Future climate of Ethiopia from PRECIS Regional Climate Model

Experimental Design

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PRECIS Regional Climate Model Experimental Design over Ethiopia

1. Background

1.1 Rainfall Regimes in Ethiopia

The rainfall regime in Ethiopia is characterised as uni-modal and bi-modal systems influenced by topographical variation in the country, seasonal cycles and opposing responses to regional and global weather systems, consequently, three rainfall regimes are commonly identified (Figure 1).

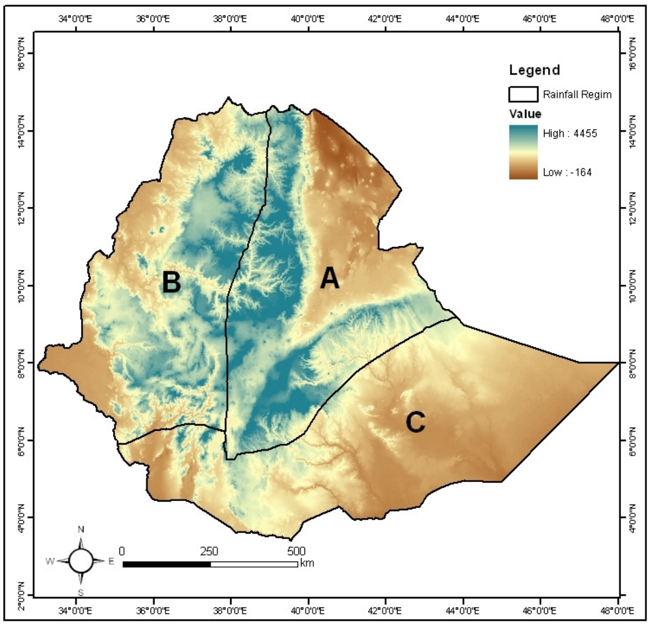


Figure 1. Topographic map of Ethiopia showing Rainfall Regimes (Modified from NMSA, 1996)

Regime A that comprises the central and the eastern part of the country has a bi-modal rain classified as the long rainy season (June –September) and short rains (March-May) locally referred as *Kiremt* and *Belg* rains respectively (Figure 2). The rest of the months (October to February) are dry period.

Regime B in the western part of the country (from southwest through to northwest) has a mono-modal rainfall pattern (June – September), and the rainy period ranges from February through November mainly in the western and south-western part of the country (Figure 3), and decreases northwards (Figure 4).

Regime C that comprises the south and south-eastern part of Ethiopia has two distinct wet and dry seasons. The main rain season is from February through May, and short rains from

October to November, and the dry periods are June to September and December to February (Figure 5).

Figure 2. Mean monthly rainfall distribution for Central and Eastern Ethiopia (Region A)

