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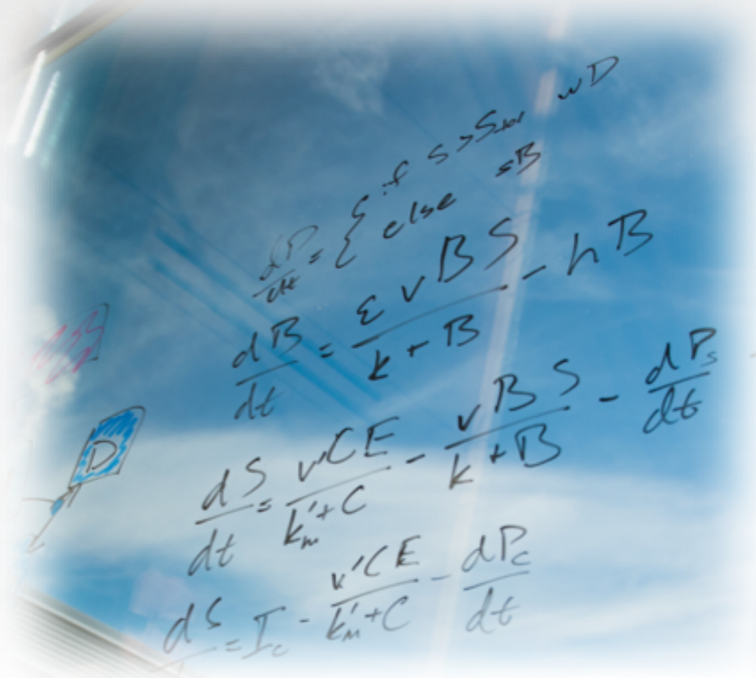
Scaling complexity in soil carbon models



KATHERINE TODD-BROWN

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8 February 2018
Pacific Northwest National Laboratory, Richland, WA, USA

U.S. DEPARTMENT OF
ENERGY

Talk outline

Predictions of future soil carbon stock in Earth system models

- Reduce complexity
  - Mathematical cleverness
  - Model-data integration
- Enriching complexity
  - Formalizing assumptions
  - Targeted experimental opportunities

Complexity in space-time

Why is predicting atmospheric CO_2 levels hard?

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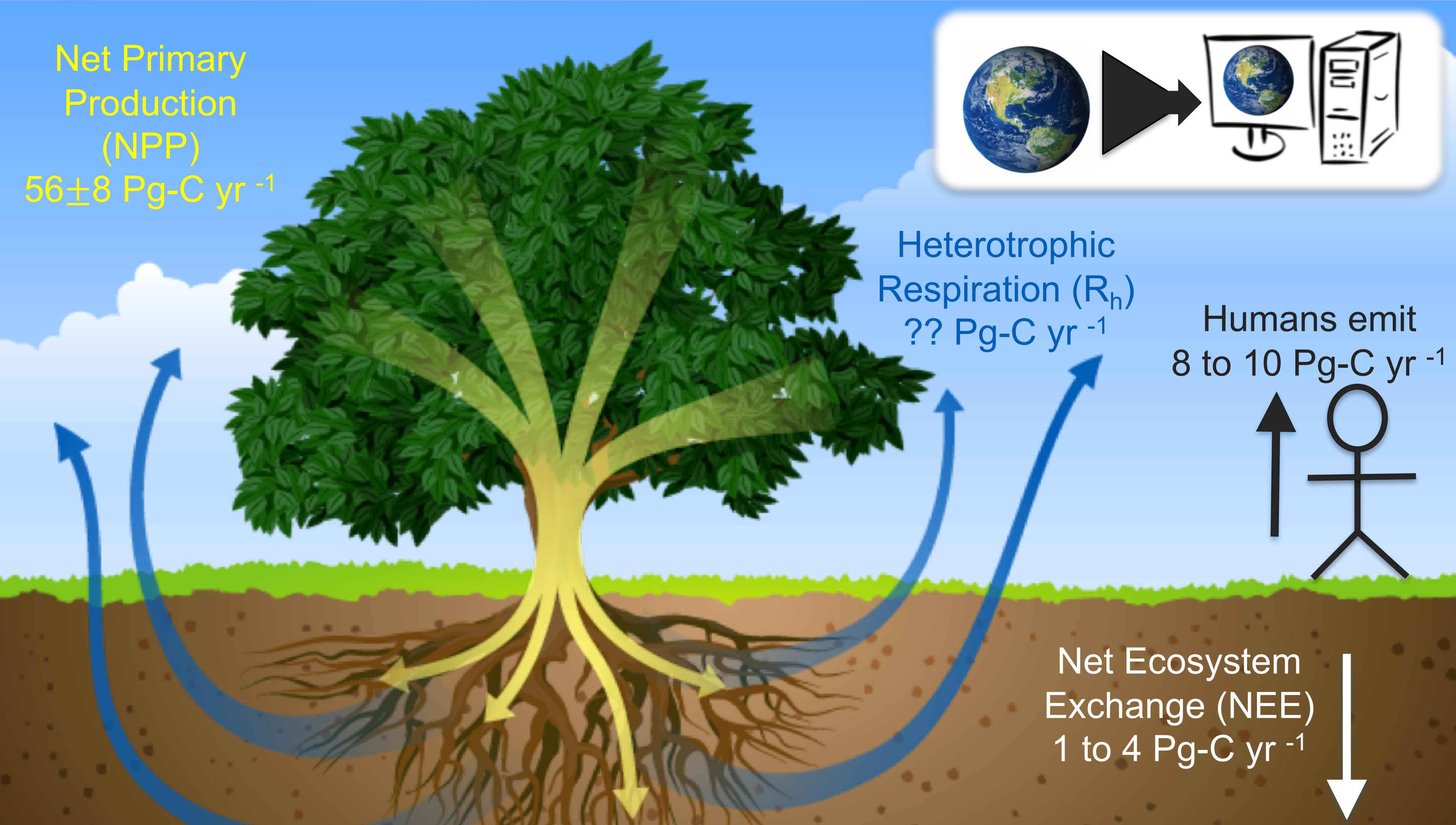

Ito, Global Change Biology (2011)
Le Quere, et al. Nature Geoscience (2009)

Change in soil carbon stock over the 21st century are very diverse

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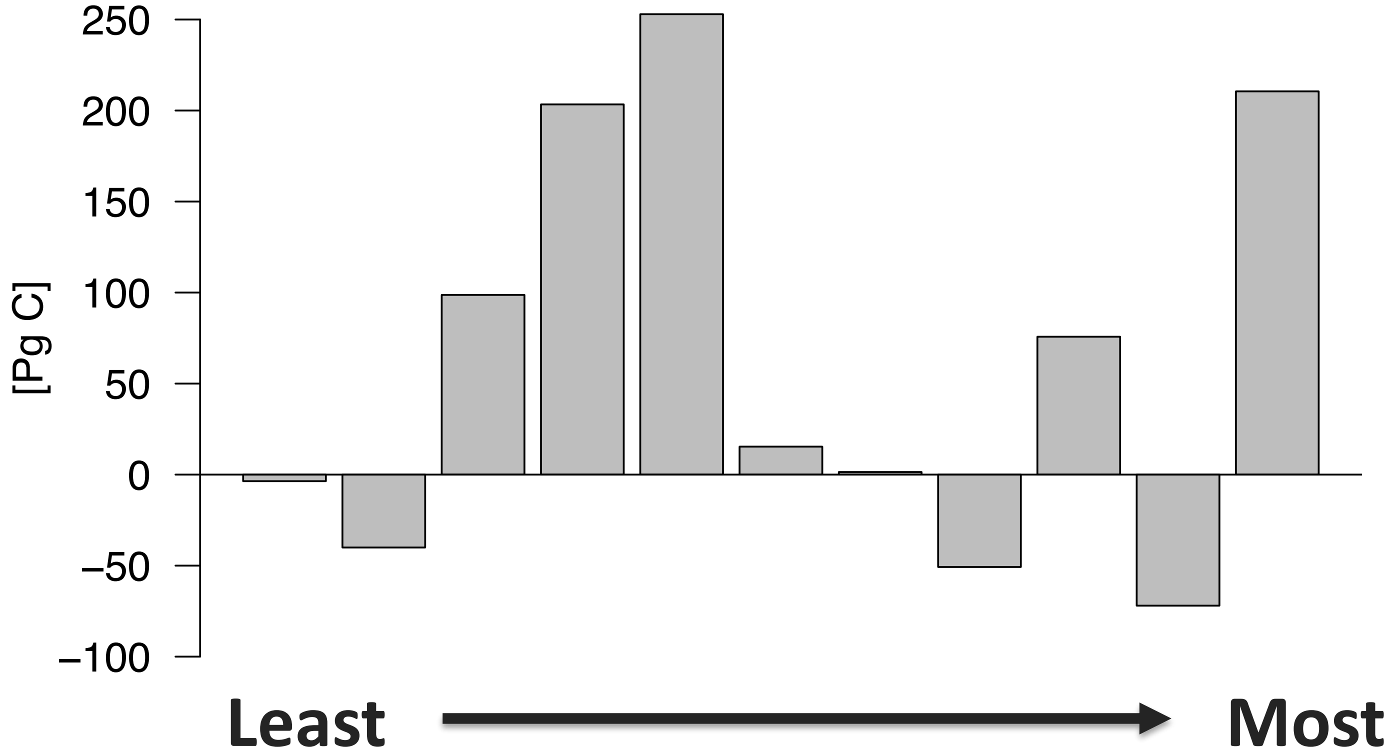

Modern soil carbon stock
CMIP5 Earth system models

Todd-Brown, et al. *Biogeosciences*. 2014

Modern benchmarks for global soil carbon and NPP do not constrain projections

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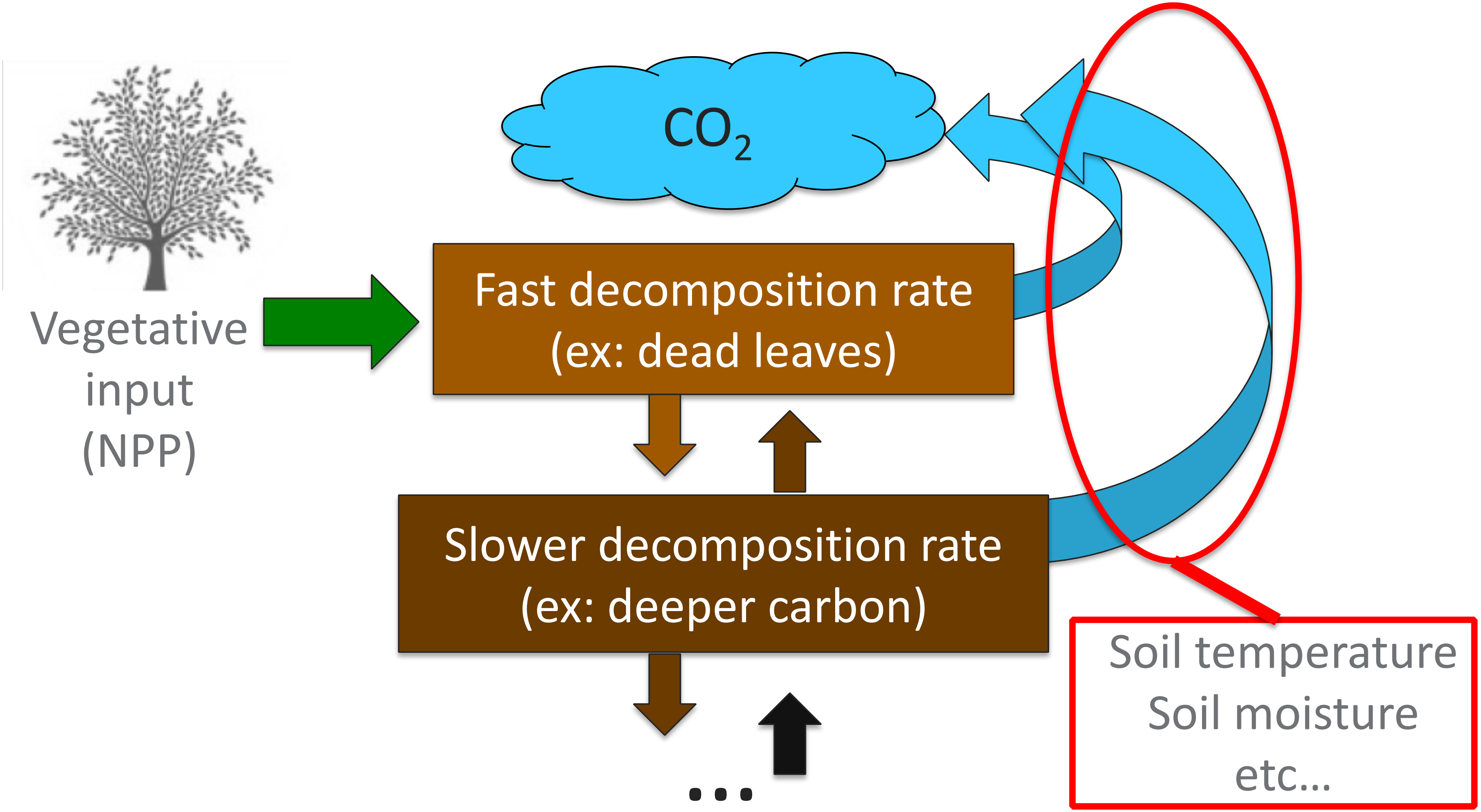
Modern soil carbon stock

