Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2019-110-AC1, 2019

Atmospheric Chemistry and Physics Discussions
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Interactive comment on "Comparison of equatorial wave activity in the tropical tropopause layer and stratosphere represented in reanalyses" *by* Young-Ha Kim et al.

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Received and published: 10 June 2019

$>>$ We deeply appreciate the reviewer for providing constructive comments. The manuscript is revised following the comments below. Regarding the comment #6, a new figure is added in the Supplement (Fig. S5). Please also note that the averaging latitude band for the EP flux diagnostics in Section 3.4 is changed to 5°N–5°S in response to another reviewer's comment, and one figure is added (Fig. 12). Figures A1–A3 used for the responses below are attached separately (see the bottom).

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Discussion paper

This paper presents analysis of stratospheric equatorial waves in several reanalysis data sets, focusing on standard space-time spectral analysis of Kelvin and Mixed Rossby Gravity waves. The analyses are mostly straightforward and the results show reasonable agreement among the reanalyses (and with previous publications), with a few outliers identified. Long-term variations in wave variances show changes likely related to input satellite data sets, in particular the transition from TOVS to ATOVS in 1998. Comparisons are also made for derived EP fluxes for the Kelvin and MRG waves. The overall results provide quantitative information on tropical wave behavior among the reanalyses, and the paper makes an original and useful contribution to the SRIP evaluations. The paper is reasonably well written and is appropriate for ACP. I have a number of mostly minor comments for the authors to consider in revision.

1) The inclusion of JRA55C (no satellite data) is especially nice for quantifying the influence of satellite data in the reanalyses, and I'm surprised at how small the differences are with JRA55 at upper levels (where radiosonde data are sparse). How should this result be interpreted, i.e. are these wave spectra mostly characteristic of the forecast model, or are upper levels constrained by lower levels?

$>>$ In the middle stratosphere ($\sim$10 hPa) where the radiosonde data are sparse, wave fields in JRA-55C are likely partly determined by the analysis of lower-level fields (20–50 hPa), when one considers that there will be upward propagation of assimilated waves, and also by the dynamics of the forecast model. Provided that the lower-level fields have been reasonably well constrained in JRA-55C (as reflected by the agreement with the other five reanalyses at $\sim$50 hPa; Figs. 1–5), the forecast-model dynamics are likely to be capable of maintaining the spectral signals of the waves at $\sim$10 hPa from below in JRA-55C as well as in JRA-55.

Characteristics of the forecast model could affect the amplitudes of waves in the middle stratosphere rather than their spectral features, given that the spectra have been well constrained in the lower levels. The wave amplitudes might depend on the model diffusion which arises from the dynamics/numerics and vertical resolution, especially in JRA-55C with less observational constraints in the middle stratosphere. In this regard, it is seen in Fig. 8 that the difference in the wave amplitudes between JRA-55 and JRA-55C increase with height above ∼10 hPa, in particular in 1999–2010 when the constraint is stronger than before in JRA-55 from the new satellite instruments.

In short, the small difference between JRA-55 and JRA-55C at ∼10 hPa could be interpreted as a consequence of these constraints in the lower levels. In addition, in the early period (1981–1997), the constraint in the lower stratosphere could mostly be attributed to the radiosonde observations even in JRA-55. Additional impacts of satellite measurements seem to be minor in this period (Fig. 7), which likely result in the rather small differences in the upper levels between JRA-55 and JRA-55C (Fig. 8, left).

2) Figure 11 uses the Singapore zonal winds as a standard reference for all reanalyses. Are there any systematic differences found using the zonal winds from the separate reanalyses instead of a single reference? Does behavior of the equatorial waves in the different reanalyses 'feel' the differences in zonal winds identified in Kawatani et al (2016)?

$>>$ Yes, there are systematic differences in the altitudes of the Kelvin wave forcing, which are consistent with the differences in the zonal wind :

The zonal-mean zonal winds in each reanalysis are added in Fig. 11 in the revised manuscript. It is seen that the shear layers are located at different heights between the reanalyses, consistent with the results in Kawatani et al. (2016). The maximum Kelvin-wave forcing is found to occur at the altitudes where the wind is near zero in each reanalysis. The relevant explanation in the original manuscript [P12 L26–28] is complemented using this updated figure in the revised manuscript [P13 L16–31], and the abstract is also updated [P1 L13–15]. The authors appreciate this comment which greatly helps to improve the paper.

3) Can you please add a right hand axis indicating period (in days) for the various spectra (Fig. 1, 2, 9,10,13). The discussions in the text are all based on wave period, and it would be helpful to simply see this on the figures.

$>>$ All the figures showing the spectra are updated following this suggestion.

4) Are there any systematic seasonal variations in the Kelvin and MRG spectra at lower levels (100 hPa) identified in the reanalyses? Since you have long records of monthly statistics it would be easy to identify such behavior.

