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Contributions of Atlantic Ocean to June-August Rainfall over Uganda and Western Kenya

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Abstract

This study investigates the contributions of Atlantic Ocean to June-August rainfall over Uganda and western Kenya (KU). The study has utilized the datasets including precipitation from the Global Precipitation Climatology Centre, North Atlantic Oscillation Index (NAOI), South Atlantic Ocean Dipole Index (SAODI), ERA-interim reanalysis, and the Atlantic Ocean Sea Surface Temperature (SST). Singular value decomposition (SVD), composite analysis and correlation analysis are used to achieve the objective of the study. Results show that the recent extreme rainfall events of June - August (JJA) season were experienced in 2007 (above normal) and 2009 (below normal). Further analysis reveals that there are significant coupled modes of variability; the first mode explains 32% whereas the second mode explains 16% of the total covariance. The first SVD mode captures the positive phase of the South Atlantic Ocean Dipole (SAOD) over Atlantic Ocean. This is associated with positive anomaly of rainfall in most parts of KU. The second SVD mode captures the negative phase of SAOD. The North Atlantic Ocean Index (NAOI) exhibits a significant positive correlation of coefficient ≥ 0.3 with the mean JJA rainfall anomaly over most parts of KU at 95% confidence level. The correlation between the mean JJA rainfall over most parts of KU and NAOI is higher compared to that with SAODI. The dominant moisture source in the region during JJA season is the Atlantic Ocean and the Congo rainforest. The findings from this study provide insight into the influence of Atlantic Ocean on the mean JJA rainfall over KU. The study recommends further research on the utilization of NAOI and SAODI as predictors of the JJA seasonal rainfall over the study area. The production of the JJA seasonal rainfall forecast in the region will enhance better utilization of water resources in the region

Keywords: Atlantic Ocean, JJA Rainfall, Kenya and Uganda, NAOI, SAODI, SVD.

1. Introduction

Weather affects virtually all socio-economic sectors in Uganda and western Kenya (KU), particularly rainfall as the weather parameter has the highest impact (Muthama et al., 2012; Ongoma, 2013). This is true in most developing nations, especially in Africa, whose economy is mainly dependent on rain fed agriculture. Extreme weather events such as floods and droughts are thus associated with huge socio-economic losses in the nations (Noble et al., 2005; Hasternrath and Polzin, 2004; IPCC, 2007). Although the region has experienced frequent occurrence of floods and drought, the situation has been exacerbated by climate change (Shongwe et al., 2011; IPCC, 2012; Funk et al., 2012). Kenya and Uganda are examples of nations where climate variability and change adversely affects socio-economy. This calls for proper understanding of the factors controlling the weather, especially the rainfall to help improve the quality of the forecasting. In response, this investigates the contributions of Atlantic Ocean to June-August rainfall over KU. The study area is located within longitudes 29°E – 38°E and latitudes 2°S – 4.5°N (Fig. 1).

Rainfall in most parts of Kenya and Uganda has bimodal characteristic; with the ‘long rainy’ season observed in March– May (MAM) and the ‘short rainy’ period in October– December (OND). However, some localities especially in western and

