A Traceability Framework to Facilitate Evaluation and Improvement of Global Carbon Cycle Models

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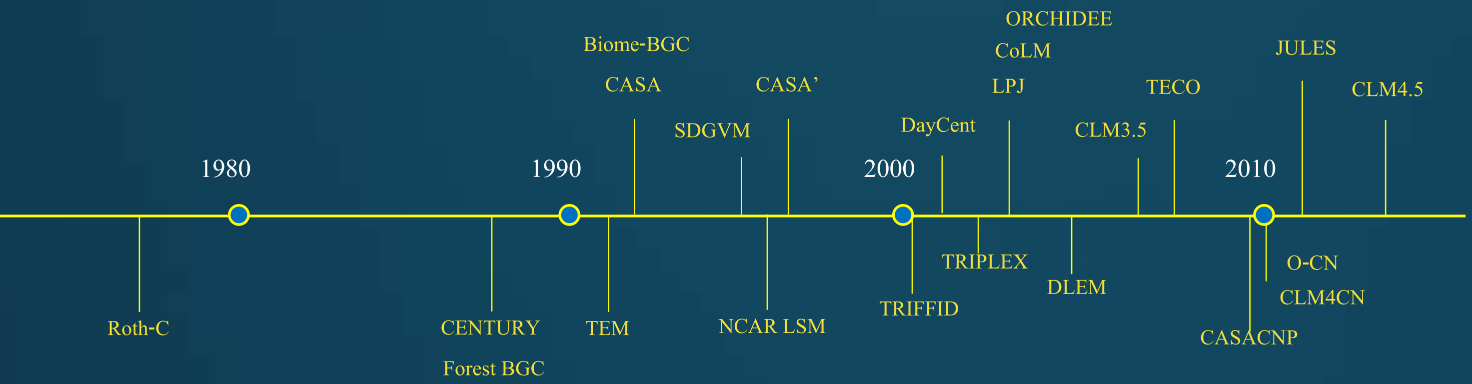
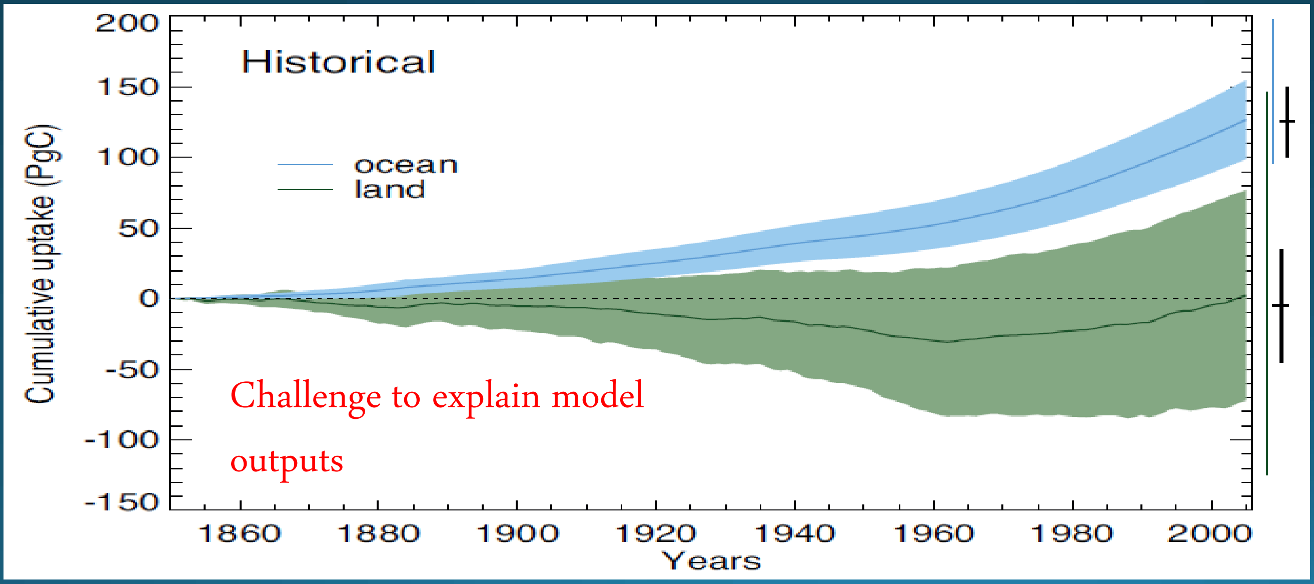
Challenge



Soil microbial dynamics
Soil depth
Priming effect
Wetland
Land use
Erosion
DOC
Fire
… …

Low **Complexity** High

High **Tractability** Low



IPCC AR5
Chapter 6

Why models behave so differently?

Forcings

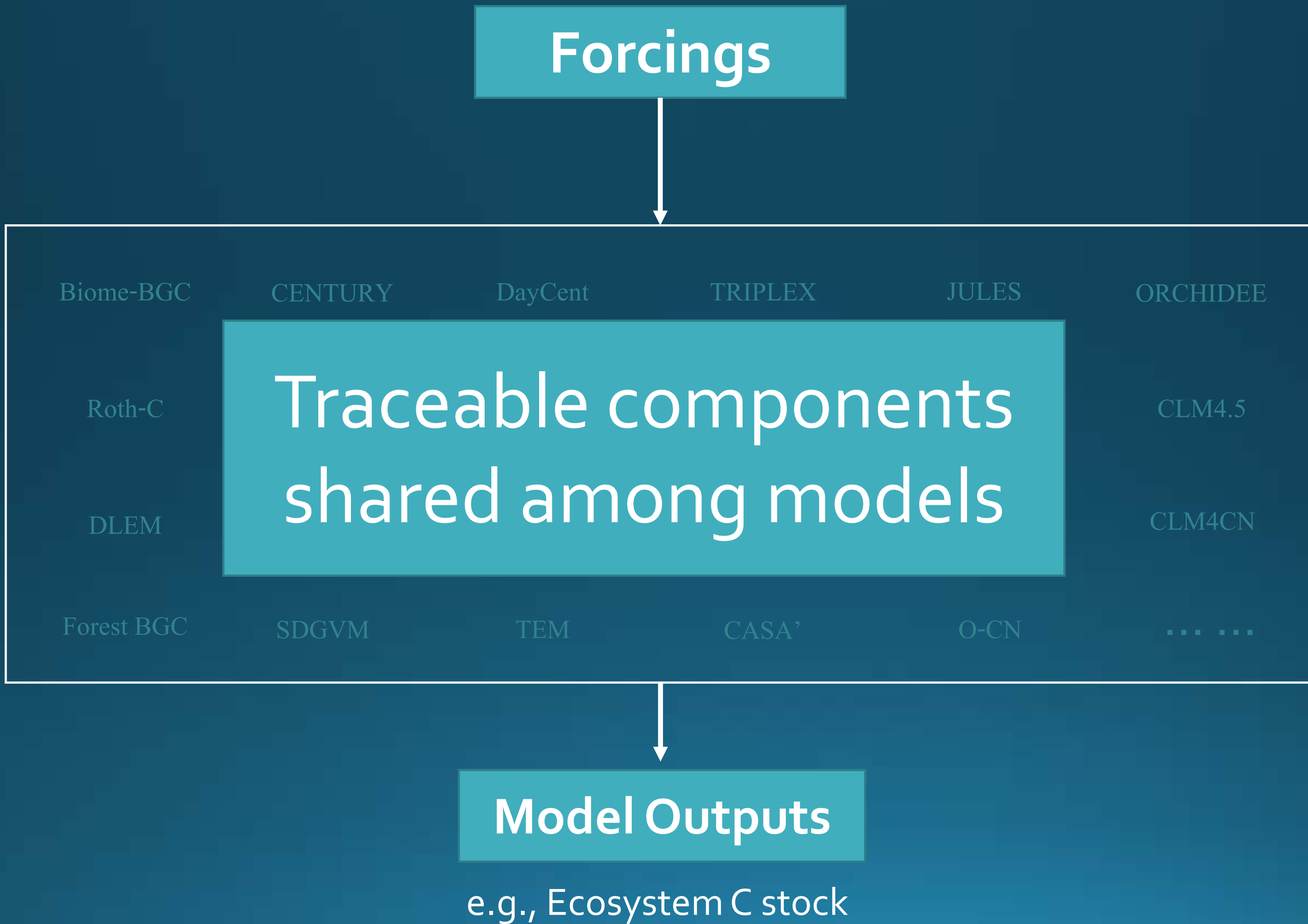
↓

Biome-BGC	CENTURY	DayCent	TRIPLEX	JULES	ORCHIDEE
Roth-C	CASA	CLM3.5	CoLM	TECO	CLM4.5
DLEM	LPJ	NCAR LSM	TRIFFID	CASACNP	CLM4CN
Forest BGC	SDGVM	TEM	CASA’	O-CN	… …

