Markus Reichstein

The importance of multiple observational constraints for modelling soil organic matter cycling

Thomas Wutzler

Marion Schrumpf

Bernhard Ahrens

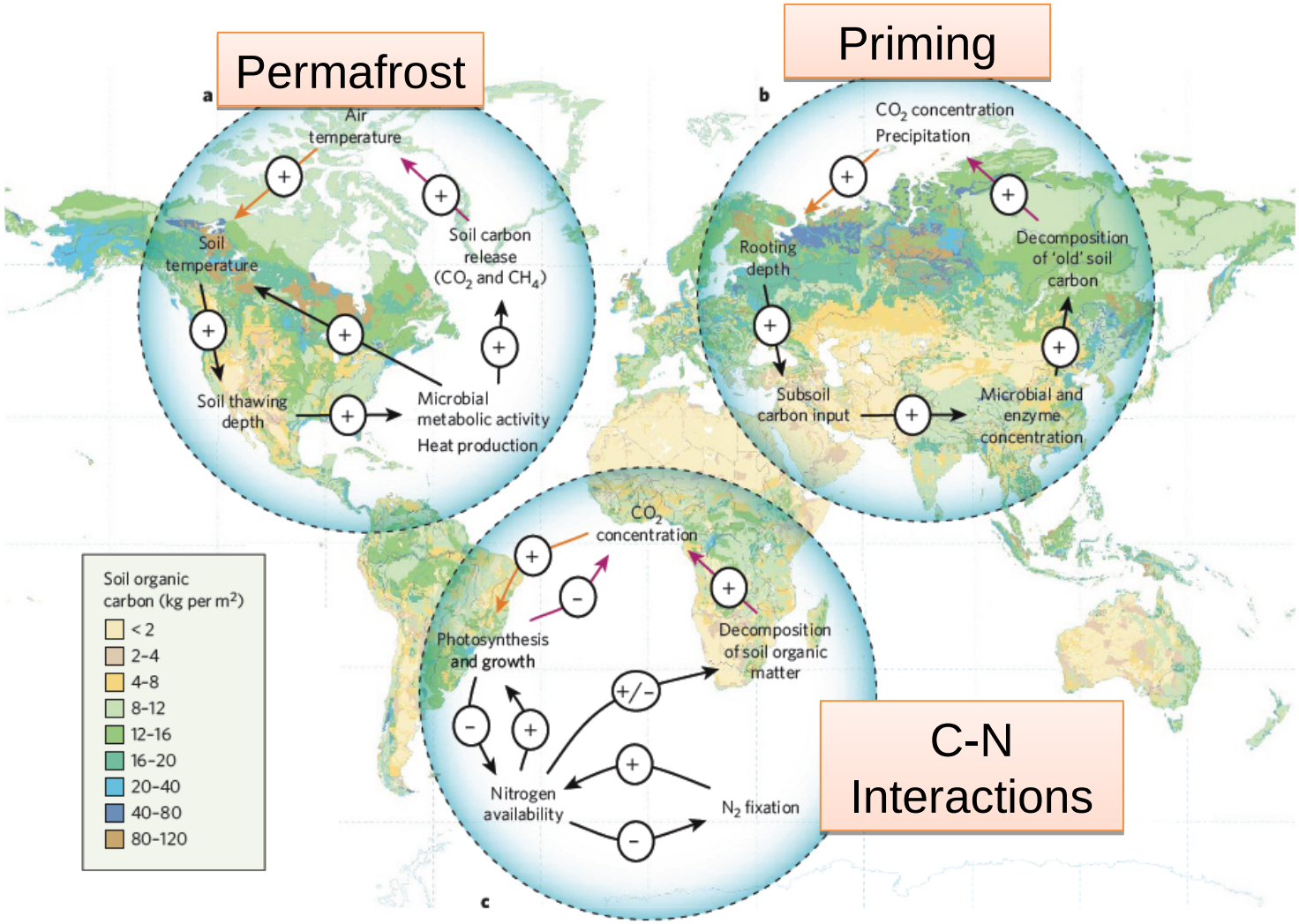
Thomas Wutzler, Markus Reichstein, Bernhard Ahrens, Marion Schrumpf, Sönke Zaehle

MPI-Biogeochemistry, Jena

Sönke Zaehle

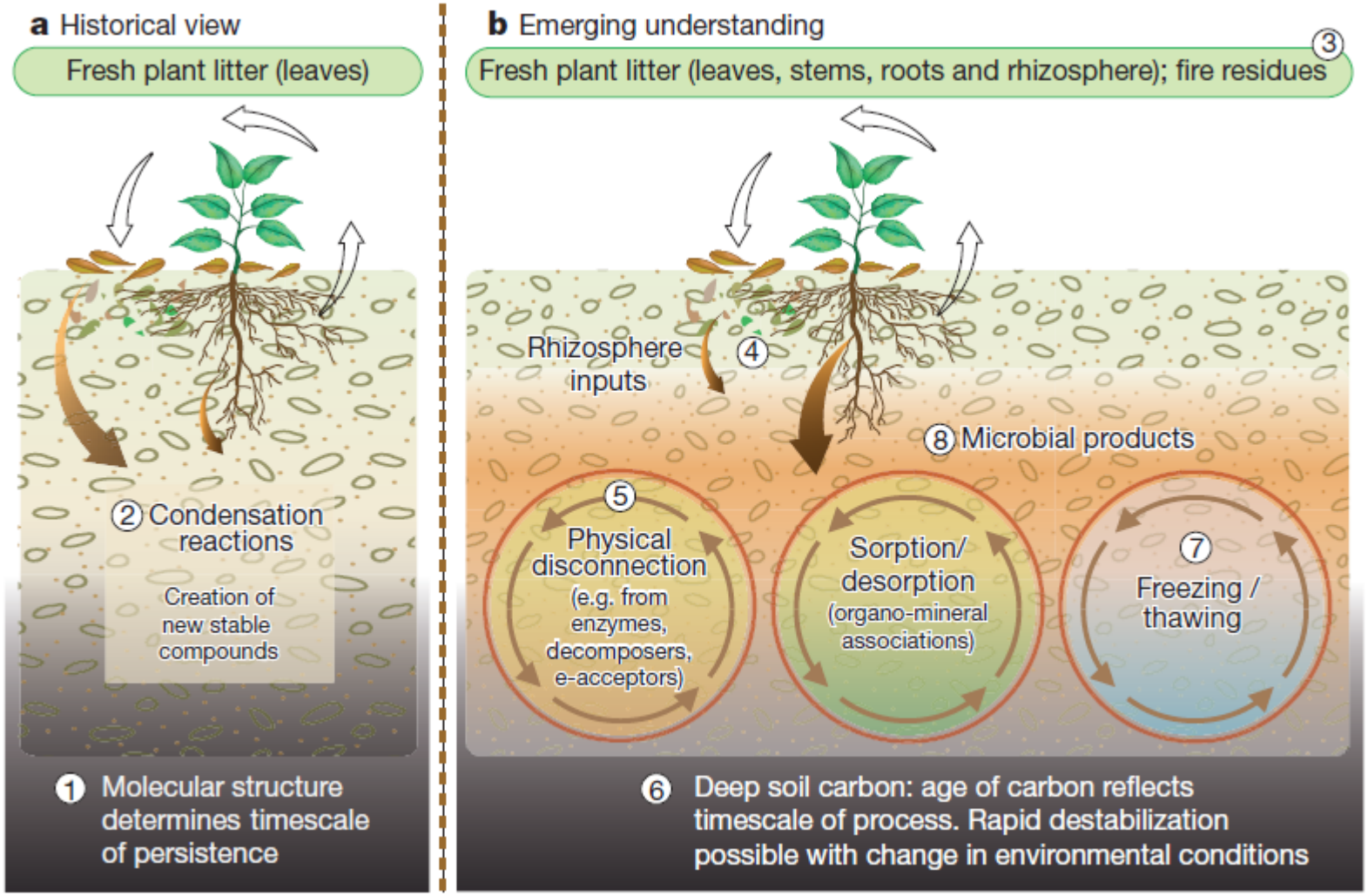
Isocycles 2017 : 15-20 October, Monte Verità, Ascona, Switzerland

Soils feed back to climate change



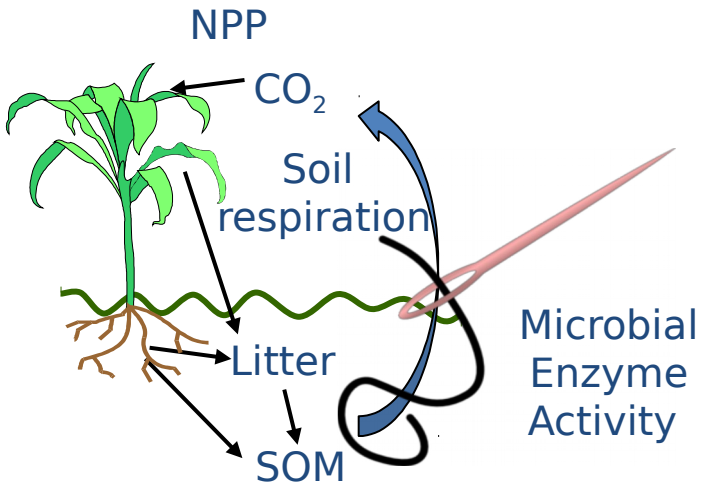
Heimann M & Reichstein M (2008)

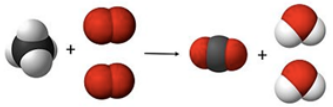
SOM explained by ecosystem properties
more than by chemical litter properties



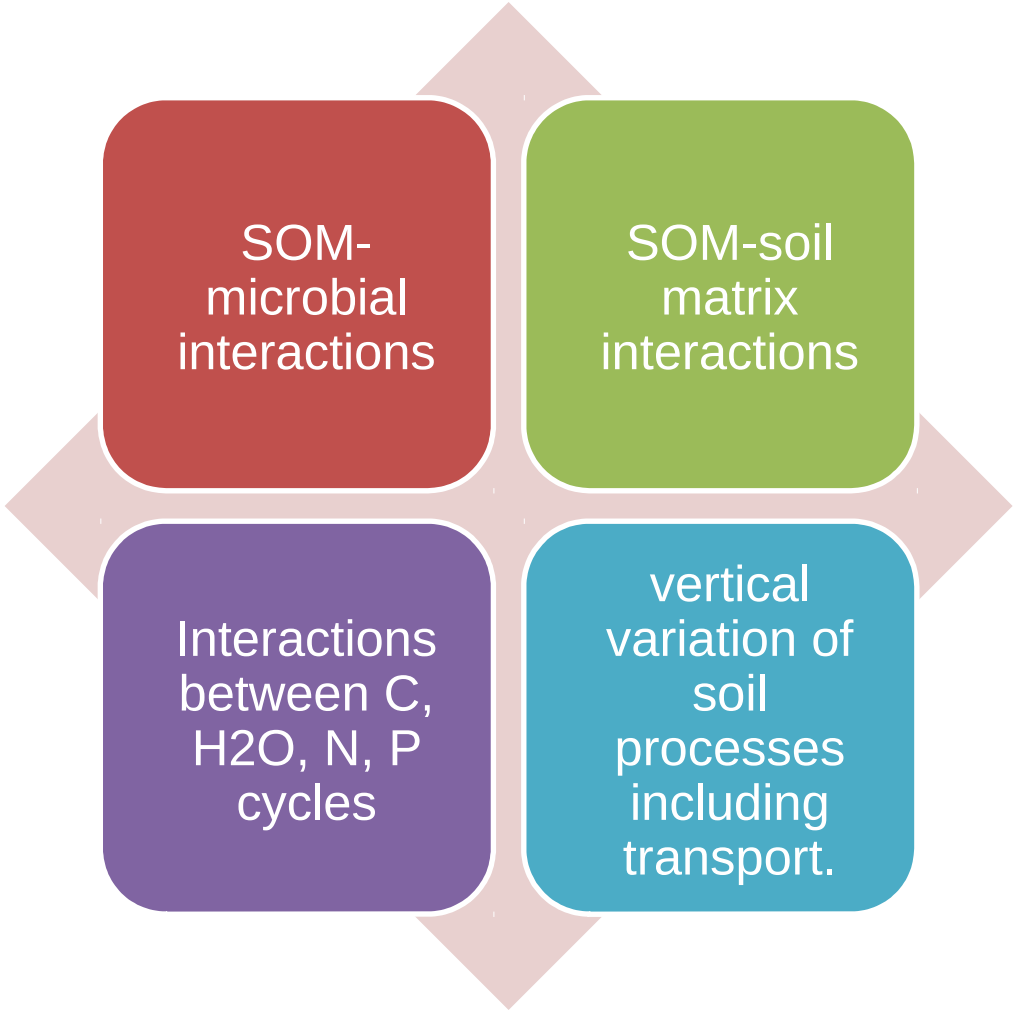
Schmidt M, et al. (2011)

Soil microbes couple C and N cycle
by narrow stoichiometric constraints



- "The eye of the needle"
- Stoichiometry:  Microbes need about 1 mol N per 25 mol C (C/N = 25)
- Control mineralization flux
  - C: respiration
  - N: to inorganic N
    - Leaching
    - Plant availability

Essential requirements for SOM models



Outline

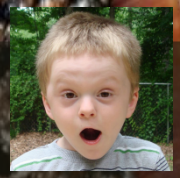
What is a surprise ? => mental models

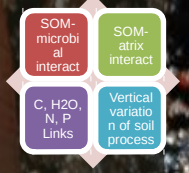
Soil model developments

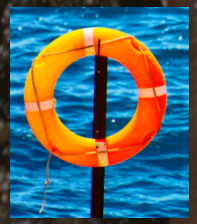
Equifinality: Isotopes to the rescue

Challenges with multiple data streams

Discussion: ^{13}C to study microbial processing







What is a surprise?
or
On modelling for data interpretation

A surprise…

… is an observation we have not expected

(very subjective!)

