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Interactive comment on "Role of equatorial planetary and gravity waves in the 2015–16 quasi-biennial oscillation disruption" *by* Min-Jee Kang et al.

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General Comment:

Summary: This paper provides a detailed examination of the equatorial wave structures and their evolution during October 2015 through February 2016, a time when the quasi-biennial oscillation experienced a significant disruption. This investigation, based on MERRA-2, a global assimilation system, breaks down the wind, temperature, and precipitation fields into Rossby, Mixed Rossby Gravity (MRG), inertia-Gravity (IG), and Convective Gravity (CG) waves. A novel aspect of this work is the use of a convective gravity wave parameterization to calculate the CG wave effects. The different Eliassen

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Palm (EP) fluxes and their divergences are evaluated. Quantities calculated for the QBO disruption are compared to their corresponding climate signatures. The results show how during October-November of 2015 MRG and IG waves acted to precondition the QBO winds before the strong Rossby waves that occurred in 2016 and created the anomalous QBO easterlies. Why these waves were stronger than usual during this time is still unknown.

Strengths: This work provides a comprehensive view of the UT/LS equatorial waves during the QBO disruption. It expands on the work of Lin et al. (2019) by including aspects of the tropospheric forcing by precipitation and the addition of CG wave model and also differs in the choice of assimilation system from Lin et al. (2019). Figure 16 provides an especially useful summary of the changes roles played by the different waves.

Weaknesses: No major weaknesses. There are a few points that could be improved for clarity that are detailed below. There are a large number of figures. These provide a comprehensive record but it can be difficult for readers to locate the features of interest as described in the text.

Recommendation: Publish after minor revisions noted below. This is a well written, well organized, manuscript. The figures are appropriately captioned and the abstract accurately summaries the work. The topic should be of interest to many readers of ACP interested the the QBO and equatorial waves.

Response: First of all, we would like to thank the reviewer for the time spent on reviewing our long manuscript. All reviews have been beneficial and made us aware of important points which had to be addressed. We, the authors, are therefore thankful for the reviewer's contribution to improve the manuscript. We carefully addressed all comments and tried our best to improve the manuscript based on the suggestions and comments.

Comments:

1. Line 44: "El Nino" Coy et al. (2017) only mentioned a possibility of an ENSO connect. The terms El Nino or ENSO are not found in Osprey et al. (2016) so this sentence should be rewritten.

Response: Thank you for pointing this out! The reference by Osprey et al. (2016) is deleted in the revised manuscript.

2. Line 58: Should be "Coy et al. (2017)". There is a Coy et al. (2016) describing the MERRA-2 QBO before the disruption that could probably be mentioned somewhere in the data section: Coy, L., K. Wargan, A. M. Molod, W. R. McCarty, and S. Pawson. 2016. "Structure and Dynamics of the Quasi-Biennial Oscillation in MERRA-2." J. Climate, 29:14: 5339-5354 [10.1175/jcli-d-15-0809.1]

Response: Thank you for pointing out this error! It is corrected. [p.2, L58]

3. Line 67: Each MERRA-2 data set has a DOI number that researchers are encouraged to reference and clarifies exactly what data set was used. For example from https://disc.gsfc.nasa.gov/datasets/M2I3NVASM_5.12.4/summary?keywords=%22MERRA-2%22 To cite the data in publications: Global Modeling and Assimilation Office (GMAO) (2015), MERRA-2 inst3_3d_asm_Nv: 3d,3-Hourly,Instantaneous,Model-Level,Assimilation,Assimilated Meteorological Fields V5.12.4, Greenbelt, MD, USA, Goddard Earth Sciences Data and Information Services Center (GES DISC), Accessed: [Data Access Date], 10.5067/WWQSXQ8IVFW8

Response: Thank you for your important point. We added MERRA-2 data reference in the revised manuscript. [p.3, L68]

4. Lines 248-249: How is the budget formulated so that resolved MRG and IG wave forcing acts to "enhance" the momentum budget residual, REQ? Maybe this could be rewritten for clarity.