↓

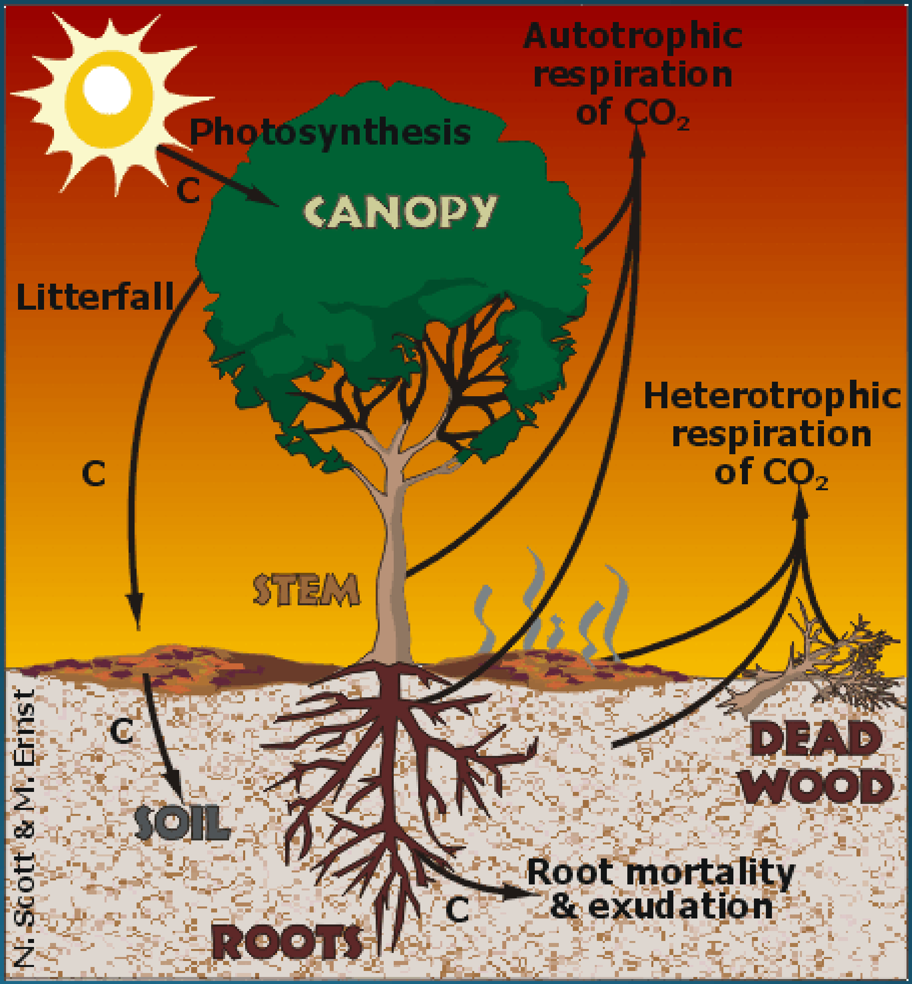
Model Outputs

Traceability to diagnose model differences



Common properties of terrestrial C cycle

1. Photosynthesis is the primary carbon influx pathway;
2. Compartmentalization of C pools
3. C partitioning and transfer among pools;
4. donor-pool dominated carbon transfer;
5. first-order linear transfer from the donor pool.



Luo & Weng 2011 *TREE*

Model representation of ecosystem carbon cycle

$$\frac{dX(t)}{dt} = BU(t) - \xi(t)ACX(t)$$
$$X(0) = X_0$$

Luo et al. 2003
Luo & Weng 2011 *TREE*

<u>**Variations among models:**</u>

(1) Pool number

(2) B, ξ, A, and C

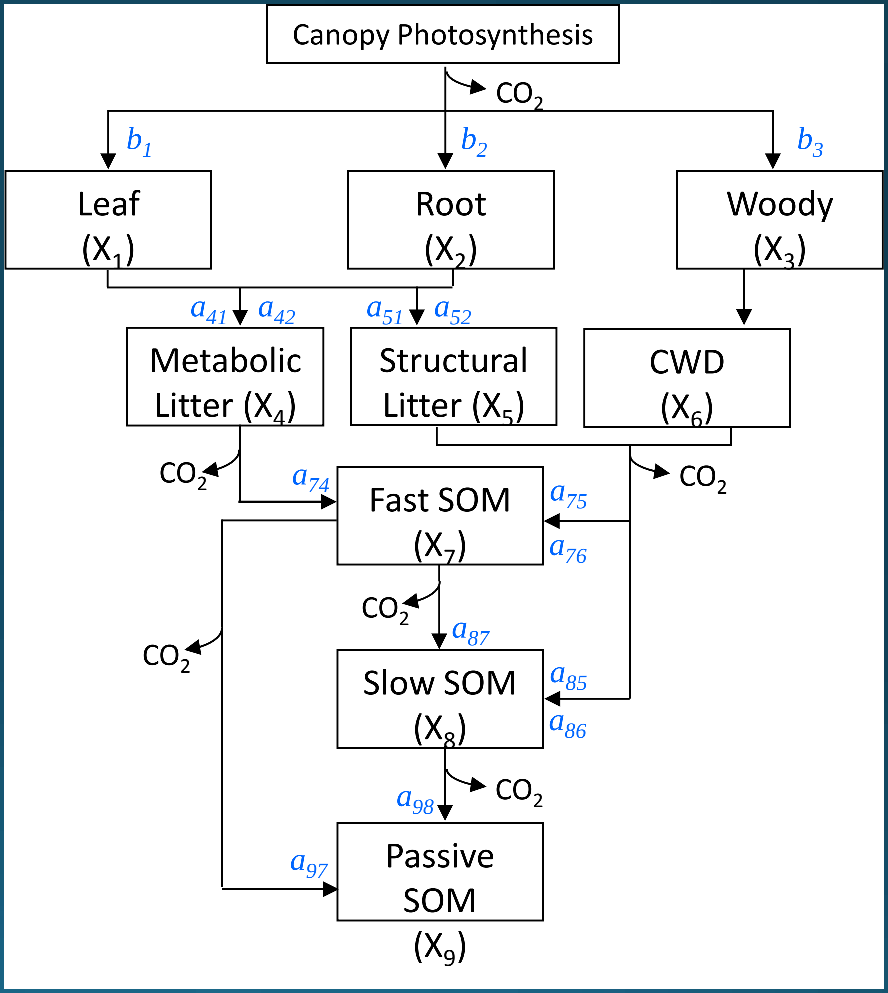


Diagram of C process of CABLE.

Xia *et al.* 2012 *GMD*

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:

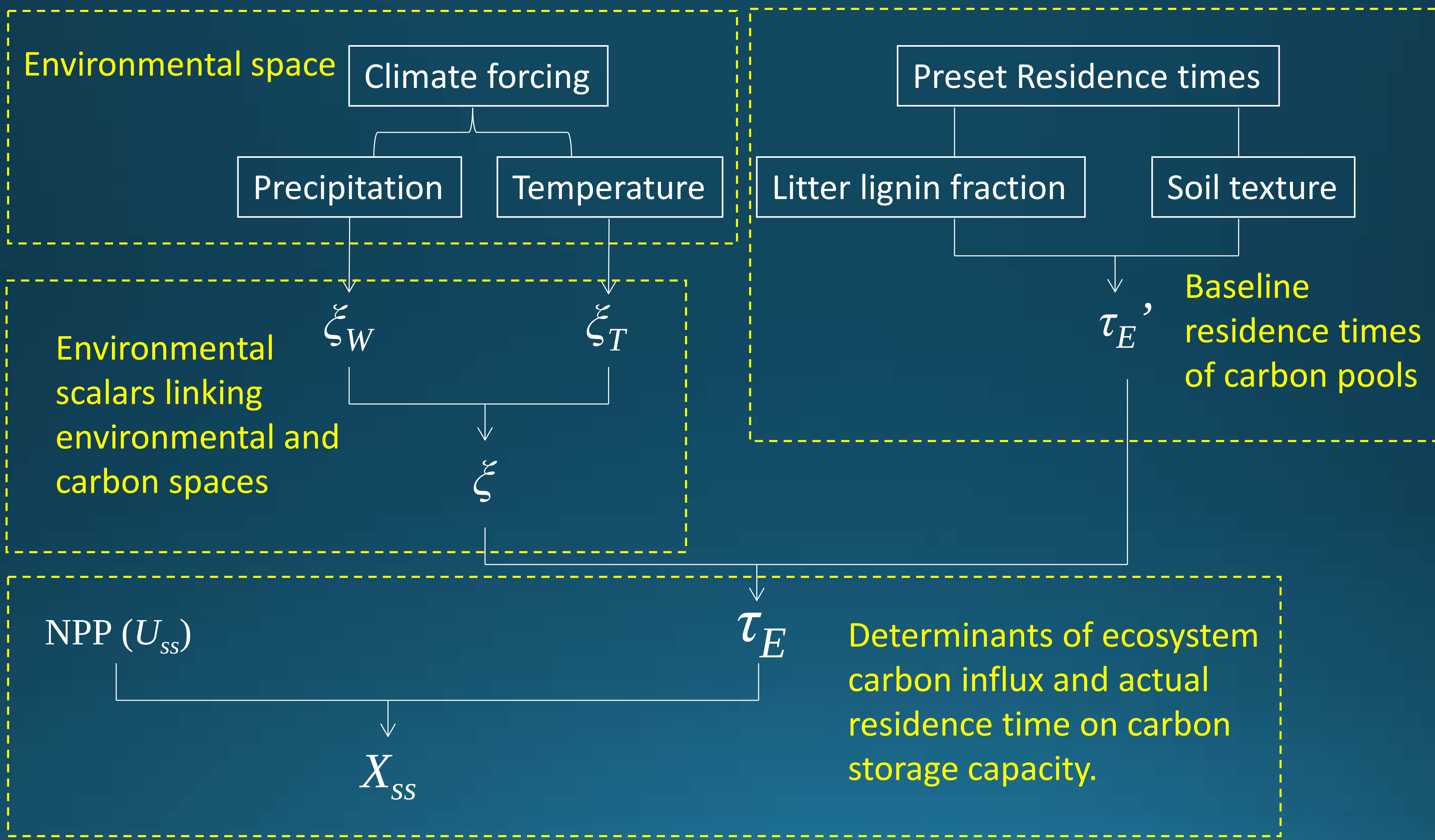
$$\tau_E = \xi^{-1}\tau_E^{'} \qquad (4)$$

