INTERANNUAL AND INTERDECADAL LINKS VARIATIONS IN THE STREAMFLOW OF SOUTH AMERICAN RIVERS AND THEIR LINKS TO CLIMATE

Alvaro Diaz(1) and C. Roberto Mechoso(2)

(1)Institute of Fluid Mechanics and Environmental Engineering,
Julio Herrera y Reissig 565, Montevideo, Uruguay
adiaz@fing.edu.uy
(2) Department of Atmospheric and Oceanic Sciences,
University of California Los Angeles, USA
mechoso@atmos.ucla.edu

Abstract

Interannual and interdecadal variations in annual-mean streamflow for eight major rivers in South America during most of the 20th century are examined. A singular spectrum analysis method (SSA) is applied to extract contributions to the variance in the periods 2-3 years, 3-5 years, and 6-13 years. The reconstructed time series are correlated with indices representative of known global climate variations. It is shown that, while almost all of the rivers in this study show increasing trends during the 20th century, their reconstructed time series for the three selected bands present different behaviors.

1. INTRODUCTION

The relationships between the variability of a basin's climate and the behaviour of its rivers are complex. In spite of this, several studies have shown that major climate variations (e.g., El Niño) leave an imprint on the discharge of major rivers ([1]). The analysis of such imprints can contribute to a better understanding of climate variations up to decadal time scales, since large rivers have been monitored for periods that can be as long as centuries.

South America has several major rivers. Analysis of their streamflows has revealed trends and quasi periodicities. Reference [2] reported an increasing trend since the early 1970s, and suggested that a continental-scale climate change took place around that time. Reference [1] found changes in trends and means around the early 1970s in all but one of the rivers selected (in which the changes occurred in the late 1970's). All rivers have El Niño-like periodicities. These explain a larger part of the total variance than the others in La Plata Basin (LPB) rivers only. Reference [1] also found quasi-oscillations with periods around 9 and 17 years. These oscillations have been linked to the sea-surface temperature anomalies in the tropical North Atlantic Ocean.

In this paper, we revisit the time series of streamflows of 8 large rivers in South America during a period that, in most cases, covers the 20th century (see Table 1). Our goal is further identify similarities and differences in behaviours that support a climate link. We apply a singular spectrum analysis method (SSA, [3]) to find significant quasi-oscillations and extract contributions to the variance in frequency bands associated to the periods 2-3 years, 3-5 years, and 6-13 years. We form the reconstructed time series for quasi-oscillations with periods in each one of those frequency bands, and determine the percentage of variance explained along the records.

Table 1. Rivers and their gauging stations, beginning and end years of the record for each river, and the mean annual streamflow or level.

Rivers-gauging station	Period	Annual mean streamflow or level
Magdalena-Calamar	1940-1991	7,170 m^3s^{-1}
Negro- Bonete (Bon)	1908-2003	7,247 m^3s^{-1}
Negro-Manaos	1903-1993	28,060 m
Orinoco-C.Bolívar	1926-1995	33,055 m^3s^{-1}
Paraná-Corrientes	1904-2001	17,123 m^3s^{-1}
San Francisco-Itaparica	1931-1992	2,881 m^3s^{-1}
Tocantins-Tucurui	1931-1999	11,441 m^3s^{-1}
Uruguay-Concordia	1898-1997	54, 580 m^3s^{-1}

2. Reconstructed time series based on the 3 selected quasi-periodicities

In this section we examine the reconstructed time series for each selected band (2-3 yr; 3-5 yr; and 6-13 yr; Figs. 1, 3 and 5 respectively). Table 2 shows the variance contributions of each band to the total variance of the raw series. The contributions range from around 50% of the total variance for the Tocantins/San Francisco Rivers to about 88% of the variance for the Uruguay River.

Table 2. Percentage of explained variance by the reconstructed time series for each of the three selected bands.

