Dear Referee #2,

We would like to thank you for your constructive comments and suggestions to improve the quality of our manuscript "Mitigation of the double ITCZ syndrome in BCC-CSM2-MR through improving parameterizations of boundary-layer turbulence and shallow convection" by Yixiong Lu et al., submitted to *Geoscientific Model Development*.

We have revised our manuscript and answered all the comments given by the referee. Please find our detailed point-by-point responses to the comments below. The reviewer's comments are in black, and our responses are in red.

Best regards,

Yixiong Lu and all co-authors

Response to Anonymous Referee #2

Review of Manuscript gmd-2020-40

Title: Mitigation of the double ITCZ syndrome in BCC-CSM2-MR through improving parameterizations of boundary-layer turbulence and shallow convection
Authors: Yixiong Lu et al.

Recommendation: major revision

Summary

The authors examine how the Pacific double ITCZ bias responds to modifying the boundary layer turbulence and shallow convection schemes in the BCC-CSM2-MR GCM. They suggest than an improved representation of the stratocumulus-to-shallow cumulus transition in the new parameterization leads to increased cloud cover and reduced SST in the southeastern tropical Pacific. This, they argue, alleviates the double ITCZ bias.

The paper is generally well written and concise. It is not clear, however, if the changes in the new model version objectively constitute an improvement. Rather, it seems that the modest improvement seen in the Pacific ITCZ is achieved at the expense of an unrealistically high cloud fraction and excessively cold SST in the southeastern tropical Pacific. This raises the question of the role of error compensation. I believe the results of the study are worth publishing but there needs to more objective/quantitative assessment of the bias reduction. There also needs to be more discussion regarding the aspects that deteriorate in the new model version, and discussion of the potential role of error compensation. Detailed comments follow below.

We would like to thank the reviewer for taking the time to carefully read our manuscript, for very valuable comments and suggestions and English grammatical corrections. We have revised our manuscript and answered all the comments given by the reviewer. Following your suggestion, we have added two tables to present the quantitative assessment of the bias reduction. Moreover, discussions about the aspects that deteriorate in the modified model are also included in the revised manuscript. Please also note Figure 10 and 13 are expanded with more panels.

Major Comments

1) Figure 3 (longitude-height sections of cloud fraction) While REF_amip undeniably underestimates cloud fraction, NEW_amip certainly overestimates it, to the point where one wonders which version is better. Even qualitatively, the superiority of NEW_amip is not that obvious. In the Peruvian stratus region, e.g, there is a spurious offshore maximum at 95W, 850 hPa. Thus, it is important to have an objective measure of model performance. I suggest adding a table with pattern correlations and area-averaged root-mean-square errors (RMSEs) for all regions.

   Thank you for the comment and suggestion. Figure 3 is intended to show a better representation of the qualitative characteristics of subtropical stratocumulus-to-cumulus transition. It is true that the vertical distribution of the cloud fraction needs further improvement. Following your suggestion, we have added a table to illustrate better model performance in NEW_amip and related discussion have been included in the revised manuscript, as follows,

   "For more quantitative comparisons, Table 2 presents the area-averaged biases and root-mean-square errors (RMSEs) of the REF_amip and NEW_amip low cloud simulations to the GOCCP observations over the globe, in the tropics and for the five main subtropical marine stratocumulus regions shown in Figure 2. For all regions, REF_amip significantly underestimates the low cloud amounts and has large biases and RMSEs. Although the low cloud cover simulated by NEW_amip is still less, biases and RMSEs are substantially reduced for most regions, except for Canara where the cloud fraction is overestimated to some extent. Spatial pattern correlations are also calculated to evaluate the simulated low cloud distribution. For the global low cloud pattern, the correlation increases from 0.76 in REF_amip to 0.84 in NEW_amip. More obviously, the tropical pattern correlation increases from 0.72 in REF_amip to 0.89 in NEW_amip. Based on these objective measures, it is clear that NEW_amip performs better than REF_amip with improved parameterizations of BL turbulence and shallow convection."

