Historical and Future Trends of Summer Mean Air Temperature over South Asia

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Abstract

Mean air temperature is an important meteorological parameter. The signal of climate change is often describe by the changes in the mean temperature. Keeping in view the importance of the mean air temperature, in this study we used twenty four CMIP5 GCMs to analyze the future changes in summer (June July August September) mean air temperature. The historical run of the GCMs were first compared with the ERA Interim mean temperature for the period 1979-2005. The spatial analysis shows the warm biases of the GCMs over the plain areas and cold biases over the mountainous regions. Taylor diagram analysis shows that most of the GCMs are in good accordance with the ERA Interim mean air temperature for the summer season. The future projections of the selected GCMs were then presented in mulitmodel ensemble for each decade from 2011-2100. The change has in increasing trend all over the study area. The significant change has been projected for the northern and north western parts of Pakistan and south eastern India region. The change in mean temperature is below 4°C under RCP 4.5 whereas it is above 5 °C under RCP 8.5. Multimodel ensemble of CMIP5 GCMs projections for the future under both the RCPs, show higher spread over the northern and central parts of Pakistan; and central India. Projected change is robust and it is anticipated that this increase will enhance the erratic behavior of the monsoon in future.

Key Words: CMIP5, Mean Air Temperature, summer, RCP 4.5, RCP 8.5

Introduction

The Coupled Model Inter-comparison Project phase 5 (CMIP5) is actively participating in the preparation of Intergovernmental Panel on Climate Change (IPCC) fifth Assessment report (AR5). Therefore the climate modeling and related researchers are focusing on the outputs of the simulations of CMIP5 GCMs. The main aim of this project is to improve the understanding of changing climate of the Earth. The detailed information and experiment design regarding the CMIP5 simulations can be seen in Taylor et al (2012). There are more than 20 modeling groups participating in this project. The outputs of CMIP5 GCMs are being used for dynamical downscaling and different impact assessment studies all over the world.

Mean air temperature is very important meteorological parameter. It is the mean air temperature which plays a vital role in the germination and growth of the crops. The warming is recognized by the higher mean temperature. The globe mean temperature has risen by 0.6°C whereas a decrease of 2°C has been observed for the southeastern and central parts of United States (Zaitao et al 2013). According to IPCC AR4 there has been an increase of more than 1.5 degree Celsius temperature for South Asia region. Particularly, for Pakistan this increase is higher in the northern parts and smaller in the southern parts. This increase in the temperature has caused the change in the bowing and sowing seasons of crops, movements of the inhabitants. The previous climate change studies by Islam et al 2009 show that the increase in mean temperature for the region is more than 3 degree in future. The rise in temperature over the land causes the glaciers to melt down at a faster rate which then causes in flash flooding and more evaporation (Rasul et al., 2008). The hind cast studies on temperature reported a risk of more intense and frequent heat waves in the near future (Meehl and Tebaldi, 2004; Schär et al., 2004; Clark et al., 2006; Zahid and Rasul 2012). Consistent increase in temperature and humidity for a certain period over a region are the recognized as significant weather hazardous (Zahid and Rasul 2010). The scientific reports

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show that more than 5 years in the past decade were among the warmest years of the history. Therefore the importance of temperature cannot be overruled.

Although there are a number of regional climate change studies but no one has performed the evaluation of the GCMs which are being downscaled for different regions and the detailed future scenarios are projected. It is very important to first understand the performance of the GCM which are being downscaled for the further analysis, if we don't do so the systematic biases will be increased and the reliability of the results will be a huge question mark. Therefore in order to avoid this inconvenience, this study is being performed. The purpose is to point out those GCMs which show good results in simulating the present mean temperatures so that.

There are two main seasons in south Asia summer and winter. In this study we have taken summer as the season JJAS – June July August September and the winter as the season DJFM – December January February March. Both the seasons are of grave importance for the economy of the south Asian countries. 80 % of the total rainfall is received during the JJAS season where as the rest of the rain is received in DJFM season. The main source for the rains in JJAS is the monsoon currents which arise in the Arabian Sea and Bay of Bengal and penetrate to the land areas. The source for the winter rains is the Western Disturbances.

