Ⓞ Environmental Systems Research

CrossMark

Ethiopian summer temperature from the global circulation model output data and its outlooks

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Abstract

Background: Agriculture is the most susceptible sector to climate change related hazards in Ethiopia. Any minor change in temperature from the normal conditions imposes a severe challenge on the agricultural dependent people of Ethiopia. This research work, entitled *'Ethiopian Summer Temperature from the Global Circulation Model Output Data and its Outlooks'* has been conducted to fill such knowledge gaps of the target population. The objective of the research was to analyze summer temperature from the global circulation model output data and its outlooks with the change of global climate. To attain this specific objective, global circulation model output data were used. These data were analyzed by using Xcon, Matlab and Grid Analysis and Display System computer software programs.

Results: The results revealed that the mean temperature has shown a general increasing trend (0.548 °C) since 1971–2010. The best performed models having similar trends to the historical observed temperature data analysis predicted that the future summer mean temperature has been predicted to increase by 0.59 °C (model *bccr*) and 0.743 °C (model *cccma*) from 2015 to 2054.

Conclusion: It is therefore recommended that the legislative bodies and development planners should design strategies and plans by taking into account impacts of increasing temperature on rural livelihoods. Moreover, adverse impacts of climate change and adaptation strategies should be a crosscutting issue.

Keywords: Global circulation model, Climate change, Temperature, Ethiopian summer

Background

Model simulations show wide disagreements in projected changes in the amplitude of future climate conditions (Temesgen et al. 2014). Ethiopian highlands seasonal rainfall in particular and East Africa's seasonal rainfall can be strongly influenced by the surface temperature and pressure variations across the tropical eastern pacific ocean warming and cooling (El Nino and La Ninas) respectively. And this attribute to ambiguity in climate forecasts, predominantly in the future inter-annual variability (McSweeney et al. 2008).

According to IPCC (2001a) report, Africa had already warmed by 0.7 °C over the twentieth century. Many researches based on the outputs of general circulation models (GCMs) showed that the continent could be warming by temperature ranging from 0.2 °C per decade (low scenario) to more than 0.5 °C per decade (high scenario) (McSweeney et al. 2008).

Simulation of future climate for 2030 and 2050 Canadian Climate Center Model, CCCM; Geophysical Fluid Dynamics Laboratory Model (GFDL), the United Kingdom Meteorological Office-1989 model, (UKMO-89); and GFDL-Transient Models indicated an increase in temperature and a decrease in rainfall over Ethiopia (NMSA 2001). According to this simulation study, there will be an increase in temperature and a decrease of rainfall by about 1 and 2% by 2030 and 2050, respectively. These changes in rainfall and temperature are expected to decrease revenue per hectare. Although the exact nature of the changes in weather conditions, and extreme events are not known and still controversial, there is general

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consensus that extreme events will increase and may get worse (UNFCCC 2006). According to IPCC (2001a, b), changes will be manifested in some extreme climate phenomena indicating that extreme events, including flood and drought, will be increasingly frequent and severe in Africa, particularly in the Horn of Africa where Ethiopia is the core. According to Elasha et al. (2006), frequently occurring types of disasters in Ethiopia is drought, flood, landslide, thunderstorms accompanied by lightning and hail, frost, forest fire, and earthquake. The first two are the most common. Associated with adverse weather conditions, outbreaks of locusts (on crops), tsetse fly (a vector for trypanosomiasis), human disease outbreak like yellow fever, malaria and meningitis were also observed. Flooding and drought are now common across Ethiopia. It is probable that the increased frequency of recorded disasters results from a combination of climatic change and socioeconomic and demographic changes (UNFCCC 2006).

GCMs have been employed to study the impacts of increased greenhouse gas concentrations on future climate conditions. The model data estimates changes for dozens of meteorological variables for grid boxes that are typically 250 km in width and 600 km in length or (2.5°latitude and 3.75°longitudes). Their resolution is therefore quite coarse. The most advanced GCMs couple atmosphere and ocean models and are mentioned to as coupled ocean–atmosphere GCMs (Schindelegger and Ray 2014). Two types of GCM runs can be useful for impact assessments.

Almost all GCMs have been practiced to simulate both current (1CO_2) and future (2CO_2 or occasionally 4CO_2) climate conditions. The difference between these simulated climates is a scenario of how climate may change with an effective doubling (or quadrupling) of atmospheric CO_2. Hence, it is referred to as equilibrium experiments since both the current and future climates are assumed by modelers to be in equilibrium i.e., stationary. GCMs used for equilibrium experiments generally have just a very simple representation of the oceans. To be sure, the climate is never in equilibrium (Schindelegger and Ray 2014). Greenhouse gas concentrations are not kept constant, because of human activities or other causes. The assumption of a stable climate makes it milder; however, climate modelers applied to calculate the effect of increased greenhouse gases on climate and for impact assessors to examine potential influences.

Hence, the specific objectives of this research was to examine the global circulation model output temperature data over Ethiopian summer for the past 40 years (1971–2010) and its 40 years future predictions (2015–2054).

Materials and methods

Description of the study area

Ethiopia is located in Northeastern or East Central Horn of Africa lying between 3 and 15° north latitude, 33 to 48° east longitude. Ethiopia is bordered in the east Somalia and Djibouti, in the south by Kenya, in the northeast by Eritrea and in the west by the North and South Sudan. The country has a total area of about 1.1 million km^2 and comprises of 12 river basins with varying size and water resource potential (CSA 2007). Diverse rainfall and temperature patterns are largely the results of Ethiopia's location in Africa's tropical zone and the country's varied landscape. Elevation induced climatic conditions form the basis for three environmental zones as cool, temperate, and hot, which have been known locally as *dega*, *weinadega*, and *kolla*, respectively. The central parts of the western and eastern sections of the northwestern plateau and a small area around *Harer* are covered the cool zone. The topography in these areas is generally above 2400 m.a.s.l. in altitude; average daily highs ranges from near freezing to 16 °C. Areas between 1500 and 2400 m.a.s.l. in elevation constitute the temperate zone. Daily highs range from 16 to 30 °C. The hot zone consists of areas where the altitude is lower than 1, 500 m.a.s.l. This part of the region encompasses the eastern *Ogaden*, *Denakil* depression, the deep tropical valleys of the Blue Nile River and the peripheral areas along the South Sudanese and the Kenyan borders (UNEP 2007).

