Model structure uncertainty of SOC dynamics studied in a single modeling framework

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Problem

When having formulated a model using existing knowledge on possible driving processes, we wonder what is the importance of each considered mechanism, are there interaction effects between them and which ones could be neglected..

- Current discussions of mechanisms involve comparison of models with very different model structures.

- However, it is difficult to compare model parameters in such comparison studies. Rather it is convenient to proceed in a single modeling framework.

- Perspective of introducing soil microbial C models at Earth system scale requires understanding of structural uncertainty related to formulation of microbial activity.

The aim of our study was to analyze model structural uncertainty in soil organic carbon (SOC) models.

Carbon cycle confidence and uncertainty: Exploring variation among soil biogeochemical models

William R. Wieder, Melannie D. Hartman, Benjamin N. Sulman, Ying-Ping Wang, Charles D. Koven, Gordon B. Bonan

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Explicitly representing soil microbial processes in Earth system models

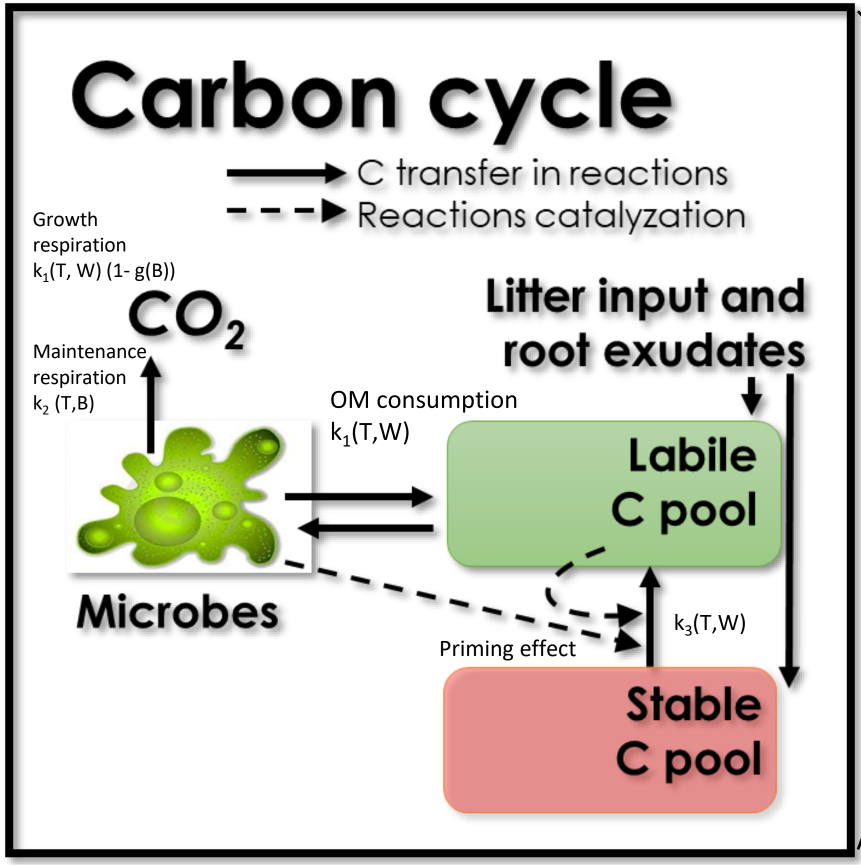
William R. Wieder, Steven D. Allison, Eric A. Davidson, Katerina Georgiou, Oleksandra Hararuk, Yujie He, Francesca Hopkins, Yiqi Luo, Matthew J. Smith, Benjamin Sulman ... See all authors

First published: 22 September 2015 | https://doi.org/10.1002/2015GB005188 | Cited by: 48