CMIP5 Earth system models

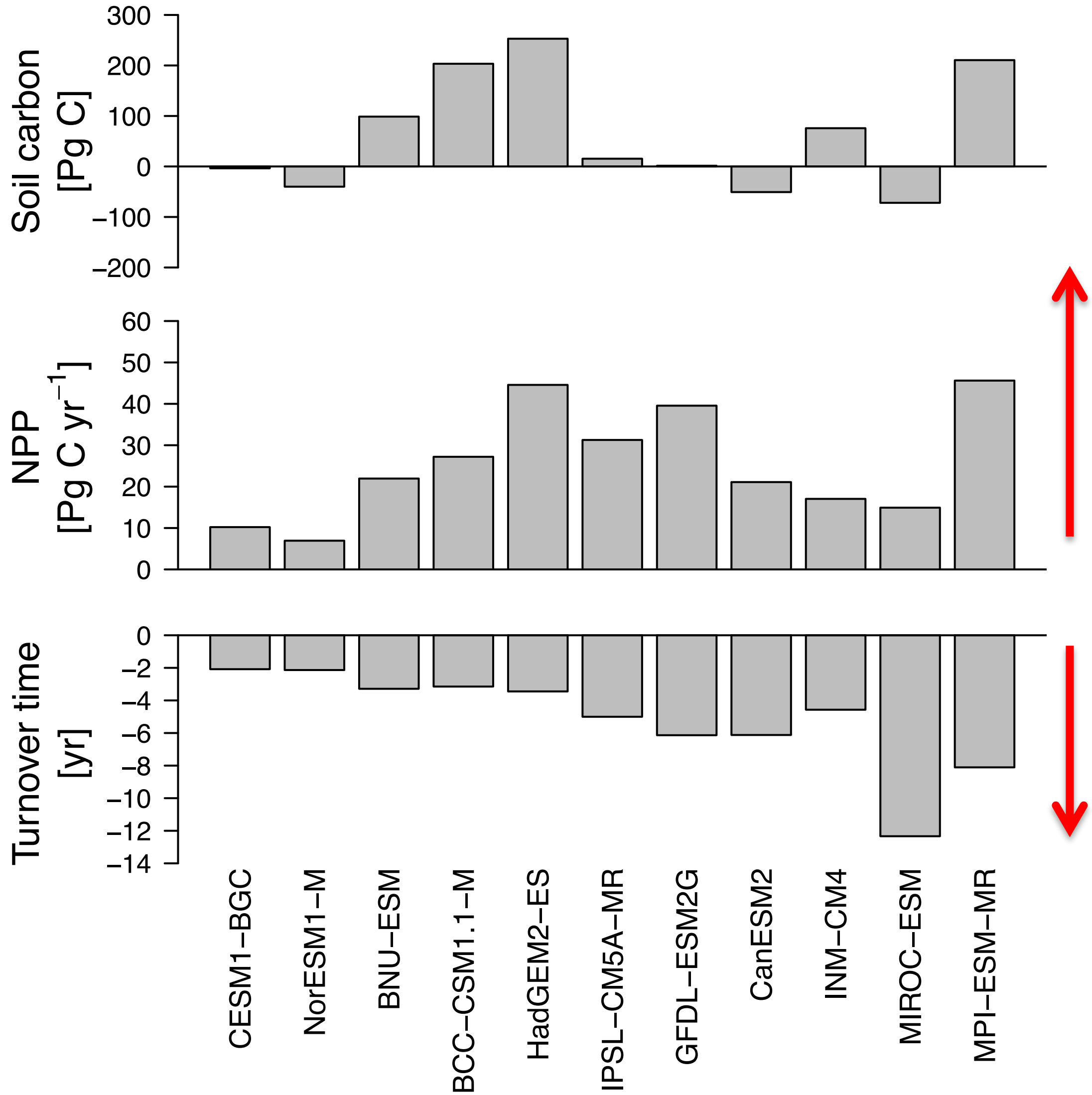
Todd-Brown, et al. *Biogeosciences*. 2014

Models can have different inputs, model structure, environmental drivers, and model parameters.



CENTURY: Parton et. al. 1987, 1988, 1992, 1993
CLM: Oleson et. al. *Tech. description of vs 4.0 of CLM 2010*

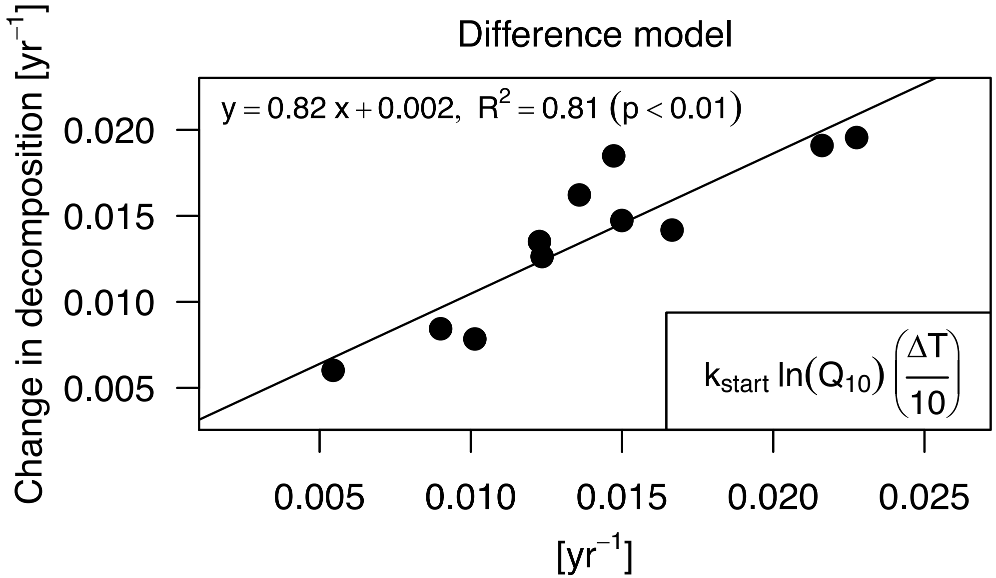
Shifts in inputs and soil warming are the main drivers of soil carbon shifts.



CMIP5 RCP 8.5 difference between start and end of 21st century (10yr means)

Todd-Brown, et al. *Biogeosciences*. 2014

Using a one pool model to explain multi-pool simulation results.



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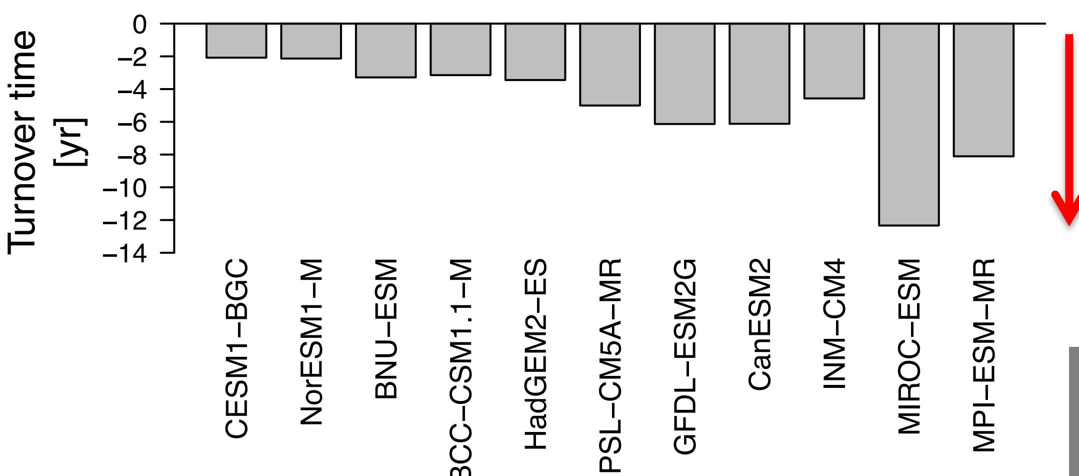
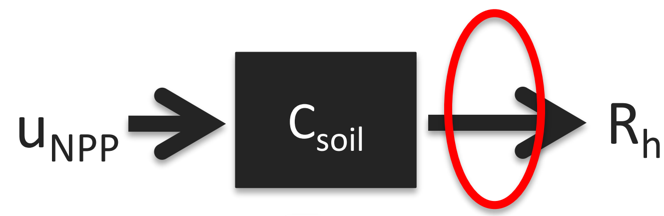


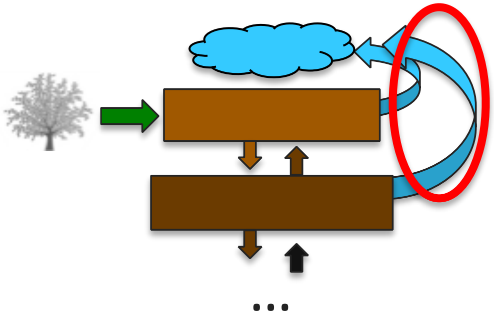


$$R_h = C_{soil} k Q_{10}^{(T-15)/10}$$

Intrinsic decomposition rate

Temperature sensitivity

Todd-Brown, et al. Biogeosciences. 2014

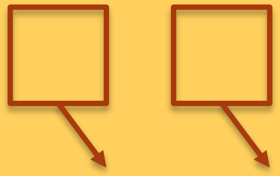


When can you use a one pool model for soils simulations?

Soil carbon…

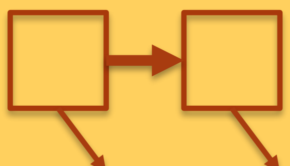
Independent

Diagonal matrix



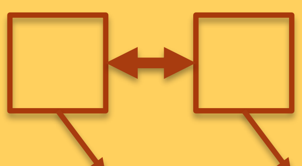
Cascade

Lower trigonal matrix



Feedback

Dense matrix

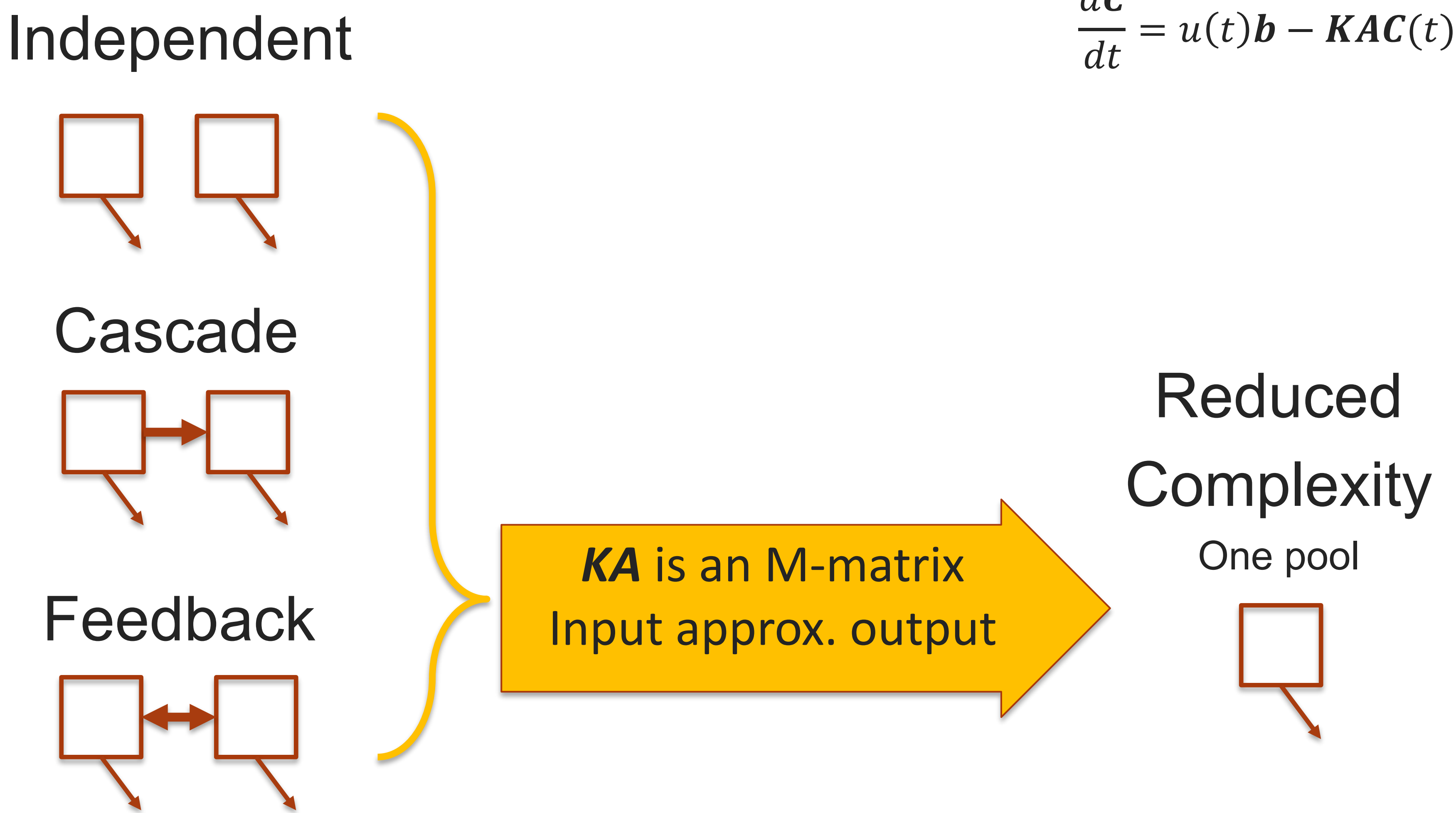


$$\frac{d\boldsymbol{C}}{dt} = u(t)\boldsymbol{b} - \boldsymbol{KAC}(t)$$

Todd-Brown, Zheng, Crowther, *Biogeosciences* (in submission)

Soil carbon as a one pool model when inputs approximates outputs.

$$\frac{d\boldsymbol{C}}{dt} = u(t)\boldsymbol{b} - \boldsymbol{KAC}(t)$$



Todd-Brown, Zheng, Crowther, *Biogeosciences* (in submission)

Soil carbon as a one pool model when inputs approximates outputs or (in some cases) single timescale.

