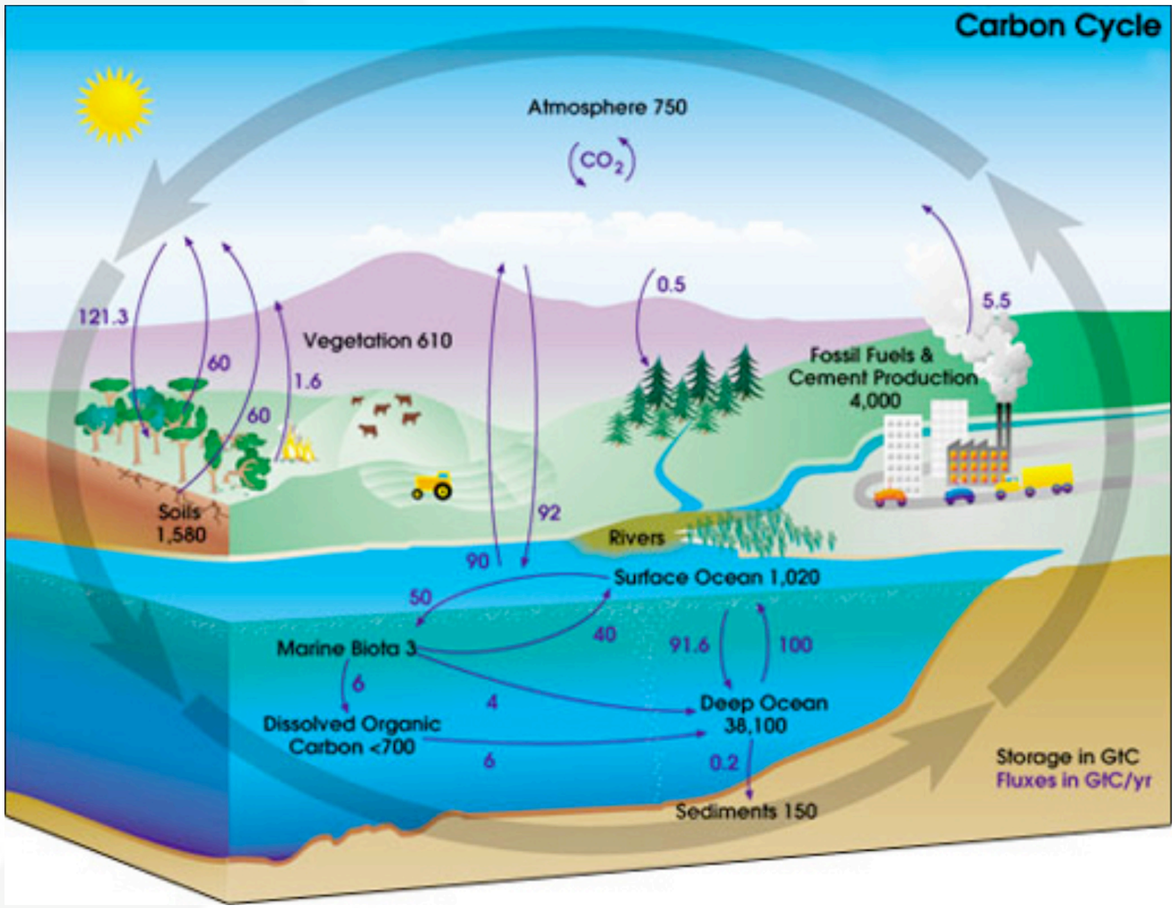
The soil carbon in ORCHIDEE

GUENET Bertrand

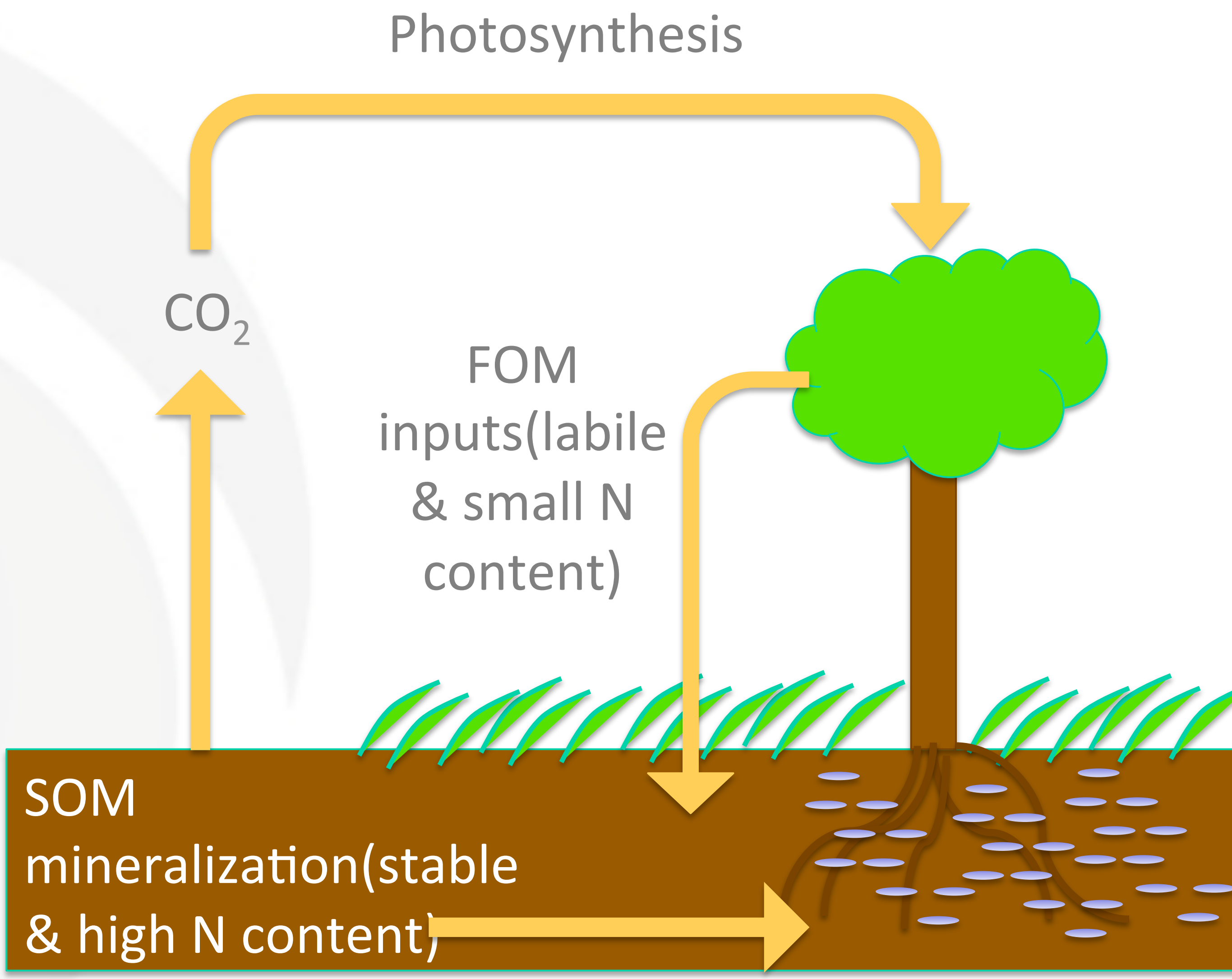
THE GLOBAL C CYCLE AND ITS SOIL COMPONENT

- The C cycle: a complex cycle composed of different pools.
- These pools interact *via* different fluxes.

