The authors proposed an interesting hypothesis that the SST pattern in the warm Pliocene has contributed to weaker weatherability and thus helped to maintain the warmer Pliocene climate. To test their hypothesis, the study first calculated weathering fluxes in El Nino years versus La Nina years using reanalysis data. They find reduced (silicate) weathering fluxes during El Nino years due (mainly) to a shift in the precipitation pattern. Next, a set of “Pliocene” simulations were created to further explore how SST patterns in the Pliocene might have affected the weatherability. The results show that regional increases and decreases in weathering fluxes largely cancel out one another. Overall, I am not fully convinced that the Pliocene simulations used in this study well reproduced the Pliocene climate. However, the study highlighted the importance of the SST pattern and mean climatic state on silicate weathering. A valuable lesson is that robust global SST reconstructions integrated with climate simulations are critical in evaluating Earth’s thermostat. I propose minor revisions before acceptance.

Major comments:

- Line 213-264: “In order to create a Pliocene SST field for the tropics only”. It seems to me this is a scenario with a zonal SST gradient similar to the Pliocene while maintaining a modern meridional SST gradient. But what is the motivation and justification to create an SST field for the tropics only? And why results from this tropical-SST scenario were not included in Figure 15?

This experiment is indeed a way to generate a zonal SST gradient similar to the Pliocene while maintaining a meridional SST gradient. The motivation for isolating the “close-to-equator” zonal SST gradient is that El Niño events consist in the collapse of the tropical Pacific zonal gradient of SST, without major changes in extra-tropical SST patterns while Pliocene climate proxies indicate a reduction of both gradients. Yet, El Niño is viewed as analogy for Pliocene climate, in particular, the same teleconnections are assumed to occur (Molnar & Cane 2002). Isolating the “close-to-equator” SST pattern allows us to investigate the teleconnections caused to the tropical part of the Pliocene SST estimate, without the effects of the reduced meridional gradient, to better compare it to El Niño events. We added this justification in section 3.2 of the revised manuscript (lines 219–226)
We also merged former Figs. 15 and 12 into Fig. 8, in the revised manuscript. This new figure shows the CO_2-temperature and the temperature-weathering relationships for both of the Pliocene SST simulations (and the pre-industrial simulation).

Molnar, P. and Cane, M.A., 2002. El Niño's tropical climate and teleconnections as a blueprint for pre-Ice Age climates. Paleoceanography, 17(2), pp.11-1.

- Line 352-362:
  “to go back down to pre-industrial temperature, with full Pliocene SST, CO_2 needs to be lowered to ∼140 ppmv.”
  “For this reason, we cannot perform the inversion to compute the equilibrium CO_2 where silicate weathering flux balances pre-industrial degassing. We instead analyse the weathering fluxes at fixed CO_2.”

  This paragraph raises some puzzles. Figure 15 seems to suggest that both global temperature and pCO_2 will be much lower in the Pliocene in order to balance the pre- industrial CO_2 degassing rates. The inference is that (silicate) chemical weathering fluxes must be higher in the Pliocene given the fact that Pliocene was warmer. However, there is no evidence suggesting that Pliocene CO_2 degassing rates were higher than today. Based on Figure 15, if we assume Pliocene has the same pCO_2 as today (correspondingly ~2.5C warming), the silicate weathering anomaly is almost ~1 T mol/yr. This is almost a 20% increase from the modern value (Line 153), a very large number for the long-term carbon cycle. If we extrapolate the red curve (full-Pliocene-SST scenario) to the level where weathering flux anomaly = 0, the global temperature probably will be (much) lower.

Thus, the full-Pliocene-SST scenario seems to produce a combination of climate-and-weatherability that is inconsistent with geological evidence. This leads me to suspect that either the simulated Pliocene climate is a poor representation of the Pliocene climate or the sensitivity of GEOCLIM to climate changes needs some revision.

Furthermore, if we extrapolate the red curve to modern global temperature, it seems to suggest a positive anomaly in weathering fluxes. This would indicate a higher weatherability in the Pliocene, as opposed to what Molnar and Cronin proposed? Am I missing something?

My sense is that discussions in lines 380-405 are trying to address some of these puzzles. I would recommend the authors reorganize the discussions in sec 4 a little bit and make a tighter link to Figure 15.

