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Interactive comment

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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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. In order to improve the analyses, following your suggestion and from referee #1/2, we add new results: 1) analysis of polar amplification from observational data (Figure 1) and sea ice analysis from different CMIP5 models (Figure 3, Figure 4 and Table 1). 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. Also, appropriate changes

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were made in the revised manuscript (expanding discussion) according to the suggestions.

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 follow-

ing 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.

1) In relation to the objective, we changed to: The main objective is to investigate the seasonality of the surface and vertical warming, the seasonal response of sea ice, as well as the coupled processes underlying the polar amplification.

2) We have improved both, introduction and conclusions on revised manuscript including the new results and as suggested by the referee.

Specific Comments: Page 2, L. 40: "Numerous Scientific Publications"? I suggest rewriting this paragraph because it is confusing. 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).

Page 2, L. 56: References ..? Reply: ok

Page 5, L. 129: Replaced "parsed" with "parsed" Reply: ok

Page, L. 132: Attention to section description: 3.1 Polar ... Reply: ok

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2019.

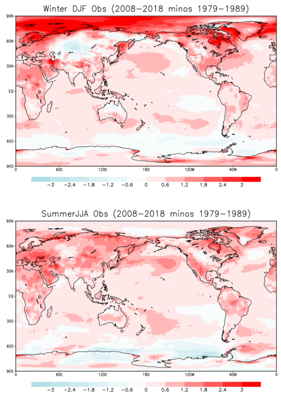

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Fig. 1.

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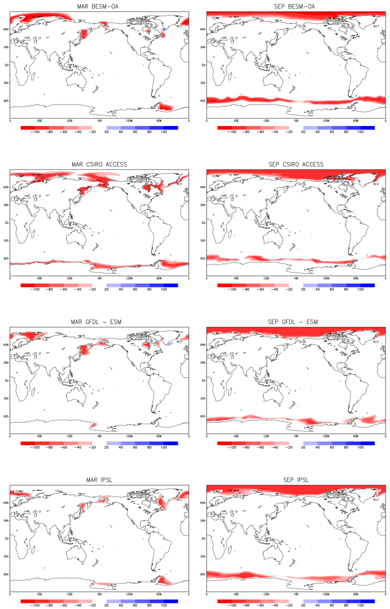
MAR BESM-OA
SEP BESM-OA
MAR CSIRO ACCESS
SEP CSIRO ACCESS
MAR GFDL – ESM
SEP GFDL – ESM
MAR IPSL
SEP IPSL

Fig. 2.

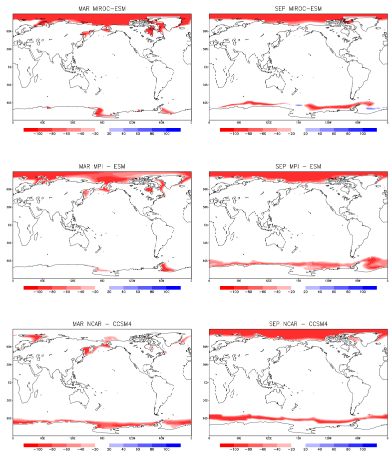

Figure 3. Sea ice concentration for the last 30 years of abrupt4xCO_2 numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO-ACCESS, IPSL and MIROC-ESM in March (left column) and September (right column).

Fig. 3.

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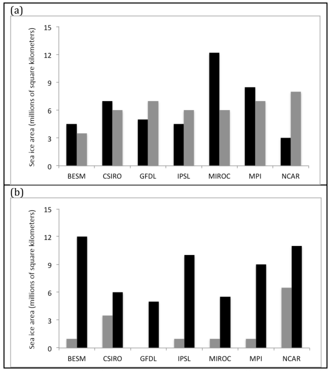

Figure 4. Climatology of maximum and minimum Sea ice area (million square kilometers) for the last 30 years of the abrupt $4xCO_2$ numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM.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

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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.

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