Nearly Synchronous Multidecadal Oscillations of Surface Air Temperature in Punta Arenas and the Atlantic Multidecadal Oscillation Index

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(Manuscript received 20 November 2017, in final form 22 May 2018)

ABSTRACT

The Atlantic multidecadal oscillation (AMO) signature in southern South America (SA) is examined using the surface air temperature (T-air) of Punta Arenas, Chile (53.0°S, 70.85°W), during the 1888–2016 period. The T-air shows multidecadal oscillations with a significant positive correlation of 0.77 to the AMO index. The relations of the Punta Arenas T-air time series with the AMO-related global sea surface temperature (SST) and regional circulation anomaly patterns are discussed. During the warm (cold) AMO phase, a cold (warm) center in southwestern Atlantic waters induces low-level anticyclonic (cyclonic) anomalies in the region, which together with the cyclonic (anticyclonic) anomalies in the southeastern Pacific channel the northerly (southerly) flow over southern SA. This meridional flow transports warm (cold) air from lower (higher) latitudes into the Punta Arenas region. Therefore, the temperature horizontal advection at the low level is the main thermodynamic process that alters the Punta Arenas T-air in a multidecadal time scale. The use of a relation between a long T-air surface sensor series in southern SA with the AMO presents a novel approach in climate monitoring and modeling.

1. Introduction

Increase in greenhouse gas concentrations drives the current global warming and the associated changes in the climate system (IPCC 1990). Therefore, surface air temperature (T-air) is one of the most important climate variables, not only in this context, but also because of its natural variations. Nevertheless, reliable instrumental long T-air records are few and restricted to some regions in the globe. Consequently, detailed studies on the T-air variations have been hampered for many regions, including large regions of the South American continent, where reliable surface observations in a relatively dense network are available beginning mainly in the 1950s (Garreau et al. 2009). Thus, the few studies found in the literature on T-air variations over South America (SA) examined mostly the interannual time-scale variability or trends during the last decades. Studies on T-air long-term trends over SA, in general, used extreme temperatures and were restricted to regions such as the Brazilian Amazon (Victoria et al. 1998), Venezuela and Colombia (Quintana-Gomez 1999), Argentina (Rusticucci and Barrucand 2004), and southern Brazil (Marengo and Camargo 2008; Sansigolo and Kayano 2010). Vargas and Naumann (2008) suggested that secular trends identified in the minimum and maximum temperature time series in eight stations in southern South America are driven by the set of wet days. Naumann and Vargas (2017) showed that these time series contain also oscillations with periods varying from 18 to 25 years. They also showed that these periodicities vary over time, in particular during the 1950–70 decades when higher variability predominated. In the southern high latitudes, Zazulic et al. (2010) analyzed T-air variations in the Antarctic South Orkney/Orcadas del Sur Island station (60.7°S, 44.7°W) and found no statistically significant trends from 1903 to 1950; however, for the remainder of the series a statistically significant warming was noticed throughout the four seasons of the year. Vincent et al. (2005) analyzed the trends in daily temperature extremes during the 1960–2000 period in eight countries of SA and found a consistent positive trend for the daily minimum temperature for stations located in its west and east coasts.

For the interannual time scale, the El Niño–Southern Oscillation (ENSO) is the most important coupled ocean–atmosphere mode responsible for climate variations over
SA (Ropelewski and Halpert 1987, 1989; Zhou and Lau 2001). This climate linkage occurs through alterations in the Walker and Hadley cells creating an atmospheric circulation bridge between the tropical Pacific and tropical SA, or through the anomalous large-scale Rossby wave train patterns that connect the tropical Pacific and extratropical SA (Zhou and Lau 2001). Because of the regional surface differences, the ENSO effects on the South American T-air present seasonal and regional dependences documented in previous studies. An El Niño (a La Niña) related abnormal warming (cooling) occurs in subtropical and southeastern SA during winter, in tropical SA during summer and autumn, and in northern and western tropical SA during spring (Kiladis and Diaz 1989; Halpert and Ropelewski 1992; Grimm 2003, 2004; Grimm et al. 2007; Grimm and Zilli 2009; Kayano et al. 2017).

