THE RELATIONSHIPS BETWEEN EL NIÑO SOUTHERN OSCILLATION AND CLIMATE EXTREMES IN PARANÁ RIVER BASIN, BRAZIL

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1. INTRODUCTION

The basin of Paraná River is located in the southeast and center-south of Brazil and in the center-east of South America (Figure 1). It is the second largest hydrographic region of Brazil and it has great importance in the national context, since it concentrates more than 32% of the Brazilian population, and due to the high rate of industrialization, presents the highest energy demand of the country.

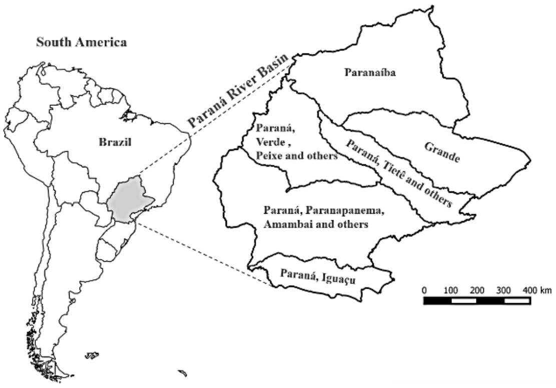

Fig. 1 Location of the Paraná river basin (brazilian part), with emphasis on its sub-basins.

This region has been affected by several extreme precipitation events, both with prolonged periods with and without rain, and with the increase of events with heavy rains. To understand how these events are defined, where and why they occur, it is necessary to look at the global climate; usually the occurrence of a climatic extreme is part of an global pattern (Silva Dias, 2014). Although there are no definitive answers about what causes a certain pattern of global climate that leads to the occurrence of these events, There are many research results indicating that there is a connection between them (Grimm and Silva Dias, 1995).

Climatic extremes, most of the time, are related to El Niño-Southern Oscillation (ENSO), interannual phenomenon that changes the weather and climate in diverse places of the planet, including Brazil. The oceanic component of the ENSO phenomenon is characterized by anomalies, positive (El Niño) or negative (La Niña), of sea surface temperature (SST) in the equatorial Pacific. These SST anomalies cause changes in the general circulation of the atmosphere and, as a result, cause variations in temperature and precipitation in several regions of the globe.

Previous studies have shown that South American rainfall is strongly affected by El Niño and La Niña phenomena (eg, Grimm et al, 1998, 2000; Ceolho et al., 2002; Grimm, 2003, 2004), both in the tropics as extratropical. In Brazil, the regions with consistent signs of El Niño / La Niña are Northeast-Amazonia and Southern Brazil. The other regions do not show a clear sign of impacts in the rain. That is, it is not known what the impact of ENSO on the rainfall regime in the region of the Paraná river basin. The lack of this information gives rise to an even greater difficulty in forecasting the region, which, due to topographical and latitude issues, already has high complexity. In this sense, the objective of this study is to evaluate the possible influence of the El Niño Southern Oscillation (ENSO) phenomenon in wet and dry events in Paraná River basin.

2. MATERIALS AND METHODS

Datasets

The daily rainfall dataset was obtained from the National Water Agency (Agência Nacional de Águas - ANA) and Department of Water and Electrical Energy (Departamento de Águas e Energia Elétrica - DAEE). These data went through a series of steps in order to be organized and analyzed, based on the availability and uniformity of data. Following Lau and Sheu (1988) and Coelho et al. (2002), only stations

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with less then 10% missing data were used. Thereby, 986 stations were selected, for the period of 1975 and 2014.

Besides the precipitation dataset, data sea surface temperature (SST) anomalies for the Pacific regions, Niño 1 + 2 (0-10S, 90W-80W), Niño 3 (5N-5S, 150W-90W), Niño 3.4 (5N- 5S, 170-120W) and Niño 4 (5N-5S, 160E-150W) were used. These data were obtained from the Web site of the Climate Prediction Center (CPC) of the National Oceanic and Atmospheric Administration (NOAA) (http:/www.cpc.ncep.noaa.gov/data/indices). These indexes named Niño are mean SST anomalies in different regions of the equatorial Pacific used to characterize the ENSO phenomenon.

