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GLOBAL CLIMATE MODEL FOR PROJECTING FUTURE CLIMATE CHANGES OVER UPPER INDUS RIVER BASIN

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ABSTRACT

Evaluation of scenarios has become a critical component of climate change research. The performance of various GCMs in simulating observed climate at several stations in the Upper Indus River Basin was evaluated using different statistical indicators. The HadCM3, SRNIES, ECHAM4, and NCAR models simulated the spatial variability of mean temperature well, but the precipitation simulation was found to be inadequate. The results indicate that all the models substantially underestimated the magnitude of temperature on a monthly basis. The projected precipitation, however, showed much higher inter-model variability compared to mean temperature at all stations. Overall, a considerable inter-model variability in the simulation of observed climate was found at all stations. Owing to its ability to simulate the observed climate well, the HadCM3 model was selected for projection of future climate in the Upper Indus River Basin under several emission scenarios. Using the HadCM3 model, the temperature and precipitation changes across the UIRB were determined for two time periods; 2021-2050 (F_1), and 2061-2090 (F_2), relative to 1961-1990. The projected mean annual temperature across the study area varied from 1.7 to 4.3°C (for F_1 and F_2). The HadCM3 model predicted higher increase in mean winter temperature (from 2.1 to 4.5°C) compared to other seasons, whereas the increase in precipitation was observed in all seasons except winter. The increase in annual precipitation of 16 to 28% was projected for the two future periods considered in the present study.

Keyword: GCM, A_2 and B_2, sres scenario, upper Indus River Basin

INTRODUCTION

During the last few decades, studies related to evaluation of scenarios of future climate change have become a critical component of climate change research. Projections from a range of global climate models (GCMs) have been utilized by various researchers to evaluate likely future changes in meteorological variables in different regions of the world. An important challenge in climate research,

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however, is to evaluate the magnitude of these changes owing to large inter-model variability in the projections. The GCMs experiments simulate the climate response to past and assumed future changes in atmospheric concentration based on emission scenarios described in the special report on emission scenarios (IPCC, 2001a; IPCC, 2000). The Special Report on Emissions Scenarios (SRES) focuses on possible future concentrations and emissions of greenhouse gases and uses four main socioeconomic future trends (A_1, A_2, B_1 and B_2) to describe possible future changes. The A_1 and B_1 storylines focus on global development, while A_2 and B_2 emphasis on regional solutions. The A_1 and A_2 predict higher cumulative emissions between 1990-2100, whereas B_1 and B_2 predict that emissions will level off with time (IPCC-TGCIA, 1999).

The effectiveness of GCMs in simulating future climate has been evaluated by different researchers. For example, Kundzewicz and Somlyody (1997) suggested that GCMs should be evaluated with both current and past observed climate data sets before being used in impact assessments. Turnpenny *et al.* (2002) evaluated Regional Climate Model (RCM) outputs of HadRM2 - a widely used GCM- with the observed temperature and precipitation data over the United Kingdom. It was concluded that HadRM2 simulated temperature well as compared to precipitation across the region. The conclusion deduced by Turnpenny *et al.* (2002) clearly points towards difficulty in modeling precipitation processes that are considered highly complex in nature. Similar studies that have been conducted in various regions of Canada (for example, Bonsal *et al*., 2003; Toyra, 2005) reported that surface mean temperature was simulated relatively well, whereas the modeled precipitation was overestimated by most of the GCMs.

IPCC (2014) reported that climate change has already impacted all continents and worse is yet to come. Different studies have been conducted related to the impacts of climate (Dhorde *et al*., 2009; Schewe *et al*., 2011; Chaturvedi *et al*., 2012; Mahmood 2016). Chen *et al*. (2007) examined the output of various GCMs (e.g., HadCM3, CCSRNIES, CSRIO and GFDL) with the observed time series data of more than 30 years over the Hanjiang River Basin in China. In their study, the coefficient of determination for temperature varied from 0.97-0.98 and for precipitation it ranged from 0.43-0.70. The authors evaluated projections of temperature and precipitation anomalies over the basin for the 21st century relative to 1961-1990. The results showed an increase in precipitation accompanied by warming in all seasons for the whole basin for the period 2021-2050. Sharma (2007) compared the statistics of various GCMs and observed data with the aim to select a suitable GCM for two river basins namely, the Ping and the Mae Klong in Thailand. The author concluded that none of the models represent the present day climate adequately. Overland *et al.* (2011) reported that the uncertainty range may be narrowed down by eliminating some GCMs having poor performance. McSweeney *et al.* (2015) developed a methodology for selecting suitable GCM from the available CMIP5 models to be used in regional climate studies for various regions such as Africa, Europe and Southeast Asia. Todd *et al.* (2011) described in detail the uncertainty in climate change impacts studies.

The IPCC (2007) has summarized the future climate projection under different emission scenarios for Asia. The South Asian region is projected to be warmer in winter (DJF) than other seasons. A temperature rise of more than 4°C was estimated under the SRES A_1F_I scenario as compared to IPCC BAU scenario. Monsoonal temperature (JJA) increase is likely to be the lowest among all seasons. Unlike temperature, the seasonal precipitation did not show any definitive trend. Under A_1F_I scenario, the model projected decreased precipitation during the winter months. The highest precipitation change was projected for the spring months (MAM), followed by most of the monsoon season (JJA) (IPCC, 2007). Climate models, in general, project an increase in precipitation in summer (JJA) because the warming of air is greater over the land than ocean.

