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# Inter-hemispheric seasonal comparison of Polar Amplification using radiative forcing of quadrupling $CO_2$ experiment

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**Abstract.** The numerical climate simulation from Brazilian Earth System Model (BESM) are used here to investigate the response of Polar Regions to a forced increase of $CO_2$(Abrupt-4x$CO_2$) and compared with Coupled Model Intercomparison Project 5 (CMIP5) simulations. Polar Regions are described as the most climatically sensitive areas of the globe, with an enhanced warming occurring during the cold seasons. The asymmetry between the two poles is related to the thermal inertia and the coupled ocean atmosphere processes involved. While in the northern high latitudes the amplified warming signal is associated to a positive snow and sea ice albedo feedback, for southern high latitudes the warming is related to a combination of ozone depletion and changes in the winds pattern. The numerical experiments conducted here demonstrated a very clear evidence of seasonality in the polar amplification response. In winter, for the northern high latitudes (southern high latitudes) the range of simulated polar warming varied from 15 K to 30 K (2.6 K to 10 K). In summer, for northern high latitudes (southern high latitudes) the simulated warming varies from 3 K to 15 K (3 K to 7 K). The vertical profiles of air temperature indicated stronger warming at surface, particularly for the Arctic region, suggesting that the albedo-sea ice feedback overlaps with the warming caused by meridional transport of heat in atmosphere. The latitude of the maximum warming was inversely correlated with changes in the sea ice within the model's control run. Three climate models were identified as having high polar amplification for cold season in both poles: MIROC-ESM, BESM-OA V2.5 and GFDL-ESM2M. We suggest that the large BIAS found between models can be related to the differences in each model to represent the feedback process and also as a consequence of the distinct sea ice initial conditions of each model. The polar amplification phenomenon has been observed previously and is expected to become stronger in coming decades. The consequences for the atmospheric and ocean circulation are still subject to intense debate in the scientific community.

## 1 Introduction

Polar regions have been shown to be more sensitive to climate change than the rest of the world (Smith et al., 2019; Serreze and Barry, 2011). The Arctic is warming at least twice as fast as the northern hemisphere and as the globe as a whole. This phenomenon is known as the Arctic Amplification (AA) and is combined with a fast shrinking of the sea ice cover (Serreze and Barry, 2011; Kumar et al., 2010; Screen and Simmonds, 2010). Previous research had indicated that the enhanced Arctic warming is a response to anthropogenic Greenhouse Gas (GHC) forcing, which, in turn, intensify many

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complex non-linear coupled ocean-atmosphere feedbacks (e.g the sea ice albedo feedback) (Stuecker et al., 2018; Pithan and Mauritsen, 2014; Alexeev et al., 2005). In contrast to the Arctic sea ice, the total sea ice cover surrounding the Antarctic continent has increased in association with a cooling over eastern Antarctica and a warming over the Antarctic Peninsula. The Southern Ocean's behavior has a quite different explanation: it is due to a combination of changes in the wind pattern, the ocean circulation, accelerated basal melting Antarctica's ice shelf and the ozone depletion (Marshall et al., 2014 Thompson et al., 2011; Bintanja et al., 2013; Thompson and Solomon, 2002). According Marshall et al., (2014), these two-poles inter-hemispheric asymmetries in the mean ocean circulation strongly influence the Sea Surface Temperature (SST) response to an increase in the global $CO_2$ forcing, accelerating the warming in the Arctic while delaying it in Antarctica.

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 (Vaughan et al., 2013). These works suggest that the Surface Air Temperature (SAT) will continue to increase with effects extending beyond the Arctic region (Dethloff et al., 2019; Smith et al., 2019; Holland and Bitz, 2003; Serreze and Barry, 2011; Winton 2006; Bintanja et al., 2013).

