A semi-analytical solution to accelerate spin-up for carbon and nitrogen coupled ecosystem models

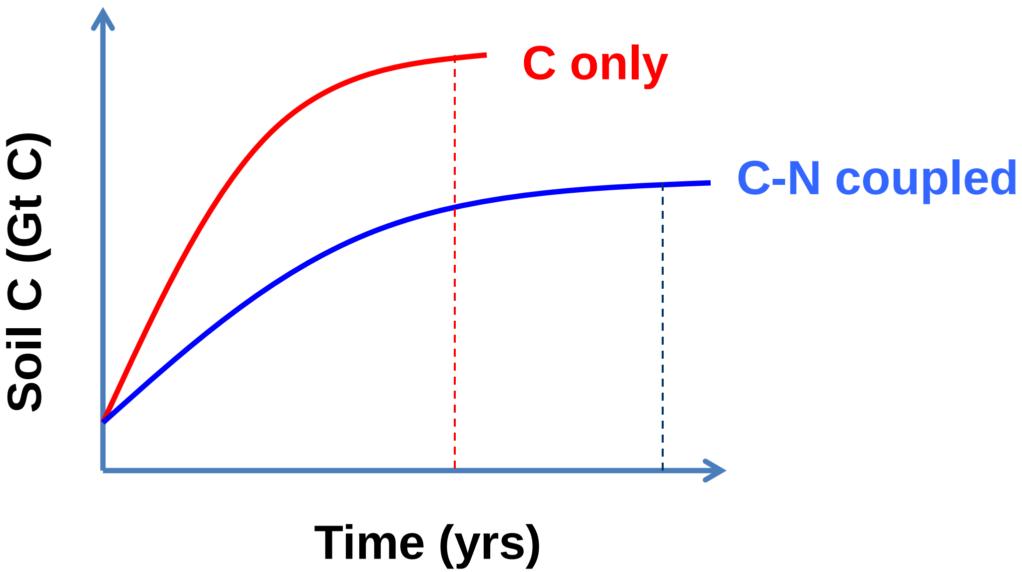
Jianyang Xia[1], Yiqi Luo[1], Yingping Wang[2], Ensheng Weng[1], Oleksandra Hararuk[1]

1. Department of Botany and Microbiology, University of Oklahoma, OK, USA.
2. CSIRO Marine and Atmospheric Research, Centre for Australian Weather and Climate Research, Aspendale, Victoria, Australia

06/22/2011
Breckenridge, CO

Climate change studies with models commonly require all variables

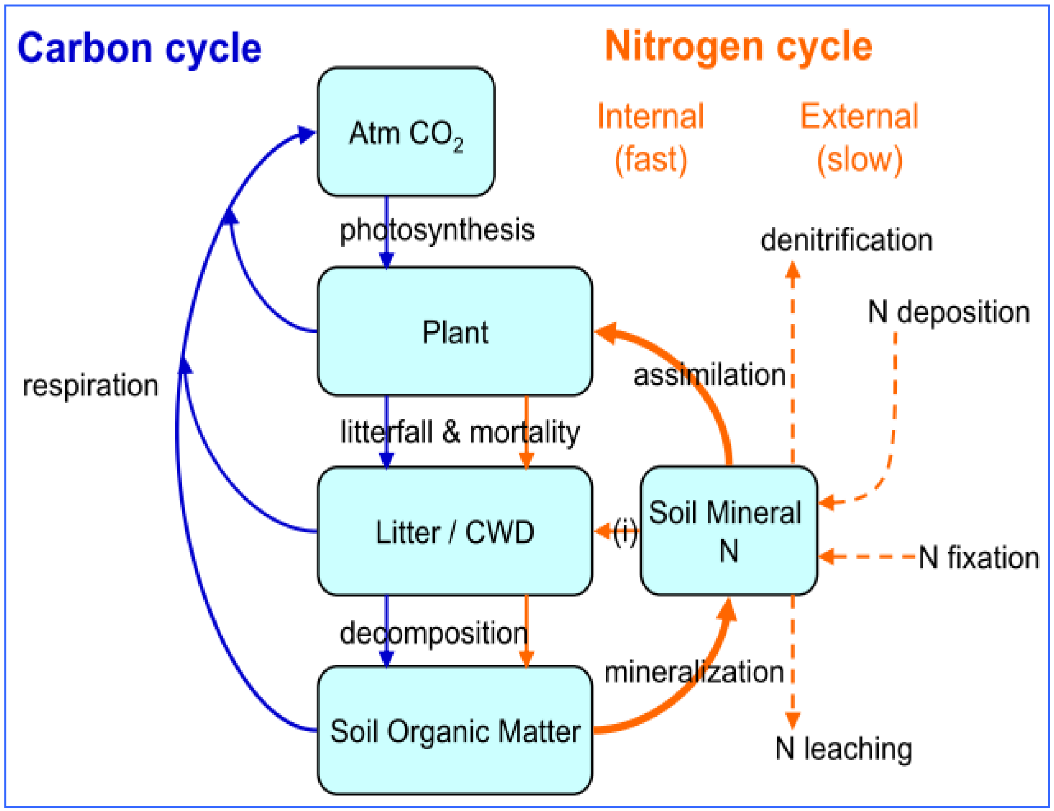
"spin-up" to steady-state



Traditional method: Perform long model stimulations to reach steady-state.