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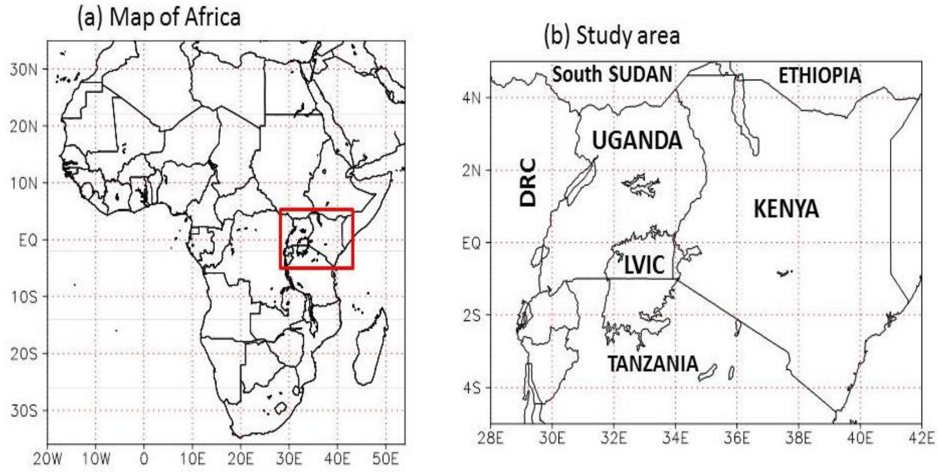
northwestern Uganda and western Kenya experience trimodal rainfall pattern. The third rain season is experienced in the months of June to August (JJA) (Mutai et al., 1998). The rainfall in the study area is generally highly variable both in space and time (Anyah and Semazzi, 2004; Mukabana and Pielke, 1996). The observation is attributed to the underlying orography and presence of large water bodies such as Lake Victoria (Indeje et al., 2001; Oettli and Camberlin, 2005). This makes the population of the region highly vulnerable to extreme weather events.

The observed bimodal rainfall pattern in most areas is mainly influenced by the migratory nature of the Inter-Tropical Convergence Zone (ITCZ) (Nicholson, 2008; Okoola, 1998). The monsoon winds driven by ITCZ are associated with moisture influx over KU (Nicholson, 2008; Okoola, 1998). El Niño Southern Oscillation (ENSO), a global climate phenomenon caused by ocean-atmosphere interactions, occurs mainly in the tropical-subtropical Pacific and Indian Ocean basins. It has widely been studied in the east African region (Bowden and Semazzi, 2007; Chang and Zebiak, 2003; Mutai and Ward 2000; Camberlin et al., 2001; Neng et al., 2002; Korecha and Barnston, 2007; Zaroug et al., 2014). In the area of study, El Niño is associated with abnormally wet conditions while La Niña is associated with abnormally dry conditions during the ‘short rainy’ season (McHugh, 2006).

The Indian Ocean Dipole (IOD); a coupled ocean-atmosphere system, with fluctuations in Sea Surface Temperature (SST) anomalies across the Indian Ocean has also been found to influence east Africa short rainy period (Owiti et al., 2008; Marchant et al., 2007; Black et al., 2003; Clark et al., 2003; Behera et al., 2005; Fischer et al., 2005). Nyakwada et al. (2009) studied the Atlantic-Indian Ocean Dipole (AIOD) and its influence on East African seasonal rainfall. He mainly focused on the ‘long rainy’ and ‘short rainy’ seasons. According to the study, the AIOD has significant influence on regional rainfall for both seasons. The study noted that the SST gradient mode associated with the AIOD had significant relationships with the rains in the two seasons, although it accounted for the highest rainfall variance with the ‘short rainy’ season.

Madden-Julian Oscillation (MJO) has also been identified to have great influence on intra-seasonal climate variability over Kenya, being a determinant on the ranges of weather forecasting in the region (Omeny et al., 2008). The MJO is a tropical atmospheric phenomenon, which develops over the Indian Ocean and progresses east across the tropics with a period of 30-60 days (Madden and Julian, 1994). It has observed that the active phase of the MJO brings enhanced precipitation followed by suppressed precipitation in the western parts of east Africa, especially around Lake Victoria region (Pohl and Camberlin, 2006; Omeny et al., 2008).



(a) (b)

Fig. 1. (a) Map of Africa showing the region of study (KU red rectangle), (b) Map of Uganda and Kenya, showing parts of the neighboring countries. DRC and LVIC denote Democratic Republic of Congo and Lake Victoria, respectively.

In western and northwestern Uganda and western Kenya (KU), the observed JJA rainfall has been associated with the influx of a moist westerly airstream from the Atlantic Ocean and tropical Congo rainforest air mass (Mutai et al., 1998). There have been several studies in the region (e.g., McHugh and Rogers, 2001; Camberlin and Philippon, 2002; McHugh, 2004; Omondi et al., 2013) that have investigated positive rainfall anomalies in East Africa and the periods of westerly outbreaks bringing moist Atlantic air into the east Africa region. The rainfall tends to occur during the positive phase of the North Atlantic Oscillation (NAO) (McHugh and Rogers, 2001).

