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The role of tectonic uplift, climate and vegetation in the long-term terrestrial phosphorous cycle

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Phosphorus (P) is a crucial element for life and therefore for maintaining ecosystem productivity. Its local availability to the terrestrial biosphere results from the interactions between climate, tectonic uplift, atmospheric transport and biotic cycling. To understand to what extent terrestrial productivity may feed back on the atmospheric CO_2 concentration and climate change, a model that is capable of synthesizing the P-cycle is essential. Here we present a mathematical model that describes the terrestrial P-cycle considering the interactions between climate, tectonic uplift, atmospheric transport and the biologically controlled P re-cycling. The resulting dynamical system can be solved analytically for steady-state conditions, allowing us to test the sensitivity of the simulated P-availability to key model parameters and processes.

We find that humid ecosystems in steady-state will normally exhibit lower P availability due to higher runoff and losses. Tectonic uplift is a fundamental constraint as it is the main source of P for terrestrial ecosystems through weathering. Our model represents this fundamental constraint and clearly shows the difference between the P dynamics on volcanic islands and continental crusts. We demonstrate this using the time-dependent P dynamics for the Franz Josef and Hawaii chronosequences as an example. While tectonic uplift is an important constraint on ecosystem productivity, hydroclimatic conditions control the rate P-losses and speed of convergence towards a steady-state. For the case of the Amazon Basin, the model also illustrates that ecosystems with limited uplift and atmospheric P input must rely on mechanisms that enhance P-availability and retention to sustain their productivity. Our analysis underlines the need to include P dynamics in global vegetation-atmosphere models for a reliable representation of the response of the terrestrial biosphere to global change.