Climate change studies with models commonly require all variables

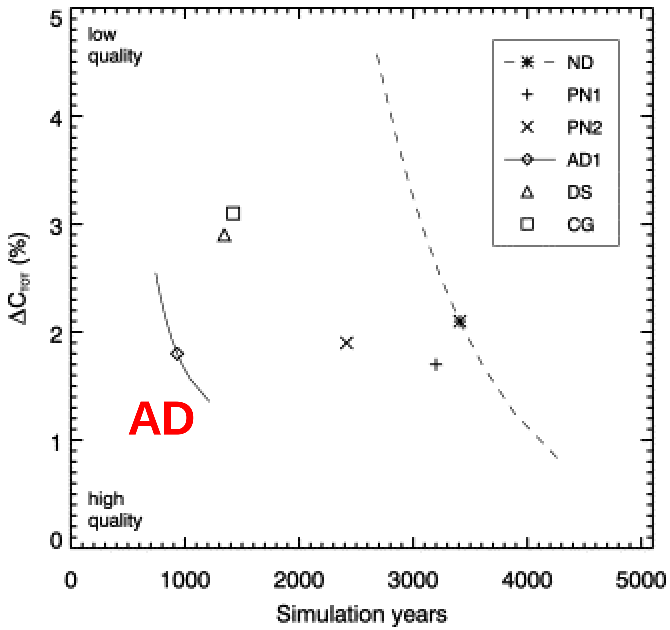
"spin-up" to steady-state



Thornton *et al*. 2009

Adding N cycles significantly complicates the spin-up because of the feedbacks.

Attempts to solve the ‘spin-up’ problem

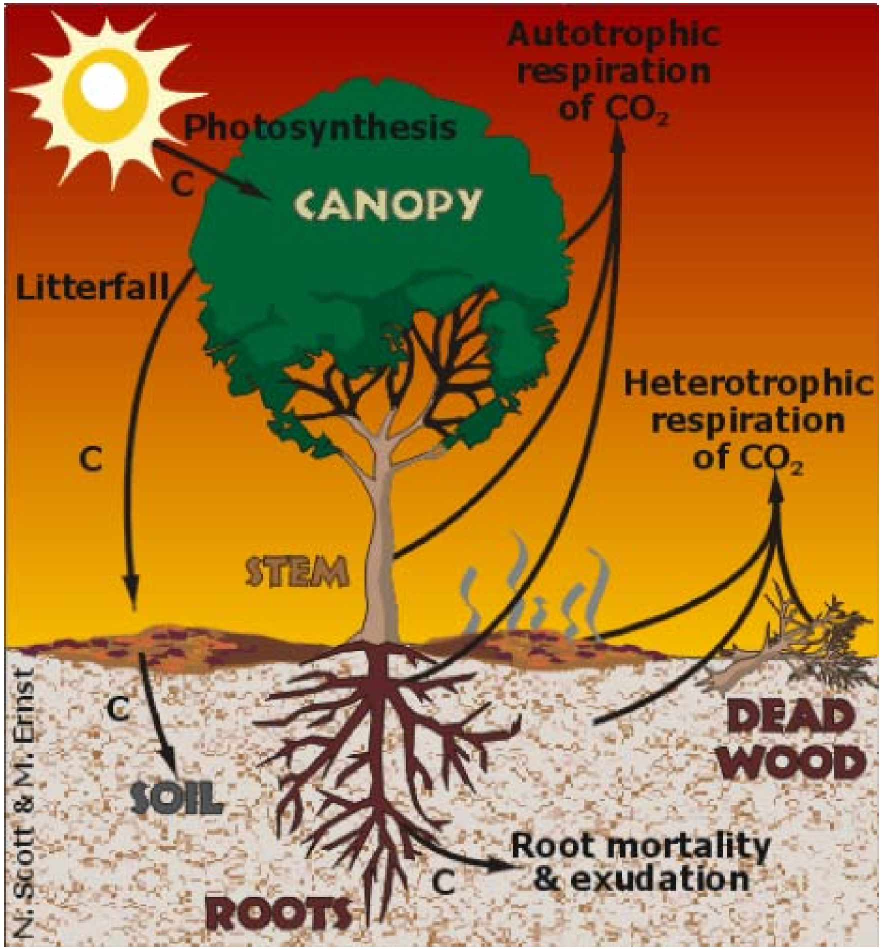


- Punctuated nitrogen addition
- Accelerated decomposition
- General multivariate minimization methods
- Downhill simplex method
- Conjugate gradient method

Both the ad hoc and the generalized methods could provided reductions in computational cost of **50-75%** compared to the model’s native dynamics.