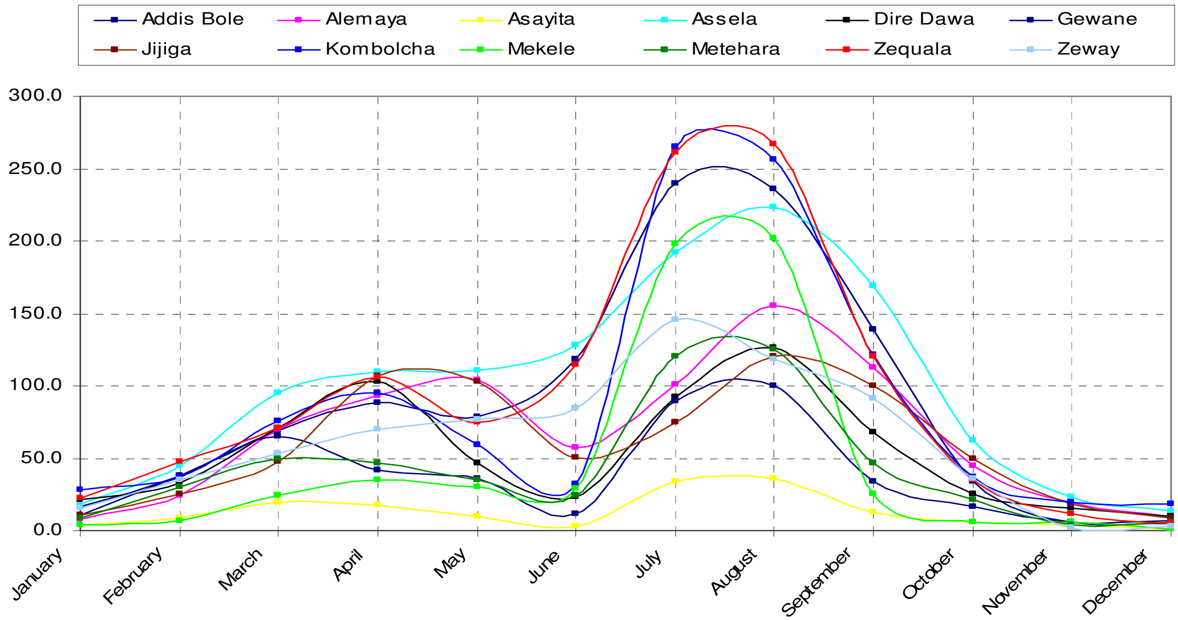


Figure 3 Mean monthly rainfall distribution for the western Ethiopia (Region B1)

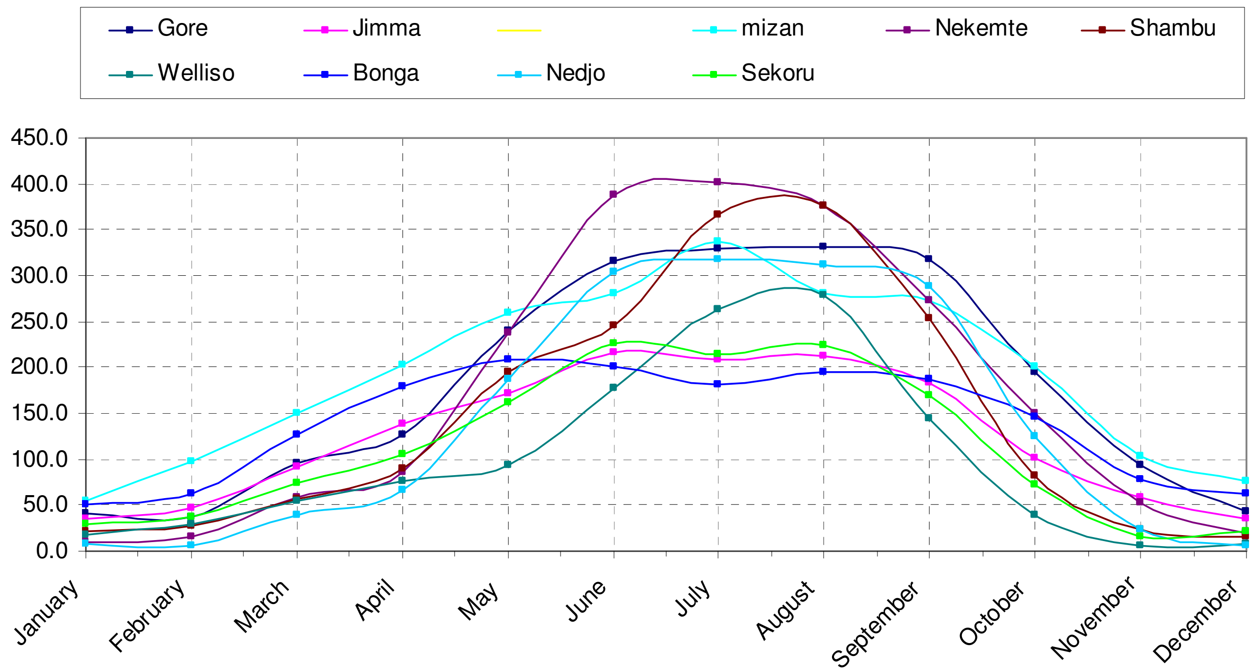


Figure 4 Mean monthly rainfall distribution for north-western Ethiopia (Region B)