Bekryaev et al., (2010), for instance, found a warming rate of $1.36^{o}$C century$^{-1}$ for the period from between 1875 and 2008 using an extensive set of observational data from meteorological stations located at high latitudes of northern hemisphere (> $60^{o}$N). That trend is almost double that of the northern hemisphere trend as a whole ($0.79^{o}$C century$^{-1}$), with an accelerated warming rate in the most recent decade. Rigor et al., (2000) also using an observational dataset showed that the Arctic warming varies largely between regions and that changes in SAT are also related to the Arctic Oscillation (Ambaum et al., 2001).

The Arctic Ocean temperature and ocean heat fluxes also have increased over the past several decades (Walsh, 2014; Polyakov et al., 2010; Polyakov et al., 2008). According to Polyakov et al., (2017), the recent sea ice shrinking, weakening of the halocline and shoaling of the intermediate-deep Atlantic water masses layer in eastern Eurasia Basin have increased the winter ventilation in the ocean interior, making the region structurally similar to the western Eurasian Basin. The authors described this processes as the "Atlantification" (Ocean is becoming more like the Atlantic ocean). The phenomenon represents an essential step toward a new Arctic climate state.

Holland and Bitz, (2003) using a set of 15 state-of-the-art CMIP models found that the range of simulated Arctic warming as response to a doubling of $CO_2$ concentration varies largely between the models ranging from 1.5 to 4.5 times the global mean warming. The large differences among the models is related to differences in simulating the ocean's meridional heat transport, the polar cloud cover and the sea ice (e.g a simulation with thinner sea ice cover presents a higher polar amplification).

According to Shu et al., (2015), Global Climate Models simulations in general offer much better simulations for the Arctic than for the Antarctica. For 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. The instrumental network for data collection in Antarctica and the Southern Ocean is considered scarce (even more than in the Arctic), inhomogeneous

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and insufficiently dense to validate climate models. Turner et al., (2015) suggested that the main problem 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.

How the polar climate will change as response to an external forcing deeply depends on feedback processes, which operate to amplify or diminish the effects of climate change forcing. These feedbacks are also dependend on the integrated coupled processes between ocean-atmosphere-cryosphere over a large spectrum of spatial and temporal scales making the quantification of them even more complicated.

Here the seasonal sensitivity of high latitudes as a response to quadrupling atmospheric $CO_2$ is investigated using the recently developed Brazilian Earth System Model, coupled ocean-atmosphere version 2.5 (BESM-OA V2.5) and comparing its results with those from six other Coupled General Circulation Models participating in CMIP5. Our goal is to investigate the coupled processes underlying the polar warming by seasons. The paper was organized as follows: Section 2 provides a description of the climate models and experimental design[s] used in this work, focusing on the BESM-OA V2.5 model (Veiga et al., 2019; Giarolla et al., 2015; Nobre et al., 2013). In Section 3, the seasonality of the surface warming in high latitudes is examined of both northern and southern hemispheres and results from different models are compared. Section 4 provides an analysis of the vertical structure of air temperature warming and a discussion about the coupled ocean-atmosphere processes and feedback mechanisms involved. A summary of results and conclusions are presented in Section 5

## 2 Data Sources

### 2.1 Numerical Design

This study used two CMIP5 numerical experiments: (i) piControl: it runs for 700 years, forced by invariant pre-industrial atmospheric $CO_2$ concentration level (280ppmv) and (ii) Abrupt 4x$CO_2$: it runs for 460 years, comprising an abrupt instantaneous quadrupling of atmospheric $CO_2$ level concentration from the piControl simulation. The design of both experiments follows the CMIP5 protocol (Taylor et al., 2012) and was described by Veiga et al., (2019).

Although a instantaneous quadrupling $CO_2$ scenario is not realistic for 21st century compared with RCP scenarios and observations, this scenario can give us a measure of climate sensitivity and how amplified can be the response of the polar region in comparison to the globe as a whole. The results are compared only for polar amplification (changes in air temperature) for the same numerical experiment using the models presented in Table 1.

