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ENSO-Controlled Flooding in the Paraná River (1904–1991)

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Since the poineering work of Walker [1, 2], evidence has been mounting that the El Niño-Southern Oscillation (ENSO) phenomenon causes rainfall anomalies in various parts of the globe [3, 4]. These anomalies are particularly well defined over the region of South America [4–6].

Rivers exhibit the advantage of being rainfall integrators over large areas. This approach was used by Richey et al. [7], who have shown a significant (5% level) coherent relationship in the cross-spectral analysis of deseasonalized Amazon discharge data and atmospheric pressure anomalies at Port Darwin, Australia. Precipitation over the Amazon basin appears to be stimulated by the ascending motions associated with the Southern Oscillation (SO) positive phase and, hence, its positive level departures occur mainly during cold events, also known as La Niña [3].

Early in the study of the SO, a keen interest arose on the connection which might exist between the SO and the flow regime of the Paraná River. Originally Mossman [8], and, a few years later, Bliss [9], pointed to the relationship of the SO with rainfall over southern Brazil, Paraguay, and northern Argentina, as presented by the level of the Paraná River 420 km above the mouth, at Rosario, Argentina. In opposition to the Amazon, the Paraná positive level departures are significantly correlated with ENSO warm extremes. Moreover, the "season" of ENSO-related precipitation in the Paraná River drainage basin is in phase with the normal annual precipitation cycle [10], thus causing flooding events – often disastrous – during El Niño years. To the best of our knowledge, the Paraná is the largest river system in the world which exhibits such a behavior.

A relatively long record of the Paraná discharge oscillations is available for the Corrientes section (Fig. 1). In analyzing this daily record (Fig. 2A), we seek to establish the frequency of the variability and the significance of the teleconnection with the ENSO phenomenon. This record reflects the hydrologic conditions prevailing over 1.95×10^6 km^2 (ca. 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.

When the discharge time series of Fig. 2A is considered, the most outstanding features which arise are the pronounced seasonality – with high waters in February/March and low waters in August/September – the substantial variability, and the magnitude of the 1982/83 flood. This flood, obviously related to the strong 1982 El Niño event, caused profound modifications in the biogeochemical functioning of the river [11, 12]. Other large floods, such as those of 1904, 1911, 1932, and 1965, also occurred in accordance with ENSO warm events [4]. Worthy of attention are the negative deviations in the record (Fig. 2B), which persisted longer than positive ones, at least until

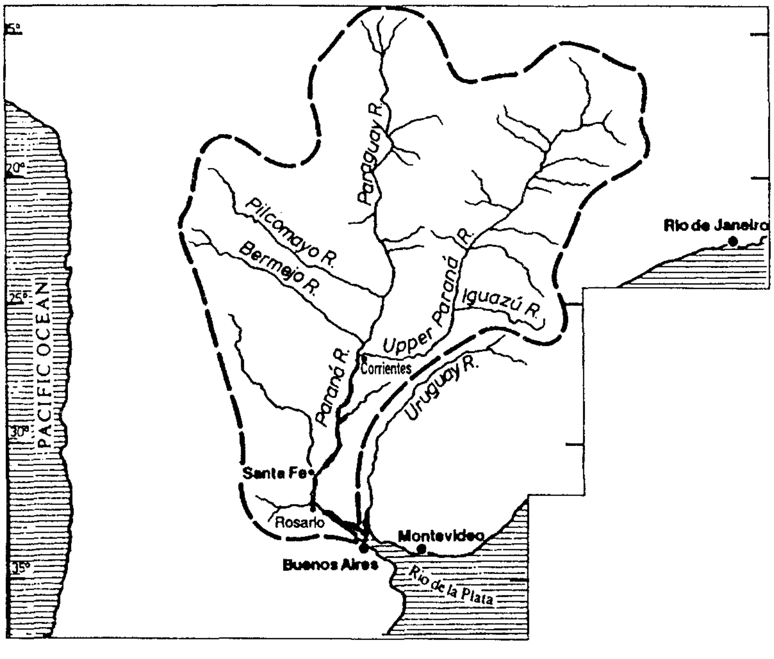

Fig. 1. Map of the Paraná River drainage basin showing main tributaries. The cities of Corrientes and Rosario are referred to in the text. Other cities shown for reference

