



University of Nairobi

School of Physical Sciences

Department of Meteorology

THE ASSOCIATION OF TROPICAL SEA SURFACE
TEMPERATURES AND WIND FEATURES WITH 'KIREMT'
SEASON RAINFALL OVER ETHIOPIA.

PROJECT WORK SUBMITTED IN PARTIAL FULFILMENT FOR THE
REQUIREMENTS OF POST GRADUATE DIPLOMA IN METEOROLOGY

Submitted by: HENOCK HAILU MISGANAW

Reg. No.: I45/69930/2013

Supervisors: Dr. J. MUTEMI

Dr. W. GITAU

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DECLARATION

I hereby declare that this project work is my original work and has not been presented by anyone in any university for academic award;


Signature:  Date: 30/07/2014

Henock Hailu Misganaw

Registration number I45/69930/2013

Supervised by:

Dr. J. N. Mutemi

Signature:  Date: 30/07/2014

DR. W. Gitau

Signature:  Date: 30/07/2014

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DEPT. OF METEOROLOGY
UNIVERSITY OF NAIROBI

Abstract

Ethiopia, which is found in the Greater Horn of Africa, enjoys different climatic conditions ranging from temperate to desert. Ethiopia is agrarian country where agriculture employs 84% of the working force and 48% of the countries' GDP. The climate of the country is driven by different local, regional and global weather systems. Tropical SST and wind features that persist during the Kiremt season and their changes are responsible to the performance of the Kiremt rain season. Teleconnections in the tropical Pacific Ocean are one of the prominent causes of wet and dry Kiremt seasons over Ethiopia. Winds that persist during this season like tropical easterly jet and the southwest monsoons are among the weather features that play role in the performance of the season. As the Kiremt season is the most important season in terms of agriculture and hydropower among other socio-economic sectors, it must be given due emphasis in understanding the weather systems that govern the dynamics of the Kiremt season.

This project aims to investigate the association of tropical sea surface temperatures and wind features with Kiremt rainfall over Ethiopia by investigating the typical tropical SST and wind patterns and their shifts and changes during wet and dry Kiremt seasons.

The project used both conventional and gridded model data sets for the study. Twenty four rainfall stations of 30-34 year rainfall observations will be used in the study. Gridded data sets of sea surface temperature and upper wind data of 34 year span from NCEP-NCAR are used in the project. The methods of analysis included graphical, correlation, and linear regression all used to investigate the association of tropical ocean sea surface temperature and wind features with Kiremt rainfall over Ethiopia.

The results showed that kiremt rainfall over the country responds to various extends to SST variability patterns in the tropical oceans and also to wind features, but there is good pattern association for prediction models. The prediction models using combined SST at various tropical ocean areas, wind at various levels performed reasonably well in prediction of seasonal extremes. The model developed for most of the homogeneous zones have percent correct between 53% to 60%.

Key word: Kiremt, SST, wind

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My family, brothers and sisters also take big credit for their financial and moral support. I cannot forget my friends who were supporting me in all aspects. Last but not least, my lovely wife, Helen Damte, is the key for my success, she carried all the burden when I was away for the study.

Dedication

I dedicate this project work to my late brother Tsegaye Hailu. The days are counted since you departed us to heaven, but the love will be cherished forever.

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Acronyms

ADBG	African Development Bank Group
CIA	Central Intelligence Agency
CSA	Central Statistical Agency
ICPAC	IGAD Climate Prediction and Application Center
ITCZ	Inter-Tropical Convergence Zone
MJO	Madden-Julian Oscillation
NCEP	National Center for Environmental Prediction
QBO	Quasibiennial Oscillation
SO	Southern Oscillation
SST	Sea Surface Temperature
TEJ	Tropical Easterly Jet
USD	United States Dollar

Chapter one: Background

1.1 Introduction

Climate is one of the most important resources of a country or region. All social and economic activities in the world are directly or indirectly depend on climate. Climate of a particular part of the globe is driven or controlled by the sun's relative position, moist air movements and thermodynamic changes, topography and other local factors like proximity to oceans, mountains and so on.

The economy of developing countries that depend on rain fed agriculture activities are the most vulnerable to climatic shifts, changes and variability. The production level of these economies depends on the availability of moisture for their crops and cattle to survive.

The economy of Ethiopia, which is one of the developing countries of Africa, depends on seasonal rainfall as an important climatic resource. Subsistence agriculture is the main employer of the population. It employs 85% of the working force and accounts up to 47% of the GDP.

The weather systems that persist for longer time and dominate the rainfall of Ethiopia include the ITCZ, the Southwest and Northeast Monsoons, TCs, TEJ, Subtropical highs namely Masccharin, St. Helena, Saharan, Azores and Arabian highs.

Specifically, the 'Kiremt' wet period occurring from June to September is the main rain season in most parts of the country and it is influenced by the South to North migration of the ITCZ, the Southwest Monsoon, TEJ, the subtropical high pressure systems and ENSO teleconnections.

The Kiremt season is the major rain season over Ethiopia where it covers up to 90% of the total rain of a year over some regions of the country. The southwestern, western, northwestern, northern, eastern and central parts of the country are the major regions that benefit from the Kiremt rains.

The south to north migration of the ITCZ, southwest monsoons and Tropical Ocean SSTs are considered as major drivers of the Kiremt rainfall over Ethiopia. El Nino episodes tend to suppress the Kiremt (June-September) rainfall and enhance Belg (February-May) rainfall. To the contrary, La Nina conditions over the eastern tropical Pacific Ocean tend to enhance Kiremt rainfall and depress Belg rainfall.

Wind features like easterlies and the south west monsoon winds, tropical easterly jet stream are typical features of the Kiremt season. Their strength and relative position is vital in determining the performance of the season.

1.2 Statement of the problem

Ethiopia is one of the underdeveloped countries of the world with subsistence agricultural practices adopted by 85% of the workforce of the country. In addition to the dependence of the agriculture sector on water, the energy sector also depends on water collected from rainfall. In general, the prediction models using combined SST at various tropical ocean areas, wind at various levels performed reasonably well in prediction of seasonal extremes.

The use of meteorological information and forecasts in the agriculture sector is crucial due to the heavy and risky investments made by farmers. The farming practice is subsistence and there is no reserve food at their disposal. If the rains fail, lifetime savings will be lost.

Kiremt rainfall is the focus of not only the farmers but it also attracts the attention of researchers. As a result, different researches have conducted on the variability and forecasting of Kiremt rainfall over Ethiopia (Degefu 1987, Segele 2005, Viste 2012). The various studies have also come up with statistical models that can be used to forecast Kiremt rainfall over Ethiopia. Unfortunately, most of the models are focused on SSTs only or winds at 850mb only. They didn't consider winds at 150mb levels which are the typical wind features during the Kiremt season.

Even though, the atmosphere is considered to have short memory, some wind features persist in the atmosphere for longer time. Among these, the TEJ is one of the northern summer events that persist during the Kiremt season. Its relative position and strength is associated with onset and cessation of the Kiremt season.

The statistical approaches depend on past observations of events like SST and wind. The observations are made both on surface (land and ocean) and upper air. Therefore, identification of the typical pattern of these features during different seasons and their linkage with the local weather and climate is an important input in the management of resources and decision making.

The availability of wind data at different levels of the atmosphere generated using satellite and model outputs make it very important to consider winds at various levels in the forecasting process.

1.3 Objective of the study

1.3.1 General Objective

The objective of this project work is to assess changes in tropical sea surface temperatures including ENSO conditions in the tropical Pacific Ocean together with atmospheric circulation processes which lead to enhanced or suppressed Kiremt rainfall over Ethiopia.

1.3.2 Specific objectives:

- ✓ Determine the typical SST patterns and modes in the tropical oceans which correspond to wet and dry conditions during Kiremt (June to September) season
- ✓ Determine the typical atmospheric circulation features including JJA monsoons and associated atmospheric circulation in Indian and Atlantic Oceans at 850mb, 700mb, 150mb levels during the Kiremt season
- ✓ Determine the predictive linkage of Tropical Sea surface temperature and atmospheric circulations with Kiremet rainfall in the country.

1.4 Literature review

The classification of rainfall regimes based on the rainfall received during the year is applied over Ethiopia by different authors and it has been indicated that there exist three rainfall regimes that receive rainfall once or twice a year of different magnitudes (Segele 2005, Korecha 2013). The seasons over Ethiopia are classified as ‘Belg’ (February – May), ‘Kiremt’ (June – September) and ‘Bega’ (October to January of the subsequent year) as they are locally referred. The classification of the seasons is different from the one used by the northern hemisphere regions.

According to Bekele (1993), the rainfall regimes have unimodal and bimodal rainfall distribution and the bimodal rainfall regions benefit from Belg (MAM) and Kiremt rainfall following the south-north migration of the ITCZ and its reverse migration. The western southwestern and northwestern part of the country (regime I in fig. 1) receive rainfall during Kiremt while the central eastern and northeastern parts of the country (regime II in fig. 1) receive rainfall during both short and long rain seasons (Belg and Kiremt). The southern and the southeastern parts of the country (regime III in fig. 1) have two distinct dry periods (December to February and June to August).

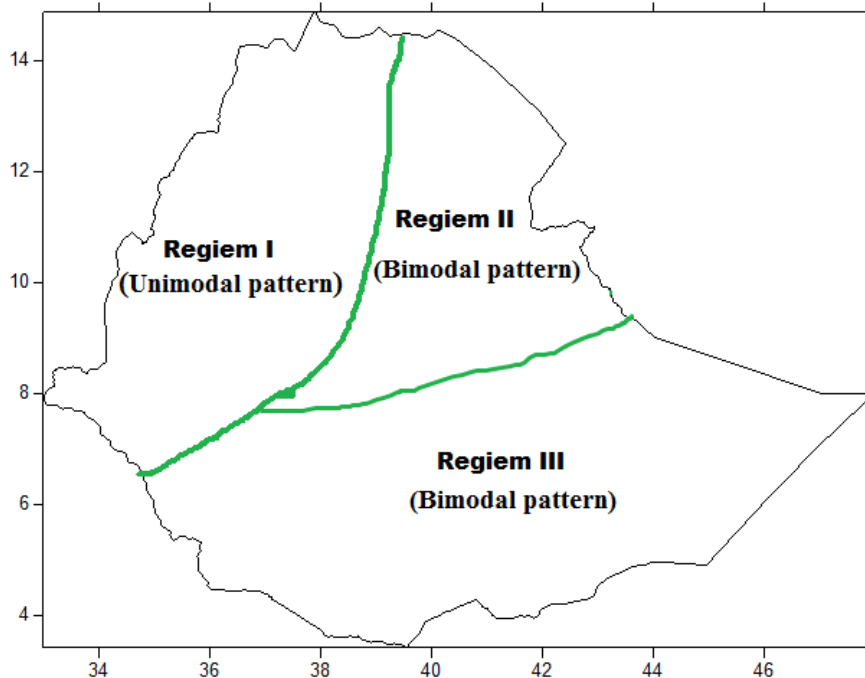


Fig. 1 Rainfall regimes over Ethiopia. (Adopted from Bekele 1993)

Gissila (2004) assessed that Kiremt rainfall over Ethiopia was thought to be difficult to predict because people were trying to analyze it without demarcating the regions that benefit from Kiremt rainfall. But he suggested and showed that by excluding or clustering areas in homogeneous zones and picking zones that benefit from Kiremt rainfall, the season's rainfall can be predicted.

The Kiremt season rainfall is mostly driven by the seasonal migration of the ITCZ and its performance is affected by ENSO and other teleconnections. Other regional and global systems that affect the Kiremt rainfall include TC, Southwest monsoons, Subtropical high pressure systems and Tropical easterly jet stream. For instance Shanko *et al* (1998) found out that the southwest Indian Ocean tropical cyclones tend to divert moisture coming from the Masccharine high and affect the Kiremt rainfall over Ethiopia.

The global teleconnections like tropical Pacific SST enhance or depresses the Kiremt and Belg rains over Ethiopia. The impact of ENSO on the Kiremt rainfall has been documented by various researchers (Nicolson 2000, Segele and Lamb 2005, Gissila *et al*, 2004, Diro *et al*, 2011) and they indicated that El Nino conditions tend to depress Kiremt rainfall over Ethiopia and suppress Belg rains. La Nina condition, to the contrary, enhances the Kiremt rains and depresses Belg rains. Recent research done by Zaroug *et al* 2014 indicated that an El Nino event followed by a La Nina event to have 67% of chance to cause extreme flooding in the upper catchment of

the Blue Nile. They also found out that El Nino events starting in April – June to cause a drought condition in the same region.

Shukla and Misra (1977) have also studied the association of SSTs on rainfall over Indian continent. They found that the Indian Ocean SST in July can be used for the prediction of monsoon rainfall over the Indian continent.

Mutemi et al, (2007) have investigated the linkage of Indian Ocean Dipole indices during the October – December season over east Africa and found out that some of the extreme rainfall events are linked to positive and negative IOD conditions. This indicates the investigation can be extended to other parts of the tropical oceans at specific region.

The monsoonal flow during the northern hemisphere spring studied by Okoola (1999) indicated that the wind patterns at various atmospheric levels show easterly alignment as in all the monsoonal regions. His results show that topography can also play key role in the frequency of lower troposphere westerlies.

TEJ is one of the northern summer weather phenomenon observed stretching from south Indian region up to eastern Africa. The maximum is observed between 50°-80° east and 15° north (Rao and Sirinivasa 2013) but they indicated that the trend of the TEJ is increasing recently and this is associated with decreased TCs. Even though the cause of the generation of TEJ is not well known, it is believed that the Tibetan high ground plays important role in the process. Segele and lamb (2005) found out that the onset and cessation of Kiremt rainfall is closely associated with the evolution and dissipation of TEJ.

1.5 Justification of the study

The backbone of the economy of Ethiopia is the agriculture sector. This sector employs 84% of the working force who practice subsistence agricultural activities. This sector is highly dependent on the rainfall which normally comes in the Kiremt (main rain season) and Belg (small rain season).

The main rain season is influenced by various local, regional and global weather systems including the influence of SST variability in the tropical oceans (Indian, Atlantic, Pacific oceans), Subtropical highs, the ITCZ, TEJ, QBO, SO, MJO, etc.

Among the weather systems that influence the rainfall over Ethiopia, SSTs over the tropical pacific and the Indian Ocean have been studied and the influences have been well documented by different authors. The propagation of ITCZ and the associated rainfall over Ethiopia is also well studied and documented.

The forecasts given for seasonal outlook are strongly based on SSTs. The associated wind and overall atmospheric circulation features on the Kiremt rainfall has not been given much emphasis. Wind features are believed to have association with Kiremt rainfall through dynamics in advection of moisture as well as clouds to the Kiremt rain benefiting areas of the country.

The availability of data, both surface and upper air, has improved substantially recently. Therefore, it is imperative to investigate the association of the tropical SSTs and wind features with Kiremt rainfall and avail the information for further use in forecasting and analysis of Kiremt season rainfall over Ethiopia.

1.6 Study Area

1.6.1 Location and topography

Ethiopia is located between 3°N - 15°N and 33°E - 48°E above the equator covering an area of 1.12 million km². The country shares boards with Kenya to the south, Somalia to south east, Djibouti to the east, South Sudan to the west, Sudan to the north west, Somalia to south east, Eritrea to the North.

The country is broadly divided into highland and lowland regions with altitude ranging from 4,620 m above sea level to 120 m below sea level. Three major physiographic regions are identified in Ethiopia : the North, Central, and South-western Highlands and surrounding Lowlands; the South-eastern Highlands and the surrounding Lowlands; and the Rift Valley that is an extension of the Great East African Rift Valley dividing the Highlands into two.

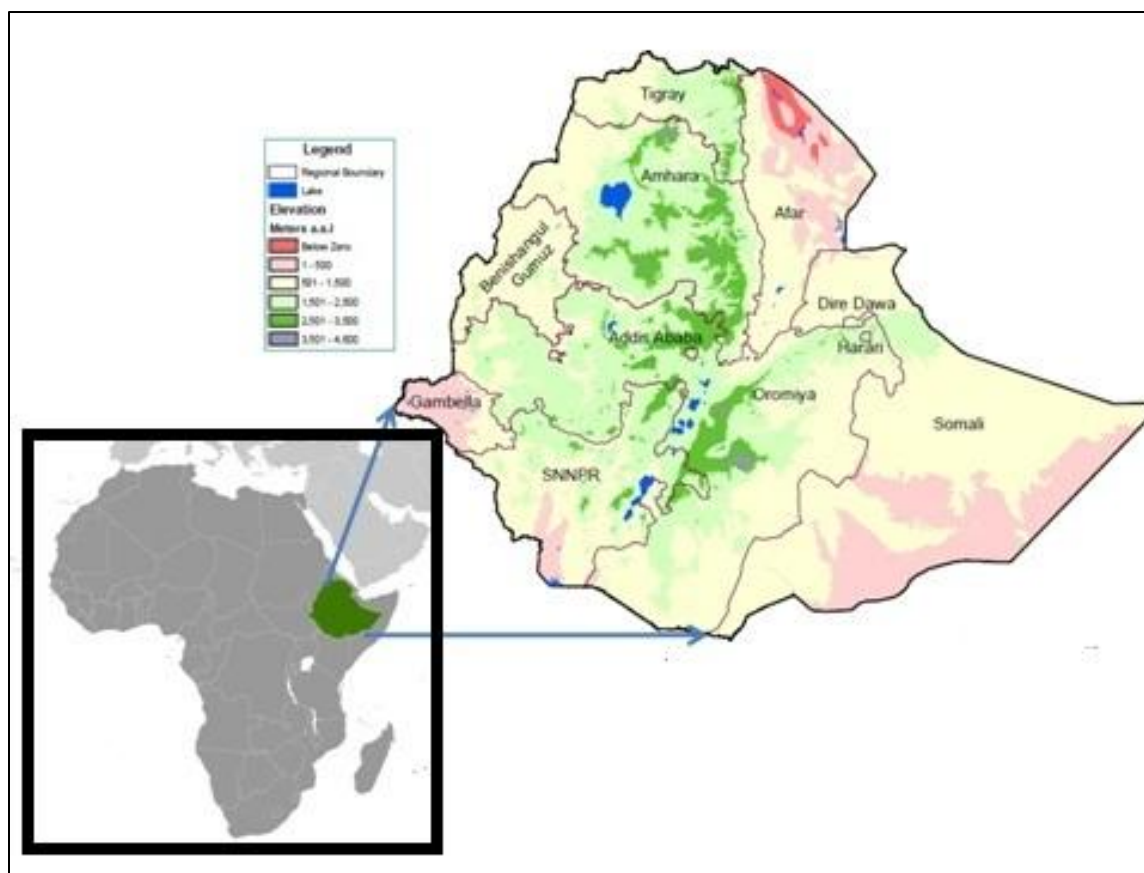


Fig. 2 Location of Ethiopia in the Greater Horn of Africa (GHA). (Source: <http://reliefweb.int/map/ethiopia/ethiopia-digital-elevation-model-dem-0>, accessed 22nd June 2014)

1.6.2 Climate

The presence of topographic variation and geographical location has made Ethiopia to possess various climatic zones. Based on the Copen climate classification, Ethiopia has 10 climate types (Gonfa 1996) ranging from the hot arid climate (Bwh) to warm temperate rainy climate (Cfb).

Rainfall is characterized by high temporal and spatial variability. Some regions like the south western part of the country enjoy plenty of rainfall while the south eastern and north eastern parts receive very small amount of rainfall over a year.

The climate of the country is controlled by various local, regional and global weather systems and factors. The major drivers of the climate system over Ethiopia include ITCZ, subtropical high pressure systems (St. Helena, Masccharin, Azores, Sahara and Arabian high), tropical cyclones (Indian and Pacific oceans) and tropical pacific ocean SST.

