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RESPOSTA DESFASADA DO OCEANO ATLÂNTICO TROPICAL AO PULSO DE ÁGUA FRIA E DOCE DE DERRETIMENTO DO GELO MARINHO ANTÁRTICO

São Luís, MA

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Monografia apresentada ao curso de Graduação em Oceanografia da Universidade Federal do Maranhão, como requisito para obtenção do Grau de Bacharel em Oceanografia.

Orientadora: Profa Dra Cláudia Klose Parise

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DEDICATÓRIA

Ao meu irmão Lucca Felice, não sei por que você se foi quantas saudades eu senti, e de tristezas vou viver, e aquele adeus não pude dar, você marcou na minha vida, viveu, morreu na minha história, chego a ter medo do futuro, e da solidão que em minha porta bate, e eu gostava tanto de você.

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LISTA DE ABREVIAÇÕES

ASI – Antarctic Sea Ice
GMA – Gelo Marinho Antártico
TAO – Tropical Atlantic Ocean
OAT – Oceano Atlântico Tropical
A-ITCZ – Atlantic Intertropical Convergence Zone

CM2.1 – Coupled Climate Model
GFDL – Geophysical Fluid Dynamics Laboratory
MOM – Modular Ocean Model
SODA – Simple Ocean Data Assimilation
RMSE – Root Mean Square Error
SST – Sea Surface Temperature
SSS – Sea Surface Salinity

AABW – Antarctic Bottom Water
NADW – North Atlantic Deep Water
NASH – North Atlantic Subtropical High
SAMW – Mode Water
AAIW – Antarctic Intermediate Water
AASW – Antarctic Surface Water
SACW – South Atlantic Central Water
SAC – South Atlantic Current
LCDW – Lower Circumpolar Deep Water
ACC – Antarctic Circumpolar Current SH – Southern Hemisphere
STC – Subtropical Cell

JAS – July–August–September
MJJ – May, June, July
NDJ – November, December, January
DJF – December, January, February
AMJ – April, May, June
MAM – March, April, May

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I. CONSIDERAÇÕES INICIAIS

Esse documento de Trabalho de Conclusão de Curso foi elaborado na forma de Artigo Científico, o qual foi submetido aos **Anais da Academia Brasileira de Ciências (AABC), Volume Especial - Antártica** (Qualis Capes A2), em maio de 2021. Em agosto recebemos a decisão da revista indicando que o mesmo foi aceito para publicação, com correções. As normas de publicação da revista, o e-mail de aceitação e o parecer do revisor estão nos Anexos deste documento.

Os experimentos numéricos utilizados neste estudo foram configurados e realizados pela Dra. Profa. Cláudia Klose Parise durante o desenvolvimento da sua tese de doutorado no INPE (Parise, 2014). No artigo de Parise et al. (2015) foi discutida a atuação de um mecanismo climático de restauração do equilíbrio térmico em resposta aos extremos positivos aplicados ao campo de gelo marinho antártico (GMA). Dando seguimento, o presente estudo busca complementar essas respostas encontradas por Parise, avaliando a transferência dessa água fria e doce para o OAT, o qual tem grande influência no clima do NE e N do Brasil, além de abrigar grandes formações recifais como os Corais da Amazônia e o Parcel Manuel de São Luís, destacando a grande importância desse estudo, afim de entender como o campo do GMA pode influenciar na hidrodinâmica nessa região. Determinando via quais camadas do oceano ocorreu o maior transporte meridional (sentido pólo-equador) do sinal climático e estabelecer a faixa de latitude mais impactada.

Somada a essas **I) Considerações Iniciais**, este documento segue com o **II) Capítulo 1**, constando, na íntegra, o artigo científico submetido, seguido das **III) Considerações Finais**, e as **Referências** e **Anexos** (Normas da Revista, Aceite da Revista e Parecer do Revisor).

II. CAPÍTULO 1

LAGGED RESPONSE OF TROPICAL ATLANTIC OCEAN TO COLD AND FRESH WATER PULSE FROM ANTARCTIC SEA ICE MELTING

RUNNING TITLE: **ATLANTIC OCEAN RESPONSE TO SEA ICE EXTREMES**

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ABSTRACT

The formation of dense water masses at polar regions has been largely influenced by climate changes arising from global warming. In this context, based on ensemble simulations with a coupled model we evaluate the meridional shift of a climate signal (i.e., a cold and fresh water input pulse generated from melting of positive Antarctic sea ice (ASI) extremes) towards the Tropical Atlantic Ocean (TAO). This oceanic signal propagated from Southern Ocean towards the equator through the upper layers due to an increase in its buoyance. Its northward shift has given by the Subantarctic Mode Water (SAMW) and Antarctic Intermediate Water (AAIW) flows, that inject cold and fresh mode/intermediate waters from into subtropical basin. The signal has reached low latitudes through the equatorial upwelling and spreads out southwards, through the upper branch of southern subtropical gyre. We concluded that 10 years of coupled simulations was enough time to propagate the climate signal generated by ASI positive extremes melting, which reached TOA around 2 year later. The oceanic connection between Southern Ocean and TAO is indeed established within the timescale analyzed in the study (10 years). Nonetheless, the period needed to completely dissipate the disturbance generated from ASI seems to be longer.

Keywords: Sea Ice Melting, Freshwater Input, Teleconnections, Oceanic Bridge, Oceanography.

INTRODUCTION

Considered as one of the early indicators of global warming through the months when sea ice typically reaches its minimum and maximum extent, the Antarctic sea ice (ASI) has a great influence on the heat balance in Earth, since it acts as a natural thermal insulator on the ocean surface (Eicken et al. 1995; Maksym et al. 2012; Parise 2014). Besides affecting the heat and mass exchanges between sea ice and ocean and sea ice and atmosphere, the ASI also acts directly on the formation of important water masses responsible for the global thermohaline circulation, such as the Antarctic Bottom Water (AABW) and the North Atlantic Deep Water (NADW) (Toggweiler & Samuels 1995a; Nadeau et al. 2019). Therefore, due to intrinsic characteristics of the sea ice, the impacts of the current scenario of global warming have been amplified in polar regions (Thomas & Dieckmann 2010; Stuecker et al. 2018; Casagrande et al. 2020).

The low-frequency oscillations analysis brings a broad view of the propagation of planetary wave trains, so that local forces end up influencing remote regions of the globe via oceanic or atmospheric teleconnections. Thus, the identification of teleconnection mechanisms is useful in the diagnostic studies and prognostics of climate anomalies (Stammerjohn et al. 2012), such as those associated with extreme ASI advance or retreat events (Massom et al. 2008; Massom & Stammerjohn 2010; Raphael et al. 2011; Parise et al. 2015). The study of teleconnections, in addition to provide information on the possible triggers and mechanisms, enables the understanding of causes and effects in climate studies (Wallace & Gutzler 1981; Liu et al. 2002; Purich & England 2019). Through teleconnection modes that arise from the natural internal variability of the coupled climate system, the sea surface temperature (SST) of the Tropical Atlantic Ocean (TAO) has its patterns changed by the passing of atmospheric planetary wave trains (Li et al. 2015), ending up directing the meridional positioning of the Atlantic Intertropical Convergence Zone, with severe impacts on the precipitation of the northern and southern regions of South America (Giannini et al. 2001; Wu et al. 2007; Chiang et al. 2008).

Since it is essential to identify the mechanisms that influence the internal variability of lower frequency oscillations between remote regions of the globe, analytical performance becomes necessary for a better understanding of this dynamical system. With this in mind, coupled climate models have become increasingly important in climate change studies, given their ability to simulate global and regional variability (Randall et al. 2007; Flato et al. 2013). Parise et al. (2015) analyzed the sensitivity and memory of the Southern Hemisphere climate under ASI positive extremes through ensemble simulations performed with a climate model. According to these authors, the Southern Ocean has a climate memory of ~ 4 years to the ASI extremes, in both concentration and thickness, imposed as the initial condition in the sensitivity experiments performed. After this time, the melting freshwater pulse has persisted for the following 4 years over the Southern Ocean surface under current climate conditions. Even after all the imposed ice been melted, a cold and fresh water persisted at surface of the Southern Ocean, continuing to influence the vertical heat fluxes. After the period of 8 years of model simulation, a reduction in ASI was observed compared to the control simulation, as a result of the heat release stored at the subsurface layers of the Southern Ocean. As soon as the extreme applied to the ASI has melted, the cold and fresh water resulting from it advanced northwards. As a consequence, the Southern Ocean started to transfer heat back to the atmosphere (Parise et al. 2015). These authors concluded that the restoring of the climate thermal balance is triggered by a two distinct time-scale mechanism, which is initiated by the insulating effect of sea ice and the resulting pulse of cold and fresh water (rapid response) and restored by the heat stored in the subsurface layers of the Southern Ocean as the cold and fresh surface water is transported towards the lower-latitudes (slow response). A similar mechanism was found and discussed by Ferreira et al. (2015).

Based on the information provided by Parise et al. (2015), the hypotheses of this study were elaborated. Given the answers found by Parise, together with the mechanism that showed the impacts on the atmosphere and the Southern Ocean, one of the questions generated was whether this climate signal was transferred via the ocean to the TAO, how this transport would occur, in what magnitude and how long it would take for it to arrive. Thus, this study aims to complement the answers found by Parise et al. 2015. A decades-long satellite-based study revealed that the gradual increase in the ASI extents has reversed in 2014, with subsequent rates of decrease from 2014 to 2017, far exceeding the more widely decay rates experienced in the Arctic (Parkinson 2019). In 2017, the rapid decreases reduced the ASI extents to their lowest values in the 40 years record of observations, presenting both a new yearly (2017) and monthly (February) record low. However, the fact that the ASI decreases during this short period does not assurance that the 1979–2014 overall positive trend in Southern Ocean ice extents has reversed to a long-term negative trend (Parkinson 2019). The last two positive records of ASI extent have also occurred recently, in September 2013 (19.77 x 10^6 km^2) and October 2014 (20.11 x 10^6 km^2) (NOAA 2014).

