Responses to reviewers and editor (W. Roberts)

First, we would like to thank reviewers/editorial team for their patience and constructive comments on our paper. Below we first describe the latest changes to the manuscript and later provide point-by-point responses to the editor (W. Roberts).

Following the comments by reviewer 3 and W. Roberts we made substantial changes to the manuscript.

1. We have removed sections on oscillator models, results from a climate model (NorCPM1), and prediction implications. While the latter two have now been completely omitted, we still discuss implications for oscillator models in section 6 of the latest manuscript version, but we do not go into details. If the reviewers would like to have more text on oscillator models from the original manuscript, we could potentially add them in the supplement, though we deem it unnecessary.
2. We have re-ordered the manuscript so that MEMD algorithm and red noise significance tests are now described in more detail in the main text (sections 3 and 4 in the latest version). Similarly, we start the abstract, introduction, conclusion with statistical methods for climate science and MEMD, while ENSO is only briefly mentioned in the introduction and further expanded on in sections 5,6 of the latest version.
3. We tried emphasizing the novel results more.
    a. MEMD has not been used in climate science before (except for an idealized study), even though it is data-adaptive and thus fully nonlinear and nonstationary. The latter means that modes that emerge from MEMD, i.e., IMFs are nonstationary and thus have time-evolving spatial patterns of variability. Additionally, MEMD can identify timescales of variability within a given system objectively (without window pre-selection).
    b. We developed a red noise test, which has not been used with EMD or MEMD in the past. Now, both methods can be used for extracting quasi-periodic signals within climate system.
    c. We test MEMD + red noise test on tropical Pacific atmosphere-ocean variability as we know ENSO exists there and it thus provides a clear test case for the new method. We confirm MEMD can extract ENSO. Moreover, it can extract quasi-biennial and quasi-quadrennial ENSO modes as well as ENSO nonstationarity.
    d. MEMD modes that emerge are physical as they can isolate recharge-discharge oscillator and other relevant dynamics. We also find some interesting novel results for ENSO dynamics (e.g., different behaviour on quasi-periodic timescales versus other ENSO-relevant timescales) and suggest a re-evaluation of the unified oscillator model.

Additionally, we found an error in our PC/EOF analysis (inputs for MEMD) and hence some numbers/figures are now slightly different from our previous manuscript version. However, results remain consistent.

Hopefully, the manuscript is now clearer. Below are point-by-point responses to W. Roberts.

At this point I cannot approve this manuscript for publication. Although the reviewers do not question the validity of the science, the third reviewer indicates that the presentation lacks clarity and leaves a reader confused. As my editorial colleagues have already pointed out, this paper aims to present a lot of material in a very short space which, while possible, requires careful crafting of the arguments to guide a reader through. Shortening the paper by putting bits of it into an appendix and changing the title does nothing to increase its clarity.

All the authors need to sit down together to discuss how best to present this work, as it currently falls short of the quality that's needed to be published in WCD. What is needed to move this paper towards being publishable, is a clear motivation for why the paper is long and then clear signposting as the paper unfolds to keep a reader engaged. Ultimately you need to convince a reader that it's worth reading this paper, otherwise no one will bother.

I suggest that the authors re-read and reflect on the original comments from the third reviewer, particularly those major comments where the reviewer requires more clarity. Although you did respond to these comments, the reviewer found the revision weak. As editor I agree: in reading the revised manuscript I had the exact same questions as the reviewer, thus the reviewer's comments remain unaddressed.

A revision to this manuscript requires edits that are more comprehensive than tweaking a few sentences. Reviewer 3's major comments should be more substantially addressed along with the new comments in their report. More clear motivation for what the paper hopes to achieve must be given. Sections should be restructured to give a clearer map for where the paper is going and how it will address the research question.

Below are some suggestions for how to increase the clarity, along with a few "Other Points" that I noticed while reading the manuscript.

Again, thank you for these constructive comments.

