — $n_{root}(i)$ is the mean root density with $\Sigma_i n_{root}(i) = 1$

↓

It controls:

(1) the water stress on transpiration in each soil layer i

$$u_i = n_{\text{root}}(i) \max(0, \min(1, (W_i - W_w)/(W_\% - W_w)))$$

(2) the increase of Ks towards the surface (F_{Kroot})

Soil temperatures

thermosoil module

- Calculates the soil temperatures by solving the heat diffusion equation within the soil
  - the soil is divided into several layers, reaching at least 10m down within the soil.The user can adapt the model to the application.
  - Thickness follows a geometric series.
  - No more interpolation with soil water layers

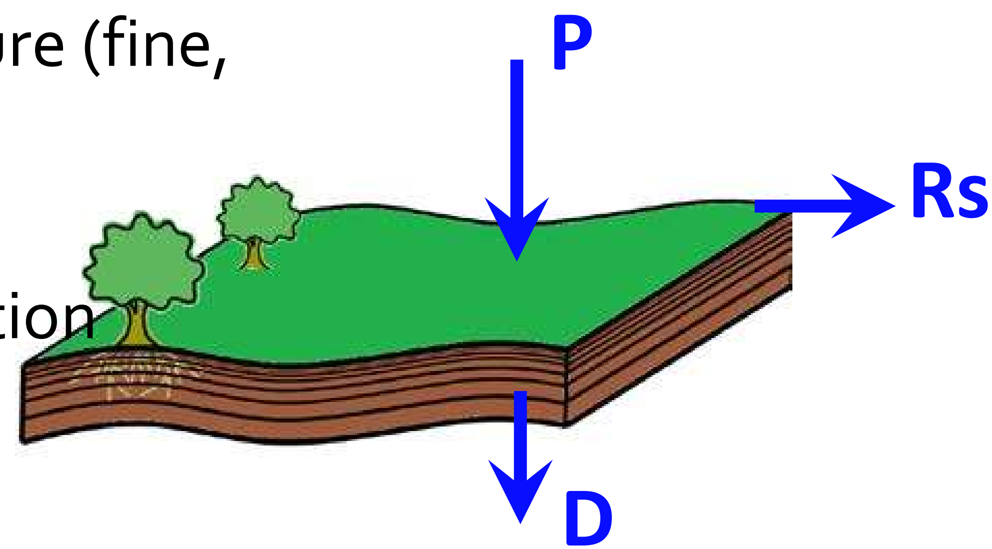
Soil water balance

Hydrol module

- Physically-based description of soil water fluxes using Richards equation : 2m soil discretized in at least 11-layers.

- Hydraulic properties based on van Genuchten-Mualem formulation
- Related parameter based on texture (fine, medium, coarse)

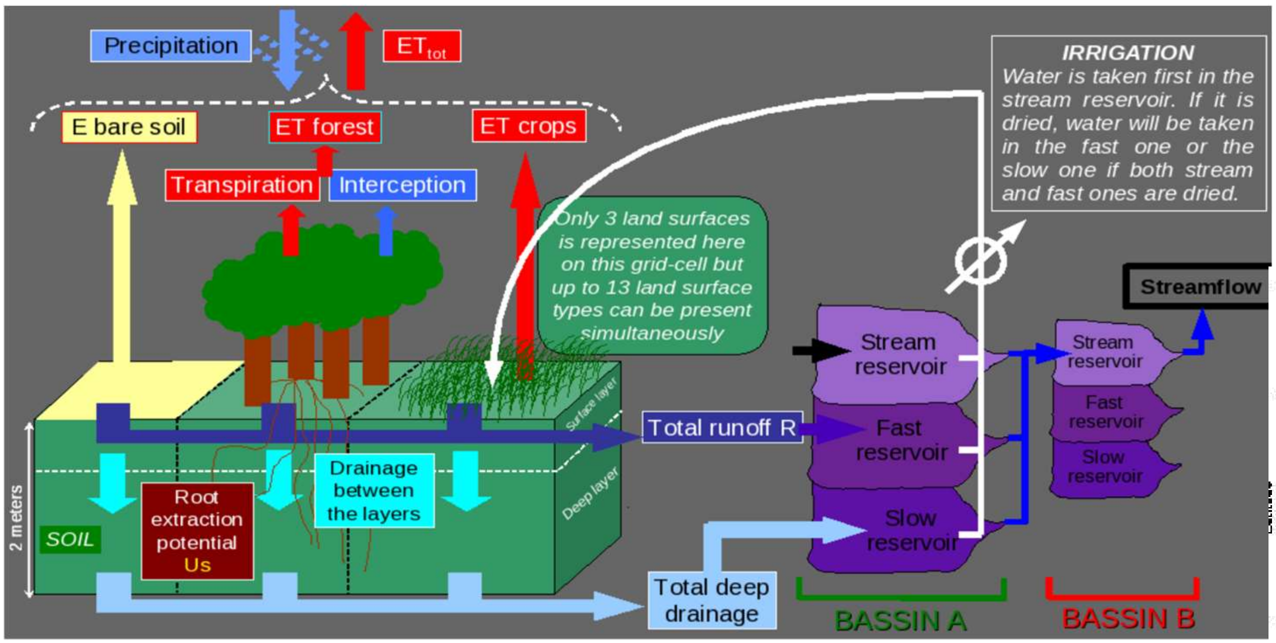
- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom



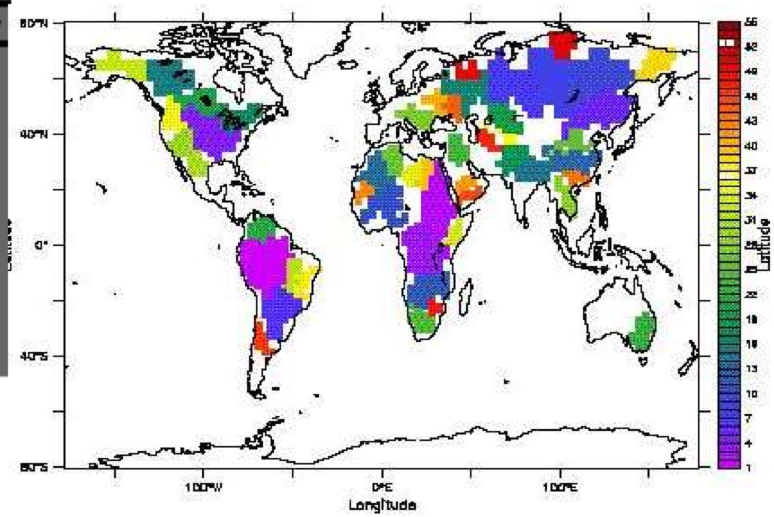
Routing / Irrigation

routing module

- Routing parametrization to calculate water discharge to river



From Guimberteau (thesis, 2010)



The 50 major river basins on the LMD-GCM grid

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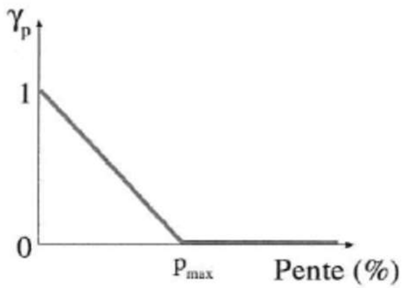
Slope and reinfiltration

Reinfiltration fraction = γ_p

$R_s = (1-\gamma_p)\, R_s^{pot}$

Based on slope



In run.def , you can change:

p_{max}: SLOPE_NOREINF = 0.5 (%)

(but 0 may not work to cancel reinfiltration!)

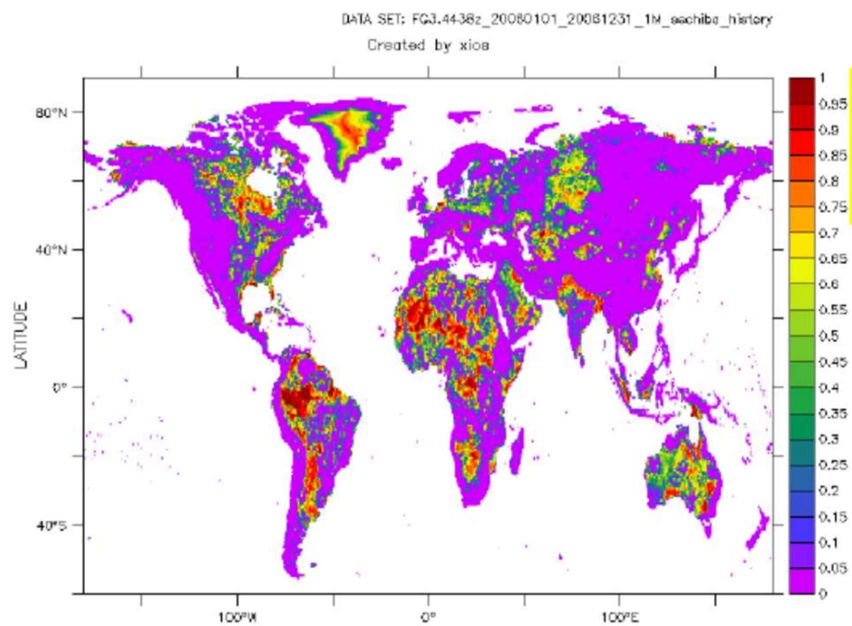
1. Slope is read at the resolution of 0.25°

(cartepente2d_15min.nc)