Under the scenario of global warming, it is of great interest to understand the impacts of ASI extremes in the TAO, since this oceanic region has large impacts on the climate of the north and northeast regions of Brazil (Pezzi & Cavalcanti 2001; Yoon & Zeng 2010; Utida et al. 2019) and houses important coral reef formations, such as the Amazonian and Manoel Luís Reefs (Moura 2016). Thus, we study the impacts and the lagged response of the TAO to the climate signal generated from southern high latitudes due to the increasing in area and volume of ASI. The northernmost latitude impacted and the mechanisms that act on the propagation via oceanic teleconnections of this climate disturbance from Antarctica to the TAO are also studied.

CLIMATE DATA AND NUMERICAL EXPERIMENTS

The ocean temperature and salinity data used in this study were obtained from two ensemble simulations performed with 30–members each, using the Coupled Climate Model version 2.1 (CM2.1, Delworth et al. 2006) developed at the Geophysical Fluid Dynamics Laboratory (GFDL). The CM2.1 model can simulate the climate system from weather to climate change scales without using flux adjustment to maintain a stable climate (Parise et al. 2015). It is composed of four separate (atmosphere–land–ocean–sea ice) components that interact with each other through the Flexible Modeling System coupling system. The ocean component of CM2.1 model is the version 5.0.2 of the Modular Ocean Model (Griffies et al. 2001). The sea ice component is a multi-layer sea ice model that resolves rheological processes of ice such as internal stresses and its resulting deformations, making it more dynamic in its heat and salt exchanges at sea ice-atmosphere and sea ice-ocean interfaces (Parise et al. 2015).The ensemble experiments (hereafter named as *layerctl* and *layermax*) were configured to assess the sensitivity of the Southern Hemisphere's climate to a historical maximum condition in ASI under the current climate conditions, for a period of 10 years (from July 2020 to June 2030, Table 1). The initial conditions for the both ensemble experiments were derived from a control run of 10 years forward from a spin-up run, where the climate conditions for each July–August–September (JAS) were used. This procedure has saved the climate conditions as close as possible to the period of the seasonal ASI maximum (September) and also includes the interannual variability of the climate by saving the JAS period for the first year, second year, third year, and so on. These 30 (10 years x 3 months; middle–late winter and early spring) climate conditions were used as initial conditions for the ensemble experiments, which were initialized in the month of July. Except for the ASI maximum fields, the ensemble initial conditions were the same for all experiments (Table 1). The maximum concentration of ASI, in turn, was calculated from the Met Office Hadley Center data set (HadISST1, 1870–2008) (Rayner et al. 2003), while the maximum thickness was calculated from a monthly climatology provided by the GFDL (1979–1996) (Taylor et al. 2000). Both conditions (area and volume) represented the maximum value of sea ice in the time series for each grid point, regardless of when it has occurred in time (Supplementary Material, Figure S1). More details about configuration and performance of the sensitivity experiments used in the present study can be seen in Parise (2014) and Parise et al. (2015).

Table 1

Firstly, the annual mean biases of the *layerctl* experiment were evaluated for the TAO domain through the comparison with the Simple Ocean Data Assimilation version 3.3.1 (SODA; Carton et al. 2018) oceanic reanalysis database (2006–2015). To measure the seasonal differences between two time series, the metric of Root Mean Square Error (RMSE) was used, as defined below according to Hyndman & Koehler (2006) and Chai & Draxler (2014):

$$RMSE = \sqrt{\sum_{i=1}^{n} \frac{(\hat{y}_i - y_i)^2}{n}}$$

where $\hat{y}_i$ are the predicted values, y_i are the observed values and n is the total number of observations.

Then, the impacts of ASI changes on TAO were evaluated for the whole simulated period (2020–2030) and also separately for three predetermined periods based on the criteria established in Parise et al. (2015) (Supplementary Material, Figure S2): from July 2020 to June 2024 when the ASI differences (*layermax–layerctl*) were still positive; from July 2024 to June 2028 when the ASI differences were close to zero; and from July 2028 to June 2030 when the differences were negative, that is, the ASI coverage became larger in the control experiment (*layerctl*) compared to the experiment that has received the disturbance (*layermax*).

The propagation time of the climate signal from high to low latitudes was here analyzed through

Hovmöller diagrams (latitude *vs* time) for the ocean temperature and salinity. These were obtained by calculating their zonal and vertical means in order to show the meridional propagation (Antarctica–Tropics) of the disturbance over time. In order to know through of which layer in the TAO the largest meridional transport of heat and mass has occurred, an average vertical profile (latitude *vs* depth) was obtained over time for the predetermined periods studied here (i.e., July 2020–June 2024; July 2024–June 2028; and July 2028–June 2030).

RESULTS

MERIDIONAL SHIFT OF THE CLIMATE SIGN GENERATED FROM ANTARCTICA

Our results are all based on the differences between the *layermax–layerctl* ensemble experiments means. The largest SST and SSS changes faced to ASI positive extremes have occurred during the middle–late spring to early-middle summer (Oct–Nov–Dec–Jan) (Figure 1). In general, the ASI positive extremes have resulted in a cold (-0.8°C) and fresh (-0.2) water anomalous pulse from the Antarctica to the north (Figure 1a-b). The main SST and SSS changes in the Southern Ocean have propagated from the sea ice edge (60°S–70°S), where the intensified heat and salt fluxes contribute to sea ice melting (Parise 2014), towards the TAO (Figure 1a). Near the Antarctic continent, the SST biases were larger during the melting seasons (southern summer and autumn), once during the freezing seasons the ASI coverage is also large in control (climatological) simulation. As the cold bias propagates towards the equator, warmer biases are observed over the southern high latitudes (Figure 1a, since 2027). Although some changes in SST can be found in certain regions of the southern TAO, a large warm bias has occurred in this from 30°S to 20°N in the sixth year of simulation, indicating an intensification of both subtropical oceanic gyres, especially in the southern cell (Figure 1a, in 2026). In the last 2 years, the southern TAO presented a cold bias, that became even larger in the end of simulation (-0.4°C). This indicates that, in terms of TAO response to ASI extremes, 10 years of coupled simulation was not time enough to completely dissipate the resultant climate signal.

The impacts of ASI positive extremes on sea surface salinity (SSS), in turn, were persistent along the yearly cycle in the Southern Ocean, with the fresh water continually propagating from Antarctica towards the tropics, reaching 30°S at the end of the fourth year of simulation (Figure 1b). Near the equator (5°S–5°N), SST changes have appeared firstly as a dipole structure, with a fresher (saltier) bias in southern (northern) sector, respectively (Figure 2, from 2020 to 2021). Then, the equatorial fresh biases start to move southwards, spreading the freshwater over the southern tropical latitudes (until 30°S). It seems that SSS biases found in southern high latitudes do not reach the low latitudes by the ocean surface of Southern Hemisphere, once they have appeared there before the freshwater pulse has reach the parallel of 30°S, as we will discuss forward. The response of SSS to ASI positive extremes has also shown the intense action of meridional teleconnections in TAO, which propagated especially from low to mid latitudes until the end of simulation (Figure 1b).

Figure 1

The ocean temperature and salinity biases found through the zonal (from 90°S to 30°N) profiles (0 to 500 m) during the predetermined periods (i.e., July 2020–June 2024; July 2024–June 2028; and July 2028–June 2030) are showed in Figure 2 e 3. During the first 4 years of simulation, the ASI positive extremes resulted in cold biases (-0.4°C) in the upper layers of Southern Ocean, from south pole to 30°S, and more intensely south of 50°S (Figure 2a, in blue). As the same time, warm biases (+0.4°C) are found occurring just below 50 m, in subsurface layers of southern high latitudes (Figure 2a, in red). The cold biases have moved towards the mid latitudes during the following 4 years of model integration, with the largest changes occurring around 50°S, over the Antarctic Convergence (Figure 2b). As the cold water is displaced towards the equator by the enhanced Ekman transport in mid latitudes (Parise et al. 2014), the warmer subsurface water is allowed to exchange heat fluxes with the southern atmosphere again (Figure 2c). Still in the last 2 years of the experiments, the cold bias is found spreading over the mixed-layer of the whole TAO (Figure 2c). Before the climate signal is spread over the surface, cold biases are found over the southern subtropics, indicating a weakening of the oceanic gyre. We also observed a cold bias around 30°N, from surface to 200 m depth, whose changes can be related to Mediterranean Intermediate Water flow (Giorgi & Lionello 2008). This is associated with a slight subsurface warming (+ 0.1°C) in the northern TAO, first in 20°N (Figure 2a) and last in 10°N (Figure 2c).

Negative biases of ocean salinity (~ -0.2) from the surface down to approximately 80 m depth were found over southern mid and high latitudes during the first 8 years of model simulation (Figure 3a-b). In the first 4 years, the fresh bias extends until the latitude of 50°S (Figure 3a) and up to 40°S for the next 4 years (Figure 3b). Then, the fresh biases have spread out all over the whole Atlantic surface, except over the southern high latitudes where a saltier bias is found (-0.05). The fresher water peaks at 50°S and also at 4°N, both from the surface to 110 m depth (Figure 3c).

In short, our study has shown that the melting-resulted cold and fresh water has been shifted from the Southern Ocean towards the low latitude through the Subantarctic Mode Water (SAMW) flow, in the upper ocean layers (0–50m). At the Antarctic Convergence (50°S), this climate signal eventually influences the Antarctic Intermediate Water (AAIW) flow by buoyancy gain, once it has resulted from the melting of ASI extremes. The low salinity core of AAIW extends northwards from the Antarctic Polar Front zone at a depth of about 1000 m beneath the subtropical gyres (Sloyan & Rintoul 2001). Here, the increased AAIW flow became shallower, eventually modifying the whole subtropical cell (Figure 2a-b).

Figure 2

Figure 3

RESPONSE OF TROPICAL ATLANTIC OCEAN TO POSITIVE EXTREMES APPLIED TO ANTARCTIC SEA ICE FIELD

From this section onwards, we started to show the results from our study obtained through numerical modeling experiments of climate, when extremes ASI were imposed as initial conditions for each ensemble member. First, the performance of the GFDL/CM2.1 model in simulating the TAO surface fields was evaluated. The results from RMSE show that the SST (SSS) fields in the TAO are better simulated by CM2.1 model during MJJ (NDJ and DJF quarters) quarters, respectively (Table 2). For SST, the largest errors were found in the middle of year (AMJ), while for SSS they occurred in the beginning of the year (MAM) (Table 2).

