Spectral characteristics and ENSO relationship of the Paraná river streamflow

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सार – परना नदी के जलप्रवाह का स्पेक्ट्रमी विश्लेषण 1904 से लेकर 1999 तक की अवधि में तीनों ऋतुओं में किया गया है। विश्लेषण से पता चला है कि सभी ऋतुओं में आवर्तिता सामान्यतः ~8.5 वर्षों की रही है। जनवरी, फरवरी, मार्च और अप्रैल के महीनों में विशेष आवर्तिता क्रमशः ~17, ~5, ~3.7 और ~2.8 (क्यू..बी..ओ.) तथा मार्च, अप्रैल, मई और जून के महीनों में क्रमशः ~29, ~13, ~4.7, ~3.7, ~2.4 और ~2.1 (क्यू. बी. ओ.) वर्षों और सितंबर, अक्तूबर, नवंबर और दिसंबर के महीनों में ~27 और ~3.4 (बिना क्यू. बी. ओ.) वर्षों के होने का पता चला है। वर्ष के अंतिम महीनों में नदी के जलप्रवाह में सकारात्मक विसंगतियों (बाढ़) के साथ एल निनो की संबद्धता का भी पता चला है। वर्ष 1982 और 1997 के दौरान एल निनों की समरूपी उग्रता के साथ प्रशांत महासागर में समुद्र सतह तापमान में विसंगतियों का पता चला है लेकिन 1997 की तुलना में 1983 में जलप्रवाह में विसंगतियाँ ज्यादा पाई गई हैं। ~5 महीनों की चरम अवधि के दौरान नदी के जलप्रवाह में विसंगतियों में घट–बढ़ दोलनात्मक रही है।

ABSTRACT. A spectral analysis of the Paraná river stream flow for 1904-1999 for 3 seasons indicated a periodicity of ~8.5 years in all seasons, with extra periodicities at ~17, ~5, ~3.7 and ~2.8 (QBO) years in JFMA months, at ~29, ~13, ~4.7, ~3.7, ~2.4 and ~2.1(QBO) years in MAMJ months, and at ~27 and ~3.4 years (no QBO) in SOND months. El Niños were associated with positive anomalies (floods) of the stream flow, with lags of few months. Pacific SST anomalies were of the same peak magnitude in the giant El Niño events of 1982 and 1997, but the stream flow anomalies were much larger in 1983 as compared to 1997. The rise and fall of the stream flow anomalies was oscillatory with peak separation of ~5 months.

Key words – QBO, El Niño, SST anomalies

1. Introduction

Paraná is the largest river in the Plata river basin that covers a vast area of subtropical South America (Fig. 1). Large areas have been deforested to make way for beef and soybean farming. Some details are: Basin Area: 2,582,672 sq km; Forest: 12%; Loss of Original Forest: 71%; Deforestation Rate: 18%; Cropland: 45%; Grassland: 36%; Wetlands: 11%; Arid: 10%; Large Dams: 29; Large Cities: 54; Population Density: 23 people per sq km. A relatively long record of the Paraná discharge oscillations is available for the streamflow at Corrientes (27° S, 56° W) located downstream of the major Paraná-Paraguay river confluence. This record reflects the hydrological condition prevailing over about 1,950,000 sq km (70% of the total basin area), including the runoff supplied by the Andean headwaters of the Bermejo and Pilcomayo rivers, the discharge provided by the Mato Grosso through the Paraguay river, and the water output delivered by the Upper Paraná River basin with headwaters in Brazil's Serra dos Preneos. Earlier, this record has shown an ENSO signal (Depetris *et al.*, 1996), a near-decadal cycle associated with SST (Sea surface temperature) anomalies over the northern tropical Atlantic (Robertson and Mechoso, 1998), and a 15-18 yr cycle in the north-south difference between streamflows of the Uruguay and Negro rivers to the south and the Paraná and Paraguay rivers to the north (Robertson and Mechoso, 2000). Recently, Robertson *et al.* (2001) investigated the interannual-to-decadal predictability of the Paraná river for the summer-season (JFM, January-March). In the present communication, the streamflow series at Corrientes for different seasons (4-monthly intervals) are spectrally analysed and their ENSO relationship is re-examined.

