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The anomalous wet 2020 southeast Brazil austral summer: characterization and possible mechanisms

Short title: The anomalous wet 2020 southeast Brazil austral summer

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Highlights:

- The austral summer 2020 in SEB was the wettest in almost twenty years.
- Colder SST near SEB and positive SAM phase were important to the wet pattern.
- Wavetrain from the Indian Ocean also contributed to the circulation over SEB.

Graphical Abstract:

Austral summer precipitation anomaly (mm day$^{-1}$): (a) 1981–2020 time series area-averaged over the SEB, and (b) 2020, with the thick black contour encloses the area of SEB. Data Source: GPCP.
Abstract

This paper analyzed the anomalous rainy austral summer 2020 over the Southeastern Region of Brazil (SEB), investigating the possible mechanisms. The SEB has been experiencing dry summers in the years before 2020. However, the austral summer 2020 in this region was the wettest summer since 1991. A wavetrain started from the Indian Ocean to the Pacific Ocean, plus a wavetrain from tropical north (U-shape), and another from western equatorial Pacific (PSA-like) contributed for an anomalous anticyclonic circulation at high levels southward South America. This merged wavetrain continued its path with an anomalous cyclonic circulation over the Southern region of Brazil and Sao Paulo State and anticyclonic northward, enhancing (inhibiting) convection over SEB (Southern Brazil). Besides, the Southern Annular Mode (SAM) pattern was in a positive phase, and there were negative sea surface temperature (SST) anomalies near SEB and Argentina, contributing for the configuration over the continent. Comparisons for the main differences between austral summer 2019 (dry) from summer 2020 have shown there is no anomalous divergence at high levels over the Indian Ocean in 2019, triggering a wavetrain from this region to Pacific. The two wavetrains from Pacific merged in an anomalous anticyclonic circulation, over the southeastern Pacific, near South America Coast. The SAM pattern was neutral in 2019. However, there were positive SST anomalies near SEB, Southern Brazil and Argentina coastal. The South Atlantic SST and the wavetrains generated an anticyclonic anomalous circulation over the Southern Region of Brazil and cyclonic northward, in opposition configuration of 2020.

1. Introduction

South America is affected by teleconnections, both east-west and south-north, which have an impact on the climate of this continent (Cavalcanti and Ambrizzi, 2009). However, the influences of those patterns are different over the continent, and not clear in some areas, especially over regions of transition between tropics and extratropics. The Southeastern Brazil region (SEB) - that includes Sao Paulo, Rio de Janeiro, Minas Gerais, and Espirito Santo States - is one of these regions, being cut by the Tropic of Capricorn (northern region of Sao Paulo State). SEB is the most populous region of Brazil, concentrating 42.1% of country people (IBGE, 2011), and also has the highest Gross Domestic Product (GDP) of the country (IPEA, 2020). This region is affected by synoptic systems such as frontal systems and the South Atlantic Convergence Zone (SACZ) during austral summer, which can produce intense
precipitation with floods and landslides occurrences near the coastal regions (Vasconcellos and Cavalcanti, 2010). The climate variability modes can impact the occurrence and intensity of these main summer precipitation systems.

The Pacific Sea Surface Temperature (SST) anomalies impact the South America climate on different scales. These anomalies can, for example, trigger wavetrains from the Pacific, generating anomalous circulations at high level over the continent and consequently, inducing the convection (e.g., Cunningham and Cavalcanti, 2006; Vasconcellos and Cavalcanti, 2010; Coelho et al., 2016; Bernardino, Vasconcellos and Nunes, 2018). Carvalho, Jones and Liebmann (2004) found a relationship between El Niño-Southern Oscillation (ENSO) and SACZ, in which there is more occurrence of oceanic SACZ during El Niño years (warmer SST over Niño 3.4 region), whereas in La Niña (colder SST over Niño 3.4 region) and neutral years, the continental SACZ would be more frequent. Particularly about SEB, several studies have suggested the impacts of ENSO over this region are different, depending on area of SEB, the time of year, phase, and type of ENSO (e.g., Tedeschi, Cavalcanti and Grimm, 2013; Tedeschi, Grimm and Cavalcanti, 2016).