2. γ_p is calculated at the resolution of 0.25°

$$\gamma_p = 1 - \min(1, p/p_{max})$$

3. γ_p is averaged at the resolution of ORCHIDEE



A lot of reinfil in flat areas

No reinfil if p>0.5%

Example of reinf_slope from a 0.5° simulation

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Biomass and soil pools

- 8 pools of living biomass
  - Leaves, fine roots, above and below sapwood, above and below heartwood, ‘fruits’ and ‘reserves’
- 4 pools of litter
  - Above/below, Structural & Metabolic
- 3 pools of soil
  - Active, Slow and Passive

Allocation of assimilates

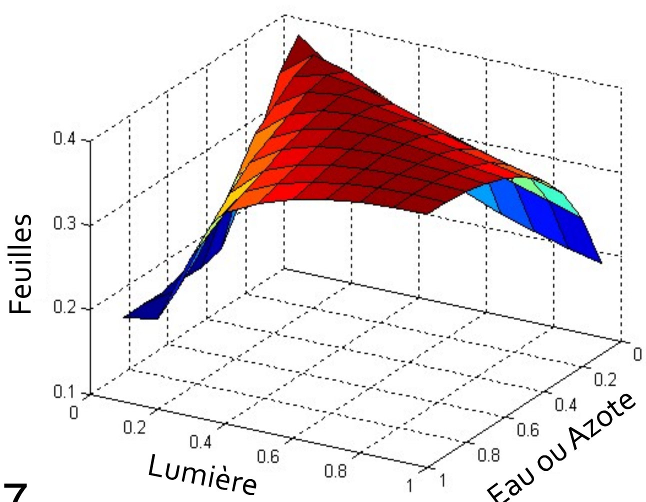
stomate_alloc module

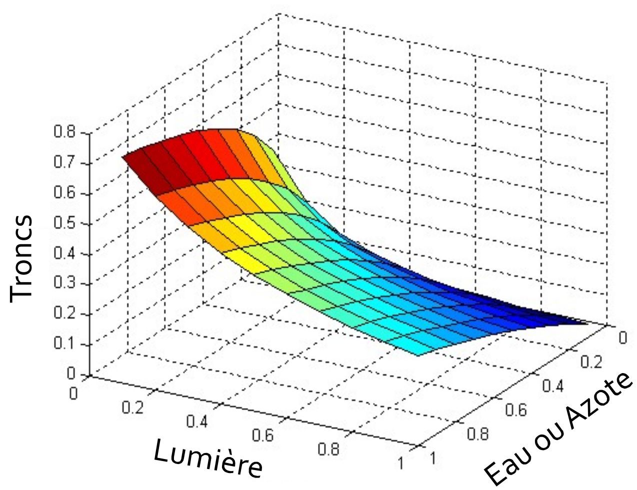
- Principle of resource optimisation
- Allocation to leaves, branches, roots as a function of resources : water (H), nitrogen (N) and light (L)

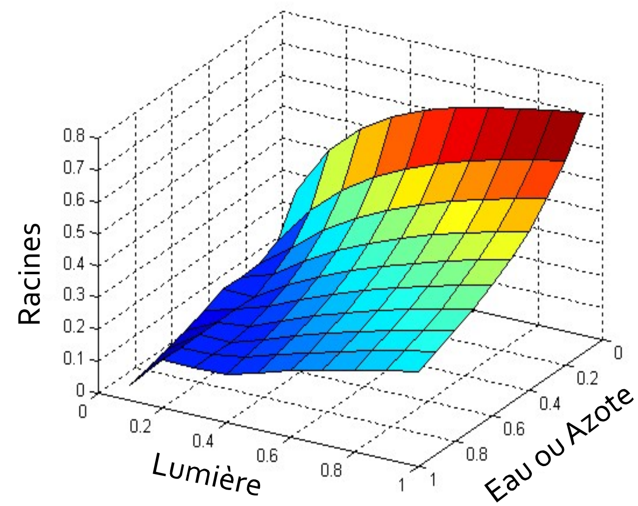
Leaf = 1 - Branch - Root

$$\text{Branch} = \frac{3\,T_0\,\min(H,N)}{2\,L + \min(H,N)}$$

$$\text{Root} = \frac{3\,R_0\,L}{L + 2\,\min(H,N)}$$







Friedlingstein et al., 1998

Phenology

stomate_phenology module

- Bud-burst model (Botta el al. 2000)
  - Defined for each PFT based on Growing degree days, Number of chilling days, soil water, …
  - Calibrated at global scale from bud-burst estimated by satellite
- Senescence
  - Function of leaf age and environmental conditions *stomate_turnover module*
  - For trees, a senescence stage is considered until all leaves fall (while for grass senescence it is a continuous process)

Respirations

- Autotrophic respiration

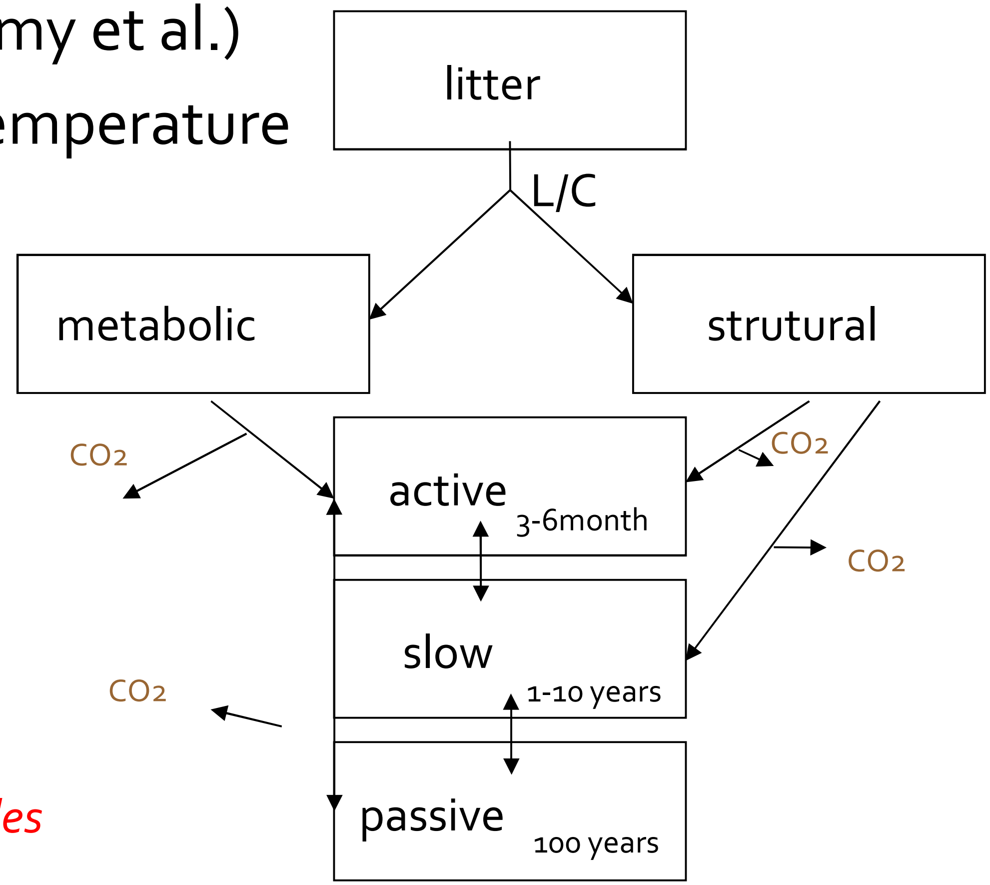
stomate_resp module

  - Maintenance
    - linear response to temperature (Ruimy et al.)
    - potential adaptation to long term temperature
  - Growth
    - a fixed part of assimilates

stomate_npp module

- Heterotrophic respiration
  - Century-like model

stomate_litter & stomate_soilcarbon modules



Land cover change

stomate_lcchange module

- Vegetation map can vary from one year to another
  - For decreasing PFT
    - A part of biomass is exported and goes to 3 decomposition pools (1 year, 10 year 100 years), the rest goes to litter of increasing PFTs.
    - Soil carbon of decreasing PFT is diluted to soil carbon of increasing PFT's
  - When a PFT disappears => reset to its inital state
  - When a PFT appears => growth from seed
- Wood harvest is also considered by removing a part of forest biomass. Then added to 3 decomposition pools like for deforestation

Vegetation dynamic

lpj_kill, lpj_pftinout, lpj_constraints modules

- Taken from LPJ model
- All PFT's are able to growth in each grid cell
  - Climate constraints define regeneration and adaptation of PFT's (e.g min temperature define adaptation, max temperature define regeneration)
  - Light competition when canopy closure (PFT with NPPmax dominate)
  - Trees always dominate grasses

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Main ongoing developments around ORCHIDEE

- High latitude processes: permafrost, snow
  - Permafrost, snow ….
- Agrosystems:
  - Crop
  - Grasslands+animals
  - Forest
- Nutrients cycling: C and P cycles
- Soil processes: priming effect, carbon discretization ….
- Functional traits.

