Investigation of the Onset, Cessation and Length of the Rainy Season over Ghana

by

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Declaration

I hereby declare that this thesis is my own work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

This study seeks to investigate the onset, cessation and length of the rainy season using a simulated rainfall data from the fourth generation Regional Climate Model (RegCM4) and measured rainfall data from the Ghana Meteorological Agency (GMet) over Ghana from 1998 to 2012. The results from the RegCM4 was compared with those derived from the measured rainfall data. The results showed that the mean rainfall onset dates for the Forest, Coastal, Transition and Northern zones of the country, from the RegCM4 was calculated to be 31st March, 4th April, 13th April and 2nd May respectively. The GMet measured rainfall values also had the mean rainfall onset dates determined to be 27th March, 27th April, 8th April and 27th April for the Forest, Coastal, Transition and Northern zones. The mean rainfall cessation dates from the RegCM4 was recorded to be 2nd November for the Forest zone, 29th October for the Coastal zone, 15th November for the Transition zone and 20th October for the Northern zone. The mean rainfall cessation dates from the GMet measured rainfall values was also determined to be 16th November for the Forest zone, 3rd November for the Coastal zone, 24th November for the Transitional zone and 9th November for the Northern zone. The average length of the rainy season from the RegCM4 was computed to be about 216 days for the Forest zone, 209 days for the Coastal zone, 216 days for the Transition zone and 171 days for the Northern zone. The GMet rainfall measured data also measured similar average lengths of 234 days for the Forest, 191 days for the Coastal zone, 230 days for the Transition zone and 196 days for the Northern zone. These results may have very useful applications for water resource management and food security in Ghana.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Rainfall is the key factor that determines yields and success of other socio-economic activities over West Africa, especially Ghana. The annual rainfall prediction conforms with the World Meteorological Organisation (WMO) Climate Information and Prediction Services (CLIPS) project, which forms part of the Ghana Meteorological Agency's effort to provide scientific information on weather for planning and decision making in agriculture, water resources management, hydro-electric power generation (which is the main source of electricity for Ghana), as well as other sectors of the national economy.

The rainfall characteristics considered in this report are the onset date, cessation date, length of the rainy/growing season and total annual rainfall, that are all based on regional climate modeling, which places emphasis on the strong tele- connections between the general atmospheric circulations (Oduro-Afriyie and Adukpo, 2006). Thus, the knowledge on past and present onset, length and cessation of the rainy/growing season would inform predictions and planning of appropriate interventions to ensure yield stability in agriculture. Information on the past and present onset and cessation of rainfall is to serve as a guide to farmers on when to start planting to prevent frequent crop failures and also to fishermen on when to expect bumper harvest of fishes. Management policies could be put in place in the planting of new cultivars of crops that could resist drought and still ensure food production during the dry season (Omotosho et al., 2000).

1.2 PROBLEM STATEMENT

With the increasing disruption to agricultural calendars, changes in climatic patterns have direct impact on the onset, duration and seizure of most of crops in agriculture which in turn affects the rate of food production (Owusu and Waylen, 2009). Moreover, the large increase in population anticipated by 2050 is a concern for food availability and conservation of the natural resource base (Neng et al., 2002), and thus, the need to investigate the irregularities of the onset, length and cessation of the rainfall season over the West African Climate. These variation in climatic conditions have also led to unsustainable agricultural practices, insufficient water resources management in the area of industry, hydro-power and other services which result in famine and food insecurity (Manzanas et al., 2014).

This study aims to investigate the effect of the changes in the onset, duration and seizure of the rains on agriculture in West Africa and more specifically over Ghana. The performance of the International Centre for Theoretical Physics (ICTP) RegCM4 to simulate the moving rainbelt, the position and strength of the ITCZ and its associated changes affecting the rainy period (the growing season of most crops in West Africa) would be used in this study. This assessment is carried out in view of the future use of this Regional Climate Model for climate change projections over the region (Yorke and Omotosho, 2010).

1.3 JUSTIFICATION

Since the mid- 1980s, an increasing delay of rainfall onset dates in the Volta basin of West Africa has been suspected by local farmers (Laux et al., 2008). With respect to our agrarian economy (agricultural economy), if the rains are limited to a few months per year only, reliable determination of the onset and seizure of the rainy season and the start of the growing season is of great importance to high crop yield and food production. For growing, it is very necessary to know when and how continuous the rains would be to ensure enough soil moisture and length of planting days. Efficient prediction of the onset of the rains and its seizure would help climatologists and meteorologists to come out with a seasonal forecast which would guide farmers in deciding when they could start planting.

Regional Climate Modeling (RCM) provides a better way in capturing the variation in climate over short distances, especially with precipitation and wind (Giorgi et al., 2012). The RCM can be run at the higher horizontal resolution required to capture complex terrain and land-use cover which takes into account the regional and small scale detail effects of climate characteristics like topography which are important to local climate (Giorgi et al., 2012). This can therefore be important tools that will enable and provide climate scientists with better and large-scale weather information of high resolution (15 km or 20 km), to study processes and mechanisms leading to the West African rainfall variability. Global coupled climate models are not yet mature enough to simulate the West-African climate accurately (Team, 2007). For example, a number of models do not locate the rainfall maxima over West Africa correctly during the monsoon season (Cook et al., 2006). The RegCM has proved over the years to be suitable for studies in the tropics.

Moreover, another factor which has also been found to affect rainfall season over the West African vegetation has been the moisture fluxes in the tropical North Atlantic Ocean which also contributes to the rainfall of the West African region, with local evaporation as the second largest contributor to rainfall in July over the same region. The season length ranges from 1 to 2 months in the north to 4 to 5 months in the south of the region (Nicholson and Grist, 2001).

Team (2007) shows that climate change is unequivocal and its impacts are here with us. In comparison with other parts of Africa, West Africa has witnessed the most outstanding climatic shift in the late 20th century, with a sustained 10-20% rainfall decrease and multi-year episodes of extreme drought (Friesen and van de Giesen, 2002). Consequently, we are unable to determine whether such changes, e.g. in the frequency or intensity of rainfall events, are consistent with expectations from anthropogenic climate change. The occurrence of climate change has caused the shortening of the rainy season with consequences in agriculture (Grist and Nicholson, 2001). The trend of anthropogenic climate change is expected to induce atmospheric warming and thus, an increase in specific humidity would drive events of increased intensity (Yengoh et al., 2010). Also, the region is likely to undergo longer dry spells within the agricultural season and recurrent floods leading to more food insecurity because of food crops failure. That idea is backed by New et al. (2001) who noticed statistically significant trends in daily rainfall intensity and dry spell duration in the West African region.

Thus, this study would seek to investigate the changes in determining the onset, length and cessation of the rainy season over West Africa, using the RegCM4.

1.4 OBJECTIVES

1.4.1 MAIN OBJECTIVE

The main objective of this studies is to investigate how the changes in the onset, cessation and length of the rainy season and its direct impact on farming in Ghana.

1.4.2 SPECIFIC OBJECTIVES

- To determine the onset and cessation of the rainy season over Ghana using RegCM4.
- To determine the length of the rainy season over Ghana using the RegCM4.
- To inter-compare rainfall data from RegCM4 for onset and cessation dates with rainfall data from the Ghana Meteorological Agency over Ghana.

1.5 RESEARCH QUESTIONS

This study would seek to respond to the following major research question: How has the changes in the onset, cessation and length of the rainy season in West Africa occurred over the past thirteen years, with Ghana as a case study? Much specifically, it attempts to know:

- What the key definition of the onset and cessation of the rainy season in Ghana is?
- What the dry spells in the rainy season are?
- What the length of the rainy season in Ghana has been?
- When farmers are to be advised on planting their crops in Ghana?

1.6 THESIS OUTLINE

Chapter Two compares similar scientific works done in the field of study on similar topics and also further define other mechanisms of the West African Monsoon. The RegCM4 model is explained in this chapter, especially on its operational processes and its schemes of operation.

Chapter Three discusses more on the study area and methodology of the work. In this chapter, a statistical climatic programming tool known as Instat is implored in comparing the changes of the onsets and cessation on rainfall data collected from the Ghana Meteorological Agency from 1998 to 2010 over 20 synoptic stations. Simulated precipitation data from the RegCM4 model developed by the International Centre for Theoretical Physics is downscaled and validated against the observational rainfall datasets from the Ghana Meteorological Agency.

The onset of the rains for this investigation is defined by the Fuzzy Logic Approach method used by Kunstmann and Jung (2005) for Burkina Faso for a first group of rainfall definitions with site- scaled threshold values.

Chapter Four discusses the observations and analysis made on the comparison of both the onset and cessation dates for all the 20 synoptic stations used in this study. The analysis is made with respect to the different agro- ecological zones defined by the Ghana Meteorological Agency for Ghana. The various onset and cessation dates helps to provide the length or duration of the rainfall season over the years under study for each zone.

Chapter Five covers the conclusion and recommendation that was deduced from the discussion made on the analysis from the previous chapter. The recommendations made from this chapter will help inform farmers better on the different onset and cessation dates for the different agro-ecological zones of the country, so they could adequately prepare for the planting season.

CHAPTER 2

LITERATURE REVIEW

2.1 BACKGROUND

Rainfall is a key climatic factor that influences plant growth and crop productivity. The variability of rainfall at the start of the seasons as well as mid-season breaks in the rains often result in poor crop growth and yield reduction. For a better understanding of the issue of water availability in tropical rain fed agriculture, much more attention needs to be given to the quantification of within-season rainfall variability. This will allow a prior assessment of the expected severity and duration of dry spells during the season and provide a sounder basis for developing improved water management technique in tropical agriculture. Thus, there is the need to define the onset of rainy season in order to avoid the false start owing to the variable nature of tropical rainfall. The false start is said to happen when rainfall meeting the chosen criterion is followed by a long dry spell. According to the fuzzy- logic approach which would be used in helping define the onset for the rains (Laux et al., 2008).

- A total of at least 20 mm of rainfall are observed within a 5- day period
- The starting day and at least two other days in this 5 day period should be wet (at least 1 mm of rainfall recorded).
- No dry period of seven (7) or more consecutive days occurring in the following 30 days.

The definition of dry spell is based on the break of several days between two successive rainfall events, which is the significant decrease in water availability that result in plant wilting and dying. The causes of such anomalies depend on the general and synoptic circulation pattern of the tropical atmosphere and its very important mechanism.

Agriculture and its products provides employment for over 70% of the employed people in a developing country like Ghana, therefore efforts targeting at improving this sector, and reducing the economic loss will be highly appreciated (Oduro-Afriyie and Adukpo, 2006). The onset and cessation of rain determines the cultural practices of farmers; the main problem lies in accurately predicting the time of onset and cessation of the rain, as well as the irregularities in the distribution of the rain once it has commenced. These irregularities results in uneconomic destabilization of both labour and farm machineries. Predicting the start and end of rain is a very challenging task because of the irregularities in its distribution.

Forecasting of onset and cessation of precipitation over West Africa has been given attention by researchers such as Omotosho et al. (2000), Odekunle (2006), and Omogbai (2010). Lacombe et al. (2012) also investigated the trend of rainfall series in 16 synoptic stations of the Ghana Meteorological Agency over 1960-2005. Laux et al. (2009) also did a similar work by predicting the regional onset of the rainy season in West Africa.

Most studies used observations and reanalysis to study the West African monsoon (WAM) mechanism, with Cook et al. (2006), studying the response of the WAM to tropical oceanic heating. Jenkins et al. (2005) and Giorgi et al. (2012) also investigated the main drivers of the present day and future Sahel droughts. Whiles Omogbai (2010) studied the rain days and their predictability in South Western region of Nigeria. Yengoh et al. (2010) examined the effect of soil moisture initialization on the WAM simulation. Browne and Sylla (2012) also investigated the sensitivity of the RegCM to domain size for the simulation of the West Africa Summer monsoon Rainfall. It can be observed from all of these studies that there has been great progress in understanding the WAM dynamical and physical features using regional climate models.

Omogbai (2010) worked on the rainfall variability in Ghana from 1961 to 2005 for four synoptic stations, and found out that wet years have early onset and late cessation dates, whiles the dry years recorded late onset of rains and early cessation dates respectively. This variability was explained to have resulted in longer rainfall season for the wet years whiles shorter rainfall season for the dry years. It was also deduced from their study that, rainfall amount and the length of the rainy season during the dry years were reduced by about 2 months after the moisture influx had attained a maximum value over all the stations. They also found out that, the early onset and late cessation dates that occurred in the 1960s and early 70s have now changed significantly.

2.2 SEASONAL CHARACTERISTICS OF RAINFALL OVER WEST AFRICA

Agriculture in Ghana is highly dependent on the seasonal characteristics of rainfall, in terms of the onset, length and retreat of rainfall season (Janicot et al., 2011). A dry spell occurring during a critical stage of crop development can induce a bad yield even if the total season rainfall amount is good (Sultan and Janicot, 2003).

The rainfall over West Africa is mostly linked to the abrupt shift of the Inter Tropical Convergence Zone (ITCZ) from a quasi- stationary location at 4N (in mid October) with respect to the apparent movement of the sun (which should be at the equator by then), to another quasi- stationary location as far as about 20N in mid March to late June. As the ITCZ migrates between its north and south positions over the course of the year, the regions between the northern and southernmost positions of the ITCZ experience a shift between the two opposing prevailing wind directions (ie. the dry north easterly wind and the wet south westerly wind). This pattern is referred to as the West African Monsoon. Nevertheless, it must be noted that there is a lag between when the ITCZ shifts either ways and the suns position (Sultan et al., 2003).

The onset of the rainy season ensures enough moisture in the soil at the time of the planting and not followed by prolonged dry spells or harmattan that could prevent the survival of seedlings after sowing. There is no unique definition for the date of the onset of the rainy season but it can be determined from either traditional or scientific techniques depending on the local meteorological conditions (Ati et al., 2002). The movement of the ITCZ up north not only heralds the onset of the rainy season, but other local topographical features also come into play.

The monsoon winds are controlled by the pressure gradient between the low pressures of the Heat Low centered along the Inter Tropical Discontinuity and the oceanic high pressures of the Saint Helena anticyclone. Harmattan winds are also controlled by the pressure gradient between the Heat Low and Azores High and less interactively with the Libyan High. Thus, the length of the rainy season depends on the interaction of these major subtropical high pressures (Azores High and the Saint Helena High pressures) over West Africa. The monsoon is fully developed, due to the highest pressures in the Southern tropical Atlantic and the Northernmost location of the Heat Low over land (Hastenrath, 1990). It has also been observed that the length of these rainfall seasons vary yearly between June and mid- August.

Rainfall is associated with the annual passage of the Inter-Tropical Convergence Zone (ITCZ), the meeting point of the dry northeastern low-pressure air mass and a moist southwestern high-pressure air mass. Thus, the onset of the rainy season is usually marked by the northeastern movement of the ITCZ and the rain-bearing winds that accompany it. Its southwestward movement with its accompanying harmattan winds, mark the beginning of the dry season. Annual rainfall and its reliability decrease from the south northwards (Camberlin and Diop, 2003).

The northern part of the Guinea Savannah zone has a unimodal rainfall distribution where the rains increase in frequency and amount, starting in May and peaking in August. In the southern part of West Africa, the rainfall pattern is bimodal, the first peak occurs in March to July, with the second in September, and August remaining relatively dry. Much of the sub humid zone is transitional between unimodal and bimodal rainfall distribution (Sultan and Janicot, 2000);(Le Barbe et al., 2002). The rains normally reach the southern boundary of the sub humid zone in early March, and the northern boundary 2 months later. In the northern zone, the rainy season normally ends in early October and at the southern boundary 6 weeks later. The expected duration of the wet season in the sub humid zone ranges from 5 months in the north to more than 8 months in the south. Nevertheless the season (April to October) is invariably punctuated by dry spells, the length of which varies from a few days to a few weeks.

The transitional stage of the rainfall season is marked by minimal amount of rainfall along the Guinea Coast region(between 6N and 8N in particular over Ghana along 5N), characterizing a climatological feature of the rainfall area. This condition is normally associated with the Little Dry Season (Le Barbe et al., 2002).

In addition, local topographical features which induce the onset, cessation and length of the rainfall season include orographic effect, foehn winds and nature of the coast line.

2.3 CLIMATE VARIABILITY OVER GHANA

The Inter governmental Panel on Climate Change (IPCC) predicts that in the short term, the number of extremely dry and wet years will increase during the present century due to climate change (Team, 2007).

Rainfall over the Ghanaian Climate is controlled by global climate telconnections and regional climate systems, which has already been explained in the first chapter. These global teleconnections also include those associated with El Nino Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO), and the rainfall patterns respond significantly to the different phases of the ENSO cycle forcing. Over Ghana, ENSO events tend to result in enhanced north-easterlies or reduced monsoon flow, coupled with weakened upper easterlies and this lead to dry conditions close to the surface of the Inter Tropical Convergence Zone (ITCZ) in July to September and also in January to March (Sultan and Janicot, 2000). A strengthening of the African Easterly Jet (AEJ) or the north easterly wind anomalies over the Sahara has also been proven to lead to drought conditions over Ghana in the major rainy season of July to September and January to March (Nicholson, 2001) and (Biederlack and Rivers, 2009a).

The Wet season has also been characterized by a pattern of Sea Surface Temperatures (SSTs) in which the tropical Atlantic is much warmer as compared to the dry years. In the dry years, the Tropical Easterly Jet (TEJ) is unusually weak (Nicholson and Paloa, 1993). With the Ocean basin's warm SST anomalies being the main source of heat energy and moisture, which drive the entire climate system and atmosphere of the globe.

It has been proven from studies by Biederlack and Rivers (2009b), that the changes in latent heat release over the West African monsoon region have great impact on the large scale tropical circulation. Another study by Allen and Ingram (2002) showed that upper troposphere thermal regimes are associated with rainfall anomalies like floods and droughts and confirmed that temperature is the most important parameter in a moist troposphere as it controls the geopotentials, determines the wind field/circulations, cloud development, amount of latent heat release and the entire atmospheric stability that generates spatial and temporal rainfall anomalies over the entire globe. Thus, with the issue of global warming, the onset dates and cessation for rainfall is much likely to change with regards to the mechanisms mentioned above. Droughts comes along with a fundamental change of the global SST pattern (Giannini et al., 2003); (Ati et al., 2008). It is also induced by a more direct anthropogenic impact in the form of land use changes, affecting vegetational cover, surface albedo and soil moisture (Laux et al., 2009); (De La Casa, 2009); (Nicholson et al., 2000).

2.4 CIRCULATION THAT CONTROLS RAINFALL OVER GHANA

Janicot et al. (2011) presented a paper on the large-scale overview of the summer monsoon over West Africa, where the area of study is enclosed. This provided a large and regional scale overview of the 2006 summer monsoon season, which included the consideration of the convective activity, mean atmospheric circulation and synoptic/intra-seasonal weather systems, oceanic and land surface conditions, continental hydrology, dust concentration and ozone distribution. The 2006 African summer monsoon was a near-normal rainy season except for a large-scale rainfall excess north of 15 N. This monsoon season was also characterized by a 10-day delayed onset compared to climatology. This onset delay impacted the continental hydrology, soil moisture and vegetation dynamics as well as dust emission (Nicholson and Grist, 2001).

Rainfall over Ghana has been found to be controlled by the advection of moisture from the Gulf of Guinea in the low levels of the atmosphere. With the seasonal excursion of the Sun, the monsoon develops over this part of the African continent during the northern summer, bringing the Inter- Tropical Convergence Zone (ITCZ) and the associated rainfall maxima to their northernmost location in mid- July and early part of August, and this determines the time for the rainy season in this region. There are also both vertical and horizontal motions in the atmosphere that carry water vapor across the water bodies from the continents and especially the oceans to produce significant precipitation over the area of study. This water content of the atmosphere varies in response to the loss of water as precipitation and the gain from evaporation along a streamline (Kunstmann and Jung, 2005).

Giorgi et al. (2012) described the main tropical circulation features associated with the West African monsoon that affects Ghana, as being the upper-level Tropical Easterly Jet (TEJ), the mid-level African Easterly Jet (AEJ), and low-level equatorial westerlies which gives the southwest monsoon flow. In wet years, these westerlies become a bona fide jet stream that has a core near 850 mb and is independent of the low-level monsoon flow. The AEJ and monsoon westerlies are stronger over the western portion of the region, while the TEJ is stronger over the eastern portion of the region. Superimposed upon these zonal flows are two meridional overturning circulations: a deep circulation associated with low-level contrasts in deep moist convection and a shallow circulation associated with contrasts in dry convection. Both consist of southerly flow at low levels and northerly flow at higher levels. The shallow cell is associated with the Saharan heat low and transports dry air towards the rainbelt at mid-levels of the atmosphere. The major role of the West African monsoon system is transporting moisture into West Africa from the Atlantic. This transport takes place in periodic northward excursions of moisture flux that have a 3 to 5 day time scale (Nicholson and Grist, 2001).

2.5 REGIONAL CLIMATE MODELLING IN SEASONAL RAINFALL PREDICTION

Regional Climate Modeling (RCMs) has become an active area of research for the past decades. It has the capacity of providing a high resolution climate information which placed it advantagious over the General Circulation Models (GCMs). The added resolution allows for a better representation of fine-scale forcing and land surface heterogeneity like variations in vegetation, complex topography and coastlines, which are important parameters of the physical response in local and regional climate change signals (Giorgi et al., 2012). RCMs are better able to assess the major processes associated with the interactions between the atmosphere, land and ocean, as well as between the dynamics and convection. They have also contributed to the improvement and understanding our climate processes and in the ability of predicting rainfall variability (Giorgi et al., 2012). Performance of RCMs can also be affected by the choice of the domain size and location of lateral boundaries (Browne and Sylla, 2012).

One of the most important applications of regional models has been in the study of land surface processes where there has been uniform consensus that interactive land surface schemes improve the performance of climate models. They improve the simulation of hydrological processes, circulation features, and enhance predictive capacity. The net result is a confirmation that land-atmosphere interaction is an inherent feature of the mean climatology of the region. Some of the most promising working on land surface processes is the studies linking them to convection. In the West African region, the surface fluxes of heat and moisture are strongly impacted by the occurrence of convective rainfall, but the so-produced surface anomalies also influence the development of convective rainfall. The relevant characteristic is not the overall state of the land surface, but the spatial heterogeneity of the characteristics of moisture and temperature that play a role (Browne and Sylla, 2012).

Another application of regional models has been in the use of atmosphere and ocean interaction, where there have been cases in which the fine scale feedbacks associated with air-sea interactions have been substantially influenced in the spatial and temporal structure of regional climates. For instance, in a study where the Mediterranean Sea is being modeled by, an atmosphere-ocean regional climate model (AORCM) was developed for the Mediterranean basin, called the PROTHEUS system, composed by the regional climate model RegCM3 as the atmospheric component and by a regional configuration of the MITgcm model as the oceanic component. The model has been applied to an area encompassing the Mediterranean Sea and compared to a stand-alone version of its atmospheric component. An assessment of the model performances is done by using available observational datasets, and so far, results has shown that there has been strange sea level behaviour observed between 1993 and 1998 in the Eastern Mediterranean. Researchers attribute this to a probable cooncomitant in the Eastern Mediterranean Transient (Giorgi et al., 2012).

Regional Climate Modeling (RCM) has provided a better way of capturing the variation in climate over short distances, especially with precipitation and wind (Sylla et al, 2009). It can be run at a higher horizontal resolution required to capture complex terrain and land-use cover (Giorgi et al., 2012). Thus, these models are important tools that enables and provides climate scientists with better and large-scale weather information of high resolution (15 km or 20 km), to study processes and mechanisms leading to the West African rainfall variability. The RegCM has proved over the years to be suitable for studies in the tropics (Browne and Sylla, 2012), especially where the domain is carefully chosen to include the main circulation features that control the climate of the area.

CHAPTER 3

DATA AND METHODOLOGY

3.1 BACKGROUND

This chapter begins with the description of the study area followed by the model and data (data collection and source, and the type of regional model) used. It also describes the methods employed to analyze the data collected.

3.2 STUDY AREA

The study area is Ghana and is divided into four main agro- ecological zones as used by the Ghana Meteorological Agency (Owusu and Waylen, 2009). These zones are the Forest Zone (Abetifi, Akim Oda, Axim, Ho, Koforidua, Kumasi and Takoradi), the Coastal Zone (Accra, Ada, Akatsi, Saltpond, and Tema), the Transition Zone (Kete Krachie, Sunyani and Wenchi) and the Northern Zone (Bole, Navrongo, Tamale, Wa, and Yendi). The Forest Zone covers the tropical forest and the southwestern coast of the country. The Coastal Zone covers the dry coastal strip of southeastern Ghana, where mean rainfall between 740mm and 890mm support very little agriculture. The Transition Zone also covers the middle part of Ghana. The Northern Zone covers the northern part of the country, which experiences similar rainfall totals as that of other zones, but has a single wet season. The agriculture potential in this zone is diminished by high rainfall variability and poor soils (Owusu and Waylen, 2009).

In terms of agriculture, the Forest and Transition zones are the most productive zones of the country in terms of food and cash crop production. They are extremely dependent on much traditional rain-fed form of farming practices (Mounier et al., 2008). The Coastal Zone which starts from the coast of Cape Three Points in Ghana to Benin (Dahomey Gap) is characterized by low rainfall. The low rainfall is attributed to a complex series of coastal (oceanic) and atmospheric interactions (Odekunle, 2004b). The Northern Zone has a single wet season and the agricultural potential in this area is reduced by high rainfall variability and poor soils (Browne and Sylla, 2012). Figure 3.1 shows a map of the synoptic stations and the agro-ecological zones in Ghana. The GMet observational data was also obtained from the synoptic stations shown in Figure 3.1.

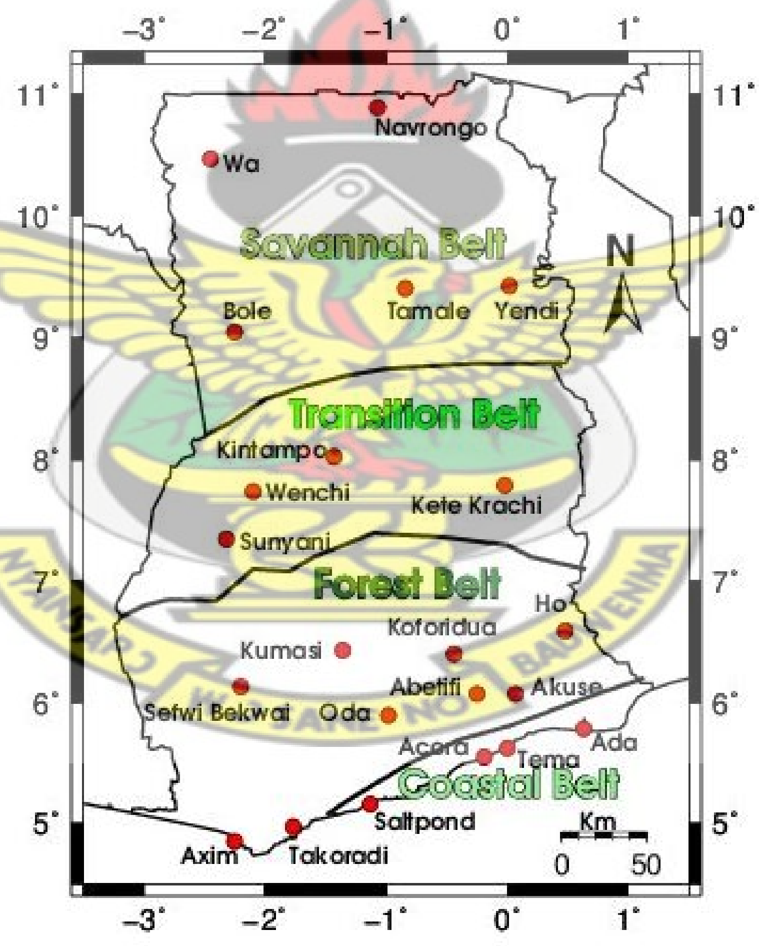

Figure 3.1: Synoptic Stations of Ghana;Courtesy (Manzanas et al., 2014)

3.3 METHODOLOGY

Daily rainfall data from twenty (20) hydro meteorological stations over Ghana as shown in Figure 3.1 from 1998 to 2010. The data was collected from both the Ghana Meteorological Agency (GMet) and the Earth Science Department of the Abdus Salaam International Centre for Theoretical Physics (ITCP), the administrators of the RegCM4 model.

