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Tropical Atlantic and rainfall variability in Côte d'Ivoire

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[1] A statistical analysis is performed between the rainfall anomalies in Côte d'Ivoire (West Africa) and those of sea surface temperature and pseudo-wind stress in the tropical Atlantic. The correlation structures show that the coastal and northern regions of Côte d'Ivoire are differently related to the meteo-oceanic variables. While the main rainy seasons of these two Ivorian regions are both related to a negative SST/rain correlation pattern, itself strongly linked to the abnormal position of the intertropical convergence zone, the dry season of the littoral zone is related to a positive SST/rain correlation pattern which remains offshore of Côte d'Ivoire. Our study illustrates the inverse climatic behaviour observed between the northern and the littoral zones during the two "Atlantic's El Niños" of 1968 and 1984. **INDEX TERMS:** 1854 Hydrology: Precipitation (3354); 3322 Meteorology and Atmospheric Dynamics: Land/atmosphere interactions; 3307 Meteorology and Atmospheric Dynamics: Boundary layer processes; 4215 Oceanography: General: Climate and interannual variability (3309); **KEYWORDS:** Rainfall in Côte d'Ivoire, Tropical Atlantic, sea surface temperature, wind stress. **Citation:** Kouadio, Y. K., D. A. Ochou, and J. Servain, Tropical Atlantic and rainfall variability in Côte d'Ivoire, *Geophys. Res. Lett.*, 30(5), 8005, doi:10.1029/2002GL015290, 2003.

1. Introduction

[2] The rainfall in West Africa depends largely to large-scale atmospheric circulation and continental meteorological conditions [Fontaine and Janicot, 1992]. Its seasonal range follows the same variation that the latitudinal displacement of the inter-tropical convergence zone (ITCZ), itself linked to fluctuations in the trade wind system and the oceanic variables over the tropical Atlantic [Nicholson, 1980; Ward, 1998]. Many studies have investigated the relationships between the tropical Atlantic sea surface temperature (SST) and the rainfall over large regions of West Africa [Folland *et al.*, 1986; Lough, 1986; Janicot and Fontaine, 1997; Fontaine *et al.*, 1999]. However, studies related specifically to Côte d'Ivoire are not numerous and only partially documented [Cautenet and Rosset, 1989; Gallardo, 1993]. Furthermore they take into account rainfall and oceanic data which are limited in time and space. For example, using SST and wind coastal data, Cautenet and Rosset [1989] showed that precipitation episodes on Ivorian coast during the boreal winter (long dry season) are particularly linked to sea breeze conditions.

[3] The goal of this study is to go further in the understanding of the climatic impact of the tropical Atlantic Ocean on different regions of Côte d'Ivoire of which the economy is largely based to food crops and other agricultural resources.

2. Data and Method of Analysis

[4] The rainfall data were obtained from 22 meteorological stations distributed on the Ivorian territory between 5 to 11°N and 3 to 8.5°W. A statistical reduction of the rainfall monthly time series 1964–1997 has been realized from a Varimax principal components analysis. We kept the three first components which account for 75.9% of the total variance. This allows us to divide the country into three climatic zones (Figure 1): a northern one at the southern limit of the Sahel, a coastal one in the vicinity of the Gulf of Guinea, and an intermediary one in the middle of Côte d'Ivoire (see zoom on panels of Figure 2). Mean annual cycles of rainfall for the three regions are presented in Figure 1. The northern zone (mainly grassy savanna) presents a unimodal behaviour that resembles that of the Sahelian region: the rainy season occurs during the boreal summer (July–August–September) with a peak of about 270 mm of rain in August. The seasonal cycle of rainfall for the center region (forested savanna and deteriorated forest) presents a weakly pronounced bimodal structure with two maxima around 200 mm in June and September. The rainfall over the littoral zone (forest and swamp) also presents a bimodal seasonal cycle with a marked peak in June (up to 500 mm) and a second maximum less pronounced in October (120 mm). These two rainy seasons are separated by a long dry season in December–February and a short dry season in August.