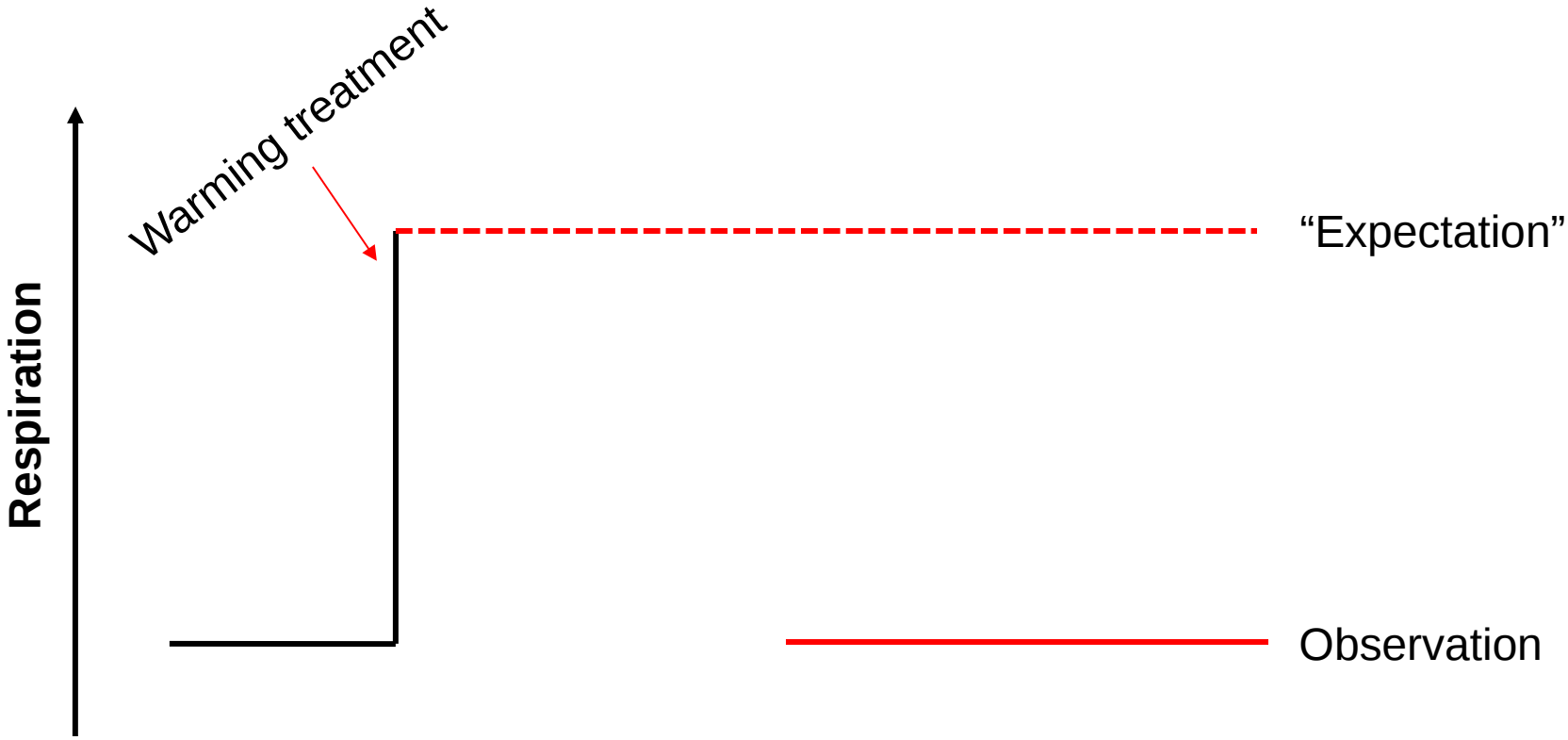
Better: … is an observation which would not have predicted by our (mind) model.

 model needs to be made explicit.

➔ “Given our current understanding embedded in model XYZ, observation ABC is unexpected (or unlikely).”

 No model, no surprise !!

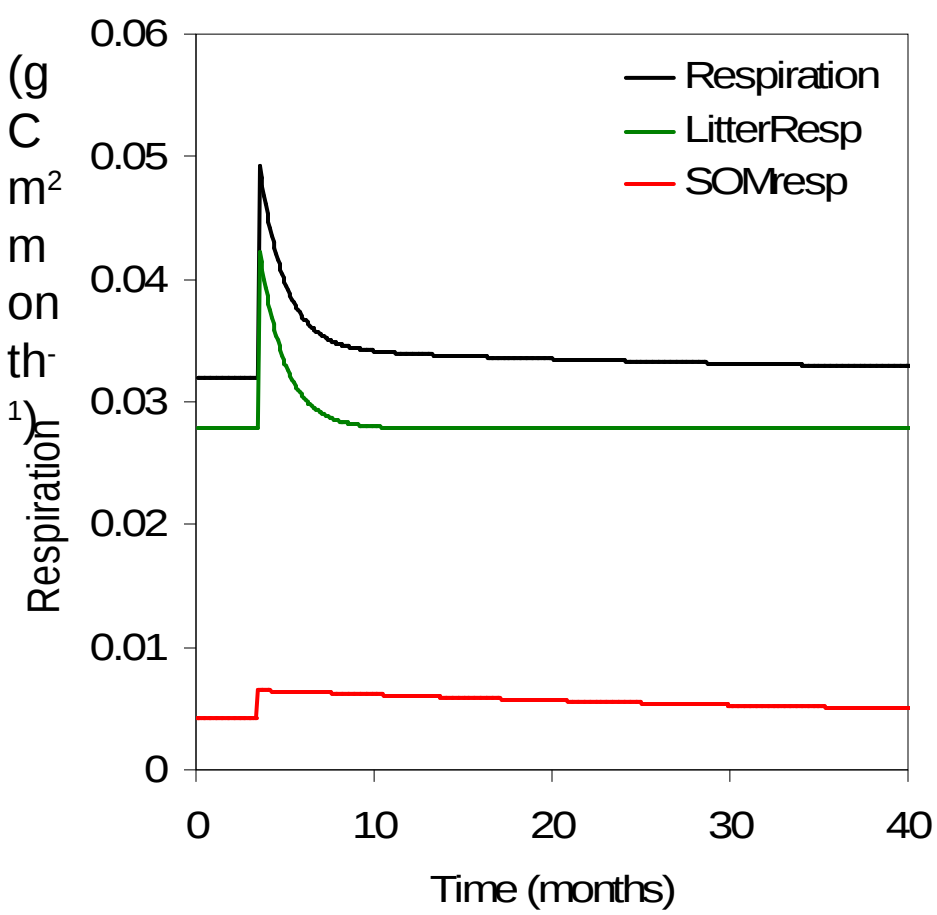
Example: warming experiment

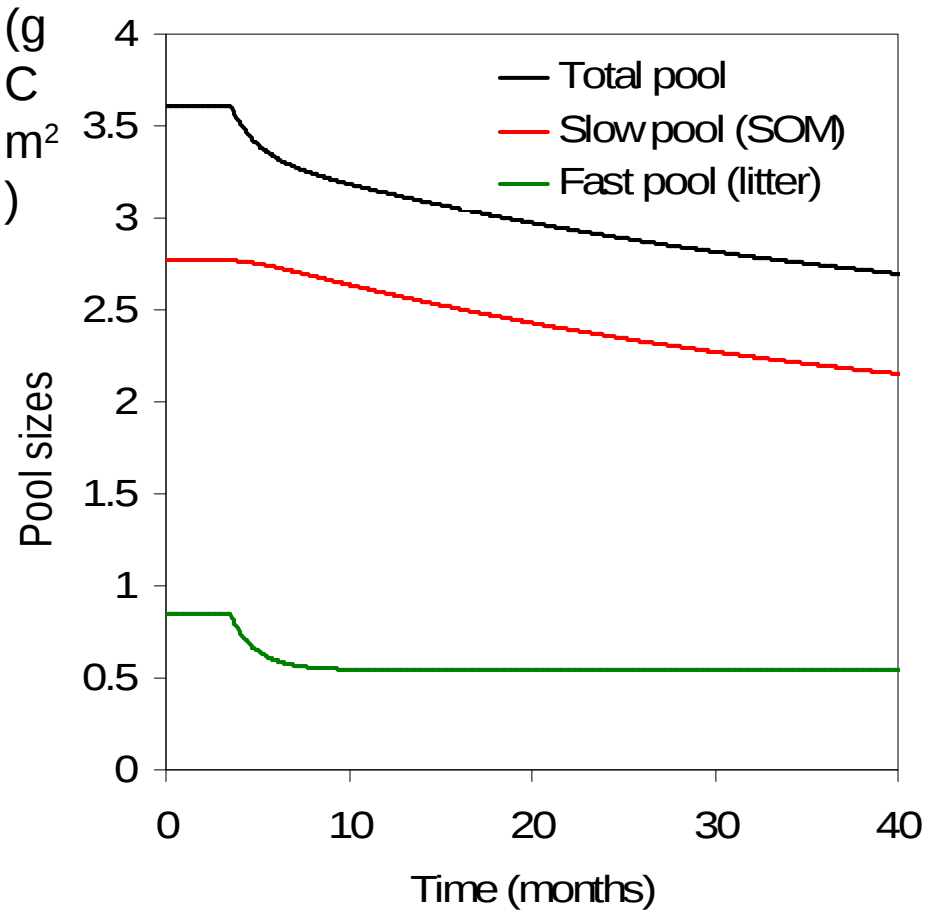


mental model: non-dynamic system

Complicated explanation for “surprise”: acclimation

Response to a soil warming (model experiment)





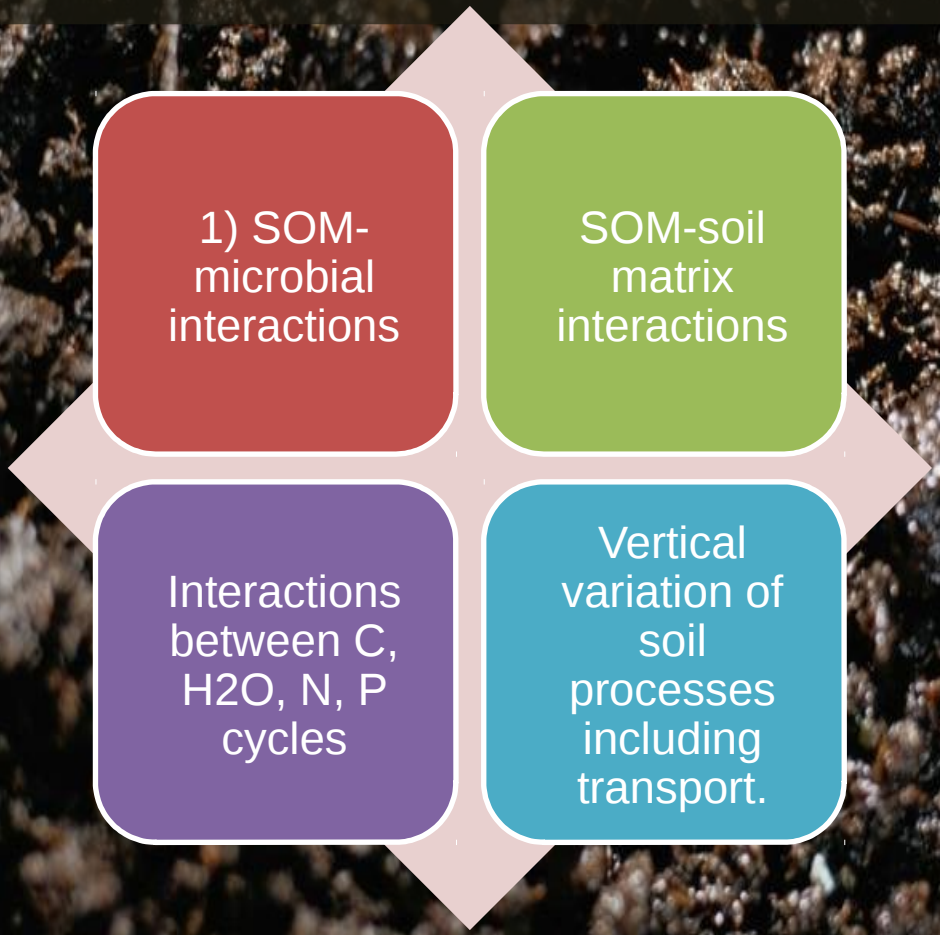
What is a surprise?

What is your mental model?

Make it explicit.

