Maximum and Minimum Temperatures in South-Western Nigeria: Time trends, Seasonality and Persistence

*OGUNSOLA, O.E.¹ and YAYA, O.S.²

¹Department of Physics, University of Ibadan, Ibadan, Nigeria
²Department of Statistics, University of Ibadan, Ibadan, Nigeria

seyiogunsola22@gmail.com

Abstract. Global temperature which is obtained as the average of both the zonal and national temperatures is a very fundamental quantity in determining global warming. The difference between the monthly diurnal temperature range (DTR) changes at different locations of the world is also responsible for the current warming being experienced worldwide. Monthly maximum and minimum temperature data for the South-western region of Nigeria (January, 1979 – December, 2014) obtained from the Nigerian Meteorological Agency (NIMET), Lagos were analyzed for their time trends, seasonality and persistence using standard statistical procedures including the fractional integration approach. The results of analyses obtained showed that significant positive time trend coefficients were obtained for the minimum temperature, while negative coefficients were obtained for the DTR at the stations considered which implied that global warming is also being experienced in this region of the country.

Keywords: Fractional integration, Maximum and minimum temperatures, Time Trend, Seasonality, South-Western Nigeria

1. Introduction
The issue of global warming is a current topic in climate and environmental studies due to the troposphere being gradually destroyed as a consequence of atmospheric pollution linked to the burning of fossil fuel. This global warming is usually measured from global temperature which is obtained as the average of both zonal and national temperatures [1]. In recent time, heat waves have become more frequent as a result of the continuous increase in the temperature of the earth due to global warming [2]. Evidence abounds that a decrease in the monthly diurnal temperature range (DTR) i.e. the difference between the mean monthly maximum temperature ($T_{\text{max}}$) and minimum temperature ($T_{\text{min}}$) has a strong connection with global warming [3]. For example, the increase in both the annual and seasonal mean minimum temperature over Ibadan, a city in Southwest Nigeria showed that there is an ongoing warming and this was linked to the anthropogenic global warming effect [4]. Also, the statistically significant increase in these temperature trends was attributed to both the continuous urbanization and industrialization taking place within the city. However, this increase in temperature is not a healthy signature for its inhabitants, including the water resources and crop production [5]. Evidence of increase in temperature all over the world requires accurate estimation of time trend, with possible seasonality and structural breaks. This is still an open issue among
climatological researchers [6-7]. Analysis of the annual maximum and minimum temperatures in the United States over the period 1895 to 2017 (using only January observations to form these annual series), showed a significant positive trend, however, the Diurnal Temperature Range (DTR) indicated negative trend which implied that the minimum temperature is increasing faster than the maximum temperature[7]. Moreover, analysis of obtained global temperature data requires accurate estimation in order to be able to decipher correctly the future temperature trends [8-9].

In this present paper, time trends including the seasonality and persistence in the maximum and minimum temperature in the South-Western region of Nigeria were investigated. However, some of the researchers in similar climatological study have applied regression modelling approach which assumed that time series under investigation is I(0) series, i.e. such series is restrictively stationary, having constant mean and variance [10-13]. Whereas, climatic series possesses autocorrelations in which there is the dependency of current observations over past lags of observations. This dependency is known as structural persistence and is estimated using fractional integration approach. However, the assumption by these researchers that the series are non-stationary and of order 1 i.e. I(1) has led to over-differencing which could result in wrong results. Hence, the analyzing of the autocorrelation structure of the series over its lags value using I(d) process would be of interest, because in the I(d = 0), the series is stationary and possess short memory, while for I(-0.5<d<0.5), the series is invertible, possesses long memory and is stationary (i.e. there is strong dependency over its lag values). Secondly, climatic series are seasonal, and the fractional integration approach allows for simultaneous estimation of seasonal coefficient to be estimated. The use of fractional integration approach which is a more general technique to the standard modelling approach employing I(0) and I(1) behaviour of the series has also been applied in studying climatic series[14-18].