Table1. CMIP5 models main characteristics

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| Institute/Country | Model | Reference |
|---|---|---|
| National Institute for Space Research (INPE) – Brazil | Brazilian Earth System Model BESM-OA V2.5 | Nobre et al., (2013) Veiga et al., (2019) |
| Commonwealth Scientific and Industrial Research Organization, Australia (CSIRO)-Australia | Australian Community Climate and Earth-System Simulator ACCESS-3 | Bi et al., (2013) Collier and Uhe, (2012) |
| National Oceanic and Atmospheric Administration-Geophysical Fluid Dynamics Laboratory (GFDL-NOOA)-U.S.A | Geophysical Fluid Dyanmics Laboratory-Climate Models - GFDL-ESM2M | Griffies, (2012) |
| Atmospheric and Ocean Research Institute-University of Tokyo (AORI)-Japan | Model for Interdisciplinary Research on Climate - MIROC-ESM | Watanabe et al., (2011) |
| Max Planck Institute for Meteorology (MPI)-German | Max Planck Institute-Earth System Model –MPI-ESM-LR | Stevens et al., (2013) |
| NCAR- United States | Community Climate System Model - CCSM4 | Gent et al., (2011) |
| Institut Pierre-Simon Laplace-France | IPSL-CM5-LR | Dufresne et al., (2013) |

### 1.2 Brazilian Earth System Model

The Brazilian Earth System Model, Version 2.5 (BESM-OAV2.5) used here is a global climate coupled ocean-atmosphere-sea ice model, and is part of CMIP5 project. The atmospheric component of BESM-OAV2.5 is BAM (Brazilian Atmospheric Model) and was described in detail by Figueroa et al., (2016). BAM, developed at Center for Weather Forecasting and Climate Studies of the National Institute for Space Research CPTEC-INPE has been constantly reformulated over the last years (Figueroa et al., 2016; Nobre et al., 2013). The last version, used here and described by Veiga et al.,

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(2019), has spectral horizontal representation truncated at triangular wave number 62, grid resolution of approximately 1.875◦×1.875◦, and 28 sigma levels in the vertical, with unequal increments between the vertical levels (i.e., a T62L28). Two important changes were implemented on the BESM last version: (i) a new microphysics scheme, described by Ferrier et al., (2002) and Capistrano et al., (2018) and (ii) a new surface layer scheme, described by Capistrano et al., (2018) and Jimenez and Dudhia, (2012). These key changes represent an improvement in surface layer, resulting in better representation of near-surface air temperature, wind and humidity at 10 m. The main improvements occur over the ocean, where temperature, wind and humidity are important to calculate the heat fluxes at ocean-atmosphere-sea ice interface.

The oceanic component of BESM-OAV2.5 is the Modular Ocean Model, Version 4p1, from National Oceanic and Atmospheric Administration-Geophysical Fluid Dynamics Laboratory (MOM4p1/NOAA-GFDL), described in detail by Griffies, (2009). The MOM4p1 includes a Sea Ice Simulator (SIS) built-in ice model (Winton 2000). The SIS has five ice thickness categories and three vertical layers (one snow and two ice). To calculate ice internal stresses are used the elastic-viscous-plastic technique described by Hunke and Dukowicz, (1997). The thermodynamics is given by a modified Semtner's three-layer scheme (Semtner, 1976). SIS is able to calculate sea ice concentration, snow cover, thickness, brine content and temperature. Furthermore, SIS calculates ice-ocean fluxes and transmits fluxes between atmosphere and ocean. The horizontal grid resolution of MOM4p1 in the longitudinal direction is a set to 1°. The latitudinal direction varies uniformly, in both hemispheres, from 1⁄4° between 10° S and 10° N to 1° of resolution at 45° and to 2° of resolution at 90°. The vertical axis has 50 levels (upper 220m, has 10 m resolution, increasing to about 360 at deeper levels. The MOM4p1 and BAM models were coupled using FMS coupler. FMS coupled was developed by NOAA-GFDL. The BAM model receives SST and ocean albedo from MOM4p1 and SIS (hour by hour). The MOM4p1 receives momentum fluxes, specific humidity, pressure, heat fluxes, vertical diffusion of velocity components and freshwater. The Monin-Obukhov scheme is used to calculate the wind stress fields (Obukov, 1971).

