The new features in the trunk some above ground and some belowground

GUENET Bertrand, BASTRIKOV Vladislav, CHAO Yue, CHEN Yi-Ying, GHATTAS Josefine, JEONG Jina, LANSO Anne Sofie, LUYSSAERT Sebastiaan, MAIGNAN Fabienne, MARIE Guillaume, McGRATH Matthew, NAUDTS Kim, OTTLE Catherine, OTTO Juliane, PEYLIN Philippe, RESOVSKY Alex, RYDER James, VALADE Aude, VUICHARD Nicolas, WANG-FAIVRE Xiaoni, etc…

ORCHIDEE-CAN

(known as ORCHIDEE-DOFOCO on svn)

+

ORCHIDEE-CN

N-version of ORCHIDEE updated with the trunk, June 2017

=

ORCHIDEE-CN-CAN

=

TRUNK

Courtesy of S. Luyssaert

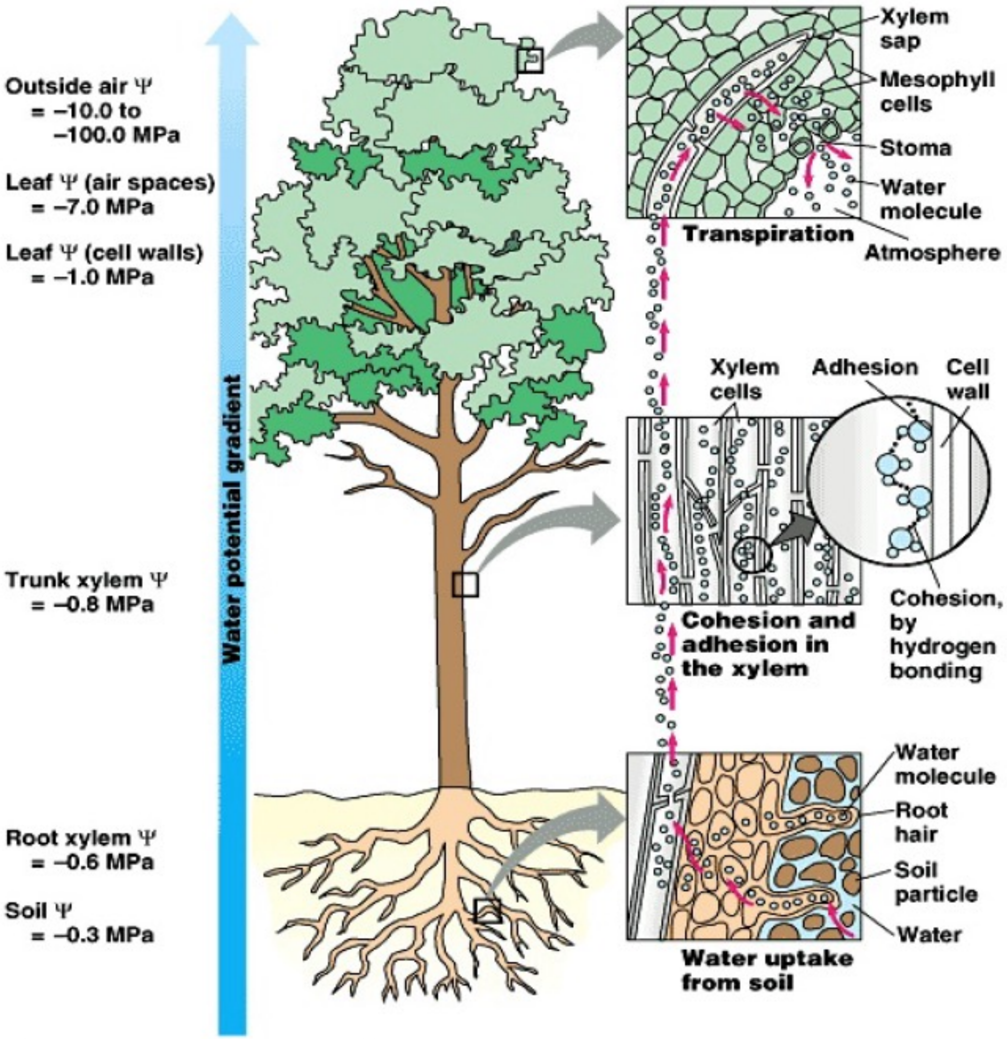
SIMULATING THE CANOPY

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

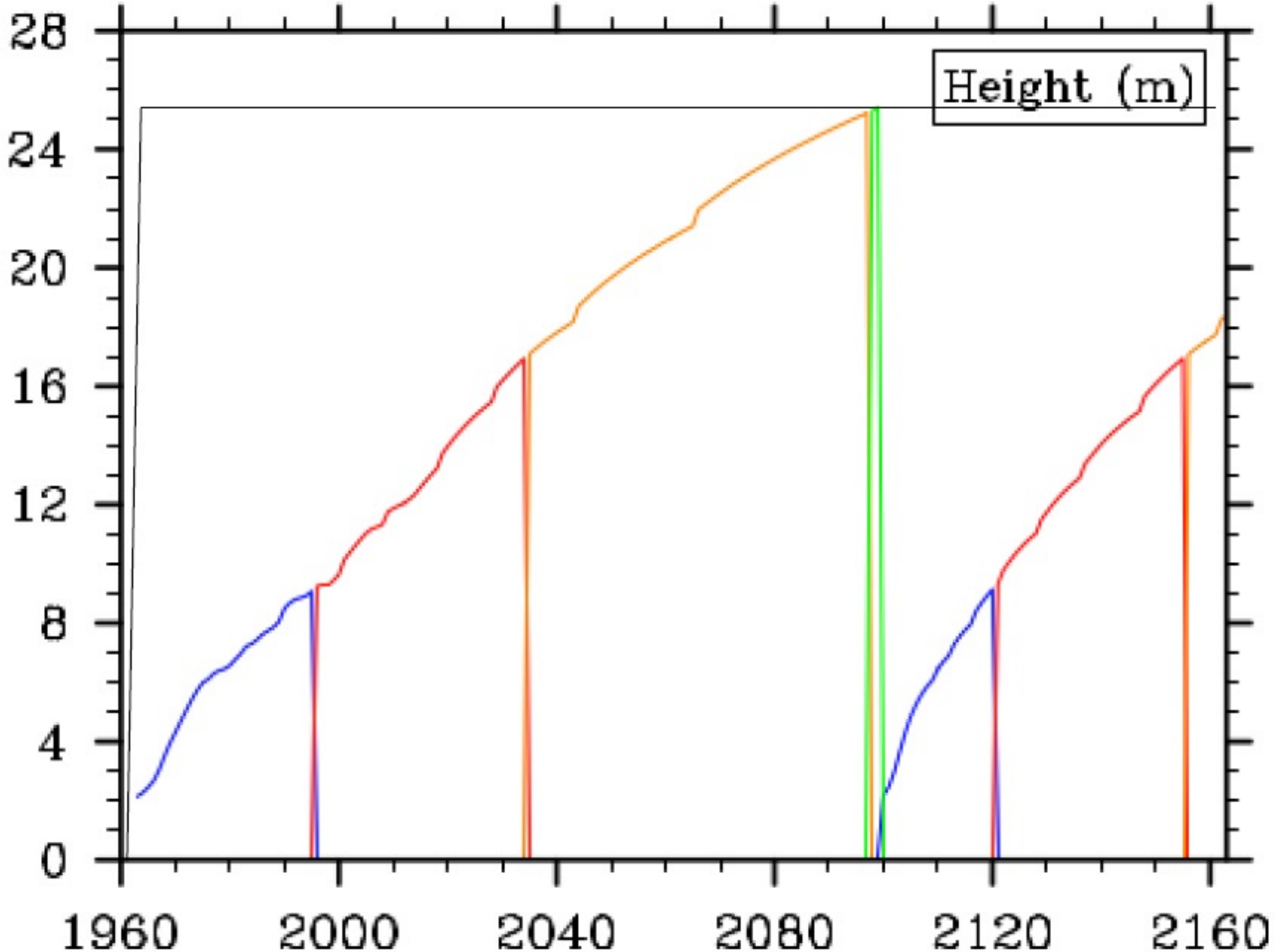
Water stress

- Hydraulic architecture



Courtesy of S. Luyssaert

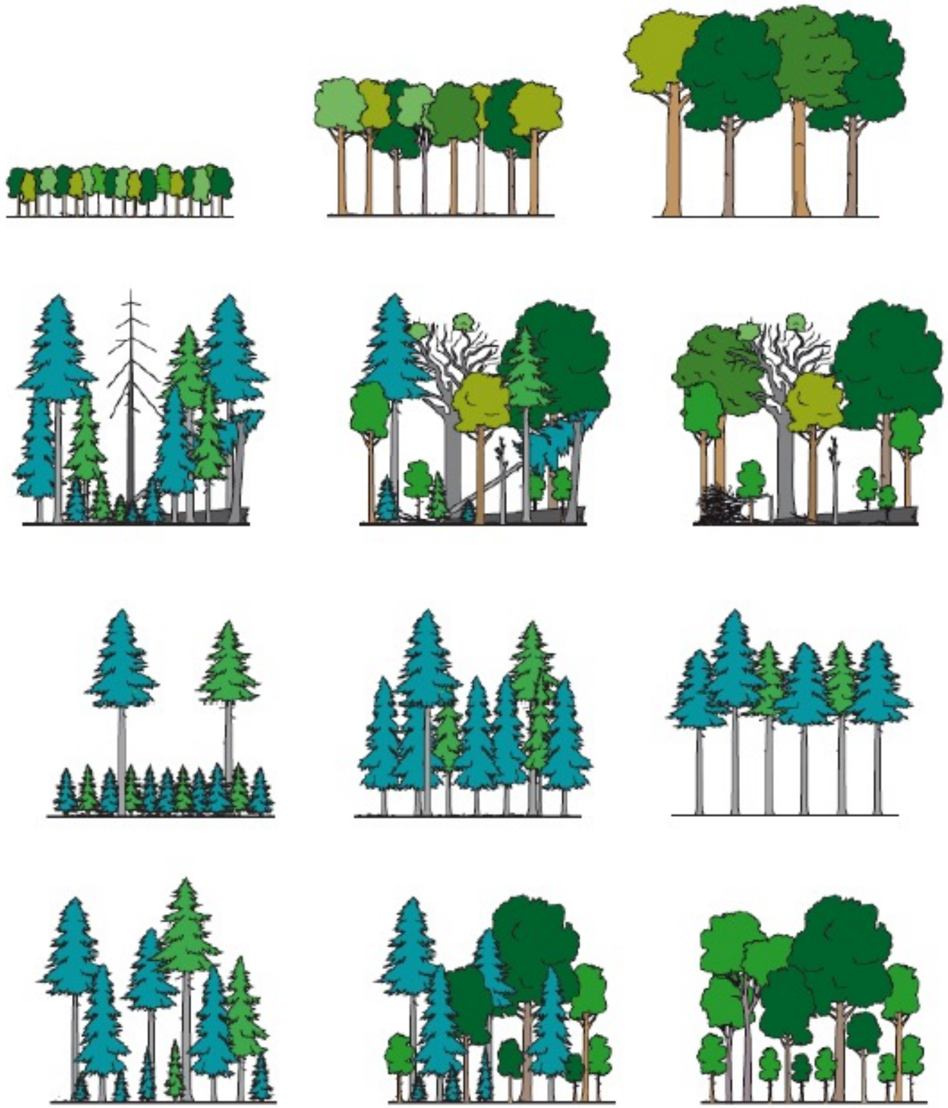
SIMULATING THE CANOPY



Courtesy of S. Luyssaert

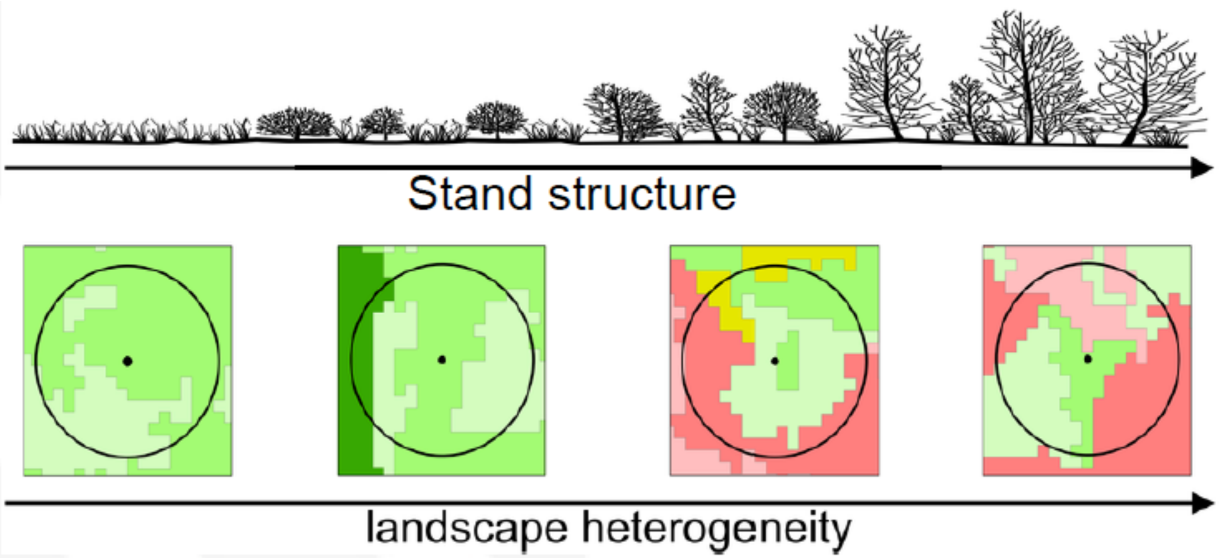
SIMULATING THE CANOPY

- Diameter classes and age classes are introduced
- Number of PFTs depend on number of age classes
- Each PFT has x numbers of diameter class
- Each diameter class has x number of trees depending on basal area - self-thinning rule



