The Global Land Surface Model
ORCHIDEE
(ORganizing Carbon and Hydrology In Dynamic Ecosystems Environment)

Presented by Jan Polcher
LMD/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

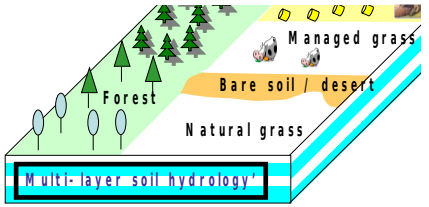
+Forest management

+Crops module

+Permafrost

+Nitrogen Cycle

Toward a single community tool



(Laval et al., 1981) *(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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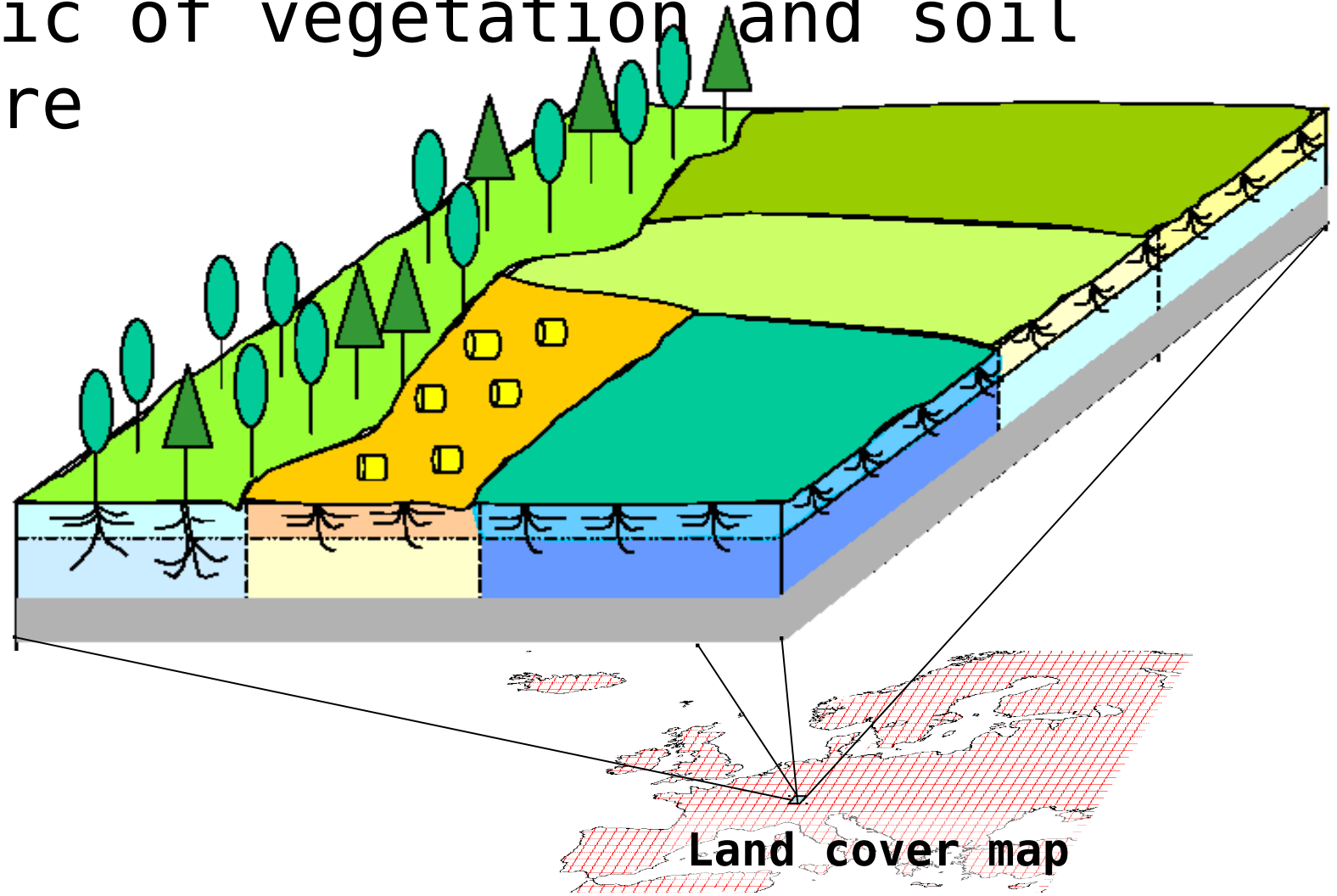
Surface variability representation ?

- A mosaïc of vegetation and soil moisture



Surface variability representation ?

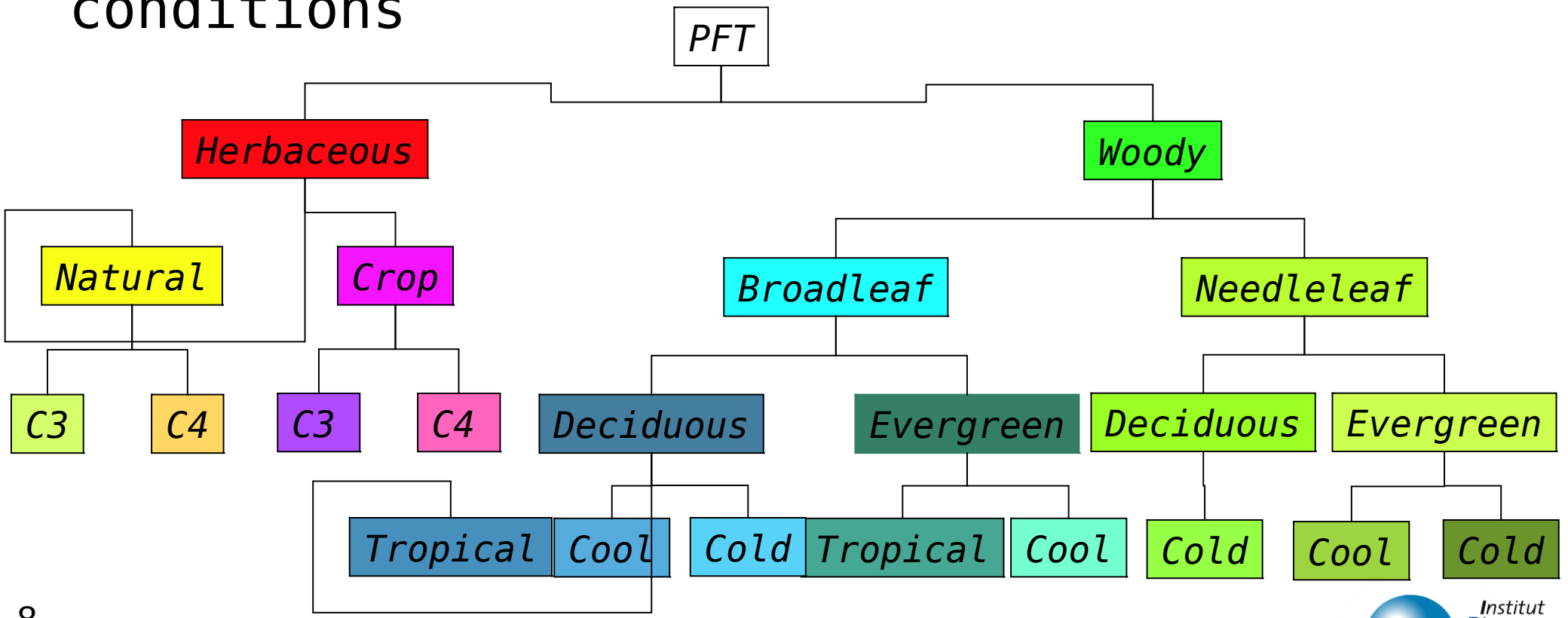
- In each grid cell, we account for:
  - Bare soil
    - *veget_max(1)*
  - Vegetated lands
    - *veget_max(2:nvm)*
  - Other lands (so far, only the continental ice)
    - *frac_nobio*