The major objective of this paper is to evaluate the capability of various GCMs in simulating the magnitude and spatial pattern of observed mean surface air temperature and total precipitation climatology (1991-2005) in the Upper Indus River Basin (UIRB). The focus of the present study is on two climate variables; surface air temperature and precipitation which are interconnected. Temperature and precipitation were chosen because they are two important and commonly used parameters affecting multiple sectors of the environment. The performance of different GCMs has been evaluated with observed data of temperature and precipitation and then a most suitable GCM was selected for projecting future climate in the study area. Finally, a comparison of two scenarios (A_2 and B_2) for future climate predictions is presented for two time slices, namely 2021-2050 and 2061-2090, relative to 1961-1990.

Data and methods

The detailed description of various GCMs experiments under various scenarios is given in the IPCC (2001b) report. The data for all the model runs are available at the IPCC Data Distribution Center. All the models presented here, simulate SRES scenario A_2 and B_2 and the outputs were readily available for this study and thus, were considered for the present climate comparisons. The A_2 scenario family describes a very heterogeneous world with self-reliance and preservation of local identities as a major theme. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change is more fragmented and slower than in other storylines. The B_2 scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with continuously increasing global population at a rate lower than A_2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B_1 and A_1 storylines. While the scenario is also oriented toward environmental protection and social equity, it focuses on local and regional levels. The representative concentration pathways (RCPs) are the latest iteration of the scenario process, and are used in the IPCC Assessment Report Five (AR5) (IPCC, 2013) in preference to the scenarios described in SRES (IPCC, 2000). These RCPs provide time-dependent projections of greenhouse concentrations in the atmosphere. There are four pathways: RCP8.5, RCP6.0, RCP4.5 and RCP2.6 that are in use presently with RCP8.5 projecting the largest concentration of greenhouse gases in the atmosphere. These projections are based on assumptions about changes with respect to time in economic activity, energy sources, population growth and other socioeconomic factors. RCP6.0

corresponds to the SRES A_2 with similar median temperature increase by 2100 (Moss *et al.,* 2010), whereas the RCP 8.5 is based on a revised version of the SRES A_2 scenario (Van Vuuren *et al.,* 2011).

Temperature and precipitation were evaluated because they are two important and commonly used parameters affecting multiple sectors of the environment. The outcome of this analysis helps in identifying the best GCM for further use in the present study framework and for other researchers conducting research related to climate impacts in the study area. In the present study, the GCM was selected based on its ability to simulate the present climate in an efficient manner when compared with the observed data (Smith and Hulme, 1998). Statistical parameters including mean and the standard deviation between model simulated STD (S) and observed STD (O) values, root mean square error (RMSE), and coefficient of determination (R^2) have been calculated. The R^2 and RMSE values provide complementary statistical information describing the correspondence between two patterns. A value of R^2 is associated with a low RMSE and vice versa. The closeness of these two parameters shows that a model is good at simulating the magnitude of variability.

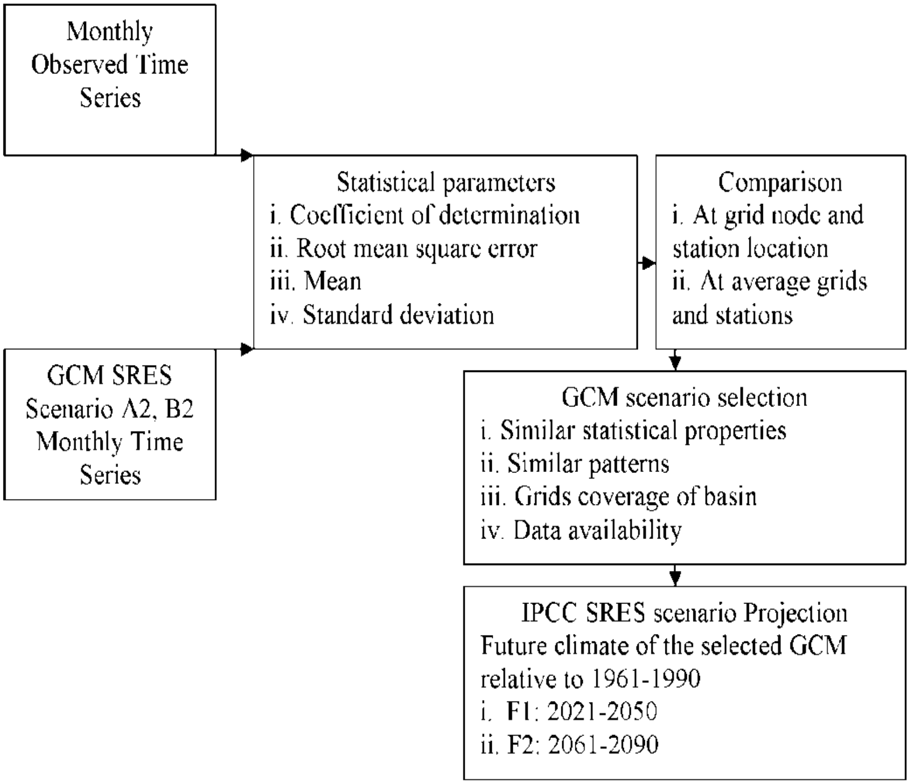


Figure 1. GCMs SRES scenario selection

The steps followed for GCM scenario selection are illustrated in Figure 1. The observed time series data of 17 climate stations (Table 1) were taken from Pakistan Meteorological Department (PMD). As these stations are located in Pakistan territory and thus are regularly monitored by PMD. The time series data of various scenarios of different GCMs was downloaded from IPCC data distribution center. The data availability and time scale was checked and then the analysis of monthly temperature and precipitation series was carried out for 13 experiments of seven different GCMs. The data was preprocessed and then analyzed on both stations and the average level for the period 1991-2005. The statistical parameters of the observed data set of 17 climate stations (Table 1) were computed and compared with the grid node of GCM lying in it. Based on data availability, resolution and statistical parameters, the HadCM3 GCM is selected. For future prediction of climate, Delta change method is used for temperature and ratio method was used for rainfall (Hay *et al*., 2000; Chen *et al*., 2007). The detailed description of various downscaling techniques can be seen in Teutschbein and Seibert (2012) article. At the end, climate (temperature and precipitation) of two scenarios A_2 and B_2 was calculated for two future periods 2021-2050 (F_1) and 2061-2090 (F_2) relative to 1961-1990 (Baseline). The period F_1 presents mid century and F_2 shows end century climate.

