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► To cite this version:

Serge Janicot, Benjamin Sultan. Intra-seasonal modulation of convection in the West African monsoon. Geophysical Research Letters, 2001, 28 (3), pp.523-526. 10.1029/2000GL012424 . hal-00162234

HAL Id: hal-00162234

<https://hal.science/hal-00162234>

Submitted on 25 Jan 2021

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Intra-seasonal modulation of convection in the West African monsoon

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Abstract. By using daily gridded rainfall data and NCEP/NCAR 925 hPa wind reanalyses over the period 1968-1990, it is shown the evidence of large and coherent fluctuations in the rainfall and wind fields at intra-seasonal time scale (10-60-day period) over West Africa. A composite analysis based on the dates of maximum (minimum) of a regional rainfall index in wet (dry) sequences shows that these sequences belong to a quasi-periodic signal of about 15 days. These enhanced (weakened) phases in the West African monsoon are characterized by a westward propagation of positive (negative) rainfall anomalies north of 10°N associated with a more cyclonic (anticyclonic) circulation over the Sahel consistent with a stronger (weaker) moisture advection over West Africa.

Introduction

Rainfall variability over West Africa has been most of the time analyzed through the meso-scale of the convective complexes, the synoptic scale of the easterly waves, or the interannual and decadal time scales of the long-term drought over the Sahel. Very few studies have investigated the West African monsoon through the intra-seasonal time scale: Kiladis and Weickmann [1997] have shown some connections at the 6-30-day time scale between convection in the region $5^{\circ}\text{N} - 15^{\circ}\text{N}/10^{\circ}\text{E} - 20^{\circ}\text{E}$ and moisture advection over West Africa during northern summer; more recently Sultan and Janicot [2000] established some links between a "jump" of the West African Inter-Tropical Convergence Zone (ITCZ) around late June and a cyclonic circulation at the 10-60-day time scale moving westward over the Sahel.

A more precise investigation of such intra-seasonal fluctuations have been performed over the period 1968-1990, a dry one over West Africa compared to the long-term mean [Hastenrath, 1995]. Two datasets have been used. Daily rainfall amount at stations located in the West African domain $3^{\circ}\text{N} - 20^{\circ}\text{N}/18^{\circ}\text{W} - 25^{\circ}\text{E}$ have been compiled by IRD (Institut de Recherche pour le Développement; previously ORSTOM), ASECNA (Agence pour la Sécurité de la Navigation Aérienne

en Afrique et à Madagascar) and CIEH (Comité Inter-africain d'Etudes Hydrauliques). These data are available for the period 1968-1990, including more than 1300 stations from 1968 and 1980, and between 700 and 860 stations on the period 1981-90. These daily values were interpolated on the $2.5^{\circ} \times 2.5^{\circ}$ grid of NCEP/NCAR reanalyses (see below), by assigning each station daily value to the nearest grid point and averaging all the values related to each grid point. The greatest density of stations is located between the latitudes 5°N to 15°N . Data on latitude 17.5°N can also be taken into account where between 30 and 40 stations are available. The NCEP/NCAR dataset consists of a reanalysis of the global observational network of meteorological variables (wind, temperature, geopotential height, humidity on pressure levels, and surface and flux variables) with the "frozen" state-of-the-art analysis and forecast system of the NCEP (National Centers for Environmental Prediction).

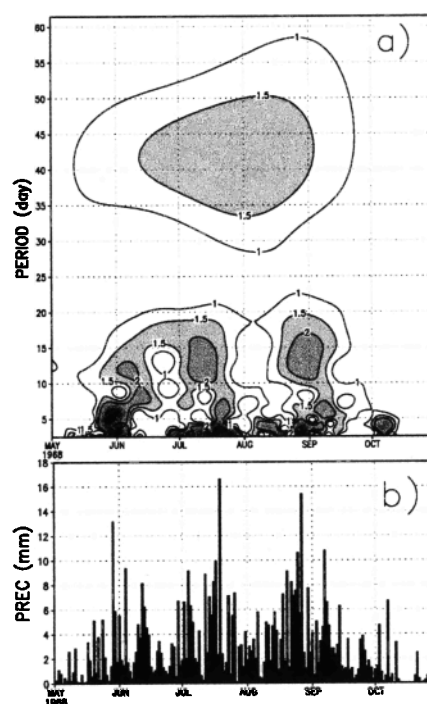


Figure 1. (a) Wavelet analysis of the daily rainfall time series from 1st May to 31st October 1968 averaged over the grid points from 2.5°W to 2.5°E and 12.5°N to 15°N . Only periods lower than 60 days are presented. Values greater than 1.5 are shaded. (b) Daily rainfall time series from 1st May to 31st October 1968 averaged over the grid points from 2.5°W to 2.5°E and 12.5°N to 15°N . Values are expressed in mm.

