

Rainfall Variability at Regional and Local Scales in the Ouémé Upper Valley in Bénin

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Abstract— In West Africa, many climatic simulations show that significant changes to deal with will be exacerbation of climatic extremes (droughts, floods etc.). In the case of the Ouémé Upper Valley region where agricultural activities are essentially dependent on precipitations, it's important to analyze impacts of climate fluctuations on the rainfall pattern. Two spatial scales have been considered to access the rainfall pattern variability in that region: especially the regional one and the local one. A seasonal rainfall analysis has been made with observed or regionalized daily rainfall data for 1950-2005 period. Dry and wet composite analysis of the rainfall signal shows that the pluviometric shortage of dry years is amplified after the “monsoon onset”. On the same way, dry years are characterized by early monsoon withdrawal which might have started since 1970. Furthermore, the years after 1970 show a shift lag in rainfall. The length of these lags depends on spatial scale. Rainfall maximum are earlier observed. The early monsoon withdrawal and the shift lag in rainfall revealed should have several consequences on agricultural production, especially on some crops yield.

Keywords- *monsoon; variability; seasonal cycle; rainfall*

I. INTRODUCTION

Several studies of rainfall variability in West Africa [5; 6; 8; 10] have shown, at this spatial scale, that rainfall is characterized by high inter-annual variability combined with a decadal signal. But some concerns remain, as to the characteristics of rainfall and the seasonal cycle of

precipitations in areas of only a few square kilometers and locally. This study therefore proposes to revisit the variability of rainfall in the Hydrometeorological Observatory of the Upper Ouémé Valley (Observatoire Hydrométéorologique de la Haute Vallée de l'Ouémé: OHHVO) which covers an area of approximately 15,000 km². The region's climate is Sudanian type with a rainy season from mid-March to late October and a cumulative annual average of 1200 mm over the period 1954 to 2005 [4; 7].

This study focuses on the rainfall variability analysis at regional and local scales and compares the results of both scales in order to highlight the issues of scale to consider when dealing with rainfall variability in a given region. First, the inter-annual variability of rainfall is analyzed. Then, changes in the seasonal cycle of precipitations using both spatial scales considered are studied. Periods before and after 1970 are distinguished.

II. MATERIAL AND METHODS

A. Study area and data

The area of interest is the upper valley of Ouémé river called “Observatoire Hydrométéorologique de la Haute Vallée de l'Ouémé: OHHVO”. It's located in Benin Republic (West Africa) between 9° N and 10° N latitude and 1.5°E et 2.8°E longitude (Fig. 1 left). Daily rainfall data over the years 1954 to

2005 are provided by twelve rain gauges selected from the operational network of the National Weather Service (Service National de la Météorologie, SNM), (Fig. 1 right). Those data are used to compute the spatial average rainfall of the study area. For the local rainfall variability analysis, two rain gauges are selected: Parakou at the eastern part of the study area and Djougou at West (Fig. 1 left).

Where $Z(x_i)$ and $Z(x_i + h)$ represented the values of the random variable Z at the stations x_i and $x_i + h$ respectively and $N(h)$ is the number of pairs of stations at the inter-distance h .

