

## Climate predictions for central Kashmir of great Himalayas under different emission scenarios of IPCC

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**सार** – जलवायु परिवर्तन से प्राकृतिक संसाधनों और खाद्य फसलों के वितरण के घटना विज्ञान और उत्पादन के प्रभावित होने की संभावना है। वर्तमान अध्ययन का उद्देश्य हिमालय के मध्य कश्मीर के लिए भविष्य की जलवायु के पूर्वानुमान को परिभाषित करने हेतु एसडीएसएम के अंशांकन और सत्यापन के लिए दैनिक जलवायु डेटा ( $T_{max}$ ,  $T_{min}$  और वर्षण), हेडली सेंटर युग्मित मॉडल के जीसीएम डेटा और एनसीईपी रीएनेलिसिस डेटा का उपयोग करके भविष्य के जलवायु प्रक्षेपण को तैयार करना था। IPCC द्वारा परिभाषित A2 और B2 परिदृश्यों के तहत 1961 से 2099 तक का दैनिक जलवायु डेटा ( $T_{max}$ ,  $T_{min}$  और वर्षा) तैयार किया गया। मध्य कश्मीर में जलवायु परिवर्तन की सीमा को निर्धारित करने के लिए दो उत्सर्जन परिदृश्यों के बीच तुलना की गई। पिछले 30 वर्षों का प्रेक्षित औसत तापमान और वर्षा क्रमशः 13.24 °C और 824.52 मिमी रही, जिसे तुलनात्मक उद्देश्य के लिए आधारभूत माना जाता है। A2 परिदृश्य के तहत परिणामों से पता चला है कि निकट भविष्य (2016-2043) में औसत तापमान और वर्षा में 0.18 °C, 243.56 मिमी (29.54%) की वृद्धि होगी; मिड फ्यूचर (2044-2071) में 0.32 °C और 259.16 मिमी (31.43%), और सुदूर भविष्य (2072-2099) में क्रमशः 0.63 °C, और 229.10 मिमी (27.79%)। जबकि, B2 परिदृश्य के तहत परिणामों से पता चला है कि निकट भविष्य (2016-2043) में औसत तापमान और वर्षा 0.09 °C, 224.67 मिमी (27.25%) बढ़ेगी; मध्य भविष्य (2044-2071) में 0.09 °C और 214.47 मिमी (26.01%), और सुदूर भविष्य (2072-2099) में क्रमशः 0.14 °C और 243.03 मिमी (29.48%)। यह निष्कर्ष निकला कि A2 परिदृश्य के तहत जलवायु परिवर्तन B2 की तुलना में काफी महत्वपूर्ण था, जो कि स्थानीय पर्यावरणीय स्थिरता के आधार पर क्षेत्रीय रूप से उन्मुख आर्थिक विकास और कम उत्सर्जन परिदृश्य (B2) पर आधारित IPCC उच्च उत्सर्जन (A2 परिदृश्य) के अनुरूप है। यह अध्ययन प्राकृतिक संसाधनों के प्रबंधन और खाद्य सुरक्षा के लिए उचित शमन योजना उपलब्ध कराने के लिए नीति निर्माताओं के लिए फायदेमंद होगा।

**ABSTRACT.** Climate change is likely to impact the distribution of natural resources and food crops by altering their phenology and production. The present study was aimed to generate the future climate projection using daily climate data ( $T_{max}$ ,  $T_{min}$  and precipitation), GCM data of Hadley Centre Coupled Model and NCEP reanalysis data for calibration and validation of SDSM to define the future climate prediction for the Central Kashmir of Great Himalayas. Daily climate data ( $T_{max}$ ,  $T_{min}$  and precipitation) was generated from 1961 to 2099 under A2 and B2 scenarios defined by IPCC. Comparison between two emissions scenarios was done to determine the climate change extent in Central Kashmir. The past 30 years observed average temperature and precipitation was 13.24 °C and 824.52 mm, respectively considered as a baseline for comparison purpose. The results under A2 Scenario showed that average temperature and precipitation would increase by 0.18 °C, 243.56 mm (29.54%) during Near Future (2016-2043); 0.32 °C and 259.16 mm (31.43%) during Mid Future (2044-2071) and 0.63 °C and 229.10 mm (27.79%) during Far Future (2072-2099), respectively. Whereas, the results under B2 Scenario showed that average temperature and precipitation would increase by 0.09 °C, 224.67 mm (27.25%) during Near Future (2016-2043); 0.09 °C and 214.47 mm (26.01%) during Mid Future (2044-2071) and 0.14 °C and 243.03 mm (29.48%) during Far Future (2072-2099), respectively. It was concluded that under A2 scenario climate change was quite significant than B2, which is well according to the IPCC high emission (A2 scenario) based on regionally oriented economic development and low emission scenario (B2) based on local environmental sustainability. The study will be beneficial for policymakers to provide proper mitigation plans for natural resources management and food security.