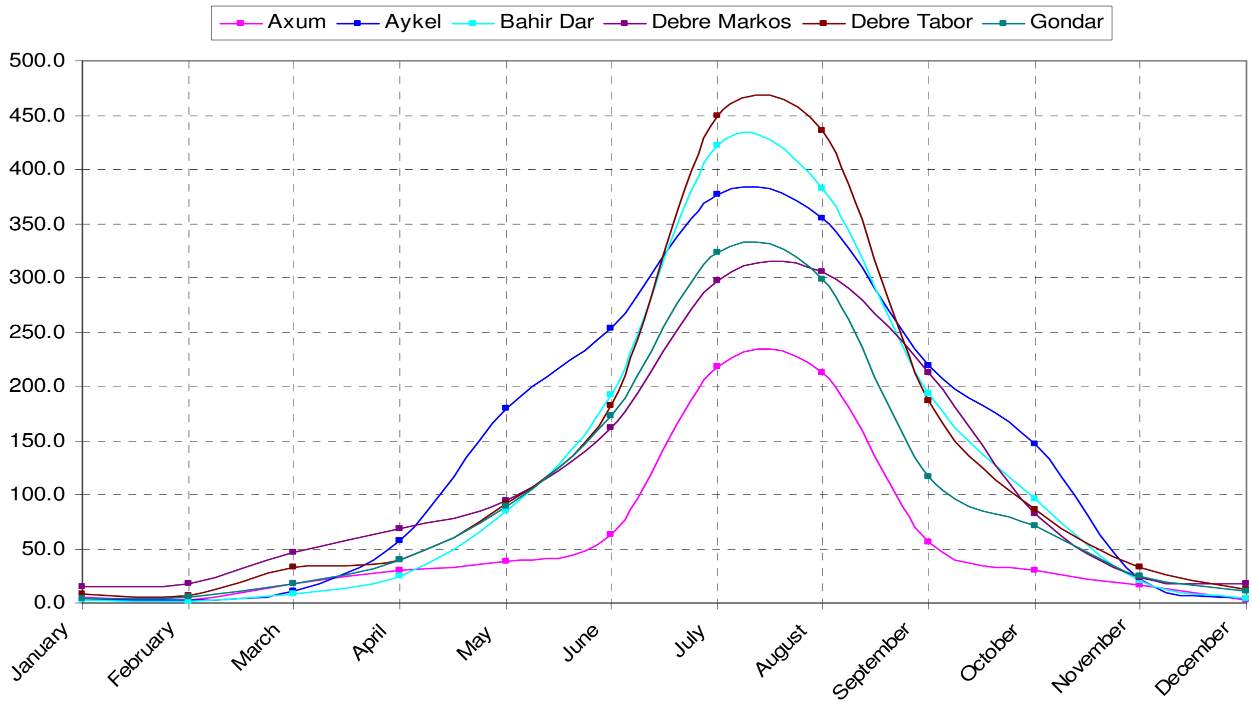
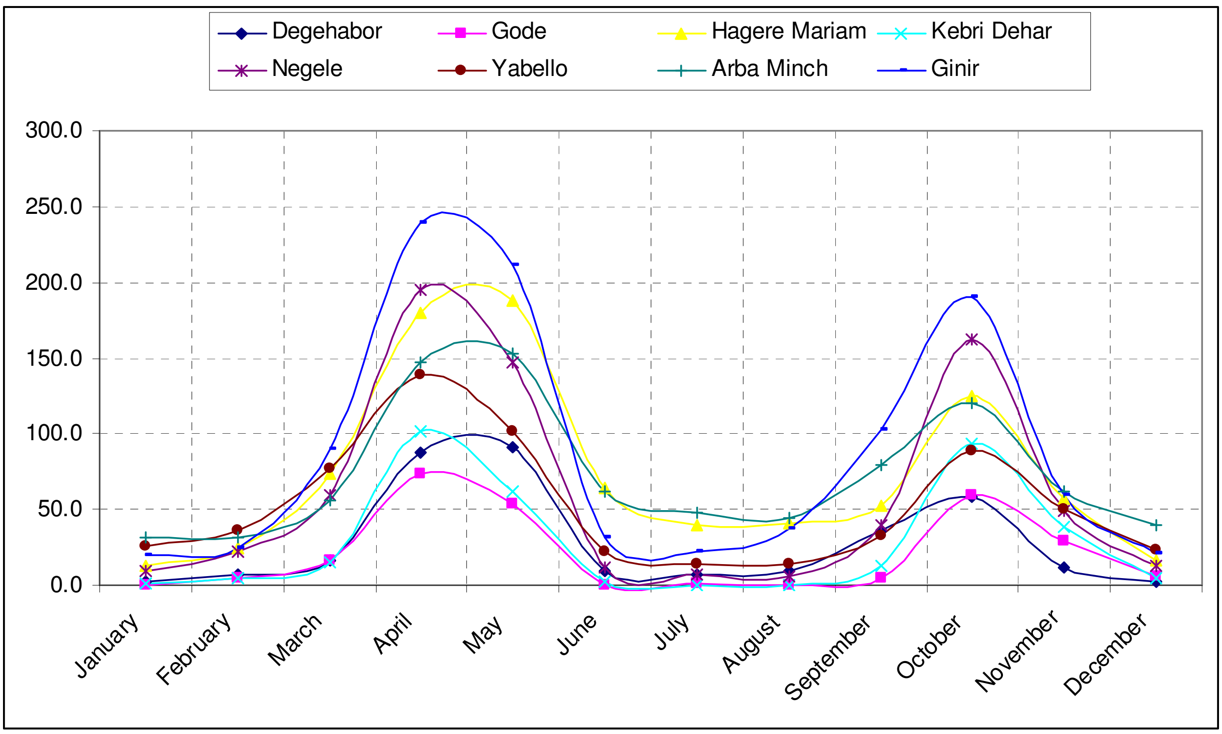