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 Biol.*

A traceability framework for terrestrial C cycle



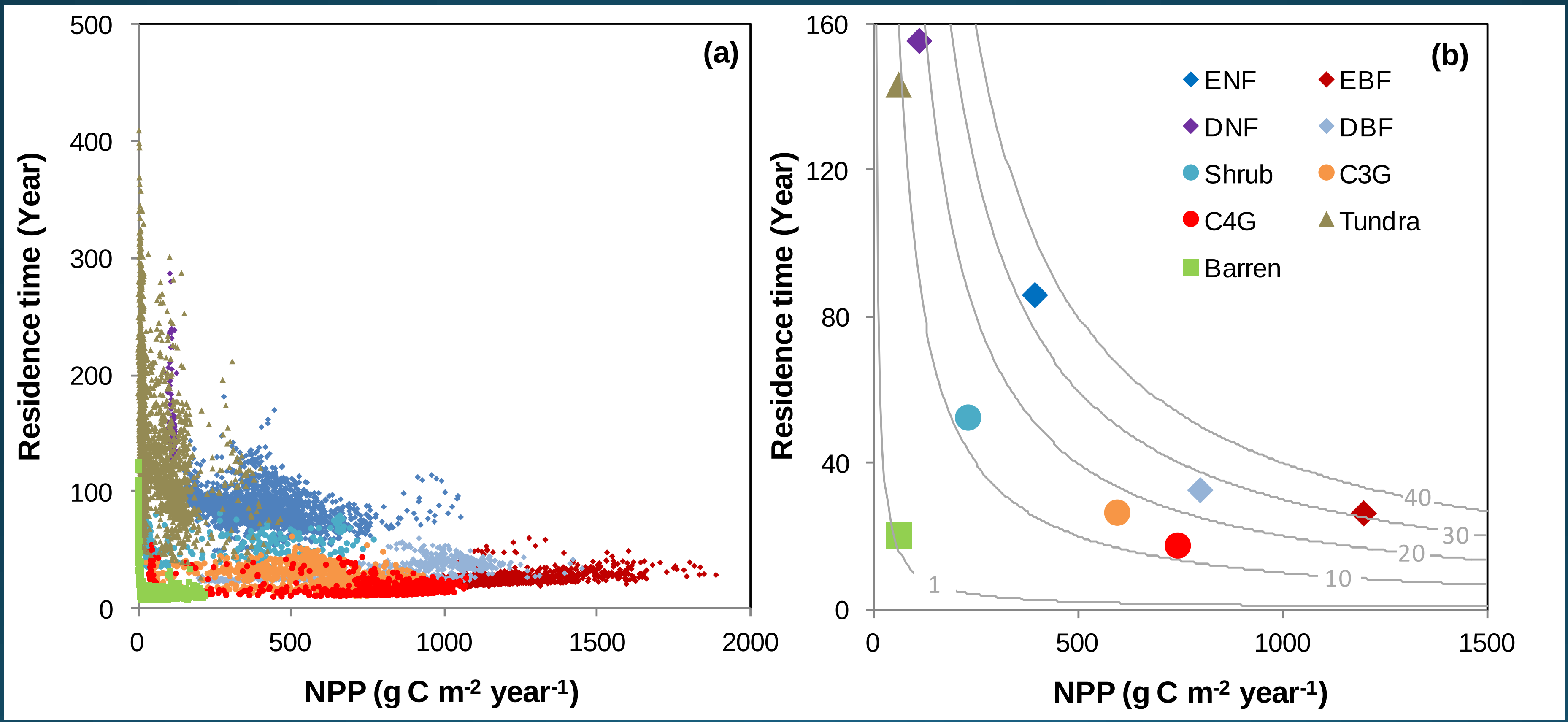
Xia *et al.* 2013 *Global Change Biol.*

Applications

1. Inter-biome differences in CABLE
2. Model intercomparison between CABLE and CLM-CASA'
3. Impacts of adding model component on carbon cycle prediction

Application 1: Inter-biome differences in CABLE

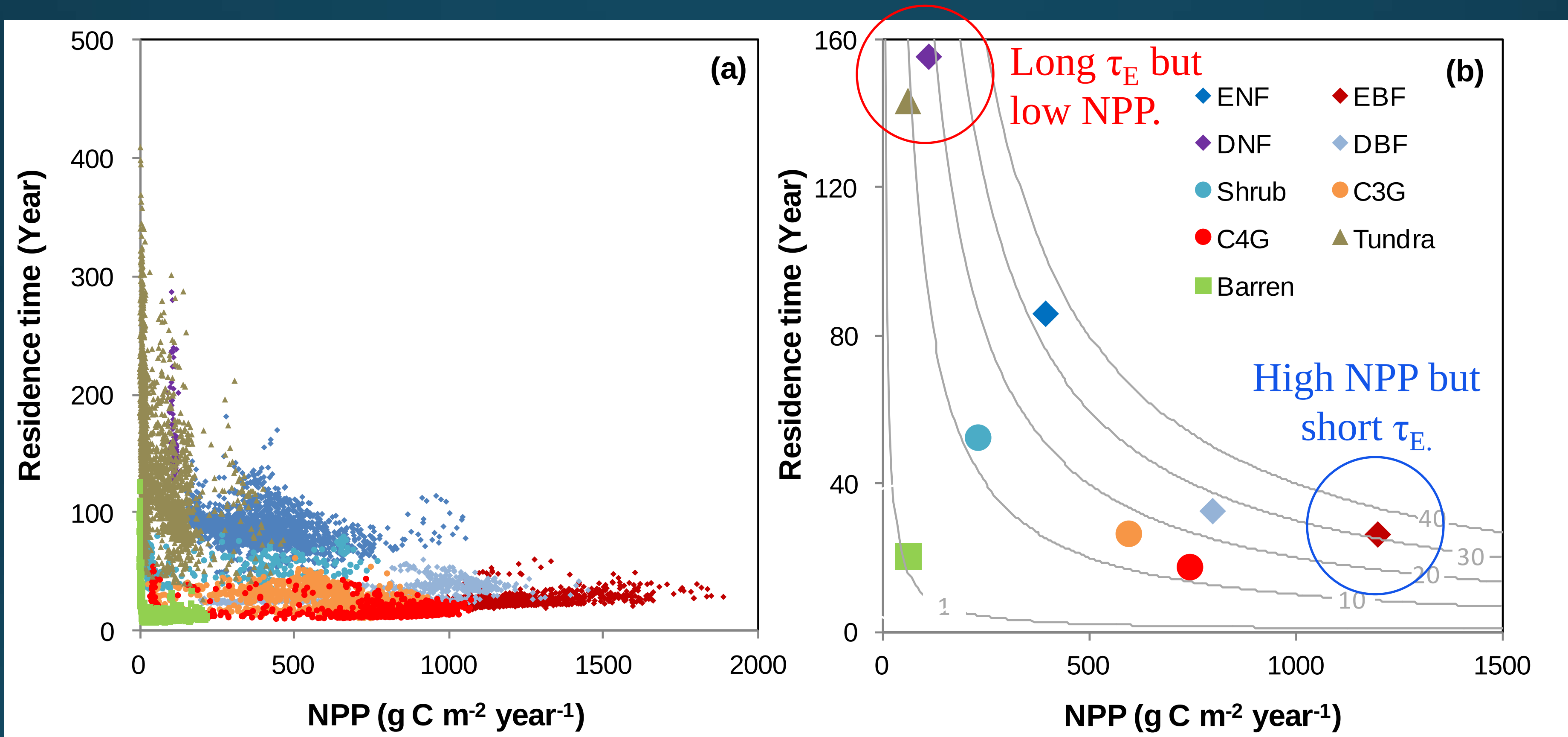
Differential determinants on carbon storage capacity among biomes



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

Xia *et al*. 2013 *Global Change Biol.*

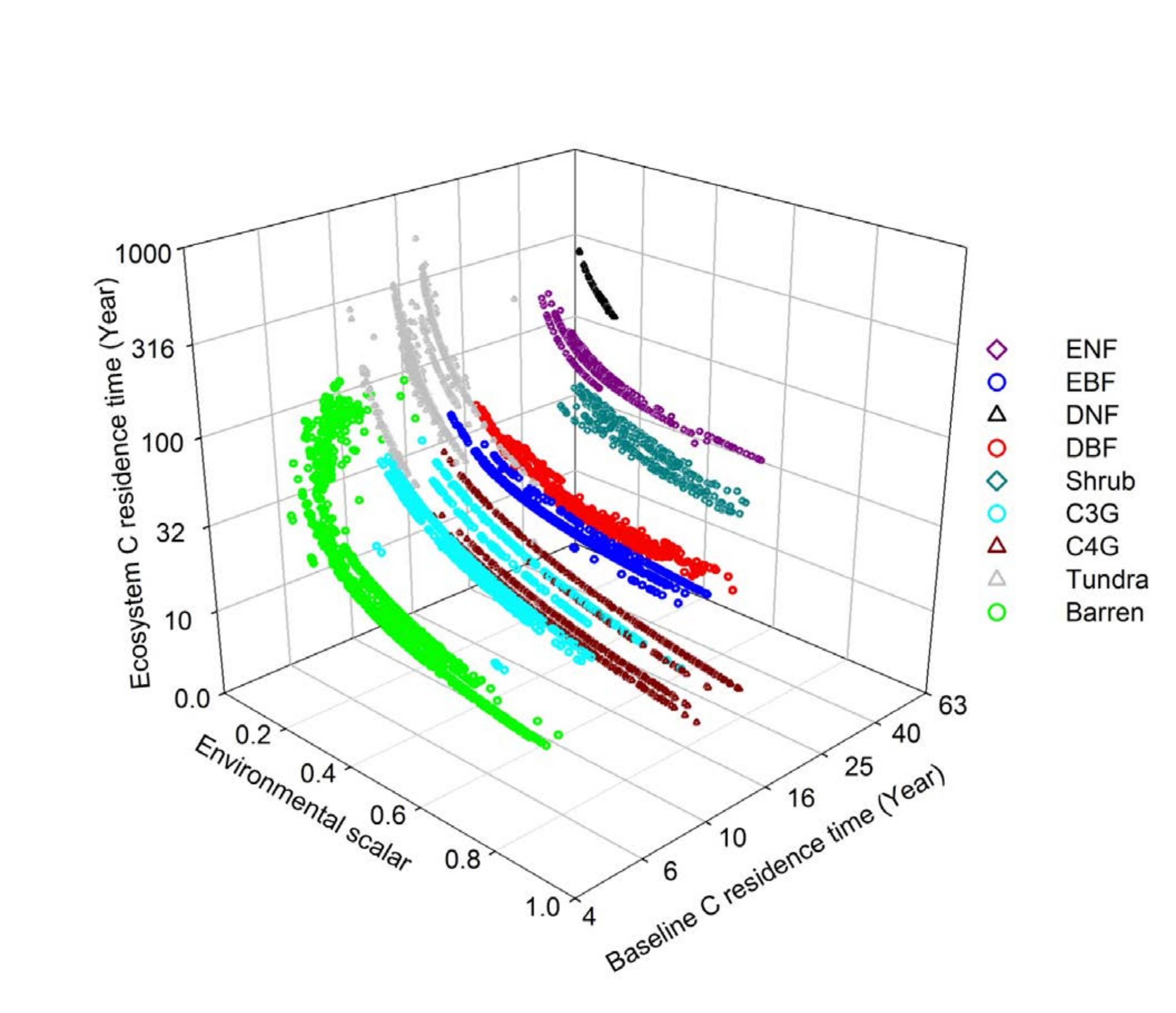
Differential determinants on carbon storage capacity among biomes



