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

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

Thornton et al. 2009
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.
Ecoiloigcal Theory

Luo et al. 2001 Ecol. Mongraph

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

\[
X_{eq} = \overline{\xi}^{-1} A^{-1} C^{-1} BU_{eq}
\]

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

Luo & Weng. 2011 TREE

\[
X = (x_1 \ldots x_n)^T
\]

\[
A = \begin{pmatrix}
-1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & a_{44} & 0 & a_{43} & -1 & 0 \\
0 & 0 & 0 & a_{54} & 0 & a_{53} & 0 & -1 \\
0 & 0 & 0 & a_{64} & a_{65} & 0 & 0 & 0 \\
0 & 0 & 0 & a_7 & a_8 & a_9 & a_{10} & a_{11} \\
0 & 0 & 0 & a_{12} & a_{13} & a_{14} & a_{15} & a_{16}
\end{pmatrix}
\]

\[
C = \text{diag}(c)
\]

\[
c = (c_1 \ldots c_n)^T
\]

\[
B = (b_1 \ b_2 \ b_3 \ 0 \ \ldots)^T
\]
Ecoloigical Theory

\[
\begin{align*}
\frac{dX(t)}{dt} &= \xi ACX(t) + BU(t) \\
\frac{dN(t)}{dt} &= \xi AC R^{-1} X(t) + \kappa_u N_{\text{min}} \Pi
\end{align*}
\]

\[R = \text{diag}(\rho)\]

\(\kappa_u\) is the rate of N uptake

\(N_{\text{min}}\) is the N in the mineral pool

\(\Pi = (\pi_1 \ \pi_2 \ 1 - \pi_1 - \pi_2 \ 0 \ 0 \ 0 \ 0)^T\)
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 state trajectories for all nitrogen pools and total N storage.
Case II (CABLE with IGBP database (1986))

CABLE: Community Atmosphere Biosphere Land Exchange

- **Interface to the GCM**
  - **Process**
    - Canopy radiation; sunlit & shaded visible & near infra-red, albedo
    - SEB & fluxes; for soil-vegetation system: \( \lambda E_t, H_f, \lambda E_g, H_g \); evapotranspiration
    - Soil (6 layers)
    - Snow (3 layers)
    - Routing
  - **Daily**
    - Plant phenology and allocation
    - Soil biogeochemistry (C, N and P)
  - **Yearly**
    - Vegetation dynamics/disturbance

Kowalczyk et al., CMAR Research Paper 013, 2006
CASA-CNP model

Diagram of C process of CASA-CNP.  

Wang et al. 2010 Biogeosciences
Spin-up strategy of CABLE

1. Read in initial information (biome types)
2. Create initial pools and fluxes (grids)
3. Spin-up CASACNP
Modified Spin-up strategy of CABLE

Read in initial information (biome types)

Create initial pools and fluxes (grids)

Spin-up NPP to quasi-steady state

Output matrix of environmental modifiers and transfer coefficients

Analytical solution of initial pools (grids)
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.