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Earth Without Life: A Systems Model of a Global Abiotic Nitrogen Cycle

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Introduction: Nitrogen is the major component of Earth's atmosphere and plays important roles in biochemistry [1,2]. Presently, the Earth's surface nitrogen cycle is dominated by biological (including human) fluxes, with abiological fluxes being relatively small. However, prior to advent of biology, all nitrogen cycling would have been abiological, and this cycling would have set the stage for the origin of life.

Model Description: We constructed a kinetic mass-flux model of N cycling, in its various major chemical forms (N_2 and NO_x, NH_x, which stand for oxidized and reduced species, respectively), between the Earth's major reservoirs (atmosphere, oceans, crust, mantle), and including inputs and losses to space, taking into account the rates of fluxes between reservoirs and the total amount of N species which can be accommodated in each, and explore how these fluxes and reservoirs may change over time in the absence of biology. The model topology is shown in Fig. 1.

Flux are estimated from present observed day values and several possible time evolutions, anchored either by geodynamics consideration or rock measurements are modeled.

Discussion: Understanding what controls such a cycle may therefore be used as remote observable for planetary dynamics. We found that the timescales involved in the evolution allow the system to track the steady state closely, and that any long term evolution is due to variations in the steady state due to model parameters. This allows us to map the phase space of possible nitrogen distribution between the different reservoirs, irrespective of potential early transients. We also characterize, all else being constant, how life influences this phase space.

References: [1] Galloway JN et al. (1994) Biogeochemistry. 70:153-226. [2] Johnson B and Goldblatt C (2015) Earth Science Reviews. 148:150-173.

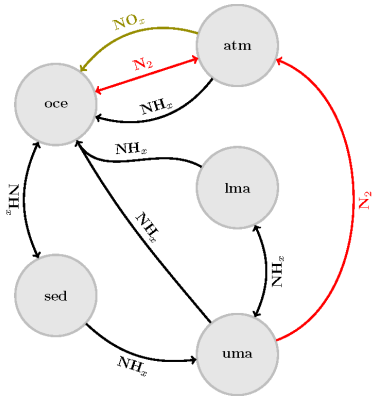

Figure 1 - Coupled model topology showing NO_x, N_2 and NH_x fluxes between Earth's reservoirs. The 'atm', 'oce', 'sed', 'uma' and 'lma' labels stand for atmosphere, oceans, sediments, upper and lower mantle, respectively.