Authors response to comments by reviewer #1of the manuscript "Seasonal cycle of sea surface temperature in the tropical Angolan upwelling system" by Mareike Körner (*mkoerner@geomar.de*), Peter Brandt and Marcus Dengler.

We would like to thank the reviewer for the detailed and helpful comments to improve the manuscript. Below, we use black text for the reviewer's comments and blue text for our response.

The seasonal cycle of the mixed layer heat budget is analyzed in the southeastern tropical Atlantic near the African coast. There is a significant residual in the budget when comparing the rate of change of mixed layer heat content and the sum of the surface heat flux and horizontal oceanic heat advection. The residual is larger near the coast in the annual mean, suggesting a larger contribution from vertical turbulent cooling through the base of the mixed layer. Direct measurements of turbulence from several cross-shore cruises reveal stronger mixing and turbulent cooling in the near-shore region, consistent with the heat budget results. It is also hypothesized that seasonal variations in temperature stratification my generate a seasonal cycle in turbulent cooling that drives seasonal differences in the cross-shore SST gradient.

The manuscript is well-written and organized, though there are numerous minor edits that are needed to the language/grammar (see detailed comments below). The results are interesting and will be useful for understanding the mechanisms of mixing and SST variability in the Angolan region and possibly more generally in coastal areas, and for validating models since many have large biases in the southeastern tropical Atlantic. The conclusions are supported well by the analysis and results. I have a few main comments for the authors to consider during their revision.

Thank you for very much for the positive evaluation of our manuscript. Please find the detailed replies to your comments below.

Main comments:

Lines 301 and 381: the turbulent heat flux is averaged between 2 and 15 m below the ML: why use this depth range? Are results similar for smaller depth ranges? 15 m seems deep for mixing to affect SST. Is there any precedent for using this depth range?

Thank you, indeed, we did not motivate our choice of depth range in the previous version of the manuscript. The depth range 2m to 15m below the ML is a trade-off between regions where we are able to estimate turbulent eddy diffusivities from microstructure data and statistical reliability of our results. We will explain this in more detail here, but also included additional text in the manuscript motivating this choice. Previous studies that used similar depth ranges to estimate turbulent heat loss of the ML include Hummels et al. (2013; 2014) (5-15m below ML), Hummels et al. (2020) (1m-10m below ML) and Moum et al. (2013) who calculated a mean heat flux from values between 20m and 60m depth in the equatorial Pacific, but omitted values from within the ML.

Our aim is to determine the turbulent heat flux across the base of the ML. As the turbulent heat flux vanishes at the sea surface, its value across the ML base represents the turbulent heat flux divergence of the ML and thus the ML heat loss. However, we are facing two issues, the inability to accurately determine eddy diffusivities in regions of low or vanishing stratification, and the need for many statistically independent estimates of turbulent dissipation rates to gain statistical confidence in our results.
The first issue is related to the uncertainty of mixing efficiency Γ in low or unstratified environments, as in the ML. Γ is needed to infer turbulent eddy diffusivities from dissipation rates of turbulent kinetic energy (TKE) (see Equation 4 of manuscript). While it has been shown

in several studies that Γ=0.2 is a good approximation in most oceanic regions where turbulence and stratification is elevated (recently summarized by Gregg et al. 2018), this approach is not valid in regions of low or vanishing stratification. Γ, defined as the ratio of change of background potential energy and expended energy, must greatly decrease in regions of near-vanishing stratification, but it is unclear how to parametrize this adequately (e.g. Gregg et al., 2018). Thus, to spare from making inadequate assumptions, we refrain from estimating turbulent eddy diffusivities and thus turbulent heat flux in the ML and across the mixed layer base where stratification is low.
The other issue is related to statistical uncertainty. Dissipation rates of TKE follow a near-lognormal distribution (e.g. Davis, 1996) spanning 5 orders of magnitude in our data set. Strongly elevated values occur very rarely but to a large extend determine the magnitude of the heat flux. It is this suggested that heat flux estimates should be carried out with large data ensembles. Our data processing allows to determine a statistical independent estimate of the dissipation rate of TKE about every 1.2m in the water column. Due to the limited number of microstructure profiles available, we found that including samples from 2m to 15m below the ML was an optimal choice to obtain reasonable confidence limits of our heat flux estimates. Certainly, as the turbulent heat flux is (mostly) convergent with increasing depth below the ML, our estimates are likely biased low.