**Key words** – Climate change, Central Kashmir, Temperature, Precipitation, Emission scenario.

## 1. Introduction

Climate change is one of the most debated topics in recent times. Climate models are the primary tools available for development of climate change projections. Over the Himalayan region, changes in temperature and precipitation patterns and their impacts on natural resources like water resources, glaciers, ecology, agriculture, etc. are being attributed to the changing climate (Dimri and Dash, 2012; Shekhar *et al.*, 2010). Various studies pertaining to climate change in the Himalayas have published different results on impact of natural resources differently. Bhutiya *et al.* (2007) revealed a significant increase in air temperature by about 1.6 °C in the region of the Northwest Himalayan over the last century, with winters warming at a faster rate. Based on observed data and model reanalyzed fields, Dash *et al.* (2007) found that the atmospheric surface temperature in India has increased by about 1 and 1.1 °C during winter and post-monsoon months, respectively. Yadav *et al.* (2004) reported that substantial fall in minimum temperatures at a rate nearly three times greater than the rate of increase in maximum temperatures found in local climate records is responsible for the cooling trend in mean pre-monsoon temperature. Trends in winter temperature were noted by Dimri and Dash (2012); Archer and Fowler (2004). Jhajharia and Singh (2011) reported an increase in temperature during monsoon and post-monsoon seasons. However, as the Himalayas cover a vast spatial expanse, therefore, its sub-regions respond differently to the climate change.

During the last decade, increase in temperature and CO<sub>2</sub> concentration due to various factors including change in the pattern of land use and greenhouse gas (GHG) emissions from industrial and agricultural sectors; have caused changes in the earth's climate. This enhanced concentration of GHG was probable to affect the temperature of the earth as well as precipitation and shifts in sea level. It has been noted that India's annual mean and maximum temperatures have risen by about 0.7 and 0.8 °C, respectively (Dash *et al.*, 2007). Many regions in India including the west coast, central India, the internal peninsula and north-east have shown a warming trend in climate (Dash *et al.*, 2007).

The quantification of knowledge on occurrence, circulation and distribution of the water on the earth becomes increasingly complex under climate projections because of uncertain effects due to anthropogenic emissions. According to the sixth Intergovernmental Panel on Climate Change (IPCC) Technical Paper on Climate Change and Water reported by Bates *et al.* (2008) that changes in the large-scale hydrological cycle have been

related to increase in the observed temperature over several decades.

These projections of future emissions are called IPCC SRES Scenarios (Special Report on Emissions Scenarios) and based on a number of assumptions in driving forces IPCC 2000 (Nakicenovic *et al.*, 2000). The SRES team defined four narrative storylines describing different social, technological, economic, demographic and environmental developments, which are labeled A1, B1, A2 and B2. Out of these A2 and B2 scenarios project CO<sub>2</sub> concentrations of approximately 850 ppm and 600 ppm, respectively. Based on these scenarios, a number of general circulation models (GCMs) have been developed.

