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Interactive comment on "Causes and timing of future biosphere extinction" *by* S. Franck et al.

S. Franck et al.

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Reply to Dr. T. M. Lenton (referee 1)

1. We think that the title of the manuscript is more appropriate than the proposed one. We have investigated both the timing and the causes of extinctions.

2. The revised abstract contains the numbers of the total life spans of each biosphere type.

3. Lovelock and Whitfield have used a semi-quantitative model, e.g. they proposed a simple relation between evolution of solar luminosity and atmospheric CO_2 content.

4. In principle our model can attribute different biotic enhancement factors of weathering to each life form. But as a first approximation we considered a biotic enhancement of weathering only by complex multicellular life ($\beta_1 = \beta_2 = 1, \beta_3 > 1$). According to Schwartzman (1999, Fig.8-3) complex multicellular life contributes about 7 times more to the biotic enhancement of weathering than primitive life.

5. To illustrate equations (1)-(6) we have added in the revised manuscript a box diagram with the basic mechanisms and interactions of the global carbon cycle. Some of the fluxes depend on reservoir sizes, e.g. F_{weath}=F_{weath}(C_{o+a},C_c). Such dependencies on reservoir sizes are now explicitly marked in the set of equations. This makes the calculation of the steady state solution difficult.

6. Corresponding formulations are included in the revised manuscript.

7. The referee is right, that the equation (9) needs a modification. We are now using a multiplicative ansatz for the biotic enhancement factor β:

$$\beta = \prod_{i=1}^{n} \left(\frac{1}{\beta_i} + \left(1 - \frac{1}{\beta_i} \right) \frac{\Pi_i}{\Pi_i^*} \right) \tag{1}$$

.

This is a generalization of the formula given by Lenton and von Bloh (2001). For the specific set of used β_i ($\beta_1 = \beta_2 = 1, \beta_3 > 1$) the results for β are identical to the results of the old formulation.

8. In order to investigate the influence of the temperature tolerances on the results we applied a second parameter set based on Schwartzman (1999). We find that the specific life spans of eucaryotes and complex multicellular life extend by some hundred million years. The ultimate life span determined by the extinction of the procaryotes stays remarkably constant.

The biosphere pool has the fastest turnover time of all carbon pools and therefore stays always in equilibrium. The ratio of Π_{max} and τ_{bio}^{-1} yields the maximum equilibrium value of biomass. Choosing $\tau_{bio,i}$=6.25 yr and $\Pi_{max,i}$=40 Gt/yr we get an aggregated maximum biological productivity of 120 Gt/yr, which is identical to the proposed value of the referee. Such a change would have no influence on the model results.

P_{min} is a typical lower limit for C4 photosynthesis. We assume that in future procary-

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otes and eucaryotes can adapt to such low CO_2 concentrations. An adaptation to lower CO_2 concentrations seems to be easier than to higher temperatures.

Changes of $P_{1/2}$ have only minor influence on the model results. Therefore we assume identical values for all life forms.

9. We examined a second set of potentially critical parameters by using values of Schwartzman (1999) for the upper temperature limit as already mentioned in 8.

10. We agree with the reviewer and will comment in the revised manuscript.

11.+12. Up to -1.75 Gyr there is only a unique solution (no bistability). Therefore, the Huronian glaciations circa 2.4 Gyr ago cannot trigger a prematurely emergence of eucaryotic or even complex life. On the other hand, Neoproterozoic snowball Earth events have the potential to initiate an earlier appearance of complex life forms. However, these global glaciations are followed by a global hot house (Hoffman and Schrag, 2002) that immediately pushes the temperatures again above the upper tolerance limit. This is mentioned in the revised manuscript.

13. The reviewer is right that the appearance of vascular plants is not linked with the Cambrian explosion. According to our view, the rise of lichens (complex multicellular life form) happened with the Cambrian explosion and is a causal factor of global cooling.

14. There is evidence for small metazoans and multicellular algae well before the Ediacarans (appeared 600 Myr ago), but they had no influence on weathering and possibly a higher temperature tolerance.

15. It is right that β could exceed the value of 5 as found in experimental and field studies. For the Schwartzman parameterization of the temperature tolerance we get β=17.5.

16. We marked as dashed lines the time of the Cambrian explosion (horizontal) and the corresponding value of the biotic enhancement factor (vertical). Rotating the figure by 90 deg would decrease the resolution of the (3 axis and is therefore not desirable.

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All technical corrections were taken into account.

We want to thank Dr. Lenton for his constructive remarks that helped to improve the quality of the manuscript.

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