The computer software programs which were used for this study are *Matlab* (Mathematical modeling), Grid Analysis and Display System and Xcon (X converter).

Methods

For the accuracy and reliability of the real climate situation of the study area, observed climate station data from different sites and more sophisticated and recent models' output data were used. GCMs output data were used to simulate the climatic effect of increased atmospheric concentration of greenhouse gases (GHGs) and the climate model output was interpolated to the scale of Ethiopia using a regular grid bilinear interpolation method. The interpolated climate data were consisting of IPCC core variable such as temperature in the study area. This was determined by the local knowledge and experts' opinion of the study area. The performance of GCM was evaluated and the best model, which has a high hit rate for the observed data was used to predict the future temperature.

GCM output data acquisition

For the period from 1971 to 2010 and from 2015 to 2054, appropriate scenarios were selected based on the data availability. These data represent a subset of the

IPCC model output archive run by Program for Climate Model Diagnosis and Inter-comparison (PCMDI). The complete set of core data variables in monthly temporal resolution was obtained from the IPCC-data distribution center (IPCC-DDC), at the website http://www.ipccdata. org/gcm/monthly/SRES_AR4/index.html. Since the data were developed for global scale and is at a suitable spatial resolution, the extent of Ethiopia was considered for selected high performance model data output. This was done by bilinear interpolation Xcon computer program (Yatagai et al. 2009).

The future climate predictions provide information on the actual values of climatic variables (e.g. temperature, which are common in the study area). On their own, they don't give any indication about the magnitude of change from the present day. That is the reason that the low resolution present day datasets for each corresponding model are required to provide baseline information which allows estimation of the magnitude of climate change.

NCEP data

Observations are from many different sources, including satellites, ship, ground stations, and radar. Currently, earth system research laboratory, physical sciences division (PSD) makes available these reanalysis datasets to the public in standard *netCDF* file format at the website '10.1175/15200477(1996)077%3C0437%3ATNYRP%3E2.0.CO%3B2'. It is possible to extract useful information about rainfall, temperature and humidity observation from satellites, or to infer large-scale features of the global circulation in the early twentieth century using only surface pressure observations available at that time (Compo et al. 2011). Reanalysis is a rapidly evolving field and new reanalysis products benefit from recent modeling capabilities, improved techniques in data assimilation, in the latest observation techniques (i.e. from satellite measurements), and newly digitalized historical datasets (Compo et al. 2011). Reanalysis also allows the user to estimate temperature over regions where in situ observations are not available (e.g. Polar Regions, or large areas of Africa). In recent years, datasets from reanalysis have been widely used for research in the atmospheric and ocean sciences and in climate services. Reanalysis data were downloaded from the website of Earth System Laboratory Physical Science Division (ESL-PSD). This dataset for Ethiopian summer comprises monthly temperature of each year from 1971 to 2010 at a resolution of 0.5° (approximately 55 km at the equator) were downloaded and crucially contains the climate variables which are common parameters to Ethiopia. This period was selected since the observation data before 1971 was not reliable and digital in the case of Ethiopia. It has been since 1971 that modern and standardized meteorological weather instruments were installed by (World Meteorological Organization) WMO standards (NMSA 2007).

Data analysis

In accordance with current best practice for analyzing the outputs of climate modeling exercises, the data from six runs of six different climate models were used. The model name and its origin are stated in Table 1.

A total of 23.6 GB data were downloaded and stored. The data were available in *netCDF* file format which is not a flat file construction, relatively a self-describing multi-layered structure for storing and documenting large amounts of numerical temperature data files. Each file downloaded contains monthly data for all years for the entire earth. In order to extract 'slices' of the multilayered *NetCDF* datasets, it was necessary to use certain tools which were designed specifically for the *NetCDF* file format. The climate data analysis tool was (*Xcon*) was downloaded. Using this software, both temporal (1971–2054) and spatial (from the global scale to Ethiopian latitudinal and longitudinal extent) slices of a *NetCDF* file were extracted. It was important to recognize that from a temporal perspective, what was actually extracted were the monthly normal calculated from the data for 40 years either side of the year of interest. The reason for calculating monthly normal was to eliminate single year anomalies that may show up in the temperature data from a single year only. Due to the spatial sub-setting routine to remove data outside of Ethiopia, in addition to the calculation of monthly normal, the size of this entire data set was reduced from 23.6 GB to 210 MB. Further compression has reduced the total size of the dataset.

The mask file was prepared using excel sheet by putting a zero value for areas not touched and one value for areas covered by the latitudinal and longitudinal extent of Ethiopia. This value was used to limit the study only for the area covered by map of Ethiopia. The mathematical modeling (Matlab) cod (program was developed to calculate the different statistical analysis, such as climatology (clim), standard deviation (sd), root mean square errors (rmse), Coefficient of variations (cv) and correlations (corr) (Fig. 1).

