

High-End Climate Change for Specific Warming Levels and Their Implications in the Ganga River Basin

Ashvani K. Gosain

Professor, Indian Institute of Technology Delhi

gosain@civil.iitd.ac.in

Objectives

- What do 4°C and 6°C worlds look like in comparison to 1.5°C and 2°C
- What are the associated Uncertainties
- What are the plausible Adaptation options

Contributions

- INRM team lead by Dr Sandhya Rao
- This work was done under The High-End cLimate Impacts and eXtremes (HELIX), a European Union Collaborative project

Climate Change Scenario Used

- Scenario: IPCC SRES AR5 RCP 8.5
- South Asia Cordex Models for simulated weather data
 - Bias corrected 3 RCMs (11 model runs)
 - CSIRO-CCAM-1391M – (4)
 - MPI-CSC-REMO2009 – (1)
 - SMHI-RCA4 – (6)
- Model Boundary Conditions
 - 9 boundary conditions
- 3 Specific Warming Levels (SWL)
 - SWL:1.5°C
 - SWL:2°C
 - SWL:4°C
- Grid resolution of 0.5° x 0.5°.

Climate Change and its Impact on Water Resources of Ganga Basin



- Tools used
 - Modelling: SWAT (Soil and Water Assessment Tool)
 - GIS framework: acts as a pre-processor
- Data used
 - Digital Elevation Model: SRTM 90 m
 - Land use: Global data, 1:2M USGS
 - Soil: Global data, 1:5M FAO
 - Drainage: 1:250,000
 - Weather: IPCC AR5 RCP 8.5 scenario, CORDEX Bias Corrected at $0.5^0 \times 0.5^0$ resolution from HELIX
 - Existing man made interventions (dams/reservoirs)
 - Current Crop management practices
- Impacts Studied
 - Impact on annual water availability
 - Impact on seasonal water availability
 - Impact on inter annual water availability
 - Regional Variability of Water availability
 - Extreme events – Floods and Droughts

RCM weather grids

Specific Warming Levels, their respective Passing Time and average CO₂ levels

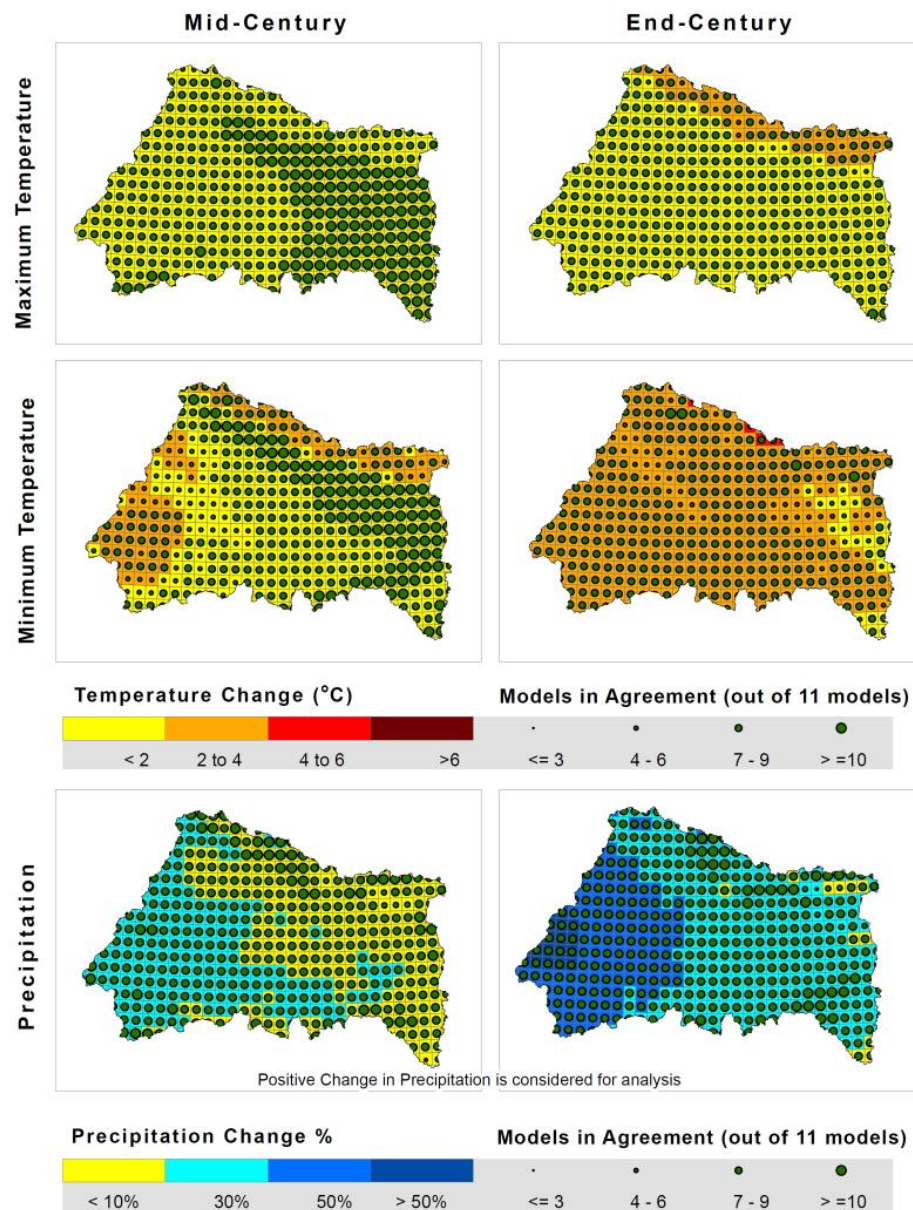
CORDEX Models	Driving GCM	SWL Passing Year			
		SWL:1.5	SWL:2	SWL:4	SWL:6
ACCESS1-0_CSIRO-CCAM-1391M	ACCESS1-0	2034	2046	2085	
CCSM4_CSIRO-CCAM-1391M	CCSM4	2016	2031	2079	2128
CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	CNRM-CM5	2032	2046	2088	2132
CNRM-CM5_CSIRO-CCAM-1391M	CNRM-CM5	2032	2046	2088	2132
ICHEC-EC-EARTH_SMHI-RCA4	EC-EARTH	2019	2035	2083	
IPSL-CM5A-MR_SMHI-RCA4	IPSL-CM5A-MR	2020	2034	2069	
MIROC-MIROC5_SMHI-RCA4	MIROC-MIROC5	2038	2052		
MPI-ESM-LR_CSIRO-CCAM-1391M	MPI-ESM-LR	2021	2040	2083	2123
MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009	MPI-ESM-LR	2021	2040	2083	2123
MPI-M-MPI-ESM-LR_SMHI-RCA4	MPI-ESM-LR	2021	2040	2083	2123
NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	GFDL-ESM2M	2040	2055	2113	2186
GFDL-CM3_r1_CSIRO-CCAM-1391M	GFDL-CM3				