Response: Thank you for your good comment. We found that the original sentence was unclear. We intended to say that the strong MRG and IG wave forcing may account for the relatively strong negative REQ in November 2015. We changed the sentence as follows: "IG waves exert a strong negative forcing in November 2015, which might be related to the enhancement of negative REQ at 40 hPa along with the MRG wave forcing". [p.9, L272–273]

5. Lines 277-287: This is a good discussion of the CGWD. It would help to see the vertical zonal mean zonal wind shear at 40 hPa as a part of Fig. 4 as that should determined in large part the GWD forcing. In addition the meridional shear of the zonal mean zonal wind across the equator might correspond to the changes in the Rossby wave forcing and be helpful to see plotted.

Response: Thank you for your good suggestion. During the revision process, we plotted meridional wind shear across the equator and vertical wind shear averaged over 5°N–5°S, which are included as a new figure (Fig. 4d) in the revised manuscript. We found that the temporal evolution of CGW (Rossby wave) forcing is similar to that of vertical (meridional) wind shear. The related discussion is included in the revised manuscript. [p.10, L303–306]

6. Lines 357-362: Figures 3, 4, and 7 all illustrate aspects of MRG waves, however it is difficult to put together a consistent picture of support for the mid-jet easterly acceleration described here. Most of the easterly acceleration appears to take place in the regions of strong wind shear, not mid-jet. In particular the contribution from MRG waves in Fig. 4 at 40 hPa is small and appears nearly constant in time. The mid-jet should be identified more quantitatively and MRG wave aspects calculated with respect to the jet at each month, at least for the earlier months, to justify this conclusion.

Response: Thank you for your comment. Although the MRG wave forcing is generally strong in the regions of strong wind shear, the easterly acceleration by the MRG waves in the mid-jet (5°N–5°S) is evident at 40 hPa in October, November, and December 2015 with magnitudes of -0.4, -0.6, and -0.6 m/s/mon, respectively (Table 1). The magnitude of mid-jet in 5°N–5°S is 12.3, 11.1, and 8.2 m/s in October, November, and

December, respectively (Figure 4a), which implies that the MRG wave forcing can at least partly account for the weakening of the mid-jet. During the revision process, we additionally plotted a time–latitude cross section of the MRG wave forcing at the altitude range of 40–60 hPa, where the MRG wave forcing was strong (Figure A2), which also shows a deceleration of the jet core by the MRG waves in the early period. The related discussion is included in the revised manuscript. [p.13, L389–390]

7. Lines 375-392: This instability analysis is based on zonal mean winds. A stronger case for instability might be possible with non-zonally average winds, especially when the focus is on the relatively small region defined by the box in Figure 8.

Response: Thank you for your comment. We found that the number of grids with $q_{phi}<0$ is much larger than the original calculation when calculating baroclinic instability based on each longitudinal grid (Figure A3). However, we thought that the background flow defined to extract the MRG waves should be used to evaluate baroclinic instability as a possible source of the MRG waves. Therefore, we would like to keep the calculation of q_phi based on zonal averages.

8. Lines 443-485: The "...apparent positive wind shear..." Is difficult to find in Fig. 14a.The specific levels should be specified in the text.

Response: Thank you for your comment. The specific levels (140–200 hPa) are included in the revised manuscript. [p.17, L515–516]

9. Lines 499-502: The white and gray curves described in the text appear to be different from the Fig. 15 caption description.

Response: Thank you. The description on the gray curves is modified in the revised manuscript. [p.17, L534]

Minor Comments: 1. Line 375: The units in Fig. 8 suggest that q_y is plotted not q_phi. This is a small point. Perhaps the units could be described in the figure caption.

Response: Thank you for pointing out the error! The unit is corrected and described in the figure caption. [Fig. 8]

2. Lines 732-733: The year is missing from the reference.

Response: Thank you, but we think the year '2011' was included in the original manuscript.

