A traceability framework to facilitate model evaluation

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Terrestrial Ecosystem SCIENCE

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CSIRO

Division of Biological Infrastructure (DBI)

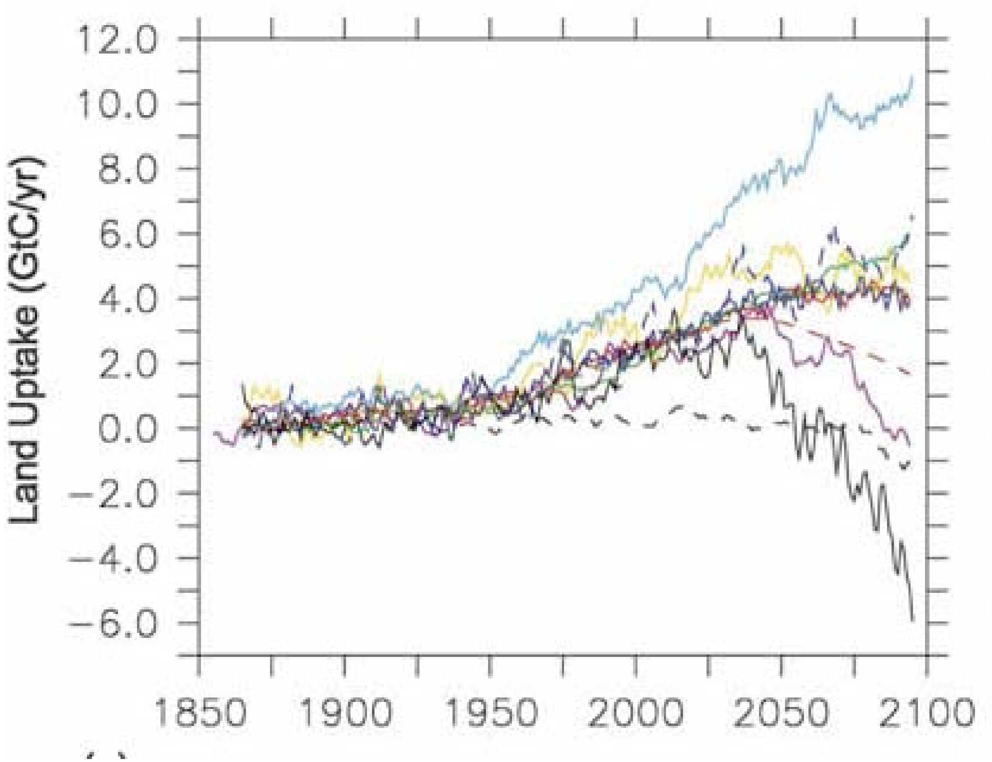
NCAR LMWG/BGCWG (Feb. 21. 2013)

Model Tractability

"There is a danger that we shall replace a world we do not understand by a model of the world we do not understand"

-----John Maynard Smith 1992 *Nature*

Challenges

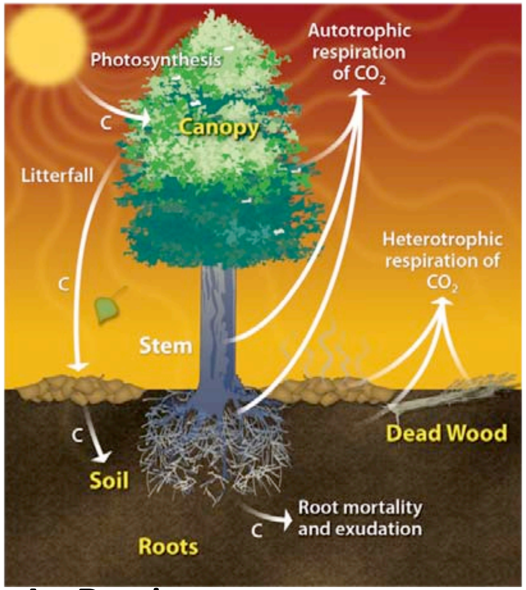


- Models behave so differently;
- Does the uncertainty reflect natural variability or mainly result from artifacts in models? ;
- It's essential to eliminate model artifacts as much as possible.
- How to identify them?

Friedlingstein et al. 2006

"Metrics/diagnostics for component model assessment"

--- Brian O'Neill
CESM guidance



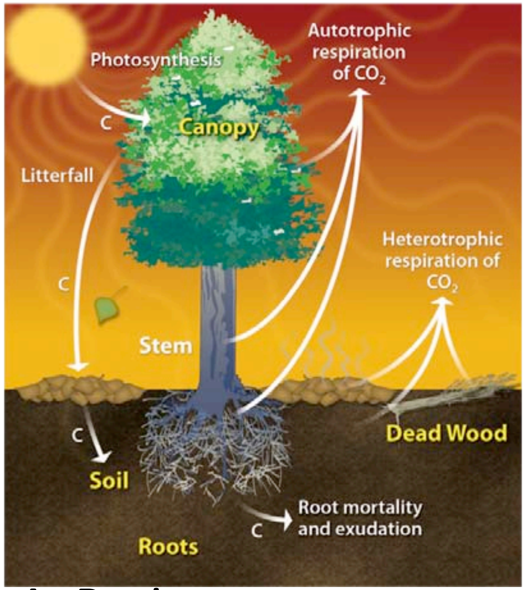
A: Basic processes

Theoretical analysis

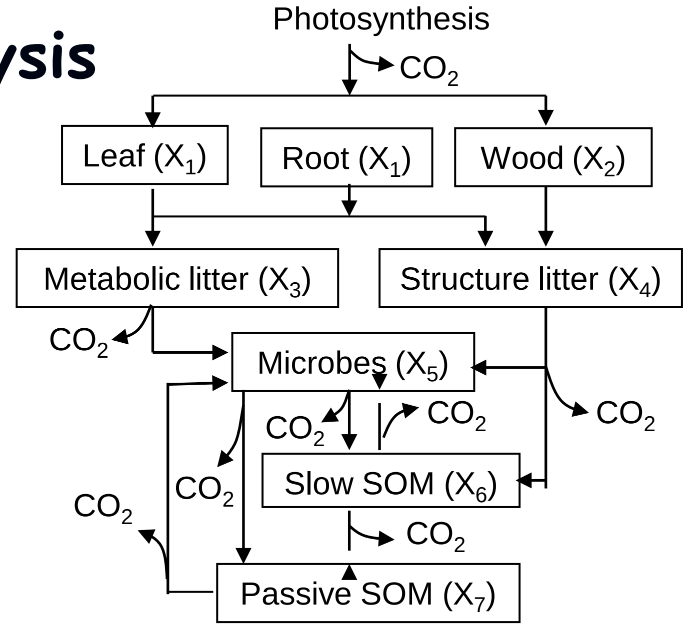
1. Photosynthesis as the primary C influx pathway
2. Compartmentalization,
3. Partitioning among pools
4. Donor-pool dominated carbon transfers
5. 1st-order kinetic transfers from the donor pools

Luo et al. 2003 GBC
Luo and Weng 2011 TREE
Luo et al. 2012

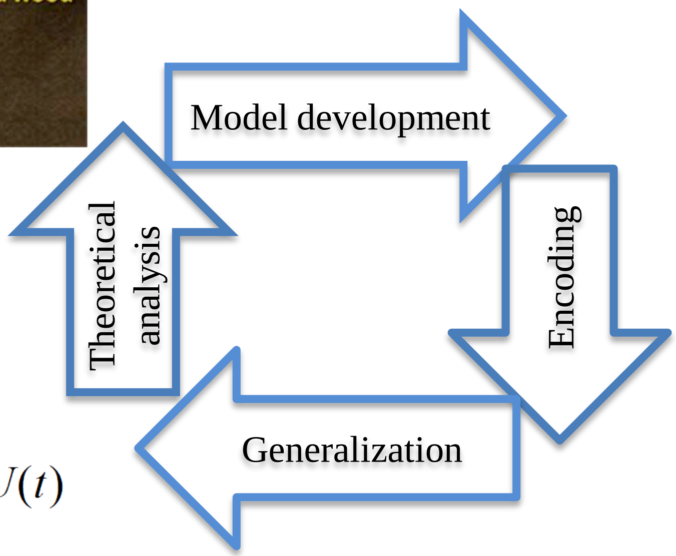
Theoretical analysis



A: Basic processes



B: Shared model structure



D: General model

$$\begin{cases} \dfrac{dX(t)}{dt} = \xi ACX(t) + BU(t) \\ X(t=0) = X_0 \end{cases}$$

C: Similar algorithm

$$Plant \begin{cases} dX_1(t)/dt = b_1U(t) - \xi c_1 X_1(t) \\ \end{cases}$$

$$a_{75}x_5(t) + c_6a_{76}x_6(t) - c_7X_7(t)]$$

$$dX_8(t)/dt = \xi[c_6a_{86}x_6(t) + c_7a_{87}x_7(t) - c_8X_8(t)]$$

Luo et al. 2003 GBC
Luo and Weng 2011 TREE
Luo et al. 2012

System equations

Empirical evidence

1. First-order decay of litter decomposition (Zhang et al. 2008)
2. Carbon release from soil incubation data (Schaedel et al. 2012)
3. Ecosystem recovery after disturbance (Yang et al. 2011)
4. General behavior of CMIP5 models (Todd-Brown et al. 2013)

$$\begin{cases} \dfrac{dX(t)}{dt} = \xi(t)AX(t) + bU(t) \\ X(0) = X_0 \end{cases}$$

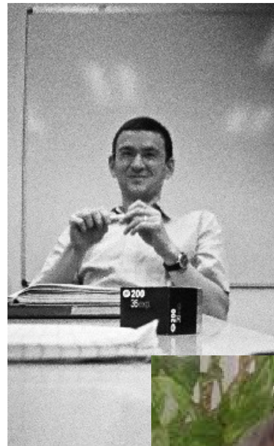
Mathematical and ecological properties (Luo et al. 2012)

Dynamic disequilibrium (Luo and Weng 2011)

NIMBioS working group

National Institute for Mathematical and Biological Synthesis



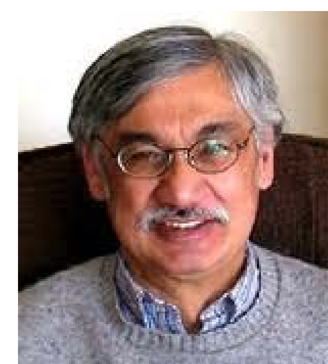













Applications

$$\begin{cases} \dfrac{dX(t)}{dt} = \xi(t)AX(t) + bU(t) \\ X(0) = X_0 \end{cases}$$