30 years To_From around SWL				Average CO2 levels (From global)- RCP8.5			
SWL:1.5	SWL:2	SWL:4	SWL:6	CO2_SWL15	CO2_SWL2	CO2_SWL4	CO2_SWL-6
2019 to 2049	2031 to 2061	2070 to 2100		467.45	523.26	802.94	
2001 to 2031	2016 to 2046	2064 to 2094	2113 to 2143	407.02	455.62	752.15	1206.31
2017 to 2047	2031 to 2061	2073 to 2103	2117 to 2147	459.48	523.26	829.02	1246.25
2017 to 2047	2031 to 2061	2073 to 2103	2117 to 2147	459.48	523.26	829.02	1246.25
2004 to 2034	2020 to 2050	2068 to 2098		415.47	471.57	785.79	
2005 to 2035	2019 to 2049	2054 to 2084		418.41	467.45	672.53	
2023 to 2053	2037 to 2067			484.48	556.88		
2006 to 2036	2025 to 2055	2068 to 2098	2108 to 2138	421.42	493.57	785.79	1156.88
2006 to 2036	2025 to 2055	2068 to 2098	2108 to 2138	421.42	493.57	785.79	1156.88
2006 to 2036	2025 to 2055	2068 to 2098	2108 to 2138	421.42	493.57	785.79	1156.88
2025 to 2055	2040 to 2070	2098 to 2128	2171 to 2201	493.57	575.15	1059.71	1738.75
2015 to 2045	2027 to 2057	2062 to 2092					

Model Agreement in Projected Maximum, Minimum and Precipitation

- 11 CORDEX RCMs

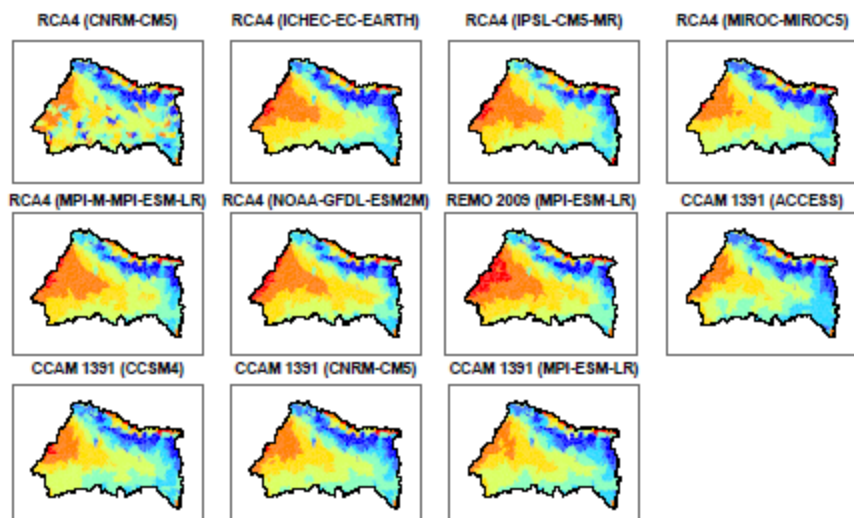
Model Agreement for Projected Changes in Minimum, Maximum Temperature and Precipitation Change for Mid-Century & End-Century with respect to Baseline (1981 - 2010) for Ganga Basin



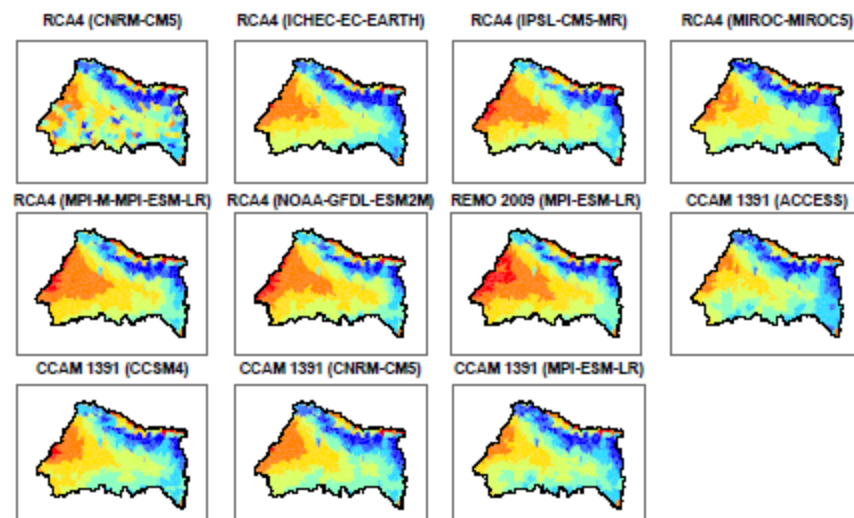
*Source: Bias adjusted CorDEX South Asia daily weather datasets provided by Technical University of Crete, Greece
RCM's : CSIRO-CCAM-1391M, SMHI-RCA4 and MPI-CSC-REMO2009 Baseline (1981-2010), Mid-Century (2021-2050), End-Century (2071-2100)

Annual Precipitation for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario*

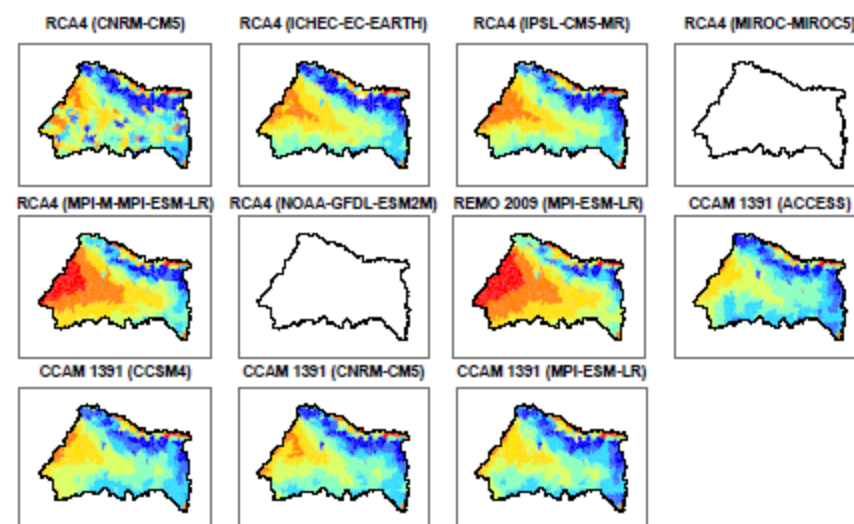
Specific Warming Level : 1.5 °C



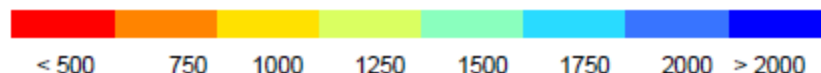
Specific Warming Level : 2 °C



Specific Warming Level : 4 °C



Precipitation (mm)