Table 2. Evaluation of the low-level cloud fraction (%) from REF_amip and NEW_amip simulations against GOCCP observations. Shown are the area-averaged biases and root-mean-square errors (RMSEs) between simulated and observed low-level cloud amounts over the globe, in the tropics and for the five main subtropical marine stratocumulus regions, which is indicated in Figure 2. Pattern correlations are calculated for the global and tropical low-level cloud distribution in the simulations, respectively.

Region	Bias		RMSE		Pattern Correlation	
	REF_amip	NEW_amip	REF_amip	NEW_amip	REF_amip	NEW_amip
Global	-12.48	-8.35	12.57	8.49	0.76	0.84
Tropical	-14.18	-8.64	14.26	8.74	0.72	0.89
Peruvian	-35.73	-7.63	36.91	14.89		
Californian	-32.61	-22.40	33.69	24.80		
Australian	-38.43	-11.41	39.56	18.81		
Namibian	-28.37	-3.45	30.11	12.55		
Canarian	-12.56	6.03	15.95	20.68		

2) Figure 4 Again, it would be helpful to have an objective measure of improvements in the equatorial Pacific, like the RMSE. The unrealistically zonal orientation of the SPCZ seems to be pretty much the same in both experiments. It is true that the 3 mm/day contour does not extend to 90W anymore in NEW_amip, but that is just a very narrow protrusion whose elimination should have little impact on the area average. Interestingly, the improvements look more convincing in the equatorial Atlantic.

Thank you for the comment. Following your suggestion, we have calculated the area-averaged biases and RMSEs, and pattern correlations between simulated and observed precipitation rate in the tropical Pacific. Both biases and RMSEs significantly decrease in NEW_cmip, indicating that the simulation of the precipitation in the tropical Pacific is improved in NEW_cmip. The elimination of the narrow protrusion also leads to a slight increase in the pattern correlation. The manuscript has been revised as follows,

"Table 3 summarizes the area-averaged biases and RMSEs, and pattern correlations between simulated and observed precipitation rate in the tropical Pacific. Compared with GPCP (CMAP), the bias of simulated precipitation rate is reduced from 0.89 (0.33) in REF_cmip to 0.44 (-0.12) in NEW_cmip. Correspondingly, the RMSE decreases from 0.94 (0.48) in REF_cmip to 0.54 (0.36) in NEW_cmip. The elimination of excessive precipitation in the SEP leads to an increase of the pattern correlation, which is raised from 0.78 (0.80) in REF_cmip to 0.81 (0.81) in NEW_cmip. It is also interesting to note that the spurious southern precipitation belt in the equatorial Atlantic completely disappears in NEW_cmip, which agrees well with observations."

Table 3. Evaluation of the precipitation rate (mm day^{-1}) from REF_cmip and NEW_cmip simulations against GPCP and CMAP observational estimates. Shown are the area-averaged biases and root-mean-square errors (RMSEs), and pattern correlations between simulated and observed precipitation rate in the tropical Pacific (30°S–30°N, 120°E–90°W).

Observational	Bias		RMSE		Pattern Correlation	
Data	REF_cmip	NEW_cmip	REF_cmip	NEW_cmip	REF_cmip	NEW_cmip
GPCP	0.89	0.44	0.94	0.54	0.78	0.81
CMAP	0.33	-0.12	0.48	0.36	0.80	0.81

3) Figure 7 No mention is made of the cold bias in the target region that is incurred by using the new parameterization. Visual inspection suggests that the area-averaged RMSE of SST may actually deteriorate in NEW_cmip. Please calculate those metrics and discuss them.