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

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

Vegetated lands

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

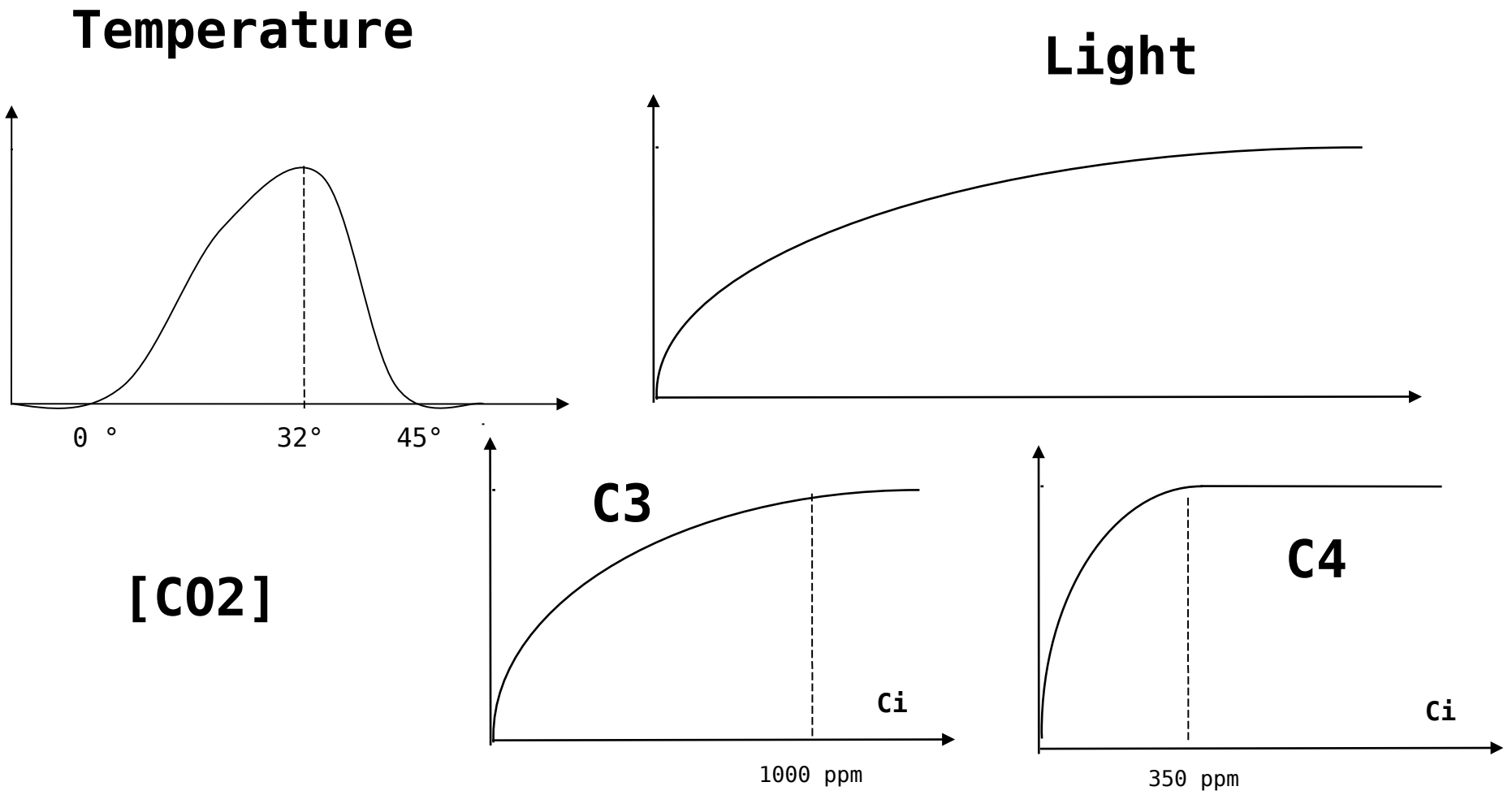


Plant Functional Types

- 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 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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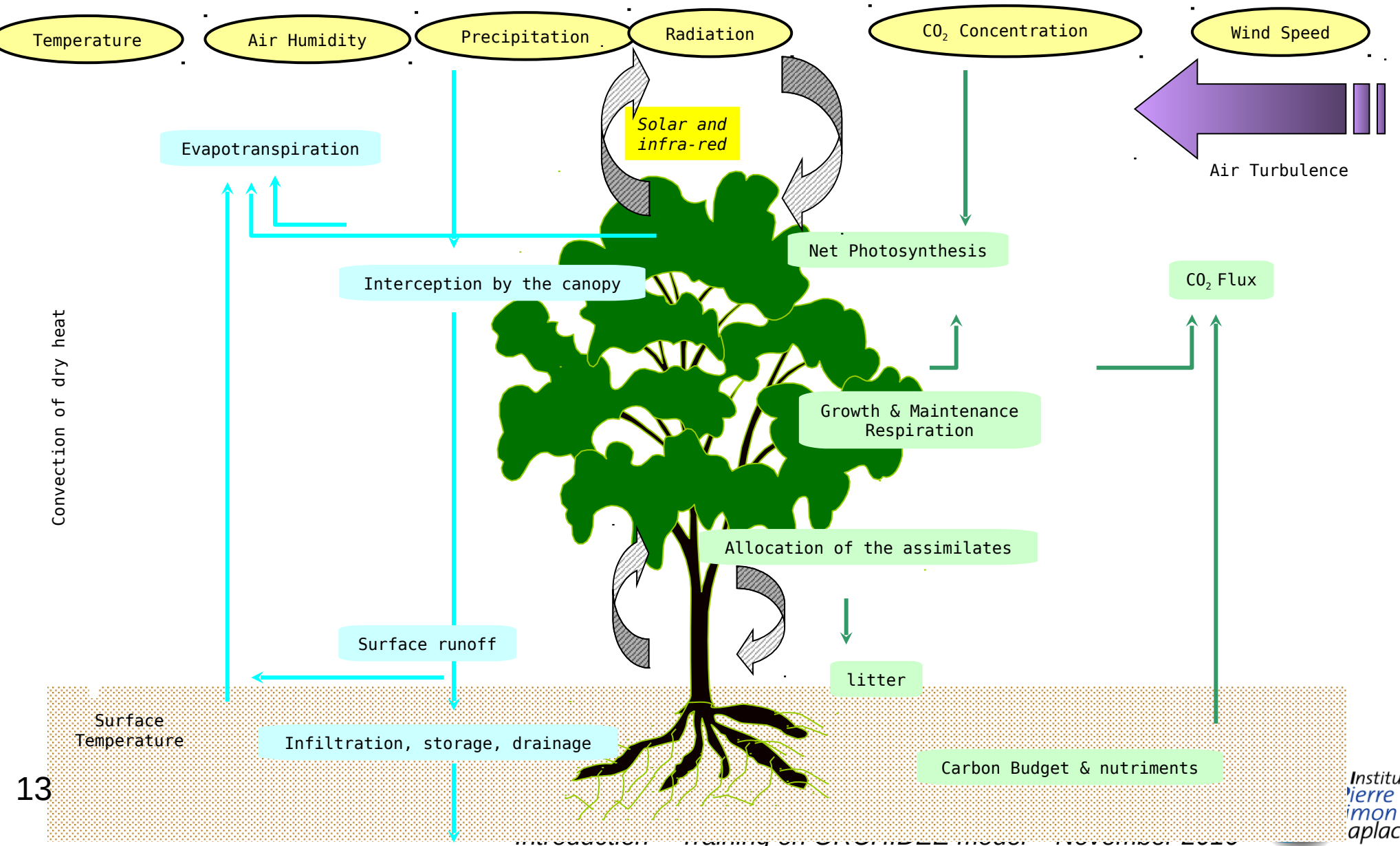
Main processes



