Atlantic modulation of El Niño influence on summertime rainfall over Southeastern South America

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Abstract

This study addresses the effect of Atlantic sea surface temperature (SST) anomalies on rainfall over southeastern South America during January-February, particularly during El Niño years, using observations as well as model simulations. It is found that the state of the equatorial Atlantic during El Niño years can modulate its influence on rainfall over southeastern South America, such that when the equatorial Atlantic is warm, the El Niño influence is weaker. This Atlantic influence is shown to occur through the response of the low level winds to equatorial SST anomalies: the convergence of westerly anomalies onto the warm anomaly decreases the equatorial trades and moisture flow into the Amazon and, moreover, reduces the northerly flow that brings moisture to southeastern South America. The total rainfall response in this region can thus be thought as the combination of rainfall anomalies from the equatorial Pacific and Atlantic oceans.
Southeastern South America (SESA, here defined as the region [65°W-47°W,19°S-37°S]) is one of the regions of the world most influenced by El Niño [e.g Ropelewski and Halpert, 1987, 1989; Pisciottano et al, 1994]: a warm SST anomaly in the equatorial Pacific induces a tendency for higher precipitations. The influence depends on the season, with largest signal during spring of the El Niño years, tends to weaken during January-February (JF) of the following year, and then strengthens again in March [Pisciottano et al, 1994; Cazes-Boezio et al, 2003]. Here we focus on El Niño influence in high summer (JF) to determine what factors may induce the observed inter-event variability. The La Niña influence on SESA during summer is even less clear [Pisciottano et al, 1994; Silvestri, 2004] and is not considered here.

The mechanisms through which El Niño influences SESA involve both upper and lower level atmospheric circulation anomalies. During El Niño the strengthening and meandering of the subtropical jet in upper levels due to Rossby wave trains propagating from the equatorial Pacific increases baroclinicity and the advection of cyclonic vorticity over SESA. In lower levels the northerly flow from the Amazon basin strengthens increasing the availability of moisture south of 20°S [Silvestri, 2004]. Both conditions favor the increase in precipitation for a canonical El Niño in spring. During high summer, however, the subtropical jet moves poleward weakening the upper level mechanism [Cazes-Boezio et al, 2003].

Even though there is a tendency to rain more there is significant variability in the influence of El Niños on precipitation over SESA during JF. It has been recently proposed for February-March that some of the differences in this influence lies in the strength of El Niño [Silvestri, 2004]. According to this study only strong events induce the wave trains in upper levels that propagate toward South America enhancing the subtropical jet at about 30°S. On the other hand, Barros and Silvestri [2002] and Vera et al [2004] pointed out the importance of SST variations in the south central Pacific in modulating the influence of El Niño events during spring over SESA. They find that the influence is larger if the
equatorial Pacific SST anomalies has a different sign than the SST anomalies in the south central Pacific.

In this work we study, using observations and model simulations, the possibility that the state of the tropical Atlantic during El Niño events induces inter-El Niño differences in the rainfall anomalies over SESA. Among others, Giannini et al [2004] and Chang et al [2006] have pointed out the importance of the preconditioning of the tropical Atlantic in the response of this basin to the remote El Niño influence. Moreover, it has been shown that increased rainfall over SESA is associated with a strengthened Low-Level Jet [e.g. Doyle and Barros, 2002]. Since low level winds respond to equatorial SST it is possible that equatorial Atlantic anomalies change the low level flow that brings moisture from the Amazon to SESA, strengthening/weakening the anomaly induced by the Pacific. Here we show that this is indeed the case: El Niño events that coincide with a warm equatorial Atlantic tend to induce smaller rainfall anomalies over SESA than those events that coincide with negative or neutral conditions in the Atlantic.