Forest: CAN version

Simulating the canopy

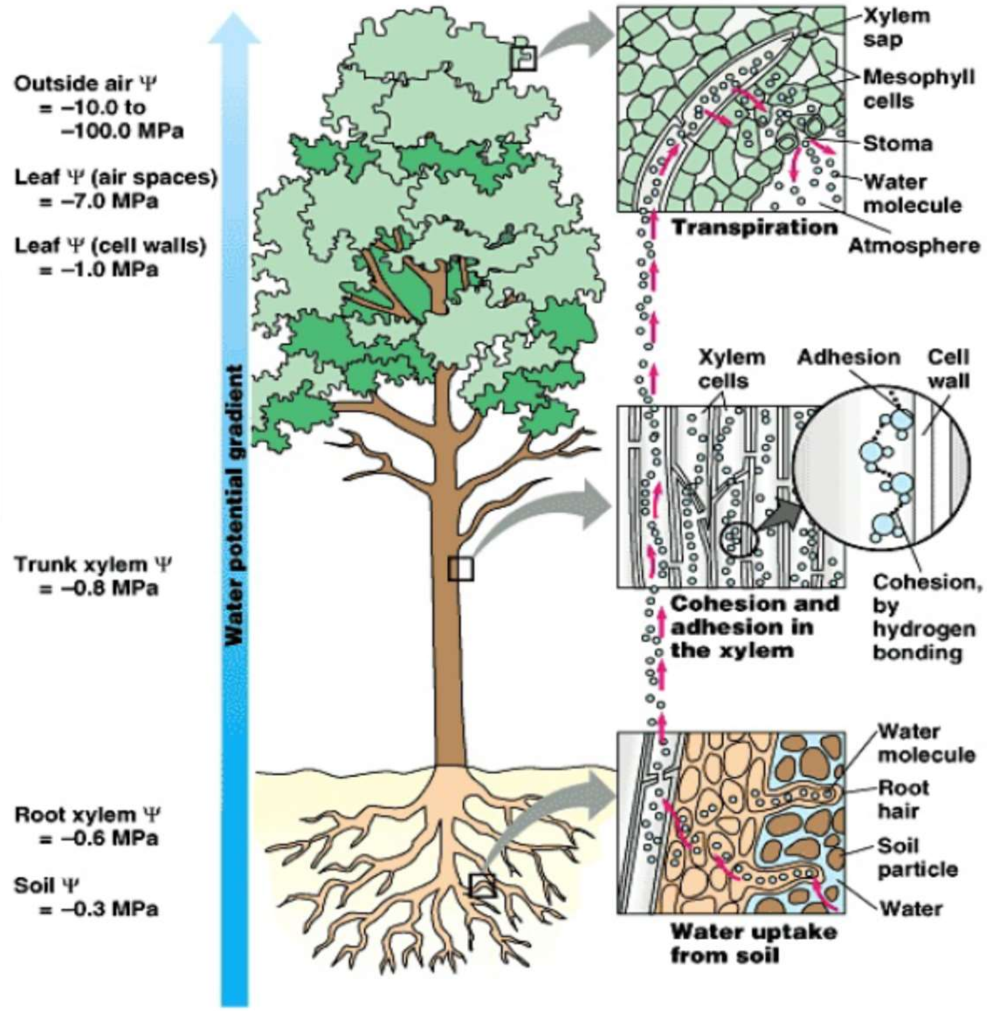
Pipe model theory

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

Water stress

- Hydraulic architecture

Forest management



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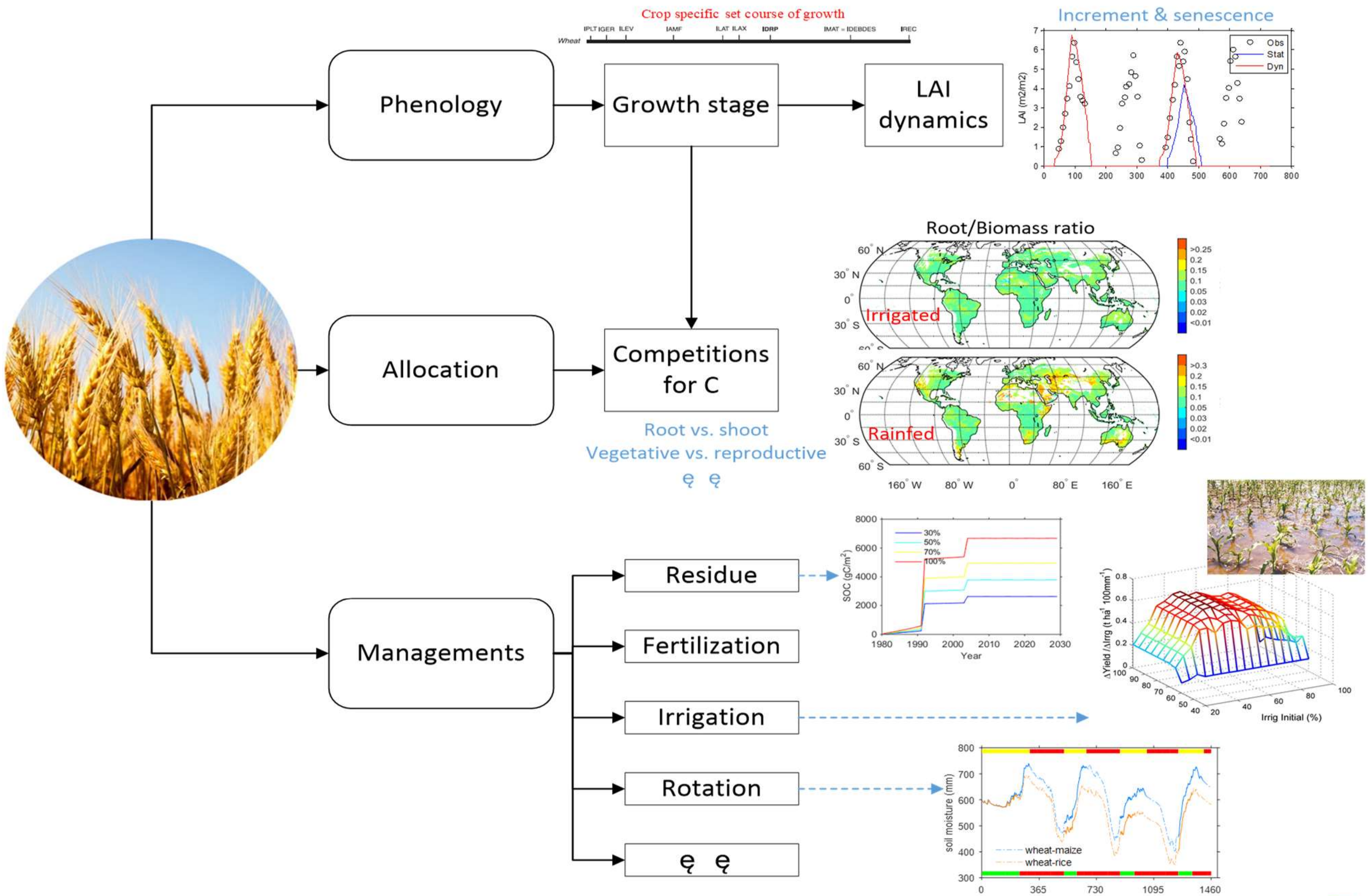
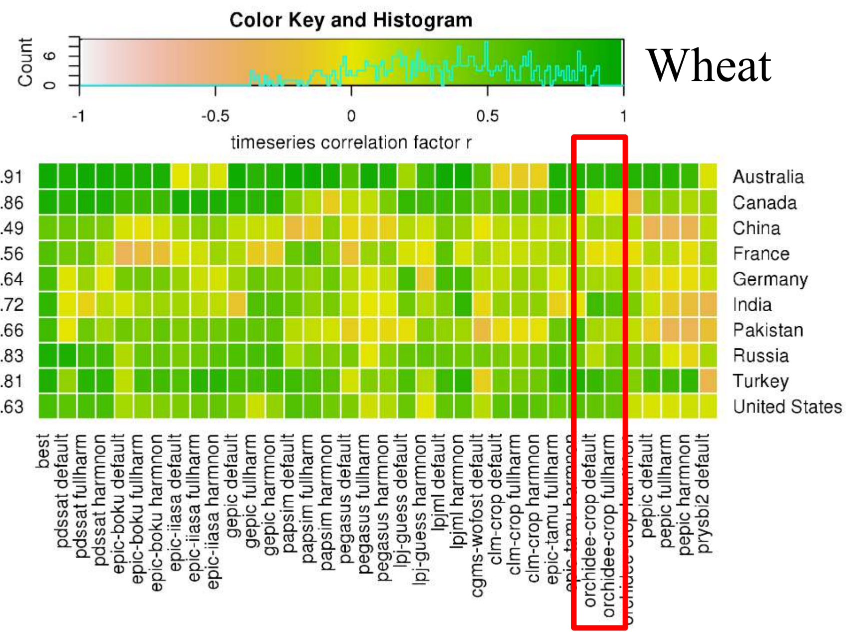
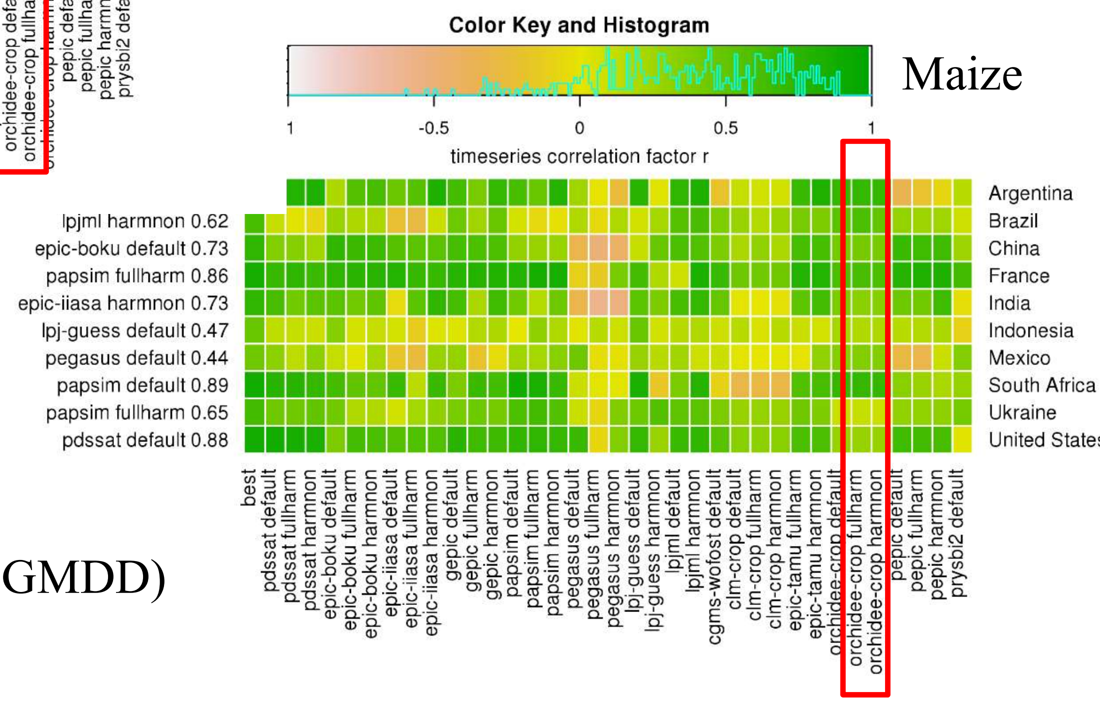
Crop: coupling to STICS crop model



