<u>Replay to the review of "The ENSO-driven bias in the assessment of long-term cloud feedback to global warming" by Liu et al.</u>

We thank the editor and the reviewers for their time and constructive comments, which have helped us significantly improve the clarify and quality of our work. We have addressed all comments point by point and revised the manuscript and Supplemental Information (SI) accordingly. Before presenting our specific answers to all the referees' comments and questions, we open by a short summary of the major changes done in the revised manuscript:

1) The term "bias" and "deENSO" have been replaced with more neutral and descriptive terminology; the manuscript title has been updated accordingly.

2) The Materials and Methods section has been revised for greater clarity and methodological rigor.

3) Significance tests have been incorporated for key results to provide statistical support for our conclusions.

4) SST from GCMs is now used to compute ONI to enhance the internal consistency of the study.

5) New analyses based on satellite observations (CERES EBAF Ed4.2) have been added to strengthen the physical interpretation of the findings.

6) The contribution of ENSO to global-mean cloud radiative effects is now included to broader the relevance of our results.

7) Throughout the text, figures and metrics have been refined to better articulate the implications of our findings and provide stronger justification for the methodology.

Please see below the specific answers to all the comments (marked in blue). Citations from the revised manuscript appear in *italics*.

Response to Referee #1

General comments:

This study investigates the influence of ENSO on cloud feedback estimates under global warming, using a regression-based de-ENSO method. Based on reanalysis observations and GCM simulations, the authors find that ENSO variability biases estimates of long-term cloud feedback to global warming both in the historical record and the abrupt-4×CO_2 experiment, with large impacts on regional scales.

Overall, the paper addresses an interesting topic. However, I have several major concerns regarding the methodology and the main findings. Some of them may arise from a lack of clarity in the Method section. I strongly suggest that the authors improve the clarity of the manuscript, particularly by providing a clearer and more detailed explanation of the main framework.

Answer: We sincerely thank the reviewer for the insightful comments on our manuscript. The detailed feedback has greatly improved the clarity of our work. We have carefully considered all points raised and revised the manuscript and SI accordingly.

Before presenting our specific responses, we begin with a brief summary of the main changes that were made in the manuscript: (1) The Materials and Methods section was carefully revised to describe clearer of the methodology; (2) the analysis of significance tests for all relevant results was added to provide statistical justification; (3) SST from GCMs is now used to compute ONI to ensure consistency; and (4) the text, figures and metric have been improved to better articulate the implications of our findings and to provide stronger justification for the proposed methodology.

Our point-by-point response is provided below, with citations from the revised manuscript and newly added supplementary materials (SI) appearing in *italics*.

Major comments on the methodology:

1. My main question regarding the method: Is the ONI (ENSO timeseries) detrended? This is critical because the proposed linear framework (Eq. 1)

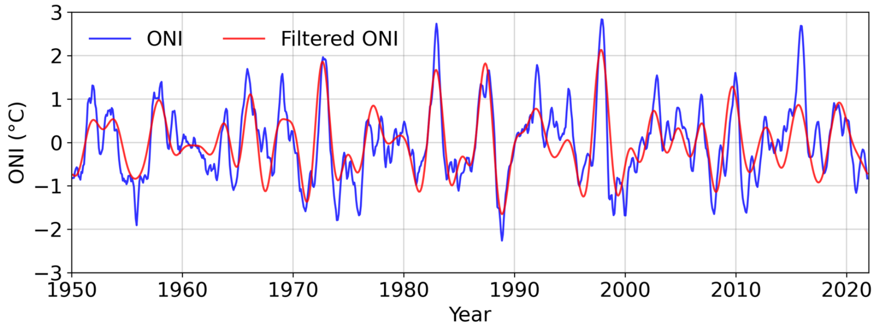
$$Y = a \times time + b \times ONI + c,$$

aims to separate the long-term trends (the first term, a x time) from ENSO-related variability (the second term, b x ONI). If the ONI itself contains a long-term trend, this could lead to double-counting of changes in the targeted variable (CRE or GMST) that are associated with tropical mean-state SST changes. I'm wondering if this may be the case in the abrupt-4×CO_2 analysis (see more on this below). In its current form, the manuscript doesn't clearly state whether the ONI has been detrended. The text mentions that the ONI was bandpass-filtered, but the filtering timescale was not specified (it only says "to remove ONI variations beyond ENSO's typical periodicities"). Also, Line 106 "it retains the ENSO-induced long-term trend effect" seems to suggest the ONI trend is retained. Moreover, Lines 134-136, which discuss results from GCMs, also suggest that no detrending is applied to the ONI timeseries before the decomposition. In either case, more clarification is needed. If the ONI is indeed not detrended, I'm concerned about the linearity of this method and would appreciate the authors' comments.

Answer: We appreciate this thoughtful comment that is central to our analysis and helped us clarify our method.

Yes, the ONI is detrended when estimating ENSO-related bias (rephrased as "ENSO contribution" in the revised manuscript and hereafter, as it more accurately reflects that we are quantifying the component of the estimated feedback that is linearly attributable to ENSO variability) in cloud feedback estimates (Sections 3.3–3.4). The original ONI (blue curves in Fig. 1) is used only for the general discussion of ENSO impact on GMST (Sections 3.1) and CREs (Sections 3.2).

More specifically, to investigate ENSO contribution, we use the bandpass-filtered ONI (red curve in Fig. 1), which retains only variability within the 2–7 year band. This excludes any (even if naturally occurring) long-term trends (> 7 years) in ONI, ensuring they are not mis-attributed to ENSO.



"*Figure 1: Time series of the original ONI (blue curve) and the bandpass-filtered ONI (red curve), derived from ERA5 data during January 1950 – December 2021.*"

To better clarify these points, we have revised the corresponding text, as cited below:

Revised text in Section 2.3: "*In this study, we use a regression-based ENSO-correction method due to its conceptual simplicity and computational efficiency. Specifically, we first use a bandpass filter to remove ONI variances outside the typical ENSO periodicity band of 2 – 7 years (Fig. 1). This filtering isolates the core ENSO signal and helps to decouple it from other climate perturbations, like long-term trends, the Atlantic Multi-decadal Variability, and the Pacific Decadal Oscillation.*".

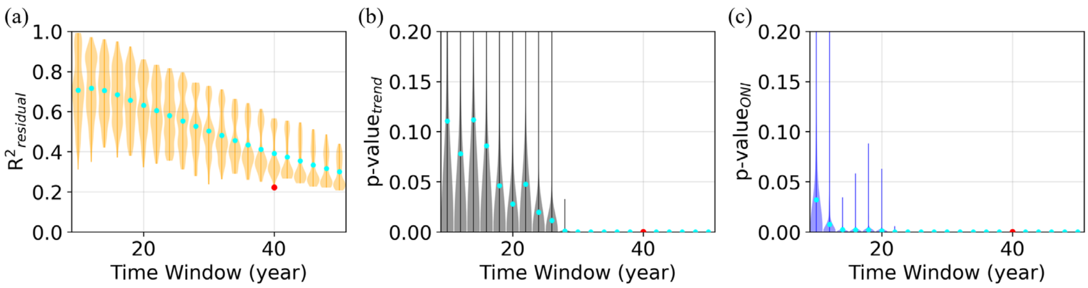
"*Importantly, because Eq. (1) uses the bandpass-filtered ONI and assumes no time lag, this OLS-based ENSO-correction method may retain some ENSO-related variations in Y. These include potential low-frequency natural trends in ENSO itself and any delayed or non-linear impacts of ENSO on GMST and CREs. Consequently, this method is likely to provide a conservative estimate of ENSO contribution (see Section 2.4) (Kelly and*

Jones, 1996; Compo and Sardeshmukh, 2010).".

Revised text in Section 3.1: "*To quantify this, we calculate the coefficient of partial determination (partial R^2) using OLS multivariate regression models (similar to Eq. (1), but using the original ONI rather than the bandpass-filtered one) and present the results as a function of the time window*".

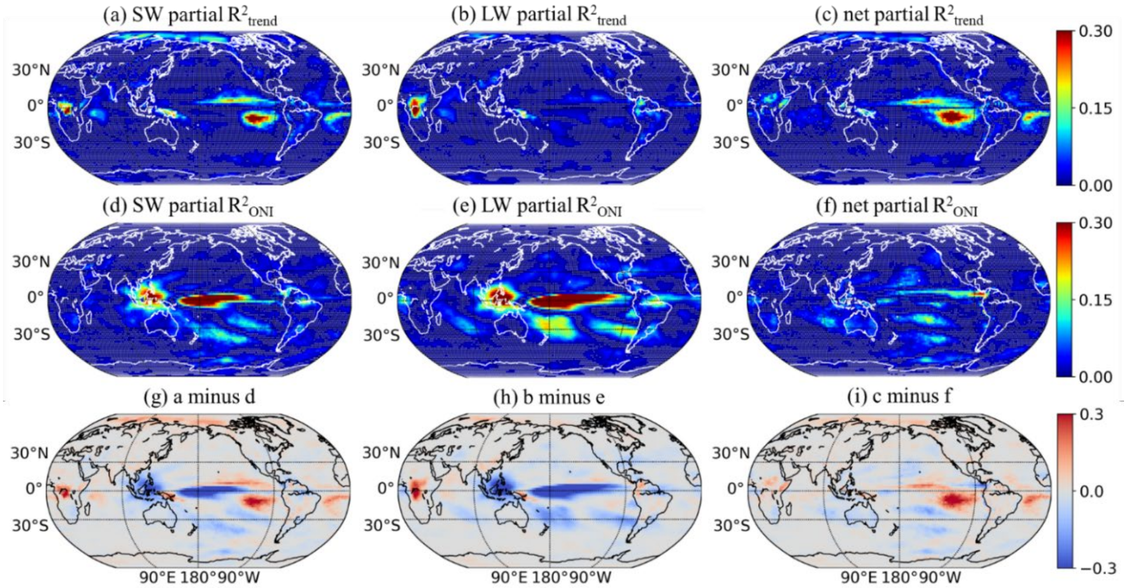
2. My second methodological concern is related to the residual term (c in Eq. 1): How large is its contribution? Is it sufficiently small that one can justify focusing only on the first two terms, as done in the paper? Figs. 2bc show that the sum of GMST variance explained by the first two terms is notably less than 1, and can be even smaller than 0.5 (depending on the period). This again raises questions about whether this linear decomposition is appropriate and whether the unexplained residual term undermines the interpretation of the results.