## 3 Results and Discussion

First we discuss the seasonality of near surface warming in the Arctic, differences between models and coupled process involved. Follow, we do the same analyzes for the southern high latitudes and accesses the reasons for asymmetries between poles.

### 1.2 Polar Amplification

In order to evaluate the seasonality of near surface polar warming, the seasons are defined as follows: December to February (DJF) as boreal winter, March to May (MAM) as boreal spring, June to August (JJA) as boreal summer, and September to November (SON) as boreal fall. Figure 1 shows the seasonality of the polar amplification (change in zonally SAT average) simulated by BESM-AO V2.5 and six state-of-art CMIP5 models. To assesses the climate sensitivity of polar amplification, seasonally and coupled processes involved we used the difference between Abrupt 4x$CO_2$ and piControl numerical experiments, considering only the last 30 years of the 150 years of model integration after quadrupling $CO_2$ concentration (when the model reaches a new equilibrium state). This procedure been largely used by researchers since allows us to evaluate and compare potential warming and sensitivities between low and high latitudes as well as to compare differences between models (Manabe et al., 2004; Holand and Bitz, 2003).

Under the largest future GHG forcing ($4xCO_2$), the Polar Regions are found to be the most sensitive areas of the globe, with a very pronounced seasonality (Figure 1). The high southern latitude warming predicted by the models analyzed is modest in relation to the Arctic's, but still not negligible. This asymmetry is partly due to the smaller area covered by ocean in Northern Hemisphere that induces a smaller thermal inertia. Contrasting, the tropical warming for both, northern and southern hemisphere, is pretty similar with not so accentuated SAT increase in summer and for regions close to 30$^o$N. Salzmann (2017) suggested that 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. BESM model has no ozone chemistry as a climate component, so we suggest that even neglecting the ozone depletion, the weaker warming in Antarctica will be shown. Also is expected a weak albedo sea ice feedback compared with Arctic region (because the fast retreat of sea ice on the northern hemisphere). The role of the Antarctica surface height for both feedbacks processes and meridional transports is similarly important to consider. According Salzmann (2017), the polar amplification asymmetry is explained by the difference in surface height. If Antarctica is considered to be Flat in a climate simulation with $CO_2$-doubling experiment, the north-south asymmetry is reduced.

From September to February (boreal autumn and winter), the surface warming is maximum at northern high latitudes, decreasing with latitude to reaching a minimum at 70$^o$S and then increasing towards the South Pole. Consistent with previous analyses based on climate simulations and observations, this enhanced Arctic Amplification appears as an inherent characteristic for the Arctic region (Pithan and Mauritsen, 2014). From March to August, the reverse signal shows the maximum warming close to 70$^o$S, decreasing towards to tropical region, with no so enhanced warming at northern high latitudes.

The main reason for winter (DJF) Arctic Amplification pointed by Serreze et al., (2009) is largely driven by changes in sea ice, allowing for intense heat transfers from the ocean to the atmosphere. During boreal summer, when Arctic warming is not prominent and solar radiation is maximal, the energy is used to melt sea ice and increase the sensible heat content of the upper ocean. The atmosphere looses heat to the ocean during summer whereas the flux of heat is reverse in winter. The sea ice loss in summer allows a large warming of the upper ocean but the atmospheric warming at surface or lower troposphere is modest (promoting more open water). The excess heat stored in the upper ocean is subsequently released to the atmosphere during winter (Serreze et al., 2009). According Lu and Cai, (2009), in summertime the positive surface albedo feedback is mainly canceled out by the negative cloud radiative forcing feedback. The positive surface albedo feedback is relatively much weaker in winter when compared to its amplitude in summer, therefore does not contribute to the pronounced polar amplification in winter.

