UNIVERSITY OF CAPE COAST

WEST AFRICAN MONSOON (WAM) JUMP AND ITS IMPLICATION FOR RAIN-FED AGRICULTURE IN THE TRANSITION AND COASTAL SAVANNAH AGRO-ECOLOGICAL ZONES OF GHANA

BY

KWESI AKUMENYI QUAGRAINE

Thesis submitted to the Department of Physics of the School of Physical Sciences, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for award of Master of Philosophy Degree in Physics

JUNE, 2014

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original work and that no part of it has been presented for another degree in this University or elsewhere.

Candidate's Signature:…………………… Date:………………..

Name: Kwesi Akumenyi Quagraine

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:………………… Date:……………….

Name: Mr. David Cudjoe Adukpo

Co-Supervisor's Signature:……………………..… Date:………………..

Name: Dr. Mrs. Nana Ama Browne Klutse

ABSTRACT

West African rainfall variability plays an essential role in the economies of West African countries it has a major influence on industrial and agricultural production, which is largely, weather dependent. This plays an important role in food security and water availability. This work focuses on the West African Monsoon (WAM) jump and its implication for rain-fed agriculture in the Transition and Coastal Savannah agro-ecological zones of Ghana. In this study, the seasonal rainfall variability over West Africa is investigated using GPCP satellite data. Again, rainfall data from Wenchi in the Transition zone and Saltpond in the Coastal Savannah agro-ecological zone from 1990 to 2008 were acquired from the Ghana Meteorological (GMet) Agency for the study. The seasonal rainfall variability over these synoptic stations was studied in two climatological periods from 1990-1998 and 2000-2008 hereafter called CP1 and CP2 respectively. The agricultural implication is also checked. The results helped establish the rainfall regimes between these two climatological periods with CP1 being wet and CP2 being dry across West Africa. The rainfall peaks was found to have been shifting to later dates in CP2. Rainfall intensity in Wenchi was found to have a little reduction in the later part of the year across both CP1 and CP2 with the effect much felt in CP2. Saltpond also suffered a significant decrease in rainfall intensity over the minor season. Length of rainfall in high maize yield years selected randomly was found to be higher than that of randomly selected low maize yield years in Wenchi whereas in Saltpond, rainfall length was higher in low yield years than the that of the high yield years.

ACKNOWLEDGEMENTS

It's been His mercies and His grace that has kept me entirely through the course of this study and I am grateful. This dissertation would not have been completed without the help from a number of people. I would like to express my appreciation to those who contributed in diverse forms to this work.

I thank my family for showing me a lot of love, support and encouragement during my study period. I am so much lucky for having you.

This research has benefited greatly from the contribution that I enjoyed from my supervisors, Dr. Nana Ama Browne Klutse and Mr. David C. Adukpo. Their support, patience and critical comments enriched the quality of the study. I am much grateful and will forever be indebted to them.

I thank the office of the United State Agency for International Development (USAID) for their support in diverse ways through the Partnership for Enhanced Engagement in Research (PEER) Science Project carried out in the Department of Physics. This gave me the platform to attend conferences and various workshops. I am most appreciative.

I am also grateful to all lecturers and staff of the Department of Physics for their support in various ways. Words cannot express my sincere gratitude to my friend and colleague, Francis Nkrumah, for all the support you gave me to make my study a success. I am much gratifying.

Ultimately, my unreserved appreciation goes to all others who in diverse ways contributed to the progress of my studies. My unreserved apologies to all I couldn't mention. I say God bless you.

DEDICATION

To my family and friends.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Rain-fed agriculture is an essential economic activity in the developing world. Universally, rain-fed agriculture is practiced in about 80% of the total agricultural area and it generates around 60% of the world's staple food (FAOSTAT, 2005; Bhattacharya, 2008). In sub-Saharan Africa, 93% of cultivated land is rain-fed according to FAO (2002) and thus the crucial role of food security and water availability (Hagos et al., 2007; Wani et al., 2009).

Evidence has shown that the rainfall pattern has changed and continues to change worldwide (IPCC, 2007). In West Africa, the changes occurring in rainfall has been attributed to a number of activities but strongly linked to the Monsoon system (Redelsperger et al. 2002). The West African Monsoon system is normally used to describe the seasonal rains that occur in West Africa. Over the years, it is directly tied to the food and water security in the West African sub-region region. Ward et al., (1992) studied the Sahel rainfall variability using corrected surface wind data, Shinoda and Kawamura, (1994) worked on the Sahalien rainfall trend vis-à-vis the tropical rain-belt circulation and sea surface temperatures, Sultan and Janicot (2000) also studied the abrupt shift of the ITCZ over the West African region and its intra-seasonal variability, Nicholson and Grist, (2001) also reported on the seasonal variability of atmospheric circulation.

Rainfall variability has been a global concern as most of the world's population resides in monsoon regions and these growing societies are becoming increasingly vulnerable to the variability in the monsoon precipitation (Wang and Ding, 2006). Floods and droughts which occur as a result of changes in monsoon system affect agricultural and industrial production and most often than not causes damage to properties, human suffering through diseases and in the long run deaths to the people residing in these monsoon regions. This makes the monsoon a very important system to understand. By understanding the monsoon system, there is the potential for predicting the probability of the occurrence of the relevant climate related socio-economic impacts.

Figure 1 shows the interaction frame of the monsoon system on various socially relevant climate related factors. The monsoon system, which consists of an interaction between coupled ocean-atmosphere system and land processes such as the hydrological cycle, interact with rain-fed agriculture through drought or flooding conditions and the biosphere through high, warm or cool sea surface temperatures. These go on to influence the socio economic impacts of the world at large by increasing or decreasing crop yield (agriculture) and the spreading of diseases (biosphere).

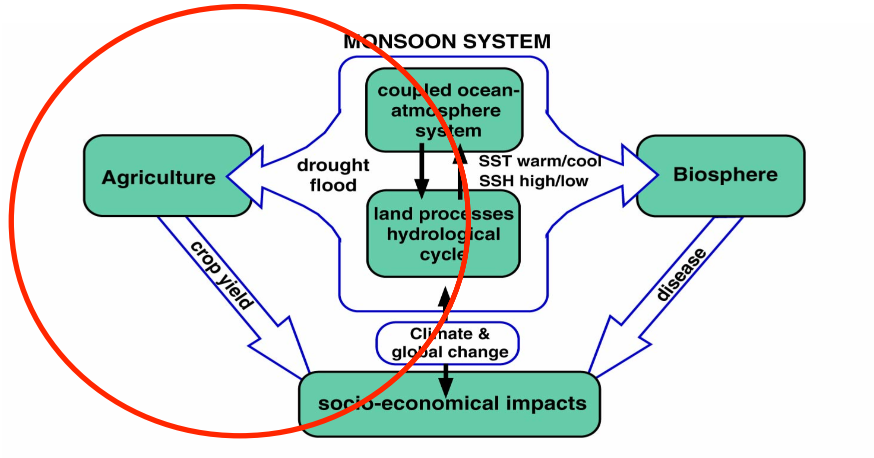

Figure 1: Pictorial representation of Monsoon interaction with other socially relevant climate related impacts. (Georgia Institute of Technology, School of Earth and Atmospheric Sciences)

Research Objectives

The main objective of the thesis is to investigate the variability of the WAM jump and its effect on the rainfall pattern of the Transition and Coastal Savannah agro-ecological zones of Ghana. The study will specifically:

1. Compare the intensities of the rainfall for past and present climate referred to as Climatological Period 1 (CP1) and Climatological Period 2 (CP2) respectively over the Transition (Wenchi) and the Coastal Savannah (Saltpond) agro-ecological zones.
2. Examine the effect of monsoon jump on agriculture in these agro-ecological zones using Maize production and its yield over the years to justify the effect.

Organization of Thesis

This thesis consists of five main chapters. The first chapter gives an introduction of monsoons and their economic importance. The objectives of the study and the organization of the thesis are also incorporated in this chapter. Chapter two reviews the literature on monsoon, its formation and its variability across West Africa. It also gives an overview of agriculture in both the Coastal Savannah and the Transition agro-ecological zones. Chapter three offers the methodology used for the simulation as well as analysis for the research work. Results and discussion are presented in Chapter four. In the fifth chapter, conclusions are drawn and recommendations are given to aid further research in this area.

CHAPTER TWO

LITERATURE REVIEW

The Monsoon System

Monsoon, a borrowed Arabic word which means 'season' was used by early sailors to represent the reversal of wind, which were mainly accompanied by changes in precipitation. A monsoon is simply wind in low-latitude climates that seasonally changes its course between winter and summer. Edmond Halley, an astronomer in 1686, first suggested monsoon formation. In his proposed model, monsoon was viewed as a giant sea-breeze circulation, which was driven by the differences in heat capacities between land and ocean surfaces. Once heated by sunlight, it led to temperature differences between the warm land and the cool ocean surface.

Gilbert Walker began to study the effects of monsoons in India looking for patterns in climate data when India experienced some drought and famine in 1876-1879. Walker was convinced after his studies that there was a seasonal and directional reason for monsoon variability. He went on to use “Southern Oscillation” in describing the east-west seesaw effect of pressure changes he saw in the climate data acquired. Walker proposed that Asian monsoon seasons were often to blame for some of the drought in Australia, India, Indonesia and parts of Africa. Bjerknes later confirmed that the wind circulation as well as rain and the weather in a big picture were all linked to Pacific-wide air circulation he named Walker circulation. It is known that during winter, the winds blow from the cool land to the warm ocean and this can be attributed to the change in position of the sun over the Earth over the course of the year. These winds are giant land and sea breezes, which come about as a result of the seasonal changes in the circulation (Griffiths, 1972). The difference in temperature, that is when the sun's rays is directly focused on the land and when it is not drives the surface pressure contrast between the ocean at high pressure and the land at low pressure and this creates the monsoon circulation. It is known that monsoon circulation is caused by factors such as the distribution of solar heating due to seasonal oscillation where in the summer hemisphere the net radiation is positive, again, the distribution of heat between land and sea which results in large temperature difference as a result of apparent heat capacity of land and oceanic surfaces (Griffiths, 1972; Nicholson, 2013). The land-ocean interaction occurs as a result of molecular diffusion that transports heat downward in the land whereas in the ocean allows heat to be transported downwards and stored easily. Moreover, the Earth's rotation plays a role in ensuring that the coriolis force affects location and intensity of winds and ocean currents.

During monsoon circulation, the winds are weak in springtime but stronger in the summer and opposite in direction during the winter season in the Northern Hemisphere. According to Ramage (1971) and Fontaine et al. (1998), maximum Sea Surface Temperatures (SSTs) are recorded mostly in March-April-May and are comprehensibly low in December-January-February. Monsoon moisture comes from the Southern Hemisphere water cycle with divergence occurring in the Southern Hemisphere and convergence in the Northern Hemisphere. Hence the driving force that shapes monsoons is the difference in the heating of land and ocean surfaces leading to the formation of land-ocean pressure differences.

Researchers, Schneider and Bordoni (2008), used computer generated, water-covered, hypothetical earth to simulate the formation of monsoon found that the differences in heat capacities between land and sea were not necessary in the formation of monsoon. They attributed monsoon formation to tropical circulation and large-scale turbulent eddies generated in the mid latitudes in the atmosphere. According to their theory, the eddies which can span more than 300 miles across, form the familiar systems that govern the weather in middle latitudes. They go on to assert that the eddies which are large waves crash into the tropical circulation and 'break' like water waves on the beach leading to the modification of the tropical circulation. The impact of the 'break' sends feedbacks between the circulation and the winds associated with it in the upper atmosphere and its propagation characteristics altered making it possible for exhibition of rapid circulation change. This then generates high surface winds and leads to heavy monsoon rainfall. Schneider and Bordoni (2008) suggested that these feedbacks provide one possible explanation for the rapidity of monsoon onset and those substantial differences between land and sea temperatures can only develop slowly through solar heating.

There are two forms of monsoon systems, the Dry monsoon (dominant North-easterly winds) and Moist monsoon (dominant South-westerly winds).

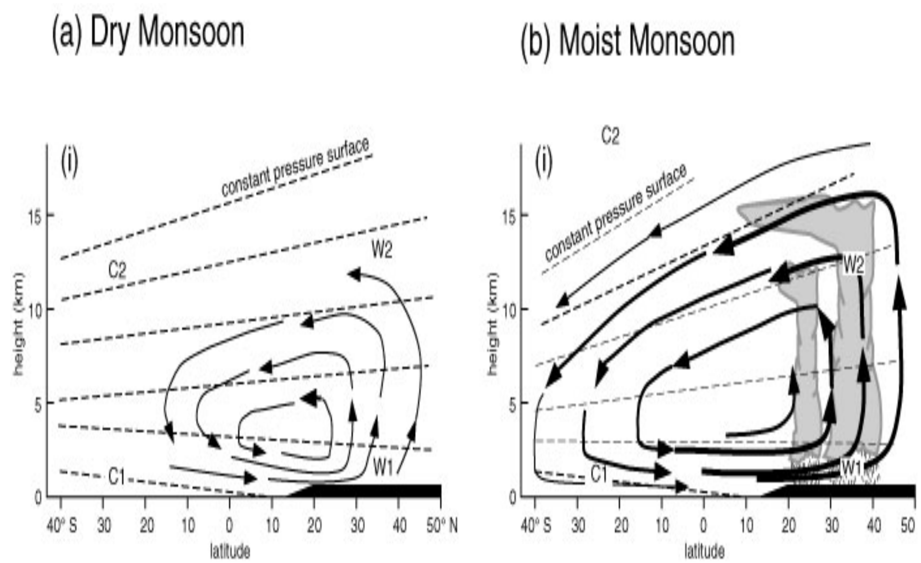

Figure 2: Two forms of monsoon systems (a) Dry monsoon and (b) Moist monsoon

West African Climate

West Africa covers an area between longitudes 20°W and 20°E and latitudes 20°N and 0° spread. West Africa is situated in the tropics covering four tropical regions. Humid areas like the equatorial forests in the south, semi-humid areas as the Guinea savanna, semi-arid areas like the Sudan savanna, and the arid Sahel in the north. Climate is the weather averaged over a long period of time preferably 30 years and over as described by the WMO. This includes statistics other than the average, such as the magnitudes of day-to-day or year to year or sometimes decadal variations. Different climate zones can be defined using parameters such as temperature and rainfall. The rainfall trend in West Africa is linked to the seasonal movement of the ITCZ where the dry and hot tropical easterly winds blowing in from the northeast meet with the humid air masses coming from the Southern Atlantic Ocean which is connected to the onset of the monsoon. The Sahel and Sahel-Saharan belt experiences a single rainy season and together are called the semi-arid region, there is much rains in the Sahel around July and September whereas further south, somewhere along the Guinean coast, there is an alternation of two rainy seasons and two dry seasons.

The northern and southern Atlantic Ocean and Indian Ocean water surface temperature changes as well as the surface temperature discrepancies in the Pacific linked with El Nino are an important driving force for the WAM activity. As a result of temperature variations in oceans, which in turn is sensitive to the global climate changes, there would be serious consequence on the WAM. Sub-Saharan Africa is an area in the world which has experienced significant climate discrepancies over the last century and as such has experienced a sharp metamorphosis from wet conditions around 1950 to dry conditions in 1980 and this has been recorded as one of the major inter-decadal signals of the twentieth century (Redelsperger et al. 2006). Again, according to the Intergovernmental Panel on Climate Change (IPCC) report in 2007, the drought experienced in late 1970 is the severe and longest drought on a continental scale in the century in the world. The climate in Sub-Saharan Africa is purely dominated by the WAM system, which can boast of about 1500mm to 2500mm mean annual rainfall per year.

The West African Monsoon Characteristics

Air mass systems over West Africa are mainly African Easterly Waves (AEW), African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ). The predominant air masses influence the weather patterns across the Sahara. A typical air mass is the African Easterly wave, which has its source from northern of Africa (Sylla et al., 2013). The Jet streams such as Tropical Easterly Jet stream and African Easterly Jet, plays an important role in monsoon formation and circulation. The role of the air masses on the West African weather pattern are discussed vis à vis monsoon formation.

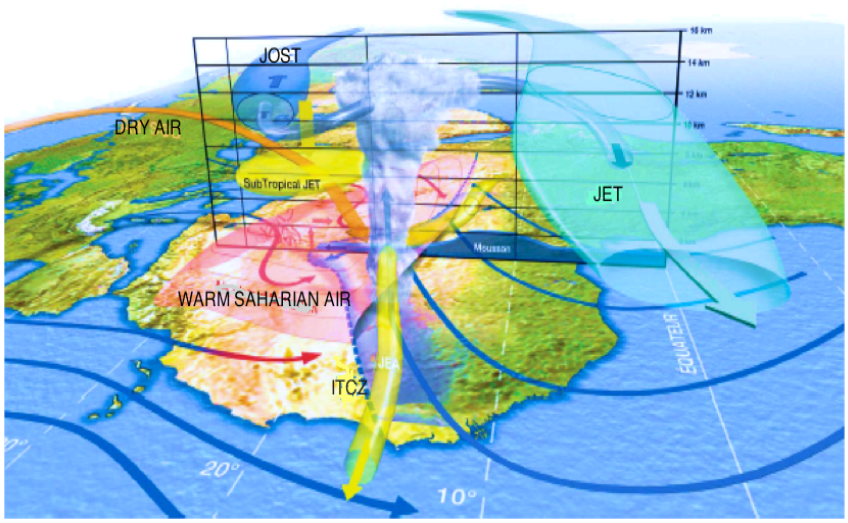

Figure 3: Schematic view of the West African Monsoon system adopted from Lafore et al. (2010)

African Easterly Waves

African easterly waves (AEWs), are waves that travel west and begin across northern Africa mainly between June and October. They exhibit a horizontal wavelength of around 2500 km within a period of 3-5 days, and travel westward at a pace of 500-800 km per day. The formation of AEW suggests that they are formed as a result of the breakdown of the ITCZ or the growth of the instabilities associated with the African easterly jet (AEJ). Currently, a new theory, however, suggests that AEWs are formed as a result of latent heating associated with mesoscale convective systems over eastern Africa (DeLonge et al. 2006). AEW expands as result of combined barotropic-baroclinic energy conversion process to the detriment of the AEJ.

Again, their largest amplitude is obtained near the west coast of Africa and decays after emerging over the eastern Atlantic Ocean 6-8 days after their formation. The largest wave amplitude is found at approximately 650 hPa and the waves exhibit a vertical tilt against the shear vector such that under easterly vertical wind shear, AEWs tilt to the east with increasing height. (Cornforth et al. 2009) Substantial variability in AEW structure and evolution exists due to variability in the side of the AEJ on which they form and the intensity and structure of the AEJ. AEWs, particularly those that form in moist environments south of the AEJ, serve as the seedling disturbances for tropical cyclone formation in the north Atlantic and eastern north Pacific Ocean basins.

