RAINFALL REGIONALIZATION ON THE AMAZON BASIN

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1. INTRODUCTION

The Amazon Basin (AB) is dominated by tropical rainforest and is considered as one of the major continental region of active convection. The convection over the AB is modulated by various physical processes and circulation features in different space-time scales.

The rainfall over Amazon shows a clear seasonal modulation (Rao and Hada, 1990) with maximum values in the summer season due to the moisture availability provided by the monsoonal circulation (Zhou and Lau, 1998), but one of the problems in studing the rainfall variability is the scarcity of rainfall data with long record over the AB, and by this fact the spatial and temporal pattern of rainfall at different scales is poorly known. Nevertheless some studies reveal that the inter-annual rainfall variability over the AB is strongly related to the ENOS phenomenon (e. g. Marengo, 1992) and to the SST of both the tropical Pacific and Atlantic (Liebmann and Marengo, 2001), and the long term variability appears linked to the quasi-decadal oscillation "like –ENOS" related to the Pacific Decadal Oscillation.

The lack of rainfall data over AB associated with its continental characteristics restrict the study of the rainfall variability in representative limited areas, such as the north or south Amazonia (e. g. Marengo, 2004,) or the southern region (Li and Fu, 2004.), without to take in account the regional characteristics, which can result in biased analyses for rainfall variability over the AB.

The present study is motivated by two scientific issues. One pertains to the rainfall spatial regionalization, based on gridded daily rainfall data for the period of 1979 to 1993, and the other to the study the time-scales variability of indices representative of each region.

2. MATERIALS AND METHODS

The base of this study is the gridded daily rainfall data for Amazon Basin (2^o X 2^o degrees) for 15 years (1979-1993). The rainfall regionalization was carried out by the "K-means" method of cluster analysis, and the average daily rainfall from each region is denominated rainfall regional index (RRI). The wavelet analysis (Torrence and Compo, 1998) were calculated for each RRI to find the intra-seasonal variability, and Empirical Mode Decomposition (EMD), developed by Huang et al. (1998), are applied to monthly time series of RRI to determine the different inter-annual oscillatory modes of regional rainfall.

3. RESULTS AND DISCUSSION

3.1 Rainfall regionalization

The rainfall cluster analysis over the Amazon Basin revel five homogeneous regions (Fig. 1). These regions are distributed mainly in the NW-SE direction, two are located at northwestern Amazonia (R1) and around the Amazon River Mouth (R2), and the other three regions are distributed from the western Amazonia (R3), followed by the southwest and part of the central Amazonia (R4), to the southeastern Amazonia (R5). The Fig. 1 shows the result of the harmonic analysis of the average of the total monthly RRI. The amplitude (explained variance standardized all amplitudes) and the phase of the annual and semi-annual harmonic cycle easily can be used to see that the main feature of the rainfall cluster is the seasonality, with strong annual cycle and very weak semi-annual cycle, with exception of the R1 where these values reach up to 14%. The phase of the annual (semi-annual) cycle indicates that the maximum rainfall in the R1 occurs in April (September), in the R2 in February (July), in R3 in February (June), in R4 in January (June) and in R5 in January (June). Besides the differentiated phase behavior of the annual and semi-annual harmonic over the different regions, it is appropriated to carry out an analysis of the explained variance average and variability for each harmonic component and region to clarify the difference between them, related to the rainfall seasonality.

The mean explained variance of the three first harmonics for each region (Fig 2a) and their coefficient of variability (Fig. 2b) yield an accentuate difference between the regions. The annual cycle is stronger in R5 and R4 followed by R2, and in R1 and R3 it is weak. The semi-annual cycle is strongest in R1 (11%) than in the others regions, and the third harmonic is almost insignificant in all of them. On the other hand, the coefficient of variability of the first harmonic shows that in R5, R3 and R2 the amplitude values are more similar than in R1 and R2. This fact means, besides that the annual cycle are strong in R5, R4 and R3, they are homogeneous.

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The coefficient of variability of the amplitudes of the second and third harmonic show higher values than the first harmonic, which is probably a result of the strong intra-seasonal variability inside each region. Hence, the spatial distribution of the amplitudes and phase of the first two harmonics (Fig. 1), and their temporal variability (Fig. 2) seems to confirm that the five regions have intrinsic characteristics, at least of intra-seasonal time scales.

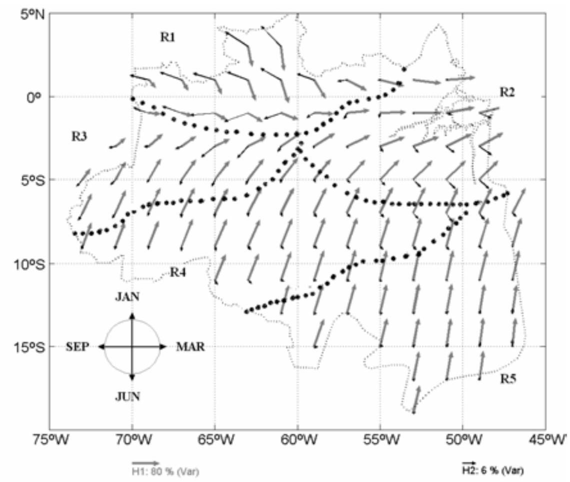

Figure 1: Amplitudes (explained variance in %) and phase (month) of the first (annual) and second (semi-annual) harmonic of the monthly average rainfall over the Amazon Basin. Annul (semi-annual) amplitude scales are indicated at left (right) bottom.

