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Title: ***Using Sea Surface Temperatures to Predict Seasonal Rainfall over East Africa.***

By

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Abstract

In East Africa (Uganda, Kenya and Tanzania) agriculture sector employs over 80% of the work force and export earnings from the sector constitute a major part of the national budgets. Subsistence farming is the major source of food. However food shortages as well as negative impacts on several sectors of the economies have been attributed to the seasonal weather variations among other factors. Therefore, the objective of this study was to determine the Long-Range prediction potential of seasonal rainfall as derived from SST modes of the neighboring oceans.

The SST data used in the study were obtained from the United Kingdom Meteorological Office. The data were available on both 10° x 10° grid mesh and 5° x 5° grid mesh. The point rainfall data were obtained from the headquarters of the respective meteorological departments. The quality-controlled data were subjected to principal component analysis to delineate the major rainfall modes. Linkages between rainfall anomalies in these delineated homogeneous rainfall zones were then investigated through correlation and regression analyses. The period 1940-1975 was used for model building while the period 1976-1990 was used to train the model. Three-month time lags were used in this study.

In this study spatial patterns of the factor loadings were used to delineate East Africa into 36 homogeneous regions which were used to build regional models. Correlation analysis indicated that different ocean locations were significantly correlated to regional seasonal rainfall during different seasons. These formed the fundamental base for the choice of the predictors. Results from the regression analysis indicated that SST variations explained maximum seasonal rainfall variance of 56.1%, 48.1%, 71.6% and 58.7% during the seasons of December-February, March-May, June--August and September-November respectively. The March to May season indicated the lowest prediction skill while the September to November indicated the highest predictive skill at most of the regions. Higher predictive skills were generally observed during El-niño and La-Nina. Comparing El-niño and La-niña cases, the prediction skills were higher with El-niño signals. The results generally indicated that SST modes could be used to give some useful lead time seasonal rainfall forecasts which could be used to minimize the impacts of climatic variability in several areas of socio-economics.

1.0 INTRODUCTION

Climatic variability impacts several socio-economic sectors (agriculture, hydropower, water resources, human health, transport and communication among others. Therefore the objective of this study was to investigate the potential of predicting seasonal rainfall over East Africa by using sea-surface temperatures. The results of the study would enhance socio- economic planning in order to mitigate the impacts of climatic variability. Studies done in East Africa indicated strong relationship between the seasonal rainfall and the fluctuations in the global parameters (El-Niño/Southern oscillation (SO), SST anomalies, Quasi-Biennial Oscillations (QBO)) (Bazira and Ogallo 2000 among others) . Spectral peaks of 2-2.5, 3-3.7, 4.8-6, 10-12 years have also been observed in the regional rainfall time series (Ogallo et al. 1993).It has also been noted that terrain, tropical high forests and inland lakes play a significant role in meso- scale circulations (Mukabana 1992 among many others).Intra-seasonal variability in the regional seasonal rainfall has been associated with the 40-50 day oscillation (Madden and Julian 1971 among others).

1.2 The location of the study region

This study was conducted in East Africa (Uganda, Kenya and Tanzania) located between latitudes 5°N to 12°S and longitudes 29°E to 43°E. The areas near the equator experience bimodal seasonal rainfall (March to May and late September to November/early December) due to the migratory nature of Inter Tropical Convergence Zone (ITCZ) (Bazira and Ogallo 2000 among others). The southern portion of the region (southern Tanzania) experiences unimodal rainfall regime from (November-March). Western areas of the region experience a third rainfall peak (July and August). The rainfall over the Indian ocean coastal strip during June-August season has been attributed to the shears in the East African Low Level Jet (EALLJ) (Bazira and Ogallo 2000 among others).

2.0 Data , methods used in the study and results.

The data used in the study are discussed first and the results for each method used are presented. Monthly (station) rainfall was used in the study with a total of 76/67/57 stations from Uganda/Tanzania/Kenya respectively. The study covered the period 1940-1990.The period 1940 to 1976 was used for model building while the period 1976 to 1990 was used for testing the skill of the regression models. The forecast skills of the models were tested by root mean square error (RMSE). The second data set consisted of the Meteorological Historical Sea-surface Data Set (HOMSSDS) for Atlantic and Indian oceans (45°N to 45°S) and west Pacific ocean (20°N to 20°S) with a spatial resolution of 10° x 10° Latitude-Longitude. These data had been derived from the averages of the 5° x 5° grid mesh by the United Kingdom Meteorological Office. Corrections had already been applied to the SST data to compensate for use of uninsulated canvas buckets prior to 1942.

