Antarctic Oscillation signal on precipitation anomalies over southeastern South America

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[1] The relation between the Antarctic Oscillation (AAO) and the precipitation in southeastern South America (SESA) is examined. The AAO influence is particularly strong during winter and late spring although of opposite sign. In particular during spring, AAO positive (negative) phases are associated with the intensification of an upper-level anticyclonic (cyclonic) anomaly, weakened (enhanced) moisture convergence and decreased (increased) precipitation over SESA. The combined influence of both ENSO and AAO on SESA precipitation was also explored and significant correlation values between both oscillations are only observed during spring. Results show that during that particular season, AAO activity produces a strong modulation of the ENSO signal on SESA precipitation. *INDEX TERMS:* 1620 Global Change: Climate dynamics (3309); 3309 Meteorology and Atmospheric Dynamics: Climatology (1620); 3319 Meteorology and Atmospheric Dynamics: General circulation. **Citation:** Silvestri, G. E., and C. S. Vera, Antarctic Oscillation signal on precipitation anomalies over southeastern South America, *Geophys. Res. Lett.*, *30*(21), 2115, doi:10.1029/2003GL018277, 2003.

1. Introduction

[2] The leading mode of low-frequency variability (interannual time scales) in the Southern Hemisphere (SH) circulation, which explains around 27% of total variance, is characterized by a strong zonal symmetry with a phase reversal between high and midlatitudes with an imprint of a zonal wavenumber-2 and wavenumber-3 [e.g., *Kidson*, 1999]. This pattern identified and discussed in many previous studies [*Cai and Watterson*, 2002, provides a compilation of them] is known as the Antarctic Oscillation pattern [AAO, *Thompson and Wallace*, 2000] or High Latitude Mode [*Kidson*, 1988]. The AAO pattern is barotropic and appears all year around, although it is more active during austral spring when it amplifies upward into the stratosphere [*Thompson and Wallace*, 2000]. *Yu and Hartmann* [1993] suggested that the maintenance of this mode is due to the internal dynamics of the atmosphere through interactions with the eddy momentum fluxes. *Watterson* [2000] explored in GCM simulations, the role of the Southern zonal wind fluctuations in contributing to precipitation variability and found that those fluctuations are positively correlated with zonal mean rainfall over 25°S to 30°S, but negatively correlated further south. Although the southern portion of South America is included in the AAO area of influence, to the present there are no studies that have analyzed the relationship between AAO changes and climate variability over southern South America.

[3] The southeastern South American region (SESA) extending east of the Andes between 10°S and 40°S encompasses the most productive agriculture activities of Argentina, Brazil, Uruguay and Paraguay. The Rio de la Plata basin, one of the largest hydrological basins and fresh water reserves of the world and that includes many hydroelectric energy production plants is also included in SESA. Therefore, a better understanding of the local and remote forcing of interannual precipitation variability over this particular region is highly relevant.

[4] It is widely accepted that SESA is one of the world regions most affected by ENSO [e.g., *Aceituno*, 1988; *Grimm et al.*, 2000]. Although, not all of the precipitation variability over SESA can be explained by changes of the sea surface temperature (SST) conditions in the equatorial Pacific [*Barros and Silvestri*, 2002] another forcings might have an influence on precipitation anomalies over SESA. Therefore, this study examines to what extent the interannual precipitation variability over SESA is explained by changes in the AAO pattern activity. The modulation of the ENSO signal on precipitation over SESA by the AAO activity and vice-versa is also discussed.

2. Data and Methodology

[5] The data used to examine precipitation variability over SESA are monthly means of gridded precipitation fields produced by Willmott and Matsuura (available on line at http://climate.geog.udel.edu). 700-hPa monthly mean geopotential-heights from the NCEP-NCAR reanalyses [*Kalnay et al.*, 1996] of the period 1979–1999 are used to describe circulation features. It is worth to point out that although the NCEP-NCAR reanalysis dataset is available from 1948, we decided to focus the study between 1979 and 1999. The quality of the Antarctic analysis in the NCEP-NCAR reanalysis before the satellite era (pre-1979) has been questioned by *Marshall* [2002]. Nevertheless, a discussion of the most relevant results computed over longer periods is also included in the following sections.