Figure 5 Mean monthly rainfall distribution for Southern and South-eastern Ethiopia (Region C)



1.2 Local and regional factors affecting rainfall in Ethiopia

As reviewed in section 1.1 above Ethiopia has different rainy seasons influenced by topographic variation and rain-bearing system as discussed below.

1.2.1 Topographic variation

Ethiopia is located between $3^{0}15'$ to18^{0}N and 33^{0} to 48^{0}E above the equator. 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 see Figure 1 topographic map of Ethiopia under section 1. As a result of the topographic variation and geographical location, rainfall in Ethiopia characterised by high spatial and temporal variability. Generally speaking, the amount of rain over the mountain areas is higher than the lowlands, with the maximum rain received over the southwest and the minimum over southeast of the country.

1.2.2 Regional weather features affecting the climate system in Ethiopia

The rainfall seasons in Ethiopia influenced by different factors. *Kirmet* rain (JJAS) is the main rainy season for most part of the country except in the south and south-eastern, where the *Belg* rain (MAM) is the main rainy season. Southern and south-eastern part of the country characterised by bi-modal seasonal cycle and receives short rain during SON, which is *Beg* (Dry) season for the rest of the country. The rainy seasons in Ethiopia are influenced by different global and regional rain-bearing factors.

The main features that affect the *Kiremt* rain include the ITCZ, Tropical Easterly Jet (TEJ), South Atlantic Ocean and South West Indian Ocean anticyclone, East African Low Level Jet (EALLJ) or Somali Jet and ENSO.

The global and regional weather features that affect the *Belg* rain includes the ITCZ, Subtropical Westerly Jet (SWJ) stream, Arabian High, the frequency of tropical cyclones over the Southwest Indian Ocean and ENSO.

