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The role of the Atlantic and Pacific ocean on the La Plata Basin precipitation: Statistical Analysis and Numerical Simulations

By

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The seasonal patterns of South American precipitation observed during four El Niño four La Niña events occurred between 1970 and 1993 are analyzed in relation to Sea Surface Temperature (SST) in the tropical Pacific and Atlantic oceans, using Singular Value Decomposition (SVD). It was found that the relationships between precipitation and SST in the Atlantic and Pacific basins are strongly seasonally dependent. During austral spring, summer and autumn of ENSO warm events the Pacific ocean has the strongest influence on the precipitation patterns over South America. However, during austral autumn, the tropical Atlantic dipole influence can be equally as important as ENSO.

SVD results are presented in Figures 3, 4 and 5. Note that the areas with positive correlation coefficients in the heterogeneous correlation maps are shaded, so that regions of transition between negative and positive correlations are more evident. Areas with correlation coefficients higher than +0.4 and lower than –0.4 are consistent to a level of significance higher than or equal to 90% according to the Student’s t-test

The heterogeneous correlation maps for the experiments considering Pacific and Atlantic SST during El Niño years are shown in Figures 1 and 2. Figure 1 shows the first mode of the SVD analysis between SST anomalies over equatorial Pacific and precipitation anomalies over South America during SON (Figures 1a and 1b), DJF (Figures 1c and 1d) and MAM (Figures 1e and 1f). The correlation coefficients (CC) between the expansion coefficients of precipitation and SST during SON, DJF and MAM are 0.86, 0.89 and 0.89, respectively. From these

Figures it can be noted that there is a strong influence of El Niño on the modulation of the precipitation pattern over South America.

The pattern of positive SST anomalies in the equatorial Pacific during SON and DJF is associated with negative precipitation anomalies in a large area of the Northeast region of Brazil, northern Bolivia and central Amazonia, and with positive precipitation anomalies over Peru, Venezuela, and central and southern Brazil (Figures 1a, 1b, 1c and 1d). During MAM the correlation coefficients of the SST heterogeneous correlation map (Figure 1f) are higher than those of the equivalent maps during SON and DJF (Figures 1b and 1d). Moreover, during MAM, the El Niño-like pattern, similar to the equatorial Pacific SST anomalies pattern typical of warm episodes, is better defined (Figure 1f). The comparison of the NSC (Normalized Squared Covariance) during SON (23.4%), DJF (23.7%) and MAM (28.5%) suggests that during MAM the influence of the El Niño variability mode on the South America precipitation pattern is more important than during the other two seasons. From table 1 it can be seen that these results are in accordance with the SCF (Squared Covariance Fraction) results, which also show the highest value (64.1) during MAM (for more details about SCF and NSC see Wallace et al, 1993; and Coelho et al, 2002).

The heterogeneous precipitation map over South America (Figure 1e) associated to the highest NSC indicates negative precipitation anomalies over a large area of the northeast region of Brazil and northeastern Bolivia, and positive precipitation anomalies over Peru, Ecuador, Guyana, northern Amazonia, central and southern Brazil and northern Argentina. On the other hand, the northern portion of the continent presents anomalous wet conditions. This result is in good agreement with previous studies, which have indicated that during the autumn season, relative wet conditions prevail in this region (e.g., Souza et al, 2000), having an opposite signal during the summer (Figure 1c), when dry conditions dominate (e.g., Ropelewski and Halpert, 1987; 1989).

In Figures 1a, 1c and 1e it is possible to identify three regions of marked transition between positive and negative correlation coefficients that define the areas of opposite influences of El Niño over South America. The first area appears in the northern part of São Paulo State (around 22,5^{o}S) defining the boundary from drier conditions in the Northeast Brazil and wetter conditions in the South/Southeast Brazil; the second appears during MAM (Figure 1e) over Peru showing wetter conditions to the north and drier conditions in the south of Peru and northern Bolivia, and finally the region over central Amazonia, also during MAM, splitting wetter conditions in the western Amazonia and drier conditions in the eastern Amazonia and Northeast Brazil. These results are in agreement with the SVD analyses obtained by Coelho *et. al.*, (2002), which used a period from December to May. Some possible physical mechanisms for these transition regions were discussed by them.

Figure 2 shows the second mode of the SVD analysis between SST anomalies over Atlantic and precipitation anomalies over South America during SON (Figures 2a and 2b) and DJF (Figures 2c and 2d), and the first mode of the SVD analysis during MAM (Figures 2e and 2f). The correlation coefficients (CC) between expansion coefficients of precipitation and SST during SON, DJF and MAM are 0.86, 0.95 and 0.89, respectively. The second modes during SON and DJF are being shown because their precipitation heterogeneous maps (Figures 2a and 2c) are similar to those maps associated with the typical El Niño variability mode presented in Figures 1a and 1c, which were reproduced by the first modes of the experiments using only the equatorial Pacific SST. It is interesting to note that during MAM, the result of the first mode of the Atlantic experiment (Figures 2e and 2f) presented a similar precipitation correlation pattern to that showed by the first mode of the Pacific experiment (Figures 1e and 1f).

