
Welcome

INDICE Work Package-II, BCKV

Are CMIP3/CMIP5 GCMs able to simulate observed seasonal rainfall change over the Western Himalayan region of India?

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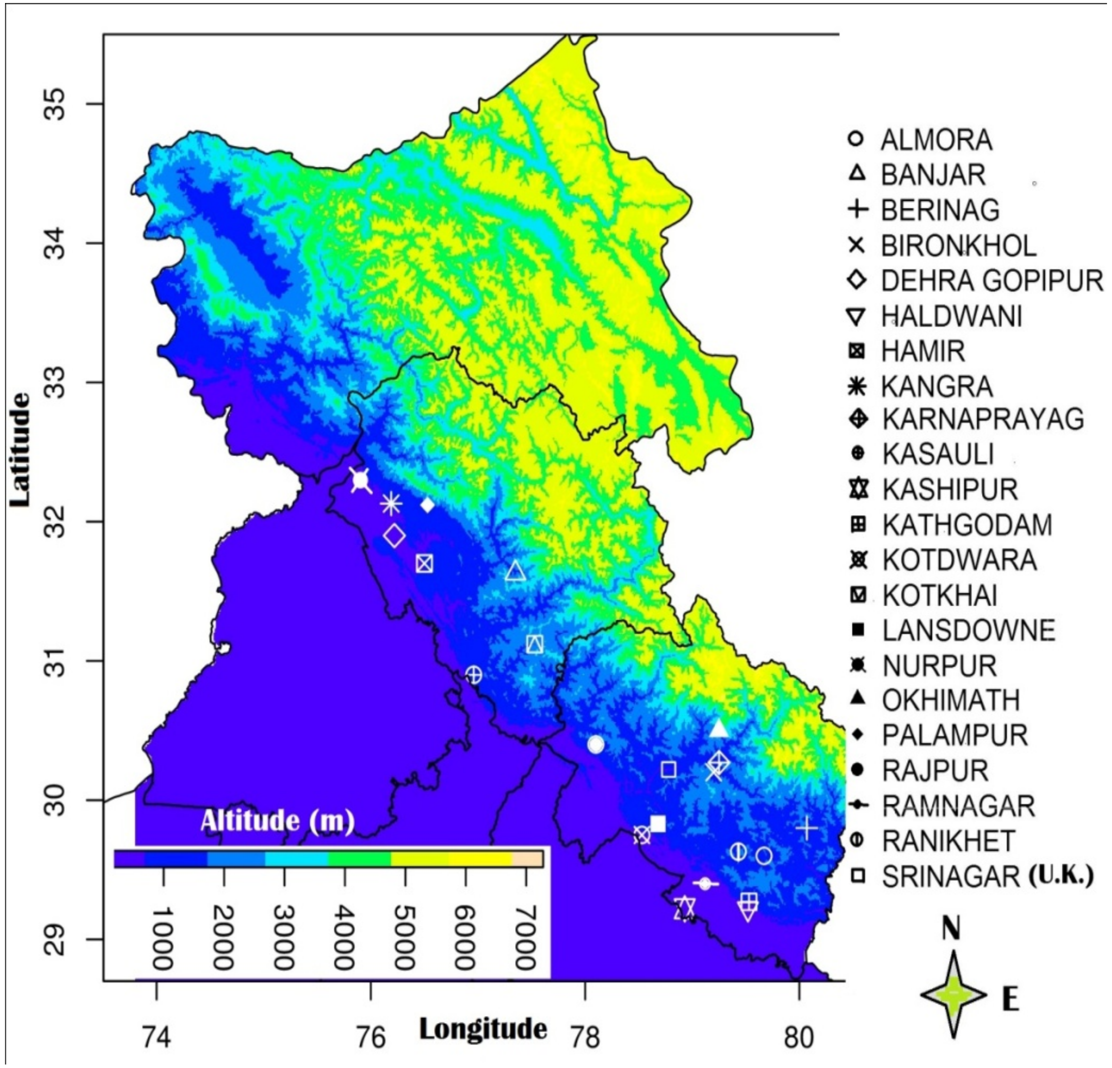
Study Region



Winter Abrupt precipitation in the form of rainfall and snow, which is caused by the extra-tropical storm known as Western Disturbances (WD)

Summer Frequency of WD decreases. So, the Indian Himalayan region gets less rainfall during the summer as compared to the winter season.

Monsoon Rainfall received from the south west-monsoon. As the summer monsoon moves from westward, the rainfall decreases from east to west due to increasing altitude of mountains.

Background

The study of rainfall change scenario over Himalayan region is very important as the livelihood of more than 1.27 billion people and the vast biodiversity of India highly depended on melt water from the Himalaya.

Detection of climate change information over this region is very challenging task due to its complex topography, sparse data availability and quality of data, although there are some stations with good quality data predominantly over the period 1901-1970, but after 1970 the data quality is sparse and inconsistent containing huge missing records.

Precipitation shows a dipole like patterns with one moderate peak (15-20% of annual rainfall) during winter (DJF) while the higher peak (39%-71% of annual rainfall) is shown during monsoon (JJAS).

Background

Rainfall over the Himalayan region is not consistent with that of all-India rainfall the reason may be the loss of tele-connection towards the ending of 1960s (Bhutiyani et al. 2007).

Rainfall has insignificant increasing trend in winter and Significant decreasing trend in monsoon and annual in the last century. Over the Uttarakhand region of the WHR the rainfall has shown a decreasing trend at various observatory sites (Basistha et al. 2009).

The GCMs neither able to simulate the observed climatology nor they can able to depict inter annual variability of rainfall correctly. Hence, appropriate statistical post processing techniques are required to improve precipitation prediction using GCMs over a region.

Background

GCMs are able to capture the mean annual cycle of the observation data coherently but most of the times failed to capture its long term trend. Over the North WHR the latest generation CMIP5 GCMs failed to capture the long term decreasing trend as shown by various observational gridded data sets (Palazzi et al. 2015)

Demand for the reliable and accurate future precipitation change scenarios on the regional, sub-regional and local scales particularly in the mountain region for implementing any suitable adaptation and mitigation policies to combat climate change.

Data

1. Observed data from India Meteorological Department (IMD)
-> Both rain gauge and gridded rainfall data (0.25×0.25)
-> Rain gauge: Monthly data, Gridded: Daily data
-> Time period for Rain gauge: 1901-2005, Gridded data: 1901-2013

2. General Circulation Model (GCM) data from Coupled Model Intercomparison Project-3 (CMIP3) and CMIP5
-> 13 GCMs from CMIP3 and 42 GCMs from CMIP5
-> Both CMIP3 and CMIP5 GCMs have 2.5×2.5 degree resolution
-> All GCMs: Monthly rainfall data

Data

-> Time period for GCM rainfall data: 1901-2100.

-> 1901-2000: Past rainfall analysis and evaluation purpose

-> 2001-2100: Construction of future rainfall scenarios

->CMIP3: SRESA1B, CMIP5: RCP

->Out 42 GCMs under different RCP scenario of CMIP5 there are 23 common GCMs common in all RCP

Objectives

1. To identify "reference rain-gauge stations" for quantifying centennial scale annual and seasonal rainfall change over the WHR.

2. To evaluate the CMIP3 and CMIP5 GCMs and ranking them based on their abilities to simulate the observed rainfall

3. To construct future rainfall change pattern from the top ranking GCMs using all available Representative Concentration Pathways (RCPs) and emission scenarios.

Methods

- ✓ Missing data substitution: k-Nearest Neighbor (kNN), Markov Chain Monte Carlo (MCMC) multiple imputation and Indian meteorological department (IMD) interpolated gridded data substitution.
- ✓ Trend analysis: Mann-Kendall trend test and Sen's slope estimator test.
- ✓ Change point detection: Pettitt's test.
- ✓ Evaluation GCMs: GCMs were ranked according to their efficiency to simulate the observed annual and seasonal rainfall data
- ✓ Construction of future rainfall scenarios: Top ranked model output and their MME in the future time period.

Objective 1

To identify "reference rain-gauge stations" for quantifying centennial scale annual and seasonal rainfall change over the WHR.

Results, Objective 1

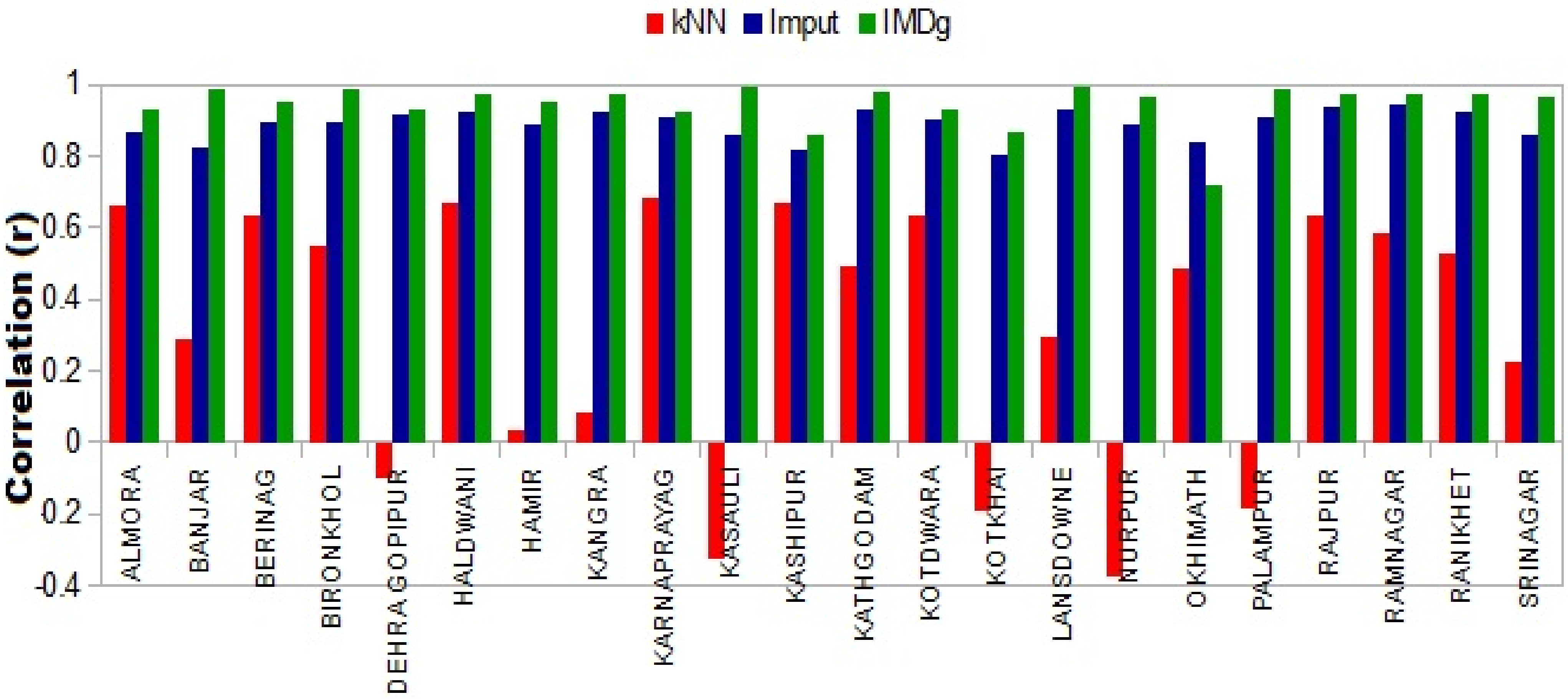
1. Took a complete data set of 50-years starting from 1901-1950 with no missing values. In a random manner the data set were inserted with 20% missing values.

2. The data generated from each of the method namely kNN, MCMC and IMD substitution were used to fill those 20% missing values.

3. We compared the estimated missing values from each method with the intentionally removed observed values for 22 rain gauge stations.

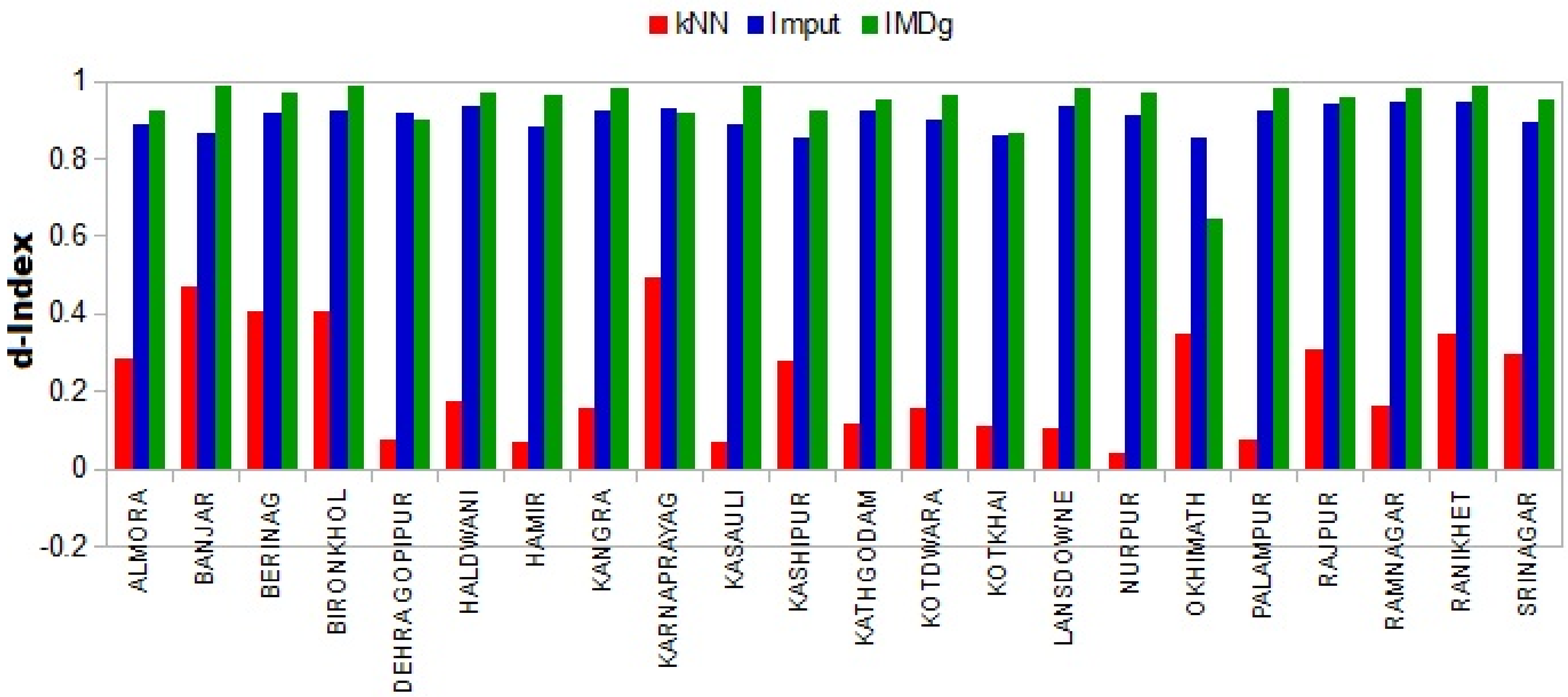
4. To visualize the efficiency of each method, different agreement indices (Correlation and d-Index) and error indices (standard deviation and Normalised root mean squared error) are used.