In the method section 3.1.3. we now state (lines 219 – 220):
“All measurements in the ML as well as 2 m below are disregarded because mixing efficiency Γ is unknown in low-stratified waters (Gregg et al., 2018) and to avoid using data impacted by ship turbulence. “

And two sentences later we state (lines 223 – 227):
„To evaluate the ML heat loss, all individual estimates in the depth range between 2 m and 15 m below the ML are averaged. The use of this depth range is a trade-off between regions where we are able to estimate turbulent eddy diffusivities from microstructure data and statistical reliability of our results. Due to the lognormal distribution of the dissipation rates of TKE (e.g., Davis, 1996), it is desired to average many individual estimates of ε to increase statistical reliability. “

As the authors mention, the use of climatological MLD introduces uncertainty. What are the expected errors introduced by the MLD climatology? How do they affect the uncertainties in the heat budget terms? Can you estimate them by comparing the clim. MLD that you used to the actual MLD calculated from the PIRATA mooring? With such a thin climatological ML, small errors could have a big impact on the magnitudes/errors of the heat budget terms and error bars on residual.

Thank you for this comment. After some further analyses we decided to use a different dataset for the MLD in the revised version. The main reason for this was our finding that the MLD of the PREFACE climatology were biased high. This is likely due to the fact that the climatology used a MLD minimum of 10 m for all individual CTD profiles that went into the climatology. Particularly in region of the continental margin, MLDs are often smaller.
In the revised manuscript we now make use of the GLORYS reanalysis product. The GLORYS reanalysis product has a higher spatial resolution and is available daily within the time span of the study (1993-2018). It compares well to the MLD at the PIRATA-SEE mooring location (Fig. R1). Furthermore, it reasonably well reproduces the shallow MLD at the coast in the tAUS found in the Nansen Data (Fig. R2).
Making use of another dataset for the MLD, changes the magnitude of the heat budget terms (Fig. R3). Due to the decreased MLD in the GLORYS product, all evaluated terms of the ML heat budget decreased so that the net effect on the residual of the heat budget is small.

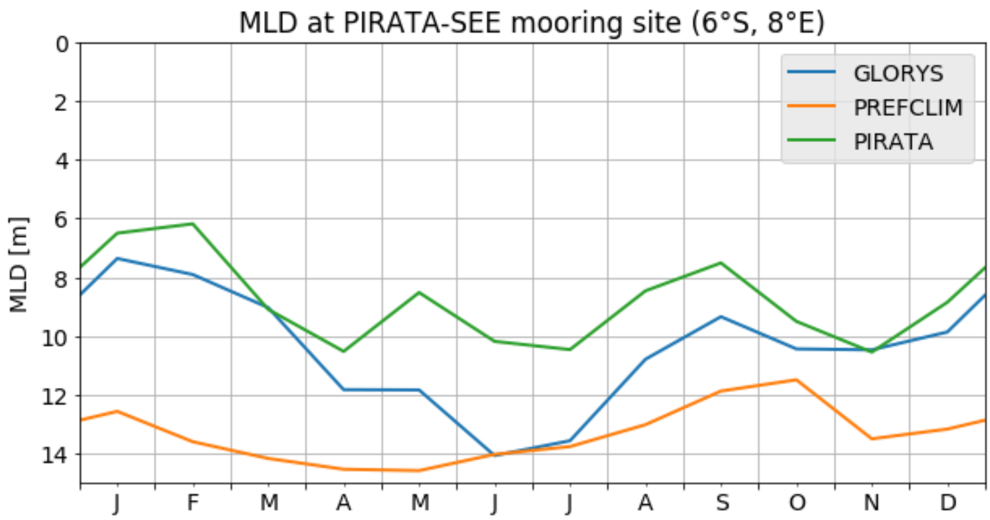

Figure R1: Climatology of the mixed layer depth at the PIRATA-SEE mooring site (6°S, 8°E) calculated with the PIRATA mooring data (green line), the GLORYS reanalysis product (blue line), and the PREFCLIM climatology (orange line).