The data was then subjected to statistical analysis through the application of Instat programming tool. The simulated precipitation data from the regional model was also run by installing the RegCM4 on a laptop and downscaling the RegCM4 to the respective 20 synoptic stations using ferret. The product was then plotted and analyzed using the same Instat programming tool. The analyzed and downscaled product was then validated against the observational rainfall datasets from GMet. The regional model was integrated over Ghana for the thirteen year period at a spatial resolution of 15 km with 18 vertical levels. The domain exhibited some localized features around Ghana. The equation used by the Instat programming tool to determine the onset date is

$$OD = D(20 - F)/R$$

Where OD is the onset date, D is the number of days in the first month with effective rain (MER). MER is the first month in which the accumulated rainfall totals equal or exceeds 20 mm. F (mm) is the accumulated rainfall total of previous months. R is the total rainfall in the MER.

$$CD = b + 275$$

This equation was used by Instat to determine the cessation dates for the rainfall data. CD is the cessation date and is defined from the equation as any day from 1st October after which there are more than 7 consecutive days of rainfall less than 50% of the soil water capacity. b denotes the number of days when the maximum pre- season moisture build- ups occur.

The Fuzzy logic approach defines the onset date for the rains as follows;

- A total of at least 20 mm of rainfall are observed within a 5- day period
- The starting day and at least two other days in this 5 day period should be wet (at least 1 mm of rainfall recorded).
- No dry period of seven or more consecutive days occurring in the following 30 days.

The regional model is integrated over the West African domain for the thirteen year period at a spatial resolution of 15 km with 18 vertical levels. The domain exhibits some localized features around Ghana. Before the regional model′s ability to capture the onset, length and cessation of the rainy season can be evaluated, the degree to which the model captures the large scale climatological processes of the West African Monsoon over the West Africa must be determined.

The fuzzy- approach logic would be used in determining the following;

- The Onset/start of the rainy season
- The cessation/end of rain
- The length of the rainy season

- dry spells during the season and their consistencies.

The Instat programming tool calls dates of the onset of the rains from the data collected from the synoptic stations based on the fuzzy logic approach. Note: A rain day implies a day with not less than 1 mm rainfall. The definition used in this project is adopted from (Dodd and Jolliffe, 2001).

According to (Omotosho et al., 2000), the first 20 to 28 days are the most critical for seed germination and crop establishment. It is thus important to have one or two initial heavy rainfall (20 mm) to moisten and soften the soil sufficiently for seed germination and also to ensure crop survival in the following twenty days.

The end of rain will be determined by defining it as the last day before a long dry spell, when the water balance drops to zero. For the model (RegCM4), a command was written to first set the data within the preferred longitude and latitude within the West Africa area under study with a shell script. After that, a programming tool known as Ferret was used to view the topography or map of the study area, and with the help of this same Ferret, a command was written to call dates from the specific synoptic stations under study, so as to help with the comparism being made with the ground based measurements from the GMet.

The dates called from January 1998 to December 2010 was analysed through the same process above with the Instat programming tool to help with easy comparison.

3.4 MODEL DESCRIPTION AND EXPERIMENT

The Regional Climate Model system (RegCM) was originally developed at the National Center for Atmospheric Research (NCAR), but is maintained in the Earth System Physics (ESP) section of the Abdus Salam International Centre for Theoretical Physics (ICTP). The first version of the model, RegCM1, was developed in 1989 but has since undergone major updates in

1993, where the RegCM2 was developed, with the RegCM2.5 also being developed in 1999, then RegCM3 in 2006 and most recently the model has undergone a substantial evolution both in terms of software code and physics representations, and this has led to the development of a fourth version of the model, RegCM4, which was released by the ICTP in June 2010 as a prototype version (RegCM4.0) and in April 2011 as a first complete version (RegCM4.1).

The latest version of the model, RegCM4, is now fully supported by the ESP, while previous versions are no longer available (Giorgi et al., 2012). The newer version includes major upgrades in the structure of the code and its pre- and post- processors, along with the inclusion of some new physics parameterizations. The model is flexible, portable and easy to use, which can also be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit), and for a wide range of studies, from process studies to paleoclimate and future climate simulation.

The Earth System Physics (ESP) also supports the Regional Climate Research Network, or RegCNET. The main objective of RegCNET is to expand and strengthen the network of model users and to develop collaborative research projects across the network to improve the understanding of climate change at the regional scale. The RegCNET also provides a forum for current and future model users to discuss relevant issues, exchange research experiences and formulate needs and priorities for further model development and dissemination.

Unlike the previous versions RegCM4 includes new land surface, planetary boundary layer, and air−sea flux schemes, a mixed convection and tropical band configuration, modifications to the pre-existing radiative transfer and boundary layer schemes, and a full upgrade of the model code towards improved flexibility, portability, and user friendliness. The model can be interactively coupled to a 1D lake model, a simplified aerosol scheme (including organic carbon, black carbon, SO4, dust, and sea spray), and a gas phase chemistry module (CBM-Z).

The model code of the RegCM 4.3 is in Fortran 90 ANSI standard with some language extensions of Fortran 2003 implemented in all the supported compilers. The development is done on Linux boxes, and the model is known to run on Oracle Solaris platforms, IBM AIX platforms, MacOS platforms (Giorgi et al., 2012).

RegCM4 is a hydrostatic, compressible, sigma-p vertical coordinate model which runs on an Arakawa B-grid where wind and thermodynamical variables are horizontally staggered. A time-splitting explicit integration scheme is used in which the two fastest gravity modes are first separated from the model solution and then integrated with smaller time steps. This allows the use of a longer time step for the rest of the model (Biederlack and Rivers, 2009b).

The latest version of the model, RegCM4, is now fully supported by the ESP, while previous versions are no longer available (Giorgi et al., 2012). The newer version includes major upgrades in the structure of the code and its pre- and post- processors, along with the inclusion of some new physics parameterizations. The model is flexible, portable and easy to use, which can also be applied to any region of the World, with grid spacing of up to about 10 km (hydrostatic limit), and for a wide range of studies, from process studies to paleoclimate and future climate simulation.

RegCM4 is a primitive equation, sigma vertical coordinate model based on the hydrostatic dynamical core of the NCAR/PSUs mesoscale meteorological model, MM5. RegCM4 is also a hydrostatic, compressible, sigma-p vertical coordinate model, which runs on an Arakawa B-grid where wind and thermodynamical variables are horizontally staggered. A time-splitting explicit integration scheme is used in which the two fastest gravity modes are first separated from the model solution and then integrated with smaller time steps. This allows the use of a longer time step for the rest of the model.

A fundamental development in RegCM4 compared to its predecessors concerns its computational aspects. Essentially, the RegCM3 code has been largely reviewed to make it more flexible, user friendly, and portable on different computing architectures. The code was made compliant to the ANSI F90 standard language, portability was enhanced with respect to compilers and computing platforms, and a single makefile for the entire system, from pre-processing to model code and postprocessing, was implemented with a configure script that greatly simplifies the use of the model. In addition, modularity and multi-tasking for the code has substantially been enhanced. With these implementations, the code can effectively run, depending on the domain size, on a large variety of high-performance computing platforms using up to several hundred processors.

3.4.0.1 BOUNDARY FORCING

The initial and lateral boundary conditions for the RegCM4 simulation are obtained from the new ERAInterim 2.5deg to 2.5deg gridded reanalysis (Biederlack and Rivers, 2009a), which is the fourth generation ECMWF reanalysis product. The main advances in this reanalysis compared to ERA-40 are a higher horizontal resolution (0.75deg to 0.75deg but available also at 1deg to 1deg and 2.5deg to 2.5deg), four-dimensional variational analysis, a better formulation of background error constraint, a new humidity analysis, an improved model physics, variational bias correction of satellite radiance data, and an improved fast radiative transfer model. ERA-Interim uses mostly the sets of observations acquired for ERA-40 with a few exceptions: acquisition of a new altimeter wave-height that provides data of more uniform quality,use of reprocessed Meteosat data for wind and clear-sky radiance, and new ozone profile information from 1995 onwards. Several problems experienced in the ERA-40 reanalysis were eliminated or substantially improved in the ERA-Interim.

In particular, an important improved performance was seen in the humidity and hydrologic cycle over the Tropics. The quality of the analysis was also validated by additional means: fit of background forecasts to the observations, fit of surface winds to independent buoy winds, agreement with independent tropical-cyclone track data, and comparison of precipitation with independent estimates from the Global Precipitation Climatology Project (GPCP). All pointed to a systematic edge in favor of the ERA-Interim reanalysis (Camberlin and Diop, 2003). Sea surface temperature (SST) used to force RegCM4 is obtained from the National Oceanic and Atmospheric Administration (NOAA) Optimum Interpolation (OI) SST. This OISST analysis is produced weekly on a one degree grid. These analyses were based on ship and buoy SST data supplemented with satellite SST retrievals. It is the most updated observed SST field and it resolves equatorial upwelling and fronts (Friesen and van de Giesen, 2002). This dataset is consistent with NOAAs 2DVAR adopted in ERA-Interim reanalysis. The ERA-Interim and the Reynolds SST are updated four times daily in RegCM4 using the relaxation procedure described by (Jenkins et al., 2005).

3.4.0.2 CUMULUS CONVECTION PHYSICS OF RegCM4

Currently, the RegCM4 has three options for representing cumulus convection. The first is a simplified version of the Kuo-type scheme of (Laux et al., 2008), as described. This scheme has been present since the earliest version RegCM and activates convection when the column moisture convergence exceeds a threshold value. This scheme, although still available, is used only very occasionally and generally provides poorer precipitation simulations than the other available parameterizations.

The second, and to date most used scheme, is that of (Nicholson, 2001) in the implementation of (Jenkins et al., 2005). This is a mass flux deep convection parameterization in which clouds are considered as two steady state circulations including an updraft and a penetrative downdraft. The scheme is triggered when a parcel lifted in the updraft eventually reaches the moist convection level. A single cloud model is used with entrainment and detrainment only at the cloud bottom and top. Two different closures can be adopted: an Arakawa-Schubert type closure in which all buoyant energy is immediately released at each time step and a Fritsch-Chappell type closure in which the available buoyant energy is released with a time scale typically on the order of 30 min.

A third scheme was introduced in RegCM3 (Le Barbe et al., 2002), the so called MIT scheme (Giorgi et al., 2012). In this parameterization, convection is triggered when the level of especially through the occurrence of very intense individual precipitation events. Previous version (RegCM3) and many other schemes, tend to maximize rain in the early afternoon, essentially in response to the surface heating by the solar cycle. This often leads to an earlier than observed diurnal precipitation maximum over tropical regions (Neng et al., 2002).

3.4.0.3 RESOLVED SCALE PRECIPITATION

The resolved scale precipitation scheme was not significantly changed in RegCM4 compared to RegCM3, other than in some of the parameter settings. The scheme is essentially based on the SUBEX parameterization of (Le Barbe et al., 2002) and includes a prognostic equation for cloud water. It first calculates fractional cloud cover at a given grid point based on the local relative humidity.

Then, in the cloudy fraction it uses a Kessler-type bulk formulation, in which cloud water is turned into precipitation via an auto conversion and an accretion term. Below-cloud evaporation of falling raindrops is accounted for based on the local relative humidity and an evaporation rate coefficient. Key sensitivity parameters in this scheme are the in-cloud liquid water threshold for the activation of the autoconversion term (Qth) and the rate of sub-cloud evaporation (Cevap). Greater values of Qth and Cevap lead to decreased precipitation amounts.

Traditionally, RegCM3 has shown a tendency to produce excessive precipitation, especially at high resolutions (Allen and Ingram, 2002), and optimizations of these parameters have proven effective in ameliorating this problem (Allen and Ingram, 2002)

3.4.0.4 LAND SURFACE PROCESSES

Since the earliest versions of the RegCM, land surface processes have been described via the Biosphere-Atmosphere Transfer Scheme (BATS) of (Giorgi et al., 2012). This scheme, which has been used for many years, includes a 1-layer vegetation module, a 1-layer snow module, a force-restore model for soil temperatures, a 3-layer soil scheme, and a simple surface runoff parameterization. This scheme also includes 20 surface types and 12 soil color and soil texture types.

In addition, a sub-grid land surface configuration can be used by which each model grid point is divided into a regular sub-grid, and land surface processes are calculated at each sub-grid point taking into account the local land use and topography (Browne and Sylla, 2012). This latter scheme was shown to be especially useful in improving the simulation of the surface hydrologic cycle in mountainous areas (Giorgi et al., 2012).

As a first augmentation, in RegCM4, two new land use types have been added to BATS to represent urban and suburban environments. Urban development does not only modify the surface albedo and the surface energy balance, but also creates impervious surfaces with large effects on runoff and evapotranspiration.

The second major addition to RegCM4 is the option to use the Community Land Model, version CLM3.5 (Odekunle, 2004b). Compared to BATS, CLM is a more advanced package, which is described in detail by (Odekunle, 2004a). It uses a series of biogeophysically-based parameterizations to describe the land - atmosphere exchanges of energy, momentum, water, and carbon. Within each RegCM4 grid cell, CLM3 divides the cell area into a first sub-grid hierarchy composed of land units (glacier, wetland, lake, urban, and vegetated land cover), and a second and third sub-grid hierarchy for vegetated land units, including different soil columns for the different vegetation fractions, and plant functional types (Odekunle, 2004b).

Biogeophysical processes are also calculated for each land unit, column, and PFT (Plant Functional Types) separately, and then averaged for return to the atmospheric model. CLM3 biogeophysical calculations include a coupled photosynthesis-stomatal conductance model, in-canopy radiation schemes, revised multi-layer snow parameterizations, and surface hydrology including a distributed river runoff scheme (Odekunle, 2004a).

Soil temperature and water content are also calculated with the use of a multiple layer model. Being much more complex than BATS, the use of CLM adds about 20% to the computing time necessary to run the model, depending on the fraction of land points in the domain. CLM also has an option for describing interactive vegetation. CLM was shown to substantially affect the land - atmosphere exchanges of moisture and energy and the associated surface climate feedbacks compared to BATS (Giannini et al., 2003).

3.4.0.5 TROPICAL BAND CONFIGURATION

A significant development of RegCM4 is the implementation of a tropical band configuration of the model. In this configuration, the model uses a Mercator projection centered over the equator for a band covering the entire tropical region, from 45deg S to 45deg N. The use of the Mercator projection allows the model grid to fully cover the tropical band with the end points in the longitudinal direction exactly overlapping.

This configuration requires the use of periodic boundary conditions in the longitudinal directions and the standard relaxation conditions at the northern and southern boundaries. In this way, information from the driving models is effectively provided only at these 2 boundaries. A test of this configuration, which offers many new applications, has been presented by (Lacombe et al., 2012).

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 RESULTS

The results obtained from the analysis of the thirteen years daily rainfall data from twenty synoptic statons will be presented in this chapter. The results will be discussed on the four agro-ecological zones of Ghana.

4.1.1 ONSET OF RAINFALL

4.1.1.1 ONSET OF RAINS OVER THE FOREST ZONE

Figure 4.1 shows the comparism between the mean onset dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Forest Zone of Ghana.

From analysis made for Abetifi, it was observed that out of the thirteen years considered for the study, only two years which were 2006 and 2009 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 1st March in 2001, with the maximum being recorded on the 23rd of May in 2000 respectively. The mean onset date for Abetifi from GMet was calculated to be 1st April. The minimum for the RegCM4 onset dates were observed to be on the 7th of February, in 2005 with the maximum being recorded on the 7th of May, 2000. The mean onset date for Abetifi from the model was calculated to be 3rd April.

Over Akim Oda, only two years which were 1999 and 2002 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 8th February in 2009, with the maximum being recorded on the 20th of April in 1998. The mean onset date for Akim Oda from GMet was calculated to be 15th March. The minimum for the RegCM4 onset dates were observed to be on the 27th of March, in 2005 with the maximum being recorded on the 25th of May, 1998. The mean onset date for Akim Oda from RegCM4 was calculated to be 25th April.

For Axim, only five years which were 1998, 2003, 2004, 2006 and 2007 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 26th January in 2010, with the maximum being recorded on the 1st of May in 2000. The mean onset date for Axim from GMet was calculated to be 28th March. The minimum for the RegCM4 onset dates were observed to be on the 5th of March, in 1999 with the maximum being recorded on the 23rd of April, 1998. The mean onset date for Axim from RegCM4 was calculated to be 26th March.

Over Ho, it was observed that, only two years which were 1999 and 2001 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 5th March in 2010, with the maximum being recorded on the 22nd of April in 1998. The mean onset date for Ho from GMet was calculated to be 11th March. The minimum for the RegCM4 onset dates were observed to be on the 8th of February, in 2005 with the maximum being recorded on the 15th of April, 2000. The mean onset date for Ho from RegCM4 was calculated to be 17th March.

For Koforidua, only five years which were 1998, 2003, 2004, 2006 and 2007 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 3rd March in 2006, with the maximum being recorded on the 7th of May in 2000. The mean onset date for Koforidua from GMet was calculated to be 4th April. The minimum for the RegCM4 onset dates were observed to be on the 7th of February, in 2005 with the maximum being recorded on the 7th of May, 2010. The mean onset date for Koforidua from RegCM4 was calculated to be 3rd April.

From Kumasi, only five years which were 1998, 2000, 2003, 2004 and 2009 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 14th February in both 2006 and 2009, with the maximum being recorded on the 23rd of April in 2005. The mean onset date for Kumasi from GMet was calculated to be 21st March. The minimum for the RegCM4 onset dates were observed to be on the 11th of February, in 2009 with the maximum being recorded on the 27th of April, 1998. The mean onset date for Kumasi from RegCM4 was calculated to be 24th March.

Takoradi had only two years which were 1998, 2000 and 2003 having the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 27th January in 2007, with the maximum being recorded on the 13th of May in both 2001 and 2004. The mean onset date for Takoradi from GMet was calculated to be 14th April. The minimum for the RegCM4 onset dates were observed to be on the 6th of March, in 1999 with the maximum being recorded on the 22nd of April, 1998. The mean onset date for Takoradi from RegCM4 was calculated to be 27th March.

In the Forest zone the RegCM4 performed very well by giving a similar mean rainfall onset date as compared with that from the GMet.

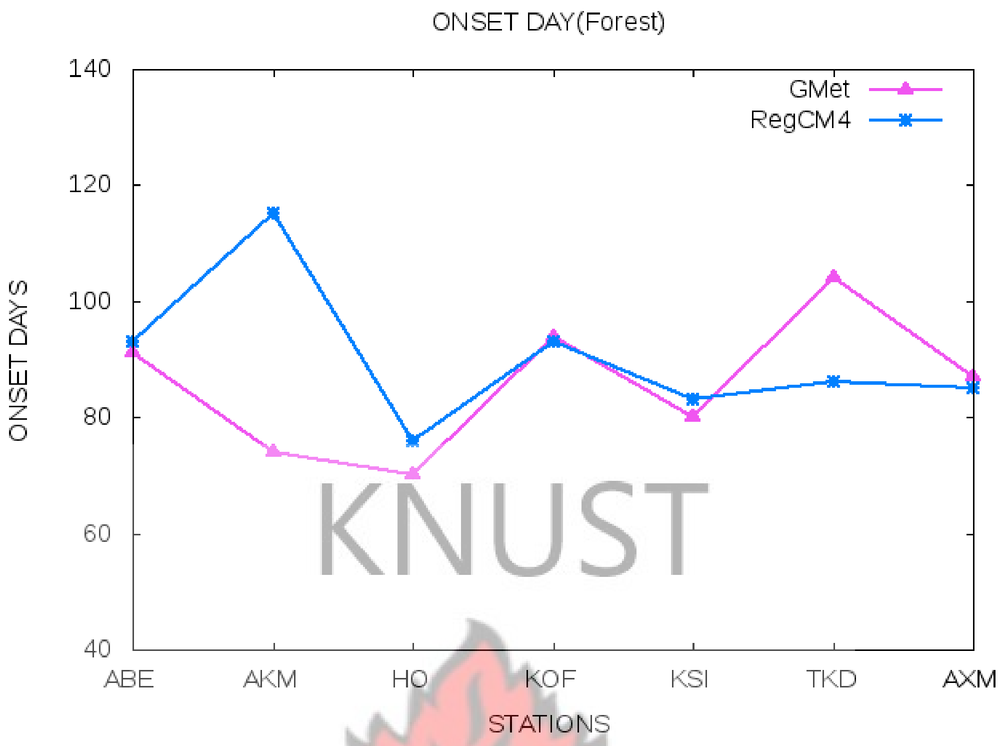

Figure 4.1: Onset Dates for the Forest Zone of Ghana

Below are also figures of each station and how they best compare with the onset dates from the two respective data sources.