Results, Objective 1



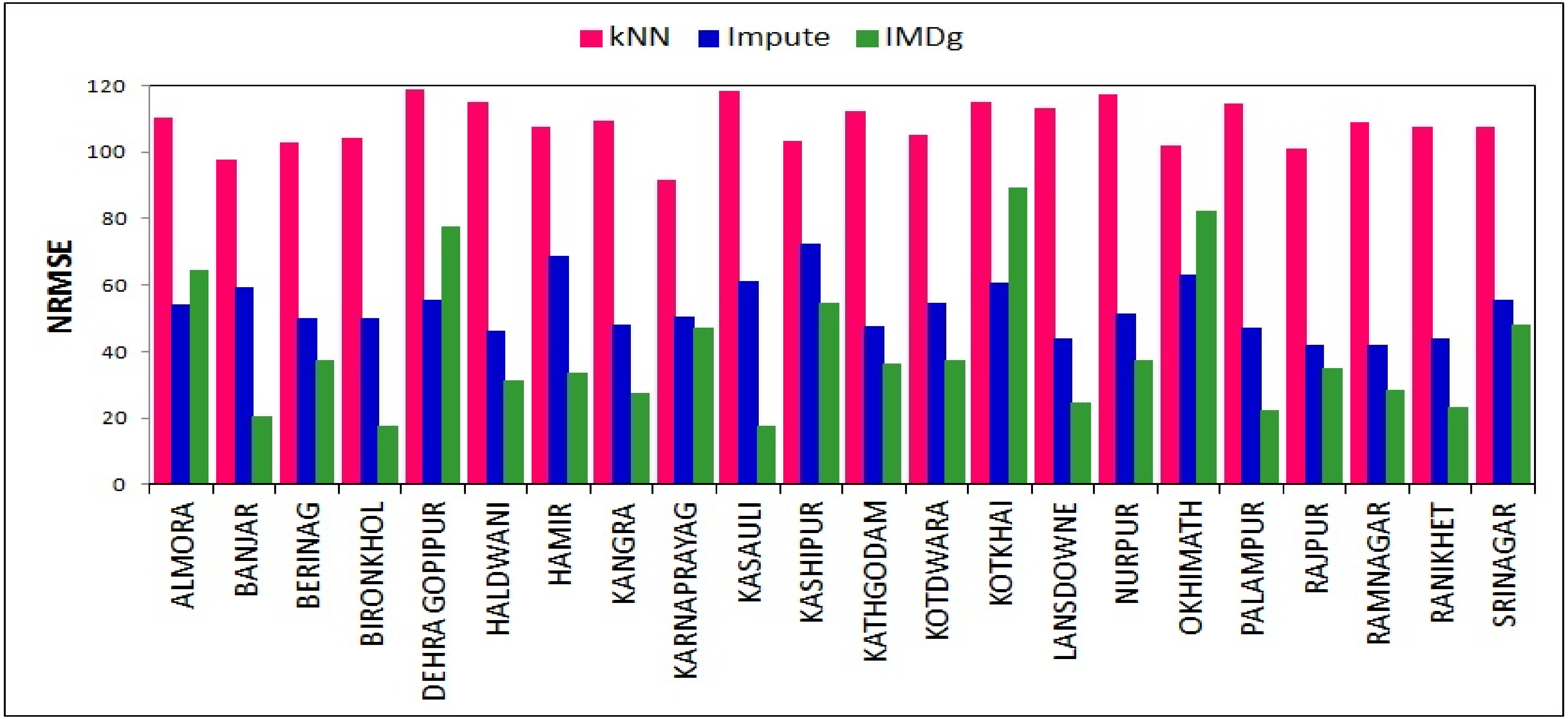
Comparison of correlation coefficient (r) among three methods of missing data substitution during the period 1901-1950.

Results, Objective 1



Comparison of d-index among three methods of missing data substitution during the period 1901-1950.

Results, Objective 1



Comparison of Normalised Root Mean Squared Error (NRMSE) among three methods of missing data substitution during the period 1901-1950.

Results, Objective 1

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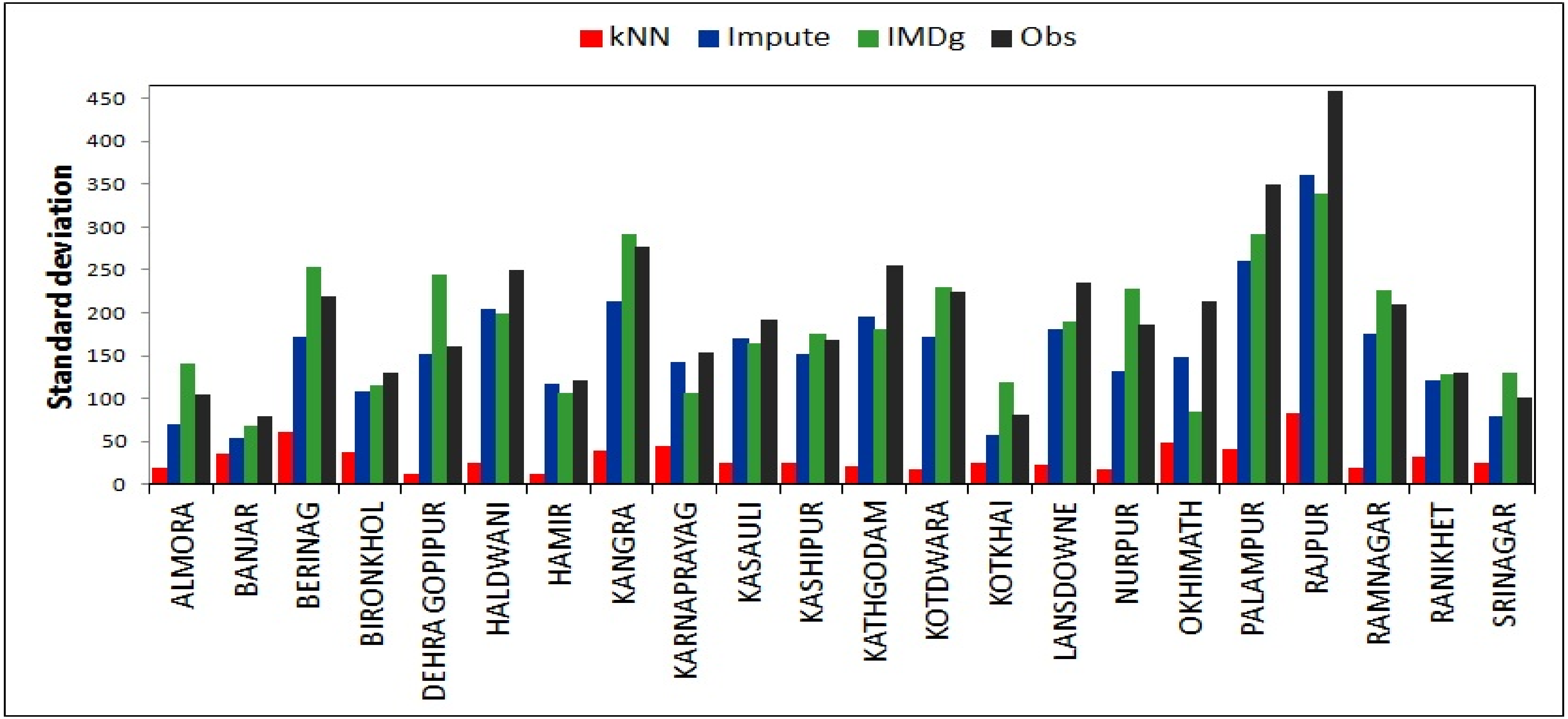

Comparison of 'Standard deviation' among three methods of missing data substitution during the period 1901-1950.

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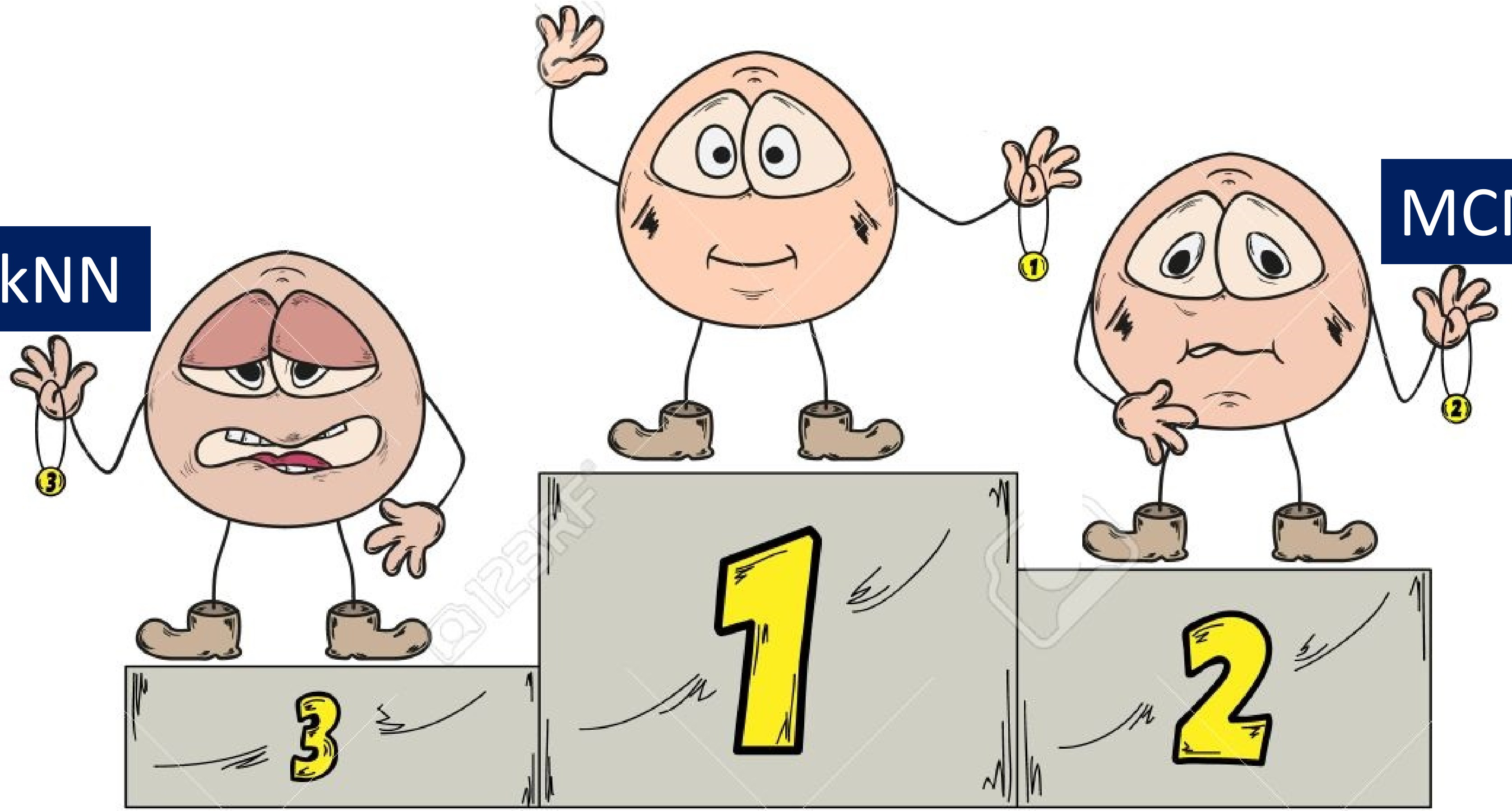
Results, Objective 1

IMD gridded data Substitution

kNN

MCMC



Results, Objective 1

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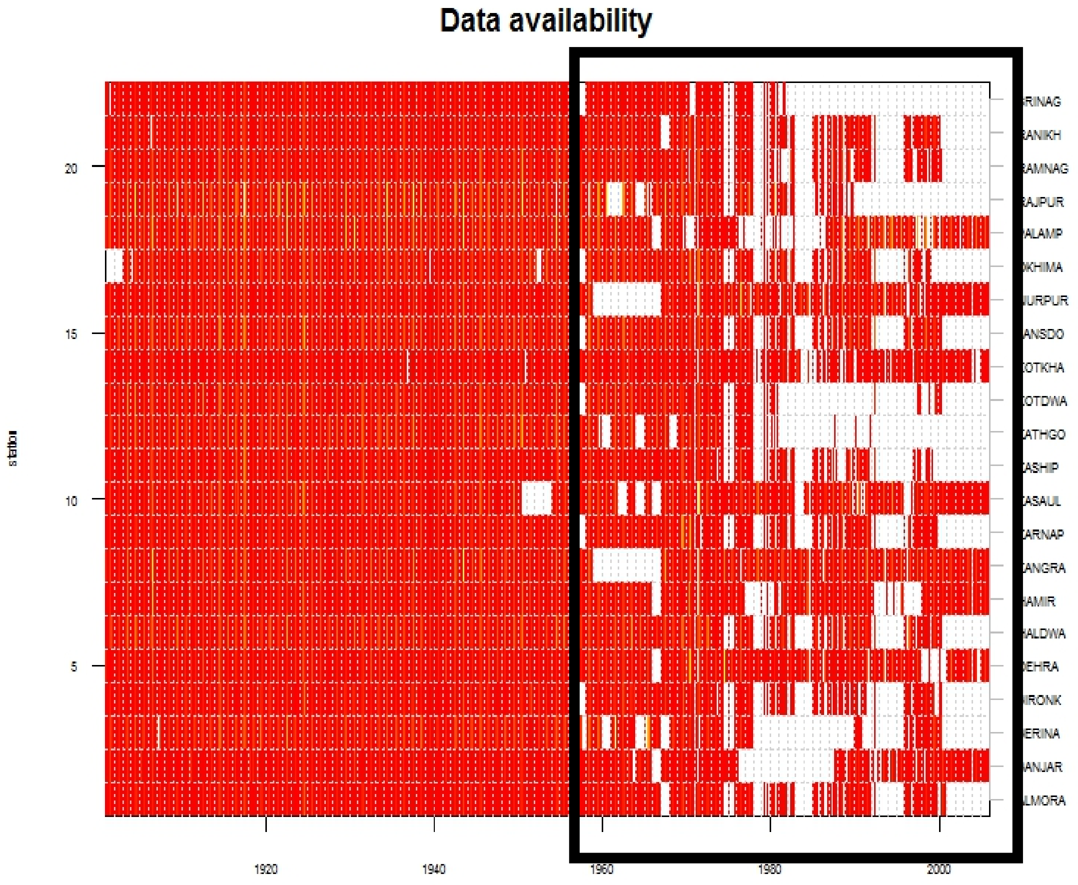

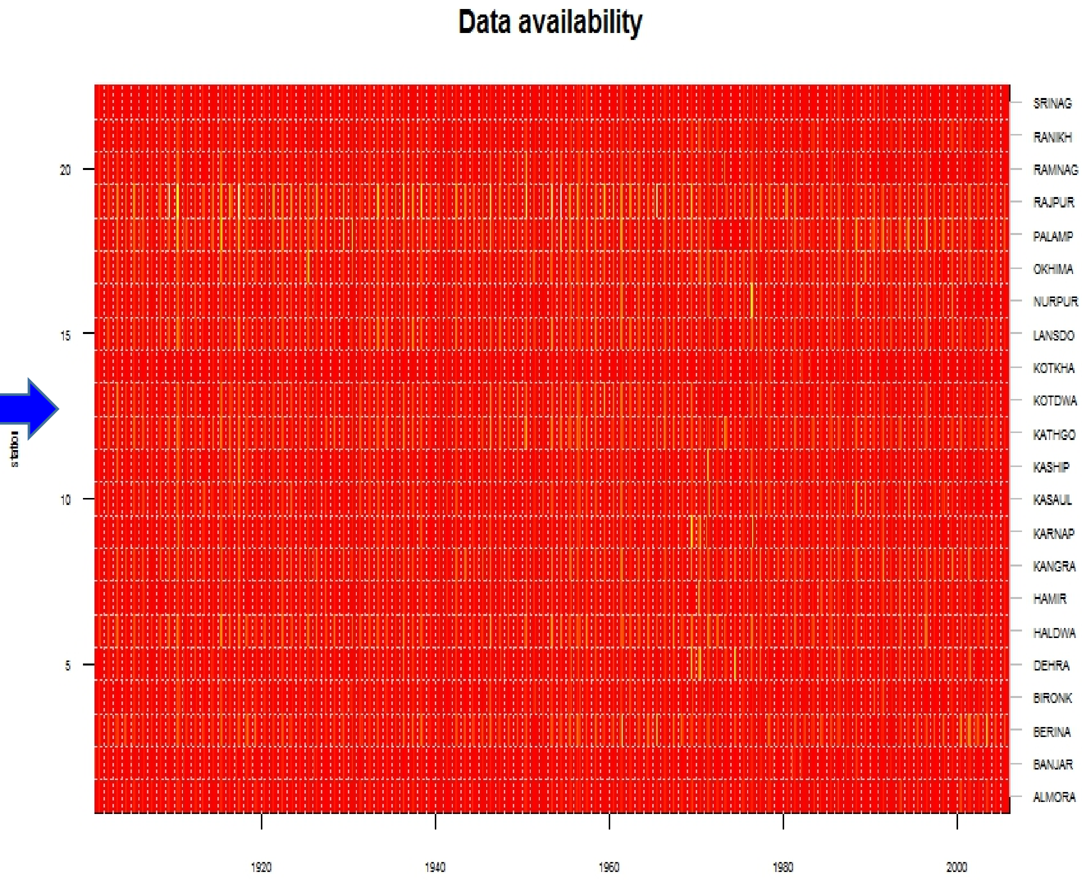

IMD rain gauge station data with missing values

IMD rain gauge station data without missing values: Missing values were substituted by the IMD gridded data

Results, Objective 1

1902-2000, mm/year	Lat. (deg)	Long. (deg.)	Alt. (m)	Annual (Jan-Dec)		Monsoon (Jun-Sep)		Winter (Dec-Feb)	
				Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)
ALMORA	29.60	79.67	1676	-0.76	1927	-0.41	1925	-0.06	1944
BANJAR	31.63	77.35	1356	-1.07	1967	-1.26	1967	-0.22	1961
BERINAG	29.80	80.07	1676	-0.73	1968	-0.40	1969	-0.32	1949
BIRONKHOL	30.20	79.20	1524	**-3.03**	1967	-2.08	1967	-0.58	1964
DEHRA GOPIPUR	31.90	76.22	503	0.62	1945	0.96	1991	0.01	1958
HALDWANI	29.22	79.52	348	-4.84	1972	-4.80	1972	-0.42	1944
HAMIRPUR	31.70	76.50	738	2.19	1941	0.99	1920	0.31	1980
KANGRA	32.13	76.19	733	0.81	1941	0.17	1941	-0.04	1935
KARNAPRAYAG	30.27	79.25	792	-1.59	1971	-2.03	1970	-0.39	1970
KASAULI	30.90	76.96	1927	-2.10	1991	-2.15	1994	-0.34	1991
KASHIPUR	29.22	78.93	183	-4.67	1971	-3.95	1978	-0.31	1961
KATHGODAM	29.27	79.53	518	-4.11	1964	-4.10	1969	-0.08	1961

Results of MK test with Sen's slope (at 5% level) and Shift Year (Pettitt's Test) for the rain gauge stations during the period 1902-2000.