Answer: We thank the reviewer for raising this point. We agree that the two-predictor linear model (time and ONI) explains a limited portion of the total GMST/CREs variance, especially over short time windows (e.g., Fig. S1a). However, we clarify in the manuscript that the primary objective of this regression framework is not to accurately predict GMST/CREs, but rather to isolate the component of variability that is linearly attributable to ENSO (the ONI term). For this purpose of separation, the key criterion is the statistical robustness of the regression coefficients. To this end, we confirmed that the ONI regression coefficient (*b* in Eq. 1) is statistically significant ($p < 0.05$) across nearly all analyses (e.g., Fig. S1c), even when the explained variance is moderate. This provides confidence that the decomposed ENSO signal is robust and not merely an artifact of residual noise. In the revised manuscript, we have also added significance tests for all relevant analyses to provide statistical justification. The corresponding revised figures (Fig. S1, Figs. 3–5, 7–8) and text appear below:

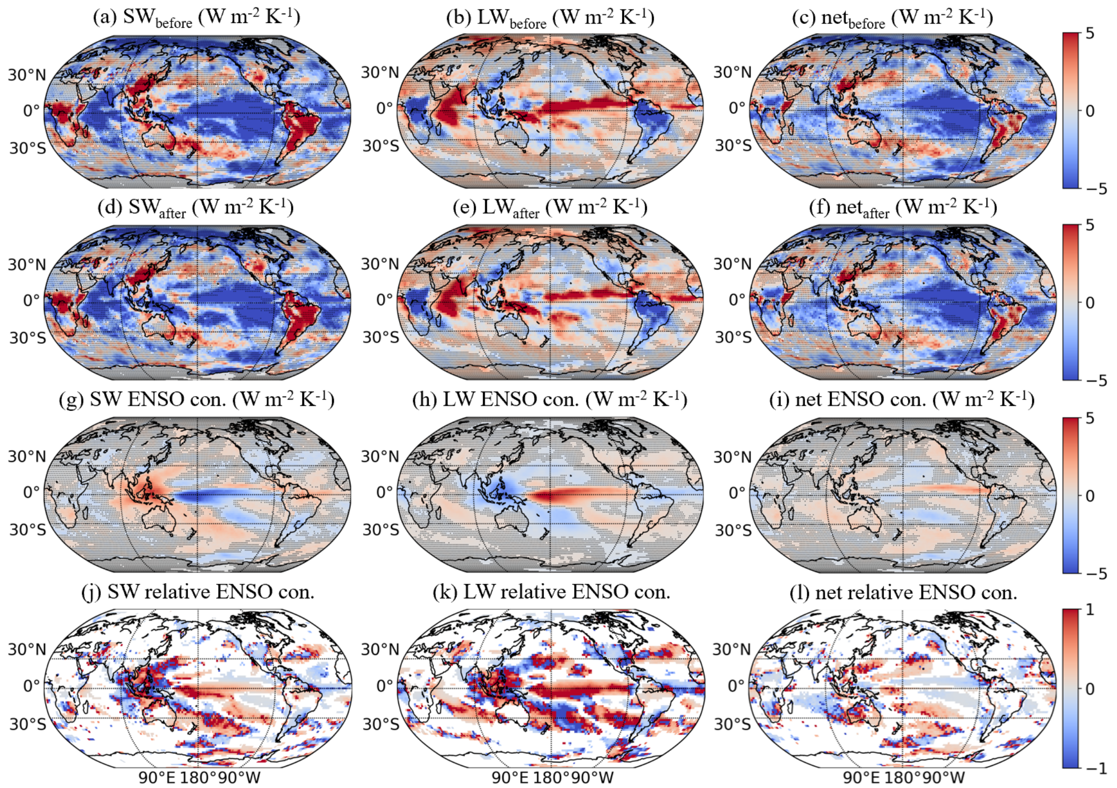


"*Figure S1: Violin plots for residual R^2 and P-value of results shown in Fig. 2b－c in the main text. (a) Residual R^2, (b) p-value of the partial regression coefficient of time (i.e., a in Eq. 1), and (c) p-value of the partial regression coefficient of ONI (i.e., b in Eq. 1).*"

Revised text in Section 3.1: "*The corresponding test statistics (Fig. S1) suggest that the ONI regression coefficient (b in Eq. 1) is statistically significant at the 95% confidence level across nearly all analyses, even when the explained variance is moderate. This allows us to assess the relative contribution of the warming trend (partial R^2_{trend}; Fig. 2b) and ENSO (partial R^2_{ONI}; Fig. 2c) to the total variance of GMST* *across different timescales with high confidence.*”.

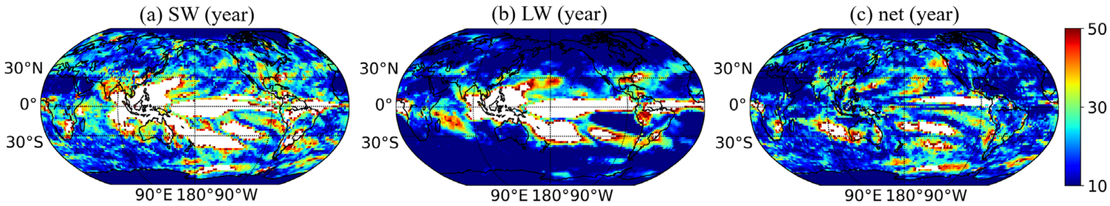


“Figure 3: A sample analysis of the variations in CREs as driven by the temporal trend and ENSO, derived from ERA5 data during January 1982 – December 2021. (a – c) Partial R^2_{trend} for (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. (d – f) Partial R^2_{ONI} for (d) CRE_{SW}, (e) CRE_{LW}, and (f) CRE_{net}. (g – i) The difference between (a – c) and (d – f). In panels (a – f), white dots denote grids with statistically insignificant partial regression coefficients of time (i.e., a in Eq. 1) and ONI (i.e., b in Eq. 1) at the 95% confidence level.”

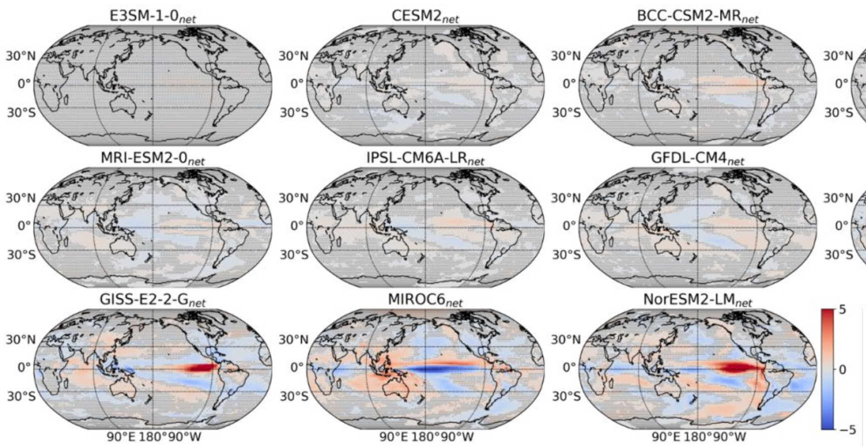


"*Figure 4: A sample analysis of ENSO contribution to cloud feedback estimates for CRE_{SW} (left column), CRE_{LW} (middle column), and CRE_{net} (right column), derived from ERA5 data during January 1982 – December 2021. (a – c) Cloud feedback estimates before ENSO correction. (d – f) Cloud feedback estimates after ENSO correction. (g – i) ENSO contribution (a – c minus d – f). (j – l) Relative ENSO contribution (g – i divided by a – c). In panels (a – i), black dots denote grids with statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or respective CRE at the 95% confidence level. In panels (j – l), these insignificant grids are masked in white.*"

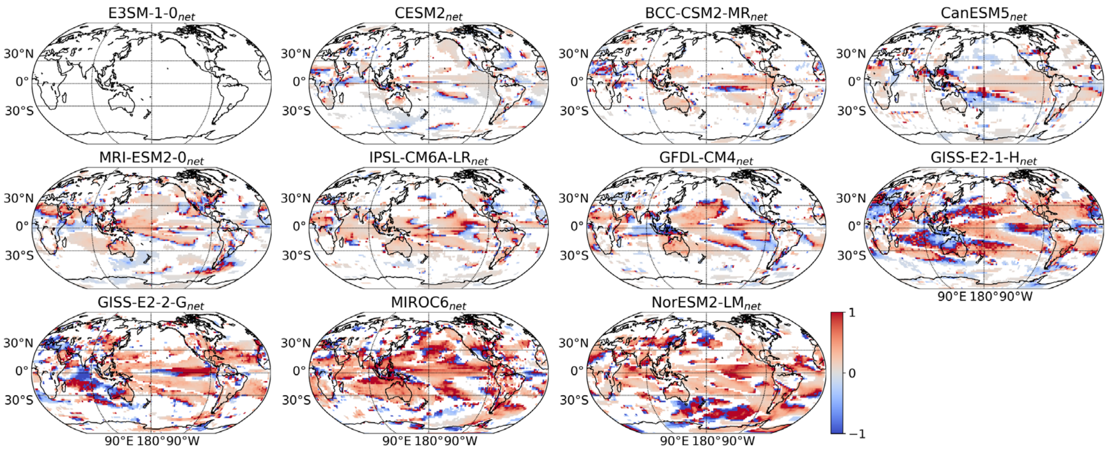
Revised text in Section 3.3: "*To quantify this timescale dependence, we calculate the ENSO contribution (e.g., Fig. 4g – i) for the same range of possible periods by applying each time window across the entire 72 years and use a metric we call "ENSO effect minimal time". This metric is defined as the shortest time window beyond which the mean magnitude of ENSO contribution (ignoring the sign) falls and remains below 1 W m^{-2} K^{-1} (i.e., $|\overline{ENSO\ con.}| < 1\ W\ m^{-2}\ K^{-1}$), or beyond which the partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE becomes and remains statistically insignificant at the 95% confidence level.*".



