The Global Land Surface Model ORCHIDEE

(ORganizing Carbon and Hydrology In Dynamic Ecosystems Environment)

ORCHIDEE
LAND SURFACE MODEL

Presented by Nicolas Vuichard
LSCE/IPSL

Outline

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

A brief history

Model

SECHIBA

Carbon Cycle (STOMATE)

Dynamic Veg. (LPJ)

ORCHIDEE

+ new hydrology

+ river routing

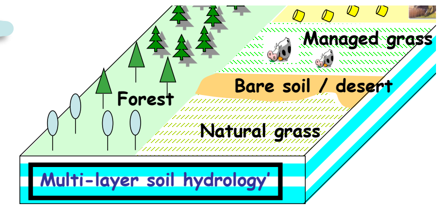
+ Forest management

+ Crops module

+ Permafrost

+ Nitrogen Cycle

Toward a single community tool



(Laval et al., 1981) — **80s**

(Ducoudré et al., 1993) — **90s**

(Viovy et al., 1997)

(Polcher et al., 1998) — **2000**

(Krinner et al., 2005)

ORCHIDEE2 New hydrology — **2018**

ORCHIDEE3 Nitrogen cycle — **2020**

ORCHIDEE4 Forest management — **2023**

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.

ORCHIDEE LAND SURFACE MODEL

Sciences de l'environnement

Institut Pierre Simon Laplace

Objective

- Simulate Energy, Water, Carbon and Nitrogen fluxes at the land surface/atmosphere interface.
  - To be used for being the 'land surface' component of a Earth system model (IPSL-CM6).
    - 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

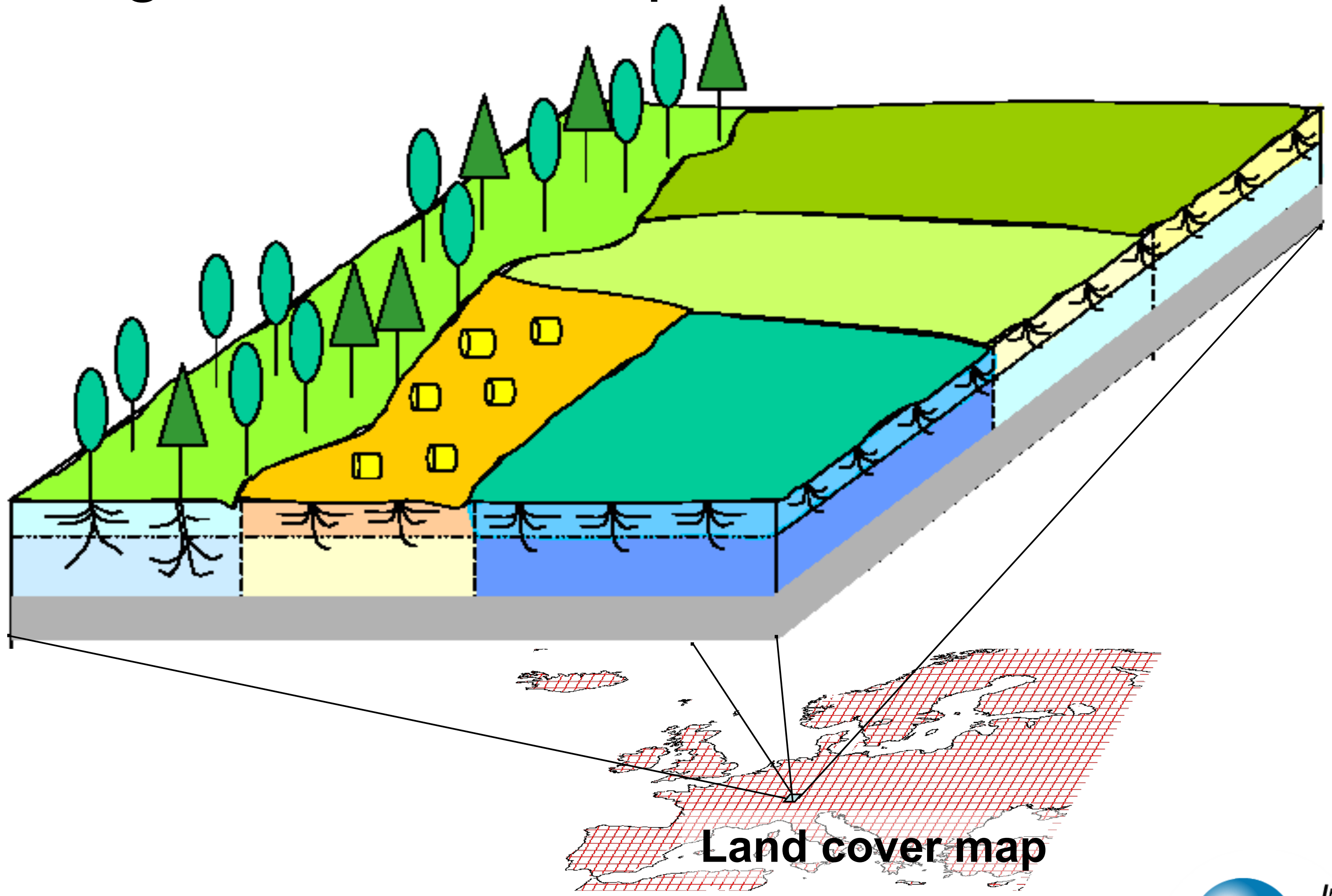
- Conservation of mass and energy is a guiding principle for ORCHIDEE.

Outline

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

A mosaïc of vegetation and soil moisture

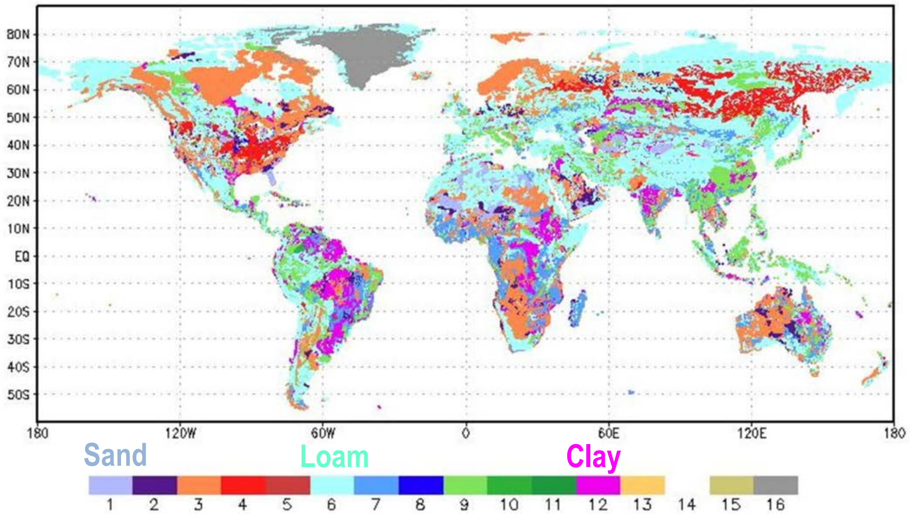
- Tiling for vegetation-related processes



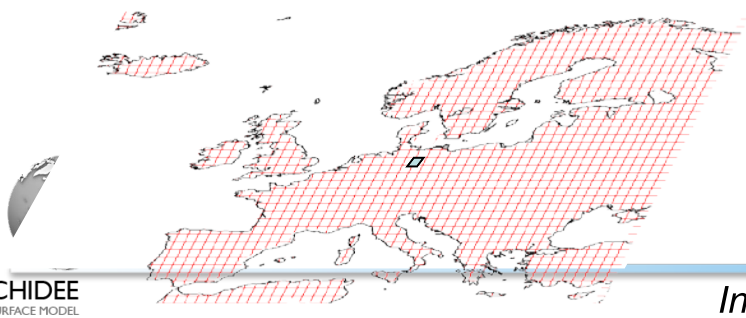
A mosaïc of vegetation and soil moisture

- Tiling for soil hydrology

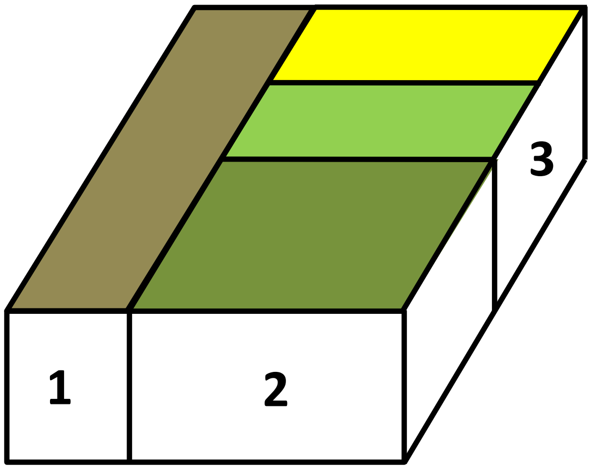
5' USDA texture map (Reynolds et al., 2000)



