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Reply on RC2

Lina Boljka et al.

Author comment on "Revisiting conceptual oscillator models for the quasi-periodic component of the El Niño Southern Oscillation" by Lina Boljka et al., Weather Clim. Dynam. Discuss., https://doi.org/10.5194/wcd-2022-51-AC4, 2023

We thank the reviewer for careful consideration of our manuscript and their constructive comments that have helped improve the original manuscript. Note that line numbers below in our responses refer to the revised manuscript.

Major comments:

1. The author clearly introduces the MEMD method in the appendix. However, in section 3, the author jumps to IMF12 and IMF13, and I am a little bit confused. Hence, I suggest inserting a section (or a section in the appendix) to summarize more details about all the IMFs. The authors should present the time series of all the IMFs, and enlist a table with characteristic frequencies for each IMF before the discussions of IMF12 and IMF13.

We have now plotted all IMFs of SST (Nino3), wind stress (Nino4,5), thermocline depth (Nino6, Pacific mean) - see Figs. S7 - S11 in the supplement. We have also provided all their characteristic timescales in Table S1. Note that we have put these figures/table in the supplement to avoid having too much information in the main text (manuscript is long as is). Fig. B1 actually shows typical timescales of each mode in a graphical way (it is timescale versus amplitude, but in a logarithmic scale). We have also realised that we never mentioned IMF12,13 in Methods and then we suddenly jumped to them in section 3 (as the reviewer pointed out).

We have added additional clarifications in the Methods section 2.2 - see l. 187-189, 232-233, 243-244, 245-252.

Also, the author needs to clarify more about Fig. B1. For example, given the doubling periodic of each consecutive IMF, it is reasonable to have 10 IMFs using the EMD for ~100-year monthly mean data (Fig B1a, B1b). However, why are there 22 IMFAs from the analysis of PC1 (Fig B1c) and 21 IMFAs from the Nino3 (Fig B1d)?

The number of IMFs for PC1 and Nino3 is the same, i.e., 22 IMFs, but one IMF in Nino3 (Fig. B1d) was too large and did not fit in the Figure. As shown in the supplement now, all PCs and all variables have 22 IMFs and IMFs have similar frequencies across different variables/PCs (see Figs. S7 - S11 and Tables S1, S2).

As for the number of IMFs, we believe that the number of IMFs is larger due to more timeseries (i.e., 20 PCs) input into MEMD algorithm versus one timeseries input in EMD algorithm. The different timeseries can have slightly different timescales represented and MEMD can pick them up (see also answer to major comment 2 below). Note, however, that the number of IMFs can also change depending on the parameters used to run MEMD (e.g., "fix_h" parameter mentioned in the text).

We have now added discussions around these points in the caption of Fig. B1 and in the text as well (see l. 861-869). Fig. B1 is also further described on l. 769-776.

2. I also suggest that the authors could clarify more about the "multi-variable" parts of the EMDs. For example, it is well-known that the sea-surface temperature is generally more "smooth" than wind stress. It is more likely that the IMF1 from the wind stress data carries more high-frequency noises than the IMF1 from the SST. Hence, the IMF1 from the wind stress and SST might have different characteristic frequencies. Again, the authors could present some figures of raw data and IMFs to clarify if each IMF function from different variables have similar frequencies.

MEMD's job is to identify typical timescales within the system of input variables and provide IMFs that can describe timeseries of all these variables. This is now shown in Figs. S7-S11 and Tables S1, S2, where IMFs across all variables and PCs generally have similar timescales. Thus, IMF1 of wind stress ultimately has the same timescale as IMF1 of SSTs. However, because input variables (or grid points) have different timescales represented, e.g., in the high frequency range (wind stress is noisier than SSTs), this can cause mode mixing in MEMD analysis when no clear timescale can be identified across different timeseries. IMF13 (or an equivalent mode with similar frequency range) thus typically emerges across different parameters and from EMD or MEMD analysis. This is because it is such a prominent mode of variability in the tropical Pacific, but other timescales can be more problematic. Again, see l. 861-869.