African Easterly Jet (AEJ)

The AEJ is a middle tropospheric jet located over much of tropical northern Africa during the northern hemisphere summer. The jet is strongest in May and June, when its mean core speed is on the order of 12 m/s in the western sector (10° West to 10° East) and 10 m/sin the eastern sector (10° East to 30° East). There is a decrease in speed by some 2 m/s during the Sahelian phase of the monsoon in the boreal summer. The mean monthly speed of either of the cores can sometimes appreciate to 16 m/s during the boreal summer. It has been observed that the intensity of both cores changes from year to year, with the western core being more prominent in wet years and the eastern core being more prominent in dry years (Nicholson and Grist 2003; Cornforth et al. 2009). It exhibits large vertical and horizontal wind shears.

The vertical wind shear associated with the AEJ is crucial to the organization of moist convection and the generation of squall lines while both horizontal and vertical wind shears are important for the growth of AEWs (Burpee, 1972 as cited in Nicholson and Grist 2003). AEWs grow at the expense of the AEJ but the AEJ plays a crucial role in the West African monsoon system and is largely in geostrophic balance.

The AEJ is associated with an ageostrophic circulation that enhances upward motion and deep convection south of the jet and downward motion along and north of the jet. It is maintained by two separate diabatically-forced meridional circulations (Tompkins et al. 2005). The first, associated with dry convection in the Sahara, is characterized by the contrast in sensible heating between the warm Saharan air over northern Africa and cooler air in the equatorial latitudes. This contrast results in a positive meridional potential temperature gradient that brings forth the strongly vertically-sheared easterly zonal wind between 850-650 hPa associated with the AEJ. The second is associated with deep, moist convection that leads to upper tropospheric heating equator-ward of the AEJ. The observed westerly vertical wind shear with the AEJ in the upper troposphere results from the reversal of the meridional potential temperature gradient associated with this heating at equatorial latitudes.

Significant intra-seasonal and inter-seasonal variability in the AEJ exists due to variability in rainfall across northern Africa. Reduced precipitation reduces the soil moisture content of the soils across the southern Sahara and northern Sahel regions of north Africa, resulting in stronger near-surface sensible heating and deeper mixed layers. The AEJ tends to be stronger when the heating is strongest and mixed layers are deepest over these regions. Such conditions lead to an enhanced meridional temperature gradient (and, subsequently, stronger AEJ) between the Sahara and equatorial regions of Africa. The AEJ tends to be weaker when heating is weak and mixed layers are shallow, thus weakening the meridional temperature gradient (and, subsequently, AEJ) across northern Africa.

Tropical Easterly Jet (TEJ)

The tropical easterly jet (TEJ) is an upper tropospheric easterly jet around 100-150 hPa, which spreads across the tropics from the Eastern Indian Ocean to Western Africa (Leroux, 2001). The jet extends to approximately 20-30 degrees and the maximum wind speed it brings along are on the order of 35-40 m/s and is found within 5-10°N from south of India towards the east coast of Africa. Indeed, the TEJ is intricately linked to monsoon, particularly its divergent upper tropospheric anticyclone, it exhibits weak characteristics when the monsoon is weak and strong when the monsoon is strong, suggesting that variability in the monsoon also modulates variability in the strength of the TEJ (Cook, 1998).

It can be explained that the jet becomes much more prominent once the monsoon starts for the season and diminishes once the monsoon has ended for the season. Thus, it is an important feature of the tropics, which occurs only during northern hemisphere summer. Deep, moist convection forms preferentially in the right entrance and left exit regions of the jet, typically located over central to western Africa. These regions are those in which upper tropospheric divergence is promoted, as can be demonstrated from concepts of geostrophic and ageostrophic flow. Thus, variability in the structure, intensity, and location of the TEJ can impact the development of deep, moist convection. The right entrance region of the jet also happens to correspond to the upward branch of the Walker circulation that extends from southeast Asia eastward across the Pacific Ocean. Kinetic energy associated with the TEJ forms preferentially in the upstream region of the jet, is transported downstream by the TEJ, and is subsequently destroyed in the exit region of the jet. The link between the TEJ and rainfall appears to be primarily upper-level divergence associated with the jet core. The divergence results from strong meridional components associated with the TEJ over Africa (Nicholson and Grist 2003). This pattern is particularly pronounced in wet years in the Sahel, and this appears to play a role in its impact on rainfall (Nicholson 2009). This is further consistent with the observation that a stronger TEJ is linked not only to more rainfall in the Sahel, but also a more intense rain-belt (Nicholson and Grist, 2003; Nicholson, 2009).

The Physics of the ITCZ

In the tropics, surface moisture and albedo distribution creates a sensible heating maximum throughout the year. This causes the air to be constantly heated and as a result, it expands and thereby becomes less dense and much more buoyant. This rising warm air expands adiabatically (since pressure decreases as you rise high in the atmosphere) by doing work to drive away the surrounding air, causing it to cool in the process and leaving behind a trail of low pressure. Again, the water vapour content of the rising air cools, leading to the formation of cloud droplets. These tend to collide with each other until they become bigger that the cloud cannot hold and it falls as rain.

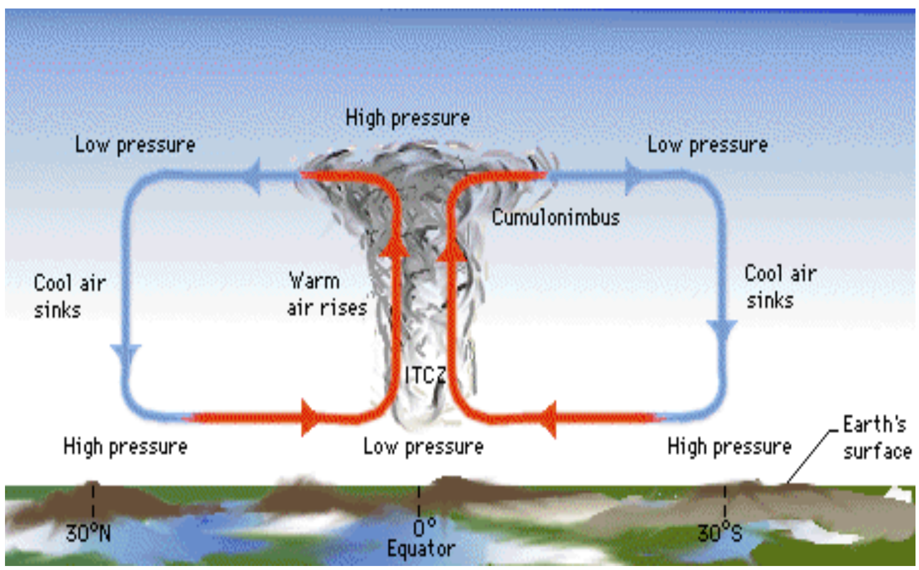

Figure 4: Formation of the ITCZ from MSN Encarta 2008

The rising air upon hitting the troposphere, spreads out towards the north and south of the equator and gives off energy into space as it travels towards the poles thereby cooling and becoming more dense. It must be noted that the excessive heat absorbed at the surface over the tropics is transferred to the lower troposphere through evaporation then transported to higher altitudes through convection. It begins to descend to the surface of the earth warming and compressing as well as arranging itself in packets filled with high pressure after traveling to about 30 degrees latitude. These packets of air rushes to the equator as a result of the fact that air moves from a region of high pressure to a region of low pressure thereby completing the loop above in figure 4. This loop of airflow is known as the Hadley cell.

West African Monsoon

West African Monsoon (WAM) arises as a result of the drift in the Inter-tropical Convergence Zone (ITCZ) and the seasonal temperature as well as the humidity differences between the Sahara and the Atlantic Ocean. The monsoon is forced and maintained by the land-sea thermal differences. The ITCZ migrates seasonally towards the north leading to the development of the monsoon, which is developed during the northern spring and summer.

Classical Understanding of the West African Monsoon

The West African monsoon in its classical sense is revealed in figure 5. It is evident that rainfall is linked with a surface feature, which is Inter-Tropical Convergence Zone (ITCZ). The ITCZ travels with the sun thereby moving northward into West Africa in the boreal summer and southward into southern Africa in the austral summer and it crosses the equatorial regions twice. In this classic picture, the ITCZ over West Africa is located by the convergence of the Harmattan winds from the northeast that originate in the Sahara and the monsoon flow from the southwest that emanates from the Atlantic. The production of rain results from local thermal instability, facilitated by the low-level wind convergence within this zone (Griffiths 1972). The rapid increase in rainfall from the Sahara to the humid equatorial zone was assumed to relate to a rapidly increasing depth of the moist layer equator-ward from the ITCZ (Griffiths 1972).

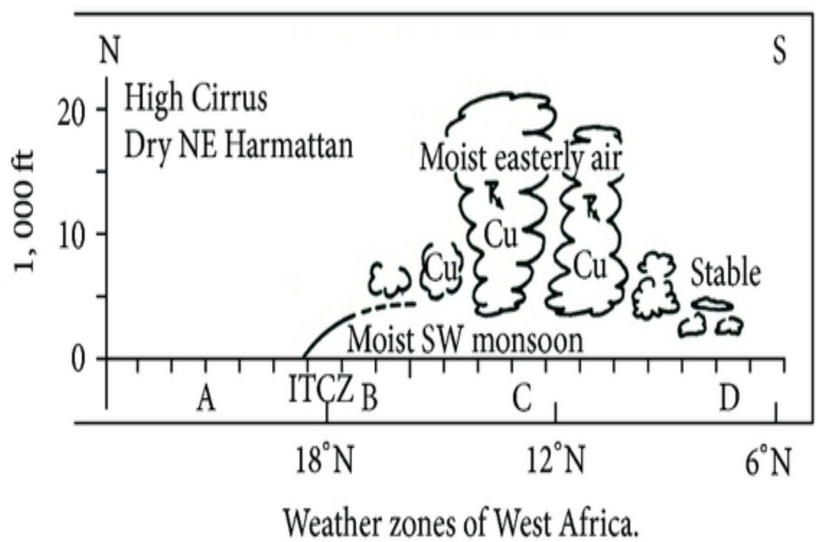

Figure 5: Classical picture of the ITCZ over Africa during the boreal summer (Griffiths 1972).

The picture of the classical West African monsoon has many defects. A typical example is its use of the concept of Hadley circulation as its origin with rising motion in the equatorial latitudes where the trade winds converge and settle down normally exhibiting sinking motion in the subtropical latitudes where the subtropical highs prevail. This ideology was adapted to describe the global mean state and not individual regions. Zhang (2006) asserts that it basically holds throughout the oceans where the trade winds are well developed but over the continents the pattern works poorly because of the absence of the trade winds. This picture of the ITCZ was also developed at a time when tropical rainfall was assumed to be local in origin, which came about as a result of thermal instability in warm and humid air, with ascent facilitated by surface wind convergence. It became well established in 1970 that tropical rainfall is instead linked to large-scale disturbances often associated with traveling waves (Mason 1975).

Moreover, the term “ITCZ” is ambiguous as various literature offer three very different definitions based respectively on wind convergence, surface air pressure and rainfall or outgoing longwave radiation. Yan and Oliver in Encyclopedia of World Climatology (2005) assert that the ITCZ is “an east-west oriented low-pressure region near the equator where surface northeasterly and southwesterly trade winds meets. When they converge, moist air is forced upward, producing cumulus clouds and heavy precipitation”. According to Miller and Schneider (1996) in the Encyclopedia of Weather and Climate, recalls that it is “a region near the equator where the trade winds converge” whiles Holton et al. (1971) defined the ITCZ as the “loci of cloud clusters associated with westward-propagating tropical wave disturbances”.

As a consequence of the ambiguity in defining the ITCZ, its tracking may be based on a pressure minimum, a surface wind convergence, a maximum in rainfall, a minimum in outgoing longwave radiation, or a maximum in cloudiness. Due to this, so many different parameters have been justified by the assumptions that (1) the pressure minimum and rainfall maximum are co-located with each other and with the wind convergence, (2) maximum cloudiness is roughly co-located with maximum rainfall, and (3) longwave radiation is at a minimum at that location. Unfortunately, these assumptions, especially the first one, do not stand up to close scrutiny. Even over the ocean regions the zone of minimum pressure does not generally coincide with that of the wind convergence or the rainfall maximum (Tomas et al. 1999). These ideas give problems when applied over West Africa, as new research on the West African monsoon has dramatically shown that the ITCZ as defined by surface wind convergence lies some 1000 kilometers to the north of the zone of maximum rainfall, as does the zone of maximum ascent by Nicholson (2009). In addition to this, rainfall over the Sahel is associated with African easterly waves and with large Mesoscale Convective Systems (MCSs), rather than local thunderstorms. It is also estimated that 12% of the total number of MCSs produce 90% of the rainfall during the peak rainy season (Lebel et al. 2003) and very intense MCSs, which comprise some 3 to 4% of the all rain events, produce up to 80% of the rainfall that occurs in the Sahel according to Nesbitt and Zipser (2003).

Revised View of the West African Monsoon

The West African atmospheric circulation portrays the most basic characteristics of the monsoon, which occurs due to the seasonal wind shift that is produced by thermodynamic contrasts existing between the Sahara and the Atlantic. This leads to the southwesterly flow being established between the Atlantic cold tongue which according to Peyrillé et al. (2007) and confirmed by Thorncroft et al. (2011) is said to be cool water close to the equator between the boreal spring and summer and the Saharan heat low, bringing moisture into the continent. The annual evolution of moisture fluxes, convergence and rainfall is closely tied to these two systems. The basic surface circulation is illustrated below:

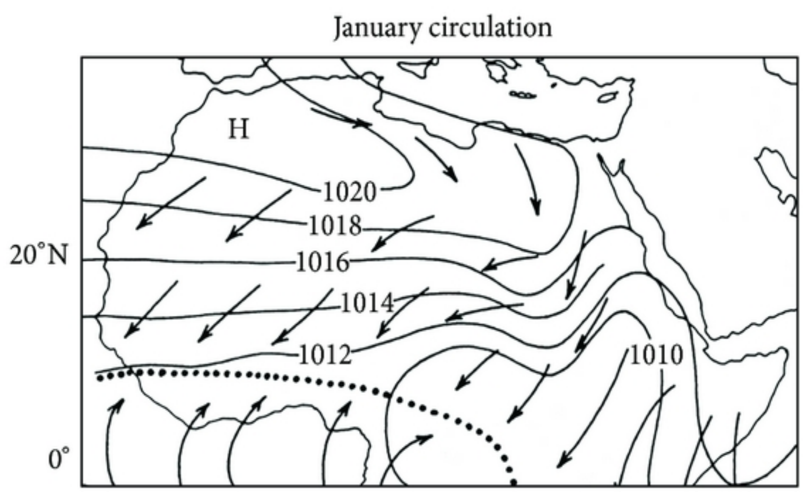

Figure 6: Schematic of surface wind (arrows) and pressure (mb) over West Africa during winter and at the peak of the summer monsoon for January circulation

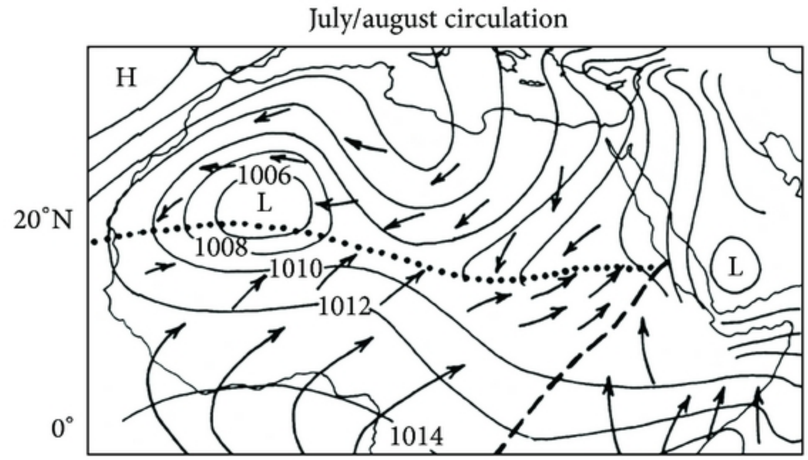

Figure 7: Schematic of surface wind (arrows) and pressure (mb) over West Africa during winter and at the peak of the summer monsoon for July/August circulation

According to Lavaysse et al. (2010), an intense heat low develops over the Western Sahara during the boreal summer bringing with it the cyclonic flow which includes the southwesterly monsoon flow to the south and the northeasterly Harmattan to the west of its core. This is termed the Saharan Heat Low or West African Heat Low and this system plays an important role in controlling the northward penetration of the monsoon as asserted by Peyrillé (2007).

It has been found that in the boundary layer close to the ITCZ, there is geostrophic balance whilst to the south there is advective balance, that is, there are parcels of air accelerating. Krishnamurti et al. (1983c) revealed that at the north of the equator, the flow is accelerated with little hindrance towards low pressure and that this acceleration may be under the influence of inertial instability.

When a zonal flow *U(y,t)* varying in both space and time and is in a geostrophic balance is perturbed, the motion is not steady but we assume that the perturbation pressure gradient and the friction are negligible. Considering a large scale, steady boundary flow, we have:

$$\frac{du}{dt} = \zeta v \qquad (1)$$

$$\frac{dv}{dt} = -fu \qquad (2)$$

where, $\boldsymbol{\zeta = f - dU/dy}$ is the absolute vorticity of the basic flow. Considering the relative vorticity to be negligible compared to $\boldsymbol{f}$, then equation 1 shows that in the northern hemisphere a velocity in the *x* direction, u, leads to an acceleration in the negative *y* direction. It is noted that once this negative *y* velocity, *v* gains prominence, according to equation 2, then a negative *x* acceleration opposing the original motion will be formed. Also, once the negative *u* is developed, then a positive acceleration in the *y* direction exists. It can be concluded from the solution of these two equations that air moves anti-cyclonically in inertial circles with a frequency $\boldsymbol{f}$. Considering a basic flow whose relative vorticity is anti-cyclonic, then, equation 1 reveals that the generation of *u* is weakened. Consistent with this, its solution shows that the trajectories around them keep decreasing. However, if the basic relative vorticity is so anti-cyclonically biased leading to the reversal of the sign of the absolute vorticity, then the restoring effect of the Coriolis parameter in the x momentum equation is lost and inertial stability is achieved.

It should also be noted that the system accountable for rainfall remains the same as that associated with large-scale rainfall over the tropics. However, the monsoon is said to be associated with the seasonal migration of the ITCZ, which is in response to the seasonal variation of the incident solar radiation. Monsoon regions are mostly characterized by larger amplitude of the seasonal variation than other areas.

West African Monsoon Jump

The WAM jumps quickly northward from about 5° N in May-June to 10° N in July-August according to Sultan and Janicot (2000) and this determines the wet and dry seasons in West Africa following the northward movement of the Inter-tropical Convergence Zone (ITCZ). The monsoon jump can be described as the onset of intense convection and rainfall along latitude 10° N accompanied by a sudden termination along the Guinean Coast. Again, it is told that the continuous seasonal migration of the ITCZ gives rise to two rainy seasons along the Guinean Coast but results in a single rainy season over the Sahel (Hagos et al. 2007).