2. Climate Change Scenario

Climate change modelling should take into account the spatial and temporal variability of climate in the specific region or location attributed to various factors which include the topographic variations across the region or location and the different regional and local weather systems at large and meso-scale.

General circulation models (GCM) are the most advanced tools currently available for simulating the responses of the global climate system to increasing greenhouse gas concentrations, however its use is limited due to the inability to explicitly simulate meso-scale process because of its cores-resolution. Regional climate model (RCM) grid boxes for climate projections are 50 km or less, a higher resolution than GCMs, and able to capture many regional and local features that GCMs cannot.

The overall aim of this research is to investigate the impact of the anthropogenic climate change on the local climate variables in the different climatologically regions of Ethiopia, and the impact of these changes on natural resources (grass pasture and water resources) specifically in the southern semi-arid regions of the country (Figure 6). Pastoralism is the major livelihood system in the southern semi-arid regions of Ethiopia, and therefore research on the impact of climate change on pasture and water resources are very crucial for vulnerability and adaptation policies.

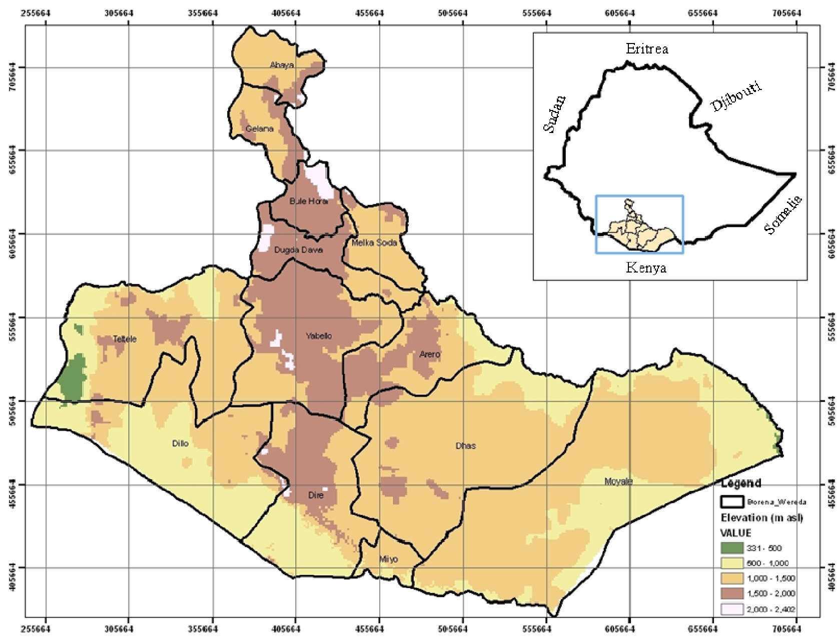


Figure 6. Boran Plateau: Climate change Vulnerability and Adaptation study area

3. Specific Research Objectives

1. To investigate future climate change scenario in the different climatological zones of Ethiopia (categorised according to the homogenous climatologically characteristics) using PRECIS Regional Climate Modelling.

2. To investigate the impact of future climate change scenario on vegetation and water resources (ground water and runoff) in the southern semi-arid region (Borana Plateau) of Ethiopia using the PRECIS RCM out puts for pasture and water impact assessment models.

4. PRECIS RCM Experimental design and Analysis method

4.1 Domain

Domain size selection has taken into consideration the topographic variation across the country and the large-scale features influencing the local weather and climate system in Ethiopia as discussed under section 1.2.1 and 1.2.2 above. As a result, the model's domain made large enough to ensure that these features are included.

4.2 Resolution

In order to appropriately capture the spatial and temporal climate variability in the different climatological zones, influenced by the topographic variation and the different weather system, the experiment will run at 0.22^0 by 0.22^0 (25km by 25km) resolution.