The T-air variability over SA on timescales longer than the interannual has been analyzed in the context of the multidecadal variability in the Pacific Ocean (Dettinger et al. 2001; Collins et al. 2009; Kayano et al. 2017). Dettinger et al. (2001) found that the climate indices in the Pacific Ocean describing the decadal ENSO-like atmospheric–oceanic mode (Zhang et al. 1997) and Pacific decadal oscillation (PDO) (Mantua et al. 1997) are positively correlated with annual T-air over western tropical SA. For positive indices, they associated a warm tropical SA and a dry condition. In a similar analysis, Kayano et al. (2017) found seasonal differences of the non-ENSO T-air modes in SA. In their analysis, the first winter and first autumn modes show a warming in subtropical SA due to the warm advection; the first spring, the first summer, the second winter, and the second autumn modes show a warming in the tropical SA and a cooling in subtropical SA, respectively, associated with the dryness and wetness in these areas. Collins et al. (2009), using T-air at 2 m above Earth’s surface from the National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) reanalysis found warmer winters in tropical SA during the 1976–2007 period in relation to the 1948–75 period.

The above studies stressed the T-air variability in SA in the context of Pacific large-scale phenomena such as ENSO, PDO, and ENSO-like decadal Pacific mode. In contrast, the signature of the Atlantic multidecadal oscillation (AMO) on the T-air variability in SA has received little attention. Nevertheless, some few studies using millennial temperature reconstructions provided indications on the existence of the AMO signature in southern SA. In fact, Villalba et al. (1996) found a main 72-yr spectral peak in the second principal component of the factor analysis of the alerce tree-ring data for the 980–1974 period in northern Patagonia. They noted that this spectral peak is close to the 65–70-yr oscillation in T-air registered in the North Atlantic by Schlesinger and Ramankutty (1994). Villalba et al. (1996) suggested a connection between T-air in northern Patagonia and North Atlantic through changes in the sea surface temperature (SST) in the Weddell Sea, which in turn occur as a response to multidecadal changes in the Atlantic thermohaline circulation shown in a modeling study by Crowley and Kim (1993). Nowadays, the T-air 65–70-yr oscillation found by Schlesinger and Ramankutty (1994) is called the AMO, a natural oceanic variability, whose signature is noted in SST and is related to decadal to multidecadal changes in the thermohaline circulation (Kerr 2000; Delworth and Mann 2000; Knight et al. 2006).

In the present analysis, the relations of the AMO and the T-air variability in southern SA are examined using an instrumental T-air record at surface level. This study was first motivated by a multidecadal oscillation in annual Punta Arenas, Chile, T-air time series noticed in an exploratory analysis. Punta Arenas (53.0°S, 70.85°W) is one of the surface stations in southern Patagonia, a region south of 51°S in SA with similar T-air variations shown in a cluster analysis (Coronato and Bisigato 1998). This station has the longest reliable monthly T-air time series in southern SA, with few missing data, and spans from the end of the nineteenth century up to the present (1888–2017). The availability of such a long period time series allows us to examine low-frequency oscillations in this station. Thus, the main objective of the present analysis is to investigate observational evidence on the multidecadal time-scale oscillations in Punta Arenas T-air time series and its relation to the AMO.

Data and methodology used in the present analysis are described in the following section. The connections of Punta Arenas T-air multidecadal variations with the AMO-related SST and atmospheric circulation anomaly patterns are discussed in section 3. Conclusions are drawn in section 4.

2. Data and methodology

The Punta Arenas monthly T-air unadjusted (hereafter referred to as PA_T-air) time series for the 1888–2016 period was obtained online (https://data.giss.nasa.gov/gistemp/stdata/; GISTEMP Team 2017; Hansen et al. 2010). The 1888–2016 period with PA_T-air data availability defined it as the analysis period. We also used monthly gridded reanalyzed SST, sea level pressure (SLP), 1000- and 850-hPa zonal and meridional winds, and T-air. The SST data for the analysis period were obtained from the NOAA Extended Reconstructed SST, version V4 (ERSST) data at a 2° by 2° latitude–longitude
resolution grid (www.esrl.noaa.gov/psd/data/gridded/data.noaa.ersst.v4.html; Huang et al. 2015). The Centennial in situ Observation-Based Estimates (COBE) SST data provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, were also used (https://www.esrl.noaa.gov/psd/; Ishii et al. 2005). The atmospheric circulation and thermodynamic data at a 1° by 1° latitude–longitude resolution grid for the 1888–2014 period were derived from the version 2C Twentieth Century Reanalysis (20CR) Project (www.esrl.noaa.gov/psd/data/gridded/data.20thC_ReanV2c.html; Compo et al. 2011). Temperature horizontal advection at 850 hPa was calculated in each grid point for the 1888–2014 period. The COBE SST data were used to test the robustness of the correlation map between PA_T-air and the SST anomalies. SST data were used for the other analyses involving the ERSST.