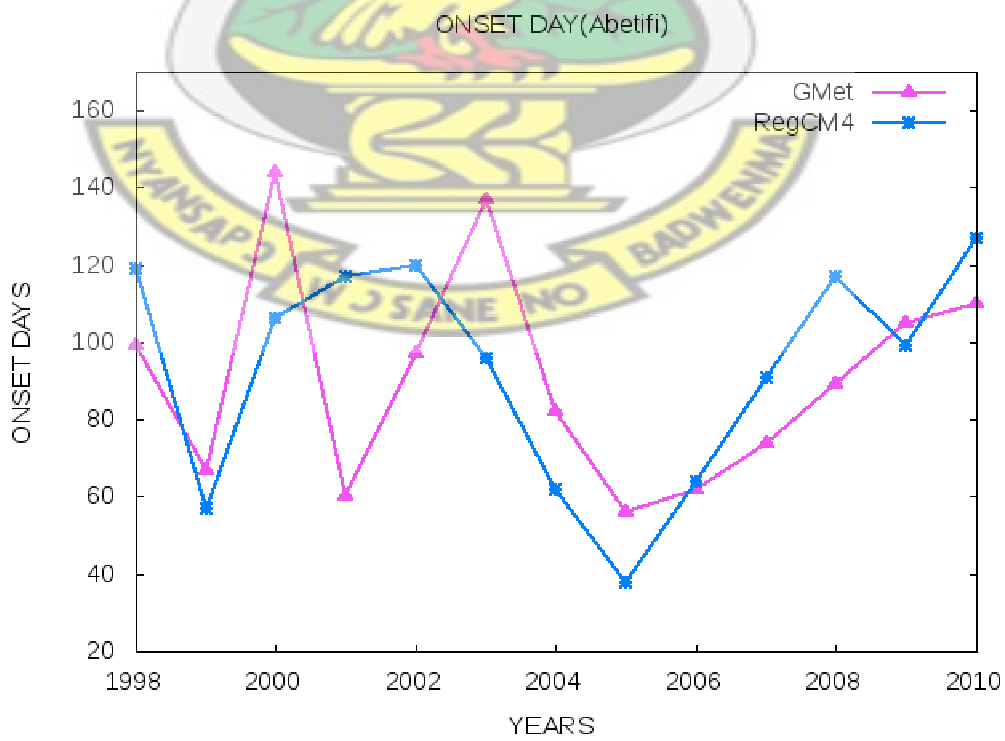

Figure 4.2: Onset Dates for Abetifi

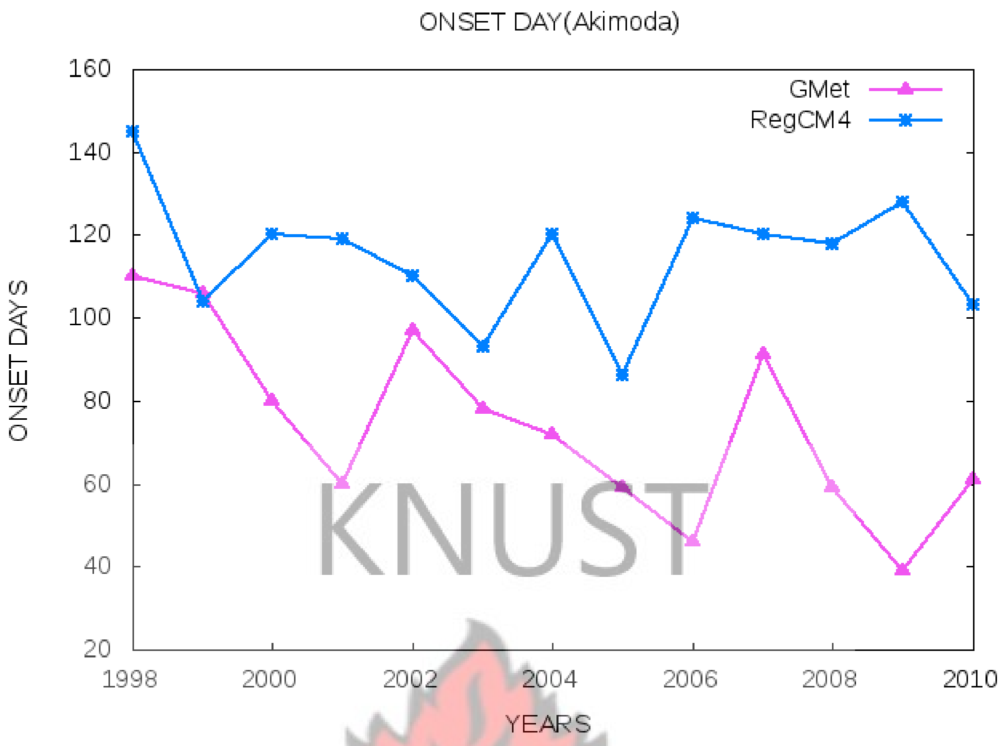

Figure 4.3: Onset Dates for Akim Oda

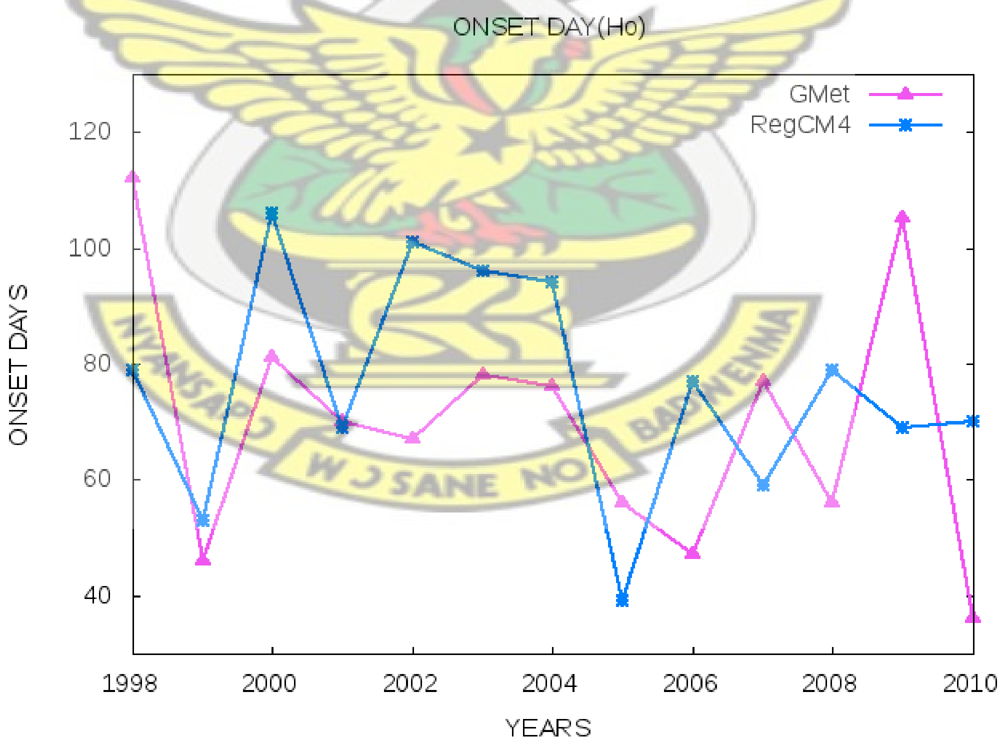

Figure 4.4: Onset Dates for Ho

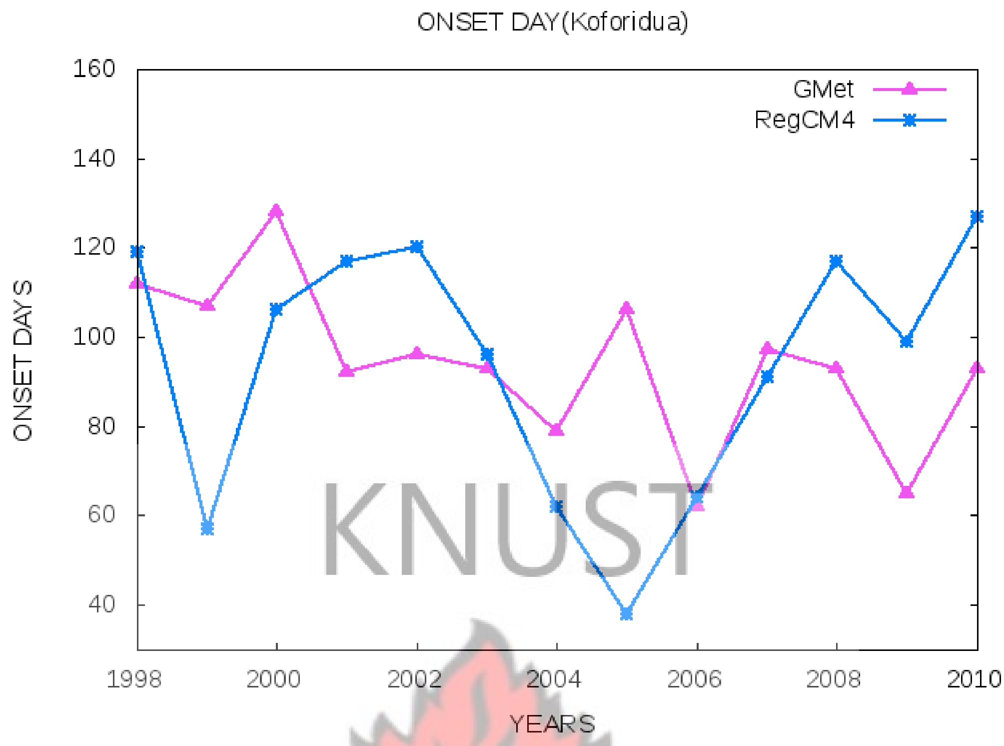

Figure 4.5: Onset Dates for Koforidua

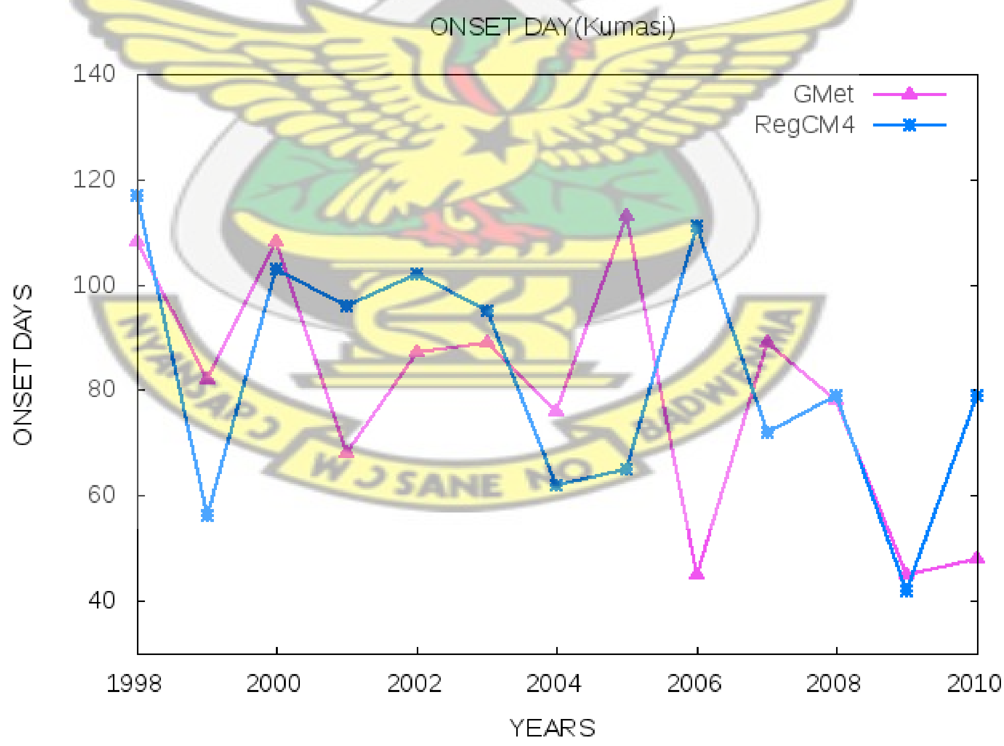

Figure 4.6: Onset Dates for Kumasi

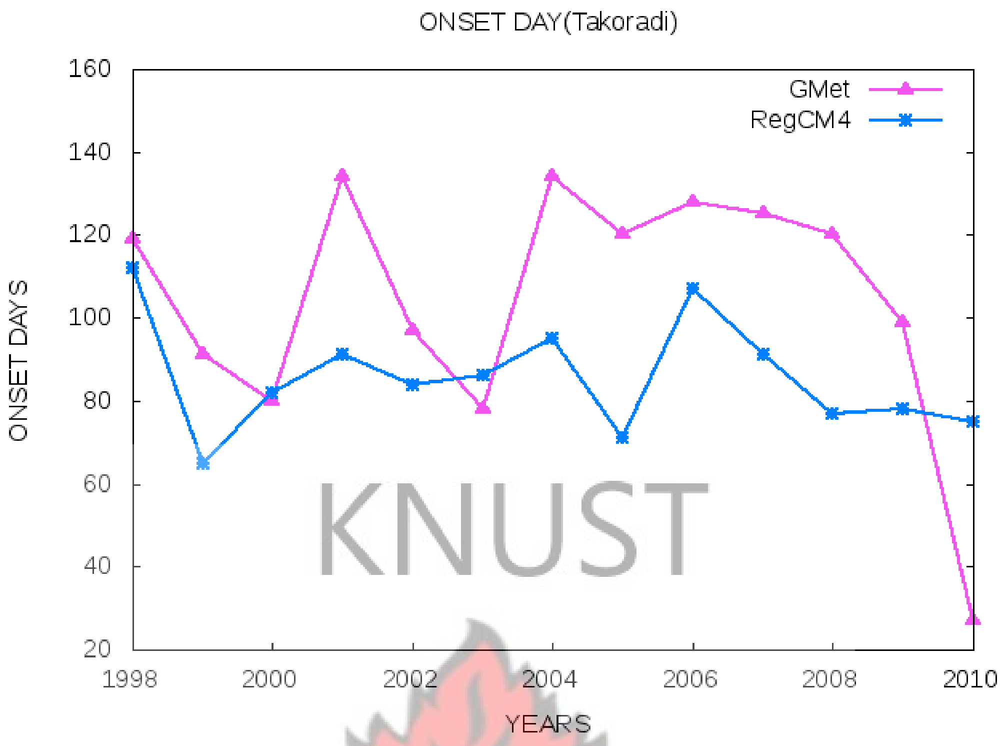

Figure 4.7: Onset Dates for Takoradi

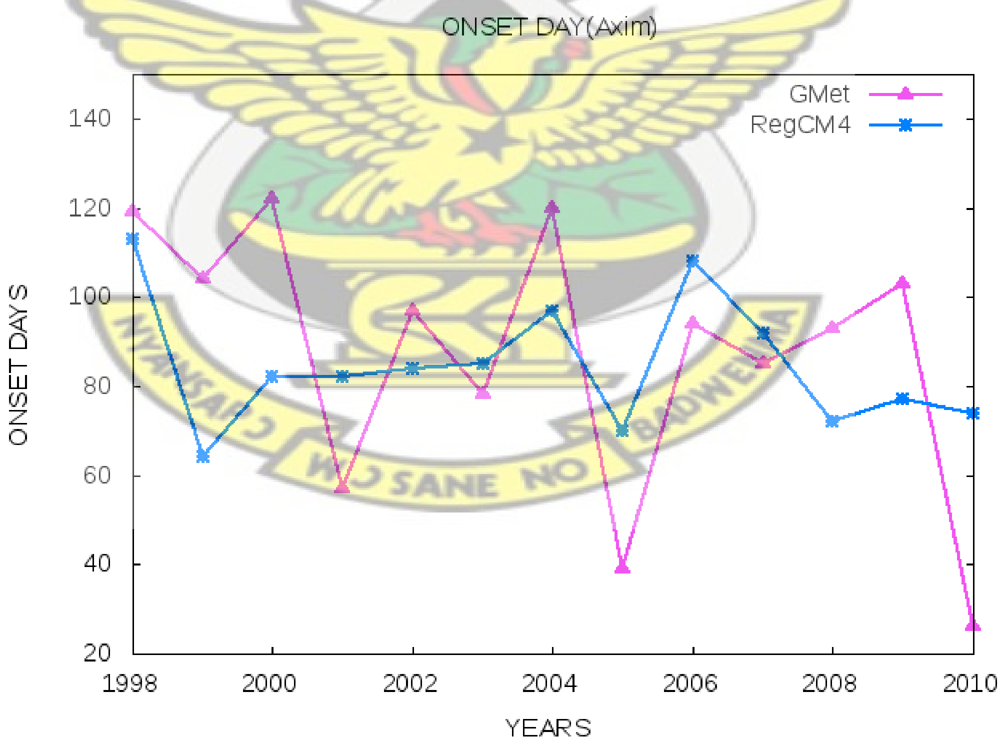

Figure 4.8: Onset Dates for Axim

4.1.1.2 ONSET OF RAINS OVER THE COASTAL ZONE

Figure 4.9 shows the comparism between the Onset dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Coastal Zone of Ghana.

Analysis made over Accra shows that out of the thirteen years considered for the study, only four years which were 1998, 2000, 2001 and 2006 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 31st March in 2008, with the maximum being recorded on the 2nd of June in 2008. The mean onset date for Accra from GMet was calculated to be 3rd May. The minimum for the RegCM4 onset dates were observed to be on the 27th of March, in 2005 with the maximum being recorded on the 8th of April, 2009. The mean onset date for Abetifi from RegCM4 was calculated to be 22nd April.

Also in the analysis made for Ada, only two years which were 1999 and 2000 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 3rd March in 2000, with the maximum being recorded on the 21st of May in 2008. The mean onset date for Ada from GMet was calculated to be 26th April. The minimum for the RegCM4 onset dates were observed to be on the 27th of March, in 2005 with the maximum being recorded on the 4th of May, 2006. The mean onset date for Ada from RegCM4 was calculated to be 20th April.

From Akatsi, it was observed that out of the thirteen years considered for the study, only two years which were 2000 and 2006 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 19th March in 2004, with the maximum being recorded on the 2nd of June in 2010. The mean onset date for Akatsi from GMet was calculated to be 19th April. The minimum for the RegCM4 onset dates were observed to be on the 8th of February, in 2005 with the maximum being recorded on the 15th of April, 2000. The mean onset date for Akatsi from RegCM4 was calculated to be 17th March.

For Saltpond, it can also be deduced that out of the thirteen years considered for the study, only two years which were 1998 and 2003 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 9th March in 2003, with the maximum being recorded on the 26th of May in 2004. The mean onset date for Saltpond from GMet was calculated to be 22nd April. The minimum for the RegCM4 onset dates were observed to be on the 31st of January, in 1999 with the maximum being recorded on the 12th of April, 1998. The mean onset date for Saltpond from RegCM4 was calculated to be 2nd March.

From Tema, it can be shown that out of the thirteen years considered for the study, only five years which were 2000, 2001, 2002, 2006 and 2008 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 9th March in 2003, with the maximum being recorded on 27th of May in 2010. The mean onset date for Tema from GMet was calculated to be 30th April. The minimum for the RegCM4 onset dates were observed to be on the 27th of March, in 2005 with the maximum being recorded on the 8th of May, 2009. The mean onset date for Tema from RegCM4 was calculated to be 22nd April.

For the Coastal zone the RegCM4 performed very well for Ada and Tema, by giving similar mean rainfall onset dates as compared that from GMet.

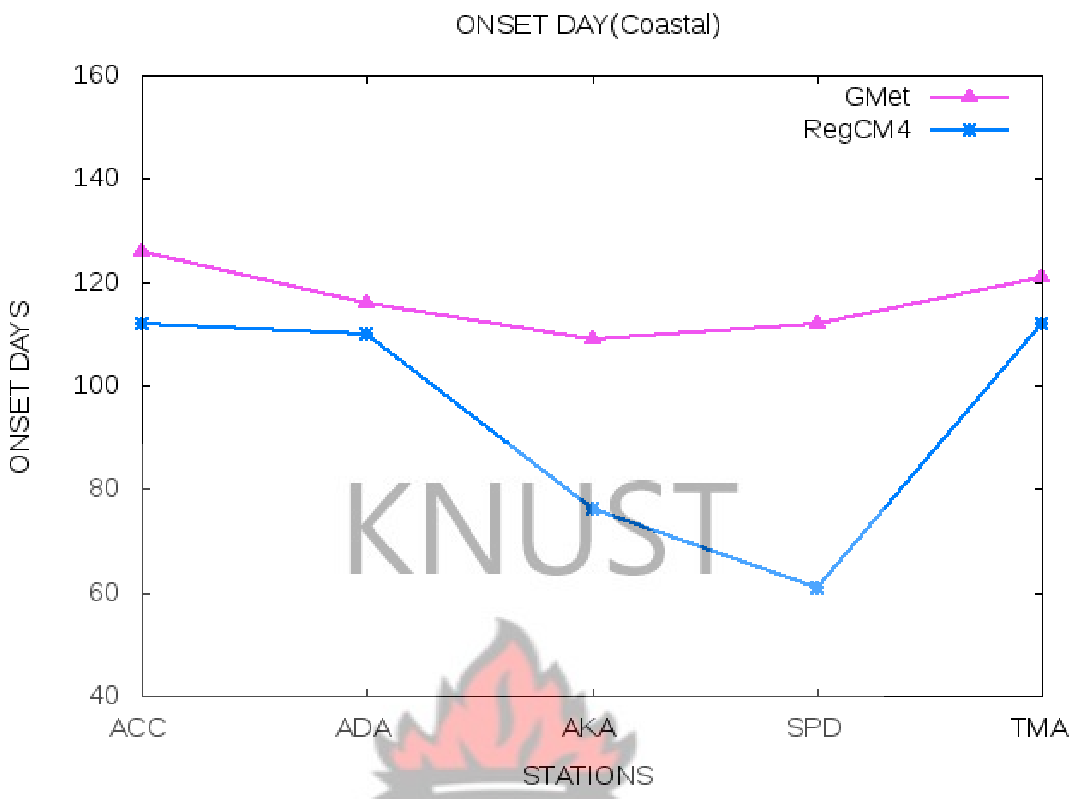

Figure 4.9: Onset Dates for the Coastal Zone of Ghana

Below are also figures of each station and how they best compare with the onset dates from the two respective data sources.

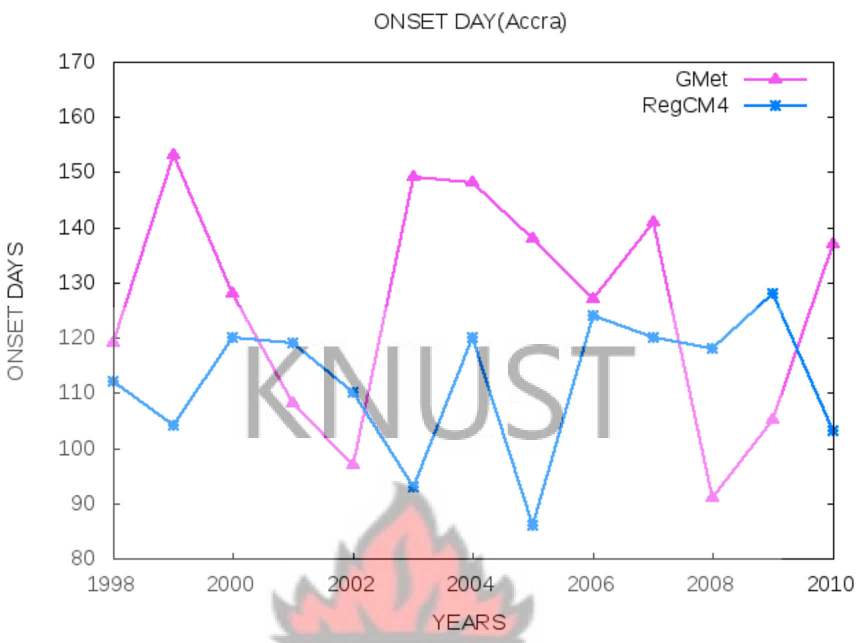

Figure 4.10: Onset Dates for Accra

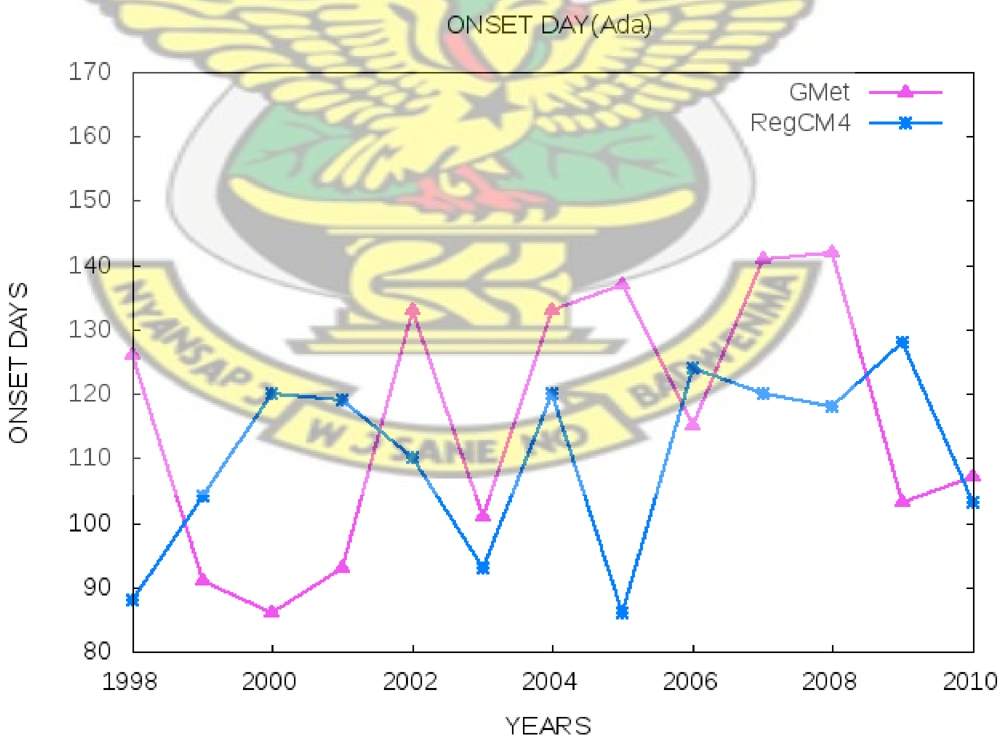

Figure 4.11: Onset Dates for Ada

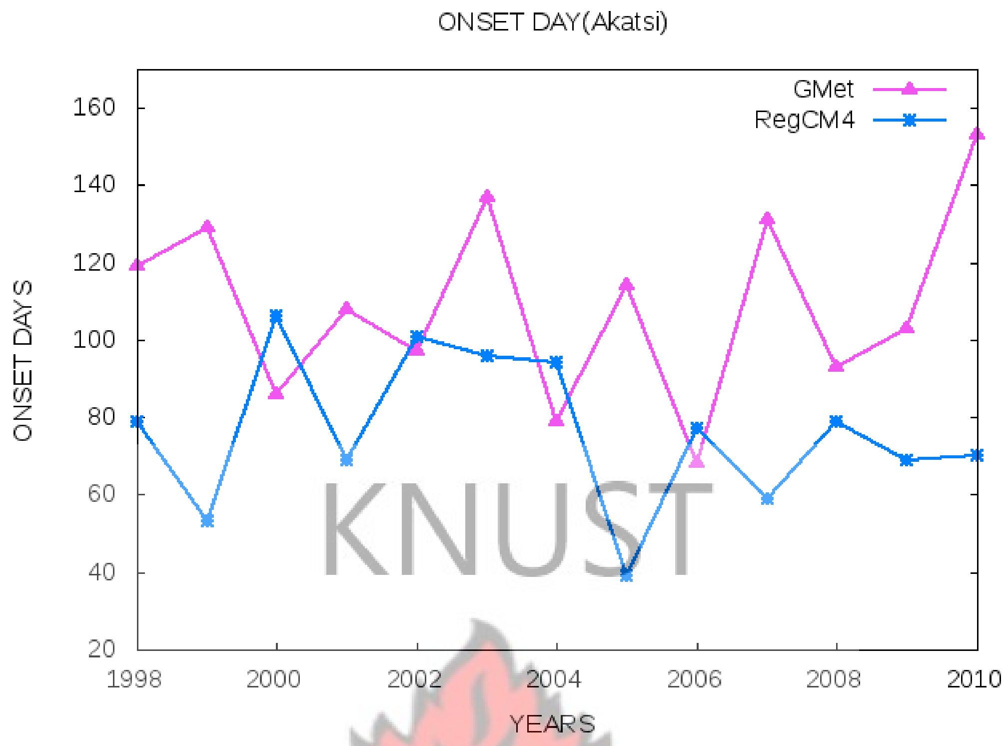

Figure 4.12: Onset Dates for Akatsi

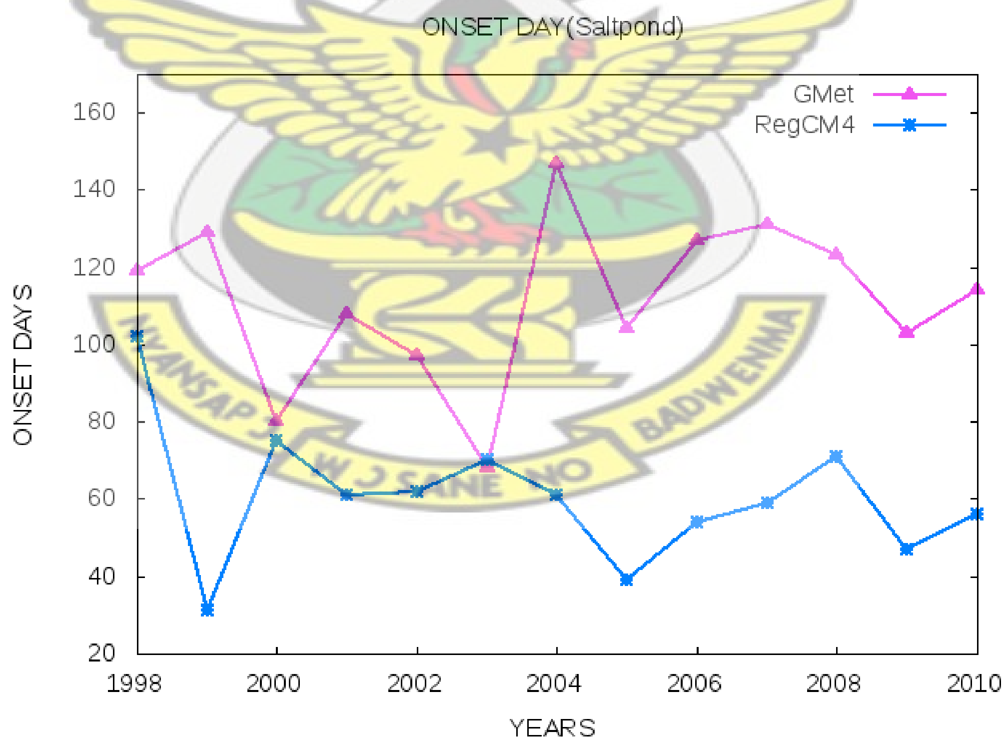

Figure 4.13: Onset Dates for Saltpond

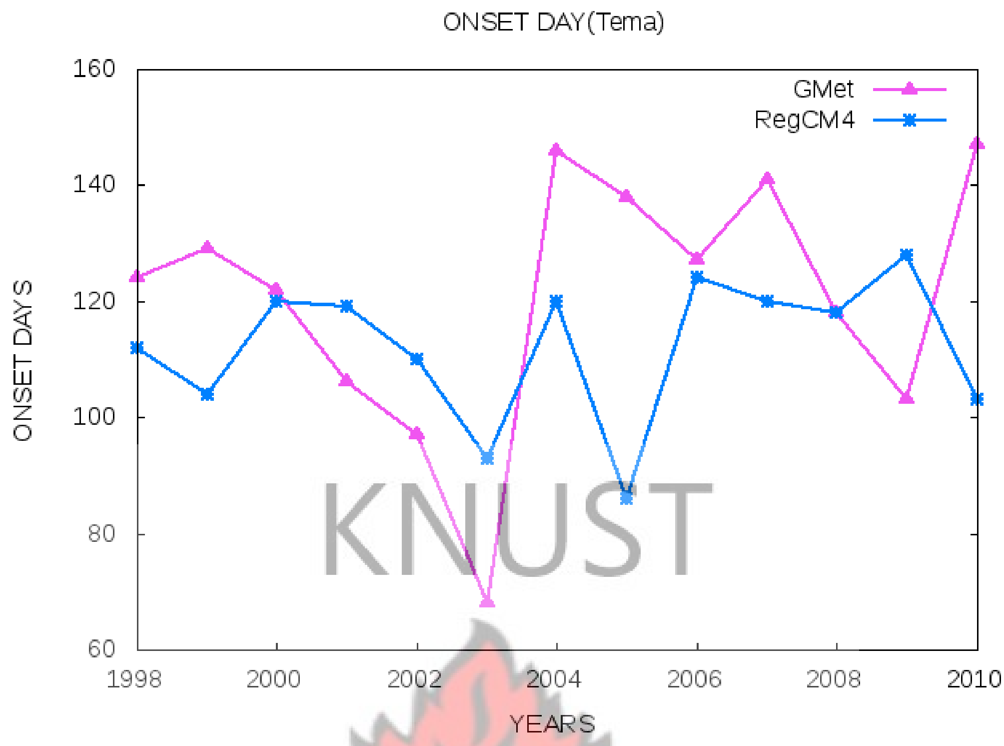

Figure 4.14: Onset Dates for Tema

4.1.1.3 ONSET OF RAINS OVER THE TRANSITION ZONE

Figure 4.15 shows the comparism between the Onset dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Transition Zone of Ghana.

From Kete Krachie, it can be shown that out of the thirteen years considered for the study, only two years which were 2001 and 2007 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 7th April in 2002, with the maximum being recorded on the 5th of June in 2009. The mean onset date for Kete Krachie from GMet was calculated to be 1st May. The minimum for the RegCM4 onset dates were observed to be on the 8th of February, in 2005 with the maximum being recorded on the 27th of May, 2009. The mean onset date for Kete Krachie from RegCM4 was calculated to be 15th April.