1. Predictability of the terrestrial carbon cycle (Luo et al. in prep.)
2. Computational efficiency of spinup (Xia et al. 2012)
3. Traceability for model analysis (Xia et al. 2013)
   a. Impacts of additional modules
   b. Attribution of uncertainty to its Sources
   c. Model intercomparison
4. Facilitating data assimilation (Hararuk et al. To be submitted)

The “traceability” of terrestrial carbon cycle is mathematically solved as:

$$\frac{dX(t)}{dt} = BU(t) - \xi(t)ACX(t) \qquad (1)$$

According to equation (1), when an ecosystem at steady state, the steady-state ecosystem carbon pool size (i.e., ecosystem carbon storage capacity; X_{ss}) is:

$$X_{ss} = \xi^{-1}(AC)^{-1}BU_{ss} = \xi^{-1}\tau_E^{'}U_{ss} = \tau_E U_{ss} \qquad (2)$$

where τ_E' represents the baseline residence times of different carbon pools which are determined by the partitioning and transfer coefficients in equation 1 as:

$$\tau_E^{'} = (AC)^{-1}B \qquad (3)$$

The actual residence time (τ_E) of an ecosystem in the equation 2 is modified from τ_E' by the environmental scalar (ξ) as:

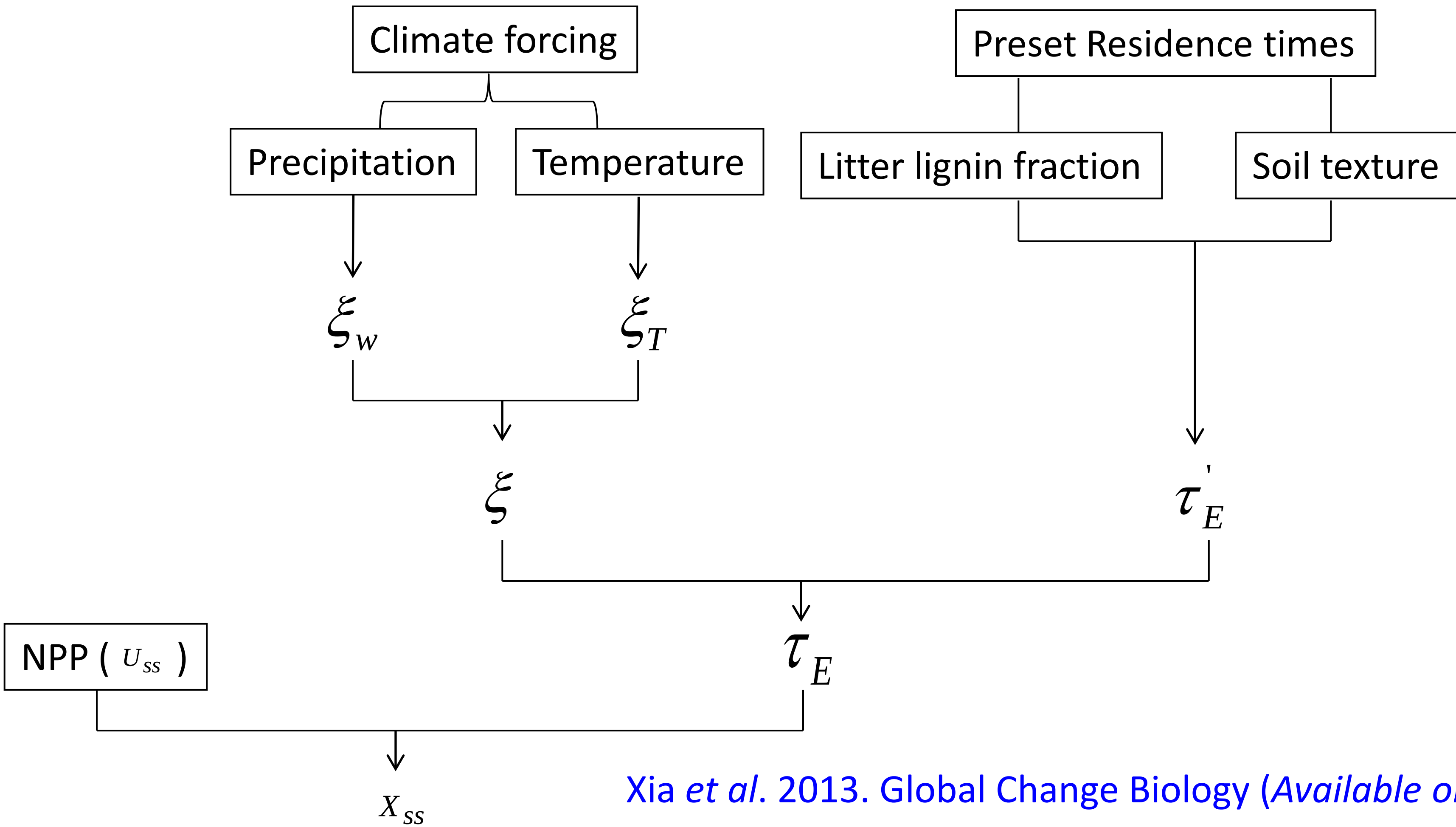
$$\tau_E = \xi^{-1}\tau_E^{'} \qquad (4)$$

For litter and soil carbon pools, ξ usually is calculated from temperature ξ_T and water ξ_W as:

$$\xi = \xi_T \xi_W \qquad (5)$$

Xia *et al*. 2013. Global Change Biology (*Available online*)

The traceability framework



Xia *et al*. 2013. Global Change Biology (*Available online*)

Ecosystem carbon storage capacity (X_{ss}) is determined by ecosystem carbon influx (i.e., NPP; U_{ss}) and ecosystem carbon residence time (τ_E).

Luo et al, 2003. GBC

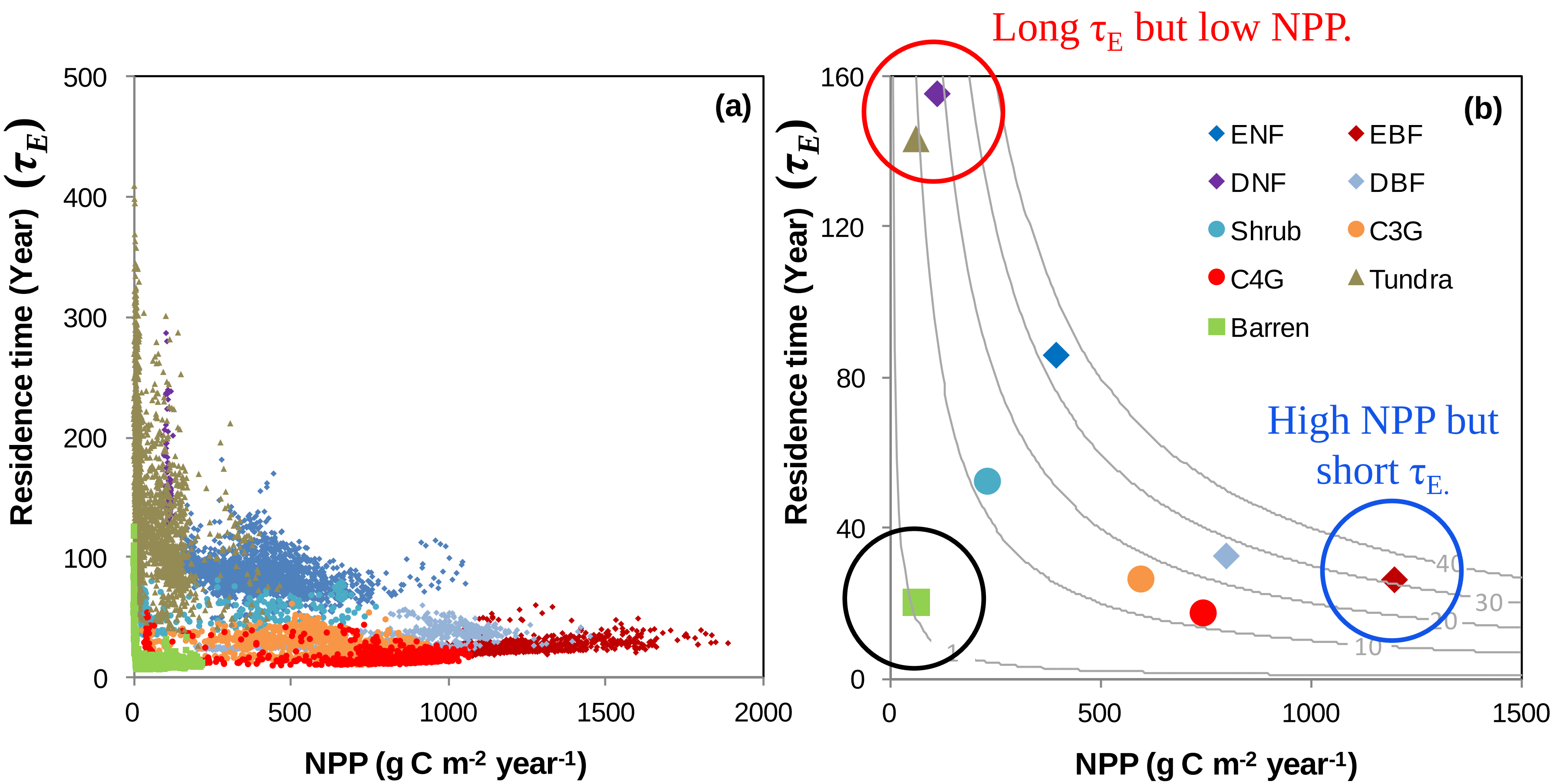
NPP (U_{ss})

carbon residence time (τ_E)