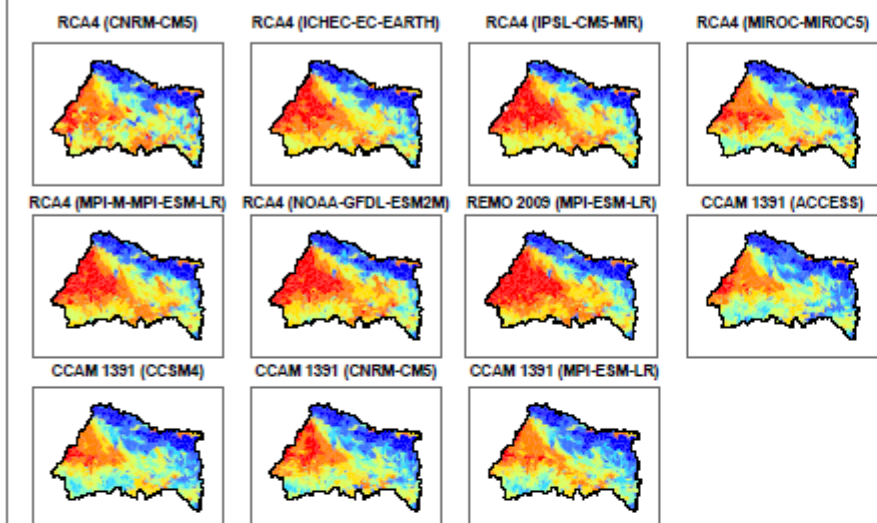
S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL-1.5°C	SWL-2°C	SWL-4°C	SWL-1.5°C	SWL-2°C	SWL-4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5, SMH-RCA4	2032	2048	2088	2017 - 2047	2031 - 2081	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH, SMH-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR, SMH-RCA4	2020	2034	2089	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROCS	MIROC-MIROCS, SMH-RCA4	2038	2052	NA	2023 - 2053	2037 - 2067	
10	MPI-ESM-LR	MPIM-MPI-ESM-LR, SMH-RCA4	2021	2040	2083	2006 - 2036	2020 - 2050	2066 - 2096
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M, SMH-RCA4	2040	2055	2113	2025 - 2055	2040 - 2070	No Data
9	MPI-ESM-LR	MPIM-MPI-ESM-LR, MP-CSC-REMO2009	2021	2040	2083	2006 - 2036	2020 - 2050	2066 - 2096
1	ACCESS1-0	ACCESS1-0, CSIRO-CCAM-1391M	2034	2048	2085	2019 - 2049	2031 - 2081	2070 - 2100
2	CCSM4	CCSM4, CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2054 - 2084
4	CNRM-CM5	CNRM-CM5, CSIRO-CCAM-1391M	2032	2048	2085	2017 - 2047	2031 - 2081	2073 - 2103
8	MPI-ESM-LR	MPIM-MPI-ESM-LR, CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2020 - 2050	2066 - 2096



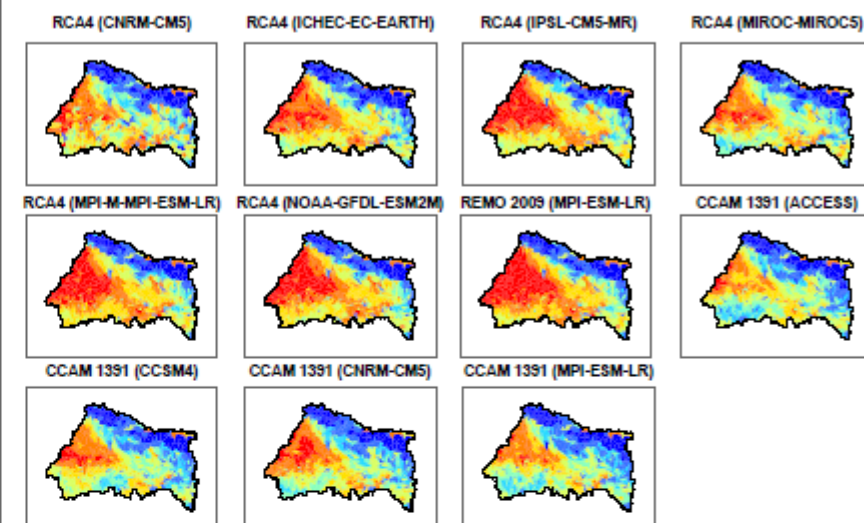
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

SWAT Simulated Annual Water Yield for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario*

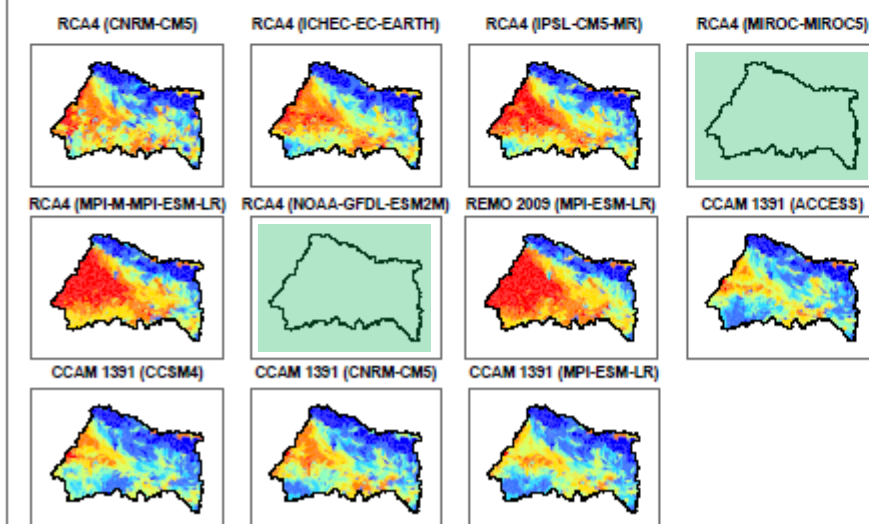
Specific Warming Level : 1.5 °C



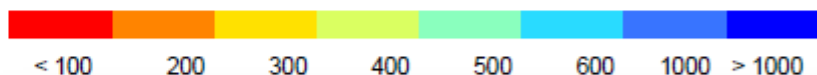
Specific Warming Level : 2 °C



Specific Warming Level : 4 °C



Water Yield (mm)



