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PRECIPITATION TRENDS IN SOUTHEASTERN SOUTH AMERICA: RELATIONSHIP WITH ENSO PHASES

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1. INTRODUCTION

Southern South America, east of the Andes, has experienced an increase in rainfall during the last 50 to 60 years, reaching values of 30% or more in some regions (Castañeda and Barros 1994, 2001).

Many studies have indicated that precipitation in this region is highly influenced by the ENSO phases, such as Ropelewski and Halpert (1987, 1989), Grimm et al (2000), Barros and Silvestri (2002) and Cazes-Boezio et al (2003)) among others. However, rainfall response to El Niño events in southeastern South America has undergone considerable changes during the second half of the twenty century, as seen not only from the precipitation fields, but from the more frequent floods in the La Plata Basin. In fact, three out of the four largest peak discharges of the twentieth century in the Paraná River occurred during the last twenty years. All of them as well as the other largest peak in 1905 occurred during El Niño events (Camilloni and Barros 2003).

This different response of rainfall to ENSO was likely related to the PDO modulation of the ENSO. In fact, the time series of the interdecadal mode had a change in its mean value around 1976 (Garreaud and Battisti 1999); this shift was part of a global climate shift (Nitta and Yamada 1989; Trenberth 1990 and others) and included the change of the SOI to predominantly negative values. Hence, rainfall trends during El Niño, La Niña and Neutral periods deserve further examination beyond that made by Barros et al. (2000).

2. DATA

Monthly precipitation series of the period 1960/1999 were obtained from the Argentine National Weather Service, the Brazilian National Electric Energy Agency (ANEEL) and the Global Historical Climatology Network (GHCN), (Vose et al, 1992). Only those series with the smallest percentage of missing data were retained. Data were gridded onto a 3º x 3º mesh using the kriging method to get results independent of the station density distribution.

The Southern Oscillation Index (SOI) calculated as the standardized monthly sea level pressure difference between Tahiti and Darwin and the monthly mean sea surface temperature for region El Niño 3.4 was used to analyze the relationship between ENSO phases and rainfall trends. Months were classified as part of an El Niño (La Niña) phase if the anomaly of a 5 month running mean was above (below) 0.4º C (-0.4º C) for a minimum period of 6 months, relative to the base period climatology 1950/1979 (Trenberth, 1997). Months not included in either of these two events were classified as belonging to the neutral phase.

3. METHODOLOGY

When splitting a series in various sub series, the linear trends of these sub series add up to the same value as the linear trend of the entire series if each of the sub series has its elements ordered in time around the same mean value and with the same variance as the complete series. A linear trend is a special case of a linear regression slope when the independent variable is time. The demonstration of this hypothesis for the more general case on regression slopes is formalized as follows:

Being x_i and y_i two series with $i = 1,..., N,$ the slope of the linear regression of $y_i = f(x_i)$ is

$$a = \frac{\frac{1}{N}\sum_{i=1}^{N} x_i y_i - \bar{x}\,\bar{y}}{S_x^2} \qquad (1)$$

If the series x and y are split in M subsets, $j = 1,., M,$ according to index $i,$ such that each has n_j disjoint (non common) elements, such that

$$\sum_{j=1}^{M} n_j = N \qquad (2)$$

that is to say, all the elements from $i = 1,., N$ are included in one and only one subset $j,$ then for any variable α

$$\sum_{j=1}^{M}\sum_{i=1}^{n_j} \alpha_i = \sum_{i=1}^{N} \alpha_i \qquad (3)$$

Each j subset is not necessarily composed of subsequent i elements. Then, under the assumption that

$$\bar{x}_j = \bar{x} \quad (4) \quad \text{and} \quad S_{xj}^2 = S_x^2 \quad (5)$$

for all j:

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$$a = \frac{1}{N}\sum_{j=1}^{M} n_j a_j \qquad (6)$$

Proof:

$$\frac{1}{N}\sum_{j=1}^{M} n_j a_j = \frac{1}{N}\sum_{j=1}^{M} n_j \frac{\left[\frac{1}{n_j}\sum_{i=1}^{n_j} x_i y_i - \bar{x}_j \bar{y}_J\right]}{S_{xj}^2} \qquad (7)$$

