UNIVERSITY OF CAPE COAST

INVESTIGATING THE EFFECT OF EL-NINO AND LA-NINA ON PRECIPITATION IN THE COASTAL BELTS OF GHANA

BY

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Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Physics

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DECLARATION

Candidate's Declaration

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

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

Name: Kwao John Einstein Kojo

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.

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ABSTRACT

The research is carried out to investigate the effect of El Nino and La Nina events of oceans and seas on the rainfall of the coastal belts of Ghana. The study is done by analysing the global Oceanic Nino Indices (ONI) and the Southern Oscillation Indices (SOI) over a thirty-year period. The result of these global indices are then compared to the annual mean rainfall for five different major coastal towns in Ghana. The five towns used for the research include Accra, Tema, Ada, Saltpond and Takoradi for the period 1986 to 2015. The data were analysed using Microsoft Excel and Statistical Package for Social Sciences (SPSS). The annual rainfall values for thirty-years in each of the five major coastal towns of Ghana and the global indices are used to identify the El Nino and La Nina years over the thirty-year climatological period. The effect of ONI and SOI values of the coast on mean annual and monthly rainfall are determined using Microsoft Excel and R-program to plot graphs. The analysis showed that the El Nino Southern Oscillation (ENSO) events contribute to a variation of rainfall in the coastal sectors of Ghana. The effect of El Nino Southern Oscillations events on the rainfall along the coastal belts of Ghana do not provide a consistent trend for accurate prediction. It was however noted in the research that all five study stations recorded a slightly higher amount of both monthly and annual rainfall during the La Nina regimes.

KEY WORDS

El Nino

La Nina

Oceanic Nino Index

Rainfall

Southern Oscillation Index

Walker circulation

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DEDICATION

To my late Dad Konyi Kwao and Elder brother Samuel Yao.

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LIST OF ABBREVIATIONS

ASI	Agricultural Stress Index
ATOC	Acoustic Thermometry of Ocean Climate
CPC	Climate Prediction Centre
ENSO	El Nino Southern Oscillation
FAO	Food and Agriculture Organisation
Gmet	Ghana Meteorological Agency
ITCZ	Intertropical convergence Zone
LW	Long Waves
MODIS	Moderate Resolution Imaging Spectra Radiometer
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
ONI	Oceanic Nino Index
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
SW	Short Waves
UNDP	United Nations and Development Programme
WAM	West African Monsoons

WHO	World Health Organisation
WMO	World Meteorological Organisation

CHAPTER ONE

INTRODUCTION

Background to the study

A prominent aspect of Ghana and West African's weather and climate is its variability. This variability such as localized thunder ranges over time and space, excessive rainfall, larger-scale storms and prolonged droughts. A year-to-year variations in the weather patterns are often associated with changes in the wind, air pressure, storm tracks, and jet streams that encompass areas far larger than that of a particular region. At times, the year-to-year changes in weather patterns are linked to specific weather, temperature and rainfall patterns occurring throughout the world due to the naturally occurring phenomena known as El Nino and La Nina events. In most years, the easterly trade winds that flow into the ITCZ pushed (www.NOAA climate.gov.) the warmed surface waters of the Pacific Ocean West-ward along the equator through zonal circulation of the Ocean waters towards South-East Asia. This results in the sea surface temperature being higher, by about half a degree Celsius than the normal temperature and which is consistent for at least over three months. Rain is therefore formed from the cooling of the rising warm air and consequently falls in the West of the Pacific while the East experiences relatively dry weather (Glantz, 2002).

Ghana is a country which is located in the West African sub region. Ghana is bounded in the north by Burkina Faso, in the West by Cote d'Ivore and in the East by the Republic of Togo. In the southern part of Ghana is the Gulf of Guinea.

As a coastal country, some of its towns lie along the coast. Some of these towns include Accra, Tema, Keta, Mankesim, Saltpong, Cape Coast, Axim, Takoradi and many other towns. In Ghana agriculture is the major source of livelihood for over 70 percent of its population (WOFAGRIC, 2019). The people depend on farming activities for survival. Less than 10 percent in sub-Saharan Africa including Ghana depend on irrigation to water their crops as reported by the (Food and Agriculture Organization, 2005). It is obvious to note that climate change remains one of the most serious threats to humanity, (Palmer and Hagedorn, 2006). It is important to note that El Niño and La Niña are not the only factors that drive global climate patterns, and that the strength of ENSO does not automatically correspond to the strength of its effects. At the regional level, seasonal outlooks need to assess the relative effects of both the El Niño/Southern Oscillation state and other locally relevant climate drivers. For example, sea surface temperatures of the Indian Ocean, the southeastern Pacific Ocean and the Tropical Atlantic Ocean are also known to influence the climate in the adjacent land areas as proposed by Oscar Rojas and others (FAO, 2014).

Farmers face a crucial dilemma with respect to the quantity of rain to expect in a given year that will adequately meet the requirement of cropping. Most importantly, the people staying along the coast of Ghana persistently are interrupted with unpredictable extreme weather events such as excessive rainfall, high sea surface temperatures, very cold weather conditions in sea and prolonged drought and severe cold temperature regimes in the lands along the coast (Guilyardi et al 2010. From the UK inter agency regional analysis network, global report on ENSO events (October, 2015) El Niño and La Niña events are the extremes in a vast repeating cycle of large-scale fluctuations of air pressure called the Southern Oscillation (often referred to as ENSO - El Niño/La Niña Southern Oscillation), Eric Guilyardi, (2009). The ENSO cycle originates in the tropical Pacific with El Niño and La Niña events recurring, on average, every four years (the period can vary between two and seven years) and usually lasting approximately 9 to 12 months. El Niño and La Niña events have a significant effect on weather patterns in countries such as Indonesia, Papua New Guinea, Ecuador and Peru. However, although they take place in a relatively small portion of the Pacific, the changes caused by the Southern Oscillation can affect patterns of weather variability in large parts of Asia, Africa and North and South America (Tollefson, 2015). El Nino Southern Oscillation events take place in the tropics.

In some seasons, individual rainfalls are numerous and well distributed, whereas in others they are scattered and infrequent. The result of variations in the seasons is of great variability in monthly rainfall totals and also in yearly totals. It is not unusual for an entire month in a season customarily regarded as rainy season to be without significant amount of rain. In the southern parts of Ghana, June tends to be wet with average monthly values between 152mm and 254 mm. During the northern summer months when the moist monsoon current is at its strongest, its average direction is approximately that of the orientation of the coast line. In addition, there is an area of relatively cold water just off the coast from Cape Three Points eastwards AKER Energy report (2019). The monsoon current therefore passes over land gradually losing its moisture or becomes more stable, as a result of cooling over the ocean, with a decrease in precipitation. The reason for the existence of the relatively cold water may be associated with a northward extension of the cold Benguela current which sweeps northward from the Cape of Good Hope and is deflected Westerly through the Gulf of Guinea. Alternatively, the orientation of the coast is favourable for the 'Ekman' effect, whereby the sea surface layers near the coast set an angle of 45^0 from the coast and are replaced by cooler water from below. The extent of the reduction in temperature suggests that the earlier explanation is more likely, although changes in the set of the currents indicate that both may occur.

Several questions arrived earlier by scientists in the 1900 as whether the ocean circulation is thermally or mechanically forced. Sandström (1908) concluded from his laboratory experiments that the heating and cooling at the ocean surface by itself would not be able to excite a circulation in the interior of the ocean. His arguments were elaborated by Jeffreys (1925) and Defant (1961), who concluded that the circulation must be mechanically forced. Nevertheless, for a long time, a widespread view among oceanographers was that a significant part of the ocean circulation (the thermohaline circulation) is forced by buoyancy fluxes at the surface (most importantly by the differential heating). According to a research conducted on the impact of El Nino and La Nina on the production of Cocoa across the globe by the Executive Committee "One Hundred and Forty-Second Meeting" in London. July, 2010, it was concluded that differential heating of the oceans across the globe are some of the main cause of the rise in sea surface temperature which lead to the emergence of El Nino and La Nina events across the oceans of the world of which our country is not an exception. According to Jackson et al (2003) closely related to the rise in sea temperature is the Walker circulation which induces ENSO episodes over the Pacific Ocean.

ENSO events and Ghana's Climate

In Ghana, less effort has been done by early researchers to find out the effect of ENSO events on rainfall and prolonged drought. This research deals with how the climate of Ghana is affected by El Nino and La Nina events. The method adopted to find this non-periodic pattern and the behavior of the meteorological elements such as rainfall along the towns of the coasts of Ghana is the analysis of the ENSO events along the coast. This research is not claiming that precipitation events are only caused by El Nino and La Nina events along the coast of Ghana. On the contrary the onset of rainfall and variability of daily temperatures over land are greatly controlled by many other factors including:

i) The position of the inter- tropical convergence zone

ii) The wind circulation over the coast of West Africa

iii) The upper level disturbances

iv) The tropical plumes and the geography of the area of the coastal towns.

v). The West African Monsoons (WAM) which carries moisture from the Atlantic ocean to land.

The effects of the El Nino and La Nina events in the precipitation and temperature variation in the coastal sectors would be of importance but usually are triggered by the influence of these synoptic conditions listed earlier in this thesis.

However, the objective of this research is to find whether any direct or reliable indicators or link between the precipitation in the coastal belts of Ghana and the El Nino and La Nina episodes. This together with the synoptic conditions already known may help to decide whether or not the extreme weather patterns such as excess rainfall and prolonged drought has to do with El Nino and La Nina events in the coasts.

Statement of the problem

The inconsistency of Ghana’s rainfall along the coastal belts over the years and the fluctuations of rainfall pose a problem to Ghana’s climate.

There is insufficient literature in Ghana to estimate the contribution of El Nino and La Nina episodes of the oceans to the rainfall along the coast. The people in Ghana mainly depend on crop farming for feeding the inhabitants. The various farming systems depend on natural rainfall for watering the crops. The inconsistent nature of rainfall in various coastal towns poses a burden to farming. At certain seasons there is excess rainfall or limited rainfall while at other periods there is normal rainfall. The actual is difficult to predict by past and present meteorologists. It these and other problems which makes it necessary this thesis to be done on El Nino and La Nina events on coastal rainfall.

Research question

How is the impact of the variations of sea surface temperature due to ENSO episodes on rainfall along the coastal belt of Ghana? If the ENSO events affect rainfall along the coastal towns, does the effect increases or decreases the amount of precipitation?

Research Objective

The objective of the research is;

to investigate the impact of El Nino and La Nina events on precipitation at the coastal belts of Ghana.

Significance of the study

This research would serve as a new source of literature to provide more information on the effects of ENSO episodes on rainfall along the coast.

The outline of the thesis

The entire thesis is grouped into five chapters as follows: Chapter two gives a detailed literature review of El Nino and La Nina events along the coast of Ghana and the rest of the world. Chapter Three is on data and methodology used in the research, while Chapters Four and Five discuss the results, conclusions and recommendations respectively.

Delimitations

No work was done to study how the ENSO episode affects rainfall in the Non-coastal towns. The position of Inter Tropical Convergence Zone (ITCZ) or Mesoscales motions and their effect on rainfall is not part of this study.

Limitations

Precipitation data was obtained from Ghana Meteorological Agency (GMet) covering five meteorological stations along the coast.

The stations are Accra, Ada, Tema, Takoradi and Saltpond.

ONI values were limited to those collected with the Nino 3.4 index of 120^0 West Latitude and 170^0 East longitude in the Pacific Ocean and SOI values were obtained between the Darwin, Northern Australia and the Tahiti in the Pacific Ocean.

Summary of the Chapter

This part of the thesis deals with the background to the study, some concepts of ENSO events, the research questions and the objectives of the thesis. It also includes the outline of the entire thesis, the limitations and delimitations as well as the identification of the problem.

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter deals with the literature review of the research topic, basic mathematics of the oceans, the total energy budget of the earth, heating and cooling of the land and the sea or oceans and lastly the diurnal range of temperature over the sea and the land. It also reviews scientific work already done by Meteorologists on ENSO events and their contribution to rainfall in Africa and other parts of the world.

El Nino and La Nina

El Nino is the local warming of the surface of water that takes place in the entire equatorial zones of Central and Eastern Pacific of the ocean. From (Kilads and Diaz, 1998). The warming originates from the Pacific Ocean of the Peruvian Coast and which affects Oceanic circulation worldwide. It usually peaks or climaxes around Christmas hence the name Christ Child. An early recorded mention of the term "El Niño with regard to climate occurred in 1892. The phenomenon had long been of interest because of its effects on the rainfall. Russel (1896) suggested droughts in India and Australia tended to occur at the same periods and timed the concurrence of ENSO events in the two towns. This was however confirmed by Walker (1904), when he identified that droughts can occur in different geographical locations at the same time due to the effect of ENSO.

The major 1982–83 El Niño in the California of the USA led to an upsurge of interest from the scientific community.

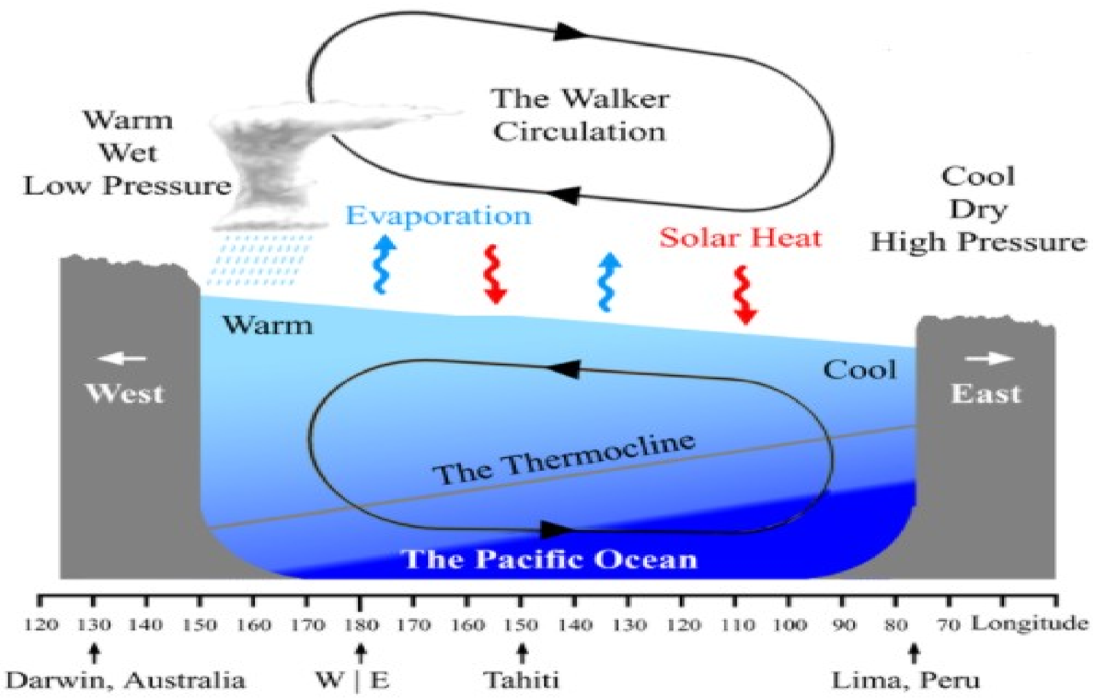


Figure 1: Schematic diagram of the El Nino and La Nina phase of the Pacific Ocean. (Source: National Science Review (2020), Perking University, China. Department of Atmospheric and oceanic Sciences, School of Physics)

The diagram in the Figure 2 illustrates the variation of ocean temperature. The water and air which are warmed by the sun are carried towards the West of the Pacific Ocean by the Walker Circulations. The far end of the West is thus warmed above the average temperature of the Ocean. The warming is termed El Nino. There is precipitation at the west due to sufficient convections. The reverse process of the Walker Circulations causes the East to be cool and dry with high pressure. The cool phase is thus termed La Nina.

An intense El Niño event in 1997/1998 caused an estimated 16% of the world's coral reef systems to die Walker (1924). The event temporarily warmed air temperature by 1.5 °C, compared to the usual increase of 0.25 °C associated with El Niño events globally. From Ahrens (2007) ENSO is defined as the see-saw patterns of reversing surface air pressure at the opposite ends of the Pacific Ocean. During typical El Nino events the sea surface temperature can rise up to 2^0 C warmer than normal (Glantz, 1996). Practically ENSOs are identified by any of the following methods.

i. Oceanic Nino Index (ONI) approach which is based on SST departures or anomalies which is calculated by a buoying satellite coupled to an appropriate computer program such as the python. The values of the ONI give an indication of whether there was an occurrence of El Nino, La Nina or Normal ocean temperature for a particular period. If the ONI is positively high, then there is an indication that El Nino has occurred. On the other hand, high negative indexes during a period from the computer show that La Nina events occurred. Low ONI values which are positive or negative is an indication that the ocean temperatures are normal during that period.

ii. Southern oscillation index (SOI). This is an East-West balancing movements of air masses between the pacific and the Indo-Australian areas. From Parker, 1983 SOI are typical wind pattern. The differences in the atmospheric pressure between the East results in the measurement of SOI. Contrary to the ONI values where high negative values indicate El Nino or warming events and the high positive values indicate cold episodes or La Nina events on the oceans, the SOI values that are negatively high rather show El Nino event and positively high values of SOI indicate La Nina or cold episodes.

The research is conducted in order to investigate the effect of ENSO events on rainfall along the coastal belts of Ghana. Although ENSO has been shown to be one of the primary determinants of the inter-annual variability of rainfall in the low-latitudes, its influence over Africa remains controversial. (Nicholson, 1996). A number of studies have confirmed a relationship between rainfall and ENSO in parts of Western and southern Africa. From literature the warm and cold events such as prolonged droughts or excessive floods or storms and other abnormal weather conditions are linked with ENSO episodes of the Oceans (Entekhabi, 1986). Although flooding conditions in a given locality may not be due to El Nino and La Nina events but due to poor community and town planning, design and building construction. But not withstanding this the possibility of warm and cold episodes of the oceans and the seas cannot be ruled out. From the American Meteorological society (AMS) the atmospheric manifestation of warm and cold episodes of the ocean is the southern oscillation that trigger a large scale tropical East –West see-saw in southern pacific level surface pressure although ENSO originates from the tropical Pacific and the Atlantic Ocean of which Ghana forms a part. The ENSO in general affects global climate and weather event such as drought/ flooding and tropical storms. El Niño-Southern Oscillation substantially affects the climate of the countries lying close to the oceans and the sea water. Although not every area is affected severely in each episode, El Niño does lead to an increased likelihood of substantial climate anomalies in each of these areas. It tends to amplify the climate variability, imposes a specific temporal pattern on droughts and excessive rainfall periods or prolonged droughts, and allows some predictability of these variations. Nicholls (1988) found that the relative variability of annual rainfall was typically one-third to one-half higher for rainfall stations in areas affected by the El Niño-Southern Oscillation, compared with stations with the same mean rainfall in areas not affected by El Niño-Southern Oscillation.

Nicholls et al (1990) confirmed, on recent data and using the coefficient of variation as a measure of relative variability, that the El Niño-Southern Oscillation does amplify rainfall variability in the areas it affects, relative to elsewhere. This effect was strongest at lower latitudes and low rainfalls and so is especially relevant to the semi-arid areas of Africa. The amplification factor is substantial. The variance of annual rainfall in an area strongly affected by the Southern Oscillation might be, depending on latitude and mean rainfall, more than double that in an area with similar mean rainfall that is not influenced by the Southern Oscillation. The higher climate variability (i.e., more severe droughts and floods) in countries affected by El Niño-Southern Oscillation may provide a partial explanation of why in these countries droughts can lead to shortage in food supply.

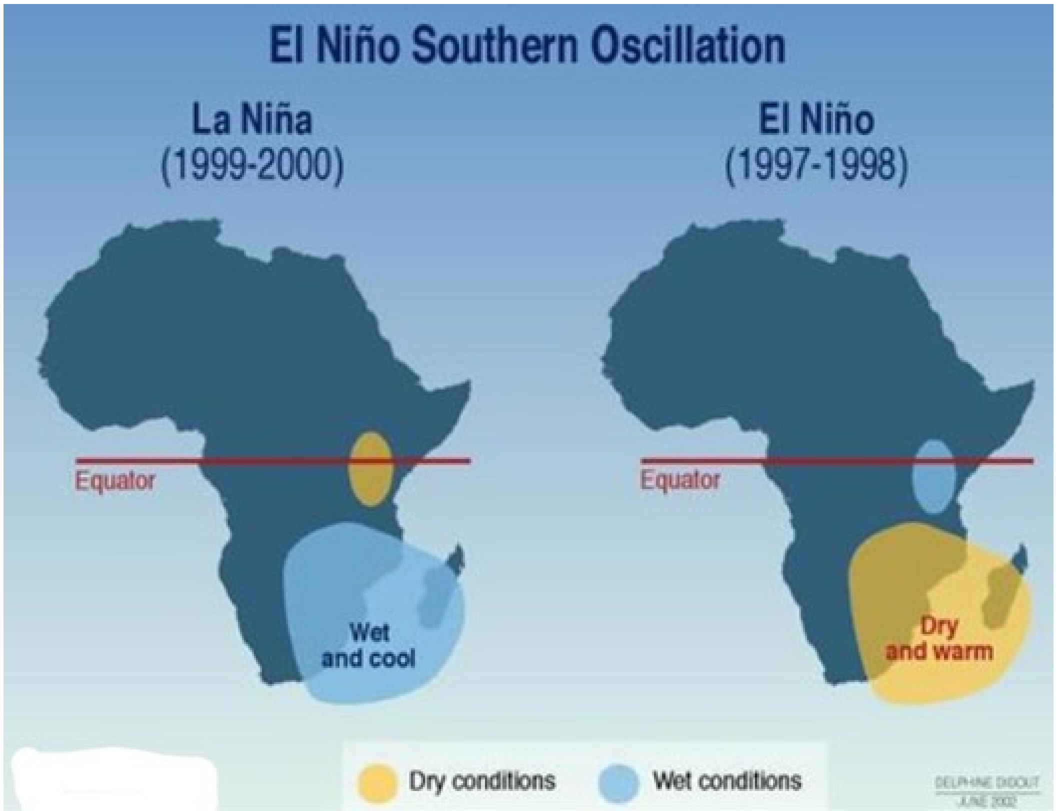


Figure 2: The impact of ENSO on Southern African climate (Source: WWW. Science direct.gov.)

The Figure 1 illustrates the impact of ENSO events in Southern Africa including Zimbabwe, Mozambique and South Africa These countries suffered prolonged drought during the 1997 El Nino episodes and in the 1999 La Nina episode suffered excessive rainfall. This extreme weather conditions could equally happen in Ghana since El Nino and La Nina episodes are tele connected.

Predicting ENSO is crucial to both the scientific community and the general public (Mcphaden et al, 2006). From the works of (Picaut, 2004), theoretical explanation of ENSO can be grouped into two frame works. From one framework ENSO is self- sustaining and on other hand, ENSO has a natural oscillatory mode which couples Ocean and atmospheric system. El Nino is a local warming of the surface of water that takes place in the entire equatorial zones of central and Eastern Pacific of the ocean. From (Kilads and Diaz, 1998), the warming originates from the Pacific Ocean of the Peruvian Coast and which affects oceanic circulation worldwide.

Near the equator in the tropical Pacific, these easterly (east to west) winds tend to pull the surface water of the ocean along with them, and in particular, the warm surface water westward, to an area that includes Indonesia, eastern Australia and many Pacific Islands. Meanwhile, along the coast of South America, colder water from the ocean depths rises to the top, as the warmer water is blown westward. Since cool air is denser than warm air, it limits the formation of clouds and, therefore, of rainfall. La Niña, the cold phase of El Nino Southern oscillation, is characterized by stronger-than-normal trade winds, colder tropical Pacific sea surface temperatures (by 1°to 3° C), which accentuate the shift in heavy rainfall to the far western tropical Pacific. During El Niño events, the trade winds weaken along the equator as atmospheric pressure rises in the western Pacific and falls in the eastern Pacific. Weaker trade winds allow the western Pacific warm water to migrate eastward. El Niño episodes reflect periods of abnormally high sea surface temperatures (by 2° to 3.5°C).

The principal feature of rainfall in Ghana is its seasonal character and its variability from year to year. According to the Ghana Meteorology Agency (GMet) there are three types of rainfall which are recognized in Ghana, although adjacent types shade into one another. No very definite lines of differences or clear cut exist, as they are a consequence of the north and south movement of the inter-tropical convergence zones (ITCZ) and its associated weather zones. The main cause of most rainfalls in Ghana from literature is due to the movement of the West African Monsoon Winds (WAM). Which represents a major wind systems that affect the West African sub region between latitudes 90 and 200 N and is characterized by winds South-westerly during warmer months North-Easterly during cooler months of the year. The rise in these moist winds is helped by heights such tall vegetation or mountains.

