Reply to the reviewers' comments: Variability of Surface Climate in Simulations of Past and Future (esd-2019-92)

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April 16, 2020

Summary of changes

We thank both reviewers for their constructive comments and detailed reading. In response to the suggestions by two reviewers we have

- updated the plots, enhancing Fig. 6 and SFig. 1
- revised text throughout the manuscript to bring out key findings better, differentiate local and global, continental vs. oceanic variability changes and improve clarity
- enhanced the discussion on ENSO changes, temperature-precipitation relationships and potential hydroclimate constraints
- added three new supplementary figures to support the additional discussion
- corrected spelling.

A detailed response to the helpful remarks of the referees is given below.

1 Reply to the second reviewer

(Original report cited in italics)

Thank you for asking me to review paper: "Variability of surface climate in simulations of past and future" by Rehfeld et al. Do please accept my apologies for the delay in returning this review. Any high-quality paper on climate variability is useful, and to say the obvious, it is changes to inter-annual variability that could as much of an effect on society as background climatic changes. This paper provides quite critical information on how the climate system might evolve by a careful scanning across available climate model simulations. The Abstract is clear and captures what the analysis does. The paper builds on what is an under-utilised resource of paleoclimate simulations. The Reference list is

comprehensive, and that in itself makes the paper useful to the climate modelling community.
We thank the reviewer for this positive assessment.

A few comments: The research has been undertaken well, and so I can only really offer a few points which the authors might like to consider. (1) The decrease in local variability as global temperatures increase is always a fascinating feature of the climate system. This reduction also goes against much-perceived wisdom that a warmer world will be a more climatically-volatile world. The authors might like just to note that, possibly in the discussion?
Indeed, the findings at the global scale do contradict the intuitive expectation (rooted in the molecular physics of gases, perhaps, in the Maxwell-Boltzmann-distribution?). In the revised manuscript we will differentiate more strongly between the global and regional scales in the discussion, and will take up this suggestion.

(2) The approach taken is predominantly statistical, which is correct and proper. However, ultimately it would be nice to understand better the background physical processes behind all of the discovered correlations and features. This understanding is not easy when using outputs from climate models developed at research centres across the global, because it can be difficult to "get inside" the models for extra diagnostics. However, a few sentences saying that this analysis could trigger future investigations of the driving processes might help (and possibly with references). For instance, one suggestion is that lower sea-ice coverage in a warmer world will suppress yearly variations in temperature – fitting with the findings of this paper. Other authors have investigated "teleconnections" between the key oceanic forcings and related adjustments to meteorology over land areas. Some of these authors will have offered how atmospheric advection has a role to enforce such connections.
We absolutely agree with the reviewer in that a better understanding of the physical mechanisms of changing climate variability is crucial to understand our results. Some research on this exists, but a conclusive view across regions, seasons and timescales is difficult. On interannual timescales, sea-ice extent has been shown to correlate with global temperature variability (Huntingford et al., 2013). However, it remains unclear whether this would remain to be the case if a summer-ice-free Arctic has been reached, and how it influences low-latitude climate variability. A key role from the seasonal (Holmes et al., 2016) to the millennial (Rehfeld et al., 2018) timescale is certainly played by the meridional temperature gradients that modulate atmospheric flows. However, due to the turbulent nature of the atmosphere changes to the contributions of latent and sensible heat transport to mid-to-high latitude temperature variability are difficult to assess (Schneider et al., 2015). Therefore, as the reviewer notes, better understanding of the background physical processes behind the correlations and features is required. Our analysis and results therefore clearly calls for extending future research on the driving processes of variability changes. We add this

to the discussion and conclusion of the manuscript.

3) As so much of this paper describes common features between Earth System Models, then maybe at least some sort of mention should be made of the Emergent Constraint (EC) technique? ECs could potentially use the discovered inter-model agreements, in tandem with any additional contemporary measurement, to constrain future projections? Just a sentence or two hinting at this might be useful.
This a good suggestion that we will adopt in the revised manuscript. There have so far been few examples of variability-based observational constraints (e.g., Cox et al., 2018). We will add this idea as motivation in the introduction, and then return to the theme in the discussion.

(4) There are substantial sets of paleo measurements that are rarely used by the climate modelling community. Again, maybe for Discussion, but this paper, with its thoughtful aligning of both paleo and future climate simulations, illustrates their huge potential to constrain climate projection. In other words, if the past can tell us more about the future (e.g. Figure 1, hydrological sensitivity is a valid statistic both for the past and the future), then any past records of simultaneous precipitation and temperature estimates provide valuable extra information.

Again this is very useful comment. It is something that we have started thinking seriously about. Highlighting the potential in our revised discussion will not only make the manuscript stronger, but help motivate our own future research. There are some methodological issues that need to be resolved before it can be deployed in earnest though. Crucially, obtaining joint (or closeby) and robust estimates of temperature and precipitation from proxy data is a fundamental challenge (Rehfeld and Laepple, 2016; Rehfeld et al., 2016).

(5) One thing I especially like about the manuscript is the emphasis on oceanic modes of variability (ENSO, IPO, IOD etc). And this is obviously important given the paper is about variability. The authors will know (i.e. in numerical code) where the boundaries are. Would it be appropriate to give a map somewhere, with each of the oceanic modes of oscillation marked? Most will know where ENSO is, but some of the others are less well known.
We agree with the reviewer that both atmospheric and oceanic modes of variability are important to consider. We have provided Supplementary Fig. 1 with the boundaries of the modes, and will highlight it in the manuscript revision.

(6) Do please work through the paper checking clarity. In general, the manuscript reads well, but in some places, it takes time to fully appreciate the analysis, along with a risk of ambiguity. In addition, the captions should be self-contained. As an example, the Caption

for Figure 5, it takes some time to realise that the key point is for each location (as in the subplot headers) corresponds to high rainfall amounts The vague "selected regions" should be expanded more. Or even mark the epic-centre of each region with an annotated arrow for instance.
We have modified the caption. We also note that here, as in the original submission, the regions are marked by green boxes. Furthermore, we worked through the manuscript again to ensure each figure/caption is more self-explanatory.

(7) Some sentences are difficult to read. For instance, in the Conclusions "Global mean precipitation increases with temperature from cold to as-warm-as-preindustrial to warm scenarios.". Maybe better something like: "Modelled global mean precipitation is found to increase as global temperatures also increase. This finding is valid for simulations from pre-industrial periods into a future warmer world, as adjusted by the burning of fossil fuels. However, our paleo-simulations also show this finding to be true, in the transition from colder periods to the warmer period at the beginning of the industrial revolution".

We thank the reviewer for the detailed reading and this suggestion. We will re-phrase this sentence in the revision and are checking through the entire manuscript again to ensure more clarity.

(8) The diagrams are good and informative, but a little attention to formatting and detail could turn them into something exceptional. Just check the basics, such that in each, all annotation are clear and in sufficiently large font size. Figure 6, make it standard format - so remove the dotted lines maybe?

Thank you for this suggestion. The revised version of Fig. 6 follows a more standard aspect ratio, includes boxes around the panels and consistent label sizes.

References

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