The heterogeneous correlation SST map for the period SON (Figure 2b) emphasize a dipole pattern over South Atlantic, marked by positive correlation around the usual climatological location of the Subtropical High, and negative correlations over tropical Atlantic. A reverse sign of this SST pattern is observed during DJF (Figure 2d). It should be noted that though the correlation coefficients of the heterogeneous correlation maps of SON and DJF show opposite signals, they represent the same mode of variability. It can be confirmed by the heterogeneous correlation precipitation maps (Figures 2a and 2c), which also show opposite correlation signals on the same regions. On the other hand, the heterogeneous correlation SST map of MAM (Figure 2f) seems to be associated to the tropical Atlantic dipole pattern as defined in the literature, with opposite SST anomaly signals between the northern and southern regions of the tropical Atlantic.

Comparing the NSC of SVD analysis performed during El Niño years using Atlantic SST during SON (13.3%), DJF (13.3%) and MAM (22.6%), it is possible to note that the most important influence on the precipitation pattern over South America appears through the tropical Atlantic variability mode during the MAM period, which shows the highest NSC.

The precipitation patterns of Figures 2a, 2c, and 2d are similar to those obtained using equatorial Pacific SST (Figures 1a, 1c and 1d). However, it is interesting to notice that for all these seasons it was possible to observe positive correlation between precipitation over Northeast Brazil and SST in the tropical South Atlantic.

From Figures 1 and 2 it can be observed that the precipitation patterns do not show great variability. The same is true when both oceans are considered simultaneously (figures not shown). It is possible that the ocean-atmosphere system keeps some memory (coupling) of its influence that makes difficult to separate the specific impact of each ocean. Since both experiments presented equivalent precipitation patterns, it may be suggests that this coupling is associated with the SST variability modes reproduced in Figures 1 and 2. The comparison of the NSC of El Niño experiments considering the SST of each ocean individually (table 1) shows that during SON, DJF and MAM, the Pacific Ocean always appears as the most important precipitation pattern modulator over South America.

During the Austral autumn (MAM), the Atlantic Ocean seems to gain importance, probably because of the tropical SST dipole influence. A NSC of 22.6%, in contrast with 13.3% both during SON and DJF, suggests that the Atlantic may play an important role for determining the precipitation pattern over South America. It must be emphasized that MAM is the period of the main rainy season over the northeast region of Brazil. It seems that even during El Niño years, the

Atlantic Ocean plays an important role in the precipitation variability of this region (Uvo *et. al.*, 1998; Pezzi and Cavalcanti, 2001). The NSC of the experiments considering Atlantic and Pacific SST simultaneously (Table 1) indicates an important link between these two oceans and precipitation over South America.

The NSC and SCF of the first modes of the December-May experiments are also shown in table 1. These results confirm the importance of El Niño and the tropical Atlantic dipole variability modes for determining the precipitation patterns over South America. Some discussion about the heterogeneous correlation maps of the December-May period can be found in Coelho and Ambrizzi (2001). The NSC for the experiments considering Pacific, Atlantic and both oceans together are 18.4%, 13.6% and 15.6%, respectively. These results are slightly below those found during MAM.

Heterogeneous correlation maps for La Niña experiments considering Atlantic SST are shown in Figure 3. This figure shows the first mode of the SVD analysis between SST anomalies over Atlantic and precipitation anomalies over South America during SON, DJF and MAM. The correlation coefficients (CC) between expansion coefficients of precipitation and SST during SON, DJF and MAM are 0.82, 0.92 and 0.94, respectively.

The heterogeneous SST correlation map for the period SON (Figure 3b) emphasizes the tropical Atlantic dipole pattern, with positive correlation coefficients in the north Atlantic and negative coefficients in the south Atlantic, and a positive center in the subtropical South Atlantic, near the climatological position where the Subtropical High is usually located. During DJF (Figure 3d) the tropical Atlantic dipole pattern is better defined. The main feature during MAM (Figure 3f) is the pattern of positive correlation coefficients in the South Atlantic and negative in the North Atlantic.

Comparing the NSC of the La Niña SVD experiments considering only Atlantic SST during SON (18.9%), DJF (23.9%) and MAM (20.2%) it can be seen that the most important influence on the precipitation pattern over South America is due to the tropical Atlantic variability mode and is observed during the DJF period, which presents the highest NSC.

