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INTERANNUAL VARIABILITY OF RAINFALL AND STREAMFLOW IN PATOS LAGOON BASIN: PRELIMINARY RESULTS

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1. Introduction

Patos Lagoon basin (in southern Brazil) has a drainage area of approximately 200,000 km^2 and covers almost half of Rio Grande do Sul state (figure 1). Furthermore, its discharge is an environmental key factor for circulation, fisheries, local tourism and navigation. These facts lead to a better understanding of climatic induced hydrological variations in the basin. Although interannual variability of rainfall and streamflow in Southeastern South America (SSA) are already well studied, the specific case of Patos Lagoon basin was not focused before.

This lagoon is morphologically classified as a choked coastal lagoon (Kjerve 1986) where circulation is generally forced by wind and freshwater discharge (Möller et al. 2001). It is connected to the Atlantic Ocean through a channel that strongly attenuates tidal oscillations, confining them to the estuary (Fernandes et al. 2001). This channel is the only connection between the basin and the ocean. Northeasterly winds prevail during the whole year, forcing seaward flow. Southwesterly winds, instead, favors oceanic water to enter the estuarine area and are dominant in austral fall/winter when the frequency of passages of frontal systems increases (Stech and Lorenzzetti 1992). Climate in Southern Brazil is a transition between two adjacent regimes: summer monsoon with maximum precipitation rates observed in January (to the north) and the midlatitude regime (to the south), with maximum precipitation rates in July (Grimm et al. 2000). This 'transition' is marked by a well-distributed precipitation regime, with several peaks of rainfall through the year.

Wind was considered to be the most important factor controlling local circulation patterns, but recent studies have shown that wind only acts as major forcing when fluvial discharge are lower than 3,000 m^3/sec. When the discharge is higher, wind action is restricted by the barotropic gradient towards the ocean (Möller et al. 2001). The mean annual freshwater discharge of the tributaries of this lagoon is 2,400 m^3/sec, but peaks of 12,000 m^3/sec were observed in El Niño (EN) years (Möller 1996). Fernandes et al. (2002), modelling Patos Lagoon circulation during the 1998 El Niño event, reported a mean freshwater discharge at the mouth of approximately 5,000 m^3/sec.

According to Mann and Park (1999), the understanding of several climatic characters reside in significant signals in the quasi-biannual and interannual (3-7 years period) frequency bands, among others. Previous studies about climatic anomalies presented consistent relationships between SSA (specifically northeastern Argentina, Uruguay and Southern Brazil) and extreme phases of Southern Oscillation (SO) (Ropelwski and Halpert 1987, Aceituno 1988, Kiladiz and Diaz 1989, Rao and Hada 1990, Pisciottano et al. 1994, Grimm et al. 1998 and 2000).

Ribera and Mann (2003) reported that the only climatic oscillation signal in Southern Hemisphere during the second half of the last century at the interannual frequency band were associated with El Niño/Southern Oscillation (ENSO). Approximate 3 and 6 years signals, both in the range of variability of the ENSO cycles, were identified as dominant oscillation modes for streamflow in Uruguay river basin (Krepper et al. 2003). Robertson and Mechoso (1998) also found the same signals, related to ENSO, in Paraná, Paraguai, Uruguay and Negro rivers (from La Plata river basin). Investigating variations in streamflow of Uruguay and Negro rivers, Mechoso and Perez-Irribaren (1992) detected a relationship between the SO and streamflow: lower than average in La Niña (LN) years and higher than average in El Niño years. Spectral analysis of oceanic and atmospheric variables that are commonly used to detect ENSO (sea surface temperature anomalies or atmospheric pressure differences) show significant components with periods of approximately 2 and 3 to 7 years (Allan 2000). In this scenario, Patos Lagoon basin should present spectral peaks matching these periods.