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

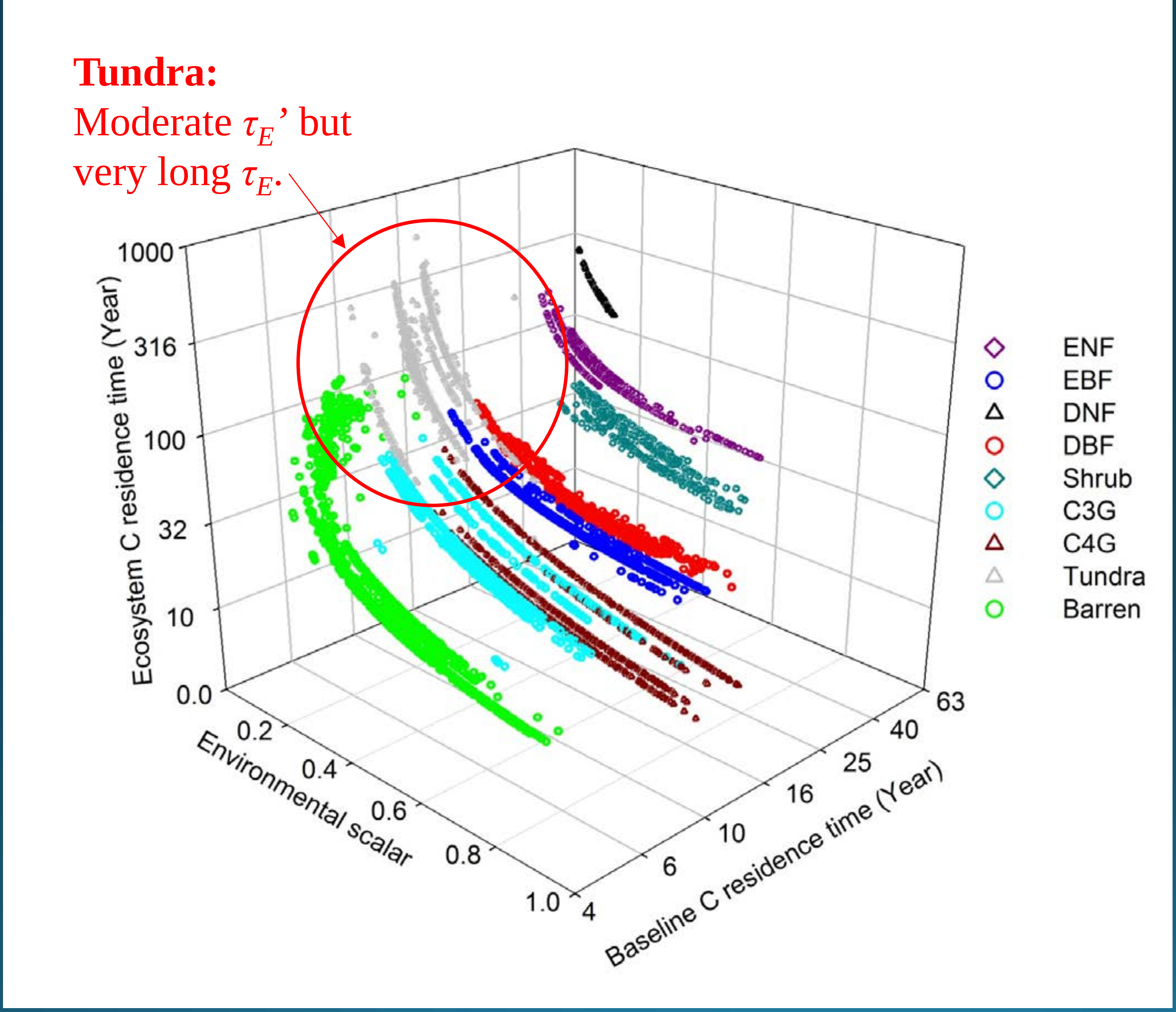
Xia *et al.* 2013 *Global Change Biol.*

Modification of environmental scalars on baseline carbon residence times



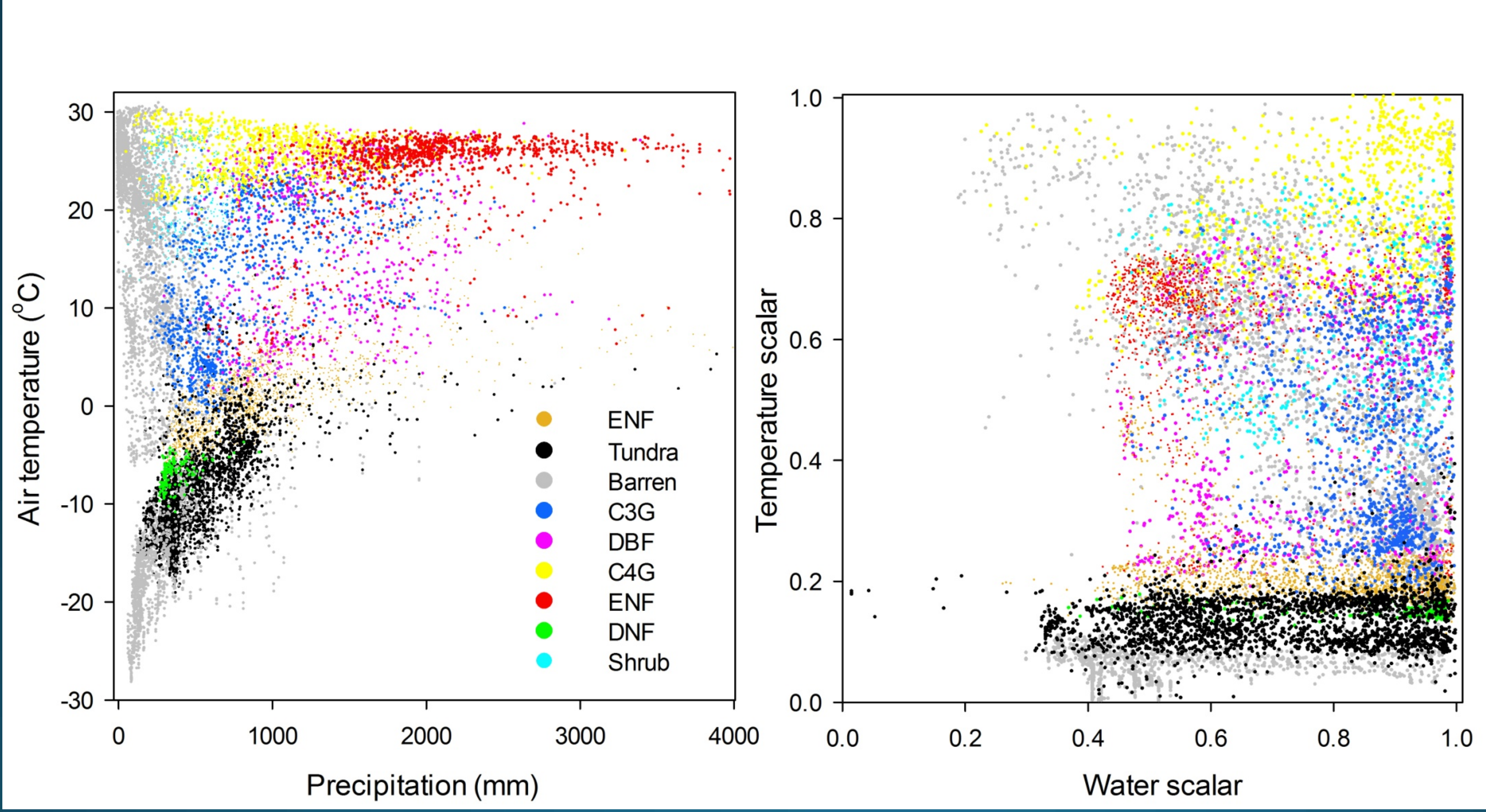
Xia *et al.* 2013 *Global Change Biol.*

Modification of environmental scalars on baseline carbon residence times



Xia *et al*. 2013 *Global Change Biol.*

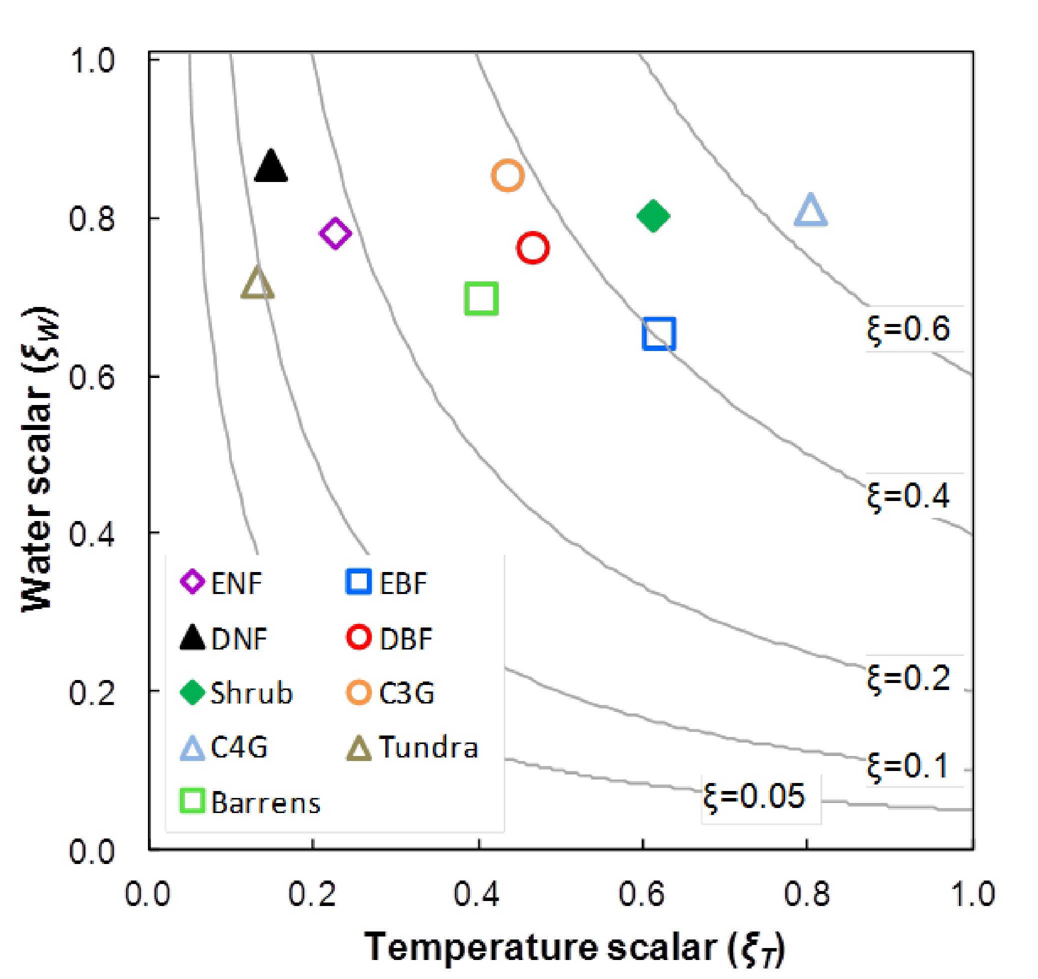
Temperature and water scalars link environmental space (air temperature and precipitation) into the C space.



