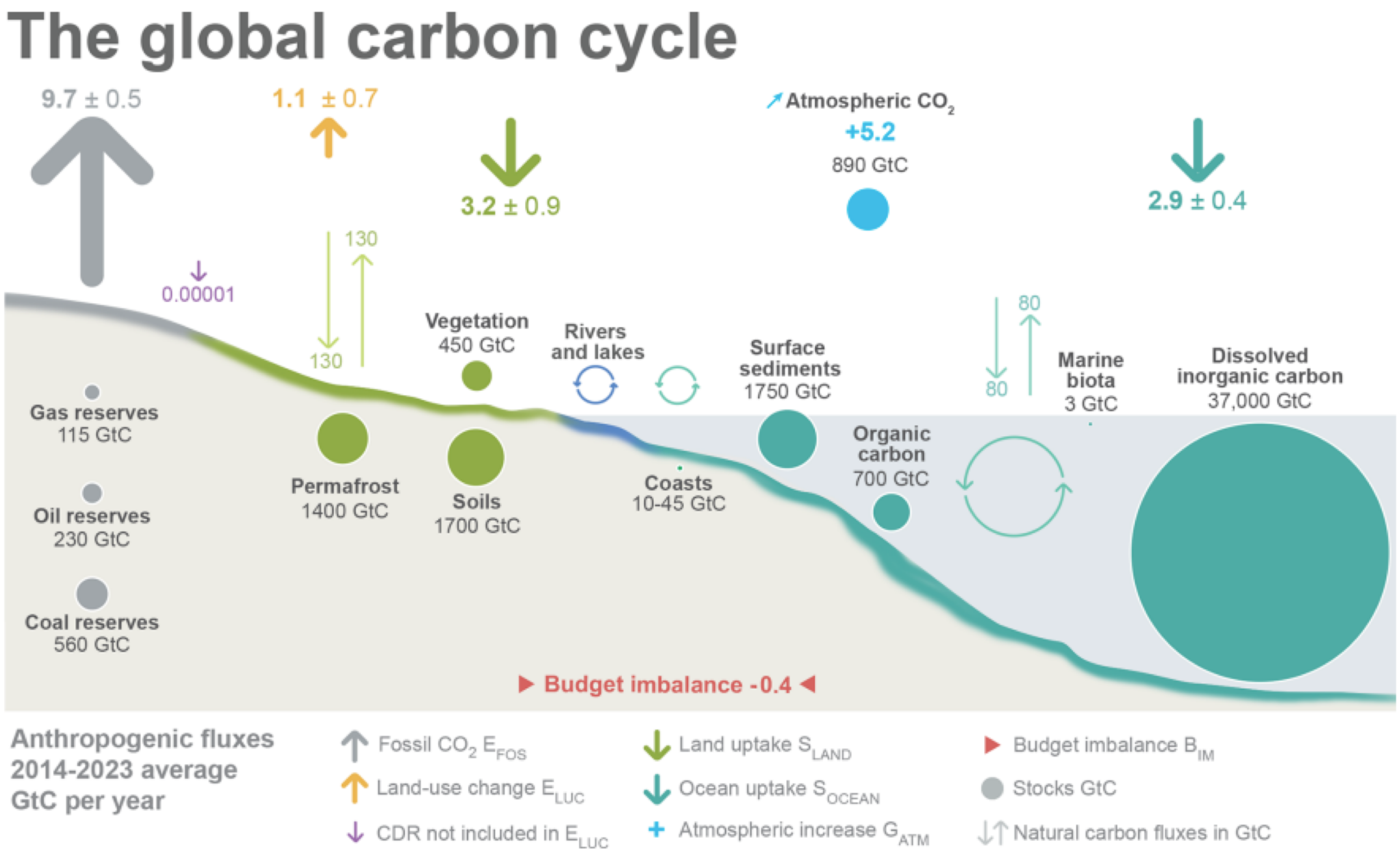
Soil Dynamics

Slides based off of dissucssions in

Bolker et al. (1998). Linear analysis of soil decomposition: Insights from the CENTURY model. *Ecological Applications* 8(2): 425-439.

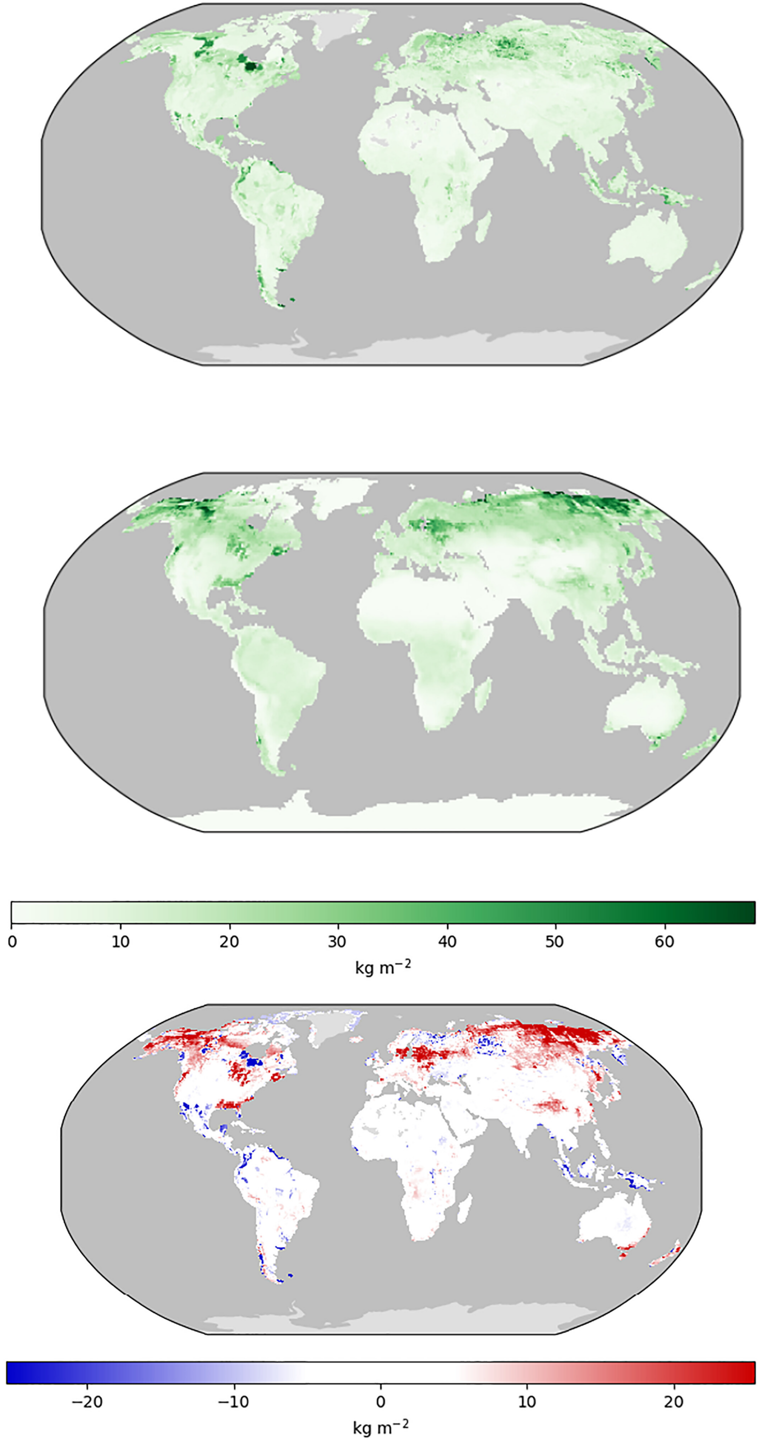
Why soils?

Lots of C in soils!



Friedlingstein et al. (2024)

Why soils?



Observation 1

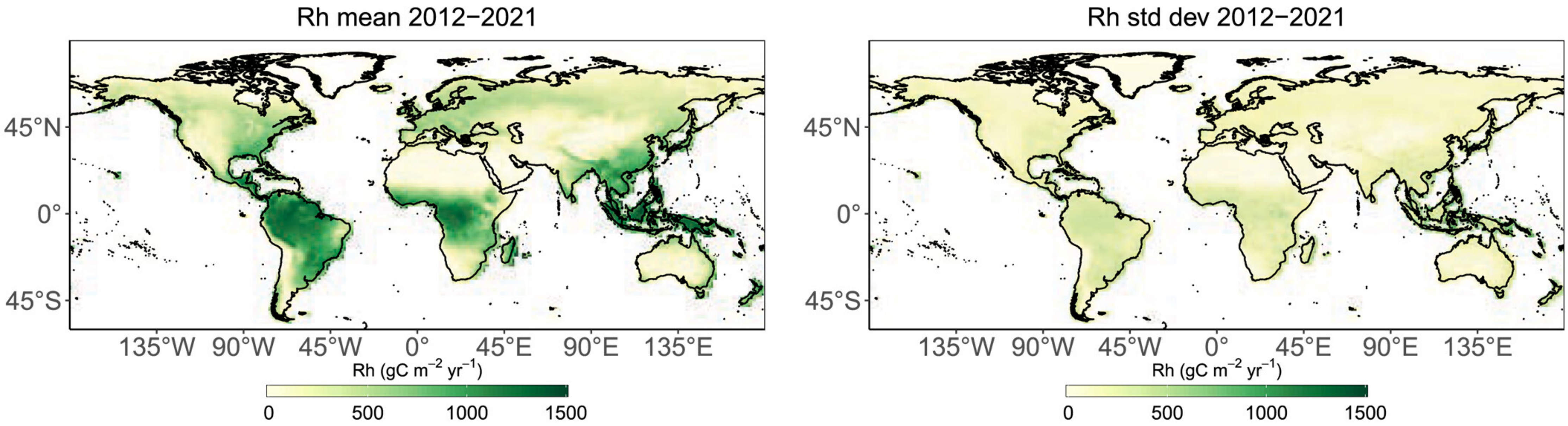
Observation 2

Although it's hard to know how much!