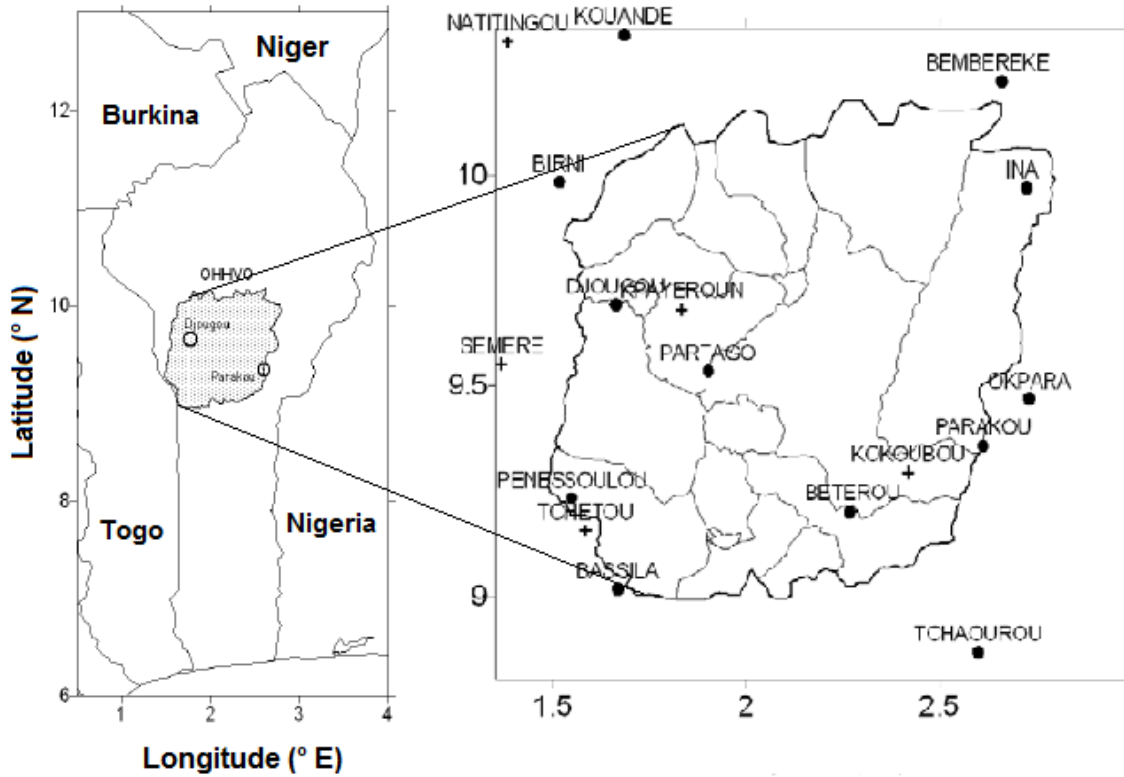


Fig. 1 Localization of the study area (left) and the synoptic rain gauge network of the SNM (right). The black dots indicate the rain gauges used.

B. Data analysis

From punctual daily rainfall series, spatial daily averages are calculated using kriging method [1; 3; 9]. The first step in computing these spatial averages is to build the spatial structure of precipitation by the semi-variogram, simply called variogram. For a given random variable Z , let x_i and $x_i + h$ two stations separated by the inter-distance h in a two-dimensional space. The variogram is estimated by (1)

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i + h) - Z(x_i)]^2 \quad (1)$$

The variogram was calculated for each day of the period and the spatial structure of daily rainfall was modeled by a climatological variogram (2).

$$\gamma(h) = C_0 + (C - C_0) \left[1 - \exp\left(\frac{-h}{\alpha}\right) \right] \quad (2)$$

With $C_0 = 0.3$; $C = 1.11$ and $\alpha = 25$ Km, respectively the nugget, the sill and the length parameters of the variogram.

The next step is the estimation by interpolation of daily rainfall values at grid point on the field of study. But, in any interpolation method, the value of Z at x_0 is given by a weighted sum of the observed values $Z(x_i)$ (3).

$$Z^*(x_0) = \sum_{i=1}^M \lambda_i Z(x_i) \quad (3)$$

With M , the total number of observed values and λ_i the weight or weighting factor for the observation Z at x_i . In the kriging method, λ_i are determined by solving (4) from the fact that kriging is unbiased and optimal (minimum estimation variance).

$$\begin{cases} \sum_{j=1}^M \lambda_j \gamma(x_i, x_j) + \mu = \gamma(x_0, x_i) & ; \quad i = 1, 2, 3, \dots, M \\ \sum_{j=1}^M \lambda_j = 1 \end{cases} \quad (4)$$

Where μ is the Lagrange multiplier [9] and $\gamma(x_i, x_j)$, the variogram value between two points x_i and x_j .

Finally, the spatial average daily rainfall for the entire region is determined as the statistical average of all grid points located inside the contour which is delimited.

since it is relatively low. However, it can discriminate well dry and wet years. The standardized precipitation index also allows analysis of the interannual variability of rainfall at the considered spatial scales.

To further analyze the variability of rainfall, we have implemented the methodology proposed by Le Lay and Galle [7] by re-sampling each rainfall series into four composites: P2H and P1H, respectively, the seven wettest years of the periods 1954 - 1969 and 1970 - 2005; P1S and P2S respectively the seven driest years of the periods from 1954 up to 1969 and from 1970 to 2005. The number seven is a limiting factor from the period 1954 to 1969.

III. RESULTS AND DISCUSSION

A. Interannual Variability

The regional rainfall is characterized by strong interannual fluctuation combined with a decadal variability (Fig. 2). However, a particularly dry period (1970 - 1987) and two wet

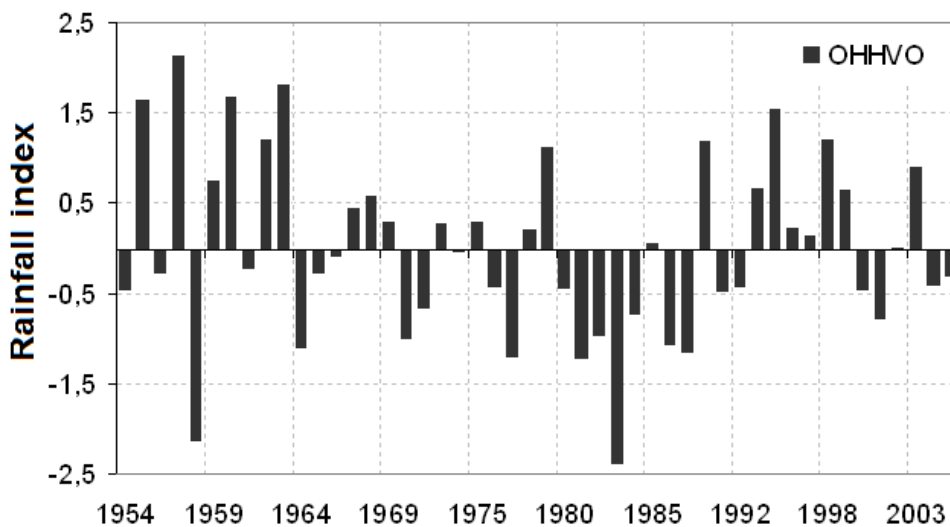


Fig. 2 Variability of regional rainfall (1954 to 2005)