The points raised by the reviewer are true, to a certain extent.
One important element of answer is that we cannot extrapolate the red curve of Fig. 15 (now Fig. 8b) to the level where the weathering flux anomaly = 0. This was discussed in the former manuscript lines 355–358 (ending by: "Therefore, it is not possible to properly simulate silicate weathering with GEOCLIM"). We now explicitly state that the curves cannot be extrapolated (lines 356–357). This extrapolation makes no sense because CO2 would be too low, plants behaviour will radically change: shutting stomates will mean a drastically reduced GPP, so weathering would behave differently than the model is able to computes. One should expect weathering rates to drop because weathering reaction are fostered by plants. So this would mean a lower weatherability, the "red curve" would drop below the black curve, and the temperature where the weathering flux anomaly = 0 may actually be higher than pre-industrial, depending on where exactly this drop would occur, and how strong it would be. However, there is currently no way to quantitatively predict those values. Furthermore, determining them is not necessary relevant, knowing that there are strong evidences that such low CO2 level was never reached in the recent past.
The question "does the full Pliocene SST simulation have a higher weatherability than the pre-industrial" therefore does not have a clear answer. Around 15°C of global temperature, it seems it does (the red curve is above the black curve), but at higher temperature (> 16°C), the 2 curves are superimposed, so the weatherability is the same (as it was already stated in the former manuscript, lines 364–366). And at lower temperature (and CO2), the weatherability should theoretically be lower the pre-industrial for the reason explained here-above.
Concerning the fact that if we assume that CO2 is the same than pre-industrial, weathering flux would be 20% higher; it is true indeed, as temperature is 2.5°C higher and the weatherability is unchanged (in our simulations). This simply means that the "full Pliocene" SST pattern cannot be – carbon cycle mass balance in mind – the reason why Pliocene was 2.5°C warmer, and there must be another reason. Such other reasons could be a reduction of weatherability due to less emerged area in the Maritime continent (e.g., Molnar & Cronin 2015, Park et al., 2020), or another C flux that was reduced (for instance less organic C burial)…
Section 3.2.2 was partially re-written to make those points more evident (lines 343–357).

- Line 210: Can the authors comment on how well the simulated SST agrees with proxy data, rather than simply citing Burls and Fedorov, 2014? For instance, what is the magnitude of warming in the EEP relative to the proxies?

We added SST proxies from 10 ODP sites (following Burls and Fedorov, 2015). The Pliocene SST anomaly from these proxies is now shown on Fig. 4 (former Fig. 7). The agreement with the proxy is also discussed lines 227–232 The details on the ODP sites, source studies, and averaging time interval is given in Appendix D, and Table D1.
The warming of the Tropical East Pacific is the coupled ocean simulations is about half of what is observed in the proxies (~2.5°C versus ~4°C, see also extra figures at the end of the rebuttal).
This remark made us notice that we already provided a value: 2°C, for the Tropical East Pacific warming (actually, the reduction of the west-to-east Pacific gradient), line 284 of the former manuscript. This value is closer to 2.5°C, so we corrected that sentence (now line 265)

Some minor points:

- The authors may want to mention at the beginning that there is little evidence of changes in CO_2 degassing rates since the Pliocene. Thus, a change in weatherability (e.g. Molnar and Cronin) is the most likely explanation for the long-term coolling.

This is a good suggestion. We added this information lines 23–25. We also modify the conclusion, when we mention decreasing degassing as a potential driver (formerly line 408, now lines 403–404), to specify that “no clear change is noted since the Pliocene”.

- Line 68-69: It seems to be a little bit controversial now to say “El Niño events is a good representation of Pliocene permanent El Niño.”

This is an accurate remark, given our conclusions. We replaced it by “with the assumption that the average climate of El Niño events can be used as a proxy for Pliocene permanent El Niño” (now line 74–75).

- Line 71-73: “However, one cannot quantitatively estimate this warming … yet, if silicate weathering is disturbed, CO_2 will adjust …” This sentence can be confusing to some readers. Maybe reword it a little bit?

We split the sentence in two, and added more precision (now lines 77–80)

- Line 106-122: consider to provide a supplementary figure showing the time series of the ENSO index you calculated?

We moved the details of the calculation of the ENSO index (former lines 110–120) from section 2.2 to Appendix A, and added a figure (Fig. A1) showing the index time-series.

- Line 155: probably point out what climate field they used.

We added this information (now lines 158–159)

- Line 366: "This result means that Pliocene SST does not generate any significant increase or decrease of weatherability, save perhaps at low CO2" typo?