The revised AMO index was calculated using the SST time series in the North Atlantic region limited at the equator, 70°N, 80°W, and the Greenwich longitude, and the global SST in the band between 70°N and 70°S. This index is defined as the detrended SST anomalies averaged in the North Atlantic region from which the global SST averaged anomalies are removed (Trenberth and Shea 2006). This index was smoothed with a 121-month running mean filter. The monthly SST anomalies were obtained as the departures from means of the 1888–2016 period.

Because the long-term trends are not of interest here, the linear trends in the anomaly time series were removed by subtracting the linear least squares trends. So, monthly detrended SST, SLP, 1000-hPa zonal and meridional winds and T-air, and 850-hPa temperature horizontal advection anomalies were calculated in each grid point. Prior to calculating the monthly detrended PA_T-air anomaly time series, its missing values were linearly interpolated. The climatologies and the linear trends were based on the 1888–2016 period for the PA_T-air and SST, and on the 1888–2014 period for the SLP, 1000-hPa zonal and meridional winds and T-air, and 850-hPa temperature horizontal advection.

The Morlet wavelet analysis was used to perform a spectrum analysis of the detrended PA_T-air anomaly time series, after Torrence and Compo’s (1998) procedure. As for the AMO definition, the 121-month running mean was the filter used for the PA_T-air and the reanalyzed variables. The relation between the filtered PA_T-air and AMO index time series was obtained through the linear simultaneous correlation calculation. Also, linear simultaneous correlation maps between filtered PA_T-air and the other filtered variables (SLP, 1000-hPa winds, 850-hPa temperature horizontal advection) were constructed. To assess the statistical significance of the correlations, the Ebisuzaki (1997) test with 1000 pairs of Fourier series with random phases of the filtered PA_T-air time series and of the other involved time series was used. The significance was obtained in a manner similar to the bootstrap method. In the case of the correlation maps, it is common practice that absolute correlations greater than 0.6 are significant at the 90% confidence level.

Annual average PA_T-air values for the 1888–2016 period were used to identify the cold and warm years in Punta Arenas. These values, ranked from 1 for the smallest value to 129 for the largest value, provided the percentile rank (R) time series varying from approximately zero to 1. The lower (20%) and upper (80%) percentiles were used to classify cold and warm years in Punta Arenas, respectively. These years were stratified in the AMO phases and are listed in Table 1. Anomaly composites of the unfiltered 1000-hPa T-air, SLP, and low-level wind anomalies of the cold years during the cold AMO phase, and of the warm events during the warm AMO phase were calculated. The statistical significance of the composites was assessed using the Student’s t test and considering the number of years in the composite as degrees of freedom. For a variable X with n values and S standard deviation showing a Student’s t-test distribution, only the means with absolute values exceeding $t_{a(n-1)}S/\sqrt{(n-1)}$ are statistically significant (Panofsky and Brier 1968). The confidence level of 90% was used in all composites.

### Table 1. Cold and warm years in Punta Arenas stratified according to the AMO phases.

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<th>Cold Punta Arenas during cold AMO phase</th>
<th>Warm Punta Arenas during warm AMO phase</th>
<th>Cold Punta Arenas during warm AMO phase</th>
<th>Warm Punta Arenas during cold AMO phase</th>
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### 3. Results

#### a. Punta Arenas T-air and AMO index

The Global Wavelet Power (GWP) of PA_T-air time series shows a main 80-yr peak, and two secondary...
peaks: one at 8 years and another one at 28 years (Fig. 1b). All three peaks are significant at a 5% level. The 8-yr peak in the GWP is due to the significant variances observed during the 1888–1920 period; and the 28-yr peak is due to the significant variances during the 1888–1940 and 1970–2000 periods, and the main 80-yr peak is due to the significant variances during the entire period of analysis (Fig. 1a). For this latter peak, the significant variances are within the cone of influence, the region where the edge effects are important (Torrence and Compo 1998), and an option is to disregard this peak. However, Villalba et al. (1996) found a main 72-yr spectral peak in the second principal component of the factor analysis of the alerce tree-ring T-air data for the 980–1974 period in northern Patagonia. Although their analysis was based on locations north of Punta Arenas, the similar magnitude of the peaks give us more confidence in the existence of a multidecadal signal in PA_T-air time series.

