Linkages between the Indian Ocean Dipole and East African Seasonal Rainfall Anomalies

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ABSTRACT

This study was designed to understand the nature of the relationship between the Indian Ocean Dipole (IOD) index and seasonal rainfall in East Africa using statistical approaches. The statistical methods used in this study include correlation, regression and composite analyses.

Results from the analyses suggested that the pattern in Sea Surface Temperature (SST) anomalies manifested during the IOD events have strong signals on the regional climate system during the October to December rainfall season. The study has demonstrated that some of the extreme rainfall conditions over East Africa were associated with positive and negative IOD phases. The linkages were strong during El Niño/La Niña years.

Such information will help to improve monitoring, prediction and early warning of extreme rainfall events over east Africa to reduce the vulnerability of the society of the region to negative impacts of extreme rainfall events that are common in the region.

1. INTRODUCTION

Extreme climate occurrences such as droughts and floods are common in the East African region. In some cases one climate extreme is immediately followed by another one of a different type. For example, extreme floods associated with heavy rainfall being followed immediately with severe drought persisting for several seasons. Such extreme climate events have been associated with many miseries in the region including loss of life, property, destruction of infrastructure, large losses to the economy, and many devastating socio-economic impacts. The severe impacts associated with extreme climate events can be reduced through good understanding of previous climate events and their impacts and vulnerability; enhanced climate monitoring and timely early warning; improved awareness of the usefulness of climate information and prediction products in decision making; as well as existence and availability of good disaster management policies that effectively address the vulnerability of various climate sensitive socio-economic sectors and sustainable resilience of the society.

East African region experiences two rainy seasons, the March – May (MAM) "long rains season" and the October – December (OND) "short rains season. The highest precipitation occurs during the long rains. The OND season, however experiences a larger degree of interannual variability relative to climatology.

Studies by Ininda (1998); Nyenzi (1992); Ogallo *et al* (1988); Indeje (2000); Semazzi and Indeje (1999); among others have explained the link between seasonal rainfall over East Africa and the SST in the global ocean. The role of Indian Ocean SSTs in climate variability has been discussed in a number of studies. These works have linked the climate variability over the African subcontinent to the air-sea interactions over the Indian Ocean. Nicholls (1985), for instance described a relationship between Indian Ocean SST anomalies and Australian winter rainfall.

Recently, an ocean-atmosphere coupled mode of variability referred to as Indian Ocean Dipole (IOD) has been documented (Saji *et al*., 1999; Webster *et al*. 1999; Murtugudde *et al*. 2000). The IOD is associated with the east-west gradient in the tropical Indian Ocean SST anomalies.

The dipole pattern related to IOD has also been identified in other parameters such as sea level anomalies (Rao *et al*, 2002), outgoing long wave radiation (OLR) anomalies (Behera *et al*, 1999, 2003; Yamagata *et al,* 2002), and sea level pressure anomalies (Behera and Yamagata, 2003). Saji *et al.* (1999) have defined an Indian Ocean Dipole Mode Index (IODMI) to characterize the IOD as the difference in SST anomalies of the Tropical western Indian Ocean (50^0E – 70^0E, 10^0S – 10^0N) and the Tropical southeastern Indian Ocean (90^0E – 110^0E, 10^0S – 0^0). IOD is a seasonally phase-locked phenomenon that initiates in May, peaks in October and decays in by December. The positive phase of the IOD is associated with warm SST in the Tropical western Indian Ocean and cold SST in Tropical southeastern Indian Ocean.

Investigations using a variety of ocean models suggest that the SST modulation is largely due to oceanic processes, mainly vertical and horizontal advection and upwelling (Behera *et al*., 1999; Murtugudde *et al*. 2000). In turn, the oceanic processes are a result of the ocean adjusting through equatorial wave dynamics to the strong equatorial wind anomalies associated with Indian Ocean Dipole (IOD) events (Rao *et al*. 2002; Feng and Meyes, 2003; Guan *et al*. 2003; Iizuka *et al*. 2000).

Studies by Saji *et al*. (1999), Hastenrath, (2000; 2002), Hastenrath and Polzin (2003) and Webster *et al.* (1999) have furnished evidence of some large-scale interactions between the Indian Ocean and the overlaying atmosphere and indications of climatic consequences. They related the Indian Ocean temperature distribution to increase/decrease in rainfall over East Africa/Indonesia. Webster *et al.* (1999) further indicates that there is little statistical relationship between IOD and El Niño, as the dipole has been observed to occur in both El Niño and non-El Niño years.

The involvement of ocean dynamics suggests a certain amount of predictability to the IOD development once it is triggered (Saji and Yamagata*,* 2003). Currently, however, it is not clear what triggers IOD events, though there are various hypothesis suggesting different triggering mechanisms. For instance, noting a strong correlation between IOD and ENSO events during boreal fall, Xie *et al*. (2001) suggested that ENSO is a possible trigger for IOD events. However, a number of strong IOD events have occurred in the absence of ENSO (Saji and Yamagata, 2003). Some research suggests that some of the independent IOD events may be forced by either intraseasonal oscillations (Li and Mu 2001). On the other hand, Yamagata *et al.* (2002) have also suggested the possibility of IOD as a self-sustained oscillation.

In Eastern Africa, Sea Surface Temperatures (SSTs) and the ENSO phenomenon, the southern oscillation, among others are currently used as the major predictors of seasonal rainfall anomalies due to the current scientific capability to provide projections of ENSO signals many months ahead. It has however been noted that prediction skills based on ENSO only as a predictor still have many limitations. For example, ENSO based prediction skills have been noted to be more significant during July - December period especially during the years with strong ENSO (Indeje, 2000). Low skills are generally common for some seasons and years with weak SST anomalies. The need to explore for more predictors of seasonal rainfall is therefore one of the key challenges in the region.

The purpose of this study is to explore the linkages between IOD evolution phases and the East African seasonal rainfall, and the potential of using the derived teleconnections for improving seasonal rainfall monitoring; prediction and early warning of extreme rainfall events. The improved early warning of extreme rainfall events is essential to reducing the vulnerability of the society to negative impacts of extreme rainfall events such as floods and drought that are common in the region.

The rest of this paper is organized as follows. Section 2 briefly describes the details of the data sets used, and the analysis methods. Section 3 describes the results from the analyses while section 4 presents the summary and conclusions.

2. DATA AND METHODOLOGY

The data used in the study were rainfall data for the three East African countries (Kenya, Uganda and Tanzania) and the global sea surface temperatures (SSTs) for the period 1950 to 2003. The rainfall data were obtained from the IGAD Climate Prediction and Applications Centre (ICPAC) while the global sea surface temperature (SST) data used in the study were from National Center for Environmental Prediction/Climate Prediction Center (NCEP/CPC). The SSTs data are on 2.5^0 x 2.5^0 grid resolutions and is often known as optimal interpolation (OI) SST in literature following Reynolds and Smith (1994). The Dipole Mode Index (DMI) as described by Saji *et al.* (1999) was adopted in this study. Figure 3 provides the annual cycle of the dipole index for some events.

Standardized indices were used to

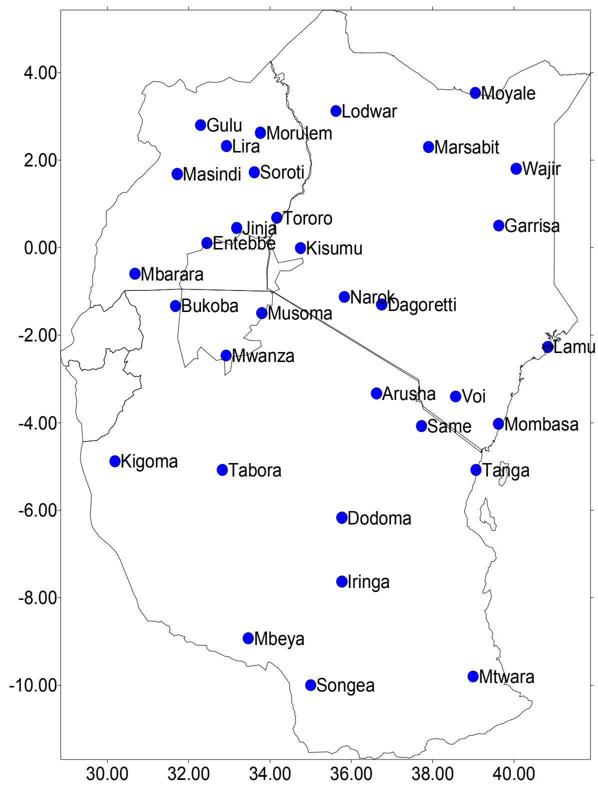


Figure 1: Distribution of the representative stations over the study region.

enable comparisons of the anomalies within specific periods and/or locations, while simple correlation analysis examined simple relationships between pairs of variables.