Long-term: balance you inputs

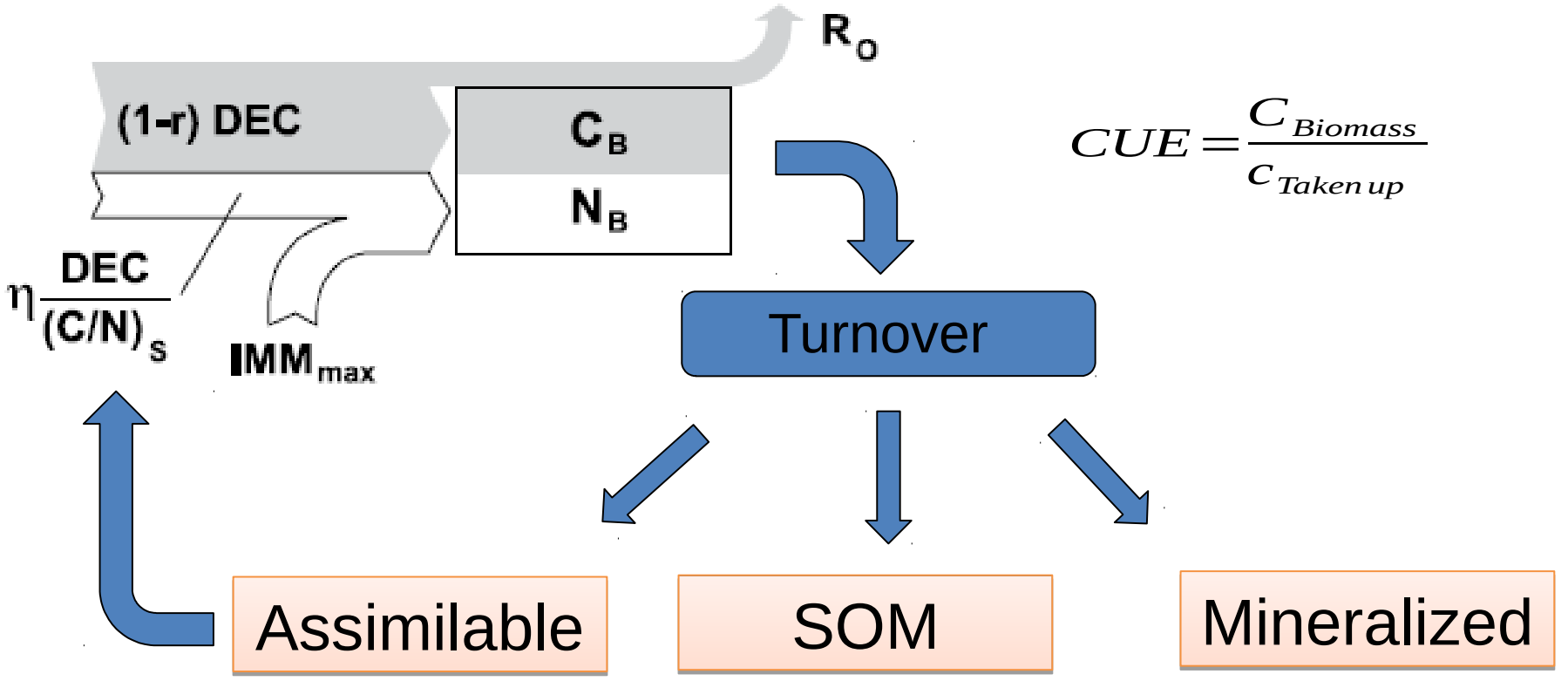
Soil Model developments



1) SOM-microbial interactions

3) C-N Interactions

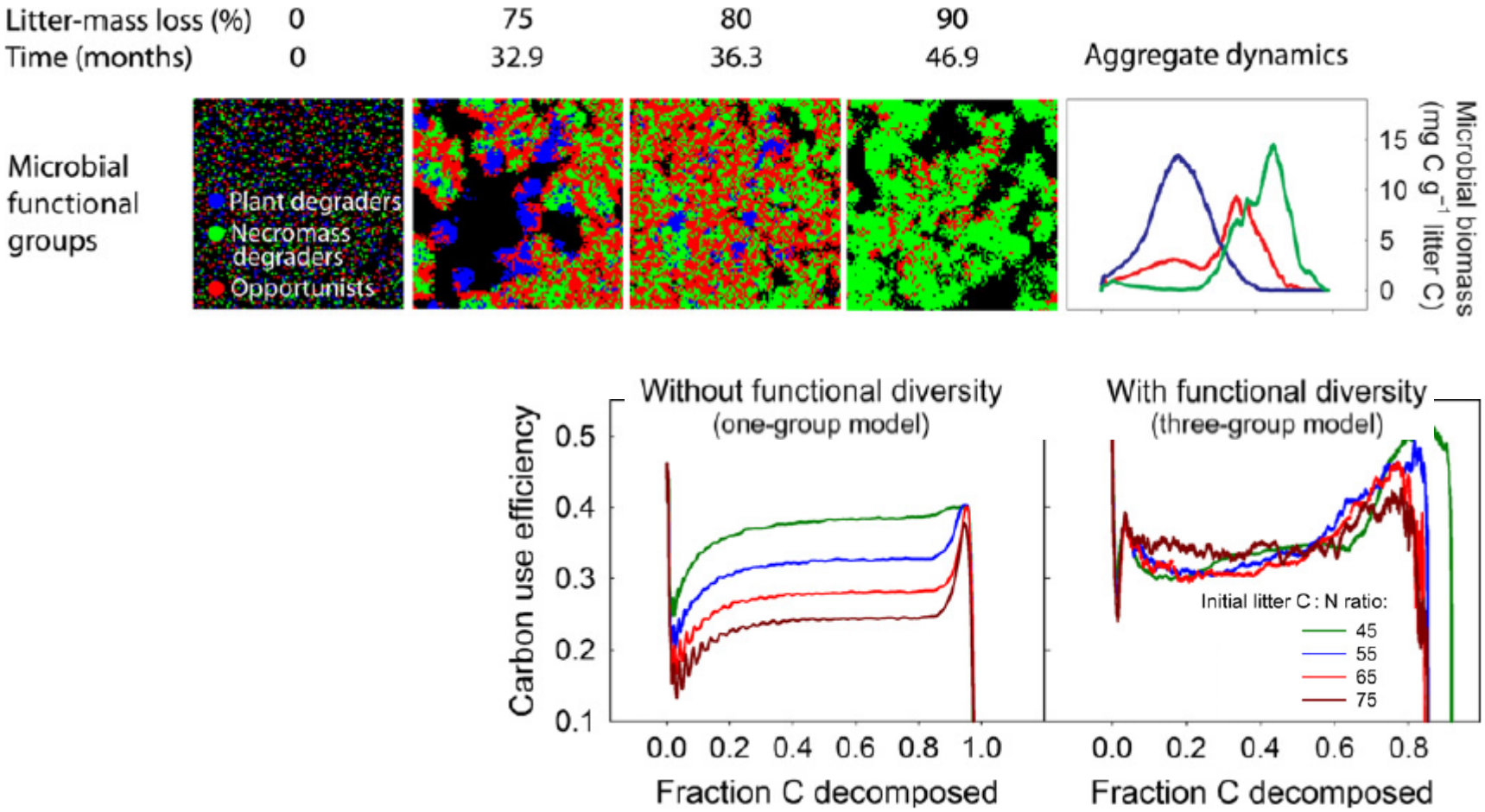
Microbial turnover
partitions between recycling and SOM



$$CUE = \frac{C_{Biomass}}{C_{Taken\ up}}$$

Adapted from Manzoni 2009

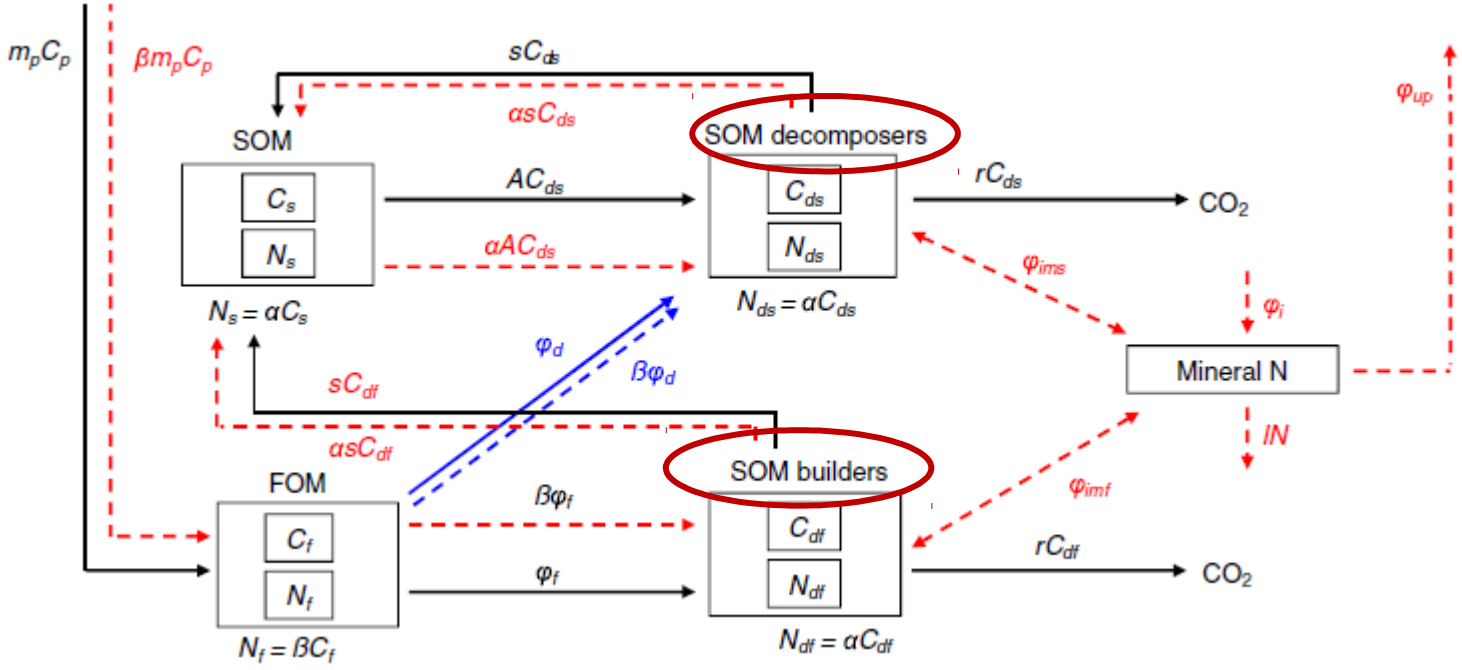
Emergent community controls on CUE by Individual based modelling



Recycling of N from microbial turnvover

Kaiser 2014

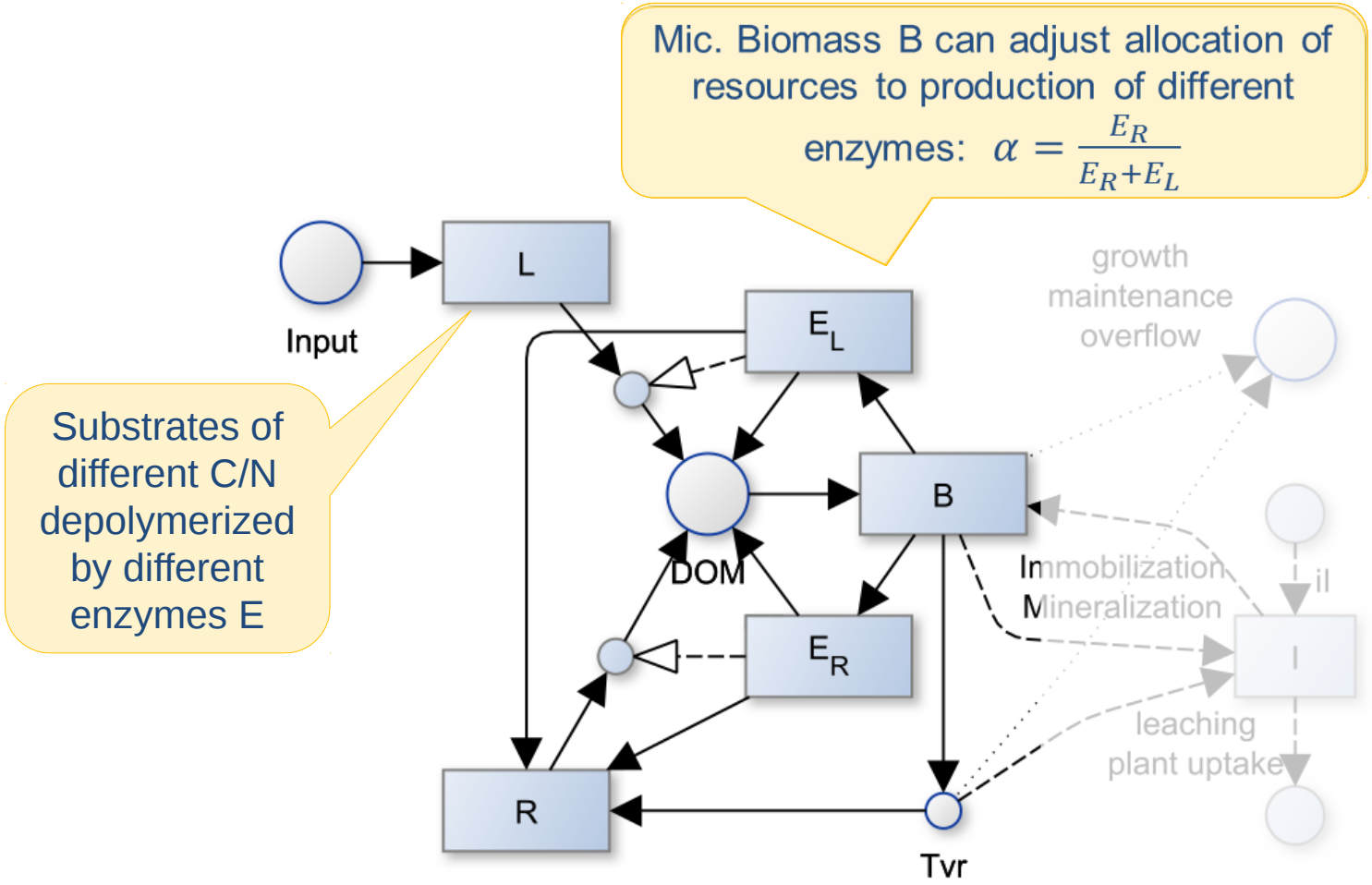
Functional groups
model adaptations to resource stoichiometry



Needs parameterization of several functional populations

SEAM models adaptation of enzyme production

Conceptual Soil Enzyme Allocation Model



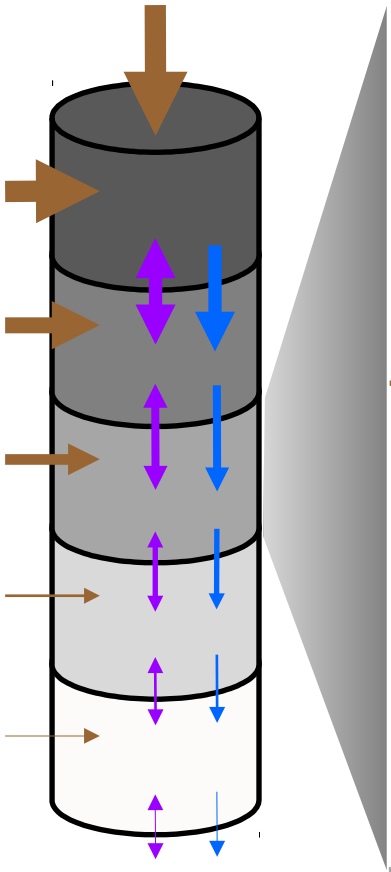
SOM-soil matrix interactions

Vertical variation of soil processes including transport.