January is a dry month throughout the country. However, the driest month in the eastern coastal districts is August. (From Ghana Meteorological Agency 1998-2006 AD). La Nina events are more pronounced from January to March when the entire country experiences drought. El Nino events were first detected to have been occurring around December when this warm water events emerge on the oceans of the world. This warming of the seas and oceans have the ability of melting ice on the surface of the oceans which can cause flooding. In addition to flooding as result of the El Nino events there is more evaporation of water into the troposphere which results in extreme rainfall events such storms, hurricanes and many other associated weather complications. The La Nina events on the other hand are periods of below average sea surface temperatures (SST). During La Nina events the general environmental temperatures tend to increase along the southeast and decrease along the northwest of the globe (CPC, NOAA, 2018). This is however suggested by the USA centre for National Oceanic and Atmospheric Administration in the journal ‘’Basic ocean facts’’ in 2015. An especially strong Walker circulation causes a La Niña, resulting in cooler ocean temperatures in the central and eastern tropical Pacific Ocean due to increased upwelling. La Niña is a coupled ocean-atmosphere phenomenon that is the counterpart of El Niño as part of the broader El Niño Southern Oscillation climate pattern. The name La Niña originates from Spanish, meaning "the girl", and the El Niño which means "the boy". During a period of La Niña, the sea surface temperature across the equatorial eastern central Pacific will be lower than normal by 3–5 °C. In the United States, an appearance of La Niña happens for at least five months of El Nino conditions. However, each country and an island nation has a different threshold for what constitutes a La Niña event, which is tailored to their specific interests. El Nino and La Nina events are regarded as warm and cold episodes respectively Adiku and Stone (1995). They used Southern Oscillation Index (SOI) to investigate the onset of rainfall variability over West Africa. The Southern Oscillation Index is defined as the measure of the oscillation of the atmospheric pressure between the Eastern and the Western Pacific (Ayilari-Naa, 2008). In the work of Adiku and his co researchers the Southern Oscillation Index was correlated to the total rainfall across coastal towns such as Accra, Axim, Takoradi and some non -coastal towns such Kumasi and Tamale. Though their work produces a positive correlation coefficient and proved worthy for predicting precipitation atmospheric warming it is worthy to note that SOI method are quite difficult to predict onset of warming of Oceans. Hence in this research El Nino and La Nina events which is respectively the warming and cooling episodes along the sea surface of Ghana were predicted using the abnormality of the Sea Surface temperature(SST) based on the Oceanic Nino Indices (ONI) and as well as the Southern Oscillation Indices (SOI) the thirty-year period from the 1986 to 2015.

The sketched graph in Figure 3 illustrates the various ENSO events in the oceans.

The figure 3 further illustrates the area of rainfall during La Nina and El Nino periods as we as during the normal period. The rainfall occurs at the western part of the Pacific. Thus is further understood that the rains may be a little at pacific during the El Nino episodes as in the Figure 3. Ghana and the West African sub region which lies in the Eastern Pacific are bound to experience more rain during the La Nina periods.

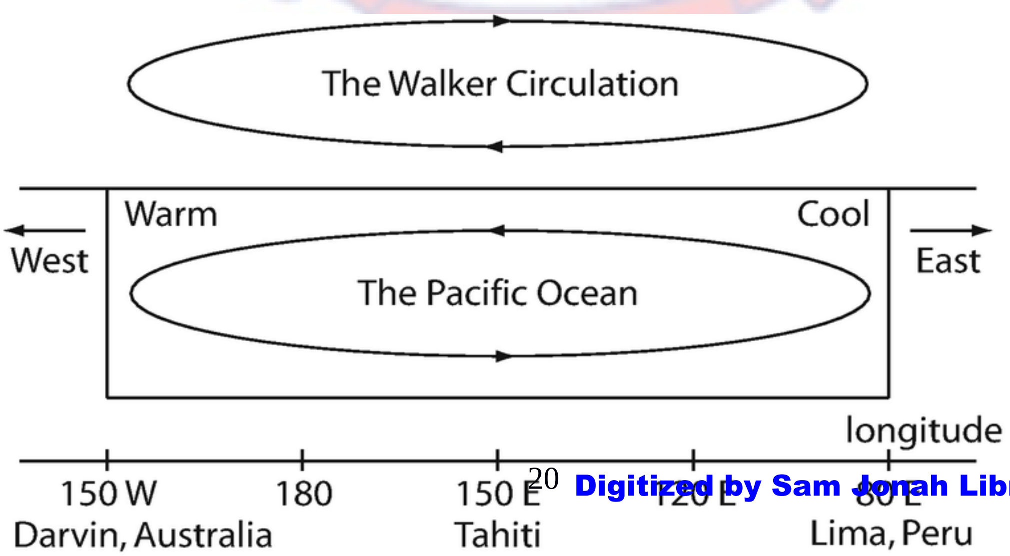


Figure 3: Variations of the position of rainfall with El Nino and La Nina episodes. (Tan ma et al 2019.) (Source: Geophysical fluids dynamic and climate).

Managing floods and other extreme weather events

The accuracy of weather prediction and forecasting is extremely important in any weather studies. The Physics of the weather is a complex one since the clouds and moisture content of the atmosphere are in constant motion. Analyzing the variations of the temperature of the seas and oceans in a thermodynamic perspective can be a key aspect of weather forecasting. The Ghana Meteorological Agency often in newsletters and television warnings try informing the general public of the onset of rain and heat waves across the country. But often this is not enough as extreme weather events such as floods, rain storms and high temperature across the lands destroy lives and property often every year and this is more pronounced in the major coastal towns of Ghana. In 2011 June, over three hundred people lost their live and several property in Accra due to severe rain which lasted for more than six hours as reported by the Daily graphic in 6th June, 2015. In this March, 2018, the minister for Works and Housing, Mr. Attah Akyea has earmarked several means of checking flooding and its untold disasters in the regional capital cities in particular Accra which include dislodging sands collected in our main drainage routes and gutters and draining of the local river along Accra, Kwame Nkrumah Circle to Korlebu popularly called Odaw Ona. Other coastal sectors such Axim in Western region and Keta of the Volta region often suffer several losses due extreme rainfall and storms. The change in rainfall trends due to the El Niño and La Niña has been discussed by weather researchers world-wide. For example, Kane, (1999)

Extreme weather events due to Enso episodes

The dangers associated with extreme weather events due to ENSO episodes include but not limited to excess rainfall during certain periods, prolonged droughts in the West African Sahel regions of which Ghana is no exception, temperatures above the normal along in-land and coastal environment, low temperatures for both aquatic in-land organisms. Accurate information on the effects of ENSO episodes will help us play a role in

i. Complying with water drainage systems in towns during heavy rainfall

ii. Reducing the drainage flow for areas with limited disposal options

iii. Maintain water quality standards of surface water bodies for other water users

iv. Prevent loss of life during extreme weather events by issuing appropriate weather warning on time and at the right time.

Enso events managements

In Ghana, most lives are lost through extreme weather related events such as floods and rain storms. This is however larger in the coastal belts of Ghana. The damage of property, reduction in agricultural yield, strained water resources, sanitation problems and health related issues are some problems any researcher in the weather of Ghana will want to reduce if not completely eliminated.

Mitigate adverse climate impacts

There is a need for systematic and periodic study of the weather to enhance the long term weather forecasts for early warning systems in order to cut down the loss of lives and property in the communities of Ghana. According to J. Houghton (2005) rainfall patterns which could lead to floods and severe droughts especially in the tropics is strongly influenced by surging Sea Surface Temperature of the Oceans and seas. The West African monsoon rainfall, varies widely both in space and time. The rainfall variation within the season over the study area of any research is often termed the intra seasonal variations of the rainfall. The factors responsible for the intra-seasonal variability of rainfall according Houze et al (2010) are:

i. Early onset of rainfall and rapid advance of the rains

ii. Late onset of the rainfall and slow response rain

iii. Breaks and discontinuities of rainfall pattern

iv. Early and rapid withdrawal of the rainfall.

Fishing and crop farming can benefit a lot from accurate long-term seasonal climate forecasts. More importantly agriculture in it entity depends on the weather, climate and water availability. An unexpected departure from the anticipated climate conditions can curtail the progress and yield of agriculture produce. Timely climate forecasts will offer an adequate means of reducing losses in prolonged drought events and nevertheless increase productivity in good years. In addition, accurate weather prediction along the coast will form the basis of choosing appropriate risk management strategies.

El Nino and La Nina is far older than their name, dating back thousands of years according to geological records. Long before climate scientists started to study it, South American fishermen knew how to read it in the water. In a strong El Nino year, the eastern Pacific can rise 30cm and feels palpably warmer to the touch. Species of fish usually caught in June are netted in December. Epic rains fill coastal deserts with lakes and vegetation.

On the west coast of South America, residents have long interpreted warming water as the sign of an impending El Nino. By the time coastal temperatures rise, however, the phenomenon is typically well on its way. The problem scientists are still trying to solve — the one Pierce was working on in 1997, and that has given researchers special trouble in 2014 — is how to foresee an ENSO episode coming many months or years in advance.

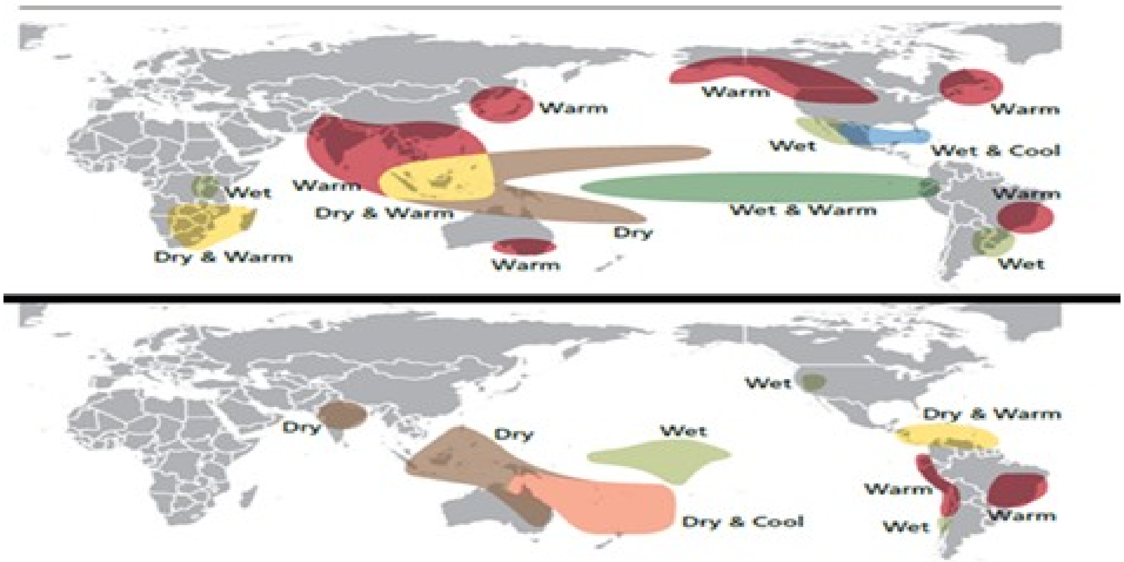


Figure 4: Variation of the Ocean temperatures at different periods of the year due ENSO events. (Source: Understanding the drought impact of El Nino on the global Agricultural areas: The assessment using the FAO's Agricultural Stress Index (ASI) of the UN, Rome, 2005).

The basic idea of El Nino and La Nina events are illustrated in the Figure 3 where the Ocean is divided into two halves: The upper half indicates the Northern Hemisphere winters which are due to the trade winds from March to October and the other half shows the weather impact from April to September. In the Figure 4 dry conditions means prolonged drought, wet conditions mean excess rainfall during the period and warm indicates abnormal warmth. The difference is just a few degrees, but in a global context, the extra heat can transform the seasonal climate. Some years, the warm region spreads outward and eventually upward, where it meets with easterly trade winds. This creates a feedback loop. Warm water undermines easterly winds that normally enable an upwelling of cool water, which amplifies warming and in turn further slows the winds. It's this moment of atmospheric-oceanic coupling that helps scientists define the start of El Nino.

In a tangled and interconnected system like the climate, a seemingly regional phenomenon like El Nino becomes global—and so does the science deployed to understand it. In the 19th century, El Nino was understood as warming in the Pacific, but its secondary effects (if any) were a matter of debate. Scientists were just starting to consider that patterns of regional weather might be connected over vast distances. Increasing air pressure in one part of the world, for instance, was surprisingly correlated with decreasing air pressure elsewhere in the world

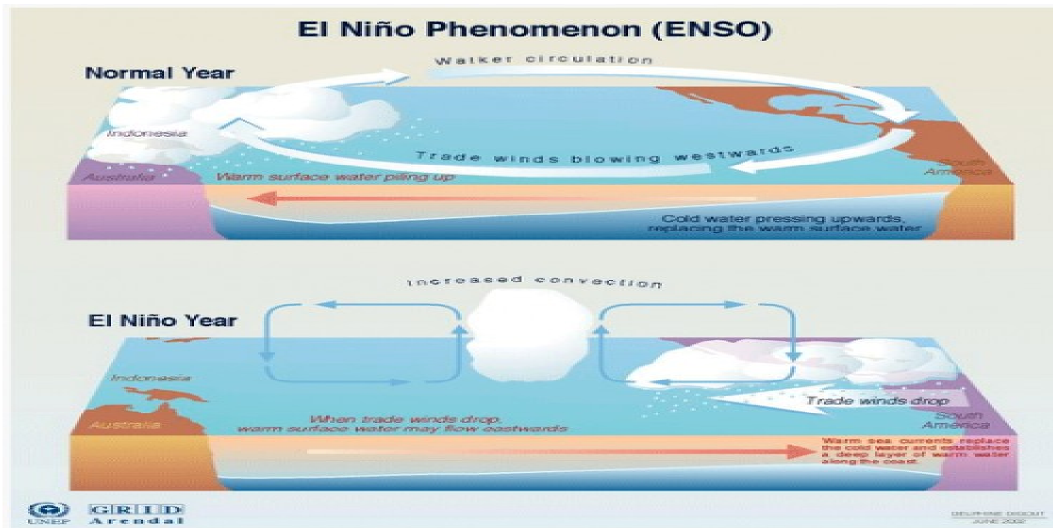


Figure 5: The Ocean circulation and its impact on the ENSO events. (Source: Climate Prediction Center-NCEP, NOAA).

Climate science developed regionally, like pieces of a puzzle that has only gradually been put together. In 1895, Victor Eguiguren postulated a link between heavy rains in Peru and the El Nino cycle. Early in the 20th century, Gilbert Walker theorized a link called the Southern Oscillation between atmospheric pressure in the Indian and Pacific oceans. These pieces were refined independently until the 1960s, when Jacob Jerkins put them together and found he had a match: The Southern Oscillation and El Nino could be understood as two faces of the same phenomenon, soon known as the El Nino Southern Oscillation (ENSO). Fluctuating pressure provided a causal link between the behavior of wind and water. It also helped explain cooling phases called La Nina, which alternated with El Nino years as in the Figure 5.

ENSO's impacts have proven to be subtle and far-reaching. The climate historian César Caviedes (2005) argued that ENSO helped chill the winter of Napoleon's march to Moscow, just as it helped freeze the soil during Hitler's attempt at the same maneuver. It contributed to drought in the Horn of Africa that, in 1974, led to the collapse of the Ethiopian Empire. The scope and diversity of these impacts makes it clear that accurate ENSO prediction would revolutionize our understanding of the climate. Advancing science has made it possible to trace El Nino's many consequences in the past and the present, all across the globe. But a crucial question remains: Can scientists reliably see an El Nino coming? The answer is no for the mean time the mechanism that bring about an increase or decrease in the sea or ocean temperatures are many and one cannot point out a single factor which leads ENSO variation.

El Niño–Southern Oscillation (*ENSO*) is an irregularly periodic variation in and over the tropical eastern Pacific Ocean, affecting climate of much of the tropics and subtropics. The warming phase of the sea temperature is known as and the cooling phase as. Southern Oscillation *is* the accompanying atmospheric component, coupled with the sea temperature change: El Niño is accompanied with high, and La Niña with low air temperature in the tropical western Pacific. The two periods last several months each (typically occurring every few years) and their effects vary in intensity. The two phases relate to what was discovered by the fisher men during the early twentieth century. The Walker circulation is caused by the variation of Ocean temperature that results from the Eastern Pacific Ocean. When the Walker circulation weakens or reverses, an El Niño results, causing the ocean surface to be warmer than average, as upwelling of cold water occurs less or not at all. An especially strong Walker circulation causes a La Niña, resulting in cooler ocean temperatures due to increased upwelling.

Mechanisms that cause the oscillation remain under study. The extremes of this climate pattern's oscillations cause extreme weather (such as floods and droughts) in many regions of the world. Developing countries dependent upon agriculture and fishing, particularly those bordering the Pacific Ocean, are the most affected.

Since the arrival of the ENSO events most effort has been made to clearly study the onset of ENSO events and predict their impact on rainfall and other precipitation phenomena. Although in the developed countries such as the USA, Japan, the UK and Austria have done extensive studies on El Nino and La Nina events on the precipitation. Weather scientists such as Rodney Martinez and other scientists in Ecuador, did extensive research on the ENSO events and the contribution to rainfall. All the early warning signs for a large El Nino are from oceanic warming to atmospheric coupling to early shifts in rainfall and temperature. Studies have shown that El Nino events were likely to cause the storms of the 1998 Rio Nido mud slides in northern California, damaging houses and cars. Mosquitoes multiplied in standing water; houses and even villages were washed away by flooding. One main experience gathered by humans in the area of Science was partly due to the onset of the El Nino 1997/98 and its devastating effect on life and climate. The research on the effects of warm and cold episodes of sea could traced back in the 19th century. These days, ENSO is a much larger part of academic and national research programs, and there are more than 20 major climate models that help predict it. Not every El Nino gives as strong a signal as 1997/98, and newer models aim to extract a prediction even when the warning signs are weak. That was exactly the challenge in 2014. It is on record that not much work has been done on ENSO episodes in Ghana in order to ascertain the contribution of ENSO events to rainfall in Ghana, Dr. Adiku G. et al (2008) did some works on ENSO events and their effect to Agriculture. This thesis is done to find out how the rainfall in Ghana is affected by El Nino and La Nina events in particular the coastal towns of Ghana.

There are many studies which confirm in the United States of America that most serious storms are a result El Nino storms. Still, complex models create new challenges: Scientists don't always understand how they work, or how to improve them. Which brings us to the present, when even after two decades of advancing climate science, uncertainty can win the day.

Early in 2014, the water beneath the Pacific started getting warmer. Data from buoys and satellites, many deployed by the National Oceanic and Atmospheric Administration in the United States, fed into climate models around the world, which produced a fairly uniform result: an El Nino seemed to be brewing, with approximately 75 percent likelihood of developing.

ENSO predictions have come a long way since the 1990s, but there's plenty of work left to do. A 2012 survey of many ENSO models showed that 6-month forecasts have slowly but steadily improved since the 1990s. Even so, thanks to limitations of computer power, data quality, and model reliability, however, the 2014 forecasts were tentative.

In the spring of 2014, word of a potentially developing El Nino reached media organizations. From there, the news spread quickly and loudly. Many publications announced an impending "monster" El Nino, while some scientists went so far as to compare 2014 conditions to the destructive winter of 1997/98. And then—very little happened. Waters near the coast of South America warmed up, and rainfall spiked in some regions near the coast. But as autumn began, atmospheric coupling still hadn't occurred, leaving many scientists scratching their heads.

The obvious problem is that the climate is layered and complicated. Climate models aim to simplify real-world phenomena, but sometimes can be simplified by climate scientists. "They are almost as complex as the real world although but using climate indicators such as ENSO variations of the sea, rainfall data, temperature variation of the sea one can model the rainfall pattern of a given geographical location. Regardless of the outcome, future models will need to reckon with the bizarre mixed signals that have emerged in 2014. Although the general principles of climate models seem sound, many scientists suspect something crucial is misrepresented or missing. Every new El Nino event trigger new approach to identify and revise a new theory about how El Nino seems to be working.

Perhaps we don't study climate phenomena despite their complexity, but because of their complexity. The science of El Nino provides some profound insights about the climate at large. In brief El Nino and La Nina events contribute to the following weather patterns according to National Oceanic and Atmospheric Administration the typical El Nino and La Nina are generally atmospheric and oceanic conditions which occurs in tends one after the other and cannot occur at the same time. Typical El Nino characteristics in the environment include the following:

i. A deep layer of very warm ocean water across the sea surface in which temperatures generally $1.5^0 – 2.5^0$ C above the average and subsurface oceans temperatures typically 3^0 -6^0 C above average at the depth of the oceanic thermocline

ii. Across the eastern half of the equatorial Pacific.

iii. Suppressed convective rainfall and above-average air pressure across Indonesia, the western equatorial Pacific, and northern Australia.

iv. Weaker than average easterly trade winds across the eastern half of the equatorial Pacific.

v. Westerly winds at low levels of the atmosphere across the western equatorial Pacific. In August-October increased upper level westerly winds lead to higher-than-average vertical wind shear and reduced hurricane activity across the tropical North Atlantic, and to below-average vertical wind shear and increased hurricane activity over the eastern tropical North Pacific

Also the corresponding La Nina events across the atmosphere is characterized by the following:

i. A deep layer of cooler than average ocean temperatures across the oceans and seas around the towns and countries, with sea-surface temperatures generally 1^{o}-$2^{o}C$ below average, and sub-surface temperatures typically 2^{o}-$4^{o}C$ below average at the depth of the oceanic thermocline.

ii. Suppressed convective rainfall and above average air pressure across the eastern half of the equatorial Pacific.

iii. Enhanced convective rainfall and below-average air pressure across countries in particular the western equatorial Pacific states such as Indonesia, and northern Australia.

iv. Stronger than average easterly winds across the entire equatorial Pacific.

v. A strong positive value of the Southern Oscillation Index (SOI), due to higher-than-average surface air pressure at surrounded by oceans typically the island countries such Tahiti, Jamaica to mention but few which normally suffer from extreme weather related events.

vi. In the upper atmosphere, lower than average air pressure over the subtropical eastern Pacific of both hemispheres flanking the region of suppressed equatorial convection located over the east-central equatorial Pacific.

vii. Items i-v above reflect an enhanced equatorial Walker Circulation.

viii. A weaker mean winter time jet stream along the pole ward flanks of these anomalous low-pressure cells (over the eastern half of the Pacific Ocean) in both hemispheres.

ix. Above-average air pressure in the upper atmosphere over the subtropical Atlantic Ocean of both hemispheres, along with a stronger-than average

Tropical Easterly Jet over the equatorial Atlantic Ocean.

x. In August-October, the enhanced upper-level easterly winds lead to reduced vertical wind shear and increased hurricane activity across the tropical North Atlantic, and to above-average vertical wind shear and decreased hurricane activity over the eastern tropical North Pacific.

The El Niño-Southern Oscillation

According to Robert Rohli et al (2011) El Nino southern oscillations (ENSO) is used to refer to only usually extreme sea surface temperatures occurring for several months approximately every three to seven years in the central and eastern equatorial Pacific Ocean. La Nina on the other hand is the opposite of El Nino and refers to strengthened normal situation which typically reinforces cold water conditions in the Eastern Equatorial pacific and warm water conditions in the Western topical pacific near the maritime continent.

Closely linked to the Inter Tropical Convergence zone (ICTZ) is another climate driver known as the El Niño-Southern Oscillation (ENSO). Rain, from the cooling of the rising warm air, falls in the west of the Pacific while the east experiences relatively dry weather (Glantz, 2002). Sometimes, however, the pattern is reversed, with wide ranging consequences. Every 3-7 years El Niño sets in and the easterly trade winds collapse or even reverse (Trenberth, 2002).

The water of the western Pacific flows back eastward producing warm seas off the South American coast, but resulting in droughts in Southeast Asia and Australia. The phenomenon is called El Niño, the Spanish for 'the boy child,' because the warm waters have tended to arrive off the South American coast at Christmas time. La Niña, 'the girl child' is the more common phenomenon. There are many theories as to why this oscillation occurs, some of which include solar radiations, wind disturbances of the ocean waters, geological events such as earth quakes and moon and earth attraction from gravitational.

The Southern Oscillation Index, or SOI, gives an indication of the development and intensity of El Niño or La Niña events in the Pacific Ocean. The SOI is calculated using the pressure differences between Tahiti and Darwin. Sustained negative values of the SOI below −7 often indicate episodes. These negative values are usually accompanied by sustained warming of the central and eastern tropical Pacific Ocean, a decrease in the strength of the Pacific Trade Winds, and a reduction in winter and spring rainfall over much of eastern Australia and the Top End. Sustained positive values of the SOI above +7 are typical La Nina episode.