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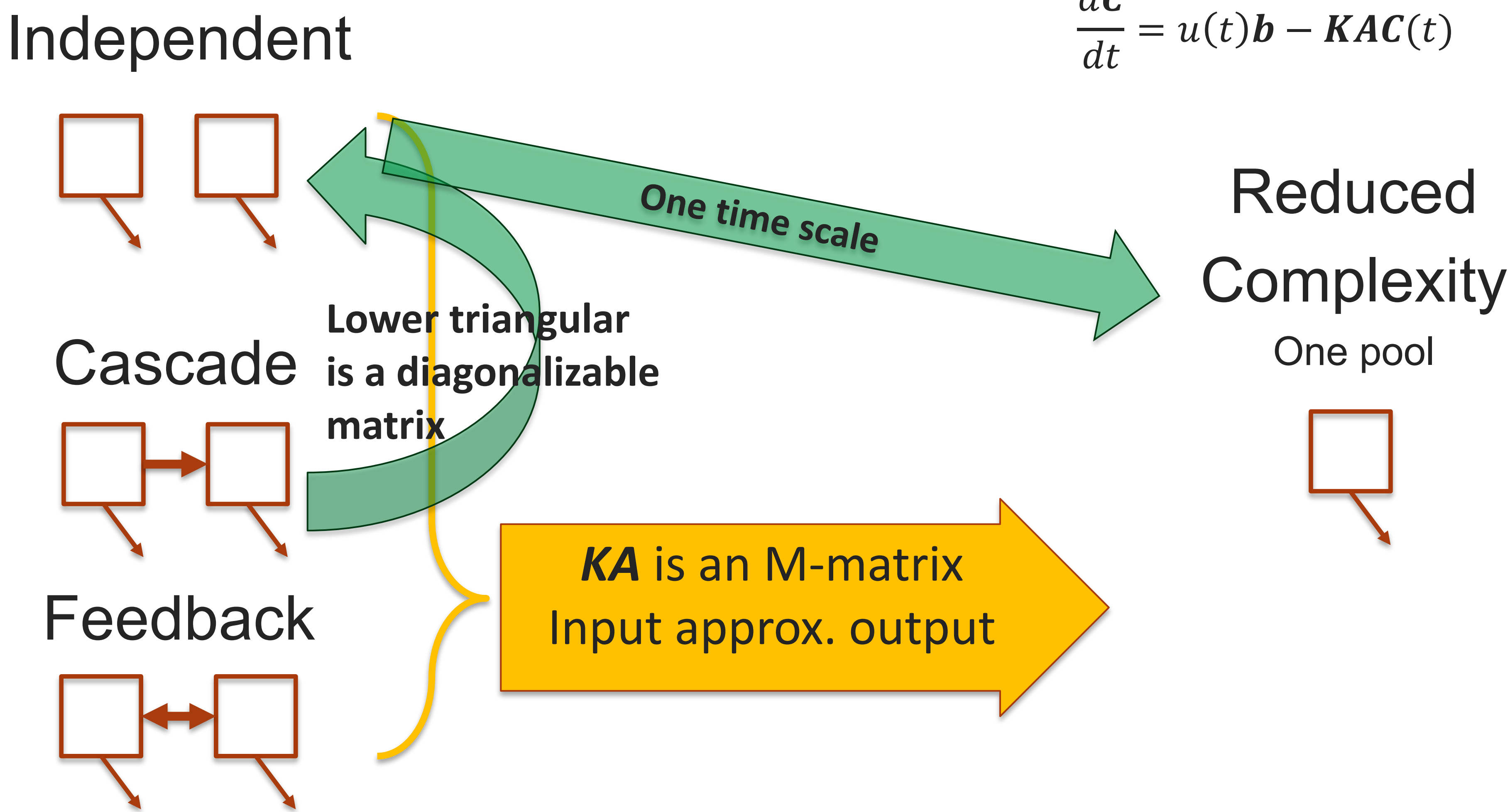
$$\frac{d\boldsymbol{C}}{dt} = u(t)\boldsymbol{b} - \boldsymbol{KAC}(t)$$



Todd-Brown, Zheng, Crowther, *Biogeosciences* (in submission)

Using one pool models to “What If” Earth system model outputs without reruns.

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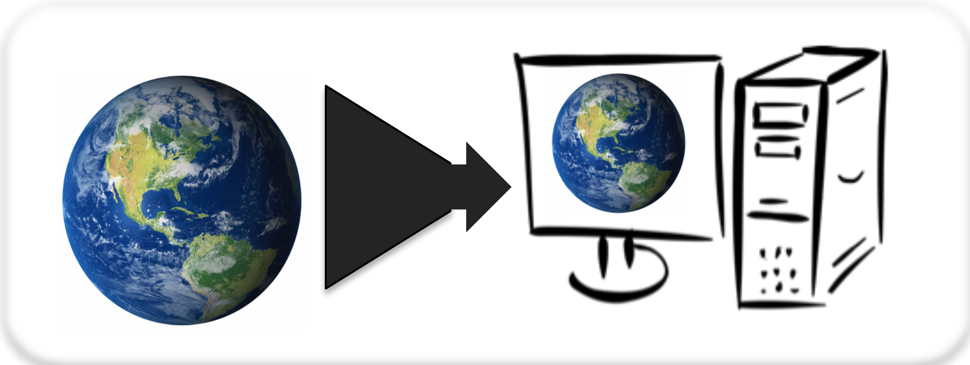
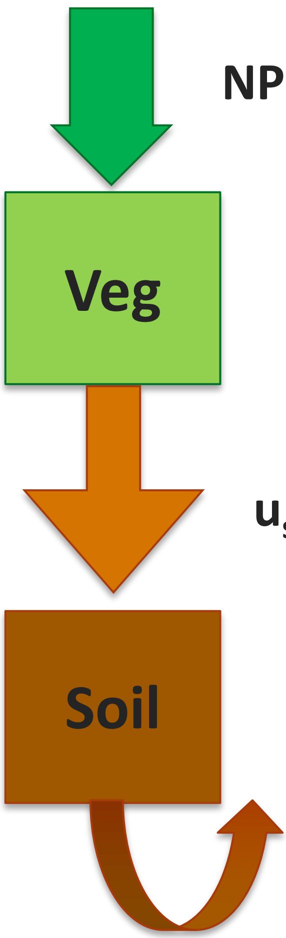


What if…

… plant productivity was limited by C:N:P?

… temperature sensitivity of soil decay was uncertain?

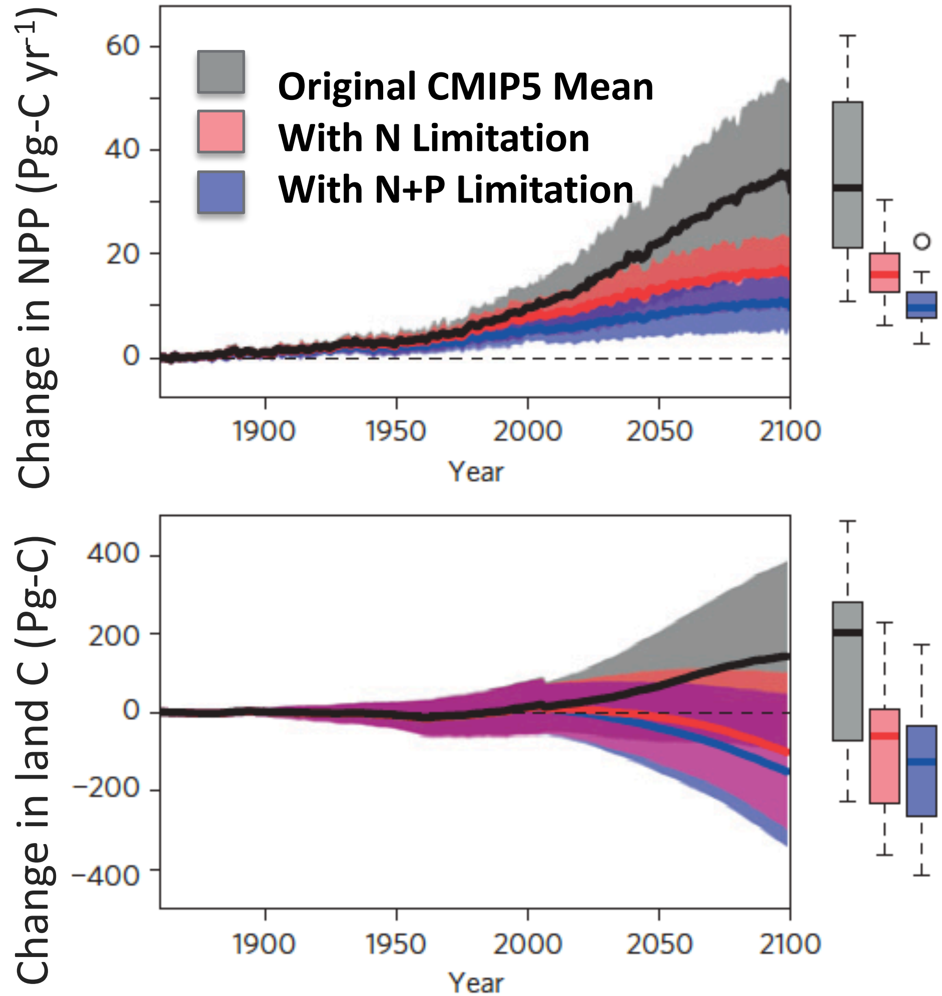
Nutrient limited NPP lowers land carbon estimates in Earth system models.



NPP = min(model, C:N:P)

$\mathbf{u_{soil} = u_{org}\ NPP/NPP_{org}}$

$\mathbf{R_h = C_{soil}\ k_{org}}$

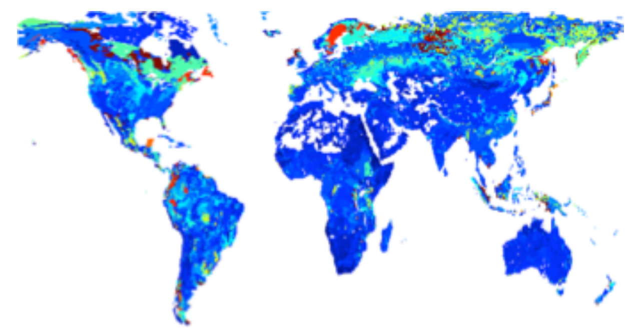


Wieder, Cleveland, Smith, and Todd-Brown. *Nature Geoscience*, 2015.

Derive field Q_{10} from soil carbon, shift ESM Q_{10}, and recalculate new SOC shift.

36 field warming experiments

20 Earth system models (CMIP5)



Reduced complexity model
at quasi-steady state

$$u_{in} \rightarrow \boxed{C_{soil}} \rightarrow R_h$$

$$u_{in} = C_{soil} \underbrace{k}_{\text{Intrinsic decomposition rate}} \underbrace{Q_{10}^{(T-15)/10}}_{\text{Temperature sensitivity}}$$

Todd-Brown, Zheng, Crowther, *Biogeosciences* (in submission)

Data-Q_{10} uncertainty led to high ESM-dSOC variation.

