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Ethiopian Seasonal Rainfall Variability and Prediction Using Canonical Correlation Analysis (CCA)

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Abstract: Because Ethiopia's economy is mainly dependent on rain-fed agriculture, the failure or the goodness of seasonal rainfall is incredibly decisive the country's socio economic functioning- in particular, food production. As a result, the reliable seasonal rainfall prediction would have several advantages for agricultural activities, water management, health (Malaria control) and drought related disaster mitigation. In this paper an attempt is made to study the variability and predictability of two Ethiopian rainy seasons using statistical methods. Canonical Correlation Analysis (CCA) applied to analyze and predict seasonal rainfall over Ethiopia using global sea surface temperature (SST) predictor data and historical monthly total Ethiopian rainfall and merged both satellite and rain gauge rainfall data predictand data. It is found that in general, ENSO is the main source of predictive skill for Ethiopian seasonal rainfall. This is the case for both the Belg (small rainy season) from February to May and Kiremt (main rainy season) from June to September, during which other, more regional SST in the Atlantic and Indian Ocean also contribute. The objective approach provided by the CAA approach resulted in higher mean skill than the more subjective methods used traditionally by the Ethiopian National Meteorological Agency (NMA) since the late 1980's.

Keywords: ENSO, El Nino, La Nina, SST, Belg (Feb-May), Kiremt (Jun-Sep)

1. Introduction

Ethiopia is located along 3°N latitude – 14°N&33°E – 48°E longitude, with an area of about 1.02 million square km. It is a country of geographical contrasts, varying from as much as 116 m (381 ft) below sea level in the Danakil depression to more than 4,600 m (15,000 ft) above sea level in the mountainous regions. The climate of the country varies from humid to arid zones. The mean annual rainfall ranges from 2400 mm over south western portion, to as little as 500 mm (over northeastern and southeastern low lands.

In Ethiopia there are three seasons, based on climatological means of rainfall and temperature. These seasons are locally known as Bega, Belg and Kiremt (Degefu, 1987; Gissila et al, 2004).

Bega is the dry and cool season, running from October to January. The northern hemispheric sub tropical anticyclones, the seasonal Siberian High and dry cool northeasterly monsoon are the dominant features. The weather during the period is sunny and hazy with cold nights and early mornings.

Belg is the small rainy season, lasting from February to May. It is described by varying dry and wet days. The weather pattern of the season is controlled by the interaction between mid- latitude weather systems and tropical weather systems. The penetration of large, deep troughs in the easterly flow in to lower latitudes, and the southward bend of the westerly jet stream at upper levels, signifies the major rain producing configuration.

Kiremt is the main rainy season, occurring from June to September. During this season, the Inter-Tropical Convergence Zone (ITCZ) and the moist southwesterly monsoon flow from the southern hemisphere are the main rain producing structure. The onset and spatial distribution of rainfall are also found to follow the oscillation of the ITCZ and the intensity of the southern hemispheric anticyclones (Kassahun, 1987; Tadesse, 1994; Segele and Lamb, 2005).

In addition to the various atmospheric systems affecting Ethiopian rainfall, the temporal and spatial variations of mean rainfall discussed above are the result of the geography (particularly topography) of the country. The great African Rift valley extending northeast to southwest across Ethiopia, the mountains and highlands to the east and west of this Rift Valley, and the lowlands surroundings these mountains and highlands in every direction can be described as the country's main climate-determining topographical features (Fig. 1) (Bekele, 1997).

The intra-seasonal and inter-annual variability of rainfall over tropical and extratropical area are teleconnected with the global atmospheric and oceanic parameters. Several investigations have been done on the relation between the Ethiopian rainfall and the state of the El-Niño/ Southern Oscillation Index (ENSO). Most of these and other previous related studies found good correlation between ENSO and Ethiopian rainfall (Gissila, et al, 2004; Korecha and Barnston, 2007; Block and Rajagopalan, 2007; Diro, et al, 2008). Although using a subjective method whose the skill has not been examined using objective technique, since 1987 the National Meteorological Agency (NMA) of Ethiopia has issued its seasonal forecast using, among other tools, analogue-based statistical approach keying to the Southern Oscillation Index (SOI) during past years.

This work follows on the above mentioned previous studies on Ethiopian seasonal rainfall prediction, using a software/Graphics package called the Climate Predictability Tool (CPT). The statistical method applied using CPT is, Canonical Correlation Analysis (CCA). In the CCA, precursor tropical and extra tropical SSTs are used as predictor fields, and observed station rainfall data is used as predictand in an attempt to define the sources of predictive skill in the interannual variability of rainfall over Ethiopia. The ultimate goal is to develop the best possible statistical seasonal forecast models for use in real-time rainfall forecasting, both Belg and Kiremt seasons.