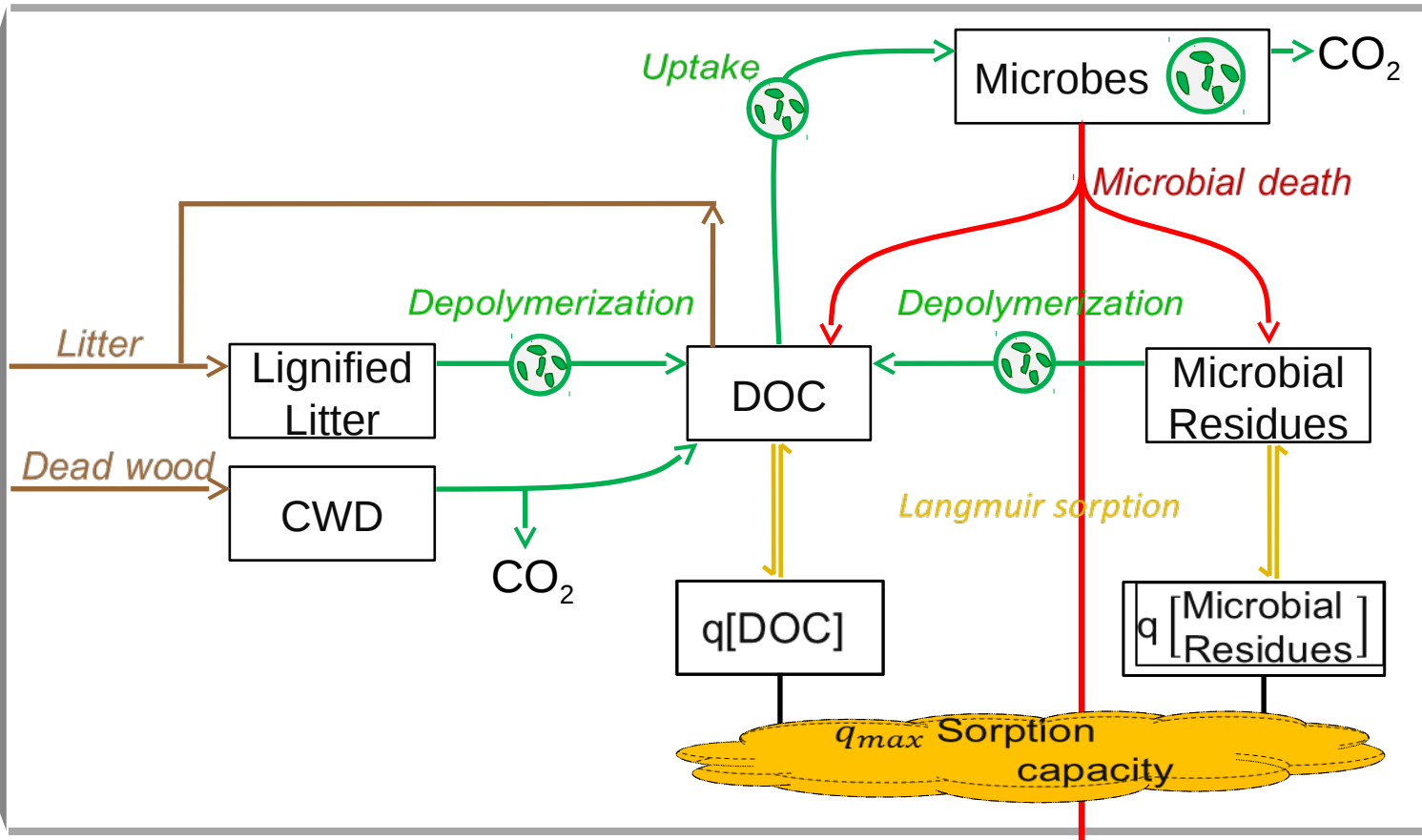
COMISSION model

Above- and belowground plant inputs

Bernhard Ahrens

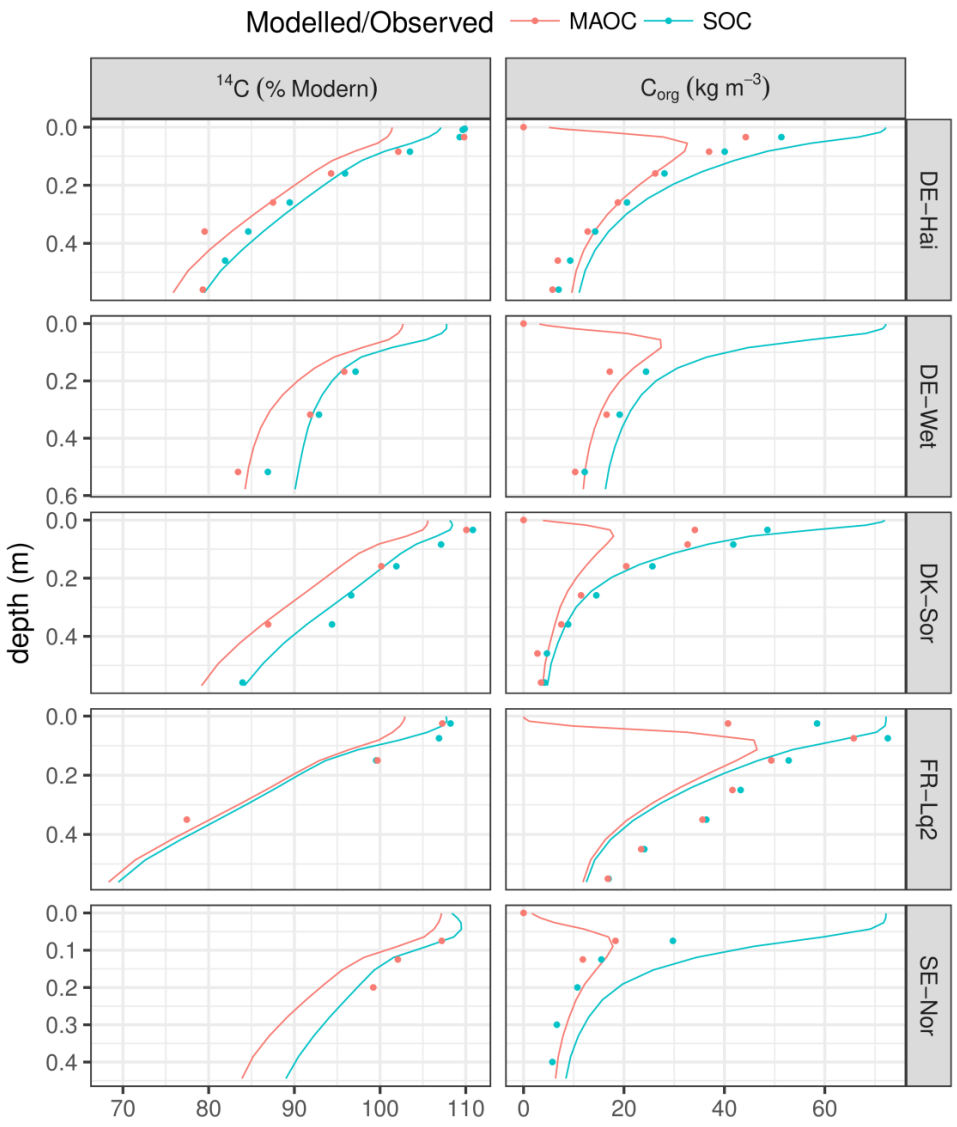


BioturbationDOC transport



Decomposition step controlled by microbial interactions

COMISSION at CarboEurope sites



Soil model developments

CUE

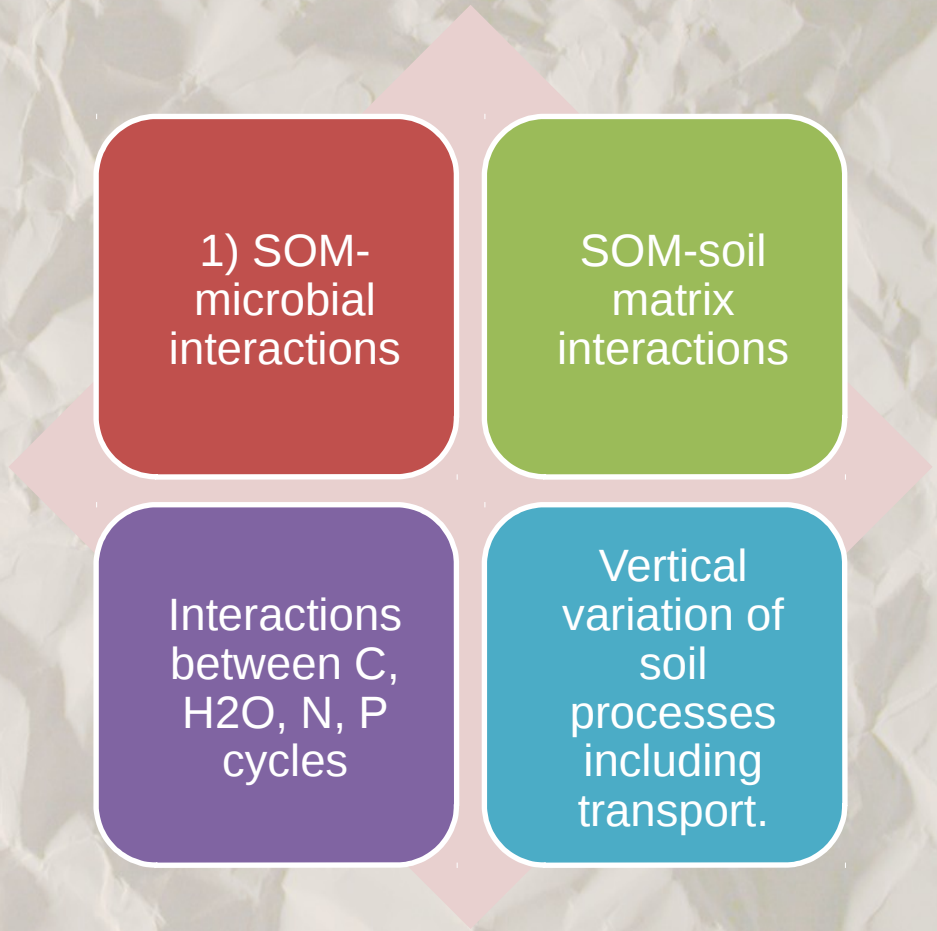
Microbial stoichiometry

Microbial diversity

Vertical transport

Sorptive stabilization

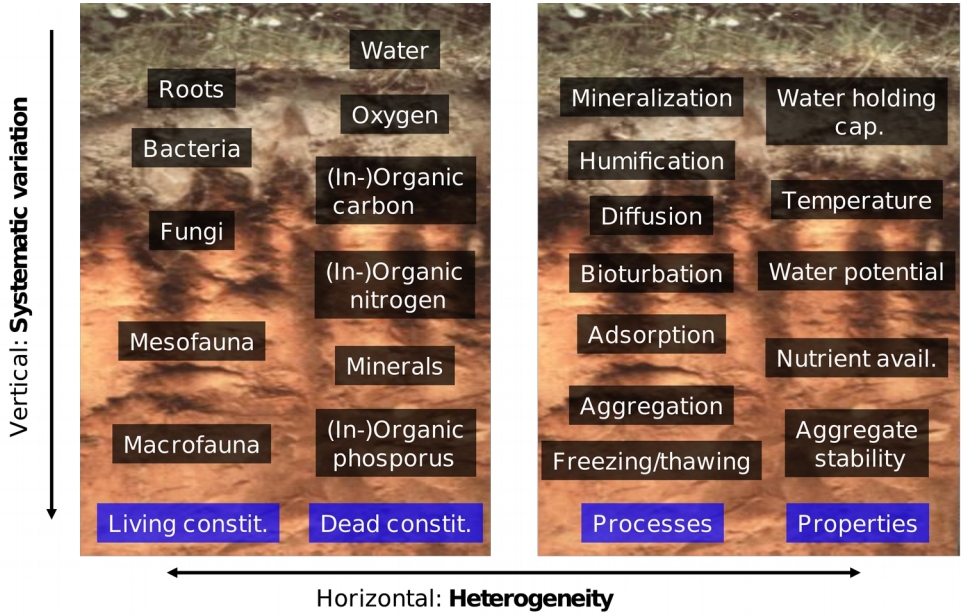
Comission model

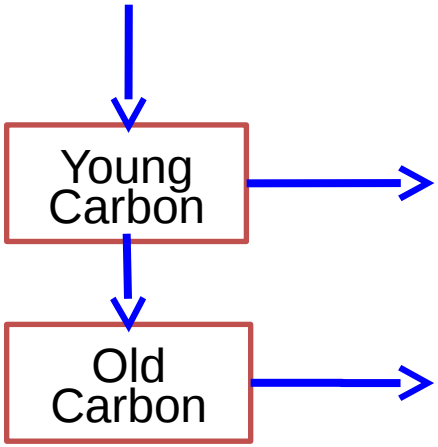


Isotopes to the rescue

How can we constrain the daunting complexity?

Increase in model complexity





How can we constrain the complexity?

Philosophical Debate about Validation

- “All models are wrong, but some models are useful”
  - After George Box 1976

- Model should be parsimonious
  - As simple a possible -> Abstract from some reality features
  - Models can only be as complex as we have data to constrain them

- Always think about purpose
  - Heuristics: Representations that guide further study
  - Most useful when challenging existing formulations

