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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Equatorial wave analysis from SABER and ECMWF temperatures" *by* M. Ern et al.

M. Ern et al.

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Again, the authors would like to thank George Kiladis for his effort!

In the following we will address to the Reviewer's Specific Comments and Technical Corrections:

Specific Comments:

(1) p.11688: "The tropospheric values can be attributed to the vertical scale of convective processes" ... it is probably more correct to say "attributed to the

convective coupling" As discussed above it is likely the nature of convective coupling that determines the phase speed and therefore the vertical scale of the waves discussed by WK, whereas in the case of "free" waves it is the vertical scale of the heating.

The text will be changed accordingly starting from p.11688, l.20:

"... and 19 km in the troposphere.

For the convectively coupled equatorial waves which are mainly observed in the troposphere (e.g., Wheeler and Kiladis (1999)) the nature of convective coupling determines the phase speed and therefore the vertical scale of the waves. Different from this, for the "free" wave modes mainly observed in the stratosphere the tropospheric vertical wavelength values (like the ones given above) can be attributed to the vertical scale of the convective systems acting as source (e.g., Chang (1976), Fulton and Schubert (1985), Salby and Garcia (1987)) which is in good agreement with the vertical scale of the heating. Typical vertical profiles of thermal forcing in convective systems have a broad maximum over about 2–8 km in the troposphere (e.g., Chang (1976), Fulton and Schubert (1985), Johnson and Ciesielski (2000)). The vertical scales of gravity waves excited by convection are determined by the vertical scale of the heating in a similar way (Alexander et al., 1995).

The phenomenon of Kelvin waves..."

(2) p.11689: "these analyses cover the source processes of the waves observed at higher altitudes" Actually based on the arguments above I would say that WK only discuss the largest scale, lowest mode convectively coupled waves which account for only a relatively small fraction of the free waves launched by "background" convection not organized into such waves.

The text will be rewritten accordingly, starting from p.11689, l.26:

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"...using TRMM rainfall data. These analyses discuss the largest scale, lowest mode convectively coupled waves which account for only a relatively small fraction of the free waves launched by "background" convection not organized into such waves.

In the stratosphere, different from the troposphere, in particular the Kelvin waves observed (but also other equatorial wave types) cover a larger range..."

(3) p.11693: In Fig. 2 and 3 color scales are different for symmetric versus antisymmetric.

The differences are too large to use a common color scale. We will add the following sentence on p.11693 after l.18 to clarify:

"Please note that in Fig. 2 the color scales are different for symmetric and antisymmetric spectra."

And on p.11696 after l.9:

"Please note that again the color scales are different for symmetric and antisymmetric spectra."

(4) p.11693: A large portion of the faster stratospheric signals are likely independent of the tropospheric waves studied by WK.

The text will be rewritten accordingly, starting from p.11693, l.26:

"In Fig. 2 we can see that already in the lower stratosphere spectral contributions are somewhat shifted with respect to the tropospheric observations by Wheeler and Kiladis (1999) or Cho et al. (2004). There are also contributions of the different wave types outside the 8–90 m equivalent depth wave bands and a large portion of the

faster stratospheric signals are likely independent of the tropospheric waves studied by Wheeler and Kiladis (1999)...."

For further changes see also Specific Comment (5) by Anonymous Reviewer #1.

(5) p.11694: are the symm/anti background variances roughly equal?

Yes, the backgrounds are roughly equal! This will become evident in the new Fig. 10 we will introduce (see Substantial Concern #3). For example, the color scale for SABER will be 0–7 K^2 for the new Fig. 10a (two times antisymmetric background from frequencies $<$0 cpd) instead of 0–9 K^2 for Fig. 9a (symmetric and antisymmetric added for whole frequency range).

(6) p.11694: Are SABER data assimilated into the ECMWF operational analyses?

No, they are not, but there are other satellite data (TOVS/ATOVS radiances) that are assimilated into ECMWF! See discussion of Specific Comment (10) by Anonymous Reviewer #1.

(7) p.11695: just to clarify: SABER residuals are calculated from the zonal mean, but here you are using temporal residuals? This is not quite clear.

Yes, for SABER the data were detrended by zonal means estimated daily by using a zonal wavenumber 0–7 Kalman filter. The ECMWF data were detrended time-window by time-window by subtracting linear fits over the whole 31-day windows for given latitude and altitude.

