Midtropospheric Circulation Patterns Associated with Extreme Dry and Wet Episodes over Equatorial Eastern Africa during the Northern Hemisphere Spring

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ABSTRACT

The anomaly circulation patterns of contrasting wet and dry episodes over the equatorial eastern Africa (EEA) region are studied using the European Centre for Medium-Range Weather Forecasts analyses. The study focuses on the Northern Hemisphere spring (NHS). Examination of composite synoptic-scale features indicates that cyclonic circulation over southern Madagascar in the midtroposphere forces southerly flow through the Mozambique Channel. The southerlies turn eastward on approaching latitude 10°S giving broad westerlies in the latitude belt 10°S to the equator. These southerlies followed by westerlies were associated with wet spells over the EEA region. Dry spells exhibit stronger than normal easterly wind flow over the EEA region. These dry spells are associated with a cyclonic circulation with a center near the point 25°S, 25°E and an anticyclonic circulation over Madagascar that causes northerly winds to blow through the Mozambique Channel. Thus, the southerlies act as a trigger for active convection over EEA during the NHS by providing a surface leaning poleward with height over which the equatorial air mass rises.

1. Introduction

In the Tropics the most important climate element is rainfall. Rainfall determines the economies of most tropical countries. Rainy seasons alternate with dry seasons and each has its distinct pattern of prevailing winds (Matarira and Jury 1992; Nakamura 1968; Johnson and Morth 1961). Rainfall has the highest space–time variability. Matarira and Jury (1992) have shown that the meridional wind was generally southerly over and to the east of Zimbabwe at the 700-hPa level during the dry spells, whereas it was northerly during the wet spells. The meridional flow during the dry spells suggests that convergence between the southerlies and the moist Congo Basin northerlies occurs well to the north of Zimbabwe. Nakamura (1968) and Johnson and Morth (1961) have shown that midtropospheric westerly winds over equatorial eastern Africa (EEA) were associated with transport of moisture into the region. However, they did not suggest the origin of these westerlies. The above research results suggest that both meridional and zonal winds may be important for the occurrence of anomalous rains over the EEA region.

The location of the intertropical convergence zone (ITCZ) and its overall horizontal and vertical structure

influence the space–time patterns of rainfall in the EEA region. Although there is some descriptive information on the characteristics of the ITCZ, there are no available quantitative descriptions of the space–time evolution of ITCZ over this region. Characteristics of the ITCZ over the region are complicated by the topographic inhomogeneity and the associated thermally induced mesoscale circulations that make the ITCZ patterns near the earth's surface very diffused (Mukabana and Pielke 1996). However, the ITCZ has been observed most clearly in the wind field near 700 hPa level (Anyamba 1983; Mukabana and Pielke 1996). Thus, accurate assessment of the circulation regimes that support various rainfall patterns over this region may be based on circulation patterns at the 700-hPa level.

The prediction of wet or dry seasons is useful for agricultural and water resource use planning. However, the monitoring of crop yield requires a shorter event scale since it is often not the amount of seasonal rainfall that is important, but rather the steadiness of rainfall supplied by repeated wet or dry spells that is crucial to high crop yields. Thus, in order to construct a scenario for wet-spell forecasting, a diagnostic study of the wet spell is necessary. This paper addresses this problem through analysis of wind patterns over EEA region composited over periods characterized by wet and dry pentad (five-day totals) rainfall cases in EEA. The objective of the study is to identify the vector wind patterns and intensity associated with these wet and dry cases.

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2. Data used in the study

The data used in this study include daily and monthly station rainfall totals and the European Centre for Medium-Range Weather Forecasts (ECMWF) global analyses datasets.

The rainfall data consists of daily and monthly records at 81 stations distributed over eastern Africa within the period 1961–90 (Fig. 1 and Table 1). The Northern Hemisphere spring (NHS), that is, March, April, and May monthly records, the long rains season over eastern Africa, were used to generate the NHS regional time series for 1961–90 from which the anomalously wet and dry years were delineated. The monthly rainfall totals used were obtained from the individual National Meteorological Services of Kenya, Uganda, and Tanzania through the Drought Monitoring Centre, Nairobi. The daily rainfall data for the selected anomalous wet and dry years were supplied by Kenya and Tanzania Meteorological Services (those for Uganda were not available). These daily records were used to generate pentad records that were used to delineate the wet and dry clusters within the selected years for further study.

