Reply to the comments by Referee #2

We thank the reviewer for the comments and suggestions to further improve our revised manuscript. Below is our point-by-point response to these comments. The reviewer's comments are in italics, our responses are in normal font, and manuscript revisions are in blue.

The authors have largely addressed my comments in the original review, and their editorial modifications have clarified most of the paper's results. But meanwhile, the authors included some discussions absent in the original manuscript, which raises additional questions as below.

Reply: We thank the reviewer for the positive remarks on our efforts to improve the original manuscript. Please see our response to the additional questions below.

Comments

Comment 1:

L140-142: "improvements are made to Sun scheme" It might be inappropriate to directly say the modified scheme is an improvement. -> "We propose two methods below based on the subgrid surface energy partitioning between sensible and latent heat fluxes"

Reply: Done.

Comment 2:

L152: "input" -> "passed"

Reply: Done.

Comment 3:

L155: "this process does not alter the sampled subgrid values just arranging them in a given sequence" -> "this process just rearranges the sequence of heat fluxes rather than altering their values"

Reply: Done.

Comment 4:

L159: "One" -> "The"

Reply: Done.

Comment 5:

L160: "another" -> "the".

Reply: Done.

Comment 6:
L161: "the third ..." -> "the EXP_COR uses the modifications as described in Sect. 2.2"

Reply: Done.

Comment 7:
L179-180: "one improvement we expected in the new scheme is the alleviation of the overestimated summer precipitation on the southern and eastern margins of the Tibetan Plateau" Why should we expect the precipitation bias will be reduced on the southern and eastern margins of TP? It is clueless for readers to get this point at this place. Rephrase this paragraph for clarity.

Reply: We rephrased the paragraph in Lines 165-168 in the revision for clarity:

"Sun et al. (2021) found that the improved precipitation simulation with the parameterization of subgrid surface heat fluxes to the atmosphere is most prominent for boreal summer. Therefore, to compare with Sun et al. (2021), the analyses are first focused on boreal summer followed by a thorough evaluation of the two parameterizations on simulated climate variables for four seasons at the global scale."

Comment 8:
L185-186: "The simulated precipitation over Arabia and Indonesia is improved as well while that over the southeastern US is degraded." This sentence may be removed cause there are barely any differences between Fig. 3c and 3e, as well as Fig. 3b, 3d, and 3f, except that the improved precipitation in eastern China is visible in EXP.

Reply: Done.

Comment 9:
L190: "the improved boreal summer precipitation over eastern China" It seems like the EXP_COR does not simulate better precipitation than EXP over eastern China as we see negative biases over there in Fig. 3f.

Reply: The indicated improvements in the sentence are relative to the CTL simulation rather than the EXP run. To avoid confusion, we removed this sentence in the revision.

Comment 10:
L195: Fig. 3 - It looks like the changes induced by EXP and EXP_COR are minor, particularly at a global scale. Does a figure of relative bias difference (e.g., (EXP-CTL)/(CTL-TRMM)) help if the authors want to highlight the improvement on the southern and eastern margins of TP? Also, the Figs. 7-12 in this manuscript have

similar issues as in Fig. 3. See the comments as follows.

Reply: Following the suggestion, the global distributions of the differences in the relative biases of EXP and EXP_COR are shown in Fig. R1. There are many regions (especially over oceans) showing dramatic relative changes. However, most of them are uninformative and unrealistic, which are magnified by the extremely small biases in CTL (CTL - TRMM) although the absolute changes in EXP and EXP_COR (EXP – CTL and EXP_COR - CTL) are quite minor (Fig. 3 in the main text). Thus, a demonstration of the relative bias difference largely screens out informative signals in the regions with absolute biases largely reduced.

To make the reviewer convinced that the reduction of the relative biases on the southern and eastern margins of the TP can be approximately 25% (a considerable improvement for the absolute biases up to 11 mm d^{-1} there in CTL), which is indicated in the revised manuscript (Lines 186-188), Fig. R2, same as Fig. R1, but zooms in on the region (20-50°N, 75-125°E). It is clear that the biases over the southern and eastern margins of the TP decreased by approximately 25% - 50%. Given that this relative improvement is feasibly derived from the absolute biases in Fig. 4c&e in the main text, we prefer not to add Figure R2 in the revision.

Figures 7-12 in Sect. 3.2 aim to present a thorough evaluation of the performance of two parametrizations on simulated climate variables rather than particularly seeking significant improvements to all the variables in the EXP_COR run compared to the EXP run. Therefore, the comparable performance between EXP and EXP_COR is acceptable. We have revised the discussion regarding Figs. 7-12 in the revision. See our response to the comments below in detail.