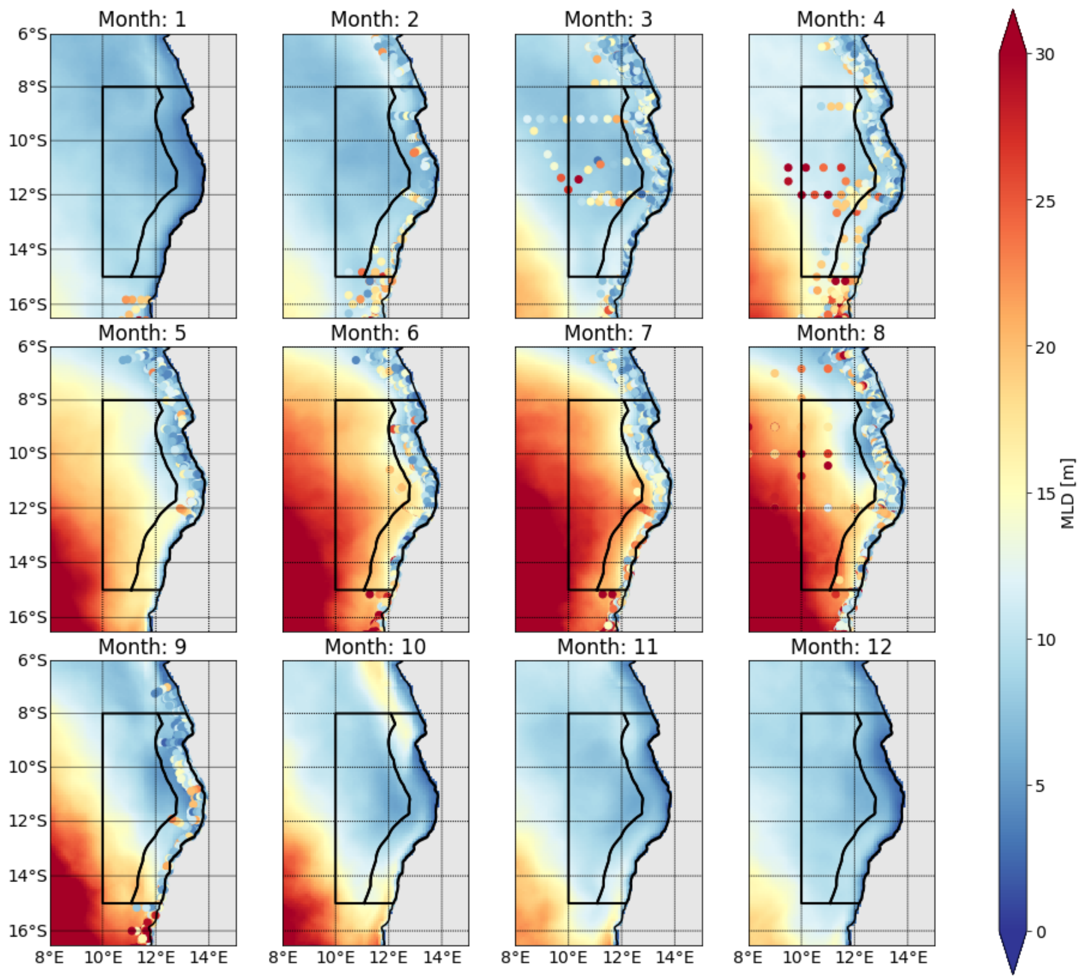

Figure R2: Monthly climatology of the MLD calculated from the GLORYS reanalysis product. MLD from the Nansen CTD dataset (Tchipalanga et al., 2018) are plotted above.

