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Discussions

Interactive comment on "Inter-hemispheric seasonal comparison of Polar Amplification using radiative forcing of quadrupling CO_2 experiment" *by* Fernanda Casagrande et al.

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Casagrande et al. (2019).

Referee #1

Answer:

Thank you very much for your consideration. We really appreciate the comments and have learned a lot. Appropriate changes were made in the revised manuscript according to the suggestions.

First, this paper is an article. We added results as you suggest, for example: analysis

of polar amplification from observational data (Figure 1) and sea ice analysis from different CMIP5 models (Figure 3, Table 1 and Figure 4). This analysis provided greater robustness in the results, which were included here in several parts of the revised manuscript. Thus replacing, expressions as "we suggest" with more complete discussions.

Figure 1. Polar Amplification using Long-term observations of Surface Air Temperatures (oC) at 2008-2018 (seasonal average) relative to 1979 -1989 (seasonal average) in (a) Winter (DJF) and (b) Summer (JJA). Source: Era Interim Reanalysis.

Figure 1 shows the enhanced surface warming at high latitudes compared to the rest of globe, with a slightly greater rate of warming in the 20th century. The observed Polar Amplification is not symmetric, most evidence is from Arctic region (during the boreal winter). According to Stocker et al., (2013), the enhanced warming at northern high latitudes was linked with decrease in snow cover and sea ice concentration, sea level rise and increase in land precipitation. Besides that, changes in atmospheric and ocean circulation (Chylek et al., 2019; Pedersen et al., 2016; Pithan and Mauritsen, 2014; Stocker et al., 2013; Yang et al., 2010; Graversen et al., 2008).

Following the reviewer's suggestion and in order to better discuss the relationship between enhanced warming at high latitudes (Figure 1) and sea ice changes, we include the Figure 3, Figure 4 and Table1.

Figure 3 (new - attached here) shows, under the largest future GHG (4xCO2), the spatial pattern of sea ice changes for both, Arctic and Antarctic (difference between sea ice concentration for the last 30 years of abrupt4xCO2 numerical experiment and the last 30 years of the piControl run). This new Figure complements and makes the discussion shown in Figure 1 (old manuscript) more robust. The maximum of the Arctic warming obtained from observations (new Figure 1) and different CMIP5 simulations (old Figure 1) occurs in boreal winter (DJF). According to Figure 1 (old manuscript), the following models, in descending order, appears as having greater amplification:

MIROC – ESM, MPI-ESM, BESM-OA V2.5 and CSIRO-ACCESS. Similar response, for the same period is observed in Figure 3 and Figure 4, related to sea ice changes. The large decrease in sea ice concentration is more evident in models with great Polar Amplification, and for the same range of latitude (75o N – 90o N). The end of melting period (when sea ice reaches its minimum annual value) for all models shows sea ice-free conditions. Models that have strong Polar Amplification exhibit expressive changes in the sea ice annual amplitude with outstanding ice-free condition from may to December (MIROC-ESM) and June to December (MPI-ESM). Then, the end of melting period is expected early, likely, associated a large decrease in sea ice thickness and contributing to a delay in sea ice formation. We suggest, based in Figure 3 and Table 1, that, the Arctic will become covered only by first year sea ice (more vulnerable to melting), making the region more sensitive thermodynamically and dynamically to temperature changes. These new evidences presented here, corroborates with the theory, that the Polar Amplification is closely linked to sea ice albedo feedback. For Antarctica, however, the same physical processes cannot be used to explain the Polar Amplification (as discussed in the manuscript). Although, according to Figure 1 (old manuscript) and Figure 3 (new - attached here), there is a small indication of the contribution of sea ice albedo feedback in Antarctic Polar Amplification. Latitudes between 60oN and 65oN (greater Polar Amplification, models BESM-OAV2.5, MIROC-ESM and NCAR-CCSM4) for Austral winter also have trace of relation with abrupt changes in sea ice (Figure 3). Here, it is important to consider the contribution of the ice sheet in Polar Amplification that is not represented by the most of CMIP5 current models. According to Salzmann (2017 the overall weaker warming in Antarctica is due to a more efficient ocean heat uptake in the southern ocean, weaker surface albedo feedback in combination with ozone depletion.