[5] The Atlantic data (SST and pseudo wind stress, called hereafter PWS) have been obtained through a 1964–1997 monthly analysis of the merchant ships' meteorological observations [Servain and Lukas, 1990]. These data are gridded from 30°N to 20°S at 2 degree resolution. SST, PWS and rainfall monthly anomalies have been standardized in order to eliminate some seasonality effect in the data. Correlation coefficients between Atlantic and rainfall data have been calculated for the period 1964–1997, using a time lag varying from 0 to 3 months between the Atlantic and the rainfall time series (the Atlantic data being in phase or in advance vs. the rainfall). The correlation computations are summarized by mapping 2D correlation coefficients on the oceanic domain, which are either scalar values (SST with rainfall, noted hereafter SST/rain), or complex values (x-y components of PWS with rainfall, noted hereafter PWS/rain). For the scalar SST/rain correlation patterns, the interpretation is obvious. To interpret the vector PWS/rain maps, note that positive zonal PWS are positive eastward and meridional PWS are positive northward (for a

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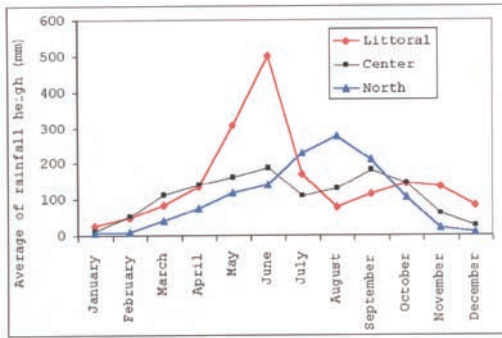


Figure 1. Monthly seasonal cycle of rainfall for the three climatic regions of Côte d'Ivoire.

climatology of PWS fields see for example *Servain and Lukas, [1990]*.

3. Results

[6] Monthly correlation analyses are preferred to quarterly analyses because they allow us to take into account the fast climatic variations during the intermediate seasons. They are completed for each one of the twelve calendar months and for the three Ivorian regions defined before [*Kouadio, 2002*], but only some of the most significant results are discussed here. Figures 2a and 2b show examples of the relationship between the tropical Atlantic variables and the rainfall in the littoral region. For 0-month lag correlation in May (i.e. the beginning of the long rainy season) the correlated pattern between SST and rainfall anomalies is significantly negative in the southern basin, especially in the Gulf of Guinea (Figure 2a). Correlation maps of 2 and 1-month lag backward from May display similar negative structures with a progressive intensification of the signal in the Gulf of Guinea as the time lag decreases. That means that a cooling of SST occurring in Gulf of Guinea in early austral fall (the highest seasonal values of SST in that region) precedes a rise of rainfall on the Ivorian littoral, in agreement with previous studies [*Janicot and Fontaine, 1997; Fontaine et al., 1999*]. In the meantime, a large correlation PWS/rain pattern is observed along the mean position of the ITCZ (Figure 2a), which includes the latitude of the Ivorian coast at this period of the year. That indicates a stronger northern extension of the monsoon, i.e. a more important advection of the potential precipitable water on the African Continent, and induces an increase of rainfall on the coast of Côte d'Ivoire in May. Obviously, the inverse occurs for an inverse sign of the SST/rain and PWS/rain correlation signals. The spatial distribution is somewhat different for the similar 0-month lag correlation in June (not shown) which is the month when we observe the extreme values of the long rainy season on the littoral (Figure 1), but is also the period of the beginning of the seasonal upwelling in the Gulf of Guinea. Indeed, although a large negative SST/rain correlation structure remains from May (Figure 2a) to June, we observe between these two months a northern displacement of that structure from the Gulf of Guinea (as seen on Figure 2a) through the coast of Guinea and Senegal (from 5°N to 15°N). That northern displacement of the correlated structures follows the seasonal latitudinal movement of the ITCZ between May and June,

and relates rapid changes in the region for the air-sea variables [*Grodsky and Carton, 2001*]. It seems therefore that the larger SST/rain relationship relates to the seasonal location of the ITCZ, apart from considering whether this zone spreads along the coast of Côte d'Ivoire, as observed in May (Figure 2a), or spreads off the coast of Guinea, as observed in June.

