Earth, With a Twist: How Orbital Parameters Affect the Photochemistry and Climate of Earth-like Exoplanet Atmospheres with ROCKE-3D

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Introduction: The interpretation of future observations of habitable exoplanets will depend critically on our understanding of how spectrally active gases are generated, maintained, and destroyed by photochemical reactions, transported throughout the atmosphere, and ultimately expressed in the disk-integrated spectrum. However, exoplanets are expected to have orbital parameters that differ from those of modern Earth, which will drive changes in both chemistry and climate. Studies of the impact on and by photochemistry with 3D models have begun exploring this parameter space (e.g., Chen et al., 2019; Braam et al., 2025), demonstrating that changes in orbital parameters and bulk atmospheric composition of essentially Earth-twin exoplanets could affect the abundances, distributions, and detectability of key biosignature gases like ozone (O_3) and methane (CH_4).

We present here simulations of nearly identical modern Earth-twin planets that have differing rotation rates, eccentricities, and obliquities using ROCKE-3D, a planetary general circulation model (GCM). ROCKE-3D has been used to model Earth-like planets (e.g., Way et al., 2017), but without a specific focus on atmospheric composition or biosignature gases. The updated Planet 2.0 version (Tsigaridis et al., 2025) includes updated physics covering surface and lake hydrology, finer spatial resolution options, and more atmospheric composition options.

We explore how errors in climatology arise from assumed vs. prognostic chemical composition. We re-affirm that these factors can and often do produce substantial variations in the distributions of important biosignature gases, and in particular, that habitability could be directly impacted. These variations can be detectable, especially considering the viewing geometries, and may help to break some degeneracies in largely unconstrained orbital parameters.

References:

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