Thank you for the comment. We have mentioned the cold bias in the stratocumulus regions in NEW_cmip. The area-averaged RMSEs of SST have been calculated and indeed deteriorate in NEW_cmip. We have added discussion regarding this aspect that deteriorate in the modified model, as follows,

“It seems that the warm SST biases in REF_cmip are overcorrected in NEW_cmip by using new BL and shallow convection schemes, leading to a few degrees of cold bias in the SEP region. The area-averaged RMSE of SST in the tropical Pacific is 0.43 K in REF_cmip and actually deteriorates to 1.57 K in NEW_cmip. The common warm SST biases in CGCMs may come from several sources. Besides the underestimation of the shadowing effect due to a lack of stratocumulus that cover the SEP region, a poor representation of the oceanic surface cooling, by advection or mixing with the colder subsurface water, may also contribute to the warm biases (Richter, 2015). Also, some studies have found that shortwave radiation biases in marine stratocumulus regions are overcompensated for by excessive latent heat flux, which suggests a different origin of the warm SST biases (de Szoeke and Xie, 2008; Toniazzo and Woonough, 2014; Vanniere et al., 2014; Xu et al., 2014; Zheng et al., 2011). Recently, Hourdin et al. (2015) revealed that coupled models with warmer SST over the eastern tropical oceans present a lack of surface evaporative cooling in atmospheric simulations forced by SST. In the NEW_cmip simulation, an overestimation of the shadowing effect due to increased stratocumulus clouds may act to compensate for less surface evaporative cooling and make the sea surface cool enough to reduce precipitation in the SEP region.”

4) Figure 10 How does the simulated wind stress compare to observations/reanalysis? Please add a panel.

Thank you for the question. We have added three panels for the results from reanalysis and two simulations. Please note that the wind stress magnitude is replaced by surface convergence according to the comments of referee 1. Discussions are included in the revised manuscript, as follows,

“Figure 10 compares the annual mean surface wind stress vectors and surface convergence from REF_cmip and NEW_cmip simulations with JRA-55 reanalysis. In the eastern Pacific, the reanalysis shows convergence of northeasterly and southeasterly wind stresses in the northern ITCZ. The easterly and southeasterly wind stresses dominant central and eastern Pacific between 0° and 15°S, and no distinct convergence exists in these regions (Figure 10a). In the REF_cmip simulation (Figure 10b), the wind stress between 0° and 5°S is northeasterly compared to the observed easterlies, resulting in a convergence band in the central and eastern Pacific between 5°S and 10°S, which corresponding to the spurious southern ITCZ rainfall band. A prominent divergence zone also appears across the equatorial Pacific, which corresponds to the dry tongue in precipitation. The modified boundary-layer turbulence and shallow convection schemes result in increased southeasterly winds off the west coast of South America in NEW_cmip (Figure 10c). Specifically, the difference between NEW_cmip and REF_cmip clearly shows the strengthened southeasterly trade winds in the eastern Pacific between 5°S and 10°S (Figure 10d), corresponding to the stronger descending branch of the Walker circulation in NEW_cmip. Boundary layer convergence is primarily affected by SST gradients and can be usefully viewed as a forcing on deep convection over the tropical oceans (Back and Bretherton, 2009a, b). It is shown in Figure 10d that NEW_cmip produces relative divergence in the southern Pacific between 5°S and 15°S compared to REF_cmip, which corresponds to the eliminated southern ITCZ rainfall band resulting from weaker deep convection.”

