Response to Referee #2 of "The ENSO-driven bias in the assessment of long-term cloud feedback to global warming" by Liu et al.

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. Revised and added portions of the new manuscript and supplementary materials (SI) are indicated in *italics*.

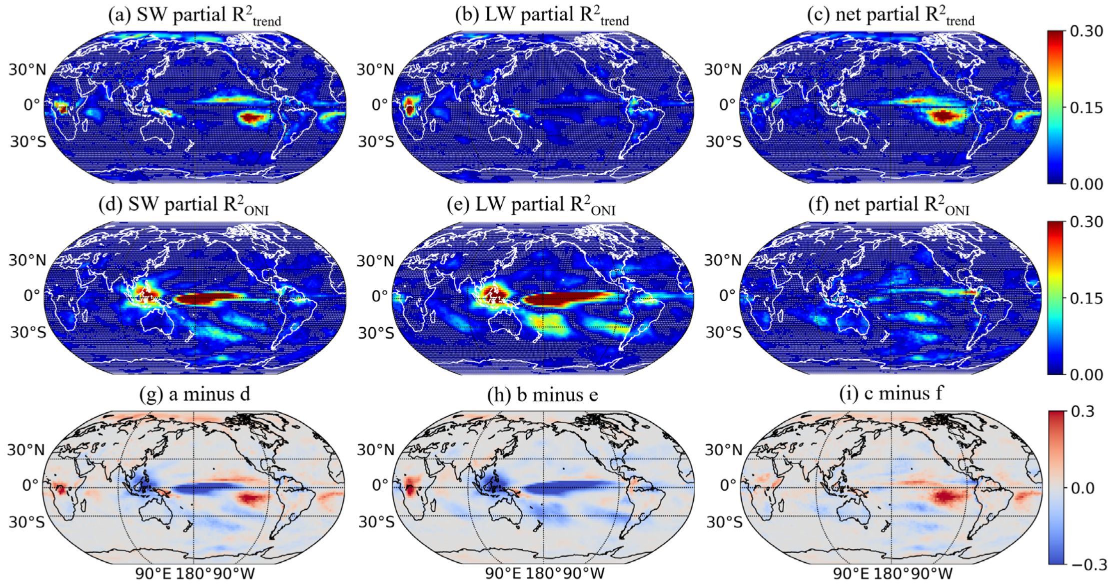
Major suggestions:

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:



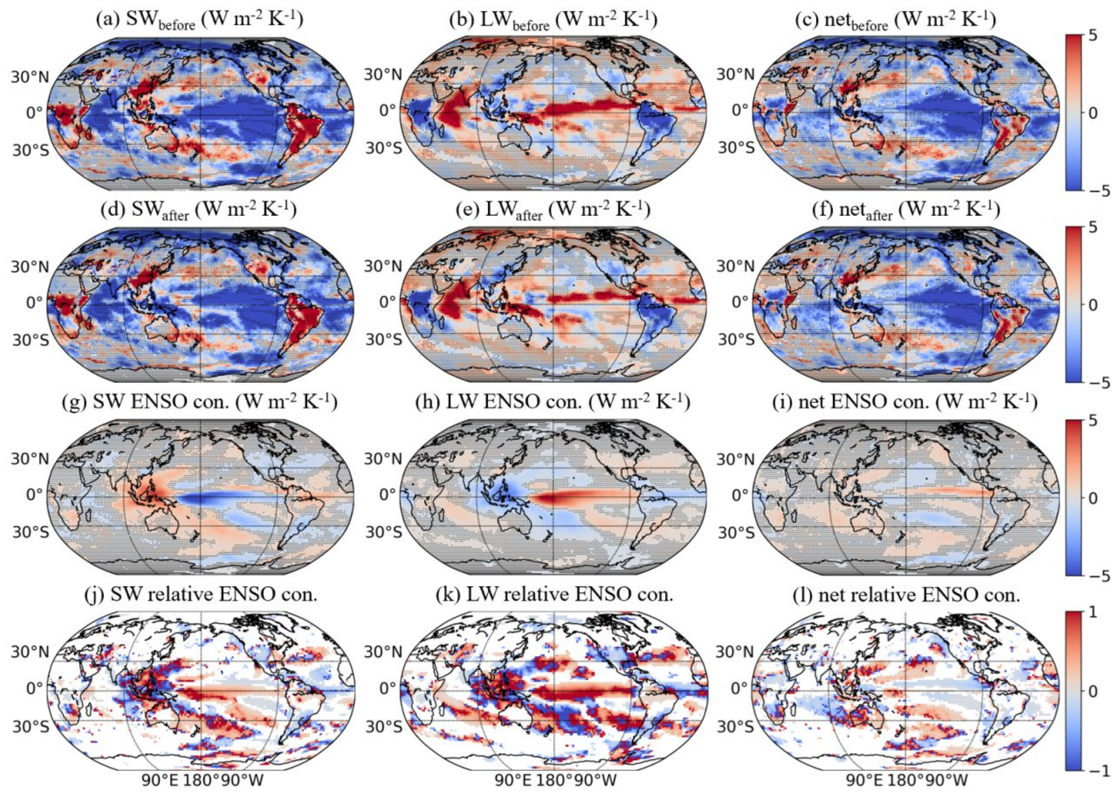
"*Figure 3: A sample analysis of the variations in CREs as driven by the temporal trend and ENSO, derived from ERA5 data during January 1982–December 2021. (a–c) Partial R^2_{trend} for (a) CRE_{SW}, (b) CRE_{LW}, and (c) CRE_{net}. (d–f) Partial R^2_{ONI} for (d) CRE_{SW}, (e) CRE_{LW}, and (f) CRE_{net}. (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:

