



Contrasting regional discharge evolutions in the Amazon basin (1974–2004)

Jhan Carlo Espinoza Villar^{a,*}, Jean Loup Guyot^b, Josyane Ronchail^c, Gérard Cochonneau^b, Naziano Filizola^d, Pascal Fraizy^e, David Labat^f, Eurides de Oliveira^g, Juan Julio Ordoñez^h, Philippe Vauchel^e

^a Laboratoire d'Océanographie et du Climat: Expérimentation et Approches Numériques – LOCEAN (Institut de Recherche pour le Développement – IRD, Centre National de la Recherche Scientifique – CNRS, Université Pierre et Marie Curie – UPMC and Muséum National d'Histoire Naturelle – MNHN) and Universidad Agraria La Molina (UNALM – Peru), Boite 100, 4 Place Jussieu, 75252 Paris, France

^b Laboratoire de Mécanismes et Transferts en Géologie – LMTG (CNRS, IRD and Université Paul Sabatier – UPS), CP 7091, Lago Sul, 71619-970 Brasília, DF, Brazil

^c Université Paris 7 and LOCEAN, Boite 100, 4 Place Jussieu, 75252 Paris Cedex 05, France

^d Universidade do Estado do Amazonas (UEA) and Potencias Impactos Ambientais no Transporte de gás natural e petróleo na Amazônia (I.PIATAM), Av. Ramos Ferreira, 199, 69010-120 Manaus, Brazil

^e LMTG, Casilla 18-1209, Lima 18, Peru

^f LMTG, 14, Avenue Edouard Belin, 31400 Toulouse, France

^g Agência Nacional da Águas (ANA), Setor Policial, CEP, 70610-200 Brasília, Brazil

^h Servicio Nacional de Meteorología e Hidrología (SENAMHI), Lima 11, 1308, Peru

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SUMMARY

Former hydrological studies in the Amazon Basin generally describe annual discharge variability on the main stem. However, the downstream Amazon River only represents the mean state of the Amazonian hydrological system. This study therefore uses a new data set including daily discharge in 18 sub-basins to analyze the variability of regional extremes in the Amazon basin, after recalling the diversity of the hydrological annual cycles within the Amazon basin. Several statistical tests are applied in order to detect trends and breaks in the time series. We show that during the 1974–2004 period, the stability of the mean discharge on the main stem in Óbidos is explained by opposite regional features that principally involve Andean rivers: a decrease in the low stage runoff, particularly important in the southern regions, and an increase in the high stage runoff in the northwestern region. Both features are observed from the beginning of the nineties. These features are also observed in smaller meridian sub-basins in Peru and Bolivia. Moreover we show that the changes in discharge extremes are related to the regional pluriannual rainfall variability and the associated atmospheric circulation as well as to tropical large-scale climatic indicators.

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Introduction

The Amazon drainage basin is the world's major hydrological basin. Its watershed covers about 6,000,000 km², almost 5% of all the above – water lands. Its average discharge is the greatest in the world (209,000 m³/s) (Molinier et al., 1996). Due to its size and its position astride the Equator, the Amazon basin includes very different regions with various discharge regimes. Some works have documented interannual variability on the main stem (Richey et al., 1989; Marengo, 1992; Callède et al., 2004; etc.). However, re-

gional scale discharge variability has been incompletely discussed in the whole Amazon basin at annual and pluriannual time scales. Furthermore, some recent dramatic events such as the 2005 drought (Zeng et al., 2008; Marengo et al., 2008) and the 2006 flooding show it is not sufficient to analyze mean annual discharge and it is important to pay attention to extremes values. That is why the aim of this paper is to investigate high and low water changes at annual and pluriannual time scales in the main stem and in all the main sub-basins of the Amazon Basin.

This study is made possible thanks to the cooperation of the HY-BAM program (Hydrology and Geodynamic of the Amazon Basin, <http://www.mpl.ird.fr/hybam>) between IRD (Institut de Recherche pour le Développement/Institute for Research and Development) and national hydrological institutions. This has permitted, for the

* Corresponding author. Tel.: +331 44 27 84 67; fax: +331 44 27 38 05.
E-mail address: jhancarlo.espinoza@locean-ipsl.upmc.fr (J.C. Espinoza Villar).

first time, the integration of data from the different countries which form part of the Amazon basin.

After the introduction, we recall some features of the regional hydrological and climatic characteristics and their variability as described by former works. The discharge database and the methods used in this paper are then described. The annual cycles in the different sub-basins are depicted and we show how they contribute to the annual cycle in Óbidos, the last gauged station on the Amazon River main stem. We then comment on trends and breaks in regional maximum and minimum discharge annual series, with special attention to the Andean rivers of Peru and Bolivia. The discharge time evolution at Óbidos is then explained using former results. Finally, discharge variability is related to rainfall in the Amazon Basin and to regional climatic indicators. A summary and concluding remarks are provided in the last section.

Hydro-climatic characteristics of the Amazon basin

The Amazon basin is characterized by an important spatial rainfall variability. The rainiest regions (3000 mm/year and more) of the Amazon basin are located in the Amazon delta, close to the Atlantic Ocean, exposed to the Intertropical Convergence Zone (ITCZ) and in the northwest of the basin (Colombia, North of the Ecuadorian Amazon, Northeast of Peru and Northwest of Brazil). Rainfall is also abundant close to the average position of the South Atlantic Convergence Zone (SACZ), established during austral summer from the Northwest of the Amazon to the Subtropical South Atlantic. Rainfall decreases towards the tropics reaching 2000 mm/year in the Southeast of Brazil and less than 1500 mm/year in the Peruvian–Bolivian plain and in the Roraima Brazilian state which is protected from the Atlantic humid flows by the Guyanese shield. Generally, lower rainfall is observed in the high Andes regions where less than 1000 mm/year is measured over 3000 masl. Though, at lower elevation, a strong spatial variability is observed with rainfall varying from 500 to 3000 mm/year. This spatial variability is related to the prevailing eastern direction of the moist trade winds and to the exposure of the stations on the windward side or, on the contrary, on the leeward side of the mountains.

