Uncertainty analysis of land carbon prediction

Matrix approach

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ECOLAB OF DR. YIQI LUO

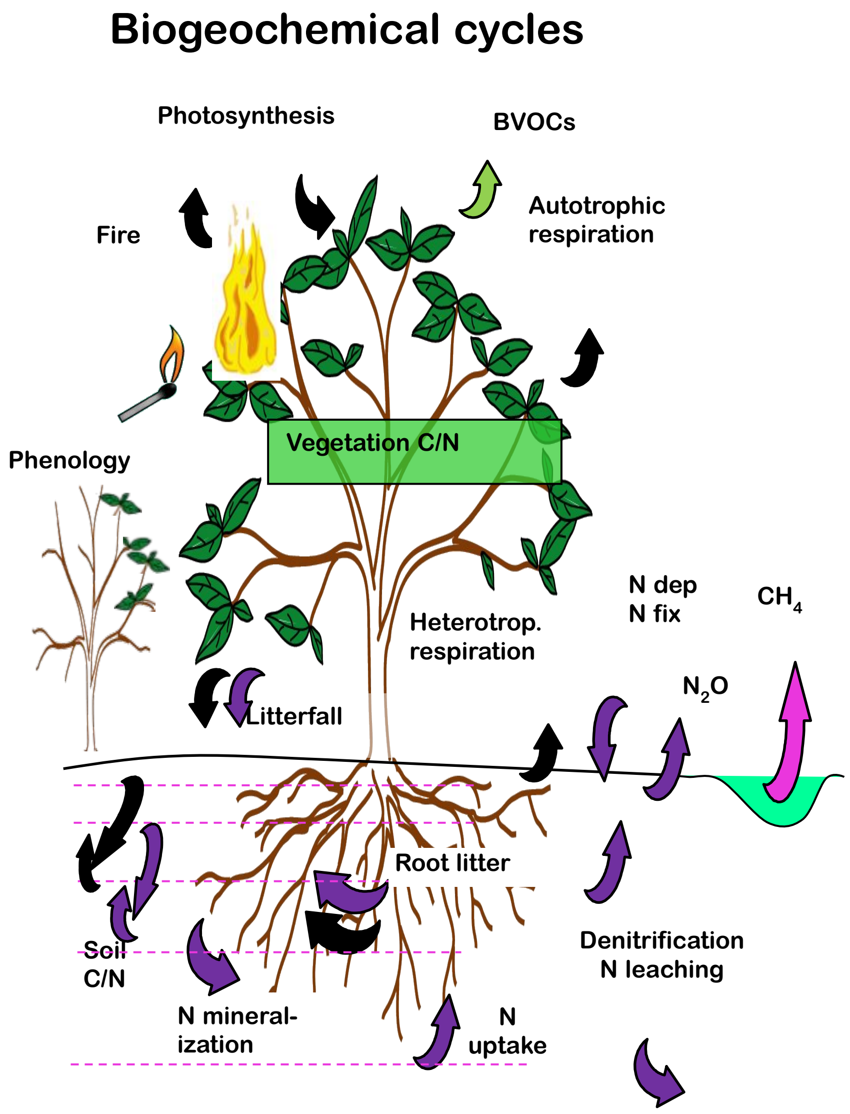
ECOS[S] Center for Ecosystem Science and Society at Northern Arizona University

NCAR working group meeting, February 23-25, 2021

NORTHERN ARIZONA UNIVERSITY

Matrix CLM5

https://github.com/chrislxj/ctsm, Branch: cn-matrix_v3.



Vegetation carbon and nitrogen cycles

$$\frac{dC_{veg}}{dt} = BI_{Cup} + \left(A_{phc}(t)K_{phc} + A_{gmc}(t)K_{gmc} + A_{fic}(t)K_{fic}\right)C_{veg}(t)$$

$$\frac{dN_{veg}}{dt} = BI_{Nup} + \left(A_{phn}(t)K_{phn} + A_{gmn}(t)K_{gmn} + A_{fin}(t)K_{fin}\right)N_{veg}(t)$$

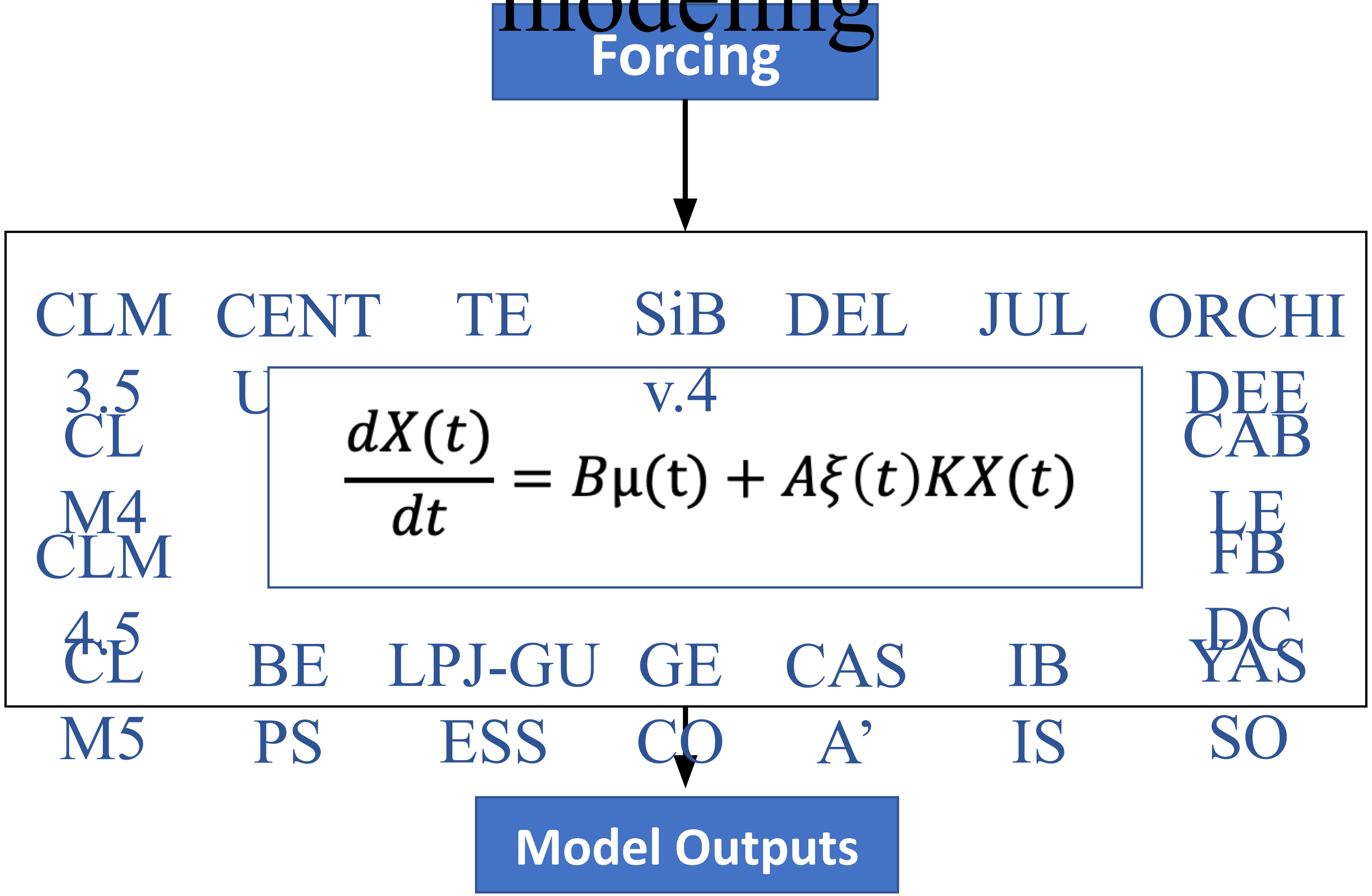
Soil carbon and nitrogen cycles

$$\frac{dC_{soil}}{dt} = I_C + \left(A_{hc}\xi(t)K_h + V(t) + K_f(t)\right)C_{soil}(t)$$

$$\frac{dN_{soil}}{dt} = I_N + \left(A_{hn}\xi(t)K_h + V(t) + K_f(t)\right)N_{soil}(t)$$

