# NOTES AND CORRESPONDENCE

## Sea Surface Temperature Fields Associated with West African Rainfall Anomaly Types

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ABSTRACT

Four West African rainfall anomaly types are defined in relation to the northern summer rainfall departure signs in the Sahel and in the Guinean region in order to investigate the statistical links between interannual variability of West African rainfall and sea surface temperature (SST) through the period 1950–90. Composite analysis depicts the setup of four different mean SST anomaly fields. Drought over all of West Africa is associated with the growth of positive SST anomalies in the eastern Pacific and in the Indian Ocean, and negative SST anomalies in the northern Atlantic and in the Gulf of Guinea. In contrast, drought limited to the Sahel corresponds mostly to a northward expansion of positive SST anomalies in the southern Atlantic, and negative SST anomalies in the northern Atlantic. Northward expansion of negative SST anomalies in the southern Atlantic, positive SST departures in the northern Atlantic, and development of negative SST anomalies in the eastern Pacific appear to be synchronous of flood limited to the Sahel. Flooding over all of West Africa is mainly associated with positive SST anomalies in the northern Atlantic. This approach complements previous papers dealing with rainfall anomalies located in the Sahel alone. In particular, it points out different associations between Atlantic/Pacific SST anomalies and Sahel rainfall variability. Individual cases are also discussed, especially the case of 1972 when a West African rainfall deficit was concomitant to a southward location of the intertropical convergence zone over the tropical Atlantic.

### 1. Introduction

For the last 15 years, many authors have investigated the connections between regional/global sea surface temperatures (SST) and Sahel rainfall in northern summer. Some of these authors (Lamb 1978a,b; Hastenrath 1984, 1987, 1990; Folland et al. 1986; Palmer 1986; Semazzi et al. 1988; Druyan 1991; Ward 1992; Rowell et al. 1995) linked interannual and longer-term Sahel rainfall variability to occurrences of Atlantic and/or global SST dipole patterns. In particular, Sahel drought has been associated with warmer than normal SST in the southern Atlantic, the southern Pacific, and the Indian Ocean, and colder than normal SST in the northern Atlantic and the northern Pacific (Folland et al. 1986). However, further studies (Lough 1986; Janicot 1992b; Fontaine and Bigot 1993; Rowell et al. 1995) suggest that other SST patterns are also important, for instance during the 1983 Sahel dry year. Lamb and Peppler (1992) have shown that other occasional years do not fit the composite patterns in the tropical Atlantic.

Tanaka et al. (1975) pointed out the different character of Sahel droughts in 1968 and 1972. Then Motha et al. (1980) and Nicholson (1981, 1986) showed that most of the West African rainfall anomaly patterns can be summed up by four basic rainfall anomaly types, which will be delineated by "++", "−−", "+−", and "−+" hereafter, in reference to the rainfall departure signs north/south of 10°N. A given rainfall departure character over the Sahel can then be included into two different West African rainfall anomaly patterns, and may be associated with different SST arrangements.

This paper examines through the period 1950–1990 the connections between occurrences of West African rainfall anomaly types and SST departures covering the well-documented subdomain (70°N–40°S, 120°W–60°E). The West African rainfall dataset, the definition of the four rainfall anomaly types, and the SST dataset are described in section 2. Mean composite SST departure fields related to the four rainfall anomaly types are presented in section 3 for northern winter (January–February–March), spring (April–May–June), and

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summer (July–August–September). These composite analyses, which refer to the signs of both Sahel rainfall anomalies and rainfall departures south of 10°N, complement those performed in previous papers (Lamb 1978b; Hastenrath 1984; Folland et al. 1986; Ward 1992). Lamb and Peppler (1992) acknowledged the problems inherent in composite analysis, that is combination of data from similar patterns of varying magnitudes or from somewhat different patterns. Then in section 4, individual cases already considered by Lamb (1978a), Lamb and Peppler (1992), and Ward (1992) are examined and a final discussion is given.