Results, Objective 1

1902-2000, mm/year	Lat. (deg)	Long. (deg.)	Alt. (m)	Annual (Jan-Dec)		Monsoon (Jun-Sep)		Winter (Dec-Feb)	
				Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)
ALMORA	29.60	79.67	1676	-0.76	1927	-0.41	1925	-0.06	1944
BANJAR	31.63	77.35	1356	-1.07	1967	-1.26	1967	-0.22	1961
BERINAG	29.80	80.07	1676	-0.73	1968	-0.40	1969	-0.32	1949
BIRONKHOL	30.20	79.20	1524	**-3.03**	1967	-2.08	1967	-0.58	1964
DEHRA GOPIPUR	31.90	76.22	503	0.62	1945	0.96	1991	0.01	1958
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KARNAPRAYAG	30.27	79.25	792	-1.59	1971	-2.03	1970	-0.39	1970
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KASHIPUR	29.22	78.93	183	-4.67	1971	-3.95	1978	-0.31	1961
KATHGODAM	29.27	79.53	518	-4.11	1964	-4.10	1969	-0.08	1961

Results of MK test with Sen's slope (at 5% level) and Shift Year (Pettitt's Test) for the rain gauge stations during the period 1902-2000.

Results, Objective 1

1902-2000, mm/year	Lat. (deg)	Long. (deg.)	Alt. (m)	Annual (Jan-Dec)		Monsoon (Jun-Sep)		Winter (Dec-Feb)	
				Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)
KOTDWARA	29.75	78.53	399	-7.71	1969	-7.02	1969	-0.58	1969
KOTKHAI	31.12	77.53	1881	[illegible]	[illegible]	[illegible]	[illegible]	-0.62	1967
LANSDOWNE	29.83	78.68	1532	[illegible]	[illegible]	[illegible]	[illegible]	-0.65	1961
NURPUR	32.30	75.90	643	[illegible]	[illegible]	[illegible]	[illegible]	-0.22	1994
OKHIMATH	30.50	79.25	1861	[illegible]	[illegible]	[illegible]	[illegible]	-0.06	1927
PALAMPUR	32.12	76.53	1472	[illegible]	[illegible]	[illegible]	[illegible]	-0.71	1958
RAJPUR	30.40	78.10	732	-11.38	1967	-10.50	1967	-0.54	1942
RAMNAGAR	29.40	79.12	360	-5.33	1971	-4.94	1971	-0.45	1964
RANIKHET	29.63	79.43	1824	0.29	1971	0.25	1971	-0.08	1944
SRINAGAR	30.22	78.78	564	-1.61	1957	-1.00	1954	-0.29	1961

Winter

17 Station: Decreasing trend

5 Station: Increasing trend

Results of MK test with Sen's slope (grey colour: Significant 5% level) and Shift Year (Pettitt's Test) for the rain gauge stations during the period 1902-2000.

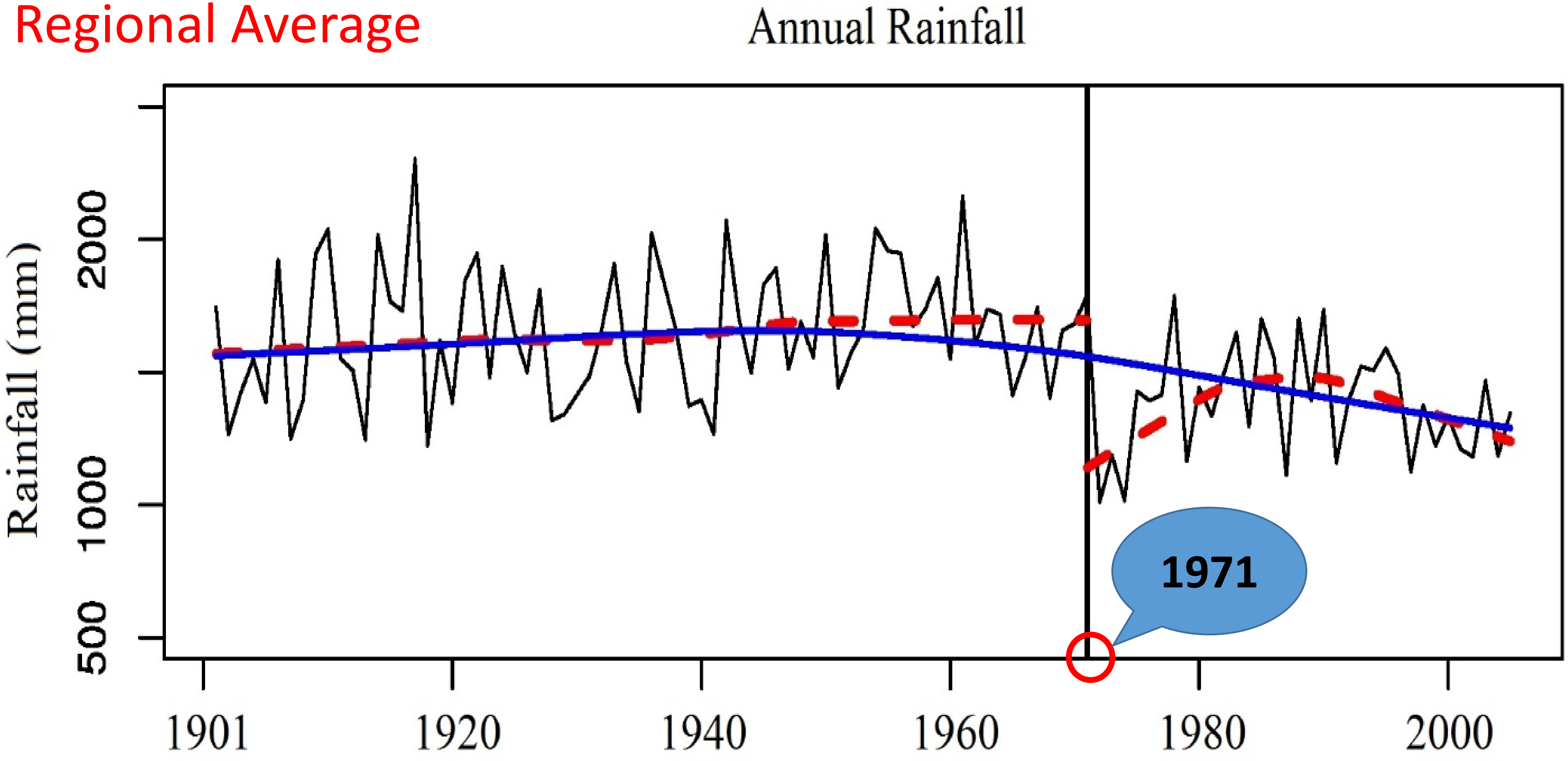
Results, Objective 1

1902-2000, mm/year	Annual (Jan-Dec)		Monsoon (Jun-Sep)		Winter (Dec-Feb)	
	Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)	Sen's Slope	Shift Year (PT)
WHR-1902-2005	-2.89	1971	-2.83	1971	-0.21	1961
WHR-1902-71	2.66	-	2.02	-	-0.01	-
WHR-1975-2000	-3.85	-	-2.35	-	0.50	-
WHR-1902-61	4.21*	-	2.92	-	0.37	-
WHR-1962-2000	-5.5	-	-6.02*	-	0.55	-
WHR-1902-2000	-2.23	-	-2.42*	-	-0.2	-

Results of MK test with Sen's slope (at 5% level) and Shift Year (Pettitt's Test) for the regional averaged rainfll during the period 1902-2000.

Results, Objective 1

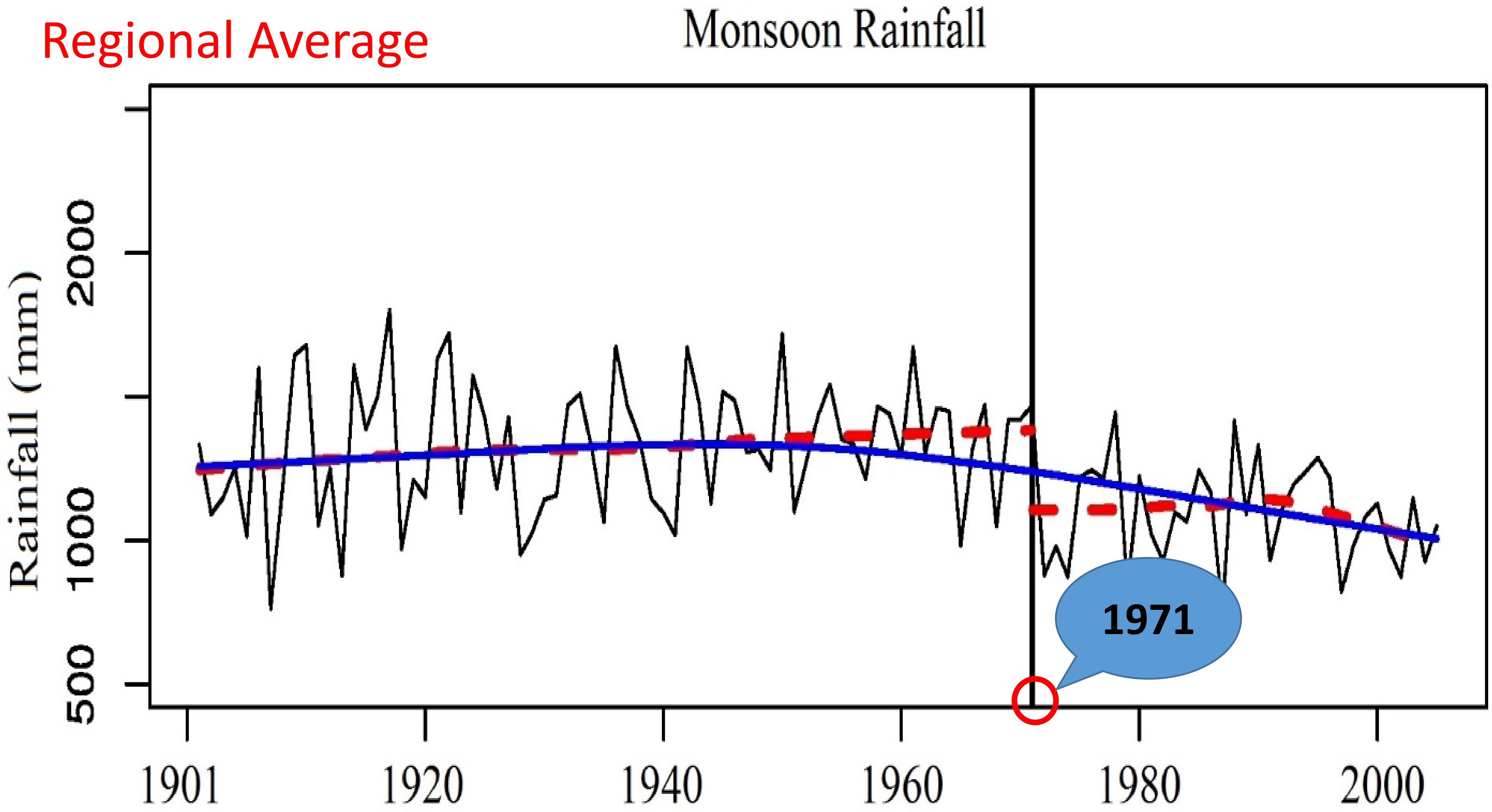
Regional Average



Regional averaged rainfall for the period 1902-2005. The solid vertical line at 1971 shows the year of probable shift as detected from Pettitt's test. The solid blue colored line shows the long term trend while the dotted red color line shows the trend after and before the shift

Results, Objective 1

Regional Average



Results, Objective 1

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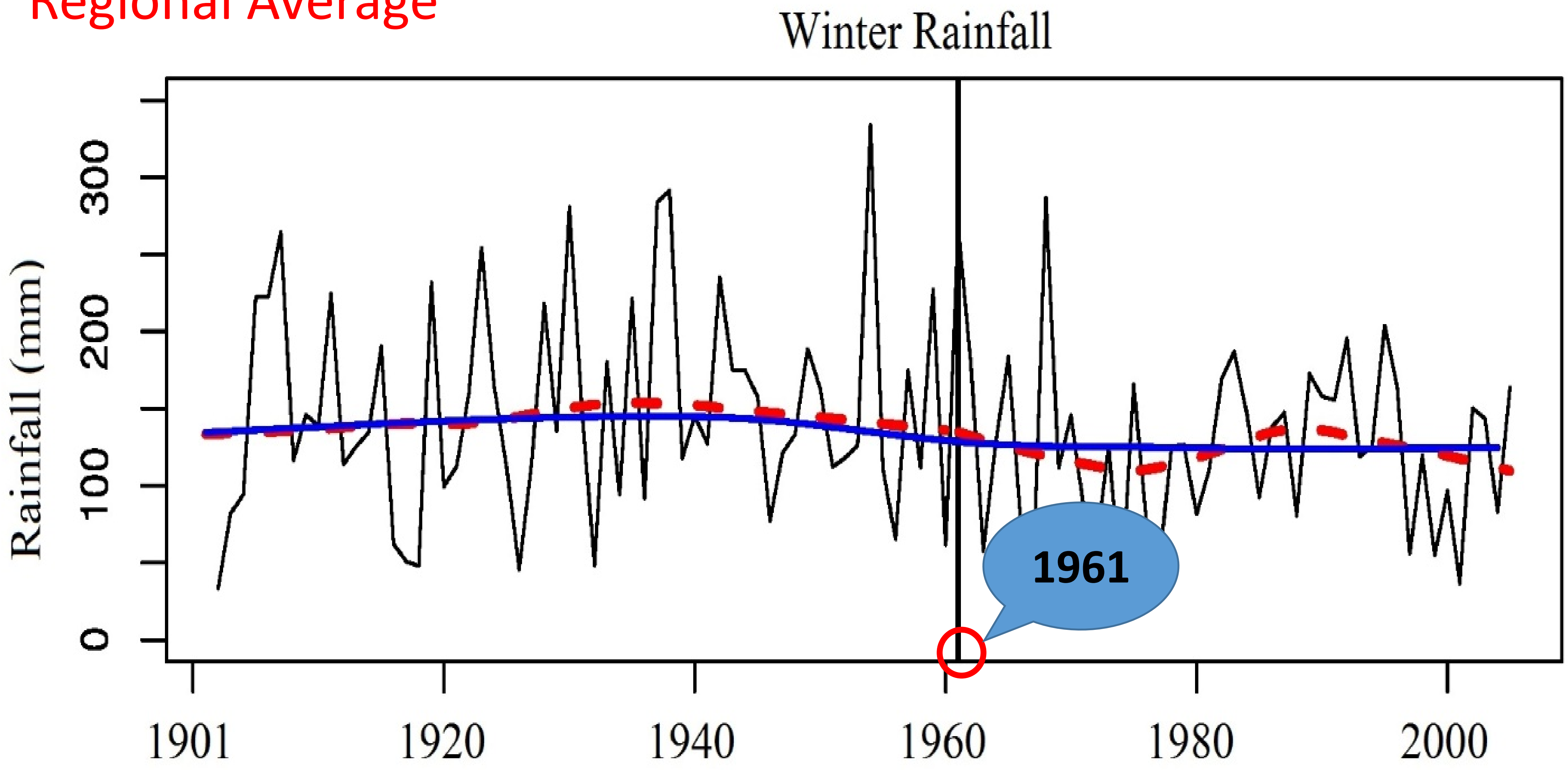
Regional Average



Probable causes of change in rainfall

1. Global climate shift or weakening of monsoon circulation
2. Reduction in forest cover and change in land use including introduction of irrigated agriculture
3. Increasing aerosol due to anthropogenic activity

Climatic Change (2007) 85:159–177
DOI 10.1007/s10584-006-9196-1

Abstract The study reveals significant rise in air temperature in the northwest Himalayan (NWH) region by about 1.6°C in the last century, with winters warming at a faster rate. The diurnal temperature range (DTR) has also shown a significantly increasing trend. This appears to be due to rise in both the maximum as well as minimum temperatures, with the maximum increasing much more rapidly. The results are in contrast to the findings in the Alps and Rockies where the minimum temperatures have increased at an elevated rate. Conforming to the global trends, the study confirms episodes of strong warming and cooling in the NWH in the last century. Real warming appears to have started from late-1960s and highest rate of increase was experienced in the last two decades. The study also shows teleconnections between temperatures and an epochal behaviour of the precipitation till late-1960s. These teleconnections seem to have weakened gradually since then and rapidly in the post-1991 period, indicating the waning effect of the natural forcings in this period.

