Earth System Dynamics Discussions

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Comment on esd-2022-46

Anonymous Referee #1

Referee comment on "Multi-million year cycles in modelled $\delta^{13}C$ as a response to astronomical forcing of organic matter fluxes" by Gaëlle Leloup and Didier Paillard, Earth Syst. Dynam. Discuss., https://doi.org/10.5194/esd-2022-46-RC1, 2022

Leloup and Paillard present a new model to link astronomical forcing with multi-million-year oscillations in Earth's carbon cycle. I will immediately admit to not being an expert on astronomical forcing of Earth's surface environment or the mathematical modelling of how different modulations may have influenced surface processes. As such, it is difficult for me to make detailed comments about the modelled approach. However, I do have some general thoughts on the assumptions made by the model.

The authors are very open about the fact that this is a very simple model and that they have been unable to include several processes that may complicate the relationship between astronomical forcing and the carbon cycle. I am the first to acknowledge that any model of geological processes has to make simplifications, and that it is impossible to consider every possible control. However, I do worry that there are some potentially major factors that have not been considered, and whose exclusion from the model makes it potentially unrealistic.

Firstly, and very importantly, whilst the rate of organic-carbon burial is indeed related to global oxygen levels, the reverse is also true. Several studies have highlighted that a large increase in organic-matter deposition will cause surface oxygen levels to rise (see e.g., Lenton and Watson, 2000, Global Biogeochemical Cycles; Berner, 2004, Oxford University Press; but there are many others). It's not clear whether the authors have considered this as a two-way process. On the subject of oxygen, at the moment the model seems to consider surface oxygen as a single inventory of oceanic and atmospheric oxygen levels, but the reality is that different parts of the marine realm can be very oxygen depleted regardless of overall oxygen levels. This is particularly the case for for small restricted epicontinental basins, and these varied in abundance due to tectonic configuration at various times in Earth's past, and were highly influenced by local processes and sea level changes, both of which are related to astronomical forcing. Also, the authors consider oxidation of non-carbon elements as an important control, but not the potential reduction of these elements, which I find curious. And what about sulfur and phosphorus?

I also wonder if the authors have considered the potential role of terrestrial organic-

matter burial in their model. Of course, organic carbon burial in the ocean will typically be the more important sink, but there are times in Earth's history when terrestrial burial is thought to have had a massive influence on the global cycle, most famously during the Late Devonian–Carboniferous, but also in the Mesozoic (e.g., Valanginian; see Westermann et al., 2010, EPSL). This is important because the terrestrial sink is likely controlled by very different factors (not directly linked to surface oxygen) than the marine sink.

If it isn't possible to incorporate these factors into the model, then at the very least there needs to be more open consideration of them (as well as other processes which will vary over time). But as things stand, I worry that the list of missing controls is so long at present that the model cannot really be a strong representation of reality, and that at least some of them need to be included as separate terms regarding the sources and sinks of carbon and oxygen etc.

Minor comments:

Line 51: Here 'favour' is written. Elsewhere it is 'favor'. Be consistent.

Line 99: A constant fractionation factor of -25 per mil for organic matter is a probably a big assumption given the differences in different organisms, and especially following the rise of C4 plants in the Cenozoic (considering that this paper discusses that time interval).

Line 117: How is the carbon cycle forced astronomically? Simply invoking an unnamed link feels rather vague to me.

Lines 132–133: Yes, but this will not be evenly distributed and even when surface oxygen levels rise, there can still be places in the ocean that can be very anoxic.

Line 154–155: This will then cool the climate and reduce organic-matter oxidation, raising surface oxygen levels, both of which will act to mitigate the organic-carbon burial.

Lines 162–168: What are 'lower', 'intermediate', and 'higher' carbon values defined as? What range?

Line 175: '…we place ourselves here in one of the simplest case possible.' is rather casual language for me.

Line 201: I assume that the organic-matter burial being referred to here is oceanic. What about terrestrial organic-carbon burial?

Line 258: What about reduction of other elements?

Line 422: I'm not sure a mechanism is being proposed per say. It's been assumed that astronomical forcing influences carbon supply vs burial and oxygen levels, and that long-term cycles can be reproduced for a certain set of parameters. But this is all very theoretical still and there isn't a cause-and-effect link proposed for how the astronomical forcing is influenced these carbon and oxygen sources and sinks. For me, that would be the mechanism.