In case of 'long rainy' failure, the JJA rainfall is the key to minimize the intensity of the depression/ drought. The 'short rainy' is also utilized to produce fast maturing crops that require less rainfall thus boosting food security in the region. Despite the need to improve the accuracy of seasonal forecast in KU, especially under the current era of climate variability and change, little attention has been paid to the influence of Atlantic Ocean (AO) on JJA seasonal rainfall. This study, therefore, investigates the influence of AO on the JJA rainfall over KU.

2. Data and Methodology

Due to uncertainty in the surface climate observations over the African region (Nikulin et al., 2012; Sylla et al., 2013; Ogwang et al., 2014), the gridded precipitation datasets are used in this study. These datasets are available in University of East Anglia Climatic Research Unit (CRU TS3.22) for the period 1901-2013 at a resolution of 0.5x 0.5 (Harris et al., 2014) and in the Global Precipitation Climatology Centre (GPCC), monthly precipitation dataset provided for 1901-present (Schneider et al., 2013). The GPCP version 2.2 combined precipitation dataset, gridded at 2.5 degree resolution (Adler et al., 2003; Huffman et al., 2011), can be obtained by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at http://www.esrl.noaa.gov/psd/.

The SST data is the Extended Reconstructed Sea Surface Temperature (ERSST) version 3b from the National Oceanic and Atmospheric Administration/National Climatic Data Center (Smith et al., 2008), available in their website at http://iridl.ldeo.columbia.edu/SOURCES/.NOAA/.NCDC/.ERSST/.version3b/.sst/.

Reanalysis of the datasets used to determine moisture transports were obtained from ERA-interim reanalysis, gridded at 0.75 degree resolution (Dee et al., 2011). The variables are including the meridional and zonal winds, relative humidity and temperature at 850 hPa level. The data sets have been used to study various phenomena in the region e.g., Žagar et al. (2011) used ERA Interim reanalysis data for the period 1990 - 2009 to study climatology of ITCZ. Zaroug et al. (2014) used data from CRU and GPCP to simulate the connections of ENSO and the rainfall regime of East Africa and the upper Blue Nile region using a climate model of the tropics. In a study by Ogwang et al.(2014) on the influence of topography on east Africa climate, CRU, ERA Interim reanalysis and GPCP datasets were used to evaluate the performance of the Regional Climate Model (RegCM).

The South Atlantic Ocean Dipole (SAOD) Index is defined by differences in the domain-averaged normalized SST anomaly (SSTA) of the two centers of intense warming and cooling associated with the SAOD, given by Equation 1.

$$SAODI = [SSTA]_{NEP} - [SSTA]_{SWP} \quad (1)$$

where the square brackets indicate domain averages, the subscripts show the two regions over which the SSTA averages are computed. These domains are described by their locations in the South Atlantic Ocean as the northeast pole (NEP: 10ºE - 20ºW, 0º-15ºS) and the southwest pole (SWP: 10º - 40ºW, 25ºS - 40ºS) (Nnamchi et al., 2011; Nnamchi and Li, 2011).

The North Atlantic Oscillation (NAO) index data is provided by the climate prediction center in its website available at http://www.cpc.ncep.noaa.gov/data/teledoc/nao.shtml.

The singular value decomposition (SVD) technique is one of the powerful and popularly applied methods in atmospheric sciences in this study. This technique is applied in two data matrices of two jointly analyzed fields to identify pairs of the coupled spatial pattern and their respective temporal variations. Each pair explains a fraction of covariance between the two jointly analyzed fields. This decomposition allows the identified dominant modes of coupled covariability between the two analyzed fields. Details about SVD analysis may be obtained from previous studies (Juneng and Tangang, 2006; Hannachi et al., 2007). In this study, SVD analysis is applied between the mean JJA rainfall and SST anomalies to determine the dominant coupled modes of variability between the two variables.