2. Plots

The streamflow at Corrientes (Mean discharge 15745 m^3/sec; Maximum monthly mean 54500 m^3/sec, in June 1983; Minimum monthly mean 4100 m^3/sec, in October 1944) has a pronounced average seasonality (~±25%) (Depetris *et al.*, 1996), with high waters in February-March (local summer) and low waters in August-September. For analysis, three data series were produced, JFMA, MJJA, SOND, during 1904-1999 (96 data points).
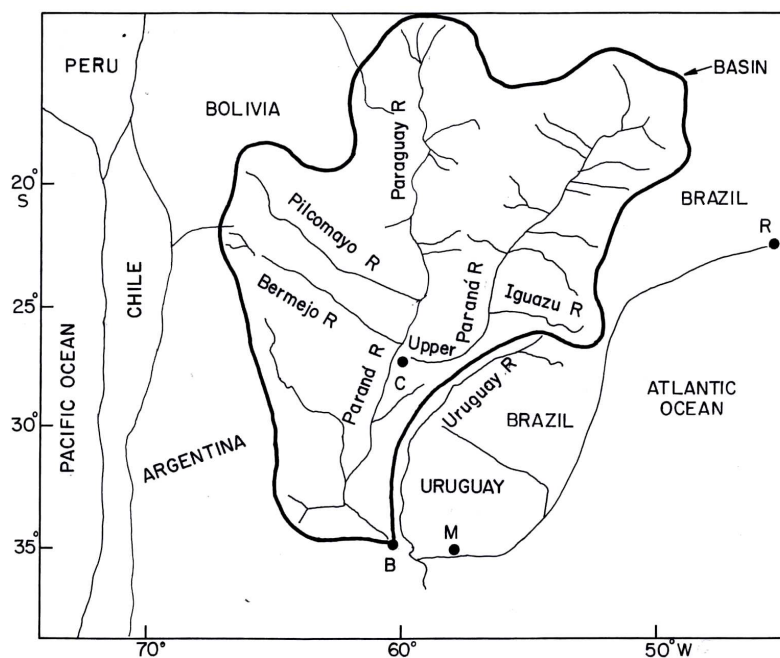
