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Sea surface temperature trends and its relationship with precipitation in the Western and Central Equatorial Africa

Akeem Shola Ayinde, Regina Folorunsho, Adeyemi Ekundayo Oluwaseun

Nigerian Institute for Oceanography and Marine Research (Climate and Marine meteorology dept.), Nigeria

Corresponding author:
Ayinde Akeem Shola
3, Wilmot Point Road, Off Ahmadu Bello Way, Victoria Island, Lagos, Nigeria
P.M.B. 12729
Phone number: +2348081609213
E-Mail: ayindeakeemshola@yahoo.com

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ABSTRACT
We examine Sea Surface Temperature (SST) trends and its relationship with precipitation in the Western Equatorial Africa (WEA), Central Equatorial Africa (CEA) and Western and Central Equatorial Africa (WCEA) regions. Global Precipitation Climatological Project (GPCP) and revised version 5 of Extended Reconstructed Sea Surface Temperature (ERSSTv5) data from 1979 – 2018 were used for the study. SST show an increasing trend with highest value recorded in 2015. Variations in SST is strongly influence the precipitation

in the regions with strong positive Pearson (ρ) and Spearman (r_s) correlation coefficients recorded for WEA ($\rho = 0.627, r_s = 0.627$), CEA ($\rho = 0.501, r_s = 0.565$) and WCEA ($\rho = 0.601, r_s = 0.651$). SST in the equatorial Atlantic respond to both longitudinal and latitudinal changes with decrease trend toward the coast and increase away from the equatorial region before further decrease. This behavior is well translated to the precipitation of the study area where precipitation increases with latitudes and decreases across the longitudes and as it goes further away from the coast. Analysis also show a remarkable seasonal change in SST and precipitation with peak SST and precipitation across the CEA correspond to the lowest SST and precipitation across the WEA and vice versa, for winter and spring respectively. Coastal upwelling is suggested in Republic of Congo, DR Congo and Angola coast with rapid decrease in coastal SST in July, August and September.

Keywords: Western and Central Equatorial Africa, Sea Surface Temperature, Precipitation

1. INTRODUCTION

Temperature of the topmost water of the ocean i.e. sea surface temperature (SST) is one of the most important variables for ocean climate change and variability studies. it is one of the significant outcomes of Atmosphere-Ocean interactions in the climate system which has been suggested to have strong relationship with precipitation (Giannini et al., 2003, Lu and Delworth 2005, Hoerling et al., 2006, Shanahan et al., 2009, Dai 2013) in Africa. World oceans which constitute about 71% of the Earth continuously interact with the atmosphere, exchanges heat, mass and momentum, thereby increasing the sea surface temperature which could have profound effects on global climate. Water vapor that is considered to be the most important greenhouse gas in the atmosphere is primarily sourced from the ocean. Increases in sea surface temperature have led to an increase in the amount of atmospheric water vapor over the oceans (IPCC, 2013). This water vapor furnishes weather systems that produce precipitation, increasing the risk of heavy rain and snow. Even a slight increase in SST can influence a large-scale Atmospheric circulation, thereby, causing a prevalent weather phenomenon such as monsoon, cyclone, El Niño etc. Owing to the position of Africa i.e. up to the northern hemisphere, center to the equator i.e. the equatorial latitude and down to the southern hemisphere, surrounded by North Atlantic Ocean in the north, South Atlantic Ocean in the south, Atlantic Ocean in the west and India Ocean in the east, constitutes a distinct type of climate system. African climate could be characterized by an extensive diversity of climate system spanning from humid equatorial system, through sub-tropical Mediterranean climate system and to seasonal-arid tropical climate system (Hulme et al., 2001). Humid equatorial climate system mostly found in the Gulf of Guinea area is subdivided into tropical monsoon predominant in west Africa and tropical rainforest dominating most central African countries. Seasonal variations in SST have been strongly linked to seasonal evolution west Africa monsoon and intertropical convergence zone(ITCZ) over the equatorial Atlantic Ocean (L. R. Ceespo et al 2018), he concluded that equatorial Atlantic SST contributes to the seasonal cycle in precipitation and meridional winds over the entire equatorial Atlantic, but only strongly influences zonal winds in the western equatorial Atlantic and has little influence on the northward penetration of the west Africa monsoon. Similarly, (Wenjian Hua et al., 2016) studied the possible causes of the central equatorial African long-term drought; he reported that long-term drought during April, May and June over central equatorial Africa may reflect the large-scale response of the atmosphere to tropical SST variations. Generally, the climate and atmospheric circulation of West Africa and central Africa is driven by both seasonal variation of SST in the Gulf of Guinea and seasonal movement of intertropical tropical convergence zone (ITCZ). The mickle volume of water vapor that sustains the high rainfall amount at both regions emanates mainly from Gulf of Guinea. However, rainfall amounts are relatively limited in central equatorial Africa compare to west Africa because the coastal areas adjoining the Congo basin are frequently cooled by the Benguela current flowing northward, lessening the influx of water vapor into the atmosphere. African socio-economic and developments is tied to agriculture and water resources (MoluaE. L. 2008), for this reason, sizable number of studies on African climate has been centered on relevant forcing factors affecting rainfall for possible seasonal to inter-annual time scales forecasts that will facilitate farmers to plan with greater confidence.

Literatures have shown a lot of studies that have been done on correlation between SST and precipitation in the Gulf of Guinea e.g. (K. E. Ali et al., 2011) studied influence of the Gulf of Guinea coastal upwelling on the precipitations along its northern coast during boreal summer period, they show that coastal precipitations of the July-September are correlated by both the coastal and equatorial sea surface temperature. However, the study couldn't report the level of their association. Central Equatorial Africa (CEA), on the other hand, is the least studied region in Africa and is a region that has been the subject of much less investigation than other large-scale convective regions in the tropics (Washington et al., 2013).

Due to the important of rainfall and its effects on biogeochemical and ecological processes on a local scale, that could also enhance coastal upwelling, changes in coastal salinities, biological productivity etc. This study uses NOAA_ERSST_V5 2x2 grids monthly mean SST dataset and gridded reanalysis precipitation data from (NCEP–NCAR) to study the spatio-temporal trends of SST and precipitation and their corresponding relationship to establish the level of their connections over west Africa and central equatorial Africa for possible future predictions, by examining SST variability on potential rainfall in the region.

Study regions

Western and Central Equatorial Africa (WCEA, $0^oE - 20^oE$ and $10^oN - 10^oS$) comprise the coastal Gulf of Guinea and Congo basin (fig. 1). This region is characterized with warm temperature owing to its latitudinal position, high precipitation because of its proximity to the large body of ocean waters and movement of ITCZ with densely populated vegetations. The region is directly affected by five principal ocean currents: Benguela current, Canary current, South Equatorial Current, Counter Equatorial Current and Guinea Current (Longhurst, 1962). The region exhibits humid equatorial system of climate, this system of climate is subdivided into two climatic systems; the tropical monsoon in the west equatorial Africa and tropical rainforest in the central equatorial Africa i.e. the Congo basin. Although both tropical monsoon and tropical rainforest are similar in terms of conditions for their occurrences, however, tropical monsoon climate system could exhibit seasonal changes i.e. wet and dry monsoon, this translates into what is generally.