The precipitation patterns of Figures 3a, 3c, and 3d are similar to those obtained using the equatorial Pacific SST (figures not shown). However, as during El Niño experiments, the most important feature over South America is the positive correlation between precipitation over Northeast Brazil and SST in the tropical South Atlantic. This feature can mainly be noted during DJF and MAM.

Comparing the NSC of cold episodes considering each ocean individually (table 2), the Pacific Ocean also appears as the most important modulator of precipitation over South America during SON and DJF. The comparison of the NSC during SON (28.1%), DJF (25.7%) and MAM (14.3%) suggests that the most important influence of the La Niña variability mode on the South American precipitation pattern occurs in fact during SON.

On the other hand, the NSC of La Niña experiments performed using only Atlantic SST (table 2) are in general considerably higher than those obtained in the El Niño experiments (table 1). It suggests that the Atlantic Ocean influence in the modulation of precipitation over South America is more effective during La Niña years than during El Niño years. Table 2 shows that DJF holds the highest NSC (23.9% in contrast with 18.9% and 20.2% during SON and MAM, respectively), indicating that during this period the Atlantic Ocean is important for determining the precipitation pattern over South America. The NSC values of the December-May experiments (Table 2) are also in agreement with the results found for the summer and autumn seasons.

Over de La Plata Basin, the Pacific ocean seems to have a mixture of influence. The Paraná basin shows positive correlation with the SSTs, particularly during the Dec-Jan-Feb (DJF) and Mar-Apr-May (MAM) period (Fig.1). However, there is not a clear signal on the west part of the basin. On the other hand, during Austral summer, there appears to be a clear positive correlation between tropical Atlantic and the La Plata basin (Fig.2). Both results indicate that warm SSTs may have some influence on the precipitation over this region, as suggested by the general discussion from Figs. 1, 2 and 3 above.

Using observed monthly mean SST data, a series of numerical experiments were carried out to evaluate the impact of different SST forcing on the South

America low level atmospheric circulation, in particular, the characterization of the South American Low Level Jet (SALLJ) over the La Plata Basin during the period January-February-March of 2001. A General Circulation Model (CCM3.6/NCAR) was integrated from September/2000 to April/2001. Climatological initial condition relative to September was used.

To evaluate the influence of the SST forcing on the SALLJ, boundary conditions from regions of the South Atlantic, South Pacific and South Indian oceans have been used (Fig.4). From observational data, an anomalous anticyclone circulation is seen to the east of Brazil, and the SALLJ core seems to be displaced to southeast of its climatological position. Positive precipitation anomalies has been observed over the La Plata Basin and neighboring (Fig.5a), i.e., Bolivia, Paraguay, northeast Argentina and south of Brazil, possibly associated to the changes in the moisture transport (Fig.5b). On the hand, in the southeast and center west of Brazil, negative precipitation anomalies have occurred, contributing to the precipitation deficits and the electric power crises in this country.

Numerical experiments (Fig.6) suggested that it was the combined influence of the SST forcing observed in the South Pacific and South Indian oceans that was responsible for the observed rainfall anomalies during the 2001 Austral Summer and the positioning changes in the SALLJ. When only the SST from the South Atlantic was considered, the precipitation patterns over South America did not show any significant influence (Fig.6a). In fact, a reversed sign was found for these experiments, indicating that the SALLJ was near to its climatological position and therefore, there was positive precipitation anomaly in the area of the climatological manifestation of the South Atlantic Convergence Zone, which was suppressed during the JFM period.

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Figure captions

Figure 1 - Heterogeneous correlation maps for the first mode of SVD between precipitation and equatorial Pacific SST during (a and b) SON, (c and d) DJF and (e and f) MAM of El Niño episodes. The numbers at the top left of the SST maps are the correlation coefficients between the SST and the precipitation expansion coefficients, and the ones at the top center and top right are the Normalized Squared Covariance (NSC) and Squared Covariance Fraction (SCF) of the mode in percentage, respectively. Contour intervals are 0.1. Dashed (solid) lines indicate negative (positive) values. Shaded areas represent regions with positive correlation. Correlation coefficients higher than +0.4 and lower than –0.4 are statistically significant at the level higher than or equal to 90%.

Figure 2 - Same as Figure 1 for El Niño episodes but using Atlantic SST. Maps (a), (b), (c) and (d) refer to the second mode of the SVD analysis, while maps (e) and (f) are to the first mode.

Figure 3 - Same as Figure 1 for La Niña episodes but using Atlantic SST. All maps refer to the first mode of the SVD analysis.