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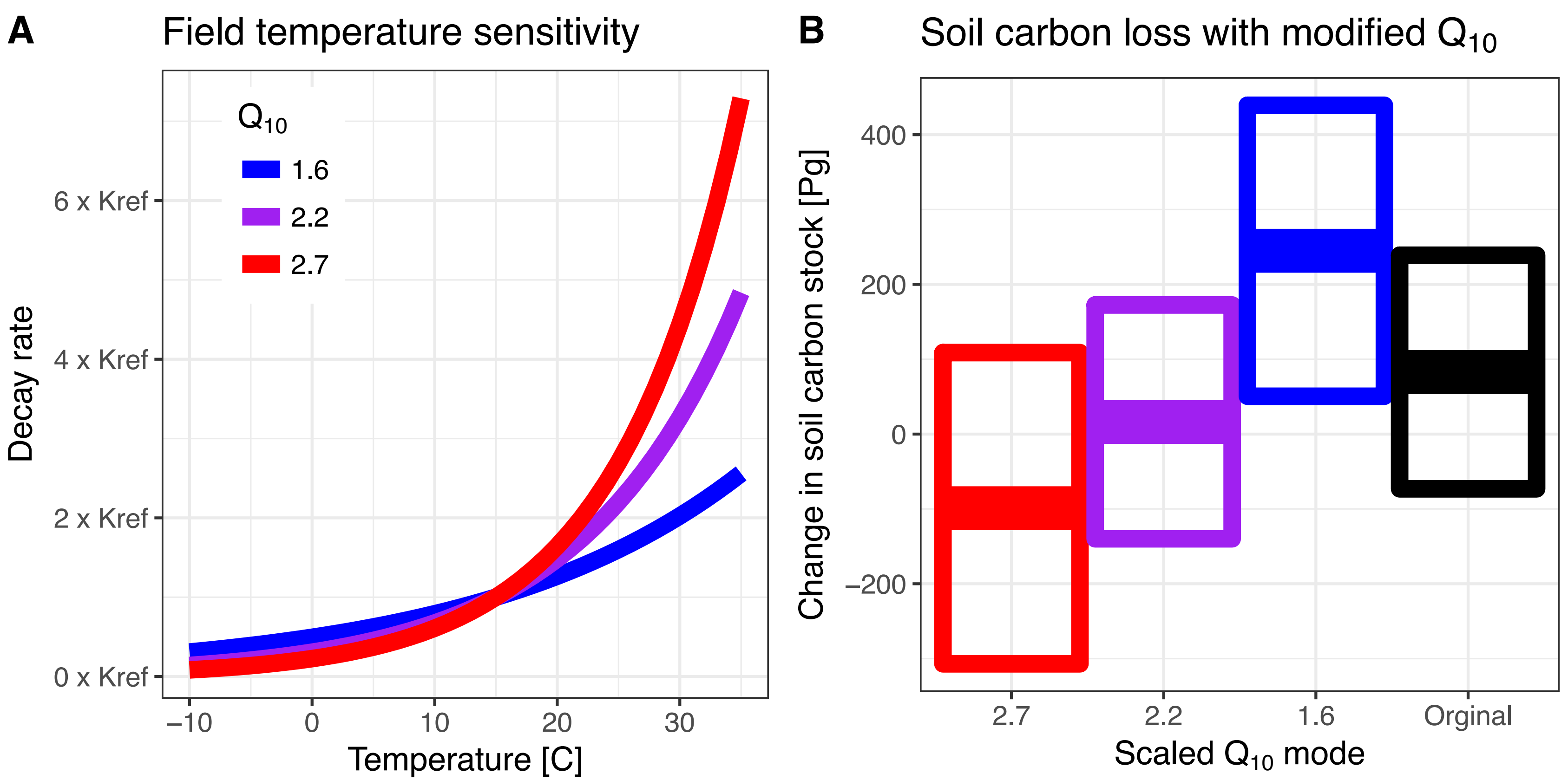

Todd-Brown, Zheng, Crowther, *Biogeosciences* (in submission)

Talk outline

Predictions of future soil carbon stock in Earth system models

- Reduce complexity
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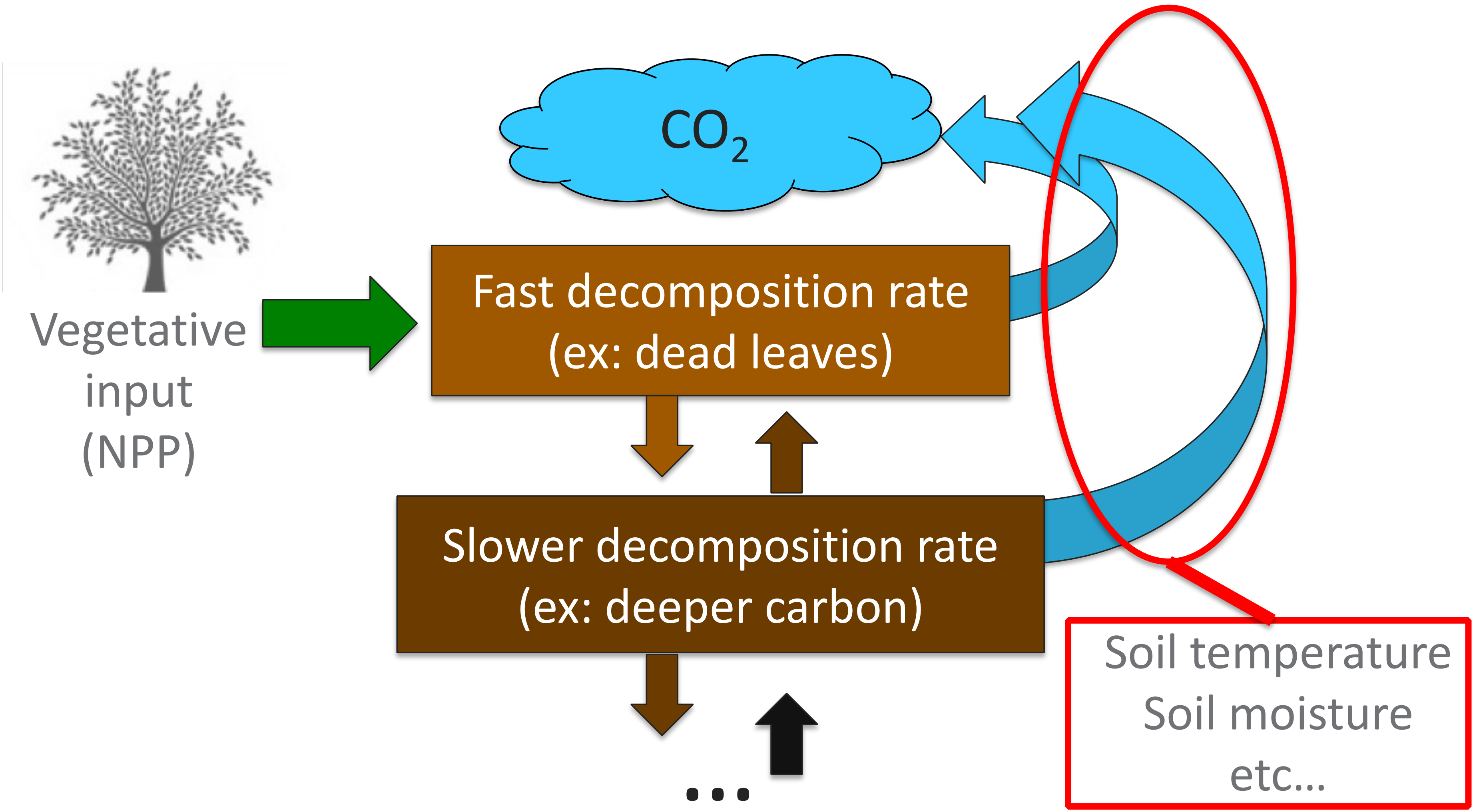
  - Targeted experimental opportunities

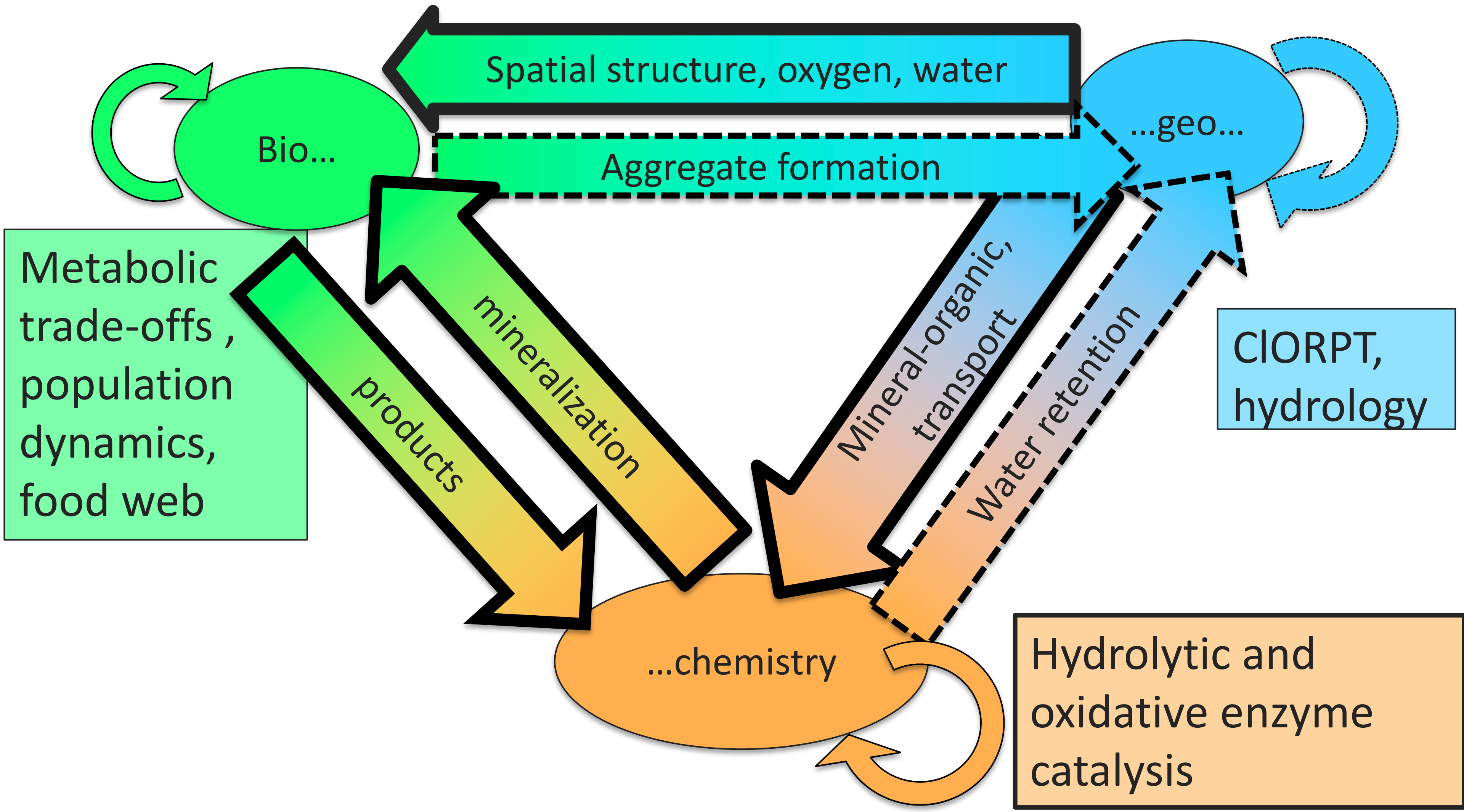
Complexity in space-time

Traditional models hide a great deal of complexity.