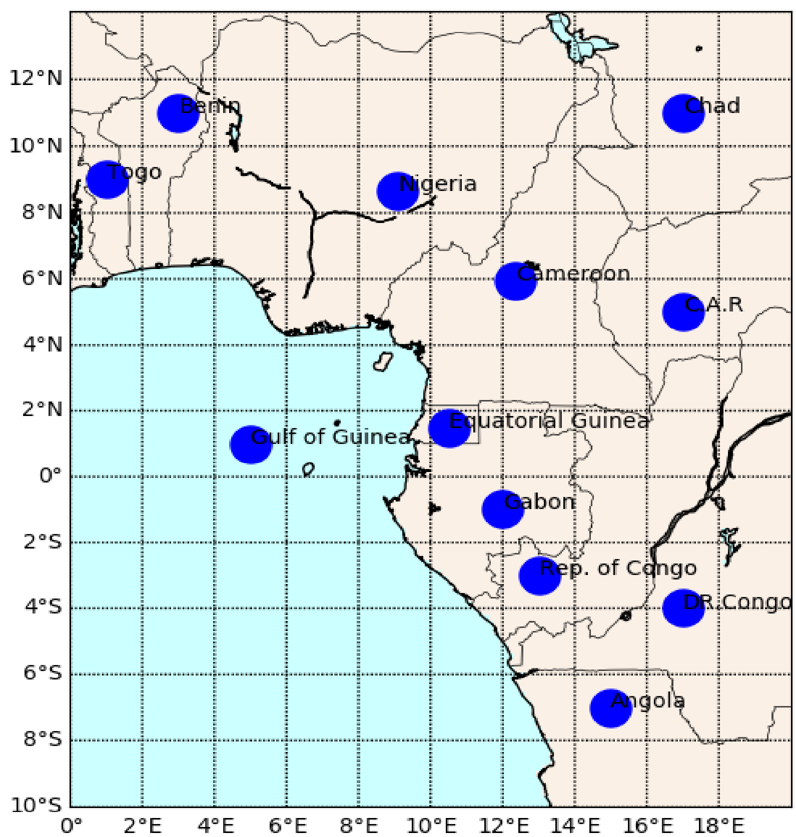


Figure 1 Map showing coastal countries of Western and Central Equatorial Africa (WCEA) called wet and dry seasons in western equatorial Africa countries like Nigeria. Unlike tropical monsoon, tropical rainforest receives lower annual precipitation, in general less than 2000 mm/year (UNESCO, 1978) as it is in Congo basin.

2. DATA AND METHODS

SST data description

Monthly mean SST obtained from revised version 5 Extended Reconstructed Sea Surface Temperature (ERSSTv5) were used for the present study (Huang et al., 2017). ERSST dataset is a global monthly sea surface temperature dataset derived from the International Comprehensive Ocean-Atmosphere Dataset (ICOADS). Production ERSST is on a $2^o \times 2^o$ grid with spatial completeness enhanced using statistical methods. This dataset begins in January 1854 to the present date; the newest version of the dataset is ERSSTv5, which uses new data sets from ICOADS Release 3.0 (Sea Surface Temperature) SST. The dataset is a blended data from combination of both satellite and observational *in-situ* data from buoy and ships, the methods used to derive the data are described in Reynolds et al. (2003). The data is available at (http://www.ersl.noaa.gov/psd/data/gridded/data.noaa.ersst.v5.html) on $2^o \times 2^o$ grid resolution on netcdf4 data format.

Precipitation data description

Monthly mean precipitation data from Global Precipitation climatology Project (GPCP) (Adler et al., 2003) were used for the study. The data is an integration of satellite datasets over land and ocean, and gauge analysis over land blended with some sounding observations on netcdf4 data format. The data is available on monthly average at global scale at (https://www.esrl.noaa.gov/psd/data/gridded/data.cmap.html) on $2.5^o \times 2.5^o$ grid resolution spanning from 1979 to present.

Data analysis

Observational netcdf4monthly mean SST and precipitation data downloaded from their respective website link provided were on a global scale, a particular software codes were used to extract time series data for the study area and period. Sub-extractions were performed, and anomalies (deviation from average value) were calculated to meet the objectives of the study such as monthly SST and Precipitation anomaly, yearly average, SST and Precipitation across both latitude and longitude of the area under study. We exploit both Pearson and Spearman correlation methods to quantify the level of connections between SSTs and Precipitations.

Pearson's correlation coefficient

The Person correlation coefficient was named after British statistician Karl Pearson, it is bivariate i.e. it can be used to summarize the strength of the linear relationship between two data samples, and require a gaussian like distribution. It is calculated as the covariance of the two variables divided by the product of the standard deviation of each data sample. It is the normalization of the covariance between the two variables to give an interpretable score.

$$\rho = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (1)$$

Where,

ρ = Pearson correlation coefficient

x = value in the first set of data

y = value in the second set of data

n = total number of values.

Equation (1) returns a value between -1 and 1 that represent the limits of correlation from a full negative correlation to a full positive correlation. A value of 0 means no correlation. The value must be interpreted, where often a value below -0.5 or above 0.5 indicate a notable correlation, and values below those values suggest a less notable correlation.

Spearman's correlation coefficient

Spearman correlation coefficient was named after British psychologist (Edward Spearman), can be used to summarized the strength between two data samples. Unlike Pearson correlation, Spearman correlation is best used for nonlinear variables. As with the Pearson correlation coefficient, the scores are between -1 and 1 for perfectly negatively correlated variables and perfectly positively correlated respectively. Instead of calculating the coefficient using covariance and standard deviations on the samples themselves, these statistics are calculated from the relative rank of values on each sample. It is normally used for non-parametric statistics i.e. a non-gaussian statistical distribution. Pearson and Spearman correlation have been widely used in climate analysis (von Storch, H. and Zwiers, F. W. 1999).

$$r_s = \frac{\sum_i (x_i - m)(y_i - n)}{\sqrt{\sum_i (x_i - m)^2 \sum_i (y_i - n)^2}} \quad (2)$$

Where

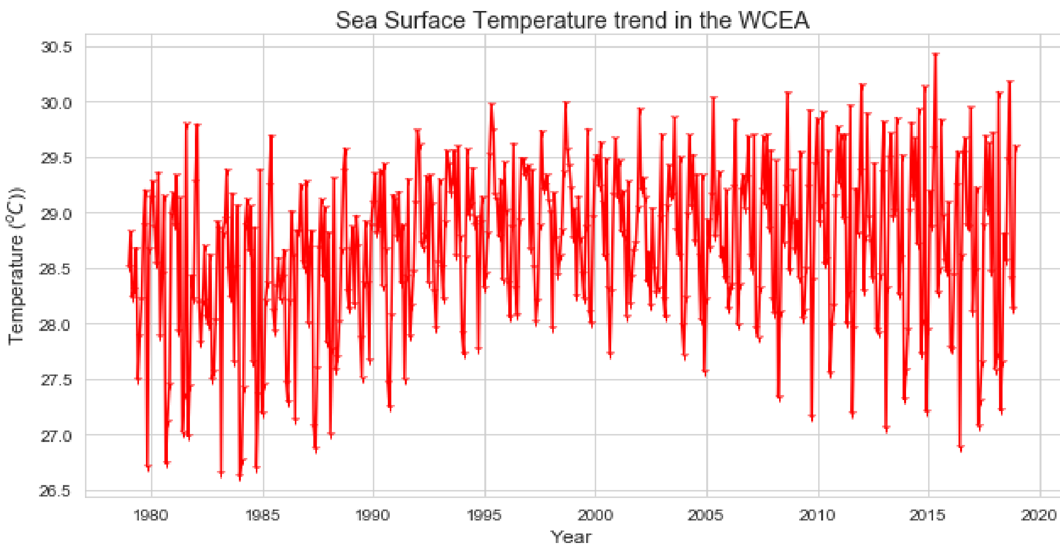
r_s = Spearman correlation coefficient

x_i = value in the first set of data
y_i = value in the second set of data
m = mean of the first data
n = mean of the second data.

3. RESULTS

Temporal SST and Precipitation trend (WCEA)

Figure 2a shows climatological annual average Sea Surface Temperature and Precipitation time series trends of the WCEA for the period of 1979 – 2018 from ERSSTv5 and GPCP respectively. The plot shows similarity in trends by maintaining almost similar shape with some degree of variations observes in 1995, this variation continues for almost two decades. Sea surface temperature is completely on increasing trends with highest amounts recorded in 2015, it is noted that this same year was pronounced as the world hottest year on record with 0.87-degree Celsius global average temperature increase from January through December (NASA, 2016).