Fig. 1. Map of the Paraná River drainage basin. C = Corrientes, Argentina, R = Rio de Janeiro, Brazil, M = Montavideo, Uruguay, B=Buenos Aires, Argentina
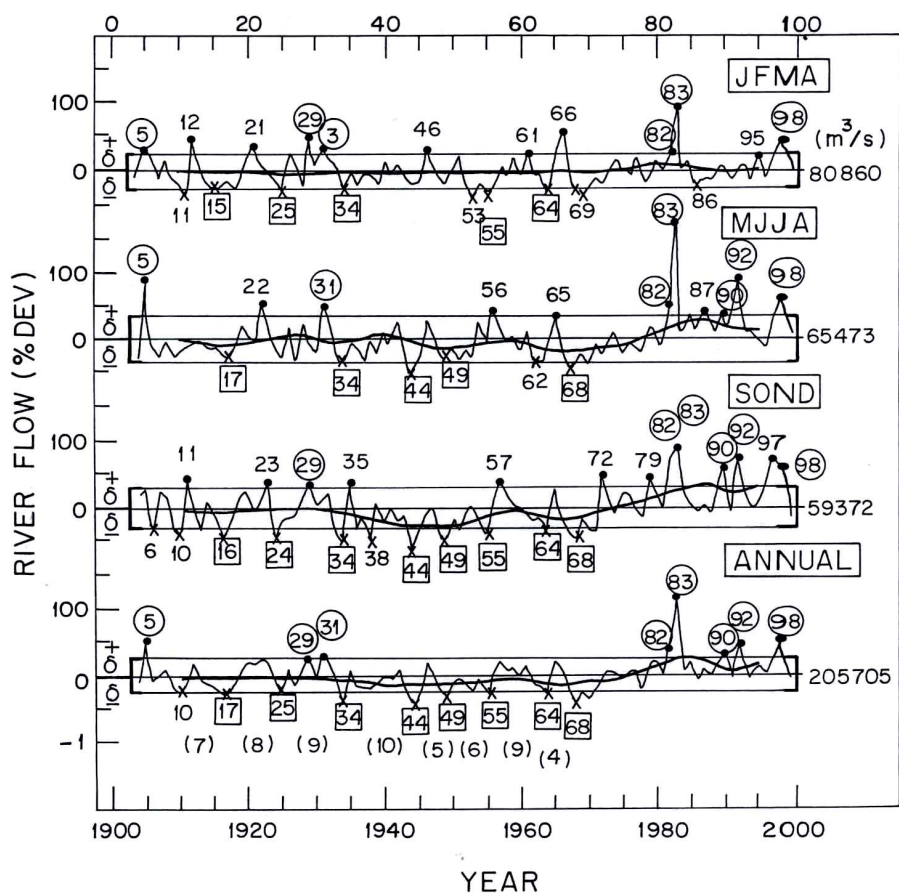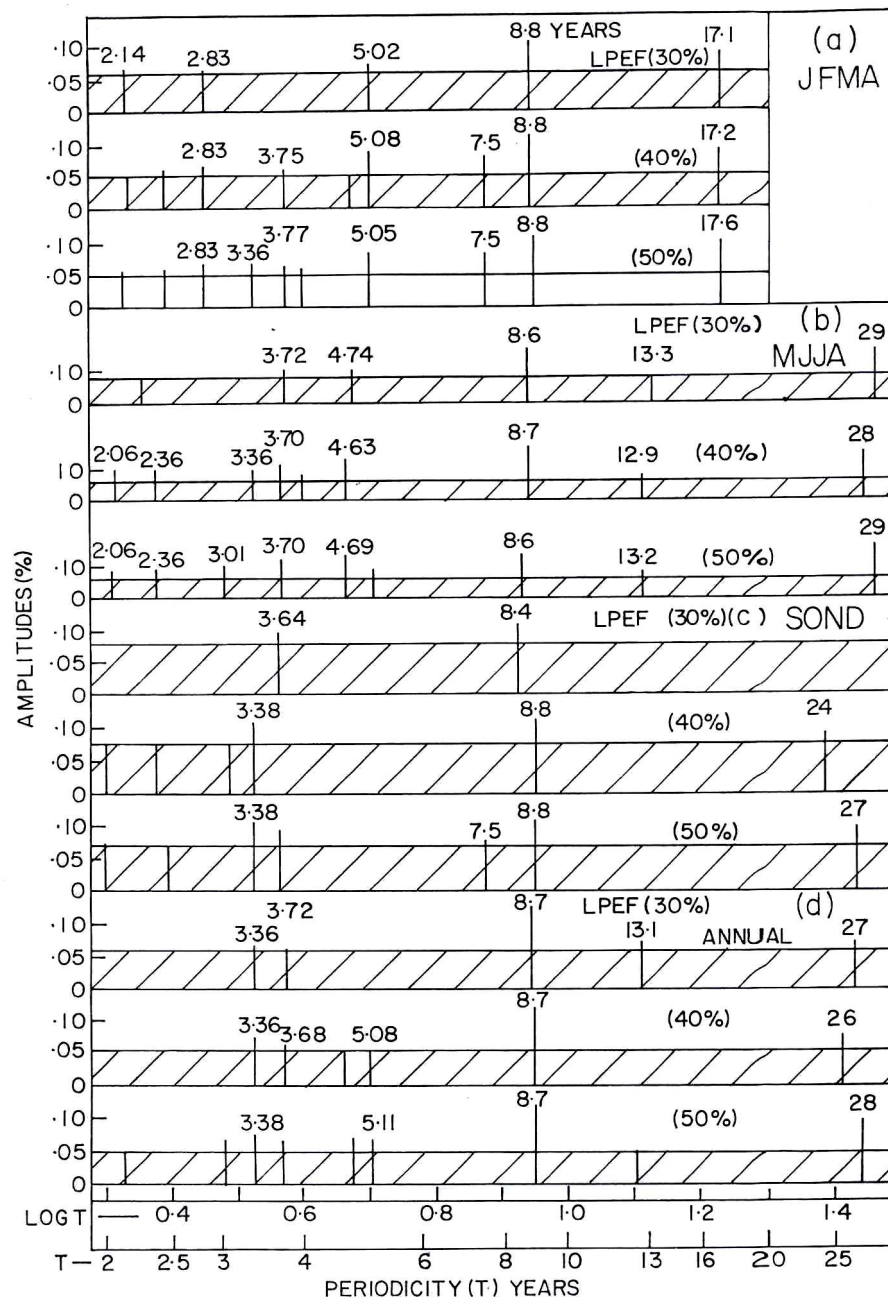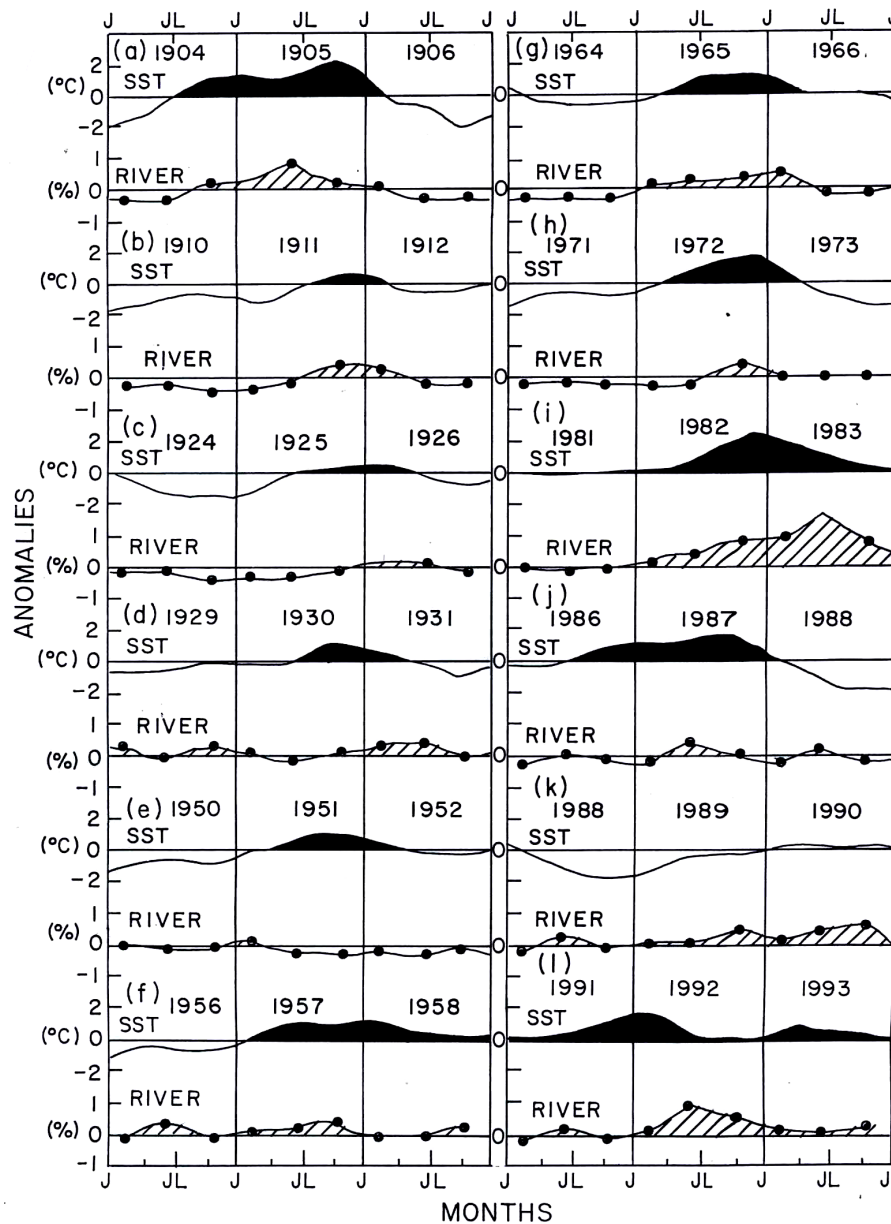