Figure 3. Sea ice concentration for the last 30 years of Abrupt4xCO2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM in March (left column) and September (right column).

Table 1. Sea ice area (million square kilometers) for the last 30 years of the abrupt 4xCO2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM. I Arctic (Antarctic) sea ice reach its annual maximum area in march (february) and the minimum period in September.

Figure 4. Climatology of maximum and minimum Sea ice area (million square kilometers) for the last 30 years of the abrupt 4xCO2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM. (a) Arctic, (b) Antarctic. Black color represents the maximum (minimum) period of sea ice concentration, march (february) month for Arctic (Antarctic). Gray color bar represents September month.

Figure 5. Scatter plot of the SAT (K) and SIC (%) for the last 30 years of Abrupt4xCO2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM. The blue (black) dots represent march (september) month average, respectively the maximum and the minimum of sea ice concentration.

Specific comments: L40: You mentioned 'numerous scientific publications', but there is only one reference in the end of this sentence. Reply: ok Numerous scientific publications based on both, observations and state-of-the-art Global Climate Model simulations for the high latitudes of the northern hemisphere have shown that AA is an intrinsic feature of the Earth's climate system (Smith et al., 2019; Vaughan et al., 2013; Serreze and Barry, 2011; Screen and Simmonds, 2010).

L42: suggest->suggested Reply: ok

L63: Please give explanations regarding why the performance of Arctic simulation is better. Reply: ok According to Shu et al., (2015), Global Climate Models simulations in general offer much better simulations for the Arctic than for the Antarctica. Turner et al., (2015) suggested that the main p roblem of climate models in the high latitudes of the southern hemisphere is their inability to reproduce the observed (although slight) increase in Sea Ice Extent (SIE). Bintanja et al., (2015) and Swart and Fyfe, (2013) have demonstrated the importance to include the effect of the increasing freshwater input from Antarctic continental ice into the Southern Ocean. The authors describe that the ice sheet dynamics, essential for having accurate sea ice simulations, is currently disregarded in all CMIP5 models. Swart and Fyfe (2013) also suggested that this deficiency may significantly influence the simulated sea ice trend because the subsurface ocean warming causes basal ice-shelf melt, freshening the surface waters, which eventually leads to an increase in sea ice formation.. Moreover, the instrumental network for data collection in Antarctica and the Southern Ocean is considered scarce (even more than in the Arctic), inhomogeneous and insufficiently dense to validate climate models. Therefore, or the high latitudes regions of the southern hemisphere, the effects of the ongoing climate change and its associated processes are still considered hot topics that lack conclusive answers.

L75: are also depended on-> depend on Reply: ok

L76: making -> which makes Reply: ok

L105: last -> latest Reply: ok

L158: 'with no so enhanced warming' is confusing. Please rephrase it. Reply: ok From March to August, the reverse signal shows the maximum warming close to 70oS, decreasing towards to tropical region, lacking the enhanced warming at the northern high latitudes.

L163: looses heat to -> heats Reply: ok

L174-L178: Why the authors mentioned the linkage between Arctic sea ice loss and mid-latitude weather? I think it is irrelevant to your topic. Reply: ok , it is out.

L197: It may be better to have a spatial distribution of sea ice trends to support your

hypothesis, see my major comments. Reply: ok , Figure 3 and Table 1.

L209: last->latest Reply: ok

L247: It is difficult for me to link Fig.3 to deep convection. I think the authors should give more evidences to support your conclusions. See my major comments.

Reply: ok, we agree with suggestion.

Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-106, 2019.

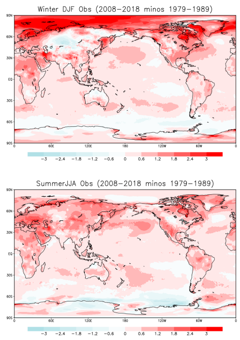

Figure 1. Polar Amplification using Long-term observations of Surface Air Temperatures (^{o}C) at 2008-2018 (seasonal average) relative to 1979 -1989 (seasonal average) in (a) Winter (DJF) and (b) Summer (JJA). Source: Era Interim Reanalysis.

