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Biosignatures independent of population dynamics

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With the characterisations of potentially habitable exoplanet atmospheres on the horizon, the search for biosignatures is set to become a major area of research in the coming decades [1]. To understand the atmospheric characteristics that might indicate alien life we must understand not only the abiotic characteristics of a planet but also how life interacts with its planet as a coupled system. In the field of biogeochemistry, sophisticated models of life-environment coupled systems are used to accurately model marine ecology. These models demonstrate that many assumptions specific to Earth-based life, e.g. specific ATP maintenance costs, are unnecessary and that a biosphere can be reduced to a few well-defined assumptions (e.g. [2]). Determining the minimal number of assumptions needed to accurately model biogeochemical reactions will be key for forming biosignature hypotheses for exoplanets.

We developed a simple model of a single-species biosphere consisting of methane producing microbes, interacting with a well-mixed ocean. Via gas-exchange between the atmosphere and the ocean, life impacts the atmospheric composition and in turn the average surface temperature of the planet - in our model determined by a state-of-the-art climate model [3]. We set up our abiotic environment such that hydrogen is the limiting resource on microbe growth. We demonstrate that while significantly changing the biological parameters describing the microbes, such as their average lifespan, can have a large impact on the total population of the biosphere, such changes have a minimal impact on the strength of the resulting biosignature, in our case atmospheric methane. Conversely, changing the abiotic input of hydrogen to the system (via e.g. increased volcanic activity) has a large impact on the abundance of biologically produced methane in the atmosphere. We find that it is more important to identify the limiting resource of the biosphere and understand the abiotic processes that control its abundance than to understand the details of the population dynamics of the biosphere when considering potential exoplanet biosignatures.

[1] Quanz et. al. (2021) Experimental Astronomy, 1-25

[2] Lenton, Daines & Mills (2018) Earth Science Reviews. 178, 1-28

[3] Mayne et al. (2014) Geosci. Model Dev. 7, 3059–3087