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DOMINANT MODES OF VARIABILITY OF RAINFALL OVER CÔTE D'IVOIRE DURING 1901-2010 PERIOD

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ABSTRACT

This study focuses on the variability of rainfall over Cote d'Ivoire (CI) during the last century (1901-2010). It aims to determine the dominant modes of variability of rainfall across the country in the context of climate change and its associated increasing rate of flooding observed during these last years. The three first dominant modes of variability count for more than 70 % of the total signal. The first dominant mode showed strong variability in entire country while the second and third dominant modes are characterized by strong variability respectively in the western part and northern part of the country while the southern part and the coastal area undergo weak variabilities. The highest variability is observed in the West where relief and vegetation are dominated by mountains and trees. These high variabilities occur at frequencies ranging from 2 years to 10 years. This study may be useful in adaptation and resilience policy regarding climate stresses and we recommend strategies taking in account the erratic nature of rainfall in CI.

Keywords : *Côte d'Ivoire, West Africa, precipitation, mode of variability, wavelet, frequency.*

RÉSUMÉ

Les modes dominants de la variabilité des précipitations en Côte d'Ivoire pendant la période 1901-2010

Cette étude s'intéresse à la variabilité des précipitations en Côte d'Ivoire (CI) pendant ce dernier siècle à partir des données grillées GPCPv7 (Global Precipitation and Climate Centre). La question principale est de déterminer les modes qui dominent la variabilité des précipitations dans cette région dans cette dynamique du changement climatique et le nombre croissant d'inondations observé dans ce pays durant ces dernières années. Cette étude a montré que les trois premiers modes dominants la variabilité des précipitations représentent plus de 70 % de la variabilité du signal total. Le premier mode montre une forte variabilité sur tout le pays tandis que le second et le troisième mode sont caractérisés respectivement par une forte variabilité dans l'Ouest et le Nord du pays. La région du Sud et le littoral montre une faible variabilité. En général, la forte variabilité est observée à l'Ouest ou le relief et la végétation sont caractérisés respectivement par les hauts plateaux et la forêt. Ces fortes variabilités sont observées à des fréquences de 2 à 10 ans. Ce résultat peut être d'une grande utilité dans les politiques d'adaptations au changement climatique en CI durant ces dernières années et nous recommandons des stratégies qui prennent en compte la tendance à la baisse et la nature aléatoire des pluies dans ce pays.

Mots-clés : *Côte d'Ivoire, Afrique de l'Ouest, précipitation, mode de variabilité, Ondelettes, fréquence.*

I - INTRODUCTION

Cote d'Ivoire (CI) is located in the southern West Africa at 8°N, 5°W in the Sub-Saharan region ***(Figure 1)***. The Climate of Cote d'Ivoire (CI), west African country, is mainly warm and humid, alternating dry and wet seasons predominately linked to the West Africa Monsoon ([1, 2, 3]) Regarding the importance of the rains, several studies like [4, 5] focused on rainfall variability in the country and they underlined the existence of four seasons in the South while the northern part has two seasons.

Figure 1 : *Map of West Africa. Cote d'Ivoire is represented in the Gulf of Guinea with big blue dot showing the main city Abidjan*

The southern part of the country ***(Figure 2)***, located in the Gulf of Guinea of Cote d'Ivoire, records the highest amount of rainfall (1800mm/year). It is characterized by 4 seasons: a long (main) dry season from December to March, a major rainy season from April to June with a peak in June, a little dry season during July and August and, a little rainy season from September to November ([6]). The Soudano-Guinean zone of the domain is a transitional area between the forest in the south and the Savannah in the northern zone ***(Figure 2)***. Like the southern area, the transitional zone has 4 seasons. A long dry season from November to march, a major rainy season from April to July and a small dry season during August and a little rainy season from September to October ([6]). In the most northern part ***(Figure 2)***, lays the Soudanian zone of the country. It has a climate modulated by a long dry season from November to June follows by a short rainy season (July to September) ([6]). The climate of the country appears so diverse and makes its description complicated. This motivates the use of a statistical analysis coupling at the same time the spatial and temporal scales, then justifying an empirical decomposition or mode variability analysis.