Difference

Stitch et al. (2024)

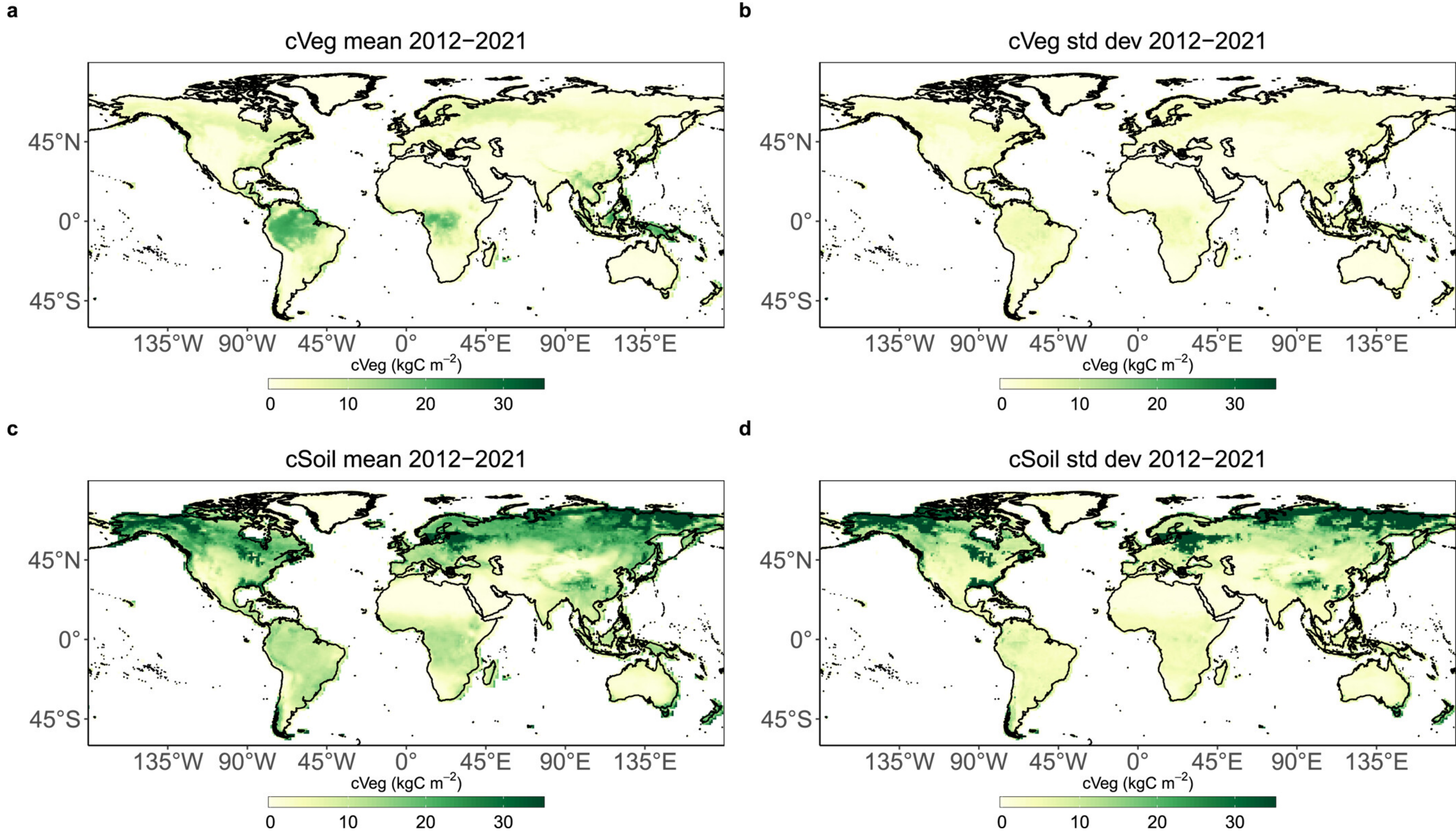
Why soils?



Soils are alive! But how much so?

Stitch et al. (2024)

Why soils?

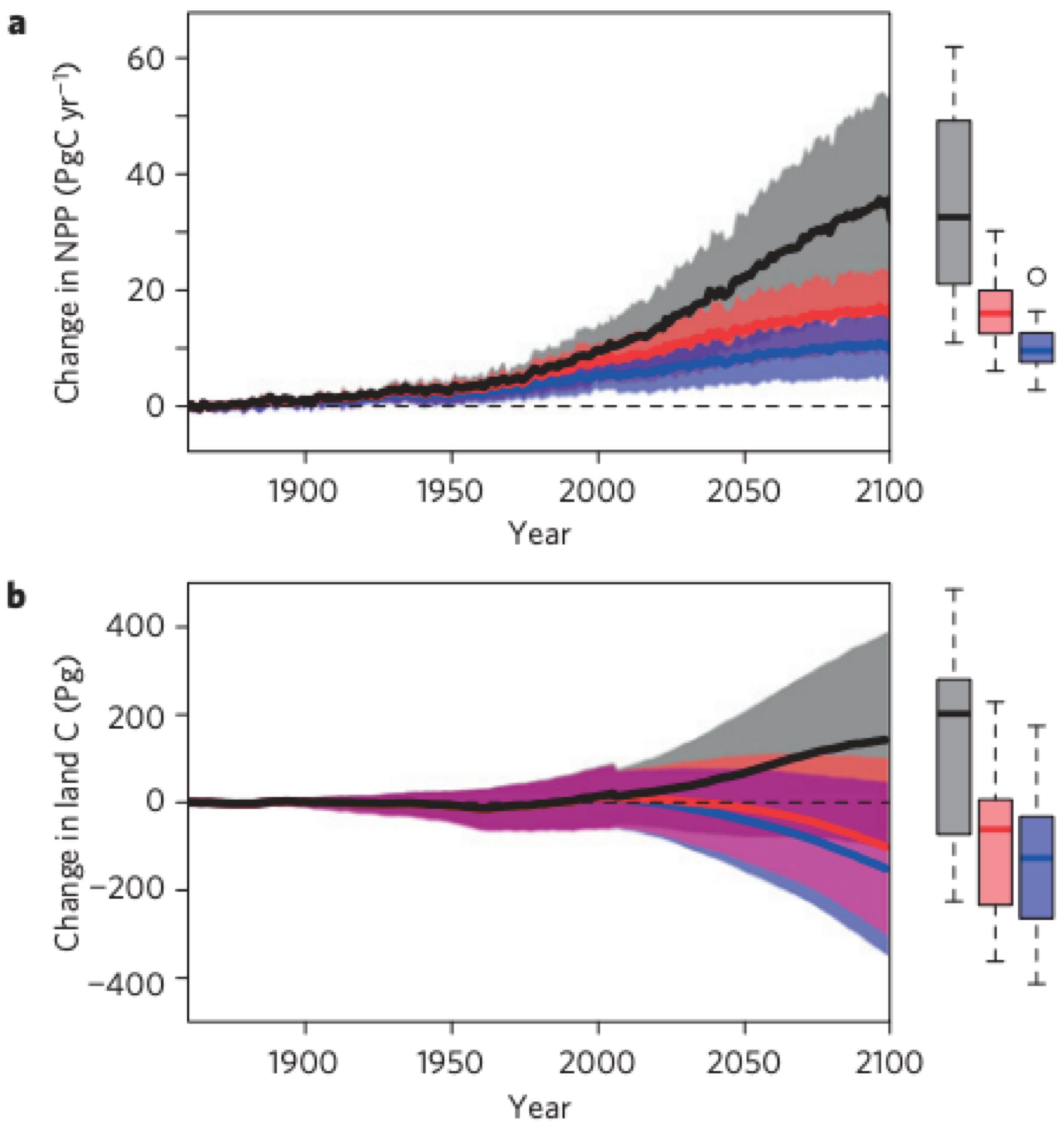


Models are uncertain!

Stitch et al. (2024)

Why soils?