## 2. Data and methods

### *a. Definition of rainfall anomaly types*

The West African rainfall anomaly patterns in the current dataset have been investigated by Moron (1994) over the period 1933–1990 with a subset of 110 selected stations regularly distributed in West Africa. This author performed Varimax rotated principal component analyses (RPCA) on July, August, and September rainfall amounts to detect the dominant coherent modes of variability and define regional rainfall anomaly indexes. This enabled him to delineate three main coherent regions at the peak of the Sahelian rainy season: a "continental" Sahel, a "western" Sahel, and a "Guinean" region (Fig. 5 of Moron 1994). This regionalization conforms to Janicot (1992a) and Nicholson and Palao (1993). Over the subperiod 1950–1990, some particular rainfall seasons have been retained in order to analyze SST patterns associated with an extensive rainfall signal over the whole Sahel. A simple criterium based on the sign of the July–September RPCA time series (scores) corresponding to the rainfall departures of western and continental Sahel, enables us to keep 32 seasons out of the 41 available, during which western and continental Sahel rainfall anomalies were of the same sign. This leads to a classification into four West African rainfall anomaly types. Two of them depict Sahelian rainfall deficits: type −− (negative rainfall anomalies in western and continental Sahel, and in the Guinean region), which occurs in 1972, 76, 82, 83, 86, 90; type −+ (negative anomalies in western and continental Sahel, and positive in the Guinean region) occurring in 1963, 68, 71, 73, 79, 80, 81, 84, 85, 87. The two others depict wet July–September seasons in the Sahel: type ++ (positive rainfall anomalies in western and continental Sahel, and in the Guinean region), which occurs in 1951, 52, 55, 57, 62, 65, 88; type +− (positive anomalies in western and continental Sahel, and negative in the Guinean region) occurring in 1950, 53, 54, 56, 58, 61, 64, 66, 67. It appears that 14 out of 16 selected Sahel drought summers (types −− and −+) occurred after 1970, whereas 15 out of 16 selected Sahel wet summers (types ++ and +−) occurred before this date. Such a long-term downward trend in Sahelian summer rainfall is a unique feature in recent tropical rainfall fluctuations. It has been widely discussed and associated with similar positive or negative trends in SST, in particular, in the Atlantic and Indian Oceans (Folland et al. 1986; Wolter 1989; Wolter and Hastenrath 1989; Shinoda and Kawamura 1994; Smith 1994; Rowell et al. 1995).

### *b. The SST data*

The SST dataset was obtained from the U.K. Meteorological Office, Bracknell (Bottomley et al. 1990). It contains a "File 31" of measurements corrected for presumed observational bias before 1942, where global monthly SST anomalies (1856–1990) are computed on as many 5° lat. × 5° long. grid meshes as possible. A "File 38," used here, was available in the dataset by performing the following space–time smoothing on the "File 31" SST fields. If a value was more than 1.5°C different from the average of the eight surrounding areas (minimum of two areas), then the value was replaced by the average. This procedure was performed three times for each field. The running seasonal fields were computed by taking for each square the average of the previous month, the month and the following month, with only one month needed to calculate a mean. To increase the space–time density of the data, only the subperiod 1950–1990 has been retained. Oceanic grid points with more than 20% of missing data were not included in the analyses. For the remaining grid points, missing values were replaced by their monthly mean computed on the period 1950–1990 in order to avoid any spatial extent of large anomalies over poorly documented areas. This concerns mainly the Southern Hemisphere south of 35°S and some areas in the central Pacific. Finally the subdomain (70°N–40°S, 120°W–60°E) appeared to be the best compromise between the spatial extent and the space–time density of data. First, this includes most of the Atlantic Ocean where the multiyear variability in SST is prominent (Wolter and Hastenrath 1989). Second, the subdomain whose western boundary bissects "Niño region 3" (90°–150°W), stresses the near-coastal signal in the eastern Pacific. However, because of the strong spatial coherence of SST anomalies in File 38, it also includes much of the El Niño and Southern Oscillation (ENSO) signal in the central Pacific (not shown). Finally, the eastern boundary at 60°E includes a large part of the Indian Ocean SST signal (see Kawamura 1994).

## 3. Composite seasonal SST anomaly fields

Figure 1 shows SST anomaly patterns associated with each of the four West African rainfall anomaly types during the northern winter (January–March), spring (April–June), and summer (July–September). It is clear that the two types of Sahelian droughts (patterns −− and −+) as the two types of floods (patterns