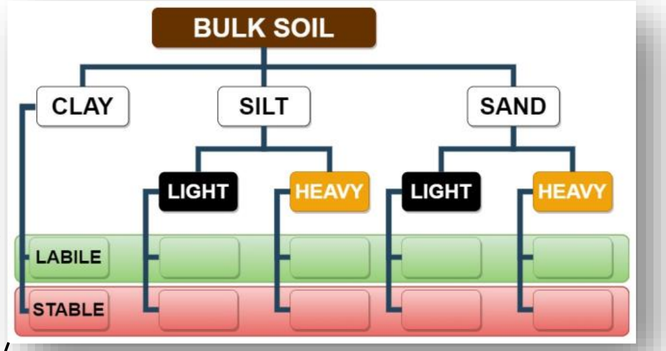
SOC modeling framework with switchable biological and physical mechanisms

Main mechanisms:

- ✔ Microbial growth with dynamic CUE and turnover rate
- ✔ Priming effect: decay of stable organic matter pool is possible if labile OM is present
- ✔ Temperature and moisture dependence of reaction rates
- ✔ *Physical protection*: SOM decay accelerates with adsorbed SOM and decelerates with microaggregation related to LF content



Carbon pools



Soil organic matter (SOM) is divided into 10 pools by it's biochemical availability and location in measurable physical size and density fractions.

C cycle takes place in each fraction, while reaction rates are modified according to fraction size and density

Model input data, simulation and parametrization

Parametrization: the model family was tested on experimental data of C and $\delta^{13}C$ dynamics from a long-term chronosequence bare fallow study (no C input) 1929-2008 in Versailles, France, measured in size and density

Size fractions (clay, silt and sand) were divided into light fraction (LF) and heavy fraction (HF) at 2 g/cm^3. Fractions were obtained from soils of historical collection sampled every 10 years in 3 field replicates.

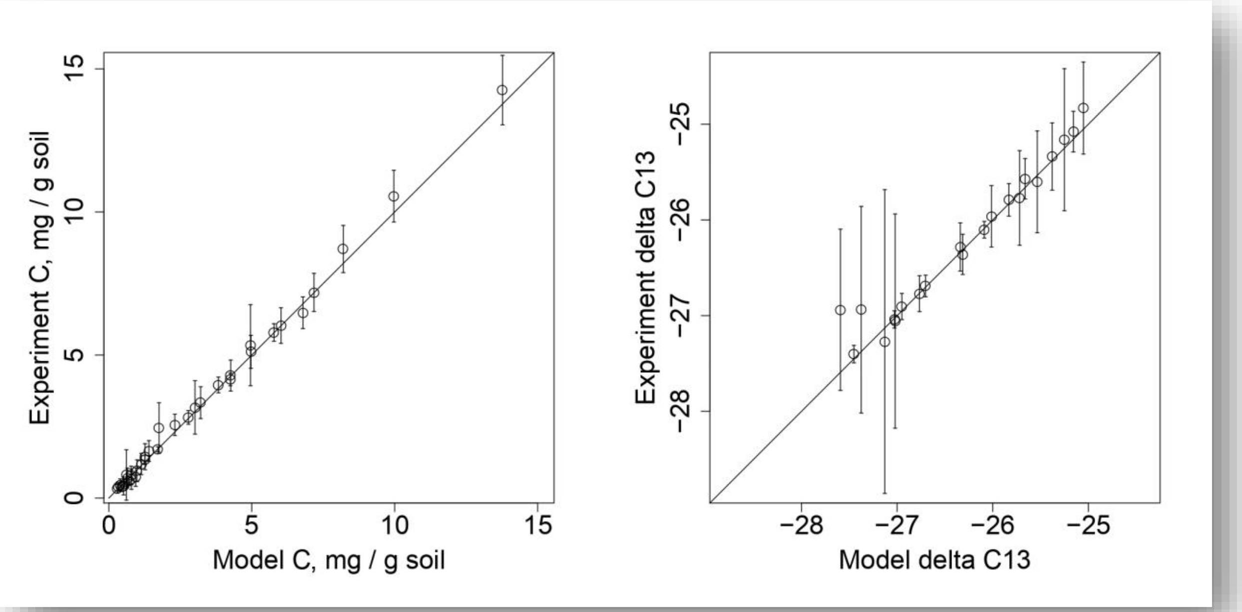


Figure shows 1:1 plots of simulated vs measured C and $\delta^{13}C$ by the full model. Model simulation included 400 years spin-up with average temperature, moisture and litter fall followed by model run with input data.