The objective of this study is to analyze the trends of mean air temperature for the past and future runs of CMIP5 GCMS over South Asia region. The performance of the CMIP5 GCMs in simulating the past mean air temperature for the period 1979-2005. The models are compared with ERA-Interim mean air temperature. Both the spatial and temporal analysis has been performed. Taylor diagram has been plotted to point out the GCMs which have better tendency to simulate the recent past climatology of temperature for South Asia region. These models are proposed to be used for the downscaling to emphasize the more detailed study for the region

South Asia is a region with complex topography and diverse climates. Global Models have not been fully able to be applied to this region for fine scale information. The parameterization schemes and other factors are although improved in the latest versions but still it needs much improvements and modifications. There are a limited number of studies using the GCMs for the climate change studies in Pakistan. The performance evaluation will also help the scientists from other disciplines like hydrology which use the output of GCMs/RCMs to their models. This particular study deals with the evaluation of the mean temperature of the GCMs which is more often used as input in different hydrological and agro-meteorological models. Therefore it is very important to first choose/ point out the best GCMs for the desired area of study so that the systematic error is reduced. Further detail analysis of temperature on decadal basis will also be helpful for all the stakeholders to get the idea of climate change occurring in the region.

Data and Methodology

The monthly mean air temperature data for the historical run of 24 GCMs have been downloaded from the CMIP5 GCMs data portal (http://cmip-pcmdi.llnl.gov/cmip5/). The CMIP5 GCMs data is available at different resolutions for different time slices. The list of these 24 GCMs along with their affiliation and horizontal resolutions is given in Table no. 1. The data obtained from CMIP5 data portal has heterogeneous resolutions; therefore all the GCMs were further regrided to 2 degree horizontal resolution; so that, the comparisons can be performed. In order to find the biases and spatial differences, the Reanalysis data set of ERA-Interim (Dee et al 2011) has been used. The horizontal resolution of the data is 1.87 degree. This data has also been regrided to 2 degree resolution. Both the GCMs and Reanalysis data sets are in monthly temporal resolutions. The Taylor diagram (Taylor, 2001) is very helpful tool which comparing a number of GCMs with the observations/ or some reference data set. This diagram provides three important statistical parameter (i) Correlation (ii) Root Mean Square Error (RMSE) and (iii) Standard Deviation (SD). In order to analyze the variability in the spread of the mean air temperature projections; the standard deviation plots for the ensemble mean are also presented.

Results and Discussion

Recent Past Climate

First we show the spatial biases of each GCM with respect to Reanalysis data set ERA-Interim. Figure 1 shows the mean air temperature for the JJAS season from 24 GCMs and the reanalysis data set ERA-Interim. The first panel in this figure shows the climatology of the surface temperature for the period 1979-2005. The highest temperatures are observed in the south of Pakistan along Afghanistan and Iran border where the mean temperature exceeds 35 °C. The minimum values of mean temperature are observed the extreme north of Pakistan along the HKH region and China where the average temperature is below than -5 °C. The spatial biases of each GCM with ERA Interim mean temperature represent a non-uniform pattern. Some CMIP5 GCMs show warm bias and some cold bias. Overall performance for the spatial biases shows that the CMIP5 GCMs have a cold bias over the mountainous regions and a warm bias over the central and eastern India region. The mixed behavior has been observed for the biasness. However over the Pakistan region the general behavior of the CMIP5 GCM is cold over the north and warm over the southern half.

In order to analyze the performance of these twenty four CMIP5 GCMs we plotted Taylor diagram taking ERA Interim mean temperature as reference. Figure 2 shows the Taylor diagram, where we can see that most of the GCMs have good pattern correlation with the ERA Interim reanalysis data. However we selected the 6 GCMs for future projections. The list of these GCMs is presented in the Table 2. Future projections (RCP 4.5 and RCP 8.5) of summer mean temperature for selected GCMs are presented in the next section.