Temporal stability correlation coefficients were also examined in order to investigate the stability of the computed IOD-East African rainfall associations. This involved the comparison of several running 30 years average windows for example 1950-1979, 1951-1980, 1952-1981, until the end of the analyzed time scale and so on. Composite analysis was included in the study in order to further study patterns of associations between east African seasonal rainfall anomalies and the IOD phases.

3. RESULTS

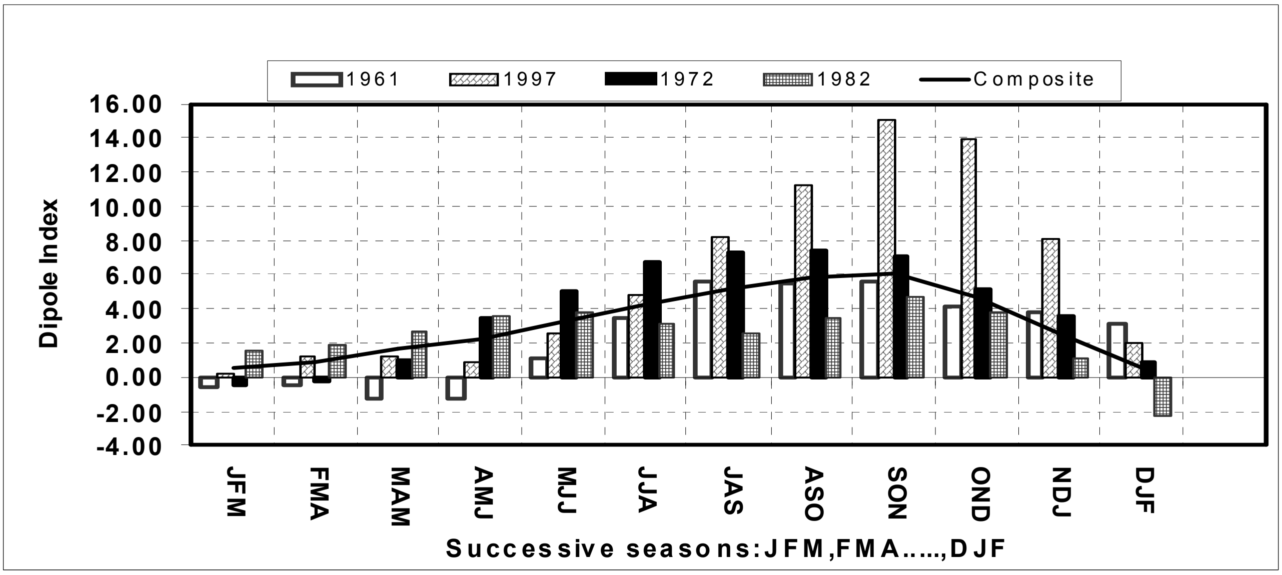
3.1. Homogeneous regions used in the study

In this study, the homogeneous rainfall zones developed at IGAD Climate Prediction and Application Centre (ICPAC) were adopted. The rainfall data from 1960 to 2001 obtained from ICPAC for stations that had long records (Figure 1) and are distributed in the different climatic zones (Table 1).

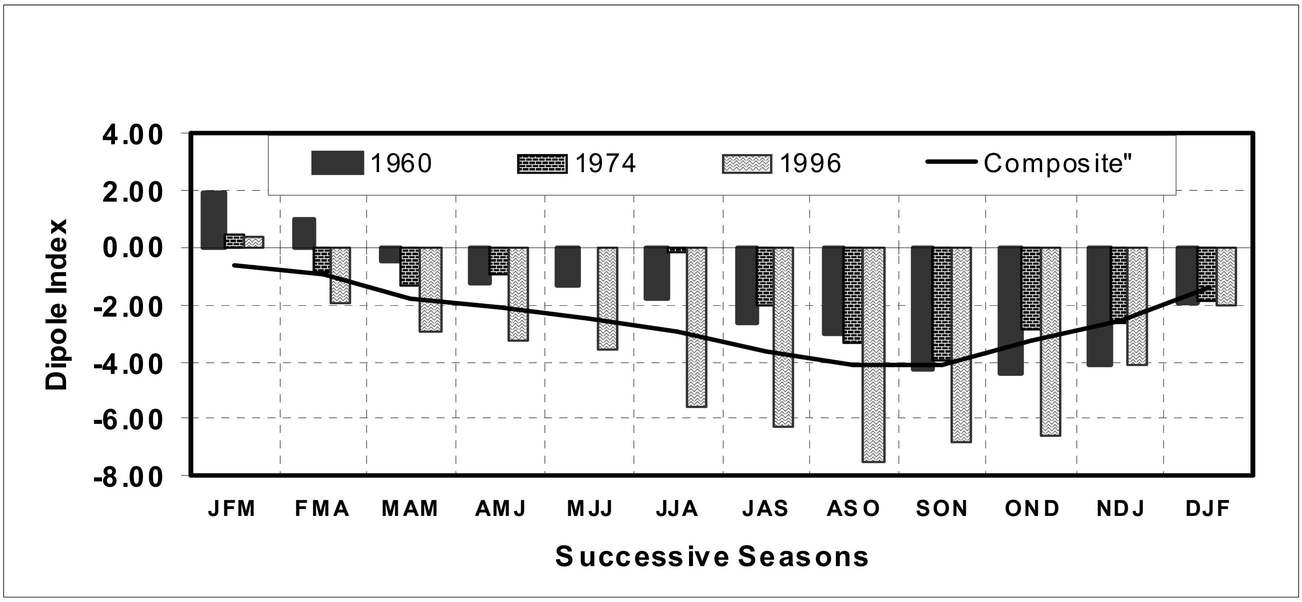
3.2. Standardized anomaly indices

The positive and negative dipole phases are presented in Figures 2a and 2b respectively. From the figures, strong seasonal cycle is evident. In general, significant anomalies begin to appear around April reaching maximum peak around October/November. Most of cycles never extended beyond one year.

Figure 3 shows the interannual variability of the dipole mode index for the October to December (OND) season. The figure shows recurrences of the years with positive and negative phases of the IOD events. Results show that 8 strong positive and 9 strong negative IOD events (defined as years during which the DMI exceeds one standard deviation) occurred within the period 1950-2003. The strong positive phase of the dipole events were observed during 1961, 1963, 1967, 1972, 1982, 1991, 1994, and 1997 while the strong negative phase during 1954/55, 1956, 1960, 1971, 1974, 1975, 1992,and 1996. Available records show that out of these events, the strong positive events of 1972, 1982,



a)



b)

Figure 2: Mean monthly patterns for Indian Ocean dipole indices (a) positive IOD event years namely 1961, 1972, 1982, and 1997 (a) negative IOD event years namely 1974, 1960 and 1996

Table 1(a): Rainfall Stations used to represent March – May (MAM) climatic zones

ZONE	REPRESENTATIVE STATION	ZONE	REPRESENTATIVE STATION	ZONE	REPRESENTATIVE STATION
1	NEBBI	10	BUSHENYI	19	SAME
2	LIRA	11	JINJA	20	DODOMA
3	MASINDI	12	BUKOBA	21	MOMBASA
4	SOROTI	13	MBULU	22	LAMU
5	KAKAMEGA	14	DAGORRETI	23	MBEYA
6	LODWAR	15	MOYALE	24	SONGEA
7	WAJIR	16	GARISSA	25	MTWARA
8	ISIOLO	17	KIGOMA	26	KISUMU
9	MBARARA	18	TABORA	27	MWANZA

Table 1(b): Rainfall Stations used to represent October – December (OND) climatic zones

ZONE	REPRESENTATIVE STATION	ZONE	REPRESENTATIVE STATION	ZONE	REPRESENTATIVE STATION
1	GULU	9	MBARARA	17	TABORA
2	LIRA	10	MARSABIT	18	KIGOMA
3	MORULEM	11	WAJIR	19	DODOMA
4	NAROK	12	GARISSA	20	MBEYA
5	DAGORETTI	13	VOI	21	SONGEA
6	MASINDI	14	LAMU	22	MTWARA
7	ENTEBBE	15	MOMBASA	23	BUKOBA
8	KISUMU	16	SAME	24	MWANZA

1991 and 1997 co-occurred with El Niño episodes; while the strong negative events of 1954, 1964, 1971, 1974/75, 1984, and 1998 co-occurred with La Niña episodes. This may be indicative of some possible interactions between ENSO and IOD as highlighted by Yamagata *et al*. (2002), who found that during the last 127 years, 14(19) strong negative (positive) IOD events developed of which 5(7) co-occurred during ENSO events.