Variability of the seasonal cycle is analyzed using moving averages over a window of 11 days. Once averages are determined daily, the annual rainfall of the region is obtained by summing the daily averages. Discrimination of wet year and dry years is then made through the standardized rainfall index: $I(i) = (P(i) - \bar{P}) / \sigma$, with $P(i)$, the annual average obtained by kriging on the study area for year i , \bar{P} and σ respectively the mean and standard deviation of the considered series. Thus, one year will be considered as normal if its index is between -0.1 and +0.1. It will be wet if its index is greater than +0.1 and dry below -0.1. This interval is questionable

periods (1954 - 1969 and 1988 - 1999) are observed. The 2000s seem to be the beginning of a dry phase because since 2000, except the year 2003 which is wet, the others are dry. But, when integrating the rainfall signal since 1990 it is observed that the period after 1990 is generally wetter than the period from 1970 to 1989.

At local scale, the rainfall is also characterized by strong interannual fluctuation (Fig. 3) which seems to have similar dynamic as at the regional. However, some particularities mark the difference between local and regional scales. Indeed, a wet year at the regional scale can be dry at the local level and vice

versa. For example, as one can see in Figure 3, during the last two decades, the year 1984 is dry at regional scale. But, at local scale, year 1984 is wet at Parakou (if a threshold of significance of ± 0.5 is considered). Furthermore, season 1997 moderately wet on the OHHVO is very dry at Parakou. Similarly, seasons 1959, 1973, 1996 and 1997, that are wet at the regional scale are dry at Djougou while seasons 2004 and 2005 that are dry at the study region scale are wet locally at Djougou.

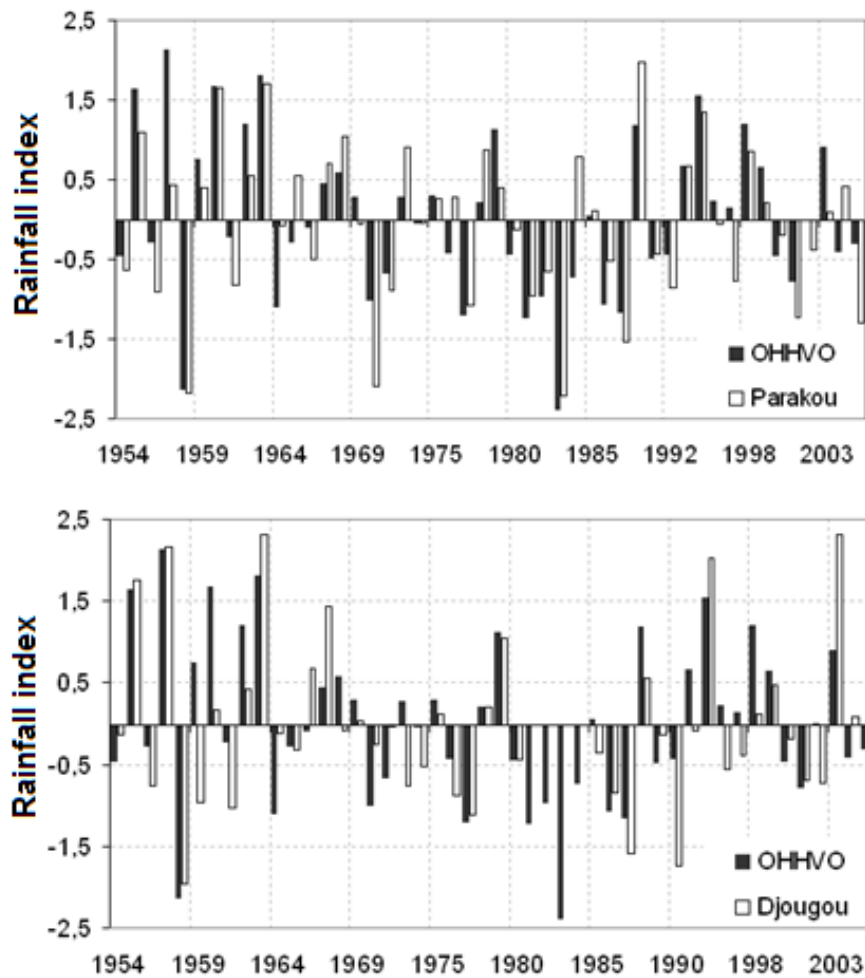


Fig. 3 Interannual variability of rainfall: comparison between regional and local scales for Parakou (top) and Djougou (bottom).

