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# Rainfall Variability over Ghana: Model versus Rain Gauge Observation

**Francis Nkrumah[1], Nana Ama Browne Klutse[2], David Cudjoe Adukpo[1], Kwadwo Owusu[3*], Kwesi Akumenyi Quagraine[1], Alfred Owusu[1], William Gutowski Jr.[4]**

[1]Department of Physics, University of Cape Coast, Cape Coast, Ghana
[2]Ghana Space Science and Technology Institute, Ghana Atomic Energy Commission, Accra, Ghana
[3]Department of Geography and Resource Development, University of Ghana, Legon, Ghana
[4]Department of Geological and Atmospheric Sciences, Iowa State University, Iowa, USA
Email: *kowusu@ug.edu.gh

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## Abstract

**This paper used the International Centre for Theoretical Physics (ICTP) Regional Climate Model, Version 3 (RegCM3) and rain gauge data selected from the Ghana Meteorological Agency (GMet) from 1990 to 2008 to investigate the extent and nature of variability in the annual rainfall and pattern of the raining seasons in Ghana. In the study, six meteorological stations selected from three rainfall distribution zones according to the divisions of the GMet were used to study the pattern of rainfall and its departure from the normal trend. The study also assessed the performance of the RegCM3 simulation with reference to the observed gauge data. Results confirmed the unimodal nature of the rainfall annual cycle over the northern belt and bi-modal rainfall nature over the middle and southern belts of Ghana. Negative departures of rainfall implying consistent downward trend were observed at all the stations. Our analysis showed that RegCM3 captured the average rainfall over Ghana but demonstrated an underestimation as compared to the observed gauge data. The model also had difficulty stimulating the departures accurately in direction and in magnitude in all the stations except for Accra where RegCM3 simulated the right direction of the departures.**

## Keywords

**Rainfall Variability, Ghana, RegCM3, Temporal Rainfall Distribution, Rain Gauge Data**

## 1. Introduction

Ghana shares boundary with the Gulf of Guinea to the south and extends between latitude 4˚N and 11˚N and

*Corresponding author.

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longitude 4˚W and 2˚E. It is a region that is strongly influenced by the West African Monsoon. It undergoes various variations in climate that are marked by severe droughts and floods. Ghana's rainfall seasons are mostly influenced by the movement of the tropical rain belt (also known as the Inter-Tropical Convergence Zone, ITCZ), which swings back and forth between the northern and southern tropics in each year. The prevailing wind direction in regions south of the ITCZ is southwesterly, blowing moist air from the Atlantic Ocean onto the continent and the prevailing winds to the north of the ITCZ is known as the Harmattan. The Harmattan originates from the northeast, bringing in hot and dusty air from the Sahara Desert between December and March. As the ITCZ moves north and south over the year, the zones between the northern and the southernmost positions of the ITCZ experience a shift between the two opposing prevailing wind directions. This pattern is known as the West African Monsoon. The northern part of Ghana experiences a single wet season occurring between May and November of the year when the ITCZ is in its northern position and the prevailing wind is south-westerly. The northern part of the region receives 150 - 250 mm of rainfall per month in the peak months of the wet season (July to September). The southern parts of Ghana have two wet seasons: the major season from March to July, and a minor season from September to November [1]. These seasons correspond to the northern and southern passages of the ITCZ across Ghana. The seasonal rainfall in this region varies due to variations in the intensity and movements of the ITCZ, and variations in the intensity and timing of the West African Monsoon.

Studies have shown that the annual rainfall in Ghana is highly variable on inter-annual and inter-decadal timescales [2]. This means that there are difficulties in identifying long term trends. The amount of rainfall over Ghana is known to have been particularly high in the 1960s. This amount decreased to low levels in the late 1970s and early 1980s, causing an overall decreasing trend in the period 1960 to 2008, with an average decrease of 2.3 mm per month (2.4%) per decade. [3] [4] observed the tendency of more intense dry spell during the rainy season in the south (Accra) than the north (Tamale). Similar patterns are observed in the analysis of rainfall variability in Ho and in Tamale [5].