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Objective 2

To evaluate the CMIP3 and CMIP5 GCMs and ranking them based on their abilities to simulate the observed rainfall

CMIP3

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SI.No.	Model	Center	Atmospheric resolution (Lon. ×Lat.)	Source	A1B
1	BCCR-BCM2.0	Bjerknes Centre for Climate Research, Norway	T63,L31	Déqué et al., 1994	
2	CCCMA-CGCM3.1 (T47)	Canadian Centre for Climate Modelling and Analysis, Canada	T47 (3.75×3.75), L31	Flato, 2005	
3	CNRM-CM3	Météo-France/Centre National de Recherches Météorologiques, France	T63 (2.8×2.8), L45	Déqué et al., 1994	
4	CSIRO-MK3.0	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	T63, L18	Gordon et al., 2002	
5	CSIRO-MK3.5	Commonwealth Scientific and Industrial Research Organisation (CSIRO) Atmospheric Research, Australia	T63, L18	Gordon et al., 2010	
6	GFDL-CM2.0	U.S. Department of Commerce/ National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	2.5×2.0, L24	GFDL GAMDT, 2004	
7	GFDL-CM2.1	U.S. Department of Commerce/ National Oceanic and Atmospheric Administration (NOAA)/Geophysical Fluid Dynamics Laboratory (GFDL), USA	2.5×2.0, L24	GFDL GAMDT, 2004	
8	INGV-ECHAM4	Max-Planck-Institute for Meteorology, Hamburg, Germany.	T42, L19	Roeckner et al., 1996	
9	INM-CM3.0	Institute for Numerical Mathematics, Russia	5×4, L21	Galin et al., 2003	
10	IPSL-CM4	Institut Pierre Simon Laplace, France	2.5×3.7[illegible]	Hourdin et al., 2006	
11	MIROC3.2 (hires)	Center for Climate System Research (University of Tokyo), National Institute for Environmental Studies, and Frontier Research Center for Global Change (JAMSTEC), Japan	T106[illegible]	[illegible]	
12	UKMO-HadCM3	Hadley Centre for Climate Prediction and Research/Met Offi ce, UK	3.75×2.5, L19	[illegible] 2000	
13	UKMO-HadGEM1	Hadley Centre for Climate Prediction and Research/Met Offi ce, UK	1.875×1.25, L38	Martin et al., 2004	

13 CMIP3 GCMs

CMIP5

42 CMIP5 GCMs

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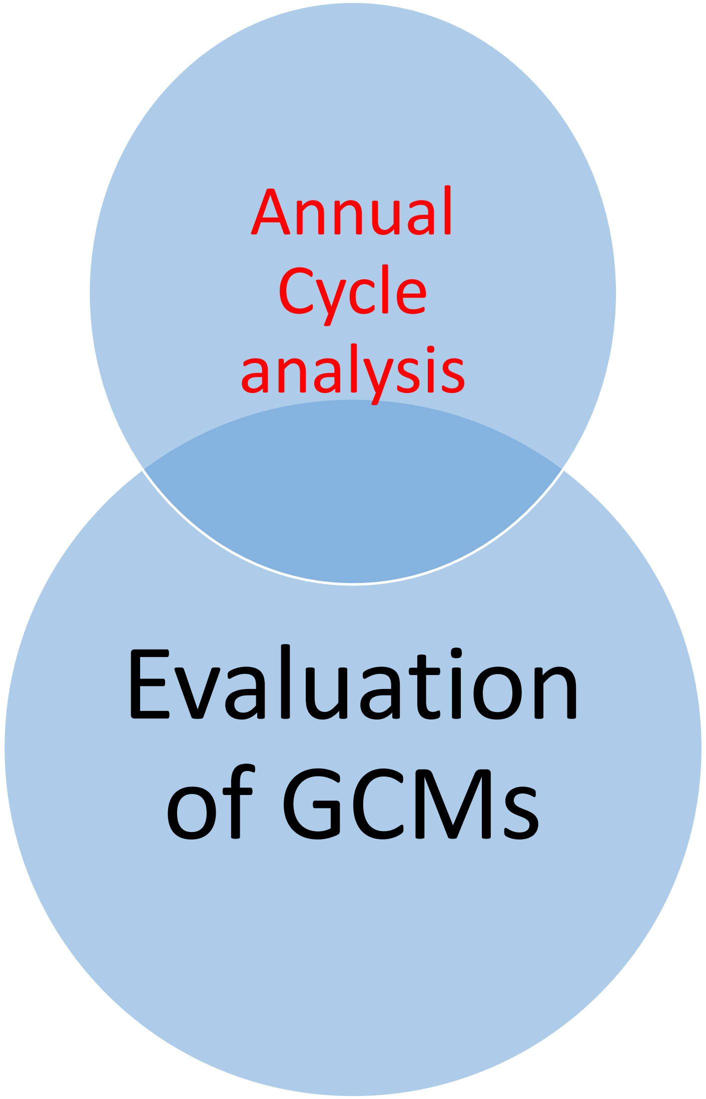
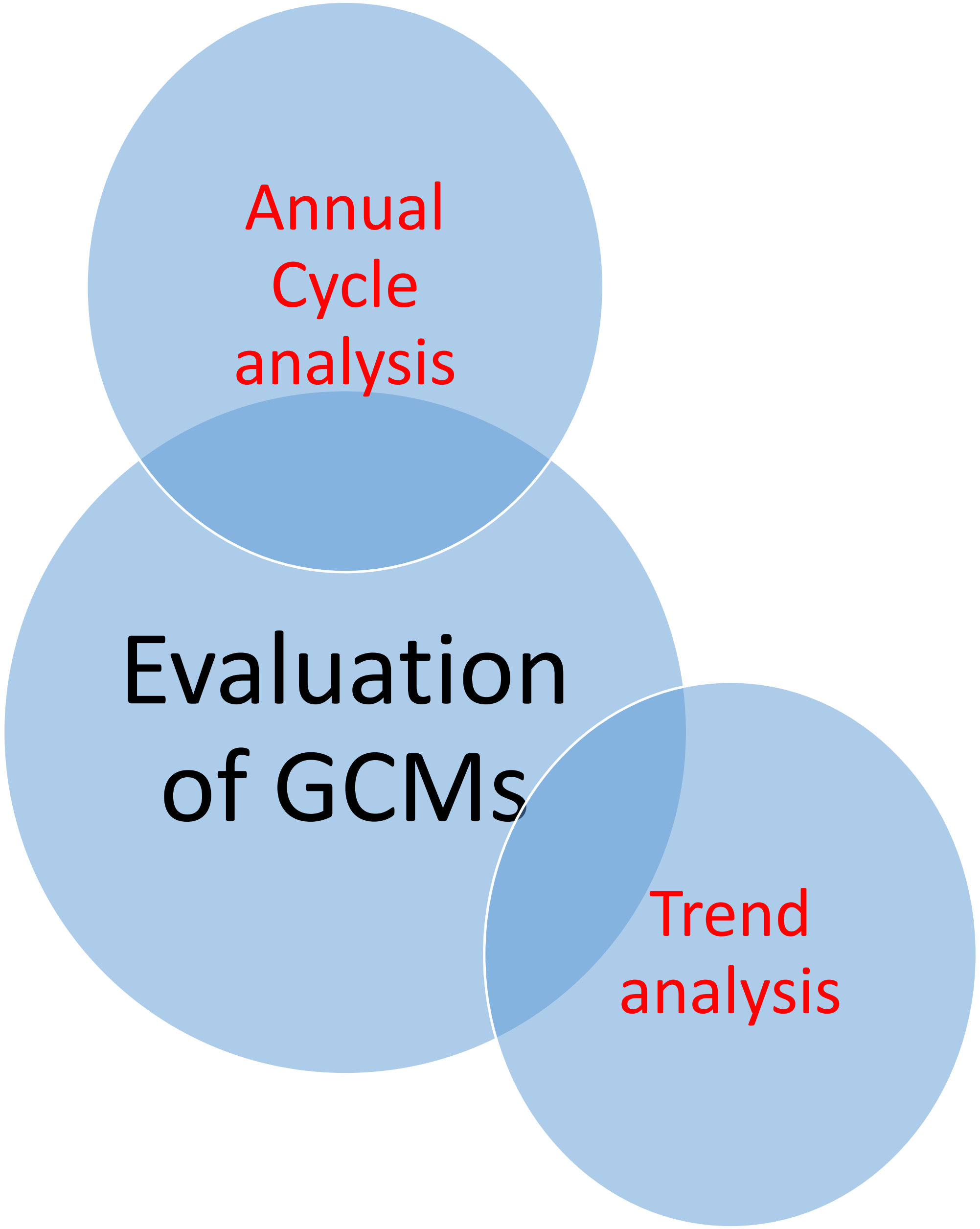
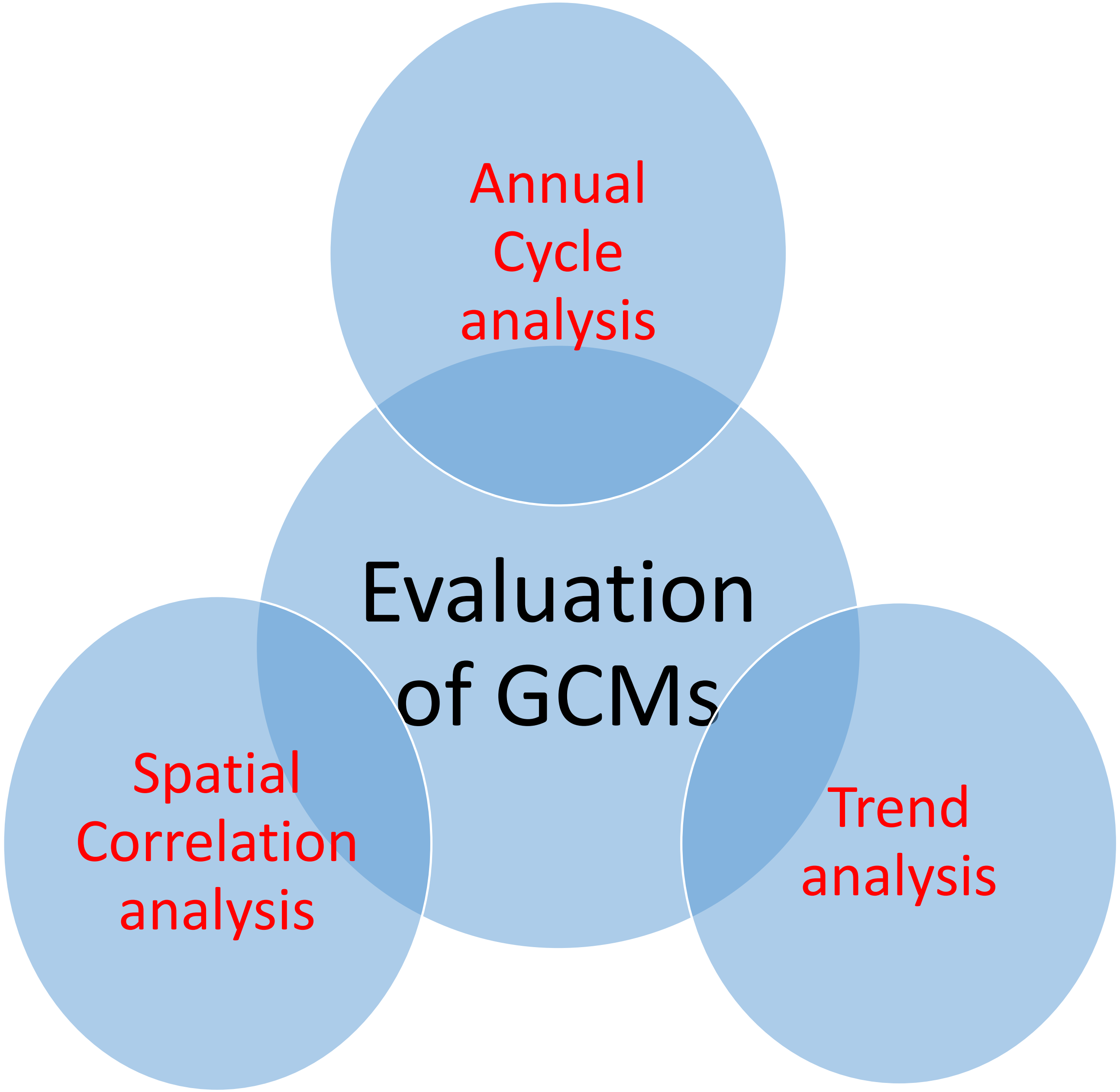
Si.No	Model	Center	Atmospheric resolution (Lon. ×Lat.)	Source	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
1	ACCESS1-0	Commonwealth Scientific and Industrial Research Organization-Bureau of Meteorology (CSIRO-BOM), Australia	1.875 × 1.25	Bi et al. (2013)				
2	ACCESS1.3	Commonwealth Scientific and Industrial Research Organization-Bureau of Meteorology (CSIRO-BOM), Australia	1.875 × 1.25	Bi et al. (2013)				
3	bcc-csm1-1	Beijing Climate Center, China Meteorological Administration	2.8 ×2.8	Wu et al. (2013)				
4	bcc-csm1-1-m	Beijing Climate Center, China Meteorological Administration	1.12 ×1.12	Wu et al. (2013)				
5	BNU-ESM	College of Global Change and Earth System Science, Beijing Normal University, China	2.8 ×2.8	Ji et al. (2014)				
6	CanESM2	Canadian Centre for Climate Modeling and Analysis	2.8 ×2.8	von Salzen et al. (2013)				
7	CCSM4	National Center of Atmospheric Research, USA	1.25 ×0.94	Meehl et al. (2012)				
8	CESM1-BGC	Community Earth System Model Contributors	1.25 ×0.94	Hurrell et al. (2013)				
9	CESM1-CAM5	Community Earth System Model Contributors	1.25 ×0.94	Hurrell et al. (2013)				
10	CMCC-CM	Centro Euro-MediterraneopeI Cambiamenti Climatici	0.75 ×0.75	Scoccimarro et al. (2011)				
11	CMCC-CMS	Centro Euro-MediterraneopeI Cambiamenti Climatici	1.88 ×1.87	Davini et al. (2013)				
12	CNRM-CM5	National Centre of Meteorological Research, France	1.4 ×1.4	Voldoire et al. (2013)				
13	CSIRO-Mk3-6-0	Commonwealth Scientific and Industrial Research Organization Queensland Climate Change Centre of Excellence, Australia	1.8 ×1.8	Rotstayn et al. (2012)				
14	EC-EARTH	EC-EARTH consortium	1.13 ×1.12	Hazeleger et al. (2012)				
15	FGOALS-g2	LASG, Institute of Atmospheric Physics, Chinese Academy of Sciences	2.8 ×2.8	Li et al. (2013)				
16	FIO-ESM	The First Institute of Oceanography, SOA, China	2.81 ×2.79	Song et al. (2012)				
17	GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 ×2.0	Delworth et al. (2006)				
18	GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 ×2.0	Delworth et al. (2006)				
19	GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory, USA	2.5 ×2.0	Delworth et al. (2006)				
20	GISS-E2-H-p1	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
21	GISS-E2-H-p2	NASA Goddard Institute for Space Studies, USA		chmidt et al. (2014)				
22	GISS-E2-H-p3	NASA Goddard Institute for Space Studies, USA	×2.0	Schmidt et al. (2014)				
23	GISS-E2-H-CC	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
24	GISS-E2-R-p1	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
25	GISS-E2-R-p2	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
26	GISS-E2-R-p3	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
27	GISS-E2-R-CC	NASA Goddard Institute for Space Studies, USA	2.5 ×2.0	Schmidt et al. (2014)				
28	HadGEM2-AO	Met Office Hadley Center, UK	1.88 × 1.25	Collins et al. (2011)				
29	HadGEM2-CC	Met Office Hadley Center, UK	1.88 × 1.25	Martin et al. (2011)				
30	HadGEM2-ES	Met Office Hadley Center, UK	1.88 × 1.25	Bellouin et al. (2011)				
31	inmcm44	Institute for Numerical Mathematics, Russia	2.0 × 1.5	Volodin et al. (2010)				
32	IPSL-CM5A-LR	Institut Pierre Simon Laplace, France	3.75 × 1.8	Hourdin et al. (2013)				
33	IPSL-CM5A-MR	Institut Pierre Simon Laplace, France	2.5 × 1.25	Hourdin et al. (2013)				
34	IPSL-CM5B-LR	Institut Pierre Simon Laplace, France	3.75 × 1.8	Hourdin et al. (2013)				
35	MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	1.4 × 1.4	Watanabe et al. (2010)				
36	MIROC-ESM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 × 2.8	Watanabe et al. (2011)				
37	MIROC-ESM-CHEM	Japan Agency for Marine-Earth Science and Technology, Atmosphere and Ocean Research Institute (The University of Tokyo), and National Institute for Environmental Studies	2.8 × 2.8	Watanabe et al. (2011)				
38	MPI-ESM-LR	Max Planck Institute for Meteorology, Germany	1.88 × 1.87	Giorgetta et al. (2013)				
39	MPI-ESM-MR	Max Planck Institute for Meteorology, Germany	1.88 × 1.87	Giorgetta et al. (2013)				
40	MRI-CGCM3	Meteorological Research Institute, Japan	1.1 × 1.1	Yukimoto et al. (2012)				
41	NorESM1-M	Norwegian Climate Center, Norway	2.5 × 1.9	Bentsen et al. (2013)				
42	NorESM1-ME	Norwegian Climate Center, Norway	2.5 × 1.9	Tjiputra et al. (2013)				