The SST anomalies in the South Atlantic also influences the climate in South America, including SEB. Studies have shown the negative SST anomalies over subtropical South Atlantic, near SEB coastal enhances the SACZ (Doyle and Barros, 2002; Bombardi, Carvalho and Jones, 2014; Bombardi et al., 2014; Jorgetti, Silva Dias and Freitas, 2014). Doyle and Barros (2002) showed that negative SST anomalies in the subtropical South Atlantic in midsummer favor SACZ activity. Bombardi, Carvalho and Jones (2014) analyzing the period from November to March, showed the negative SST anomalies over tropical is associated with the increase of cyclogenesis in the ocean near SEB, as well as the migration of extratropical cyclones further north. However, their tropical SST results includes the SEB coastal. Thus, these studies have suggested that the negative SST anomalies near SEB would lead to an increase in precipitation over the SEB during the rainy season.

Southern Annular Mode (SAM) is the leading mode of extratropical variability in the Southern Hemisphere, characterized by north-south seesaws of atmospheric mass between the high latitudes and parts of the midlatitudes (Thompson and Wallace, 2000). Some studies have indicated SAM has impacts in the South America climate (Carvalho, Jones and Ambrizzi, 2005; Gillett, Kell and Jones, 2006; Vasconcellos and Cavalcanti, 2010; Rosso et al., 2018; Vasconcellos, Pizzochero and Cavalcanti, 2019). Rosso et al. (2018) found the frequency, persistence, and total precipitation in SACZ events are higher in the positive SAM phase, compared to the negative phase. Vasconcellos, Pizzochero and Cavalcanti (2019) studied the
month-by-month impacts of SAM phases on precipitation and air temperature in South America (in years of neutral ENSO). Their results showed the SAM has different impacts depending on the month and the phase of this pattern. For precipitation, the authors revealed that the impacts in the SEB are irregular. However, for January-March months, the positive (negative) SAM promotes rainy (dry) months over the northern parts of SEB.

Although there are studies indicating the influence of low-frequency modes on the SEB climate, the predictability of climate precipitation over SEB has proven to be difficult due to the lack of knowledge on the combined effects of the climate variability modes on large-scale circulations, which impact precipitation variability over this region (Koster, Suarez and Heister, 2000; Nobre et al., 2006). Therefore, the improvements of knowledge of the precipitation variability mechanisms might provide the basis for an increase in climate predictability, particularly in the warm and rainy seasons of the SEB. Due to the importance for economic and population and the low climate predictability, an increase on the learning of climate variability over this region becomes essential.

SEB has been experiencing consecutive drought years, including extreme drought of austral summer 2014 (e.g., Coelho et al., 2016; Coelho, Cardoso and Firpo, 2016). However, unlike the last years, the austral summer 2020 appears to have been unusually rainy. The goal of this paper is to characterize the SEB precipitation at this season and investigate possible causes for this change of anomaly pattern, analyzing the circulation and the influence of variability modes. With the aim of contributing to advance on understanding the causes of the austral summer 2020 wet anomalies over the SEB, this paper will:

- Diagnose the observed austral summer (January–March) precipitation conditions over the SEB;
- Investigate regional mechanisms and possible oceanic and atmospheric teleconnection patterns associated with the wetter austral summer 2020 over the SEB;
- Compare the SST and atmospheric circulation patterns of 2020 austral summer (rainy) with 2019 (dry) one.