Thornton *et al*. 2005

Carbon Cycling in Terrestrial Ecosystem



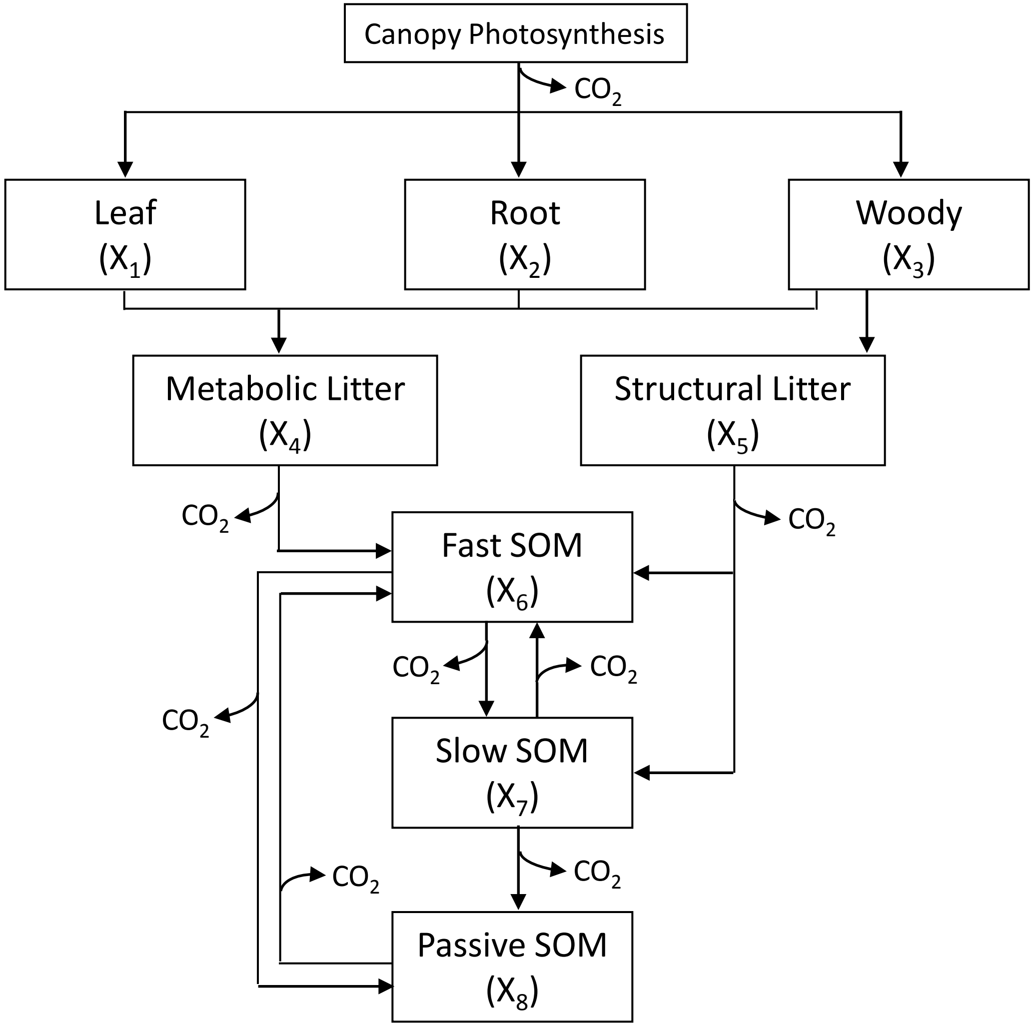


Diagram of C process of TECO-CN.

Ecoloigcal Theory

Luo *et al*. 2001 *Ecol. Mongraph*

$$\frac{dX(t)}{dt} = \xi ACX(t) + BU(t)$$

$$X_{eq} = \bar{\xi}^{-1} A^{-1} C^{-1} B U_{eq}$$

The rate of the recovery of ecosystem to equilibrium is determined by the photosynthetic capacity and C residence time.

Luo & Weng. 2011 *TREE*

$$X = (x_1 \quad \dots \quad x_n)^T$$

$$A = \begin{pmatrix} -1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\ a_{41} & 0 & a_{43} & -1 & 0 & 0 & 0 & 0 \\ a_{51} & 0 & a_{53} & 0 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{64} & a_{65} & -1 & a_{67} & a_{68} \\ 0 & 0 & 0 & 0 & a_{75} & a_{76} & -1 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{86} & a_{87} & -1 \end{pmatrix}$$

$$C = diag(c)$$

$$c = (c_1 \quad \dots \quad c_n)^T$$

$$B = (b_1 \quad b_2 \quad b_3 \quad 0 \quad \dots)^T$$

Ecoloigcal Theory

$$\begin{cases} \dfrac{dX(t)}{dt} = \xi ACX(t) + BU(t) \\ \dfrac{dN(t)}{dt} = \xi ACR^{-1}X(t) + \kappa_u N_{\min} \Pi \end{cases}$$