Table 2

Through the *layermax–layerctl* differences for the ocean fields simulated by the GFDL/CM2.1 model we found that temperature and salinity of the TAO are sensitive to the ASI extremes, as following details. The average profile (time x depth) for the ocean temperature differences calculated from the spatial average in the TAO domain (from 30°S to 30°N) clearly showed a cold bias (-0.15°C) from the surface down to 150 m depth approximately (Figure 4a). This has become more intense at surface after 2 years of simulation (2022), being deepened in the following year (2023). This subsurface signal has persisted for the next 4 years (2024–2027), when it is weakened. That is associated with a warm bias (+ 0,15°C) near the surface from 2026 to 2027. Afterwards, the climate signal propagated as an oscillatory pattern that alternated between cold and warm waters in the first layers of ocean (0–50 m). When the cold bias dominated the superficial layers of the TAO in 2027, it was associated with a warm bias (+ 0.01°C) at subsurface layers in the following year (Figure 4). It is also noted that the disturbance applied to the ASI field was not fully dissipated after the 10th year of model simulation, which was evaluated in this study.

The time x depth mean profile for the TAO salinity is shown in Figure 4. The result shows that TAO presented a small (-0.01) but persistent fresh bias at the surface of the experiment *layermax* compared to *layerctl*. The superficial (upper to 100 m) fresher biases were larger after 2 years of simulation (from 2022) and have persisted until the end of the experiment. This indicates that 10 years of simulation was not time enough to dissipate the climate signal generated by ASI positive extremes, which has propagated northwards as cold and fresh water, first at surface and then through sub-superficial layers (Figure 4b).

Figure 4

DISCUSSION

The cold and fresh water pulse found in the present study as a result of melting ASI extremes has moved towards the TAO through the SAMW flow (Sloyan & Rintoul 2001). This water mass is usually formed on the northern face of the Antarctic Polar Front and then transported to the South Atlantic and North Atlantic basins (Williams et al. 2006). As the subsurface Antarctic waters flow northwards, warm subtropical waters are taken southward to replace them. The subsurface cooling mitigates an intensification of the subtropical gyre which is linked to the transport from the AAIW and SAMW water masses that naturally inject cold and fresh water into the subtropical basins, where together with the South Atlantic Current feeds the gyre, strengthening it (Jacobs et al. 2002; Curry et al. 2003).

In the period when the ASI was still higher in comparison to the control simulation (first 4 years of simulations), the condition was associated to the freshwater input into the Southern Ocean (Parise et al. 2015), that was transported northwards by intensified flows of Antarctic superficial waters. Such freshening of the upper Southern Ocean is responsible for a reduction in the AAIW salinity (Curry et al. 2003). Reduced salinity implies an enhanced freshwater input on the ocean surface, and normally is associated with increase of precipitation, sea ice melting, ice shelves melting, ice sheets and glaciers melting, and also changes in oceanic processes, such as reduced upwelling of Lower Circumpolar Deep Water (Cook et al. 2005; Carter et al. 2008).

The freshwater exchange between sea ice and ocean has a substantial influence on deep ocean heat uptake in the Southern Ocean (Kirkman & Bitz 2011). According to these authors, the freshwater input mainly from sea ice reduces the convection process, which in turns reduces the entrainment of heat into the mixed-layer and reduces the upward heat transport along isopycnals. The reduced upward heat transport causes deep-ocean heating south of 60°S and below 500–m depth, with a corresponding surface cooling in large parts of the Southern Ocean. These results indicate that changing sea ice freshwater and salt fluxes are key component in the surface warming of the Southern Ocean and the weak reduction in ASI in model projections (Mackie 2020).

The northward melting freshwater transport implies on changes in the ocean salinity of waters entering the lower and upper overturning cells. This process of northward freshwater transport by sea ice effectively removes freshwater from a region making up the lower overturning cell, in particular AABW, and adds freshwater to the upper circulation cell, especially AAIW (Haumann et al. 2016). Therefore, as the salinity dominates the density structure in polar oceans, the sea ice changes and the meridional transport of melting-resulted freshwater are the major contributors to recent salinity changes in the Southern Ocean. The mid-depth salinity minimum layer characterizing the AAIW is one of the most prominent features of the Southern Hemisphere oceans. The low-salinity core extends northwards from the Antarctic Polar Front zone at a depth of about 1000 m beneath the subtropical gyres in each basin. In the Atlantic, the AAIW core can be traced across the equator and into the North Atlantic, where it supplies a large fraction of the northward flow required to balance the export of North Atlantic Deep Water (Schmitz & Richardson 1991). Using satellite observations supplemented by sea-ice reconstructions, the authors still estimated that the wind-driven northward freshwater transport by sea ice increased by 20±10 per cent between 1982 and 2008 (+6± 3 mSv decade-1). This enhanced divergence of sea ice and freshwater may also result from an maximum of ASI, followed by its melting and freshwater pulse into the Southern Ocean, as shown in our study.

Early studies suggested that the circumpolar formation of AAIW is resulted from the sinking of Antarctic Surface Water below the Subantarctic Front (Deacon 1937). This circumpolar formation mechanism was essentially replaced by theories that suggest the formation of AAIW is explicitly linked to SAMW, instead of to Antarctic Surface Water (McCartney 1977) and that the renewal of AAIW occurs in specific regions of the Southern Ocean, such as the southwest Atlantic sectors (Georgi 1979; Molinelli 1981; Piola & Georgi 1982; Piola & Gordon 1989).

The SAMW and AAIW are important linkage ways from Antarctica to tropical regions since they act as main conduits for the supply of ocean proprieties. After being formed in the Southern Ocean these mode and intermediate waters are transported eastward with the Antarctic Circumpolar Current and northward into the adjacent subtropical gyres. In the Atlantic Ocean, SAMW and AAIW initially move northward with Malvinas Current adjacent to South American continent, but its penetration into the subtropical gyre along the western boundary is blocked by the southward flow of the Brazil Current (see forward in Figure 5). SAMW and AAIW are eventually transported into the subtropical gyre at the eastern boundary when part of the South Atlantic Current turns northward, feeding the Benguela Current (Stramma & Peterson 1990; Peterson & Stramma 1991). The northward currents transport of SAMW and AAIW from South Atlantic oceans injects cold, fresh mode and intermediate waters into the subtropical ocean basin. SAMW and AAIW circulate in the wind-driven gyres on each subtropical basin. In the western Brazil, Agulhas, and East Australian currents, modified warm, salty mode and intermediate waters are returned to the Southern Ocean. The exchange of ‘new’ mode and intermediate water with ‘older’ mode and intermediate water represents the mechanism by which Antarctic upper waters ventilate the subtropical gyres (Sloyan & Rintoul).

Our results also show a reduction in the TAO salinity from the fourth year of simulation (2024), just when the ASI field returns to its climatological condition. After that period, even though ASI field has already returned to its climatological state, a climate memory to the initial conditions of sea ice has persisted for the next four years (until 2028) as an input pulse of cold and fresh water into the Southern Ocean (Parise et al. 2015). This was transported northwards by the SAMW flow, through the oceanic upper layers, in response to increased Ekman transport in mid latitudes (Parise 2014). The decrease in TAO temperature and salinity just below the mixed-layer (from 100 to 700 m) suggests an intensification of the shallow Subtropical Cell (STC), which consists of a warm Ekman flux at the surface towards the pole. In compensation, the STC provides cold source waters towards the equator. The STC provides the oceanic bridging of the climate signals (Kröger et al. 2005).

It is known that the rate of global ocean water masses formation and transport are limited not only by the efficiency of high latitude convective mixing, but also by the southern density gradient (pole-tropics) and the ability of the ocean to heat up the deep waters that emerge (Bryan 1987; Marotzke & Scott 1999). The larger stratification of the Southern Ocean has resulted from salinity changes related to melting of ASI extremes. Increased stratification in the surface layers has also reduced the ability of ocean to lose heat to the atmosphere, resulting in a warming in the subsurface layers of the Southern Ocean (Parise et al. 2015). As a consequence, the subduction processes of water masses under a stratified ocean are generally suppressed (Bitz et al. 2006; Aiken & England 2008).

In addition to the sea ice cover, the colder surface of the ocean also affects the atmosphere by providing less heat fluxes transfer (Pezzi et al. 2009; Parise et al. 2015; Pezzi et al. 2016 and 2021). At mid latitudes, the air temperature decreases and the westerly winds decrease from 45°S to 60°S and intensify from 30°S to 45°S in response to increased ASI (Raphael et al. 2011). According to Parise et al. (2015), the more intense the interactions between sea ice and the other components of the coupled climate system, the faster the maximum anomalies imposed on the ASI field melts, and consequently the larger the input of cold and fresh water into the Southern Ocean. This ocean-sea ice-atmosphere interaction is greater at the sea ice edges and basal layers (Parise et al. 2015). Both the insulating effect of sea ice and the cold and fresh water input on the surface of Southern Ocean contribute to intensify the southern heat gradient, causing more heat to be transported southwards, especially at the latitudes over the ASI edge (Parise 2014).

The presence of sea ice at the poles strongly influences the surface temperature (Raphael et al. 2011). During the melting season (summer), where ocean surface temperatures are warmer, the heat flux from the ocean to the atmosphere is more intense. As they are regions of larger contact with relatively warmer waters, they contribute to the sea ice melting and the release of this heat into the atmosphere. Temperature differences close to the continental edge can be reasonably explained as a direct thermal response to the sea ice distribution.

Our results have also shown a fresh bias near 30°N, which can be related to changes in the Mediterranean Intermediate Water (MIW) flow. The mean cross section of the deep circulation in the Atlantic Ocean shows the presence of the MIW that flows through the Straits of Gibraltar into the Atlantic Ocean (Oppo & Fairbanks 1987). This water is warm and salty from the warm temperatures and high evaporation characteristic of the Mediterranean Sea, so it is denser than the normal surface water and forms a layer about 1–1.5 km deep. Eventually this water will move north to the Greenland Sea, where it will be cooled and will sink, becoming the dense NADW (Giorgi & Lionello 2008). The surface waters of the eastern Mediterranean Sea have a salinity of about 38. As this water is more dense than the Atlantic Ocean surface water (35) so it sinks around 35°N. Carbon isotope records suggest that the influence of Mediterranean Sea extended until the Caribbean Sea during the last glaciation, being the most volumetrically important water mass in the intermediate-depth Atlantic (Oppo & Fairbanks 1987).