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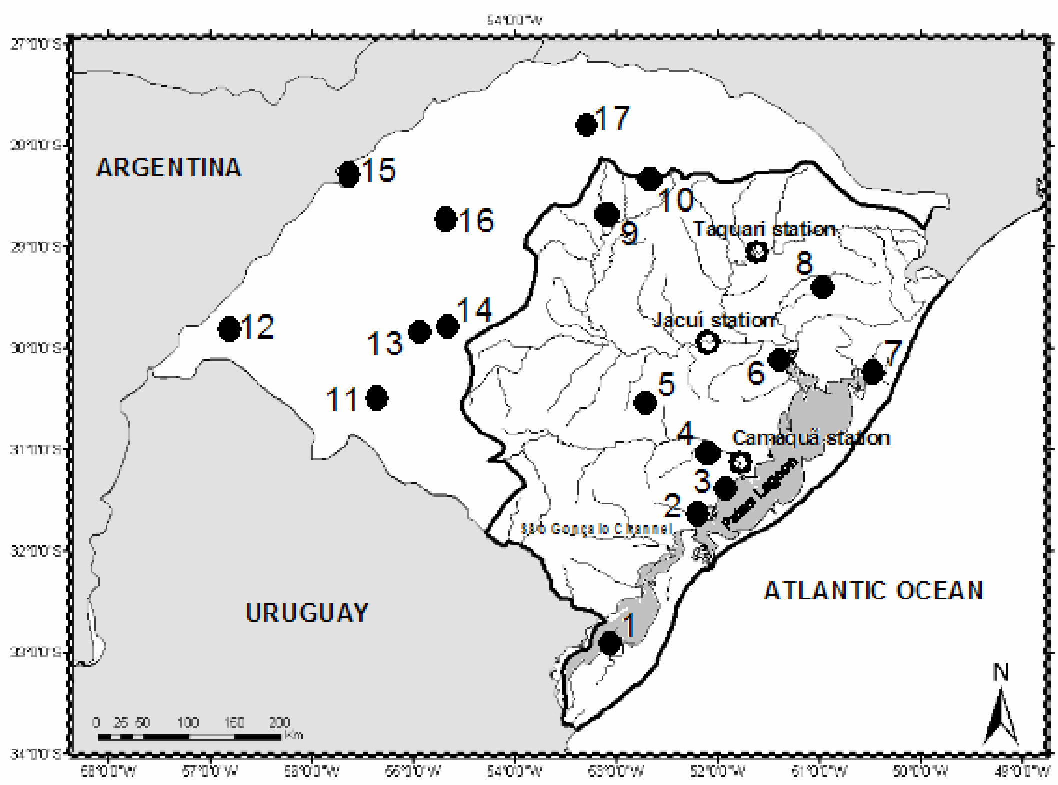

Fig. 1. Rio Grande do Sul State with Jacuí, Taquari and Camaquã rivers in Patos Lagoon basin and the location of all rainfall (numbered) and river flow stations (identified by a circle) used in this study. Stations 1 to 10 are inside Patos Lagoon basin. Stations 11 to 17 belong to Uruguay river basin. 1 – Santa Vitória do Palmar; 2 – Pelotas; 3 – São Lourenço do Sul; 4 – Canguçu; 5 – Encruzilhada do Sul; 6 – Guaíba; 7 – Palmares do Sul; 8 – Caxias do Sul; 9 – Cruz Alta; 10 – Carazinho; 11 – Santana do Livramento; 12 – Uruguaiana; 13 – Cacequi; 14 – Júlio de Castilhos; 15 – São Borja; 16 – Santo Ângelo; 17 – Palmeira das Missões.

The objective of this study is to identify the main periodicities of rainfall and streamflow in Patos Lagoon basin and test the hypothesis that the hydrological regime in the region shows the same patterns of variability observed for adjacent basins in interannual timescale.

