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**RESPOSTA DA CIRCULAÇÃO MERIDIONAL DA TROPOSFERA AUSTRAL AO
MÁXIMO HISTÓRICO DE GELO MARINHO ANTÁRTICO**

SÃO LUÍS – MA
2022

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Trabalho de Conclusão de Curso apresentado 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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*Aos meus amados pais,
Cândida e Hiltonildo.*

Dedico

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RESUMO

A variabilidade do gelo marinho Antártico (GMA) tem grande potencial para afetar a circulação atmosférica, com impactos que podem se estender desde a superfície até os níveis médio e alto da troposfera. O presente estudo avaliou a resposta da circulação da troposfera do Atlântico Sul ao aumento da cobertura em área e volume de GMA. Dados mensais de temperatura do ar, vento zonal e meridional e pressão média ao nível do mar foram obtidos a partir de duas simulações de conjunto realizadas com o modelo GDFL/CM2.1, abrangendo o período de julho de 2020 a junho de 2030. Em geral, a resposta da circulação da troposfera do Atlântico Sul ao aumento do GMA mostrou que o sinal climático se estendia da superfície para os altos níveis, propagando-se como uma teleconexão Polo Sul-Trópicos. Os resultados mostram um resfriamento geral da troposfera austral, que levou, por exemplo, a um fortalecimento e deslocamento para norte do jato polar e deslocamento para sul do jato subtropical e a uma inversão da fase positiva para negativa do Modo Anular Sul. Este estudo tem grande relevância para o entendimento das mudanças climáticas globais em curto prazo, ao avaliar a sensibilidade da circulação da troposfera do Atlântico Sul a variações extremas no GMA.

Palavras-chave: Gelo Marinho Antártico, Circulação Atmosférica, Oceano Atlântico Sul, Célula de Hadley, Célula Polar.

ABSTRACT

The variability of Antarctic sea ice (ASI) has great potential to affect atmospheric circulation, with impacts that can extend from the surface to the middle and high levels of troposphere. The present study has evaluated the response of South Atlantic tropospheric circulation to increased coverage in area and volume of ASI. Monthly data of air temperature, zonal and meridional wind and mean sea level pressure were obtained from two ensemble simulations performed with the GDFL/CM2.1 model, covering the period from July 2020 to June 2030. In general, the response of South Atlantic tropospheric circulation to increased ASI showed that the climatic signal extended up from the surface to the high levels, propagating as a South Pole–Tropics teleconnection. The results show a general cooling of the southern troposphere, which lead, for instance, to a strengthening and northward shift of the polar jet and southward shift of the subtropical jet and to an inversion from the positive to negative phase of the Southern Annular Mode. This study has great relevance for understanding the global climate changes in short term, by assessing the sensitivity of South Atlantic tropospheric circulation to extreme variations in ASI.

Key words: Antarctic Sea Ice, Atmospheric Circulation, South Atlantic Ocean, Hadley Cell, Polar Cell.

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LISTA DE ABREVIATURAS E SIGLAS

AMOC – Atlantic Meridional Overturning Circulation

ASI – Antarctic Sea Ice

GFDL – Geophysical Fluid Dynamics Laboratory

IPCC – Intergovernmental Panel on Climate Change

ITCZ – Intertropical Convergence Zone

JJA – June-July-August

MAM – March-April-May

MSLP – Mean Sea Level Pressure

NOAA – National Oceanic and Atmospheric Administration

PSA – Pacific-South American

SAM – Southern Annular Mode

SASH – South Atlantic Subtropical High

SON – September-October-November

SST – Sea Surface Temperature

I. CONSIDERAÇÕES INICIAIS

O presente trabalho parte do pressuposto de que os estudos da circulação atmosférica são de grande importância para a compreensão do clima em diversas regiões do globo, uma vez que os elementos e fatores climáticos de um local apresentam enorme influência nas atividades humanas.

A circulação geral da atmosfera corresponde ao movimento em larga escala da atmosfera no tempo e no espaço (AYODE, 1996) e tem papel fundamental no clima em diversas regiões da Terra. Esse movimento ocorre particularmente na Troposfera e corresponde ao deslocamento do ar (vento) da alta para a baixa pressão, resultando na dinâmica das células de circulação meridional (Hadley, Ferrel e Polar) em ambos os hemisférios e da célula de circulação zonal (Walker) na região tropical (VAREJÃO-SILVA, 2006). Basicamente, essa circulação é influenciada pelo desequilíbrio na radiação, na umidade, no *momentum* e na massa entre as baixas e altas latitudes (AYODE, 1996). Outros fatores que também influenciam nessa circulação são a topografia, a distribuição das superfícies continentais e oceânicas e a circulação oceânica (AYODE, 1996).

O Gelo Marinho Antártico também tem grande importância para o clima global, uma vez que os eventos de expansão e retração do gelo podem afetar a dinâmica do oceano austral e da atmosfera, resultando em impactos que se propagam da superfície aos altos níveis da troposfera como verificado, por exemplo, nos estudos de Hudson e Hewitson (2001), Raphael et al. (2011), Kidston et al. (2011), Parise (2014) e Parise et al. (2015).

Neste contexto, o presente trabalho buscou investigar o comportamento da circulação meridional da atmosfera no setor do Atlântico em cenários futuros de extremos máximos de gelo marinho antártico e as possíveis teleconexões climáticas responsáveis por propagar o sinal climático de altas latitudes austrais até a região tropical. Dessa forma, o estudo apresenta grande importância no entendimento das mudanças climáticas de curto prazo associadas aos eventos extremos de gelo marinho antártico e visa contribuir com os estudos de Parise (2014) e Parise et al. (2015), pois tem o objetivo de avaliar as respostas atmosféricas observadas na escala interanual.

O presente Trabalho de Conclusão de Curso aqui apresentado como capítulo 1, está no formato de artigo científico submetido aos Anais da Academia Brasileira de Ciências (Qualis Capes A2) - Volume Especial sobre Pesquisa Antártica, submetido em maio de 2021 e aceito em julho de 2021. Assim, essas considerações iniciais são seguidas do Capítulo 1, considerações finais e anexos.

II. CAPÍTULO 1

RESPONSE OF SOUTHERN TROPOSPHERE MERIDIONAL CIRCULATION TO HISTORICAL MAXIMA OF ANTARCTIC SEA ICE

RUNNING TITLE: MERIDIONAL SHIFT OF CLIMATE SIGNAL FROM ANTARCTICA

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ABSTRACT

The variability of Antarctic sea ice (ASI) has great potential to affect atmospheric circulation, with impacts that can extend from the surface to the middle and high levels of troposphere. The present study has evaluated the response of South Atlantic tropospheric circulation to increased coverage in area and volume of ASI. Monthly data of air temperature, zonal and meridional wind and mean sea level pressure were obtained from two ensemble simulations performed with the GDFL/CM2.1 model, covering the period from July 2020 to June 2030. In general, the response of South Atlantic tropospheric circulation to increased ASI showed that the climatic signal extended up from the surface to the high levels, propagating as a South Pole–Tropics teleconnection. The results show a general cooling of the southern troposphere, which lead, for instance, to a strengthening and northward shift of the polar jet and southward shift of the subtropical jet and to an inversion from the positive to negative phase of the Southern Annular Mode. This study has great relevance for understanding the global climate changes in short term, by assessing the sensitivity of South Atlantic tropospheric circulation to extreme variations in ASI.

Key words: Antarctic Sea Ice, Atmospheric Circulation, South Atlantic Ocean, Hadley Cell, Polar Cell.

1. INTRODUCTION

The variability of Antarctic sea ice (ASI) is of a great importance for the thermal balance of global climate system, since it affects the dynamics of the southern ocean and atmosphere, with impacts that propagate from the surface to the high levels of troposphere (e.g., Hudson & Hewitson 2001, Raphael et al. 2011, Kidston et al. 2011, Parise 2014, England et al. 2018, Ayres & Screen 2019). As a consequence, expansion and reduction events of ASI end up generating local disturbances that can spread out to remote areas of globe, impacting the tropical climate through teleconnections (Yuan & Martinson 2000, Liu & Alexander 2007). In this context of teleconnections, changes in the tropics can also impact the polar climate (Carleton 2003, Liu & Alexander 2007, Yuan & Li 2008, Yuan et al. 2018). In El Niño events, for instance, sea surface temperature (SST) anomalies in the central-eastern Tropical Pacific increase the air convection in the region, altering the southern meridional thermal gradient (Yuan 2004, Yuan et al. 2018). A planetary waves train spreads from Tropical Pacific towards South America (Pacific-South American mode - PSA) (Mo & Paegle 2001) and acts on the atmospheric patterns of meridional circulation cells and the interannual variability of ASI, especially in Pacific and Atlantic sectors (Yuan & Martinson 2001, Liu et al. 2002, Carpenedo & Ambrizzi 2016, Cerrone & Fusco 2018).