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

Xia *et al.* 2013 *Global Change Biol.*

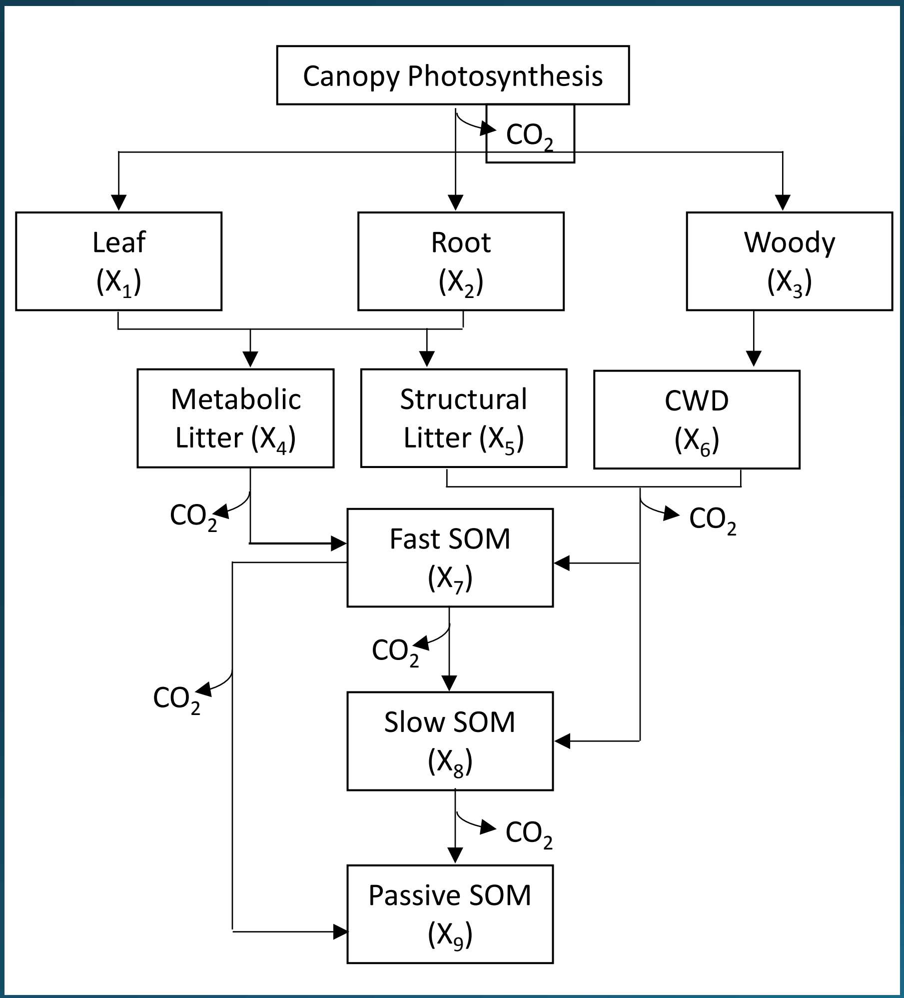
Temperature and water scalars link environmental space (air temperature and precipitation) into the C space.



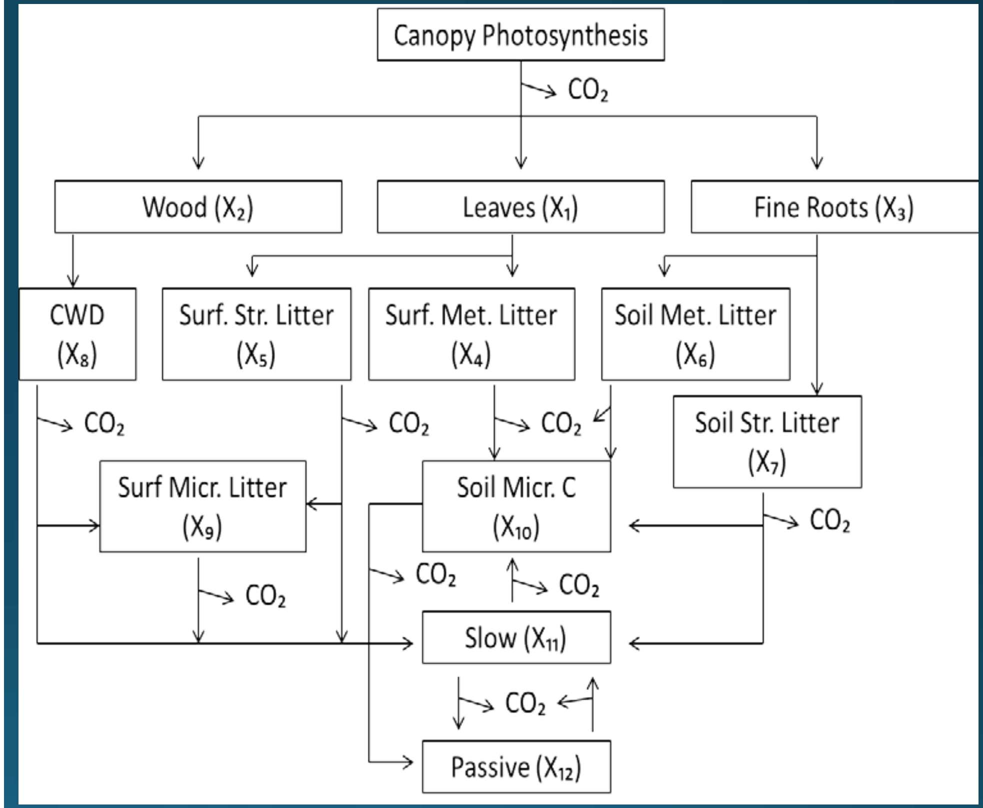
- In CABLE model, the differences in environmental scalars among biomes are more determined by the temperature scalar.
- The environmental limitation on τ_E' is largest in Tundra and needleleaf forests.

