

## Response to Referee #2

We want to thank the three anonymous referees for the very thorough review of our manuscript. In particular, the comments helped us to better articulate the science question of the manuscript, and this hopefully resolves some of the major concerns. We shifted the focus of the paper from general low-frequency variability to multi-annual oscillations, and changed the title to “Multi-annual modes in the 20th century temperature variability in reanalyses and CMIP5 models”.

The comments led to substantial changes in the manuscript. One of the main changes is that we have made is the way the data sets are preprocessed. We have now used a common scaling factor for all the data sets in order to be able to compare the total spectra of the data sets (based on the reasoning of Referee #3). Because of this comment, we have recalculated all results and also made substantial changes to the text, especially in the section describing the Results. Re-calculation did not change the big picture, but the results are now much better justifiable, especially as there is now a new Supplement available.

Because of these substantial changes, we kindly ask the Referees to read the whole manuscript once again.

We hope that these and the changes explained below help to better convey our message. Below are our detailed responses to the reviewer #2 (In the following, our response to each comment is in red font, and the referee's comment in black).

### **(1) comments from referees/public**

1. Fig. 1 shows that the greatest variance is explained by decadal-multidecadal variabilities (after detrending). However, the decadal-multidecadal variabilities are not examined in this paper, including their spatial patterns and potential mechanisms as well as model biases.

### **(2) author's response**

The comment is exactly right: we did not provide many details about these slower modes although it would be very interesting to see some more details. The revised manuscript is even scarcer in this respect since due to the review comments, the scope is now firmly on multi-annual modes. We think the Referees' comments were justified (that there is no statistical significance in the results related to the slow modes) and followed the advice in scoping the manuscript anew. We only note briefly in the revised manuscript that the models behave quite differently regarding the variability in decadal and multi-decadal scales

### **(3) author's changes in manuscript**

These are changes throughout the revised manuscript due to the refined scope, especially in Section 3.3, 2nd para.

### **(1) comments from referees/public**

2. Table 2: Some of the periods identified by the RMSSA are very close to each other (for example, 2.2, 2.3, and 2.5; 3.5 and 3.6). It is unclear whether those identified periods truly represent significantly different physical modes or they could merely represent the artifacts of the RMSSA method.

### **(2) author's response**

Thank you for this remark which is now addressed in the revised text. The identified modes in the reanalysis data and CMIP5 models are quasi-periodic, meaning that the oscillation is wobbly and within some neighborhood of a given frequency. Thus, more than one frequency in this neighborhood will be identified as significant. This seems to explain Table 2 of the original submission. In addition, the method itself has a certain spectral resolution depending on the analysis window and temporal resolution of the original data set (monthly data in this case).

Based on the review comments, we realised that Table 2 is not very reader-friendly, and is now removed. The information is now incorporated in Figure 5 instead, which is more compact regarding the significant multi-annual periods. Figure S2 in the Supplementary material provides the test results exhaustively.

**(3) author's changes in manuscript**

Text has been changed (Section 3.4), Table 2 is removed and the information is incorporated in Figure 5. Supplementary material added.

**(1) comments from referees/public**

3. Figs. 1 and 3: In addition to ENSO, it will be useful to display the spatial patterns of other significant periods and examine the models' performance in simulating them.

**(2) author's response**

We totally agree with this comment. The snag with this option is that there would soon be an excessive number of figures. In the revised manuscript, we selected to visualize a mode that is simulated reasonably well by most models, and the 3-4 yr variability pattern was the best option for this purpose.

**(3) author's changes in manuscript**

New figures available in the Supplement.

4. Specific comments:

**(1) comments from referees/public**

a) Last paragraph of Page 1: Atmosphere's memory is too short to explain the signal with a period of 1.7 years.

**(2) author's response**

This is true. In the revised manuscript, the explanatory power of the 1.7 yr mode has become weaker, presumably because of the new normalization with the common variance, and the mode no longer pop up so dramatically. There is thus no longer discussion about this mode in the revised manuscript.

**(3) author's changes in manuscript**

Text removed about the 1.7 yr mode.

**(1) comments from referees/public**

b) First paragraph of Page 2: Ocean dynamics responsible for the decadal-multidecadal variabilities needs to be discussed.

**(2) author's response**

This is completely true. However, with the focus on multi-annual modes, the revised manuscript no longer have this issue.

**(3) author's changes in manuscript**

No action taken.

**(1) comments from referees/public**

c) Page 5, Line 19-20: Components 15-17 of ERA-20C appears to capture the decadal variability of ENSO.

**(2) author's response**

The visualisation of all modes would be very nice. The new normalization with the common variance

changed the results somewhat especially regarding the modes with low explanatory power. Therefore the components 15-17 of ERA-20C were affected.

**(3) author's changes in manuscript**

No action taken.

**(1) comments from referees/public**

d) page 7, Line 16-25: Replace "a warm pool" and "a cold pool" by "a warm anomaly" and "a cold anomaly"

**(2) author's response**

Thanks, this is now corrected.

**(3) author's changes in manuscript**

Text is corrected.