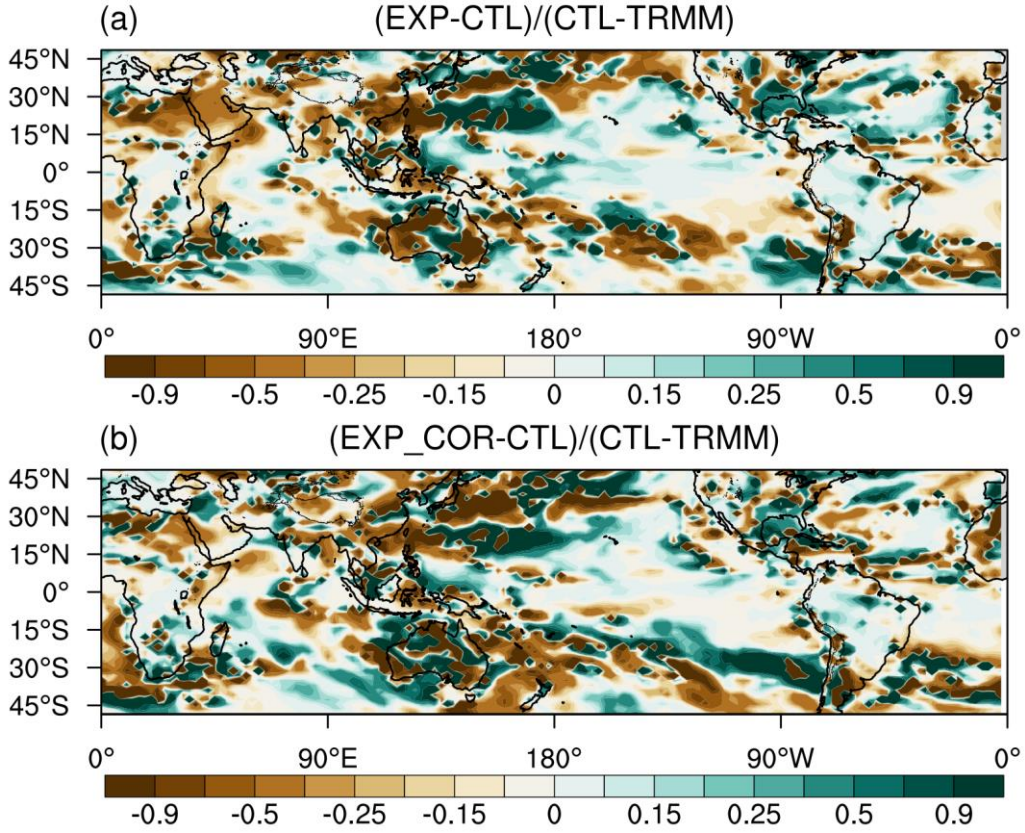

Figure R1. Global distributions of the differences in the biases of EXP and EXP_COR relative to CTL.

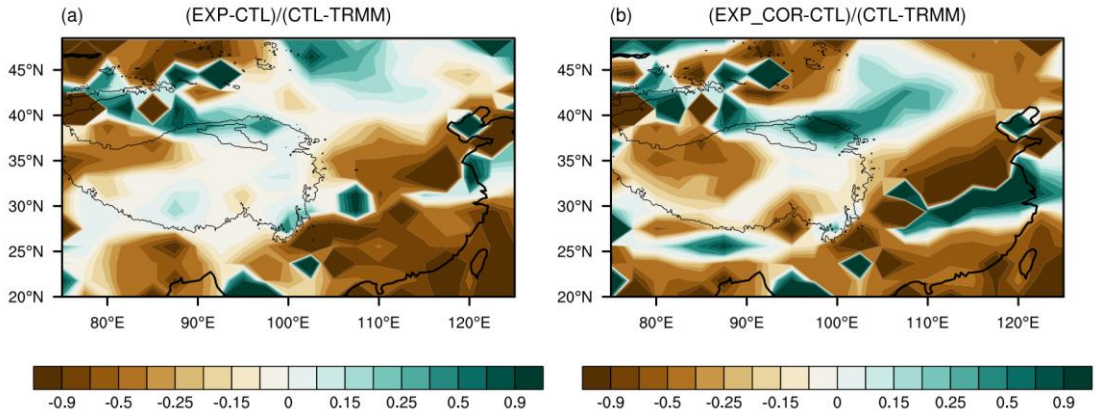

Figure R2. Same as Fig. R1, but focusing on the study area (20-50°N, 75-125°E).

