Responses to Editor's Comments

I would like to thank you for preparing the revised version and mostly reflecting the referee and my comments. I think that the manuscript has been improved substantially and I am particularly happy that your results hold also for the fluxes at 84hPa.

Based on my own quick assessment I identify a few minor remaining points that should be clarified before the publication. Please read them as a set of unbinding editorial suggestions.

>> I appreciate the editor's comments with careful attention to the manuscript. During this revision, we have additionally carried out the analysis suggested originally by Referee #3 and the editor, and included a new section discussing its results. We have also made effort to clarity the points raised by the editor.

1) The comment from Ref#3 regarding.. Alternatives to this correlational analysis are possible. For example, I expected that the paper was
going to take advantage of the descent rate formalism in Equation 2 to formulate a quantitative descent rate budget...
I think that this is a very valid comment and providing a quantitative proof of your hypothesis would be superior to the correlation analysis.
I see that this would practically mean a whole new analysis, but, I think that it would be great, if you add a few lines in the conclusions, where you recommend alternative ways how your hypothesis can be further examined and mention this suggestion by the referee. (As you present a new paradigm shifting hypothesis, you must expect that there will be papers testing it in the future and you should support this process).

>> In the revision, this analysis suggested previously by Referee #3 has been performed and its results have been added in the revised manuscript, with new Fig. 9 and Table 1 and the corresponding text in a new section (4.3). Please see Sect. 4.3 for the results.

2) The issue of indirect estimate-
>> Equation (1) is the generally applied momentum equation, not specific to reanalyses (no external forcing from unresolved/parameterized processes or data assimilation is introduced on its RHS). Therefore, the EP flux in Eq. (1) accounts for the total wave forcing from waves of all scales. We have
clarified this in the revised manuscript [L91–92]. The indirect estimate, therefore, represents the same quantity...

Of course that Eq. 1 is general and does not include the processes that I mentioned. But, you have to acknowledge that you are applying it on reanalysis data, where the zonal mean momentum tendency is affected also by the parameterized tendencies and analysis increments. Further, the fact that you are diagnosing the terms on a non-native grid and output sampling results in possible inaccuracy of your computation that would also project to the indirect estimate. Please provide a detailed reasoning, why you think that I am wrong here and reflect this clearly in the manuscript.

>> We fully agree that the wind tendency in reanalysis includes contributions from parameterized tendencies and analysis increments. However, our study does not attempt to separate or quantify these individual contributions. Rather, we apply the momentum equation as written and calculate the total wave forcing indirectly as the residual between the wind tendency and the remaining term (Adv). In this framework, the indirect estimate formally reflects the total wave forcing as defined by the governing

equation, without further consideration of how the wind tendency is produced within the reanalysis system. Any contributions from parameterizations or data assimilation are inherently included in the residual and are not treated as separate sources.

As noted in the manuscript [L222], we acknowledge that uncertainty in the indirect estimate arises from potential errors in Adv, by construction. Since the purpose of this study is not to analyze reanalysis-specific processes or their attribution, we respectfully maintain that the current level of explanation is sufficient.

3) In your responses you made the case for different latitudinal averaging and cut-off utilization throughout the manuscript. Please reflect this in the manuscript, where applicable, to make any subjective choice you made absolutely transparent for the interested readers.

>> We have reviewed the latitudinal averaging and cut-off values specified in the manuscript and confirmed that the reasoning behind these choices are clearly stated.

- The latitude band for the stratospheric fluxes in Fig. 1 has been changed to 5°N–5°S (matching with the winds). We realized during this revision that the consistent averaging with the winds is more appropriate here, as this figure focuses on fluxes at stratospheric levels where the QBO is forced (cf. flux entering the stratosphere). Thank you for the comment. Now, the wider latitude band is used only for the fluxes entering the stratosphere (at 84 hPa) or lower.

- Regarding the cut-off value, we have added an additional justification for our choice [L154].

L71 I reiterate that 1-2-1 smoothing definition needs to be provided (or give a reference here).

>> It is now further clarified: “the three-point moving average with coefficients [1, 2, 1]/4”

L136 and eq. 2 - provide a reference or an analytical proof that the vertical propagation assumption can be relaxed when using the Lindzen and Holton approximation for the EPFD in the presence of critical layers.

>> Lindzen and Holton’s derivation of momentum forcing due to the critical-level absorption relies essentially on the dimensionality of wind shear rather than that of wave propagation. If the variation in the ambient flow along the wave path in the critical layer is dominated by the vertical change of the flow (namely, its meridional change is relatively ignorable), then the situation is the same as in LH’s case, even for oblique wave propagation (except the path of waves). In this context, no additional derivation is required beyond that of LH. We have now clarified in the revised manuscript that we consider the critical-level absorption under vertical shear [L134–135].

L201 and other (not shown) statements in the manuscript - Consider presenting these results in the Appendix.

>> We have carefully reviewed all instances of “(not shown)” in the manuscript during this revision.

- The paragraph containing L201 (on the limited contribution of larger-scale waves) has been removed, since this content is now addressed more effectively in the newly added Sect. 4.3 (in response to Comment #1) [L280–282]. The analysis in this section examines the contribution of momentum forcing exerted locally on the descent speed, providing a more quantitative view than the correlation-based regression analysis done in Sect. 4.1. The larger-scale momentum forcing and its seasonal variation are much smaller (deduced from older reanalyses with less small-scale waves being resolved; Figs. B1–B2) compared to those seen in Figs. 6–8 and 9. This may provide a stronger argument for the limited role of

large-scale waves than the original discussion around L201 (which was based on the regression performance alone).

- The eastward momentum fluxes due to small-scale waves are now presented in Fig. C1 (cf. Fig. 10).

- We have chosen to retain the remaining "(not shown)" statements, as the omitted results are rather too detailed and would not substantially benefit the clarity or focus of the manuscript.

Code and data availability - Although this is not yet strictly required by ACP, consider publishing your code in some public repository (Zenodo). As I wrote above, you present a new paradigm shifting hypothesis and you must expect and solicit further work on testing the hypothesis.

>> I appreciate the suggestion to make the analysis code publicly available, and fully agree that this practice can facilitate transparency and reproducibility. However, the current scripts were written for internal use and are not yet in a form suitable for public release. Preparing and documenting them for external use would require substantial time and effort.

At this stage, I have chosen to make the scripts and data available upon request, as noted in the manuscript. I hope this will still support further work and collaboration, and I am open to sharing specific parts of the code with interested researchers if needed.