Model Evaluation



Wheat

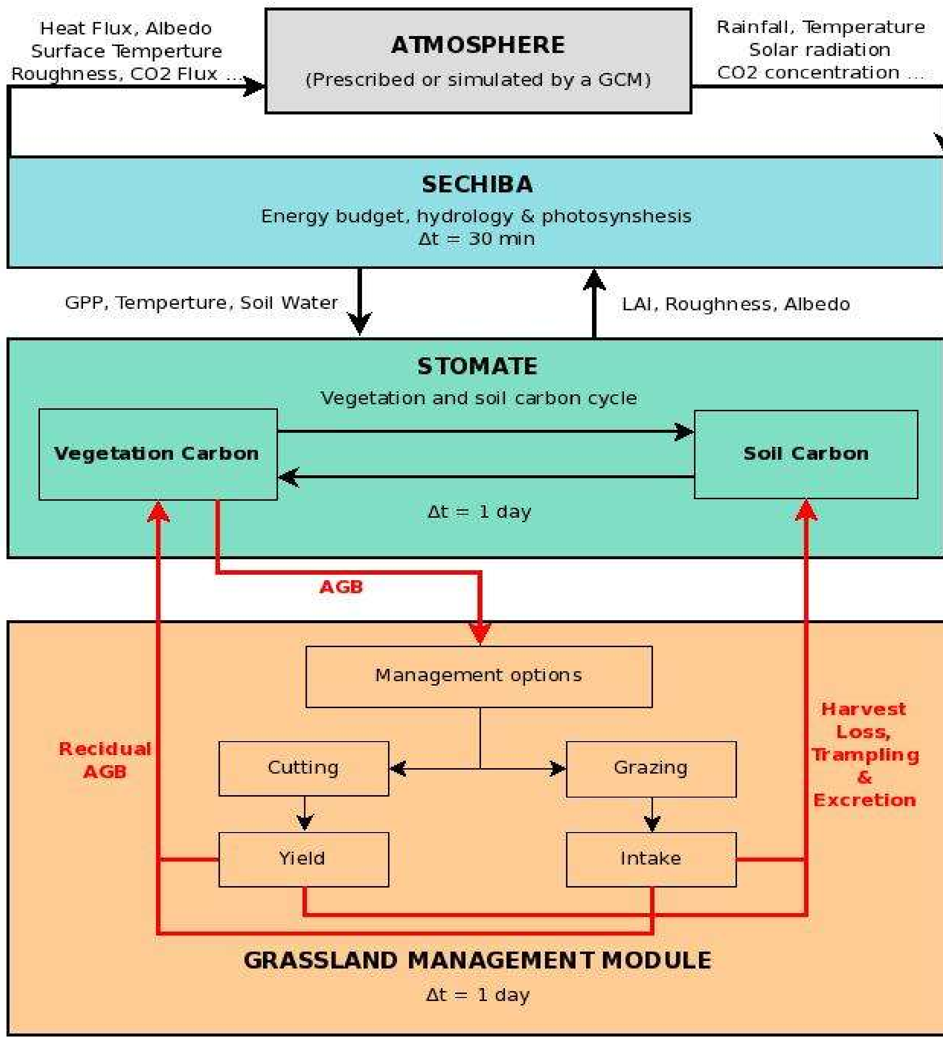


Maize

(Muller et al., 2016 GMDD)

Grassland: ORCHIDEE-GM, coupling with PASIM

ORCHIDEE-GM (Grassland Management)



Management optimization of PaSim

Initial method and its limitations:

- Self-sufficient assumption →

Grazing 220	Cutting Yield
Animals at barn 145 days	

- Optimized static management:

1) A maximum stocking rate
2) corresponding fraction of grazed/cut grassland

- Limitation: it can be used for spin-up, but not in real time

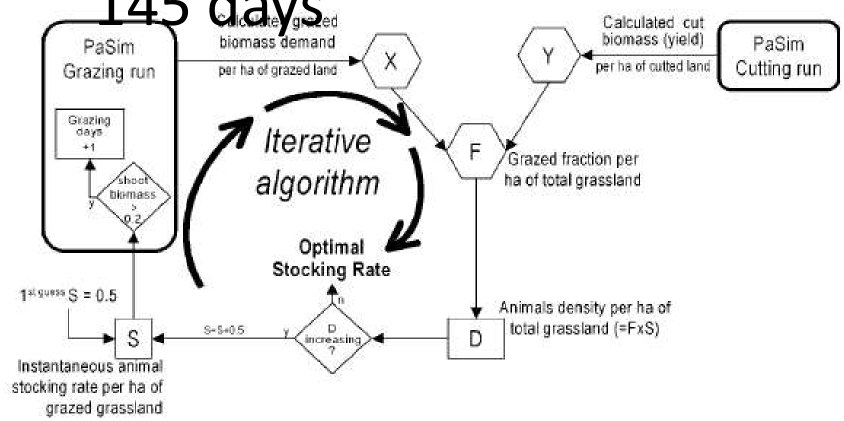
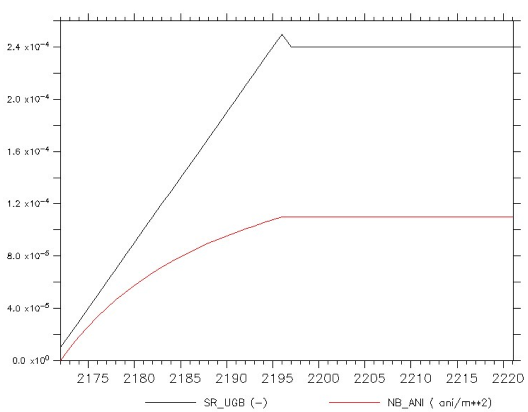
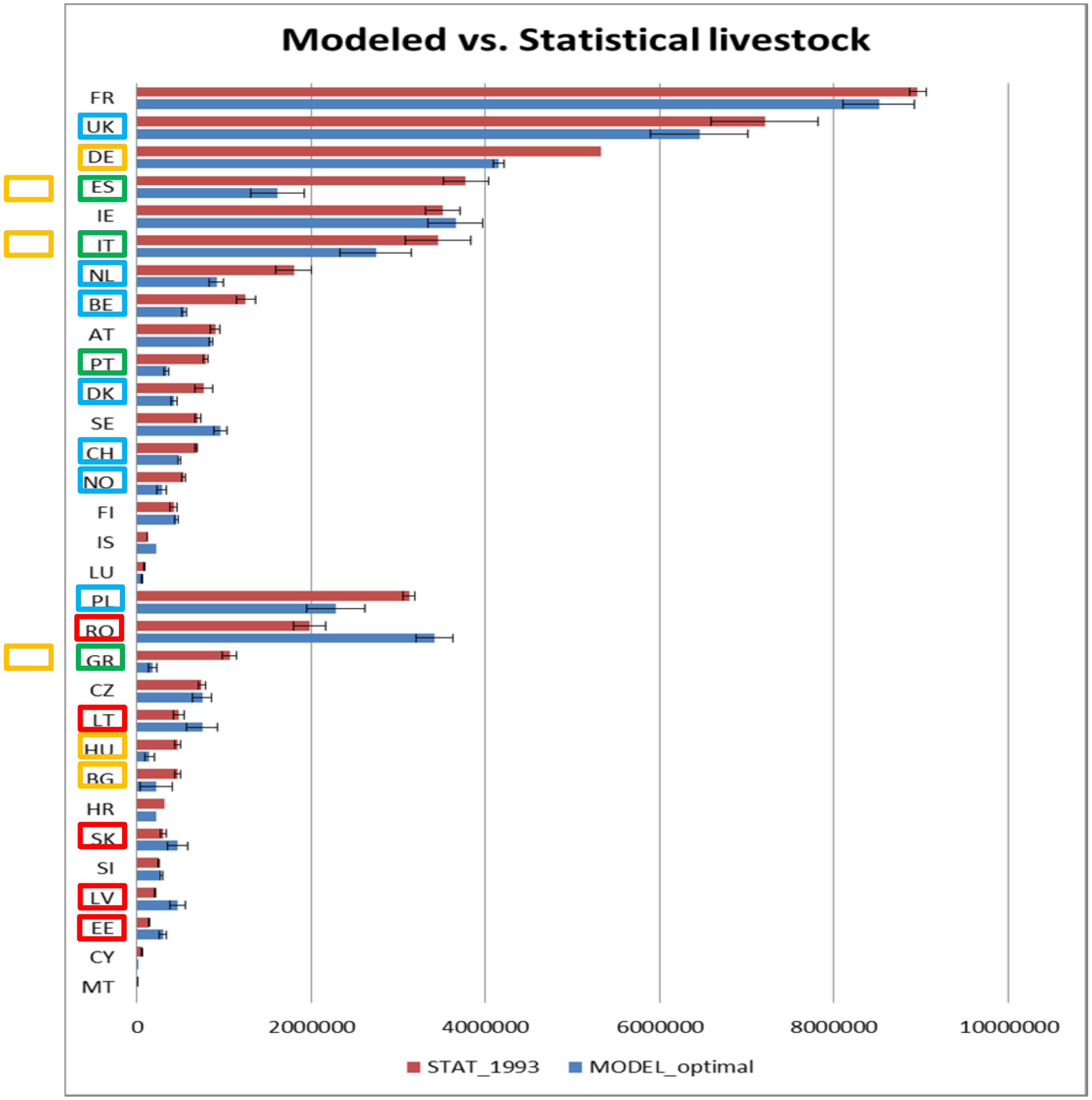