The objectives of the study are:

- To develop statistical seasonal rainfall forecasting model for operational use
- To re-confirm and quantify the relationship between Ethiopian seasonal rainfall and ENSO
- To evaluate the expected skill of the seasonal forecast using CCA

In section 2, the data and methods used in this study are described. The main findings for Belg and Kiremt seasons that is results are discussion are reported in section 3,. Concluding remarks are provided in section 4.

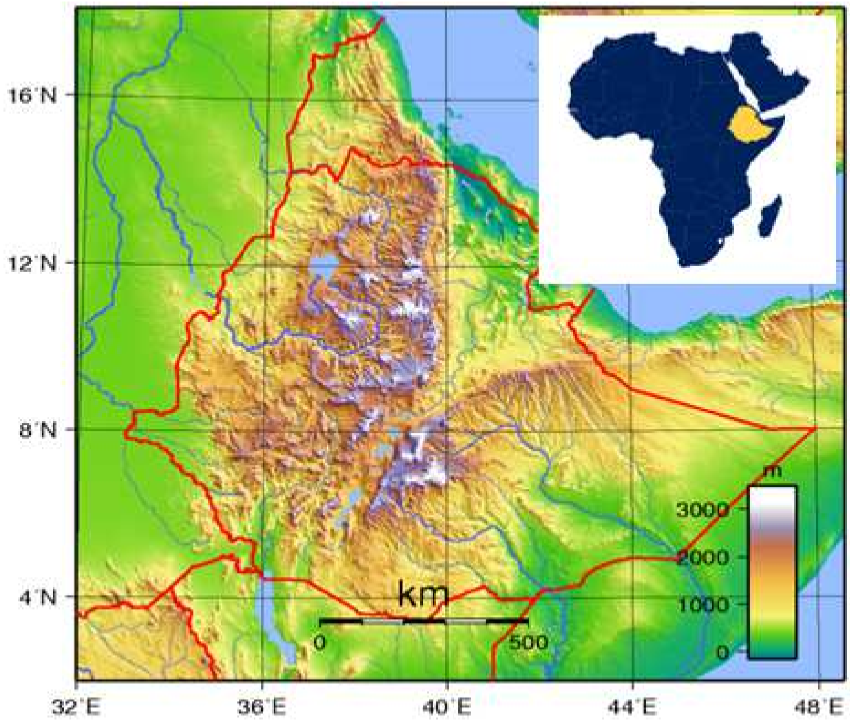


Figure 1. *Topography and location of Ethiopia.*

2. Data and Methodology

The monthly rain gauge data set used in this study is acquired from the National Meteorological Agency (NMA) of Ethiopia. The gauge data includes 389 stations having records from early 1950 to current years. However, most of the stations having more than 30 years of data before 1970 are of limited value overall, because they stopped recording after 1970. Hence, the set of stations was selected by first setting the base period to 1970-2006, and then eliminating stations having less than 26 years of record within those 37 years. Thus, the data set includes stations with no more than about 30% of data missing. Accordingly, 162 stations are retained used for the 1970-2006 analyses. The station rain gauge network is not evenly distributed across the country, but rather is dense in the central region and increasingly sparse in all directions away from the center of the country (Fig. 2). The monthly total rainfall data quality was verified with multivariate correlation analysis, whereby outliers from the dominant loading pattern of a principal component analysis (PCA) were carefully checked.

The new data set satellite data merged with station data used in developing seasonal rainfall forecast for both Belg (FMAM) and Kiremt (JJAS) seasons.