Comment 11:

L206-208: The values of RMSE and the correlation coefficient in the context differ from Fig. 4.

Reply: Thank you very much for pointing out this mismatch. The values of RMSE and correlation coefficient in the context are calculated over the region (20°N-50°N, 75°E-

125°E), while those in Fig. 4 are for a slightly different region (i.e., 20°N-48°N, 75°E-125°E). In the revision, their calculations have been unified to the same region (20°N-50°N, 75°E-125°E), and Fig. 4 has been updated correspondingly (Fig. R3 below).

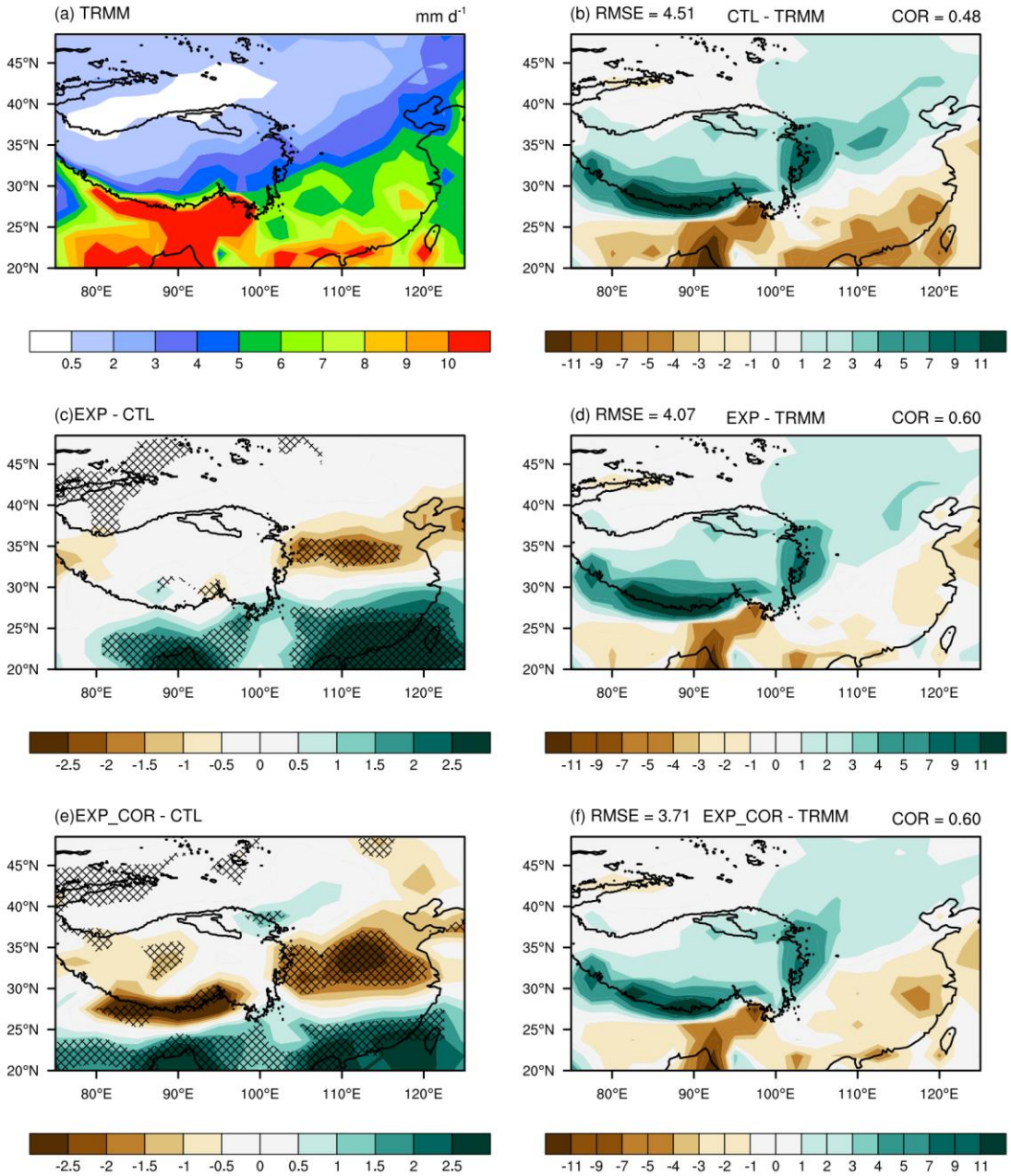

Figure R3. Spatial distributions of the JJA (June-July-August) mean precipitation in the region (20-50°N, 75-125°E) for (a) TRMM, the biases of (b) CTL, (d) EXP, and (f) EXP_COR with respect to TRMM, and the differences between EXP and CTL (c) and between EXP_COR and CTL (e). The crossed areas are significant at the 95% level. The regionally averaged spatial correlation coefficient (COR) and root mean square error (RMSE) are given at the top of (b), (d) and (f).

