Response to SC2 (01st October 2017)

Title: Importance of vertical mixing and barrier layer variation on seasonal mixed layer heat balance in the Bay of Bengal

We would like to thank you for the time and effort used to review our manuscript. Your helpful and constructive comments are highly appreciated. This reply addresses all the points highlighted by you.

Specific comments

The abstract should be shorten and clearly state what's new in this study associated with the previous ones..

Time series measurements from the Research Moored Array for African-Asian-Australian Monsoon Analysis and Prediction (RAMA) moorings at 15° N, 90° E; 12° N, 90° E; 8° N, 90° E; 4° N, 90° E; 1.5° N, 90° E; 0° N, 90° E are used to investigate the seasonal mixed-layer heat balance and the importance of barrier layer thickness (BLT) and vertical mixing (Q_{-h}) in the Bay of Bengal (BoB). It is found that the BLT, Q_{-h} and mixed-layer heat balance all have a strong seasonality in the central BoB. Sea surface temperature (SST), salinity and wind are important for the observed strongest seasonal cycle of BLT in the central BoB, and wind is more important than the SST in the southern BoB. The heat storage rate (HSR) is primarily driven by latent heat flux and shortwave radiation ($Q_{SW}\ and\ Q_L$). Seasonal variations and the magnitudes of longwave radiation (Q_{LW}), sensible heat flux (Q_S), and horizontal mixed-layer heat advection are much weaker compared to those of $Q_{SW}\ and\ Q_L$. Q_{-h} follows a pronounced seasonal cycle in the central BoB and is significantly positively correlated with the seasonal cycle of BLT at each mooring location. The seasonal variability of the stability favors the Q_{-h} during winter and summer monsoon and suppress Q_{-h} during monsoon transition periods. We found that Q_{-h} plays the secondary role in the seasonal mixed-layer heat balance in the BoB. It is evident from the analysis that Q_{-h} associated with temperature inversion (ΔT) warms the mixed layer during winter and cools the mixed layer during summer. The warming tendency during winter is strong in the central BoB and weakens towards the equator, indicating a cooling tendency around the year. Our analysis further indicates the weakening of Q_{-h} during monsoon transition periods favors the existence of warmer SST in the BoB, associated with thermal and salinity stratification in the central BoB.

The following changes were made to the manuscript;

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The "Results" section includes many discussions which often distract the readers from the results. I would suggest organize those discussions into a "Discussion" section and also revise the "Summary" section to separate the previous results from other research and the new findings in the current study..

Summary and Conclusions: In this study, we examine the seasonal mixed-layer heat balance and the importance of the vertical process and BLT in the BoB, using time series measurements recorded at 15°N, 90°E; 12°N, 90°E; 8°N, 90°E; 4°N, 90°E; 1.5°N, 90°E; 0°N, 90°E by the RAMA moorings. At all the mooring locations, it is found that the seasonal changes in mixed-layer HSR is primarily driven by shortwave radiation (Q_{SW}) and latent heat flux (Q_L). The seasonality of HSR is more pronounced in the central BoB. Seasonal variations and magnitudes of longwave radiation (Q_{LW}), sensible heat flux (Q_S) are smaller compared to those of Q_{SW} and Q_L. The horizontal mixed-layer heat advection also weaker compared to that of vertical mixing. The vertical mixing at the base of the mixed layer (Q_{-h}), estimated as the residual in the heat balance following Foltz and McPhaden (2009), also follows a pronounced seasonal cycle in the central BoB, and is correlated positively with the seasonal cycle of BLT at each mooring location. We find that Q_{-h} plays the secondary role in mixed-layer heat balance in the BoB. It is evident from the analysis that the vertical mixing associated with temperature inversion (ΔT) warms the mixed layer during winter and cools the mixed layer during summer. The warming tendency during winter is strong in the central BoB and weakens towards the equator, indicating a cooling tendency around the year. The impact of BLT on Q_{-h} is the strongest at 15°N, 90°E where the seasonal cycle of BLT is the strongest, which is consistent with the results of Foltz and McPhaden (2009) in the central tropical Atlanctic.

To examine the importance of entrainment and vertical diffusion in the vertical process, we estimated vertical mixing following Girishkumar et al. (2013), and found that entrainment is more important in the vertical process. We have found a missing source of warming during August–September in the central BoB up to ~25 Wm^{-2}. The uncertinities are mainly associated with measurement errors, calculation errors and parameterization of the vertical process. Our results further indicate that entrainment is weaker during post-summer monsoon period, which tends to weaken the SST cooling by vertical mixing and helps to maintain warmer surface temperature at all the locations. The seasonal variability of the upper ocean stability favors the Q_{-h} during winter and summer monsoon and suppress Q_{-h} during monsoon transition periods in the BoB. The surface heat fluxes alone do not account for the changes observed in seasonal mixed-layer heat balance. Thus, it brings the importance of vertical mixing, which influences the seasonal variability of mixed-layer heat balance in the BoB.

