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Prediction of Northern Nigeria Rainfall Using Sea Surface Temperature

B.E. Omogbai

Department of Geography and Regional Planning, Ambrose Alli University, Ekpoma, Edo State, Nigeria

KEYWORDS Savanna JAS Rainfall. SST Anomalies. Rainfall Prediction. Models Construction

ABSTRACT Large-scale vertical motion in the atmosphere in the tropics is tied to high sea surface temperatures (SST). Enhanced moisture content of the boundary layer over sea leads to enhanced moisture convergence because of the low pressure created over the high sea surface temperature regions. This leads to a feed-back mechanism that enhanced moisture convergence because vertical ascent of air through the release of latent heat in deep convection. All these phenomena are associated with high sea surface temperatures (SST) and are widely believed to induce large scale atmospheric circulation and heating anomalies. These anomalies in the tropical atmosphere can have consequences in locations far and remote from the direct sea surface temperatures (SST). In order to have data coverage sufficient and adequate for this study, the region was enlarged to include stations at the outskirts of northern Nigeria. All the stations lie approximately between latitudes 9°N and 15°N were used to analyse the data covering a period of 1901 to 2006. Sytat software was used to analyse rainfall and temperature data of cities of northern Nigeria and its outlying geographic areas for predicting rainfall. Correlation and regression was carried out on the data set to estimate the model. Using the results of the regression, models were constructed for April, May and June. Testing the models on the correlation between the forecast and the actual savanna July, August and September (JAS) rainfall shows that it can be predicted with 62.10% accuracy using April model, 74% accuracy using May and 64.5% accuracy using June model. The model showed a more robust prediction when more recent data (2000- 2006) are used. The result obtained for April was 70%, May was 90% and June was 80% when evaluated by common statistics, the model performed well as the magnitude of error was low.

INTRODUCTION

Most cases of environmental degradation in Nigeria are associated with serious rainfall anomalies. Too much rainfall leads to excessive flooding of low lying areas and overflowing of river banks, while gully erosion and land slides are common features in hilly areas. At the other extreme, excessive lack of rainfall leads to drought and desertification.

Environmental degradation and its socio-economic implications cannot be over- emphasized. Rainfall prediction, especially on a seasonal scale can therefore provide a comfortable index for estimating and monitoring environmental degradation. It is on the basis of this background that this paper is focused.

Evidence has shown that slow and predictable variations in the lower boundary layer forcing (especially sea surface temperature, SST), influence the statistics of the atmospheric circulation. There is, in fact an implicit assumption that physical based models of ocean and atmosphere coupled system will eventually be the best tool for seasonal rainfall prediction.

Much has been said and written about the direct impact of SST gradient on the boundary layer temperature gradient, and therefore, also on the pressure gradient, winds and divergence (Hastenrath 1991; Adedokun 1978; Adejuwon 1988; Adejuwon et al. 1990 and Ayoade 1974). Also, seasonal rainfall in the Sahel have been related to variation in SSTA (Folland et al. 1991; 2002; Bjerkens 1969 and Chang 2002).

Large scale vertical motions is strongly tied to high SST. Enhanced moisture content of the boundary layer over the high SST regions, enhanced moisture convergence as a result of low pressure created over high SST regions and a feed-back mechanism to enhance large- scale vertical ascent through release of latent heat in deep convection, are all phenomena associated with sea surface temperatures (SST).

It is, therefore, widely believed that anomalies in SST induce large-scale atmospheric circulation and heating anomalies in the atmosphere, which can have consequences for the tropical and extra-tropical atmosphere in location remote from the direct SST forcing.

This paper is therefore set out to study the rainfall pattern of Northern Nigeria and its relationship with Sea Surface Temperature. Emphasis is focused on the rainy season of this region which normally comes up around July, August and September. The choice of this region was prompted by the flood disasters that affected most towns and cities in northern Nigeria in the last decade.

The aim is to see the possibility of using sea surface temperature (SST) as predictors to establish an effective model for predicting rainfall in this region and possibly to establish drought severity index for drought monitoring in the region.

In order to have data coverage sufficient and adequate enough for this, the region was enlarged to include stations at the outskirts of northern Nigeria. These include parts of northern Cameroon, south-western Chad, south Niger republic, northern Ghana, northern Togo and Benin republic and east of Burkina Faso.

All these stations lie approximately between latitudes 9°N and 15°N and longitude 5°W and 15°W. For the purpose of this study this region is named SAVANNA (see Fig. 1a).