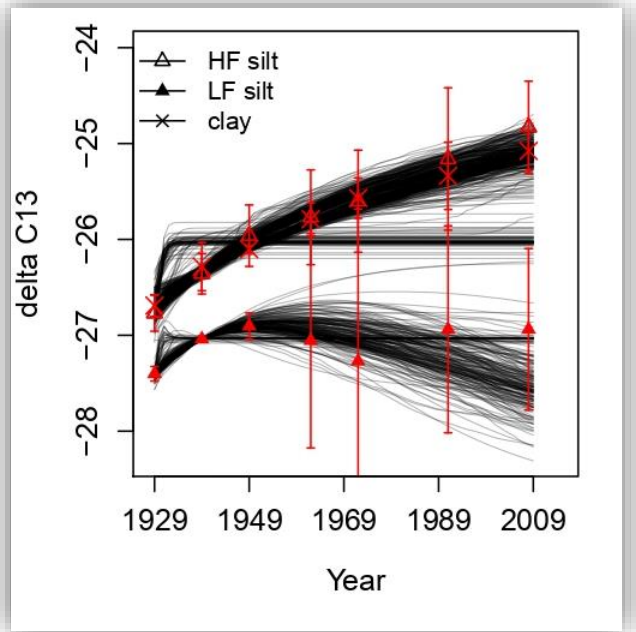
Model parameters:

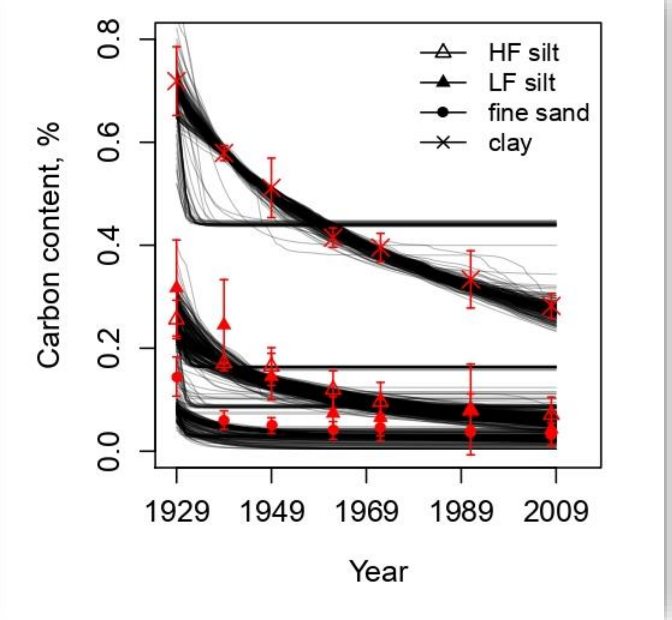
- Distribution ratio of litter fall C input between physical fractions
- Reaction rates of SOM decomposition for each physical fraction
- Microbial CUE, microbial maintenance respiration (turnover), SOM temperature and moisture sensitivity
- In total 28 parameters in the most complex model structure

Model input data:

- litter fall
- soil surface temperature (proxy from air temperature)
- soil moisture (proxy from precipitation)

Results: C and δ^{13}C dynamics in soil fractions simulated by model family





Analysis of SOC models family with different combinations of mechanisms showed that the best (estimated by BIC) description of SOC dynamics in physical fractions was with microbially-explicit models either in case of a feedback via dynamics of microbial turnover or CUE.