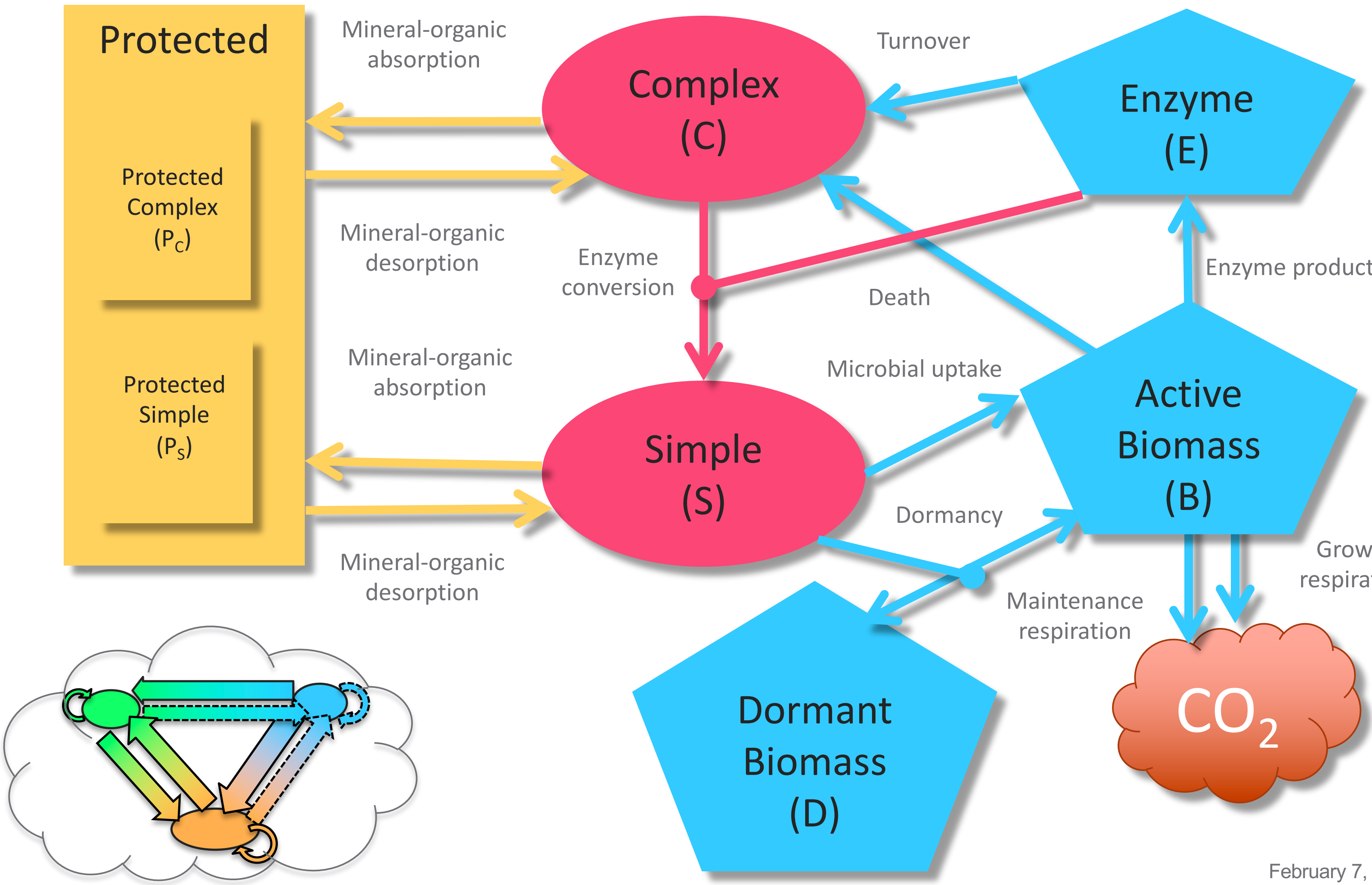


CENTURY: Parton et. al. 1987, 1988, 1992, 1993
CLM: Oleson et. al. *Tech. description of vs 4.0 of CLM 2010*

Soil carbon dynamics governed by biological, chemical and geophysical processes.



Just Another Microbial (JAM) model



A reasonable set of assumptions linking process-rich and reduced complexity:

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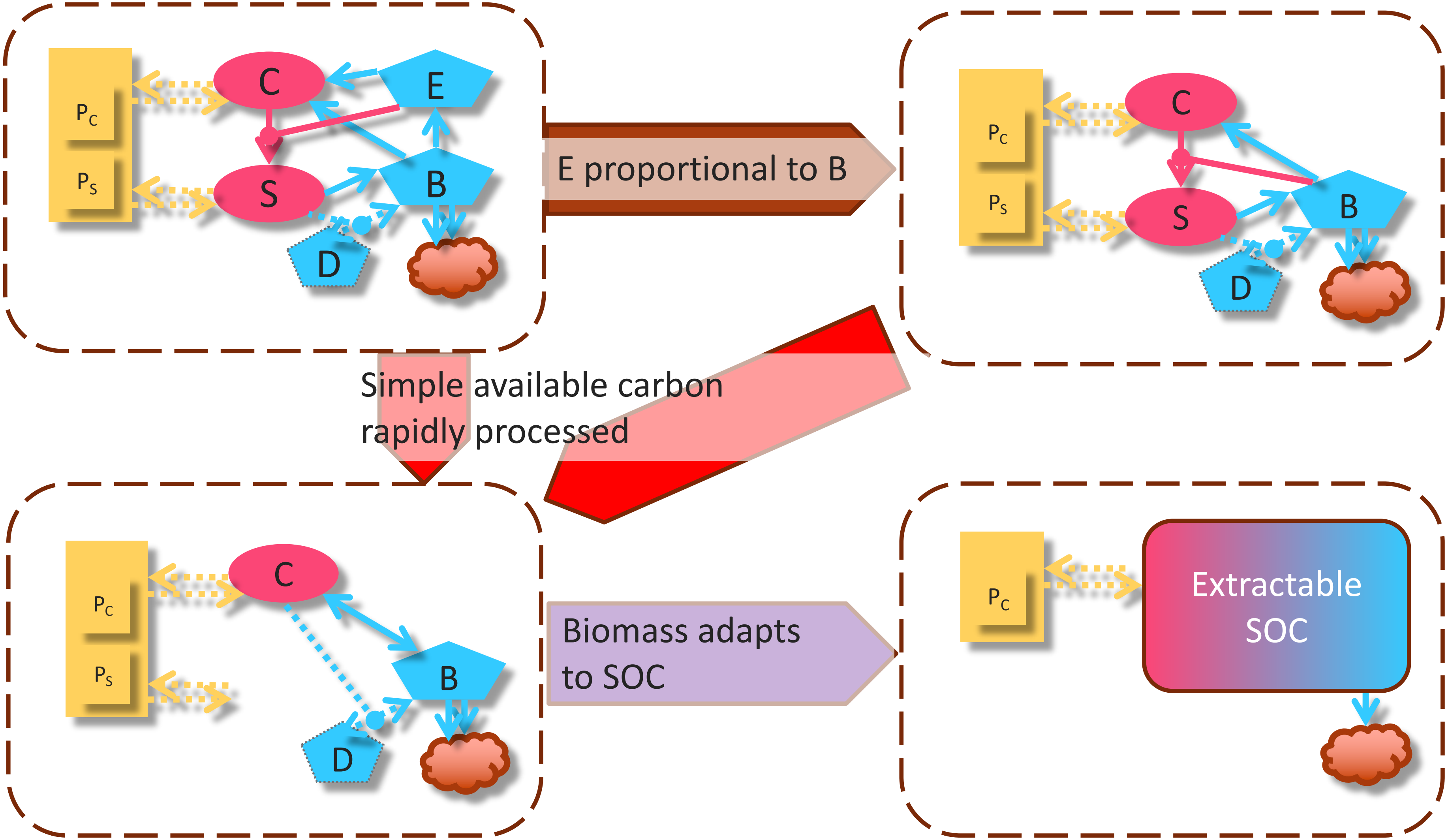
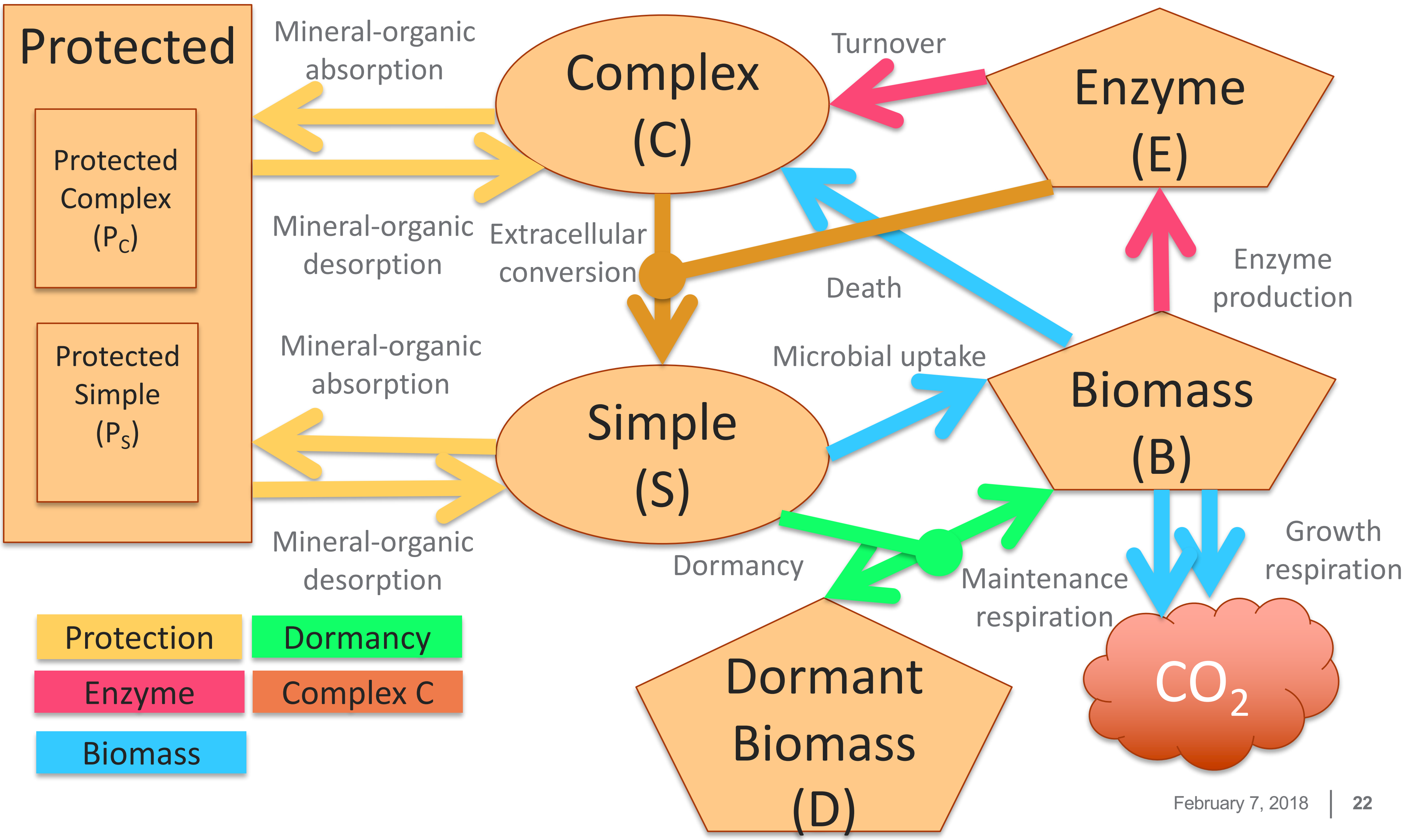


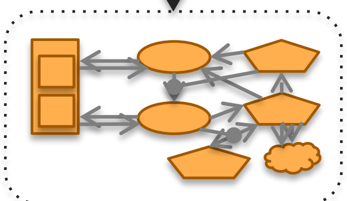
Just Another Microbial (JAM) model integrates biotic and abiotic processes



Sensitivity of cumulative CO_2 to parameter perturbations…

Perturbed parameter set

$p_i = (p_1+\varepsilon, \ldots, p_{23})$

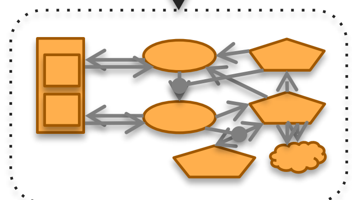


$CO_2(p_i)$

\-

Parameter set

$p_k = (p_1, \ldots, p_{23})$



$CO_2(p_k)$

=

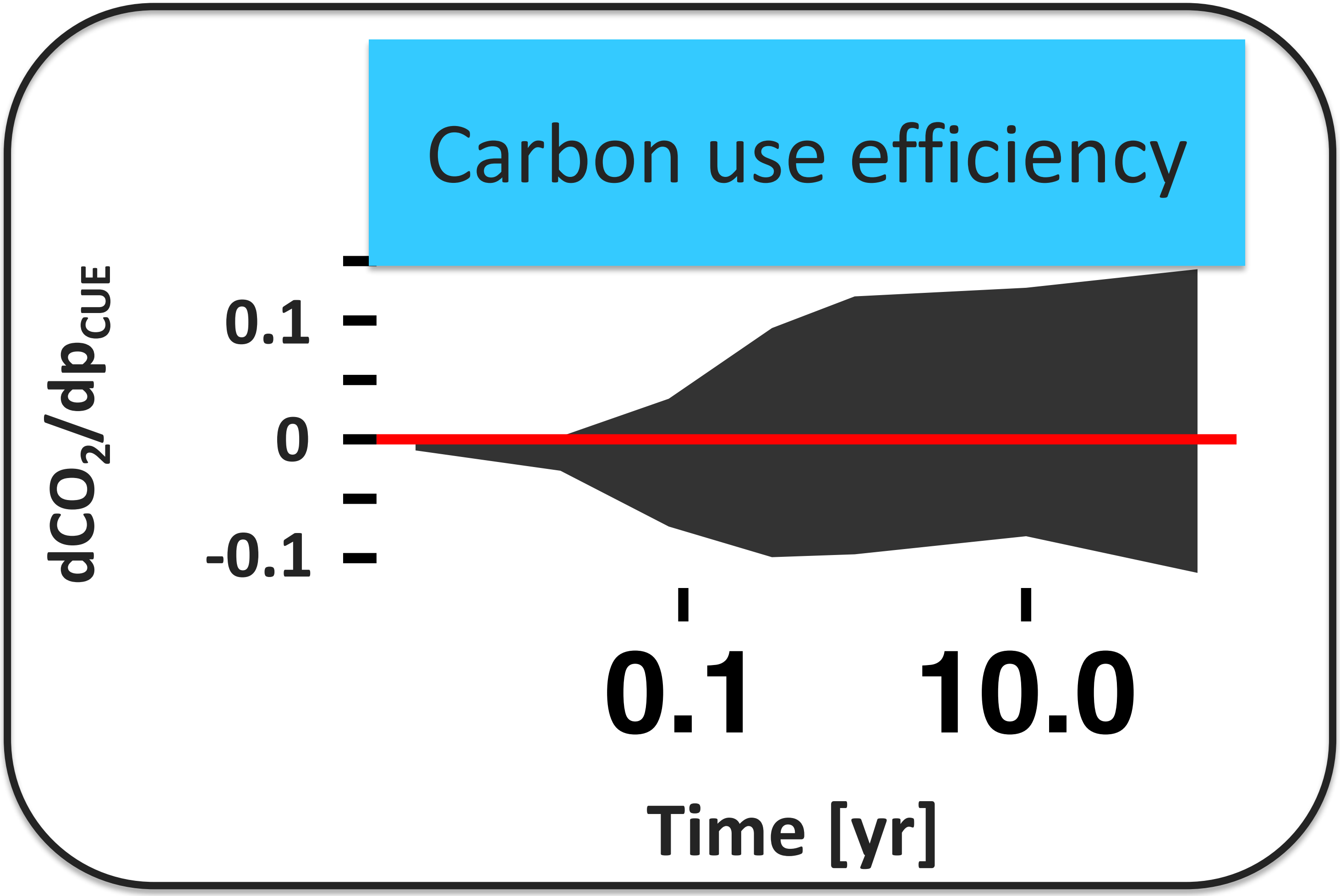
CO_2 response to perturbation

$$\frac{dCO_2}{dp_1} = \frac{\left[C_{CO2}(p_i) - C_{CO2}(p_k)\right] \Big/ \sum_i C_i}{\varepsilon \big/ p_{1\ range}}$$

1 unit = a parameter shift over the parameter range drives 100% increase in cumulative CO_2

Direction of effect of parameter on CO_2 depends on other parameters (e.g. CUE).

