Characteristics and Changes in SON Rainfall over Uganda (1901-2013)

Bob Alex Ogwang
African Centre of Meteorological Applications for Development (ACMAD)

Godwin Ayesiga
University of Reading

Moses Ojara
Nanjing University of Information Science & Technology

Abubakar Kalema
Uganda National Meteorological Authority

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Bob Alex Ogwang[1,2,*], Alex Nimusiima[3], Teddy Tindamanyire[1], Margaret N. Serwanga[1], Godwin Ayesiga[1], Moses Ojara[1], Fred Ssebabi[1], Gordon Gugwa[1], Yusuf Nsubuga[1], Rhoda Atim[1], Robert Kibwika[1], Joseph Kiwuwa Balikudembe[1], Herbert Kikonyogo[1], Abubakar Kalema[1], Victor Ongoma[2,4], Aggrey Taire[1], Anne Kiryhabwe[1], Musa Semujju[1], Felix Einyu[1], Rashid Kituusa[1], Lawrence Aribo[1]

[1]Uganda National Meteorological Authority, P. O. Box 7025, Kampala, Uganda
[2]College of Atmospheric Science, Nanjing University of Information Science and Technology, Nanjing, Jiangsu, 210044, P. R. China
[3]Department of Geography, Geo-Informatics and Climatic Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda
[4]South Eastern Kenya University, P. O. Box 170-90200, Kitui, Kenya

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Abstract: This study investigated the characteristics and changes in September-November (SON) rainfall over Uganda. The dominant mode of variability of SON rainfall was identified by performing Empirical orthogonal functions (EOF) analysis, using rainfall data from Climate Research Unit (CRU) for the period 1901 to 2013. Results indicate that the dominant mode of variability of SON rainfall exhibits a unimodal pattern, explaining 50.2% of the total variance. Mann-Kendall analysis was deployed to examine sudden changes in SON rainfall over the country. The findings show that the abrupt change in SON rainfall occurred in 1994. Further analysis reveal that SON rainfall over Uganda has a correlation pattern with the sea surface temperature (SST) over Indian, which depicts the positive phase of the Indian Ocean Dipole (IOD). Positive correlation is exhibited in the western IOD sub-region, while negative correlation is shown in the southeastern IOD sub-region. Further study of the both driest and wettest years during the investigated time span indicate that throughout the wettest year, there were positive anomalies in the western sub-region, contrary to the driest year, when same sub-region observed distinct negative anomalies. This illustrates that the positive phase of IOD enhances SON rainfall over Uganda, as opposed to the negative phase which inhibits SON rainfall. The evolution of the IOD can therefore be monitored for the improvement of SON rainfall forecasts, especially over Uganda so as to avoid the losses associated with weather extremes.

***Corresponding authors:** Bob Alex Ogwang**:** bob_ogwang@yahoo.co.uk

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1. Introduction

Rainfall is an imperative weather parameter in Uganda, just like in many other developing nations whose economy is based on rainfed agriculture (Okoola, 1999; Funk and Brown, 2009; Ogwang et al, 2012). Occurrence of extreme weather events adversely affects socio-economic activities in the country (Kodamura, 1994; Nicholson, 1996; Tumwesigye and Musiitwa, 2004; UNFCCC, 2006; Otieno and Awange, 2006; IPCC, 2007).The understanding of weather and climate of the country; Uganda and east Africa region at large is thus essential for the planning purpose to minimize huge socio-economic losses associated with extreme weather events. The common extreme weather events in the region are floods and drought (Lyon and DeWitt, 2012).

Uganda lies along the equator, in east Africa(Figure 1).The region generally experiences rainfall that has high variability at spatiotemporal scales (Indeje et al., 2001). The mean rainfall over Uganda is bimodal, with 'long rains' experienced from March to May (MAM) whereas 'short rains' occur during September to November (SON) (Yang et al., 2015). The bimodal pattern in most parts of the country is influenced by the movement of the Inter-tropical Convergence Zone (ITCZ) following the overhead sun (Okoola, 1996; Mutemi, 2003; Basalirwa, 1995).

Two distinct dry spells, first from June to August and second December to February separates the wet seasons. However, in sections of western and northwestern Uganda tri-modal regimes exists, mainly due to significant rainfall during July to September. Mid tropospheric moist westerly flow penetration from Atlantic Ocean and tropical Congo Rainforest air mass were attributed to the third rainy season (Davies et al., 1985; Mutai et al., 1998; Ogwang et al., 2016; Owiti and Zhu 2012).

