Sea surface Temperature in the Physical Mechanism of the Interannual Variability of Precipitation in the Saint Louis Region in the Context of Climate Change

Aichetou Dia Diop, Malick Wade, Adoulaye B. Diop, Djiby Sarr and Bouya Diop

ABSTRACT

The Saint-Louis Region runs along the Senegal River on the Mauritanian border, an interface region between the dry Sahelian and hot and dry Saharan climates. It is one of the regions of Senegal located in the northwest of this country. Its total population is nearly one million inhabitants living mainly from the resources of the river, and from agriculture.

To understand the interannual variability of precipitation in this buffer region between the Sahel and the Sahara, more particularly in the region of Saint Louis, we have studied the meteorological parameters involved in the establishment of precipitation.

This region is located in the extreme north of Senegal between $12^{\circ} 62' 16''$ 52 west longitude and $14^{\circ} 4' 16''$ 67 north latitude. On its western facade, it is bounded by the Atlantic Ocean.

It has a strong agricultural vocation because of its significant water and land potential. Indeed, the Senegal River flows into the Atlantic at Saint Louis, it has source in Guinea. Its regime is very irregular and depends entirely on monsoon rains.

However, rain is the most important factor in the climate and is one of the main sources of water for the river in this climatic zone. It is characterized by its insufficiency, its irregularity, and significant inter-annual differences.

The influence of the nearby ocean appears to play an important role in climate activity in this region.

Using the monsoon depth and height from meridian and zonal winds, we have established the correlations between monsoon rains and Sea Surface Temperature (SST). From these parameters, we were able to predict the rainfall breaks in this region of Senegal.

Keywords: Monsoon, Monsoon rains, Sahel, SST, climate change.

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I. INTRODUCTION

West Africa in general, Senegal in particular, is subject to strong variation in rainfall over widely varying scales of time and space. It is necessary to know all the parameters involved in the establishment of precipitation. However, rain is the most important climatic factor and the main regional differentiator. It is characterized by its insufficiency, with precipitation of year i and mean of the series irregularity and significant inter-annual differences. These inter-annual differences are more significant in the Sahelian region [1], [2] where our study area is located. Saint Louis is located in the extreme north of Senegal between $14^{\circ} 62' 16''$ 52 west longitude and $14^{\circ} 4' 16''$ 67 north latitude with an oceanic border (Atlantic Ocean). It has a strong agricultural vocation because of its significant water and land potential. Indeed, the Senegal River flows into the Atlantic at Saint Louis, it has

source in Guinea. Its regime is very irregular and depends entirely on monsoon rains. Monsoon represents the seasonal reversal of wind direction, and therefore the presence of rains. By extension and abuse of language, the land regions undergoing an alternation between the dry season and the wet season are called "monsoon zones" [3].

The data are taken from NCEP-NCAR Reanalyzes data for the period 1948-2013. They are used by Biljana et al. [4] Berges et al. [5]. They appear at the daily time step and on a mesh of 5×5 km. Rainfall, sea surface temperature, zonal U wind, and southern wind V data are used.

Our study consists, using the depth of the monsoon and its height from meridian and zonal winds, to explain the correlations between monsoon rains and the Sea Surface Temperature (SST).

II. RESULTS AND DISCUSSION

A. Precipitation Anomaly

The rainfall regime is characterized by dry or wet periods, to know if a year is rainy or dry, the standardized rain index (IPS) is often used. We use the precipitation anomaly given by formula (1) to show the evolution of rainfall. Soit X' precipitation anomaly given by expression (1):

$$X' = X_i - X_m \quad (1)$$

with precipitation of year i and mean of the series.

With X_i the precipitation of year i and X_m mean rain of the series.

Consider the threshold noted s to characterize the dry, wet and normal years of precipitation.

$$s = std(X')$$

This threshold allows the study of the variability of rainfall in our study area. The red dotted lines indicate a threshold equal to approximately 17mm for determining wet, dry and normal years. Between the two lines we denote the normal years, the red line located above zero in the figure represents the wet years, below the other red line, the dry years.

Fig. 1 shows the great drought between 1970 and 1980 and a slight upturn in rainfall from 2005. And we notice in the figure that the years 2005, 2006, 2009, 2010 and 2012 are wet. This resumption of rainfall confirms the work of Ali et al. [6] and Bodian [7].

Fig. 1. JJAS precipitation index on Saint Louis.