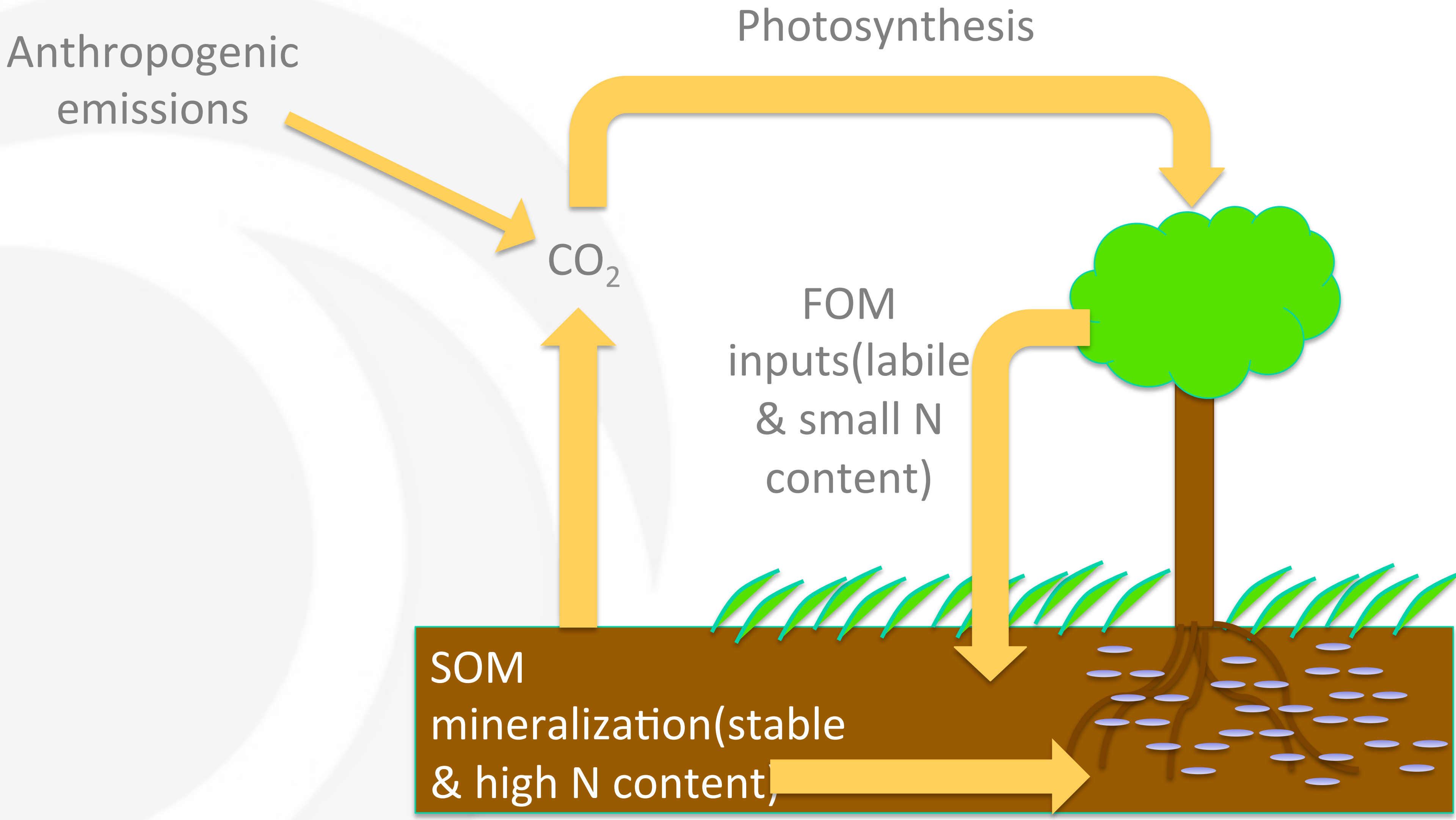


SOILS: MAJOR ACTORS OF THE C CYCLE

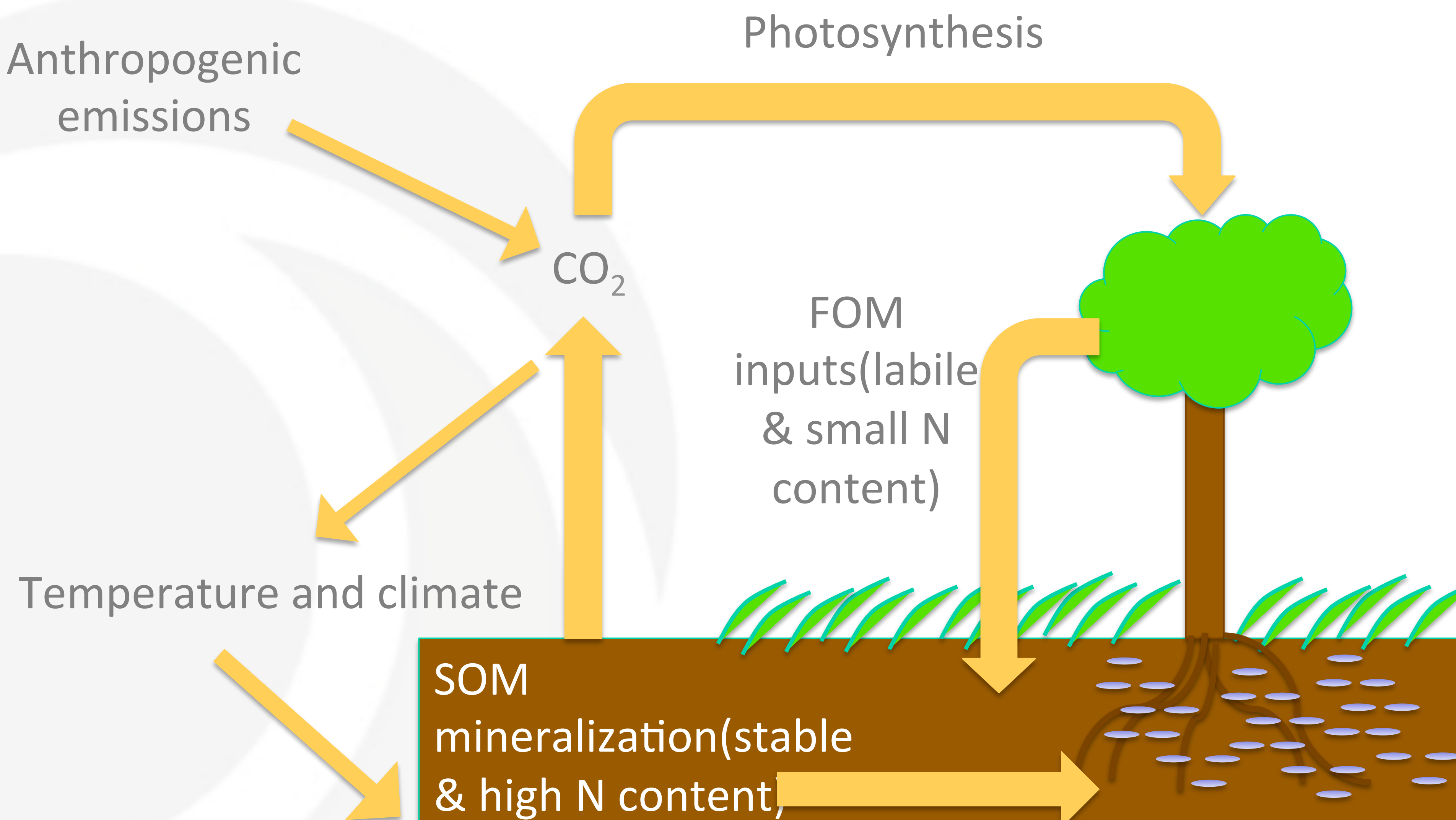
- Temperature and humidity(Reichstein et al., 2003)
- Amount and chemical composition of the Fresh Organic Matter (FOM) (Guenet et al., 2010)



SOILS AND GLOBAL CHANGES



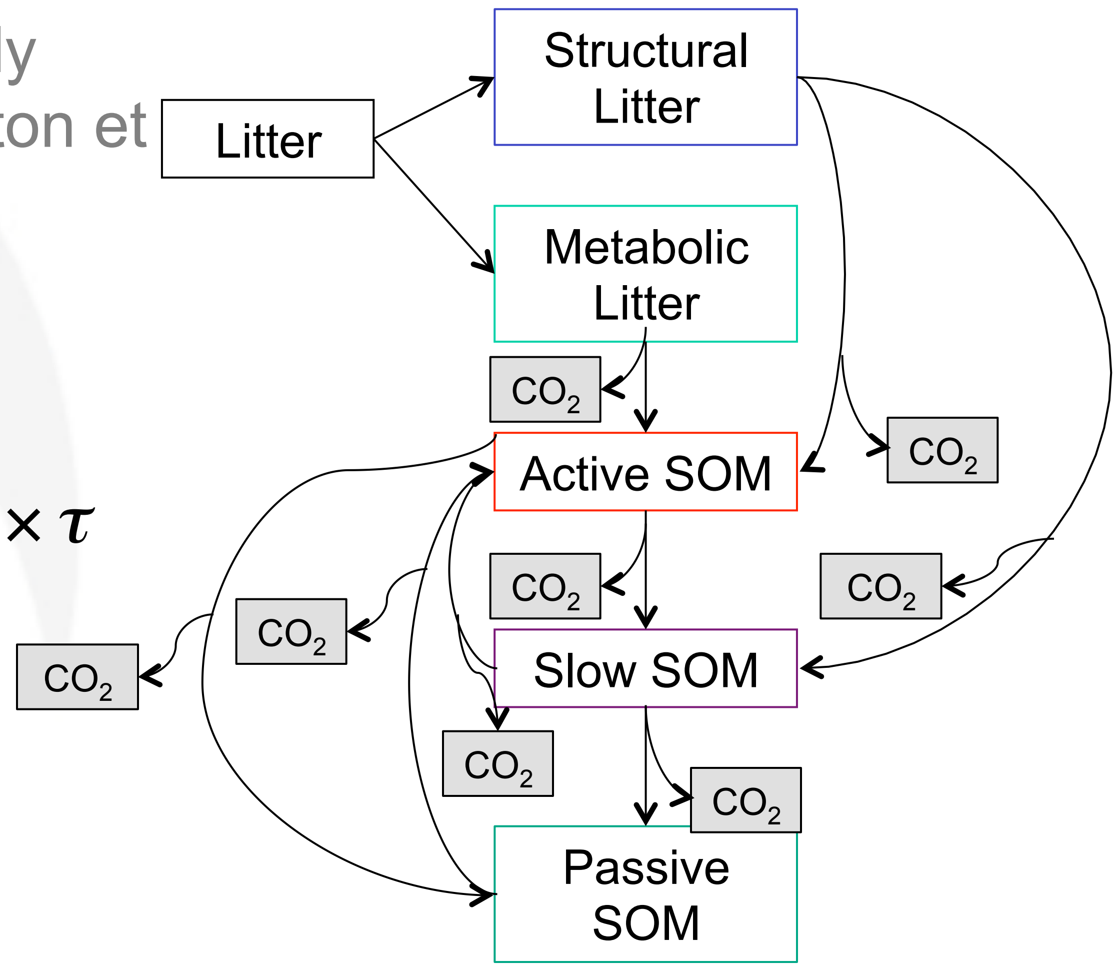
SOILS AND GLOBAL CHANGES



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

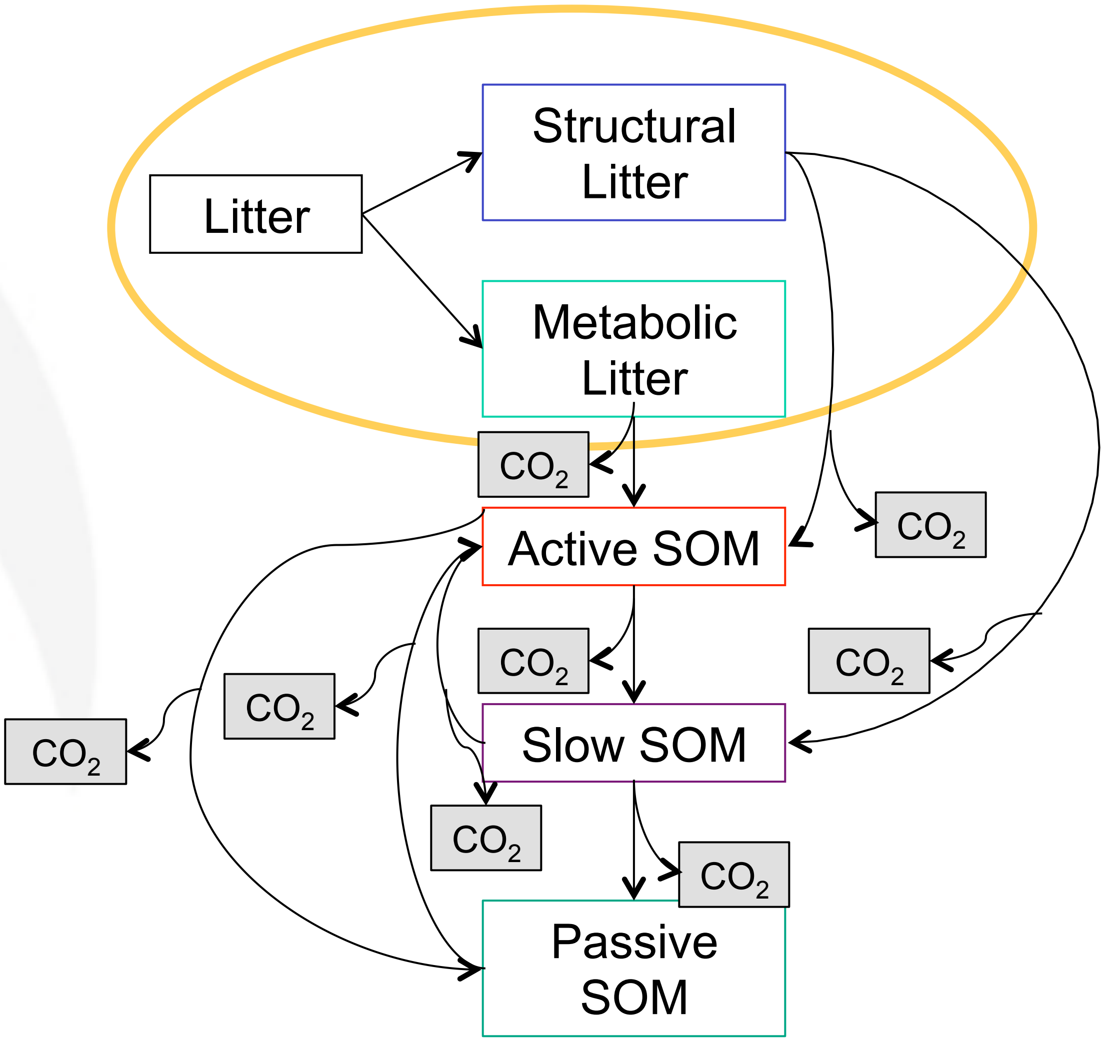
$$\tau = Q_{10}^{(T-Topt)/10}$$

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

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

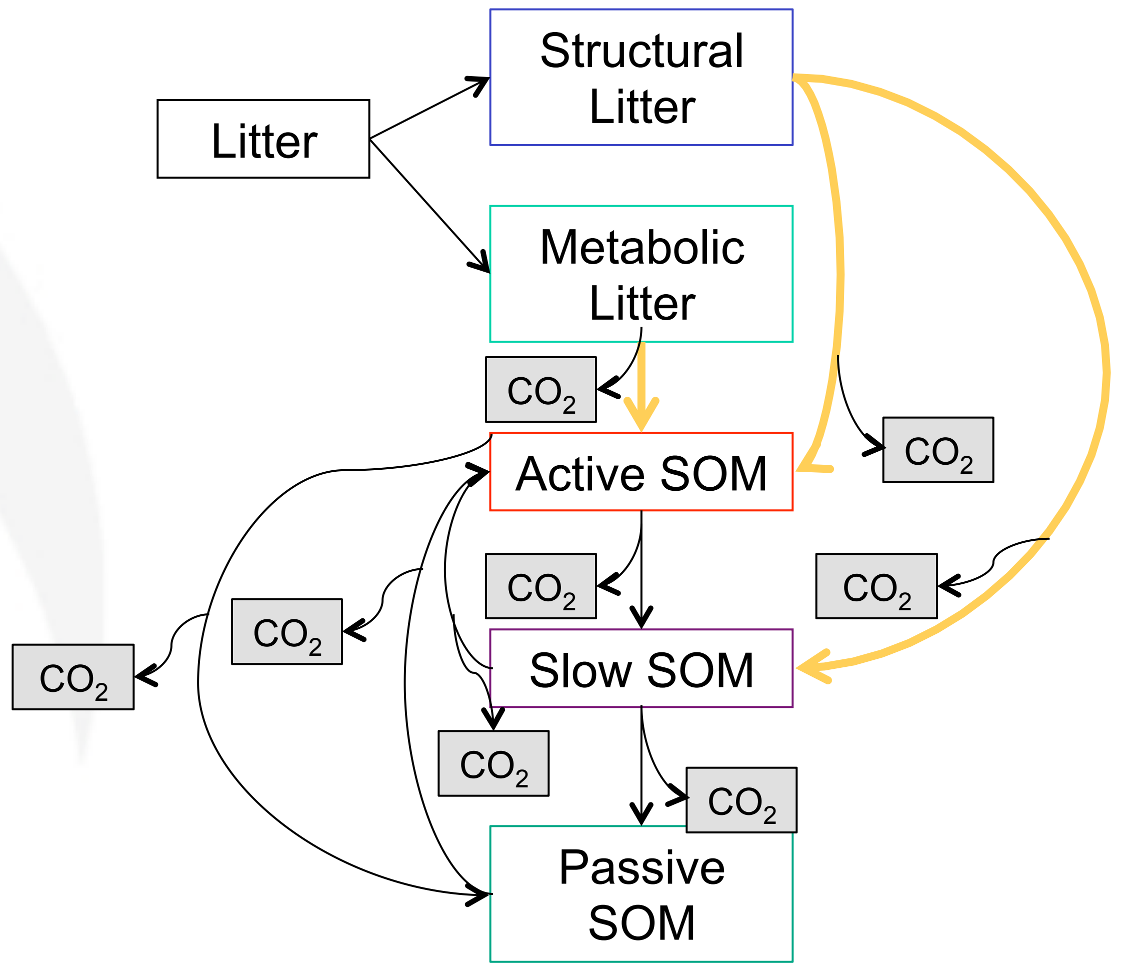
THE SOIL C IN ORCHIDEE

- 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.