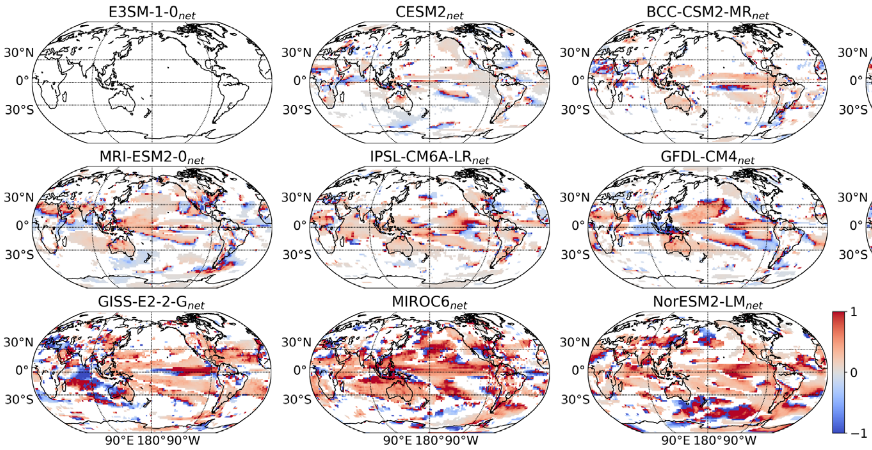
- Masked out grid points where ENSO contribution is statistically insignificant, as the ratio loses meaning if the identified ENSO contribution is not robust.
- Considered the sign and ensured it is physically interpreted: positive values indicate ENSO amplifies the feedback estimate, while negative 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."

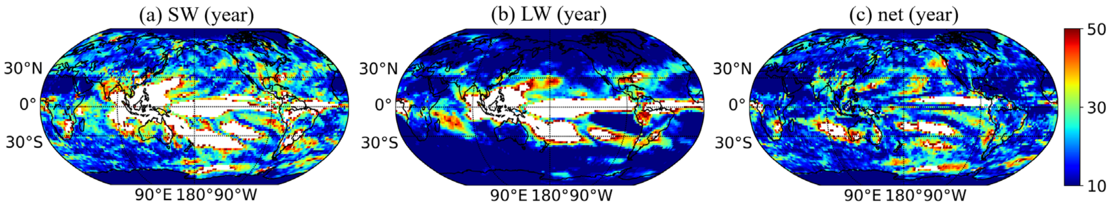
Revised text in Section 3.3: "*Figure 4j – l shows the distributions of the relative ENSO contribution, which is calculated as the ratio between ENSO contribution (Fig. 4g – i) and the original cloud feedback estimates (Fig. 4a – c). The ratio reaches ±1 (dark reddish and bluish shades) over a substantial 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:



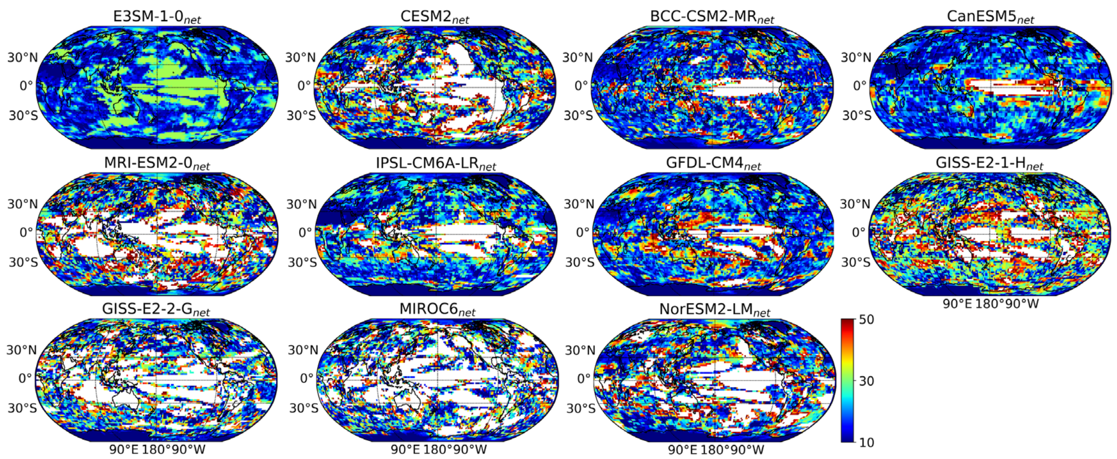
"*Figure 5: Maps of "ENSO effect minimal time" for different CREs, derived from*

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.

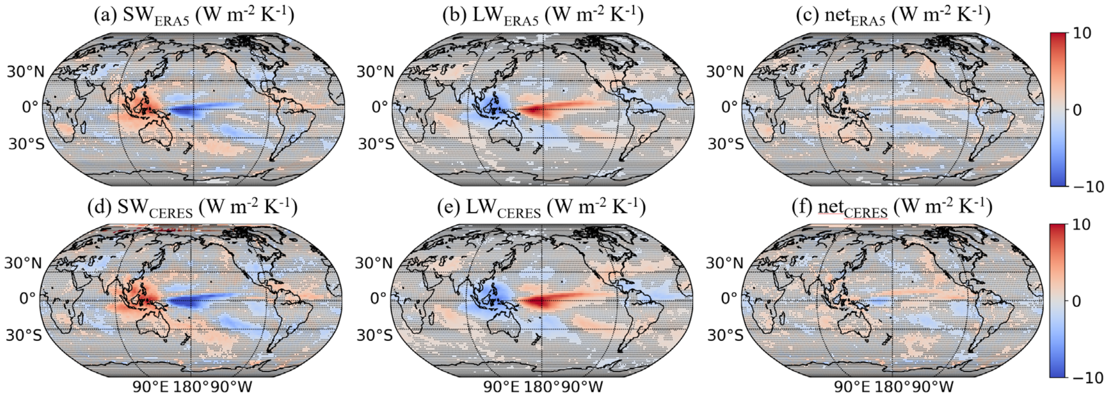
Answer: We thank the reviewer for this exceptionally detailed suggestion. In response , we have performed a full parallel analysis using the CERES EBAF Ed4.2 product for a direct comparison with the reanalysis-based ENSO contribution to cloud feedback estimates. The results demonstrate that the spatial 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.*"

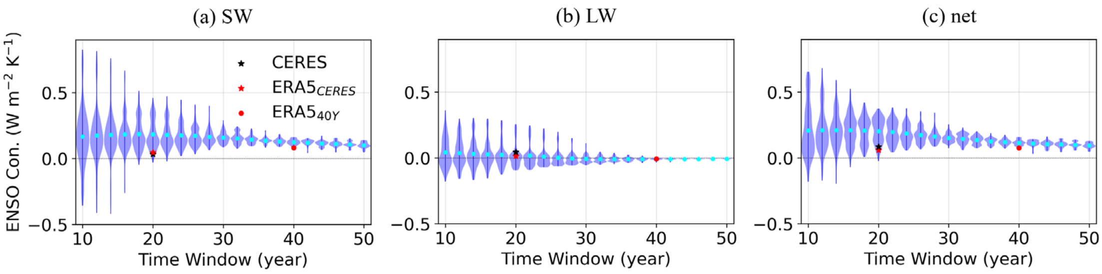
We also fully agree that a comprehensive analysis of ENSO contribution in observed cloud feedback is a compelling topic to the climate dynamics community. But in this study, as the first step, we would like to maintain our focus on illustrating the methodological framework and its implications for interpreting 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:

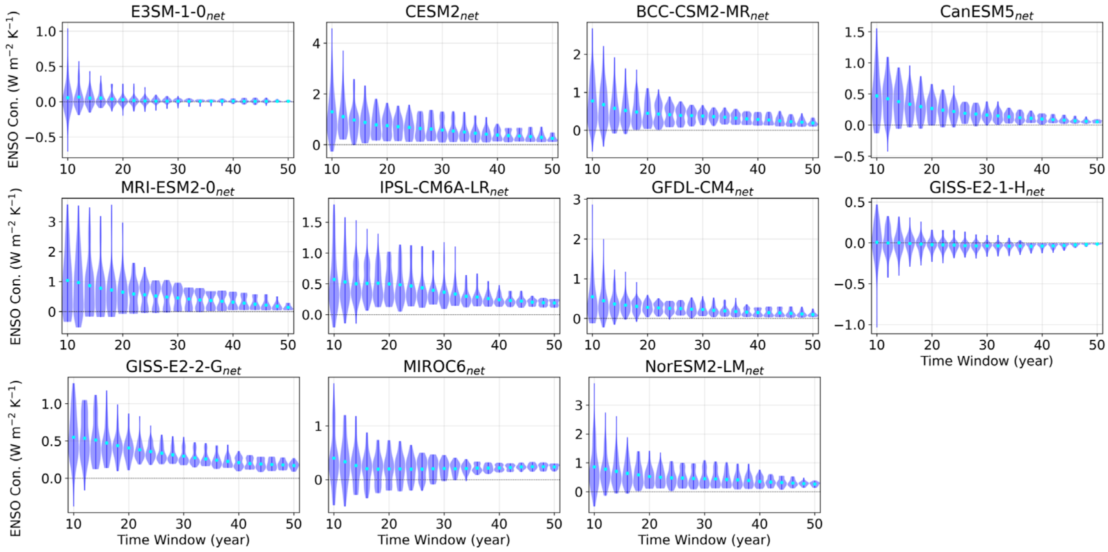


"*Figure 6: Violin plots of ENSO contribution to global-mean CREs, derived from ERA5 data during January 1950 – December 2021. (a) CRE$_{SW}$, (b) CRE$_{LW}$, and (c) CRE$_{net}$. The black star, red star, and red dot denote the results from CERES measurements, ERA5 data during the CERES period, and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

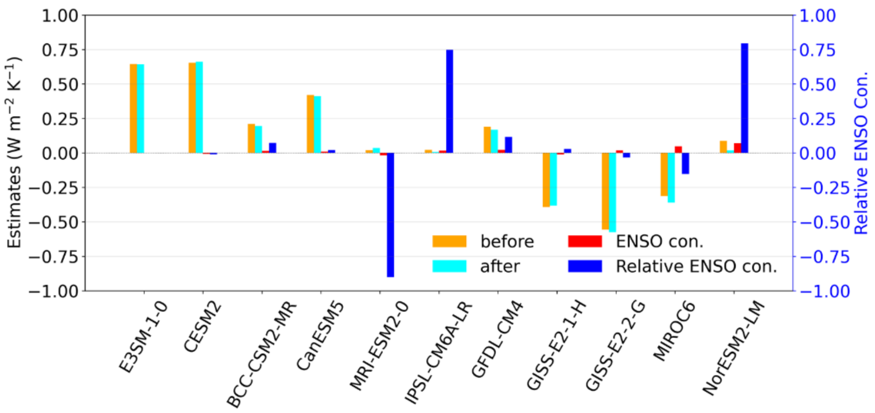
Revised text in Section 3.3: "*Figure 6 then gives the ENSO contribution to global-mean CREs as a function of the time window. The corresponding results derived from CERES measurements, ERA5 data during the CERES period, and ERA5 data during the representative 40-year subset are also shown. As expected, 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-$4\times CO_2$ 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 have 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 clarify 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.