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

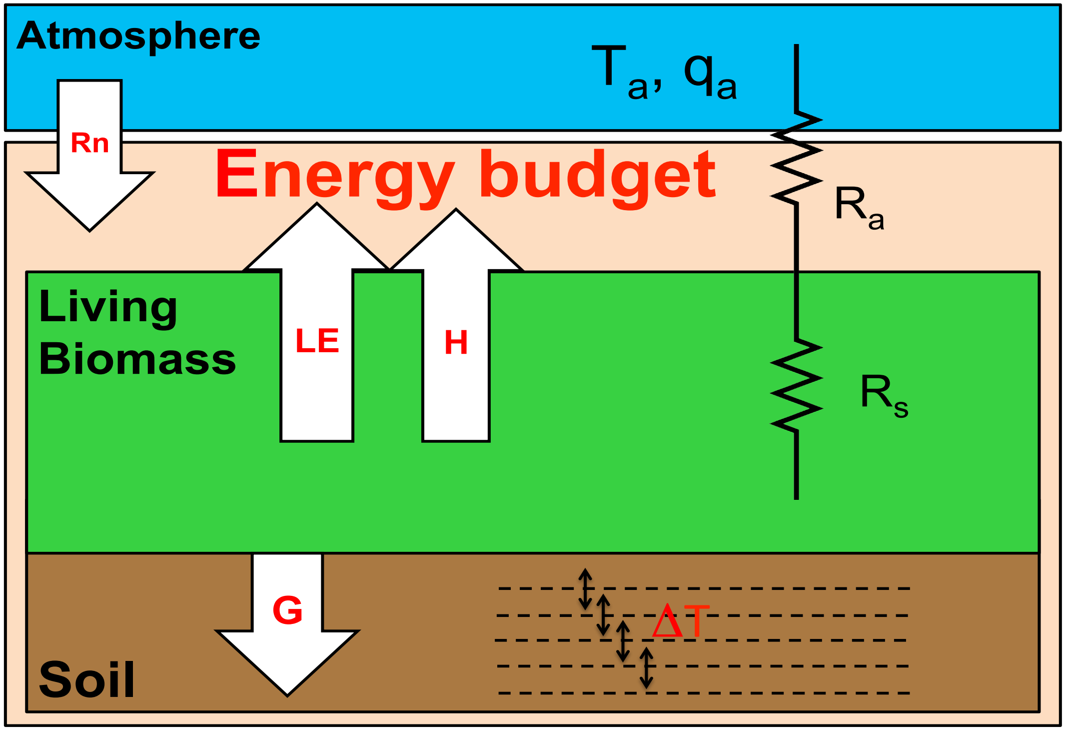


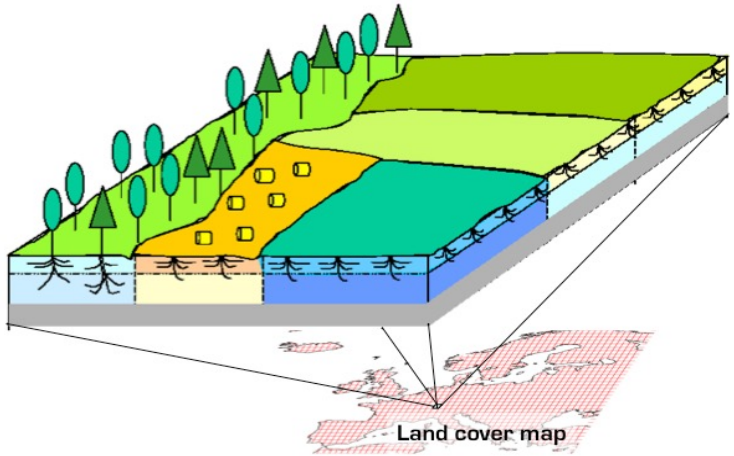
Sub-grid scale heterogenity:
3 soil columns based on PFTs
with independent water budget
but same texture



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

A single energy budget



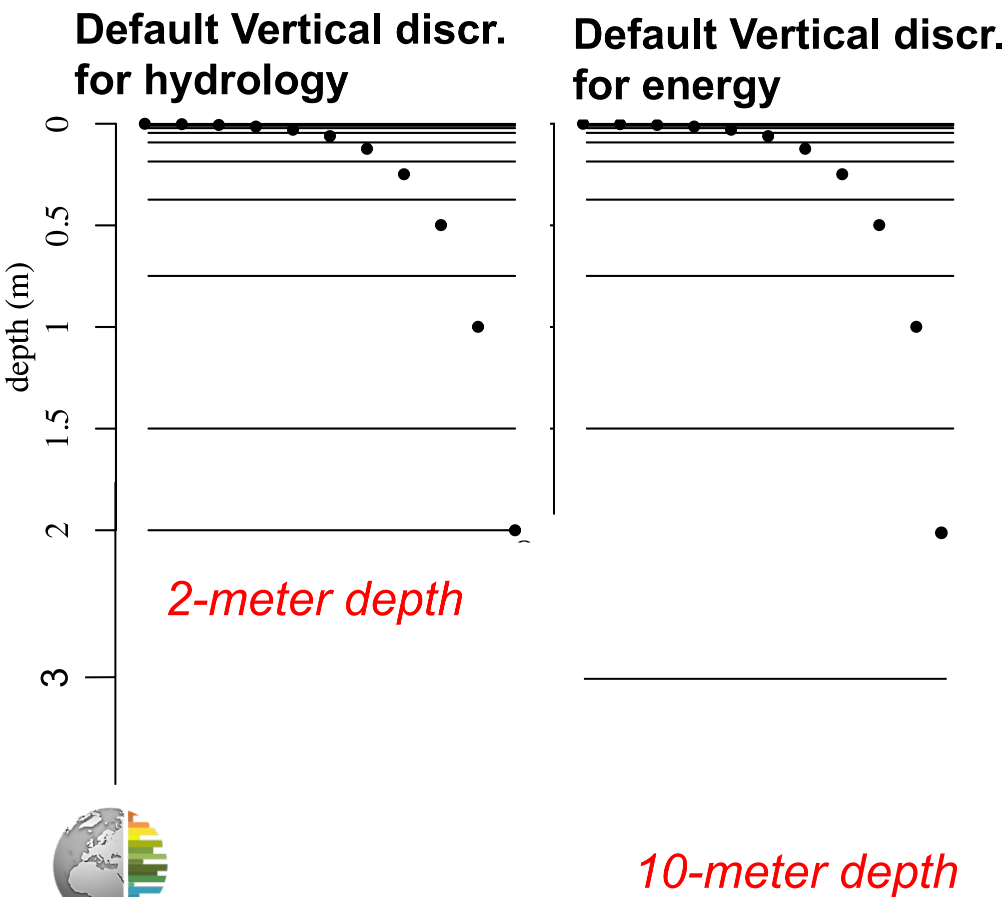


- One surface temperature per grid cell
- No vertical discretization within the canopy

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.



- 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

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)

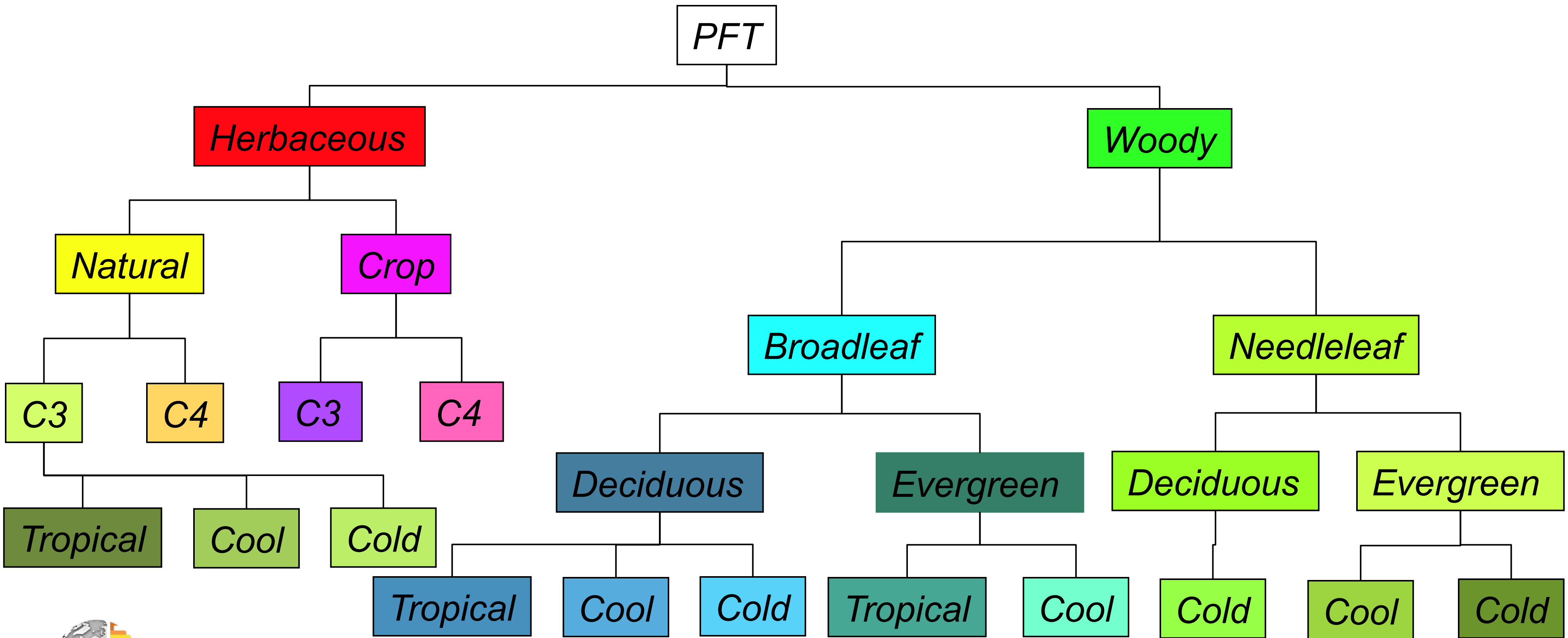
    frac_nobio

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

    - Use also of veget_cov_max = veget_max/(1-frac_nobio)
- One soil type per grid cell but different soil moisture profiles.