They are also drivers of C-N dynamics



Weider et al. (2015)

How do we model soils? CENTURY as an example

Soil Science Society of America Journal

SSSA
Soil Science Society of America

Division S-3—Soil Microbiology and Biochemistry

Analysis of Factors Controlling Soil Organic Matter Levels in Great Plains Grasslands†

W. J. Parton, D. S. Schimel, C. V. Cole, D. S. Ojima

First published: 01 September 1987 |
https://doi.org/10.2136/sssaj1987.03615995005100050015x

‡ Contribution from the Natural Resource Ecology Lab., Colorado State Univ., Fort Collins, CO 80523.

Outline of Bolker et al. (1998)

- Structure of CENTURY
- Modeling soil C decay in CENTURY
  - Carbon
  - Carbon + Nutrients
- Simplification of ecosystem Models

Ecological Applications, 8(2), 1998, pp. 425–439

LINEAR ANALYSIS OF SOIL DECOMPOSITION:
INSIGHTS FROM THE CENTURY MODEL

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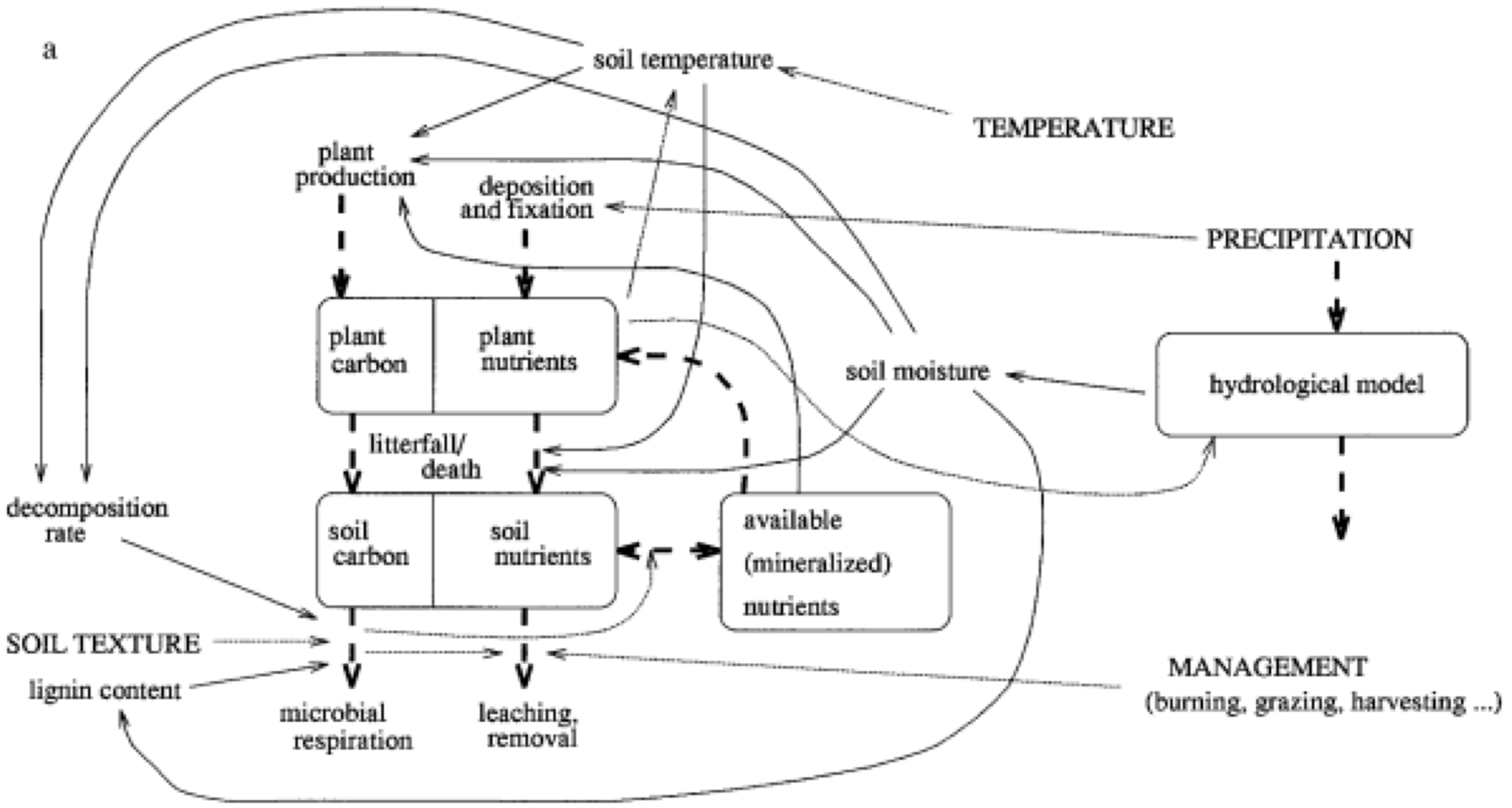
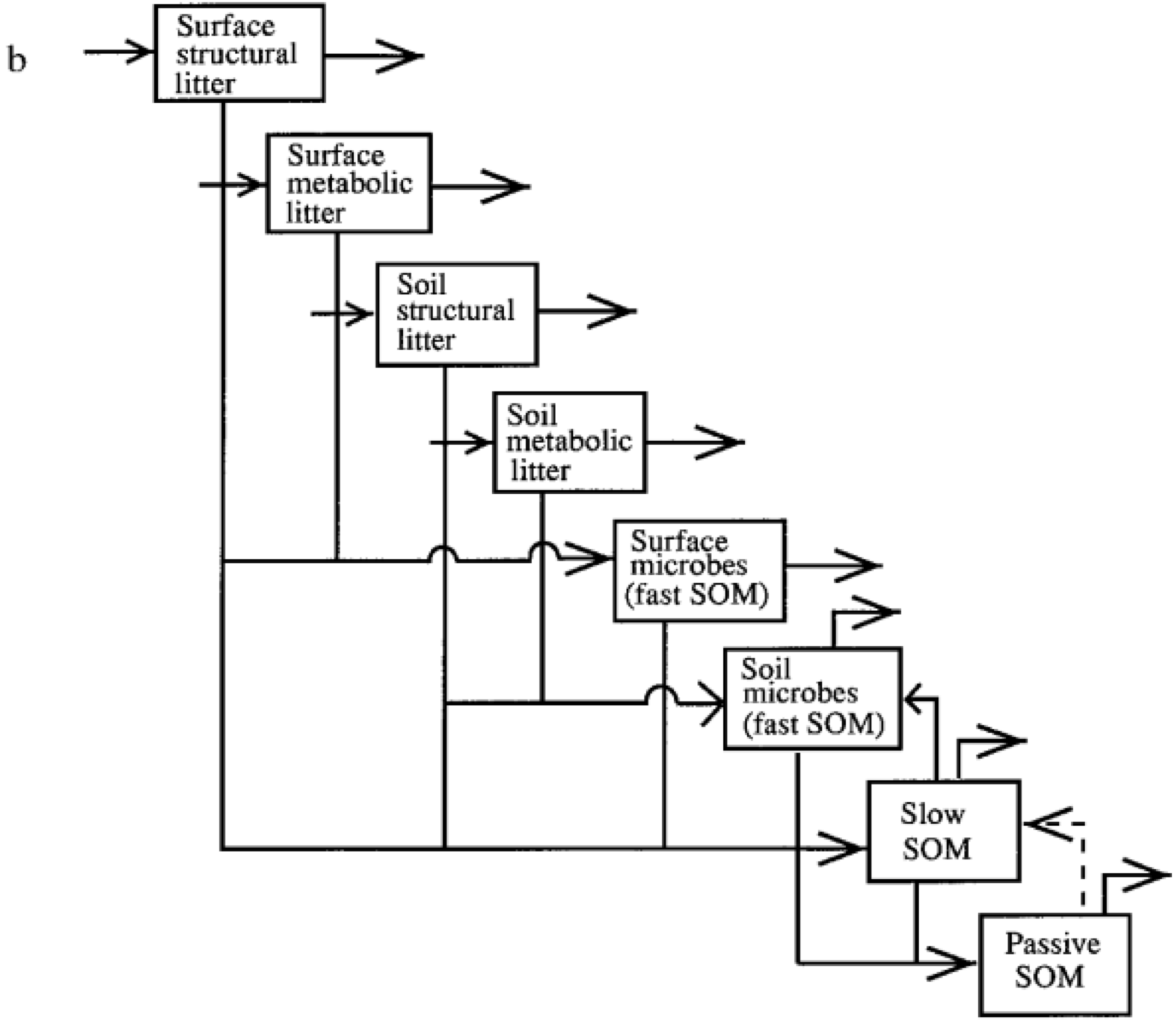
Structure of CENTURY



Bolker et al. (1998)



Bolker et al. (1998)

Modeling soil C decay

$$\frac{dC}{dT} = \delta(t)MC$$

C = vector of C in each compartment (g)

T = time (yr)

δ(t) = decomposition factor (unitless?)