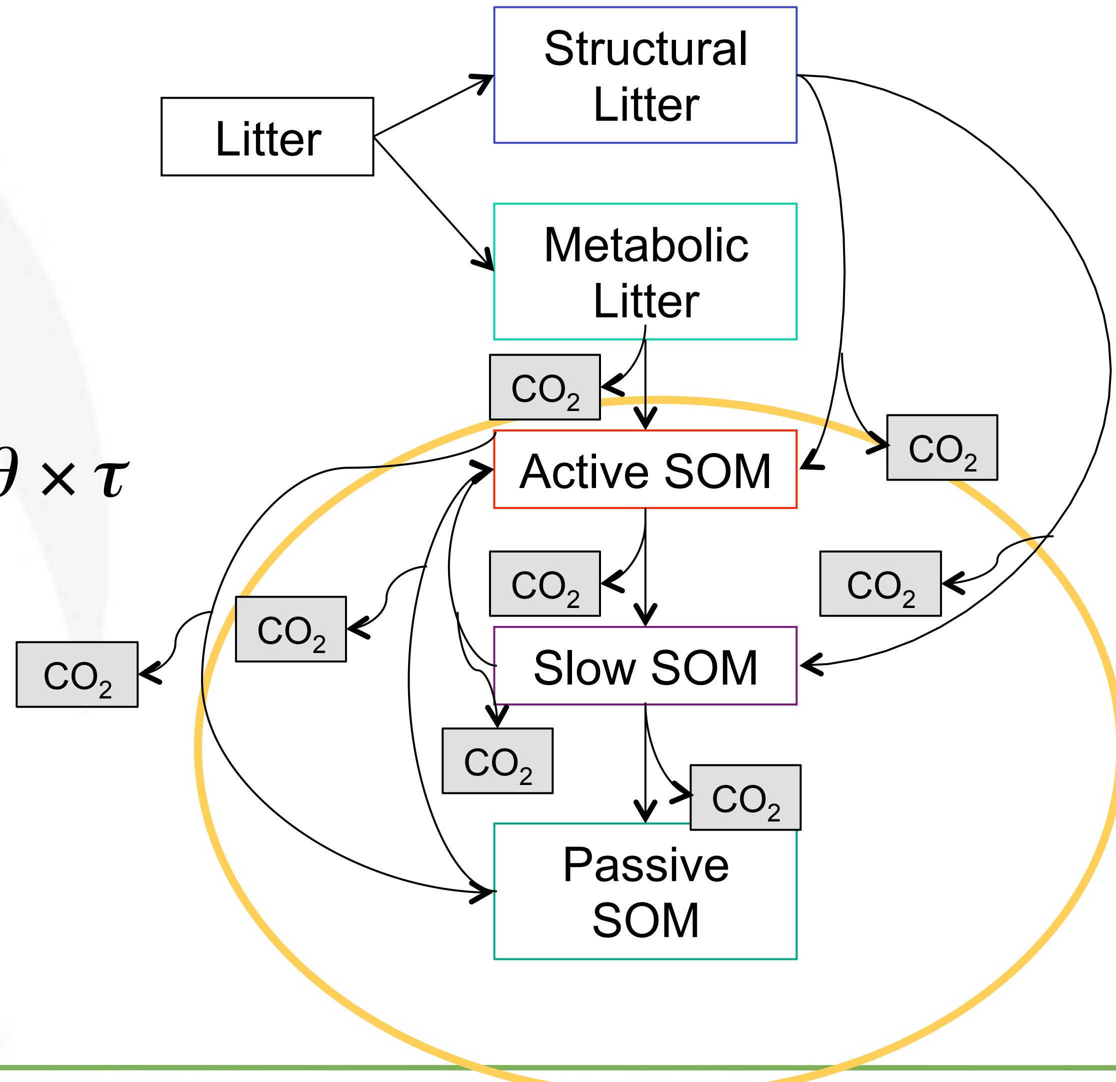


THE SOIL C IN ORCHIDEE

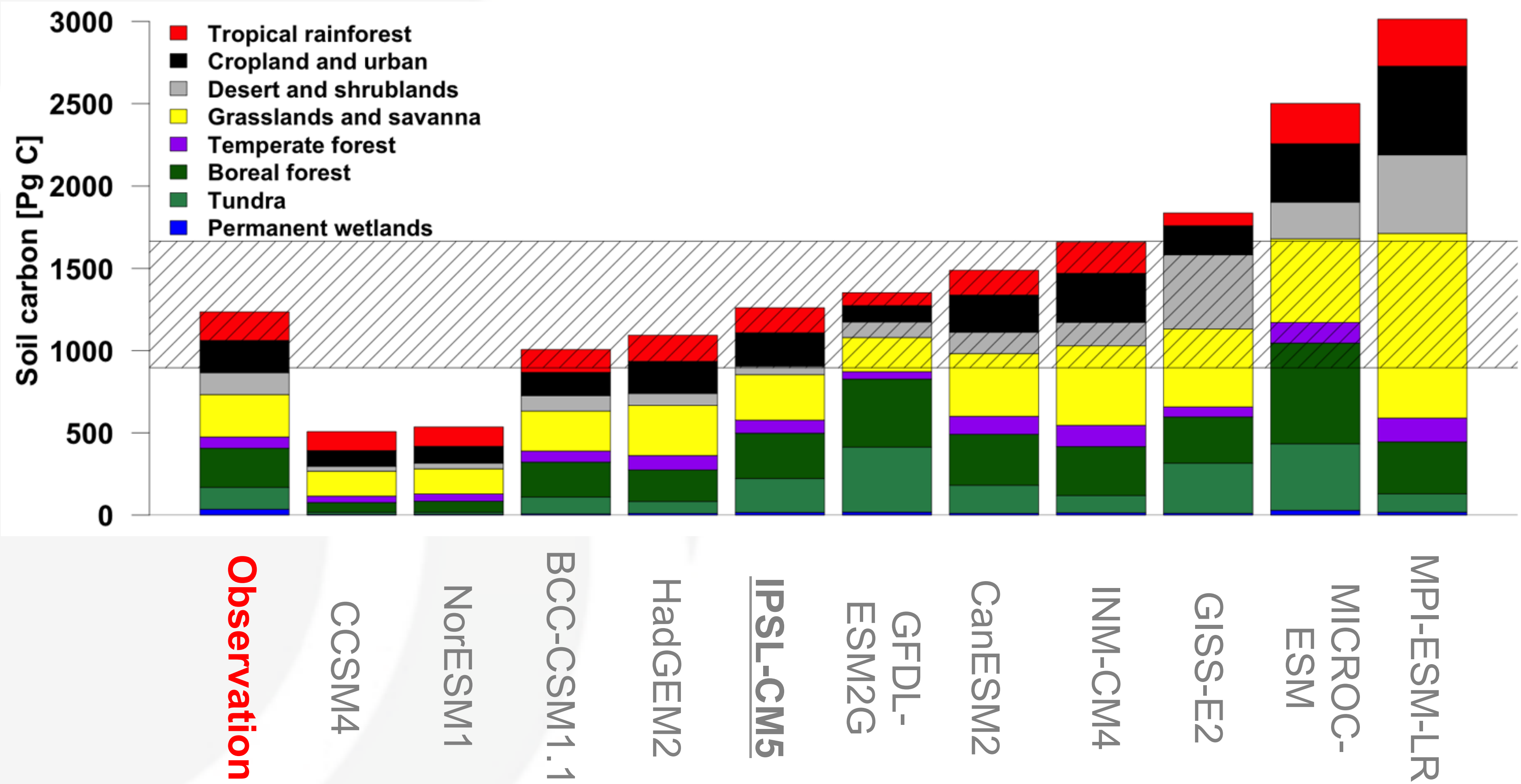
- Decomposition following 1st order kinetics.

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

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

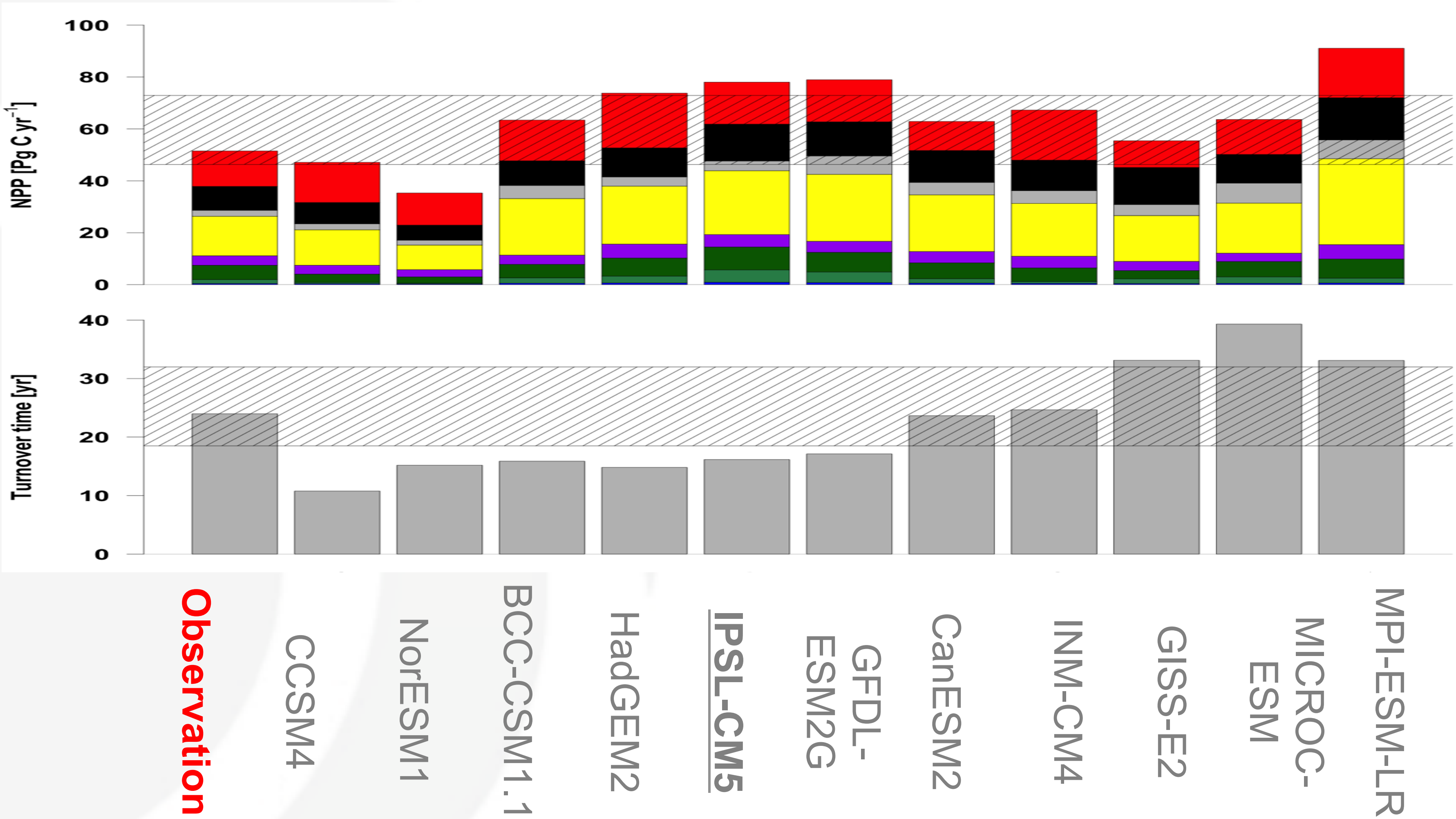


HOW GOOD ARE EARTH SYSTEM MODELS TO REPRESENT SOIL C STOCK



Todd-Brown et al. (2013)

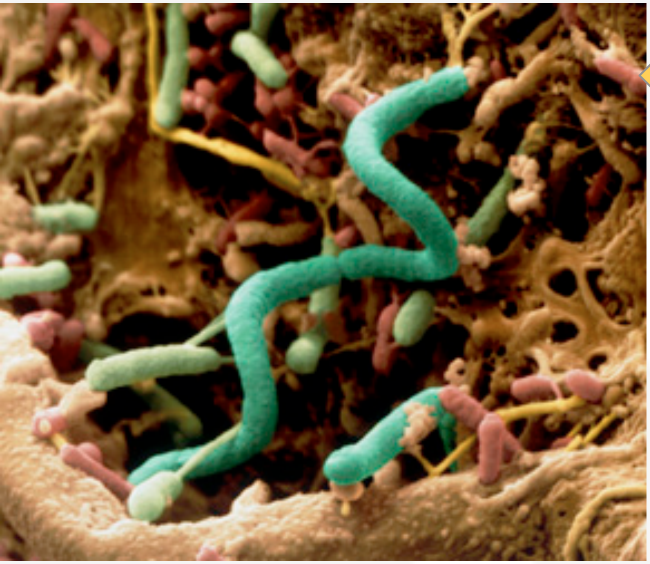
HOW GOOD ARE EARTH SYSTEM MODELS TO REPRESENT SOIL C STOCK



Todd-Brown et al. (2013)