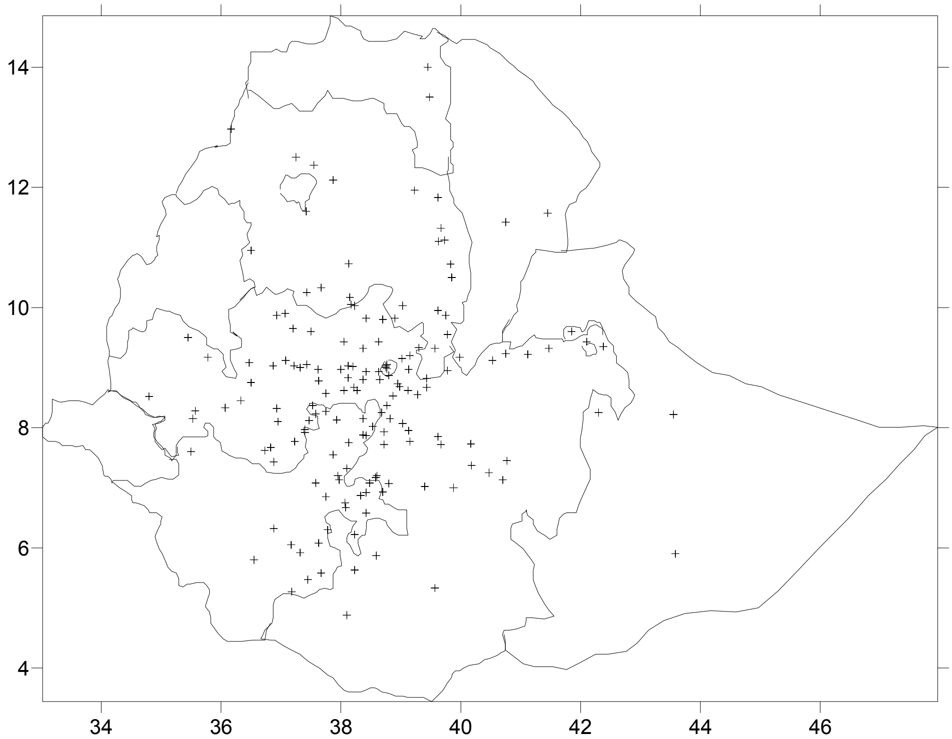


Figure 2. *Stations network used in this study.*

The Sea Surface Temperature (SST) data was obtained from the National Oceanic and Atmospheric Administration/National Climatic Data Center (NOAA/NCDC) version 2 the ERSSTv2 data set. The data represent monthly SST averages over the globe for 40°N – 40°S, with 2° x 2° resolution, continuous over the1949-2008 period. This coverage includes the Nino3.4 ENSO index, demonstrated to be critical to tropical and extra tropical teleconnections (Barnston, et al. 1997) and suggested to be important to Ethiopia's interannual Kiremt rainfall variability (Korecha and Barnston 2007).

To diagnose and predict Ethiopian rainfall for two rainy seasons (Belg and Kiremt), the Climate Predictability Tool (CPT) software/Graphics package is used, specifically applying the empirical statistical techniques of canonical correlation analysis (CCA) and principal component regression (PCR). These two multivariate techniques linearly relate the predictand (the Y variable here, Ethiopia rainfall) to the predictor (the X variable either precursor SSTs or atmospheric general circulation model [AGCM] outputs). The simple, univariate, form of linear regression, $y = bx + a$, is the basis of the more complex, multivariate, versions of linear regression used in CCA and PCR. To develop predictive models for both Belg and Kiremt rainfall, CCA is used. The predictor and predictand data are separately standardized and condensed using standard empirical orthogonal function (EOF) analysis. The main purpose of the EOF analyses is data compaction and noise filtering (Barnston and Smith, 1996).

3. Results and Discussion

3.1. Belg (FMAM) and ENSO

Belg season rainfall (FMAM) (Fig. 3) makes a significant contribution to total annual rainfall in the northeast, east and central portions of Ethiopia, as seen clearly in the annual rainfall cycle (Fig. 4, top). Inhabitants of these parts of the country are agricultural and hydrological beneficiaries despite that the largest share of rainfall occurs during Kiremt season (JJAS). However, during Belg the southern and southeastern parts of the country enjoy their main rainy season (Fig 4, bottom). The residents of this area are nomads whose livelihoods revolve around cattle, and the FMAM rainfall over the area is crucial for social and economic benefits such as water harvesting and grazing. The El Niño - Southern Oscillation (ENSO) phenomenon is a global event arising from large-scale interactions between the ocean and the atmosphere in the tropical Pacific Ocean. Much has been established about ENSO and its impacts, as well documented (Zebiak and Cane 1987; Mason et al. 1999). Regarding ENSO and Belg rainfall relationship previous studies have had little to say about ENSO and the Ethiopian Belg rainfall, and those that have addressed this relationship have concluded that an ENSO-Belg signal is weak. Nonetheless, this study suggests a clear link between ENSO and Belg rainfall. The linkage can be illustrated using CCA, whose dominant loading pattern depicts an ENSO versus FMAM rainfall relationship in which In La Niña state the main recipients of Belg rainfall experience deficient rainfall, while in El Niño situation most of the Belg rainfall-benefitting areas experience enhanced rainfall (Fig.5).