Fig. 2. Thin lines : Percentage deviations from mean of the Paraná river streamflow series (1904-1999) for the seasons JFMA, MJJA, SOND, annual. Thick lines : Moving averages over 11 consecutive values

Figs. 3(a-d). Spectra (amplitudes *versus* periodicities detected by MEM) in the series 1904-1999 (96 values) for (a) JFMA, (b) MJJA, (c) SOND, (d) annual. The hatched portion is the 2σ limit. In each frame (a, b, c, d), the three successive plots are for LPEF = 30%, 40%, 50%. The abscissa scale is logarithm of periodicity T (years)

Each series was expressed as percentage deviations from its mean of 96 years. Fig. 2 shows the plots. The horizontal lines above and below the zero line are the σ limits, ± 24% for JFMA, ± 34% for MJJA, ± 32% for SOND, and ± 25% for the annual. The thick lines are moving averages over 11 consecutive values. The JFMA plot shows steady values up to about 1970 but a slightly increased flow thereafter (noted by Depetris *et al.*, 1996, for 1904-1991), including the abnormal increases in 1983 (100%), 1966 (61%) and 1998 (47%). For MJJA and SOND, there is seen a decrease from 1904 to ~1970, and a considerable increase in recent decades (largest increases in 1983). The maxima are marked by dots and minima by crosses and the numbers indicate corresponding years (5=1905, 12=1912 etc.). The circled numbers are years of maxima and the numbers in rectangles are years of
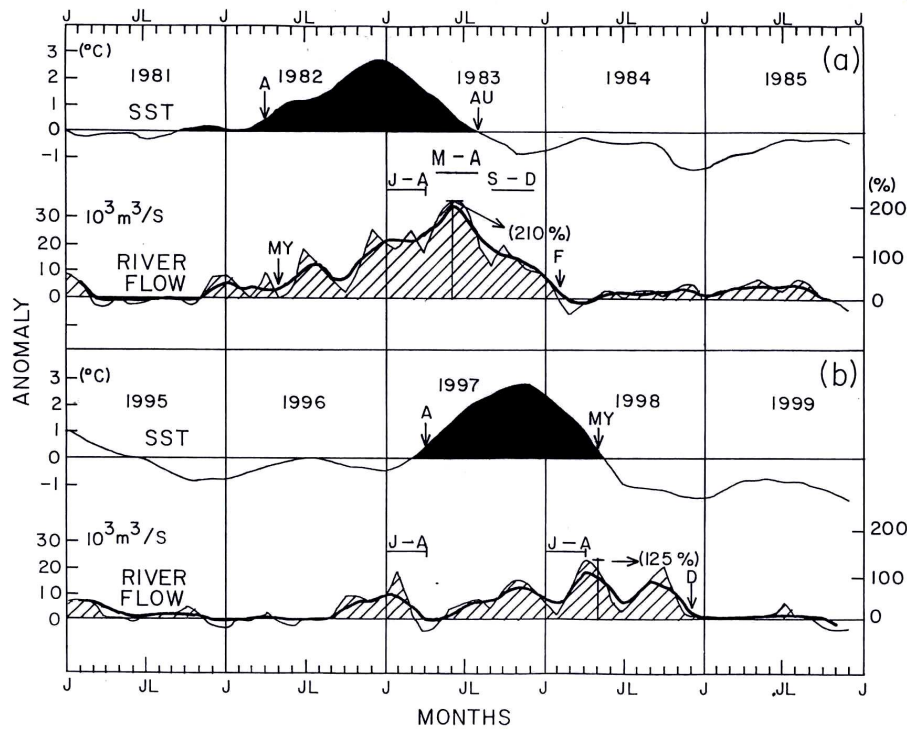
Figs. 4(a-l). The SST anomalies in the central and eastern Pacific (positive values painted black, representing an El Niño), followed by percentage deviations from mean of the Paraná river streamflow (positive values shown hatched, representing floods). The middle year is an El Niño year