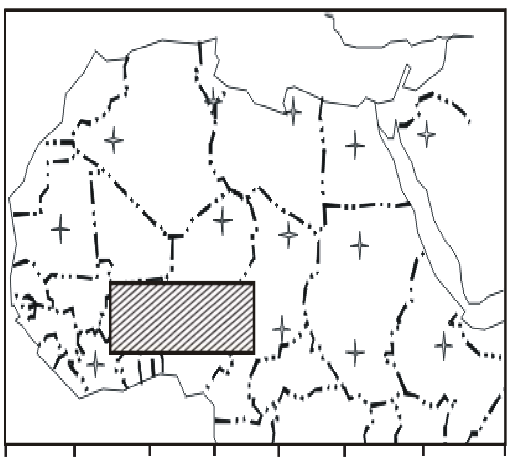

Fig. 1a. Savana region used to study northern Nigeria rainfall

In order to have effective lead time for predicting the SST for the months of April, May and June were chosen to study the rainfall of July, August and September. In the tropics, a balance is achieved by vertical motion which creates vertical temperature advection to balance the heating sources (see Fig. 1b).

Approximate equations
Where Q is Geopotential
,, k is Constant of surface resistance
,, w is Vertical Velocity.

$$Ku - Fu \frac{dQ}{dx} = 0 \quad \text{Momentum Balance}$$

$$Ku + Fu + \frac{dQ}{dx} = 0$$

$$\frac{dQ}{dx} + \frac{du}{dx} + \frac{dv}{dy} = 0 \quad \text{continuity equation}$$

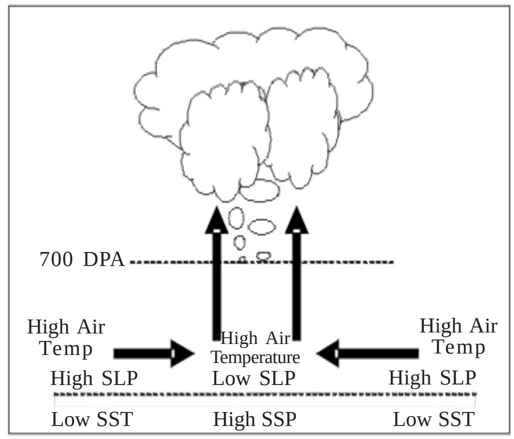

Fig. 1b. The theory

Thus, geopotential in the above equation can be substituted by a heating function. (Matsuno 1966; Miller 1991; Miller et al. 1992 and Miller 1993). The high sea surface temperature (SST) will lead to high air temperature at the boundary layer, thereby creating a low sea level pressure and leading to convergence at the surface and consequently a vertical motion is ensure (Chang 2002 and Barnett 1988).

MATERIALS AND METHODS

The data set of systat comprising of rainfall data from 1901 to 2006 and sea surface temperature (SST) data from 1949 to 2006, were used for this work. The rainfall data is available in the form of monthly and seasonal rainfall totals and stored as given in table 1.

Where each row contains a time series of monthly rainfall totals from Year 1 to Year N for latitude and longitude (Lat. and Lon.) and identified on the location map by a number of called mapnum (see Fig. 2).

Dataset of monthly and seasonal sea surface temperature anomalies (SSTA) are also available and stored in a similar manner as the rainfall data, that is, each row contains a time series of SST anomalies for a location indicated by Latitude, Longitude and Mapnum.

Table 1: Rainfall data

Mapnum	*Lat.*	*Lon.*	*Year 1*	*Year 2*	*Year 3*	*Year 4*	*Year N*
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X
X	X	X	X	X	X	X	X

The systat software was used to analyse the rainfall for (July, August and September called JAS. The period covered by the rainfall dataset analysed is 1901 - 2006. Standardized rainfall anomaly time series and area average index for the months of July, August and September and for the season JAS were calculated and stored in Systat files call SavaJUL, SavaAUG, SavaSEP and Savana3 respectively.

$$Y = \frac{\Sigma X^1 Y^1}{NQ_X Q_Y}$$

Where X = X - X

Y = Y - Y

N = number of values in the time series

QX = standard deviation of series X

QY = standard deviation of series Y

Was used to calculate the correlations between the various rainfall time series.

The correlations between SAVANA JAS rainfall time series (savanna 3) and SST anomaly at each grid box for the months of April, May and June were calculated and plotted on correlation MAPS (see Figs. 3,4 and 5). Using correlation maps the areas with significant correlation with SAVANA JAS rainfall were extracted and used as predictors. The area average SST anomaly (SSTA) time series for these predictors were calculated and stored. Correlation of each predictor with savanna JAS rainfall (savana3) were calculated and plotted (see Figs. 6 and 7).