$R = diag(\rho)$

κ_u is the rate of N uptake

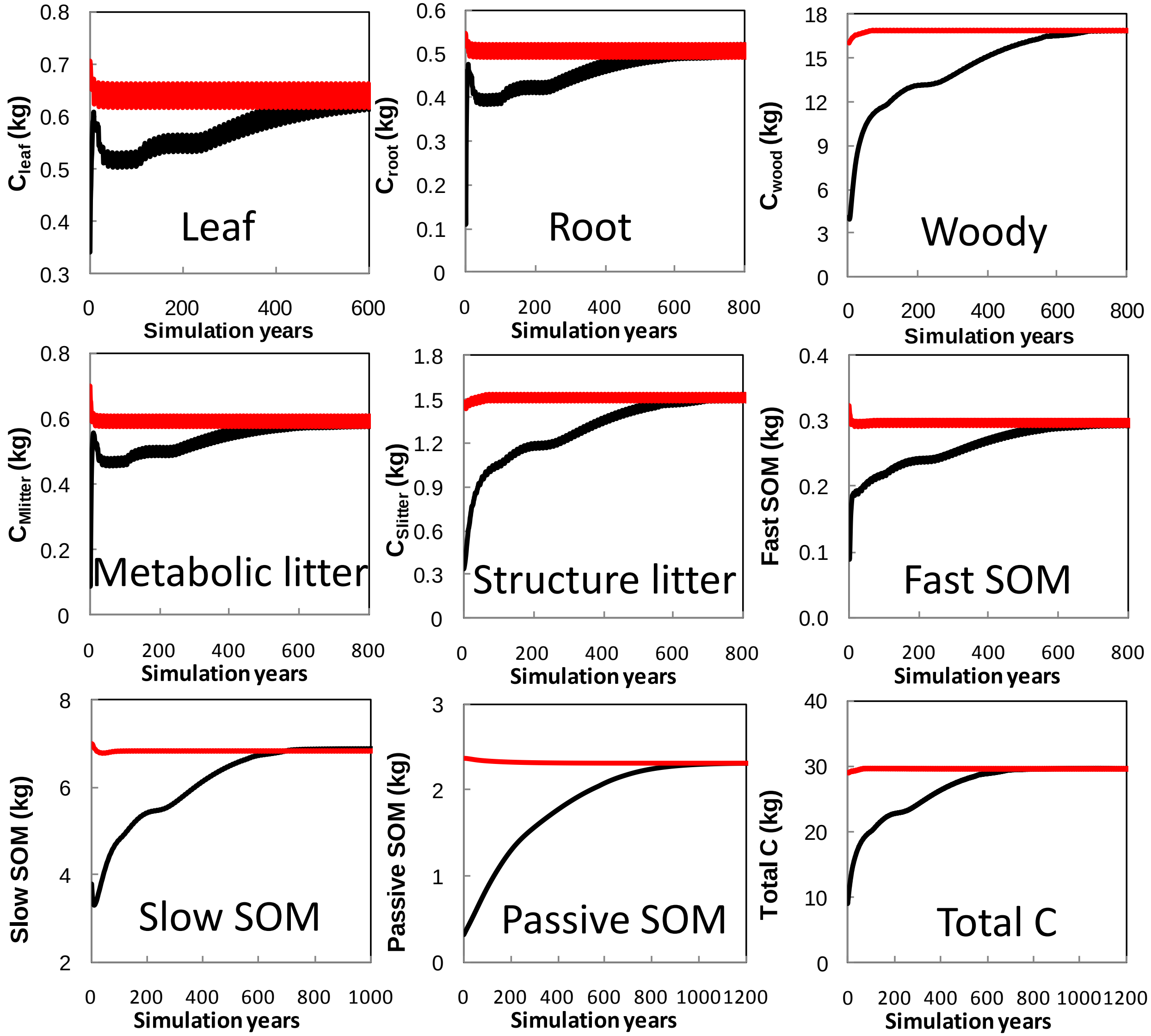
N_{min} is the N in the mineral pool

$\Pi = (\pi_1 \ \ \pi_2 \ \ 1 - \pi_1 - \pi_2 \ \ 0 \ \ 0 \ \ 0 \ \ 0 \ \ 0)^T$

Case I (TECO-CN with Duke Forest Dataset (1998-2007))

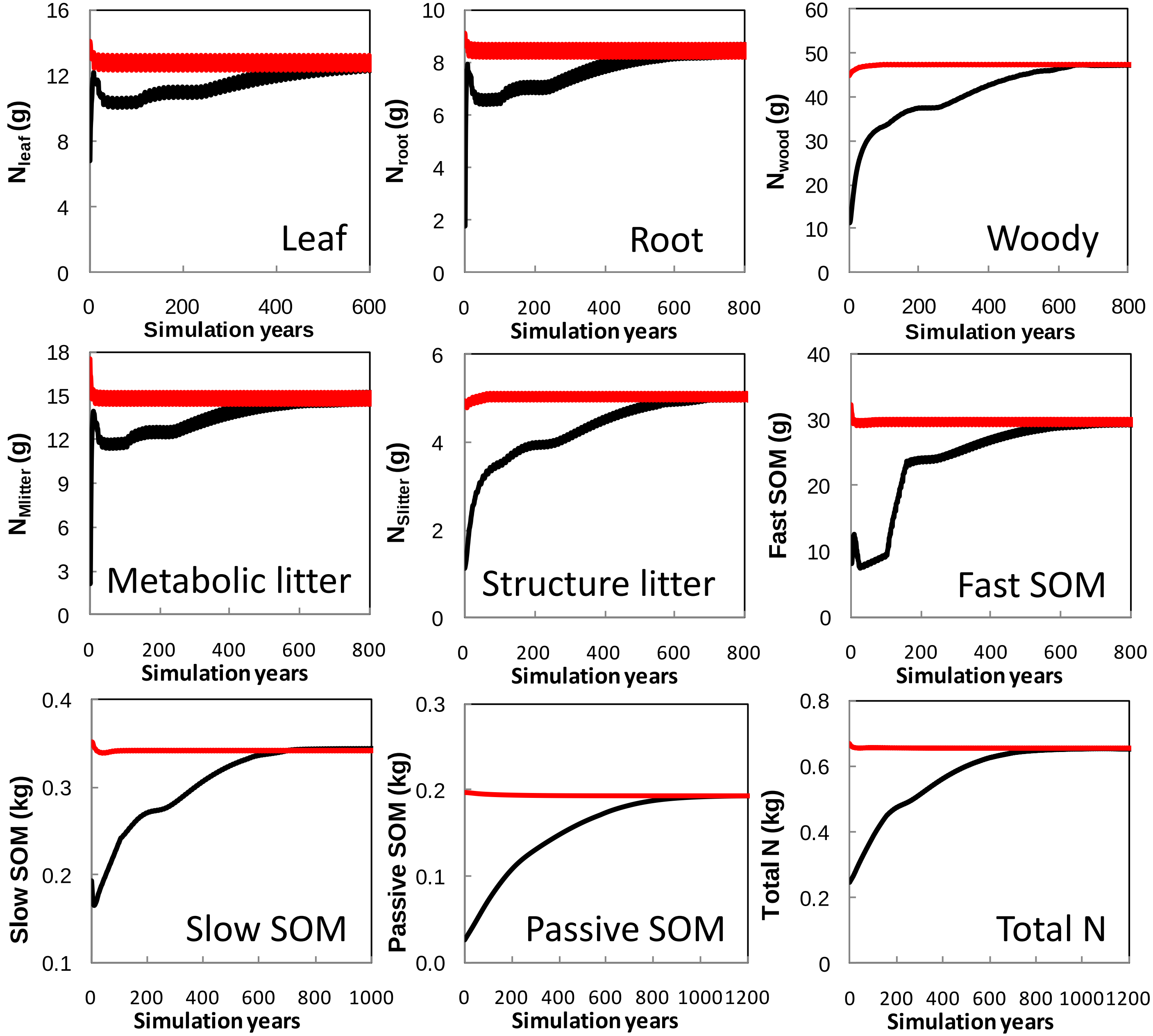
1324.1 yr 155.6 yr Save **88.3%** computational cost