Even with high seasonal variability, studies have shown an increasing trend in ASI until the year 2014 (e.g., Holland & Kwok 2012, Bintanja et al. 2013, Meehl et al. 2016, Li et al. 2020). From 2014 to 2017, a decreasing trend in ASI was documented, with 2017 presenting the last low record (e.g., Parkinson 2019, Wang et al. 2019, Turner et al. 2020). Although a significant reduction in ASI coverage may also modify the atmospheric circulation, expansion events of ASI have a much greater impact, likely because the sea ice melts faster and freezes more slowly (Carpenedo & Ambrizzi 2016, Carpenedo 2017). Under the scenario of historical increase in ASI, Parise (2014) and Parise et al. (2015) observed a cooling of the air temperature in high and mid-latitudes, an intensification of the polar jet, and the establishment of the positive phase of the Southern Annular Mode (SAM), with impacts varying seasonally and accordingly to the sector (Atlantic, Pacific and Indian Oceans). These authors have shown that the maxima applied to the ASI field have persisted during the first 4 years of model simulation, when eventually the ASI field passes to present the climatological pattern. The disturbance applied to the ASI, however, resulted in cold and fresh melting water, which was able to influence the

buoyancy of the Southern Ocean and the surrounding atmosphere, by limiting ocean-atmosphere heat exchanges also during the following 4 years of simulation (Parise et al. 2015).

By examining the influence of ASI distribution on the Southern Hemisphere large-scale circulation based on a fully coupled general circulation model, Hudson & Hewitson (2001) found that minimum ASI conditions in the southern summer caused a strengthening and a poleward shifting of the Hadley circulation. Also, in an ASI reduction scenario, Raphael et al. (2011) showed that there is an expansion of the Polar cell and subsequent displacement of the Ferrel cell towards the equator. In addition to these results, Raphael et al. (2011) pointed out that small changes in surface air temperature can result in large impacts on the southern climate, since the ASI edge is located in the latitudinal zone (approximately 60°S) of high thermal gradients, known as the Polar Front or Antarctic Convergence (Rabelo et al. 2009). Therefore, these ASI changes alter the surface circulation and the deep-water formation, with impacts on the ecosystem and the atmosphere-ocean-ice interactions (Li et al. 2020).

In this way, due to the influence of polar regions on global climate variability and to the most pronounced changes on atmospheric circulation over the twentieth and twenty-first century taking place in the South Atlantic and Pacific sectors (Screen et al. 2018), the present study evaluates the response of the meridional circulation cells, in the South Atlantic sector, to a historical increase in ASI area and volume. In addition, we investigate the time required for the climate signal generated from the ASI disturbances finally reaches the tropical troposphere. The propagation mechanisms of the climate signal from southern high to low-latitudes are also evaluated.

2. ATMOSPHERIC DATA AND ANALYSES

Monthly air temperature, zonal and meridional wind and mean sea level pressure (MSLP) data simulated by the Coupled Climate Model of the Geophysical Fluid Dynamics Laboratory of the National Oceanic and Atmospheric Administration (GFDL/NOAA), version 2.1 (Model CM2.1) were obtained from the study of Parise (2014), comprising the period from July 2020 to June 2030 (10 years of simulation). The CM2.1 stands out among the models used for the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, for presenting one of the best performances in terms of atmospheric dynamics (Knutson et al. 2006, Reichler & Kim 2008). It is

composed of four components (oceanic, atmospheric, sea ice and terrestrial) that interact with each other through a flux coupling module, the Flexible Modeling System. More detailed information about each model component is found in Bryan (1969), Semtner (1976), Winton (2000), Delworth et al. (2002), Milly & Shmakin (2002), Gnanadesikan et al. (2006), Stouffer et al. (2006) and Wittenberg et al. (2006). Regarding the sea ice component (Sea Ice Simulator, Winton 2000), the numerical experiments used in this study were conducted with a sophisticated multi-layer model (3 layers, 1 of snow and 2 of ice), that considers thermodynamic and dynamic processes and rheological features of the sea ice.

The climate sensitivity experiments to ASI changes, here named *layer*, had their initial conditions of ASI concentration and thickness perturbed with an expansion extreme field (*layermax* experiment). This was compared to a control experiment initialized from a climatological condition of ASI (*layerctl* experiment). Each experiment was carried out as an ensemble with 30 members each. The initial conditions for the *layerctl* ensemble were generated from restarts files for the months of July, August and September (the two months preceding and the month that presents, climatologically, the largest sea ice cover in the Southern Hemisphere) of a coupled simulation integrated for 10 years (totaling 30 members). The maximum concentration of ASI, in turn, was calculated from the Met Office Hadley Center (HadISST1) data set (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 of ASI area and volume were designed to represent the maximum value of sea ice in the whole time series for each grid point, regardless of when it has occurred in time. More details on the sensitivity experiments used in this study are found in Parise (2014) and Parise et al. (2015).

In the present study, the impacts of the increase in ASI in the South Atlantic troposphere are assessed through the *layermax-layerctl* differences of the zonal mean profiles and Hovmöller diagrams (latitude vs time) for the lower (850 hPa) and higher (250 hPa) levels. This diagram stands out in showing the movement or displacement of an anomaly through static images, calculating the average of all values in a single line of longitude or latitude (Hovmöller 1949). In this study, the y axis represents the latitudes from 90°S to 30°N, while the x axis represents time in years (from July 2020 to June 2030). In order to verify the tropospheric changes between the middle (40°S) and high (65°S) latitudes over the 10 years of the coupled model simulation, we analyzed the *layermax-layerctl* differences for air temperature, zonal and meridional wind at 850 hPa and 250 hPa levels and MSLP. The MSLP

differences between middle and high latitudes were calculated based on the methodology proposed of Marshall et al. (2003).

To verify the response timing of vertical structure of the Atlantic troposphere in view of the extreme expansion imposed on the ASI, the zonal mean profiles were calculated separately for three specific periods. These periods were predetermined as a function of the Southern Ocean memory to the initial condition of ASI (Parise et al. 2015), it means, based on its distinct phases: when the *layermax-layerctl* differences were positive (July 2020 – June 2024), close to zero (July 2024 – June 2028) and negative (July 2028 – June 2030), respectively, in relation to the ASI maxima (Parise 2014, Parise et al. 2015). In this way, the study sought to evaluate the behavior of climate response on an interannual timescale, aiming to discuss the possible consequences for the South America climate. The whole domain analyzed here comprises the latitudes from 90°S to 30°N and longitudes from 65°W to 15°E.

3. RESPONSE OF SOUTH ATLANTIC MERIDIONAL CIRCULATION TO ANTARCTIC SEA ICE MAXIMA

From this section onwards, we started to show the results from our study obtained through numerical modeling experiments, when ASI extremes were imposed as initial conditions for each ensemble member. The differences of ASI concentration (%) and thickness (m) between the *layermax-layerctl* ensemble experiment averages in the Atlantic sector (60°W – 20°E) for the 10 years of model simulation (2020 – 2030) are shown in Figure 1. The results show that the ASI in Atlantic sector was larger than climatological pattern during the first 7 years of simulation, when it has passed to a negative phase of ASI. Parise et al. (2015), by analyzing the climate memory to ASI changes, have found a period of 4 years for the whole perturbation applied to ASI completely melts and more 4 years for the cold and fresh surface melting water be transported from Southern Ocean to the Tropical Ocean. The interannual variability of the Weddell Sea ice has large influence on the atmospheric circulation over the South Atlantic sector (Morioka et al. 2017). Furthermore, accurate initialization of sea ice conditions during southern winter is a key element for a skillful prediction of climate variability over the Weddell Sea during the next season, i.e., in southern spring (Morioka et al. 2019).

cooling of -0.6°C in the period from July 2020 to June 2024. On the other hand, a slight warming of $\sim+0.2^{\circ}\text{C}$ is found from the surface to the mid-levels of troposphere five years later, in the period from July 2028 to June 2030. By analyzing the atmospheric response to ASI loss, England et al. (2018) have found a confined latitudinally (over the high-latitudes) and vertically (up to 600 hPa) warming at the high levels of troposphere. Even though the present study is analyzing the impacts of an ASI increase, it is important to understand that, since the experiments were conducted with a coupled model without any flux or variable adjustments, there is a progressive loss of sea ice as the CM2.1 model runs. Due to the presence of sea ice normally acts on decreasing the surface air temperature, and vice-versa, this thermodynamic response was already expected. Therefore, in the present study we found the air temperature biases can generate anomalies that reach the upper-levels of troposphere. These results corroborate with Raphael (2011), Parise (2014), Parise et al. (2015) and Carpenedo & Ambrizzi (2016), who also found a cooling of the atmosphere in an extremely positive ASI condition. Parise (2014) and Parise et al. (2015) showed that this colder air mass was displaced towards the lower latitudes (from Antarctic to Equator) in its greatest amount during the southern spring (SON), precisely in the season of the ASI climatological maximum (Parkinson 2019). When ASI is at its extreme maximum, there is an increase in albedo and a consequent reduction in absorption of shortwave radiation. With less energy being absorbed by the surface, a reduction occurs in both SST and vertical heat fluxes, especially over the ASI edge. Morioka et al. (2017) found that the reduction of sea ice in the Weddell Sea sector contributes to the anomalous warming of the surface temperature in the range of $60\text{-}70^{\circ}\text{S}$ and, as a consequence, there is an increase in stability in the atmospheric boundary layer to the north of this strip, implying favorable conditions for the support of anticyclonic anomalies in the lower troposphere in the South Atlantic.