## 2. Data and methodology

The present study focuses on the Central Kashmir of Great Himalayas which lies on latitude 34°8'59" N, longitude 74°52'55" E and altitude of 1600 amsl. The historical meteorological data (predictands) for weather parameters (maximum temperature ( $T_{max}$ ), minimum temperature ( $T_{min}$ ) and precipitation) collected from Agromet Field Unit (AMFU) Srinagar, Sher-e-Kashmir University of Agriculture Sciences and Technology of Kashmir, Shalimar Campus from (1985-2015) and used for the generation of weather files in the Multiple Linear Regression (MLR) based Statistical Downscaling Model (SDSM) version 5.2 for the observed period of the study. Large-scale atmospheric variables (predictors): SDSM version 5.2 was used for climate modeling.  $T_{max}$ ,  $T_{min}$  and precipitation were forecasted up to year 2099 using GCM data. GCM data were downloaded from Canadian Climate Scenarios Network from 1961-2099. The data comprised of two data sets NCEP\_1961-2001 and H3a2a\_1961-2099. National Centers for Environmental Prediction (NCEP\_1961-2001) data set was used to calibrate and validate the model. Then for future  $T_{max}$ ,  $T_{min}$  and precipitation predictions, Hadley Centre Coupled Model, Version 3 (HadCM3) data sets for A2 scenario (H3a2a\_1961-2099) and B2 scenario (H3b2a\_1961-2099) were used. Future forecasts of daily annual maximum temperature ( $T_{max}$ ), minimum temperature ( $T_{min}$ ) and precipitation as well as monthly averaged total precipitations were made under two different IPCC emission scenarios, namely A2 and B2. Comparison between two emissions scenario, *i.e.*, SRES A2 and B2 using SDSM was done to determine the future climate change extent under both the scenarios in Central Kashmir of the Valley.

The SDSM is widely accepted Statistical Downscaling (SD) technique in practice for the projection of climate scenarios for various related impact studies. The technique is mainly based on multivariate regression

method. It is designed to simulate sequences of daily climate data for present and future periods through combinations of regression and weather generators by extracting statistical parameter from observed data series. It combines a stochastic weather generator approach and transfer function model that needs two types of daily data (Wilby *et al.*, 2002). The first type corresponds to local predictands of interest (*e.g.*, temperature and precipitation) and the second type corresponds to the data of large-scale predictors (NCEP and GCM) of a grid box closest to the study area (Hashmi *et al.*, 2010). During downscaling with the SDSM, a multiple linear regression model is derived from a few selected large-scale predictor variables and local-scale predictands such as temperature and precipitation. Large-scale relevant predictors are selected by the results of correlation analysis, partial correlation analysis and scatter plots and the physical sensitivity between selected predictors and predictand should also be considered in study. SDSM provides two means of optimizing the model dual simplex and ordinary least squares (Wilby and Dawson, 2007) and both approaches give comparable results; ordinary least squares is much faster. The model is structured as monthly model for both daily precipitation and temperature downscaling.

The output of SDSM 5.2 is daily weather series when the model is established; NCEP and GCM daily data are used to construct current and future daily weather series. Generally, the application of SDSM contains five steps (Wilby *et al.*, 2002; Wilby and Harris, 2006) : (i) selection of predictors, (ii) model parameter calibration, (iii) simulation, (iv) model validation, and (v) Scenario generation of future series of the predictand.

The Scenario Generation process produces daily base data for maximum temperature, minimum temperature and precipitation for the period 1961-2099. Each predictand (*i.e.*, precipitation, maximum and minimum temperature) scenario is generated based on the calibration result and the daily atmospheric predictors of the HadCM3. The calibration result is used based on assumption that predictor-predict and relationships under the current condition remain valid for the future climate conditions. HadCM3 has two emission scenarios A2 and B2. For both the emission scenario twenty ensembles of synthetic daily time series data were produced for 139 years. The stochastic component of SDSM enables up to 100 ensembles to be generated. Selection of only twenty ensembles was done due to reasonably match between observed and simulated daily temperature and precipitation. In addition, large number of ensembles notably did not improve and subjective for large deviation among ensembles output, only 20 individual ensemble outputs were averaged to improve the performance of

model for future time horizon. For time horizons 1961-2099, the A2 and B2 emission scenario precipitation, maximum and minimum temperature outputs were generated.

Data for the time slices representing periods 1985-2015 (baseline), near future (NF) climate change projection (2016-2043), mid future (MF) projection (2044-2071) and far future (FF) projection (2072-2099) were used for further analysis.

### 3. Results and discussion

The model calibration process constructs downscaling models based on multiple regression equations for daily  $T_{max}$ ,  $T_{min}$  and precipitation data of the study area (the predictand) and regional-scale, atmospheric (predictor) variables. SDSM optimizes the model using either dual simplex or ordinary least squares optimization in the advanced settings in the said model. The monthly temperature and precipitation were derived as per A2 and B2 SRES emission Scenarios by using as sub model of SDSM with the unconditional and conditional settings. Monthly average of 20 years (1985-2004) of the observed weather data and SDSM weather generated values using calibrated output file (NCEP data) of maximum temperature ( $T_{max}$ ) and minimum temperature ( $T_{min}$ ) for the location found that the observed values were at par with weather generated values using calibrated OUT file in SDSM. The adjusted  $R^2$  value for both  $T_{max}$  and  $T_{min}$  parameters during calibration period was 0.99 in both A2 and B2 scenario which indicates that 99% accuracy with the regression model. In case of precipitation, the weather generated precipitation was higher than observed precipitation among all months from January to December. The statistical analysis of parameters revealed that the mean ( $\mu$ ) of weather generated precipitation was 17 percent (A2) and 19 percent (B2) more than that of the observed precipitation with adjusted  $R^2$  value was 0.97 that showed the accuracy of up to 97% for both the scenarios.