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

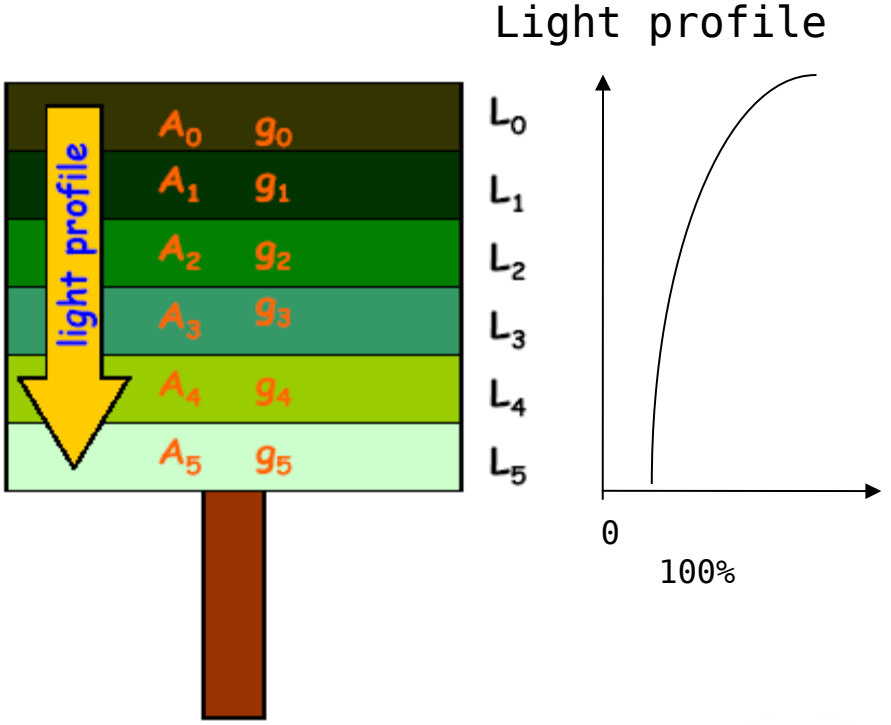
C assimilation/stomatal conductance

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 CO_2, rel hum..) are held constants.

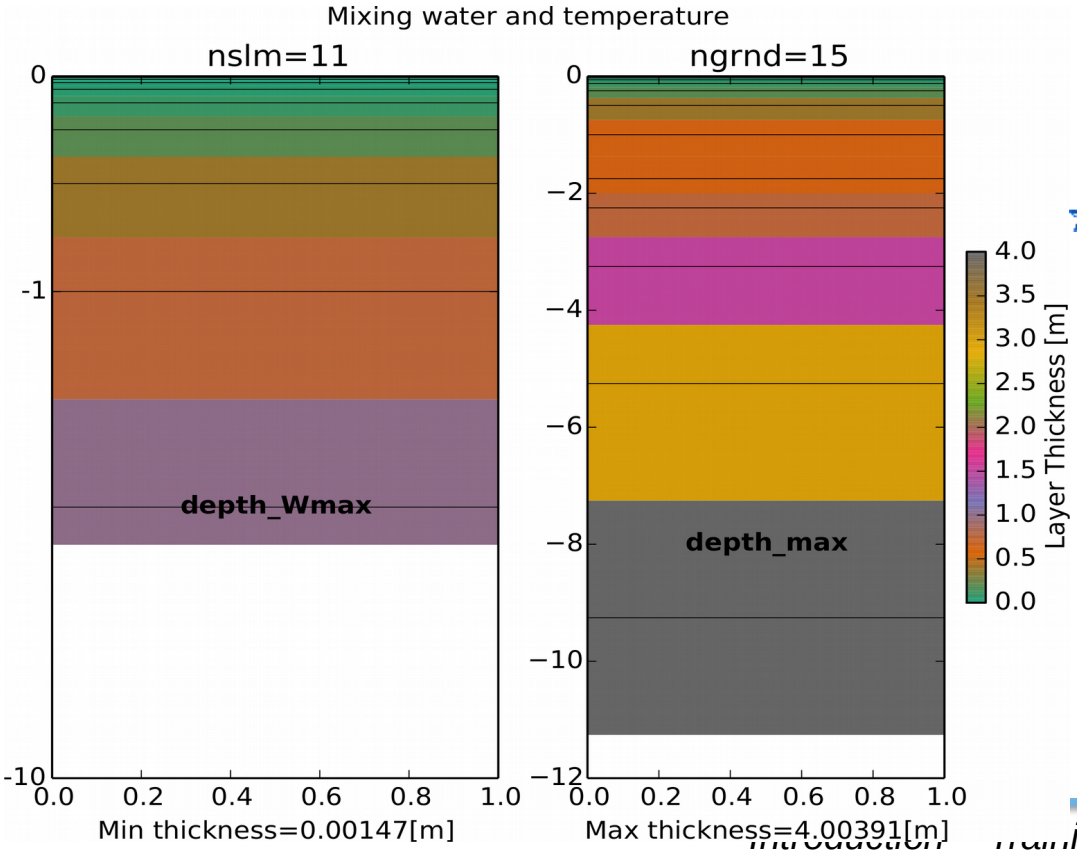
From the leaf to canopy



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 5 parameters to configure the soils.
  - depth_max
  - depth_Wmax
  - depth_topticknessss (currently : 1. 10-3m)
  - refinebottom
  - ratio_geom_below

Soil temperatures

thermosoil module

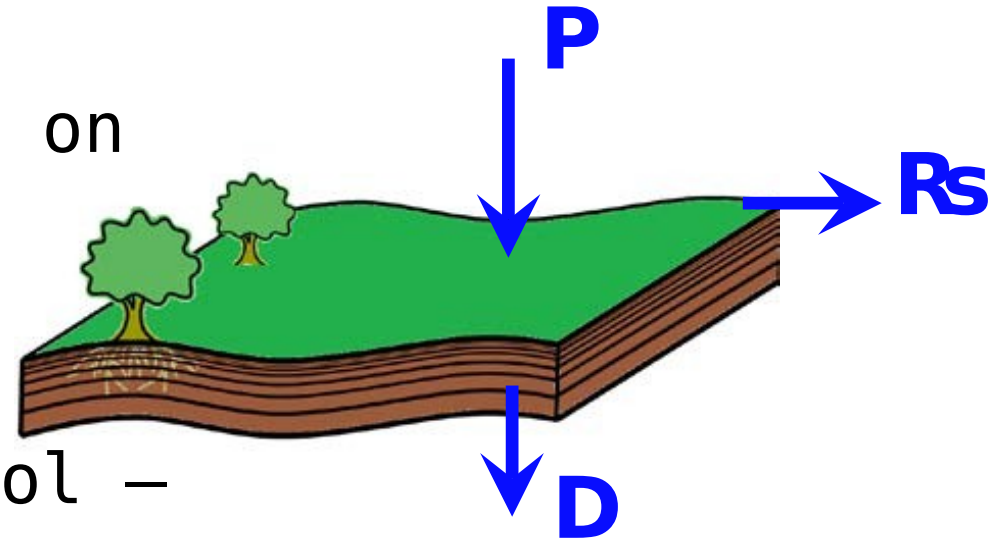
- Calculates the soil temperatures by solving the heat diffusion equation within the soil

  - 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)