Lu et al. 2020 JAMES

Matrix approach to land carbon cycle modeling



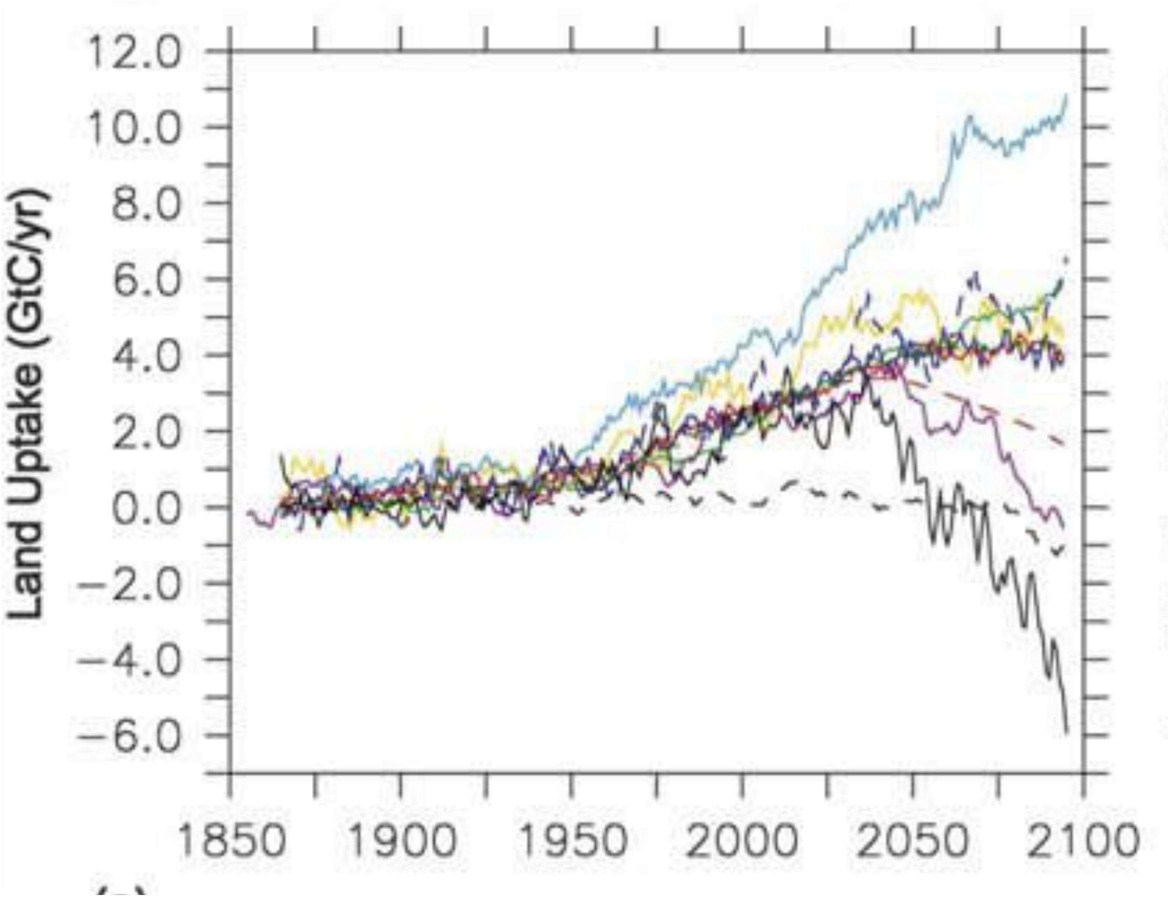
e.g., Ecosystem C stock

Advantages

- Simplicity in model structure
- High modularity in code
- Clarity in diagnostics
- Computational efficiency in spin-up