Regression

Multiple regression was used to calculate the constants and coefficients of the predictors for each month (April, May and June) and thereby construct THREE MODELS called savaAFC, savaMFC and savaJFC, to predict Savana JAS rainfall using April, May and June SST anomalies (SSTA).

The Multiple Regression Equation used is of the form

$$R = a + a_1 V_1 + a_2 V_2 + \ldots\ldots\ldots anV_n$$

Where R is the variable being predicted (savanna JAS rainfall)

V_1 ……. V_n are variables used to predict R (predictors)

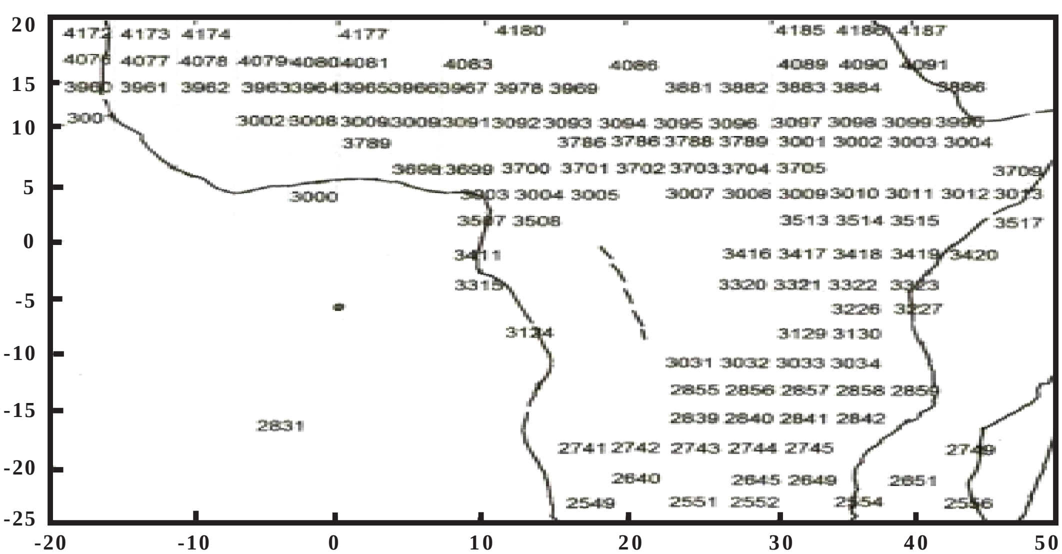

Fig. 2. A location map [Mapnum] of Sub-Sahara Africa showing monthly rainfll totals from 1901 to 2006 [for latitude and longitude].