By (4) and (5), equation (7) becomes:

$$\frac{1}{N}\sum_{j=1}^{M} n_j a_j = \frac{1}{S_x^2 N}\left[\sum_{j=1}^{M}\sum_{i=1}^{n_j} x_i y_i - \bar{x}\sum_{j=1}^{M}\bar{y}_j n_j\right] \qquad (8)$$

but

$$\sum_{j=1}^{M}\bar{y}_j n_j = N\,\bar{y}$$

so

$$\frac{1}{N}\sum_{j=1}^{M} n_j a_j = \frac{1}{S_x^2}\left[\frac{1}{N}\left[\sum_{j=1}^{M}\sum_{i=1}^{n_j} x_i y_i\right] - \bar{x}\,\bar{y}\right]$$

Applying (3), the above equation becomes

$$\frac{1}{N}\sum_{j=1}^{M} n_j a_j = \frac{\left[\frac{1}{N}\sum_{i=1}^{N} x_i y_i - \bar{x}\,\bar{y}\right]}{S_x^2} \qquad (9)$$

Thus, according to (1)

$$\frac{1}{N}\sum_{j=1}^{M} n_j a_j = a$$

In the particular case of annual or seasonal precipitation series, its linear trend is the slope of the linear regression of these variables as a function of the year. When considering ENSO events separately, it is not possible to calculate annual or seasonal trends directly, because the different events of a given phase may start and end at different months of the year. Therefore, precipitation linear trends were calculated for every month of each event, considering only the years where the event took place in that month. The seasonal trend was then calculated as the weighted sum of the three months defining the season. The weights were taken as the number of years in which an event occurred in a given month divided by the total number of years. Then the seasons were added to obtain the annual linear trend for each event.

Table 1 shows the mean year and its standard deviation for each month, and the mean year and standard deviation for El Niño, La Niña and Neutral events in the period 1960/1999. El Niño and La Niña phases have almost the same annual mean and not very different standard deviation; in the case of the neutral phase, the annual mean is a little different, but the standard deviation was again rather close to those of the other two phases.

4. RESULTS

The annual rainfall linear trends for the 1960-1999 period between 70 – 40 ºW and 15 – 40º S, are presented in figure 1. Trends were calculated applying a linear regression model, and the regression coefficients were tested through a t-test (Darlington 1990). Positive linear trends can be observed south of 22º S and negative ones dominate to the north. These positive trends are significant at the 95% level in a large area in the west and southwest of subtropical Argentina. In the southern area, there were positive significant trends of 4 mm/year or more, i.e. precipitation exceeding 160 mm in the last 4 decades of the twenty century, which means an increase of about 30 % of the initial value. Significant values extend northward from its southern nucleus along the east side of Andes Mountains where the climate is considerably dry. Similar trends stretch in a strip from northern Argentina to the extreme south of Brazil, though with statistical significance only over small areas. On the other hand, the region of the South Atlantic Convective Zone (SACZ) has a negative trend of up to 4mm/year, which in a total of 40 years adds to almost 160 mm decrease in rainfall.

Annual rainfall linear trends for El Niño, La Niña and Neutral events are presented in figure 2a, b and c respectively. Shaded areas indicate regions where the annual trend is greater than its standard deviation; and where the sign is significant at the 80 % level. El Niño events contribute with positive trends to the total rainfall trend in most of the region (Fig. 2a). The largest trends are over Paraguay, northeastern Argentina, and southern Brazil. La Niña trends (Fig. 2b) are almost everywhere small, and this phase practically did not contribute to the total trend. Neutral trends have a remarkable resemblance with the pattern of the linear trend of the complete series (Fig. 2c); there are two large areas with opposite trends, negative over the south of the SACZ and positive elsewhere. The magnitudes of the neutral trends are large, being positive with statistical significance over most of Argentina and Uruguay south of 32 ºS. There is a second important area of positive values over Argentina, near the border with Paraguay.

The total annual trends obtained from adding the weighted linear trends calculated for each ENSO phase are shown in figure 3a. The pattern and values are very close to those obtained directly from the annual rainfall trends (Fig. 1), as can be verified by figure 3b which presents the difference between figures 1 and 3a. It may be concluded that the method presented here for splitting linear trends into partial trends of the

ENSO phases is applicable during 1960-1999, especially in areas with high linear trends.

5. CONCLUSION

Each of the ENSO phases has a different contribution to the total trend; during La Niña events, very small trends were observed over the entire region. El Niño events highly contribute to the annual trend in northeastern Argentina, southern Brazil and Paraguay. However, in western and eastern Argentina, and southern Uruguay the most important contribution to the total trends comes from the neutral phase. Hence, an important conclusion is that precipitation trends during the extreme phases of the ENSO contribute only to a small part of the observed trends in most of the region. Therefore, there must be some other processes causing most of the regional precipitation trends.