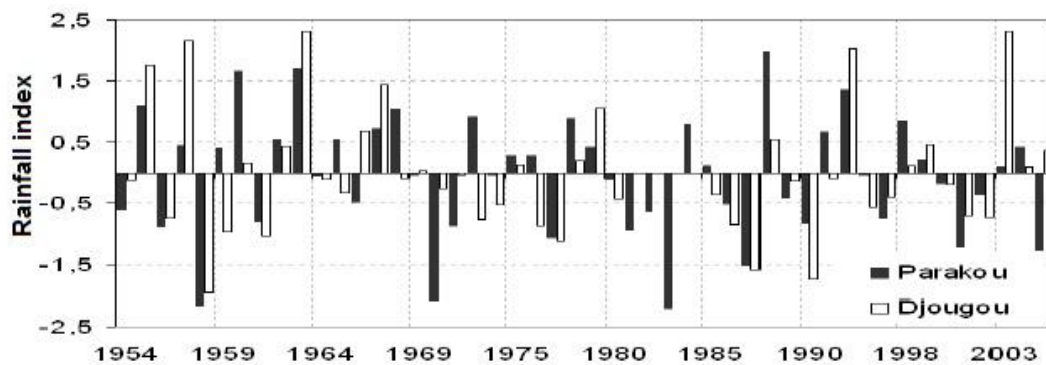


Fig. 4 Rainfall interannual variability at local scale for two rain stations (Parakou and Djougou).

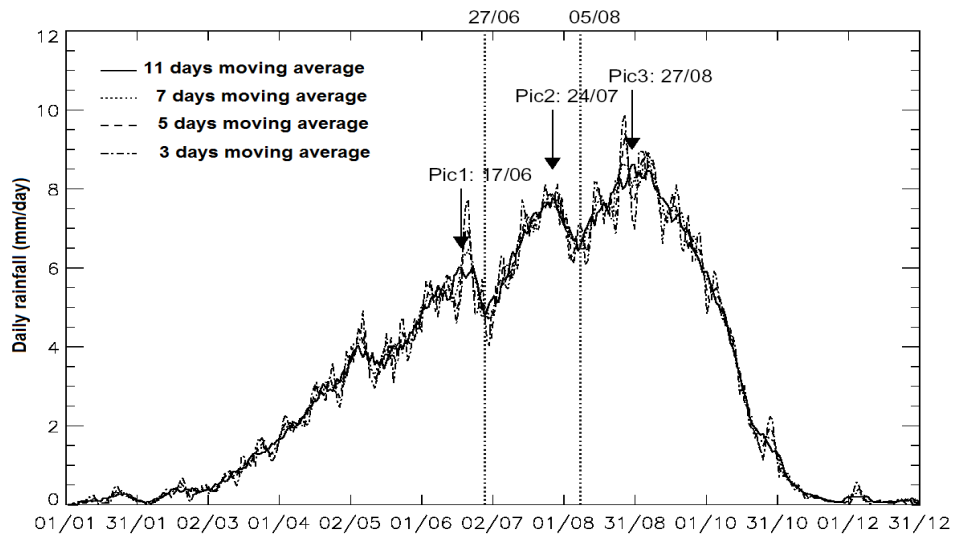


Fig. 5 Rainfall seasonal cycle on the OHHVO from 1954 to 2005 for four moving average: Pic1, Pic2 and Pic3 are the three precipitation peaks.

These observations highlight the issues of scale and sampling to be considered in quantifying the variability of rainfall in a given region. Even at the local level only, the comparison between two localities shows that significant differences may appear. Indeed, Fig. 4 compares rainfall variability at Parakou and Djougou, and it is noticed that in 1990 (dry year at regional scale), the deficit is 8% at Parakou while it is 29% at Djougou. However, in 2003 (wet at the region scale), the excess is only 2% at Parakou against 39% at Djougou.

B. Rainfall seasonal cycle variability

At the intra-seasonal scale the rainfall distribution (Fig. 5), match up the results of le Lay and Galle [7] over the period 1954 to 2002 and confirms that precipitation settled on the

region from March and retire in late October with three peaks. The first peak occurs late May. The second precipitation increasing starts in late June (June 27) and corresponds to what has been described as the monsoon "onset" [11]. The precipitation maximum (Pic3) is reached late in August (August 27).

Analysis of the seasonal cycle modifications between dry and wet years on the period 1954 - 2005 shows that wet years dynamic seems to be the same as dry years (Fig. 6). However, the difference is that dry years are characterized by: i) a marked lack of rainfall especially in the second phase of the monsoon (after the monsoon onset) where it reaches 25% at the maximum of precipitation and ii) an early withdrawal of the monsoon.