M = m_{ij} or rate which material from j goes to i (yr^{-1})

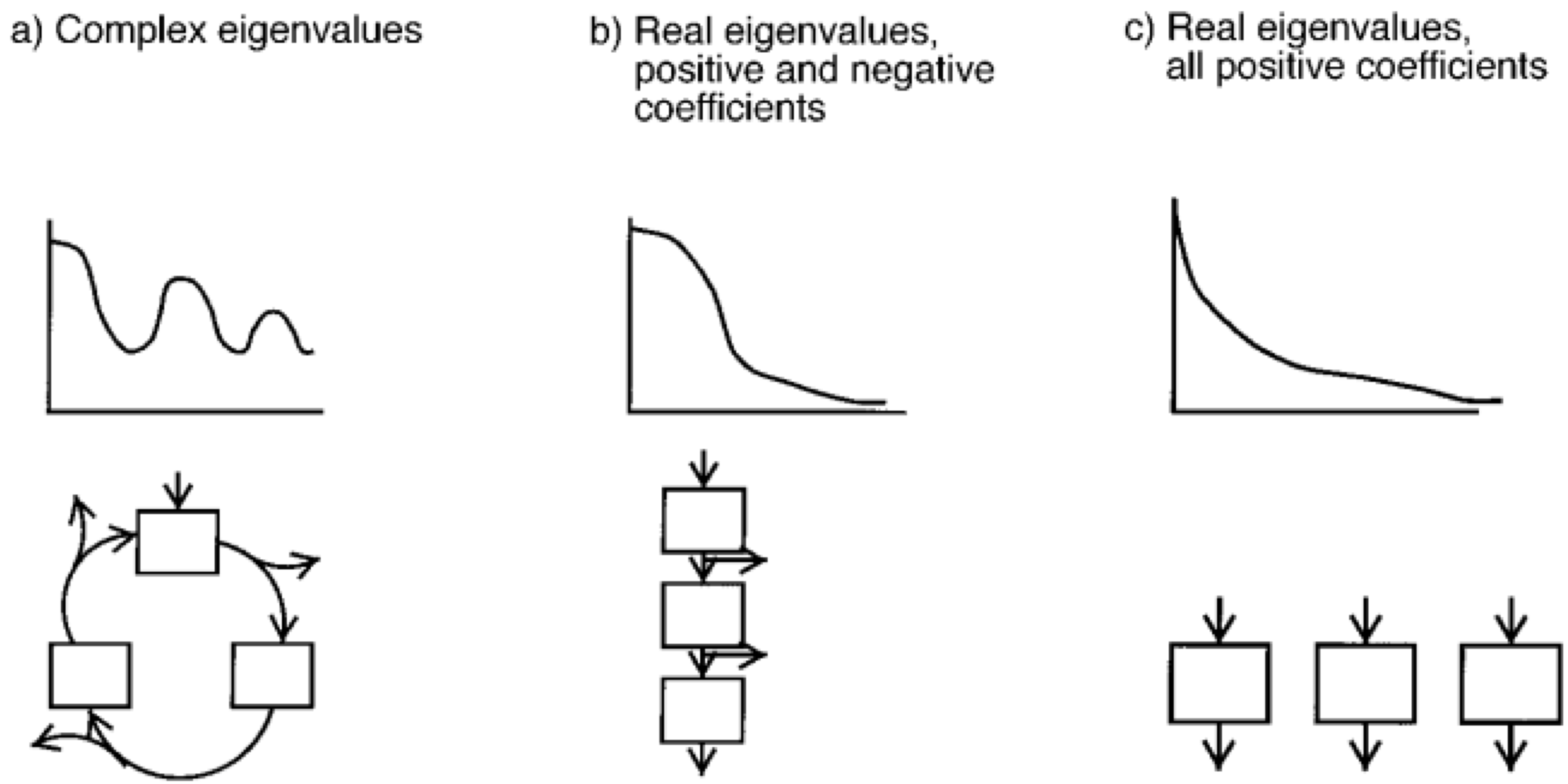


FIG. 2. Dynamical possibilities of a linear decay system: (a) damped oscillations; (b) serial transfer; (c) pure decay.

CENTURY tends to devolve to (c)

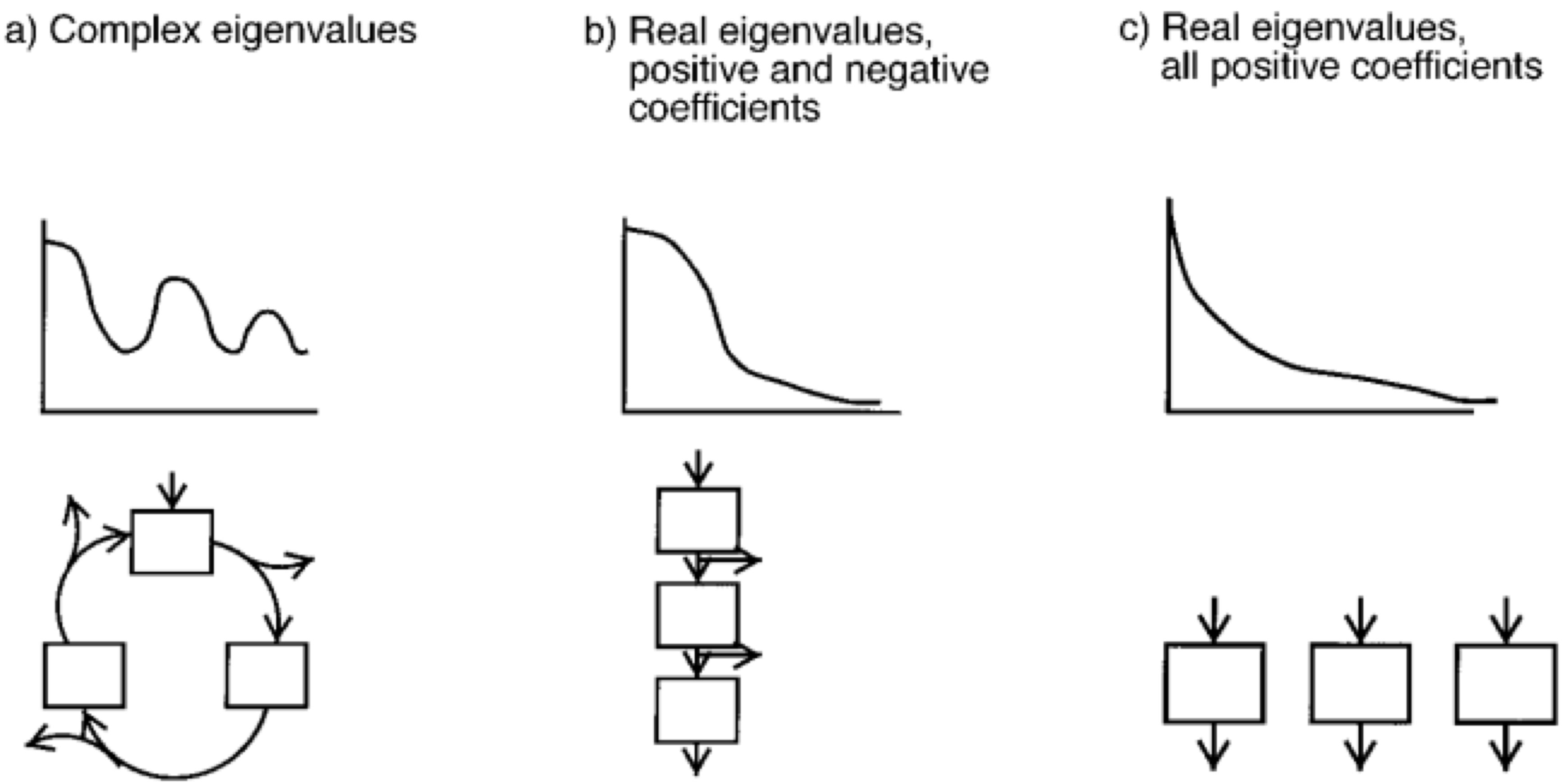


FIG. 2. Dynamical possibilities of a linear decay system: (a) damped oscillations; (b) serial transfer; (c) pure decay.