TABELAS

Table 1 – NSC (%), SCF (%) and SVD Mode number related to the El Niño experiments performed using the Pacific SST, both Pacific and Atlantic SST and the Atlantic SST during SON, DJF, MAM and DEZMAI.

Table 2 – Same as table 1 but related to the La Niña experiments.

El Niño	**Pacific**			**Pacific and Atlantic**			**Atlantic**		
	NSC	***SCF***	***Mode***	***NSC***	***SCF***	***Mode***	***NSC***	***SCF***	***Mode***
SON	23.4	49.1	1	16.9	28.1	2	13.3	18.4	2
DJF	23.7	56.2	1	18.9	36.3	1	13.3	19.5	2
MAM	28.5	64.1	1	25.1	56.4	1	22.6	49.3	1
DEZMAI	18.4	60.6	1	15.6	45.7	1	13.6	37.8	1

Table 1 – NSC (%), SCF (%) and SVD Mode number related to the El Niño experiments performed using the Pacific SST, both Pacific and Atlantic SST and the Atlantic SST during SON, DJF, MAM and DEZMAI.

La Niña	**Pacfic**			**Pacific and Atlantic**			**Atlantic**		
	NSC	***SCF***	***Mode***	***NSC***	***SCF***	***Mode***	***NSC***	***SCF***	***Mode***
SON	28.1	69.8	1	21.5	46.7	1	18.9	38.9	1
DJF	25.7	60.3	1	22.4	46.1	1	23.9	50.2	1
MAM	14.3	23.8	2	16.1	28.7	1	20.2	42.1	1
DEZMAI	18.9	58.8	1	15.0	42.1	1	16.1	46.8	1

Table 2 – Same as table 3 but related to the La Niña experiments.