2. Materials and Methods

The required long time maximum and minimum temperature data (January 1979 to December 2014) for the lag computation at Ikeja, Akure and Ibadan meteorological stations used in determining their time trends, seasonality and persistence in the South Western region of Nigeria was obtained from the Nigerian Meteorological Agency (NIMET), Oshodi, Lagos. These monthly dataset were first checked for their seasonal effect before their DTR which is the difference between the maximum and minimum temperature was computed. Their maximum and minimum monthly temperature time plots for each of these stations were also carried out and the non-seasonal integration of the series further investigated by using the Augmented Dickley-Fuller (ADF) unit root test [19]. The ADF testing procedure utilises three regression levels: no intercept, intercept only and trend with intercept. The lag lengths for the augmentation were also obtained.

3. Results and Discussion

The time series plot of the monthly temperature data (maximum and minimum) at the considered stations in the south-western region of Nigeria (Fig. 1) is of the form represented in equation (1), where \( X_t \) is the maximum and minimum temperature series, \( \beta_0 \) and \( \beta_1 \) are the intercept and linear time trend coefficients, and \( Y_t \) is the fractional integrated series,
integrated based on the first operation in equation (2). Also, $B$ is the backward shift operator, and $d$ is the fractional integrated parameter. 

$$X_t = \beta_0 + \beta_1 t + Y_t, \quad t = 1, 2, \ldots$$ 

with,

$$ (1 - B)^d Y_t = u_t, \quad u_t = \phi_{12} u_{t-12} + \epsilon_t, \quad t = 1, 2, \ldots$$

The $u_t$ is the serial error process, assumed to be seasonally autoregressive (AR) as shown in equation (2) with parameter $\phi_{12}$ and $\epsilon_t$ is the white noise error process.

Fig. 1 showed that the seasonal pattern peaked around the end of the year i.e. during the intense dry months (December and January), while the maximum temperature fluctuates more than the minimum temperature. Thus, the DTR mimicked a similar pattern observed for maximum temperature series. However, the trending pattern obtained in the case of DTR was not easily noticed in the three (DTR) series obtained for the three meteorological stations (Ikeja, Akure and Ibadan). Hence, the non-seasonal integration of the series investigated using the Augmented Dickey-Fuller (ADF) unit root for the three regression levels: no intercept, intercept only and trend with intercept and the lag lengths for augmentation are also given in squared brackets (Table 1). It was observed that there was no rejection of unit integration/root when no intercept is assumed in the test regression for Ikeja, Akure and Ibadan temperatures. However, with the testing procedure in which there is intercept and trend, the unit root hypothesis was sternly rejected. Moreover, it was also observed that for the testing procedure with intercept only, the unit root hypothesis was sternly rejected for temperatures at Ikeja and Ibadan, while it was not rejected in the case of Akure (except in Akure DTR).
Fig. 1: Time plots of Maximum and Minimum Temperature in the three meteorological Stations considered
Table 1: ADF Non seasonal Unit Integration test

| Meteorological Station | No intercept | Intercept only | Intercept with trend |
|------------------------|--------------|----------------|---------------------|
| Lagos                  |              |                |                     |
| Ikeja_Max              | 0.2426[11]   | -4.9066[12]*** | -5.2339[13]***      |
| Ikeja_Min              | 0.4702[11]   | -3.6774[13]*** | -4.3302[14]***      |
| Ikeja_DTR              | -0.4622[11]  | -3.6687[11]*** | -3.7274[11]***      |
| Akure                  |              |                |                     |
| Akure_Max              | 0.2743[12]   | -2.5642[12]    | -4.4681[12]***      |
| Akure_Min              | 0.4018[11]   | -2.2836[11]    | -3.9546[12]***      |
| Akure_DTR              | -0.1762[11]  | -4.3438[11]*** | -4.6677[11]***      |
| Ibadan                 |              |                |                     |
| Ibadan_Max             | -0.0538[11]  | -3.1423[11]*** | -3.7866[12]***      |
| Ibadan_Min             | 0.2918[11]   | -3.0029[12]*** | -4.6986[13]***      |
| Ibadan_DTR             | -0.3637[11]  | -3.7219[11]*** | -3.7100[11]***      |

*** indicates significant of ADF test at 5% level, that is the rejection of non seasonal root. In squared bracket is the optimal lag of the augmentation, determined by information criterion.