Numerous studies have highlighted linkage between East African rainfall and El Niño Southern Oscillation (ENSO) (Indeje, 2000; Jonawiak, 1988; Nicholson, 1996; Ogallo, 1988; Ropelewski and Halpert, 1987). Strong relationship between evolutionary phases of ENSO and rainfall in East Africa has reported earlier, highlighting significant role of ENSO in defining the monthly and seasonal patterns of rainfall in the region (Mutemi, 2003). During El-Niño events incident of rainfall generally enhanced in the region as opposed to suppressed rainfall, which have a tendency to occur during La Nina events.

It has been noted that most of the wettest periods in the region of east Africa have been linked to the Indian Ocean Dipole (IOD) and the coupled IOD-ENSO events (Owiti et al., 2008; Bowden and Semazzi, 2007; Black et al., 2003). Anomalous SST gradient between the south eastern and western equatorial Indian Ocean is termed as Dipole Mode Index (DMI), which describe the intensity of IOD. Positive IOD leads to positive DMI and vice versa (Saji et al., 1999; Webster et al., 1998; Webster et al., 1999).

To predict future climatic conditions under changing climate, it is imperative to recognize and understand climate characteristics and associated changes from the past and present dataset. This is crucial for decision making about adaptation and mitigation measures of coping with climate change, particularly in a least developed country like Uganda. Furthermore, most of the previous studies done over the East African region made use of the regional indices, which may not necessarily capture the climate events over Uganda, especially due to the influence of the local factors.

Current study was established to investigate the characteristics and changes in September to November (SON) rainfall over Uganda. This is expected to enhance knowledge on the climate of Uganda and provide a basis for climate prediction and projection over the region.

2. Data and Methodology

The datasets consisting of precipitation, temperature and sea surface temperatures (SST) are used in this study. The precipitation and temperature data were obtained from the University of East Anglia Climatic Research Unit (CRU TS3.22), which is available (1901-2013) at global scale and a resolution of 0.5° x 0.5° (Harris et al., 2013). In this study, the mean SON rainfall (precipitation) over Uganda was computed from the area average precipitation over longitudes 29ºE - 36ºE and latitudes 1.5ºS - 4.5º for the period 1901-2013.

