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Atmospheric Measurement Techniques Discussions

Interactive comment on "Atmospheric QBO and ENSO indices with high vertical resolution from GNSS radio occultation temperature measurements" *by* Hallgeir Wilhelmsen et al.

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AC3

We thank the reviewer for valuable questions and comments helping to improve this paper. They are addressed in the responses below.

Major comments

Comment 1: Page 6, line 14: "EOF3 and EOF3 resemble EOF1 and EOF2 just above the tropopause. Does this imply that ENSO is modulating the QBO in some way? Or is this some kind of numerical leakage, with no more physical meaning than the flipping of M2 PCs between QBO and ENSO dominance at different altitudes?"

Response 1: It is possible that the ENSO signal propagates through the tropopause, modulating the QBO in the lower stratosphere. There are several studies related to this topic. However, investigating this interesting subject is beyond the scope of this work.

We cite several additional studies in the revised version of the manuscript, discussing these topics.

We think that the signal seen in EOF3 at 20 km (Fig. 2) could be related to ENSO, while the signals in EOF3 and EOF4 further above in the stratosphere are probably due to numerical leakage.

Please see response to Comment 3 from Referee #1, RC1.

We added a paragraph in the introduction:

"The interaction between ENSO and QBO has been investigated in many studies (Taguchi, 2010; Schirber, 2015; Christiansen et al., 2016; Geller et al., 2016; Hansen et al., 2016). It is, however, beyond the scope of this work and would require a dedicated study. For further literature on the relationship between ENSO, QBO, and teleconnections, see e.g. the introduction in Dunkerton (2017) and references within."

Comment 2: Page 6, line 26 – 27. "The authors comment on the top half of Figure 5, where the QBO and ENSO patterns are clearly visible above and below the tropopause, respectively. But what does the bottom half of Figure 5 tell us? There are hints of a QBO-like propagation in the lower stratosphere. But other than that it is unclear how the M2 PC2s should be interpreted."

Response 2: We agree that a discussion about the lower panel of Fig. 5 is missing. In the revised version of the manuscript we make the following changes to Sect. 4.2.

We changed page 6, line 25 from

"The first set of PCs reveals a separation into a part above the tropopause and into a part below the tropopause"

to

"As for the EOFs, each PC represents an altitude level.

The first set of PCs (upper panel of Fig. 5) reveals a separation into a part above the tropopause and into a part below the tropopause."

and added the following at the end of Sect. 4.2:

"The separation is not as clear in the second set of PCs (lower panel of Fig. 5). It shows part of the residual variability that is not described by the first set of PCs. These also show downward propagating patterns, but different from the first set of PCs, and less regular in the stratosphere.

Keep in mind that both the EOFs and the PCs have been scaled by their corresponding eigenvalues (see Sect. 3.1), at each altitude level separately. The corresponding eigenvalues are proportional to the explained variance ratios (see Fig. 6). The magnitude of each time series does therefore not necessarily describe its importance, nor are the contributions from each EOF or PC directly comparable. The actual contribution can be seen in the reconstruction. See Sect. 4.3 and Sect. 4.6 for further details.

Also keep in mind that dominating atmospheric variability at different altitude levels can be caused by different physical mechanisms. The physical context of the first principal components may therefore also change with altitude because the calculations are performed separately at each altitude level for M2. Finally, if independent variability modes explain a similar amount of variance, their corresponding PC time series can

switch between two PCs (e.g., between PC1 and PC2) at neighboring altitude levels."

Comment 3: Page 6, line 25 and page 8, lines 17 – 34: "It might be helpful to the casual reader to explain more fully how Figure 5 differs from the right-hand upper and middle panels of Figure 10. The differences between plotting the M2 PC time series, and the M2 time series reconstituted from the PCs, might not be entirely clear at first glance."

Response 3: For the Page 6, line 25, see Response 2 above.

For page 8, lines 17 – 34, we inserted the following sentence:

"In contrast to Fig. 5, where the PC1s and the PC2s are plotted in EOF space, we map the PC1s and the PC2s back into anomaly space."

We also changed the paragraph starting at page 8, line 26 from

"Figure 10 (bottom left panel) shows a combination of all four principle components from M1, and the result well resembles the input temperature anomalies shown in Fig. 1."

to

"Figure 10 (bottom left panel) shows the reconstruction using all four principal components from M1. This time series well resembles the input temperature anomalies shown in Fig. 1."

Comment 4: Page 9, line 30: "It is not surprising that the second method captures more of the variability. If you think of the two analyses as being akin to different kinds of statistical curve-fitting, there are a great many more coefficients in M2 to which the "fit" is being made. Smaller residual variances will naturally follow. The key question here is, is there a physical meaning to the increased fits? I suspect the answer lies in the clear relationship between signals at different altitudes. Perhaps computing time series coherence between altitudes would show formally what the eye can clearly see."

Response 4: Figure 1 in this response shows the correlation between a specific PC (PC1 or PC2) from M2 (see Fig. 5 in the manuscript) at a given altitude level (e.g., at 17 km) and PC1/PC2 (also from M2) at all altitude levels. Correlation plots are shown for seven selected levels.