Sensitivity of cumulative CO_2 to parameter perturbation (95% CI)



Biological parameters are good targets for ‘easy’ model improvements.

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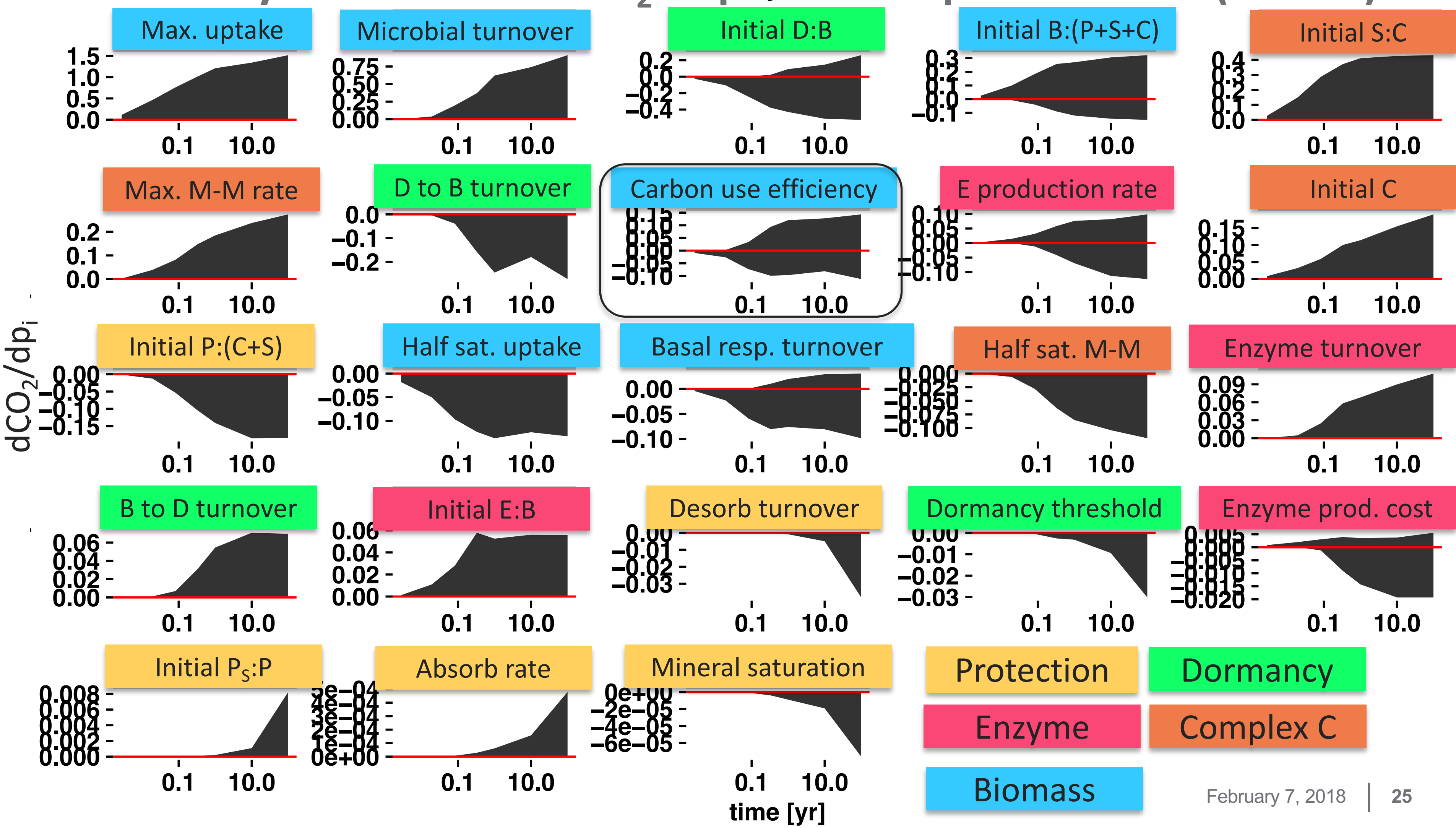
Sensitivity of cumulative CO_2 to parameter perturbation (95% CI)



The promise of data integration in process-rich models.

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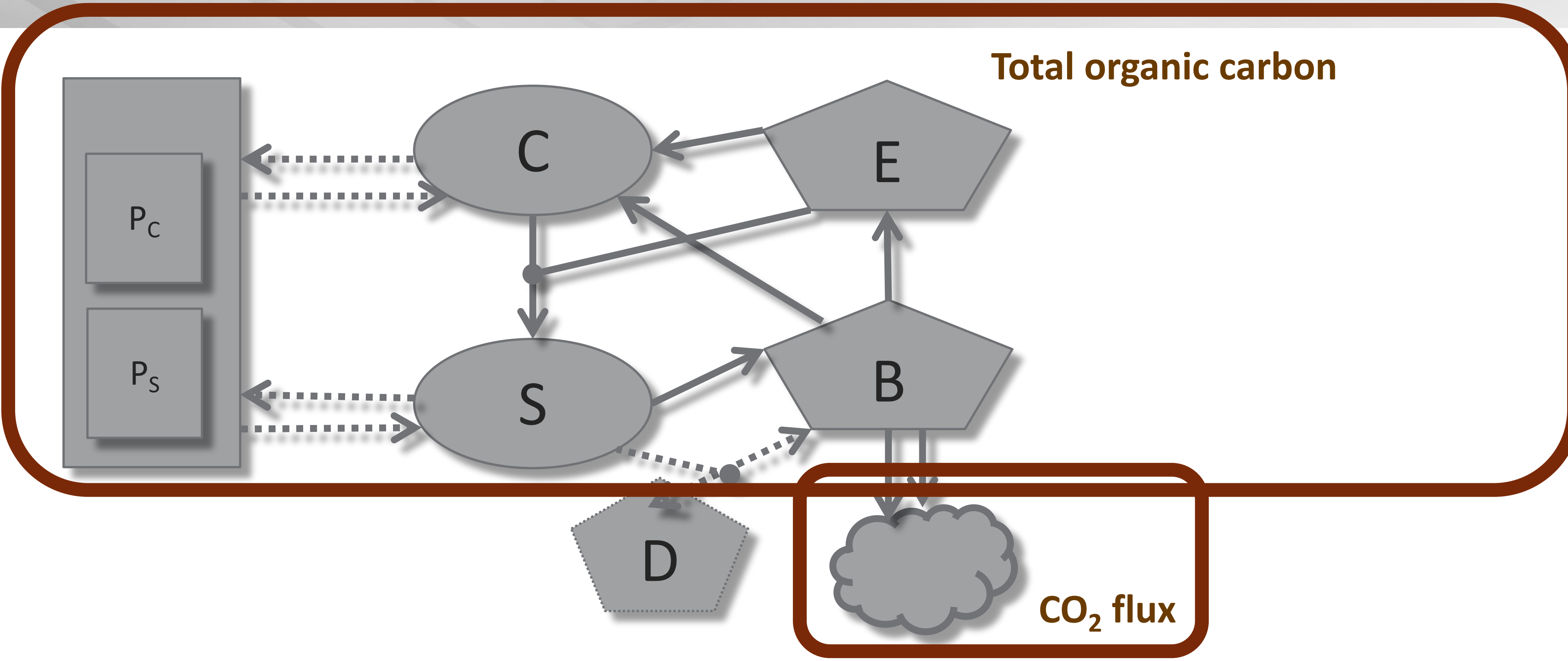

Measurements:
1. Absolute carbon mass
2.
3.
4. Carbon pool age
5.

The promise of data integration in process-rich models.

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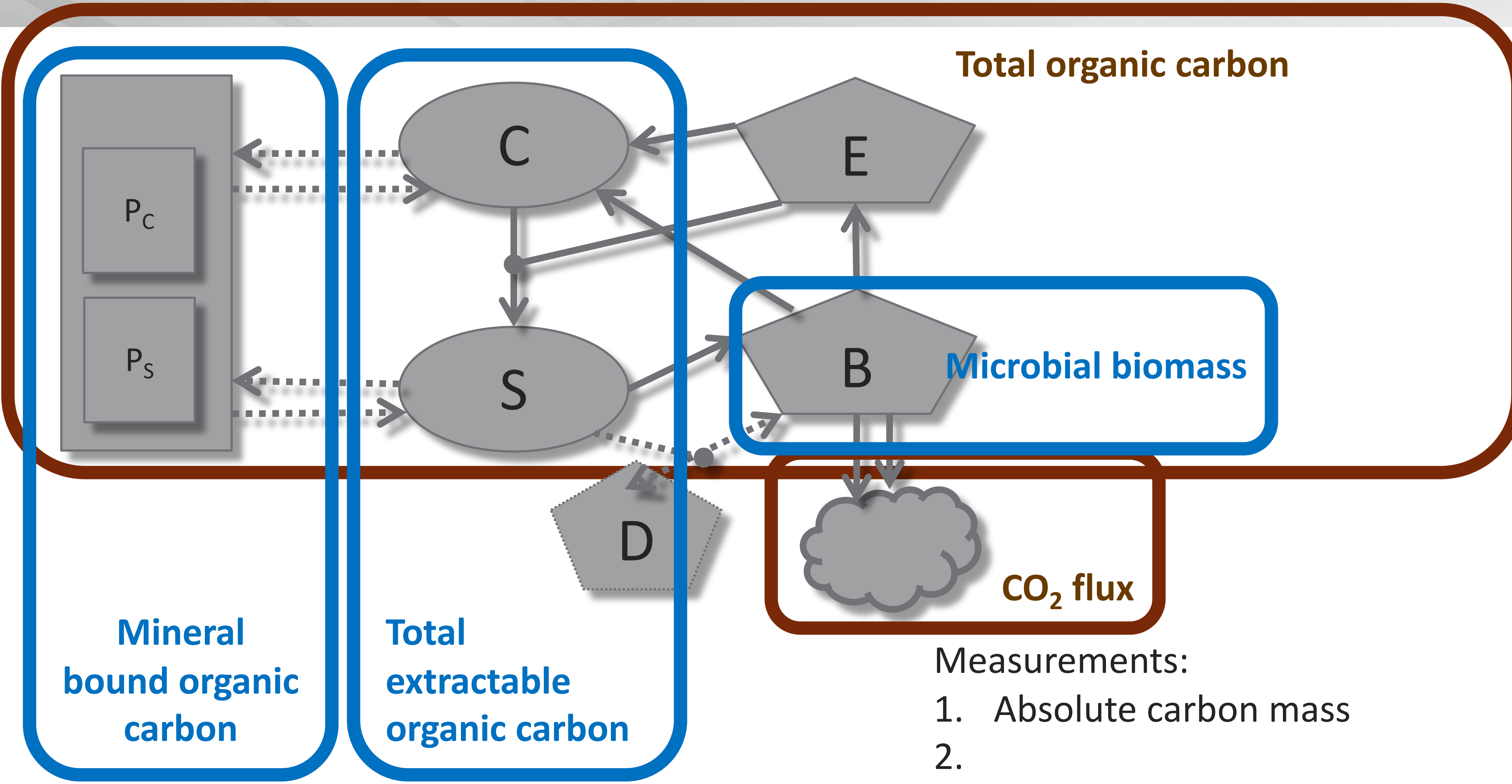