Also from Sunyani, it was observed that out of the thirteen years considered for the study, only one year which was 2005 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 5th March in 2006, with the maximum being recorded on the 4th of May in 2005. The mean onset date for Sunyani from GMet was calculated to be 24th March. The minimum for the RegCM4 onset dates were observed to be on the 30th of January, in 2006 with the maximum being recorded on the 4th of June, 1998. The mean onset date for Sunyani from RegCM4 was calculated to be 25th April.

For Wenchi, it can be shown that out of the thirteen years considered for the study, only two years which were 2001 and 2008 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 14th February in 2010, with the maximum being recorded on 9th of May in 1999. The mean onset date for Wenchi from GMet was calculated to be 31st March. The minimum for the RegCM4 onset dates were observed to be on the 30th of January, in 2006 with the maximum being recorded on the 18th of May, 2003. The mean onset date for Wenchi from RegCM4 was calculated to be 29th March.

The RegCM4 performed very well for the Transition zone by giving a similar mean rainfall onset date as compared with that from the GMet.

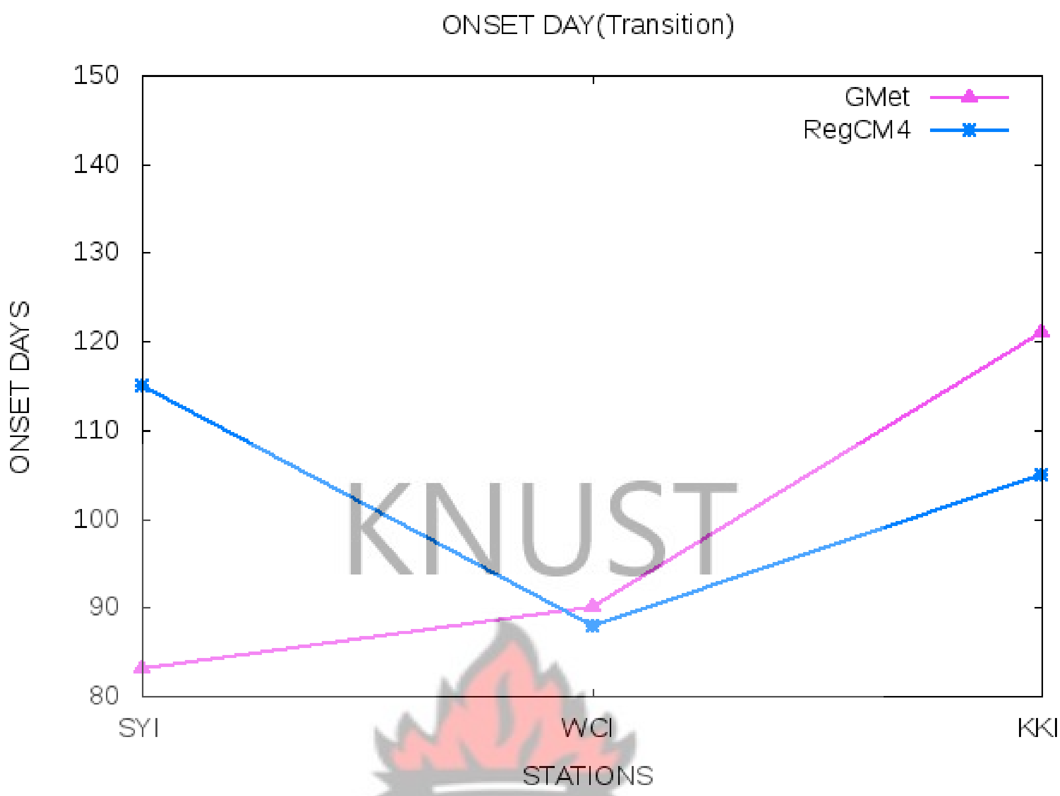

Figure 4.15: Onset Dates for the Transition Zone of Ghana

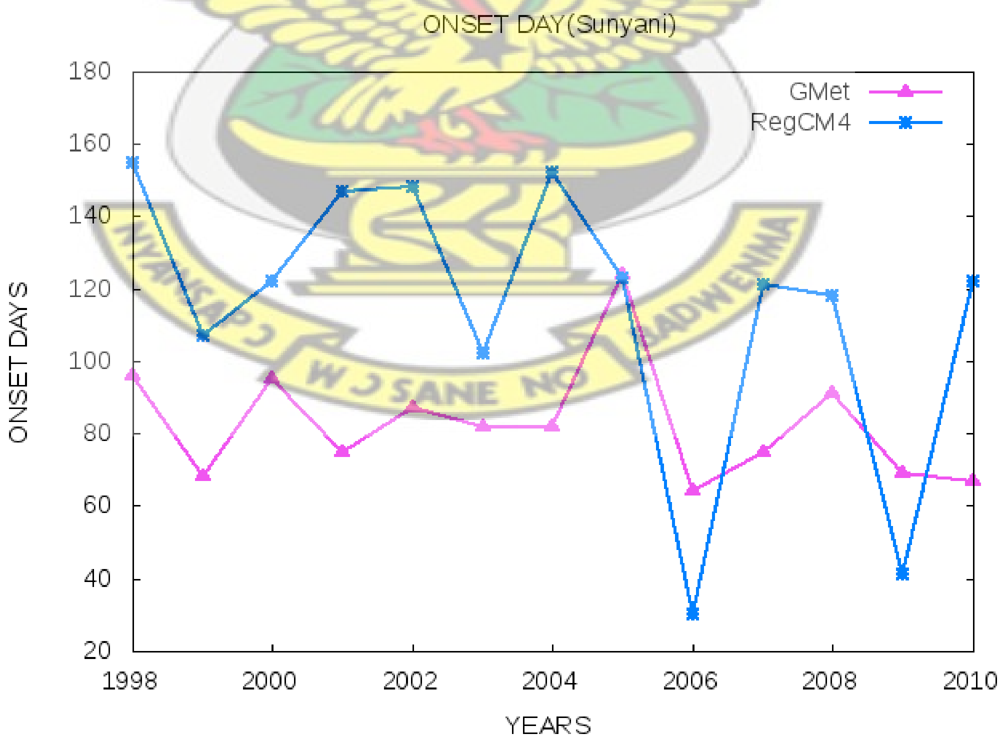

Figure 4.16: Onset Dates for Sunyani

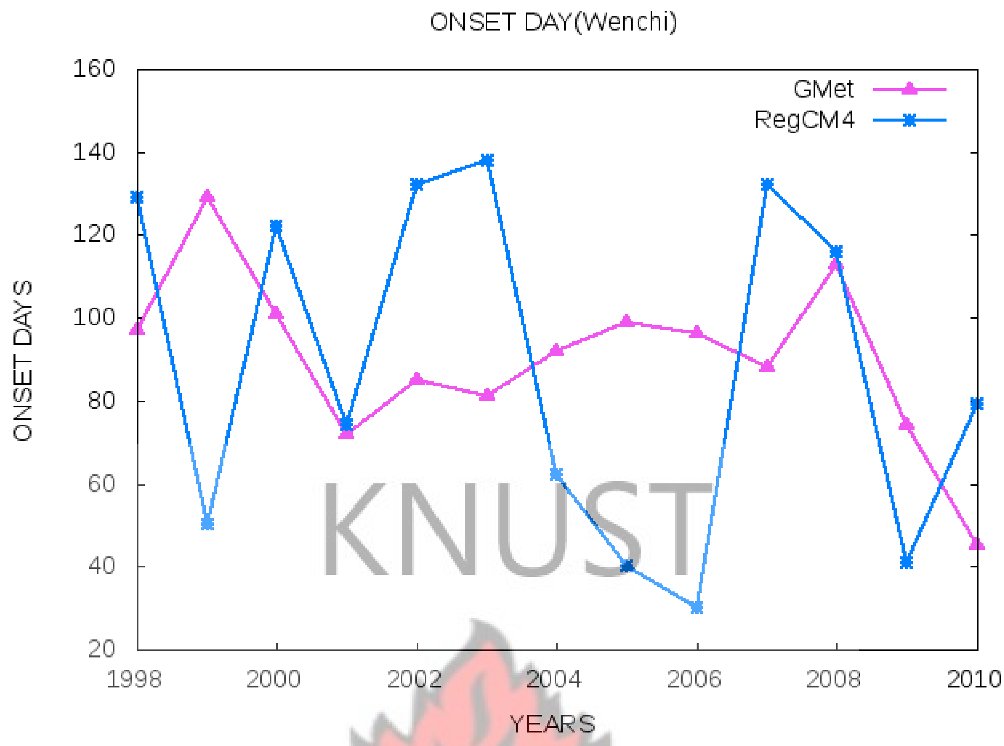

Figure 4.17: Onset Dates for Wenchi

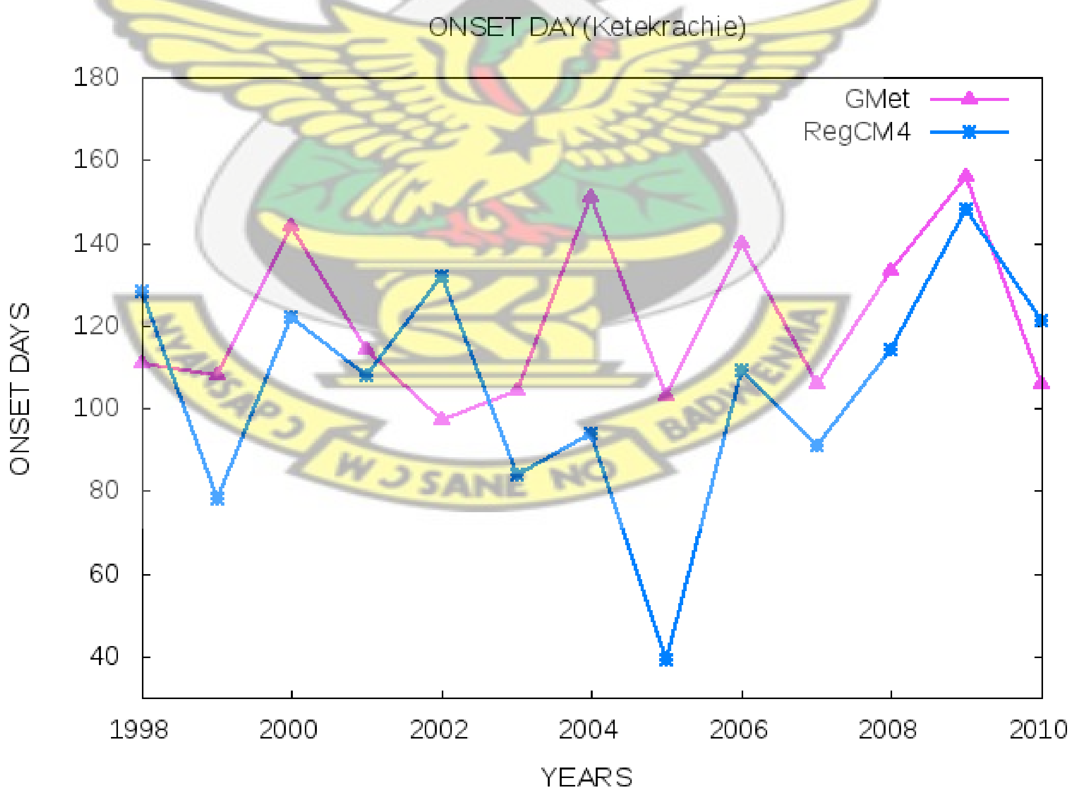

Figure 4.18: Onset Dates for Kete Krachie

4.1.1.4 ONSET OF RAINS OVER THE NORTHERN ZONE

Figure 4.19 shows the comparison between the Onset dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Northern Zone of Ghana.

From the analysis made under Bole, it was noted that out of the thirteen years considered for the study, only five years which were 1998, 1999, 2002, 2005 and 2008 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 11th March in 2009, with the maximum being recorded on the 27th of April in 2004. The mean onset date for Bole from GMet was calculated to be 10th April. The minimum for the RegCM4 onset dates were observed to be on the 25th of March, in 2003 with the maximum being recorded on the 4th of May, 2007. The mean onset date for Bole from RegCM4 was calculated to be 20th April. Over Navrongo, only eight years which were 1998, 1999, 2001, 2002, 2004, 2006, 2008 and 2009 had the similar onset dates for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 8th April in 2004, with the maximum being recorded on the 3rd of June in 2005. The mean onset date for Navrongo from GMet was calculated to be 12th May. The minimum for the RegCM4 onset dates were observed to be on the 28th of March, in 2000 with the maximum being recorded on the 18th of May, 2009. The mean onset date for Navrongo from RegCM4 was calculated to be 30th April. In Tamale, only five years which were 1998, 2000, 2005, 2006 and 2009 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 29th March in 1999, with the maximum being recorded on 3rd of June in 2010. The mean onset date for Tamale from GMet was calculated to be 7th May. The minimum for the RegCM4 onset dates were observed to be on the 25th of March, in 2008 with the maximum being recorded on the 30th of May, 2005. The mean onset date for Tamale from RegCM4 was calculated to be 8th May. Also in Wa, only four years which were 2004, 2007, 2009, and 2010 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 28th March in 1999, with the maximum being recorded on 26th of May in 2009. The mean onset date for Wa from GMet was calculated to be 21st April. The minimum for the RegCM4 onset dates were observed to be on the 24th of March, in 2008 with the maximum being recorded on the 31st of May, 2005. The mean onset date for Wa from RegCM4 was calculated to be 10th May. From Yendi, only five years which were 1998, 2002, 2005, 2007 and 2010 had the similar onset date for both the GMet and model values. The minimum onset date for the GMet measured values were observed to be 22nd March in 2003, with the maximum being recorded on 21st of May in 2005. The mean onset date for Yendi from GMet was calculated to be 2nd April. The minimum for the RegCM4 onset dates were observed to be on the 25th of March, in 2008 with the maximum being recorded on the 30th of May, 2005. The mean onset date for Yendi from RegCM4 was calculated to be 3rd May.

The RegCM4 model performed very well for the Northern Zones by giving a similar mean rainfall onset date as compared with that from the GMet.

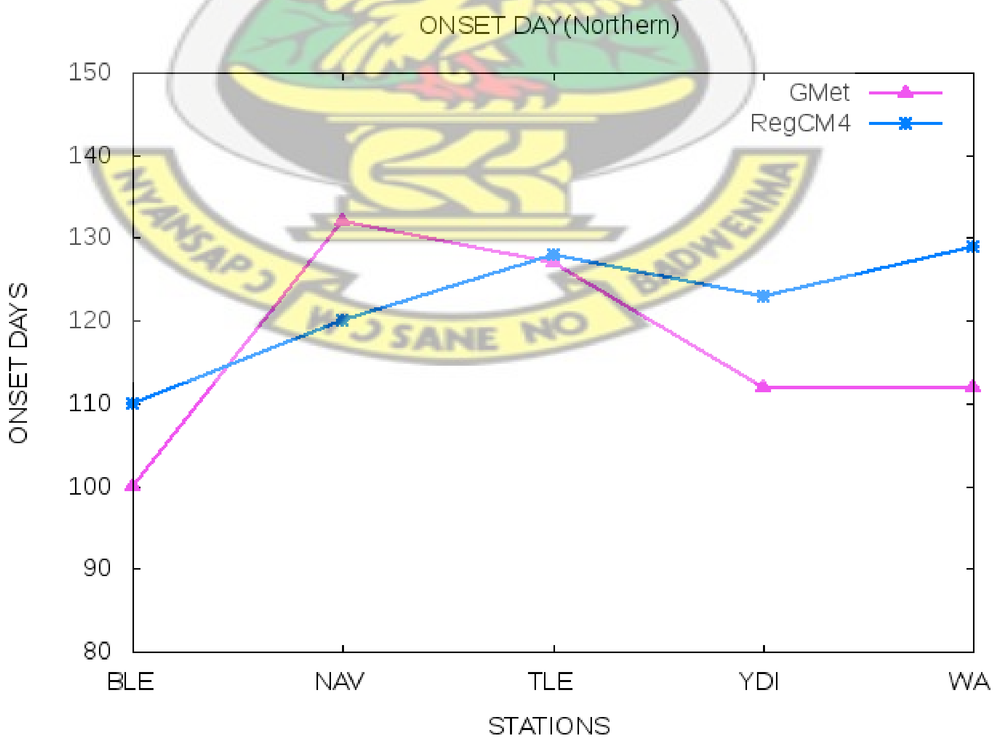

Figure 4.19: Onset Dates for the Northern Zone of Ghana

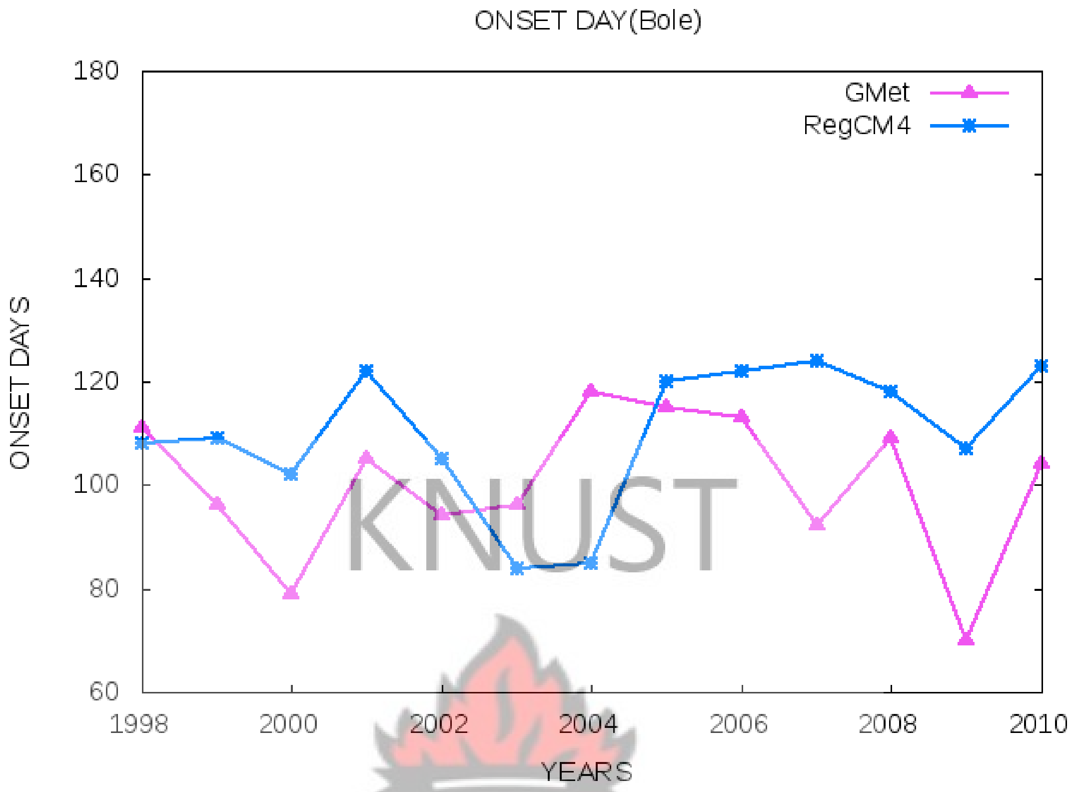

Figure 4.20: Onset Dates for Bole

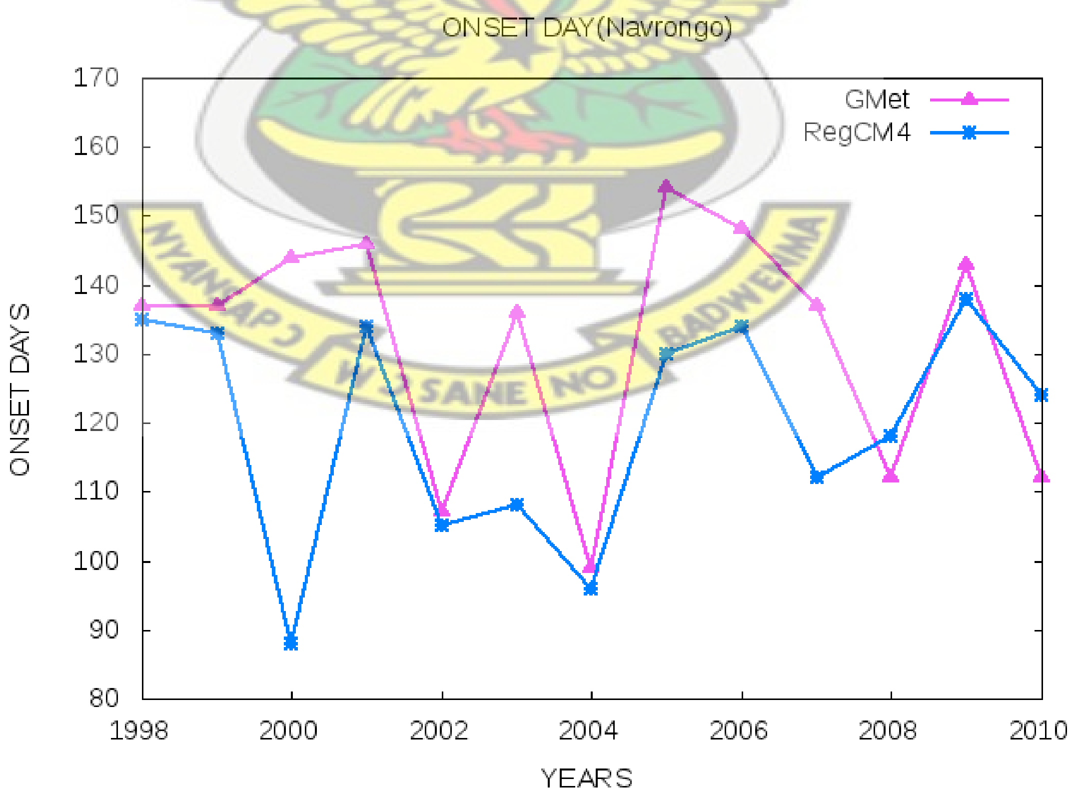

Figure 4.21: Onset Dates for Navrongo

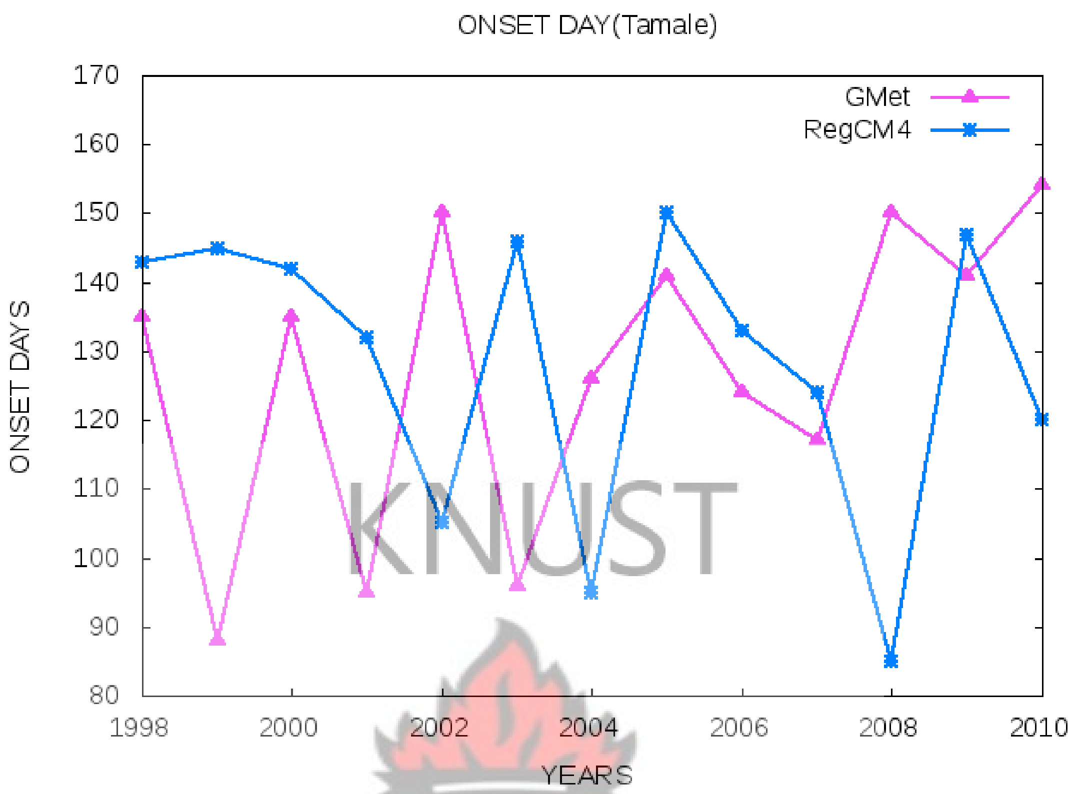

Figure 4.22: Onset Dates for Tamale

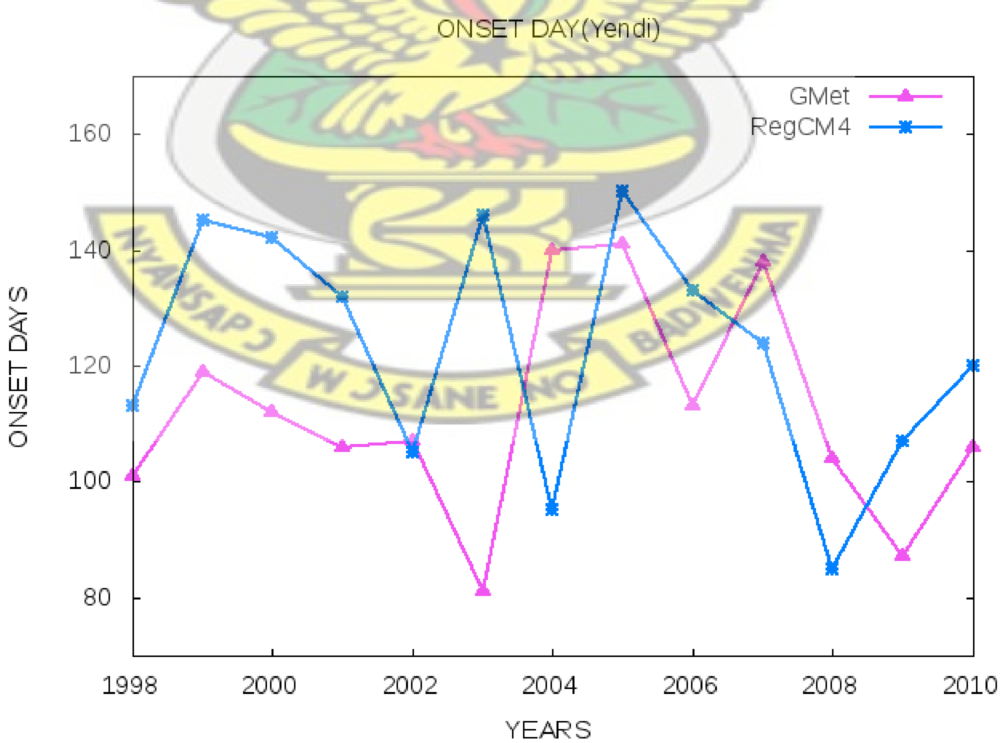

Figure 4.23: Onset Dates for Yendi

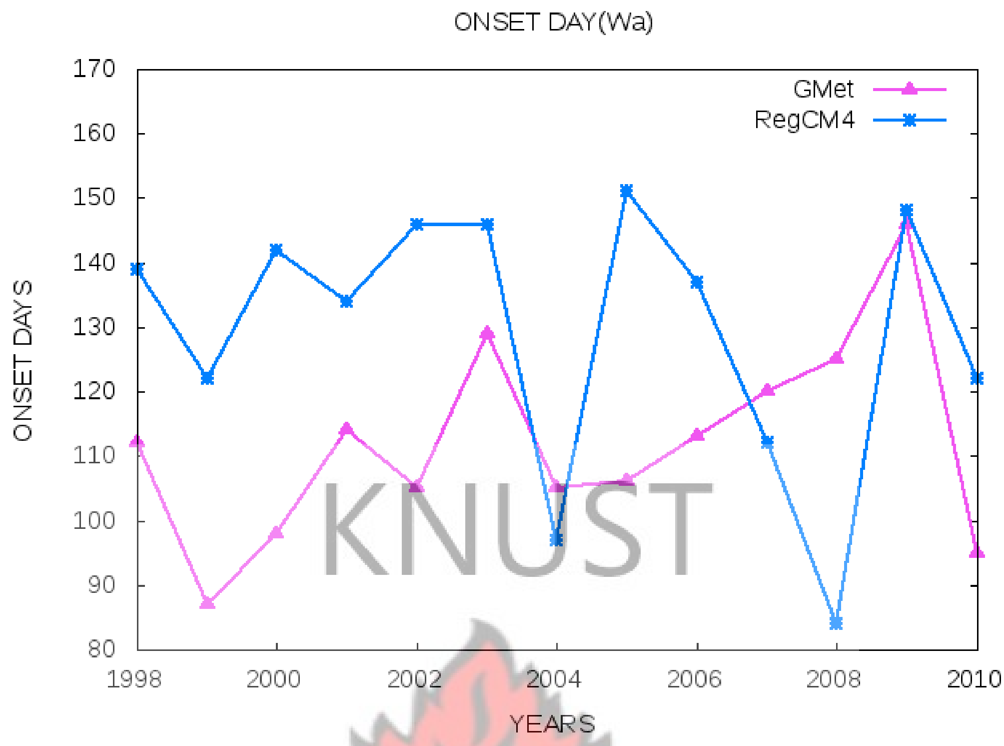

Figure 4.24: Onset Dates for Wa

Table 4.1 and Figure 4.25 show the mean onset dates computed for each station from both the GMet and RegCM4 onset dates.