Inter-Tropical Convergence Zone

This is the zone of convergence of the trade winds of the northern and the southern hemisphere. Sometimes one may term the ITZC as the equatorial trough or the Inter-Tropical boundaries which oscillates in the north-south direction towards the direction of the sun. At the southern hemisphere it occurs around January and February and it is at northern hemisphere between the months of July and August. The ITZC reaches the equator in March and September.

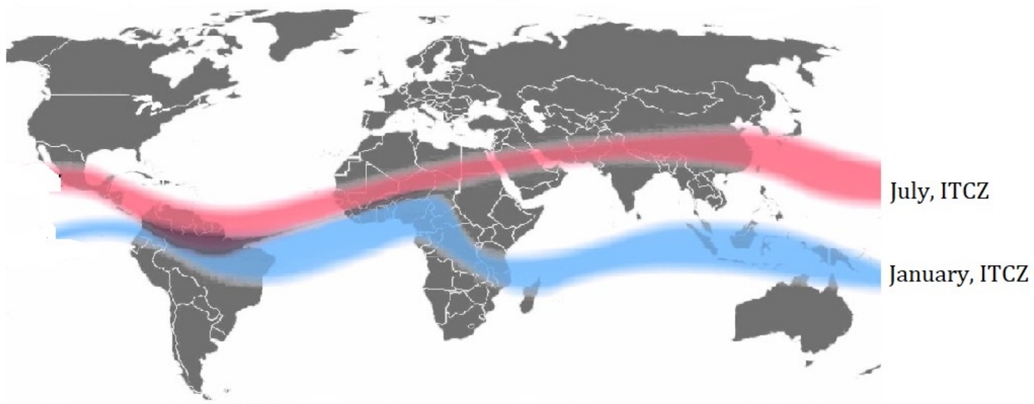


Figure 6: The variation of the inter-tropical convergence Zone during the year (https://www.youtube.com/watch)

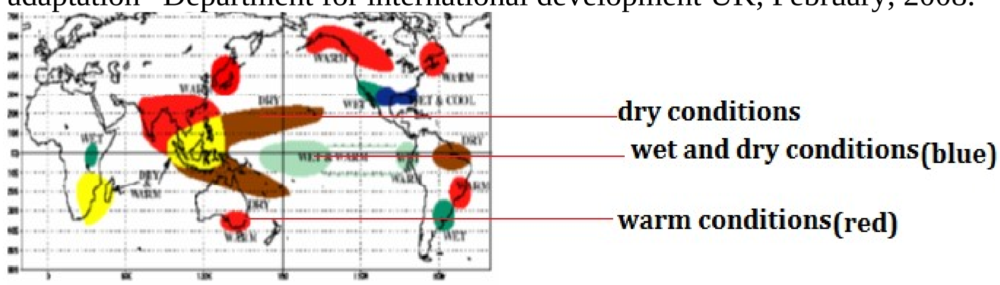
General survey of the existing methods of predicting the onset of El Nino and La Nina events

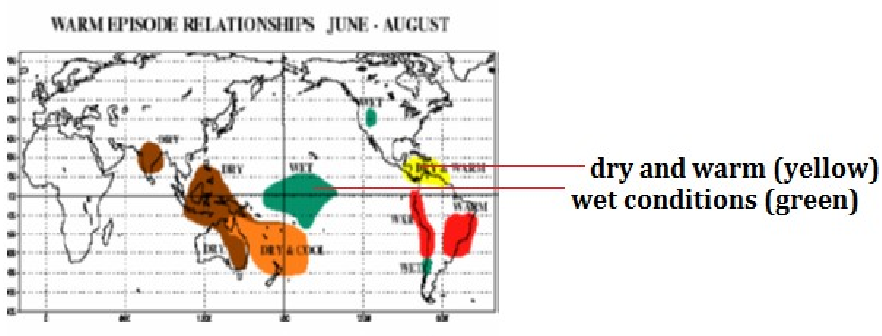
The onset of El Nino and La Nina events across a sub region is a complex phenomenon. However, the irregularities of the weather events which lead to the loss of property and life has necessitated several methods of predicting weather events and their extreme levels. Although extreme weather events are caused by several factors such as global warming, deforestation, mesoscale convective systems such the movements of squall lines and a general increase in industrialization. The onset of El Nino and La Nina events also play a major role in predicting rainfall and other weather events along the coast of Ghana. Recent models produced by the UK Meteorological Office provide fairly good short term predictions of the switchover between La Niña and El Niño, but they are complex coupled atmospheric/oceanic models and there is no evidence of a simple, single cause. There has been a tendency towards more prolonged and more frequent El Niño since the early 1990s. This appears to be unprecedented and has caused speculation that it may be a consequence of global warming.

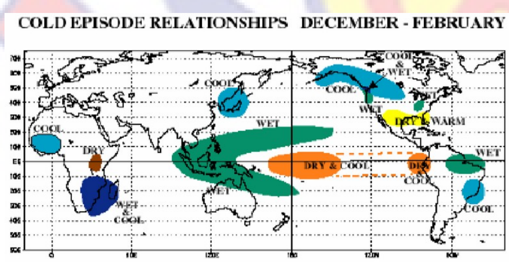
In recent years the neutral situation one in which neither El Nino nor La Nina conditions occur has been termed La Nada or ''the nothing period''. Sir Gilbert Walker (2011) explains that the change in the sea surface temperatures is responsible for the variation in pressure of the sea surface which several changes in the atmospheric pressure and temperature and the inland weather conditions. According to the National Oceanic and Atmospheric Administration (NOAA) and the World Meteorological Organization (WMO); The main indicators of predicting the onset of ENSO episodes are the early detection of the surge or rise in the Oceanic Nino Indices (ONI) which are the mean three consecutive sea surface temperatures and the three monthly mean pressure between the East and West of the Pacific Ocean called the Southern Oscillation Indices (SOI). If the mean of ONI for at least three months is +0.5 above average, then there is onset of El Nino and ONI below +0.5 means there is a La Nina event. In the contrary when the SOI for three continuous months is +0.7 and above then is concluded there is

La Nina regime and below +0.7 is an indication of El Nino event.

El Nino variation pattern December to February and from June to August. Courtesy by Gordon Conway "The Science of climate change in Africa impacts and adaptation" Department for international development UK, February, 2008.







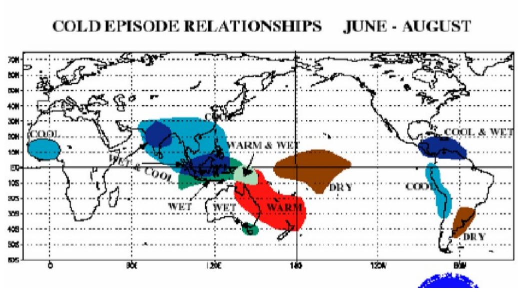


Figure 7: ENSO events and general weather descriptions in December to February and from June to August. (Source: Gordon Conway "The Science of climate change in Africa impacts and adaptation" Department for international development UK, February, 2008).

During an El Niño year the December to February weather is wetter in Eastern Africa but drier to the south, while La Niña produces the reverse. La Niña also produces cooler weather in West Africa (Figure 7). The 1997/98 El Niño was one of the strongest of the 20th century. It caused droughts and forest fires in Indonesia and north-east Brazil, and catastrophic floods in East Africa.

Fundamentals of El Nino and La Nina events

We know that there are many anthropogenic forces on the climate, particularly the volume of carbon and greenhouse gases pumped into the atmosphere as a part of our everyday lives. Yet there are a number of natural processes that affect local weather, regional climate and global conditions. Some effects on our climate are a result of fluctuations and anomalies in the complex water conveyor belts of the ocean currents of the world. These fluctuations are known as "oscillations" and the two best-known oscillations are El Niño and La Niña. The latter is the opposite of the former and make up an oscillation known as ENSO. Understanding them requires knowledge of a broad range of data from multiple disciplines.

Oscillations occur naturally in oceans all across the world; some have a limited impact on the regional weather and wider climate, and some have a much greater impact. El Niño and La Niña are examples of oscillations that have a greater impact on our climate with effects that are perhaps surprisingly felt all over the globe. Agriculture which mainly depends on certain weather conditions occurring regularly and on time can be adversely affected when the weather pattern is not regular. Knock on effects can lead to fish migrations and economic hardship for areas that rely on fish stocks. Marginal areas suffer or thrive depending on the effects of El Niño and La Niña leading to further knock on effects elsewhere. Both El Niño and La Niña are opposite effects of the same phenomenon: the ENSO (El Niño Southern Oscillation). Both are an oscillation in the temperatures between the atmosphere and the ocean of the eastern equatorial Pacific region, roughly between the International Dateline and 120 degrees west. El Niño - the conditions for which build up between June and December is caused by a change in the wind patterns. Here, the Pacific Trade Winds fail to replenish following the summer monsoons of Asia. This warmer air leads to an oscillation between the cooler and warmer waters, leading to warmer ocean temperatures than normal.

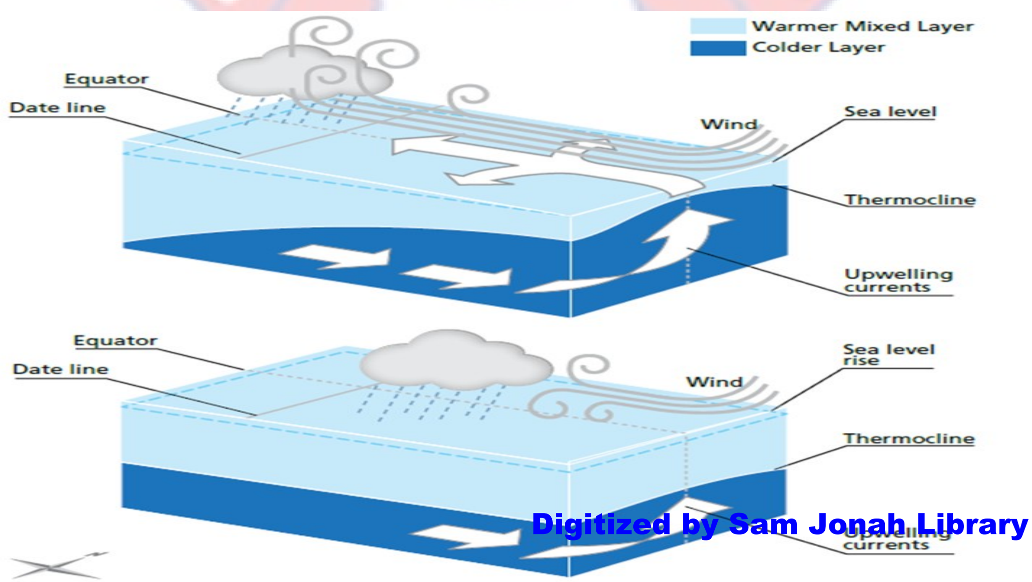


Figure 8: The upwelling or vertical circulation of the Ocean waters which leads to the variation of Ocean temperatures. (Source: (ASI) of the UN, Rome, 2005, Agricultural areas the assessment using the FAO's Agricultural Stress Index).

The diagram in the figure 8 above indicates the upwelling of the seas and oceans which lead to the increase of warm and cold episodes in the sea. This process are contribution factors that lead to the emergence of El Nino (warm temperatures) and La Nina (cold temperatures) across the oceans and seas which in effect affects the atmospheric temperature around the coasts of Ghana and consequently affect the precipitation. In the diagram, the temperature of the oceans and seas are seen increasing down at the bottom and the top layer appears colder than the down. It is the upwelling of the waters which results in mixing which leads to a slightly rise in the temperature of the sea at certain periods particularly when the solar angle is directed towards the sea and water bodies on the earth.

It was Peruvian fishermen roughly around the start of the 20th century who first noticed the correlation between temperature changes and anchovy stocks that led to the development of the study conducted by the World Health Organization (WHO) in this area, though they had noticed variations in fish stock for centuries. From the National Aeronautics and Space Administration (NASA), USA, every three to seven years and between December and January, there is a massive tailing off of stocks of the fish that the local economy relies on according to NASA. Why does this happen? Up-swellings from the sea bed occur in normal years that bring nutrients up to the plankton to feed on and in turn abundance of plankton is beneficial to marine life up the food chain. In an El Niño year, that swelling does not occur so the plankton is reduced and in turn, so are the fish stocks, mostly through failure to reproduce.

From NOAA, La Niña is effectively the opposite of El Niño, indicated by prolonged periods of sea temperatures in the same region, and the effects stated above are generally reversed. During non El Niño years, atmospheric pressure is lower than normal over the western Pacific area and higher over the colder waters of the western Pacific, as already discussed. With La Niña, the Trade Winds are particularly strong in carrying warmer water westwards across the Pacific leading to colder than average temperatures in the east and warmer than average temperatures in the west. According the National Oceanic and Atmospheric Administration-NOAA (USA) the result is that plankton increases in the areas where the temperature is cooler, leading to a positive effect on the marine life that depends on plankton or depends on those creatures that depend on plankton.

It is commonly expected that La Niña will follow immediately on from an El Niño event, but this is not always the case. From the National Oceanic and Atmospheric Administration (USA) both phenomena last anything between nine and twelve months. Typically, it comes around every five years and what usually happens is that warming in the oceans caused by the winds leads to diffusion of this warming all over the globe. It changes atmospheric pressures with consequences for rainfall, wind patterns, sea surface temperatures and can sometimes have a positive, and sometimes a negative effect on those systems. In Europe for example, El Niño reduces the instances of hurricanes in the Atlantic from NASA. ENSO events may be due to several occurrences note-able among them is the solar energy contribution to the warming of the entire earth's surface both the lands and the seas. Since the sun's energy varies at various points, the sea surface temperatures as such must vary. The ultimate source of all forms of energy on earth and on the seas and other water bodies is from the sun. Though smaller amount of heat energy comes from the stars, nuclear reactions, volcanic eruptions and other chemical reactions in the atmosphere and oceanic oscillations. Solar radiations that is absorbed is internal energy. This absorbed internal energy is eventually given off in the form of long wave radiations. Although this may not be the ultimate explanation of the origin of ENSO events, nevertheless they form a major role the ENSO events of the oceans and seas. This internal energy undergoes several energy conversions such as into kinetic, potential and latent form of atmospheric energy which gives the equation of motion.

$$\frac{dv}{dt} = \alpha\nabla P - 2\Omega x V + g + F \qquad (1)$$

Equation (1) is the statement of the Newton's 2nd law of motion relative to a rotating frame. It states that the acceleration of given air mass undergoing rotation relative to its frame of reference is the sum of the coriolis force and the pressure gradient.

Where the coriolis force, Fc and pressure gradient, P are respectively.

$F_c = 2\Omega \times V$ (2)

Where the equation (3) is given as.

$P = \alpha \nabla P$

(3)

The acceleration due to gravity is g and the frictional forces, F. When the equation (1) is multiplied through by the velocity term V, a new form of the equation below is obtained as

$$\frac{d(V.V)}{dt} = V.\alpha \nabla P - 2\Omega x V + g.V + F..V \quad (4)$$

Where

$2\Omega \times V.V = 0$

$$W = \frac{dz}{dt}$$

(5)

Thus we have the energy equation

$$\frac{d}{dt}\left[\frac{V^2}{2} + gz\right] = -\alpha V.\nabla P + V.F$$

(6)

Where $\frac{V^2}{2}$ = Kinetic energy per unit air mass

gz = potential energy at height z due to gravity

- $\alpha V \nabla P$ = Work done per unit time on a unit mass.

V.F = Work done on a unit air mass by the force of friction in a unit time. However, the equation (1) above is obtained from the equation of motion and works perfectly with the kinetic and potential energies of a system of air mass trapped in the troposphere. The first law of thermodynamics deals with the thermal energy aspect of a given air mass which is given as follows

$$\frac{d}{dt}\left[C_p T\right] = \frac{dH}{dt} + \frac{d}{dt}\left[\alpha P\right] \tag{7}$$

Where:

C_p T = Enthalpy of the system

Pα = The energy flow.

When equation (5) and equation (6) are combined, the atmospheric energy equation is obtained in equation (7) below

$$\frac{d}{dt}\left[\frac{V^2}{2} + gzC_pT\right] = \frac{dH}{dz} + \alpha\frac{\partial P}{\partial t} + V.F \qquad (8)$$

The equation (7) above illustrates the various forms of energy in a given air mass including the kinetic energy, potential energy and the enthalpy.

C_p is the specific molar heat capacity

α is the specific volume of a given water vapour air lifted

V is the velocity of the a given molecule

g is the acceleration of free fall due to gravity

T is the thermodynamic temperature

H is the height to which a given water vapour is lifted

F is the force with which a molecule of water vapour is carried

Ω is angular velocity relative to the earth at which a gas molecule rotates

Fc is the Coriolis force with which a given water vapour is carried into the atmosphere

The total Energy budget of the Oceans

The energy balance equation designed by Robert W. Christopher son (2002), which exists at the boundary separating the atmosphere from the land and water surface is

$$\text{Net R}=SW_{down}-SW_{up}+LW_{down}-LW_{up} \qquad (9)$$

Where:

SW_{down} = incoming short wave solar radiation

SW_{up} = emitted or reflected short wave solar radiation

LW_{down} = long wave infrared radiation absorbed

LW_{up} = long wave infrared radiation reflected or emitted

Net R = Net radiation

Usually atmospheric energy moving towards the surface is considered positive and the one moving away from the surface is considered negative. The sums and additions of the atmospheric energy provides the net energy on the surface. The various components of these forms of energy vary according to

i. The length of day

ii. Cloudiness of the atmosphere

iii. The season the earth surface is experiencing

iv. Solar angle of inclination to the surface of the earth.

Heating and cooling of the land and water

The rate at which land surface heats and cools is far more than how the surface of water heats and cools. The land surface is a blackbody and absorbs most of the incident radiations falling on the earth's surface. This property of absorbing heat enables the earth to be the best emitter of this absorbed heat. Water on the other hand is a fluid and can undergo mixing in several direction and hence can reduce its temperature. The ocean currents and tide process helps to mix water which eventually reduces the temperature of water in general.

Water is a transparent material and for that matter will absorb more heat from the sun to a great depth than land. Water has a specific heat capacity of 1.0units compared to the land whose specific heat capacity is approximately 0.5 units from theory. This therefore means that one will require more energy to raise the temperature of a unit mass of water by 1.0 ^{0}C than the quantity of energy needed to raise the temperature of a unit mass of the land by 1.0 ^{0}C. The heat energy arriving at the surface of the seas and oceans is not all used to raise the temperature of the water. A quantity of the energy is used up in melting and evaporating the water and not available to heat the water. Much of the latent heat used in melting and evaporating the water is carried away from the water surface by wind and tidal movements in which this latent heat is released later to in the troposphere of the atmosphere through a condensation process over colder land and ocean and sea surfaces. The Albedo of the sea and other water bodies by

Roland Stull (2015) ranges between 5 to 20%. The above explanation means that one will have little energy to raise the temperature of water (Dominic Soami P. 2008). This however offers explanation to the variation in the temperature of the lower atmosphere from 0-4km above the earth. But the atmosphere above the oceans, seas and other water bodies seems to be fairly constant and an even distribution of temperature both on seasonal and daily bases in a homogeneous atmosphere. This constant nature of temperature of the atmosphere above the oceans and water bodies is explained by most Weather scientists to be a result of Enso events G. Walker, (1972). A UNDP, (2017) report on the Zimbabwe Water Authority suggested that the abnormal temperatures in both the oceans and inland conditions are due to ENSO episodes and which affect rainfall greatly in which La Nina conditions alone contribute to about 67% of abnormal rainfall while El Nino conditions contribute to about 62% of abnormal rainfall in Zimbabwe.

Daily range of sea surface temperature

From the Stefan- Boltzmann's law of radiation, the thermal energy radiated by a black body per second per unit area is proportional to the fourth power of the absolute temperature and is given by

$$\frac{P}{A} = e\sigma T^4 \qquad (10)$$

For an ideal radiator such as the ocean or sea (e = 1)

If the hot body as in this work the sea/ocean during El Nino event time is radiating energy to its cooler surrounding at a temperature T_C, then the net radiation loss by the ocean/sea takes the form

$$P = eA\sigma\left(T^4 - T_c^4\right) \tag{11}$$

Similarly, during the periods of La Nina when the temperatures of the sea surface fall very low below average then $T_C > T$ and the Stefan-Boltzmann equations are applied.

$$P = \frac{Q}{t} \tag{12}$$

Where

P= energy radiated per unit time or the power

e = emissivity

A = the area of the sea/ocean or radiating surface

σ = the Stefan-Boltzmann's constant = 5.6703 x 10^{-8} W/m^2/K

T_c = temperature of the surrounding receiving the radiation in particular the towns around this coastal sectors. T = the temperature of the ocean at the time of measurement or the radiating body in general terms. The daily minimum and maximum sea surface temperature are averaged to get the daily mean sea surface temperature. The monthly mean sea surface temperature is the total of the mean daily sea surface temperature for the month divided by the number of days in the month. An annual mean sea surface temperature is the sum of all the mean monthly sea surface temperature divided by the number of months in each year.

The difference between the daily maximum and minimum temperatures is called the daily range of temperature. The daily range is much larger on a clear day than on a cloudy day. On the clear days the solar radiation warms the land very fast and it in turn heats the air above the earth's surface. On a clear night the strong outgoing radiation from the earth's surface creates rapid cooling of the air above the earth.

Similarly, an overcast sky /atmosphere during the day reduces the quantity of the incoming shortwave solar radiation that reaches the earth's surface. Some part of the radiation is reflected back without being absorbed. Other fraction is absorbed without being emitted or reflected. The fraction of the solar radiation which is reflected back is often called the albedo. In the night clouds at the troposphere forms a shield which cause reflection of the already absorbed long wave radiation. The albedo of the clouds lowers daily maximum temperatures and raises the night time minimum temperatures.

Typical albedos for certain bodies as put forward by Glean and Horn (1980).

Fresh snow	0.75-0.90

Clouds	0.60-0.90
Old snow	0.50-0.70
Sand	0.15-0.35
Sea (high sun angle)	0.05-0.10
Forests	0.03-0.10
Water (sea/oceans)	0.05- 0.20

Diurnal range of temperature over the seas and land

The small diurnal ranges of temperature over the sea and windward coast is the form of the winds which are blowing from the sea. Motion of water in the sea causes varying nature of sea surface temperatures over a wide distance. The moving ability of any fluid such sea water helps in the mixing of great volumes of water which enhances uniform energy distribution over a large nautical mile on the sea and oceans. Sea surface therefore shows a little temperature change over 24 hours' period and hence a variation of the temperature of air above it. Daily range of temperature over the land is influenced by the soil types. Heat conduction in the clay soils is greater than the sandy soils. Since sandy soils are more porous and contain more air masses which are bad conductor of heat and as such over the nigh temperature falls more rapid over the sandy soil than it occurs in the clayey soils. Daily temperature ranges generally are larger over soils that are poorer conductors of heat. In addition to the above daily temperature over the land is larger over dry soils than it is on the wet soils. There is more water vapour at night over the wet soils. These water vapour traps longer wave solar radiations and causes greenhouse effects. This however slows night time cooling. The sea surface temperature for three coastal towns consisting of Accra, Saltpong and Takoradi were analysed for a thirty- year period commencing from 1986 to 2015.

There are many ways to measure the temperature of an ocean. Oceans are big and temperatures at different locations vary. This research basically makes use of the ONI values which are based on the SSTS of the oceans and the SOI values which are the pressure difference between the East and West according the NOAA. To get a sense of whether the ocean is warming or cooling, lots of spread out measuring techniques are used, which include the following approaches

i. **Thermometers under buoys or ships** Since about 1990 an extensive array of moored buoys across the equatorial Pacific Ocean has beamed temperature data from a 1-meter depth up to a satellite. Lots of ships are also recording their intake water temperatures but the depths and locations vary making this data harder to use.

ii. **Satellite remote sensing** NASA's Moderate Resolution Imaging Spectra radiometer (MODIS) SST satellites have been providing global SST () data since 2000. Unlike buoys, the satellites can sense the surface temperature everywhere. The temp measured is of the surface only, though. The surface "skin" temp can be quite different than the temp of the water below because of things like evaporation, wind, sunshine, and humidity. Also, cloud cover prevents satellites from sensing surface temperatures.

iii. **Acoustic Tomography** Sound, especially low frequencies, can travel long distances under water. Since the speed of sound under water varies with temperature, measuring how long sound takes to travel a certain distance will give you the average temperature of the water over that distance. Acoustic Thermometry of Ocean Climate (ATOC) is using trans-basin acoustic transmissions to observe the world's oceans, and the ocean climate in particular.

iv. **Ocean Surface Topography** By bouncing microwaves off the ocean surface and using global positioning systems (GPS) location, satellites can precisely measure the height of any spot on the ocean surface. Reasoning that water expands and contracts as it heats and cools, then so too would the height of the sea surface. Ocean temperature information is useful in predicting hurricane season severity and forecasting individual storm severity.