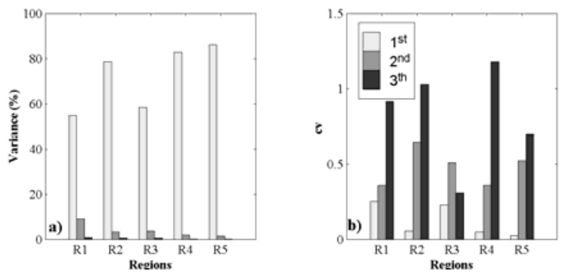

Figure 2: Regional average of the explained variance a) and the coefficient of variability b), of the first three harmonics of the monthly rainfall over the Amazon Basin.

3.2 Regional intra-seasonal rainfall variability

Fig. 3 displays the probability of density function (PDF) of the standardized RRI for the five regions. It was estimated by the normal non parametric kernel method. It provides a closer look of the daily rainfall intensities distribution for the 15 years, and obviously the main feature is the almost Gaussian distribution in R1 and R3, skewed distribution in R2 and R4, and the bi-modal distribution with two strong peaks in R5. These findings appear to distinguish four regimes, but as it was indicated before, the phases and amplitudes of the first three harmonics of R1 and R3 are different, hence there are five distinguished regions. The strong bi-modal regime (R5) is related to the strong annual cycle with long period of dry rainfall season, while the almost Gaussian distribution (R3 and R1) seems to be related to rainy region where the annual cycle is weak and the dry rainfall season is short if it exists.

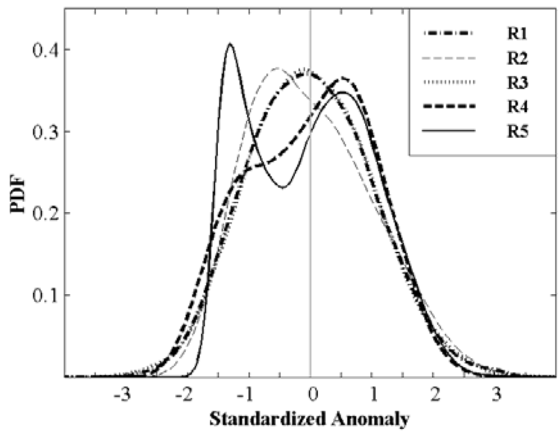

Figure 3 Probability of distribution function (PDF) of standardized daily rainfall index for each region.

The intra-seasonal regional rainfall variability is presented by the annual composite of wavelet power distribution obtained averaging the wavelet power of 15 years of RRI (Fig. 4). At intra-seasonal variability the rainfall over the different regions of Amazon Basin are largely controlled by the intra-seasonal oscillation occurring mainly during the rainy season of each region, with exception of R4, where the intra-seasonal oscillation is strong at the end of the dry season and beginning of the rainy season. Analysis of the association between periods of oscillation and rainfall regions reveals a rather complete differentiated pattern. In R1 and R2 the periods of 30-60 days are dominating from October to March, and in R3 there is a hint of bimonthly oscillation occurring between January and March. On the other hand, in R5 the intra-seasonal rainfall variability are modulated by two periods of oscillation with intense peaks, one of 20-30 days and another of 45-75 days, and both periods of oscillation occur between October and March.

The PDF distribution and the average wavelet power of the RRI display a large degree of intra-seasonal variability over a range of oscillations in timescales well known, even though this variability appears intrinsic at each region.

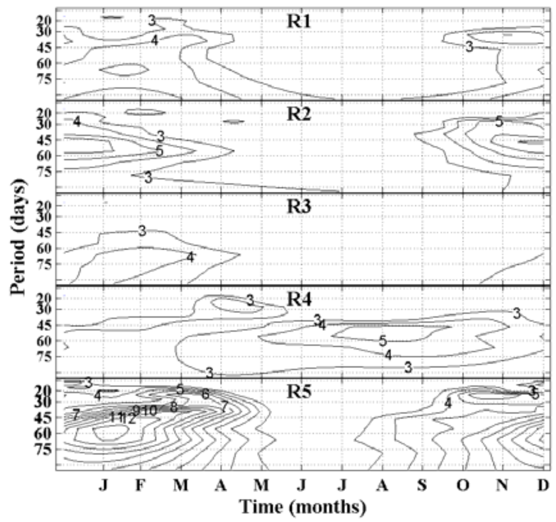

Figure 4 Average Wavelet Power of the daily rainfall index (1979-1993) for the five rainfall regions of Amazon Basin.