3.3. IOD Analogues

Standard deviation was used to determine the years which experienced IOD events with similar severity. The thresholds given in Table 2 have been used in the study to group together years with similar IOD intensity. In the table, extreme positive events are designated as (**E**), and moderate as (**M**), (*) is used to identify the negative IOD phases thus (**E***) and (**M***) represent extreme and moderate negative phases respectively. The rainfall anomalies associated with these analogue years are discussed in section 3.8.

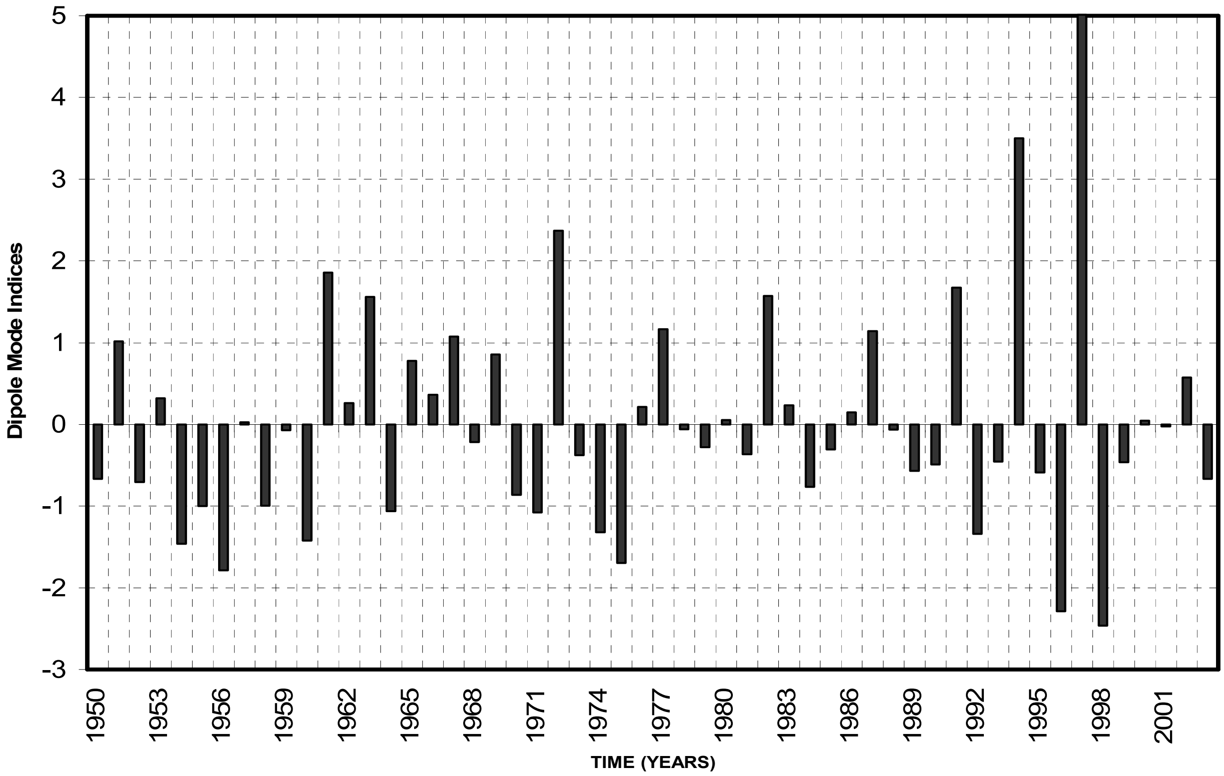


Figure 3. Interannual variability of the Dipole Mode Indices (DMI) during the October - November season

Table 2: Classification of IOD severity /s desig-

CATEGORY	THRESHOLD
Normal **(N)**	-0.5s≤ DMI ≤ 0.5s
Positive moderate **(M)**	0.5s < DMI ≤ s
Negative moderate **(M*)**	-0.5s > DMI ≥ -s
Extreme positive **(E)**	DMI > s
Extreme negative **(E*)**	DMI < -s

3.4. SST anomalies over the specific IOD centers

Figure 4a and 4b give the time series of the mean SST anomalies over the two dipole centres for some years in which the IOD event occurred. The years that were averaged for the positive phase events were 1961, 1963, 1967, 1972, 1982, 1994 and 1997 while those for the negative phase were 1960, 1974, 1975, 1992 and 1996. It is evident from the figure that large SST anomalies of opposite signs occurred over the IOD centres during these years. Such patterns have been observed in earlier works (Saji *et al*, 1999, Webster *et al*, 1999, Murtugudde *et al*. 2000 and Black *et al*. 2003).

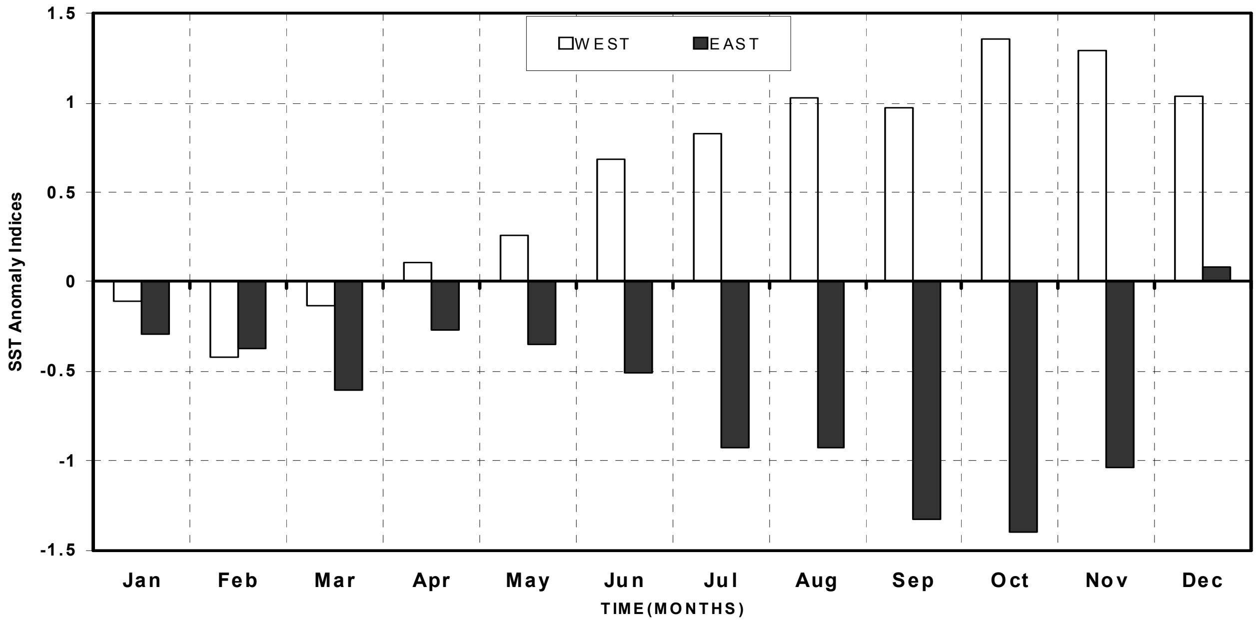
3.5. Spatial patterns of SST anomalies over the Indian Ocean associated with IOD phases

Figures 5a and 5b provide composite spatial patterns of SST anomalies over the Indian Ocean during the peak seasons of the dipole events for the normal and inverse IOD phases.

The mean locations of the dipole subregions have been presented by Saji *et al.* (1999) among others as locations enclosed by 50°E - 70°E, 10°S - 10°N and (90°E - 110°E, 10°S - 0°). However, the cooling over the Tropical eastern Indian Ocean is robust during strong dipole years while the location of the Tropical western Indian Ocean warming varies from event to event.