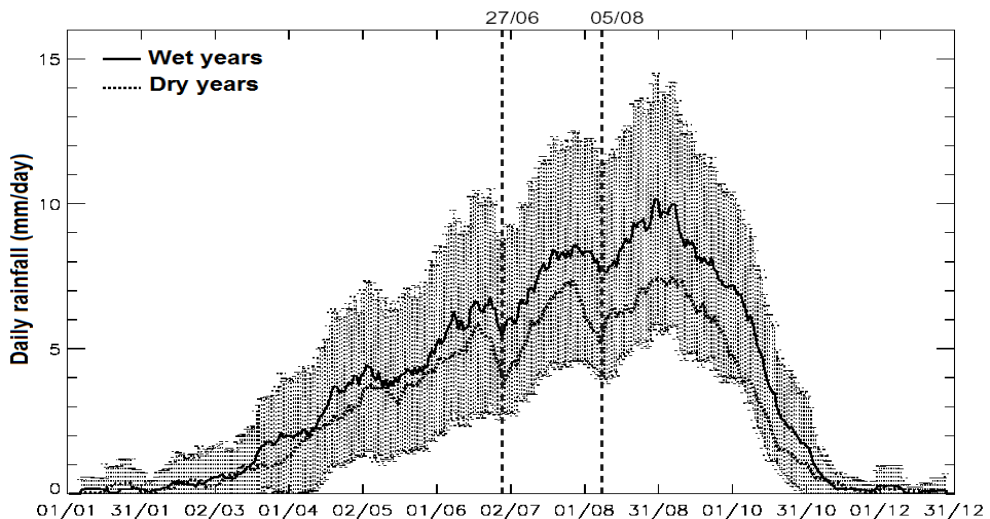


Fig. 6 Comparison seasonal cycle for dry and wet years of the period 1954 to 2005. Averages are calculated on moving window of 11 days. Dashed vertical bars represent standard deviations of wet years.

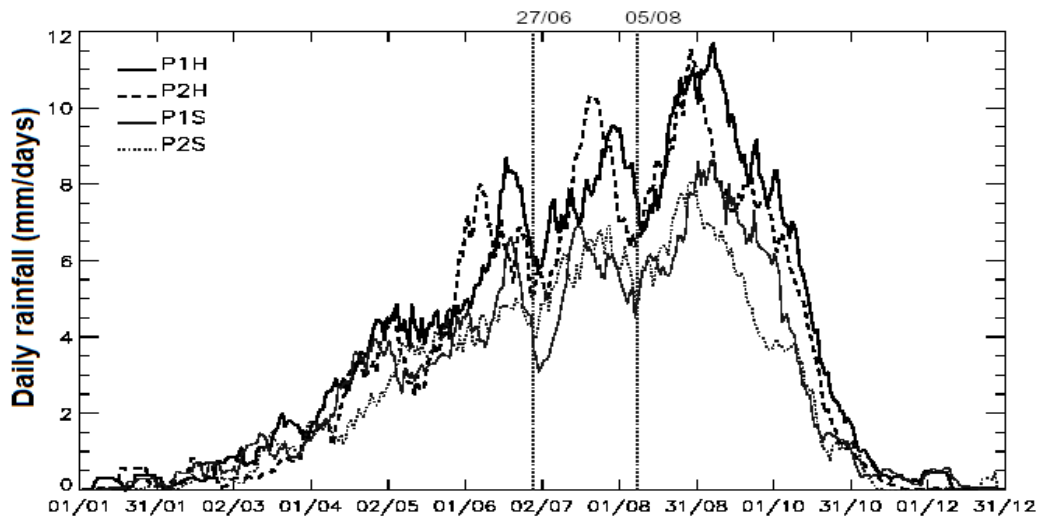


Fig. 7 Rainfall seasonal cycle for wet composite (P1H: before 1970 and P2H: after 1970) and dry years (P1S: before 1970)

