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Interactive comment on "Nonlinearity in the Tropospheric Pathway of ENSO to the North Atlantic" *by* Bernat Jiménez-Esteve and Daniela I. V. Domeisen

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Summary:

The study addresses the tropospheric pathway of ENSO via the North Pacific to the North Atlantic using an idealised atmospheric model. They isolate the tropospheric pathway by relaxing stratospheric winds towards climatology and impose linearly increasing SST anomalies in the equatorial Pacific to simulate different magnitude El Niño and La Niña events. The study focuses on the role of quasi-stationary and transient waves for the propagation of the ENSO signal across North America and into the North Atlantic. While a nonlinear and asymmetric North Atlantic SLP response to

ENSO has been previously reported in the literature, the authors found that only their strong El Niño experiment produces a response that resembles a negative phase of the NAO, whereas similar SLP responses are observed for moderate and strong La Niña events, which are of comparable magnitude to the response to moderate El Niño events. The manuscript is clear and well written and reaches substantial conclusions that add knowledge to this area of study. The analysis of the model experiments is thorough and supports the main findings.

I do have some suggestions that I believe would clarify the interpretation of the results. The relationship between the Aleutian low and the North Pacific does not appear to entirely explain the North Atlantic response simulated in the model, and therefore my suggestion is to explore other routes of the tropospheric pathway of the ENSO-North Atlantic teleconnection such as the Caribbean Sea and the tropical North Atlantic. This would also help to put the results into the context of other recent studies focusing on the Caribbean Sea.

I consider the article suitable for publication in Weather and Climate Dynamics after clarifying and strengthening your argument on the comments below.

Recommendation: Minor revisions

General comments:

1. The study is explicit that it focuses on the North Pacific influence on the North Atlantic, but several studies highlight an important role for the tropospheric pathway via the tropical Atlantic (e.g., Toniazzo and Scaife, 2006; Hardiman et al., 2019; Ayarza-guÌĹena et al., 2018). Though some discussion of this broader issue is given in the Conclusions, how important is the tropical Atlantic for the interpretation of the model results shown here? A tentative hint is given on line 265, but in my view the conclusions would be strengthened if this was made more explicit. Can you explain all of the North Atlantic/European response with the mechanisms put forth in section 6? If the model does not simulate a pathway via the Caribbean Sea is this a limitation of the

model? Or are there limitations of other studies that have argued for an important role for the tropical Atlantic pathway, e.g. they have neglected the North Pacific downstream effects?

2. Please be more consistent in the use of “linearity” and “asymmetry”. I would suggest referring to “linearity” when you describe the dependence of the response on the magnitude of an ENSO event within the same phase (El Niño o La Niña), whereas when talking about asymmetry you compare the response to El Niño to the response to La Niña and assess whether the response to each ENSO phase is similar but opposite in sign. For example, Figures 5a) and b) shows asymmetry whereas Figures 5c) and d) shows nonlinearity.

Specific comments:

Lines 27-35 - For the non-expert reader it might help to include here a brief synopsis of what we know about the observed surface climate response to ENSO in Eurasia (temperature, precipitation).

Line 28 - Suggest adding reference (e.g. Li and Lau 2012) Li, Y., and N.-C. Lau, 2012: Impact of ENSO on the atmospheric variability over the North Atlantic in late winterâĂŤ-Role of transient eddies. J. Climate, 25, 320–342, https://doi.org/10.1175/JCLI-D-11-00037.1

Line 30 - I think Bell et al. (2009) were earlier than these papers to distinguish the role of stratospheric and tropospheric pathways using experiments similar to those presented in this manuscript. I therefore suggest replacing these references or at least adding Bell et al. (2009).

Line 37 - Again, Bell et al. (2009) showed the influence of El Niño on SSWs before this paper.

Line 39 - Please keep the same methodology to determine the order of your citations, e.g. alphabetical, chronological or by degree of importance for supporting the previous

sentence.

Line 42 - You can reference here Table 2 of Trascasa-Castro et al. (2019) who provide a meta-analysis of studies of SSW changes under ENSO.

Line 43 - “longer time series” is vague - longer than what? The current reanalyses? What would constitute “long enough”?

Line 55 - Also Bell et al. (2009). Note also that Toniazzo and Scaife (2006) used a model that couldn’t reproduce the stratospheric pathway of ENSO to the North Atlantic. A more recent reference that reaches a similar conclusion using a well resolved stratosphere model is Hardiman et al. (2019):

Hardiman, S. C., Dunstone, N. J., Scaife, A. A., Smith, D. M., Ineson, S., Lim, J., & Fereday, D. (2019). The impact of strong El Niño and La Niña events on the North Atlantic. Geophysical Research Letters, 46, 2874– 2883. https://doi.org/10.1029/2018GL081776

Line 60 - To distinguish from subtropical jet suggest: tropospheric = eddy-driven.