"*Figure 5: Maps of "ENSO effect minimal time" for different CREs, derived from ERA5 data during January 1982 – December 2021. (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. Regions masked in white denote grids where ENSO contribution never consistently falls below 1 W m^{-2} K^{-1} or becomes statistically insignificant within time windows up to 50 years.*"



"*Figure 7: Maps of ENSO contribution to CRE_{net}, derived from GCM simulations from the abrupt-4 × CO_2 experiment during the first 150 years. The name of the corresponding model is indicated in each panel. Black dots denote grids with* *statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE at the 95% confidence level.*"



"*Figure 8: Maps of the relative ENSO contribution to CRE_{net}, derived from GCM simulations from the abrupt-4×CO_2 experiment during the first 150 years. The name of the corresponding model is indicated in each panel. Grids with statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE at the 95% confidence level are masked in white.*"

3. Finally, Figure 1 shows that ENSO's influence on long-term changes decreases with time. Given this, it is unclear to me why the authors choose to focus on an arbitrary 40-yr period (1982–2021) throughout the paper, especially since the ERA5 reanalysis data used in this paper spans from 1950–2021.

Overall, I think the paper suffers from a lack of clarity in the Method section and would benefit from substantial revision and clarification.

Answer: Thank you for this comment. Our primary analyses and conclusions are based on the full ERA5 record (1950–2021). The 40-year period (January 1982 to December 2021) was selected as a representative example to illustrate the method and resulting spatial patterns (e.g., Figs. 3–4) for the following reasons:

(1) Methodological Illustration: as the time-dependence of ENSO contribution is complex, we required a fixed, contiguous period to demonstrate the step-by-step output of our framework in the figures.

(2) Climatological Relevance: As shown in Fig. 2c, the influence of ENSO on GMST stabilizes (i.e., decays very slowly) for periods beyond ~40 years, making this time window a climatologically meaningful timeframe.

(3) Scientific Interest: This period is characterized by a strong warming trend coupled with a relatively weak ENSO signature (red dots in Figs. 2b–c), making it a valuable case for detailed examination due to the expectedly small ENSO contribution to cloud feedback estimates.

In response to this concern, we have clarified this rationale in the revised manuscript, as cited below:

Revised text in Section 2.1: "*To facilitate a walk-through of the methods and results (a sample analysis), a representative 40-year subset (January 1982 – December 2021) is used.*".

Revised text in Section 3.1: "*The partial R^2_{trend} values increase consistently with longer time windows, suggesting that the warming trend accounts for a steadily growing proportion of GMST variance over extended periods. In contrast, the partial R^2_{ONI} values decrease yet gradually stabilize for periods exceeding ~40 years, indicating a diminishing, though progressively attenuated, influence of ENSO as the timescale lengthens. This inverse relationship implies that ENSO contribution to cloud feedback estimates becomes less substantial in longer periods. For instance, in the 40-year subset from January 1982 to December 2021 (red dots in Fig. 2b – c), the warming trend explains approximately 74% of GMST variance, whereas ENSO accounts for only about 4%. The co-occurrence of this strong warming trend and the relatively weak ENSO signature, along with the stabilization of R^2_{ONI} beyond 40 years, makes this period particularly informative for examining ENSO contribution to cloud feedback estimates. It is therefore selected as a representative example to illustrate the methodology and resulting spatial patterns in Figs. 3 – 4*".

Major comments on the Results:

1. CRE decomposition in Fig. 3

According to Eq. 1, the linear framework decomposes total CRE variations into two components: (1) a linear trend term (a × time) and (2) the portion associated with ENSO variability (b × ONI). In Fig. 3, however, term (1) is interpreted as the CRE change driven by the warming trend, which I find difficult to justify. It assumes that the trend in CRE is equivalent to the CRE response to long-term warming, which may not be valid. This issue may arise from ambiguity in Eq. 1. Specifically, what is the unit of the coefficient a? Is it the trend unit of the targeted variable (e.g. for CRE, it would be W/m^2/year), or is it a regression coefficient with respect to long-term global warming ($W/m^2/K$)? If it's the former (seems more likely based on Eq. 1), I do not think it can be interpreted as "CER due to warming trend". Either way, this concern highlights a fundamental confusion in the framework that needs to be clarified.

Answer: Thanks for raising this point. The unit of regression coefficient a in Eq. (1) is $W\ m^{-2}\ year^{-1}$ for CRE. To avoid potential confusion, we have replaced "warming trend" with "temporal trend" throughout the revised manuscript.

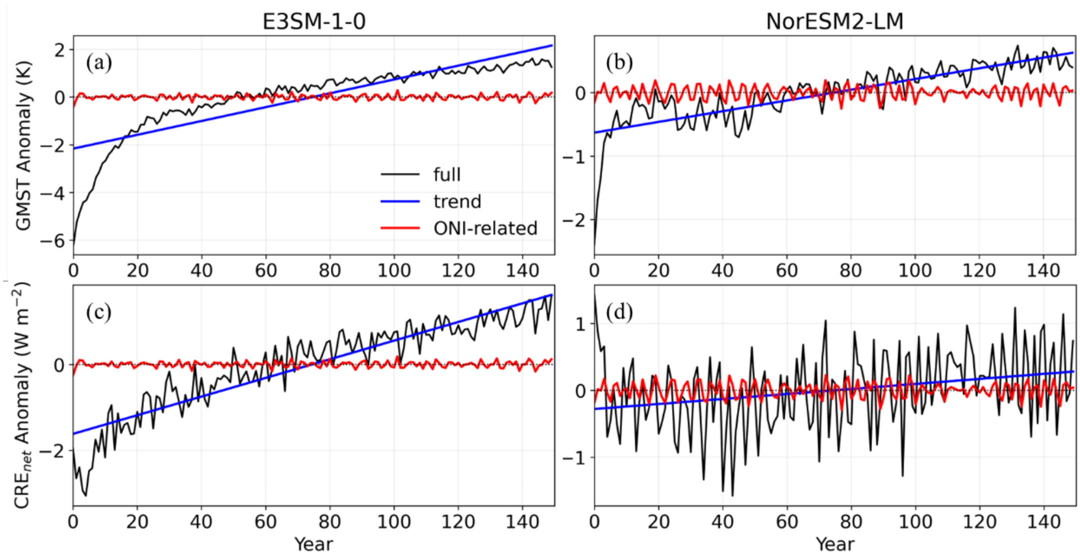
2. ENSO-related biases in 4×CO_2 experiment

I was quite surprised by the (really) large ENSO-related biases in cloud feedback estimates from the 150-yr abrupt 4×CO2 simulations (Figs. 6, 7), considering (1) the long timescales (150-yr) of the experiment and (2) the potential high signal-to-noise ratio in this strong forcing scenario. It again raises concerns related to the methodological question of whether the ONI has been detrended. If the ONI timeseries contains a strong linear trend in this case, the trend could actually reflect forced mean-state changes rather than ENSO variability. In that case, the current method might be attributing part of the long-term signal to ENSO, thus overestimating the ENSO-related contributions by double-counting tropical Pacific SST trends.

To address this, I suggest the authors show the timeseries of GMST and global-mean CRE over the course of the simulations, either for each model or one representative model. It should include both the full variations as well as their decomposed components (the long-term trends and ENSO-related variations). This would allow us to directly asses the evolution and relative magnitude of the two terms, and to verify whether the ENSO related signals are not being mixed with the global warming trend.

Answer: We appreciate this detailed feedback that actually underscores a key finding of our study. As noted in our response to major comment #1 (on methodology), the ONI is detrended when estimating ENSO contribution to cloud feedback estimates.

Following the suggestion, we have included the analysis of two representative GCMs and shown the corresponding results in Fig. S6. The two selected GCMs are E3SM-1-0, which shows almost negaligible ENSO contributions, and NorESM2-LM, which shows strong ENSO contributions (Figs. 7–9). For both models, the time series of GMST and global-mean CRE_{net} show clear separation between the trend- and ONI-related variations using our regression-based deENSO method (rephrased as “ENSO-correction method” in the revised manuscript).



“*Figure S6: Decomposition of GMST and global-mean CRE_{net}, derived from 2 GCM simulations from the abrupt-4×CO_2 experiment during the first 150 years. (a–b) GMST of (a) E3SM-1-0 and (b) NorESM2-LM. (c–d) Global-mean CRE_{net} of (c) E3SM-1-0 and (d) NorESM2-LM. The blue and red lines present the trend- and ONI-related variations, respectively.*”

Revised text in Section 3.3: "*The timeseries of GMST and global-mean CRE_{net} for two representative GCMs (E3SM-1-0 and NorESM2-LM) are also shown in Fig. S6. The results suggest a clear separation between the trend- and ONI-related variations achieved by our regression-based ENSO-correction method, thereby providing further validation for the ENSO contribution obtained by this method.*".

Specific comments:

1. Figure 1: The filtered ONI timeseries appears to have removed much of the high-frequency variability rather than the low-frequency variability?

Answer: We thank the reviewer for this attentive observation. The bandpass-filtered ONI retains only variability within the canonical ENSO band, specifically periods between 2 and 7 years. Consequently, both lower-frequency variability (periods >7 years, e.g., interdecadal trends) and higher-frequency variability (periods <2 years) were removed. The mentioned visual illusion may stem from the fact that the original ONI index exhibits only an insignificant long-term trend during the study period, as discussed in Fig. 2a. The revised text explains it: " *In contrast, the ONI does not exhibit a statistically significant trend (blue dashed line), indicating no consistent long-term intensification or weakening of ENSO over recent decades.*"

2. Line 85: Why not use SST (a readily available variable in GCM output) to compute the ONI to be consistent with observations.