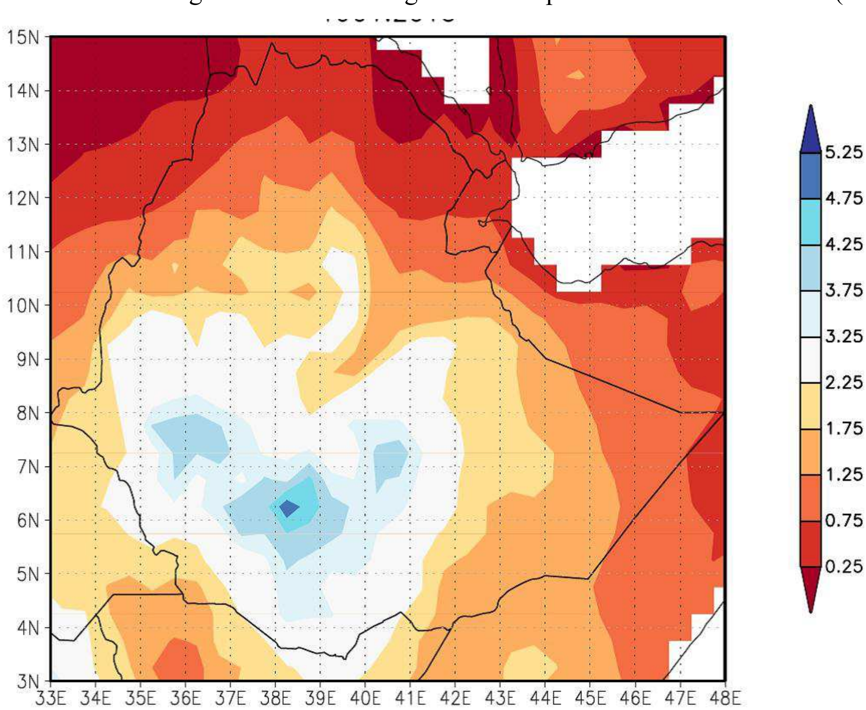


Figure 3. *Total FMAM rainfall (mm/day) climatology over Ethiopia.*

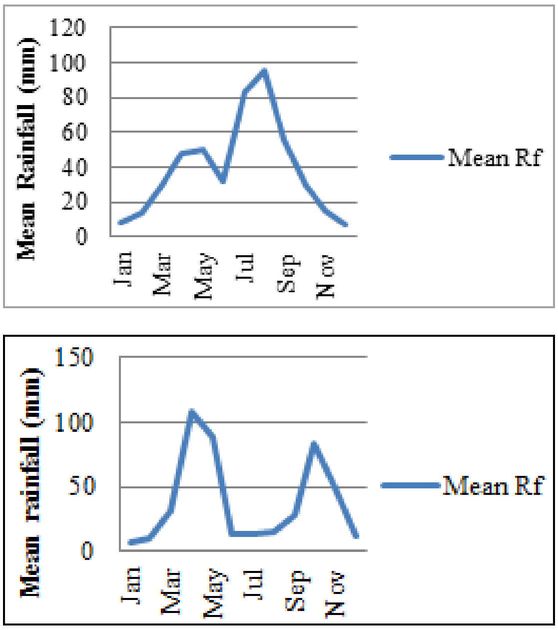
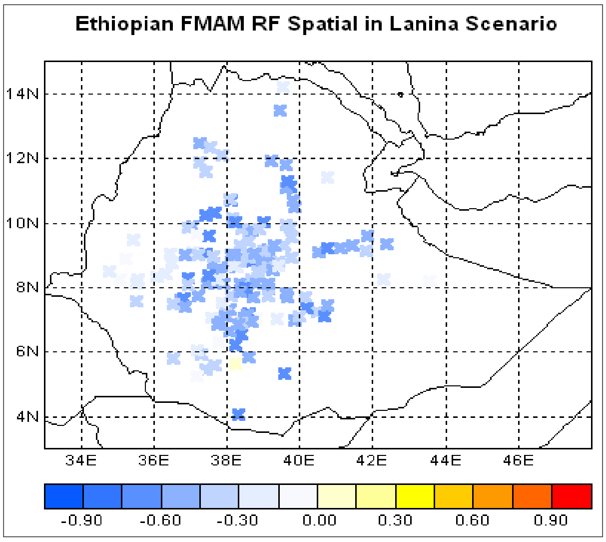
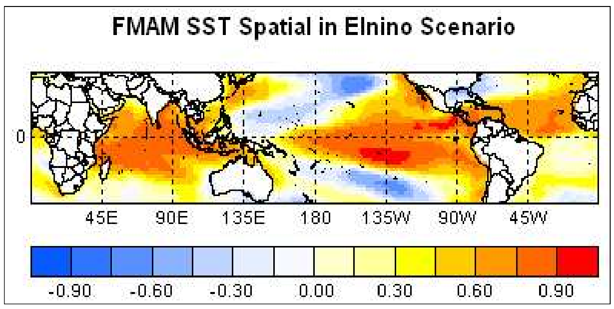
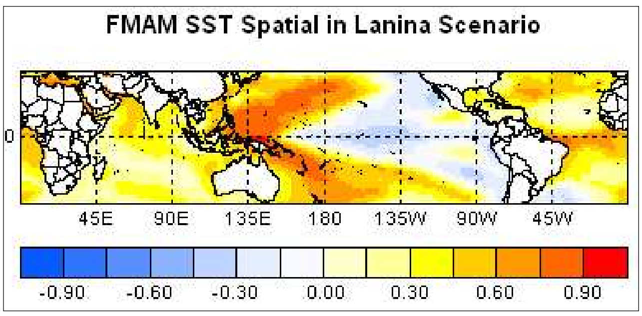