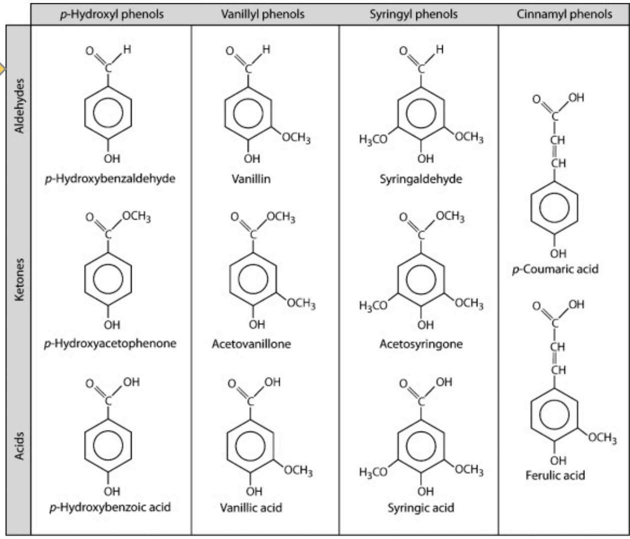
SEVERAL IMPORTANT MECHANISMS ARE STILL MISSING

Biology



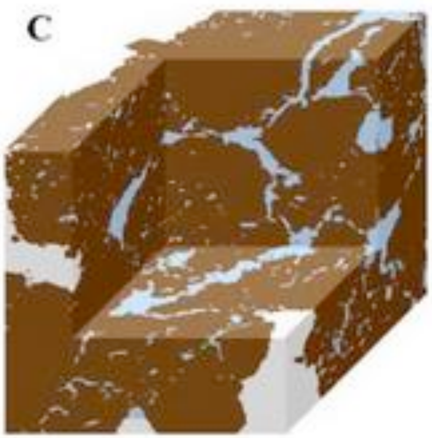
http://cropandsoil.oregonstate.edu

Chemistry



Thevenot et al., 2010

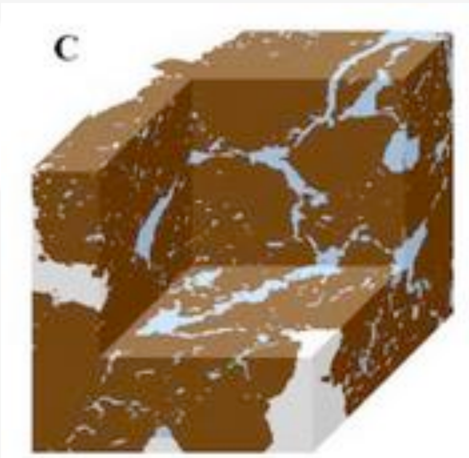
Physics



http://www.abdn.ac.uk

SEVERAL IMPORTANT MECHANISMS ARE STILL MISSING

Physics



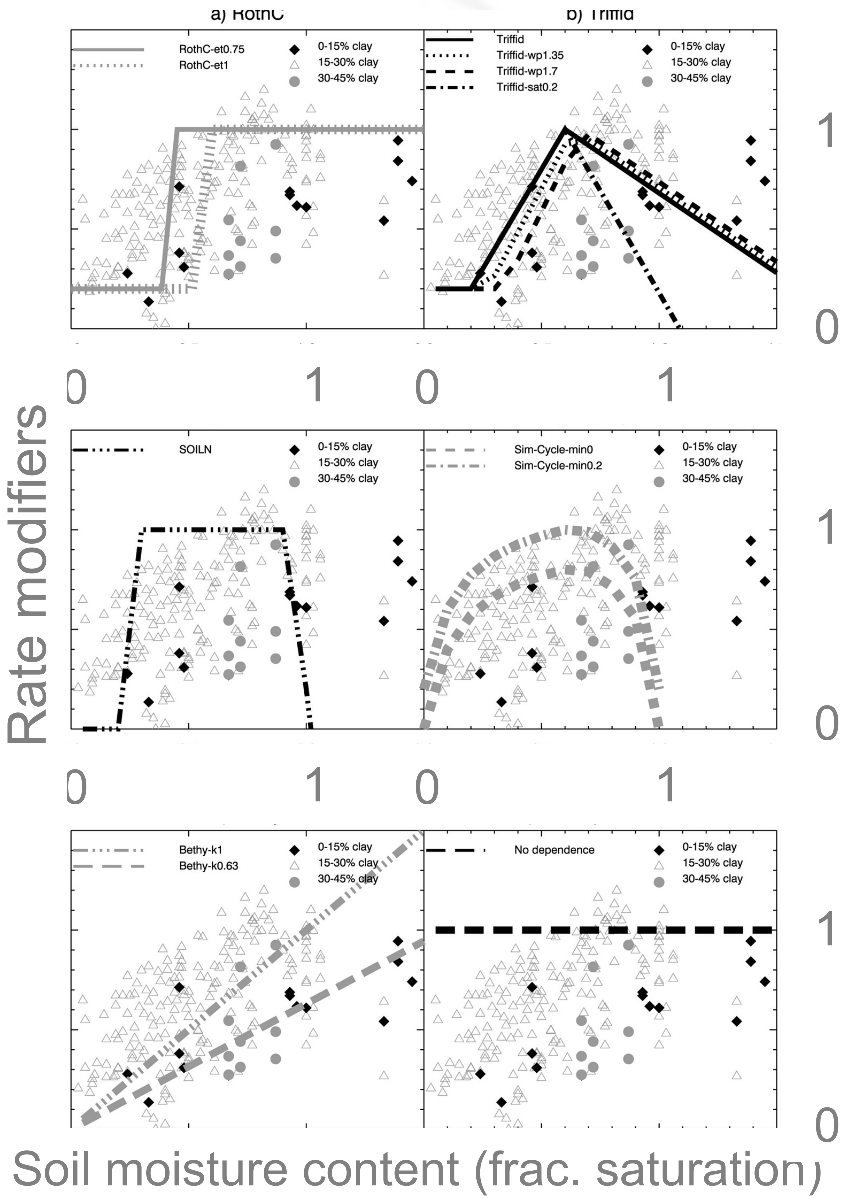
http://www.abdn.ac.uk

- Soils are not homogenous
- Composed by aggregates of SOM
- Organisation of aggregates leads to a pore network.

Gases diffusitivity (O_2, CO_2, CH_4, N_2O, …)

Water availability

WATER AVAILABILITY

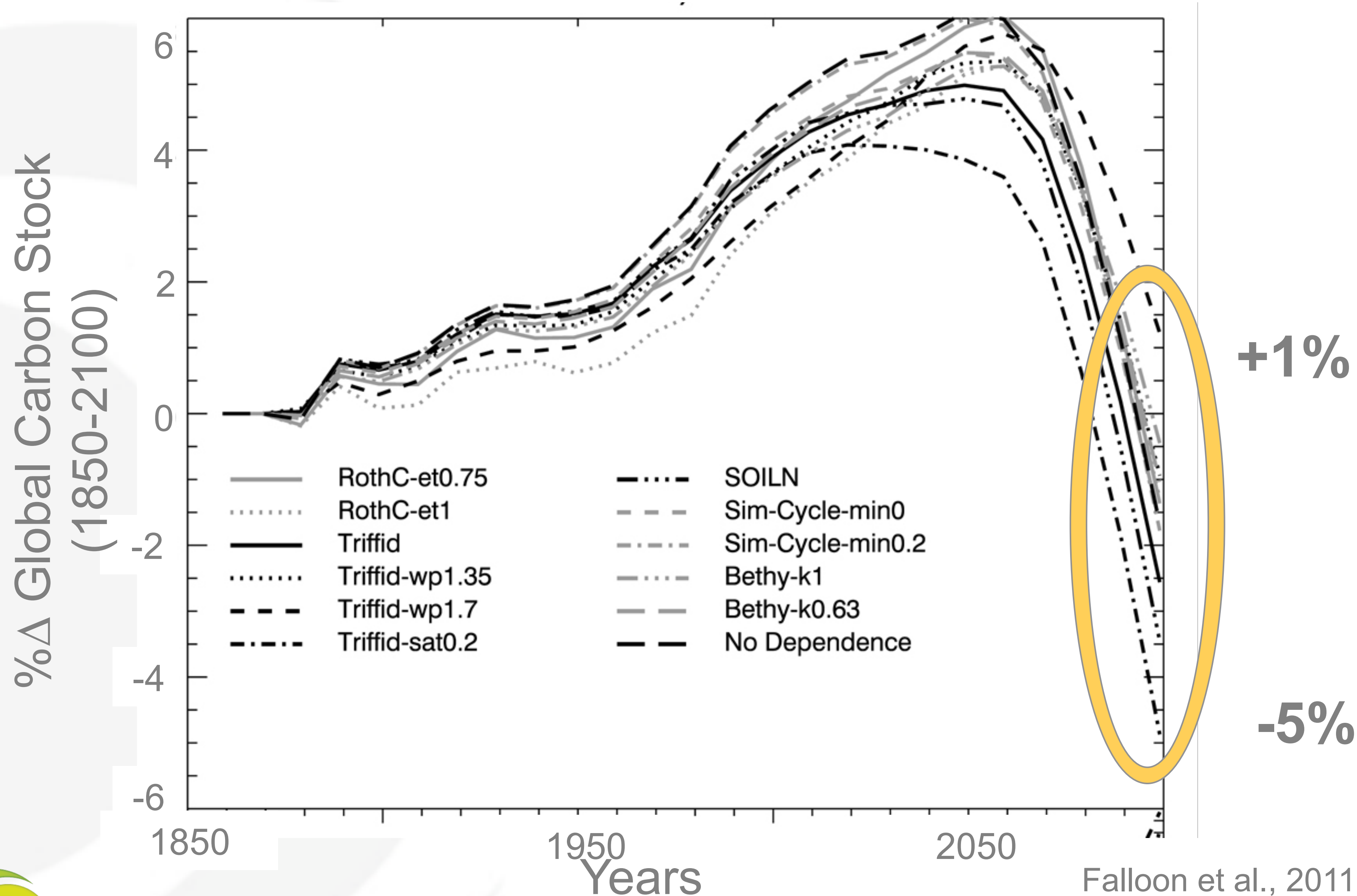


$$\frac{\partial SOC}{\partial t} = I - k \times SOC \times \theta \times \tau$$

θ is a rate modifier ($0<\theta<1$)

Falloon et al., 2011

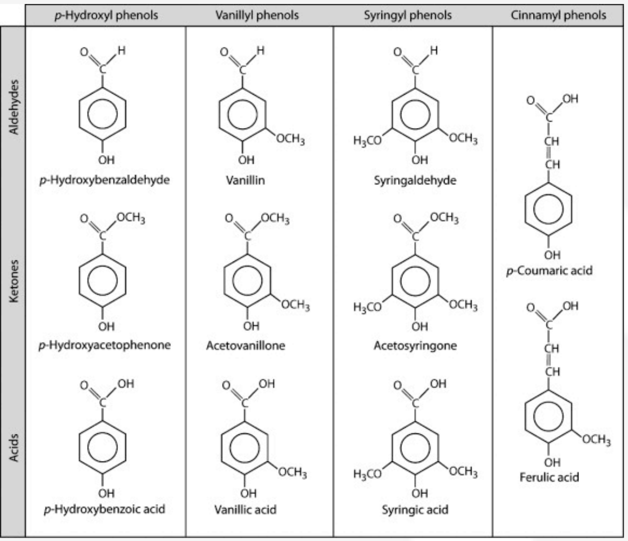
WATER AVAILABILITY



Falloon et al., 2011

SEVERAL IMPORTANT MECHANISMS ARE STILL MISSING

Chemistry



Thevenot et al., 2010

- SOM is a continuous spectrum of quality of organic matter.
- Enzymatic reactions drive by temperature.
- Discretized by non-measurable pools
- Same temperature effect for all the pools

TEMPERATURE EFFECT

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

τ is a rate modifier (0<*τ*<1)