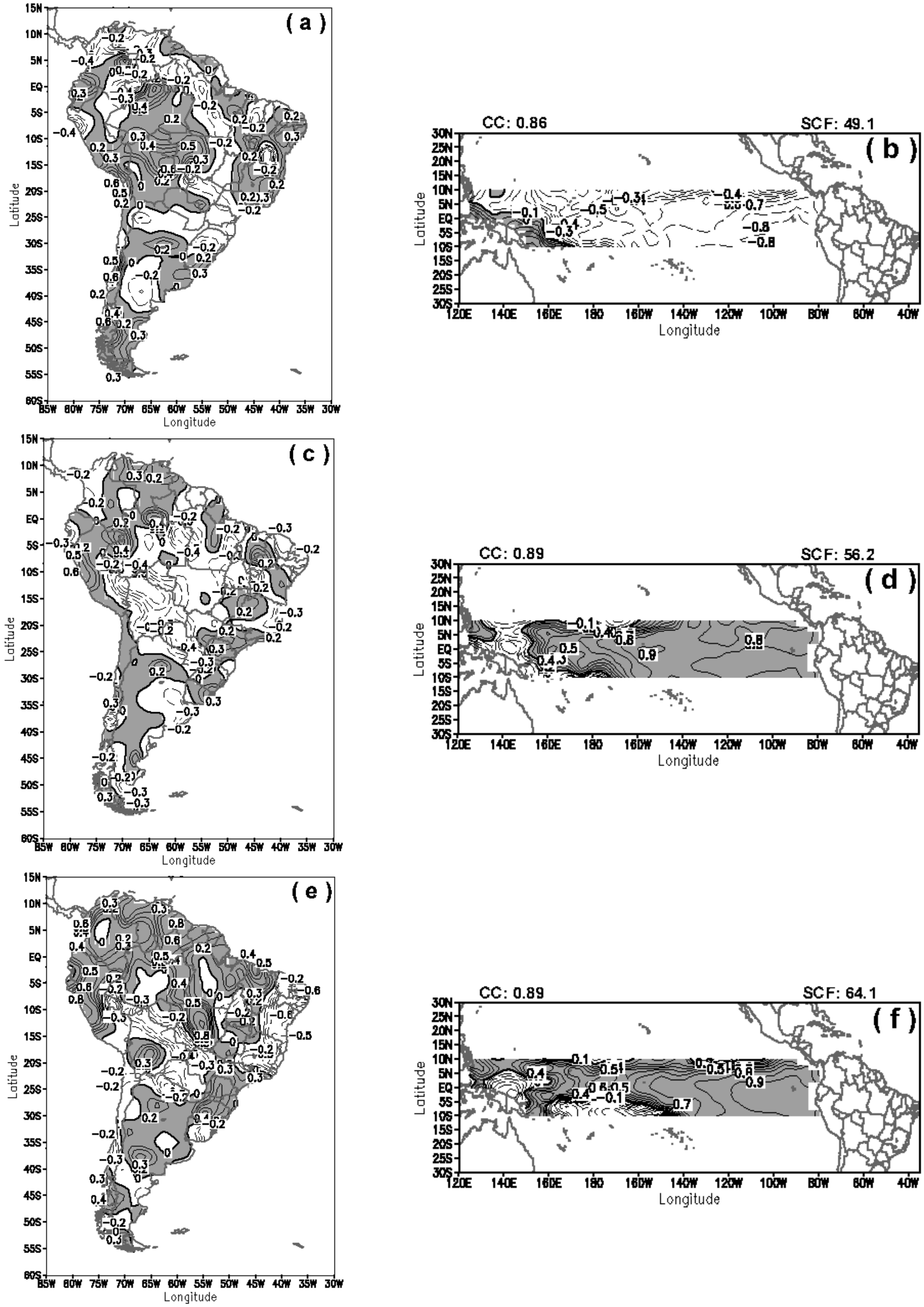


Figura 1 – SVD El Niño – Pacífico – SON (a e b – modo 1), DJF (c e d – modo 1) e MAM (e e f – modo 1)

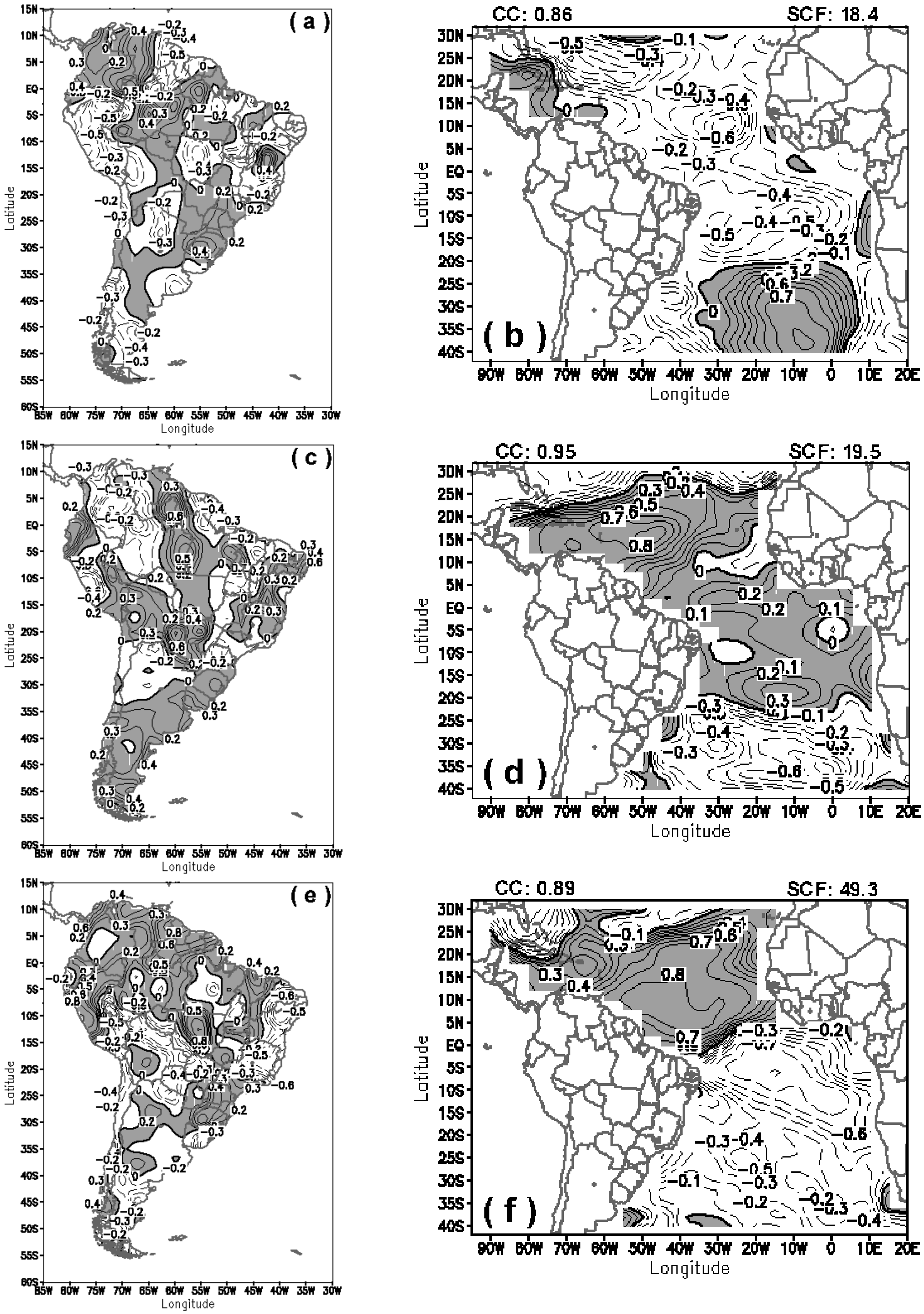


Figura 2 – SVD El Niño – Atlântico – SON (a e b – modo 2), DJF (c e d – modo 2) e MAM (e e f – modo 1)