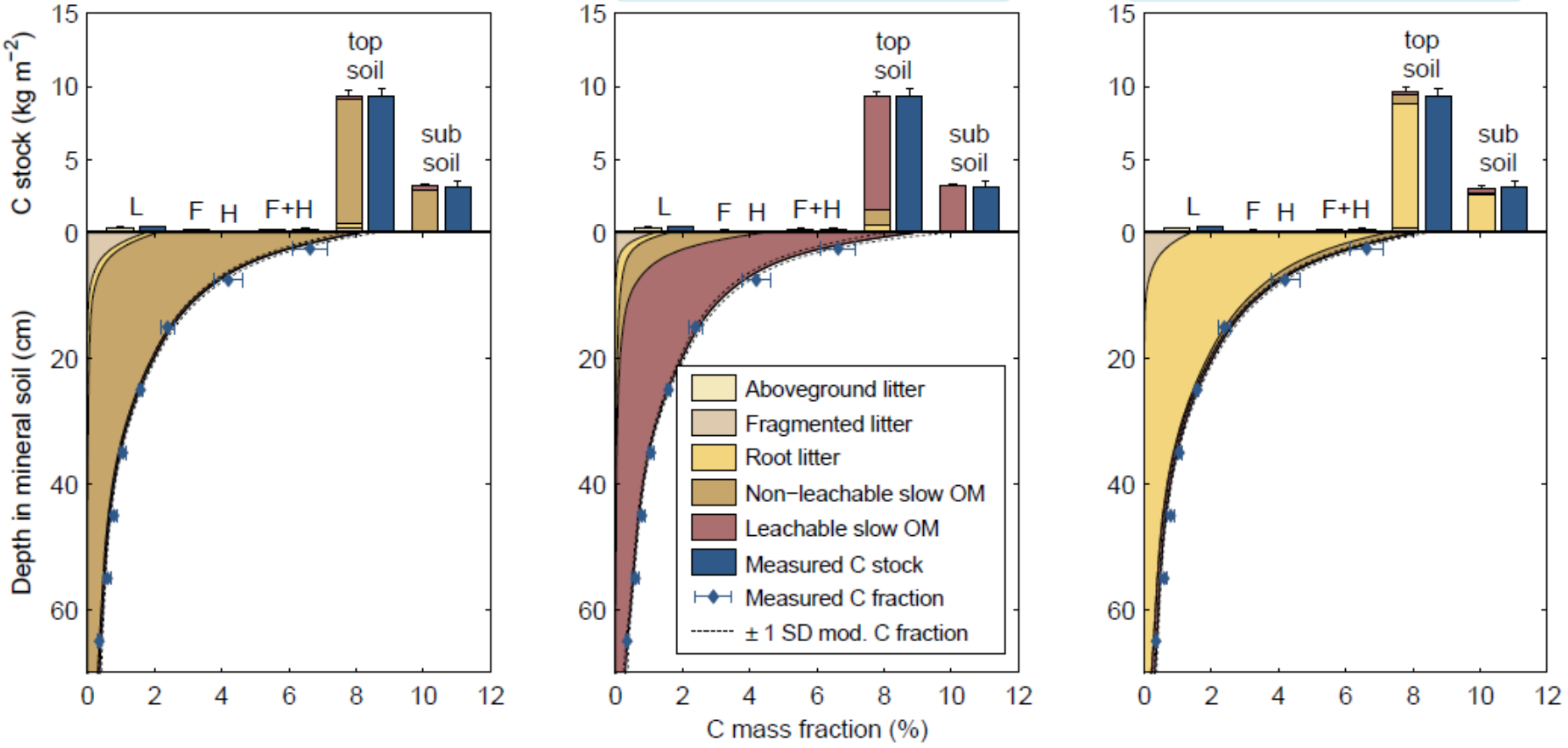
Equifinality

several models can fit a single data set

Biuturbation

DOM cycling

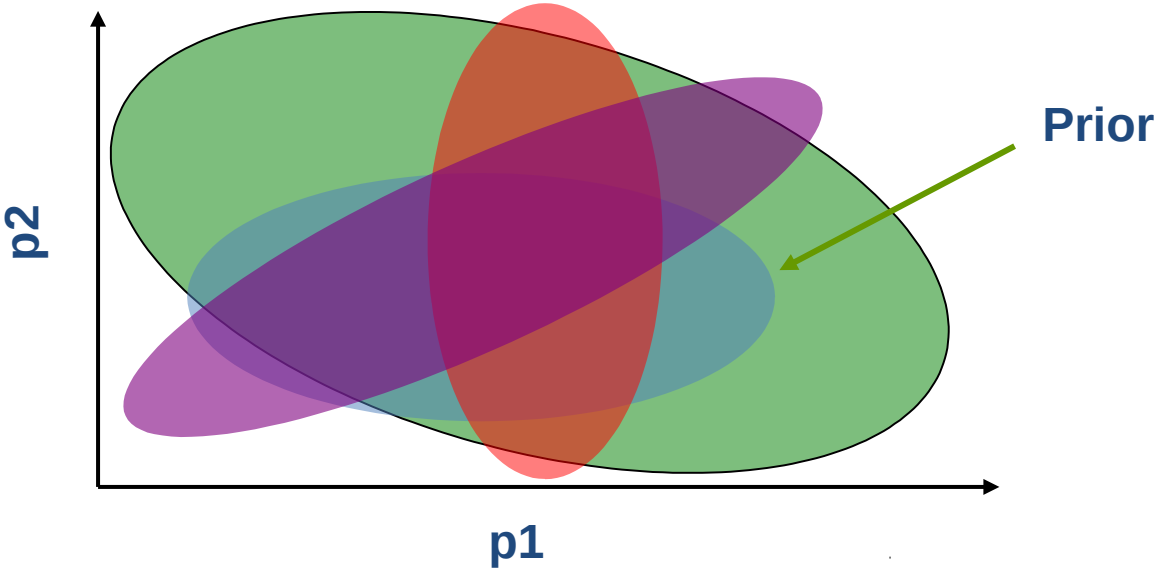
Root input



Braakhekke, M. C., Wutzler, T., et al. (2013) Modeling the vertical soil organic matter profile using Bayesian parameter estimation, Biogeosciences

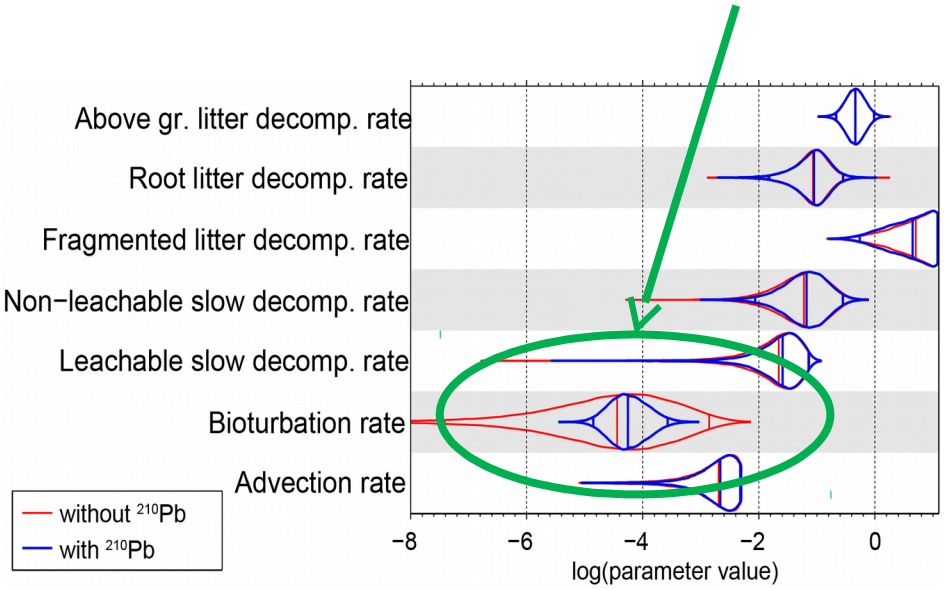
Isotopes to the Rescue!

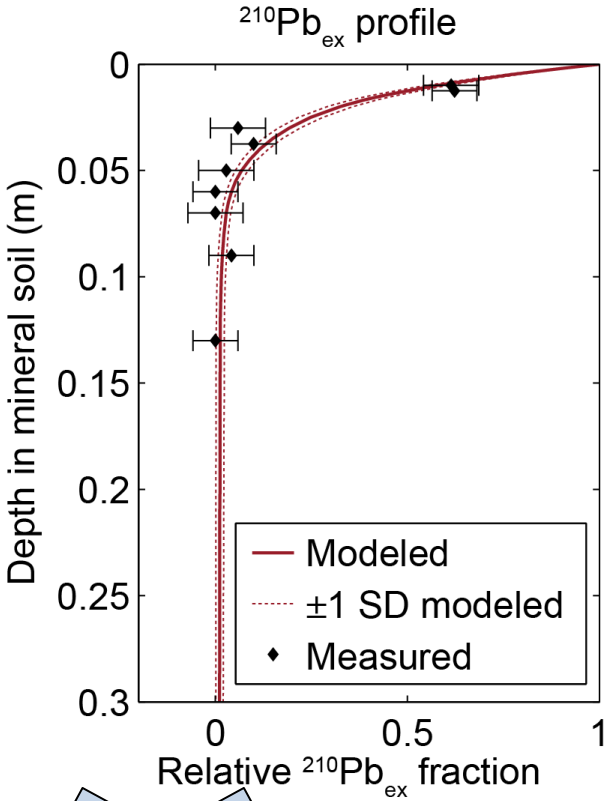
We need multiple data streams



$^{210}Pb_{ex}$ informs SOMPROF a C-profile development model

Including $^{210}Pb_{ex}$ data helps to constrain the bioturbation rate



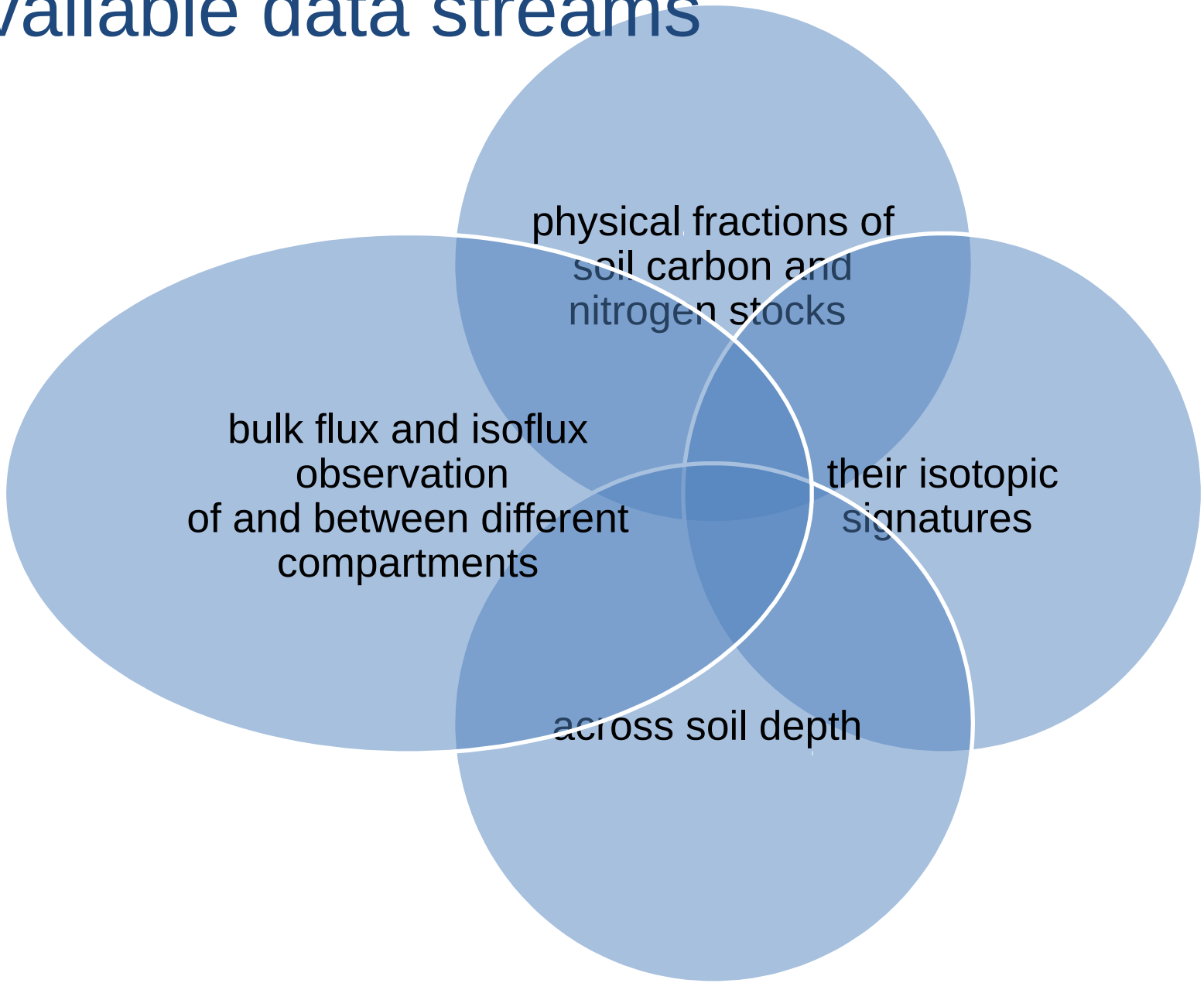


~~Biuturbation~~

DOM cycling

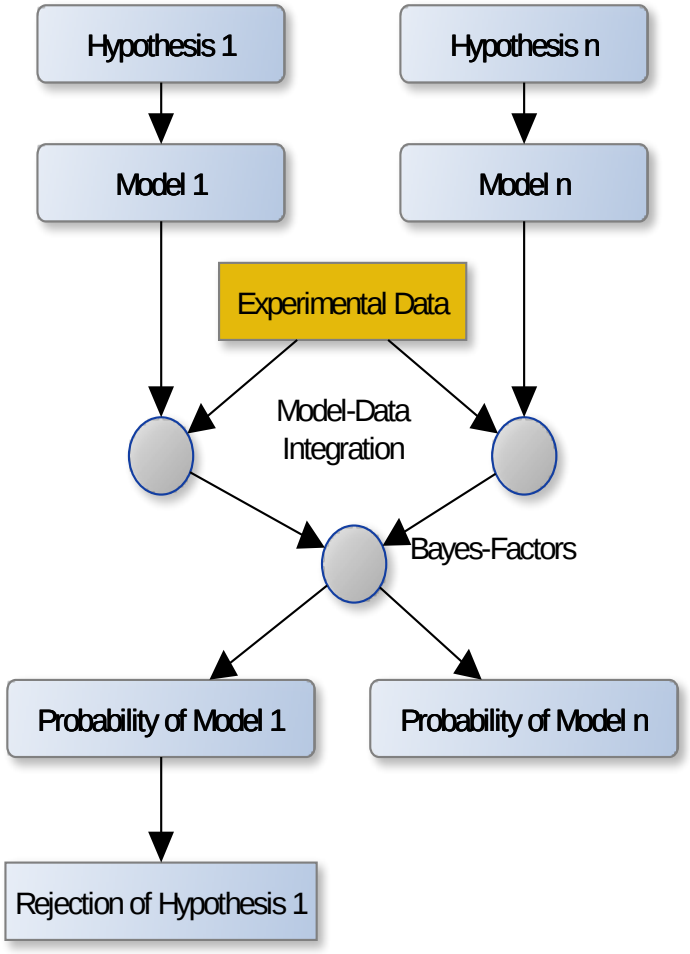
~~Root input~~ ^{13}C

Available data streams

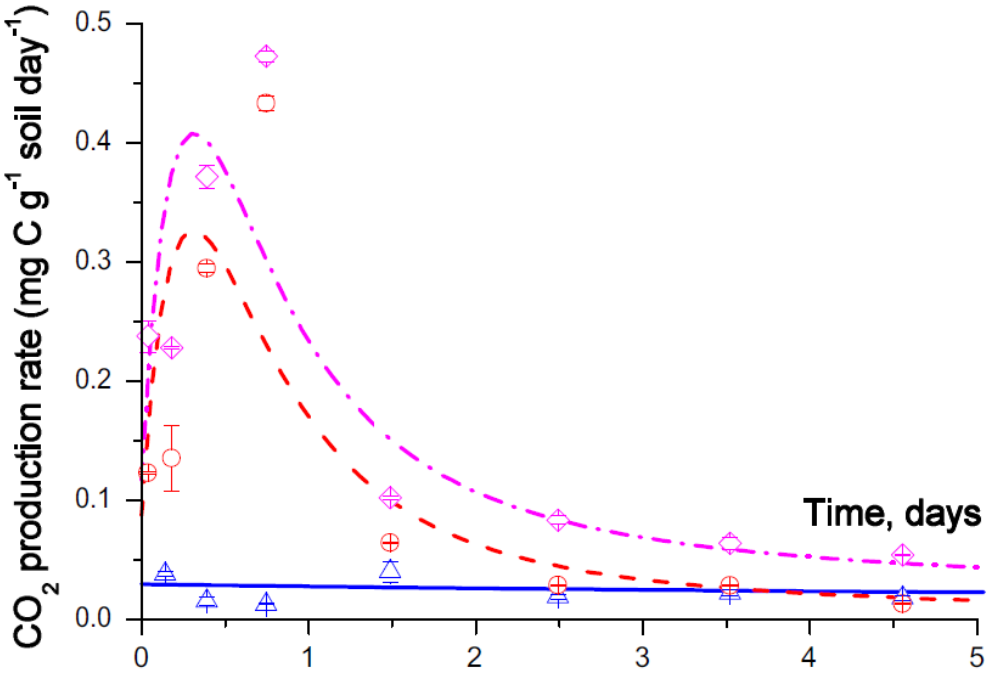


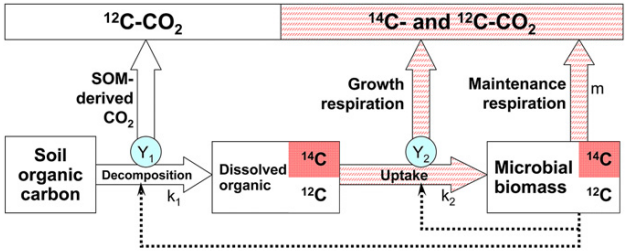
Using Model-data-integration
for testing model hypotheses