Courtesy of S. Luyssaert

SIMULATING THE CANOPY



Illustrations from Moreira et al 2015 PLoS One

Allocation + Diameter classes + recruitment → **Stand structure**

Age classes → **Landscape heterogeneity**

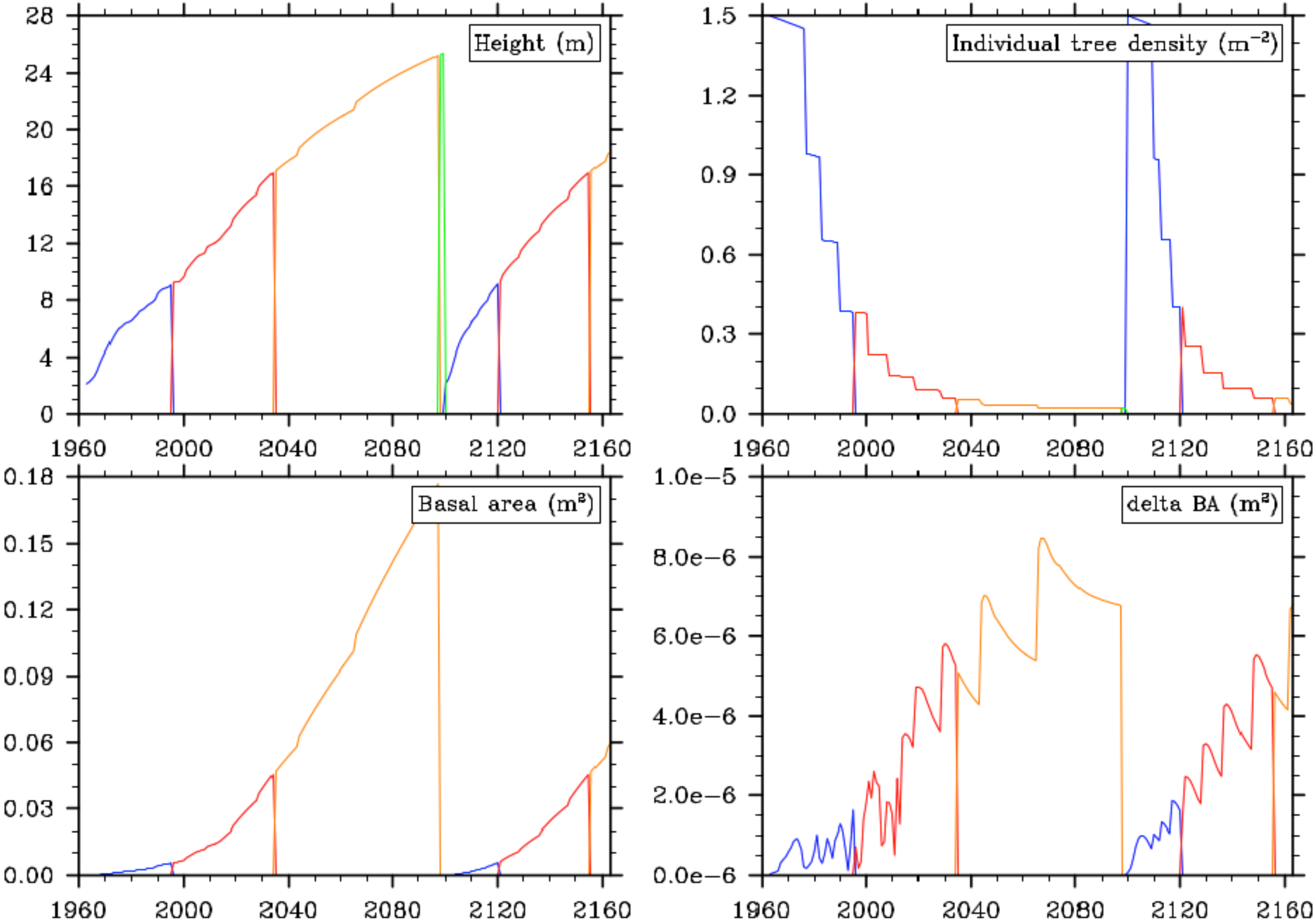
Courtesy of S. Luyssaert

SIMULATING THE CANOPY

- The trees are horizontally distributed following a Poisson distribution
- The structured canopy allows for calculations of light penetration within the canopy.
- Statistic approach to reduce memory allocation