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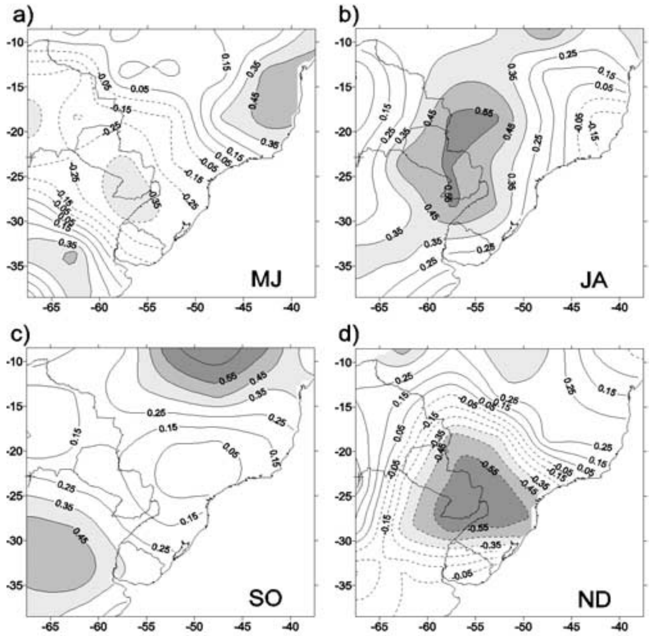

Figure 1. Correlation maps between AAO index and bi-monthly precipitation anomalies over SESA (ENSO signal removed) for a) May–Jun, b) Jul–Aug, c) Sept–Oct and d) Nov–Dec. Areas where values are statistically significant at the 90, 95 and 99% are respectively shaded.

[6] The AAO index was taken from the Climate Prediction Center (available online at http://www.cpc.noaa.gov) and defined by the temporal series of the leading mode resulting from Empirical Orthogonal Function analysis of monthly mean 700-hPa geopotential-height anomalies poleward of 20°S. Positive (negative) values of the AAO index are associated with negative (positive) height anomalies over Antarctica and positive (negative) anomalies at midlatitudes [*Thompson and Wallace*, 2000]. The AAO time series as well as the other fields have been detrended. Although, AAO has undergone a trend to higher positive polarity in recent decades [e.g., *Mo*, 2000], it exhibits a significant trend over the period considered here (1979–1999), only during summer.

3. Relationship between AAO and precipitation over SESA

[7] The seasonal evolution of the relationship between AAO index and bi-monthly precipitation anomalies over SESA is depicted in Figure 1. In order to better describe the influence of the internally-generated component of the AAO over SESA precipitation, the ENSO variability (as depicted by the time series of the EN3.4 SST anomalies) was removed from both the AAO index and the precipitation time series. While there are no significant correlation values between AAO and precipitation anomalies over the subtropical regions of SESA during summer and early fall (not shown), late fall exhibits a significant negative relationship (Figure 1a) and the largest in magnitude correlation values are observed during austral winter (Figure 1b) and late spring (Figure 1d), although of opposite sign. Also, significant correlations are observed at tropical regions between 10°S and 15°S which tend to exhibit an opposite sign than those in the subtropics. The out-phase relationship between the precipitation anomalies over both regions has been previously described on interannual and intraseasonal time scales by *Doyle and Barros* [2002], among others. The correlation maps depicted in Figure 1 were also computed for a longer period (1969–1998). While correlations for spring and fall, still reveal significant values, in magnitude larger than 0.45, significant winter correlations exhibit lower values and restricted to a small area over Paraguay (not shown).

[8] The correlation maps between the 700-hPa geopotential height anomalies and the AAO index during MJ, JA and ND, exhibit negative values at polar latitudes, while positive values with evidences of wavenumber-3 structure are discernible at midlatitudes (Figure 2). In particular, in the vicinity of South America a strong positive correlation center is observed at the southern portion of the continent during late fall (Figure 2a) and late spring (Figure 2c). *Vera et al.* [2002] show that the precipitation occurrence over