CENTURY tends to devolve to (c), meaning every C molecule is completely decomposed (returned to atmosphere or moved to more recalcitrant pool)

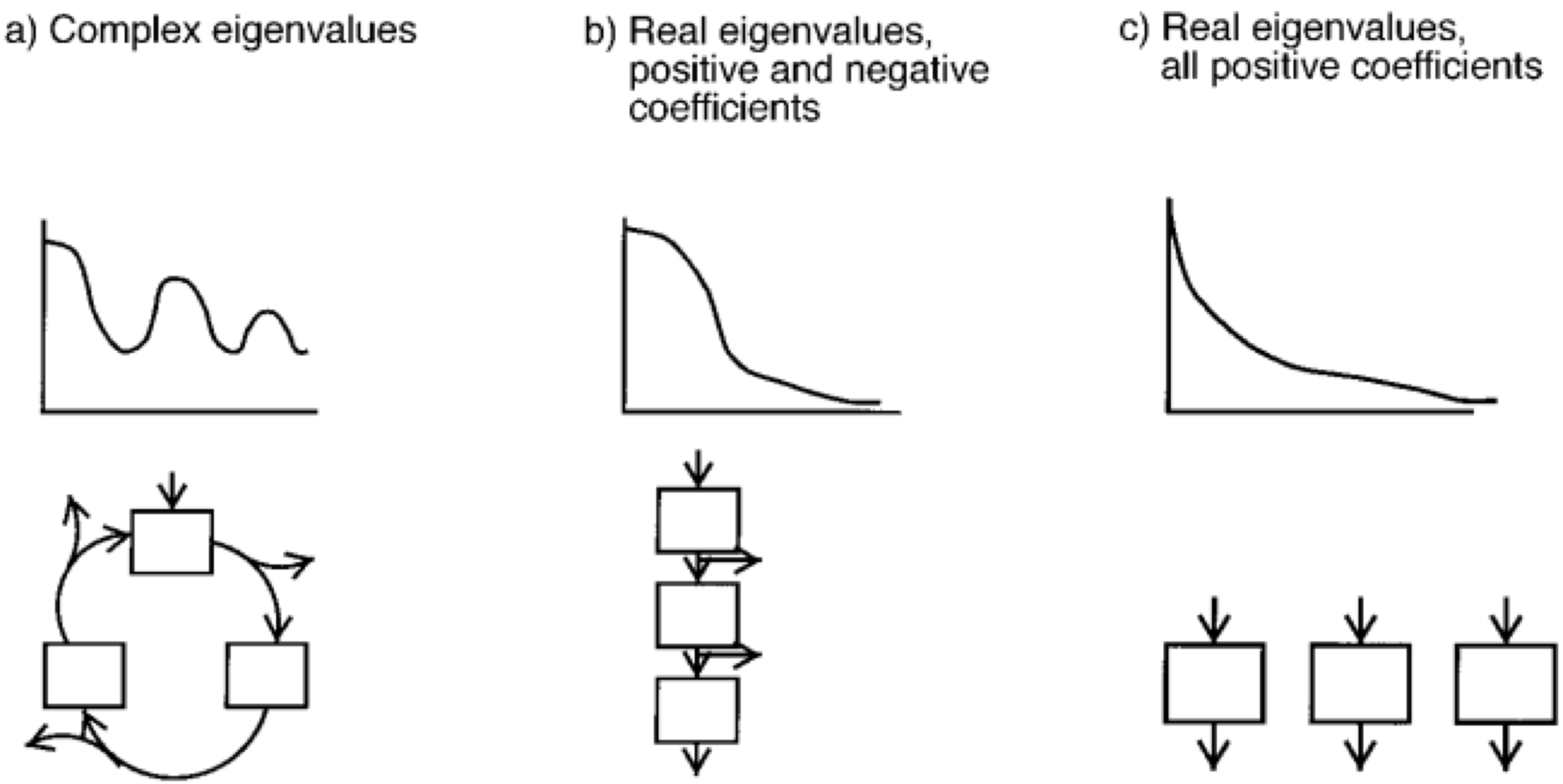
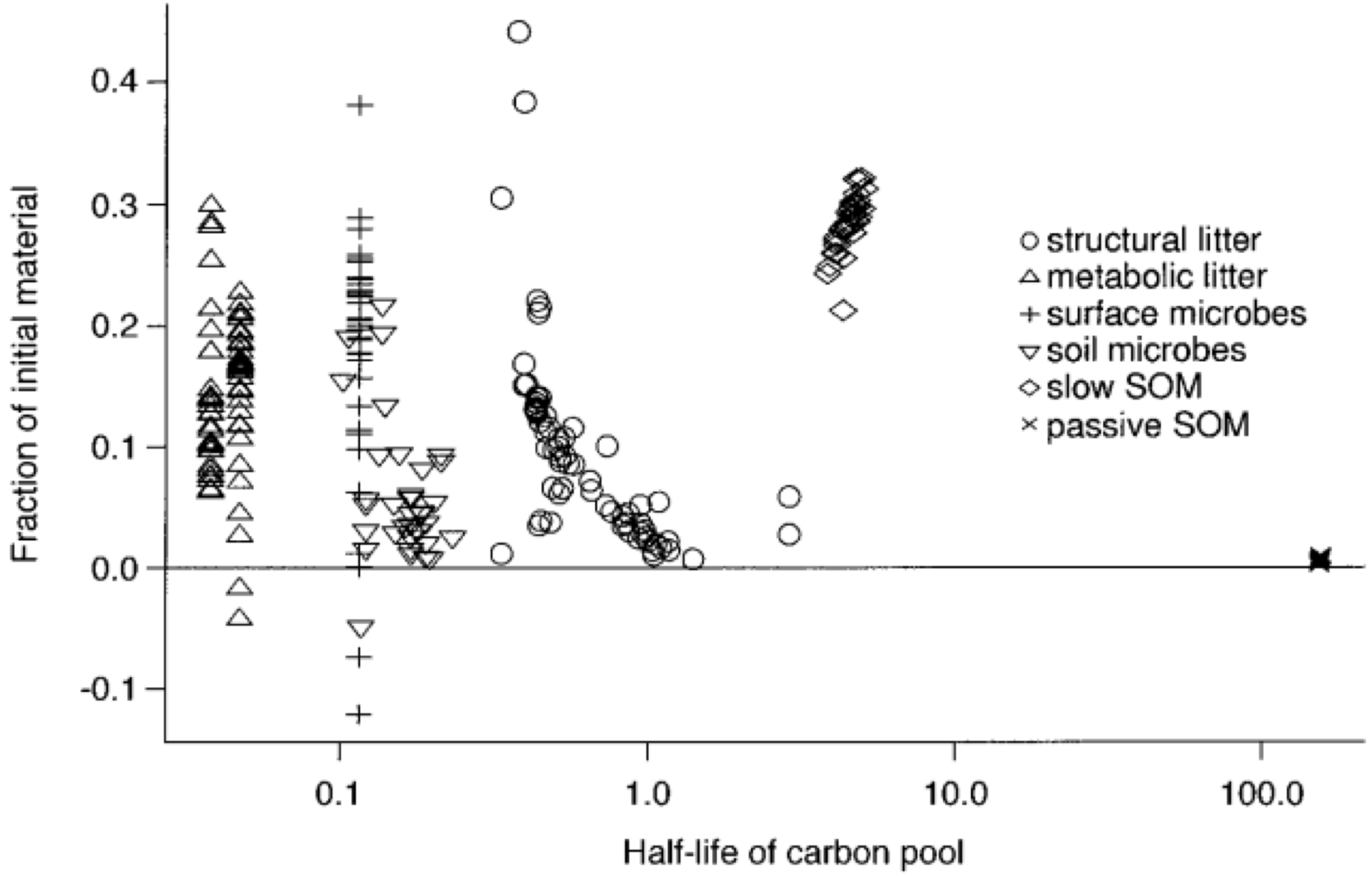


FIG. 2. Dynamical possibilities of a linear decay system: (a) damped oscillations; (b) serial transfer; (c) pure decay.

CENTURY tends to devolve to (c), meaning C can be partitioned instantaneously depending on time scale of interest



Positive values indicating continuous flow through pools (but note the passive pool)

FIG. 3. Decay rates (shown as half-lives) and loadings for 34 SCOPE sites around the world, determined by calculating the eigenvalues and eigenvectors for the soil texture, precipitation, and C:N ratios at each site. The horizontal axis shows the base decomposition half-life [$\log_2(e)/\lambda$; based on a decomposition factor of 1] for each carbon pool; the vertical axis shows the fraction of each incoming cohort of carbon in each pool (negative values represent serial transfers as in Fig. 1b). The passive pool appears as a tight cluster near (100, 0); the quantity and half-life of passive material vary little between sites.