Figure 1. Diagram of the optimization procedure used for defining optimal animal stocking rate and optimal proportion of grazed grasslands.

From Vuichard et al., 2007



Statistical and modeled ruminant livestock in Europe (NUTSo)

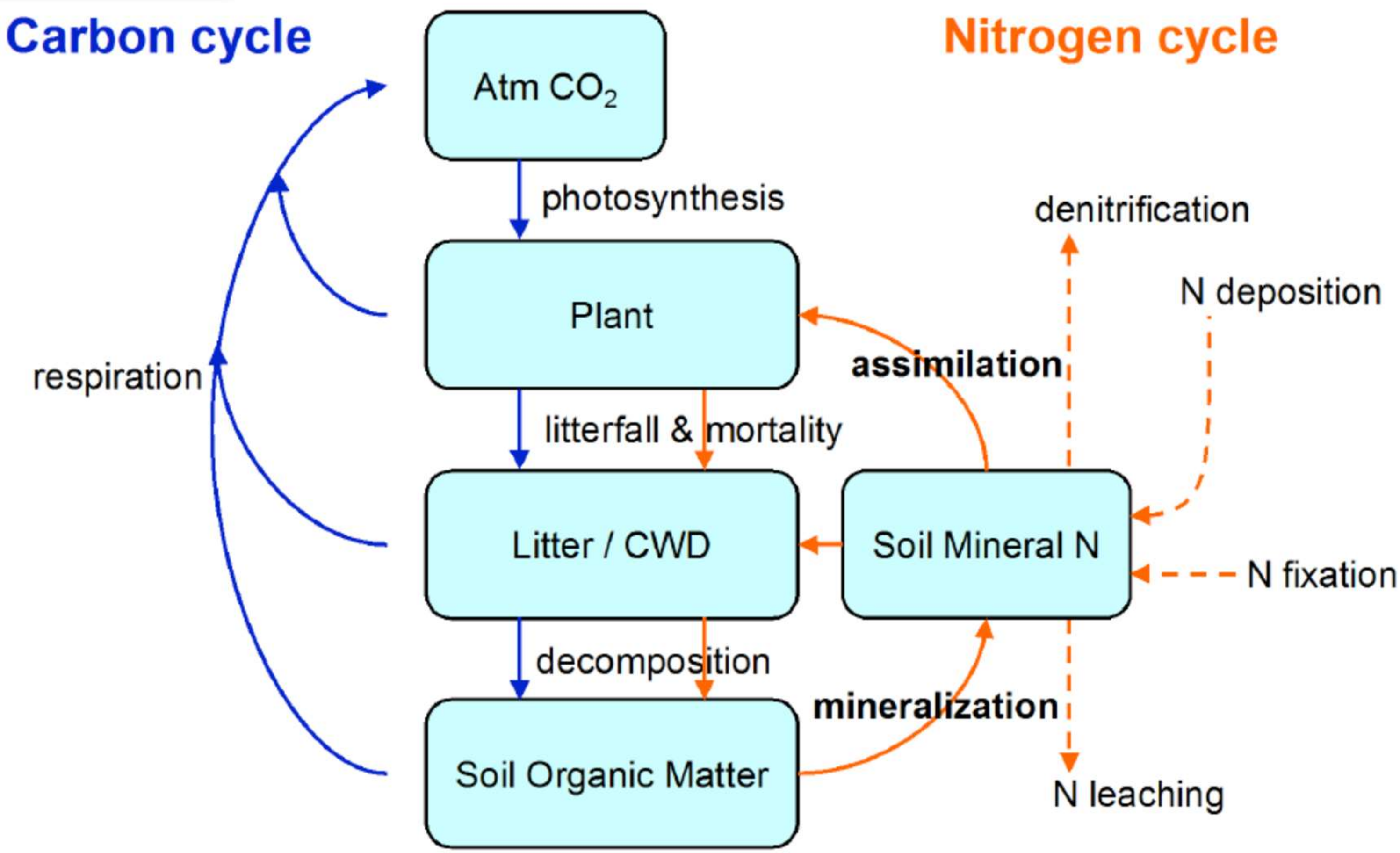


- DIET, FERTILIZER & CUT FRACTION (management related): United Kingdoms (UK), Netherlands(NL), Belgium(BE), Denmark(DK), Switzerland(CH), Norway(NO)
- AREA: Germany(DE), Spain(ES), Italy(IT), Greece(GR), Hungry(HU), Bulgaria(BG)
- GRAZING IN SHRUBS: Mediterranean → Spain(ES), Italy(IT), Portugal(PT), Greece(GR)
- UTILIZING INTENSITY : Romania(RO), Lithuania(LT), Slovakia(SK), Latvia(LV), Estonia(EE)

Fig. 8 Comparison of modeled and statistical ruminant livestock quantity (LSU) fed by European grassland by NUTS0 regions (1990-2010)