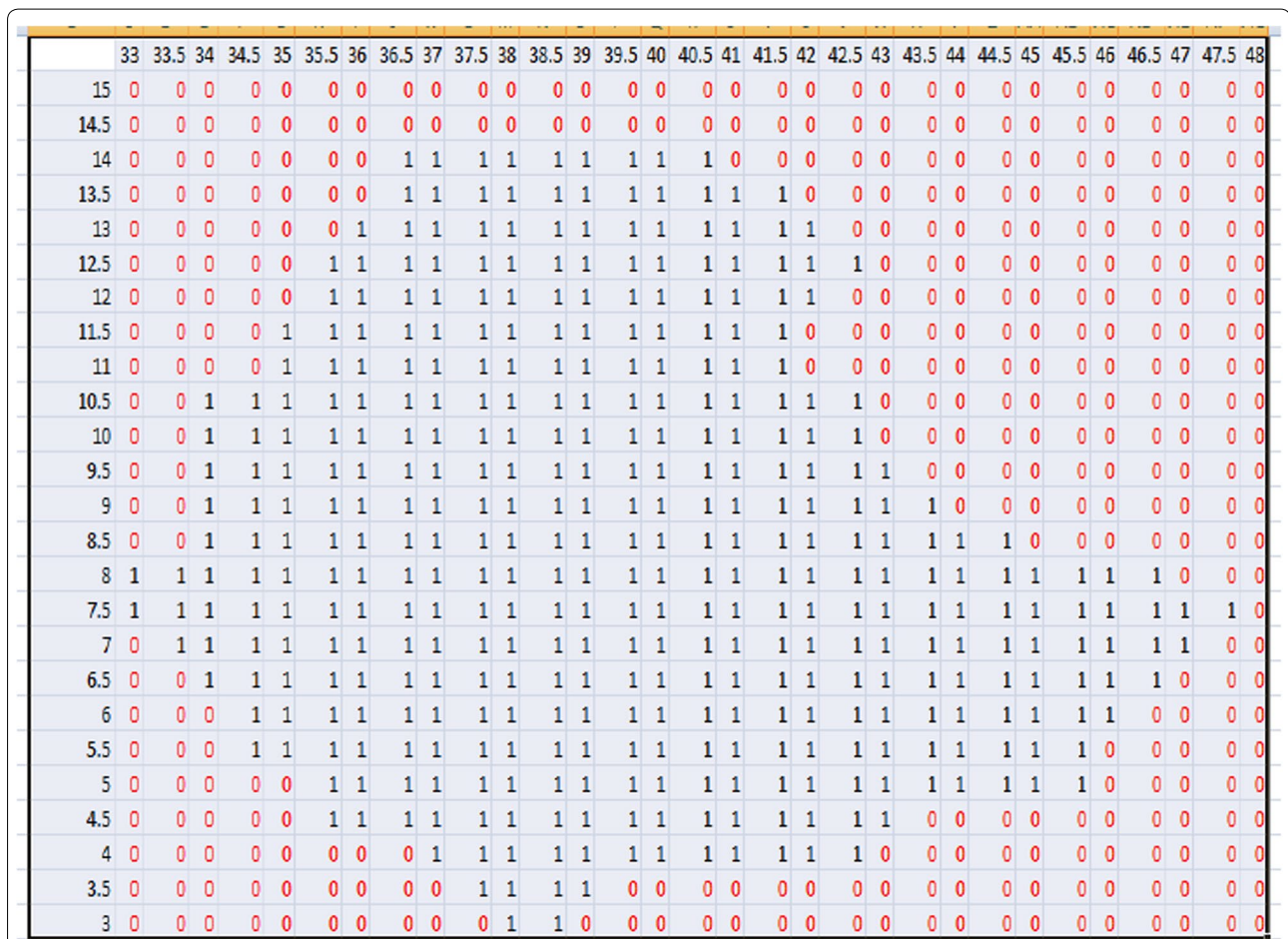## Results and discussions

Summer temperature and GCM output data

The historical temperature record was analyzed by dividing into two periods (1971 to 1990 and from 1991 to 2010 (Legesse 2016). Likewise, the future summer temperature predictions were made based on the period category of 2015–2034 and 2035–2054. Accordingly, each of the sub-period analysis is stated in the following sections.

Table 1 Summary of the models used for temperature variable

Country of run	Model name	Run	Surface air temp. m(tas.)	Max. monthly air surface temp. at 2 m (tasmax.)	Min. monthly surface temp. at 2 m (tasmin.)
Norway	bccr-bcm2.0	1	√	√	√
Canada	cccma_cgcm3_1	1	√		
USA	giss_model_e_r	1	√		
Russia	inmcm3_0	1	√	√	√
France	ipsl_cm4	3	√		
Germany	echam-5	3	√		

	33	33.5	34	34.5	35	35.5	36	36.5	37	37.5	38	38.5	39	39.5	40	40.5	41	41.5	42	42.5	43	43.5	44	44.5	45	45.5	46	46.5	47	47.5	48
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13.5	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
12.5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
11.5	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10.5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9.5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0
8.5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
7.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
7	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0
6.5	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
6	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0
5.5	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0
4.5	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3.5	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Fig. 1 Mask file of Ethiopia

Summer temperature trends (1971–1990)

Even though the standard deviation and coefficient of variation did not Mach, the modal value which has a similar record to the observation (20.58 °C) is *bccr* (20.62 °C) by long year's average (clim.) statistics. Model *inmcm* also has a better record with a coefficient of variations.

The smaller magnitude of *rmse* and bias values by model *inmcm* is found to be (5.201 and 5.132), respectively. Therefore, this model performed well as compared to the rest of the modules (Table 2). Hence, it has been clear that model *bccr* recorded the closet value to an observed temperature record.

Table 2 Statistical analysis of summer temperature (1971–1990)

Model	Clim (°C)	sd	cv	corr	rmse	bais
NNRP	20.575	0.714	3.472			
bccr	20.617	0.335	1.625	0.301	0.693	0.042
cccma	30.583	0.442	1.445	−0.427	12.049	10.008
echam	28.443	1.115	3.920	−0.187	7.998	7.868
giss	26.843	0.273	1.017	0.061	6.313	6.268
inmcm	25.707	0.482	1.876	0.049	5.201	5.132
ipsl	28.446	0.284	0.998	0.142	7.905	7.871

Table 3 POD of models for summer temperature

Model	Worm	Cold	Normal	Combined
bccr	0.5	0.33	0.77	0.65
cccma	0	0	0.7	0.45
echam	0.25	0	0.77	0.55
giss	0.25	0.33	0.54	0.45
inmcm	0.25	0	0.7	0.5
ipsl	0	0	0.46	0.3

Probability of detection (POD)

From the normalized anomaly calculations, the POD value of models has been computed. Accordingly, the warm, cold and normal temperature detection has been captured by model *bccr* (50, 33 and 77%), respectively. The combined detection power of models has also shown that model *bccr* (65%) performed best as compared to others (Table 3).

Based on the observation of the temperature record, most of the years were normal. However, the years 1973, 1978, 1985 and 1988 have been found to be warm; whereas the years 1975, 1983 and 1984 were relatively colder. The model which recorded a similar value was *bccr* as compared to other models (Table 4).