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tion) at a triangular spectral truncation of T62 [Kalnay *et al.*, 1996]. Data are reported on a $2.5^\circ \times 2.5^\circ$ grid every 6 hours (00.00, 06.00, 12.00 and 18.00 UTC), on 17 pressure levels from 1000 hPa to 10 hPa. We used data covering the period 1968-1990, with one value per day, by averaging the four outputs of each day. As we have focused on the atmospheric circulation in the monsoon layer, we present results from the wind field at 925 hPa in this paper. A previous study [Diedhiou *et al.*, 1999] has demonstrated the accuracy of these two datasets over West Africa.

An example of intra-seasonal rainfall variability over West Africa

Figure 1 shows the time series from 1st May to 31st October 1968 of daily rainfall averaged over the grid points from $2.5^\circ W$ to $2.5^\circ E$ and $12.5^\circ N$ to $15^\circ N$, and the associated wavelet analysis. On Fig.1b the seasonal cycle of rainfall over this area is very clear with weak rainfall in May and October and the greatest values during the northern summer when the ITCZ is at its highest latitude. Day-to-day fluctuations are also evident, characterizing the influence of synoptic scale weather systems like easterly waves [Diedhiou *et al.*, 1999] and of mesoscale convective systems. Moreover we can notice sequences longer than 10 days of persistent high or low rainfall amounts. The wavelet pattern (Fig. 1a) highlights this intra-seasonal time scale variability as intermittent signals with more variance in two period intervals, between 10 and 25 days, and between 25 and 60 days.

Then data have been filtered, using a non recursive filter [Scavuzzo *et al.*, 1998], to retain periodicities between 10 and 60 days. Figure 2 shows such daily rainfall time series (the black line) for 1968, averaged over a domain covering most of the Sahel in West Africa, and expressed as the ratio to the seasonal-filtered rainfall signal (periodicities greater than 60 days). A similar

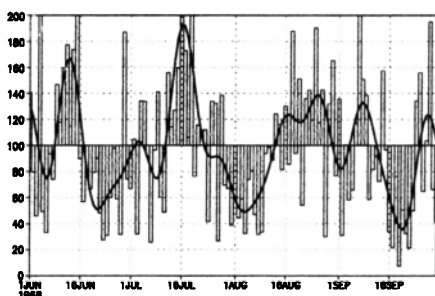


Figure 2. Daily rainfall time series from 1st June to 30th September 1968 averaged over the grid points at $12.5^\circ N$ between $10^\circ W$ and $10^\circ E$. Bars represent the ratio of the unfiltered rainfall to the seasonal-filtered rainfall signal where only periodicities greater than 60 days are retained. The black line represents the similar ratio but filtered to remove the synoptic time scale signal, that is periodicities lower than 10 days. These values are expressed in percentages of the seasonal time scale signal.

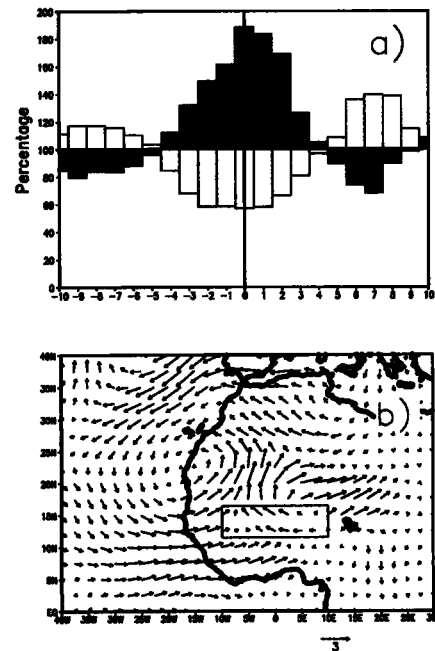


Figure 3. (a) Time series of wet (black bars) and dry (white bars) composite sequences averaged over the grid points from $10^\circ W$ to $10^\circ E$ and $12.5^\circ N$ to $15^\circ N$; this area is displayed on (b). These values represent the ratio of the daily rainfall where periodicities lower than 10 days are removed, to the seasonal-filtered rainfall signal where only periodicities greater than 60 days are retained. They are expressed in percentages of the seasonal time scale signal. The wet (dry) composites have been computed by selecting days over the periods June-September 1968-1990 where the rainfall amount is a maximum (minimum) and is greater than 130% (lower than 70%) of the seasonal time scale signal. All these wet (dry) sequences have been averaged by considering as the reference date t_0 the days of maximum (minimum) percentage and by computing the averages of the percentages from t_0 minus 10 days to t_0 plus 10 days. (b) The corresponding composite 10-60-day filtered 925 hPa wind field at t_0 computed as half of the wind difference between the wet and the dry sequences. The scale ($m.s^{-1}$) is displayed below. The rectangle represents the area over which the rainfall indexes of (a) are computed.

