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ENSO-triggered exceptional flooding in the Paraná River: Where is the excess water coming from?

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S U M M A R Y

The Paraná River has been increasing its annual flow during the last ~30 years. The relative contribution of its major tributaries (i.e., the upper Paraná and Paraguay rivers) is uneven in as much as the Paraguay is increasing its annual discharge at a higher pace than the upper Paraná does. Contrastingly, the upper Paraná has been increasing significantly its flow during the second half of the year (i.e., historical low water period) whereas the Paraguay River has been amplifying its flow throughout the hydrological year. The variability of $\delta^{18}O$ measured in the Paraná River middle reach tends to follow Paraguay's relative contribution to Paraná's total discharge. A simple model built on the basis of the mean $\delta^{18}O$ signature of rainfall (Global Network of Isotopes in Precipitation) shows significant coherency with the relative contribution time series during non-El Niño periods but it is necessary to invert the mean isotopic values in precipitation during the occurrence of a major ENSO event (i.e., assume that $\delta^{18}O$ in upper Paraná River water becomes more negative than usual) to improve the resemblance to the observed variability.

Introduction

The teleconnection existing between ENSO occurrences in the Equatorial Pacific Ocean and anomalous hydrological behavior over a significant portion of South America has been the object of extensive research for many years. The correlation found in the 1920s by Sir Gilbert Walker's group between surface pressure in Australia and the Paraná River discharge at Rosario, Argentina, is a good example of such allegation (e.g., Bliss, 1928). During the last 20 years the knowledge on such teleconnection was significantly broadened (e.g., Kousky et al., 1984; Ropelewski and Halpert, 1987; Depetris et al., 1996; Amarasekera et al., 1997; Robertson and Mechoso, 1998; Boulanger et al., 2005; García and Mechoso, 2005; Pasquini and Depetris, 2007) and more evidence was found on the linkage between ENSO dynamics and the hydrology of the Río de la Plata drainage basin (i.e., the added drainage basin areas of the Paraná and the Uruguay rivers).

In 1982–1983, the Southern Oscillation Index (SOI) – one of the most widely used indicators to assess ENSO's strength – dropped down to −3.46 in February 1983. Such markedly negative index signified a robust El Niño event, which in turn determined a record discharge of over 60,000 $m^3 s^{-1}$ in June 1983, in the Paraná River at the Corrientes gagging station, about 1200 km upstream from Paraná's mouth.

In earlier works we have evaluated discharge trends and ENSO-linked flooding periodicities in the Paraná and Uruguay drainage basins (e.g., Depetris et al., 1996; Pasquini and Depetris, 2007). In this occasion our primary objective is to analyze the relative water contributions of Paraná's main upper tributaries, seeking to establish if they are increasing their historical water supply at a similar rate. Preliminary data indicated that this may not be the case. Secondarily, we wish to examine the association between the mentioned relative discharge contributions and the response triggered in stable isotopes determined in the Paraná's middle course during strong ENSO episodes.

Study area

The Paraná River (drainage area, ~2.8×10^6 km^2) has widely differing headwaters that sometimes exhibit contrasting dynamics: from Andean sources close to South America's Pacific active margin, in the Pilcomayo and Bermejo upper catchments (~65°W), to the tropical headwaters placed at the Serra dos Preneos (~45°W), close to the Atlantic passive margin. With headwaters at the Gran Pantanal (one of the largest wetlands in the