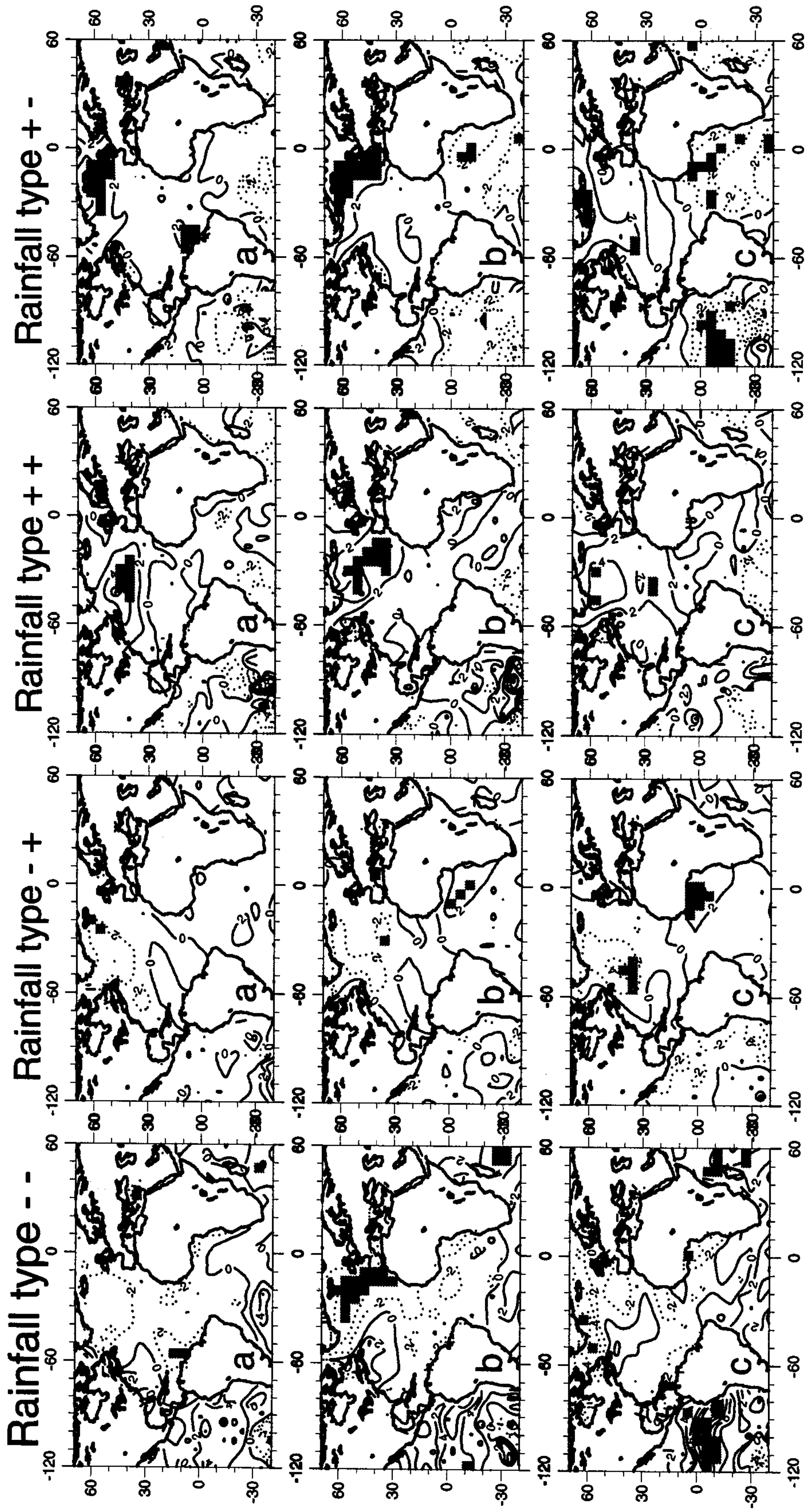


FIG. 1. Maps of composite (a) January–March (first row), (b) April–June (second row), and (c) July–September (third row) SST anomalies (referred to the period 1950–1990) for the July–September West African rainfall types "− −," "− +," "+ +," and "+ −" (see details in the text). Solid (dotted) lines for positive (negative) values by steps of 0.2°C. Significant areas at the 5% level according to local Student *t*-tests are reported in gray after taking into account autocorrelation effects.

++ and +−) are not associated with similar SST anomaly fields. The composite rainfall anomaly type −− is characterized by the growth of positive SST anomalies in the eastern Pacific and by weak negative SST anomalies in the northern Atlantic, and significant negative values in the Gulf of Guinea. Significant positive SST anomalies are also observed in the Indian Ocean. In contrast, the composite rainfall anomaly type −+ is associated with a northward expansion of positive SST anomalies in the southern Atlantic, and with negative SST anomalies in the northern Atlantic. The reversed situation occurs for the composite rainfall anomaly type +− characterized by a northward progression of negative SST anomalies in the southern Atlantic and by positive SST anomalies in the northern Atlantic. The development of negative SST anomalies in the eastern Pacific is also observed. Finally, the composite rainfall anomaly type ++ is mainly associated with positive SST anomalies in the northern Atlantic.