Analysis under A2 scenario from Table 1 average annual maximum and minimum temperatures showed an increasing trend in the near future (NF) while the average annual maximum temperature remained at par under B2 scenario, but increasing trend was found of the minimum temperature for the same scenario. The Maximum and minimum temperature under A2 scenario were found increasing at the rate of 0.12% and 4.93%, while it was found the rate of -0.20% and 2.60% under B2 scenario, respectively. The average annual precipitation was found an increasing trend for the same period under both scenarios at the rate of 29.54% and 27.25%, respectively (Table 1).

TABLE 1

Average annual based climate predictions for the four time slices of the future climate for central Kashmir

Climate Variable	Observed/ Baseline (1985-2015)	A2			B2		
		NF (2016-2043)	MF (2044-2071)	FF (2072-2099)	NF (2016-2043)	MF (2044-2071)	FF (2072-2099)
Annual $T_{max}$ (°C)	19.66	19.68	19.89	20.27	19.66	19.62	19.67
Annual $T_{min}$ (°C)	6.81	7.14	7.22	7.45	6.99	7.02	7.08
Annual $T_{average}$ (°C)	13.24	13.41	13.56	13.86	13.33	13.32	13.38
Average Annual Precipitation (mm)	824.52	1068.08	1083.68	1053.62	1049.19	1038.99	1067.55

TABLE 2

Monthly based maximum temperature (°C) averaged under four different time slices for central Kashmir

Month	Observed/ Baseline (1985-2015)	A2			B2		
		NF (2016-2043)	MF (2044-2071)	FF (2072-2099)	NF (2016-2043)	MF (2044-2071)	FF (2072-2099)
Jan	6.48	9.38	9.29	9.76	7.2	7.43	7.54
Feb	9.42	9	8.95	9.18	9.62	9.5	9.67
Mar	14.63	13.69	13.7	13.96	14.1	14.07	14.09
Apr	19.74	20	20.22	20.68	19.77	19.81	19.97
May	24.16	24.94	25.72	27.08	24.7	24.68	25.16
Jun	28.24	28.83	29.04	29.52	28.95	29.01	29.09
Jul	29.73	29.53	29.34	29.18	29.43	29.34	29.29
Aug	29.22	29.28	29.53	29.9	29.33	29.48	29.52
Sep	27.12	26.18	26.3	26.7	26.68	26.82	27.02
Oct	21.96	21.71	22.05	22.25	21.57	21.85	21.76
Nov	15.37	15.02	15.65	16.02	15.05	15.21	15.4
Dec	9	8.63	8.92	9.08	9.01	8.81	8.85

Average annual maximum and minimum temperatures showed an increasing trend in the mid future (MF) under both the scenarios. Maximum temperature and minimum temperature were also recorded increasing rate of 1.2% and 6% and 0.07% and 3.06%, for A2 and B2 scenario from baseline, respectively. For both scenarios, the average annual precipitation indicated an increasing trend over the mid future at a rate of 31.43% and 26.01%, respectively (Table 1).

Average annual maximum and minimum temperatures showed an increasing trend in the far future

(FF) under both the scenarios. Maximum temperature and minimum temperature were also recorded increasing rate of 3.15% and 9.4% and 0.72% and 3.96%, for A2 and B2 scenario from baseline, respectively. The average annual precipitation indicated an increasing trend for the end future under both scenarios at the rate of 27.79% and 29.48%, respectively (Table 1).

