RESPONSE TO ANONYMOUS REFEREE #1 COMMENTS (JUNE 2020)

Referee #1:

General Comment: "Deep time climate and ecosystem reconstructions are challenging. Understanding how Earth's climate, tectonic and ecosystem modifications are linked represent an interesting advance. Consequently, this paper is an important contribution. Overall the article is well written however the discussion can be improved (not enough well organized). I identified several areas requiring clarification (listed below). These problems being easily solvable, I recommend a minor revision (ranked by order of importance)."

Response: We thank reviewer #1 for their appreciation of this work.

Comment (1)**:** "The discussion is not very clear. Indeed short-term variations and long-term processes are included in same sub-sections without to distinguish between modeling results and proxy (for instance lines 191-225 introduce modeling results while lines 226-243 present short-term pCO2 variations and biological turnovers. I do not think this presentation is very clear for the reader, indeed these parts have no links (or there is something lacking)). Moreover the discussion about ecosystem perturbations is interesting but has a modest impact to understand links between paleo-pCO2 and biological events. To highlight their results, the authors may consider to split their discussion (long-term vs short term) or creating a new sub-section for presenting modeling results."

Response: We, respectfully, do not agree that the discussion needs to be reorganized. We chose to present the discussion holistically by integrating modeling and proxy components via time increments. That is, we present three segments that not only correspond to three climatically and ecologically unique intervals (Middle to Late Pennsylvanian, Asselian and Sakmarian portion of the early Permian, and the remainder of the early Permian) but also correspond to long term pCO_2 trends and important superimposed short-term trends. We strongly feel that removing the short-term trends into a separate section results in loss of context in relation to the long-term trends throughout the record.

That said, in order to resolve reviewer #1's concern that short- and long-term term CO_2 variability and processes are presented together in the discussion, we have reorganized the manuscript in the following manner:

We have altered lines 226-227 (**lines 230-232** after changes suggested by reviewers 1 and 2) to "Short-term fluctuations in pCO_2 are superimposed on the long-term decline through the latter portion of the Carboniferous. These short-term fluctuations have been confirmed as statistically significant (99.9 to 100% of estimates; Fig. 4b-d) and coincide with major environmental and biotic events." in order to provide a better segue the switch from discussion of the long-term trends to the superimposed short-term trends.

In addition, we have removed subsection 4.3 and rearranged and integrated that text into the latter portion of subsection 4.2 (**lines 351-382** after changes suggested by reviewers 1 and 2). In this manner, all sections in the discussion are now arranged by subsections that correspond to

time and CO_2 trends. Each subsection is structured such that the long-term proxy trends and model explanation of those long-term trends are discussed first, followed by discussion of short terms trend and their correlation ecosystem perturbation. This reconfiguration preserves the intended holistic presentation of the discussion while also clearing delineating long- and short-term trends within each subsection. We hope that this resolves the issue brought forth by reviewer 1.

***Comment (2)*:** "A few sentences of the discussion need to be rephrased or revised in order to reflect that initiation and deglaciation CO2-thresholds are different due to the climate hysteresis. Indeed the authors tend to consider the "CO2 glacial threshold" as an absolute value which determines the climate state of the Earth. The line 299 is correct because the final pCO2 (case at 270Ma, blue dote fig.5) is far above the glacial threshold however elsewhere even if the simulated CO2 overcomes the proposed glacial threshold, that does not mean the termination of the Late Paleozoic Ice Age. ex : line 314 (the sentence can be removed) ex : line 383-390 (this issue can be solved by adding error bars for age determination for each steady state - indeed boundary conditions used to force climate models have their own uncertainties, especially paleomagnetic data used to reconstruct paleographies)"

Response: We certainly did not intend to imply that the CO_2 threshold for initiation of continental ice was a threshold above which all glaciers would collapse. Also on the time scales at which we are dealing with in this paper (10s of thousands to millions of years), the time lag between the rise in CO_2 above a level at which continental glaciers can be sustained and the timing of glacier collapse determined by hysteresis (1000 of years) would not be discernable.

We have clarified the original statement (Line 314, **lines 335-339** after changes suggested by reviewers 1 and 2)) to address this by the following revision: "This finding, together with the hypothesized need (the aforementioned mechanism two) for minimally a 4-fold increase in mafic-rock outcropping in order to maintain CO_2 concentrations below the ice initiation threshold for a sustained period longer than that of hysteresis (i.e., throughout the interval of minimum CO_2 and apex of glaciation; Fig. 5), argues for a substantial increase in weatherability from the Carboniferous to early Permian driven by a compositional shift in outcropping rocks available for weathering to a higher mafic-to-granite ratio."

Concerning Lines 383-390 (**lines 401-409** after changes suggested by reviewers 1 and 2), we have added error bars to simulated steady-state CO_2 and $^{87}Sr/^{86}Sr$ trendlines, constrained by the simulated intervals (symbols on the figure) as requested.

***Comment (3)*:** "fig.3b. the chosen colour are misleading and implicitly suggests "anomalies". Moreover authors seem to assume two climate states characterized by a threshold close to 400ppmv of CO2. This point needs more explanation (why this threshold is so different compared to values used in fig.5 and published by Lowry et al. 2014 ?)"

Response: The 400 ppm value is not a threshold, but rather the mean value for the 16 million-

year record of atmospheric pCO_2 through the later Pennsylvanian reported in Montañez et al. 2016 and was used here as a guide solely. We have clarified this in the figure 3b caption (**lines 494-495** after changes suggested by reviewers 1 and 2).

***Comment (4)*:** "line 167. I don't understand how the duration of the "interglacial phase" has been estimated (104 yr). S6 suggests a range of values for the sedimentation rate. Why the duration does not seem to be affected by uncertainties (or explain why the duration does not depend on geological parameters)? In addition could you precise if the proposed duration (104 yr) is the mean value or the maximal value (or something else)? A brief paragraph summarizing limitations will be helpful for readers not familiar with this method."

Response: The Midcontinent and Appalachian cyclothems from which many of the samples were obtained, are inferred as eccentricity cycles (Fielding et al. 2020). Fielding et al. 2020 has recently concluded that "geochronological constraints are consistent with each cycle representing a 100 ky (short eccentricity) interval, most likely related to waxing and waning of contemporaneous ice centers on Gondwana." In addition, given that interglacials of today have a duration of 10s of 1000s of years, by analogy, interglacials of the past are also 10s of 1000s of years in duration. We have revised Lines 166 to 168 (**lines 167-171** after changes suggested by reviewers 1 and 2) to clarify this. The sentence now reads: "Notably, the newly integrated record confirms elevated atmospheric CO_2 concentrations (482 to 713 ppm [-28/+72 ppm]) during Pennsylvanian interglacials in comparison to pCO_2 during glacial periods (161 to 299 ppm [-96/+269 ppm]), with interglacial durations on the order of 1000s to 10s of 1000s of years given the inferred eccentricity scale duration of the glacial-interglacial cycles (Horton et al. 2012; Montañez et al. 2016; Fielding et al. 2020)."