Answer: Thank you. In the revised manuscript, we have followed the recommendation to compute ONI directly from the models' SST to ensure consistency. The results are almost identical to the previous ones.

3. Line 105-106: what "delayed components of ENSO-related variations" are referred to here?

Answer: The corresponding text has been revised to clarify this point: "*Importantly, because Eq. (1) uses the bandpass-filtered ONI and assumes no time lag, this OLS-based ENSO-correction method may retain some ENSO-related variations in Y. These include potential low-frequency natural trends in ENSO itself and any delayed or non-linear impacts of ENSO on GMST and CREs. Consequently, this method is likely to provide a conservative estimate of ENSO contribution (see Section 2.4) (Kelly and Jones, 1996; Compo and Sardeshmukh, 2010).*".

4. Line 135: Does this mean that 9 out of 12 GCMs actually show a significant ENSO/ONI trend over this period? If so, does this linear decomposition still hold?

Answer: Yes, that is correct. In the revised manuscript, 9 out of 11 evaluated GCMs show a statistically significant ONI trend over January 1950–December 2014. Simulations from TaiESM1 are excluded from the analysis because we were not able to download the corresponding SST data.

Nevertheless, such ONI trends would not undermine the analysis of ENSO contribution in cloud feedback estimates since it uses the filtered ONI (detrended). Please see our answers to the major comment #1 (on methodology) and #2 (on Results) for details.

5. Line 143-144: This sentence is very confusing and unclear, I do not understand what is meant here. Please consider rephrasing.

Answer: The sentence has been rephrased to "*This allows us to assess the relative contribution of the warming trend (partial R^2_{trend}; Fig. 2b) and ENSO (partial R^2_{ONI}; Fig. 2c) to the total variance of GMST across different timescales with high confidence.*".

6. Line 149: Based on Fig. 2b, the variance in GMST explained by the trend over a randomly-selected 40 yr period (other than 1982-2021) can be as low as 0.3. Similarly, ENSO's contribution (R^2_{ONI}) is up to 0.1. This suggests that more than 50% of the total GMST variance could come from the residual term. If so, this linear decomposition doesn't seem to work well and may not accurately reproduce the original variance.

Answer: We appreciate this thoughtful comment and fully acknowledge the limitation of the two-predictor linear model in representing the total GMST variance. Nevertheless, we respectfully emphasize that the main goal of this study is to decouple ENSO impact. To provide statistical justification and ensure the robustness of the decomposed signal, we have added significance tests for all relevant analyses. Please see our answer to the major comment #2 on methodology for more details.

7. Line 165: What exactly is meant by "covariations between clouds and the warming trend"? As noted in my major concerns, is this essentially just the trend in CRE?

Answer: The text has been revised for clarity to "*Given the significant warming trend in GMST during this period (0.02 K year^{-1}), the resulting patterns reveal strong co-variations between CREs and recent warming in regions such as the Arctic, central Africa, and the tropical eastern oceans.*".

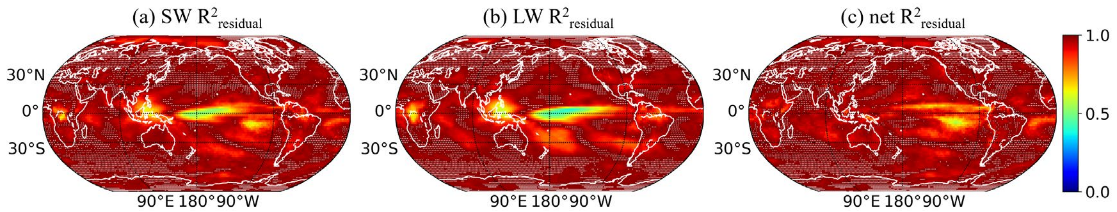
8. Line 169: While it's true that ENSO has a relatively small impact on the GMST during this period, it may have a more notable impact on regional surface temperature variations (e.g. in the tropical Pacific). If so, this statement may be unfair. For a more solid comparison, I suggest the authors show spatial maps of surface temperature variance explained by the warming trend and by ENSO (similar to Fig. 3 but for TS instead of CRE). In addition, it would also be helpful to show the global-mean CRE timeseries along with its decompositions into the linear trend and ENSO-related component (similar to Fig. 1 but for global-mean CRE instead of GMST).

Answer: Thanks for raising this point. Following this and previous comments, Fig. 3 has been reproduced (please see above), while the statement has been revised into "*Compared to ENSO, the temporal trend has a much weaker impact on CREs over a large portion of low- to mid-latitude oceans (bluish shades in Fig. 3g – i). This is* *particularly evident for CRE_{SW} and CRE_{LW} across the tropical Pacific, implying a region-dependent ENSO contribution to the assessment of long-term cloud feedback to global warming.*"

9. Related to Fig. 3: how much of the regional variance is associated with the residual term? It would be informative to provide another row of panels showing the contribution of the residual term (c in Eq. 1).

Answer: We thank the reviewer for this suggestion. We have added the analysis and shown the maps of residual variance corresponding to Fig. 3 in Fig. S2. As the reviewer anticipates and we previously discussed, the two-predictor linear model does not capture the total CRE variance, especially for regions with insignificant contributions by both the temporal trend and ENSO.

Nevertheless, since our main goal is to isolate ENSO impact rather than to predict CRE fully, we focus on the statistical significance of the regression coefficients, which has been thoroughly evaluated and added throughout the revised manuscript. Further discussion can be found in our answers to major comment #2 (on methodology) and specific comments #6.



"*Figure S2: Maps of residual R^2 for results presented in Fig. 3 in the main text. (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. White dots denote grids with statistically insignificant partial regression coefficients of both time and ONI (i.e., a and b in Eq. 1) at the 95% confidence level.*"

Revised text in Section 3.2: "*To illustrate this point, we analyze the same 40-year period (January 1982 – December 2021) as an example and present the corresponding partial R^2 maps of CREs in Fig. 3. The maps of corresponding residual R^2 are shown in Fig. S2.*".

Response to Referee #2

General comments:

This paper provides a novel, straightforward framework for assessing the separate influences of (1) externally forced long-term trends and (2) natural climate variability on regression-based estimates of climate feedbacks. The authors show that by removing ENSO from observed and modeled estimates of surface temperature and the cloud-radiative effect (CRE), the resulting local cloud feedbacks (estimated by regressing spatially-resolved CRE against global-mean surface temperature) are notably distinct from the feedbacks obtained without removing ENSO.

The "de-ENSO" methodology proposed by the authors appears robust and their results appear physically sound. However, the implications of their results for previous estimates of observed and modeled cloud feedbacks are not yet clear, and their recommendation that future related research adopt this procedure is not yet fully justified. The "relative bias" and "ENSO effect minimal time" metrics proposed by the authors may also not be robust, while other results from the de-ENSO methodology that may be of broader interest to the climate dynamics community are missing. I therefore recommend reconsideration after substantial revisions to the figures and text addressing the below concerns.

Answer: We sincerely thank the reviewer for the thorough and constructive comments and appreciate the positive feedback. We have took all the comments into consideration and revised the manuscript accordingly.

In response to the general comments, we have performed additional analyses using satellite observations and examined the role of ENSO in global-mean CRE to further strengthen the physical interpretation and broader relevance of our results. We have also carefully revised the text, figures and metric to better articulate the implications of our findings and to provide stronger justification for the proposed methodology.

Below, we provide the detailed response in a point-by-point manner.

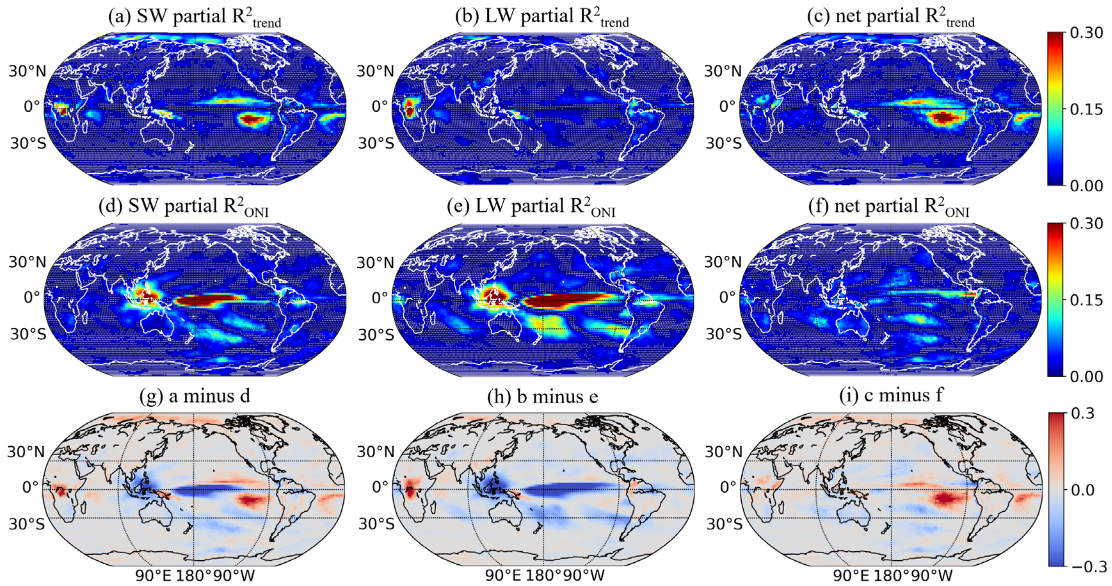
Major suggestions:

1. I suggest the authors remove the "relative bias" metrics in Figure 4, and remove Figures 3 and 7 altogether. Since the denominator in either metric may closely approach zero, the robustness and interpretation of the results is unclear. The yellow color bar in Figure 3 illustrates this issue: While cases where ENSO explains from 1 to 100 times the variance in CRE compared to long-term trends are shown very clearly, cases where the long-term trend explains from 1 to 100 times the variance in CRE compared to ENSO are hidden in pale yellow. This overemphasizes the impact of ENSO relative to long-term trends. The metrics in Figures 4 and 7 are even more vulnerable to this issue, since the local cloud feedback changes sign across different regions. The motivation behind normalizing by the local feedback may also rest on a common misconception

regarding climate feedback regressions. That is, regression slopes of 0 W m^{-2} K^{-1} may indicate physically meaningful feedback values rather than "unsuccessful" results. In the feedback context, the strongly negative Planck feedback is the reference value, while 0 W m^{-2} K^{-1} indicates that other processes are counteracting the Planck feedback. The 0 W m^{-2} K^{-1} result is also not necessarily highly uncertain, since the uncertainty of the regression slope depends only on the variance in the residuals, which can still be arbitrarily small (e.g., constant CRE with rising temperature).

