Response to Editor

(Please note that the Reviewer's comments are in italicized font and our responses are in normal font)

The authors have done a generally good job at responding to the reviewers comments in the first round. However, both reviewers raised as a major comment the lack of budget closure in ERA5, and I am not sure that this is adequately addressed.

As editor, I therefore suggest the authors further address this point in the following ways:

We thank the Editor for giving us the opportunity to improve our manuscript.

- One reviewer points out that the ERA5 dataset includes the analysis increments and sub-gridscale accelerations. Is there a reason that this data cannot be obtained to test whether this is the cause of the discrepancy?

Answer: We thank the Reviewer for this comment and the Editor for pointing out that the comment was unanswered in the Response. The 'Mean eastward wind tendency due to parameterisations' is available as a forecast category variable in the ERA5 catalog rather than the assimilated quantities used in the manuscript. Since a direct comparison cannot be made between assimilated and forecasted quantities, a meaningful interpretation of our results cannot be made using the suggested variable. Another issue is that the parameterisation tendency variable is on model levels, as pointed out by the reviewer as well. However, the code provided by ECMWF to interpolate this to pressure levels requires one to download data on all 137 model levels. The size is 125MB for a single day's data; this becomes ~ 1.8 TB for 40 years for a single variable, and converting this to pressure levels would be quite time-consuming and resource-intensive. Again, since a direct interpretation of assimilated quantities cannot be facilitated using forecast class quantities, we did not do this exercise.

- The authors suggest that convective momentum transport is unlikely to be the reason for the imbalance, but it is hard to see what else it could be. Perhaps examining the latent heating rate in ERA5 would indicate whether the region of strong imbalances is a region of strong deep convection?

Answer: The diabatic heating rate suggests that it is indeed convective momentum transport in the regions of deep convection in the tropics that contributes to the momentum budget residual, as can be seen in Figure 1. We have now modified the third paragraph of Section 3.1 to incorporate this and added the Figure 1 to the Supplementary Material.

Lines 168-181

"The residual (X in Figure 1) attains a large non-negligible value during the summer ($\sim$0.5 ms^{-1}day^{-1}) and is much stronger than the other remaining terms. This may be due to intense convective momentum transport that is known to occur over the Indian Ocean - Maritime Continent region during this season [Lin et al., 2008, Yang et al., 2013]. However, convective momentum transport is usually modeled as a vertical convergence of zonal eddy momentum flux [Carr and Bretherton, 2001, Lin et al., 2008, Yang et al., 2013], which is an explicit forcing term in our momentum equation (Equation 1; green dashed curve in Figure 1). A comparison of the spatial distributions of X and the diabatic heating rate (Figure S1) suggests that convective momentum transport by unresolved eddies is an important contributor to the budget residual X in the deep convective regions over the open oceans in the tropics. Indeed, the use of daily averaged wind fields underestimates the eddy covariances; however, the same calculation using the ERA-Interim dataset [Dee et al., 2011] resulted in a relatively smaller residual (not shown), indicating that the large residual here may be an ERA5 artifact.