Carbon Pools



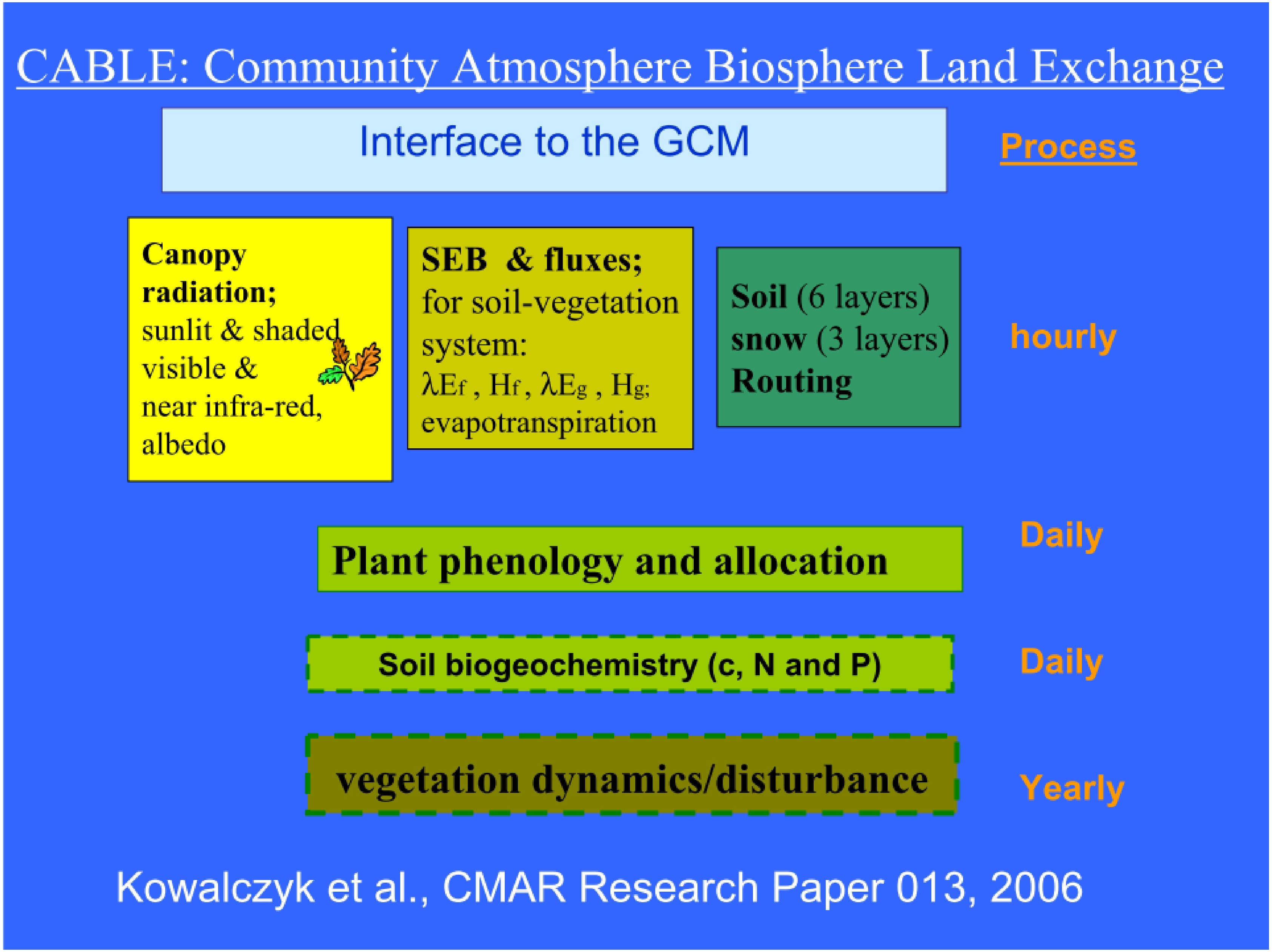
Carbon state trajectories for all carbon pools and total C storage.