1.6.3 Population and Economy

Ethiopia is land of highest populous country in Africa next to Nigeria with a population of about 74 million with population growth rate of 2.6% annually (CSA 2007). But some sources like the CIA fact book put it to 94 million currently.

The economy of the country is based on agriculture. It employs 85% of the working force. But recent figures show that the economy is heading to agriculture lead industrialization and the country aims to shift to industry based economy by 2025.

Ethiopia's economy is growing in a fast way compared to the general growth rate of the African continent (ADB 2010). As indicated in fig. 3, the economy has been showing double digit growth for five consecutive years. According to the government of Ethiopia, the recent development is also encouraging with double digit although it is contested by the IMF and WB.

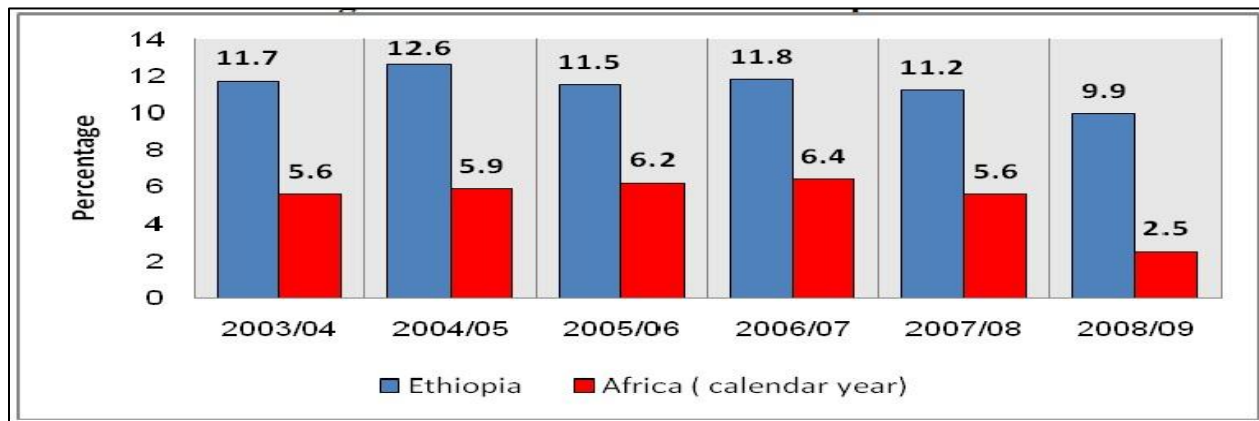


Fig. 3 Economic growth of Ethiopia compared to the whole African economic growth between 2003 and 2009)

1.7 Research question

The research question of the project is “How are tropical SST variability modes and atmospheric circulation features associated with Kiremt rainfall over Ethiopia?”

The research tends to answer this question by investigating wind, SST and rainfall linkage with Kiremt rainfall in Ethiopia.

Chapter 2: Data and Methodology

2.1 Data

The dataset used in the project was collected from two sources namely the National Meteorological Agency of Ethiopia and the National Center for Environmental Prediction (NCEP).

The first data set contains conventional monthly rainfall data spanning 34 years collected from NMA. The data has very small missing values which were filled using long term mean

The second data set used was gridded SST and wind data at 850mb, 500mb and 150mb levels from NCEP-NCAR data set downloaded from the IRI achieves (<http://iridl.ldeo.columbia.edu/SOURCES/NOAA/NCEP-NCAR/CDAS-1/MONTHLY/griblist.html>). The seasonal rainfall, SST and wind values were calculated using excel and GrADs software.

Table 1. Data required for the project

No.	Data	Data type	Number of stations	Starting year	End year	Total years
1	Rainfall	Monthly	24	1980	2013	34
2	SST	Monthly and seasonal average	gridded	1980	2013	34
3	Upper air wind and (850mb,500mb and 150mb)	Monthly and seasonal average	gridded	1980	2013	34

2.2 Methodology

2.2.1 Data quality control

Quality control on the rainfall data was done by using single mass curve to see the homogeneity of the data. The percentage of the missing data was assessed and stations with more than 10% missing data were not used in the analysis of the data. Outliers were also assessed by plotting the monthly time series and visually monitoring the range. When the exceptionally high/low values are observed, the year was investigated if it was a year where weather systems that customarily cause high/low seasonal rainfall were observed at that particular season.

2.2.2 Filling missing data

The monthly rainfall data from some stations had some missing records. Stations with more than 10% of missing data were rejected and those stations with less than 10% missing data were

considered for analysis. The missing data for the selected stations were filled using the long term arithmetic mean as indicated in equation 1.

$$\bar{X} = \frac{\sum_i^n x_i}{n} \dots\dots\dots 1$$

Where, \bar{X} is mean monthly station rainfall.

x is monthly rainfall and

n is number of months

2.2.3 Seasonal rainfall calculation

The rainfall data was first classified in to eight homogeneous regions which are currently being used by the NMA. Stations were clustered in to their corresponding homogeneous regions and the arithmetic mean was used to get the zone's mean seasonal rainfall.

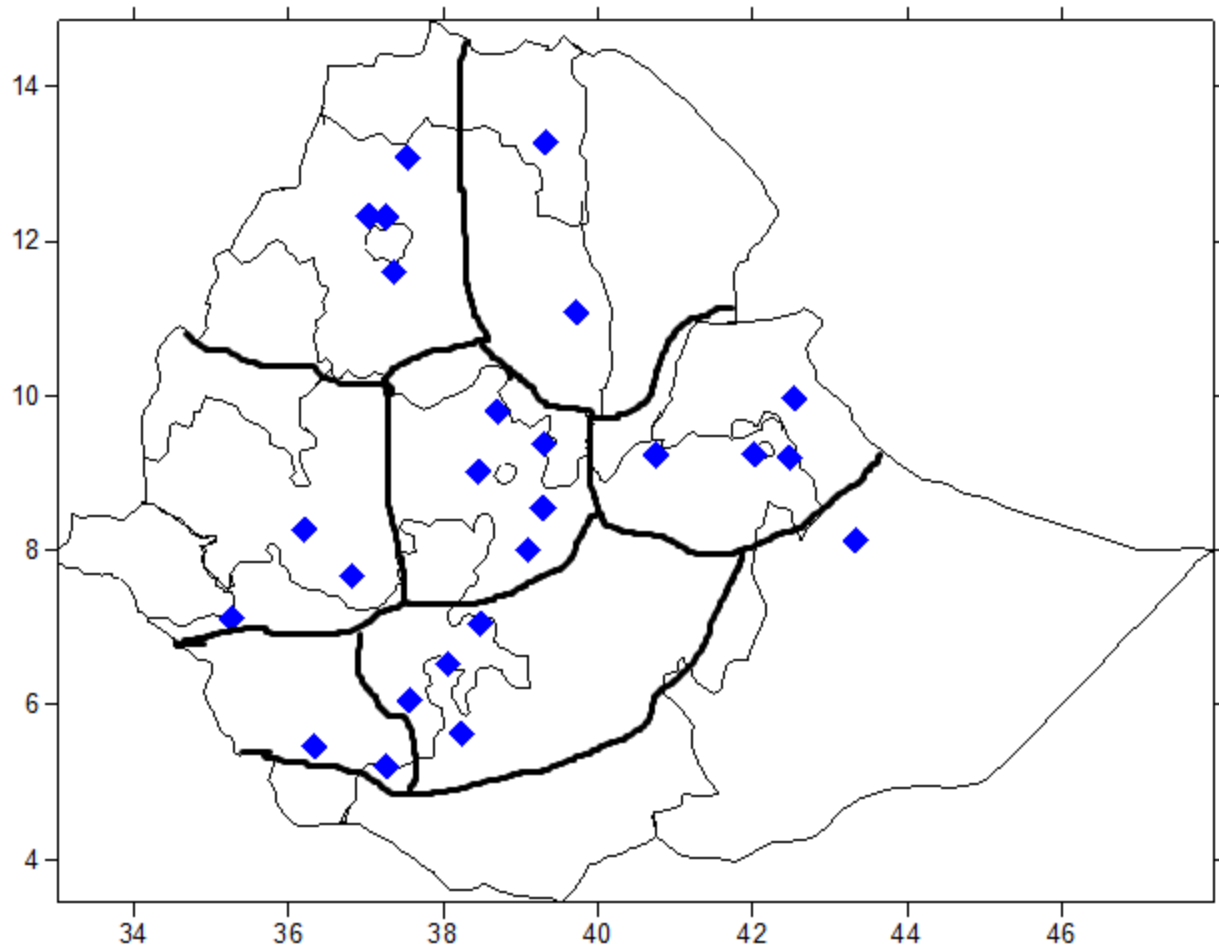


Fig. 4 Homogeneous rainfall zones currently used by the National Meteorological Agency and applied in the project (Adopted from: Koricha 2013)

2.2.4 Seasonal SST and wind feature mapping

The typical Kiremt tropical SST features were calculated and mapped by calculating monthly SSTs of June, July, August and September using GrADS software. Scripts were coded to calculate and plot seasonal anomaly SSTs patterns. The same procedure was followed to come up with the typical Kiremt wind feature in the tropics.

2.3 Correlation between zonal Kiremt rainfall and tropical SSTs

Areal correlation between zonal Kiremt rainfall which is point data and May SST in the whole SST grid was then calculated using FORTRAN and GrADS. The FORTRAN program was used to change the Kiremt seasonal rainfall series form ASCII format to binary form and the binary Kiremt rainfall values were used to calculate the correlation with SST grid point and map out the

correlation using grads. The May SSTs with in the tropics with correlation greater than 0.5 were then extracted for regression analysis.

For the wind, areas which are visibly significant and persist during the Kiremt season were identified and the May mean wind values were extracted from the gridded u and v wind dataset and used in the development of the regression model.

2.3.1 Variance analysis

Variance analysis between station Kiremt rainfall and tropical SST and wind at different levels was performed using Climate Predictability and Tool (CPT) software developed by the International Research Institute (IRI).

2.3.2 Selection of SST and wind features for the development of MVRM

Three steps were followed to select areas of the SST and wind features to develop MVRM. In the first step, specifically for SSTs, areas which have higher correlation with zonal Kiremt rainfall were considered. Secondly, composite analysis of wet and dry years was made and areas that show visible anomalies were also considered. Thirdly, specifically for winds, wind features which are permanent during the Kiremt season were considered.

After the selection of SST areas and wind features, a script was coded to extract areal average of May SST or wind speed of grid points within the selected regions.

2.3.3 Multivariate regression model development

The development of MVRM was performed using SYSTAT version 8.0 software. In this process Kiremt rainfall was used as predictand and SST and wind speed values of the selected regions ranging from 12 - 15 were used as predictors. Step wise forward method was applied to select the predictors and values combination of predictors with combined R^2 values more than 0.5 and p-values of 0.005 were selected.

The regression model developed is the form:

$$X = \alpha P_1 + \beta P_2 + \gamma P_3 + \dots$$

Where X is predicted value

P1, P2, P3,are predictors

α , β , γ are coefficients

Chapter three: Results.

3.1 Homogeneity test of the rainfall data

The homogeneity test conducted on the seasonal rainfall data at eight homogeneous zones resulted that all the rainfall data was homogeneous.

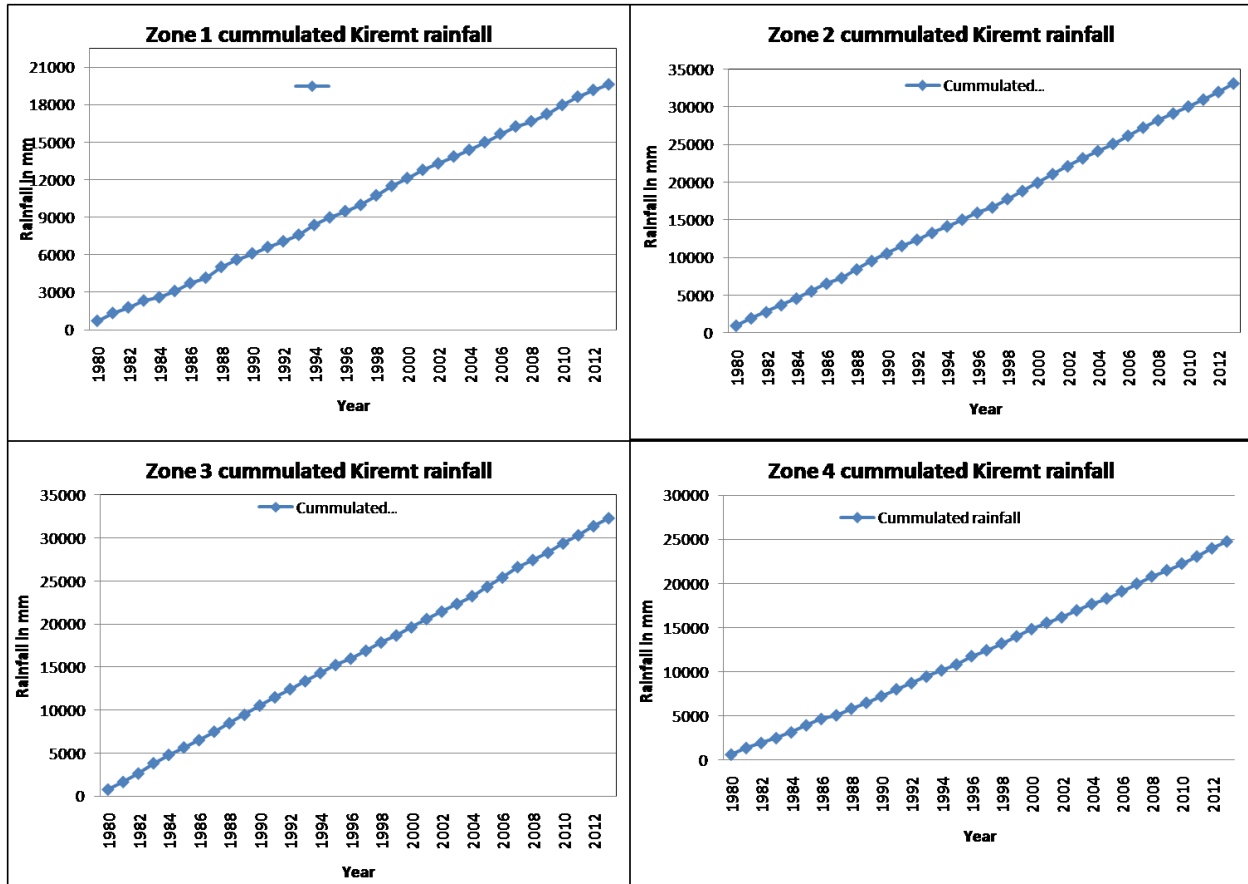


Fig. 5 Single mass curve result of homogeneity test for Zone 1, Zone 2, Zone 3 and Zone 4.

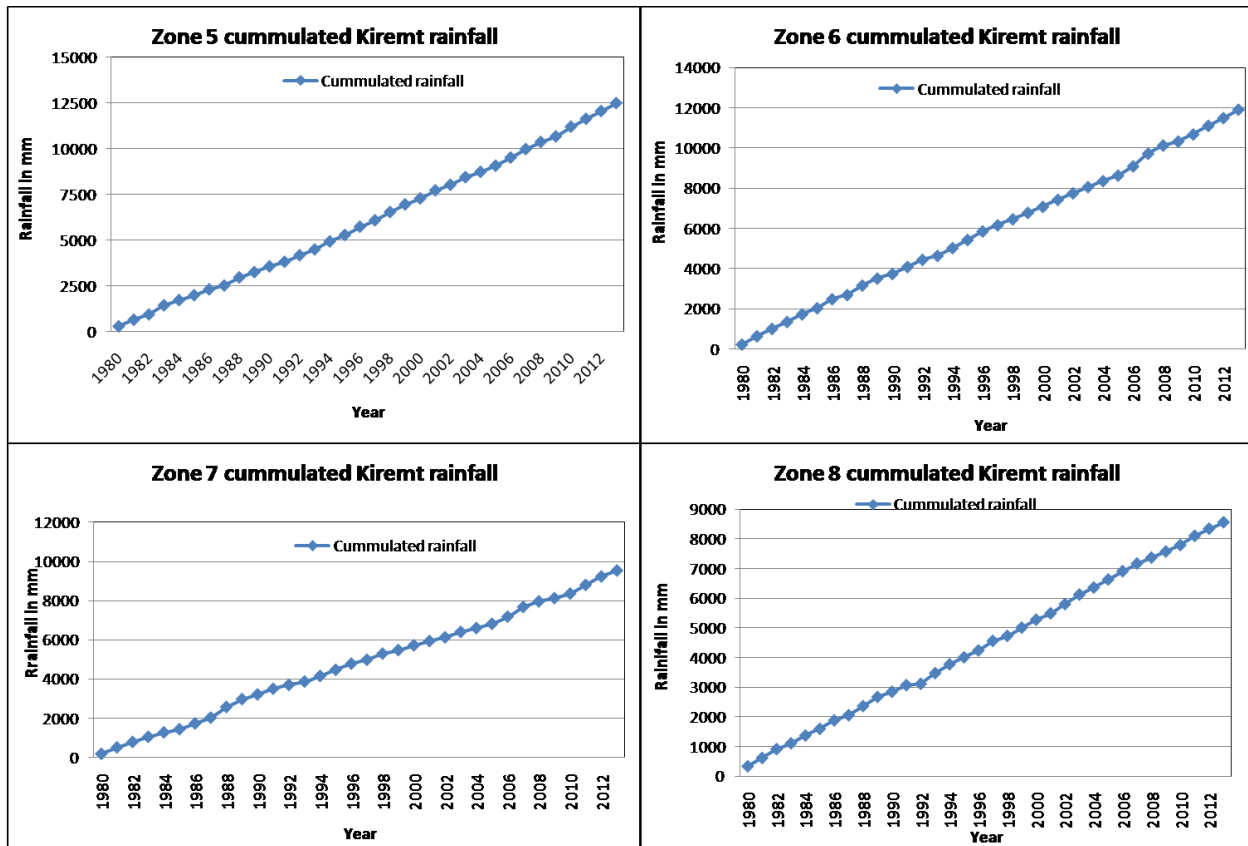


Fig. 6 Single mass curve results of homogeneity test for Zone 5, Zone 6, Zone 7 and Zone 8

3.2 Contribution of Kiremt rainfall to the annual rainfall

Kiremt rainfall is the main rain season over much parts of the country. Regions like the western, central, North West and northern parts of the country receive from 50% to 90% of the annual rainfall during this season. The southern and southeastern parts of the country receive the larger amount of their rainfall during Belg (February to May).

Table 2 summarizes the contribution of Kiremt rainfall to the annual rainfall of each homogeneous rainfall zones.

Table 2. Contribution of Kiremt rainfall to the annual rainfall

Zone	Mean Kiremt rainfall (in mm)	Mean annual rainfall (in mm)	% of Kiremt rainfall
Zone1	576	810	71
Zone2	971	1205	80
Zone3	905	1535	54
Zone4	727	992	73
Zone5	367	726	51
Zone6	350	923	38
Zone7	280	1073	27
Zone8	251	580	43

3.3 Temporal and Spatial Rainfall distribution over Ethiopia

3.3.1 Temporal distribution of monthly rainfall over Ethiopia

The temporal distribution of annual rainfall over Ethiopia as can be seen from the figures below has unimodal and bimodal distribution in the various zones used in the study. Each zone is discussed below.

3.3.1.1 Zone one

Zone 1 represents parts of the country in the north eastern region. This zone has bimodal rainfall distribution. The major rainfall occurs during the Kiremt season and the highest in terms of amount is received during July and August.