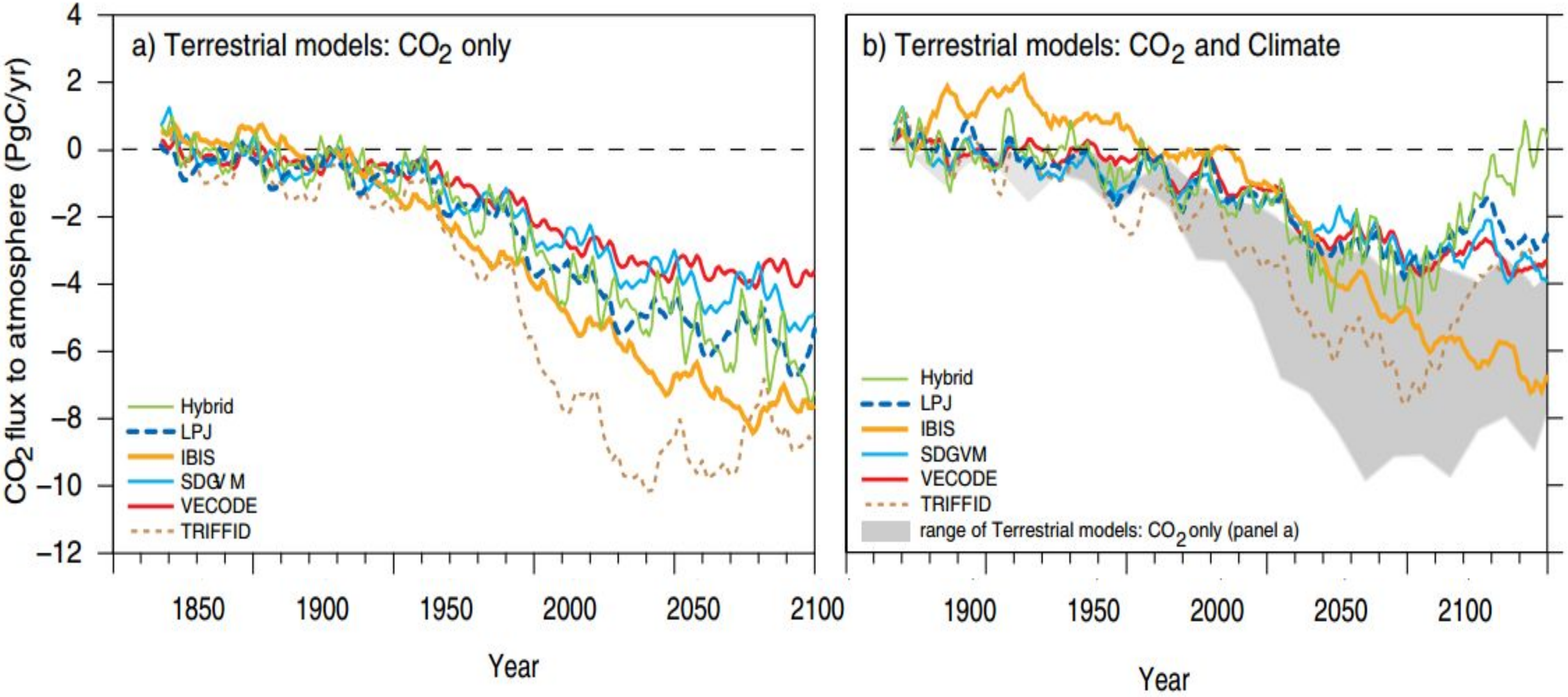
Cuijuan Liao
9:35 Thursday

Uncertainty



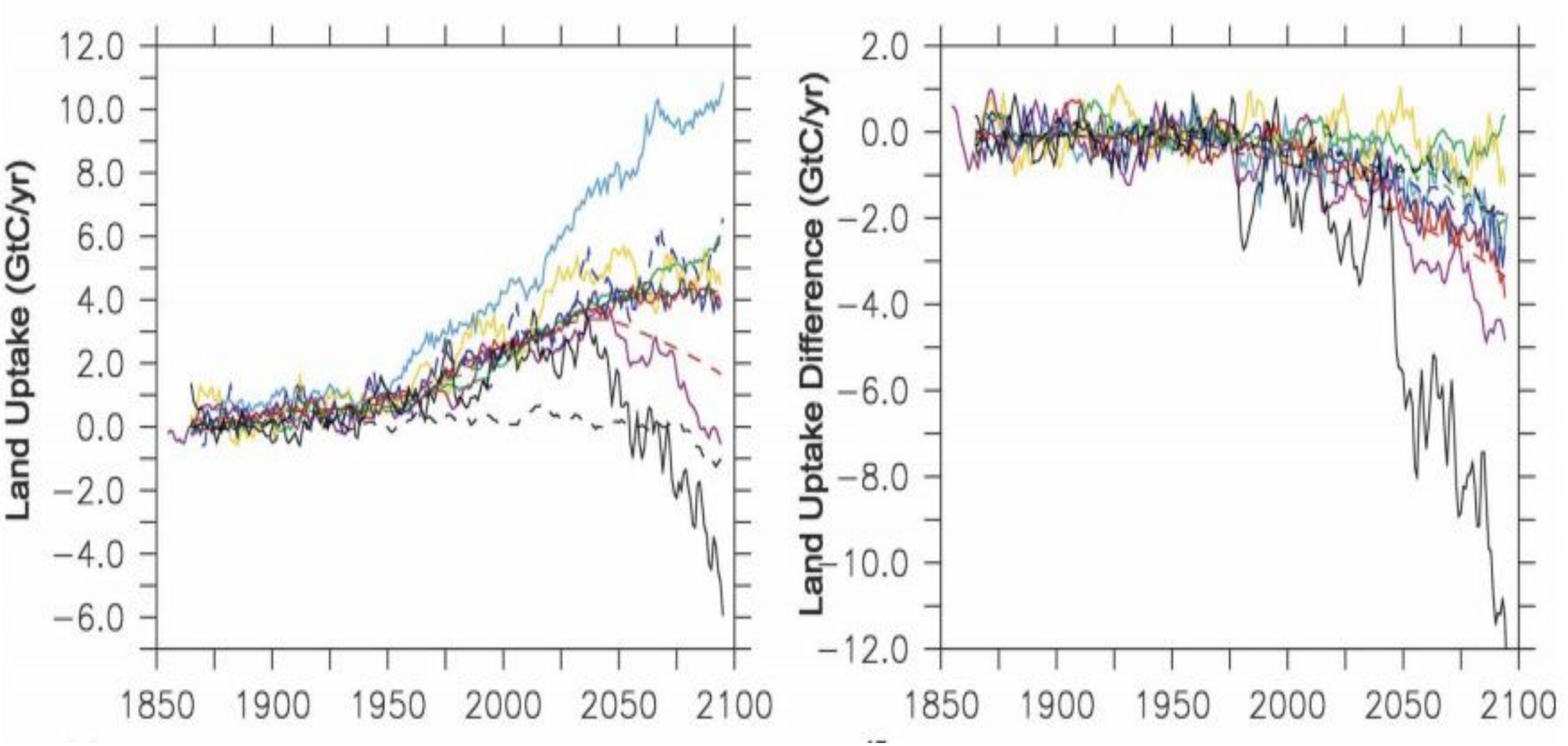
Friedlingstein et al. 2006

Third Assessment Report



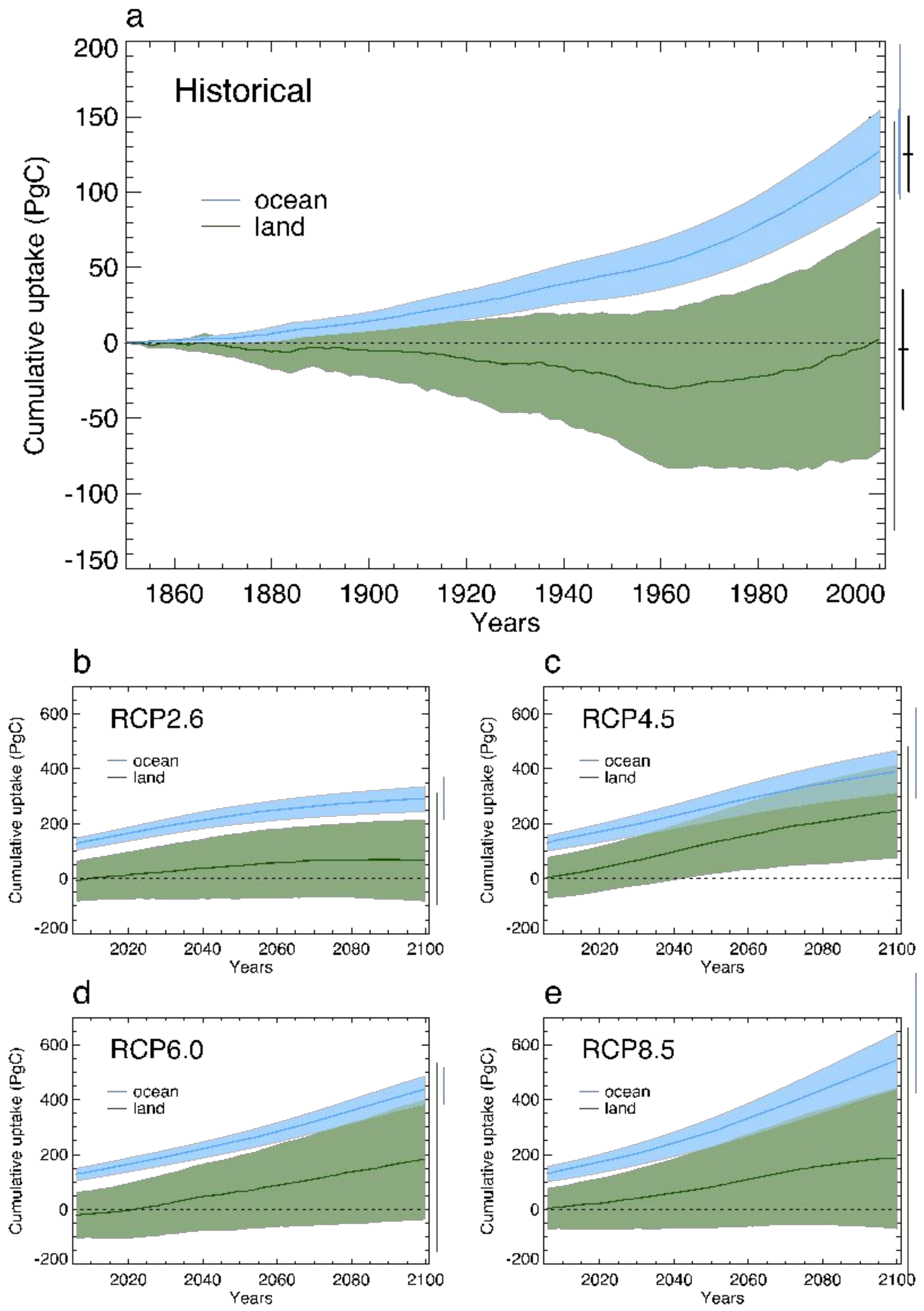
IPCC, 2001

