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Modeling Biospheric Seasonality on Early Earth and Earth-like Exoplanets

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Earth's seasons affect a number of fundamental processes in the biosphere. These include oxygenic photosynthesis, aerobic respiration, and nitrification/denitrification, whose relative rates fluctuate over the seasonal cycle in response to changes in insolation and surface temperature [1,2]. However, the implications of seasons for the co-evolution of life and its environment on early Earth remain unclear. Moreover, seasonality in the biosphere results in temporally variable atmospheric fluxes of biosignature gases like O_2, CO_2, and N_2O, which may also make it a useful life detection and characterization tool for Earth-like exoplanets [3,4,5].

Here, we study the effects of seasons on the biosphere to better understand their impact on nutrient availability for life on early Earth and the production of remotely detectable biosignatures on Earth-like exoplanets. We use cGENIE-PlaSim, a 3D marine biogeochemical model coupled to an atmospheric GCM, to quantify seasonality in an Earth-like biosphere under the atmospheric oxygenation conditions present over Earth's history, ranging from Archean (~10^{-5} PAL) to Phanerozoic (PAL) pO_2 levels [6,7]. We also vary planetary obliquity and eccentricity in our simulations to account for plausible seasonal dynamics on Earth-like exoplanets. We then describe the corresponding seasonal patterns in biologically modulated atmospheric gases such as O_2, CO_2, and N_2O. Finally, we speculate on the viability of treating biospheric seasonality as an exoplanet biosignature.

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