In many of the earlier studies (Aggarwal and Mall, 2002; Mall *et al.*, 2006) future climate was predicted in relation to the modeled climate data of baseline (1961-1990) without considering the observed data. While

TABLE 3

Monthly based minimum temperature (°C) averaged under four different time slices for central Kashmir

Month	Observed/ Baseline (1985-2015)	A2			B2		
		NF (2016-2043)	MF (2044-2071)	FF (2072-2099)	NF (2016-2043)	MF (2044-2071)	FF (2072-2099)
Jan	-2.29	0.02	-0.34	-0.16	-1.9	-1.79	-1.9
Feb	0.11	-0.07	0.07	0.28	0.13	0.11	0.21
Mar	3.3	3.47	3.57	3.78	3.24	3.33	3.36
Apr	6.59	6.93	6.99	7.4	6.9	6.93	7.02
May	9.76	10.27	10.53	10.94	10.22	10.19	10.38
Jun	13.64	14.37	14.6	14.76	14.6	14.78	14.86
Jul	17.17	17.17	17.1	17	17.24	17.16	17.15
Aug	16.65	16.42	16.29	16.18	16.41	16.34	16.34
Sep	11.97	10.85	11.06	11.52	11.55	11.66	11.87
Oct	5.38	5.05	5.04	5.19	4.96	4.84	4.96
Nov	0.7	0.92	1.18	1.48	0.68	0.84	0.9
Dec	-1.69	0.32	0.51	0.97	-0.18	-0.22	-0.17

TABLE 4

Monthly based precipitation (mm) averaged under four different time slices for central Kashmir

Month	Observed/ Baseline (1985-2015)	A2			B2		
		NF (2016-2043)	MF (2044-2071)	FF (2072-2099)	NF (2016-2043)	MF (2044-2071)	FF (2072-2099)
Jan	67.95	87.18	85.89	83.89	84.14	86.07	97.39
Feb	94.59	152.07	159.96	148.82	130.54	121.04	129.32
Mar	123.03	157.18	149.21	143.64	110.68	106.11	108.11
Apr	100.27	113.75	112.54	103.07	129.61	131.82	137.11
May	71.65	98.36	106.93	102.25	91.32	88.46	98.61
Jun	48.75	64.89	60.04	58.82	77.43	86.11	80.68
Jul	86.83	171.54	176.79	160.29	118.82	1.16	118.93
Aug	83.11	53.11	58.46	66.43	102.82	1.10	103.11
Sep	43.10	29.64	29.89	36.86	58.39	53.43	56.00
Oct	32.44	42.39	45.04	46.29	26.48	24.64	24.25
Nov	25.94	26.54	26.46	28.86	28.04	29.11	30.64
Dec	46.85	63.07	62.36	65.46	81.43	77.64	75.04

present study is considering the observed/station data as well. The projected trends for future showed increase in  $T_{max}$ ,  $T_{min}$  and precipitation under both A2 and B2

scenarios. Mean temperature and precipitation would increase considerably in all the time slices as stated in the results. These results commensurate with the findings by

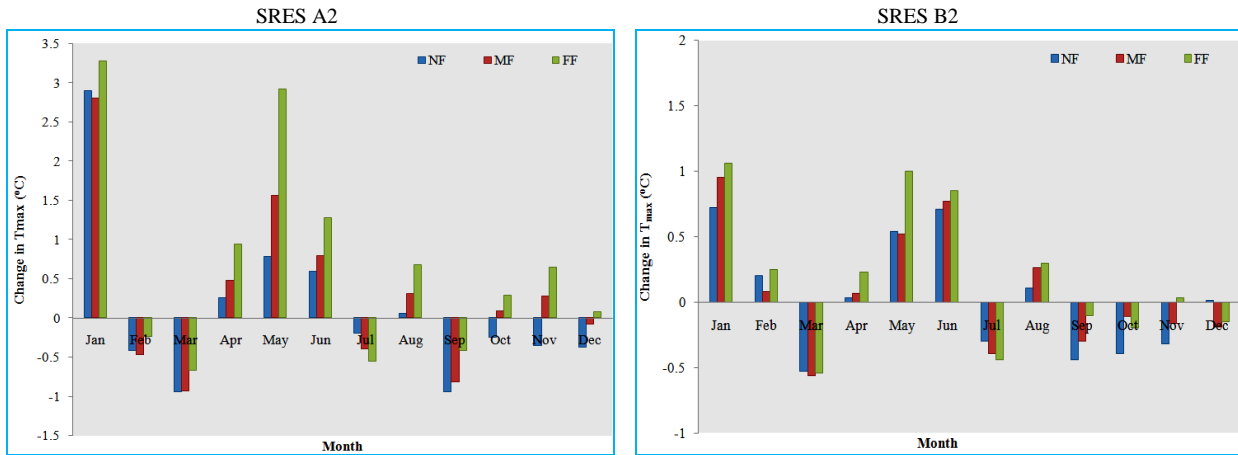


Fig. 1. Deviation from Baseline monthly maximum temperature trends in NF, MF and FF