C^4MIP

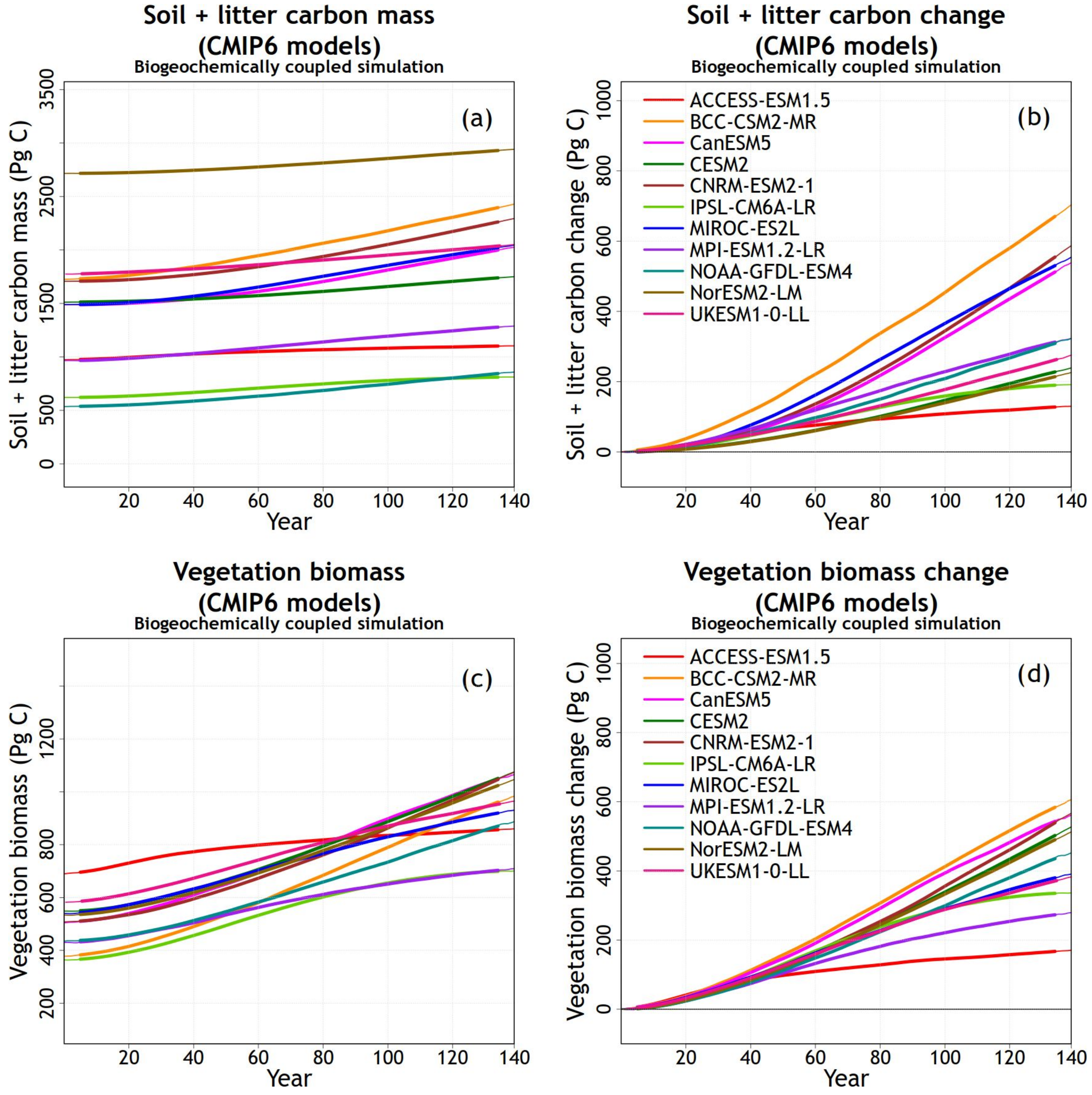


Friedlingstein et al. 2006

IPCC AR5

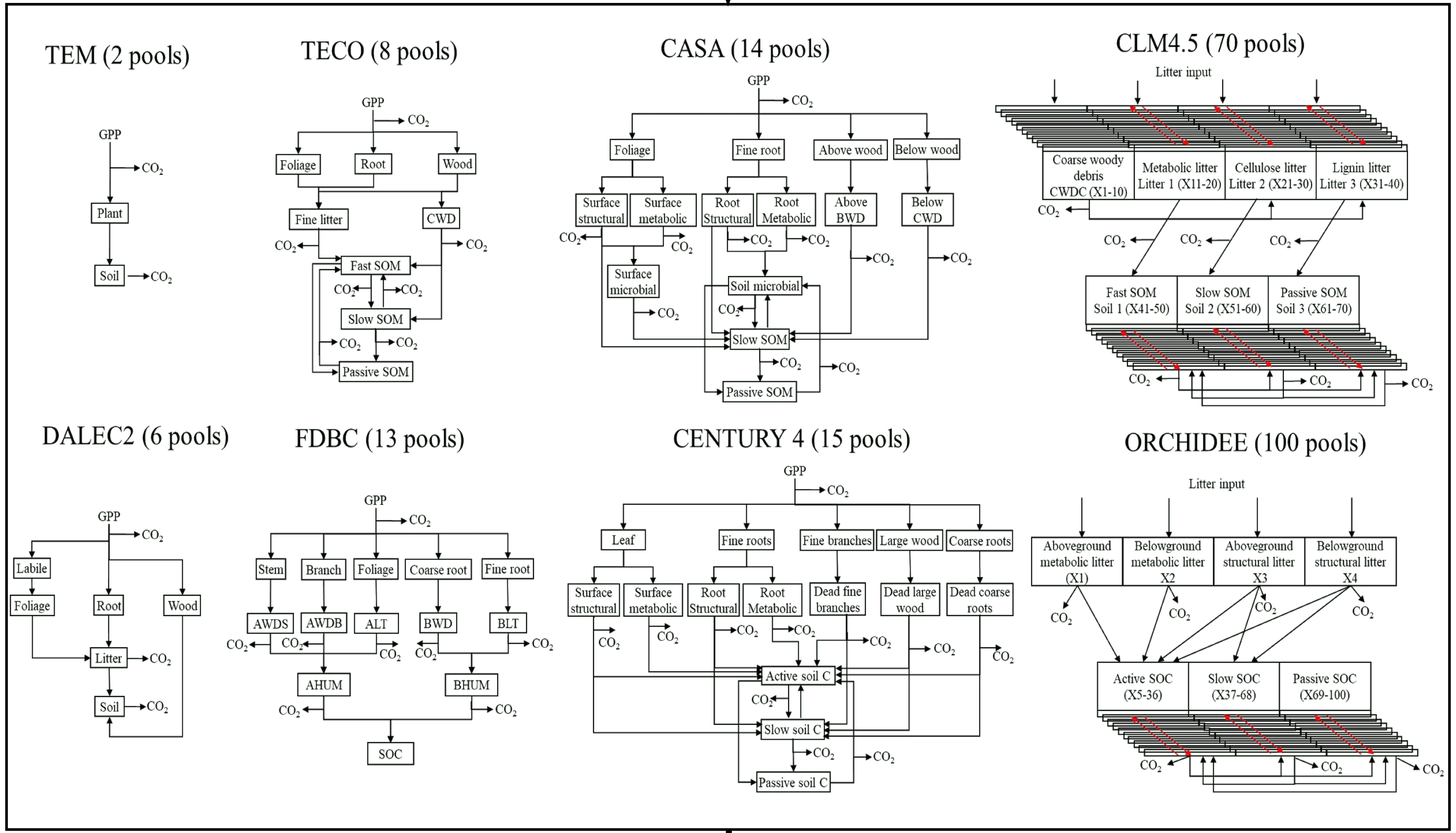

a
Historical
ocean
land
Cumulative uptake (PgC)
Years
b
RCP2.6
c
RCP4.5
d
RCP6.0
e
RCP8.5