The shift between the maximum at 5° North in the coastal phase and 10° North in the continental phase is very abrupt (Sultan et. al 2000), bringing about the term “monsoon jump”. Various explanations have been proposed to account for the abrupt shift. Sultan and Janicot (2000) suggest it is triggered by westward-propagating disturbances. Sijikumar et al. (2006) and Ramel et al. (2006) implicate the Saharan heat low, which intensifies and shifts northward at the time of the “jump” whilst Gu and Adler (2004) pointed out that the shift is associated with a northward shift of the African Easterly Jet and associated horizontal and vertical shear zones, as well as the development of westward-propagating waves. Again, it is suggested that the shift is related to the interaction of the Atlantic equatorial cold tongue and the African monsoon (Okumura and Xie 2004) whiles Sultan et al. (2003) suggests the complex interactions among convection, AEJ dynamics and local topography, especially the Ahaggar Plateau and Tibesti highland are also responsible for the jump. Their work also pointed out that when the heat low is sufficiently intense, it leads to a reversal in the potential vorticity gradient and, consequently, there is a generation of AEWs and convection. The shift begins with a release of potential instability leading to the inertial instability shifting the rain band to 10° N (Hagos and Cook 2007). The underlining of all these mechanisms is the northward shift and intensification of the latitudinal temperature and pressure gradients over West Africa. Changes in the heat low and the instability mechanisms are probably direct consequences of the increased gradients. The northward shift of the AEJ, shear zones, wave's disturbances, and convection can be viewed as results of the aforementioned factors.

Rainfall Variability over West Africa

West African populace mainly relies on rain-fed agriculture as a source of livelihood. Rainfall variability has however hindered maximization of agricultural produce, which is supposed to be their main source of income generation.

Farmer and Wigley (1985) reported a decline in rainfall in terms of intensity, duration and its seasonal expression over the West African sub region.

Ward et al., (1990), Shinoda and Kawamura, (1994) and Nicholson and Grist, (2001) all seem to confirm the existence of a correlation between inter-annual rainfall variability in West Africa and patterns of sea surface temperature (SST) anomalies in the tropical Atlantic, Pacific and Indian Oceans. Ward (1992) also found that SST forcing from all three major ocean basins might contribute to seasonal Sahelian rainfall variability. Bader and Latif (2003) suggested that the Sahelian rainfall variability is usually associated with warming in the tropical Indian Ocean SST since 1950s.

Again, according to Nicholson et al., (2000) and Hulme et al., (2001) the El Niño-Southern Oscillation (ENSO) in the tropical Pacific Ocean has vital factors influencing rainfall variability for some regions in Africa and may be more strongly associated with Sahelian rainfall than with that of the Guinea Coast region (Ward et al. 2004). Hulme et al. (2001) in their detailed analysis of African climate change observed a strong ENSO relationship for equatorial east Africa (high rainfall during a warm ENSO event) and southern Africa (low rainfall during a warm ENSO event), consistent with earlier studies. In Africa, West Africa in particular, there has been a controversy on the influence of the ENSO on rainfall. There is a controversy over its influence in the Sahel although there is a general consensus among researchers on ENSO’s influence in some regions, for instance the Guinea coast, where it tends to increase rainfall (Nicholson, 2001). Ward (1992) further noted that ENSO’s influence appears to be greater during dry years than wet years. The different opinion among several authors is due to the complex nature of ENSO's influence in the region.

To add to that, significant changes in the intensity and location of the lower and upper tropospheric jets – the African Easterly Jet (AEJ) and the Tropical Easterly Jet (TEJ) – during the summer monsoon are known to play a very important role in adjusting rainfall over West Africa. Earlier studies (Kanamitsu and Krishnamurti, 1978; Newell and Kidson, 1984) showed a consistent relationship between the AEJ and West Africa rainfall variability. Using a conceptual model for the rainfall variability in the Sahel and comparing its wet (1958-1967) and dry (1968-1997) years, Nicholson and Grist (2001) showed that the location of the AEJ and the associated shear instabilities are the most important local factors controlling Sahel rainfall variability. During wet years, the AEJ is displaced northward by well-developed low-level westerlies. Contrary to this, the dry years are characterized by poorly developed equatorial westerlies, resulting in a southward shift of the AEJ south of the Sahel. The variability of West Africa rainfall is also associated with variations in the well-organized wave disturbance, African easterly waves (AEWs). They are observed to move westward in the lower troposphere of the tropical North Atlantic. Burpee (1972, 1974) found that the westward movement disturbances are concentrated between 5° N and 15° N. The AEW activity occurs during the summer monsoon from June to September with maximum intensity in August. AEWs are generally known to have an essential role in controlling daily rainfall over West Africa during the summer monsoon season (Thorncroft, 2001; Fink and Reiner, 2003).

Rainfall Distribution in the West African Monsoon

There exists four phases of the West African monsoon, which is dependent on the rainfall peak's location that is whether it is Oceanic, Coastal, Transitional, and Sahelian. During the oceanic phase, between November and mid-April, a broad rain-belt lies just north of the equator. During the successive coastal phase, which usually predominates to mid-June, the rainfall peak lies over the ocean but in the near-coastal region around 4 to 5° North (Thorncroft et al. 2011; Schumacher et al. 2006; Gu et al. 2004; Sultan et al. 2003; Le Barbé et al. 2002). There is a transition phase whereby a decrease in rainfall is observed, it occurs in early July and the first three phases is collectively called oceanic regime (Lebel et al. 2003). It is known that the Sahelian phase lasts from mid-July to September and through this phase, there is high intensity at the rainfall peak and occurs to the south of the Sahel, around 10° North. In the Sahel, this rainfall maximum is known as the continental regime (Lebel et al. 2003).

There are some differences amongst the features connected with the two spatial rainfall maxima according to Gu and Adler (2004). During the early rainy season, that is, May-June, when the rainfall maximum nears the Gulf of Guinea, the synoptic systems that bears rain lean to be eastward-propagating wave signals. In the late rainy season, when the rainfall maximum enters into the continental interior, the wave signals that originate from the west, which are the African easterly waves are the dominant rain-bearing synoptic systems. The rain rate of convection and the ratio of the area covered by cumulonimbus anvils are lower and the stratiform fraction of rainfall is higher in the second spatial maximum, which receives the bulk of its rain during the peak monsoon season (Schumacher and House 2006; Sealy et al. 2003). Reliably, during the peak of the monsoon, the size and group of convective systems is magnified, but rainfall intensity is lower than earlier in the season (Bell and Lamb 2006). There is a difference in the two spatial maxima in terms of the patterns of variability in recent years; the second maximum (associated with the continental regime) exhibits much more change. The rainfall peak associated has also developed increasingly early in the season (Lay and Galle 2005), with the August peak disappearing in recent years (Lebel et al. 2009).

The role of circulation features in the West African rainfall and variability

The major circulation features associated with the variability of West Africa rainfall on inter-annual and decadal time scales are the TEJ, the AEJ, the AWJ, and the Saharan heat low. The influences of the three jets have been described into detail by Nicholson (2009) as well as Grist and Nicholson (2001) although not much was said on the Saharan heat low.

However, a result of Nicholson and Webster (2003) suggests its role clearly and the study is also coherent with the concept of a mid-season “monsoon jump”, when cross-equatorial pressure gradients surpass a critical threshold needed to establish inertial instability.

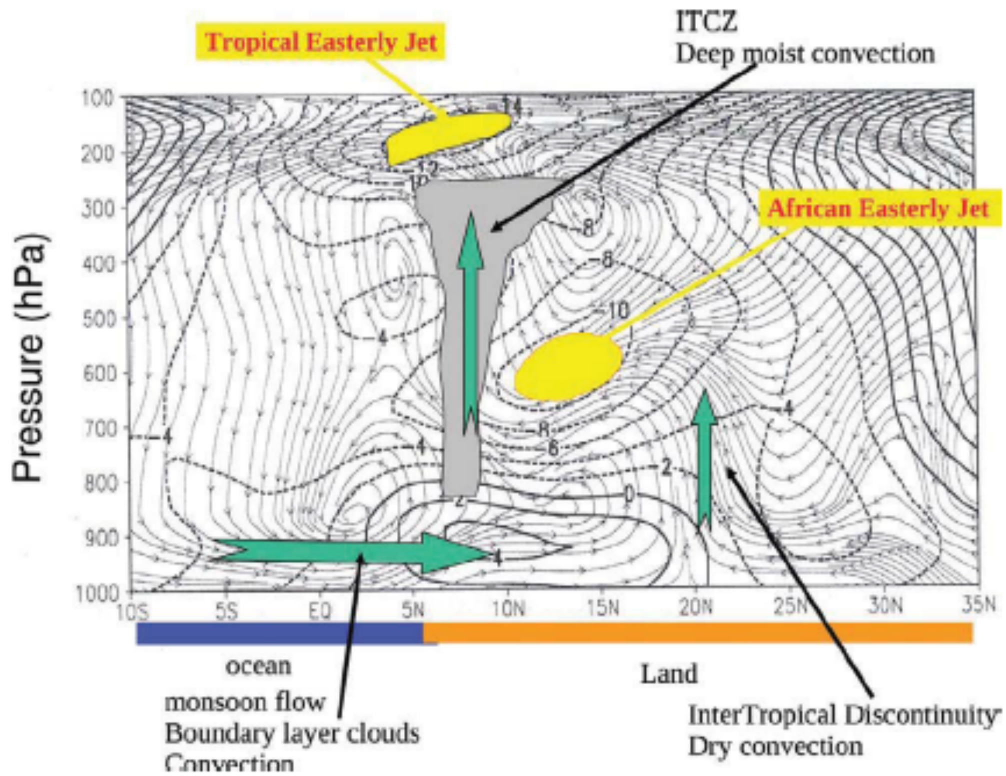

Figure 8: Mean Meridional Circulation and associated mean zonal wind (m/s in contours) over West Africa during the summer season adopted from Hourdin et al. (2010)

As we know, the inter-annual variability of rainfall exists primarily in two forms, either a latitudinal displacement or an intensity change of the tropical rain-belt over West Africa. In the former case, the issue of the dipole arises, with rainfall over the Sahel and Guinea Coast regions assigned the opposite sign with its “node” at roughly 10° N. In the latter case the rainfall anomalies that exist are of the same sign in both regions. The intensification of the Tropical Easterly Jet is unpredictably when annual rainfall in the Sahel is above average and again conflictingly low during dry years in the region. The West Africa rain-belt can be found between the cores of the African Easterly Jet and the Tropical Easterly Jet, that is, a region of strong vertical motion and divergence aloft.

The strengthening of the rain-belt and vertical motion requires a strong displacement of the two cores with respect to each other and strong vertical shear (Nicholson and Webster 2003). When locating the occurrence of the dipole, the location of the AEJ core determines it, which is adjusted to a certain proportion by the intensity of the low-level African Westerly Jet over the Guinea Coast region. With the wet conditions in the Sahel in the dipole case, the northward displacement of the AEJ whiles in the dipole case but with dry conditions in the Sahel it is displaced southward of its mean position. The wet and dry cases in the Sahel represent two independent dynamic modes, with the intra mode switching linked with inertial instability (Nicholson 2009).

The evidence accompanying this is the bimodal frequency distributions of annual rainfall and dynamics variables related to it and the existence of critical thresholds that separate the dry and wet years as seen in figures 9 and 10 below. It should be noted that these thresholds appear to be a cross-equatorial pressure gradient of 10^3 mb/km and an AWJ speed of 7 m/s (Nicholson and Webster 2007).

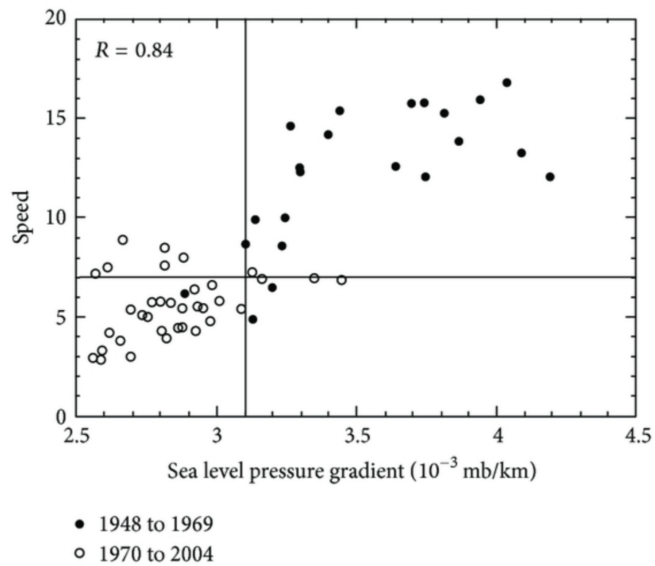

Figure 9: Speed of the westerlies (m/s) at 850hPa versus surface pressure gradient for August of the years 1948–2004 (from Nicholson and Webster 2007). The open circles represent the years 1948–1969 and the solid circles represent the years 1970–2004.

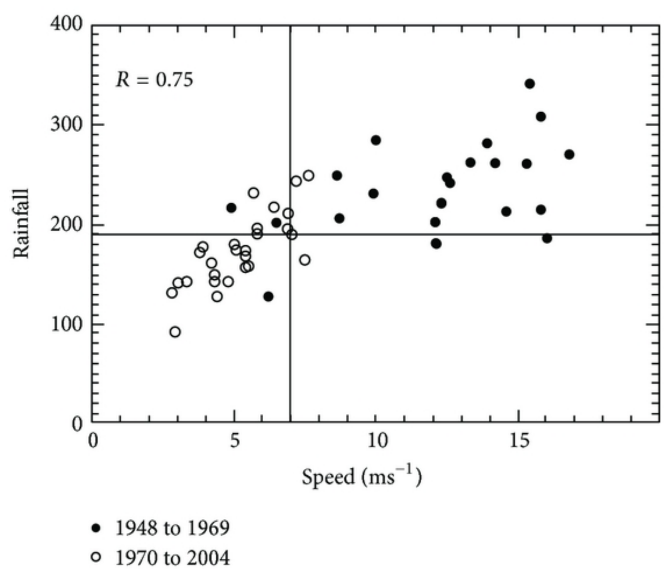

Figure 10: Annual rainfall in the Sahel (averaged within the sector 10–18° N and from the Atlantic coast to 30° E) versus speed of the westerlies at 850hPa (from Nicholson 2009).

Although, Grist and Nicholson (2001) compared the conditions of the wet and dry mode, it is obvious that the main comparison lies in the intensity of the TEJ and the AWJ and the latitude of the AEJ. It also remains that differences are also present in the building of the moist layer, the strength and properties of wave activity, and the seasonal evolution of the low-level temperature gradient.

Effect of the monsoon jump on West African rainfall

The West African monsoon system's main responsibility is to convey moisture from the Atlantic into West Africa. This transportation occurs in periodic northward excursions of moisture flux that have a 3 to 5-day time scale (Couvreux et al. 2010). These "bursts" of the monsoon can bring copious rainfall to the northern fringes of the Sahel according to (Cuesta et al. 2010). The intra-seasonal excursions in moisture flux can be stationary or exhibit a westward propagation (Couvreux et al. 2010)

The continuous seasonal migration of the ITCZ gives rise to two rainy seasons along the Guinean Coast but results in a single rainy season over the Sahel (Hagos et al. 2007). This also implies that the duration and extent of the jump determines how long or short an area can have rains over the course of the year. The extent of its effect varies from place to place, including how much rain will be seen and how long periods of rain will last. The monsoon brings a large portion of water supply and provides valuable water for subsistence farmers. The economy of most West African countries largely depends on the success of monsoon season.

Unfortunately, global circulation models (GCMs) that are used to make climate predictions are currently unable to simulate fundamental characteristics in monsoon precipitation over West Africa. This greatly undermines their ability to represent potential changes in the monsoon in a warmer climate. The WAM is a complicated system that involves many interactions between the atmosphere, ocean and land surface. The WAM is also influenced by processes that occur over a range of temporal and spatial scales (Hall and Peyrille, 2006).

Rainfall Variability over Ghana

Ghana is strongly influenced by the West African Monsoon. It is bounded by the Gulf of Guinea and extends between latitude 4° N and 11° N and longitude 4° W and 2° E. There are variations that occur in the climate, which is dominated by drought and floods. The ITCZ controls the rainfall variations that occur in this area. Its movement involves the upward and downwards swings to the north and south respectively along the year and as such dictates the schedule of rainfall over the country over the year leading to the experience of seasons. The southwesterly winds when predominant ensure the northward migration whiles blowing moist air from the Atlantic Ocean on to the continent whereas the northeasterly winds ensure the southward migration when predominant whiles also carrying hot and dusty air from the Sahara desert.

Whiles the ITCZ migrates from its north and south positions over the year, the agro-ecological zones between these maximum north and minimum south positions of the ITCZ also experience the effect of the winds migration. This movement across the year is called West African Monsoon with the difference in maximum position to minimum position referred to as West African Monsoon jump. In a year, northern Ghana, undergoes a single wet season which normally occurs between May and November, when the ITCZ is in its northern position and the prevailing wind is southwesterly, and a dry period between December and March which is normally called 'Harmattan' wind blows northeasterly. In the peak months of the wet season, that is, July to September, the northern part of the country collects 150-250mm of rainfall per month. The southern parts of the country have two wet seasons: the major from March to July, and a minor season in September to November. These seasons correspond to the northern and southern passages of the ITCZ across the region.

Ghana's annual rainfall has shown to be highly variable on both inter-annual and inter-decadal timescales according to McSweeney et al., (2010) suggesting how difficult it is to predict the long-term trends. Ghana's rainfall amounts have been seen to be very high in the 1960s and have gone on to decrease in the late 1970s and early 1980s. This has amounted to an overall decreasing trend in the period 1960 to 2008, averaging 2.3mm per month (2.4%) per decade (Owusu and Waylen, 2009). There are variations in the intensity and movement of the ITCZ, which goes on to affect the seasonal rainfall. Moreover, factors like variation in the AEJ and the TEJ, (Leroux 2001; Price et al. 2007), and ENSO (Ofori-Sarpong and Annor 2001) have been investigated. To a certain extent, ENSO is only strongly associated with rainfall in the Sahel with a non-stationary or no clear association with the Guinea Coast region as reported by

Ward et al., (2004). In Ghana, the greatest variations of seasonal temperature is found in the northern part with highest temperatures in the hot, dry season (AMJ) at 27 to-30°C, and lowest in JAS at 25 to-27°C. Further south, temperatures reach 25 to-27°C in the warmest season JFM, and 22 to-25°C at their lowest in JAS (Nkrumah et al., 2014).

Maize Production and Practices

Agriculture has proven to be that one single livelihood activity that has over half of the Ghanaian population involved in. Statistics show that out of a working population, 41.8% are engaged in agriculture and this includes farming, fishing, and livestock wearing (GSS, 2012). It is estimated that agriculture contributes to 39% of GDP as compared to 26% for Industry and 31% for Services sector (GoG, 2010). Thus the importance of agriculture in Ghana cannot be over-emphasized.