As the graph in the panel (a) of fig. 7 shows, this zone also receives rainfall between March and May but the amount received is very small compared to the rainfall received during Kiremt.

The mean annual rainfall in this zone is 810mm out of which 71% is received during the Kiremt season. In some years, the Kiremt rainfall accounts up to 95% of the annual rainfall.

3.3.1.2 Zone two

Zone two represents the North West parts of the country. This zone has unimodal rainfall distribution. The region receives much of its rainfall during the Kiremt season. Panel (b) of fig. 7 indicates that the highest amount of the Kiremt rainfall is received in July and August.

The annual rainfall in this zone is 1205mm out of which 80% is collected during the Kiremt season.

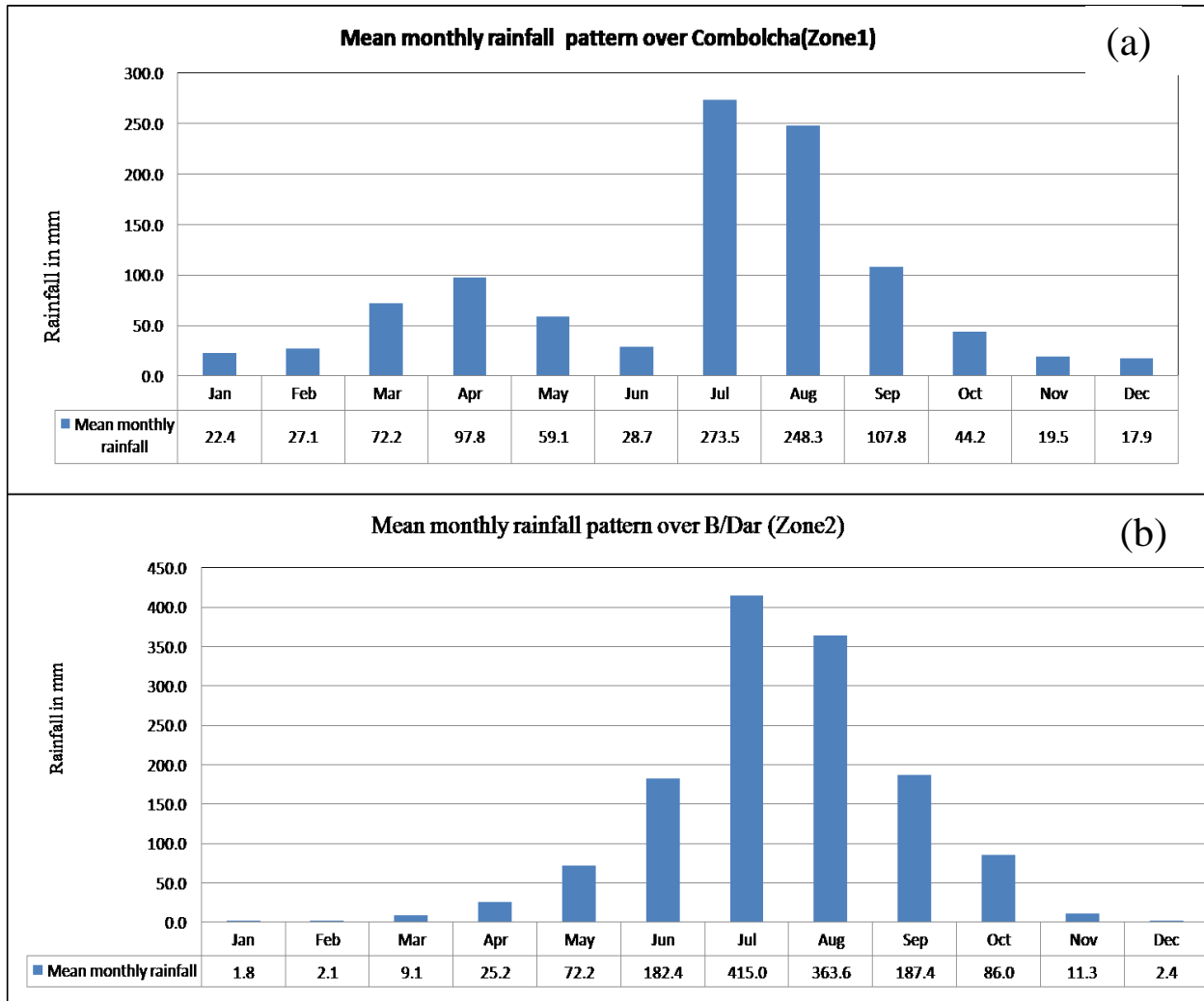


Fig. 7 Monthly rainfall temporal distribution of Zone 1 and Zone 2

3.3.1.3 Zone three

This zone covers the western parts of the country and is one of rainfall abundant regions in the country. The annual mean rainfall exceeds 1500mm.

Contrary to the other homogeneous rainfall zones which receive rainfall in seasonal basis, panel (a) of fig. 8 shows, this zone receives rainfall almost throughout the year.

Even though the rainfall in this region occurs in this region throughout the year, the Kiremt season is the major rainfall season. The season contributes 55% to the annual rainfall. At some anomalous years, the Kiremt season's rainfall contribution can reach as high as 68% and as low as 39% of the annual rainfall.

3.3.1.4 Zone four

Zone four which is found in the central parts of the country is somehow a bimodal rainfall zone. The small rainfall season locally called ‘Bega’ starts in March and extends up to mid may. The Kiremt season starts early June. In some years the Kiremt rain continuous from the Belg rain without interruption and results in excess accumulation of water and sometimes disrupts agricultural activities. This is evident in panel (b) of fig. 8.

The mean annual rainfall in this region is 993mm and the Kiremt rainfall takes the lion share of the annual rainfall, 73%.

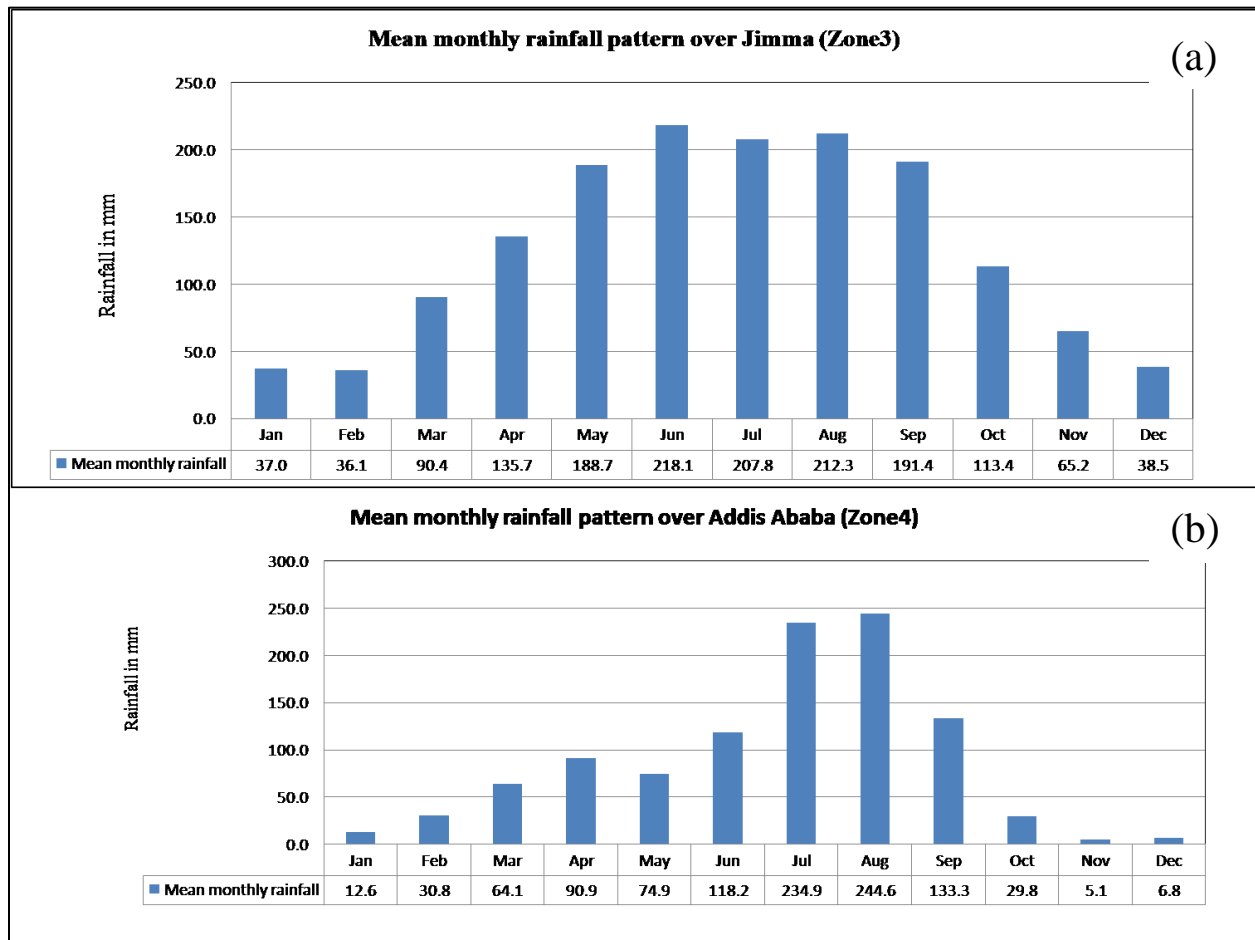


Fig. 8 Monthly temporal rainfall distribution of Zone 3 and Zone 4

3.3.1.5 Zone five

Zone five rainfall region is found in the eastern part of the country. As can be seen from panel (a) of fig. 9, this region benefits from both Belg (March-May) and Kiremt seasons in a comparable proportion.

The annual mean rainfall in this region is 725mm and both rainfall seasons contribute equally to the annual rainfall.

The peak rainfall in Belg season is received during April whom the peak in the Kiremt season in received in August.

3.3.1.6 Zone six

Zone six which covers the southern parts of the country enjoys rainfall up to eight months but the amount of rainfall collected in this zone is not much in relation to the amount of months rainfall is received. It is also visible from panel (b) of fig. 9 that November, December, January and February are the months where the smallest amount of rainfall is received.

The annual mean rainfall in this zone is 923mm and most of the rainfall is distributed in to eight months covering both Belg and Kiremt seasons.

The Kiremt season in this zone accounts for about 38% of the annual rainfall while the remaining portion of the annual rainfall is contributed by the Belg season and the months which locally are called Bega (October-February).

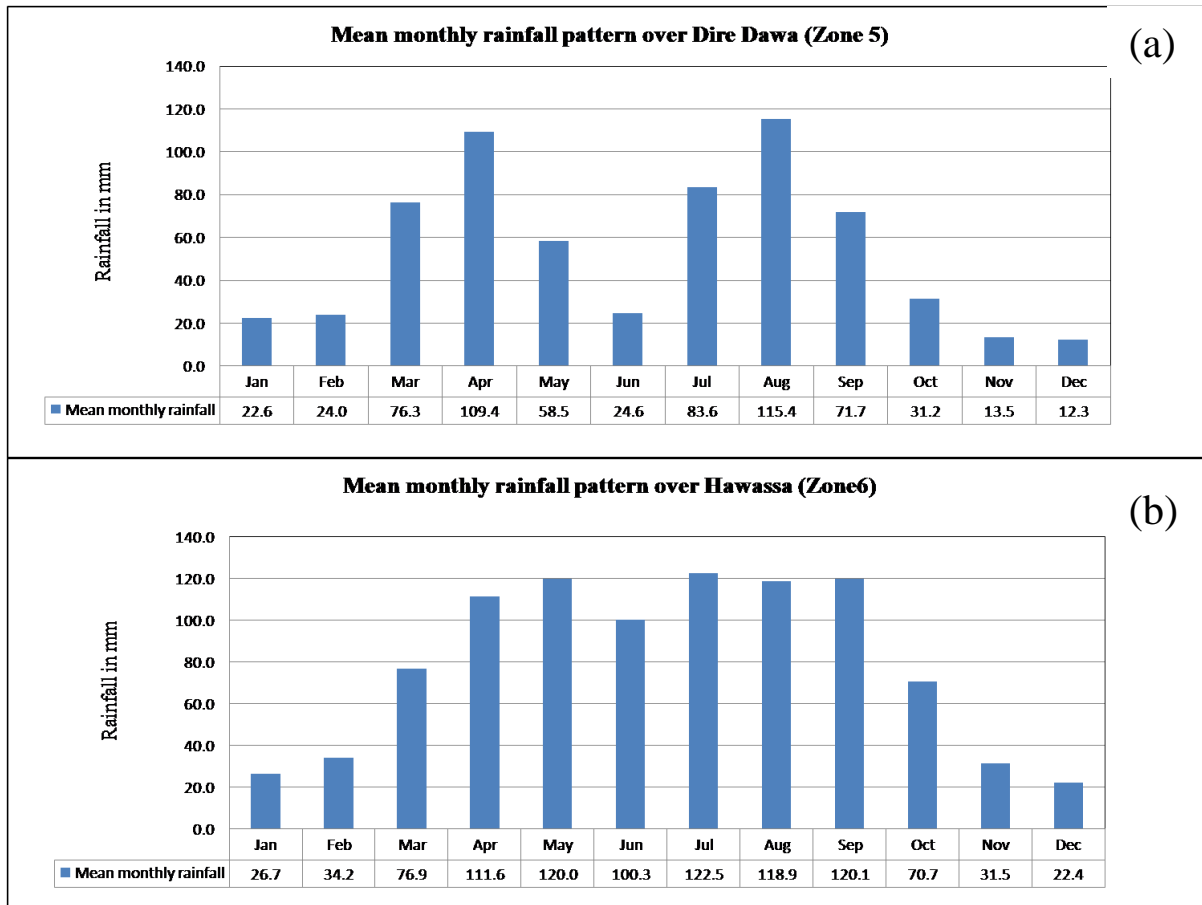


Fig. 9 Monthly temporal rainfall distribution of (a) Zone 5 and (b) Zone 6

3.3.1.7 Zone seven

Zone seven which is found in the south western parts of the country is one of the zones that receives a lot of rainfall. This zone receives 1073mm of annual rainfall and the majority of the annual rainfall is received during Belg and Bega seasons. This is indicated in the pattern in panel (a) of fig.10. The figure also shows that Kiremt season is comparatively low rainfall season.

The contribution of the Kiremt season to the annual rainfall is only 27% and this is the lowest contribution compared with the contribution of Kiremt rainfall in the other zones.

3.3.1.8 Zone eight

Zone eight is a bimodal rainfall zone which covers the southeastern and southern parts of the country. The pattern of the monthly rainfall in panel (b) of fig.10 shows that this zone receives rainfall during Belg and Kiremt. The contribution of the Kiremt rainfall to the annual rainfall is about 40%. The Belg season accounts most parts of the annual rainfall.

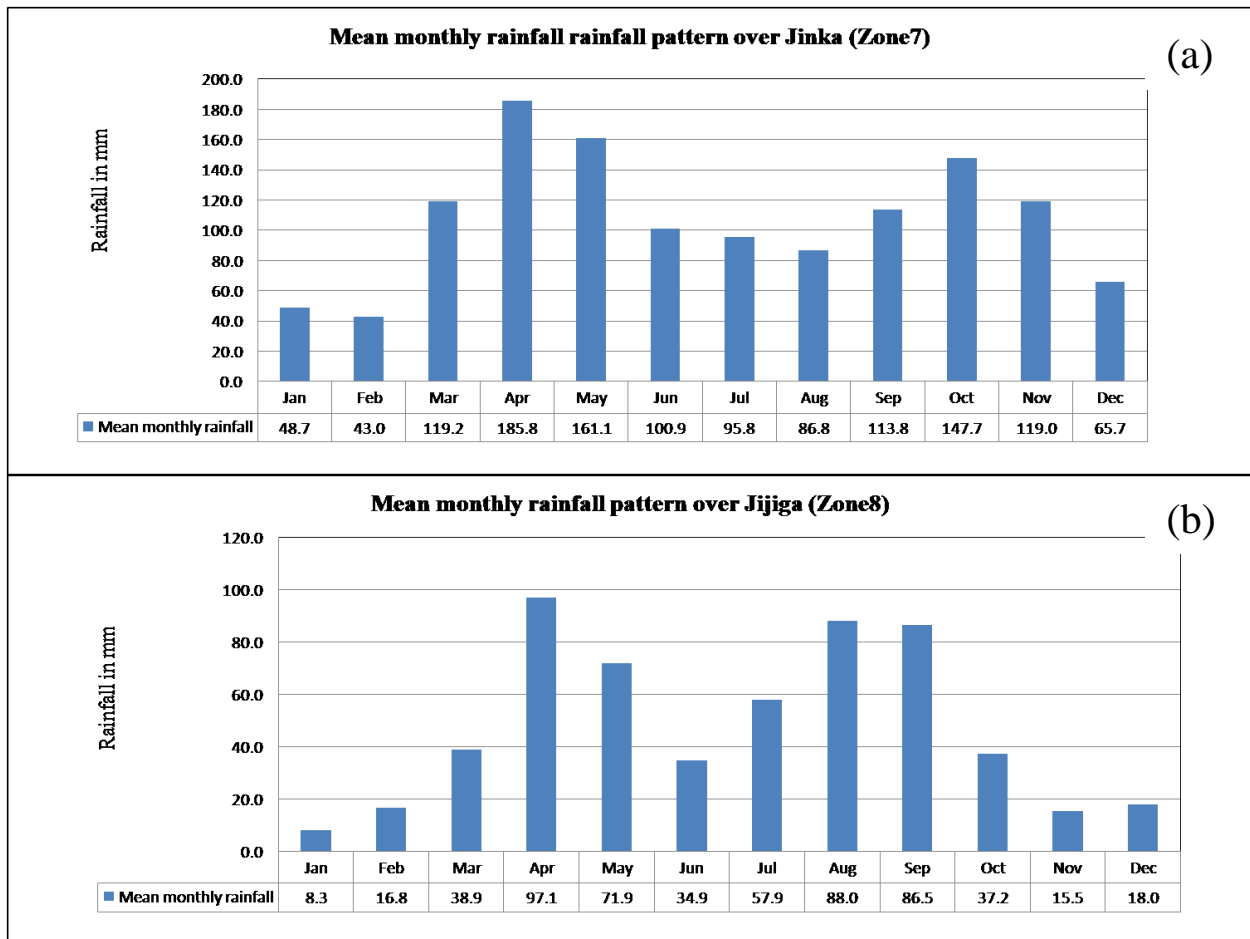


Fig. 10 Monthly temporal rainfall distribution of Zone 7 and Zone 8

3.3.2 Spatial distribution of annual over Ethiopia

3.3.2.1 Annual rainfall distribution over Ethiopia

The annual rainfall distribution over Ethiopia tends to reveal the seasonal migration of the ITCZ. The ITCZ bears rainfall over Ethiopia in both its zonal and meridional arms. The zonal arm of the ITCZ favors the northern parts of the country and relatively its migration is faster than that of the meridional arm.

The meridional arm of the ITCZ benefits the western and south western parts of the country and the also relatively stays longer than the zonal arm. This is witnessed in the higher annual rainfall in the southwestern and western parts of the country.

The distribution of the annual rainfall as depicted in fig. 11 is higher in the western half of the country compared to the eastern half of the country. This is a result of the longer stay of the meridional arm of the ITCZ over the western parts of the country.