2.1 Principal component analysis (PCA) modes.

Principal component analysis was used in this study to delineate East Africa into 36 homogeneous rainfall zones based on monthly patterns of the major PCA modes. Significant components, which adequately explained the total variance, were retained in the analysis by applying (I) The Kaiser criteria (1959). (ii) The Castell-Scree test of (Castell 1966). (iii) The Logarithm of Eigen Values (LEV) of Craddock (1965). (iv) The sampling errors test by North et al. (1982). Results from PCA analysis indicated that during the seasons of March to May four modes were extracted and they explained a total variance of 48.2%, during June to August three modes were extracted and they explained a total variance of 35.8%, and during September to November four modes were extracted and they explained a total variance of 65.7% while during December to February four modes explained a total variance of 57.4%. The spatial patterns of the significant loadings highlighted the influence of meso-scale circulations and the migratory nature of the seasonal rainfall. The spatial patterns of the factor loadings were used to delineate East Africa into 36 homogeneous rainfall zones (Fig 1).

2.2. Correlation analysis

Simple correlation technique was applied to examine zero and time lagged relationship between seasonal rainfall and grid SST values. Correlation between seasonal rainfall at three months lag and seasonal SSTs was evaluated at 95 % confidence limit. Students' t statistic was used to decide the significance of the correlations from the matrices (Yevjevich 1972). Results from correlation analysis were used to build regression models for SST - rainfall relationships as highlighted in the next sections.

2.2.1 East African regions (figure 1) during December to February which indicated significant correlations with the ocean grids for September to November.

Atlantic ocean modes (Ak) (A1 (40-50°N;10-20°W),A2 (10-20°N;40-50°W),A3 (20-30°N;10-20°W),A4 (10-20°N;20-30°W,)A5 (0-10°S;0-10°E),A6 (0-10°S;10-20°W) ,A7 (0-10°S;30-40°W),A8 (0-10°N;40-50°W),A9 (20-30°S;0-10W),A10 (10-20°S;0-10°E),A11 (40-50°S;10-20°E) A12 (40-50°S; 20-30°E)); Indian ocean modes (Ik) (I1 (20-30°N;60-70°E),I2 (0-10°N;70-80°E),I3 (20-30°S;100-110°E), I4 (20-30°S;30-40°E),I5 (20-30°S;50-60°E),I6 (30-40°S;40-50E,)I7 (30-40°S;30-40°E), I8 (10-20°N;50-60°E) ,I9 (0-10°S;70-80°E)); Pacific ocean modes (Pk) ,P1 (0-10°N;150-160°E),P2 (10-20°N;120-130°E);P3 (0-10°N;140-150°E),P4 (10-20°N;160-170°E))

(I) North Indian ocean grids I1 and I2 were correlated positively with regions R1, R4 R6, R13, R33, R35 ,R25. Positive SSTs over the north Indian Ocean would give a manifestation of enhanced convection due to cyclonic development accompanied by increase in cloud cover and precipitation over the ocean (Hastenrath et al. 1993).

(ii) Northern sector of Atlantic Ocean grids A3 and A1 had negative/positive correlations with the regions R24, R16, R9, R17, R14, R23, R22/ R15, R18, R1, R4, R5 R6 and R7 respectively. A1 & A3 are in the positions of quasi- stationary Azores sub tropical anticyclone.

(iii) Central and western pacific grids P1 to P4 had significant correlations with many locations- R12, R14, R17, R18, R19&R37. Persistence at one seasonal time lead was observed in the correlation patterns.

2.2.2 East Africa regions during March to May rainfall season which indicated significant correlations with ocean grids for December to February.