Lines 116-118 - I suggest strengthening the argument for why you impose opposite in sign but identical spatial pattern of SST anomalies. Garfinkel et al. (2018=the salience of nonlinearities…) suggested that the location of SST anomalies have a large influence, but as you said in Jimenez-Esteve and Domeisen (2019) the magnitude has a larger effect on the teleconnection than the spatial location of SSTs, and that’s what you want to know.

Lines 134-136 - A bit more on how the nudging affects the tropospheric variability changes (or not) in the set-up used here would be helpful as compared to the control model. e.g., are there changes to the major modes of variability that go on to be assessed (e.g., amplitude of the NAO) and/or the tropospheric jet decorrelation timescale?

Line 183 - In agreement with Bell et al. (2009), Cagnazzo and Manzini (2009).

Line 186 - Is stronger than "is more than" and covers a larger area. That's really asymmetry rather than nonlinearity.

Line 186 - Refer to Figure 5 as well as to Figure 2d.

Line 192 - I don't see negative SLP anomalies in the North Atlantic as a response to moderate El Niño. I would rather say that moderate El Niño events only affect the Northern lobe of the NAO by leading to positive SLP anomalies of similar magnitude to strong El Niños. The SLP pattern shown in this work for strong El Niño (Fig. 2a) resembles the pattern shown by Toniazzo and Scaife (2006) in figure a20, correspondent to the El Niño event of 1998 which had a Niño3 SST anomaly of $\sim$2.7 K. Out of 20 events they examine, this is the only situation where positive SLP anomalies in the North Atlantic extend to Europe and negative SLP anomalies dominate in the southern lobe of the NAO (weakening the Azores high).

Lines 194-5 - A more detailed comparison of Figure 2a and 2b with Bell et al (2009) Figure 10 and Figure 11 middle right and lower right panels would also be helpful here as their experiments are for moderate and strong El Niño forcing with a degraded and relaxed stratosphere. There are some differences in your results, for example the location of the positive SLP anomaly in the North Atlantic in the moderate EN case; it would be instructive to the reader to discuss these more carefully as the comparison is very similar to your experiments.

Lines 208-220 - For a "pure" NAO- signal, one would expect the low-level Atlantic jet to shift south. For the experiment with the strongest projection onto NAO-, the strong EN case, the jet weakens rather than shifts (Fig 3a). For the weaker projections onto the NAO in the moderate EN and LN experiments the NA jet shows more of a shift. It therefore seems that the NAO does not fully explain the NA jet behaviour and low-level temperature patterns in the simulations. Have you thought about examining the East Atlantic pattern to see whether the response projects onto that mode (Figure 2b)?

It also seems (lines 216-219) you are saying to response is not barotropic, whereas a

pure internally generated NAO signal would typically shown an equivalent barotropic structure. Relevant to this point is the study by Mezzina et al (2020) so I suggest you include that as part of this discussion:

Mezzina, B., J. García-Serrano, I. Bladé, and F. Kucharski, 2020: Dynamics of the ENSO Teleconnection and NAO Variability in the North Atlantic–European Late Winter. J. Climate, 33, 907–923, https://doi.org/10.1175/JCLI-D-19-0192.1

Line 216 - Only a weak strengthening for La Niña.

Line 220 - Add references: Ineson and Scaife (2009), Cagnazzo and Manzini (2009).

Lines 223-225 - "For example, the weaker baroclinicity during strong EN tends to weaken the climatological Icelandic low, whereas the strengthening of the meridional temperature gradient during LN can be linked to the intensification of the Icelandic low and 245 the associated near surface westerly winds (Figure 3c,d)."

There is some nonlinearity here between baroclinicity anomalies over North America and the strength of the Icelandic low: For that specific low pressure system, and ignoring now the Azores high, baroclinicity anomalies are double in magnitude in strong ENSO events, whereas the strength of the Icelandic low seems the same in the moderate and strong events. Why is that?

Line 255 - Wave train pattern in figure 5a? Is a Rossby wave source anomaly plot necessary to identify possible sources in the Caribbean that might explain this NAO pattern?