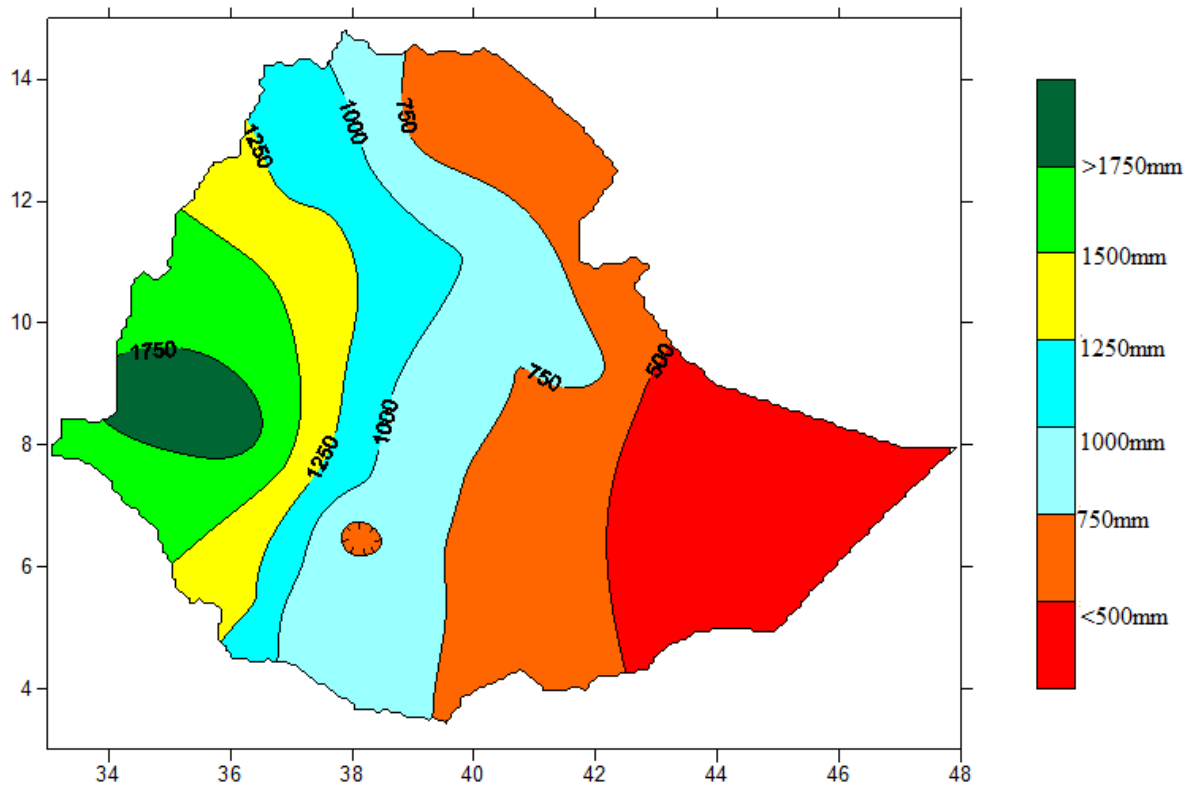


Fig. 11 Annual rainfall distribution over Ethiopia (1980 - 2013 mean)

The eastern and southeastern low lands of the country receive small amount of rainfall throughout the year. In fact, the homogeneous rainfall region depicted by zone3 represents the southern and south eastern parts of the country. This zone receives rainfall twice a year between

March to May and July through October. But the amount of rainfall received is small and erratic.

3.3.2.2 Kiremt rainfall distribution over Ethiopia

Kiremt rainfall distribution over the country based on the 24 rainfall stations used in the study indicates that the rainfall distribution during Kiremt season is almost similar like that of the annual rainfall distribution.

Fig. 12 indicates that Kiremt rainfall amount in the western and north western parts of the country is higher. The southern and south eastern parts of the country receive no small or no rainfall during this season. The southern, central and eastern highlands of the country receive small amount rainfall during this season.

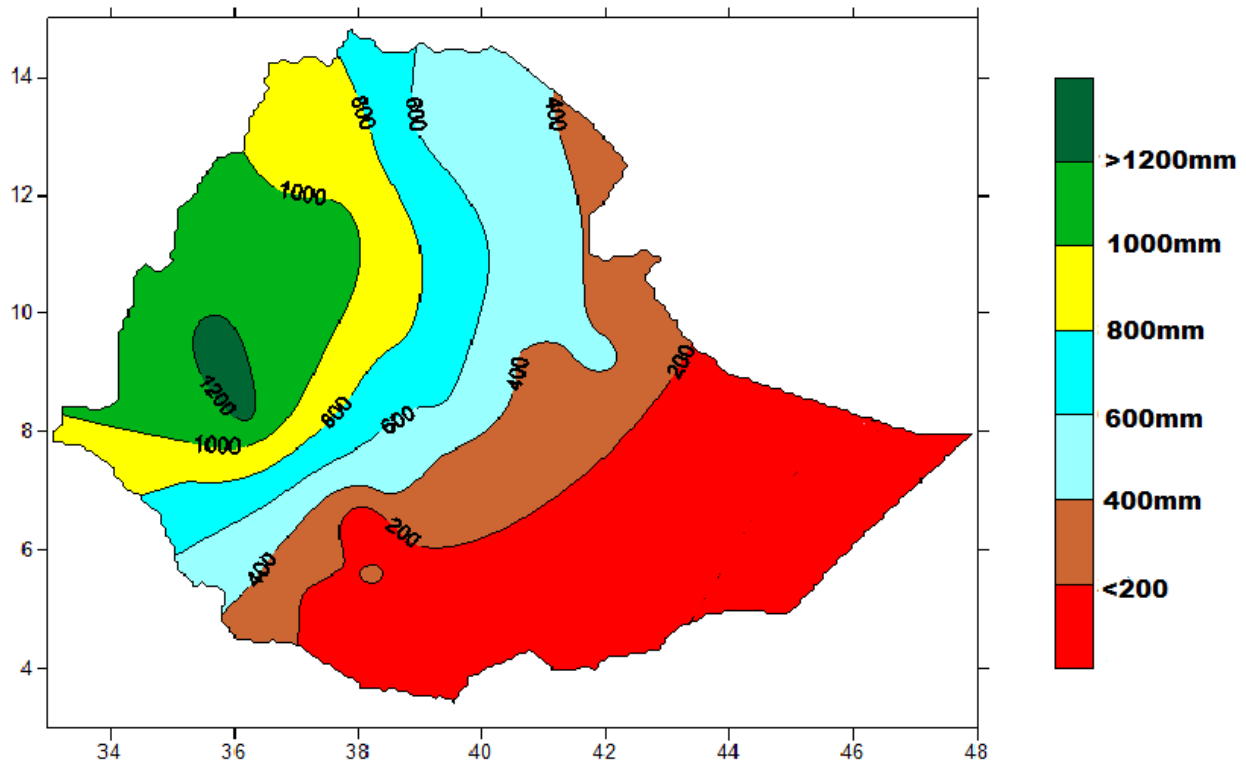


Fig. 12 Kiremt season rainfall spatial distribution over Ethiopia (1980 - 2013 mean)

The major driver of the Kiremt rainfall is the ITCZ as indicated by different researcher, the onset of the season starts in the southwestern parts of the country around early June and propagates to north and eastwards and covers Kiremt rainfall benefiting areas around mid July. The cessation follows the same root in reverse way.

3.4 Typical characteristics of tropical SSTs during the Kiremt season

The seasonal SST analysis depicted in fig. 13 indicates that the SSTs in the tropics have zonal distribution of temperature in most areas of the oceans. Meridional temperature distributions are observed over southwest Atlantic and Pacific Oceans around the southern tips of South America and Africa. The meridional SST distribution increases in size as the season progresses and during September it reaches its maximum extension.

The SSTs in the tropics range from 16°C to 30°C. The relatively cooler SSTs with temperatures around 16 °C are found within the southeastern parts of the Pacific and Atlantic Oceans around western tips of Southern parts of Africa and South America in the southern hemisphere where the meridional SST temperature distribution is observed.

The warmest SSTs are found in the northern Indian Ocean, Northwest Pacific and equatorial Atlantic Ocean. The temperature in these areas range from 26 °C to 30 °C in all months of the Kiremt season. These patterns of tropical SSTs are shown in fig.13.

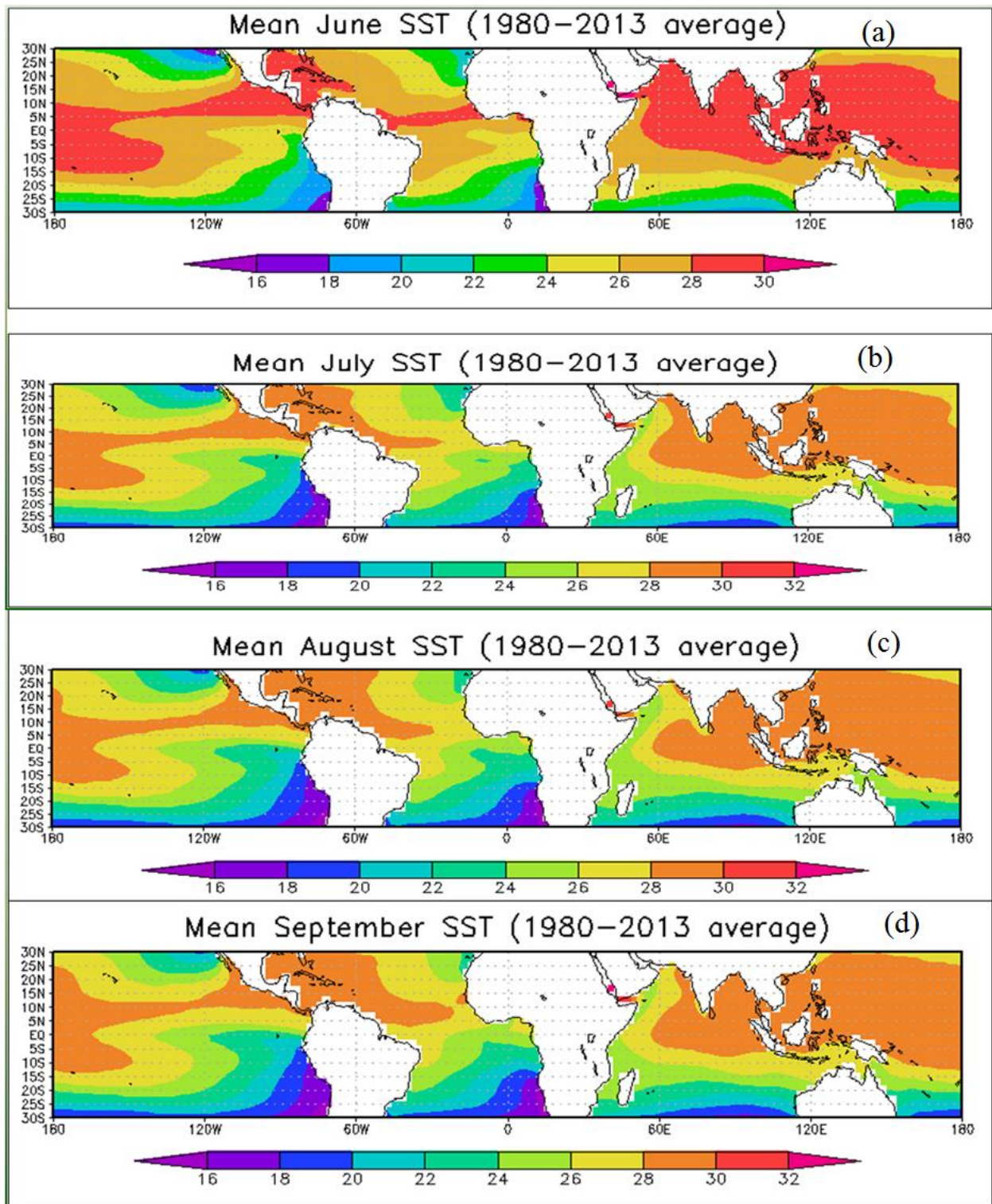


Fig. 13 Mean spatial distribution of tropical SSTs during (a) June, (b) July, (c) August and (d) September (1980 – 2013 mean)

3.5 SST changes during selected anomalous Kiremt seasons

Anomaly analysis in the SSTs during wet and dry Kiremt seasons indicated that the SSTs to have distinct changes in their patterns from their normal pattern. They either get colder or warmer than their long term mean temperature or show changes in their normal patterns.

During the 1984, Belg and the subsequent Kiremt season failed and this condition caused the most catastrophic famine in the country's history. Areas in the northeast, northwest and northern parts of the country were heavily affected by the drought.

The SST anomaly assessment during the 1984 Kiremt season, as can be seen from fig. 14, the eastern parts of the south Atlantic Ocean were warmer from the normal condition by up to 2 °C.

Cooler than normal SSTs were also observed in the western Indian Ocean that persisted for the most of the months during the 1984 Kiremt season. But the cooler than normal SST condition which was observed in the eastern equatorial Pacific Ocean dissipated starting from July and completely vanished in August.

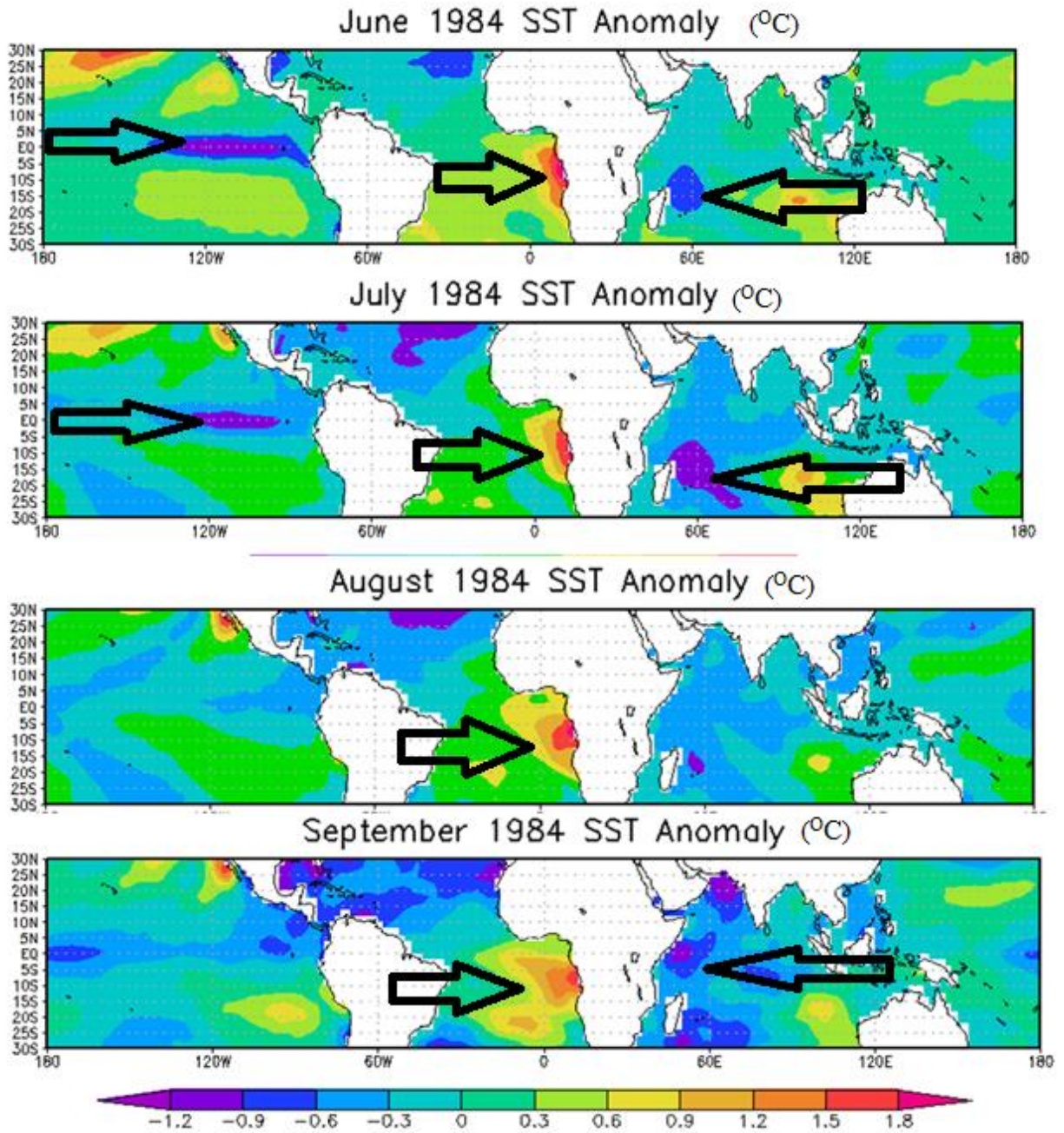


Fig. 14 Monthly anomalies observed during the 1984 severe dry Kiremt season over Ethiopia (a) June, (b) July, (c) August and (d) September.

During the 1987 Kiremt, dry condition was observed in seven homogeneous rainfall zones out of the eight homogeneous rainfall zones. The sea surface temperatures at this period also showed distinct anomalies. Fig. 14 indicates the anomalies observed in the tropical SSTs during Kiremt months in 1987. It is obviously visible that the warmer than normal SSTs were observed in most parts of central equatorial Pacific Ocean. In addition, colder than normal SSTs were observed in the southwestern Pacific Ocean and at southeastern Atlantic Ocean.

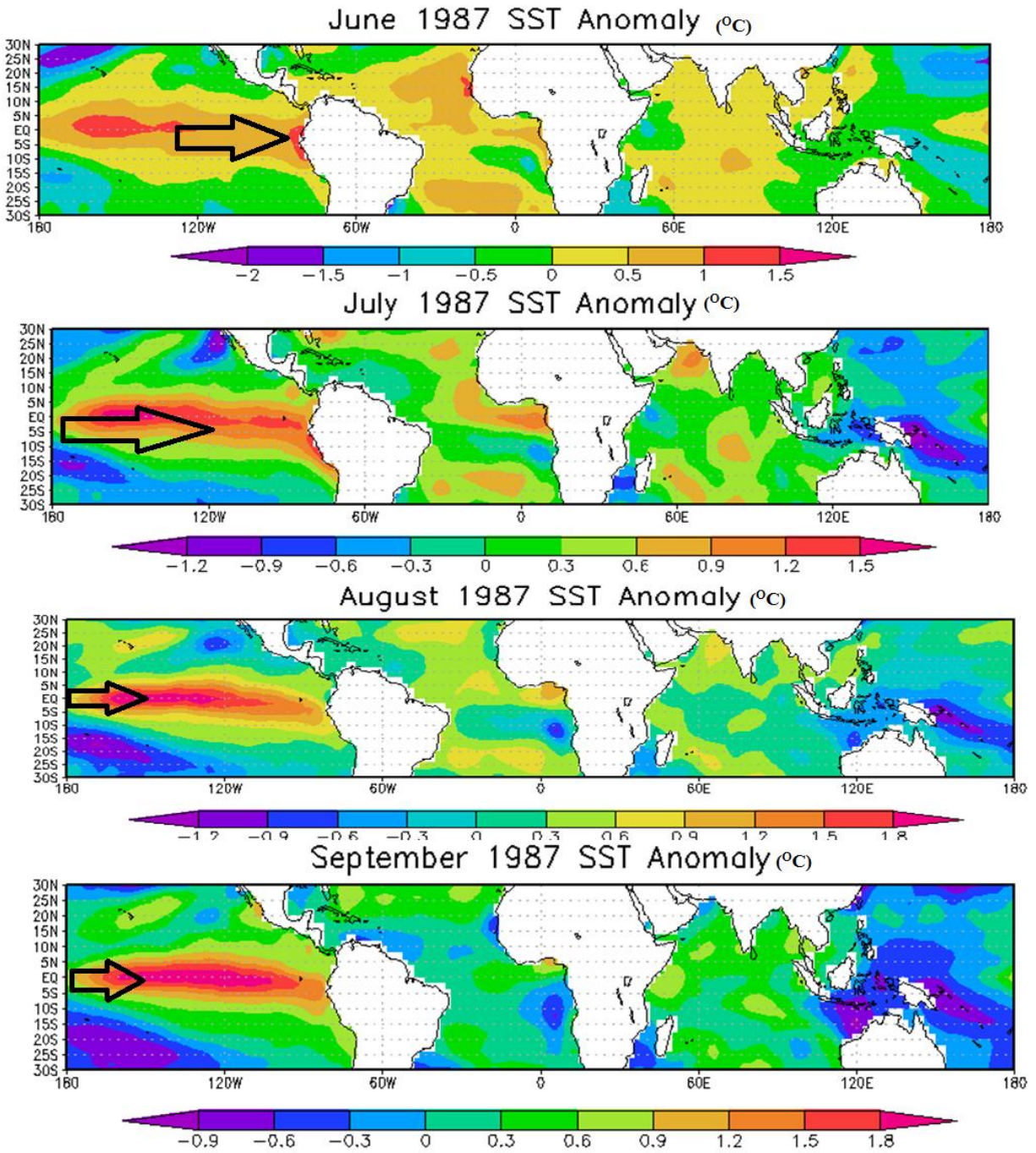


Fig. 15 Monthly SST anomalies observed during the 1987 dry Kiremt season over Ethiopia (a) June, (b) July, (c) August and (d) September.