The inhabitants of Ghana depend heavily on rainfall for many activities [1]. However, variability in rainfall has been a major challenge to agricultural production, transportation, hydro-electricity production and water supply. Many cities have had to face harsh economic and social conditions due to the strong impact of continuous reduction of rainfall in Ghana [6]. Mitigation strategies are challenging to implement because Ghana has a complex spatial climate variability [7] with the coexistence of different rainfall regimes from a bi-modal wet coastal forest to dry savanna region in the north. Rainfall patterns usually have spatial and temporal variability in Ghana. The variability negatively affects agricultural production, among other factors, which threatens the existence of its people. In cities, where the annual variability of rainfall is high, individuals often go through adversities due to floods or droughts. Based on collected data, the recent decline in rainfall in Ghana is anomalous to its duration, intensity and seasonal expression [8]. Some regional studies over Ghana have reported a decrease in rainfall (more significant in the south than in the rest of the country) in the period 1980-2000, as compared to 1950-1970, given by a sudden shift in the seventies [1] [3].

The majority of research work undertaken on rainfall in Ghana focused on selected stations or zones. For example, [4] concentrated on Accra and Tamale, [5] concentrated on Tamale, [1] focused on Wenchi, and [9] focused on northern Ghana. However, few studies have considered Ghana as a whole: [10] used 16 stations in Ghana to study the trend in the rainfall pattern over the period from 1960 to 2005, while [11] used RCMs models to study the spatial pattern of rainfall over Ghana. The current study focuses on the rainfall variability over the whole of Ghana.

In this paper we group the annual and seasonal variability of rainfall in three rainfall distribution zones in Ghana according to the GMet (**Figure 1**). Six rain gauge data sets were carefully chosen from meteorological stations to represent the various rainfall variability types in Ghana and the results were compared with those from a Regional Climate Model (RegCM3) to study how suitable the RegCM3 is for simulating the rainfall climatology of Ghana. It is hoped that the findings of the study will contribute valuable information for water resources management and planning in Ghana.

## 2. Data and Methodology

### 2.1. Gauge Data

Daily rainfall data from 1990 to 2008 for six synoptic weather stations obtained from the GMet were considered in the study. The data for the chosen period are consistent for all the synoptic weather stations. **Figure 1** shows