Table 1. Details of the meteorological station in the UIRB, Pakistan

ID	Station	Lat (N)	Long (E)	Elevation (m asl)
1	Astore	35.33	74.90	2394
2	Bunji	35.66	74.63	1372
3	Chilas	35.41	74.10	1250
4	Gilgit	35.91	74.33	1460
5	Gupis	36.01	73.40	2156
6	Skardu	35.30	75.68	2210
7	Chitral	35.85	71.78	1498
8	Drosh	35.56	71.78	1465
9	Balakot	34.55	73.35	980
10	Dir	35.20	72.20	1375
11	Kakul	34.55	73.25	1308
12	Chaklala	33.58	73.05	505
13	Cherat	33.81	71.55	995
14	Kohat	33.53	71.46	466
15	Parachinar	33.86	70.08	1748
16	Peshawar	34.01	71.58	359
17	Risalpur	34.01	71.98	305

RESULTS AND DISCUSSION

Model performance in the UIRB

The comparison results give an idea of the model performance in representing the present day climate in the UIRB. The GCM grid node and observed data at the station location show adequate simulation in the case of temperature, whereas the performance was unsatisfactory in the case of precipitation. The minimum value of R^2 at grid node and Cherat climate station was found to be 0.83 for SRNIES (A_2 and B_2) while the maximum value was 0.95 under GFDL for Astore and SRNIES for Chilas climate stations. The R^2 of HadCM3-A_2 and Astore station was found to be 0.13, and 0.23 between ECHAM-A_2 and Chitral station in case of precipitation. A considerable variability regarding the different GCMs simulations for the observed climate can be seen in the results. The HadCM3, SRNIES, ECHAM4, and NCAR models are found to be good at simulating the spatial variability of mean temperature. With most models, the R^2 values ranged from 0.913 to 0.950 for the study area indicating that these models accurately represent the spatial pattern of variation (Table 2). However, a wide range in standard deviation of CCCma and GFDL-R30 models was observed. All the models substantially under estimate the magnitude of temperature on a monthly basis (Figure 2a) for the analysis period of 1991-2005. The GCM simulated annual cycle of temperature is qualitatively similar to the observations. July is the warmest and January and February are the coldest months. One reason of this under estimation of temperature is that the large variation in the elevational characteristics of the study area makes it difficult to simulate temperature adequately.

Table 2. Comparison of statistical parameters between GCMs and observed temperature and precipitation data for the UIRB

Parameter	**Temperature Parameters**				**Precipitation Parameters**			
GCM	**R^2**	**RMSE**	**STD(S)**	**Mean (S)**	**R^2**	**RMSE**	**STD(S)**	**Mean (S)**
CCCma-A_2	0.923	18.392	11.235	-0.421	0.001	101.165	88.139	85.259
CCCma-B_2	0.913	18.903	11.205	-0.928	0.005	95.188	79.592	82.383
HADCM3-A_2	0.931	9.470	9.618	8.450	0.003	68.254	53.278	55.126
HADCM3-B_2	0.929	9.178	9.835	8.829	0.001	65.716	46.120	47.468
SRNIES-A_2	0.927	7.874	10.585	10.558	0.002	62.674	28.674	30.784
SRNIES-B_2	0.929	7.780	10.686	10.705	0.008	61.342	27.356	30.878
CSIRO-A_2	0.939	17.005	9.858	0.707	0.097	55.434	27.575	33.071
CSIRO-B_2	0.932	17.085	9.938	0.652	0.094	55.345	28.093	33.620
GFDL-A_2	0.940	13.302	12.799	5.423	0.006	66.854	51.913	52.884
GFDL-B_2	0.940	13.502	13.072	5.329	0.005	61.615	43.797	52.916
ECHAM-A_2	0.942	19.822	8.423	-2.289	0.011	54.696	29.297	45.644
ECHAM-B_2	0.938	20.020	8.334	-2.487	0.001	57.451	28.895	42.110
NCAR-A_2	0.950	14.955	9.848	2.765	0.051	70.922	32.438	29.477

Note: R^2 = Coefficient of determination; RMSE = Root mean square error, STD (s)= Standard deviation of simulated data; STD (O)= 7.570 and Mean (O)= 17.42 for temperature and STD (O) = 44.666 and Mean (O) = 66.170 for Precipitation

The precipitation comparison shows much higher variation than those for mean temperature for all models and all stations. None of the models adequately represent the observed magnitude and spatial variability of precipitation in the study area. The R^2 ranges from 0.001 to 0.09. In terms of RMSE, the ECHAM4 model has the lowest value of 54.70 mm and CCCma model has the highest value of 101.16 mm. The standard deviations of the data simulated by HadCM3 and GFDL-R30 were relatively close to the observed standard deviations when compared to other models (Table 2). In contrast to the temperature cycle, the models are unable to generate even qualitatively observed annual cycle of precipitation (Figure 2b). All the models except HadCM3 B_2 underestimate precipitation during the months of July-October while the CCCma model overestimates in the months of April-June. It is thus concluded that no single model can be considered to be the best. In the IPCC (2001a) report, the model evaluation has been discussed in detail and recommends that no single model can be considered to be the best and thus made recommendations for the use of a range of coupled models. In the present study, on the basis of similar statistical parameters of observed and simulated time series, the A_2 and B_2 SRES scenarios of HadCM3 are selected for projection of climate over the study domain for the 21st century.