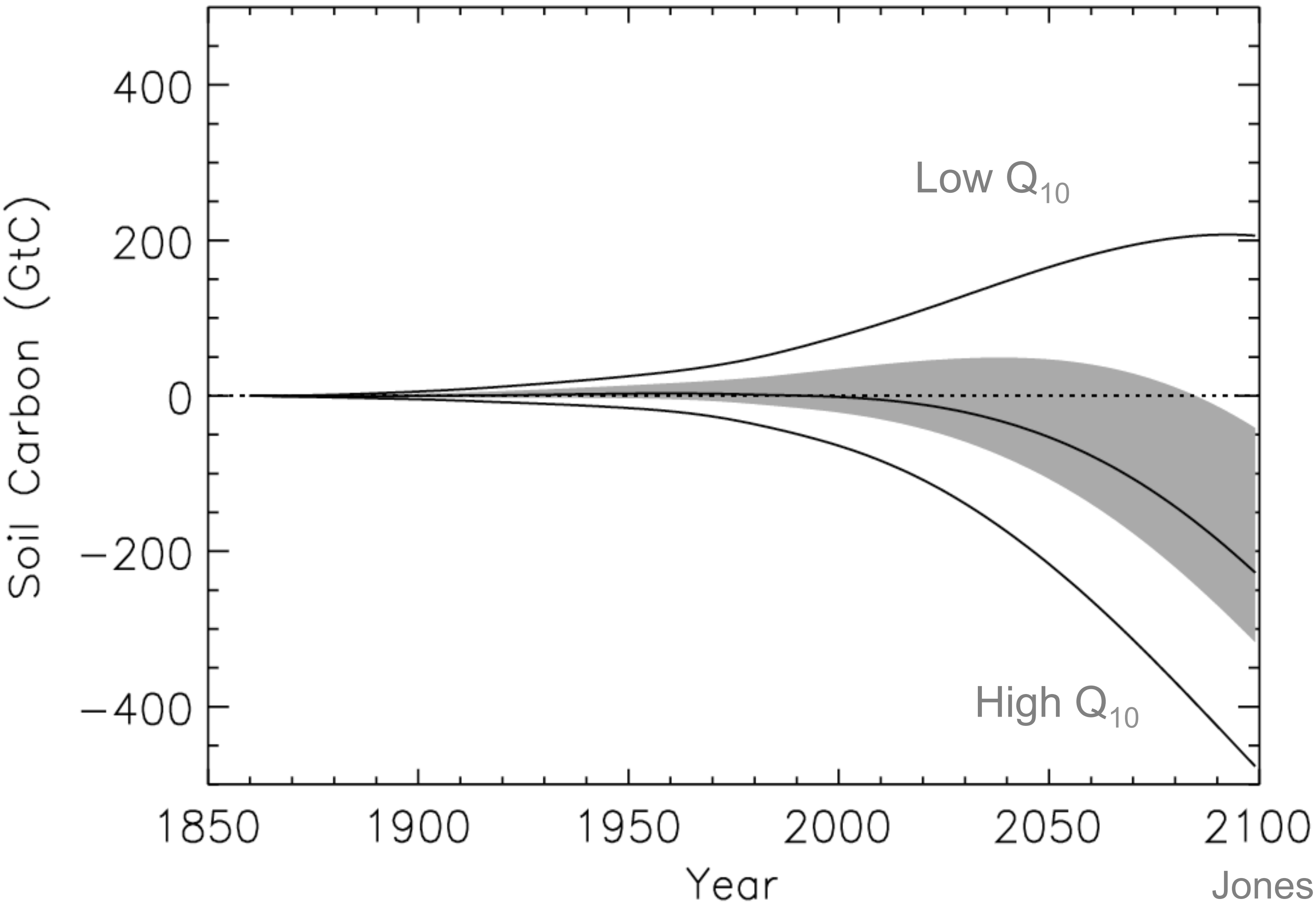
- Several ways to represent *τ*
- ESM generally used Arrhenius equation:

$$\tau = A \times e^{-Ea/RT}$$

- or Van't Hoff laws

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

TEMPERATURE EFFECT



Jones et al., 2003

SEVERAL IMPORTANT MECHANISMS ARE STILL MISSING

Biology

http://cropandsoil.oregonstate.edu

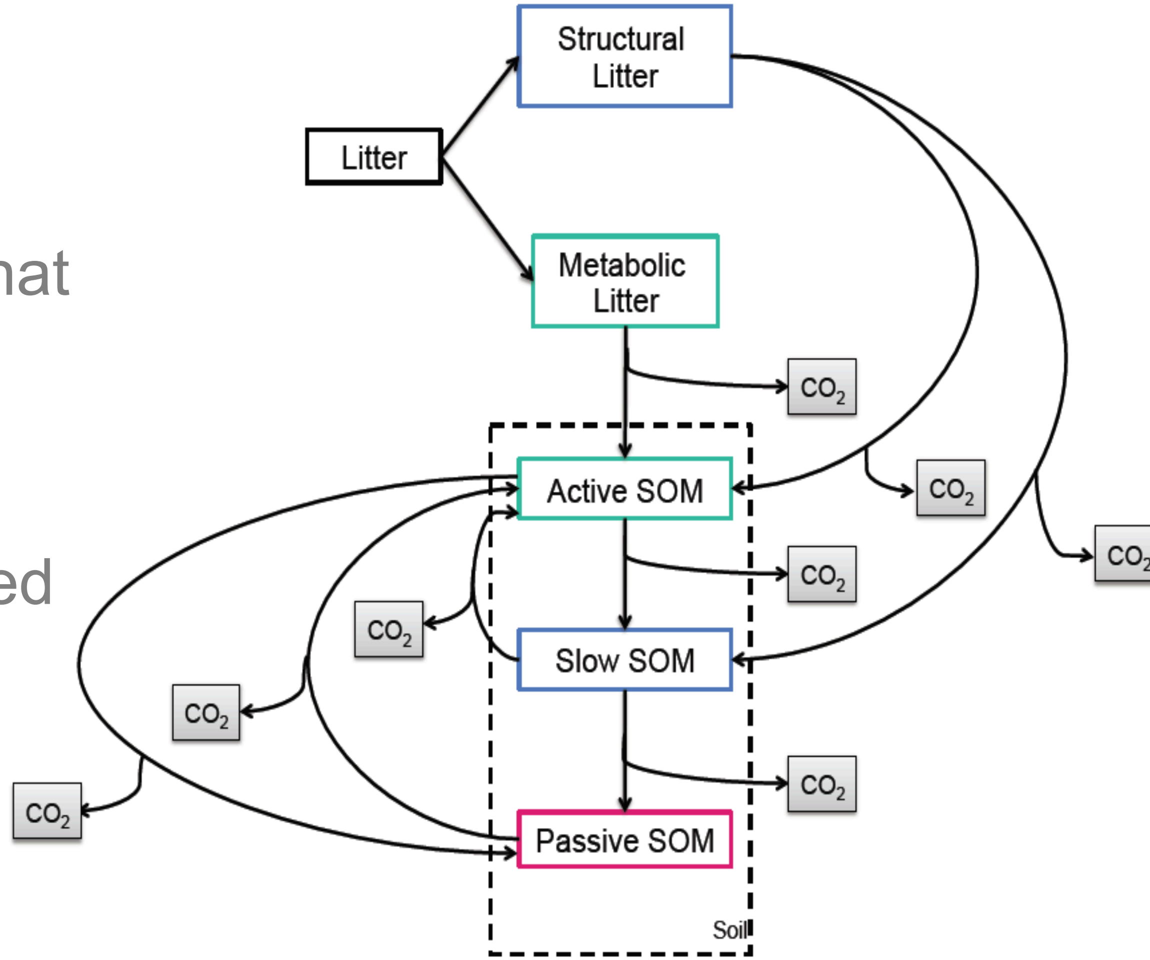
- CO_2 emissions are due to biological activity.
- Soil biology almost not represented in ESMs.

Effect of ecosystem engineers (Earthworms, ants, …)

Effect of microbial activity

MICROBIAL ACTIVITY

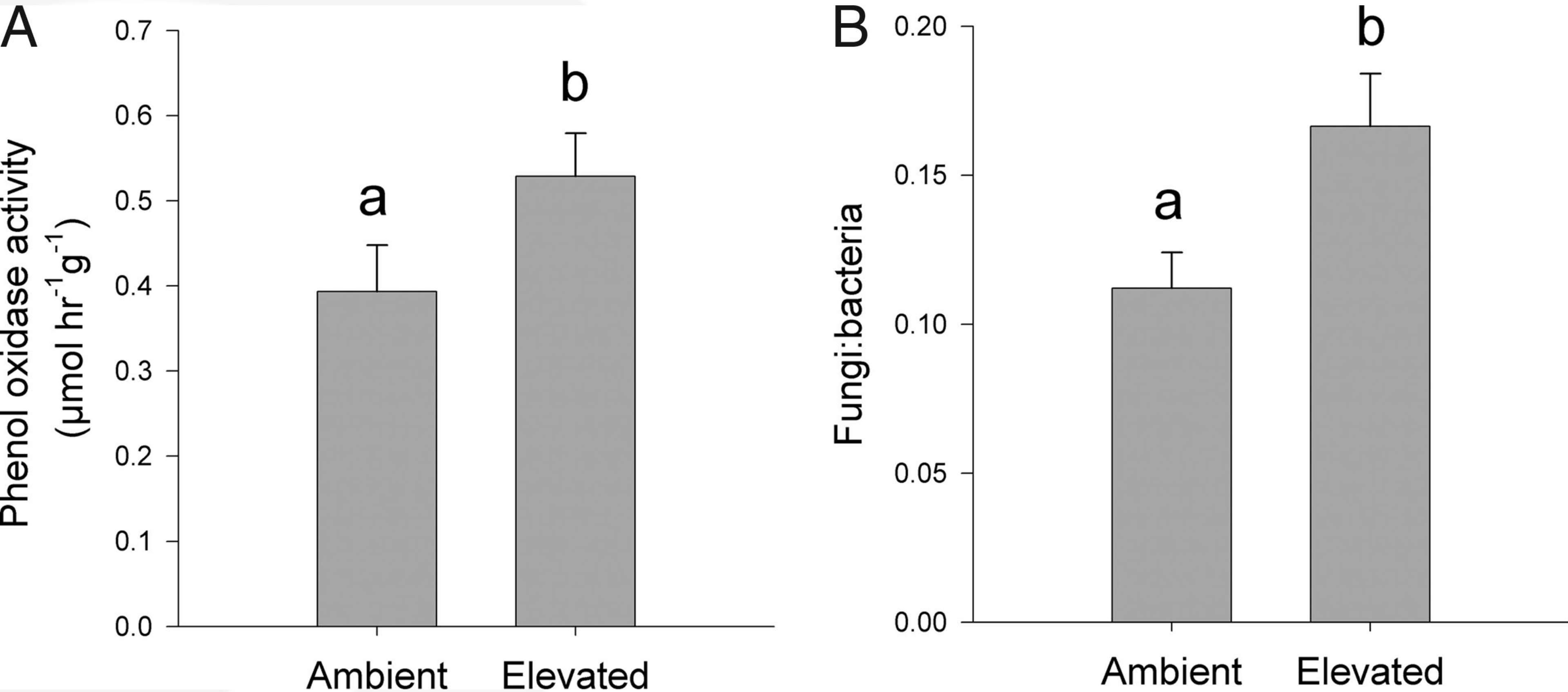
- CENTURY assumes that microbial biomass stay constant over the time.
- Mineralization controlled by soil C and not by microbial C



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

MICROBIAL ACTIVITY

- Microbial biomass, community structure and functioning is sensitive to climate change, land use change, etc.



Carney et al., 2007

MEAN RESIDENCE TIME

- Based on 14C data, ESM MRT are overestimated by ~40%

Table 1. Global soil carbon stocks and carbon uptake for CMIP5 models that experienced a quadrupling of atmospheric CO_2 from a preindustrial value of 285 ppm over a period of 140 years.

ESM	Initial SOC (Pg C)	% change in SOC	% change in SOC after ^{14}C con-straint	^{14}C-imposed sink reduction (%)	τ_{slow} (year)*	$\tau_{passive}$ (year)	r_f	r_s	^{14}C-imposed correction factors†			
									τ_{slow}	$\tau_{passive}$	r_f	r_s
CESM1 (BGC)	571	6.3	5.1	19	56 ± 16	1310 ± 241	0.06 ± 0.05	0.33 ± 0.05	–	3.7 ± 1.5	–	0.34 ± 0.75
GFDL-ESM2M	1344	26	3.3	87	231 ± 196	–	0.17 ± 0.07	–	16 ± 18	–	0.06 ± 0.14	–
HadGEM2-ES	1028	63	33	46	208 ± 84	–	0.12 ± 0.07	–	17 ± 12	–	0.07 ± 0.32	–
IPSL-CM5A-LR	1340	27	25	5.9	218 ± 82	1181 ± 347	0.06 ± 0.03	0.29 ± 0.07	–	14 ± 8.3	–	0.07 ± 0.14
MRI-ESM1‡	1403	36	22	40	347 ± 117	1065 ± 257	0.17 ± 0.09	0.10 ± 0.06	–	13 ± 7.2	0.46 ± 0.79	0.34 ± 0.74
Mean§	1137 ± 312	32 ± 18	18 ± 12	40 ± 27	212 ± 104	1185 ± 123	0.12 ± 0.06	0.24 ± 0.12	16.5 ± 0.5	10.2 ± 4.6	–	–

*τ_{slow}, $\tau_{passive}$ denote the turnover time, and r_f, r_s denote the transfer coefficient from the fast to the slow pool and from the slow to the passive pool, respectively. Reported values were estimated as an area-weighted mean and standard deviation of all model grid cells. †The mean and standard deviation of the ^{14}C-imposed correction factors were derived from using the ^{14}C observations at each site in a single optimization and then averaging these scalar adjustments across the set of 157 optimizations. ‡The ^{14}C-constrained sink reduction and correction factor for MRI were based on an inverse analysis that changed the pool size of both slow and passive pools. The reported percentage change in SOC and sink reduction were derived from transient simulations starting at steady state with the reduced complexity model. See methods in the supporting materials. §The multimodel mean and standard deviation were estimated using the mean value from each of the five ESMs.