Occurrences of West African rainfall anomaly types −+ (+−) have been previously associated to a southern (northern) location of the monsoon wedge over West Africa in response to the setup during preceding seasons of the Atlantic SST anomaly pattern shown in Fig. 1 (Lamb 1978a,b; Hastenrath 1984; Lough 1986). Present results confirm this conclusion. They also indicate the complexity of the relationships between SST anomalies and Sahel rainfall. This is evident in the Gulf of Guinea, where significant negative anomalies exist during anomalously dry and wet Sahelian rainfall seasons (types −− and +−), and where opposite and significant SST anomalies are associated with Sahel droughts (types −− and −+).

Folland et al. (1986) associated warmer (colder) waters in the global southern (northern) oceans to Sahelian drought (1972, 73, 82, 83, 84) minus wet (1950, 52, 53, 54, 58) composites (see their Fig. 2). However, according to our classification their Sahelian drought composite includes rainfall anomaly types −+ (1973, 84) and −− (1972, 82, 83), whereas their Sahelian wet composite includes rainfall anomaly types +− (1950, 53, 54, 58) and ++ (1952). So Fig. 1 complements Folland et al.'s results: it confirms the impacts of both Atlantic and Pacific SST anomalies on Sahel droughts, and enables to differentiate them: positive SST anomalies in the southern Atlantic and in the eastern Pacific are associated, respectively, with rainfall anomaly types −+ and −−.

## 4. Discussion

Lamb (1978a) and Lamb and Peppler (1992) have shown by investigating individual years that composite analyses cannot account for all SST anomaly pattern occurrences. They produced interesting case studies for the years 1967, 1968, 1972, 1975, 1977, 1983, and 1984. Years 1975 and 1977 have not been used here since their rainfall anomaly signs were different in western and continental Sahel (see section 2a). Some of the other cases concern local tropical Atlantic SST anomalies and rainfall anomaly types −+ and +−. SST anomaly patterns in 1967 (Fig. 4 of Lamb 1978a) depict a northward extension of negative SST departures south of 10°N along with the maintenance of weak positive SST departures between 10°N and 20°N, which is consistent with tropical Atlantic SST anomaly patterns related to rainfall anomaly type +− (Fig. 1). The opposite evolution is shown for 1968 (Fig. 4 of Lamb 1978a), consistent with tropical Atlantic SST anomaly patterns related to rainfall anomaly type −+. Rather similar tropical Atlantic SST departure patterns are also produced for 1984 (Fig. 2 of Lamb and Peppler 1992) but with especially high positive SST anomalies south of 10°N.

Tropical Atlantic SST departure patterns in 1972 (Fig. 2 of Lamb and Peppler 1992) are similar to those of the composite rainfall anomaly type −+ but with weak SST anomalies. Figure 2 displays the SST field for summer 1972 expressed as departures from a different reference period, 1950–1990 (1911–1970 in Lamb and Peppler). In Fig. 2 the SST dipole pattern is not so clear since there are weak negative SST anomalies in the Gulf of Guinea. Ward (1992) computed summer SST departures for 1972 with reference to the period 1969–1988. He equally noticed that the tropical Atlantic SST dipole was weak and considered that this was consistent with the absence of a rainfall anomaly dipole over West Africa and with a remote SST forcing. The composite (Fig. 1) is also consistent with remote SST forcing playing a role in type −−. Intertropical convergence zone (ITCZ) in the tropical Atlantic does shift south in −− year 1972 despite weak local SST forcing (Hastenrath 1990; Lamb and Peppler 1992). However, latitudinal location of the ITCZ in the tropical Atlantic is near the mean in other −− years (1976, 1982, 1983, 1986; see Hastenrath 1990; Lamb and Peppler 1992; Shinoda and Kawamura 1994). Over West Africa, the ITCZ is close to its normal latitude for −− years (Tanaka et al. 1975; Shinoda 1990a; Janicot 1992a): large-scale subsidence (Shinoda 1990b; Janicot 1992b; Janicot 1994a; Shinoda and Kawamura 1994) and reduced convection (Janicot 1994b; Fontaine et al. 1995; Moron 1995) account for West African rainfall deficits. GCM results (Janicot 1996, manuscript submitted to *Ann. Geophys. Lett.*) simulate ITCZ shift south in the Atlantic and reduced convection over West Africa in El Niño summers. This process involving east–west atmospheric circulation anomalies forced by equatorial SST anomalies seems to be more important after 1970 (Janicot et al. 1996).