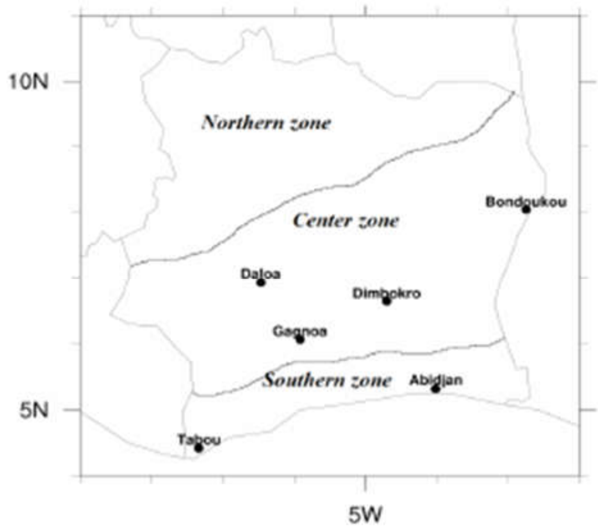


Figure 2 : *Climatic zones of Cote d'Ivoire* [7]

During these last years, strong variabilities of rainfall have been observed in many areas ([7, 8]). These variabilities are suggested to be linked to climate change through change in the availability of water vapor, increasing temperature and change in atmospheric circulation ([9]). Besides, flood events have been observed in many countries and also in CI as listed in [10]. However, studies looking at the modes of variability of rainfall and close to analysis of return period of the rainfall variability events have not been done yet for this country. This is what sustains this study which main objective is to investigate the different modes of variability of rainfall in CI from a long time series of GPCP rainfall covering 110 years from 1901 to 2010. The outline of the paper is as follow, the section 2 presents the materials used for this study. The results are presented and discussed respectively in the third and fourth sections from which the conclusion of the main results are given in the section 5.

II - MATERIAL AND METHODS

II-1. GPCP rainfall data

The Global Precipitation Climatology Project (GPCPv7) data set was established by several sources into a final unique merged product, taking advantage of the strengths of each data type ([11, 12]). These sources are measurements from ground stations and satellite data products. Many versions according to the time scale from daily to monthly are available. For this study, monthly data with 50 km horizontal resolution from January 1901 to December 2010 in version 2.3 are used.

II-2. Principal component analysis

The principal component analysis or empirical orthogonal function (EOF) is used to quantify the nonseasonal variability of rainfall and to identify the spatial and temporal patterns of variability ([13, 14]). The theory of EOF has been applied using the Climate Data Operators (CDO) software. The three first eigenvectors explaining the largest amount of variance or the leading mode of variability inside the dataset has been retained and spatially represented.

II-3. Wavelet analysis

A wavelet analysis is performed on the time series of each mode to determine the variability of the data and also to examine the processes which affect the variability of the rainfall in Cote d'Ivoire. Longer term trend of the data has been removed, allowing us to assume stationary of the data for the power spectra calculation. This wavelet analysis is a tool for analyzing localized variations of power within a time series. It is a decomposition of a time series into time-frequency space yielding to determine both the dominant modes of variability and how these modes vary in time ([15, 16]).

III - RESULTS

This study analyses the dominant modes of variability of the rainfall over CI using GPCP data. This study looks at the nonseasonal variability of the rainfall using the EOF analysis. The ***Figure 3*** shows the empirical orthogonal decomposition of the rainfall during the period 1901-2010. The three first highest modes (***Figure 3a***, ***Figure 3b***, ***Figure 3c***) of variability representing more than 70 % of the total signal are represented. The first, dominant mode ***(Figure 3a)*** shows strong variability in the West and South while weak variability is observed in the North. The maximum variability of the rainfall signal in the first mode occurs at most in the West in the area of mountains and it manifests by values of the order of 1.5mm. West of 6°W, the second dominant mode is characterized by strong variability around 2mm while, East of this position one has a negative values, a signature of weak variability of rainfall. The third highest mode is due to important and strong variability of rainfall in the North while one observes a weak variability in the western part of Cote d'Ivoire.