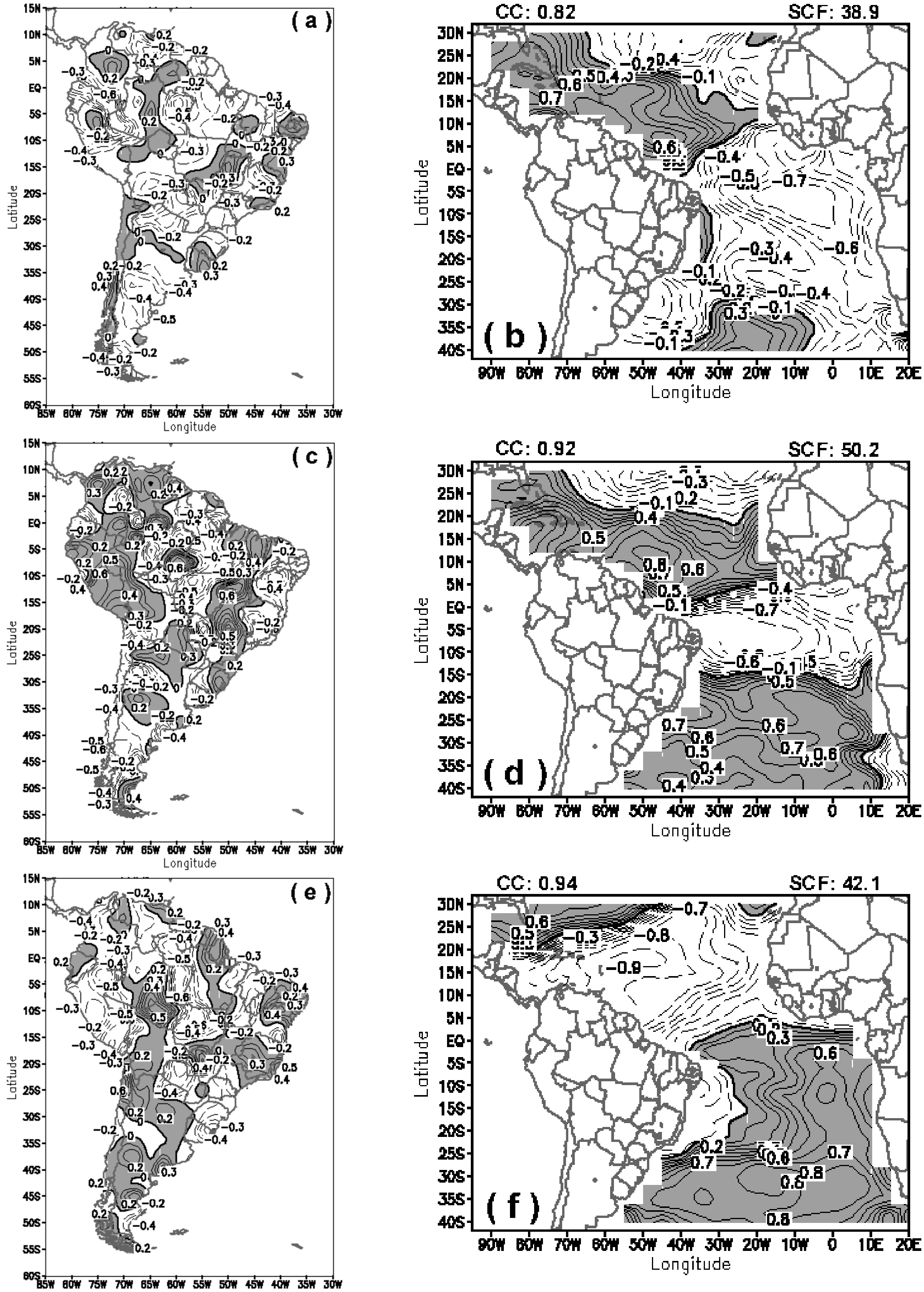


Figura 3 – SVD La Niña – Atlântico – SON (a e b – modo 1), DJF (c e d – modo 1) e MAM (e e f – modo 1)