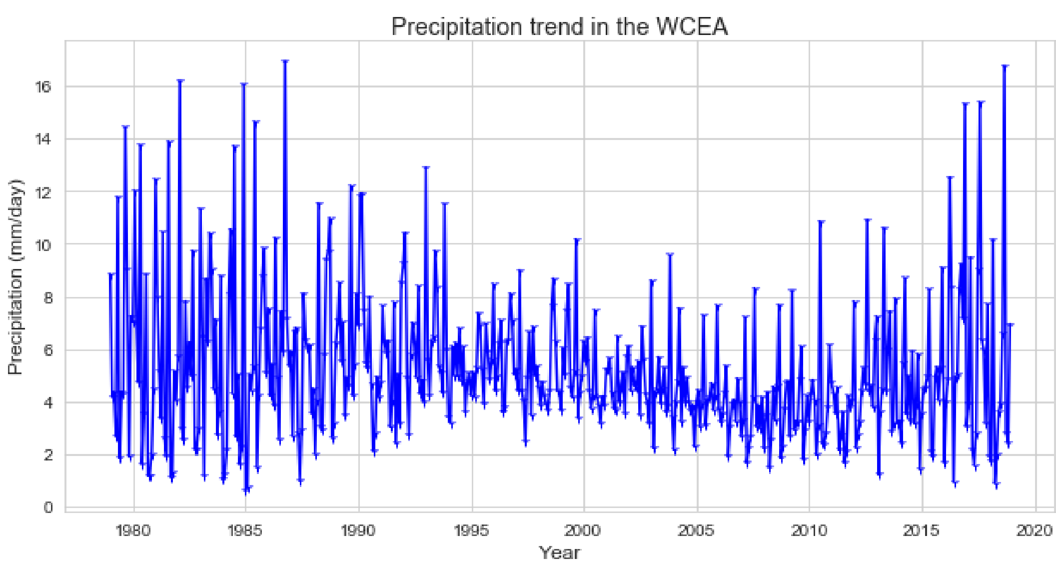


Figure 2a The climatological annual average Sea Surface Temperature (o_C) and Precipitation (mm/day) time series trend for the period of 1979 – 2918 over Western and Central Equatorial Africa (WCEA, $1^oE - 20^oE$and $10^oN- 10^oS$) from ERSSTv5 (red line plot) and GPCP (blue line plot) respectively.

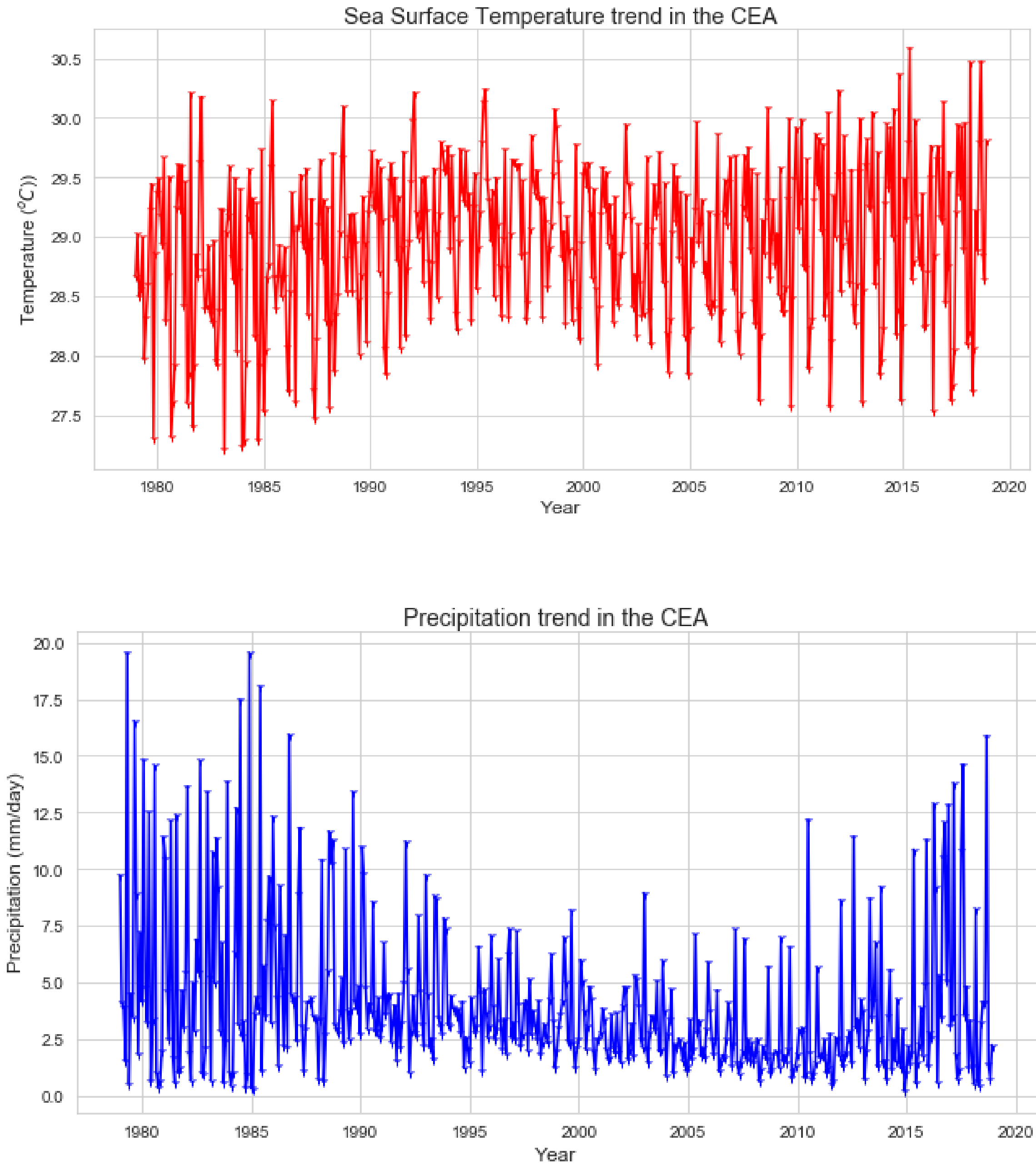
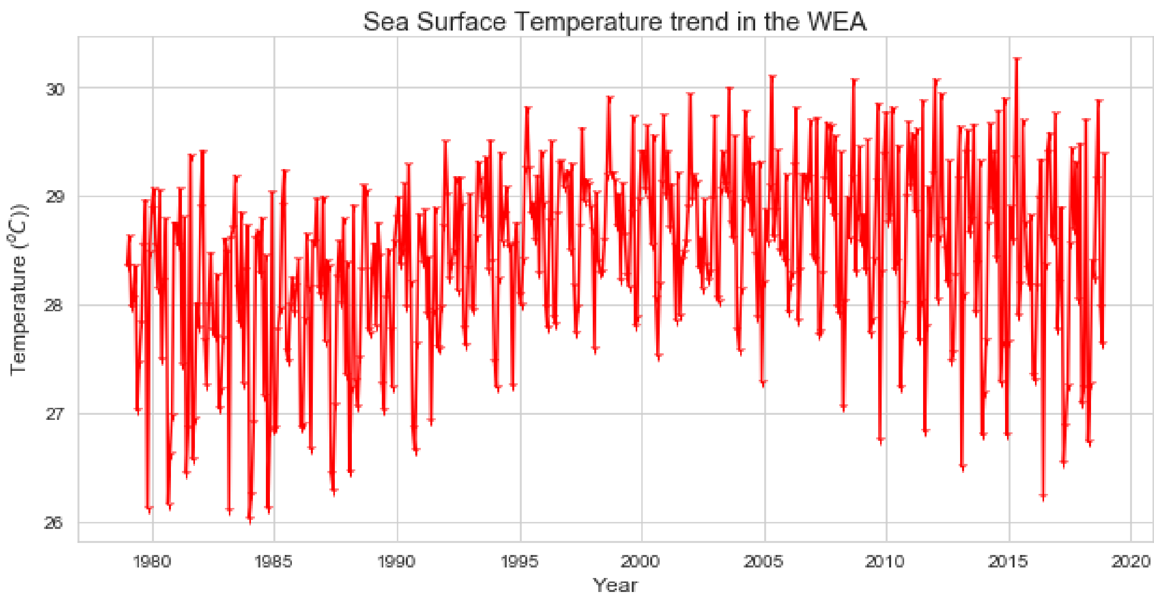


Figure 2b The climatological annual average Sea Surface Temperature (o_C) and Precipitation (mm/day) time series trend for the period of 1979 – 2918 over Western and Central Equatorial Africa (WEA, $0E - 10^oE$and $2^oN - 10^oN$) from ERSSTv5 (red line plot) and GPCP (blue line plot) respectively.