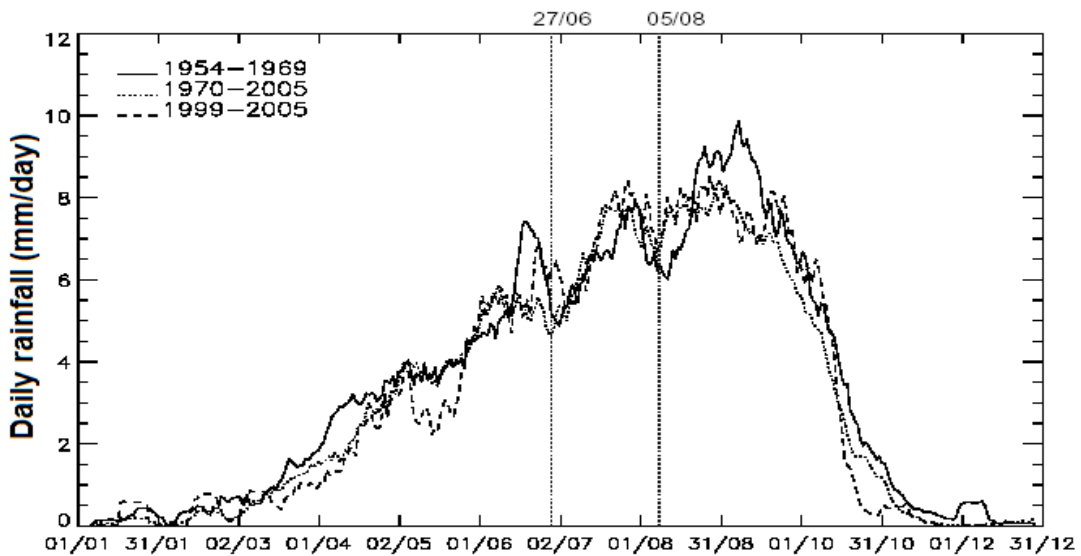


Fig. 8 Rainfall seasonal cycle variability for periods before and after 1970 on OHHVO.

This phenomenon has been reported further north for rainfall in the Sahel region by Balme [2] who analyzed the interannual variability of sahelian rainfall over the years 1950 to 1990 and showed that dry seasons are characterized by a marked deficiency in the heart of the season and a more rapid withdrawal of the monsoon.

The decomposition of the rainfall signal into four composites helped to highlight some changes in the seasonal cycle (Fig. 7). It shows that:

- For wet composite (and P2H P1H), the first peak of precipitation is shifted 9 days and is reached earlier in

the period after 1970 (June 08 instead of June 17). The second and the third precipitation peaks are also

- achieved about 10 days early in the period after 1970. Thus, the third peak is reached on August 25 instead of September 4;
- For dry composites (P1S and P2S), the date of the first peak is the same but with a significant decrease of the peak of the composite P2S. The second and third peak of precipitation are systematically shifted by about 8 days between P1S and P2S;

- Withdrawal of the monsoon is from early 1970, and appears to be ongoing over the last decade as shown in Fig. 8 for either composite wet or dry. But this early withdrawal is more pronounced for the dry composite than the wet;
- Installation of the rainy season is late after 1970, especially for wet years. This tends to shorten the rainy season, since there is also early withdrawal of the monsoon in late season.

Thus, the regional rainfall pattern is characterized by a late “onset”, a shift of the maximum precipitation that is reached early and early withdrawal of rainfall in the period after 1970.

At local scale, similar changes to those observed at the regional scale are shown in Fig. 9 to Fig. 11 for Parakou and Djougou. Fig. 9 shows for Parakou that, the first peak of precipitation is less pronounced for the period after 1970 (it has a deficit of about 30%). The last two peaks of precipitation are shifted and reached earlier. Similarly to the regional scale, the