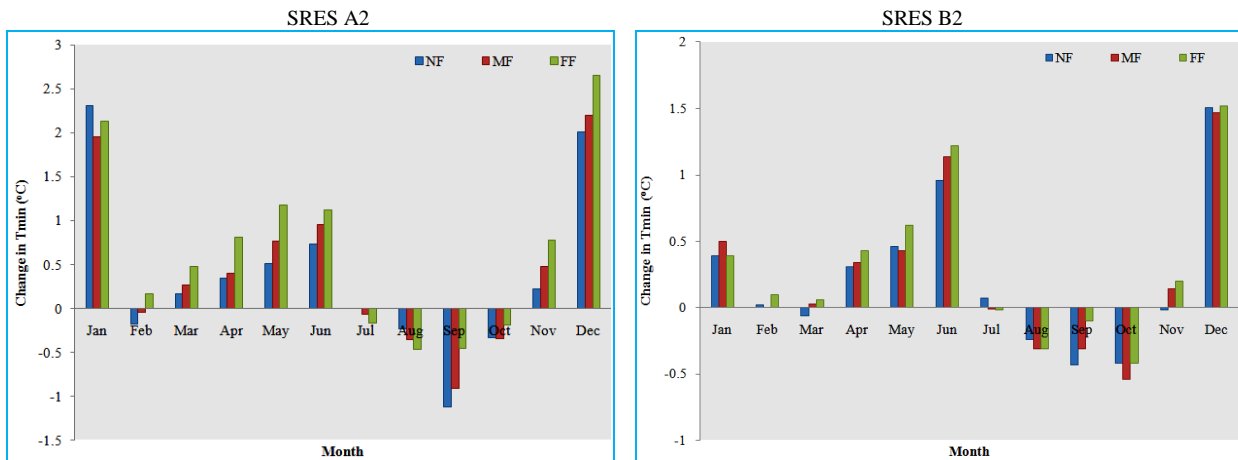


Fig. 2. Deviation from Baseline monthly minimum temperature trends in NF, MF and FF