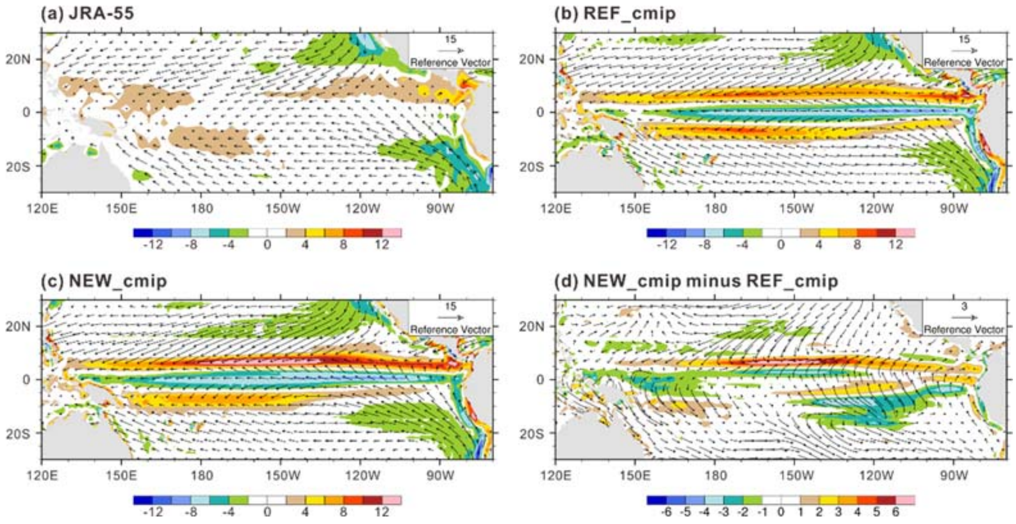


Figure 10. Annual mean wind stress vector and surface convergence (shaded, ×10^{-6}) from (a) JRA-55 reanalysis, (b) REF_cmip, (c) NEW_cmip, and (d) the difference between NEW_cmip and REF_cmip.

5) Figure 11 I suggest removing this figure or expanding the analysis. While zonal advection is certainly a plausible mechanism for the cooling, a detailed heat budget analysis would be needed to make a convincing argument. Other processes, such as upwelling and vertical mixing may play an important role as well.

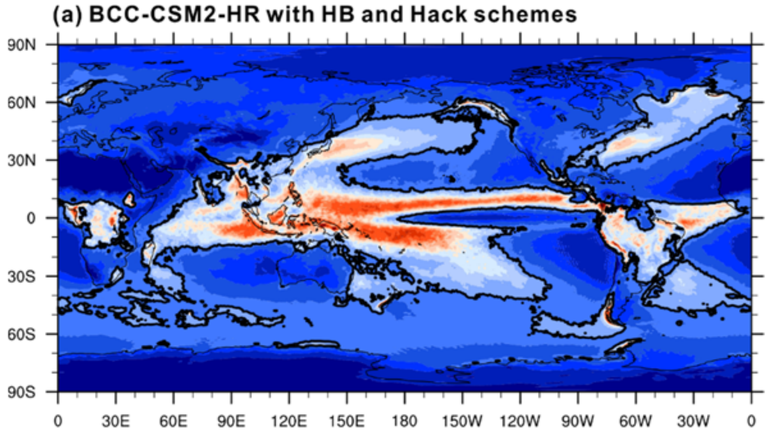
Thank you for your comments and suggestions. Figure 11 is intended to illustrate the effects of enhanced southeasterly wind stress in and northwest of the Southeast Pacific region on the South Equatorial Current. We have provided a more detailed and complete discussion about this figure. We rewrote Section 4.4 as follows,

"Because of the strengthened southeasterly wind stress in and northwest of the SEP region, the south equatorial current in the upper ocean is enhanced. Figure 11 shows the longitude-depth cross section of zonal oceanic current and temperature averaged over 5°S – 10°S for the difference between NEW_cmip and REF_cmip. Compared with REF_cmip, the climatological westward zonal current in NEW_cmip over 5°S−10°S is enhanced by more than 8 cm/s above 120 m over the central to eastern Pacific. Further analysis indicates that the simulated subsurface temperature is reduced by more than 2 K above 80 m east of 135°W in NEW_cmip. Apparently, the enhanced westward ocean current over the whole zonal band helps transport cooler water from east to west and prevents the warm water in the western Pacific from extending eastward in NEW_cmip."

6) Figure 13 If this figure is to be kept there needs to be an additional panel showing performance before the introduction of the new schemes. Otherwise it is impossible to evaluate the improvement.