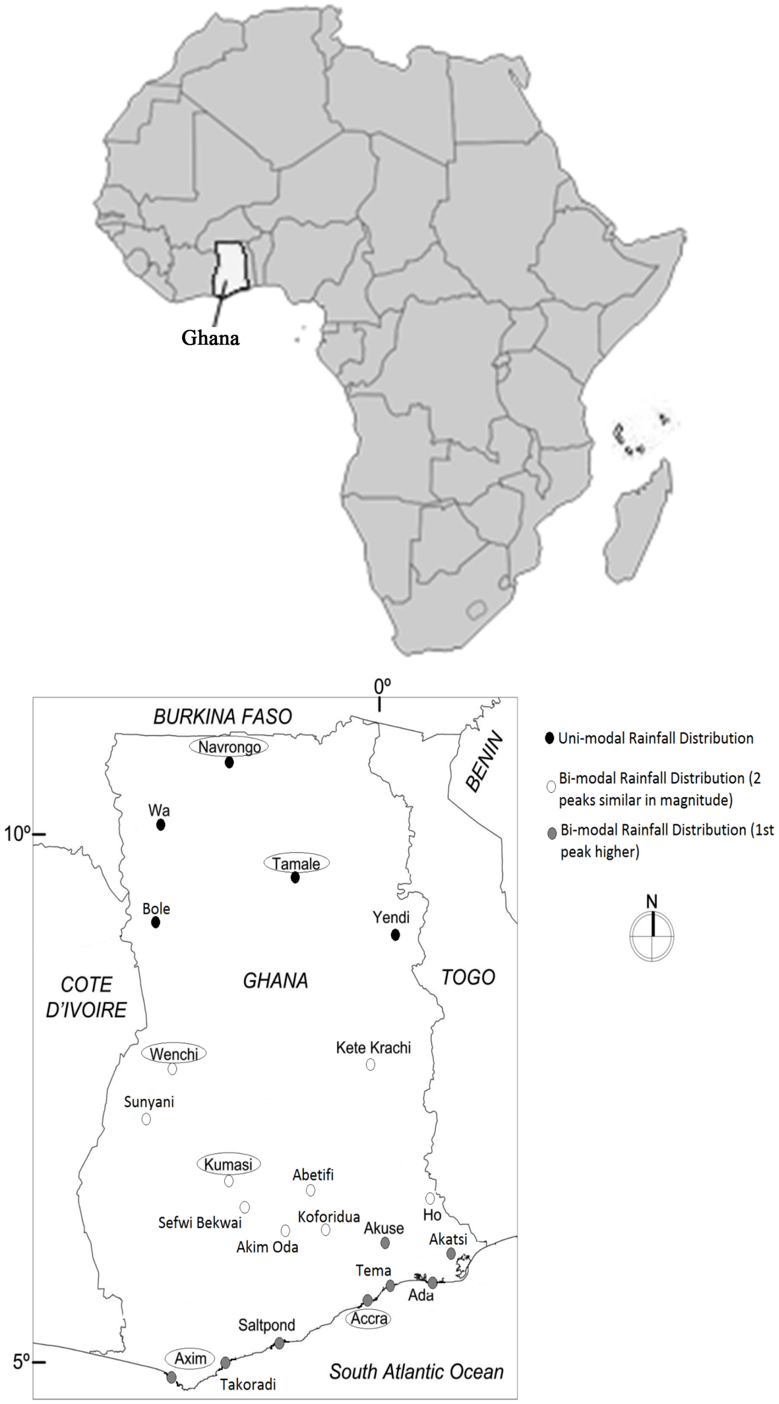


**Figure 1.** Map of Africa showing Ghana and the map of Ghana showing synoptic weather stations where rain gauge data was obtained (modified from Lacombe, 2012).

the map of Ghana with the distribution of these stations. Navrongo and Tamale stations represent uni-modal rainfall distribution region of Ghana, Kumasi and Wenchi stations represent bi-modal rainfall distributions with two (2) peaks similar in magnitude, and Accra and Axim represent bi-modal rainfall distributions with a higher first peak. For each station, the monthly rainfall values were computed. These values were then used to compute the monthly mean rainfall for the period (1990-2008) of study.

### 2.2. Model Data

The model data considered in this work is the International Center for Theoretical Physics Regional Climate Model version 3 (RegCM3) from the Coordinated Regional Climate Downscaling Experiment (CORDEX).

RegCM3 is a 3-dimensional, sigma-coordinate, hydrostatic, compressible, primitive equation regional climate model. It was originally developed in the late 1980s, and it was the first limited area model applied to climate studies [12]. Over the last 25 years, the system has been improved through successive model versions (RegCM1 to RegCM4), incorporating increasingly comprehensive physics packages and interactively coupled components of the climate system (chemistry/aerosol, ocean, lake and biosphere) [13]. RegCM3 is a flexible and versatile system which can be used for different regions of the world especially over West Africa [14] [15] and for a wide range of applications. Data from RegCM3 was analyzed for all the selected stations for the period of 1990 to 2008 and the monthly mean and total rainfall plotted over the period.