Table 4.1: A DISTRIBUTION OF THE MEAN ONSET DATES FOR ALL STATIONS

Station	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
Abetifi	1st April	3rd April
Accra	3rd May	22nd April
Ada	26th April	20th April
Akatsi	19th April	17th March
Akim Oda	15th March	25th April
Axim	28th March	26th March
Bole	10th April	20th April
Ho	11th March	17th March
Kete Krachie	1st May	15th April
Koforidua	4th April	3rd April
Kumasi	21st March	24th March
Navrongo	12th May	30th April
Saltpond	22nd April	2nd March
Sunyani	24th March	25th April
Takoradi	14th April	27th March
Tamale	7th May	8th May
Tema	30th April	22nd April
Wa	21st April	10th May
Wenchi	31st March	29th March
Yendi	2nd April	3rd May

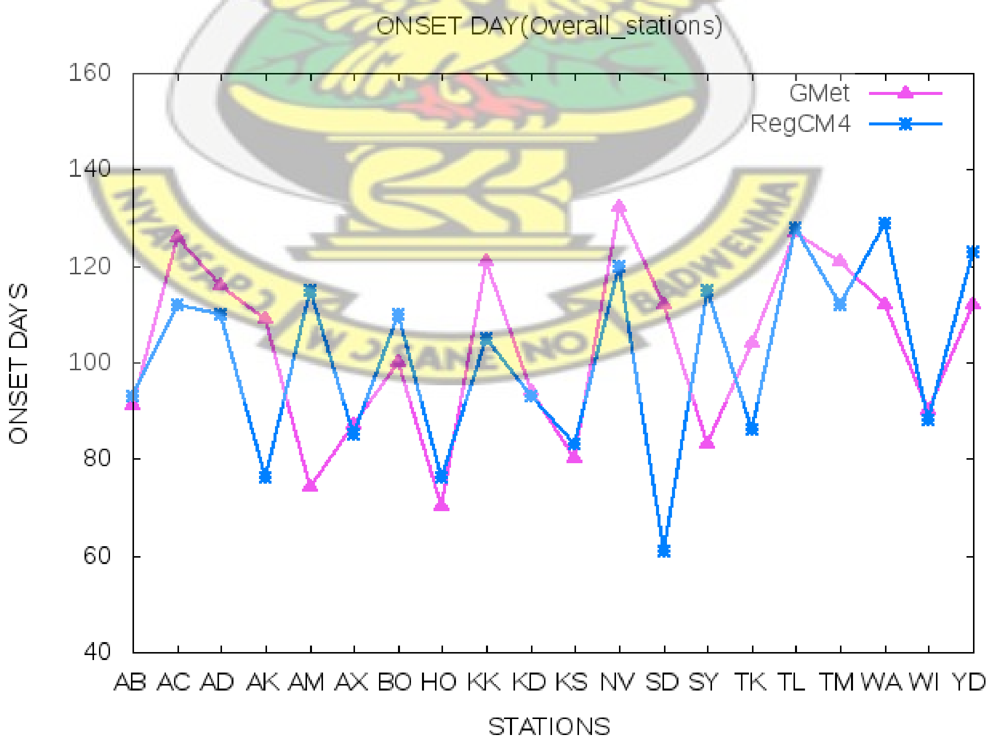

Figure 4.25: Mean Onset Dates for the Rainfall Season

4.1.2 CESSATION OF RAINFALL

4.1.2.1 CESSATION OF RAINS OVER THE FOREST ZONE

Figure 4.26 shows the comparism between the Cessation dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Forest Zone of Ghana.

Following the cessation analysis made for Abetifi, it was observed that, out of the thirteen years considered for the study, only four years; 1998, 2002, 2006 and 2010 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 2nd October in 1998, with the maximum being recorded on 11th December, 2008. The mean cessation date for Abetifi from GMet was calculated to be 13th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October for five different years (1998, 1999, 2002, 2007 and 2009) whiles the maximum cessation date recorded was on the 7th of November 2004. The mean cessation date for Abetifi from RegCM4 was calculated to be 11th October.

For Akim Oda, it was found out that out of the thirteen years considered for the study, only two years; 2000, and 2009 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 2nd October in 1998, 2001 and 2003, with the maximum being recorded on 22nd December, 2010. The mean cessation date for Akim Oda from GMet was calculated to be 10th November. The minimum for the RegCM4 cessation dates were observed to be on the 15th October for 1998 whiles the maximum cessation date recorded was on the 17th of November 2007. The mean cessation date for Akim Oda from RegCM4 was calculated to be 30th October.

Axim showed a different case where none of the years had a similar date to that from the RegCM4 model, but recorded a minimum cessation date for the GMet measured values to be 13th October in 2005, with the maximum being recorded on 23rd December, 2006. The mean cessation date for Axim from GMet was calculated to be 22nd November. The minimum for the RegCM4 cessation dates were observed to be on the 11th November in 2008 whiles the maximum cessation date recorded was on the 17th of November 2003. The mean cessation date for Axim from RegCM4 was calculated to be 27th November.

The comparism between the Cessation dates from both the Ghana Meteorological Agency and the RegCM4 for Ho showed that out of the thirteen years considered for the study, only five years; 1998, 1999, 2000, 2003 and 2009 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 2nd October in both 2006 and 2009, with the maximum being recorded on 27th December, 2008. The mean cessation date for Ho from GMet was calculated to be 16th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October 2004, whiles the maximum cessation date recorded was on the 3rd of December 2007. The mean cessation date for Ho from RegCM4 was calculated to be 26th October.

The comparism also made for Koforidua showed that out of the thirteen years considered for the study, only three years; 1998, 2001, and 2009 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 1st October in 2000, with the maximum being recorded on 27th December, 1999. The mean cessation date for Koforidua from GMet was calculated to be 10th November. The minimum for the RegCM4 cessation dates were observed to be on the 1st October in 2008, whiles the maximum cessation date recorded was on the 8th of November 2003. The mean cessation date for Koforidua from RegCM4 was calculated to be 12th October.

For Kumasi, it was observed that out of the thirteen years considered for the study, only four years; 1999, 2000, 2001 and 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 3rd October in 2003, with the maximum being recorded on 21st December, 2007.

The mean cessation date for Kumasi from GMet was calculated to be 20th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd November in 2004 whiles the maximum cessation date recorded was on the 30th of November 1998. The mean cessation date for Kumasi from RegCM4 was calculated to be 15th October.

Analysis made for Takoradi showed that only six years; 1999, 2000, 2001, 2002, 2003 and 2004 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 7th October in 2006, with the maximum being recorded on 10th December, 2009. The mean cessation date for Takoradi from GMet was calculated to be 23rd November. The minimum for the RegCM4 cessation dates were observed to be on the 27th October for 1998, whiles the maximum cessation date recorded was on the 26th of November 2004. The mean cessation date for Takoradi from RegCM4 was calculated to be 14th November.

The RegCM4 model performed very well over the Forest Zone by giving similar mean rainfall cessation dates as compared with that from the GMet.

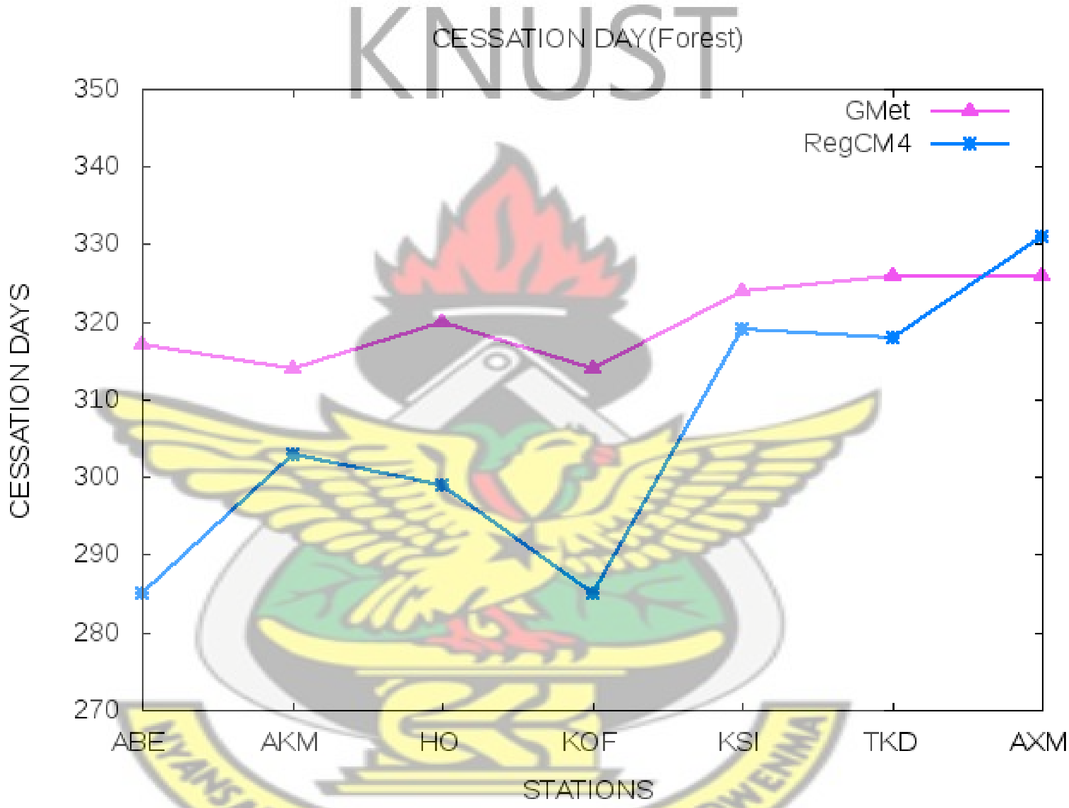

Figure 4.26: Cessation Dates for the Forest Zone of Ghana

Below are also figures of each station and how they best compare with the cessation dates from the two respective data sources.

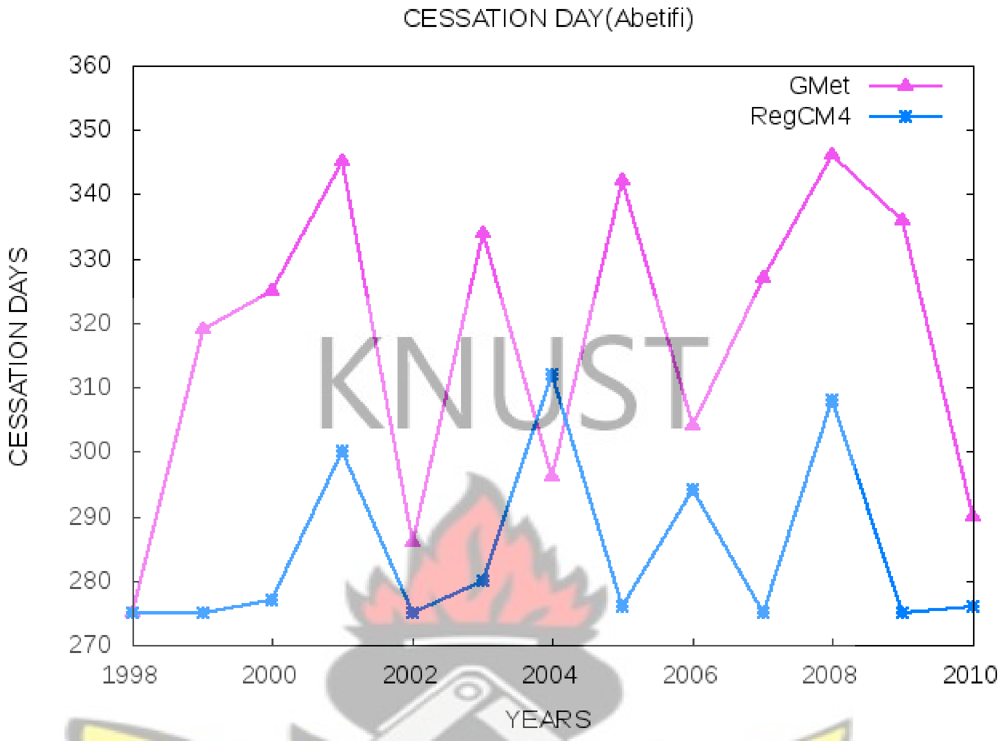

Figure 4.27: Cessation Dates for Abetifi

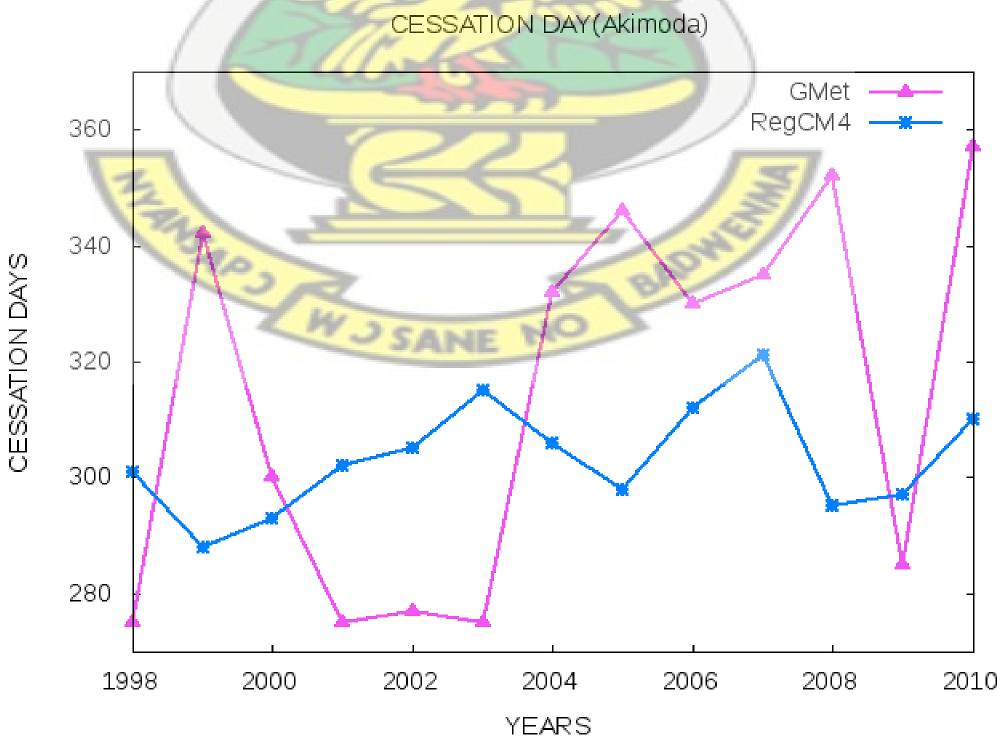

Figure 4.28: Cessation Dates for Akim Oda

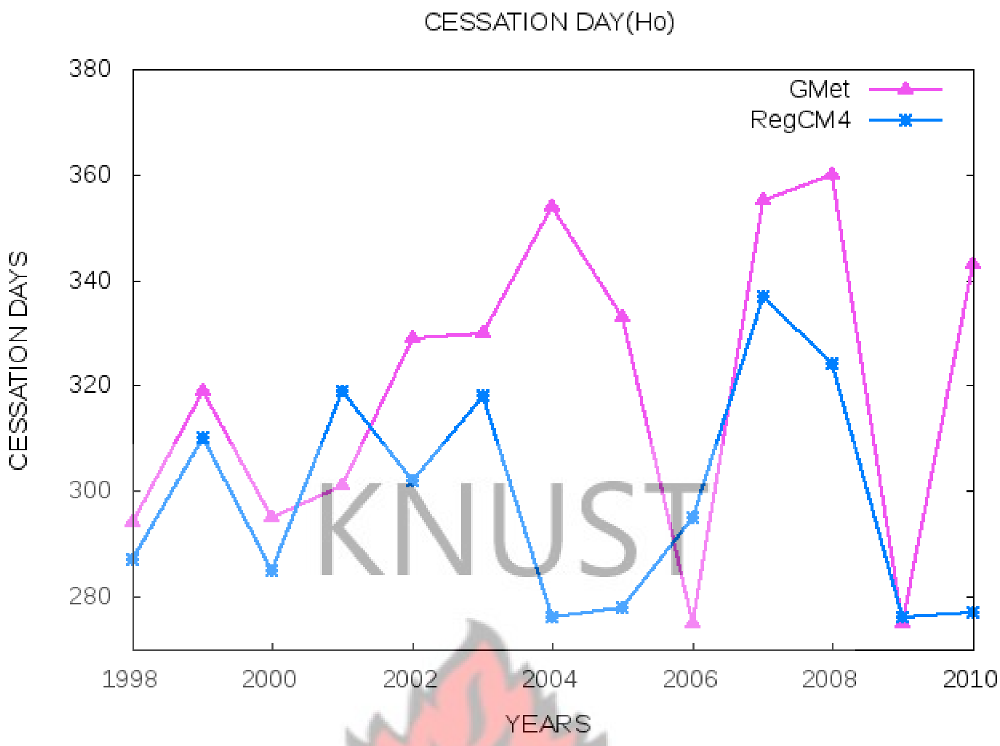

Figure 4.29: Cessation Dates for Ho

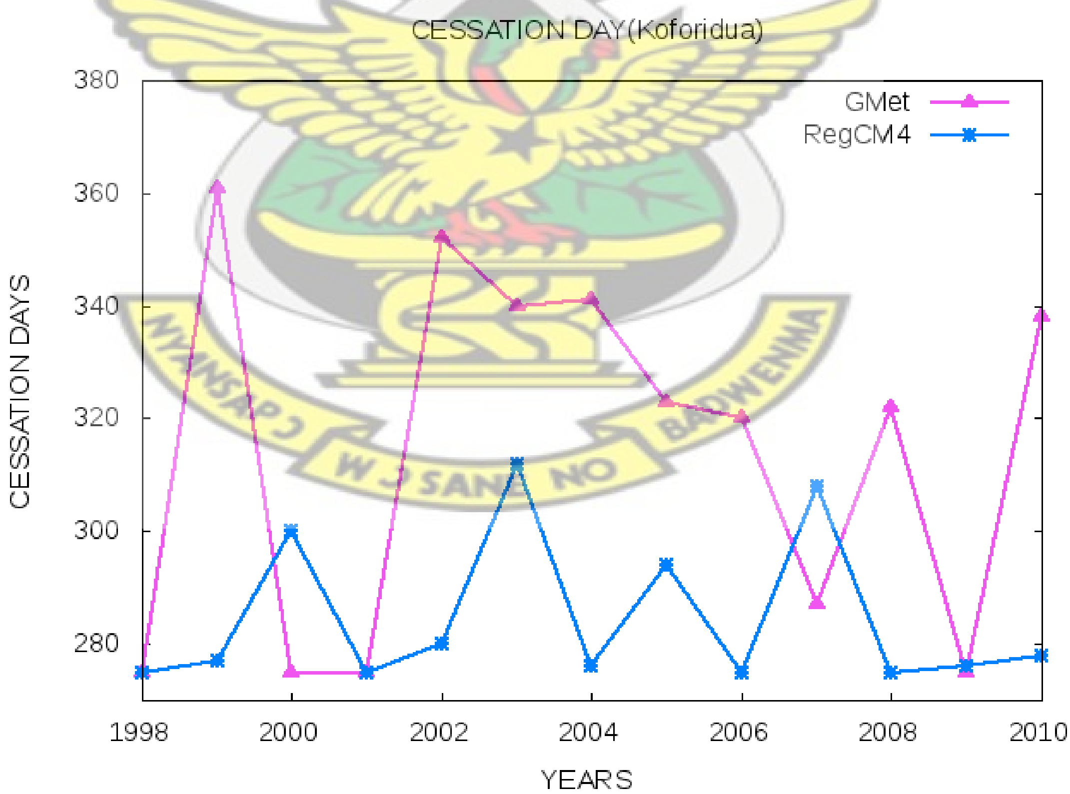

Figure 4.30: Cessation Dates for Koforidua

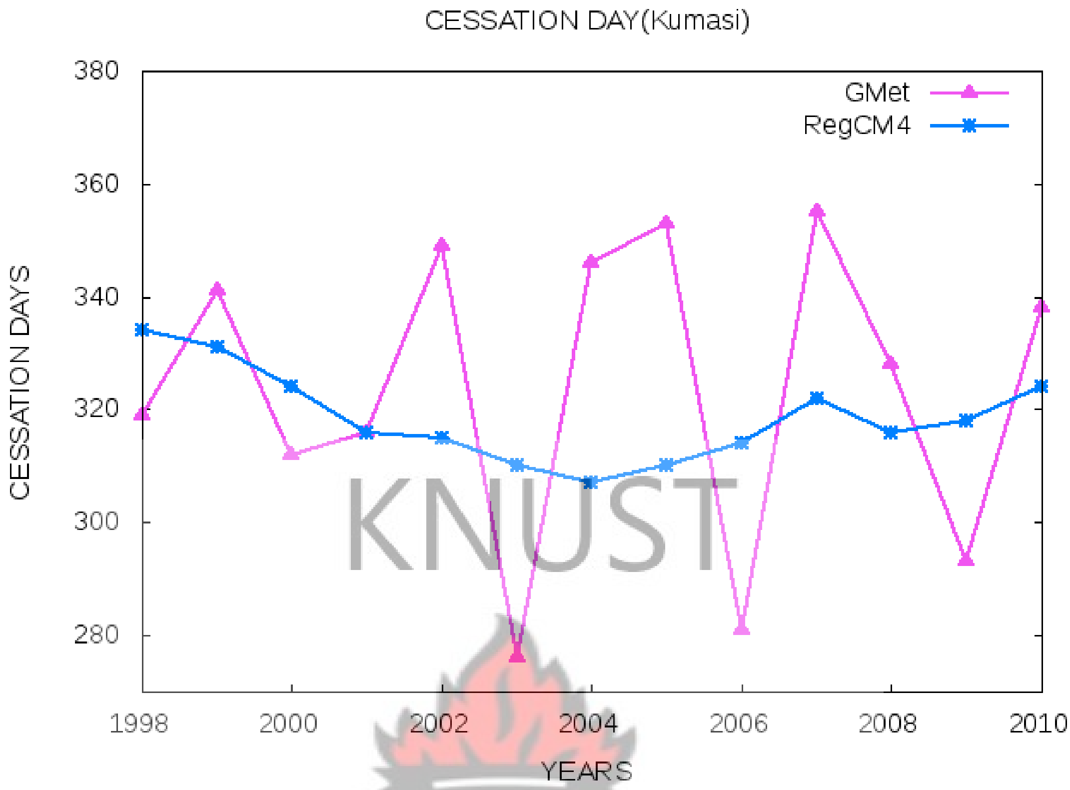

Figure 4.31: Cessation Dates for Kumasi

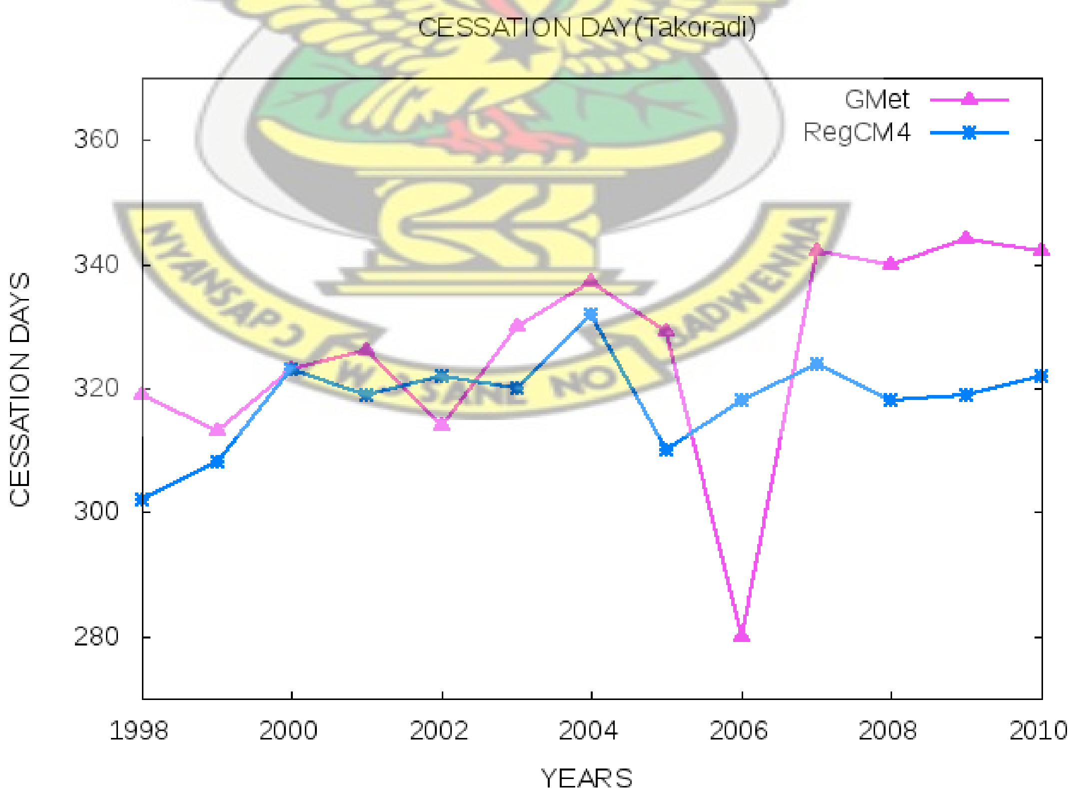

Figure 4.32: Cessation Dates for Takoradi

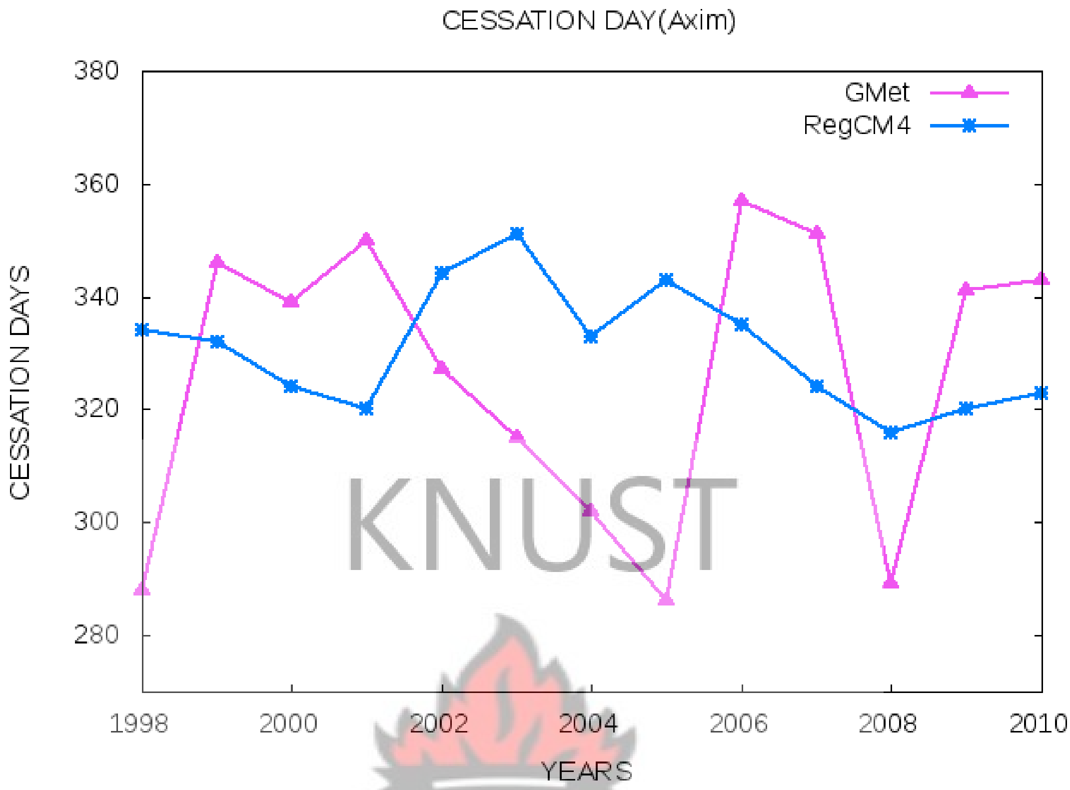

Figure 4.33: Cessation Dates for Axim

4.1.2.2 CESSATION OF RAINS OVER THE COASTAL ZONE

Figure 4.34 shows the comparism between the Cessation dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Coastal Zone of Ghana.