Due to the fact that the series at hand are expected to be seasonal, the seasonal integration test in the unit root framework with the monthly seasonal frequency version was also conducted using the Hylleberg, Engle, Granger and Yoo (HEGY) technique [20]. The results in Table 2 showed that the null hypothesis corresponding to $t_{\pi 1}$ is similar to that of ADF test when non-seasonal unit root was tested against non-seasonal no unit root. Also, mixed results were obtained here for the unit root based on the t statistic, particularly for Ikeja and Ibadan temperature series. Other test statistics (t and F) are used to test for seasonal unit root [21]. The $t_{\pi 2}$ tests seasonal unit root at monthly frequency. By cross-looking at the results, acceptance of null hypothesis of seasonal unit root was observed for DTR series when constant, trend and seasonal dummies (SD) were assumed in the testing regression. At annual frequency, F statistic $F_{\pi 3,4}$ was used and the results are also reported in table 2 with none rejection of seasonal unit root at annual frequency observed. Thus, HEGY test detected seasonality of temperature series considered in this work.
Table 2: Seasonal Unit Integration test

| Series        | Model     | $t_{π1}$  | $t_{π2}$  | $F_{π3,4}$ |
|---------------|-----------|-----------|-----------|------------|
| Ikeja_max     | C&T       | -4.10***  | -2.81***  | 9.56***    |
|               | C&T&SD    | 4.55***   | 4.41***   | 0.99       |
| Ikeja_min     | C&T       | -1.21     | -3.38***  | 5.52***    |
|               | C&T&SD    | 2.99      | 3.01***   | 2.00       |
| Ikeja_DTR     | C&T       | -3.19     | -1.97***  | 8.46***    |
|               | C&T&SD    | 1.79      | 1.36      | 0.37       |
| Akure_max     | C&T       | -3.48***  | -3.99***  | 2.88       |
|               | C&T&SD    | 4.91***   | 4.71***   | 0.85       |
| Akure_min     | C&T       | -4.34***  | -3.63***  | 2.52       |
|               | C&T&SD    | 3.94***   | 3.91***   | 0.66       |
| Akure_DTR     | C&T       | -4.74***  | -3.79***  | 4.41***    |
|               | C&T&SD    | 2.69      | 2.20      | 1.03       |
| Ibadan_max    | C&T       | -2.05     | -1.82     | 3.46***    |
|               | C&T&SD    | 2.25      | 2.12      | 1.12       |
| Ibadan_min    | C&T       | -4.53***  | -3.55***  | 2.42       |
|               | C&T&SD    | 4.55***   | 4.50***   | 1.12       |
| Ibadan_DTR    | C&T       | -2.58     | -3.77***  | 6.31***    |
|               | C&T&SD    | 1.67      | 1.08      | 0.14       |

*** indicates significant of HEGY test at 5% level, that is the rejection of seasonal root. The analysis was carried out based on optimal lag selection for the augmented component of the test regression, such optimal lag was selected based on minimum information criteria.

Table 3 showed the results of fractional persistence with trend and seasonality for the temperature series. It was observed that fractional d values were found within the long memory range \((0 < d < 0.5)\) indicating strong dependence of temperature series over its past lag values. Seasonal autoregressive parameters, AR(12) are significant in all the series, implying that seasonality is pronounced in the temperature series. In this result (Table3), the time trend coefficients are not significant.
Table 3: Estimates of $d$, time trend and seasonal autoregressive (AR)