This multidecadal signal in PA_T-air is also present when comparing the filtered PA_T-air and AMO index time series. These time series show nearly synchronous highly correlated multidecadal fluctuations with a linear simultaneous correlation of 0.77, which is statistically significant at 98% confidence level (Fig. 2). The statistical significance of this correlation was tested using the Ebisuzaki (1997) method, in which 1000 pairs of Fourier series with random phases of the filtered AMO and PA_T-air time series were obtained. The positive correlation means that Punta Arenas is anomalously warm (cold) during the warm (cold) AMO phase. This is an unexpected result because Punta Arenas is some 13 000 km away from the North Atlantic, where the largest AMO-related SST anomalies are centered. Figure 2 shows that the warm (or positive) AMO phase occurred during the 1888–98, 1930–60, and 1995–2016 periods and the cold (or negative) one, during the 1901–26 and 1964–94 periods.

To examine the AMO-related global SST anomaly patterns, the maps of the unfiltered SST anomalies averaged during the warm and cold AMO phases were obtained (Fig. 3). These maps show nearly reversed sign patterns and reproduce the AMO-related SST antisymmetric anomaly pattern between the North and South Atlantic sectors, previously obtained using distinct methods and areas of analysis from those used here (Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999; Goldenberg et al. 2001; Latif et al. 2006; Deser et al. 2010). An interesting feature is the presence of a pattern similar to that of the unfiltered SST anomalies, which reproduces the AMO-related SST antisymmetric anomaly pattern between the North and South Atlantic sectors, as previously obtained using distinct methods and areas of analysis from those used here (Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999; Goldenberg et al. 2001; Latif et al. 2006; Deser et al. 2010). An interesting feature is the presence of a pattern similar to that of the unfiltered SST anomalies, which reproduces the AMO-related SST antisymmetric anomaly pattern between the North and South Atlantic sectors, as previously obtained using distinct methods and areas of analysis from those used here (Enfield and Mestas-Nuñez 1999; Mestas-Nuñez and Enfield 1999; Goldenberg et al. 2001; Latif et al. 2006; Deser et al. 2010).
of negative (positive) SST anomalies surrounding most of southern SA during the warm (cold) AMO phase. This result strongly suggests that the positive relation between PA_T-air and the AMO index cannot be justified by the dominant low-level westerlies over southern SA and this aspect is further examined in section 3b.

b. Multidecadal relations between Punta Arenas T-air and oceanic and atmospheric conditions

Coherently with the positive correlation between the PA_T-air and AMO index time series, the correlation map for the ERSST SST shows the significant positive correlations in the Atlantic Ocean north of 5°S, and the negative ones in the extratropical South Atlantic centered approximately at 60°S, 30°W and in the southeastern Pacific (Fig. 4a). The correlation map for the COBE SST presents a similar pattern, except for less significant negative correlations in the extratropical South Atlantic and southeastern Pacific (Fig. 4b). The correlation pattern reproduces the main features noted during the warm AMO phase (Figs. 3 and 4a). This result is consistent with the maps of the observed surface temperature regressed onto the AMO index previously obtained (Fig. 2 by Ting et al. 2011; Fig. 1 by Lyu and Yu 2017). Both analyses show positive anomalies over the Punta Arenas area and the positive correlations between PA_T-air and the SST anomalies in the North Atlantic found here are consistent with previous findings.

In this context the anomalously warm (cold) condition in Punta Arenas is associated with anomalously cold (warm) surface waters in the southwest Atlantic and southeastern Pacific. However, this association cannot be explained by the dominant low-level westerlies over the southeastern Pacific and southern SA that occur throughout the year (Prohaska 1976; Barros et al. 2002). This westerly airflow over an underlying cold (warm) oceanic region in the southeastern Pacific would bring cold (warm) conditions into southern SA.