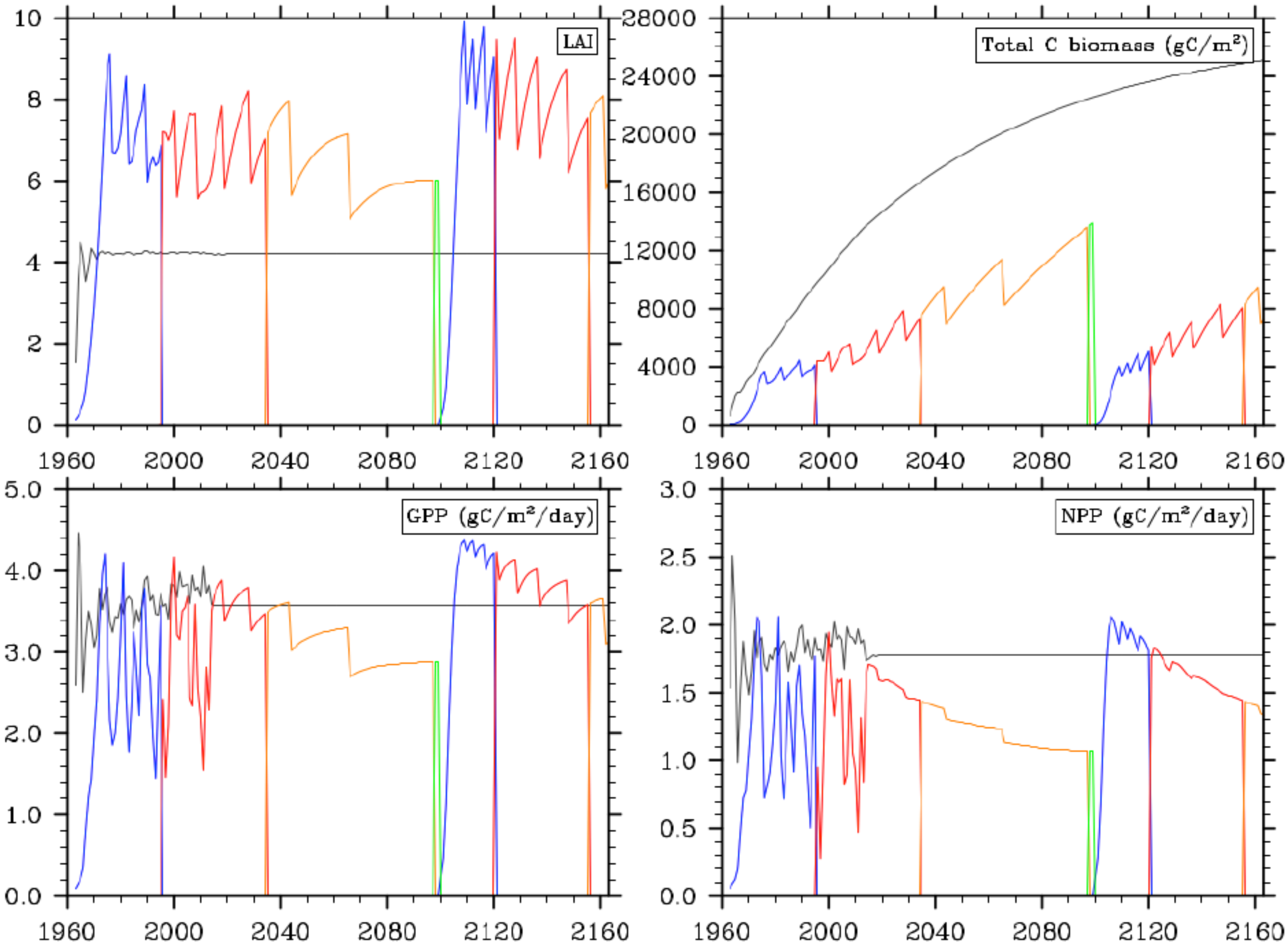
Courtesy of S. Luyssaert

ECOSYSTEM DYNAMIC



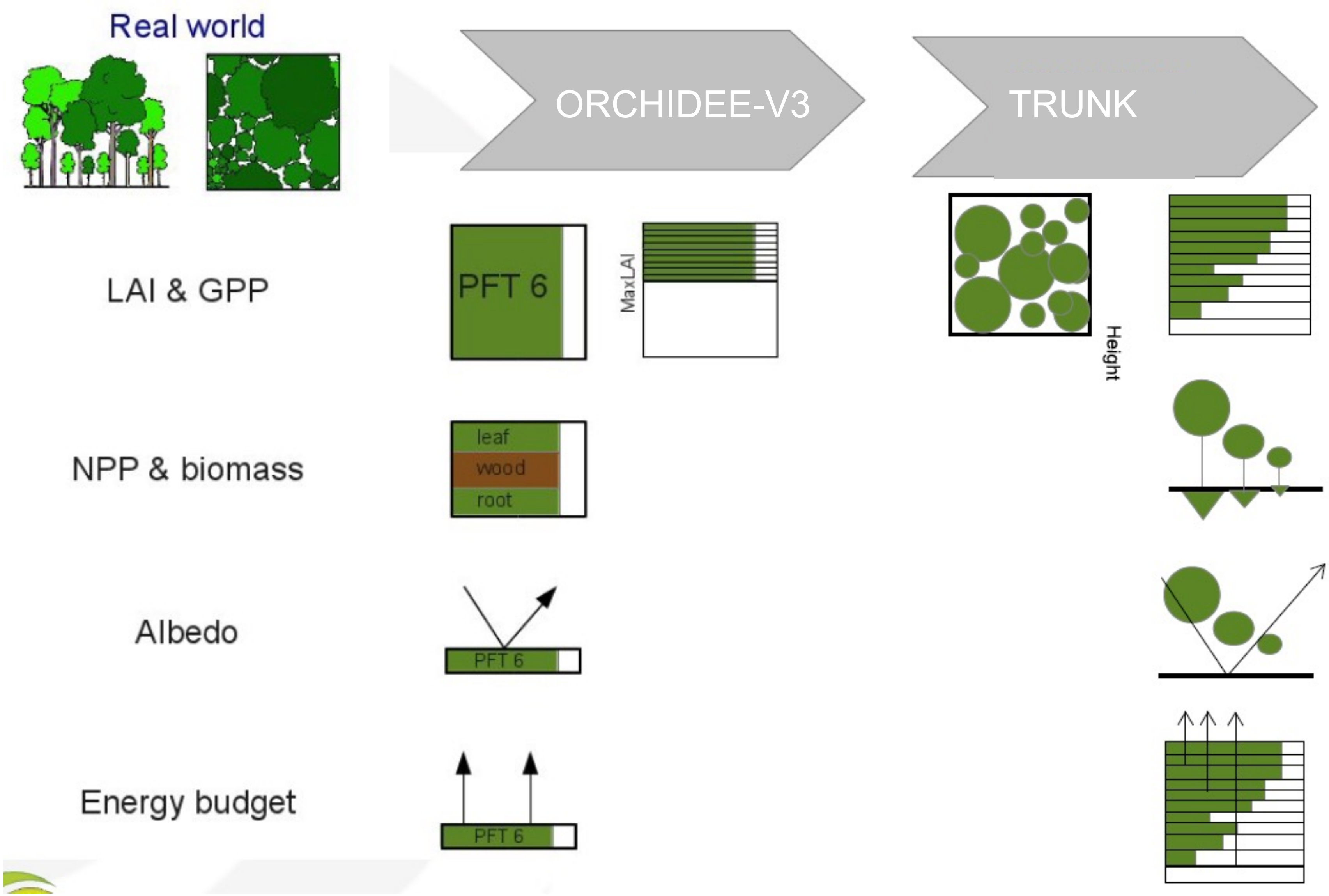
Courtesy of S. Luyssaert

ECOSYSTEM DYNAMIC



Courtesy of S. Luyssaert

ECOSYSTEM DYNAMIC



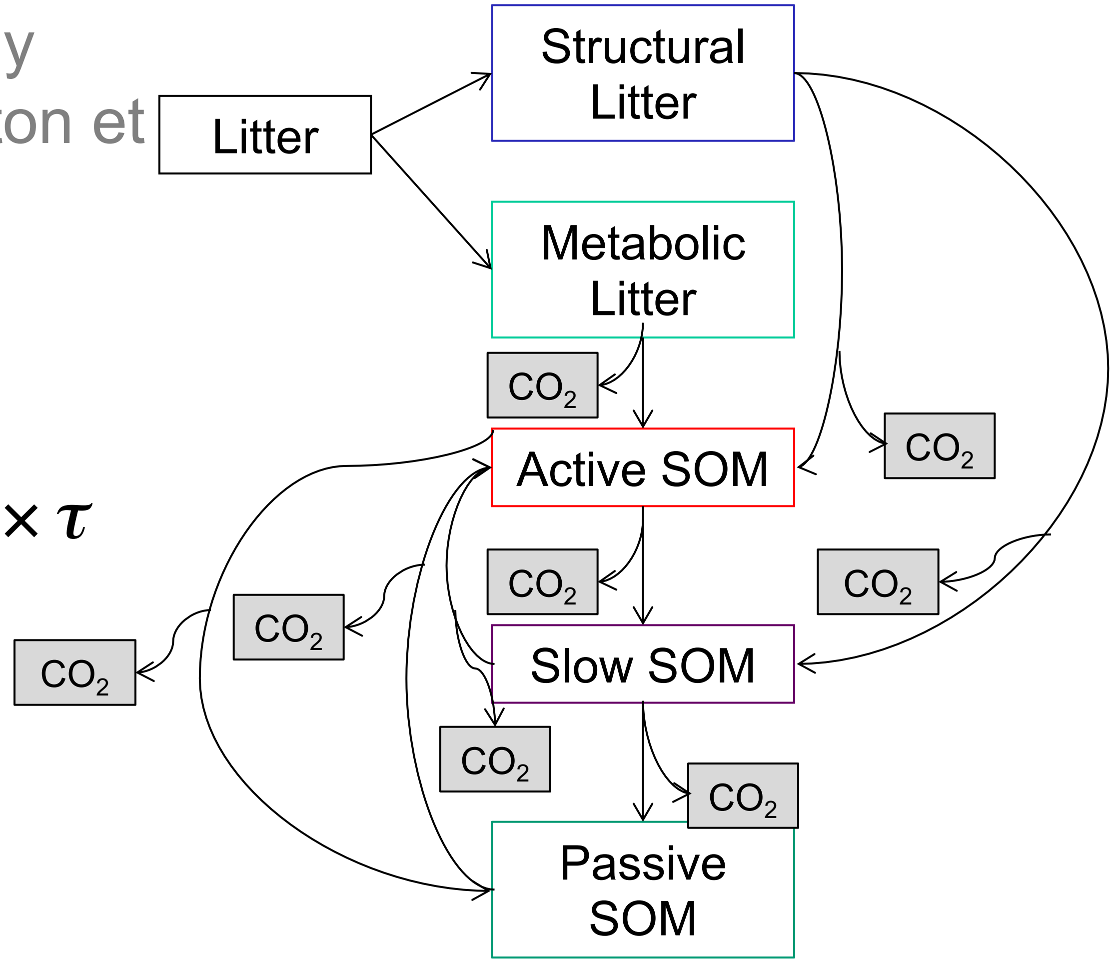
Courtesy of S. Luyssaert

The soil biogeochemistry in ORCHIDEE

THE SOIL C IN ORCHIDEE

- Soil representation mainly based on CENTURY (Parton et al., 1987).

$$\frac{\partial SOC}{\partial t} = I - k \times SOC \times \theta \times \tau$$



THE SOIL C IN ORCHIDEE

- Split between stomate_litter.f90 and stomate_soilcarbon.f90
- Run at ½ hourly time-step whereas stomate runs at daily time-step.
- Moisture and temperature function calculated in stomate_litter.f90

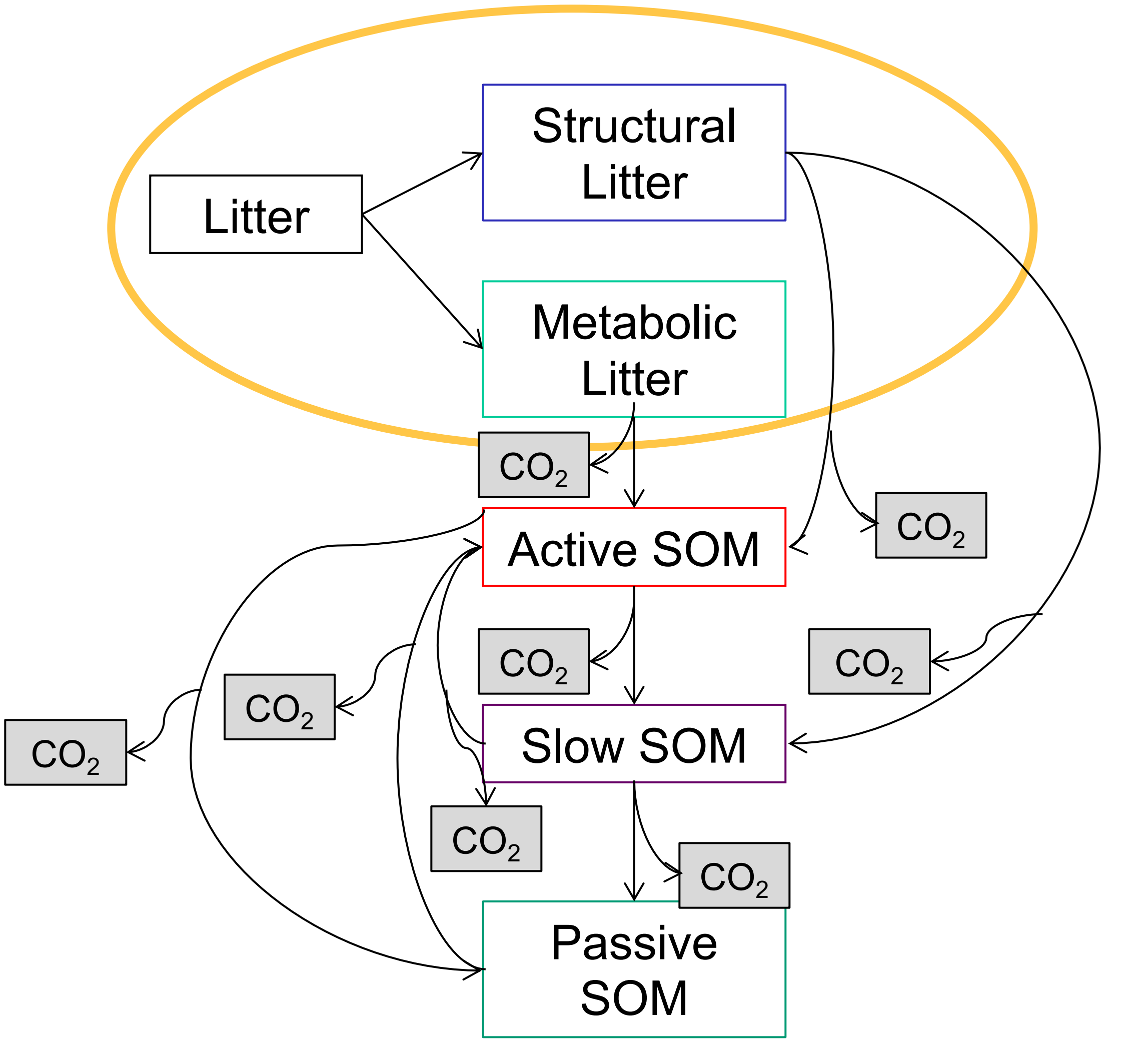
$$\tau = Q_{10}^{(T - Topt)/10}$$

$$\theta = Max(0.25, Min(1, M))$$

$$M = -1.1 * SM^2 + 2.4 * SM - 0.29$$

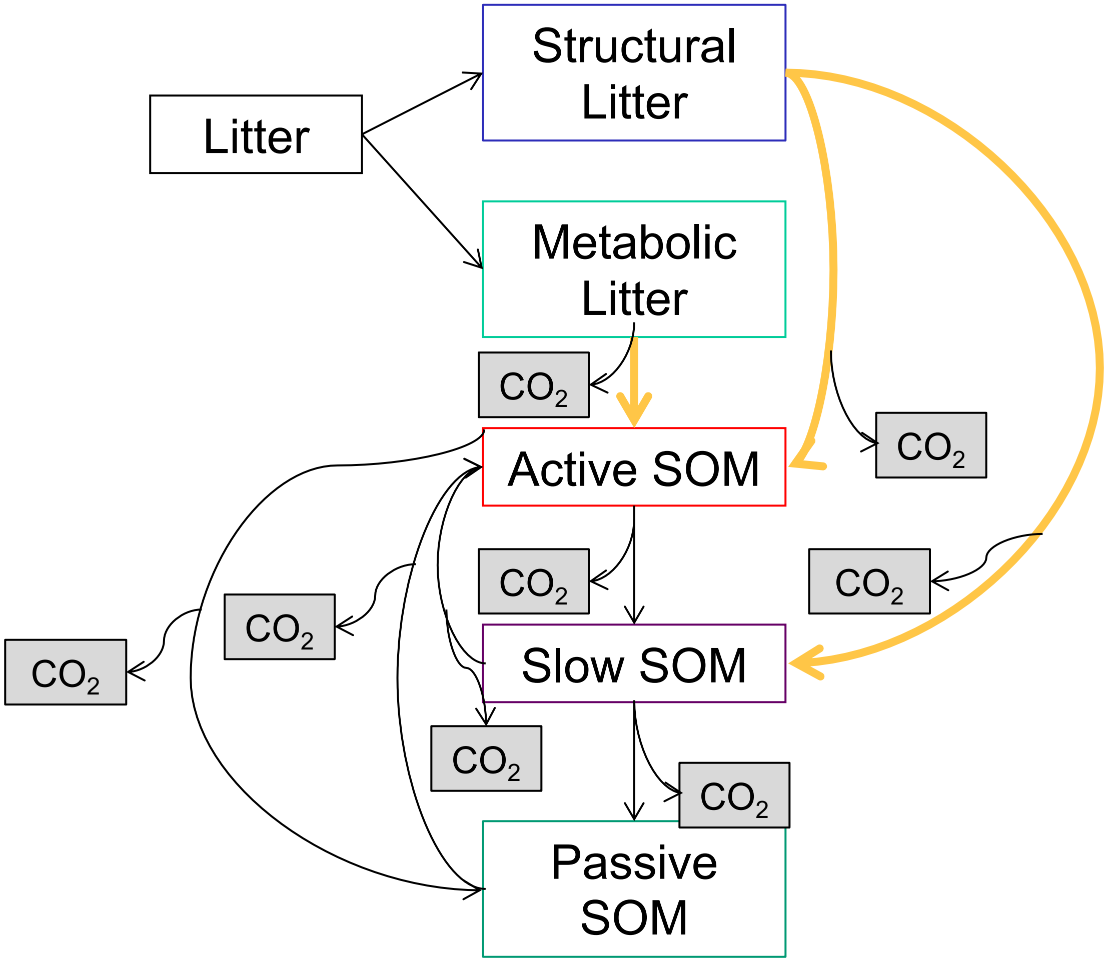
THE SOIL C IN ORCHIDEE

- Input from plants through *bm_to_litter* and *turnover*
- Split between above and below ground
- Split into two pools: metabolic/structural depending on lignin and N content of the litter.



THE SOIL C IN ORCHIDEE

- Inputs from litter decomposition in *soilcarbon_input*
- Distributed into the active and slow pools control by the lignin content.