Evaluation of GCMs


Annual Cycle analysis
Evaluation of GCMs


Annual
Cycle
analysis
Evaluation
of GCMs
Trend
analysis


Annual
Cycle
analysis
Evaluation
of GCMs
Spatial
Correlation
analysis
Trend
analysis

Results, Objective 2

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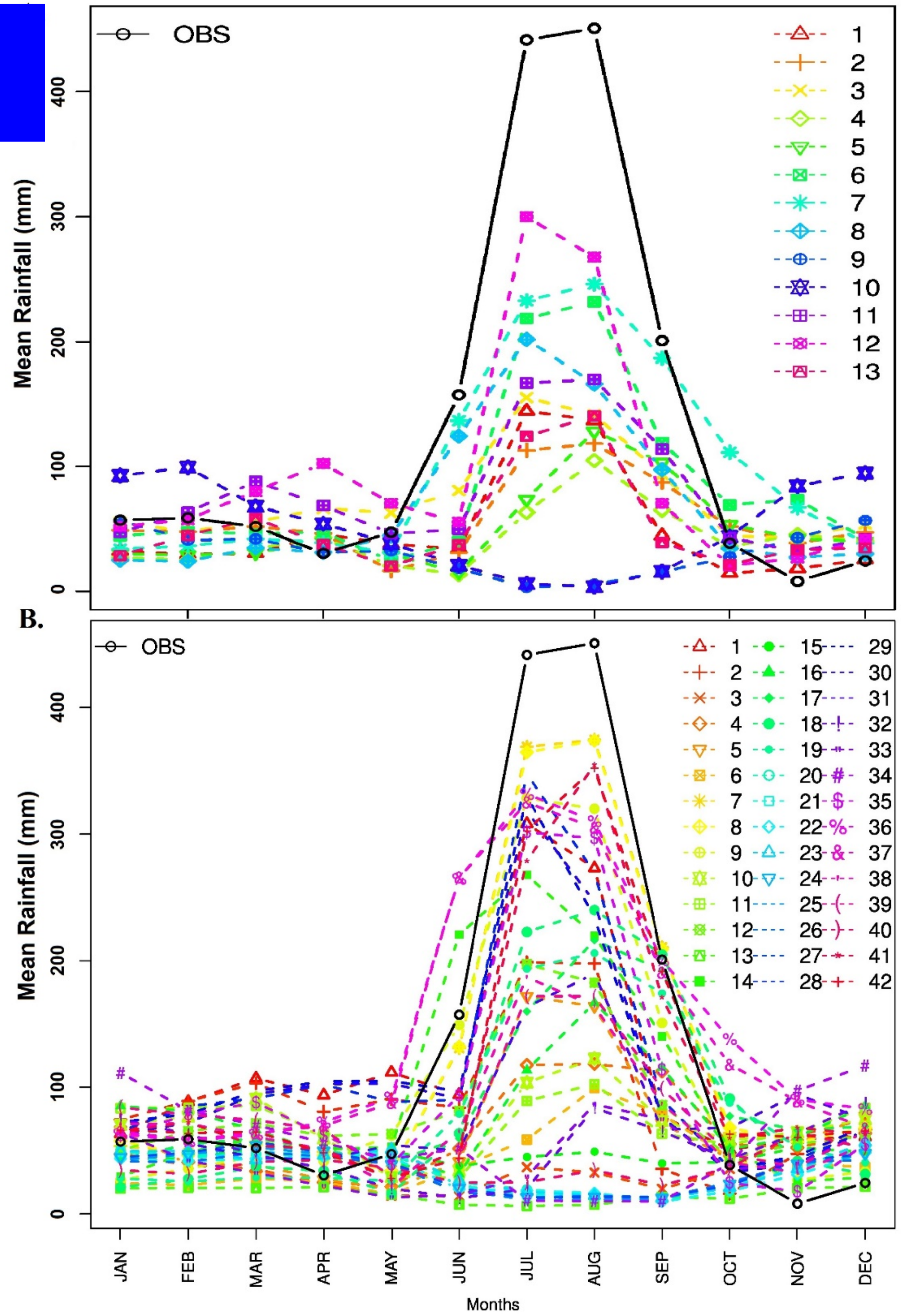
Comparison of annual cycle



CMIP3

CMIP5

Results, Objective 2

CMIP3

1902-2000	Seasonal cycle							Long term trend(mm/yr)			Spatial correlation		
	ME	NRMSE %	PBIAS %	NSE	d	r	KGE	Annual	JJAS	DJF	Annual	JJAS	DJF
BCCR-BCM2.0	-81.08	87.7	-62.1	0.16	0.58*	0.95*	0.05	0.04	-0.25	0.36	-0.10	-0.09	0.14
CCCma-CGCM3.1(T47)	-72.39	91.7	-55.4	0.08	0.50*	0.89*	0.02	0.49	0.36	0.10	-0.17	0.01	0.79*
CNRM-CM3	-55.57	81.7	-42.6	0.27	0.58*	0.98*	0.13	-0.58	0.04	-0.67	-0.07	-0.02	0.12
CSIRO-Mk3.0	-87.37	101.4	-66.9	-0.12	0.48	0.75*	-0.10	0.07	0.41	-0.19	-0.04	0.04	-0.04
CSIRO-Mk3.5	-79.29	95.7	-60.7	0.00	0.50*	0.75*	-0.02	-0.13	-0.18	-0.25	-0.03	0.04	0.57*
GFDL-CM2.0	-46.90	64.6	-35.9	0.54*	0.79*	0.94*	0.34	0.27	-0.08	0.00	0.02	0.01	0.82*
GFDL-CM2.1	-30.44	56.9	-23.3	0.65*	0.84*	0.92*	0.46	-0.29	-1.20	0.24	-0.17	-0.02	0.39
INGV-ECHAM4	-60.49	71.7	-46.3	0.44	0.73*	0.96*	0.24	0.12	0.12	-0.15	-0.11	0.02	0.56*
MIROC3.2(hires)	-53.10	77.2	-40.7	0.35	0.65*	0.93*	0.19	-0.69	-0.67	-0.26	0.01	0.04	0.86*
UKMO-HadCM3	-35.16	54.4	-26.9	0.68*	0.87*	0.92*	0.49	-0.67	-1.76	0.15	-0.22	-0.13	0.67*
UKMO-HadGEM1	-78.79	89.8	-60.3	0.12	0.55*	0.92*	0.03	-0.12	0.28	0.26	-0.09	0.00	0.85*

Evaluation of CMIP3 GCMs

Results, Objective 2

CMIP3

1902-2000,CMIP3	Seasonal cycle							Long term trend			Spatial correlation				
	ME	NRMSE %	PBIAS %	NSE	d	r	KGE	Annual	JJAS	DJF	Annual	JJAS	DJF	Sum of Rank	Overall Rank
BCCR-BCM2.0	10	7	10	7	6	3	7	7	4	11	7	6	9	94	9
CCCma-CGCM3.1(T47)	7	9	7	9	8	7	9	11	10	6	9	3	4	99	10
CNRM-CM3	5	6	5	6	6	1	6	3	7	10	5	5	10	75	6
CSIRO-Mk3.0	11	11	11	11	9	8	11	8	11	1	4	1	11	108	11
CSIRO-Mk3.5	9	10	9	10	8	8	10	5	5	3	3	1	6	87	7
GFDL-CM2.0	3	3	3	3	3	4	3	10	6	5	1	3	3	50	3
GFDL-CM2.1	1	2	1	2	2	6	2	4	2	8	10	5	8	53	4
INGV-ECHAM4	6	4	6	4	4	2	4	9	8	2	8	2	7	66	5
MIROC3.2(hires)	4	5	4	5	5	5	5	1	3	4	2	1	1	45	1
UKMO-HadCM3	2	1	2	1	1	6	1	2	1	7	11	7	5	47	2
UKMO-HadGEM1	8	8	8	8	7	6	8	6	9	9	6	4	2	89	8

Ranking of CMIP3 GCMs

Results, Objective 2

Evaluation of CMIP5

1902-2000,CMIP5	Seasonal Cycle							Long term trend			Spatial correlation		
	ME	NRMSE %	PBIAS %	NSE	d	r	KGE	Annual	JJAS	DJF	Annual	JJAS	DJF
ACCESS1-0	-14.94	53.3	-11.4	0.69*	0.87*	0.92*	0.52	-0.489	-0.578	0.170	-0.182	0.001	0.70
ACCESS1.3	-40.27	75	-30.8	0.39	0.68*	0.82*	0.26	-0.649	-0.809	-0.104	-0.142	-0.096	0.3
bcc-csm1-1-m	-68.97	89.7	-52.8	0.12	0.51*	0.86*	0.05	0.055	0.477	0.007	-0.059	-0.107	0.3
BNU-ESM	-62.58	80.2	-47.9	0.3	0.64*	0.90*	0.16	0.906	0.652	0.197	-0.106	0.014	0.2
CanESM2	-88.1	101.1	-67.5	-0.12	0.49	0.79*	-0.1	-0.314	-0.302	-0.104	-0.137	0.017	-0.4
CCSM4	-4.11	24.4	-3.1	0.94*	0.98*	0.99*	0.79	0.199	0.307	0.017	-0.184	-0.128	0.60
CESM1-BGC	-4.64	24.8	-3.6	0.93*	0.98*	0.99*	0.78	-0.476	-0.220	-0.226	-0.186	-0.122	0.64
CESM1-CAM5	-25.19	34.2	-19.3	0.87*	0.96*	0.99*	0.65	1.609	1.205	0.235	-0.154	-0.071	0.83
CMCC-CM	-59.07	93.8	-45.2	0.04	0.42	0.66	-0.01	0.791	0.629	0.348	0.036	-0.018	0.84
CNRM-CM5	-45.51	72.3	-34.9	0.43*	0.70*	0.97*	0.24	0.129	0.002	0.054	-0.112	-0.088	0.78
EC-EARTH	-31.01	55.9	-23.7	0.66*	0.86*	0.91*	0.49	0.770	0.839	-0.060	-0.091	0.032	0.87
FIO-ESM	-51.92	85.9	-39.8	0.19	0.52	0.76	0.11	0.375	0.336	-0.050	-0.102	0.021	0.5
GFDL-CM3	-39.84	71.3	-30.5	0.45*	0.71*	0.85*	0.3	0.084	-0.353	0.136	-0.169	0.002	0.74
GFDL-ESM2G	-44.6	60.3	-34.2	0.6*	0.83*	0.91*	0.42	-0.354	-0.660	0.058	-0.164	0.008	0.5
GFDL-ESM2M	-49.67	67.4	-38	0.5*	0.77*	0.91*	0.32	0.126	0.231	0.070	-0.151	0.013	0.2
HadGEM2-AO	-16.08	48.6	-12.3	0.74*	0.90*	0.93*	0.57	-1.363	-0.536	-0.624	-0.193	-0.032	0.62
HadGEM2-CC	-18.53	56	-14.2	0.66*	0.85*	0.89*	0.51	-0.727	-0.853	0.040	-0.178	-0.033	0.64
HadGEM2-ES	-21.81	54.9	-16.7	0.67*	0.86*	0.91*	0.5	-0.853	-1.007	-0.006	-0.169	-0.026	0.65
inmcm4	-49.73	79	-38.1	0.32	0.62*	0.86*	0.19	-0.288	-0.206	0.016	-0.129	0.013	0.79
IPSL-CM5A-MR	-87.46	107.3	-67	-0.26	0.44	0.34	-0.27	-0.042	-0.313	0.325	-0.106	0.003	0.73
MIROC-ESM	16.6	47.5	12.7	0.75*	0.91*	0.91*	0.62	-0.015	0.025	0.000	-0.198	-0.064	0.2
MIROC-ESM-CHEM	11.49	46.6	8.8	0.76*	0.91*	0.92*	0.63	1.086	0.383	0.374	-0.190	-0.055	0.1
MIROC5	-27.84	44.4	-21.3	0.78*	0.92*	0.98*	0.55	-0.389	-0.287	-0.308	-0.179	-0.046	0.88
MPI-ESM-LR	-55.03	75.8	-42.1	0.37	0.67*	0.95*	0.2	0.206	0.031	0.192	-0.087	-0.020	0.75
MPI-ESM-MR	-50.02	77.6	-38.3	0.34	0.64*	0.90*	0.2	-0.203	0.147	0.163	-0.081	-0.021	0.79
NorESM1-M	-20.88	42.8	-16	0.8*	0.93*	0.95*	0.62	-0.265	-0.738	0.080	-0.139	-0.020	0.0
NorESM1-ME	-17.92	40.1	-13.7	0.82*	0.94*	0.95*	0.66	0.085	0.604	0.127	-0.140	-0.020	0.1