Temporal SST and Precipitation trend (CEA)

SSTs in the Indian and Atlantic Ocean have a tremendous effect on Africa rainfall through their impacts on large-scale circulation (Hoerling et al., 2006, Ting et al., 2009). SST and precipitation over Central Equatorial Africa (CEA) show a moderate connection with precipitation on a decreasing trend as it could be seen in figure (2b), this has been reported by (Malhi and Wright 2004, Yin and Gruber 2010, Asefi-Najafabady and Saatchi 2013, Diemetal., 2014), they argue that, the variation may be connected with SST variations over Indo-Pacific associated with the enhanced and westward extended tropical Walker circulation. The escalation and stretching out of tropical Walker circulation westwardly as a result of swift warming in the Indian Ocean and warm pool, has effectively extended the warm pool westwardly and increased subsidence over the Central Equatorial Africa (CEA).



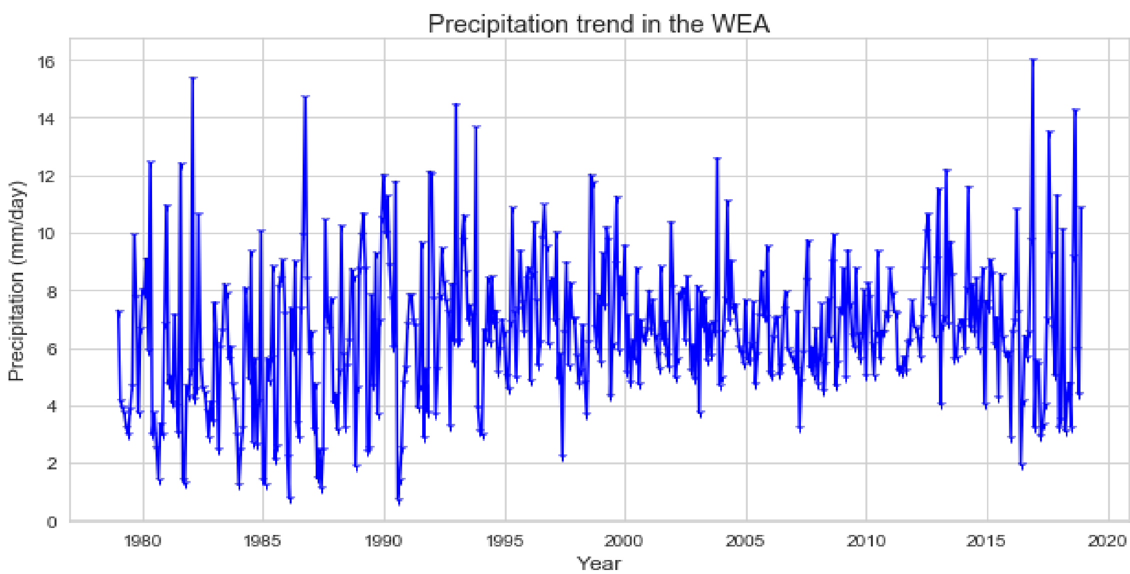


Figure 2c The climatological annual average Sea Surface Temperature (o_C) and Precipitation (mm/day) time series trend for the period of 1979 – 2918 over Western and Central Equatorial Africa (CEA, $10E - 20^oE$and $2^oN - 10^oS$) from ERSSTv5 (red line plot) and GPCP (blue line plot) respectively.

Temporal SST and Precipitation trend (WEA)

Western Equatorial Africa that form most of west African costal countries has its climate controlled by two air masses i.e. the hot dry air masses originating from Sahara Desert and moist equatorial air masses from Gulf of Guinea, as a result of Atmospheric pressure differences build up overtime between the coastal land and the Gulf of Guinea waters. Thus, the region is characterized by monsoonal climate that could be either dry monsoon or wet monsoon at some periods of the year, which are often regard as dry season and wet season respectively. Figure 2c shows a strong association between SST and precipitation as they both follow similar trend in the WEA over the year, this shows a strong linkage between SST and west Africa monsoon (WAM) as it reported by (Zeng et al., 1999; Biasutti et al., 2008).

Spatial SST and Precipitation trend

Seasonal spatial pattern of SST and Precipitation

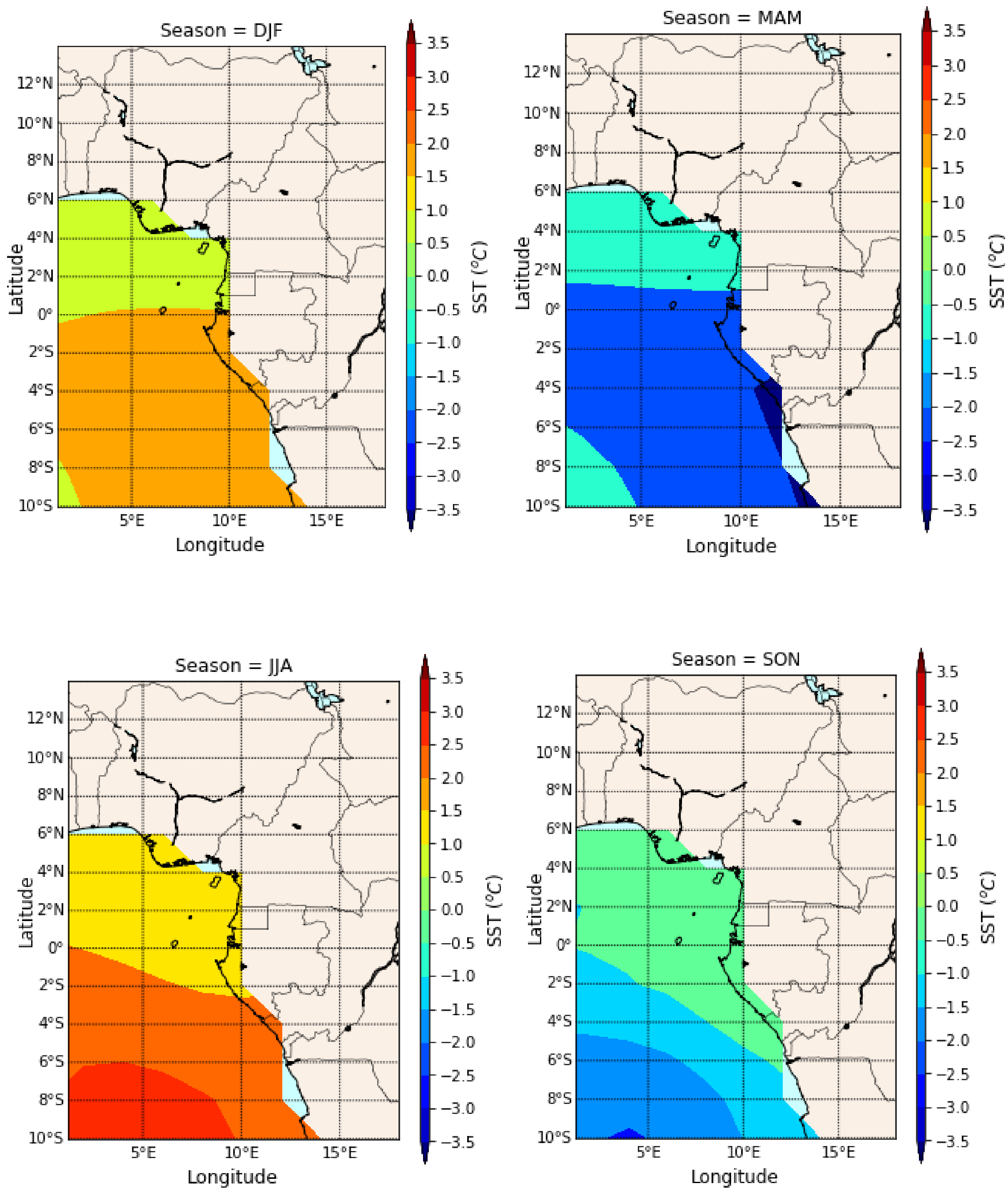


Figure 3 (a) Spatial seasonal Sea Surface Temperature anomaly for the period of 1979 – 2918 over Western and Central Equatorial Africa (WCEA, $10E - 20^{o}E$and $2^{o}N - 10^{o}S$) from ERSSTv5