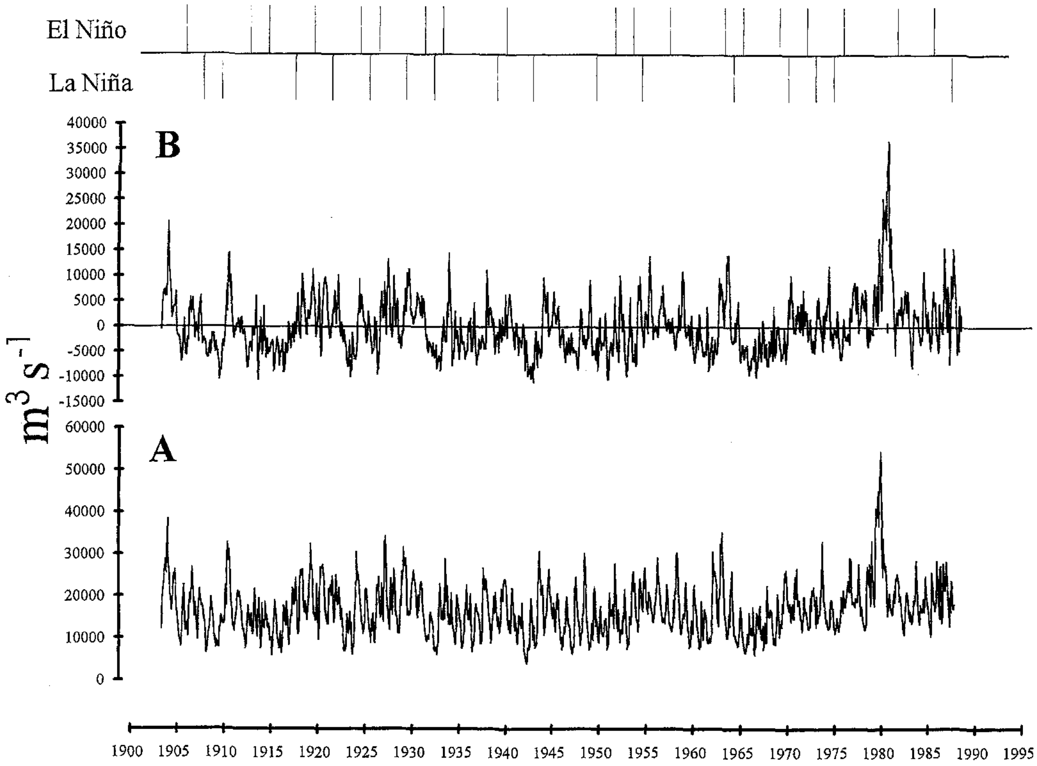

Fig. 2. Discharge of the Paraná River at Corrientes (ca. 1200 km above the mouth, 27°58′S, 58°49′W). Mean discharge, 15745 $m^3 s^{-1}$; maximum monthly mean for the record was 54500 $m^3 s^{-1}$ (June 1983) and the minimum was 4100 $m^3 s^{-1}$ (October 1944). A) Discharge time series, September 1904 to July 1991; B) deseasonalized hydrograph, 1904 to 1991. *Bars* on top indicate the occurrence of El Niño and La Niña

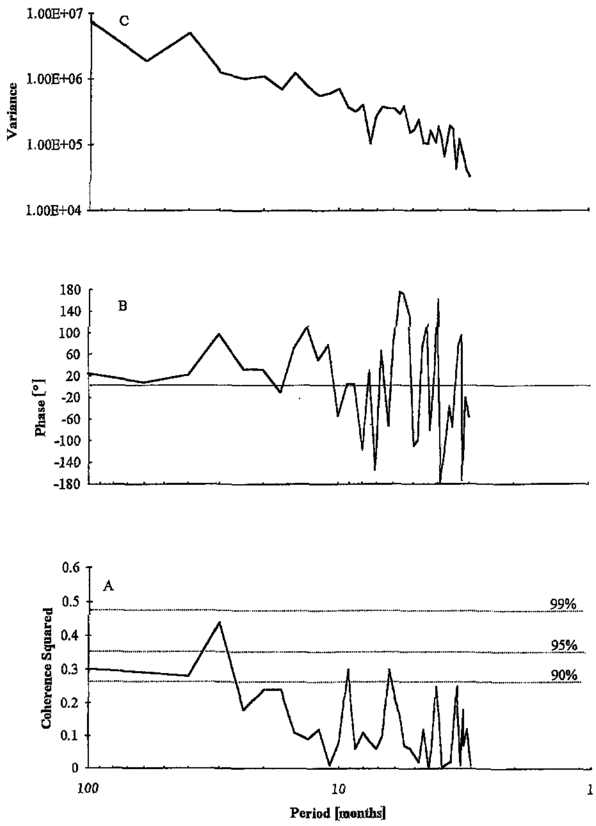

Fig. 3. Spectral analysis of the deseasonalized Paraná discharge record, 1904 to 1991. A) Coherence-squared spectrum between SST [13] and Paraná discharge data based on deseasonalized monthly means for the period 1904 to 1991; B) phase lag; C) power spectrum

ca. 1973. Then, a period of positive deviations began, with a climax in the 1982/83 ENSO-related flood.

