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Earth System Dynamics Discussions

Interactive comment on "On the time evolution of ENSO and its teleconnections in an ensemble view – a new perspective" *by* Tímea Haszpra et al.

Anonymous Referee #1

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The authors investigate changes in the ENSO phenomenon and its teleconnections using a recently proposed methodology (SEOF). ENSO is the most dominant interannual mode of variability in the climate system: studying changes in its amplitude and its impacts is then relevant to the scientific community. Differently from standard statistical methods in time series analysis, the authors used a new methodology, snapshot empirical orthogonal function (SEOF). SEOF is tailored for ensemble simulations: after a transient time, each member of an ensemble of simulations of a nonlinear dynamical system is believed to cover the distribution of states of the attractor. The authors exploit this to define a new notion of Empirical Orthogonal Function (EOF) along ensemble members, rather than along the time dimension. This methodology allows for the definition of "instantaneous" ENSO patterns. Here the authors consider as "instantaneous"

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Discussion paper

seasonal averages (JJAS and DJF) and proceed in analyzing (a) ENSO pattern and its evolution in time and (b) changes in teleconnections, using the proposed methodology. Changes in the spatial pattern of ENSO (quantified by a regression of the PC of the first SEOF mode on SST) are briefly examined qualitatively and quantitatively by linear fitting the regression maps. Interestingly, the largest changes in patterns are in the JJAS season rather than in DJF. Changes in amplitude of ENSO are also examined. In agreement with previous studies, the authors find an increase in variance of the PC1 and of the Niño 3.4 index. Finally, the authors use the proposed framework to investigate changes in the teleconnection patterns between ENSO and precipitations, using instantaneous and lagged correlations along ensemble members, rather than along the time dimension, and explore the changes of these correlations with time.

This is a well written, clear and interesting paper. Also, the application of the SEOF methodology on ENSO is new. I have some minor comments, mainly regarding the methodology.

(a) (a) The main strength of this methodology is that it allows to analyze large ensembles in a comprehensive and well defined way. Also this framework offers a route to examine teleconnections, disentangling climate variability and external forcing in a correct way. However, in my opinion, this does not mean that this method is definitively better than traditional time series analysis. Both this methodology and temporal statistics are useful for different reasons. Here some reasons:

- It is true that the choice of the time window is largely subjective. However, ENSO has a quasi-periodicity of 3 to 7 years and its teleconnections can be analyzed a 12-months range (e.g., ENSO leads the Western Indian Ocean with a lead lag of $\sim$3 months). I expect that, given a single member, time windows from 30 to 100 years of data would give robust results. If correlations between two basins, start changing when considering 30 or 100 years it can simply mean that the connections analyzed may not be "stable". This is possible in climate and can be a result of (i) local regime shifts in one of the two basins, causing qualitative changes in local dynamics and so in connections with other basins (see Dekker et al. https://www.earth-syst-dynam.net/9/1243/2018/esd-9-1243-2018.pdf or Klose et al. https://arxiv.org/pdf/1910.12042.pdf) and/or (ii) phenomena of chaotic synchronization between basins (please see this PRL paper from Duane and Tribbia https://pdfs.semanticscholar.org/cd01/9dacfa47fdc2d5b46e8d33dda956fae135b0.pdf). An example of a (possibly) unstable teleconnections is the leading from the Equatorial Atlantic to ENSO. For example, Falasca et al. (https://agupubs.onlinelibrary.wiley.com/doi/epdf/10.1029/2019MS001654) showed that this lead may exist only in certain decades (see Figures 18e, 18f for reanalyses and Figures 19e and 19f for two CESM members), possibly for phenomena of chaotic synchronization. In the case of this specific teleconnection choosing a window of 50 or 100 years would indeed give a different result, but not because of biases in the methodology but because this connection seems to change in time. Also, in the context of the CESM-LE it has been found at different times in different members, suggesting indeed a chaotic synchronization between the two basins.

- Traditional time series analysis (referred in the paper as “temporal statistics”) presents lots of desirable tools: (i) different measures of coupling between time series such as linear (e.g., Pearson correlation), nonlinear (e.g., Mutual Information), causal (e.g., PCMCI algorithm) and (ii) robust methodologies to assess statistical significance. This is possible if a large number of data points is analyzed. In the snapshot method, every measure of coupling and every test is constrained by the (very small) number of members of an ensemble. This is a limitation of the methodology since 40 members is still a (very) limited number of data points in the analysis.

- More importantly, all results of the snapshot methodology, live in model-land (see http://www.economics-ejournal.org/economics/discussionpapers/2019-23/file). In fact, in reality we have only access to one climate and we have no access to an ensemble. Therefore, the results that can be obtained using this methodology, while interesting, are always going to be constrained to the chosen climate model and its biases.

These points should be briefly discuss. Advantages and disadvantages of both the snapshot methodology and traditional time series analysis should be made clear. My view is that they are both useful and can complement each other, and not that one is definitive better than the other.

(b) Figure 2. Are the trends of the regression maps really linear? Was this checked? I would have expected to be linear in a time range of ∼30 years but not necessarily from 1950 and 2100. Can you please check two random time series in the ENSO region and in the Horse Shoe Pattern (the region with strong negative linear trend) in Fig. 2a and see the shape of the trend?

(c) Figure 3. Panels (b) and (e). It is interesting to see that while the explained variance of PC1 in DJF is relatively constant, this is not true for the season JJAS. In Figure 3b the explained variance of the PC1 experiences a steady increase from ∼45% to ∼60%. It could be interesting to analyze the second mode of the SEOF and see how it is changing. If this analysis would help in better understanding (or at least suggests an explanation) the increase in variance of the first mode I would recommend to add the analysis of the second mode in the appendix.

(d) Figure 5. Second line of the caption. Correct: DJF PRECT (b → DJF PRECT (b)

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