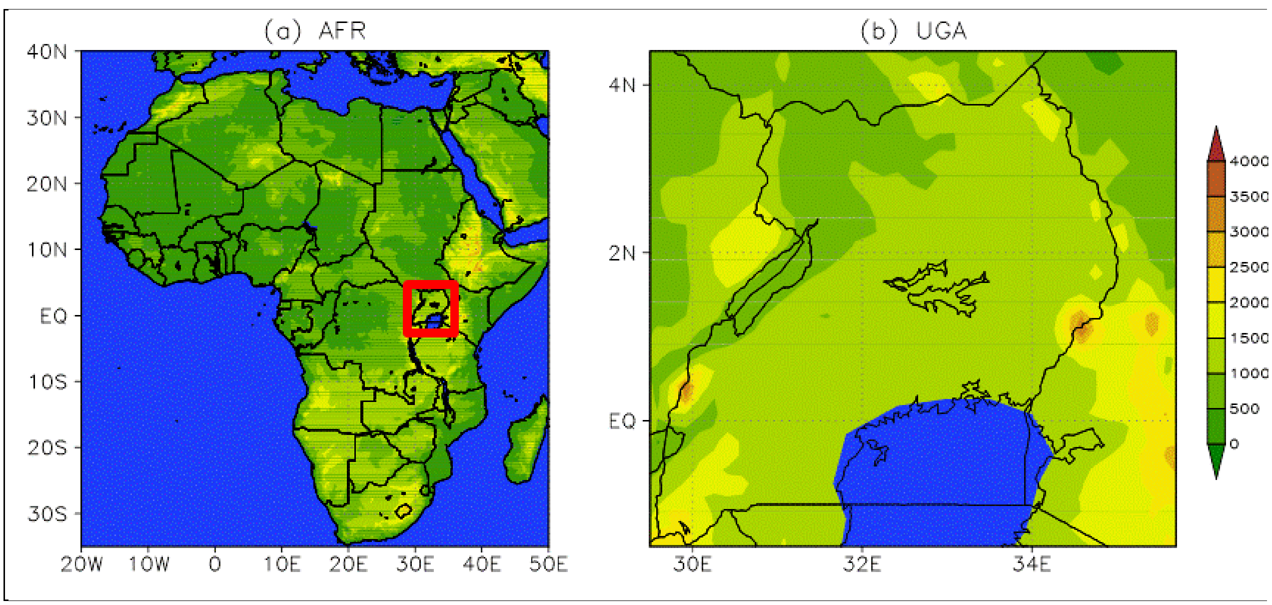

Figure 1: Map showing the area of study and the elevation in meters (a) the position of Uganda in the African continent; the red rectangle (b) Map of Uganda indicating that most areas are 1000 m above sea level.

Journal of Environmental & Agricultural Sciences (JEAS). Volume 8

Extended Reconstructed Sea Surface Temperature (ERSST) Version-4 SST data acquired from the National Oceanic and Atmospheric Administration (NOAA)/National Climatic Data Center (NCDC) was used (Smith et al., 2008). Analysis of the mean SON SST in this study is done over longitudes 32E - 125E and latitudes 32S - 25N.

Empirical Orthogonal Functions (EOF) analysis was used to examine the dominant modes in SON rainfall variability over Uganda. In order to prevent dominating the eigenvectors from spatiotemporal maximum variance dataset used was normalized following Walsh and Mostek (1980).

Z (Standardized rainfall anomaly) was calculated as described in equation [1]

$$Z = \frac{X - \overline{X}}{S_d} \qquad [1]$$

where X denotes observed SON rainfall, $\bar{X}$ long term mean SON rainfall and S_d standard deviation in the SON rainfall. The value of Z provides instantaneous information about the deviation from $\bar{X}$.

In this study, anomaly (ANO) is computed as the observed value of the variable (VAR) at a given time minus the long term mean of the variable (VAR_{LTM}). This is applied to both mean SON rainfall and mean SON sea surface temperature (SST) as described in equation [2];

$$ANO = VAR - VAR_{LTM} \qquad [2]$$

Non-parametric Mann-Kendall (MK) test was utilized to detect trend, whereas the test statistic distribution, was used to detect of abrupt change and the significance of the changing trend in SON rainfall over Uganda (Mann, 1945; Kendall, 1975). Mann-Kendall-Sneyers test was utilized with forward and backward sequential statistic from the progressive analysis to investigate temporal change in the trend (Sneyers, 1990; Jones et al., 2015).

Instead of direct comparison of the data values, test performs relative comparison, whereas standardized variable i.e., U(F) is characterized with zero mean and unit standard deviation. In the plot of sequential Mann-Kendall-Sneyers test, the confidence limits of the standard normal Z values are at α = 5%, with the upper (+1.96) and lower (-1.96) confidence limits.

In this study MK test applied to detect abrupt changes in the mean SON rainfall over Uganda as well as examine the significance of the changing trend of rainfall over the period 1901-2013.

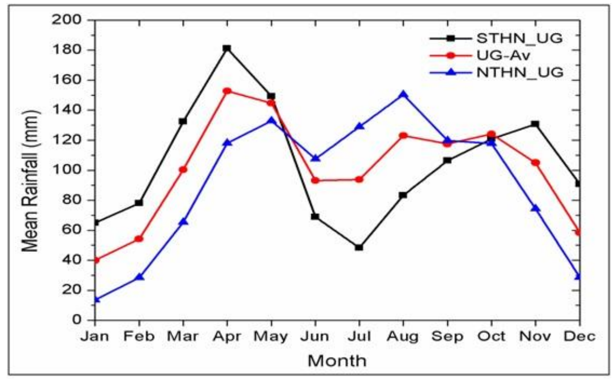

Figure 2: The mean annual cycle of rainfall over the period 1901-2013. The lines represent the mean rainfall over Uganda (red), southern sector of Uganda (black) and the northern sector of Uganda (blue).

3. Results and Discussion

3.1 Annual cycle

Mean annual rainfall cycle over the period 19011-2013was analyzed to understand the annual rainfall characteristics over Uganda (Fig. 2). Two main precipitation peaks i.e., MAM season (March to May) and SON season (September to November) were observed. The northern sector exhibits a single rainfall season, from March to November, whereas the southern region experiences two distinct rainfall peaks or rainfall seasons; MAM and SON (Ogwang et al., 2014). The rainfall pattern in the northern Uganda is expected since the area borders the areas of the northern hemisphere that receives unimodal rainfall in the months of June-August (JJA); coinciding with northern hemisphere summer.