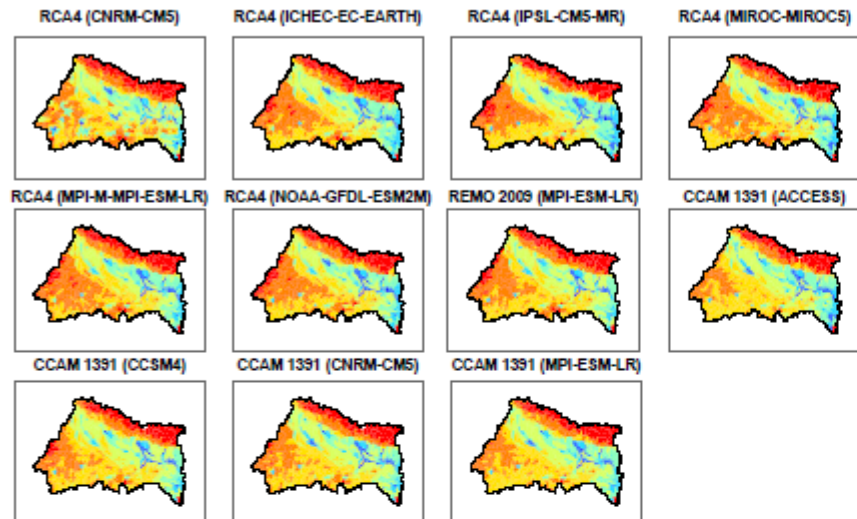
S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL:1.5°C	SWL:2°C	SWL:4°C	SWL:1.5°C	SWL:2°C	SWL:4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH_SMHI-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR_SMHI-RCA4	2020	2034	2069	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROC5	MIROC-MIROC5_SMHI-RCA4	2038	2052		2023 - 2053	2037 - 2067	
10	MPI-ESM-LR	MPIM-MPI-ESM-LR_SMHI-RCA4	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	2040	2055		2025 - 2055	2040 - 2070	
9	MPI-ESM-LR	MPIM-MPI-ESM-LR_MPI-CSC-REMO2009	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
1	ACCESS1-0	ACCESS1-0_CSIRO-CCAM-1391M	2034	2046	2085	2019 - 2049	2031 - 2061	2070 - 2100
2	CCSM	CCSM_CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2064 - 2094
4	CNRM-CM5	CNRM-CM5_CSIRO-CCAM-1391M	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
8	MPI-ESM-LR	MPI-ESM-LR_CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098



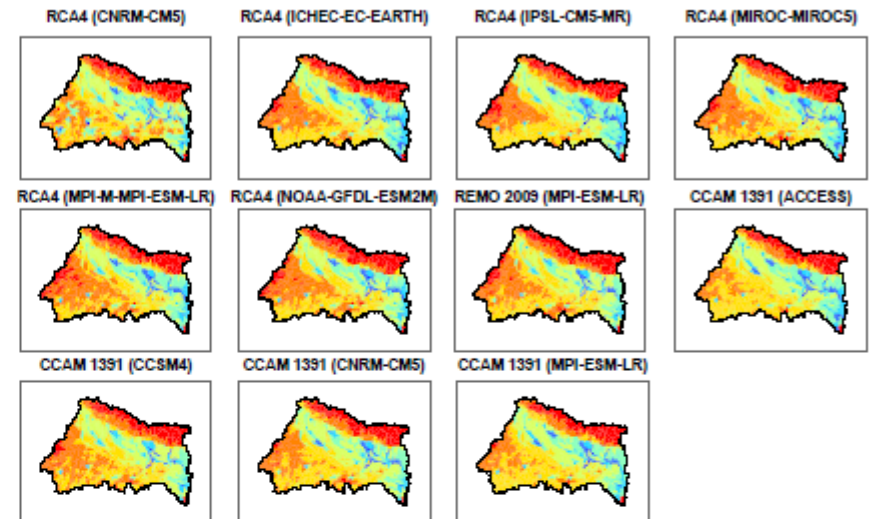
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

SWAT Simulated Annual Evapotranspiration for Ganga Basin at Specific Warming Levels (1.5°C, 2°C, 4°C) using Cordex South Asia RCM outputs - RCP8.5 Scenario*

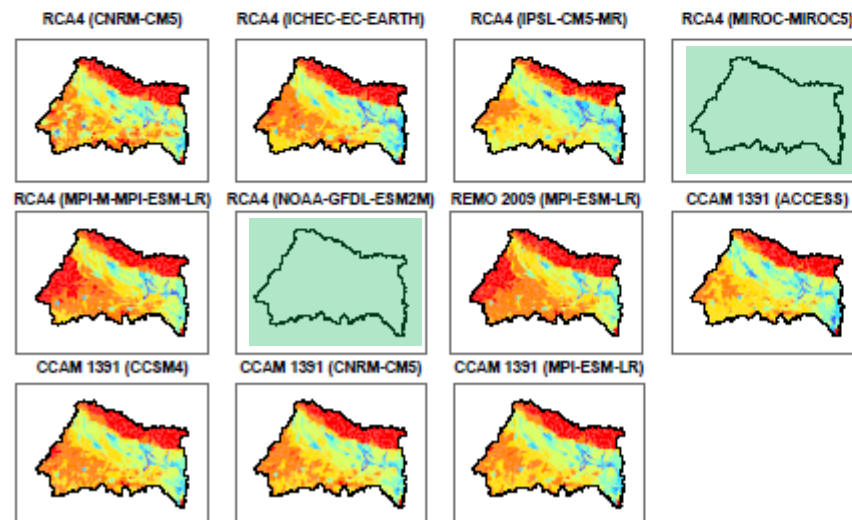
Specific Warming Level : 1.5 °C



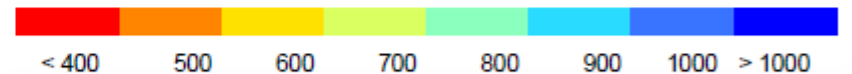
Specific Warming Level : 2 °C



Specific Warming Level : 4 °C



Evapotranspiration (mm)