minima, common to more than one season and seen in the annual plot. Some years are common but not all. In the annual plot, the numbers in parentheses are spacings (in years) between successive minima (rectangles) and vary in a wide range of 4 to 10 years, with an average value of ~7 years.

3.   Spectral analysis

For the deseasonalized record of 1904-1991, Depetris *et al.* (1996) reported a periodicity of 40 months

(3.3 years). Robertson *et al.* (2001) used data for JFM months for 1904-1999 and, using singular spectrum analysis (a variant of principal component analysis, together with the maximum entropy method, SSA, Vautard and Ghil, 1989), reported periodicities of 2-5, 8 and 17 years. We adopted the combination of MEM (Maximum Entropy Method, Ulrych and Bishop, 1975) and MRA (Multiple Regression Analysis, Bevington, 1969), to estimate amplitudes r_k and their standard error σ_k (common for all r_k in this methodology, which assumes white noise). Any r_k exceeding 2σ is significant at a 95%

Figs. 5(a&b). Monthly values of SST anomalies in the central and eastern Pacific (positive values painted black, representing an El Niño), followed by deseasoned values of the Paraná river streamflow (positive values shown hatched, representing floods), for (a) 1981-85, (b) 1995-99, when giant El Niños occurred (1982-83 and 1997-98)

(a priori) confidence level. In MEM, there is a variable LPEF (length of the prediction error filter) which can be chosen. At smaller LPEF, only very prominent periodicities are revealed. At larger and larger LPEF, more and more periodicities are revealed. In the present case, three values of LPEF were used, namely 30%, 40% and 50% of the data length.

Fig. 3 shows the spectra (amplitudes *versus* periodicities, for the series shown in Fig. 2. In Fig. 3(a) for JFMA, the top plot for LPEF = 30% reveals two prominent periodicities at 8.8 and 17.1 years and smaller but significant periodicities at 5.02, 2.14 and 2.83 years (QBO, Quasi-biennial oscillation 2-3 years). At LPEF = 40% and 50%, these periodicities are retained and some additional periodicities are revealed (7.5, 3.75, 3.36 years). In Fig. 3(b) for MJJA, the 8.6 year periodicity is seen but the ~17 year periodicity is not seen. Instead, periodicities are indicated at ~13 and ~29 years, besides ~4.6, 3.7 years and QBOs. Fig. 3(c) for SOND shows ~8.8, ~25 and ~3.5 year periodicities. Fig. 3(d) for annual values shows periodicities similar to Fig. 3(c), with no trace of a 17 years periodicity. Thus, the ~17 year periodicity is in the JFMA (summer) streamflow only, which does not have a ~27 year periodicity. The relationship with individual ENSO events is illustrated in

the next section, but it may be remembered that ENSO has a strong periodicity in the 3-4 year region and a smaller periodicity in the QBO region (Kane, 1998a). A correlation between the streamflows and ENSO index on an annual basis for 1950-1999 (reliable ENSO data only) yielded values as given in Table 1. As can be seen, correlations between streamflows and T-D are negative as expected (negative T-D indicates presence of El Niños, which are reported to be related to floods in Corrientes) and correlations between streamflows and SST in Nino 3.4 region (5° N - 5° S, 120 - 170° W) are positive, but these are not very large (less than 0.50), indicating complications due to effects other than those of ENSO.