↓

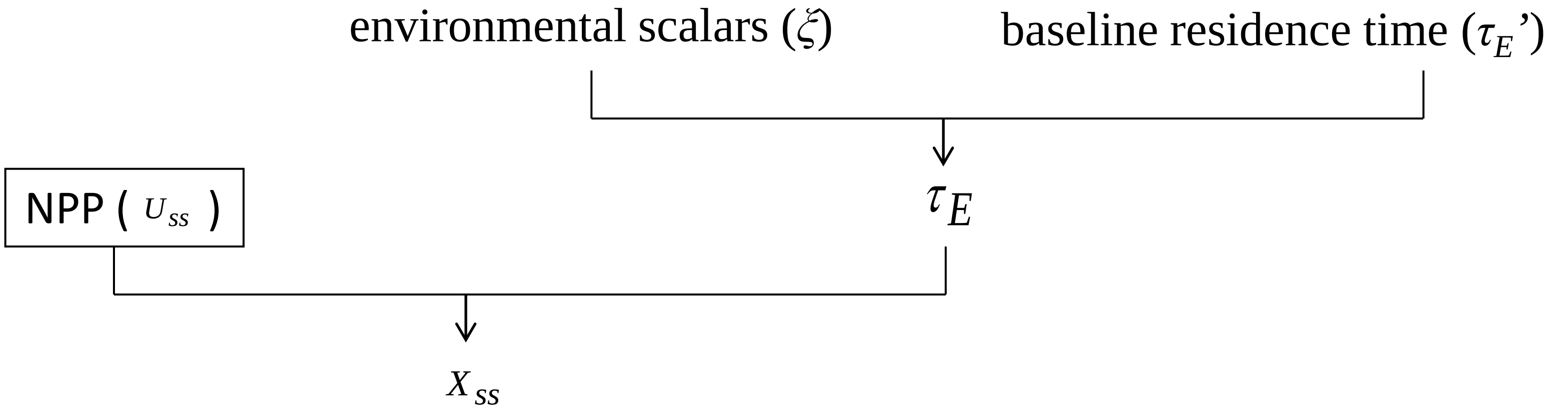
Ecosystem C storage capacity (X_{ss})

Differential determinants on carbon storage capacity among biomes



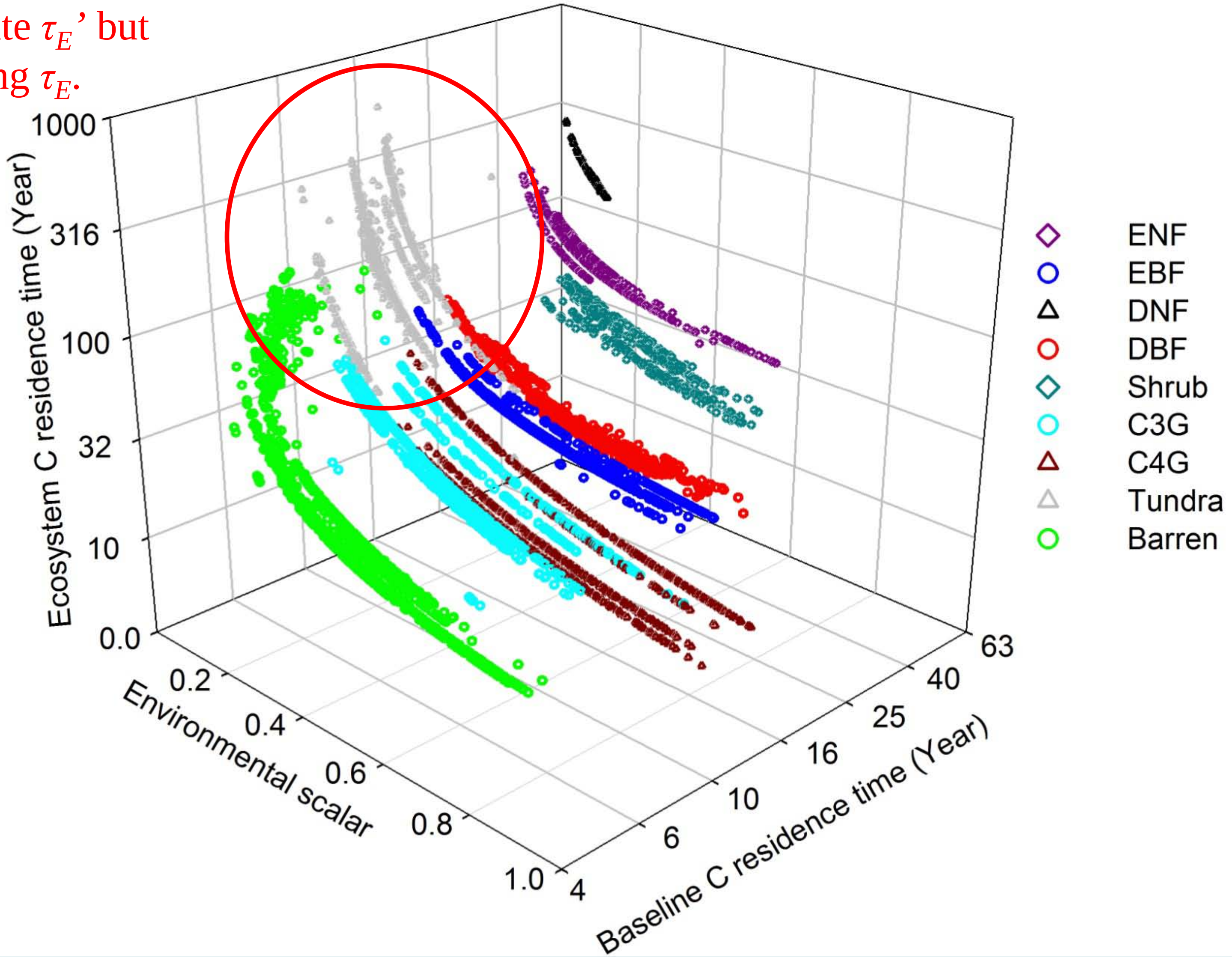
Based on spin-up results from CABLE with 1990 forcings.

Ecosystem carbon residence time (τ_E) is modified from baseline residence time (τ_E') by environmental scalars (ξ).

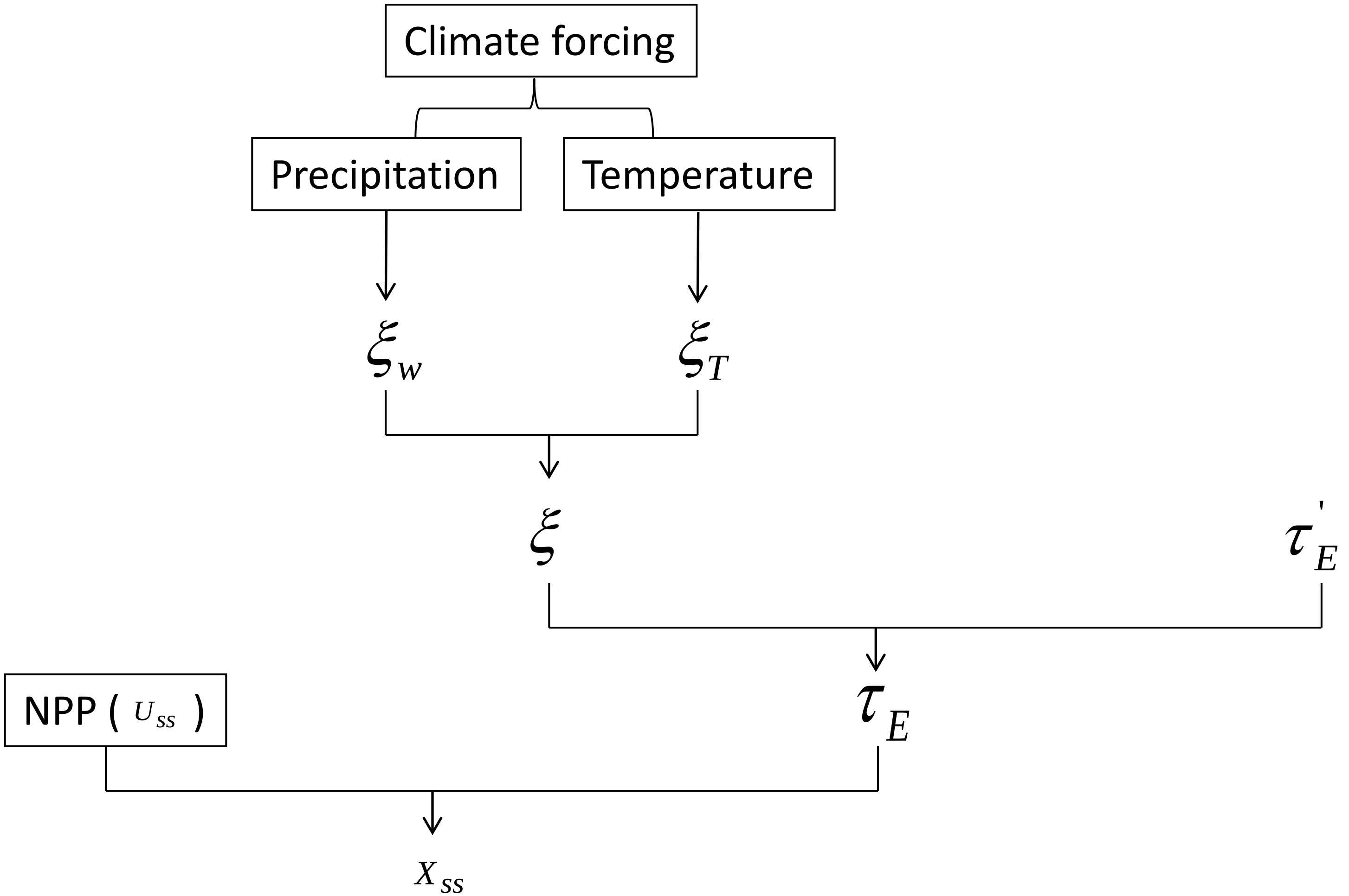


Modification of environmental scalars on baseline carbon residence times

Tundra:
Moderate τ_E' but very long τ_E.



Temperature and water scalars link environmental space (air temperature and precipitation) into the C space.