Figure 4. *Ethiopian annual cycle of Rainfall (mm), 1970-2006: (top) northeast, east and central, and (bottom) south and southeast.*







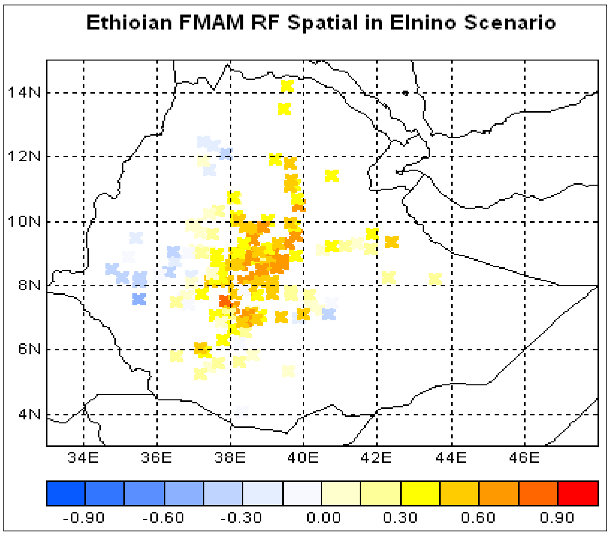


Figure 5. *spatial loading pattern relating Ethiopian FMAM rainfalls to tropical SST, for (top) La Niña and (bottom) El Niño.*

The statistical linkage between FMAM rainfall and ENSO in both scenarios is positive, as described by a canonical correlation coefficient of 0.49 for La Niña (top) and 0.33 for El Niño. Note that the signal is stronger over regions benefitting from Belg season rainfall than over remaining parts of the country.

The CCA cross validation shows relatively high skill in hindcasting the seasonal rainfall performance observed during strong La Niña and El Niño events. For instance, during the La Niña in 1988 and the El Niño in 1972, cross-validated skills were favorable.

3.2. Kiremt (JJAS) and ENSO

June to September (JJAS) is normally the major rainy season over Ethiopia. JJAS seasonal rainfall, except the south and southeast other portions of the nation benefited, particularly for the southwest, west, north, central and east regions of Ethiopia. However, the onset, cessation and the spatial and temporal distribution of Kiremt rainfall varies from place to place (Segele and Lamb, 2005). The intraseasonal rainfall variability also shows significant differences, with relatively highly variation across the lowlands and Rift Valley regions.

The long-term mean rainfall (Fig. 6) explains that western half, northeastern, eastern and central parts of the country receive diverse amount of rainfall for the JJAS season. In similar manner, temporal distribution of the seasonal rainfall has highly uneven characteristics though, play a great roll for various agricultural and water management activities inEthiopia. Conversely, for south and southeast Ethiopia JJAS is clearly differentiate from the other parts of the nation and consider as dry season apart from the few rainfall amount and rainy days occurring mainly in September with the southward withdrawal of the ITCZ.

The JJAS rain-producing systems such as the ITCZ, cross equatorial flow from (Mascarene high) southern Indian Ocean, moisture flow from (St. Helena high) Atlantic Ocean and the monsoon low and the associated trough have a great role to play for JJAS rainfall performance over Ethiopia.

El Niño–Southern Oscillation (ENSO)have an impact on a seasonal shifting of the normal rainy seasons in some regions, as a result a shortening or lengthening of the rainy seasons, particularly over tropical regions (Mason and Goddard, 2001). In line with this, there could be a significant teleconnection linkage between ENSO and the Ethiopian JJAS rainy season (Fekadu, 1997; Tsegay, 1998; Gissila et al., 2004; Segele and Lamb, 2005). Thecorrelationshowing that rainfall could be below average through El Niño episode further more high drought probabilities during strong El Niño years whereas, La Niña events favored further temporal expansion of seasonal activities beyond the normal duration of the rainy season over a region(Fig. 8).