Agriculture in Ghana is practiced in several forms including commercial agriculture and smallholder farmers. Smallholder farmers represent almost 80% of the total output of the agriculture sector. This system of farming is practiced on a small scale using simple farm tools and techniques. Common farm tools used in such small holder farming include the cutlass, hoe, baskets and other simple farm tools. It is also common to come across the use of bullocks for farming especially in the northern part of Ghana. Farming on such small scale is what the majority of the population of Ghana depends on for their food commodity for consumption and export. As a result of the non-mechanized nature of smallholder farming in

Ghana, there is a rather heavy dependence on human labour usually provided by family members such as children and wives as men own most farms. In addition to this, there is also a heavy dependence on the natural climate such as rains and sunshine and this climate dictates the specific farming practice in various communities. Thus the output of agriculture in Ghana is highly dictated by the rainfall pattern. According to the Statistical Service, most of these farms practice intercropping. The farmer and the family can attribute this to the essential reason for smallholder farming which is to cultivate food crops firstly for consumption. There are quite a number of commercial farmers cultivating crops essentially for commercial purposes. These commercial farms make use of some modern farm machinery and techniques such as tractors, combined harvesters and fertilizers. It is worth noting that despite small holder farmers' use of simple farm tools and techniques, some local farmers have adopted modern techniques such as the use of fertilizers and other chemicals in their farming practice. This could be attributed to increasing food demand coupled with new breeds of pests and diseases that destroy plants. Commercial farmers in Ghana are mostly engaged in mono cropping. Common among the crops cultivated are cassava, maize, plantain, yam, millet, tomatoes and many other food crops. Data shows that the most cropped plant-occupying majority of farmlands across the country is maize. According to the Statistical Service, maize as at 2010 occupied over 998,000 hectares of land.

Maize cultivation in Ghana forms a huge percentage of the total crops produced and consumed in Ghana. Angelucci (2013) quoting FAOSTAT (2012) states that maize is the most important cereal crop found on the domestic market in Ghana despite the fact that it ranks 7th in terms of value of production when compared to other crops between the periods of 2003 to 2010 accounting for 5.5 percent of total agricultural value (Angelucci, 2013). The reason for this was associated to the paramount role of other food crops such as yam, cassava and cocoyam in the Ghanaian diet. The production of maize has increased from the 1990s to 2010 with no specific reason attributed to this increase (MOFA, 2011). However the possibility of this increase being a direct result of increased rainfall, introduction of the fertilizer subsidy in 2008 and high food prices have been suggested yet there is no concrete evidence to prove this suggestion (Angelucci, 2013). Maize is that one single crop that is cultivated across the country however the highest producers of maize are found in the middle to southern belt representing a total of about 80% of the total maize produced in Ghana (MOFA, 2011). The consumption of maize in Ghana has had human consumption pegged against poultry and sometimes livestock consumption. However, human consumption has been limited to white maize, which is cultivated in Ghana while the animal consumption has mostly been yellow maize. As a result of the importance of maize to Ghanaians, the maize sector enjoys a couple of benefits under the 'Food and Agricultural Sector Development Policy' (FASDEP II). These benefits include fertilizer subsidy, mechanization programs, block farms programs and the buffer stock scheme all in an attempt to boost the maize production sector of the country.

It is estimated that the consumption of white maize will increase as a result of population growth and increase in per capita income resulting in a shortfall of 267, 000 mega tonnes by 2015 should productivity continue at the current levels (MOFA, 2011). This raises concerns on the challenges relating to the production of maize in Ghana, which includes irregular rainfall pattern as a result of climate change, non-mechanization of the sector, storage facilities and many other challenges. In its attempt to solve the challenges bedeviling the agricultural industry and for that matter the maize sector; the Government of Ghana has in place strategies such as the Medium Term Agriculture Sector Investment Plan (METASIP), which is derivative of the objective of FASDEP II. When these policies are successfully implemented, it is expected to increase the agriculture sector GDP growth by 6% (GoG, 2010). An overall improvement in the agricultural sector would inevitably result in an improvement in the maize sector, which plays an important role in the economy and the dietary needs of the country.

Overview of agriculture in the Coastal belt

In this agro-ecological zone, the vegetation is mainly grassland, interspersed with fire resistant trees and tall grasses in sparsely settled areas with short grasses and scattered shrubs occurring around heavily cultivated areas. The soils of the Savannah belts are generally lower in organic matter within the surface horizon due to the fact that grass is the dominant vegetation. This soil also supports maize production significantly and thus it being cultivated in the area.

Overview of agriculture in the Transition belt

The wide variety of soil type and vegetation in this agro-ecological zone is an advantage since it enhances the cultivation of a wide range of foodstuffs. In this zone, crops planted are mainly maize, cowpea, yams, beans, citrus, guinea corn, sunflower, vegetables (especially pepper and tomato), cashew nuts, tobacco, soybeans, groundnuts and fiber crops such as cotton and kenaf and they normally practice animal farming as well preferably livestock. It should be noted that this area significantly contributes to the nation's yam and maize production. The area is the food basket of the nation and farming in the area is mainly rain-fed.

Figure 11: A picture depicting the slash–burn method of land preparation

The slash-burn method of land preparation is prominent in this zone. Although the soils are inherently low in fertility and are prone to erosion and droughts, they are considered to be well suited to extensive mechanized cultivation of these crops. However, there is the need to improve the fertility of the soil for increased and sustained crop production and this is mainly done through consistent manuring and the application of commercial fertilizers such as the compound of Nitrogen-Phosphorus-Potassium-Magnesium (NPKMg).

In addition, accelerated erosion is controlled through crop rotations in which a leguminous crop is included, mulching, strip cropping or contour ploughing and appropriate water control measures during the rainy season. During the long dry season, irrigation water needs to be provided for an all year round cultivation.

CHAPTER THREE

MODELS, DATA AND METHODS

This chapter provides a narrative of the models, data and methods used in the study. It begins with a concise explanation of the model used followed by a brief description of the observation data from the Ghana Meteorological Agency in the study. A summary of the simulations is then provided.

Meteorology Station Data

Rainfall data for Wenchi and Saltpond meteorological stations was acquired from the Ghana Meteorological Agency. The data span from 1990-2008.

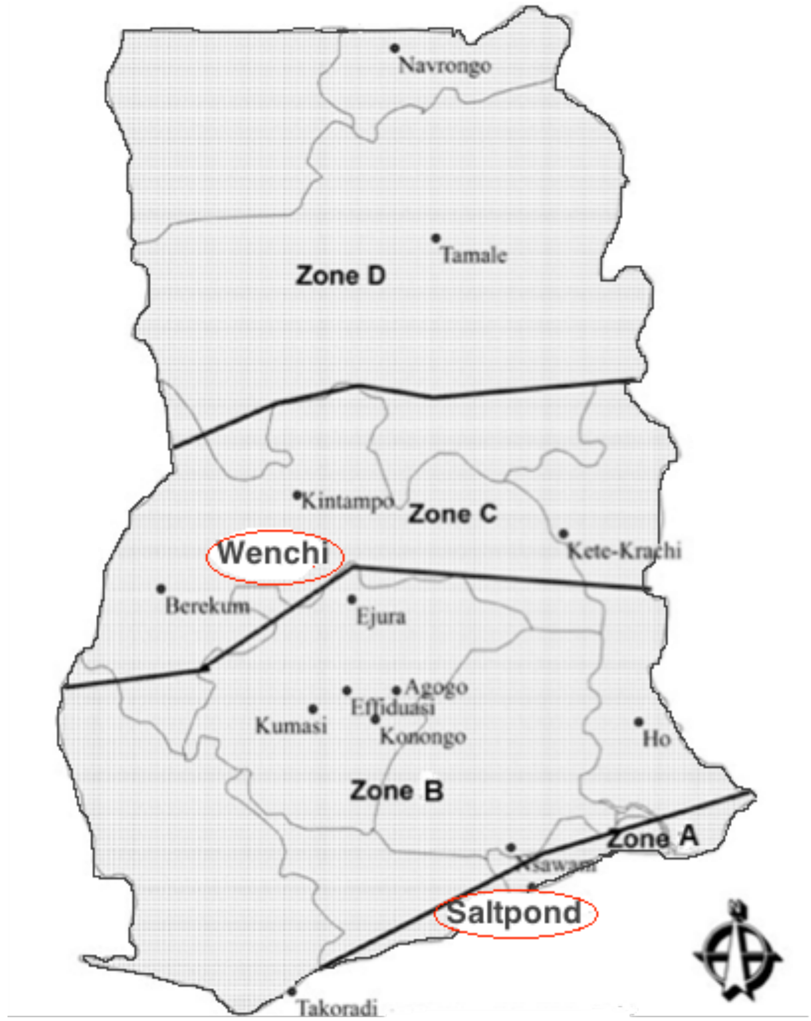

Figure 12: A map of Ghana showing synoptic weather stations where data was obtained (Lacombe, 2012)

Maize yield data

Maize yield data that span 1990-2010 was collected from Food and Agriculture Organization Statistics (FAOSTAT, 2012).

The Global Precipitation Climatology Project (GPCP)

The Global Precipitation Climatology Project (GPCP) was started by the World Climate Research Program (WCRP) to help enumerate the distribution of precipitation around the world over the years. The data has since been managed by the National Aeronautics and Space Administration (NASA) and provides daily rainfall for each 1° on the globe from October 1996 to August 2009 for version 1 (daily) and 1979-present for the version 2 (monthly). According to Huffman et al, (1997), (2001), to derive rainfall estimates, GPCP incorporates a blend of the six best quasi-global datasets. The sources of the GPCP data sets are measurements taken from ground stations and satellite data products. Again, Infrared precipitation measured is computed primarily from geostationary satellites (GOES) and the secondary measurements are from polar orbiting satellites. A merged set of IR precipitation measurements are obtained from Geostationary Satellite Precipitation Data Center (GSPDC). Microwave oceanic measurements are based on the emissions from 19 GHz channel and 85GHz channel of the Special Sensor Microwave/Imager (SSM/I) data from the Defense Meteorological Satellite Program (United States) flying in sun-synchronous low-earth orbits are used for land precipitation measurements. Moreover, Low-Earth orbit measurements made from the Atmospheric IR Sounder (AIRS) and Television and Infrared Operation Satellite (TIROS) Operational Vertical Sounder (TOVS) are also used in this data set. IR and MWave satellite measurements of precipitation are merged with in situ measurements from rain gauge data from the Global Precipitation Climatology Centre's monitoring product of the Deutscher

Wetterdienst (DWD), which is used as land-surface reference for the GPCP Satellite-Gauge Combination. Therefore the data includes gauge-biased corrections. For West Africa, high-resolution precipitation data application is essential so as to interpret the topographical variances and the sharp moisture gradient between the Gulf of Guinea and the Sahara. Again, GPCP data has been found to be good for Ghana and West Africa as a whole and has been confirmed by Manzanas et al., (2014).

Ferret

Ferret is an analysis tool for both gridded and non-gridded data. The Thermal Modeling and Analysis Project (TMAP) at PMEL in Seattle to analyze the outputs of its numerical ocean models and compare them with gridded, observational data developed it. It has an interactive computer visualization and analysis environment, which has been designed to meet the needs of oceanographers and meteorologists who analyze large and complex gridded data sets. An example is, multi-dimensional model outputs, time series and profiles, is used to visualize and analyze data output of the selected region. Model data sets used are generally multi-gigabyte in size with mixed 3 and 4-dimensional variables, which are defined on staggered grids. Ferret offers a Mathematica-like approach to analysis, that is, new variables may be defined interactively as mathematical expressions involving data set variables.

Instat Plus

Instat plus is a general statistics package, which has some special features that aid in simplifying the processing of climate data. It has been designed to support the analysis of climatic data. In this research it is used to analyze rainfall data and onset and duration of rainfall is calculated. The onset of rainfall was defined as the first occasion of rains with 25 mm over a 7-day period with minimum rainfall continuity of 4 days (Raman, 1974).

Methods

The data acquired from the GMet synoptic stations in Wenchi and Saltpond representing the Transition and Coastal Savannah agro-ecological zones of Ghana respectively was taken through an extensive data quality control to ensure research quality data. The intensity of rainfall for each station was calculated over two climatic periods, 1990-1998 and 2000-2008, hereafter called CP1 and CP2 correspondingly. The climatological periods were chosen in order to have a past and current comparison of the available data to discuss the trend of rainfall over the past years. Space-time diagrams were also made with the help of ferret for CP1 and CP2 and discussed. Again, the effect of WAM jump on agriculture factoring in maize yield was explored. A test was also conducted to see whether there has been a shift in the start of rains and also to check the rainfall length or period over some randomly selected low and high yield years.

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSION

This chapter analyzes, discusses and interperets the findings of the study. The variability of the West African Monsoon jump is studied using regionl climate model simulations. The rainfall pattern as well as intensities of CP1 and CP2 from the synoptic stations selected from the transition and coastal agro-ecological zones are also studied. Also the impact these changes has on agriculture is investigated on maize yield over CP1 and CP2.

Seasonal Rainfall Variability over West Africa

The pioneering work of Hamilton and Archbold (1945), predicted that the West African Climate is characterized at any given time by four different weather zones. These zones from north to south move with the direction of the sun and is subject to a time lag (LeBarbe, 2002). This leads to two scenarios: i) a progressive onset of rains due to the regular northward migration of the weather zones; ii) the seasonal cycle over West Africa is a progressive shift from a two rainy season regime on the coast to a single rainy season regime in the north signaling the monsoon jump with a little dry season lasting a few weeks over the coast (LeBarbe, 2002). Therefore there is the need to make space-time diagrams of rainfall pattern over West Africa to see the intensities.

Figure 13 confirms a progressive shift from a two rainy season regime on the coast to a single rainy season regime in the north signaling the monsoon jump and also the fact that rainfall peaks around JJAS over West Africa as suggested by

Gallee et al., (2004).

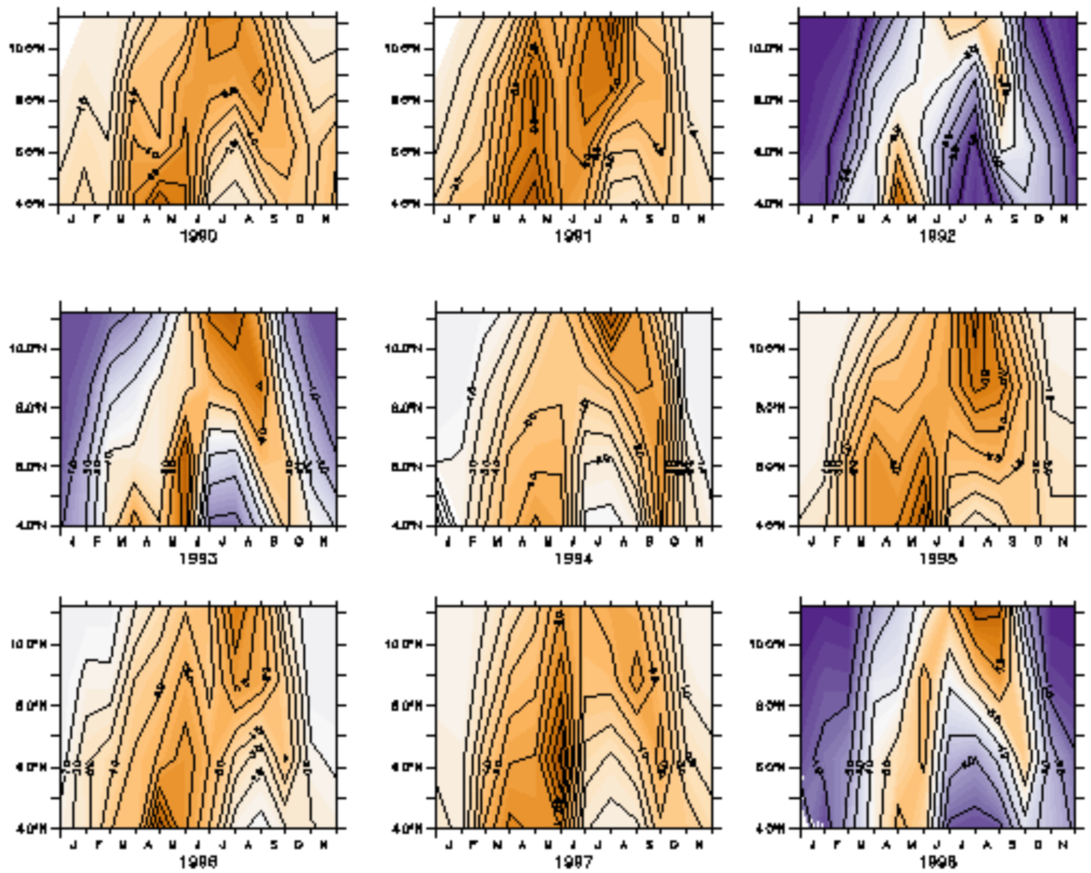

Figure 13: Space(Latitude)-time(months) diagram of rainfall distribution over West Africa for CP1 with their intensities located (High intensities->Orange, Low intensities->Purple)

Across West Africa, the monsoon jump is known to intensify around latitudes 10-12 N according to Hagos and Cook, 2007 and Thorncroft et al. 2011. The temporal plot of the ITCZ over the West African sub-region for CP1, showed that the monsoon jump starts around May and terminates in September. Again, it peaks in July as concurred by Hagos and Cook, 2007 and reasserted by Thorncroft et al. 2011. However, this study proved that there were variations recorded from year to year.

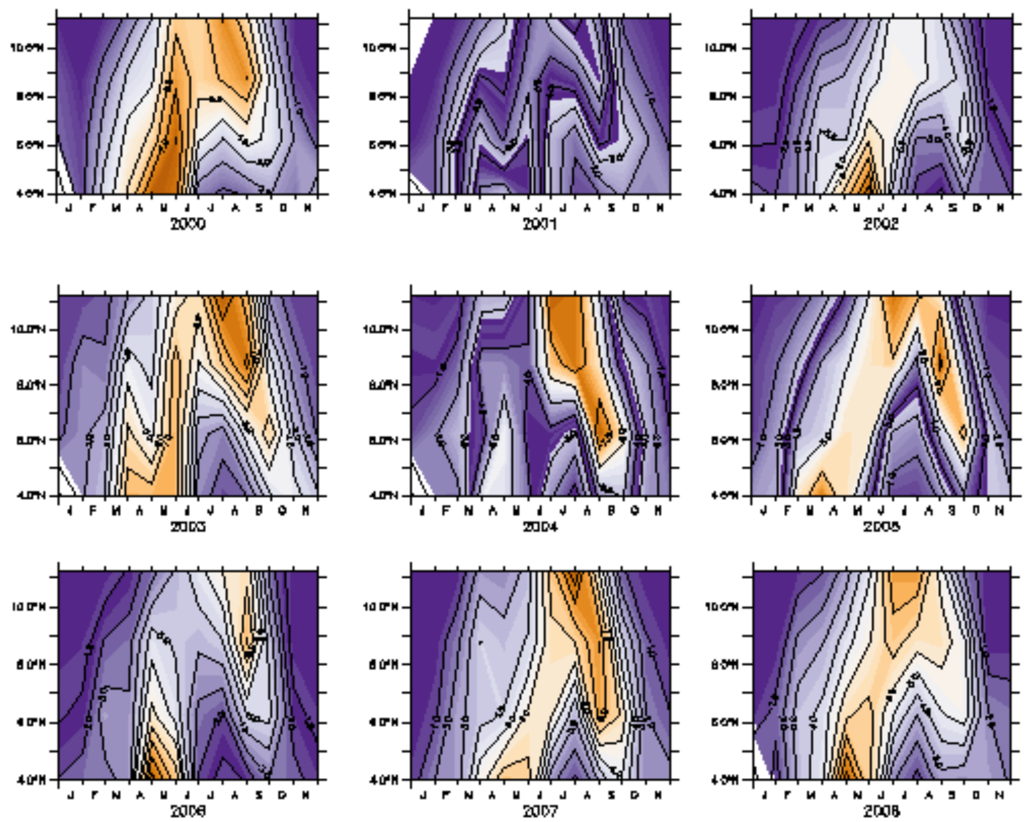

Figure 14: Space(Latitude)-time(months) diagram of rainfall distribution over West Africa for CP2 with their intensities located (High intensities->Orange, Low intensities->Purple)

Again, a plot of the ITCZ over West Africa for CP2, figure 14, also revealed that there was a late onset in this period with the peaks consistently shifting to later months. In addition, rainfall intensity has decreased as compared to the rainfall intensity in CP1. This confirms what Owusu et al., (2012) predicted that rainfall intensities are exhibiting a decreasing trend over the past years.