Please also note the supplement to this comment:
https://acp.copernicus.org/preprints/acp-2020-791/acp-2020-791-AC3-supplement.pdf

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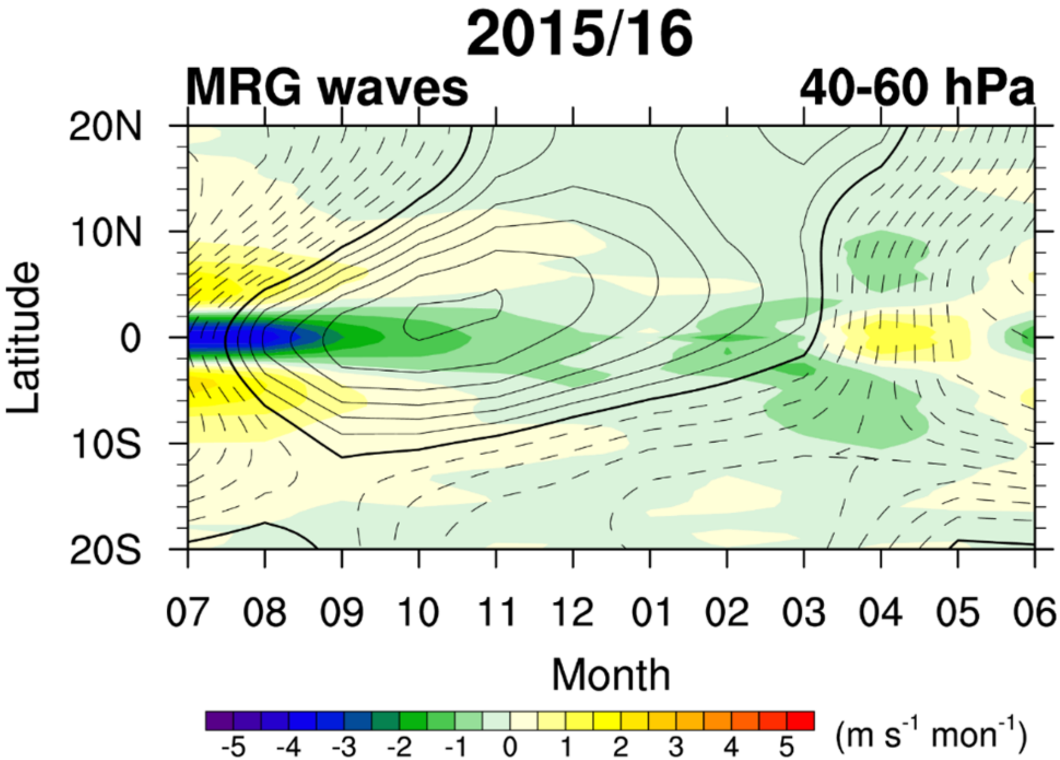

Fig. 1. Figure A2. Time–latitude cross section of EPD for the MRG waves at 40–60 hPa, superimposed with the zonal-mean zonal wind (contour lines).

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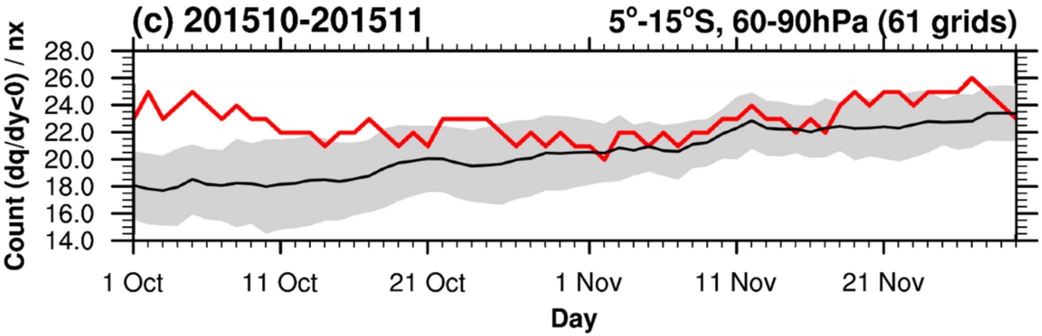

Fig. 2. Figure A3. The number of grids where daily mean q_phi in each longitude is negative in the boxed region normalized by the number of longitudes (576) in October-November 2015 (red) and its climatology.

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