| Meteorological Station | $D$ (CI) | Time trend (t stat.) | Seasonal AR(12) |
|------------------------|----------|----------------------|-----------------|
| Lagos                  |          |                      |                 |
| Ikeja_Max              | 0.4763*** (0.3660, 0.5866) | -1.77E-03 (-0.169) | 0.7720***       |
| Ikeja_Min              | 0.4556*** (0.3611, 0.5501) | -6.00E-04 (-0.122) | 0.4081***       |
| Ikeja_DTR              | 0.3906*** (0.2877, 0.4935) | -4.35E-03 (-0.619) | 0.6140***       |
| Akure                  |          |                      |                 |
| Akure_Max              | 0.4488*** (0.3412, 0.5564) | 3.59E-04 (0.025)  | 0.8682***       |
| Akure_Min              | 0.2629*** (0.1716, 0.3542) | 1.21E-03 (0.513)  | 0.5586***       |
| Akure_DTR              | 0.3699*** (0.2519, 0.4879) | -4.53E-04 (0.063) | 0.7414***       |
| Ibadan                 |          |                      |                 |
| Ibadan_Max             | 0.2666*** (0.1641, 0.3691) | -2.42E-03 (-0.352) | 0.9087***       |
| Ibadan_Min             | 0.2969*** (0.2032, 0.3906) | 1.30E-03 (0.535)  | 0.6143***       |
| Ibadan_DTR             | 0.2068*** (0.1088, 0.3048) | -3.21E-03 (-0.648) | 0.8241***       |

As a result of non-significance of time trend coefficient when I(d) process is assumed, the estimation procedure was re-adjusted by assuming I(0) process for the temperature series(Table 4). However, significant positive time trend coefficients were obtained for only the minimum temperatures in the three meteorological stations which implied that global warming is being experienced in the South West zone of Nigeria. The coefficients for DTR are negative but not significant in a similar way it appeared in Table 3. In essence, the fact that DTR coefficients are negative implies the possibility of warming in the South-Western Nigeria.
Table 4: Estimates of the time trend with Seasonal AR for d = 0

| Meteorological Station | Constant (t stat.) | Time trend (t stat.) | Seasonal AR(1) |
|------------------------|--------------------|----------------------|----------------|
| Lagos                  |                    |                      |                |
| Ikeja_Max              | 0.2052 (0.266)     | -3.39E-04 (-0.135)   | 0.8301***      |
| Ikeja_Min              | -0.2393 (-1.34)    | 1.36E-03 (2.00)***   | 0.4553***      |
| Ikeja_DTR              | 0.0434 (0.106)     | -4.99E-04 (-0.337)   | 0.6878***      |
| Akure                  |                    |                      |                |
| Akure_Max              | -0.2941 (-0.203)   | 1.54E-03 (0.379)     | 0.9042***      |
| Akure_Min              | -0.5788 (-3.28)*** | 2.59E-03 (2.00)***   | 0.5540***      |
| Akure_DTR              | 0.0207 (0.029)     | -3.268E-05 (-0.014)  | 0.8081***      |
| Ibadan                 |                    |                      |                |
| Ibadan_Max             | 2.0088 (0.817)     | -5.48E-03 (-0.910)   | 0.9274***      |
| Ibadan_Min             | -0.4253 (-2.02)*** | 1.87E-03 (2.40)***   | 0.6173***      |
| Ibadan_DTR             | 1.1576 (1.18)      | -4.29E-03 (-1.40)    | 0.8572***      |

4. Conclusion

The persistence, time trend and seasonality in the maximum and minimum temperature in the South Western part of Nigeria had been examined using the fractional I(d) technique in time series econometrics, which is an approach that is hardly employed in climatological studies. It was observed that the temperature series possess long memory property i.e. the distribution of the series is dependent on past lag observations in which there is persistent temperature and the seasonal autoregressive parameters are significant in all the series which implied that seasonality is pronounced in the temperature series. Also, the shocks to the series would have a long lasting effect before diminishing (i.e. the warming is persistent). In addition, significant positive time trend coefficients were obtained for the minimum temperature, while negative coefficients were obtained for the DTR at these stations considered which implied that global warming is also being experienced in this part of Nigeria. Hence, this warming which results from temperature increase due to climatic changes may affect many natural systems in this region of Nigeria.

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