This paper is outlined as follows. Section 2 introduces the datasets and describes the methods used to characterize the austral summer 2020 and 2019 over SEB and investigate possible causes of these anomalous seasons. Section 3 presents rainy austral summer 2020 over SEB in historical context. Section 4 discusses the potential mechanisms associated with the wet austral summer 2020 over SEB. Section 5 displays a comparison of austral summer 2019 (dry) and 2020 (rainy). Summary and conclusions are presented in Section 6.
2. Dataset and Methods

Monthly outputs of the Global Precipitation Climatology Project (GPCP) have been used in this paper. The GPCP product combines sun-synchronous low-orbit satellite microwave data, geosynchronous-orbit satellite infrared data, and observations from rain gauges, after quality control to produce precipitation estimates. The product has $2.5^\circ \times 2.5^\circ$ resolution (Adler et al., 2003). The advantage of using GPCP is its global coverage, including oceanic areas. Furthermore, Muza et al. (2009) have shown that GPCP has a satisfactory correspondence with a gridded precipitation from stations (described in Liebmann and Allured, 2005) in areas over tropical and subtropical Brazil.

The Extended Reconstructed Sea Surface Temperature (ERSST) V5 product from National Oceanic & Atmospheric Administration (NOAA) has been adopted for SST related analysis. The ERSST uses the new International Comprehensive Ocean-Atmosphere Dataset (ICOADS) Release 3.0 SST; SST comes from Argo floats above five meters, Hadley Centre Ice-SST version 2 (HadISST2) ice concentration. This dataset had improved SST spatial and temporal variability by: reducing spatial filtering in training the reconstruction functions Empirical Orthogonal Teleconnections (EOTs), removing high-latitude damping in EOTs, and adding ten more EOTs in the Arctic. The ERSSTv5 also uses unadjusted First-Guess instead of adjusted First-Guess. More information about this dataset can be found in Huang et al. (2017).

The monthly outputs of ERA5 Reanalysis were used to compute the circulation and divergences. The ERA5 is the fifth generation of European Centre for Medium-Range Weather Forecasts (ECMWF) atmospheric reanalysis, replacing ERA-Interim, with a higher spatial and temporal resolution. This reanalysis provides estimates of a large number of atmospheric, terrestrial, and oceanic variables. The data covers the entire globe with $0.25^\circ \times 0.25^\circ$ of horizontal resolution, or approximately 30 km, using 137 levels of the surface up to a height of 80 km. The data assimilation system was also renewed, and a large number of historical observations (satellite or in situ) were assimilated. More details about this reanalysis can be found in Hersbach et al. (2020).

This study evaluated the 2019 and 2020 austral summer seasons (JFM mean) over the SEB area. The analysis is presented through anomalies computations relatively to the climatologic period from 1981 to 2020.

To validate the GPCP dataset, the time series was compared to the precipitation products from the Center for Weather Forecasting and Climate Studies/National Institute for Space Research (CPTEC/INPE), available in http://clima1 cptec.inpe.br/evolucao/pt. Results had a good
agreement when compared to the time series displayed at the site (not shown). We also compared monthly anomaly precipitation maps (January, February, and March 2019 and 2020) from GPCP to the precipitation products from CPTEC/INPE (available at http://clima1.cptec.inpe.br/monitoramentobrasil/pt). The maps, in general, have good correspondence, including over SEB (not shown). After these validations of the GPCP dataset, a map of austral summer 2020 anomaly precipitation over Brazil (40°S-5°N/75°W-30°W) was created to analyze the spatial distribution of anomalies.

Maps of anomaly geopotential height at 700 hPa and SST for austral summer 2020 were examined with the goal to identify possible influences of teleconnection patterns. High-level circulation analyses were evaluated through velocity potential anomalies, divergent wind anomalies, and anomaly wind streamlines at 200 hPa. SAM index was also obtained from Climate Prediction Center (CPC/NOAA) (available at https://www.cpc.ncep.noaa.gov/products/precip/Cwlink/daily_ao_index/aaomonthly.aao.index.b.079.current.ascii.table).

In order to complement SST results over the Pacific, the Oceanic Niño Index (ONI) was obtained from CPC/NOAA (available at https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php). This index is a three months running mean of ERSST.v5 SST anomalies in the Niño 3.4 region (5°N-5°S/170°W-120°W), based on centered 30-year base periods updated every five years.