3.6. Teleconnection between IOD events and East African seasonal Rainfall

Correlation analysis was used to assess the teleconnection between IOD and East African seasonal rainfall. Zero, one, and higher SSTA and IOD time lags were correlated with the targeted rainfall seasons; (MAM) and (OND). The lead/lag relationship was examined by



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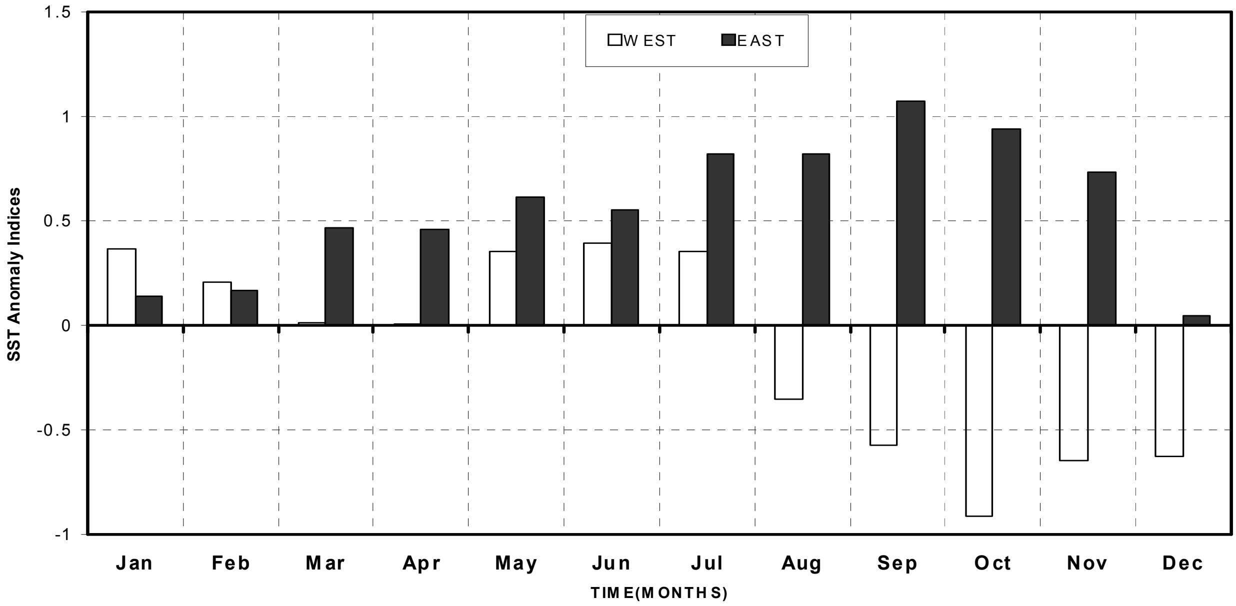


b)

Figure 4: Composite monthly profiles of the SST anomaly indices over Indian Ocean dipole sub-regions for (a) positive (1961, 1972, 1982, and 1997) and (b) negative (1974, 1960 and 1996) IOD events.

computing the correlation coefficient between the seasonal rainfall and the SST and dipole mode indices for the preceding months/seasons. Correlation coefficients of [r] ≥ 0.3 are above 5 percent significance level based on the standard correlation tables (Neave, 1978) on a sample size of 42 years (1960-2001). Figure 6 gives the spatial patterns of lagged and simultaneous correlation of IOD indices with East African October-December (OND) rainfall indices. The results indicate significant positive simultaneous and lag correlation between the IOD indices and the OND rainfall over the eastern sector of east Africa with exception of southern Tanzania where the correlation values were generally low. The coastal and eastern parts of east Africa except for parts of eastern Kenya had significant values of correlation.

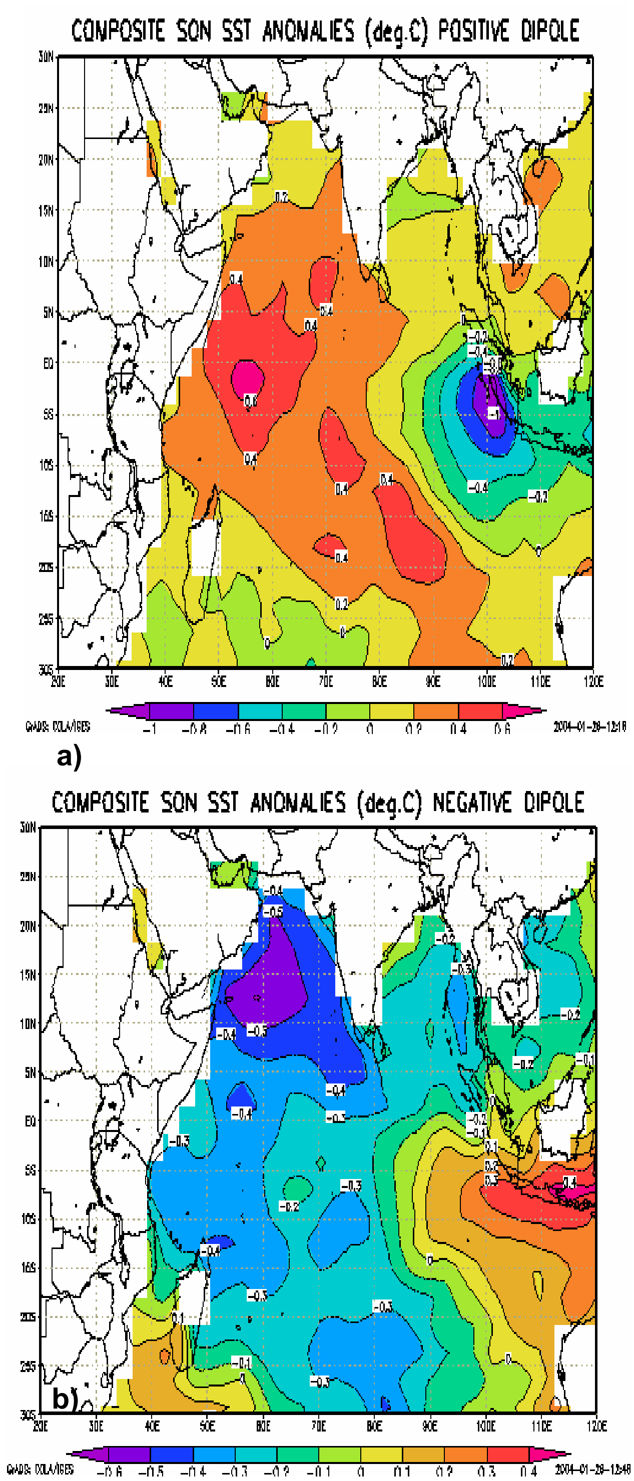


Figure 5 Composite of SST anomaly dipole pattern over the Indian Ocean during the SON season for: (a) positive and (b) negative dipole events