River	**% Var exp 2-3 yr**	**% Var exp 3-5 yr**	**% Var exp 6-13 yr**	*Total*
Magdalena	15.5	28.9	37.6	*82.0*
Orinoco	20.7	28.3	15.8	*64.8*
Negro-Manaos	24.5	22.4	23.4	*70.3*
Tocantins	19.8	17.7	15.2	*52.7*
San Francisco	16.5	19.5	15.3	*51.3*
Paraná	7.6	24.9	31.6	*64.1*
Uruguay	18.9	33.6	35.3	*87.8*
Negro-Bonete	15.6	32.6	18.9	*67.1*
Average	*17.4*	*26.0*	*24.1*	

In a second stage, for each reconstructed series, we calculate the percentage of variance explained in sliding 21-year windows with respect to the total variance of the reconstructed time series (Figs. 2, 4 and 6). We use 21-year windows in order to search for features with decadal time scales.

a. The 2-3 year band

The Magdalena, Negro-Manaos (hereafter Negro-M), Tocantins, San Francisco, and Parana Rivers show increased activity in this band during the period 1980-90(see Fig. 1). The Uruguay and Negro-Bonete (hereafter Negro-B) rivers show increased activity in the periods 1930-40, 1955-65 and 1980-95. In the four tropical rivers (Negro-M, Orinoco, San Francisco, and Tocantins), the explained variance associated to periods 2-3 years decreases strongly during the first half of the century reaching minima around the early 50's (see Fig. 2). This may be associated with the shifting southward of the South American monsoon ([4]), which was probably due to deforestation, and to the reduced influence of tropical variability on regional precipitation during the second half of past century. The extratropical rivers (Paraná, Uruguay and Negro-B) show different behaviors with increased contribution in the later parts of the period.

b. The 3-5 year band

In this band (see Fig. 3), the Magdalena and Orinoco Rivers seem to be anticorrelated. This may be due to the different El Niño-Southern Oscillation (ENSO) impacts on locations in different sides of the Andes Mountains. A clear similarity appears between the time series corresponding to the Tocantins and San Francisco Rivers. This is also the case for the LPB Rivers (Paraguay, Uruguay and Negro-B). We note that the former two rivers seem out of phase with the latter three rivers. This anticorrelation is consistent with the dipole in precipitations anomalies that have centers in the South Atlantic Convergence Zone (SACZ) and South Eastern South America ([5]).

For the three LPB rivers, the variance explained by SSA components in the 3-5 year band increases during the later part of the record. In particular, the increase happens since the 40´s for the Uruguay River, and since the 50´s for Paraná. This result suggests a strengthening of the links between streamflows in LPB and ENSO during the latter part of past century.

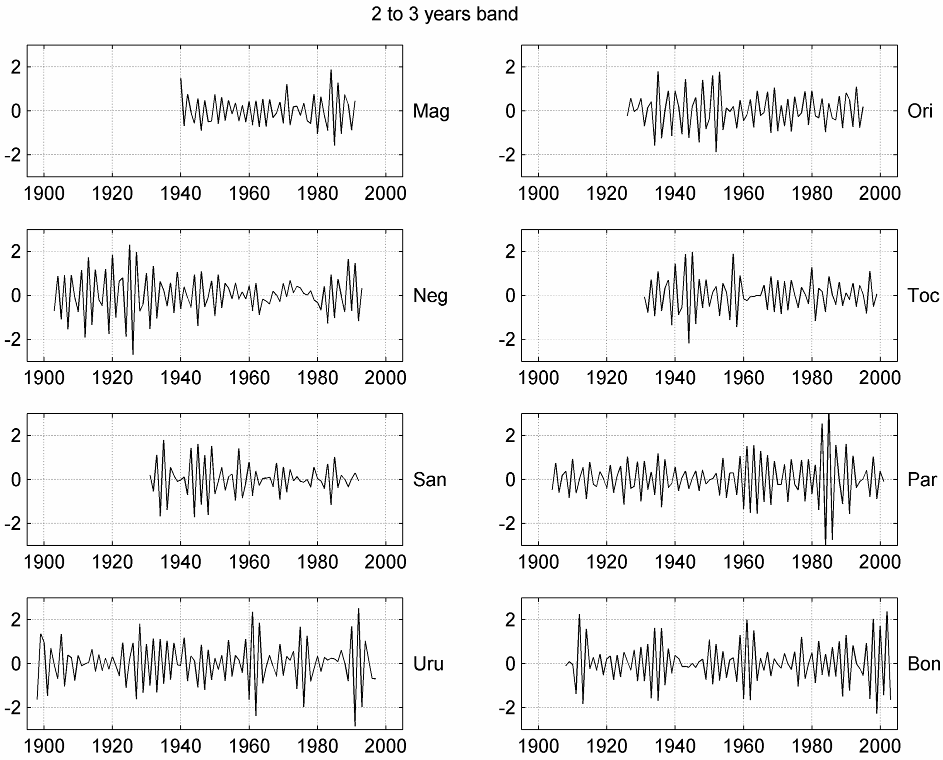

Figure 1. Reconstructed time series for the 2-to-3 years band.