Subtropical South Atlantic was further analyzed through time series (1981-2020) of austral summer anomaly SST area-averaged over the region defined by the coordinates (30°W-60°W) and (20°S-45°S) and correlation map between austral summer SST averaged over subtropical South Atlantic (same area above) and precipitation (1981-2020), both series were detrended. The Student’s t-test (Wilks, 2006) was applied to the correlation map to determine regions in which the composite variables have a confidence level of 90%.

To complement the results found to austral summer 2020 (rainy), we also created the maps from the previous paragraphs (exception of correlation map) for austral summer 2019 (dry), with the goal to compare these two summers. Additionally, the ONI index were obtained for 2019 too.

3. The rainy austral summer 2020 over SEB in a historical context

Figure 1a displays a temporal series of austral summer anomaly precipitation, averaged over SEB. It is noteworthy a change of pattern among 2020 summer and previous years. The austral summer 2020 over SEB experienced an anomaly of 1.6 mm.day⁻¹, in opposition of -1.6
mm.day$^{-1}$ of summer 2019. Since 2011, this region has not displayed summer precipitation above normal, and 2020 was the wettest summer since 1991. The precipitation pattern changed from December 2019 (dry) for January 2020 and the following months (rainy) (not shown). The driest summer identified in 2014 caused severe impacts in water availability for public consumption, hydropower generation, and agriculture in the region (Coelho et al., 2016; Coelho, Cardoso and Firpo, 2016). The austral summer 2020 presented positive precipitation anomalies over almost all SEB (Fig. 1b), with higher values over Minas Gerais State and the division between Rio de Janeiro and Espirito Santo States. These positive anomalies extended into the Atlantic Ocean in a NW-SE direction, a similar configuration to oceanic SACZ (Carvalho, Jones and Liebmann, 2004). This precipitation pattern could indicate more occurrence and/or persistence of this system. The Sao Paulo State was an exception of the SEB, showing negative precipitation anomalies. The different behaviors of precipitation anomaly within SEB ratify that the impacts of low-scales modes are not similar across SEB. Sao Paulo State had similar behavior of Southern Region of Brazil in austral summer 2020. SEB and Southern Brazil (including Sao Paulo) displayed a dipole pattern of anomaly precipitation. The dipolar pattern was also seen at previous works (e.g., Cunningham and Cavalcanti, 2006; Vasconcellos and Cavalcanti, 2010; Jorgetti, Silva Dias and Freitas, 2014; Bernardino, Vasconcellos and Nunes, 2018; Silva et al. 2020). Silva et al. (2020), for example, associated similar dipole, Sao Paulo and Southern Brazil in opposition to Southeastern Brazil, with a positive phase of Decadal Pacific Oscillation.

4. Teleconnections, circulation and mechanisms

Previous works indicated the influence of SAM over South America (e.g., Carvalho, Jones and Ambrizzi, 2005; Gillett, Kell and Jones, 2006; Vasconcellos and Cavalcanti, 2010; Vasconcellos, Pizzochero and Cavalcanti, 2019). Figure 2a shows a spatial pattern associated with the positive SAM phase (0.5 index – JFM mean) in austral summer 2020, i.e., negative (positive) geopotential height anomalies over high (middle) latitudes. These results are in accordance with Vasconcellos, Pizzochero and Cavalcanti (2019), which indicate wetter summers over the northern part of SEB in the positive SAM phases. According to Rosso et al. (2018), the positive SAM phase is related with higher frequency, persistence, and total precipitation in SACZ events, which is in agreement with positive precipitation anomalies over SEB, displayed in Figure 1. The influence of lower frequency modes, like PDO, could also be related to this dipole (Silva et al., 2020). It is noteworthy, that despite positive geopotential height anomalies at middle latitude, related by the positive SAM phase, there
was a negative anomaly over South Atlantic, reaching SEB coastal. This could be related to wavetrains started at Pacific and the Indian Oceans, as indicated by alternations of geopotential height anomalies presented in Figure 2a.