Vegetated lands

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

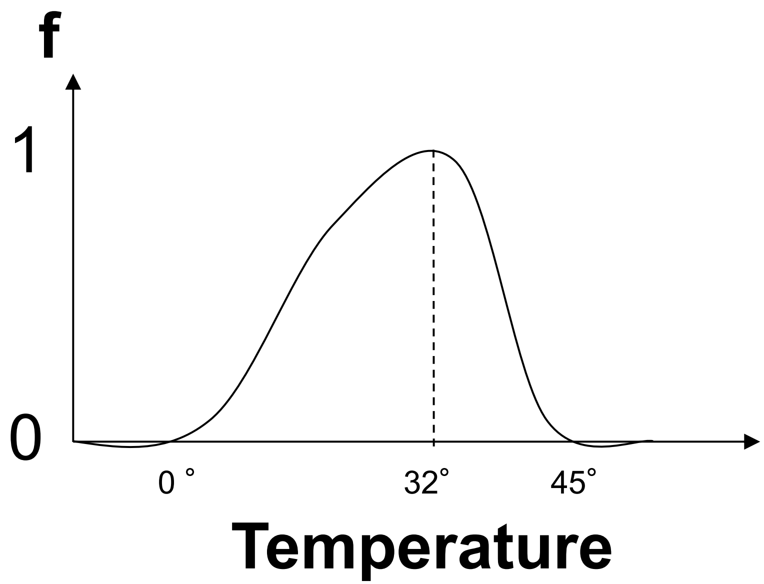


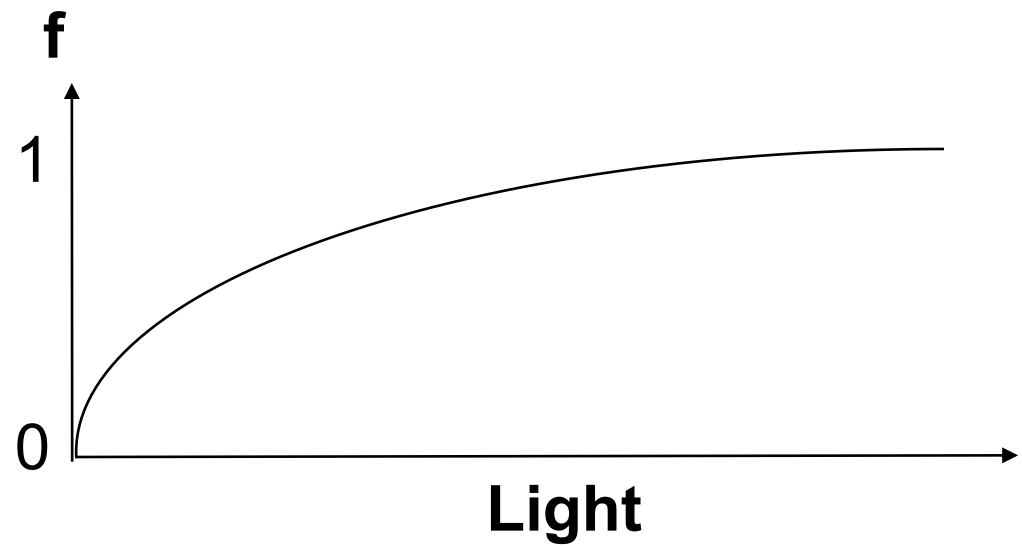
Plant Functional Types

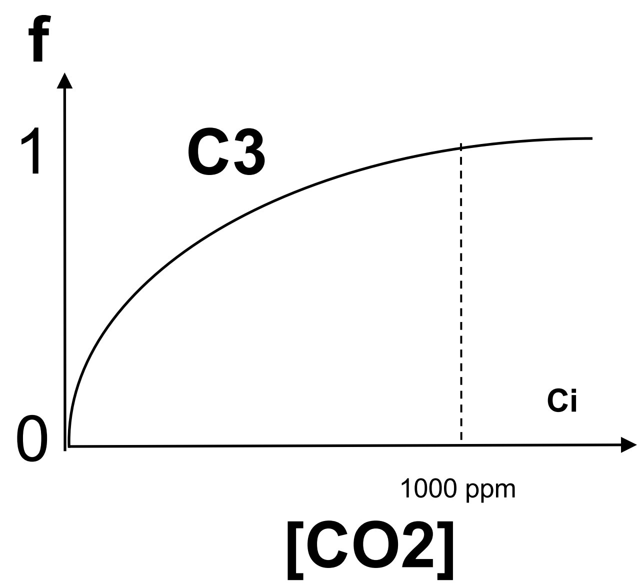
- A same set of equations governs PFT
- But parameter values differ among PFT's

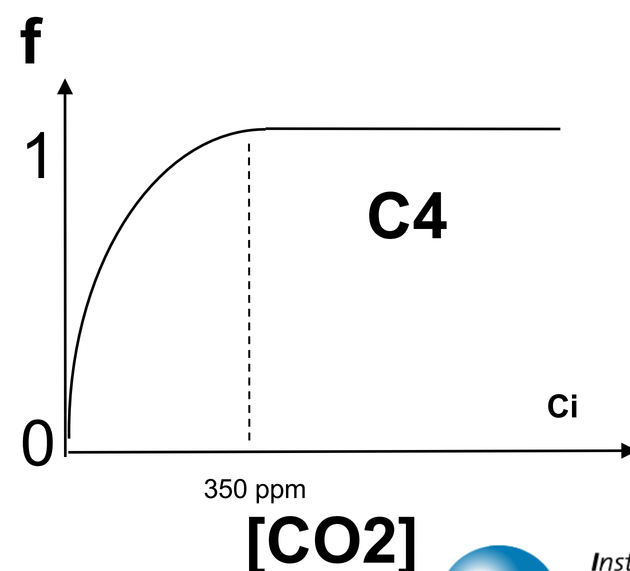
PFT	$V_{cmax,opt}$	T_{opt}	λ_{max}	z_{root}	α_{leaf}	h	A_c	T_s	H_s
TrBE	50	37	10	1.25	0.12	25	910	-	0.3
TrBR	60	37	10	1.25	0.14	25	180	-	0.3
TeNE	37.5	27	5	1.	0.14	15	910	-	-
TeBE	37.5	32	5	1.25	0.14	15	730	-	-
TeBS	37.5	28	5	1.25	0.14	15	180	12.5	-
BoNE	37.5	25	4.5	1.	0.14	10	910	-	-
BoBS	37.5	25	4.5	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









Concept of externalization

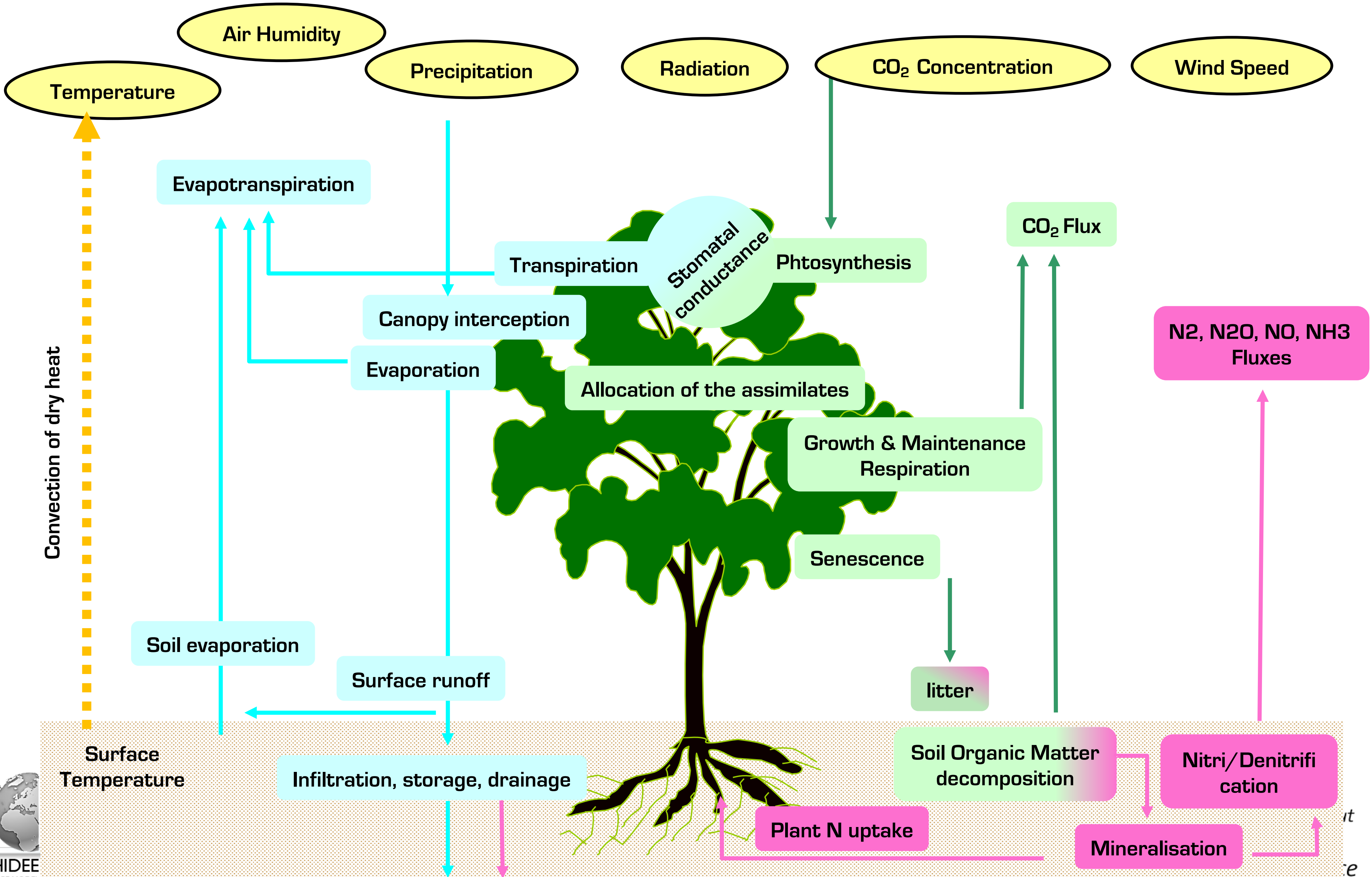
- By default 13 PFT's (named Metaclass) with pre-defined parameters setting
- Most of the parameters can be modified by the user (see orchidee.default file in the config/PARAM directory)
  The number of PFT's can be extended
  - By setting the NVM parameter and PFT_TO_MTC (correspondance array linking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