Correlation analysis was deployed in this study. It reveals simple relationships between pairs of variables (Wilks, 2006; Ogwang et al., 2012). In this study, correlation analysis is aimed at establish the relationship between JJA rainfall over the study area and SST, SAOD index and NAO index.

3. Results and Discussion

3. 1. Rainfall annual cycle and interannual variability

The rainfall over the study area is predominantly bimodal. However, less rainfall is reported during JJA season as compared with the ‘long rainy’ season (MAM) and the ‘short rainy’ season (OND). The observation is exhibited by three data sets that are in agreement with one another (Fig. 2).

The observation can support the previous studies such as Mutai et al. (1998). The JJA rains are important since they reduce their intensity of drought owing to MAM rainfall failure.

Figure 3 presents the interannual variability of the mean JJA rainfall over the study area.

The results indicate that there are more above normal rainfall events (+1) during the study period as compared to the below normal rainfall cases (-1) (Fig. 3). The recent extreme events are 2007 (2009) for above (below) normal, respectively.

3. 2. Singular value decomposition

The singular value decomposition (SVD) analysis reveals that the first mode of SVD (SVD1) explains 32% of the total covariance while the second as SVD2 dominant coupled mode explains 16% (Figs. 4 and 5). SVD1 reflects a general widespread warming in north part of 20°S over Atlantic Ocean, making SAOD not distinct. Generally, it is observed that the gulf of Guinea exhibits positive SST anomaly and south western Atlantic has negative SST anomaly (Fig. 4a). This is associated with positive anomaly of rainfall in most parts of Uganda and western Kenya (Fig. 4b). Negative rainfall anomalies are registered in the southwestern Uganda and northwestern Kenya for this mode of covariability.

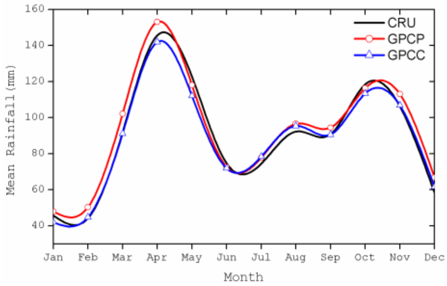


Fig. 2. The mean annual cycle of rainfall over the study area based on CRU, GPCP and GPCC datasets, averaged over longitudes 29° E - 38° E and latitudes 2° S - 4.5° N.

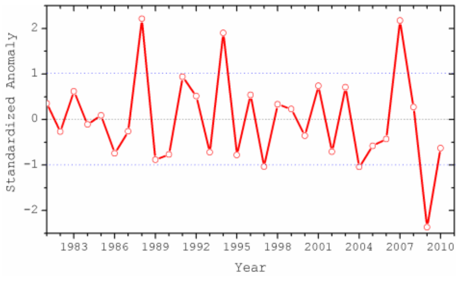


Fig. 3. The interannual variability of the mean JJA rainfall over the study area based on GPCC dataset, averaged over longitudes 29ºE - 38ºE and latitudes 2ºS - 4.5ºN.

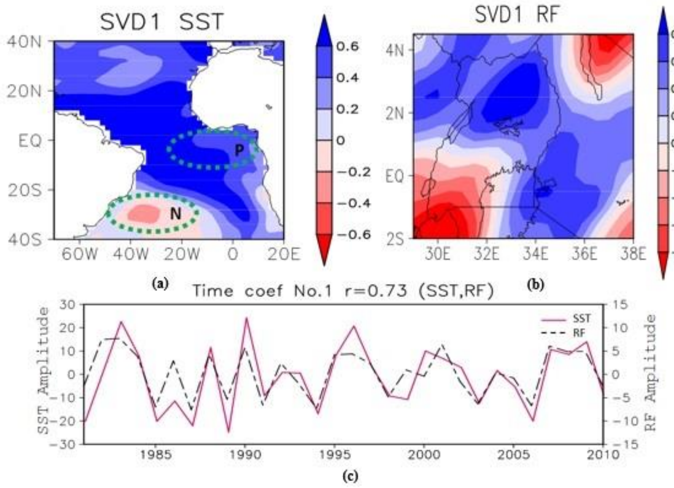


Fig. 4. The homogeneous map of the first mode of SVD for the (a) Left field (SST), (b) Right field (Rainfall, RF), and (c) The corresponding expansion coefficients.