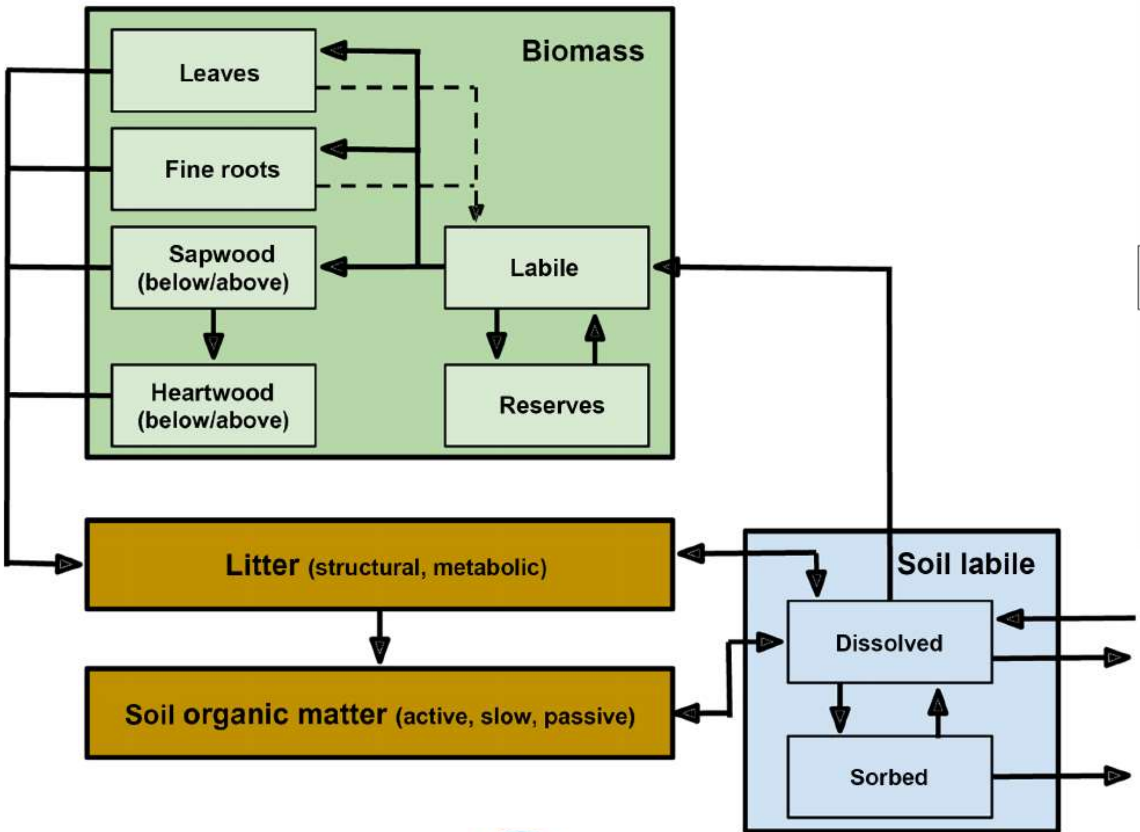
The nitrogen cycle

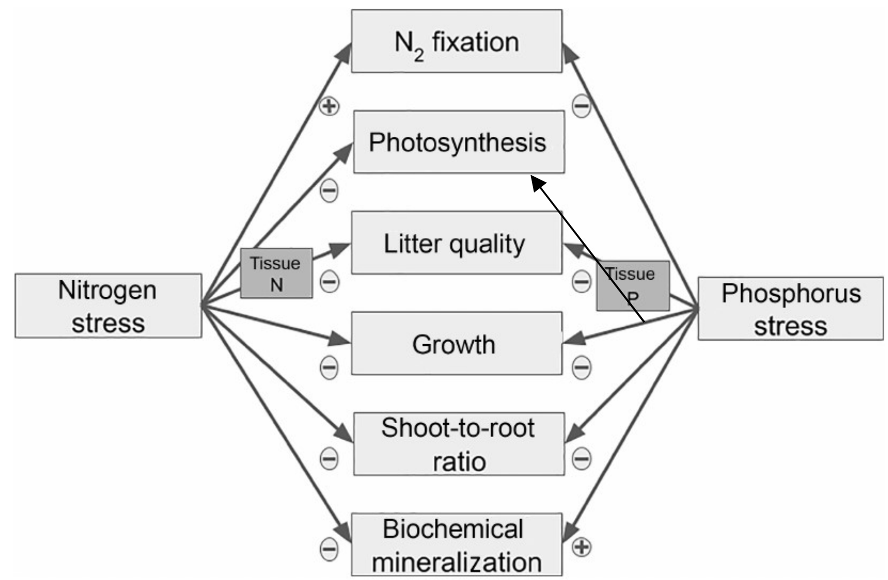
Simulating the nitrogen cycle



From S. Zaehle

ORCHIDEE-CNP



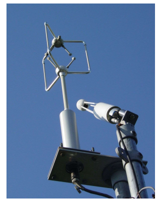


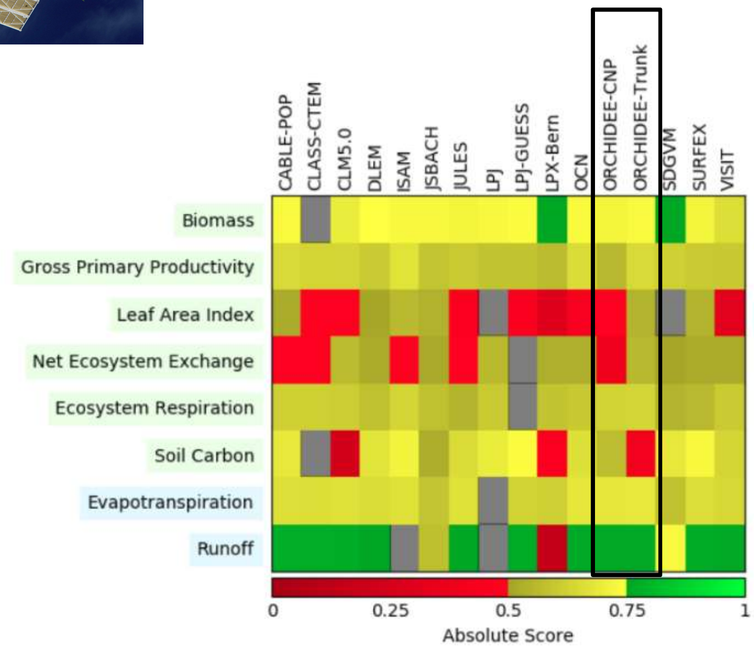
IMBALANCE P

Evaluation

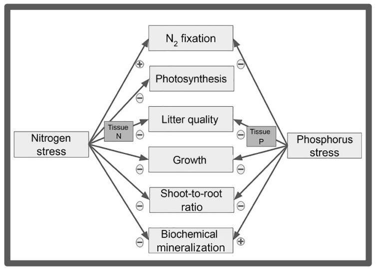
spatial extent: local (see map), regional (Guimberteau in prep.), global (Sun et al in prep.)
data: forest inventories, eddy covariance towers, satellite products, river discharge, ...
ecosystem manipulation experiments: free air carbon enrichment, fertilization, throughfall exclusion

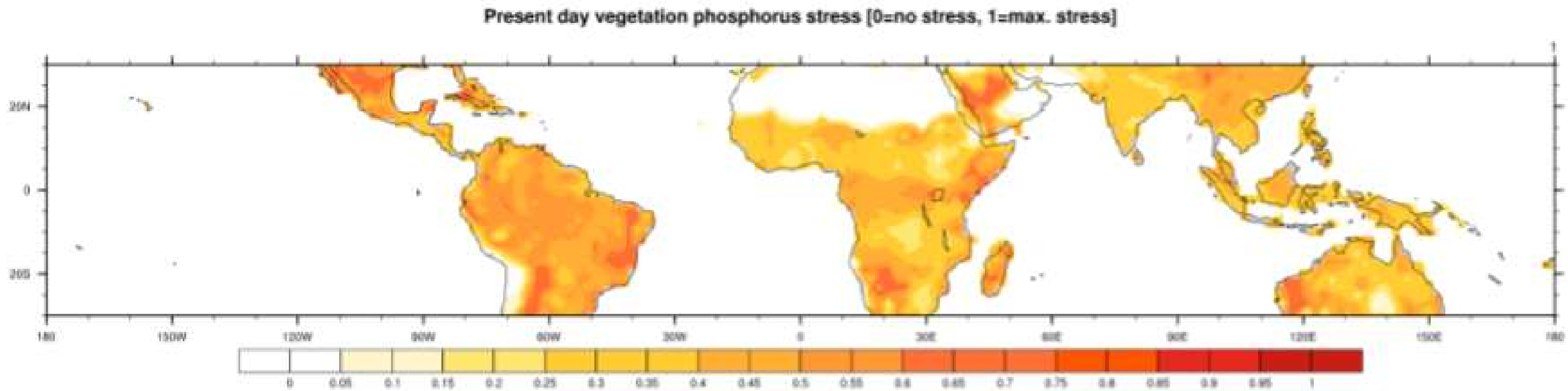


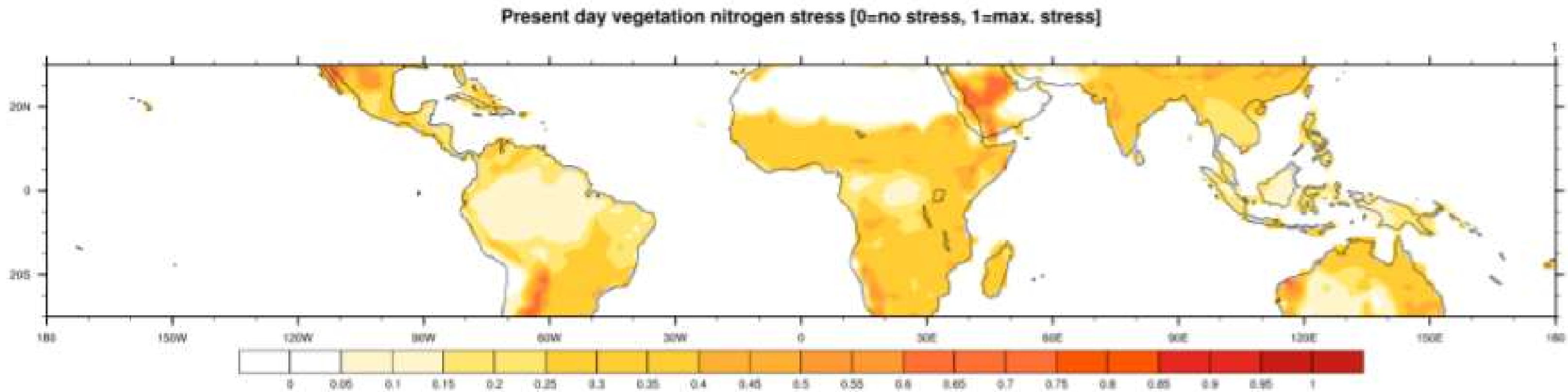



Pattern of nutrient limitation







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Outline

- A brief history of ORCHIDEE & motivations
- Formalism
- Main processes
- Ongoing developments
- **Configurations & Inputs requirements**