## 5. Conclusions

In this paper we have investigated the relationships between July–September rainfall variability over West Africa and SST anomaly patterns over a well-docu-

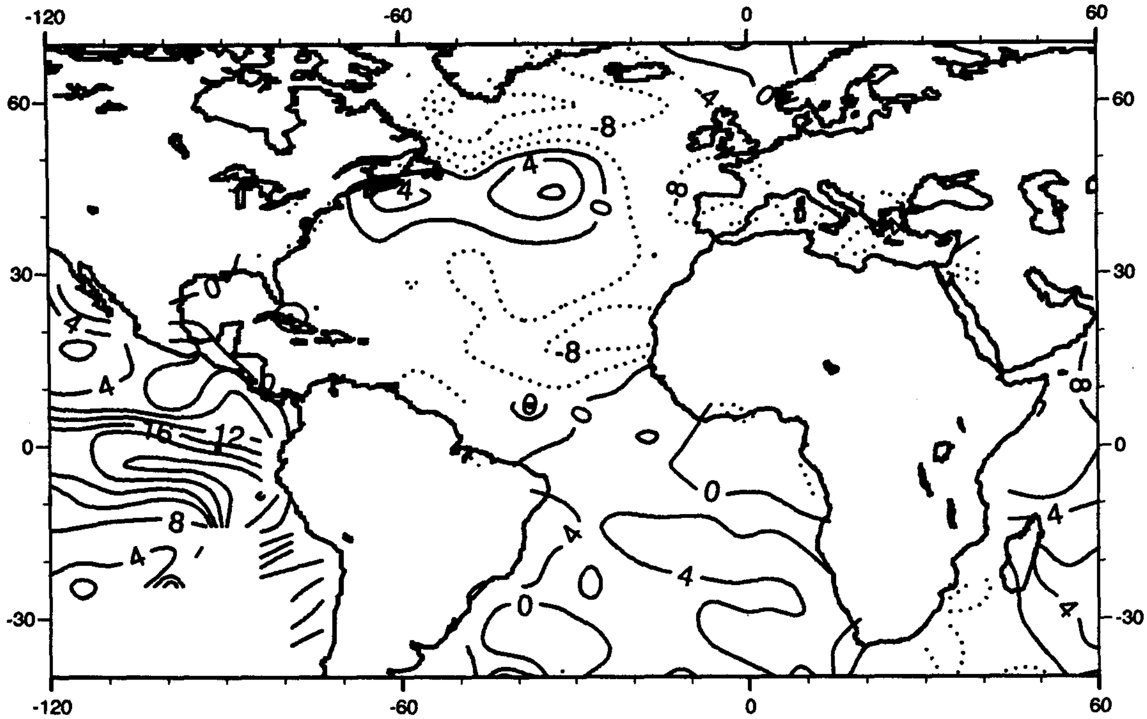

FIG. 2. Mean SST anomalies in July–September 1972 referred to the period 1950–1990. Solid (dotted) lines for positive (negative) values by steps of 0.4°C.

mented period 1950–1990. Results show clearly that Sahelian droughts (or floods) can be associated with different SST anomaly patterns. This has been shown by considering the SST anomaly patterns associated with rainfall anomalies over the whole of West Africa. Drought over all of West Africa (rainfall type −−) is associated with the growth of positive SST anomalies in the eastern Pacific and in the Indian Ocean, and weak negative SST anomalies in the northern Atlantic and in the Gulf of Guinea. In contrast, drought limited to the Sahel (rainfall type −+) mainly corresponds to a northward expansion of positive SST anomalies in the southern Atlantic and to negative SST anomalies in the northern Atlantic. Flood limited to the Sahel (rainfall type +−) is associated with a northward expansion of negative SST departures in the southern Atlantic, and with negative SST anomalies in the eastern Pacific, and positive SST departures in the northern Atlantic. Flood over all of West Africa (rainfall type ++) is mainly associated with positive SST anomalies in the northern Atlantic. This approach complements previous analyses dealing with rainfall anomalies located in the Sahel alone. In particular, it points out different associations between Atlantic/Pacific SST anomalies and Sahel rainfall variability. Individual cases have been examined. In summer 1972, the occurrence of a West African rainfall deficit is concomitant with a southward location of the ITCZ over the tropical Atlantic. Remote forcings of positive SST anomalies in the eastern Pacific and the Indian Ocean could explain this apparent contradiction. Let us notice, however, that SST patterns indicate only a tendency for a given rainfall type to occur. There is also some rainfall variance that results from internal atmospheric variability and perhaps from other forcing mechanisms.

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