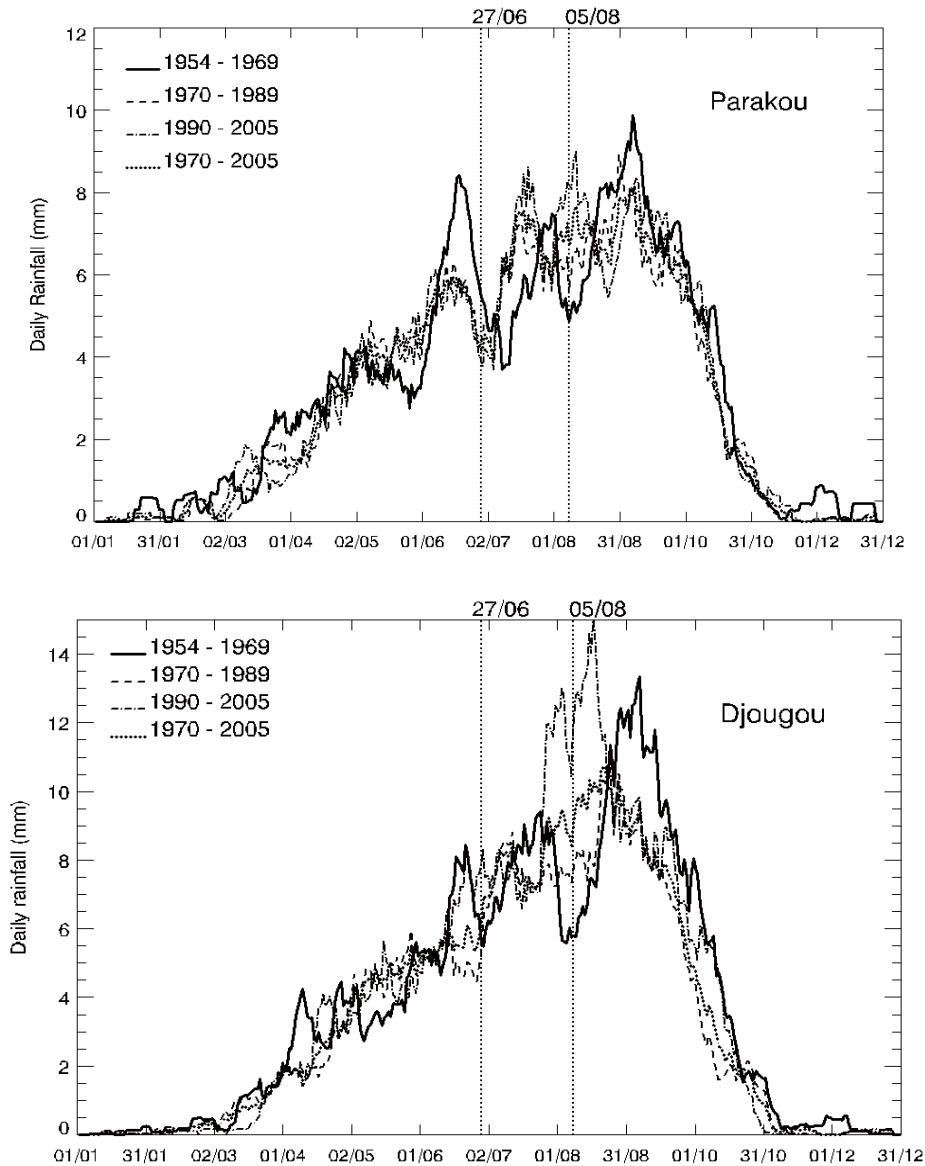


Fig. 9 Changes of the rainfall seasonal cycle at local scale between years before and after 1970 at Parakou (Top) and Djougou (bottom)

sharp fall in rainfall over the period after 1970 is marked. At Djougou, the maximum precipitation appears to be more strengthened over the period 1990 - 2005 but is reached earlier 20 days compared with the period 1954 to 1960.

Fig. 10 and Fig. 11 confirm that both at regional and local scales, dry seasons composite differs from that of wet seasons by a deficit that is well marked after the monsoon onset (Fig. 10) combined with a shift of the precipitation peak at Djougou

for dry seasons. Similarly, the earlier withdrawal of rainfall during the years after 1970 is more pronounced for dry seasons (Fig. 11). Fig. 11 also shows a shift of about 12 days of rainfall peak for the wet composite P2H and a deficit of about 8% of the maximum precipitation of the composite P2H compared to the composite P1H at Parakou. At Djougou station, this shift is slightly reduced to 10 days, with a higher deficit of 20% of the precipitation peak for the composite P2H compared to P1H.

