Review comments

Mitigation of the double ITCZ syndrome in BCC-CSM2-MR through improving parameterizations of boundary-layer turbulence and shallow convection

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This study assesses the impact of an improved parameterization of turbulence and shallow convection on the precipitation bias in the ITCZ region. According to the manuscript, the precipitation bias is reduced through an improvement in the transition from stratocumulus to shallow cumulus convection over eastern subtropical oceans. The increased low-level cloud fraction reduces net surface shortwave radiation in the southeastern Pacific, which induces stronger and wider subsiding motion of the Walker circulation and remotely impacts the precipitation band in the ITCZ.

The study is well motivated, the manuscript is clearly written and the topic is interesting and highly relevant. It is evident that turbulence and shallow convection cause a substantial impact on the ITCZ precipitation bias and the study has impressive results. However, several weak points have to be addressed to make the conclusions convincing and acceptable for publication.

Major points:

1) Although the bias in precipitation rate is reduced, the double ITCZ pattern is not significantly changed in the NEW_cmip experiment. This, in my opinion, is a weak point of the study and cannot support the main conclusion that the double ITCZ band is mitigated. Moreover, the result presented in Fig. 13 shows that it is necessary to increase the model resolution to achieve the improvement in the ITCZ pattern, which signifies that other processes or interactions between the processes are more (or at least equally) relevant than the improvements in the representation of turbulence and shallow convection and the Sc to Cu transition.

2) The manuscript demonstrates a significant improvement in the double ITCZ precipitation band in the result only marginally shown in Fig. 13 where the HR model is used. This is a great result, however, it is not well explained. I suspect that the main cause of the double ITCZ syndrome lies in the difference between the performance of BCC-CSM2-MR and BCC-CSM2-HR when the turbulence and shallow convection schemes are improved in both model configurations.

3) It is not demonstrated how the improved Sc to Cu transition is contributing to the reduction of the precipitation bias. Furthermore, it is not clear why the REF_amip and NEW_amip simulations are used to demonstrate the improvement in the Sc to Cu transition instead of evaluating these processes directly in the REF_cmip and NEW_cmip simulations. The ITCZ is evaluated in the REF and NEW_cmip simulations, so it is expected that the changes in the clouds and the Sc to Cu transition are also investigated in the REF and NEW_cmip simulations.

4) The transition from Sc to Cu is improved in NEW_amip, however, the cloud amount is largely overestimated. This might be leading to changes in the precipitation rates and a decrease of the bias, however, it might just be a spurious compensating effect of the overestimated cloud amount.

5) It cannot be excluded that the improved turbulence and shallow convection schemes act locally to reduce the bias in precipitation in the ITCZ region. Especially because the ITCZ spatial pattern does not differ significantly between REF and NEW_cmip simulations, which would assumably be expected if the large scale circulation is changed. BCC-CSM2-HR thus should also be included in the analysis as one of the main experiments to assess this important question.

Other detailed comments:

Fig. 1: Here the differences between NEW_amip and REF_amip are shown instead of NEW_amip - CERES-EBAF. This shows the performance of NEW_amip relative to REF_amip, but no evaluation of NEW_amip simulation. Later on, it is shown that the cloud amounts are overestimated in NEW_amip, so this information is missing here - how much are the cloud effects overestimated in NEW_amip?

Section 3.3 does not discuss an overestimated cloud amount in NEW_amip. Please add such a discussion.

Figs 1 and 3: How does the overestimated cloud amount in NEW_amip affect the main conclusion of the study? If the cloud effect is exaggerated, its impact on the ITCZ might also not be realistic.

L245: The bias is shown in Figure 1c, please refer to this figure here: „weak bias in the magnitude of TOA SWCRF over these regions in REF_amip „

- It is not well noted when the analysis of the results switches from _amip to _cmip simulations. Are there any qualitative or quantitative differences in the impact of the turbulence and convection schemes on the ITCZ bias in _cmip compared to _amip? If it is necessary to show the analysis of the _amip simulations, please explain why the analysis switches between these two configurations.

- It is confusing that low-level clouds are validated only in the _amip experiments but ITCZ bias is not discussed for these experiments, while clouds are not evaluated in _cmip but the ITCZ bias is discussed only for these simulations. How are the clouds changed in NEW_cmip compared to REF_cmip? Also, are there any changes in the ITCZ precipitation band in NEW_amip compared to REF_amip?

Line 305: the improvement is not so visible from these plots. I would argue that there is a quantitative difference in the precipitation rates, but no qualitative improvement in the ITCZ precipitation bands. I would suggest a more detailed plot with differences (biases). The difference in pattern correlations proves this point because the change from 0.78 to 0.81 (GPCP) or from 0.80 to 0.81 (CMAP) is not very notable.

Line 355: It is not well explained why the excessive precipitation south of the equator in boreal winter and spring is reduced and closer to the observation in NEW_cmip. How is this connected to Sc-Cu transition in subtropical regions?

Line 368. The annual mean SST in NEW_cmip simulation is not presented, only its difference to the REF_cmip is presented, which makes it very difficult to compare between the experiments and assess the changes and impacts of clouds.

Line 467: The change in the pattern of ITCZ in BCC-CSM2-HR due to the improved turbulence and shallow convection scheme is a significant and very interesting result. Figure 13 is more convincing than previous figures that were based on the coarser-resolution model. However, the causes of this improvement are not explained in the present manuscript. This marginal result is, in my opinion, more relevant and could explain the ITCZ bias better than the main experiments of the study.

Line 494: „Better consistency between the BL turbulence scheme and the shallow convection scheme results in better simulation of the Sc-to-Cu transition.“ This is not shown in the NEW_cmip simulation, so there is no evidence that the Sc-to-Cu transition is improved in the _cmip simulations. There is no guarantee that clouds behave the same in AMIP and CMIP simulations.