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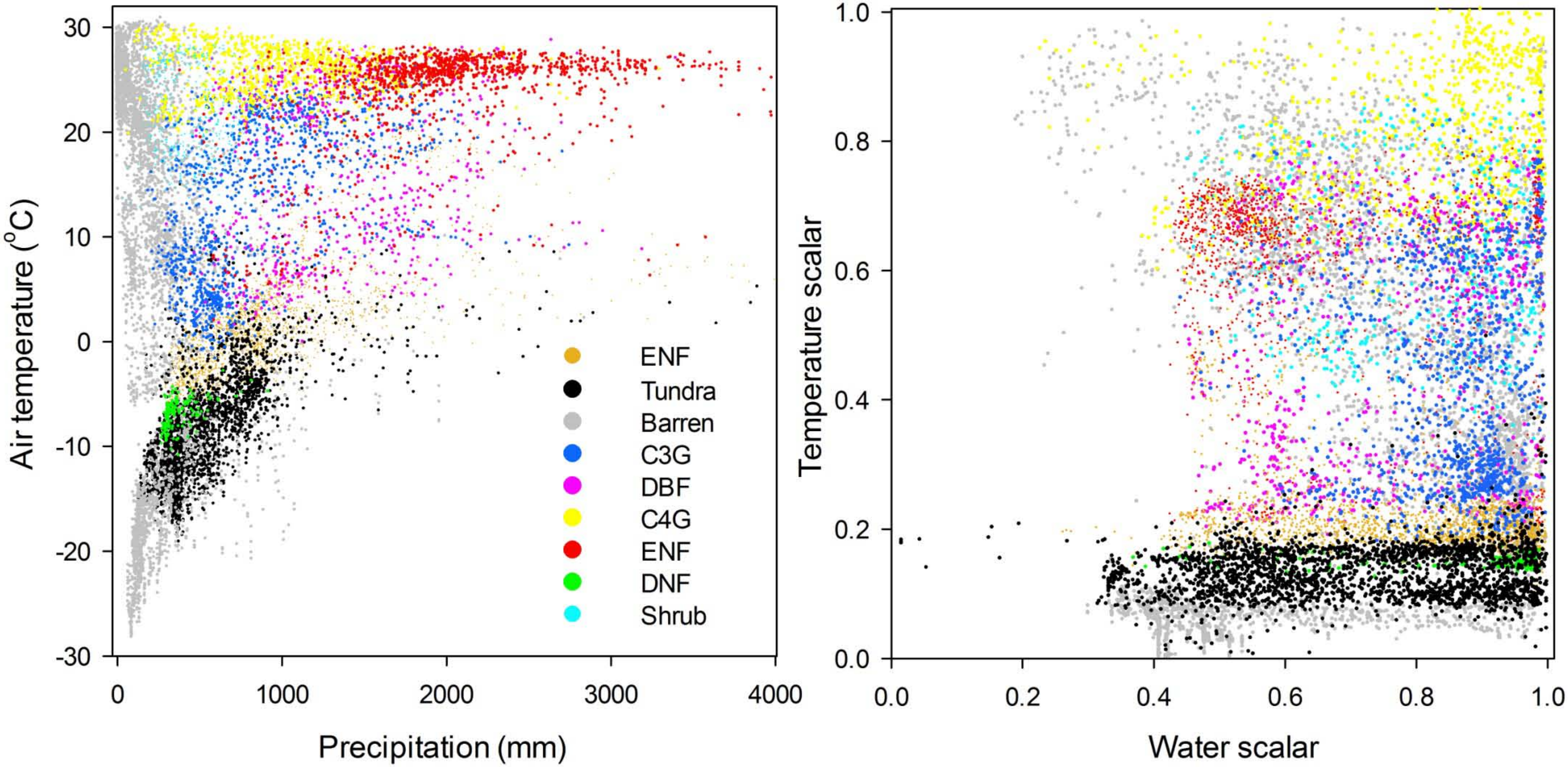
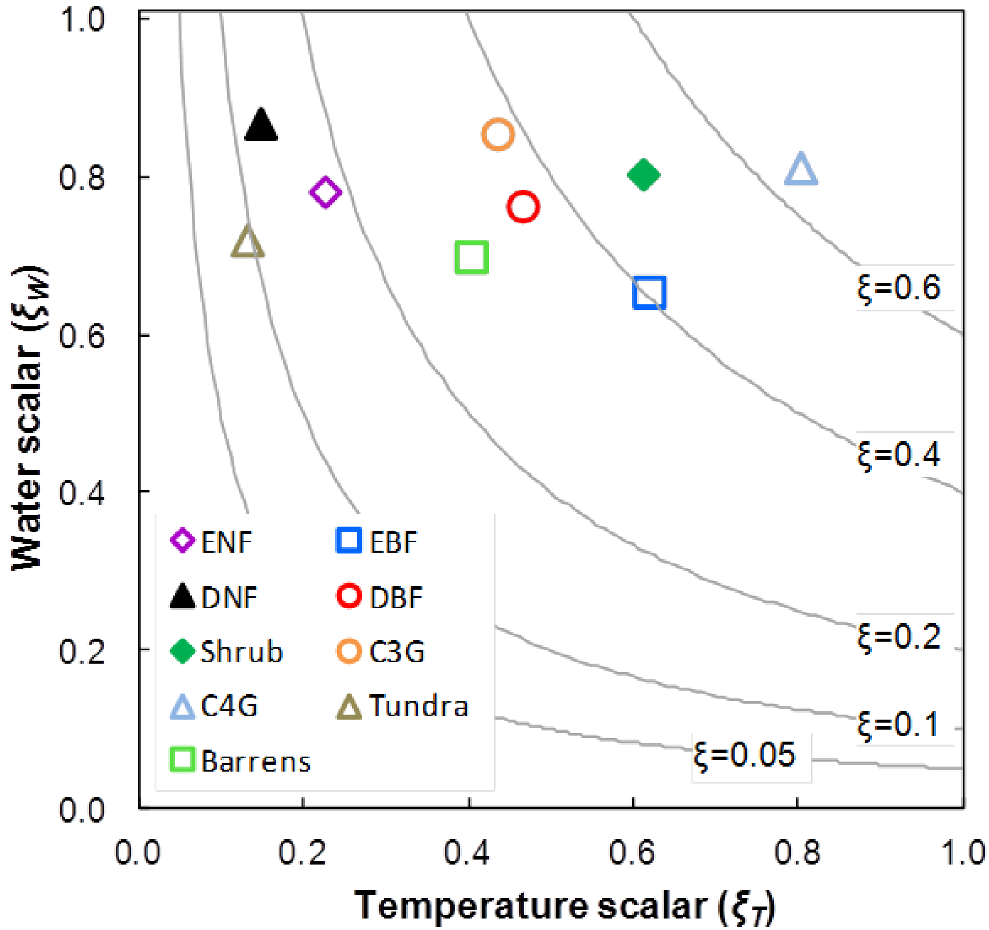


Cropland is excluded in this study. Input forcing in 1990.

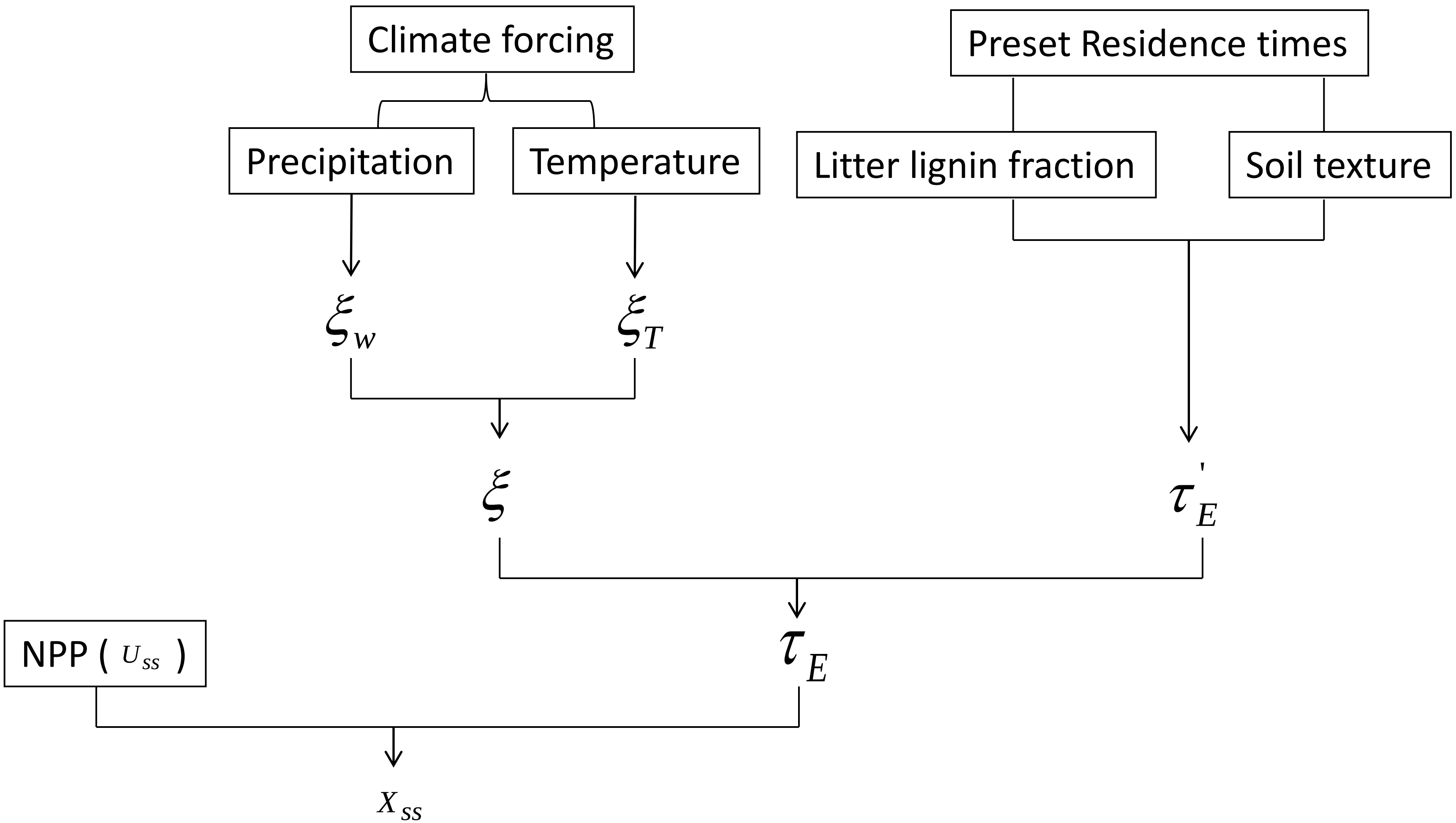
Temperature and water scalars link environmental space (air temperature and precipitation) into the C space.