[7] Figure 2b shows the 0-month lag relationship between the Atlantic variables and the rainfall anomalies over the Ivorian littoral during August, i.e. when the main period of the short dry season occurs for that region (Figure 1), but when the maximum of the seasonal equatorial and coastal upwellings occur in the Gulf of Guinea. As indicated by Figure 2b, warming events in the northern Gulf of Guinea in August are associated with westerlies over the central equatorial ocean and southerlies along the Ivorian coast, and with abnormal rainy episodes in the Ivorian littoral. Thus, the SST/rain relationship during the short dry season is fully different to that of the long rainy season: the largest signatures are negative and follow the ITCZ

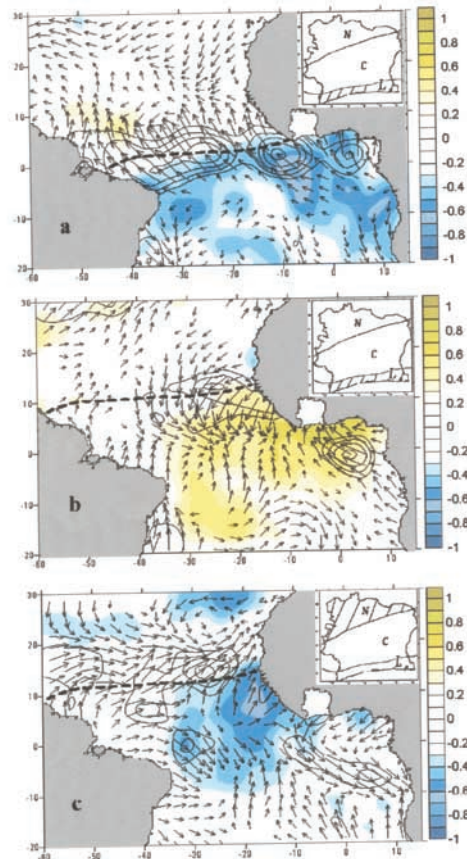


Figure 2. (a) 0-month lag (for May) standard correlation between SST and rainfall (SST/rain), and complex correlation between PWS and rainfall (PWS/rain), for the littoral region; (b) same as (a) for August; (c) same as (a) for September and for the northern region. Only colored areas for SST/rain and represented modulus contours of PWS/rain are significant at 95% level. The climatological location of the ITCZ is indicated with a dashed line. Northern, center and littoral regions are noted by N, C and L on the chart of Côte d'Ivoire superimposed on Africa.

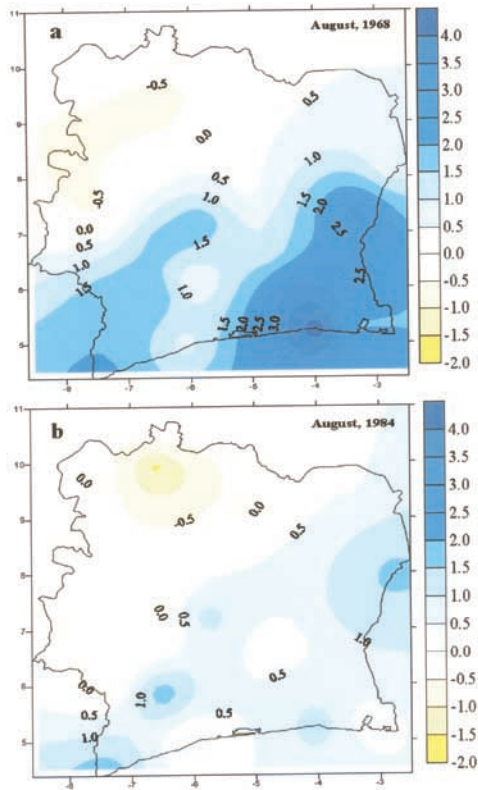


Figure 3. (a) Rainfall standardized anomalies in Côte d'Ivoire in August 1968; (b) same as (a) for 1984.

during the long rainy season (Figure 2a), whereas they are positive and remain in the vicinity of the Ivorian coast (i.e. far from ITCZ) during the short dry season (Figure 2b). We will come back later to this type of climatic occurrence.

