Known and unknown unknowns: designing observing strategies to understand the expected and surprising consequences of environmental change

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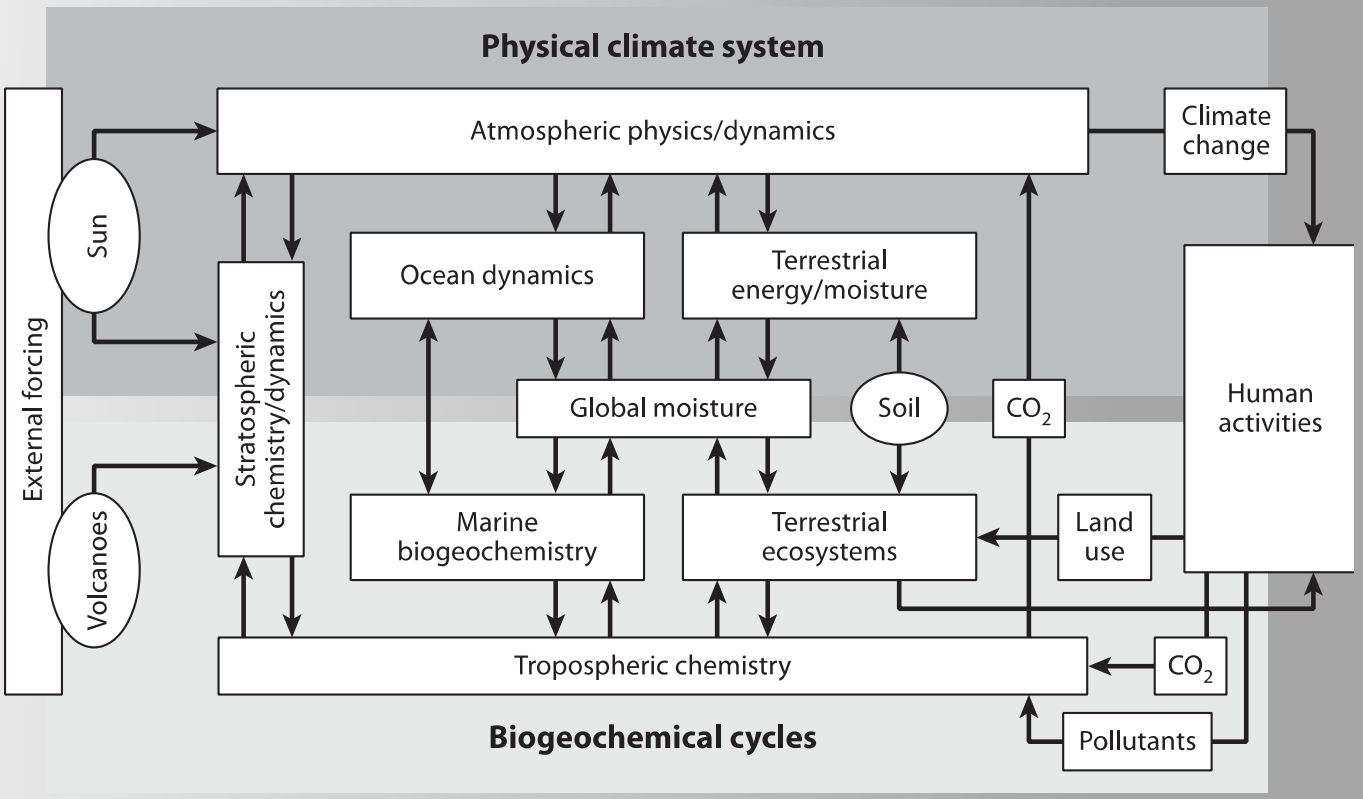
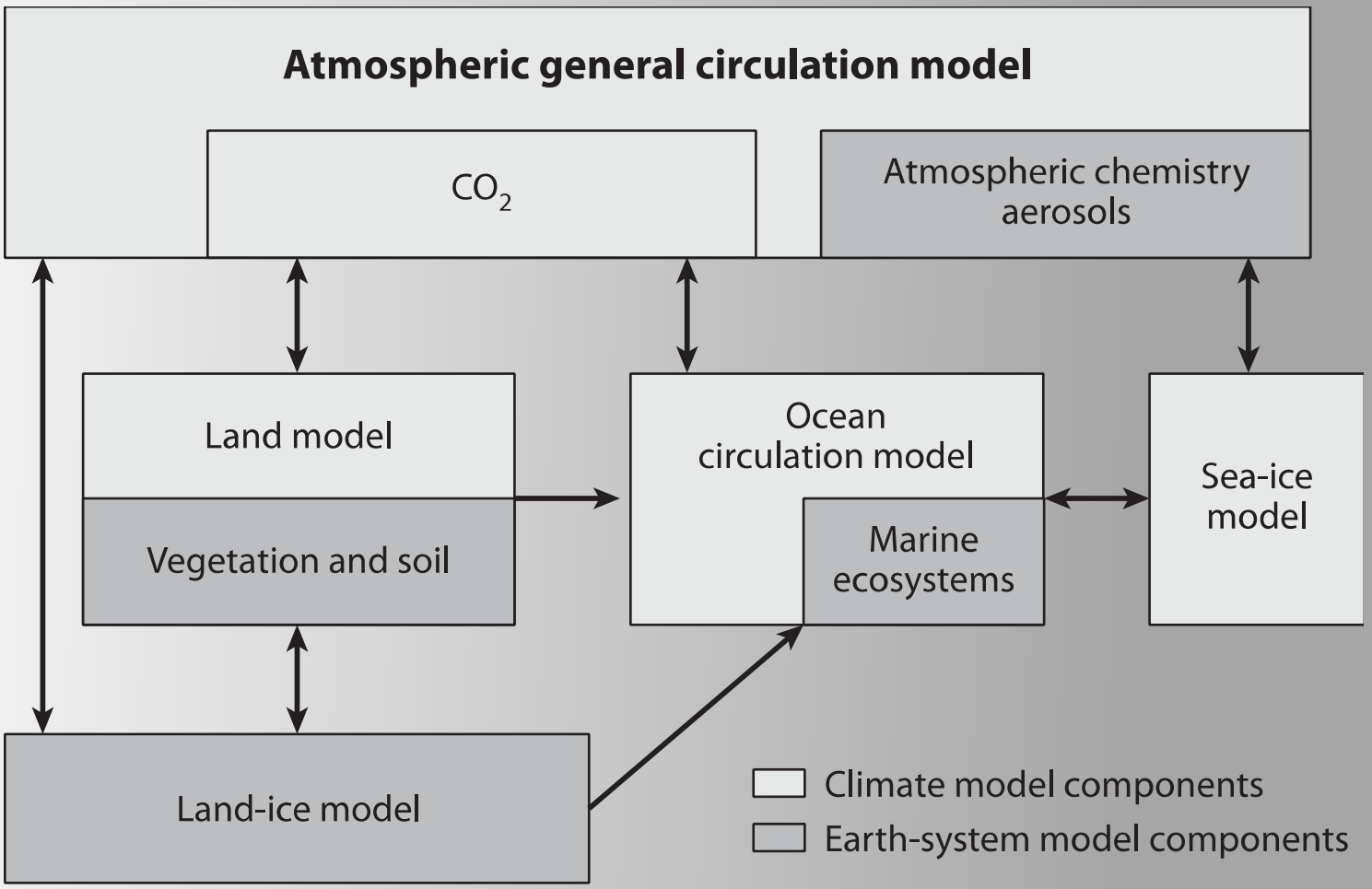
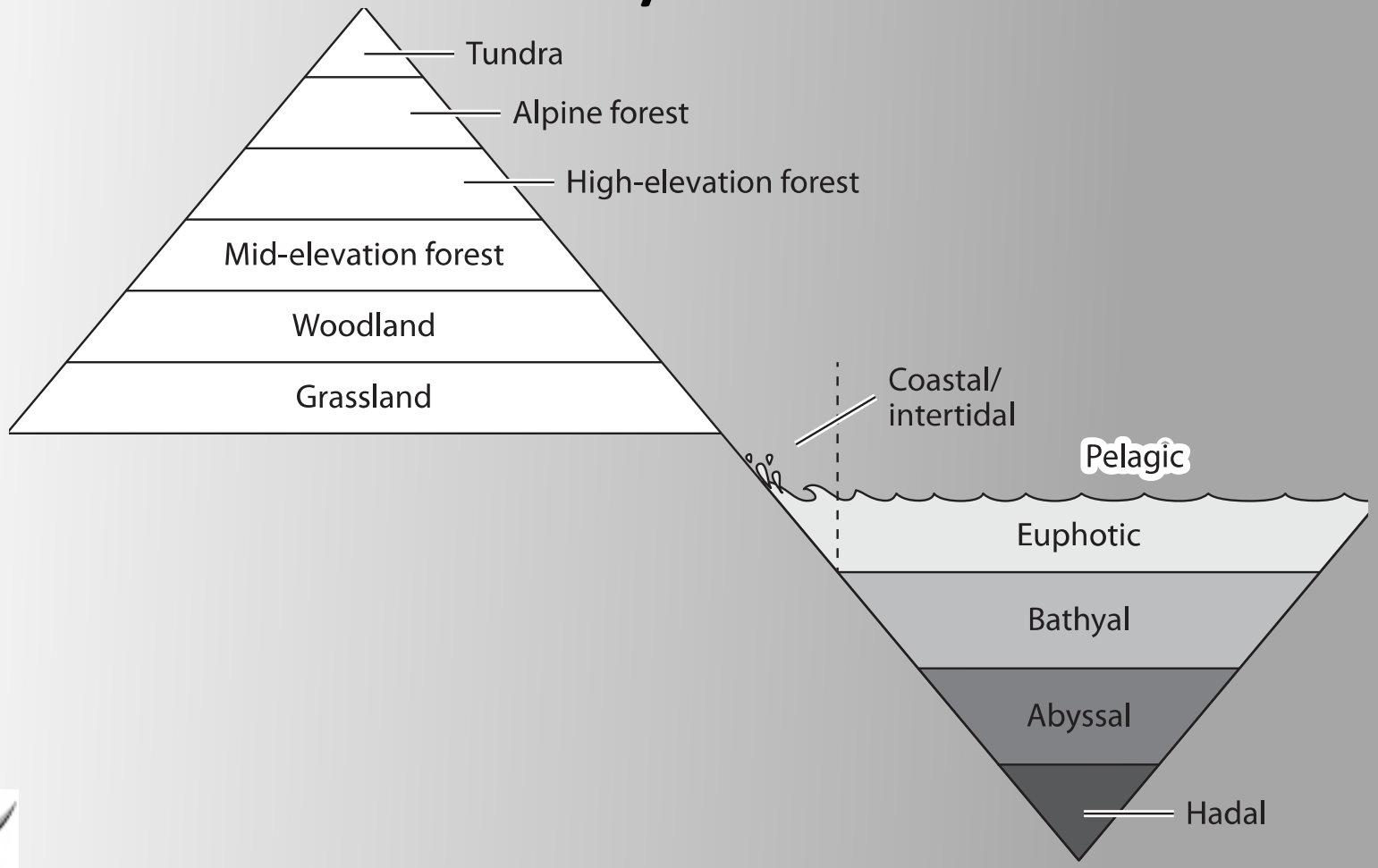