3.3 Regional inter-annual rainfall variability

The distribution of the total annual rainfall for each region of Amazon Basin (Fig. 5), calculated from the RRI, shows a weak interannual variability and the intensities range from 1600-2000 mm/year (R5) to 2500-3000 mm/year (R3). The interannual rainfall distribution in the regions do not have the same pattern, but in some years some of them appears to follow the same tendency, such as in 1983, 1987, 1992, when there was a rainfall decreasing over almost all the Amazon Basin associated with the ENOS phenomenon, and the reverse occur during the anti ENOS years 1985 and 1989.

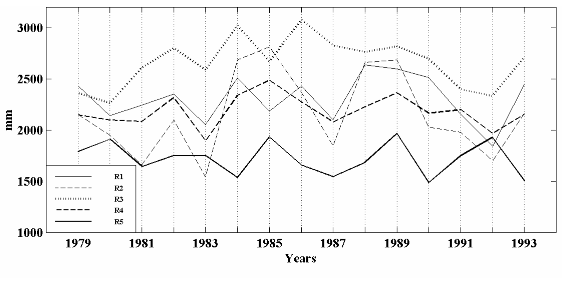

Figure 5 Distribution of the total annual rainfall, calculated from the daily rainfall index (1979-1993) for the five rainfall regions of Amazon Basin.

Analysis of oscillatory modes of the EMD applied to the monthly times series of the RRI show that, besides the intra-seasonal oscillation, the oscillatory inter-annual modes at scales of 2-3 year and 4-6 years, and the lower mode (trend) are relevant. These inter-annual timescales are commonly associated to the ENOS (Barnett, 1991), and the trend can be analyzed as a non linear. Inter-annual oscillations with period of 2-3 years are intense before 1985 mainly for R2 and R5, which are nearly in phase, and then the intensity of all them are similar and out of phase (Fig. 6). The oscillation mode of 4-6 years has opposite patterns than the observed in the quasi-biennial oscillation, with intense amplitudes after 1985, and flat amplitudes before that. The R2 does not have any oscillation with this period. Additionally, the lower oscillatory modes are different, and in the R1, R3 and R5 it shows positive trend, while in R2 it has negative trend and the R4 appears to be nearly stationary.

Thus, the R1 and R5 seems to be strongly modulated by the ENOS phenomenon at quasi-biennial scales (2-3) and weak on 4-6 years scales before 1985, and it is inverse after that, and the rainfall in the others regions appears weakly modulated by the ENOS.

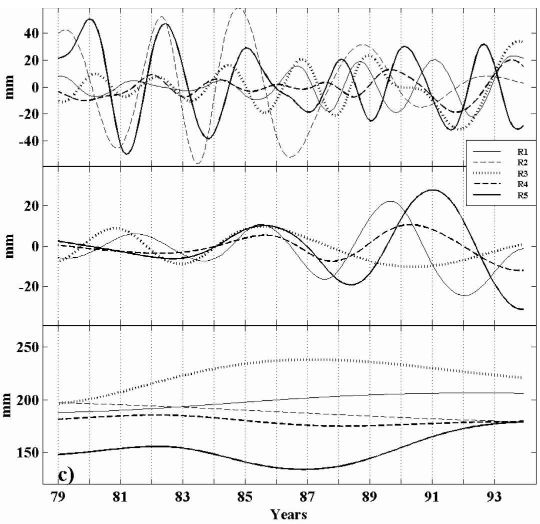

Figure 6 Distribution of the inter-annual oscillatory EMD modes of the monthly rainfall index for the five Amazon rainfall regions. 2-3 years oscillation (Top), 4-6 years (Middle), and trend (Bottom).

4. CONCLUSION

This study confirms that the spatial rainfall Amazon Basin can be clustered in five regions, distributed mainly in the NW-SE direction, with peculiar characteristics of annual rainfall cycle and their related daily PDF. The intra-seasonal variability based on wavelet analysis reveals that each region has typical oscillations with different period and intensities.

A key distinction of rainfall variability among these regions at inter-annual scales is observed analyzing the inter-annual oscillatory modes of EMD. The relevant modes are the inter-annual mode with periods of 2-3 year (quasi-biennial) and 4-6 year, and the slowest mode or trend. These inter-annual oscillation modes are quite different in each region and probably they are related to the both ENOS mode, the high and the slower frequency. The quasi-biannual oscillation is strong around the Amazon River mouth (R2) and in the southern (R5) region before 1985. On the other hand, the oscillation of 4-6 years is intense in the northwestern region (R1), southwest region (R4) and in the southern region (R5) after 1985. Also, this study shows that, besides the record is restricted to 15 years, the complex rainfall over Amazon can be clustered regionally and studies of rainfall variability would be improved instead of a simple north-south or east-west regions.

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