However, in the study the researcher made use of the global ONI and SOI values which updated by NOAA from the 1950 to date.

The statistical significance of the El Nino and La Nina data were analysed using the Oceanic Niño Index (ONI) is a standard index that is used to identify El Niño. It is the running 3-month mean sea surface temperature (SST) anomaly averaged over the Niño 3.4 region, based on 30 years' periods, updated every 5 years. When the ONI exceeds 0.5 °C for at least five consecutive months, the corresponding year is considered to be an El Niño year.

Vertical variation of daily temperature ranges over the sea surface.

For a homogeneous atmosphere the hydrostatic equation, using the hydrostatic equation

$$dP = pgdz \tag{13}$$

Integrating the pressure component from Po to 0 and the vertical height from 0 to a maximum height of H. We

$$\int_{P_O}^{P} dP = \int_{0}^{H} \rho g dz \tag{14}$$

$$\int_{P_O}^{P} dP = \rho g \int_{0}^{H} dz$$

(15)

$$P_o = \rho g H \tag{16}$$

But the equation of state at the sea level is given by

$$P_o = \rho R T_o \tag{17}$$

Equating the right hand side of the equation (16) and (17)

$$H = \frac{RT_o}{g} \tag{18}$$

The equation (18) illustrates that in a homogeneous atmosphere pressure decreases with height and also the temperature of a given air mass also decreases with height as air mass density remains constant.

Also using the ideal gas equation,

$$PV = RT \tag{19}$$

Dividing through equation (19) by a unit mass of air m then the ideal gas equation becomes

$$P = \rho R T \tag{20}$$

Differentiating the pressure and the temperature of the equation (20) with respect to the scale height z, then the equation (20) becomes

$$\frac{dP}{dz} = \rho R \frac{dT}{dz} \tag{21}$$

But the quantity at the left hand side of the equation (21) is given as

$$\frac{dP}{dz} = -\rho g \qquad (22)$$

Combining the equation (21) and equation (22) the following equation is obtained as

$$\frac{-g}{R} = \frac{dT}{dz} \qquad (23)$$

Since the quantity at the left hand side of the equation (23) gives a constant value. The conclusion is that

$$\frac{dT}{dz} = \text{constant} \qquad (24)$$

Hence, from the equation (24) it implies that the change in temperature with height in the atmosphere is constant. But the density of the air mass of the atmosphere in real situation is fairly not constant with increasing, but decreases with height. The equation (24) further introduces the quantity called the atmospheric lapse rate, which is the decrease in the temperature of the atmosphere with an increase the altitude. The standard lapse rate from theory is approximately 6.50km/h and which varies slightly according to the weather conditions of the given environment and a given geographical location and the solar inclination to the earth.

Further from the equation (24), the daily temperature range along the coastal sector of Ghana therefore decreases with increasing atmospheric elevation, which according to Millero (2013), the source of such variations are obtained from the variation of the energy obtained from the sun. This energy is responsible for the circulation of the ocean waters. These circulations are divided into two types according to Frank; the wind driven circulation carried by the wind blowing over the surface of water which affects the temperature of the upper layer few hundred metres of the oceans and the thermocline circulation which is caused by the movement of the water because of the density difference due to temperature and salinity of the ocean layers. The first circulation often called the horizontal circulation and the second type of ocean circulation is termed the vertical circulation. According to Milerro. (2013) the ocean circulations lead to ENSO events which are collectively El Nino and La Nina events. The effect of these ENSO events include but not limited to

i. Change in primary production including fishing pattern
ii. Food chain process in the ocean
iii. Patterns of Hurricanes
iv. Climate patterns either excessive rainfall or a severe drought over certain geographical location

v. Increase in diseases such as malaria, cholera.

Chapter Summary

This section discusses the concepts of El Nino and La Nina episodes in general and their link to rainfall and drought in Ghana and large the World. Literature on El Nino and La Nina have been discussed. The chapter also talks about the consequences of the Walker circulations and the El Nino Southern Oscillations (ENSO) events. In addition to the above, the chapter Two discusses the equations related to the uneven heating of the oceans and seas which results in the formation of ENSO events. Lastly, the chapter also talked about effects of extreme climate events known to be linked with ENSO episodes and how they are managed in Ghana

CHAPTER THREE

METHODOLOGY

Introduction

This chapter generally discusses the data used to identify ENSO events in this study and how this data is analysed to obtain the link between ENSO events with precipitation along the coasts of Ghana. The Chapter also discusses the geography of the study areas used for work. The methods of analyzing the rainfall data collected over the thirty year period is also explained in this chapter. It outlines various methods used to predict precipitations along the coast of Ghana which is based on the position of the Inter- tropical Convergence Zone, the geography of the coast under study and the general circulations.

Data used for the study and methodology

The data set was considered to be high quality with less than 1% error missing data based on the Ghana Meteorological Agency standards

The average or mean rainfall data for the five coastal stations chosen for the research and their corresponding rainfall deviations are summarized in Table 2 of Chapter four of this thesis. Precipitation data used in this study are from Accra, Ada, Tema, Takoradi and Saltpong. The choice of these five towns was based on the fact that at the time of these study, the Ghana Meteorological Agency (GMet) only has rainfall data on the five selected towns in the country. The data consists of monthly and mean annual precipitation from 1986 to 2015, a thirty-year climatological period. In each study station mean monthly rainfall was collected for a period of thirty years. The rainfall volumes were collected in milliliter units. The rainfall data was obtained from the Ghana Meteorological stations (GMet) in all the five selected study areas. The data were analysed into annual rainfall for each year and a thirty year mean monthly rainfall obtained for year. For example, the highest annual rainfall in Accra was recorded in 2008 which is 1264.7mm and the least rainfall is 435.2mm which is recorded in the year 2000. However, in Tema, the least rainfall was 334.9mm in the year 1998 and the highest rainfall is 1294.8mm in the 1997. It is worth noting that 1997 and 1998 were strong El Nino years. Similarly, in Ada the least rainfall recorded for the period of thirty years was in 359.2mm in the year 1992 as against the highest rainfall of 1298.0mm in the year 1991. In the Saltpond study centre, the least rainfall was 396.0mm in 1998 with a corresponding highest recorded rainfall of 1440.5mm in the year 2005. In Takoradi, a forested study station with a coastal line has its least rainfall to be 640.8mm during the thirty-year period in the year 1998 the highest annual rainfall in Takoradi for the study period was 1557.9mm recorded in the year 1987.

A 30-year annual mean rainfall in each study stations is plotted against the year in a bar chart. The 3- year annual mean rainfall is plotted versus the three -year monthly moving mean of the Oceanic Nino Indices (ONI). In addition to the rainfall values, the researcher also used the global Nino indices covering thirty years from 1986 to 2015 which are major indicators of ENSO events. These indices are Oceanic Nino Indices (ONI) and Southern Oscillation Indices (SOI).

The global SOI and the ONI values are used to help identify ENSO years throughout the 30-year climatological period from the 1986 to 2015. The basic criterion for selecting ENSO years is years that were produced as ENSO and non-ENSO years by both graphs of ONI and SOI.

Graphs of precipitation in each station against the global ONI and also against SOI gives an indication of the impact of ENSO events to rainfall in the coastal towns.

Global ONI values are measured based on the use of buoying satellites which are coupled to programmed computers in the laboratories. The global ONI values measures the mean five month running average surface temperature of the sea/oceans with the help of the Extended Reconstructed Sea Surface Temperature (ERSST) of data set in the sea. By international convection ONI value that fall below +0.5 indicates cold episodes of the sea and those ONI values that rise far above +0.5 and the indication of warm or El Nino events while smaller negative values of ONI values below -0.5 are an indication of La Nada events or normal events. The Southern Oscillation Indices (SOI) are the mean of the difference between the pressure of the Western Pacific and the eastern Pacific. Smaller values of SOI below +0.7 are indication of warm episodes and values above the +0.7 threshold show cold episode or La Nina events.

Temperature and global ONI values

The ONI values are the measure of the average sea surface temperature anomalies in area of the Pacific Ocean which is called the Nino-3.4 region. The sea surface temperature departures are averaged using a three- month time moving average so that variations of rainfall due to ENSO events can be isolated.

The variation of the 3-year running average of the ONI is plotted against precipitation in each study station/town. The global ONI values are the fractional variation in the sea surface temperature over at least a period of six continuous months. These data are collected from buoying satellites over the sea. These satellites are connected to computers via a wireless system and the variation in the temperature of the sea is collected digitally via a written computer program that helps to compute the mean ONI values. One problem associated with these data is that sea surface temperature of a particular geographical study must be related to that ocean/sea demarcation in order to measure the impact of the sea surface temperature to the rainfall in that area. But this research is within one year and the data needed is up to 30 years hence already collected values were used. The research was done with the assumption that the global ONI values collected at Nino 3.4 region affect the global rainfall and hence that of Ghana due to the teleconnection of ENSO events.

Data on ONI and SOI

The global Oceanic Nino indices (ONI) and Southern Oscillation Indices (SOI) values were obtained from the website of NOAA Climate Prediction Centre (http.www. cpc.Aeep.noaa.). These values were analysed using three- year moving average with a Microsoft excel 2013. The global mean sea surface temperature for each month is calculated by a satellite at each latitude by taking the simple mean of the temperatures of longitudes at a given latitude as follow

$$T_{av} = \frac{1}{nlong}\sum_{i=1}^{n} Tlongi$$

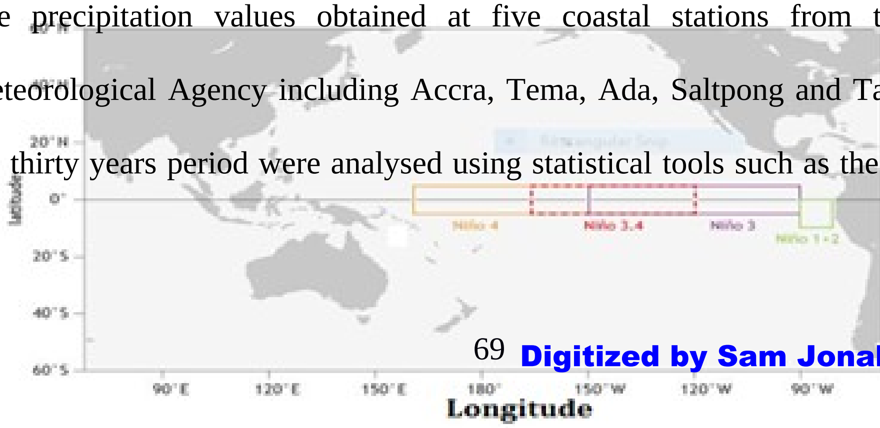
(25)

Once the mean temperature at each latitude is taken, the cosine weighted mean of those given mean global temperatures for any month is computed as in equation

$$T_{Month} = \frac{\sum_{j=1} n(Lat)\cos(Lat)T(average)lat_j}{\sum_{j=1} n(Lat)\cos(Lat_j)}$$

(26)

The precipitation values obtained at five coastal stations from the Ghana Meteorological Agency including Accra, Tema, Ada, Saltpong and Takoradi for the thirty years period were analysed using statistical tools such as the Statistical



Package for the Social Sciences (SPSS), R-Program and Excel.

Figure 9: The location of the Nino 3.4 index region on the Pacific Ocean from the 120 degrees West Latitude and 170 degrees West Longitude. (Source: NOAA climate.gov.).

The Troup's model used in the 1965 is summarized as followed in the equation (27)

$$SOI = \frac{10\left[(Pdiff) - P(diffav)\right]}{SD(Pdiff)} \quad (27)$$

P(diff) = (average Eastern pressure for the month) - (average Western pressure for the month), P(diffav) = long term average of P(diff) for the month in question, and SD(Pdiff) = long term standard deviation of P(diff) for the month in question. The Troup model used to analyse SOI.

The multiplication by 10 is a convention. Using this convention, the SOI ranges from about –35 to about +35, and the value of the SOI can be quoted as a whole number. The dataset the Bureau uses has 1933 to 1992 as the climatology period. The SOI is usually computed on a monthly basis, with values over longer periods such a year being sometimes used. Daily or weekly values of the SOI do not convey much in the way of useful information about the current state of the climate, and accordingly the Bureau of Meteorology does not issue them. Daily values in particular can fluctuate markedly because of daily weather patterns, and are usually not be used for climatic purposes. The mean monthly rainfall for each rainfall station was computed as in the equation 28

$$N_i = \frac{\sum fx_i}{\sum f} \qquad (28)$$

Where N is the mean rainfall for each year (i = 1, 2, 3, 4, 5,…..12) and f is the 30-year period each monthly rainfall is x. In addition to the above methods, a three year moving average was calculated for the precipitation values as well as ONI and the SOI values using the Microsoft excel program. The procedure for analyzing the precipitation values, ONI and the SOI global values are on the Appendix E.

The population correlation coefficient (P) between the annual mean of the monthly mean rainfall and the annual mean of the monthly mean ONI as well as the SOI is found as

$$P = \left[\frac{1}{N}\right] . \sum \left(\frac{x_i - \mu_x}{SD_x}\right) . \left[\frac{Y_i - \mu_y}{SD_y}\right]$$

(29)

Where N= the number of observations in the population which is 30 for the purpose of this work

Xi is the X value for the observation i.

μ_x is the population mean for X which also stand for the mean value of the ONI or the SOI and SD_x is the standard deviation for X. The sample correlation coefficient r is also determined by the equation (30) in a matlab defined program

$$R = \left[\frac{1}{n-1}\right] \cdot \sum \left[\frac{x_i - \bar{x}}{SD_x}\right] \cdot \left[\frac{Y_i - \bar{Y}}{SD_y}\right]$$

(30)

R is the sample correlation coefficient

Yi is the Y value for the observation i.

SDy is the standard deviation for Y

n is the number of observation in the sample.

Southern Oscillation Indices measurement

This is done by measuring the difference between the atmospheric pressure at sea level at Tahiti and at Darwin. The figure 21 below shows the variation in pressure and how these locations reflects the atmospheric component of ENSO, discovered in the early 1900s by Walker and Bliss (1932). During El

Niño, the pressure becomes below average in Tahiti and above average in Darwin, and the Southern Oscillation Index is negative. During La Niña, the pressure behaves oppositely, and the index becomes positive.

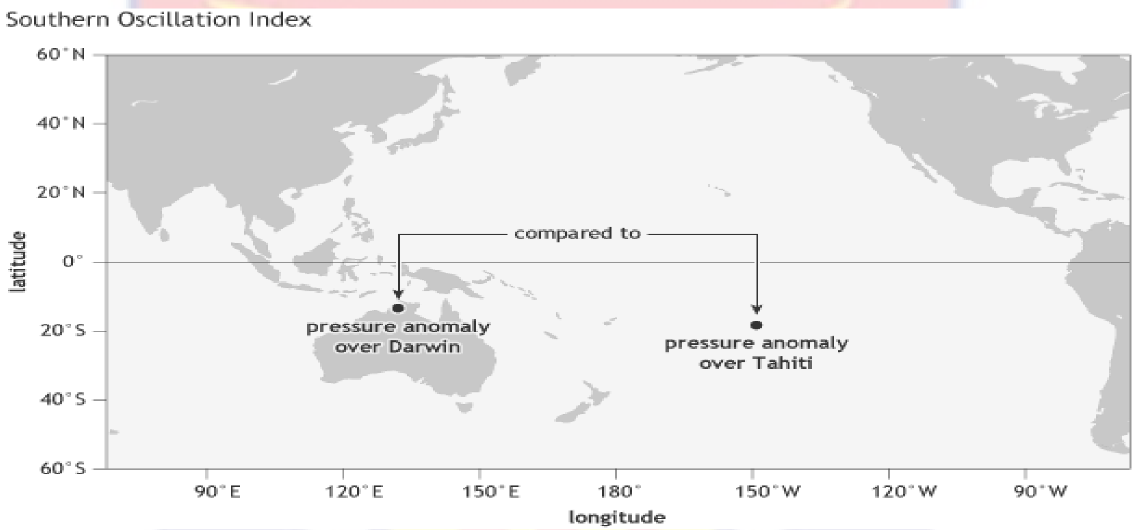


Figure 10: Location of the two stations whose sea level pressures contribute to the Southern Oscillation Index (SOI): One over Tahiti, and the other over Darwin, Australia. (Source: NOAA Climate.gov image by Fiona Martin).

The fact that the SOI is based on the sea level pressure at just two individual stations means it can be affected by shorter-term. But SOI helps to isolate more sustained deviations from the average, like those associated with ENSO. Another limitation of the Southern Oscillation Index is that both Tahiti and Darwin are located somewhat south of the equator (Tahiti at 18˚S, Darwin at 12˚S), while the ENSO phenomenon is focused more closely along the equator. The index overcomes this problem, as it uses the average sea level pressure over two large regions centered on the equator (5˚S to 5˚N) over Indonesia and the eastern equatorial Pacific (see Fig. 22).

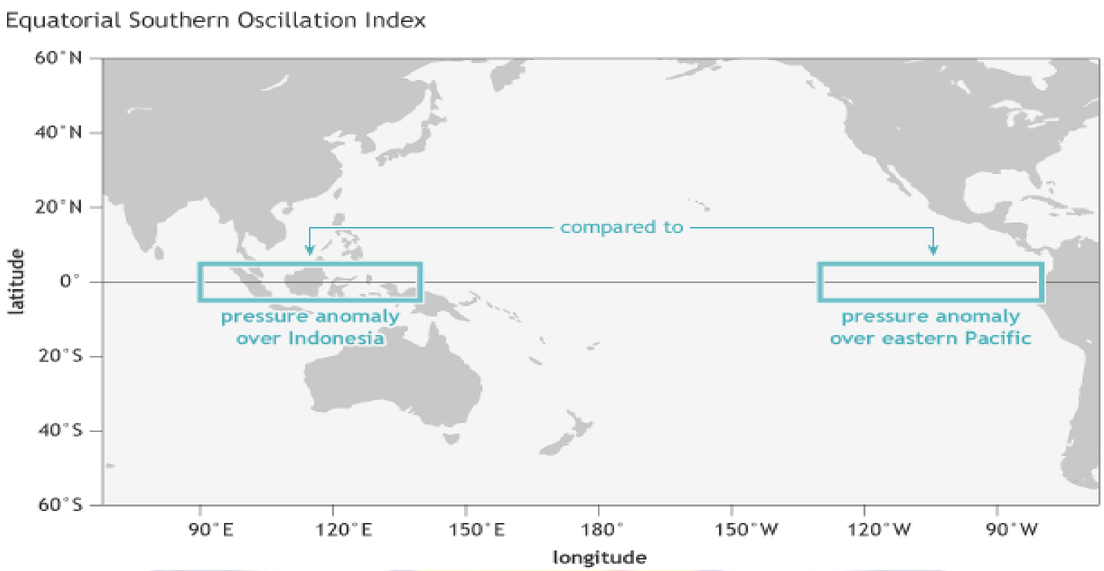


Figure 11: Location of the two rectangular regions whose average sea level pressures are used to compute the Equatorial Southern Oscillation Index: One over the eastern equatorial Pacific, and one over Indonesia. (Source: NOAA Climate.gov image by Fiona Martin).

The sea level pressure (SLP) readings at Tahiti and Darwin are each standardized, so that they fall between -1 and +1 about two-thirds of the time, and rarely go outside of -2.5 to 2.5. Standardization is done to adjust for seasonal differences in both the average and in the year-to-year range of variability at each of the two stations, so that each station always contributes equally to the index.

The difference between these two standardized SLPs is then itself standardized, so that it falls between -1 and +1 about two-thirds of the time. Standardization in this research only re-scales a set of numbers in two steps. In the first step, the average of the numbers is computed, and that average is then subtracted from each number. This causes any number below the average to become a negative number, and the ones above average to become positive. The average of all the new numbers then becomes zero. Then, in the second step, the numbers are further re-scaled so that their range typically ends up only between about -2.5 and 2.5. So, if their original range is much larger than this, then the numbers are compressed; if originally smaller, they are stretched. This second step of re-scaling is done by first computing the standard deviation of the numbers, which is a measure of the extent to which the numbers vary from one another.

The Oceanic Nino Index (ONI)

According to Oscar Rajas et al (2014) the Oceanic Nino Index is the factor standard the National Oceanic and Atmospheric Administration (NOAA) uses to identify El Nino (warming episode of the sea) and La Nina (cooling episode of the sea) events in the tropical pacific. The ONI is defined as five consecutive overlapping three month periods at or above the +0.5 anomaly for warm episode and at or below -0.5 anomaly for cold events. From the Food and Agriculture Oraganisation (FAO, 2014), for an event to be categorized as weak, moderate or strong, it must have equaled or exceeded the threshold for at least three consecutive overlapping three months. These data indicates how sea/ocean temperature varies daily. The ONI values were obtained from the website of NOAA which spans from the study period of 1986 to 20015. The ONI values indicate how the sea surface temperature (SSTs) vary a rise in ONI values will lead to an increase in evaporation subsequently a decrease in ONI values lead to a decrease in evaporation. A three year monthly moving average of the globally obtained ONI values in degree Celsius were computed and compared to the values of precipitation in each study town in order to ascertain if there is variation of rainfall with the change in the mean ONI vales.

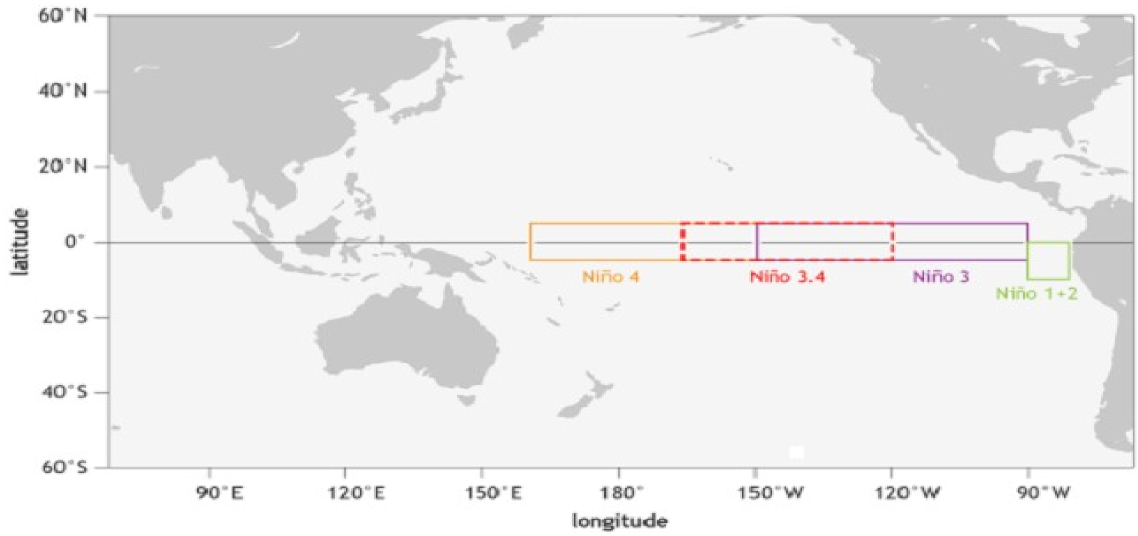


Figure 12: Location of the Niño regions for measuring sea surface temperature in the Eastern and Central tropical Pacific Ocean. The sea surface temperature in the Niño3.4 region, spanning from 120˚W to 170˚W longitude, when averaged over a 3-month period. (Source: NOAA’s official website (the ONI). NOAA Climate.gov image by Fiona Martin).

It is observed that sea surface temperature data were increasingly used because the ocean is recognized to be a key player in ENSO and significant weather variations leading to torrential rainfalls (Bjerknes 1969, Rasmussen and Carpenter 1982,). Initially, certain regions were defined for measurements—namely Niño1 and Niño 2 (combined into Niño1+2), and later weather scientist note-able among them which NOAA used the Niño 3 and Niño 4 because of consistently available data coming from ships passing through those areas. The Nino 3 and Nino 4 are combined to produce an area in the sea level called the Nino 3.4 and this forms a general representation of the ENSO events Barnston et al. (1997).

Description of the study area

The study area of this research is made up of the coastal sectors of Ghana. The Republic of Ghana is situated in the middle zone of the West African sub region of Africa at the latitude 4.8^0 N and 11.0 N. It extends beyond both side of the Greenwich Meridian to 3.0^0 W and 1.0^0 E. Ghana has a total land area of approximately 238 540km^2. The research is conducted by making use of five major towns which lie along the coast of Ghana. The five major towns selected for the study form some of the key towns of Ghana which lie along the coast and a lot of economic activities are taking place. These towns are Accra, Tema, Ada, Saltpond and Takoradi.