Motivation

The foundations for the paper need to be laid out in the Introduction. By the end of the Introduction a reader needs to have had it clearly explained:

- **Why do we need to revisit the various oscillator models for ENSO?**
- **Why do we need to use MEMD to understand the oscillators? What's wrong with existing methods?**
- **Why are you going to analyse both observations and output from a climate model?**
- **How does prediction fit into this whole picture (or drop this section)?**

The answers to these questions may already be somewhere in the Introduction. However, as an independent reader coming to this manuscript afresh, I can assure the authors that it is currently far from clear what the answers are.

As mentioned above we have removed climate model & prediction results completely. Similarly, oscillator models are only discussed when considering ENSO dynamics, which is primarily done to ensure MEMD modes (IMFs) have physical meaning. However, we still find interesting novel results when we analyse variability of tropical Pacific on different timescales, and we show the nonstationarity of IMFs and ENSO.

MEMD

The description of the MEMD is a very important part of this paper and deserves its own section. The authors may wish to de-emphasise the MEMD procedure but it is a critical part of the whole paper. If a reader doesn't understand what constitutes the components for the new oscillator, they aren't going to buy into the argument that a new oscillator is even needed – see comments from Reviewer 3.

Ending this section with a summary of the crucial points needed to understand MEMD would serve a reader well as a reference for use when reading the rest of the paper.

There are elements of the MEMD section that can't just be put into an appendix. The results in Appendix B2 are absolutely fundamental to the paper so need to be in the main text. Appendices present information that is additional to paper. If they were to be removed, the paper should still make sense: this is not the case for some of the appendices in this paper.

We have put MEMD into a new section (now section 3) and slightly expanded it and added a figure to help visualise EMD (Fig. 1). Similarly, we have moved parts of Appendix B to the main text (section 4) and split the original Fig. B1 into 3 Figures – now Fig. 2 (relevant for MEMD and Niño3 index), Fig. S2 (relevant for MEMD and PC1 of the tropical Pacific), and Fig. B1 (relevant for the white and red noise tests discussed in Appendix B; relevant for EMD analysis only). Hopefully the methodology is now clearer.

Introduction

I would suggest that the first 3 paragraphs of the Introduction are redundant: the audience for this paper already knows what ENSO is and what its impacts are. Getting straight to the point in this paper would shorten it and keep the reader engaged.

We have removed most of the ENSO text from the introduction. We only keep text on red noise in the climate system on l. 43-50, and basic text on what ENSO is on l. 59-66. The rest of the ENSO discussion appears in sections 5,6. The introduction has also been shortened.

Sections

I would suggest that the sections are restructured somewhat to have more major sections. E.g. Intro, Data, MEMD, ENSO, Oscillators, Implications, Conclusions. Remember that it is highly unlikely that this paper will be read in one go , so breaking up the paper by theme will assist a reader when they return to it. Summaries at the end of each section will help the signposting for a reader. Similarly, high level overviews of what will be achieved in each

section will help a reader understand what's going on. For example, Section S3 goes straight into the mathematical detail describing the method with no introduction to what will be achieved. It is better to give an overview first and then give the details. E.g. in section S3 begin with . "As an example we shall describe how MEMD is carried out on a simple periodic time series. We shall define 4 timeseries which have a shared angular frequency of pi/2 with other harmonics or phase shifts added on top. MEMD will be applied and should isolate this shared pi/2 mode. ..."

There is much truth in the old mantra: "tell them what you are going to tell them, tell them, then tell them what you told them"

We have now split sections as suggested, though due to different content in the second half of the manuscript the sections are called differently. Namely, we now have sections: Introduction, Data, MEMD, Statistical significance test for climate, Tropical Pacific modes of variability, ENSO dynamics, and conclusions. Hopefully this breaks the paper down into smaller bits of information.

we have generally added some text at the beginning / end of sections to help the text flow, i.e., what is the goal of the next section or what will be or has been achieved in this section. For example, see l. 232-237, 270-272, 301-305, 346-348, 350-364, 427-431, 446-447. We have also added text to the beginning of section S3 in the supplement along the lines of the editor's suggestion. See l. 4-9 in the supplement.