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Table 1: Mean and Standard Deviation of El Niño, La Niña and Neutral events 1960 – 1999

	EL NIÑO		LA NIÑA		NEUTRAL	
	Mean	Stand Dev	Mean	Stand Dev	Mean	Stand Dev
January	1980	10.9	1980.2	11.4	1978.6	13.1
February	1981.1	11.4	1983.1	10.7	1976.7	12.2
March	1982.6	10.9	1983.1	10.7	1975.8	12.1
April	1984.2	10.8	1981.3	10.1	1976.2	12.1
May	1981.5	11.7	1980.6	11.5	1978	12.1
June	1981.1	12.5	1979.8	11.1	1978.2	12
July	1981.9	11.7	1979.8	13.4	1977.7	11.3
August	1980.9	11.5	1979.8	13.4	1978.4	11.7
September	1980	11.5	1981	12.4	1977.9	12
October	1979	10.9	1981	12.4	1978.9	12.6
November	1979	10.9	1981	12.4	1978.9	12.6
December	1979	10.9	1981	12.4	1978.9	12.6
Weighted Mean	**1980.8**	**11.3**	**1980.9**	**11.9**	**1977.8**	**12.2**

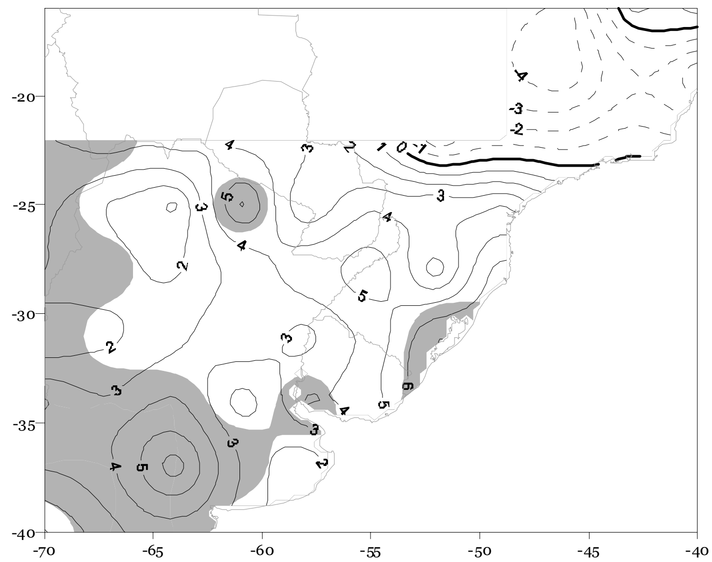

Figure 1: Annual rainfall linear trends in mm/year. Periods 1960 – 1999: Shaded area, significant at the 95 % level.