The perceived and actual causes of flood hazards in cities of sub-Saharan African countries have come under tremendous debate. In Accra, the capital of Ghana, flooding has been the key source of human vulnerability. Studies carried out on flood vulnerability in the city have given varied attributions to their frequent occurrences.

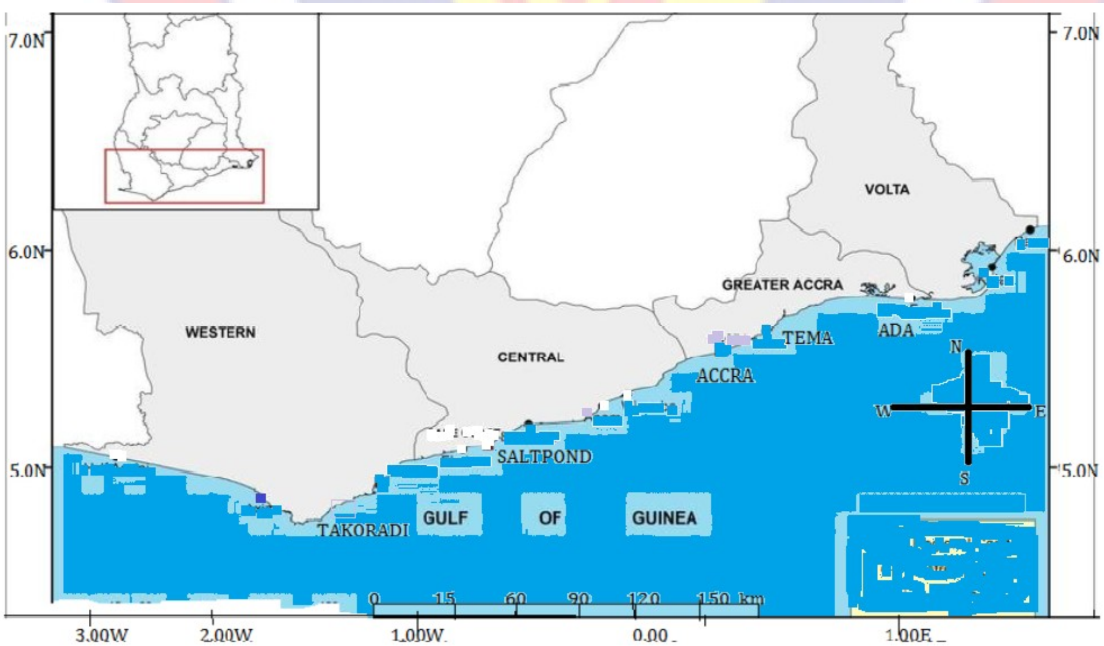


Figure 13: The coastal map of Ghana showing the study towns.

The sketch above briefly describes the position of the coastal towns Ghana used for the study. The choice of the five coastal towns for the study is as a result of the available rainfall data from the GMet.

Chapter Summary

This chapter discusses the data and methodology used in this study. It also includes the selected towns for the thesis and regions for the measurement of Nino -3.4 indices. Detailed description of Oceanic Nino Indices (ONI) and Southern Oscillation Indices (SOI) and how they are obtained is also discussed.

CHAPTER FOUR

RESULTS AND DISCUSSION

Introduction

This chapter discusses the results obtained from the research and how the ENSO events affect the precipitation in Ghana.

This part of the project analyses the precipitation data obtained from five major meteorological stations in Ghana which are located along the coast. The precipitation data are computed using SPSS and the Microsoft Excel to plot values of precipitation in order to obtain the relationship between ENSO El Nino (warming episode) and the La Nina (cold episode) of the oceans/seas to the rainfall of Ghana along the coast. Histograms of precipitation were plotted for each coastal station. The strong ENSO years which include the El Nino and La Nina years are mapped out using the red and blue colours. Further a plot of graphs involving oscillating SOI over the 30 year period as well as a graph of the changing ONI values over the study period are used together to find out the actual ENSO years throughout the 30 year study.

A summary of mean rainfall data and their corresponding deviations for the five selected coastal stations from the Ghana meteorological data for a thirty year climatological period are presented in the Table 1 below.

Results

Table 1: The annual mean of monthly mean rainfall in each study station and the corresponding anomalies. SOURCE: Ghana Meteorological Agency (www.meteo.gov.gh.gmet)

Station	Thirty- year climatological monthly mean (mm)	Deviations (mm)
Accra	64.4	-8.8
Ada	68.9	- 4.4
Tema	58.4	- 14.9
Saltpond	81.9	8.6
Takoradi	92.9	19.6
Average	73.3	0.1

The negative deviations indicate less rainfall while the high positive values show more rainfall. For the Accra coastal stations, the Bar charts in Figure 25 illustrates the distribution of precipitation form the 1986 to the year 2015 during the 30 –year climatological period.

The graph indicates the variation of rainfall for the thirty-year period using a three- year moving average analysis for the Accra station. It is shown from the graph that between the year 1986 to 1989 the average mean monthly rainfall was below 80.0mm but from the 1990 to the 1992 /93 there was fairly large amount of precipitation falling between the range of mean monthly volume of 100-120mm.

In the Accra study station the 1987 El Nino years produced slightly a lower rainfall than the corresponding 1999 La Nina year. The average rainfall is a little above 145mm monthly mean during the El Nino regime while the La Nina regime recorded an average monthly mean of a little above 145mm. A time series graph for both the El Nino and La Nina regimes of 1987 and 1999 respective ENSO years are plotted in the Figure 14 below

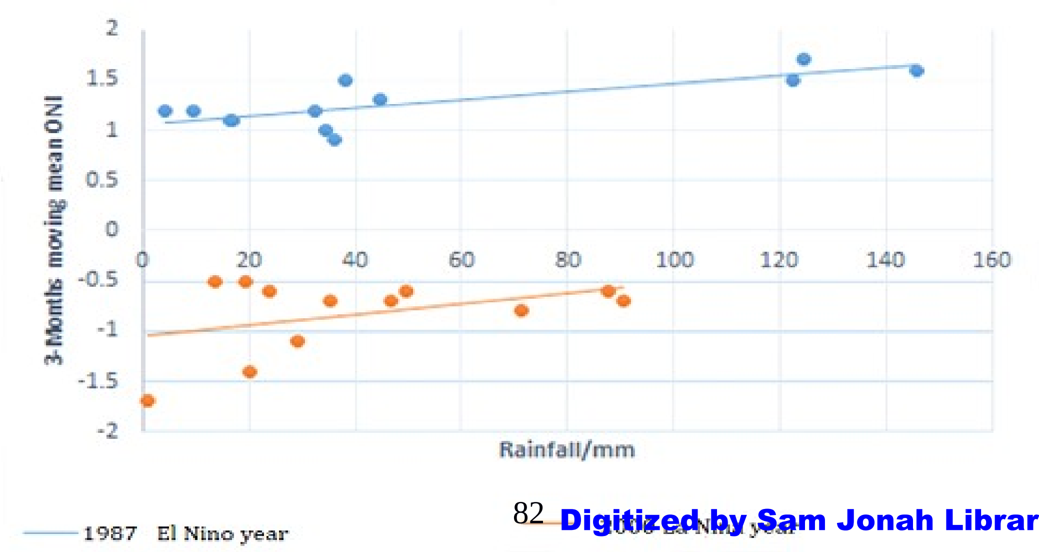


Figure 14: A graph of the variation of rainfall at Accra during 1987 El Nino and the 2000 La Nina years respectively.

The 30-year variation of rainfall is plotted in Figure 15. There is an oscillatory pattern of rainfall during each period. It is significant to note from the graph that ENSO events along the years have indeed affected the general pattern of precipitation along the coasts of Ghana, although the effect is not so huge. From the Figure 15 it is seen that the difference in rainfall at Accra during the El Nino and La Nina regimes are not so huge. The graph of the blue line and plots represent El Nino regime with the highest average monthly rainfall of a little bit below 140 mm during the La Nina regime which is the graph of the light yellow line and plots show that the rainfall is a little above 90mm an indication that Greater Accra region recorded more rainfall during the El Nino regime.

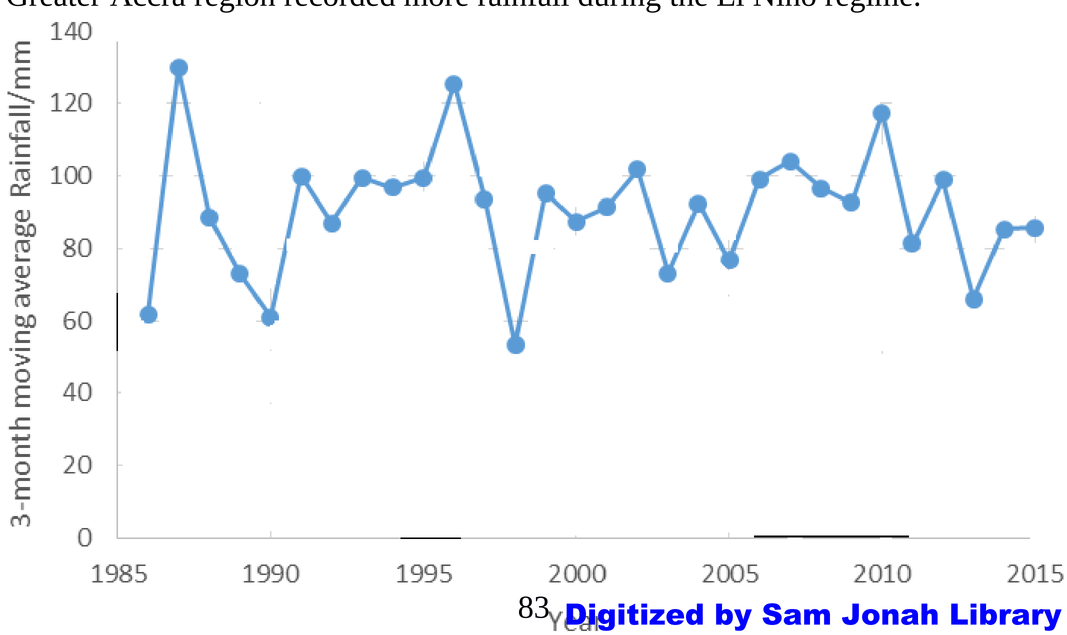


Figure 15: A graph indicating three –months moving average rainfall from the 1986 to 2015 for the Accra study station.

From 1995 to the year 2000 there was a surge in rainfall in Accra. Although the 1997 /98 El Nino year was very intensive the rainfall that year could not be very high as the total mean monthly precipitation ranges between 80.0 - 85.0mm compared to similar years in 1992/94 and the year 2006 which were La Nina years had an average monthly rainfall of about 100.0mm and upwards. Hence the graph of Figure 15 clearly shows that Accra recorded a little more rainfall during the La Nina episodes than the El Nino regimes.

The rainfall in Ada, a town located in the Greater Accra region is represented in terms of 3-year moving averages for each month covering the thirty-year study period in the graph of Figure 16.

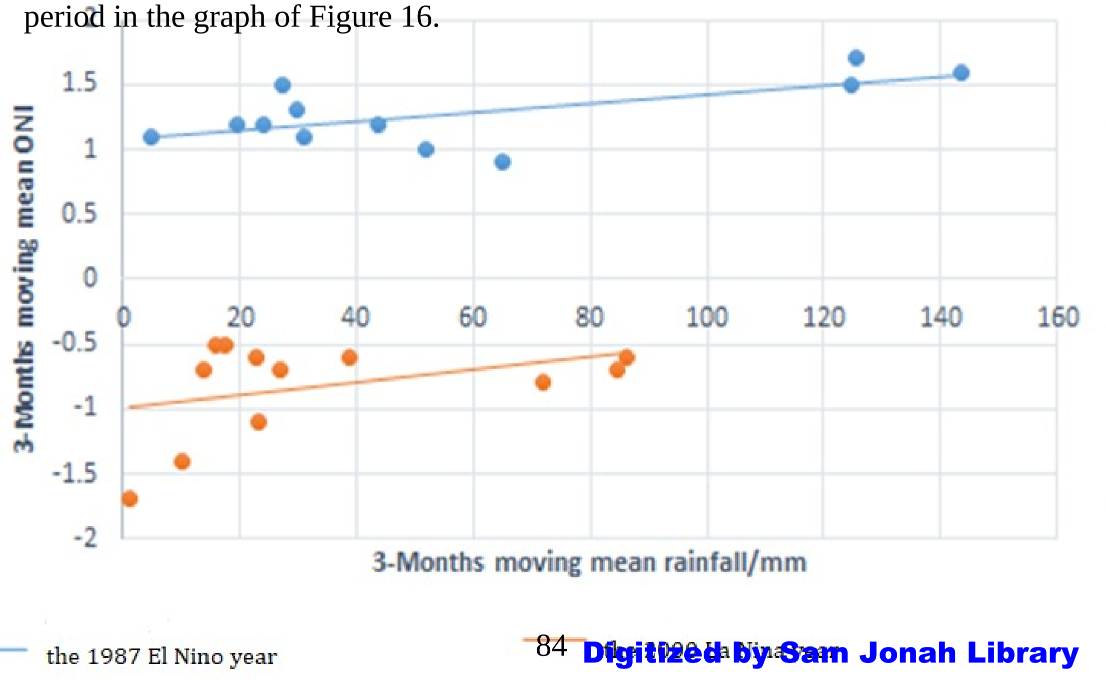


Figure 16: A graph of the variation of rainfall during the 1987 El Nino and the 2000 La Nina years for the Ada station.

The variation of precipitation at Ada during the 1987 El Nino year as well as the La Nina year is represented in the graph of Figure 16. The Figure 16 shows that there was more rain up to about 200mm monthly during the El Nino year than La Nina year which produce a little above 100mm monthly rainfall.

The Figure 17 shows the variation of 3-month moving average rainfall over the 30- year climatological period for Ada study station. It showed a similar trend as that of Accra. For example, for Ada the rainfall recorded in 1995- 96 produce mean monthly rainfall of little below 80.0mm and just from 1997 to 1998 which are El Nino years the mean monthly rainfall is a little above 80.0mm. The trend continued to 1999 and the year 2000 when monthly rainfall fell to below 80.0mm.

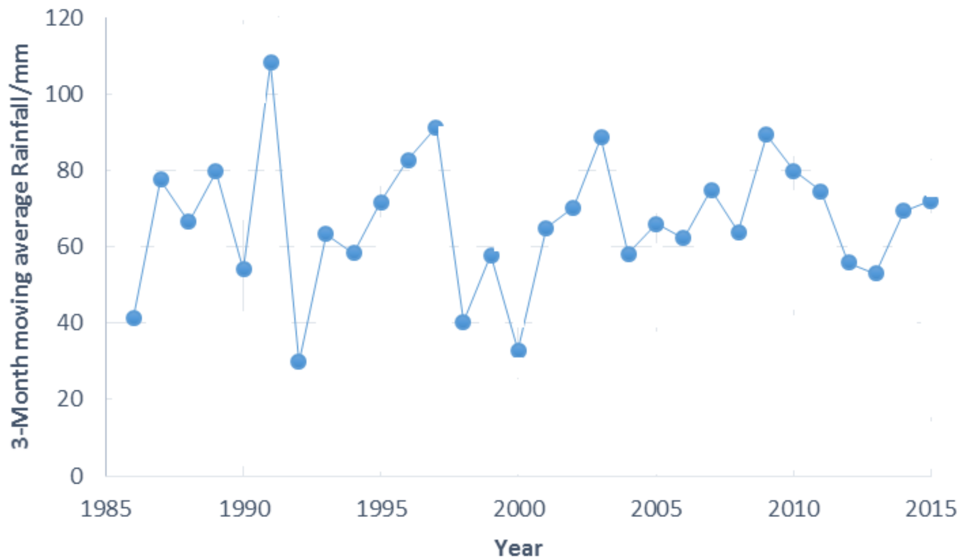


Figure 17: A graph of three-months moving average for the rainfall in Ada from the 1986-2015.

The three year moving average for the rainfall in Tema another coastal town located in the Greater Accra region is shown in the graph of figure 18.

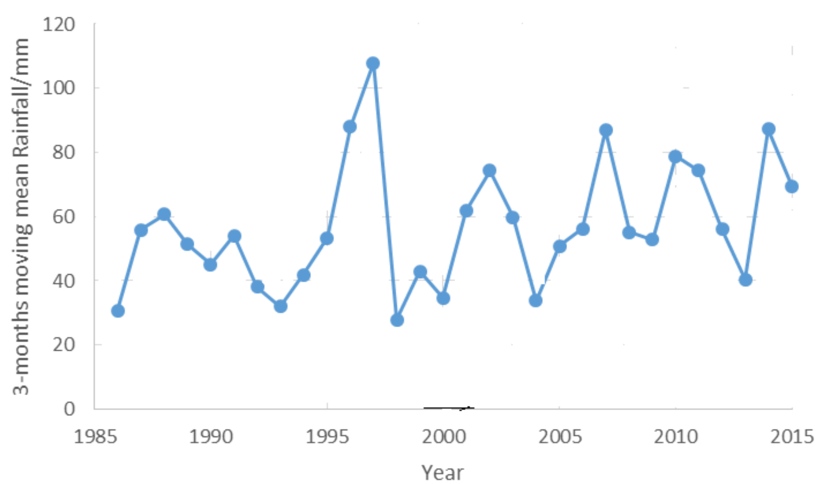


Figure 18: A graph of rainfall versus the three-months moving average from the

1986 t0 2015 for Tema.

In Tema the 1987 El Nino year as well as the 2000 La Nina year rainfall are plotted on the graph in figure 19.

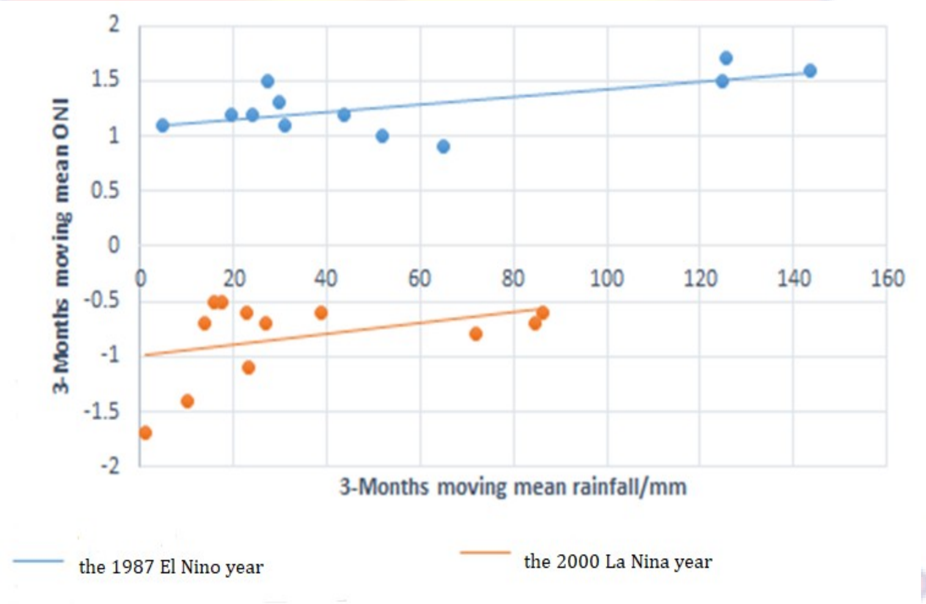


Figure 19: Variation of rainfall during 1987 El Nino and the 2000 La Nina years for Tema. The El Nino year of the 1987 had more precipitation than the La Nina year of 2000 as indicated in Figure 19.

The variation of rainfall during the 30 year period for Tema is sketched in Figure 20. The highest annual mean monthly mean rainfall at Tema was recorded 1997 which is above 120mm.

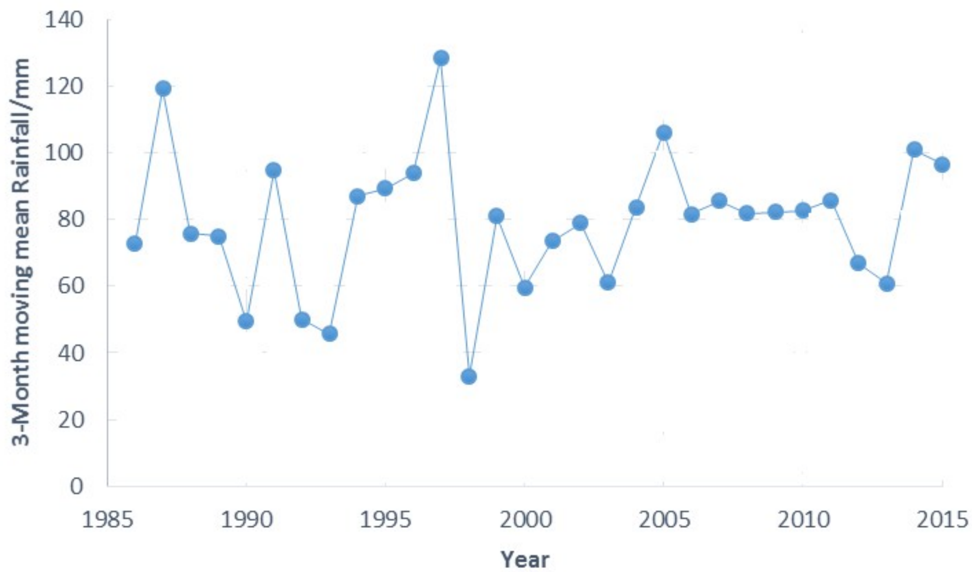


Figure 20: A graph of three-months moving average for the rainfall for Saltpond from 1986 -2015.

At Saltpond in the Central Region of Ghana, the time series graph of both the El Nino year of 1987 and the La Nina year of the 2000 for the Figure 21 shows an increase in rainfall during the El Nino or the warm regime to an average monthly rainfall of above 180.0mm while the El Nino regime of 1987 recorded a monthly mean rainfall of just a little below 100mm.

Figure 21: A variation of rainfall at Saltpond during the 1987 El Nino and 2000 La Nina years respectively.

The El Nino in the 1987 and La Nina of the 2000 respectively are done on the time series graph above in graph of Figure 22. It is observed that at the upper side of the graph which indicates the El Nino episodes of 1987 has the highest mean monthly rainfall which is a little above 180mm while the corresponding La Nina regime of 2000 whose graph the below the horizontal axis marked with the light yellow line plots records the least mean monthly rainfall of a little above 100mm.

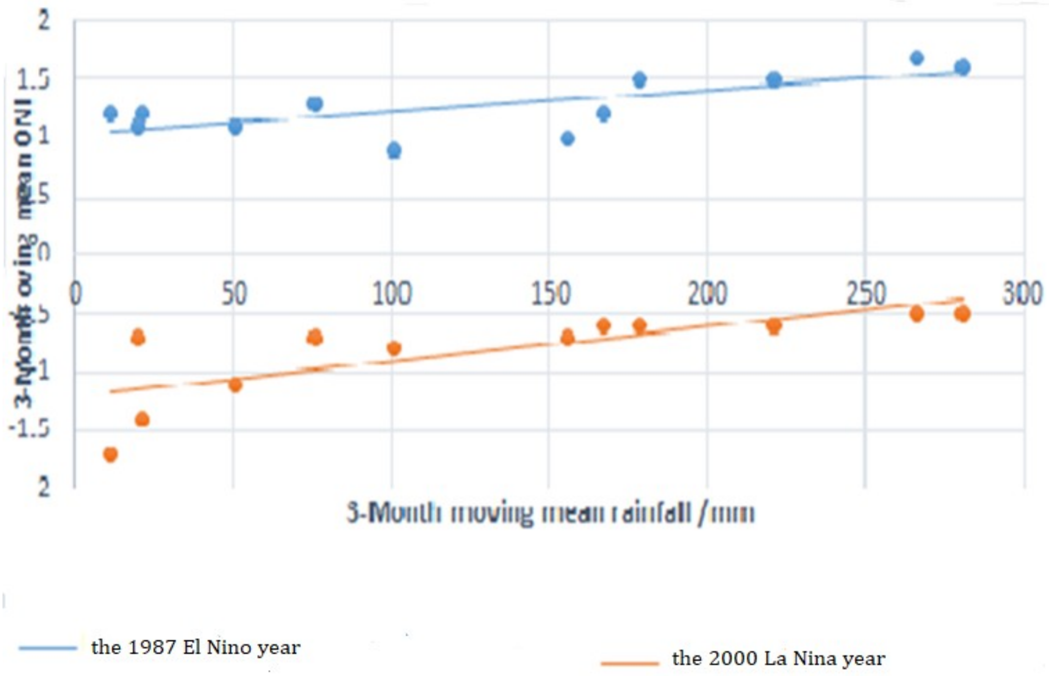


Figure 22: A graph showing the variation of rainfall during an El Nino regime in 1987 and the La Nina period of 2000 for Takoradi study station.