We will clarify by rewriting the beginning of this paragraph in the following way:

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"Residual ECMWF temperatures are obtained using a detrending method different from the one used for the SABER data, which was based on daily zonal mean values (see Sect. 2.2). Instead, for ECMWF we calculate linear fits of the data in each of the 31-day time windows for every pressure level and latitude. These fits are subtracted from the data time window by time window to remove mean values as well as temporal trends. Since the time windows used are relatively short ..."

(8) p.11695 There is a strong, time mean component spread through the lowest wavenumbers in the antisymmetric spectra of Figs. 2 and 3 that the authors do not discuss. Part of this signal cuts across the ER band, but there seems to be equal variance on the eastward side too, perhaps it is some sort of standing component? Do the authors have an explanation for this signal?

No, we do not have an explanation for this signal. This must be a standing wave component. We assume that this is a real feature and no artifact. It should also be mentioned that similar spectral features are present in both SABER and ECMWF data.

(9) p.11695, Bottom: I do not understand the argument that the EC "background is spread over a much larger spectral area". [...]

See also Specific Comment (6) by Anonymous Reviewer #1 (normalization issue). Parseval's theorem says that the power spectral density integrated (over the whole spectral domain resolved by the sampling) gives the total variance of the data analyzed. Since the spectral domain covered by ECMWF (frequency range -2cpd...2cpd and zonal wavenumbers 0...20, please note that in Figs. 2 and 3 not the complete ECMWF spectra are shown) is much larger than the one covered by SABER (frequency range -1cpd...1cpd and zonal wavenumbers 0...7) the power spectral densities from ECMWF on average would be expected to be lower than the SABER values by a factor of about 6: 2cpd/4cpd x (8 wavenos. / 21 zonal wavenos.) if both data sets would have the same

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variance. This factor would be even larger if we had used the full resolution (up to zonal waveno. 180) of ECMWF data for our analysis. And, of course, the backgrounds would be more similar if the ECMWF data analyzed were further decimated to only twice daily maps with only about 26 degrees zonal resolution.

It turns out for the spectral background variance attributed to gravity waves that the ECMWF background is lower than the SABER background by more than this expected factor of 6, indicating an underrepresentation of gravity waves in ECMWF. This is reflected in the lower values of ECMWF variances attributed to gravity waves, obtained by integrating the spectral background over the full spectral domain resolved by the sampling (Fig. 9).

For changes of the manuscript see Specific Comment (6) by Anonymous Reviewer #1.

(10) p.11696, bottom: "the average peak Kelvin signal" is this for only the one wavenumber-frequency bin that has the highest value?

Sorry for that! The term "peak signal" is somewhat misleading since we give more than one spectral component for each of the altitudes shown. The components listed are the strongest ones found at these altitudes in the 4-year average spectra.

Therefore we suggest to change the text as follows:

"The strongest Kelvin wave components in the 4-year average spectra are given in Table 1 for both SABER and ECMWF ... At higher altitudes the strongest Kelvin wave components found in ECMWF are higher than the SABER values on average..."

(11) p.11697: like (10), same for Fig. 4

Same problem as in Table 1: we do not rely on a single spectral component and use 4-year averages. But different from Table 1 we average over the ten strongest com-

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ponents at each altitude. This should be clear from the text changes suggested in Specific Comment (10).

(12) p.11698: What kind of windowing is used to produce the time-variance plots of Figs. 5-9, are these just the same 31-day windows used to obtain the spectra?

Yes, indeed! The same windows are used. The wave variances we determine in each time window are attributed to the center days of the time windows.

The following text will be added on p.11697 after l.23:

"For this analysis we use the same 31-day time windows as in Sect. 2. The temperature variances that will be determined in each time window are attributed to the center days of the time windows."

(13) Distinguish the SAO signal in the text from the annual cycle and QBO in Figs. 5-9.

We are sorry, indeed the description of the semi-annual oscillation (SAO) features is not sufficient. We will add the following text on p.11698, l.17:

"At altitudes above 40 km the zonal mean zonal wind is not longer dominated by the QBO pattern of alternating eastward and westward wind with an oscillation period of about 24 months. Instead, the zonal mean zonal wind is more and more dominated by an oscillation with a period of about 6 months. This semiannual oscillation (SAO) of the zonal wind can be found in the upper stratosphere and the mesosphere. From Figs. 5 and 6 we see that above above 40 km altitude also the temperature variances are dominated by the SAO and exhibit the same semiannual variation as the zonal wind."