[8] Figure 2c shows the 0-month lag relationship between the Atlantic variables and the rainfall in the northern Ivorian zone for September. The September case is chosen because the correlation signal is the highest from all the three months of the main rainy season in the northern zone (July–August–September; see Figure 1). The SST/rain correlated structure indicates that an abnormal cooling in the equatorial oceanic region from 40°W to 10°W is associated with strong westerlies (including a wind divergence in the core of the SST/rain correlated structure) inside a large band centered along the mean position of the ITCZ. This corresponds to an intensification of the African monsoon in the vicinity of Guinea. Such a SST/rain relation (and its inverse situation), which occurs also in August but with a weaker signal, was previously observed by various authors [Lamb, 1978; Lough, 1986; Ward, 1998; Fontaine et al., 1999]. The westerlies, noted in Figure 2c at the northern position of the mean location of the ITCZ in September, correspond not only to an abnormal decrease of the north-east trades but also to an abnormal northern migration of the ITCZ. This wind signal is thus fully comparable with that of Figure 2a describing the PWS/rain correlation related to the long rainy season over the littoral. Newell and Kidson [1984] have already noted that negative SST anomalies in the central tropical Atlantic during the boreal summer were associated with a greater convergence of the flux of humid-

ity through West Africa, in relation with an abnormal northern position of the ITCZ.

[9] In order to illustrate the inverse scenarios involving anomalies of wind, SST, and Ivorian rainfall during the boreal summer (i.e. main rainy season in the north, long dry season in the littoral), we now focus on abnormal events which occurred in 1968 and 1984 (Figures 3 and 4): the northern area of the Côte d'Ivoire (near to Sahel) experienced below normal rainfall, whereas the littoral experimented abnormal floods [Hisard, 1980; Philander, 1986]. These climatic disturbances have enormous consequences for the fragile economies of West Africa. The boreal summers of 1968 and 1984 experimented two dramatic episodes among the most important warm events which occurred in the Gulf of Guinea during the four last decades [Servain and Séva, 1987], and they were described as “Atlantic El Niño’s” [Merle, 1980; Hisard, 1980] because their dynamics follows roughly the well-known Pacific El Niño theory [Zebiak, 1993]. In 1968, positive SST anomalies, trapped along the equator in the core of Gulf of Guinea, began to be important in May ($>1^{\circ}\text{C}$) and increased in June ($>1.5^{\circ}\text{C}$). In July (Figure 4a) the positive SST anomalies were up to 2.5°C and persisted in August. That warm event just followed a relaxation of the western equatorial wind which began in May and which is represented in June on Figure 4a by the PWS anomalies. The 1984 warm event followed a similar “remote” scenario [Servain et al., 1982; Delécluse et al., 1994], although the location of the maximum of the positive SST anomalies was somewhat different. We observed SST positive anomalies off the Angolan coast in May ($>1^{\circ}\text{C}$), which increased until July (Figure 3b) and August ($>2.5^{\circ}\text{C}$), then spread in all the Gulf of Guinea. In the meantime, one observed a westerly occurrence in all the equatorial and southern tropical basin (see Figure 3b for the PWS anomaly in June), which was the consequence of