The GrADS generation of the summer temperature has depicted that higher temperature was recorded in the eastern, western and southeastern lowlands of the country by the observation record; whereas, the lower

Table 4 Normalized anomaly of summer temperature

Year	Model						
	NNRP	bccr	cccma	echam	giss	inmcm	ipsl
1971	−0.253	−0.171	−0.240	1.052	−0.940	0.938	−1.356
1972	−0.418	−0.968	0.669	0.222	1.109	1.027	1.206
1973	1.198[b]	1.213	0.589	−0.870	−0.442	0.830	−1.118
1974	0.178	−0.090	0.185	0.238	−0.805	−0.783	2.244
1975	−1.264[a]	0.543	−0.279	0.791	−1.431	0.258	−0.641
1976	−0.874	−2.295	−0.142	−1.060	1.879	−0.643	−0.232
1977	0.596	−0.349	−2.499	−0.590	0.275	−2.158	−0.027
1978	1.532[b]	−0.970	0.128	1.287	1.492	1.212	0.313
1979	−0.077	−1.034	−1.349	−0.313	0.278	0.713	1.155
1980	0.581	−0.079	0.874	−2.735	−0.021	0.976	0.411
1981	−0.079	0.184	0.152	−0.954	−1.711	0.735	0.510
1982	0.462	−0.416	1.373	0.594	1.040	0.392	0.383
1983	−2.329[a]	−1.377	1.781	1.641	0.157	0.707	0.167
1984	−1.557[a]	0.742	0.428	−0.785	0.745	0.245	−0.768
1985	1.357[b]	−0.127	−1.069	−0.861	−1.077	0.252	0.535
1986	0.427	0.816	−0.814	0.584	0.275	−0.050	1.509
1987	0.096	0.502	−0.021	0.720	−1.013	−1.784	−1.195
1988	1.426[b]	2.184	−1.248	0.574	0.699	−0.351	−0.819
1989	−0.855	0.665	1.212	0.018	−1.153	−1.928	−1.341
1990	−0.145	1.028	0.270	0.445	0.645	−0.590	−0.935

[a] Cold years

[b] Warm years

temperature has been recorded in the central highlands. Therefore, in this analysis model *bccr* and *echam* have a similar summer temperature pattern. The rest of the models failed to record Ethiopian summer temperature. Model *cccma* failed to record low temperature, whereas *inmcm* totally failed to capture the high temperature of Ethiopian summer (Fig. 2). Taking this value as a base, we can indicate the future temperature of Ethiopian summer using model *bccr*. In fact the overall value should be used to decide the best performed model for prediction.

Summer temperature trends (1991–2010)

The summer mean temperature record to the observation for the period 1991–2010 was found to be 21.12 °C. The mean temperature has shown 0.55 °C increment from the period 1971–1990. Model value, which has a

similar summer temperature record by clim, is model *bccr* (21.283 °C); whereas, by the sd. value, model *cccma* has similar record than *bccr* to the observed value. In addition, model *echam* has similar record by coefficient of variation than the rest of the models. Moreover, the smaller recorded magnitude value of the rmse and bias value were recorded by model *bccr* (0.862) and (0.160), respectively. Therefore, model *bccr* has a high probability to record summer mean temperature with a similar record to that of the observed (Table 5). This result is in line with the previous period (1971–1990). The overall performance of this model is good and enabled to predict the future summer temperature of Ethiopia. Models such as *cccma, echam* and *ipsl* have over recorded the summer temperature.

The model *bccr, giss* and and *inmcm* have been detected the warm, cold and normal summer temperature from
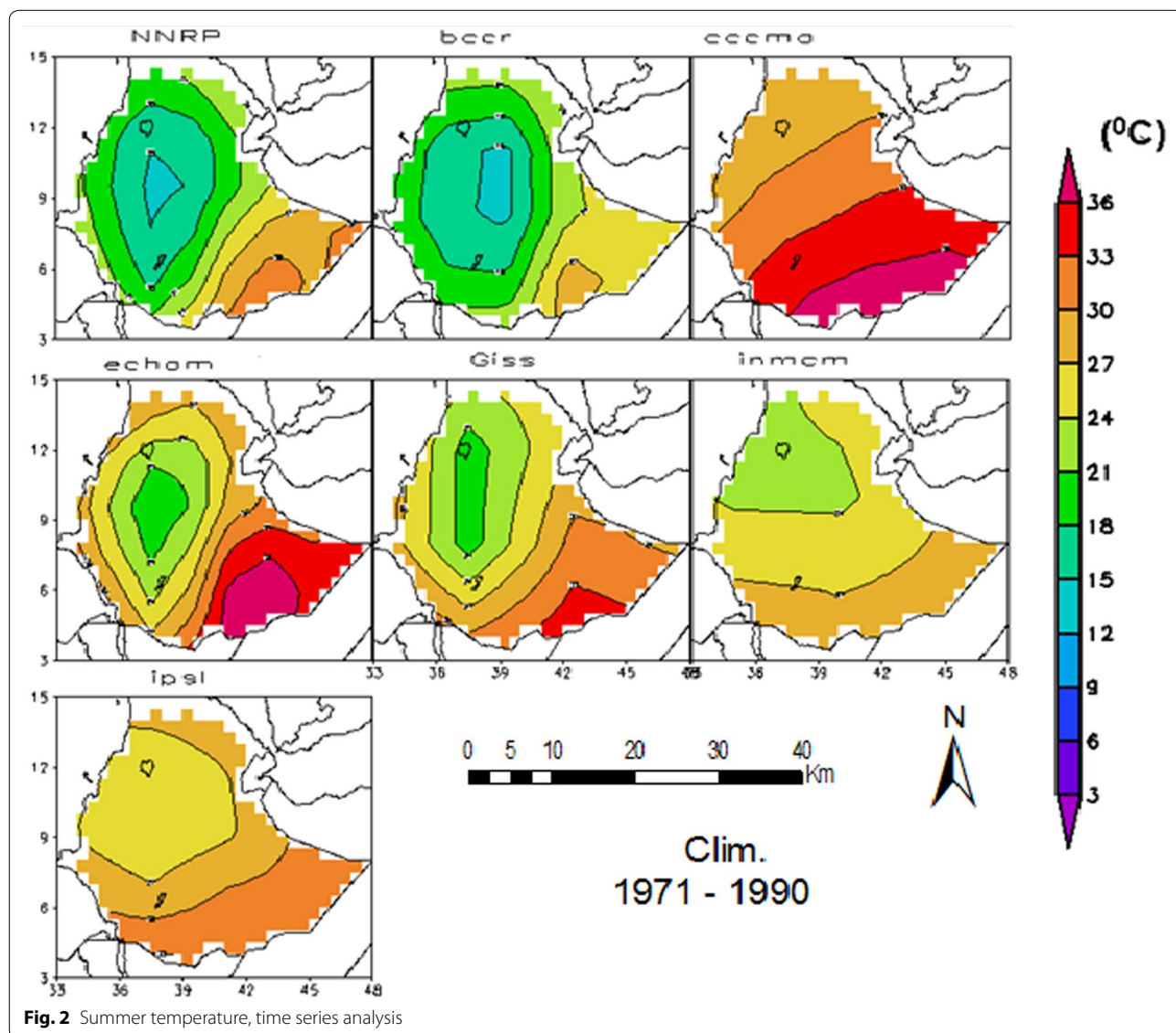
Fig. 2 Summer temperature, time series analysis