Seasonal Rainfall variability over Wenchi

Wenchi area exhibits a bi-modal rainfall distribution with two peaks similar in magnitude (Nkrumah et al., 2014).

Seasonal Rainfall variability over Wenchi for CP1

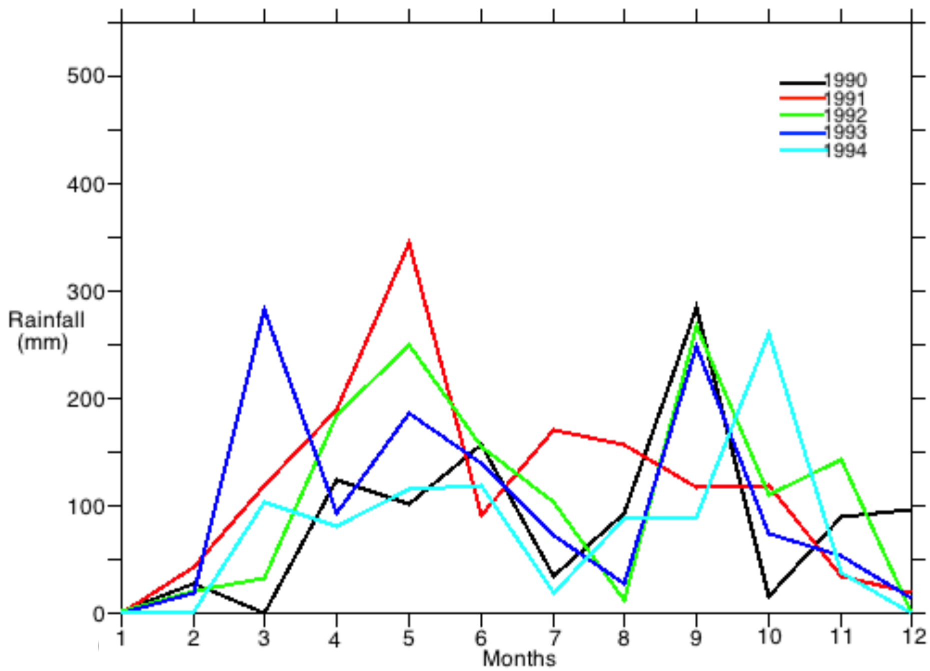

Figure 15a: Monthly rainfall amounts of CP1 showing different rainfall onset for 1990-1994

In order to study the seasonal variability of rainfall over Wenchi over CP1, a rainfall plot was made using the meteorological data from GMet. In figure 15a, in the year 1990, the month of September recorded the most of the rainfall amount (284.2 mm) for the whole rainfall season. This was however followed by a dip in rainfall in October. There was however no rains in March with other peaks in April and June (124.5 mm and 156.8 mm respectively). In 1991, maximum rainfall was recorded in the month of May (344.1 mm), there was a dip in rains in June (92.3 mm) but there was some rise in July (170.7 mm). It is realized that November to January was dry as compared to the other months. The year 1992 exhibited an interesting pattern, maximum rains were recorded in September (267.5 mm) but the first peak of the year was recorded in May (250.7 mm), however there was a small peak in October (142.8 mm). There was a serious dry spell in August and it should be noted that the year experienced its maximum rainfall right after this dry spell. In the year 1993, maximum rainfall was recorded in March (283 mm) for the rainfall season with the second highest peak in September (247.9 mm) and last peak in May (186.4 mm). There were low rains in August with dryness over December and January. For instance according to Klutse et al. (2013), farmers confirmed that they had good yields in this period since the rains did not deviate much from their perceived onset dates. Nevertheless, there were maximum rains in the month of October (260.6 mm) for the year 1994 with some slight peaks in March and July (103.7 mm and 119.3 mm respectively). There was dryness in December to February and a low rain in July (19.7 mm).

Again, in 1995, rainfall peak was recorded in September (290.6 mm) with other peaks in April and June (232.5 mm and 177.9 mm respectively). There was however dryness in November through to February which shows a lengthy period of dryness. The year 1996 did not see an outstanding peak as previous years but there were a number of close peaks across the year. The month April (202.4 mm) saw the maximum rains with June (177.8 mm) following closely. There was low rain in November with some dryness in January. The year 1997 saw rainfall maximum in October (274.1 mm) with another peak in May (183.7 mm) and March (121.8 mm).

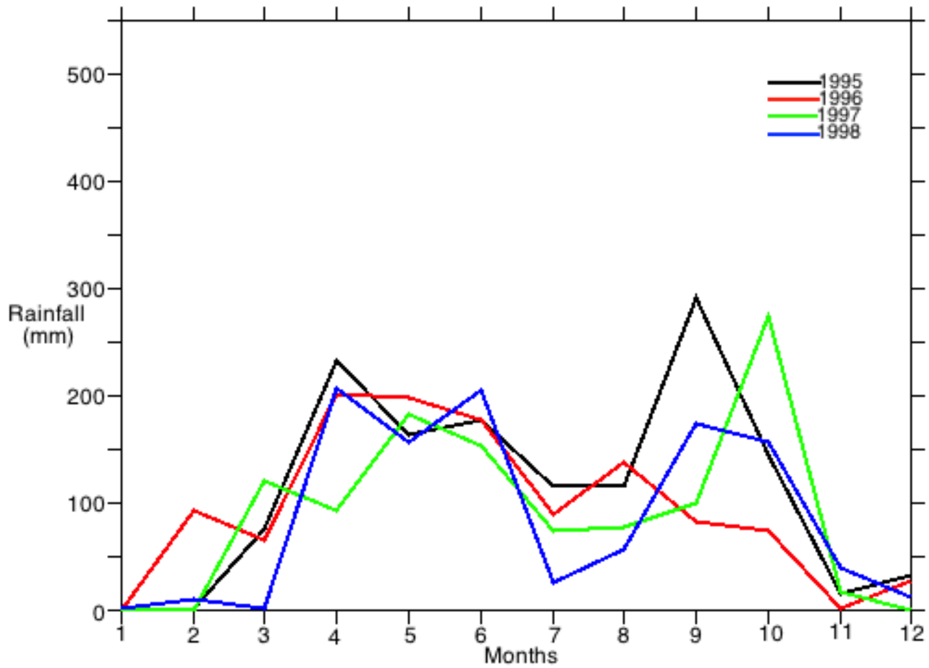

Figure 15b: Monthly rainfall amounts of CP1 showing different rainfall onset for Wenchi from 1995-1998

There was however a drop in July through to September with the dry spell from November through to February. In 1998, peak rainfall was recorded in April (207.5 mm) with June (205.8 mm) following closely. There is a dip in between the two peaks and a severe drop in rains in July (25.7 mm). There is a rise however in September (157 mm) with the dry spell starting from December to January and a severe dry spell in March. For Wenchi, it is known that the two rainfall peaks should be of almost the same height (Lacombe et al., 2012) but rather it was observed that, in the minor season, rainfall intensities were seen to be lower as compared to that of the major season and thereby affecting the total rainfall intensity over the period (Owusu and Waylen, 2012).

Seasonal Rainfall variability over Wenchi for CP2

The rainfall variability over Wenchi area continued to exhibit a bi-modal rainfall distribution.

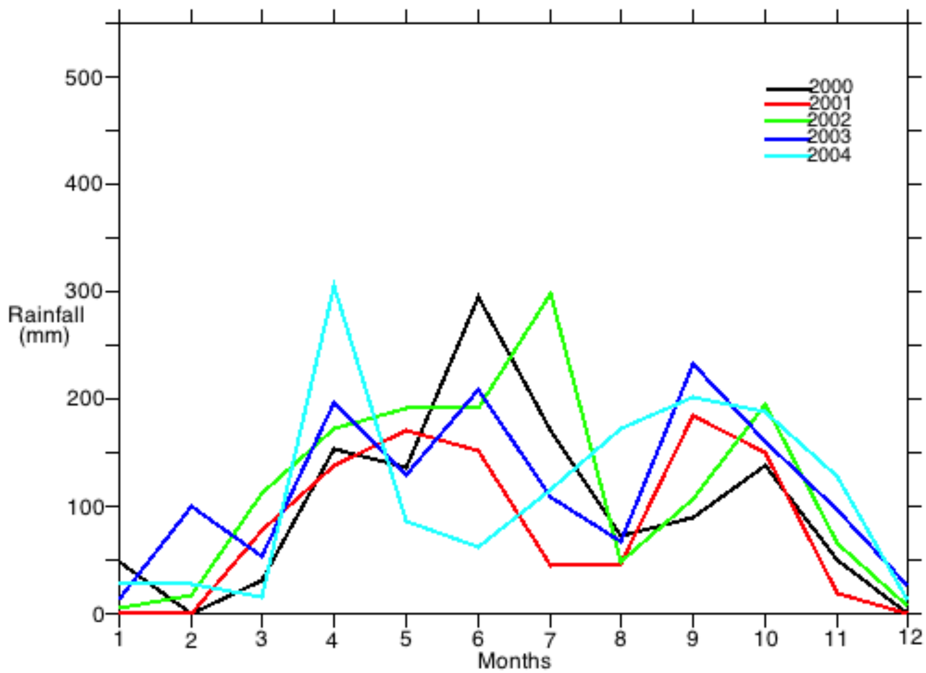

Figure 16a: Monthly rainfall amounts of CP2 showing different rainfall onset for Wenchi from 2000-2004

In figure 16a, the year 2000 had multiple peaks with the maximum of them occurring in June (294 mm) and the other peaks in April (153.2 mm) and October (138.6 mm). There was a dry spell in February and December. In 2001, there were two peaks with the first occurring in May (171.5 mm) and the maximum peak in September (184.6 mm). Dry spell was exhibited in October through to February. There was a dip in amount in August (46.4 mm). Again, 2002 also had two distinct peaks with the maximum of them occurring in July (298.2 mm) and the second maximum occurring in October (195.3 mm). There was a dry spell from December to January. Year 2003 had many rainfall peaks with the maximum peak occurring in the month of September (232.6 mm). The other peaks were recorded in February (101.1 mm), April (196.9 mm) and June (208.1 mm). Rainfall decreased steadily after the maximum peak and it was realized there was no dry spell. The year 2004 had rainfall peak in April (304.8 mm) with another lower peak in September (202 mm). Rainfall however reduced steadily from this peak. March experienced some dryness as compared to those of the other months.

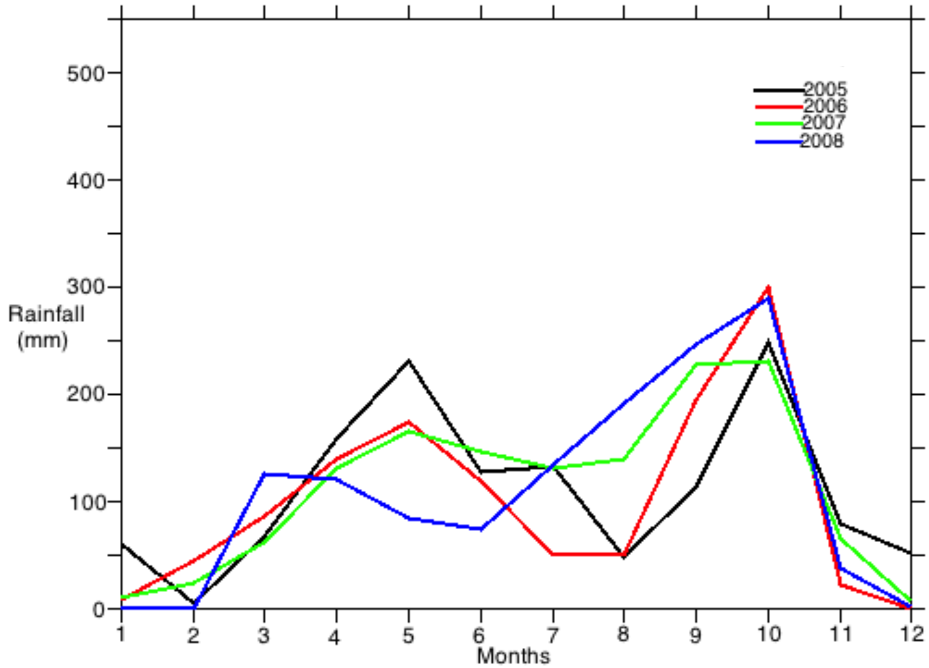

Figure 16b: Monthly rainfall amounts of CP2 showing different rainfall onset for Wenchi from 2005-2008

In figure 16b, in 2005, the season recorded two rainfall peaks, with one occurring in May (231.5 mm) and the other in October (248.1 mm), which was the maximum peak. The short dry spell occurred in February. The year 2006 experienced a lower rainfall peak in May (174.8 mm) and a higher peak in October (299.1 mm) then a dip in August (51.2 mm). There was however a dry spell from November to January. In the year 2007, rainfall maximum for the season occurred in October (231.9 mm) and then a lower peak in the month of May (166.2 mm). There was a drop in between these two peaks in the month of August (140.3 mm). It must be noted that the months of

December and January experienced dryness as compared to the other months in this year. In 2008, the maximum rainfall was recorded in October (290.3 mm) and another smaller peak in March (126.7 mm). There was a dip in June (75.1 mm) and dry spell from December to February.

Seasonal Rainfall variability over Saltpond

Saltpond is known to exhibit a bi-modal rainfall distribution with two peaks which has the first peak higher than the second (Nkrumah et al., 2014). The rainfall variability over the area is as shown in figure 17a.

Seasonal Rainfall variability over Saltpond for CP1

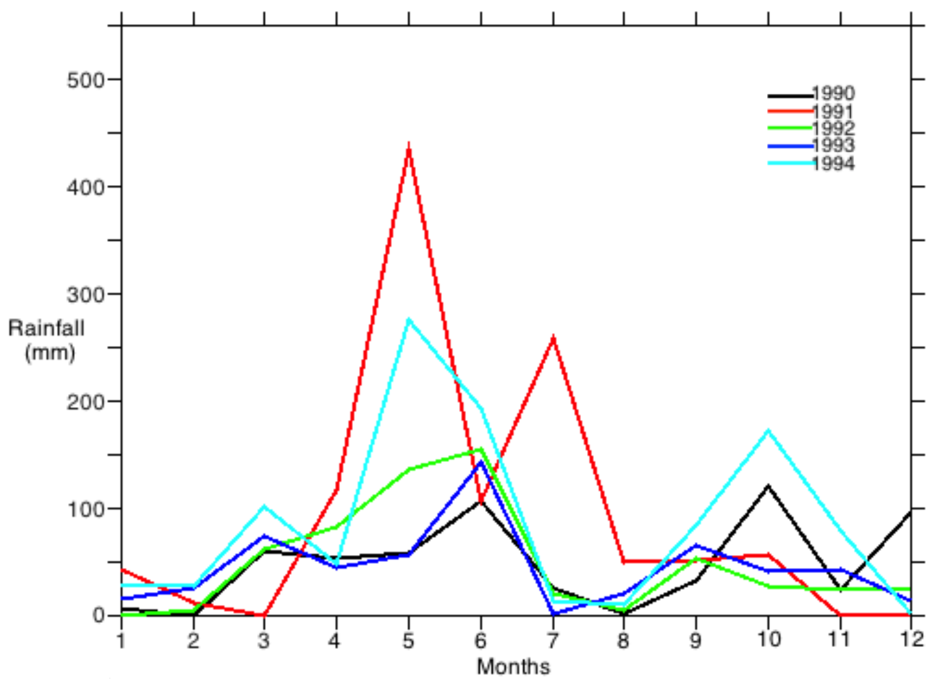

Figure 17a: Monthly rainfall amounts of CP1 showing different rainfall onset for Saltpond from 1990-1994

From figure 17a, in Saltpond, in the year 1990, the month of June recorded the most of the rainfall for the major season that was around 102 mm and maximum rainfall was observed in the minor season in October, which was around 120 mm. Again, the short dry spell between the major and minor seasons was observed in August. This signifies that the ICTZ had moved northwards and hence the monsoon jump being felt. However, the ITCZ returned after its break in the coast the month of September to bring back precipitation and hence the start of the minor season. It must be noted that here the monsoon jump duration was long, it started to drop from July to September and that is barely a three months. The year 1991 showed an interesting pattern, where after the maximum rainfall was recorded in the month of May (434 mm), there was a dip in rains in June (108 mm) but the rains surged in July (260 mm). It should be noted that the ITCZ did not move far northward this time and this is evident in the fact that there was rains even in August (51 mm) although little as compared to the maximum rainfall of the year. There was no short dry spell between the seasons and hence the monsoon jump was not prominent. The year 1992 exhibited similar characteristics to 1990 although the rainfall amounts were totally different but the pattern was barely the same. Here, maximum rainfall was recorded between April and May (156 mm) whilst the short dry spell also occurred between July and August. The rains peaked in September (54 mm) for the minor season and recorded a dip in October. The monsoon jump was short thereby exhibiting a short dry spell of barely a month. In the year 1993, rainfall maximum was recorded in June (144 mm) for the major season and that for the minor season recorded (66 mm). The short dry spell was observed around July to somewhere August. Again, the rains started in March for 1994 with maximum rainfall being observed around May

(275 mm) for the major season although there was a dip in rains as early as April. The maximum for the minor season was in October (173 mm). Again, the monsoon jump that brings about the short dry spell occurred between July and August.