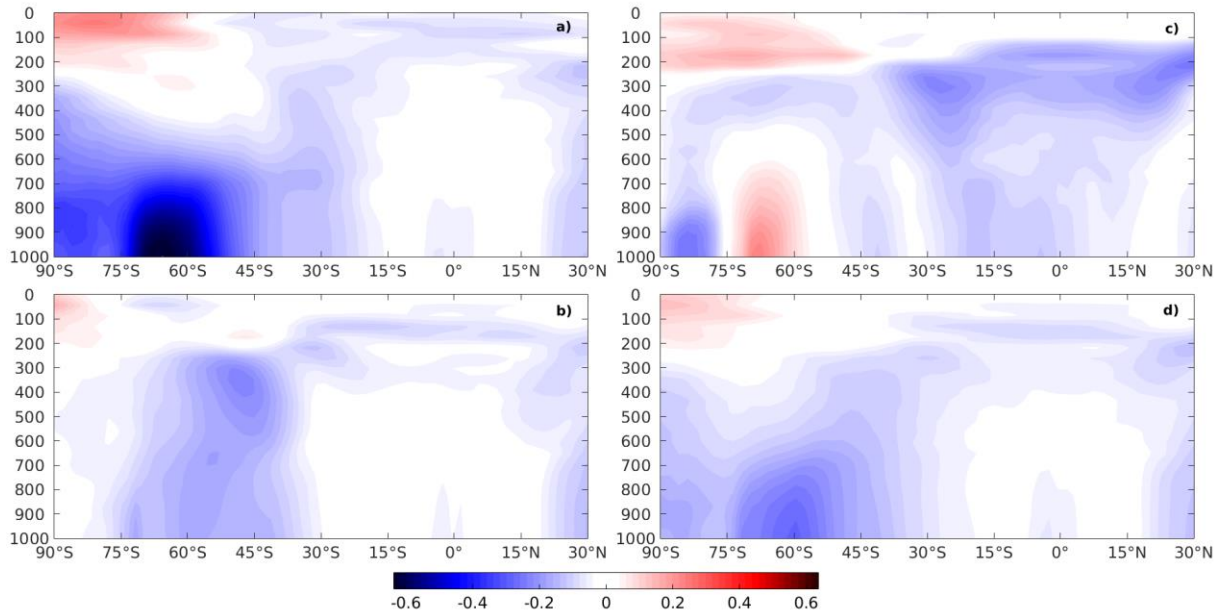


Figure 2 – Differences between the *layermax-layerctl* experiments for the zonal mean (from 90°S to 30°N) air temperature profile (°C) for the Atlantic sector (from 65°W to 15°E) during the periods: (a) July 2020 – June 2024; (b) July 2024 – June 2028; (c) July 2028 – June 2030 and (d) July 2020 – June 2030.

The vertical structure of the zonal mean wind in the Atlantic sector is shown in Figure 3. In the tropical region, the ASI sensitivity experiments showed the intensification of the Hadley cell, with trade winds more intense (easterlies, with negative sign). This intensification took place initially in the Northern Hemisphere (for the periods of 2020–2024 and 2025–2028) and later established itself in both hemispheres. The results also showed the strengthening of the Polar cell in the *layermax* in relation to the control experiment (westerlies between 50°S and the South Pole, with positive sign) and the southward expansion of the Ferrel cell (easterlies between 30°S and 50°S, with negative sign) (Figure 3a). The disturbance applied on the surface was able to generate a climatic signal that extended up to the high levels of the tropical troposphere, propagating from Antarctica to Tropics. During the first 4 years of model simulation, there was a northward shift of the polar jet and a southward shift of the subtropical jet (Figure 3a). In the following 4 years (2025–2028) there was a southward shift of the atmospheric meridional circulation cells in the South Atlantic sector, with the subtropical jet acting at 35°S and the polar jet at 55°S, approximately (Figure 3b). This response pattern has intensified the wind shear at mid-latitudes ($\sim 44^\circ\text{S}$) (Figure 3b). For the period from July 2028 to June 2030, breaks in the vertical structure of the climate oscillations generated in Antarctica were observed, resulting in a smaller wave number (Figure 3c). In the studies of Parise (2014) and Parise et al. (2015) positive zonal wind

anomalies were found at 50°S in the southern spring (SON), between 55°S and 75°S in the autumn (MAM) and south of 65°S in the winter (JJA), being stronger in the last. By analyzing maximum conditions of ASI for southern summer, Raphael (2003) found that the entire southern circulation cell seems to move northwards, with the mid-latitude surface westerly winds becoming weaker and the polar easterlies expanding further north. Also, in response to increased extent of ASI, Kidston et al. (2011) and Smith et al. (2017) observed a poleward shift of the mid-latitude jet stream, as also found in the present study.

When analyzing the climate response to the variability of the radiative (solar) forcing, Haigh et al. (2005) suggest that the expected dynamics of the troposphere is due in particular to the warming of the stratosphere, with impacts more easily detected in the subtropical and middle latitudes. This warming tends to weaken the subtropical jets and the southern tropospheric mean circulation, with a weakening and expansion of Hadley cells and a poleward shift of the Ferrel cells. In this way, the positions of the subtropical jets and the extension of Hadley cells respond to the distribution of the stratospheric warming, with the low-latitude warming forcing them to move towards the poles, and high-latitude warming forcing them to move towards the equator (Haigh et al. 2005). Kodera et al. (2016) studying the stratospheric warming events and their influence on the troposphere circulation have reported that the tropospheric connection is more directly related to the vertical structure of planetary waves than the horizontal structure of the polar vortex. The Hadley cell edge is also closely related to temperature gradients occurring over the tropical upper troposphere (Son et al. 2018). By addressing the influence of Atlantic Meridional Overturning Circulation (AMOC) on the position asymmetry of the Intertropical Convergence Zone (ITCZ), which is found slightly north of the equator, Aimola & Moura (2016) have found that anomalous Hadley cell transports particularly moisture at low levels from equator to the Northern Hemisphere and energy at high levels to the Southern Hemisphere, so that the maximum precipitation occurs to the north of equator following the ITCZ position.

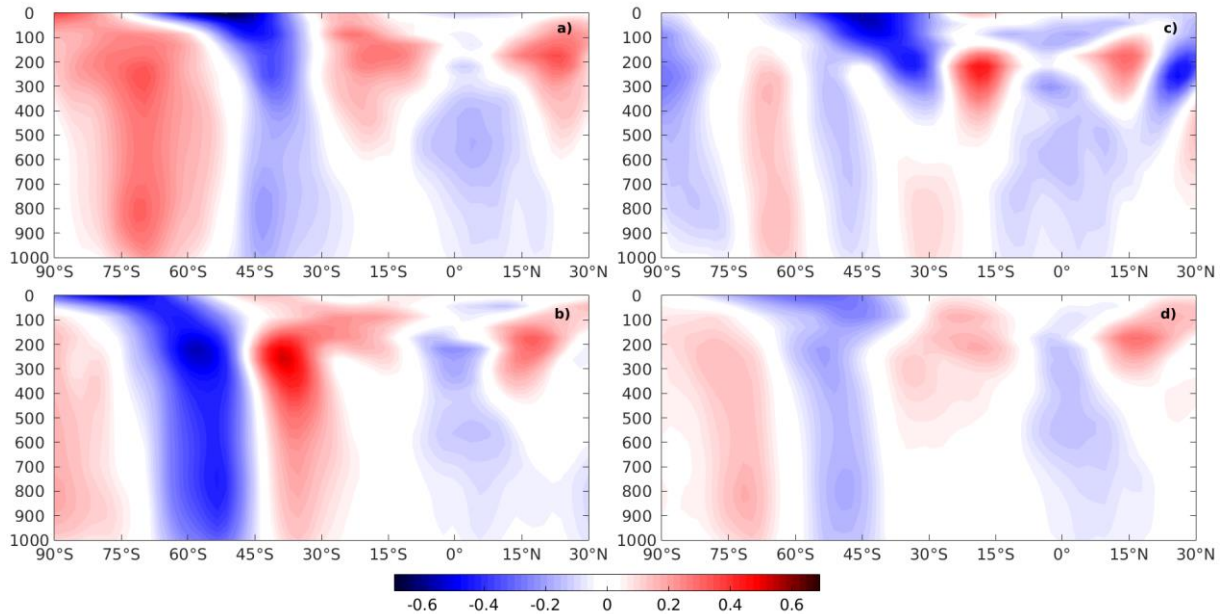


Figure 3 – Differences between the *layermax-layerctl* experiments for the zonal mean (from 90°S to 30°N) wind profile (ms^{-1}) for the Atlantic sector (from 65°W to 15°E) during the periods: (a) July 2020 – June 2024; (b) July 2024 – June 2028; (c) July 2028 – June 2030 and (d) July 2020 – June 2030.