Atlantic ocean modes(Ak)(A1(40-50°N;10-20°W),A2(30-40°N;0-10°W),A3(30-40°N;30-40°W),A4(20-30°N;40-50°W),A5(20-30°N;40-50°W),A6(20-30°N;20-30°W),A7 (0-10°N;20-30°W),A8(0-10°N;30-40°W),A9(0-10°S;30-40°W),A10(0-10°S;10-20°W),A11(10-20°S;20-30°W),A12(10-20°S;0-10°E),A13(10-20°S;10-20°E),A14(20-30°S;10-20°E),A15(20-30°S;10-20°W),A16(20-30°S;30-40°W,A17(30-40°S;0-10°E),A18(40-50°S;0-10°E),A19(0-10°N;0-10°E));Indian ocean modes(Ik)(I1(20-30°N;50-60°E),I2(10-20°N;50-60°E),I3(10-20°S;60-70°E),I4(20-30°S;30-40°E),I5(20-30°S;60-70°E),I6(30-40°S;50-60°E),I7(30-40°S;30-40°E),I8(0-10°N;90-100°E,I9(0-10°S;90-100°E),I10(10-20°S;100-110°E),I11(20-30°N;80-90°E));Pacific ocean modes (Pk)(P1(20-30°N;140-150°E),P2(0-10°N;160-170°E),P3(10-20°N;140-150°E),P4(0-10°S;170-180°E).

(I) North Indian Ocean grids I1, I2, I8 and I11 were positively/negatively correlated with regions R7,R36/R21,R37, R18, R22 & R23 respectively. Positive SST anomalies could lead to enhanced cyclonic development in the above ocean sectors which could be accompanied with eastward shift of the meridional component of ITCZ.