	Model group 1	Model group 2	Model group 3	Model group 4	Model group 5
Microbial growth	+	+	+	-	+
Turnover rate (dormant state)	dynamic	dynamic	constant	-	constant
CUE	dynamic	constant	dynamic	-	constant
Mean performance (BIC)	176	180	220	251	2301

Chronosequence data and model
C dynamics in size and density fractions

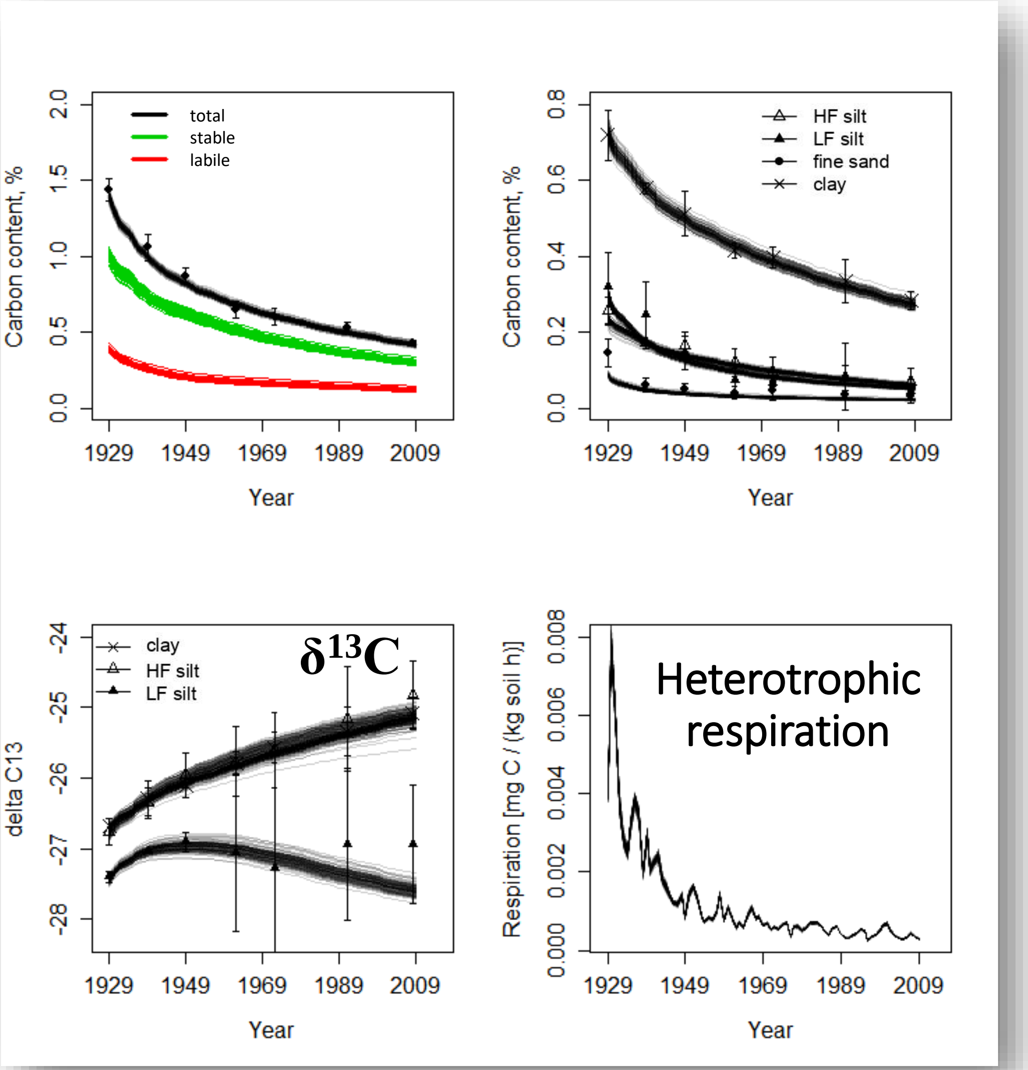
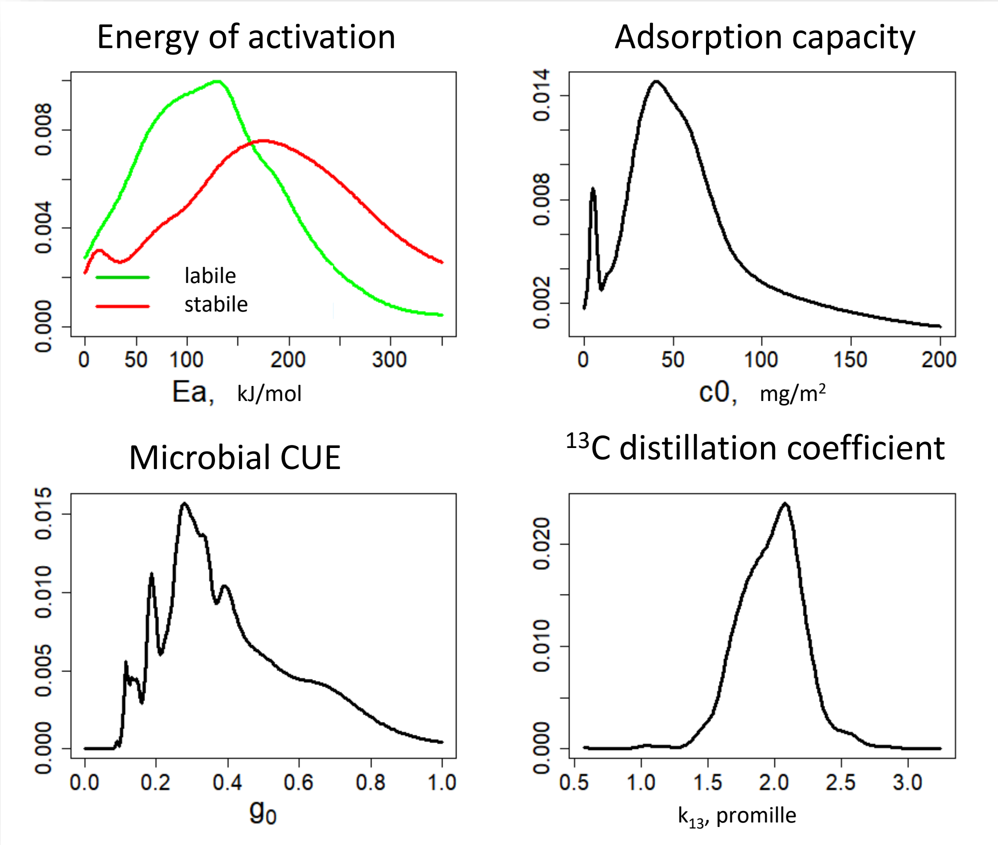