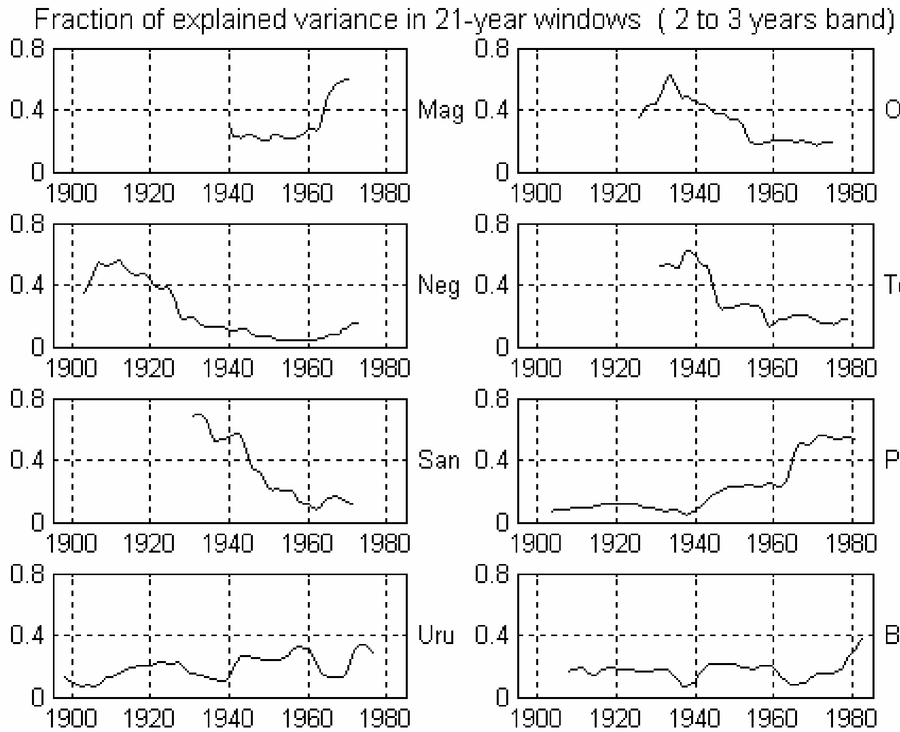

Figure 2. Fraction of explained variance for 21-year windows for the 2-to-3 years band for the eight rivers. Years correspond to the beginning of each window.