During the 1999 wet year case, significant cold SST anomalies between 1°C and 1.5°C were observed over the eastern, central and northeast Pacific Ocean in June. The eastern Atlantic was warmer but in very small magnitude (less than 0.6°C). The anomalies observed during Kiremt 1999 are indicated in fig. 16 in four panels in monthly basis.

As indicated in panel (c) of fig. 16, the cooler SSTs in the central and northern Pacific Ocean persisted up to August but became around the normal SST level at the end of the Kiremt season.

During the same time, the parts of the eastern Atlantic Ocean progressively became warmer than their normal SST level through the months.

The wet 1999 Kiremt season covered most parts of the country and Kiremt rainfall benefiting areas enjoyed rainfall which is above their normal seasonal rainfall margin.

The above mentioned anomalous Kiremt rainfall years corresponded to the changes in the SSTs at different parts of the ocean. This indicates that changes in the SSTs in the tropical oceans are associated with changes in the Kiremt rainfall in the country.

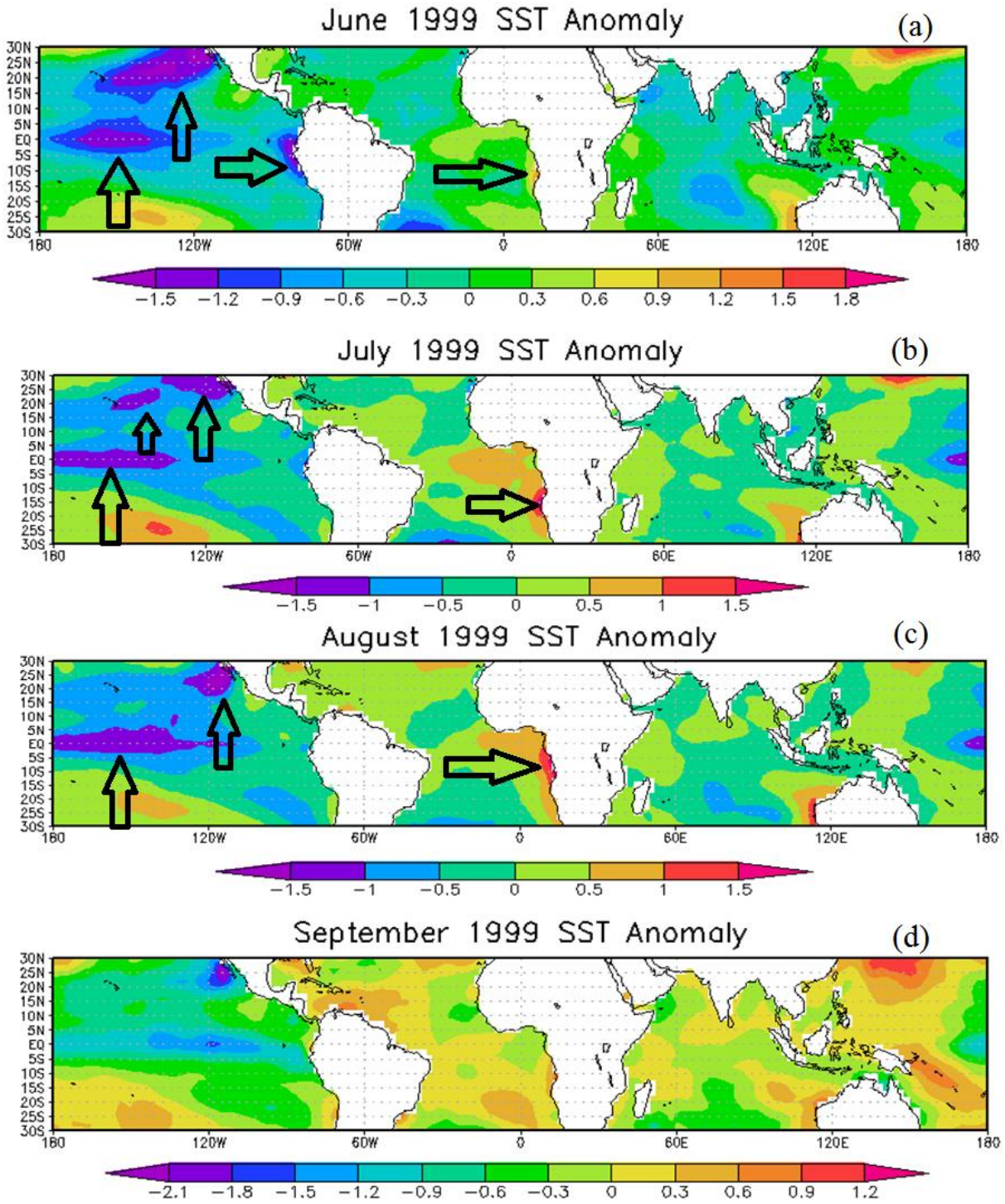


Fig. 16 Monthly tropical SST anomalies observed (a) June, (b) July (c) August and (d) September of 1999 Kiremt.

3.6 Correlation of SST with Zonal rainfall

The correlation analysis of zonal Kiremt rainfall with SST grid points shows different correlation values for different zones. Some zones show strong correlation both positive and negative. The most significant tropical ocean parts that show strong correlation with zonal Kiremt rainfall include equatorial eastern, western and central Pacific, central and south eastern Atlantic and most part of the Indian Ocean. Fig.17 shows the correlation of rainfall over the various zones with SSTs during the month of may.

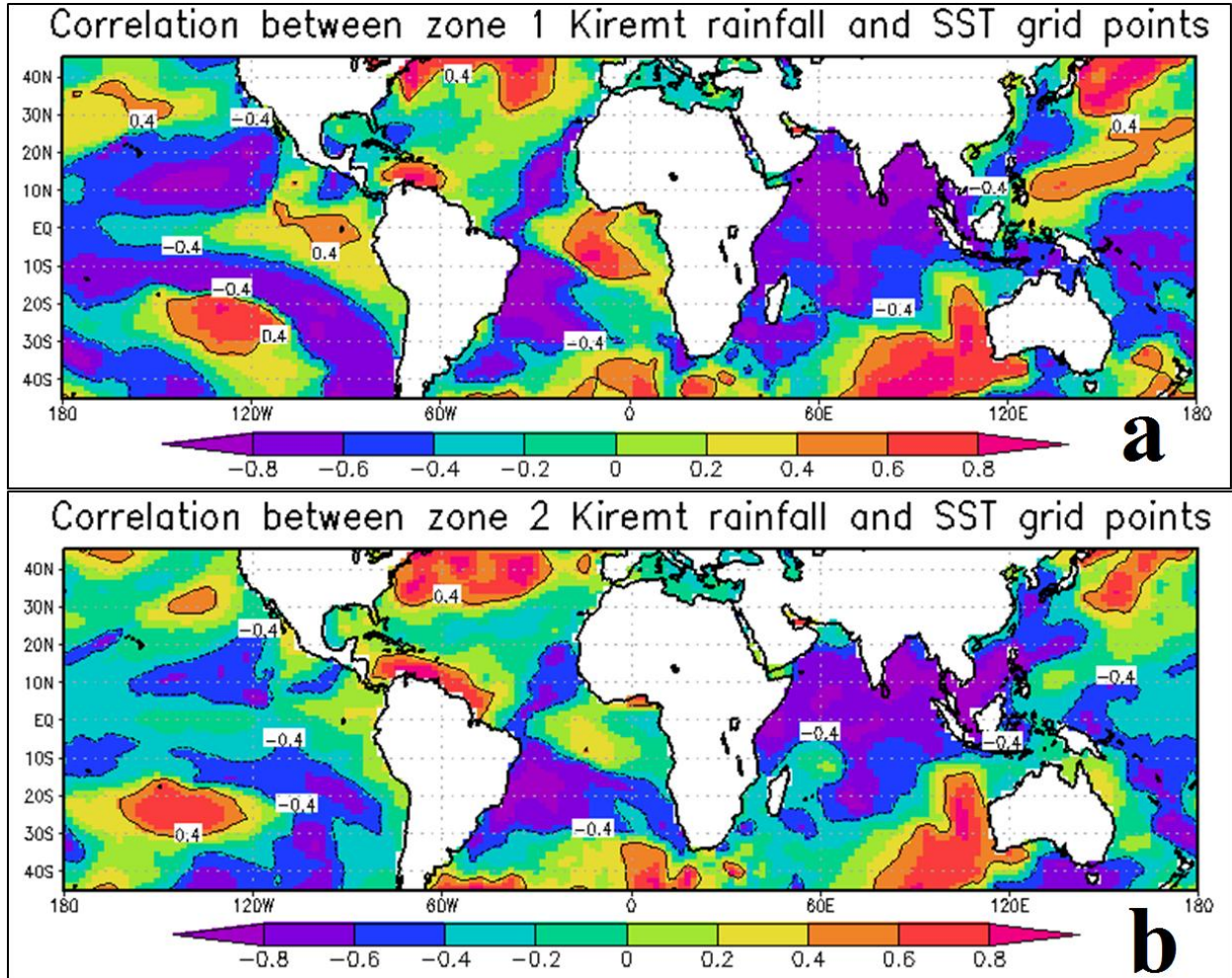


Fig. 17 Correlation map of (a) Zone 1 (b) Zone 2 Kiremt rainfall with May SSTs

Fig. 17 indicates that Zone 1 and Zone 2 have similar correlation pattern with SST in the tropics. The correlation is stronger over most parts of the Indian Ocean. Patches of strong positive and negative correlations are also observed in the Atlantic and Pacific oceans.

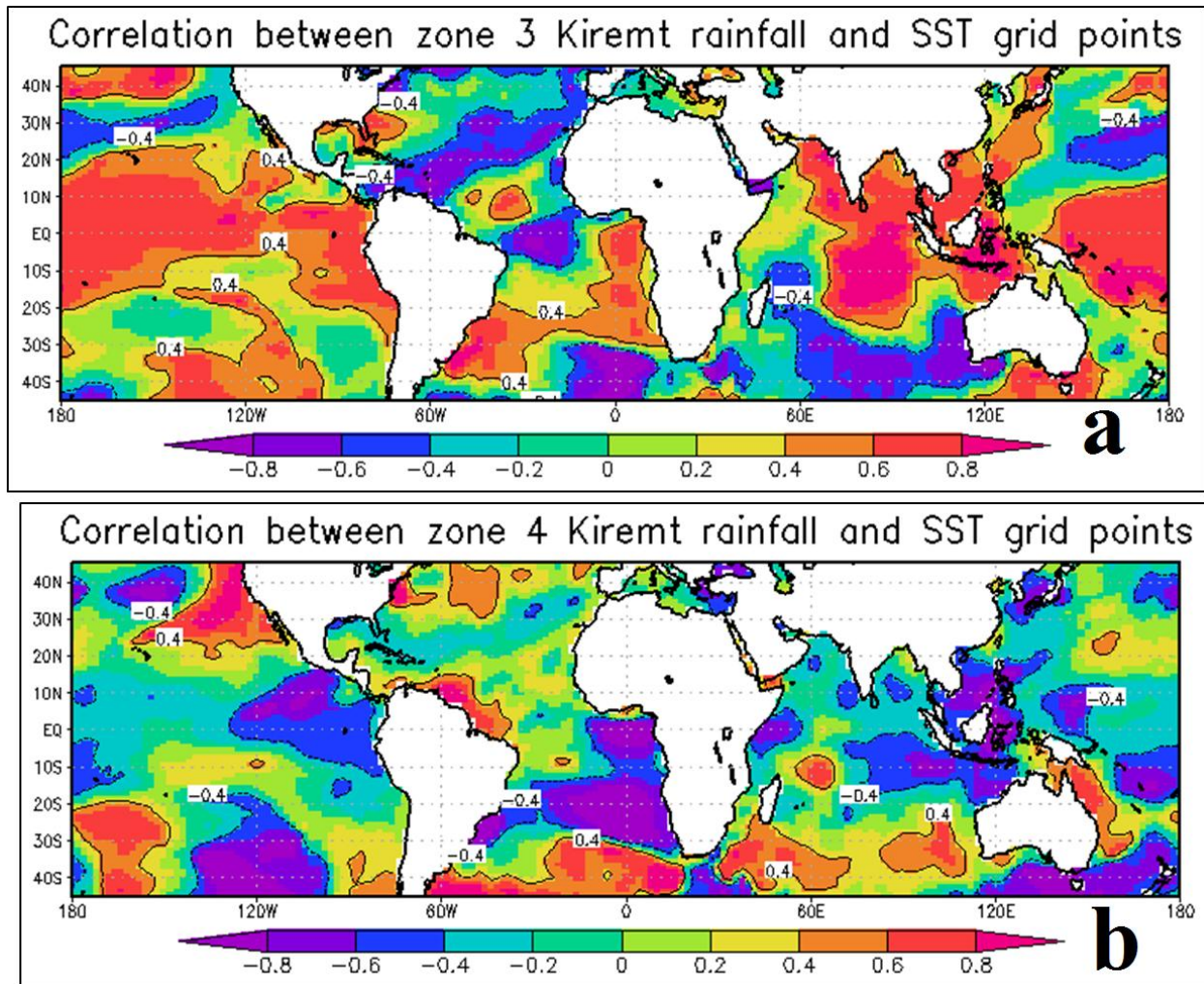


Fig. 18 Correlation map of (a) Zone 3 (b) Zone 4 Kiremt rainfall with May SSTs

The correlation between Zone 3 Kiremt rainfall with May SST as indicated in panel (a) of fig. 18, is strong and positive over most parts of western Indian, equatorial Pacific, southeast and south west Atlantic oceans. Strong but negative correlations are also observed over central Atlantic Ocean.

Panel (b) of the same figure shows, strong but negative correlation between Zone 3 Kiremt rainfall and southeast Atlantic and equatorial east Pacific Oceans. Positive and strong correlation is also observed patches of equatorial Atlantic and central Indian oceans.

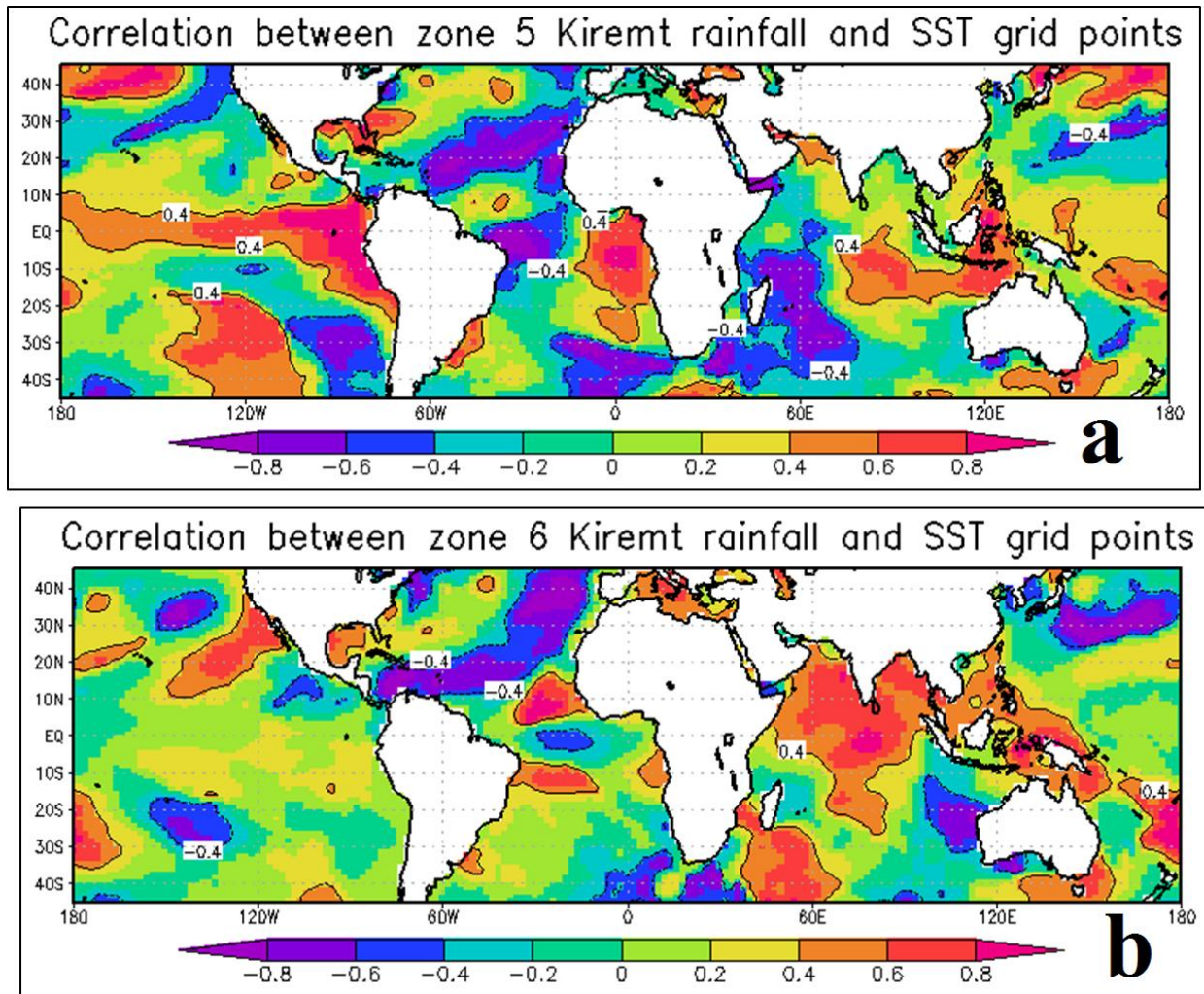


Fig. 19 Correlation between (a) Zone 5 and (b) Zone 6 Kiremt rainfall and SST grid points.

Correlation between Zone 5 Kiremt rainfall and SST in the tropics, as indicated in panel (a) of fig. 19, shows a strong positive correlation with a stretch of SST in the equatorial Pacific Ocean that extends up to the eastern part to the central Pacific Ocean. A strong correlation can also be observed in the eastern Atlantic. Negative but strong correlation can be seen over equatorial and north Atlantic as well as southwest Indian oceans.