CONCLUDING AND FINAL REMARKS

Our study showed that a maximum condition of ASI concentration and thickness has the potential to largely influence on the Southern Ocean stratification, by exporting resulted-melting cold and fresh water towards the equator. By isolating effect, the enhanced buoyance of freshwater also contributes to suppress the vertical heat fluxes, making the Southern Ocean to warm up just below the surface (from 50 to 400 m depth). As cold and fresh surface water is displaced by Ekman transport from Southern Ocean to low latitudes, the heat stored in subsurface layers is released to southern atmosphere. The major changes caused by increased ASI in Southern Ocean and how this climate signal has propagated toward the TAO discussed here are highlighted in a schematic (Figure 5), where the numbers are used to show the sequential changes. The pathways by which the climate signal was transferred via the ocean to the TAO, how this freshwater transport has occurred, in what magnitude and how long it has taken to arrive in the region are suggested to be as follows: 1) The imposed ASI maxima generated an input of cold and fresh water to the surface of Southern Ocean; 2) The freshwater ejection from sea ice melting has increased the Southern Ocean buoyance, reducing the vertical heat fluxes and generating a warming in subsurface layers; 3) As cold and fresh surface water is displaced towards the equator, by Ekman transport (Parise 2014), the heat stored in subsurface layers is then released to southern atmosphere; 4) and 5) the northward shift of the colder and fresher water was given by the flows of SAMW and AAIW, when it sinks at the Antarctic Convergence (~50°S) by the process of subduction. SAMW and AAIW are eventually transported into the subtropical gyre through the eastern boundary, when part of the South Atlantic Current turns northward, feeding the Benguela Current (Figure 5a). The northward transport of SAMW and AAIW from South Atlantic injects these cold and fresh mode/intermediate waters into the subtropical basin; 6) the climate signal reaches the low latitudes through the equatorial upwelling, eventually warming up on the surface; 7) in response to the divergent flow at surface, the climate signal spreads out southwards, through the upper branch of subtropical gyre. The TAO was sensitive to the positive extremes of ASI, with significantly changes in ocean temperature (-0.8°C on the surface and +0.2°C between 50–400 m depth) and salinity (-0.2).

Figure 5

Still, we have concluded that 10 years of coupled simulations was enough time to propagate the climate signal generated by ASI positive extremes melting, which has reached the TAO around 2 year later. That is, the oceanic connection between Southern Ocean and TAO is indeed established within the timescale analyzed in the study (i.e., 10 years). Nonetheless, the period needed to completely dissipate the disturbance generated from ASI seems to be longer, being depends on the thermodynamic and dynamic processes of sea ice, the climate mechanisms and feedbacks evolved, and the ocean memory to ASI extremes (Parise 2014; Parise et al. 2015).

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FIGURES

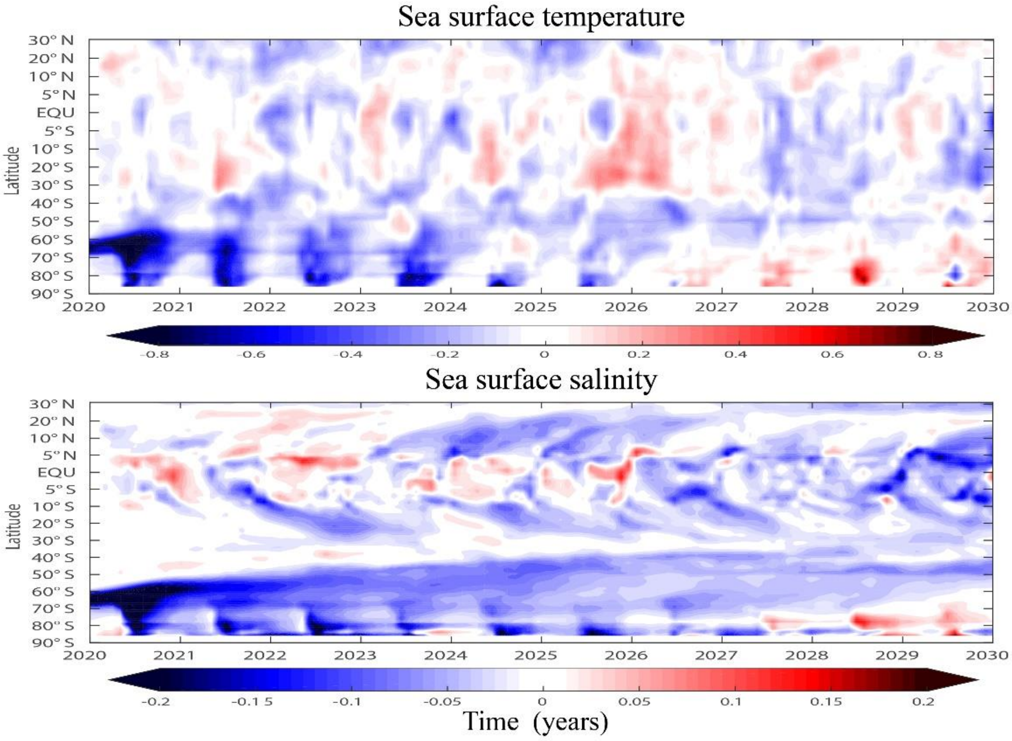

Figure 1 – Hovmöller diagrams for the zonal mean of **(a)** sea surface temperature (SST, in °C) and **(b)** sea surface salinity (SSS) in the Atlantic sector for the period from July 2020 to June 2030.

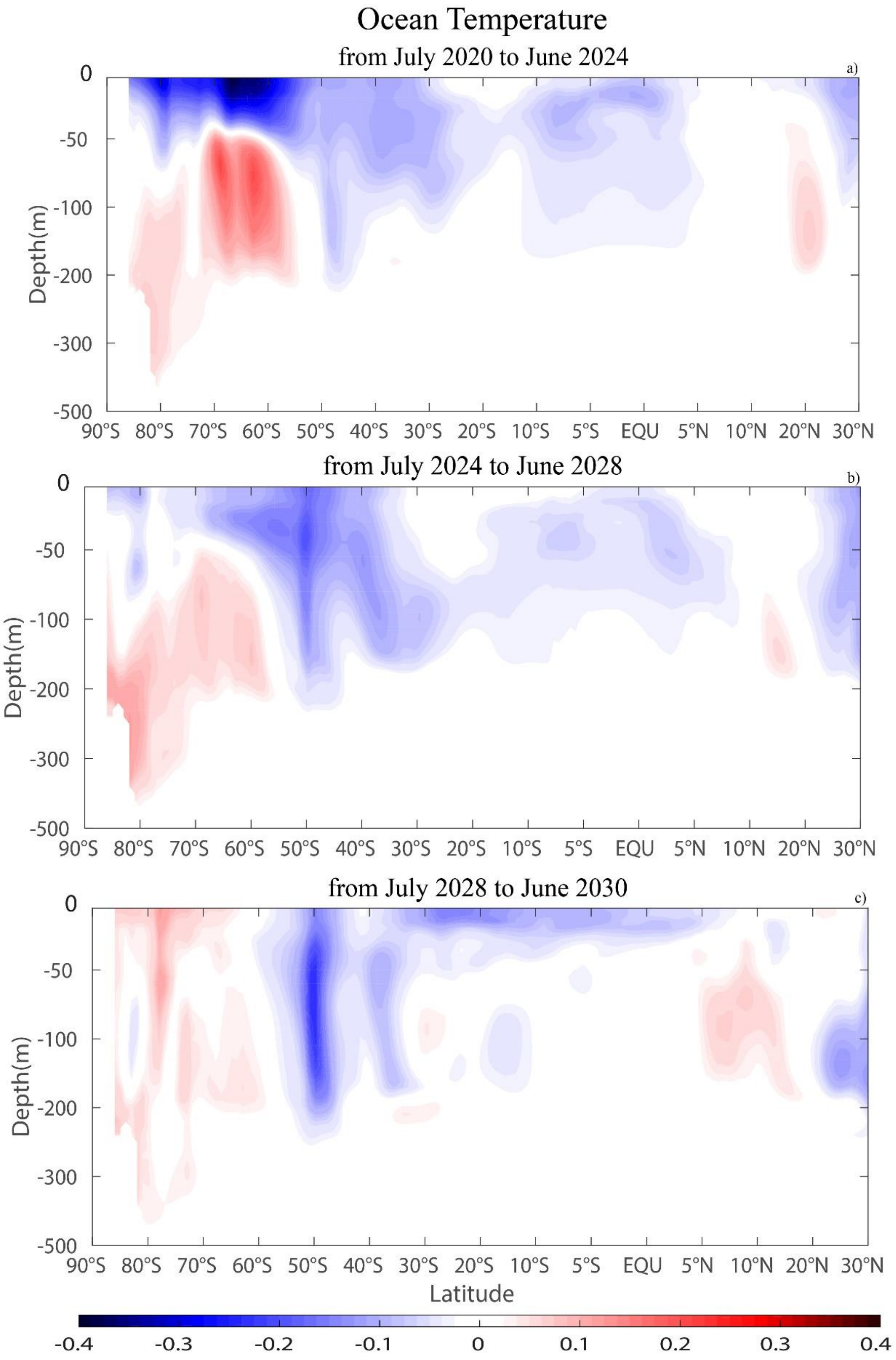

Figure 2 – Zonal mean vertical (0–500 m) profile of ocean temperature differences (*layermax–layerctl*) extending from 90°S to 30°N during the periods: **a)** July 2020–June 2024; **b)** July 2024–June 2028 and **c)** July 2028–June 2030.