### 2.3. Methodology

The deviations of the annual rainfall (Equation (1)) from the annual mean rainfall for each station were computed and subsequently, the annual rainfall departures (Equation (2)) for each station over the period of study.

$$\text{Standard Deviation, } \sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \overline{x}\right)^2} \tag{1}$$

$$X_{ij} = \frac{\left(x_{ij} - \overline{x_1}\right)}{\sigma_i} \tag{2}$$

where:

$X_{ij}$ = annual rainfall departure.

$x_{ij}$ = the annual total for station *i* and year *j*.

$\overline{x_i}$ = the annual mean rainfall in station *i* averaged over the entire 19-year period.

$\sigma_i$ = the standard deviation of the annual totals.

The stations were grouped based on their rainfall distribution patterns in Ghana as shown in **Figure 1**. Stations with solid-black dot have uni-modal rainy distributions while stations with hollow-dots have bi-modal rainfall distributions with two peaks similar in magnitude and stations with grey-shaded dot have bi-modal rainfall distributions with a higher first peak.

Bar and line graphs were plotted to show various forms of information, including trend of average monthly rainfall and rainfall departure. Rainfall departure is a way of measuring the deviation of each of the yearly rainfall values from the mean over the 19-year period.

The RegCM3 has been used for simulation of different meteorological parameters like rainfall, temperature, pressure, humidity, wind field, radiation, soil moisture, surface runoff, cloud fraction etc. In this analysis, the model simulated rainfall is compared with the observed data for 19 years from 1990 to 2008. The average monthly rainfall and the rainfall departure were also calculated for the model data and plotted along with the rain gauge data for good comparison.

## 3. Results and Discussion

This section examines the rainfall variability for a 19-year (1990-2008) period observed rain gauge data and its comparison with the RegCM3 model data.

### 3.1. Temporal Rainfall Distribution

The results from the rain gauge data confirm that stations with uni-modal rainfall distribution have rainfall periods of April to October with September and October recording the highest amount of rainfall. Stations in the middle belt of Ghana with bi-modal rainfall distribution of almost equal peaks also exhibit similarities in the nature of their rainfall patterns with lower amount of rainfall in August separating the two peaks. Stations in southern Ghana exhibit the bi-modal rainfall distribution and have its first peak higher than the second peak.