ratio including also the synoptic time scale signal, that is periodicities lower than 10 days, is also shown (bars). Several intra-seasonal time scale fluctuations are highlighted, lasting more than 10 days and greater than 50% of the signal, both for wet or dry sequences. They represent a significant modulation of the rainfall regime over the Sahel. This suggests that it could exist a persistence effect, greater than those due to the synoptic easterly waves and the meso-scale convective complexes, important for agriculture and hydrology.

Composite time sequences of enhanced and weakened monsoon phases

To better characterize these enhanced and weakened phases in the West African monsoon, composite analy-

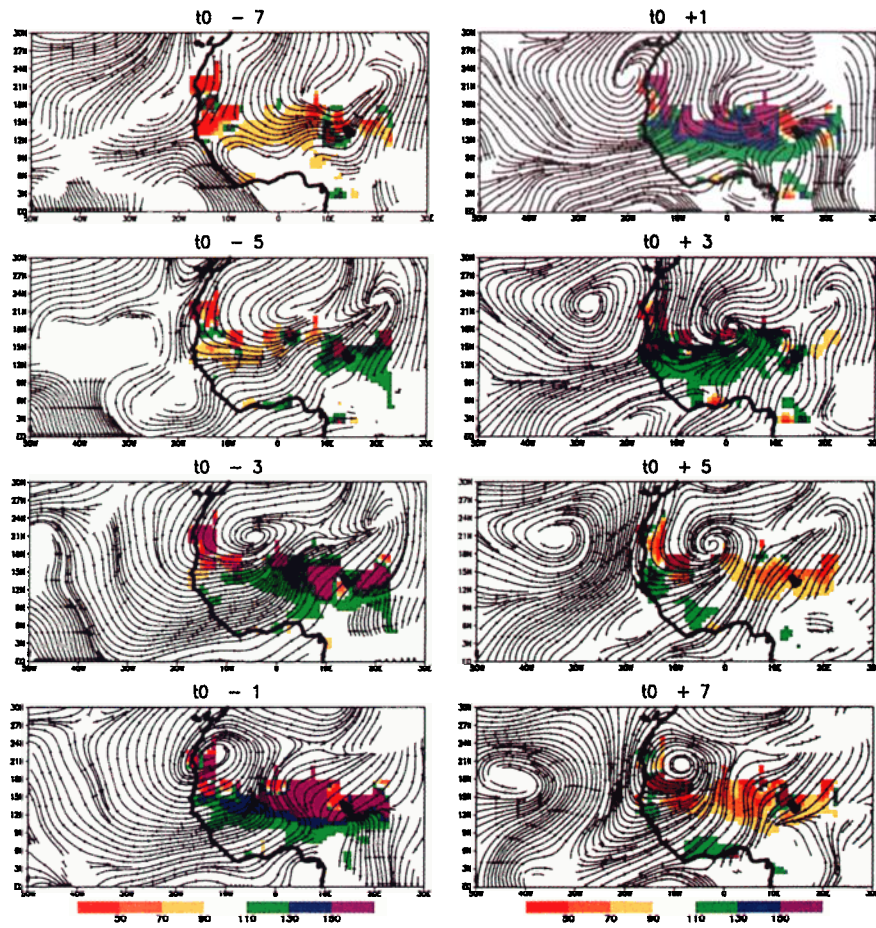


Figure 4. The composite (wet-dry)/2 time sequence of the 10-60-day filtered 925 hPa wind field (streamlines) and rainfall (shaded) from t_0 minus 7 days to t_0 plus 7 days by step of 2 days. The rainfall values are the ratio of the daily rainfall where periodicities lower than 10 days are removed, to the seasonal-filtered rainfall signal where only periodicities greater than 60 days are retained. They are expressed in percentages of the seasonal time scale signal and displayed for values lower than 90% and greater than 110%.