Nitrogen Pools



Nitrogen state trajectories for all nitrogen pools and total N storage.

Case II (CABLE with IGBP database (1986))



CASA-CNP model

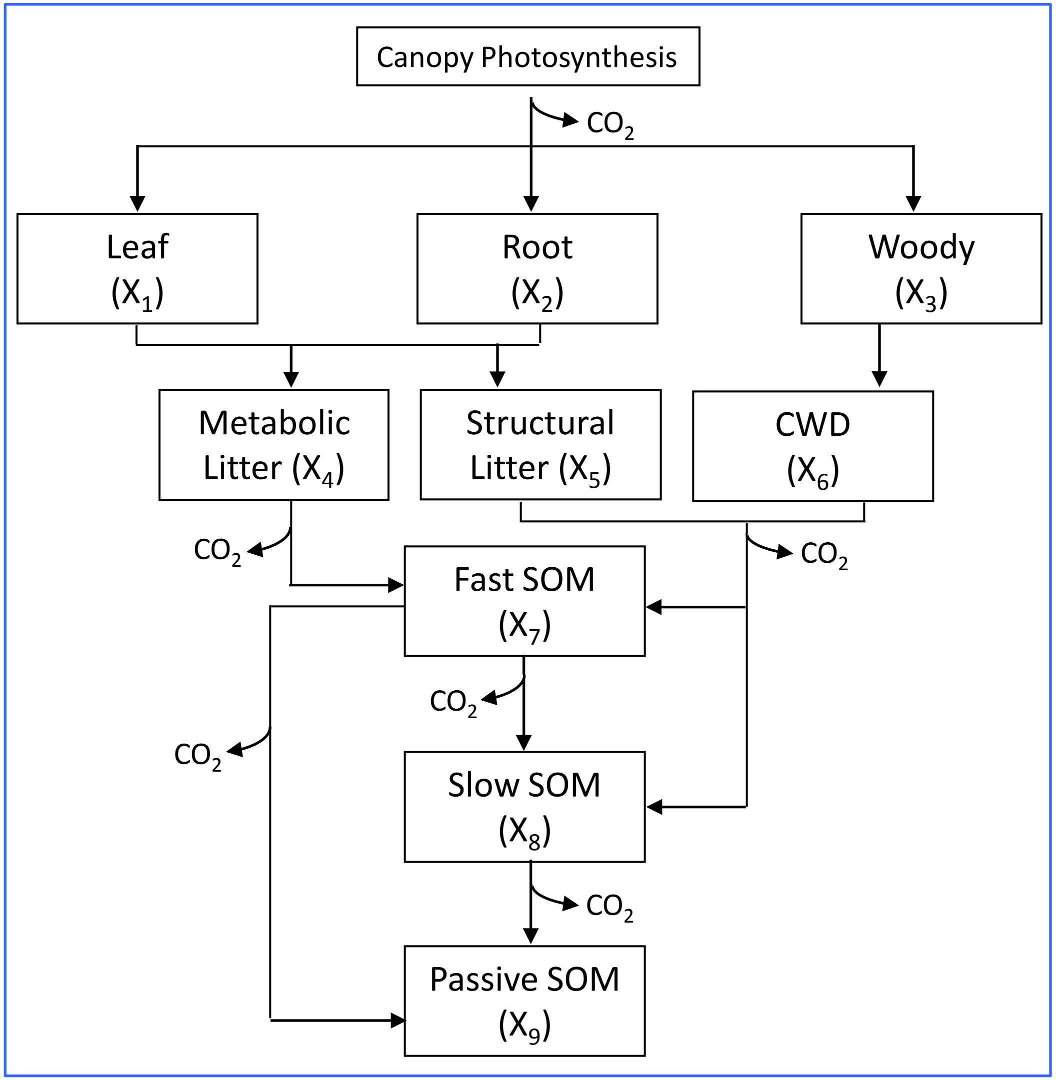
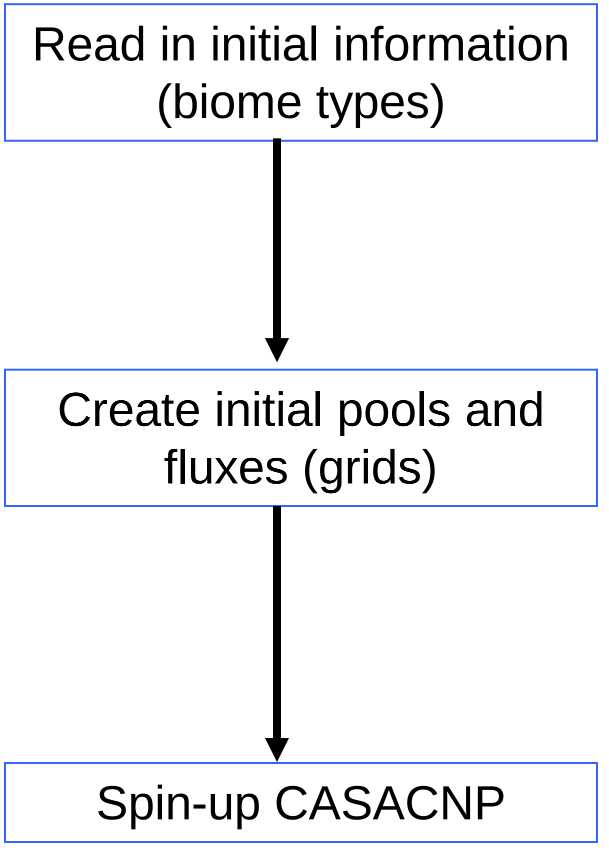
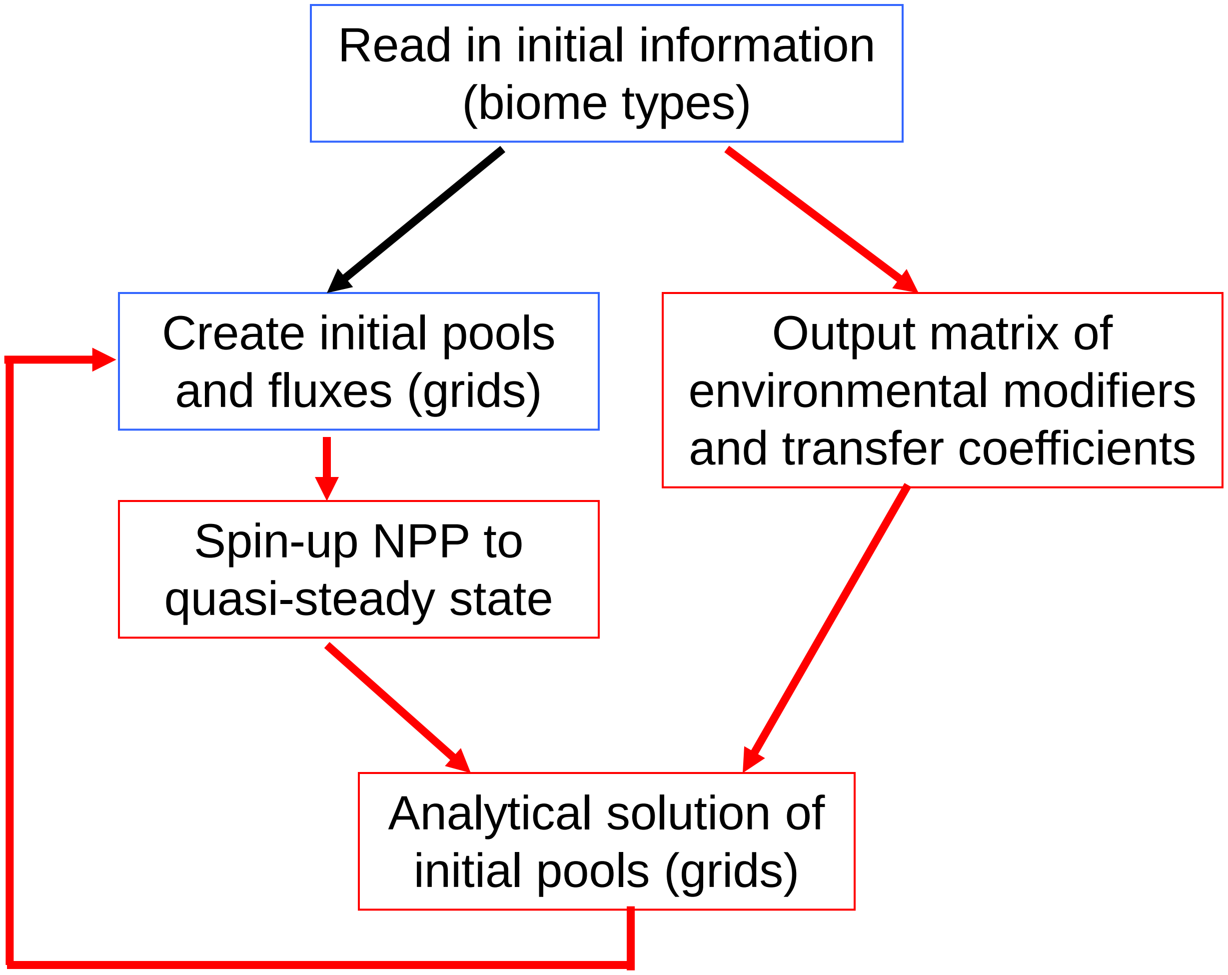