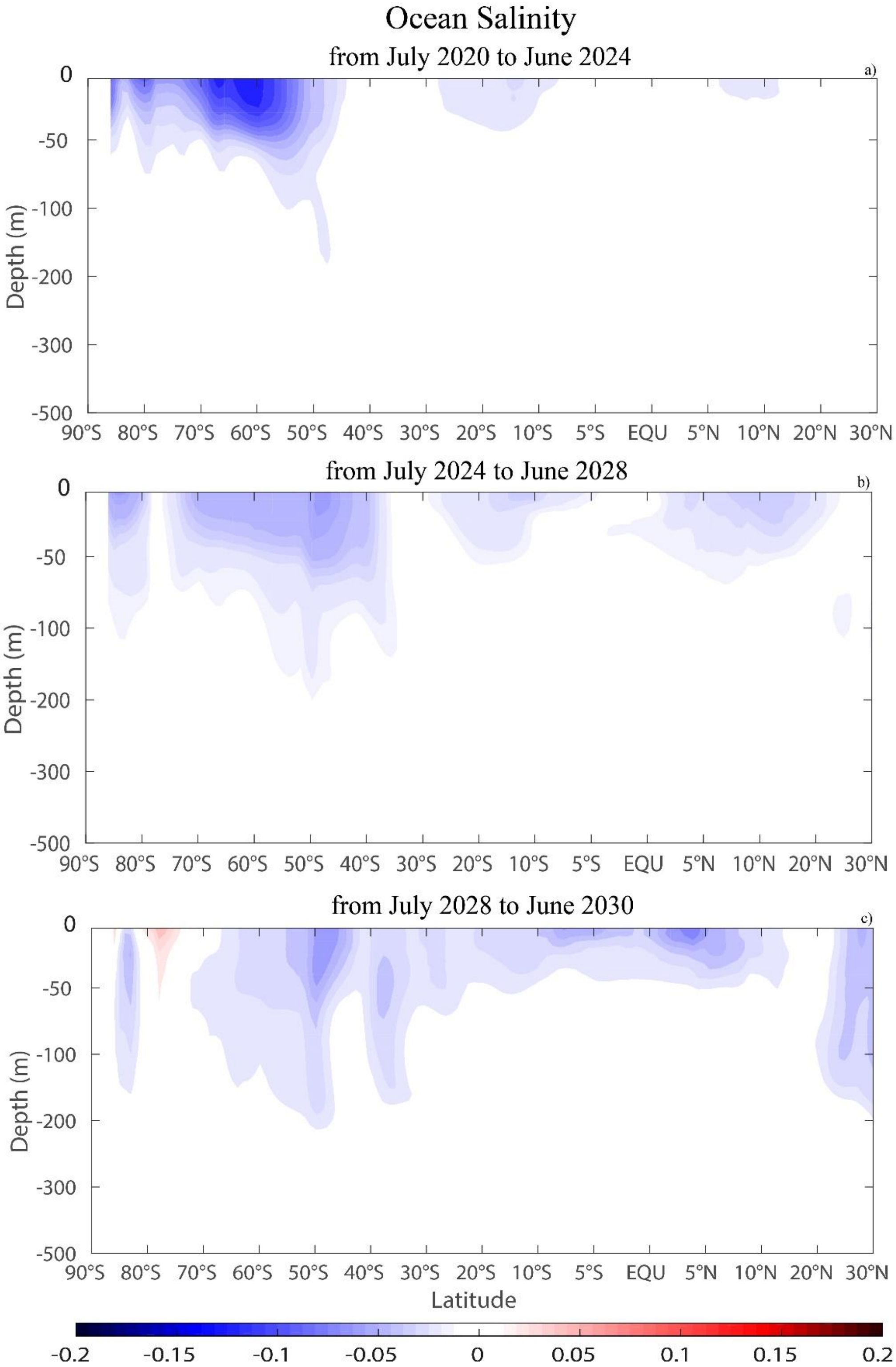

Figure 3 – Zonal mean vertical (0–500 m) profile of ocean salinity differences (*layermax–layerctl*) extending from 90°S to 30°N during the periods: **a)** July 2020–June 2024; **b)** July 2024–June 2028 and **c)** July 2028–June 2030.

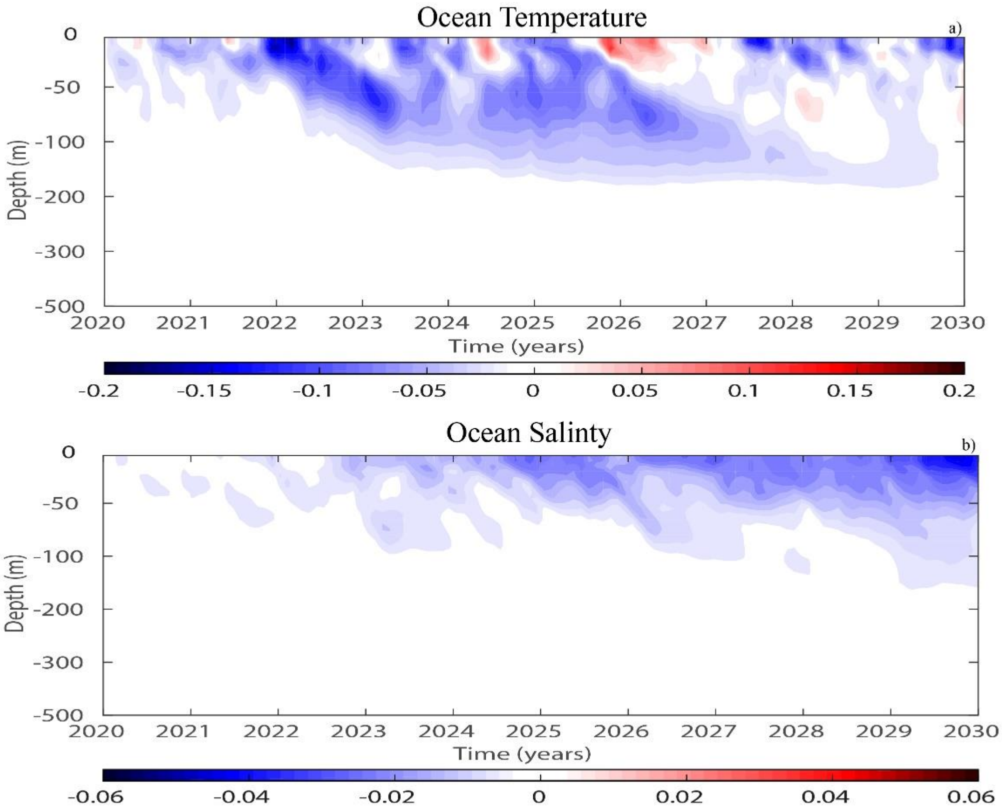

Figure 4 – Time x depth (0–500 m) mean profile of **(a)** ocean temperature and **(b)** salinity differences (*layermax–layerctl*) from the spatial average in the TAO domain (30°S–30°N), during the 10 years of model simulation (July 2020–June 2030).

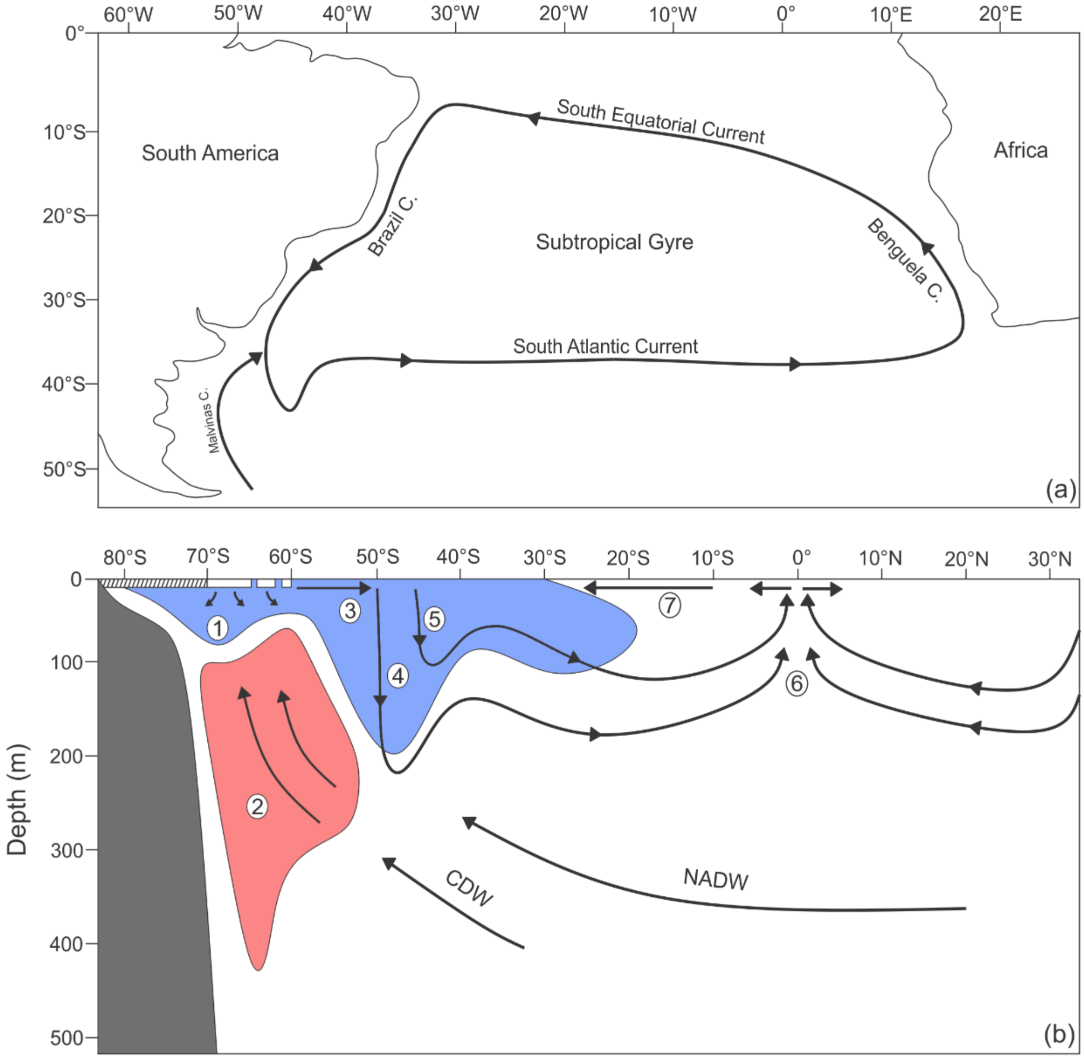

Figure 5 – Schematic of the main changes in Southern Ocean and of how the cold and fresh water pulse from Antarctic sea ice melting has transferred towards the Tropical Atlantic Ocean.