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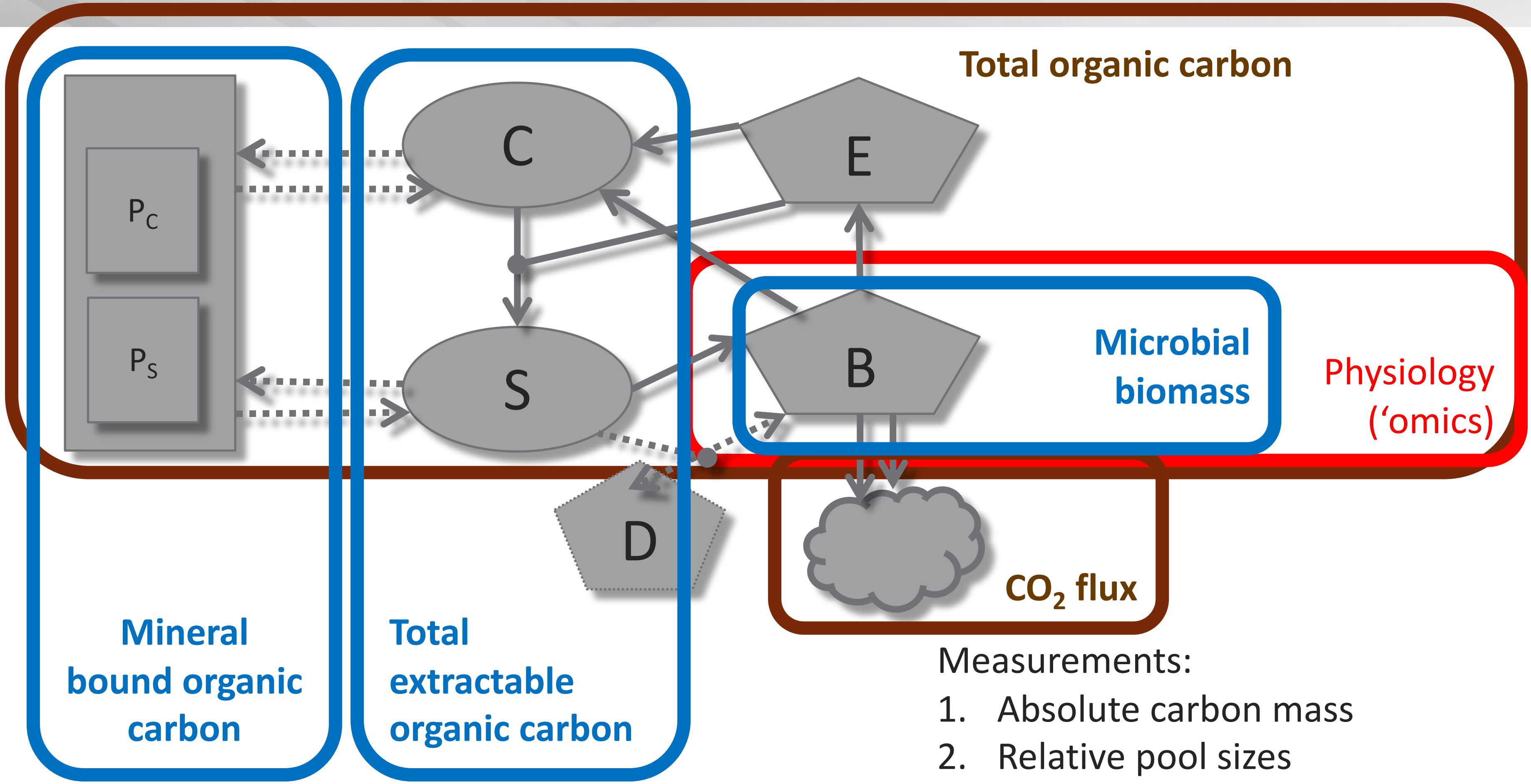

Measurements:

1. Absolute carbon mass
2. Relative pool sizes
3. Relative pool change
4. Carbon pool age
5. Theoretical parameter values

The promise of data integration in process-rich models.

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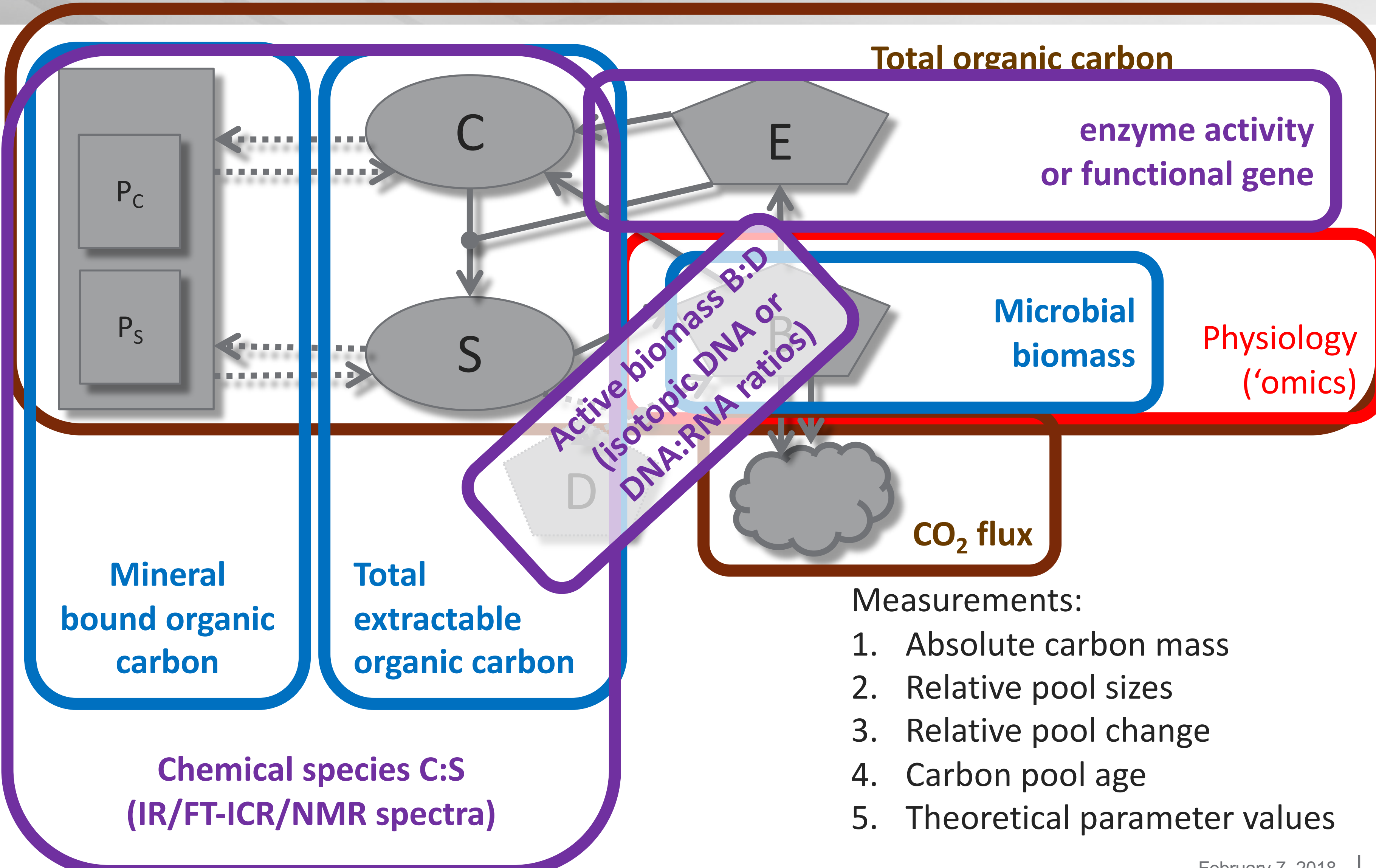

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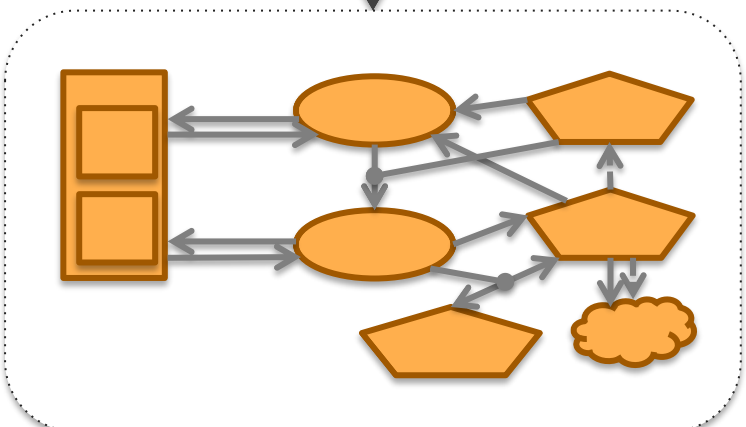
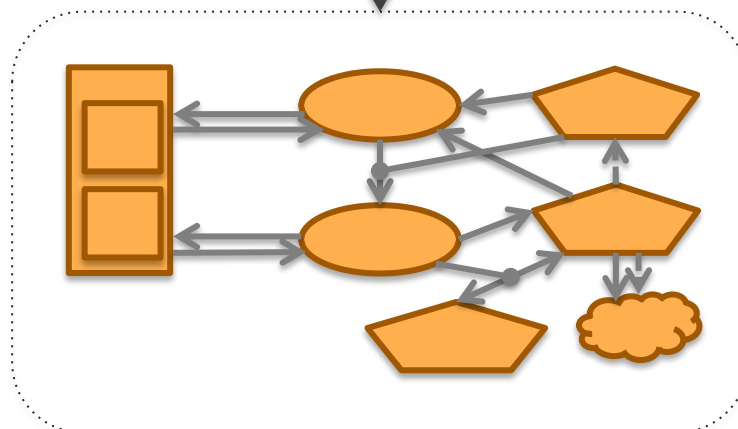
Complexity in space-time

Well-mixed vs aggregated isolated pores simulations…

Randomly sample parameter set

Calculate mean parameter set





Isolated cumulative CO_2

Aggregated mean CO_2

Well-mixed CO_2

Measuring means is not enough, parameter distribution also matters.