3. One more concern about the IMFA forms by the addition of s'th IMFs of the 20 PCs(with EOFs). However, what if the s'th IMFs have different characteristic frequencies for different PCs? It is very likely that there is a big difference between the frequencies of IMF(s, m) and IMF(s, m+1). This issue might enhance the mode-mixing and further jeopardizes the analysis. Hence, I suggest presenting the EOFs/PCs results (in the appendix or before section 3) with at least a table of PCs. In this case, readers can judge how PC1 dominates so that we don't have to worry too much about the issue.

As mentioned above, MEMD is designed for identification of common timescales across input timeseries. Thus, IMFs of all PCs should have similar frequencies within the range of frequencies belonging to that IMF (i.e., 6.7th and 93.3rd percentiles) - see also Table S2. Mode mixing does, however, occur at high frequencies, where timescales are not clear (see comment 2 above for further explanation & l. 861-869).

We have also decided to use SST (Nino3) as index for compositing and all the analysis, not PC1 to avoid issues with the PC1 dominance (see l. 324-329, caption of Figs. 2,3). For the red noise test, one can use different timeseries as basis and PC1 was just our initial thought (its analysis is kept for reference in Fig. B1, but not used further). We have realised that it is confusing and that using SST (Nino3) throughout the study makes everything more consistent across methods and figures. We updated numbers, figures and texts accordingly (see tracked changes and updated Figs.).

Minor comments:

1. (L126-129) I am a little confused about the "30-year running mean seasonal cycle". Do you take the 30-year climatology of seasonal cycle, and then make a moving window of this climatology? Need clarifications.

We have added more text about the 30-year running mean (see l. 134-144).

2. (L162) "Where timescales are not clear" I suggest giving a range of frequencies.

Added to l. 184.

3. (L197) "standard deviation" Needs to clarify how whether the standard of each variable or four variables.

Each variable in each grid point is divided by standard deviation separately - clarified on l. 223-224, 703.

4. (L232) Would IMF11 and IMF14 be involved with the ENSO? Need clarifications.

All IMFs together make up ENSO, but most of them follow the red noise spectrum. We find that the most important ones in our analysis are IMFs 11-15, which ultimately give most of the amplitude to ENSO, but only IMF13 and to some extent IMF12 are quasi-periodic. This was mentioned further down in the text, so we have now specifically mentioned IMF11,14, 15 on l. 305-308. Note (again) that we detrended timeseries, thus (multi)decadal modes of variability (like PDO, IPO) are not present in our analysis.

5. (Fig 3,4,6) The legend line styles are hard to discriminate; suggest rearranging the size.

We have fixed the legend in Figs. 3,4,6.

6. (L359) Need more details about why the time scale is about three years, or insert a reference.

We simply ran the conceptual oscillator model with provided equations, which yielded timeseries with a timescale of about 3 years. This was estimated through the timelapse between different maxima in timeseries (different "events"). We have moved up a paragraph about computing timeseries from Eqs. (5-8) and added the clarification about period. See l. 392-397.

7. (Fig 5) Hard to tell the line. I suggest using different colors or line widths.

We used these colors/lines as they are color-blind friendly (journal's policy). Also, they are consistent with lines in Fig. 3. We have now made dotted lines in Figs. 3-6 blue (similarly in the supplement) as this line was the hardest to read. Note that this line is very closely related to the grey-solid line. Wider lines were not used as that makes it harder to see the time evolution of all variables (feels crammed). Thus, "black dotted" was changed to "blue dotted" "line" everywhere in the text as well – see track changes.

8. (L521) I suggest giving meow descriptions about the linear-regression models.

We have added a schematic that can hopefully explain how the data were lagged before they were input into the statistical prediction model. - see new Fig. C1 and its caption. We have also moved the details to the Appendix C to make the main text easier to read.

9. (L675) "filed" is a typo.

10. (L679) Replace "=" by "\simeq".

11. (L682) Same as (L679).

We have fixed the typo and “equality” symbols as suggested. See l. 720, 724, 728.