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Large-scale biogeochemical cycles in the Earth system: What are the big unanswered questions?

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What are the important unanswered questions related to large-scale biogeochemical cycles? Any list provided as an answer to this question will necessarily reflect the interests of the respondent, as well as his or her ignorance and lack of creativity.

Over the next centuries, an important question is to what extent effects of CO_2-fertilization will be limited by nutrient limitation. Important related questions relate to understanding limitations on rates of nitrogen fixation, a better understanding of the phosphate cycle (including its relationship with the nitrogen cycle), and a better understanding of the role of micro-nutrients in shaping ecosystems and their effect on the climate system.

If humans continue to accelerate interventions in global biogeochemical cycles over the next centuries and millennia, what outcomes might occur that we do not yet anticipate?

Global ocean modelers have long assumed that it is important to characterize global marine biogeochemical cycles with a model that represents trophic levels and multiple nutrient limitations (e.g., phosphate, nitrogen, iron). Global ocean modelers typically seek to use the same equations and parameter values across the entire near-surface ocean. In contrast, global land surface modelers typically ignore trophic interactions and have only recently been considering multiple nutrient interactions. Futhermore, there is a history in land surface modeling of representing different ecosystem types or plant functional types, rather than attempting to apply a single set of equations with a single set of parameter values across the entire land surface. This raises several questions: are there are a single set of equations that can be evaluated across the entire land surface that will predict the observed distribution of vegetation types without prescribing in advance what those types will be?

How important are trophic interactions in structuring ecosystems and thus biogeochemical cycling?

Are there ways of representing evolutionary constraints on ecosystem development so that principles of global biogeochemical cycles emerge as a consequence of fundamental physical, geochemical, and biophysical constraints rather than being prescribed as a set of ad hoc model assumption?

It has been suggested that silicate weathering rates in forests are greater than those in grasslands and that a CO_2-mediated forest/grassland transition has modulated atmospheric CO_2 concentrations over the past 20 million years. Is this true? Can an Earth System model globally simulate interactions of the carbonate-silicate cycles, ice-sheet dynamics, and vegetation distributions over the past 65 million years?

How well do we understand controls on atmospheric oxygen concentration? A naïve point of view associates higher O_2 concentrations with net oxidation of organic carbon (e.g., less organic carbon burial), yet consideration of the phosphorus cycle suggests that this view is too simplistic. Do we understand controls on the geologic cycles of organic carbon burial and oxidation?

How well do we understand the global alkalinity cycle? In the typical geochemical carbon cycle model, we consider weathering fluxes of Ca^{2+} and Mg^{2+}, but somehow ions such as Na^{+} and K^{+} get ignored, despite the fact that these are important components of riverine alkalinity. How well do we understand the cycles of the important components ions affecting the riverine alkalinity flux, and therefore how well do we understand controls on long-term climate change?