2. Observed El Niño influence over SESA and the state of the equatorial Atlantic

We use winds and moisture fields from the NCEP-NCAR Reanalysis CDAS-1 (originally on a 2.5°x2.5° grid) that are interpolated onto the same horizontal grid as the Speedy model (see section 3). The SST data set is that of ERSSv.2, also with the same resolution as Speedy. We use the PREC-L data set of Chen et al [2002] for land precipitation. This rainfall product is based on gauge observations from the Global Historical Climate Network, regridded on a 2.5°x2.5° grid. El Niño years are defined as those years in which the SST anomaly in the region Niño3.4 during December-January is larger than 1 K, with December corresponding to the previous year we considered the anomalies over SESA. This definition was used in Giannini et al [2007], but differs from others usually used (e.g. Trenberth [1997]). Neutral years are those in which the absolute value of SST anomalies in the region Niño3.4 are less than 1 K. Throughout this work we considered the period from January 1949 to December 2006.
During summertime there are two preferential paths of moisture fluxes to the northern border of SESA: one from the south Atlantic at about 15-20°S, and one from the equatorial Atlantic that flows west to the Amazon basin and is then funneled south by the Low Level Jet [Doyle and Barros, 2002; Soares and Marengo, 2006]. Note that in the latter path, part of the moisture evaporated in the equatorial Atlantic will not reach SESA because of rainout upstream [Vimeux et al, 2005]. Thus, the moisture flow into SESA may vary due to the strength of the winds (particularly of the Low Level Jet) and/or due to the upstream availability of moisture. To characterize the flow in this latter path we define an index (ZI) as the mean 850 mb zonal winds over the western equatorial Atlantic ([60°W-20°W,5°S-5°N]). The wind stress over this region was used by Chang et al [2006] to characterize the interaction between Pacific El Niño and the Atlantic Niño. We show below that when this equatorial flow increases (ZI<0), there is enhanced moisture transport into SESA that leads to an increase in rainfall there, as humidity is the main limiting factor for rainfall in this region [Doyle and Barros 2002].

As mentioned in the introduction the influence of El Niño on SESA, although significant, is relatively weak during JF (Figures 1a,d). The composites of El Niño events stratified according to ZI show that even though there is a tendency to rain in both cases, the anomalies are much larger and statistically significant only for the composite of El Niño years that have easterly anomalies (negative ZI) in the region off the Amazon (compare Figures 1b,c). The SST composites of these two groups of El Niños reveal that the case with positive/negative ZI has large/weak SST anomalies in the equatorial Atlantic (Figure 1e,f). Note that Atlantic SST anomalies in the composite for ZI>0 are about 0.5-0.6 K, larger than the SST standard deviation during JF. Furthermore, the composite of 850mb moisture flux for the case ZI<0 shows significant easterly anomalies bringing additional moisture to the Amazon that tends to be afterward funneled southward by the Low Level Jet resulting in a positive surface moisture (precipitable water) anomaly in SESA (Figures 2b,d). In the composite for ZI>0 there is an anticyclonic anomaly centered at about (55°W,10°S) that advects moisture to the north of SESA but not into the region resulting in a tendency for moisture deficit in the southern part of SESA (Figure 2a,c).
These results suggest the existence of a mechanism through which the equatorial Atlantic can influence rainfall over SESA and modulate the El Niño influence. Nevertheless, the use of observations alone does not allow to separate other possible reasons for the observed difference in rainfall response between the different El Niños. For example, though of similar spatial structure, the composite for ZI>0 has smaller SST anomalies in the equatorial Pacific than the case for ZI<0, and thus the strength of the El Niño event may play a role. To address these issues we turn to simulations with an atmospheric general circulation model forced with historical SST.

3. Model simulations

The model used in this study is Speedy, a full atmospheric model with simplified physics and an horizontal resolution of T31 (3.75°x3.75°) with 8 vertical levels [Molteni 2003;  Kucharski et al 2005]. The model has a bias consisting in a maximum of summer rainfall in the western part of SESA, instead of a more uniform observed rainfall distribution [Kucharski et al 2005]. This bias is also reflected in the precipitation anomalies. For example, for El Niño years the simulated anomalies are centered at about (60°W, 24°S) instead of at about (55°W, 28°S) as shown in Figure 1a (not shown).