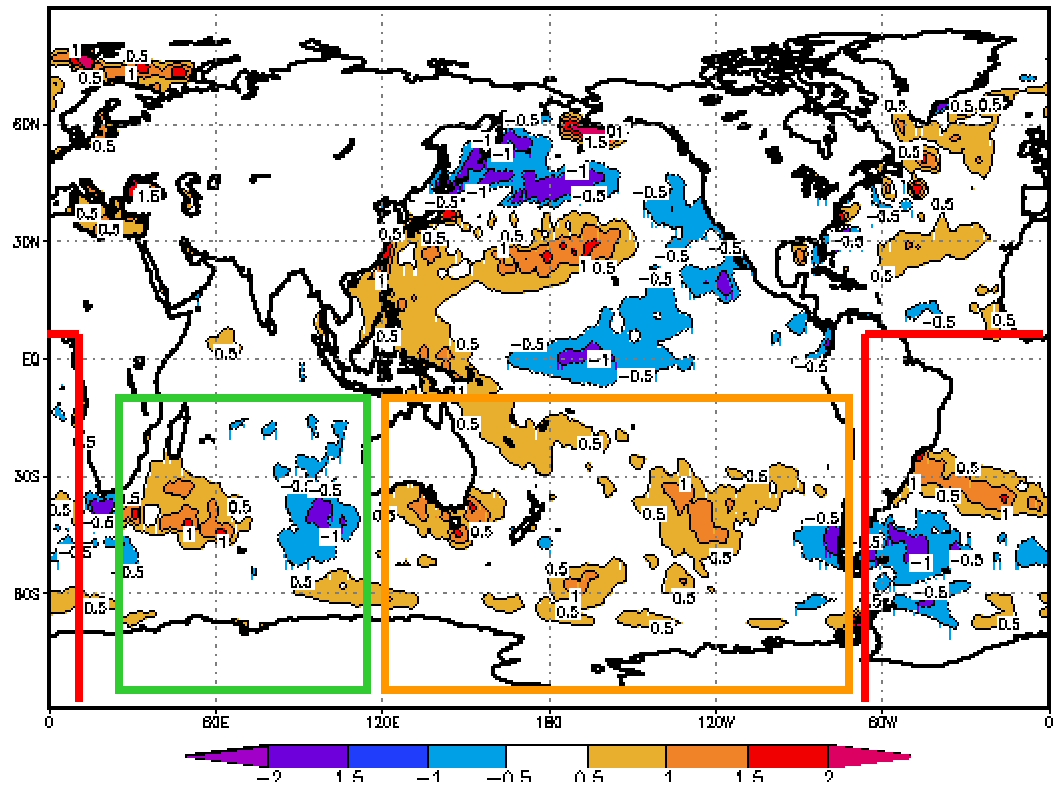
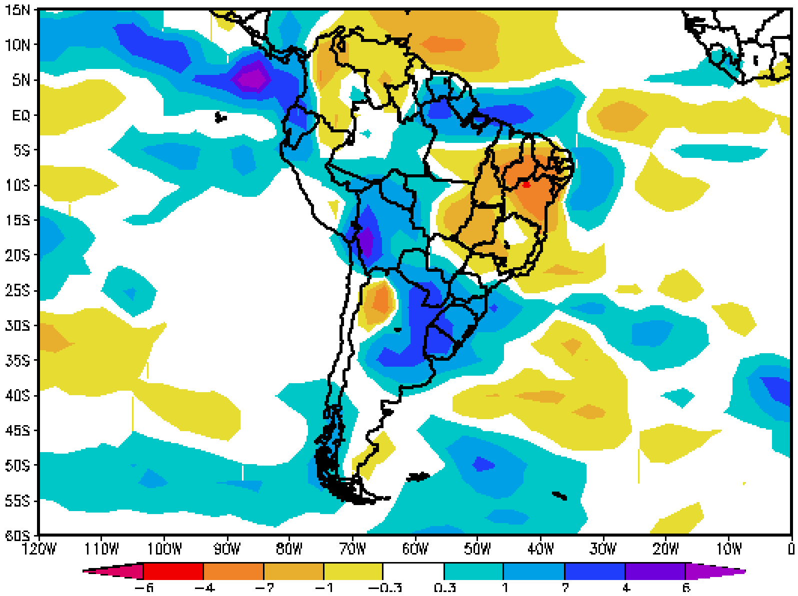
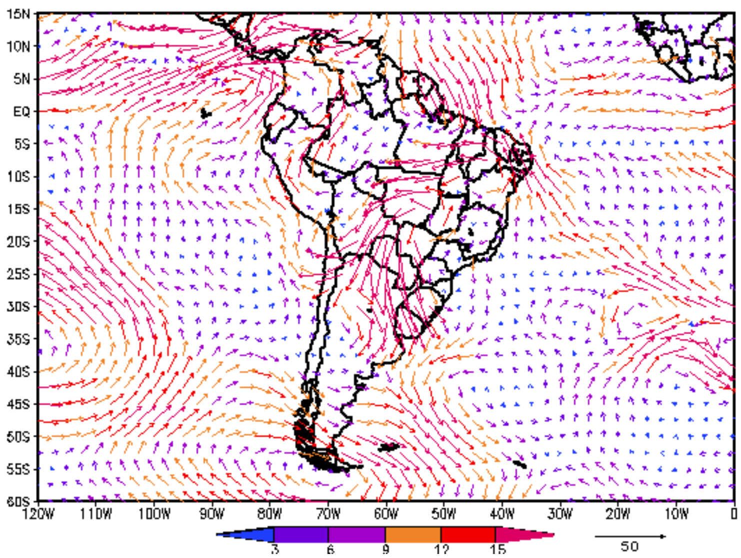