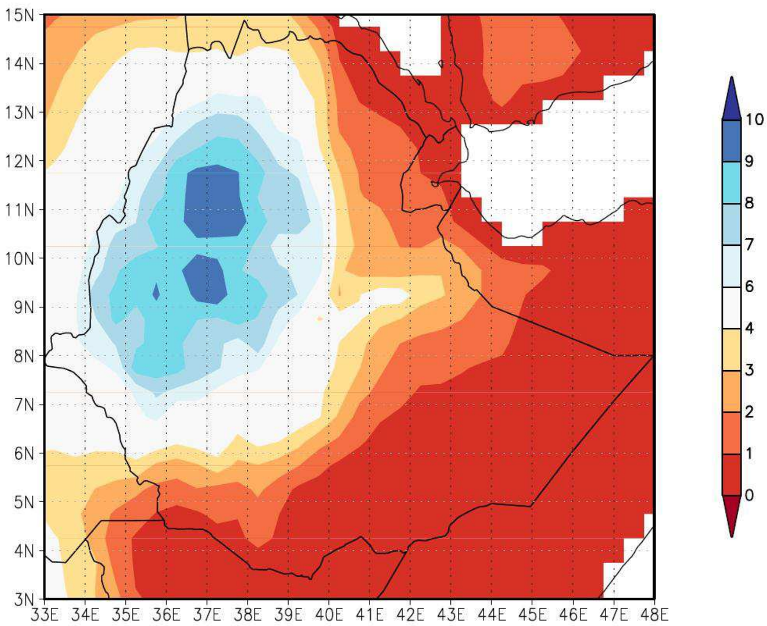


Figure 6. *TotalJJAS rainfall (mm/day) climatology over Ethiopia.*

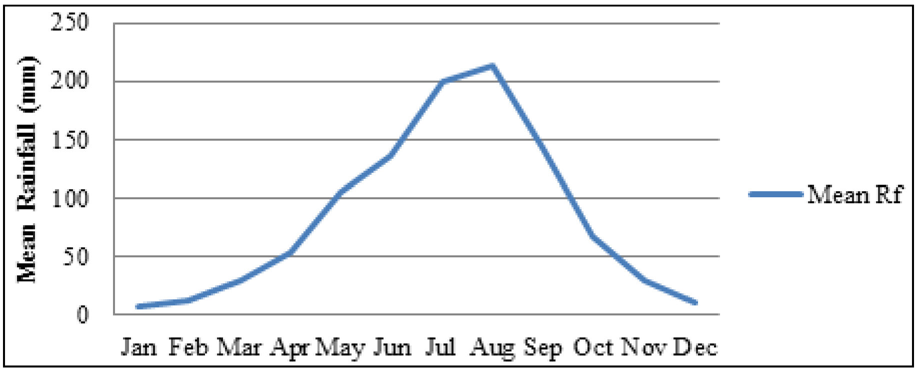
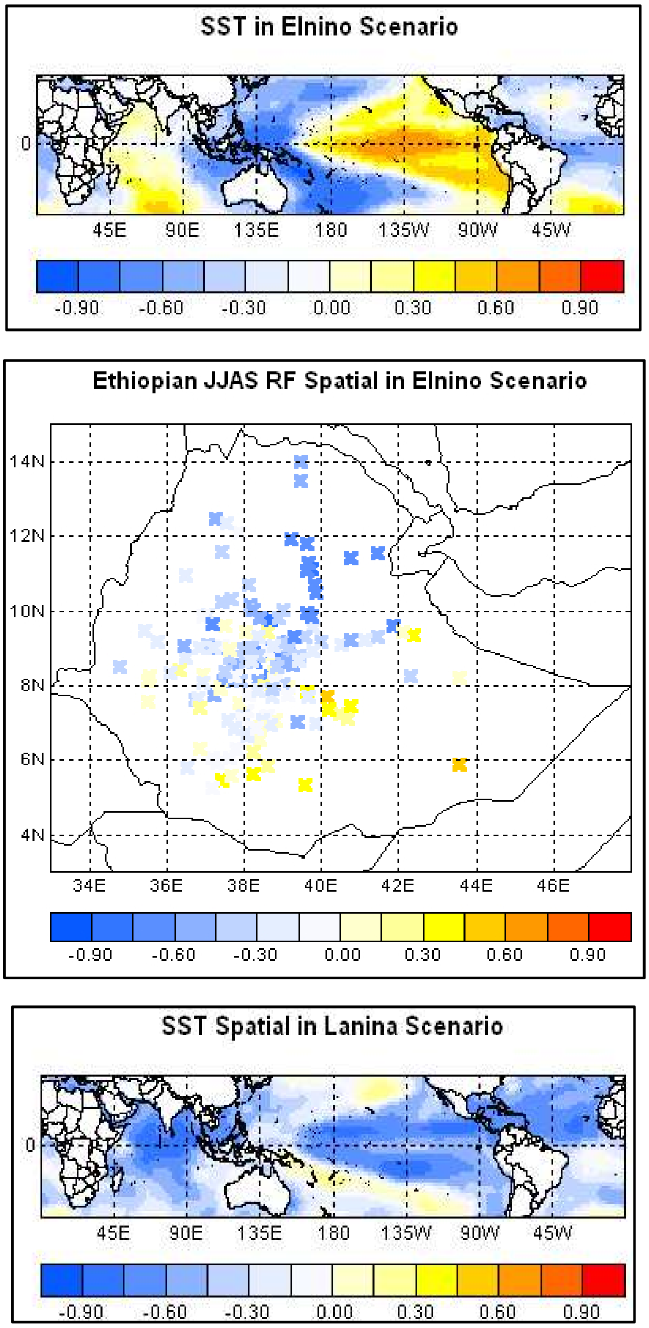