The first mode explains 32% of the total covariance, whereas the expansion coefficients exhibit a correlation (r) of coefficient 0.73. The green dotted lines indicate regions of interest (Gulf of guinea and Southwestern Atlantic Ocean), with P (N) signifying that the dotted region exhibits positive (negative) SST anomaly.

The second mode explains 16% of the total covariance, whereas the expansion coefficients exhibit a correlation (r) of coefficient 0.79. The green dotted lines indicate regions of interest, with P (N) signifying that the dotted region exhibits positive (negative) SST anomaly.

The correlation between rainfall and second dominant coupled modes is observed to be higher as compared to that with the dominant coupled modes. The correlation coefficients of 0.73 and 0.79 are observed, respectively (Figs. 4 and 5).

SVD2, on the other hand, captures the negative SAOD mode (Fig. 5a), with the gulf of Guinea extending over the western coast of Africa. This exhibits negative SST anomaly and south western Atlantic have positive SST anomaly. This is associated with negative anomaly of rainfall in most parts of Uganda and central and western Kenya. Positive rainfall anomalies are observed in the northern and south-western Kenya during the negative phase of SAOD (Fig. 5b). There exists a significant correlation coefficient of 0.79 (Fig. 5c) between the corresponding expansion coefficients.

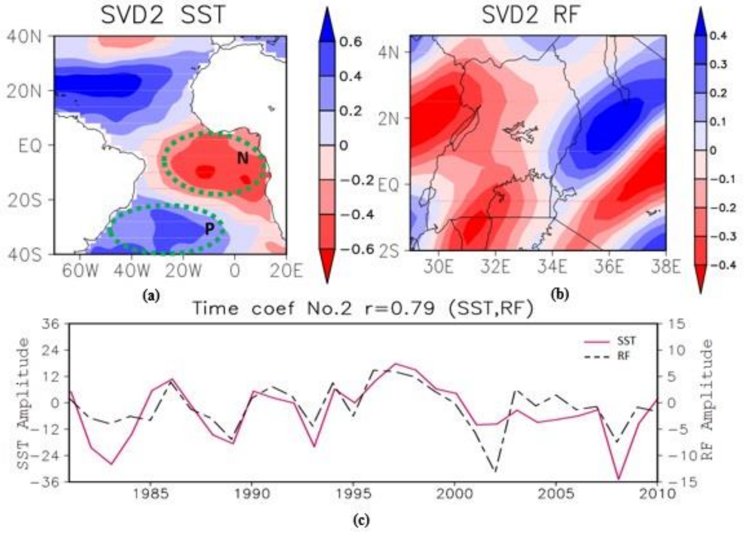


Fig. 5. The homogeneous map of the second mode of SVD for the (a) Left field (SST), (b) Right field (Rainfall, RF), and (c) The corresponding expansion coefficients.

3. 3. Correlation analysis

Figure 6 displays the spatial correlation between the mean JJA rainfall anomaly over KU (longitudes 29°E – 38°E and latitudes 2°S – 4.5°N) and SST anomaly over Atlantic Ocean. There is observed significant correlation between both South and North Atlantic Ocean SST with JJA rainfall over KU at 95% confidence level.

Examination of rainfall occurrence over KU during JJA in correlation with South Atlantic Ocean Dipole Index (SAODI) and NAOI (Fig. 7) shows that more rains are observed in the area of study as a result of NAOI as compared to SAODI. Generally, NAOI is found to have a significant positive correlation with the mean JJA rainfall anomaly over most parts of KU, as opposed to SAODI. SAODI is observed to be significantly positively correlated with rainfall over the northern sector of Kenya.