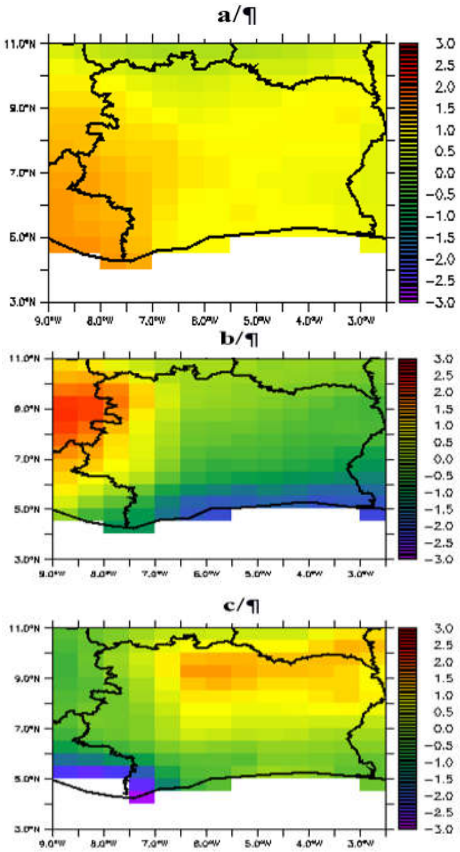
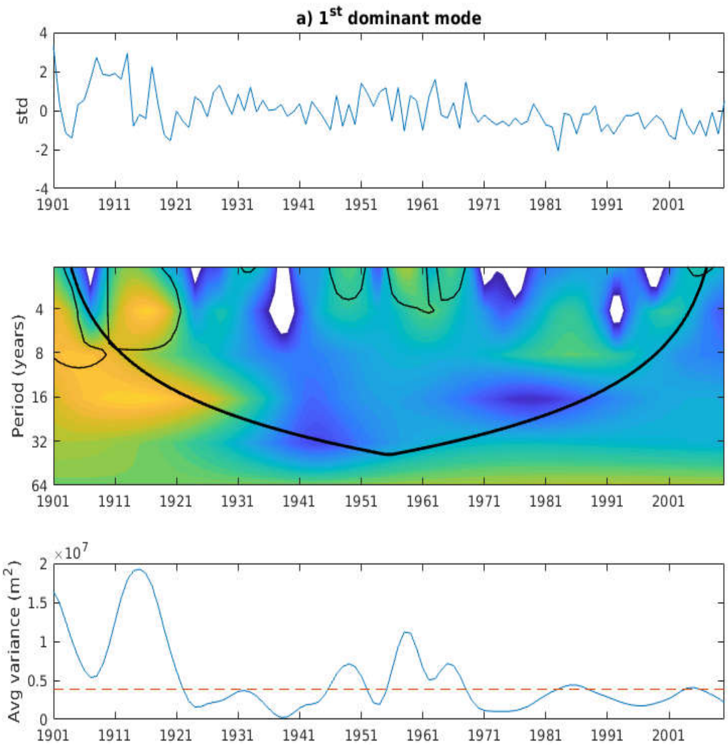


Figure 3 : *Spatial representation of the three first eigenvectors representing more than 70 % of the total variability hidden inside the data during the period 1901-2010. From the top panel to bottom panel are respectively the 1st (a), 2nd (b) and 3rd (c) highest modes*

The Interannual variability of the structure of the dominant modes represented in Figure 3 is investigated in ***Figure 4***. This Figure 4 shows the standard deviation (4.a), the wavelet analysis (4.b), the running mean of 10 year's ranges of the variances (4.c) of the three-time series associated respectively to the three modes of variability of precipitation. The first dominant mode ***(Figure 4a)*** is characterized by high variability in the frequency's ranges of 4-10 years and 1-4 years respectively from 1910 to 1921 and, from 1940 to 1971 (panel of the middle). One observes also significant variability around the mean period between 8 and 10 years and also around 2 years respectively between the years 1981 and 1991 and, after the years 2001 (bottom panel). But after 2001, these variabilities are less important than those observed between 1910 and 1921. For the second mode of variability ***(Figure 4b)***, the time series shows strong variability from 1901 to 1915, 1925 to 1941 and, 1982 to 1985. During these different intervals of years, the high variabilities observed have respective frequencies of 1 to 8 years, between 8 and 10 years, and around 4 and 2 years. Much of the variabilities are observed in the third mode ***(Figure 4c)***. These high variabilities describing the third mode have average periods around 4 years. After the years 2000, one observes an increasing of the intensity of the rainfall variability in Cote d'Ivoire.



