Replies to Reviewer #1

We thank the reviewer for their critical assessment and positive comments on our manuscript. We also thank them for their keen eye in spotting various typos and slips. Below we explain how we will address every suggestion during the revision of the manuscript. The reviewer's comments are in blue and our replies in black.

Suggestions on methodology and evaluation of results

(1) From the perspective of judging the result, I suggest adding the observed modern states, for example, the marine carbonate contents, and comparing the observed data with the absolute predicted data the model predicted. This steady state comparison would provide more convincing results for the improvement of the model. Could the observed data figures be added to Figure 4 and Fig. SI.6? Please consider.

We appreciate the motivation behind the reviewer's suggestion and are adding a comparison of the modern steady state solution from simulation PI-C-open and the observed modern carbonate system to the SI (Fig. SI.8) for context. We keep this comparison out of the main text because the purpose of our model development is not to improve the representation of the modern state but to improve the capability of the model to solve the carbonate system for oceans with Mg/Ca ratios unlike the modern. The MyAMI-derived K* that we use for this purpose have previously been validated against experimental data and theoretical models (Hain et al. 2015). In fact, our model development has slightly shifted the simulated modern carbonate system away from the previously observationally tuned modern state. In order to be able to propagate the MyAMI K* values into the calculating of carbonate preservation in deep-sea sediments, we switched from the look-up table of Ridgwell and Hargreaves (2007) to the explicit 1-D reaction transport calculation of Archer (1991). In doing so, we have somewhat lost the original sediment calibration against data of Ridgwell and Hargreaves (2007) but the differences are small (Fig. 4 in the manuscript) and our purpose here is to simply illustrate the implications of available (or none) Mg/Ca corrections in preparation of a new model release. We are currently working on a series of related GMD papers to fully describe the current state of the cGENIE universe, and one of these papers will include new parameter calibrations for a range of cGENIE applications, including geological carbon cycling and carbonate burial, and we will fully evaluate the fidelity of previous (muffin) vs. new (cookie) carbon cycle calibrations there.

Hain, M.P., Sigman, D.M., Higgins, J.A. and Haug, G.H., 2015. The effects of secular calcium and magnesium concentration changes on the thermodynamics of seawater acid/base chemistry: Implications for Eocene and Cretaceous ocean carbon chemistry and buffering. *Global Biogeochemical Cycles*, *29*(5), pp.517-533.

Hain, M.P., Sigman, D.M., Higgins, J.A. and Haug, G.H., 2018. Response to comment by Zeebe and Tyrrell on "The effects of secular calcium and magnesium concentration changes on the thermodynamics of seawater acid/base chemistry: Implications for the Eocene and Cretaceous ocean carbon chemistry and buffering". *Global Biogeochemical Cycles*.

Ridgwell, A., Hargreaves, J.C., Edwards, N.R., Annan, J.D., Lenton, T.M., Marsh, R., Yool, A. and Watson, A., 2007. Marine geochemical data assimilation in an efficient Earth System Model of global biogeochemical cycling. Biogeosciences, 4(1), pp.87-104.

Ridgwell, A. and Hargreaves, J.C., 2007. Regulation of atmospheric CO2 by deep-sea sediments in an Earth system model. *Global Biogeochemical Cycles*, *21*(2).

(2) Another suggestion is that it might be useful to add one or two depth-resolved profiles of other variables like Figure 8, to illustrate how the revised chemistry affects the deep ocean.

We will follow the suggestion and add a SI figure (Fig. SI.5) with additional depth transects for carbonate and bicarbonate ion, pH and calcite saturation.

Main text

Line 54: Suggest the electric charge should be marked on the top right as line 56 does.

Thank you for pointing this out. We will correct this as suggested.

Line 193: Typo, two "K1", the second one should be "K2".

We thank the reviewer for spotting this oversight and will correct it.

Line 232: Suggest writing clearly the abbreviation of what "fCO2" is. It is not mentioned in the preceding text.

We will add that fCO2 refers to the fugacity CO_2.

Line 240: Typo, missing the right bracket.

We will correct this.

Line 246: E25 is wrong. It should be around "0.028", not "0.000416" (this is boron value).

We thank the reviewer for spotting this error and will correct it.

Line 264, 269: Typo, should be “Ω”, not “W”.

We will correct this.

Line 275-278: Suggest rechecking about the unit. If “T” multiply “R”, they should both in “K”.

Thank you for spotting this, we will correct the unit of “T” to “K”.

Line 277-279: Typo, should be “ΔVV”, not “DV”.

We will correct this.

Line 299, 342: Suggest writing clearly the abbreviation of what “F77, f90” is.

We will correct this.

Line 360: Typo, it should be “ppm” not “pm”.

We will correct this.

Line 503-505: Suggest reorganizing the sentences. “Ω increase is largely due to the [CO32-] and, to a lesser extent, the increased Ksp,cal”, is opposite to the E28 and basic understanding.

Yes, this sentence was wrong, thank you for alerting us. We will change it to: “In the deep Atlantic, the advected [CO_3^{2-}] increase compensates for the slightly increased Ksp,cal to cause a small Ω increase”.

Line 693: Typo, “experiment”.

We will correct this.

Line 758-759: The reference format is different from others.

We will correct this.

Figures in main text

Figure 2: Suggest the name of the explanation of the figure should be changed. Not “in situ K1”, but “Ks” because “K1”, “K2”, and “Ksp,cal” are all compared.

We will correct this.

Figure 3, 6: Suggest making clear the depth ranges of ocean “surface” and “benthic”. This might be already defined in the cGENIE model. A brief explanation for this could help the readers understand the difference of “surface” and “benthic” more clearly.

We will add the following explanatory sentence to the caption of Figure 3: “The surface layer represents the uppermost 81 m of the water column and benthic values are from the deepest ocean grid box in every location.”

Figures in supplementary information

Fig. SI.2,3: Typo, missing “K” in each plot title.

We will correct this.