4.   ENSO relationship

ENSO phenomenon is known to be related to rainfall anomalies in various parts of the globe (Ropelewsky and Halpert, 1987) and the anomalies are reported to be well defined over South America (Aceituno, 1988). For the Paraná river flow, positive anomalies (larger flows) are associated with ENSO and precipitation in the Paraná river drainage basin is reported to be in phase with the normal annual precipitation cycle (Ropelewsky and Halpert, 1987), thus causing disastrous floods during El Niño years.

1950-1999	JFMA	MJJA	SOND	Annual	T-D	SST
JFMA	1.00					
MJJA	0.56	1.00				
SOND	0.48	0.68	1.00			
Annual	0.79	0.90	0.84	1.00		
T-D	-0.30	-0.32	-0.46	-0.42	1.00	
SST	0.25	0.28	0.50	0.40	-0.93	1.00

Fig. 4 shows a plot of the evolution of ENSO and Paraná streamflow at Corrientes for 3 consecutive years, in which the middle year is an El Niño year (Quinn *et al*., 1987). As a representation of ENSO, the Pacific SST anomalies (Wright, 1984, central and eastern equatorial Pacific SST) were used for 1904-1950, and thereafter, the SST values for Niño region 3.4 (5° N - 5° S, 120 - 170° W) were used, obtained from the website of the Climate Prediction Center (CPC) of NOAA, Camp Springs MD, USA. For SST, the positive anomalies are shaded black and for streamflow, the positive anomalies are shown hatched. For some events (1918, 1940), there were no SST data. It may be noted that:

(*i*)   In most of the cases, the SST positive anomalies (painted black) match with the streamflow positive anomalies (shown hatched). Thus, on the whole, the association of El Niños with flooding in Paraná river is good. In general, larger the SST anomaly, larger is the flooding.

(*ii*)   There are a few glaring exceptions. In the El Niño of 1951 (event e), the streamflow anomaly was absent (no flooding). In the El Niño of 1957 (event f) and 1987 (event j), the streamflow anomalies were rather small.

(*iii*) The 1988-1993 interval had some strange occurrences. In 1989-1990 (event k), SST positive anomalies were absent, but streamflow positive anomalies were large, particularly in 1990. In 1992-93 (event l), SST positive anomalies were substantial in both 1991 and 1992, but streamflow positive anomalies were substantial only in 1992.

(*iv*)   Streamflow positive anomalies were seen in all seasons (not just JFMA), whenever SST anomalies were strong. However, the peaks in SST anomalies did not always coincide with the peaks in streamflow anomalies. Often, there were phase lags or leads.

(*v*)   The durations of SST anomalies and streamflow anomalies were different. In general, the SST anomalies lasted longer.

(*vi*)   Since SST anomaly is the cause and streamflow anomaly the effect, the streamflow anomaly commencements should occur simultaneously or after the SST anomaly commencements. In general, this was observed.

In the last 20 years, two giant El Niño events occurred, in 1982-83 and 1997-98. Fig. 5 shows plots of the monthly values for 5 consecutive years, (a) 1981-85, (b) 1995-99. The SST positive anomalies are painted black. The streamflow anomalies were obtained by subtracting the climatological values from the actual values. Positive anomalies are shown hatched. The following may be noted :

(*i*)   In Fig. 5(a), the SST positive anomalies commenced in April (A) of 1982. The streamflow started showing fluctuations earlier, in January 1982, but these were small till April. The thick line represents moving averages over 3 consecutive monthly values and indicates that a substantial streamflow increase started only after May 1982 and peaked in July 1983, 7 months after the SST peak in January 1983. The SST anomaly terminated in August 1983, but the streamflow anomaly continued for 6 months more (until February 1984).