For the Takoradi the El Nino with the blue plots of the graph in figure 23 records the a similar mean monthly rainfall of a little above 250mm as the corresponding La Nina regime of the year 2000 whose graph is marked light yellow.

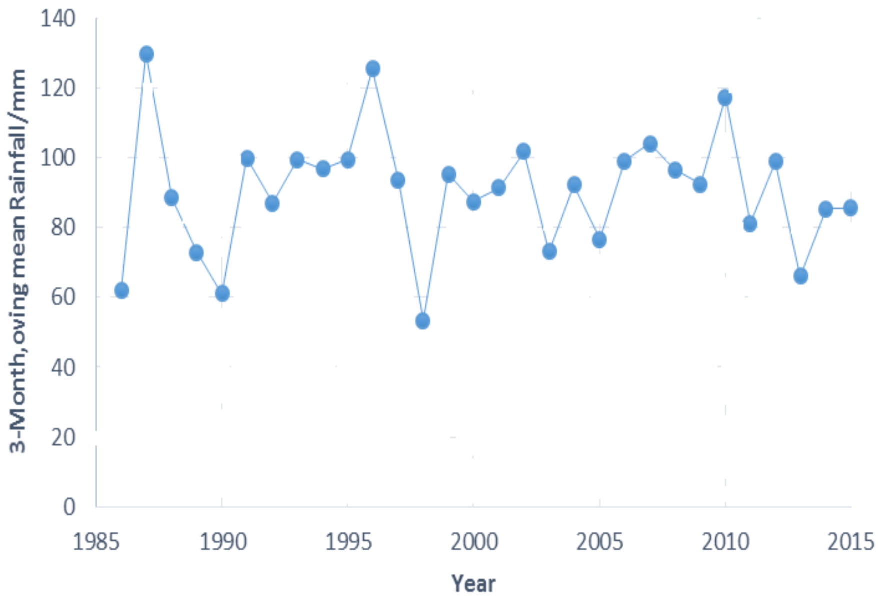


Figure 23: A graph of three-month moving average rainfall in Takoradi from 1986 to 2015. The mean Oceanic Nino Indices for the 1986 to 2015 has been analysed by calculating the 3-year moving average.

The graph in figure 24 indicates the variation of the mean ONI Values calculated using the moving average for the 30 years' period.

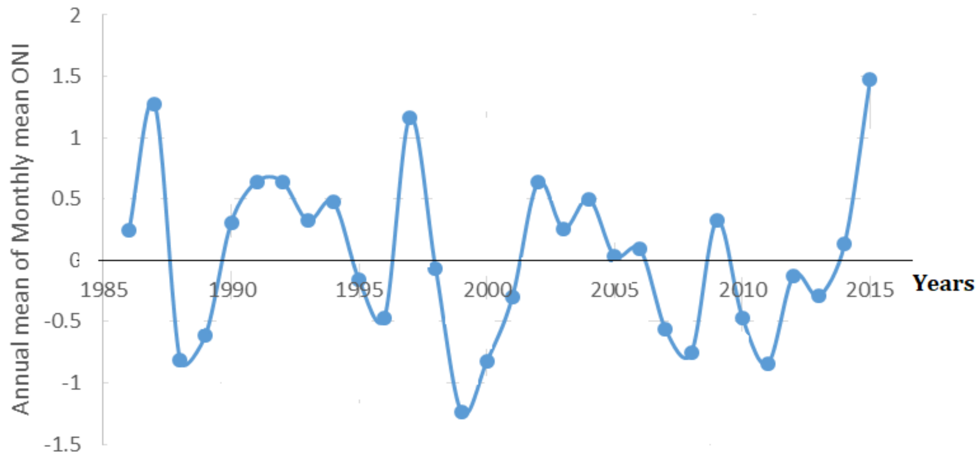


Figure 24: A graph of 3-months moving average of ONI variations for 30 years period (1986-2015).

The points above the curve are near the El Nino episodes particularly all the points above the range +0.5 on the curve. The points below the horizontal axis indicate La Nina regimes of the oceans and the sea. Hence from the graph the following years were considered as ENSO and non-ENSO years in table 2.

Table 2: A table of values showing the ENSO years and the normal years

El Nino years	ONI	La Nina years	ONI	Normal years	ONI
1987	1.20	1988	- 0.85	1986	-0.25
1991	0.65	1989	- 0.65	1990	0.30
1992	0.60	1996	- 0.50	1993	-0.30
1994	0.50	1999	-1.25	1995	-0.20
1997	1.10	2000	-0.80	1998	-0.10
2002	0.60	2007	-0.60	2001	-0.30
2004	0.50	2008	-0.75	2003	-0.45
2015	1.5	2010	-0.85	2005	0.00
				2006	-0.10
				2009	-0.30
				2012	-0.15
				2013	-0.20
				2014	0.20

From the graph in Figure 25 eight different years are selected for as El Nino years which include 1997, 1991, 1992, 1994, 1997, 2001, 2004, and 2015 as indicated in the Table 2 above.

Each of those El Nino years have ONI values ranging +0.5 and above. The selected La Nina years are nine from the Table 2, they include 1988, 1989, 1996, 1999, 2000, 2007, 2008, 2010 and 2011. Each of those years also have yearly average ONI value below -0.5.

The remaining years are considered as normal years since from the graph of figure 25 those years produce annual mean of monthly mean ONI of $-0.5 < x < 0.5$ where x is the ONI for non-ENSO years as shown in the graph of figure 24.

Figure 25 shows a descriptive statistics of annual rainfall data recorded in Accra. It was observed that annual rainfall increased sharply from 1986 (545.6 mm) to 1988(988.8mm) and decreased to 567.7mm in the year 1990. The annual rainfall decreased spanning the years 1991 (1008.3mm) to 1993 (509.3mm) and increased further to 1995 (1029.8mm), Similar trends were observed across the years to 2015 with peak annual rainfall recorded in 2008 (1264.7 mm) followed by 1997(1223.5mm) and the lowest in 2000 (435.2mm) as displayed by the histogram above. Generally, precipitation in Accra did not assume a particular trend thus both rise and falls in precipitation were observed year after year.

From the bar chart of Figure 25 for the Accra study centre above it shows that during the El Nino years there was a marked increase in precipitations along the coast where in the 1997 El Nino year the annual rainfall is 1223.5mm and the 2002 El Nino year recorded a rainfall of about 1010.0mm. It is significant to note that the normal years gives followed from an El Nino period give appreciably more rainfall while the normal years which are followed by a La Nina period produce less rainfall.

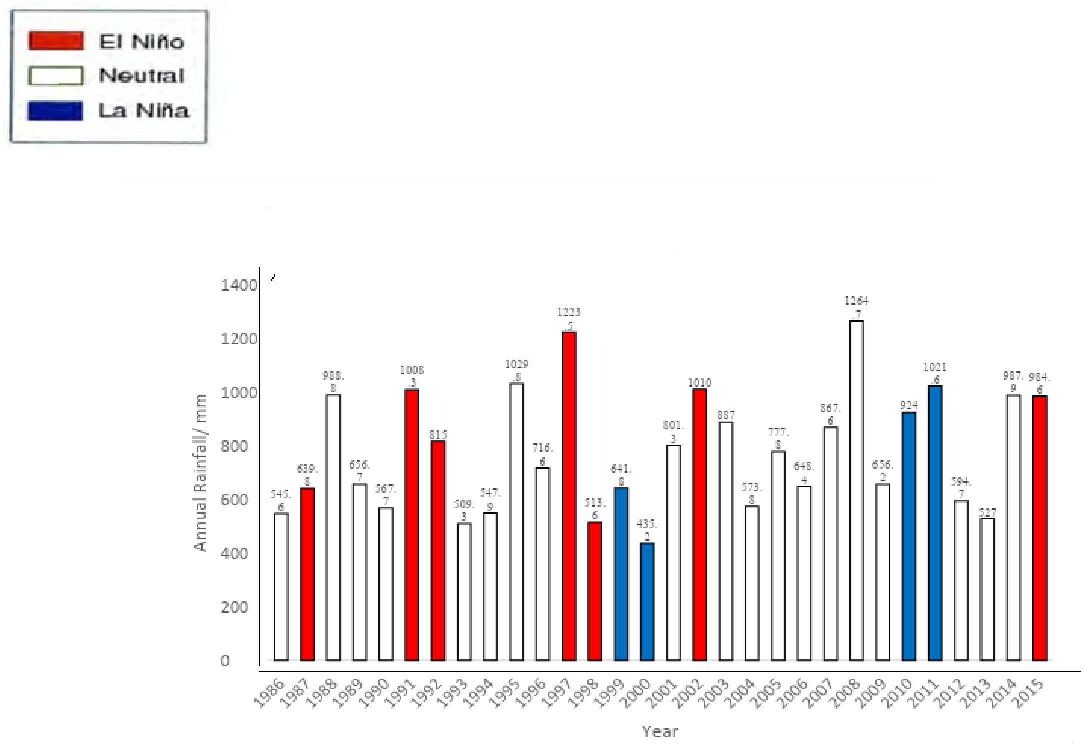


Figure 25: Descriptive Statistics of Annual Rainfall for Accra for strong ENSO years (1986-2015).

Figure 26 describes annual rainfall recorded in Ada spanning the years 1986 to 2015. An annual rainfall of 495.8mm was recorded in 1986, rose to 931mm in 1987, decreased in 1988 to 798.3mm. An increase was observed in 1989 (949.9mm) followed by a decrease to 798.3mm in 1988 and rose to 949.9mm in 1999. There was a sharp decrease recorded in 1990(655.9mm) and a peak annual precipitation observed in 1991 (1298 mm). The lowest annual rainfall was recorded in 1992 (359.2mm). In 1992, annual rainfall fell drastically to 359.2mm. It increased to 759.3mm in 1993 and averagely increased smoothly further from 1993 (759.3) to 1093.8 in 1997. Similar trends were observed in the succeeding years as portrayed in the Bar Chart of Figure 26. Generally annual precipitation in Ada from 1986 to 2015 did not assume any particular trend. In Ada the El Nino years which the 1991 has the largest annual rainfall of 1298.0mm and the 1997

El Nino year also recorded the next a little more rainfall of 1093.8mm. This is an indication that El Nino years somehow produce more precipitation which is in agreement with the works of Nicholls (1988). The Bar Charts for the precipitation data on the Tema coastal area is in Figure 27 for the Tema station.

The graph of precipitation for the Ada station is followed as in Figure 26

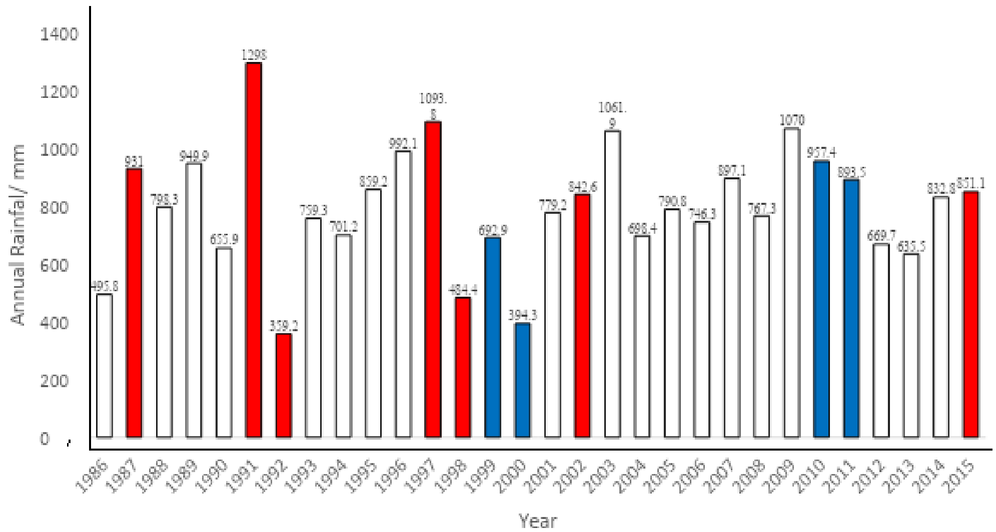


Figure 26: Descriptive Statistics of Annual Rainfall for Ada for strong ENSO years (1986-2015).

Figure 27 shows annual rainfall that was observed in Tema from the years 1986 to 2015. An annual rainfall of 368mm was recorded in 1986, rose to 730mm in 1988. It then decreased gradually to 542.9mm in 1990. An increase was observed in 1991 (647.6mm) followed by a decrease to 385mm in 1993. It rose steeply from 1993 (385mm) peaking at 1294.8mm in the year 1997. The lowest rainfall was recorded in 1998 (334.9). There was a sharp fall in the annual rainfall recorded in 1998 to 334.9mm. Similar trends were observed in the succeeding years as portrayed in the Bar chart of Figure 27 for the Saltpond station. Generally annual precipitation in Saltpond from 1986 to 2015 did not assume any particular trend. Again from the histogram the precipitation data at Saltpond it is clear that the 1997. El Nino year produced the a little more rainfall followed by the normal years including but not limited to the years 1995 and 2014 which have respective precipitation values of 1054.8mm and 1048.1mm.

For the Saltpong data on the precipitation, the Bar Chart of Figure 27 illustrates the distribution of the precipitation for all the years of El Nino, La Nina and the Normal.

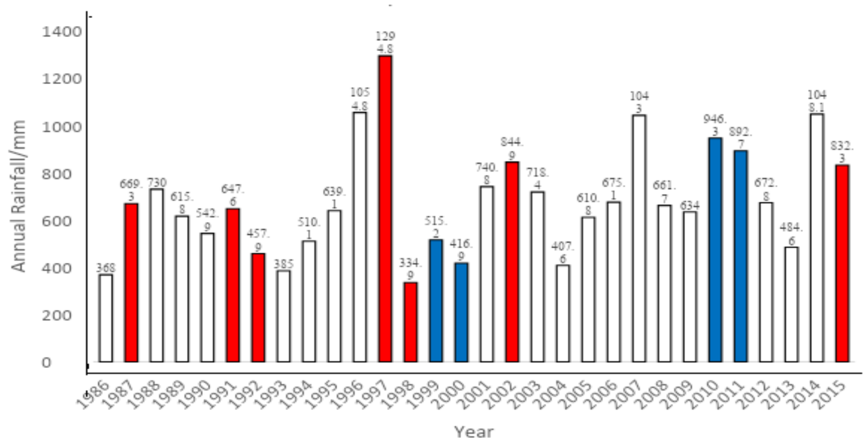


Figure 27: Descriptive Statistics of Annual Rainfall for Tema for strong ENSO years (1986-2015).

Figure 28 is a descriptive statistic of annual rainfall that was observed in Saltpond spanning the years 1986 to 2015. An annual rainfall of 874.1mm was recorded in 1986, rose to 1430.5mm in 1987. It then decreased sharply to 594.1mm in 1990. An increase was observed in 1991 (1137.2mm) followed by a decrease to 549mm in 1993. It rose steeply from 1993 (549mm) peaking at 1540.8mm in the year 1997. There was a sharp fall in the annual rainfall recorded in 1998 to 396mm which was the lowest amount of rainfall recorded. Amount of rainfall recorded from 2006 to 2010 almost stabilized. Generally annual precipitation in Saltpond from 1986 to 2015 did not assume any particular trend. The El Niño-Southern Oscillation (ENSO) phenomenon studied in this thesis is however in agreement the earlier works already done by Trenberth et al in 2001 which suggested that ENSO is the dominant mode of coupled atmosphere-ocean variability on inter-annual time scales in several regions of the world (Trenberth and Stepaniak, 2001) responsible for the variation of the global weather including excessive rainfall, prolonged drought in some case and other destructive weather events such as storms and cyclones. One of the regions with larger impacts associated with extreme precipitation and ENSO events is Southern South America (SSA). A pioneer study performed by Ropelewski and Halpert (1987) on global scale, based on their previous research for North America (Ropelewski and Halpert, 1986), identified a clear ENSO signal in precipitation patterns over SSA. This signal was characterized with an increase in precipitation over central-east Argentina, Uruguay and Southern Brazil during the summer following the development of El Niño conditions. The variation in the precipitation values during both the El Nino and La Nina years for Takoradi is as follows.

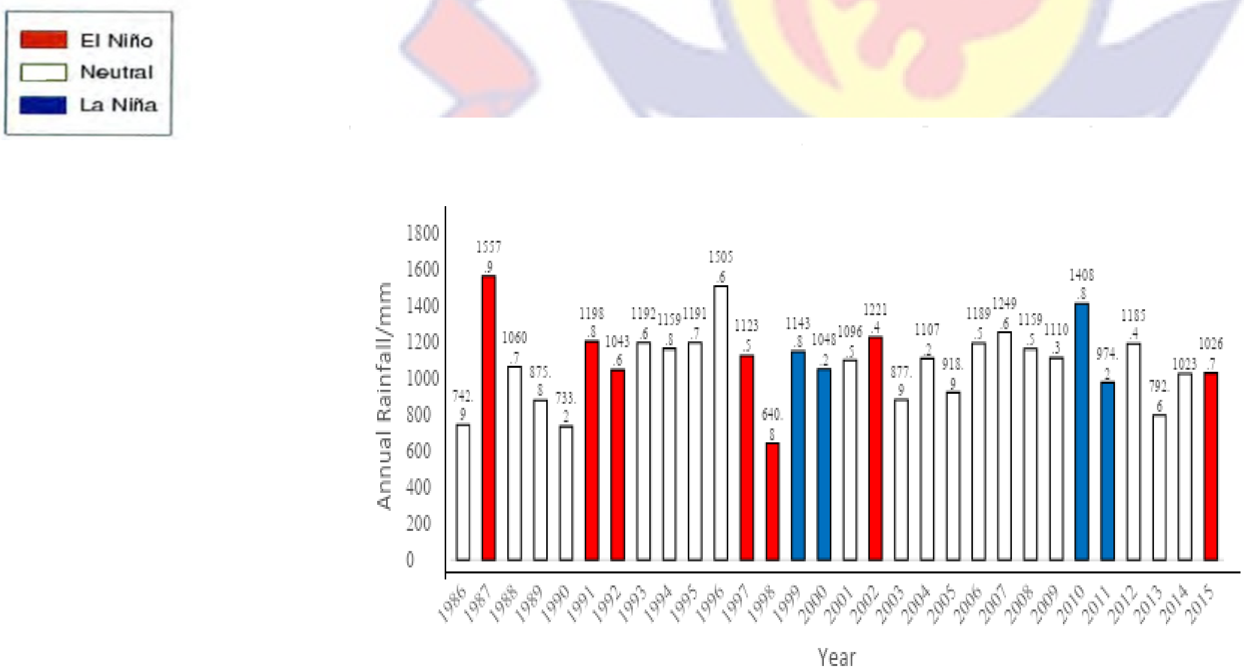


Figure 28: Descriptive Statistics of Annual Rainfall for Saltpond for strong ENSO years (1986-2015)

Figure 29 shows annual amount of rainfall that was measured from 1986 to 2015 in Takoradi. An annual amount of 742.9mm was recorded at the beginning (1986). It rose to peak of 1557.9mm in 1987. It then decreased sharply to 733.2mm in 1990. An increase to an amount of 1198.8mm was recorded in 1991 followed by a decrease to 1043.6mm in 1993. The lowest amount of rainfall 640.8mm was recorded in 1998. Similar trends were observed in the succeeding years as portrayed in the Figure 29 above till 2015. Generally annual precipitation in Takoradi from 1986 to 2015 did not assume any particular trend. ENSO phases at all coastal stations show a gradual increase in the amounts of rainfall during the major season are high in La Nina but low in El Nino years, this however is in agreement with the work done by S.G.K Adiku and others (2008, University of Ghana). Conversely, in minor rainy seasons, comparatively high rainfall amounts were observed during El Nino but low amounts in La Nina years. Rainfall during Neutral years of ENSO showed characteristics in-between La Nina and El Nino. Rainfall onset was observed to occur earlier between March 11 and 20 during La Nina and Neutral years whilst in El Nino years the onset delayed by about a month, occurring between April 11 and 20. These observed onset dates are important in the determination of crop planting periods. No significant variability in the cessation dates of the major season rainfall was observed for all the ENSO phases. The late onset and relatively earlier cessation during El Nino years resulted in a significantly shorter length of the rainy season compared with La Nina and Neutral years which had earlier onset and late cessation. Temporal rainfall distribution during the major season on 10-day time scales generally varied greatly for all ENSO phases. Variability was high towards the end but low towards the peak of the seasons. The study also showed that El Nino seasons have the highest variability in the temporal rainfall distribution followed by La Nina and Neutral in that order. These observations seem to reveal that climatological (long term) observations alone are no longer sufficient for seasonal rainfall prediction, therefore there is the need to use ENSO oceanic Nino index values obtained particularly October, November and December. Thirty years of rainfall data at Accra station indicated a dynamic linear decrease. The average annual rainfall decreased from 3100 mm to 2600 mm over the period (1990-2015). The Bar chart in Figure 30 represents rainfall trend of both the dry season (May–October) and rainy season (November–April) for all years. Average rainfall decreased by 6.8 mm/year in the dry season and 4.8 mm/year during the rainy sea.

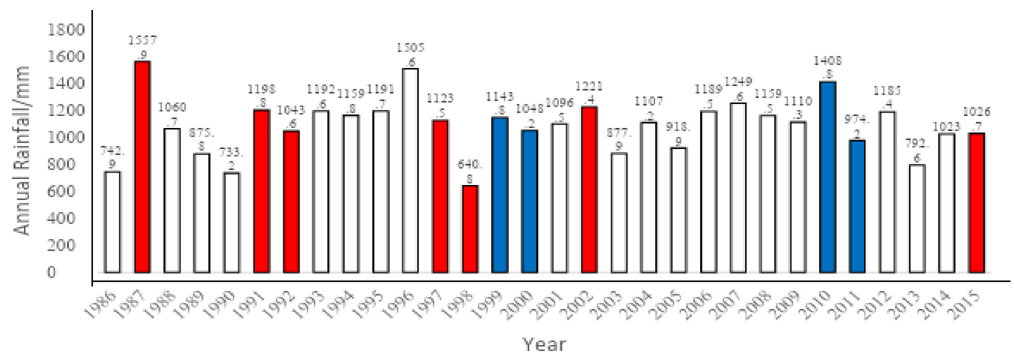


Figure 29: Descriptive Statistics of Annual Rainfall for Takoradi for strong ENSO years (1986-2015)

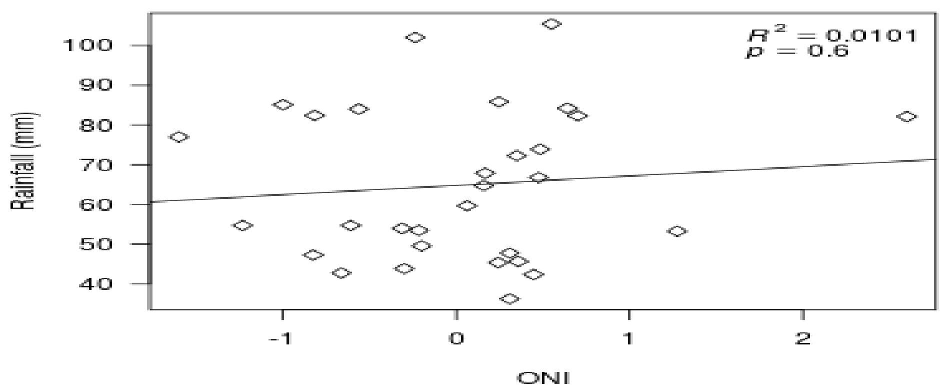


Figure 30: A graph of the variation of the 3-month moving average monthly rainfall against the 3-month moving average ONI for the Accra station.

ONI values less affect the rainfall in Accra. The value of the entire probability correlation coefficient P= 0.6 which means again that the effect of ONI on rainfall in Accra is weak since the larger the value of the probability correlation coefficient (P) between the ONI and the rainfall the weaker relationship. The general trend in the variation of the Oceanic Nino Indices with rainfall is not uniform for each month. Although from the graph of Figure 30 above the highest mean monthly rainfall was below 60.5mm which correspond to an ONI value of approximately 0.6 in Figure 30. The 0.8 ONI value only give a large precipitation of above 65.0mm monthly mean. The graph of Figure 30 for Accra does not give a general trend to predict exactly the effect of global ONI values to precipitation in the coastal sectors of Ghana. Hence in conclusion it can be observed that the relationship between rainfall and ENSO events along the coasts of Ghana is weak as it in the agreement with Adiku and Stone (2004) on the research on ENSO events at Volta Basin. For that 2000 year La Nina year in Accra the trend of the variation of rainfall did not give a uniform explanation on the dependence of rainfall with the variation Oceanic Nino Indices. The graph for the variation of rainfall with ONI values is shown below in the Figure 32.