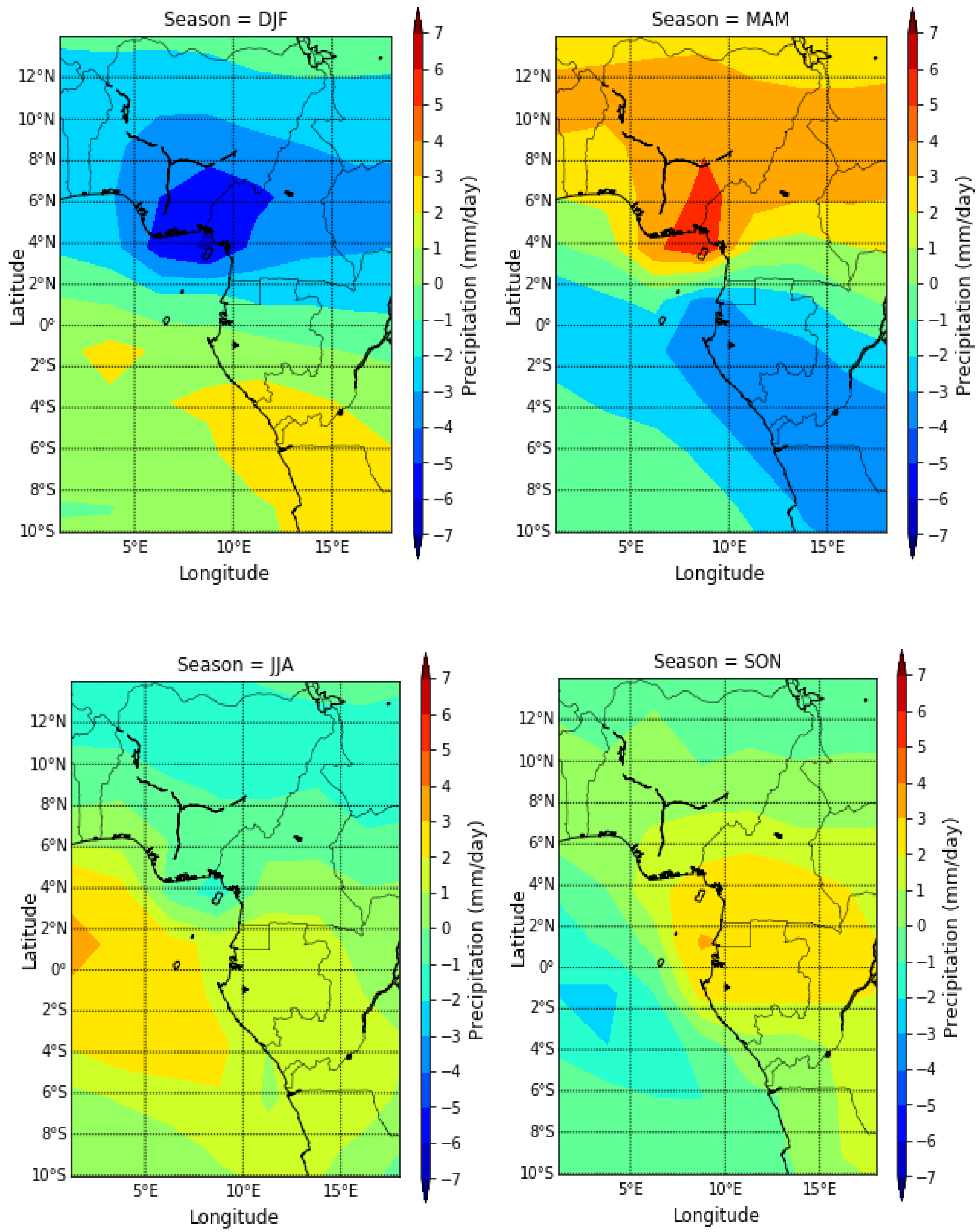
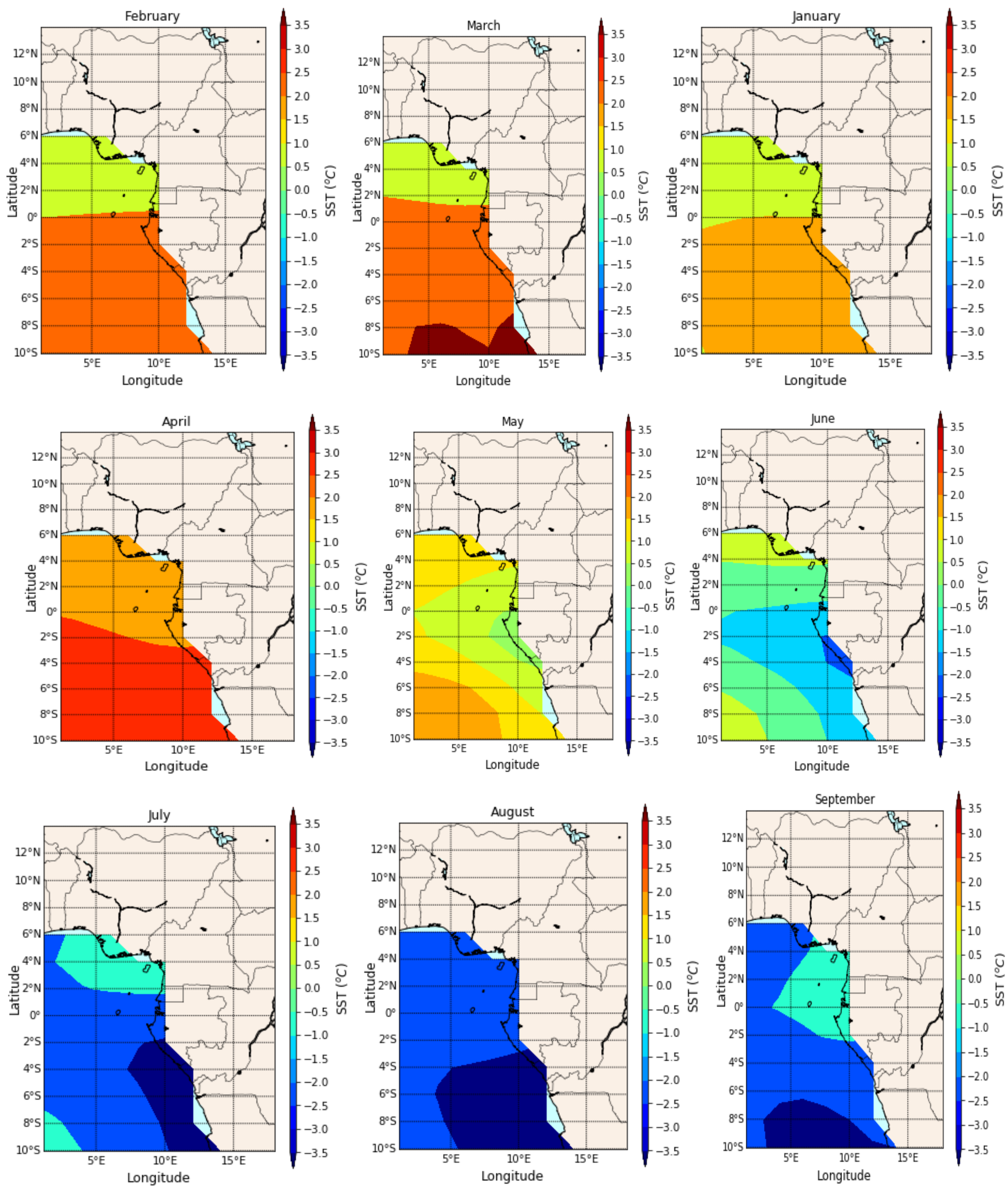


Figure 3 (b) Spatial seasonal Precipitation anomaly trend for the period of 1979 – 2918 over Western and Central Equatorial Africa (WCEA, $10E - 20^oE$and $2^oN - 10^oS$) from GPCP.