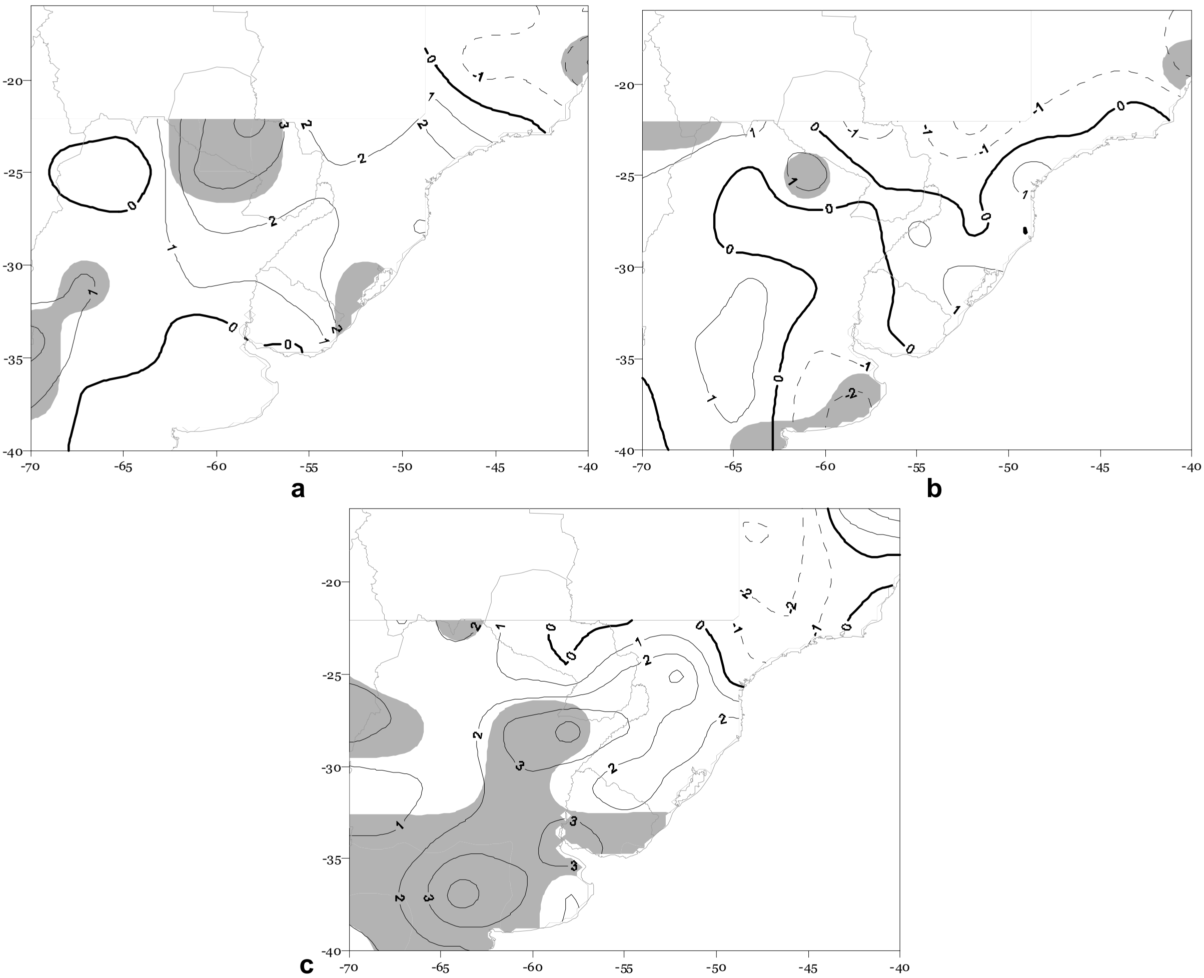

Figure 2: Annual precipitation linear trends in mm/year during a) El Niño, b) La Niña and c) neutral phase. Period 1960-1999. Shaded areas as indicated in the text.

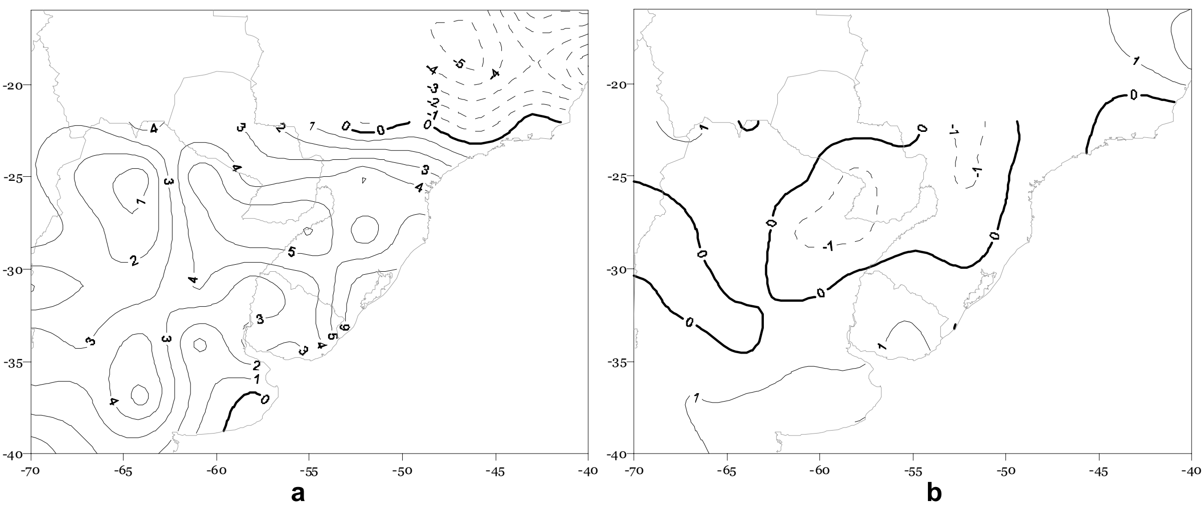

Figure 3: a) Annual precipitation linear trend when adding El Niño, La Niña and Neutral trends; b) Difference between annual trends as calculated for panel a) and calculated directly from seasonal linear trends (Fig. 1).