=> More info : technical note
https://forge.ipsl.jussieu.fr/orchidee/raw-attachment/wiki/GroupActivities/Training/parameterization_orchidee.pdf

Outline

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

Main processes



Resistance terms & Energy budget

diffuco module

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

enerbil module

- Calculation of :
  - Net radiation
  - Sensible heat flux
  - Latent heat flux
    - Transpiration
    - Evaporation of bare soil
      - and leaf water
    - Sublimation
  - Soil and surface temperature

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.

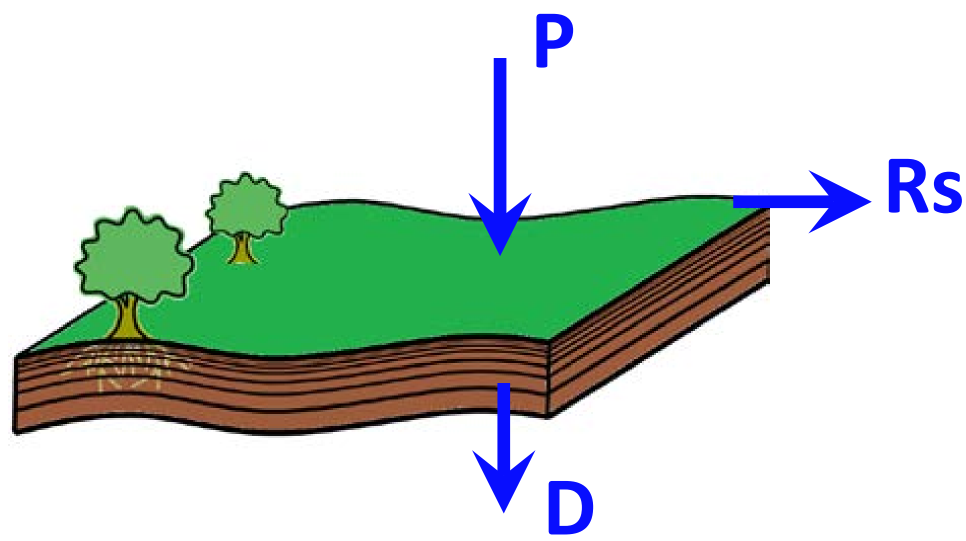
Soil water balance

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)

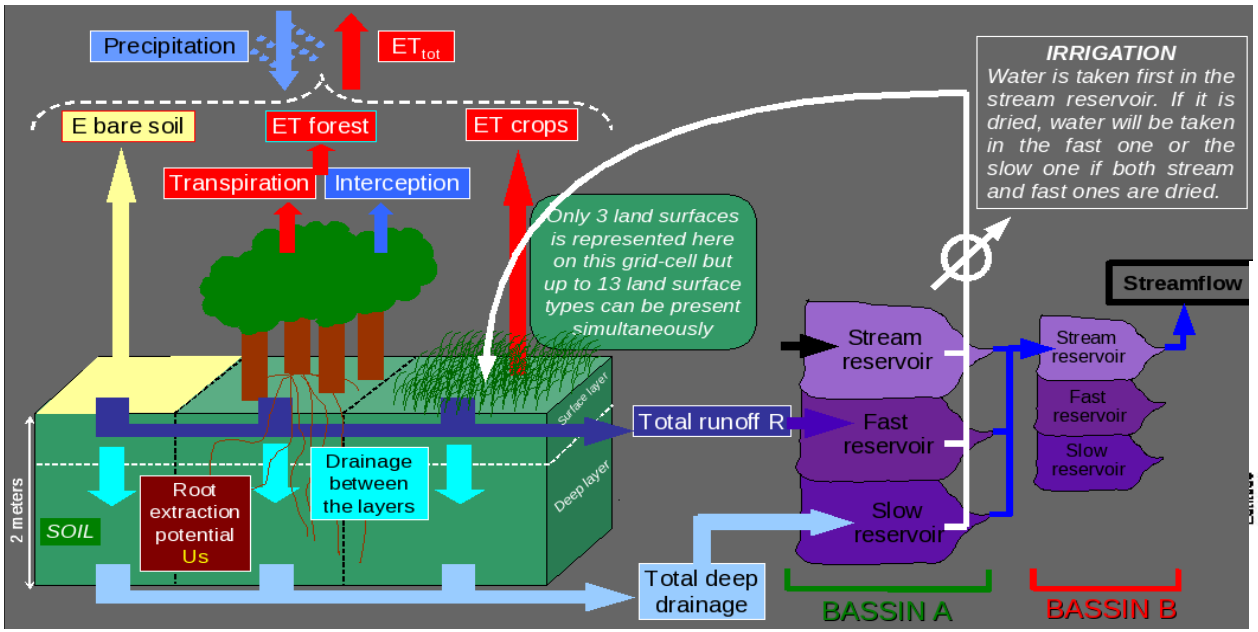
- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom



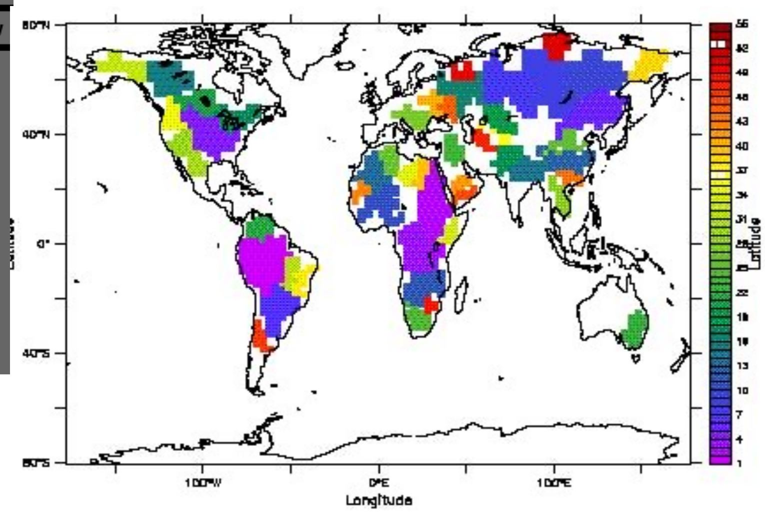
Routing / Irrigation

routing module

- Routing parametrization to calculate water discharge to river



From Guimberteau (thesis, 2010)



The 50 major river basins on the LMD-GCM grid

Biomass and soil pools

- 9 pools of living biomass
  - Leaves, fine roots, above and below sapwood, above and below heartwood, ‘fruits’ and short- and long-term ‘reserves’
- 4 pools of litter + Deadwood pool
  - Above/below, Structural & Metabolic
- 4 pools of soil
  - Surface, Active, Slow and Passive

} x2 Carbon Nitrogen

C assimilation/stomatal conductance

diffuco module: diffuco_trans_co2 routine

- A and G_s are calculated at each LAI level:
- Decrease of light in the canopy based on Pgap model
- N-limitation of assimilation:

$N_L = f(N_{leaf})$

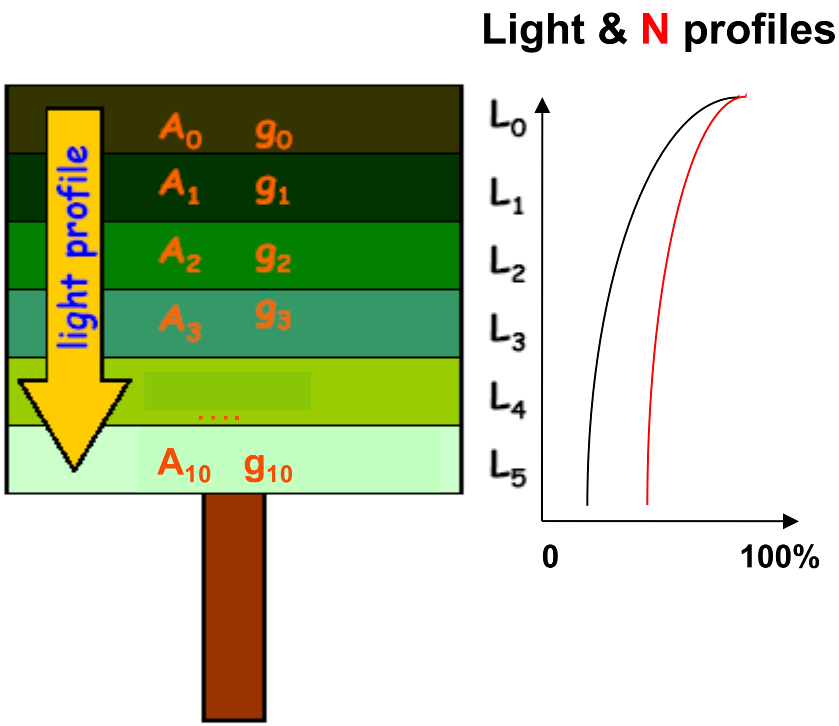
$$N_L = \frac{k_N \times N_{leaf}}{1 - exp^{-k_N \times LAI_{Lc}}} \times exp^{-k_N \times LAI_{Lc}}$$

With k_N values around 0.1-0.2 (Carrswell et al., 2000; Dewar et al. 2012)

N_{leaf} : leaf nitrogen content $m^{-2}{}_{[ground]}$

N_L : leaf nitrogen content $m^{-2}{}_{[leaf]}$ at level L

From the leaf to canopy



Photosynthesis

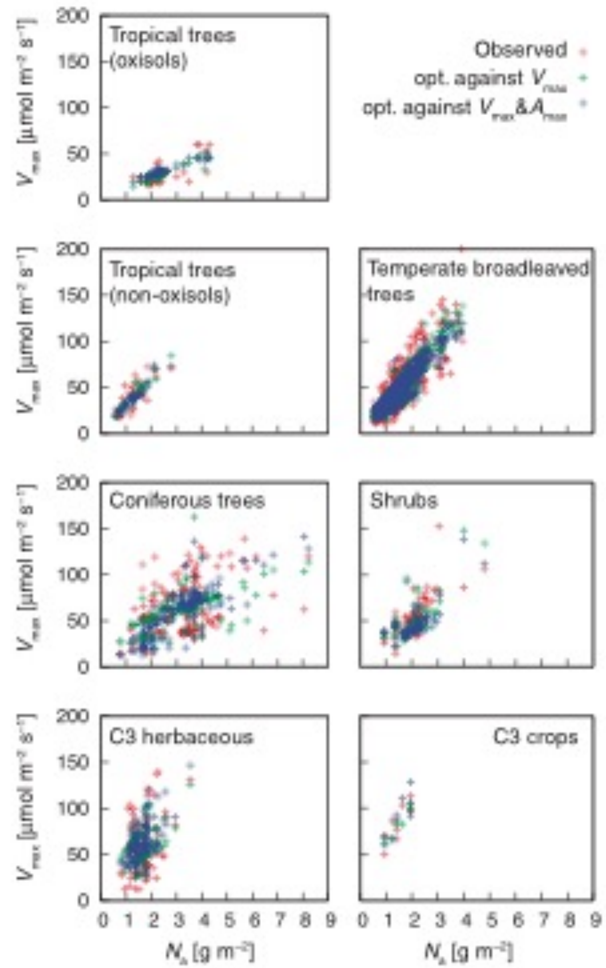
diffuco module: diffuco_trans_co2 routine

- Based on Farquahr model
- Vc_{max} : photosynthetic capacity ($\mu mol\ CO_2\ m^{-2}\ s^{-1}$)

$$Vc_{max} = NUE \times N_L$$

with *NUE* the Nitrogen Use Efficiency (PFT-dependant) and N_L the leaf N content ($gN\ m^{-2}_{[leaf]}$)

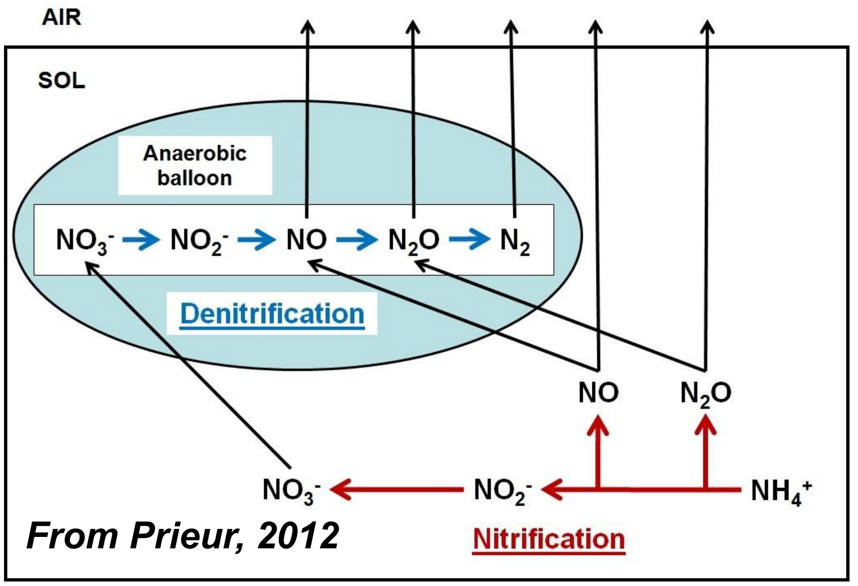
Vmax vs. Leaf N content



Kattge et al. (2009)

Soil mineral N pools

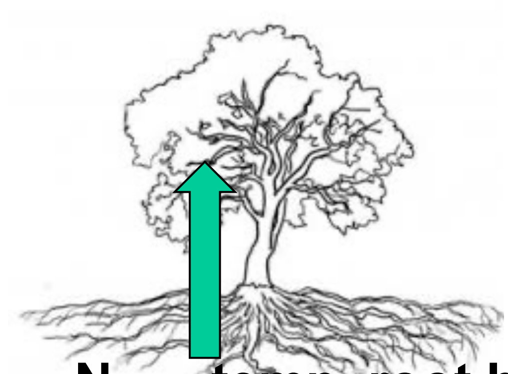
- Based on the DNDC model (Li et al., 1992, 2000).
- It accounts for:
  - Inputs of mineral through
    - mineralisation
    - N deposition
    - N fertilizers
    - Biological nitrogen fixation
  - Emissions of NH_3, NO, N_2O, N_2 by Nitrification and denitrification processes
  - Loss of soil mineral N through
    - Plant N uptake
    - Leaching



From Prieur, 2012

Plant N uptake

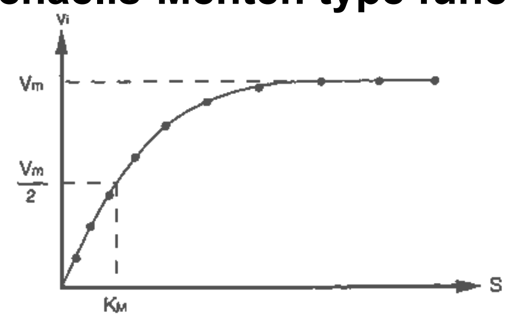
- Based on the experimental work of Kronzucker et al. (1995, 1996)



f **(CN_{leaf}, N_{min}, temp, root biomass)**

$$N_{up} = v_{max} \times N_{min} \times \left(k_{Nmin} + \frac{1}{N_{min} + K_{Nmin}}\right) \times f(T) \times f(NC_{plant}) \times C_{root}$$

Michaelis-Menten type function



Temperature

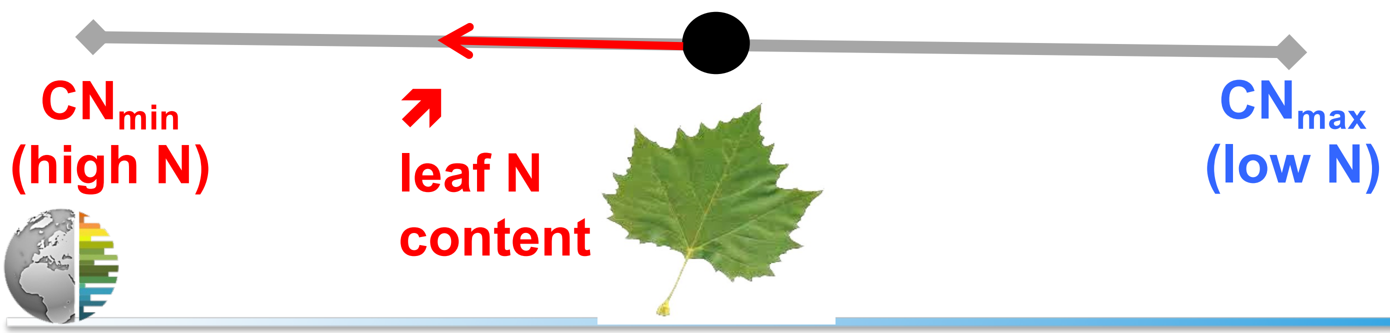
N uptake increases in N starved roots

Fine root mass

Allocation of assimilates

stomate_growth_fun_all module

- Functional allocation
  - Allometric relationship between sapwood, leaf and root biomass pools
  - Based on Forestry allocation scheme (Dhote and Deleuze)
- N allocation is function of
  - Allocation scheme for Carbon
  - N availability:
    - Leaf C/N ratio is a key variable
    - Varies across two constrained boundaries : $CN_{leaf,min}$ and $CN_{leaf,max}$