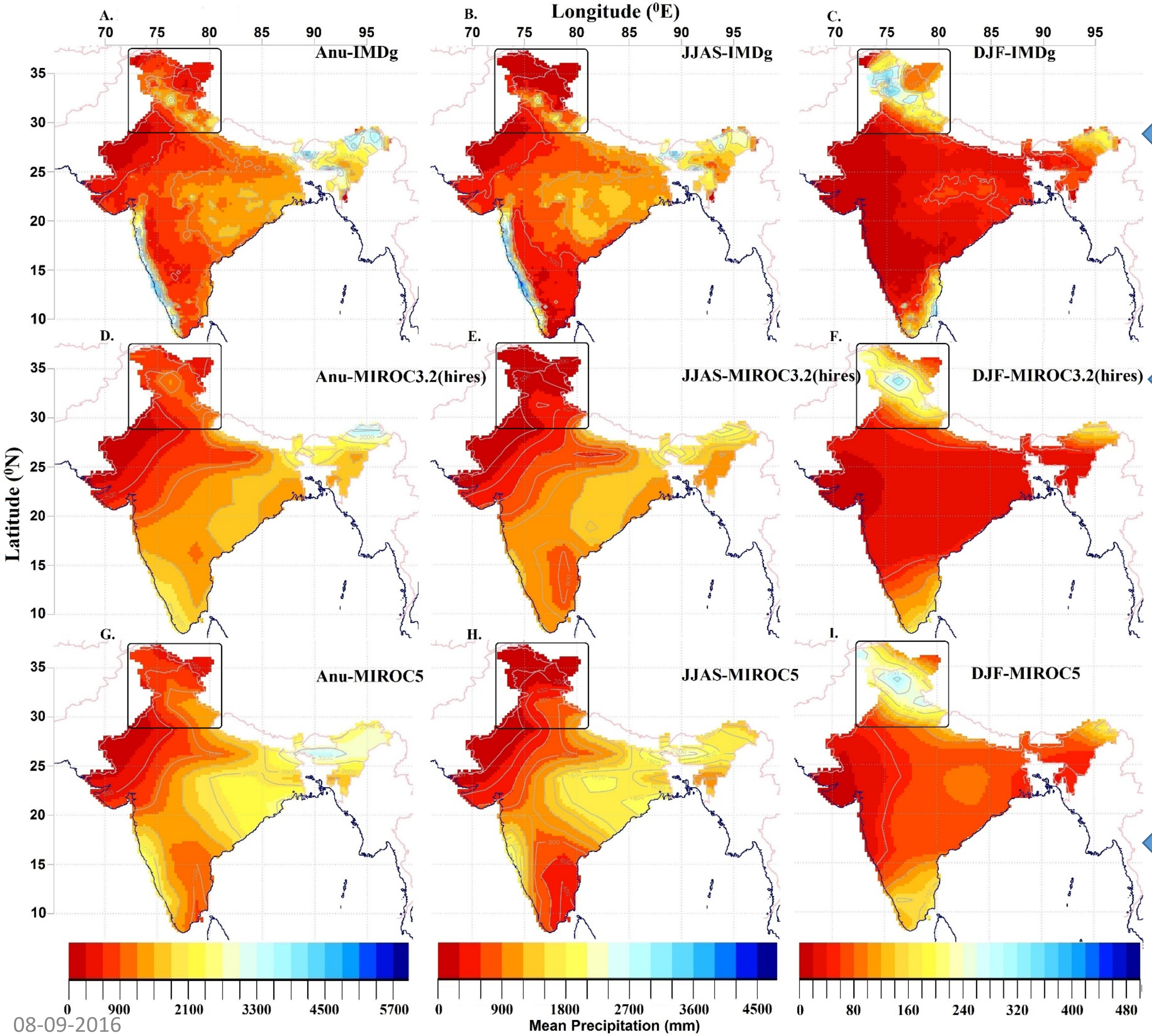
Results, Objective 2

INDICE Work Package-II, BCKV

Ranking of CMIP5 GCMs

02-2000,CMIP5	Seasonal cycle							Long term trend			Spatial correlation				
	ME	NRMSE %	PBIAS %	NSE	d	r	KGE	Annual	JJAS	DJF	Annual	JJAS	DJF	Sum of Rank	Overall Rank
CESS1-0	4	10	4	10	8	6	9	5	6	20	12	4	8	106	5
ACCESS1.3	15	18	15	17	15	12	16	4	3	3	8	11	14	151	14
bcc-csm1-1-m	25	24	25	23	20	10	22	15	22	9	2	12	15	224	24
BNU-ESM	24	22	24	21	17	8	20	25	25	22	6	3	17	234	26
CanESM2	27	26	27	25	21	13	24	9	10	2	8	2	22	216	23
CCSM4	1	1	1	1	1	1	1	20	19	11	12	14	12	95	3
CESM1-BGC	2	2	2	2	1	1	2	6	12	1	13	13	10	67	1
CESM1-CAM5	11	3	11	3	2	1	4	27	27	24	9	9	3	134	11
CMCC-CM	23	25	23	24	23	15	23	24	24	26	1	5	2	238	27
CNRM-CM5	17	17	17	16	14	3	17	19	14	13	6	10	5	168	17
EC-EARTH	13	12	13	12	9	7	12	23	26	5	4	1	1	138	12
FIO-ESM	21	23	21	22	19	14	21	22	20	6	5	2	13	209	22
GFDL-CM3	14	16	14	15	13	11	15	16	8	18	11	4	7	162	16
GFDL-ESM2G	16	14	16	13	11	7	13	8	5	14	10	3	13	143	13
GFDL-ESM2M	18	15	18	14	12	7	14	18	18	15	9	3	16	177	19
HadGEM2-AO	5	9	5	9	7	5	7	1	7	23	13	6	11	108	7
HadGEM2-CC	8	13	8	12	10	9	10	3	2	12	12	6	10	115	8
HadGEM2-ES	10	11	10	11	9	7	11	2	1	7	11	6	9	105	4
inmcm4	19	21	19	20	18	10	19	10	13	10	7	3	4	173	18
IPSL-CM5A-MR	26	27	26	26	22	16	25	13	9	25	6	4	7	232	25
MIROC-ESM	6	8	6	8	6	7	6	14	15	8	14	8	18	124	10
MIROC-ESM-CHEM	3	7	3	7	6	6	5	26	21	27	13	8	20	152	15
MIROC5	12	6	12	6	5	2	8	7	11	4	12	7	1	93	2
MPI-ESM-LR	22	19	22	18	16	4	18	21	16	21	4	5	6	192	21
MPI-ESM-MR	20	20	20	19	17	8	18	12	17	19	3	5	4	182	20
NorESM1-M	9	5	9	5	4	4	6	11	4	16	8	5	21	107	6
NorESM1-ME	7	4	7	4	3	4	3	17	23	17	8	5	19	121	9

INDICE Work Package-II, BCKV



Observation

1902-2000

MIROC3.2 (hires)

Top ranked GCM

MIROC5

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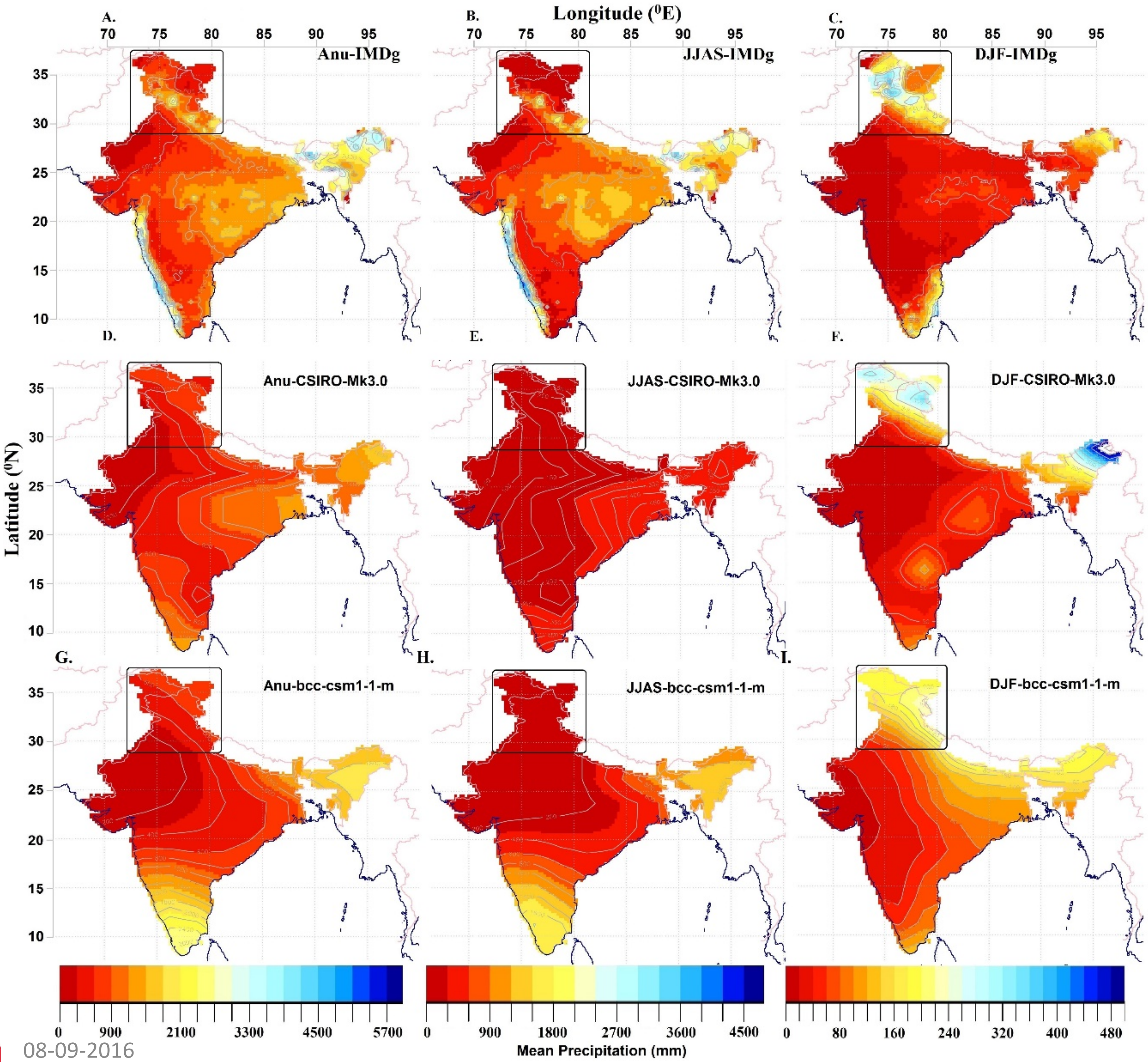


Observation

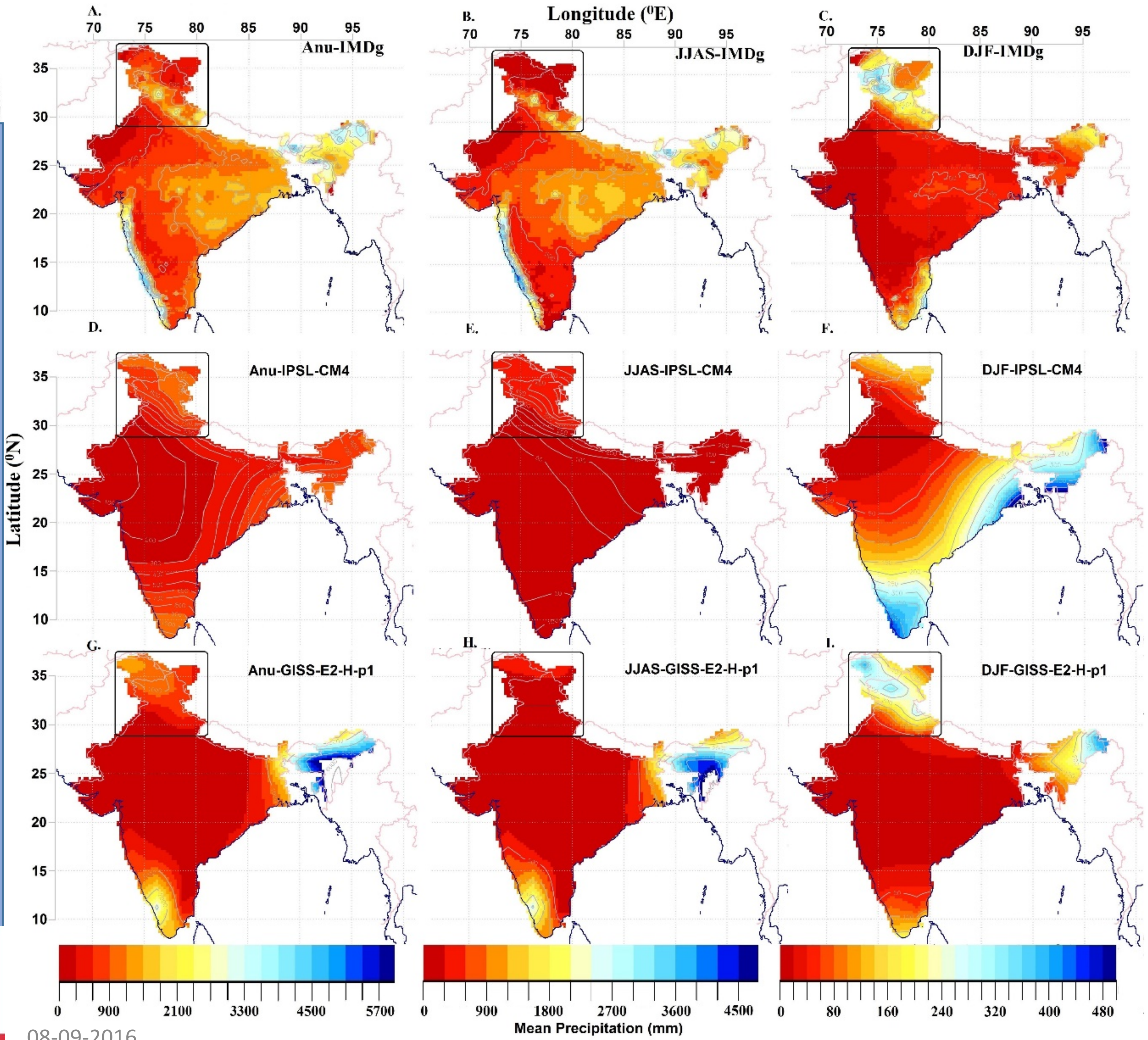
1902-2000

CSIRO-Mk3.0

Bottom ranked GCM

Bcc-csm1-1m

INDICE Work Package-II, BCKV



Observation

1902-2000

IPSL version

Excluded GCMs

GISS-E2-H-p1

NVE

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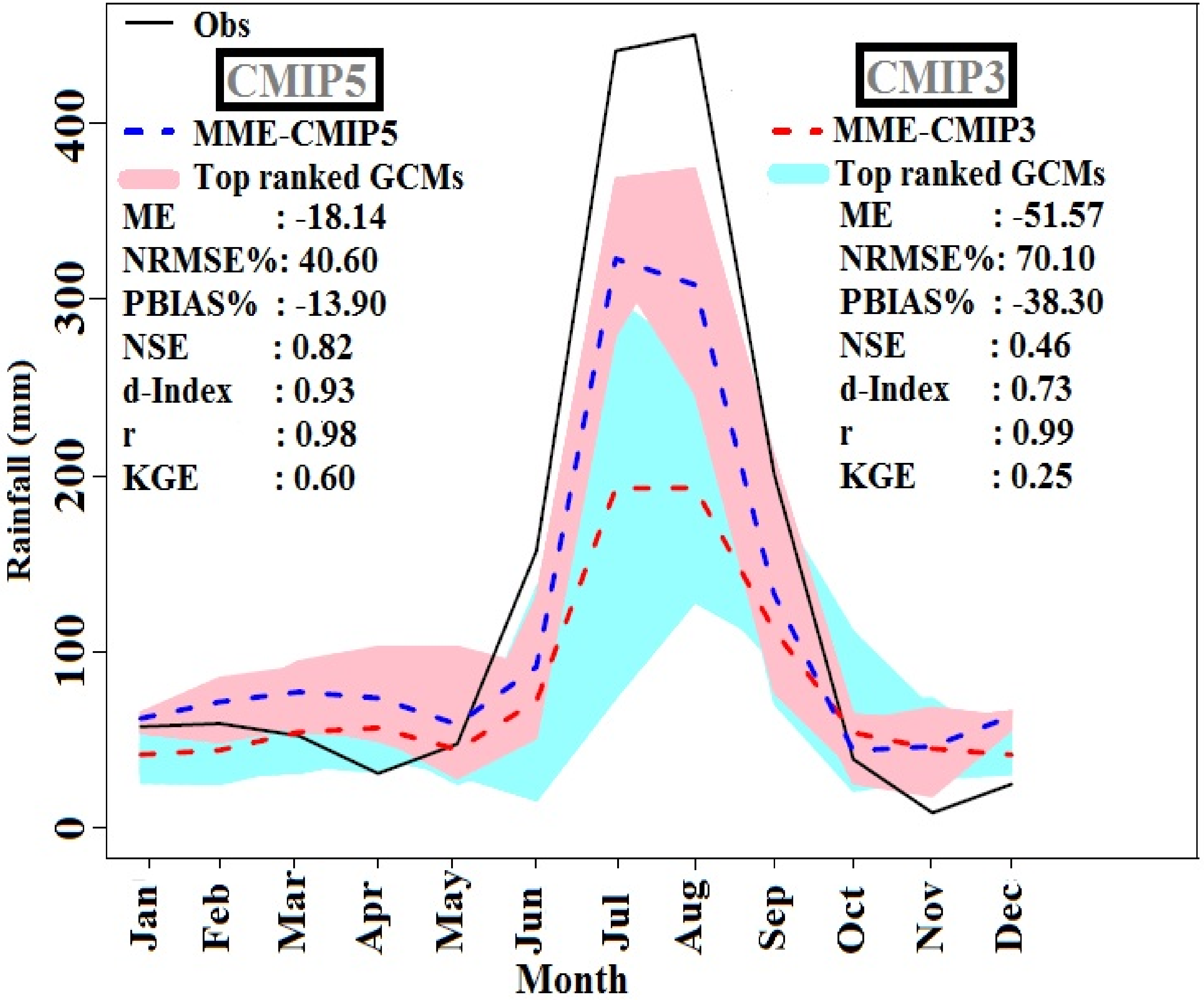
Results, Objective 2