Thank you for the comment. To support the claim that the major improvement in the HR model benefits from the UWMT boundary-layer turbulence and modified Hack shallow convection schemes, we have added a subplot in Figure 13 showing the precipitation simulation result from BCC-CSM2-HR with old boundary layer and shallow convection schemes. Correspondingly, we adjusted the sentences in the second paragraph of section 5.2, as follows,

"During the transition from BCC-CSM2-MR to BCC-CSM2-HR, the atmospheric component increased its horizontal resolution from T106 (~ 1.125°) to T266 (~ 0.45°) with a higher model top, and the physics package was essentially updated, especially the deep convection scheme. Furthermore, the oceanic component was upgraded to the Modular Ocean Model version 5 (MOM5). However, previous versions of BCC-CSM2-HR suffered from the double ITCZ syndrome until the UWMT and modified Hack schemes were introduced. Before improving parameterizations of boundary-layer turbulence and shallow convection, BCC-CSM2-HR simulated a southern rainfall band with excessive eastward extension over the central and eastern Pacific and two nearly parallel rain belts over the equatorial Atlantic (Figure 13a). This suggests that the boundary-layer and shallow convection schemes contribute primarily to the double ITCZ bias in BCC-CSM2-HR. The tropical precipitation patterns simulated in the frozen version of BCC-CSM2-HR, which is equipped with new boundary-layer turbulence and shallow convection schemes, barely manifest a double ITCZ, as shown in Figure 13b. The triangular-shaded dry region in the SEP reproduced by BCC-CSM2-HR resembles the observed much better than that simulated in the revised BCC-CSM2-MR, probably due to the improved interactions among the boundary-layer turbulence, shallow convection, and other processes. Anyway, improving parameterizations of boundary-layer turbulence and shallow convection shows robustness in mitigating the double ITCZ syndrome in different BCC coupled models."


(a) BCC-CSM2-HR with HB and Hack schemes

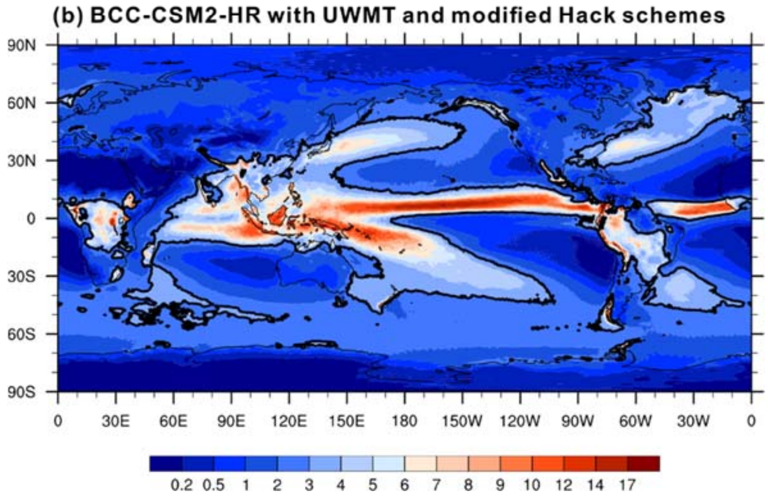

(b) BCC-CSM2-HR with UWMT and modified Hack schemes

Figure 13. Annual mean precipitation rate (mm day^{-1}) from (a) intermediate version of BCC-CSM2-HR with original boundary-layer turbulence and shallow convection schemes, and (b) frozen version of BCC-CSM2-HR with new boundary-layer turbulence and shallow convection schemes. The 3 mm day^{-1} contour is included in bold for reference.

Minor Comments

1) ll. 32-33: Please mention some references for the Atlantic ITCZ bias (e.g. Richter et al. 2014, Siongco et al. 2015).

Thank you for the suggestion. We have cited these references and included them in the reference list in the revised manuscript.