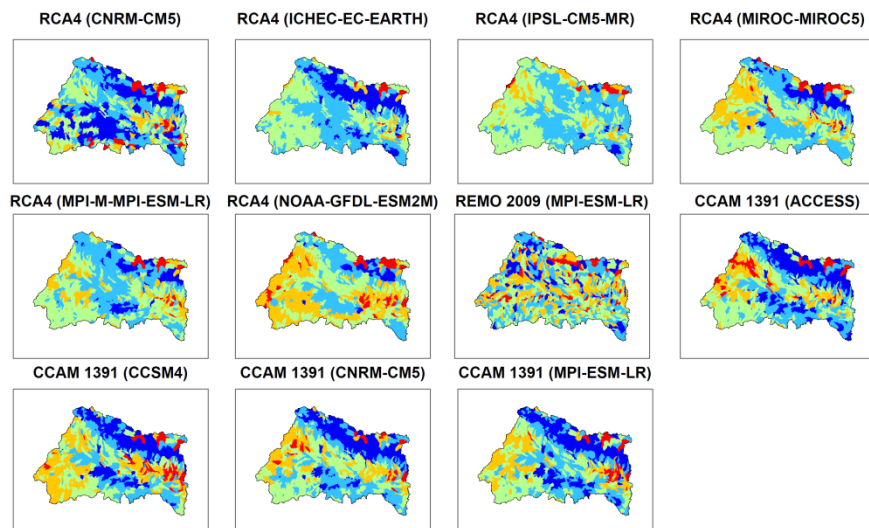
S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL:1.5°C	SWL:2°C	SWL:4°C	SWL:1.5°C	SWL:2°C	SWL:4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH_SMHI-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR_SMHI-RCA4	2020	2034	2069	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROC5	MIROC-MIROC5_SMHI-RCA4	2038	2052		2023 - 2053	2037 - 2067	
10	MPI-ESM-LR	MPI-M-MPI-ESM-LR_SMHI-RCA4	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	2040	2055		2025 - 2055	2040 - 2070	
9	MPI-ESM-LR	MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
1	ACCESS1-0	ACCESS1-0_CSIRO-CCAM-1391M	2034	2046	2085	2005 - 2035	2019 - 2049	2054 - 2084
2	CCSM4	CCSM4_CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2064 - 2094
4	CNRM-CM5	CNRM-CM5_CSIRO-CCAM-1391M	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
8	MPI-ESM-LR	MPI-ESM-LR_CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098



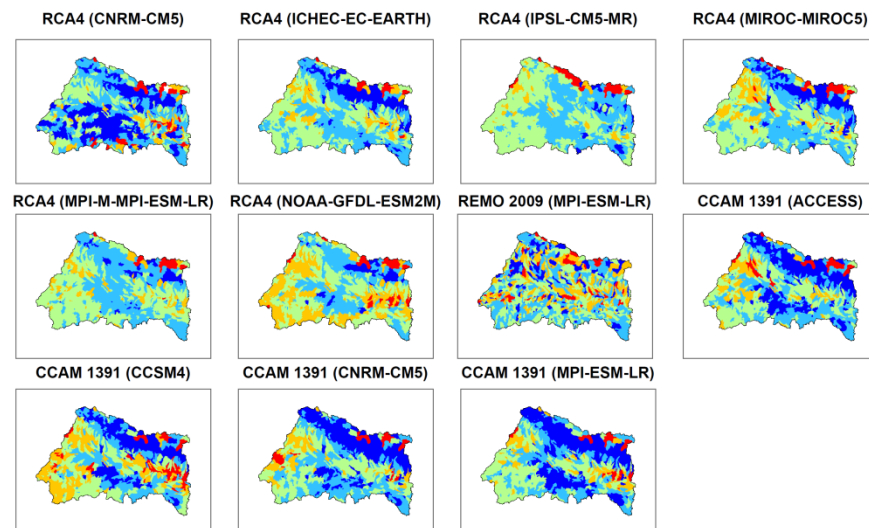
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

Monsoon Drought Weeks Based on Agriculture Drought Index -1(drought onset condition) at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP8.5 Scenario*