2. Material and Methods

Database used in this study consists of 17 rainfall and 3 streamflow stations covering the 1978-2002 period (see figure 1 for reference). All time series are available at Brazilian National Water Agency's web site (www.ana.gov.br). Some of the rainfall stations that are not localized on the basin, were included to give a better view of possible patterns of precipitation over Rio Grande do Sul State. Although São Gonçalo Channel represents an important freshwater source for Patos Lagoon, there is no data quantifying its contribution to the system and therefore it was not considered here.

Missing data were filled by linear interpolation (1 or 2 gaps). Larger gaps were filled by a spectral interpolation method described in Andersen (1974). All series were then demeaned, detrended and filtered with a low-pass Lanczos cosine filter (Duchon 1979) with a cut off frequency at 0.05 cycles per month (cpm) – minimum for Quasi-Biennial Oscillation (QBO) signal (Lau and Sheu 1988). Spatial patterns of rainfall and streamflow were identified by Empirical Orthogonal Function (EOF) analyses. Finally, spectral analyses of all series and principal modes indicated by EOF analyses were carried out following Welch's periodogram method (1967). Spectral coherence between the series and the Southern Oscillation Index (SOI) from Australian Bureau of Meteorology was calculated to verify the fraction of variance of a series ascribable to the SOI. Power spectral density estimates for spectral coherence were also calculated using Welch's method.

3. Results

EOF analysis of rainfall data revealed 2 principal modes of variability. The first principal mode (EOF1 – figure 2) is positive for the entire study area and represents 68% of total variability. Power spectral density estimate for this mode showed a major peak of energy between 0.020 and 0.026 cpm (figure 3), corresponding to periods of 4 and 3 years, respectively.

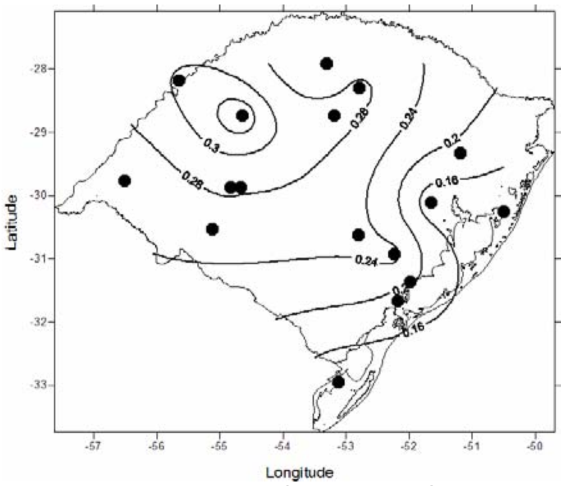

Fig. 2. First mode of variability (EOF1).

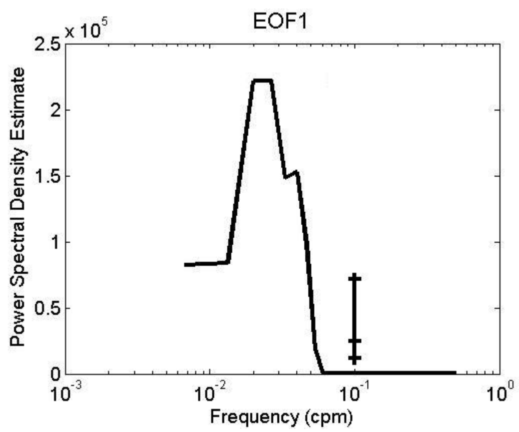

Fig. 3. Power spectral density estimate for the EOF1 series. Major peak is centered between 0.020 and 0.026 cpm. Black bar represents the 95% confidence level.