3.2Interannual variability

In order to understand the SON rainfall variability over Uganda, the standardized anomaly of SON rainfall (Fig. 3) was examined. Results show that the highest mean SON rainfall over the period 1901-2013 was observed in 1961 (extremely wet), while the least amount was noted in 1943 (extremely dry). However, based on the standard deviation of the mean SON rainfall of ≥1 (for wet years) and ≤(for dry years) as used by Ogwang et al.(2015), eighteen wet years were observed over the study period, while for dry years, sixteen cases were noted.

More wet years (~16% of the total years) were observed compared to dry years , which covered ~14% of the total years in the study period. Further analysis (Table 1) reveals that SON (MAM) season contributes 29% (33%) of the mean annual rainfall over Uganda and exhibits a higher (lower) standard deviation of 24.5 mm (17.5 mm), implying a greater (lower) interannual variability compared to MAM (SON) season.

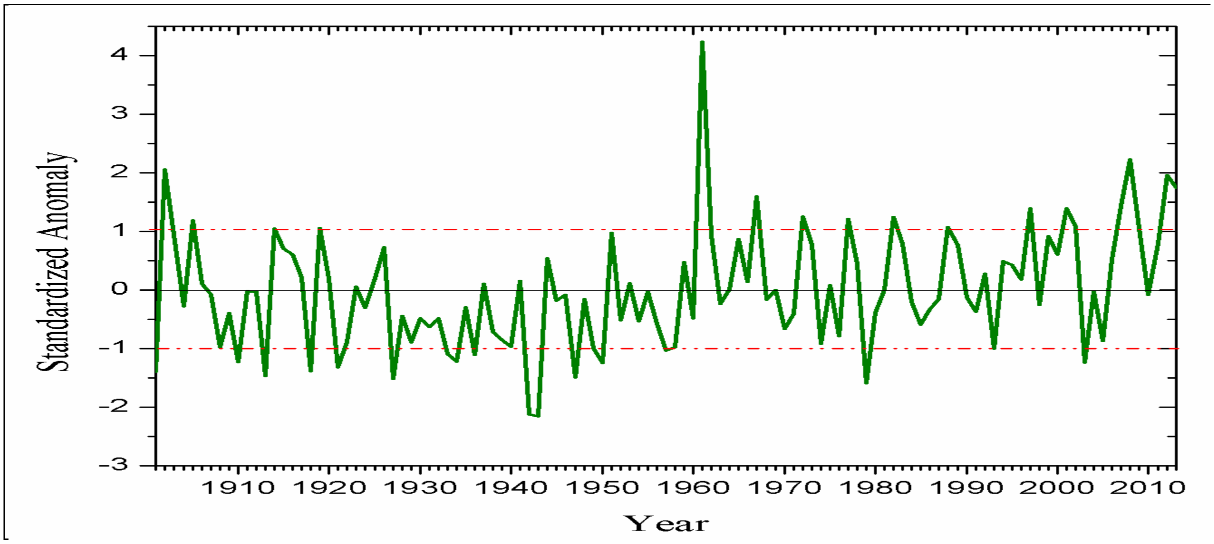

Figure 3: The interannual variability of the mean SON rainfall over Uganda averaged between longitudes 29ºE -36ºE and latitudes 1.5ºS - 4.5º for the period 1901-2013.

3.3EOF analysis

Figure 4(a) shows the spatial component of the first eigenvectors (EOF1) of rainfall in the SON season, highlighting overall positive loadings throughout the Uganda. Eastern part of the Uganda, including Victoria and Kyogabasins Lakes, showed the strongest loadings. Quasi-permanent trough due to locally induced convection, land-lake thermal contrast and orographic influence transformed rainfall pattern over the Victoria Lake and hinterlands (Asnani, 1993). Importantly this favored convection throughout the year.

Weak loadings are exhibited in the southwestern region. This may be attributed to weaker effects of local systems in the annual cycle. Figure 4(b) displays the first EOF time series (PC1) corresponding to EOF1. It displays the variability pattern (Figure 3) in the SON rainfall anomaly, with the wettest and driest years captured as 1961 and 1943, respectively.