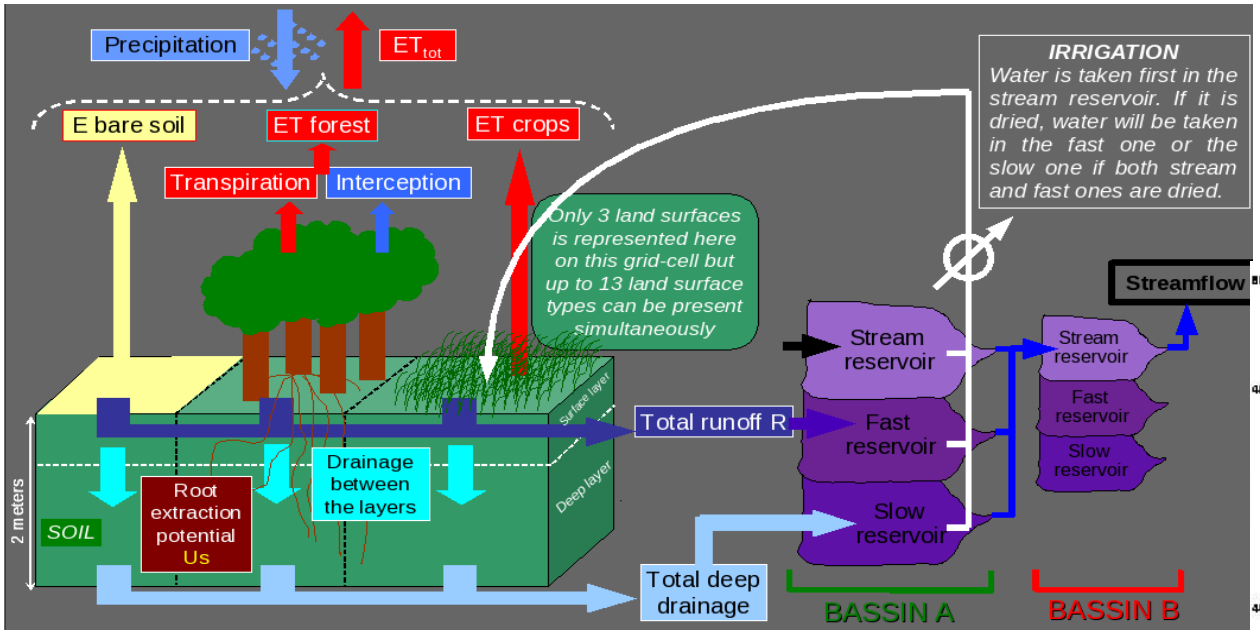


- Surface runoff = P – Esol – Infiltration
- Free drainage at the bottom

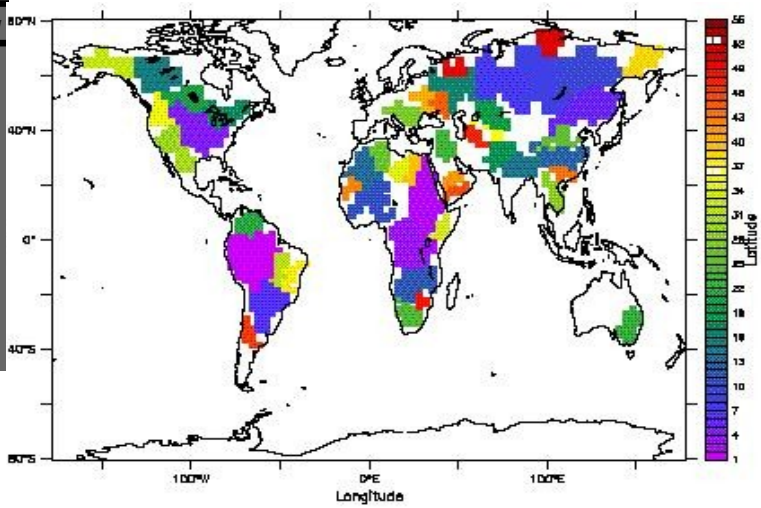
Routing / Irrigation

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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Biomass and soil pools

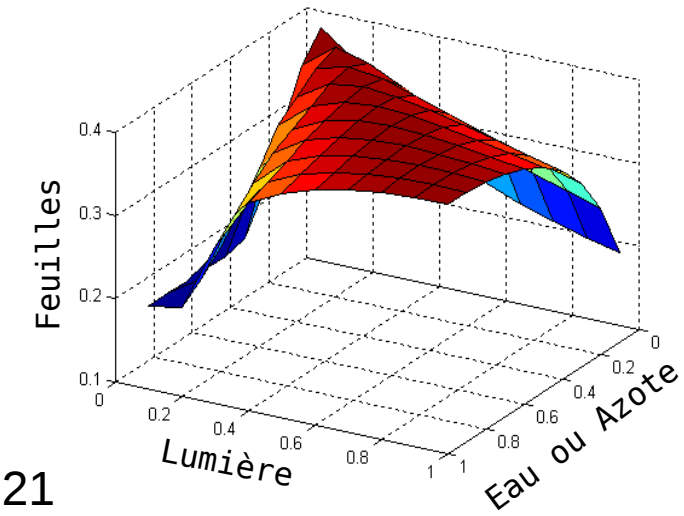
- 8 pools of living biomass
  - Leaves, fine roots, above and below sapwood, above and below heartwood, ‘fruits’ and ‘reserves’
- 4 pools of litter
  - Above/below, Structural & Metabolic
- 3 pools of soil
  - Active, Slow and Passive

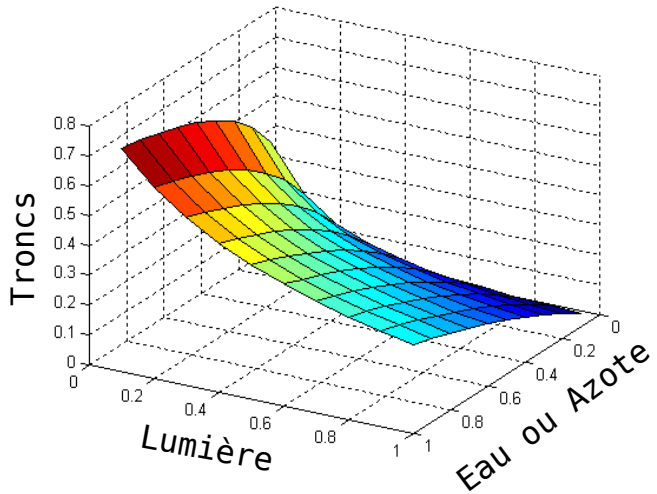
Allocation of assimilates

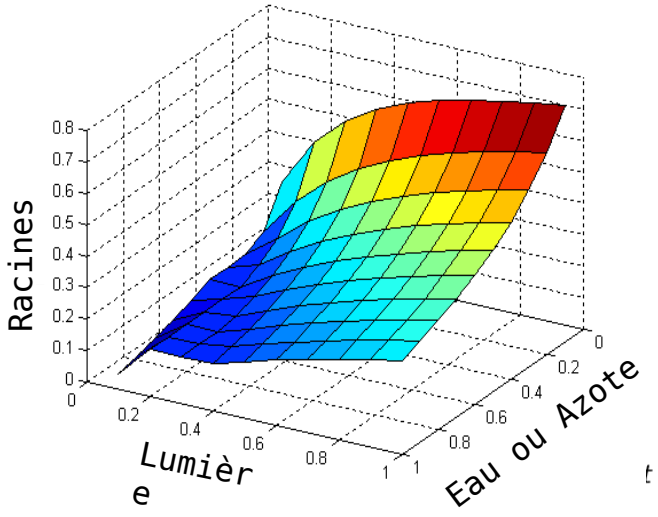
stomate_alloc module

- 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 $Branch_2 = \frac{3\ T_0\ \ min(H,N)}{L + min(H,N)}$ $Root = \frac{3\ R_0\ \ L}{L + 2\ \ min(H,N)}$