Structure of an Earth System Model



Elevation and Depth Structure Ecosystems



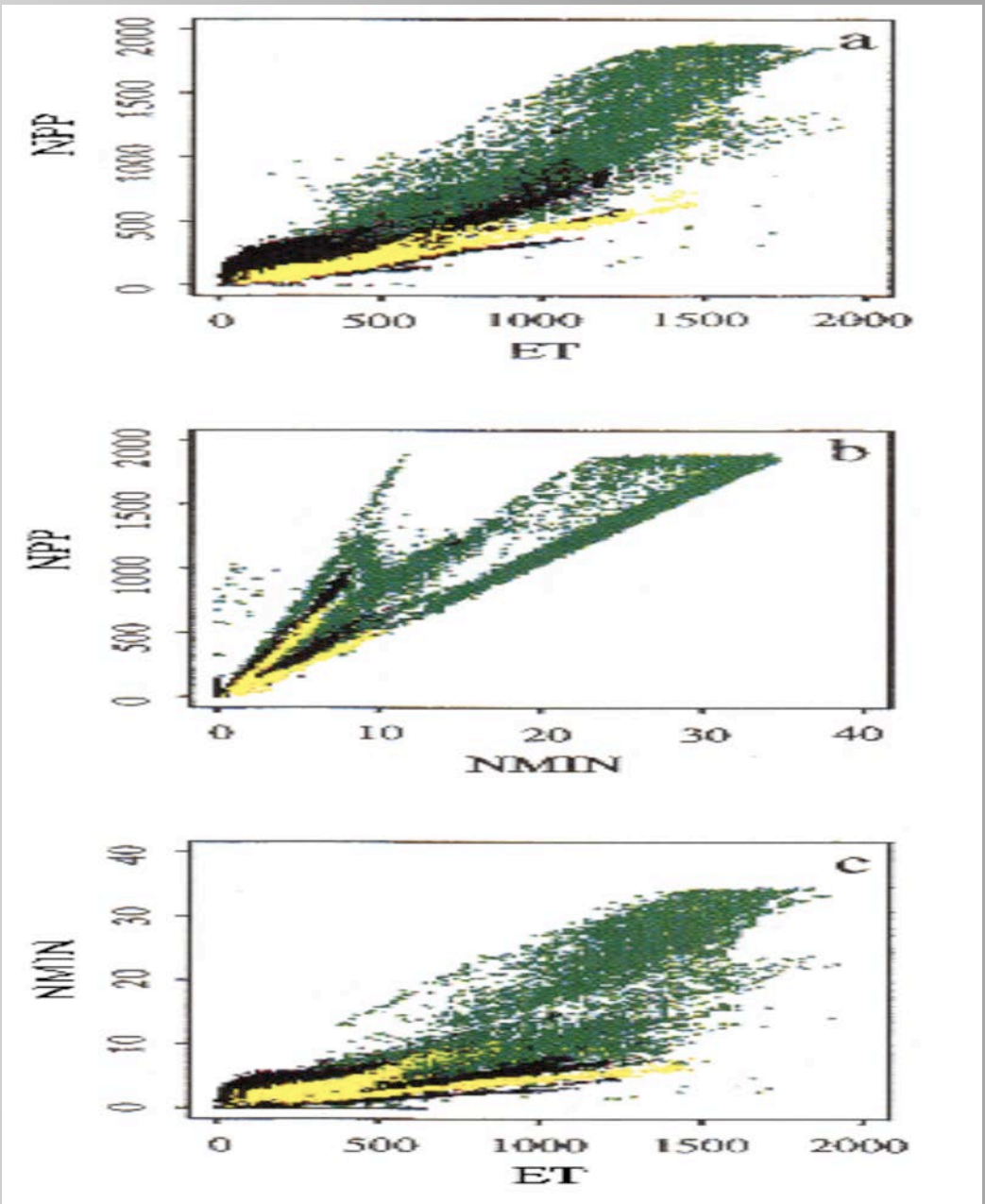
Ecosystem structure and climate; how can we constrain models with observations

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

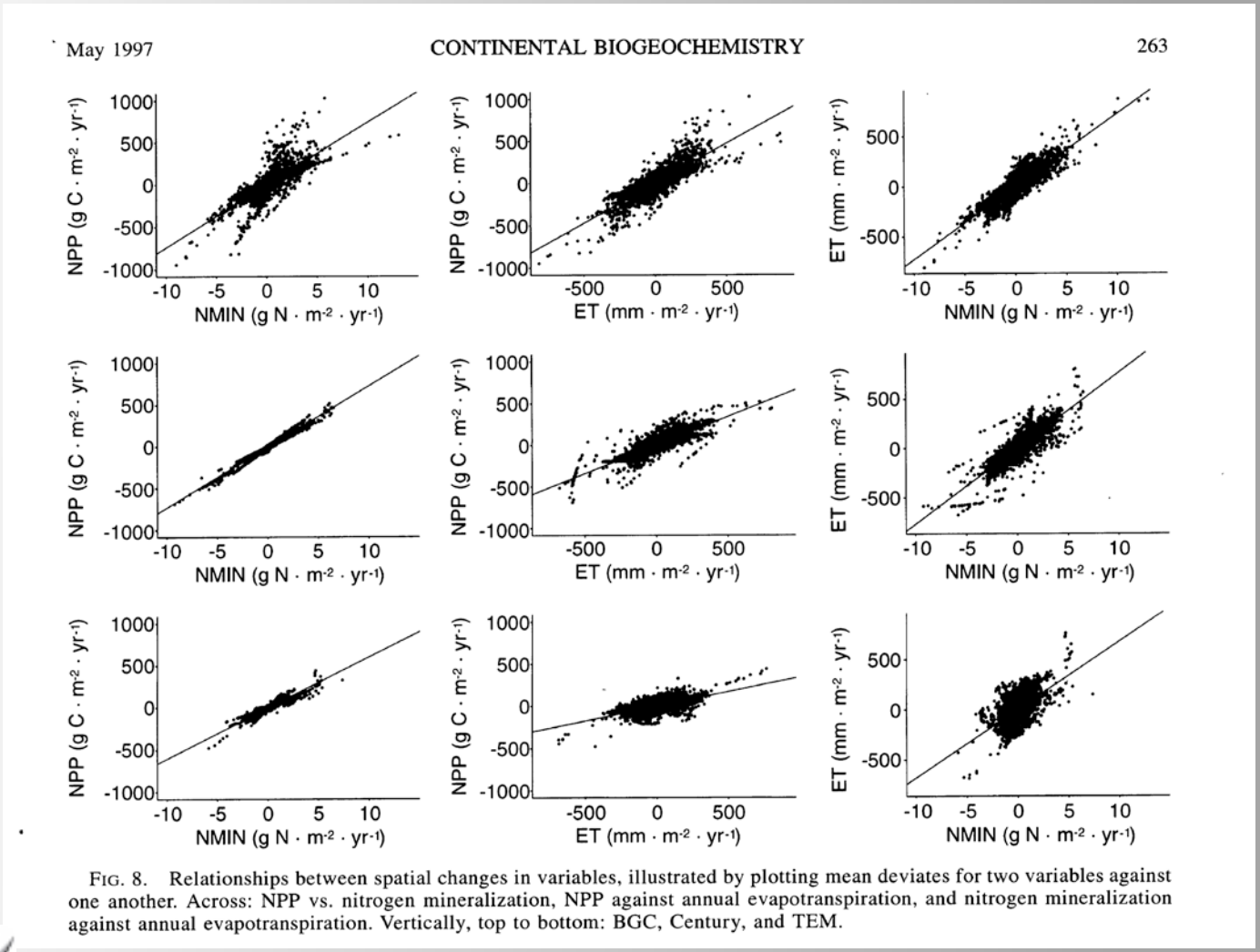


FIG. 8. Relationships between spatial changes in variables, illustrated by plotting mean deviates for two variables against one another. Across: NPP vs. nitrogen mineralization, NPP against annual evapotranspiration, and nitrogen mineralization against annual evapotranspiration. Vertically, top to bottom: BGC, Century, and TEM.