Table 5 Statistical analysis of summer temperature from 1991 to 2010

Model name	Clim (°C)	sd	cv	corr	rmse	bias
NNRP	21.122	0.695	3.290			
bccr	21.283	0.417	1.959	0.105	0.862	0.160
cccma	31.510	0.574	1.822	−0.320	11.435	10.388
echam	28.491	0.945	3.318	−0.013	7.463	7.369
giss	27.003	0.346	1.280	0.022	5.931	5.881
inmcm	25.606	0.534	2.087	−0.123	4.579	4.484
ipsl	28.540	0.267	0.935	0.244	7.448	7.417

Table 6 POD of models of summer temperature

Model	Warm	Cold	Normal	Combined
bccr	0.33	0.5	0.82	0.60
cccma	0	0.25	0.73	0.45
echam	0.33	0	0.45	0.3
giss	0.33	0.25	0.45	0.35
inmcm	0.33	0.25	0.64	0.45
ipsl	0	0.25	0.54	0.35

the normalized anomaly calculations (Table 6). The probability of detection by the model *bccr* (60%) is the highest and can be selected as the best performed model as compared to other models (Table 7). The probability of detecting warm temperature years have recorded better by most of the models than the probability of detecting the colder summer temperature. However, almost all of the models have shown that a normal summer temperature record and failed to record extreme temperature except *bccr* model.

Table 7 Normalized anomaly of summer temperature

Year	Model						
	NNRP	bccr	cccma	echam	giss	inmcm	ipsl
1991	0.431**	−0.051	−1.045	1.263	−0.918	−1.259	−0.463
1992	−1.478*	−1.105	0.220	−0.330	1.702	0.227	−1.308
1993	0.275**	−0.639	−0.221	−1.624	1.130	0.891	1.125
1994	−0.77**	0.045	−1.451	0.732	1.074	−0.763	−0.817
1995	−1.910*	1.772	−0.507	−0.465	−1.517	0.884	−0.479
1996	0.88**	−0.562	−0.928	−1.654	−0.998	1.103	−1.816
1997	−1.055*	−1.152	0.474	−0.365	0.476	−1.178	−0.505
1998	1.310***	0.689	−1.561	1.318	1.230	−1.290	0.070
1999	1.114***	−0.435	−0.530	−1.600	0.190	−0.656	0.895
2000	−0.16**	−0.896	0.020	−1.532	−1.653	−1.010	0.411
2001	−0.34**	−0.316	1.833	0.797	−0.386	1.006	−1.158
2002	0.91**	−0.478	−0.108	0.592	1.292	0.844	1.447
2003	−0.98**	−0.035	−0.118	1.156	0.453	0.693	0.325
2004	1.61***	−1.578	0.390	0.533	0.561	2.027	0.307
2005	−0.99**	−0.030	0.861	0.593	−0.657	0.577	0.522
2006	0.55**	−0.705	0.940	−0.644	−0.432	−0.794	−1.951
2007	−1.167*	1.112	2.599	−0.096	0.642	1.112	0.799
2008	0.86**	1.688	−0.466	−0.484	−1.160	−0.824	1.500
2009	0.20**	0.582	−0.666	0.635	−1.138	−0.927	0.246
2010	0.72**	2.092	0.262	1.174	0.109	−0.663	0.852

* Cold years

** Normal years

*** Warm years

Based on the normalized anomaly table, the warm years by the observed temperature record were 1998, 1999 and 2004; whereas, the cold years were recorded in 1992, 1995, 1997 and 2007; and the remaining were normal temperature years. The model which has recorded closely related value to the observation is *bccr*. It has a high hit rate as compared to others. This value again encourages the performance of the model better and it has the highest potential to use its future recorded value (Table 7).

The GrADS analysis of the summer temperature for the period 1991–2010 has recorded by the model *bccr* in a better performance than the rest of the models. Secondly, model *echam* and *giss* also have shown similar pattern though a little bit higher values of clim was recorded (Fig. 3). According to the summer temperature special and temporal patterns of the period 1991–2010, the model *cccma, ipsl, inmcm,* have been failed to

capture similar temperature record to that of the observation. Model *cccma* failed to record the cold years and *ipsl* failed to record extreme summer temperature and it is hardly important to consider its value for the future. Model *giss* failed to record the colder years, however the pattern of summer temperature is not very far from the above models.