This study also utilized the once-daily (1200 UTC) gridpoint meteorological variables operationally analyzed by the ECMWF. These ECMWF analyses are produced using the four-dimensional data assimilation system (Bengtsson et al. 1982). The spatial resolution is 2.5° latitude by 2.5° longitude for the mid- and low-latitude sector 25°N–45°S and between longitudes 30°W and 85°E. These data were for the anomalous rainfall years that were determined from seasonal rainfall data.

The 1200 UTC daily data were averaged to make pentad mean values. These data included the zonal and meridional wind components. The ECMWF datasets used in this study were obtained through the Bureau of Meteorology Research Centre, Australia.

3. Methodology

a. Determination of anomalous rainfall years

The major wet and dry years within the study period (1961–90) were determined from the regional rainfall anomaly indices. The regional rainfall anomaly indices are defined as

$$\chi_t = \frac{1}{m} \sum_{j=1}^m \frac{100X_{tj}}{\bar{X}_j}, \quad (1)$$

where m is the total number of rainfall stations within the EEA region and χ_t is the time-dependent rainfall index as a percent of the mean and averaged over all the stations used.

The wet years had large values of this index (>125%), while the drought years had low values of the index (<75%). The normal years had values of this index between 125% and 75%. The major wet and dry seasons were first delineated. Then the averaged values (composites) for each anomaly category were used to

study the space–time evolutions of the monsoonal circulation over the region during the anomalous rainfall episodes.

b. Principal component analysis

To confirm the results from Eq. (1) above, principal component analysis (PCA) was used to select rainfall events to be composed. These PCA solutions can be used to cluster together seasons or pentads with similar map patterns. Through this method rainfall records were subjected to PCA T-mode for the seasonal (March–May) rainfall. The loadings from this analysis were classified into three categories, namely, normal, large positive, and negative values. The delineated years were compared with those that had been obtained from area-average rainfall anomaly indices given in Eq. (1).

The pentad rainfall values for the anomalous years and for various locations over EEA were subjected to PCA T-mode analysis. The pentads so delineated were then used to study the detailed characteristics of the dry, normal, and wet scenarios. This included a detailed study of the wet and dry spells within the selected anomalous rainfall years.

c. Composite analysis

The composite analysis involves identifying and averaging one or more categories of fields of a variable selected according to their association with key conditions (Folland 1983). The results of these composites are then used to generate hypotheses for patterns that may be associated with the individual scenarios (Folland 1983). The key conditions for the composite analysis in the present study are the wet, normal, and drought conditions defined in section 3a above. Advantages of composite fields is that they are easy to interpret and are dimensional. A number of studies have indicated that the results obtained from composite analysis usually agree closely with those from correlation methods (Ward 1992).

In this study the anomalously wet and dry years selected using methods in section 3a above were composed in order to isolate the circulation patterns associated with the wet and dry seasons. Also, the individual selected wet/dry seasons were further expressed in pentads and these were analyzed to delineate wet and dry rainfall spells that were then composed to identify the within-the-season wet- and dry-spell circulation patterns.

4. Results and discussion

a. The dry and wet periods

Equation (1) was used to identify the seasonal values of rainfall anomaly indices. The dry/wet seasons were associated with low/high values of this index,

respectively. The time series of the computed values of the area-average rainfall indices are presented in Fig. 2. These indices showed that the wettest/driest years over the EEA region were 1981/1984, respectively. Okoola (1998) using the March–May seasonal outgoing longwave radiation (OLR) data averaged over the eastern Africa region has also shown that 1981/1984 were active/weak convective years. Further, LeCompte (1985) has shown that during the northern hemisphere spring (March–June) of 1984 one of the worst droughts of the century damaged food crops in East Africa. These wet/dry years were used in the composite analysis.

Due to the nonhomogeneous distribution of rainfall observational network and unique spatial rainfall variations over the region, PCA T-mode was further used to provide area-average rainfall estimates. The PCA T-mode isolated the years with similar spatial patterns. This method provides further individual time

series for unique homogeneous climatological sub-regions unlike the previous method, which provided a single time series for the whole region. Three significant eigenvectors were delineated and these accounted for 78% of total variance. The time series of rotated PCA T-mode analysis had large loadings during the years 1981, 1985, 1988, and 1990 and low loadings in 1979, 1982, 1983, 1984, and 1986, respectively. These large/low loadings were associated with anomalously wet/dry years over the EEA region. Through this method the years 1981/1984 were also selected as wet/dry years.