The zonal mean profile of meridional wind between 90°S and 30°N is shown in Figure 4. In the period from July 2020 to June 2024 (Figure 4a) we observe negative anomalies of meridional wind between 90°S (almost the entire troposphere) and approximately 50°S (low levels). This anomalous pattern indicates a strengthening of the upper branch of the Polar cell and a weakening of the lower branch, as well as a strengthening of the lower branch of the Ferrel cell. This weakening (strengthening) of the lower branch of Polar (Ferrel) cell may indicate its contraction, which is associated with the expansion extreme of ASI. The same pattern was also observed by Raphael et al (2011) for the months from January to March. In relation to the tropical circulation cell, a strengthening (weakening) of the upper branch of Hadley cell between $\sim 30^{\circ}\text{S}$ to 0° (at approximately 30°N), respectively, was verified (Figure 4a).

On the other hand, in the period from July 2024 to June 2028 (Figure 4b), when the maximum ASI has already been melted, there was an inversion of the anomalies observed in the previous period (2020–2024), with a predominance of positive anomalies south of 45°S. The results showed a weakening of the lower branch of Ferrel cell, between approximately 65°S and 45°S, and a strengthening (weakening) of the lower (upper) branch of Polar cell, respectively, with the largest meridional wind

anomalies at high levels. Between the middle and low-latitudes there was a predominance of negative anomalies, indicating a strengthening of the lower branch of Ferrel cell between 45°S and 35°S, approximately, and a weakening at high levels. The strengthening of the lower branch of Polar cell may indicate its expansion. One consequence of this strengthening is the displacement of Ferrel cell to the north. This expansion of the Polar cell and consequently the displacement of the middle latitude cell towards the equator was also observed by Raphael et al. (2011) under minimum conditions of ASI in the southern summer. With the Antarctic Polar Front displaced to the north, coinciding with the spatial pattern similar to the negative phase of SAM (see forward in Figure 5b), there is a favor in the propagation of transient systems in southern Brazil, since the subtropical jet is strengthened and displaced towards the equator (Carvalho et al. 2005, Rudeva & Simmonds 2015). Regarding the Hadley cell, a pattern similar to first period analyzed (2020–2024) is observed for its upper branch even if a weakening at approximately 30°S to 15°S is observed for its lower branch (Figure 4b).

Finally, in the period from July 2029 to June 2030 (Figure 4c), the strengthening (weakening) of the lower (upper) branch of Polar cell are observed south of 60°S, while around 45°S there are positive anomalies of meridional wind in practically the entire troposphere, indicating a weakening (strengthening) of the lower (upper) branch of Ferrel cell. In relation to the Hadley cell, we found a strengthening of its upper branch around 30°S and a weakening (strengthening) of its upper (lower) branch at approximately 30°N.

When analyzing the entire simulation period, from July 2020 to June 2030 (Figure 4d), we observed the predominance of positive anomalies of meridional wind at middle and high levels of high southern latitudes, while at low levels there were no biases. Thus, the results show that the largest anomalies were observed especially at high levels of the troposphere in the sector of Polar and Ferrel cells when evaluating the first two simulation periods, indicating that the ASI concentration and thickness changes have a great influence on the displacement and intensity of these tropospheric meridional cells.

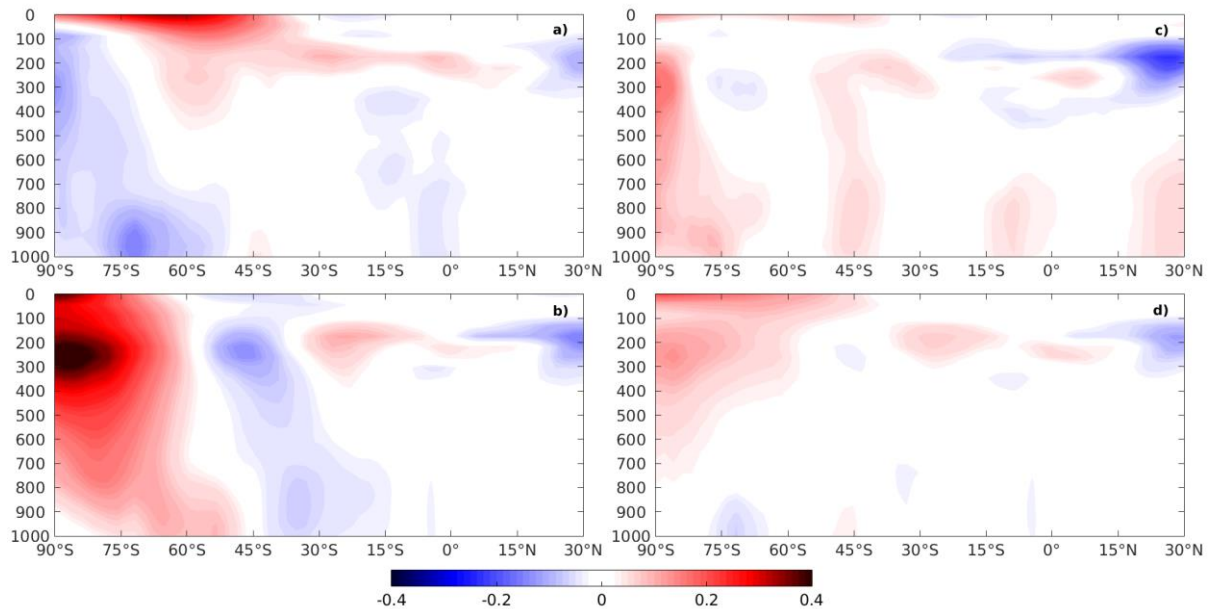


Figure 4 – Differences between the *layermax-layerctl* experiments for the meridional mean (from 90°S to 30°N) wind profile (ms⁻¹) for the Atlantic sector (from 65°W to 15°E) during the periods: **(a)** July 2020 – June 2024; **(b)** July 2024 – June 2028; **(c)** July 2028 – June 2030 and **(d)** July 2020 – June 2030.

The differences of MSLP in the Atlantic sector of Southern Ocean are shown in Figure 5. Positive (negative) differences were observed out of phase between mid- and high-latitudes, indicating an increase (decrease) in the MSLP, respectively. When analyzing the response of the Southern Hemisphere's climate in the three predetermined periods, it was found a spatial pattern similar to the positive (2020–2024) and negative (2024–2028) phase of the SAM (Thompson & Wallace 2000, Gillett et al. 2006).

The positive (negative) anomalies of MSLP found over the subtropical zone during 2020–2024 (2025–2028) periods suggests a slight strengthening (weakening) of the South Atlantic Subtropical High (SASH) (Figures 4a and 4b). For the 2020–2024 period, this positive bias of MSLP found in mid-latitudes does not reach the tropical region, where negative biases are observed. From July 2024 to June 2028, the MSLP anomalies are in association with the weakening of the Hadley cell in the Southern Hemisphere (positive anomalies of zonal wind at middle and high levels) (Figure 3b). Considering the temporal average of the entire simulation period of the coupled model, higher (lower) MSLP were found in the middle (high) latitudes, respectively (Figure 5d), which is consistent with the positive phase of SAM, as also shown in Raphael et al. (2011) and Parise et al. (2015). In the studies by Parise (2014) and Parise et al. (2015) it was found that considering the entire simulation period (2020–2030) there was a

decrease in MSLP in high-latitudes (~ 3 hPa) and an increase in mid-latitudes (~ 1.5 hPa), being the response of this field most significant in southern autumn (MAM) and winter (JJA). According to Pezza et al. (2012), in La Niña years occurring with a positive phase of SAM would present the most favorable conditions for the general growth of sea ice (except to the west of Antarctic Peninsula, where the opposite is seen). Any trend in SAM can have highly significant impacts on regional precipitation patterns (Gupta & England 2006). In the positive phase of SAM (*i.e.*, positive anomalies of MSLP in mid-latitudes), SASH tends to be positioned further south (Sun et al. 2017, Carpenedo & Ambrizzi 2020), influencing the strengthening of trade winds in some areas at south of northeast region of Brazil (Carpenedo & Ambrizzi 2020). Oppositely, in the negative phase of SAM, the SASH tends to be positioned further north, generating negative anomalies of precipitation in the north and northeast regions (Carpenedo & Ambrizzi 2020).