**Figures 2-7** show the average monthly rainfall pattern from 1990 to 2008 for six selected stations. While the

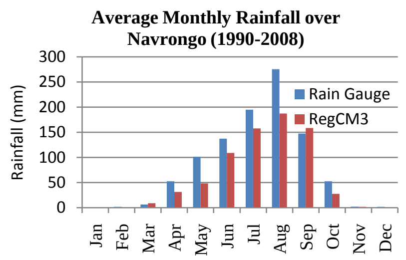


**Figure 2.** Average monthly rainfall over Navrongo from 1990 to 2008.

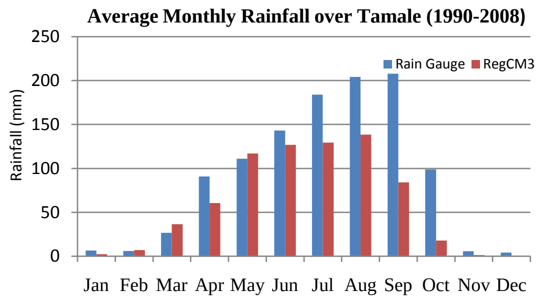


**Figure 3.** Average monthly rainfall over Tamale from 1990 to 2008.

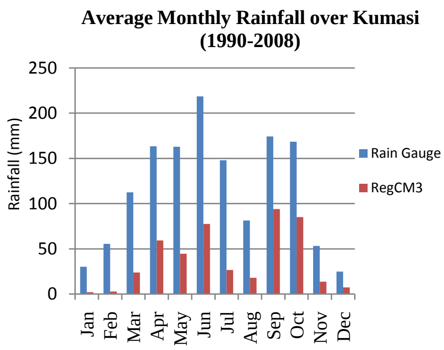


**Figure 4.** Average monthly rainfall over Kumasi from 1990 to 2008.

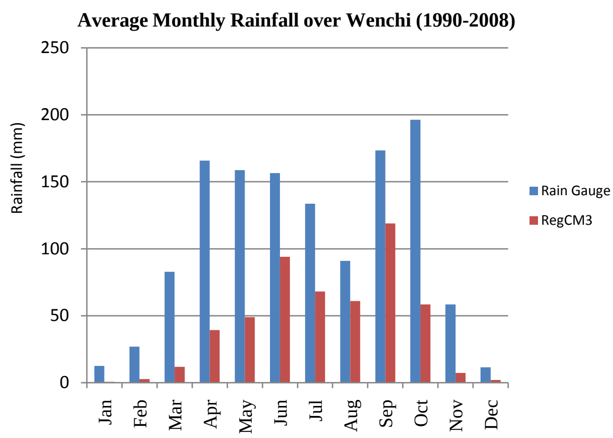


**Figure 5.** Average monthly rainfall over Wenchi from 1990 to 2008.

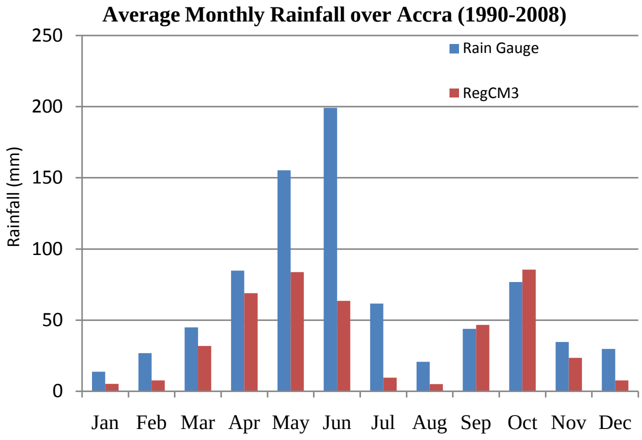


**Figure 6.** Average monthly rainfall over Accra from 1990 to 2008.

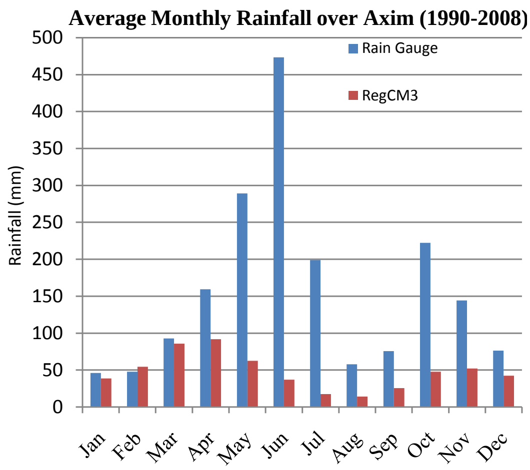


**Figure 7.** Average monthly rainfall over Axim from 1990 to 2008.

highest average rainfall at Navrongo was in month of August (**Figure 2**), Tamale recorded its highest average rainfall in September (**Figure 3**).

Generally, rainfall increases gradually from March for both Navrongo and Tamale at 6 mm and 26 mm respectively and reaches the maximum in August at 275 mm for Navrongo (**Figure 2**) and September at 208mm for Tamale (**Figure 3**). This has been the general rainfall pattern in northern Ghana (**Figure 1**) and since the maximum rainfall occurs once in a year, the pattern can be referred to as having a uni-modal rainfall distribution.

From the RegCM3 data, Navrongo shows a similar rainfall pattern to that of the rain gauge data but grossly underestimates the amount of rainfall in all the months except for March and September where RegCM3 overestimates the amounts of rainfall by 2 mm and 10 mm respectively. At Tamale, RegCM3 rainfall peaks earlier in August at about 139 mm and equally underestimates it amount in all the months except for February and March where RegCM3 overestimates the rainfall amount by about 1mm and 10 mm respectively.