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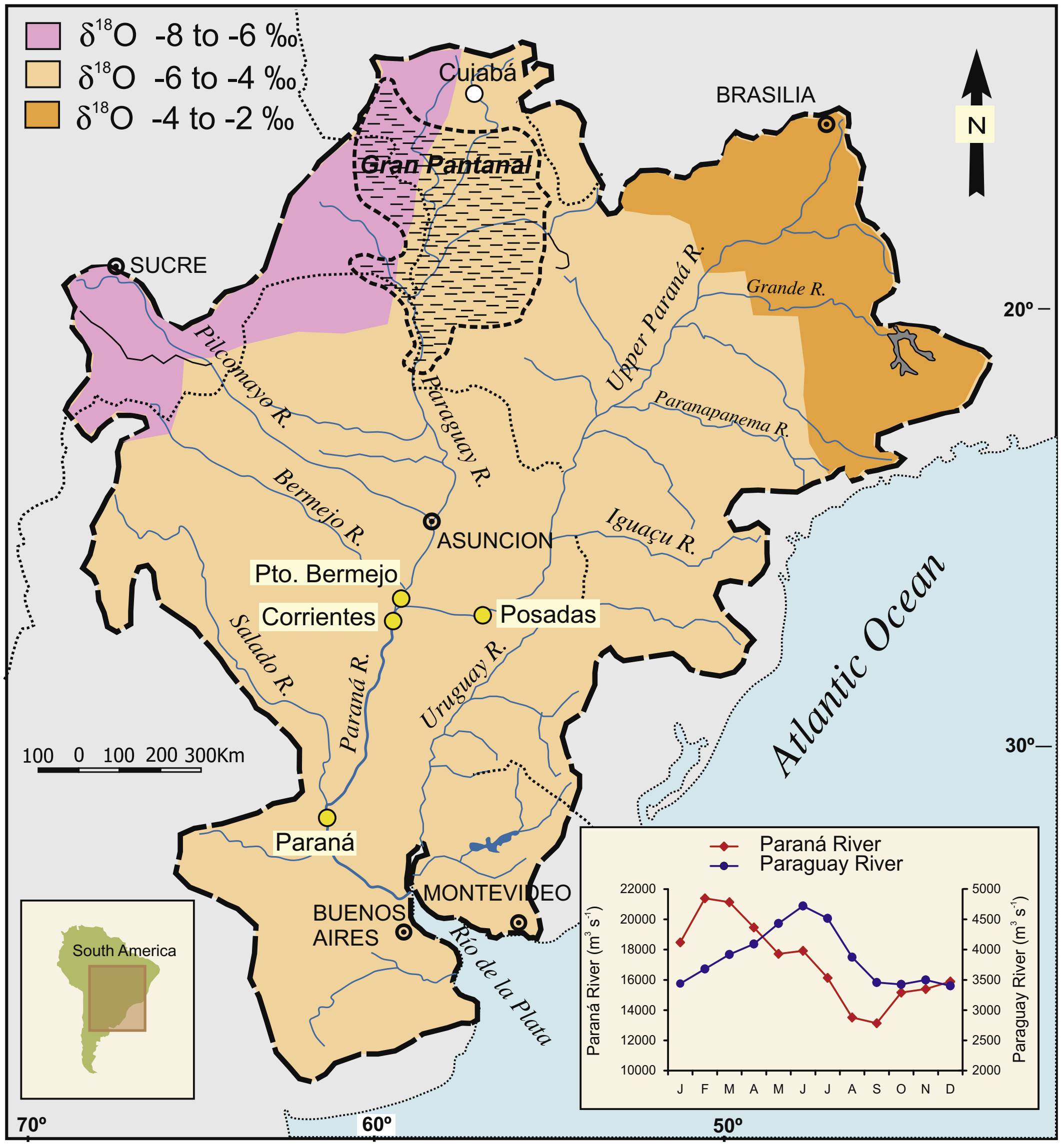

Fig. 1. Subset of South America's mean isotopic distribution map (Aggarwal et al., 2007) depicting the Río de la Plata drainage basin (~3.1 × 10^6 km^2). δ ^{18}O (‰) areas in the map are long-term precipitation annual averages from IAEA's Global Network of Isotope in Precipitation (GNIP), where the map is available (http://nds121.iaea.org). Inset shows historical monthly mean discharge in the Paraná River (at Corrientes) and Paraguay River (at Puerto Bermejo). Hydrological data was supplied by Argentina's Subsecretaría de Recursos Hídricos. Capitals and cities of South American countries are included as geographical references.

world, at ~15°S and ~55–60°W, Fig. 1) that exerts a discernible modulating effect (Junk and Nunes de Cunha, 2005), the Paraguay River runs with a N–S direction, joining the Paraná River at Corrientes, which continues southward bound in a middle and lower course that splits the Paraná drainage in two uneven halves (Pasquini and Depetris, 2007).

The Paraná River is the main contributor to the riverine water budget of the Río de la Plata drainage basin (Fig. 1). On the average, it currently delivers ~530 km^3 of water per year to the Río de la Plata estuary, of which ~73% is supplied by Paraná's upper catchments (i.e., including the Iguaçú River), ~20% by the Paraguay River and nearly 7%, jointly by the rivers draining South America's mountainous backbone (i.e., Bermejo, Pilcomayo, and Salado rivers) (e.g., Pasquini and Depetris, 2007). These relative contributions are, however, mean annual approximations, and the year-to-year hydrological functioning is quite variable, particularly when the system is subjected to anomalous episodes, like the ENSO. During El Niño-triggered flooding – which in the Paraná River normally occurs in phase with the annual high water period – the upper tributaries do not supply a constant relative flow contribution to the river's main stem. The ENSO also has a limited impact on the coastal zone. Worth mentioning is the fact that, during El Niño events, the Río de la Plata does not produce an anomalous northeastward plume extension in the Atlantic Ocean – as would be expected in a large outflow event – but spreads offshore instead (Piola et al., 2005).

The summer circulation over South America is dominated by a monsoonal system, whose major seasonal feature is the South Atlantic Convergence Zone (SACZ), placed along the north-eastern boundary of the Río de la Plata drainage basin (e.g., Robertson and Mechoso, 2000). Another significant feature in the regional climatic control is a low-level northerly/northeasterly jet that flows east of the Andes, and transports moisture along the corridor placed between the Andes and the Brazilian *altiplano* (e.g., Wang and Fu, 2004). As a consequence of these continental climatic features, the mean annual rainfall is unevenly distributed over the Paraná River drainage basin. Maximum recorded precipitation (2400 mm y^{-1}) occurs along the eastern edge of the basin and over