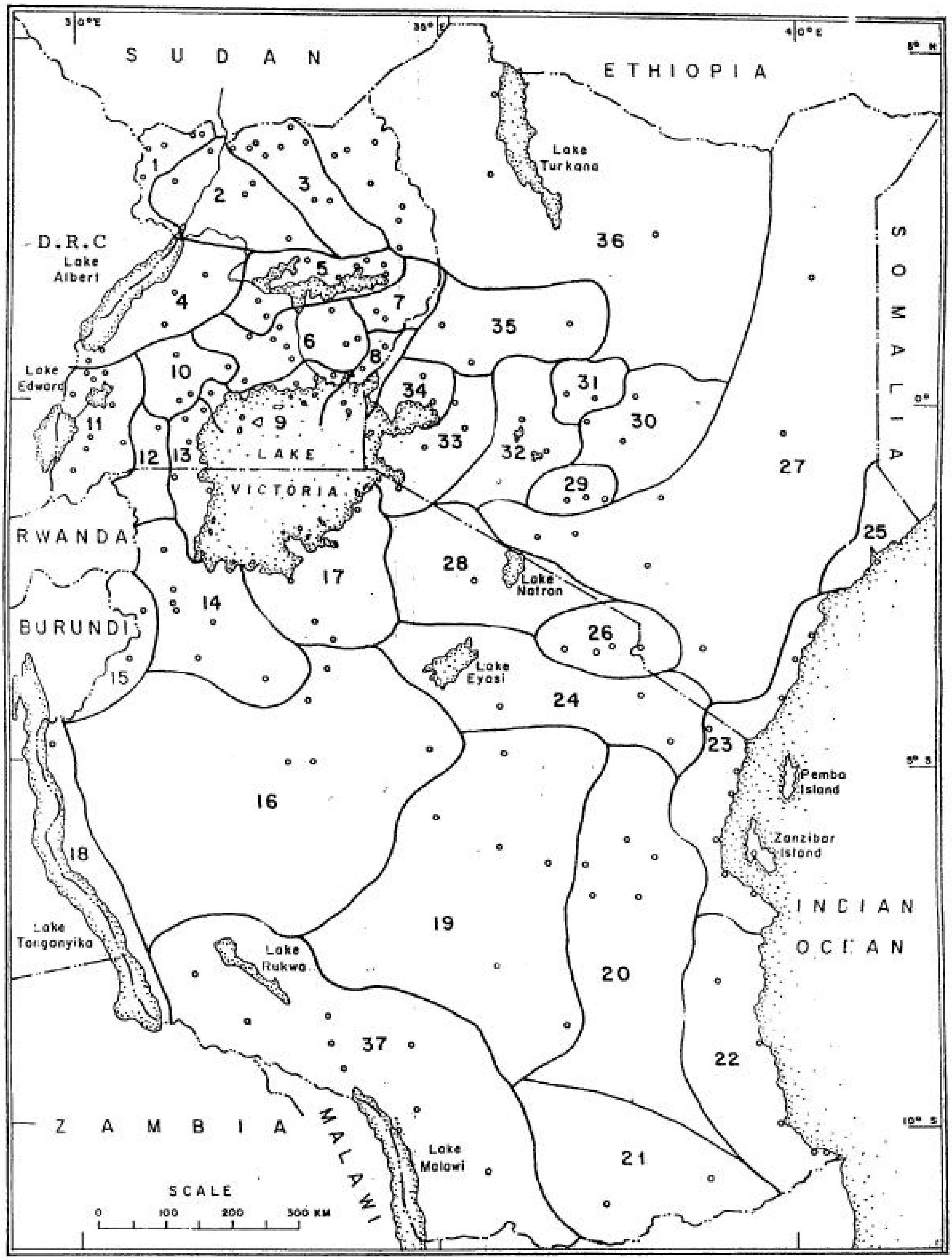

Fig. 1: Regions used in the study

(ii) South Indian ocean grids I6, I4, I7, I9 and I10 indicated negative correlations with the regions R9,R17,R13,R14,R33,R34 ,R37 ,R18 .The above ocean regions lie in the position of quasi-stationary sub-tropical anticyclone (Mascarene High).
(iii) Equatorial Atlantic ocean grids A7, A8, A9, and A10 were positively/negatively correlated with the regions R29, R32, R36/R18 respectively.
(iv) North Atlantic Ocean grids A3, A2, A4, A5 and A6 indicated negative correlations with R2, R3, R5, R6, R16, R19, R33 & R35. Similar reasons given under 2.2.1 (ii) apply here.
(v) Northwest Atlantic Ocean grids A1 indicated negative/positive correlations with R18 R27, R6/R13 respectively. Similar reasoning as in (iv) above applies here.
(vi) South Atlantic Ocean grids A11, A12, A13, A14, A15, and A16) were positively/negatively correlated with R10, R6, R1, R2, R3/R18& R27 respectively. Similar reasons given in (iii) above apply here.
(vii) Southern Atlantic Ocean grids A17 and A18) indicated positive correlations with R10 & R6.
(viii) Central Pacific ocean grids P1 to P4 were negatively correlated with R24, R27, R32,R30.This is the manifestations of global teleconnections , Ogallo el al. (1989).

2.2.3 East African regions during rainfall season of June to August that indicated significant correlations ocean grids of March to May.

Atlantic ocean modes (Ak),A1 (40-50°N;10-20°W),A2 (30-40°N;20-30°W) ,A3 (20-30°N;30-40°W), A4 (20-30°N;40-50°W),A5 (20-30°N;60-70°W),A6 (10-20°N;20-30°W),A7 (0-10°N;0-10°E) ,A8 (0-10°N;10-20°W), A9 (0-10°N;20-30°W) ,A 10 (0-10°S;10-20°E),A11 (0-10°S;10-20°W),A12 (0-10°S; 20-30°W),A13 (10-20°S;10-20°E),A14 (20-30°S;10-20°W),A15 (30-40°S;10-20°E),A16 (30-40°S;10-20°E) ,A17 (25-35°S;0-10°W),A18 (25-35°S; 20-30°W),A19 (30-40°S; 20-30°E),A20 (30-40°S;10-20°E),A21 (30-40°S;10-20°W)),Indian ocean modes (Ik) (I1 (20-30°N;50-60°E),I2 (20-30°N;60-70°E),I3 (10-20°N;50-60°E),I4 (10-20°N;70-80°E),I5 (0-10°N;90-100°E),I6 (0-10°S;90-100°E),I7 (10-20°S;100-110°E),I8 (20-30°S;100-110°E),I9 (20-30°S;60-70°E),I10 (20-30°S;50-60°E),I11 (20-30°S;30-40°E),I12 (30-40°S;50-60°E));Red sea modes (Rk) (R1 (20-30°N;30-40°E)); Pacific ocean modes (Pk) (P1 (20-30°N;120-130°E),P2 (20-30°N;140-150°E),P3 (20-30°N;150-160°E),P4 (10-20°N;160-170°E),P5 (10-20°N;130-140°E),P7 (0-10°N;130-140°E),P8 (0-10°N;160-170°E),P9 (10-20°S;160-170°E))