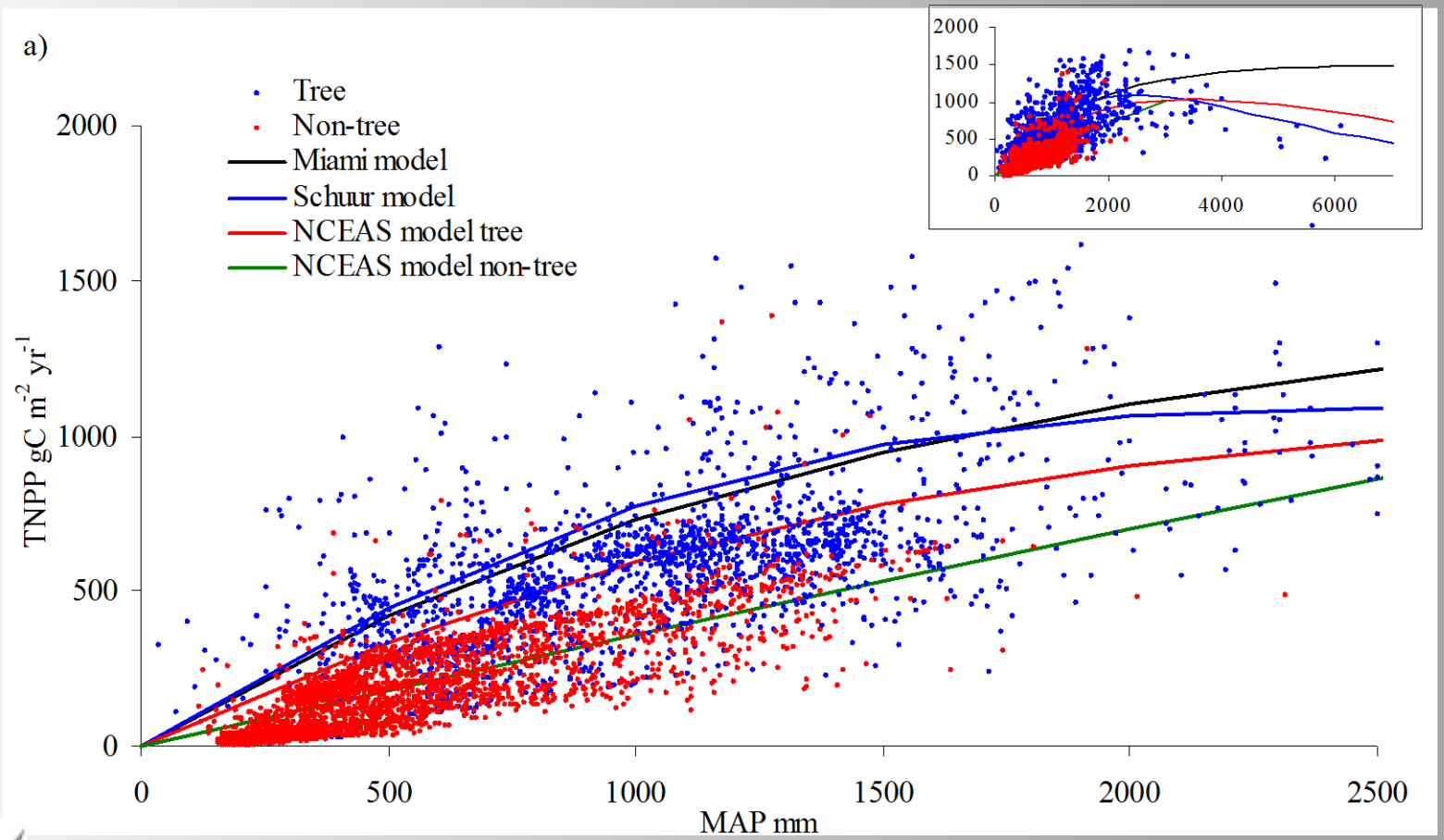
Schimel, D.S., VEMAP Participants, and B.H. Braswell. 1997. Spatial variability in ecosystem processes at the continental scale: models, data, and the role of disturbance. Ecological Monographs **67**: 251-271.

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).