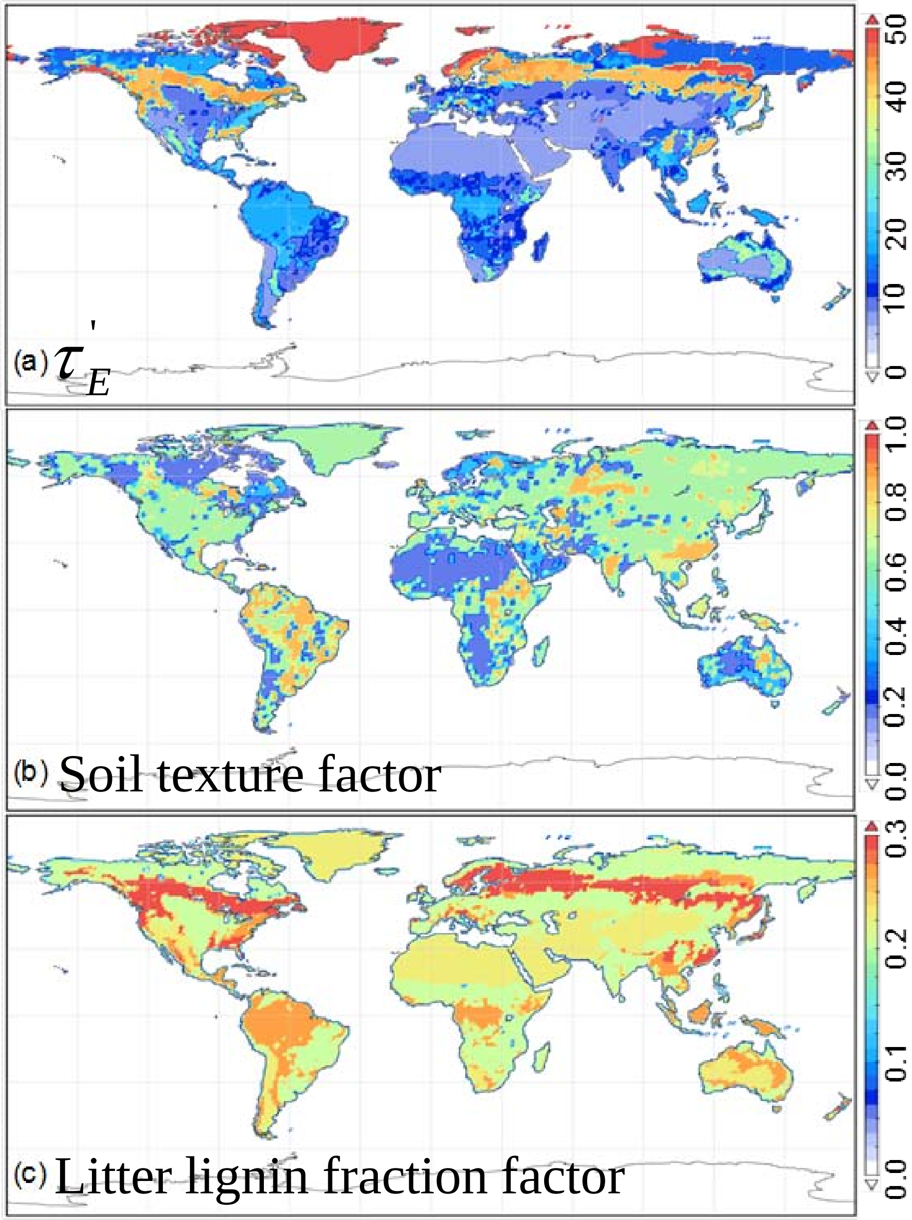


In CABLE model, the differences in environmental scalars among biomes are more determined by the temperature scalar.

The environmental limitation on τ_E' is largest in Tundra and needleleaf forests.

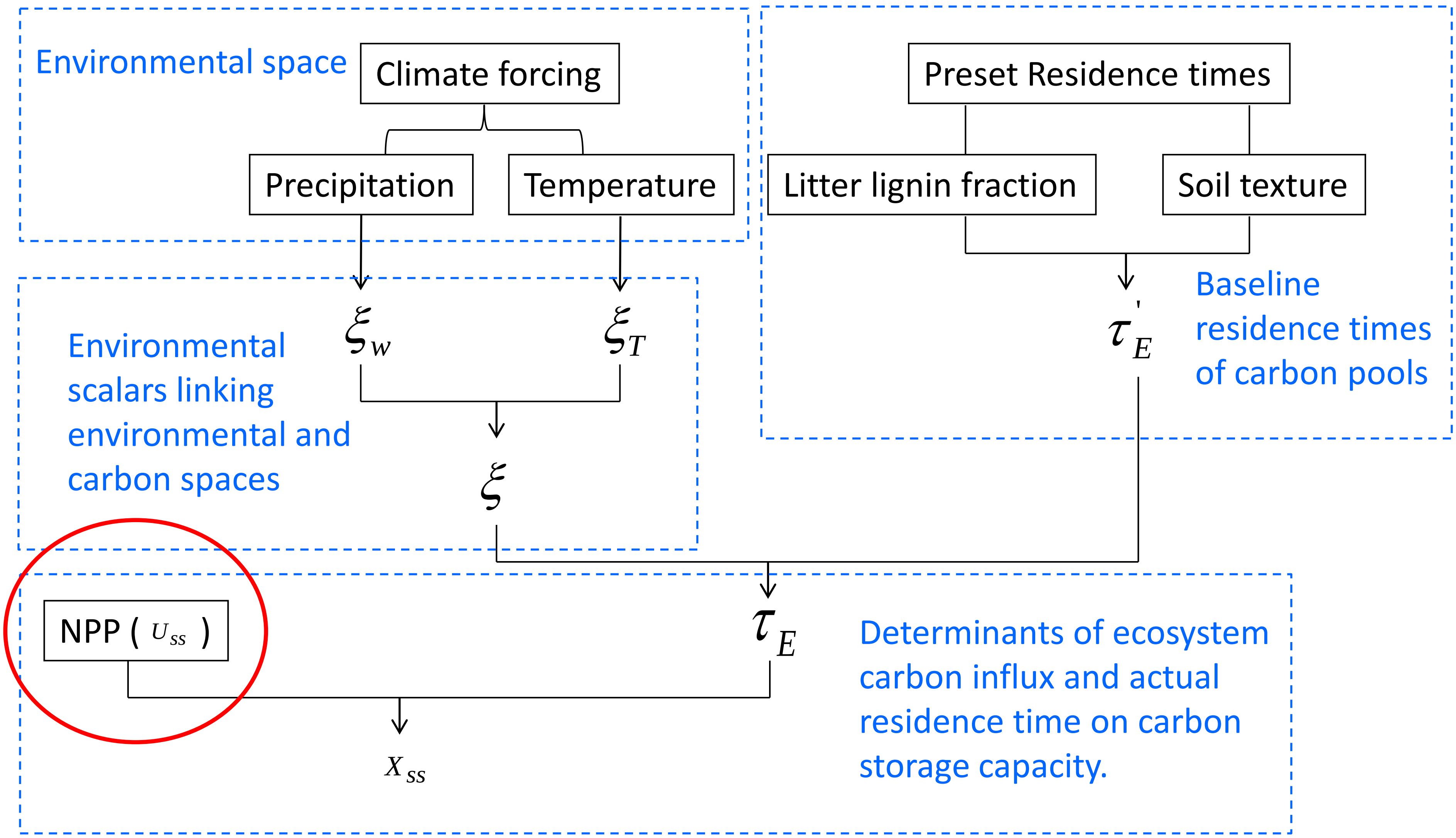
Litter lignin fraction and soil texture spatially modified the preset residence times into baseline carbon residence times in different grids.



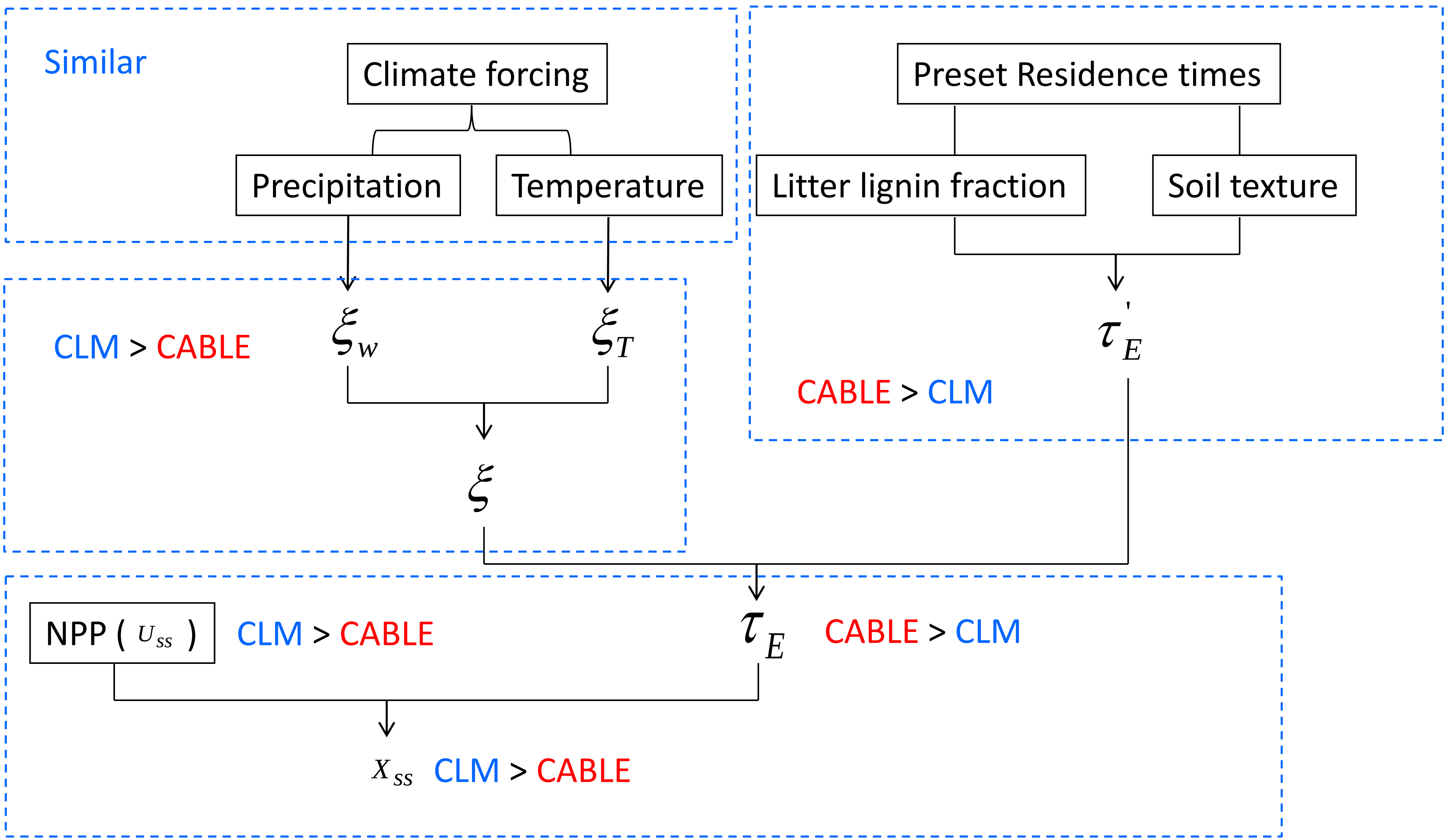


Litter lignin fraction and soil texture influence spatially distribution of C turnover rates

