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Discussions

Interactive comment on "The seasonal and interannual variabilities of the barrier layer thickness in the tropical Indian Ocean" *by* Xu Yuan and Zhongbo Su

Xu Yuan and Zhongbo Su

x.yuan@utwente.nl

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Dear Referee #1, We would like to thank you for your comments. Your valuable comments help us to improve the quality of this manuscript. In revising the paper, we have carefully considered all comments and suggestions. Major comments:

1. Line38-40: How about the definition: MLD in density with a variable threshold criterion (equivalent to a 0.2_C decrease)? Are there any differences by using the suggested new definition in calculating the MLD, and further for the BLT variation?

Many thanks for this comment. We have compared the calculated MLD using different

definitions with respect to its distribution and seasonal variation. For brevity, MLD defined by density with a fixed threshold criterion (0.03kg/m3) is termed as MLD_DR003 and MLD defined by density with a variable threshold criterion (equivalent to a 0.20C decrease) is short for MLD_D02. In terms of distribution, MLD_DR003 is shallower than MLD_D02 in the Indian Ocean, especially in the southwestern and eastern Indian Ocean (see Figure 1 below). The maximum difference between MLD calculated from those two definitions could reach 10 m difference. Although the seasonal change of MLD_DR003 and MLD_D02 is consistent with each other (Figure 2 below), MLD_DR003 is much shallower during boreal autumn, winter and early spring. Consequently, the seasonal variation of BLT may not be affected by the definition of MLD. But using deeper MLD_D02 to calculate may lead to negative BLT which is no physical meaning. Thus, we used the MLD_DR003 in this study.

2. As the author explained, the BLT is defined by the difference of the MLD and ILD. What's the seasonal and inter-annual variation of these two aspects? Which one can mainly determine the BLT?

Thank you for these comments. We have plotted the seasonal and inter-annual variations of MLD and ILD, respectively (Figure 4 in the revised manuscript). It is apparent that both the variation of MLD and ILD could have impacts on the BLT variation. But there is no robust correlation between the variations of either MLD or ILD and BLT. We conclude that the impacts of MLD and ILD on the BLT are season-dependent. For instance, the seasonal variations of MLD and ILD present an annual variation while the seasonal variation of BLT presents a semi-annual variation. The interannual variation of BLT is correlated better with the ILD change. To link to the atmospheric forcing, we mainly choose the SSS and SST which can be observed by satellites and reflect the characteristics of MLD and thermocline (which is beneath the ILD) to study the seasonal and interannual variations of BLT. The related analysis has been added in section 3 (Line 132-144).

"The seasonal and interannual variations of MLD and ILD averaged over the west sector (55°E-80°E, 5°N -12°S) and the east sector (85°E-100°E, 5°N -12°S) have also been calculated and presented in Figure 4 to investigate the dominant driver for the BLT variability. However, it is hard to conclude either MLD or ILD as the main dominator. In particular, both MLD and ILD display an annual cycle while BLT presents a semi-annual cycle in the western sector. In the eastern sector, both MLD and ILD increase from March to August and decrease from September to February, while BLT increases from March to November and decreases from December to February. Thus, the impacts of MLD and ILD on the BLT is dependent on the seasons. On the other hand, from their interannual time series, there is no BLT (negative) in the years with deeper MLD, while prominent BLT exists in the years with deeper ILD. We also calculated the correlation coefficients between BLT and MLD and ILD, which are -0.07 and 0.47 in the west sector and -0.25 and 0.38 in the east sector. The interannual variation of BLT is mainly related to the ILD variation in the TIO. To further study the seasonal and interannual variations of BLT, we choose the variables in MLD, such as SST and SSS, and thermocline (prominent variations in the deeper ocean)." 3. This paper mainly gave the seasonal and inter-annual variation of BLT in the TIO, but the mechanism for these was not explained enough. As the BLT is affected not only by the SST, SSS, thermocline, but also by the wind stress, rainfall or the fresh water input and even the net heat flux input. More work on mechanism analysis is encouraged.

Thank you for your suggestions. We agree that the forcing from the atmosphere would affect the variations of BLT, such as wind stress, net freshwater flux, and net heat flux. But results in this study have shown that the variation of BLT is not closely related with SST. Thus, in the revised manuscript, we have included the net freshwater flux to explain change of SSS and associate the wind stress to the change of thermocline. The related analysis has been added in section 4 (Line 194-208).

"According to the above analysis, we examined the corresponding atmospheric forcing in the western TIO and eastern TIO, respectively. Figure 9 shows the seasonal evolution of the upper-ocean salinity, MLD, ILD, thermocline, freshwater flux (Precipitation

minus Evaporation, P-E) and the zonal component of the wind stress. In the western TIO, freshwater flux freshens the upper-ocean water from October to April, which in turn, thickens the BLT, consisting of the analysis in Figure 7. On the other hand, westerlies lead to Ekman pumping, which in turn, results in the thinner thermocline (green line) to affect the BLT. In the eastern TIO, the seasonal variation of BLT is more complex than that in the western TIO. Firstly, the seasonal evolution of SSS has a semi-annual feature while freshwater flux does not. This may link to the Indonesian throughflow which brings the freshwater from the Pacific Ocean into the eastern TIO (Shinoda et al., 2012). Secondly, the thermocline presents the opposite seasonal cycle comparing with that in the western TIO, although the zonal wind stress displays a similar seasonal variation in both the western and eastern TIO. Last but not the least, we also noticed that the salinity in the deeper ocean varies similar to the thermocline in the eastern TIO, which is different in the western TIO. Thus, the seasonal variation of BLT in the eastern TIO is not mainly driven by freshwater flux and wind-driven upwelling. Felton et al. (2014) have suggested that the seasonal BLT variation in the eastern TIO may be related to the sea level and ILD oscillation."