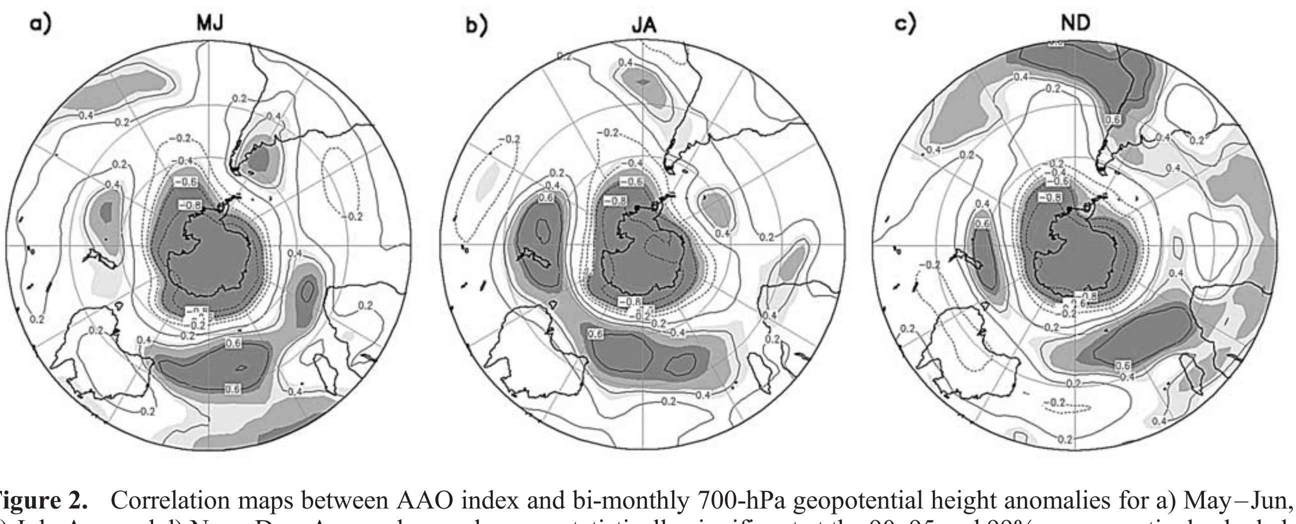

Figure 2. Correlation maps between AAO index and bi-monthly 700-hPa geopotential height anomalies for a) May–Jun, b) Jul–Aug and d) Nov–Dec. Areas where values are statistically significant at the 90, 95 and 99% are respectively shaded.

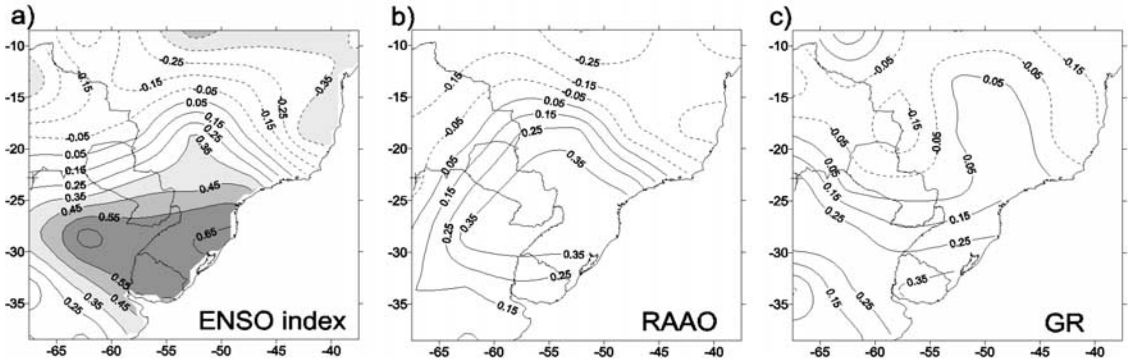

Figure 3. Correlation maps between Nov–Dec precipitation anomaly over SESA and a) ENSO index, b) fraction of ENSO index related with AAO (RAAO) and c) residual ENSO index variability (GR). The last two maps are multiplied by the explained ENSO variance fraction by RAAO and GR, respectively, so that their sum is equal to the correlation map displayed in Figure 3a. Areas where values in Figure 3a are statistically significant at the 90, 95, and 99% are respectively shaded.