Figure 1 in this response reveals that these correlation patterns are very similar to correlation plots shown in Fig. 8 of the manuscript. The cross correlation (third and fourth column) is particularly high around the tropopause which could be related to the drop in explained variance ratio (Fig. 6 in the manuscript). This is subject to further investigation.

Comment 5: Page 9, lines 25 – 27: "The lack of a known time lag in the M1 method is alluded to on p. 7 in the discussion on Figure 7. But perhaps a little more discussion of this could be added in the method discussion in Section 3.1."

Response 5: We agree that it could help to add some information leading to Fig. 7 this early in the manuscript. Since the meaning of the time lag is discussed in Sect. 4.4, we think it suffices to lead towards physical interpretation of the indices in Sect. 3.1.

We changed page 5, line 11 from

"The first few PCs from Eq. (3) can now be used as proxies for the temporal variability, which we call *indices* in the following."

to

"The first few PCs from Eq. (3) can now be used as proxies for the temporal variability. We call these *indices* in the following. Calculating cross correlations between these indices and conventional indices can point to their physical interpretation."

Grammatical/stylistic points

Comment 6: "The formatting of the spatial points if preparing for the EOF analysis is referred to in two different ways: as "stringing along a single axis" (p. 4 line 22) and "reshaping" (p. 5, line 28). The term "reshaping" seems preferable. If "stringing" is retained, please note that the past tense of "string" is "strung", not "stringed"."

Response 6: We changed the sentence

"The space dimensions are all stringed along a single axis..."

into

"The space dimensions are all reshaped into a single axis"

and

"Therefore, only the latitude and longitude dimensions are stringed along one axis"

into

"Therefore, only the latitude and longitude dimensions are reshaped into one axis"

Comment 7: Page 2, line 10: ""origins" should be "originates"."

Response 7: Corrected.

Comment 8: Page 2, line 20: ""more coarse" should be "coarser"."

Response 8: Corrected.

Comment 9: "Figure 1. If the Nino 3.4 SST index could be plotted along the bottom of this Figure, and the QBO30 and QBO50 winds plotted at their respective altitudes, it would establish for the reader early on the relationship between these traditional indices and the measured temperature field. These would not have to be quantitative plots with overlaid labelled axes; simple unlabeled time series, similar to the tropopause

altitude in gray, would suffice. Granted, the tropopause curve needs no labeling, since it varies along the labelled y-axis. But showing how the original temperatures relate to these indices would be helpful preparation for what follows in the paper."

Response 9: We added an overlay, depicting the indices in Fig. 1, or adding panels above (for QBO) and below (for ENSO) depicting the QBO winds at selected pressure levels and the Niño 3.4 SST index, respectively.

Comment 10: "Figures 2, 4, and 8: The use of small-multiple plots here is good. But instead of simple pasting together independent plots, each with its own title and color bar, these Figures would be improved by inserting the small plots into a labelled grid structure. For example, in Figure 2, the altitudes should be clearly labelled along the left-hand side, by each corresponding row of plots. Likewise, the EOF numbers should be indicated along the top of the figure, at the top of each column of plots. The explained variance could be retained in each plot's title, but moving the other title information to the grid margins would greatly improve readability. And eliminating all but one color bar would make it instantly clear that the scale is not changing from plot to plot."

Response 10: Thanks for this valuable suggestions. We improved these figures according to the suggestions.

Comment 11: "Figure 6. This Figure would be improved if the x- and y-axes in the top half were to be exchanged, so that the x-axis on the top figure matched that of the bottom, making them easier to compare."

Response 11: Thanks also for this input. We improved Fig. 6 accordingly.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2017-226, 2017.

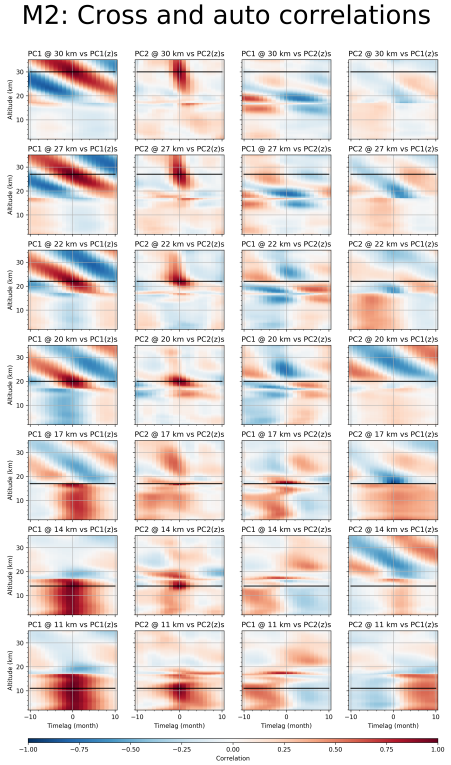

Fig. 1. Cross- and auto correlations using PC1(z)s and PC2(z)s from M2. Each column represents the correlations for a reference PC(z) (black line) vs. the PC(z)s for another (or the same) principle component.