In general the past 40 year analysis of GCM output data has shown by the well performed model *bccr*. Hence, it has indicated that a warming of summer temperature and a decreasing trend of summer monsoon rainfall over Ethiopia. These research findings are in line with other researchers. Gulilat et al. (2008) in their study indicated an investigation with three global climate models that a risk of more frequent drought due to declining of rainfall and increasing of temperature. They stated that the average annual minimum temperature over the country has increased by about 0.25 °C every decade, while average annual maximum
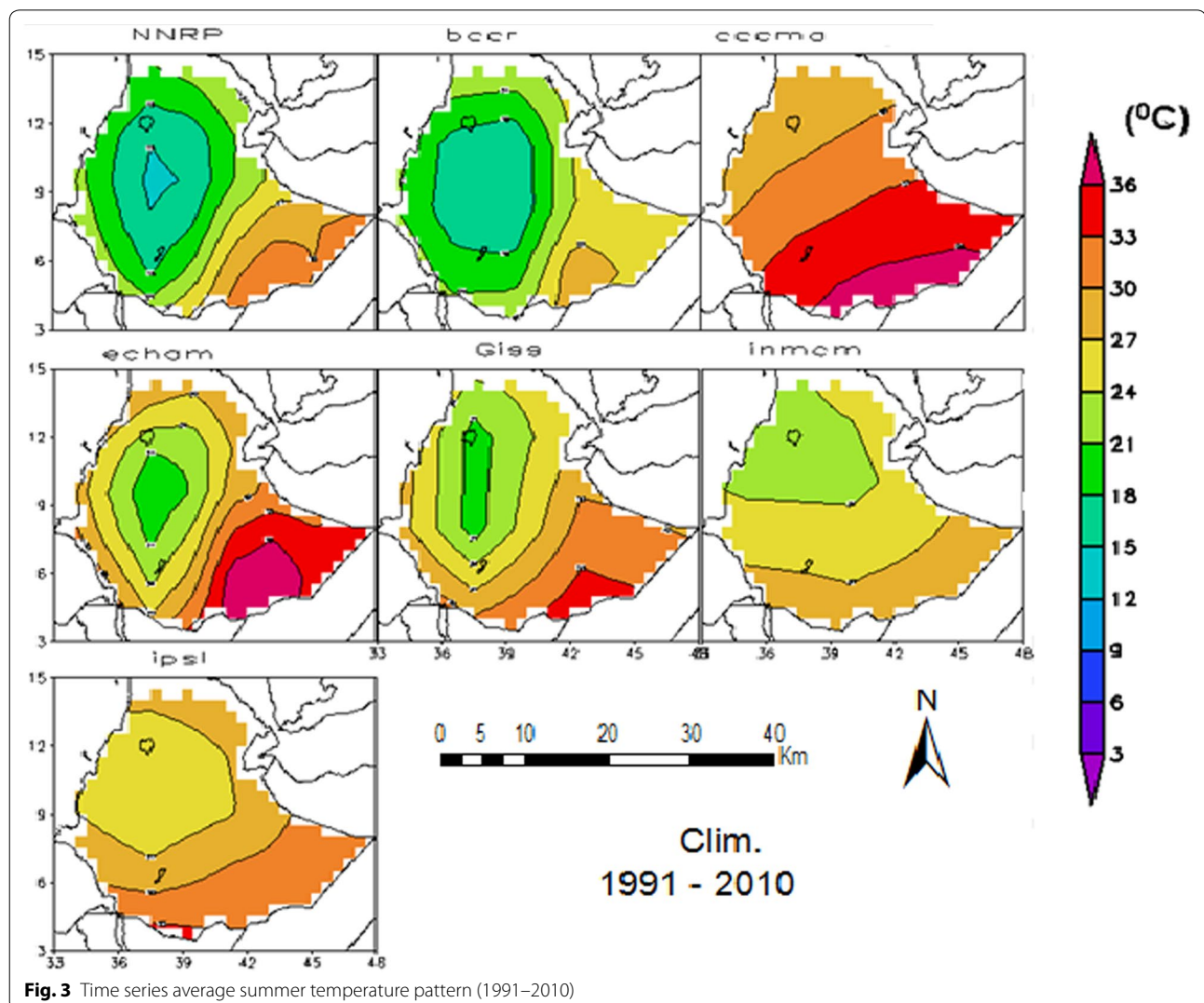

Fig. 3 Time series average summer temperature pattern (1991–2010)

Table 8 Statistical analysis of summer temperature (2015–2034)

Model name	Clim (°C)	sd	cv
bccr	21.851	0.487	2.231
cccma	32.840	0.332	1.011
echam	28.451	1.065	3.744
giss	27.169	0.276	1.018
inmcm	25.685	0.284	1.104
ipsl	28.714	0.266	0.925

temperature has increased by 0.1 °C each decade. Moreover, they indicated that drought related disasters have increased over Ethiopia since 1970s and signals negative consequences on human, environment and the economy.

As it has been approved by the trend analysis of temperature from the observation data, GCM has also shown that a general increment of the summer temperature. These might be the cause for the prevalence of malaria in the Ethiopian highlands than ever before. Moreover, in the agricultural production system, the invasion of species as well as the deprivation of the indigenous species is the consequence of the change in the environment including temperature change. Animal disease and crop loss by the instantly created pest were a day to day phenomenon in Ethiopia. Therefore, predicting the future

summer temperature of Ethiopia for the coming four decades, model *bccr* contribute a lot.

Summer temperature outlooks (2015–2034)

Understanding and predicting how the climate of Ethiopia will change over the next decades is an issue of urgent importance. Ethiopian society and its economy are strongly dependent upon its agriculture (Gulilat et al. 2008). It is clear therefore that relatively small changes in climate elements such as temperature will have large socioeconomic impacts. According to the best-performed model, the future summer temperature of the period 2015–2034 was found to be 21.85124 °C. This value has increased by 0.72885 °C from the base period 1991–2010 and by 1.27661 °C from the base period 1971–1990 (Table 8).

Based on the normalized anomaly calculation, model *bccr* has predicted that more number of warm years than the previous periods. Except 2015 and 2016, worm and normal years have been predicted for the rest of the years. Out of the 20 years, seven have been predicted to be warm, two cold and the rest normal summer mean temperature (Table 9).

This model also has shown a very good performance in its past temperature analysis compared with the observation. Therefore, its recorded summer temperature would play an immense importance for policy makers and other

Table 9 Normalized anomaly of summer temperature (2015–2034)