CENTURY approach to nitrogen

- N model ignores explicit C dynamics
- N model is a closed system (recycling between plants and soil)
- N limits growth if water and temperature are not limiting

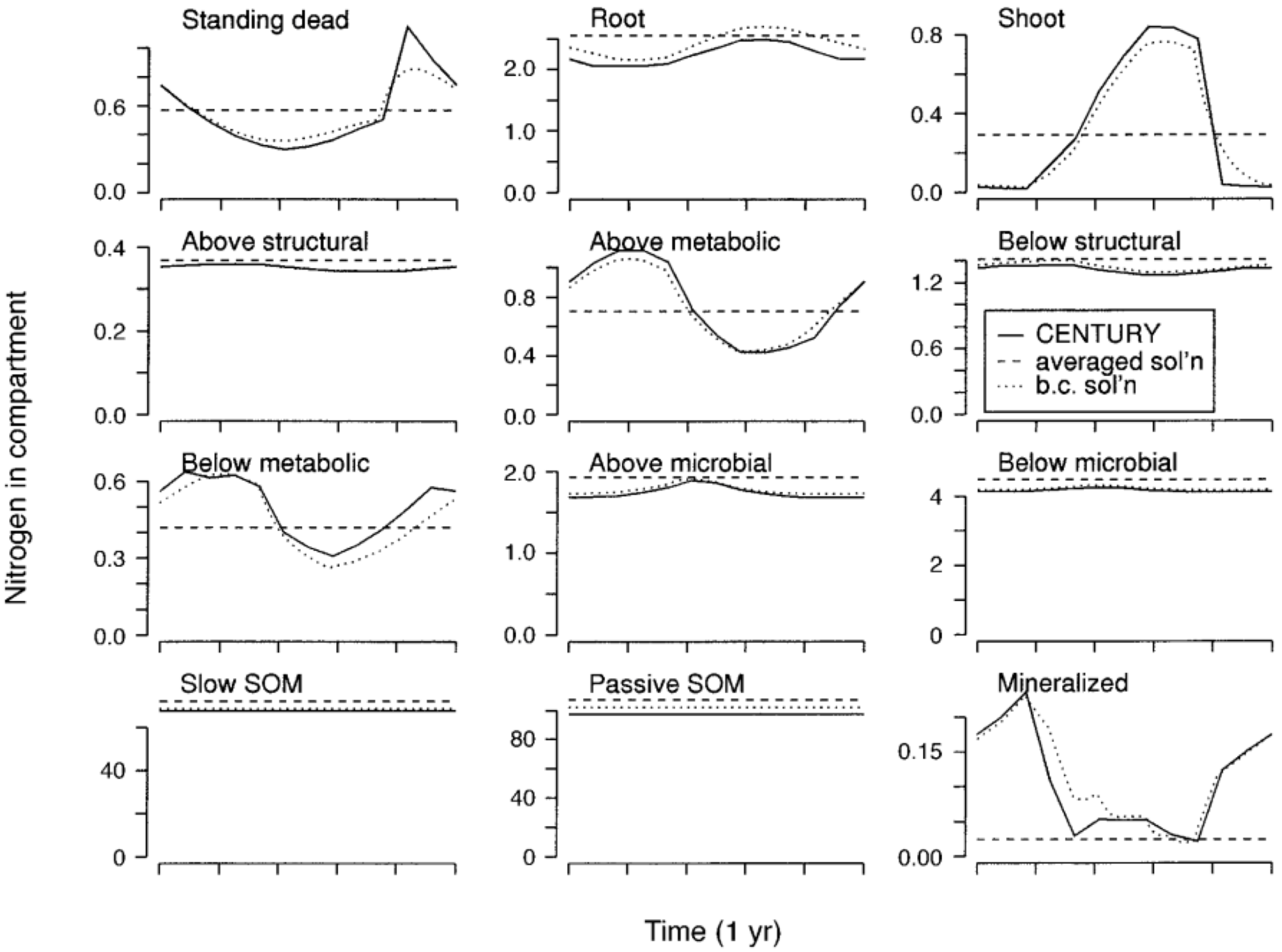


FIG. 4. Output of the CENTURY equilibrium equations (Appendix C) and boundary-condition solver compared with long-term stable seasonal variation in the real model (CENTURY model run for 5000 yr). Each subfigure shows the nitrogen content of each nitrogen pool in the model over the course of 1 yr. Abbreviations: sol'n = solution; b.c. = boundary condition.

Simplification of ecosystem models

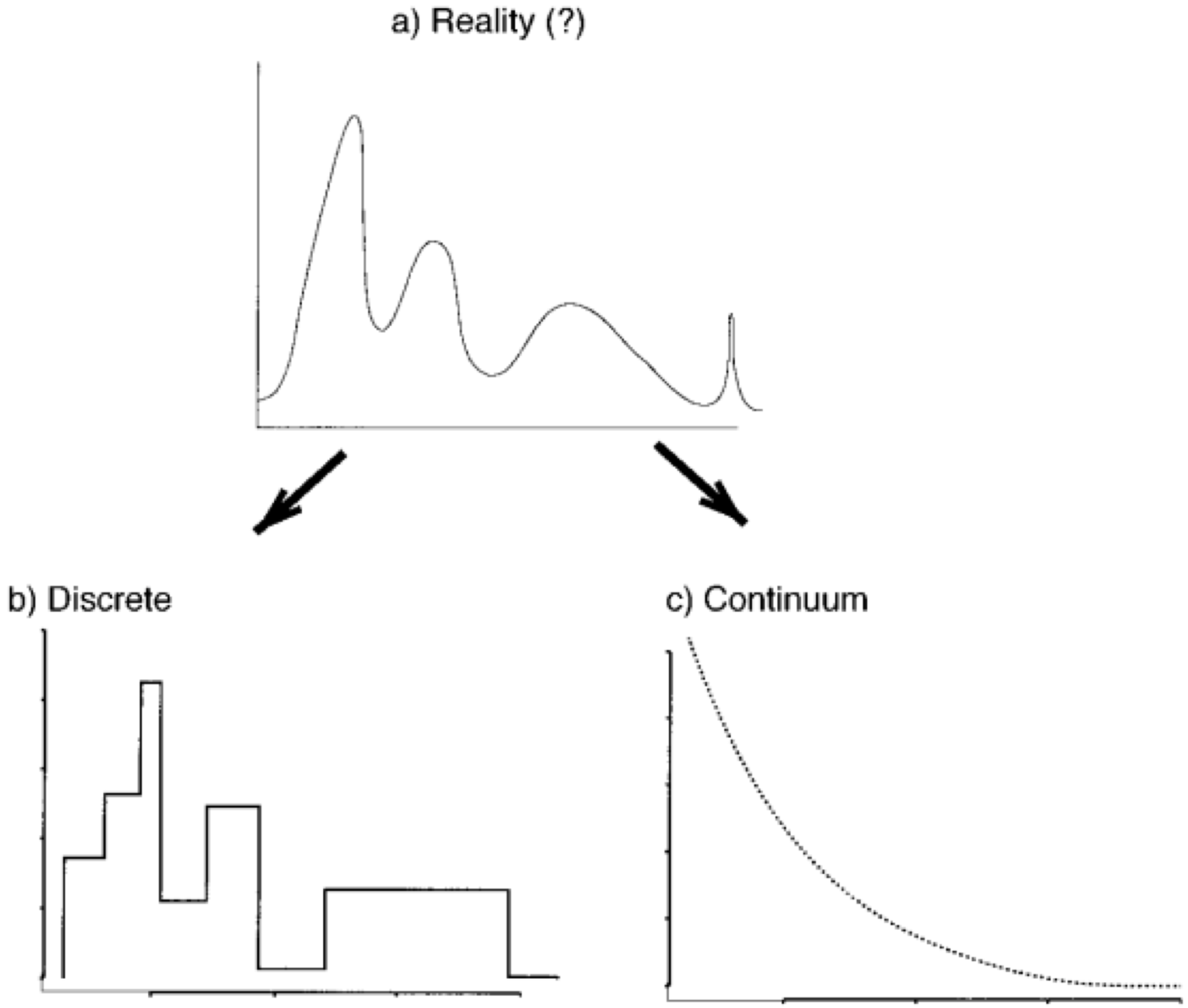
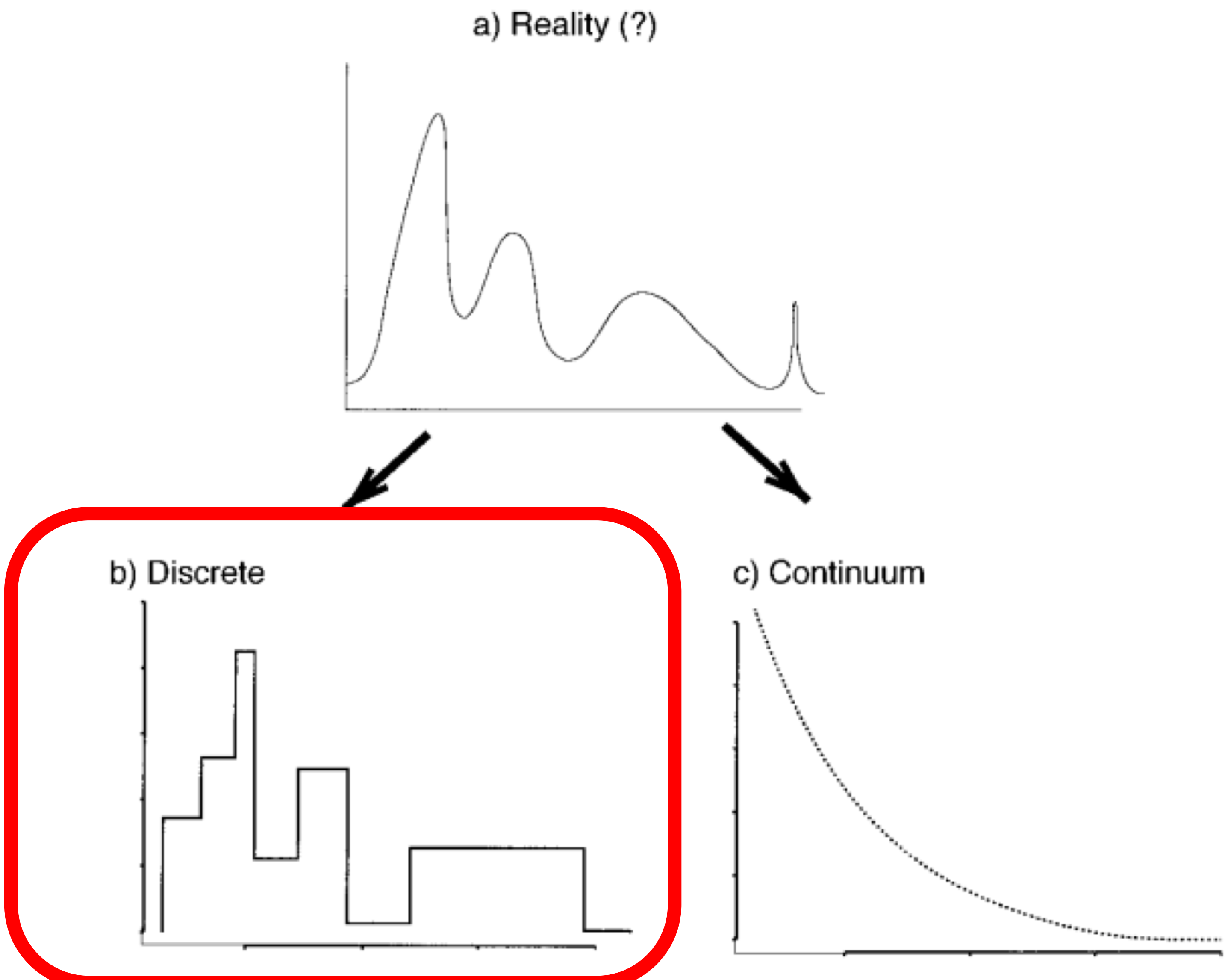