He et al., 2016

ONGOING DEVELLOPEMENT

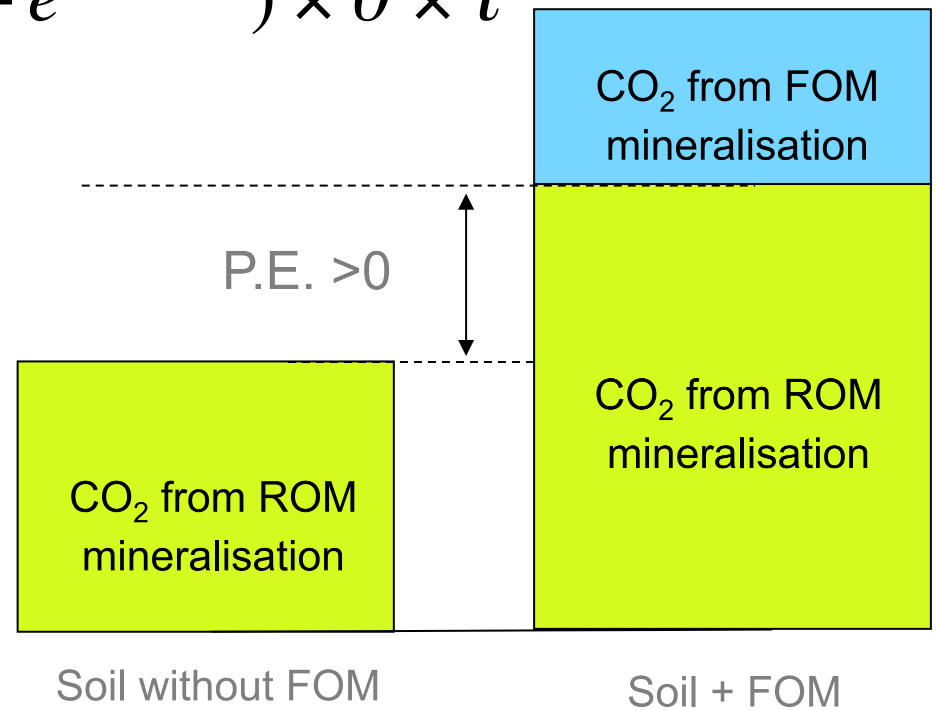
- Representation of the soil C profile
- Lateral outputs of C (DOC, Erosion)
- Representation of Priming effect.
- Carbon isotopes (^{14}C and ^{13}C)
- Peatlands

A NEW SCHEME OF DECOMPOSITION

Based on Wutzler and Reichstein (2008) and adapted by Guenet et al., (2013)

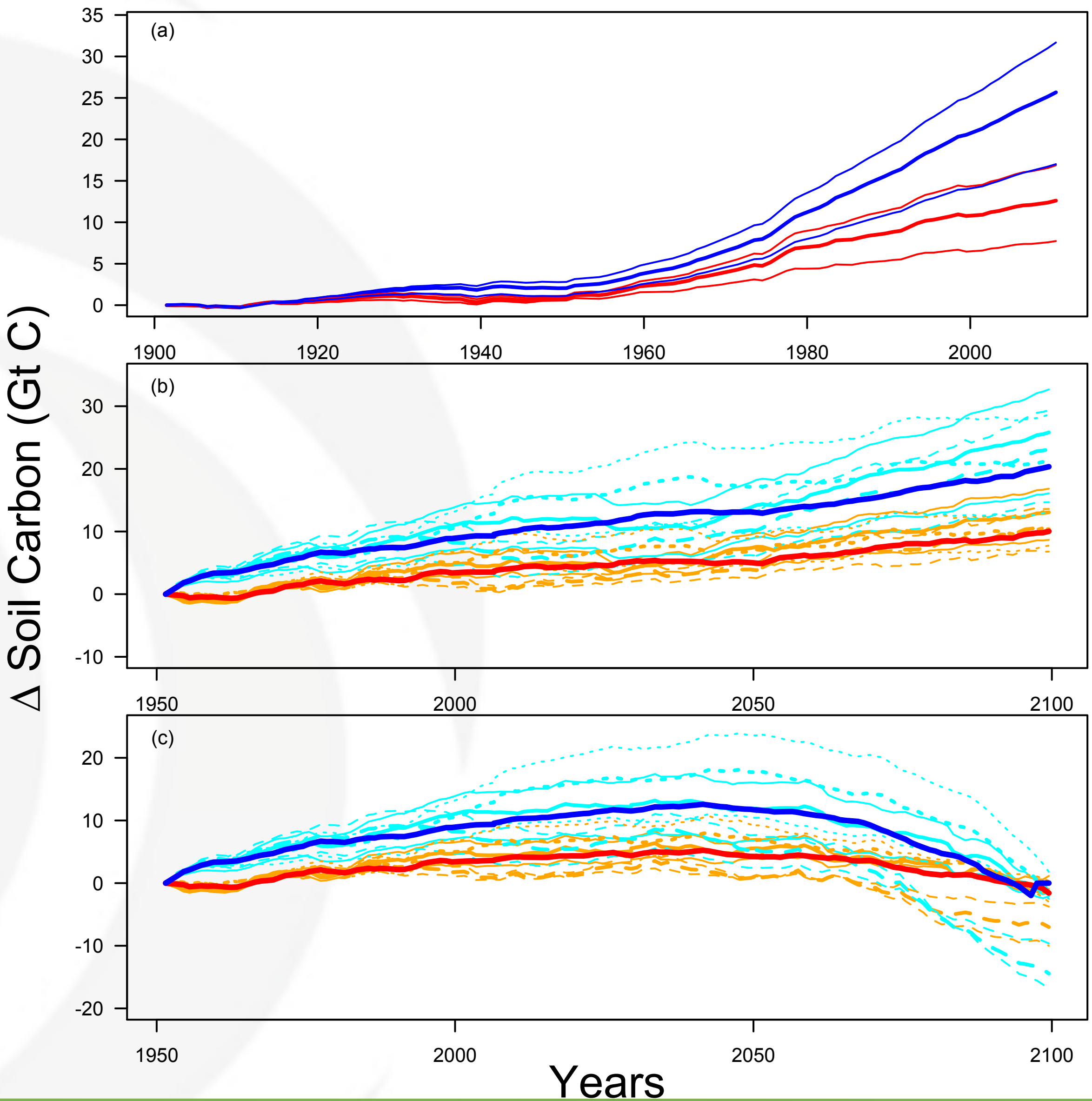
$$\frac{\partial SOC}{\partial t} = I - k_{SOC} \times SOC \times (1 - e^{-c \times FOC}) \times \theta \times \tau$$

- Such approach is able to reproduce priming effect
- Assumes that microbial biomass is always in equilibrium with FOC



Adapted from Kuzyakov *et al.*, (2000)

ONGOING DEVELLOPEMENT

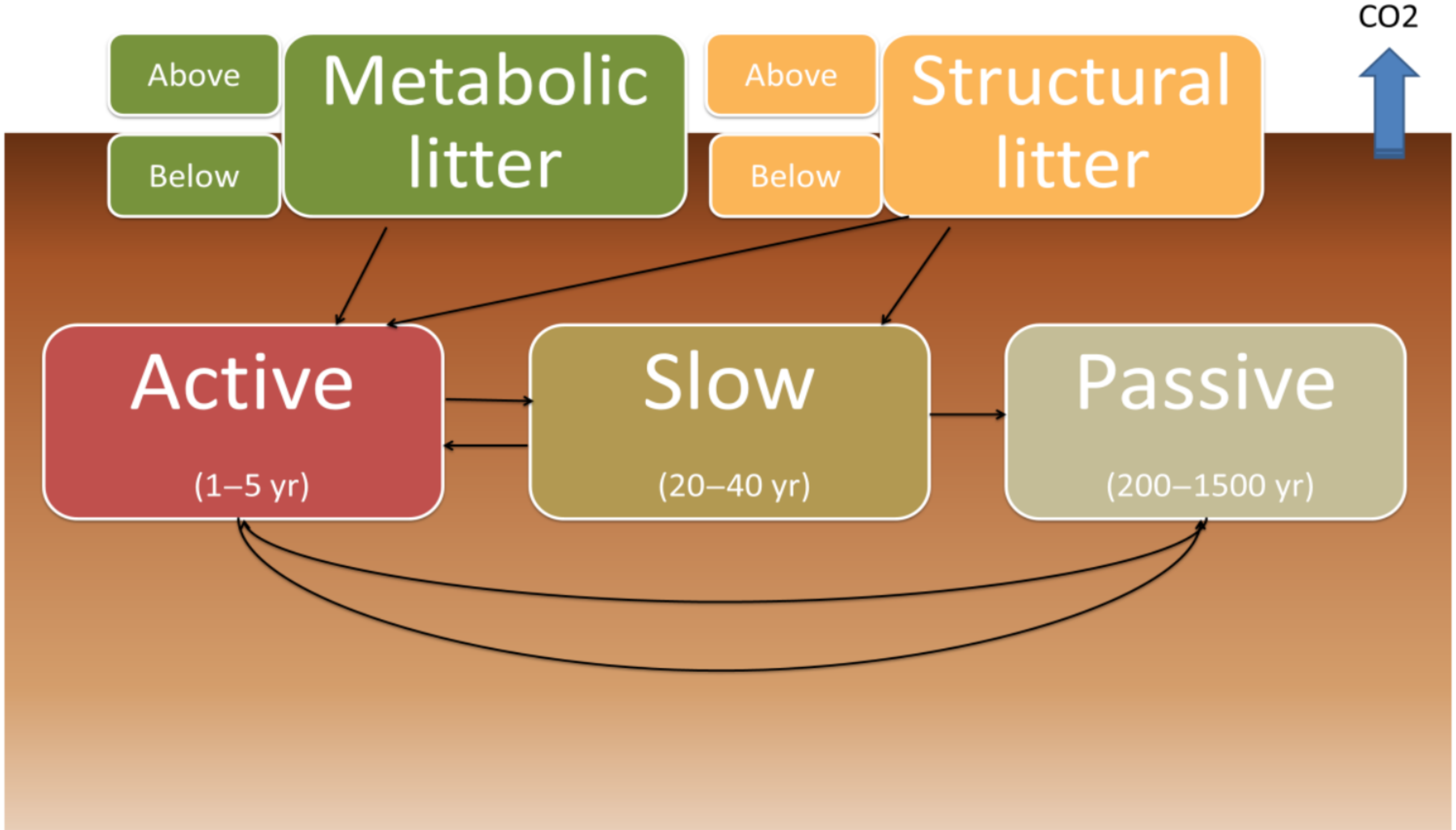


Soil Carbon discretization

- Any models used for CMIP5 represent the soil C profiles.
- A substantial part of the soil C stored in deep layers (Jobbagy and Jackson, 2000)
- Deep C dynamic different from surface C (Fontaine et al., 2007)
- In ORCHIDEE any C is lost by drainage or runoff instead of the importance of allochtonous C in the aquatic ecosystems functionning (Cole et al., 2007, Bianchi et al., 2011)