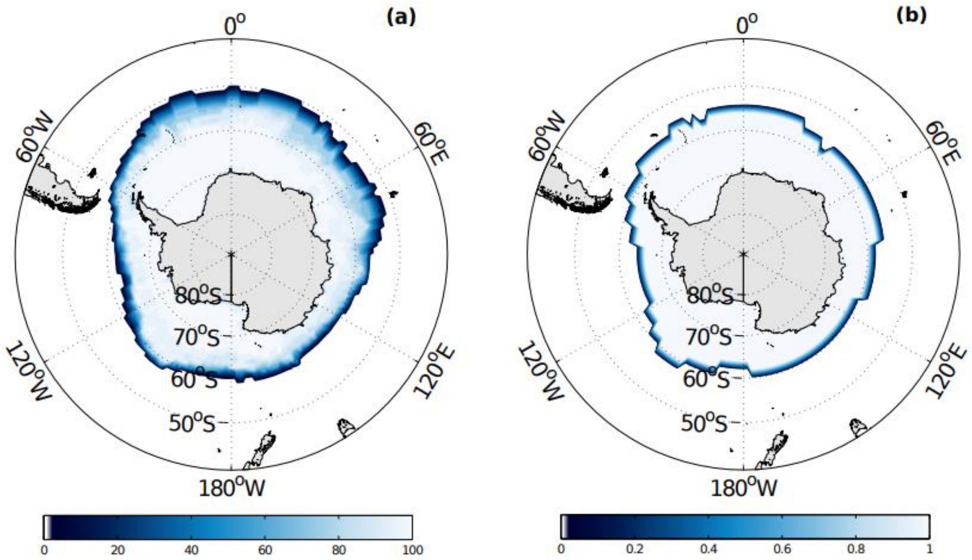

Figure S1 – Initial conditions of the positive extremes of Antarctic sea ice for the *layermax* ensemble experiment: (a) concentration, in %; and (b) thickness, in meters. Taken from Parise et al. (2015).

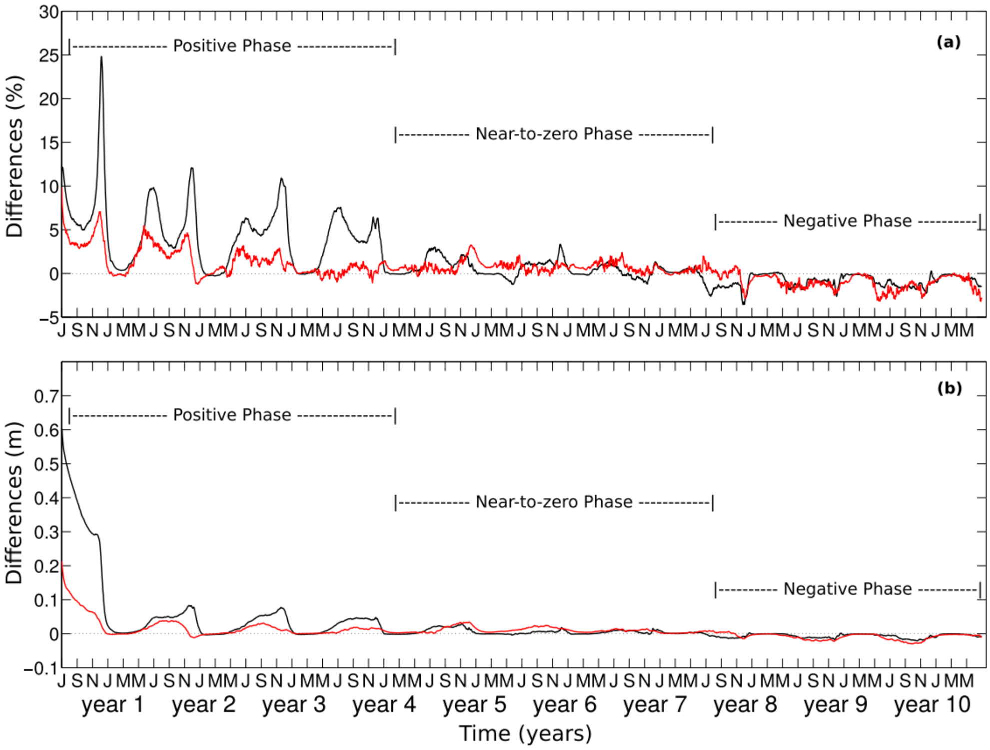

Figure S2 – Differences of Antarctic sea ice for the *layermax–layerctl* (black lines) and *slabmax–slabctl* (red lines, not evaluated in this study) experiments: (a) concentration, in %; and (b) thickness. Taken from Parise et al. (2015).

TABELAS

Table 1 – Schematic table with basic information on the sensitivity experiments performed with the CM2.1 model and used in this study, as a complement to that presented by Parise et al. (2015).

	layerctl	***layermax***
Horizontal and vertical resolution of the oceanic component	1° in latitude and 1° in longitude, this latter getting progressively finer toward the equator (0.33° resolution), with 50 z-coordinate levels	
Model spin-up	a short (1 year) uncoupled simulation, with only the ocean and sea ice models, followed by a long (30 years) fully coupled integration, from 1990 to 2020	
Initial conditions for ASI concentration (%)	a control model integration of 10 years forward from the spinup, where the restarts conditions for each July–August–September (JAS) were used	Met Office Hadley Center dataset, from 1870 to 2008 (Rayner et al. 2003)
Initial conditions for ASI thickness (m)		GFDL monthly climatology from 1979 to 1996 (Taylor et al. 2000)
Running-period (Parise, 2014)	10 years, from July 2020 to June 2030	
Running-period analyzed in the presente study	the same of Parise (2014) and also following the predetermined periods by Parise et al. (2015) in relation to the ASI *layermax-layerctl* differences: the positive phase (July 2020–June 2024); the near–to–zero phase (July 2024–June 2028) and the negative phase (July 2028–June 2030)	

Table 2 – Seasonal RMSE between *layerctl* ensemble experiment (2020–2030) and SODA3.3.1 reanalysis (2006–2015) for sea surface temperature (SST, in °C) and sea surface salinity (SSS).

	QUARTERS											
	DJF	**JFM**	**FMA**	**MAM**	**AMJ**	**MJJ**	**JJA**	**JAS**	**ASO**	**SON**	**OND**	**NDJ**
SST	0.41	0.40	0.38	0.34	0.31	0.90	0.62	0.34	0.38	0.37	0.33	0.32
SSS	0.18	0.16	0.13	0.09	0.11	0.12	0.13	0.11	0.11	0.14	0.16	0.18

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III. CONSIDERAÇÕES FINAIS

Este estudo mostrou que uma perturbação máxima na condição do GMA tem uma grande influência nos campos da temperatura e salinidade no OAT, o que repercutiu em uma intensificação no gradiente de calor do Oceano Austral e no transporte do mesmo, especialmente nas latitudes sobre as margens do GMA. Esse sinal climático (pulso de d'água fria e doce) advindo do Oceano Austral foi impulsionado para norte pelo aumento do transporte de Ekman na Divergência Antártica (60ºS), deslocando-o para as mais baixas latitudes. Esse deslocamento meridional da água de derretimento resultou na liberação do calor armazenado nas camadas sub-superficiais do Oceano Austral (Parise 2014; Parise et al. 2015).

Ao analisar a estrutura vertical do oceano, constatou-se que o sinal climático propagou-se do Oceano Austral em direção às baixas latitudes através dos fluxos de duas massas de água, a Água Modal Subantártica (SAMW) e a Água intermediária Antártica (AAIW) quando a água afunda na Convergência Antártica (~50°S) pelo processo de subducção. Os resultados mostraram que o OATé sensível aos extremos aplicados ao GMA, com o sinal climático persistindo nas camadas subsuperficiais e superficiais, assumindo um predomínio nas primeiras camadas (~ 0-50 m) do oceano a partir do 7° ano de integração do modelo.

Visto que os 10 anos de simulação do modelo acoplado GFDL/CM2.1 foram suficientes para mostrar asmudanças observadas na circulação oceânica superficial e subsuperficial do OAT como resultado do distúrbio aplicado ao GMA até o final das simulações, concluímos que o período necessário para dissipar completamente a perturbação gerada pelo GMA parece ser mais longo, sendo dependente dos processos termodinâmicos e dinâmicos do gelo marinho, os mecanismos e feedbacks climáticos evoluíram, e a memória oceânica aos extremos ASI (Parise 2014; Parise et al. 2015).

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ANEXOS

1) NORMAS DA REVISTA

Instruções aos autores

O periódico Anais da Academia Brasileira de Ciências considera para publicação as submissões feitas exclusivamente pelo sistema online de gerenciamento de artigos. Uma vez que seu artigo esteja de acordo com as instruções abaixo, favor acessar o sistema no link https://mc04.manuscriptcentral.com/aabc-scielo. Por favor, leia estas instruções com atenção e as siga rigorosamente. Desta forma você irá garantir que a avaliação e a publicação de seu artigo sejam o mais eficiente e veloz quanto possível. Os editores reservam-se ao direito de devolver artigos que não estejam de acordo com estas instruções. Apesar de dispormos de uma página de instruções em português, lembramos que só consideramos para submissão, avaliação e publicação os artigos redigidos de forma clara e concisa na língua inglesa.

Objetivo e política editorial

Todos os manuscritos submetidos devem conter pesquisa original que não tenha sido publicada ou esteja sob consideração em outro periódico. O critério primário para aceitação é qualidade científica. Artigos devem evitar o uso excessivo de abreviações ou jargões, além de ser tão inteligíveis quanto possível para o público em geral. Deve ser dada atenção particular às seções Abstract, Introduction e Discussion, as quais devem detalhar a novidade e significância dos dados relatados. Não cumprir com qualquer um dos pontos acima pode causar atraso na publicação ou até mesmo a recusa do artigo. textos podem ser publicados em forma de revisão, artigo completo ou como comunicação curta (short communications). Os volumes regulares dos AABC são publicados em março, junho, setembro e dezembro.