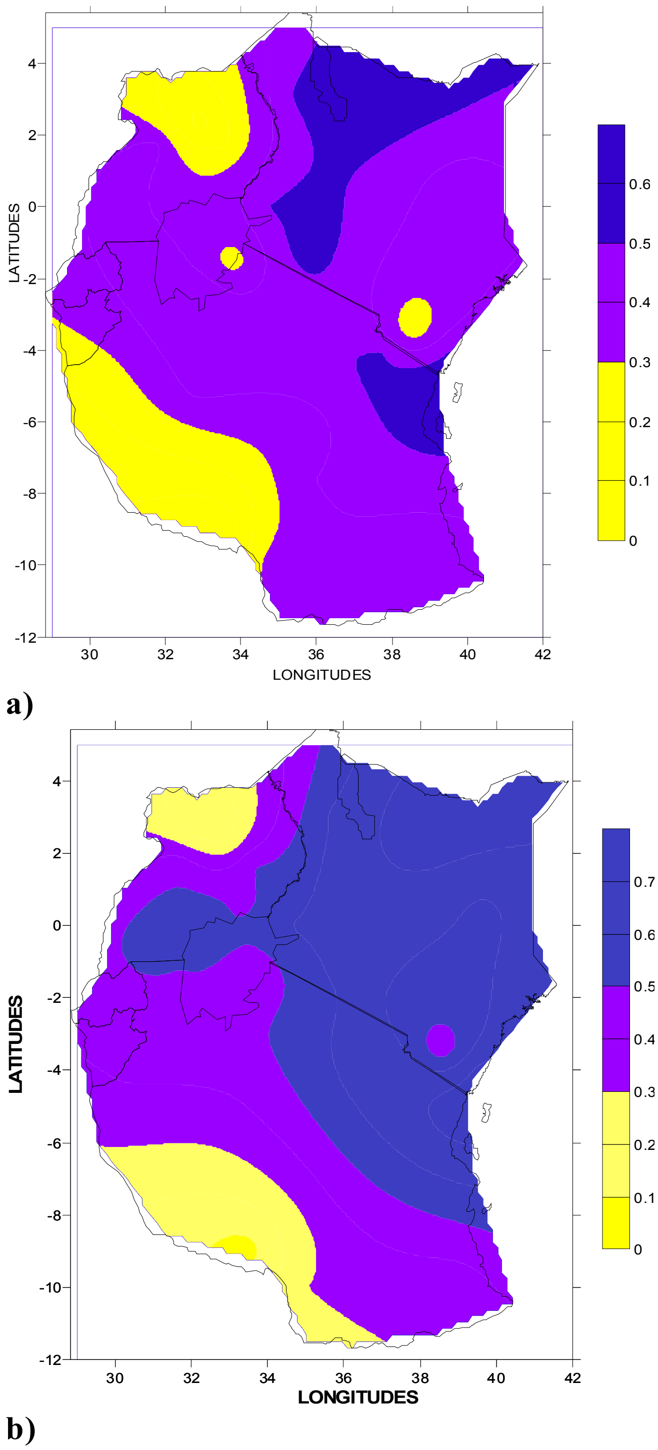
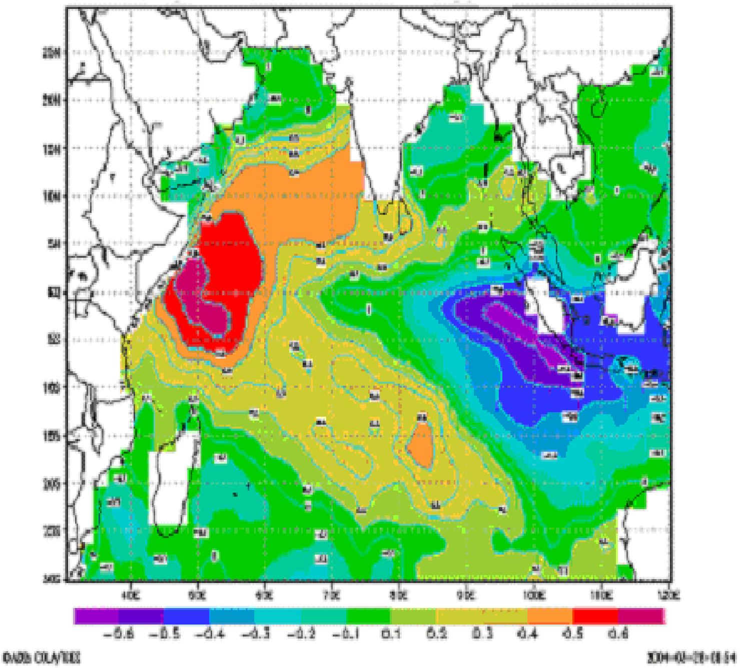


Figure 6: Correlation pattern between IOD and October-December rainfall. (a) JJA IOD one-season lag correlation with October-December rainfall (b) IOD simultaneous correlation with East African October-December rainfall index.

Maximum correlation ranged from 0.76 in northeastern parts of Kenya at zero lag correlations to about 0.6 for one season lag correlation. Many parts of western East Africa generally had low positive correlation values except for some locations around Lake Victoria. Spatial patterns of the correlations that were obtained between specific rainfall zones and Indian Ocean SST



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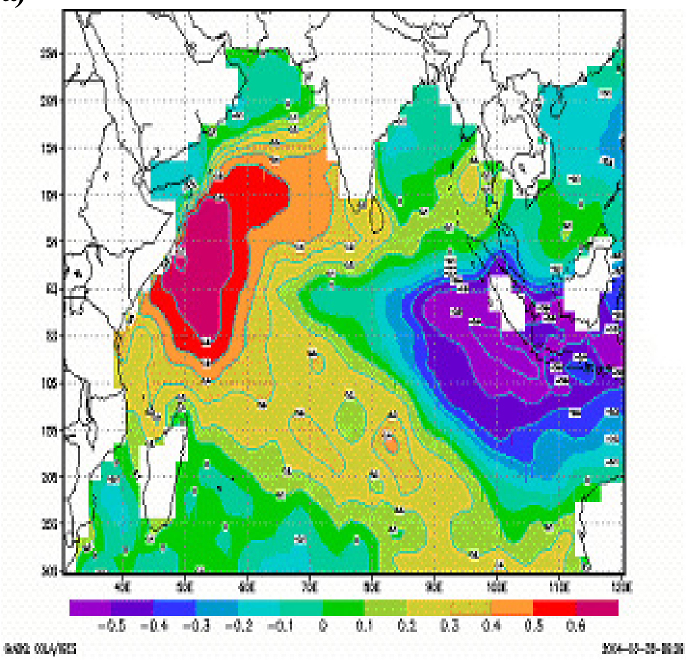


b)

Figure 7: Correlation between SST and the OND rainfall anomalies. (a) Simultaneous correlation for coastal region (b) simultaneous correlation for Northern Kenya region

are given in Figure 7. See-saw patterns in the centres of maximum correlation are quite evident, with peak values generally close to the IOD regions in the Indian Ocean. The results however show significant temporal and spatial shifts in the centres of the maximum correlation values, which signify some challenges in the use of simple IOD indices for regional rainfall prediction studies.

These results confirmed the existence of strong association between Indian Ocean SST and rainfall over parts of the region as has been observed from some past studies (Ininda 1998; Nicholson *et al*. 1997; Mutai *et al* 1998 among others).

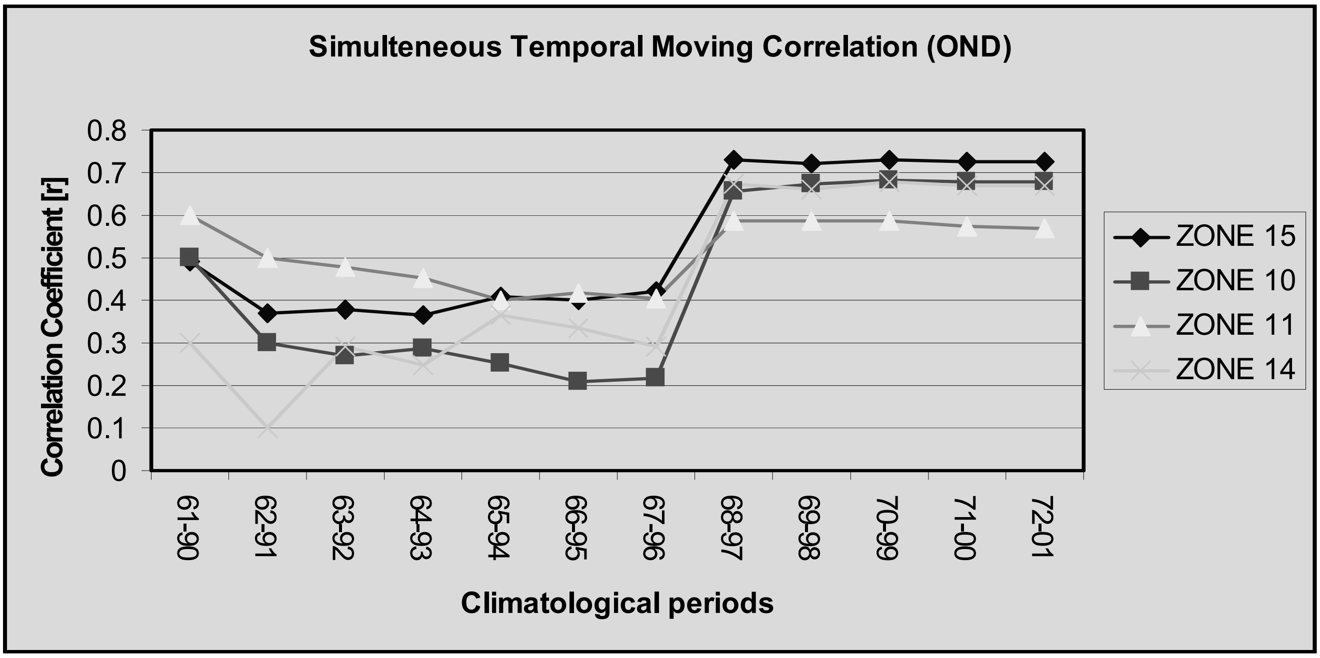
For the March to May (MAM) rainfall and the IOD Indices, the correlations values were however generally insignificant at most locations. Maximum values of [r] were about 0.35 over the northern parts of coastal Kenya at lag zero. The correlation values also decreased with the increase in the time lags.