Figure 7. *Ethiopian annual cycle of Rainfall (mm), 1970-2006: northwest, west and southwestern.*



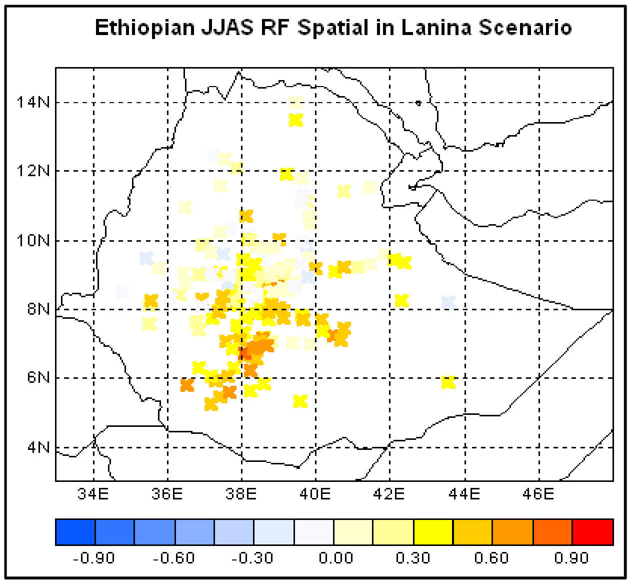


Figure 8. *spatial loading pattern relating Ethiopian JJAS rainfalls to tropical SST, for (top) El Niño and (bottom) La Niña.*

ENSO. El Nino is associated with below-normal JJAS rainfall in most of Ethiopia (exception: the southeast lowlands), while La Nina linked with above normal. Canonical Correlation: 0.6799

3.3. Rainfall Predictability

Since more than two dekades analogue technique are used in operational climate prediction in Ethiopia, the current ENSO patterns and SST patterns over the Atlantic and Indian Oceans, used as input for seasonal climate prediction. The method had a good forecast result during the entire periods. On the other hand Canonical Correlation Analysis (CCA) applied to predict seasonal rainfall over Ethiopia using global sea surface temperature (SST) predictor data and historical monthly total Ethiopian rainfall as well as merged both satellite and rain gauge rainfall data predictand data,It is found that in general, ENSO is the main source of predictive skill for Ethiopian seasonal rainfall. As a result, the rainfall predictability using CCA the forecast and observation are shown (Fig. 9 & 10).