4.3 Experimental period, Driving Data and Emission Scenario

4.3.1 Model: The experiment will be run using two RCM models namely HadCM3Q0 and ECHAM5 to compare outputs of future climate scenario from the different models and account for model uncertainties.

4.3.2 Experiments

4.3.2.1 Model validation

Before using RCM models to investigate the future climate scenario, it is necessary to evaluate how well models represent the present climate. There are different options to validate the appropriateness of a model (s) to simulate local climate. In this research two options are proposed as discussed below.

Option1. An approach in which RCM is driven by observation and compared with observation.

RCM experiments run for 'present day' using ERA40 reanalysis data as boundary condition, and compared with corresponding period observation data from meteorological stations. Model simulated and observed mean monthly, seasonal and annual time series climatology (precipitation, temperature and extremes) computed and compared.

Data and experiments:

- **Observed meteorological station data:** Climatological data as total monthly rainfall in millimetres (mm) and monthly minimum and maximum temperature in C^0 for the years 1952 to 2009 from 52 stations were obtained from the National Meteorological Services Agency (NMSA) of Ethiopia. However, the quality of data varies among the stations in terms of the time span and missing records. In order to set a representative 'present day' climate period it is important to set criteria to select stations. In this case at least 3 or more meteorological stations that has less than 20% missing data per homogenous climatelogical zone with in any given 30 years recent past time span considered as a criteria to set 'present day' climate period. Accordingly, the number of stations and percentage of missing data during the 1961 -1990 and 1971 – 2000 time series from 52 meteorological stations evaluated. As a result, overall 14 stations for 1961 – 1990 and 24 stations for 1971 – 2000 time series meets the set criteria (see Table 3). Therefore, the 1971 – 2000 time series selected as the recent past climatological baseline period. Meteorological stations representing the different climatological zones with similar annual cycles having less than 20% missing data within the 1971 – 2000 time series has been selected for this study. This data will be used for RCM model validation and as input for impact model.

- **ERA40:** RCM experiment run for 'present day' using EAR40 reanalysis data that corresponds to the same 'present day' time span (1971 – 2000) of observed data from meteorological station as its lateral boundary condition. ERA40 data sets of daily precipitation for analysis of extreme precipitation, and monthly, seasonal and annual averages for analysis of precipitation and temperature will be used to validate the model.

The quality of ERA40 reanalysis data in estimating spatial, seasonal and inter-annual variability of rainfall for *Kiremt* (JJAS) and *Belg* (FMAM) seasons in Ethiopia has been tested (Diro et al 2009). According to the finding of this evaluation ERA40 captures well the spatial pattern of the rainfall climatology, although it overestimate the particularly the *Kiremt* mean rainfall in the northwest, west and central regions, and underestimate in the south and east. ERA40 also captures well the annual cycle over most of the country but exaggerated *Kiremt* peak in the northwest and west.

- **Model simulated versus observational data analysis and comparison:** compute and compare 'present day' climatology from RCM forced by ERA40 re-analysis data and observed data from meteorological stations as follows:

1. **Precipitation:**

1.1 Spatial variability:

a. model versus observation mean spatial distribution over the whole domain
    - Analysis Method / Tools
b. model versus observation mean spatial distribution of seasonal *Kiremt* (JJAS), *Belg* (FMAM) and *Bega* (ONDJ) precipitations for the different rainfall regimes.
    - Analysis Method / Tools

1.2 Temporal variability:

a. Annual rainfall cycle (monthly rainfall) averaged over the different rainfall regimes.
    - Analysis Method / Tools
b. Inter-annual rainfall variability for the different rainfall regimes.
    - Analysis Methods / Tools

2. **Temperature:**

2.1 Spatial variability:

a. model versus observation mean spatial distribution over the whole domain

- Analysis Method / Tools

b. model versus observation mean spatial distribution of seasonal *Kiremt* (JJAS), *Belg* (FMAM) and *Bega* (ONDJ) precipitations for the different rainfall regimes.