The analysis made for Accra, shows that out of the thirteen years considered for the study, six years; 1998, 1999, 2003, 2004, 2006 and 2007 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 8th October in 2009, with the maximum being recorded on 5th December, 2008. The mean cessation date for Accra from GMet was calculated to be 9th November. The minimum for the RegCM4 cessation dates were observed to be on the 19th October for 2003, while the maximum cessation date recorded was on the 14th of December 2002. The mean cessation date for Accra from RegCM4 was also calculated to be 4th November.

For Ada, it was observed that out of the thirteen years considered for the study, only three years; 1998, 2000, and 2006 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 5th October in 2010, with the maximum being recorded on 8th December, 2003. The mean cessation date for Ada from GMet was calculated to be 6th November. The minimum for the RegCM4 cessation dates were observed to be on the 15th October for 1999 while the maximum cessation date recorded was on the 22nd of November 1998. The mean cessation date for Ada from RegCM4 was calculated to be 31st October.

Akatsi showed a much positive sign with ten years; 1999, 2000, 2001, 2002, 2003, 2006, 2007, 2008, 2009 and 2010 having the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 2nd October for four years (1999, 2002, 2005 and 2009), with the maximum being recorded on 13th December, 2003. The mean cessation date for Akatsi from GMet was calculated to be 20th October. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October for eight different years (1998, 1999, 2000, 2001, 2002, 2006, 2007 and 2008) whiles the maximum cessation date recorded was on the 14th of November 2003. The mean cessation date for Akatsi from RegCM4 was calculated to be 6th October.

For Saltpond, it was observed that out of the thirteen years considered for the study, only six years; 2001, 2002, 2003, 2005, 2007 and 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 4th October in 2009, with the maximum being recorded on 5th December, 2008. The mean cessation date for Saltpond from GMet was calculated to be 10th November. The minimum for the RegCM4 cessation dates were observed to be on the 6th October, 2000 whiles the maximum cessation date recorded was on the 9th of December, 2004. The mean cessation date for Saltpond from RegCM4 was calculated to be 21st November.

For Tema, it was found out that, out of the thirteen years considered for the study, only six years; 1998, 1999, 2003, 2004, 2007 and 2009 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 22nd October in 2006, with the maximum being recorded on 20th November, in both 2007 and 2010. The mean cessation date for Tema from GMet was calculated to be 4th November. The minimum for the RegCM4 cessation dates were observed to be on the 4th October in 2000, whiles the maximum cessation date recorded was on the 17th of November 2007. The mean cessation date for Tema from RegCM4 was calculated to be 25th October.

The RegCM4 model also performed very well over the Coastal Zone by giving similar mean rainfall cessation dates as compared with that from the GMet.

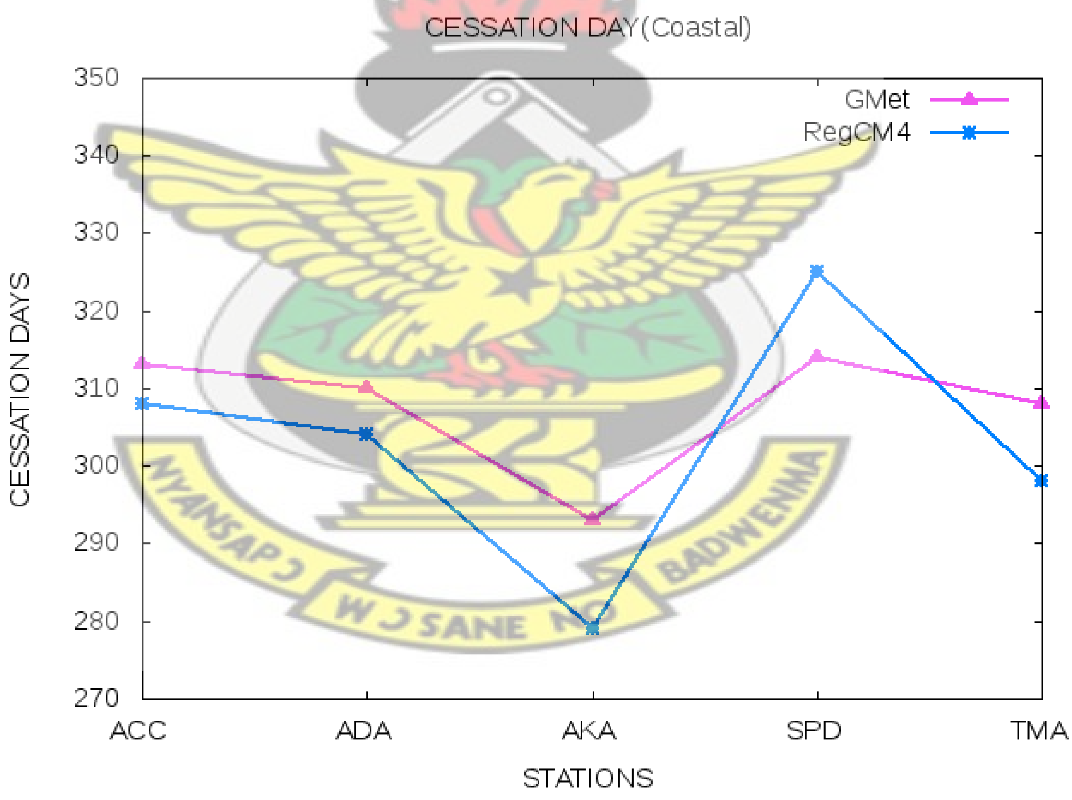

Figure 4.34: Cessation Dates for the Coastal Zone of Ghana

Below are also figures of each station and how they best compare with the cessation dates from the two respective data sources.

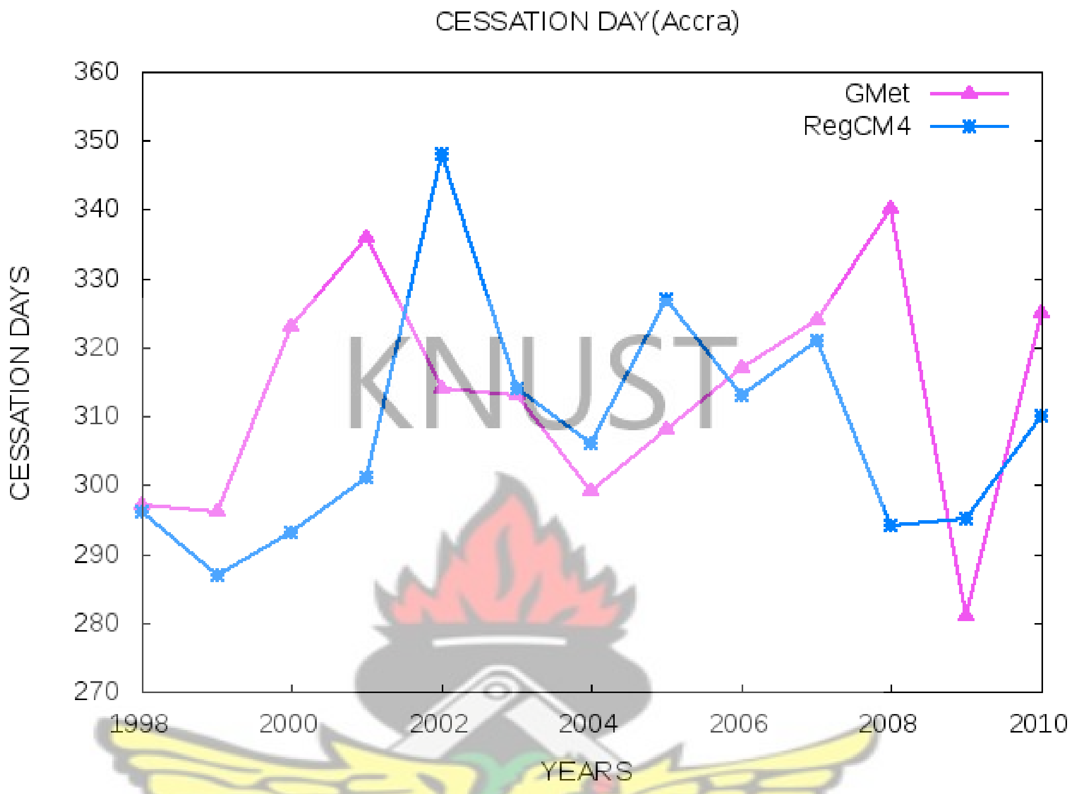

Figure 4.35: Cessation Dates for Accra

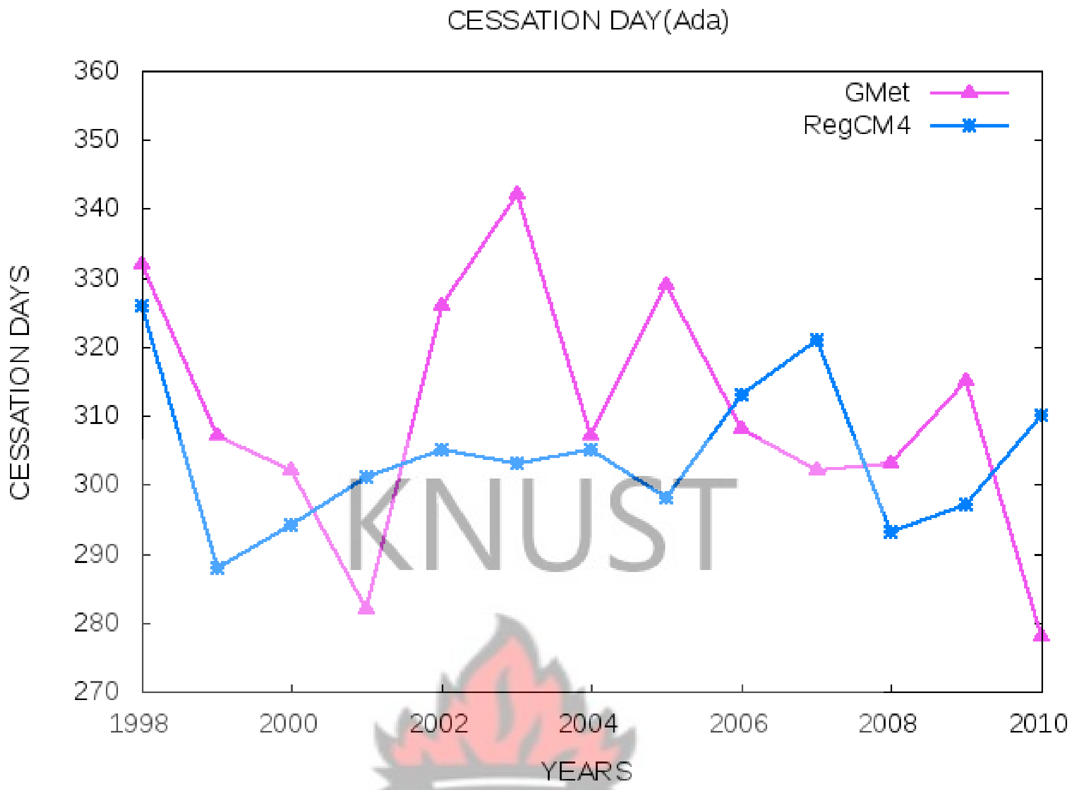

Figure 4.36: Cessation Dates for Ada

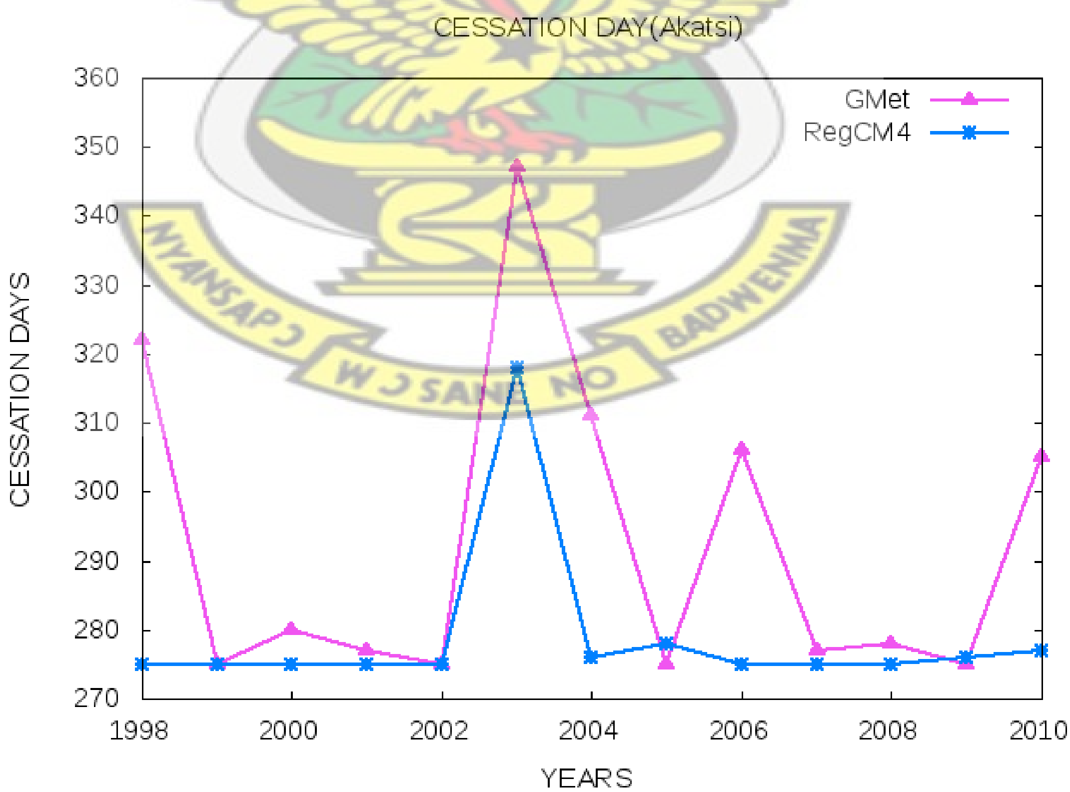

Figure 4.37: Cessation Dates for Akatsi

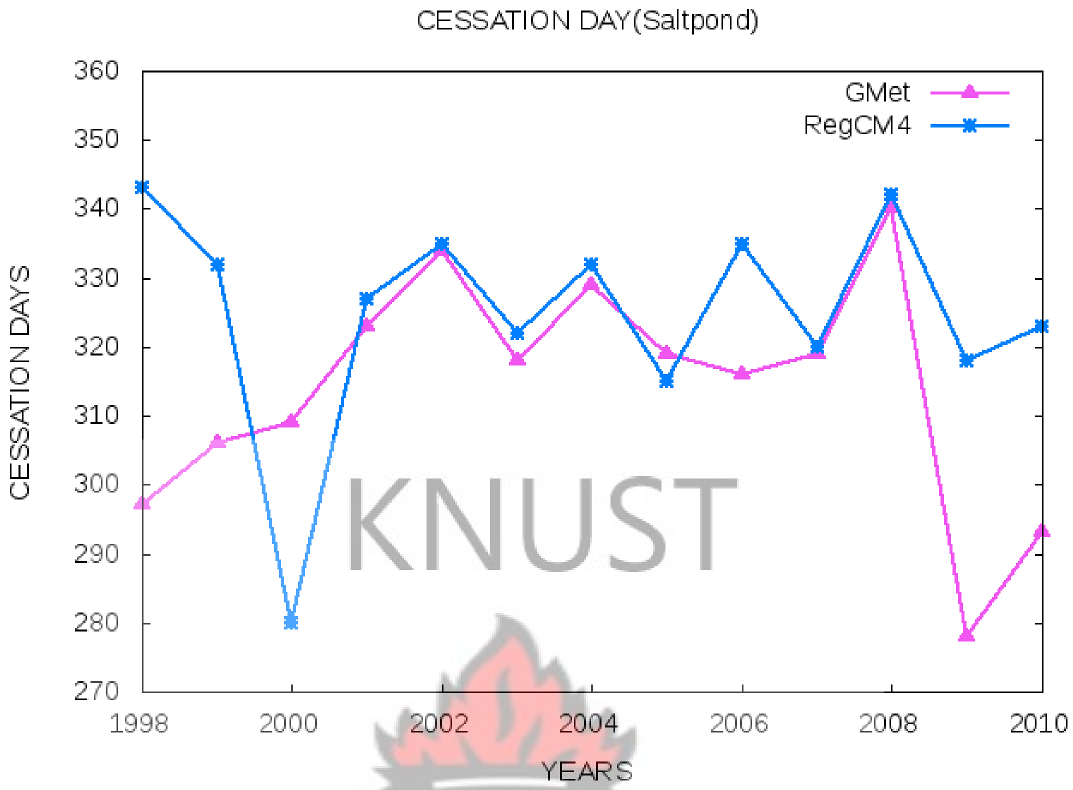

Figure 4.38: Cessation Dates for Saltpond

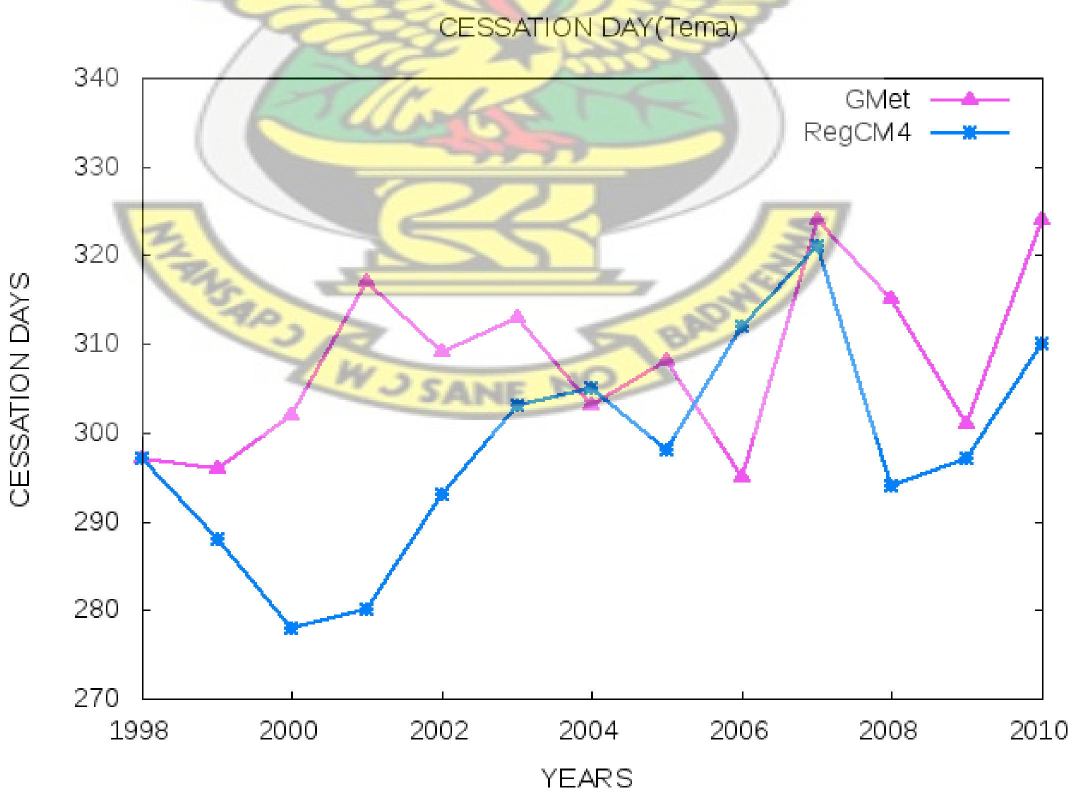

Figure 4.39: Cessation Dates for Tema

4.1.2.3 CESSATION OF RAINS OVER THE TRANSITION ZONE

Figure 4.40 shows the comparism between the Cessation dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Transition Zone of Ghana.

The cessation date analysis made for Kete Krachie, showed that out of the thirteen years considered for the study, only three years; 2006, 2007 and 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 20th October in 2001, with the maximum being recorded on 20th December, 2003. The mean cessation date for Kete Krachie from GMet was calculated to be 30th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October in 2001, whiles the maximum cessation date recorded was on the 21st of November 2010. The mean cessation date for Kete Krachie from RegCM4 was calculated to be 2nd November.

For Sunyani, it was observed that only three years; 1999, 2007, and 2010 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 2nd October in both 2001 and 2002, with the maximum being recorded on 22nd December, 2007. The mean cessation date for Sunyani from GMet was calculated to be 15th November. The minimum for the RegCM4 cessation dates were observed to be on the 27th October in 1998, whiles the maximum cessation date recorded was on the 18th of November 2007. The mean cessation date for Sunyani from RegCM4 was calculated to be 11th November.

From Wenchi, it was also observed that out of the thirteen years considered for the study, only six years; 2002, 2003, 2004, 2006, 2007 and 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 6th October in 2009, with the maximum being recorded on 22nd

December, 2007. The mean cessation date for Wenchi from GMet was calculated to be 28th November. The minimum for the RegCM4 cessation dates were observed to be on the 31st October for 1998, whiles the maximum cessation date recorded was on the 18th of December for both 2003 and 2007. The mean cessation date for Wenchi from RegCM4 was calculated to be 2nd December.

Within the Transition zone, the RegCM4 model performed very well over areas like Sunyani and Wenchi, by giving similar mean rainfall cessation dates as compared with that from the GMet.

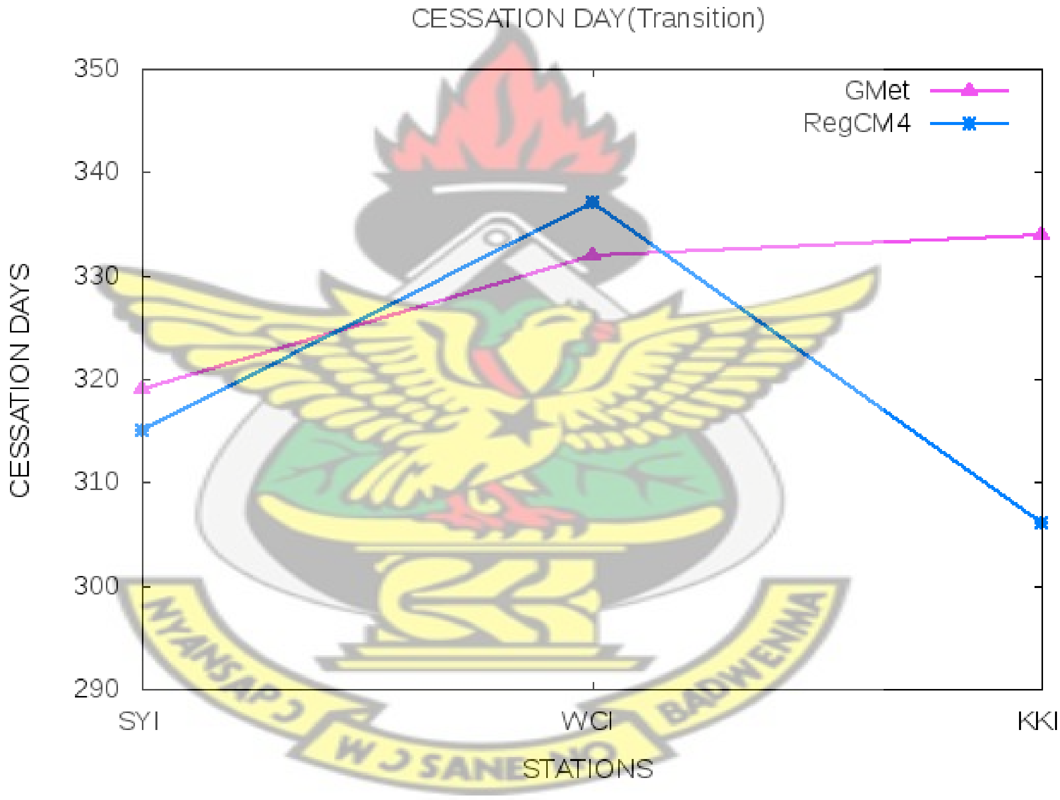

Figure 4.40: Cessation Dates for the Transition Zone of Ghana

Below are also figures of each station and how they best compare with the cessation dates from the two respective data sources.