Figure shows carbon dynamics in physical fractions, obtained with model parameters sampled from normal distributions with estimated standard error.

Uncertainty of all mechanism-specific parameters was estimated for every model in the family.

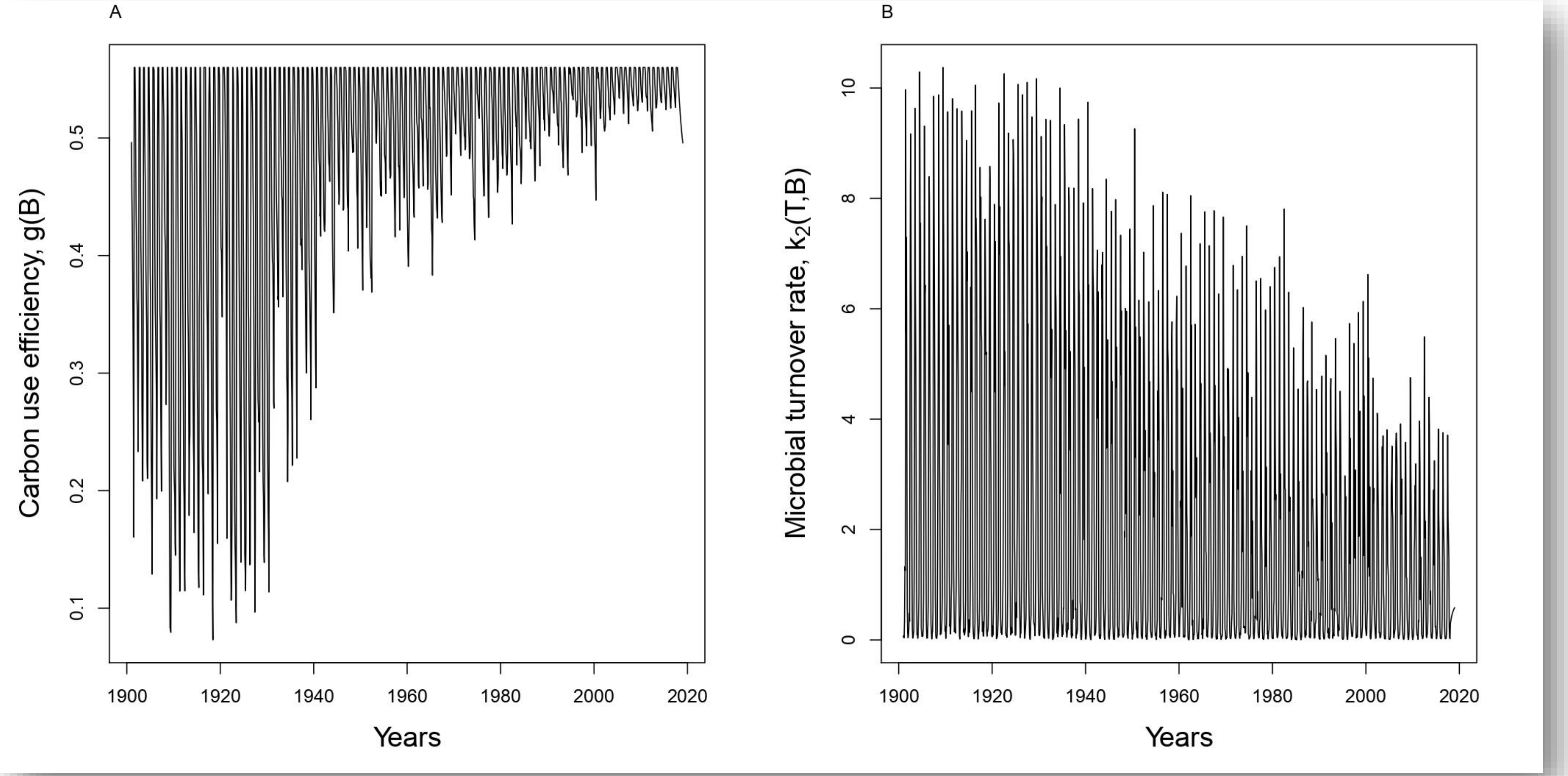
Probability density for parameters of the whole model family weighted with models likelihoods



Dynamic parameters of microbial activity

$g(B) = g_0\ (1 - B/B_{max})$

$k_2(B, T) = r_0\ A(E_3)\ (1 - B_{min}/B)$



Effects of physical protection (adsorption and occlusion) on SOM consumption rate in fractions

