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Discussions

Interactive comment on "Assessment of responses of North Atlantic winter SST to the NAO in 13 CMIP5 models on the interannual scale" *by* Yujie Jing et al.

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We would like to thank the reviewers for their time and efforts spent on reviewing our manuscript, and giving us good suggestions. We have carefully thought about these suggestions, and made a lot of changes to the article. Some new figures have been added, including some new analysis, and some inappropriate descriptions have been corrected. We have re-analyzed the influence of the NAO-driven SHF / LHF / surface seawater meridional velocity on SST and changed the time period of the analysis. We also have discussed the influences of the cutoff period of band-pass filter, different definitions of the NAO index, initial fields and external forcing of the historical experiments

on the results. All the changes are highlighted in the revised manuscript.

Responses to anonymous reviewer's comments point by point:

Reviewer #2:

General Comments

This manuscript shows that in several CMIP5 historical runs, the wintertime seasurface temperature (SST) response to the North Atlantic Oscillation (NAO) is not consistent with observations, on interannual timescales. The authors demonstrate that some models that exhibit this discrepancy fail to reproduce the observed relationship between SST and turbulent heat ïňĆuxes (TFH), particularly in the subpolar gyre. They attribute this to an over-inïňĆuential ocean. Most models examined here correctly produce the interannual NAO-SST relationship in the subtropical Atlantic because of the larger inïňĆuence of Ekman forcing. 1 Do the results show model dependence or sensitivity to initial conditions? I think readers will find the results to be more convincing if the authors could rule out dependence on initial conditions in the NAO – SST relationship. One way of doing this might be to look at a single-model large ensemble (e.g. ; Kay et al. 2015). For unfiltered output, it seems like the authors' results should hold (http://webext.cgd.ucar.edu/Multi-Case/CVDP_ex/cesm1.lens_1920-2018/nao.tempreg.djf.png) – but is that still true when bandpass filtered?

Reply: Thank you for the suggestions. Kay et al. (2015) mentioned that the ocean initial conditions can influence multi-century coupled climate model runs, so whether the CMIP5-ESMs sensitivity to initial conditions is worth exploring. We have compared the relationship of the NAO and SST simulated by the models in different experiments which were initialed from different integrated time of piControl experiments (eg., r1i1p1 and r3i1p1) (P28-29, L481-496), and found that "but it should be emphasized that the influence of the initial conditions on the result needs to be considered in the evaluation of some individual models" (P29, L495-496)

2. If the results show model dependence, how do the different models responses to historical forcing influence your results? On line 321, the authors note that the NAO has a negligible response to shortwave radiation – but shortwave radiation does affect SST. Can we be sure that the SHF and LHF are not responding to externally-forced changes in SST over this twentieth century, with the NAO being a bystander? In other words, if the models are responding in different ways to historical forcing, is that alone enough to change the relationship between the NAO and SST/SHF/LHF? One way to address this question may be to look at pre-industrial control runs of the same CMIP5 models the authors already examine.

Reply:The relationships of the NAO and SST / SHF / LHF simulated by pre-industrial control runs of the 13 CMIP5-ESMs are analyzed (Figs. S13-14). The results of pi-control experiments by the same models are very similar with those of historical experiment (r1i1p1), but there are some differences in the intensity of the response of the SST/SHF/LHF to the NAO between different experiments. We have also added this part to the discussion section. (P29-30, L497-510)

3. Can the authors make causal claims based on band-pass filtered output? Cane et al. (2017) show that it is difficult to make causal claims about the sign of the relationship between heat fluxes and SST based solely on low-pass filtered data. I think that to show the causal relationship that is described in-text, it would be useful to also present unfiltered/annual average/wintertime average plots so that readers can be sure that the relationships shown are not an artifact of filtering. If the unfiltered results are similar, Ithink that is worth mentioning in-text.

Reply: Thank you for the reviewer's suggestion. We have done regression analysis of unfiltered winter average SST anomalies and NAO indexes / NAO-driven SHF / LHF anomalies and found that the patterns of observed and simulated unfiltered relationship of the NAO and SST by most of models are consistent with the filtered results (Figs. S7-8). The difference between the filtered and unfiltered results is discussed in Section 5.2 (P25-27, L437-458).

Specific Comments:

Lines 41 – 45: The wording and structure here is a bit too close to Deser et al. 2010 (page 119). Please edit.