Prediction

I would suggest that this section be dropped. What purpose does it serve in addressing the subject: "Revisiting conceptual oscillator models for the quasi-periodic component of the El Niño Southern Oscillation"?

This section has been removed.

Other points

Paragraph beginning 115 – it is not clear from this paragraph why non-SST data are included. The emphasis of this paragraph is that SST is pre-eminent – SST weighted more in procedure, tau_x/thermocline are slaves to SST – so why even include the other variables?

This is done primarily for testing physical meaning of modes of variability that MEMD yields. Ultimately, we find some interesting relationships as well (section 6). We have added more text on l. 75-77, 85-97.

Para beginning 130 – this is confusing, see comment from Rev3, it seems to imply that the variables are averaged into these boxes before they are fed into the MEMD. State what the purpose of this averaging is.

Averaging is performed after MEMD analysis. We added some text/equations to clarify this. First on l. 100-101, and later on l. 195-200. See also Eq. (1) for IMF spatio-temporal reconstructions.

Line 155, using () here is very confusing. Just state " ordered from the highest to the lowest frequency, equivalently from the shortest to the longest period/timescale." () should only be used to indicate parenthetical statements, I.e. less important or explanatory statements, as per the usage in the following sentence. There's a weird precedent in some geosciences for their usage in other contexts, but it really should stop.

On l. 137-138 we now use "The modes are automatically ordered from highest/shortest (mode 1) to lowest/longest (last mode) frequency/period." We also changed some parentheses use in other aspects, e.g., "SST (Niño3)" is now "eastern Pacific SST (Niño3)" to include less important information in the parentheses.

Section S3: EMD description – in S3 add in an example of how the "envelopes" are computed in EMD to help the reader. This would help readers with a more graphic intuition.

We have added envelope schematic to the main text (Fig. 1).

It is Hard to parse this section.

State up front what you are doing at high level then dig into details, later. This applies to the whole paper. In most sections the procedure is described as it goes along so a reader has to work out what's going on while the detail is being described. It is better to give an overview first and then give the details. E.g. in this section state. "As an example we shall describe how MEMD is carried out on a simple periodic time series. We shall define 4 timeseries which have a shared angular frequency of pi/2 with other harmonics or phase shifts added on top. MEMD will be applied and should isolate this shared pi/2 mode. ..."

We have added text along these lines on l. 4-9 in the supplement.

Para line 196. This is a really important paragraph as it gives the motivation for the study. It needs to come way sooner in the paper.

This has been moved to the introduction, see l. 36-43.

Para line 220 – pull this out from the text for readers to refer back to. Present is as a list of steps.

We have now made a list of steps. See l. 173-183.

Line 234 – surely this is the index of the IMFs not the IMFs of the index? These aren't the same.

Technically the index is split into the IMFs, but is computed on spatio-temporal IMFs. We now use "an index for each IMF (e.g., IMF_s (SST (Niño3)) with s IMF-number)". See l. 197-198.

Figure 1 – be clear that the time series are of nino3 of the IMF, not the IMFs themselves. Confusion

We state that we have “timeseries of Niño3 index from IMF11, IMF12”. This is now Fig. 3.

Line 349 -

“Since we observe clear relationships between the relevant variables (e.g., Fig. 2) that strongly resemble a unified oscillator of Wang (2001a) (see also Fig. 5 in Wang 2018), recharge-discharge oscillator (e.g., Burgers et al., 2005), and others, we now revisit the theory of ENSO dynamics using the relevant conceptual oscillator models.”

line 379 -

“However, the results from section 3.1 suggest that the average evolution on 2-3 year (average) timescale is different from the unified model and many other oscillator models discussed in Wang (2001a).”

This highlights the confused motivation for using the MEMD to revisit the oscillators.

We have now omitted oscillators and the only motivation to use variables relevant for oscillators is to test ENSO dynamics in MEMD modes of variability. ENSO dynamics in its simplest form is related to conceptual ENSO oscillators. Additionally, as stated above we find some novel results. Hopefully text is clearer now. See the new section 6.