Multi Model Ensemble

INDICE Work Package-II, BCKV

CMIP5

GCMS	Rank
MIROC5	2
CCSM4	3
HadGEM2-ES	4
NorESM-1-M	6
HadGEM2-AO	7



CMIP3

GCMS	Rank
MIROC3.2 (hires)	1
UKMO-HadCM3	2
GFDL-CM2.0	3
GFDL-CM2.1	4
INGV-ECHAM4	5
CNRM-CM3	6
CSIRO-MK3.5	7

Results, Objective 2

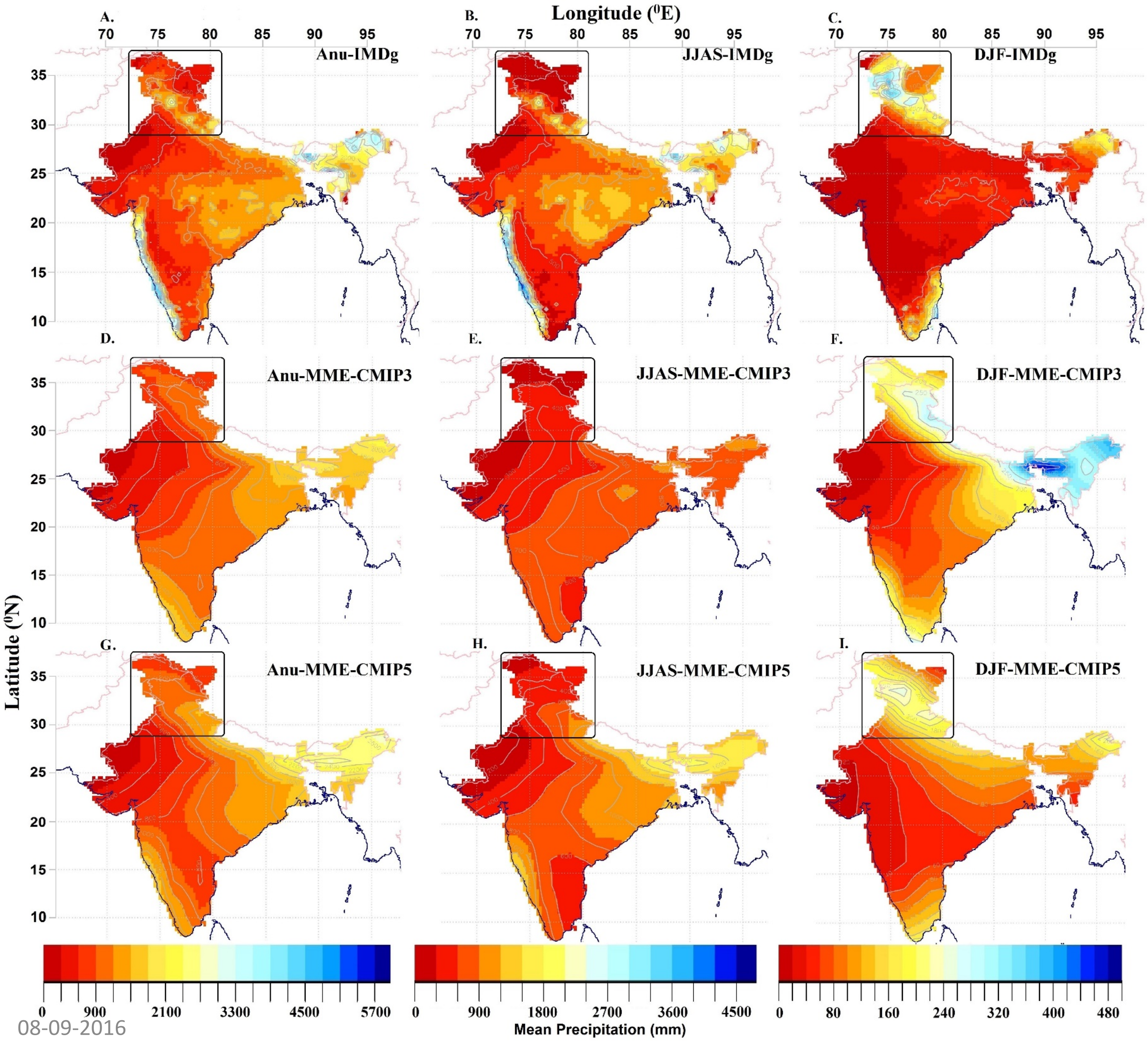
Mm/30yr	Annual			Monsoon (JJAS)			Winter (DJF)		
	OBS	MME-CMIP3	MME-CMIP5	OBS	MME-CMIP3	MME-CMIP5	OBS	MME-CMIP3	MME-CMIP5
1911-40	-103.2	-88.7	105.4*	-37.7	-50.7*	110.5*	57.6	3.5	-39.0
1941-70	-61.3	-34.3	-63.7	-33.9	-48.3	-81.0	-32.8	18.7	-22.9
1975-2000	-3.85	-34.0	-76.1	-1.6	-48.0*	-65.1	50.4	-19.0	-4.2

Results of **MK test for observation and multi model ensemble (MME)** of GCMs under both CMIP3 and CMIP5 during the period 1911-40, 1941-70, and 1971-2000.

*=Significant at 5% level

Comparison between observation and MME trend values

Results, Objective 2



1902-2000

MME of Top ranked GCM taken for future rainfall study

Objective 3

To construct future rainfall change pattern from the top ranking GCMs using all available Representative Concentration Pathways (RCPs) and emission scenarios.

