Coupling carbon, water, energy and nutrients in ecosystem models
Shameless Commerce Moment:
Climate and Ecosystems
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Structure of an Earth System Model

- Atmospheric general circulation model
  - CO$_2$
  - Atmospheric chemistry aerosols
- Land model
  - Vegetation and soil
- Ocean circulation model
  - Marine ecosystems
- Land-ice model
- Sea-ice model

Climate model components
Earth-system model components
Ecosystem structure and climate
A central paradox

- Water and energy variables parsimoniously explain global patterns of terrestrial vegetation
- Most ecosystems respond to nutrient additions, suggesting nutrients as a primary constraint
- Does water/energy or nutrient availability better explain terrestrial vegetation patterns and productivity?
Water, energy and nitrogen coupling
Global steady-state patterns of carbon, water and energy
Similar patterns across models: a blast from the past

Steady state to transient: nutrients are key controls.

Productivity will change at the rate of the slowest-adjusting variable.
(This is a pointer to Ben’s talk.)
Biological N fixation tracks water and energy availability

Figure 1. Conservative, central, and upper-bound data-based and modeled estimates of terrestrial biological nitrogen fixation by ecosystem plotted versus modeled ecosystem ET.
Mapped limiting factors from Churkina and Running (1998)
Extending Churkina and Running: Global nutrient limitation in terrestrial vegetation
Global nutrient limitation in terrestrial vegetation

Validation?
Global nutrient limitation in terrestrial vegetation

Global Biogeochemical Cycles
Theory for nutrient limited adjustment rate

The rate of change of carbon depends on the rate of change in available nutrients (not total but related).

What controls available nitrogen (nutrients)?

First, the fraction of total nutrient that is available: this fraction may change as water and energy availability change: \( f_{N_{\text{avail}}} \)

Second, the total amount of nutrient, noting water and energy affect inputs and losses: \( N_{\text{total}} \)

\[
\frac{df_{N_a}}{dt} = F(N_{\text{total}}) \text{ where } F, \text{ inputs and losses all depend on energy and water, and } F \text{ is the fractional availability of a total nutrient}
\]
Coupled carbon-nutrient modeling

- Critical to simulate nutrient cycles (mineralization, immobilization, uptake).
- But, equally important to simulate budgets (inputs, losses, mineral phases).
- The motivation for modeling budgets has often been climate, air or water quality issues, but emerging as important for the carbon cycle.
Evidence for dynamic adjustment of total and available nutrients.

- When productivity decreases, N losses increase.
- When plant uptake declines, precipitation of P into insoluble mineral forms increases.
- Long-term changes in nutrient budgets correlate with carbon stocks (eg, Hawai‘i) and nutrient partitioning, resource use efficiency.
- Microbial communities respond to changes in the relative availability of energy and nutrients, affecting the active/total partitioning.
Modeling nutrient inputs and losses

• A game changer for modeling...
• Process-level modeling of A and R requires modest site- and landscape-specific processes.
• Process modeling of local nutrient budgets requires detailed soil physics and local hydrology.
• Scale becomes a major issue, with dependence on soil pores, wetlands, hillslopes, even herbivores.
Approaches

• Simple (Schimel et al 1997) parameterization of inputs and losses and environmental functions.
• Complex models of each flux process as in DayCent or DNDC...
• Different biomes and regions have different dominant processes (BNF vs deposition, fire versus leaching).
Example control functions: complex but these are the easy part

Figure 3. Effect of (a) soil water-filled pore space, (b) soil temperature, and (c) soil pH on nitrification.
Modeling soil water

Figure 5. Comparison of simulated versus measured soil water-filled pore space (WFPS) for all the sites (a) during the growing season and (b) during the winter months. (c) Daily comparison of simulated and observed WFPS for the sandy loam site during 1992.
Model evaluation is event-scale since there is no integral constraint.
• N budgets are controlled by different factors in different environments (leaching, fire, trace gases, BNF, deposition), most of which remain incomplete in global models

• Diagnosis is needed to determine a “minimal” model for coupled C-nutrient cycles in the climate system (Wait for Ben’s talks) to determine the nutrient-limited rate of carbon change.