Table 1: List of CMIP5 GCMs used in the study along with their Institution and Horizontal resolution

Sr.#	Model	Modeling Center	Resolution
1	ACCESS1-0	CSIRO-BOM	1.85 x 1.25
2	BCC-CSM1-1	BCC	2.8125
3	CanCM4	CCCma	2.8125
4	CCSM4	NCAR	1.25 x 0.942408377
5	CNRM-CM5	CNRM-CERFACS	1.40625
6	CSIRO-Mk3-6-0	CSIRO-QCCCE	1.875
7	EC-EARTH	ICHEC	2.8125
8	FGOALS-g2	LASG-IAP	1.125
9	GISS-E2-H	NASA-GISS	2.5 x2
10	GISS-E2-R	NASA-GISS	2.5 x2
11	HadCM3	MOHC	3.75 x2.5
12	HadGEM2-AO	NIMR-KMA	1.875x1.25
13	HadGEM2-CC	MOHC	1.875x1.25
14	HadGEM2-ES	MOHC	1.875x1.25
15	INMCM4	INM	2x1.5
16	IPSL-CM5A-LR	IPSL	3.75x 1.89473724
17	IPSL-CM5A-MR	IPSL	2.5x 1.26760864
18	MIROC4h	MIROC	0.5625
19	MIROC5	MIROC	1.40625
20	MIROC-ESM	MIROC	2.8125

Sr.#	Model	Modeling Center	Resolution
21	MIROC-ESM-CHEM	MIROC	2.8125
22	MPI-ESM-LR	MPI-M	1.875
23	MPI-ESM-P	MPI-M	1.875
24	NorESM1-M	NCC	2.5 x 1.89473684

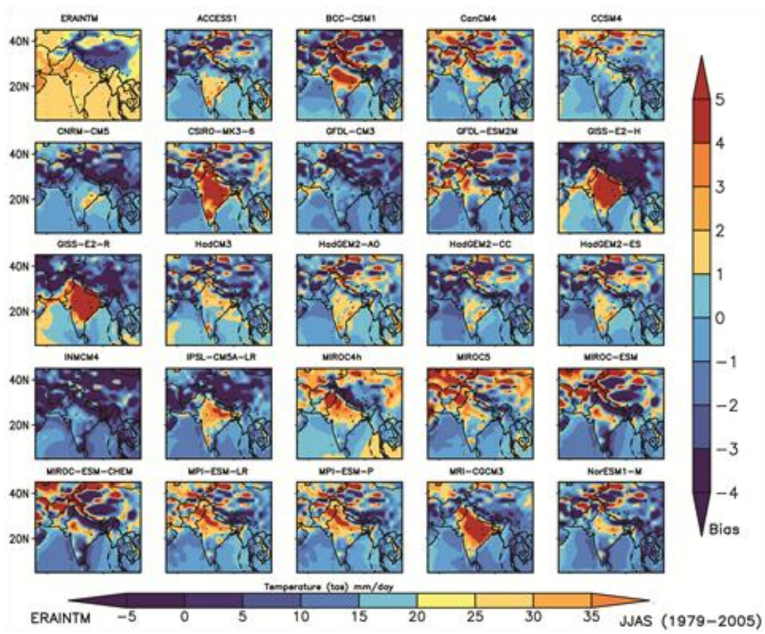

Figure 1: Summer Mean Temperature (°C) Climatology (first panel) and spatial biases of CMIP5 GCMs with ERA Interim for 1979-2005

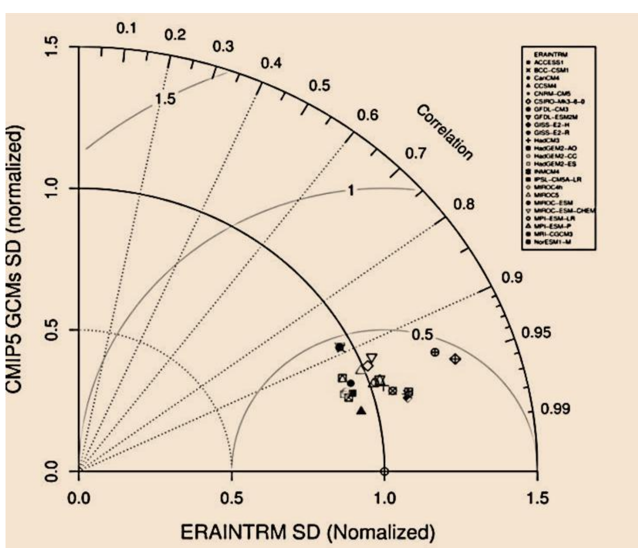

Figure 2: Taylor Diagram for JJAS mean air Temperature of ERA Interim and 24 CMIP5 GCMs (1979-2005)