Although the region is characterized with two distinct seasons (wet and dry season), for more elaboration and clarifications, this study adopts the four conventional seasons (winter, spring, summer and autumn). Figure 3 (a) and (b) depicts spatial distribution of seasonal SST and precipitation in the WCEA respectively. The first season (January, February and March represented as DJF) correspond to winter, shows a close connection between SST and precipitation with positive anomalies over CEA and negative anomalies over WEA with highest precipitations in the Congo, D.R. Congo and Angola coasts. This same season records the lowest precipitation across WEA while it records the highest across CEA. Spring (March, April and May represented as MAM) season recorded a very low SST anomaly in CEA with an extreme cooling noticed in Congo, D.R. Congo and Angola coast. The observed negative SST anomalies relates well with precipitation over CEA with a moderate correlation in WEA. The season records the lowest precipitation ever across CEA and the highest over WEA with greatest amounts in the southern Nigeria, moderately high in chad, Cameroon, Benin Togo and northern Nigeria. Spring time drought in CEA has been a subject of research presently (Hua et al, 2018) with the objective of determining the responsible climate forcing agents. In summer (June, July, August, represented as JJA) season, positive SST and precipitation anomalies dominate the whole WCEA with highest values across CEA. Larger precipitations amounts were observed in Equatorial Guinea, Gabon, Congo, D.R. Congo and Angola in the season. Autumn (September, October and November rep. as SON) season also seen with positive anomalies for both SST and precipitation in the WCEA coast except in the Angola coast with a thin negative SST anomaly. Even though positive SST anomaly were observed at both CEA and WEA in autumn, CEA recorded the highest SST and precipitation in the season with highest amount of precipitation in the Equatorial Guinea coast.

Monthly spatial pattern of SST and Precipitation



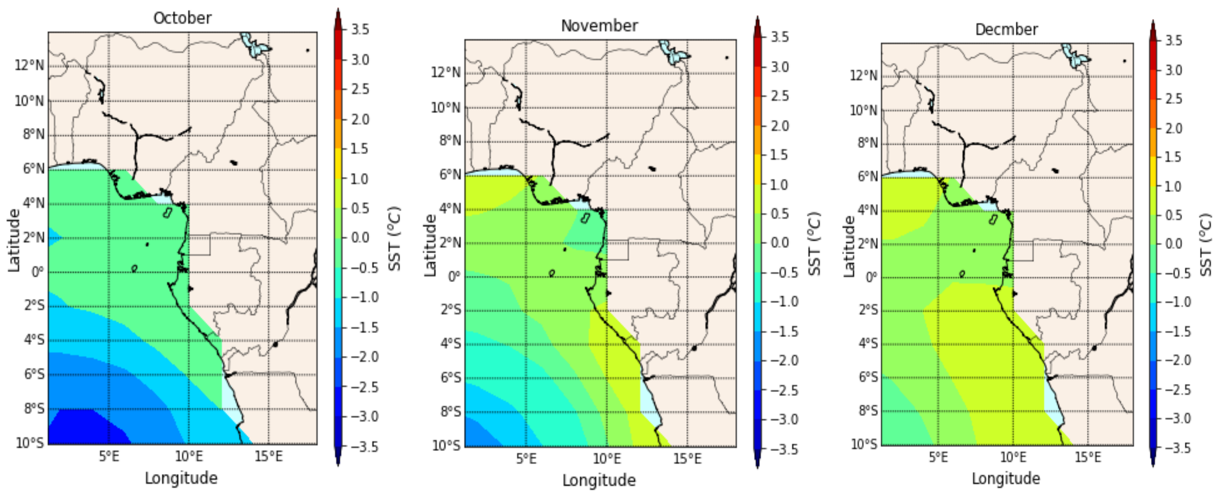
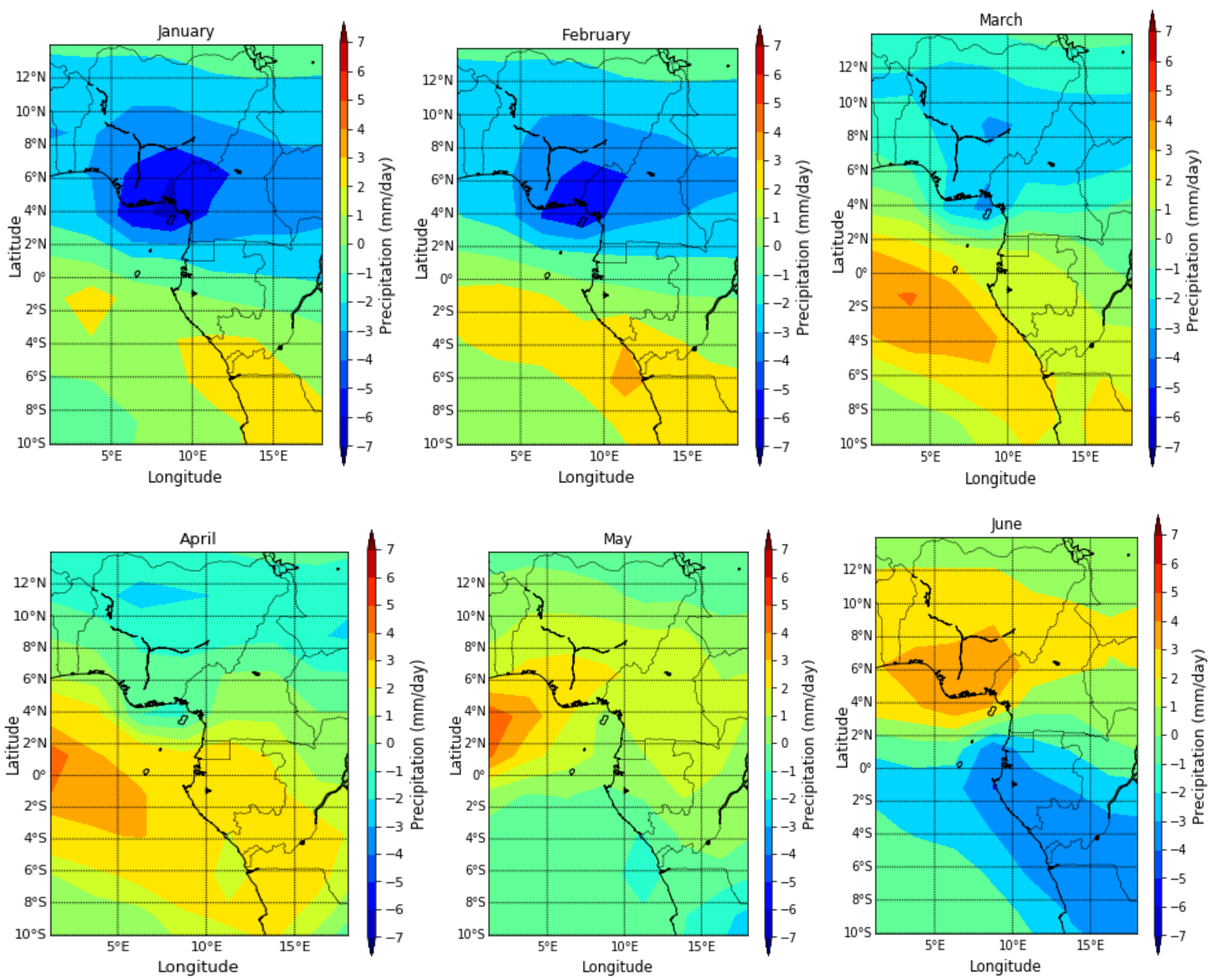


Figure 4 (a) Spatial and temporal seasonal Sea Surface Temperature anomaly in the WCEA from 1979 – 2018.