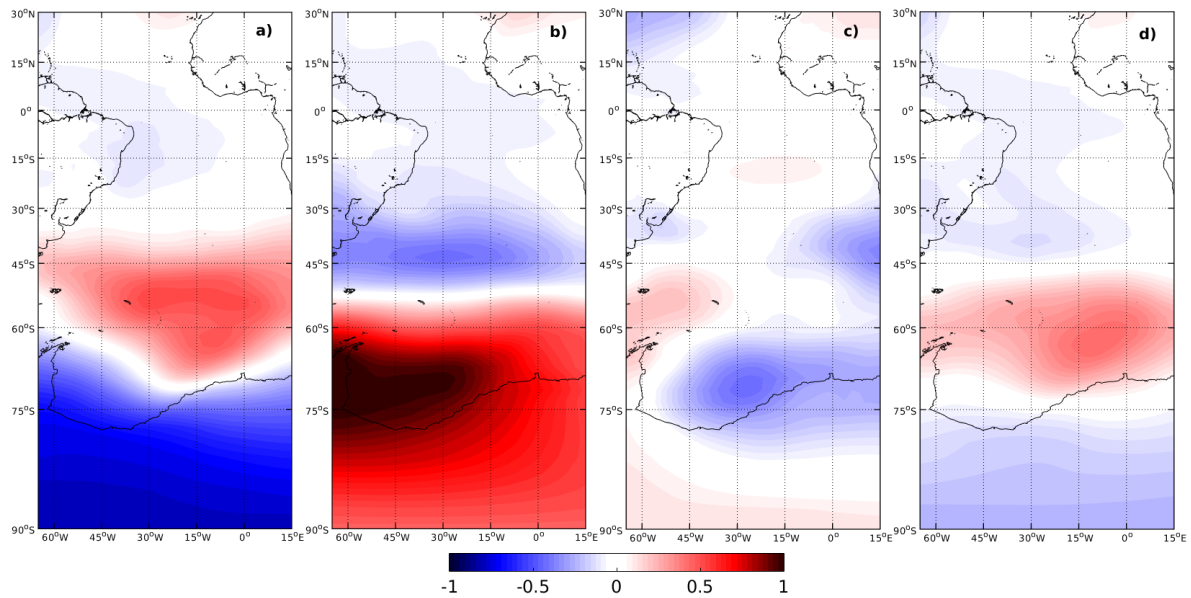


Figure 5 – Differences between *layermax-layerctl* experiments for MSLP (hPa) during the periods: (a) July 2020 – June 2024; (b) July 2024 – June 2028; (c) July 2028 – June 2030 and (d) July 2020 – June 2030.

Regarding the *layermax-layerctl* differences for air temperature (250 hPa and 850 hPa), zonal wind (250 hPa and 850 hPa) and MSLP between the 40°S and 65°S latitudes, it was found that for air temperature (Figure 6a) the positive and negative differences were higher at low levels (850 hPa), reaching up to $\sim 1.3^{\circ}\text{C}$ in the first 4 years of simulation (2020–2024). In relation to the zonal wind (Figure 6b) it was observed that the positive and negative differences were greater at high levels (250 hPa) with more positive differences in the period from July 2024 to June 2028, up to approximately 6 ms^{-1} . Finally,

the MSLP (Figure 6c) showed more positive differences in the first 4 years of simulation compared to the following 4 years (2025–2028) where more negative differences were observed, up to approximately -7.8 hPa.

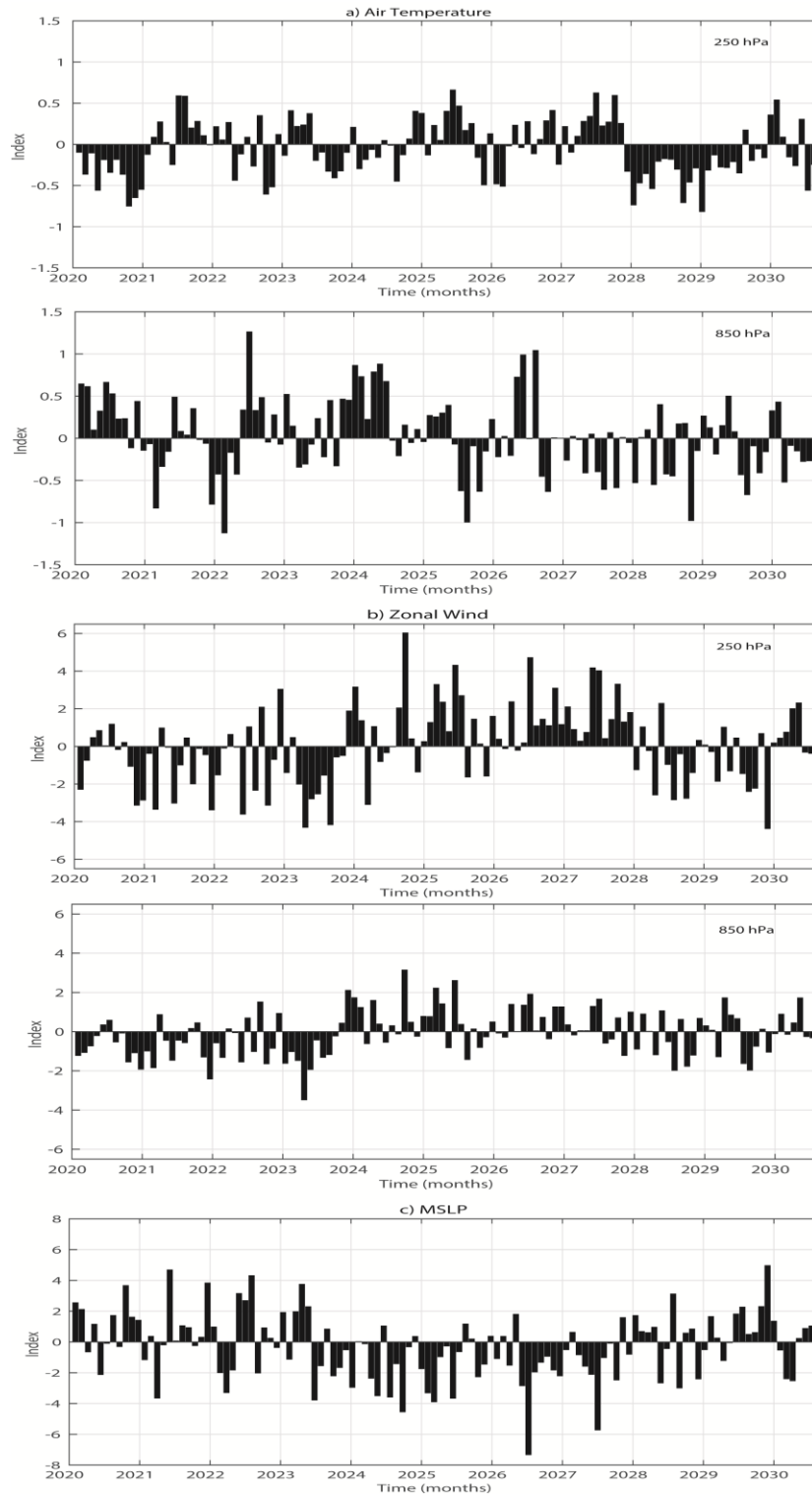


Figure 6 – Differences between *layermax-layerctl* experiments at middle (40°S) and high (65°S) latitudes for: (a) 250 hPa and 850 hPa air temperature (b) 250 hPa and 850 hPa zonal mean wind and (c) MSLP during the whole period of CM2.1 model simulation (2020-2030).

When analyzing the Hovmöller diagrams, it was found that the differences of atmospheric fields are greater. The air temperature (Figure S1, Supplementary Material), showed throughout the analyzed period (2020–2030) a heating of up to $\sim 1.5^{\circ}\text{C}$ at the upper troposphere, especially from 90°S to 45°S (Figure S1a, Supplementary Material). On the other hand, at low levels (Figure S1b, Supplementary Material) we observed a cooling of up to $\sim -1.5^{\circ}\text{C}$, with emphasis on the first 4 years of simulation (2020–2024).