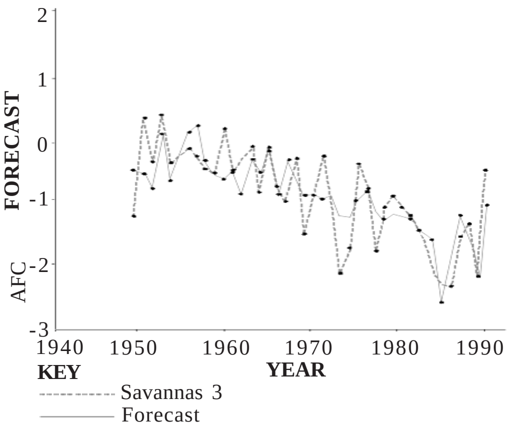

Fig. 3. Model for April forecast being plotted against Savanna JAS rainfall

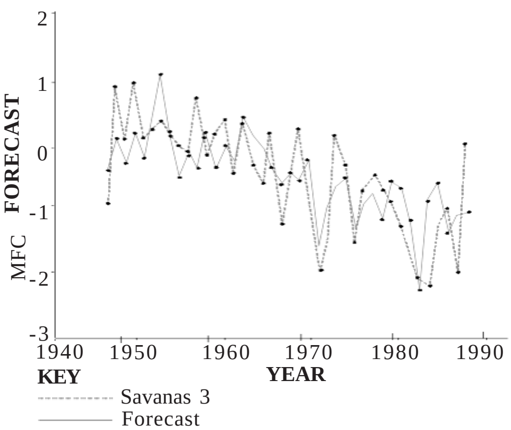

Fig. 4. Model for may forecast being plotted against Savanna Jas rainfall

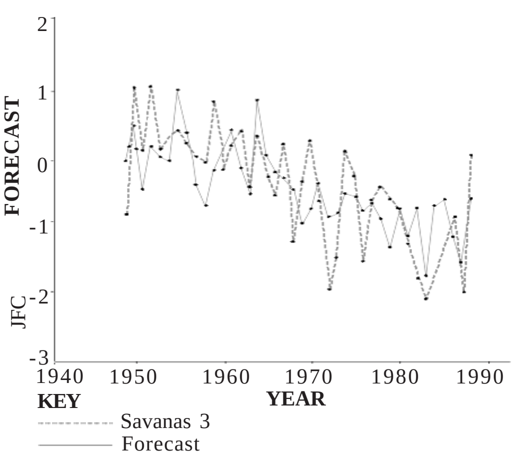

Fig. 5. Model for Jund forecast being plotted against Savanna Jas rainfall

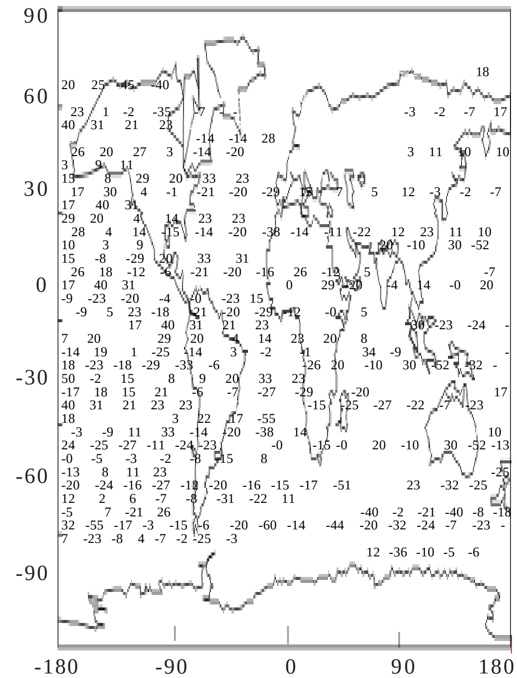

Fig. 6. Correlation between April SST and Savana Jas rainfall 1920-1980
(Shaded area are significant at 5% level)

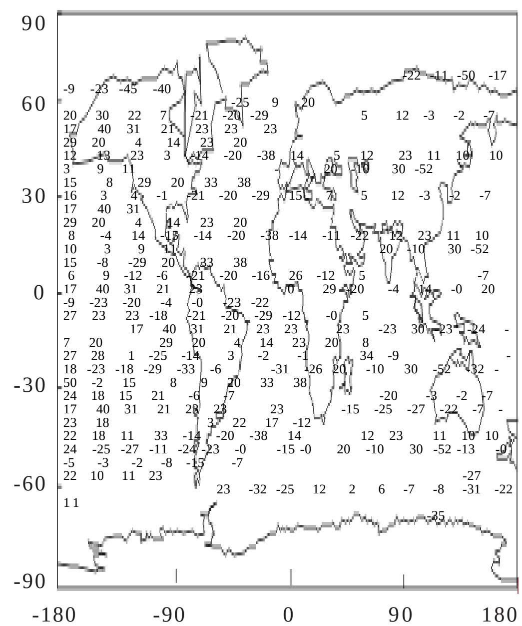

Fig. 7. Correlation between May SST and Savana JAS rainfall 1920-1980
(Shaded area are significant at 5% level)

RESULTS AND DISCUSSIONS

Models

1. The following correlations were established between Savanna Jas Rainfall (Savanna 3) and the monthly rainfall in the savanna region.

Savanna 3 /SavaAPR	=	0.012
Savanna 3 /SavaMAY	=	0.032
Savanna 3 /SavaJUN	=	0.317
Savanna 3 /SavaJUL	=	0.651
Savanna 3 /SavaAUG	=	0.864
Savanna 3 /SavaSEP	=	0.777
SavannaJUL /SavaAUG	=	0.470
SavannaSEP /SavaJU	=	0.426
SavannaSEP /SavaAUG	=	0.653

2. Correlations between Savanna Jas Rainfall and Set April

For the month of April, five areas (Predictors) were identified to have significant correlations with Savana JAS rainfall (Savana3), and the following correlations were established with the chosen predictors.

Savana3	/North Pacific SST
(Npac4)	= 0.491
Savana3	/West Pacific SST
(Wpac4)	= 0.466
Savana3	/North Atlantoc SST
(Nat14)	= 0.596
Savana3	/Indian Ocean SST
(Indo4)	= 0.533
Savana3	/East pacific SST
(Epac4)	= 0.479

May

For the month of May, four areas (4 Predictors) were identified and the following correlations were established with the predictors.