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We suggest that the Arctic surface warming can be associated with sea ice decrease through ice-albedo feedback, as shown in Figure 2. Ice free conditions are found at the end of summer indicating decrease in albedo and consequent more heat absorption on upper ocean, hence, resulting in a positive sea ice albedo feedback. Furthermore, changes in sea ice cover cause a strong impact in heat fluxes and heat transport between the atmosphere and ocean, water vapor and cloud cover, that modify the longwave radiation flux to the surface. Previous researchers, using observational and modeling dataset, have found that shrinking of sea ice (Figure 2) and enhanced Artic warming in autumn may affect the middle latitudes by weakening the west-to-east wind speed in the upper atmosphere, by increasing the frequency of wintertime blocking events that in turn lead to persistence or slower propagation of anomalous temperature in middle latitudes, and by increasing in continental snow cover that can in turn influence the atmospheric circulation (Walsh, 2014).

For southern high latitudes, a pronounced warming appears from March to August (boreal summer and spring), predominantly close from 70°S. This enhanced warming trend to decreases in the direction of the South Pole. This pattern is similar to the one obtained by Goosse and Renssen, (2001). The authors used a coupled climate model to investigate the response of the Southern Ocean to an increase in GHG concentration. They found that the response could occur separated in two distinct phases. At the first moment, the ocean damps the surface warming (because of its large heat capacity). Then, after 100 years of run simulation, the warming is enhanced due to a positive feedback that is linked to a stronger oceanic meridional heat transport toward the southern ocean.

When comparing the seasonal response to $CO_2$ forcing between CMIP5 models, for boreal winter (DJF), the enhanced Arctic warming from 75-90° N is shown to be a robust feature of all CMIP5 climate models simulations presented here. For high Northern Hemisphere (high southern Hemisphere) the warming (difference between piControl and 4x$C0_2$) ranged from 14 K to 30 K (3 K – 10 K). IPSL-CM5-LR, GFDL-ESM2M and NCAR-CCSM4 presented the lowest warming, close from 15 K for Northern high latitudes. In the other hand, MIROC-ESM and MPI-ESM-LR outputs presented a warming almost twice as large, with a high amplification close from 30 K. BESM model, for winter (DJF) season, also presented a high amplification for Northern high latitudes, close from 27 K.

One interesting feature shown in Figure 1 is related to the maximum Arctic warming obtained in different simulations. Many models have shown that the maximum warming does not always occur at the highest northern latitudes, but instead, it occurs between 80° N-85° N decreasing toward 90° N. According to Holland and Bitz, (2003) the localization of the maximum warming varies widely between CMIP outputs, but models with high polar amplification generally presented a maximum warming over the Arctic Basin. Therefore, we suggest that the spatial distribution of maximum Artic Amplification can be closely related to sea ice conditions though a sea ice albedo feedback, and this region (Arctic Basin) presents the major taxes of decrease in sea ice concentration. Similar result was found for the sea ice simulation from BESM model (See in Figure 2). Additionally, Casagrande et al.,(2016), using BESM-OA V2.3 model, showed that the sea ice spatial pattern could vary largely between CMIP5 models, especially in frontiers areas.

For the southern high latitudes, in wintertime (DJF- Figure 1d), the warming decreases to close to 60° S for most CMIP5 models, increasing toward South Pole, with the maximum warming close to 10 K. The minimum warming is register by

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GFDL-ESM2M model (close to 0K in 60° S) and the maximum south polar amplification between models is presented by NCAR-CCSM4, close to 90° S.

