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Reply on RC1

Nicholas L. Tyrrell et al.

Author comment on "Sudden stratospheric warmings during El Niño and La Niña: sensitivity to atmospheric model biases" by Nicholas L. Tyrrell et al., Weather Clim. Dynam. Discuss., https://doi.org/10.5194/wcd-2021-62-AC1, 2021

General comments:

This study investigates whether atmospheric bias correction in a climate model can improve the representation of SSWs, in particular during ENSO. Detailed analyses were performed on both reanalysis and model runs. The authors were able to demonstrate the benefits of a more realistic atmospheric climatology in better SSW simulations. This study also stressed again the uncertainty in the ENSO-SSW relationship based on limited reanalysis data. I have just a few major concerns. In addition, the way information is conveyed can be clearer at times, which I have also suggested below.

Specific comments:

L155-162: In ERA5, the ENSO SST anomaly varies seasonally. But in the experiments, the ENSO SST anomalies "were kept constant in time i.e. the anomaly did not vary seasonally (L85)". Is this the reason why the experiments do not show enough seasonal variation in SSWs compared to ERA5 (L157)?

Thank you for the excellent question, this is something that we have considered but we don't think it's possible to fully answer with the current set of experiments (or with the amount of observational data available). We would need a separate set of experiments with an evolving ENSO pattern, which would certainly be interesting data to analyze but is beyond the scope of this paper. However, while we can't comment on the role of ENSO variability and SSW seasonality, we can say that the SSW seasonality in our model is already too low, even without the constant ENSO signal. For example, take the neutral years and control experiments in Figure 5, where there are too many SSWs in November, and too few in Jan/Feb. So, while we can't say whether an evolving ENSO pattern would improve SSW seasonality, we can say that SSW seasonality is already too low in our model.

We have added the following text to state this point more clearly:

"Note that the model does not have a seasonally evolving ENSO pattern which may affect the seasonality of SSWs in the ENSO experiments but not in experiments with neutral ENSO conditions which have seasonally evolving SSTs. Yet the neutral ENSO experiments

similarly lack seasonal SSW variations."

L170: But there are clearly regions of red in the troposphere in Fig 5 (e,h,k,n), so I am unsure why the authors say that "this corresponds to a slightly weaker tropospheric response".

We agree our interpretation of the effect of El Nino on the tropospheric and surface response is not correct for all experiments. To see this quantity more clearly we've added a figure (Figure 7). It shows the composite time-average Zcap for 30 and 90 days after an SSW. Looking at those plots we can say that the polar cap tropospheric response to SSWs is weaker during El Nino years in the CTRL and FullBC experiments, similar in TropBC and in fact slightly stronger in the StratBC experiment for the 30 day mean. We have added text to describe this.

L180-181: I agree that "the negative AO pattern is stronger in La Nina experiments for the FullBC and StratBC runs", but I am unsure about the next sentence "which relates to the stronger stratospheric Zcap response in Figure (5) i and o". The stratospheric Zcap response in CTRL_LN (Fig5f) is also stronger, yet the projection onto the AO pattern isweak (Fig6f). So I am unsure if the AO response is related to the stratospheric response in a simple way. Meanwhile, the tropospheric response in CTRL_LN (fig5f) 30 days after SSW is weaker than that in FullBC_LN (fig5i) and StratBC_LN (fig5o), which is consistent with the results in Fig6(f,i,o), as it should be because these are two ways of looking at the same picture.

Thank you for the comment, we agree our initial interpretation is too simplified. To better see the relationship between Zcap and the SLP responses we have added a figure (Figure 7, also discussed in the previous reply) of the composite mean Zcap response for the 30 and 90 days after an SSW, so, similar to Fig. 8 but as a function of height. The figure shows the values for neutral/El Nino/La Nina years, and also the values of El Nino/La Nina relative to neutral years (i.e. the change in the composite SSW response due to ENSO). The results are also qualitatively similar for 90 day means after SSWs (with the exception of the StratBC tropospheric La Nina response). All models show a stronger stratospheric Zcap response in La Nina years and weaker in El Nino. But indeed, as you note, the magnitude of the stratospheric anomalies does not correspond neatly to the tropospheric and surface response. We have edited the text as follows:

"The negative AO pattern is stronger in La Niña experiments for the FullBC and StratBC runs. These runs both have a stronger La Niña stratospheric Zcap response (Figure 6 i, o, and Figure 7 h, j), however, there is not a linear relationship between the stratospheric ENSO response and the surface response. TropBC has a smaller La Niña stratospheric response and surface pressure response (Figure 8 l), but CTRL has a large stratospheric La Niña response (Figure 6 f and Figure 7 g) without a surface pressure response (Figure 8 f)."

L253: But as concluded in L215, "there is a smaller improvement (in the number of SSWs) in the StratBC runs, despite the improvement in the strength of the vortex being similar to FullBC". So I am not completely convinced that the authors have shown that "improvements to the strength of the polar vortex can improve the SSW statistics of a model in relation to the number of SSWs per year" in L253. Similarly in L13-14.

To answer this question we have performed Monte Carlo simulations, in order to estimate the significance of the difference between the number of SSWs in each experiment. This analysis showed, as you suggested, that bias corrections of the polar vortex alone is not sufficient to improve SSW statistics, and there is no improvement of SSW statistics in StratBC despite the improved strength of the polar vortex. It does show more clearly that the FullBC corrections improve SSW statistics for neutral and El Nino years, and capture the ERA5 statistics for all experiments. Note that, the observed SSW statistics for La Nina years is captured in all experiments, including CTRL. We have added the figure (Figure 4), edited the text in the abstract and conclusion, and added a description in section 3.2.

Technical comments:

L1: Can be more specific about what kind of model bias is being investigated e.g. "sensitivity to model atmospheric biases" instead of, for example, bias in the ocean which is not investigated.

Agree, changed

L55 and L242: heat flux

Changed

L82: maybe briefly explain why only the Pacific SST anomalies are chosen, whereas ENSO is associated with SST anomalies in other ocean basins too.

Good point, the main reason was to reduce the complexity of the forced signal, text and reference has been added.

L93: statistical significance

Changed

L148-150: the values do not agree exactly with those in the third column in table 1.

Changed

L164 and subsequent lines: Should be figure 5 instead of 4. Similarly in L181 and L182.

Changed

L218: Any examples of parameterisation?

Yes, specifically orographic and nonorographic gravity wave drag. Text and citation added.

L370 Fig1: it should be (d) not (c). Also, maybe include a description of the dotted and bold lines in the caption as in L118.

Changed, and description added to text.

L390 Fig4: Are there no SSWs in November in ERA5?

According to, for example, Butler et al. 2017: A sudden stratospheric warming compendium, there have been SSWs in November 1958 and November 1968, but no November SSWs for the ERA5 period 1979-2019.

Butler, A. H., Sjoberg, J. P., Seidel, D. J., & Rosenlof, K. H. (2017). A sudden stratospheric warming compendium. Earth System Science Data, 9(1), 63-76.