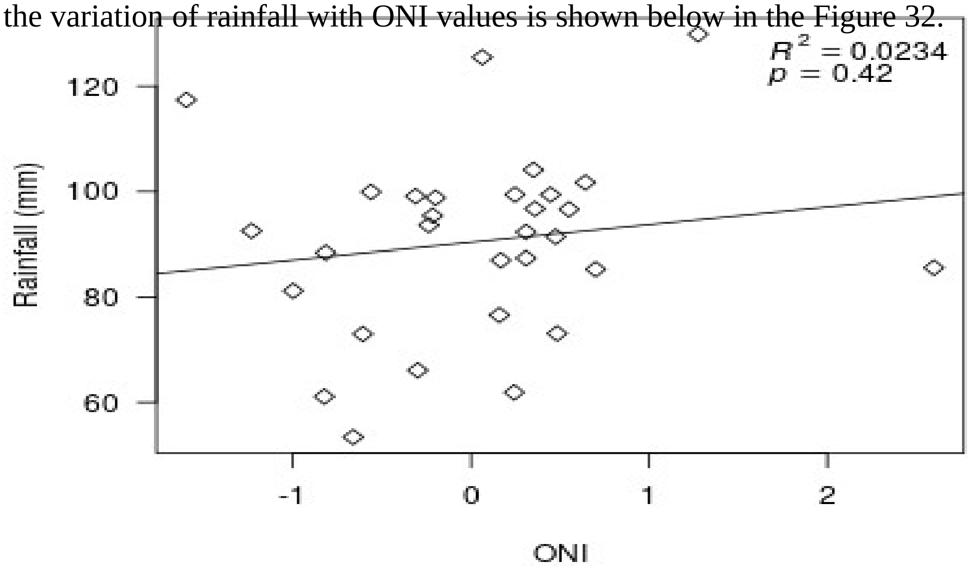


Figure 31: The variation of values with the 3- year moving average rainfall with 3-year moving average ONI for the Takoradi station.

At the Takoradi station, the value of R = 0.15 which shows that the contribution of ENSO to rainfall is not very large. This is also confirmed by the population correlation coefficient value P= 0.42. This value means that there is an effect on rainfall by ENSO but the effect is small. It is a known fact that for P values less than or equal to (0.05) is an indication that there a strong relationship the dependent variable and the independent variable. Some progress has been made in the amount of daily, monthly or annual rainfall prediction particular geographical location based on signals from some natural modes, such as the El Niño-Southern Oscillation (ENSO) by Walker G. (1904), Martinez (1998) and so on. In S G. K. Adiku et al (2004) their work on ENSO was to find out how ENSO affect rainfall in the Volta basin and the consequent effect to cropping. In their work ENSO is defined as a shifts in the sea surface temperatures (SST) in the Eastern and Western Equatorial Pacific, coupled with shifts in barometric pressure gradients and wind patterns in the tropical Pacific (the Southern Oscillation) which consequently lead to increase or a decrease in the West African's rainfall and the global climate variations. This study has virtually confirmed the assertion that ENSO really has effect on the daily, monthly or annual rainfall in the coastal belts of Ghana. The results of the graph did give trend which indicates that rainfall during ENSO years were necessarily dependent on the effect of ENSO episodes. A similar meteorological analysis was done for the Saltpond synoptic station for the El Nino, La Nina and the Normal year. For the 1987 El Nino year the graph of the variation of rainfall with the global ONI values is shown in figure 32. The variation of precipitation with the ONI is analysed on a three-year moving average in Saltpond is sketched in the scatter graph of figure 32.

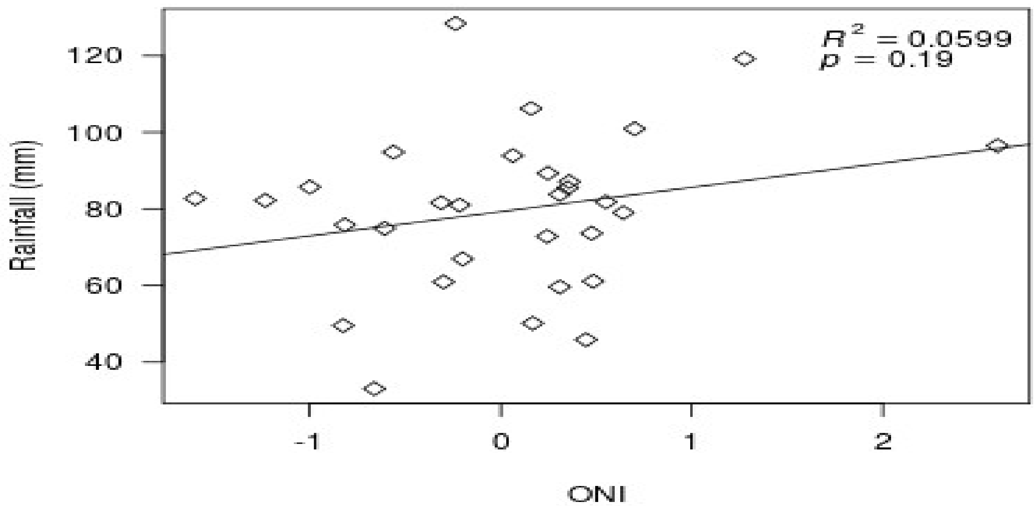


Figure 32: The variation of values with the 3- year moving average rainfall with 3-year moving average ONI for the Saltpond station.

3- Months moving Annual monthly mean rainfall for the Saltpond study station.

The graph in figure 32 illustrates the variation of a 3-year moving average ONI values for the 30 year period with annual mean of the monthly mean rainfall. The sample Correlation coefficients (R) is about 0.026 for the Saltpond station which shows that there is weak correlation between rainfall and ONI but the Population correlation coefficient (P) which covers the entire data is 0.19 which is an indication that the effect of ONI to precipitation is moderately large.

Figure 33: The variation of values with the 3- year moving average rainfall with

3-year moving average ONI for the Ada station.

Also the variation of annual mean of the monthly moving average rainfall with Annual mean of monthly moving average ONI at the Tema in figure 34 study station showed a similar trend as the other stations.

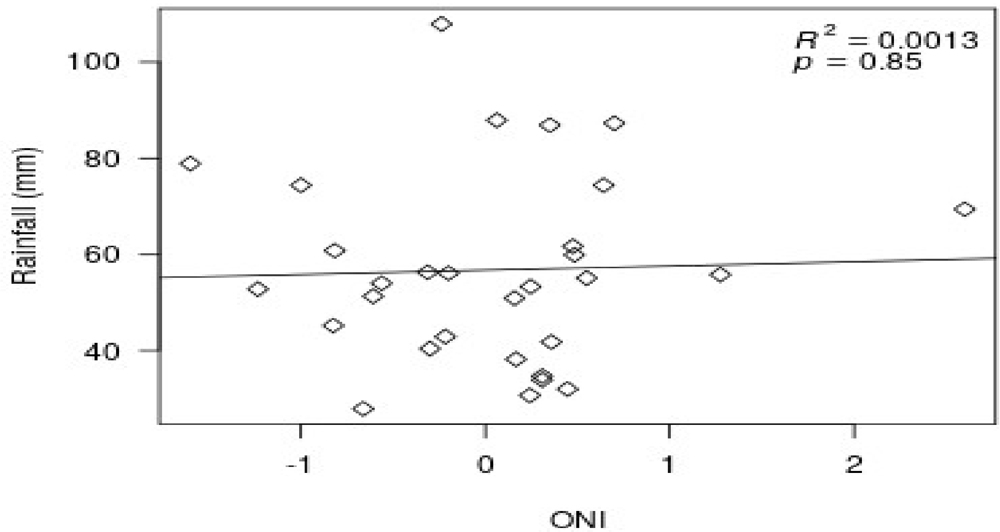
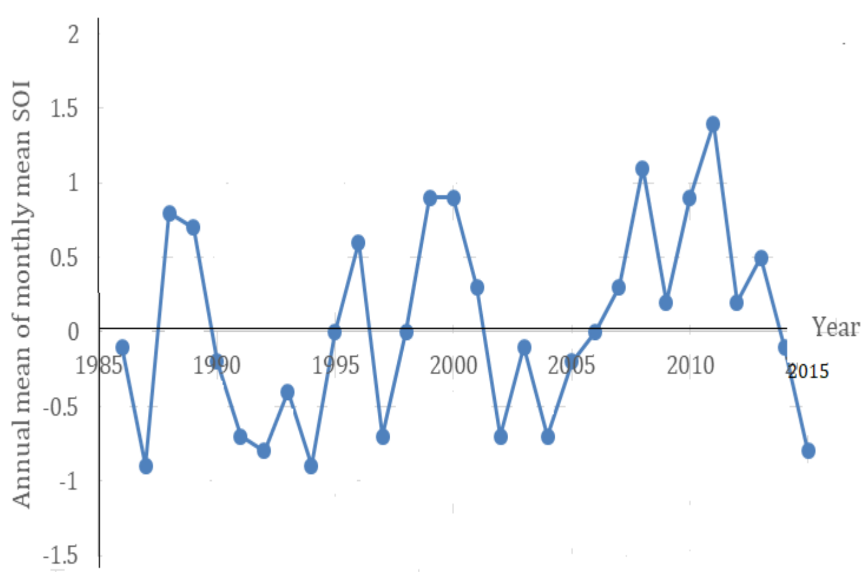


Figure 33: The variation of values with the 3- year moving average rainfall with 3-year moving average ONI for the Tema station.



In Tema the $R^2 = 0.00013$ this is a positive correlation between the rainfall and the ONI. The P= 0.85 is the probability correlation coefficient for the rainfall and the ONI at Tema. As indicated already, the larger the value of P the lesser the effect of ONI on rainfall.

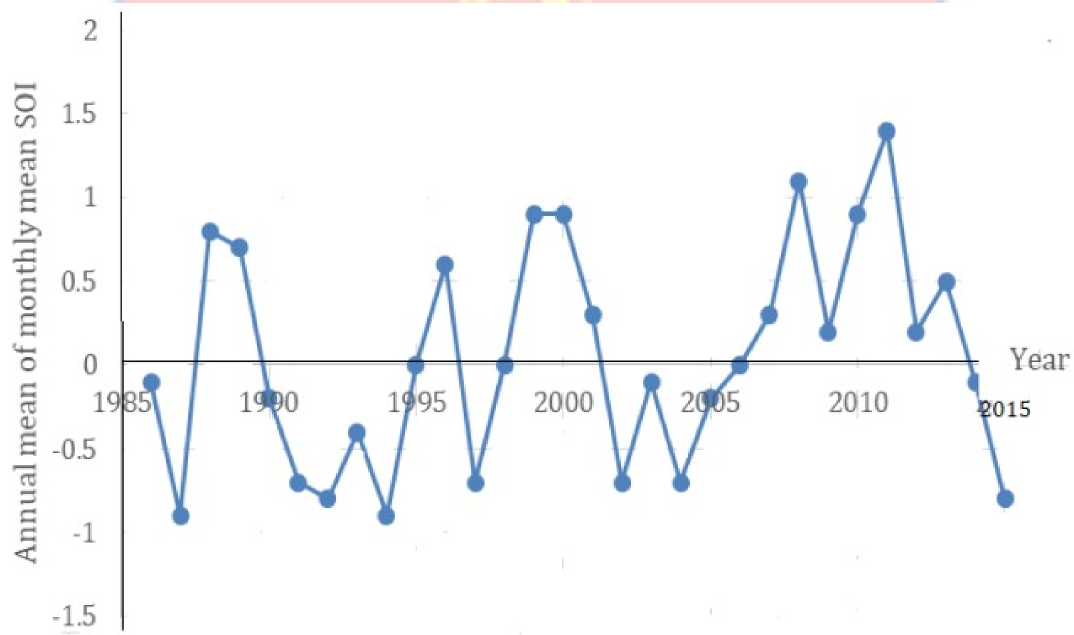


Figure 34: The variation of SOI over the 30-year period (1986-2015)

The high positive values of the SOI indicates La Nina regimes and the high negative values show the El Nino episodes. For example, in the graph Figure 34 above from the 1997 towards the year 2000 El Nino period and the 1990 towards the 1995 mark the La Nina time. In summary from the SOI graph in figure 35 we have the table 3 below which illustrates the various ENSO years and the normal or neutral years. El Nino years have SOI values from -0.70 and below while the La Nina years have SOI values 0f +0.70 and below. The normal years have SOI ranging from -0.70<Y< +0.70 where Y represents the SOI values for neutral years within the 30 years study period.

Table 3: A table of values showing the ENSO years and the normal years from the graph of SOI variation through 1986-2015

El Nino years	SOI	La Nina years	SOI	Normal years	SOI
1987	-0.80	1988	+0.75	1986	+0.25
1991	-0.75	1989	+0.70	1990	+0.2
1992	-0.85	1996	+0.70	1993	+0.3
1994	-0.70	1999	+0.70	1995	-0.10
1997	-0.8	2000	+0.80	1998	-0.10
2002	-0.86	2007	+0.70	2001	+0.30
2004	-0.7	2008	+1.10	2003	-0.10
2015	-1.4	2010	+0.70	2005	-0.30
		2011	+1.40	2006	+0.10
				2009	
					+0.30
				2012	
					+0.30

2013
2014
+0.50
+0.01

Most of the graphs indicates situations in which there is more rain after major El Nino events or a La Nina events. Generally, a decrease in rainfall in Accra, Tema and Ada, did not clearly show that it was ENSO episodes of the sea that were responsible. This may be due to the quantity of vegetation cover which would have improved uplifting of vapour in the troposphere. This trend is consistent with previous results showing that El Niño events, characterized by negative ONI values more than -0.5, typically occur between June and October in West Africa and the most tropical areas along the Coast of the world (Hamada, J. *et al*.). The results also show that El Niño events corresponded to more average monthly rainfall, suggesting that drought conditions in this area are related to La Nina events. Previous studies have shown that El Niño is associated with drought events in many parts of the world dry season. El Niño increased the amount of rainfall in the season and followed by La Nina years. From the bar chart of the graphs for eight El Nino years and the Eight La Nina years compared to some eight normal years graph it is clear that El Nino years recorded more rainfall both monthly and annually than La Nina years in all five study Stations in general . Normal years gave the least rainfall.

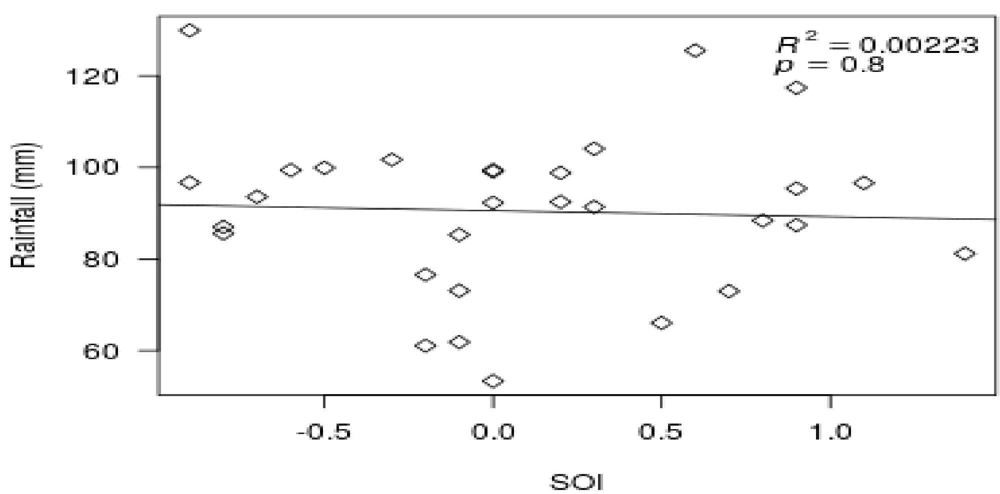


Figure 35: A graph showing the variation of annual mean monthly mean rainfall with the annual mean monthly mean SOI for the Takoradi station for the 30-year study period.

For the Takoradi station a graph of the variation of annual mean of the monthly mean rainfall with annual mean of monthly mean SOI, the P= 0.8 which is large indicating that the contribution of SOI to both monthly or annual rainfall was minimal.

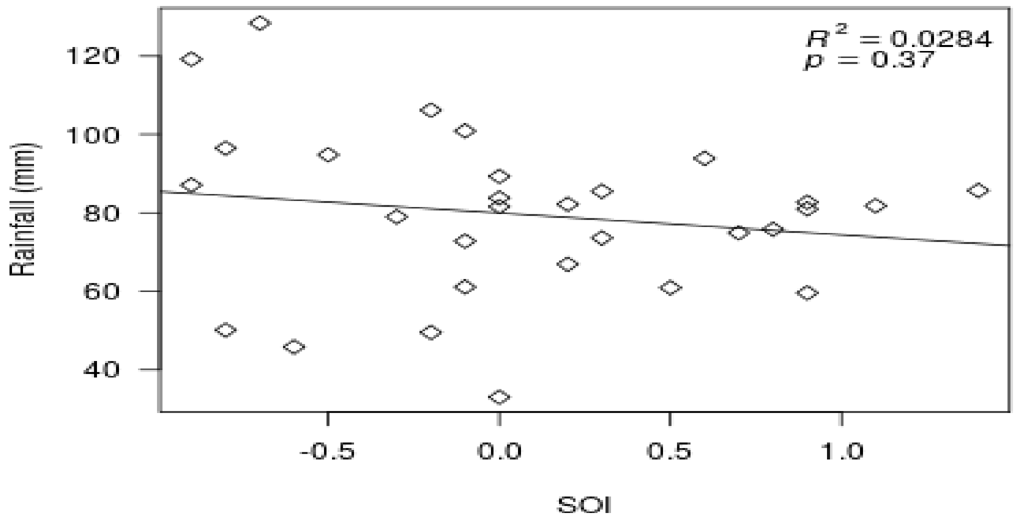


Figure 36: A graph showing the variation of annual mean monthly mean rainfall with the annual mean monthly mean SOI for the Saltpond station for the 30-year study period.

The Figure 37 for the Saltpond station also produces a similar results as that of Takoradi in Figure 36. All graphs show that the SOI although contribute to the tropical rainfall, its effect is very minimal.

In the Ada station the graph figure 38 for the variation of rainfall with SOI produce a probability correlation coefficient P= 0.37 and sample correlation coefficient of R= 0.37. Which is an indication that significance of SOI on rainfall along the coastal belt is small and not as large as one may think.

Figure 38: A graph of the variation of annual mean of 3-month moving average rainfall against annual mean of 3-month moving mean SOI at the Ada station. The Accra station is sketched on the graph of figure with a P= 0.7. The value shows

that in Accra the effect of SOI on rainfall is more pronounced than other stations.

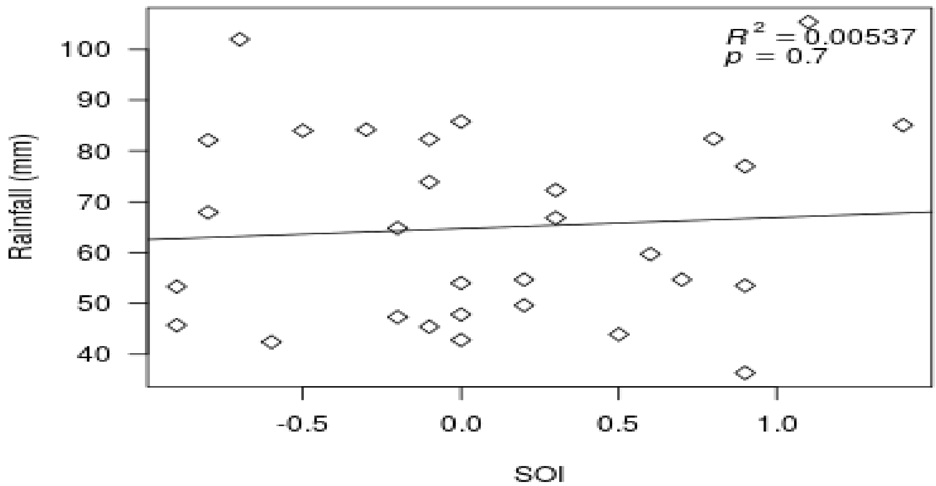


Figure 37: A graph of the variation of annual mean of the monthly moving average rainfall against the SOI at Accra station.

In Tema, the variation of annual mean of the monthly moving average rainfall with the annual mean SOI are sketched in Figure 40. In Tema the value of P=0.69 is less than that of Accra.

Hence the effect of SOI on the rainfall in Tema is significant.

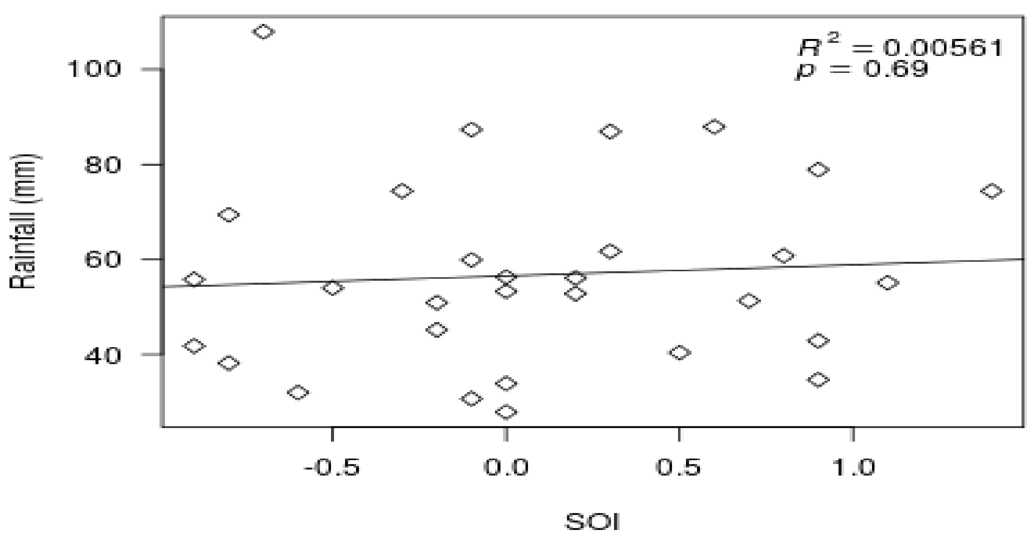


Figure 38: A graph of the variation of annual mean of monthly mean moving average of the SOI at Tema station.

The ENSO events oscillate the amount of measurable rainfall in a given period. This can be explained by the fact that El Niño events increase sea-surface temperature due to the movement of warm water vapour in the Pacific Ocean. As a consequence, cloud production in the atmosphere above the atmosphere (troposphere) is reduced, further decreasing rainfall production. The effects of El Niño events in Ghana and the West African sub region can also be exacerbated by forest fires that are more likely to occur during the dry season, releasing smog emissions into the atmosphere. This smog can be extensively distributed throughout the atmosphere and persist for long periods, and may also reduce cloud generation.

For the Ada station the sample correlation coefficient P= 0.85 gives an indication there is a relationship between the rainfall at Ada and the rising SOI values.

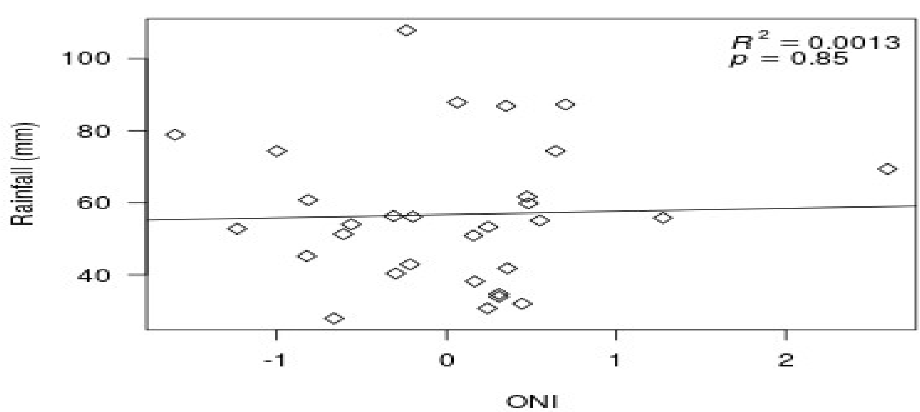


Figure 39: A graph of the variation of annual mean of monthly mean moving average of the SOI at Ada station.