FIG. 5. Different approximations of distributions of decay times. The real (unknown) distribution of eventual decay times for the carbon compounds in a given sample of litter may look something like (a), with particular classes of compounds giving rise to particular peaks of different heights (total quantity) and widths (variability in chemical and physical properties). A model could represent this unknown distribution as (b) a series of discrete boxes, as in CENTURY, or as (c) a continuous distribution of decay times (see Fig. 7).



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Discrete: how many levels to use?

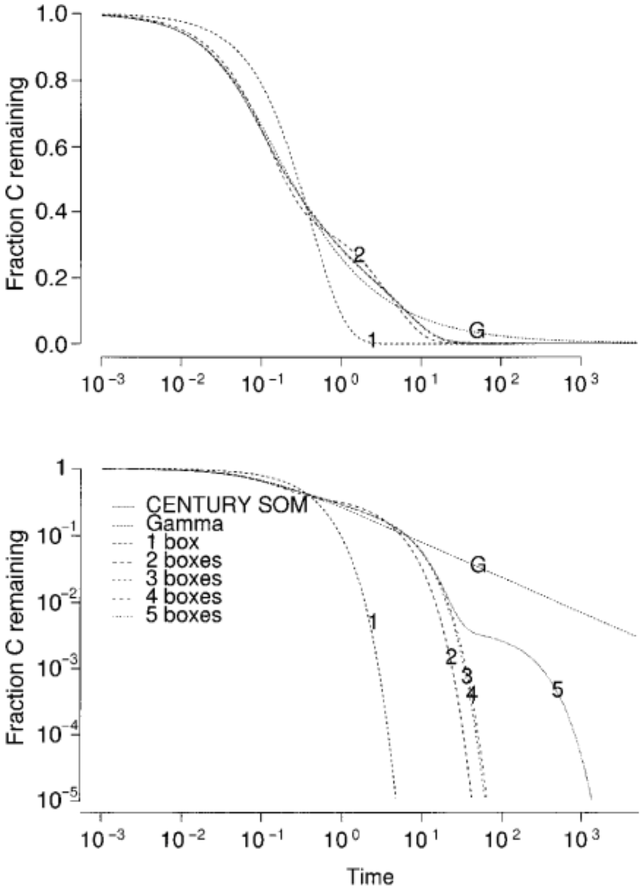
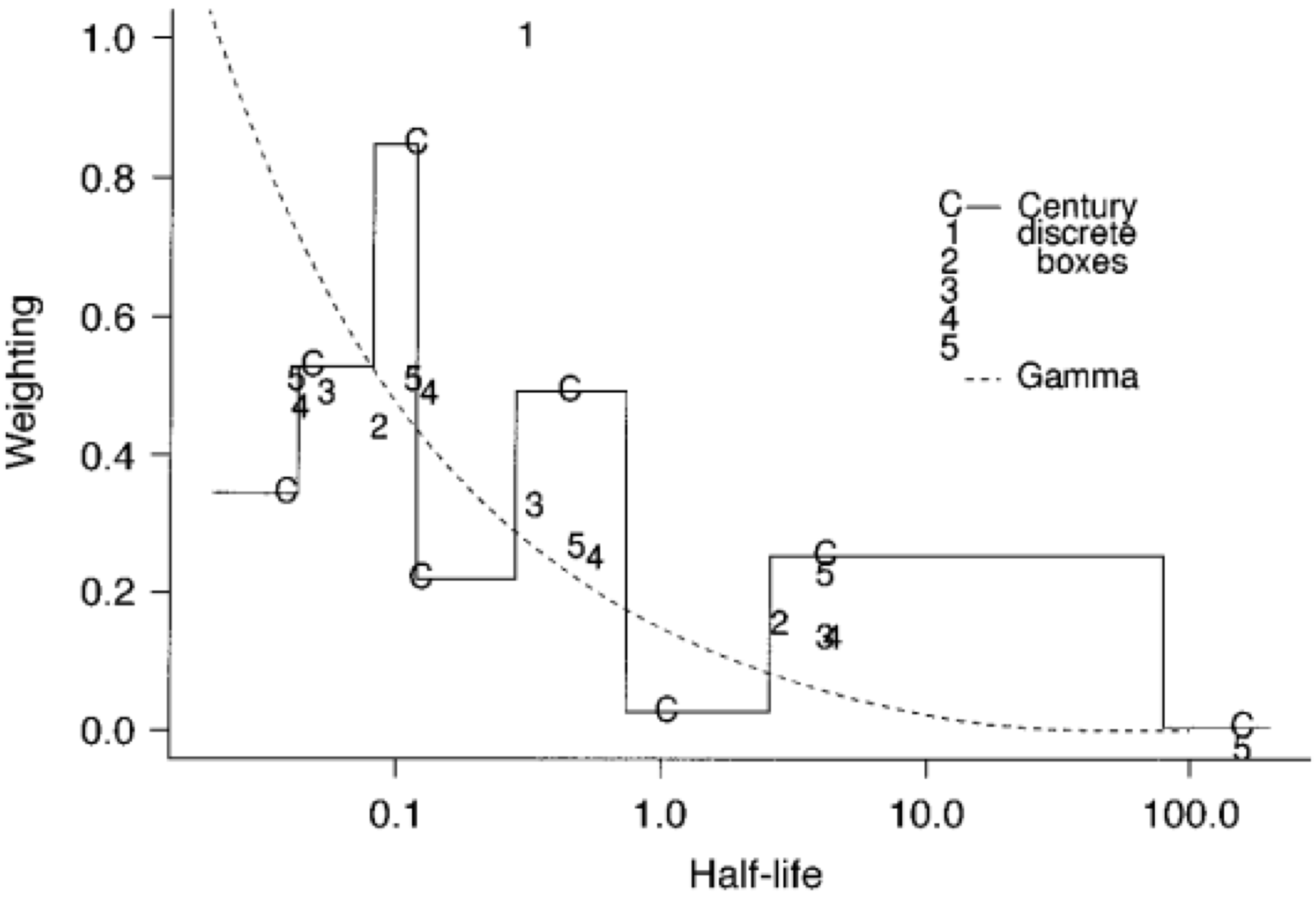


FIG. 6. Decay of one litter cohort over time for typical (CPER) parameters, as approximated by continuous (gamma distribution) and discrete models. The horizontal (time) axis is logarithmic. (a) Linear vertical scale: 3-, 4-, and 5-box models are indistinguishable from the full 8-box dynamics. (b) Logarithmic vertical scale: 5-box model is indistinguishable from the full 8-box dynamics.

FIG. 7. Distribution of decay rates and loadings for different fitted models. The horizontal axis shows half-life of carbon decay on a logarithmic scale, as in Fig. 3. The vertical axis shows the coefficients, normalized by the distance between boxes, so that the figure shows a rough frequency distribution of material with different half-lives. (The choice of normalization depends on the minimum and maximum possible decay rates and on the the horizontal axis scaling.) The solid line shows the distribution for the CENTURY model with CPER parameters; different numbers show n-box fit parameters; the dashed line shows the fit for the gamma distribution. Some loadings for the 5-box model are offset slightly for legibility.