In panel (b) of the same figure, it is clearly visible that Kiremt rainfall of Zone 6 having strong positive correlation with most parts of the Indian Ocean and few areas of central Atlantic Ocean.

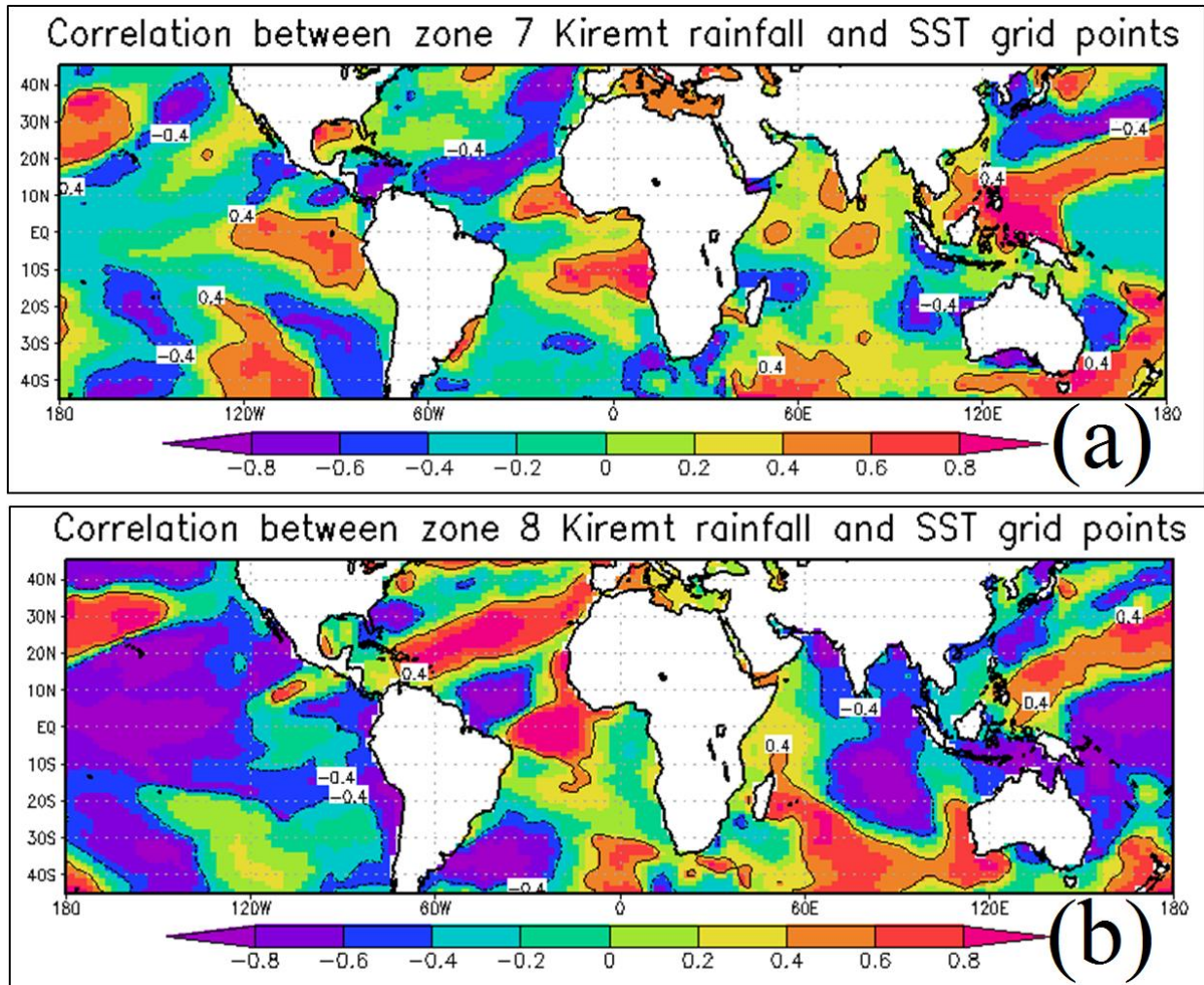


Fig. 20 Correlation between (a) zone 7 and (b) zone 8 Kiremt rainfall with SST grid points.

Correlation between Zone 7 Kiremt rainfall and tropical oceans SSTs show both positive and negative correlations. Panel (a) of fig. 20 shows that the strong positive correlations are in eastern Atlantic, eastern equatorial Pacific and patches of over patches of the Indian oceans. The strong but negative correlations are observed over northeast Atlantic and southeast Pacific oceans.

Panel (b) of fig. 20 also shows strong positive correlations between Kiremt rainfall and May SSTs over eastern and northern Pacific Ocean and southwest of the Indian Ocean. The strong but negative correlations are observed over much parts of the Pacific and the west Indian Ocean with a patch of an area in the central Atlantic.

3.7 Dominant wind patterns during the Kiremt season

The grid wind data analysis indicates that there are some features of the wind at different levels of the atmosphere that persist during the Kiremt season. Their position and intensity varies from year to year but the general feature are the same.

3.7.1 Wind at 850mb

During Kiremt season winds at 850mb level that influence the weather over Ethiopia are the southwest monsoon winds which are customarily called the Somali Jet or Low Level East Africa Jet (LLEAJ). These winds are originated from the southern Indian Ocean as easterlies but due to the heat lows over the Indian continent and the Tibetan high plateau they curve around east Africa and become south easterlies as they cross the equator.

These winds start to develop and get in shape during the beginning of the Indian monsoon season starting from May and they reach their full strength and pattern in July. As indicated in fig. 21 in panel (a), relatively strong westerly winds are observed between the 0° and 15°N extending from 40°E to 120°E . In a comparable latitude region within 5°S and 15°S , slightly weak easterlies are observed.

In panel (b) of the same figure, the most visible v-wind pattern with in the neighborhood of east Africa is the strong southerly wind which is observed in the around the horn of Africa $35^{\circ}\text{E} - 55^{\circ}\text{E}$ and $15^{\circ}\text{S} - 10^{\circ}\text{N}$.

In panel (c) the resultant wind pattern of u-wind and v-wind indicates the a pattern of wind speed that clearly indicate the EALLJ. Panel (d) also shows the typical southwest monsoon wind patterns during the Kiremt season.

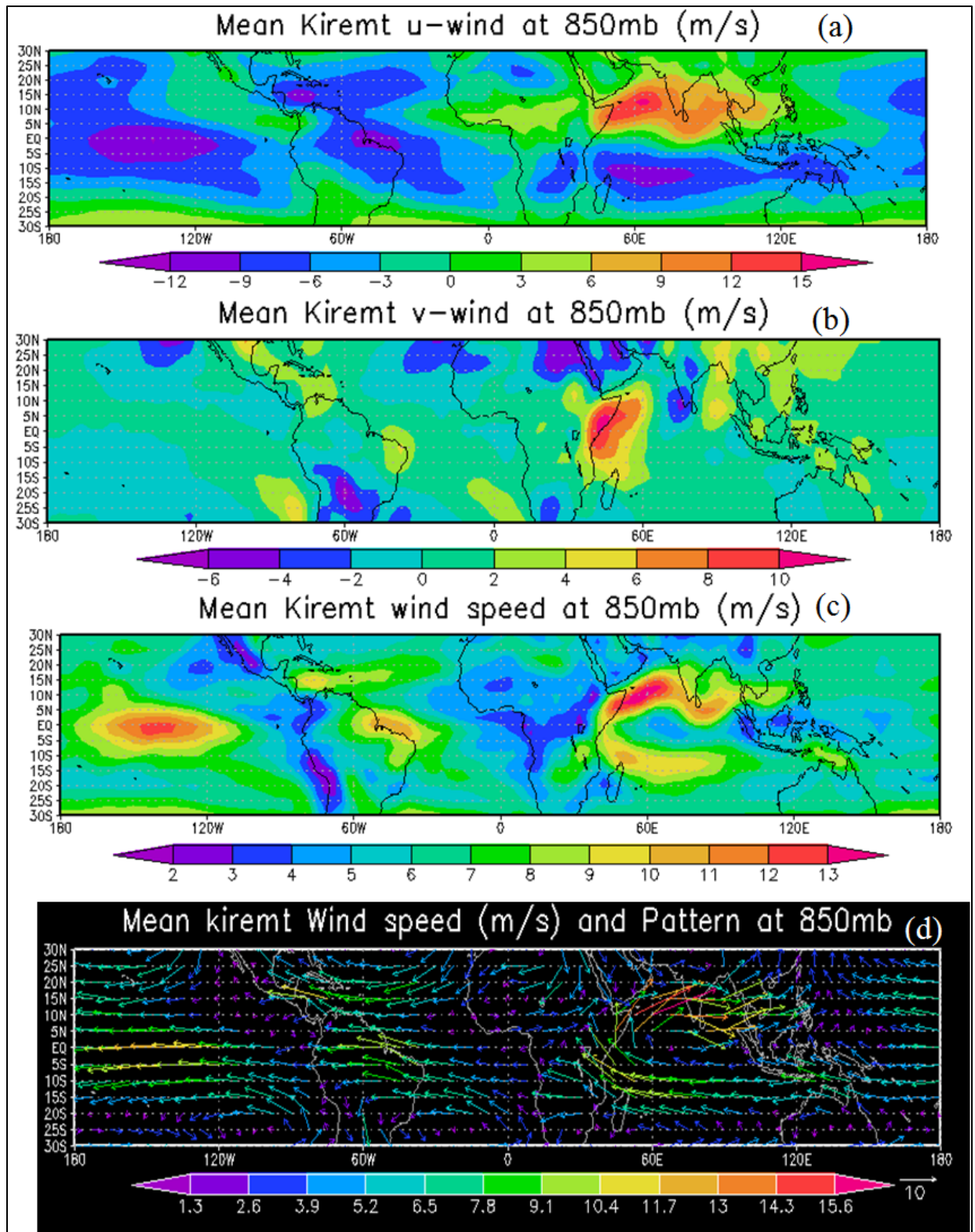


Fig. 21 Mean wind conditions at 850mb ((a) u-wind, (b) v-wind, (c) wind speed and (c) wind patterns at 850mb during Kiremt season. Negative wind speed values indicate easterly winds in the case of u-wind and southerly winds in the case of v-wind

3.7.2 Wind at 500mb level

At 500mb level, most parts of Ethiopia is dominated by easterly winds except the southern and south eastern parts of the country. As can be seen from panel (a) of fig. 22, the u-wind distribution is dominated by easterly winds covering almost all portions of Ethiopia with wind speeds ranging from 3-9 m/s. The strongest winds are located over the northern parts of Ethiopia.

In panel (b), the visible patterns in v-wind is northeasterly pattern which extends from the Arabian land in the position of the great rift valley up to the southern parts of Ethiopia.

The resultant of the u-wind and v-wind in panel (c) shows that the wind speed at 500mb level reaches up to 10m/s. almost in the whole tropical region. Considering wind speeds over Ethiopia, most parts of the country are having wind speeds 6-8m/s. In the northern parts of the country, the wind speed reaches up to 10m/s at 500mb level.

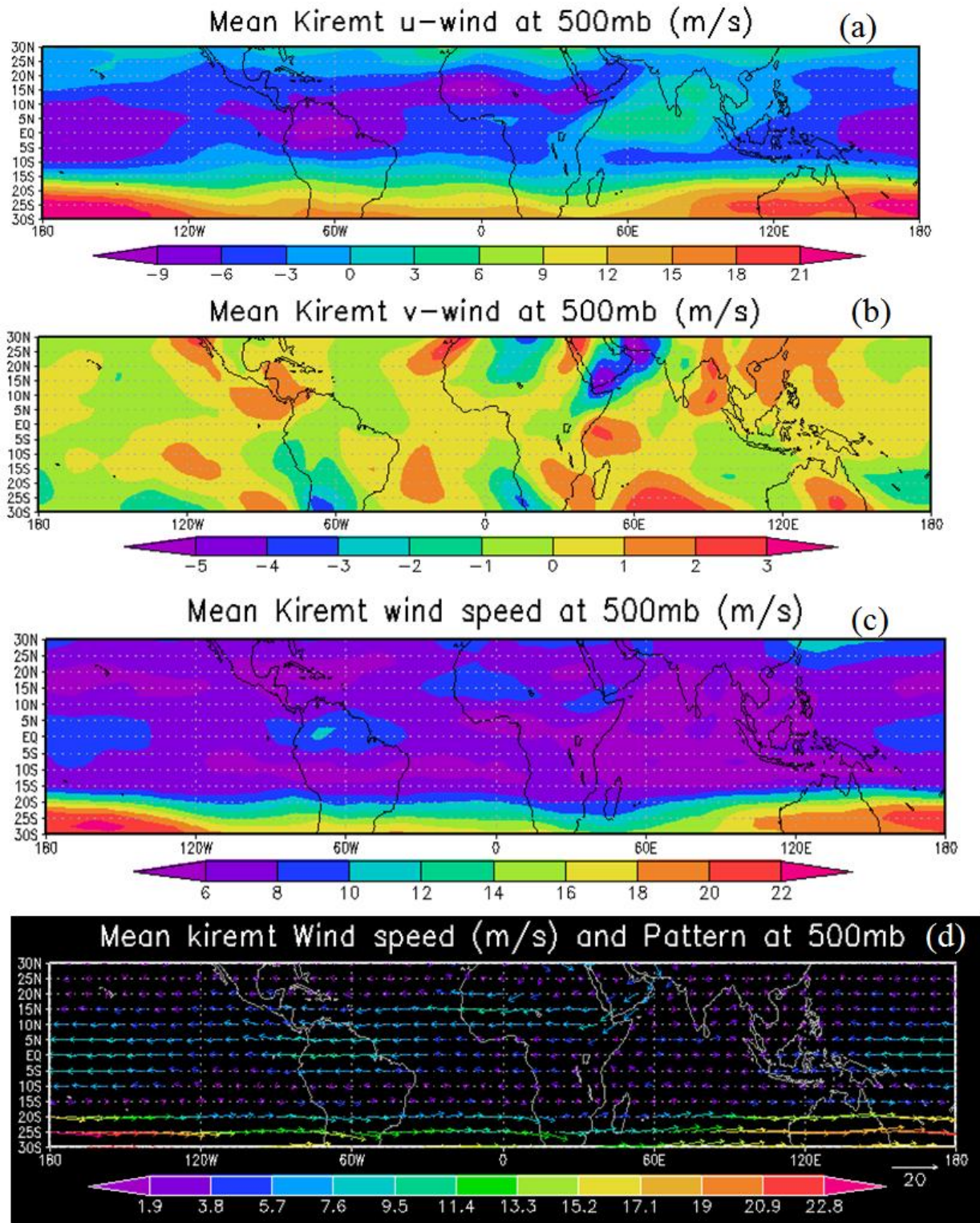


Fig. 22 Mean (a) u-wind, (b) v-wind, (c) wind speed and (d) wind pattern at 500mb during Kiremt season in m/s. Negative wind speed values indicate easterly winds in the case of u-wind and southerly winds in the case of v-wind

3.7.3 Wind at 150mb level

The tropical easterly jet stream whose core extends between 50°E to 80°E and 10°N to 15° N is one of the prominent wind features at this level. This jet stream is a northern summer phenomenon that extends from central Indian Ocean to Eastern Africa at 150mb during the Kiremt season.

The Jet stream's genesis which is located around the southern tip of the Indian continent starts in around May and progressively develops through July and August and starts dying out in September after reaching its peak wind speed around July.

The average seasonal wind speed at this level can reach more than 35 m/s in July and August. But the average for the whole Kiremt season is between 20-30m/s with the core speed of more than 30m/s.

The zonal component of the wind is more dominant and persistent compared to the meridional component of the wind.

Fig. 23 shows u-wind panel (a), v-wind panel (b), resultant wind panel (c) and the wind pattern panel (d) during the Kiremt season. As can be observed from panel (c), the resultant wind takes almost the pattern of the u-wind indicating the strength and persistence of the u-wind throughout the Kiremt season.

The u-wind as panel (a) of fig. 23 indicates has core wind speed of more than 35 m/s and its direction is westwards. The component of this u-wind that covers the whole parts of Ethiopia has wind speed between 20 m/s to 30 m/s.

The v-wind at this level specially at the location of the TEJ is very weak compared to the u-wind. It can be clearly identified that within and around and within the TEJ, the v-wind takes southerly direction north of the TEJ and takes northerly direction south of the TEJ.

The wind pattern at this level is strong easterly in the east Africa region with the strongest winds located over the southern tip of the Indian continent. These features are indicated in panel (d) of fig. 23.

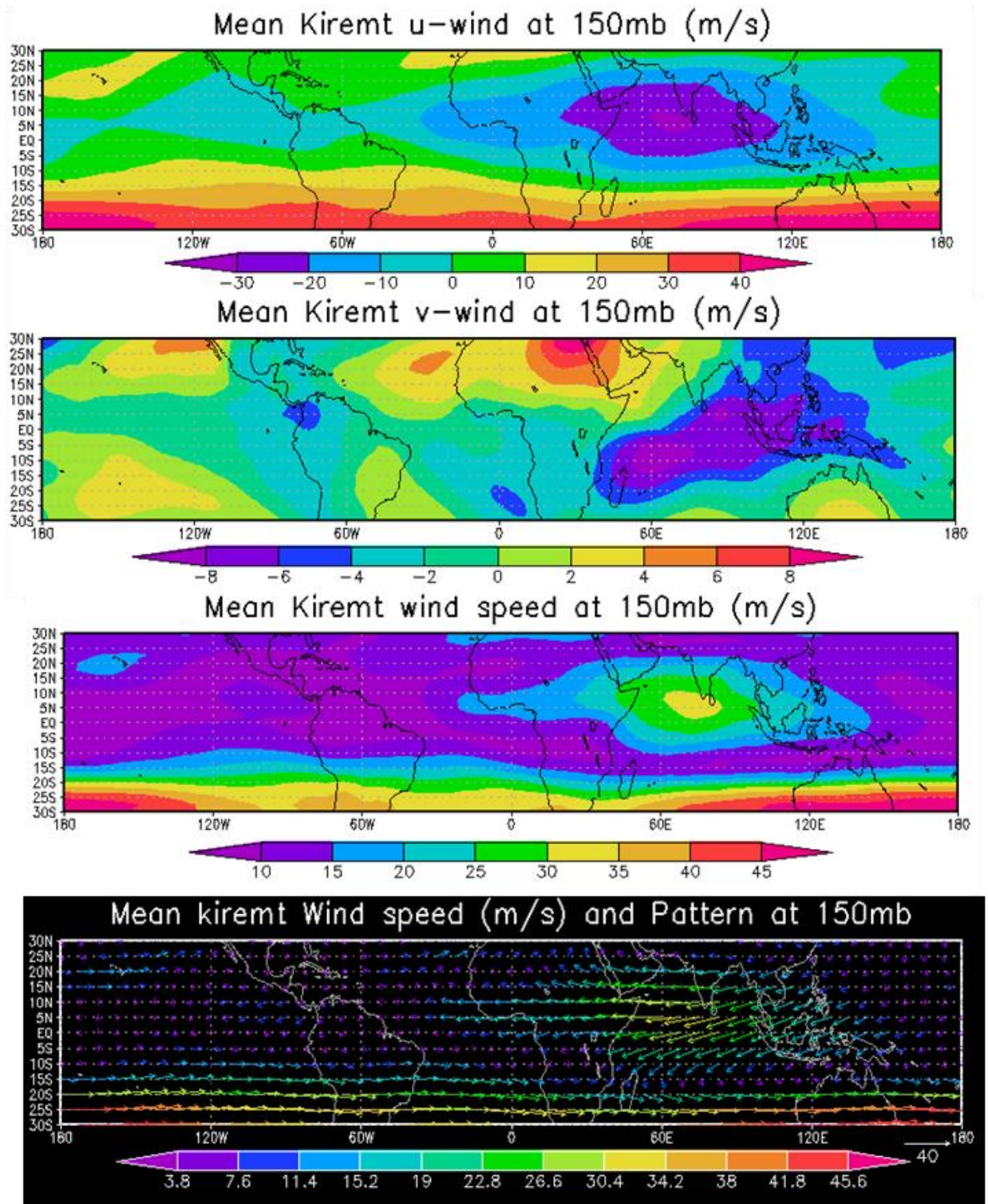


Fig. 23 Mean (a) u-wind, (b) v-wind, (c) wind speed and (d) wind pattern at 500mb during June (m/s). Negative wind speed values indicate easterly winds in the case of u-wind and southerly winds in the case of v-wind

3.8 Observed anomalies in wind speed and pattern during selected wet and dry Kiremt seasons.

The composite analysis of wet and dry Kiremt seasons and wind features reveals that the wind patterns and speeds differ from the long term means. For instance, as fig. 20 indicates during the severe drought year of 1984, significant anomalies were observed in wind patterns and speed in the typical features which are observed during the Kiremt season.