In fact, a low-level circulation pattern with a strong meridional component over southern SA replaces the
low-level westerlies, as shown in the correlation map between PA_T-air and SLP and 1000-hPa winds (Fig. 5b). The interpretation is that the low-level northerly (southern) flow channels the lower (higher) latitude warm (cold) air into southern SA. This flow is part of the strong anticyclonic (cyclonic) anomalies associated with an anomalous high (low) pressure center in the southwestern Atlantic and relatively weak opposite circulation and SLP anomaly patterns in the southeastern Pacific (Figs. 5a and 5b). The anomalous high (low) pressure center is consistent with cold (warm) surface waters in the southwestern Atlantic during the warm (cold) AMO phase (Figs. 4 and 5a). Concordantly, the correlation map between filtered PA_T-air and 850-hPa temperature horizontal advection shows positive correlations in eastern southern SA (Fig. 6). Therefore, the warm (cold) advection from the lower (higher) latitudes is the main process that alters PA_T-air in a multi-decadal time scale.

c. Composite analyses

Table 1 shows the years in lower (20%) and upper (80%) quintiles of PA_T-air, which were stratified in the AMO phases. Out of 22 years in the lower quintile, 20 occurred during the cold AMO phase. This means that 91% of the cold years in Punta Arenas occurred during the cold AMO phase. Furthermore, some of these years occurred sequentially, as for the cold period of 1905–09 and 1969–74, which indicates the low-frequency modulation of the PA_T-air variations. Concerning the upper quintile, 12 out of 25 occurred during the warm AMO phase. This result indicates no predominance of the warm Punta Arenas years in relation to the AMO phases. This apparent inconsistent result is due to the occurrence of warm years during the cold AMO phase from 1893 to 1923 (Fig. 7). However, there is a predominance of warm years after 1923 during the warm AMO phase. Recalling that the quintile analysis was based on the PA_T-air data.
without any filtering process, the coherency of the upper and lower quintiles with the warm and cold AMO phases gives us more confidence on the results from the correlation analysis for filtered data.

To illustrate the coherency of the above results, composite analyses were done using unfiltered data for two cases: warm Punta Arenas during the warm AMO phase and cold Punta Arenas during the cold AMO phase. Most characteristics of the SST anomaly pattern noted during the warm (cold) AMO phase are reproduced for the warm (cold) Punta Arenas composite of 1000-hPa T-air (Figs. 3a, 3b, 8a, and 9a). Also, the positive (negative) 1000-hPa T-air anomalies found over Punta Arenas and the north of the Antarctic Peninsula for the warm (cold) composite confirm Lyu and Yu (2017) findings for Punta Arenas. Consistent with the

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**FIG. 5.** Correlations between filtered PA_T-air and filtered (a) SLP and (b) 1000-hPa winds. In (a), the continuous (dashed) line encompasses positive (negative) significant values at the 90% confidence level using the Ebisuzaki (1997) test for correlation. In (b), shaded areas encompass significant vector correlation at the 90% confidence level using the Crosby et al. (1993) test for vector correlation. The arrow at the bottom illustrates the base magnitude of the correlation vector. The purple dot in both maps illustrates the location of Punta Arenas.

**FIG. 6.** Correlations between filtered PA_T-air and filtered 850-hPa temperature horizontal advection. The display is as in Fig. 5a.

**FIG. 7.** Temporal occurrence of upper (red) and lower (blue) quintiles of the PA_T-air indicated, respectively, by 1 and -1 and the AMO index (°C) multiplied by 3 (black continuous line).
above analyses, for the warm (cold) Punta Arenas composite, the low-level wind anomaly patterns show anticyclonic (cyclonic) anomalies in the southwestern Atlantic and opposite sign circulation anomalies in the southeastern Pacific (Figs. 8b and 9b).

4. Discussion and conclusions

Using an instrumental surface air temperature (T-air) record in Punta Arenas (53.0°S, 70.85°W), PA_T-air, for the 1888–2016 period, the AMO signature in South America (SA) T-air is examined. It is worth recalling that we detrended the data by removing the linear least squares trend in each time series, and thus the anthropic effects are not considered in the present analysis.

