This study investigates the silicate weathering and carbon cycle for the Pliocene climate that featured a reduced SST gradient in both zonal and meridional directions (the so- called “permanent El Niño”). The authors first explore the impact of present-day El Nino events on the weathering flux using the present-day observation/analysis. Their analysis suggests a small net impact (~2–3%) of ENSO SST patterns on the weathering flux. Next, using climate model simulations, the authors find a similarly small net impact of Pliocene- like SST patterns on the weathering flux.

The research question of the manuscript is very relevant for understanding the global cooling since the Miocene and Pliocene. The introduction is very well written, reflecting that the authors have very good understanding of the problem and relevant dynamical processes. However, I must admit that, to understand the manuscript (such as the motivation and the complicated procedure for creating the Pliocene slab ocean simulation with altered ocean q-flux), I had to read the manuscript several times. This makes me wonder whether the authors can work out a simpler approach to highlight the key experiments and results. Please see also below for a few other comments. These comments need to be addressed before the publication of the manuscript.

Major comments

- Title. Since the main conclusion of the manuscript seem to be that the weathering flux change from the Pliocene-like SST pattern is small in global mean, I think the authors could use a better title to clearly deliver the message, such as “A potentially small net effect of the Pliocene temperature pattern on the silicate weathering and the Pliocene- Pleistocene cooling”.

We have modified the title to now be “The effect of the Pliocene temperature pattern on silicate weathering and Pliocene-Pleistocene cooling”.

The main advance of our study is in introducing and exploring the weatherability pattern effect to global silicate weathering changes. As our El Nino and reduced zonal gradient examples show, the magnitude of regional silicate weathering changes resulting from SST pattern changes are sizable. If they do not cancel, there is a significant net imbalance to the carbon flux resulting the Earth system to reach a new carbon and temperature equilibrium.

The small net effect seen in our Pliocene simulation should not be interpreted as what happens in the Pliocene – there are too many uncertainties, from the SST pattern reconstruction to climate model simulation of rainfall to the GEOCLIM model. In this sense, the cancellation in the full Pliocene simulation can be seen as fortuitous, and a proper evaluation of the weatherability pattern effect requires (as pointed out by reviewer 3) a robust reconstruction of Pliocene SST patterns.

- Related to 1, the authors conclude that “We find support for this hypothesis…” (Line 416). Given the small net contribution from the SST pattern effect and the abundant uncertainties from SST pattern reconstruction, precipitation bias from model/reanalysis, assumptions built in the silicate weathering model, I wouldn’t conclude that “We find support for this hypothesis”. The authors’ analysis actually lends little support for the hypothesis.

We rewrote a bit the conclusion, and state instead (line 411–417): “We explored this hypothesis by running […] Significant regional changes of both signs are found […] These changes largely cancel, but can produce a modest but significant weatherability increase should they not entirely compensate. These results highlight the potential importance of the weatherability pattern effect on Earth's long-term carbon cycle, though a proper evaluation requires a robust reconstruction of the relevant SST patterns."

- The manuscript is too long with too many figures (17 figures!), which may decrease the readability and reduce the focus of the manuscript. One way to improve, I think, is toreduce the number of main figures though combining multiple figures into a single figure with a common theme. For example, Figures 2–4 could be combined into one figure showing the average chemical weathering rates and the separation into different regions. Similarly, Figures 5 and 6 could be combined with a focus on the visual and quantitative comparison of the weather rates between El Nino and La Nina events. Same for Figures 10 and 11, and for Figures 16 and 17.

This is a useful advice. In the revised article, we merged figures 2–4 in new Fig. 2, figures 5 and 6 in new Fig. 3, figures 10 and 11 in new Fig. 7, figures 12 and 15 in new Fig. 8, and figures 16 and 17 in new Fig. 11. The revised manuscript now has 11 figures, plus 1 in Appendix A.