2) ll. 59-60: Please provide some references for the claim that stratocumulus biases contribute to the double ITCZ problem. Also, some studies have found that shortwave radiation biases in marine stratocumulus regions are overcompensated for by excessive latent heat flux (even in AGCM-only simulations with prescribed observed SST), which suggests a different origin of the warm SST biases (de Szoeke and Xie 2008, Toniazzo and Woonough 2014, Vanniere et al. 2014, Xu et al. 2014, Zheng et al. 2011). This should be discussed.

   Thank you for the comment. References have been added for the claim that stratocumulus biases contribute to the double ITCZ problem. We also included the discussion about the error compensation between shortwave radiation biases and latent heat biases. In particular, we cited the work of Hourdin et al. (2015) that identified a lack of surface evaporative cooling as a different origin of the warm SST biases. These discussions are added in section 4.2, as follows,

   "The common warm SST biases in CGCMs may come from several sources. Besides the underestimation of the shadowing effect due to a lack of stratocumulus that cover the SEP region, a poor representation of the oceanic surface cooling, by advection or mixing with the colder subsurface water, may also contribute to the warm biases (Richter, 2015). Also, some studies have found that shortwave radiation biases in marine stratocumulus regions are overcompensated for by excessive latent heat flux, which suggests a different origin of the warm SST biases (de Szoeke and Xie, 2008; Toniazzo and Woonough, 2014; Vanniere et al., 2014; Xu et al., 2014; Zheng et al., 2011). Recently, Hourdin et al. (2015) revealed that coupled models with warmer SST over the eastern tropical oceans present a lack of surface evaporative cooling in atmospheric simulations forced by SST."

3) ll. 69-70: Please provide a reference for this claim.

   Thank you for the suggestion. Two references are cited for the claim that the low-level cloud near the South American west coast is the steadiest and most persistent stratocumulus regime in the world, i.e.,

   1. Wood, R. and Bretherton, C. S.: On the relationship between stratiform low cloud cover and lower-tropospheric stability, J. Climate, 19, 6425-6432, 2006.
   2. Wood, R.: Stratocumulus clouds, Mon. Wea. Rev., 140, 2373-2423, 2012.

4) ll. 91-92: The atmospheric component ultimately traces its origins to the NCAR Community Atmospheric Model (CAM). It is important to note this origin and to explain to what extent the BCC version has diverged over the years. Does the

BCC model feature similar biases as current incarnations of CESM?

Thank you for your attention to the BCC model development. BCC-AGCM indeed originates from the CAM3 developed by NCAR. However, the dynamics in BCC-AGCM substantially different from the Eulerian spectral formulation of the dynamical equations in CAM3, and is featured by introducing a reference stratified atmospheric temperature and a reference surface pressure into the governing equations. Besides, new physical parameterizations have replaced the corresponding original ones, including a new convection scheme, a new cloud cover scheme, a dry adiabatic adjustment scheme, a modified scheme to calculate the air-sea turbulent fluxes, an empirical equation to compute the snow cover fraction, etc. The vertical discretization of the BCC-AGCM also differs from CAM3. Detailed model development description of the BCC-AGCM can be found in a series of relevant publications (Wu et al., 2008, 2010, 2012, 2013, 2019; Lu et al., 2013, 2020). So, BCC-AGCM has evolved into a largely different model and has different error characteristics from CAM. These descriptions have been added in the revised manuscript.

