A MID-LIFE CRISIS FOR EARTH'S GREENHOUSE. Stephanie L. Olson,[1] Christopher T. Reinhard[2], and Timothy W. Lyons[1], [1]University of California—Riverside, Riverside, CA 92521, [2]Georgia Institute of Technology, Atlanta, GA 30332

The temporal proximity between oxygenation events and Snowball Earth events in the Proterozoic supports speculation that a reduced gas, most likely biogenic CH_4, regulated Proterozoic climate—compensating for the Faint Young Sun and explaining the apparent dearth of Mesoproterozoic glacial deposits. Although low O_2 and SO_4 conditions in the Proterozoic likely favored large CH_4 fluxes from the marine biosphere, the geologic record does not provide quantitative constraints on either biogenic CH_4 fluxes or the CH_4 content of the Proterozoic atmosphere. Characterization of the Proterozoic greenhouse is further complicated by: (1) strong nonlinearity in biospheric CH_4 fluxes as a function of marine SO_4^{2-}, which arises because both CH_4 production and CH_4 consumption are affected by SO_4^{2-}; and (2) strong nonlinearity in the atmospheric lifetime of CH_4 as a function of atmospheric pO_2, which reflects the competing effects of O_2 content and UV shielding by ozone in oxidizing atmospheres.

We use an Earth system model to quantify CH_4 fluxes on the Proterozoic Earth and to critically evaluate the role of CH_4 in regulating Proterozoic climate. Our model consists of a 3D marine biogeochemical model, a 2D climate model, and a 1D atmospheric photochemical model. We find that although oxidant-deficient conditions in the Proterozoic would have allowed substantial CH_4 production in, and escape from, the ocean, CH_4 survival in the atmosphere would have been severely limited by rapid photochemical destruction under the atmospheric pO_2 conditions suggested by the Proterozoic Cr isotope record ($<10^{-3}$ times present atmospheric level). Thus, in light of recent pO_2 constraints, our numerical results suggest the absence of a substantial CH_4 greenhouse and introduce a potential Mesoproterozoic climate paradox. Our results, however, do not preclude a critical role for CH_4 in triggering Neoproterozoic climate collapse. Instead, our model highlights a dynamic relationship between atmospheric O_2, the marine biosphere, and climate, and provides a novel mechanism for triggering Snowball Earth events via perturbation to the CH_4 cycle.

We suggest that a minor oxygenation event in the Neoproterozoic enhanced UV shielding of CH_4 via ozone and allowed the buildup of a CH_4 greenhouse—which resulted in the drawdown of atmospheric CO_2 to precariously low levels through silicate weathering feedbacks. In this scenario, the resulting CH_4 greenhouse is inherently unstable because rapid destabilization of the atmospheric CH_4 reservoir would be triggered by either: (1) a return to low O_2, as suggested by some proxy records, or (2) the accumulation of SO_4^{2-} in the ocean as a consequence of progressive Earth system oxygenation, which would severely throttle CH_4 supply via inhibition of methanogenesis and enhanced anaerobic oxidation of CH_4. Regardless, during the ensuing glaciation, inhibition of chemical weathering, combined with continued anaerobic respiration, would allow dramatic reduction of the marine SO_4^{2-} reservoir—priming the marine biosphere to generate huge CH_4 fluxes upon deglaciation and leaving the Earth system vulnerable to repeated climate perturbation until a critical oxygenation threshold was achieved in the latest Neoproterozoic or later.