Reply: Following the reviewer's suggestion, we have rewritten those sentences. "During the positive phase of the NAO, the westerly winds in the subpolar NA and the northeast trade winds in the tropical NA are strengthened, which causes the increased turbulent heat flux from the ocean to the atmosphere, while in the middle latitudes of the NA wind speeds are weakened, which causes the reduced turbulent heat flux out of the ocean" (P3, L37-40).

Line 46 – 48: I would recommend re-wording to emphasize that the "uniform SST warming" occurs after the NAO+ in observations and pre-industrial control runs of climate models (see Delworth et al. 2017). Further, I would caution that this mechanism is not established as causal in observations (e.g. Buckley and Marshall 2016).

Reply: Thanks for the reviewer's recommendation. We have rewritten these sentences to "After the positive phase of the NAO, some studies based on models suggest that, the Atlantic meridional overturning circulation (AMOC) is intensified, and the strengthened meridional heat transport associated with enhanced AMOC leads to broad scale SST warming (Sun et al., 2015, Delworth et al., 2017). Compared with other seasons, this phenomenon is more obvious in winter (Flatau et al., 2003; Bellucci et al., 2006), and probably occurs on the interdecadal and multidecadal scales (Eden and Jung, 2001, Gastineau et al., 2012). It should be noted that because there is a lack of long-time AMOC observations and the AMOC plays a more active influence on the change of SST on the long timescale (interdecadal and multidecadal scales), observational studies have not successfully linked the SST changes to the AMOC variability (Buckley and Marshall 2016)." (P3, L41-48)

Sun, C., Li, J. P., and Jin, F. F.: A delayed oscillator model for the quasi-periodic multidecadal variability of the NAO, Clim. Dyn., 45(7), 2083-2099,

https://doi.org/10.1146/10.1007/s00382-014-2459-z, 2015.

Delworth, T. L., Zeng, F. R., Zhang, L. P., Zhang, R., Vecchi, G. A., and Yang, X. S.: The central role of ocean dynamics in connecting the North Atlantic Oscillation to the extratropical component of the Atlantic Multidecadal Oscillation, J. Clim., 30(10), 3789–3805, https://doi.org/10.1175/JCLI-D-16-0358, 2017.

Flatau, M. K., Talley, L., and Niiler, P. P.: The North Atlantic Oscillation, surface current velocities, and SST changes in the subpolar North Atlantic, J. Clim., 2355-2369, https://doi.org/10.1175/2787.1, 2003.

Bellucci, A., and Richards, K. J.: Effects of NAO variability on the North Atlantic Ocean circulation, Geophys. Res. Lett., 33(2), L02612, https://doi.org/10.1029/2005gl024890, 2006.

Eden, C., and Jung, T.: North Atlantic interdecadal variability: oceanic response to the North Atlantic Oscillation (1865-1997), J. Clim., 14(5), 676-691, https://doi.org/10.1175/1520-0442(2001)0142.0.CO;2, 2001.

Gastineau, G., D'Andrea, F., Frankignoul, C.: Atmospheric response to the North Atlantic Ocean variability on seasonal to decadal time scales, Clim. Dyn., 40(9-10), 2311-2330, https://doi.org/10.1007/s00382-012-1333-0, 2012.

Line 64: Please clarify that Wang et al. (2014) found the NA SST was "underestimated" and "unreasonable" relative to observations (i.e. biased).

Reply: We have clarified the content in the revised version: "Wang et al. (2014) evaluated the global SST simulated by the CMIP5 models and found that the SST in the Northern Hemisphere, especially in the NA, is underestimated relative to the observation, and pointed out that it is mainly caused by the weaker AMOC and shallower AMOC cell compared to the observations.". (P4, L63-66)

Lines 157 – 160: So, the NAO centers of action are stable with time in models, but not observations? I think that's interesting! That figure might be worth including –especially

if your later results can explain it. It could be instructive about models.

Reply: This figure has been added to the supplement (Fig. S1). We regret that we haven't found the cause of this situation, so we have not added the figure in main text. We will continue to study this in the future.

How sensitive are these NAO "spectral peaks" to the authors choice of dataset? How sensitive are they to the time period analyzed? I'll admit, my understanding of the spectral properties of the NAO index is heavily influenced by Wunsch (1999) – so my guess is that the red bands in Fig 3a will move around a bit. If they do move, it is worth asking, how do the authors' results change for different filter cutoffs?