- Table 1 and the discussion on the Pliocene experiments are lengthy and difficult to follow. I am sure the authors have carefully thought about the purpose of these experiments, but it is not necessary to list and show all the experiments. For example, the "control" simulations with CO_2 of 1138.8 and 854.1 ppmv are not discussed in the manuscript (854.1-ppmv simulation is shown in Figure 12 but may not be needed); same is true for a few other simulations. I think it will help readers to follow and help highlight the most important findings of the manuscript if the authors could carefully examine their simulations and delete unnecessary ones.

We agree that former Table 1 and section 3.2 were difficult to follow, and moving the reader away from the main focus of the manuscript (this point was also raised by reviewer #2).
We restructured the manuscript to keep the focus the 3 series of slab ocean simulations (control, Full Pliocene SST and 10°SN Pliocene SST). We now only briefly present the coupled simulation, and mention the fixed SST as a necessary intermediate step. All the details were moved to Appendix B. Therefore, we did not judge it necessary to keep Table 1 in the main text, and moved it to Appendix B (now Table B1).

- The authors' simulations highly rely on the SST pattern adapted from Burls and Fedorov (2014), but they failed to provide information on how well the SST pattern match the proxy record. I suggest the authors adding values of the meridional and zonal SST gradients from the simulations and the comparison with proxy data. Values of the SST gradients should be provided for COA-ctrl, COA-Plio and all the slab ocean simulations, with Pliocene values compared with proxy reconstruction. This information could be added to Table 1. Also, the global mean surface temperature of each simulation could also be added to Table 1. These key features will help readers better understand each simulation. A short discussion on the implication/caveats should be added if the simulated SST pattern does not match the proxy reconstruction.

We added the alkenone SST proxies presented in Fedorov et al. (2015). Appendix D indicates the source of the data, the averaging interval we considered for Pliocene, and the values (in Table D1).
We added the proxy SST anomalies (with respect to modern) to the map in Fig. 4 (former Fig. 7). The coupled ocean-atmosphere simulation does reproduce the high latitude and East Pacific warming of the proxies (which we now indicate lines 229–232) although the East Pacific only warms up by 2.5°C instead of ~4°C in the proxies (see also extra figures at the end of the rebuttal).

Since we moved Table 1 to the Appendix B, we chose not to add information, to keep it a mere description of how the simulations were design. We believe that the SST map and proxies (Fig. 4 a and b) provide enough information regarding the SST gradients.

Finally, we point out that the main goal of our study is in introducing the weatherability pattern effect to global silicate weathering changes, using SST patterns motivated from the Pliocene to explore this hypothesis. In this sense, our study should be seen as a 'proof of concept' and that a proper evaluation of the Pliocene case requires a robust reconstruction of said SST pattern changes.

- Please add significance test for many of the analysis, such as the difference map in Figures 1, 5, 8, 10, 14, and 16.

Performing statistical tests is possible for some of the difference maps, but not all them.

For the GCM simulations (former Figs. 8 and 14, now Figs. 5 and 10), there is no methodological issue. Each 30-years climatology output can be considered as a N=30 sample of independent observations (i.e., 30 one-year averages). The question "is the average of the 'perturbed' sample statistically different from the average of the 'control' sample" is then relevant, and can be answered with a Welch's t-test (which is what we did).
This approach consider that the relevant entity is the annual mean. Indeed, it does not make sense to determine whether the anomaly caused by the permanent flattening of meridional and zonal gradient can be achieved through the natural intra-annual, or day-to-day variability of climate.

For the ERA5 reanalysis, the question is not as straightforward, because there are not 2 distinct equal size samples. El Niño is a part of the natural variability of climate. So if the question is "Can an El Niño anomaly be achieved by 'chance'", the answer is yes. One cannot reject the null hypothesis because El Niño belongs to the natural variability.
We needed to formulate the question differently: "can the El Niño anomaly be achieved through the natural variability of climate not considering the ENSO variability". In other words, we sought to determine if the average of El Niño years is statistically different from the average of non El Niño nor La Niña years. We designed the statistical test this way. We modified Fig. 1 to show the difference between "El Niño years average" and "non El Niño nor La Niña years average" (instead of "El Niño years" minus the whole time-series average, in the former manuscript), and we performed a Welch's t-test between the N=29 sample of non El Niño nor La Niña years and the N=6 sample of El Niño years.