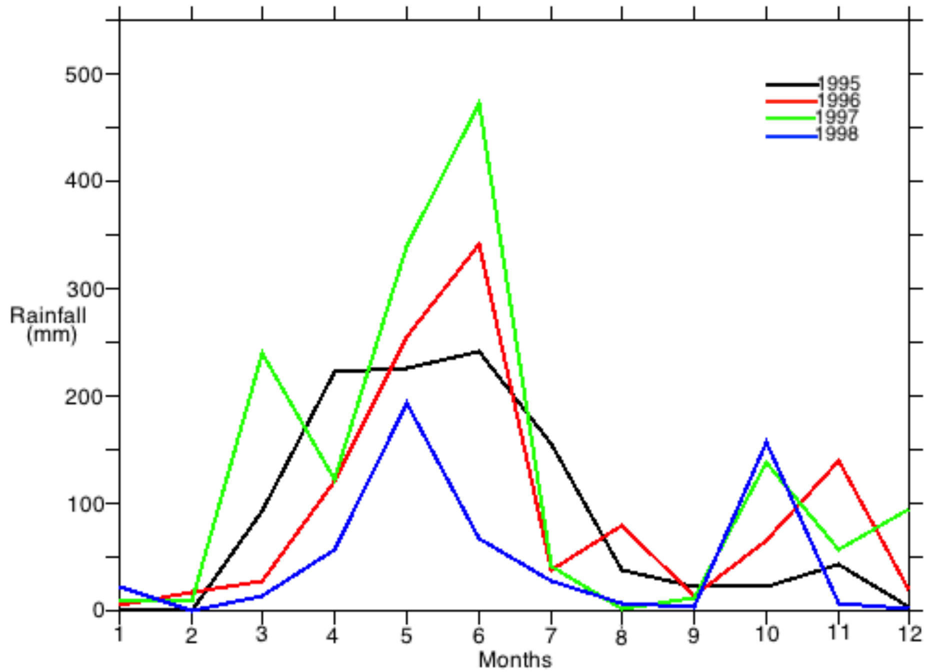

Figure 17b: Monthly rainfall amounts of CP1 showing different rainfall onset for Saltpond from 1995-1998

Again, figure 17b showed in 1995, rainfall peak was in June (242 mm) but the rains extended to August and dropped from August to October. The rains picked up in November (44 mm) for the minor season. The precipitation that occurred between August and October can be explained by the fact that the ITCZ did not move much northward and as such Saltpond experienced some rains over the period. It must also be noted how wide the period was and hence the delay in major rains for the minor season. The year 1996 saw maximum rains in June (340 mm), a dip was recorded right afterwards and a small peak also appeared in August (81 mm). It was noted that there was no dry spell in this year but rather the period saw some rains. The minor season peaked in October (141 mm). This year also exhibits the fact that the northward migration of the ITCZ (monsoon jump) was not prominent and hence the rains gained in the period between the major and minor season. The year 1997 saw rains start as early as February with the major season experiencing two peaks with the first occurring in March (239 mm) and the other in June (472 mm). There was a prolonged dry spell, which started from July to September indicating this time the duration of the migration of the ITCZ was longer. The minor season saw peak rainfall in October (139 mm). In 1998, peak rainfall was recorded in May (193 mm) with a sharp decline from July to August and a short dry spell around September. However, the rains peaked again for the minor season in October (157 mm). Again, it has to be noted there was not much difference in rainfall amount in both the major and minor seasons. In the years, 1997 and 1998, there were promising signs of rains in the minor season. Owusu and Waylen (2012) discussed that there is desiccation of rains in the minor season however this particular year exhibited an isolated case, thereby recording peaks in the minor season in October with appreciable rains of 139 mm and 157 mm respectively.

Seasonal Rainfall variability over Saltpond for CP2

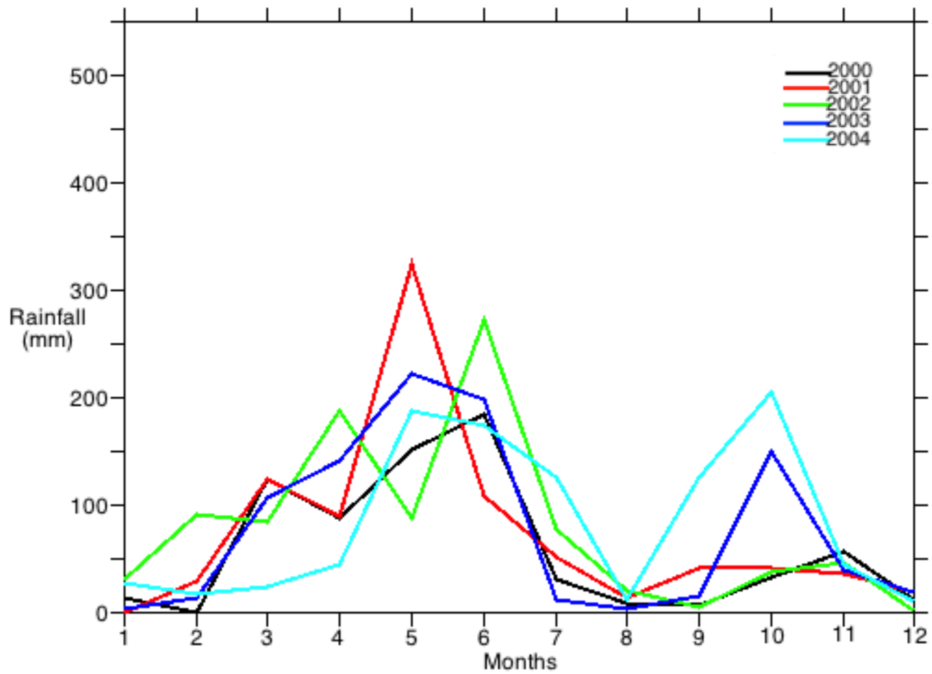

Figure 18a: Monthly rainfall amounts of CP2 showing different rainfall onset for Saltpond from 2000-2004

In order to study the seasonal variability of rainfall over Saltpond for CP2, a rainfall plot was made using the meteorological data from GMet. There were two peaks for the major rainfall season in 2000 with the first peak occurring in March (124 mm) and the other in June (185 mm). There was however a drop in rains from July to September which meant a delay in the start of the minor season. This can be attributed again to the ITCZ migration (jump). The minor season saw rainfall peak in November (57 mm). Again, 2001 also had two peaks with the first occurring in March (125 mm) and the other at May (323 mm). There was a decline as the ITCZ begun its northward migration around June. In this year, the short dry spell occurred in August and the minor season did not record an outstanding peak. In 2002, again the major season recorded three different peaks with the maximum of them occurring in June (272 mm) and the second maximum occurring in April (187 mm) and the third in February (91 mm). The short dry spell was around August to September in this year. The minor season recorded its peak in October (47 mm). The year 2003 had its peak of rainfall in the major season in May (199 mm) with a peak in March (108 mm). There is a special interest in this particular year since dry spell over this year started in July through to September before the rains set in and peaked in October (150 mm). The rainfall peak for year 2004 occurred in May (188 mm) and the month of August experienced some dry spell. However, the month of October (205 mm) recorded the highest amount of rainfall in the minor season. It must be noted that in this year, we had more rains in the minor season than in the major season

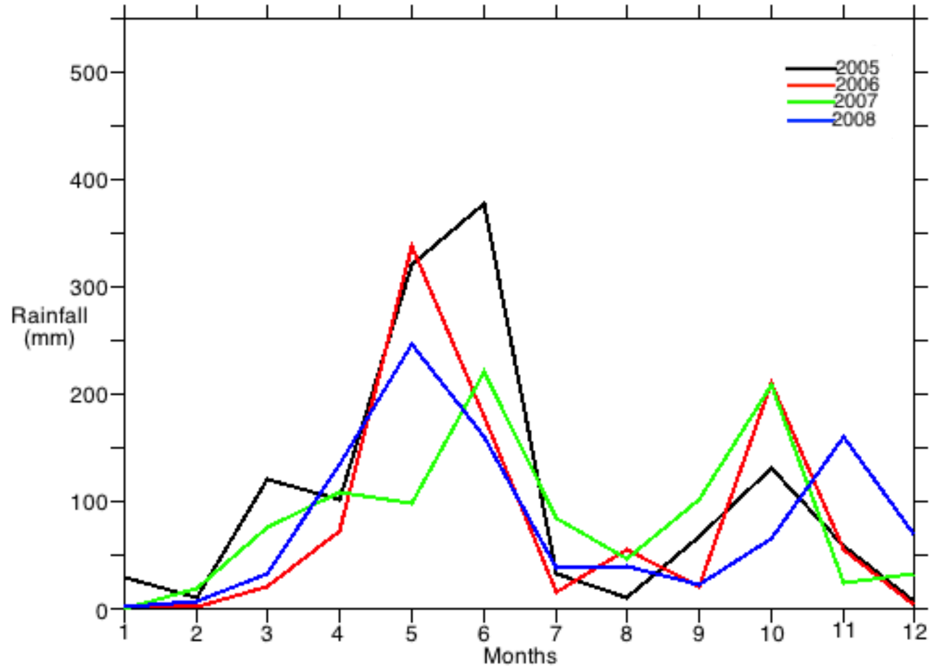

Figure 18b: Monthly rainfall amounts of CP2 showing different rainfall onset for Saltpond from 2005-2008

From figure 18b, in the year 2005, the major season recorded two rainfall peaks, March (121 mm) and June (378 mm). The short dry spell occurred in August whilst the peak of the minor season occurring in October (131 mm). The year 2006 experienced rainfall peak in May (338 mm) and then a dip in July but a minor peak in the month of August (56 mm) which normally is the month we experience the short dry spell and another dip in September and then there was a rise in rainfall amount which peaked in October (211 mm). In 2007, rainfall maximum for the major season occurred in June (220 mm) and then there was a drop in August (48 mm). Interestingly, 2007 did not experience a short dry spell, as it should have. The minor season recorded its peak in October (209 mm). In

2008, the major season saw rainfall peak in May (246 mm) and then the month of August saw some rains then came the minor season with its peak recorded as late as November (161 mm).

Monsoon Jump and its effect on Agriculture (Effect on Maize Yields)

Agriculture in Ghana is largely rain-fed and also the climate of Ghana is much dependent on the WAM jump. It is the monsoon that brings about the rains that are needed for agriculture. The impact of the monsoon on the country depends largely on its progress and its distribution. The timely onset of the monsoon augurs well for the economy of the country since a boost in agricultural produce and yield goes a long way to contribute positively to the GDP of the nation. Again, it also plays a crucial role in food security and water availability (Wani et al. 2009). In equal measures, variability of the monsoon also affects greatly the economy of the country. The monsoon becomes the fundamental cause of food inflation due to it being vital for the sowing of major crops such as maize, millet and cocoa. The impact of a poor monsoon is felt across several industries. It has big influence on purchasing power of a large portion of the population who depend on agriculture. In summary, a good monsoon season has great bearing on agricultural produce and a positive impact on the economy of the country.

Maize is a staple crop grown throughout Ghana but the main producing areas are the middle and southern parts of the country. These are mainly in the transition and coastal agro-ecological zones.

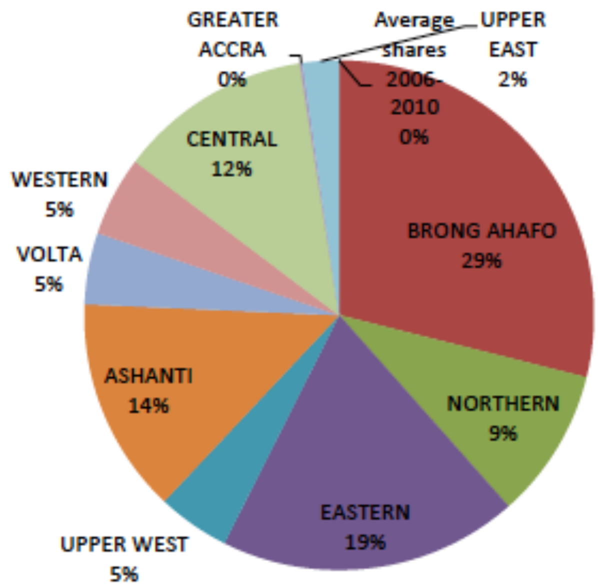

Figure 19: Distribution of production of maize in Ghana from 2006-2010 (MoFA, Statistics, Research and Information Directorate (SRID), 2011)

About 80% of maize is grown in these areas (MOFA, 2011; FAOSTAT, 2012). It is the most important cereal crop in the domestic market.

Comparing this yield versus year plot of maize over Ghana from 1990 to 2010, it is evident there were some fluctuations over the CP1 and CP2 years. A particular year of importance was 1992, from the yield versus year plot, it was realized the country had a very low yield, that is, 1200 ton/ha and from the rainfall data over the Transition zone, we can attribute this to the late rains and the dry spell that occurred in that year. Although there were rains in the beginning of the year, the rains begun to drop just after it had peaked after the dry spell. This made more farmers to lose their produce before they could be harvested because the maize could not get enough rains to flower and they end up dying off.

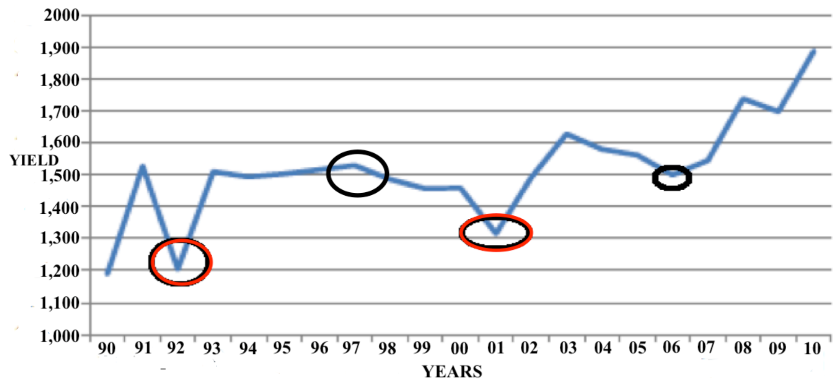

Figure 20: Maize yields in Ghana 1990-2010 (Source; FAOSTAT, 2012)

Less rain was experienced in 2001 with the months of July to August seeing a decreasing pattern. This went on to hinder the maize to get essential rains to flower. However, there was an upward turn in yield from 2002 to 2003 and a downward turn from 2004 to 2006, this also agrees with rainfall pattern over the transition zone. It should be noted that although in the years 2007 and 2008 the Government of Ghana subsidized fertilizers it did not necessarily warrant an increase in yield in those years respectively (Angelucci, 2012). These scenarios give evidence to the fact that the monsoon jump, which is the northward shift of the ITCZ affects the rainfall pattern which then goes on to affect agriculture in Ghana. Hence it can be said that the monsoon jump affects agriculture.

Seasonal variability for selected low maize yield years (1992 and 2001)

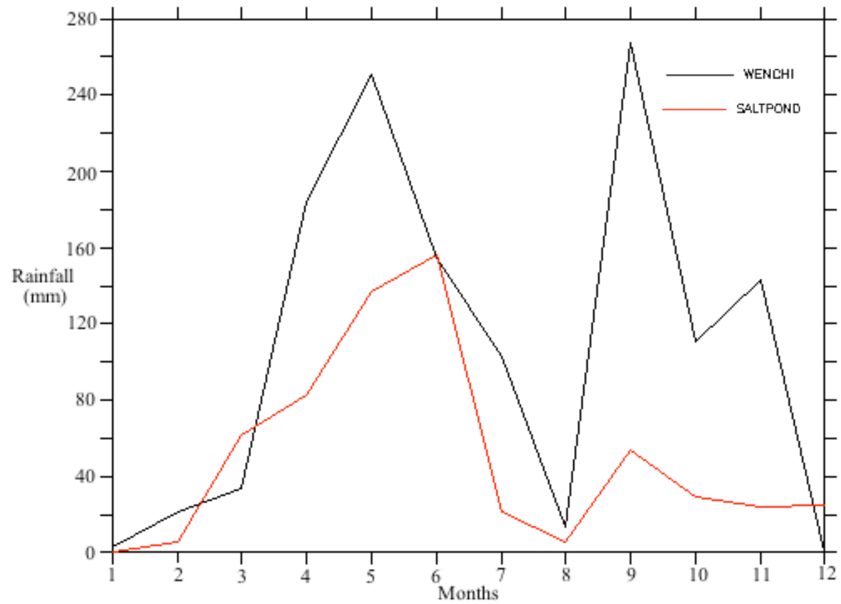

Figure 21: A plot showing Seasonal Rainfall variability for low yield year 1992 for both Wenchi and Saltpond

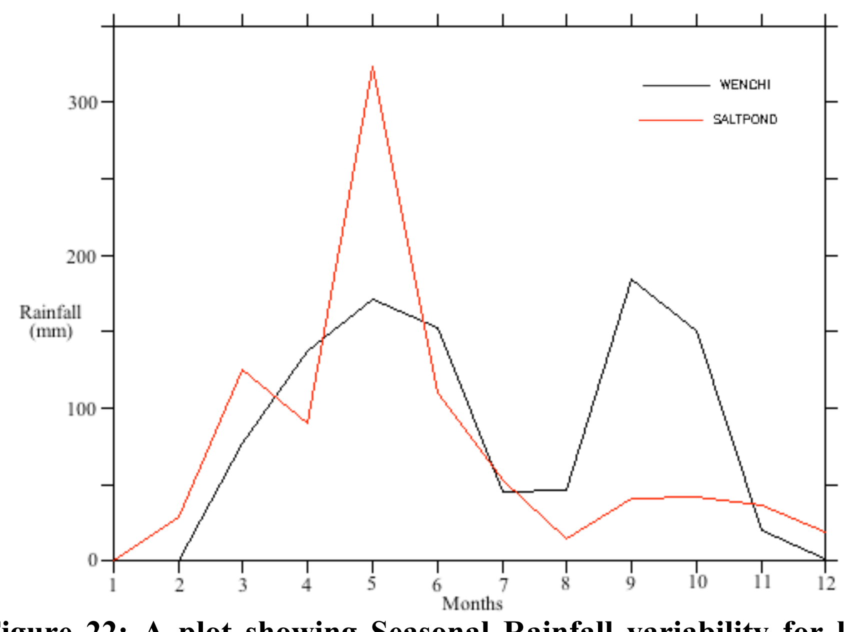

Figure 22: A plot showing Seasonal Rainfall variability for low yield year 2001 for both Wenchi and Saltpond

Rainfall amounts were found to have decreased significantly in these years as shown in figures, 16a and 17a. It is also realized that there are shifts in the peak location across some years emphasizing the late arrival of the rains and the widening of the short dry spell. These factors may have contributed to the low yield in these years.

Seasonal variability for selected high maize yield years (1997 and 2006)

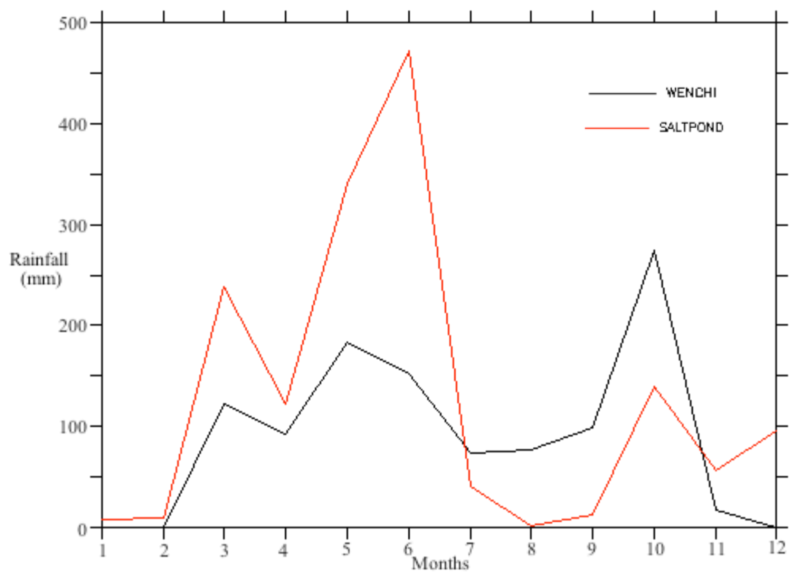

Figure 23: A plot showing Seasonal Rainfall variability for high yield year 1997 for both Wenchi and Saltpond.