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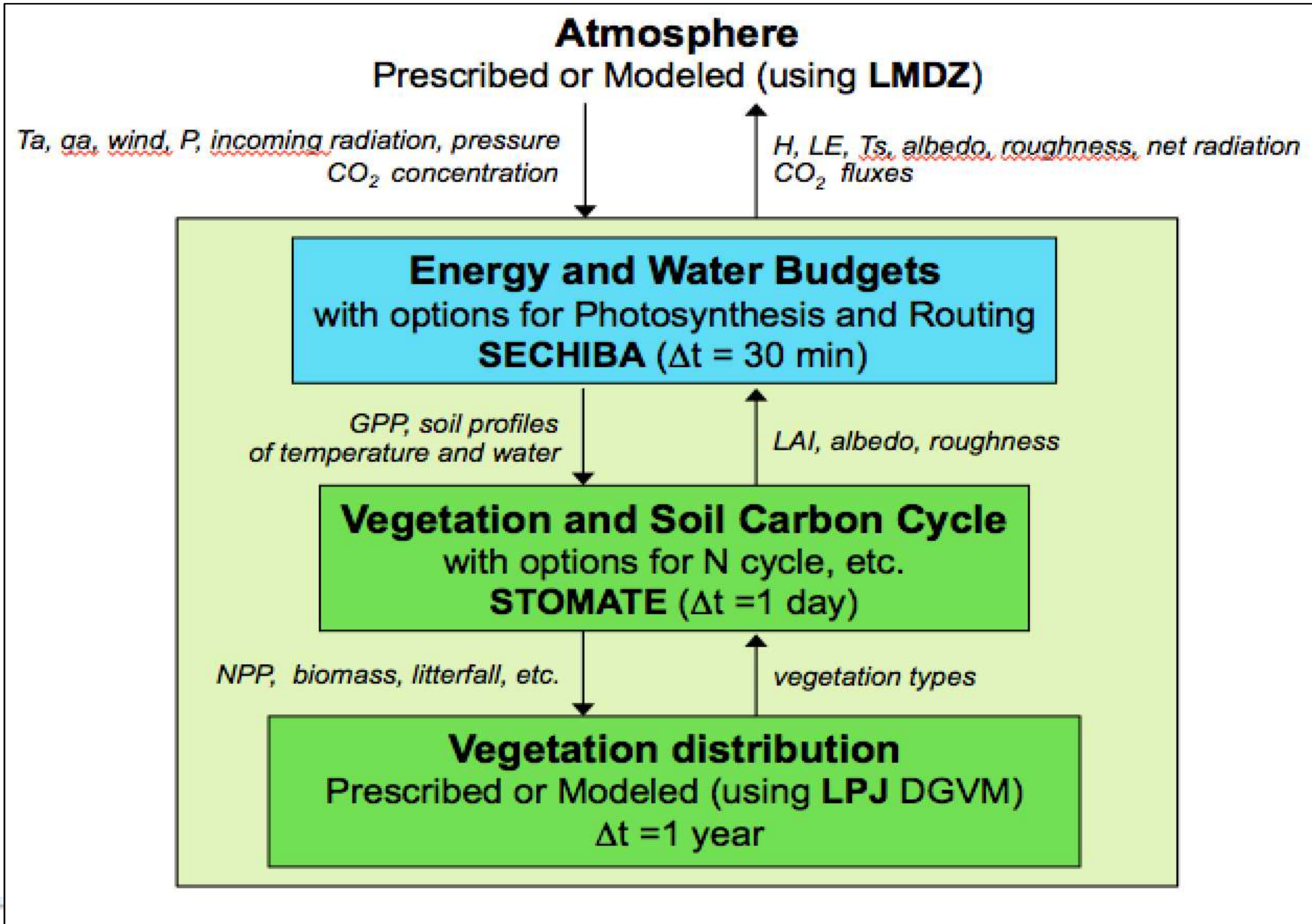
Tasks performed by ORCHIDEE for the IPSL ESM



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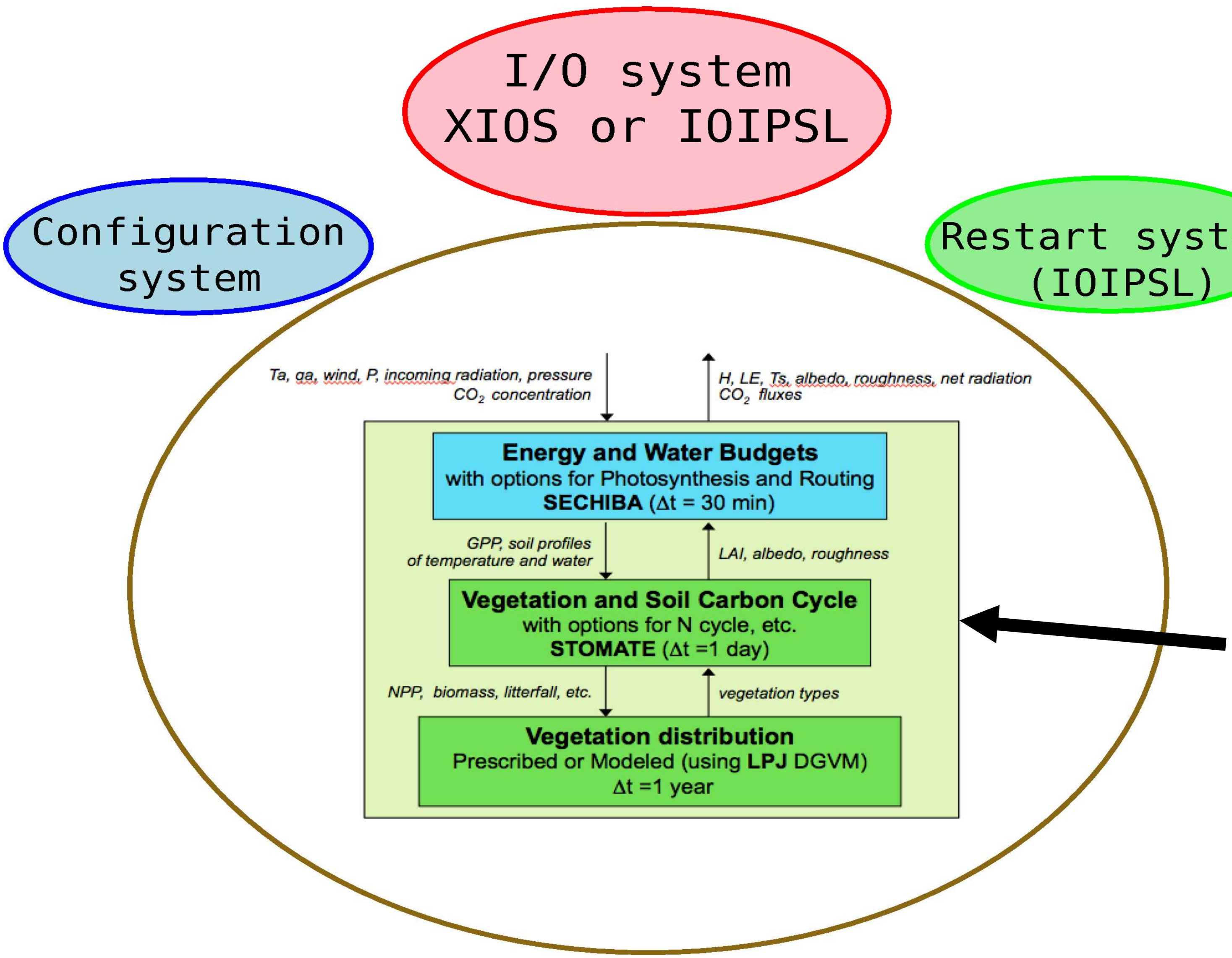
Infrastructure surrounding ORCHIDEE



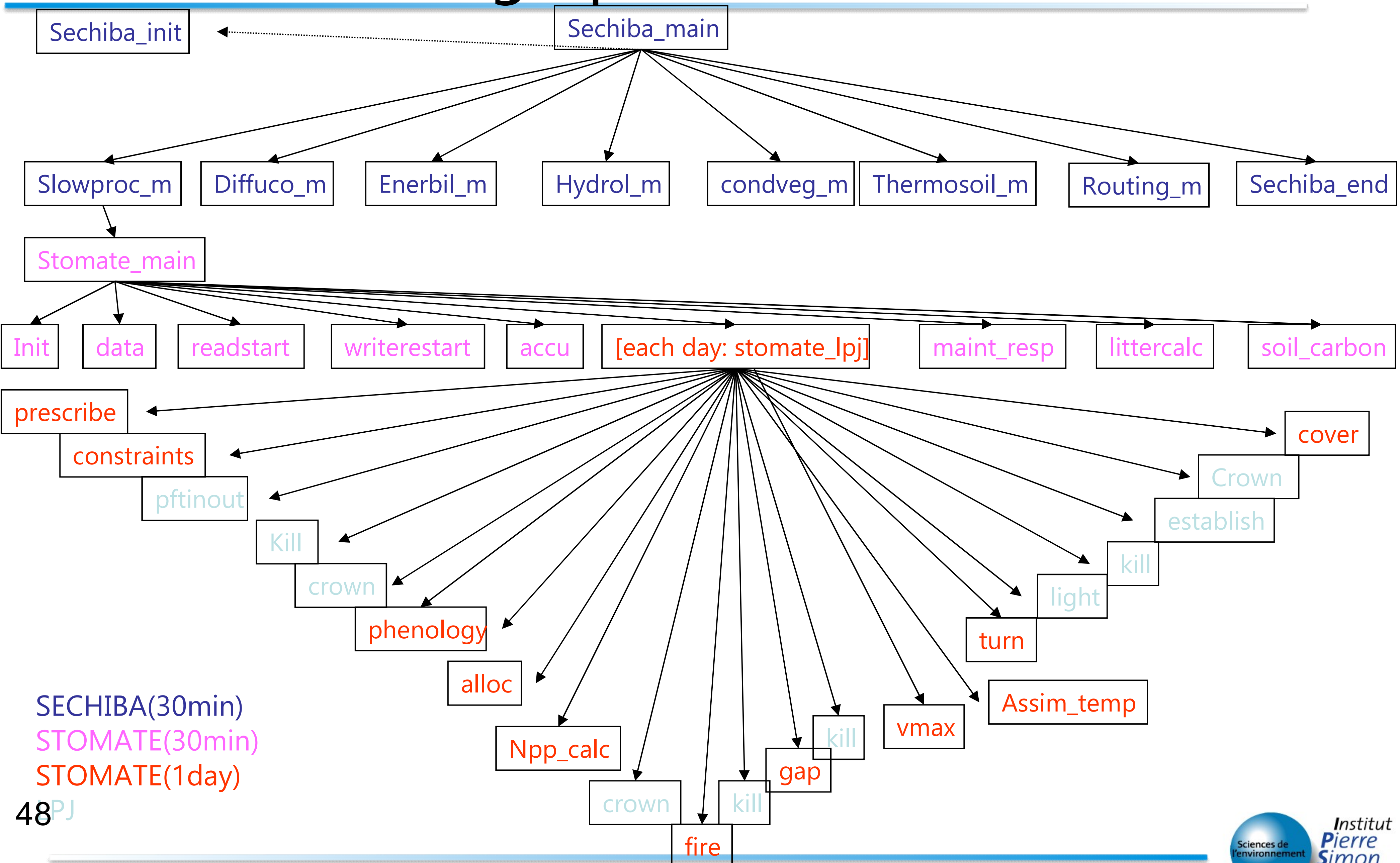
Some numbers to ORCHIDEE's code :