Global primary productivity



Biological N fixation tracks water and energy availability

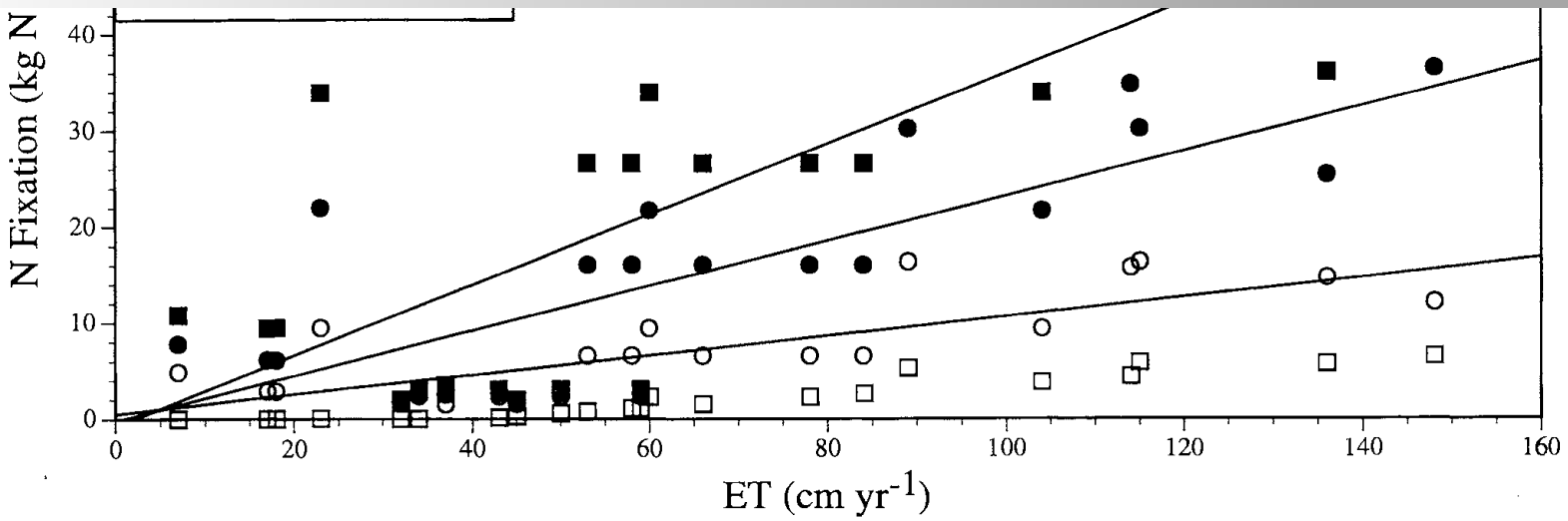
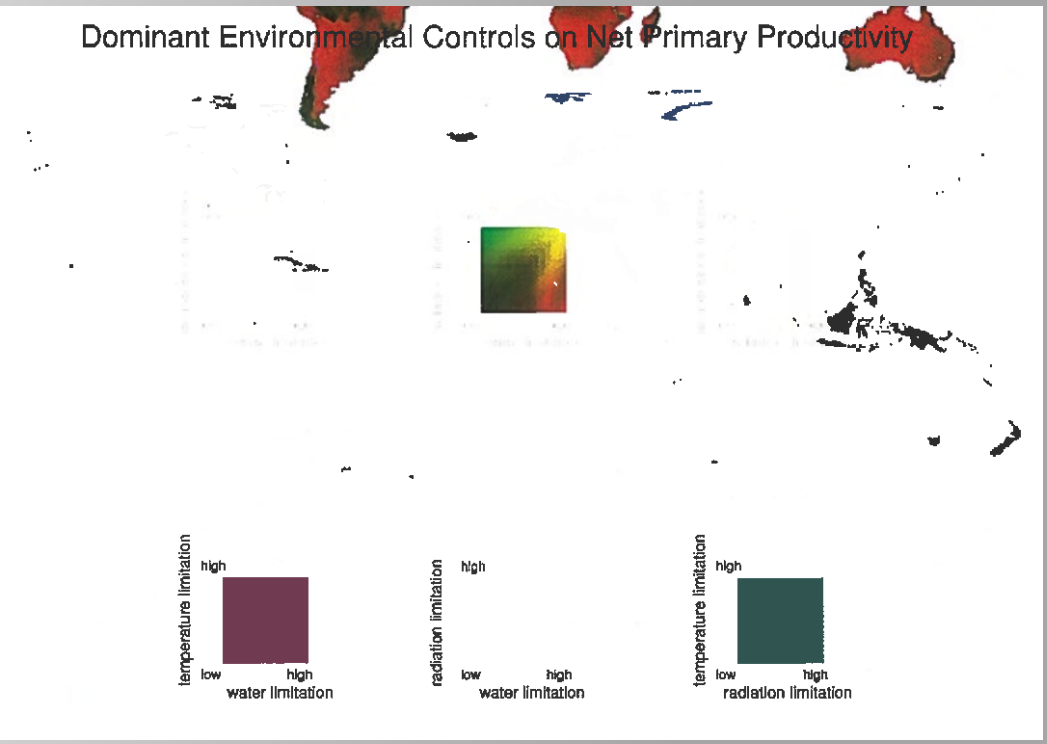


Figure 1. Conservative, central, and upper-bound data-based and modeled estimates of terrestrial biological nitrogen fixation by ecosystem plotted versus modeled ecosystem ET.

abundant in some parts and/or successional stages of all ecosystems, we believe that it is extremely unlikely that this value represents a realistic average spatial and temporal coverage. The contribution suggested by the conservative and central data-based estimates (100 Tg N yr^{-1} and 195 Tg N yr^{-1}, respectively) are much more reasonable values, and since our central value is based on an average of explicitly reported coverages of N fixers, our best estimate of potential N fixation in natural ecosystems globally is 195 Tg N yr^{-1}, or an average of ~15 kg N yr^{-1} for each hectare of the Earth's land surface. Our failure to include an error term on this central value reflects the fact that we are unaware of an appropriate statistical

Mapped limiting factors from Churkina and Running (1998)



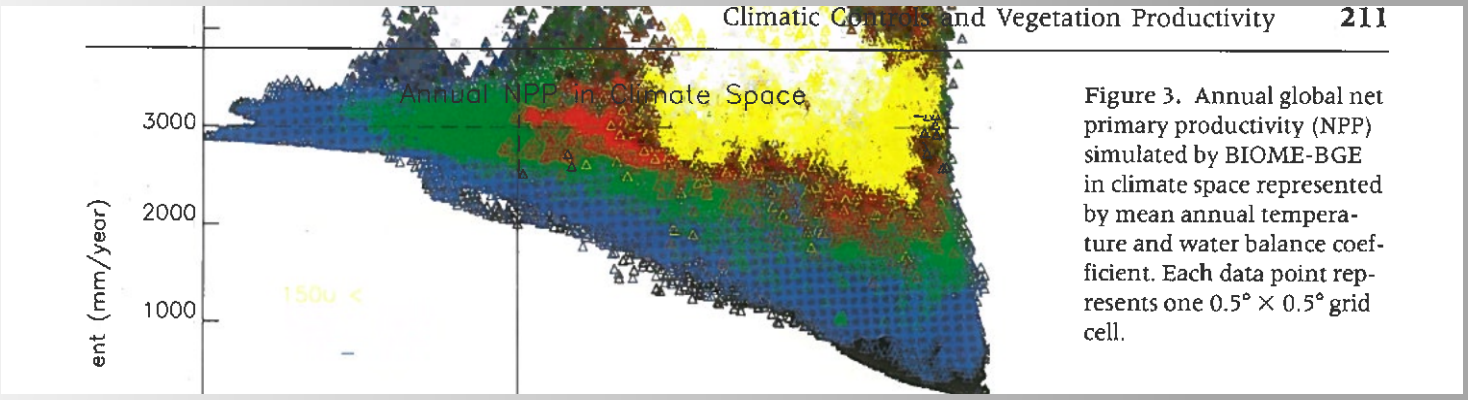
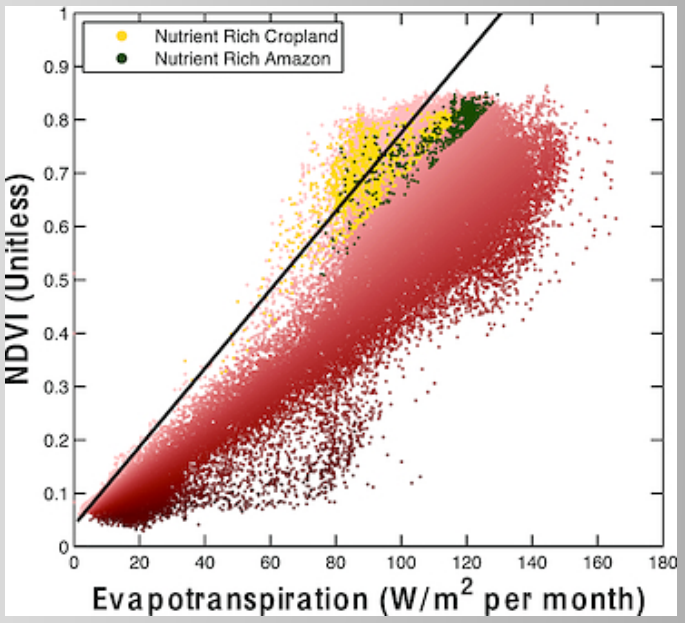