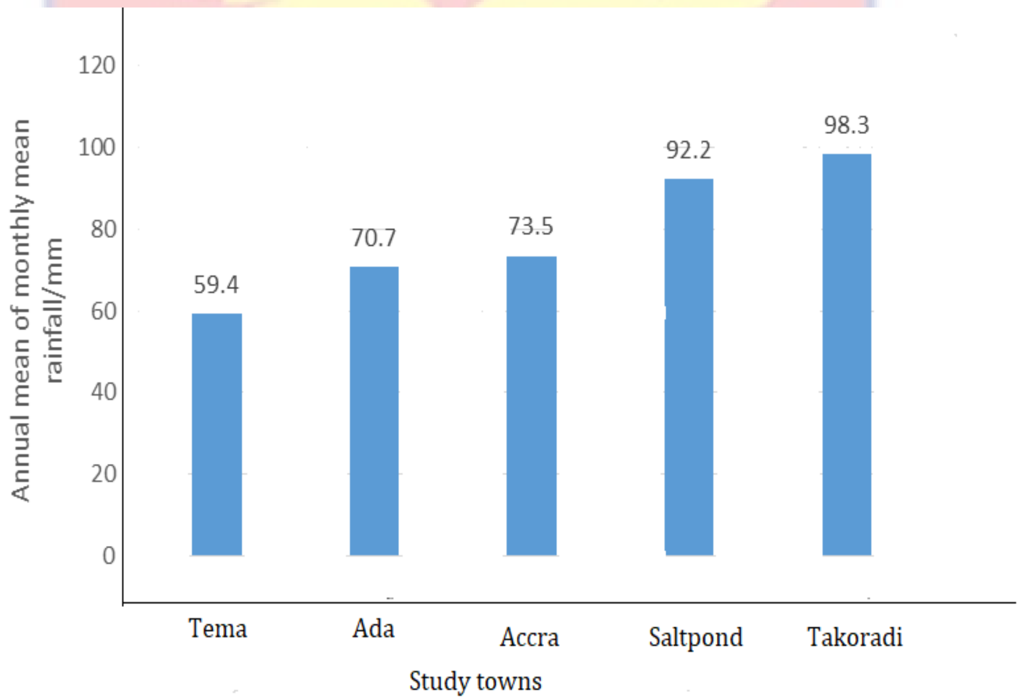


Figure 40: A bar chart showing the annual mean of the monthly mean rainfall for the 8 El Nino years of (1987, 1991, 1992, 1994, 1997, 2002, 2004 and 2015) for the five study stations.

The impacts of ENSO on rainfall appear to be increasing annually as shown by the positive trend in both dry and rainy seasons. This suggests that El

Niño events drive the decline in rainfall during both seasons. The positive trend in the data indicates the dynamic increase of El Niño effects on the rainfall decrease. However, El Niño-related impacts on rainfall are not as substantial in the rainy season as compared to the dry season. It was also determined that ENSO events are not the only factors affecting rainfall trends in Accra during the rainy season. Although the results in this study do not address this aspect of the question, deforestation in this region could be another factor affecting rainfall trends in Accra. Although the ENSO phenomenon occurs in the Pacific, the associated ocean temperature changes also alter the atmosphere which, in turn, affects climate on a more global scale. The approach in their studies was to first estimate the implications of the ENSO phase for crop production through econometric methods or crop simulation models. A value-of-information framework is then used to simulate how farmers or decision makers might adjust their behavior with and without ENSO phase information.

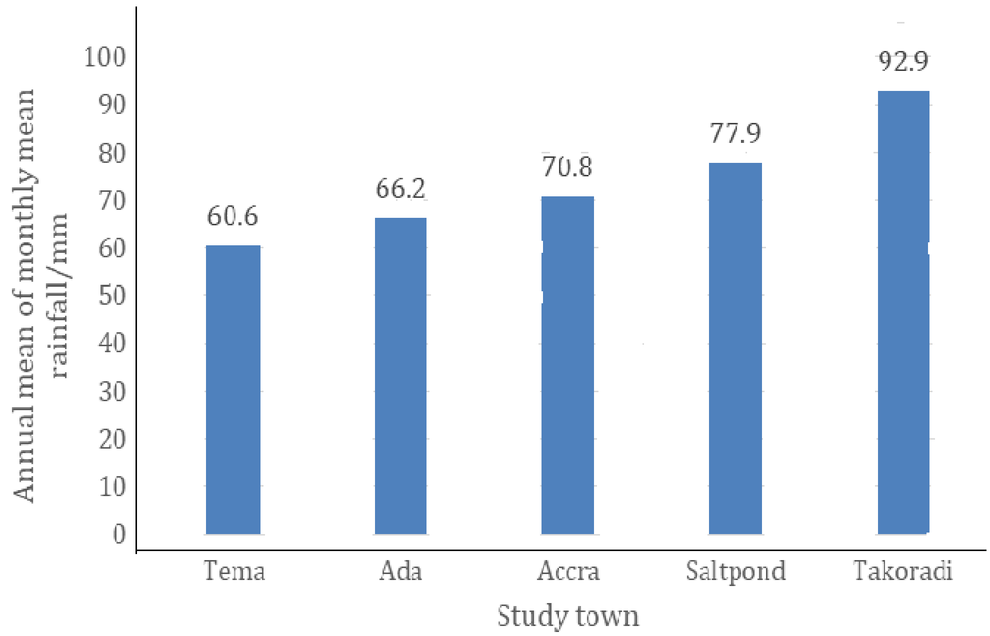


Figure 41: A bar chart showing the annual mean of the monthly mean rainfall for 8 La Nina years of (1988, 1989, 1999, 2000, 2007, 2008, 2010 and 2011) for the five study stations.

This information gives estimates on how the aggregate market supply curve is shifted by the provision of phase information. Subsequently, welfare effects with and without the information are developed and, using event probabilities, are combined into an overall value-of-information estimate. In conclusion the research showed a significant overall increase in precipitation across the coastal sectors of Ghana during El Nino years. The bar chart representing the annual mean of the monthly mean rainfall for eight different Strong non ENSO years also referred to as normal years for each study town along the coastal belt is represented as in Figure 41.

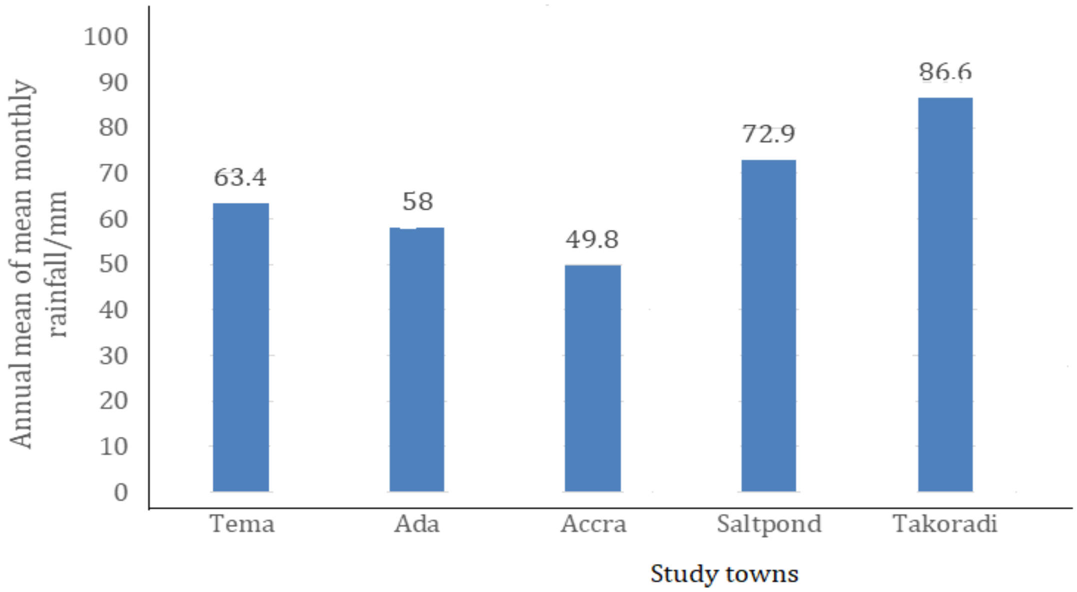


Figure 42: A bar chart showing the annual mean of the monthly mean rainfall for the 8 Normal years of (1986, 1990, 1993, 1995, 1996, 1998, 2001 and 2003, for the five study stations.

Chapter Summary

This chapter discusses the results obtained in the study. It also talks about the contribution of ENSO events to rainfall in Ghana, particularly the study towns.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Overview Summary

This chapter of the research deals with the recommendations made by the researcher to stake holders of Ghana's weather systems and measures to take in order to prevent or reduce moderately the negative effects of extreme weather conditions.

The purpose of the research was to find the correlations of El Nino and La Nina episodes to Ghana's rainfall along the coastal belts. The research studied Oceanic Nino Index (ONI) and Southern Oscillation Indices (SOI) values as provided by the National Oceanic Atmospheric Administration. The ONI and SOI values are the modern means by which the world meteorological society measures the effect of ENSO events and the cold and the warm episodes of our sea and oceans. From studies of ENSO events by S.E. Nichols (1999) the variation of ocean temperature affects the rainfall of West Africa and in this study it was realized that more annual rainfall is recorded during the El Nino or warm periods in all the coastal sectors selected for the study and less annual rainfall was recorded in all the five coastal sectors selected for the study during the La Nina or the cold episodes. The research also made use of Southern Oscillation Values (SOI) and in each analysis the variation of rainfall along the coast with the variation in the ocean surface temperature was significant.

From the data obtained and the figures on the histograms it is evident that the annual rainfall among the coastal sectors under consideration appear oscillatory. The correlation analysis did not give an information that the rainfall in the coastal sectors are weakly dependent on the ENSO events. The low rainfall at some of the selected coastal sectors such as Tema and Accra could be attributed to the low vegetation of those areas. The lesser vegetation cover in those study towns might have contributed to low rainfall. Although generally there was a significant variations in the rainfall in those areas during the warming or El Nino and La Nina.

Conclusion

The rainfall characteristics and variation as well as the trend are necessary for the proper plan of farming, mitigating flood related disasters, prolonged drought and clean water supply to the coastal sectors of Ghana. From the histograms and the graphs for both El Nino and La Nina years of 1987 and 2000 respectively it is seen that all the two main ENSO episodes alter weather patterns and hence cause a variation of rainfall from one coastal sector to another within Ghana. This might be dependent on the intensity of the particular ENSO events. The analysis conducted on the data of rainfall and ONI values shows there were no consistent trend in the rainfall of Ghana along the coastal sectors. The effect of La Nina and El Nino on the rainfall of Ghana along the coast is weak and there any much significance of ENSO episodes on the precipitation in Ghana along the coastal belts. Although it is a known fact that the effect of effect of La Nina on rainfall is much higher during August to October and consequently reduces precipitation drastically during to December to March. As the study shows a slight increase in the rainfall during La Nina regime and a somehow less rainfall during the El Nino periods of the raining seasons of Ghana in general. This is however in agreement with the earlier research carried out by Acheampong, (2002) where in his work on ‘The rainfall anomaly along the coast of Ghana its nature and causes ‘he suggested that the variation in the sea surface temperatures causes a change in the pattern of rainfall along the coast. The rainfall variations however suggest that it is not only the warming or cooling episodes of the seas and oceans that cause the trend in rainfall in the coastal sectors but other weather and climate change phenomena and parameters such as the point of ITCZ, squall line motion, mesoscale convective systems, the West African Monsoons(WAM), the forest cover which enhances evaporations and uplifting, wind motion and others such as the variations in temperatures of the land during the day and night.

Recommendations

This research was done to determine the impact of El Nino and La Nina events on the rainfall of Ghana along the coastal sectors. There are several approaches used today to identify El Nino and La Nina years which include the use of SOI collection method, analysis of daily sea surface temperature by buoying satellites, global Oceanic Nino index and other standard meteorological approach. Each of the above methods mentioned come with their individual cost and disadvantages. For example, the use of the global SOI values are not very reliable means of predicting ENSO events since the global pressure variations is so rapid and not stable.

However, this study made use of the available global ONI values collected by the National Oceanic and Atmospheric Administration (NOAA) to predict El Nino and La Nina episodes as well as the Southern Oscillation Indices (SOI). Much more information could have been obtained on the precipitation along the coastal sectors of Ghana if the detecting system of ENSO events were including all the possible methods such as direct sea surface temperature measurement along the study areas of the Coast.

Most of the data collected were obtained from standard bodies responsible for collecting and analyzing data on the weather which include the Ghana meteorology Agency for the provision of precipitation data on five major coastal sectors of Ghana and collection of global ONI and SOI values from the website of NOAA for the period of 30 climatological years. It is believed that if the data was collected by the researcher himself during the research, accuracy of the data would have been more enhanced in order to achieve the expected results.

Artificial satellites are needed to collect the sea surface temperature and measure the oscillation in the sea surface pressure differences between the East and the West for a long period of time for analysis to ascertain ENSO events better in any future research. In addition to that it is recommended that a large amount of data on precipitation along the coasts of Ghana which spans up to at least ninety (90) years is more reliable to predict ENSO events along the coast and the relationship to precipitation. In addition to the above the Government of Ghana and other stake holders of weather and climate issues should form a habit of monitoring the temperature and pressure variations along Coast of Ghana as a daily routine so early predictions and warnings are provided to the locals of any impending weather extremes. This would help the people in communities to prepare for any extreme weather events in order to help prevent loss of lives and property during adverse weather conditions that might have been triggered by typical El Nino and La Nina events.

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APPENDICES

APPENDIX A

DESCRIPTIVE STATISTICS OF ANNUAL RAINFALL DATA OF ACCRA

FOR THE YEARS 1986 -2015

YEAR	ANNUAL (mm)	MEAN(mm)	DEVIATIONS(mm)
1986	545.6	45.4	500.2
1987	639.8	53.3	586.6
1988	988.8	82.4	906.4
1989	656.7	54.7	602.0
1990	567.7	47.3	520.4

1991	1008.3	84.0	924.3
1992	815.0	67.9	747.1
1993	509.3	42.4	466.9
1994	547.9	45.7	502.2
1995	1029.8	85.8	944.0
1996	716.6	59.7	656.9
1997	1223.5	102.0	1121.5
1998	513.6	42.8	470.8

1999	641.8	53.5	588.3
2000	435.2	36.3	398.9
2001	801.3	66.8	734.5
2002	1010.0	84.2	925.8
2003	887.0	73.9	813.1
2004	573.8	47.8	526.0
2005	777.8	64.8	713.0
2006	648.4	54.0	594.4

2007	867.6	72.3	795.3
2008	1264.7	105.4	1159.3
2009	656.2	54.7	601.5
2010	924.0	77.0	847.0
2011	1021.6	85.1	936.5
2012	594.7	49.6	545.1
2013	527.0	43.9	483.1
2014	987.9	82.3	905.6

2015	984.6	82.1	
			902.5

APPENDIX B

DESCRIPTIVE STATISTICS OF ANNUAL RAINFALL DATA OF TEMA

FOR THE YEARS 1986-2015

YEAR	ANNUALS (mm)	MEAN (mm)	DEVIATIONS (mm)
1986	368.0	30.7	337.3
1987	669.3	55.8	613.5
1988	730.0	60.8	669.2
1989	615.8	51.3	564.5
1990	542.9	45.2	497.7
1991	647.6	54.0	593.6
1992	457.9	38.2	419.7
1993	385.0	32.0	353.0
1994	510.1	41.8	468.3
1995	639.1	53.3	585.8
1996	1054.8	87.9	966.9
1997	1294.8	107.9	1186.9
1998	334.9	27.9	307.0
1999	515.2	42.9	472.3
2000	416.9	34.7	382.2
2001	740.8	61.7	679.1
2002	844.9	74.4	770.5
2003	718.4	59.9	658.5
2004	407.6	33.9	373.7
2005	610.8	50.9	559.9

2006	675.1	56.3	618.8
2007	1043.0	86.9	956.1
2008	661.7	55.1	606.6
2009	634.0	52.8	581.2
2010	946.3	78.9	867.4
2011	892.7	74.4	818.3
2012	672.8	56.1	616.7
2013	484.6	40.4	444.2
2014	1048.1	87.3	960.8
2015	832.3	69.4	762.9

APPENDIX C

DESCRIPTIVE STATISTICS OF ANNUAL RAINFALL DATA OF ADA FOR THE YEARS 1986-2015

YEAR	ANNUALS (mm)	MEAN (mm)	DEVIATIONS (mm)
1986	495.8	41.3	454.5
1987	931.0	77.6	853.4
1988	798.3	66.5	731.8
1989	949.9	79.6	870.3
1990	655.9	54.7	601.2
1991	1298.0	108.2	1189.8
1992	359.2	29.9	329.3
1993	759.3	63.3	696.0
1994	701.2	58.3	642.9
1995	859.2	71.6	787.6
1996	992.1	82.7	909.9
1997	1093.8	91.2	1002.6
1998	484.4	40.4	444.0
1999	692.9	57.7	635.2
2000	394.3	32.9	361.4
2001	779.2	64.9	714.3
2002	842.6	70.2	772.4
2003	1061.9	88.5	973.4
2004	698.4	58.2	640.2
2005	790.8	65.9	724.9
2006	746.3	62.2	684.1

2007	897.1	74.8	822.3
2008	767.3	63.9	703.4
2009	1070.0	89.2	980.8
2010	957.4	79.8	877.6
2011	893.5	74.5	819.0
2012	669.7	55.8	613.9
2013	635.5	52.9	582.6
2014	832.8	69.4	763.4
2015	851.1	72.1	779.0

APPENDIX D

DESCRIPTIVE STATISTICS OF ANNUAL RAINFALL DATA OF SALTPONG FOR THE YEARS 1986-2015

YEAR	ANNUALS (mm)	MEAN (mm)	DEVIATIONS (mm)
1986	874.1	72.8	801.3
1987	1430.5	119.2	1311.3
1988	910.0	75.8	834.2
1989	898.5	74.9	823.6
1990	594.1	49.5	544.6
1991	1137.2	94.8	1042.4
1992	601.0	50.1	550.9
1993	549.0	45.8	503.2
1994	1044.9	87.1	957.8
1995	1072.3	89.3	983.0
1996	1127.1	93.9	1033.2
1997	1540.8	128.4	1412.4
1998	396.0	33.0	363.0
1999	972.3	81.0	891.3
2000	715.0	59.6	655.4
2001	882.8	73.6	809.2
2002	947.5	79.0	868.5
2003	733.5	61.1	672.4
2004	1005.6	83.8	921.8
2005	1274.9	106.2	1168.7
2006	979.9	81.6	898.3

2007	1025.6	85.5	940.1
2008	981.3	81.8	899.5
2009	986.2	82.2	904.0
2010	992.7	82.7	910.0
2011	1028.8	85.7	943.1
2012	802.6	66.9	735.7
2013	730.7	60.9	669.8
2014	1211.3	100.9	1110.4
2015	1158.0	96.5	1061.5

APPENDIX E

DESCRIPTIVE STATISTICS OF ANNUAL RAINFALL DATA OF TAKORADI FOR THE YEARS 1986-2015

YEAR	ANNUALS (mm)	MEAN (mm)	DEVIATIONS (mm)
1986	742.9	61.9	681.0
1987	1557.9	129.8	1428.1
1988	1060.7	88.4	972.3
1999	875.8	73.0	802.8
1990	733.2	61.1	672.1
1991	1198.8	99.9	1098.9
1992	1043.6	87.0	956.6
1993	1192.6	99.4	1093.2
1994	1159.8	96.7	1063.1
1995	1191.7	99.4	1092.3
1996	1505.6	125.5	1380.1
1997	1123.5	93.6	1029.9
1998	640.8	53.4	587.4
1999	1143.8	95.4	1048.4
2000	1048.2	87.4	960.8
2001	1096.5	91.4	1005.1
2002	1221.4	101.7	1119.7
2003	877.9	73.1	804.8
2004	1107.2	92.3	1014.9
2005	918.9	76.6	842.3
2006	1189.5	99.1	1090.4

2007	1249.6	104.1	1145.5
2008	1159.5	96.6	1062.9
2009	1110.3	92.5	1017.8
2010	1408.8	117.4	1291.4
2011	974.2	81.2	893.0
2012	1185.4	98.8	1086.6
2013	792.6	66.1	726.5
2014	1023.0	85.3	937.7
2015	1026.7	85.6	941.1

APPENDIX F

VARIATION OF RAINFALL WITH EL NINO OF 1987 FOR THE STUDY TOWNS

3-year moving mean ONI

1.2 1.1 1.0 1.0 1.2 1.5 1.6 1.6 1.5

El Nino 1.3

-1.3 -1.1 -1.0 -1.0 -1.0 -1.0 -1.1 -1.2 -1.3

La Nina -1.5

3-month moving mean rainfall/mm (1987)-El Nino episode

Accra

3.8 3.3 21.7 24.6 62.2 16.7 18.7 79.3 275.3 83.2 9.1 41.9

Takoradi

5.1 19.5 39.8 92.2 170.3 203.9 126.3 333.4 339.2 169.5 28.0 30.7

Saltpond												
	9.7	0.0	112.2	42.2	104.0	31.7	67.7	108.9	374.9	217.2	34.1	42.6
Ada												
	0.0	0.0	55.3	18.3	35.6	148.7	19.9	160.6	339.9	135.7	7.6	9.4
Tema												
	24.0	5.2	42.6	45.5	106.4	3.4	21.2	57.4	297.9	75.7	0.0	14.0

APPENDIX G

VARIATION OF MONTHLY IN (2000)-LA NINA YEAR FOR ALL STUDY TOWNS

Accra

0.7	0.0	59.2	28.2	127.1	116.4	19.9	12.4	8.6	36.8	25.9	77.0

Tkoaradi

27.2	0.0	68.0	145.1	195.1	296.3	24.7	34.1	33.3	42.1	30.2	152.2

Saltpond

14.3	0.0	124.1	88.8	151.8	185.0	31.8	9.4	7.0	33.9	56.8	12.1

Tema

0.0	0.0	30.0	39.2	146.8	67.7	44.7	4.2	3.4	39.9	25.7	15.3

Ada

0.0	0.0	44.6	78.5	100.1	60.5	56.5	10.8	8.8	32.9	0.0	1.6

APPENDIX H

DATA ON THE ONI, SOI AND PRECIPITATIONS IN ALL STUDY STATIONS FROM 1986-2015

ONI	ACCRA(RAIN)	TAKORADI	ONI	TEMA(RAIN	ACCRA(RAIN)	ADA(RAIN)	SALTPOND
0.2	45.4	61.9	0.2	30.7	45.4	41.3	72.8
1.3	53.3	129.9	1.3	55.8	53.3	77.6	119.2
-0.8	82.4	88.4	-0.8	60.8	82.4	66.5	75.8
-0.6	54.7	73	-0.6	51.3	54.7	79.6	74.9
-0.8	47.3	61.1	-0.8	45.2	47.3	54.1	49.5
-0.5	84	99.9	-0.5	54	84	108.2	94.8
0.2	67.9	87	0.2	38.2	67.9	29.9	50.1
0.4	42.4	99.4	0.4	32	42.4	63.3	45.8
0.4	45.7	96.7	0.4	41.8	45.7	58.3	87.1
0.2	85.8	99.4	0.2	53.3	85.8	71.6	89.3
0.1	59.7	125.5	0.1	87.9	59.7	82.7	93.9
-0.2	102	93.6	-0.2	107.9	102	91.2	128.4
-0.7	42.8	53.4	-0.7	27.9	42.8	40.4	33
-0.2	53.5	95.4	-0.2	42.9	53.5	57.7	81

0.3	36.3	87.4	0.3	34.7	36.3	32.9	59.6
0.5	66.8	91.4	0.5	61.7	66.8	64.9	73.6
0.6	84.2	101.7	0.6	74.4	84.2	70.2	79
0.5	73.9	73.1	0.5	59.9	73.9	88.5	61.1
0.3	47.8	92.3	0.3	33.9	47.8	58.2	83.8
0.2	64.8	76.6	0.2	50.9	64.8	65.9	106.2
-0.3	54	99.1	-0.3	56.3	54	62.2	81.6
0.4	72.3	104.1	0.4	86.9	72.3	74.8	85.5
0.4	105.4	96.6	0.4	55.1	105.4	63.9	81.8
-1.2	54.7	92.5	-1.2	52.8	54.7	89.2	82.2
-1.6	77	117.4	-1.6	78.9	77	79.8	82.7
-1	85.1	81.2	-1	74.4	85.1	74.5	85.7
-0.2	49.6	98.8	-0.2	56.1	49.6	55.8	66.9
-0.3	43.9	66.1	-0.3	40.4	43.9	52.9	60.9
0.7	82.3	85.3	0.7	87.3	82.3	69.4	100.9
2.6	82.1	85.6	2.6	69.4	82.1	72.1	96.5