Reply: We have tested the sensibility of the periods of the NAO indexes to dataset and the time period analyzed in Jing et al., (2019). For example, the period of the NAO index provided by NOAA in 1950-2017 is 2.3-2.7 and 6 years, and that provided by NCAR in 1865-2017 is 2.3–2.7, 4.5 and 8.3 years. In this manuscript the period of the NAO index provided by NCAR from 1965 to 2015 are 3, 4.8, and 8-10. Therefore, the period of the NAO index is slightly different in different dataset or time range. According to this, we agree with the reviewer's suggestion to test how the results change with different filter cutoffs. We have done regression analysis of winter average SST anomalies and NAO indexes on the interannual scale calculated by 2-4 year filtering , and found that the observed and simulated values of the RCs and their patterns of the SST against the NAO based on 2-4 year filtering are close to the results based on 2-6 year filtering, so we think that the influence of the cutoff period used in the filter can be ignored (Fig. S9). (P27, L459-470)

Figures: I found the figures a bit too small to see details. If possible, please increase the size/resolution of the images. Thanks!

Reply: Sorry about that. We have improved the resolution of the figures, and some information such as spatial correlation coefficient and root mean square error has been enlarged.

Figure 6: Is this a pixel-wise regression or a regression that takes place at each grid point? I assume, but please clarify in-text. Figure 8a: Same as Figure 6

Reply: Yes, the regression takes place at each grid. We add a sentence "The regression and covariance are performed with the standardized variables, for which the regression is conducted at each grid." (P7, L109-110)

Technical Comments:

Line 16: Please clarify the word "obvious".

Reply: We have rewritten the abstract, so this sentence was deleted.

Lines 21-23: For readers of the abstract, please clarify whether the authors are referring to "meridional advection" by ocean currents (e.g. Ekman) or winds (e.g. southerly component alongside eastern North America).

Reply: Done. The meridional advection means ocean currents.

Line 28: I don't think I would consider the NAO an "event".

Reply: Thanks for the reminder. We have rewritten this sentence to "There is a strong inverse relationship between Iceland's and the Azores' monthly mean sea level pressure (most significant in winter) in the North Atlantic (NA), which is called the North Atlantic Oscillation (NAO) (Walker, 1924)" (P2, L26-27)

Line 40: I recommend changing "period" to "phase" since so much analysis of the NAO takes place in frequency-space.

Reply: Done.

Lines 59 – 60: Please clarify the sentence containing "CMIP5-ESMs".

Reply: The CMIP5-ESMs means the CMIP5 Earth System Models. We have changed "CMIP5-ESMs" to "CMIP5 models"

Line 88: You refer to "sea water Y velocity data" as "sea-surface meridional velocity"

later in the paper. I think meridional velocity is a bit more clear – I would recommend using throughout.

Reply: We use "sea-surface meridional velocity" throughout in the revision.

Lines 101 – 104: Please clarify where the stations are for the station-based NAO index.

Reply: We have clarified in section 2.2. 'The site-based observation-based NAO index is the difference of standardized sea level pressure between Lisbon, Portugal and Stykkisholmur / Reykjavik, Iceland' (P7, L111-113)

Lines 116 – 117: Can the authors please clarify this sentence. From this sentence alone, I can't understand how "8 year" periods and the "decadal" NAO go together. Interesting paper, though!

Reply: We have changed the analysis period, so the period of the NAO has changed. In this revised version, the observation-based NAO has the period of 8-10 years. It is generally believed that the period of 8 years or longer time can be treated as decadal signals.

Line 154: I think "biased" might be the wrong word here, since the authors are comparing observations to observations.

Reply: We have changed "biased" to "shift", "this shift is related to the phase of the NAO" (P11, L183)

Lines 254 - 258: This sentence is a bit long an awkward.

Reply: We've rewritten this sentence: "There may be two reasons for the bias of the locations and magnitude of negative response centers of the winter-averaged SST anomalies to the NAO-driven SHF anomalies by models: The areas where air-sea interaction is dominated by the atmosphere are different from the observation; there may be other factors which play dominate role to the variation of the SST and further impact the relationship between the anomalies of the SST and SHF".(P19, L321-324)

Lines 268 – 272: Again, the sentence here is distracting from the useful analysis.

Reply: Sorry about that. We've rewritten this sentence: "When the SST anomalies lags by 2 months onto SHF anomalies, all CMIP5 models can reproduce the negative covariance between SHF and SST anomalies in the most regions of the NA, although there are some models that simulate weak positive covariance in some regions of the subpolar NA, such as GFDL-ESM2M, HadGEM2-CC/ES, IPSL-CM5A-L/MR, MPI-ESM-LR, and MRI-ESM1, indicating that other factors (such as the internal motion of ocean) have an impact on the variations of the SST in the regions beyond the SHF in these models."(P19-18, L332-336)

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