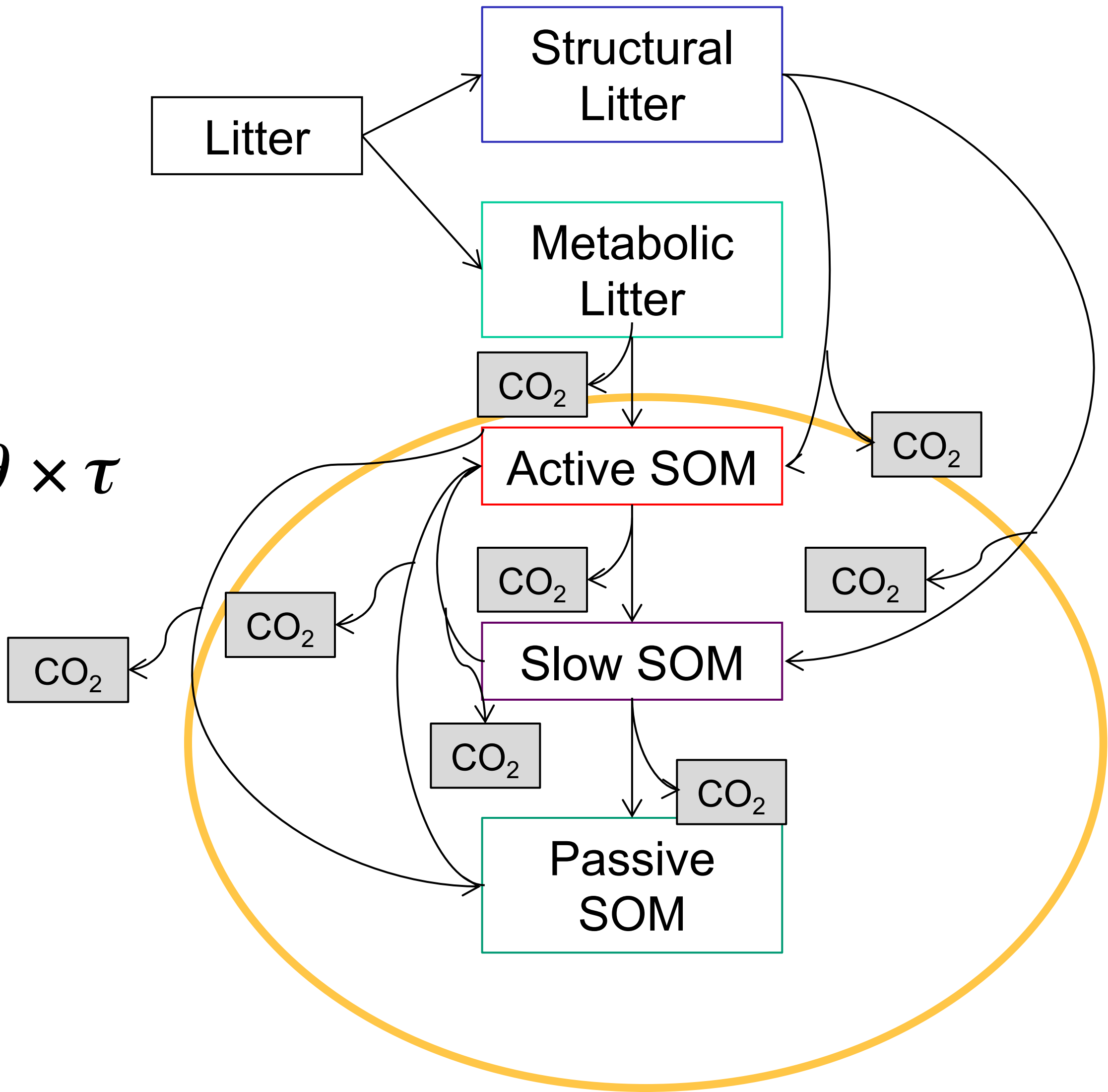


THE SOIL C IN ORCHIDEE

- Decomposition following 1st order kinetics.

$$\frac{\partial SOC}{\partial t} = I - k \times SOC \times \theta \times \tau$$

- A fraction of C decomposed is respired the 1-resp is distributed in the other pools.

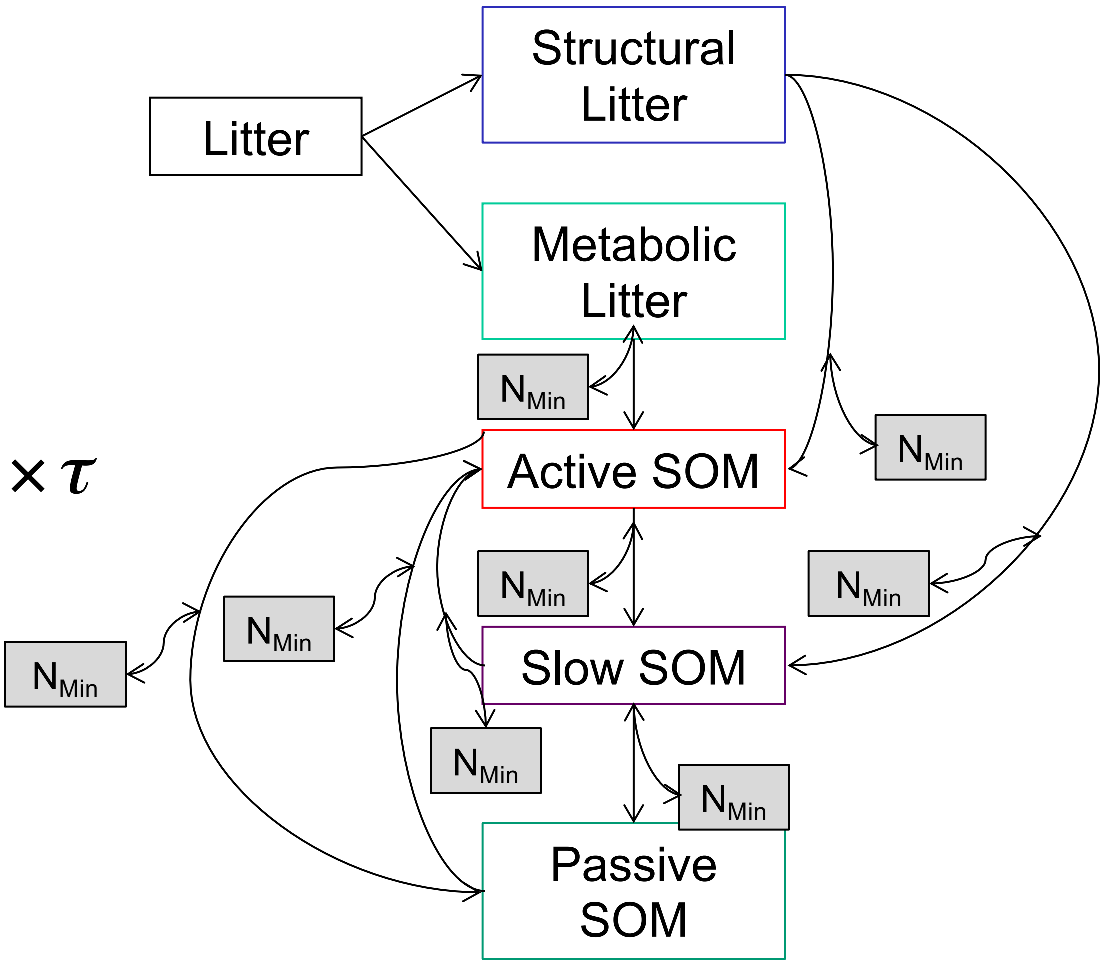


THE SOIL N IN ORCHIDEE

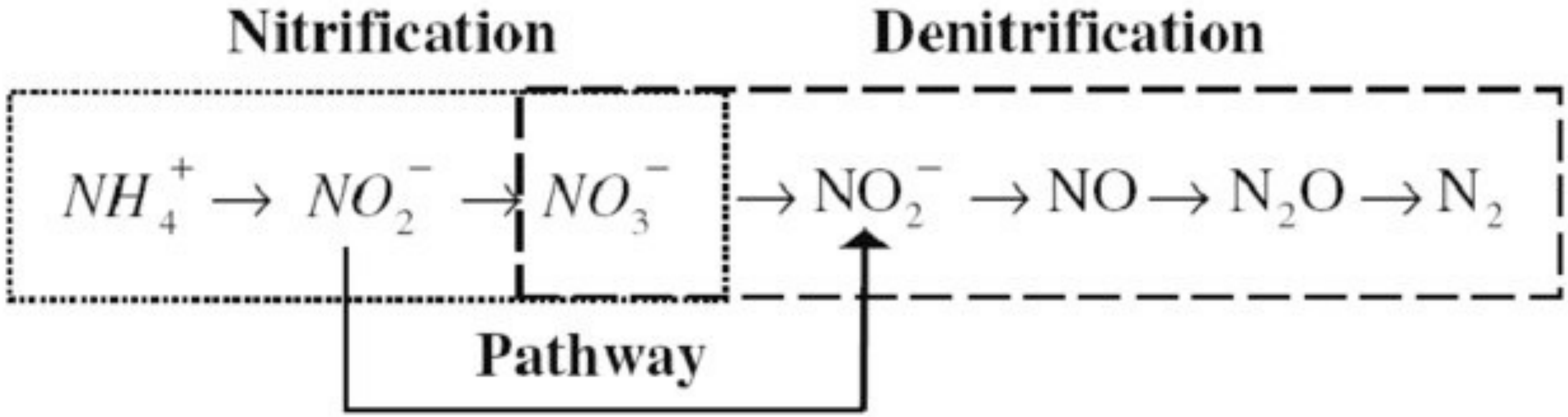
- Decomposition following 1st order kinetics.

$$\frac{\partial SON}{\partial t} = I - k \times SON \times \theta \times \tau$$

- The flux of N from one pool to another must satisfy the CN_target of the receiving pools



HOW THE NITRIFICATION/DENITRIFICATION PROCESSES ARE REPRESENTED

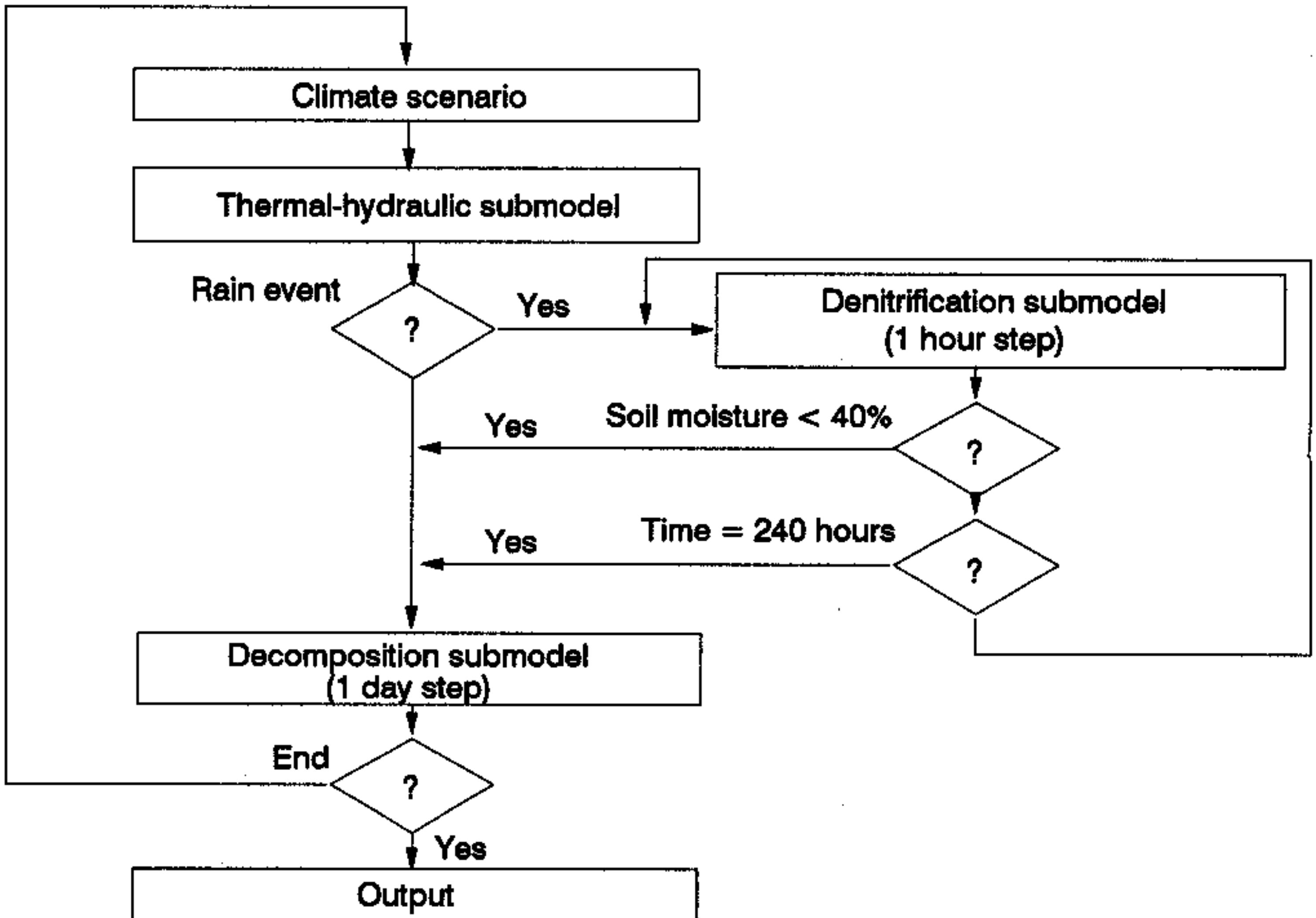


Peng and Zhu (2006)