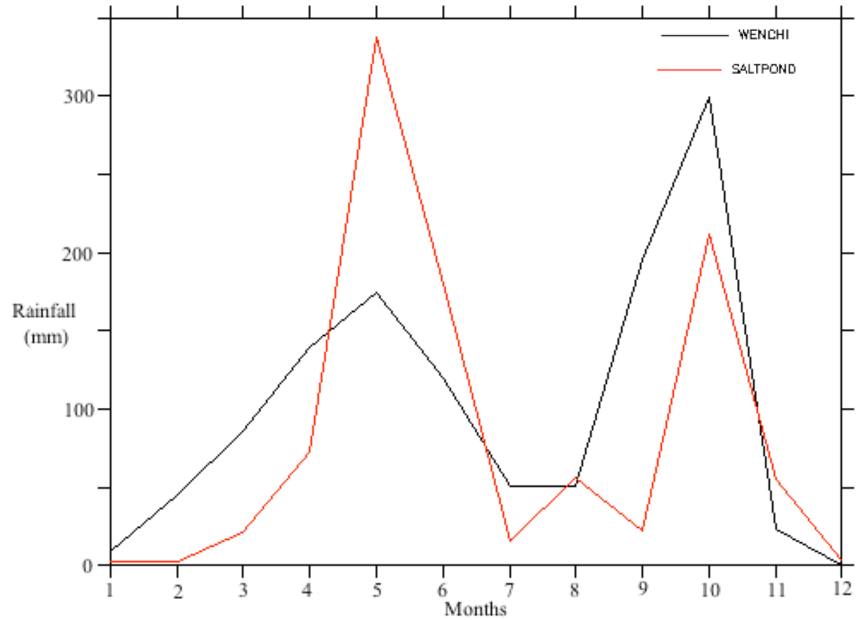

Figure 24: A plot showing Seasonal Rainfall variability for high yield year 2006 for both Wenchi and Saltpond.

In the high yield years, it is seen that the rainfall amounts has increased significantly than that of the low yield years and this inadvertently covered for the small dry spell around the month of August. High yield may be due to timely rains in these years.

Investigating the West African rainfall over the Low and High yield years

The low and high yield years are investigated to see what happened in those years. According to LeBarbe, (2002), maximum precipitation over West Africa occurs in the months from June-July-August-September (JJAS) so it was expedient to check the behavior of rainfall in this period since it goes a long way to affect the rainfall pattern and intensity over Ghana; hence the JJAS diagram of the low and high yield years.

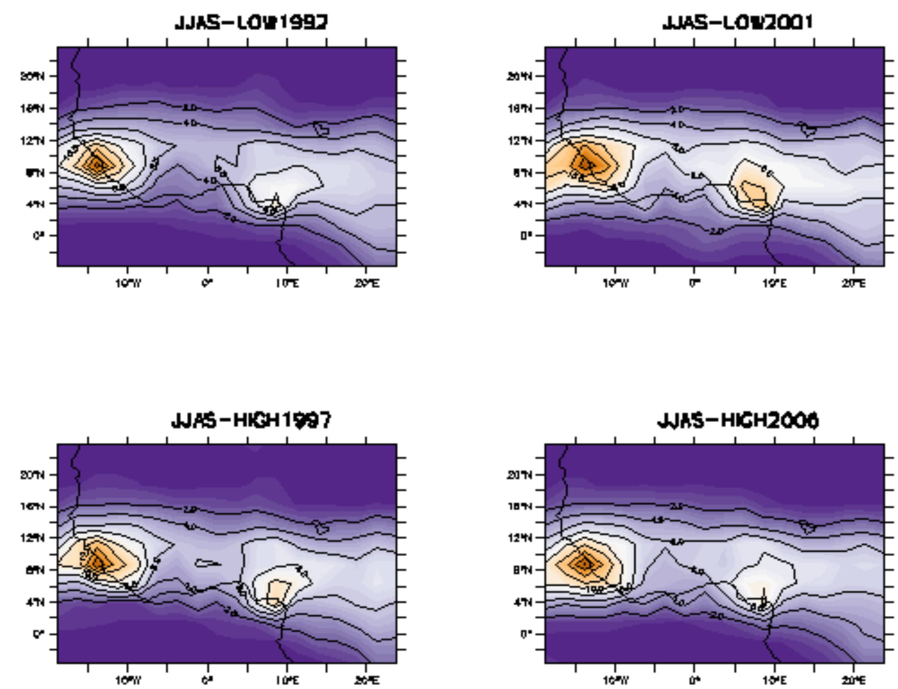

Figure 25: Spatial distribution of mean JJAS daily rainfall over West Africa for GPCP (High intensities->Orange, Low intensities->Purple)

Generally, the mean JJAS daily rainfall over West Africa in 1992 was low and therefore West Africa had insufficient rains to begin with. It should be noted that the climate of Ghana more often than not is a reflection of the climate of West Africa. Hence the low yield in Ghana over this period. Although there were high rains in the mean JJAS daily rainfall over West Africa in 2001 that is evident by the very high intensities (rainfall maxima) recorded over the Guinea Highlands (Deep yellow spot on the right) and Jos Plateau (Deep yellow spot on the left).

Ghana recorded low yield because it experienced flooding in this year. According to reports, which is justified also by the spatial distribution of mean JJAS daily rainfall plot for 2001, there were so much rains in the beginning of the year (major season) in the Coastal Savannah zone that crops were destroyed where as there was not much rains in the Transition zone and hence this affected the yield across the country especially in the middle belt which has Wenchi placed in there (SRID, 2011).

Rainfall over West Africa in 1997 showed very high intensities in the JJAS plots. This shows that much rains was expected in this year and the observation data from GMet confirmed that Ghana had its fair share of these rains and this went a long way to help farmers reap their produce thereby increasing our yield in maize. The year 2006 was not much different with the rainfall peaks across the West African sub-region being located at the Guinea Highlands with some small intensity of precipitation over both the Jos Plateau and the Cameroon Mountains. It should be said that however, Ghana did experience some rains much to the benefit of mechanized farmers and smallholder farmers as seen in the increasing yield in 2006 from figure 20.

Onset Days of high and low yield years in Saltpond and Wenchi

The study went on to test to see whether there has been a shift in the start of rains and also to check the rainfall length or period over these years. The onset daily rainfall amount was set at more than 20mm of rainfall in a day (Kurji et al., 2011). The onset of rainfall in the low and high yield years for both Saltpond and

Wenchi were computed with the aid of InStat plus.

Table 1: A table showing onset day and rainfall length for Saltpond

Saltpond	Onset Day	Rainfall Length
1992	109	114
1997	140	140
2001	108	113
2006	104	104

Table 2: A table showing onset day and rainfall length for Wenchi

Wenchi	Onset Day	Rainfall Length
1992	98	234
1997	88	122
2001	76	77
2006	62	130

A plot was made over the low and high yield years. It was found that the onset of the rains in Saltpond for 1992 was on April 18 that for 1997 was on May 20. In 2001 and 2006, the rains started on April 17 and April 13 respectively.

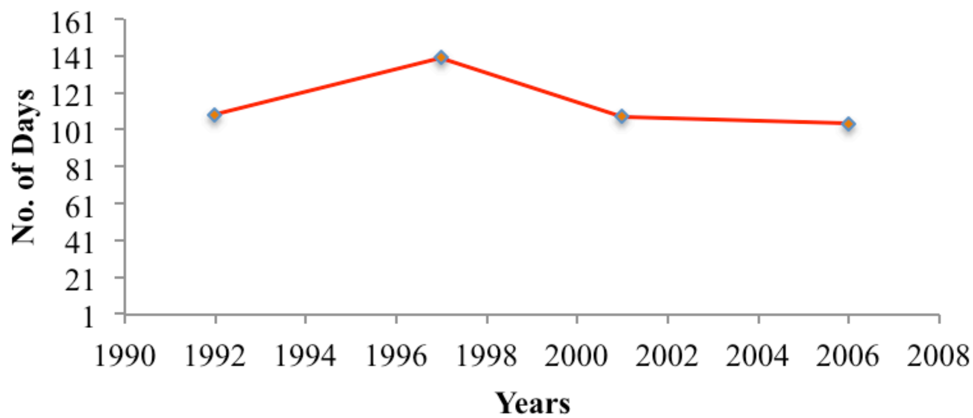

Figure 26: Graphical representation of Onset in Saltpond over Low and High yield years

For Wenchi, the rains started on April 7 for the year 1992 with the onset of rains in 1997 on March 28. Again, March 16 was the day the rains begun in 2001 and March 3 for 2006. This confirms what Klutse et al. (2013) reported that there has generally been late onset of rains especially in the Transition zone since normally rains were expected as early as February.

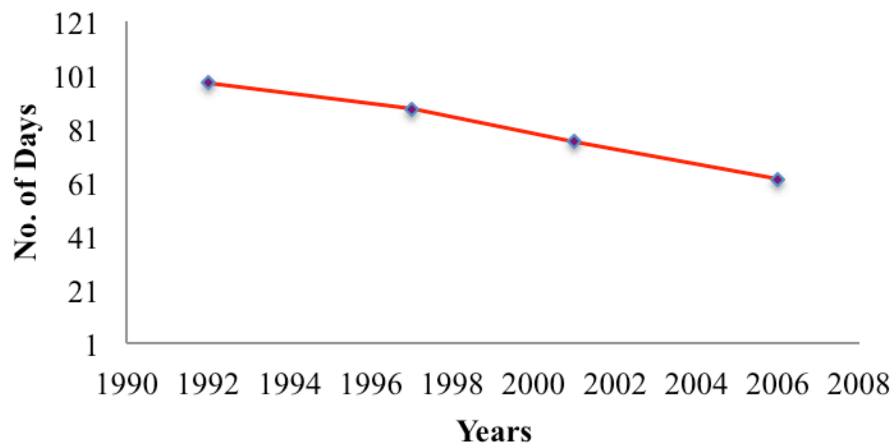

Figure 27: Graphical representation of Onset in Wenchi over Low and High yield years

The rainfall length of rainfall in 1992 was higher in Wenchi as compared to all the other yield years. It was also realized that 2006 had the lowest rainfall length, which goes to prove that there could be other factors in play in the increase in yield across the country. Again from the onset date in 2006 it should be noted that there were early rains and this can account for the increase in yield in this year. Farmers did not struggle to forecast the variability since the rains came when expected. However, the year 1997 had a good length of rainfall and hence the increase in yield. Again, it should be noted that in Wenchi, the length of rainfall in the high yield years were longer than that of the low yield years where as in Saltpond, the rainfall length in low yield years were sometimes higher than the high yield year, categorically that of 2006. The year 1997 recorded the highest rainfall length value of both the low and the other high yield year.

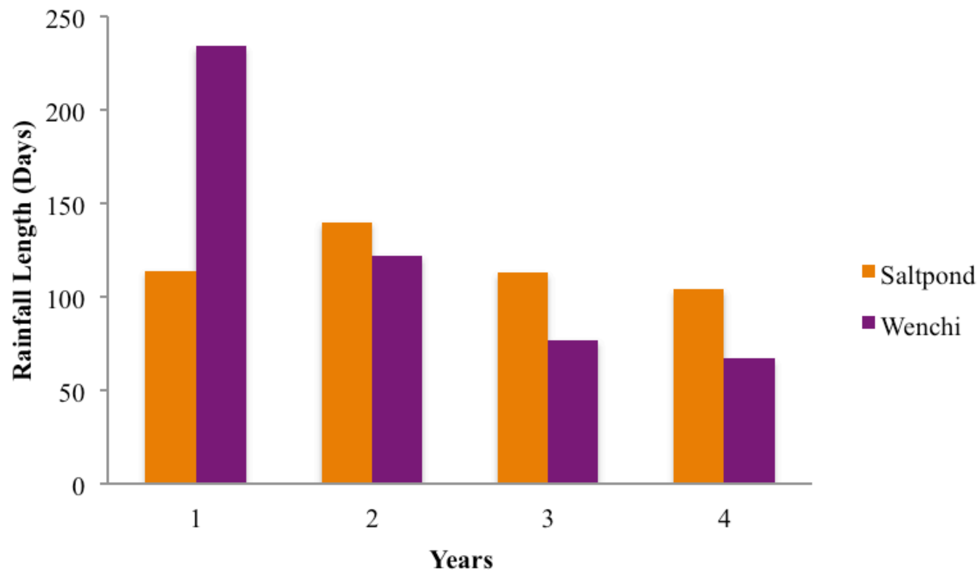

Figure 28: Graphical representation of rainfall length over low and high yield (1~1992, 2~1997, 3~2001 and 4~2006) years

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

With the aid of regional climate models, the variability of the West African Monsoon (WAM) and its jump has been able to be simulated. A Space-time diagram was obtained over CP1 (1990-1998) and CP2 (2000-2008) and has been analyzed. The analysis showed that indeed the rainfall intensity has been reducing over the years (Owusu and Waylen, 2012). CP1 was found to have higher intensities than CP2 thereby establishing CP1 as a wet rainfall regime as compared to CP2, which, was found to be dry, and also with the rainfall peaks shifting to later dates in CP2.

Using rainfall data from Ghana Meteorological Agency (GMet), over the period CP1 and CP2, rainfall pattern and its corresponding intensities for the Transition and Coastal Savannah agro-ecological zones using synoptic stations, Wenchi and Saltpond over the respectively have been analyzed. These zones both exhibited bi-modal rainfall distribution as classified by GMet. However, the peaks in the Wenchi were not of equal heights as expected. Saltpond was also exhibited a significant decrease in rainfall over its minor season and this is evidence that rainfall amounts have been decreasing especially in the minor season. There was a lot of variability in rainfall over both periods with the rainfall peaks oscillating much more. The little dry spell between seasons was also found to have widened in CP2.

From these findings, the effect of the WAM and the jump on agriculture was investigated. This effect was however zoomed down to maize production in the Transition and Coastal Savannah agro-ecological zones. Low yield years (1992 and 2001) and high yield years (1997 and 2007) were randomly selected and investigated.

Using GPCP satellite data, it was observed that in JJAS in 1997 as well as 2006 very high intensity of rains were recorded whereas generally, rainfall in 1992 across West Africa was low. The exploring the onset of rains in these years showed that there was late onset for Wenchi in the year 1992 whereas Saltpond had a late onset in 1997. Again, there was a very early onset of rains in 2006 at Wenchi whereas the rains delayed in Saltpond. Rainfall length for Wenchi showed that all the high yield years (1997 and 2006) had higher rainfall length than the low yield years (1992 and 2001) whereas in Saltpond, the rainfall lengths of the low yield years were most often than not higher than that of the high yield years with the exception of 2006.

Recommendations

It is recommended that further work in the future can focus on making wind diagrams to see the contribution of the AEW, AEJ and TEJ to rainfall especially in the low and high yield years. This will help climatologists to further understand the dynamics of rainfall and the winds vis-à-vis low and high yield.

Again, different agricultural yields can be explored to solidify the pattern exhibited in this work. For instance work on millet, rice and sorghum yields will further strengthen the perceived pattern in this work.

A much detailed onset analysis will also help explain further the cause of the low and high yield obtained in those years. For instance, an investigation should be conducted into finding the number of dry spell days, Consecutive Wet Days (CWD) and Consecutive Dry Days (CDD).

REFERENCES

Angelucci F., (2012). *Analysis of incentives and disincentives for maize in Ghana*. Technical series, MAFAP, FAO, Rome.

Bader, J., & Latif, M. (2003). The impact of decadal-scale Indian Ocean sea surface temperature anomalies on Sahelian rainfall and the North Atlantic Oscillation. *Geophysical Research Letters 30: doi; 10.1029/2003GL018426*

Bell, M. A. & Lamb, P. J. (2006). Integration of weather system variability to multi-decadal regional climate change: the West African Sudan-Sahel zone, 1951–98, *Journal of Climate,19*(20), 5343–5365.

Bhattacharya, A. (2008). *Sustainable Livelihood Based Watershed Management – Watershed Plus Approach*, 2nd Working Group meeting of ERIA, Japan IGES.

Bordoni, S. (2007). *On the role of eddies in monsoonal circulations: Observations and Theory*. Ph.D. Thesis, University of California, Los Angeles, 223.

Burpee, R. W. (1972). Origin and structure of easterly waves in lower troposphere of North Africa, *Journal of the Atmospheric Sciences*, *29*, 77–90.

Cook, K. H. (1999). Generation of the African easterly jet and its role in determining West African precipitation, *Journal of Climate,12*(5), 1165–1184.

Cornforth, R. J., Hoskins, B. J., & Thorncroft, C. D. (2009). The impact of moist processes on the African Easterly Jet-African Easterly Wave system, *Quarterly Journal of the Royal Meteorological Society, 135*(641), 894–913.

Couvreux, F., Guichard, F., Bock, O., Campistron, B., Lafore, J. P., &

Redelsperger, J. L. (2010).Synoptic variability of the monsoon flux over West Africa prior to the onset, *Quarterly Journal of the Royal Meteorological Society, 136*(1), 159–173.

Cuesta, J., Lavaysse, C., Flamant, C., Mimouni, M., & Knippertz, P. (2010).Northward bursts of the West African monsoon leading to rainfall over the Hoggar Massif, Algeria, *Quarterly Journal of the Royal Meteorological Society, 136*(1), 174 - 189.

DeLonge, M. S., Fuentes, J. D., Chan, S., Kucera, P. A., Joseph, E., Gaye, A. T.,& Daouda, B. (2010). Attributes of mesoscale convective systems at the land-ocean transition in Senegal during NASA African Monsoon Multidisciplinary Analyses 2006*, Journal of Geophysical Research, 115*, D10213, doi:10.1029/2009JD012518.

Eltahir, E. A. B., Gong, C. (1996). Dynamics of wet and dry years in the West Africa.*Journal of Climate*, (9), 1030-1042**.**

Emanuel, K. A. (1995). On thermally direct circulations in moist atmospheres. *Journal of Atmospheric Science.(52)***,** 1529-1534.

Fink, A. H., & Reiner, A. (2003). Spatiotemporal variability of the relation between African Easterly Waves and West African Squall lines in 1998 and 1999, *Journal of Geophysical Research D, 108(*11), 1-17.

Food and Agriculture Organisation Statistics (FAOSTAT) (2005). *FAO Statistics*, http://www.fao.org(Accessed on 12th October 2013).