Line 258 - There are other mechanisms through which ENSO can affect the NAO besides the one proposed in this study. In order to be able to explain the anomalous winds and temperature anomalies associated with both moderate and especially strong El Niño events, more analysis is necessary. I would suggest to plot Rossby waves source anomalies as well as SLP response by months to look for a non-stationary NAO response.

Garcia Serrano (2017) (https://doi.org/10.1175/JCLI-D-16-0641.1) studies the lagged ENSO-Tropical North Atlantic relationship which consist on a Gill-type response associated with a perturbed Walker Circulation. In your experiments SST are fixed so you cannot look at a lagged SST response in the TNA but you could look at the lagged SLP response in the North Atlantic, month by month as in Bell et al (2009) or Trascasa-Castro et al (2019) to see if there is any differences in the SLP response in the North Atlantic in late winter that might suggest an influence of the ENSO-TNA teleconnection as well as the ENSO-PNA teleconnection that you have described in your article.

Line 268 - Those studies suggest the dominance of the tropospheric pathway for strong EN is due to a saturation of the stratospheric pathway. However, in Hardiman et al (2019) their weak El Nino case shows a less active stratospheric pathway than observations which may highlight as issue with their approach. Trascasa-Castro et al (2019) showed the stratospheric pathway may not saturate for strong EN and hence there is still some debate around the proposed "saturation mechanism" which you should mention here.

Line 277 - I think this is a non-standard definition of the NAO index (neither station based nor EOF based). What are the implications of averaging over such a large area to calculate the NAO index rather than using Iceland and Azores?

Line 279 - Difficult to compare these (DJFM) with Fig 2 (DJF)

Lines 291-292 - I see what you are talking about, but is it partly a plotting issue? The amplitude of North Atlantic anomalies in Fig 6a is smaller than in 6b and you white out values <|0.5|hPa. If you add another contour does the dipole appear to extend further to Europe?

Lines 294-295 - Can you comment on whether there are changes to the shapes of the pdfs? It appears there might be so you could mention higher order moments than the mean if the differences are significant.

Line 293 - These other mechanisms could include the stratosphere but also the tropical Atlantic pathway; more analysis is needed to fully explain the positive SLP anomaly over Europe.

Line 303 - I don't agree that Fig 2b) shows that moderate EN projects onto a negative phase of the NAO. It might weakly project onto the NAO index as defined here, but it also looks like a blocking pattern.

Line 307 - Response might be lagged.

Line 314 - Is it remarkable? You did run the model for 80 years to get a high signal-to-noise ratio!

Line 316 - Trascasa-Castro et al. (2019) also show this result for the NAO so please add citation.

Lines 400-410 - While this synthesis of studies is useful some key points are missing:

âĂć Hardiman et al (2019) use ensemble of seasonal hindcasts, so the experiments are initialised and are individual ensemble members for only a few observed ENSO cases. This is a very different approach to the other atmospheric model studies described so is worth highlighting.

âĂć Rao and Ren (2016a) uses observations so is beset by small sample sizes, as you highlight as an issue on line 77

âĂć Weinberger et al (2019) use experiments with observed SSTs so their results capture differences in ENSO magnitude and pattern while this study, Rao and Ren (2016b) and Trascasa-Castro et al (2019) remove differences in pattern through an idealised experiment design.

Some editing of this paragraph to better clarify the above points would be helpful.

Lines 412-413 - Also likely to be important for determining how important the tropospheric and stratospheric pathways are would be the model's climatology in the stratosphere, e.g. Bell et al (2009) used a model with relatively few SSWs and Toniazzo and Scaife (2006) used a low top model with weak stratospheric variability.

Lines 432 - Add reference Rodriguez-Fonseca et al. (2016).

Lines 433 - Again mention this relies on a saturation of the stratospheric pathway for strong EN and it is still an open research issue as to whether this would occur. Even if the stratospheric pathway saturates at some point, its effect should no disappear altogether at strong EN as the results of Bell et al (2009) in their damped stratosphere case suggest.

Technical Corrections:

Line 17 - Define SST acronym in main text

Line 44 - “On average, Arctic stratospheric anomalies ...”

Line 59 - lead = leads

Line 74 - Therefore, the tropospheric pathway for ENSO impact

Line 152 - Previous = prior

Line 201 - Remove "do"

Line 314-315 - Remove “Figure 7 also serves to illustrate the large internal variability in the extratropics” = repeated sentence.

Line 321 - dominantly = predominantly

Line 401-402 - Replace “an state-of-the-art seasonal prediction model” with “atmospheric model” – the model is HadGEM3 which is in the same family as GloSea5 but run in a different configuration.

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