A traceable framework for terrestrial C cycle

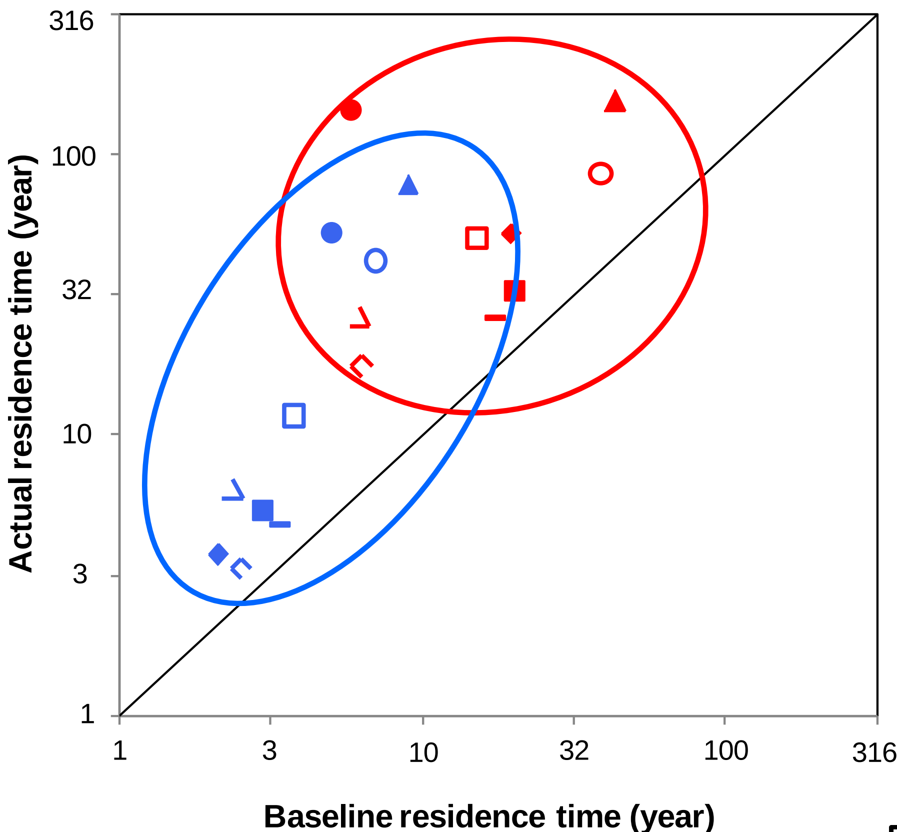


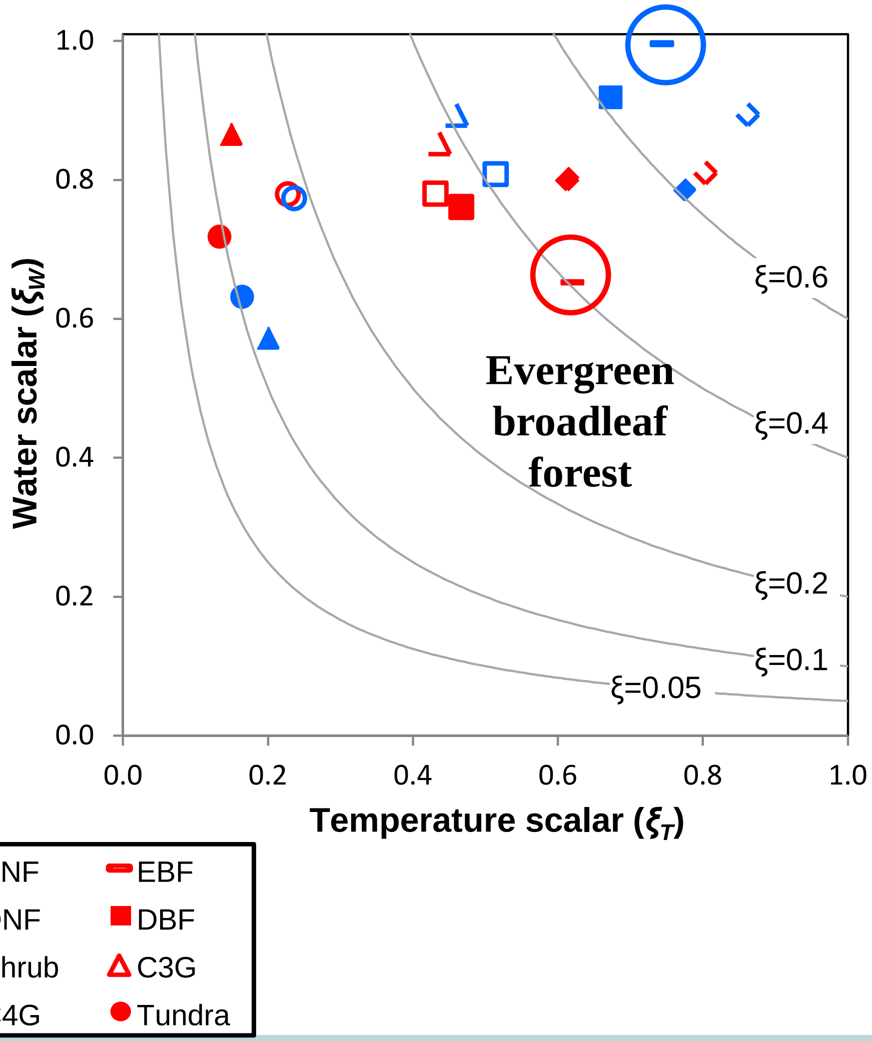
Model intercomparison



Longer residence times in CABLE than CLM-CASA

$$\tau_E = \xi^{-1}\,\tau'_E$$

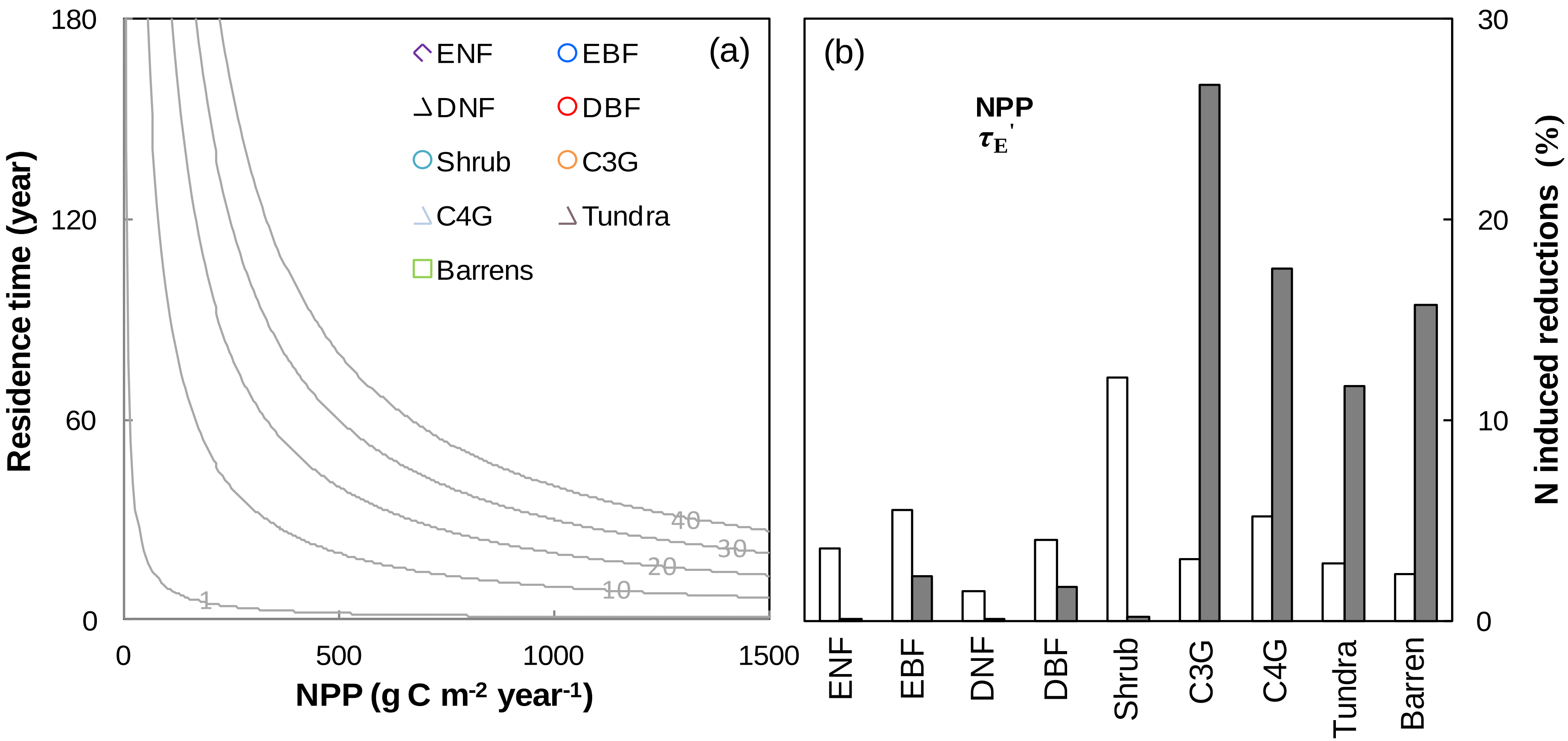




CABLE
CLM-CASA

Impacts of incorporating nitrogen cycle into CABLE model

Xia *et al*. 2013 Global Change Biology



- reduces X_{ss} in all biomes in comparison with that in the carbon-only model;
- mainly by decreasing NPP in woody biomass and via shortened τ_E' in other biomes.