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(14a) p.11700: What do you mean by median value?

In brief: A median is a type of average, found by arranging the values in order and then selecting the one in the middle. This technique is frequently used if the data contain some outliers that shall be disregarded. Such outliers bias a conventional mean-value average. We calculate the median of the symmetric and antisymmetric spectra of each 31-day time window to estimate the spectral background for each of those spectra. The number of "outliers" is reduced before by omitting the strongest spectral peaks at zonal wavenumbers 1–3 and as well as frequencies -1 cpd, 0 cpd and 1 cpd.

We will rewrite the first paragraph in Sect. 3.2:

"We also calculate the temperature variances due to gravity waves by estimating the spectral background separately for each 31-day window and altitude for both the symmetric and antisymmetric spectra. To avoid contamination of these background values by the equatorial wave modes we omit the tidal peaks, as well as zonal wavenumbers lower than 3 (where the main contributions of equatorial waves are located) in each of the spectra and calculate the median of the squared spectral amplitudes from the remaining spectrum.

A median is a type of average, found by arranging the values in order and then selecting the one in the middle. We use this method instead of the conventional mean-value average because even in the remaining parts of the spectra there will be "outliers" (localized spectral signatures of equatorial wave modes with amplitudes much higher than the spectral background) that will high-bias the mean value of the spectral background. This is avoided by using the median because in the remaining parts of the spectra the majority of spectral values is dominated by the spectral background (see Figs. 2 and 3)."

And also some kind of cross-check for the median method will be provided on p.11701 following l.9:

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"Some kind of cross-check for the median technique can be made by comparing the average variances at 21 and 41 km altitude in Fig. 9 with the background variances that were estimated from the 4-year average spectra in Sections 2.2 and 2.4. The values obtained there are about 2 K^2 and 7 K^2 for SABER and 0.5–0.7 K^2 and 3–4 K^2 for ECMWF at 21 and 41 km altitude, respectively. As we can see these values are in good agreement with the average values obtained from Fig. 9 at 21 and 41 km altitude."

(14b) It seems that you haven't effectively isolated the background because Fig. 9 looks suspiciously like Figs. 7a and 8a (Kelvin waves).

See reply to Major Concern #3.

(15) p.11701: at the start of section 4.1, already at 21 km the equivalent depths associated with the waves are substantially higher than in the troposphere, and this discrepancy becomes greater with altitude, so I don't think it's quite correct to say that your results are "similar" to WK and Cho et al.

Yes, indeed there is a significant shift towards higher equivalent depths at 21 km altitude compared to the observations in the troposphere. This will be accounted for by rewriting the first paragraph of Sect. 4.1. For changes of the manuscript see Substantial Concern #1.

(16) Pg. 11703 line 4 from bottom: Since the Preusse et al. 2006 analysis concerns only one month, this statement is confusing.

Yes, indeed this is somewhat confusing: The Preusse et al. (2006) paper shows SABER squared amplitudes due to gravity waves and the method how these are determined is described in more detail. Therefore we also cited this paper although only one month of data is shown. In Krebsbach and Preusse (2007) only amplitudes of the

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variation of those SABER gravity wave amplitudes are shown (and not the squared amplitudes themselves). Therefore the reader would have to look into both papers for the complete picture.

To avoid further confusion we will omit the reference Preusse et al. (2006) and rewrite this sentence as follows:

"In an analysis by Krebsbach and Preusse (2007) based on SABER gravity wave squared amplitudes annual variations as well as QBO related variations..."

(17) Pg. 11705: I assume "91-day analysis windows" refers to the length of the series used for spectral filtering?

Seems like we need some more explanation here to avoid confusion! For the Hovmoeller diagram we use 91-day time windows for the space-time spectral analysis instead of the 31-day time windows used before. We could also have used the 31-day windows here (the results look quite the same) but at the transitions from one 31-day window to the next one minor inconsistencies would show up because Fourier analysis assumes that the data set analyzed is periodic in time. To avoid these artifacts and allow for a better comparison between SABER and ECMWF results we chose to calculate the Hovmoeller diagram from only one single (longer) time window, containing the whole time period shown.