HOW THE NITRIFICATION/DENITRIFICATION PROCESSES ARE REPRESENTED

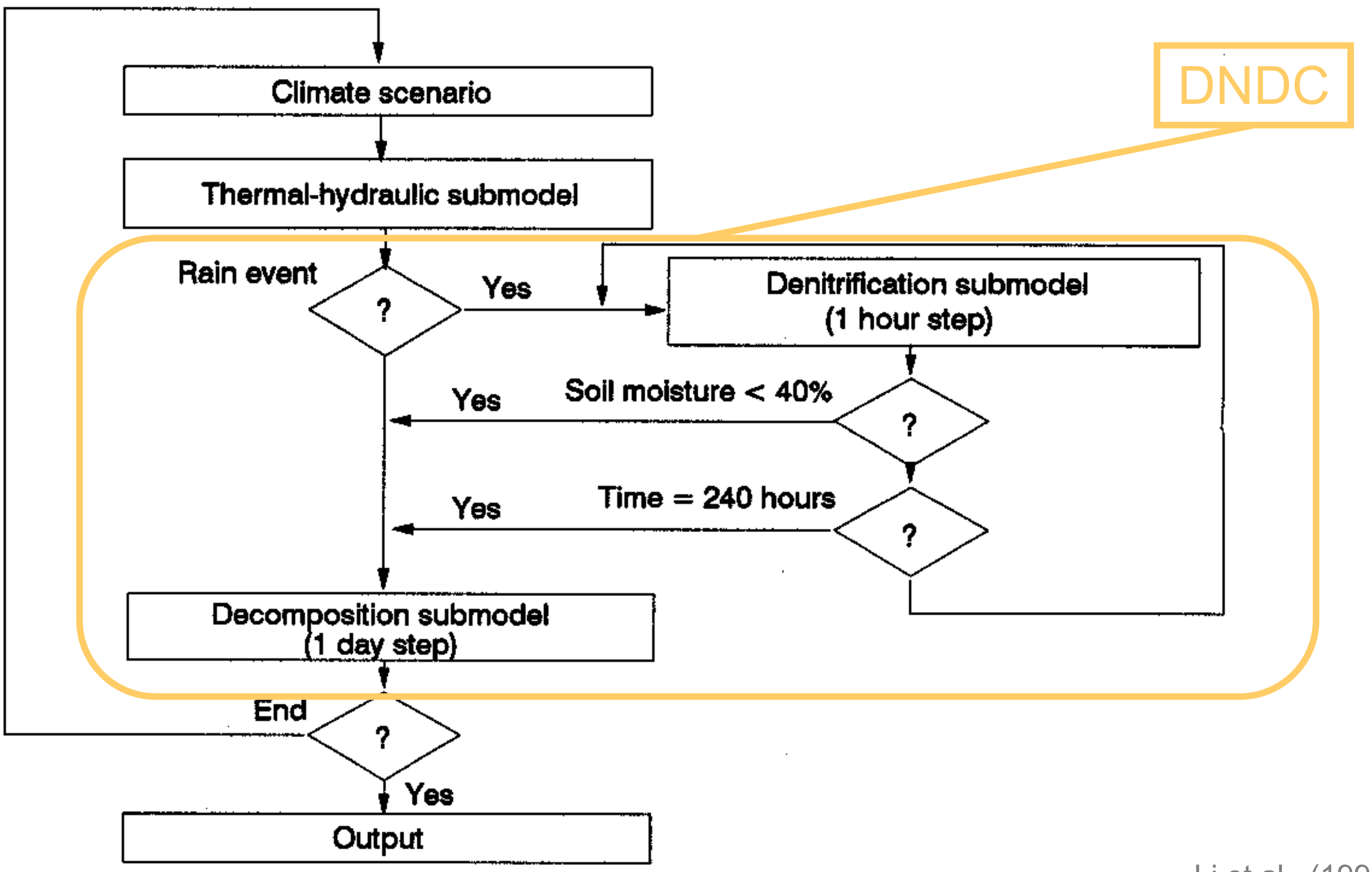
- Key point -> N outputs fluxes & GHG production
- DNDC is an old model based on Li et al. 1992.
- Design to represent denitrification *and* decomposition.
- In ORCHIDEE, only the N-related aspects are used but in a simplified way.

ORIGINAL DNDC



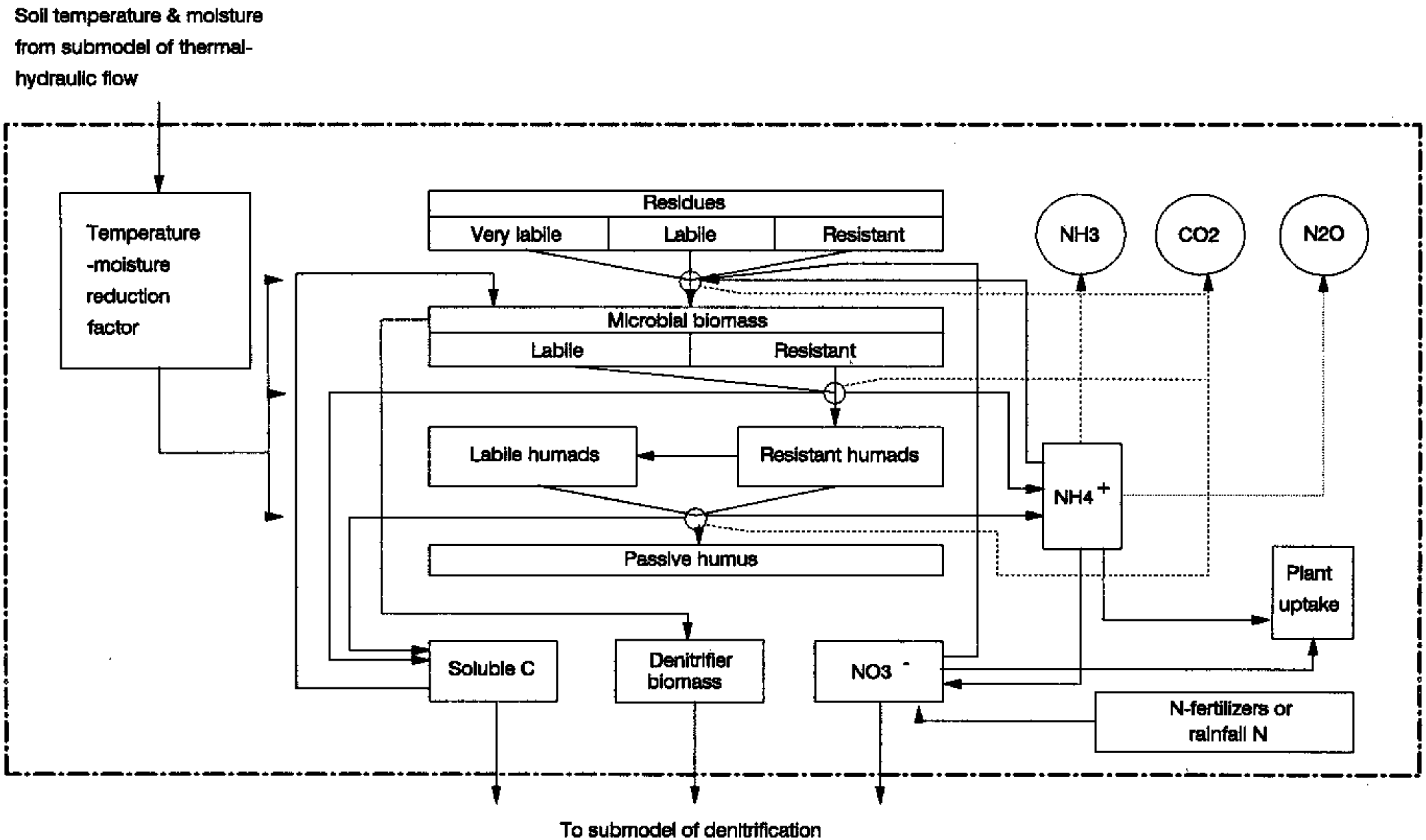
Li et al., (1992)

ORIGINAL DNDC



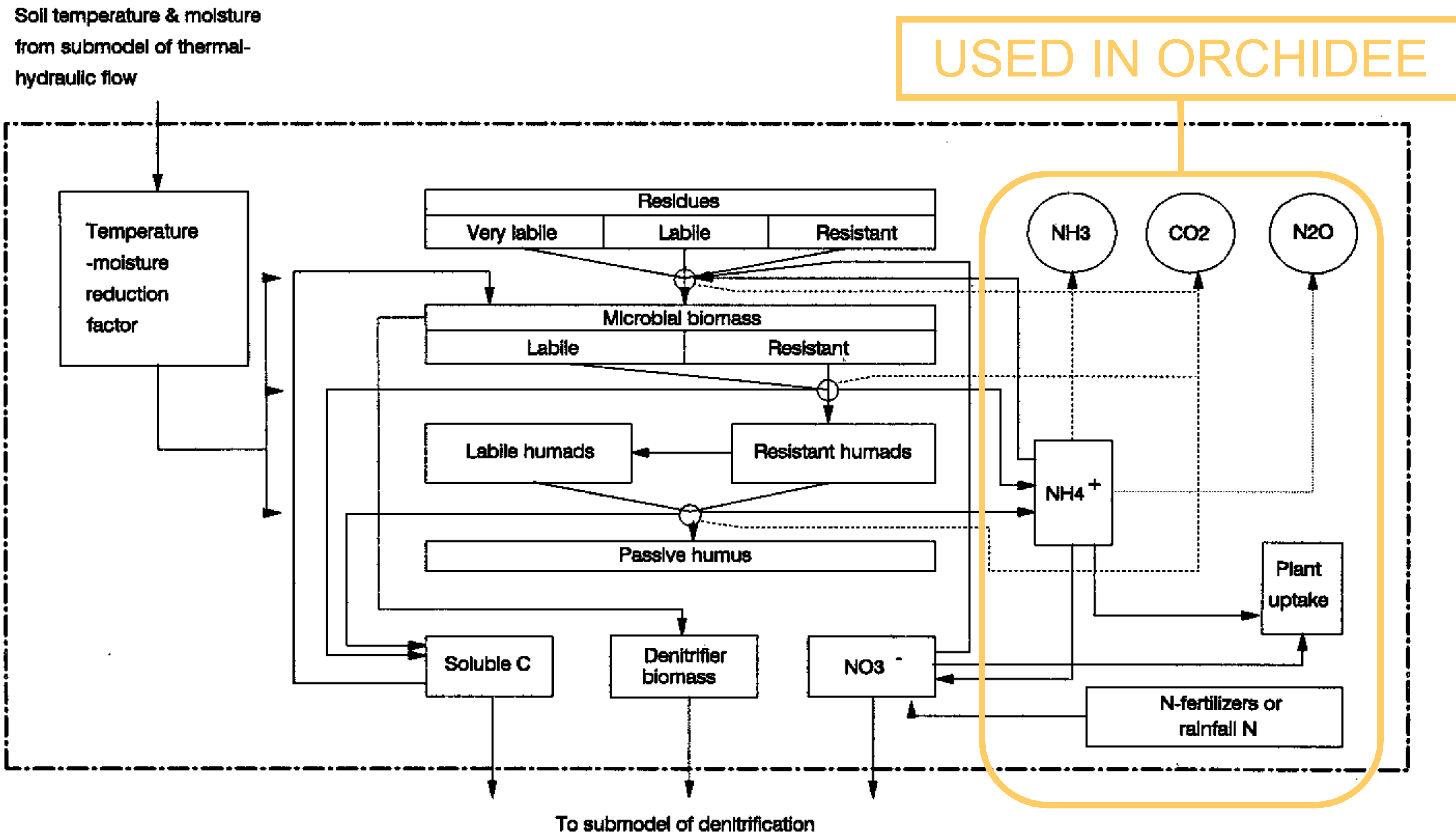
Li et al., (1992)