3. 4. Water vapor/ Moisture transport

Figure 8a shows the climatology of the mean JJA water vapor/moisture transport further to support the higher influence of NAOI as compared to SAODI. During wet year, a convergence is observed to the west of Uganda and divergence is observed in the same region during a dry event (Figs. 8b, 8c).

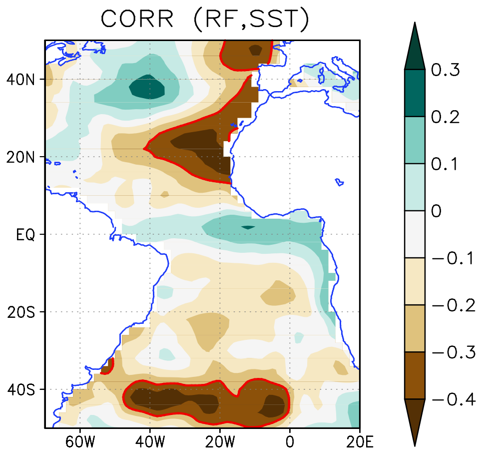
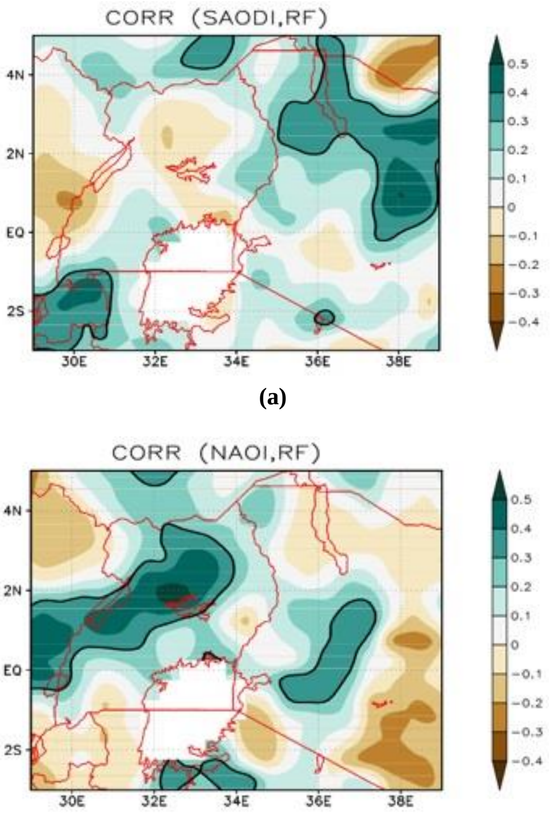


Fig. 6. Spatial map of correlation between the mean JJA rainfall anomaly over KU region averaged between longitudes 29°E – 38°E and latitudes 2°S – 4.5°N and SST anomaly over Atlantic Ocean. The thick red contours indicate regions with significant correlation at 95% confidence level.



(a)

(b)

Fig. 7. Spatial correlation map over KU region (a) for correlation between SAODI and the mean JJA rainfall anomaly, and (b) for correlation between NAOI and rainfall anomaly. The thick black contours indicate regions with significant correlation at 95% confidence level.