CMIP6



Arora et al. 2020

Forcing

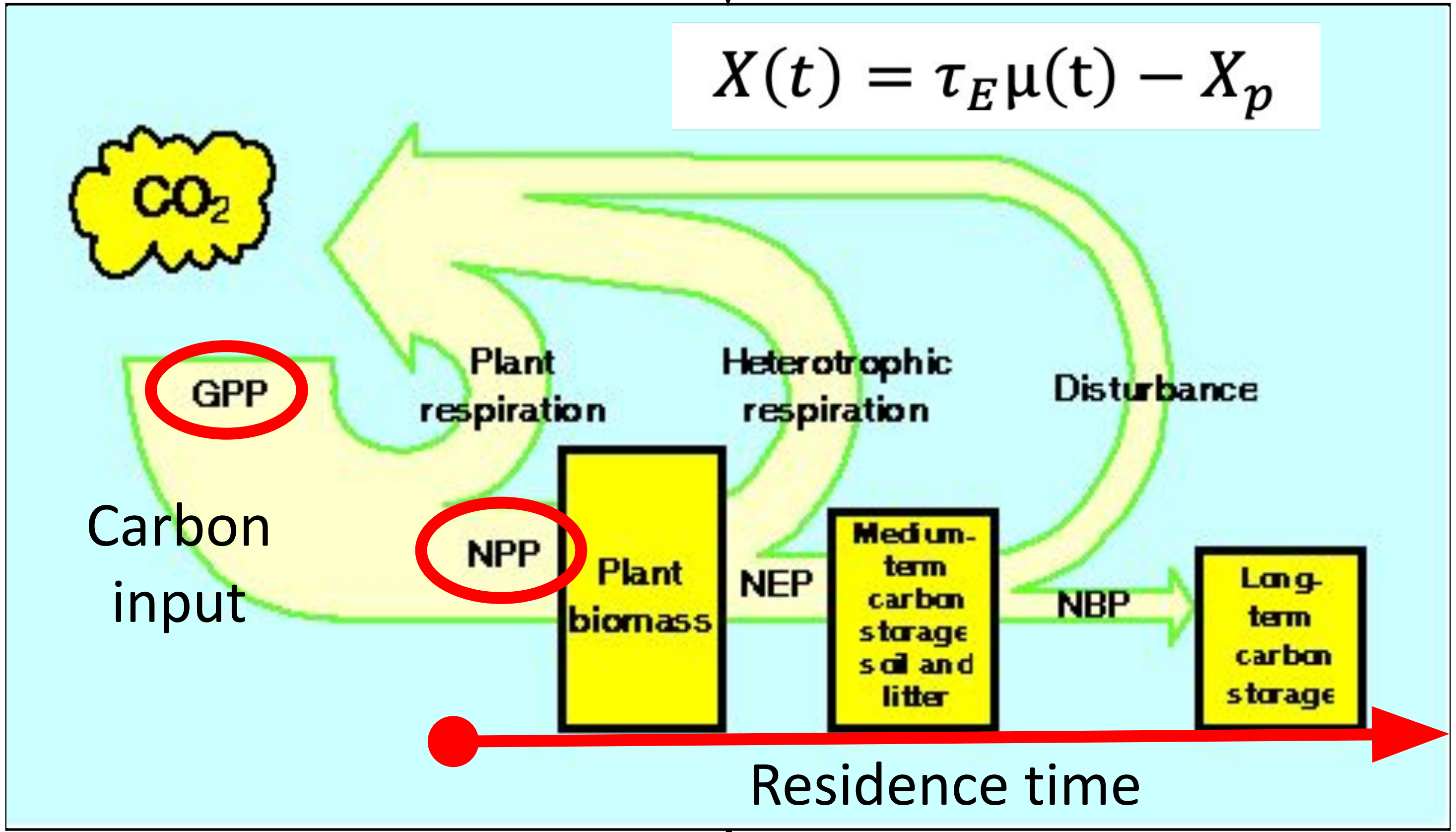


Uncertainty in model outputs

Sources of uncertainty

1

Variation in Forcing



2

Variation in NPP

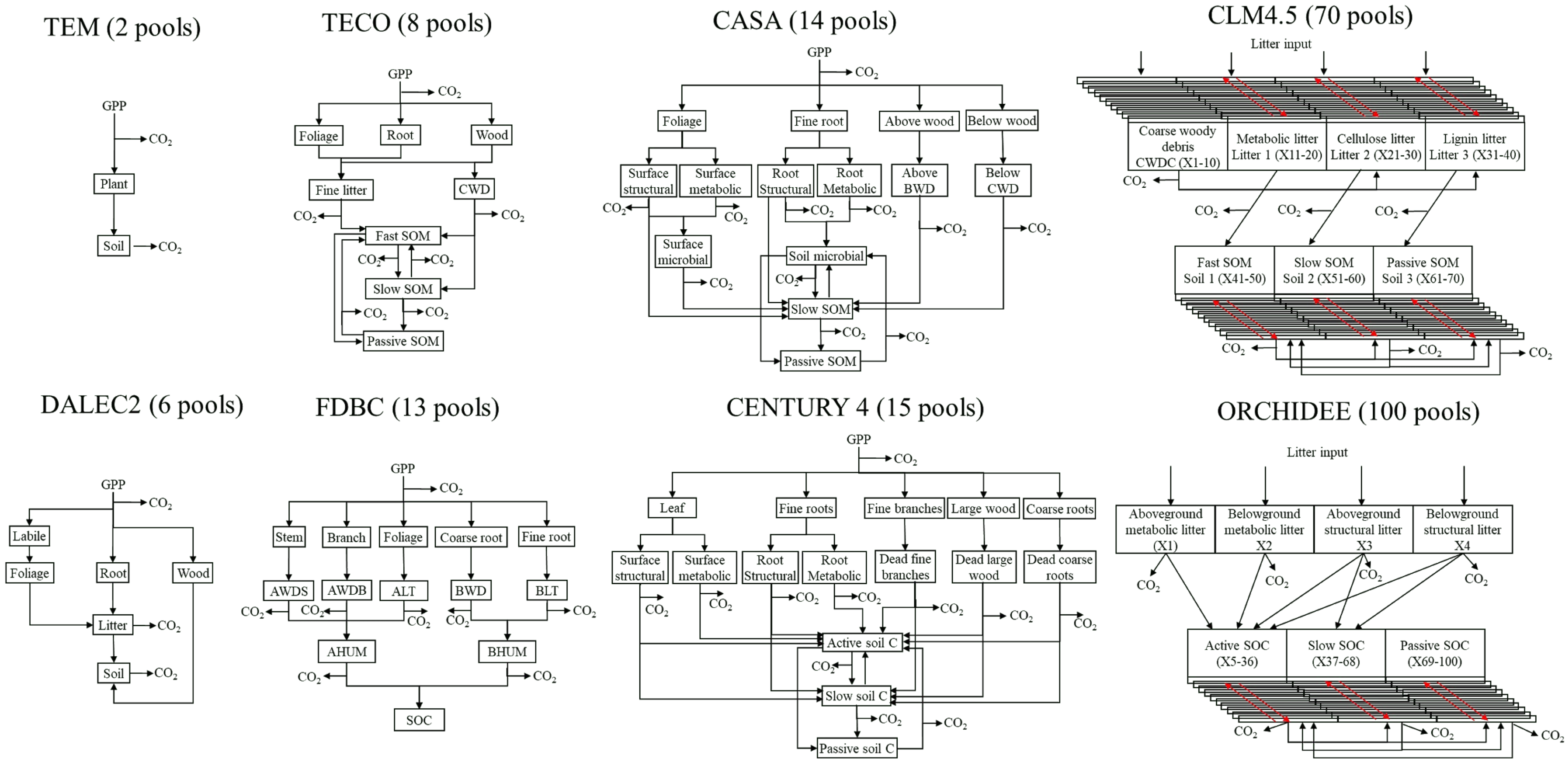
3

Variation in residence time

Uncertainty in model outputs

Enqing Hou 1:30pm Thursday

Matrix approach to uncertainty analysis



All model in a unified matrix form

$$\frac{dX(t)}{dt} = B \times u(t) - (A\xi K + V) \times X(t)$$

C change rate

Allocation

B
0.35
0.1
0
0
0
0
0

Carbon input

Date	GPP
1/1/2011	0
1/2/2011	0.0032
1/3/2011	4.00E-04
1/4/2011	0.0054
1/5/2011	0.0091
1/6/2011	0.0022
1/7/2011	9.00E-04
1/8/2011	0.0046
1/9/2011	0.0085
1/10/2011	0.0093

Transfer among C pools

A_1	A_2	A_3	A_4	A_5	A_6	A_7
1	0	0	0	0	0	0
0	1	0	0	0	0	0
-0.71	0	1	0	0	0	0
-0.29	-1	0	1	0	0	0
0	0	-0.45	-0.28	1	-0.42	-0.45
0	0	0	-0.28	-0.3	1	0
0	0	0	0	-0	-0.03	1

Baseline C turnover rate

K_1	K_2	K_3	K_4	K_5	K_6	K_7
2.74E-03	0	0	0	0	0	0
0	6.84E-05	0	0	0	0	0
0	0	9.13E-03	0	0	0	0
0	0	0	4.72E-04	0	0	0
0	0	0	0	6.84E-03	0	0
0	0	0	0	0	5.48E-05	0
0	0	0	0	0	0	1.37E-06