Figure 3. Annual global net primary productivity (NPP) simulated by BIOME-BGE in climate space represented by mean annual temperature and water balance coefficient. Each data point represents one 0.5° × 0.5° grid cell.

Extending Churkina and Running: Global nutrient limitation in terrestrial vegetation



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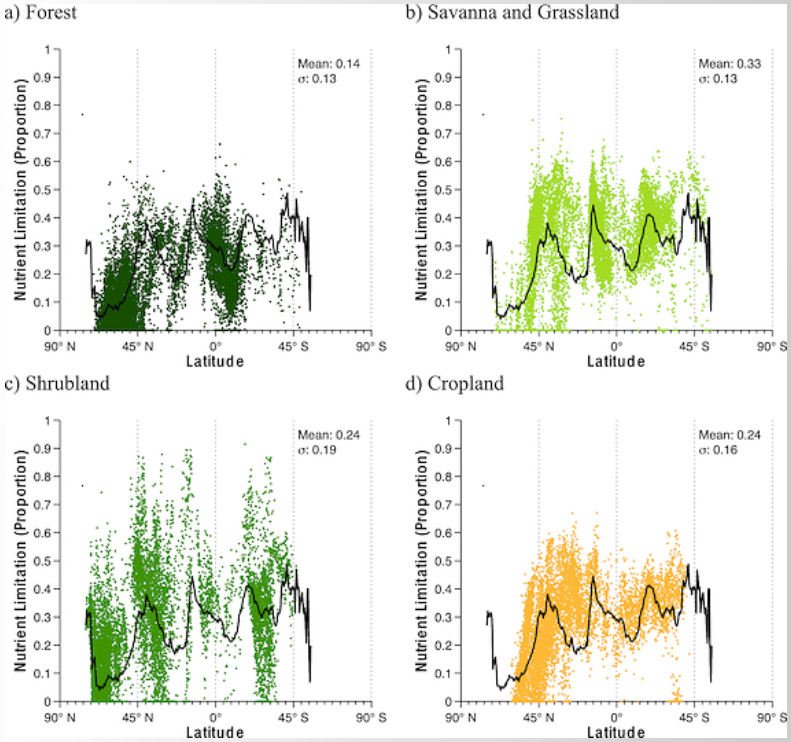
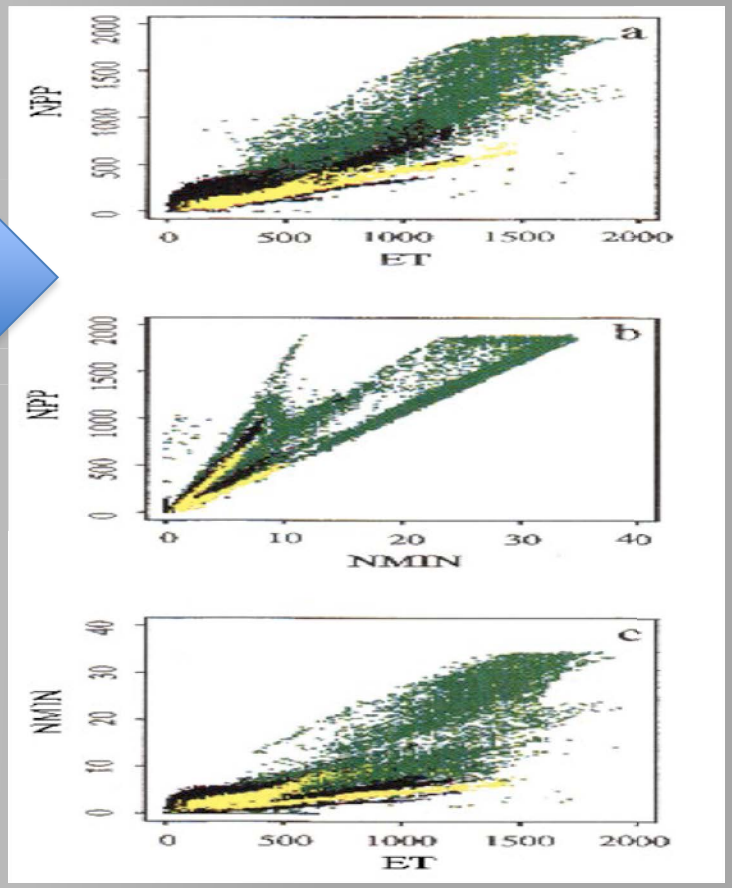
Global nutrient limitation in terrestrial vegetation



Validation?