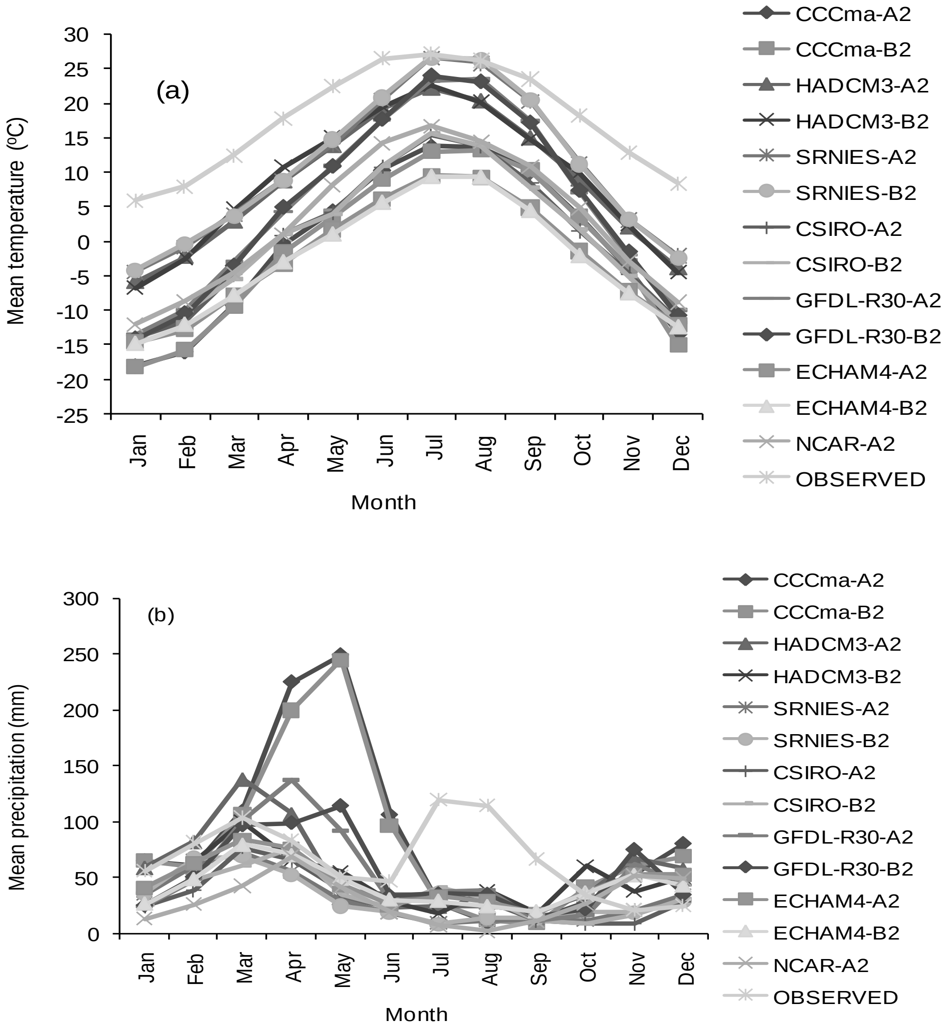


Figure 2. Comparisons of mean monthly GCMs with observed (a) temperature and (b) precipitation in the UIRB (1991-2005)

Temperature and precipitation projection for 21^{st} century

The spatial distribution of HadCM3 grids lying in the study area are given in Figure 3. The overall projected temperature and precipitation trend at seasonal scale across the study domain is given in Figure 4. High variability is predicted in winter and spring temperature and precipitation over the region. Among all seasons, the highest positive variability is predicted in autumn. Overall an increasing trend of temperature and precipitation is predicted across the UIRB on annual scale and seasonal features of climate change can be seen in Tables 3 and 4 for two time slices (2021-2050 (F_1), 2061-2090 (F_2). On an annual scale, a temperature rise of 1.7 to 4.3°C is projected across the UIRB for the next two time slots (F_1 and F_2) across the UIRB. The projected mean temperature has increased in all seasons for both time slices. Both model scenarios A_2, B_2 predict higher mean winter temperature increases as compared with other seasons, ranging from 2.1 to 4.5°C. These warming trends may result in more frequent, intense and persistent periods of hot temperatures in summer, and generally higher temperatures in winter as compared to present temperature. In precipitation there is qualitative disagreement between the two scenarios; however, both A_2 and B_2 scenarios for two time slices, 2021-2050 and 2061-2099, show an increase of precipitation in all seasons, except winter. The highest increase is predicted in the summer season during the period 2021-2050 (B_2) and 2061-2090 (A_2), 55% and 41%, respectively. Overall the increase of precipitation is observed on annual scale, which is projected to vary from 16% to 28% across the UIRB.