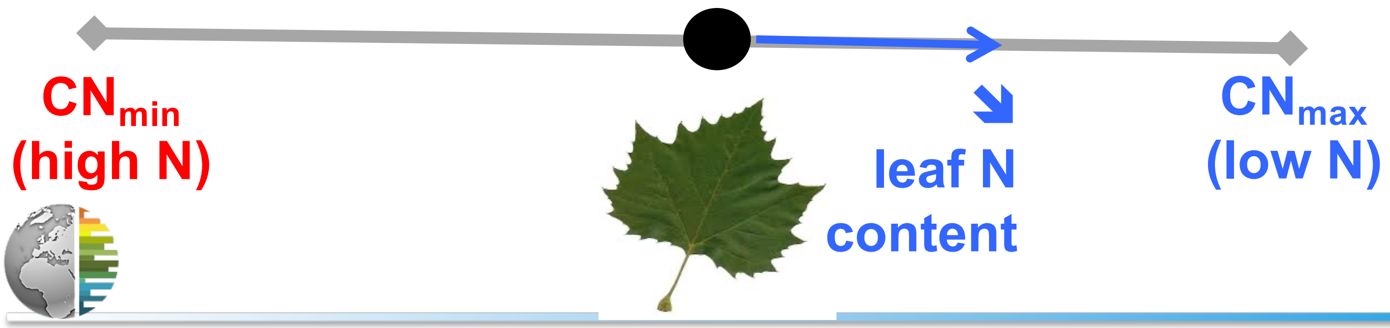


$N_{reserve} > N_{alloc}$ needed for maintaining CN

Allocation of assimilates

stomate_growth_fun_all module

- Functional allocation
  - Allometric relationship between sapwood, leaf and root biomass pools
  - Based on Forestry allocation scheme (Dhote and Deleuze)
- N allocation is function of
  - Allocation scheme for Carbon
  - N availability:
    - Leaf C/N ratio is a key variable
    - Varies across two constrained boundaries : $CN_{leaf,min}$ and $CN_{leaf,max}$



$N_{reserve} < N_{alloc}$ needed for maintaining CN

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

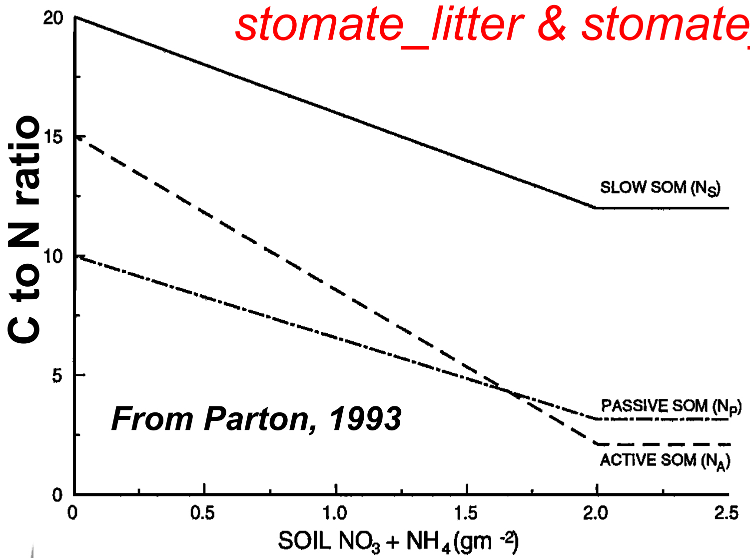
stomate_turnover module

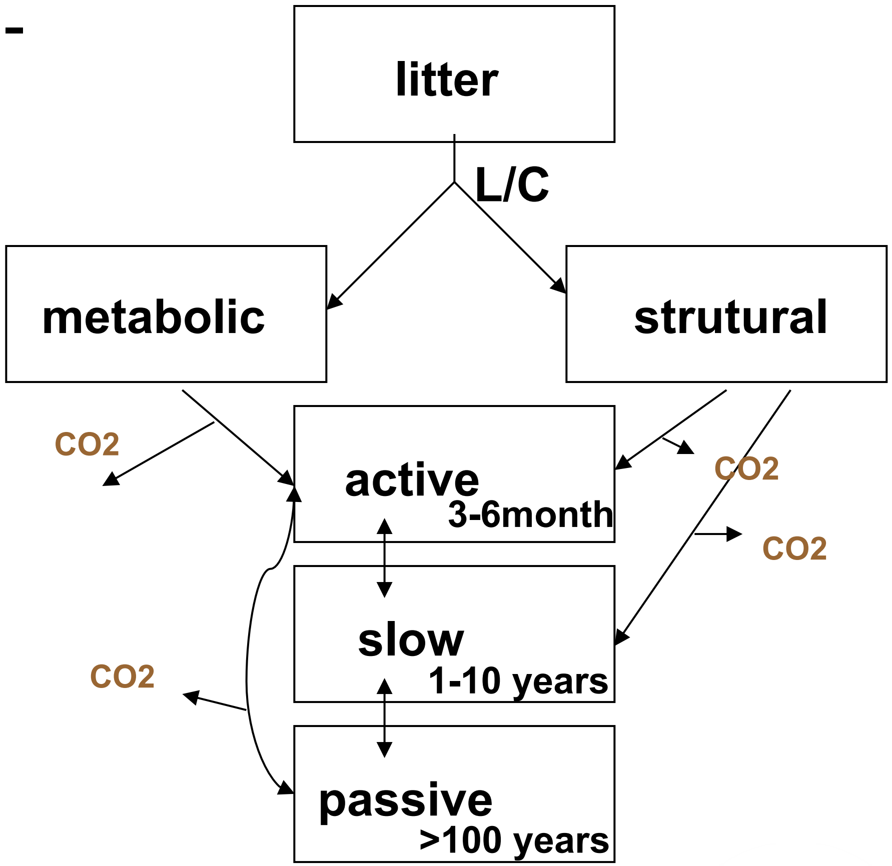
- Senescence
  - Function of leaf age and environmental conditions
  - For trees, a senescence stage is considered until all leaves fall (while for grass senescence it is a continuous process)

Respirations

- Autotrophic respiration
  - Maintenance *stomate_resp module*
    - linear response to temperature with potential adaptation to long-term temperature
    - function of Nitrogen content
  - Growth *stomate_growth_fun_all*
    - a fixed part of assimilates
- Heterotrophic respiration