The design of these statistical tests is explained in in Appendix C of the revised manuscript.

For the weathering results (former Figs. 5, 10 and 16, now Figs. 3, 7a and 11a), it is not possible to design a statistical test.
There are various sources of uncertainties (or variability) that should be considered. The one we show with error bars on (new) Figs. 2C, 3c, 7b and 11b, or boxplots on Figs. 6 and 8b is the uncertainty associated with the parameters of the weathering model. We considered 573 selected parameter combinations that fitted the data with r^2>0.5 (cf Park et al., 2020), however, this ensemble can not be considered as a sample of 573 independent and identically distributed observations.
Aside from the parameters uncertainty, there is also the uncertainty due to the natural variability in the climate simulations (or reanalysis) whose outputs are fed to the weathering model. Because of the non-linearity of the model, it is not possible to analytically propagates the variance of the temperature and runoff fields in to the weathering field. This variability will also interact non-linearly with the uncertainty associated with the weathering parameters.

For these reasons, we are not able to provide statistical significance test for the weathering model outputs.

- At many places, when summarizing the effect of weathering flux changes, the authors used the estimated temperature changes, such as Lines 10–11. The authors need to clarify how the temperature changes are estimated and what is the associated uncertainty.

We provided such summarized weathering effect as a temperature change in the abstract (lines 10–11), at the beginning of section 3.1.2 (formerly line 169, now lines 177–178), in section 3.2.1 (formerly line 283, now line 263), and at the beginning of the discussion (section 4, formerly lines 381–382, now lines 369–372). Section 3.2.1 was indeed the only place where we describe how this temperature change is computed (inversion that GEOCLIM performs to find the equilibrium CO2 level at which silicate weathering balances the imposed CO2 degassing), while the previous statement (section 3.1.2) gave little explanation. We added (lines 173–178) a couple of sentences explaining how we converted the weathering anomaly computed with ERA5 reanalysis into a global temperature change, and what is the assumption behind that conversion (linear weathering feedback, with an increase of global weathering flux by 0.4 Tmol/yr per °C of global warming by CO2, compensating the "initial" weathering anomaly).
In the discussion, we remind this assumption of linear weathering feedback (lines 369–371)
In section 3.2.1, the inversion perform by the model to compute the equilibrium CO2 was already explained (lines 275–280 of former manuscript), so we did not modify the text (now lines 255–260).

- When explaining the SST offset between Pliocene and preindustrial slab ocean simulations (Lines 305–351), the authors could mention the SST pattern effect on the cloud radiative effects (such as Zhou et al., 2017, doi:10.1002/2017MS001096).

This is a good suggestion. We added this reference lines 300–301.

Minor comments

- Line 13: Spell the "C cycle" fully.

We spelled "carbon cycle" fully there (now line 14), and a few lines above (line 8)

- Line 27: Change "net net (upward)" to "net (upward)".

Done (former line **227**, now line 464, in Appendix B2)

- Line 205: Change "seeks" to "seek"