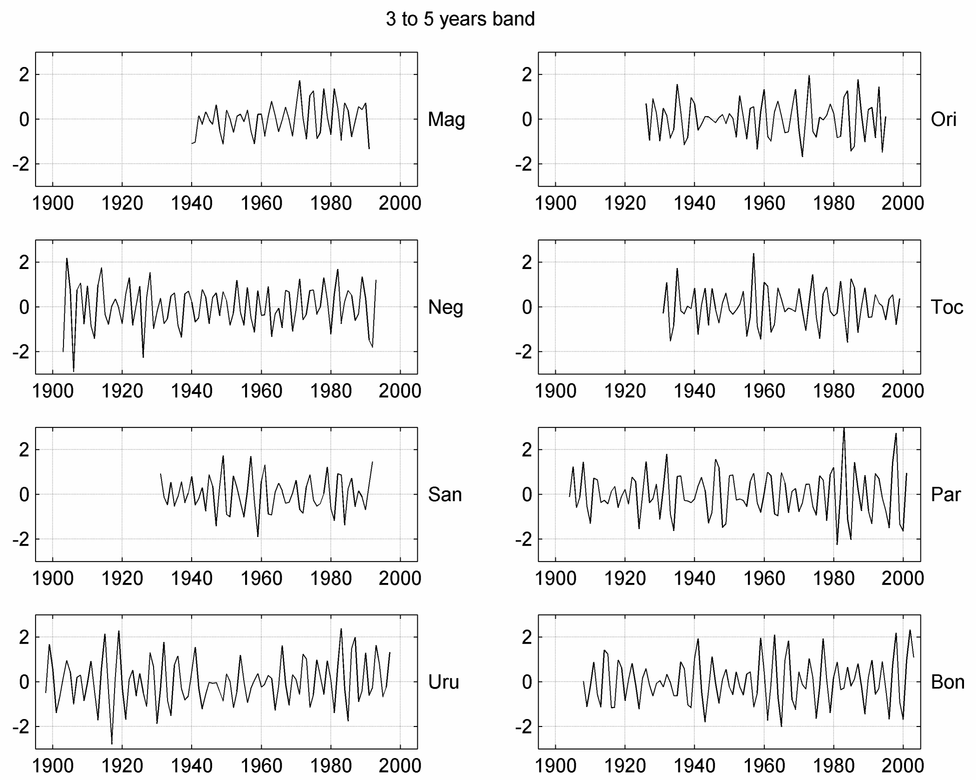

Figure 3. Same as Fig. 1 but for the 3-to-5 years band.