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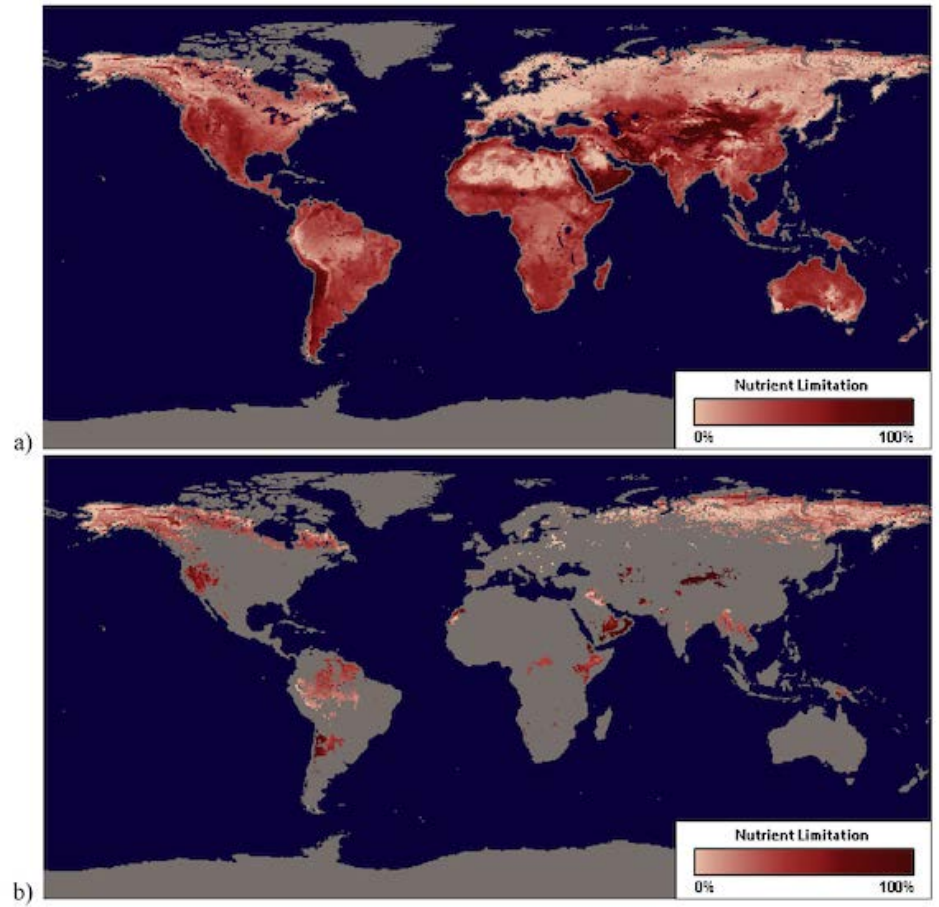
Global nutrient limitation in terrestrial vegetation



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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**:** $\mathbf{fN_{avail}}$

Second, the total amount of nutrient, noting water and energy affect inputs and losses: $\mathbf{N_{total}}$

$dfN_a/dt = F(N_{total})$ where F, inputs and losses all depend on energy and water, anf F 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

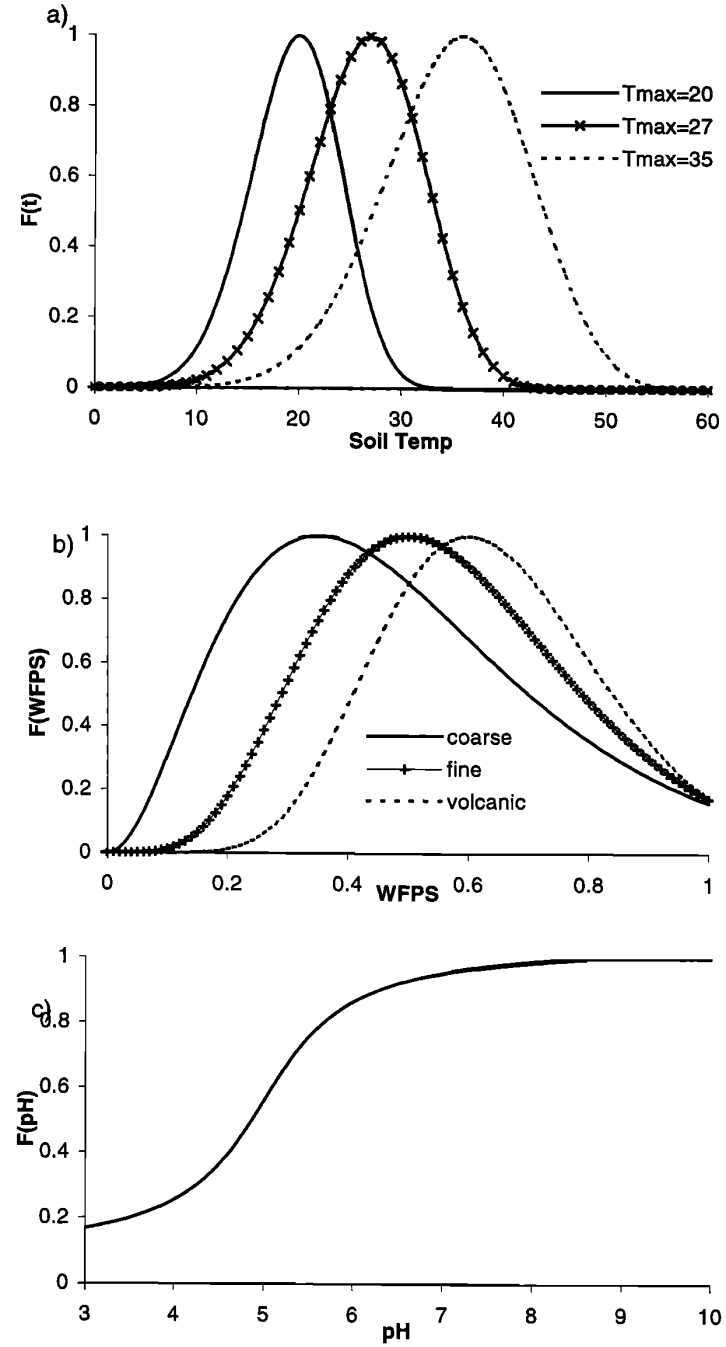

Figure 3. Effect of (a) soil water-filled pore space, (b) soil temperature, and (c) soil pH on nitrification.