We performed 3 experiments in order to separate the influence of SST anomalies in different basins on rainfall over SESA: GOGA (Global Ocean-Global Atmosphere), where the model is forced with global historical SST, and POGA/AOGA where the model is forced with historical SST only in the Pacific/Atlantic basin between 50°S-30°N and climatological SST is prescribed elsewhere. We considered the same period as observations, and constructed an ensemble of 10 runs for each experiment. Results are based on the ensemble mean for each experiment during the months of JF.

Figure 3 shows the composites of horizontal moisture advection at 850mb for the three experiments during El Niño years stratified according to the observed ZI (that is, the equivalent maps to those in Figures 2a,b). A decomposition of the changes in moisture advection due to humidity and wind anomalies reveals that the moisture transport anomalies of Figure 3 are mainly due to changes in the
circulation. The effect of El Niño on the moisture flux can be readily seen in the composites for POGA (Figures 3b,e). Both panels show increased easterly flux toward the Amazon basin in equatorial region (in agreement with Chang et al [2006]) and a strengthening in the northerly moisture transport from the Amazon into the SESA region. Moreover, the larger anomalies in the composite for ZI<0 shows that the strength of El Niño is an important player in generating inter-event variability during JF [cf. Silvestri 2004]. Comparison of composites for GOGA and POGA experiments reveals that the Atlantic ocean plays an important role in changing this Pacific influence. For example, in the composite for ZI>0 GOGA shows westerly flux anomalies on the equatorial Atlantic, the opposite from POGA, and weaker northerly flow into SESA. These differences can be reconciled using the results of the AOGA experiment. In the latter, the warm equatorial Atlantic (case ZI>0) induces westerly equatorial moisture flux anomalies due to wind convergence onto the positive SST anomaly and southerly transport anomalies between 10-20°S that tend to decrease the moisture flux from the Amazon to SESA, both changes opposing the influence from the Pacific. Consequently, for El Niño years with ZI>0 the precipitation over SESA is the result of increased rainfall due to El Niño and decreased rainfall due to a warm equatorial Atlantic. Indeed, the composite of precipitation anomalies associated with the upper panels of Figure 3 show that the average rainfall over SESA in GOGA= +0.03 mm day$^{-1}$, in POGA= +0.21 mm day$^{-1}$, and in AOGA= -0.18 mm day$^{-1}$, suggesting a linear response to the equatorial Pacific and Atlantic oceans.

For El Niño years with ZI<0 the AOGA experiment shows weak 850mb moisture transport anomalies, as expected due to small equatorial Atlantic SST anomalies. Nevertheless, even small changes in Atlantic SST are able to significantly reduce the Pacific influence over the that basin as can be seen from the comparison between the POGA and GOGA composites of moisture flux (Figures 3d,e).

Lastly, we show that the proposed mechanism is actually the one that induces the extreme rainfall anomalies in SESA during neutral (not El Niño nor La Niña) years. To do so we considered the years of extreme rainfall over SESA in AOGA that do not coincide with El Niño or La Niña years and
constructed the composite of atmospheric anomalies for positive minus negative cases (Figure 4). Consistent with our previous findings the composite shows that negative SST anomalies in the equatorial Atlantic force positive rainfall anomalies over SESA due to increased northerly moisture transport at low levels into SESA. In the upper levels winds are statistically significant only over the equatorial Atlantic and correspond to the usual baroclinic response to an atmospheric cooling (not shown).

The pattern of SST anomaly that is related to rainfall over SESA in AOGA has its maximum in the central equatorial Atlantic region. A composite of observed rainfall anomalies during neutral years based on extremes of the ATL3 index (SST averaged over [20°W-0°E,3°S-3°N]) does not show a clear picture over SESA. This may be due to insufficient statistics (small number of cases) and/or because the Atlantic influence is relatively weak compared to internal atmospheric variability.