Correlation between the dipole mode indices and the rainfall indices on 30 years running windows was carried out in an attempt to assess the stability of the linear associations between the Dipole mode and rainfall indices. Since the results indicated weak association between the dipole indices and the March – May (MAM) rainfall indices, only the short rainfall season were considered.

The temporal variations in the values of the correlation coefficients between OND rainfall and IOD indices for some selected locations shown in Figure 8 indicated strong correlations. It is quite evident from the figure that a significant correlation increase, indicated by the jump in the graphs occurred from the period 1960s to date at most locations. Few locations such as zone 11 have however maintained steady correlation values. Strong IOD events also occurred during 1961, 1963 and 1967, and some later years and we envisage that these events could have contributed to the apparent jump in correlation coefficient.

3.7. Reality of the observed correlation results

In order to give more insights to the correlation results, the space and time characteristics of rainfall during the various IOD phases are presented in this section. Correlation results indicated positive linkages between IOD and seasonal rainfall during the two wet seasons over the East Africa sub region. Thus, a negative and positive IOD and rainfall anomalies occurs at the same time if the correlations were real. Figures 9 gives normalized time series for the long and short rainfall seasons for some zones over the region.



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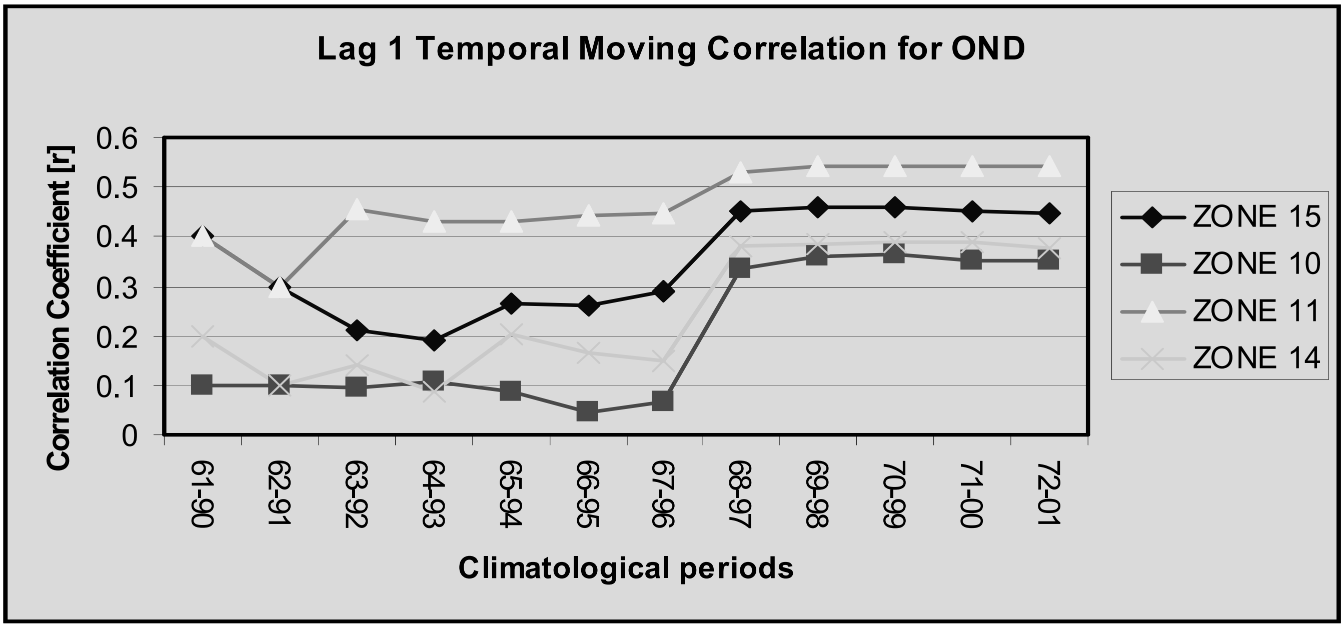
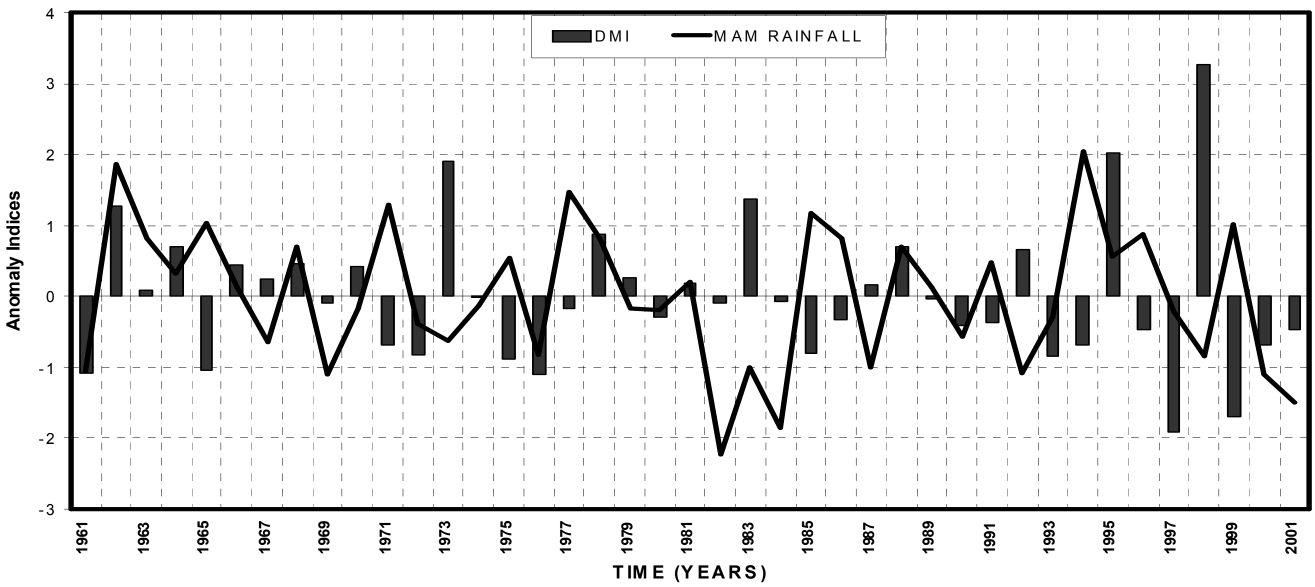


b)

Figure 8: The temporal patterns of DMI correlation with October-December rainfall over some East African homogeneous rainfall zones (a) simultaneous correlation (b) 1 season lag correlation with July-September DMI.

It is evident from the figures that dry and wet events are recurrent in all parts of the region. There is however strong spatial variability in the pattern of the linkages. It is observed from figures 9a that during the OND season, some of the driest and wettest years over east Africa coincide with some of the positive and negative dipole phases respectively. Another important observation from the figure is that the years that had SSTA of the same sign (monopole SSTA pattern) over the dipole sub-regions appear to be associated with normal to below normal rainfall conditions for the OND season. Examples of such years include 1964, 1966, 1983, 1995, 1998 and 2001. For the MAM season (*Figure 9b*), the association is very weak since most of the extreme rainfall cases do not coincide with some of the strong IOD events.