C pool

Date	Non_woc	Woody	Fine_litt	CWD	Fast_SOC	Slow_SO	Passive_
1/1/2011	398.159	4560.67	85.1473	1327.14	100.297	6849.03	10221.8
1/2/2011	397.835	4560.58	85.1471	1327.14	100.297	6849.03	10221.8
1/3/2011	397.51	4560.48	85.1467	1327.14	100.297	6849.03	10221.8
1/4/2011	397.187	4560.39	85.1462	1327.14	100.297	6849.03	10221.8
1/5/2011	396.866	4560.3	85.1454	1327.13	100.297	6849.03	10221.8
1/6/2011	396.542	4560.21	85.1445	1327.13	100.297	6849.03	10221.8
1/7/2011	396.219	4560.11	85.1433	1327.13	100.297	6849.03	10221.8
1/8/2011	395.897	4560.02	85.142	1327.13	100.297	6849.03	10221.8
1/9/2011	395.576	4559.93	85.1405	1327.13	100.297	6849.03	10221.8
1/10/2011	395.252	4559.84	85.1389	1327.13	100.297	6849.03	10221.8

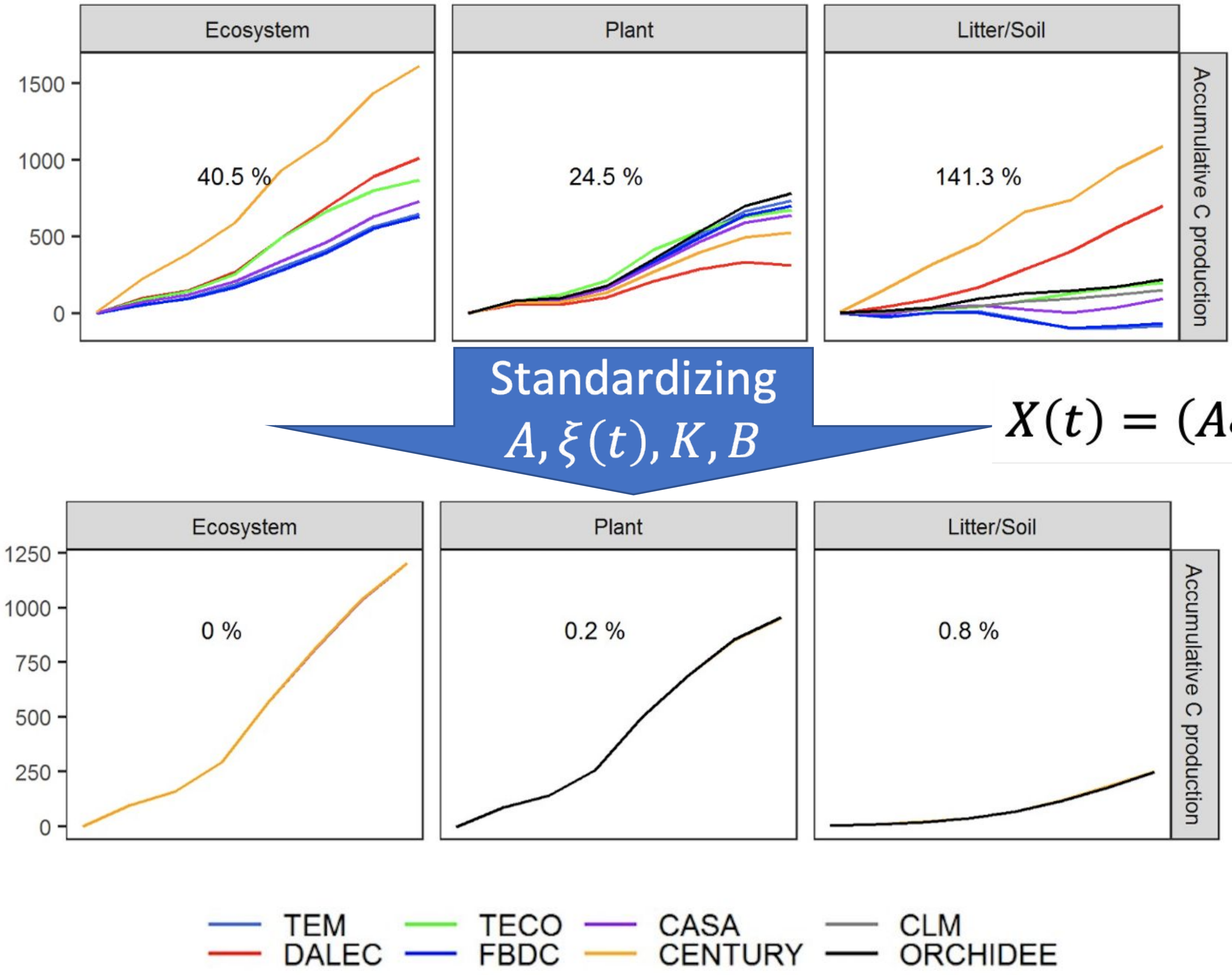
Environmental scaler

Date	Scaler1	Scaler2	Scaler3	Scaler4	Scaler5	Scaler6	Scaler7
1/1/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/2/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/3/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/4/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/5/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/6/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/7/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812
1/8/2011	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812	0.29812

Vertical mix

Tr_1	Tr_2	Tr_3	Tr_4	Tr_5	Tr_6	Tr_7
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Enqing Hou 1:30pm Thursday



$$X(t) = (A\xi(t)K)^{-1}B\mu(t) - X_p$$

Enqing Hou
1:30pm Thursday

What did we learn from Enqing's study?

- Model structure does not matter for projecting carbon dynamics
  - It may be important to represent different biological and/or geochemical processes
- Residence time, in addition to forcing and carbon input, matters for projecting carbon dynamics.
- Not about eliminating model-model differences
- Matrix approach makes model uncertainty a tractable issue
  - An analytic framework to understand and quantify model uncertainty

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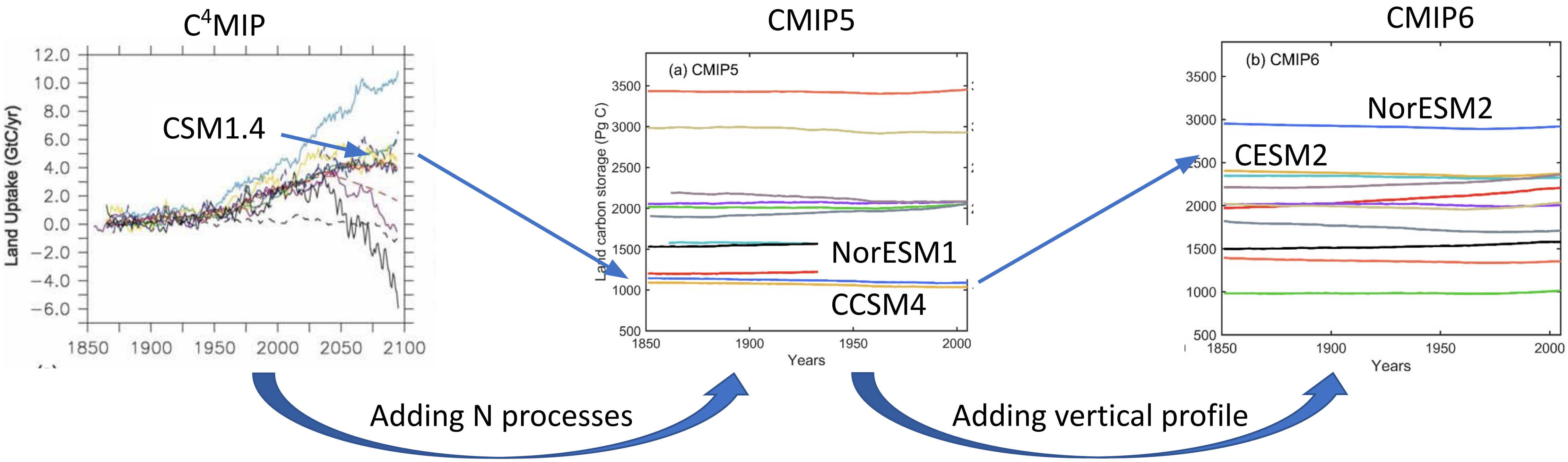
  - **An analytic framework to understand and quantify model uncertainty**

Evolution of NCAR's land model



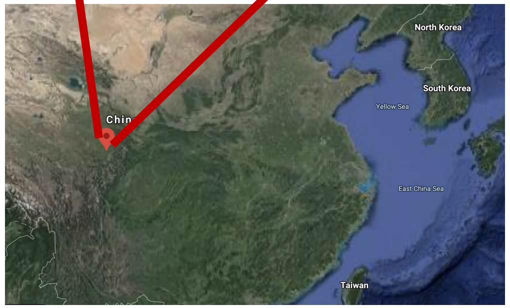
In the modeling world, it all makes sense: carbon is cycling faster when nitrogen processes are added but slower when vertical profiles are added.