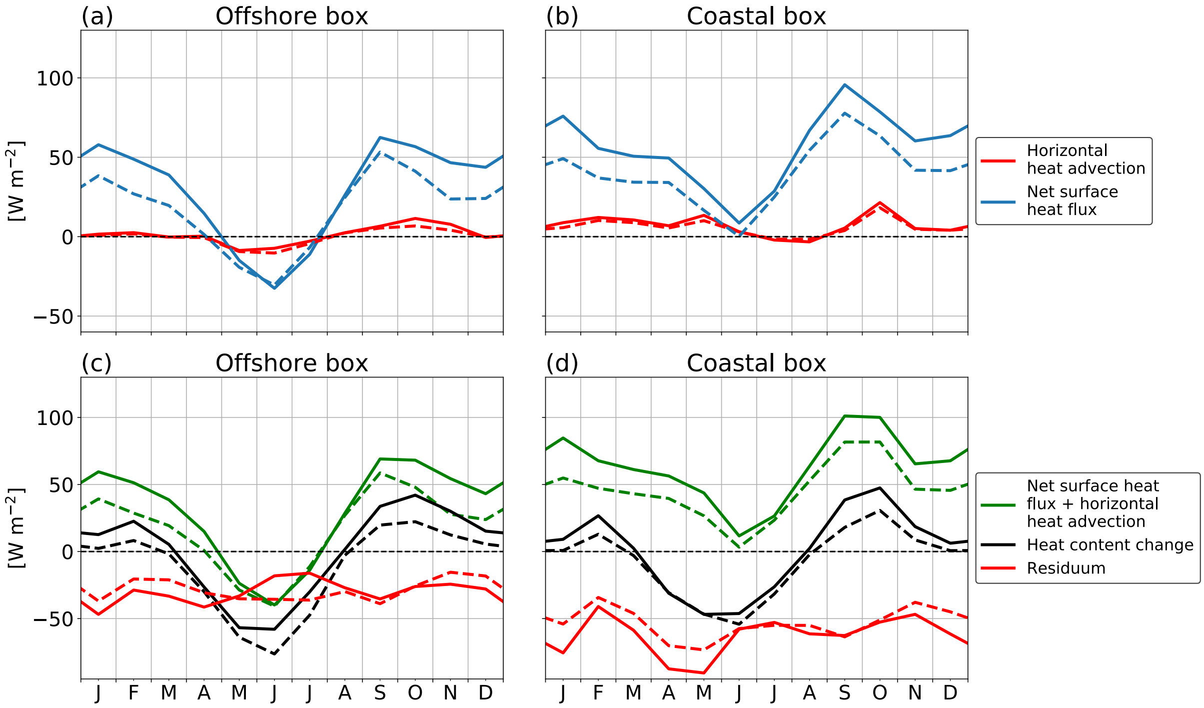

Figure R3: (a) & (b) Individual contributions to the ML heat budget. Colours are explained in the legend. (c) & (d) Sum of net surface heat flux and horizontal heat advection (green lines), the observed heat content change (black lines), and the resulting residuum between both (red dashed line). (a) & (c) show the result averaged over the offshore box, (b) & (d) display the results averaged over the coastal box. Solid lines give the results using the PREFCLIM mixed layer depth. Dashed lines give the results using the MLD calculated from the GLORYS reanalysis product.

Lines 326-327: It looks like the combination of a relative maximum in dissipation (Fig. 7a) and minimum in dT/dz (Fig. 7c) causes the maximum in turbulent cooling 7 m below the ML (Fig. 7d). This might be worth pointing out. Without the max. in dissipation, I'm not sure the pronounced max. in cooling would be there.

Yes, you are right. Due to the large uncertainties (shading in Fig. 8 of the manuscript), we decided to refrain from discussing the structure of the profiles in such great details in the revised version. We therefore deleted the respective paragraph.

Minor edits:

line 35: Delete 'Additionally' and change 'southeast' to 'southeastern' Done
line 53: Insert 'the' after 'reveals' Done
line 54: Change 'propagate' to 'propagates' Done
line 63: Change 'intrude' to 'intrudes' Done
line 65: Change to '...Current, with the Congo River an important...' Done
line 71: Either 'Southeast' or 'southeastern' (and in other places in the manuscript) Done
line 77: Change 'help' to 'helps' Done
line 84: Change to '...area different processes lead to the cooling of the ML compared to further offshore.' Done
line 102: Change 'location' to 'locations' Done
line 118: Change 'mention' to 'mentioned' Done
line 159: Change to '...within 1-deg of the coast.' Done
line 160: Change '...over the extend of the boxes.' to '...over the boxes.' Done
line 171: Change to 'It decays on length scales between 0 and 0.267 m.' and 'exponential' to 'exponentials' Done

line 191: Change to 'Integration of the shear wave number...' Done
line 197: Change to '...spectra are... Done
line 241: Change to '...amplitudes and strengths...' Done
line 242: Change to 'The minimum in July is driven by the...' Done
line 242: Change to 'The largest differences...' Done
line 251: Change 'lead' to 'leads' Done
line 257: Change 'differences' to 'difference' Done
line 261: Change to '...coastal box temperature decreases...' Done
line 268: Delete 'in' Done
line 284: Change to '...amounts to 21.5...' Done
line 285: Change to '...heat advection is...' Done
line 290: Change 'indicates' to 'indicate' Done
line 318: Change 'shows' to 'show' Done
line 331: Change 'contribute' to 'contributes' Done
line 336: Insert comma between 'same' and 'leading' Done
line 343: Change 'shows' to 'show' Done

Thank you very much for providing the edits.

Additional References:

Davis, R. (1996) Sampling turbulent dissipation, *J. Phys. Oceanogr.*, 26, 341-358.

Hummels, R., Dengler, M., Rath, W., Foltz, G. R., Schütte, F., Fischer, T., & Brandt, P. (2020). Surface cooling caused by rare but intense near-inertial wave induced mixing in the tropical Atlantic. Nature Communications, 11(1). https://doi.org/10.1038/s41467-020-17601-x

Moum, J. N., Perlin, A., Nash, J. D., & McPhaden, M. J. (2013). Seasonal sea surface cooling in the equatorial Pacific cold tongue controlled by ocean mixing. Nature, 500(7460), 64–67. https://doi.org/10.1038/nature12363