Correlation results during the season of June to August show that:
(I) Northern Indian Ocean grids I1, I2, I3, I4 and I5 were negatively correlated with regions R2&3,R5, R8, R34, R33, R32, and R31. Oceanic cooling in northern Indian Ocean may indicate anticyclonic development that could strengthen moisture influx in the above regions whereas oceanic warming seems to have the opposite effect.
(ii) Equatorial Atlantic ocean grids A7, A8 and A10 indicated negative correlations with R1, R5, R14, R17, R34, R33 , R32. Oceanic cooling in the above sectors of Atlantic ocean during this season could be indicative of enhanced anticyclonic developments which could strengthen tropospheric westerlies that influence rainfall in the above zones, Bazira and Ogallo (2000).
(iii) South Atlantic Ocean grids A13, A16, A21, A20 and A19 indicated positive correlations with R1, R2, R3, R7, and R8. Oceanic warming could be associated with enhanced rainfall in the above regions while oceanic cooling could be related to reduced rainfall.
(iv) Northwest Atlantic Ocean grids A1 and A2 indicated positive correlations with R23. Positive SSTs during this season might enhance cyclonic development over the ocean and a reduction in the maritime ridging which gives extended continental ridging. This would reduce the negative effect of the dry northwesterly winds. Oceanic cooling might increase maritime ridging and intensify the continental ridging.
(v) South Indian Ocean grids I12, I11, I10 and I9 indicated positive correlations with R16, R19, R20, R21, R31&R33. Oceanic cooling during this season could strengthen pressure systems over the ocean and enhance southeasterly winds that drive the East African low level jet which are diffluent over the above regions, Bazira and Ogallo (2000).

(vi) West and central Pacific ocean grids P1 to P9 indicated negative correlations with R1 to R3, R4, R27 & R23. This is a manifestation of the global teleconnections as note in section 2.2.2

2.2.4 East African regions during September to November rainfall season that indicated significant correlations with ocean grids of June to August.

Atlantic ocean modes (Ak) (A1 (40-50°N;0-10°W),A2 (30-40°N;10-20°W),A3 (20-30°N;40-50°W),A4 (0-10°N;10-20°W),A5 (0-10°N;0-10°E),A6(0-10°S;10-20°E),A7 (0-10°S;10-20°W),A8 (0-10°;20-30°W),A9(0-10°S;40-50°W),A10 (10-20°S;10-20°E),A11 (10-20°S;10-20°W),A12 (20-30°S;10-20°E),A13 (20-30°S;0-10°W), A14 (20-30°S;10-20°W),A15 (20-30°S; 20-30°W),A16 (30-40°S; 20-30°E),A17 (30-40°S;10-20°E)); Indian ocean modes (Ik)(I1 (20-30°N;50-60°E), I2 (10-20°N;50-60°E),I3 (0-10°N;80-90°E),I4 (0-10°S;80-90°E),I5 (20-30°S;60-70°E), I6 (10-20°S;100-110°E),I7 (30-40°E;50-60°E),I8 (20-30°S;100-110°E),I9 (20-30°S;70-80°E)); Red sea modes (Rk) (R1 (20-30°N;30-40°E),R2 (20-30°N;30-40E°));Pacific ocean modes (Pk) (P1 (0-10°N,130-140°E), P2 (10-20°N;130-140°E), P3 (10-20°N;110-120°E),P4 (10-20°S;140-150°E)).

September-November is the other major rainfall season (short rainfall season) for the region. The results from correlation analysis during this season indicated that:

(I) Equatorial Atlantic ocean grids A5 and A6 indicated positive correlations with R13, Rl, R16, R19, R37, R24, R25, R23, R30, R36. Positive SSTs seem to indicate cyclonic development over the ocean accompanied with convection and cloud development which could be advected eastwards in the low level westerlies and enhance rainfall in the above regions as seen in sections 2.2.2 and 2.2.3

(ii) Northern Indian Ocean grids I1 and I2 indicated positive correlations with R34, R33, R25, R23, R24, and R30. Positive SSTs could enhance cyclonic development over the ocean, as noted above, which could be advected westwards to the coastal regions and the immediate hinterlands. The lake Victoria shores could be responding to the eastward shift of the meridional component of ITCZ following a weakness in north Indian Ocean.

(iii) A northwestern Atlantic Ocean grid A4 was negatively correlated with R8, R18, and R27. This again could be the response to the strength of the Azores sub- tropical anticyclone as noted earlier in 2.2.1 (ii).

(iv) South Indian Ocean grids I5, I6 and I7 indicated negative correlations with R3, R5 & R8, R23, R22 & R25, R28.Oceanic cooling might enhance anticyclonic development and enhance southeasterly that might increase moisture fetch into the above regions as noted in 2.2.2 (ii).

(v) South Atlantic Ocean grids A10 to A21 were negatively correlated with R3, R15, R28, R37, R21, R25, R23, R22, R30, R13, R32, R36. Oceanic cooling in south Atlantic ocean could lead to enhanced anticyclonic development and strengthen moisture transport eastward as noted in 2.2.2 (iii).