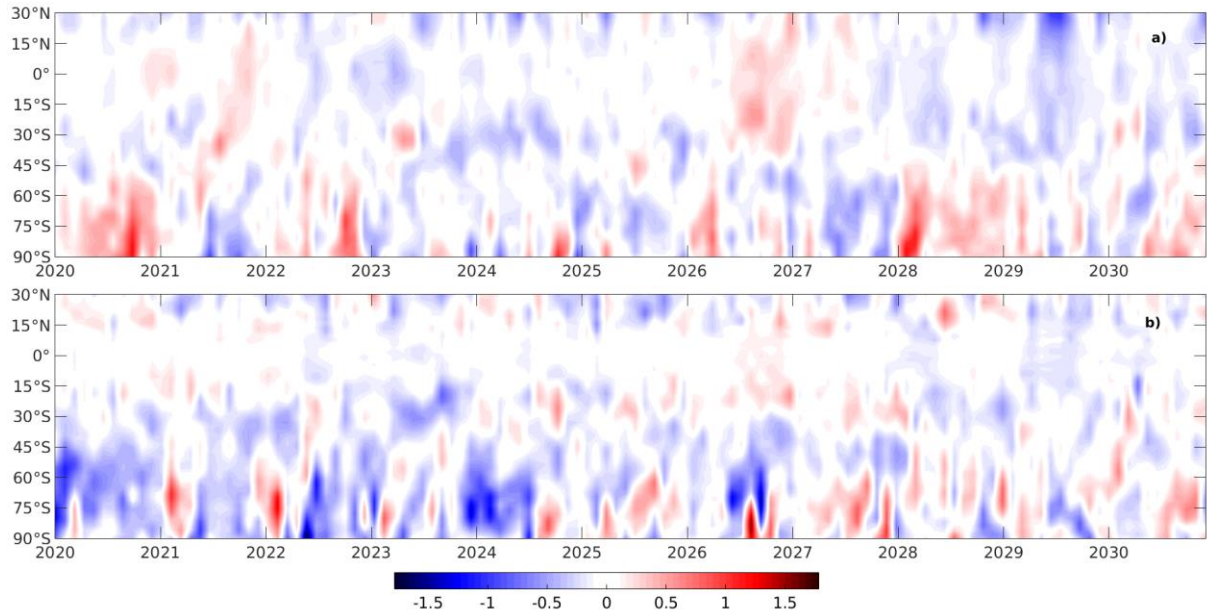


Figure 7 (**Figure S1**) – Hovmöller's diagram of the air temperature ($^{\circ}\text{C}$) differences between the *layermax-layerctl* experiments at 250 hPa (**a**) and 850 hPa (**b**) levels during the 10 years of model simulation (July 2020 – June 2030).

Regarding the zonal wind (Figure S2, Supplementary Material), it was observed that the biggest changes occurred at the high levels of troposphere, with an intensification of winds up to 3.5 ms^{-1} in high and middle latitudes (from 90°S to 45°S) for the first 4 years of simulation (2020–2024). In the first 4 years of simulation (2020–2024), the MSLP showed a predominance of negative differences in the high-latitudes and positive differences in the mid-latitudes (up to $\sim 8.0 \text{ hPa}$) (Figure S3, Supplementary Material). The opposite pattern was observed in the following 4 years (2025–2028).

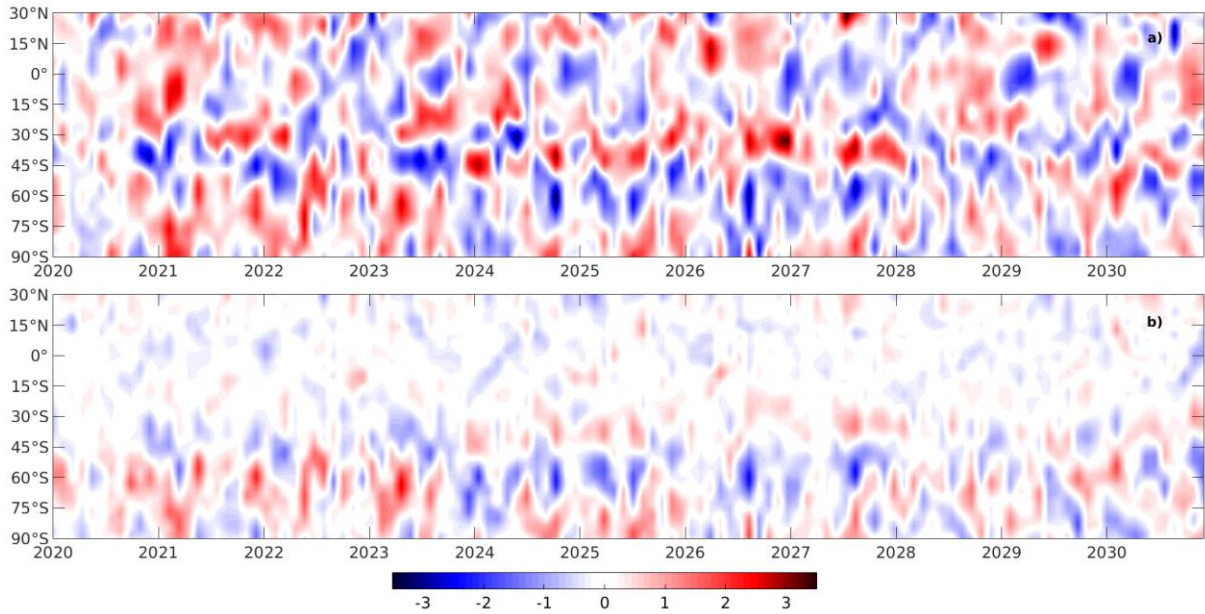


Figure 8 (**Figure S2**) – Hovmöller diagram of the mean zonal wind differences (m s^{-1}) between the *layermax-layerctl* experiments at 250 hPa (a) and 850 hPa (b) levels during the 10 years of model simulation (July 2020 – June 2030).

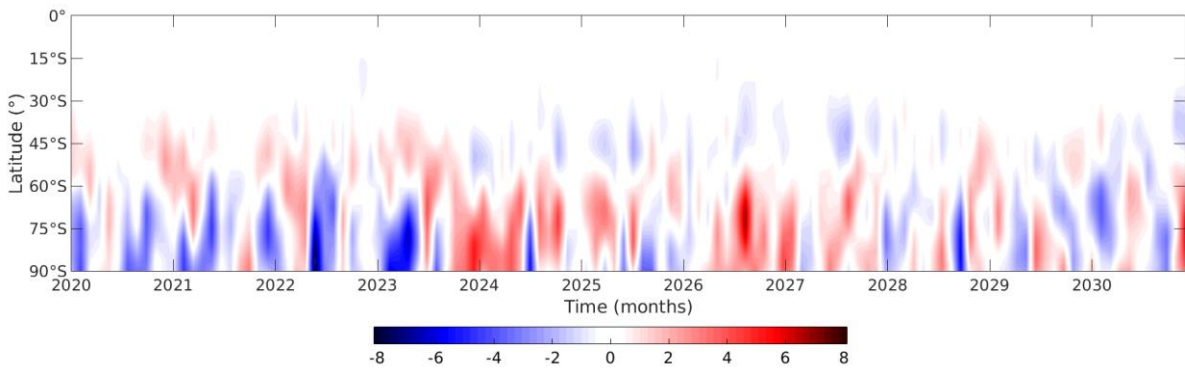


Figure 9 (**Figure S3**) – Hovmöller diagram of the mean sea level pressure (MSLP, in hPa) between the *layermax-layerctl* experiments during the 10 years of model simulation (July 2020 – June 2030).

Regarding climate teleconnections, Cabré et al. (2017) found that changes in deep ocean convection have large and rapid implications for both the extratropics and tropics, causing significant changes in atmospheric temperatures, westerly wind speeds, Hadley circulation, as well as in the inter-hemispheric thermal gradients, atmospheric transport of energy and the position of ITCZ. Bowman & Carrie (2002) showed that there is a semipermeable barrier for transporting properties between the tropics and extratropics. According to them, the atmosphere can be divided into three main parts, the extratropics of Southern Hemisphere, the tropics and the extratropics of Northern Hemisphere.

Climatologically, the dispersion of particles within each part of the atmosphere is fast, while the exchange between the different parts is very slower. The entrainment of extratropical air into the tropics in the boundary layer must be matched in the long run by transporting air from the tropics back to the extratropics through the transport barrier (Bowman & Carrie 2002). Liu & Alexander (2007) concluded that the tropical impact on the extratropical climate occurs mainly through the atmosphere, while changes in the extratropics can also impact the tropical climate through the subtropical cells of the upper ocean in decadal and longer time scales. Raphael (2003) and Raphael et al. (2011) also showed that the southern atmosphere is sensitive to extreme ASI scenarios from the surface to the upper-levels, with the largest impacts occurring at middle and low-latitudes. The inversion between the phases of SAM associated to changes in air temperature, winds and MSLP found in our study have a great influence on climate variability in the South Atlantic sector, with impacts on the occurrence of cold fronts in South America, as discussed in the studies performed by Parise (2014) and Caldas et al. (2020). Although a decrease in the ASI has been observed in recent years, with a large impact also on global climate variability, the present study has showed that the ASI increase has the potential to significantly affect the atmospheric circulation in short term. However, a better assessment of the long-term ice-ocean-atmosphere relationship is important to understand the impacts of this scenario.

4. CONCLUSIONS

The present study sought to evaluate the response of the southern meridional atmospheric circulation cells in the Atlantic sector of the Southern Ocean under a historical maximum condition of ASI, with the focus on the changes occurred in air temperature, zonal and meridional wind and MSLP. For all the ASI anomalies analyzed (positive, close to zero and negative phases), the results have showed a general cooling of the southern troposphere, from the surface to the upper-levels, which led, for instance, to a strengthening and northward shift of the polar jet, a southward shift of the subtropical jet and an inversion from the positive to negative phase of SAM between the positive and close to zero ASI phases. As Parise et al. (2015) have evaluated the SAM based on the average for the whole simulation period (10 years), this inversion on the SAM phase had not yet been shown.