Fig. 1.

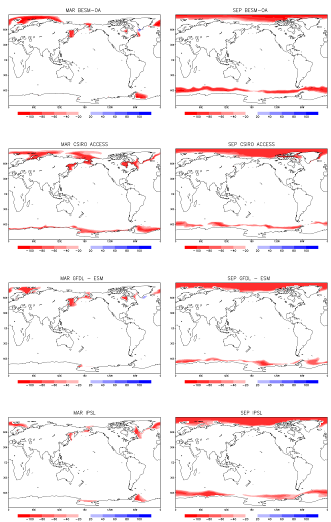

Fig. 2.

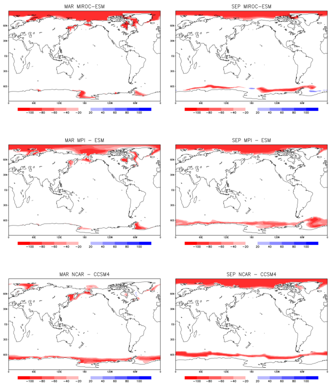

Figure 3. Sea ice concentration for the last 30 years of abrupt4xCO_2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO-ACCESS, IPSL and MIROC-ESM in March (left column) and September (right column).

Fig. 3.

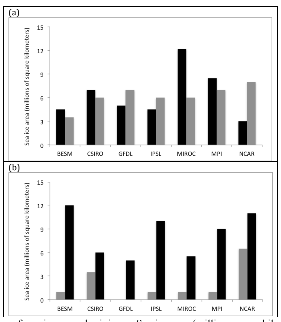

Figure 4. Climatology of maximum and minimum Sea ice area (million square kilometers) for the last 30 years of the abrupt 4xCO_2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM. (a) Arctic, (b) Antarctic. Black color represents the maximum (minimum) period of sea ice concentration, march (february) month for Arctic (Antarctic). Gray color bar represents September month.

Fig. 4.

CMIP5 Models	Arctic			Antarctic		
BESM-OA		March	Sept		Feb	Sept
	piControl	16	3.5	piControl	1	29
	$4xCO_2$	11.5	Ice-Free [Aug-Nov]	$4xCO_2$	Ice-Free	17
CSIRO ACCESS		March	Sept		Feb	Sept
	piControl	14	6	piControl	4.5	17
	$4xCO_2$	7	Ice-Free [Jul-Nov]	$4xCO_2$	1	11
GFDL –ESM2M	Arctic	March	Sept	Antarctic	Feb	Sept
	piControl	14	7	piControl	Ice-Free	9
	$4xCO_2$	9	Ice-Free	$4xCO_2$	Ice-Free [Feb-Mar]	4
IPSL –CM5-LR		March	Sept		Feb	Sept
	piControl	13	6	piControl	1	17
	$4xCO_2$	8.5	Ice-Free [Jul-Oct]	$4xCO_2$	Ice -Free [Jan-Mar]	7
MIROC-ESM		March	Sept		Feb	Sept
	piControl	13	6	piControl	1	14
	$4xCO_2$	0.8	Ice-Free [May-Dec]	$4xCO_2$	Ice free	8.5
MPI –ESM		March	Sept		Feb	Sep
	piControl	12	7	piControl	1	13
	$4xCO_2$	3.5	Ice-Free [Jun-Dec]	$4xCO_2$	Ice-Free [Jan-Apr]	4
NCAR –CCSM4		March	Sept		Feb	Mar
	piControl	13	8	piControl	7.5	22
	$4xCO_2$	10	Ice-Free [Aug-Oct]	$4xCO_2$	1	11

Table 1. Climatology of maximum and minimum Sea ice area (million square kilometers) for the last 30 years of the abrupt $4xCO_2$ numerical experiment and the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM.

Fig. 5.