Tipos de artigos

Revisões

Revisões são publicadas apenas por meio de convite, tendo ainda que passer pelo processo de revisão por pares. Contudo, uma proposta de revisão pode ser enviada por e-mail para a Assessoria de publicações (aabc@abc.org.br). O e-mail deve conter os tópicos e autores da revisão proposta, bem como o abstract, área dos AABC na qual o artigo se encaixa e a justificativa pela qual este tópico seria de particular interesse à área. Os AABC permitem que os autores depositem preprints de seus artigos em servidores de preprint tais como, mas não limitados a, ArXiv.org e bioRxiv.org. Contudo, os autores devem atualizar os registros informando que o artigo foi aceito/publicado pelos AABC.

Cartas ao editor

Cartas ao editor (Letters to the Editor) estarão sujeitas à edição e revisão, não podendo conter material que tenha sido submetido ou publicado em outro periódico. Cartas que venham a se referir a um artigo publicado nos AABC não podem exceder 250 palavras (não contando com referências) e devem ser recebidas em até 4 semanas após a publicação online do artigo. Cartas não relacionadas a um artigo publicados pelos AABC não podem exceder 500 palavras (não contando com referências). Uma carta não pode ter mais de dez referências, além de uma figura ou tabela.

Articles

Sempre que possível, artigos devem estar subdivididos nas seguintes partes: 1. Página de rosto; 2. Abstract (em página separada, 200 palavras ou menos, sem abreviações); 3. Introduction; 4. Materials and Methods; 5. Results; 6. Discussion; 7. Acknowledgments, se aplicável; 8. Author contributions (se o artigo tiver mais de um autor); 9. References; 10. Legendas de figuras e tabelas, se aplicável. Artigos de algumas áreas, como por exemplo Ciências Matemáticas, devem seguir seu formato padrão. Em alguns casos, pode ser aconselhável omitir a seção (4) e juntar as partes (5) e (6). Quando aplicável, a seção Materials and Methods deve indicar o Comitê de Ética que avaliou os procedimentos para estudos em seres humanos ou as normas seguidas para tratamentos experimentais em animais.

Short communications

Short communications procuram relatar uma importante e concisa contribuição para pesquisa, a qual progrediu para o estágio em que os resultados devem ser tornados públicos para outros pesquisadores do mesmo campo. Uma short communication também deve possuir Abstract (100 palavras ou menos, neste caso), uma pequena introdução (até 200 palavras) e não pode exceder 1500 palavras. Tabelas e Figuras podem ser incluídas no texto, mas este deve ser proporcionalmente reduzido. Este tipo de publicação nos AABC deve conter contribuições extremamente relevantes, sendo um tipo de artigo com alta competição. Após recebimento e primeira triagem editorial, artigos serão avaliados por pelo menos dois revisores, sendo eles de instituições educacionais e/ou de pesquisa tanto nacionais quanto internacionais, desde que comprovada sua produção científica. Após possíveis correções e sugestões, o artigo pode ser aceito ou recusado, considerando os pareceres recebidos. Nós utilizamos o programa integrado

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Todas as seções do manuscrito devem possuir espaçamento duplo. Após o aceite, nenhuma mudança será feita no artigo, de modo que as provas de prelo precisem apenas de correções em erros tipográficos. Lembramos que o envio de artigos é feito exclusivamente pelos autores através do nosso sistema de gerenciamento de artigos.

Tamanho do artigo

Os artigos podem ser de qualquer tamanho necessário para a apresentação e discussão concisa dos dados, mas mantendo-se conciso e cuidadosamente preparado tanto em termos de impacto quanto de legibilidade. No entanto, os artigos não devem exceder 50 páginas, incluindo todos ositens (figuras, tabelas, referências, etc.), a menos que possua autorização prévia do Editor-Chefe.

Página de rosto

A página de rosto do artigo deve apresentar os seguintes itens: 1. Título do artigo com até 150 caracteres, sem abreviações e com a tentativa de manter o interesse amplo da comunidade científica; 2. Nomes completos de todos os autores. Utilize números sobrescritos para indicar a filiação de cada autor. 3. Endereços profissionais e ORCID de todos os autores, incluindo instituição, departamento, rua, número, CEP, cidade, estado e país; 4. Key words (de 4 a 6 em ordem alfabética e separadas por vírgulas); 5. Running title (versão resumida – e não abreviada - do título com até 50 caracteres, incluindo espaços); 6. Seção dos AABC à qual o artigo pertence; 7. Nome, endereço, telefone e e-mail do autor para correspondência, a quem serão enviadas as mensagens mais relevantes do processo de avaliação. Este autor ou autora deve ser indicado com um asterisco após seu nome. Não cumprir com qualquer dos requisitos acima fará com que o artigo seja devolvido (unsubmitted) para correções.

Abstract

O abstract deve conter até 200 palavras e apresentar as principais descobertas do artigo, incluindo uma breve introdução, os objetivos do trabalho e uma conclusão baseada nas presentes descobertas. Caso os autores estejam submetendo uma revisão convidada/autorizada, o abstract deve abordar o principal tema da revisão e explicitar a contribuição de tal revisão à área. O abstract não deve possuir títulos nem citações/referências.

Texto do manuscrito

Todo o texto deve ser escrito com espaçamento duplo utilizando a fonte Times New Roman tamanho 12 ou equivalente, desde que mantida a legibilidade. Por favor, organize seu texto nas seguintes partes sempre que possível: 1. Página de rosto; 2. Abstract (em página separada, 200 palavras ou menos, sem abreviações); 3. Introduction; 4. Materials and Methods; 5. Results; 6. Discussion; 7. Acknowledgments, se aplicável; 8. Author contributions (se o artigo tiver mais de um autor); 9. References; 10. Legendas de figuras e tabelas, se aplicável. Artigos de algumas áreas, como por exemplo Ciências Matemáticas, devem seguir seu formato padrão. Em alguns casos, pode ser aconselhável omitir a seção (4) e juntar as partes (5) e (6). Quando aplicável, a seção Materials and Methods deve indicar o Comitê de Ética que avaliou os procedimentos para estudos em seres humanos ou as normas seguidas para tratamentos experimentais em animais. Todos os procedimentos devem ser detalhadamente descritos. Utilize inglês norte-americano para escrever o texto. Nomenclaturas da área de Química devem ser fornecidas de acordo com a União Internacional de Química Pura e Aplicada (IUPAC). Cepas de organismos também devem estar identificadas. Informe nomes de fornecedores de reagentes e/ou equipamentos. Utilize unidades e símbolos de acordo com o Bureau International des Poids et Mesures (SI) sempre que possível.

Acknowledgments

Devem ser incluídos ao fim do texto, antes das referências. Agradecimentos pessoais devem preceder nomes de instituições e agências. De forma ideal, as notas de rodapé devem ser evitadas, mas, quando necessário, devem estar numeradas. Agradecimentos a financiamentos, subsídios, bolsas de estudo e dívidas com outros colegas, bem como menções à origem do artigo (como uma tese, por exemplo), devem estar nesta seção. Favor incluir o nome completo da agência de fomento, país e número do projeto (se aplicável).

Abreviações

Devem ser definidas em sua primeira ocorrência no texto, exceto por abreviações padrão e oficiais. Unidades e seus símbolos devem estar em conformidade com as aprovadas pelo Bureau International des Poids et Mesures (SI).

Legendas de figuras

Esta informação deve ser fornecida ao fim do manuscrito, após as referências. Todas as figuras devem conter legenda. A legenda deve possuir uma sentença introdutória que descreve as principais descobertas. Todas as divisões na figura devem ser identificadas com letras minúsculas, quando aplicável (1a, 2a, 2b, 3c, 3d, etc.). Quando for o caso da utilização de barras de erro, favor informar se um número que vem após o símbolo ± é um Standard Error Of Mean (SEM) ou standard deviation of mean (SD). Deve ser informado na legenda se o resultado apresentado representa N experimentos individuais.

Tabelas

Cada tabela deve possuir um pequeno título acima da mesma. Notas abaixo das tabelas também podem ser utilizadas. Tabelas devem ser citadas no artigo em algarismos romanos (Table I, Table II, Tables IV and V, etc.). Tabelas devem ser submetidas separadamente em arquivos editáveis, preferencialmente .doc ou .docx.

Figuras

Só serão aceitas figuras de alta qualidade (mínimo de 300 dpi). Todas as ilustrações serão consideradas figuras, incluindo desenhos, gráficos, mapas, fotografias, esquemas, etc. Seu posicionamento tentativo deve ser indicado, assim como todas as figuras devem ser citadas com seu respectivo número ao longo do texto. Figuras devem ser enviadas de acordo com as seguintes especificações: 1. Desenhos e ilustrações devem estar em formato .PS/.EPS ou .CDR (PostScript ou Corel Draw) e nunca inseridas no texto; 2. Imagens ou figuras em escala de cinza devem estar em formato .TIF e nunca inseridas no texto; 3. Cada figura deve ser enviada em arquivo separado; 4. Figuras devem, a princípio, ser submetidas no tamanho em que espera-se que estejam publicadas no periódico, ou seja, largura de 8cm (uma coluna) ou 16,2cm (duas colunas), com a altura máxima de cada figura e respectiva legenda sendo menor ou igual a 22cm. As legendas das figuras devem ser enviadas com espaçamento duplo em página separada. Cada dimensão linear dos menores caracteres e símbolos não pode ser menor que 2 mm após redução. Figuras coloridas são aceitas tanto como figuras em preto e branco. No entanto, 5 figuras em p/b são sem custo aos autores, enquanto cada figura colorida na versão impressa será cobrada dos autores, com a comunicação sendo feita durante a fase de produção (após o processo de avaliação). De modo a padronizar a contagem e cobrança de figuras preto e branco, tabelas que ocupem dois terços da página ou que tenham mais que 12 colunas ou 24 colunas serão consideradas figuras p/b. Manuscritos de Matemática, Física ou Química podem ser redigidos em TEX, AMS-TEX ou LaTeX, desde que o arquivo .BIB seja enviado junto. Manuscritos sem fórmulas podem ser enviados em .RTF ou doc/docx para Windows.