  - Analysis Method / Tools

2.2 Temporal variability:

a. model versus observation mean monthly temperature comparison for the different climatologically regimes.

  - Analysis Methods / Tools

b. model versus observation mean annual temperature comparison for the different climatologically regimes.

  - Analysis Methods / Tools

c. model versus observation mean monthly minimum and maximum comparison for the different climatologically regimes.

  - Analysis Methods / Tools

3. **Extreme Precipitation:**

The ability of HadCM3Q0 and ECHAM5 to reproduce extreme precipitation events under current climate condition will also be assessed. Extreme precipitation indices that will be analysed includes Maximum number of Consecutive Dry Days (CCD), Number of heavy precipitation days (R10), Maximum 5 day precipitation amount (R5d) and Extreme rainfall (R95p). The following experiments will be carried out to assess and validate the model for extreme precipitations.

a. RCM experiment forced by ERA40 re-analysis data described above will be performed. ERA40 re-analysis quasi-observed data sets for daily precipitation for 'present day' (1971 – 2000) will be used as lateral boundary condition to test the skill of the model in simulating extreme events.

b. Observational data sets for daily precipitation from CRU for the same time span of validation period will be used to analyse trends in observed extreme precipitation.

Option2. RCM driven by GCM compared with RCM driven using observation data:

Baseline RCM experiment driven by HadCM3Q0 and ECHAM5 (GCMs) lateral boundary data for present day climate (1971 – 2000), will be compared to the RCM forced by ERA40 re-analysis data for the same period (1971 - 2000).

4.3.2.2 Recent past to future climate scenario

Two RCM experiments in transient mode that integrate the recent past to the future (1950 - 2050) will be run under SERES A1B scenario using HadCM3Q0 and ECHAM5 as lateral boundary condition.

Output Variables	**Analysis**
1. **Precipitation**	
1.1. Spatial variability	• Mean annual spatial distribution and percentage change over the whole domain. • Mean seasonal spatial distribution and percentage change for *Kiremt* (JJA), *Belg* (MAM) and *Bega* (SON) season precipitations for the different rainfall regimes; • Mean spatial distribution and percentage change of seasonal precipitation of the MAM and SON seasons in the southern part of Ethiopia.
1.2 Temporal variability	• Mean monthly changes for the different rainfall region calculated and statistically analysed • Mean seasonal changes for the different rainfall region calculated and statistically analysed • Mean annual changes for the different rainfall region calculated and statistically analysed.
2. Temperature	
• Spatial variability	• Mean annual spatial distribution and change in temperature for the whole domain • Mean seasonal spatial distribution and absolute change in

Output Variables	Analysis
	temperature for JJA, MAM and SON and DJF seasons for the different climate zone; • Mean spatial distribution and absolute changes in temperature for DJF, MAM, JJA and SON seasons in the southern part of Ethiopia.
• Temporal variability	• Mean monthly temperature changes for the whole domain calculated and statistically analysed • Mean monthly temperature changes for each climatic zone calculated and statistically analysed. • Mean monthly minimum and maximum temperature for the whole domain calculated and statistically analysed • Mean monthly minimum and maximum temperature for each climatic zone calculated and statistically analysed.
3. Extreme precipitation: analysis will focus only for the southern region of Ethiopia	
• Maximum number of consecutive dry days (CCD) when $R_{day} < 1$mm	Spatial distribution and trends of CCD index for southern region of Ethiopia calculated and statistically analysed
• Number of heavy precipitation days (R10) when $R_{day} \geq 10$ mm	Spatial distribution and trends in number of heavy precipitation days in southern region of Ethiopia calculated and statistically analysed
• Maximum 5 day precipitation amount (R5d)	Spatial distribution and trends of R5d in southern region of Ethiopia calculated and statistically analysed
• Extreme rainfall (R95p)	Spatial distribution and trends of extreme rainfall in southern region of Ethiopia calculated and statistically analysed
4. Relative humidity	Input for water impact model
5. Wind speed	Input for water impact model
6. Radiation	Input for water impact model