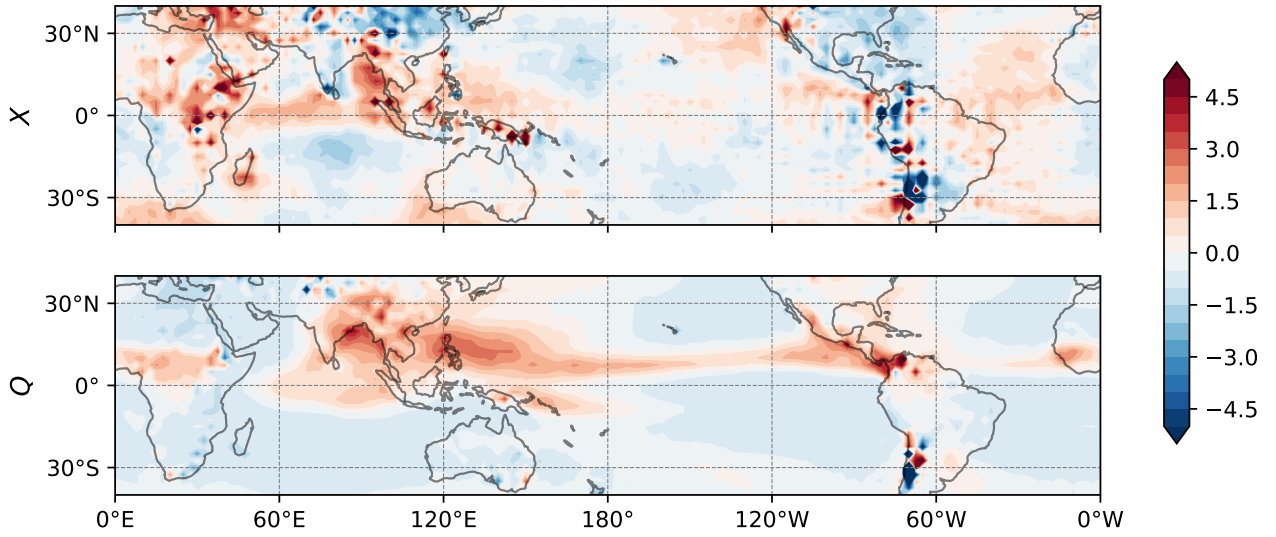

Figure 1: JJAS and 150-300 mbar averaged (top) Momentum budget residual (unit $ms^{-1}day^{-1}$) and (bottom) diabatic heating rate (unit K day^{-1}) estimated as a residual from the thermodynamic energy equation [Holton and Hakim, 2012].

However, the budget terms in the pressure-latitude plane averaged over the boreal summer season suggest that the residual is much smaller than the horizontal eddy and mean flow terms (Figure S2). The residual term weakens after the monsoon and becomes comparable in magnitude to the other terms that remain small throughout the year. Given the systematic dominance of the mean meridional advection and eddy momentum flux convergence throughout the year, the discussion that follows will be focused entirely on these two terms."

- The CMIP6 multi-model mean also seems to show a fairly large residual. Is this of a similar magnitude and spatial pattern as the one for ERA5? Could this be further evidence that the missing processes are subgrid-scale model terms?

Answer: Thank you for the comment. We would like to clarify that we have not explicitly calculated the full momentum budget for the CMIP6 models. As we explained in our response to Reviewer 1 as well as in lines 287-289 of the manuscript, having identified the dominant terms using the ERA5 reanalysis, we have only evaluated the warming-induced changes to these terms. This approach streamlined and simplified our analysis significantly. Indeed, the CMIP models suffer from their own set of biases, and their manifestation in the budget residual could be an avenue for future investigation.

I think the paper is overall sound, and a bit more discussion of this point will allow the reader to assess the budget and any impacts of the imbalance appropriately.

Also note that the WCD policy on data availability (`https://www.weather-climate-dynamics.net/policies/data_policy.html`) requires authors to make their data available in a publicly accessible repository. Please ensure that either the simulation outputs, or information (namelists, config files) sufficient to reproduce the simulations are placed in a public repository and made available.

Answer: Thank you. We have included the details of the publicly accessible repositories.

Minor comments

Line 34: remove "however"

Line 130: Specify that the last term is the "X" term.

Libe 145: Rossby waves -> Rossby wave

Line 386: This is a bit confusing because you earlier talk about a decrease in the tropical mass flux. I assume here you are talking about mass flux through the tropopause, and that is the difference, but it might make sense to note this explicitly

Answer: Thank you. Corrected.

References

Matthew T Carr and Christopher S Bretherton. Convective momentum transport over the tropical pacific: Budget estimates. *Journal of the atmospheric sciences*, 58(13):1673–1693, 2001.

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Jia-Lin Lin, Brian E Mapes, and Weiqing Han. What are the sources of mechanical damping in matsuno–gill-type models? *Journal of Climate*, 21(2):165–179, 2008. doi: 10.1175/2007JCLI1546.1.

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