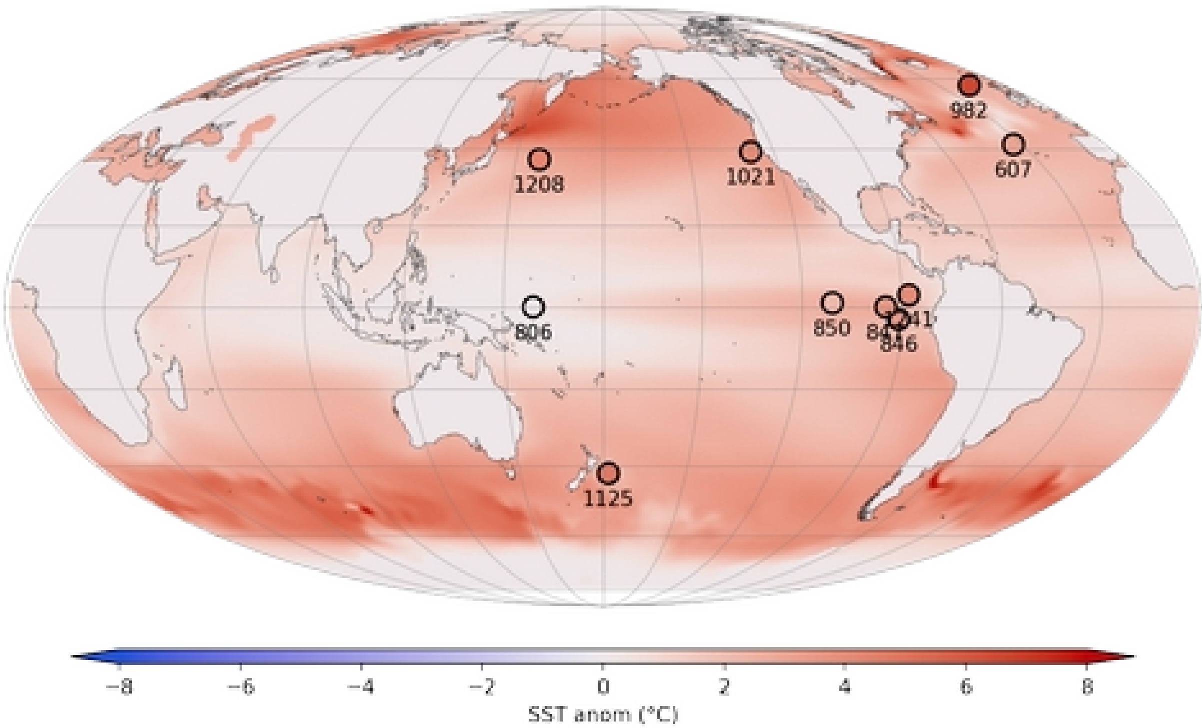
This sentence was changed (as the section was partially re-written) to "This result means that Pliocene SST does not generate any significant increase or decrease of weatherability – except at low CO2 [...]" (lines 353–354).

- Line 410: "could plan an important role" typo?

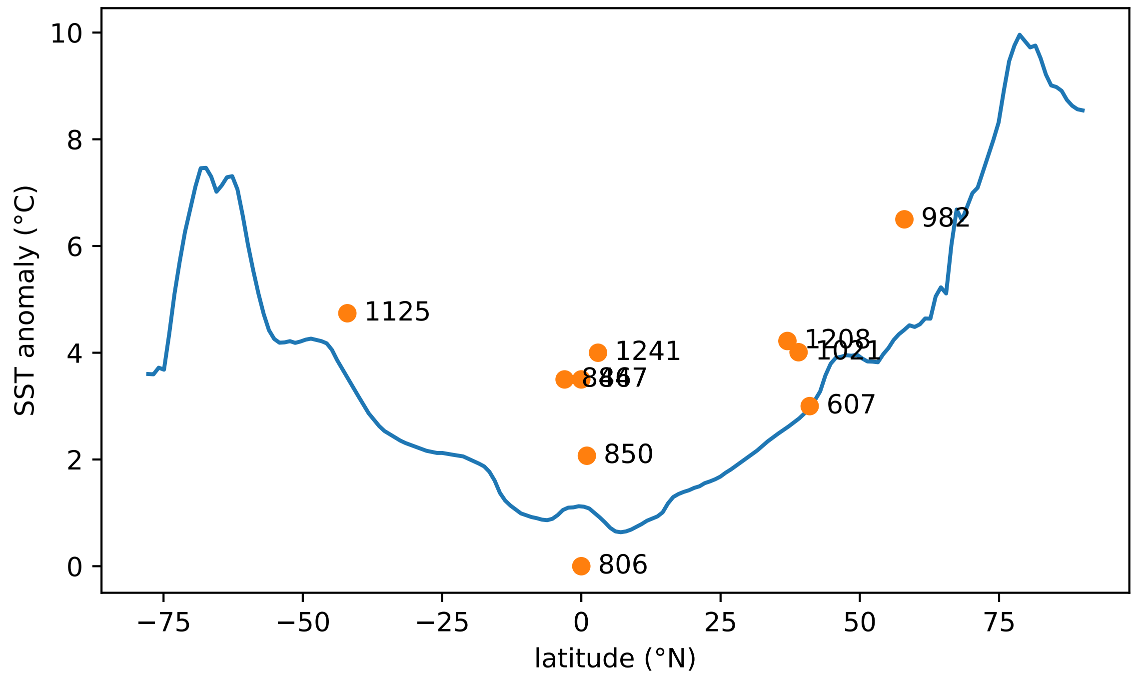
Indeed. This was corrected (now line 405)

