Hydrologic variability over the Amazon basin and its relationship with ENOS and NAO

Guillermo O. Obregón and Carlos A. Nobre

Center for Weather Forecasting and Climate Studies - CPTEC, National Institute for Space Research – INPE.
Cachoeira Paulista, São Paulo, Brazil.

INTRODUCTION

The availability of long-term streamflow records of the Amazon river at Manacapurú station, representative of the rainfall integrate over the western portion of the basin, is useful as a proxy for precipitation. Since this data provides a natural integration of the hidroclimatic variations, it will allow us a better understanding of the relationship between the hydrologic processes over Amazonia and the large-scale circulation, which drives the variability of the precipitation.

Past studies found that the rainfall over Amazonia is strong related to ENSO phenomena (e. g. Marengo 1992), and it explains part of the interannual variance of the river discharge (Amarasekera et al. 1997) with significant coherency at the period of 2-3 year (Richlet et al. 1989). The rainfall (Nobre and Shukla 1996) and the hydrologic trends (Costa and Foley 1999) over Amazonia are also linked to the Tropical Atlantic SST. Besides it, there is a relationship between the Tropical North Atlantic SST and the North Atlantic Oscillation (NAO) at times scales of 8 - 20 year (Rajagopalan et al. 1998), and model evidence that there is some dependency between the NAO and the tropical Atlantic SST (Robertson et al. 2000)

Thus, the goals of this work are twofold: first to reveal structures of a characteristic scale of monthly river discharge using wavelet transform. Secondly, search for relationship between the discharges and both the SOI and NAO through the cross wavelet analyses, because they depict part of the variability of the global climatic system and appear to be independent manifestations of climate variability (Giannini at al. 2001). The use of the wavelet transform analysis offers significant advantages over other techniques for analysis of streamflow records because periodic and non-periodic events are precisely located in time, permitting transient or time-dependent features to be detected, that may otherwise be obscure.

DATA AND METHODS

The basic data is the river flow for the Amazon river, derived from the monthly records of the stage of the Rio Negro in Manaus following Richey at al. (1989) for the period 1903-2003. Climatic indices SOI and NAO are used as manifestations of global climatic forcing.

In order to investigate characteristic time scales of the Amazon river discharge and its association to both the SOI and the NAO, we employed the Morlet wavelet transform. Details of wavelet analysis method are described in Torrence and Compo (1998). Firstly we computed the wavelet power spectrum and the global wavelet of the standardized monthly discharge anomalies to separate the significant oscillation within frequency bands. Besides the periods with statistical significant wavelet power spectrum, we have chosen other periods with significant oscillations which give insight on space-time Amazon River discharge variability. Then, it was calculated the coherency wavelet spectrum (Liu 1994) between the standardized monthly discharge anomalies and both the climatic indices SOI and NAO. The instantaneous wavelet phase $\theta(t,s_i)$, between the two series *x(t)* and *y(t)* at scale S_i, of the chosen oscillations was determined as:

$$\theta(t,s_i) = \tan\left(\frac{\mathrm{Im}(W_{xy}(t,s_i))}{\mathrm{Re}(W_{xy}(t,s_i))}\right)$$

where $\mathrm{Re}(W_{xy}(t,s_i))$ and $\mathrm{Im}(W_{xy}(t,s_i))$ real and imaginary part of the cross-wavelet spectrum , and the instantaneous time lag *T(t)* between *x(t)* and *y(t)* at each scale S_i is then obtained from the rela $T(t) = \frac{\theta(t,s_i)}{2\pi s_i}$. This variable will be used as indicative of the phase difference, but in time lags relative to the Amazon river discharge.

RESULTS

The Morlet wavelet power spectrum of the Amazon River discharge (Fig. 1 a) shows the complex non-linear response to the underlying dynamic climate with four dominant regimes of quasi-periodic oscillation, which can be identified more easily in the global wavelet power spectrum (Fig. 1 b, indicated by arrows). During the first half of the past century and after 1980 a strong non-linear interaction between oscillations in time scales less than decadal ones dominate by quasi-biennial (2-3 years) oscillation can be seen, and presence of other two oscillations at time-scales of 5-6 years and 9-11 years. The period of 2-3 years was found in previous studies through spectral analysis (Richey et al. 1989) and it was related to the ENOS phenomena. Another remarkable fact is the dominance of the quasi-bidecadal oscillation (16-20 years) between around 1945 – 1990, with strongest amplitude in the 1970's decade. The shape of this change suggests an abrupt climate shift as a suddenly response to any disturbance of finite amplitude (Lau and Weng 1995).