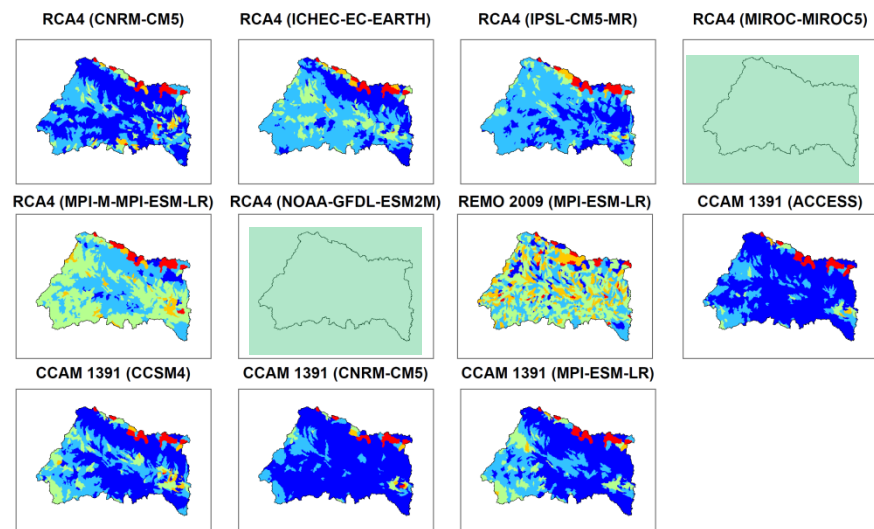
Specific Warming Level : 1.5 °C



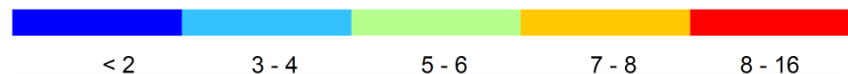
Specific Warming Level : 2 °C



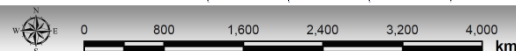
Specific Warming Level : 4 °C



Number of Monsoon Drought Weeks



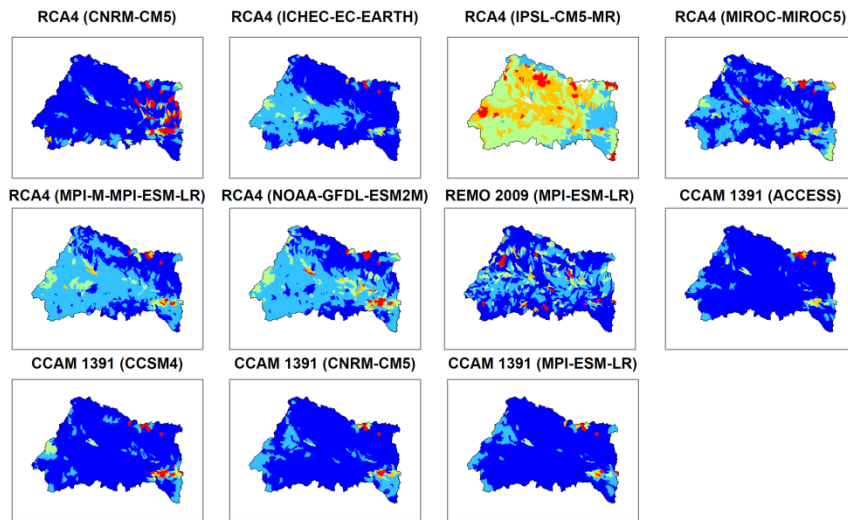
S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL:1.5°C	SWL:2°C	SWL:4°C	SWL:1.5°C	SWL:2°C	SWL:4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH_SMHI-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR_SMHI-RCA4	2020	2034	2069	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROC5	MIROC-MIROC5_SMHI-RCA4	2038	2052		2023 - 2053	2037 - 2067	
10	MPH-ESM-LR	MPH-MPH-ESM-LR_SMHI-RCA4	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	2040	2055		2025 - 2055	2040 - 2070	
9	MPH-ESM-LR	MPH-MPH-ESM-LR_MPI-CSC-REMO2009	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
1	ACCESS1-0	ACCESS1-0_CSIRO-CCAM-1391M	2034	2046	2085	2019 - 2049	2031 - 2061	2070 - 2100
2	CCSM4	CCSM4_CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2064 - 2094
4	CNRM-CM5	CNRM-CM5_CSIRO-CCAM-1391M	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
8	MPH-ESM-LR	MPH-ESM-LR_CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098



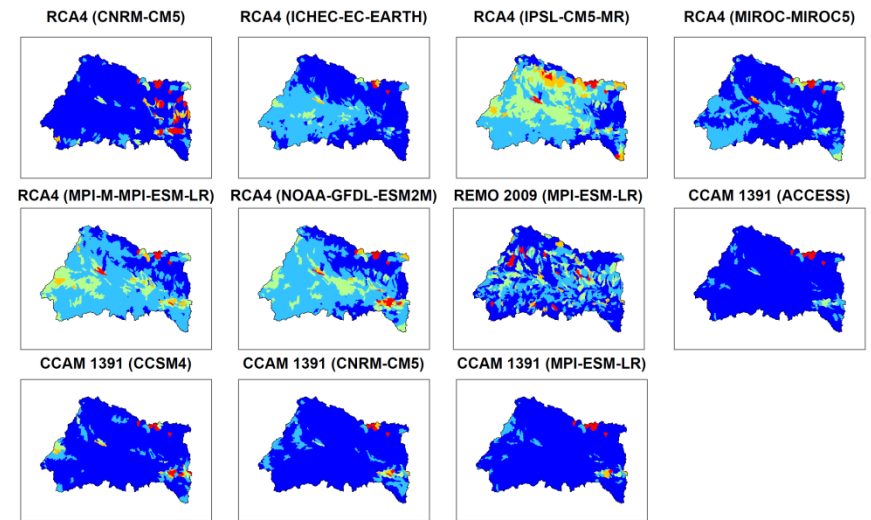
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

Monsoon Drought Weeks Based on Agriculture Drought Index ranging from -2 to -4 (moderate to extreme soil moisture stress during critical growth stages of crops) at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP8.5 Scenario*