Regarding the *layermax-layerctl* differences between the latitudes of 40°S and 65°S, it was verified that for the air temperature the positive and negative differences were larger at low levels, while for the zonal wind they were larger at high levels. The MSLP presented more positive differences in the first 4 years of simulation compared to the following 4 years (2025–2028), where more negative differences were observed.

In general, the response of the South Atlantic tropospheric circulation to increased ASI showed that the climatic signal extended up from the surface to the high levels, propagating as a South Pole–Tropics teleconnection. Our results showed that the largest anomalies in the meridional circulation cells occurred especially at high levels of troposphere for Polar and Ferrel cells during the first two periods of simulation, from July 2020 to June 2028. In relation to the Hadley cell, we found a strengthening (weakening) of its upper branch between 30°S to 0° (at approximately 30°N). In the Southern Hemisphere, a strengthening of the Polar and Ferrel cells further south of their climatological positions has occurred, as a mechanism for transferring thermal energy to Antarctica to balance the cold bias observed on the surface of Southern Ocean. This surface cooling was resulted from the ASI anomalies applied and by the melting fresh and cold water.

Our study showed a response mechanism of atmospheric circulation cells in the Atlantic sector to the ASI positive extremes, indicating that the ASI concentration and thickness changes have a great influence on the displacement and intensity of these tropospheric meridional cells. The response of the southern troposphere to the ASI positive extremes reported here showed that the disturbance applied on the surface was able to generate a climatic oscillation that extended up to the upper-levels of troposphere, propagating as a Pole–Tropics teleconnection. Although the results found are relevant in the context of global climate changes related to ASI changes, a more detailed assessment of the climate mechanisms acting on the propagation of the climate oscillation from Antarctica to the lower latitudes of the Atlantic sector is needed.

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REFERENCES

- AIMOLA L & MOURA M. 2016. A Influência da Circulação de Revolvimento Meridional do Atlântico na Definição da Posição Média da ZCIT ao Norte do Equador. Uma Revisão. *Rev bras meteorol* 31 (4): 555-563.
- AYRES HC & SCREEN JA. 2019. Multimodel Analysis of the Atmospheric Response to Antarctic Sea Ice Loss at Quadrupled CO₂. *Geophys Res Lett* 46 (16): 9861-9869.
- BINTANJA R, OLDENBORGH GJV, DRIJFHOUT SS, WOUTERS B & KATSMAN CA. 2013. Important role for ocean warming and increased ice-shelf melt in Antarctic sea-ice expansion. *Nat Geosci* 6 (5): 376–379.
- BOWMAN KP & CARRIE GD. 2002. The Mean Meridional Transport Circulation of the Troposphere in an Idealized GCM. *J Atmos Sci* 59 (9): 1502–1514.
- BRYAN K. 1969. Climate and the ocean circulation: III. The ocean model. *Mon Wea Rev* 97 (11): 806–827.
- CABRÉ A, MARINOV I & GNANADESIKAN A. 2017. Global Atmospheric Teleconnections and Multidecadal Climate Oscillations Driven by Southern Ocean Convection. *J Clim* 30 (20): 8107–8126.

- CALDAS CF, VASCONCELLOS FC, CAVALCANTI IFA, CARVALHO NO & LOPES IR. 2020. Impact of Antarctic Sea Ice, ENOS, and Southern Annular Mode on Cold Fronts in South America. *Anu Inst Geociênc* 43 (4): 229-237.
- CARLETON AM. 2003. Atmospheric teleconnections involving the Southern Ocean. *J Geophys Res* 108 (C4): 8080.
- CARPENEDO CB & AMBRIZZI T. 2016. Células de Circulação Meridional Durante os Eventos Extremos de Gelo Marinho Antártico. *Rev bras meteorol* 31 (3): 251-261.
- CARPENEDO CB. 2017. Atmospheric blockings associated with the extreme variability of Antarctic sea ice and impacts over South America. Ph.D. thesis, Astronomy, Geophysics and Atmospheric Sciences Institute, University of São Paulo, 237 pp.
- CARPENEDO CB & AMBRIZZI T. 2020. Anticiclone Subtropical do Atlântico Sul Associado ao Modo Anular Sul e Impactos Climáticos no Brasil. *Rev bras meteorol* 35 (4): 605-613.
- CARVALHO LMV, JONES C & AMBRIZZI T. 2005. Opposite phases of the Antarctic Oscillation and relationships with intraseasonal to interannual activity in the tropics during the austral summer. *J Clim* 18 (5): 702-718.
- CERRONE D & FUSCO G. 2018. Low-frequency climate modes and Antarctic sea ice variations, 1982-2013. *J Clim* 31 (1): 147-175.
- DELWORTH T, STOUFFER R, DIXON K, SPELMAN M, KNUTSON T, BROCCOLI A, KUSHNER P & WETHERALD R. 2002. Review of simulations of climate variability and change with the GFDL R30 coupled climate model. *Clim Dyn* 19: 555–574.
- ENGLAND M, POLVANI L & SUN L. 2018. Contrasting the Antarctic and Arctic atmospheric responses to projected sea ice loss in the late twenty first century. *J Clim* 31 (16): 6353-6370.
- GILLETT NP, KELL TD & JONES PD. 2006. Regional climate impacts of the Southern Annular Mode. *Geophys Res Lett* 33 (23): 1-4.
- GNANADESIKAN A, DIXON KW, GRIFFIES SM, BALAJI V, BARREIRO M, BEESLEY JA, COOKE WF, DELWORTH TL, GERDES R, HARRISON MJ, HELD IM, HURLIN WJ, LEE H, LIANG Z, NONG G, PACANOWSKI RC, ROSATI A, RUSSELL J, SAMUELS BL, SONG Q, SPELMAN MJ, STOUFFER RJ, SWEENEY CO, VECCHI G, WINTON M, WITTENBERG AT, ZENG F, ZHANG R & DUNNE JP. 2006. GFDL's CM2 Global Coupled Climate Models. Part II: The Baseline Ocean Simulation, *J Clim*, 19(5), 675–697.

- GUPTA AS & ENGLAND MH. 2006. Coupled Ocean–Atmosphere–Ice Response to Variations in the Southern Annular Mode. *J Clim* 19 (18): 4457–4486.
- HAIGH J, BLACKBURN M & DAY R. 2005. The Response of Tropospheric Circulation to Perturbations in Lower Stratospheric Temperature. *J Clim* 18 (17): 3672–3685.
- HOLLAND PR & KWOK R. 2012. Wind-driven trends in Antarctic sea-ice drift. *Nat Geosci* 5: 872–875.
- HOVMÖLLER E. 1949. The Trough-and-Ridge diagram. *Tellus* 1: 62–66.
- HUDSON DA & HEWITSON BC. 2001. The atmospheric response to a reduction in summer Antarctic sea-ice extent. *Clim Res* 16 (2): 79–99.
- KIDSTON J, TASCHETTO AS, THOMPSON DWJ & ENGLAND MH. 2011. The influence of Southern Hemisphere sea-ice extent on the latitude of the mid-latitude jet stream. *Geophys Res Lett* 38: L15804.
- KODERA K, MUKOUGAWA H, MAURY P, UEDA M & CLAUD C. 2016. Absorbing and reflecting sudden stratospheric warming events and their relationship with tropospheric circulation. *J Geophys Res Atmos* 121 (1): 80–94.
- LI S, CAI W & WU L. 2020. Attenuated Interannual Variability of Austral Winter Antarctic Sea Ice Over Recent Decades. *Geophys Res Lett* 47 (22): e2020GL090590.
- LIU J, YUAN X, RIND D & MARTINSON DG. Mechanism study of the ENSO and southern high latitude climate teleconnections, *Geophys. Res. Lett.*, 29(14), doi:10.1029/2002GL015143, 2002.
- LIU Z & ALEXANDER M. 2007. Atmospheric bridge, oceanic tunnel, and global climatic teleconnections. *Rev Geophys* 45 (2): RG2005.
- MARSHALL GJ. 2003. Trends in the Southern Annular Mode from Observations and Reanalyses, *J Clim*, 16(24), 4134-4143.
- MEEHL GA, ARBLASTER JM, BITZ CM, CHUNG CTY & TENG H. 2016. Antarctic sea-ice expansion between 2000 and 2014 driven by tropical Pacific decadal climate variability. *Nat Geosci* 9: 590–595.
- MILLY PCD & SHMAKIN AB. 2002. Global Modeling of Land Water and Energy Balances. Part I: The Land Dynamics (LaD) Model. *J Hydrometeorol* 3 (3): 283–299.
- MO KC & PAEGLE JN. 2001. The Pacific–South American modes and their downstream effects. *Int J Climatol* 21 (10): 1211-1229.