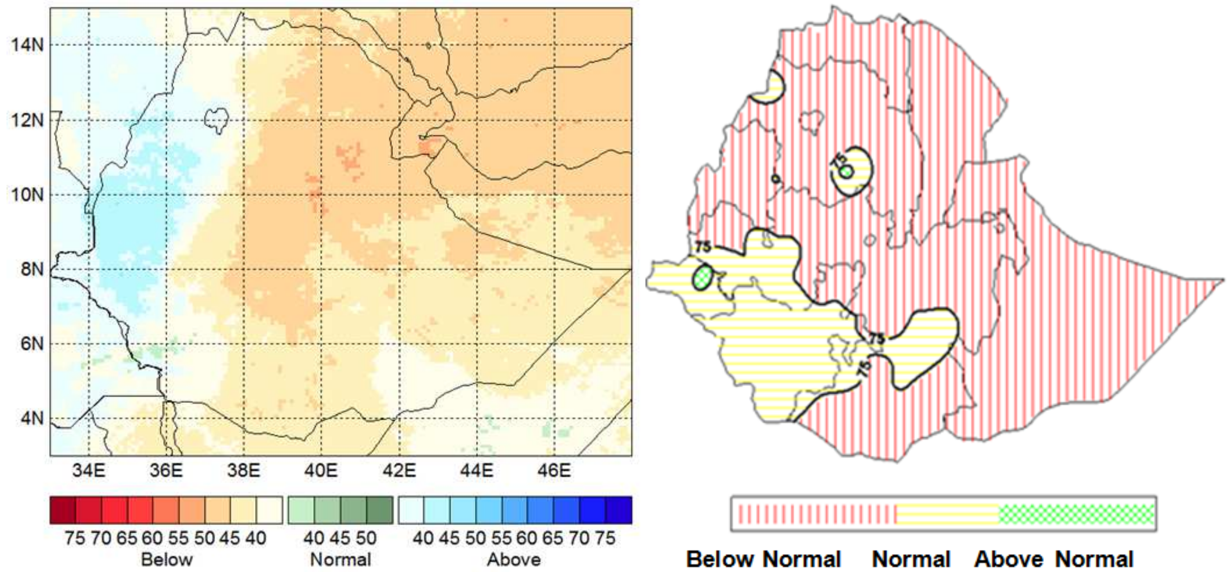


Figure 9. Spatial 2009 Ethiopian FMAM rainfalls for (top) forecast and (bottom)Observation.

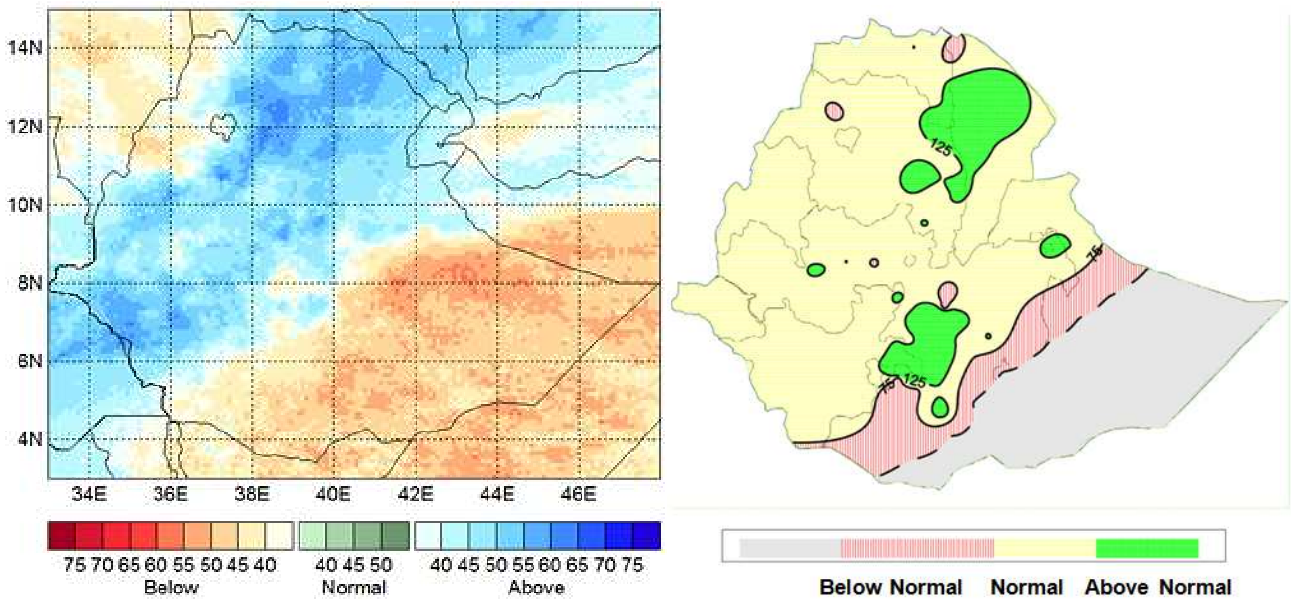


Figure 10. Spatial 2014 Ethiopian JJAS rainfalls for (top) forecast and (bottom) Observation.

In both seasons the forecast and the observed one are in agreement over much of the country however, some discrepancy over northwestern parts of the country.

4. Conclusion

- Apart form this paper many studies had been made ENSO and Ethiopian seasonal rainfall relationship this paper reconfirmed linkage between ENSO and Ethiopian seasonal rainfall with Climate Prediction Tool (CPT) using Canonical Cooroloation Analysis (CCA)
- Factors other than the state of tropical Pacific Ocean SSTs may influence regional climate variability (including internal atmospheric dynamics, SST in other ocean basins and land surface conditions). Therefore, impacts noted below may not necessarily be caused directly by El Niño and La Niña but appear consistent with the event.
- In this paper diagnosed seasonal rainfall, Kiremt and Belg (JJAS and FMAM) model skills, the models skills are good over much of the country
- The relative skill of empirical approach is better than dynamical approach for Ethiopian seasonal rainfall
- In addition to traditional, analouge methode there is a possiblity to develop operational statistical seasonal rainfall forecasting model using CPT,CCA

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