Earth System Dynamics Discussions

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Comment on esd-2022-46

Anonymous Referee #2

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-RC2, 2022

Peer review of „Multi-million year cycles in modelled d13C as a response to astronomical forcing of organic matter fluxes".

In this paper, the authors built a simplified numerical representation of the carbon cycle, assuming a mass balance without carbon reservoirs (and hence no lag-times there), unlimited nutrients (otherwise organic burial B would also depend on weathering W), and with constant $[Ca^{2+}]$ concentration in the ocean. Without applying any forcing, their model evolves into steady-state equilibrium when the oxidation of other elements than organic carbon (Ox) increases steeply with oxygen content (O). When the Ox term increases less steeply with O, the model produces oscillations in d13C without any astronomical forcing. Finally, the authors add an eccentricity forcing to the burial of organic carbon and they observe that the resulting d13C is oscillating with preferential periodicities of 2.4, 4.8 and 7.2 Myr. The authors thus built a model that is prone to oscillate at multi-million-year timescales between multiple equilibria, and by adding the forcing they are making sure that the model resides around one equilibrium value until the astronomical forcing becomes strong enough to push the system towards the second equilibrium. Finally, the authors compare their model results to the Westerhold et al. (2020) benthic d13C compilation and point out to the reader that the multi-million-year oscillations in this record could be the result of self-sustained oscillations in the Earth system.

Major concern.

This is a nice "back-of-the-envelope" carbon cycle exercise, but I do not see the immediate merit in this paper. The authors set the model variables such that it is prone to produce multi-million-year cycles. They force it with an eccentricity cycle (including the 2.4 Myr component) and come back home with a simulated d13C signal that emphasizes these same 2.4 Myr cycles, as well as multiples of that cycle. I would be interested to read

why the authors believe their approach provides additional insights into the behavior of the carbon cycle in addition to other previous attempts to simulate the global carbon cycle. I am especially thinking about Bachan et al. (2017), who reports on carbon cycle stabilization pathways in response to a sinusoidal forcing.

I also feel that some simplifications in the model need to be more clearly justified. It seems contra-intuitive to de-couple silicate weathering from the organic carbon flux (B does not depend on W). The ocean cannot recycle the same nutrients ad infinitum. You have to introduce new nutrients to compensate for the ones lost to mineralization and burial. Those nutrients come from terrestrial weathering. Moreover, that weathering also modulates the availability of alkalinity, which balances out the atmospheric CO2, and allows for calcification. One ends up with a triangle of calcification (take alkalinity and nutrients, releases CO2), weathering (take CO2, releases alkalinity and nutrients) and organic matter burial (take CO2 and nutrients). But these three are not in phase with each other, which in itself already results in an oscillatory pattern.

Bachan, Aviv, et al. "A model for the decrease in amplitude of carbon isotope excursions across the Phanerozoic." American Journal of Science 317.6 (2017): 641-676.

Minor concern.

The y-axes in Figures 2 and 3 are incorrectly labeled.

- In Figure 2, the y-axis represents B, not dC/dt. My suggestion would be that the authors hatch the area in-between the organic and inorganic terms and label them with dC/dt>0 when the inorganic term is larger than the organic term, and vice versa.
- In Figure 3, the y-axis represents B for the green curve and Ox for the blue curve. Not dO/dt. Again, here the authors could hatch