# Anoxic Atmospheres with ROCKE-3D: Early Earth Analogs

C. E. HARMAN[12*], K. TSIGARIDIS[23] , E. T. WOLF[4], M. J. WAY[2], L. E. SOHL[23], A. D. DEL GENIO[2]

[1]Department of Applied Physics and Applied Mathematics, Columbia University, New York, New York 10025, USA
[2]NASA Goddard Institute for Space Studies, New York, New York 10025, USA; *chester.e.harman@nasa.gov
[3]Center for Climate Systems Research, Columbia University, New York, New York 10025, USA
[4]Laboratory for Atmospheric and Space Physics, Department of Atmospheric and Oceanic Sciences, University of Colorado, Boulder, CO 80303, USA

The ROCKE-3D General Circulation Model (GCM) [1] leverages our understanding of the Earth's atmospheric chemistry and climate to simulate an increasingly diverse pool of planet types. ROCKE-3D has been used to simulate the climatology of modern and paleo-Earths [1], early Venus [2], and temperate terrestrial planets orbiting M dwarf host stars [3,4].

Here, we describe some of the more recent developments, including the implementation of the kinetic pre-processor (KPP)[5], which replaces the original ModelE2-derived oxygen-dominated atmospheric chemistry scheme [6]. KPP is a highly customizable framework for novel chemistry schemes, which we have used to study the composition of a putative anoxic Archean atmosphere (4-2.5 Gya). We have also begun investigating the differences between 1- and 3-dimensional photochemical model results, taking a cue from studies which have demonstrated substantial climatological differences between 1-D and 3-D simulations (e.g., [3]). We plan to pay particular attention to simulations of anoxic, $CO_2$-dominated atmospheres for terrestrial planets orbiting M dwarfs, which have given rise to several published false positives for oxygen using 1-D models (e.g., [7]). M-dwarf-hosted planets are also likely to be tidally locked, which is difficult to accurately capture in 1-D.

Finally, we show synthetic spectra and phase curves derived from early Earth analog scenarios. Retrievals could be used to differentiate some surface types like open ocean and ice cover, for example, with implications for habitability (and by extension, biosignature detection and false positive discrimination).

[1] Way *et al* 2017 *ApJS* **231** 12; [2] Way *et al* 2016 *GRL* **43** 12; [3] Fujii *et al* 2017 *ApJ* **848** 100; [4] Del Genio *et al* 2017 *arxiv:*1709.02051; [5] Sandu & Sander 2006 *ACP* **6** 187; [6] Schmidt *et al* 2014, *J. Adv. Model. Earth Syst.* **6** 1; [7] Harman *et al* 2015 *ApJ* **812** 137.