**Figure 4** and **Figure 5** have a bi-modal rainfall distribution with almost equal amount of rainfall at both peaks, which is typical of rainfall pattern in the middle belt of Ghana (**Figure 1**). The first average maximum was in June for Kumasi and in April for Wenchi recording rainfall amounts of 218 mm and 168 mm respectively, and the second maximum was in September and October, respectively (**Figure 4** and **Figure 5**). From the RegCM3 data, Kumasi shows a similar rainfall pattern to that of the rain gauge data but with a high underestimation of the rainfall amount. Wenchi, unlike the rain gauge data, recorded its first average maximum rainfall in June with 94 mm of rainfall and its second average maximum recorded in September with 119 mm of rainfall, which is still an underestimation in the amount of rainfall.

**Figure 6** and **Figure 7** show a bi-modal rainfall distribution with its first peak higher than the second peak. This is the case of rainfall pattern in southern Ghana as indicated in **Figure 1**. The first average maximum was June for both Accra and Axim, and the second maximum was in October for both stations. Accra recorded an average maximum amount of 199 mm of rainfall in its major rainfall season and 77 mm in its minor rainfall season (**Figure 6**). In Axim, the major rainfall season starts in March with an amount of 93 mm and peaks in June with an amount of 473 mm rainfall (**Figure 7**).

The minor rainfall season starts in September and peaks in October recording 222 mm of rainfall. This city experiences a little dry season between the major and minor rainfall seasons. Similar pattern of rainfall is observed in the RegCM3 data in both Accra and Axim but with a high underestimation of rainfall amount at both stations except for Accra which recorded an overestimation of rainfall amount in September and October where RegCM3 overestimates by close to 3 mm and 8 mm respectively. The case presented in Axim, using the RegCM3, deviates from the normal pattern of rainfall in southern Ghana. Generally, Axim recorded a low rainfall amount over the period of study (1990-2008) as compared to the rain gauge data. This might be due to inconsistencies in the model data over this period, since the model data shows a good correlation with the rain gauge data (**Table 1**).

Rainfall in **Figures 4-7** is very similar in nature in the period June-October, whereas rainfalls in **Figure 2** and **Figure 3** are similar but different from the other stations. These rainfall patterns account for the one farming season in northern Ghana and two in the southern Ghana (see **Figure 1**). These climatic zones are strongly influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ), which is responsible for both rainfall regimes [16] [17]. The differences in the variability of rainfall in Ghana as suggested in the national study of [18] is due to the movement of ITCZ and influence of Atlantic SSTs of the Guinea coast, as noted by [19].

Analysis of the regions with the two peaks (the middle belt and southern belt), the first around May/June/July and a second in September/October, saw a relative minimum rainfall in August (**Figures 4-7**). This rainfall minimum in August by [20] [21] is likely connected with the relative stability that exists over the coastal area as a result of lower sea surface temperature and divergence of specific humidity during this period.

### 3.2. Rainfall Departure from Annual Mean

From the rainfall departure plots (**Figures 8-13**), it was realized that rainfall generally recorded negative departures from the mean over the 19-year period in all the stations. The negative departure in the 1990's may be due to the influence of ENSO on West Africa [22].

A consistent downward trend implying occasional droughts is observed throughout the years. The study of [6] not only confirms the declining trend observed in rainfall but also found that the dry season has become longer over the last half century. It was also observed for Navrongo in 1991 (**Figure 8**), Tamale in 1992 (**Figure 9**) and Kumasi in 1996 (**Figure 10**) that the model stimulation was in a rather opposite direction to that of the rain gauge data.

In **Figure 12**, the RegCM3 simulates the right direction of the departure; however, the magnitude of the departure is mostly not accurately simulated.

[23] suggested the tendency for the model to over predict precipitation in Guinean Coast due to the highly biased nature of precipitation in this area.