4. Summary

The influence of El Niño during high summer in the precipitation over SESA varies considerably. As found by Silvestri [2004] for February-March using observations, we showed using model simulations that the strength of El Niño accounts for a part of the observed inter-event variability of rainfall anomalies in JF. Moreover, we propose that the equatorial Atlantic SST plays a role in modulating the El Niño signal. We found that when the equatorial Atlantic is warm the influence of El Niño over SESA is weaker than when there are no significant equatorial anomalies. Using modeling experiments we showed that a warm equatorial Atlantic induces equatorial westerlies and, most importantly, weakens the Low Level Jet that transports moisture from the Amazon to SESA, thus limiting the availability of moisture in the region. This opposes the influence of the equatorial Pacific SST, and as result, it rains less when the model is forced with global SST than when only SST anomalies in the Pacific are used. Further modeling studies are needed to test the sensitivity of the proposed mechanism to model formulation.
It is worth noting that the ATL3 index has maximum variance during June-August associated with the Atlantic Niño [Zebiak, 1993], and a secondary maximum in November-January associated with a different mode that is independent on the Pacific El Niño [Okumura and Xie, 2006]. Most of the studies of the equatorial Atlantic modes have focused on the austral winter season. Our results point to the importance of understanding the dynamics of the equatorial ocean-atmosphere interaction during austral summer and underscores the need for monitoring the equatorial Atlantic. A better understanding of the influence of this basin on South American climate may help improving seasonal climate prediction.

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**Figure Captions**

**Figure 1** – Composite of observed precipitation (mm day$^{-1}$) and SST anomalies (K) of El Niño years versus neutral years. The leftmost panels show the composites for all El Niño years (a,d). The two other columns show the composite of El Niño events stratified according to ZI: (b,e) El Niño events that have ZI>0 (westerlies off the Amazon), and (c,f) El Niño events that have ZI<0. The light/dark shading marks the regions that are statistically significant at the 10%/5% level using a two-sided Student t-test.

The box marks the SESA region.

**Figure 2** – Composites of observed 850 mb moisture flux and specific humidity integrated between 850 and 1000 mb for the composite of El Niño years vs. neutral years stratified according to ZI. (a,c) El Niño events that have ZI>0 (same years as in Figures 1b,e); (b,d) El Niño events that have ZI<0 (same years as in Figures 1c,f). Shading and box as in Figure 1.

**Figure 3** – Composites of simulated 850 mb moisture transport for El Niño events that have ZI>0 (upper panels), and for El Niño events that have ZI<0 (lower panels). Columns show the maps for GOGA (left), POGA (middle) and AOGA (right) experiments. The El Niño years in each ZI-class are the same of Figure 1. The composites are constructed as the average during stratified El Niño years minus the average of neutral years in the ensemble mean of each experiment. Shading and box as in Figure 1.
**Figure 4** – Composite during years of extreme rainfall (larger than one standard deviation) over SESA in the AOGA experiment that are neutral years. The composites are constructed as the average of positive minus negative extreme precipitation events. (a) Precipitation (mm day$^{-1}$), (b) 850 mb moisture transport, and (c) SST (K). Shading and box as in Figure 1.
a. Nino years

b. Nino years & ZI positive

c. Nino years & ZI negative

d.
e.
f.
a. Nino years & ZI positive
850mb moisture flux

b. Nino years & ZI negative
850mb moisture flux

c. Moisture

d. Moisture
a. GOGA, Nino years & ZI positive

b. POGA, Nino years & ZI positive
c. AOGA, Nino years & ZI positive
d. GOGA, Nino years & ZI negative
e. POGA, Nino years & ZI negative
f. AOGA, Nino years & ZI negative
a. Precipitation

b. 850mb moisture flux
c. SST