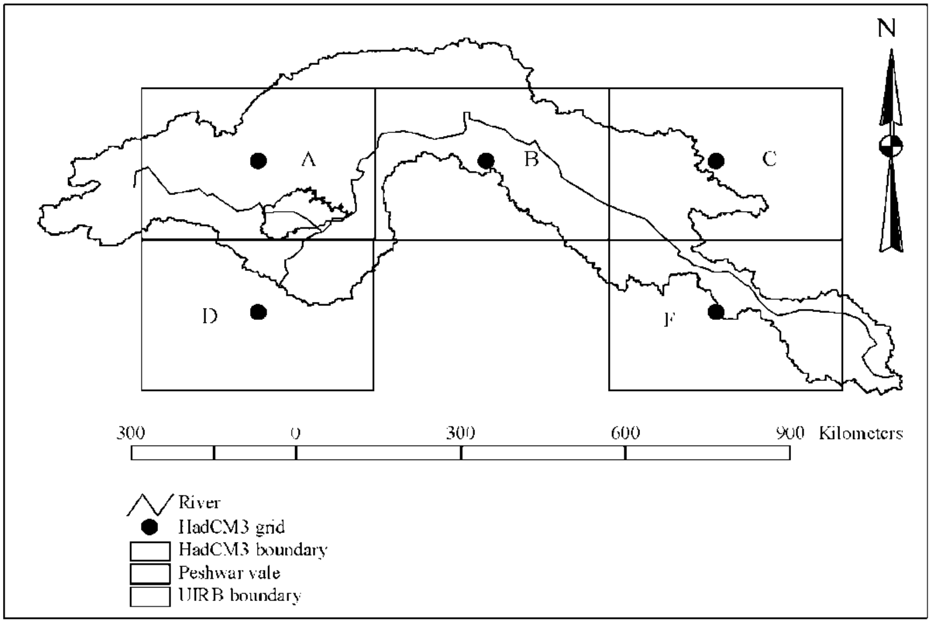
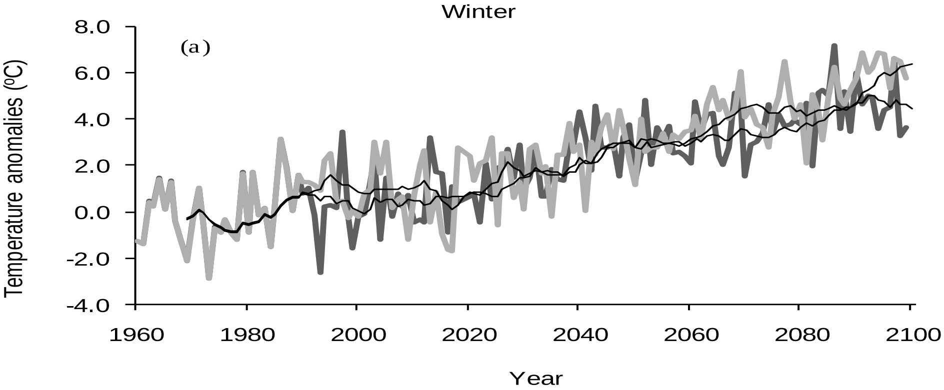
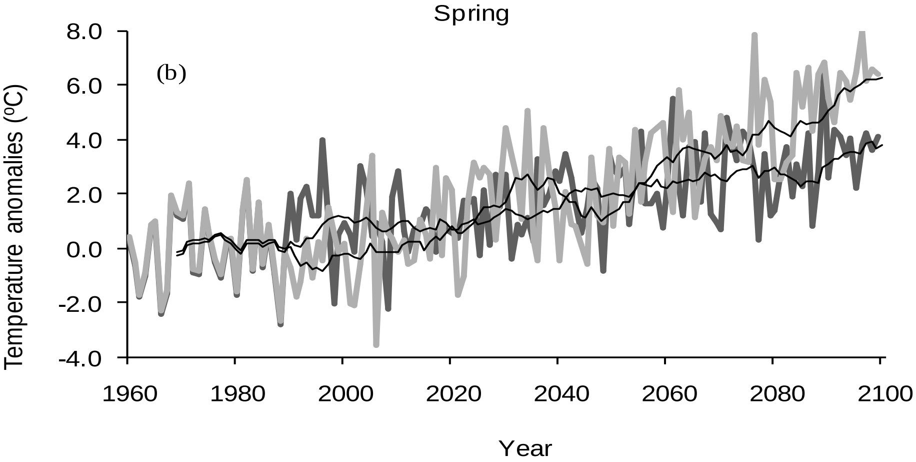
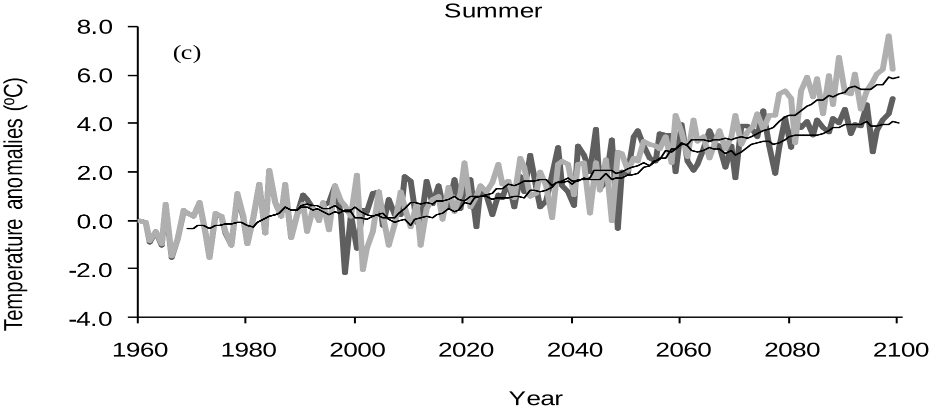
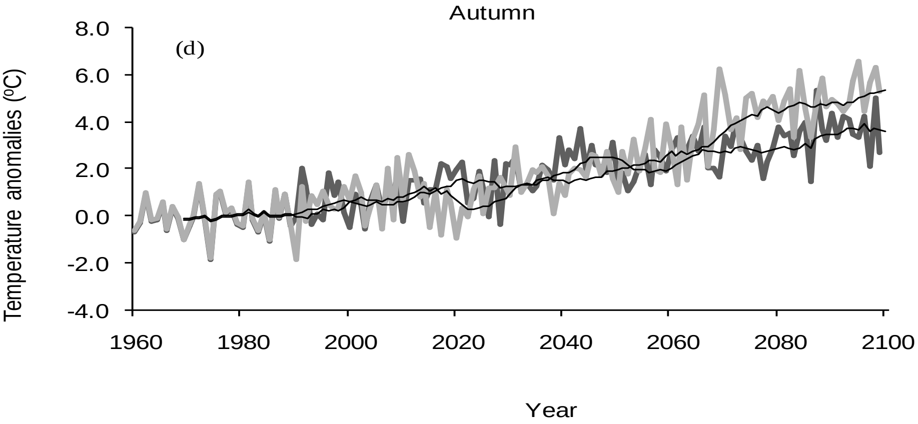