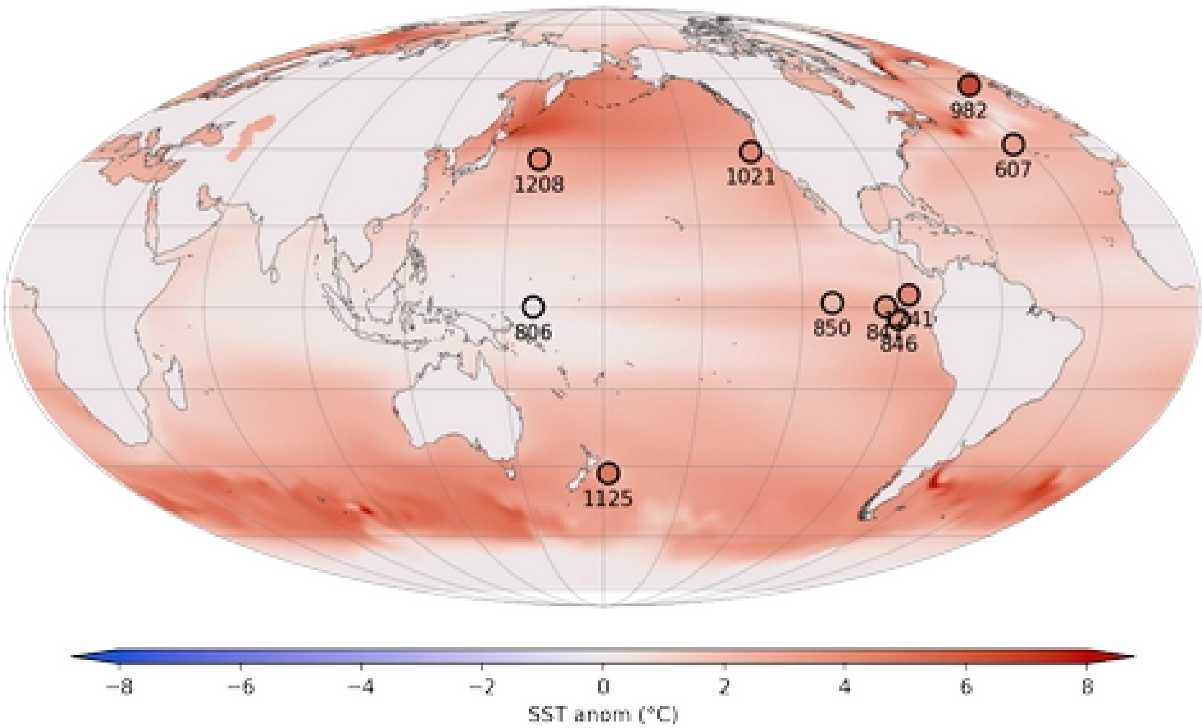
Done (now line 439, in Appendix B1)

- Line 310: Change "than" to "as"

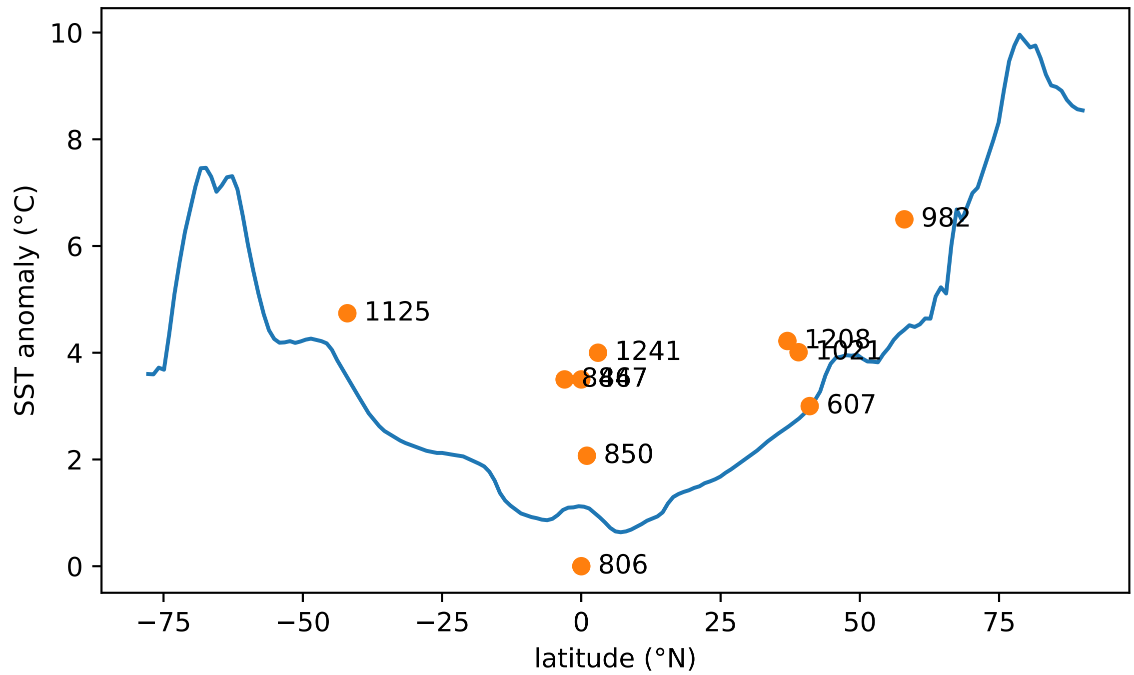
Done (now line 294)