Friedlingstein et al., 1998

Phenology

stomate_phenology module

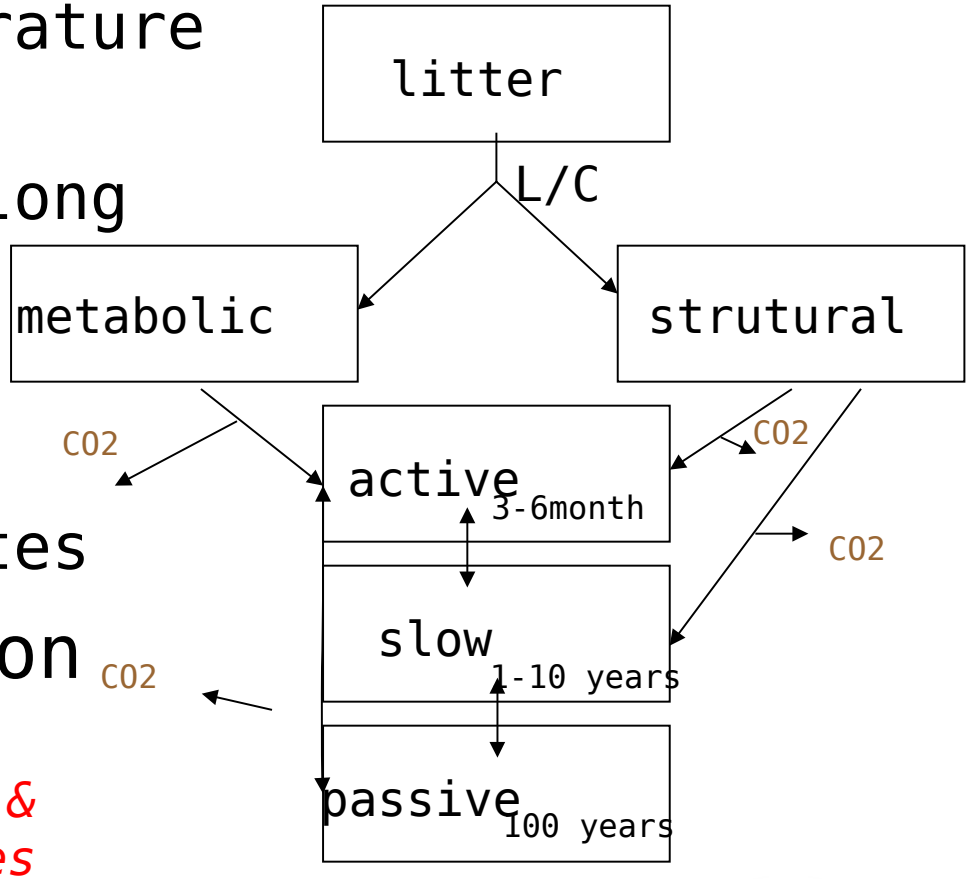
- Bud-burst model (Botta el al. 2000)
  - Defined for each PFT based on Growing degree days, Number of chilling days, soil water, …
  - Calibrated at global scale from bud-burst estimated by satellite
- Senescence

stomate_turnover module

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

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

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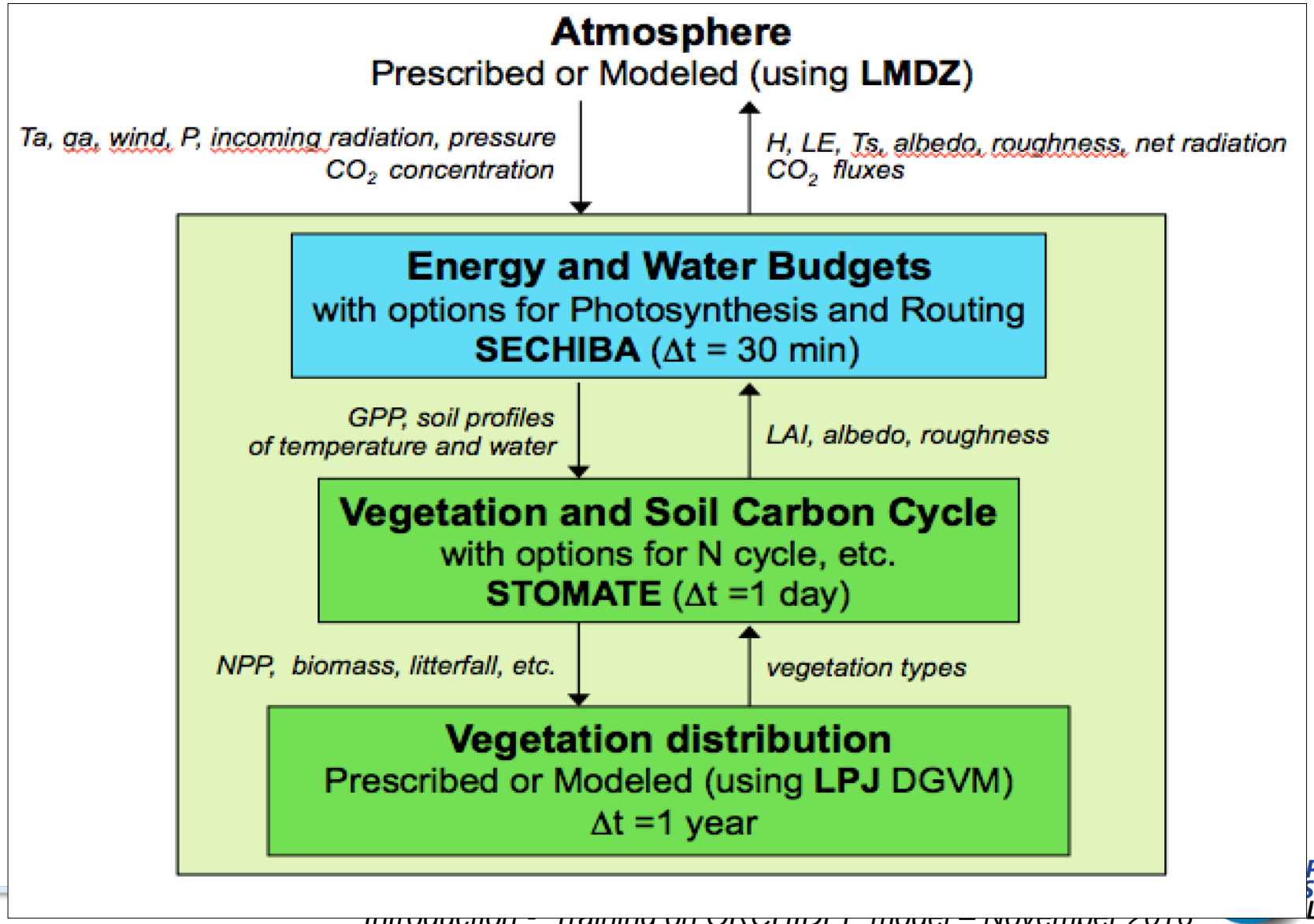
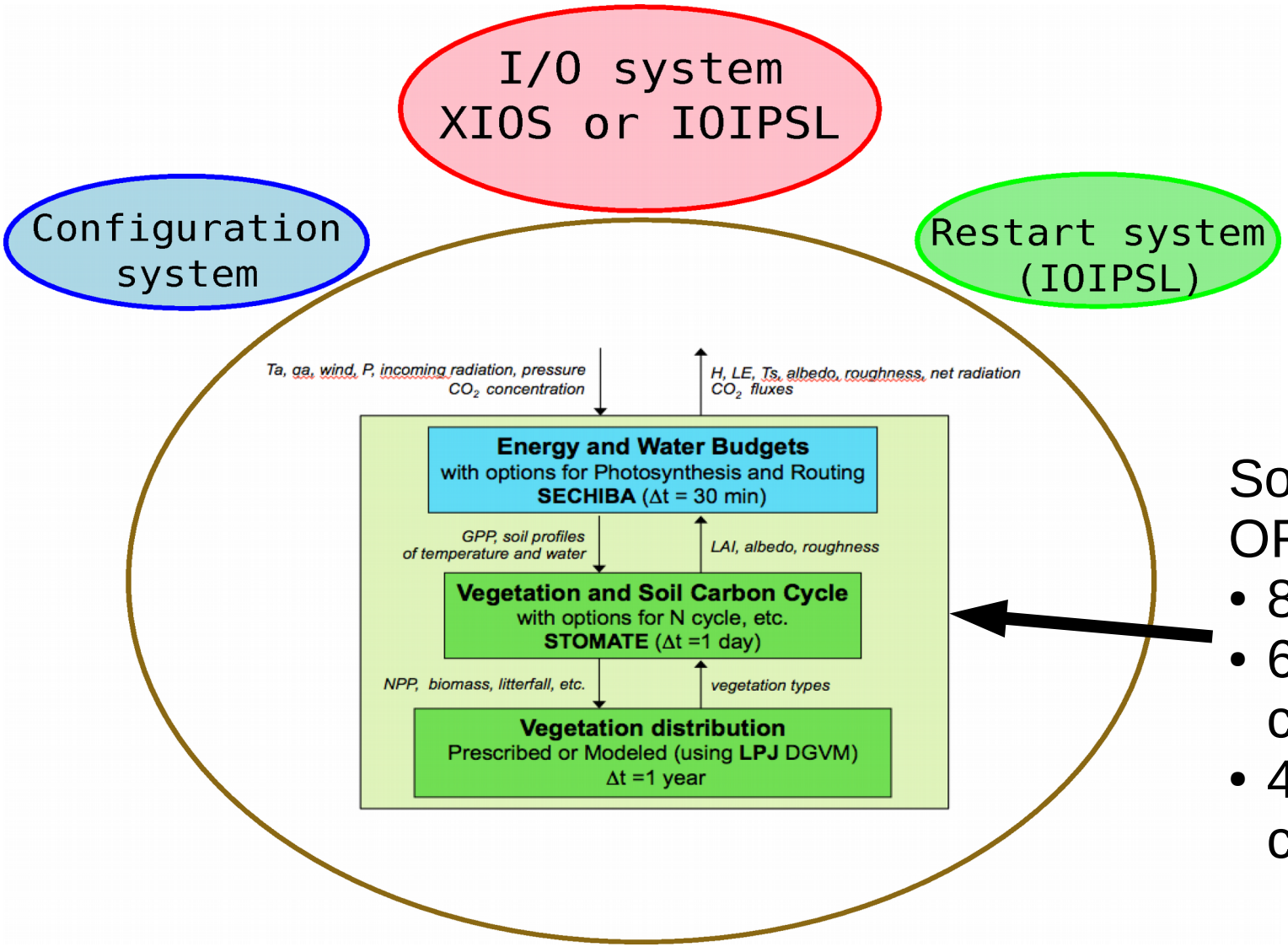
Tasks performed by ORCHIDEE for the IPSL Earth System Model.