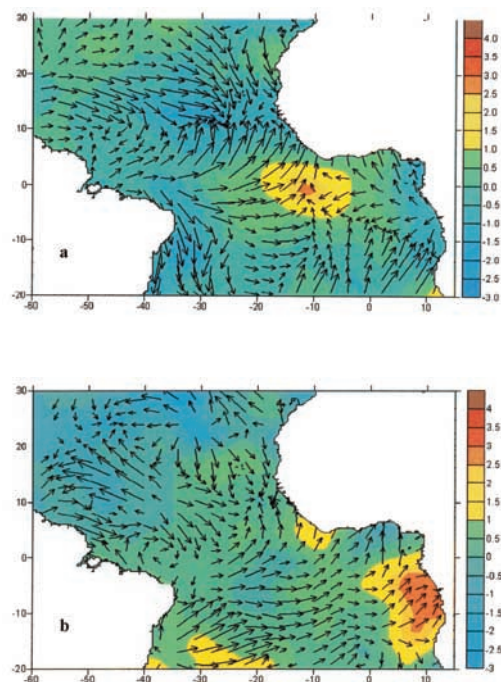


Figure 4. (a) June 1968 PWS and July 1968 SST anomalies in the tropical Atlantic; (b) same as (a) for 1984.

the drastic relaxation of the atmospheric circulation from the mid-1983 until the beginning of 1984 above the western tropical Atlantic. That relaxation was itself related to the 1982–1983 Pacific El Niño [Delécluse *et al.*, 1994].

4. Conclusion

[10] We analyzed the statistical connection between meteo-oceanic variables over the tropical Atlantic and the abnormal distribution of rainfall in Côte d'Ivoire. That relationship covers various aspects which can be classified according to two criteria: (i) the specific Côte d'Ivoire region which accounts for the rainfall (i.e. the northern zone or the littoral band, as notified in the present study), and (ii) the time of the seasonal rainfall variability which is related to that continental region (i.e. either its rainy or dry seasons). We noted important differences in the observed ocean/rain relationship. These differences are mainly related to Atlantic seasonal features, themselves intimately linked: a first feature is the ITCZ position over the ocean, especially its latitudinal position vs. the mean latitude of the specific Côte d'Ivoire region accounted for in the rainfall distribution; a second feature is the seasonal range of the SST values in the equatorial basin (e.g. the highest SST values, close to 29–30 °C, during the second quarter of the year, or the lowest SST values, close to 23–25 °C, during the seasonal upwelling occurrences); a third feature is the seasonal range of the wind distribution (speed and direction) over the Gulf of Guinea (larger monsoon effect during the boreal summer, weaker wind during the springtime).

[11] The rainfall response over the Ivorian littoral to the interannual SST variability is very different for the long rainy season (May–June) compared to the short dry season (August). Thus, significant SST/rain relationship spread accordingly negative patterns during the long rainy season, whereas they spread accordingly positive patterns during the short dry season. Furthermore, the negative SST/rain relationship of May–June is largely associated with the sharp northward displacement of the ITCZ from May to June. On the other hand, the positive SST/rain relationship pattern of August is limited to the immediate oceanic area off Côte d'Ivoire, and relates well to southerlies in that region, in association with an increase of the West Africa monsoon.

[12] The negative SST/rain relationship in the northern zone of Côte d'Ivoire during the main rainy season July–September is very similar to that of the relationship with the Ivorian littoral during its own long rainy season. This negative pattern is also associated with the latitudinal position of ITCZ, which is usually located off the Guinean coast at this time of the year, thus in a region relatively far from Côte d'Ivoire. This PWS/rain relationship relates also an abnormal northward position of the ITCZ.

[13] The climatic consequences of the two warm episodes of 1968 and 1984 which occurred in the Gulf of Guinea illustrate well the inverse wind/SST/rain relationship over the Côte d'Ivoire as described in our analysis during the boreal summer: while the main rainy season in the northern region was abnormally weak (as for the Sahel), the Ivorian littoral experienced important rainfall episodes which are

exceptional for that period of the year. The time lag observed in these individual events between the wind, SST and rainfall anomaly signatures (1 to 3 months) suggests a potential for seasonal forecasting. Dynamical studies are however necessary to better understand how these various effects interact.

[14] **Acknowledgments.** This work was supported by IRD and a grant from the French Administration of Cooperation (Project SUP2000 N° 2001-43).

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