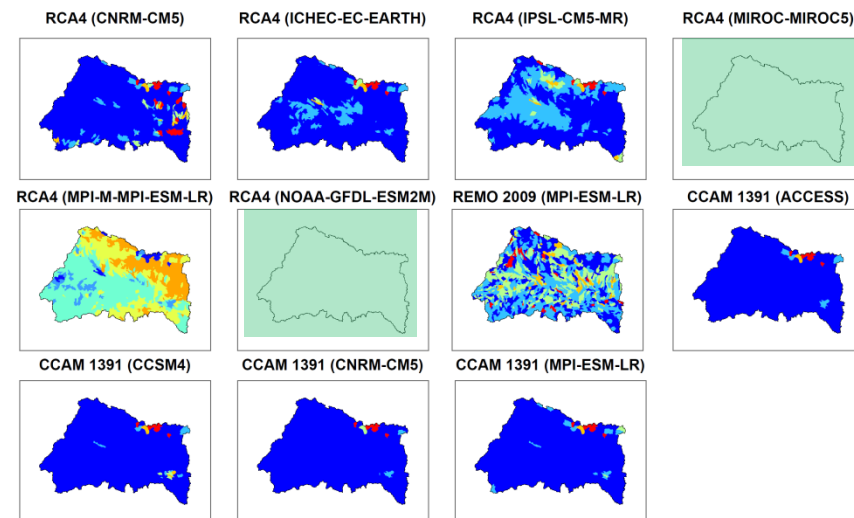
Specific Warming Level : 1.5 °C



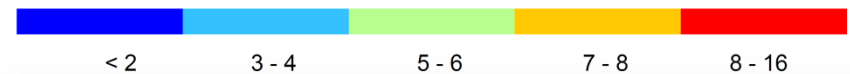
Specific Warming Level : 2 °C



Specific Warming Level : 4 °C



Number of Monsoon Drought Weeks



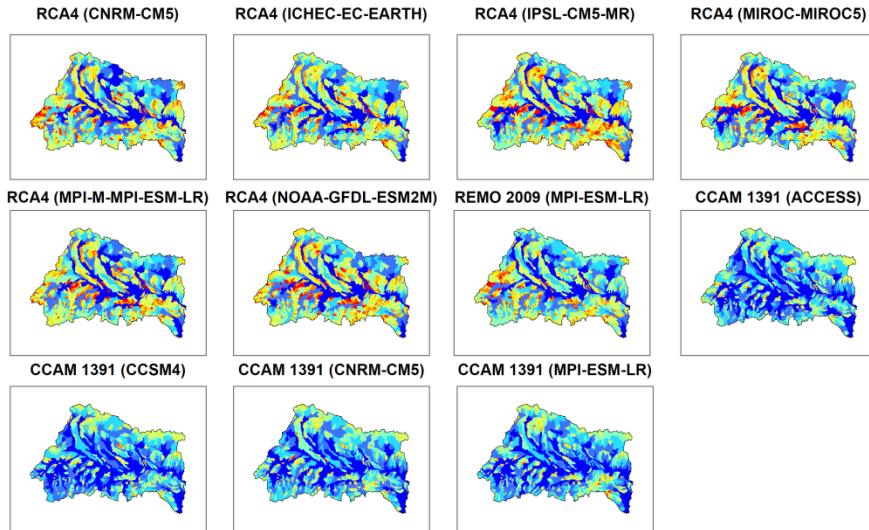
S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL:1.5°C	SWL:2°C	SWL:4°C	SWL:1.5°C	SWL:2°C	SWL:4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH_SMHI-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR_SMHI-RCA4	2020	2034	2069	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROC5	MIROC-MIROC5_SMHI-RCA4	2038	2052		2023 - 2053	2037 - 2067	
10	MPI-ESM-LR	MPH-MPI-ESM-LR_SMHI-RCA4	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	2040	2055		2025 - 2055	2040 - 2070	
9	MPI-ESM-LR	MPH-MPI-ESM-LR_MP-CSC-REMO2009	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
1	ACCESS1-0	ACCESS1-0_CSIRO-CCAM-1391M	2034	2046	2085	2019 - 2049	2031 - 2061	2070 - 2100
2	CCSM4	CCSM4_CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2064 - 2094
4	CNRM-CM5	CNRM-CM5_CSIRO-CCAM-1391M	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
8	MPI-ESM-LR	MPHESM-LR_CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098



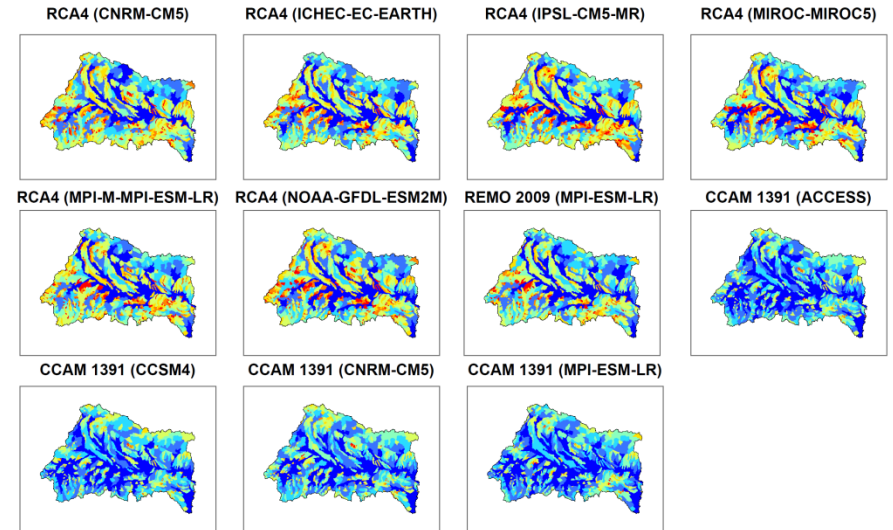
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

SWAT Simulated Annual Maximum Flow Based on Daily Stream Flow at Specific Warming Levels (1.5°C, 2°C, 4°C), using Cordex South Asia RCM outputs - RCP8.5 Scenario*

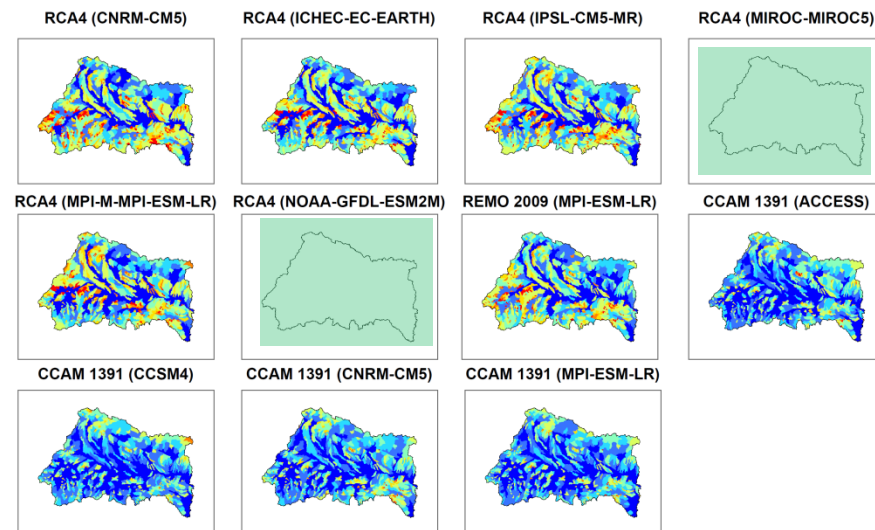
Specific Warming Level : 1.5 °C



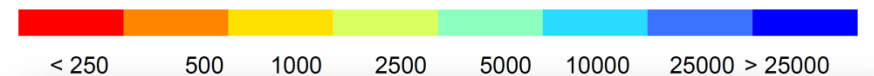
Specific Warming Level : 2 °C



Specific Warming Level : 4 °C



Maximum Discharge (CMS)