Savana3	/North Pacific SST
(Npac5)	= 0.393
Savana3	/West Pacific SST
(Wpac5)	= 0.388
Savana3	/North Atlantic SST
(Nat15)	= 0.598
Savana3	/India Ocean SST

June

For the month of June, four areas (4 Predictors) were identified and the following correlations were established.

Savana3	/West Pacific SST
(Wpac6)	= 0.429
Savana3	/North Atlantoc SST
(Nat16)	= 0.519
Savana3	/Indian Ocean SST
(Indo6)	= 0.0625

Multiple Regressions

The following constants and coefficients were established

1.	**For April**		
Constant	=	-	0.190
Npac4	=	-	0.044
Wpac4	=	-	0.25
Nat14	=	-	0.087
Indo4	=	-	0.047
Epac4	=	-	0.028
2.	**For May**		
Constant	=	-	0.258
Npac5	=	-	0.021
Wpac5	=	-	0.016
Nat15	=	-	0.0126
Indo5	=	-	0.0052
3.	**For June**		
Constant	=	-	0.142
Wpac6	=	-	0.16
Nat16	=	-	0.065
Indo6	=	-	0.0119

Models

Using the results of the Regression, the Models were constructed for April, May and June.

1. Savanna Forecast using April SST anomality (SAVAFC)

R = -0190 + 0.044*Npac4 + 0.087*Nac14 - 0.025*Npac4 + 0.087*Nac14 - 0.047*Indo4 + 0.028*epac4.

2. Savanna Forecast using May SST anomaly (SAVAMFC)

R = 0.258 + 0.021*Npac5 - 0.016*Npac + 0.126*Nat15 - 0.0552*Indo5

3. Savanna Forecast using June SST anomaly (SAVAJFC)

R = -0.142 - 0.16*Npac5 + 0.056* Nat16 - 0.119*Ind05

Testing of the Models

1. The correlation between each forecast and the actual Savanna JAS rainfall were calculated and the results are as follows;

AFC	/Savana3	=	0.791
MFC	/Savana3	=	0.700
JFC	/Savana3	=	0.735

The actual SST data (Historic) for the periods not used in the construction of the models were fitted into the Model Equations and the results compared with the actual rainfall anomalies. The results are as follows;

April	18/19	=	62.1%
May	17/23	=	74%
June	20/31	=	64.5%

This means that the model can predict whether the rainfall in this region will be above normal or below normal with 62.1% accuracy using April model, 74% accuracy using May model and 64.5% accuracy using June model.

Further analysis of the result shows a more robust when more recent data are used, e.g. when data of 1940 - 1948 were used; the following results were obtained:

April	7/10	=	70%
May	9/10	=	90%
June	8/10	=	80%

Evaluation of the Model

The actual values were compared with the forecast values using the following;

1. BIAS OR MEAN ERROR (ME)

$$\frac{1}{N}\ \Sigma\left(F\Sigma_1 - A_1\right)$$

2. MEAN ABSOLUTE ERROR (MAE)

$$\underline{1}\ \ \Sigma\left(F\Sigma_1 - A_1\right)$$

3. ROOT MEAN SQUARE ERROR

$$(\mathrm{RMSE}) = \underline{1}\sqrt{\frac{\Sigma\ (F\Sigma_1 - A_1)}{N}}$$

Where N = number of years considered
Fi = ith forecast
Ai = the ith actual

These are common verification statistics used to analyse the performance of a model. The following results were obtained. (see Table 2).

Table 2: Model evaluation

ELS	*ME*	*MAE*	*RMSE*
AFC	-0.745	0.745	0.898
MFC	0.032	0.576	0.768
JFC	0.002	0.551	0.649

This means that the model for April (AFC), is under forecasting the JAS rainfall of Northern Nigeria while MFC and JFC are over forecasting the rainfall. The magnitude of the error is not much for MFC and JFC as can seen for MAE and RMSE.

CONCLUSION

These prediction models were arrived at through purely statistical analysis, and the theoretical assumptions of the impact of SST anomalies on the boundary layer parameters, it is therefore necessary to subject them to physical and dynamic processes before they can be put into proper use.

It may also be noted that it is assumed that the correlation and regression models used for the calculations are within acceptable degree of accuracy. It is also assume that it is only the SST anomalies that are producing the high correlations recorded in this work. However, as already emphasized, the models should be subjected to serious tests in order to give them some fine - tuning and adjustment before they can be put into serious use.

The work is in its experimental stage, it is therefore advisable that the models should be used with caution.

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APPENDIX 1

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