| Year	Model					
	bccr	cccma	echam	giss	inmcm	ipsl
2015	−1.240	−0.970	−0.766	−0.200	−0.085	1.515
2016	−1.483	−2.203	−1.238	0.655	0.387	−1.726
2017	−0.108	0.821	−0.285	0.340	−1.102	1.581
2018	1.107	0.290	2.003	0.112	−1.244	−2.106
2019	0.322	−1.205	−0.042	0.227	−1.500	−1.682
2020	−0.509	−1.332	0.640	1.189	−0.475	0.335
2021	0.355	0.926	−0.726	0.784	−0.486	−0.923
2022	0.045	−0.261	0.343	−1.567	0.933	0.258
2023	1.171	−0.495	0.208	0.591	1.484	−0.060
2024	−0.427	−0.994	−1.066	−0.203	0.382	0.317
2025	0.697	0.789	0.052	0.160	0.752	1.525
2026	1.086	0.389	−0.498	−1.343	−1.467	−0.091
2027	1.328	0.346	−1.491	−0.401	1.378	0.398
2028	0.882	−0.236	0.353	0.608	−0.222	−0.107
2029	0.052	0.572	1.914	1.043	−0.702	0.066
2030	1.003	0.949	0.001	0.651	1.912	0.288
2031	0.427	1.789	1.988	−0.608	0.914	−0.220
2032	0.761	1.036	−0.013	0.144	−0.778	0.994
2033	1.090	−0.996	−1.131	−3.070	0.627	0.079
2034	2.525	0.786	−0.244	0.888	−0.708	−0.439
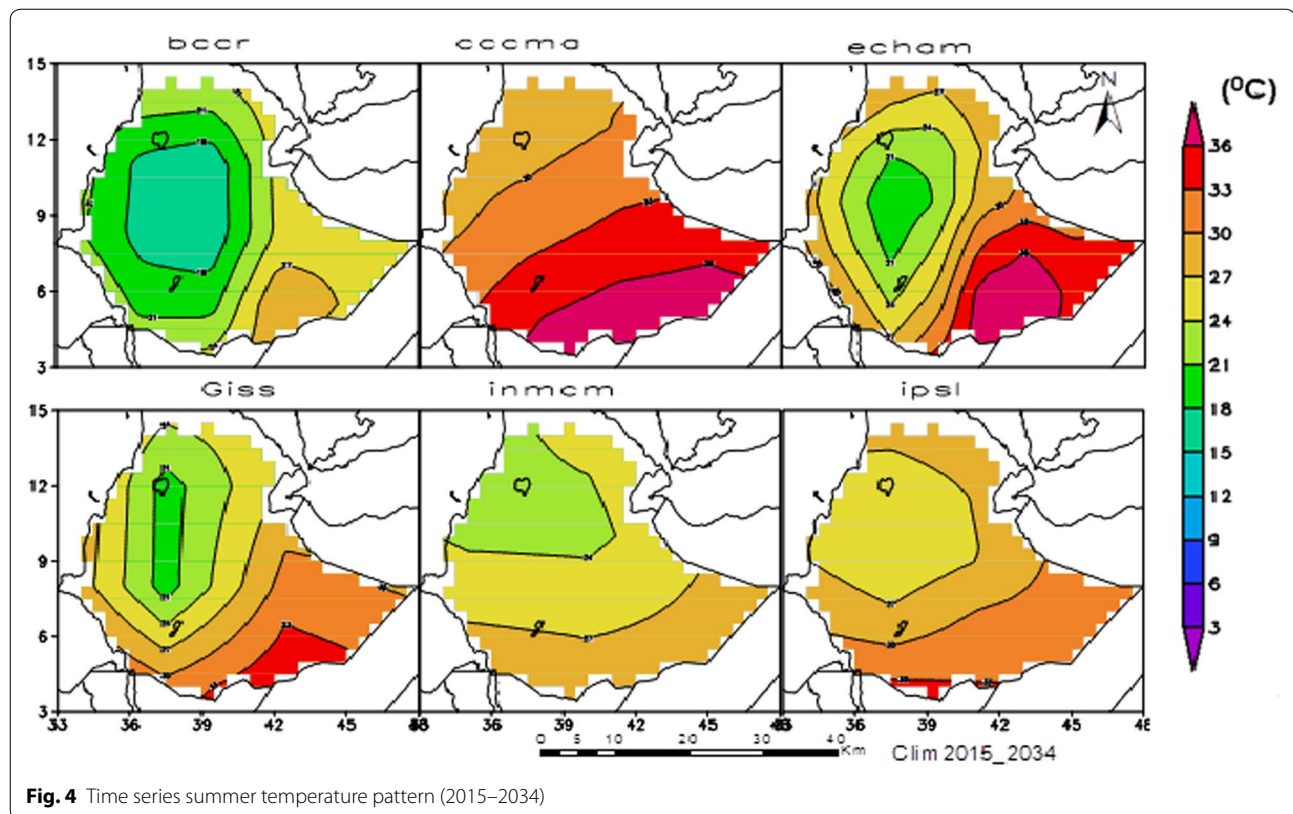
Fig. 4 Time series summer temperature pattern (2015–2034)

stakeholders in adapting and overcoming the consequences of the mean temperature change over the country. Moreover, it would contribute a lot to the selection of appropriate adaptation measures in selecting the right variety of crops and livestock for the predicted temperature ranges.

The spatial and temporal variations of the future temperature predictions have shown in Fig. 4. The patterns of the model *bccr*, *echam* and *giss* resembled each other and the values are closer as compared to the other three. Therefore, the value of the model *bccr* could be taken and important to take actions before the disasters which will be happened due to extremes of temperature in the country. Higher temperature may result in the invention of new species, creation of plant and animal pests, prevalence of malaria and related hazards would be managed once the warmest, the coldest and the normal years of temperature have predicted.

Summer temperature outlooks (2035–2054)

The summer temperature of the period 2035–2054 based on the model *bccr* was found to be 22.44137 °C. This value is increased by 0.59013 °C from the period 2015 to 2034, 1.31898 °C from the base period 1991 to 2010 and 1.86674 °C from the period 1971 to 1990. The mean summer temperature increased across periods by the model *bccr* (Table 10).

Based on the normalized anomaly value, the number of warmer years predicted to be increasing. Except the 2035, model *bccr* recorded warm and normal years (Table 11).

In the analysis of GrADS, The future summer temperature predictions have better represented by the model *bccr*, *echam*, *giss*, and *inmcm* based on the past records (Fig. 5). Higher temperature has been recorded by most of the models.