Panel (a) in fig. 20 indicates that the u-wind speed which was supposed to be higher around 10°N is shifted southwards.

In panel (b) of the same figure, it clearly visible that the v-wind along 40°E was weaker. This condition shows that the transport of moisture from the southern Indian Ocean is hampered by weak winds at that particular season.

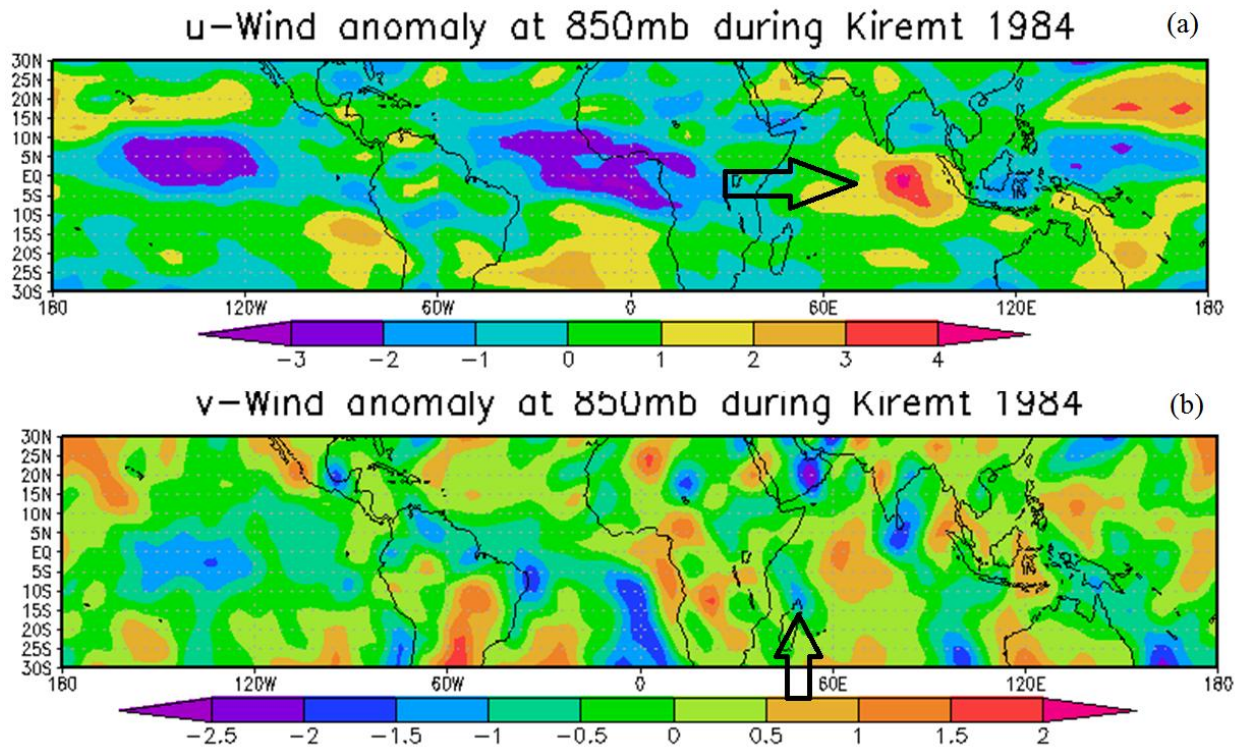


Fig. 24 Anomalies observed (a) in u-wind and (b) in v-wind during the dry 1984 Kiremt season

3.9 Association of sea surface temperatures and wind features with Kiremt rainfall.

Sea surface temperatures show annual as well as seasonal variations. The variability however, is not in the same pattern except in few parts of the oceans. The most visible annual and significant variability are observed in the equatorial Pacific Ocean and eastern Atlantic Ocean and they influence the Kiremt rainfall variability over Ethiopia.

The Kiremt rainfall variability evaluation between equatorial SST and Kiremt rainfall using CPT software indicates that the equatorial SSTs of Indian, Pacific and Atlantic Oceans can explain the variability of Kiremt rainfall up to 32% each.

The output from the CPT software as indicated in fig. 21 below shows the regions selected for the assessment of variability of Kiremt rainfall and explaining the variability in terms of the SST of the three Oceans. The May Indian Ocean SST can explain 42% of the Kiremt rainfall variability over Ethiopia. This is one month in advance of the Kiremt season indicating the prediction potential of the Indian Ocean one month in advance of the Kiremt season.

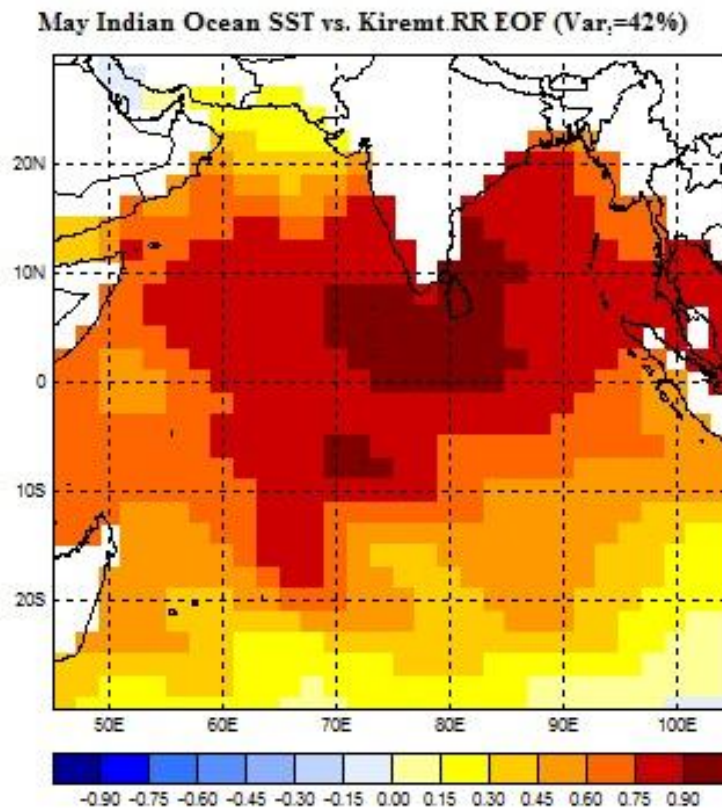


Fig. 25 EOF of May Indian Ocean SST and Kiremt rainfall over Ethiopia (mode 1)

The May Atlantic Ocean SST also can explain 32% of the variance of the Kiremt rainfall. In addition the Pacific Ocean SST explains the Kiremt rainfall variability up to 33%.

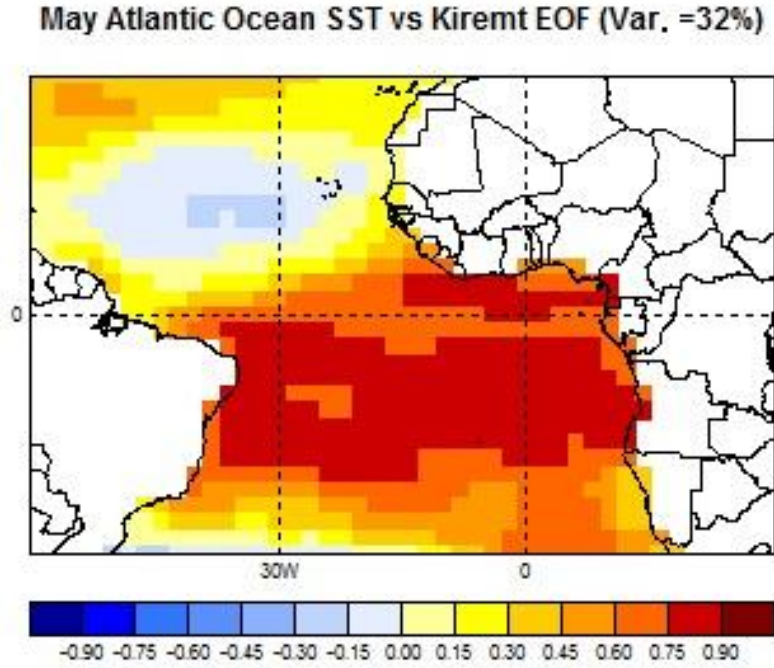


Fig. 26 EOF of May Atlantic Ocean SST and Kiremt rainfall over Ethiopia (mode 1)

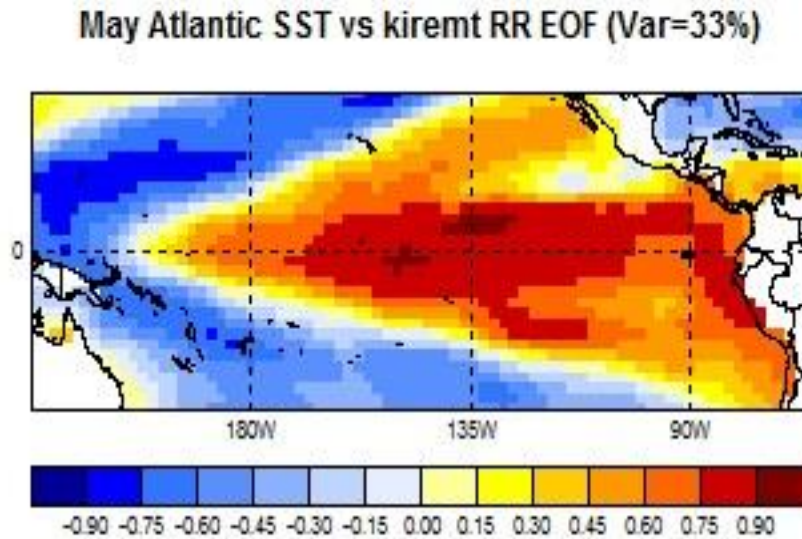


Fig. 27 EOF of May Pacific Ocean SST and Kiremt rainfall over Ethiopia (mode 1)

Winds at different level of the atmosphere also play vital role in the Kiremt rainfall. Winds at the surface and 850mb level are important in advection moisture from the oceans and the Congo basin. The winds from the two major sources of moisture to Ethiopia, the Atlantic and Indian Oceans, are the decisive factors for the performance of the Kiremt season. In fact, the dynamics should also be conducive for the moisture to be uplifted and reach the level of condensation. In this case topography and winds at different level play important role.

In terms of variability, the winds at 150mb level have high percentage of explaining the variability of the Kiremt rainfall. This high percentage of variance explained by u-winds at 150mb is considered in the regression model development of Kiremt rainfall. It should be noted that winds at this level do not bring moisture but play important role in the dynamics of the rain making.

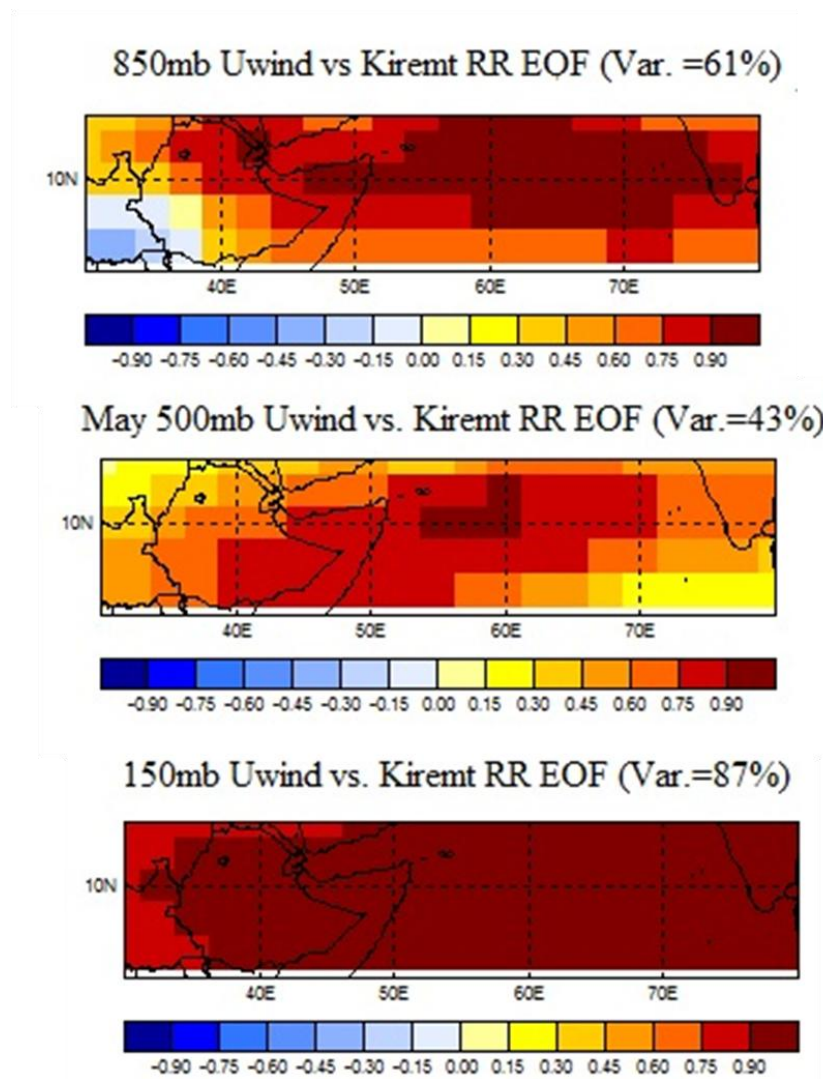


Fig. 28 EOF of May Wind at 850mb, 500mb and 150mb and Kiremt rainfall over Ethiopia (mode 1)

The variance of Kiremt rainfall explained by wind and SSTs one month ahead of the season and the correlation between Zonal Kiremt rainfall and May SSTs can be used to develop regression model that uses May SSTs and wind features that persist during the Kiremt season.

The areas selected for the regression model development were given coded names and the mean SSTs and mean wind speeds were extracted.

The model was developed using May SSTs and wind speeds extracted from the selected SSTs and winds at 850mb, 500mb and 150mb. SYTAT software of version 8.0 was used to select the coefficients and the predictors in a step forward technique. Combinations of predictors with R squared values greater than 0.5 were selected for the model.

The training period for the model was set to 25 years (1980 - 2004) and the remaining seven years were used for validation (2005 - 2003).

Table 3. SSTs and atmospheric coordinates selected to develop the MVRM

Parameter	Code	latitude	longitude	Parameter	Code	latitude	longitude
SST Zone 1	Z1I	0°-5° N	60° E- 75° E	SST Zone 7	Z7CWA	10°N – 20°N	30°W – 60°W
	Z1AE	0° -10°S	10° W – 10° W		Z7CWP	0° – 15°N	115°E – 150°E
	Z1EP	5°S - 5°N	90° W –100° W		Z7CI	0° – 5°S	75°E – 85°E
	Z1AW	10°S – 25°S	25° W – 40° W		Z7NI	5°S – 10°N	60°E – 75°E
SST Zone 2	Z2CI	0° – 10° N	50°E – 95°E	SST Zone 8	Z8WP	5°S – 5°N	155°E – 175°E
	Z2SWP	10°S – 20°S	25°W – 40°W		Z8SEI	5°S – 25°S	80°E – 90°E
	Z2SWI	5°S – 5°N	40°W – 50°W		Z8CA	5°S – 5°N	10°W – 35°W
SST Zone 3	Z3WP1	15°S – 10°N	150°E – 180°E	U wind	Z8CWA	5°N – 12°N	35°W – 50°W
	Z3CI	20°S – 5°N	80°E – 95°E		Z8CNA	20°N – 25°N	30°W – 60°W
	Z3NI	5°N – 20°N	63°E – 75°E		Z8CP	10°S – 10°N	130°W – 175°W
	Z3EA	0° – 30°S	5°W – 10°E		U850CIO	0° – 10°N	75°E – 95°E
	Z3CA	0° -5°S	15°W – 30°W		U850SIO	10°S - 20°S	55°E – 85°E
SST Zone 4	Z4WP	10°N – 15°N	110°E – 130°E	V wind	U500E	25°E – 45°E	0° – 6°N
	Z4SEI	5°S – 15°S	90°E -130°E		V850SJ	15°S – 8°N	35°E – 45°E
	Z4SWI	55°S – 65°S	45°E – 55°E		V500NWI	20°N – 30°N	60°E – 70°E
	Z4WI	5°S – 5°N	45°E – 55°E		V500NAL	20°N – 30°N	30°E – 45°E
	Z4EP	30°S – 5°S	10°W – 10°E		V150DIO	10°S – 20°S	40°E – 80°E
	Z4NEA	5°S – 5°N	40°W – 65°W				
SST Zone 5	Z5EP	0° – 15°N	95°W – 120°W				
	Z5EI	0° – 18°S	75°E - 130°E				
	Z5SWI	5°S – 30°S	45E° – 65°E				
	Z5EA	20°S – 5°N	10°W – 15°E				
	Z5CWA	10°S – 5°N	20°W – 40°W				
	Z5NEA	15°N – 25°N	20°W -60°W				
SST Zone 6	Z5NEA	15°N - 25°N	20°W – 60°W				
	Z5EEP	5°S – 5°N	75°W – 160°W				
	Z6SWI	15°S – 30°S	100°E – 115°E				
	Z6SI	10°S – 25°S	75°E – 85°E				
	Z6EA	5°S – 15°S	0° – 15°E				
	ZSWA	5°S – 15°S	10°W – 35°W				
	Z6CA	0° – 5°S	10°W – 25°W				
Z6CEA	5°N – 15°N	15°W – 30°W					
Z6CWA	10°N – 20°N	35°W – 75°W					

The models developed for six of the eight homogeneous zones using Systat 8.0 software indicated that both SSTs and winds at various levels can be used to predict Kiremt rainfall one month ahead from the starting of the Kiremt season. This one month lead prediction can be used for decision making in various sectors especially in the agriculture sector.

The linear regression models developed are:

$$\text{Zone 1} = 0.184*U500E + 0.160*V500NAL + 1.036*V850SJ$$

$$\text{Zone 2} = 0.342*Z2SWP + 0.268*V500NAL + 0.670*V850SJ$$

$$\text{Zone 3} = 0.283*U850SIO + 0.354*U500E + 0.832*V500NWI$$

$$\text{Zone 6} = 0.566*Z6SI - 0.535*Z6CNI + 0.589*V500NWI + 0.280*Z6CA$$

$$\text{Zone 7} = 0.385*Z7SWA - 0.229*Z7CWP - 0.566*V150SIO + 0.264*V500NAL + 0.447*V500NWI$$

Table 4 indicates that the regression models developed using wind and SST parameters from May (one month ahead from Kiremt season) show good skill in predicting the above normal and below normal rainfall during the season. It can also be observed from the table that the percent correct for most of the Zones is more than 52% showing some skill of prediction.

