Response to Yves Godderis

We thank Yves Godderis for his positive comments about the development of the TAlkEaSy model, our review of existing models, and the clarity of the model description.

The main comment to show sensitivity analyses of the model outputs to key parameter choices and associated process assumptions is very well taken.

In response, we have undertaken a thorough exploration of the effect of uncertain parameters and processes and identified a subset of 7 that have significant effects on the results of the idealised experiments (Table R1).

In revising the paper, we intend to show the effect of these different changes on the model response to a progressive increase in degassing, as that most clearly demonstrates their effects. We have already prepared these results (e.g. Figures R1, R2) and will discuss them in the revised paper.

All the minor points are well taken and will be addressed:

We will clarify that the current GEOCLIM v7 does not include a nitrogen cycle.

We are fully aware that carbonate precipitation on the ocean floor is governed by the depth of the lysocline and that a power law of saturation state may not accurately capture this dynamic. This is a limitation of the one box ocean formulation. We have constructed a more sophisticated version of TAlkEaSy with a multi-box ocean and have explored whether explicitly resolving lysocline and carbonate compensation depth affects the main model predictions. This is beyond the scope of the present paper describing the simplest version of the model. Nevertheless, what we discovered is that including a variable lysocline and CCD does not significantly alter the prediction of key variables including CO_2, O_2 ocean major ion concentrations and total alkalinity (TAlk). This will be described in separate work.

We agree that total net primary productivity (NPP) on the continents could include a dependence on water availability. Here we can draw on the work of Gurung et al. (2022) who suggest a sigmoidal dependence of water availability on the runoff forcing. We have already experimented with including this and intend to show its effect in the revised paper. Essentially, increased runoff increasing terrestrial NPP tends to lower CO2 and increase O2.

We intend to address the comments on the temperature of low-temperature hydrothermal interactions and ocean-atmosphere coupling together, adopting the suggestion to use empirical correlations from GCM runs to establish the relationship between global mean surface temperature (GMST) and deep ocean temperatures. Specifically, we will adopt the relationship derived from paleoclimate simulations with HadCM3L by Valdes et al. (2021). Their Figure 11 plots GMST against deep sea temperature (DST), giving an overall slope of 0.64 (reported range 0.59–0.69), with $R^2 = 0.74$ (Valdes et al., 2021). Anchoring the relationship to the present day GMST (15°C) and DST (1.5°C) gives:

$$DST = 1.5 + \frac{GMST-15}{0.64} \quad (1)$$

We intend to use the resulting DST to drive seafloor weathering (*sfw*) and low-temperature hydrothermal interactions, showing how this alters the main model results.

We will revise the model to use dynamical functional forms of the carbonate speciation constants, affected by temperature, salinity and pressure. Using constants was an oversight in the original formulation.

Regarding the biogeochemical response to CO_2 degassing events, as represented in the model, this does tend to increase ocean anoxia, which is recognised as a major cause of past marine mass extinction events, which are primarily recorded in animal phyla (not primary producers). It is just that in the idealised model experiments the background state of the ocean (for the present day) is relatively well oxygenated, so the response is small. The effect is much more pronounced if the baseline anoxia is greater, as it was at times of mass extinction in the past. We will discuss this in revising the paper.

The typo spotted will be corrected.

Thanks for the generous evaluation and useful suggestions.

References

Gurung, K., Field, K.J., Batterman, S.A., Goddéris, Y., Donnadieu, Y., Porada, P., Taylor, L.L., Mills, B.J., 2022. Climate windows of opportunity for plant expansion during the Phanerozoic. Nat. Commun. 13, 4530.

Valdes, P.J., Scotese, C.R., Lunt, D.J., 2021. Deep ocean temperatures through time. Clim. Past 17, 1483–1506.

Table R1. Sensitivity analyses.