The observed time lagged correlations formed the basis for the regression models. The magnitude of the variance ratio and the square of multiple correlation based on the period, which was used to develop model parameters were used to, test the significance of the predictors in regression equations.

2.3.0 Regression models for the December to February rainfall season.

In section 2.2.1, major September-November SST modes for the specific ocean/seas that significantly correlated with December-February rainfall for the various climatological regions of East Africa were indicated. December-February is generally dry and hot in many locations apart from some parts of southern Tanzania as noted in sec.1.2. Results from the regression analysis during this rainfall season indicated that maximum seasonal rainfall variance of 56.1% was accounted for in Southern Tanzania. Most of the seasonal rainfall variances were accounted for by the first few SST modes. RMSE ranged from 0.9 to 1.3 during this season. Regression results for the rainfall season of March-May are presented in the next section.

2.3.1 Regression models for March to May rainfall season.

March to May is the rainfall season for the East African region (locally known as the long rainfall season) as noted in sec.1.2. Section 2.2.2 gave the significant SST modes for the specific oceans, which significantly correlated with March-May seasonal rainfall. Maximum rainfall variance explained by all of the SST modes during this season was 48.1%.RMSE ranged from 0.9 to 1.5 for different regions. It has been observed that SST modes explain low variance during this season (Bazira and Ogallo 2000 among many others).

2.3.2 Regression models for June to August rainfall season.

June-August is generally dry and relatively cold over most parts of the region apart from western parts of the region which receive rainfall as noted in 1.2 During June-August a maximum variance of 71.6% was accounted for by the SST modes over eastern Uganda. Over the northern Uganda, western Kenya and coastal strip the SST modes explained about 67.9%, 43.9%, and 34.3% of the rainfall variances respectively. Over eastern Kenya, northwestern Kenya including northeastern Uganda relatively low variance of about 39% and 40.2% respectively was explained by the SST modes during this season. RMSE ranged from 0.7 to 1.7 for the different regions.

2.3.3 Regression models for September to November rainfall season.

September-November is generally a major rainfall season for most areas as noted in 1.2 June-August SST modes were which were indicated in section 2.2.3 were used in the regression models. Regression models during this season indicated the significant influence of Atlantic ,Indian and equatorial Pacific oceans on regional rainfall. During this season (September-November) the SST modes generally explained higher rainfall variance at most of the locations with a maximum explained variance of 58.7%. RMSE ranged from 0.8 to 1.4 for the different regions. Skillful prediction of the seasonal rainfall over the region would therefore require the incorporation of other predictors.

3.0 Major conclusions of the study.

The main objective of the study was to determine the Long-range seasonal rainfall predictive potential over East Africa as derived from SST modes.

- Generally southeastern Atlantic and southwestern Indian oceans SSTs were negatively correlated with several regions although the extreme southeastern Atlantic was positively correlated with several regions.
- Northeastern Atlantic ocean SSTs indicated negative correlations with several regions during March to May and September to November rainfall seasons and positive correlations with December to February rainfall season.
- Equatorial Atlantic SSTs indicated positive correlations with several regions during September to November as well as March to May rainfall seasons but indicated negative correlations during June to August season.
- Northwestern Indian Ocean SST modes generally indicated positive correlations with several regions.
- Significant correlations between seasonal rainfall over several regions and SSTs over western and central Pacific ocean were noted during the four rainfall seasons.
- Regression analysis indicated that SST modes explained maximum seasonal rainfall variances of 56.1%, 48.1%, 71.6% and 58.7% during the seasons of December to February, March to May, June to August and September to November respectively. Generally high prediction skills were observed during September to November while low skills were observed during March to May.

  Generally the results from the study indicated that SST modes could give a useful seasonal prediction at 3 months time lag. This prediction could provide a vital improvement in the early warning techniques of the regions of East Africa. Since most socio-economic sectors of the region are weather dependent, a timely and accurate seasonal rainfall prediction could minimize the negative impacts which are associated with seasonal rainfall variability.

4.0 Recommendations

(I) During the season of March-May, the predictive skill was low for most of the regions. So other parameters that will be available from MSG could be incorporated in the multiple linear regression equations.

(ii) One month proceeding the rainfall season should be investigated to find out if the skill could be improved instead of 3 months time lag.

(iii) Sea surface temperatures which will be obtained from MSG could be used to enhance operational regression techniques.

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