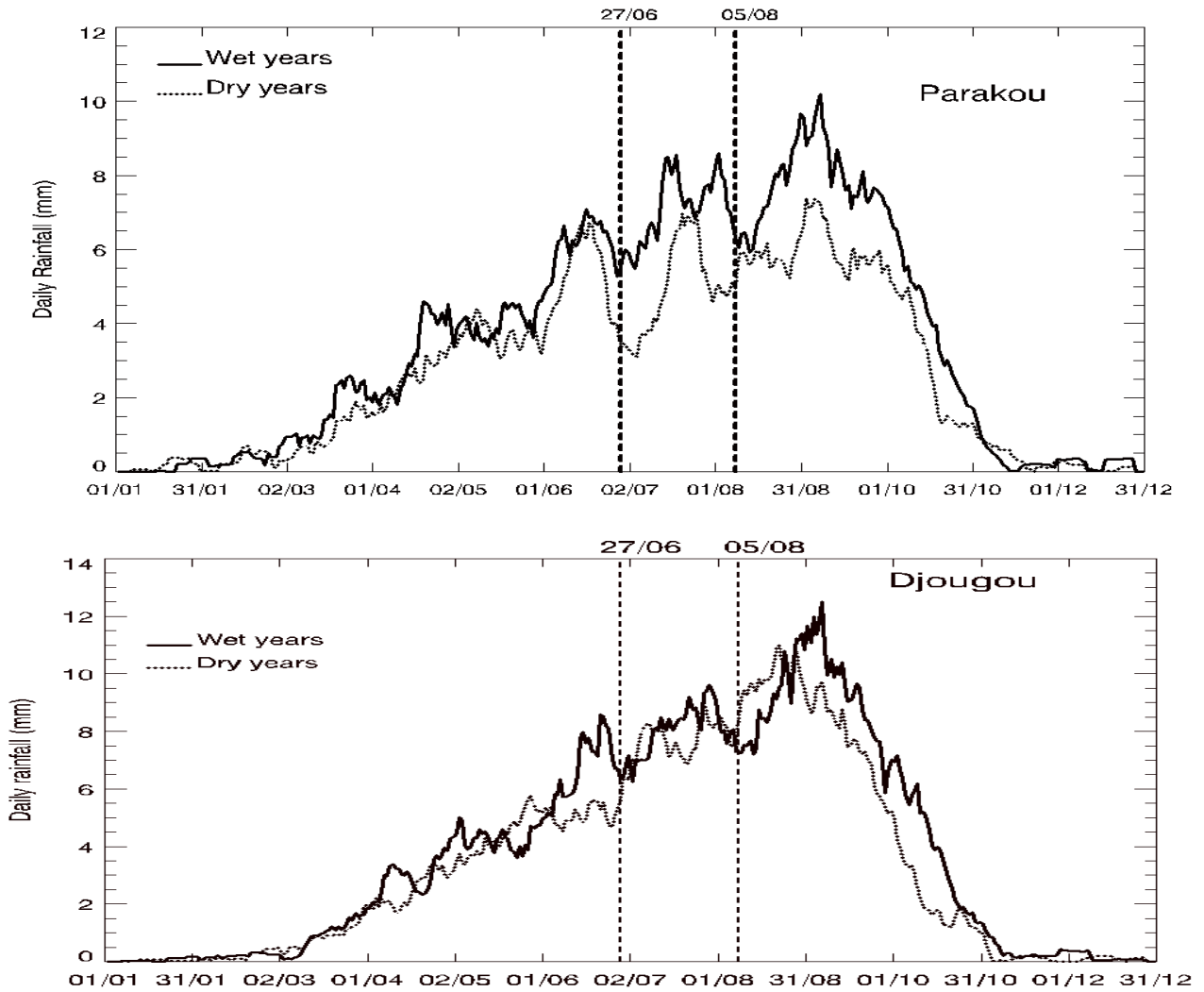


Fig. 10 Dynamic of the rainfall seasonal cycle at local scale for wet and dry years at Parakou (top) and Djougou (Bottom)

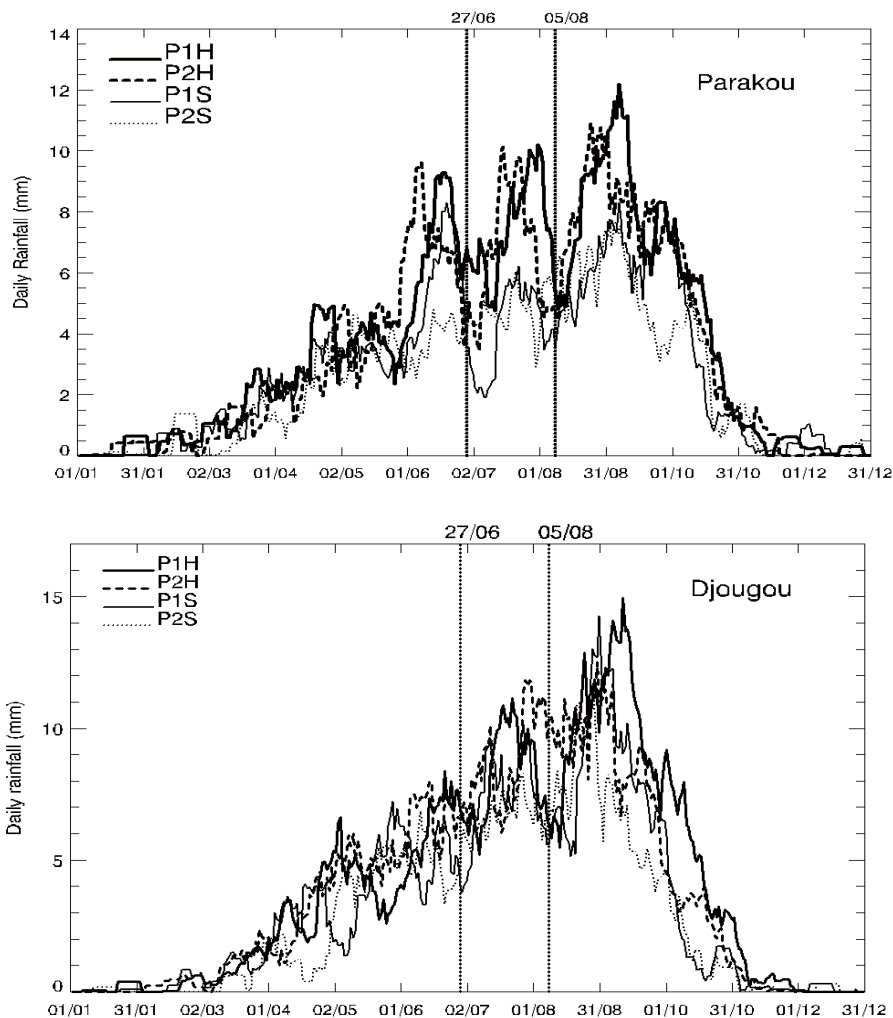


Fig. 11 Variability of the seven wettest years and the seven driest years before and after 1970 at Parakou (top) and Djougou (bottom)

IV. CONCLUSION

This paper used historical daily rainfall data of the upper valley of Ouémé to analyze the variability of rainfall at the regional and local scale. It shows that the rainfall is characterized by high interannual variability superimposed on decadal variability both regionally and locally. At these two spatial scales, the average seasonal cycle is characterized by late onset and earlier withdrawal of rainfall with consequence of reducing the duration of the rainy season. Furthermore, there is a shift of precipitation peaks which are reached earlier for the period after 1970 that is also marked by an increased in the frequency of dry years. The length of the shift of precipitation peak depends on the considered spatial scale. These results are comparable to those shown on sahelian rainfall by others authors.

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