1. Wu Tongwen, Rucong Yu, and Fang Zhang, 2008: A modified dynamic framework for atmospheric spectral model and its application, J. Atmos.Sci., 65, 2235-2253.
2. Wu, T., Yu, R., Zhang, F., Wang, Z., Dong, M., Wang, L., Jin, X., Chen, D., Li, L.: The Beijing Climate Center atmospheric general circulation model: description and its performance for the present-day climate, Climate Dynamics, 34, 123-147, DOI 10.1007/s00382-008-0487-2, 2010.
3. Wu, T.: A mass-flux cumulus parameterization scheme for large-scale models: Description and test with observations, Clim. Dynam., 38, 725-744, doi:10.1007/s00382-011-0995-3, 2012.
4. Wu, T., Li, W., Ji, J., Xin, X., Li, L., Wang, Z, Zhang, Y., Li, J., Zhang, F., Wei, M., Shi, X., Wu, F., Zhang, L., Chu, M., Jie, W., Liu, Y., Wang, F., Liu, X., Li, Q., Dong, M., Liang, X., Gao, Y., Zhang, J.: Global carbon budgets simulated by the Beijing climate center climate system model for the last century. J Geophys Res Atmos, 118, 4326-4347. doi: 10.1002/jgrd.50320, 2013.
5. Wu, T., Lu, Y., Fang, Y., Xin, X., Li, L., Li, W., Jie, W., Zhang, J., Liu, Y., Zhang, L., Zhang, F., Zhang, Y., Wu, F., Li, J., Chu, M., Wang, Z., Shi, X., Liu, X., Wei, M., Huang, A., Zhang, Y., and Liu, X.: The Beijing Climate Center Climate System Model (BCC-CSM): the main progress from CMIP5 to CMIP6, Geosci. Model Dev., 12, 1573-1600, doi:10.5194/gmd-12-1573-2019, 2019.
6. Lu, Y., Zhou, M., and Wu, T.: Validation of parameterizations for the surface turbulent fluxes over sea ice with CHINARE 2010 and SHEBA data, Polar Res., 32, 20818, doi:10.3402/polar.v32i0.20818, 2013.
7. Lu, Y., Wu, T., Jie, W., Scaife, A. A., Andrews, M. B., and Richter, J. H.:

Variability of the stratospheric quasi-biennial oscillation and its wave forcing simulated in the Beijing Climate Center Atmospheric General Circulation Model, J. Atmos. Sci., 77, 149-165, doi:10.1175/JAS-D-19-0123.1, 2020.

5) l. 143: What does "roots in level k+1" mean?

Thank you for the question. We have changed "roots in level k+1" to "originated from level k+1".

6) section 2.3, last para: In the light of the substantial progress made in the field, the LTS criterion appears crude and outdated. There must be more sophisticated criteria.

Thank you for the comment. The LTS criterion is relatively crude and we also notice that there are some improved criteria. Testing more sophisticated criteria is in our future study plans. Discussion about this aspect is included in the revised manuscript, as follows,

"It should be noted that the LTS criterion has been developed into physically more plausible formula. Wood and Bretherton (2006) modified the LTS to account for the strength of the BL inversion, called the estimated inversion strength (EIS) which is shown to be more useful than LTS for determining low cloud cover in the present climate. EIS is then further revised to take into account cloud-top entrainment and transformed into the estimated cloud-top entrainment index (ECTEI), which shows dependence on sea surface temperature (Kawai et al., 2017). Impacts of more sophisticated criteria on cloud representation and precipitation simulation in BCC-CSM2-MR is beyond the scope of this paper and will be explored in future work."

1. Wood, R. and Bretherton, C. S.: On the relationship between stratiform low cloud cover and lower-tropospheric stability, J. Climate, 19, 6425-6432, 2006.
2. Kawai, H., Koshiro, T., Webb, M. J.: Interpretation of factors controlling low cloud cover and low cloud feedback using a unified predictive index, J. Climate, 30, 9119-9131, 2017.

7) l. 256: "Below will clarity" –> "Below we examine"

Revised. Thank you for the correction.

8) l. 267: "triangular-shaded" –> "triangular" or "triangle-shaped"

Done. Thank you for the correction. We have corrected "triangular-shaded" to "triangular-shaped".

9) Figure 6: Given the relatively small improvement in precipitation seen in Fig. 4, the large improvement in this figure is somewhat surprising. I guess the improvement is diluted in the annual mean (Fig. 4)?

   You are right. In fact, the double-ITCZ bias presents obvious seasonal variations. In the BCC model, this bias is most prominent in the cold season, e.g., from January to April. If we look at the annual average, the improvement is weaker.