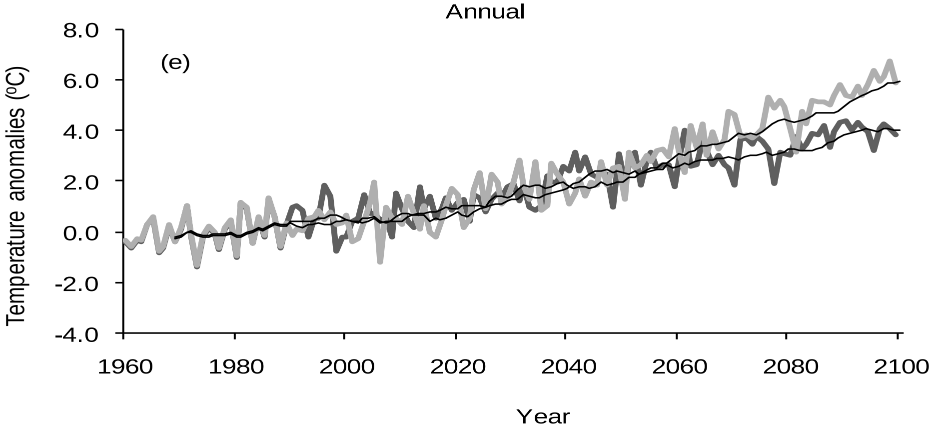
Figure 3. HadCM3 GCM grids lying in the UIRB

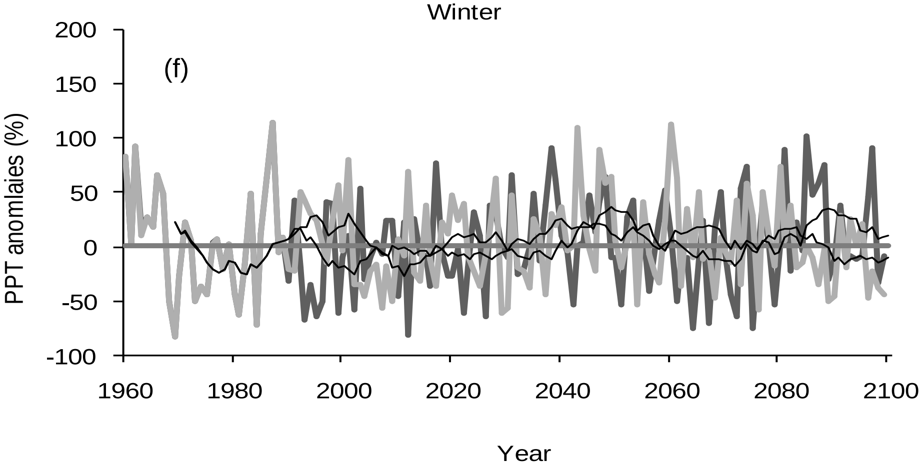

Winter
(a)
Temperature anomalies (ºC)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1960
1980
2000
2020
2040
2060
2080
2100
Year


Spring
(b)
Temperature anomalies (ºC)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1960
1980
2000
2020
2040
2060
2080
2100
Year


Summer
(c)
Temperature anomalies (ºC)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1960
1980
2000
2020
2040
2060
2080
2100
Year


Autumn
(d)
Temperature anomalies (ºC)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1960
1980
2000
2020
2040
2060
2080
2100
Year


Annual
(e)
Temperature anomalies (ºC)
8.0
6.0
4.0
2.0
0.0
-2.0
-4.0
1960
1980
2000
2020
2040
2060
2080
2100
Year


Winter
(f)
PPT anomlaies (%)
200
150
100
50
0
-50
-100
1960
1980
2000
2020
2040
2060
2080
2100
Year