Diagram of C process of CASA-CNP. **Wang et al. 2010 *Biogeosciences***

Spin-up strategy of CABLE

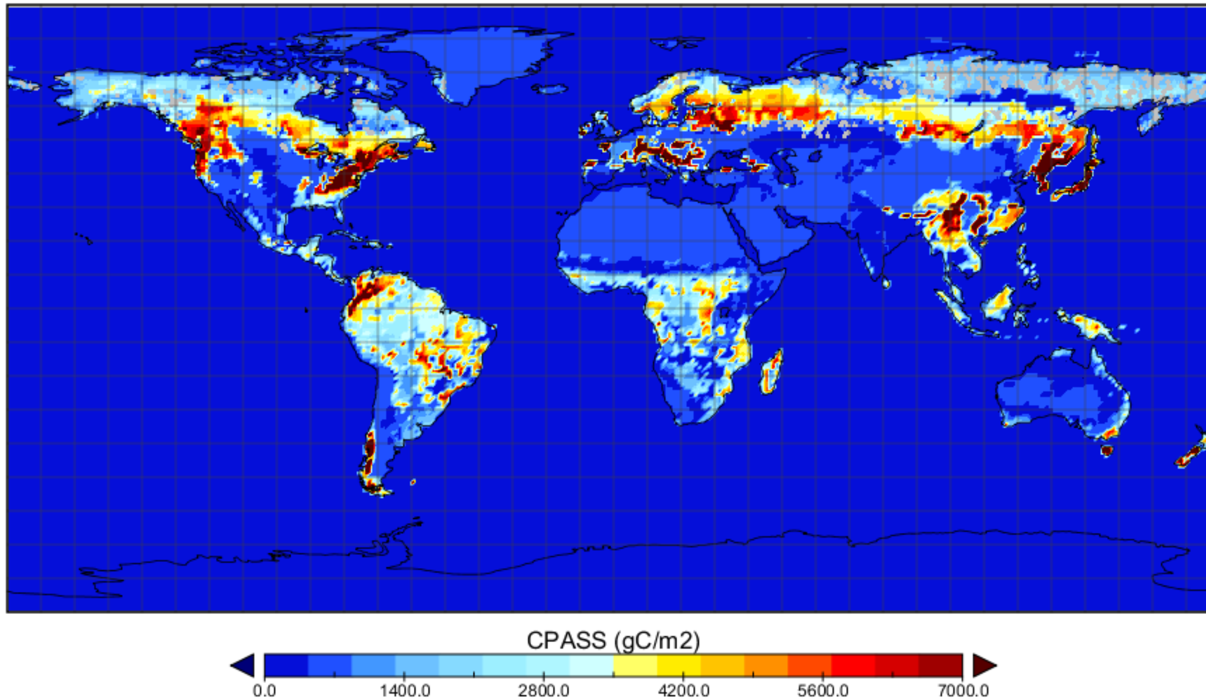


Modified Spin-up strategy of CABLE

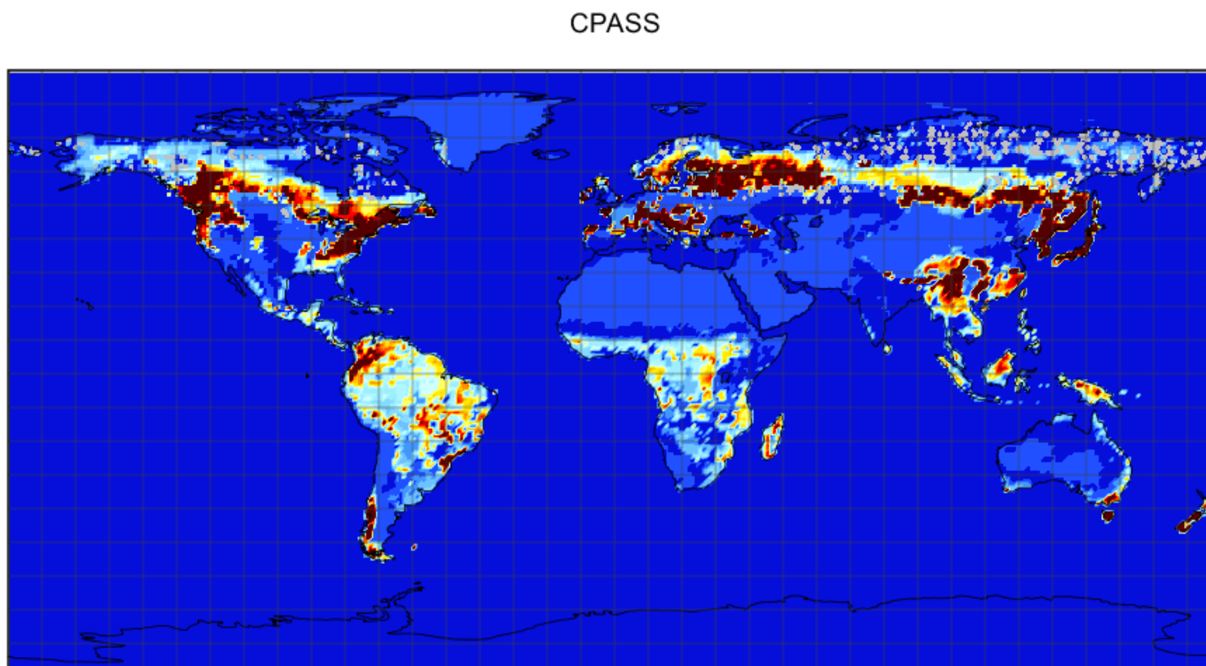


Preliminary Results

4000 years



Analytical solution with 100-yr NPP run



Summary

- The semi-analytical solution can greatly reduce the computational cost (88%) but not affect the simulation quality.

- The strategy of the method mainly includes 3 steps:

1. Spin-up NPP to equilibrium;
2. Get analytical solution of initial pools size;
3. Run the model to steady-state with the analytical initial pools size.

- Implications to global modeling studies.