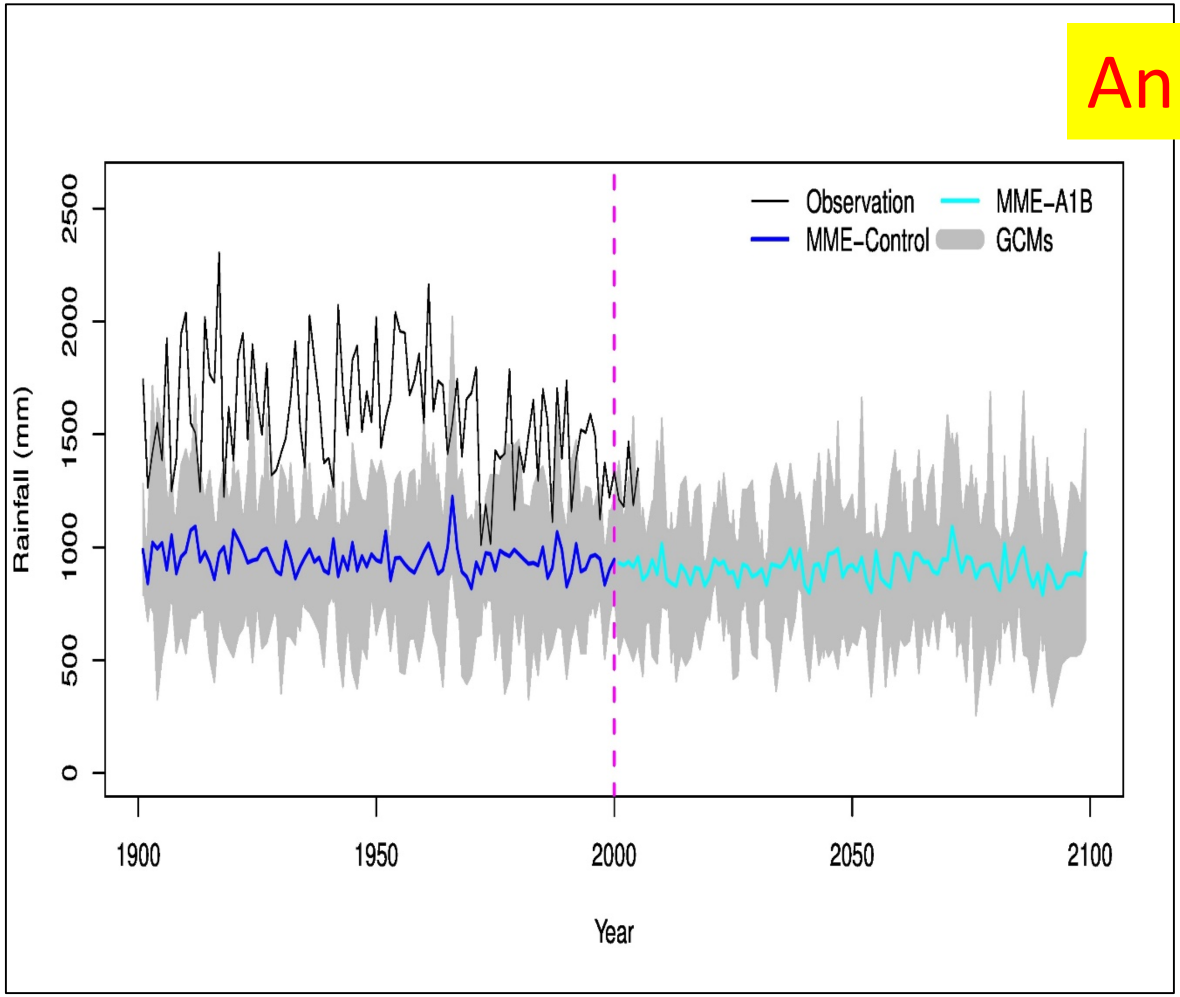
Results, Objective 3

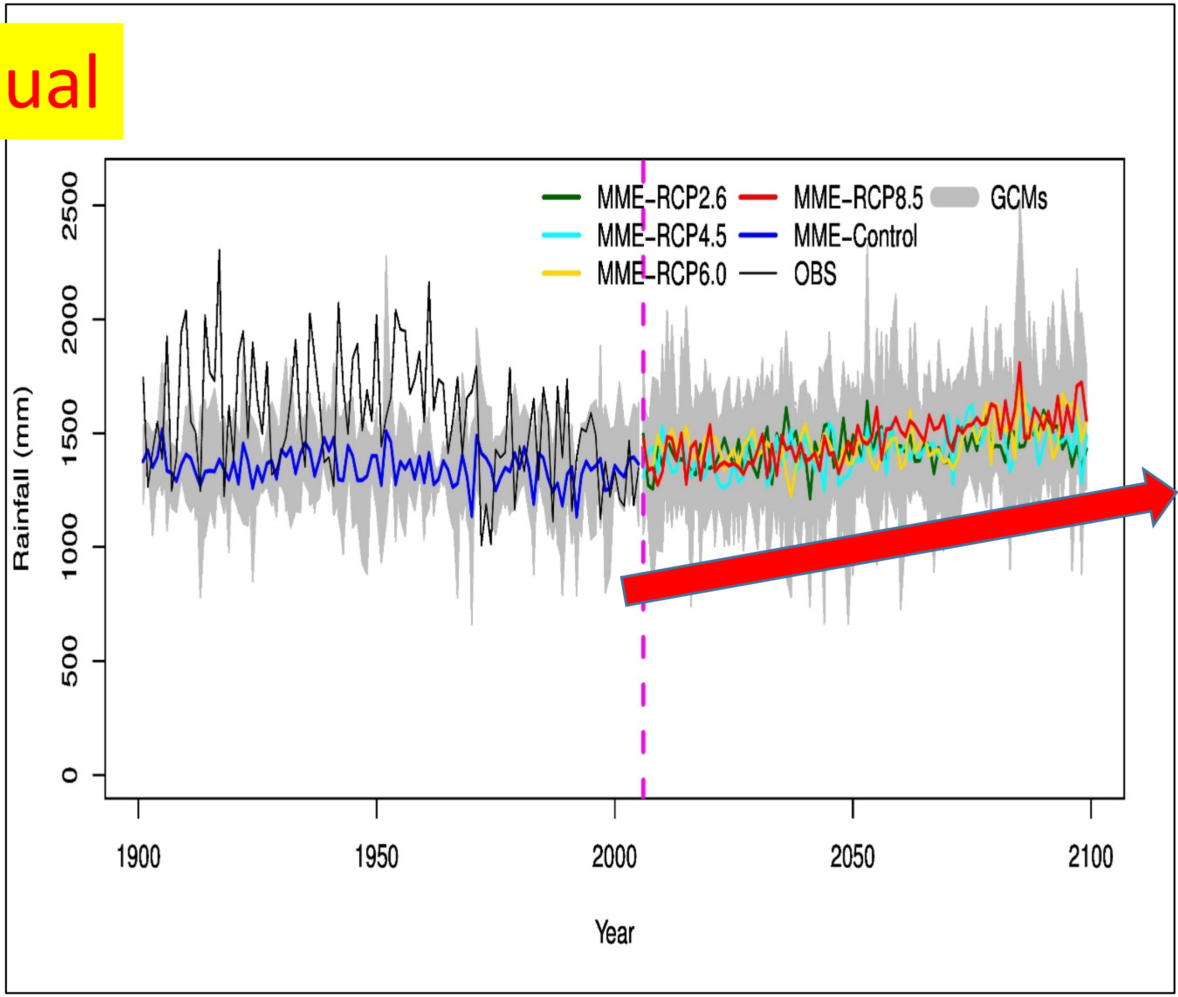
INDICE Work Package-II, BCKV

CMIP3

Annual

CMIP5

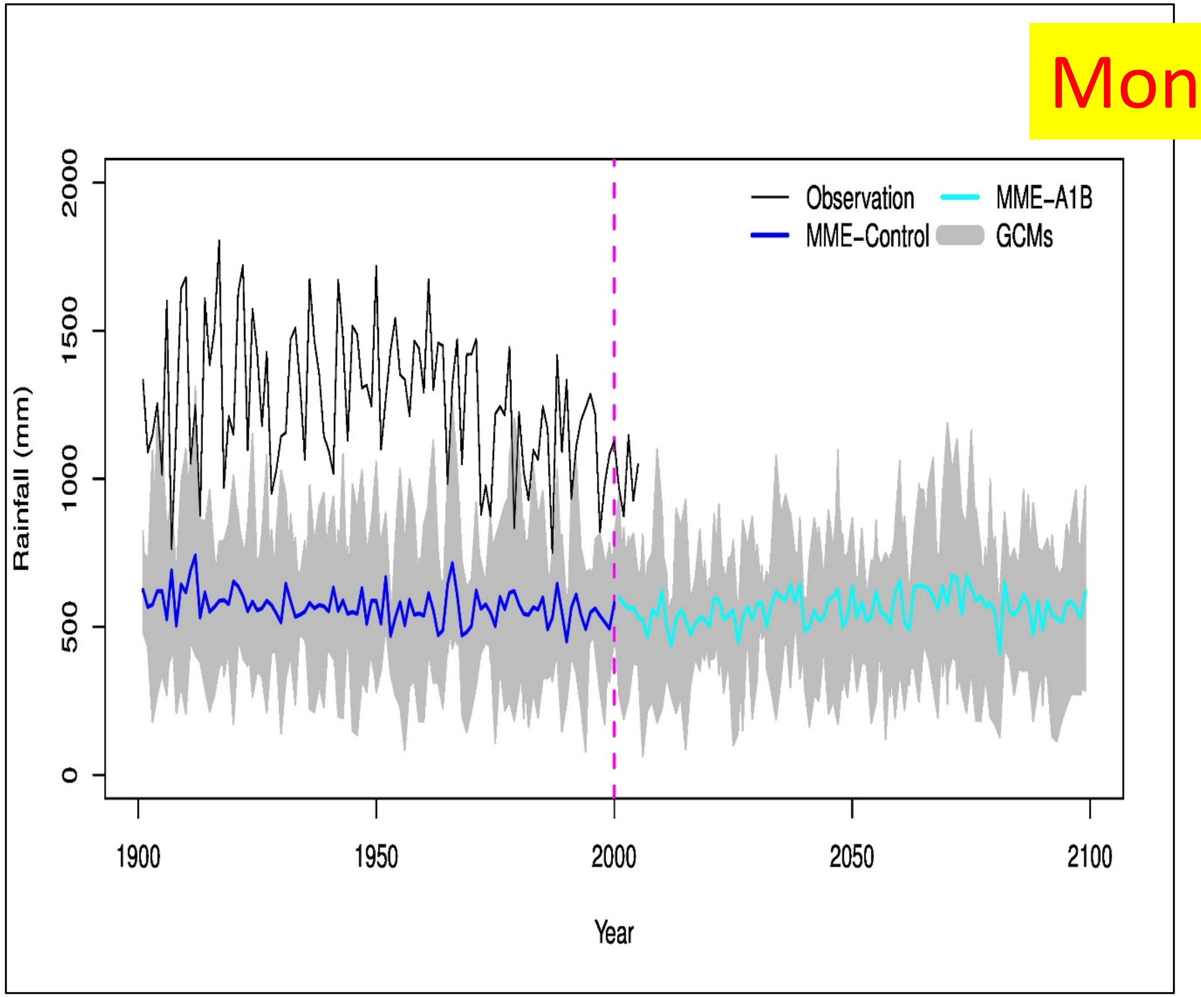




Annual Rainfall projection in the future

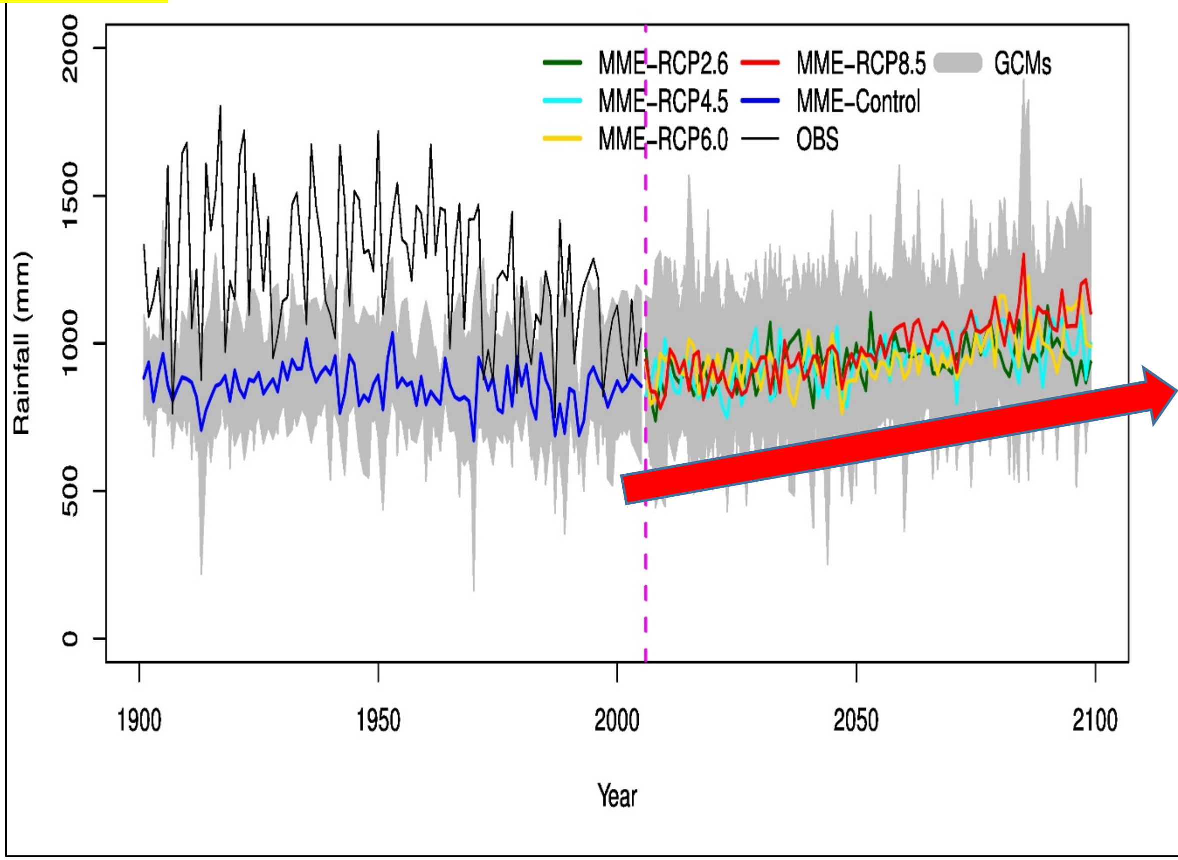
Results, Objective 3

CMIP3



Monsoon

CMIP5



Monsoon Rainfall projection in the future

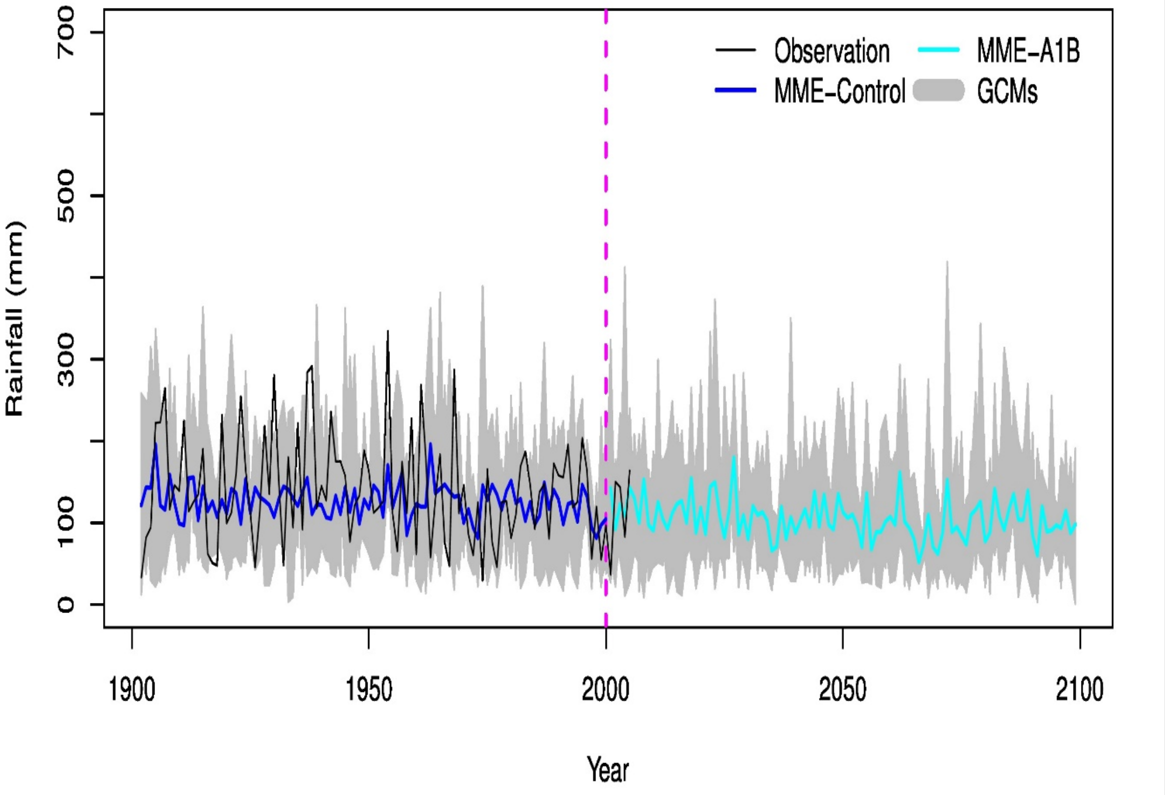
Results, Objective 3

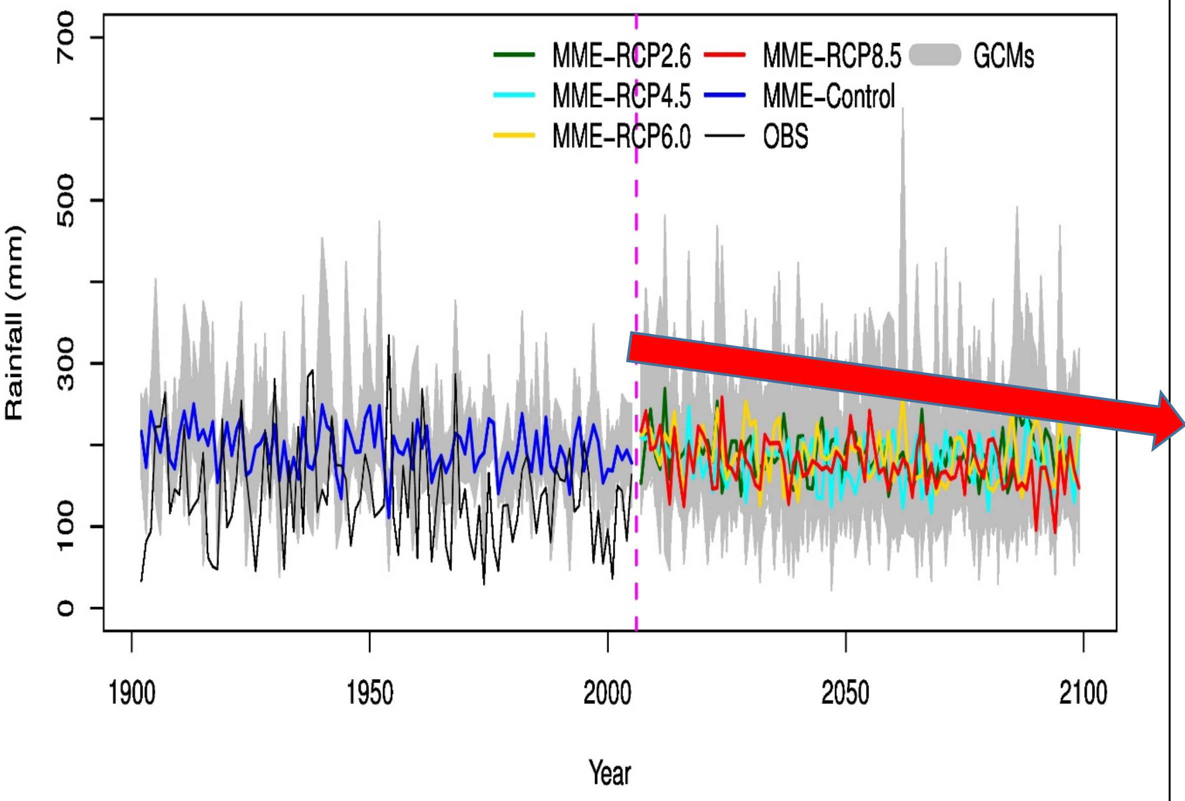
INDICE Work Package-II, BCKV

CMIP3

Winter

CMIP5





Winter Rainfall projection in the future

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Results, Objective 3

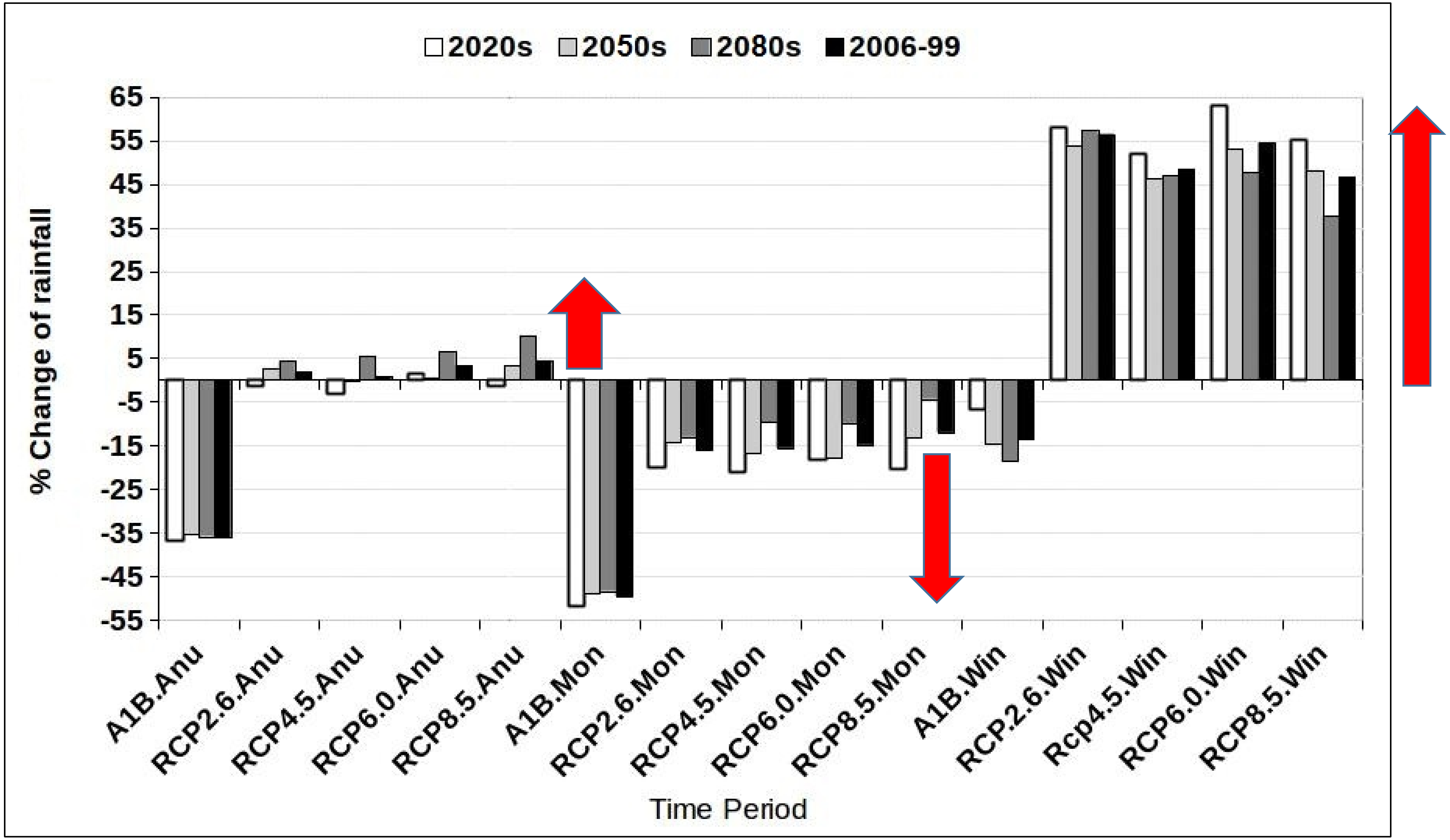
Future rainfall trend

Trend	Annual					JJAS					DJF				
	A1B	RCP2.6	RCP4.5	RCP6.0	RCP8.5	A1B	RCP2.6	RCP4.5	RCP6.0	RCP8.5	A1B	RCP2.6	RCP4.5	RCP6.0	RCP8.5
2006-35	16.2	48.4	27.2	-23.3	-12.8	70.4*	76.5	9.9	1.3	18.6	-19.8	-18.9	-31.5	-14.8	-27.5
2036-65	-3.9	-18.0	59.5	60.9	148.5*	22.8	18.0	71.5	58.3	143.2*	-3.0	-28.1	9.0	7.2	-1.6
2066-95	-89.3*	106.0*	21.3	171.4*	69.0	-94.2*	51.6	12.8	135.4*	51.0*	27.9	26.0	4.9	13.0	-24.9
2006-99	2.4	33.0*	54.2*	36.2*	84.4*	17.3*	31.9*	61.9*	45.6*	89.8*	-5.5*	-0.8	-2.4	-8.7*	-11.4*

Results of MK test from multi model ensemble of different future scenarios for both CMIP3 and CMIP5 during the period 2006-35, 2036-65, 2066-2099 and 2006-99.

*=0.05 % significant

Results, Objective 3



Percentage change of annual, monsoon and winter rainfall in the 2020s, 2050s, 2080s and 2006-99 calculated from the multi model ensemble of better performing GCMs (CMIP3: A1B scenario, CMIP5: all the four RCP scenarios) with respect to the IMD base line period of 1971-2000.

Conclusions

INDICE Work Package-II, BCKV

- Interpolated IMD gridded data are found to be more close to observation.

- Sudden variation, rather than gradual trend of rainfall in the last century

Most probable year of shift

- Winter: 1961
- Monsoon and annual: 1971

- 1902–1971: Increasing trend for annual and monsoon rainfall while decreasing trend for winter rainfall
- 1975–2000: Reversed

Conclusions

GCMs able to reproduce observed annual cycle

- CMIP3: GFDL, INGV, MIROC3.2 (hires) and UKMO
- CMIP5: ACCESS1-0, CCSM4, CESM1, HadGEM2, MIROC, NorESM

Climatology

GCMs able to reproduce the winter climatology satisfactorily while annual and monsoon rainfall pattern is poorly simulated.

Better performing GCMs

- CMIP3: MIROC3.2 (hires), UKMO-HadCM3 and GFDL-CM2.0
- CMIP5: CESM1-BGC, MIROC5, CCSM4, HadGEM2-ES, and ACCESS1-0

Conclusions

RCP2.6 and A1B:

Winter: decrease till about 2050s, when it stabilises and increasing starts.

RCP4.5 and RCP6.0:

Winter: Stabilised increasing trend achieved earlier just after the 2020s.

RCP8.5:

- Monsoon: significant increasing after the 2020s.
- Winter: non-significant decreasing trend.

Monsoon and Annual (2006-2100):

$Slope_{[RCP2.6]} < Slope_{[RCP6.0]} < Slope_{[RCP8.5]}$.

Dry monsoon season (5-20% deficient rainfall) and wetter (45-55%) winter season is projected under all the emission scenarios in 2020s, 50s and 80s.

Thank You!