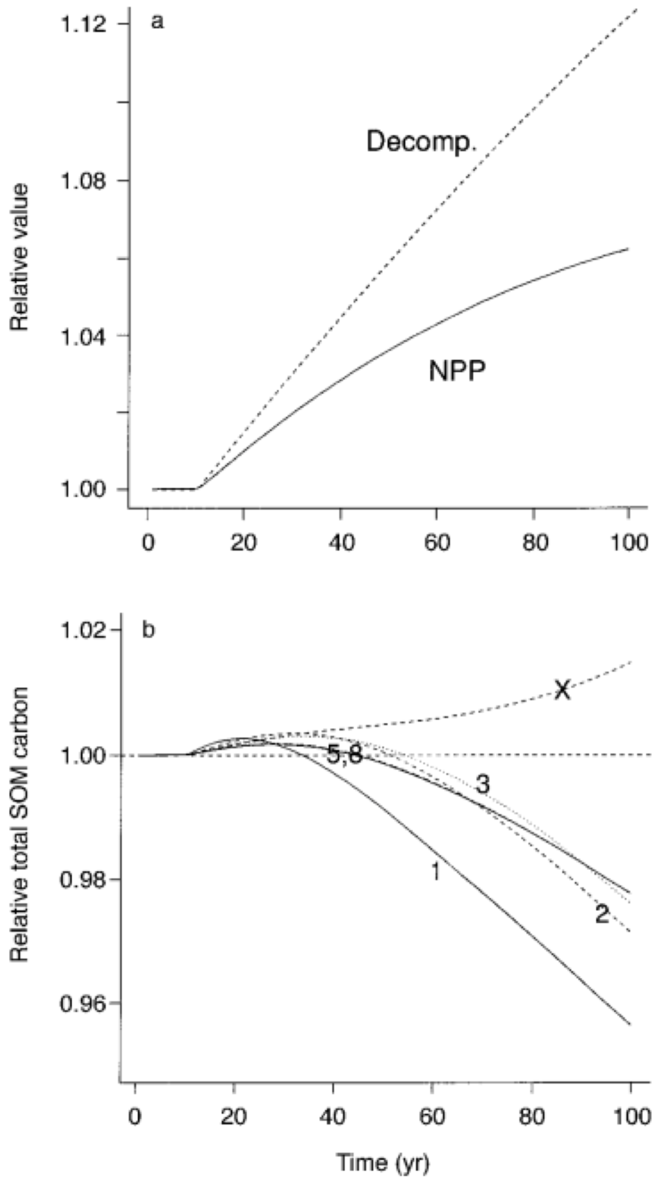
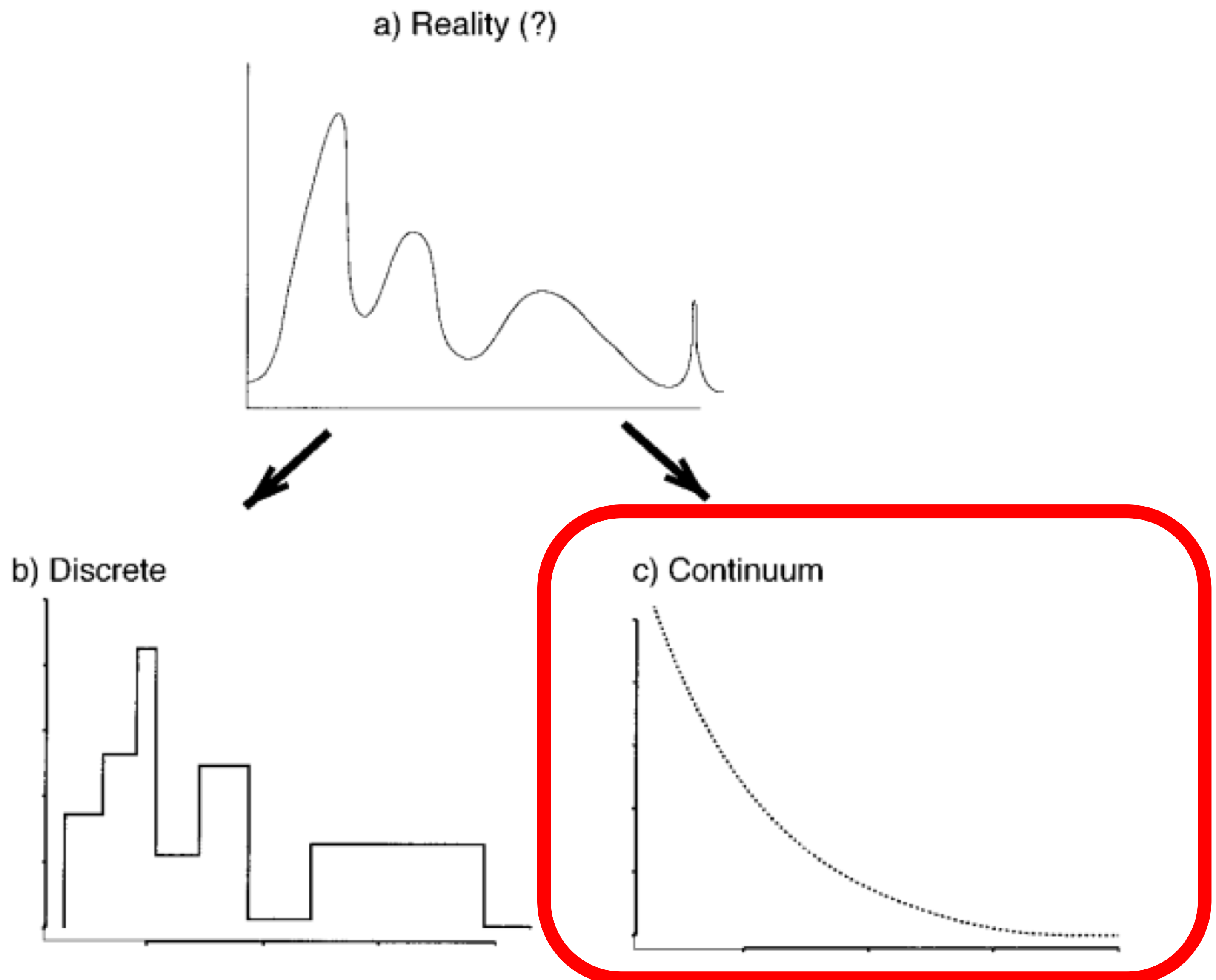


FIG. 8. Effects of SOM model simplification on a global-change scenario. (a) Relative changes in NPP (net primary productivity) and decomposition factor [$\delta(t)$] over time. Decomp. = decomposition. (b) Relative changes in total SOM carbon over time, for different numbers of compartments. Numbers label results from n-compartment models; × labels results of increasing passive carbon. (The vertical axis is strongly expanded to show differences among models.)



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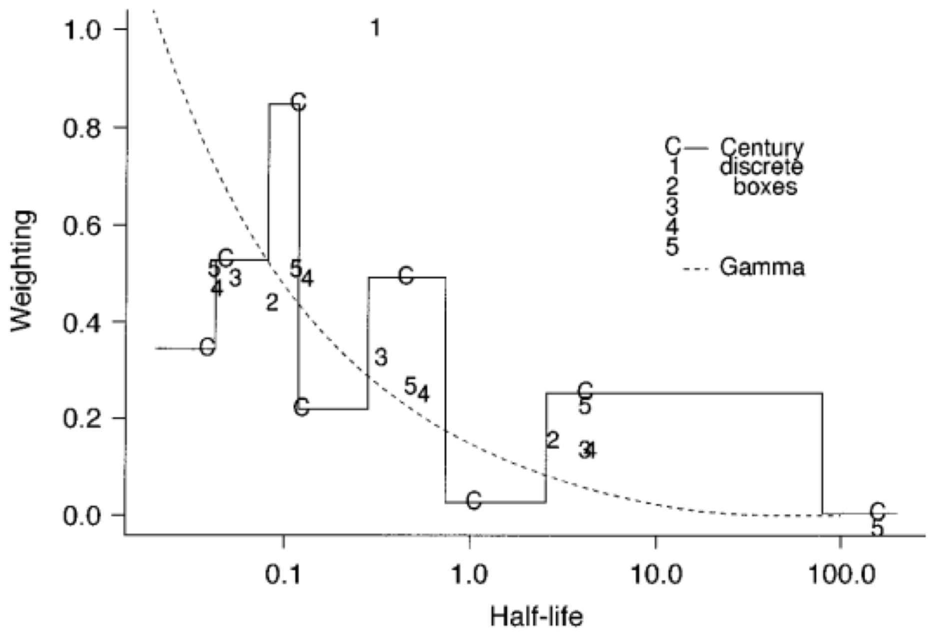
Is a continuous model distribution better?

- Need to pick a distribution
- And associate parameters
- Depends on availability of data and application for the model



Some general takehomes

- CENTURY can be simplified
- Simple models are easier to understand
  - E.g., parameter sensitivity
- Construct simplest model first and continuously test added complexity
  - More validation for the class approach!