B. Precipitation and SST

Several studies have shown that West African rainfall anomalies are statically related to ocean surface temperature anomalies (SST) [8], [9]. There are robust statistical links between the interannual variability of the African monsoon, and that of the SSTs of the Gulf of Guinea and the Mediterranean [10]. Thus the standardized SST index, for the Gulf of Guinea, i.e., on latitude 10° north and 10° south and longitude 50° West and 20° East, is correlated with precipitation in the Sahel (figure 2). Figure 2 is composed of the SST index of June July August (JJA) on precipitation for July August September (JAS) (Lag = -1), the SST index of July August September (JAS) on precipitation July August September (JAS) (Lag = 0), the SST index for June July

September (JAS) on precipitation for August September October (ASO) (Lag = 1), and the SST index for July August September (JAS) on the precipitation of September October November (SON) (Lag = 2).

We have noticed that the SST index June July August (JJA) has a strong regression with the precipitation of July August September (JAS). For a degree of variation of the JJA SST, we note an excess of rain at the level of the study area St Louis is at latitude 16° north. On the other hand, for the SST index of JAS, we note a deficit in rainfall.

The regression is obtained from expression (2), denoted reg. We observe that the SST index JJA has a regression of the order of 10 mm to 18 mm on the precipitation of JAS.

$$reg = r * std(pr) \quad (2)$$

$$\text{with } r = \frac{\sum_i^n x_i * y_i}{n}$$

x_i, y_i time parameters at a given point which change over time.

According to Bah [11] and Janicot [12], the appearance of a rainfall deficit north of 10° N and a surplus in the south coincides with the warming of the surface waters of the Gulf of Guinea. In this context, a rainfall deficit observed along the northern coast of Senegal more particularly in Saint Louis could correspond to a cooling of the surface waters of the tropical Atlantic Ocean.

Fig. 2. Regression Precipitation on SST index.

The Fig. 3 indicates the study area in the north of Senegal. There are 6 stations to measure precipitation.

Fig. 3. Study area in the North of Senegal.

C. The Wind

Wind is an essential parameter of the ocean-atmosphere system which governs the climate. The analysis of the displacement of the intertropical convergence zone (ITCZ) represented on the ground by the InterTropical Front (ITF) highlights the rainy season. According to Nicholson (2000) [13], the position of the ITCZ is not the major determinant of cumulative annual precipitation. The monsoon system is managed by the surface temperature and energy gradients between this continental unit and the surrounding Atlantic Ocean basin. The intertropical convergence zone (ITCZ), also called the “meteorological equator” (TIF), constitutes a belt of low pressure in an East-West direction all around the globe. The thermal gradients are weakly marked there, allowing air masses laden with water vapor to rise.

Fig. 4 confirms the position of the TIF represented in gray at 10° N as mentioned in the literature Benjamin Sultan, [14], it also shows the difference in temperature in color and the meridian and vertical wind in arrows between latitudes 10° South and 20° North (on the y-axis) and longitudes 40° West and 5° East (on the x-axis). We note that the FIT is accompanied by the sea surface temperature (SST) above 27° C, the convergence of the winds. This confirms that the Atlantic Ocean plays a fundamental role in the position of the ITF. Xie and Carton [15], show that the Atlantic Ocean is a link of strong air-sea interactions, and much of the upper ocean variability is associated with the meridian shift of the ITCZ, which modulates the trade winds. The regional circulation in West Africa is mainly characterized by different zonal wind regimes [16]. Precipitation in sub-Saharan West Africa, as well as in Central and Equatorial Africa, has one thing in common: they come mainly from the moisture flow transported by the maritime trade wind of the South Atlantic, deviated when crossing the equator and which then takes the name of monsoon, with reference to the mechanism of the Asian monsoon [17].

Fig. 4. FIT in gray, SST in color, the arrows are the wind.

On the surface, the monsoon height in August of between 800 and 1000 hPa is shown in Fig. 5. It shows the south-north gradient of precipitation in the Sahel. At Saint Louis in August, the monsoon height is between 850 and 900 hPa (Fig. 5).

Fig. 5. the monsoon height in August.

III. CONCLUSION

From the standard deviation of the precipitation anomaly, we see that the St Louis region is characterized by significant interannual variations. According to several studies, rainfall anomalies in West Africa are statically linked to ocean surface temperature anomalies (SST). Thus, the regression between the SST index and the precipitation shows that the SST of June July August (JJA) is related to the precipitation of July August September (JAS). The position of the FIT located at 10° N and the Saint Louis monsoon height of between 850 and 900 hPa confirms the rainfall breaks in the region. As perspectives, it is necessary to study, the vertical humidity flux between 1000hPa and 950 hPa, the composites of dry, normal, and wet years.

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