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Os autores são responsáveis pela exatidão das referências, bem como suas respectivas citações. Artigos publicados ou ainda ‘In press’ podem ser incluídos. Comunicações pessoais (Smith, personal communication) devem ser autorizadas por escrito pelos envolvidos. Referências a teses, abstracts de encontros (não publicados em jornais indexados) e manuscritos em preparação ou apenas submetidos, mas não ainda aceitos, devem ser citados no texto no formato (Smith et al., unpublished data) e NÃO devem ser incluídos na lista de referências. Referências devem ser citadas no texto no formato a seguir sem a aspa simples, ‘Smith 2004’, ‘Smith & Wesson 2005’ ou, quando há 3 ou mais autores, ‘Smith et al. 2006’. Quando houver dois ou mais artigos cujo nome do primeiro autor e ano de publicação são idênticos, as referências devem ser diferenciadas por letras minúsculas, como em ‘Smith 2004a', ‘Smith 2004b’, etc. As referências devem ser listadas alfabeticamente de acordo com o nome do primeiro autor, sempre na ordem SOBRENOME XY, sendo X e Y as iniciais. Se há mais de 10 autores na referência, usar SOBRENOME XY ET AL., sem listar os demais autores. Referências devem conter também o título do artigo. Os nomes dos periódicos devem estar abreviados sem itálico, pontos ou vírgulas. Para as abreviações corretas, verifique listas das maiores bases de dados nas quais o periódico está indexado, ou consulte a World List of Scientific Periodicals. A abreviação a ser usada em referências dos Anais da Academia Brasileira de Ciências é An Acad Bras Cienc. Os seguintes exemplos devem servir de guias para sua lista de referências em nossa revista:

ALBE-FESSARD D, CONDES-LARA M, SANDERSON P & LEVANTE A. 1984a. Tentative explanation of the special role played by the areas of paleospinothalamic projection in patients with deafferentation pain syndromes. Adv Pain Res Ther 6: 167-182.

ALBE-FESSARD D, SANDERSON P, CONDES-LARA M, DELAND-SHEER E, GIUFFRIDA R & CESARO P. 1984b. Utilisation de la depression envahissante de Leão pour l’étude de relations entre structures centrales. An Acad Bras Cienc 56: 371-383.

KNOWLES RG & MONCADA S. 1994. Nitric oxide synthases in mammals. Biochem J 298: 249-258.

PINTO ID & SANGUINETTI YT. 1984. Mesozoic Ostracode Genus Theriosynoecum Branson, 1936 and validity of related Genera. An Acad Bras Cienc 56: 207-215.

DAVIES M. 1947. An outline of the development of Science. Thinker′s Library, n. 120. London: Watts, 214 p.

PREHN RT. 1964. Role of immunity in biology of cancer. In: NATIONAL CANCER CONFERENCE, 5., Philadelphia. Proceedings ..., Philadelphia: J. B. Lippincott, p. 97-104.

UYTENBOGAARDT W & BURKE EAJ. 1971. Tables for microscopic identification of minerals, 2nd ed., Amsterdam: Elsevier, 430 p.

WOODY RW. 1974. Studies of theoretical circular dichroism of polipeptides: contributions of B-turns. In: BLOUTS ER ET AL. (Eds), Peptides, polypeptides and proteins, New York: J Wiley& Sons, New York, USA, p. 338-350.

2) E-MAIL DE ACEITE DA AABC E PARECER DO REVISOR

Claudia Parise <claudiakparise@gmail.com>

Annals of the Brazilian Academy of Sciences - Decision on Manuscript ID AABC-2021-0800

Juliana Sayão <onbehalfof@manuscriptcentral.com> 19 de agosto de 2021 18:16
Responder a: jmsayao@gmail.com
Para: claudiakparise@gmail.com

19-Aug-2021

Dear Dr. Parise:

Manuscript ID AABC-2021-0800 entitled "LAGGED RESPONSE OF TROPICAL ATLANTIC OCEAN TO ANTARCTIC SEA ICE POSITIVE EXTREMES" which you submitted to the Annals of the Brazilian Academy of Sciences, has been reviewed. The comments of the reviewer(s) are included at the bottom of this letter.

The reviewer(s) have recommended publication, but also suggest some revisions to your manuscript. Therefore, I invite you to respond to the reviewer(s)' comments and revise your manuscript.

To revise your manuscript, log into https://mc04.manuscriptcentral.com/aabc-scielo and enter your Author Center, where you will find your manuscript title listed under "Manuscripts with Decisions." Under "Actions," click on "Create a Revision." Your manuscript number has been appended to denote a revision.

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Once again, thank you for submitting your manuscript to the Annals of the Brazilian Academy of Sciences and I look forward to receiving your revision.

Sincerely,
Dr. Juliana Sayão
Editor-in-Chief, Annals of the Brazilian Academy of Sciences
jmsayao@gmail.com

Associate Editor

Comments to the Author:
First, we like to apologize for the delay in delivering our decision associate with you manuscript. We had a hard time finding a reviewer that was willing to assess the merits of your submission. We managed to find 1 reviewer that provides a series of constructive comments as you can see below. I hope the authors find it useful.

Entire Scoresheet:
Reviewer: 1

Recommendation: Major Revision

Comments:
This manuscript shows that the positive extremes of Antarctic Sea Ice have a lagged response of tens of years on the ocean properties of the tropical Atlantic Ocean. The hydrographic properties are changed near the northern boundary of the sea ice extension, and then are propagated with SAMW and AAIW to the tropics. I found this work well developed with clear aims and results. I support the publication of this manuscript, after correction / better explanations of the question below.

- I think the order of the figures was wrong in the pdf file I received. In addition, the fact that the captions didn't bring the information of the figure number, make the reading confusing. I suggest the authors, for the next papers, be careful with these small details.
- the text has minor grammatical errors that could be fixed. For instance, the use of excessive commas (e.g., page 3 line 26 no need for the comma before "brings") of the lack of "the" (page 3 line 16 "the global thermohaline"). I suggest a double-check of text and correct these minor errors.
- Page 2 line 15: add what climate sign are you investigating
- Page 2 line 21 and the whole text: be careful with the word surface. I think you mean here "upper", no? "Surface" is used for the couple few metres of the ocean, whereas upper is used to refer to a bigger layer usually a couple of hundreds of metres.
- Page 2 line 26: the word "performance" does not fit here. Maybe "pathways"? I think performance is more related to the assessment/evaluation of the water mass, and the authors didn't do that.
- In some parts of the introduction the authors need to state how this work is different from Parise et al. (2015) since they use this work as a basis for the current manuscript. Or maybe state what was not addressed in that paper and how the current manuscript complements Parise et al. (2015).
- Page 4 line 22: in Parkinson (2019) they show long-term "increasing" sea ice (although from 2014 the sea ice extent decreased to minimum values on record). Also, need to state what trend the authors are talking about.
- Page 5 line 59: I think it's mean instead of integral (see caption of Fig. 1)?
- Fig. 1: in the Hovmoller there are blank patterns that seem suspicious. Why do the authors blank them? I suggest not do that. For the same figure, you should not see any signal of the ocean south of ~80˚S because it's land. Double-check your code, because the figure shows anomalies of T and S where should be land only.
- Is the period 2020-2030 just after the spin-up? I think the methods need a better explanation about the model: e.g., initial conditions, atmospheric forcing, resolutions...
- Page 6 lines 23-24: could the authors add a figure to show/prove the migration of the subtropical gyre? Also, how this happens? What is the mechanism that triggers the shift of the subtropical gyre? Need to clarify this question better. You could discuss this in the discussion section.
- Page 6 lines 35-36: that sentence regarding temperature should be placed in the first paragraph where you talk bout SST.
- Page 6 lines 43-50: not sure how you do the connection with the NASH. Please explain it better. You could discuss this in the discussion section.
- Page 7 line 7: the magnitude of the cold bias reported does not seem to be the same as the figure.
- Page 7 line 17: weakened for >20N, but increased at ~10N. Why? You could discuss this in the discussion section.
- Page 7 line 25: maybe expanded instead of increased? You're talking about spatial scales.
- Page 7 line 37: I'd change indicating to suggesting since you don't show directly that this is happening. If you can show in your model, that would be a good result. Also, is 8 years enough time for a particle sinking in the SAMW/AAIW region to be transported up to TAO? I think you could do a simple velocity vs distance calculation. For instance, assuming a mean velocity of these water masses and the distance between the two regions, how long would take for the particle to propagate from south to north?
- Page 8 line 7: Could you discuss possible reasons for these differences in these periods?
- Figs. 3 and 4: Or add a bathymetry mask or change the colour scheme to cmocean, for instance, for the value zero be grey-ish instead of white (as your current bathymetry).
- you need to cite more frequently your figures to guide the reader
- Page 8 line 31: Isn't figure 4? And by the colour you use, it's not clear the bias up to 500, but up to 150 m depth.
- Page 9 line 36: you could cite Haumann et al. (2016; Nature) to exemplify this sentence.
- Page 9 lines 36-43: how your study helps to address those causes?
- MC, BC, SAC, SEU: don't need to use acronyms for these currents. You already use many acronyms for the water masses.
- The discussion needs some work. It's not clear to understand because the authors bring many ideas. Maybe if

you focus on the explanation of the things you see if your results and possible consequences, would be better. I don't see much relevance in all that explanation about the water masses and the circulation in the first few paragraphs. Could be more objective.
- Page 10 lines 27-31: I don't see the relevance of discussing these things here since the focus of your work is not related to phytoplankton.
- Page 10 lines 43-48: I don't see how the drops in temperature and salinity are related to SEU. Could you explain better, please?
- Page 11 lines 34-37: You didn't show this result. How can you affirm that?
- Pages 11/12 lines 58-60/4: You didn't show this result. How can you affirm that? I think or you show your figures with those results or you need to rely more on citations to explain and confirm the feedbacks you'retalking about.

Additional Questions:
Does the manuscript contain new and significant information to justify publication?: Yes

Does the Abstract (Summary) clearly and accurately describe the content of the article?: Yes

Is the problem significant and concisely stated?: Yes

Are the methods described comprehensively?: Yes

Are the interpretations and conclusions justified by the results?: Yes

Is adequate reference made to other work in the field?: Yes

Is the language acceptable?: Yes

Please rate the priority for publishing this article (1 is the highest priority, 10 is the lowest priority): 7

Length of article is: Adequate

Number of tables is: Adequate

Number of figures is: Adequate

Please state any conflict(s) of interest that you have in relation to the review of this paper (state “none” if this is not applicable).:

Rating:

Interest: 2. Good

Quality: 2. Good

Originality: 3. Average

Overall: 2. Good