The wet and dry pentads during each of the selected years (1981 and 1984) were delineated using the PCA T-mode analysis of the seasonal rainfall series running from pentad 10 (15–19 February) to pentad 32 (5–9 June). Six wet pentads (pentads 18–21 and 26–27) occurred in 1981 and three wet pentads (pentads 20–22) occurred in 1984. One dry pentad (pentad 25)

TABLE 1. Location of rainfall stations and their elevations above mean sea level where monthly rainfall data were available and starred (*) where daily rainfall data were also available.

Country and stations	Station code name	Latitude	Longitude	Elevation (m)	Length of record
BURUNDI					
Bujumbura	*bjr	3°19'N	29°19'	782	1961–89
KENYA					
Dagoretti	*dag	1°18'S	36°45'	1798	1961–92
Eldoret	*eld	0°31'N	35°17'	2084	1967–92
El Wak	elw	2°47'N	40°57'	394	1961–92
Garissa	*gar	0°28'S	39°38'	128	1967–92
Kakamega	*kkg	0°17'N	34°45'	1555	1961–92
Kaputir	Kap	2°6'N	35°28'	754	1971–92
Kericho	*Krk	0°29'N	35°11'	2184	1961–92
Kisii	*Ksi	0°41'S	34°47'	1837	1963–92
Kisumu	*Ksm	0°6'S	34°45'	1146	1961–92
Kitale	*Ktl	1°1'N	35°0'	1890	1961–92
Kitui	Ktu	1°22'S	38°1'	1177	1961–92
Lamu	*Lam	2°16'S	40°50'	9	1961–92
Lodwar	*Lod	3°7'N	35°37'	566	1961–92
Makindu	*Mkd	2°17'S	37°50'	1000	1961–92
Malindi	*Mld	3°14'S	40°6'	3	1962–92
Mandera	*Mdr	3°56'N	41°52'	230	1961–92
Maralal	Mrl	1°5'S	36°42'	1951	1961–92
Marsabit	*Mrb	2°18'N	37°54'	1219	1961–92
Meru	*Mer	0°3'N	37°39'	1570	1966–92
Mombasa	*Msa	4°2'S	39°37'	57	1961–92
Moyale	*Moy	3°32'N	39°3'	1113	1961–92
Mudogashi	Mds	0°45'N	39°11'	262	1964–92
Nakuru	*Nkr	0°17'S	36°4'	1991	1961–92
Narok	*Nrk	1°8'S	35°50'	1890	1961–92
North Horr	Nhr	3°19'N	37°4'		1961–92
Nyeri	Nyr	0°30'S	36°58'	1759	1961–92
Saberei	Sab	4°21'N	36°54'	250	1962–92
Voi	*Voi	3°24'S	38°34'	579	1961–92
Wajir	*Wjr	1°45'N	40°4'	244	1961–92
RWANDA					
Rubona	*Rub	2°27'S	29°44'	1706	1961–90
TANZANIA					
Arusha	*Ars	3°20'S	36°37'	1387	1961–90
Biharamulo	Bih	2°38'S	31°19'	1478	1961–90
Bukoba	*Buk	1°20'S	31°49'	1143	1961–90
Dar-es-Salaam	*Dar	6°52'S	39°12'	53	1961–90
Dodoma	*Dod	6°10'S	35°46'	1120	1961–90
Iringa	*Iri	7°38'S	35°46'	1428	1961–90
Kaisho	Kai	1°15'S	30°41'	1372	1961–90
Kibondo	Kib	3°34'S	30°40'	1515	1961–90
Kigoma	*Kig	4°53'S	29°38'	999	1961–90
Kilindoni	Kil	7°55'S	39°40'	21	1961–90
Lindi	Lin	10°0'S	39°42'	41	1961–90
Lupatingatinga	Lup	7°40'S	33°25'	1524	1961–90
Mahenge	Mah	8°41'S	36°43'	1106	1961–90
Mbeya	*Mby	8°56'S	33°28'	1758	1961–90
Morogoro	Mor	6°50'S	37°39'	579	1961–90
Mpanda	Mpa	6°20'S	31°5'	1097	1961–90
Musoma	*Msm	1°30'S	33°48'	1147	1961–90
Mtwara	*Mtr	10°21'S	40°11'	113	1961–90
Mwadui	Mwd	3°31'S	33°36'	1219	1961–90
Mwanza	*Mza	2°28'S	32°55'	1139	1961–90
Nachingwea	Nac	10°21'S	38°45'	463	1961–90
Ngorongoro	Ngr	3°12'S	35°27'	2288	1961–90
Njombe	Njb	9°20'S	34°46'	1829	1961–90
Same	*Sam	5°5'S	37°43'	860	1961–90
Singida	Sig	4°48'S	34°45'	1498	1961–90
Songea	*Son	10°41'S	35°35'	1036	1961–90
Sumbawanga	Sbg	7°57'S	31°36'	1722	1961–90
Tabora	*Tab	5°5'S	32°50'	1182	1961–90