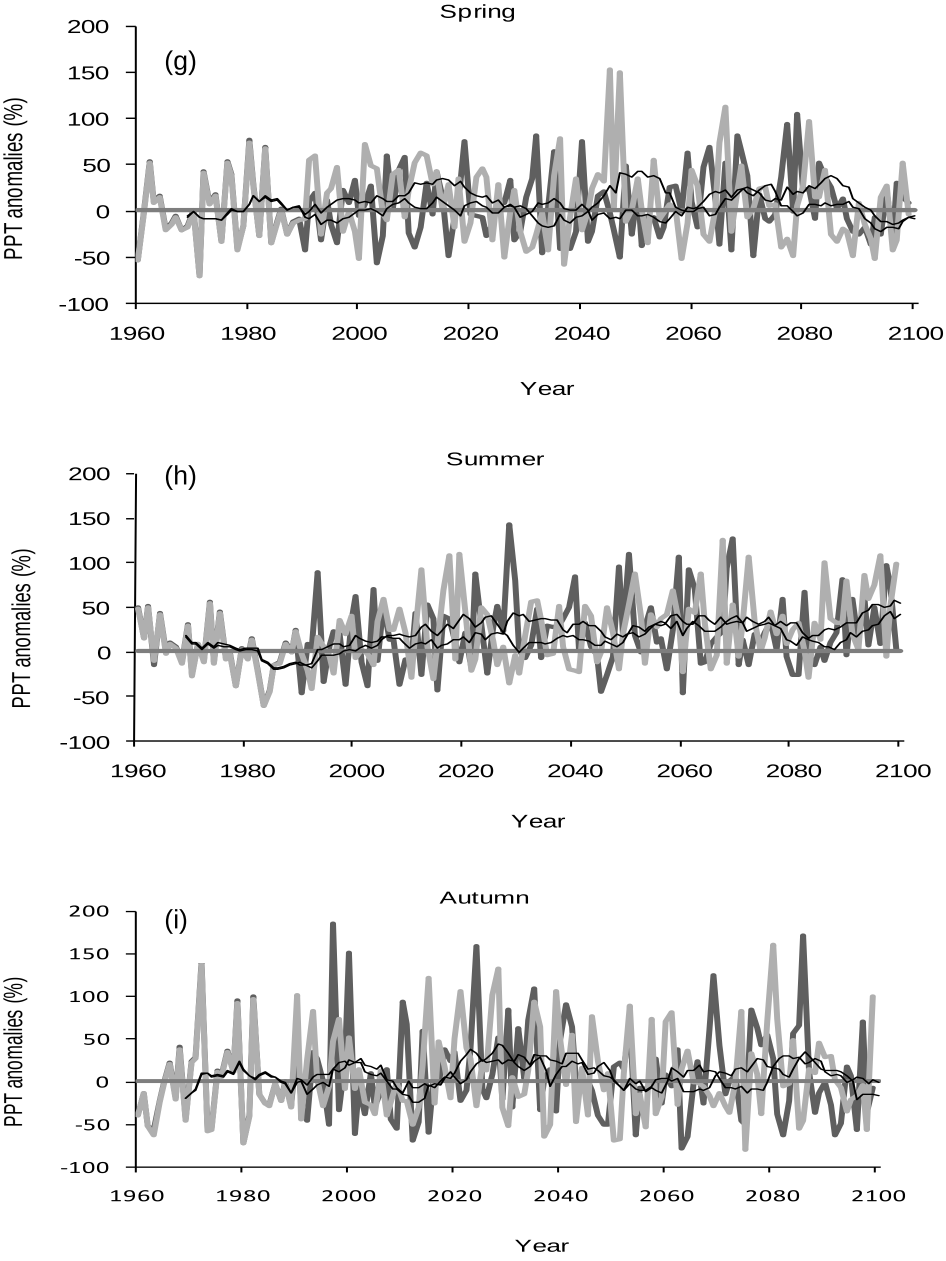


Figure 4. Seasonal and annual mean temperature (a,b,c,d,e) and precipitation (f,g,h,i) anomalies in the UIRB relative to mean of 1961-1990 (The bold lines give the ten year moving mean). The dotted line indicates the trend under A_2 while solid shows the trend of B_2 scenario

Table 3. Projected seasonal and annual mean temperature (°C) changes relative to 1961-1990 under A_2 and B_2 scenarios of HadCM3 over the UIRB

Time slot	**Scenario**	**Wi**	**Sp**	**Su**	**Au**	**An**
2021-2050 (F_1)	A_2	2.2	1.7	1.6	1.5	1.7
2061-2090 (F_2)	A_2	4.5	4.3	4.3	4.3	4.3
2021-2050 (F_1)	B_2	2.1	1.6	1.5	1.9	1.8
2061-2090 (F_2)	B_2	3.9	2.8	3.4	3.1	3.3

Note: Wi = Winter, Sp = Spring, Su = Summer, Au = Autumn and An = Annual while F_1 and F_2 show the future time slot.

Table 4. Projected seasonal and annual mean precipitation (%) changes relative to 1961-1990 under A_2 and B_2 scenarios of HadCM3 over the UIRB

Time slot	**Scenario**	**Wi**	**Sp**	**Su**	**Au**	**An**
2021-2050 (F_1)	A_2	7.0	38.1	30.2	19.1	26.1
2061-2090 (F_2)	A_2	-3.0	3.1	41.1	10.0	15.9
2021-2050 (F_1)	B_2	6.7	4.3	55.2	44.6	27.8
2061-2090 (F_2)	B_2	-4.9	26.6	20.9	44.5	20.6

Note: Same as Table 3

The present day climate that prevails over UIRB was simulated very well by HadCM3 under the high atmospheric forcing (A_2), which indicates that the time rate of change in various meteorological parameters is very high. This situation demands a regular study of UIRB as it shares a greater part of water both for agriculture and hydro power generation. The non-linear trend of temperature change under A_2 forcing in UIRB poses a serious threat to locals adapted to present observed temperatures. A comprehensive study must be carried out to find causes of such high rate of change in climatic variables and its possible impacts on water availability for various sectors especially in summer. Since the model output is based on the scenarios described in the fourth assessment report of IPCC (IPPC 2007), some uncertainty due to non-linear change in concentration of carbon emissions is inherent in the simulations. Climate change studies over UIRB in near future should be based on the updated scenarios described in the fifth assessment of IPCC published in 2014. The ability of HadCM3 to represent present observed climatic features of UIRB indicates its higher suitability to study climate change in hilly areas of Pakistan where mean temperature is comparatively lower than the plains of Pakistan. The use of a particular model for studying climate change in any region must be based on its ability to accurately represent change in meteorological parameters that occurred in the baseline period (1960-1990). This will ensure predictions of future temperature and precipitation with greater accuracy and highest possible confidence. When the projected temperatures over UIRB (Table 3) are compared with projected temperature over South Asia (IPCC 2007) for the period 2061-2090, it can be concluded that warming in UIRB is moderate at all levels especially in winter as compared to the whole of South Asian region. As compared to the relative projected changes in precipitation over South Asia, UIRB will receive more precipitation in all seasons except winter, which will remain dry in the period 2060-2090. Thus, it can be concluded with a fair degree of confidence that UIRB will be less affected by climate change as compared to the rest of sub-continent. It means that spatial distribution of climate change is not uniform over the whole region and mostly depends on the present observed climate of the study area. Projections for both South Asia and UIRB indicated the highest warming in winter, although the magnitude of projected warming under different models is considerably different.