Methods

To characterize the dry and wet events, the Standard Precipitation Index (SPI) was used, developed by McKee et al. (1993), commonly used to monitor conditions associated with droughts and excess rainfall. The SPI calculation for any location is based on the long-term precipitation record for a desired period (Bordi and Sutera, 2007), and may be computed using different time Periods (e.g., one month, three months and 24 Months) (McKee et al., 1993).

The SPI was calculated assuming that precipitation follows the Gamma Distribution. Calculation of SPI requires a Gamma distribution curve fitting for a given Precipitation data sequence. The Gamma distribution is defined by a probability density function given by the equation (Cacciamani et al., 2007):

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}} \qquad (1)$$

where $\alpha > 0$ is the shape parameter, $\beta > 0$ is the scale parameter, and $x > 0$ is the amount of precipitation. $\Gamma(\alpha)$ is the gamma function, which is defined as (Cacciamani et al., 2007):

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \qquad (2)$$

The parameters α and β are estimated using the approximation of (Thom, 1958) for maximum likelihood as follows:

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right), \ \hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (3)$$

where n for observations

$$A = \ln(\bar{x}) - \frac{\sum \ln(x)}{n} \qquad (4)$$

Based on the probability density function (equation (5)), the cumulative probability $G(x)$ at the selected time scale is given as follows (Cacciamani et al., 2007):

$$G(x) = \int_0^x g(x)dx = \frac{1}{\hat{\beta}\Gamma(\hat{\alpha})} = \int_0^x x^{\hat{\alpha}-1} e^{-\frac{x}{\beta}} dx \qquad (5)$$

In order to account for zero value probability, since the gamma distribution is not defined for x = 0, the cumulative probability function for gamma distribution is modified as (Cacciamani et al., 2007):

$$H(x) = q + (1-q)G(x) \qquad (6)$$

where q is the probability of no precipitation.

Finally, the cumulative probability distribution is transformed into the standard normal distribution to yield the SPI, using the following equations:

$$SPI = \begin{cases} -\left(t - \frac{c_0 + c_1 t + c_2 t_2}{1 + d_1 t + d_2 t_2 + d_3 t_3}\right) \rightarrow 0 < H(X) \leq 0.5 \\ +\left(t - \frac{c_0 + c_1 t + c_2 t_2}{1 + d_1 t + d_2 t_2 + d_3 t_3}\right) \rightarrow 0.5 < H(X) < 1 \end{cases}$$

(7)

where

$$t = \begin{cases} \sqrt{\ln\left[\frac{1}{(H(x))^2}\right]} \rightarrow 0 < H(X) \leq 0.5 \\ \sqrt{\ln\left[\frac{1}{(1 - H(x))^2}\right]} \rightarrow 0.5 < H(X) < 1 \end{cases}$$

and x is precipitation, $H(x)$ is the cumulative probability of precipitation observed, and $c_0, c_1, c_2, d_1, d_2, d_3$ are constants with the following values:

$c_0 = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$

Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Thus, the SPI may be used for monitoring both dry and wet conditions. The wet and dry events levels can be classified according to SPI range in Table 1 (McKee et al., 1993; Al-Faraj et al., 2015).

Table 1 Wet and dry events levels according to SPI values

SPI Range	Classes
[2.0, +∞)	Extremely wet
[1.5, 2.0)	Severely wet
[1.0, 1.5)	Moderately wet
(−1.0, 1.0)	Near normal
(−1.5, −1.0]	Moderately dry
(−2.0, −1.5]	Severely dry
(−∞, −2.0]	Extremely dry

In order to verify the relationship between the El Niño and La Niña episodes and the dry and wet events in the Paraná river basin, SPI-3 was used, corresponding to the cumulative rainfall periods of 3 months. The SPI-3 was correlated with the quarterly anomalies of the Niño indices (Niño 1 + 2, Niño 3, Niño 3.4 and Niño 4). For the correlation calculus, it was used the Pearson correlation method and the significance level (of 5%) of the correlation coefficients was defined using the Student's t-test.