This study further indicates that MLD, ILD and BLT undergo a strong seasonal cycle in the central BoB. It is evident from our results the change in ILD with SST is important for the change in BLT during winter and pre-summer monsoons, while the change in MLD with wind and surface freshning is important during summer and post-summer monsoons in the central BoB. The significant positive correlation between BLT and Q_{-h} means that vertical mixing is the weakest when the BL is the thickest. We have found that, time periods with the thicker and thinner barrier layers are associated with significant vertical mixing where the moderate BLT supresses the vertical mixing in the central BoB during the periods with strong upper ocean stability. The warming and cooling tendencies by vertical mixing associated with the variability of BLT in the central BoB are consistent with the results of Vialard and Delecluse (1998b) in the western equatorial Pacific and Foltz and McPhaden (2009) in the central tropical Atlantic. Thus, it illustrates the imporatnce of the seasonal cycle of BLT on the mixed-layer heat balnce in the central BoB.

The results of this study thus indicate the importance of BLT and vertical mixing on the seasonal mixed-layer heat balance in the BoB. Late phase of summer monsoon and post-summer monsoon are a period of active air-sea interaction in the BoB, and it is possible that weakening of vertical mixing and strong stratification (higher stability) during this period influence the intensity and frequency of BoB cyclones. Moreover, studies with systematic measurements are needed to understand the upper-ocean dynamics, the process of vertical mixing and its influence on mixed-layer temperature in the BoB, which can influence the weather and climate in the region and beyond.

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Discussion: In this study, we examine the seasonal mixed-layer heat balance and the importance of the vertical process and BLT in the BoB, using time series measurements recorded at 15°N, 90°E; 12°N, 90°E; 8°N, 90°E; 4°N, 90°E; 1.5°N, 90°E; 0°N, 90°E by the RAMA moorings. At all the mooring locations, it is found that the seasonal changes in mixed-layer HSR is primarily driven by shortwave radiation (Q_{SW}) and latent heat flux (Q_L). The seasonality of HSR is more pronounced in the central BoB. Seasonal variations and magnitudes of longwave radiation (Q_{LW}), sensible heat flux (Q_S) are smaller compared to those of Q_{SW} *and* Q_L. The horizontal mixed-layer heat advection also weaker compared to that of vertical mixing. The vertical mixing at the base of the mixed layer (Q_{-h}), estimated as the residual in the heat balance following Foltz and McPhaden (2009), also follows a pronounced seasonal cycle in the central BoB, and is correlated positively with the seasonal cycle of BLT at each mooring location. We find that Q_{-h} plays the secondary role in mixed-layer heat balance in the BoB. It is evident from the analysis that the vertical mixing associated with temperature inversion (ΔT) warms the mixed layer during winter and cools the mixed layer during summer. The warming tendency during winter is strong in the central BoB and weakens towards the equator, indicating a cooling tendency around the year. The impact of BLT on Q_{-h} is the strongest at 15°N, 90°E where the seasonal cycle of BLT is the strongest, which is consistent with the results of Foltz and McPhaden (2009) in the central tropical Atlanctic.

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Summary: Consistent with earlier studies, our results reveals that the seasonal mixed-layer heat balance is primarily controls by Q_{SW} and Q_L. Q_{-h} plays the seconadary role in mixed-layer heat balance in the BoB. Seasonal variability of BLT influences the Q_{-h} and brings the relative importance to the mixed-layer heat balance in the BoB. Entrainment is more important in Q_{-h} compared to that of vertical diffusion. Sengupta et al. (2008) pointed out that SST-cooling along the track of pre-summer monsoon tropical cyclones (TCs) is about 3 °C, whereas cooling due to post-summer monsoon TCs is ~1 °C. It is evident from our results that BoB is more stable during monsoon transition periods and variability observed in Q_{-h} points out that upper-ocean is more stable during post-summer monsoon. Further it suggests salinity stratification provides more stability compared to thermal stratification in the BoB. The results of this study thus indicate the importance of BLT and vertical mixing on the seasonal mixed-layer heat balance in the

BoB. Late phase of summer monsoon and post-summer monsoon are a period of active air-sea interaction, and it is possible that weakening of vertical mixing and strong stratification (higher stability) during this period influence the intensity and frequency of BoB cyclones. Moreover, studies with systematic measurements are needed to understand the upper-ocean dynamics, the process of vertical mixing and its influence on mixed-layer temperature in the BoB, which can influence the weather and climate in the region and beyond.

Line 135, why choosing a constant e folding depth of 25m?

The penetrating shortwave radiation below the mixed layer is estimated using $Q_{pen} = 0.47 \times Q_{sw} . e^{-kh}$ (Jouanno et al., 2011), considering a constant e^{-} folding depth of 25 m (*k=0.04*) and h (MLD).

- Here we use the equation described in Jouanno et al., 2011 to estimate the penetrative shortwave radiation below the mixed-layer. Based on their calculations, we assumed that the shortwave penetration depth is ~25m at all the mooring locations.
- Thangaprakash et al., 2016 (cited in this paper), have estimated the Q_{pen} using, ($Q_{pen} = Q_{shortwave} \times (1-\alpha)^{-h/\varsigma}$). They have calculated the attenuation depth (ς) using MODIS chlorophyll data and pointed out during the study period average attenuation depth is ~20m.

Lines 145-150, "Q_0 is the surface heat flux adjusted for the penetrative shortwave radiation through the base of the mixed layer...".Should Q_0 be the Q_{net} defined in equation (2)?

$$Q_0 = Q_{net} - Q_{pen}$$

Q_0 is the surface heat flux adjusted for the penetrative shortwave radiation through the base of the mixed layer.

The text should be go through to avoid some obvious typos and mistakes. For example, Line64, "thesurface" should be “the surface”

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