3.4Trend analysis

Results from Mann-Kendall analysis (Fig. 5) indicated general decreasing trend in the mean SON rainfall between 1901 and early 1940s. The observed decrease became significant between 1933 and 1957. After 1957, the mean rainfall exhibited an insignificant increasing trend, until a sudden change in rainfall was noted in the year 1994.

Table 1: Mean (Mn) and standard deviation (SD) of rainfall for MAM and SON seasons, and their respective contribution (CONT) to the mean annual rainfall over Uganda based on CRU data for the period 1901-2013.

	Mn (mm)	SD (mm)	CONT (%)
MAM	132.6	17.5	33%
SON	115.6	24.5	29%

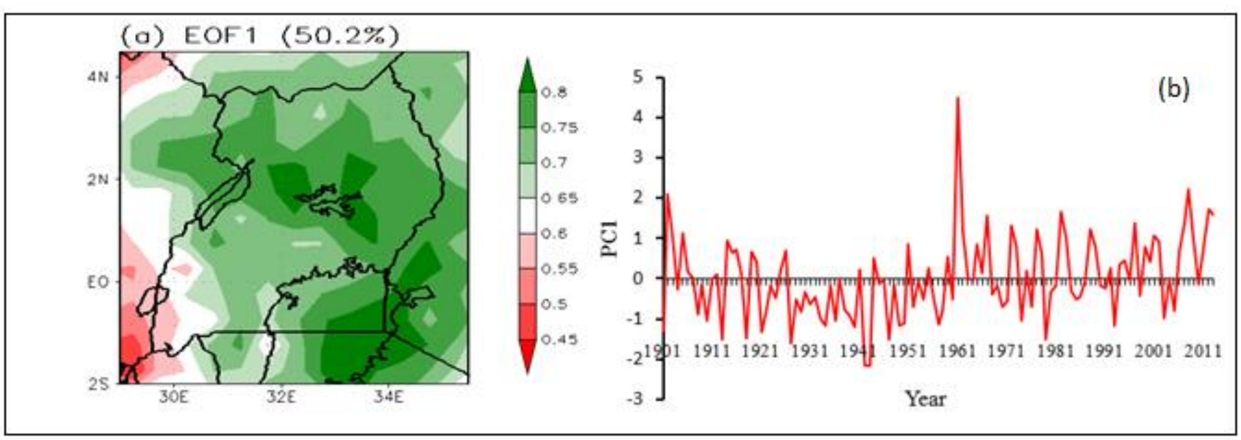

Figure 4: (a) EOF's first spatial mode, EOF1 (explains 50.2% of the total variance) of the mean SON rainfall (b) its corresponding principal component (PC1).

Table 2. The mean SON rainfall(RF) and temperature (TMP), showing the long term mean (LTM, 1901 - 2013), the mean values (1901-1993) before the change in 1994, and those after the change (1995 - 2013).

	RF (mm)	TMP (°C)	RFD(mm)	TMPD(°C)
LTM (1901-2013)	115.6	22.4		
Before change (1901-1993)	111.9	22.2		
After change (1995-2013)	132.6	23.3	20.7	1.1

Where RF is rainfall, LTM is long term mean, RFD and TMPD denote rainfall and temperature differences between the mean values before and after the observed change in 1994.

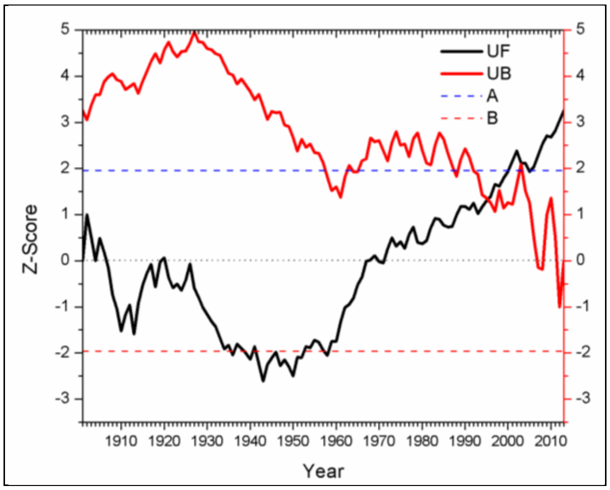

Fig. 5: Mann-Kendall analysis of the mean SON rainfall over Uganda for the period 1901-2013. The dashed lines, above (A) and below (B) the line denoting zero (dotted) represent critical values at 95% confidence level. The sequential Mann-Kendall test statistic; forward sequential statistic and back sequential statistic are denoted by UF and UB, respectively.