Future Climate

The Representative Concentration Pathway (RCP) scenarios are used as future projections in CMIP5 project. Initially RCP 4.5 (radiative forces 4.5 Wm-2) and RCP 8.5 (radiative forces 8.5 Wm-2) are available for the diagnostic analysis of variation in monsoon dynamics (Taylor et al. 2009). RCPs are consistent sets of projections of only the components of radiative forcing (the change in the balance between incoming and outgoing radiation to the atmosphere caused primarily by changes in atmospheric composition) that are meant to serve as input for climate modeling. RCP8.5 is one of the highest priority scenarios in CORDEX (COordinated Regional climate Downscaling Experiment) project; it has rising radiative forcing pathway leading to 8.5 W/m2 in 2100 while RCP4.5 is the moderate scenario of stabilization without overshoot pathway to 4.5 W/m^2 at stabilization after 2100 (Moss et al. 2010).

The changes in the mean air temperature as compared with the base line are analyzed in three time slices namely Near Future (2011-2040), Mid Century (2041-2070) and Far Future (2071-2100) under two RCPs. Figure 3 shows the changes in the mean air temperature for three time slices, near future, mid century and far future under RCP 4.5. A steady increasing trend has been observed from near future to far future for the summer mean air temperature. There is a decreasing projection for the first decade (2011-2020) over the strong monsoon zone and south of Pakistan. This increase in the temperature for the first decade is around 1.5 °C over extreme north of Pakistan and in the west to Afghanistan (Fig 3 a). The near future projections under RCP 4.5 show more increase in the summer mean air temperature for the northern half of South Asia region to that of the Southern half. This is due to the monsoon phenomenon which produces strong moisture transport and heavy rainfall over the surface during the months of June-September. Increase in the near future temperature is less than 2 °C. The mean air temperature moves on increasing the mid-century as well and this increase reaches up to 3 °C (Fig 3 e-g) and even higher in some parts over Afghanistan and North of Pakistan. The projections of the multimodel ensemble for the far future time slice show a uniform increase in all the three decades (Fig 3 h-i). This increase reaches upt to 4 °C over the central parts of India, central and northern parts of Pakistan and Afghanistan. The warming signal is much prominent over the whole domain. The spread of multimodel ensemble projection under RCP 4.5 for the near future shows higher values over the northern parts of Pakistan, North West and central parts of India (Fig 4 a-c). During the mid century the higher spread values move from the north to the central and south of India. The central and south of India shows a maximum spread in far future time slice for the summer mean air temperature projections. This analysis shows that the future projections are widely spread over the monsoon zone which shows the higher variability in the temperature projections for the monsoon region.

The future projections were presented as the change compared to the baseline period from the CMIP5 GCMs multimodel ensemble under RCP 8.5 are shown in Figure 5. RCP 8.5 is future scenario where the radiative forcing reaches to a value of 8.5 m/watt in 2100. The results are presented in three time slices to better understand the changes for each time period. The spread in the projections are presented in the Figure 6 to show the variability in the projections. The results of the change from the baseline period show a low warming trend for near future but the change in temperature reaches above 2 °C for the third decade (Fig 6 c) in the near feature time slice. This increase in the mid-century is projected to be stronger with more increase over the glaciated zone and monsoon influenced regions of South Asia. The warming for the mid-century is more than 3 °C. The temperature change in the far future time slice is projected to be about 6 °C which is very high as compared to the projections under RCP 4.5. This higher increase in the mean air temperatures will result in more surface heating. This may result in more erratic monsoon in far future. The spread in the mean air temperature projections under RCP 8.5 shows higher spread over the central Pakistan in near future (Fig 7 a-c). The spread is higher over the foothills of Himalayas and a smaller area in the central India for the mid-century. The same has been observed for the far feature except for the last decade (Figure 7 j) where the spread values are not much pronounced.