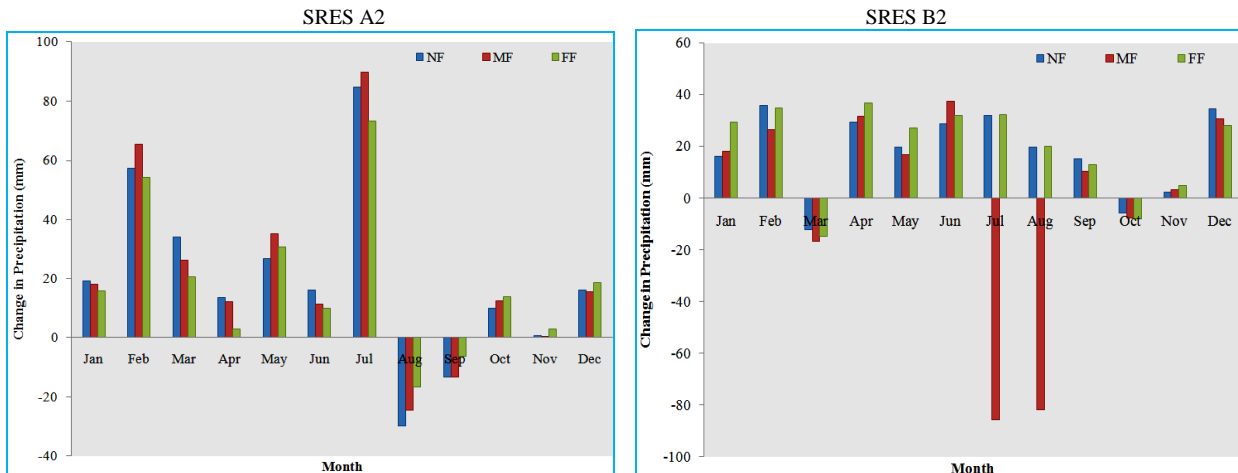


Fig. 3. Deviation from baseline monthly precipitation trends in NF, MF and FF

Kumar *et al.* (2011) indicating significant warming and increasing rainfall over India towards the end of the 21<sup>st</sup> century using PRECIS under A1B scenario and with Chaturvedi *et al.* (2012) who used multi model outputs for climate projections indicating northern India are projected to experience higher levels of warming than the rest of the country. Gosain *et al.* (2006) also reported that Indo-Gangetic plains is likely to experience a 0.5-1 °C rise in average temperatures during mid of century and 3.5-4.5 °C rise in the end of century and increased frequency of extremely wet rainy seasons from PRECIS climate model. Another study of climate prediction under RCP 4.5 and 8.5 for Ludhiana, Punjab reported temperature and rainfall would increase in mid and end-century under both these scenarios (Dar *et al.*, 2019).

### 3.1. Maximum temperature

In NF, MF and FF under A2 scenario when compared with baseline the maximum temperature showed an increasing trend, with the rate of 2.9 °C, 2.81 °C and 3.28 °C in the month of January for NF, MF and FF, respectively. But, it showed a decreasing trend in the remaining months. It was observed that maximum decrease was in the month of March being 0.94 °C, 0.93 °C and 0.67 °C for NF, MF and FF, respectively for the same scenario. The analysis of maximum temperature under B2 scenarios when comparing with baseline time series showed an increasing trend in the majority of months with the maximum increase at the rate of 0.72 °C, 0.95 °C and 1.06 °C in the month of January for NF, MF and FF, respectively. The decreasing trend was seen maximum in the month of March for all the three time slices and the decreasing rates were 0.53 °C, 0.56 °C and 0.54 °C for NF, MF and FF, respectively (Tables 2-4) (Fig. 1). The results are obtained according to the IPCC high emission (A2 scenario) based on regionally oriented economic development and low emission scenario (B2) based on local environmental sustainability hence A2 scenario showed more increase as compared to B2.

### 3.2. Minimum temperature

Minimum temperature showed a rising trend in the most of the months except July, August, September and October showing decreasing trends. The highest increasing trend found 2.31 °C in the month of January for FF and 2.2 °C and 2.66 °C in the month of December for MF and FF, respectively relative to baseline under A2 scenario of IPCC. The decreasing trend in the minimum temperature with rate of 1.12 °C, 0.91 °C and 0.45 °C being maximum in the month of September was shown for NF, MF and FF, respectively. Relative to the baseline, the

minimum temperature analysis under B2 scenarios showed an increasing trend in most of the months, with a maximum increase of 1.51 °C, 1.47 °C and 1.52 °C in the month of December for NF, MF and FF, respectively. The highest decreasing trend among all time slices was seen in the month of October. The decreasing trends for NF, MF and FF were 0.42 °C, 0.54 °C and 0.42 °C, respectively (Tables 2-4) (Fig. 2). The results under both the scenarios were well according to the recommendations of IPCC generated scenarios as stated above in maximum temperature case; hence under A2 scenario more increase in minimum temperature was observed than under B2.

### 3.3. Precipitation

The monthly trends of precipitation for the time slices of NF, MF and FF showed a significant increase in all the months except August and September in both scenarios of A2 and B2. The maximum increase was observed at the rate 84.71 mm in NF, 89.96 mm in MF and 73.46 mm in FF during the month of July under the A2 scenario relative to the baseline time series. Whereas for B2 scenario the decreasing trends were observed with an amount of 35.95 mm in NF (February), 37.36 mm in MF (June) and 36.84 mm in FF (April) from the baseline (Tables 2-4) (Fig. 3). The maximum increase in precipitation under A2 scenario than B2 is due to regionally oriented economic development and local environmental sustainability cases, respectively as defined by IPCC.

## 4. Conclusions

Monthly average as well as annual average  $T_{\max}$  and  $T_{\min}$  observed and weather generated results of calibration were almost same with accuracy up to 99% for A2 and B2 scenarios and in case of precipitation model showed the accuracy of 97% for both the scenarios. The climate projections for 21<sup>st</sup> century under A2 scenario showed a significant increase in average annual temperature and precipitation for all the time slices whereas annual climate projections under B2 scenario showed less rise compared to A2 scenario.

This study will be beneficial for policymakers to provide valuable reference results for developing natural resources management and food crop security plans for Central Kashmir.

### Disclaimer

The contents and views expressed in this research paper are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

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