ORIGINAL DNDC



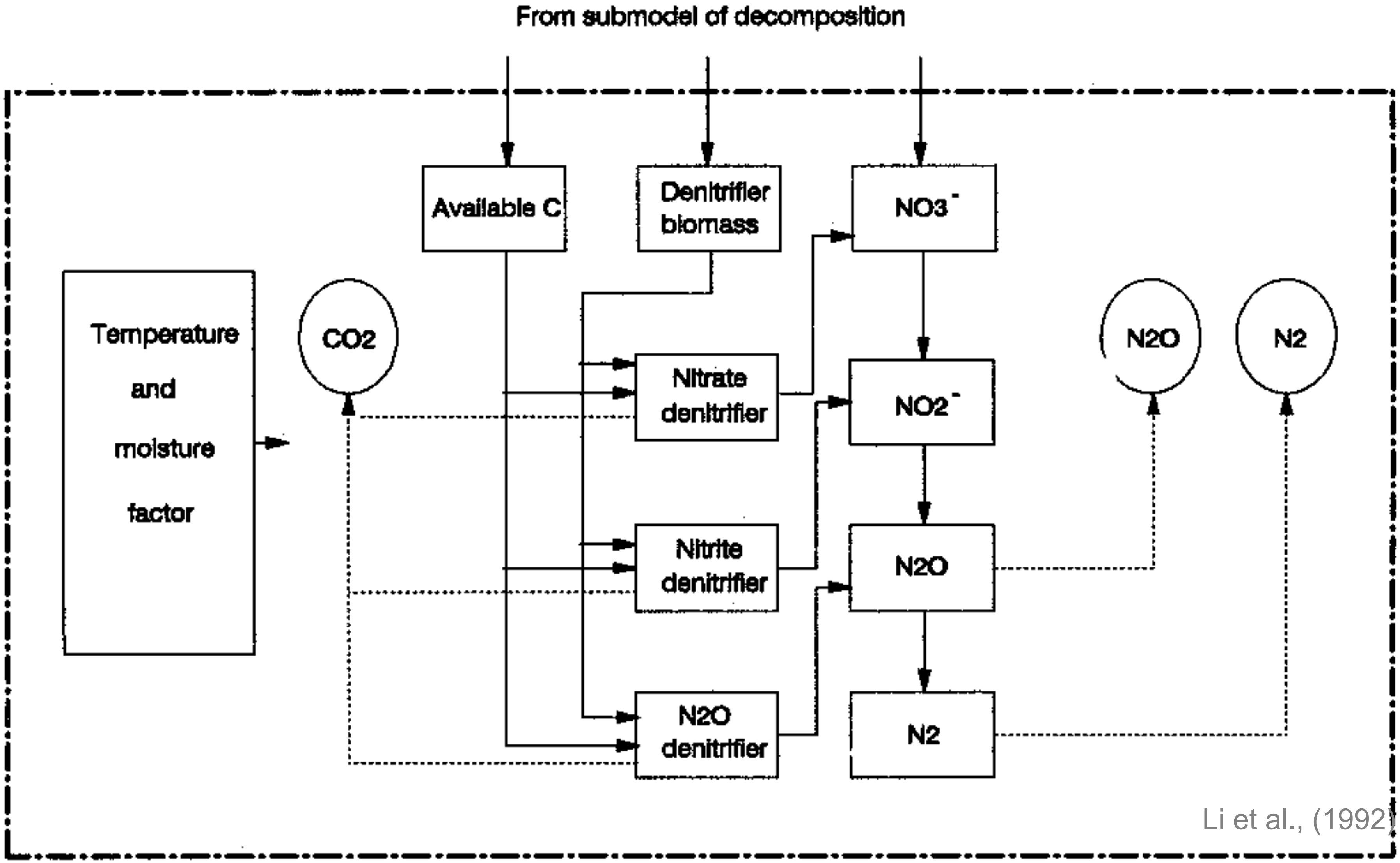
Li et al., (1992)

ORIGINAL DNDC

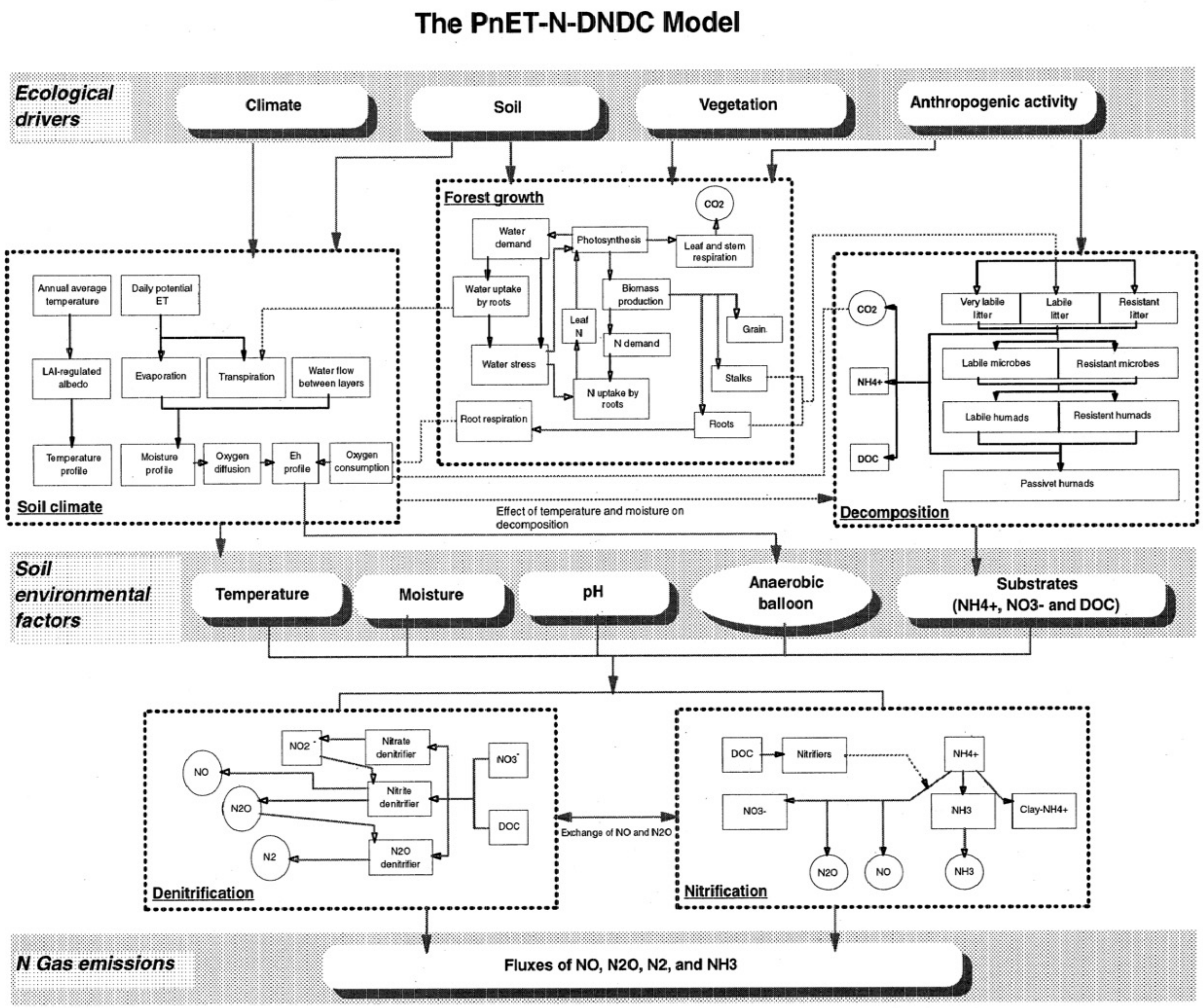


Li et al., (1992)

ORIGINAL DNDC

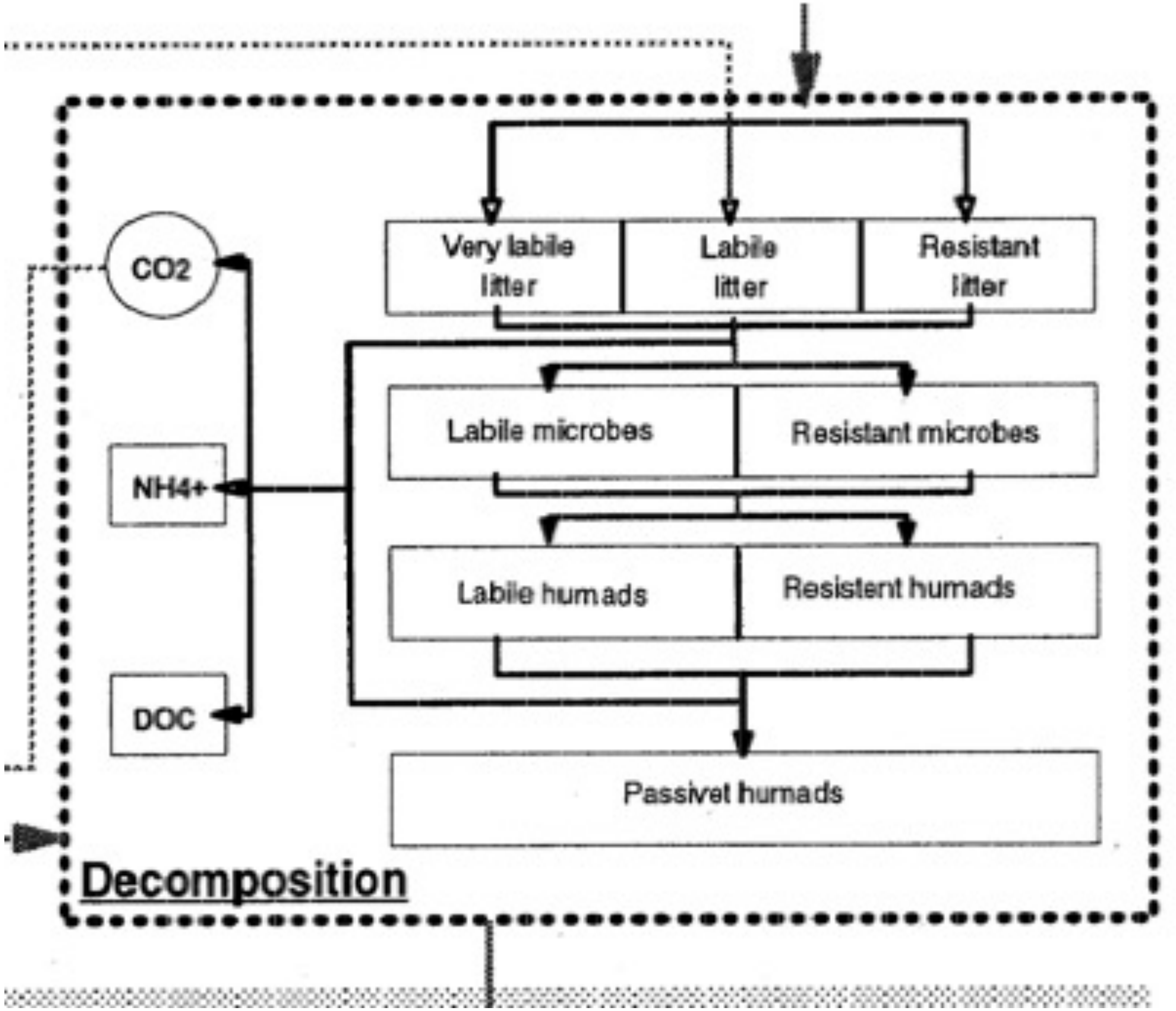


IMPROVED DNDC



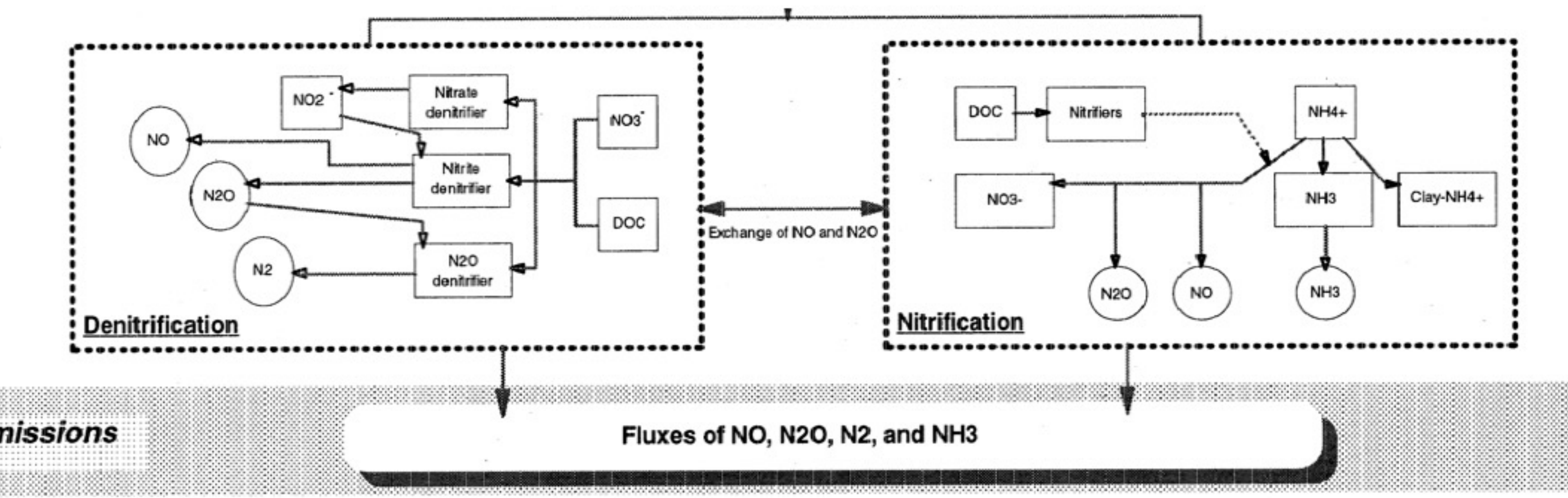
Li et al., (2000)