Answer: We appreciate this insightful comment that raises important points regarding the robustness and interpretation of the relative metrics. In response, we have made the following revisions:

(1) **Figure 3:** We have replaced panels g–i with maps showing the simple difference in explained variance (partial R^2_{trend} minus partial R^2_{ONI}) to demonstrate the relative importance of the temporal trend and ENSO, thus eliminating the issue of ratio-based metrics. The revised figure and corresponding text are cited below:



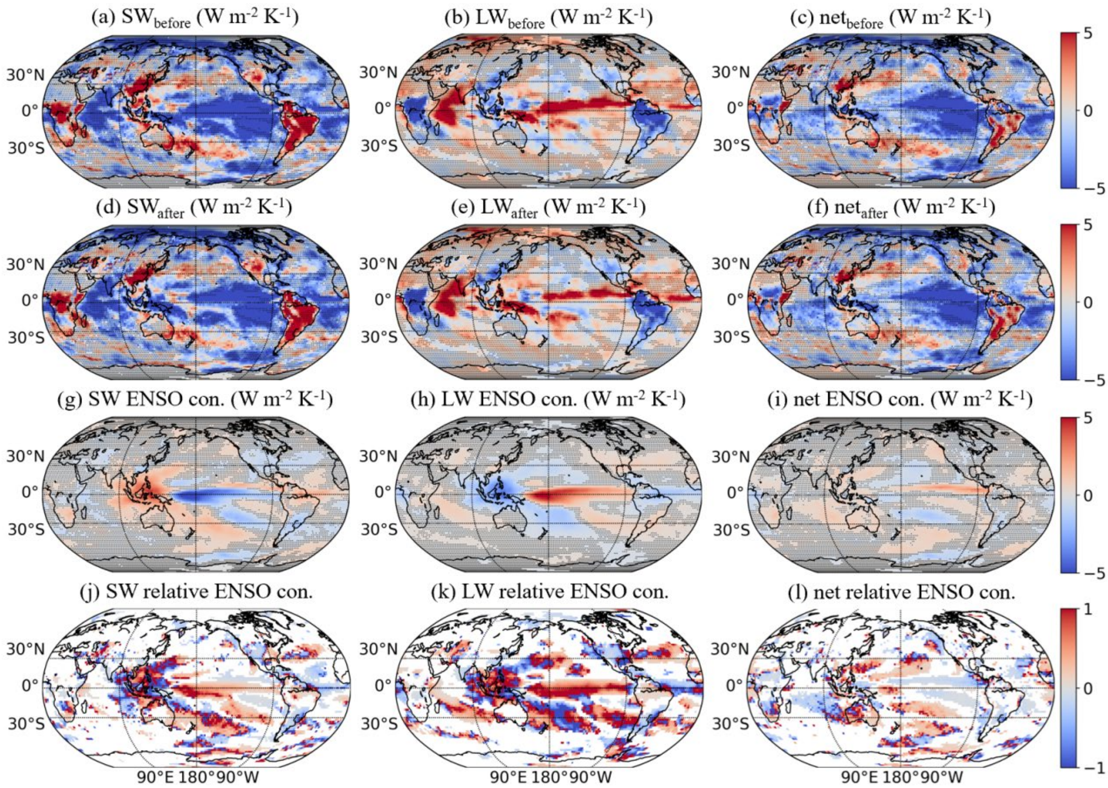
"Figure 3: A sample analysis of the variations in CREs as driven by the temporal trend and ENSO, derived from ERA5 data during January 1982–December 2021. (a–c) Partial R^2_{trend} for (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. (d–f) Partial R^2_{ONI} for (d) CRE_{SW}, (e) CRE_{LW}, and (f) CRE_{net}. (g–i) The difference between (a–c) and (d–f). In panels (a–f), white dots denote grids with statistically insignificant partial regression coefficients of time (i.e., a in Eq. 1) and ONI (i.e., b in Eq. 1) at the 95% confidence level."

(2) **Figures 4 and 7 (now Figs. 4 and 8):** We recognize the reviewer's concern about normalizing by local feedback values. But the "relative ENSO-related bias" (rephrased as "relative ENSO contribution" in the revised manuscript and hereafter by following major suggestion #6) metric adds valuable information by emphasizing regions where ENSO could be a dominant contributor in the local cloud feedback estimate. Therefore, in order to improve the robustness and address your concerns, we have:

- Masked out grid points where ENSO contribution is statistically insignificant, as the ratio loses meaning if the identified ENSO contribution is not robust.

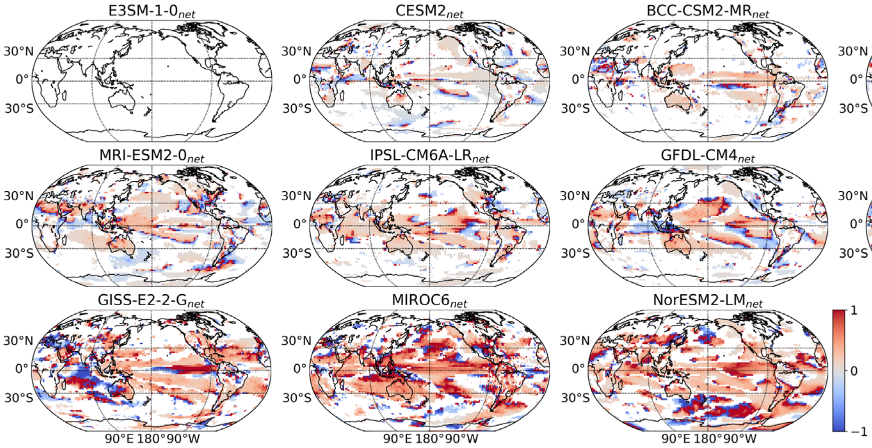
- Considered the sign and ensured it is physically interpreted: positive values indicate ENSO amplifies the feedback estimate, while negative values indicate damping.
- Adopted a revised, more balanced color bar to represent values in a visual manner that is relatively fair.
- Added a detailed explanation in the text to clarify the mathematical formulation and physical interpretation of this metric, acknowledging that values with near 0 denominator should be taken with caution.

The corresponding changes in the revised manuscript is cited below:



"*Figure 4: A sample analysis of ENSO contribution to cloud feedback estimates for CRE_{SW} (left column), CRE_{LW} (middle column), and CRE_{net} (right column), derived from ERA5 data during January 1982 – December 2021. (a – c) Cloud feedback estimates before ENSO correction. (d – f) Cloud feedback estimates after ENSO correction. (g – i) ENSO contribution (a – c minus d – f). (j – l) Relative ENSO contribution (g – i divided by a – c). In panels (a – i), black dots denote grids with statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or respective CRE at the 95% confidence level. In panels (j – l), these insignificant grids are masked in white.*"

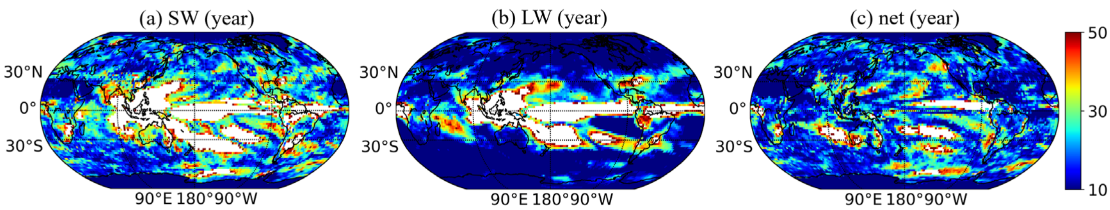
Revised text in Section 3.3: "*Figure 4j – l shows the distributions of the relative ENSO contribution, which is calculated as the ratio between ENSO contribution (Fig. 4g – i) and the original cloud feedback estimates (Fig. 4a – c). The ratio reaches ±1 (dark* *reddish and bluish shades) over a substantial part of low- to mid-latitude oceans, indicating comparable ENSO- and non-ENSO-forced cloud feedback over these regions. But, by definition, the robustness of this relative metric suffers from near zero denominators and should be taken with caution.*".



"*Figure 8: Maps of the relative ENSO contribution to CRE_{net}, derived from GCM simulations from the abrupt-4×CO_2 experiment during the first 150 years. The name of the corresponding model is indicated in each panel. Grids with statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE at the 95% confidence level are masked in white.*"

2. I suggest the authors remove Figure 5 (the CMIP-based "ENSO effect minimal time"), then either (1) remove the ERA5-based "ENSO effect minimal time" in Figure 4, or (2) replace this metric with an alternative metric based on the "absolute bias". The robustness of the current metric is unclear, since it depends on the uncertain relative bias term (see above). As an example for an alternative metric, the authors could pick a reasonable precision threshold (e.g., 0.1 W m^{-2} K^{-1}) and show the average number of years required until the absolute value of the "absolute bias" falls and remains below the threshold.