Xia *et al.* 2013 *Global Change Biol.*

Application 2: Inter-model difference between CABLE and CLM-CASA’



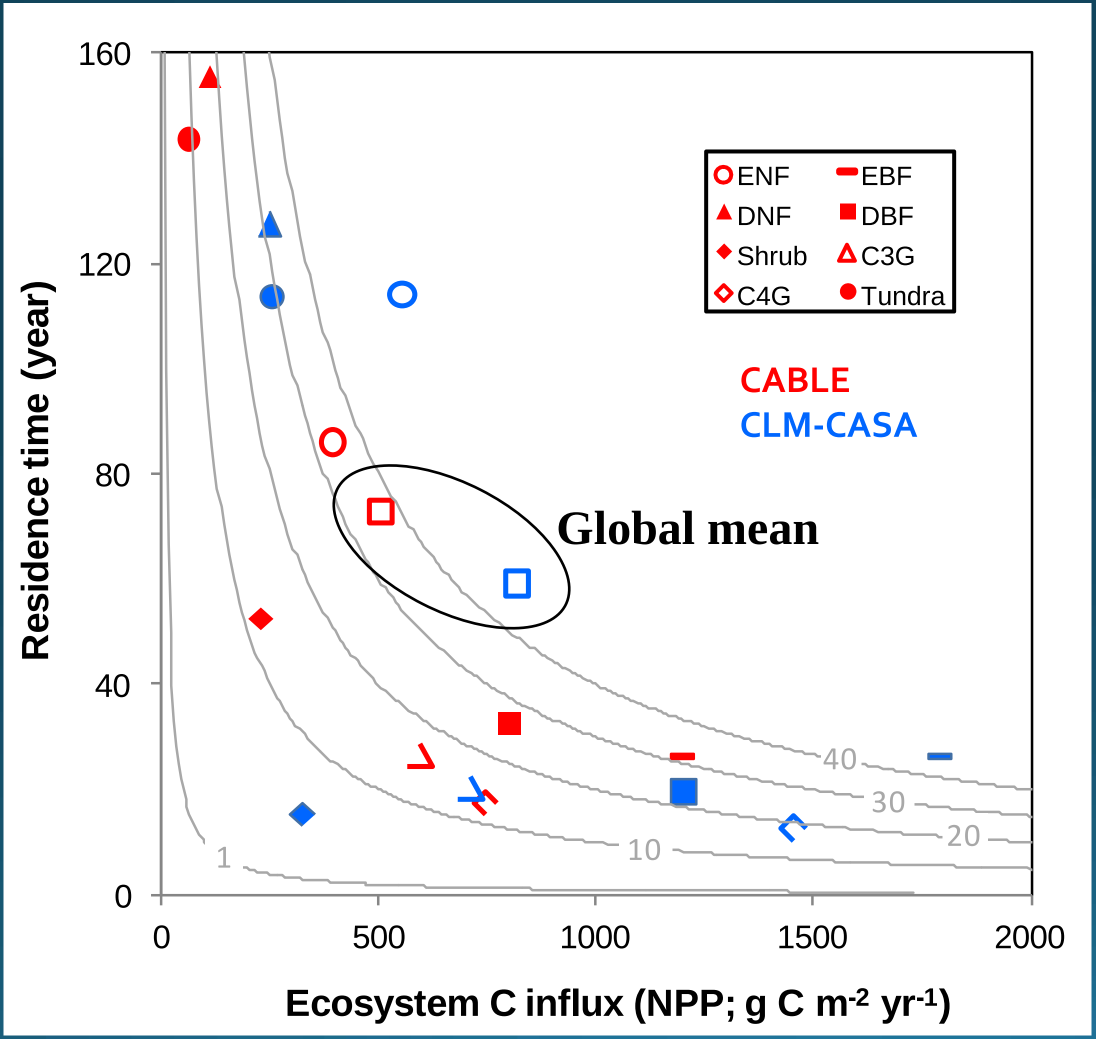
CABLE



CLM-CASA’

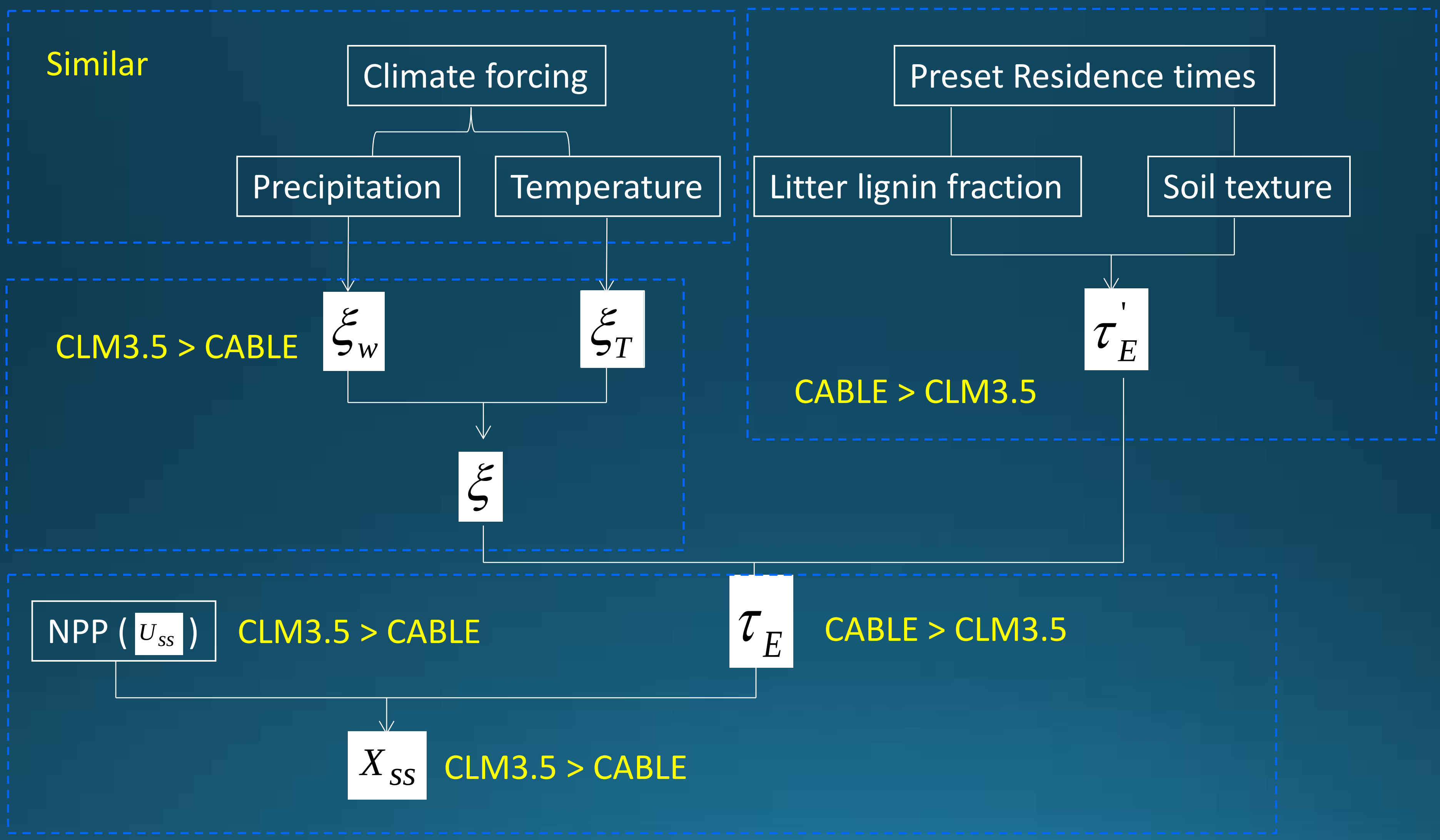
Rafique *et al*. In Prep.

Carbon storage capacity is differently determined by τ_E and NPP between CABLE and CLM-CASA’

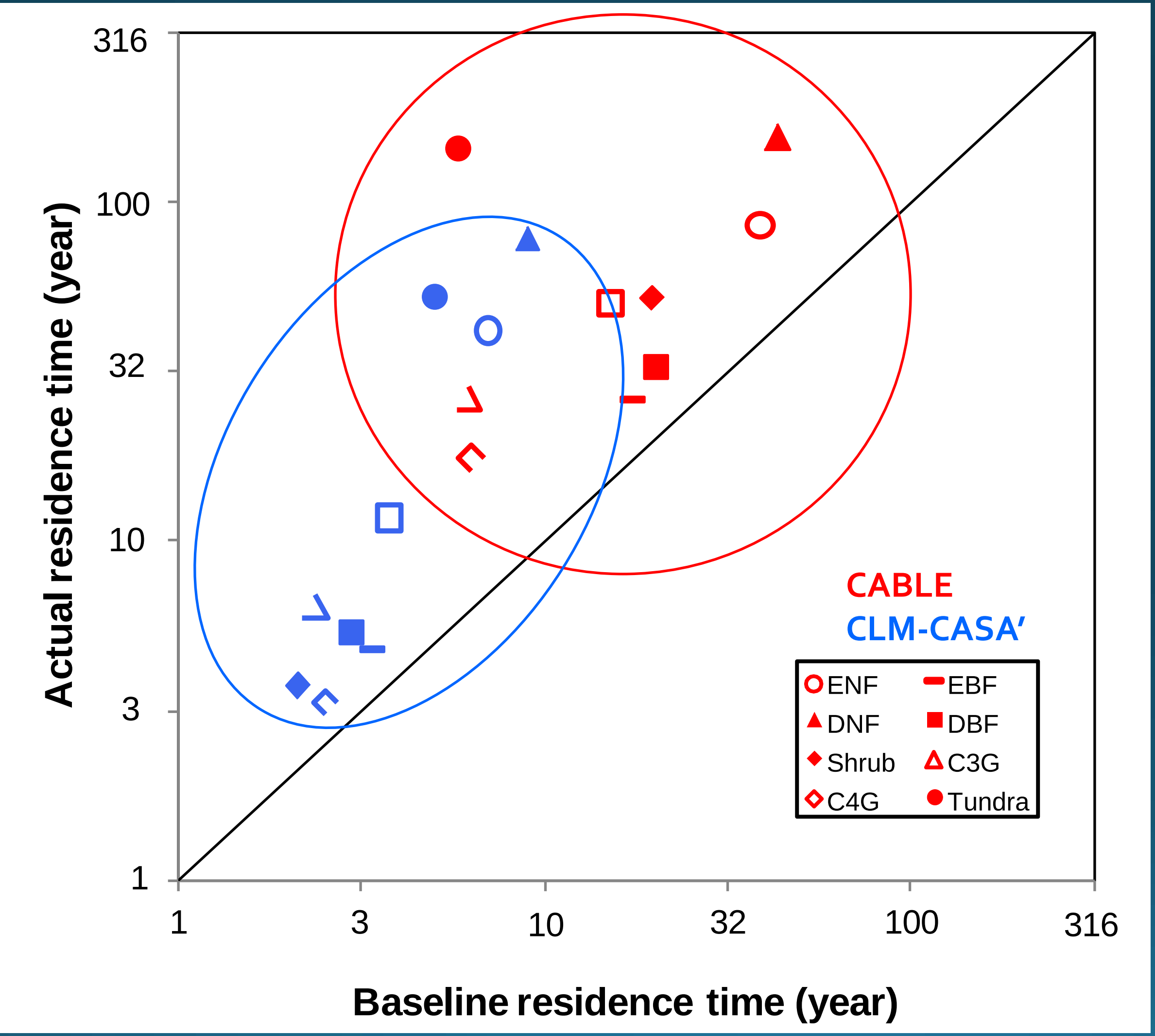


Rafique *et al*. In Prep.