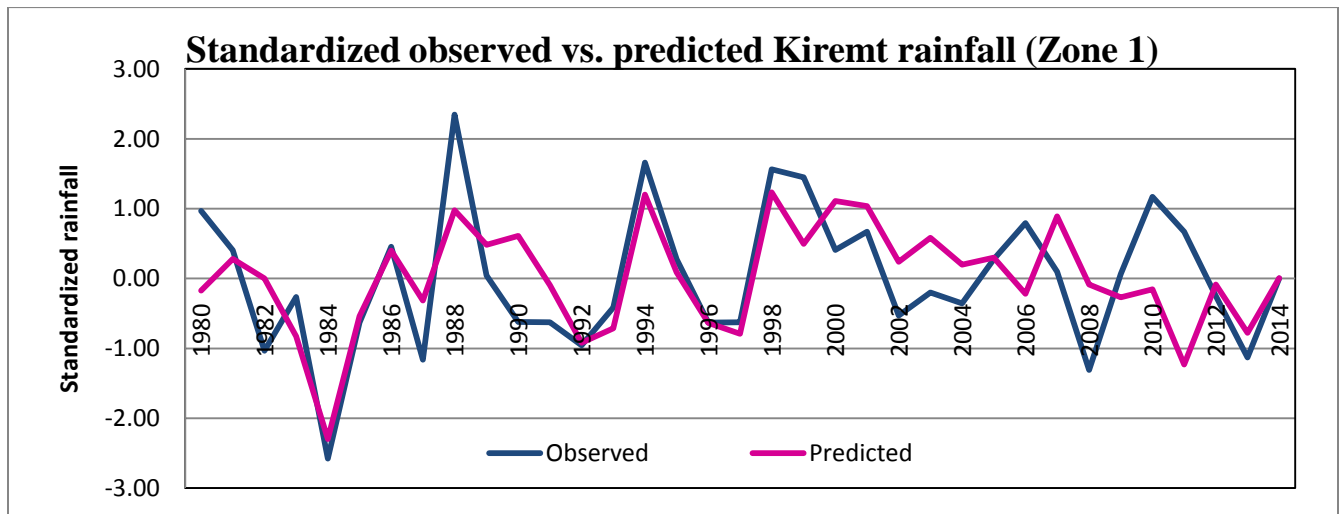


Fig. 29 Model predicted versus observed Kiremt rainfall over Zone 1

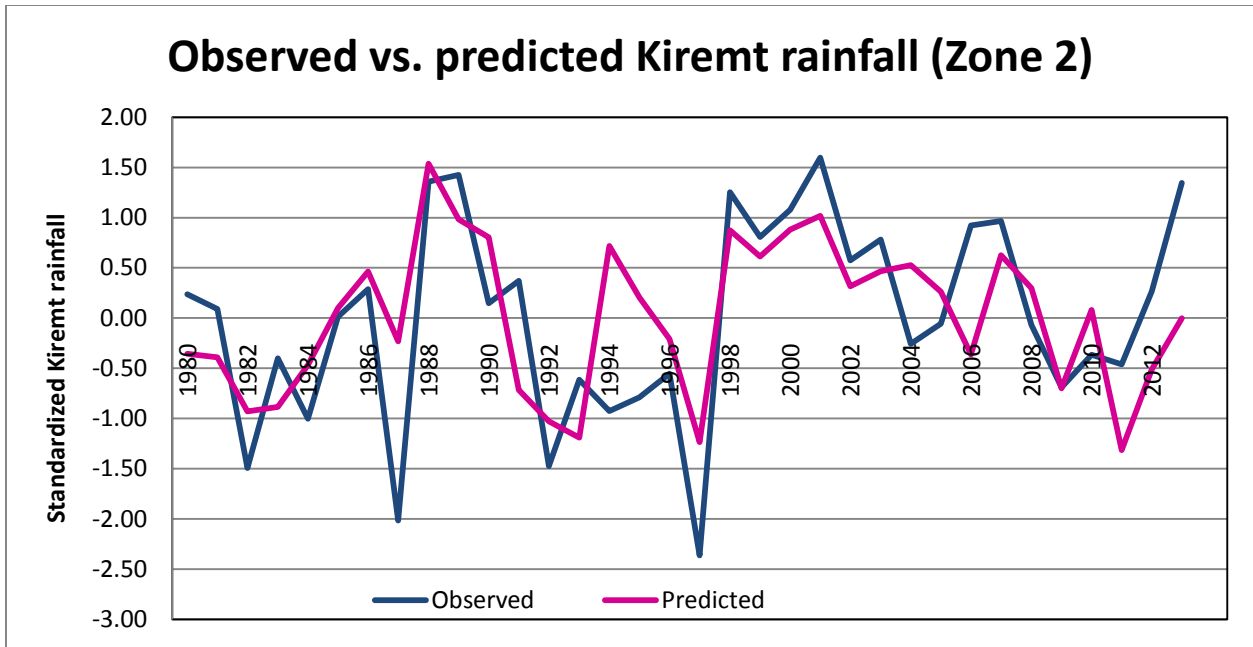


Fig. 30 Model predicted versus observed Kiremt rainfall over Zone 2

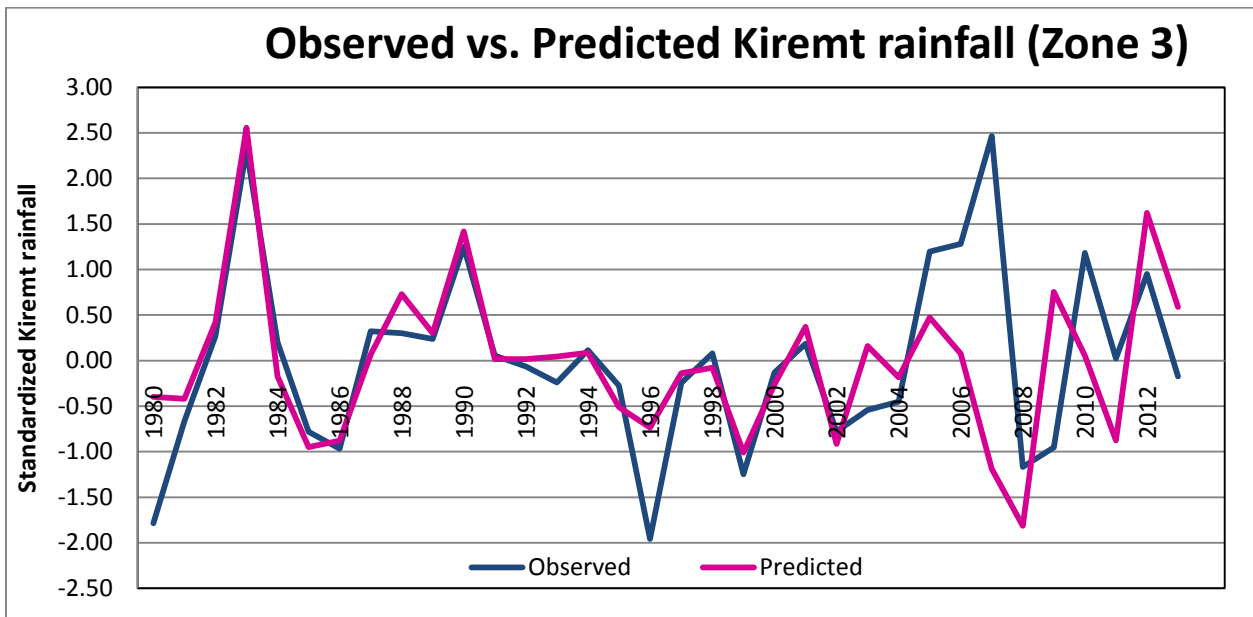


Fig. 31 Model predicted versus observed Kiremt rainfall over Zone 3

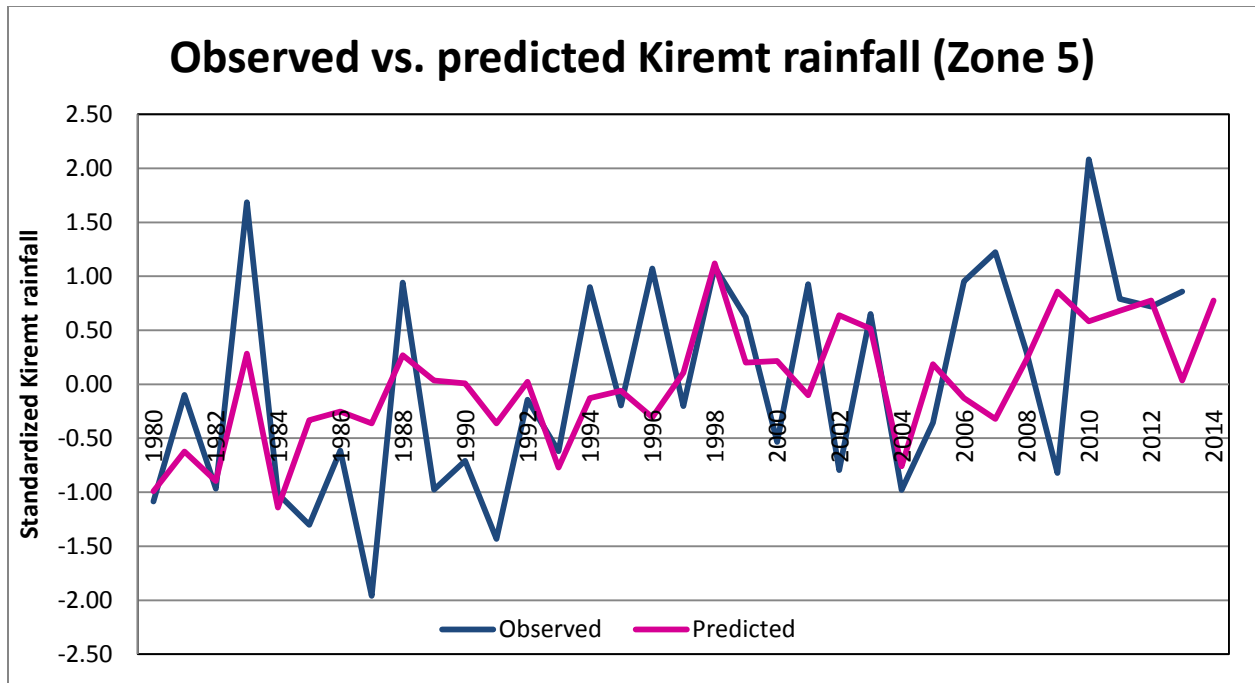


Fig. 32 Model predicted versus observed Kiremt rainfall over Zone 5

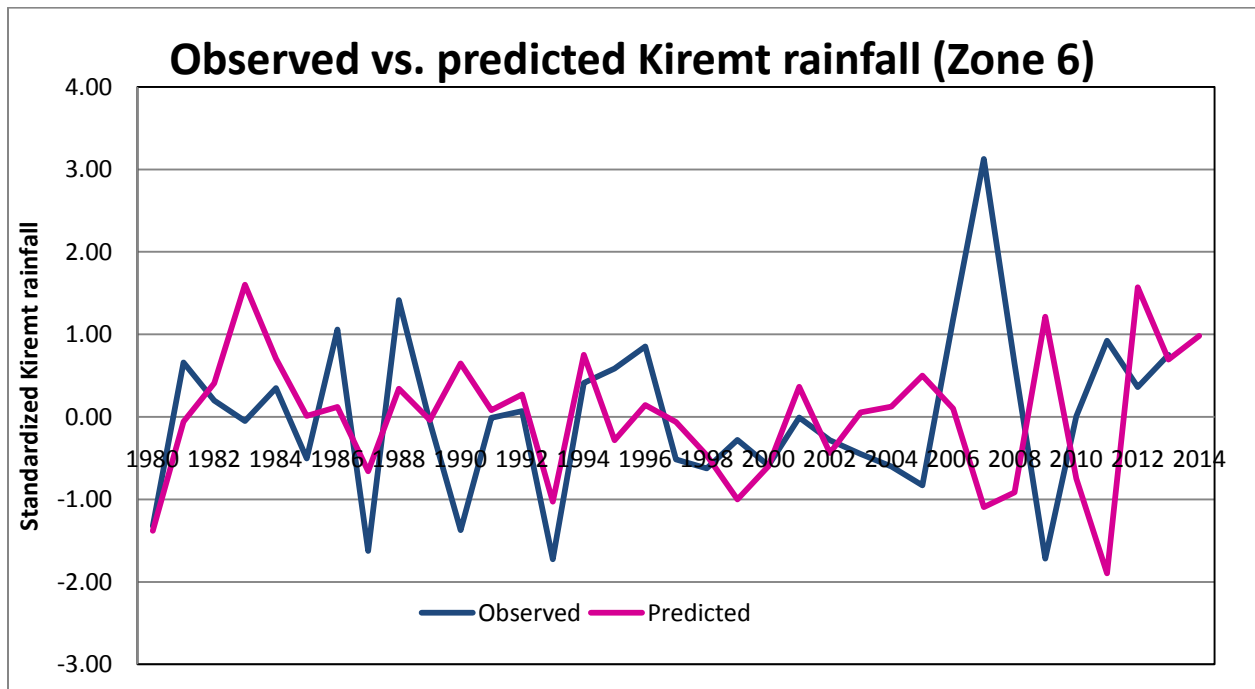


Fig. 33 Model predicted versus observed Kiremt rainfall over Zone 6

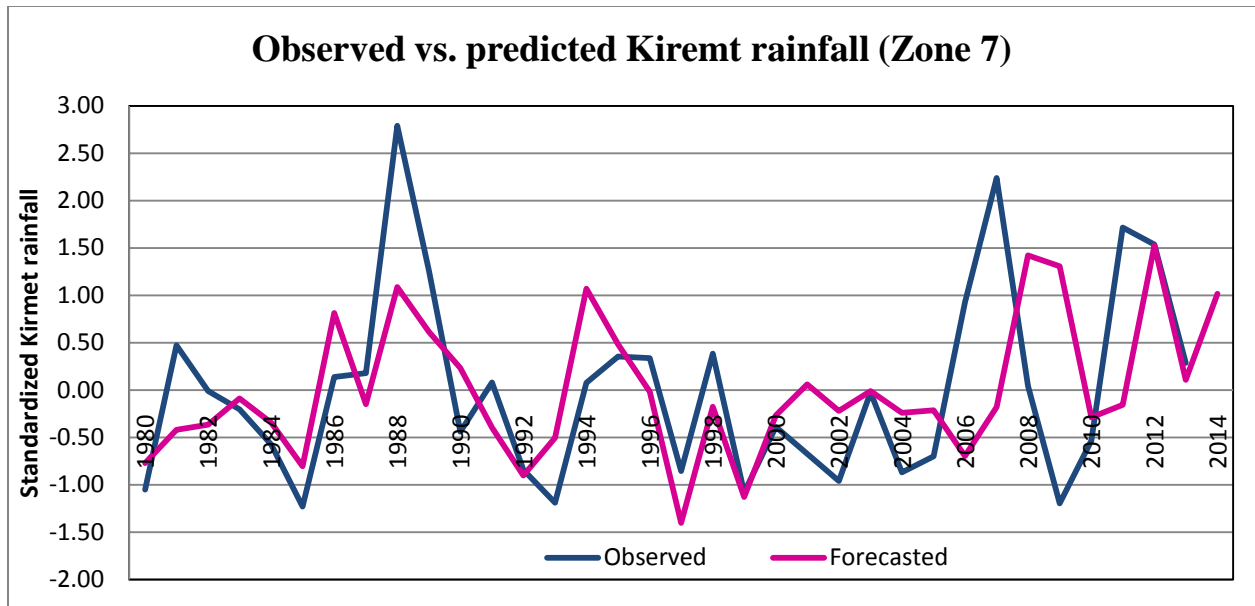


Fig. 34 Model predicted versus observed Kiremt rainfall over Zone 7

Table 4. Contingency table of the MVRM developed for each zone

	Zone 1			Zone 2			Zone 3		
	BN	N	AN	BN	N	AN	BN	N	AN
Percent correct (%)	53			59			62		
Post Agreement (%)	62.5	40	63.6	60	50	67	67	53	70
False Alarm Rate	37.5	60	36.4	40	50	33	33	47	30
HSS	0.294			0.38			0.42		
CSI	0.36	0.3	0.44	0.43	0.32	0.53	0.46	0.42	0.47
POD HR	45.5	54.5	58.3	60.0	46.2	72.7	60	67	58
	Zone 5			Zone 6			Zone 7		
	BN	N	AN	BN	N	AN	BN	N	AN
Percent correct (%)	53			41			56		
Post Agreement (%)	80	41	71	44	38	41	83	44	60
False Alarm Rate	20	59	28	55	61	58	16	55	40
HSS	0.31			0.11			0.34		
CSI	0.36	0.39	0.31	0.26	0.26	0.25	0.45	0.38	0.35
POD HR	40	90	35.7	40	45	38	50	73	46

As indicated in table 3 the model for Zones 1,2,3,5and 7 can predict more than 53 % correctly. The post agreement values for above normal and normal are more than 60% meaning that the models can capture above normal and below normal Kiremt rainfall more than 60% of the time.

Chapter four: Conclusions and recommendations

4.1 Conclusions

The Kiremt season is the major rainfall season for most parts of Ethiopia except southern, southeast parts of the country. The season is very important season for the different sectors that rely on moisture and water for their activities.

One of the most rainfall reliant sectors is the agriculture sector that engages about 84% of the working force. As the agriculture sector in the country is subsistence rain fed agriculture, it is extremely sensitive to Kiremt rainfall variability.

In the other hands the Kiremt rainfall performance is shown its dependence on the SST and wind features that persist during the Kiremt season. When there is a change in the pattern of the SSTs and wind features, the performance of the Kiremt season changes depending on the change in the SST and the corresponding change in the wind features.

It has been identified that changes in SSTs in different parts of the Atlantic, Indian and Pacific Oceans to cause wet and dry conditions in Kiremt season.

The variability of the Kiremt season rainfall is found out to be corresponding to the variability of the SSTs of the Oceans.

In general, the following conclusions can be made from this project work:

- The tropical SSTs generally have zonal temperature distribution
- The southern tips of the eastern parts of the Atlantic and Pacific Oceans have meridional SST distribution.
- Different rainfall zones over Ethiopia respond differently to specific changes in the tropical ocean SSTs and there is a predictive association with lead time of one month before the kirmt rainfall season.
- Wind patterns in the tropics have specific patterns during the Kiremt season. Specially, the monsoon wind patterns are peculiar patterns during the Kiremt season.
- The SST patterns in different parts of the tropical ocean SSTs can be used to predict the performance of the Kiremt rainfall over some homogeneous rainfall zones over Ethiopia.
- Wind pattern at different pressure level in the atmosphere play in advection moisture and enhancing the dynamics for cloud formation and rain during the Kiremt season.
- In general, the prediction models using combined SST at various tropical ocean areas, wind at various levels performed reasonably well in prediction of seasonal extremes.

4.2 Recommendations

The role of SST patterns and wind features over the performance of the Kiremt season rainfall has been identified in this project work. It has been indicated that in addition to the customary use of SSTs to predict rainfall during Kiremt season, wind features at different pressure levels can also be incorporated in the prediction. Therefore, based on the outputs of this project work, it is recommended that

- Detail research to be conducted at daily and monthly level to investigate the link between tropical SST patterns and wind features to Kiremt season rainfall over Ethiopia.
- It is recommended that wind features at different pressure level to be considered in seasonal rainfall prediction over Ethiopia
- It is also recommended that the impacts of regional SSTs to be considered in the impacts of tropical SSTs

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