IMPROVED DNDC



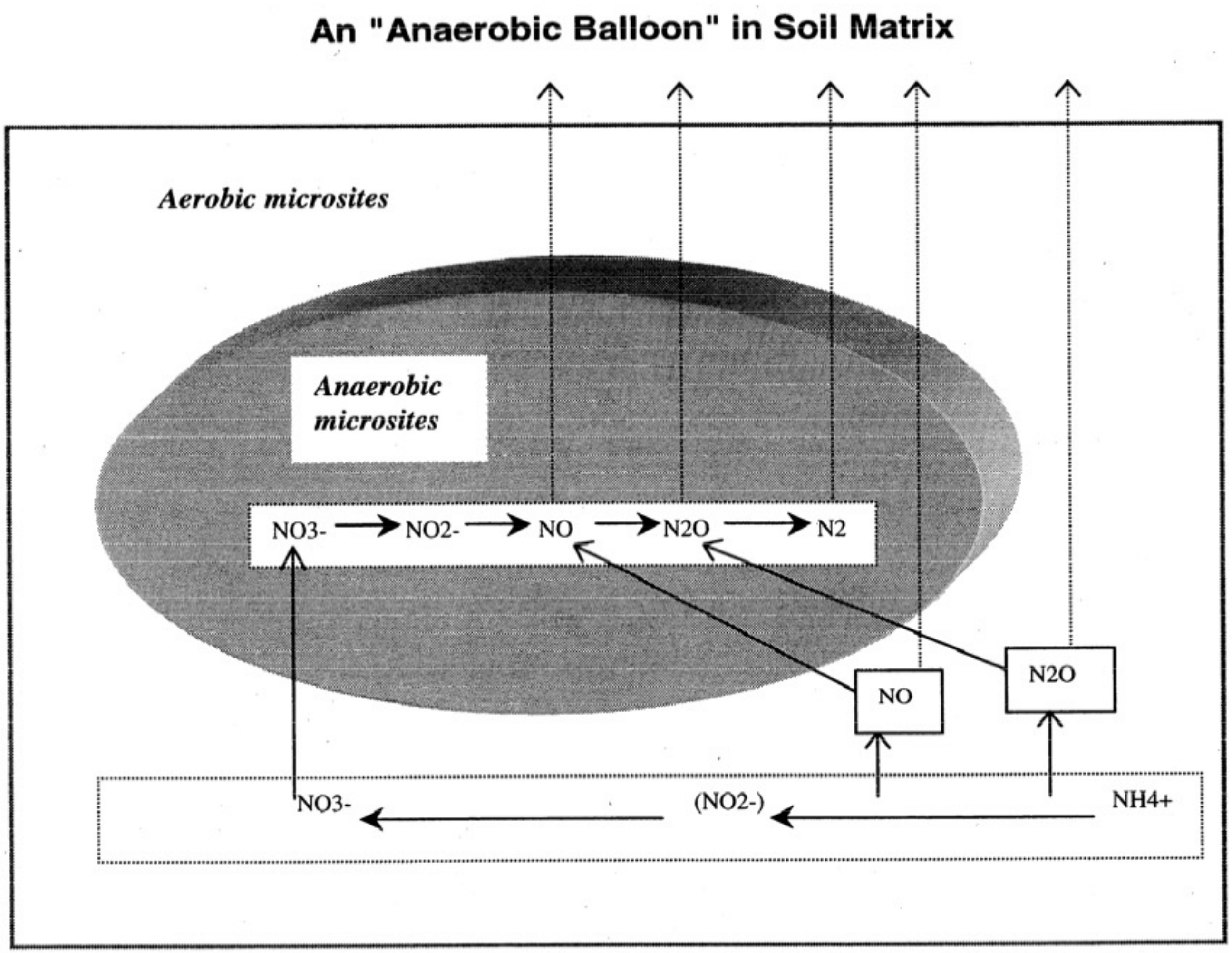
Li et al., (2000)

IMPROVED DNDC



Li et al., (2000)

THE ANAEROBIC BALLOON CONCEPT



Li et al., (2000)

THE ANAEROBIC BALLOON CONCEPT

Table 2. Functions and Parameters for O_2 Diffusion and Volumetric Fraction of Anaerobic Microsites (ANVF)

Equation No.	Function	Equation
1	oxygen diffusion coefficient in soil	$D_{s[L]} = D_{air}\ afps_{[L]}^{3.33} / afps_{max[L]}^{2.0}$;
2	oxygen diffusion rate affected by frost	$D_{s[L]} = D_{s[L]}\ F\_frost;\ \ 0 < D_{s[L]} < 1$ if $T > 0$ °C, F_frost = 1.2; if $T <= 0$ °C, F_frost = 0.8; $D_{s[L]} = D_{s[L]}\ F\_frost;\ \ 0 < D_{s[L]} < 1$ if $T > 0$ °C, F_frost = 1.2; if $T <= 0$ °C, F_frost = 0.8;
3	oxygen partial pressure	$d(pO_{2[L]})/dt = (d(D_{s[L]}\ d(pO2_{[L]})/dz)/dz - R)/afps$;
4	Volumetric fraction of anaerobic microsites	$anvf_{[L]} = a\ (1-(b\ \ pO_{2[L]} / pO_{2air}))$;

a, b, constant coefficients; afps, air-filled porosity; $afps_{max}$, porosity; anvf, volumetric fraction of anaerobic microsites; D_{air}, oxygen diffusion rate in the air, 0.07236 m^2/h [*Beisecker*, 1994]; D_s, oxygen diffusion coefficient in soil; F_frost, frost factor; L, layer number; pO_2, oxygen partial pressure; R, oxygen consumption rate (kg C $ha^{-1}h^{-1}$); t, time (h); z, soil depth (m).

Li et al., (2000)

THE EQUATIONS

Table 3. Functions and Parameters for Nitrification

Equation No.	Function	Equation
1	relative growth rate of nitrifiers	$\mu_g = \mu_{MAX} (([DOC] / (1 + [DOC]) + F_m / (1 + F_m));$
2	relative death rate of nitrifiers	$\mu_d = a_{MAX} B_n / (5 + [DOC]) / (1 + F_m);$
3	net increase in nitrifiers biomass	$\mu_b = (\mu_g - \mu_d) B_n F_t F_m;$
4	nitrification rate	$R_n = R_{max} [NH4] B_n pH;$
5	temperature factor	$F_t = ((60-T)/ 25.78)^{3.503} e^{(3.503 (T-34.22)/ 25.78)};$
6	moisture factor	if wfps > 0.05 $F_m = 1.01 - 0.21$ wfps; if wfps <= 0.05 $F_m = 0;$
7	NO production from nitrification	$NO = .0025 R_n F_t;$
8	N_2O production from nitrification	$N_2O = 0.0006 R_n F_t$ wfps;

a_{MAX}, maximum death rate for nitrifiers (1.44 1/d [from *Blagodatsky and Richter*, 1998]); B_n, biomass of nitrifiers (kg C/ha); [DOC], concentration of dissolved organic C (kg C/ha); F_m, moisture factor; F_t, temperature factor; [NH4], concentration of ammonium (kg N/ha); NO, NO production from nitrification; N_2O, N_2O production from nitrification [*Ingwersen et al.*, 1999]; pH, soil pH; R_n, nitrification rate; R_{max}, maximum nitrification rate (1/h); T, soil temperature (°C); wfps, water-filled porosity; μ_{MAX}, maximum growth rate for nitrifiers (4.87 1/d [from *Blagodatsky and Richter*, 1998]); μ_b, net increase in nitrifiers biomass; μ_d, relative death rate of nitrifiers; μ_g, relative growth rate of nitrifiers.

Li et al., (2000)

THE EQUATIONS

Table 4. Functions and Parameters for Denitrification

Equation No.	Function	Equation
1	relative growth rate of Nox denitrifiers	$\mu_{NOx} = \mu_{NOx(max)}$ [DOC]/(Kc+[DOC]) $[No_x]/(Kn+[NO_x])$;
2	relative growth rate of total denitrifiers	$\mu_g = F_t\,(\mu_{NO3}\,F_{PH1} + \mu_{NO2}\,F_{PH2} + \mu_{NO}\,F_{PH2} + \mu_{N2O}\,F_{PH3}$; $F_t = 2^{((T-22.5)/10)}$; $F_{PH1} = 1 - 1\,/\,(1 + e^{[pH-4.25/0.5)})$; $F_{PH2} = 1 - 1\,/\,(1 + e^{[pH-5.25/1.0)})$; $F_{PH3} = 1 - 1\,/\,(1 + e^{[pH-6.25/1.5)})$;
3	denitrifier growth rate, death rate, and consumption rate of soluble carbon	$R_g = \mu_g\,B_d$; $R_d = M_c\,Y_c\,B_d$; $R_C = (\mu_g\,/\,Y_c + M_c)\,B_d$;
4	consumption rates of N oxides	$R_{NOx} = (\mu_{NOx}/Y_{NOx} + M_{NOx}\,[No_x]/[N])\,B_d$;
5	nitrogen assimiliation rate	$q_N = R_g\,/CN$;
6	gas diffusion factor	$v = D_{max}$ afps (1 - anvf) $F_{clay}\,2^{T/20}$; $F_{clay} = 0.13 - 0.079$ clay;

afps, air-filled porosity; anvf, volumetric fraction of anaerobic microsites; B_d, denitrifier biomass (kg C/m^3); clay, clay fraction in the soil; CN, C/N ratio in denitrifiers (3.45 [*Van Verseveld and Stouthamer* 1978]); D_c, consumption rate of soluble carbon by denitrifiers (kg C m^{-3}h^{-1}); D_{max}, maximum diffusion rate in air (m^2/h); D_{NOx}, consumption rate of N oxides by denitrifiers (kg C m^{-3}h^{-1}); [DOC], soluble C concentration (kg C/m^3); F_{clay}, clay factor; F_t, temperature factor; F_{PH1}, pH factors for NO_3^- denitrifiers; F_{PH2}, pH factors for NO_2^- and NO denitrifiers; F_{PH3}, pH factors for N_2O denitrifiers; Kc, half-saturation value of soluble carbon (0.017 kg C/m^3 [*Shan and Coulman*, 1978]); Kn, half-saturation value of N oxides (0.083 kg N/m^3 [*Shan and Coulman*, 1978]); M_c, maintenance coefficient on carbon (0.0076 kg N kg^{-1}h^{-1} [*Van Verseveld et al.*, 1977]); [N], concentration of all NO_x (kg N/ m^3); $[No_x]$, concentration of for NO_3^-, NO_2^-, NO and N_2O (kg N/m^3); pH, soil pH; q_n, nitrogen assimilaion rate (kg N ha^{-1}h^{-1}); T, soil temperature (ºC); v, gas diffusion factor (%); Y_c, maximum growth rate of denitrifiers on soluble carbon (0.503 kg C/kg C [*Van Verseveld et al.*, 1977]); M_{NOx}, maintainance coefficient on N oxides (0.09, 0.035 and 0.079 kg N/kg/ for NO_3^-, NO_2^- (+NO*) and N_2O, respectively, based on *Van Verseveld et al.* [1977]); R_d, denitrifier death rate; R_g, denitrifier growth rate; Y_{NOx}, maximum growth rate on N oxides (0.401, 0.428 and 0.151 kg C/kg N for NO_3^-, NO_2^- (+NO*) and N_2O, respectively, based on *Van Verseveld et al.* [1977]); μ_g, relative growth rate of total denitrifiers (1/h); μ_{NO3}, μ_{NO2}, μ_{NO}, μ_{N2O}, relative growth rate of NO_3^--, NO_2^--, NO-, and N_2O denitrifiers; μNOx, relative growth rate of NO_x denitrifiers (1/h); $\mu_{NOx(max)}$, maximum growth rates (0.67 1/h for NO_3^-, NO_2^- denitrifiers, and 0.34 1/h for NO and N_2O denitrifiers, based on *Hartel and Alexander* [1987]). The parameters are shared by NO_2^- and NO due to the lack of data for NO.

Li et al., (2000)

WHAT IS DONE IN ORCHIDEE

- Implemented by Zaehle et al., (2010)
- At that time, no DOC and no soil C discretization.
- Active C pools used instead of DOC.
- Gas diffusion is calculated using a fixed soil depth value of 20cm.
- Several parameters tuned.
- With Nicolas, we decided to let the original parameter values.