stomate_litter & stomate_soilcarbon



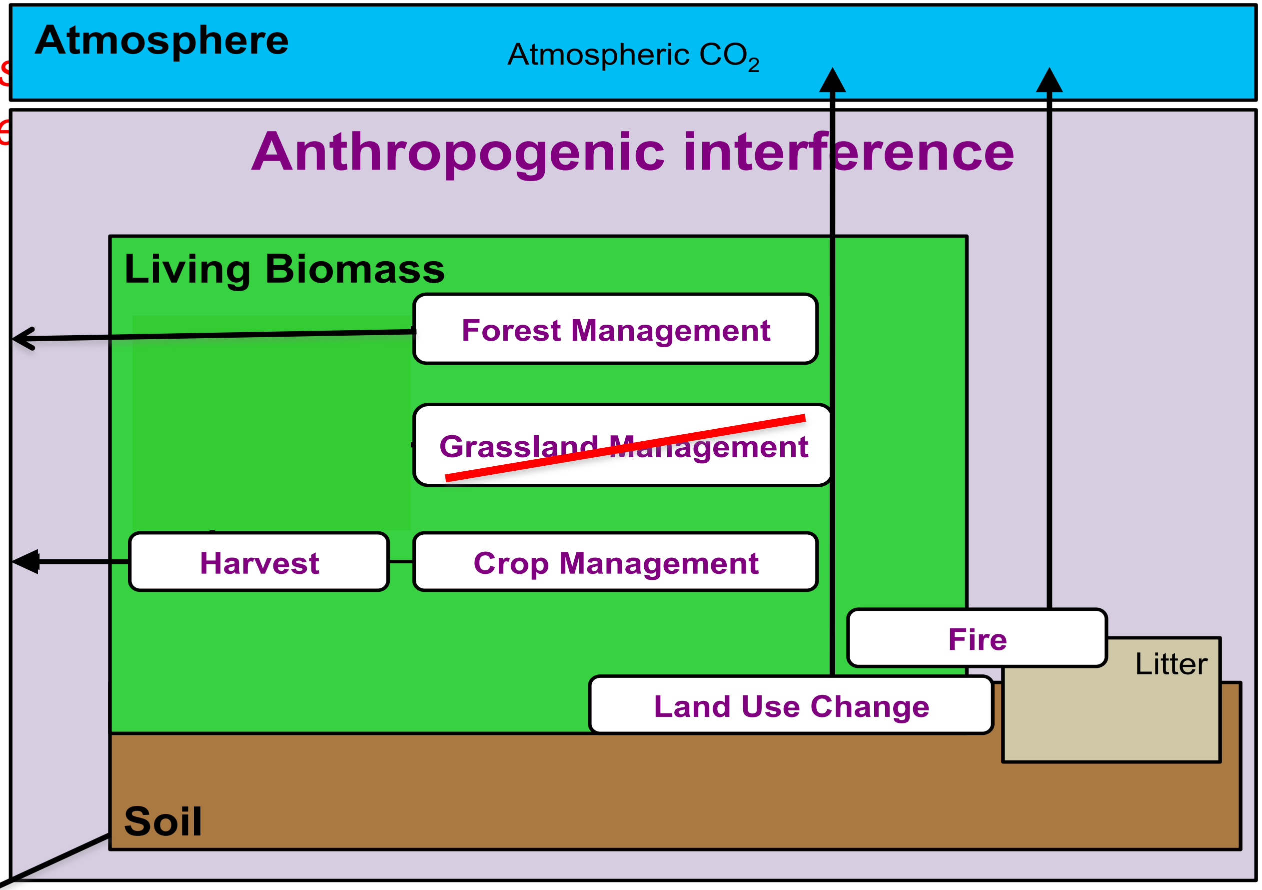


ORCHIDEE
LAND SURFACE MODEL

Sciences de l'environnement
Institut Pierre Simon Laplace

Land-use and land-use change

* *stomate_lcchange module*
  lcchange + wood_use routines
* *stomate_woodharvest module*



Wood Harvest

Crop Harvest

45 % of NPP is harvested and respired within the year

SOM decomposition rate of crop is 20% higher

Only net LUC

1 woody pool

Vegetation dynamic

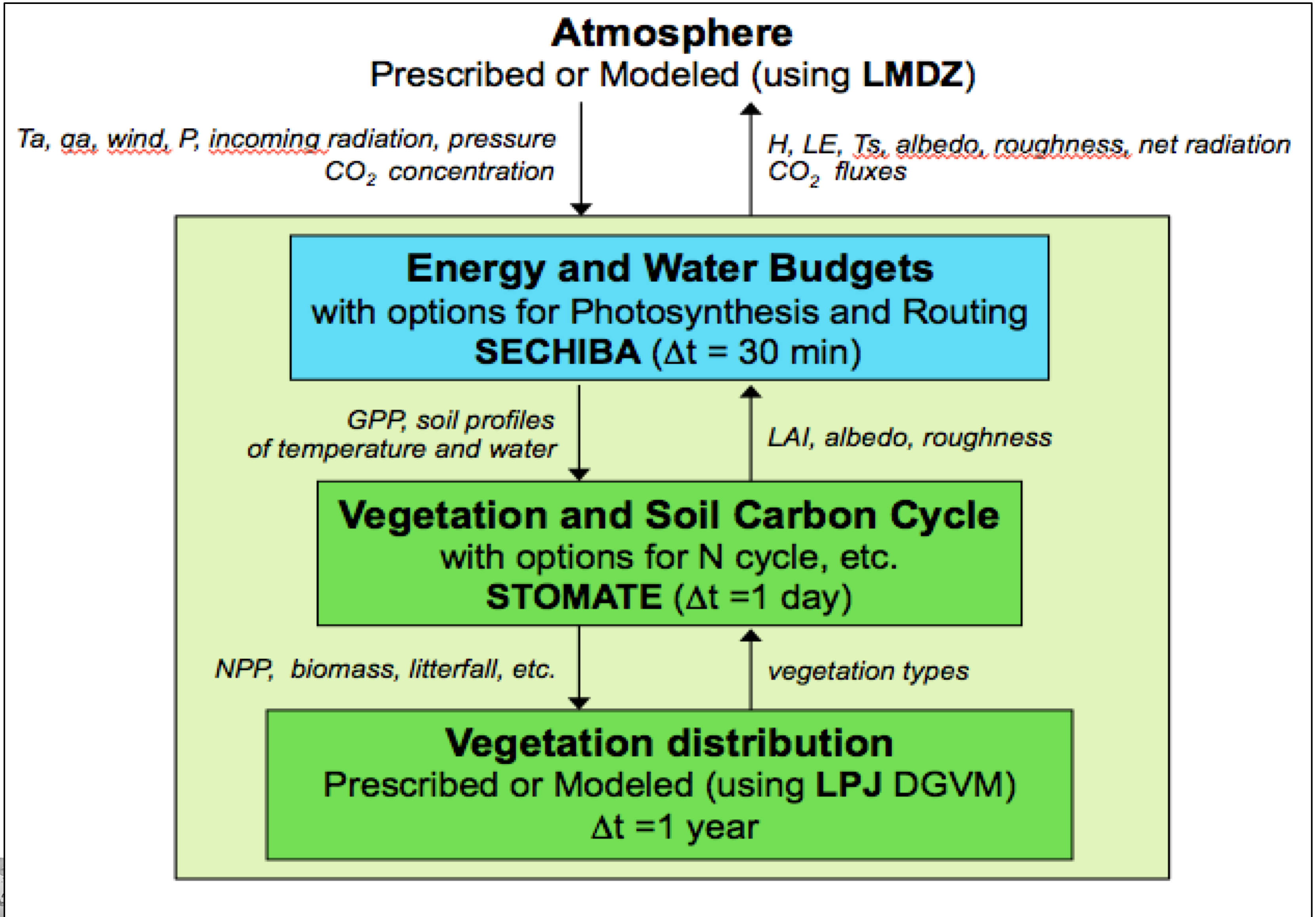
lpj_kill, lpj_pftinout, lpj_constraints modules