After this abrupt change, the increasing rainfall trend continued and became significant in 1999. This trend persisted significantly and continued until 2013, but with a temporary reduction in rainfall between 2002 and 2004.

Analysis of the mean rainfall recorded pre- and post-1994 showed the 20.7 mm higher rainfall after the 1994 (i.e., 1995-2013), when comparing with the pre-1994 mean rainfall (1901-1993). Further analysis showed ~1.1ºC warming trend in the region (Table 2) after anomalous 1994 season, compared to the mean value for the pre-1994 period (1901-1993).

3.5Case studies of 1943 and 1961

To understand the spatial distribution of rainfall during the identified wettest (1961) and driest (1943) years, as compared to the long term mean (LTM) of SON rainfall, anomalies were computed for the both years. The result from the LTM rainfall analysis indicates that higher rainfall amounts are usually received in the western Uganda (Fig. 6).

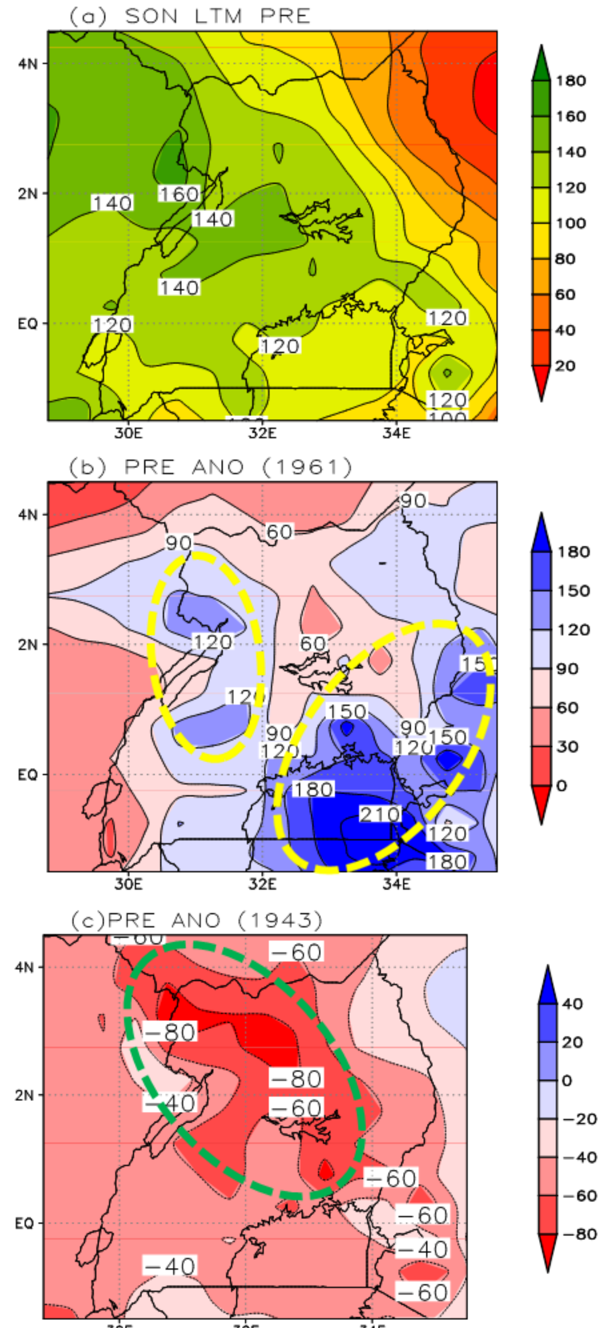

Fig. 6: (a) The long term mean (LTM) SON rainfall (mm) over the period 1901-2013, (b) rainfall anomaly (mm) in 1961 and (c) rainfall anomaly (mm) in 1943.