Rainfall regimes in the Amazon Basin show the strong opposition between the northern and southern tropics, with a rainy season in June, July and August – JJA (in December, January, February – DJF) in the North (South), due to the alternating warming of each hemisphere and to American monsoons. Next to the Amazon delta, a March, April and May (MAM) maximum and a September, October, November (SON) minimum are associated with the seasonal migration of the Intertropical Convergence Zone (ITCZ). In the Northwest equatorial region a better rainfall distribution within the year is observed with quarterly rainfall percentages close to 25%. Various intermediate regimes are described between equatorial and tropical regions (for more information see [Figueroa and Nobre, 1990](#); [Marengo, 1992](#); [Espinoza et al., in press](#); among others).

Interannual discharge variability on the Amazon mean stem may cause inundations or very low water stages. For instance, the recent 2005 drought that affected the western sub-basins (Solimões and Madeira Rivers) during the low water stage (October and November) received important attention from the scientific community ([Zeng et al., 2008](#); [Marengo et al., 2008](#)) as it had serious impacts on human activity (transport, fishing, water supply, etc.) and on the biosphere. This event is attributed to high sea surface temperature (SST) in the tropical North Atlantic ([Zeng et al., 2008](#); [Marengo et al., 2008](#)), a feature that is also pointed out by [Marengo \(1992\)](#) and [Labat et al. \(2004\)](#). [Ronchail et al. \(2005b\)](#)

specify that higher than normal low-flow associated with cold SST in the tropical North Atlantic are particularly strong and wide spread in the central regions of the basin. Interannual discharge variability is also related to the SST in the Equatorial Pacific: authors coincide in finding lower (higher) discharge during El Niño (La Niña) in the main stem ([Richey et al., 1989](#); [Marengo, 1992](#); [Marengo et al., 1998](#)). Some works analyzing the regional discharge variability inside the Amazon Basin show that the ENSO signal is particularly strong in the northeastern basins ([Molion and Moraes, 1987](#); [Uvo and Graham, 1998](#); [Guyot et al., 1998](#); [Uvo et al., 2000](#); [Foley et al., 2002](#); [Ronchail et al., 2005b](#)). [Ronchail et al. \(2005a\)](#) also find that in the upper Madeira River (southern Amazon) the ENSO signal is opposite to the signal found in north-eastern Amazon.

[Richey et al. \(1989\)](#), [Marengo \(1995\)](#) and [Marengo et al. \(1998\)](#) point out that the Solimões River discharge in Manacapuru and the Rio Negro in Manaus do not exhibit any significant trend during the twentieth century but they note that discharge increases at the end of the sixties. This feature is also noted by [Callède et al. \(2004, 2008\)](#) in the Amazon River in Óbidos; they find a break in the mean, maximum and minimum discharge times series at the beginning of the 1970s, with higher values after that date. Afterwards, mean and maximum discharge remain high until the beginning of the XXI century while minimum discharge decreases since the mid-1970s. Consistently, [Genta et al. \(1998\)](#), [García and Vargas \(1998\)](#), [Collischonn et al. \(2001\)](#), [García and Mechoso \(2005\)](#) and [Krepper et al. \(2008\)](#) all find an increasing trend since the early 1970s in the La Plata Basin discharge. At a regional scale, [Rocha et al. \(1989\)](#) highlight that rainfall and discharge in the Madeira, the Solimões and the Negro rivers increase during the 1960s and the early 1970s, but the records return to the long-term average values in the late 1970s and 1980s (except in the Madeira River). [Espinoza et al. \(2006\)](#) support a significant diminishing trend in the Peruvian Amazon (at Tamshiyacu station, near to Iquitos) for the 1970–2005 period, especially in the low-flow discharge series.

Analyzing Óbidos discharge long time series, [Labat et al. \(2004, 2005\)](#) highlight low-flow interdecadal processes (15.5 years) and high-flow bidecadal variability that can be related to the northern Tropical Atlantic and Pacific variability (low-flow) and the Southern Tropical Atlantic variability (high-flow). [García and Mechoso \(2005\)](#) find a 9-year period in the Paraguay–Paraná River and a dominant quasi oscillation with a period of around 17 years in mean annual discharge in the Amazon at Óbidos, in the Tocantins and São Francisco Rivers. In the southern part of South America, [Pasquini and Depetris \(2007\)](#) find a quasi-decadal variability in the tributaries of the La Plata River, in the Patagonia's Colorado River and quasibidecadal periodicities in discharge of La Plata, Colorado and Santa Cruz Rivers. [Robertson and Mechoso \(2000\)](#) attribute the quasi-bidecadal variability to the 17-year cycle of the South American Monsoon System.

In conclusion, most authors mention the possible links between long-term discharge variability and climate variability. They generally deny the role of deforestation on the 1970 change, described for instance by [Callède et al. \(2004\)](#) or [Baines and Folland \(2007\)](#), as it occurred when deforestation was just beginning in southern Amazonia.

Data and methods

Daily water level data are compiled and their quality is checked by the national institutions in charge of hydrological monitoring in the different countries of the Amazon Basin: Agência Nacional de Águas (Water National Office – ANA, Brazil) and Servicio Nacional de Meteorología e Hidrología (National Meteorology

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