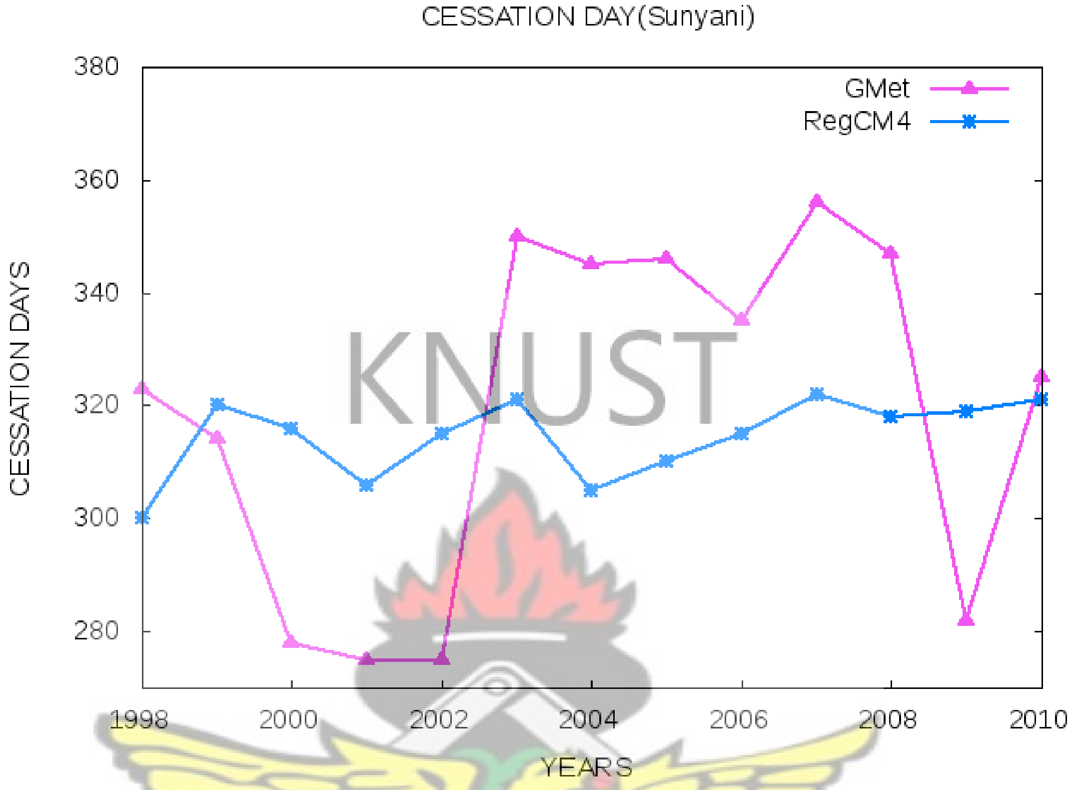

Figure 4.41: Cessation Dates for Sunyani

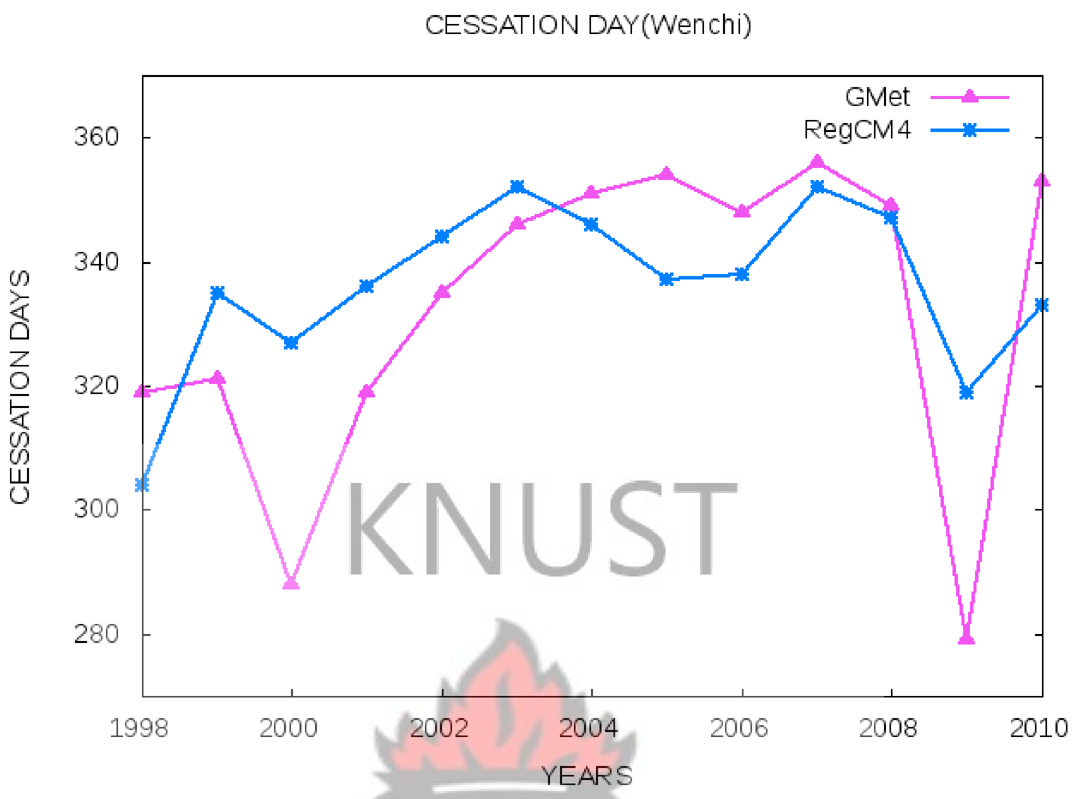

Figure 4.42: Cessation Dates for Wenchi

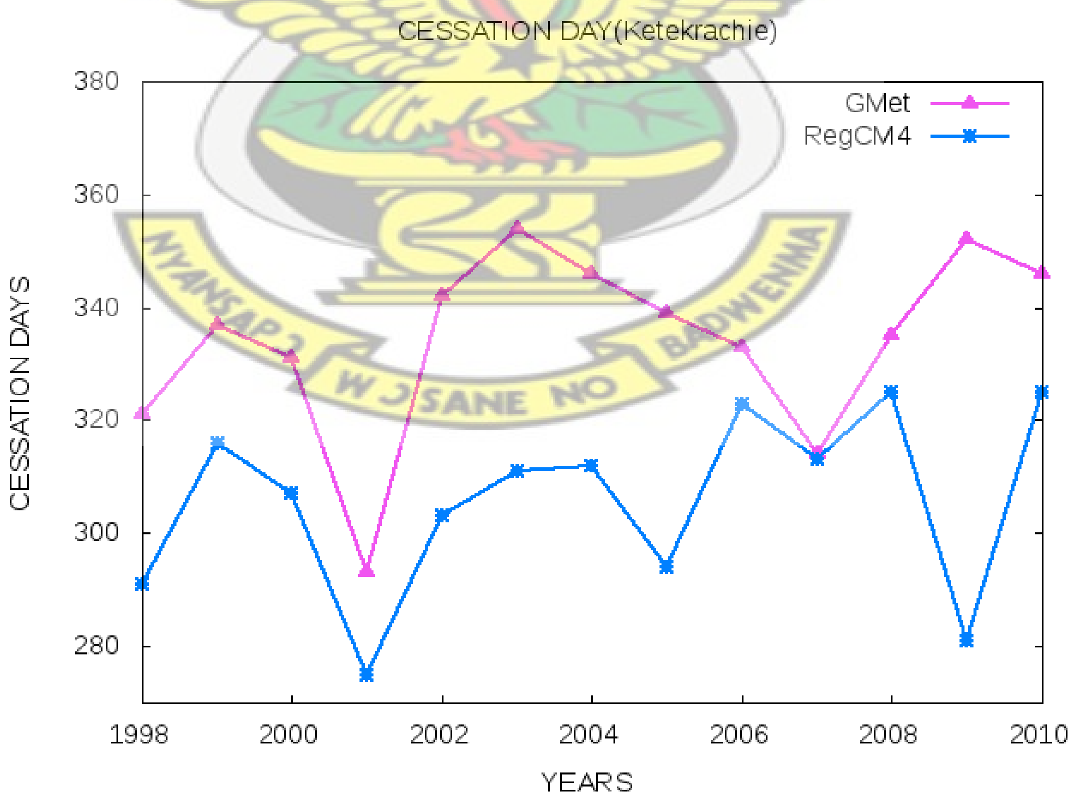

Figure 4.43: Cessation Dates for Kete Krachie

4.1.2.4 CESSATION OF RAINS OVER THE NORTHERN ZONE

Figure 4.44 shows the comparism between the Cessation dates from both the Ghana Meteorological Agency and the RegCM4 for the synoptic stations within the Northern Zone of Ghana.

For Bole, it was observed that out of the thirteen years considered for the study, only five years; 1998, 2001, 2004, 2008 and 2010 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 25th October in 2001, with the maximum being recorded on 28th November, 2010. The mean cessation date for Bole from GMet was calculated to be 11th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October for two different years (2002, and 2010) whiles the maximum cessation date recorded was on the 9th of November 2008. The mean cessation date for Bole from RegCM4 was calculated to be 16th October.

For analysis made from Navrongo, it was observed that eight years; 1999, 2001, 2002, 2003, 2004, 2005, 2008 and 2010 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 22nd October in 2005, with the maximum being recorded on 27th November, 2010. The mean cessation date for Navrongo from GMet was calculated to be 11th November. The minimum for the RegCM4 cessation dates were observed to be on the 4th October 2009, whiles the maximum cessation date recorded was on the 20th of November 2010. The mean cessation date for Navrongo from RegCM4 was calculated to be 28th October.

From the analysis made over Tamale, it was found that out of the thirteen years considered for the study, only three years; 2001, 2004 and 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 16th October in 2001, with the maximum being recorded on 28th November, 2010. The mean cessation date for Tamale from GMet was calculated to be 8th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd

October for four different years (2002, 2006, 2009, and 2010) whiles the maximum cessation date recorded was on the 8th of November 2008. The mean cessation date for Tamale from RegCM4 was calculated to be 15th October.

For Wa, it was observed that six years; 1998, 1999, 2002, 2005, 2006 and 2007 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 12th October in 2007, with the maximum being recorded on 12th November, 2009. The mean cessation date for Wa from GMet was calculated to be 2nd November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October for 2009, whiles the maximum cessation date recorded was on the 12th of November 2006. The mean cessation date for Wa from RegCM4 was calculated to be 27th October.

For Yendi, it was also found that only one year, which was 2008 had the similar cessation date for both the GMet and RegCM4 model values. The minimum cessation date for the GMet measured values were observed to be 28th October in 2002, with the maximum being recorded on 26th November, 2009. The mean cessation date for Yendi from GMet was calculated to be 11th November. The minimum for the RegCM4 cessation dates were observed to be on the 2nd October for four different years (2002, 2006, 2009, and 2010) in this station, whiles the maximum cessation date recorded was on the 8th of November 2008. The mean cessation date for Yendi from RegCM4 was calculated to be 15th October.

Over the Northern Zone, the RegCM4 performed well over Wa than the other areas within this zone, by giving a similar mean rainfall cessation date to that from GMet.

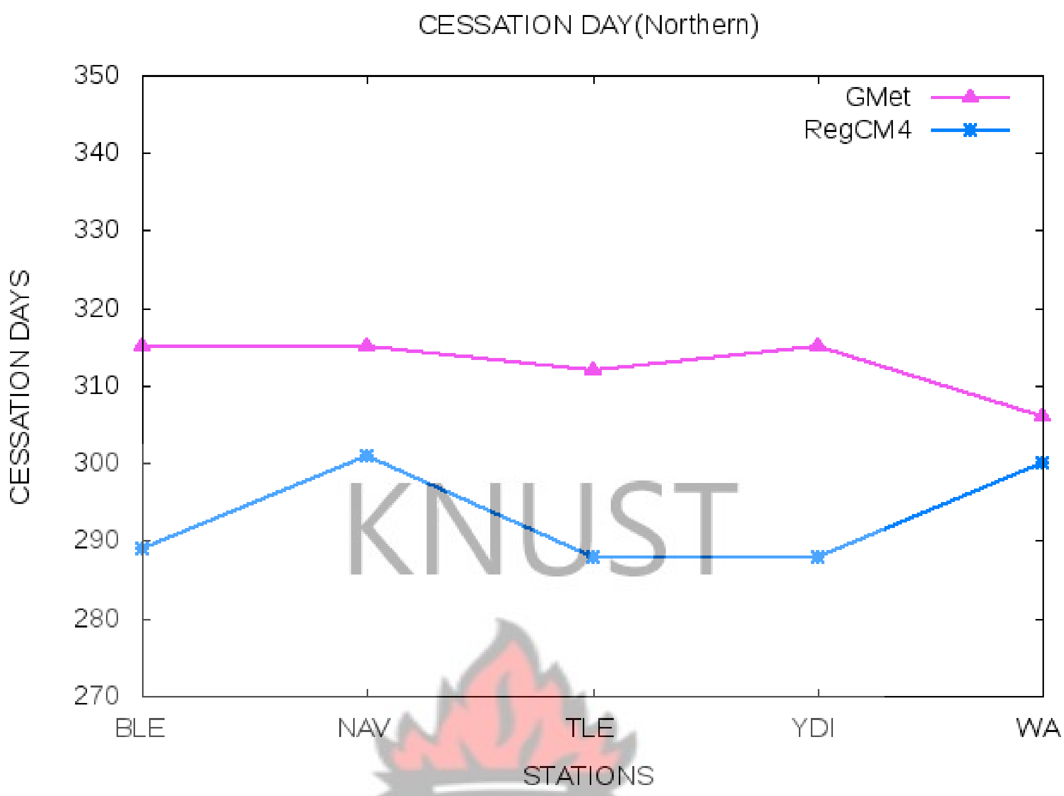

Figure 4.44: Cessation Dates for the Northern Zone of Ghana

Below are also figures of each station and how they best compare with the cessation dates from the two respective data sources.

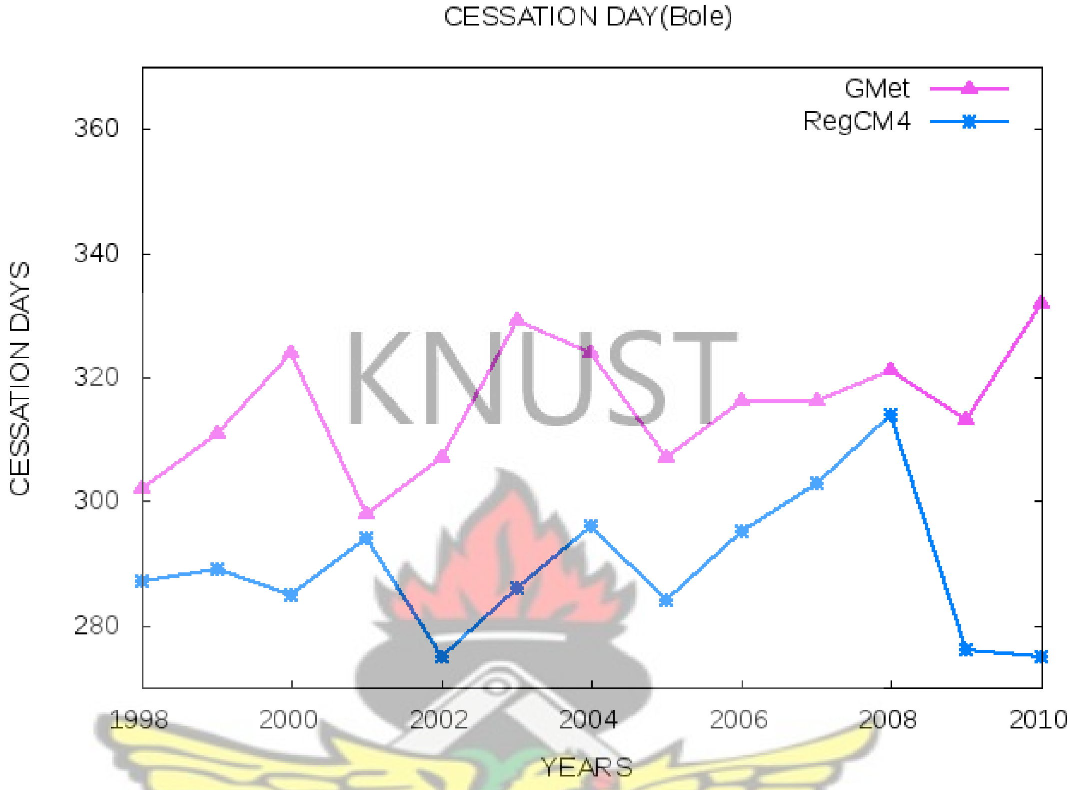

Figure 4.45: Cessation Dates for Bole

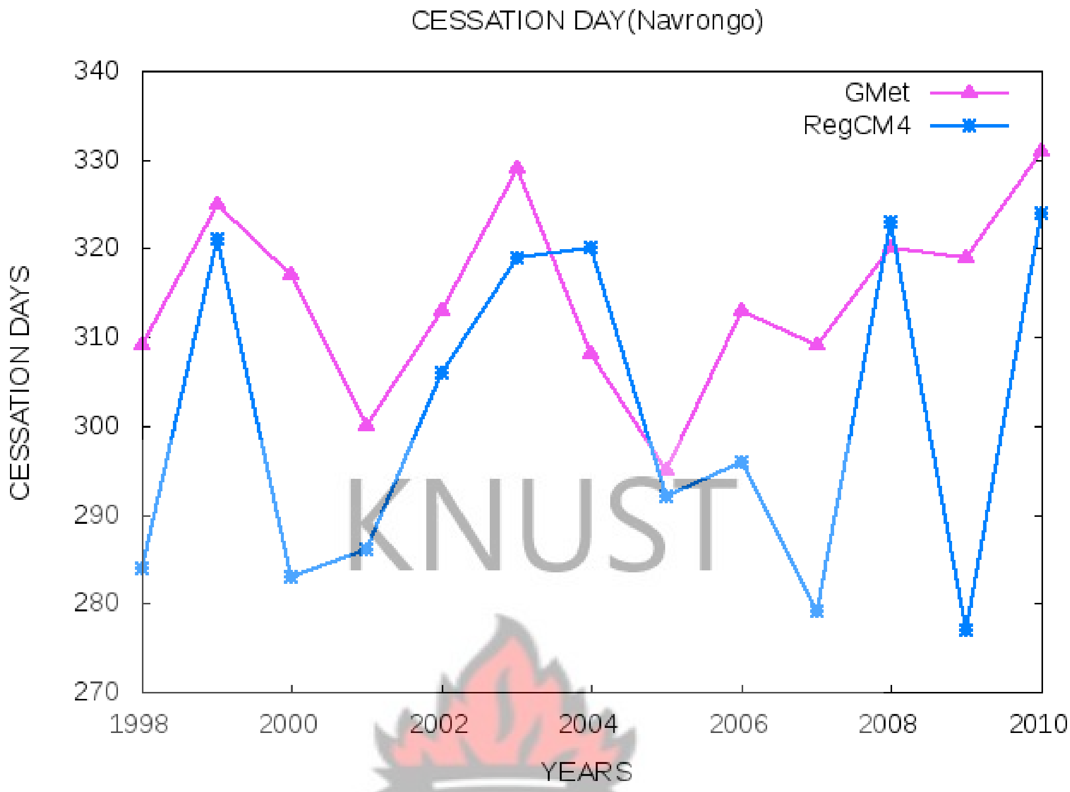

Figure 4.46: Cessation Dates for Navrongo

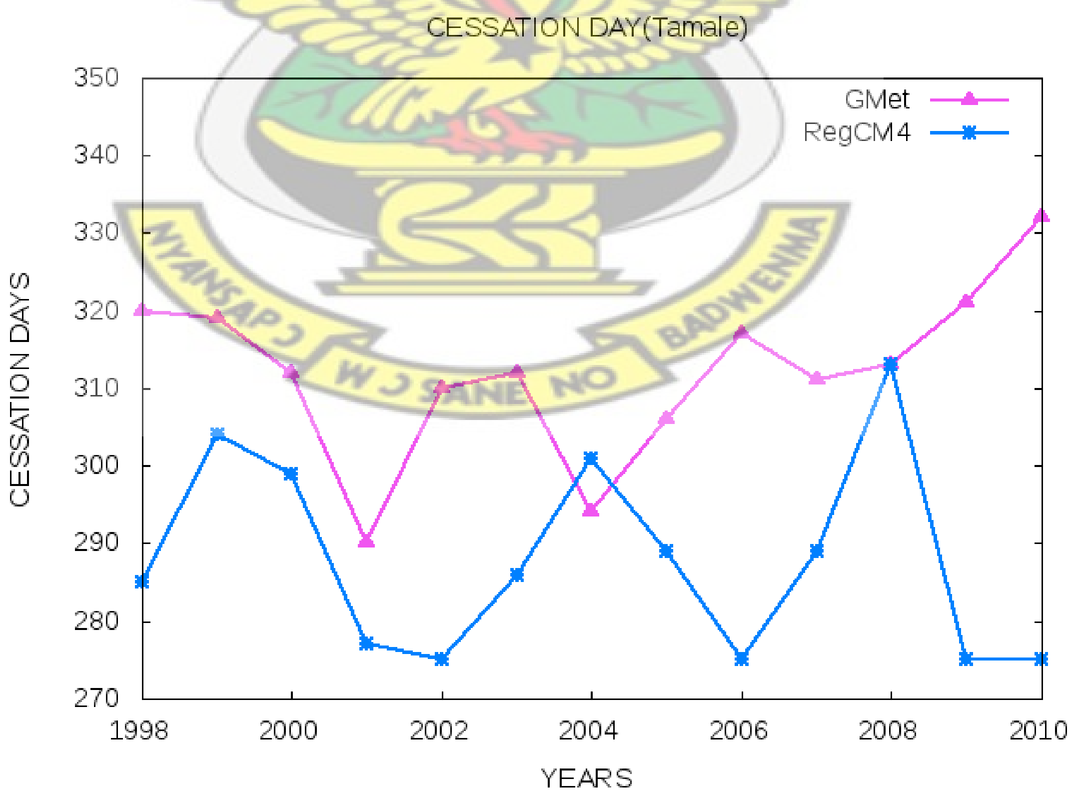

Figure 4.47: Cessation Dates for Tamale

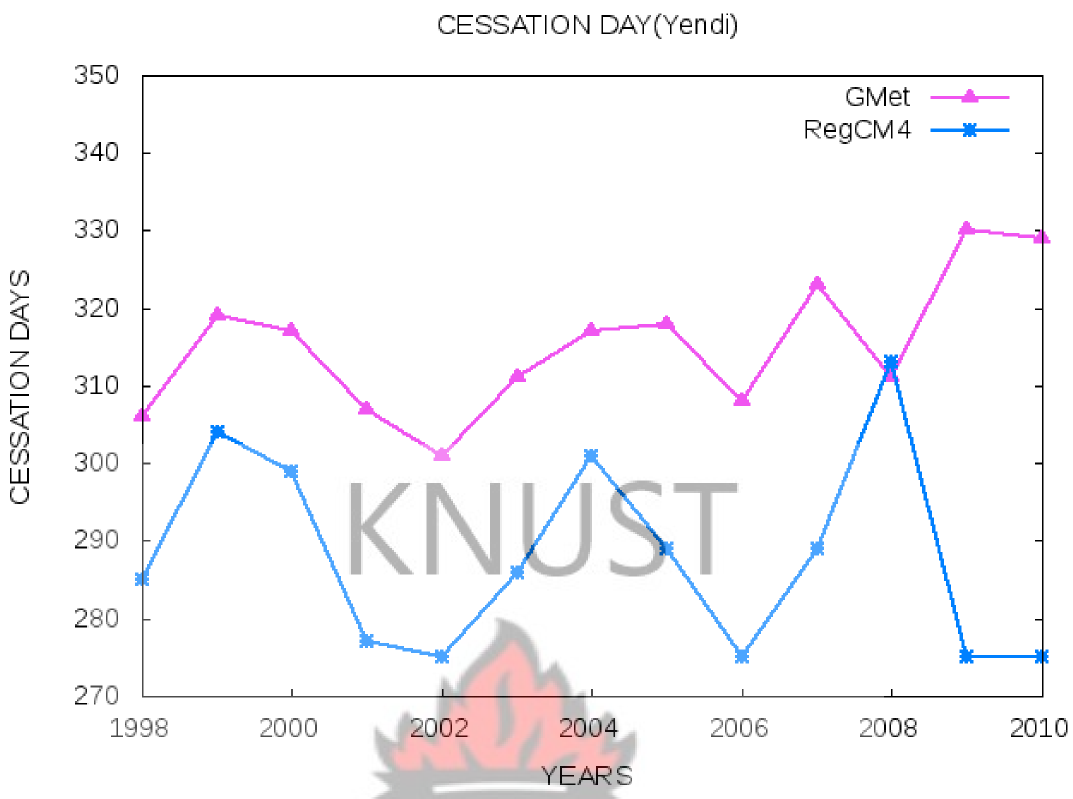

Figure 4.48: Cessation Dates for Yendi

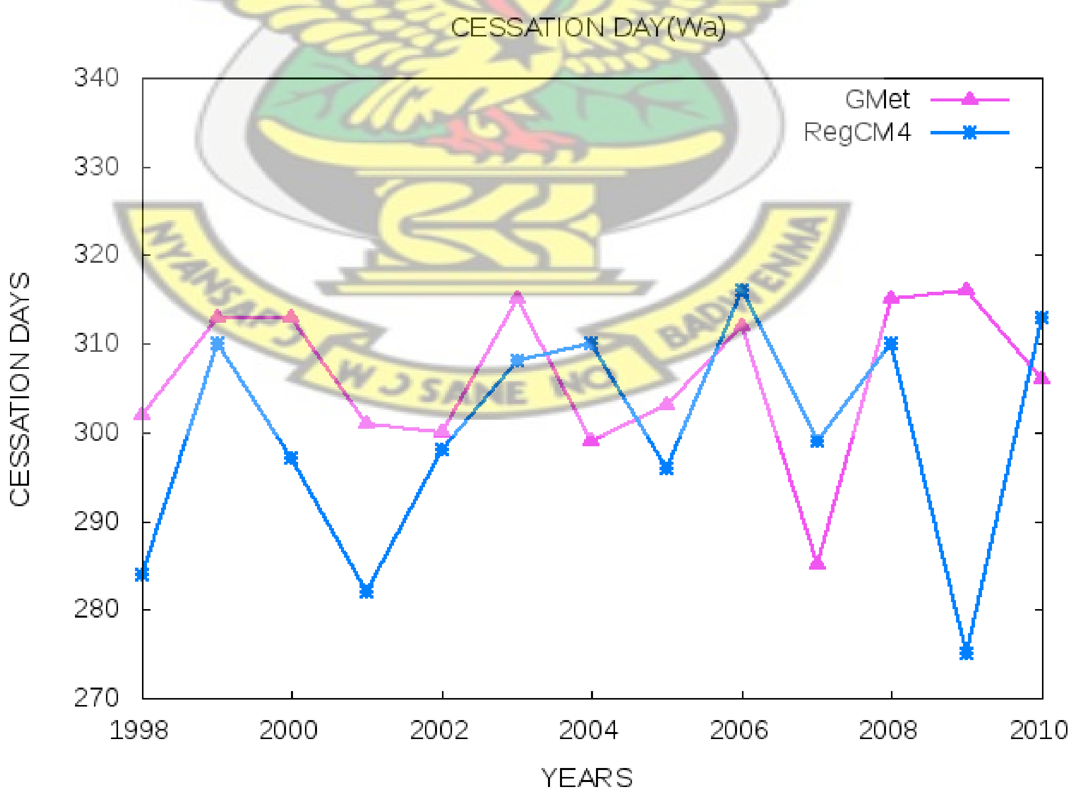

Figure 4.49: Cessation Dates for Wa

Table 4.2 and Table 4.3 show the mean rainfall onset dates with the length and cessation dates for each station from the GMet ground based measurements and RegCM4 model respectively. Figure 4.50 also gives a graphical representation of the mean cessation dates of the rainfall season for all stations from GMet and RegCM4 model.