3. RESULTS

In Figure 2, it is observed that the highest occurrence of the dry events (severely or extremely dry) was registered in the austral winter (June, July and August - JJA). More than 50% of these events occurred in JJA in almost all stations analyzed (in 95% of stations). The dry events in JJA, may be associated to South Atlantic subtropical anticyclone performance, because in this period this system reaches its westernmost position, extending to the southeastern region of Brazil (Reboita et al., 2010).

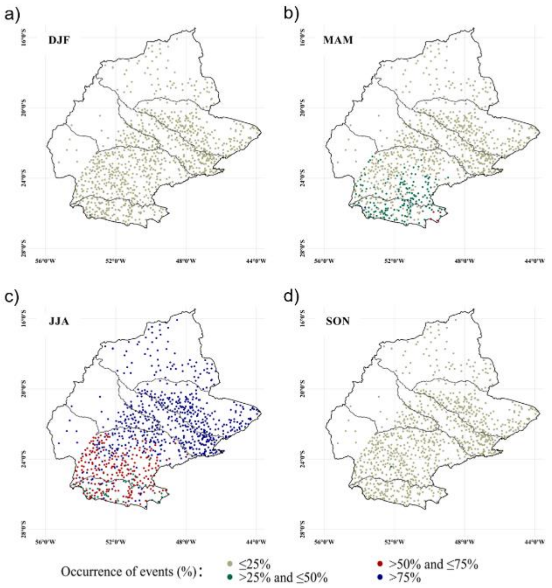

Fig 2 Percentage of the number of dry events (severely and extremely dry) registered in: a) Austral summer, b) Austral autumn, c) Austral winter and d) Austral spring.

The lowest number of the dry events was registered in the austral summer (December, January and February - DJF), period that occurred the largest number of the wet events (Figure 3). The severely and extremely wet are concentrated in DJF, with more than 50% of cases in the greater part of the Paraná river basin, with the exception of the Iguaçu sub-basin and southeastern of the Paranapanema sub-basin, where the wet events are well distributed among the seasons, but with greater occurrence also in DJF.

According to Lima et al. (2010), heavy rainfall events in austral summer are responsible for almost all the natural disasters in Southeast Brazil and are mostly associated with two types of atmospheric perturbations: Cold Front (53%) and the South Atlantic Convergence Zone - SACZ (47%).

It is important to highlight that South American precipitation regimes vary at different spatio-temporal scales and are modulated by interaction mechanisms at the ocean-atmosphere interface, which may promote rainfall above and/or below the climatological mean. Liebmann et al. (2001) pointed out that during the austral summer, the amount of extreme interannual precipitation events in the State of São Paulo is positively correlated with the SST anomalies in the equatorial Pacific. Carvalho et al. (2004) showed that the hot (cold and neutral) phase (s) of the ENSO favor (favor) the occurrence of oceanic (continental) SACZ.

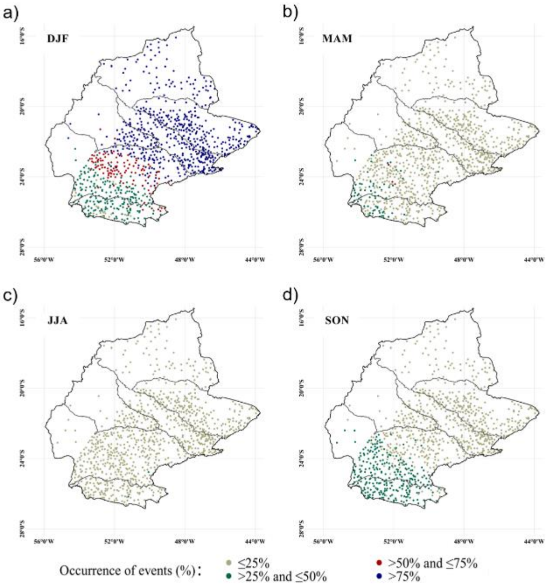

Fig 3 Percentage of the number of wet events (severely and extremely dry) registered in: a) Austral summer, b) Austral autumn, c) Austral winter and d) Austral spring.

To show the relation between the SST anomalies of the Pacific regions and dry/wet events in the Paraná river basin, correlations among the quarterly anomalies of the Niño indices (Niño 1 + 2, Niño 3, Niño 3.4 and Niño 4) and the SPI-3 were performed. In Figure 4, correlations with Niño 1 + 2 and Niño 3 indices are shown, indices that had the highest correlation coefficients.