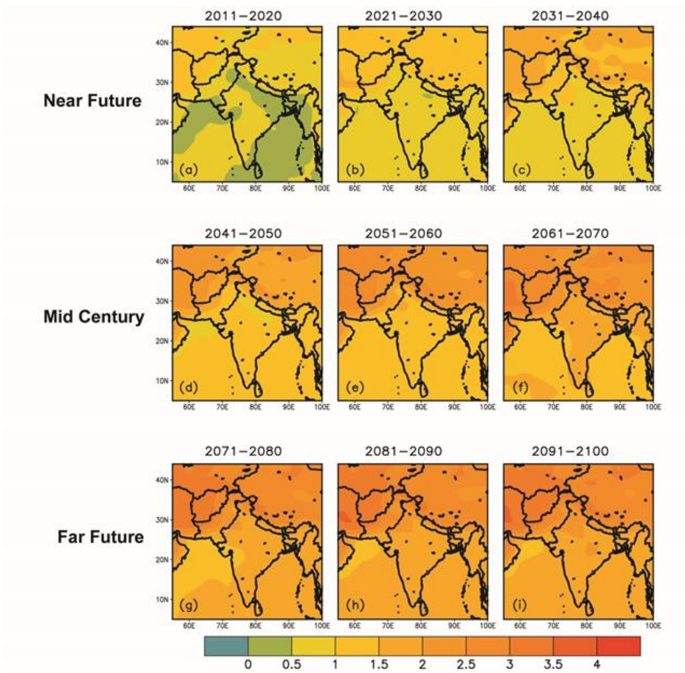

Figure 3: Mean Air Temperature change (°C) from CMIP5 Ensemble under RCP 4.5 for 2011-2100

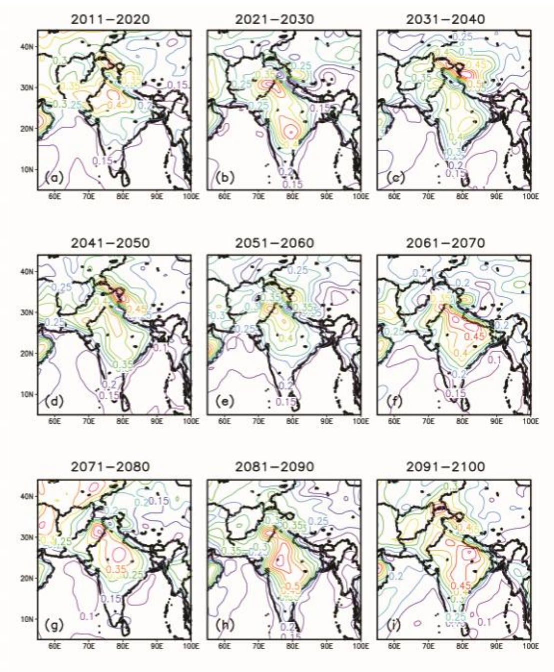

Figure 4: Spread in the ensemble mean projection of summer air Temperature under RCP 4.5 for near future, mid-century and far future