SESA during the cold season is associated with the passage of cyclonic baroclinic systems. Thus, the maintenance of a low-frequency anticyclonic (cyclonic) anomaly over that region during positive (negative) AAO phases will reduce (enhance) the activity of the cyclonic synoptic systems and thus decrease (intensify) precipitation over SESA. Moreover, the AAO related circulation anomaly pattern seems to affect the moisture transport and convergence over extratropical South America. Long-term mean fields show that moisture is transported from the Amazon region and the tropical South Atlantic southward into SESA [e.g., *Vera et al.*, 2002]. During fall and spring the anticyclonic (cyclonic) anomaly related with positive (negative) AAO phase (Figures 2a and 2c), will reduce (enhance) the northerly moisture fluxes into SESA. On the other hand, the AAO signal on circulation anomalies over South America during winter (Figure 2b) are relatively weak and thus unable to explain the apparently strong AAO signal observed in winter precipitation (Figure 1b).

4. AAO and ENSO

[9] The largest ENSO signal on SESA precipitation is observed during spring with significant correlation values of above 0.5 (Figure 3a). However, that signal exhibits considerable variability among different ENSO warm events [*Barros and Silvestri*, 2002]. Recently *Vera et al.* [Differences in El Niño response over the Southern Hemisphere, submitted to J. Climate, 2003] show that variations in the response of the SH circulation to different ENSO warm events can be in some extent explained by changes in the AAO pattern.

[10] The correlation coefficient between ENSO and AAO indexes is not significant all year around over the period considered, excepting during austral spring in which both indexes are significantly correlated by a coefficient of -0.6. Therefore, in order to explore the influence of the AAO activity on the ENSO response over SESA precipitation for that transition season, a partition of the ENSO index time series (EN) was made (EN = RAAO + GR). RAAO is the ENSO index variability related with the AAO (represented by the linear square fit of the ENSO index to the AAO index), while GR is the ENSO index residual variability (not related with AAO). The correlation maps between both, RAAO and GR time series and the SESA precipitation anomalies (only detrended) were then computed and multiplied by the corresponding explained variance fraction of the ENSO index (Figures 3b and 3c), so that their sum is equal to the correlation map between ENSO index and SESA precipitation (Figure 3a). The combined influence of ENSO and AAO variability mainly affects the region encompassed by northeastern Argentina, eastern Paraguay and southern Brazil (Figure 3b) while over northwestern and eastern Argentina and Uruguay, the ENSO influence over precipitation anomalies is more independent of AAO fluctuations (Figure 3c).

[11] Previous works show that during winter and spring, the circulation response to ENSO is characterized in the SH by a well-defined wave train extended from tropical Pacific to Argentina, being their main features a cyclone anomaly over the southeastern Pacific and southern South America and a strong anticyclonic anomaly located westward of the Antarctica Peninsula [not shown, *Karoly*, 1989]. The analysis of the correlation map between the SH circulation anomalies and the ENSO index with the AAO variability removed show a weakening of those two main circulation features (not shown). The latter suggests that the changes that the AAO variability produces on SH circulation during austral spring contribute to enhance the ENSO signal in the vicinity of South America.

5. Conclusions

[12] The analysis of the influence of the AAO variability onto precipitation anomalies over SESA shows that AAO signal is significantly strong during both winter and late spring although of opposite sign. Distinctive circulation changes explain the remote AAO influence over SESA during fall and spring although not during winter. The fact that AAO variability is strongly related with precipitation changes is of importance because it contributes to explain the precipitation variance fraction not related with ENSO. The latter means a predictability decrease considering that the mechanism of the AAO limits its own predictability [e.g., *Watterson*, 2002], and that of related fields [*Watterson*, 2001].

[13] The relationship between ENSO and AAO seems to be only significant during austral spring. The explanation of this result is beyond the scope of this paper and certainly deserves further investigations. However, *Thompson and Wallace* [2000] shows that spring is the most active season of the SH lower stratosphere circulation and AAO fluctuations during that particular season are associated with significant cooling (warming) at the tropopause level at the polar (tropical) regions. This out-of-phase relationship between tropical and polar temperatures is not evident in the other seasons.

[14] The combined influence of both ENSO and AAO signal on precipitation variability was explored over SESA during spring and it was found that AAO changes provide a significant modulation of the precipitation response to ENSO over SESA.

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