Attribution of model uncertainty to its sources

$$\begin{cases} \frac{dX(t)}{dt} = \xi(t)AX(t) + bU(t) \\ X(0) = X_0 \end{cases}$$

Environmental scalar: $\xi(t)$

Transfer coefficient: A

Partitioning coefficient: b

Carbon influx: $U(t)$

Initial values of carbon pools: X_0

$$X_{ss} = \xi^{-1}\tau_E^{'}U_{ss} = \tau_E U_{ss}$$

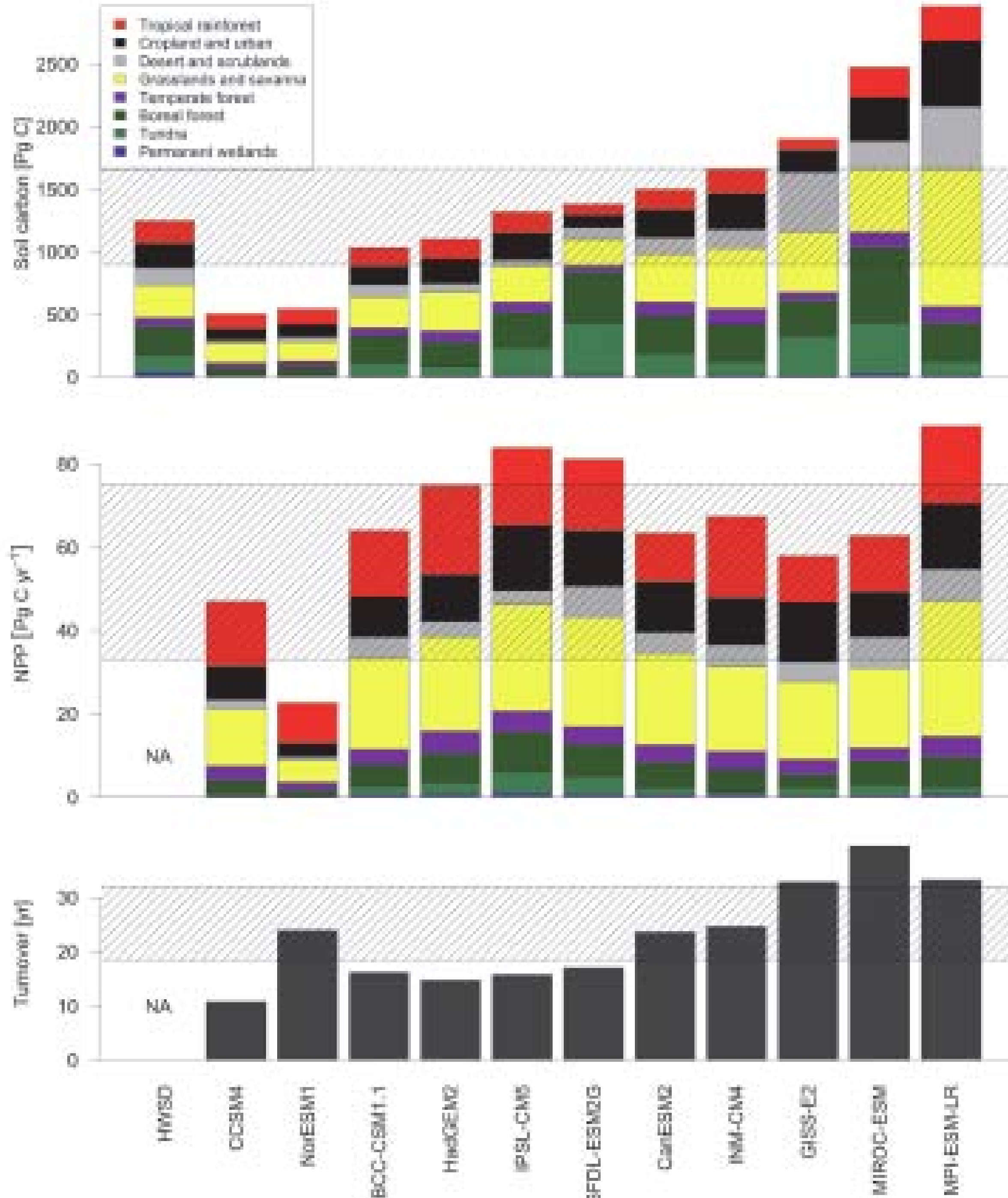
Carbon influx: U_{ss}

Residence time: τ_E

$$\tau_E = \xi^{-1}\tau_E^{'} = (\xi_T\xi_W)^{-1}(A^{-1}B)$$

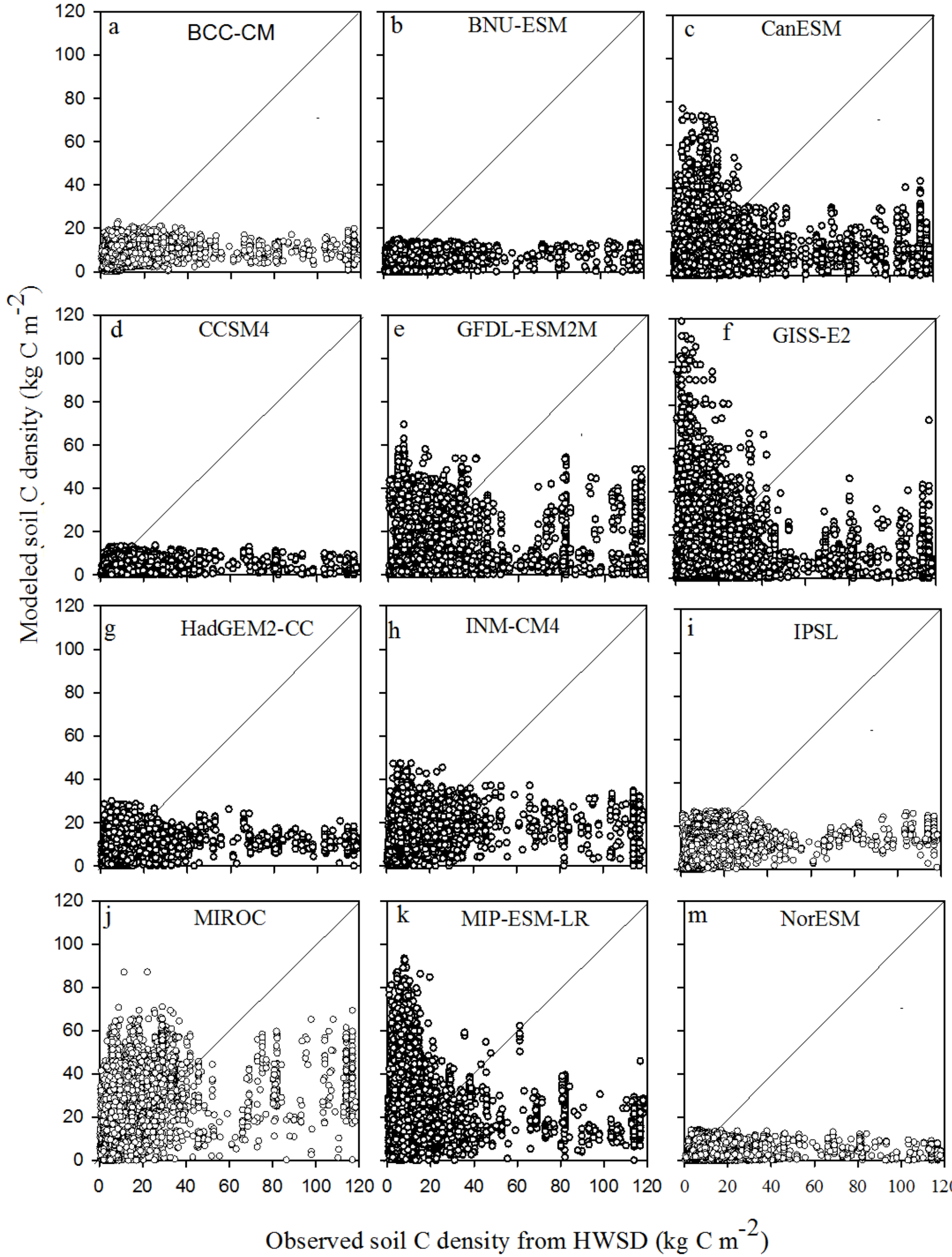
Soil carbon modeled in CMIP5 vs. HWSD

Todd-Brown et al. 2012 BGD



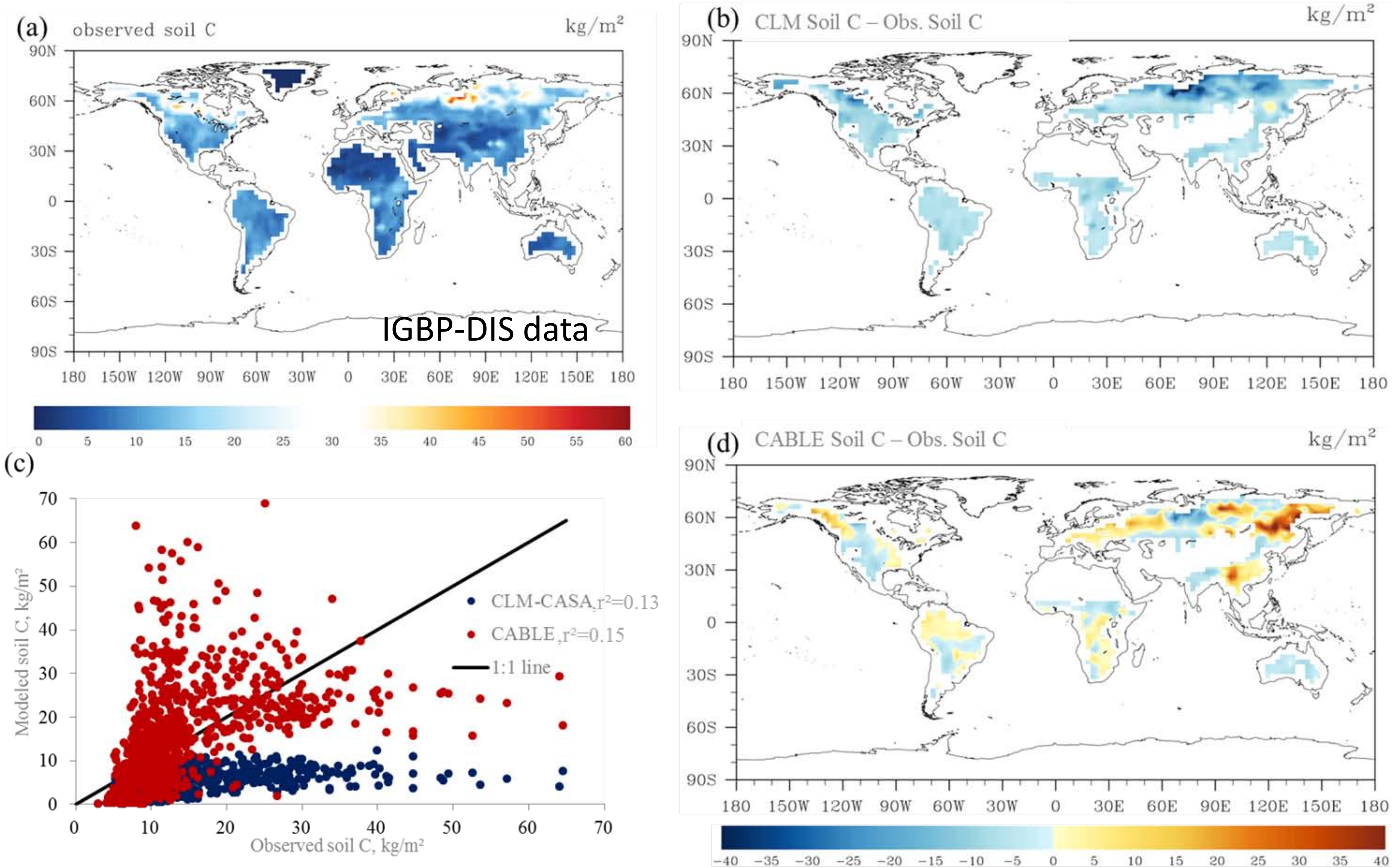
Soil carbon modeled in CMIP5 vs. HWSD

Yan et al. unpublished

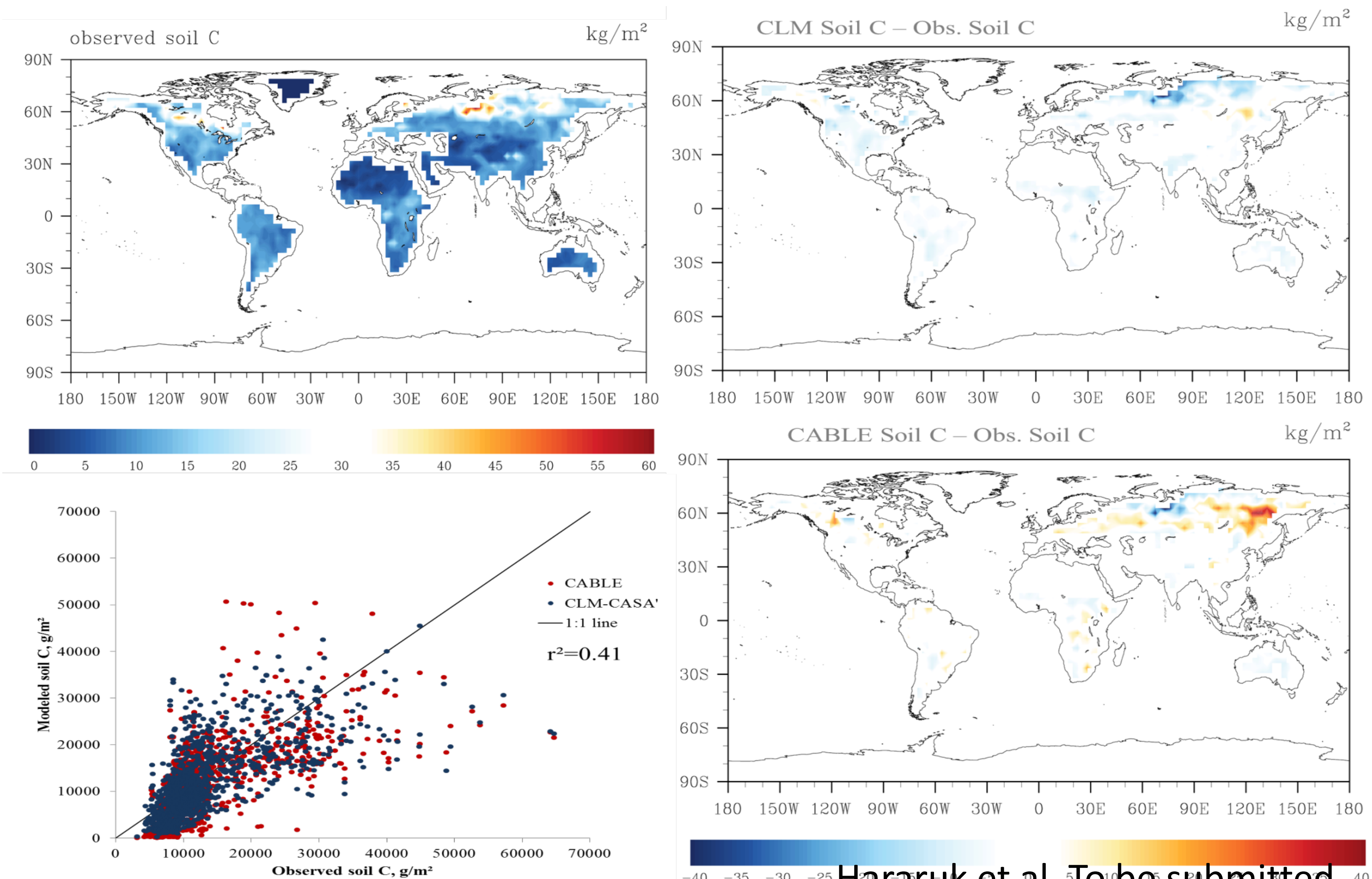