Run No.	Description
1	Default run
2	Change biotic weathering rates (k_{15}: $0.15 \rightarrow 0.30$), to test the effects of land vegetation on continental weathering rate and inorganic carbon cycle.
3	Increase the fraction of phosphorus buried on land (k_{11}: $0.0588 \rightarrow 0.1176$), to test the effects of enlarged vegetation feedbacks on land phosphorus and organic carbon cycles.
4	Decrease the ratio of carbon to phosphorus in marine organic matter (k_{anoxic}: $4000 \rightarrow 2000$), to test the effects of weaker anoxia-dependent phosphorus recycling on the marine phosphorus and organic-carbon cycles.
5	Increase seafloor weathering thermodynamic rates (k_T^{sfw}: $0.0608 \rightarrow 0.1216$), to test their contribution to global carbon cycle and related ocean major ion concentrations.
6	Strengthen the feedbacks between ocean major ion concentrations and reverse weathering fluxes by a square relationship ($rw_{Mg,Na,K}$: $\propto \left(\frac{Mg,Na,K}{Mg,0,Na,0,K,0}\right)^{1.0} \rightarrow \propto \left(\frac{Mg,Na,K}{Mg,0,Na,0,K,0}\right)^{2.0}$), to test stronger and nonlinear effects to global carbon cycle and related ocean major ion concentrations.
7	Strengthen the feedbacks between degassing forcing and high-temperature hydrothermal fluxes by a square relationship ($hydhT_{Mg,Ca,Na,K}$: $\propto DEGASS^{1.0} \rightarrow \propto DEGASS^{2.0}$), to test their contribution to global carbon cycle and related ocean major ion concentrations.
8	Double the temperature-sensitivity coefficient of the low-temperature hydrothermal process to test its contribution to global carbon cycle and related ocean major ion concentrations.