There were positive SST anomalies over most of the central and western equatorial Pacific (Fig. 3a) and the ONI index confirms the El Niño phase. Positive SST anomalies are also shown over the tropical Indian Ocean (Fig. 3a).

The Atlantic Ocean also influences the South American climate (Fig. 4). Correlation map between SST over subtropical South Atlantic and precipitation showed the SST over this region are negatively (positively) correlated with precipitation over SEB, northward Sao Paulo State (Southeastern South America, including Uruguay, northern Argentina and Rio Grande do Sul State, Brazil; Fig. 4a). There is a positive tendency of austral summer SST over subtropical South Atlantic, with the highest values in last years (Fig. 4b). Nonetheless, austral summer 2020 presented an intense decrease of SST, compared to austral summer 2019.

There were positive SST anomalies over the tropical South Atlantic and in a band near 60ºS. However, there were negative SST anomalies near SEB and Argentina (Fig. 3). According to previous studies, the negative SST anomalies over tropical South Atlantic (near SEB) influences the intensification of SACZ, the increase of cyclogenesis in the ocean near SEB, and the migration of extratropical cyclones northward (Doyle and Barros, 2002; Bombardi, Carvalho and Jones, 2014; Bombardi et al., 2014; Jorgetti, Silva Dias and Freitas, 2014). However, in some of these studies, the tropical South Atlantic SST presented the same signal of the subtropic region, opposite results were found here.

The anomalous high-level divergence was present over the tropical Indian Ocean (approximately 0º/50ºE), western equatorial Pacific (approximately 0º/180ºW), and eastern tropical North Pacific (approximately 10ºN/140ºW) on summer 2020 (Fig. 5a). These anomalous divergences were created by warmer waters over these regions (Fig. 3a) and, consequently, more convection in the underneath layer (not shown). The anomalous divergence over the Indian Ocean triggered a wavetrain from Indian to the Pacific Ocean (Fig. 5b). The other two regions of anomalous divergence also triggered wavetrains: the western equatorial Pacific divergence started a PSA-like wavetrain, while the eastern tropical North Pacific started a U-shape wavetrain. All these wavetrains merged southward South America, in an anomalous anticyclonic circulation, which continued its path with a cyclonic anomalous circulation over the Southern region of Brazil and Sao Paulo State and an anticyclonic one northward, enhancing (inhibiting) convection over SEB (Southern Brazil). The SST anomalies over SEB and Argentina coastal also contributed to this configuration.
5. Comparison with 2019 austral summer

To improve the knowledge on SEB precipitation variability, the austral summer 2019 (dry) was compared to 2020 (rainy) one. Austral summer 2019 displayed an inversion of precipitation anomaly dipole over South America, compared with 2020, presenting negative anomalous precipitation over SEB and positive anomalies in Southern Brazil (Fig. 6). This could suggest less occurrence of SACZ. Unlike 2020, the precipitation anomaly over Sao Paulo State in summer 2019 was similar to the rest of SEB. This non-uniformity of precipitation patterns within the SEB between 2020 and 2019 ratify the understanding difficulty of the climatic variability in this region.

Differently of austral summer 2020, the SAM pattern was not well defined on summer 2019 (Fig. 2b). The SAM index showed a neutral phase (0.31 index – JFM mean). There were warm waters over all equatorial Pacific (Fig. 3b). ONI confirms the occurrence of El Niño on summer 2019 (Table II). The tropical South Atlantic Ocean presented positive SST anomalies, similar to 2020. However, these anomalies extended southward, reaching SEB, Southern Brazil and Argentina coastal. Besides, there was a region of negative SST anomalies near 60ºS (Fig. 3b). The subtropical and extratropical South Atlantic presented an opposite configuration of austral summer 2020(Fig. 3a).