Figure 4: JFM 2001 observed sea surface temperature anomalies (º).The legend is denoted at the bottom. The red box indicates the South Atlantic region (90ºS – 5ºN; 290º - 10º). The orange box indicates the South Pacific region (90ºS – 10ºS; 120º - 285º). The green box indicates the South Indian region (90ºS – 10ºS; 20º – 110º).

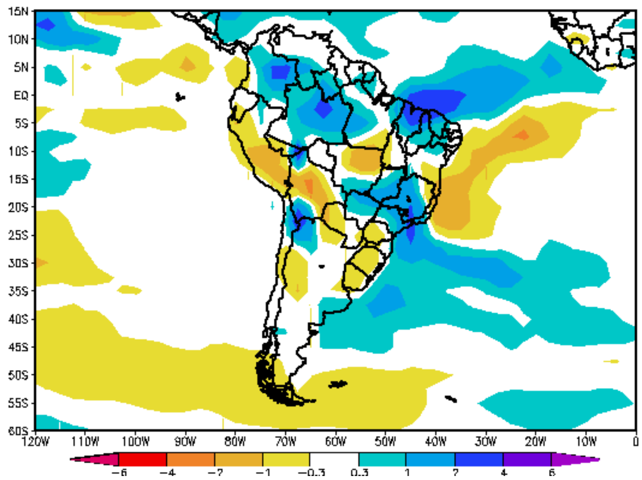


(a)

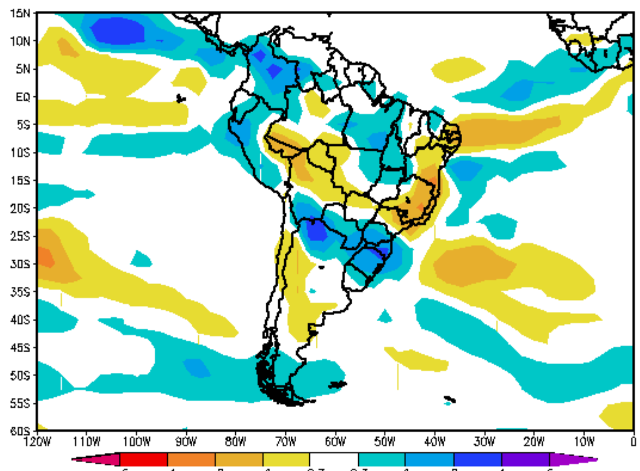


(b)

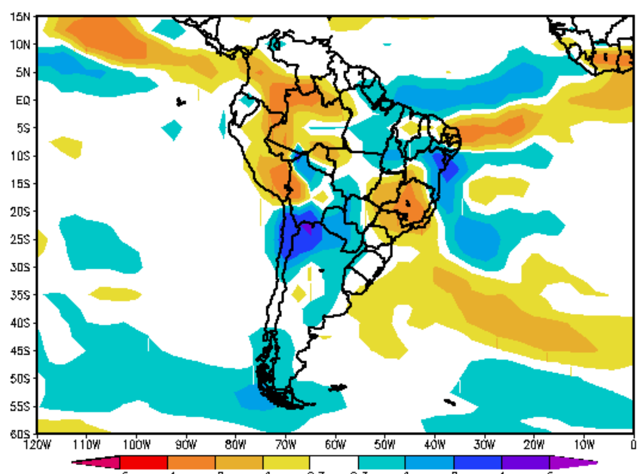
Figure 5: (a) JFM 2001 observed precipitation anomalies (mm/day); (b): anomalous moisture flux at 925hPa ($g.kg^{-1}.m.s^{-1}$) observed during the same period as (a). The legend is at the bottom of the figures.



(a)



(b)



(c)

Figure 6: (a) Precipitation anomalies (mm/day) simulated by the South Atlantic Experiment for the period JFM 2001; (b): The same as (a), simulated by the South Pacific Experiment; (c): The same as (a), simulated by the South Indian Experiment. The legend is at the bottom of the figures.