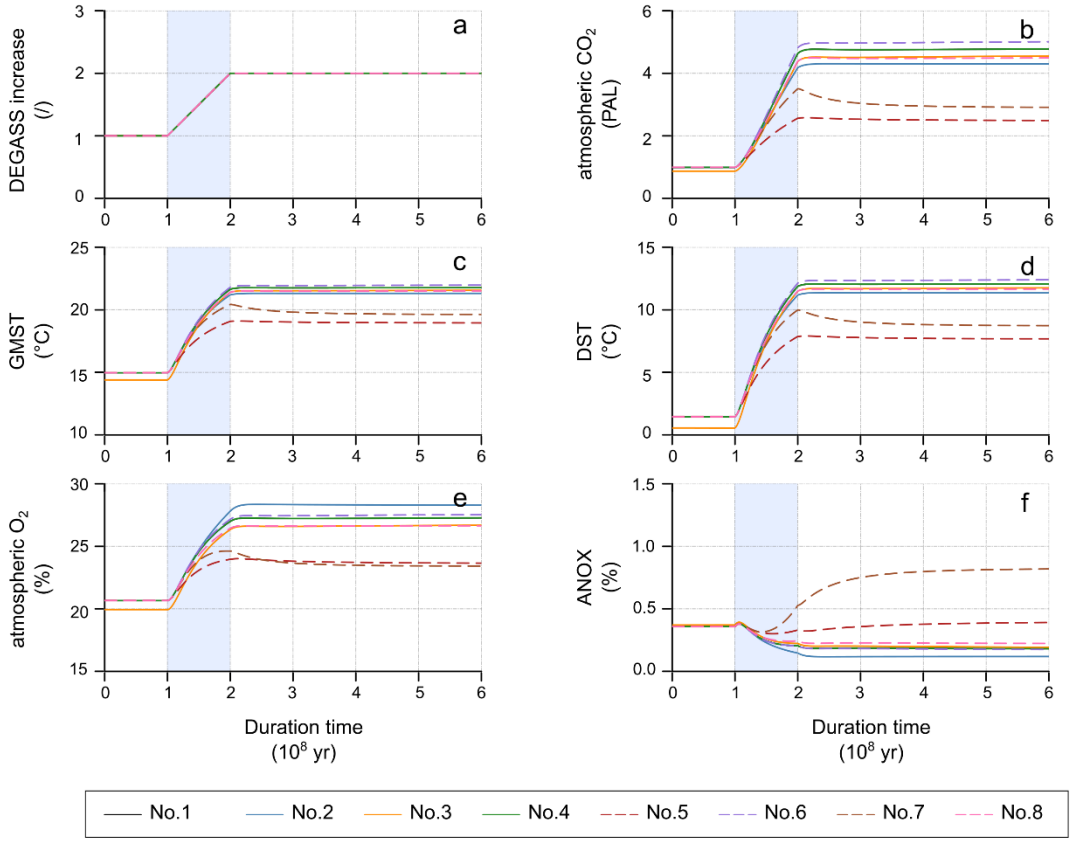


Figure R1. Sensitivity analysis of global carbon and oxygen cycle responses to increasing degassing. (a) Degassing increase. (b) Atmospheric CO_2. (c) GMST. (d) DST. (e) Atmospheric O_2. (f) ANOX.

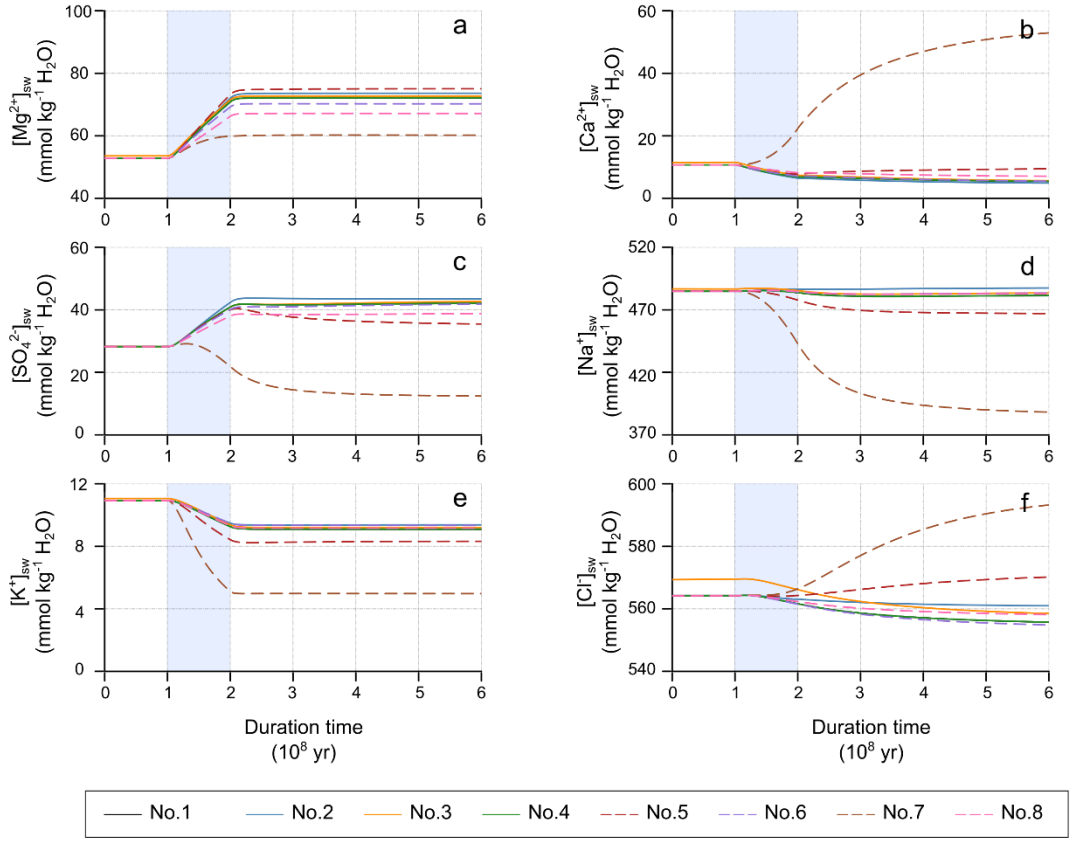


Figure R2. Sensitivity analysis of changes in ocean major ions to increasing degassing. (a) $[Mg^{2+}]_{sw}$. (b) $[Ca^{2+}]_{sw}$. (c) $[SO_4^{2-}]_{sw}$. (d) $[Na^{+}]_{sw}$. (e) $[K^{+}]_{sw}$. (f) $[Cl^{-}]_{sw}$.