Answer: We sincerely thank the reviewer for this constructive suggestion. Following your recommendation no. (2), we have redefined the "ENSO effect minimal time" based on the absolute ENSO contribution using the threshold of 1 W m^{-2} K^{-1}. The revised results (Fig. 5 in the new manuscript) and corresponding text are cited below:

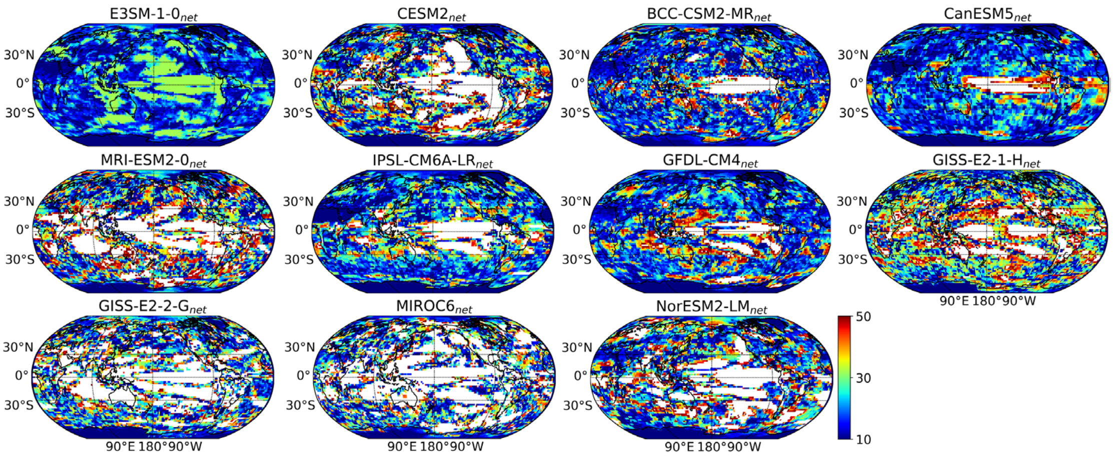


"*Figure 5: Maps of "ENSO effect minimal time" for different CREs, derived from ERA5 data during January 1982 – December 2021. (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. Regions masked in white denote grids where ENSO contribution never consistently falls below 1 W m^{-2} K^{-1} or becomes statistically insignificant within time* *windows up to 50 years.*"

Revised text in Section 3.3: "*This metric is defined as the shortest time window beyond which the mean magnitude of ENSO contribution (ignoring the sign) falls and remains below 1 W m*$^{-2}$ *K*$^{-1}$ *(i.e.,* $|\overline{ENSO\ con.}| < 1\,W\,m^{-2}\,K^{-1}$*), or beyond which the partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE becomes and remains statistically insignificant at the 95% confidence level. The threshold of 1 W m*$^{-2}$ *K*$^{-1}$ *is chosen to demonstrate a non-negligible ENSO contribution relative to the local cloud feedback estimates, which is typically on the order of several W m*$^{-2}$ *K*$^{-1}$*, as simulated by current GCMs (Forster et al., 2021; Ceppi & Nowack, 2021; 301 Zelinka et al., 2016; Myers et al., 2021).*

Figure 5 presents the spatial distribution of "ENSO effect minimal time" for CRE_{SW}*,* CRE_{LW}*, and* CRE_{net}*, revealing complex patterns and notable differences among the three variables. In most subtropical regions, the minimal time is shorter than 30 years (bluish to greenish shades). However, in some tropical and mid-latitude regions, particularly the Pacific Ocean, the mean ENSO contribution never consistently falls below 1 W m*$^{-2}$ *K*$^{-1}$ *or becomes statistically insignificant within time windows up to 50 years (white shades). These results align with the slow decay of ENSO impact on GMST (Fig. 2c) and the patterns revealed for ENSO impact on CREs (Fig. 3d – f), illustrating clearly that ENSO contributes significantly to the assessment of long-term cloud feedback to global warming, especially over the Pacific and during relatively short periods characterized by intense ENSO activity.*".

Regarding Fig. 5 in the previous manuscript, we have reproduced it following the new definition of "ENSO effect minimal time" and have moved it to SI (Fig. S4), which you can see below:



"*Figure S4: Maps of "ENSO effect minimal time" for* CRE_{net}*, derived from GCM simulations from the historical experiment during January 1950 – December 2014. The name of the corresponding model is indicated in each panel.*"

3. I suggest the authors only use ERA5 to (1) illustrate the robustness and physical interpretation of the de-ENSO methodology (Figures 2B and 2C), and optionally (2) estimate the "ENSO effect minimal time" (Figure 4, bottom row; see above). Beyond

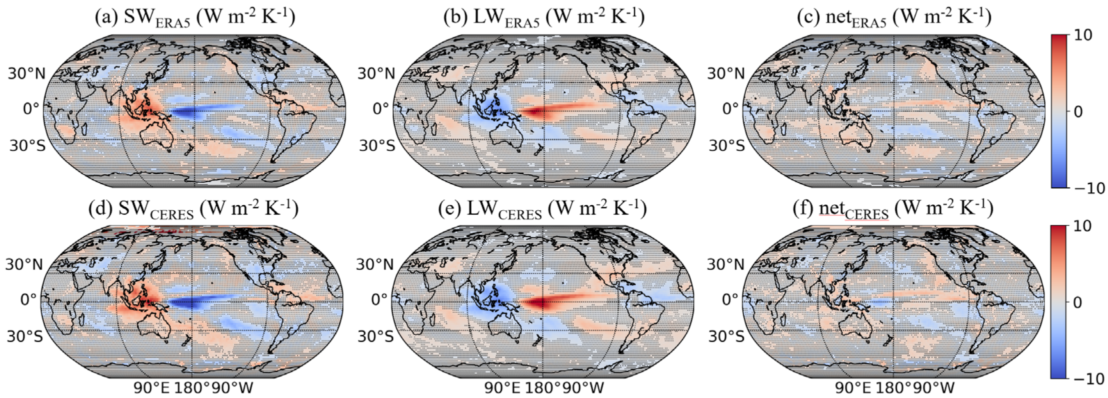
this, I recommend the authors replace the ENSO bias estimates in the top row of Figure 4 with results obtained from observational data rather than a reanalysis product. The results should be much more robust, since ERA5 estimates of cloud-radiative effect (CRE) are significantly biased compared to satellite-based estimates of CRE (e.g., Loeb et al. 2022, DOI 10.1029/2022JD036686). The results should also be more directly relevant to the climate dynamics community, since a large number of recent studies use satellite observations to estimate climate feedbacks (more than cited here). To estimate CRE, the authors could use the energy-balanced-and-filled (EBAF) CERES product (e.g., He et al. 2021, DOI 10.1029/2020GL092309; Davis et al. 2024, DOI 10.1029/2024GL112774), a combination of CERES and ERBE (e.g., Uribe et al. 2024, DOI 10.5194/acp-24-13371-2024), or optionally estimate clear-sky fluxes from ERA5 (e.g., Dessler and Loeb 2013, DOI 10.1002/jgrd.50199). To estimate surface temperature, a more direct observational data set like HadCRUT5 or GISTEMP4 could be used. The full available record should also be used instead of the 1982-2021 example period.

Answer: We thank the reviewer for this exceptionally detailed suggestion. In response , we have performed a full parallel analysis using the CERES EBAF Ed4.2 product for a direct comparison with the reanalysis-based ENSO contribution to cloud feedback estimates. The results demonstrate that the spatial pattern and magnitude of ENSO contribution identified in ERA5 are corroborated by satellite observations. To maintain the logical flow and consistency of our narrative, which focuses on quantifying ENSO contribution to long-term feedback estimates, we chose to add these new observational results to the revised SI (Fig. S3):

Revised text in Section 2.2: "*The primary analysis uses 72 years of reanalysis data from the ERA5 dataset, 20 years of satellite measurements from the CERES EBAF product, and 150 years of GCM simulations from the abrupt-4×CO_2 experiment.*"

"*(2) CERES measurements (January 2002 – December 2021). We conduct a comparison between ENSO contribution derived from ERA5 data and satellite measurements using TOA fluxes from the Earth's Radiant Energy System (CERES) Energy Balanced and Filled (EBAF) data product (Loeb et al., 2018; updated to Edition 4.2). It is specifically designed for climate trend analysis, as it minimizes errors from instrument calibration and orbital drift by integrating measurements from multiple satellites (Loeb et al., 2018). Here, this product is regarded as a benchmark observational dataset for evaluating reanalysis of the Earth's energy budget.*"

Revised text in Section 3.3: "*But before further discussion of the ERA5 results, we conducted a similar analysis of ENSO contribution using the CERES data (for the period January 2002–December 2021) and compared the results of the two datasets (Fig. S3). The remarkably consistent patterns between ERA5- and CERES-based ENSO contributions suggest that the ERA5 data is able to reproduce the essential features of ENSO-caused variations in CREs.*"



"*Figure S3: A sample analysis of ENSO contribution to cloud feedback estimates for CRE_{SW} (left column), CRE_{LW} (middle column), and CRE_{net} (right column), derived from ERA5 data and CERES measurements during January 2002 – December 2021. (a – c) Maps for ERA5 data. (d – f) Maps for CERES measurements. Black dots denote grids with statistically insignificant partial regression coefficient of ONI (i.e., b in Eq. 1) for either GMST or CRE at the 95% confidence level.*"

The added reference: "*Loeb, N. G., Doelling, D. R., Wang, H., Su, W., Nguyen, C., Corbett, J. G., et al.: Clouds and the earth' s radiant energy system (CERES) energy balanced and filled (EBAF) top-ofatmosphere (TOA) edition-4.0 data product, J. Clim., 31, 895-918, doi.org/10.1175/JCLI-D-17-0208.1, 2018.*"

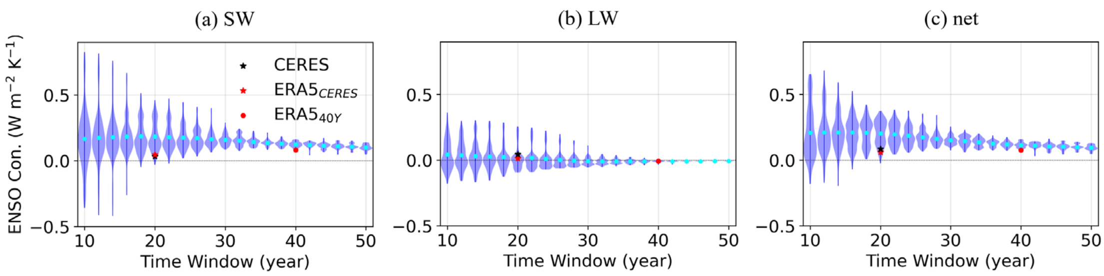
We also fully agree that a comprehensive analysis of ENSO contribution in observed cloud feedback is a compelling topic to the climate dynamics community. But in this study, as the first step, we would like to maintain our focus on illustrating the methodological framework and its implications for interpreting model-based long-term cloud feedback assessments, which often rely on reanalysis data and GCM simulations for full spatial coverage and long temporal records.