Carbon storage differences between CABLE and CLM-CASA'

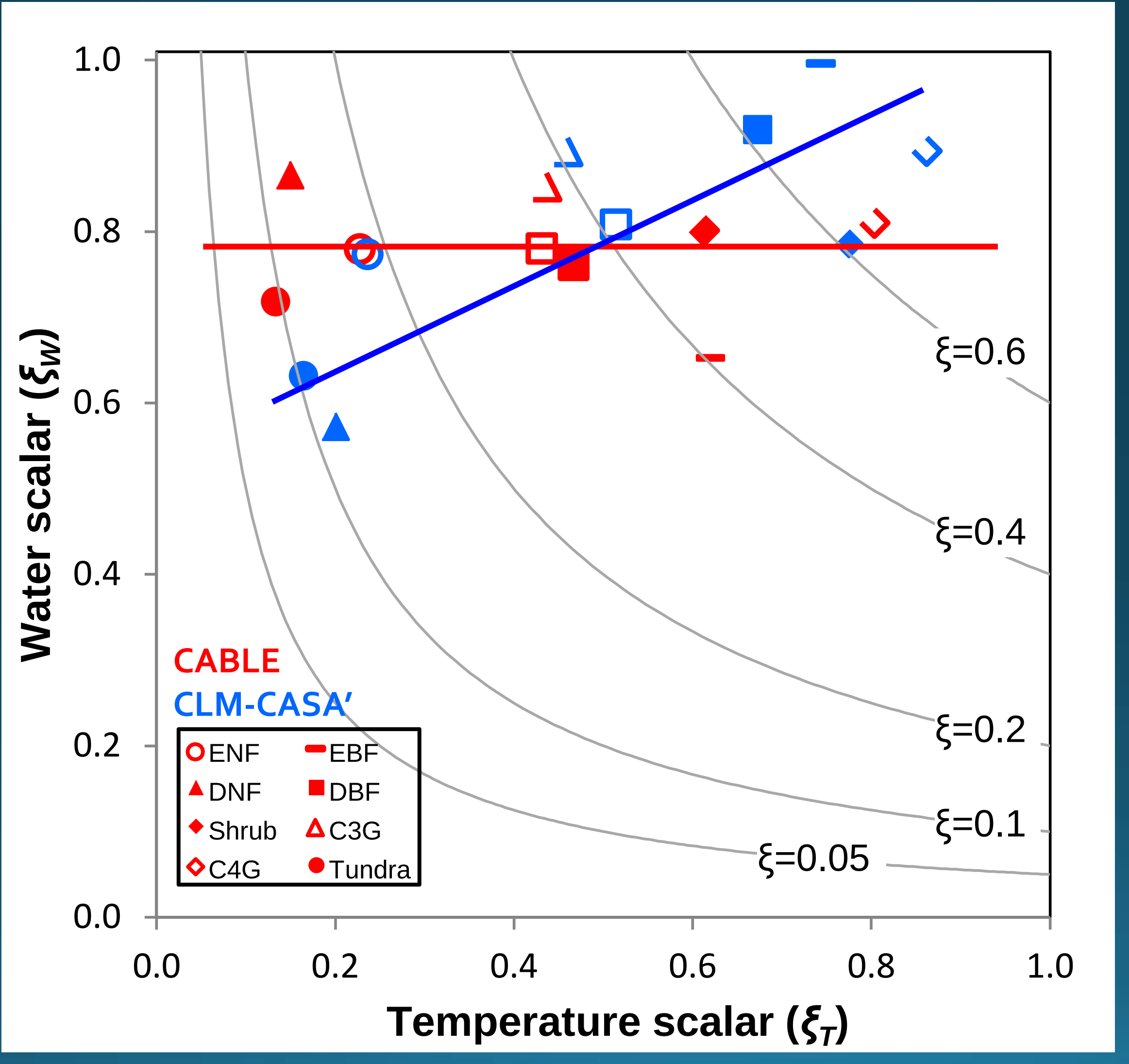


Longer residence times in CABLE than CLM-CASA’



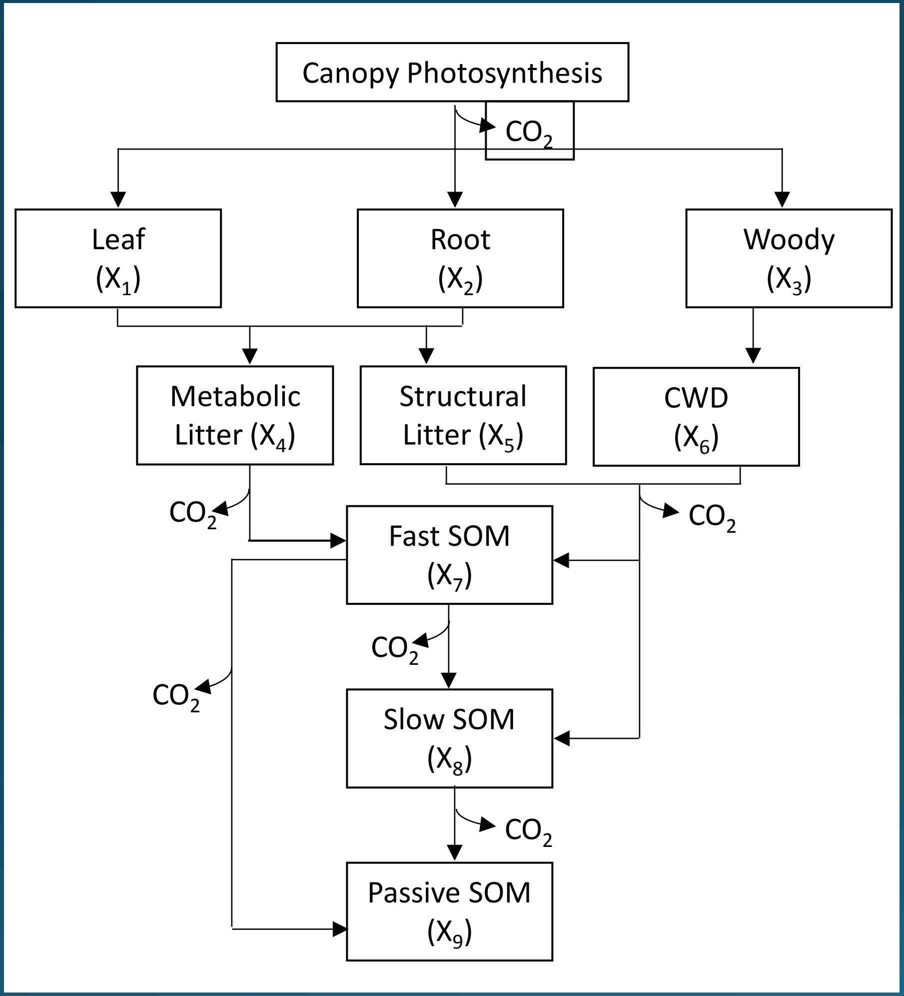
Rafique *et al*. In Prep.

Temperature and water scalars



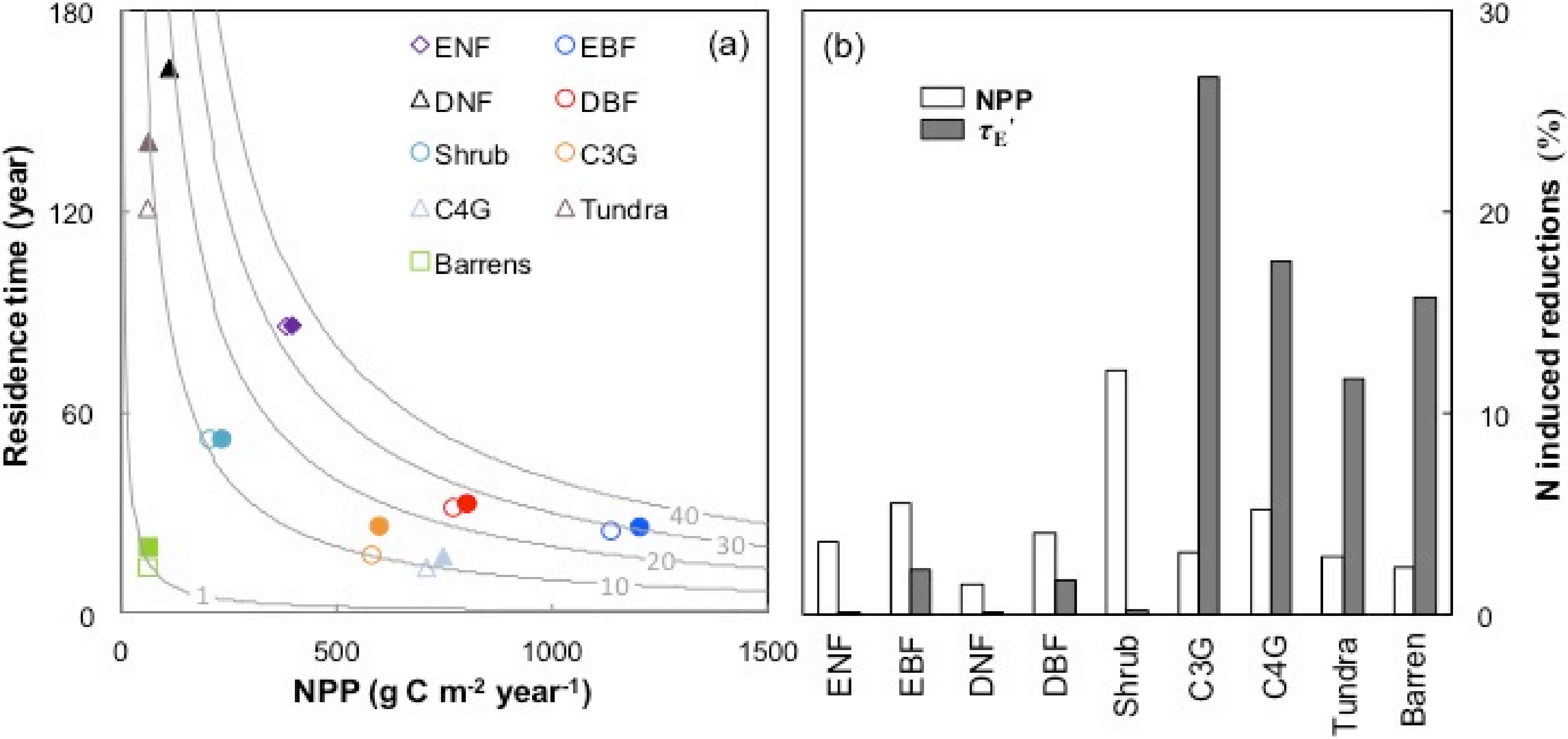
Rafique *et al*. In Prep.