Infrastructure surrounding ORCHIDEE



Some numbers to ORCHIDEE's code :

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

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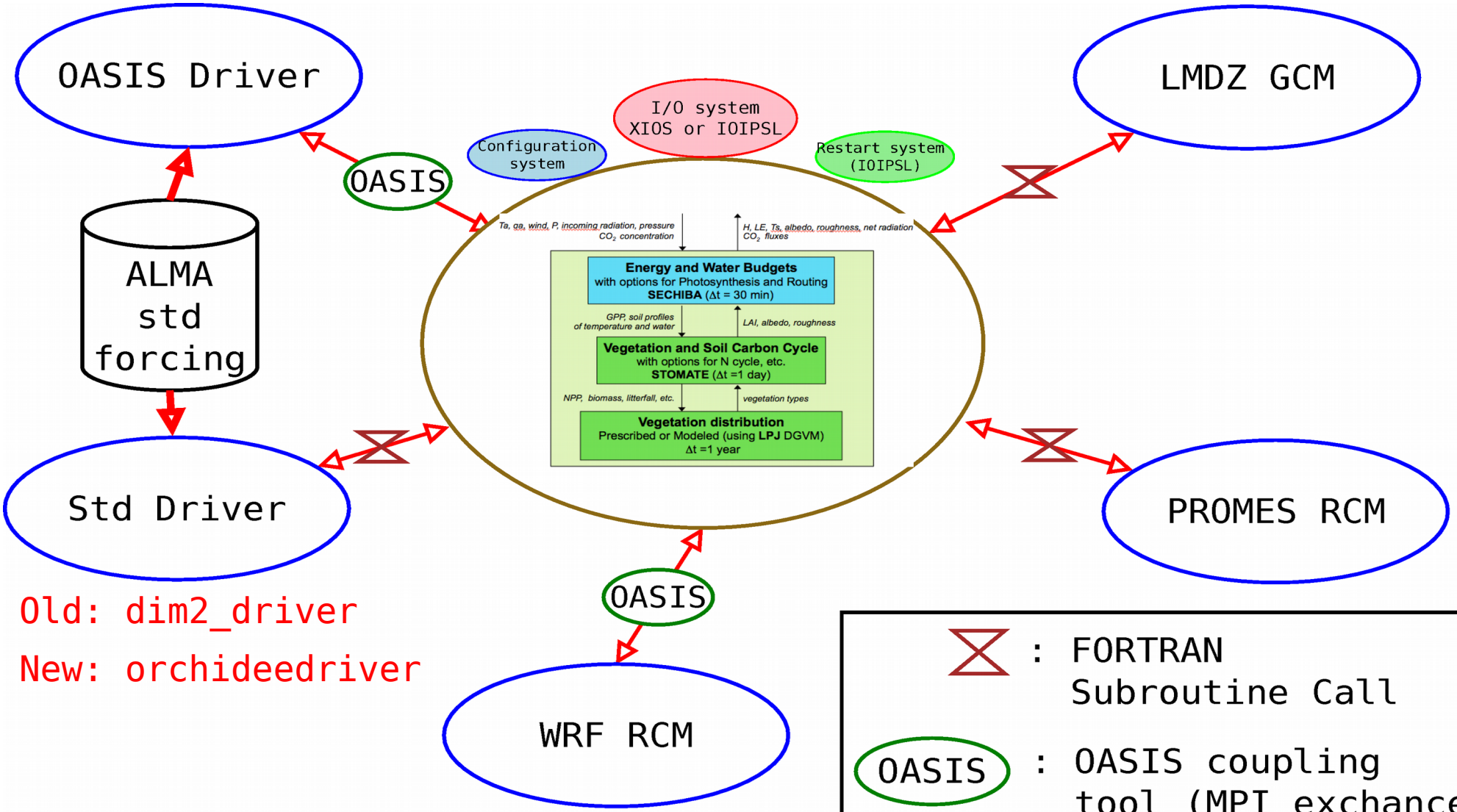
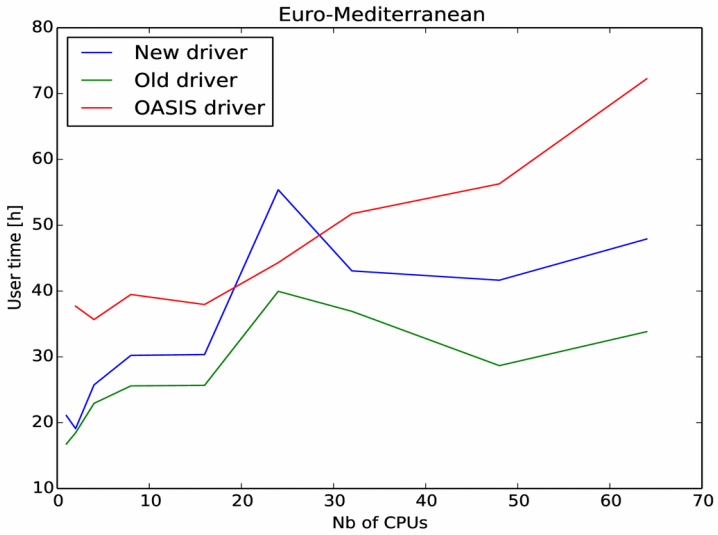
General philosophy for coupling ORCHIDEE

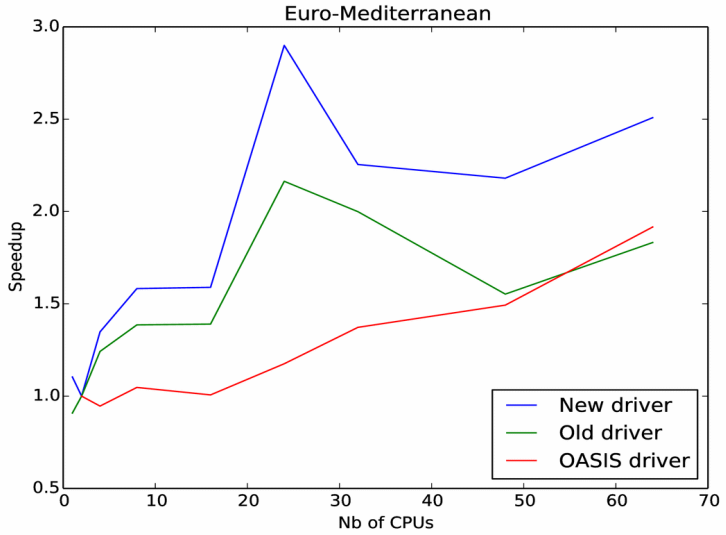
- ORCHIDEE is as independent of the forcing model/data as possible.
- The interface implemented is documented in Polcher et al. 1998 and Best et al. 2004.
- We have chosen an implicit coupling for historical reasons but also to ensure a dynamic surface energy balance.
  - The atmospheric boundary layer scheme and the surface processes involving temperature are solved at the same time.
  - Some components are solved with predictor-corrector methods : turbulence coefficients, plant stress to evaporation.
  - Taylor expansions are used for the radiative terms and saturation humidity.
- Some consequences :
  - The surface energy balance is very sensitive and explicit coupling is difficult (currently used for WRF).
  - Multiple energy balances probably mean multiple PBLs !
  - Interpolations between atmosphere and surface are probably incompatible with the stability of the scheme.

