Atmospheric seasonality as an exoplanet biosignature

STEPHANIE L. OLSON[1], EDWARD W. SCHWIETERMAN[1], CHRISTOPHER T. REINHARD[2], ANDY RIDGWELL[1], VICTORA S. MEADOWS[3], TIMOTHY W. LYONS[1]

[1]Department of Earth Sciences, University of California, Riverisde, Riverside, CA, USA
[2]School of Earth and Atmospheric Sciences, Georgia Institute of Technology, Atlanta, GA, USA
[3]Department of Astronomy, University of Washington, Seattle, WA, USA

Investigations of exoplanet biosignatures have focused on static evidence of life, such as the presence of biogenic gases like O_2 or CH_4. However, the expected diversity of terrestrial planet atmospheres and the likelihood of both 'false positives' and 'false negatives' for these conventional biosignatures requires consideration of additional life detection strategies—including time-varying signals. For example, seasonal variation in atmospheric composition is a biologically modulated phenomenon on Earth that is likely to occur elsewhere because it arises naturally from the interplay between the biosphere and time-variable insolation. The search for seasonality as a biosignature would avoid many assumptions about specific metabolisms and provide an opportunity to quantify biospheric fluxes—allowing us to characterize, rather than simply recognize, life elsewhere. Seasonality may also allow life detection via gases that are readily detectable but are not uniquely biological in origin and may thus provide important context for evaluating potential false positive scenarios. Despite this potential, there have been no comprehensive studies of seasonality as an exoplanet biosignature. We will review both biological and abiological controls on the magnitude and detectability of the seasonality of atmospheric CO_2, CH_4, O_2, and O_3 on Earth throughout its history. We will show that life on a low O_2 planet similar to the mid-Proterozoic Earth could be most reliably fingerprinted by seasonal variation in O_3 as revealed in its UV Hartley-Huggins bands, and we will further argue that strong seasonality, independent of its origin, may obscure static biosignatures. These examples illustrate the diagnostic importance of temporally resolved signals for confident remote life detection.