4. I suggest the authors add two rows above the "absolute bias" term in Figure 4: The first row showing local CRE feedbacks before the de-ENSO procedure, the second row showing local CRE feedbacks after the de-ENSO procedure (note these should be based on satellite observations rather than ERA5; see above). The "absolute bias" can then be understood visually as the difference between the first and second rows. Each row should also use the same blue-red colorbar and (if possible) the same minimum and maximum colorbar values. This will give a qualitative picture of the sign and relative magnitude of each term across regions. Without these results, it is difficult to contextualize the importance of "ENSO biases" and their possible impact on the interpretation of local feedback processes (e.g., over the Southern Ocean or in the subtropical stratocumulus regions).

Answer: Following this suggestion and our answer to major suggestion #3, we have generated maps of the local CRE feedbacks both before and after applying the de-ENSO (rephrased as "ENSO-correction" in the revised manuscript and hereafter by following minor suggestion #4) procedure using ERA5 data. As suggested, these results use the same blue-red colorbar with the same value range and have been added to the top of Fig. 4, please see above.

5. In most studies, local climate feedbacks are used to interpret the physical and regional processes contributing to global climate feedbacks. Thus, while "ENSO biases" in local feedbacks may affect this interpretation, any biases in the global feedbacks themselves may be more directly relevant to the climate dynamics community. I therefore suggest the authors add a new table or bar-plot after Figure 4, showing satellite-based estimates of (1) global CRE feedbacks before the de-ENSO procedure, (2) global CRE feedbacks after the de-ENSO procedure, and (3) the difference between these terms (i.e., the global-average ENSO bias). Note that since the least-squares linear regression slope Sum[Y'X']/Sum[X'^2] is a linear operator on Y, these terms should be equivalent to the global average of each panel in Figure 4. Similarly, I suggest the authors add a new table or bar-plot after Figure 6, showing CMIP6 estimates of the global-average ENSO bias. To further address recent literature, the authors may also wish to explore "ENSO biases" in the short-term (typically years 1-20; Andrews et al. 2015, DOI 10.1175/JCLI-D-14-00545.1) and long-term (years 21-150) components of the 4×CO_2 response. But this last suggestion is not critical.

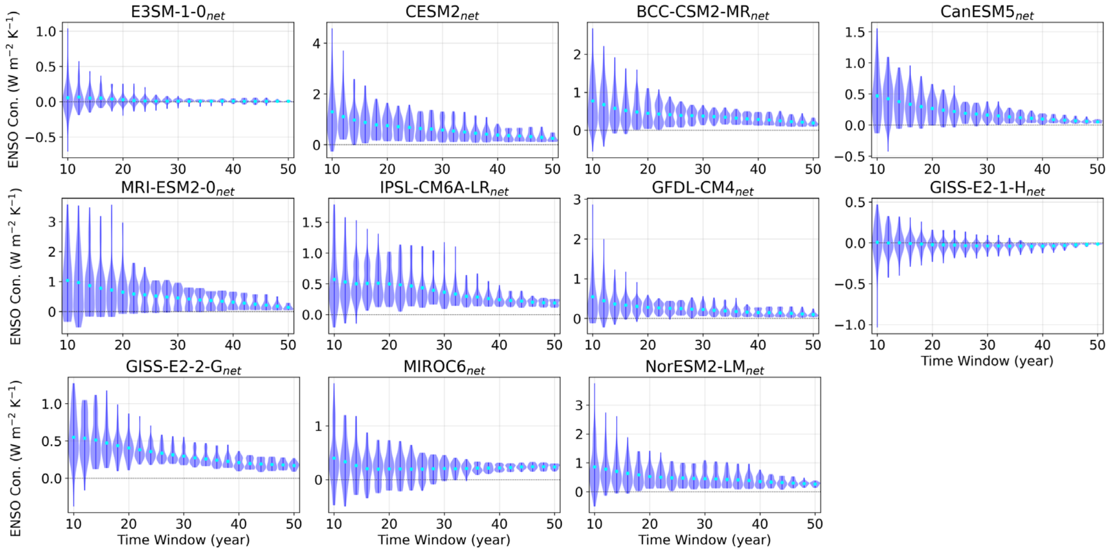
Answer: We thank the reviewer for this highly relevant suggestions. We agree that quantifying ENSO contribution to global-mean cloud feedback is of great importance, as it directly affects the interpretation of Earth's energy balance and climate sensitivity. In direct response to this comment, we have added the following new analyses and revised the corresponding text:



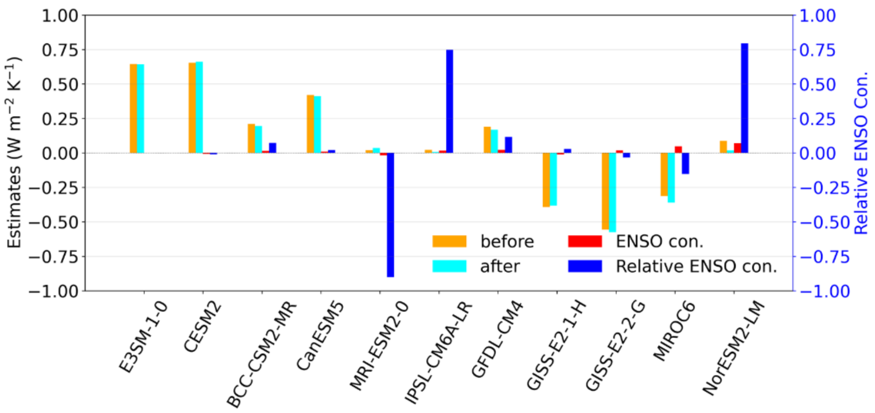
"*Figure 6: Violin plots of ENSO contribution to global-mean CREs, derived from ERA5 data during January 1950 – December 2021. (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. The black star, red star, and red dot denote the results from CERES measurements, ERA5 data during the CERES period, and ERA5 data during the exampled 40-year period, respectively.*"

Revised text in Section 3.3: "*Figure 6 then gives the ENSO contribution to global-mean CREs as a function of the time window. The corresponding results derived from CERES measurements, ERA5 data during the CERES period, and ERA5 data during the representative 40-year subset are also shown. As expected, the results change with time and converge toward small values (about 0.1, 0.0, and 0.1 W m^{-2} K^{-1} for CRE_{SW}, CRE_{LW}, and CRE_{net}, respectively) due to the cancellation of positive and negative local ENSO contributions across different regions. This convergence also agrees well with* *the revealed behaviour of ENSO impact on GMST in Fig. 2c.*

To provide a partial validation of our findings within current climate models, taking the CRE_{net} as an example, we analyzed the "ENSO effect minimal time" and the global-mean ENSO contribution for 11 GCM simulations from the historical experiment (Figs. S2 – S3). Though obvious inter-model discrepancies exist, the general message that ENSO can significantly affect long-term cloud feedback estimates remains consistent."



"*Figure S5: Violin plots for ENSO contribution to global-mean CRE_{net}, derived from GCM simulations from the historical experiment during January 1950 – December 2014. The name of the corresponding model is indicated in each panel.*"



"*Figure 9: Bar charts of ENSO contribution to global-mean CRE_{net}, derived from GCM simulations from the abrupt-4×CO_2 experiment during the first 150 years. The orange and cyan bars indicate global-mean cloud feedback estimates before and after ENSO correction, respectively. The red and blue bars indicate ENSO contribution (orange minus cyan bars) and relative ENSO contribution (red divided by orange bars; right y-axis), respectively.*"

Revised text in Section 3.4: "*ENSO contribution to global-mean CRE_{net} (Fig. 9) shows large inter-model spread as well. As discussed above, these differences indicate* *deficiencies of models in accurately representing ENSO, global warming, and their relative impacts on GMST and clouds (Bellenger et al., 2014; Coburn and Pryor, 2021). For example, previous studies suggest that, compared to observations, many GCMs present a too-strong equatorial Pacific cold tongue (Jiang et al., 2021) and fail to capture the recent strengthening of the west-to-east equatorial Pacific SST gradient (Seager et al., 2019). These two deficiencies introduce critical uncertainties into projections of ENSO, and hence clouds, under global warming (e.g., Guilyardi et al., 2020; Beobide-Arsuaga et al., 2021).”*

6. Previous studies have quantified the "feedbacks" associated with (primarily ENSO-driven) internal variability by regressing observed radiative flux against surface temperature after subtracting the long-term trend from each term (e.g., Zhou et al. 2015, DOI 10.1002/2015GL066698; Dessler and Forster 2018, DOI 10.1029/2018JD028481; Lutsko 2018, DOI 10.1029/2018GL079236; Davis et al. 2024, DOI 10.1029/2024GL112774). These "interannual feedbacks" may be similar to the "ENSO bias" term used in this paper -- but the referenced papers frame them as metrics for a different physical process rather than a bias, and the referenced papers show the "interannual feedback" is itself related to the long-term climate feedback across CMIP models. I therefore suggest the authors use more neutral language for the "ENSO bias" term, e.g. "ENSO contribution" or "ENSO adjustment". For added relevance, the authors may also wish to compare their local or global-average "ENSO bias" results with results from these papers.