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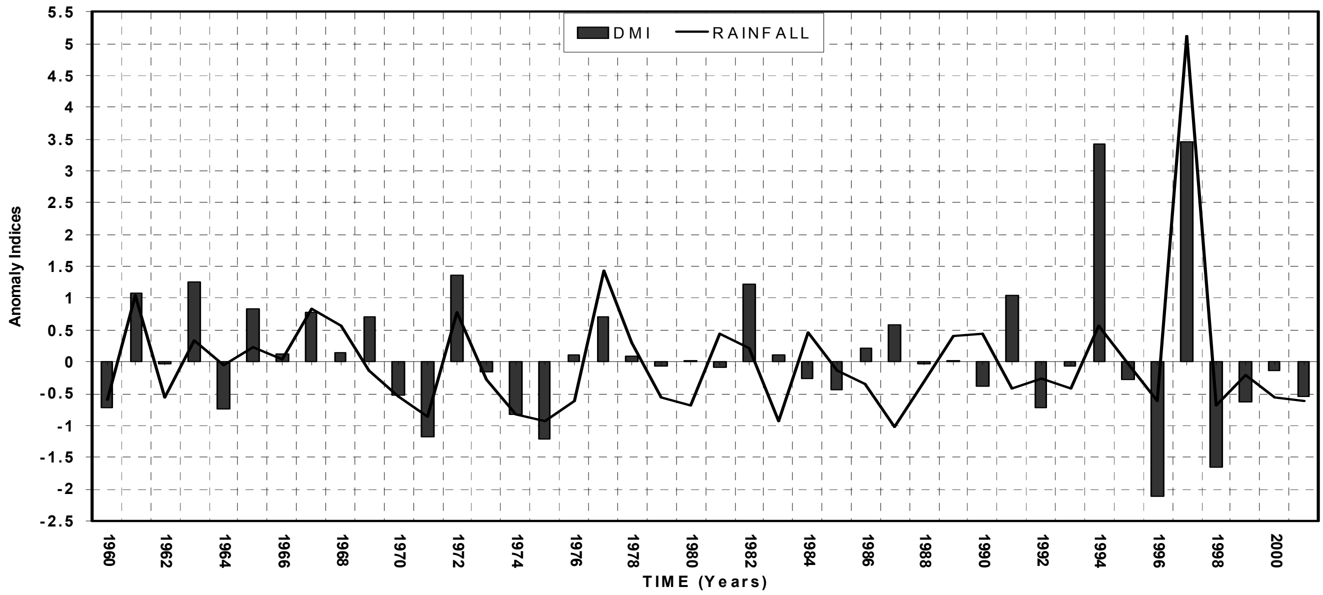

b)

Figure 9: Year-to-year variability of DMI with seasonal rainfall indices over Coastal east Africa for: (a) March – May season and (b) October – December season.

3.8. Rainfall anomaly patterns associated with IOD analogues during short rain fall season

Figures 10 shows composites of the spatial rainfall anomaly indices associated with the IOD analogues during the October-December (OND) rainfall season. The years 1961, 1963, 1972, 1994, and 1997 were used to develop composites for positive, while the years 1960, 1975, 1992 and 1996 were composited for negative IOD phases used for analogue studies.

In the spatial pattern plots, rainfall indices are grouped into three categories: above normal (Green), normal (Light green) and below normal (Yellow). Figure 10a and 10b show that positive\negative IOD phases are generally associated with wet/dry conditions over the region. Figure 10a for example indicate dominance of wet conditions during years of large positive IOD phases, while negative IOD events are associated with below normal rainfall conditions over most parts of east African region (*Figure 10b*).

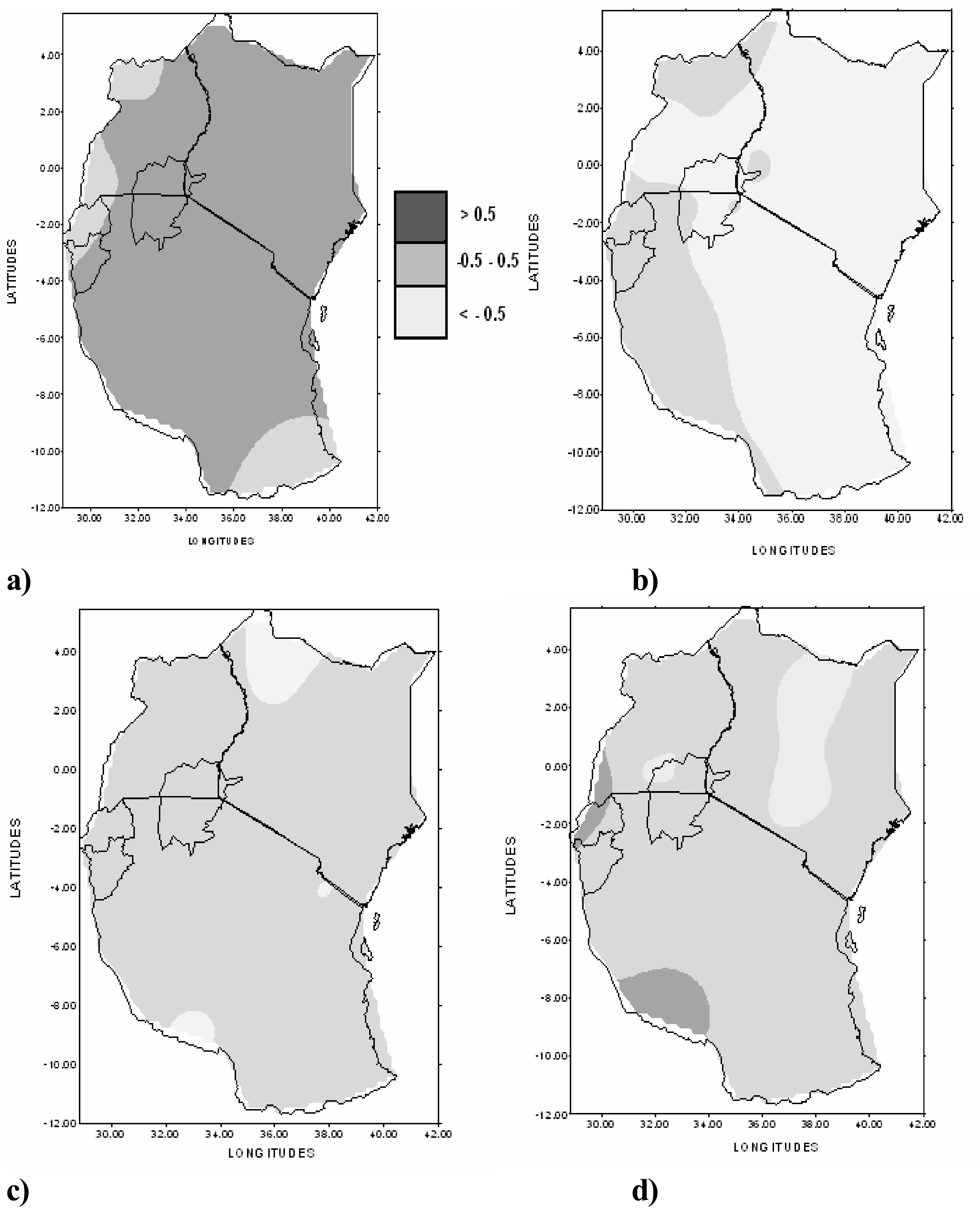

Figure 10: Composite of seasonal rainfall anomalies associated with the phases of the Indian Ocean dipole: (a) OND season during positive phase (b) OND season during negative phase (c) MAM season during positive phase (d) MAM season during negative phase .

Results from section **3** showed that the IOD events peak during the September-November season, for the March – April season we therefore considered the March-May (MAM) rainfall season for the years following a dipole event year (post dipole years). The post dipole years composited for the positive IOD events included 1962, 1964, 1973, 1983, 1995 and 1998. For the negative dipole phases 1961, 1976, 1997 and 1999 were composited.

Figure 10c provides the composite rainfall anomaly patterns for the March-May (MAM) season corresponding to the IOD phases. The figures show that post positive dipole years are associated with normal rainfall over the region. Figure 10d provides the composite of March-May rainfall anomalies for the post- negative IOD events. It is again noticed that most of the region experienced normal rainfall conditions with the exception of the northern and highlands of Kenya, which showed dry conditions. These results indicate that the IOD has no significant influence on the March – May rainfall season. This may not be surprising since peak IOD index values are concentrated between July-December. Thus, significant positive correlation values were observed at many locations during the short rainfall season.

4. SUMMARY AND CONCLUSIONS

Results of this study have confirmed the major IOD events that have been observed during the period of study as have been documented in previous studies (Saji *et al*. 1999). Normalized IOD indices indicated that strong positive phase of the dipole events were observed during 1961, 1963, 1967, 1972, 1982, 1991, 1994, and 1997 while the strong negative phase during 1954/55, 1956, 1960, 1971, 1974, 1975, 1992,and 1996. Available records also showed that out of these events, the strong positive events of 1972, 1982, 1991 and 1997 co-occurred with El Niño episodes; while the strong negative events of 1954, 1964, 1971, 1974/75, 1984, and 1998 co-occurred with La Niña episodes. This may be indicative of some possible interactions between ENSO and IOD. Yamagata *et al* (2002) indicated that during the last 127 years 14(19) strong negative (positive) events developed of which 5(7) co-occurred during ENSO events. However, some strong IOD events were observed in non-ENSO years. These include the 1961, 1967, and 1994 IOD events.