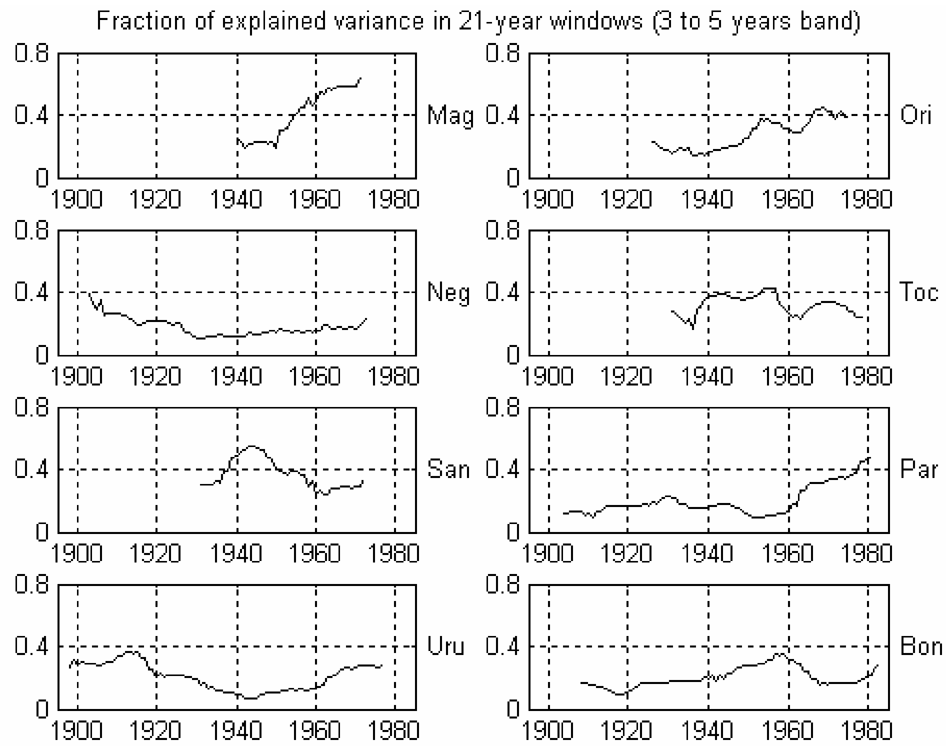

Figure 4. Same as Fig. 2 but for the 3-to-5 years band

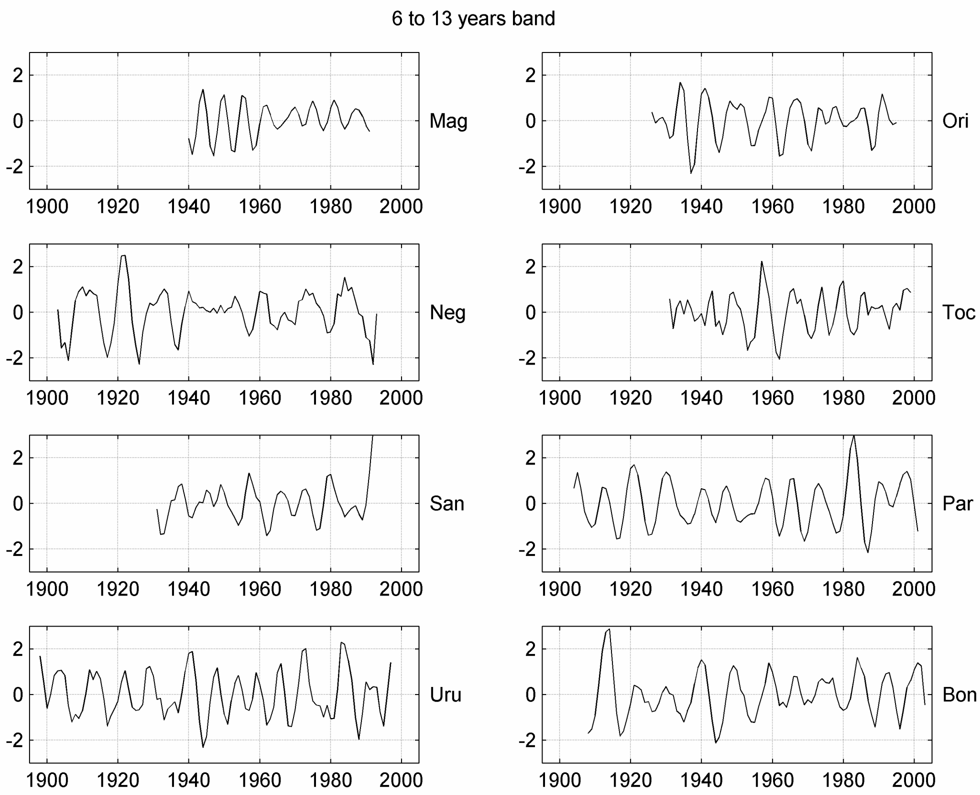

Figure 5. Same as Fig. 1 but for the 6-to-13 years band

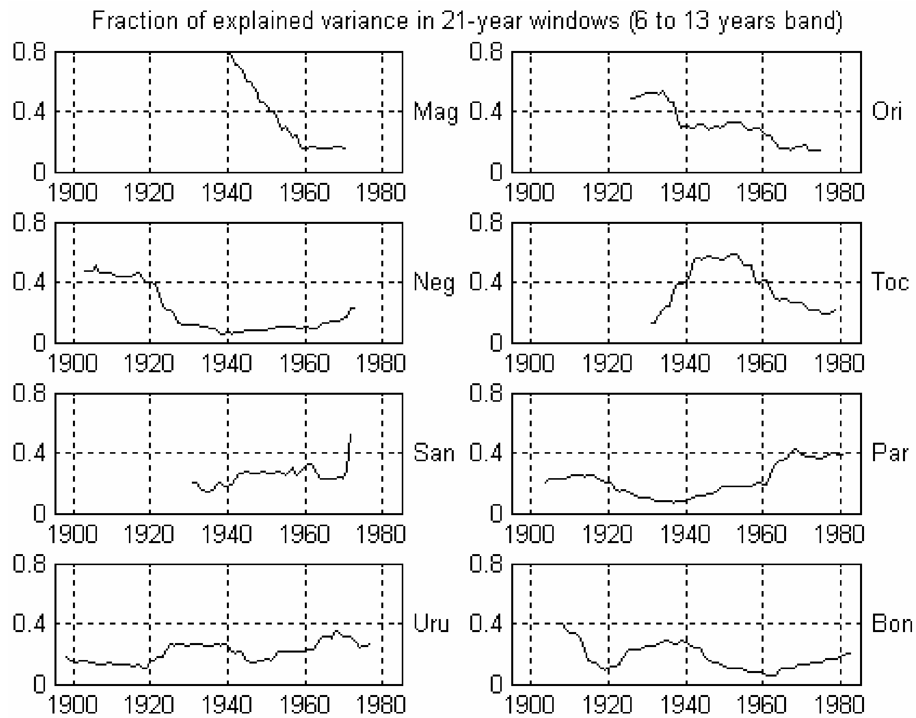

Figure 6. Same as Fig. 2 but for the 6-to-13 years band.

c. The 6-13 year band: Decadal variability

This band was selected because the Parana and Uruguay rivers show decadal variability that could be used for streamflow predictions ([6]). There seems to be a coherent signal for all the rivers considered which will be analyzed in more detail in the discussion Section.

d. Trends

Table 3 present the slope of linear trends for the eight rivers selected. It is clear that all rivers except Tocantins show an increasing trend along their own records.