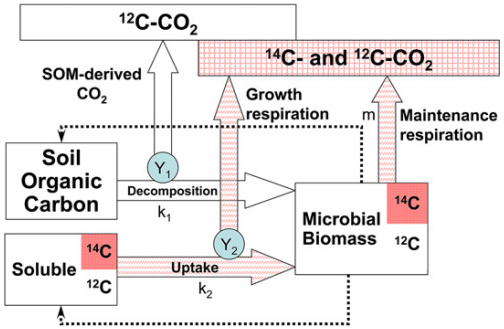
src: www.economicsuk.com/blog/001487.html



^{14}C helps deciding
between model structures



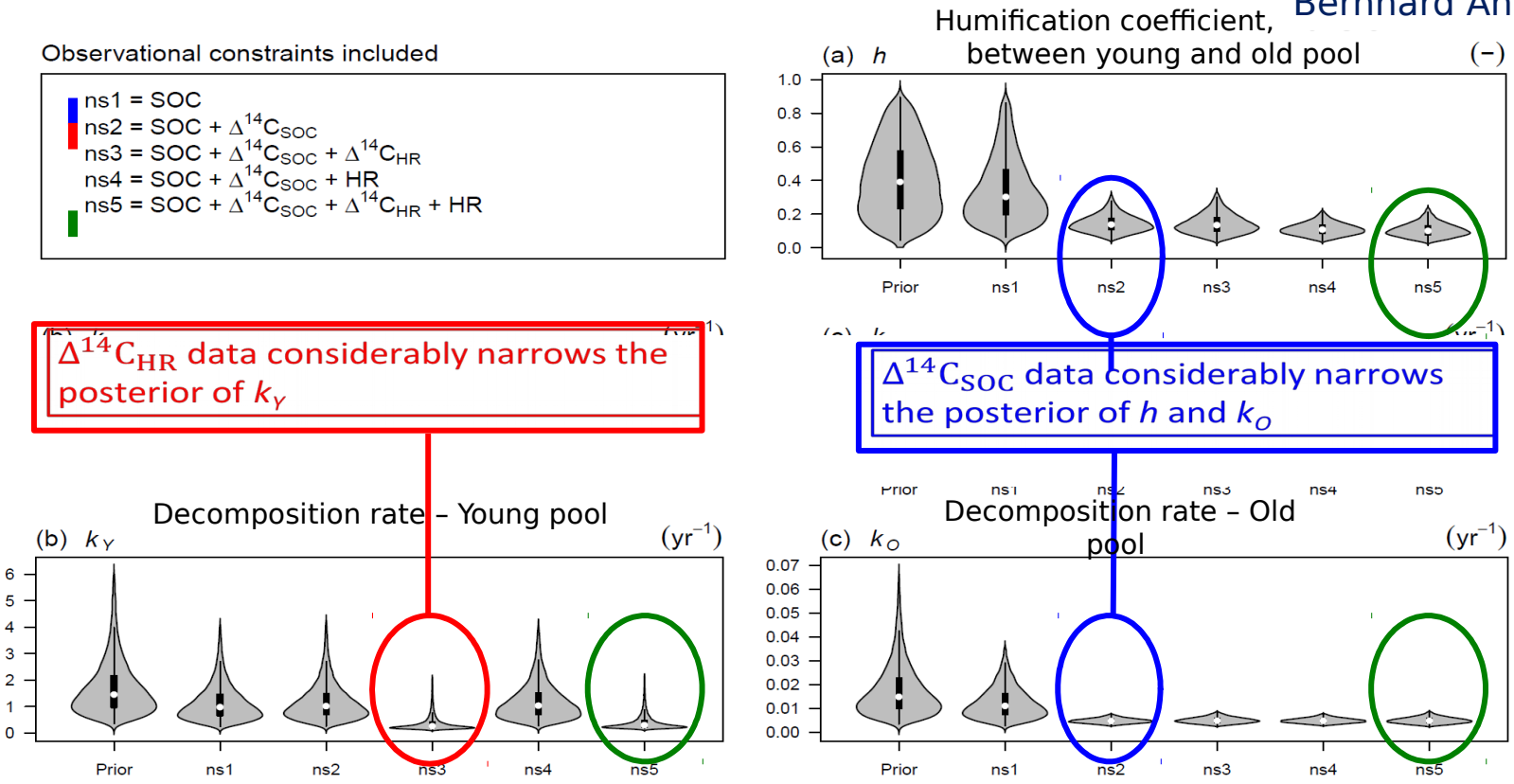




Blagodatsky, S.; Blagodatskaya, E.; Yuyukina, T. & Kuzyakov, Y. (2010). SBB

^{14}C informs a two-pool model

Bernhard Ahrens



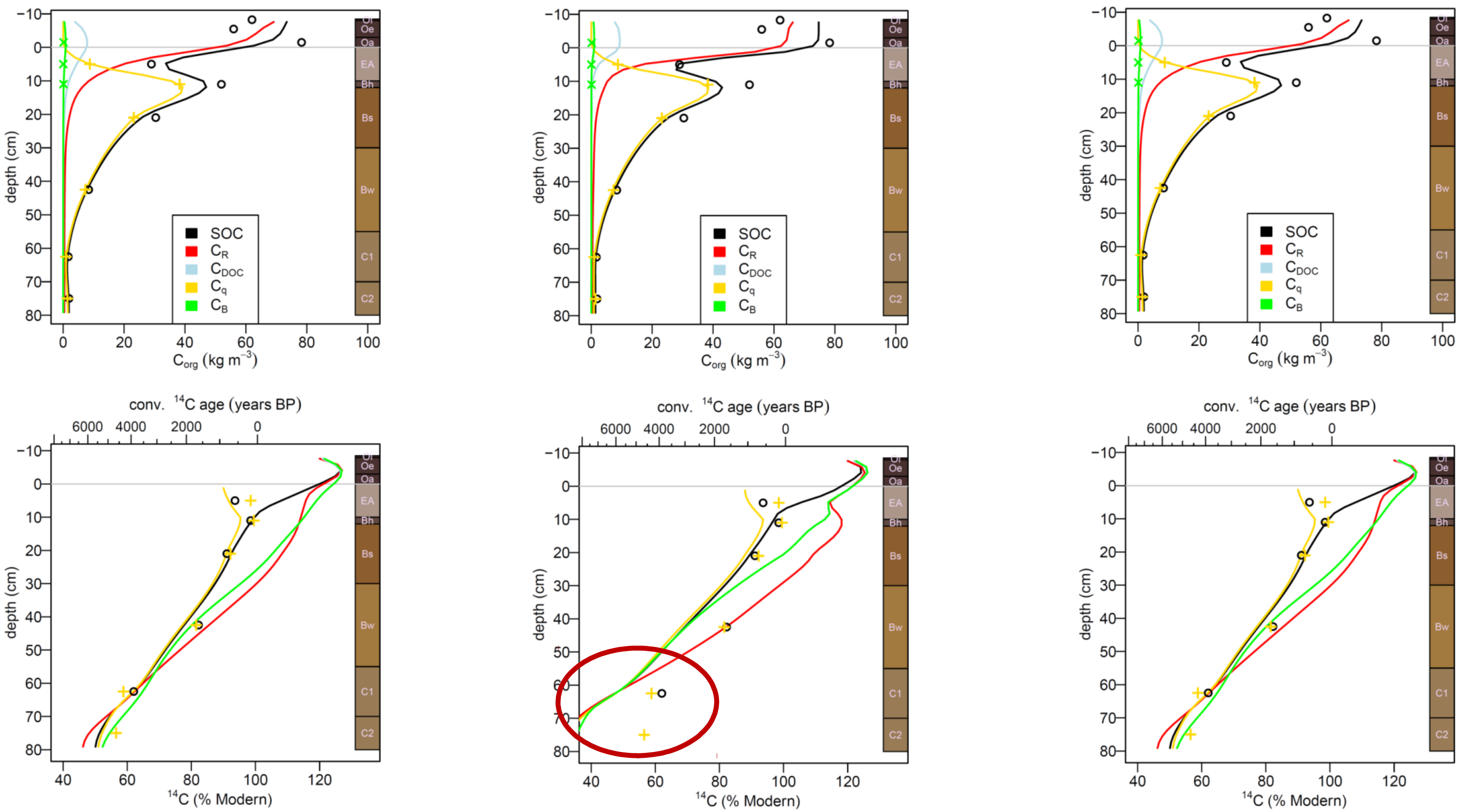
Posterior distributions of three selected parameters calibrated for a serial 2-pool SOC model using 4 different data constraints from the Howland Tower site. The multi-constraints setup allows to quantify the information content of individual data constraints for certain parameters.

^{14}C tells which processes are important

Comission

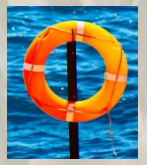
No Advection

No Bioturbation



Ahrens B, Braakhekke M, Guggenberger G, Schrumpf M & Reichstein M (2015) SBB

Isotopes to the rescue



Model complexity, equifinality, multiple datastreams

Model data integration, Bayes Factors

Examples of ^{13}C, ^{14}C, ^{210}Pb informing models

Challenges with multiple data streams

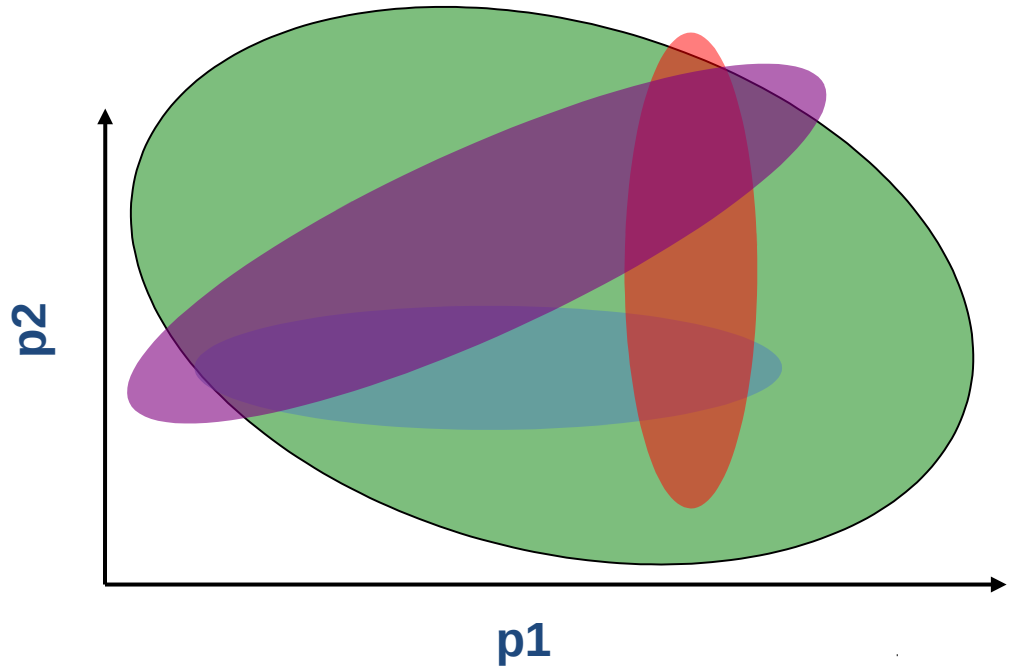
Inconsistent information
given the model

