THE THERMODYNAMICS OF LIFE ON A PLANETARY SCALE. S. D. Domagal-Goldman[1,2] and S. Som[2,3,4], [1]NASA Goddard Space Flight Center, 8800 Greenbelt Road, Greenbelt Road, Greenbelt, MD 20771, USA (email: shawn.goldman@nasa.gov), [2]Virtual Planetary Laboratory, Seattle, WA 98125, [3]Blue Marble Space Institute of Science, Seattle, WA 98019, USA, [4]NASA Ames Research Center, Moffett Field, CA 94035, USA.

It is known that atmospheric methane (CH_4) concentrations could have been much higher on Archean Earth. Because CH_4 is an efficient greenhouse gas, this may have contributed to solutions to the faint young Sun paradox[1]. Additionally, H_2 has been proposed as an important greenhouse gas for Archean Earth [2], early Mars [4], and exoplanets [5]. However, there are previously unconsidered feedbacks in this system. The conversion of H_2 and CO_2 (or CO) to CH_4 by biology is temperature-dependent, because of changes to the Gibb's free energy for CH_4 production from biology, and because the maintenance energy of organisms (the minimum amount of energy required by biology to fix what the environment breaks) is higher at increased temperatures [6]. We will present a study of these feedbacks that leverages a suite of models. Specifically, we couple a thermodynamic model (after 6) to calculate the relationship between surface temperature and biological CH_4 production, a photochemical model (7) to predict the resulting H_2 and CH_4 concentrations, and a climate model (8) to predict the effects of this on surface temperature

The ecosystem model is based on the work of Hoehler (6). It utilizes Geochemists' Workbench (9) to compute dissolved equilibrium concentrations of CO_2 and CH_4, which are then diffused into a single-cell bioenergetic model [10]. We use this model to predict the "H_2 demand" of biology to produce a certain amount of CH_4 at a given temperature and dissolved inorganic carbon concentration. The photochemical model is a 1-D code that solves the mass balance equations for 74 species connected by 392 reactions. It predicts the vertical profiles of each species. This model has been previously used to simulate low-$_{O2}$ atmospheres, in particular those of Archean Earth [7]. We use this model to simulate the atmospheric response to biological H_2 demand and CH_4 production. The climate model is a 1-D radiative-convective code (8) that uses k-coefficients to simulate the radiative effects of H_2O, CO_2, and CH_4, and includes absorption cross sections from H_2 and collision-induced features of CO_2. This model predicts surface temperatures, given the atmospheric state from the photochemical model.

We will present preliminary results from this model. These will include a study of the strength of the feedbacks between CH_4, temperature, and biological productivity, and identification of stable points in the CH_4/temperature/productivity system, and resulting insights into the climate of Archean Earth. Additionally, we will discuss the implications of these feedbacks for other planets, including ancient Mars and H2-dominated exoplanets.

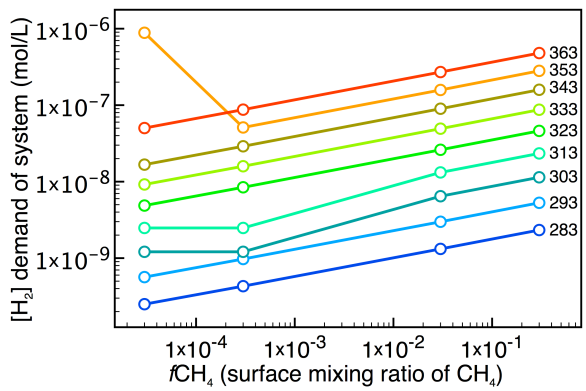

Figure 1. H_2 demand on an ecosystem to maintain different surface CH_4 mixing ratios, as a function of temperature. At higher temperatures, it takes more H_2 to maintain a given CH_4 concentration. This creates stable points in the system (so long as a thick haze is not present). For example, increases to CH_4 concentrations would lead to increased surface temperatures, but that would lead to a lower CH_4 concentration given the H_2 present in the system.

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