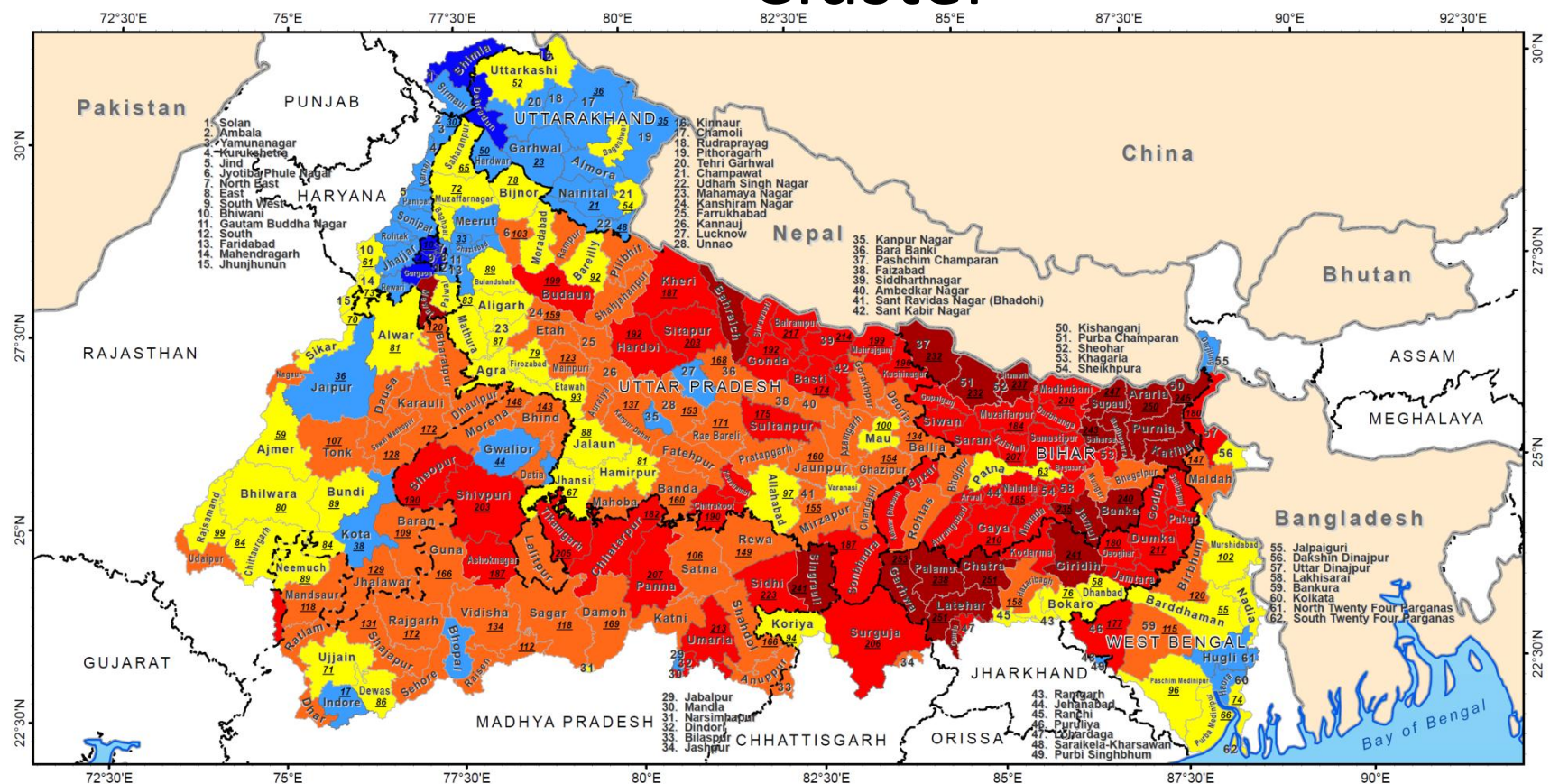


S.No	Driving GCM	CORDEX Models	SWL Passing Year for RCP 8.5			30 years Simulation around SWL		
			SWL:1.5°C	SWL:2°C	SWL:4°C	SWL:1.5°C	SWL:2°C	SWL:4°C
3	CNRM-CM5	CNRM-CERFACS-CNRM-CM5_SMHI-RCA4	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
5	EC-EARTH	ICHEC-EC-EARTH_SMHI-RCA4	2019	2035	2083	2004 - 2034	2020 - 2050	2068 - 2098
6	IPSL-CM5A-MR	IPSL-CM5A-MR_SMHI-RCA4	2020	2034	2069	2005 - 2035	2019 - 2049	2054 - 2084
7	MIROC-MIROC5	MIROC-MIROC5_SMHI-RCA4	2038	2052		2023 - 2053	2037 - 2067	
10	MPI-ESM-LR	MPH-MPI-ESM-LR_SMHI-RCA4	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
11	GFDL-ESM2M	NOAA-GFDL-GFDL-ESM2M_SMHI-RCA4	2040	2055		2025 - 2055	2040 - 2070	
9	MPI-ESM-LR	MPH-MPI-ESM-LR_MPI-CSC-REMO2009	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098
1	ACCESS1-0	ACCESS1-0_CSIRO-CCAM-1391M	2034	2046	2085	2019 - 2049	2031 - 2061	2070 - 2100
2	CCSM4	CCSM4_CSIRO-CCAM-1391M	2016	2031	2079	2001 - 2031	2016 - 2046	2064 - 2094
4	CNRM-CM5	CNRM-CM5_CSIRO-CCAM-1391M	2032	2046	2088	2017 - 2047	2031 - 2061	2073 - 2103
8	MPI-ESM-LR	MPHESM-LR_CSIRO-CCAM-1391M	2021	2040	2083	2006 - 2036	2025 - 2055	2068 - 2098



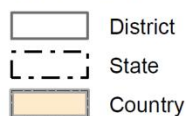
*Source: Bias adjusted Cordex South Asia daily weather datasets provided by Technical University of Crete, Greece

Spatial Representation of SEVI- Rank, Cluster



Socio-Economic Vulnerability Index Map GANGA BASIN

Boundaries

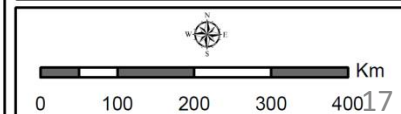


District Ranks

Vulnerability Index



* Source : Census of India, Department of Rural Development of States, Ministry of Health & Family Welfare , Government of India, District Information System for Education, Planning Commission, Government of India, Reserve Bank of India



Key Inferences

- At annual level precipitation, water yield and evapotranspiration, extreme events ranges for 11 models

	Precipitation (mm)	Water Yield (mm)	Evapo-transpiration (mm)	Drought (weeks)	Flood Magnitude (cumecs)
BL	1089 - 1189	388 - 473	554 - 569		
SWL15	1089 - 1330	388 - 567	554 - 592	3.6 - 5.3	176900 – 510400
SWL2	1083 - 1376	388 - 592	552 - 597	3.4 - 4.9	195500 - 533700
SWL4	959 – 1490	361 - 653	498 – 599	1.3 – 4.5	242800 - 525500

- ACCESS1-0_CSIRO-CCAM-1391M** (highest),
MPI-M-MPI-ESM-LR_MPI-CSC-REMO2009 (lowest)

Dissemination Tool Developed

- <http://inrm.co.in/climatechange/helix/homepage.html>

Thank You