Obviously we have to add some explanation to the manuscript and we will rewrite the text from p.11705 l.7 onward:

"... Again we average over the latitudes 15 S–15 N. But different from Sects. 2–4 we use 91-day time windows for the space-time spectral analysis instead of 31-day windows to avoid small inconsistencies at the transitions between the 31-day windows. The results are very similar. For a better comparison between SABER and ECMWF

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results we therefore chose to calculate the Hovmoeller diagram from only one single (longer) time window, containing the whole time period shown.

Figure 10a shows..."

(18) As I understand it EC stratospheric data assimilation are heavily dependent on satellite measurements. The comparison between SABER and ECMWF is remarkably good. If these data sets are truly independent this should be pointed out here and also at the start of Sections 2.3 and 6.

Yes, indeed SABER data are not used for assimilation in the ECMWF analyses. This will be mentioned in Sections 2.3 and 6.

But it is correct that other satellite data (TOVS/ATOVS radiances) are assimilated in ECMWF. Therefore better agreement between SABER and ECMWF Kelvin waves would be expected at higher altitudes but the opposite is the case (see Specific Comment (10) by Anonymous Reviewer #1).

(19) Pg. 11706: "..one (,is the...) reason why residual temperatures are maximum at.." I do not follow the logic here.

If the temperature variances were dominated by a single monochromatic Kelvin wave the temperature residuals shown in the Hovmoeller plots would show sinusoidal variations over the whole longitude range with constant amplitude, independent of longitude. Different from this we find no clear coherent sinusoidal structure over the whole longitude range in the residual temperatures shown. In addition, on average, residual temperatures are lower for longitudes $<$0deg. This indicates that not only one single sinusoidal wave is responsible for the temperature residuals observed. There has to be some kind of mixture of different Kelvin waves, involving different zonal wavenumbers and frequencies.

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To clarify this point we will rewrite the second paragraph on p.11706:

"The Kelvin waves observed have pronounced periods of about 10–15 days, and, indeed, there is a mixture of Kelvin waves leading to the observed residual temperatures of about $\pm$3 K maximum. If the temperature variances were dominated by a single monochromatic Kelvin wave the temperature residuals shown in Fig. 10 would show sinusoidal variations over the whole longitude range with constant amplitude, independent of longitude. Different from this we find no clear coherent sinusoidal structure over the whole longitude range in the residual temperatures shown. In addition, on average, residual temperatures are lower for longitudes $<$0deg. In particular, residual temperatures are enhanced at longitudes 50 E–180 E, i.e., in the Darwin region where the SCOUT-O3 measurement campaign took place. This indicates that not only one single sinusoidal wave is responsible for the temperature residuals observed. There has to be some kind of superposition of different Kelvin waves, involving different zonal wavenumbers and frequencies."

Technical Corrections:

(1) Pg. 11689, bottom line: "in the stratosphere" used twice.

Second occurrence will be removed.

(2) Pg. 11690, middle: "some kind of" suggest "a" instead.

Will be changed.

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(3) Pg. 11692, top: I suggest saying something like "and each averaged over a latitude band (e.g. 15S-15N) after first calculating the power at each individual latitude".

Will be changed accordingly.

(4) Pg. 11694: a minor point, but you are using pressure level ECMWF data yet results are plotted by altitude, how is this conversion made?

The conversion is made in the following way:

The ECMWF pressure levels p_i are converted to pressure-altitude coordinates z_i using a constant scale height of 7 km:

$$z_i = 7\text{km} * \ln(p_0/p)$$

with p_0=1013.25 hPa These altitudes are used for comparison with the SABER data given on a geometrical altitude grid.

The paragraph starting in l.20 on p.11694 will be rewritten in the following way:

"... on 28 pressure levels p_i between 1013.25 and 0.1 mbar. For comparison with the SABER data given on geometric altitudes the ECMWF pressure levels are converted to pressure-altitude coordinates z_i using a constant scale height of 7 km:

$$z_i = 7\textit{km} * \ln(p_0/p)$$

with p_0=1013.25 hPa. Because we are mainly..."

(5) Pg. 11696: suggest "This likely reflects the increase of the amplitudes"

Will be changed accordingly.

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(6) Year is missing on Preusse et al. 2006 reference.

Year will be added.

(7) Krebsbach and Preusse reference should be 2007, not 2006 throughout.

Will be changed.

Interactive comment on Atmos. Chem. Phys. Discuss., 7, 11685, 2007.

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