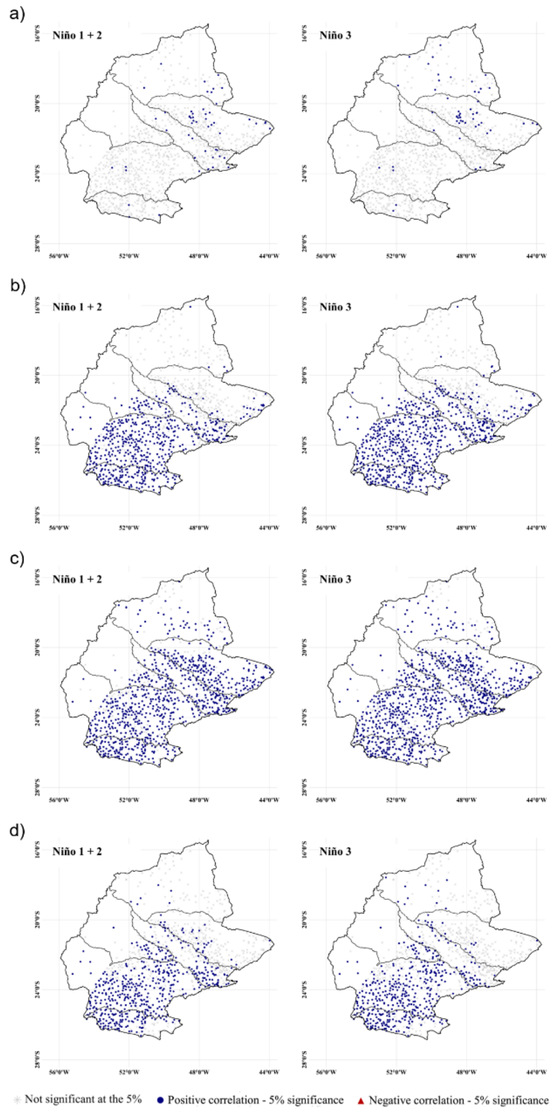

Fig 4 Space correlation among the SPI-3 and the quarterly anomalies of the Niño indices (Niño 1+2 and Niño 3), for the: a) Austral summer, b) Austral autumn, c) Austral winter and d) Austral spring.

As shown in Figure 4, the impact of ENSO on rainfall of the Paraná river basin is stronger in austral winter (JJA), where the largest number of stations with significant coefficients were found. However, in the austral summer (DJF), period with greater occurrence of wet events, was not found relationship with ENSO, with the exception of some stations. The correlations with significant coefficients at 5% were positives, showing an direct relation among the climate indices and the SPI-3, that is, the SST anomalies of the Pacific regions were positive (negative) when the SPI-3 were positive (negative). As the ENSO phenomenon is characterized by anomalies, positive (El Niño) or negative (La Niña), this result suggests that the El Niño (La Niña) contributes to the excess (lack) of rainfall in the region. This direct relationship between SST anomalies of the equatorial Pacific and rainfall anomalies in the Paraná river basin is in agreement with the results identified in studies in the south / southeast region of Brazil performed by Grimm et al. (1998), Liebmann et al. (2001) and Coelho et al. (2016), among others.

4. CONCLUSION

The results obtained suggests that SST anomalies of the Pacific regions play a relevant role on rainfall regime in the Paraná river basin, causing increase and / or decrease rainfall, mainly in the autumn and austral winter, periods with greater occurrence of dry events in the region. However, in the austral summer, period with greater occurrence of wet events in all sub-basins, was not found relationship with ENSO, with the exception of some stations.

The Niño 1 + 2 and Niño 3 indices (SST anomalies located in the east equatorial Pacific) had the highest correlation coefficients. The correlations with significant coefficients at 5% were positive, showing an direct relation between the climate indices and the SPI-3, that is, the SST anomalies of the Pacific regions were positive (negative) when the SPI were positive (negative). As the ENSO phenomenon is characterized by anomalies, positive (El Niño) or negative (La Niña), this result suggests that o El Niño (La Niña) contributes to the excess (lack) of rainfall in the region.