Modeling soil water

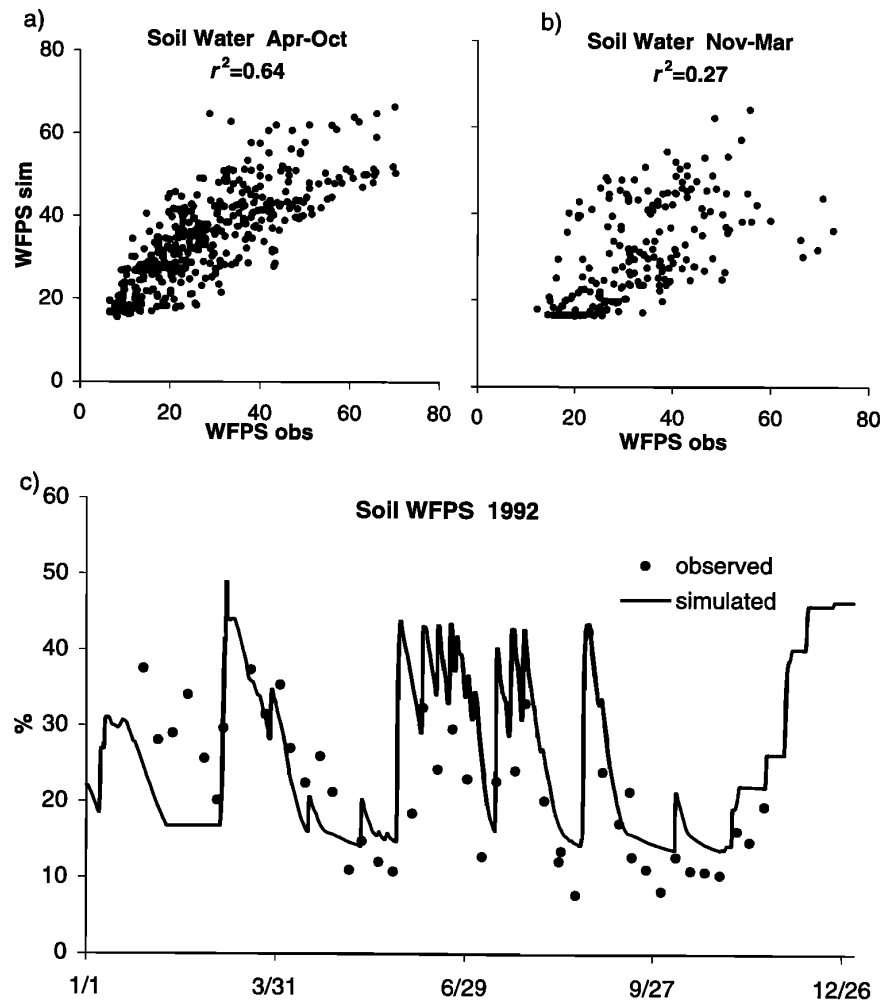

Figure 5. Comparison of simulated versus measured soil water-filled pore space (WFPS) for all the sites (a) during the growing season and (b) during the winter months. (c) Daily comparison of simulated and observed WFPS for the sandy loam site during 1992.

Model evaluation is event-scale since there is no integral constraint.

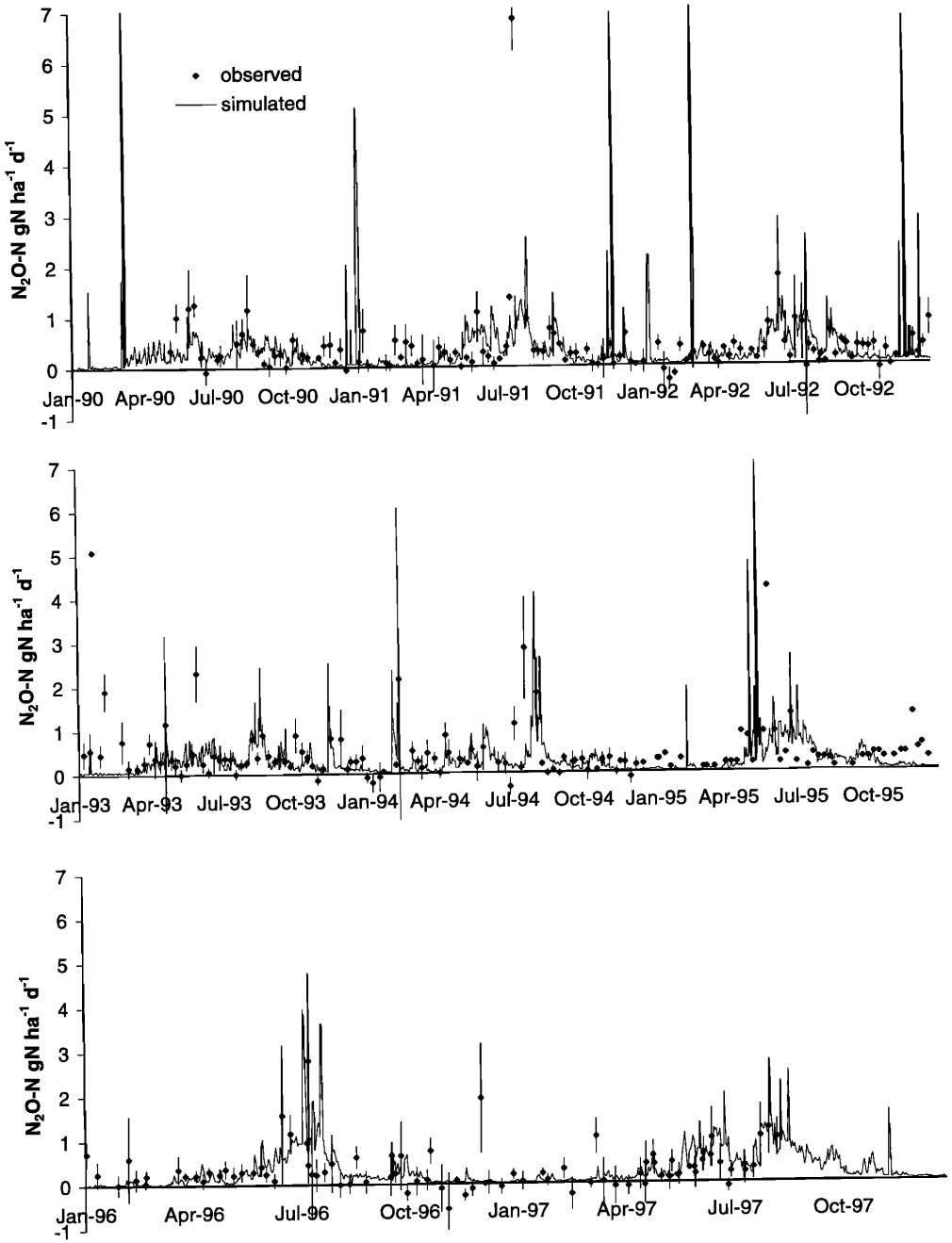

Figure 9. Comparison of observed and simulated daily N_2O fluxes for the native sandy loam site. Error bars represent standard deviations of measurement repetitions (n=4); standard deviations were not available for all measurements.

- 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 to determine the nutrient-limited rate of carbon change.