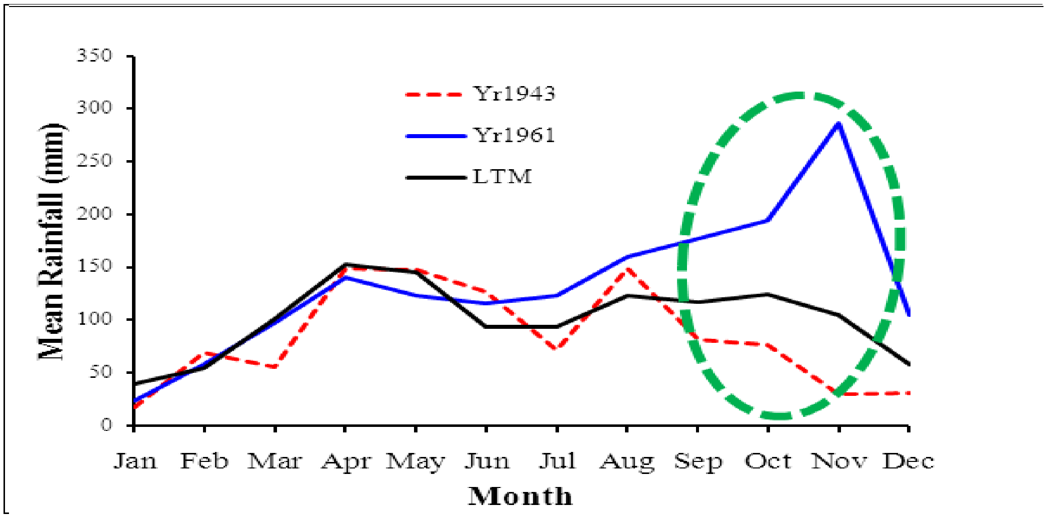

Figure 7: The mean annual cycle of rainfall over Uganda for the wettest year (1961, blue line), the driest year (1943, red line) and the long term mean (LTM, black line) over the period 1901-2013. The green-dotted line depict SON season.

Analysis of the spatial circulation of the anomalous rainfall patterns indicate that during the wettest year; 1961 (Fig. 6b), the entire country of Uganda experienced above normal rainfall, with the highest rainfall recorded over the Victoria Lake basin, the eastern and northwestern regions of Uganda (yellow dashed lines). On the other hand, during the driest year; 1943 (Fig. 6b), the whole country received below normal rainfall, with the least rainfall amounts recorded over the northwestern sector of Uganda.

Analysis of rainfall temporal distribution during 1961 and 1943 (Fig. 7) showed rainfall amounts received in 1943 from September through November were far below the long term mean rainfall, as opposed to that received in 1961, which exhibited far above the long term mean values. The relationship between the mean SON rainfall anomaly and the mean SON sea surface temperature (SST) anomaly over Indian Ocean was examined to understand the possible linkage between SON rainfall and SST anomalies over the IOD sub-regions.

Correlation results (Fig. 8) indicate that the relationship between the mean SON rainfall anomaly over Uganda and the mean SON SST anomaly over Indian Ocean captures the IOD pattern, with significant positive and negative correlations in the western sector of Indian Ocean and south eastern sector. This exhibits the positive phase of IOD, during which above normal rainfall is recorded in the region.

Further, results show that during the year 1961 (Fig. 9a), the SST anomalies depicted the positive phase of IOD, where positive anomalies in SST are shown in the western sub-region of IOD, as opposed to the negative anomalies in SST of the southeastern sub-region of IOD. The positive IOD phase is connected with above average rainfall in the region, hence wettest year. On the other hand, during the driest year (Fig. 9b), the negative IOD phase is exhibited over Indian Ocean, where positive anomalies in SST were observed in the southeastern sector, with negative SST anomalies noted in the western sector of the Indian Ocean. The negative phase of IOD results in below normal rainfall over Uganda and the rest of East Africa (Saji et al, 1999).

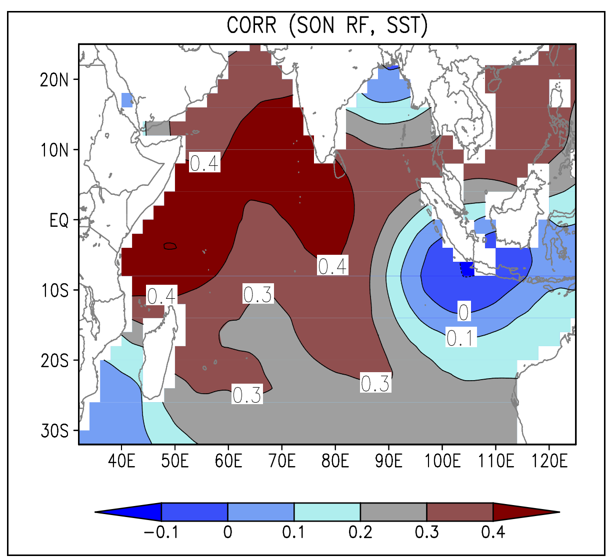

Figure 8: The correlation between the mean SON rainfall anomaly over Uganda and the mean SON SST anomaly over Indian Ocean for the period 1901 - 2013.