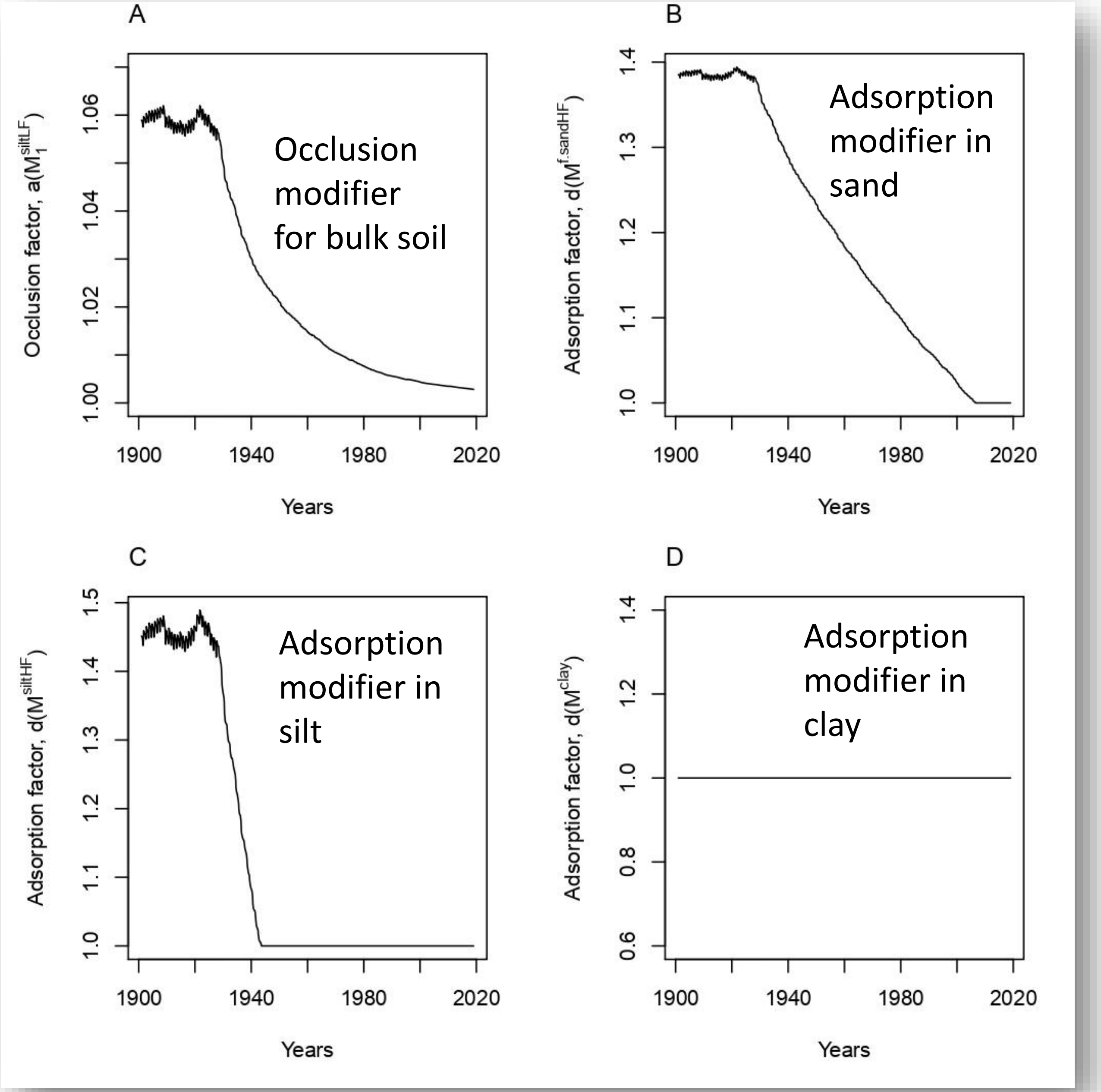
$$k_1^f = \frac{k_0 \cdot k^f}{a} \cdot d$$

k_1^f - SOM consumption rate

k^f - fraction modifier

a - occlusion modifier

d - adsorption modifier



Summary

- Studying SOC models in a single framework gives insights into model structural uncertainty, revealing neglectable or interchangeable components
  - Best performance was shown by microbial model groups with dynamic CUE or turnover rate
  - Microbial models with constant CUE and turnover rate were not suitable to describe long-term SOC dynamics under no C input (bare fallow)
  - Climate controls and physical mechanisms do not significantly reduce model uncertainty for this set of data. Other experimental data will be used for reliable estimate of corresponding parameters
- Distributions for model parameters among all models has evident maximum and we can already estimate these parameters within a certain range independently of individual model structure
  - The obtained range for microbial distillation coefficient for ^{13}C covered the value published by Menichetti et al., 2015 for this experiment
  - The obtained ranges for temperature sensitivity of labile and stable SOM (E_a) covered the values published by Moyano et al., 2018 for this experiment
  - The obtained distribution for CUE showed a maximum in a realistic range
- We discuss the use of the study results to estimate relevance of observed parameter and structural uncertainties for global SOC projections obtained using different model structures (EGU2020-12481).

Thank you very much for your attention!