The second mode (EOF2 – figure 4) represents 16% of total variability and displays a dipole-like pattern, being slightly positive to the north and negative to the south. Power spectral density estimate for this mode (figure 5) showed 2 peaks of energy, one at the 0.0133 cpm and another at the 0.040 cpm frequency band, corresponding to periods of 6 and 2 years, respectively. SOI power spectral density estimate showed a major peak at 0.02 cpm for the period focused in this study. Estimates for each station also showed energy concentration between 0.020 and 0.026 cpm. Differences in spectral estimates were found for Santa Vitória do Palmar and Canguçu stations, with observed peaks at 0.0133 (Santa Vitória do Palmar) and 0.033 cpm (Canguçu), corresponding to 6 and 2.5 years respectively. Concerning river flow time series, the EOF analysis revealed a first mode that corresponds to 88% of total variance, positive for the 3 major contributors of Patos Lagoon (Jacuí, Taquari and Camaquã). The power spectral density estimate of this principal mode indicated a dominant peak for the 4 years period.

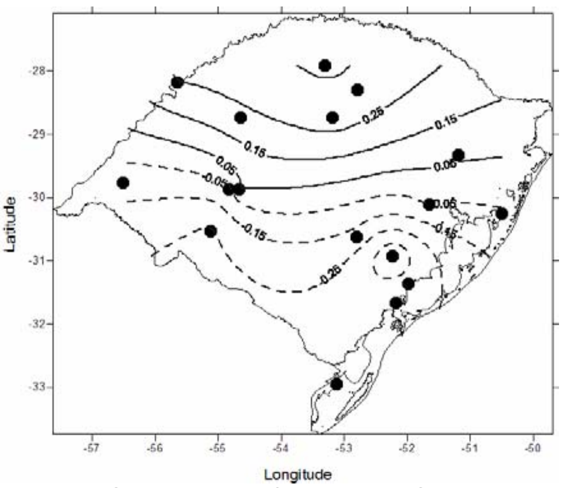

Fig. 4. Second mode of variability (EOF2). Negative values are contoured by dashed lines.

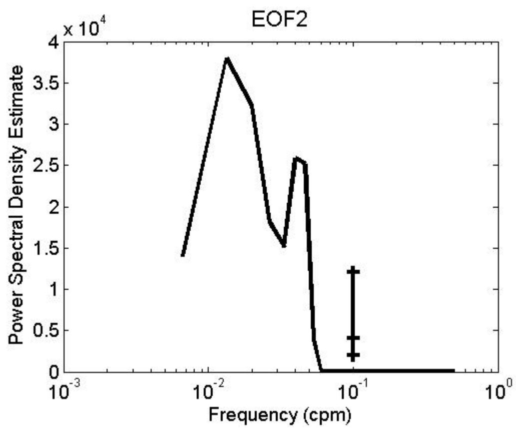

Fig. 5. Power spectral density estimate forf EOF2 series. Highest density peak is observed at 0.013 cpm and a secondary one at 0.033 cpm. Black bar represents the 95% confidence level.

Higher spectral coherence between rainfall data and SOI were found for São Lourenço do Sul station (0.98) at 0.020 cpm. Lower coherence were found for some other stations that showed better results at 0.026 cpm. Spectral coherence between EOF1, EOF2 and SOI are shown in figure 6 and 7. EOF1 shows spectral coherence higher than the 95% significance level, as expected. EOF2, in contrast, shows two peaks of spectral coherence above the 95% significance level. None of them correspond to 2 or 6 years period but for the frequency corresponding to 6 years there is an energy peak below the 95% significance level. For streamflow, spectral coherence varies for frequencies correspondent to periods between 2 and 4 years, all above the 95% significance level.

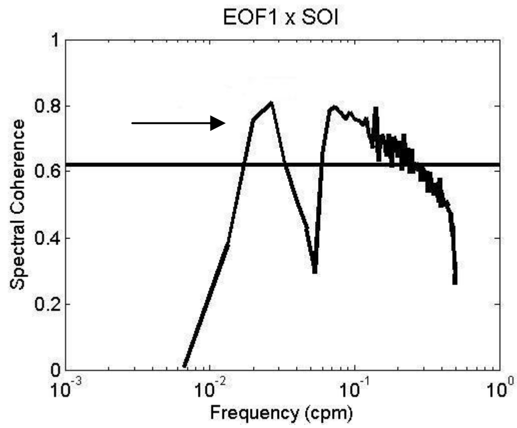

Fig. 6. Spectral coherence between EOF1 and SOI. Arrow indicates the 0.020-0.026 cpm frequency band peak. Black line represents the 95% confidence level.