In summer (JJA), the compared response to $CO_2$ forcing in CMIP5 models is amplified (damped) at southern (northern) hemisphere. A pronounced amplification was found close to 70°S with a range of 1.5K to 13K, decreasing towards the South Pole. In this region the maximum was obtained by BESM-OA V2.5 model, close to 13K. According Casagrande et al (2016), in the last version of BESM model, the atmosphere was warmer than the previously version (BESM V2.3), leaving BESM-OA V2.5 as a model with high amplification. The explanation for this model behavior is related to a new surface scheme implement at the last version (BESM-OA V2.5), that changes the cloud cover and consequently modify the energy balance at surface.

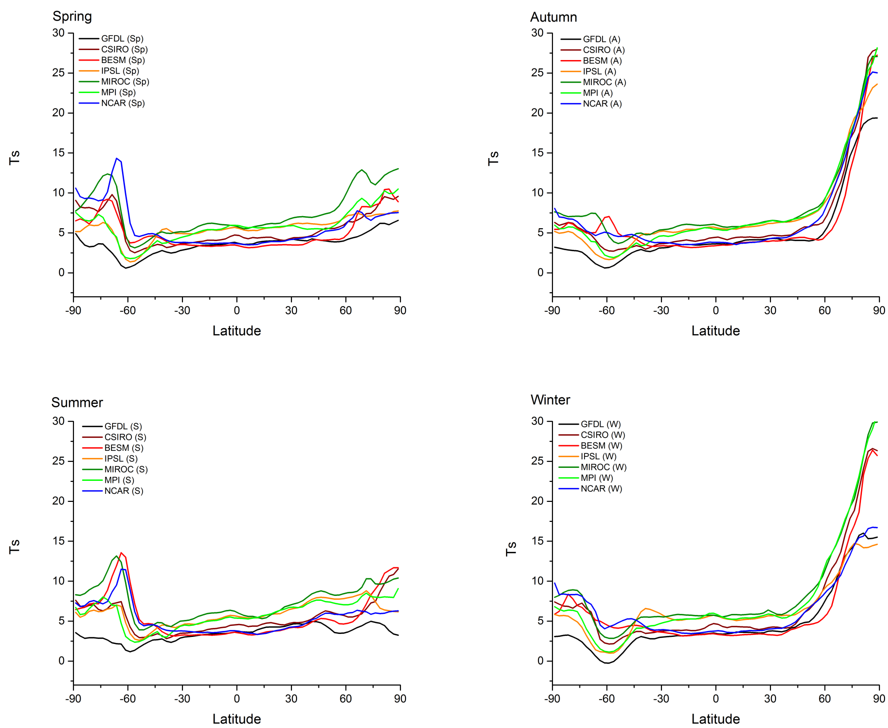

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**Figure 1. Seasonal zonal mean surface temperature differences (K) for the last 30 years of Abrupt4x$CO_2$ numerical experiment minus the last 30 years of the piControl run for the following models: BESM-OA V2.5, NCAR-CCSM4, GFDL-ESM-LR, MPI-ESM-LR, CSIRO, IPSL and MIROC-ESM in (a) Winter (DJF), (b) Spring (MAM), (c) Summer (JJA) and (d) autumn (SON).**

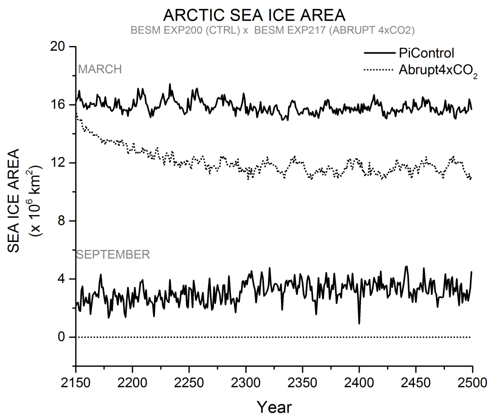


**Figure 2. Arctic sea ice area for March and September. Abrupt4x$CO_2$ increase numerical experiment (dashed line) and piControl run (solid line).**

The pronounced seasonality of near surface warming in Polar Regions has been found in observations (Bekryaev et al., 2010) and climate simulations (Holland and Bitz, 2003), but less emphasis has been placed in the vertical structure of the atmosphere. To understand if this enhanced warming occurs only in surface or also well above, Figure 3 presents results obtained with three different models with high (BESM-OA V2.5/MPI-ESM-LR) and low (NCAR-CCSM4) polar amplification (based on Figure 1).