10) ll. 411-412: “cold tough bias” –> “cold tongue bias”

   Revised. Thank you for the correction.

11) The authors should discuss the work of Hourdin et al. (2020) as those authors also stress the importance of the marine boundary layer in tropical biases.

   We have carefully read this important paper, which claims that the surface evaporative cooling plays a role as large as the shadowing effect of stratocumulus. We will pay special attention to this control mechanism in our future model development. Actually, our study follows the eddy diffusion mass flux (EDMF) approach, aiming to unify BL and shallow convective processes as in the IPSL model. More work should be done to improve the BL convection represented by the modified Hack scheme used in this study. We have added a paragraph in the section of Summary and conclusions to discuss the implication of Hourdin et al. (2020) and its inspiration for our future work, as follows,

   “The BL processes can not only affect SST by changing the stratocumulus and its radiative effect, but also control the surface evaporative cooling by convective transport of humidity at the surface and then SST (Hourdin et al., 2020). Using a mass flux representation of the organized structures of the convective BL coupled to eddy diffusion, Hourdin et al. (2020) showed that an increased near-surface drying led to a reduction of the warm bias in the eastern tropical oceans in the Institute Pierre Simon Laplace coupled model, IPSL-CM6A. They concluded that a good representation of BL convection is required to maintain a strong contrast between trade winds cumulus regions and stratocumulus regions. Similarly, this study adopts the eddy diffusion mass flux (EDMF) approach, which seeks to unify BL and shallow convective processes by the marriage of UWMT and modified Hack schemes. However, there are still large discrepancies in the simulated Sc-to-Cu transition compared to observations, as shown in Figure 3, which suggests that parameterization of BL convection should be further improved. Moreover, the role of surface evaporative cooling needs to be explored when improving representation of BL convection.”

References

de Szoeke, S. P., and S. Xie, 2008: The Tropical Eastern Pacific Seasonal Cycle:

Assessment of Errors and Mechanisms in IPCC AR4 Coupled Ocean–Atmosphere General Circulation Models. J. Climate, 21, 2573–2590, https://doi.org/10.1175/2007JCLI1975.1.

Hourdin, F., Rio, C., Jam, A., Traore, A.â˘ARˇ K., & Musat, I. (2020). Convective boundary layer control of the sea surface temperature in the tropics. Journal of Advances in Modeling Earth Systems, 12, e2019MS001988. https://doi.org/10.1029/2019MS001988

Richter, I., Xie, S., Behera, S.K. et al. Equatorial Atlantic variability and its relation to mean state biases in CMIP5. Clim Dyn 42, 171–188 (2014). https://doi.org/10.1007/s00382-012-1624-5

Siongco, A.C., Hohenegger, C. & Stevens, B. The Atlantic ITCZ bias in CMIP5 models. Clim Dyn 45, 1169–1180 (2015). https://doi.org/10.1007/s00382-014-2366-3

Toniazzo T, Woolnough S. Development of warm SST errors in the southern tropical Atlantic in CMIP5 decadal hindcasts. Clim Dyn 2014, 43:2889–2913.

Vannière B, Guilyardi E, Toniazzo T, Madec G, Woolnough S. A systematic approach to identify the sources of tropical SST errors in coupled models using the adjustment of initialised experiments. Clim Dyn 2014, 43:2261–2282.

Xu Z, Chang P, Richter I, Kim W, Tang G. Diagnosing southeast tropical Atlantic SST and ocean circulation biases in the CMIP5 ensemble. Clim Dyn 2014, 43:3123–3145.

Zheng Y, Shinoda T, Lin JL, Kiladis GN. Sea surface temperature biases under the stratus cloud deck in the Southeast Pacific Ocean in 19 IPCC AR4 coupled general circulation models. J Clim 2011, 24:4139–4164.

Thank you for providing these references which extend the breadth and depth of the manuscript. We have cited all the references.