Table 4.2: A DISTRIBUTION OF THE MEAN RAINFALL ONSET AND CESSATION DATES FOR ALL STATIONS FROM GMet

Station	GMet Mean Onset Dates	Length, $(days)$	GMet Mean Cessation Dates
Abetifi	1st April	226	13th November
Accra	3rd May	187	9th November
Ada	26th April	194	6th November
Akatsi	19th April	184	20th October
Akim Oda	15th March	240	10th November
Axim	28th March	239	22nd November
Bole	10th April	215	11th November
Ho	11th March	250	16th November
Kete Krachie	1st May	213	30th November
Koforidua	4th April	220	10th November
Kumasi	21st March	244	20th November
Navrongo	12th May	183	11th November
Saltpond	22nd April	202	10th November
Sunyani	24th March	236	15th November
Takoradi	14th April	222	23rd November
Tamale	7th May	185	8th November
Tema	30th April	187	4th November
Wa	21st April	194	2nd November
Wenchi	31st March	242	28th November
Yendi	2nd April	203	11th November

Table 4.3: A DISTRIBUTION OF THE MEAN RAINFALL ONSET AND CESSATION DATES FOR ALL STATIONS FROM THE RegCM4 MODEL

Station	RegCM4 Mean Onset Dates	Length, $(days)$	RegCM4 Mean Cessation Dates
Abetifi	3rd April	192	11th October
Accra	22nd April	196	4th November
Ada	20th April	194	31st October
Akatsi	17th March	203	6th October
Akim Oda	25th April	188	30th October
Axim	26th March	246	27th November
Bole	20th April	179	16th October
Ho	17th March	223	26th October
Kete Krachie	15th April	201	2nd November
Koforidua	3rd April	192	12th October
Kumasi	24th March	236	15th November
Navrongo	30th April	181	28th October
Saltpond	2nd March	264	21st November
Sunyani	25th April	200	11th November
Takoradi	27th March	232	14th November
Tamale	8th May	160	15th October
Tema	22nd April	186	25th October
Wa	10th May	171	27th October
Wenchi	29th March	249	2nd December
Yendi	3rd May	165	15th October

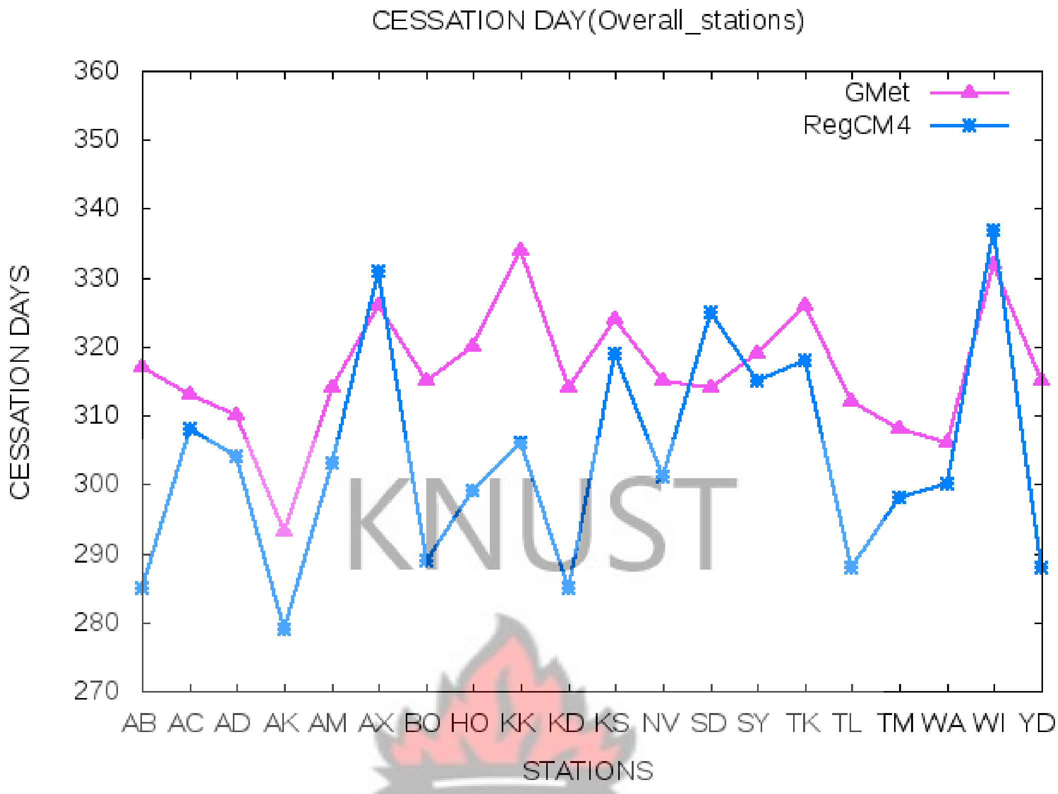

Figure 4.50: Mean Rainfall Onset, Length and Cessation Dates for the Rainfall Season from both GMet and RegCM4

4.1.3 LENGTH OF RAINY SEASON

Table 4.2 and table 4.3 with figure 4.50 show the mean lengths of the rainy season for each station. The mean maximum length from the GMet measured dates was found to be for Ho with 250 days, followed by Wenchi with 242 days. The minimum length in Ghana was found to be for Navrongo with 183 days.

From the RegCM4 model, the maximum length of the rainy season was recorded at Saltpond with 264 days, followed by Wenchi with 249 days. The minimum length for the rainy season was recorded at Tamale with 160 days.

Table 4.4 and Table 4.5 shows the mean onset and cessation dates for the different agro-ecological zones in Ghana, with the length of the growing season also shown from both the rainfall analysed values of GMet and the RegCM4 model respectively.

Table 4.4: A DISTRIBUTION OF THE MEAN RAINFALL ONSET AND CESSATION DATES FOR THE VARIOUS ZONES FROM GMet

Zones	GMet Mean Onset Dates	Length, ($days$)	GMet Mean Cessation Dates
Forest	27th March	234	16th November
Coastal	27th April	191	3rd November
Transition	8th April	230	24th November
Northern	27th April	196	9th November

Table 4.5: A DISTRIBUTION OF THE MEAN RAINFALL ONSET AND CESSATION DATES FOR THE VARIOUS ZONES FROM THE RegCM4 MODEL

Zones	RegCM4 Mean Onset Dates	Length, ($days$)	RegCM4 Mean Cessation Dates
Forest	31st March	216	2nd November
Coastal	4th April	209	29th October
Transition	13th April	216	15th November
Northern	2nd May	171	20th October

The results from this study as compared with the seasonal forecast as in 4.6 made by the Ghana Meteorological Agency in 2013, shows quite similar dates.

Table 4.6: A SEASONAL FORECAST MADE FOR THE VARIOUS ZONES BY GMet IN 2013

Zones	Onset Dates	Length, ($days$)	Cessation Dates
Forest	15th - 25th March/ 14th -24th April	253	3rd- 27th December
Coastal	3rd - 23rd April	245	24th October - 4th December
Transition	26th March - 5th April	185	30th October - 9th November
Northern	18th - 28th April	169	10th October

In all the three tables, the mean rainfall onset date for the forest zone was found to be around the last week of March (15th March - 14th April), with a mean cessation date in the early part of November. The length of the rainy season for this zone was found to be similar for all the tables but few for the RegCM4 model output. Whereas, the Coastal showed an mean rainfall onset date in the month of April but gave different dates for the cessation of the rains. The length of the rains for this zone was fewer from the analysis made from the GMet measured rainfall values but higher for the seasonal forecast. The mean rainfall onset date for the Transition zone was determined to be in the early part of April, whiles the mean cessation date was found to be in November. The length of the rains for this zone is similar but fewer for the seasonal forecast. Finally, for the Northern zone, the mean rainfall onset and cessation dates for this zone was determined to be in late April and late October respectively. The length of the rainy season for this zone was the same in all of the 3 tables.

The Forest, Coastal and Transition zones enjoy a bi- modal rainfall season which makes it the most productive zones in the country and also experiences an earlier onset dates of the rain than the other zones. The Coastal and Northern zone experiences lower rainfall amount and lesser length of the rainy season as compared with the other zones.

The results compared well with the seasonal forecast from the Ghana Meteorological Agency in 2013.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study investigated the onset, cessation and length of the rainy season using a simulated rainfall data from the fourth generation Regional Climate Model (RegCM4) and measured rainfall data from the Ghana Meteorological Agency (GMet) over Ghana from 1998 to 2012. The results from the RegCM4 was compared with those derived from the measured rainfall data. The following conclusions were made based on these research questions;

- What is the key definition of the onset and cessation dates of the rainy season in Ghana?
- What are the dry spells in the rainy season?
- What is the length of the rainy season in Ghana?
- When do we advise farmers to start planting their crops in Ghana?

The onset dates for the rains in a specific zone was determined as the first date within a five- day period, where the least total amount of rainfall was recorded to be at 20 mm. There was also not to be more than 7 days of dry period (without rain) between two rainy days. Any such date which did not meet these criteria was to be counted as a false date, hinting at a cessation date. Thus, an end of rain was determined as the last day before a long dry spell, when the water balance drops to zero. This definition as used in this project is adopted from (Dodd and Jolliffe, 2001). From the study, it was found out that that most of onset dates from both the RegCM4 and GMet rainfall datasets occurred within the second week of April (10th to 13th April), with some occurring within the last week of March and in the first week of May. Whiles the mean cessation date was computed to be 30th and 31st October (304 days) for the leap and perpetual years respectively from the RegCM4 downscaled rainfall model data. The mean cessation date was also found to be 11th and 12th November (316 days) for leap and perpetual years from GMet measured rainfall data.

In investigating the second question, a dry spell is based on the break of several days between two sucessive rainfall events, which is the significant decrease in water availability that result in plant wilting and dying. This was very instrumental in helping compute which dates was to be termed as wet and dry periods. The risk of seven (7) days of dry spells following planting tends to decrease rapidly, while it was noted that after thirty (30) days of planting, the average risk of having a seven (7) day dry spell period is about fifty (50) percent high.

The third question on the length of the rainy season was computed for each rainfall season for both the RegCM4 model and GMet rainfall dtasets by counting the number of days from the onset date to the cessation date for each of the agro-ecological zones in Ghana. The average length of the growing season was calculated to be about 202 days (almost 7 months) for the RegCM4 model rainfall periods, and about 213 days (7 months) for GMet rainfall periods.

The last objective was addressed using the length of the rainfall season from both the RegCM4 model and Gmet rainfall data as a guide. With seven (7) months length of the rainfall season, farmers can plan for two cropping and one cropping in respect of medium crops. If late maturing crops are to be cultivated, irrigation must be in place.

These results may have useful applications for water resource management and food security in Ghana.

5.2 Recommendations

It is recommended that this research should be used as a useful tool for determining the planting dates for the various agro-ecological zones.

A comparison of the results of this study with a similar work on a Markov Chain model, which is a representation of the overall chance of having rain during the growing period, starting from onset to the peaks/peak, and to the cessation could be carried out to provide the probability of having rains especially on specific days within the growing season.

The work was carried out for twenty synoptic stations to help determine the onset, cessation and length of the rainy season. Further work should be carried out using both the synoptic and agro- climatological stations within the country.

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Appendix A

MEAN ONSET OF RAINFALL

This consists of the table for all the stations which showing the respective onset dates from both the GMet measured rainfall values or the RegCM4 model.

A.1 FOREST ZONE

Table A.1: A DISTRIBUTION OF THE MEAN ONSET DATES FOR ABETIFI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	9th April	29th April
1999	8th March	26th February
2000	23rd May	15th April
2001	1st March	27th April
2002	7th April	30th April
2003	17th May	6th April
2004	22nd March	2nd March
2005	25th February	7th February
2006	3rd March	5th March
2007	15th March	1st April
2008	29th March	26th April
2009	15th April	9th April
2010	20th April	7th May

Table A.2: A DISTRIBUTION OF THE MEAN ONSET DATES FOR AKIM ODA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	20th April	25th May
1999	16th April	14th April
2000	20th March	29th April
2001	1st March	29th April
2002	7th April	20th April
2003	19th March	3rd April
2004	12th March	29th April
2005	28th February	27th March
2006	15th February	4th May
2007	1st April	30th April
2008	28th February	27th April
2009	8th February	8th May
2010	2nd March	13th April

Table A.3: A DISTRIBUTION OF THE MEAN ONSET DATES FOR AXIM FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	29th April	23rd April
1999	14th April	5th March
2000	1st May	22nd March
2001	20th February	23rd March
2002	7th April	25th March
2003	19th March	26th March
2004	29th April	7th April
2005	8th February	11th March
2006	4th April	18th April
2007	26th March	2nd April
2008	2nd April	12th March
2009	13th April	18th March
2010	26th January	15th March

Table A.4: A DISTRIBUTION OF THE MEAN ONSET DATES FOR TAKORADI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	29th April	22nd April
1999	1st April	6th March
2000	20th March	22nd March
2001	14th May	1st April
2002	7th April	25th March
2003	19th March	26th March
2004	13th May	4th April
2005	30th April	12th March
2006	8th May	17th April
2007	5th May	1st April
2008	29th April	17th March
2009	9th April	19th March
2010	27th January	16th March

Table A.5: A DISTRIBUTION OF THE MEAN ONSET DATES FOR KUMASI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	18th April	27th April
1999	23rd March	25th February
2000	17th April	12th April
2001	9th March	6th April
2002	28th March	12th April
2003	30th March	5th April
2004	16th March	2nd March
2005	23rd April	6th March
2006	14th February	21st April
2007	30th March	13th March
2008	18th March	19th March
2009	14th February	11th February
2010	17th February	20th March

Table A.6: A DISTRIBUTION OF THE MEAN ONSET DATES FOR KOFORIDUA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	22nd April	29th April
1999	17th April	26th February
2000	7th May	15th April
2001	2nd April	27th April
2002	6th April	30th April
2003	3rd April	6th April
2004	19th March	2nd March
2005	16th April	7th February
2006	3rd March	5th March
2007	7th April	1st April
2008	2nd April	26th April
2009	3rd March	9th April
2010	3rd April	7th May

Table A.7: A DISTRIBUTION OF THE MEAN ONSET DATES FOR HO FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	22nd April	20th March
1999	15th February	22nd February
2000	21st March	15th April
2001	11th March	10th March
2002	8th March	11th April
2003	19th March	6th April
2004	16th March	3rd April
2005	25th March	8th February
2006	16th February	18th March
2007	18th March	28th February
2008	25th February	19th March
2009	15th April	10th March
2010	5th February	11th March

A.2 COASTAL ZONE

Table A.8: A DISTRIBUTION OF THE MEAN ONSET DATES FOR ACCRA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	29th April	22nd April
1999	2nd June	14th April
2000	7th May	29th April
2001	18th April	29th April
2002	7th April	20th April
2003	29th May	3rd April
2004	27th May	29th April
2005	18th May	27th March
2006	7th May	4th May
2007	21st May	30th April
2008	31st March	27th April
2009	15th April	8th April
2010	17th May	13th April

Table A.9: A DISTRIBUTION OF THE MEAN ONSET DATES FOR ADA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	3rd May	29th March
1999	1st April	14th April
2000	3rd March	29th April
2001	3rd April	29th April
2002	13th May	20th April
2003	17th May	3rd April
2004	12th May	29th April
2005	17th May	27th March
2006	25th April	4th May
2007	21st May	30th April
2008	21st May	27th April
2009	13th April	7th May
2010	17th April	13th April

Table A.10: A DISTRIBUTION OF THE MEAN ONSET DATES FOR AKATSI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	29th April	20th March
1999	9th May	22nd February
2000	3rd March	15th April
2001	18th April	10th March
2002	7th April	11th April
2003	17th May	6th April
2004	19th March	3rd April
2005	24th April	8th February
2006	9th March	18th March
2007	11th May	28th February
2008	2nd April	19th March
2009	13th April	10th March
2010	2nd June	11th March

Table A.11: A DISTRIBUTION OF THE MEAN ONSET DATES FOR SALTPOND FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	29th April	12th April
1999	9th May	31st January
2000	20th March	15th March
2001	18th May	2nd March
2002	15th March	3rd March
2003	9th March	11th March
2004	26th May	1st March
2005	14th April	8th February
2006	7th May	23rd February
2007	11th May	28th February
2008	2nd May	11th March
2009	13th April	16th February
2010	24th April	25th February

Table A.12: A DISTRIBUTION OF THE MEAN ONSET DATES FOR TEMA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	4th May	22nd April
1999	9th May	14th April
2000	1st May	29th April
2001	16th April	29th April
2002	7th April	20th April
2003	9th March	3rd April
2004	25th May	29th April
2005	18th May	27th March
2006	7th May	4th May
2007	21st May	30th April
2008	27th April	27th April
2009	13th April	8th May
2010	27th May	13th April

A.3 TRANSITION ZONE

Table A.13: A DISTRIBUTION OF THE MEAN ONSET DATES FOR KETE KRACHIE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	21st April	8th May
1999	18th April	19th March
2000	23rd May	1st May
2001	24th April	18th April
2002	7th April	12th May
2003	14th April	25th March
2004	30th May	3rd April
2005	13th April	8th February
2006	20th May	19th April
2007	16th April	1st April
2008	12th May	23rd April
2009	5th June	27th May
2010	16th April	1st May

Table A.14: A DISTRIBUTION OF THE MEAN ONSET DATES FOR SUNYANI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	6th April	4th June
1999	9th March	17th April
2000	4th April	1st May
2001	16th March	27th May
2002	28th March	28th May
2003	23rd March	12th April
2004	22nd March	31st May
2005	4th May	3rd May
2006	5th March	30th January
2007	16th March	1st May
2008	31st March	27th April
2009	10th March	10th February
2010	8th March	2nd May

Table A.15: A DISTRIBUTION OF THE MEAN ONSET DATES FOR WENCHI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	7th April	9th May
1999	9th May	19th February
2000	10th April	1st May
2001	12th March	14th March
2002	26th March	12th May
2003	21st March	18th May
2004	1st April	3rd March
2005	9th April	9th February
2006	6th April	30th January
2007	29th March	12th May
2008	22nd April	25th April
2009	15th March	10th February
2010	14th February	20th March

A.4 NORTHERN ZONE

Table A.16: A DISTRIBUTION OF THE MEAN ONSET DATES FOR BOLE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	21st April	18th April
1999	6th April	19th April
2000	19th March	11th April
2001	15th April	2nd May
2002	4th April	15th April
2003	6th April	25th March
2004	27th April	25th March
2005	25th April	30th April
2006	23rd April	2nd May
2007	2nd April	4th May
2008	18th April	27th April
2009	11th March	16th April
2010	14th April	3rd May

Table A.17: A DISTRIBUTION OF THE MEAN ONSET DATES FOR NAVRONGO FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	17th May	15th May
1999	17th May	13th May
2000	23rd May	28th March
2001	26th May	14th May
2002	17th April	15th April
2003	16th April	18th May
2004	8th April	5th April
2005	3rd June	10th May
2006	28th May	14th May
2007	17th May	22nd April
2008	21st April	27th April
2009	23rd May	18th May
2010	22nd May	4th May

Table A.18: A DISTRIBUTION OF THE MEAN ONSET DATES FOR TAMALE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	15th May	23rd May
1999	29th March	25th May
2000	14th May	21st May
2001	5th April	12th May
2002	30th May	15th April
2003	6th April	26th May
2004	5th May	4th April
2005	21st May	30th May
2006	4th May	13th May
2007	27th April	4th May
2008	29th May	25th March
2009	21st May	27th May
2010	3rd June	30th April

Table A.19: A DISTRIBUTION OF THE MEAN ONSET DATES FOR WA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	22nd April	19th May
1999	28th March	2nd May
2000	7th April	21st May
2001	24th April	14th May
2002	15th April	26th May
2003	9th March	26th May
2004	14th April	6th April
2005	16th April	31st May
2006	23rd April	17th May
2007	30th April	22nd April
2008	4th May	24th May
2009	26th May	28th May
2010	5th April	2nd May

Table A.20: A DISTRIBUTION OF THE MEAN ONSET DATES FOR YENDI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	11th April	23rd April
1999	29th April	25th May
2000	21st April	21st May
2001	16th April	12th May
2002	17th April	15th April
2003	22nd March	26th May
2004	19th May	4th April
2005	21st May	30th May
2006	23rd April	13th May
2007	18th May	4th May
2008	14th April	25th March
2009	28th March	17th April
2010	16th April	30th April

Appendix B

MEAN CESSATION OF RAINFALL

This consists of the table for all the stations which showing the respective cessation dates from both the GMet measured rainfall values or the RegCM4 model.

B.1 FOREST ZONE

Table B.1: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR ABETIFI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	2nd October	2nd October
1999	15th November	2nd October
2000	20th November	3rd October
2001	11th December	27th October
2002	13th October	2nd October
2003	30th November	7th October
2004	22nd October	7th November
2005	8th December	3rd October
2006	31st October	21st October
2007	23rd November	2nd October
2008	11th December	3rd November
2009	2nd December	2nd October
2010	17th October	3rd October

Table B.2: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR AKIM ODA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	2nd October	28th October
1999	8th December	15th October
2000	26th October	19th October
2001	2nd October	29th October
2002	4th October	1st November
2003	2nd Ocotober	11th November
2004	27th November	1st November
2005	12th December	25th Ocotober
2006	26th November	8th November
2007	1st December	17th November
2008	17th December	21st October
2009	12th October	24th October
2010	22nd December	6th November

Table B.3: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR AXIM FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	15th October	30th November
1999	12th December	28th November
2000	5th December	20th November
2001	16th December	16th November
2002	23rd November	10th December
2003	11th November	17th December
2004	28th October	28th November
2005	13th October	9th December
2006	23rd December	1st December
2007	17th December	20th November
2008	15th October	11th November
2009	7th December	16th November
2010	9th December	18th November

Table B.4: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR TAKORADI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	15th November	27th October
1999	9th November	4th November
2000	18th November	18th November
2001	22nd November	15th November
2002	10th November	18th November
2003	26th November	16th November
2004	2nd December	26th November
2005	25th November	6th November
2006	7th October	14th November
2007	8th December	20th November
2008	5th December	13th November
2009	10th December	15th November
2010	8th December	18th November

Table B.5: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR KUMASI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	15th November	30th November
1999	7th December	27th November
2000	7th November	19th November
2001	8th November	12th November
2002	15th December	11th November
2003	3rd October	6th November
2004	11th December	2nd November
2005	3rd October	6th November
2006	8th October	10th November
2007	21st December	18th November
2008	23rd November	11th November
2009	20th October	14th November
2010	4th December	20th November

Table B.6: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR KOFORIDUA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	2nd October	2nd October
1999	27th December	4th October
2000	1st October	26th October
2001	2nd October	2nd October
2002	18th December	7th October
2003	6th December	8th November
2004	6th December	2nd October
2005	19th November	21st October
2006	16th November	2nd October
2007	14th October	4th November
2008	17th November	1st October
2009	2nd October	3rd October
2010	4th December	5th October

Table B.7: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR HO FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	21st October	14th October
1999	15th November	6th November
2000	21st October	11th October
2001	28th October	15th November
2002	25th November	29th October
2003	26th November	14th November
2004	19th December	2nd October
2005	29th November	5th October
2006	2nd October	22nd October
2007	21st December	3rd December
2008	27th December	20th November
2009	2nd October	3rd October
2010	9th December	4th October

B.2 COASTAL ZONE

Table B.8: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR ACCRA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	24th October	23rd October
1999	23rd October	14th October
2000	18th November	19th October
2001	2nd December	28th October
2002	10th November	14th December
2003	9th November	10th November
2004	25th October	1st November
2005	4th November	23rd November
2006	13th November	9th November
2007	20th November	17th November
2008	5th December	20th October
2009	8th October	21st October
2010	21st November	6th November

Table B.9: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR ADA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	28th November	22nd November
1999	3rd November	15th October
2000	28th October	20th October
2001	9th October	28th October
2002	22nd November	1st November
2003	8th December	30th October
2004	2nd November	31st October
2005	24th November	25th October
2006	4th November	9th November
2007	29th October	17th November
2008	29th October	19th November
2009	11th November	24th October
2010	5th October	6th November

Table B.10: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR AKATSI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	18th November	2nd October
1999	2nd October	2nd October
2000	6th October	1st October
2001	4th October	2nd October
2002	2nd October	2nd October
2003	13th December	14th November
2004	6th November	2nd October
2005	2nd October	5th October
2006	2nd November	2nd October
2007	4th October	2nd October
2008	4th October	1st October
2009	2nd October	3rd October
2010	1st November	4th October

Table B.11: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR SALTPOND FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	24th October	9th December
1999	2nd November	28th November
2000	4th November	6th October
2001	19th November	23rd November
2002	30th November	1st December
2003	14th November	18th November
2004	4th December	27th November
2005	15th November	11th November
2006	12th November	1st December
2007	15th November	16th November
2008	4th October	14th November
2009	20th October	19th November
2010	20th October	19th November

Table B.12: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR TEMA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	24th October	24th October
1999	23rd October	15th October
2000	29th October	4th October
2001	13th November	7th October
2002	5th November	20th October
2003	9th November	30th October
2004	29th October	31st October
2005	4th November	25th October
2006	22nd October	8th November
2007	20th November	17th November
2008	10th November	20th October
2009	28th October	24th October
2010	20th November	6th November

B.3 TRANSITION ZONE

Table B.13: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR KETE KRACHIE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	17th November	18th October
1999	3rd December	12th November
2000	26th November	2nd November
2001	20th October	2nd October
2002	8th December	30th October
2003	20th December	7th November
2004	11th December	7th November
2005	5th December	21st October
2006	29th November	19th November
2007	10th November	9th November
2008	30th November	20th November
2009	18th December	8th October
2010	12th December	21st November

Table B.14: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR SUNYANI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	19th November	27th October
1999	10th November	16th November
2000	4th October	11th November
2001	2nd October	2nd November
2002	2nd October	11th November
2003	16th December	17th November
2004	10th December	31st October
2005	12th December	6th November
2006	1st December	11th November
2007	22nd November	18th November
2008	12th December	13th November
2009	9th October	15th November
2010	21st November	17th November

Table B.15: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR WENCHI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Onset Dates,	RegCM4 Mean Onset Dates
1998	15th November	31st October
1999	17th November	1st December
2000	14th October	23rd November
2001	15th November	2nd December
2002	1st December	10th December
2003	12th December	18th December
2004	16th December	11th December
2005	20th December	3rd December
2006	14th December	4th December
2007	22nd December	18th December
2008	14th December	12th December
2009	6th October	15th November
2010	19th December	29th November

B.4 NORTHERN ZONE

Table B.16: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR BOLE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	29th October	14th October
1999	7th November	16th October
2000	19th November	11th October
2001	25th October	21st October
2002	3rd November	2nd October
2003	25th November	12th October
2004	19th Ocotober	22nd October
2005	3rd November	11th Ocotober
2006	12th November	22nd October
2007	12th November	30th October
2008	16th November	9th November
2009	9th November	3rd October
2010	28th November	2nd October

Table B.17: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR NAVRONGO FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	5th November	11th November
1999	21st November	17th November
2000	12th November	9th October
2001	27th October	13th October
2002	9th November	2nd November
2003	25th November	15th November
2004	3rd November	15th November
2005	22nd October	19th October
2006	9th November	23rd October
2007	5th November	6th October
2008	15th November	18th November
2009	15th November	4th October
2010	27th November	20th November

Table B.18: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR TAMALE FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	16th November	12th October
1999	15th November	31st October
2000	7th November	25th October
2001	16th October	4th October
2002	6th November	2nd October
2003	8th November	13th October
2004	20th October	27th October
2005	2nd November	16th October
2006	13th November	2nd October
2007	7th November	16th October
2008	8th November	8th November
2009	17th November	2nd October
2010	28th November	2nd October

Table B.19: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR WA FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	29th October	11th October
1999	9th November	6th November
2000	8th November	23rd October
2001	28th October	9th October
2002	27th October	25th October
2003	11th October	4th November
2004	25th October	5th November
2005	30th October	23rd October
2006	8th November	12th November
2007	12th October	26th October
2008	10th November	5th November
2009	12th November	2nd October
2010	2nd November	9th November

Table B.20: A DISTRIBUTION OF THE MEAN CESSATION DATES FOR YENDI FROM BOTH GMET AND REGCM4 MODEL

Years	GMet Mean Cessation Dates,	RegCM4 Mean Cessation Dates
1998	2nd November	12th October
1999	15th November	31st October
2000	12th November	25th October
2001	3rd November	4th October
2002	28th October	2nd October
2003	7th November	13th October
2004	12th November	27th October
2005	14th November	16th October
2006	4th November	2nd October
2007	18th November	15th October
2008	6th November	8th November
2009	26th November	2nd October
2010	25th November	2nd October