4. The explanation of the impact of ENSO on the BLT variation is simply accorded to the theory of Xie et al. (2002). Did you find the anomalous easterlies? The Walker Circulation is also needed to be verified.

Many thanks for pointing out this. In Figure 13 of the revised manuscript, the lagged correlations propagate westward. We have added the lag correlation of precipitation and zonal wind stress with the Nino3.4 index in Figure 13. In the lag correlation of precipitation, negative correlation coefficients are in the eastern TIO while positive correlation coefficients are in the western TIO, indicating the downwelling branch of Walker Circulation in the eastern TIO and the upwelling branch of Walker Circulation in the western TIO. The anomalies in easterlies are invoked in the eastern TIO during the El Niño developing and mature phases.

5. Can you show the time series of the SSS, BLT and thermocline during the whole pe-

riod of 1980-2015? Do the IOD or the ENSO event mainly contribute to the interannual variation?

Thank you for this comment. We have added this time series plot as Figure 11in the revised manuscript. The related analysis is stated follows (Line254-260). "The relationship between BLT and El Niño could also be detected in the time series of BLT, SSS and thermocline anomalies averaged over the western TIO during winter and spring from 1980 to 2015 (Figure 12). During winter (Figure 12a), deeper BLT and thermocline could be found in 1983, 1992, 1998, corresponding to the mature phase of El Niño. During spring (Figure 8b), deeper BLT and thermocline could also be observed in these decaying phase of El Niño years, accompanying with fresher water. On the other hand, the effect of IOD on the interannual variability of BLT could be observed in specific years as well, such as 1983,1998 and 2006. ". Minor comments: 1. Line33-34: What variation?

Thank you for pointing out this. We have added the proper word in front of variation.

2. Line 53-54: INTER-TROPICAL CONVERGENCE ZONE (ITCZ)?

Thank you for your correcting. Corrected.

3. Line 124: 2005-2015 => 2005-2015?

Thank you for pointing out this. We have corrected it.

4. Section 3 might be too short. The author could explain more about figure 1 or move this section to the next section.

Thank you for your suggestion. We have added more content in section 3.

5. Line 213: The caption of figure 4: lead-leg?

Many thanks for pointing out this. We have revised it to lead-lag.

6. Line 252: The lines could be plotted above the shaded area in figure 6.

Thanks for pointing out this. We have re-plotted Figure 10 and Figure 11 in revised manuscript.

Please also note the supplement to this comment:
https://www.ocean-sci-discuss.net/os-2019-12/os-2019-12-AC1-supplement.pdf

Interactive comment on Ocean Sci. Discuss., https://doi.org/10.5194/os-2019-12, 2019.

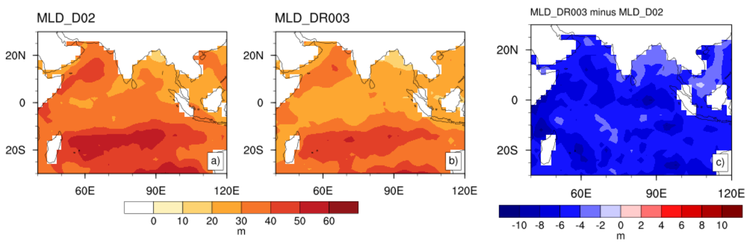

Fig. 1. The distributions of MLD_D02 and MLD_DR003 and their difference.

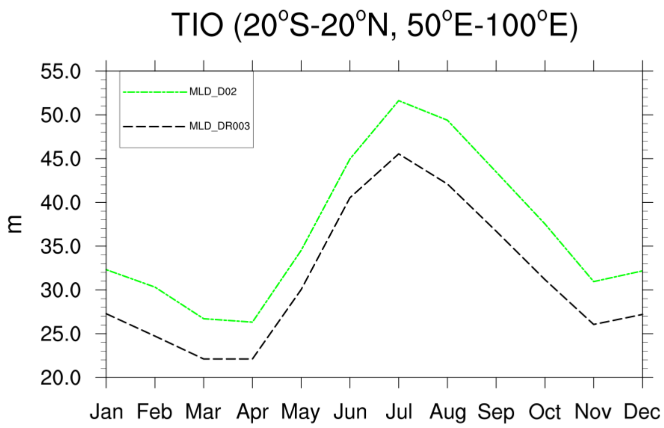

Fig. 2. Seasonal variation of MLD_D02 and MLD_DR003 in the TIO.