Figure 3 shows evidence of temperature amplification well above the surface with enhanced warming during the cold season for both, northern and southern high latitudes. Snow and ice feedback cannot explain the warming above the lowermost part of the atmosphere because this feedback is expected to primarily affect the near surface air temperature. Part of the vertical warming may be explained by physical mechanisms that induce to a warming as changes in the atmospheric heat transport into the Arctic. According to Graversen et al., (2008), a substantial proportion of the vertical warming can be caused by changes in this variable, especially in summertime (JJA). Graversen and Wang (2009) used an idealized numerical experiment (doubling $CO_2$) with a climate model that had no ice albedo feedback. Their results also reveled a polar warming as a response to anthropogenic forcing (doubling $CO_2$). It was found that the enhanced Arctic warming is due to an increase of the atmospheric northward transport of heat and moisture. These results are supported by observational analyses (Graversen et al., 2014; Graversen et al., 2006). In addition to ice-albedo feedback, the strength of the atmospheric stratification is an important factor to explain the vertical warming. The troposphere is more stably stratified in high

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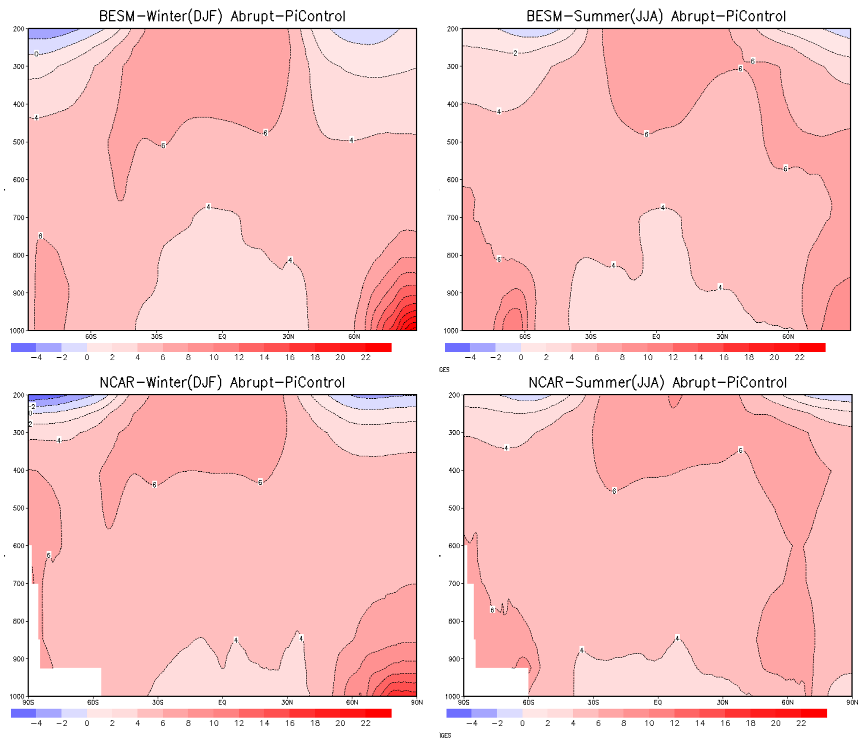
latitudes. An increase in GHG forcing generates an increase in downwelling long-wave radiation at the surface, consequently causing a warming, which in Polar Regions is confined to the lower troposphere. On the other hand, the warming in the tropics is distributed vertically by deep convection. Same tropical feature can be recognized through Figure 3.