5 Summary of experiments to be carried out:

No.	Experiment type	Domain	Resolution (km)	Data Period	Driving conditions	
					SRES	LBCs Data
1	Validation	Ethiopia	50	1971 - 2000		ERA40
2	Validation (for extremes)	Ethiopia	50	1971 - 2000		CRU
2	Validation	Ethiopia	50	1971 - 2000		HadCM3Q0
3	Validation	Ethiopia	50	1971 - 2000		ECHAM5
4	Transient climates	Ethiopia	50	1961 - 2050	SRESA1B	HadCM3Q0
5	Transient climates	Ethiopia	50	1961 - 2050	SRESA1B	ECHAM5

6 Resource (Computer) to run the experiment: new machine

Processor (CPU)	Intel® Core™ i5 CPU M430 @2.27GHz
Speed	2,267.00 MHz
Cores	4
RAM	2.8GB
Hard Disk	271GB

7 Impact assessment

The out put of RCM experiment will be used to investigate the impact of future climate scenario on the grass pasture (vegetation) and water resources, specifically ground water (which is the main sources of water for human and livestock in the semi-arid regions in the southern part of Ethiopia) and runoff. It is intended to use CENTURY and Soil-moisture Balance Model (SMBM) impact models to study the impact of future climate scenario on pasture and water respectively.

7.1 Climate information needed for the impact assessment:

- Pasture (Vegetation) impact: CENTURY model
  - Monthly average maximum and minimum air temperature
  - Monthly precipitation
- Soil-moisture Balance Model (SMBM)
  - Precipitation
  - Temperature
  - Wind speed
  - Relative Humidity
  - Net Radiation

7.2 Impact experiment

(a) Observed climates: 1971 – 2000 baseline experiment using ERA40 reanalysis data

(b) RCM baseline climate: 1971 – 2000 RCM experiment using HadCM3Q0 as driving boundary condition.

(c) RCM future climate: 2020 – 2050 using A1B SRES scenarios as driving condition and HadCM3Q0 providing lateral boundary data

(d) Future climate scenario for impact study will be calculated as:

Value of observed climate plus (Value of RCM future climate minus value of RCM baseline climate).

7.3 Impact analysis: impact of the future climate scenario will be assessed by comparing the impact of baseline climate against the impact of the future climate scenario, this can mathematically expressed as:

- Baseline climate impact = Impact model run using baseline climate (a - above)……………………………………………………………………..(X)
- Future climate impact = Impact model run using future climate scenario (d-above)…………………………………………………………………..….(Y)
- Future impact is the difference between X and Y

Table3. Meteorological stations representing the different climatological zones

Regions	1961 - 1990			1971 - 2000		
	Stations	**Data Years**	**Missing Data (%)**	**Stations**	**Data Years**	**Missing Data (%)**
Central and Eastern (A)	Addis Ababa		8.61	Addis Ababa		0.00
	Dire Dewa		0.00	Assela		10.28
	Jijiga		3.06	Awassa		5.00
	Kombolcha		0.00	Bati		1.67
	Mekele		10.56	Dire Dewa		0.83
	Mille		8.89	Harare		12.50
				Jijiga		5.83
				Kombolcha		0.28
				Mekele		12.22
				Mille		8.06
				Zewaye		0.28
North-western (B1)	Debre Markos		0.56	Baher Dare		0.83
	Gonder		8.06	Debre Markos		0.83
				Gonder		1.39
Western (B2)	Asosa		8.89	Bedele		10.28
	Gore		2.78	Gore		0.00
	Jimma		6.94	Jimma		0.00
				Nekmete		11.93
				Shambu		8.33
South and South-eastern (C)	Dege Habure		11.67	Dege Habure		12.22
	Kebridehar		13.06	Ginir		10.56
	Negele		9.17	Jinka		7.50
				Kebridehar		18.61
				Negele		7.78