Would that happen in the real world?

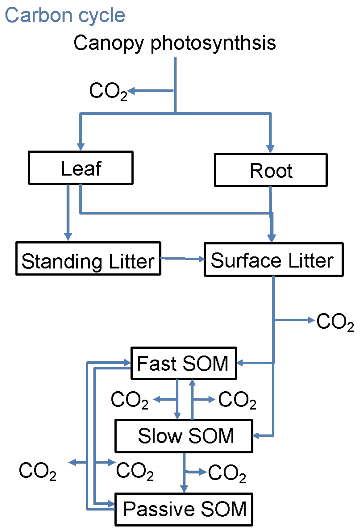
Would carbon processes in the real-world change with different processes being modeled?

Model structure, parametrization, and prediction

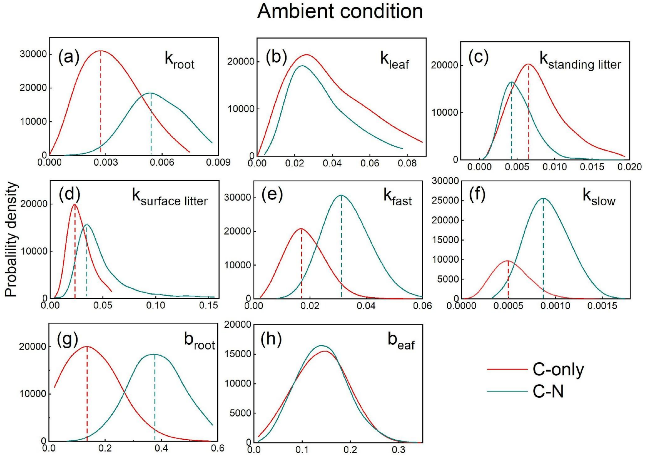
Data



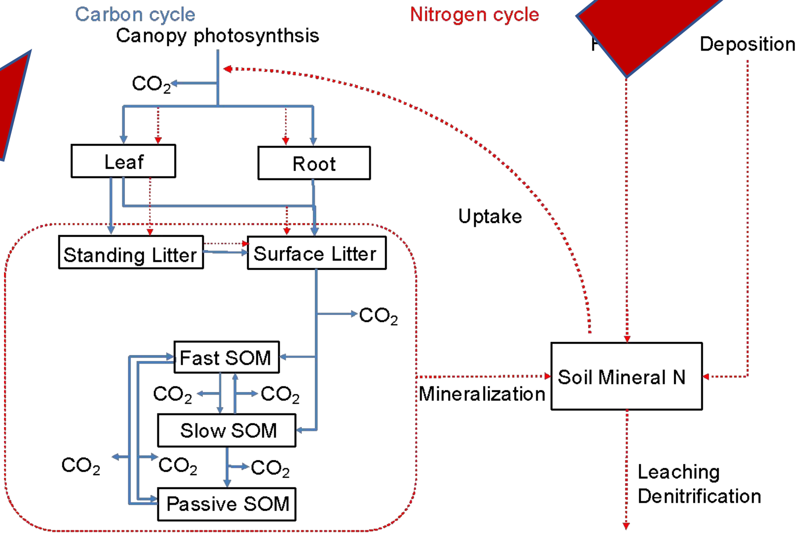
Structure I



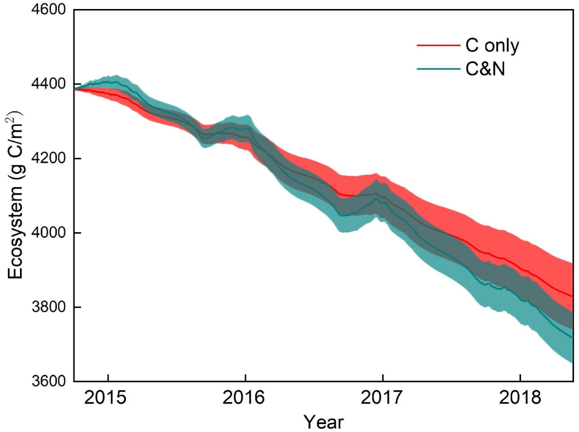
Parameterization



Structure II



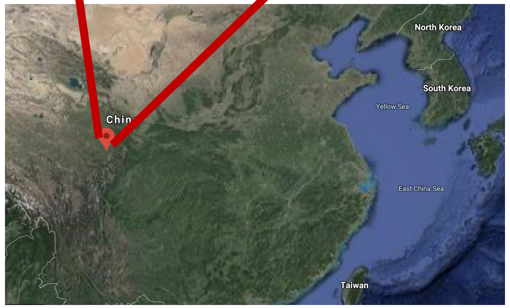
Prediction



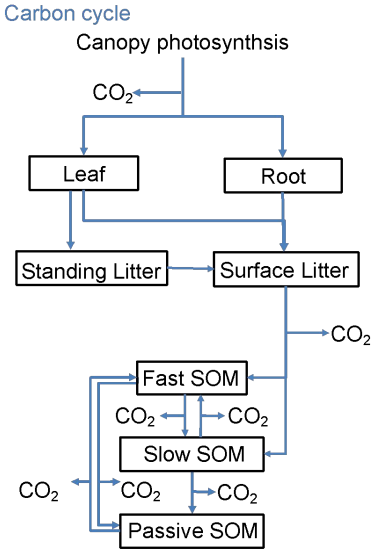
Wang et al. *In prep.*

When we use two model structures to estimate two sets of parameters, we generate similar predictions