At quasi-biennial time scales the strong coherency between IOS and discharge (Fig. 2 a), just along the periods where the amplitude of wavelet power spectrum is large (1915-1930 and 1985-2003), with IOS leading by 3-6 months (Fig 3 a), indicates that the IOS plays the main role on the river discharge. Also, the coherency between NAO and discharge is large only from 1920 to 1930, with NAO leading by around 3 months. Whereas at 5-6 year time scales, the coherency is large between NAO (SOI) and discharge prior 1915, 1965-1975 and after 1990 (after 1995), when NAO leads (SOI lags) the discharge by about 9 (5) months. It seems to be that the NAO drives the climate over Amazonia at this interannual time scales.

At quasi-decadal (9-11 year) time scales both the IOS and the NAO are linked to discharge prior to 1930 (Fig. 2 a-b), just during the period of large amplitude of oscillation observed in the wavelet power spectrum (Fig. 1a). An examination of the time lag among them (Fig. 3 c) points out that the IOS leads the discharge by about 36 months, while NAO lags it by 3 months during that period. This fact appears to indicate that the IOS is the main forcing for quasi-decadal oscillations. Also, there is an abrupt phase change around 1945 mainly between IOS and discharge. Furthermore, at quasi-bidecadal oscillations the coherency between IOS and discharge is stronger from 1940-1980 (Fig. 2 b), when the discharge lags IOS by 6 months. Apparently this relationship is reinforced by the NAO as it is indicated by the coherency between NAO and discharge after 1960, with NAO leading discharge from zero at 1960 to 12 months at 2000 (Fig. 3 d).

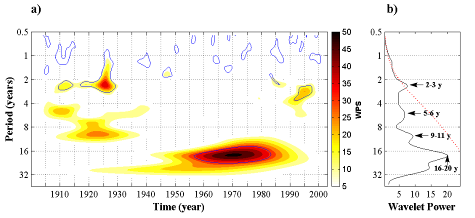

Fig. 1 – Amplitude of the continuous wavelet transform of the desazonalized monthly Amazon river discharge (a) and the global wavelet power spectrum (b). The blue line in (a) shows regions with values at 95% confidence level. The red line in (b) represents 95% confidence level, and the arrows indicate the most important periods of the analysis.

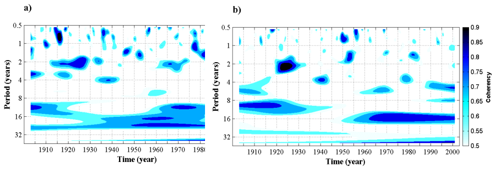

Fig. 2 - Wavelet coherency between the SOI and Amazon river discharge (a), and between NAO and Amazon river discharge (b).

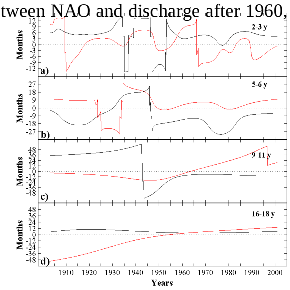

Fig. 3 – Instantaneous time difference between the SOI and Amazon river discharge (black line) and between NAO and Amazon river discharge (red line) for biennial oscillation (a), interannual oscillation (5-6 year) (b), quasi-decadal oscillation (c), and quasi-bidecadal oscillation (d). Values shown here were calculate as the average between scales of the period range. Positive (negative) values indicate lead (lag) of the index with respect to the discharge.

CONCLUTIONS

The complexity of the climate variability over the Amazon basin and its relationship to SOI and NAO, as their probable large-scale forcings at different time-scales, was analyzed. The main findings can be summarized as follow.

- It appears that there is a strong non-linear response of the Amazon river discharge at times scales shorter than quasi-decadal related to underlying climate dynamics of global scale (IOS and NAO). In this sense, the SOI appears to be the main drive of the river discharge at quasi-biennial scales (2-3 year), and it leads the discharge by 3-6 months.
- At interannual time scales (5-6 year), it seems that the NAO plays the main role in the discharge and it leads the discharge by about 9 months.
- In quasi-decadal time scales the IOS appears to be the forcing of the river discharge again, and it leads the discharge by nearly 36 months.
- Finally, for quasi-bidecadal time scales the IOS shows to have the main relationship to the discharge variability and apparently it is reinforced by NAO after 1970.

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