TABLE 1. (Continued).

Country and stations	Station code name	Latitude	Longitude	Elevation (m)	Length of record
Tanga	*Tan	11°6'S	39°4'	49	1961–90
Tunduru	Tdr	6°13'S	37°22'	701	1961–90
Zanzibar	Zan	2°28'S	39°13'	18	1961–90
UGANDA					
Entebbe	Etb	0°3'S	32°27'	1183	1961–92
Gulu	Gul	2°45'N	32°20'	1106	1961–91
Jinja	Jin	0°27'N	33°11'	1175	1961–92
Kabale	Kab	1°15'N	29°59'	1867	1961–91
Kasese	Kas	0°11'N	30°6'	959	1961–92
Katigondo	Kto	0°13'S	31°44'	1311	1964–92
Kawanda	Kwd	0°25'N	32°32'	1196	1961–92
Lira	Lir	2°15'N	32°54'	1085	1961–91
Masindi	Msd	1°41'N	31°43'	1146	1961–91
Mbarara	Mbr	0°37'S	30°39'	1412	1961–91
Mubende	Mub	0°35'N	31°22'	1553	1961–90
Soroti	Srt	1°43'N	33°37'	1127	1961–90
Tororo	Tor	0°42'N	34°10'	1226	1961–91
MALAWI					
Chitipa	*Ctp	9°42'S	33°16'	1278	1961–87
Mzimba	*Mzb	11°53'S	33°37'	1349	1961–90
ZAMBIA					
Kasama	*Ksa	10°13'S	31°8'	1382	1961–90
Kawambwa	*Kaw	9°48'S	29°5'	1323	1961–90
Mansa	*Mns	11°6'S	28°51'	1259	1961–90
SUDAN					
Juba	Jub	4°52'N	31°36'	460	1961–87

occurred in 1981 and three dry pentads (pentads 23–25) in 1984. More wet pentads occurred during the wet year and more dry pentads occurred in the dry year.

b. Circulation patterns for the wet and dry rainfall composites

Vector wind patterns for the wet year (1981) during the long rains season pentads (16–28) are shown in Fig. 3 at 700-hPa level. Figure 3 shows relatively stronger easterlies along approximately latitude 4°N and also along latitude 14°S with weaker and variable flow in between. Maximum intensity of 3.7 m s^{-1} was observed near the point 5°N, 27°E. A minimum in wind intensity is located at the point 5°S, 35°E within the region of

FIG. 2. Time series of area-average seasonal rainfall indices.

study. A closed circulation is observed around this point of minimum wind intensity with westerlies to the south and relatively stronger easterlies to the north. To the east of the above minimum (east of 35°E), and over the west Indian Ocean, southwesterly winds prevail, turning into easterlies near the equator. Figure 3 shows that generally westerly winds occurred between 10°S and the equator and to the east of 35°E during the wet season.

FIG. 3. Long rains season wind vectors at 700 hPa during a wet year (1981). Shaded where wind is greater than 4 m s^{-1} .

FIG. 4. Long rains season wind vectors at 700 hPa during a dry year (1984). Shaded where wind is greater than 4 m s^{-1} .

Okoola (1999) has shown, using latitude–time cross sections for the longitudes of eastern Africa, that during 1981 the frequency of westerly wind component was high, totalling six pentads from two westerly wind events.