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REFERENCES

Al-Faraj, F. A. M.; Scholz, M.; Tigkas, D.; Boni, M. 2015: Drought indices supporting drought management in transboundary watersheds subject to climate alterations. Water Policy 17: 865–886

Cacciamani, C.; Morgillo, A.; Marchesi, S.; Pavan, V. 2007: Monitoring and forecasting drought on a regional scale: emilia-romagna region, n: Rossi G, Vega T, Bonaccorso B. (Eds.), Methods and Tools For Drought Analysis and Management. Water Sci Technol Lib 62: 29-48. doi: 10.1007/978-1-4020-5924-7_2

Carvalho, L. M. V.; Jones, C.; Liebmann, B. 2004: The South Atlantic Convergence Zone: Intensity, Form, Persistence, and Relationships with Intraseasonal to Interannual Activity and Extreme Rainfall. J Climate 17: 88-108. doi: 10.1175/1520-0442(2004)017<0088:TSACZI>2.0.CO;2

Coelho, C. A. S.; Cardoso, D. H. F.; Firpo, M. A. F. 2016: Precipitation diagnostics of an exceptionally dry event in São Paulo, Brazil. Theor Appl Climatol 126(3): 769–784. doi: 10.1007/s00704-015-1540-9

Coelho, C. A. S.; Uvo, C. B.; Ambrizzi, T. 2002: Exploring the impacts of the tropical Pacific SST on the precipitation patterns over South America during ENSO periods. Theor Appl Climatol 71(3):185-197. doi:10.1007/s007040200004

Grimm, A. M. 2003: The El Niño impact on summer monsoon in Brazil: Regional processes versus remote influences. J Climate 16: 263–280. doi: 10.1175/1520-0442(2003)016<0263:TENIOT>2.0.CO;2

Grimm, A. M. 2004: How do La Nin ˜a events disturb the summer monsoon system in Brazil? Clim Dyn 22: 123–138.

Grimm, A. M.; Barros, V. R.; Doyle, M. E. 2000: Climate variability in southern South America associated with El Niño and La Niña events. J Climate 13: 35-58. doi: 10.1175/1520-0442(2000)013<0035:CVISSA>2.0.CO;2

Grimm, A. M.; Ferraz, S. E. T.; Gomes, J. 1998: Precipitation anomalies in southern Brazil associated with El Niño and La Niña events. J Climate 11: 2863-2880. doi: 10.1175/1520-0442(1998)011<2863:PAISBA>2.0.CO;2

Grimm, A. M.; Silva Dias, P. L. 1995: Analysis of Tropical-Extratropical Interactions with Influence Functions of a Barotropic Model. J Atmos Sci 52: 3538-3555. Dói: 10.1175/1520-0469(1995)052<3538:AOTIWI>2.0.CO;2

Lau, K-M.; Sheu, P. J. 1988: Annual cycle, quasi-biennial oscillation, and southern oscillation in global precipitation. J Geophys Res Atmos 93: 10975–10988. doi: 10.1029/JD093iD09p10975

Liebmann, B.; Jones, C.; Carvalho, L. M. V. 2001: Interannual variability of daily extreme precipitation events in the State of São Paulo, Brazil. J Climate 14: 208-218. doi: 10.1175/1520-0442(2001)014<0208:IVODEP>2.0.CO;2

Lima, K. C.; Satyamurty, P. 2010: Large-scale atmospheric conditions associated with heavy rainfall episodes in Southeast Brazil. Theor Appl Climatol 101: 121-135. doi: 10.1007/s00704-009-0207-9

McKee, T. B.; Doesken, N. J.; Kleist, J. 1993: The relationship of drought frequency and duration to time scales. In: Preprints, 8th Conf Appl Clim, Anaheim, California, January 17 e 22, 179-184

Reboita, M. S.; Gan, M. A.; Rocha, R. P.; Ambrizzi, T. 2010: Regimes de precipitação na América do Sul: uma revisão bibliográfica. Rev Bras Meteoro 25: 185-204.

Silva Dias, M. A. F. 2014: Eventos climáticos extremos. Revista USP, São Paulo 103: 33-40.

Thom, H. C. S. 1958: A Note on the Gamma Distribution. Mon Weather Rev 86(4): 117 -122