Currently available coupling for ORCHIDEE



The cost of using OASIS





The cost of OASIS is compared to 2 different drivers. A domain of 15909 land points is run over a year with very limited I/O.

Compared to the old/simpler driver, OASIS (without any interpolation !) doubles the user time.

For the new driver (which uses the same methodology as for driving OASIS) the factor is only 1.5.

The speed-up for parallelisation is not as good with OASIS.

OASIS simplifies the coupling and especially dealing with the parallelization of the models. But it has a substantial cost in terms of computing !

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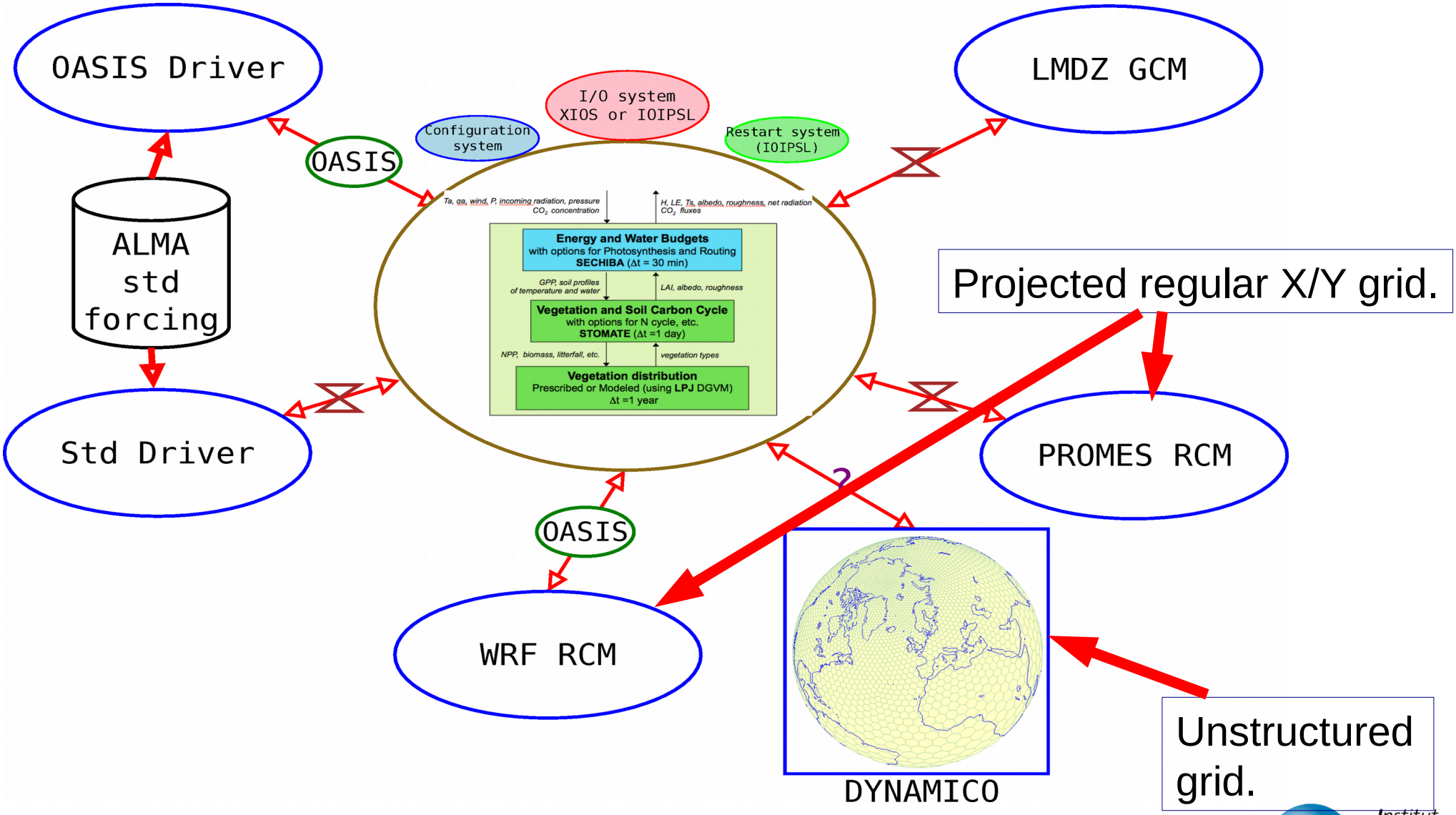
Future coupling under development



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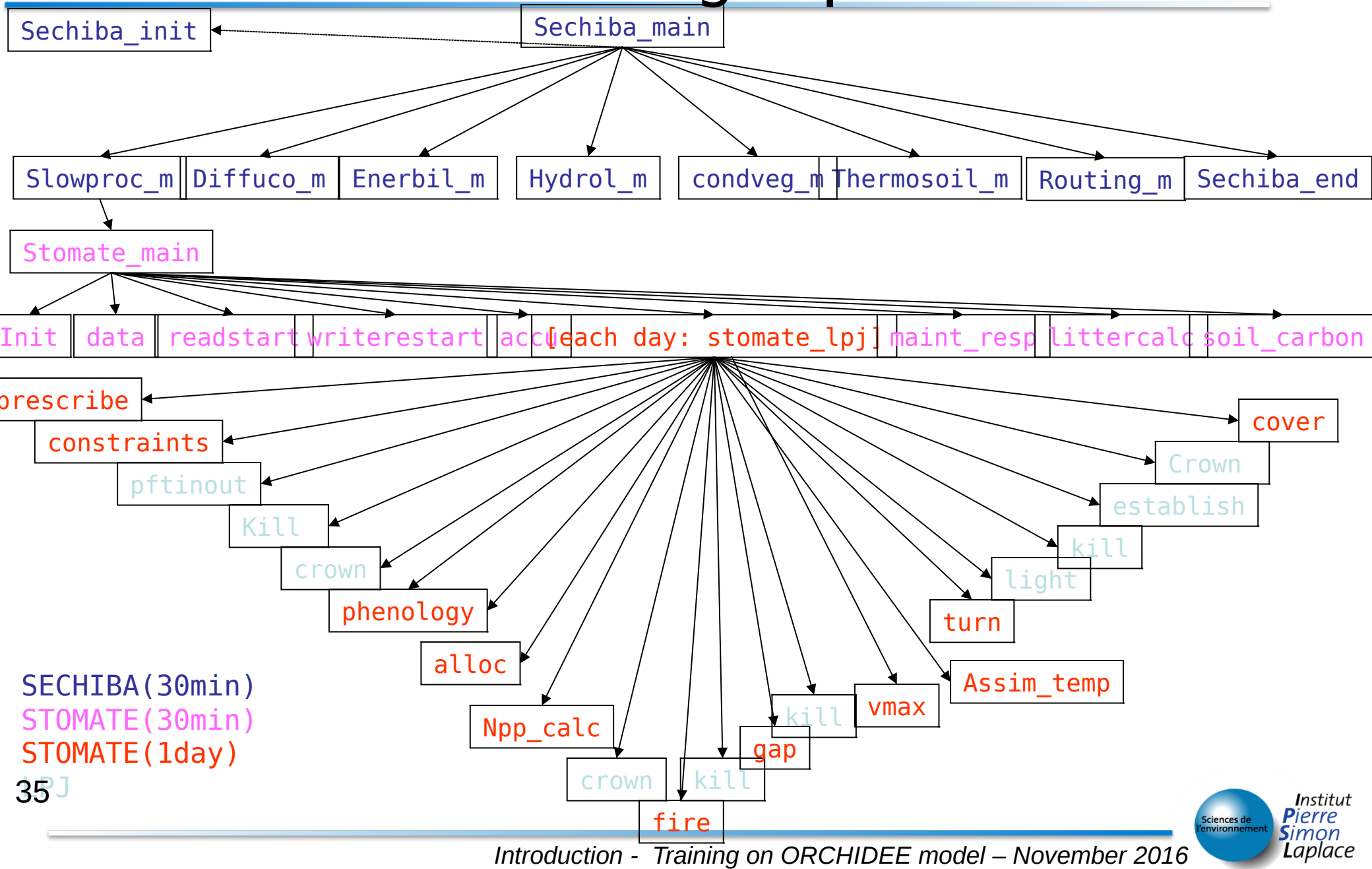
The complexity of an unstructured grid !