Table 3. Slopes of straight lines adjusted to the river streamflows

River	Slope
Magdalena	18.0 $m^3/s/yr$
Orinoco	12.6 $m^3/s/yr$
Negro-M	0.11 m/yr
Tocantins	-0.04 $m^3/s/yr$
San Francisco	2.7 $m^3/s/yr$
Paraná	38 $m^3/s/yr$
Uruguay	122 $m^3/s/yr$
Negro-B	39.3 $m^3/s/yr$

4. Fraction of explained variance

a. Quasi-Biennial band (2 to 3 years)

In this band the tropical rivers (Negro-M, Orinoco, Tocantins and San Francisco) show a stronger signal prior to 1950 than in the remainder of the century (see Fig. 2). This is not the case for the LPB rivers, which show increasing amplitudes in the last years of the record. Fig. 7 (upper panel) shows the fraction of explained variance for 21-year windows for the 2-to-3 years band reconstructed Niño 3 index (N3) (1856-2002). There are lower values in the first half of the century in agreement with [7]. It is apparent that, while the corresponding figures for the tropical rivers (see Fig. 2) show higher values at the beginning than at the end of the period, the opposite holds for N3. The LPB rivers, particularly the Paraná, display a more similar pattern to that of N3 in this band.

b. The 3-5 year band.

In this band, an initial decrease in amplitudes is clearly in the Negro-M and Uruguay (see Fig. 3), but not in Paraná and Negro-B, the remaining rivers not having enough data at the beginning of the century. Amplitudes increase later on Magdalena and Paraná. This increase is less clear in the other rivers; the Tocantins in particular, shows a decrease later in the period. Fig. 7 (middle panel) shows the fraction of explained variance for the 3-5 year band for 21-year windows for N3. The signal weakens from the beginning of the 20th century up to 1950, and then increases strongly until the end of record. As expected, negative correlations appear between the time series of the Uruguay/ Negro-B rivers, and the Tocantins/San Francisco. These features correspond to the well-known dipoles in precipitation anomalies in interannual time scales between the SACZ and Southeastern South America mentioned earlier.

c. The decadal band (6 to 13 years)

Figure 7 (lower panel) shows for 1856-2002 the explained variance for 21-year segments of a North Atlantic SST index (NATL) defined as the SST in the region (5-20 N, 60-30 W). The index decreases from the first decade of the 19th century until late 1940´s, increases steeply up to the 1970´s, and decreases again in the end of the record. The time series associated to 6-13 years band for Paraná River (see Fig. 6) shows a similar behavior. Table 4 shows the correlations between all rivers considered in this study for this band. We can see that the time series of streamflow for Negro-M is significantly and positively correlated with those of the Paraná, Uruguay and Negro-B, and negatively correlated with those of the Tocantins and San Francisco. A plausible explanation for this feature is that these links are established through anomalies in the South American Low Level Jet (LLJ). The Negro-M basin is the path of the LLJ and LPB rivers are downstream of it. When positive (negative) anomalies of the Low Level Jet (LLJ) intensity occur, SACZ tend to be weakened (strengthened), and moisture convergence in LPB is enhanced (attenuated).