A NEW SOIL SCHEME FROM THE MICT BRANCH

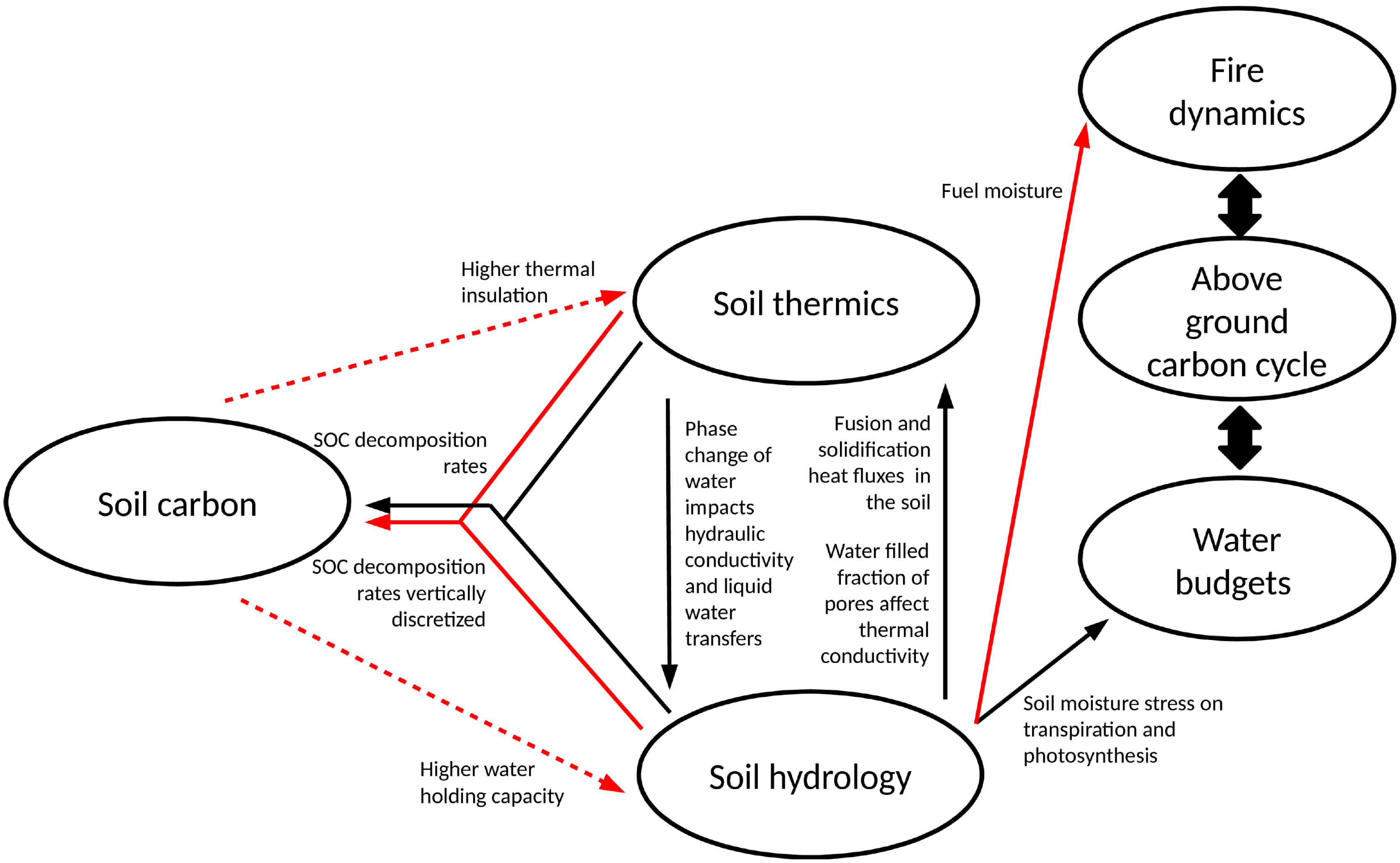
- For CMIP6, some LSMs will have permafrost C, explicit N cycle and perhaps both
- All the necessary piece of code exist within the « orchidee environment »
- Opportunity to benefit from the huge effort done in the MICT branch by many colleagues (Dan Zhu, Philippe Ciais, Matthieu Guimberteau, Charlie Koven, …)

Only an option in the trunk controlled by OK_SOIL_CARBON_DISCRETIZATION

WHAT DO WE TOOK FROM MICT?

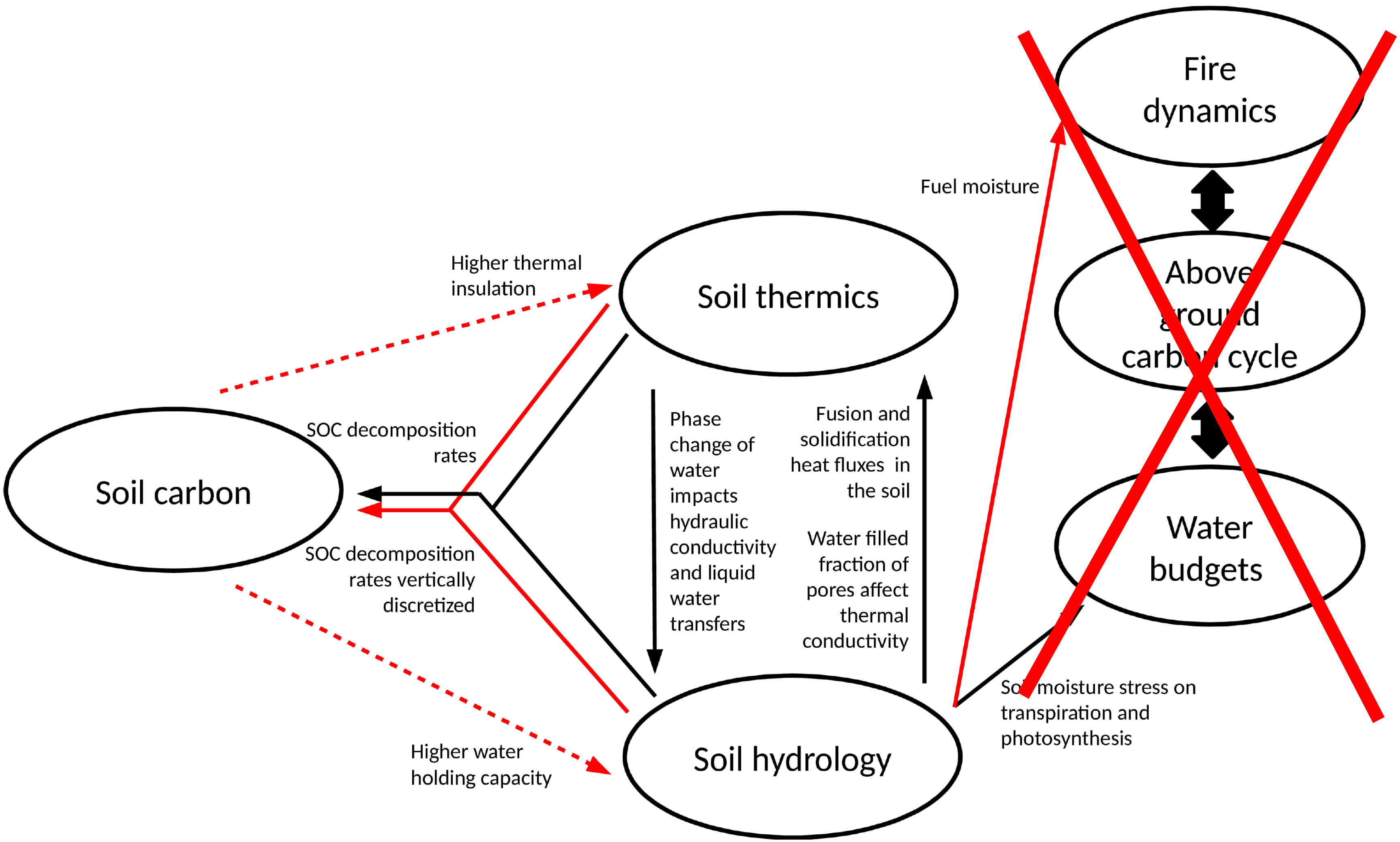
- Several options are available in MICT but not in the trunk (fire, grassland management, permafrost C)
- Focus on permafrost C
- Not only adding « frozen C »
- Soil C is discretized
- Diffusion is added (including bioturbation and cryoturbation)
- Temperature effect on SOC mineralization
- When frozen, nroot is set to -> impact on water stress and on transpiration.
- Optional
  - Zimov effect
  - Insolation effect (thermal conductivity affected by SOC)

WHAT DO WE TOOK FROM MICT?



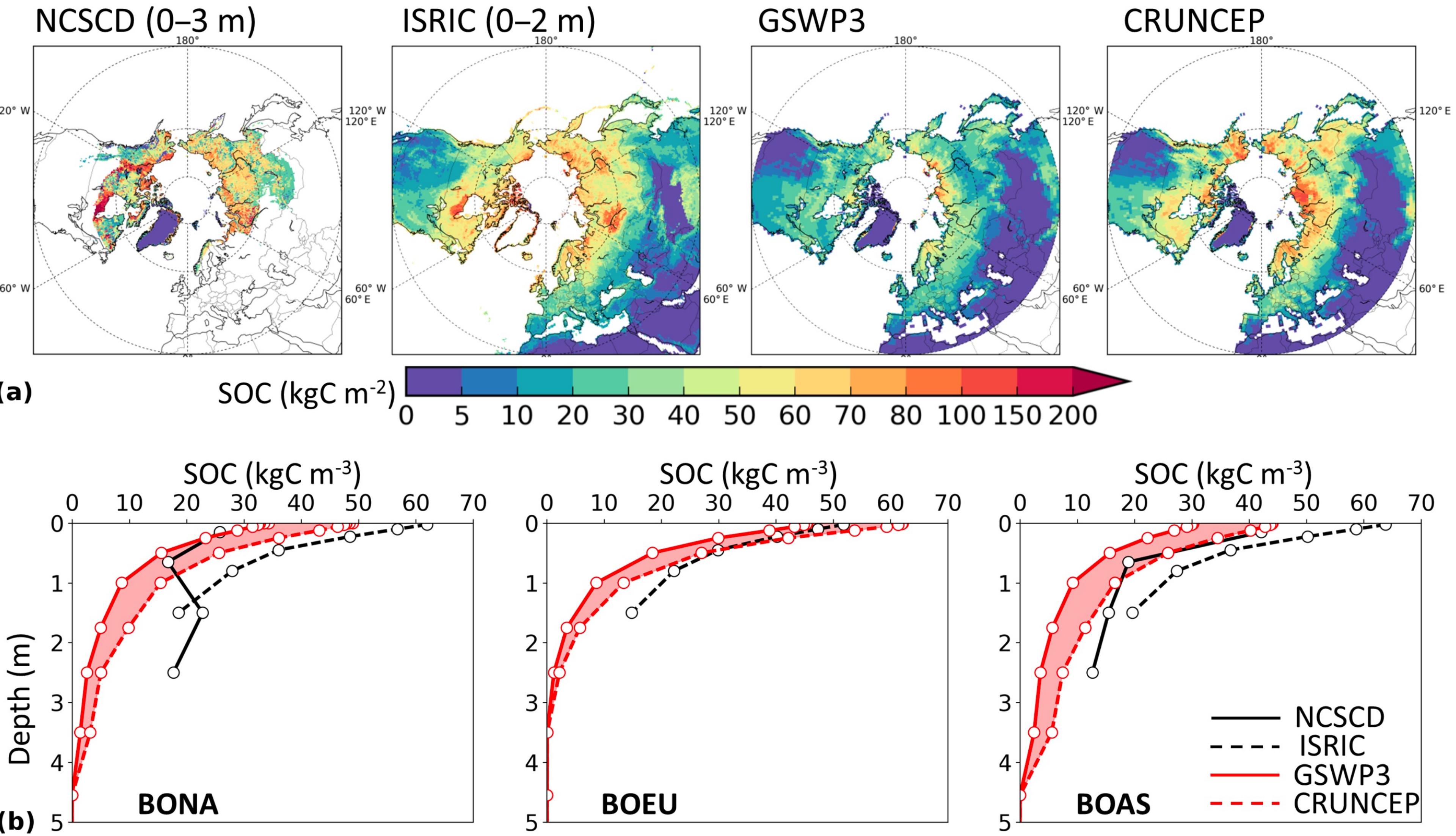
Guimberteau et al 2018

WHAT DO WE TOOK FROM MICT?



Guimberteau et al 2018

WHAT DO WE TOOK FROM MICT?



Guimberteau et al 2018

WHAT IS NEW

- Soil organic N is also discretized
- Mineral N is not
- No effect on N plant uptake

ONGOING DEVELLOPEMENT

- Representation of the soil C/N profile
- Lateral outputs of C (DOC, Erosion)
- Representation of Priming effect.
- Carbon isotopes (^{14}C and ^{13}C)
- Peatlands

THANK YOU FOR YOUR ATTENTION!