How do CLM-CASA' and CABLE simulate Soil C?

Hararuk et al. To be submitted

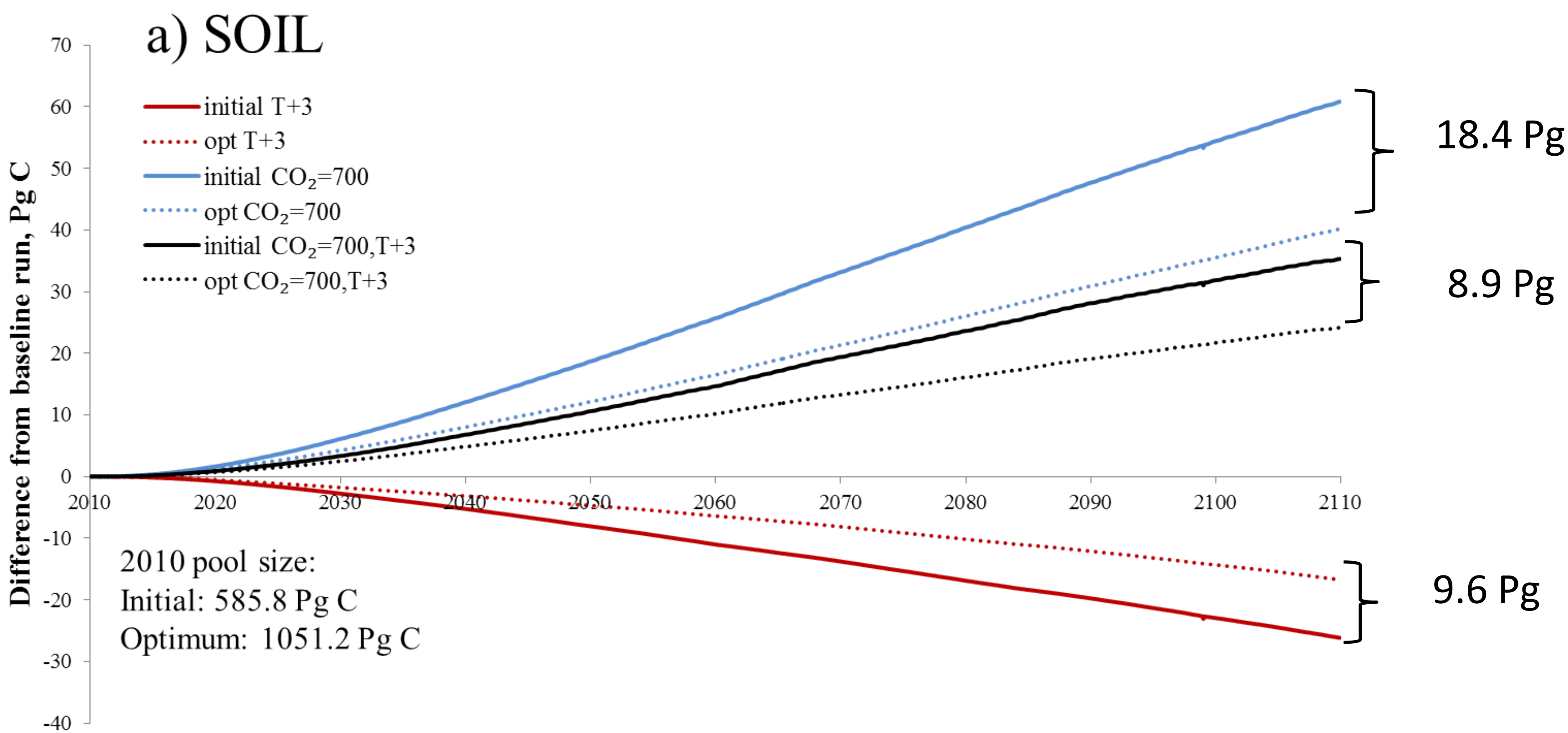


Data assimilation to improve soil C simulation by two global models:



Hararuk et al. To be submitted

Changes in temporal dynamics: CLM-CASA'



Hararuk et al. To be submitted

Summary

- Improvement and applications of the traceability framework to make carbon cycle models more tractable. Procedure will be available at http://ecolab.ou.edu
- The traceability framework makes it possible evaluate impacts of adding components on model performance skills before we do so.
- It is urgent to correct the initial value problem of global carbon cycle models before they are used for CMIP6. It is also relatively easy to do so