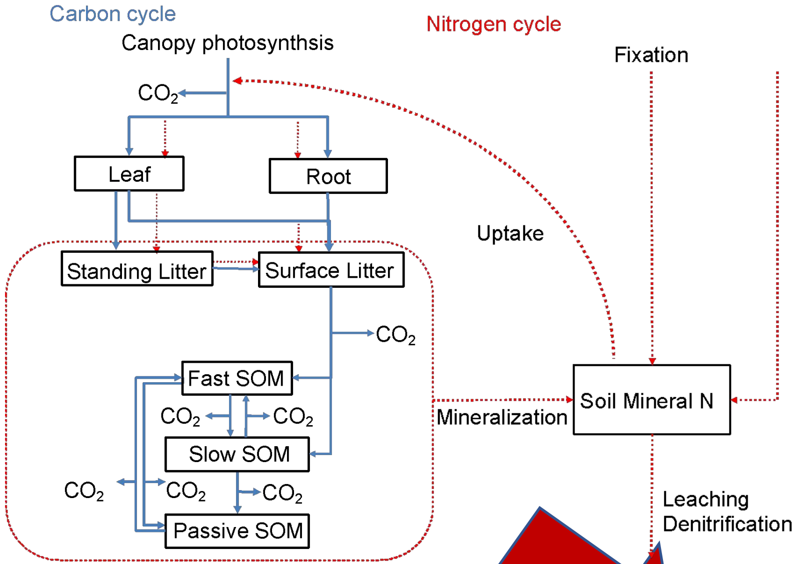
Data



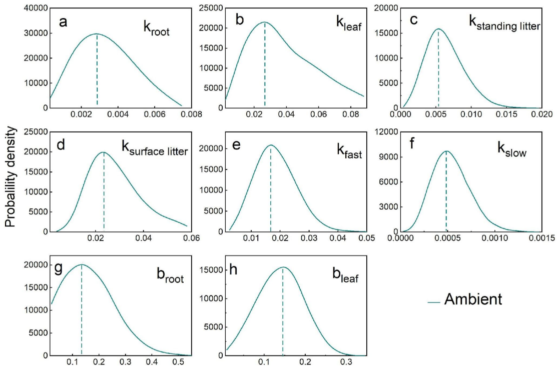
Structure



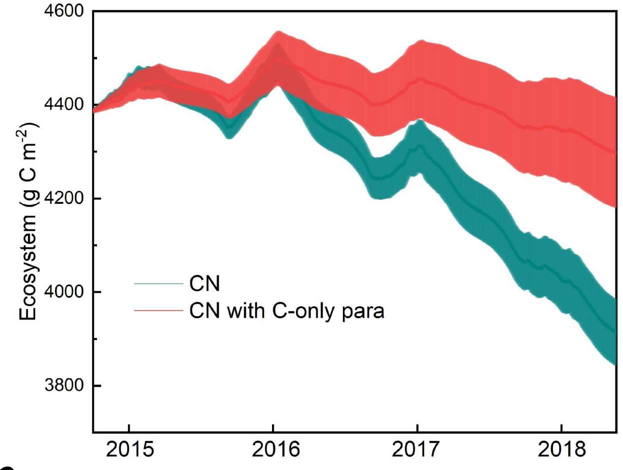
Changed structure



Parameterization



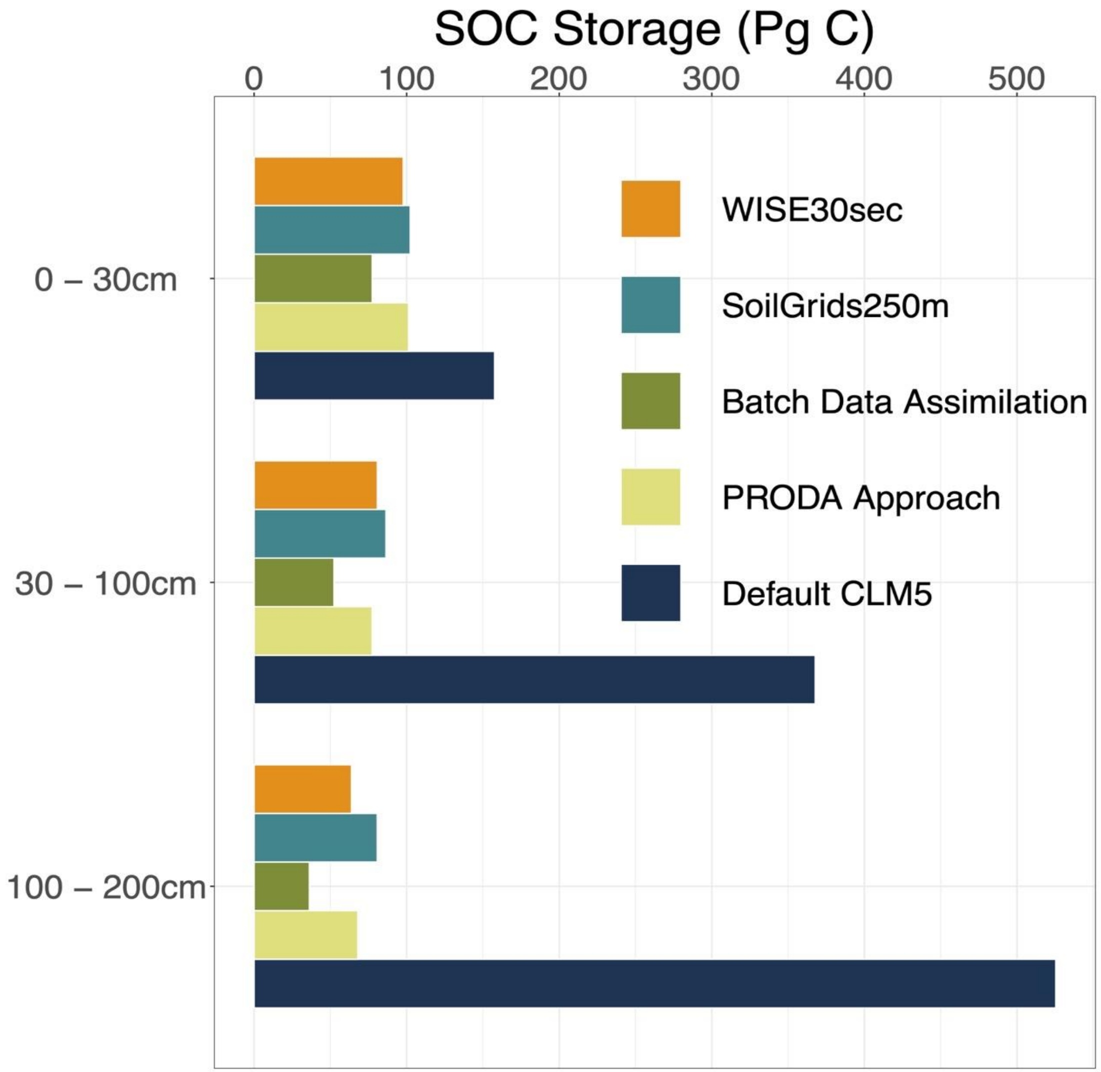
Prediction



Wang et al. *In prep.*

When we change model structure without corresponding changes in parameters, we generate different predictions

Adding vertical profiles leads to overestimation of soil carbon in deep layers By CLM4.5/5

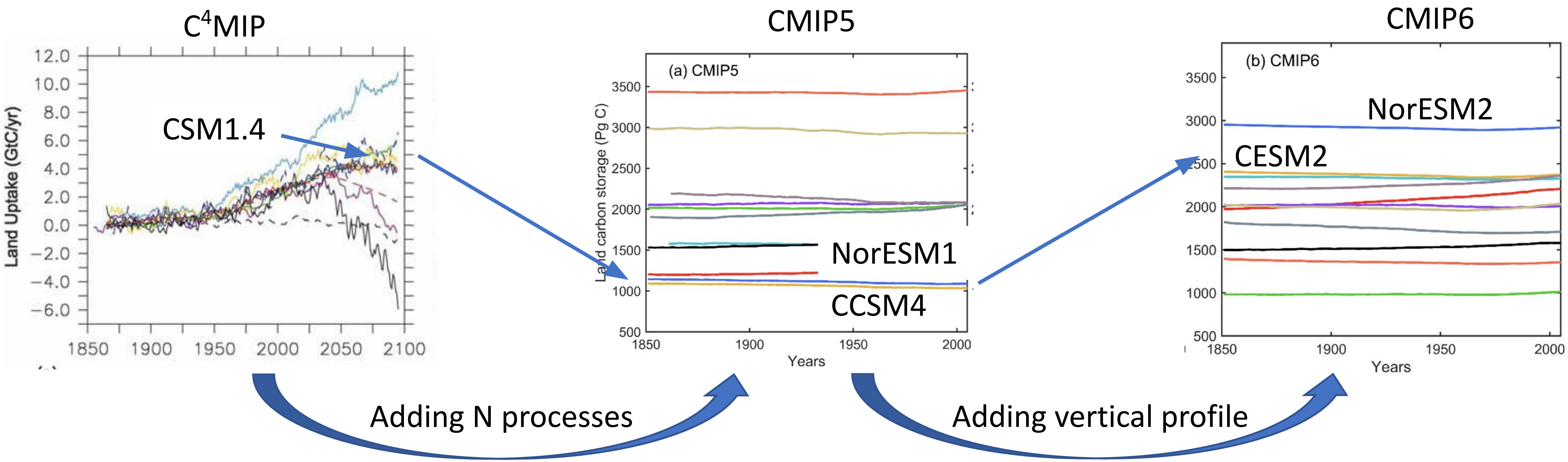


Tao et al. 2020

PROcess-guided deep learning and DAta-driven modelling (PRODA)

Feng Tao
Thursday morning

Re-parameterization is required when model structure is modified



Summary

- Matrix approach makes the uncertainty analysis a transparent, tractable issue
- When we change model structure, parameter values need to change accordingly. Otherwise, the model projects different trajectories of carbon dynamics.
- Re-parameterization becomes essential each time after model structure is modified.
- PRODA is an approach that combines data assimilation and machine learning with matrix models. It makes it possible to integrate big data with complex models

4th Training course May 17-28, 2021

New Advances in Land Carbon Cycle Modeling

https://www2.nau.edu/luo-lab/?workshop

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