The projected temperature departures predicted by HadCM3 for the period 2021-2050 (F_1) under A_2 and B_2 are similar in magnitude as shown in Table 3. This means that both moderate and high scenarios predict same change in mean temperature at all levels (seasonal and annual) in the period 2021-2050. It can also be concluded that temperature change in UIRB in F_1 will be moderate to allow human survival without any serious problems as rise in temperature up to 2°C is moderate for human activities. A study by Manoj *et al*. (2011) has already revealed that the 2°C threshold will probably be exceeded over large parts of Eurasia, North Africa and Canada by 2040 if emissions continue to increase. The temperature change in UIRB, however, does not seem to be affected by high carbon emissions till 2050 under all scenarios.

Under A_2 the projected departure in mean temperature predicted by HadCM3 for the period 2061-2090 (F_2) over UIRB is same in magnitude (4.3°C) at all levels except winter (4.5°C). This is suggestive of greatest warming in winter, which could be attributed to climate change in the region. Such high temperature rise will have multiple consequences resulting in more rainfall rather than snow, which is a key source of water availability for summer season in the plain areas of Pakistan. Early snowmelt caused by a high temperature in that period will diminish all snow packs acting as water stocks for later periods. In the absence of snow stocks that ensure water availability till end of summer season, agriculture will face serious problems in that period. The temperature–health relationship is also of growing interest (Huang *et al*., 2012). It is, therefore, critically important to incorporate these greatest temperature changes in policy making for very effective water management. Every effort should be made to construct water storage structures as soon as possible to control water losses and sustain agriculture for human survival in Pakistan. Under B_2 scenario HadCM3 has projected temperature rise of less than 3.5°C at all levels except winter in F_2 (Table 3). It means that the moderate scenario (B_2) predicts temperature change that is almost one degree less than under A_2 in most cases for F_2. Overall we conclude that even in the absence of mitigation strategies temperature rise in UIRB will be moderate in F_1 (2021-2050) allowing human survival without considerable impacts but it will create serious socio-economic problems in F_2 (2061-2090).

Precipitation changes predicted by HadCM3 under all scenarios relative to the baseline periods 1969-1990 indicate a rise in amount of precipitation at all levels except winter (Table 4). This indicates above-normal rainfall in UIRB from 2021 to 2090 in all seasons except winter, which will be dry in F_2 under all scenarios. Thus more water will be available in all seasons except winter which demands efficient water storage particularly in summer so that it can be used till the end of winter. It is worth noting that water demands decrease to a considerable extent in winter, and therefore scarcity of rain may not affect domestic water demands to a significant level. Research must be carried out to see possible impacts of dry winter in UIRB on water availability in downstream areas. One pronounced associated hazard with more rainfall in coming decades is the flood that causes great financial and human loss to the country. Floods are very common in Pakistan and no significant policy has so far been framed to control them. It is strongly emphasized to store each drop of water to avoid human losses and make it available when needed for irrigation purpose downstream.

The relative increase in precipitation amount is higher in 2021-2050 (F_1) under A_2 than 2061-2090 (F_2) at all levels except summer (Table 4). It means that summer tends to get cooler and wetter with respect to time and winter tends to get dry and warmer, a phenomenon that should be kept in mind by the policy makers while formulating water management policy for the future. The apparent cause of moderate temperature rise till 2050 is the relative increase in precipitation amount and precipitation seems to be a dominant factor in controlling temperature rise. Overall, it can be concluded that UIRB will be a key source of water supply for irrigation and domestic demands though snow stocks will gradually disappear with time. Precipitation amount may cause severe floods in plains that lie downstream causing considerable financial losses. With effective water management and flood control structures UIRB will continue to sustain agriculture and hence human survival in future as well.

CONCLUSION

The selection of a suitable GCM was made based on its ability to simulate the observed climate, study area coverage and data accessibility at the station locations and grid nodes. The two important climate variables namely, temperature and precipitation were evaluated. A considerable variability among different GCMs simulations for the observed climate is noted. The HadCM3, SRNIES, ECHAM4, and NCAR models were able to adequately simulate the spatial variability of mean temperature. All models substantially underestimate the magnitude of temperature on a monthly scale. The annual cycle of temperature simulated by all the GCMs is qualitatively similar to the observations; July being the warmest and January or February being the coldest month. The GCM simulated precipitation showed much higher variations than the mean temperature for all models and at all stations. None of the models could represent the observed magnitude and spatial variability of precipitation in the study area. There is a qualitative inter-model disagreement for precipitation. All the models (except HadCM3 B_2) under-predicted precipitation during July-October while the CCCma model over-predicts in the months of April-June. However, on the basis of similar statistical characteristics of the observed and simulated time series, the HadCM3 GCM for IPCC A_2 and B_2 scenarios were selected for future climate prediction in this study area. The study area was covered within five grids of HadCM3. Temperature and precipitation anomalies series relative to the mean of 1961-1990 were analyzed across the UIRB for two future periods, 2021-2050 (F_1) and 2061-2090 (F_2). The mean temperature would increase in all seasons for both the time slices. For both A_2 and B_2 scenarios the model projections indicated higher mean winter temperature increase (ranging from 2.1 to 4.5°C) compared to other seasons. An increase in precipitation was noted in all seasons except winter. On an annual basis, an increase in precipitation varying from 16 to 28% across the UIRB for the future periods (F_1 and F_2) was projected.

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