(*ii*)   In Fig. 5(b), the positive SST anomalies commenced in April (A) of 1997. Here again, the streamflow had small positive anomalies in January-February 1997, a few months earlier. The 3-month moving average (thick line) still shows positive anomalies in January 1997. Thus, this pre-increase [seen even in Fig. 5(a)] may not be random and may have some physical significance. Though the SST anomalies in 1997 were substantial (2.9° C, almost the same as in 1982) and peaked in November 1997, the streamflow anomalies in Fig. 5(b) had a smaller peak (125%) in this event as compared to the peak (210%) in Fig. 5(a) and showed a distinct oscillatory behavior lasting up to December 1998, 7 months after the termination of the SST anomaly in May 1998. Thus, the El Niño effects in these two events were different, both qualitatively and quantitatively.

5.   Conclusions and discussion

(a)   A spectral analysis of the series of the streamflow of Paraná river (South America) as recorded at Corrientes

(27° S, 56° W) indicated that (*i*) All seasons had a significant periodicity of ~8.5 years; (*ii*) Additionally, JFMA had significant periodicities at ~17, ~5, ~3.7 and ~2.8 (QBO) years, MJJA had ~29, ~13, ~4.7, ~3.7, ~2.4 and ~2.1 (QBO) years, while SOND had ~27 and ~3.4 years (no QBO).

(b) During El Niño years, (*i*) In a majority of cases, positive SST anomalies in central and eastern Pacific (El Niños) were associated with positive anomalies (floods) of the river flow, confirming a good ENSO relationship. Only in a few cases, no flow anomalies were noticed; (*ii*) Generally, streamflow positive anomalies commenced after the commencement of the SST positive anomalies (phase lags of a few months), as expected. However, in the cases of the two giant El Niños of 1982-83 and 1997-98 when SST anomalies commenced in April 1982 and April 1997, the streamflow anomalies were slightly positive a few months earlier (January of 1982 and 1997). This could be a random variation but could also be a sort of pre-cursor effect. The streamflow anomalies disappeared with a few months delay after the disappearance of SST anomalies; (*iii*) Generally, larger the SST anomalies, larger were the river flow anomalies. However, whereas the SST anomalies were of the same peak magnitude (2.9° C) in 1982 and 1997, the streamflow anomalies were much larger, (210%) in 1983 as compared to (125%) in 1997. Also, the rise and fall of the streamflow anomalies was oscillatory (much more so in 1997-98 as compared to 1982-83), with peak separation of ~5 months; (*iv*) In very few cases, streamflow positive anomalies occurred without the presence of SST positive anomalies.

The near-decadal cycle of ~8-9 years is reported to be associated with SST anomalies over the northern tropical Atlantic (Robertson and Mechoso, 1998). However, this is in contradiction with the spectral analysis of the North and South Atlantic SST indices (Kane, 1998b), where for data for 1964-90 (obtained from Servain, 1991), North Atlantic SST (28° N - 5° N) showed a periodicity of 10.9 years and the South-Atlantic SST (5° N - 20° S) showed a periodicity of 13.9 years. Mehta (1998) reported a distinct decadal time scale of 12-13 years of SST variations in the tropical South Atlantic, but no distinct decadal timescale in the tropical North Atlantic. Thus, the origin of the ~8.5 year periodicity observed in the Paraná streamflow remains obscure. A 15-18 year cycle was seen in the north-south difference between streamflows of the Uruguay and Negro rivers to the south, and the Paraná and Paraguay rivers to the north (Robertson and Mechoso, 2000). An association was suggested with changes in the intensity of the South American summer monsoon and the southward moisture

transport by the low-level jet along the eastern slopes of the Andes. The origin of a 26-29 year cycle (seen only in the May-December months, not in January-April) needs further exploration. The periodicities in the ~3.5 year region and the 2-3 year (QBO) region are reflections of an average ENSO effect.

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