Journal of Environmental & Agricultural Sciences (JEAS). Volume 8

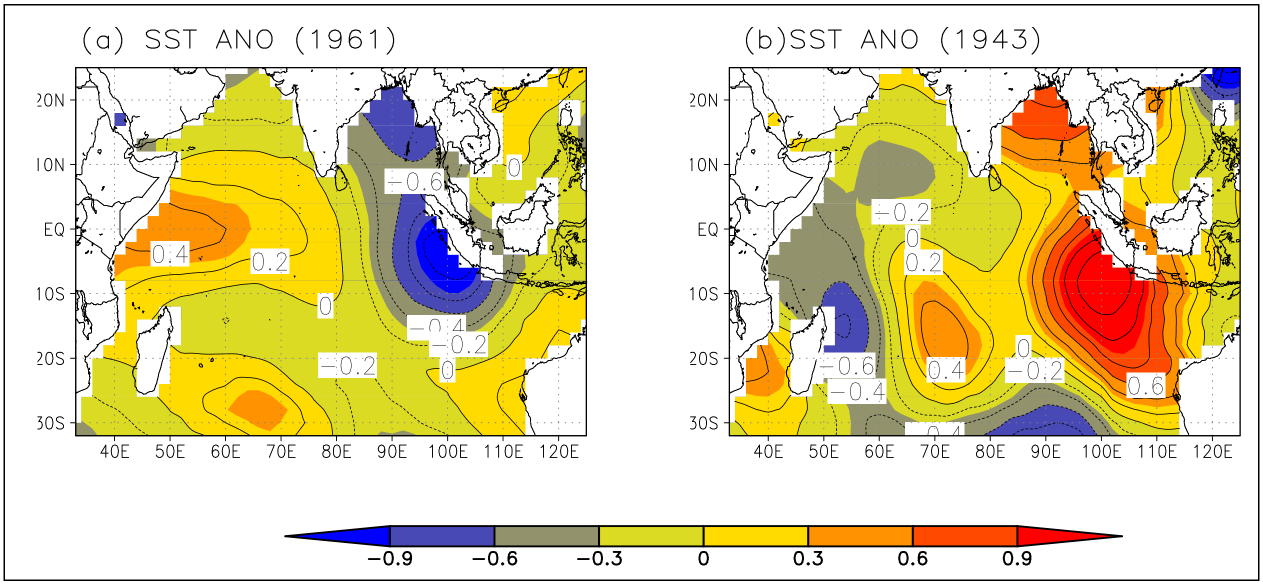

Figure 9: The mean SON SST anomaly during (a) the wettest year (1961) and (b) the driest year (1943).

4. Conclusion

Present study investigates the characteristics and abrupt changes in September- November SON rainfall over Uganda. Dominant modes of variability of rainfall were identified by performing empirical orthogonal function (EOF) analysis, using rainfall data from Climate Research Unit for the period 1901 to 2013. Results indicate that the dominant mode of variability of SON rainfall exhibits a unimodal pattern, explaining 50.2% of the total variance. During the study period, there were generally more wet years than dry years. SON rainfall was shown to exhibit higher interannual variability than March to May rainfall. Mann-Kendall analysis was deployed to examine sudden changes in SON rainfall over the country. The findings show that the abrupt change in SON rainfall occurred in 1994.

Further analysis reveal that the mean SON rainfall over Uganda has a correlation pattern with sea surface temperature (SST) over Indian Ocean, which depicts the positive phase of the Indian Ocean Dipole (IOD), exhibiting positive correlation in the western IOD sub-region, whereas negative correlation for the southeastern sub-region. This indicates that the positive phase of IOD enhances SON rainfall over Uganda, as opposed to the negative phase which inhibits SON rainfall.

Case studies of the driest and wettest years in the study period indicate that during the wettest year, there were positive anomalies in the western sub-region, contrary to the driest year, characterized with the negative anomalies in the same sub-region. The evolution of IOD can thus be monitored for the improvement of SON rainfall forecasts, especially over Uganda so as to avoid the losses associated with weather extremes.

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Competing Interests: The authors declare that there is no conflict of interest.

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