Answer: We sincerely appreciate this insightful comment and key references. We agree that the terminology "bias" may carry unintended connotations, suggesting a methodological error rather than a physically meaningful component of variability. Following this suggestion, the term "ENSO-related bias" has been replaced with the more neutral and descriptive term "ENSO contribution". We believe this term more accurately reflects that we are quantifying the component of the estimated feedback that is linearly attributable to ENSO variability. In addition, to align with this conceptual reframing, the title of the revised manuscript has been modified to: "*ENSO contribution to the assessment of long-term cloud feedback to global warming*".

By applying the linear regression slope, Zhou et al. (2015) identified a robust relationship between interannual and long-term cloud feedbacks in CMIP5 simulations. Dessler and Forster (2018) subsequently leveraged such relationships to estimate the equilibrium climate sensitivity using short-term observations. Further building on this line of inquiry, Davis et al. (2024) demonstrated that such relationships exhibits stronger correlations in CMIP6 simulaitons compared to CMIP5. As recommended, these studies serve us valuable references. However, it is important to note that while the interannual feedbacks they identified are strongly linked to the ENSO contributions highlighted in our work, their analyses of long-term feedbacks did not account for such ENSO contributions. Consequently, their findings provide an important layer of implications or future investigations of our study, prompting the question of to what extent ENSO contributions modulate the interannual and long-term feedback relationships. Since previous studies aiming for different scientific goals and used different datasets with data processeing, we didn't add direct comparisons in the revised manuscript. Rather, we revised the Results to better claritfy the links between our findings and results from previous studies, please see details below.

Revised text in Section 3.4: "*But the specific magnitudes and detailed spatial features vary considerably across the 11 models. For instance, simulations from GISS-E2-2-G, MIROC6 and NorESM2-LM show that ENSO contribution to cloud feedback estimates remains on the order of a few W m^{-2} K^{-1} over extensive regions, even for a 150-year period, which is comparable to the local cloud feedback estimates (Forster et al., 2021; Ceppi & Nowack, 2021; Zelinka et al., 2016; Myers et al., 2021). These findings also align with and extend previous studies that identified robust correlations between interannual and long-term cloud feedback (e.g., Zhou et al., 2015; Dessler and Forster, 2018; Davis et al., 2024) by highlighting the potential modulating role of ENSO contributions.*"

The added reference:

"*Davis, L. L. B., Thompson, D. W. J., Rugenstein, M. and Birner, T.: Links between internal variability and forced climate feedbacks: The importance of patterns of temperature variability and change. Geophys. Res. Lett., 51, e2024GL112774, doi.org/10.1029/2024GL112774, 2024.*

Dessler, A. E. and Forster, P. M.: An estimate of equilibrium climate sensitivity from interannual variability. J. Geophys. Res. Atmos., 123, 8634-8645, doi.org/10.1029/2018JD028481, 2018."

Minor suggestions:

1. All paragraphs: Please add vertical space or indentation before each paragraph. Currently it is a bit difficult to differentiate separate paragraphs.

Answer: Thank you for this comment. Indentation has been added before each paragraph throughout the manuscript.

2. Lines 112, 106, 117: Please re-format the numbered equations to follow ACP style guidelines (horizontal centering on separate lines, with empty space above and below, and equation numbers in parentheses on the right-hand side).

Answer: Thank you. The equations have been re-formated.

3. Lines 178, 179, 182, 217, 219, 226, 232: I suggest replacing the term "absolute bias" with e.g. "ENSO contribution" or "ENSO adjustment" (see above).

Answer: As explained above (see major comment #6), according to your suggestion, the term "ENSO-related bias" has been replaced with the more neutral and descriptive term "ENSO contribution".

4. Lines 38, 91, 92, 97, 103, 105, 115, 174, 192, 245, 249: The term "de-ENSO" is grammatically unusual. I suggest replacing "de-ENSO method" on the referenced lines with "ENSO-correction method", or consider not naming the method at all (e.g., on line 38, "regression-based de-ENSO method" can be replaced with "regression-based method", since it is clear from the subsequent clause that this method removes ENSO). The subscript "deENSO" used in equations could then be replaced with e.g. "trend" (since the method seeks to capture the trend component), or an asterisk or prime superscript denoting an anomaly (since each de-ENSO result is a residual with respect to the ENSO-fit).

Answer: Thanks for this detailed feedback. The term “de-ENSO” has been replaced with “ENSO-correction” throughout the revised manuscript.

5. Lines 17-19: The formatting used to describe each CRE term is unusual. I suggest replacing with "shortwave cloud-radiative effect", "longwave cloud-radiative effect" and "net cloud-radiative effect".

Answer: The CRE terms have been replaced as suggested.

6. Lines 54-57: The formatting used to describe each radiative flux term is unusual. I suggest replacing with "net top-of-atmosphere (TOA) shortwave flux", "TOA longwave flux", "TOA clear-sky shortwave flux", and "TOA clear-sky longwave flux". The additional information in parentheses can be deleted (see below).

Answer: Thank you, the terms and corresponding text have been revised as suggested.

7. Lines 54-57, Lines 71-72, Lines 78-79: I don't think it's necessary to spell out the variable names used in the ERA5 and CMIP6 data files (i.e., TSR, TSRC, TTR, TTRC, tas, rsut, rsutcs, rlut, rlutcs). Tracking them all is a bit confusing, and the relevant variables in each data set should be clear from your descriptions. I suggest deleting the abbreviations and replacing with the descriptions suggested above when referencing these quantities.

Answer: We thank the reviewer for this suggestion that helped us improve the clarity and flow of the manuscript. Following it, we now list the variables right after a general introduction of the datasets and have replaced the corresponding terms with those suggested in your minor suggestion #6.

Revised text in Section 2.1: “*The analysed variables include sea-surface temperature, air temperature at 2 meters, all-sky and clear-sky TOA shortwave flux, as well as all-sky and clear-sky TOA longwave flux.*”.

Revised text in Section 2.2: “*CRE_{SW} is calculated as the difference between all-sky and clear-sky TOA shortwave flux; CRE_{LW} is calculated as the difference between all-sky and clear-sky TOA longwave flux; and CRE_{net} is obtained by summing CRE_{SW} and CRE_{LW}.*”.

8. Lines 66, 110, 122, 127, 148, 157, 161, 175, 178, 212: The date format "MM.YYYY" may not follow ACP style guidelines. I suggest either spelling out the calendar month (e.g. January 1950 to December 2021) or using 3-character abbreviations (e.g. Jan. 1950 to Dec. 2021).

Answer: Thanks. The date format has been revised throughout the manuscript to follow the recommended style, using the full spelling of calendar months (e.g., January 1950 to December 2021).

9. Lines 14, 26, 36, 149, 169 (twice), 208, 210, 234: The phrase "the ENSO" is unusual, since acronyms are typically used without definite articles. Please replace instances of "the ENSO" on the referenced lines with "ENSO"

Answer: We thank the reviewer for catching this grammatical oversight. All instances of "the ENSO" on the referenced lines have been corrected to "ENSO".

10. Lines 50-64, Lines 76-85: The items (1) and (2) should be formatted as a numbered list. The sentence introducing the numbered list can also be shorter and less specific, e.g. "For each data set, our analysis is based on the following two-step approach:".

Answer: The format and text have been revised as recommended.

11. Lines 61-63: The description of the variant label "r1i1f1p1" can be deleted and replaced with a reference to Eyring et al. 2016 (as in the following sentence).

Answer: Thanks. We have revised it as suggested.

12. Lines 85-87: The weighting methodology and details here are unnecessary. The authors can closely approximate grid cell area using the product of the cosine of the central latitude (in radians) with the longitude- and latitude-widths of the cell (only required if they vary in space). Plotting the cosine weights against the exact arc length weights should reveal very close agreement up to grid cell widths outside the range used by CMIP6 models.

Answer: Thank you for this comment. we would like to keep this short description of our methodology.

Additional suggestions:

There are a number of other grammatical and typographical errors throughout the text that should be addressed before re-submission. Some examples and suggested corrections:

1. Line 10: "in these estimations" -> "in these estimates".

2. Line 20: "climate predictions" -> "climate change projections" or "projections of

climate change".

3. Line 23: There is an extra space after the comma following "natural climate variability".

4. Line 45: "Based on which, the Oceanic Niño Index (ONI) is derived for measuring" -> "For each dataset, we derive the Oceanic Niño Index (ONI) to measure"

5. Line 54: "sea surface temperature" -> "sea-surface temperature"

6. Line 61: "usethe" -> "use the"

7. Line 67: "is a baseline experiment of the [...] experiments" -> "is a [...] experiment"

8. Line 68: "immediate climate response" -> "climate response" (the forcing is immediate, but the response is studied over decades and centuries)

9. Line 79: "Global Mean Surface Temperature" -> "global-mean surface temperature" (upper case should be reserved for proper nouns)

10. Line 112: "OLS correlation slope" -> "OLS regression slope"

11. Line 125: "marks" -> "indicates"

12. Line 140: "Of course, " can be deleted.

13. Line 145: "As shown, " can be deleted.

14. Line 150: "Please note that " can be deleted.

15. Line 149: The dash after "ENSO" should be removed.

16. Line 151: "get similar results" -> "found similar results".

17. Line 158: The comma after "ENSO" should be removed.

18. Line 168: "It's clear that, " can be deleted.

19. Line 175: "presents" -> "shows"

20. Line 190: "an almost opposite one" -> "almost opposite changes"

21. Line 195: "As mentioned in" -> "As shown by".

22. Line 195: "To quantify it" -> "To quantify the impact".

23. Line 197: "introduce the concept of" -> "using a metric we call"

24. Line 198: Commas surrounding "for which" can be deleted.

25. Line 221: "on one hand" can be deleted.

26. Line 221: "on the other hand" -> "However" (new sentence).

27. Line 225: "between the 12 models, GCMs like" -> "between the 12 models. For example,"

28. Line 233: "As discussed before" -> "As discussed above".

29. Line 235: "Current GCMs present" -> "many GCMs have".

Answer: We sincerely appreciate all these detailed comments and we have adopted them as part of polishing the writing of the revised manuscript.