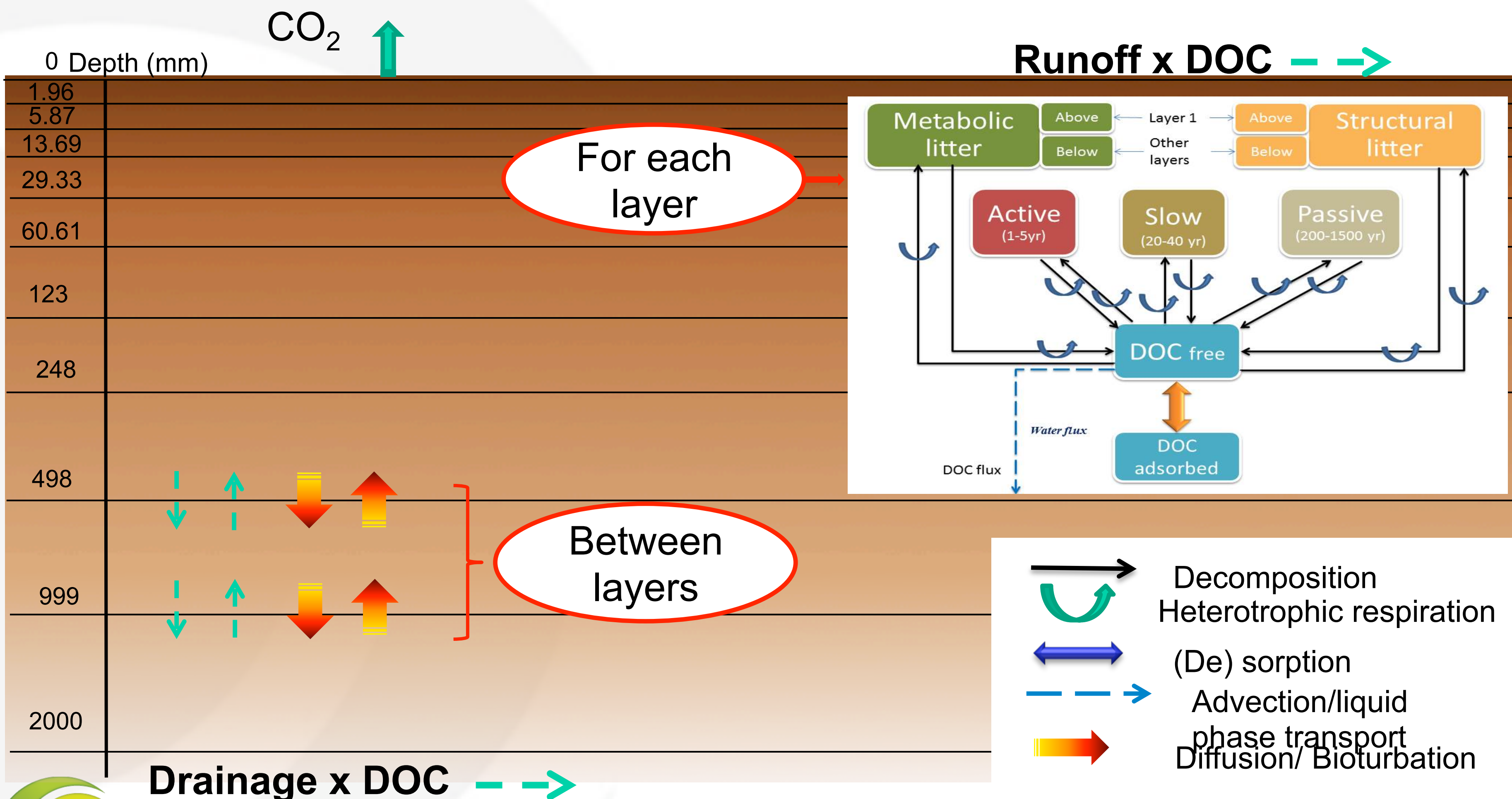
Soil Carbon discretization

ORCHIDEE SVN r3340



Soil Carbon discretization

Soil C discretized using the same layers than hydrology scheme (11 layers). A new pool introduced (DOC)



Soil Carbon discretization

- Adsorption of DOC following initial mass isotherms

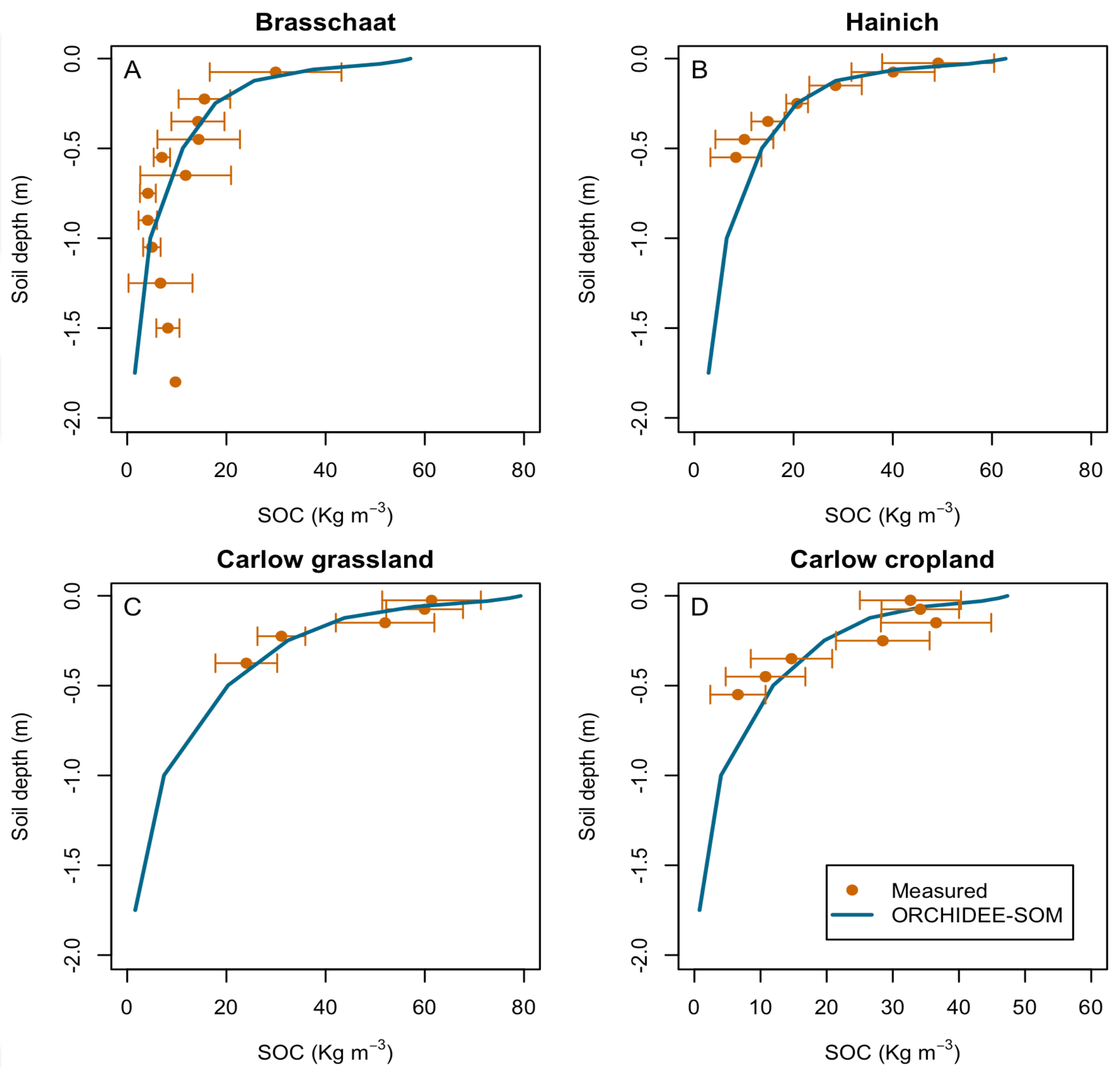
$$DOC_{ads} = Kd \times DOC_{free}$$

- DOC transported within the profile following the water movements (Futter et al., 2007) and exported following the runoff and the drainage fluxes

- POC and DOC transported using the second Fick's law

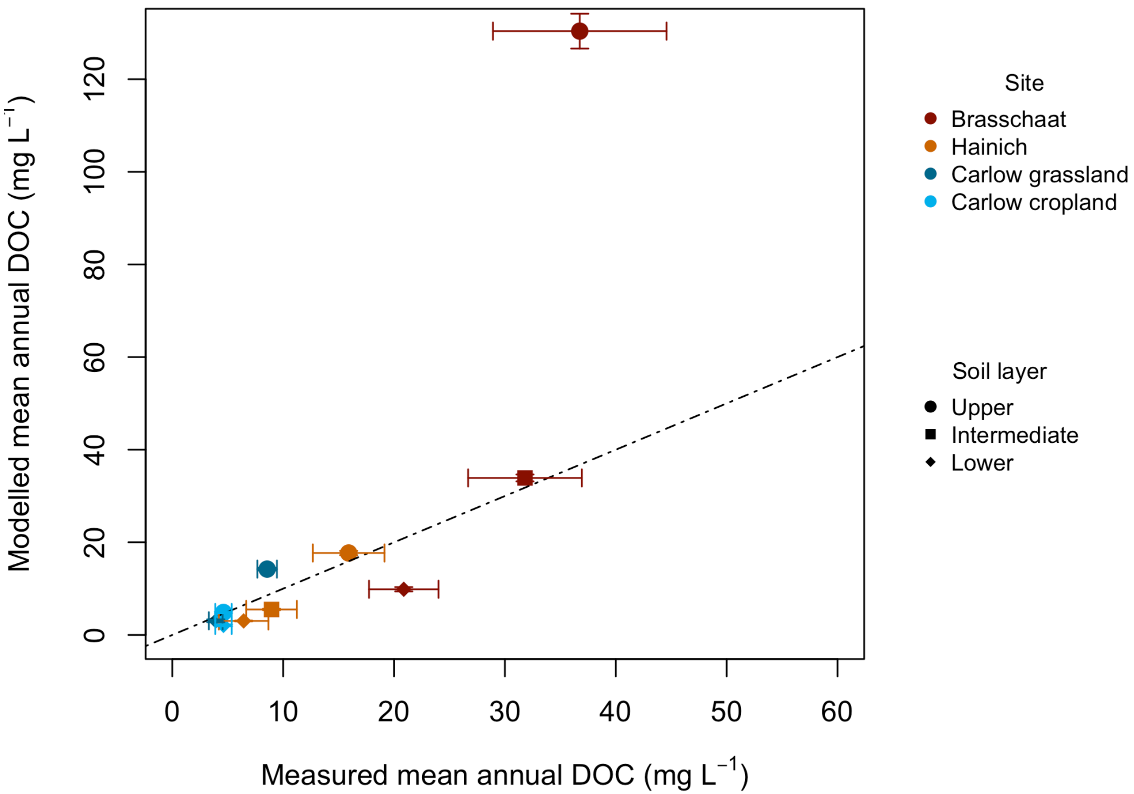
$$F_D = -D \times \frac{\partial^2 C}{\partial z^2}$$

SITE SIMULATIONS



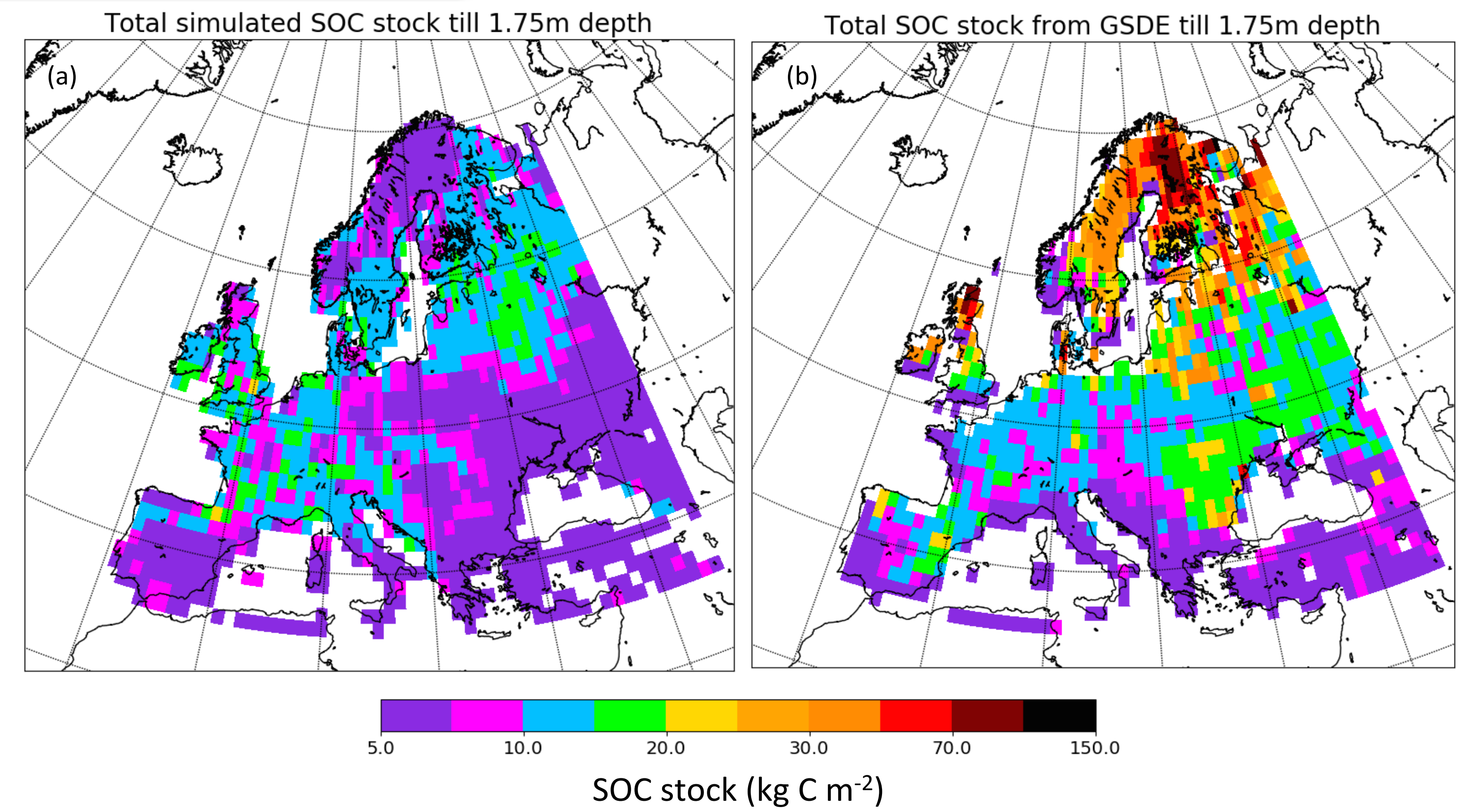
Camino-Serrano et al., (2018)