Comment 12:

L213-214: "both large-scale precipitation and convective precipitation slightly increase on the southern border of the TP" If so, an increase in the total precipitation

should be seen in the southern margin of TP from Fig. 3c. It's apparently not the case here.

Reply: Following Comment 13, the context regarding EXP TP margins is removed.

Comment 13:
L214-215: "large-scale precipitation increases" It appears that the large-scale precipitation increases in the southeastern but decreases in the northeastern. In fact, the EXP run mostly improves the simulated precipitation over eastern China and has little impact on TP margins. Maybe removing the context regarding EXP TP margins is more acceptable than an inaccurate description.

Reply: Done.

Comment 14:
L250-251: Why does the anticyclone over northern China decrease the precipitation on the eastern border of TP?

Reply: Higher sea level pressure anomalies over northern China are generated in EXP_COR than in EXP (Fig. 6e&g in the main text). In particular, compared with the EXP, the anomalous high SLP over northern China extends further to the south and the eastern border of the TP. The resulting downdraft associated with the anomalous anticyclone causes decreased precipitation there. The decrease of precipitation on the eastern border of the TP is directly from the further westward expansion of the anomalous anticyclone over northern China rather than indirectly from a remote effect of the anomalous anticyclone over northern China. In this revision, we clarified the discussion in Lines 230-234:

"In particular, compared with the EXP run, the anomalous high SLP over northern China extends further to the south as well as the eastern border of the TP with the anomalous low SLP over southern China retreating (Fig. 6d-h). The anomalous anticyclonic moisture transport associated with downdraft expands accordingly, which engenders decreased precipitation on the eastern border of the TP and slight dry biases over southern China."

Comment 15:
L264: Section 3.2 could be shortened to be more concise and organized. As it reads now, this section does not make much sense for improving the mechanistic understanding of climate response to the proposed surface heat flux parameterization. Most of the comparisons between CTL versus EXP/EXP_COR or observations versus simulations are not distinctly shown in the corresponding plots, such that the analysis in this part is a bit vague and unconvincing.
For example, in L275, the authors stated that the positive biases over southern China are reduced, but Fig. 7c and 7d are almost identical to each other and that improvement

is not noticeable actually. In L339, "the underestimation over northern China and the TP in both the CTL and EXP runs is alleviated in EXP_COR", but Fig. 11d even shows darker green than Fig. 11c for northern China (i.e., EXP_COR has more negative bias than EXP in net surface shortwave flux).

Reply: Thank you for the suggestion. Section 3.2 has been shortened in the revision.

Comment 16:
L307: "larger" -> "large"

Reply: Done.

Comment 17:
L319: "distributions of the CTL run" -> "distributions of the low, middle, and high clouds in the CTL run"

Reply: Done.

Comment 18:
L371: "improves the simulations of summer precipitation in Asia" Does EXP or EXP_COR improve the precipitation in Asia? It seems like only for eastern China in EXP and TP area in EXP_COR.

Reply: Thanks. We clarified this in Lines 338-340 in the revision:

"The analyses presented above demonstrate that the introduction of the subgrid heat flux schemes (EXP and EXP_COR), compared to the default model, improves the simulations of summer precipitation in eastern China in EXP and additional TP regions in EXP_COR."

Comment 19:
L398-399: What values? Fig. S8 depicts the vertical structure of clouds.

Reply: We apologize for the typo. It should be Fig. S10f in the revision.

Comment 20:
L433-435: "Compared with MAM4 ... cloud macrophysics schemes in CAM6" Needs to be clarified. Are the authors comparing EXP_COR with physics parameterizations or comparing the physics parameterizations from different CESM versions?

Reply: We are comparing EXP_COR with physics parameterizations. This has been clarified in Lines 400-403 in the revision:

"However, compared with the additional computational costs of the four-mode version

of the Modal Aerosol Module (MAM4) updated from MAM3 and the Cloud Layers Unified by Binormals (CLUBB) scheme instead of the CAM5 boundary layer turbulence, shallow convection, and cloud macrophysics schemes, respectively in CESM2 (CESM version 2), the increased computational cost in EXP_COR relative to CTL is much smaller and thus acceptable."

Comment 21:
Have a native speaker assist with the writing

Reply: In the original manuscript, the native English speaker has polished the language. In this round of revision, we went through the manuscript carefully again for language polishing.