- Originally ORCHIDEE was designed to work on a list of points and it was written for a regular longitude latitude grids.
- It is now generalised to run on a list of polygons of which only the coordinates of the *n* summits are known.
  - A module exists to compute all the needed information for these polygons
  - For most processes the extension was trivial as only the area of the polygon is needed.
- The interpolation of ancillary data is more difficult. For this we now use XIOS which provides general interpolation tools.
- XIOS had to be extended to interpolate classes. This is done by returning the distribution of occurrences.
- The generalisation of the routing is completed.
- Some work on the parallelization of the code will be needed.

Structure of the code

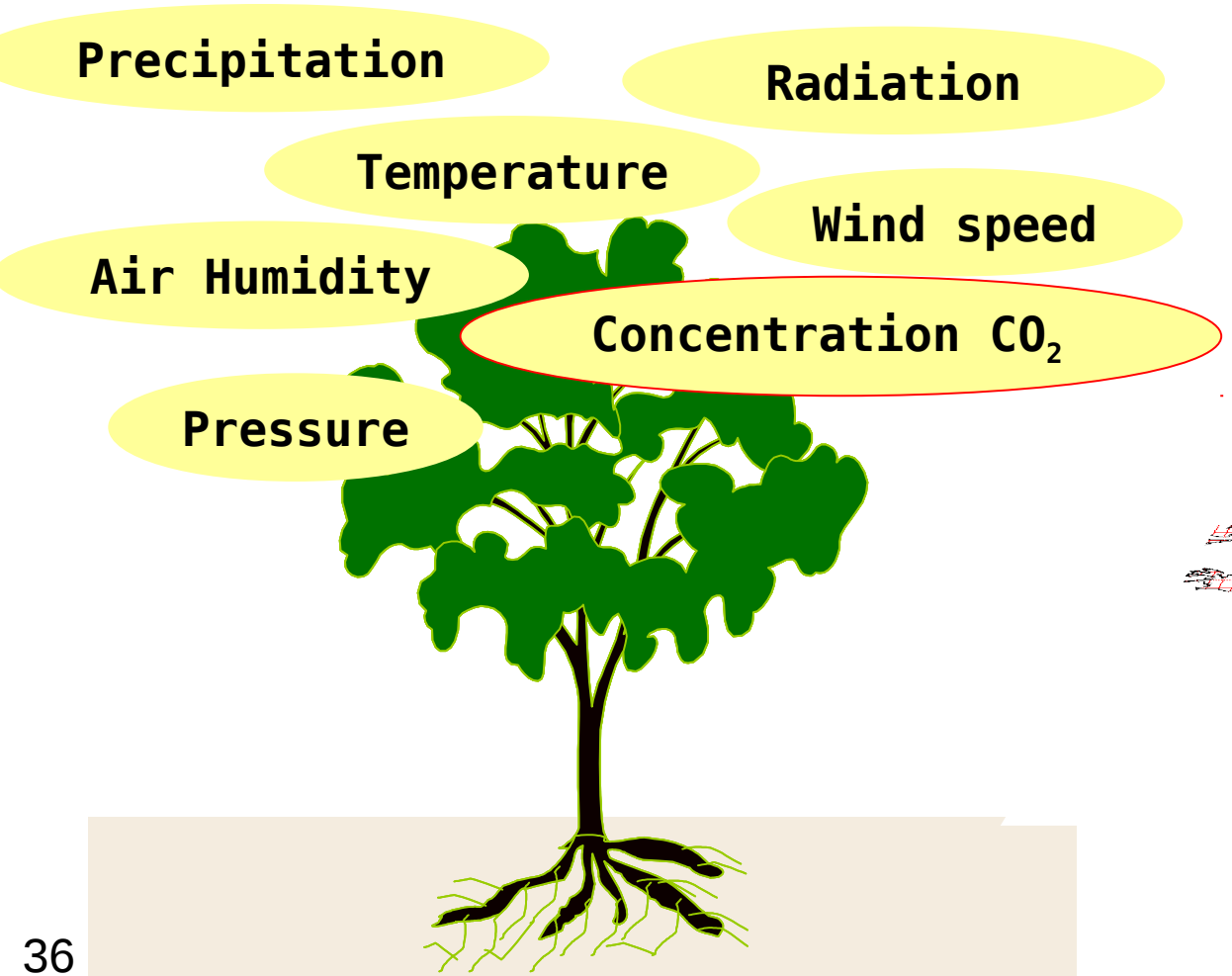
- Use of a modular structure
  - All the variables are dynamics (allocatable)
  - For each module:
    - A main entry point : <module>_main
    - An initialisation procedure : <module>_initialize
    - An end procedure : <module>_finalize
    - An procedure to clear memory : <module>_clear
  - All the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

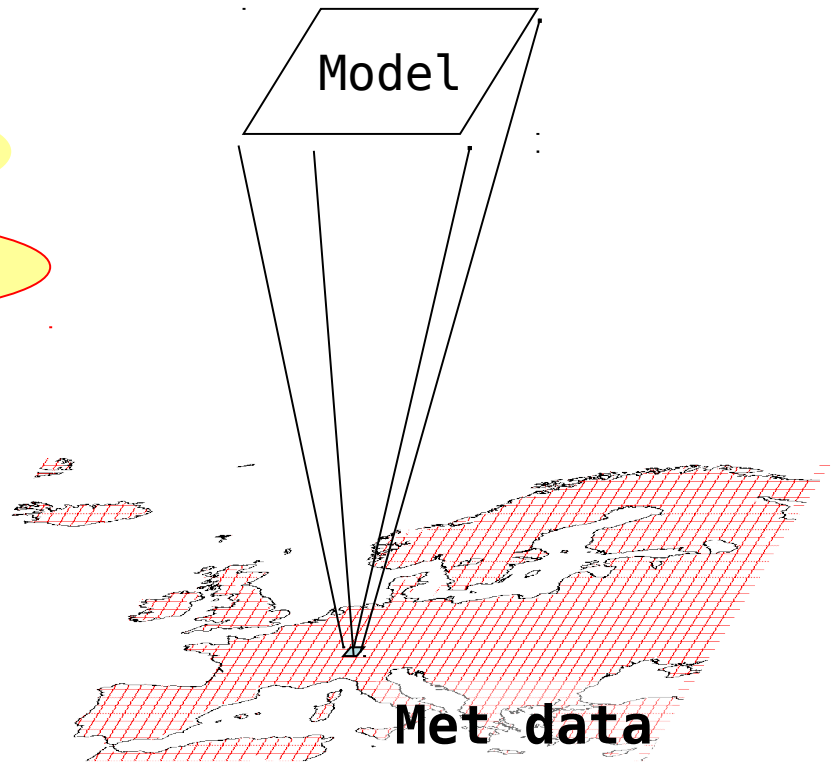
Subroutine Call graph



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
  - soil texture
  - Background albedo
  - Topographic slopes
  - River graphs

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 !