SITE SIMULATIONS



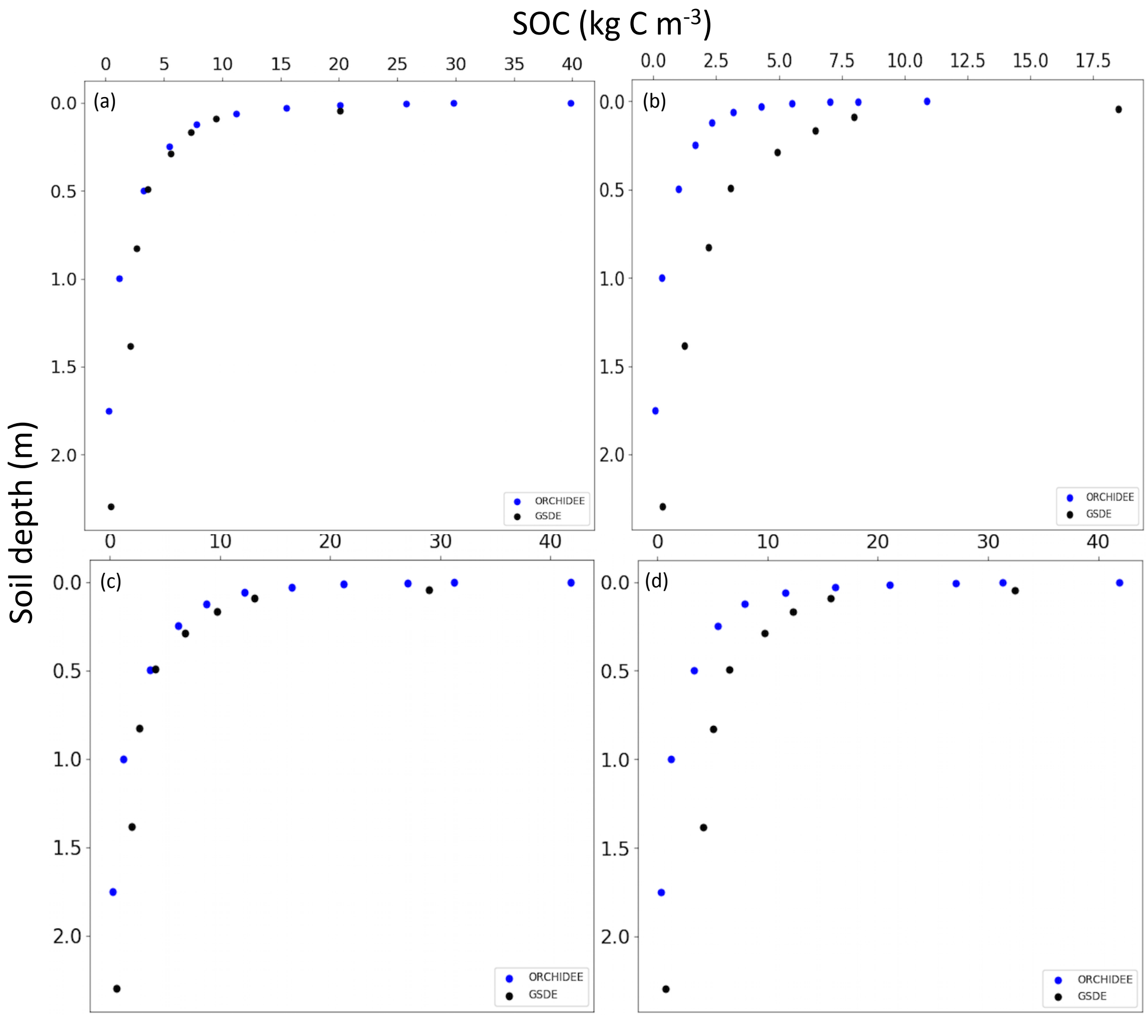
Camino-Serrano et al., (2018)

OVER EUROPE



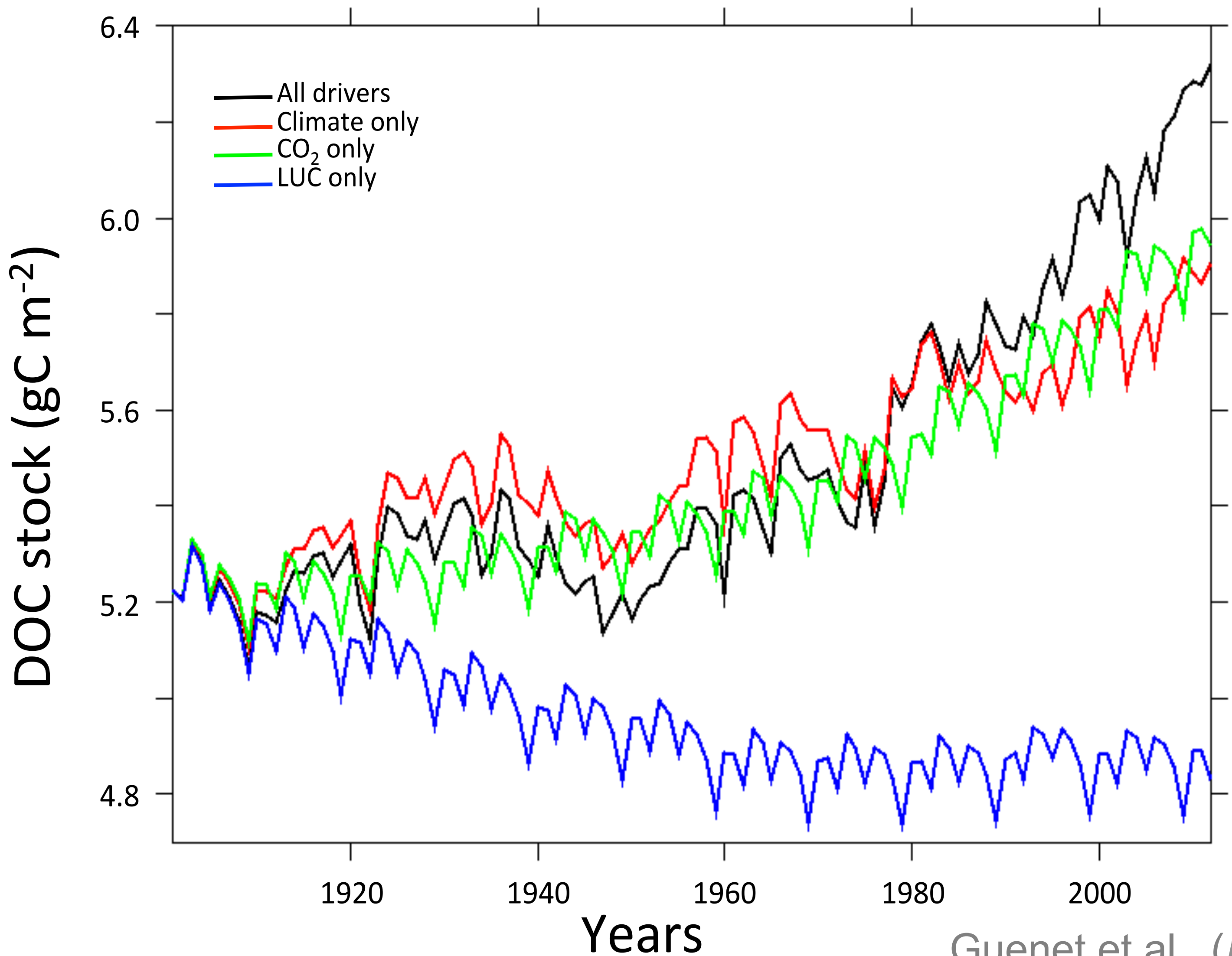
Guenet et al., (*In prep*)

OVER EUROPE



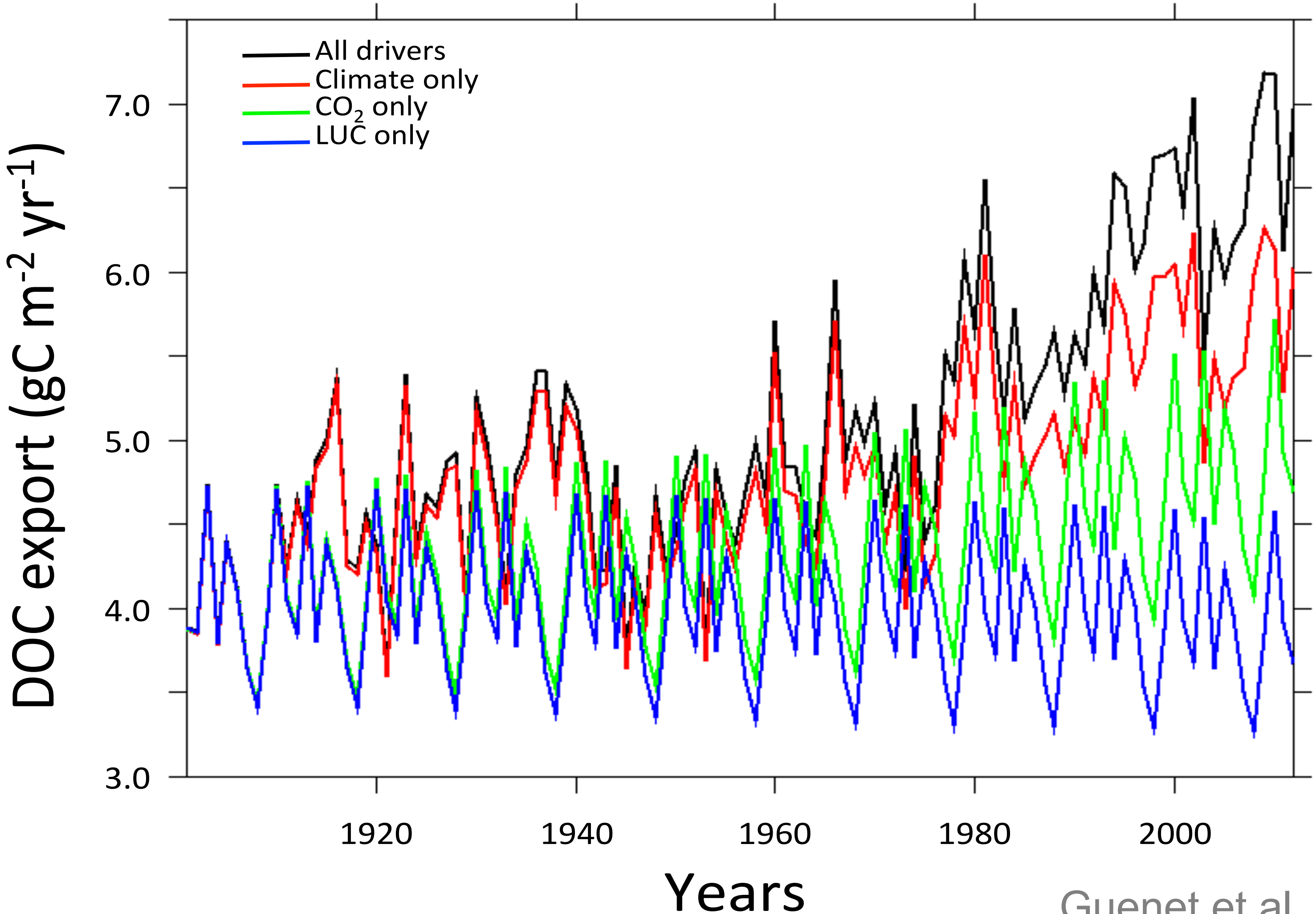
Guenet et al., (*In prep*)

OVER EUROPE



Guenet et al., (*In prep*)

OVER EUROPE



Guenet et al., (*In prep*)

THANK YOU FOR YOUR ATTENTION!