Similar to 2020, there was, in 2019, an anomalous high-level divergence at western equatorial Pacific (Fig. 7a). The eastern tropical North Pacific also presented anomalous divergence (approximately 20ºN/140ºW), northward and stronger that in 2020 (Fig. 7a). They also triggered two wavetrains: a PSA-like wavetrain from the western equatorial Pacific and a U-shape wavetrain, from the eastern tropical North Pacific passing over the southern South America (Fig. 7b). However, contrasting to 2020, there was no anomalous divergence at high-levels over the Indian Ocean, and, consequently, there was no wavetrain from this region to the South Pacific. Then, the circulation over South America and the Atlantic Ocean in austral summer 2019 was different from 2020 one. The U-shape and PSA-like wavetrains over the Pacific merged in an anomalous anticyclonic circulation, over the southeastern Pacific, near South America coast. The continuation of this wavetrain downstream, over the continent, generated anticyclonic anomalous circulation over the Southern Region of Brazil and cyclonic one northward, an inversion of 2020 configuration. The SST anomalies over SEB and Argentina coastal also contributed to this configuration. These results inhibited (enhanced) the convection over SEB (Southern Brazil) during austral summer 2019. A U-shape wavetrain was also found by Coelho et al. (2016), associated with the summer 2014 drought over SEB.
Thus, the main conclusion from this comparing analysis is the distinct South America climatic patterns for two El Niño conditions.

6. Summary and Conclusions
In the SEB, the predictability of climate precipitation has proven to be difficult due to the unclear impact of the climate variability modes on large-scale circulations that influence precipitation variability over this region (Koster, Suarez and Heister, 2000; Nobre et al., 2006). Therefore, a better knowledge of the causes of the precipitation variability might provide the basis for increasing predictability, mainly in the summers.

The SEB has been experiencing dry summers in the last years, including the severe 2014 drought (Coelho et al., 2016; Coelho, Cardoso and Firpo, 2016). However, the austral summer 2020 in this region was anomaly rainy, being the wettest summer in almost twenty years. The positive precipitation anomalies reached almost all SEB, with the exception of Sao Paulo State, ratifying that the variability impacts are not similar at all SEB. These positive anomalies extended to the Atlantic Ocean, in a NW-SE direction, indicating a greater role of SACZ. Sao Paulo State had similar behavior of the Southern Region of Brazil, i.e., negative precipitation anomalies. These two regions revealed a dipole pattern of anomaly precipitation, also displayed by previous work (e.g., Cunningham and Cavalcanti, 2006; Vasconcellos and Cavalcanti, 2010; Jorgetti, Silva Dias and Freitas, 2014; Bernardino, Vasconcellos and Nunes, 2018; Silva et al., 2020).

The precipitation anomalies over SEB in austral summer 2020 were influenced by different mechanisms. The SAM pattern was in a positive phase, which according to Vasconcellos and Cavalcanti (2010), Rosso et al. (2018), and Vasconcellos, Pizzochero and Cavalcanti (2019), could lead to wetter summers at part of SEB. The ENSO pattern was positive (El Niño). The austral summer 2020 also presented negative SST anomalies over South Atlantic near SEB and Argentina. Previous studies indicated the negative SST over SEB coastal lead to an increase in precipitation over the SEB during the rainy season (Doyle and Barros, 2002; Bombardi, Carvalho and Jones, 2014; Bombardi et al., 2014; Jorgetti, Silva Dias and Freitas, 2014).

High-levels anomalous divergence over the Indian Ocean triggered a wavetrain from Indian to the Pacific Ocean. Two other wavetrains, originated from western equatorial Pacific and eastern north tropical Pacific, also contributed for an anomalous anticyclonic circulation southward South America, which continued its path with a cyclonic anomalous circulation over the Southern region of Brazil and Sao Paulo State and anticyclonic one northward,
enhancing (inhibiting) convection over SEB (Southern Brazil). The South Atlantic SST anomalies and the positive SAM phase contributed for this configuration over the continent.