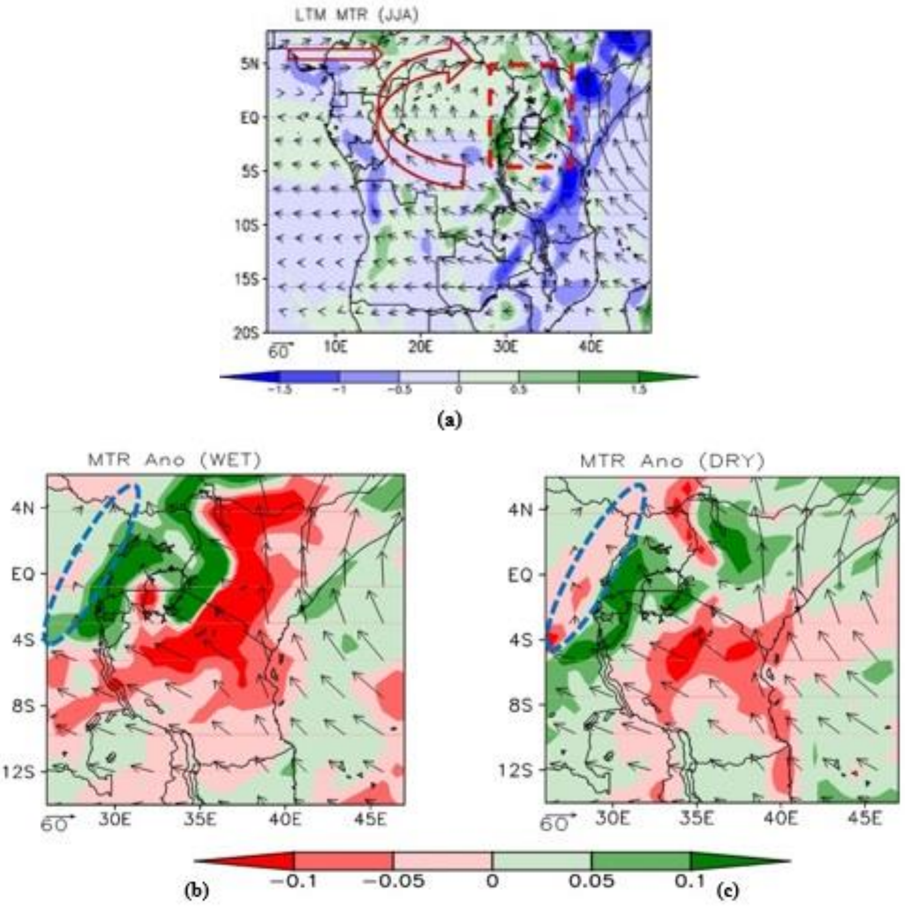


Fig. 8. (a) The climatology of the mean JJA water vapor/moisture transport (MTR) at 850 hPa in g $kg^{-1}ms^{-1}$ is shown over the region between longitudes 2-47°E and latitudes 20°S-8°N. The red arrows in (a) show the general moisture sources and transport (from Atlantic Ocean and Congo rainforest), (b) the mean composite MTR anomaly for wet years (1988 and 2007), and c) the mean composite MTR anomaly for dry year (2009). The shaded regions indicate moisture convergence (c) *(Positive),* moisture divergence *(negative),* and the vectors show water vapor transport. Figures (b) and (c) are represented over longitudes 2°6E – 47°E and latitudes 14°S – 6°N, with the blue dotted lines denoting regions with anomalous convergence (divergence) in (b) (c).

The dominant moisture source in the region during JJA season is the Atlantic Ocean and the moist air mass from Congo basin (Fig. 8a). The observation is similar to the ones made by Mapande and Reason (2005), who studied interannual rainfall variability over western Tanzania. Generally, Mapande and Reason (2005) noted that enhanced (reduced) westerly moisture flux from the southern Congo basin occurs during the wet (dry) seasons.

4. Conclusions

Most areas over east Africa experience a bimodal rainfall pattern; however, some regions especially in the east Uganda and west Kenya experience a 'short' third rain season in June to August (JJA). Results showed that the recent extreme events during JJA season were observed in the year 2007 (2009) for above (below) normal, respectively. The SVD analysis showed that the first mode of SVD (SVD1) explains about 32% of the total covariance between JJA seasonal rainfall over KU and Sea Surface Temperature (SST) over Atlantic Ocean. The positive SAOD mode over Atlantic Ocean, with the gulf of Guinea, exhibits positive SST anomaly and south western Atlantic shows negative SST anomaly. These are associated with positive anomaly of mean JJA rainfall in most parts of Uganda and western Kenya. NAOI is significantly correlated with the mean JJA rainfall over a wide section of KU. This is associated with a better distribution of JJA rainfall over KU as compared to SAODI. The study recommends further research on and possible adoption of NAOI and SAODI as predictors of the JJA seasonal rainfall over KU. The production of the JJA seasonal rainfall forecast in the region will enhance better utilization of water resources, especially in case of failure in 'long rainy' periiod.

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