PA_T-air shows multidecadal oscillations that are simultaneously highly and positively correlated with the Atlantic multidecadal oscillation (AMO) index. This positive correlation is an unexpected result because Punta Arenas is 13,000 km away from the North Atlantic, where

![Diagram](image_url)
the AMO signature is strong (Fig. 3) (Enfield et al. 2001; Goldenberg et al. 2001; Latif et al. 2006; Deser et al. 2010). \( \text{PA}_T \)-air time series shows a main 80-yr spectral peak that agrees with Villalba et al.’s (1996) findings using the alerce tree-ring T-air data for the 980–1974 period in northern Patagonia; they found a main 72-yr spectral peak in the second principal component of the factor analysis of these data.

This highly significant simultaneous correlation between \( \text{PA}_T \)-air and AMO index does not imply a causal relation and means that both time series may reflect the same phenomenon. Here we examined this relation and provided observational evidence that it occurs through changes in the regional low-level circulation modulated by the AMO. The AMO-related near-global sea surface temperature (SST) anomaly pattern previously found (Enfield and Mestas-Núñez 1999; Mestas-Núñez and Enfield 1999; Deser et al. 2010) was reproduced using the 1888–2016 data. A meridional SST anomaly pattern with positive (negative) values in the North Atlantic and opposite sign anomalies in the extratropical South Atlantic is established during the warm (cold) AMO phase (Fig. 4). The anomalously cold (warm) center induces low-level anticyclonic (cyclonic) anomalies associated with an anomalously high (low) pressure system in the southwestern Atlantic (Fig. 5). This center, together with the low-level cyclonic (anticyclonic) anomalies in the southeastern Pacific channels the low-level northerly

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**Fig. 9.** (a) Composites for cold Punta Arenas during the cold AMO phase of (a) 1000-hPa T-air anomalies and (b) 1000-hPa wind anomalies. The display is as in Fig. 8.
(southerly) flow over southern SA, so that warm (cold) air is advected from the lower (higher) latitudes into the Punta Arenas region (Figs. 5 and 6). Therefore, the low-level westerlies that blow throughout the year and influence the climate in this region (Prohaska 1976; Barros et al. 2002) are weakened because of a multidecadal low-level circulation background with a dominant meridional component. Thus, the temperature horizontal advection from the lower (higher) latitudes is the main thermodynamic process that alters \( \text{PA}_T \)-air in a multidecadal time scale. Punta Arenas is one of the surface stations in southern Patagonia, a region south of 51°S in SA with similar T-air variations shown in a cluster analysis (Coronato and Bisigato 1998). So, it is likely that the results for Punta Arenas might be extended for other stations in southern SA.

The analysis here showed that an unambiguous relation between \( \text{PA}_T \)-air and the AMO occurs throughout the associated atmospheric circulation changes in the southern SA region and surrounding oceanic areas. This result strongly suggests that other local atmospheric systems, such as the South American low-level jet, the South Atlantic convergence zone, the Antarctic Oscillation, and the South Atlantic variability modes might also be modulated to some extent by the AMO. These aspects are out of the scope of the present analysis and will be analyzed in future studies. We acknowledge that uncertainties might exist in the reconstructed SST data and in the reanalyzed atmospheric (20CR) data used here. We tested the sensitivity of the results to the period used by recalculating the SST and 1000-hPa wind composites considering the events before and after 1950 separately. The main SST and wind anomaly patterns for the total period were reproduced for both periods (before and after 1950). In the case of cold Punta Arenas during the cold AMO phase, the patterns for the period after 1950 represent better the corresponding patterns of the total period. In contrast, for the case of warm Punta Arenas during the warm AMO phase, the patterns for the period before 1950 represent better the corresponding patterns of the total period. The weaker representation of the cold (warm) Punta Arenas during the cold (warm) AMO phase patterns during the period before (after) 1950 is due to the smaller number of events than during the complementary period. Therefore, the number of the events in the composites is more crucial than the period of the analysis in defining the variable patterns. This test indicated that the uncertainties at the beginning of the time series did not affect our results and thus it guarantees the robustness of our results.

As far as we know, the relations of the T-air variations in southern SA registered in an instrumental time series and the AMO have not been discussed before. Our knowledge about these relations might be useful for climate monitoring purposes. Furthermore, the results here reinforce that climate modeling studies should pay attention to the regional variations of the AMO-related variability.

Acknowledgments. The authors thank the two anonymous reviewers for their helpful comments and suggestions. The first author was partially supported by the Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) of Brazil under Grant 302322/2017-5.

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