Causes

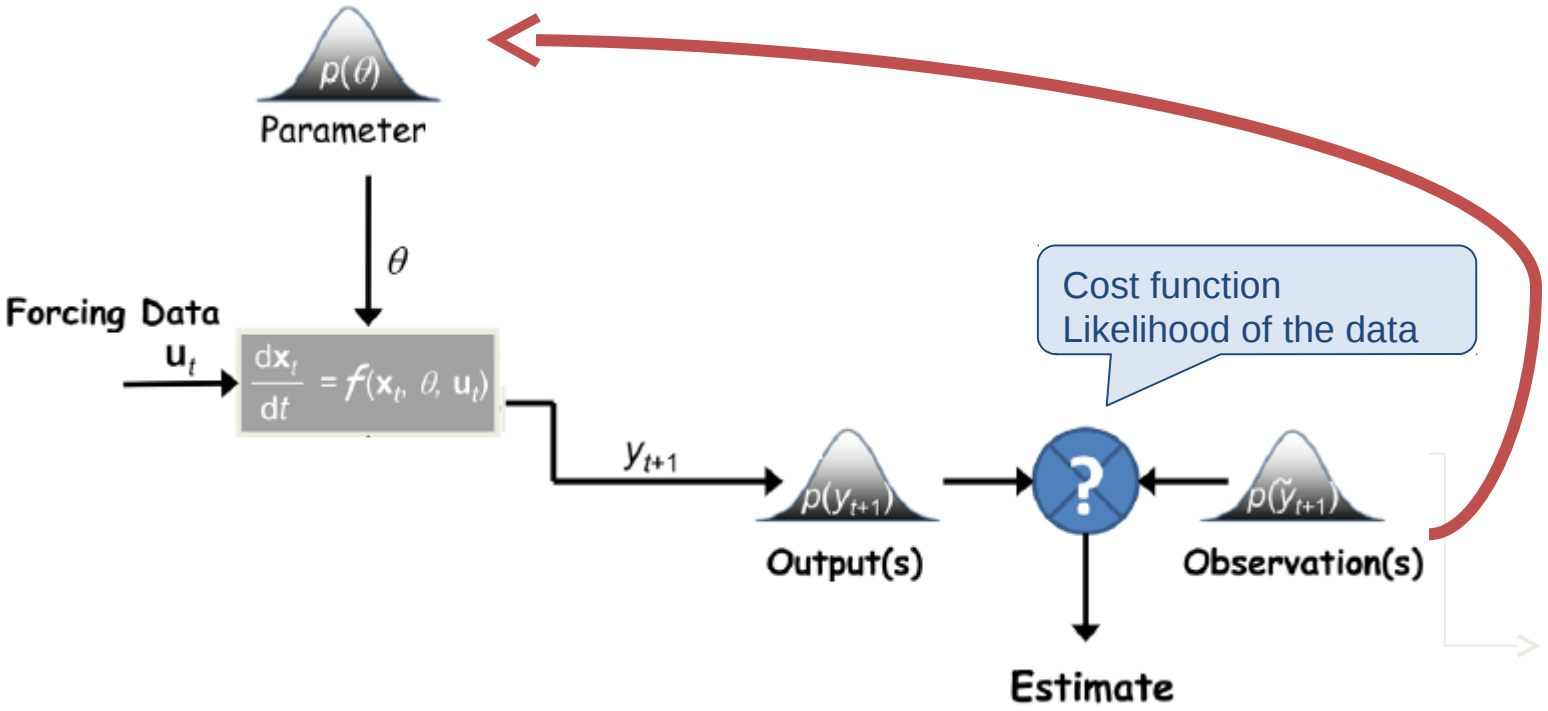
- Bias in measurements or model drivers
- Scale / Abstraction in time and space
- Insufficient model

Problem:

- Violation of assumptions
- Unreasonable inversions

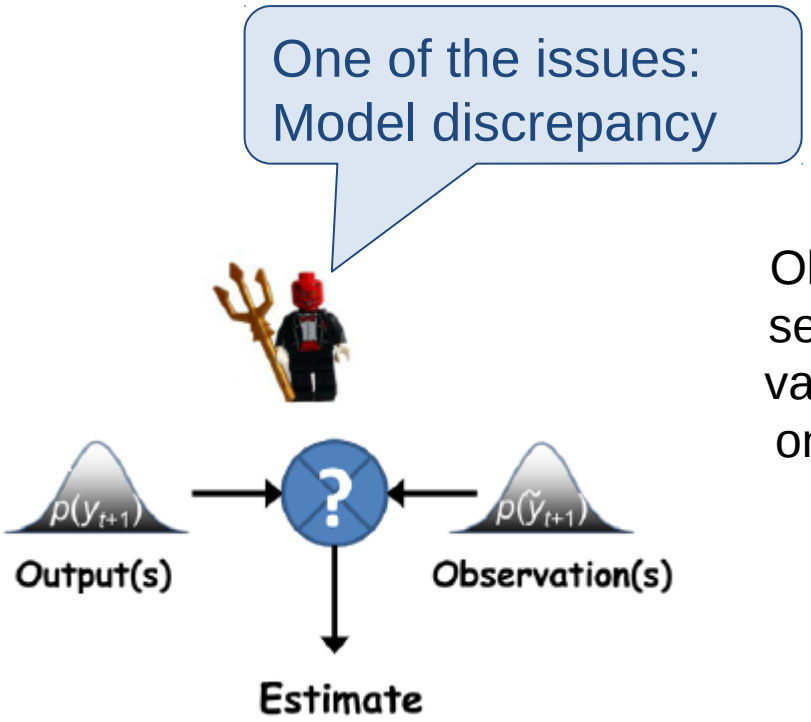


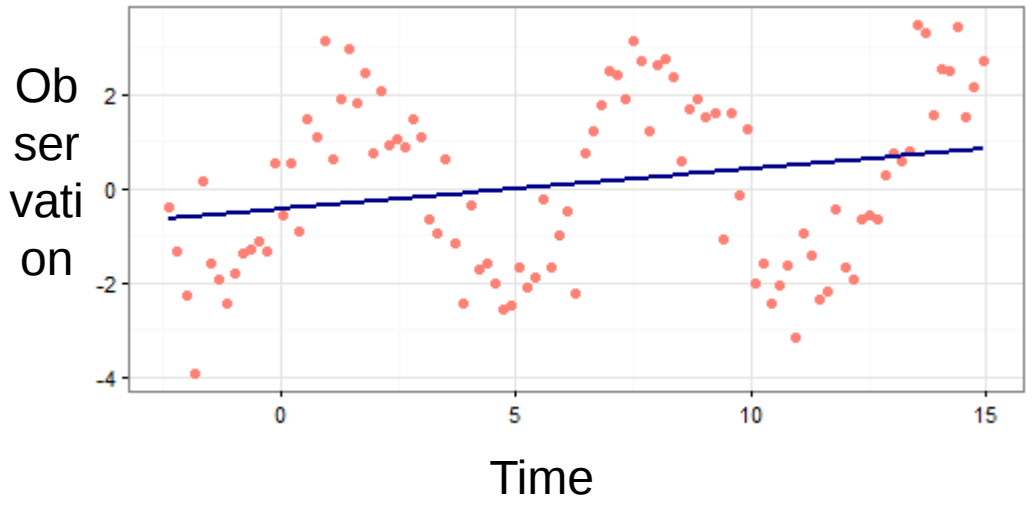
Model inversion:
Inferring uncertainty of model parameters



adapted from Vrugt 2013

Model discrepancy
violates assumption of uncorrelated errors



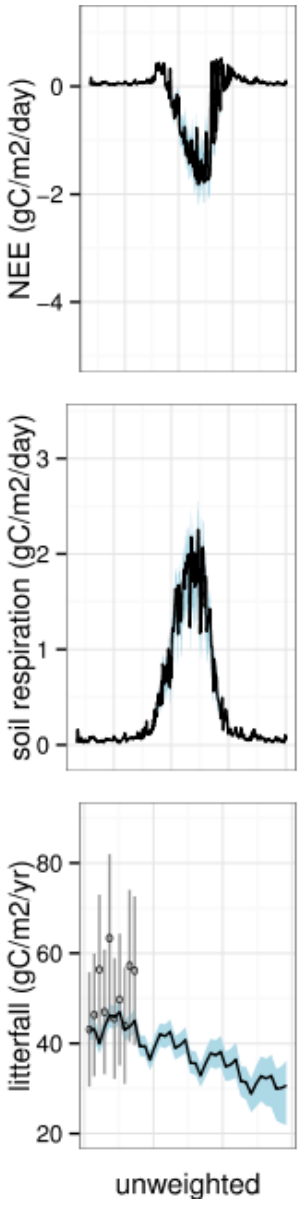


Requires complex statistical and numerical treatment

- Alternate parameter blocks sampling
- Explicitly modelling discrepancy (Gaussian Processes)
- Temperated Cost

adapted from Vrugt 2013

Example: Howland inversion



Challenges with multiple datastreams

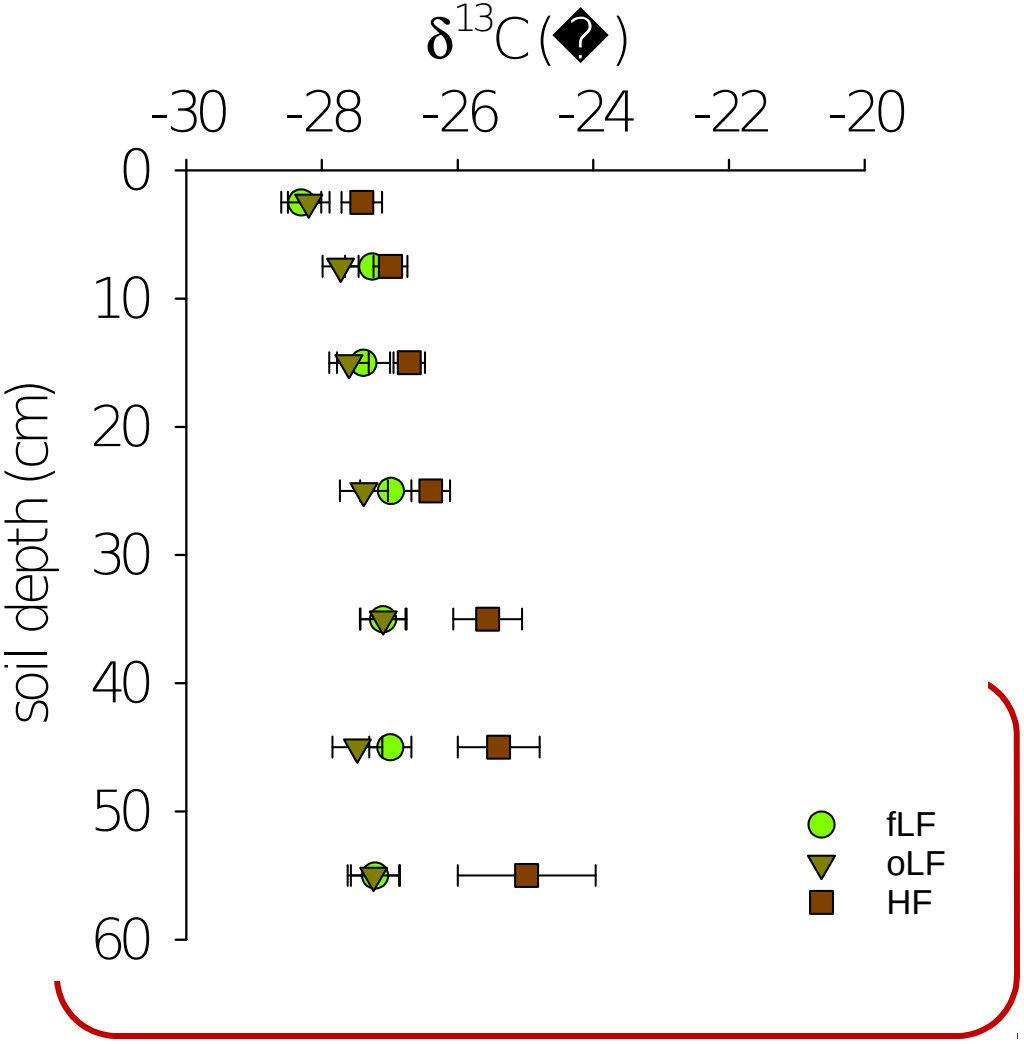
Inconsistent data streams -> model discrepancy

Violation of inversion assumptions

Need (subjective) weighting of data streams or sophisticated numerical statistics

Discussion:
^{13}C and microbial processing

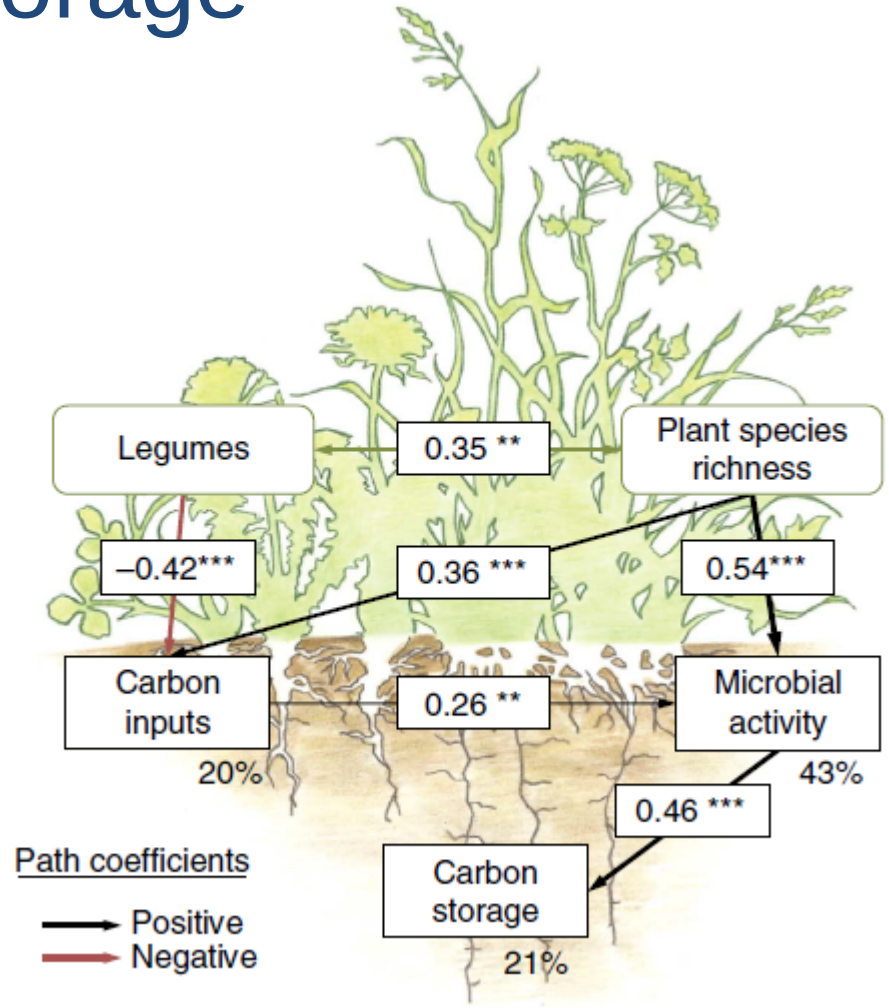
^{13}C: mineral-assoc SOM is strongly processed