Correlation analyses results showed that the association between the IOD and regional rainfall is stronger during the short (OND) rainfall season. The correlation values were not generally significant during the long (MAM) rainfall seasons. The results indicated that significant positive correlation values were observed at many locations during the short rainfall season. Maximum significant positive simultaneous and lag correlation between the IOD indices and the OND rainfall concentrated over the eastern sector of east Africa with exception of southern Tanzania where the correlation values were generally low. The coastal and eastern parts of East Africa except for parts of eastern Kenya had significant values of correlation. Maximum correlation ranged from 0.76 for zero lag correlations to about 0.6 for lag one correlation. Similar IOD-rainfall linkage studies have been carried out in some recent studies (Black *et al*. 2003 and Clark *et al.* 2003). However, their focus was on the coastal region of East Africa.

The results from the time series indicated that some of the driest and wettest years over east Africa coincide with some of the positive and negative dipole phases during the short rainfall season. For the MAM season, the association was very weak since most of the extreme rainfall cases did not coincide with some of the strong IOD events.

Results from composite analyses further indicated that extreme IOD events are associated with the East African rainfall. The linkages seemed to be stronger when the large positive IOD indices coincided with El Niño events. In general, correlation and composite analyses indicated above normal rainfall conditions during the positive IOD events. However, the opposite is not true during the negative IOD events. These results are consistent with the suggestions in recent studies (Kijazi, 2003; Black *et al.* 2003; Saji and Yamagata 2003; Clark *et al* 2003; Behera *et al.* 2003).

The problem addressed in this study was the nature of the relationship between the dipole index and rainfall in East Africa on the basis of observational analysis. The results suggested that the pattern in SST anomalies quantified by the IOD indices affect the climate system during the OND season and that some of the extreme rainfall conditions over East Africa were associated with positive and negative IOD phases. It is however noted that the strength of such relationships vary across the region. Such information, integrated in the early warning system for the region, will help to in reducing the vulnerability of the society of the region to negative impacts of extreme rainfall events that are common in the region.

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REFERENCES

Behera, S. K., Krishnan, R., Yamagata, T., 2003, "Influence of the Indian Ocean Dipole on the Southern Oscillation", *J. Meteor. Soc. Japan*, **81**, 169-177.

Behera, S. K., Krishnan, R., Yamagata, T., 1999: Un-usual ocean-atmosphere conditions in the tropical Indian Ocean during 1994, *Geophysical Research Letters* **26** (19), p. 3001-3004.

Black, E., J. Slingo, and K. R. Sperber, 2003, "An observational study of the Relationship between Excessively Strong Short Rains in Coastal East Africa and Indian Ocean SST", *Mon Weather Rev,* **131***,* 74-94.

Clark, C. O., P. J. Webster, and J.E. Cole, 2003, "Interdecadal variability of the relationship between the Indian Ocean Zonal Mode and East African coastal rainfall anomalies", *J. Clim*., **16**, 548-554.

Feng, M. and G. Meyes, 2003, "Interannual variability in the tropical Indian Ocean: A two-year time-scale of IOD", *Deep-Sea Res. Part 2*.

Guan, Z., K. Ashok, and T. Yamagata, 2003, "Summertime response of the tropical atmosphere to the Indian Ocean dipole sea surface temperature anomalies", *J. Meteor. Soc. Japan*, **81,** 531-561

Hastenrath, S, 2000, "Zonal circulations over the equatorial Indian Ocean", *J. Climate*, **13**, 2746-2756.

Hastenrath, S., and Polzin. D, 2003, "Circulation mechanisms of climate anomalies in the equatorial Indian Ocean", *Meteorolgische Zeitschrif*, **12**, 81-93.

Hastenrath, S., 2002, "Dipoles, temperature gradients, and tropical climate anomalies", *Bull. Amer. Meteor. Soc.*, **83**, 735-738.

Iizuka, S., T. Matsuura, and T. Yamagata, 2000, "The Indian Ocean SST dipole simulated in a coupled general circulation model", *Geophys. Res. Lett*., **27,** 3369-3372.

Indeje, M., 2000, "Predictions and Numerical Simulations of the regional climate of Equatorial Eastern Africa", *Ph. D Thesis, North Carolina State University, USA.*

Ininda, J. M, 1998, "Simulation of the impact of sea surface temperature anomalies on the short rains over East Africa", *J. African Meteo. Soc.*, **3**, 1, 127-140.

Kijazi, A. L., 2003, "Teleconnections between seasonal rainfall in coastal Tanzania", *M.Sc. Thesis, University of Cape Town, South Africa.*

Li, C., and M. Mu, 2001, "Influence of the Indian Ocean Dipole on Asian monsoon circulation", *CLIVAR Exchange*, 6, 2, 11-14.

Murtugudde, R.G., J.P McCreary, and A.J. Busalacchi, 2000, "Oceanic processes associated with anomalous events in the Indian Ocean with relevance to 1997-199", *J Geophys Res.*, **105**, 3295-3306.

Mutai, C. C., M. N. Ward, and A. W. Colman, 1998, "Towards the prediction of East African short rains based on sea surface temperature-atmosphere coupling", *Int. J. Climatol.*, **17**, 117-135.

Neave, H.R., 1978, "Statistical Tables", *George Allen & Unwin, London.*

Nicholls, N., 1985, "El Nino-Southern Oscillation impact prediction", *Bull. Amer. Meteor. Soc.,* **69,** 173-176.

Nicholson, S.E., 1997, "Analysis of ENSO signal in the tropical Atlantic and Western Indian Oceans", *Int .J .Climatol.*, **17**, 117-135.

Nyenzi B.S, 1992: An analysis of the interannual variability of rainfall over East Africa. *J. African Met. Soc.,* **1**, 57-79.

Ogallo, L.J, J.E. Jonawiak, and M.S. Halpert, 1988, "Teleconnections between seasonal rainfall over East Africa and Global sea surface temperature anomalies", J. *Meteor. Soc. Japan*, **66**, 807-822.

Rao, A.S., S.K. Behera, Y. Masumoto, and T. Yamagata, 2002, "Interannual variability in the subsurface tropical Indian Ocean", *Deep-Sea Res. Part 2*, **49**, 1549-1572.

Reynolds, R. W., and T. M. Smith, 1994, "Improved global sea surface temperature analysis using optimum interpolation", *J. Climate,* **7,** 929-948.

Saji, N.H., Goswani, B.N., Vinayachandran, P.N., Yamagata, T., 1999 "A dipole mode in the tropical Indian Ocean", *Nature,* **401**, p. 360-363.

Saji, N.H., and Yamagata, T., 2003, "Structure of SST and surface wind variability during Indian Ocean dipole mode events: COADS observations", *J. Climate*, **16,** 2735-2751.

Semazzi, F .H. M, and M. Indeje, 1999, "Inter-seasonal variability of the ENSO rainfall signal over Africa", *J. African Meteo. Soc.*, **4**, 1, 81-94.

Atmos. Phys., **44,** 43-61.

Webster, P.J., Moore, A.M., Loschigg, J.P., Leben, R.R., 1999, "Coupled ocean-atmosphere dynamics in the Indian Ocean during 1997/98", *Nature* **401,** 356-360.

Xie, S. P., H. Annamalia, F. A. Schott, J. P McCreary, 2001, "Structure and mechanisms of Southern Indian Ocean climate variability", *J. Clim.*, **15,** 864-878.

Yamagata, T., S. K. Behera, S.A. Rao, Z. Guan, K. Ashok, and H.N. Saji, 2002, "The Indian Ocean dipole: a physical entity", CLIVAR *Exchange*s, **24,** 15-18, 20-22.

Yamagata, T., S. K. Behera, S.A. Rao, Z. Guan, K. Ashok, and H.N. Saji, 2003, "Comments on: dipoles, temperature gradients, and tropical climate anomalies", *Bull. Amer. Meteor. Soc.*, **84**, 1440-1442.