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

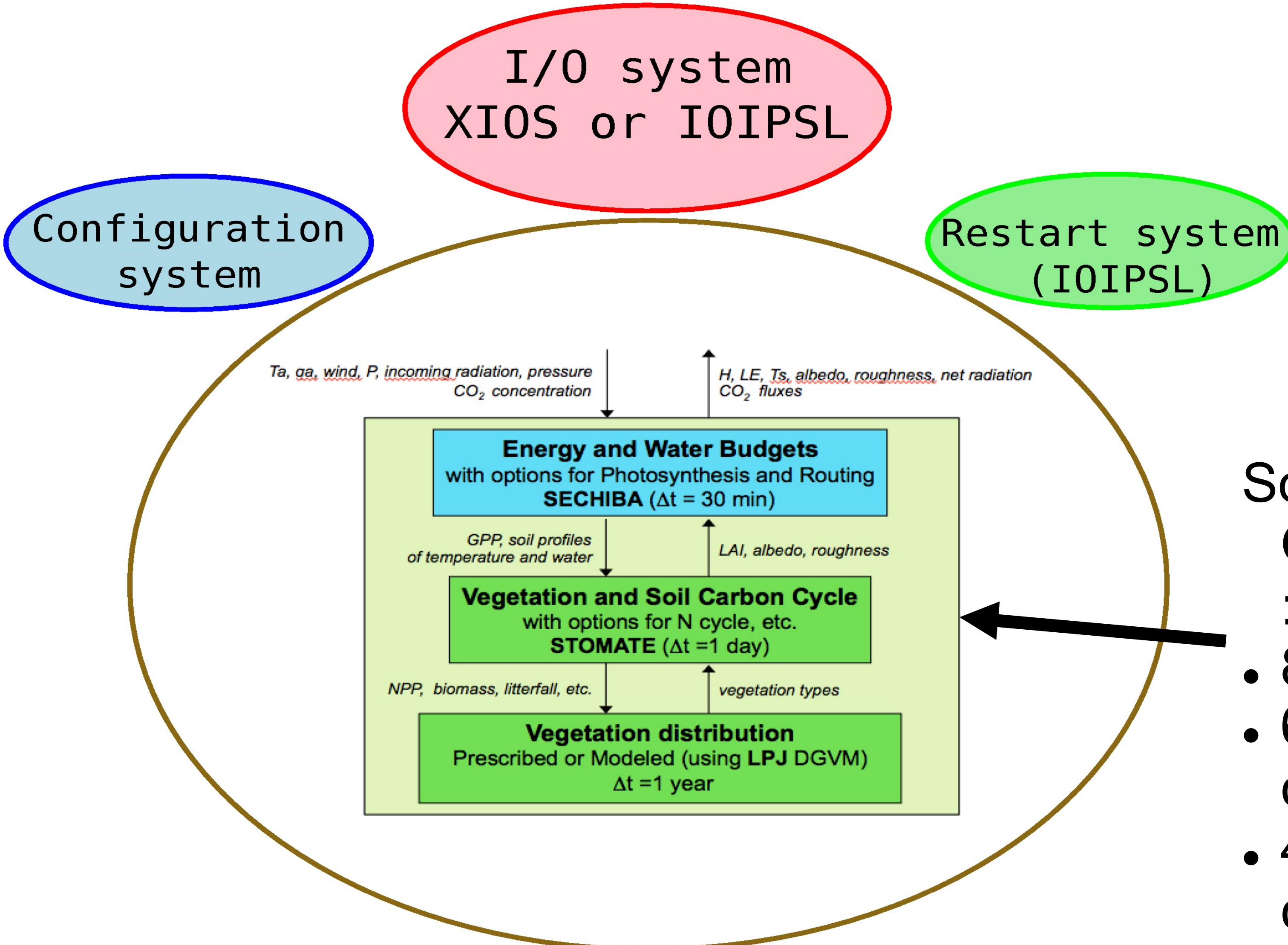
Outline

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

Tasks performed by ORCHIDEE



Infrastructure surrounding ORCHIDEE



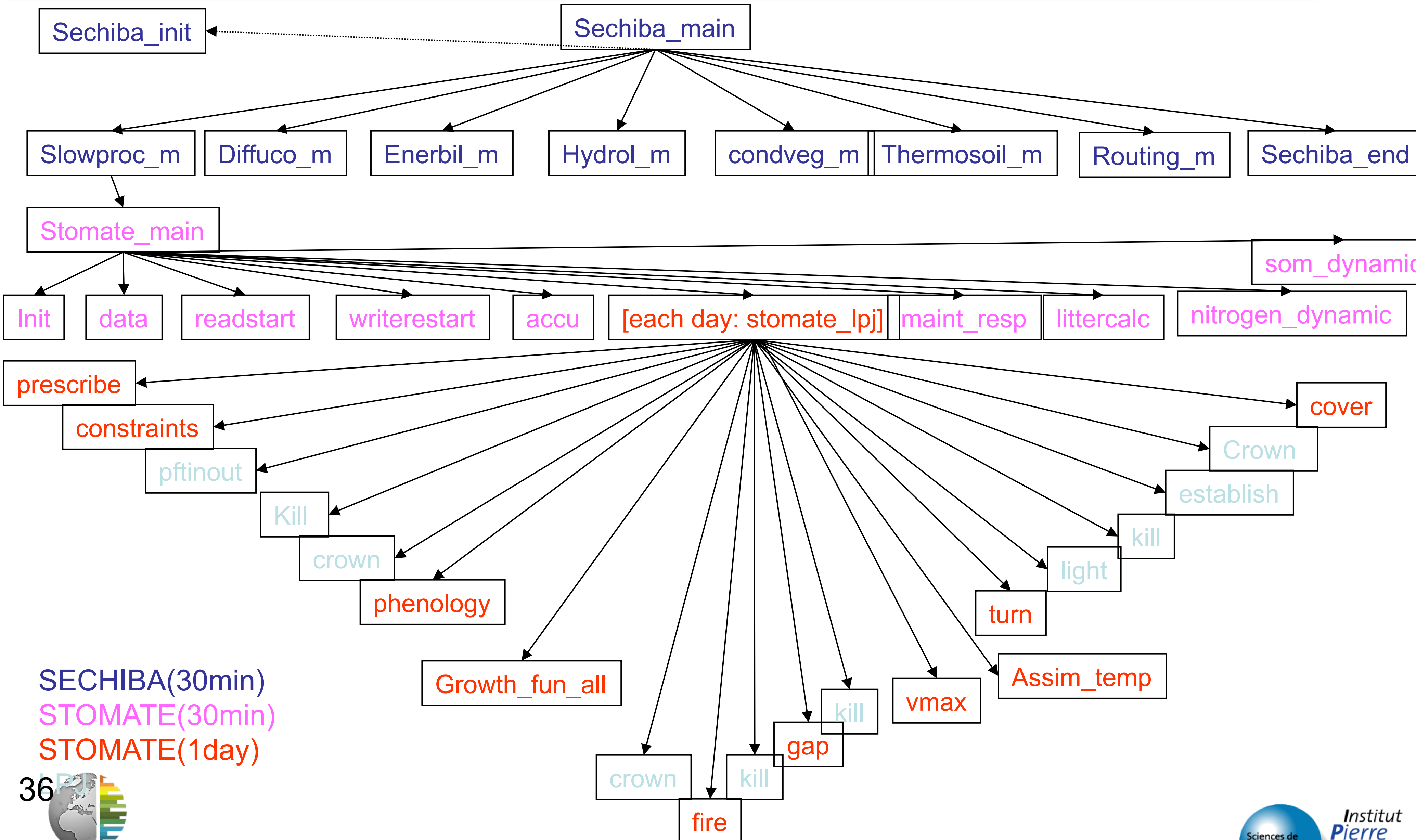
Some numbers to ORCHIDEE's code :

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

Structure of the code

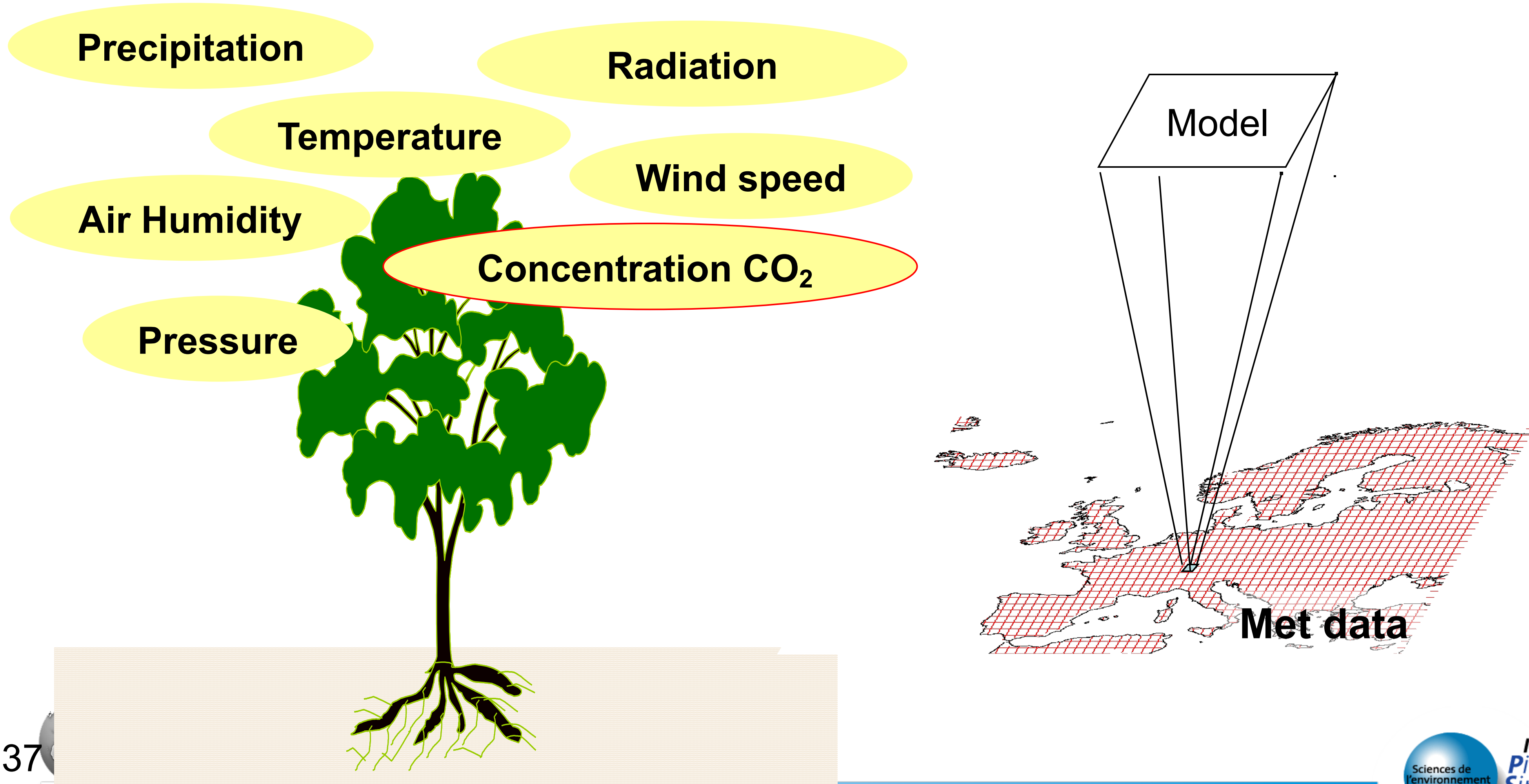
- Use of a modular structure
  - All the variables are dynamics (allocatable)
  - For each module:
    - A main entry point : <module>_main
    - An initialisation procedure : <module>_initialize
    - An end procedure : <module>_finalize
    - An procedure to clear memory : <module>_clear
  - All the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

- Ancillary data needed will depend on the configuration chosen.
- All variables will be interpolated to the grid of ORCHIDEE.
- Some exemples :
  - PFT map and land use
  - Wood harvest intensity
  - Soil texture
  - Soil pH
  - Soil bulk density
  - Background albedo
  - River graphs
  - Topographic slopes
  - Nitrogen deposition
  - Nitrogen fertilisation

Conclusions

- ORCHIDEE is a complex system !
  - too many options / configurations

  ⇒ You may get lost!
- But you have the chance to use a system which was developed at IPSL and by people who are still present.

  ⇒ **Do not hesitate to ask advices**
    - To your supervisor
    - To the core developers team orchidee-help@listes.ipsl.fr