Averages across 12 Carbo-Europe sites

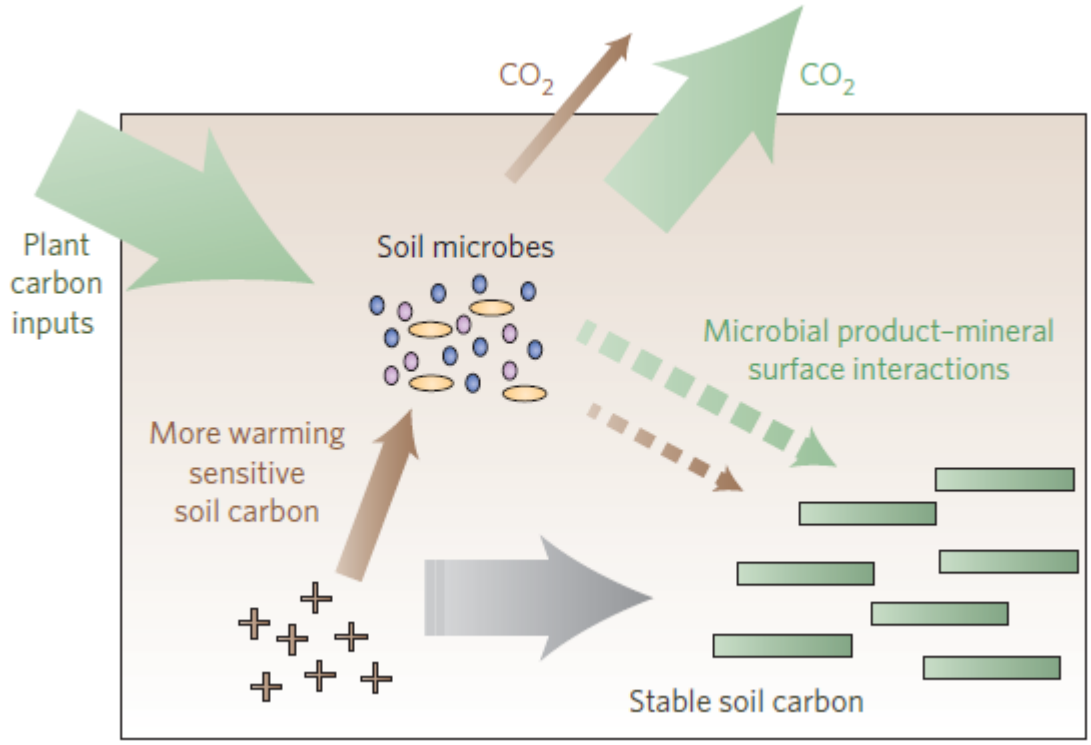
Schrumpf M et al. (2013) *Biogeosciences*

Soil microbial activity increases soil carbon storage



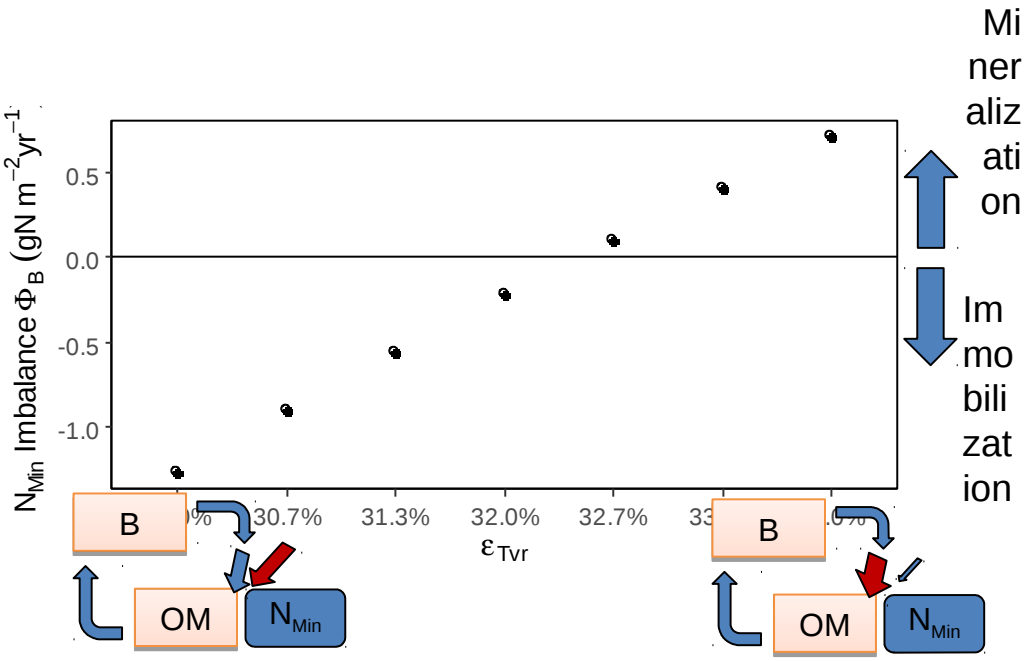
Lange M, et al. (2015). *Nature Communications*

Does microbial activity enhance the stable pool?



Bradford M, et al. (2016) *Nature Climate Change*

Nutrient recycling depends on microbivory



Wutzler T, Sönke Zaehle, Schrumpf M, Ahrens B & Reichstein M (2017) SBB

How can we use isotopes to study microbial processing?

^{13}C and microbial processing

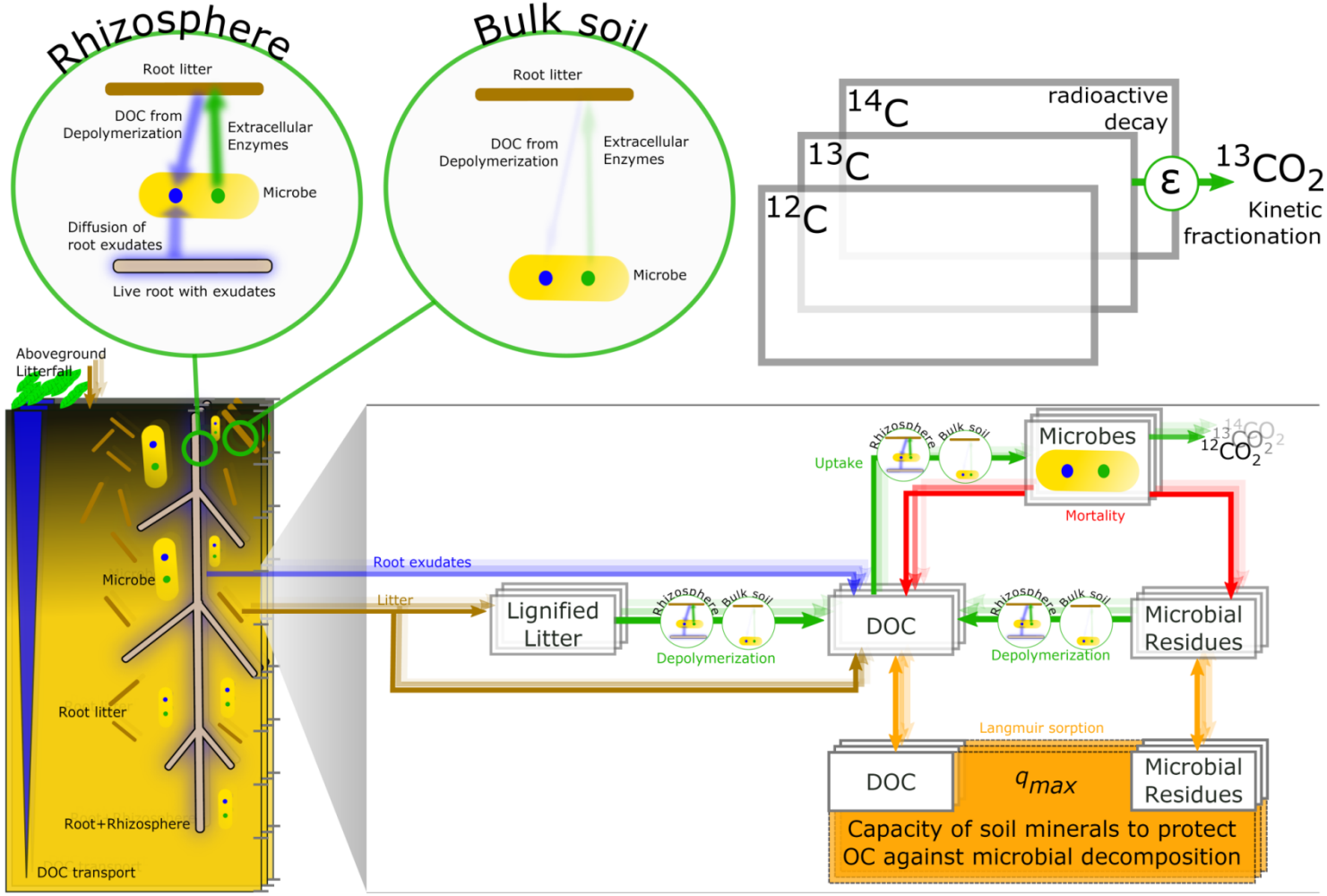
^{13}C: mineral-assoc SOM is strongly processed

Soil microbial activity increases soil carbon storage and controls nutrient recycling

How can we use isotopes to study microbial processing?

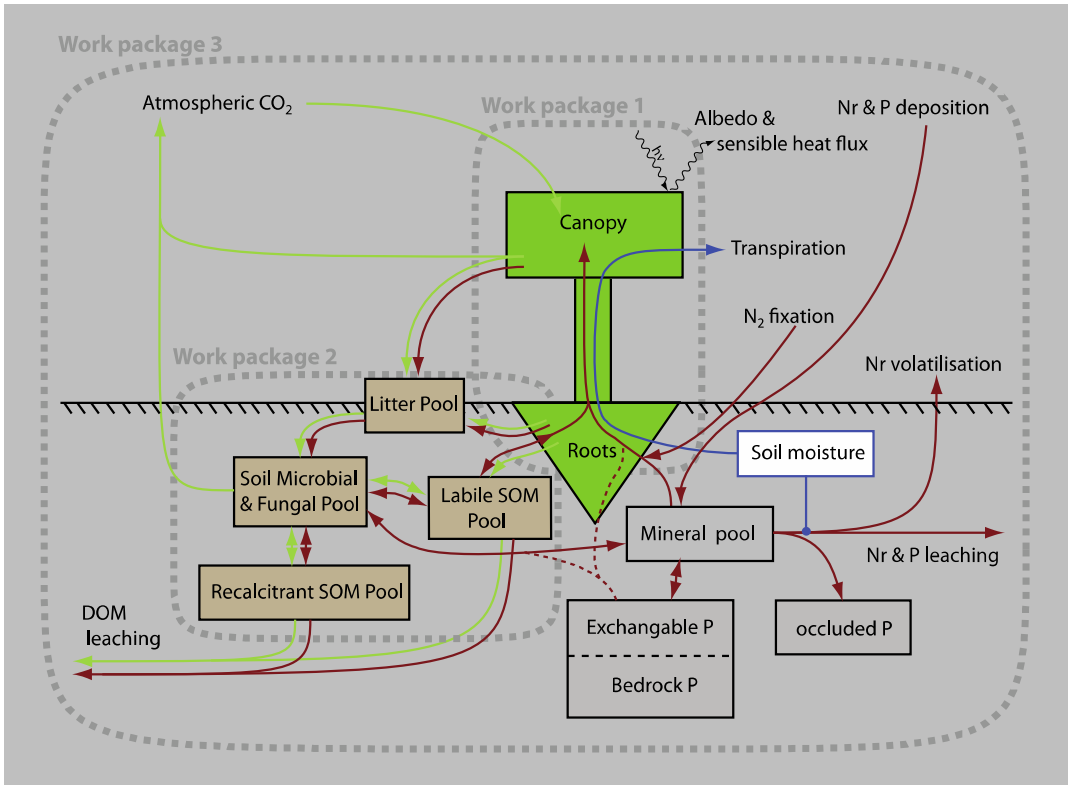
Outlook 1

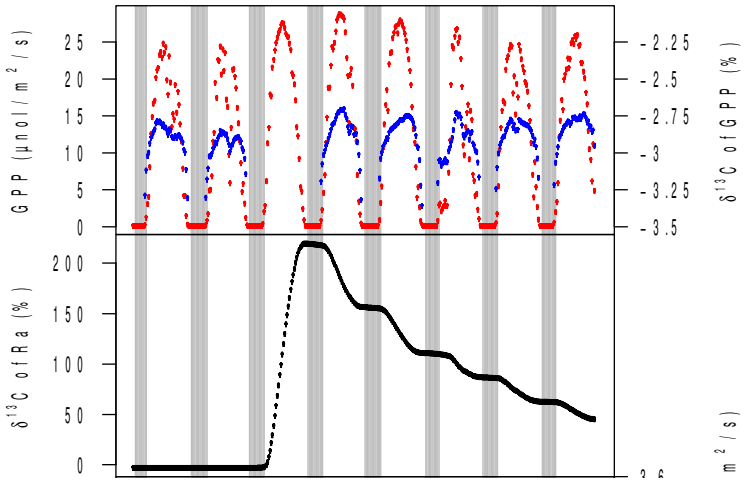
Comisssion in the SUBSOM project



Outlook 2a Future ecosystem model development at MPI-BGC: Quincy

Sönke Zaehle





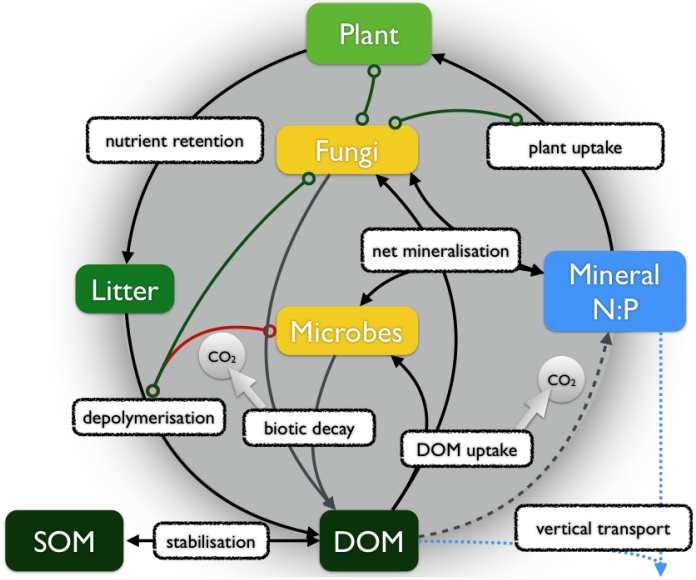
^{13}C of respiration constraining storage pools

Phosphorous submodel (Lin Yu)

Outlook2b:
Constraining plant/soil interaction

- Coupling of COMISSION/SEAM to new vegetation model, including ^{13}C and ^{15}N tracer / fractionation processes
- Use tracer studies to evaluate simulated fate of C and N

Ecotron experiment with elevated CO_2 using a dual $^{13}C/^{15}N$ labelling approach



Summary

What is a surprise ? => mental models

Soil model developments

Equifinality: Isotopes to the rescue

Challenges with multiple data streams

Discussion: ^{13}C to study microbial processing