- 83 FORTRAN files
- 61000 lines of code
- 43000 lines of comments

Structure of the code

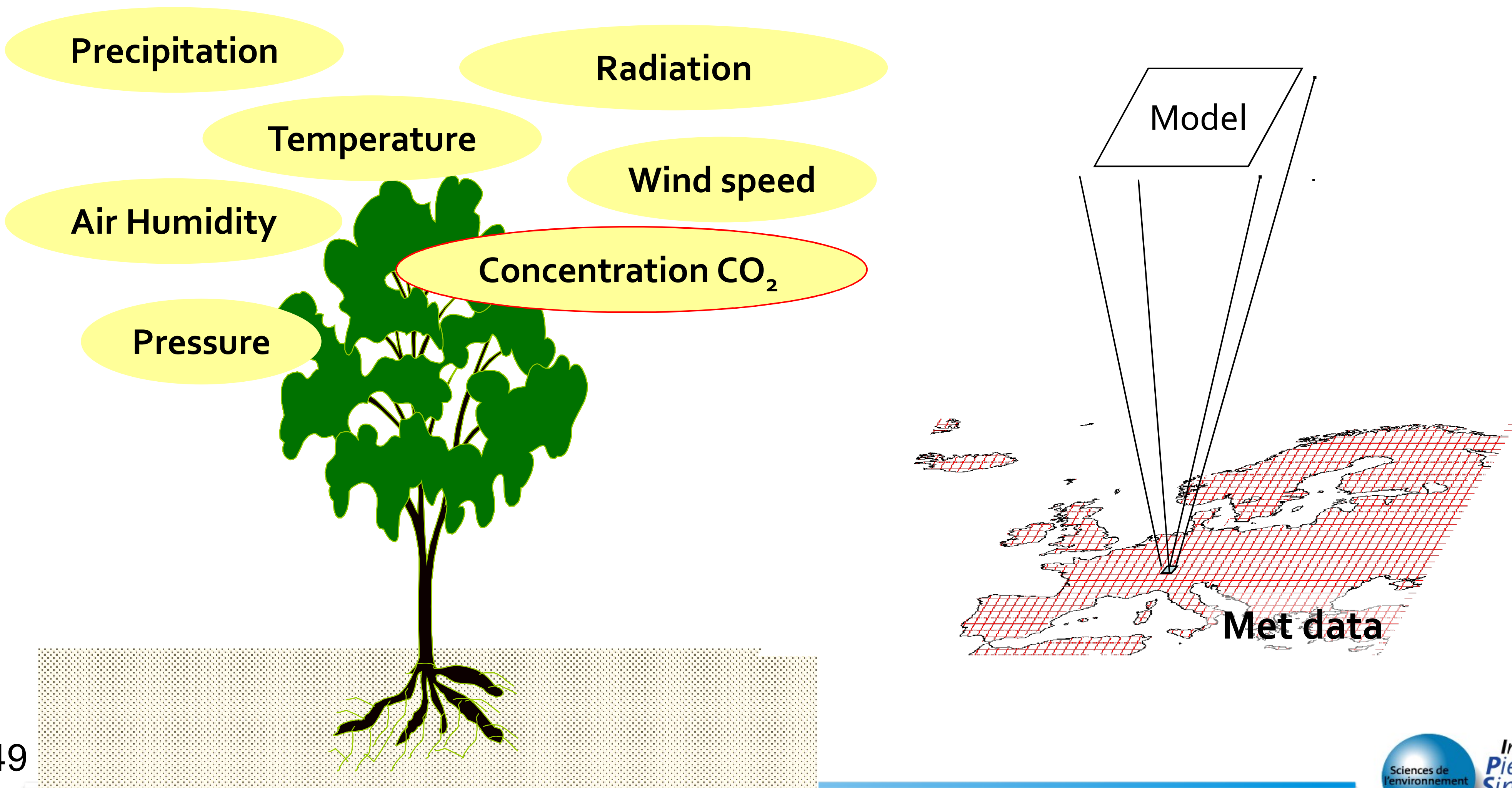
- Use of a modular structure
  - All the variables are dynamics (allocatable)
  - For each module:
    - A main entry point : <module>_main
    - An initialisation procedure : <module>_initialize
    - An end procedure : <module>_finalize
    - An procedure to clear memory : <module>_clear
  - All the variables are transmitted by subroutine parameters.
  - Prognostic variables are local to the modules.

Subroutine Call graph



Atmospheric Interface

- Meteorological forcing (from monthly to half-hourly)

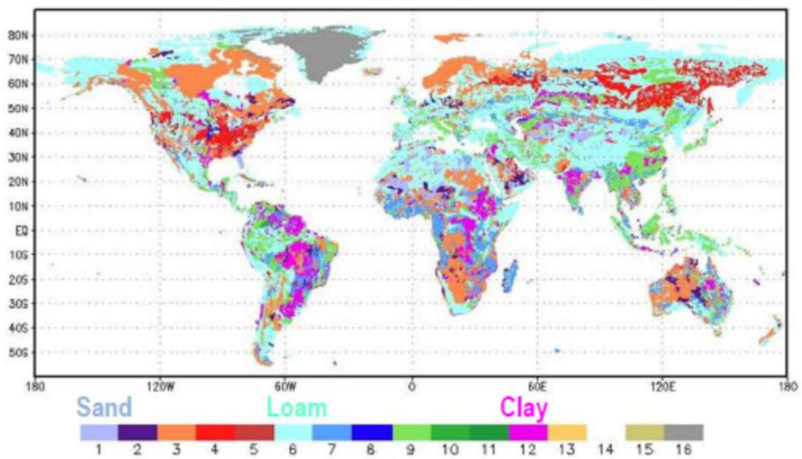


Forcing files

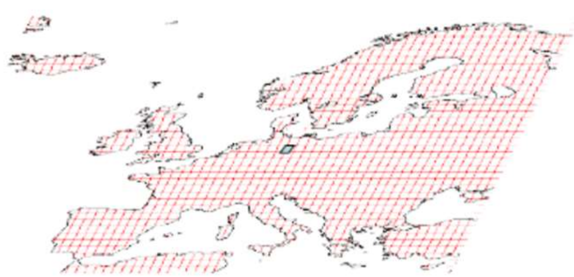
- Meteorological data
  - One often uses reanalysis or in-situ data with different time resolution (3h, 6h, ½ hour, ...)
  - The spatial resolution of the simulation is driven by the resolution of the meteo forcing file.
  - The time step of a simulation is defined by the parameter TIME_STEP (30 min by default).
  - The meteorological data often needs to be interpolated in time to the ORCHIDEE time step.
- Ancillary data depending of the configuration and version:
  - Basic: PFT map, soil texture, albedo
  - Nitrogen input etc...

The role of soil texture

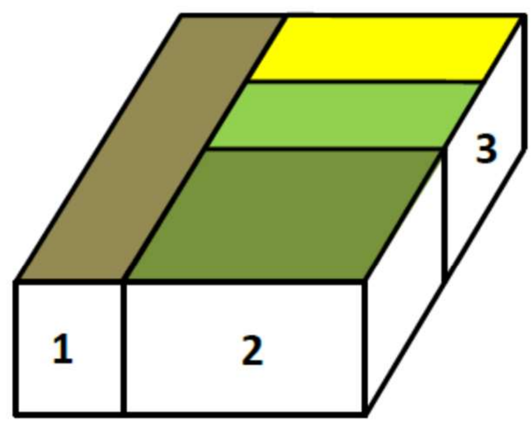
5' USDA texture map (Reynolds et al., 2000)



Dominant texture in each ORCHIDEE grid-cell:
defining the hydraulic properties



Sub-grid scale heterogenity:
3 soil columns based on PFTs
with independent water budget
but same texture



1: Bare soil PFT
2: All Forest PFTs
3: All grassland and cropland PFTs

Conclusions

- ORCHIDEE is a complex system !
- But you have the chance to use a system which was developed at IPSL and by people who are still present.
- The model has too many options and you will get lost!
- Do not hesitate to ask the original developers if you have problems.
- Enjoy the training !