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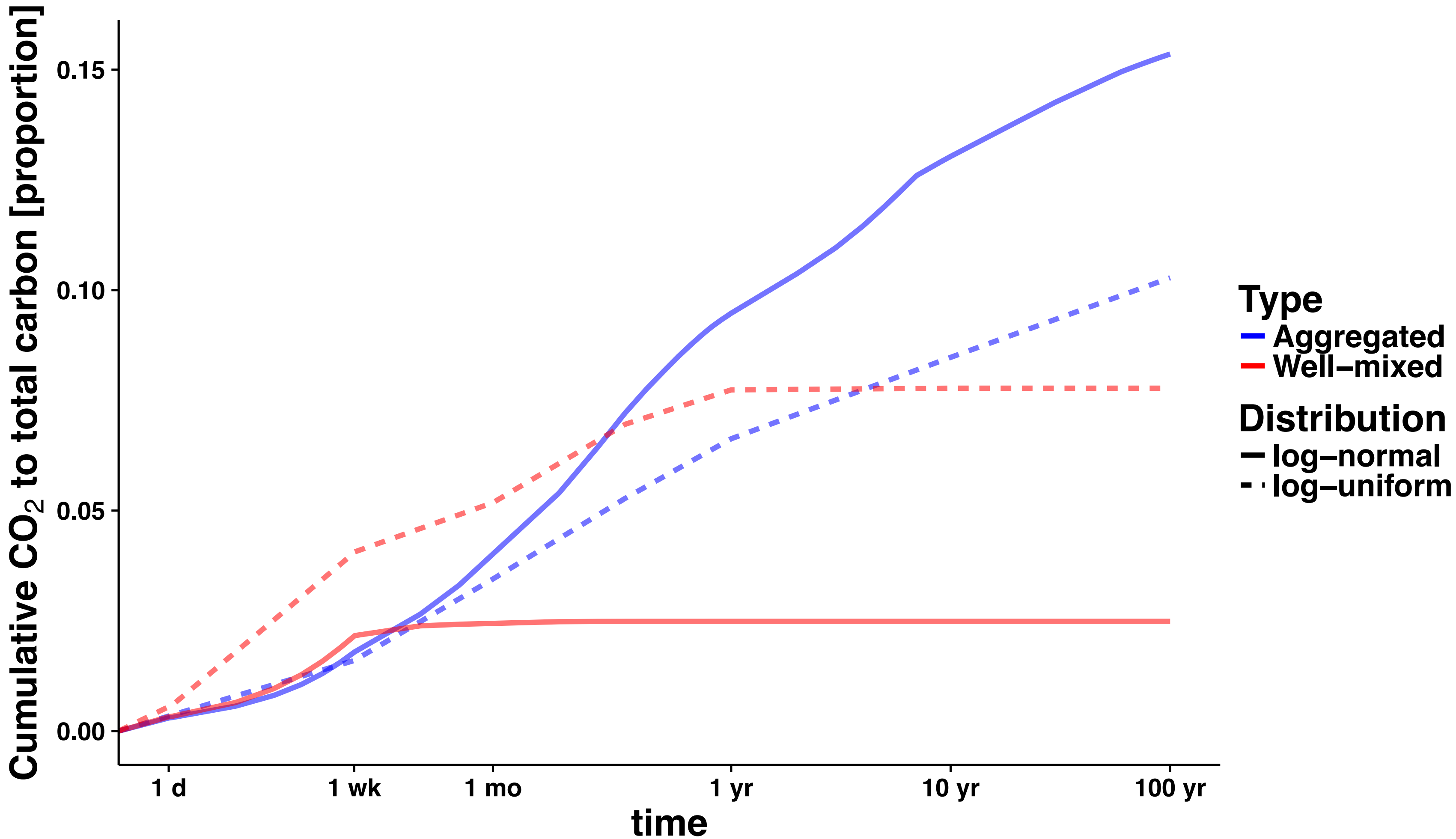
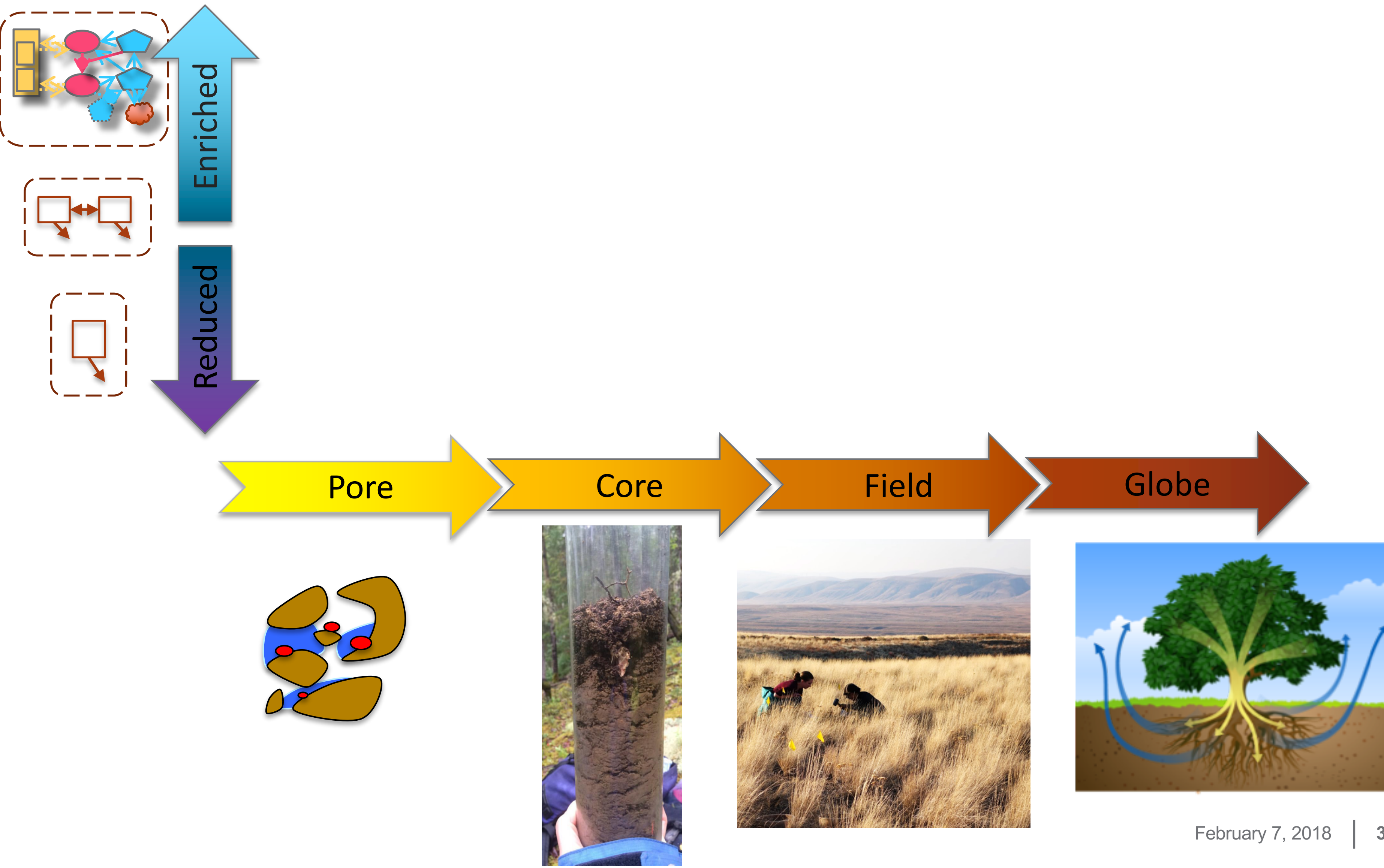


Future work integrating data and models across complexity in soils.



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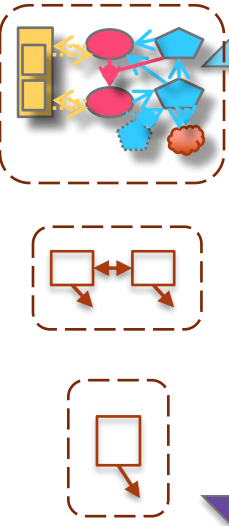
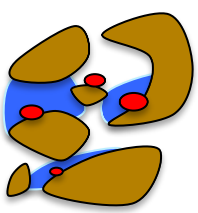


Enriched

Reduced

Moisture signal in soils?
Field & ESMs

Pore → Core → Field → Globe



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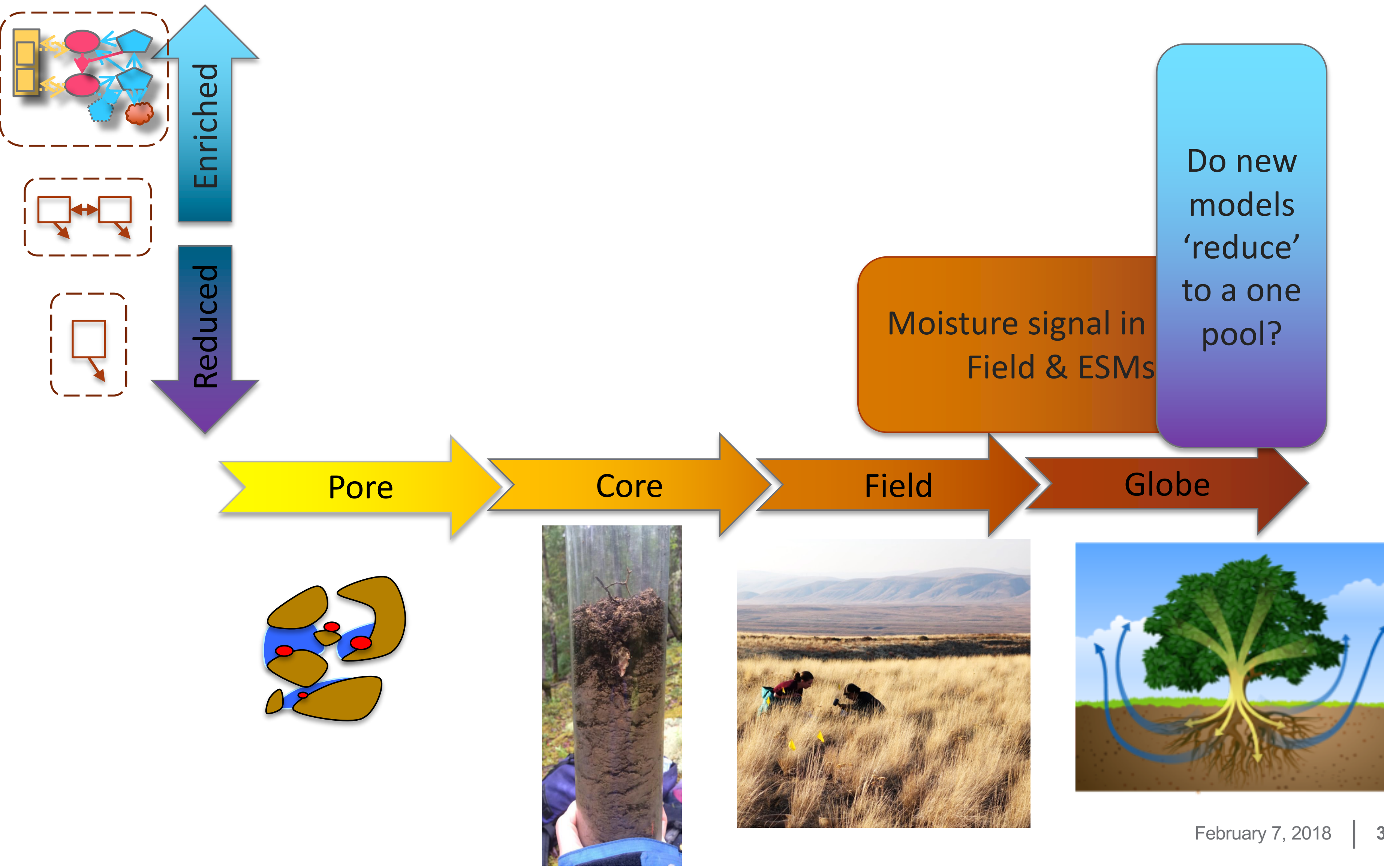

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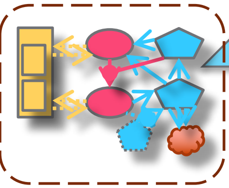
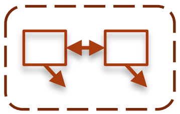
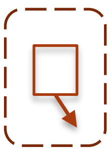






Enriched

Reduced

Do process rich models in pore-networks shift community parameters?

Moisture signal in Field & ESMs

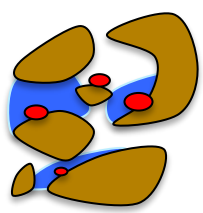
Do new models 'reduce' to a one pool?

Pore

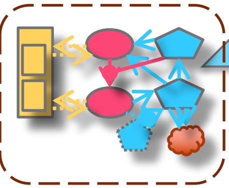
Core

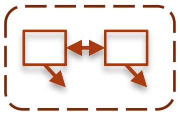
Field

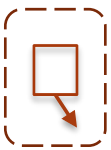
Globe



Future work integrating data and models across complexity in soils.







Enriched

Reduced

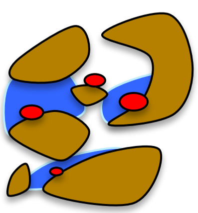
Redox and beyond!

in pore-networks shift community parameters?

Moisture signal in Field & ESMs

Do new models 'reduce' to a one pool?

Pore → Core → Field → Globe



Future work integrating data and models across complexity in soils.

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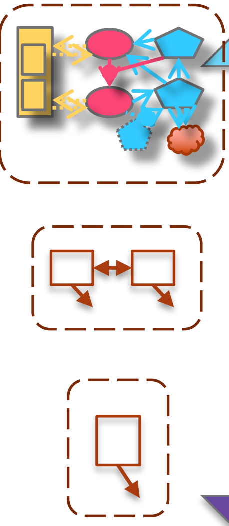


Enriched

Reduced

Redox and beyond!

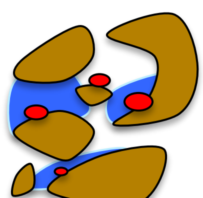
networks shift in pore-
param ...unity

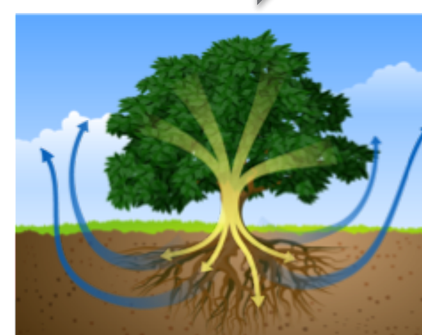
Relative information content – what to measure?

Moisture signal in Field & ESMs

Do new model structures ‘reduce’ to a one pool?

Pore → Core → Field → Globe





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Acknowledgements

- ESM SOC analysis: James Randerson (UCI), Steven Allison (UCI), W. Mac Post (ORNL), Charles Tarnocai (AAFC), E. Ted Schuur (NAU), and CMIP5 modelers (9 institutes)
- ESM post-hoc analysis: Tom Crowther (NIOO), Mark Bradford (Yale), Will Wieder (NCAR), Cory Cleveland (U Montana), Bin Zheng (PNNL), and data providers (40 institutes)
- Process explicit models: Vanessa Bailey (PNNL), Nancy Hess (PNNL), Tim Scheibe (PNNL), Jeremy Zucker (PNNL), Peyton Smith (PNNL), Matthew Smith (Microsoft), Josh Schimel (UCSB), Melanie Mayes (ORNL), Julie Jastrow (ANL), Stefano Manzoni (Stockholm U), Jennifer Talbot (BU)

Linus Pauling Postdoctoral Fellowship, Pacific Northwest National Lab

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