**Table 1.** Correlation between rain gauge and RegCM3 simulation rainfall data.

| Station | Correlation coefficient |
|---|---|
| Navrongo | −0.0176 |
| Tamale | 0.0621 |
| Kumasi | 0.1264 |
| Wenchi | 0.1826 |
| Accra | 0.5720 |
| Axim | 0.0667 |

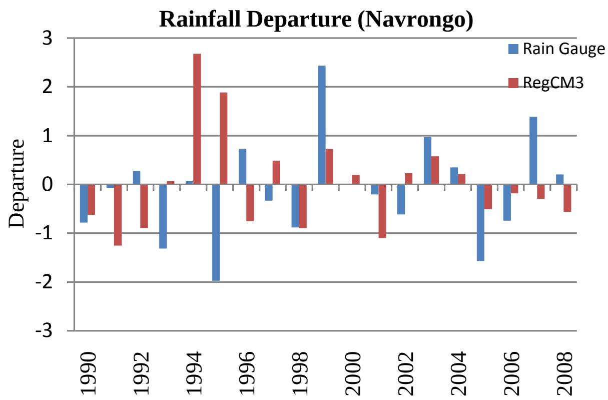


**Figure 8.** Rainfall departure in Navrongo from 1990 to 2008.

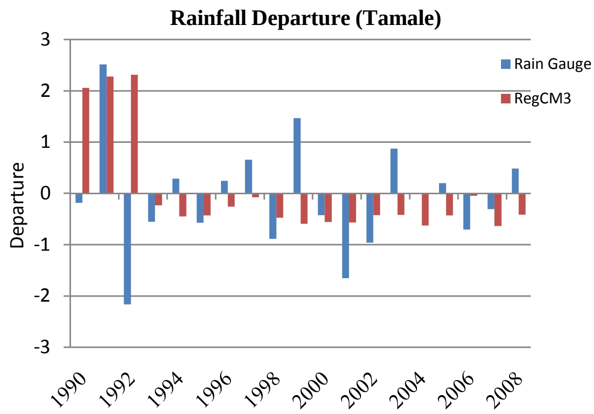


**Figure 9.** Rainfall departure in Tamale from 1990 to 2008.

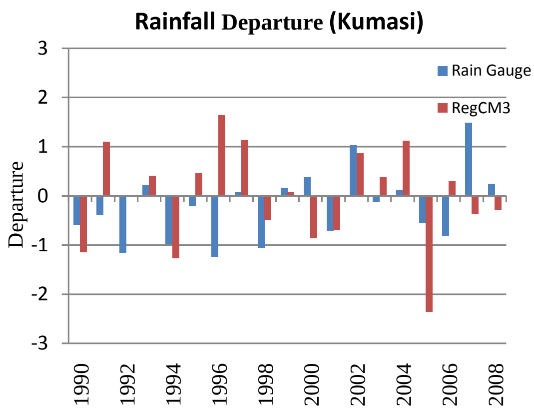


**Figure 10.** Rainfall departure in Kumasi from 1990 to 2008.

### 3.3. Correlation between Rain Gauge and Model Rainfall Data

From the analysis in the departure in rainfall amount, it was realized that there is a decrease in the accuracy of the model data as compared to the rain gauge data. This is due to the low correlation between the model and rain gauge data. Rainfall from most synoptic stations showed little or no correlation except for Accra which showed a moderate positive correlation of 0.57 between the model and rain gauge data. It is therefore observed in **Figure 12** that the model demonstrated the ability to simulate well the variability in rainfall with correct direction of the departure and a moderate accuracy in the magnitude of the departure over Accra. The correlation analysis