- Line 345: "This goes against our initial hypothesis, based on the "wet gets dryer, dry gets wetter" feature from Burls and Fedorov (2017)." I think this is the first time you mention this. It is better to front load this in the introduction.

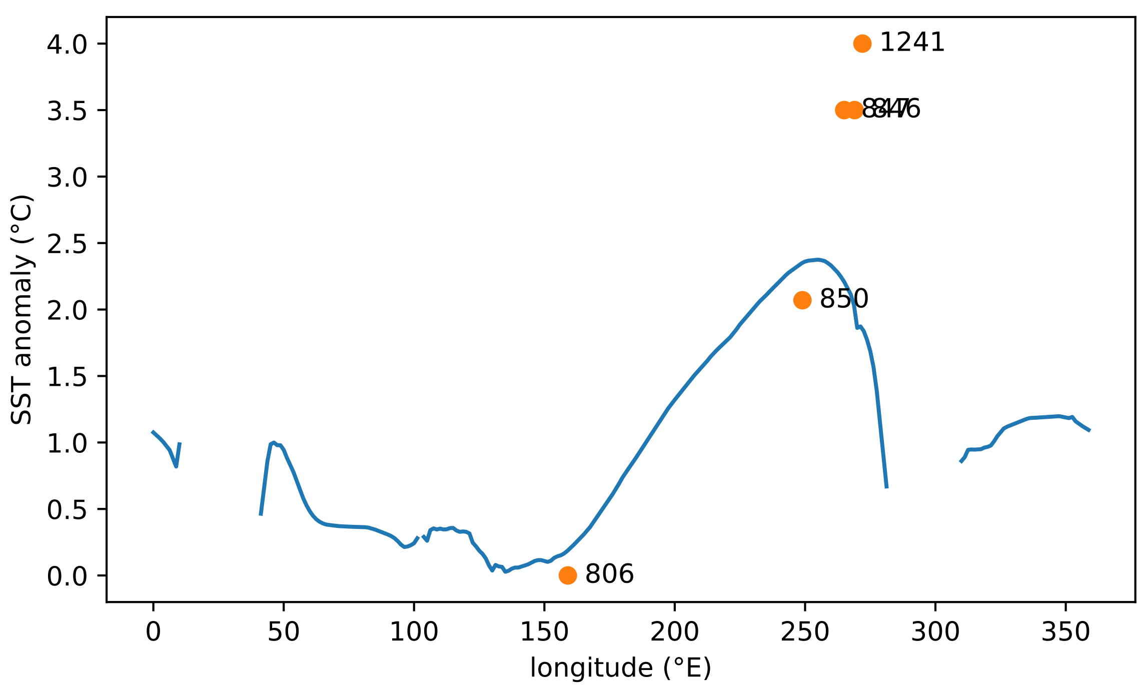
We meant to refer to the behaviour of reduced equatorward moisture transport (lines 49–50 of the former manuscript, now lines 54–55), that is at the root of the "wet gets dryer, dry gets wetter" feature. In the revised manuscript, we explicitly mention that feature in the introduction, after mentioning the reduction of equatorward moisture transport (lines 55–56).



Map of SST anomaly (with respect to pre-industrial) of the coupled ocean-atmosphere simulation with altered clouds visible albedo, and Pliocene SST proxy. This figure is identical to main text Fig. 4A, with the name of the ODP sites added.



Anomaly (with respect to pre-industrial) of zonally-averaged SST of the coupled ocean-atmosphere simulation with altered clouds visible albedo, and SST proxy.



Anomaly (with respect to pre-industrial) of SST meridionally averaged between 5°S and 5°N, in the coupled ocean-atmosphere simulation with altered clouds visible albedo, and SST proxy (5°S-5°N ODP sites).