$>>$ We calculated the symmetric and antisymmetric spectra at 100 hPa in different months and found seasonal variations in the spectra. For example, the Kelvin wave temperature variances at k = 2–3 seem to be largest (smallest) in boreal summer (winter) in the six reanalyses (see Fig. A1 below). The antisymmetric spectra seem to have the largest (smallest) powers in boreal winter (summer), and the low-frequency power at periods of $\sim$20 days disappear in boreal summer and early autumn (Fig. A2). However, quantitative analysis of the seasonal variations in the Kelvin and MRG waves may require a more rigorous methodology because the MJO-related and Rossby wave spectra also have very strong annual variations. When these spectral signals are strong (e.g., in boreal winter for MJO signals, Fig. A1), it becomes more complicated to define the Kelvin and MRG wave spectra properly such that their annual variations are not influenced. In this reason, we do not include the seasonal variations in the paper but focus on the climatological-mean properties and long-term variations. We hope to continue to study the seasonal variations of the equatorial waves in the future.

5) The EP flux calculations are complicated and it would be helpful to have a direct reference to the calculations used here (beyond the standard Andrews 1987 textbook). Are these calculations identical to those used in Kim and Chun (2015)? How do the climatological EP fluxes here compare to other published results?

$>>$ The method of EP flux calculation is described in more detail in the revised manuscript (Section 2) [P4 L19–31]. To identify the wave types, we used only the (k, ω)-spectral filters defined in P13 L2–3 in the revised manuscript, which is probably the simplest way among the methods used in the literature (cf. Yang et al., 2003; Tindall et al., 2006; Kim and Chun, 2015). These filters are defined in the same way as those used in the previous sections for consistency. The wave separation method used in Kim and Chun (2015) is more complicated and is not applied here to facilitate comparison of the results with other studies.

The climatological vertical EP fluxes for Kelvin waves, averaged over 5°N–5°S using ERA-Interim, are 0.89 mPa at 100 hPa and 0.42 mPa at 70 hPa in our study. These values are comparable to those obtained using the method of Kim and Chun (2015): 0.87 mPa at 100 hPa and 0.37 mPa at 70 hPa. Tindall et al. (2006) applied another method based on the linear wave theory to ERA-15, and estimated the climatological zonal-momentum flux $(u'w')$ of Kelvin waves as 0.0013 and 0.0017 m^2 s^{-2} at 100 and 70 hPa, respectively. These values can be converted approximately to vertical EP fluxes of $\sim$0.23 and 0.20 mPa, respectively, which are 50–75% smaller than those obtained in our study. The differences in both the method and data likely cause the difference in the results.

6) The composited phase-speed spectra results are very nice (Fig. 11). For the conversion from frequency to phase-speed there is a factor of zonal wavenumber

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needed to conserve spectral density (see Randel and Held, 1991, JAS). Has this been incorporated in these calculations?

>> Yes, it is incorporated such that the integral of the spectral density is conserved.

While the composite results are revealing, it would be interesting to see the variability of some of these diagnostics within the composites, for example perhaps showing a 'spaghetti plot' of the separate composited time series to see the actual variability, within and among the reanalyses. Could this be included as a Supplementary figure?

>> Thank you for this suggestion. We tried to examine the variability in the EP flux diagnostics, and could see that there are significant cycle-to-cycle variations in the EP flux diagnostics as well as in the wind profiles. We add this figure in the Supplement (Fig. S5) and include a brief statement in the revised manuscript [P14 L29–32].

7) A recent paper on observed lower stratosphere Kelvin waves is Scherrlin-Pirscher et al 2017 doi:10.5194/acp-2016-576, and this might be a useful reference to include.

>> Thank you for this information. We include this reference in the revised manuscript [P10 L24–25].

8) The high frequency disturbance in the meridional wind at upper levels has some characteristics similar to the so-called 2-day wave (zonal waves 3–4, ∼2 day period, occurrence in strong easterly winds); see e.g. https://doi.org/10.1029/2009JD012239. It might be useful to look at the latitude-height structure of the waves for a tentative identification.

$>>$ We agree that the spectral characteristics of the high-frequency meridional-wind disturbances at 20 hPa are similar to those of the quasi-two-day wave (QTDW), although the QTDW has appeared as a disturbance in the summer mesosphere and uppermost stratosphere in the literature. It has been proposed that the QTDW is a mixed Rossby-gravity mode triggered by the baroclinic and/or barotropic instabilities associated with the easterly jet in the summer mesosphere (e.g., Salby 1981; Pfister, 1985; McCormack et al., 2009). The 20-hPa high-frequency disturbances detected in our study may likely be related to baroclinic/barotropic instabilities as well, but associated with the easterly QBO jet, although more detailed investigations will be required to make conclusion. In any case, these disturbances may not be necessarily connected from the QTDW above, given that the occurrence of the 20-hPa disturbances is strongly tied to certain phases of the QBO, as seen in Figs. 13 and 14. We add the statements regarding the similarity in the characteristics between the 20-hPa disturbances and QTDW in the revised manuscript [P16 L12–17].

An examination of the vertical structure of the disturbances is not so simple because when the disturbances are clearly identified at 20 hPa with an easterly background wind, the spectra at the altitudes above $\sim$10 hPa (Fig. A3, left) are partly occupied by another wave signal (e.g., at 0.3 cyc/day with $k=$ 4–5). Further analysis of the vertical structure will require more detailed investigation, which is beyond the scope of the current study.

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Please also note the supplement to this comment:
https://www.atmos-chem-phys-discuss.net/acp-2019-110/acp-2019-110-AC1-supplement.pdf

Interactive comment on Atmos. Chem. Phys. Discuss., https://doi.org/10.5194/acp-2019-110, 2019.