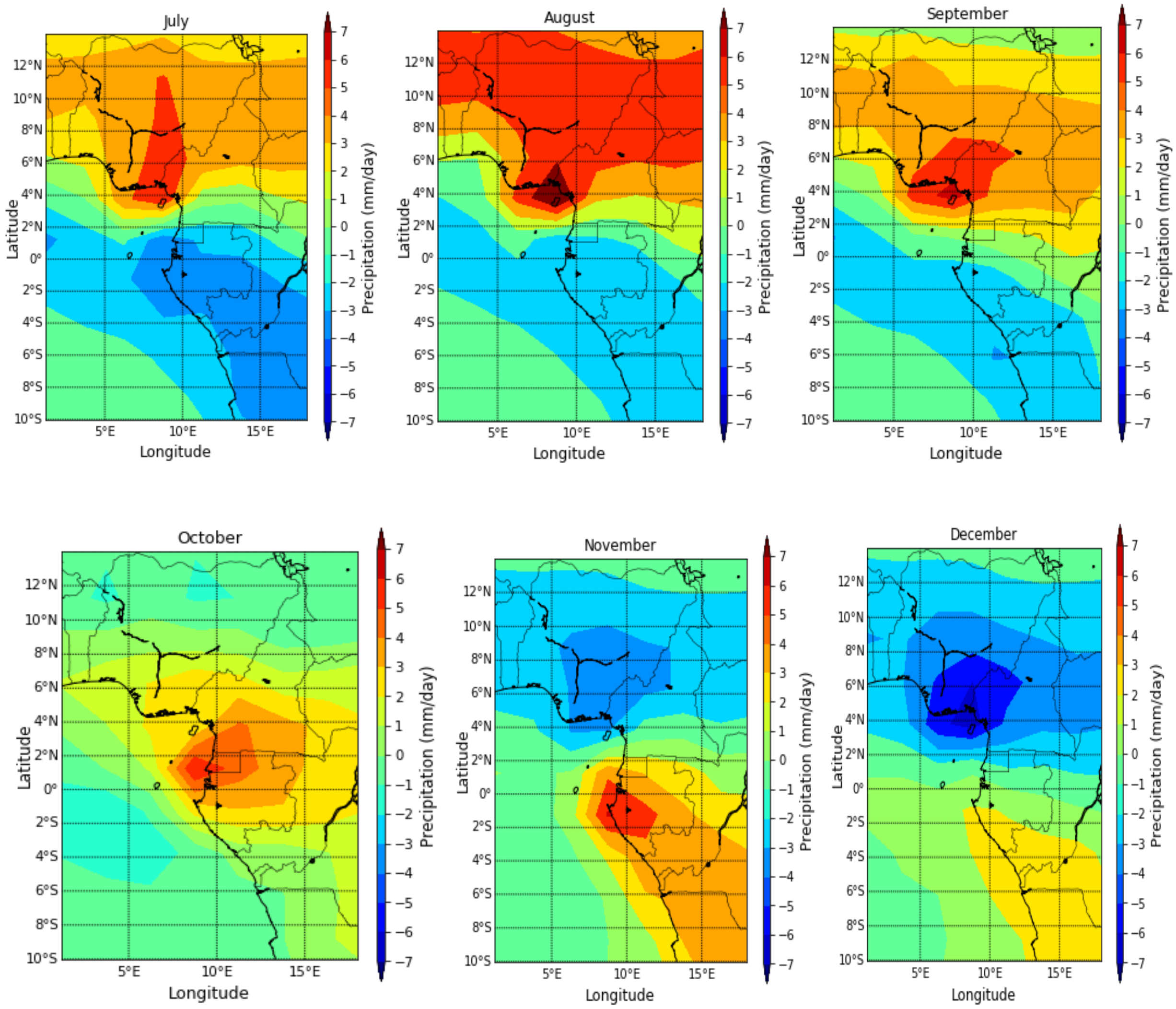


Figure 4 (b) Spatial and temporal seasonal Precipitation anomaly in the (WCEA) from 1979 – 2018.

Figure 4 (a) and (b) show monthly spatial pattern of both SST and precipitation in the WCEA, it was observed that SST and precipitation anomalies are reciprocal of each other at both WEA and CEA for all the months. Monthly precipitation trends show that CEA records its highest amount of precipitation in November with highest values in Gabon coast, and the lowest in June, July, August and September accordingly. WEA records its highest precipitation in August with highest values recorded in the southern Nigeria and Western Cameroon. WEA recorded very low precipitation in November, December, January, February and March with lowest in January. These months coincide with the dry season as it usually referred in the region. Rapid drop in SST were discovered in July, august and September in WCEA, with lower values in Congo, DR Congo and Gabon, this suggests coastal upwelling around this period in the region. The rapid reduction is often term as the Atlantic Cold Tongue (ACT) which Okumura and Xie (2004) showed that, the ACT could enhance the southerly winds in the Gulf of Guinea, and drive rain band farther north over the land.

Next, we analyzed spatial variabilities of SST and precipitation. Figure (5) shows SST and precipitation trend over longitude and latitude in WCEA for the period of 40 years. It is noted that both SST and precipitation move with the same trend over the year under study. SST and precipitation decrease with longitude, this suggests decrease in precipitation as we move farther away from coastal region. It is also observed that both SST and precipitation increase over the latitudes on either side (North and South) from the equator up to about 6^oN to the North and to about 9^oS to the South before a notable decrease. The result agrees with Gu et al. (2004) that studied Seasonal evolution and variability associated with the West African Monsoon System, they conclude that the coast is the wettest period of the whole West African monsoon.