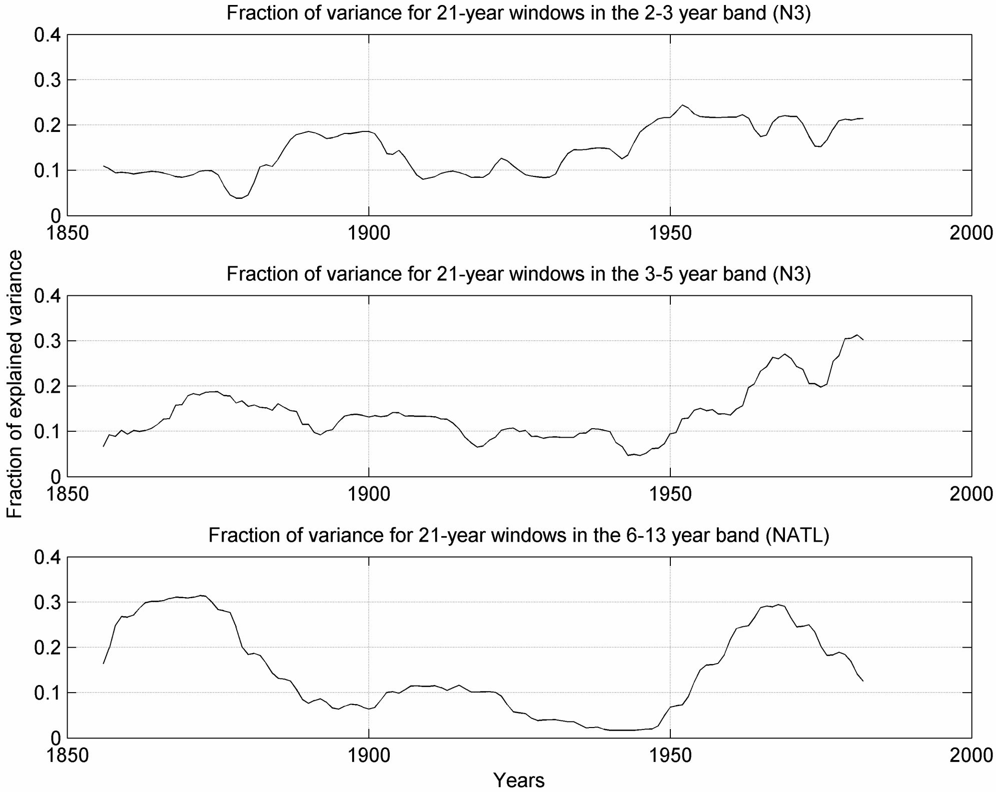

Figure 7. Fraction of explained variance for 21-year windows for: N3, 2-to-3 years band (upper panel); N3, 3-to-5 years band (middle panel) and NATL, 6-to-13 years band (lower panel).

Table 4. Correlation coefficients between pairs of reconstructed time series corresponding to the 6-to-13 years band. Bold figures correspond to values significant at the 1% level Dark and light shadings correspond to positive and negative values respectively

	Mag	Ori	Neg-M	Toc	San	Par	Uru	Bon
Mag		**-0.457**	0.014	-0.043	-0.033	-0.341	**-0.501**	-0.297
Ori			0.128	**0.383**	0.138	0.220	**0.348**	**0.485**
Neg-M				**-0.335**	**-0.620**	**0.270**	**0.310**	**0.305**
Toc					**0.493**	0.143	-0.040	0.146
San						0.201	0.054	0.127
Par							**0.627**	**0.314**
Uru								**0.606**
Bon								

5. Summary

While it is apparent that almost all of the South American river streamflows examined in this study show increasing trends during the 20th century, their reconstructed time series for the three selected bands present different kinds of variability. Within this broad variety of behaviours, we can identify some similarities. For the three bands, there are two groups of rivers that display similar patterns, 1) the three LPB rivers for one side (Paraná, Uruguay and Negro-B), and 2) the easternmost rivers (Tocantins and San Francisco). These two sets of rivers are usually anticorrelated, probably in response to the precipitation dipole between SACZ and southeastern South America. For the quasi-biennial band, the 4 tropical rivers (Tocantins, San Francisco, Orinoco and Negro-M) exhibit a steady decreasing variance during the first half of the century, remaining nearly constant up to the end of the record. The opposite happens for the LPB rivers, which show a considerable increase near the end of the considered period. In this band, N3 shows an increasing trend since the 1920´s up to near the end of the record. For the ENSO band, a similar behaviour can again be detected for both groups of rivers and also for N3. These results for both bands, which cover quasi-periods from 2 to 5 years, confirm the findings of [8], who detected a strong widespread climatic signal associated to ENSO in the Southern Hemisphere.

The present study also suggests that links between LPB rivers and ENSO strengthened in the second half of the century. The link between NATL and the river streamflows is less clear for the decadal band. However, the correlation values between the reconstructed series in this band (see Table 4) are striking. Northernmost rivers (Orinoco and Negro-M) show positive significant correlations with almost all the LPB rivers, suggesting the presence of a climatic connection between northern and southern portions of the continent to the east of the Andes mountains through anomalies in the South American LLJ.

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