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Modeling N Cycle Seasonality on Early Earth and Beyond

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Nitrous oxide (N_2O) is released as a byproduct of partial denitrification in Earth's marine and terrestrial biospheres [1]. N_2O surface fluxes to the atmosphere experience seasonal oscillations driven primarily by denitrification, which responds to fluctuations in primary productivity or bioavailable nitrate concentrations stemming from environmental changes [2]. Because N is an essential element for life, N cycle seasonality may amplify or mute the expression of seasonally variable marine biosphere productivity. This phenomenon could also lead to atmospheric fluctuations in remotely detectable biosignature gases. However, the extent to which seasons have affected the N cycle, marine life, and atmospheric biosignatures throughout Earth's history is poorly constrained. We examine the effects of seasons on the N cycle and nutrient availability via simulation of anoxic and partially oxygenated early Earth conditions. We also gain insights that can be applied to the production of biosignatures.

We use cGENIE-PLASIM, a 3D marine biogeochemical model coupled to an atmospheric general circulation model (GCM), to quantify seasonal fluctuations in the biological N cycle [3]. We consider 3 biosphere scenarios with O_2 levels based on Earth's Archean (pO_2 = ~0.001% PAL), Proterozoic (pO_2 = ~1% PAL), and Phanerozoic (pO_2 = PAL) eons [4]. We also scale oceanic P inventory to determine the response of the N cycle to P availability in the biosphere. Finally, we vary orbital parameters such as eccentricity and obliquity to account for plausible seasonal dynamics on Earth-like exoplanets.

We find that substantial biospheric N_2O production (fixed N loss) is possible under early Earth conditions. We describe the spatiotemporal patterns of N cycling on early Earth and their implications for the evolution of the marine biosphere. We discuss N cycle dynamics on Earth-like exoplanets and speculate on the viability of treating atmospheric N_2O seasonality as a potential biosignature.

References:

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