- Line 320: Change "visible" to "shortwave"

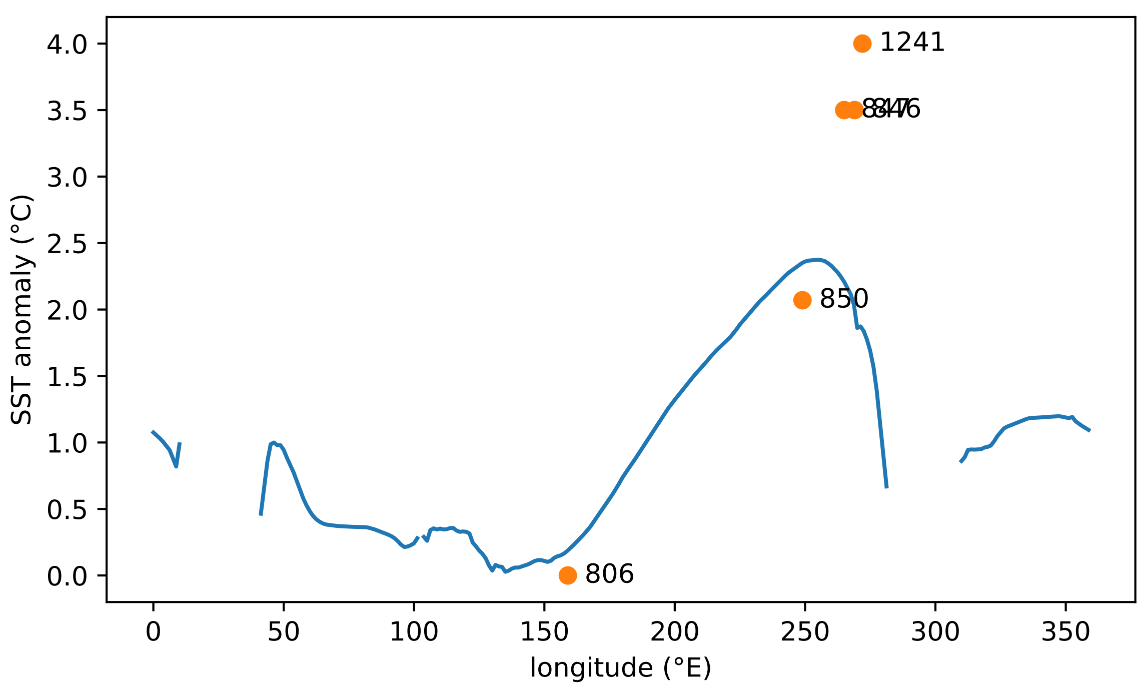
We have changed "visible albedo" to shortwave albedo in all the occurrences (line 199, line 306, line 388, line 392 and line 441).



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).