Spectral analysis of the deseasonalized discharge record discloses a spectral peak at a period of 40 months (3.3 years; Fig. 3 A), about 12 months longer than the dominant period observed in the Amazon [7]. Its remarkable regularity probably accounts for a somewhat stronger periodicity than in the Paraná. The periods of recurrence of ENSO warm and cold events [4], on the other hand, exhibit asymmetrical frequency distributions with geometric means of 3.7 years for the warm events and 4.5 years for the cold ones.

To appraise the statistical significance of the apparent relationship existing between ENSO events and Paraná River anomalous discharges, we performed cross-spectral analysis between the deseasonalized 1904–91 Paraná River record and the equatorial Pacific sea-surface temperature (SST) [13]. The coherence-square between the Paraná discharge at Corrientes and the SST was significant at the 5% confidence level in the neighborhood of the 30-month periods range (Fig. 3 B), and similar in value to that of the Amazon [7]. The corresponding phase relation between both records also shows that anomalous high Paraná discharge at Corrientes lags behind positive SST anomalies by about 8 months (Fig. 3 C).

Arkin [14] has pointed out that stronger than normal 200-mb subtropical westerly winds, which exhibit a tendency to coexist with ENSO episodes, may be in part responsible for the enhanced precipitation observed in southern Brazil, northeastern Argentina, and Uruguay. The consistency of the relationship existing between ENSO warm events and wet episodes in that region of southern South America is noticeable: 14 of the latter correspond to 16 ENSO warm extremes [15]. A convergence zone with a south-southeastward orientation often develops in association with the prevailing wind pattern and results in the above-normal ENSO-related rainfall in southern South America [10, 15].

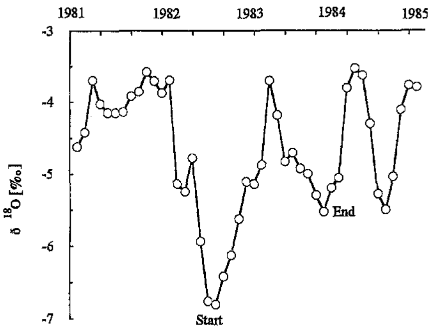

Fig. 4. $\delta^{18}O$ record in the Paraná River, 1981 to 1985, measured at Santa Fe (ca. 500 km above the mouth). The beginning and the end of the 1982 El Niño event in the Equatorial Pacific are shown; $\delta^{18}O = \{[(^{18}O/^{16}O)_s - (^{18}O/^{16}O)_{st}]/(^{18}O/^{16}O)_{st}\} \times 1000$, where s denotes the isotope ratio measured in the sample, and st the ratio measured in SMOW (standard mean ocean water)

Within the framework of the SCOPE/UNEP International Carbon Project [16], a relatively long sequence of $\delta^{18}O$ determinations was made in Paraná River water samples, collected about 600 km upstream from the mouth. Measurements started in March 1981 and were continued until November 1984 (Fig. 4). A markedly negative $\delta^{18}O$ signal was registered in coincidence with the initiation of the strong 1982 El Niño episode in the Pacific. Afterwards, the signal returned to what appeared to be the regular seasonal variation.

Due to a Rayleigh fractionation, rain becomes progressively lighter in $\delta^{18}O$ as it occurs farther from the water vapor source. Therefore, we have interpreted the above described behavior as an indication that El Niño-related atmospheric processes – such as the south-southeastward convergence zone mentioned by Arkin [14] – determined the occurrence of excess rainfall which carried a more negative signature, probably distinctive of water vapor originated in a distant oceanic source (i.e., excess water vapor injected into the continent). Clearly, the isotope data suggest that, after the onset of the El Niño, rainfall over the Paraná drainage basin returned to its usual variability.

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Offshore Atmospheric Phosphine

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In the summer of 1995, gaseous phosphine (PH_3) as a potential volatile participant in the atmospheric phosphorus cycle was observed for the first time in the lower troposphere close to the sea surface in the German Bight (North Sea). While the daytime concentration of atmospheric PH_3 remained at a low level of 41 $pg\,m^{-3}$, the postmidnight concentration peaked at a value of 885 $pg\,m^{-3}$ ($\pm 30\%$ rel.s.d.).

Throughout the past century, PH_3 was considered to be solely an industrial product. Its existence on earth was believed to be uniquely extraterrestrial in origin, for example, meteoric schreibersite (Fe_3P) [1]. Surprisingly enough, in 1968, Iverson [2] detected biogenic iron phosphide (Fe_2P) generated by bacterial iron corrosion processes. Natural gaseous PH_3 was first discovered as a planetary constituent of the atmospheres of Jupiter [3] and Saturn [4] in