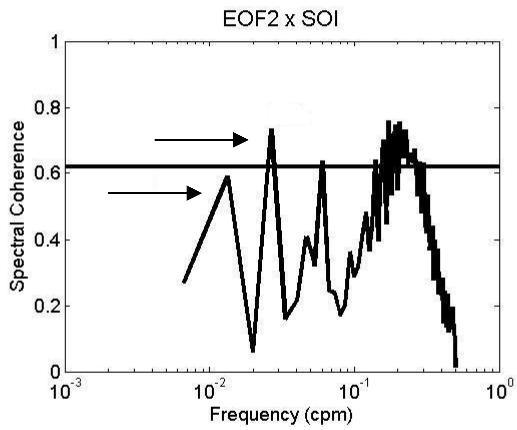

Fig. 7. Spectral coherence between EOF2 and SOI. Arrows indicate the 0.013 (below black line) and the 0.026 cpm (above black line) spectral peaks. Black line represents the 95% confidence level.

4. Discussion

All spectral analyses showed periodicities closer to the 3-4 years period, with some signals of 2 and 6 years. When compared to the SOI, higher values of spectral coherence were calculated for the 3-4 years signal. These results are in agreement with the reported relationship between SO and climate over SSA. Results of EOF analyses also confirm it. EOF1 and EOF2 are related to different oscillation components of the irregular behaviour of SO that is discussed by Rasmusson et al. (1990) and Philander (1990). Allan (2000) reports that the main period of variability of SO is around 4 to 5 years between 1970 and 1990. The author also affirms that interactions of quasi-biennial and low frequency (3-7 years) components are common modulations which may lead to the amplification of the ENSO signal.

Thus, EOF1, as positive precipitation pattern over Rio Grande do Sul, seems to represent the variability associated to El Niño over the region reported by Grimm et al. (1998). The second mode (EOF2) is, apparently, an interaction between a quasi-biennial and a low frequency component (Allan, 2000), despite the low values of spectral coherence between this mode and the SOI. The low frequency component is a common feature of the SO and is the only one that shows spectral coherence (0.58) above the 95% confidence level.

The biennial character of the SO is the tendency of warm events to be followed by cold anomalies and an even higher tendency of cold events to be preceded by warm anomalies (Torrence and Webster, 1998). As argued by Ribera and Mann (2003), analyzing other atmospheric variables, a quasi-quadrennial band of variance centered at 3-6 year period and a weaker quasi-biennial band centered at 2-3 year period constitutes the only oscillatory interannual signal in tropospheric climate during the later half of 20th century in the Southern Hemisphere and are associated with ENSO. Robertson and Mechoso (1998) indicate that interannual atmospheric circulation anomalies over the Pacific sector directly influence SSA in ENSO timescales. As precipitation is well known to be related to ENSO in SSA (Ropelewski and Halpert 1987, Aceituno 1988, Kiladis and Diaz 1989, Pisciottano et al. 1994, Grim et al. 1998 and 2000), the higher spectral coherence found in this study between EOF1 and SOI at 0.020-0.026 cpm frequency band and EOF2 and SOI at 0.013 and 0.026 cpm are evidences of this relationship.

Future goals involve the necessity to identify the true nature of the components of the second mode as well as the influence of other climatic modes already discussed in the literature. Moreover, a comparison of the time series with other indices may enhance spectral coherence and different statistical methods could improve spectral resolution. In the case of the streamflow data, a denser net of stations may refine the results.

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