Geoscientific Model Development Discussions

Geosci. Model Dev. Discuss., referee comment RC1
https://doi.org/10.5194/gmd-2022-12-RC1, 2022

Comment on gmd-2022-12

Anonymous Referee #1

Referee comment on "CANOPS-GRB v1.0: a new Earth system model for simulating the evolution of ocean–atmosphere chemistry over geologic timescales" by Kazumi Ozaki et al., Geosci. Model Dev. Discuss., https://doi.org/10.5194/gmd-2022-12-RC1, 2022

Review of “CANOPS-GRB v1.0: a new Earth 1 system model for simulating the evolution of ocean-atmosphere chemistry over geologic timescales”

This paper describes a new version of the CANOPS Earth system model, CANOPS-GRB (Global Redox Budget). The main improvements of this model over previous versions include dynamic atmospheric O_2, sedimentary reservoirs that evolve self-consistently with the atmosphere-ocean system, and a simplified global redox budget. Collectively, these improvements make the model suitable for investigating long timescale geochemical evolution, but with the benefits of resolving ocean transport and sediment diagenesis. Model outputs are validated against the observed modern Earth steady state, and example time-evolution calculations are also presented to illustrate feedbacks on multiple timescales.

I will preface this review by saying evaluating the validity of model assumptions in the abstract is challenging; the appropriateness of the chosen functions, parameterizations, and simplifications are strongly context dependent. However, I have no doubt that this manuscript and open-source model it describes will be incredibly valuable to the biogeochemistry community. The authors ought to be commended for such a thorough description of model features – this will be invaluable for trying to understand future applications of the model. I don’t have any major criticisms – the primary limitations of the model are largely already identified and discussed in the manuscript. However, I do have several minor suggestions for improvement:

The Introduction motivates the CANOPS-GRB model through a discussion of terrestrial exoplanets and exoplanet biosignatures such as oxygen and methane. Moreover, the abstract mentions exoplanet biogeochemistry as one potential application of CANOPS-GRB. It would be helpful if the discussion also had a paragraph or two on both the potential and limitations of the current model for terrestrial exoplanets. For example, by adopting the Claire et al. photochemical parameterization and by omitting a climate model, the ability to investigate O2-CH4 biosignatures is limited to Earth-twins around a sun-like stars (see also line 351). Obviously, these parameterizations could be modified to accommodate different stellar types etc., but I think it is helpful to make the current limitations of the model clear to the exoplanet community.

Line 229-230: I appreciate that the omission of Fe^{2+} is discussed later in the paper, but it might be worth mentioning this here (e.g. see discussion of iron species below) since upon first reading I immediately wondered why the iron budget was being ignored.

Line 291-292: Neglecting the inorganic carbon cycle is an interesting choice that merits more discussion. To be clear, I understand the reasoning behind this simplification – carbon cycle feedbacks are uncertain and introduce more unconstrained complexity to an already complex model. However, changes in inorganic carbon cycling have been proposed as drivers of atmospheric oxygenation (e.g. Williams et al. 2019; Nature Communications), and the 13C record provides a useful sanity check on any proposed oxygenation story. Neglecting the inorganic carbon cycle also means climate feedbacks are absent, which prevents the model from exploring the coevolution of life and the environment in many deep time contexts. More discussion of these limitations would be helpful in preventing misapplications or misunderstandings of the model.

Line 329: 14.3 Tmol/yr total organic carbon burial feels a bit on the high side. For example, see the compilation of estimates in Table 1 of Kipp et al. (2020; Global Biogeochemical Cycles). Similarly, organic weathering in CANOPS-GRB is about double most literature estimates. The discrepancy is noted on line 1368, but I am left wondering why such a high organic carbon flux is required. Given isotope mass balance, a high organic burial flux would also imply quite a high total carbon burial flux, which potentially conflicts with other literature estimates.

Equation 2: This is another place where it might be worth mentioning that climate feedbacks on silicate weathering are an important omission that could have consequences for global redox.

Line 458: Although this is stated later in the manuscript, this discussion of sulfur oxidation might be a good place to mention that the model in its current form is not suitable for modeling the Archean atmosphere-ocean system.

Section 2.4.2: I appreciate that the vertical and horizontal transport parameterizations developed here are carefully validated later in the paper. However, one unanswered question I had is how well do the authors expect these parameterizations to work when they are applied to radically different surface climates in deep time (e.g. hothouse Earth, snowball Earth)? Some discussion of this might be helpful for readers considering applying the model to different times in Earth's history (or indeed different exoplanet climates, continental configurations etc.)

Equation 108 and 109: It's possible I'm misunderstanding a sign convention here, but it's not clear to me why H escape represents a loss of oxygen mass from the atmosphere system. The signs in equations (13) and (14) seem more intuitive. A word of explanation would be helpful.

Finally, somewhere in the paper (perhaps in the introduction) it would be helpful to provide a brief history of the CANOPS model and its previous applications. This would help give the reader a better appreciation of the recent GRB improvements, as well as how the improved model might be applied.