Food and Agriculture Organization (FAO) (2002).*World Agriculture: Towards 2015/2030*: *Summary Report*, Rome.

Fontaine, B., Trazaska, S., & Janicot, S. (1998). Evolution of the relationship between near and global and Atlantic SST modes and the rainy season in West Africa: Statistical analyses and sensitivity experiments. *Climate Dynamics, 14*, 353-368.

Government of Ghana (2010). Medium Term Agriculture Sector Investment Plan 2011-2015.Ministry of Food and Agriculture, Accra.

Ghana Statistical Service (2012). 2010 Population and Housing Census; Summary report for final results, Ghana Statistical Service, Accra.

Griffiths, J. F. (1972). *World Survey of Climatology*, *10*, Elsevier.

Grist, J. P., & Nicholson, E. (2001). A study of the dynamic factors influencing the rainfall variability in the West African Sahel, *Journal of Climate, 14*(7), 1337–1359.

Gu, G. J., & Adler, R. F. (2004). Seasonal evolution and variability associated with the West African monsoon system, *Journal of Climate, 17*, 3364–3377.

Hagos S. M., & Cook, K. H. (2007). Dynamics of the West African monsoon jump, *Journal of Climate, 20*(21), 5264–5284.

Holton, J. R., Wallace, J. M., & Young, J. A. (1971). On boundary layer dynamics and the ITCZ, *Journal of the Atmospheric Sciences, 28*, 275–280.

Hsieh, J. S., & Cook, K. H. (2005). Generation of African easterly wave disturbances: relationship to the African easterly jet, *Monthly Weather Review, 133*(5), 1311–1327.

Hulme, M., Doherty, R., Ngara, T., New, M., & Lister, D. (2001). African climate change: 1900 – 2100. *Climate Research, 17*,145-168.

Kalapureddy, M. C. R., Lothon, M., Campistron, B., Lohou, F., & Saïd, F. (2010). Wind profiler analysis of the African Easterly Jet in relation with the boundary layer and the Saharan heat-low, *Quarterly Journal of the Royal Meteorological Society, 136*(1), 77–91.

Kanamitsu and Krishnamurti, 1978 Kanamitsu, M., & Krishnamurti, T. N. (1978). Northern Summer Tropical Circulations During Drought and Normal Rainfall Months. *Monthly Weather Review, 106*, 331–347. *doi: http://dx.doi.org/10.1175/1520-0493(1978)106<0331:NSTCDD>2.0.CO;2*

Krishnamurti, T. N., Wong, V., Pan H. L., Pasch, R., Molinary, J., & Ardanuy, P. (1983c). A three-dimensional planetary boundary layer model for the Somali jet, *Journal of Atmospheric Science, 40*, 894-908.

Kurji, P., Nanja, D., & Stern, R. (2011). Exploring daily rainfall data to investigate evidence of climate change in southern Zambia and its implication for farmers in the area; *Biometrics and Research Methods Teaching Resource Case Study (7). Nairobi, Kenya: ILRI.*

Klutse, N. A. B., Owusu, K., Adukpo, D. C., Nkrumah, F., Quagraine, K., Owusu, A., & Gutowski, W. J. (2013). Farmer's observation on climate change impacts on maize (*Zea mays*) production in a selected agro-ecological zone in Ghana, *Research Journal of Agriculture and Environmental Management 2013, 2*(12), 394-402.

Lavaysse, C., Flamant, C., & Janicot, S. (2010). Regional-scale convection patterns during strong and weak phases of the Saharan heat low, *Atmospheric Science Letters, 11*(4), 255–264.

Lebel, T., Diedhiou, A., & Laurent, H. (2003). Seasonal cycle and interannual variability of the Sahelian rainfall at hydrological scales, *Journal of Geophysical Research, D 108*(8), 14–11.

Leroux, M. (2001). *The Meteorology and Climate of Tropical Africa*. Springer-Praxis Publishing, Chichester, 550.

Le Barbé, L., Lebel, T., & Tapsoba, D. (2002). Rainfall variability in West Africa during the years 1950–90, *Journal of Climate, 15*(2), 187–202.

Le Lay, M. & Galle, S. (2005). Seasonal cycle and interannual variability of rainfall at hydrological scales. The West African monsoon in a Sudanese climate, *Hydrological Sciences Journal, 50*(3), 509–524.

Manzanas, R., Amekudzi, L., Preko, K., Herrera, S. & Gutierrez, J. (2014). A comparison of methods to determine the onset of the growing season in Nigeria, *Climatic Change ,124*, 805-819.

Mason, B. J. (1975). The GARP Atlantic tropical experiment, *Nature, 255*(5503), 17–20.

McSweeney, C., Lizcano, G., New, M. & Lu, X. (2010) The UNDP Climate Change Country Profiles.

http://journals.ametsoc.org/doi/abs/10.1175/2009BAMS2826.1

Miller, R. L. (1996). The intertropical convergence zone, *Encyclopedia of Climate and Weather, S. H. Schneider, Ed., 1*, 445–448.

Ministry of Food and Agriculture (2011). Agriculture in Ghana; facts and figures, 2010. Statistics, Research and Information Directorate (SRID), Accra

Nesbitt, S. W., & Zipser, E. J. (2003). The diurnal cycle of rainfall and convective intensity according to three years of TRMM measurements, *Journal of Climate, 16*(10), 1456–1475.

Newell, R. E., & Kidson, J. W. (1984). African mean wind changes between sahelian wet and dry periods. *Journal of Climatology,4*, 27–33. doi: 10.1002/joc.337004010

Nicholson, S. E., & Grist, J. P. (2001). A conceptual model for understanding rainfall variability in the West African Sahel on interannual and interdecadal timescales, *International Journal of Climatology, 21*(14), 1733–1757.

Nicholson, S. E., Some, B., McCollum, J. (2003). Validation of TRMM and other rainfall estimates with a high-density gauge dataset for West Africa - part II: validation of TRMM rainfall products, *Journal of Applied Meteorology, 42*, 1355–1368.

Nicholson, S. E., & Grist, J. P. (2003). The seasonal evolution of the atmospheric circulation over West Africa and equatorial Africa, *Journal of Climate, 16*, 1013–1030.

Nicholson, S. E., & Webster, P. J. (2007). A physical basis for the inter-annual variability of rainfall in the Sahel, *Quarterly Journal of the Royal Meteorological Society, 133*(629), 2065–2084.

Nicholson, S. E. (2008). The intensity, location and structure of the tropical rain-belt over west Africa as factors in inter-annual variability, *International Journal of Climatology, 28*(13), 1775–1785.

Nicholson, S. E. (2009). A revised picture of the structure of the "monsoon" and land ITCZ over West Africa, *Climate Dynamics, 32*(7-8), 1155–1171.

Nicholson, S. E. (2009). On the factors modulating the intensity of the tropical rain-belt over West Africa, *International Journal of Climatology, 29*(5), 673–689.

Nkrumah, F., Klutse, N. A. B., Adukpo, D. C., Owusu, K., Quagraine, K. A., Owusu, A., & Gutowsky, W. (2014). Rainfall Variability over Ghana: Model versus Rain Gauge Observation, *International Journal of Geosciences, 4*, 673-683.

Ofori-Sarpong, E., & Annor, B. (2001). Rainfall over Accra, 1901-90. *Weather, 56*, 55-62.

Okumura, Y., & Xie, S. P. (2004). Interaction of the Atlantic equatorial cold tongue and the African monsoon, *Journal of Climate, 17*, 3589-3602.

Owusu K., & Waylen, P. R. (2009). Trends in Spatio-Temporal Rainfall Variability in Ghana, (1951-2000), *Weather*, *64*(5), 115-120.

Peyrillé, P., Lafore, J. P., & Redelsperger, J. L. (2007). An idealized two-dimensional framework to study the West African Monsoon—part I: validation and key controlling factors, *Journal of the Atmospheric Sciences, 64*(8), 2765-2782.

Price, C., Yair, Y., & Asfur, M. (2007). East African lightning as a precursor of Atlantic hurricane activity. *Geophysical Research Letters,34*, L09805, doi:10.1029/2006GL028884

Raman, C. V. R., (1974). Analysis of commencement of monsoon rains over

Maharashta State for agricultural planning. *Scientific Report, 216*, India Meteorological Department, Poona.

Ramel, R., Gallé, H., & Messager, C. (2006). On the northward shift of the West African monsoon, *Climate Dynamics, 26*(4), 429–440.

Redelsperger, J. L., Diongue, A., Diedhiou, A., Ceron, J. P., Diop, M., Gueremy, F., & Lafore, J. P. (2002). Multi-scale description of Sahelian synoptic weather system representative of the West African Monsoon. *Quaternary Journal of Royal Meteorological Society, 128*, 1229-1257.

Sathiyamoorthy, V. (2005). Large scale reduction in the size of the Tropical Easterly Jet, *Geophysical Research Letters, 32*(14), Article ID L14802.

Schumacher, C., & House, R. A. (2006). Stratiform precipitation production over sub-Saharan Africa and the tropical East Atlantic as observed by TRMM, *Quarterly Journal of the Royal Meteorological Society, 132*(620), 2235–2255.

Sealy, A., Jenkins, G. S., & Walford, S. C. (2003). Seasonal/regional comparisons of rain rates and rain characteristics in West Africa using TRMM observations, *Journal of Geophysical Research D, 108*(10), 3–21.

Shinoda, M., & Kawamura, R. (1994). Tropical rain-belt circulation and sea surface temps associated with the sahelian rainfall trend, *Journal of Meteorological Society of Japan, 72*, 341-357.

Sijikumar, S., Roucou, P., &Fontaine, B. (2006). Monsoon onset over Sudan-Sahel: simulation by the regional scale model MM5, *Geophysical Research Letters, 33*(3), Article ID L03814.

Sultan, B., & Janicot, S. (2000). Abrupt shift of the ITCZ over West Africa and intra-seasonal variability, *Geophysical Research Letters, 27*(20), 3353–3356.

Sultan, B., Janicot, S., & Diedhiou, A. (2003). The West African monsoon dynamics. Part I: documentation of interaseasonal variability, *Journal of Climate, 21*, 3389–3406.

Sylla, B., Diallo, I., & Pal, J.S. (2013). West African Monsoon in State-of-the-Science Regional Climate Models, *Climate Variability - Regional and Thematic Patterns, ISBN: 978-953-51-1187-0, InTech, DOI: 10.5772/55140*

Thorncroft, C. D., Hodges, K. (2001). African Easterly Wave Variability and Its Relationship to Atlantic Tropical Cyclone Activity. *Journal of Climate*, *14*, 1166–1179. doi: http://dx.doi.org/10.1175/1520-0442(2001)014<1166:AEWVAI>2.0.CO;2

Thorncroft, C. D., Nguyen, H., Zhang, C., and Peyrille, P. (2011). Annual cycle of the West African monsoon: regional circulations and associated water vapour transport, *Quarterly Journal of the Royal Meteorological Society, 137*(654), 129–147.

Tomas, R. A., Holton, J. R., and Webster, P. J. (1999). The influence of cross-equatorial pressure gradients on the location of near-equatorial convection, *Quarterly Journal of the Royal Meteorological Society, 125*(556), 1107–

1127.

Tompkins, A. M., Cardinali, C., Morcrette, J. J., & Rodwell, M. (2005). Influence of aerosol climatology on forecasts of the African Easterly Jet. *Geophysical Research Letters, 32*(10), Article ID L10801.

Wani S. P., Rockstrom, J., & Oweis, T. (2009). *Rainfed Agriculture: unlocking the potential*, Oxfordshire: CABI International.

Ward, M. N. (1992). Provisionally corrected surface wind data, worldwide ocean-atmosphere surface fields and Sahel rainfall variability. *Journal of Climate, 5*, 454-475.

Ward, M. N., Cook, K., Diedhiou, A., Fontaine, B. Giannini, A., Kamga, A., Lamb, P. J., Mohamed, B., Nassor, A., & Thomcroft, C. (2004). Seasonal-to-Decadal Predictability and Prediction of West African Climate.*CLIVAR Exchanges*, *9,*14-20.

Yan, Y. Y., (2005). Intertropical Convergence Zone (ITCZ), *Encyclopedia of World Climatology, J. E. Oliver, Ed*., 429–432.

Zhang, C., Woodworth, P., & Gu, G., (2006). The seasonal cycle in the lower troposphere over West Africa from sounding observations, *Quarterly Journal of the Royal Meteorological Society, 132*(621), 2559–2582.

APPENDIX

CODES FOR FERRET PLOTS

```
! NOAA/PMEL TMAP
 ! FERRET v6.85
 ! Linux 2.6.32-358.23.2.el6.x86_64 32-bit - 11/12/13
 !  7-Feb-14 09:30

use GPCP.1990-1998.nc
sh d
define viewport/xlimits=0.0,0.37/ylim=0.62,1.0 ul
define viewport/xlimits=0.32,0.69/ylim=0.62,1.0 um
define viewport/xlimits=0.63,1.0/ylim=0.62,1.0 ur

define viewport/xlimits=0.0,0.37/ylim=0.30,0.71 ml
define viewport/xlimits=0.32,0.69/ylim=0.30,0.71 mm
define viewport/xlimits=0.63,1.0/ylim=0.30,0.71 mr

define viewport/xlimits=0.0,0.37/ylim=0.0,0.42 ll
define viewport/xlimits=0.32,0.69/ylim=0.0,0.42 lm
define viewport/xlimits=0.63,1.0/ylim=0.0,0.42 lr
set viewport ul
```

```
fill /nolabel/pal=orange_purple/nokeypr[l=1:12,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=1:12,x=-4:2@ave,y=4:12]; GO land

set viewport um
fill /nolabel/pal=orange_purple/nokeypr[l=13:24,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=13:24,x=-4:2@ave,y=4:12]; GO
land

set viewport ur
fill /nolabel/pal=orange_purple/nokeypr[l=25:36,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=25:36,x=-4:2@ave,y=4:12]; GO
land

set viewport ml
fill /nolabel/pal=orange_purple/nokeypr[l=37:48,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=37:48,x=-4:2@ave,y=4:12]; GO
land

set viewport mm
fill /nolabel/pal=orange_purple/nokeypr[l=49:60,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=49:60,x=-4:2@ave,y=4:12]; GO
land
```

set viewport mr

fill /nolabel/pal=orange_purple/nokeypr[l=61:72,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=61:72,x=-4:2@ave,y=4:12]; GO land

set viewport ll

fill /nolabel/pal=orange_purple/nokeypr[l=73:84,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=73:84,x=-4:2@ave,y=4:12]; GO land

set viewport lm

fill /nolabel/pal=orange_purple/nokeypr[l=85:96,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=85:96,x=-4:2@ave,y=4:12]; GO land

set viewport lr

fill /nolabel/level=(2,18,2)/pal=orange_purplepr[l=97:108,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=97:108,x=-4:2@ave,y=4:12]; GO land

```
! NOAA/PMEL TMAP
 ! FERRET v6.85
 ! Linux 2.6.32-358.23.2.el6.x86_64 32-bit - 11/12/13
 !  7-Feb-14 09:30

use GPCP.2000-2008.nc
sh d


define viewport/xlimits=0.0,0.37/ylim=0.62,1.0 ul
define viewport/xlimits=0.32,0.69/ylim=0.62,1.0 um
define viewport/xlimits=0.63,1.0/ylim=0.62,1.0 ur


define viewport/xlimits=0.0,0.37/ylim=0.30,0.71 ml
define viewport/xlimits=0.32,0.69/ylim=0.30,0.71 mm
define viewport/xlimits=0.63,1.0/ylim=0.30,0.71 mr
define viewport/xlimits=0.0,0.37/ylim=0.0,0.42 ll
define viewport/xlimits=0.32,0.69/ylim=0.0,0.42 lm
define viewport/xlimits=0.63,1.0/ylim=0.0,0.42 lr


set viewport ul
fill /nolabel/pal=orange_purple/nokeypr[l=1:12,x=-4:2@ave,y=4:12]; GO land
contour/over /nolabel/pal=orange_purplepr[l=1:12,x=-4:2@ave,y=4:12]; GO land
```

set viewport um

fill /nolabel/pal=orange_purple/nokeypr[l=13:24,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=13:24,x=-4:2@ave,y=4:12]; GO land

set viewport ur

fill /nolabel/pal=orange_purple/nokeypr[l=25:36,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=25:36,x=-4:2@ave,y=4:12]; GO land

set viewport ml

fill /nolabel/pal=orange_purple/nokeypr[l=37:48,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=37:48,x=-4:2@ave,y=4:12]; GO land

set viewport mm

fill /nolabel/pal=orange_purple/nokeypr[l=49:60,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=49:60,x=-4:2@ave,y=4:12]; GO land

set viewport mr

fill /nolabel/pal=orange_purple/nokeypr[l=61:72,x=-4:2@ave,y=4:12]; GO land

contour/over /nolabel/pal=orange_purplepr[l=61:72,x=-4:2@ave,y=4:12]; GO

```
land

set viewport ll

fill /nolabel/pal=orange_purple/nokeypr[l=73:84,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=73:84,x=-4:2@ave,y=4:12]; GO
land


set viewport lm

fill /nolabel/pal=orange_purple/nokeypr[l=85:96,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=85:96,x=-4:2@ave,y=4:12]; GO
land


set viewport lr

fill /nolabel/pal=orange_purple/nokeypr[l=97:108,x=-4:2@ave,y=4:12]; go land

contour/over /nolabel/pal=orange_purplepr[l=97:108,x=-4:2@ave,y=4:12]; GO
land


! NOAA/PMEL TMAP

 ! FERRET v6.82

 ! Linux 2.6.18-308.8.2.el5PAE 32-bit - 08/03/12

 ! 16-Jan-13 11:16


use GPCP.1990-1998.nc

sh d
```

```
set viewport ul

fill /nolabel/pal=orange_purple/nokeypr[l=30:33@ave,x=-20:25,y=-5:25]; GO

land

contour/over /nolabel/pal=orange_purplepr[l=30:33@ave,x=-20:25,y=-5:25]; GO

land

label 05,26,0,0,0.2 @SR@P7 JJAS-LOW1992


set viewport ur

fill /nolabel/pal=orange_purple/nokeypr[l=18:21@ave,x=-20:25,y=-5:25]; GO

land

contour/over /nolabel/pal=orange_purplepr[l=18:21@ave,x=-20:25,y=-5:25]; GO

land

label 05,26,0,0,0.2 @SR@P7 JJAS-LOW2001


set viewport ll

fill /nolabel/pal=orange_purple/nokeypr[l=90:93@ave,x=-20:25,y=-5:25]; GO

land

contour/over /nolabel/pal=orange_purplepr[l=90:93@ave,x=-20:25,y=-5:25]; GO

land

label 05,26,0,0,0.2 @SR@P7 JJAS-HIGH1997


set viewport lr

fill /nolabel/pal=orange_purple/nokeypr[l=78:81@ave,x=-20:25,y=-5:25]; GO
```

```
land

contour/over /nolabel/pal=orange_purplepr[l=78:81@ave,x=-20:25,y=-5:25]; GO

land

label 05,26,0,0,0.2 @SR@P7 JJAS-HIGH2006
```