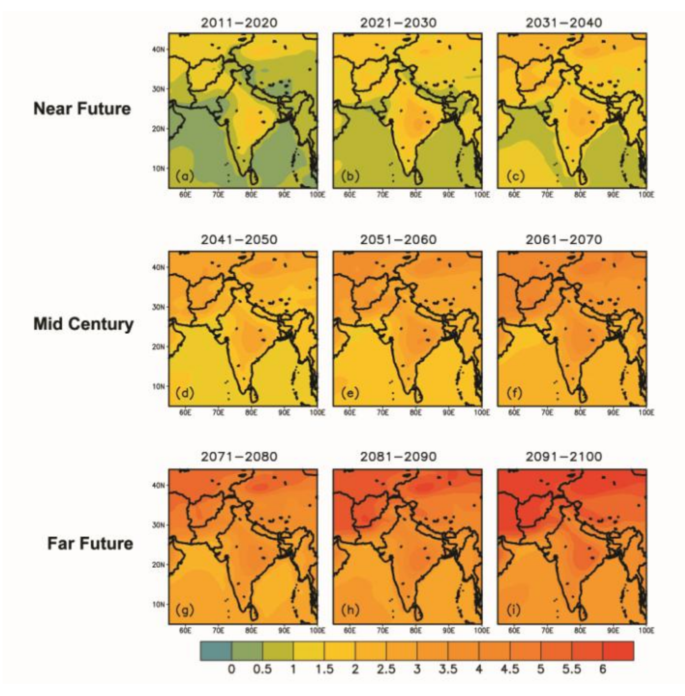

Figure 5: Mean Air Temperature change (°C) from CMIP5 Ensemble under RCP 8.5 for 2011-2100

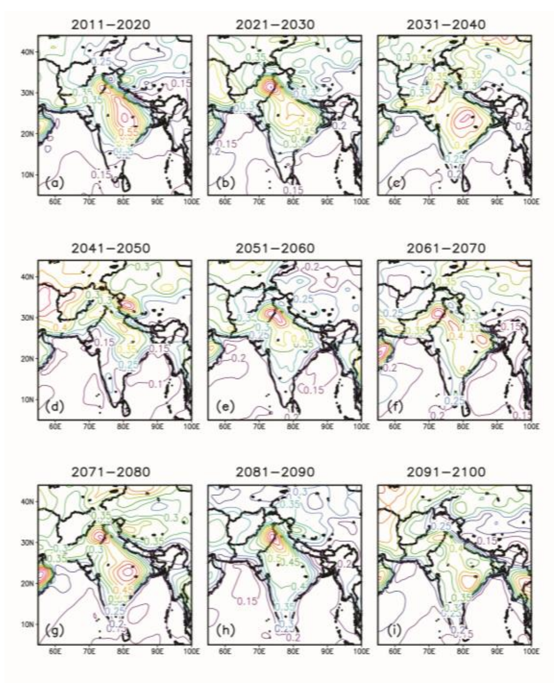

Figure 6: Spread in the ensemble mean projection of summer air Temperature under RCP 8.5 for near future, mid-century and far future

Table 2: Selected GCMs for future projections

Sr.#	Model	Modeling Center	Resolution
1	ACCESS1-0	CSIRO-BOM	1.85 x 1.25
2	CCSM4	NCAR	1.25 x 0.9424
3	EC-EARTH	ICHEC	2.8125
4	HadCM3	MOHC	3.75 x2.5
5	HadGEM2-AO	NIMR-KMA	1.875x1.25
6	MIROC5	MIROC	0.5625

Conclusion

In this study we evaluated the mean temperature from twenty four CMIP5 GCMs with the ERA Interim data for the JJAS season from 1979-2005. The spatial biases were calculated and then the Taylor diagram statistics were calculated for all the GCMs. Future projections for the multimodel ensemble were presented under the two RCPs namely RCP 4.5 and RCP8.5. These projections were analyzed on the decade basis in three different time slices; near future (2011-2040), mid century (2041-2070) and far future (2071-2100). The spread in the ensemble projections of CMIP5 under both the RCPs (RCP 4.5 and RCP 8.5) is also presented to explore the variability in the changes of mean air temperature. The conclusions derived from this study are:

- The spatial patterns of JJAS mean Air Temperature are well captured by CMIP5 GCMs over Pakistan.
- CMIP5 GCMs are cold bias over the mountainous regions especially HKH region.
- Warm biases from CMIP5 GCMs are observed for the Pakistan region.
- Pattern correlation is very high for all the GCMs with Era Interim temperature.
- The change in temperature is uniform; a steady increase from one decade to other.
- The northern and central parts of Pakistan experienced high spread in the mean air temperature projections under both the RCPs in near, mid and far future.
- The decade 2091-2100 is the warmest projected decade by RCP 4.5 and RCP 8.5.
- Mean temperature changes are higher for the Northern and north western parts of Pakistan.
- The change in mean air temperature is robust for both RCPs and all decades.

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