Comparison between austral summers 2020 (rainy SEB) and 2019 (dry SEB) revealed an opposition of precipitation anomaly dipole between SEB and Southern Brazil. Like in 2020, there was an El Niño event in austral summer 2019. The SAM pattern was not well configured in 2019. The subtropical and extratropical South Atlantic presented positive SST anomalies over SEB, Southern Brazil and Argentina coastal in summer 2019, in opposition to summer 2020. There was no anomalous divergence at high levels over the Indian Ocean, and as a result, there was no wavetrain from this region to Pacific in austral summer 2019, differently of 2020. The U-shape and PSA-like wavetrains over the Pacific also were present in austral summer 2019. However, they merged in an abnormal anticyclonic circulation, over the southeastern Pacific, near the South America coast. Therefore, this combined wavetrain and the warmer South Atlantic SST contributed to an anticyclonic anomalous circulation over the Southern Region of Brazil and cyclonic one northward, an opposite configuration of 2020.

Thus, this study compared analysis is the distinct South America climatic patterns for two El Niño conditions (austral summer 2019 and 2020). The occurrence of negative SST near SEB, the positive SAM phase, and a wavetrain started over the Indian Ocean revealed to be very important to change the dry pattern seen in the 2019 summer over this region. Enhancing the knowledge on SEB climate variability and its mechanisms have a great potential to guide several socioeconomic sectors to better manage the risks of climate variability, by developing adaptation strategies to deal with the climate conditions.

References


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Figure 1 – Austral summer precipitation anomaly (mm day$^{-1}$): (a) 1981–2020 time series area-averaged over the SEB, and (b) 2020, with the thick black contour encloses the area of SEB.

Data Source: GPCP.
Figure 2 – Geopotential height anomaly at 700 hPa (m): (a) austral summer 2020, and (b) austral summer 2019. Data Source: ERA5.
Figure 3 – SST (°C) anomaly: (a) austral summer 2020, and (b) austral summer 2019. Data Source: NOAA ERSSTv5.
Table I. Austral summer 2020 CPC/NOAA indices: Oceanic Niño Index (ONI) and SAM index. Values above (below) 0.5°C (-0.5°C) are in red (blue).

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<td><strong>SAM</strong></td>
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Figure 4 – (a) Correlation map between austral summer SST averaged over subtropical South Atlantic (30°W-60°W/20°S-45°S) and precipitation (1981-2020), detrended, with statistical significance level for $p = 0.90$ (student’s t-test), and (b) 1981–2020 time series of anomaly SST (°C) area-averaged over the subtropical South Atlantic (same area described above). Green line is linear trend. Data Source: GPCP and NOAA ERSSTv5.
Figure 5 – Austral summer 2020: (a) velocity potential anomalies ($10^6$ m$^2$ s$^{-1}$ - contours and colours) and divergent wind anomalies (m s$^{-1}$ – vectors) at 200 hPa, and (b) wind anomaly streamlines at 200 hPa. Red plus (minus) signals show anticlockwise (clockwise) circulations associated with wavetrains. Data Source: ERA5.
Figure 6 - Austral summer 2019 precipitation anomaly (mm day$^{-1}$, relative to 1981-2020 period). Data Source: GPCP.
Table II – Austral summer 2019 CPC/NOAA indices: Oceanic Niño Index (ONI) (https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php), and SAM index (https://www.cpc.ncep.noaa.gov/products/precip/Cwlink/daily_ao_index/ao/monthly.aoa.index.b79.current.ascii.table). Values above (below) 0.5°C (-0.5°C) are in red (blue).

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Figure 7 – Austral summer 2019: (a) velocity potential anomalies ($10^6$ m$^2$ s$^{-1}$ - contours and colours) and divergent wind anomalies (m s$^{-1}$ – vectors) at 200 hPa, and (b) wind anomaly streamlines at 200 hPa. Red plus (minus) signals show anticlockwise (clockwise) circulations associated with wavetrains. Data Source: ERA5.