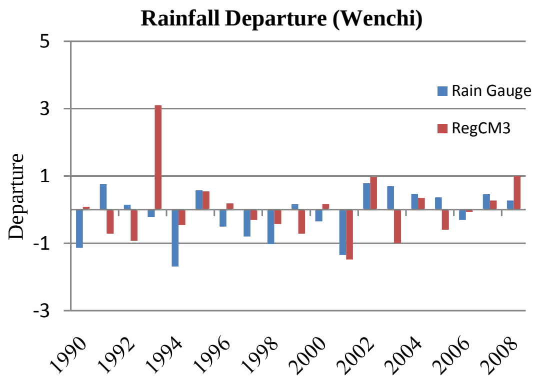


**Figure 11.** Rainfall departure in Wenchi from 1990 to 2008.

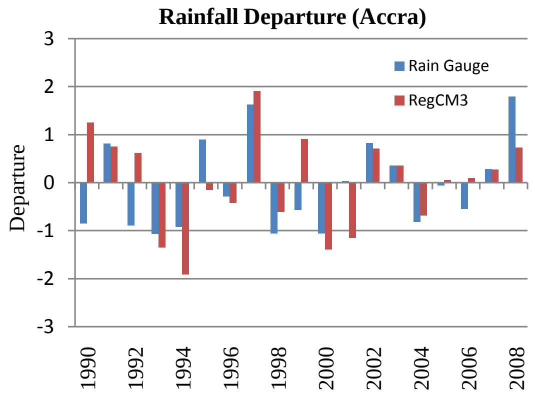


**Figure 12.** Rainfall departure in Accra from 1990 to 2008.

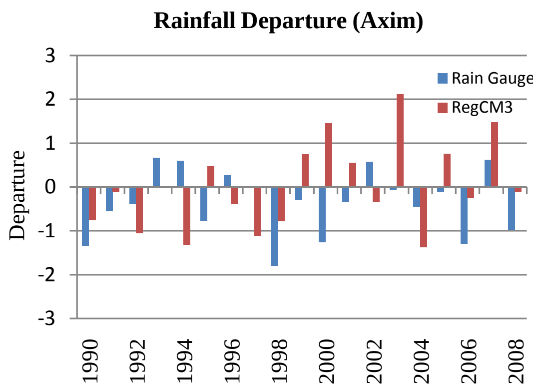


**Figure 13.** Rainfall departure in Axim from 1990 to 2008.

indicates that there was almost no major change in annual rainfall depths over the period of study (1990-2008).

## 4. Conclusions

The study investigated the extent and nature of variability in the annual rainfall and pattern of the rainy seasons in Ghana. An assessment of the suitability of the RegCM3 data commonly used for rainfall variability and trends studies over Africa was carried out over Ghana and compared with rain gauge data from meteorological stations in Ghana. In the analysis, data from six synoptic stations were used as reference for the period 1990-2008.

The results confirmed the uni-modal nature of rainfall over the northern and bi-modal rainfall nature over the middle and southern belts of Ghana. Negative departures of rainfall implying consistent downward trend were observed in most of the stations especially in the 1990s. This has the implication on droughts and even longer dry season [6] during the 1990s. Mostly positive departures or negative departures of rather low magnitudes were observed in the 2000s implying expectation of floods or normal rainfall season in the 2000s. For most of the stations, the RegCM3 data showed consistent agreement with the rain gauge data but with some biases. For example, a similar pattern of rainfall is shown by RegCM3 over the southern belt where the major and minor rainfall seasons are clearly demonstrated. However, the magnitude of the variability was not always accurately simulated. In addition, the model underestimated rainfall amounts generally over Ghana. As a result, the model produced less rain over this region. As suggested by [23] the differences in the model results and rain gauge results may be due to the coarse nature of the horizontal grid of the model to accurately simulate the mesoscale systems over West Africa. Overall, the outcome of this study suggests that the RegCM3 has the potential to be suitable for the study of rainfall variability and trend studies over Ghana. However, there is a need to improve on the parameterization of the model to accurately simulate rainfall variability as the observed data. When this is achieved, then the model simulations could play a vital role in water resources management in Ghana as gauge data are generally sparse and riddled with gaps.

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