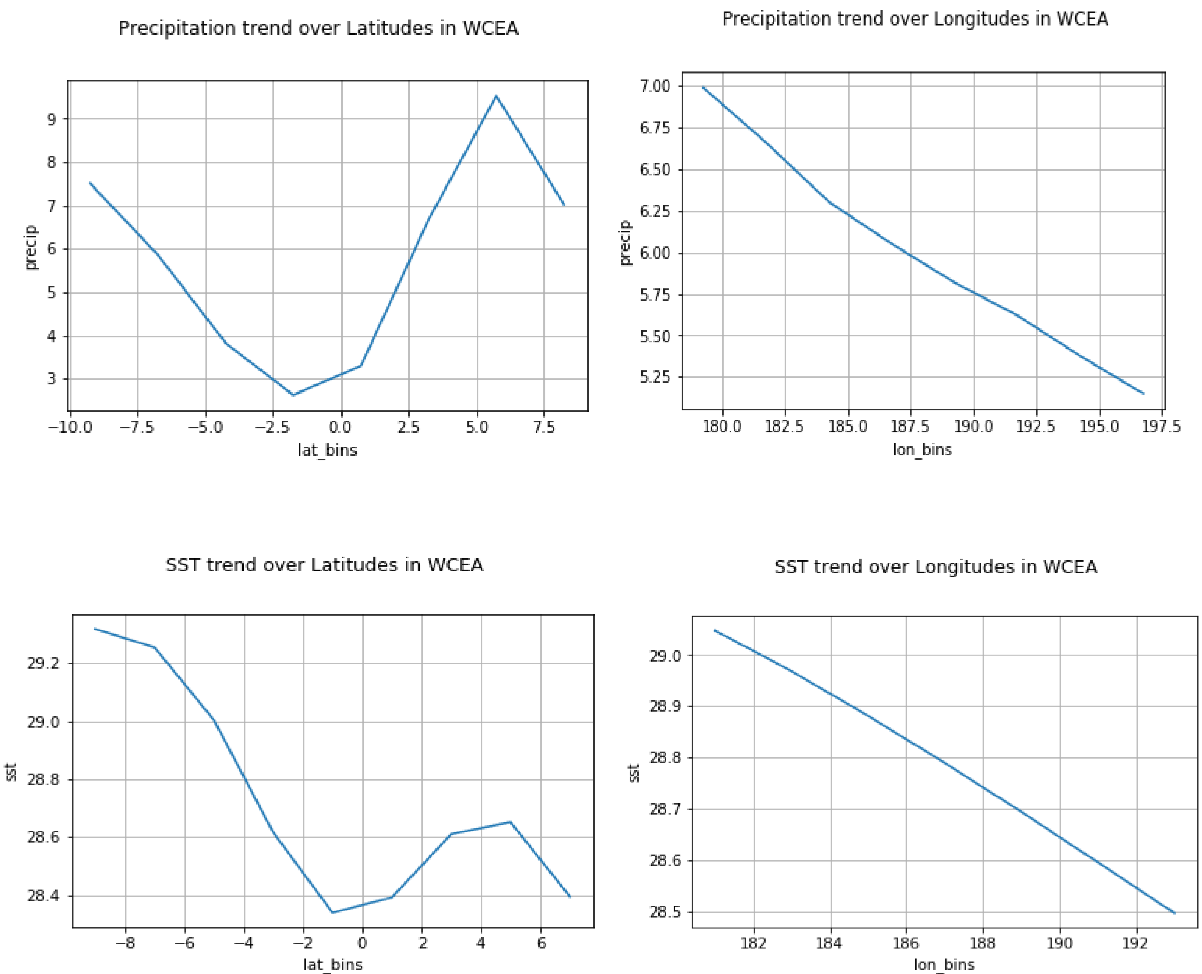
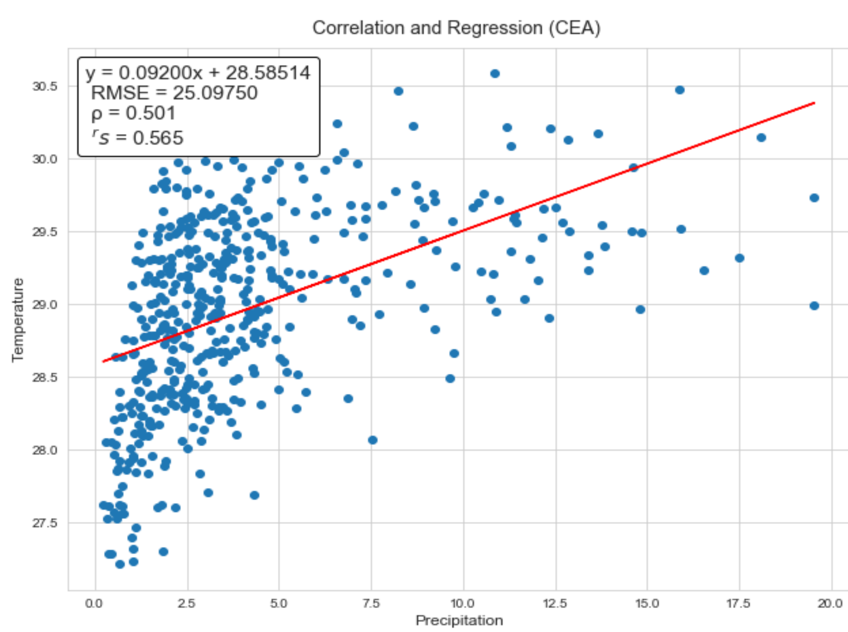


Figure 5 Spatial trends of SST and Precipitation trends over longitude and latitude in the WCEA for the period of 1979 – 2018.



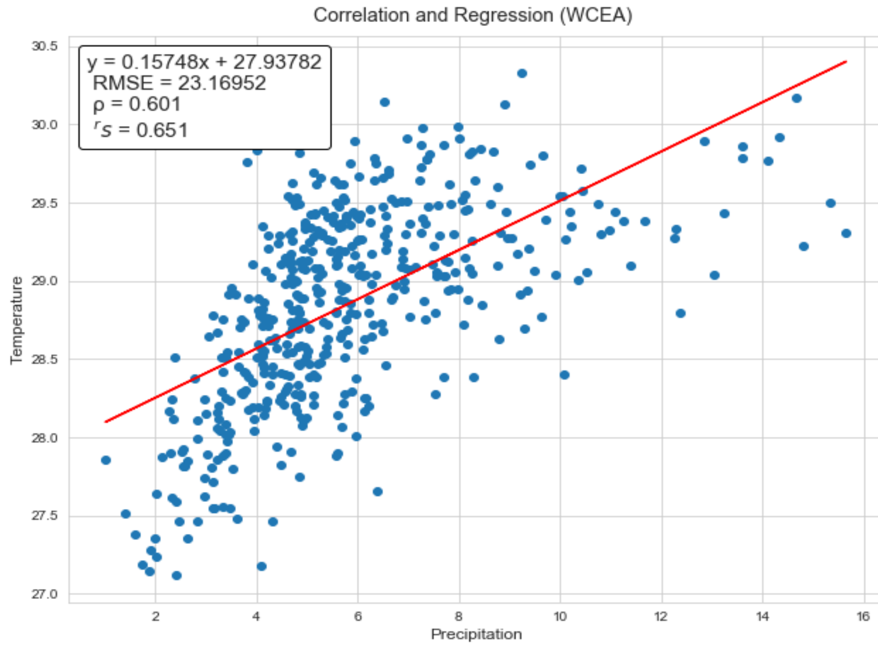


Figure 6 The magnitude of correlation between SST and Precipitation represented by their respective values of correlation coefficients i.e. Pearson (ρ) and Spearman (r_s) for WCEA, CEA and WEA respectively, with a regression line of best fit (Red line).

5. CONCLUSION

African economy depends greatly on rainfall and SSTs in the Atlantic and Indian oceans have large impacts on the African rainfall (Hoerling et al., 2006, Ting et al., 2009). This study has critically examined spatial and temporal SST trends and its connections with precipitation in the Western and Central Equatorial Africa region (WCEA) holistically, and the two subregion that make up WCEA separately i.e. the Western Equatorial Africa (WEA) and Central Equatorial Africa (CEA). In other to know the magnitude of their connections, we performed Pearson and Spearman correlations on ERSSTv5 SST and GPCP precipitation data from, the result is presented in figure (6) as calculated from eqn. (2 and 3) for Pearson and Spearman respectively for WCEA, CEA and WEA. Results indicate that there is a strong correlation between SST and precipitation in WCEA with correlation coefficients of 0.601 and 0.651 for Pearson and Spearman correlation respectively. It will be noted that the lowest correlation coefficient of 0.501 and 0.565 for Pearson and Spearman respectively were recorded in CEA as compared with the two other results, as though, the result is worthy of a good correlation by convention. WEA region shows stronger correlation between SST and Precipitation with correlation coefficient of

0.627 and 0.627 for both Pearson and Spearman respectively. It was observed that Spearman correlation coefficient values are always higher than Pearson except for WEA where they both have the same value. The higher correlation seen in WEA may be link to the large-scale atmospheric circulations and stronger ITCZ in the region. We analyzed both seasonal and monthly SST and precipitation trends with their respective anomalies, we discovered that CEA receives its highest precipitation in winter season and its lowest in the spring while WEA is other way round i.e. precipitation is at it peak across WEA and at minimum across CEA in the spring, but other way in the winter, and vice versa. These occurrences could be attributed to the seasonal movement of ITCZ in the region. Finally, we examine the spatial trend of both SST and precipitation along longitude and latitude, we noted a longitudinal dependency of SST and precipitation in the WCEA where there was high precipitation across the coast and decreases further away from the coast. They also display a latitudinal dependency as they both increase from the equator in the Northern and Southern hemisphere and consequently decrease at the same latitude.

This study shows that SST is related to precipitation and can be used to study and improve the precipitation forecast over Western and Central Equatorial Africa to proliferate our warning capacity to harsh weather conditions in the region. Adequate rain prediction could inform decision maker on the mitigation of flood and perhaps fish farmers for when to go for floodplain fishes and crop farmers in the region.

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Author contributions

Ayinde Akeem Shola → sourced for the data, handled the software used for the data analysis and wrote methodology

Regina Folorunsho→ wrote the introduction and results

Ekundayo Adeyemi → wrote the conclusions

Conflict of interests

No conflict of interest.

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