The dry year (1984) composites at 700-hPa level (Fig. 4) shows that the wind intensity is, on average, stronger than normal. Maximum intensity of 6.7 m s^{-1} was observed near the point 4°N , 25°E . Missing from the 1984 flow is the circulation centered at about 5°S , 35°E observed during the wet year (1981). Clearly the flow out of the EEA region was stronger than normal during the dry year (1984). Also, during the dry year a local anticyclonic circulation was observed in the winds near the point 5°N , 45°E . This local anticyclonic circulation seems to be a feature of the dry years. Okoola (1999) has further shown from time–latitude sections that the frequency of westerly wind component was low with only three pentads (from one westerly wind event) during the 1984 long rains season. The fewer incidences of westerly winds resulted in the observed stronger easterly winds when compared to the wet case. Generally, Figs. 3 and 4 show that the midtropospheric wind intensity over the EEA region was relatively weak/strong during the wet/dry years.

The wind anomalies for the wet (1981) minus the dry (1984) were computed in order to show contrast between the two years (Fig. 5). Figure 5 at 700-hPa level depicts more clearly the spatial scale of the anomaly wind fields. A westerly wind anomaly over the region 10°S to the equator and from 20° to 80°E can be seen. A significant feature of this anomalous midtropospheric flow was the cyclonic circulation observed to the south of Madagascar with the cyclonic center near the point 25°S , 50°E (marked C). This cyclonic circulation was associated with anomalous southerly winds through the Mozambique Channel. The region affected by the anomalous

FIG. 5. Wind anomaly for the wet year (1981) minus the dry year (1984) at 700 hPa (C = cyclonic circulation).

southerly winds extended westward to cover the area $40^\circ\text{--}10^\circ\text{E}$ and between 30° and 10°S .

Two distinct rainfall episodes were selected for further study one from each of the selected anomalous years, namely, the persistent wet spells lasting two pentads or more, and the persistent dry spells, also lasting two pentads or more. The vector wind patterns for these wet/dry spells are independently discussed below.

Figure 6 displays an example of the midtropospheric circulation for the wet-spell pentads (a total of six pentads were averaged) during the wet year (1981). Weak westerlies dominated in the EEA region with maximum intensity (4.1 m s^{-1}) near the point 6°S , 40°E . A notable feature was the trough to the south of Madagascar (marked T) with southerlies in the Mozambique Channel. The equatorial westerlies to the south of the equator, together with easterlies to the north of the equator, formed an equatorial vortex with a center near the equator point, 35°E (marked EV). This equatorial vortex was associated with active convection over the EEA region.

FIG. 6. An example of composite wind vectors at 700 hPa during wet spell pentads. Centers of low/high wind intensity are marked by L/H (EV = equatorial vortex, T = trough).

FIG. 7. An example of composite wind vectors at 700 hPa during the dry spell pentads. Centers of low/high wind intensity are marked by L/H (C = cyclonic circulation, A = anticyclonic circulation).

Figure 7 displays an example of the midtropospheric (700-hPa level) vector wind patterns for the dry pentads (a total of three pentads were averaged). The EEA region was dominated by easterly winds. The most significant feature in the midtropospheric wind flow was the cy-

clonic circulation with a center at about 25°S, 25°E (marked C) in the composites for the dry pentads. Also, anticyclonic flow was observed over Madagascar (marked A). These cyclonic and anticyclonic circulations were associated with strong northerly winds through the Mozambique Channel. These northerly winds blocked the surge of cold air from the southern extratropics from reaching into the equatorial eastern Africa region.

The southerly meridional wind component at 700-hPa level (Fig. 8a) shows a maximum in the intensity at the point 23°S, 22°E. This meridional wind component decreases to zero, along 40°E, at latitude 13°S (Fig. 8a) and is more equatorward to the west of this meridian. The meridional wind component penetrated further equatorward at lower levels, reaching 7°S at 850 hPa (Fig. 8b) and 3°S at 1000-hPa level (Fig. 8c). This suggests that the meridional southerly flow undercuts the equatorial air mass and this promotes uplift over much of the EEA region. Tyson (1984, 1986) has observed a similar undercutting action of southerly meridional flow over South Africa that he noted was an important mechanism in summer rainfall events.

