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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "Momentum forcing of the QBO by equatorial waves in recent reanalyses" *by* Y.-H. Kim and H.-Y. Chun

**Y.-H. Kim and H.-Y. Chun**

kimyh@yonsei.ac.kr

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The authors thank the referee 1 for his/her valuable comments. In the revised paper, we clarify what the referee pointed out. The responses to each of the referee's comments are listed below.

Comment (1) *p.5176, l.4ff: Zonal wind tendencies are generally given in m/s/month. Because calendar months can have varying numbers of days, the unit m/s/day is more commonly used. It should therefore be clarified once in the text that "month" in this context refers to a fixed number of 30days, for example on p.5181, l.18. Once this has been clarified, numbers can easily be converted.*

Response: We clarify this point in the revised manuscript [L147], following the referee's comment.

Comment (2) *p.5177, l.26: suggestion: inertio-gravity waves → gravity waves For inertio-gravity waves, it is usually assumed that* $\omega \sim f$*. Satellite observations, however, cover a larger range of intrinsic frequencies. As shown in Alexander et al., QJRMS, 2010, their Fig. 8b, satellites can observe gravity waves with intrinsic periods as short as* $\sim$*1–2hours, much shorter than the intrinsic period given by the Coriolis parameter.*

*Reference:*

*Alexander, M. J., et al.: Recent developments in gravity-wave effects in climate models and the global distribution of gravity-wave momentum flux from observations and models, Q. J. R. Meteorol. Soc., 136, 1103–1124, doi:10.1002/qj.637, 2010.*

Response: We correct this point in the revised manuscript [L45], following the referee's suggestion.

Comment (3) *p.5179, l.20: It should be mentioned that comparison with observations shows that the ECMWF model strongly underestimates temperature fluctuations of mesoscale gravity waves (for example, Schroeder et al., 2009). Therefore reanalyses based on the ECMWF model, as well as other reanalyses, are also expected to generally underestimate such small-scale fluctuations.*

*Citation;*

*Schroeder, S., Preusse, P., Ern, M., and Riese, M.: Gravity waves resolved in ECMWF and measured by SABER, Geophys. Res. Lett., 36, L10805, doi:10.1029/2008GL037054, 2009.*

Response: Following the suggestion, we mention this point and add the reference in the revised manuscript [L94–95].



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Comment (4) *p.5179: Not all parameters in equations (1)–(3) are defined in the text. Instead, it is referred to Andrews et al. (1987). Omitting these definitions is comprehensible because this is textbook knowledge. Including all these definitions would considerably lengthen this section and reduce legibility. Further, I suppose that most readers interested in the topic of this study will be familiar with this notation. Therefore, I leave it to the authors whether the parameters should be explained here again, or not.*

Response: For the reasons the referee mentioned, we do not change this part in the revised manuscript.

Comment (5) *Fig.1: The text in the lower left of each panel describing the different wave types is not easy to recognize. Suggestion: Either use a different color for this text, maybe red, or move this text to the left of the panels.*

Response: The text in Fig. 1 is moved to the top of the panels in the revised figure.

Comment (6a) *p.5180, ll.3/4: Here, all zonal wavenumbers $|k| \leq 20$ are attributed to RGW waves. Usually, however, only $k < 0$ waves are attributed to the RGW wave band. By combining all $|k| \leq 20$, the wave bands of westward propagating RGW waves, and of eastward propagating n=0 inertia-gravity waves are mixed. It is not clear whether:*

*(a) RGW waves and n=0 inertia-gravity waves are summarized in one contribution This could be justified by the fact that the combined spectral band of RGW and n=0 inertia-gravity waves runs continuously from negative to positive zonal wavenumbers.*

*or:*

*(b) The further restriction of $F^{(z,H)}F^{(z,M)} < 0$ suppresses most or all contributions of n=0 inertia-gravity waves.*

Response: We clarify that the MRG wave refers to both of the westward and eastward



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propagating n = 0 waves in the revised manuscript [L107].