- MORIOKA Y, ENGELBRECHT F, BEHERA SK. 2017. Role of Weddell Sea ice in South Atlantic Atmospheric Variability. *Clim Res* 74: 171–184.
- MORIOKA Y, DOI T, IOVINO D, MASINA S, BEHERA SK. 2019. Role of Sea-Ice Initialization in Climate Predictability over the Weddell Sea. *Sci Rep* 9: 2457.
- PARISE CK. 2014. Sensitivity and memory of the current mean climate to increased Antarctic sea ice: The role of sea ice dynamics. Ph.D. thesis, National Institute for Space Research (INPE), 218 pp.
- PARISE CK, PEZZI LP, HODGES KI & JUSTINO F. 2015. The Influence of Sea Ice Dynamics on the Climate Sensitivity and Memory to Increased Antarctic Sea Ice. *J Clim* 28 (24): 9642-9668.
- PARKINSON CL. 2019. A 40-y record reveals gradual Antarctic sea ice increases followed by decreases at rates far exceeding the rates seen in the Arctic. *PNAS* 116 (29): 14414-14423.
- PEZZA AB, RASHID HA & SIMMONDS I. 2012. Climate links and recent extremes in Antarctic sea ice, high-latitude cyclones, Southern Annular Mode and ENSO. *Clim Dyn* 38: 57–73.
- RABELO LB, CRAUSS M & SOUZA RB DE. 2009. Estrutura Termal da Frente Polar na região da Passagem de Drake através de perfis verticais de temperatura obtidos com XBT. *Ciênc Nat* 31: 313-316.
- RAPHAEL MN. 2003. Impact of observed sea-ice concentration on the Southern Hemisphere extratropical atmospheric circulation in summer. *J Geophys Res* 108 (D22): 4687.
- RAPHAEL MN, HOBBS W & WAINER I. 2011. The effect of Antarctic sea ice on the Southern Hemisphere atmosphere during the southern summer. *Clim Dyn* 36: 1403–1417.
- RAYNER NA, PARKER DE, HORTON EB, FOLLAND CK, ALEXANDER LV, ROWELL DP, KENT EC & KAPLAN A. 2003. Global analyses of sea surface temperature, sea ice, and night marine air temperature since the late nineteenth century. *J Geophys Res* 108 (D14): 4407.
- REICHLER T & KIM J. 2008. How Well Do Coupled Models Simulate Today's Climate? *Amer Meteor Soc* 89 (3): 303–311.
- RUDEVA I & SIMMONDS I. 2015. Variability and Trends of Global Atmospheric Frontal Activity and Links with Large-Scale Modes of Variability. *J Clim* 28 (8): 3311-3330.
- SCREEN JA, BRACEGIRDLE TJ & SIMMONDS I. 2018. Polar Climate Change as Manifest in Atmospheric Circulation. *Curr Clim Change Rep* 4: 383–395.
- SEMTNER AJ. 1976. A Model for the Thermodynamic Growth of Sea Ice in Numerical Investigations of Climate. *J Phys Oceanogr* 6 (3): 379–389.

- SMITH DM, DUNSTONE NJ, SCAIFE AA, FIEDLER EK, COPSEY D & HARDIMAN SC. 2017. Atmospheric Response to Arctic and Antarctic Sea Ice: The Importance of Ocean–Atmosphere Coupling and the Background State. *J Clim* 30 (12): 4547–4565.
- SON SW, KIM SY & MIN SK. 2018. Widening of the Hadley Cell from Last Glacial Maximum to Future Climate. *J Clim* 31 (1): 267–281.
- STOUFFER RJ, BROCCOLI AJ, DELWORTH TL, DIXON KW, GUDGEL R, HELD I, HEMLER R, KNUTSON T, LEE H, SCHWARZKOPF MD, SODEN B, SPELMAN MJ, WINTON M & ZENG F. 2006. GFDL's CM2 Global Coupled Climate Models. Part IV: Idealized Climate Response, *J Clim*, 19(5), 723–740.
- SUN X, COOK KH & VIZY EK. 2017. The South Atlantic sub-tropical high: Climatology and interannual variability. *J Clim* 30 (9): 3279-3296.
- TAYLOR K, WILLIAMSON D & ZWIERS F. 2000. The Sea Surface Temperature and Sea-ice Concentration Boundary Conditions for AMIP II Simulations. PCMDI: p. 28.
- THOMPSON DWJ & WALLACE JM. 2000. Annular modes in the extratropical circulation. Part I: Month-to-month variability. *J Clim* 13 (5): 1000-1016.
- TURNER J, GUARINO MV, ARNATT J, JENA B, MARSHALL G J, PHILLIPS T. 2020. Recent decrease of summer sea ice in the Weddell Sea, Antarctica. *Geophysical Research Letters*, 47, e2020GL087127.
- WANG Z, TURNER J, WU Y & LIU C. 2019. Rapid Decline of Total Antarctic Sea Ice Extent during 2014–16 Controlled by Wind-Driven Sea Ice Drift. *J Clim* 32 (17): 5381–5395.
- WINTON M. 2000. A Reformulated Three-Layer Sea Ice Model. *J Atmos Oceanic Technol* 17 (4): 525–531.
- WITTENBERG AT, ROSATI A, LAU NC & PLOSHAY JJ. 2006. GFDL'S CM2 Global Coupled Climate Models. Part III: Tropical Pacific Climate and ENSO. *J Clim* 19 (5): 698–722.
- YUAN X & MARTINSON DG. 2000. Antarctic Sea Ice Extent Variability and Its Global Connectivity. *J Clim* 13 (10): 1697–1717.
- YUAN X & MARTINSON DG. 2001. The Antarctic Dipole and its Predictability. *Geophys Res Lett* 28 (18): 3609–3612.
- YUAN X & LI C. 2008. Climate Modes in Southern High Latitudes and Their Impacts on Antarctic Sea Ice. *J Geophys Res Oceans* 113 (C6): C06S91.

YUAN X, KAPLAN MR & CANE MA. 2018. The Interconnected Global Climate System - A Review of Tropical-Polar Teleconnections. *J Clim* 31 (15): 5765–5792.

YUAN X. 2004. ENSO-Related Impacts on Antarctic Sea Ice: A Synthesis of Phenomenon and Mechanisms. *Antarct Sci* 16 (4): 415-425.

III. CONSIDERAÇÕES FINAIS

Nos estudos de Parise (2014) e Parise et al. (2015), foi investigado a resposta da atmosfera austral aos extremos positivos de gelo marinho antártico compreendendo o período de 2020 a 2030, com impactos variando sazonalmente e setorialmente (Oceano Atlântico, Pacífico e Índico). Já o presente estudo buscou avaliar a resposta da circulação atmosférica meridional no setor do Atlântico Sul a um aumento histórico de área e volume de gelo marinho antártico, com foco na escala interanual em relação às mudanças ocorridas na temperatura do ar, vento zonal e meridional e pressão ao nível médio do mar. Em geral, a resposta da circulação da troposfera no setor do Atlântico Sul aos eventos extremos de gelo marinho antártico mostrou que o sinal climático se estendeu da superfície aos níveis elevados, propagando-se das altas latitudes austrais até a região tropical.

O presente estudo mostrou um mecanismo de resposta das células de circulação atmosférica no setor do Atlântico Sul aos extremos positivos de gelo marinho antártico, indicando que as mudanças na concentração e na espessura desse gelo apresentam grande influência no deslocamento e na intensidade das células, principalmente, nas células Polar e Ferrel. Além disso, mostrou como a atmosfera responde à diferentes cenários futuros de concentração de gelo marinho antártico simulados por um modelo climático acoplado e o tempo necessário para que o sinal climático gerado pelos distúrbios do gelo marinho alcance a troposfera tropical. Avaliando esse comportamento da circulação meridional da troposfera austral no setor do Atlântico, o estudo abordou também possíveis consequências no clima da América do Sul.

Embora os resultados encontrados aqui sejam relevantes no contexto das mudanças climáticas globais associadas aos eventos extremos de gelo marinho antártico, é necessária uma avaliação mais detalhada dos mecanismos climáticos responsáveis pela propagação da oscilação do clima da Antártica para as latitudes mais baixas do setor do Atlântico. Além dessa avaliação das teleconexões climáticas Polo Sul-Trópicos, estudar os impactos da variabilidade do gelo marinho antártico nos diferentes setores do Oceano Atlântico e das regiões continentais adjacentes, são também estudos fundamentais para um melhor entendimento das mudanças climáticas de curto prazo, uma vez que o setor do Atlântico tem grande influência no clima da América do Sul. Esses estudos dos impactos do gelo marinho antártico mencionados acima, são portanto, trabalhos futuros que estão sendo desenvolvidos a partir da presente pesquisa de Trabalho de Conclusão de Curso.

REFERÊNCIAS

AYODE, J.O. **Introdução à Climatologia para os Trópicos**. 4. ed. Rio de Janeiro: Bertrand Brasil, 1996. 332p.

VAREJÃO-SILVA, M.A. **Meteorologia e Climatologia**. Recife – PE, Brasil. Versão Digital 2. 2006. 463 p.

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REFERENCES

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.

Livros e capítulos de livros:

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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.