Wet episodes over the EEA region are associated with

- 1) cyclonic circulation to the southeast of Madagascar with resultant southerlies in the Mozambique Channel and mainland southern Africa between longitudes 10° and 40°E; and

FIG. 8. Examples of composite meridional wind component for the wet spell pentads at (a) 700-hPa, (b) 850-hPa, and (c) 1000-hPa levels. Continuous contours are for meridional southerly flow while the dashed contours are for northerly flow. Centers of low/high intensity are marked by L/H.

FIG. 9. (a) Seasonal SST anomaly patterns for the wet year (1981). Contour interval is 0.25°C. Regions of positive anomalies are shaded. (b) Seasonal SST anomaly patterns for the dry year (1984). Contour interval is 0.25°C. Regions of positive anomalies are shaded. (c) Differences of the seasonal SST between a wet year (1981) and a dry year (1984) during April. The contour interval is 0.25°C. Regions of positive anomalies are shaded.

- 2) westerly winds over the EEA region, extending from 20° to 80°E and over the latitude belt 10°S to the equator.

The dry episodes indicate that

- 1) stronger than normal easterlies occurred over the EEA and the west Indian Ocean, and
- 2) northerlies were observed in the Mozambique Channel.

The westerlies over the EEA region have originated from the Atlantic Ocean/Congo Basin and as such are moisture laden. Some of this moisture is deposited over EEA as rain. Also, the westerlies have been observed at the sea surface level over the western Indian Ocean during the NHS (Sadler et al. 1987). These westerlies turn into easterlies as part of the EV circulation (Fig. 6) and therefore the easterlies entering into EEA region north of the equator, during this period, are moist and result in enhanced rainfall episodes.

The above illustrations (Figs. 6 and 8) suggest that the marked southerlies during this period may constitute

an interaction of the extratropics with the equatorial region bringing in a surge of extratropical cold air mass. Also, through conservation of potential vorticity the long northward trajectory must turn eastward. It is apparent that the air having travelled from about 30°S is forced to turn eastward in the latitude band 10°S and equator. This trajectory modification will be investigated further in a subsequent study.

c. Sea surface temperature anomaly patterns associated with anomalous rainfall events

Sea surface temperature (SST) anomaly patterns for long rains (March–May) season within the period 1979–88 have also been investigated here in order to determine the major SST modes that are dominant over the Southwest Indian and Eastern Atlantic oceans during the wet/dry years over EEA.

Figures 9a,b present the SST anomalies for the March–May period during 1981 and 1984, respectively. During 1981, a wet year, the western Indian Ocean

(WIO) sector was generally characterized by warm SST anomalies, while the eastern Atlantic Ocean (EAO) had generally dominant cold SST anomalies. During the dry year of 1984, the WIO had cold SST anomalies while the EAO had warm SST anomalies. These SST anomaly patterns are consistent with the observed stronger than normal midtropospheric easterly winds during the dry year (Fig. 4) over the WIO, while the wet year had weaker than normal easterly winds or even westerlies (Fig. 3).

Figure 9c displays the differences between 1981 and 1984 for April SSTs. These differences emphasize more clearly the amplification of the unique patterns observed that dominated the dry/wet scenarios above. It may be concluded that the equatorial westerlies observed over the EEA region and the WIO in the middle levels during the EEA long rains season are consistent with the observed warm/cold SST anomalies over the Indian/Atlantic oceans that encourage westerly flow over equatorial Africa and the WIO. This effect is expected to extend up to the middle levels (near 700-hPa level) due to enhanced moisture availability with convective mixing in the lower troposphere over the warm water pools.

During the wet/dry long rains seasons the wind intensity was weak/strong over EEA and west Indian Ocean regions. These wet and dry cases were closely connected with pools of warm and cool water over the surrounding oceans. The SST anomalies were positive/negative over WIO for the wet/dry cases. The corresponding SST anomalies over the EAO were also negative/positive, respectively.

5. Conclusions

Wet events over EEA region during the NHS are associated with both westerly anomalies over EEA in the latitude belt 10°S and the equator, and southerly winds between 30° and 10°S. Dry events have generally stronger than normal easterlies in the region 10°S and the equator with northerly winds observed in the Mozambique Channel.

These wet/dry events were associated with pools of warm/cool water over the west Indian Ocean and cool/warm water over the eastern Atlantic Ocean, respectively.

Occurrences of anomalous rainfall in the equatorial east African region may be described (modeled) in terms of the 700-hPa velocity fields.

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