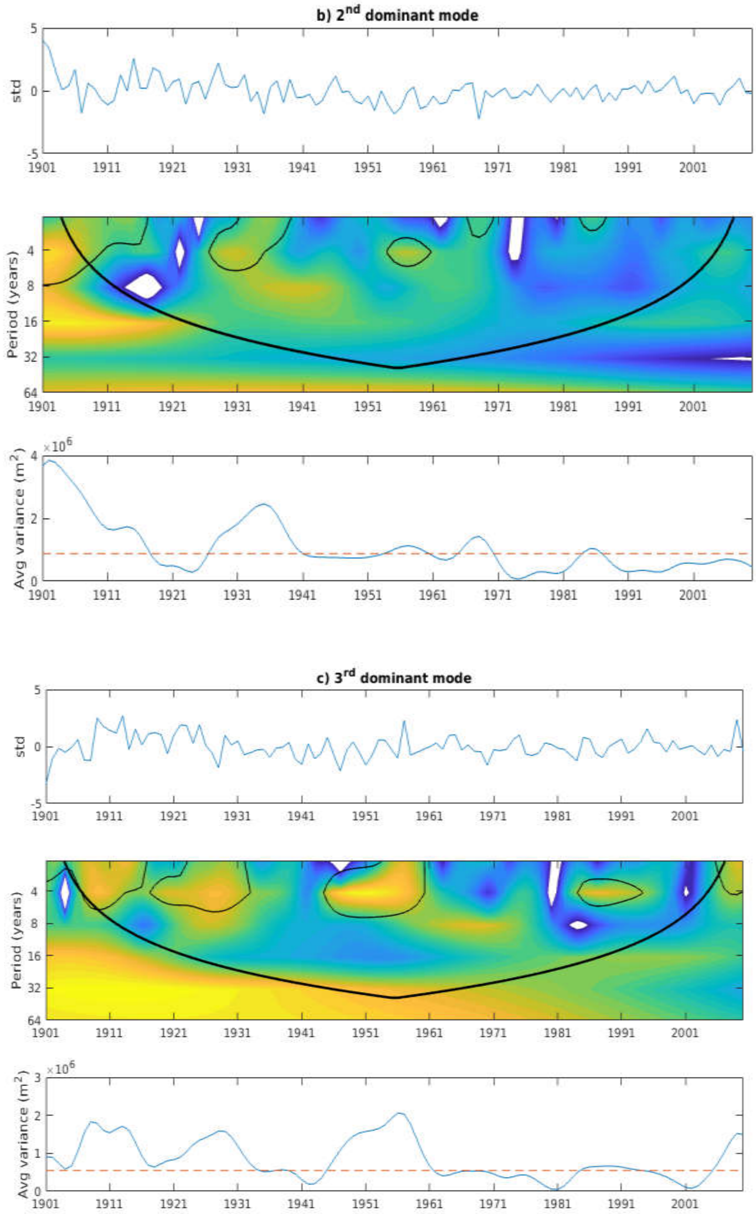


Figure 4 : *Statistical analysis of the time series corresponding respectively to the first mode (a), second mode (b) and third mode (c) of the rainfall over Cote d'Ivoire. Panel of the top : Interannual variability of the standardized anomalies. Panel of the middle : Wavelet power spectrum of the standardized anomalies of rainfall. The thick line delineates the significant level for the global wavelet spectrum. Bottom panel: The scale average power spectrum over 1-10 years band; the dashed line represents the 95 % confidence level*

IV - DISCUSSION

The large amount of precipitation observed in CI is attributed to the WAM and from previous studies, the modes of variability of rainfall in CI at seasonal scale exhibit 3 climatic zones ([6]) corresponding to three latitudinal bands associated to the seasonal march of the West African Monsoon (WAM) flow ([6]). What is the mode of variability of the rainfall observed outside the season of WAM? Our analysis uses the same EOF decomposition but not the same approach as we removed the seasonal cycle to investigate the non-seasonal patterns. This was motivated by the question above and also by the increasing's occurrence of extreme rain as discussed in ([10]). Our analysis reveals that different zones of variability not following the seasonal migration of WAM flow characterize also the rainfall pattern in CI. This result doesn't agree with the previous result in [6]. But this present work shows the erratic nature of precipitation in CI in agreement with the results of [10].

V - CONCLUSION

This study uses GPCP data over the period 1901-2010 (110 years) to determine and describe the different modes of variability of rainfall in CI. The years to years variability shows strong variance with three different regions (the West, the North and, the South) of highest modes of variability. An important result is that rainfall pattern in CI is not distributed latitudinally, it follows instead a random spatial distribution. These significant variabilities occur at a frequency range less than 10 years with highest variability occurring at frequencies around 2, 4 or 8 years. The nature of rainfall over CI is erratic with some years recording high variabilities as these recent decades starting from the year 2000.

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