Table 10 Statistical analysis of summer temperature (2035–2054)

Model	Clim (°C)	sd	cv
bccr	22.441	0.573	2.553
cccma	33.583	0.442	1.316
echam	28.222	1.196	4.238
giss	27.249	0.265	0.973
inmcm	25.804	0.462	1.790
ipsl	28.705	0.316	1.102

Table 11 Normalized anomaly of summer temperature (2035–2054)

Year	Model					
	bccr	*cccma*	*echam*	*giss*	*inmcm*	*ipsl*
2035	−1.30156	−0.23982	1.30082	−0.31637	−0.31579	−0.14156
2036	0.713461	0.669402	−0.40007	1.711062	−0.20081	1.142423
2037	0.061947	0.588938	−0.39305	−0.3866	1.097353	0.107541
2038	0.226238	0.184847	2.080953	−0.93029	0.334498	0.261101
2039	1.08294	−0.27943	−0.28473	−1.21464	0.0469	0.548573
2040	0.541471	−0.14171	−2.24713	−0.00936	−1.39397	1.028182
2041	−0.5646	−2.49896	−0.48473	0.806751	0.502629	1.53339
2042	1.486996	0.128042	0.059789	0.260424	−0.49555	0.65951
2043	0.033793	−1.34915	0.56702	1.106122	1.387351	−1.69064
2044	−0.07265	0.874292	0.398034	0.893468	0.807256	−1.28854
2045	0.95166	0.152064	−1.5464	−0.4003	1.629768	−0.51201
2046	2.091573	1.372943	0.210411	−0.45831	0.638212	−1.60738
2047	−0.49334	1.781099	1.550836	2.283125	−1.28267	−1.59417
2048	−0.6029	0.42769	−0.23542	0.922433	0.851752	−0.48211
2049	1.09799	−1.06939	−0.91743	−0.99269	−0.00583	1.098931
2050	1.02979	−0.81408	0.786115	−1.78299	−0.27963	0.483137
2051	−0.25986	−0.02052	−0.07611	−0.81115	0.999085	0.805043
2052	1.26427	−1.24796	−0.62907	−0.69253	−0.99523	0.602262
2053	2.14859	1.212169	−0.58501	−0.0463	−1.16573	−1.31526
2054	0.815348	0.269506	0.84515	0.058125	−2.15962	0.361593

Fig. 5 Time series summer temperature pattern (2035–2054)
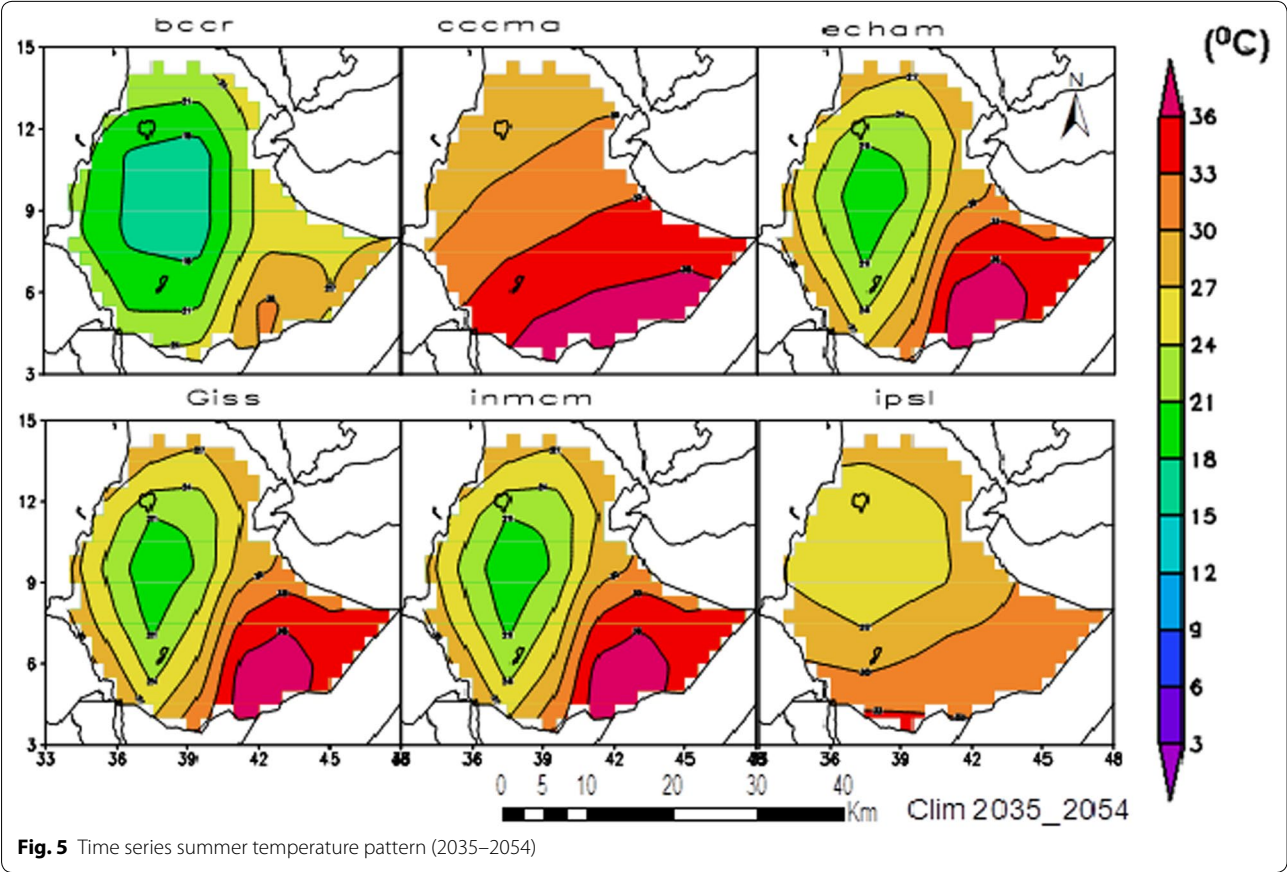
Table 12 Summary of summer temperature (1971–2010 and 2015–2054)

Period	NNRP	bccr	cccma	echam	giss	inmcm	ipsl
1971–1990	20.575	20.617	30.583	28.443	26.843	25.707	28.446
1991–2010	21.122	21.283	31.510	28.491	27.003	25.606	28.540
Change	*0.548*	0.666	0.928	0.048	0.161	−0.101	0.094
2015–2034		21.851	32.840	28.451	27.169	25.685	28.714
2035–2054		22.441	33.583	28.222	27.249	25.804	28.705
Change		*0.590*	*0.743*	−0.229	0.080	0.119	−0.009

Conclusions

From the overall analysis of the past four decades of summer mean temperature, the following conclusions are drawn. The summer temperature of the past four decades has been changed by 0.548 °C and based on the best performed model (bccr and cccma), it has predicted to increase by 0.59 and 0.743 °C, respectively by the next four decades (Table 12). Therefore, based on this research findings, it is possible to recommend the policy makers and other concerned bodies to consider the increasing summer temperature while planning the future development strategies.

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