Comment (6b) *p.5180, ll.9/10: This comment is related to (6a). On p.5180, ll.9/10 it is stated that all remaining non-Kelvin and non-RGW waves with $|k| \leq 20$ are assumed to be Rossby waves, if $\omega < 0.4$cycle/day. This, however, includes also eastward propagating waves that are no Rossby waves, for example n=0 inertia-gravity waves, if they have not been classified as RGW waves before. On the other hand, the contribution of n=0 inertia-gravity waves may be negligible compared to the RGW or to the Rossby waves, and therefore would not be relevant for the exact definition of wave types. Please clarify!*

Response: Although the Rossby wave can have only negative k in the theory based on the nontransient solution, in reality, part of the Rossby wave can have some spectral power in k > 0 (see Figs. 3 and 4 in KC15) when the wave packet is confined to a short time period. In the spectral domain of $\omega$ < 0.4 cycle/day and 0 < k < 20, after removing the Kelvin and MRG waves (i.e., n = 0 eastward wave), the remaining waves are primarily the Rossby waves because the inertia-gravity waves with n > 0 have much higher frequencies. We also confirmed that these low-frequency waves are in rotational mode (not shown). We refer to KC15 in the manuscript [L101, L109] for the details of the wave separation, because including the explanation of the details in this paper requires additional figures and repetition of a lengthy discussion which was already done in KC15.

Comment (7) *p.5180, l.18: It should be mentioned that in all figures the x-axis ticks correspond to 1st of January of the given year.*

Response: We mention this point in the revised manuscript [L120–121] following the referee's comment.



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Comment (8) *p.5182, l.26: It should be mentioned that the net resolved wave forcing obtained for ERA-I_ml is similar to previous ERA-I estimates by Ern et al. (2014). Somewhat lower values in Ern et al. (2014) may arise from the larger latitude range of 10S–10N in their study.*

Response: Because the net resolved wave forcing is calculated using the same formulation of E–P flux and the same dataset as in Ern et al. (2014), the results must be similar. We do not point out this in the revised manuscript.

Comment (9) *p.5184, l.16: zonal wind shear → vertical shear of the zonal wind*

Response: It is changed in the revised manuscript [L219] following the correction.

Comment (10) *p.5184, l.26: SD → standard deviation (SD)*

Response: It is changed in the revised manuscript [L228] following the correction.

Comment (11) *p.5184, l.26/27: Suggested rewording: This represents the magnitude of $\overline{u}_z$ alternating → These values are governed by the magnitude of $\overline{u}_z$ that alternates*

Response: It is changed in the revised manuscript [L229] following the suggestion.

Comment (12) *p.5185, l.9: It should be pointed out more clearly that relative differences of ADVz between ERA-I and ERA-I_ml in Fig.4b may appear small. However, these differences of 2–4m/s/month can still be an important effect when calculating the residual drag from the tendency equation, which has typical values of ∼10m/s/month.*

Response: We clarify this point in the revised manuscript [L239–241] as the referee pointed out.



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Comment (13) *p.5186, l.1: It should be more clearly mentioned that all terms in the curly brackets are from ERA-I_ml. Only the EP flux divergence of the resolved waves is from the other respective reanalysis.*

Response: We clarify this point in the revised manuscript [L257–258] as the referee pointed out.

Comment (14) *p.5186, ll.6/7: It should be mentioned that these values of* $\overline{X}^*$ *are similar to estimates by Ern et al. (2014). Somewhat higher values in Ern et al. (2014) may arise from a larger latitude range in their study.*

Response: We mention this point in the revised manuscript [L264] as the referee suggested.

Comment (15) *p.5186, ll.9/10: Some care has to be taken with this statement. Kelvin wave forcing is not a net forcing, while* $\overline{X}^*$ *is a net forcing. However, I have the impression that not only the Kelvin wave forcing, but also positive values of the ERA-I_ml net resolved forcing in Fig. 3 show somewhat stronger peak values than* $\overline{X}^*$*. For clarification, I would suggest to just add the word "net": the mesoscale gravity wave forcing* $\rightarrow$ *the net mesoscale gravity wave forcing*

Response: It is changed in the revised manuscript [L265–266] following the referee's suggestion.

Comment (16) *p.5187, l.18: the mesoscale gravity wave forcing* $\rightarrow$ *the net mesoscale gravity wave forcing*

Response: It is changed in the revised manuscript [L302] following the suggestion.

Comment (17) *p.5187, l.26: (2–4*$\Delta_V$ *)* $\rightarrow$ *(2*$\Delta_V$*–4*$\Delta_V$ *)*



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Response: It is changed in the revised manuscript [L309] following the correction.

Comment (18) *p.5191, ll.16–19: Reference Kobayashi et al., 2015 should be updated. The final version of this article is now available at J. Meteorol. Soc. Jpn.*

Response: It is updated in the reference section of the revised manuscript.

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Interactive comment on Atmos. Chem. Phys. Discuss., 15, 5175, 2015.