When examining Arctic warming at different levels computed by the three different models shown in Figure 3, we find that MPI-ESM-LR presented the strongest warming in both, near surface temperature and in high levels. Similar behavior is found at tropical regions, with robust warming at high levels (400-200 hPa). Holland and Bitz, (2003) suggested that sea ice conditions are more important than continental ice and snow cover to enhanced polar warming. According to these authors, models with relatively thin sea ice in control run tend to have higher warming. The same feature was found in BESM-OA V2.5. According Casagrande et al. (2016) and Casagrande (2016), the last version of BESM model (Version 2.5) is considered to be a climate model with high polar amplification exhibiting thin sea ice conditions on the control run. This occurs, in part, because of the new surface scheme based on Jimenez and Dudhia, (2012) and the microphysics of Ferrier et al. (2002). The advantage of these changes in the BESM´s last version is an improvement in the representation of precipitation, wind and humidity at tropical regions. Comparatively, NCAR-CCSM4 is considered a model with moderate polar amplification for both, Northern and Southern Ocean. The warming at high levels in boreal summer is not as amplified as in boreal winter. These results are in agreement with Holland and Bitz, (2003).



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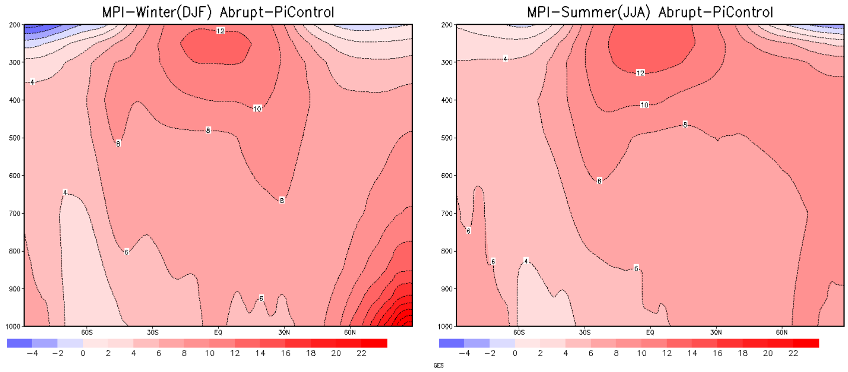


**Figure 3. Zonal-average atmosphere temperature changes (Abrupt 4xCO2 minus piControl) at each level (solid line) for the last 30 years run for (a) BESM OA V2.5, (b) NCAR-CCSM4 and (c) MPI-ESM-LR model, in DJF (left) and JJA (right) columns.**

## 3 Conclusion

Robust patterns of near surface temperature response to global warming at high latitudes have been identified in recent studies. Here we analyzed the seasonality of polar amplification using CMIP5 coupled climate models in a quadrupling $CO_2$ numerical experiment. Our results showed that the Polar Regions are much more vulnerable to a large warming due to an increase in atmospheric $CO_2$ forcing, than the rest of the world, particularly during the cold season. Despite the asymmetry in warming between Arctic and Antarctic, both poles showed enhanced amplification in all climate models. The reasons for sensibilities between poles can not be explained by the same physical process. While in Northern high latitudes the warming is closely related to sea ice albedo feedback, in southern high latitudes the amplification is related to a combination changes in winds and ozone depletion. We detected three climate models as having high amplification in both poles: MIROC-ESM, BESM-OA V2.5 and GFDL-ESM2M. We suggest that the differences between models are related to sea ice initial condition for each climate models and the parameterizations used to represent changes in clouds and energy balance. The physical processes involved in high-latitudes climate changes are not necessarily independent of each other and involve complicated structures occurring at many scales. The complexities of the multiples coupled processes combined with sparse and short data record deviate the numerical climate models from more realistic simulations. Nevertheless, even with inherent limitations and uncertainties, the Global Climate Models are the most powerful tools available for simulating the climatic response to GHG forcing and to providing future scenarios to community.

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