Application 3: Adding nitrogen processes into CABLE



CABLE Carbon-Nitrogen-Phosphorus

Effects of incorporating nitrogen cycle into carbon cycle

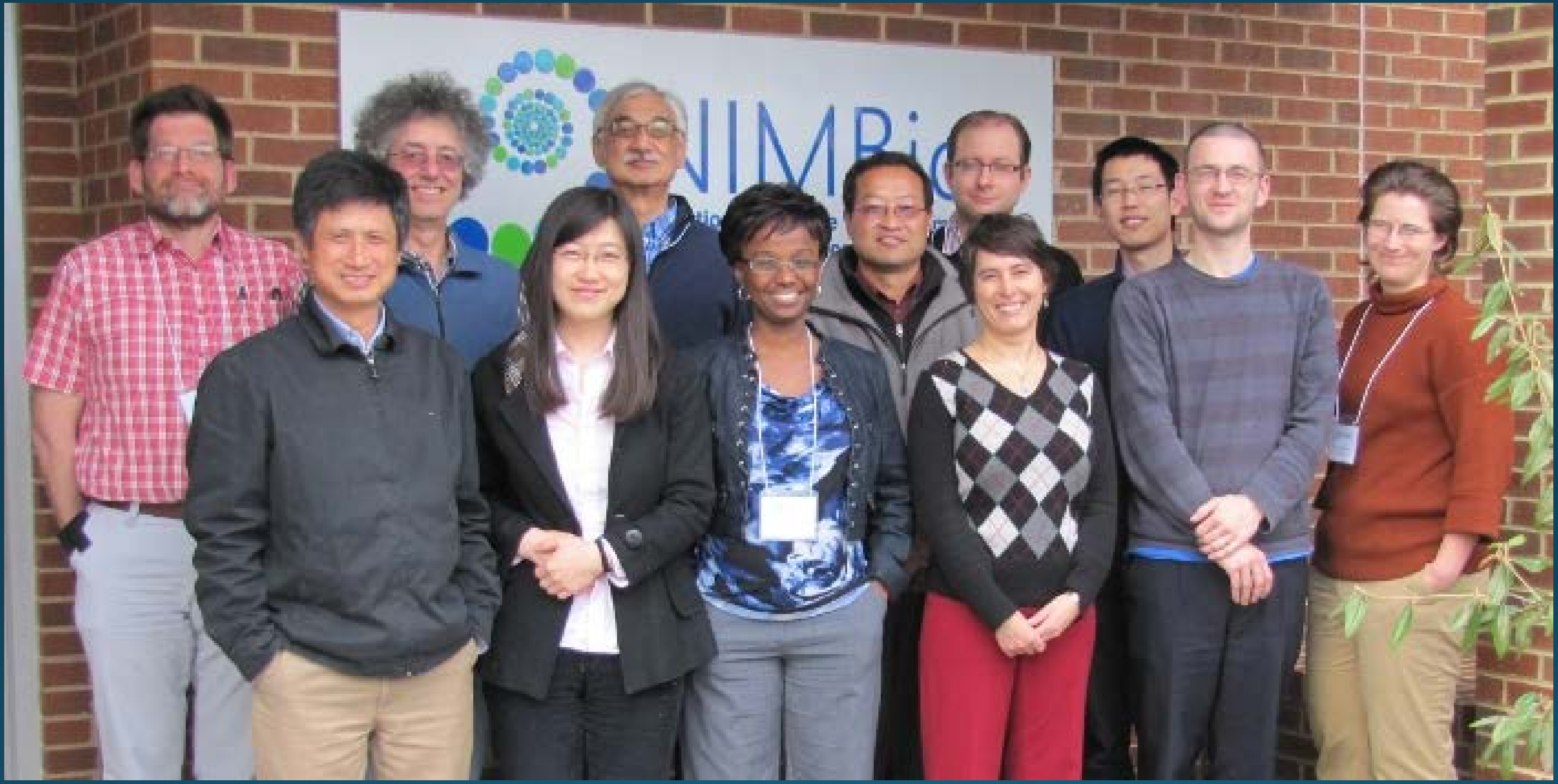


Xia et al. 2013 GCB

Ongoing Development and Applications

NIMBioS
National Institute for Mathematical and Biological Synthesis

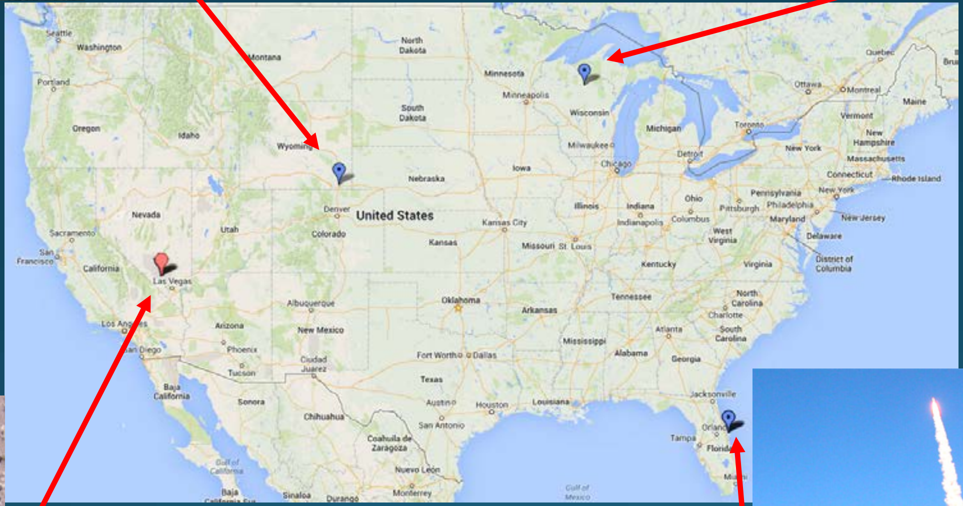
Working group



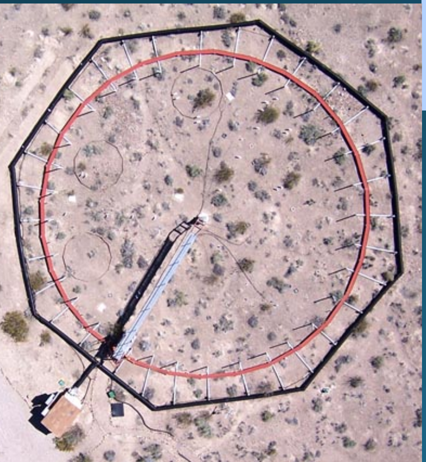
Traceability of transient simulation

FACE model-data intercomparison project

Site name: PHAC
Location: West of Cheyenne, Wyoming
Veg: Grassland
Period: 2006-2012
CO_2 treatment: 594 ppm



Site name: RHIN
Location: Harshaw Experimental Forest, Wisconsin
Veg: Broadleaf Deciduous Forest
Period: 1998-2008
CO_2 treatment: 543 ppm



Site name: NDFF
Location: Nevada Test Site, Mojave Desert
Veg: Desert
Period: 1997-2008
CO_2 treatment: 507 ppm

Site name: KSCO
Location: Cape Canaveral, Florida
Veg: Broadleaf Evergreen Forest
Period: 1996-2006
CO_2 treatment: 673 ppm

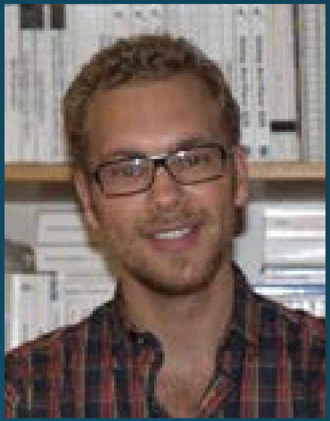
PLUME ecosystem model MIP

Anders Ahlström LU, Sweden

Almut Arneth KIT, Germany

Benjamin Smith LU, Sweden

Yiqi Luo, OU, USA



Potential participants:

LPJ-GUESS, LPJ-GUESS N, JULES, JULES CN, LPX, LPJmL, VISIT, ORCHIDEE, JEDI,ORCHIDEE CN, HYBRID, SDGVM, CABLE-POP, CABLE, aDGVM/JS-BACH, SEIB-DGVM

Other potential applications

1. Evaluating impacts of adding new component on modeled carbon cycle (Disturbance, DGVM, land use change etc)
2. Data assimilation with traceable components of the model (Hararuk et al. 2014)
3. Benchmark analysis of traceable components

Summary

- The carbon cycle can be decomposed into a few traceable components.
- Traceability of land models is important to improve our understanding of the different behaviors among models;
- The traceability framework is a diagnostics tool with wide applications for global carbon cycle modeling