ses have been performed at the intra-seasonal time scale over the 23 year-period 1968-1990, both for rainfall and the 925 hPa wind fields, to look at the possible connections between the atmospheric circulation in the monsoon layer and the resulting rainfall patterns. June-September 10-60-day filtered rainfall time series over the Sahel (this area is displayed on figure 3b) have been considered for each year. We retained the dates (called t_0) where this rainfall index is maximum (minimum) and greater (lower) than 130% (70%) of the seasonal-filtered rainfall signal to define wet (dry) sequences. We computed the corresponding sequences t_0 minus 10 days / t_0 plus 10 days. Over the period 1968-1990 we got in average 3.9 wet and 4.5 dry sequences during June-September. Finally we averaged separately all the wet sequences and all the dry sequences from t_0-10 to t_0+10 to define a composite mean (Fig. 3a). The mean modulation of the regional rainfall amount is quite high and not strictly symmetric, up to 180% for wet sequences and down to 60% for dry sequences. These high values result in part from the rainfall fluctuations at $15^\circ N$ where the ratio to the seasonal time scale signal can be

very high. These sequences are preceded and followed by weak rainfall anomalies of opposite sign. Whereas the signal results from the rainfall variability between 10 and 60 days, the mean wet and dry sequences last 9 days and belong to a quasi-periodic fluctuation whose corresponding period is quite short, about 15 days. Similar analyses done with 25-60-day filtered time series point out a second composite periodicity at about 38 days, consistent with the wavelet diagram of Fig. 1a, but with weaker rainfall fluctuations (from 140% to 70%; not shown). When considering the whole 10-60-day signal, the 15-day periodicity appears as the dominant one.

The corresponding composite 10-60-day filtered 925 hPa wind field at t_0 , computed as half of the wind difference between the wet and the dry sequences, is displayed on Fig. 3b. If we neglect the non totally symmetric character of wet and dry rainfall sequences, it then characterizes the wind field modulation for a typical wet sequence. This wind field highlights a large cyclonic circulation centered between $20^\circ N$ and $25^\circ N$ over the western coast of West Africa. This circulation controls westerly winds south of $10^\circ N$ and southerly

ones over the Sahelian area considered. This pattern is consistent with an increase of moisture advection inland and the occurrence of a wet sequence over the Sahel.

Figure 4 shows the composite wind field sequence from t_0 minus 7 days to t_0 plus 7 days, by step of 2 days, as well as the corresponding 10-60-day filtered rainfall modulations. These patterns characterize a typical wet sequence. Reverse patterns occur for a dry one. Both the rainfall and atmospheric patterns show a westward propagation, moving at a speed of about 4 degrees per day. The atmospheric structure has a mean wavelength of about 60° of longitude at $20^\circ N$. The rainfall modulation extends from the Sahelian latitudes to $10^\circ N$ and we see again a strong association between positive rainfall anomalies and the cyclonic circulation, consistent with a moisture advection increase over West Africa. Before and after the wet sequence occurrence, negative rainfall anomalies are present concomitantly with an anticyclonic circulation.

Discussion

We have pointed out large and coherent fluctuations in the rainfall and wind fields at intra-seasonal time scale over West Africa on the period 1968-1990. These enhanced (weakened) phases of the West African monsoon last in average 9 days and are included in a dominant quasi-periodic signal of about 15 days. They are characterized by a westward propagation of positive (negative) rainfall anomalies north of $10^\circ N$ associated with a more cyclonic (anticyclonic) circulation over the Sahel, consistent with a stronger (weaker) moisture advection over West Africa. More must be done to understand the origin of such fluctuations. Kiladis and Weickmann [1997] suggested that such a signal could be induced by convection. On the other hand it might represent either a particular perturbation of the synoptic easterly wave regime or a specific slowly moving easterly wave. Similar intra-seasonal rainfall fluctuations occur also over the Guinean region, especially during the first rainy season (not shown). This point must be investigated further. Another point would be to quantify the contribution of such intra-seasonal variability in the interannual variability. Dennett et al. [1985] and

Nicholson et al. [2000] pointed out the impact of rainfall decrease in August and September on the long-term downward trend in the Sahel. Intra-seasonal variability should be analyzed before 1968 to answer this last question.

Acknowledgments. We are thankful to H. Laurent, for providing the IRD rainfall data and to Climate Diagnostics Center (NOAA, Boulder, CO) for providing the NCEP/NCAR Reanalysis dataset. This research was in part supported by the EC Environment and Climate Research Programme (contract: ENV4-CT97-0500; Climate and Natural Hazards).

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(Received October 2, 2000; revised November 27, 2000; accepted November 28, 2000.)