Atmospheric Seasonality on the Early Earth: Implications for Remote Life Detection

S.L. OLSON[1]*, E.W. SCHWIETERMAN[1], C.T. REINHARD[2], T.W. LYONS[1]

[1]Department of Earth Sciences, University of California, Riverside, CA 92521, USA (*solso002@ucr.edu)
[2]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA 30332, USA.

Seasonal oscillation in the composition of Earth's atmosphere is a biologically modulated phenomenon that arises from seasonal differences in several important environmental parameters (e.g., light, temperature). On the modern Earth, atmospheric seasonality is particularly well expressed in the abundance of CO_2 in the Northern Hemisphere, which rises and falls throughout the year in response to a shifting balance of the relative rates of photosynthesis and respiration [1]. Similar temporal variability in atmospheric composition is likely on other inhabited worlds that also experience seasons as the result of oblique or highly eccentric orbits—and such seasonality may be remotely characterizable by direct imaging of exoplanets via space-based telescopes. To date, however, the discussion of seasonality as an exoplanetary biosignature has remained qualitative, lacking quantitative consideration of the spectral features that are most likely to be impacted by *observable* seasonality for biospheres or surface chemistries that differ from the example provided by the present-day Earth.

As a starting point, we explore constraints on the spectral expression of biologically modulated seasonality throughout Earth history. In particular, we focus on the so-called Boring Billion of the mid-Proterozoic which, when viewed as an exoplanet, lacks detectable O_2 or a reliable disequilibrium biosignature [2]. Based on insight from biogeochemical, photochemical and spectral models, we suggest that seasonality in biological O_2 cycling may induce observable seasonality in spectrally active O_3, the abundance of which is strongly sensitive to intermediate (Proterozoic) levels of O_2. We further argue that time variable O_3 absorption may be observable in distant atmospheres even if O_2 itself never achieves detectable levels throughout the seasonal cycle—potentially providing a tool to mitigate against 'false negatives' and to identify otherwise cryptic biospheres, including the diverse and increasingly complex life of the mid-Proterozoic Earth.

[1] Keeling *et al*. (1992) *Nature* **358**, 723-727. [2] Reinhard *et al*. *Astrobiology*, in press.