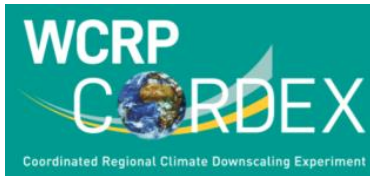


TRAINING ON
Spatial and temporal analysis of climate change indices using the
Climate Data Analytical Tool and CORDEX datasets over South Asia

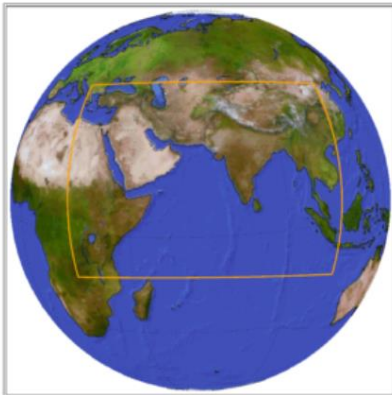
Training organised by ICIMOD,
in collaboration with the UKMO, WCRP/CORDEX, SMHI, and IITM
21–24 June 2022, Dhulikhel and Kathmandu, Nepal

CORDEX South Asia datasets based
climate data indices used in the
IPCC WG1 AR6



Region 6: South Asia

Sanjay Jayanarayanan

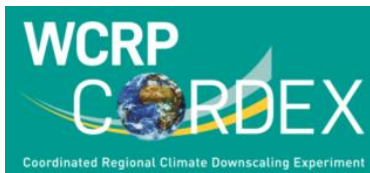


Scientist, Centre for Climate Change Research (CCCR)
Indian Institute of Tropical Meteorology (IITM), Pune, India
An Autonomous Institute of the Ministry of Earth Sciences, Govt. of India

&
CORDEX Science Advisory Team (SAT) Member

Regional Climate Information for Application Studies

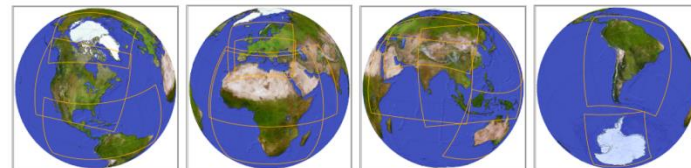
CORDEX South Asia



The CORDEX vision is to advance and coordinate the science and application of regional climate downscaling through global partnerships.

<https://cordex.org/domains/region-6-south-asia-2/>

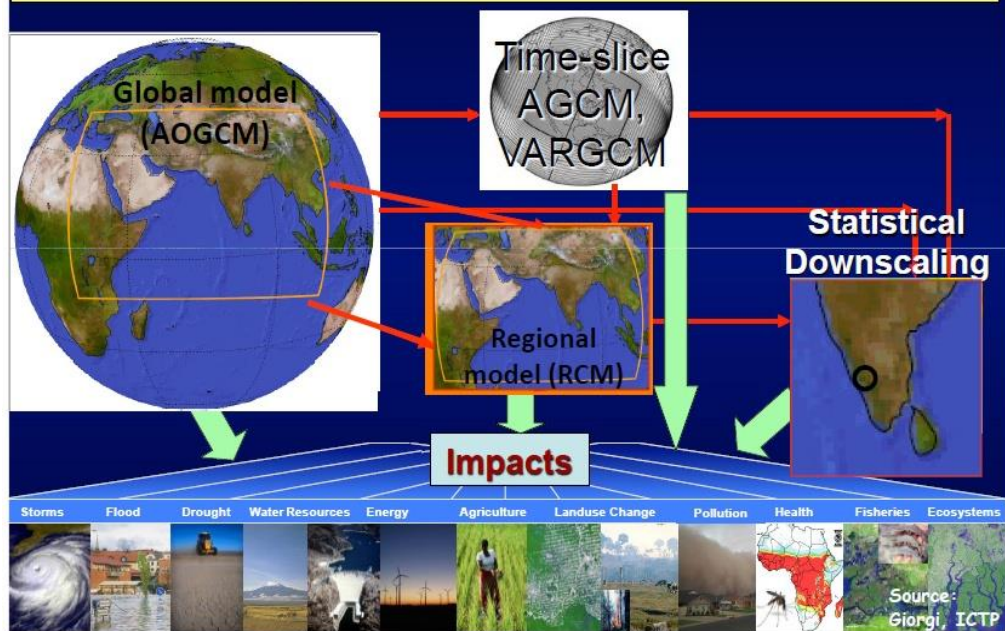
The CORDEX community



The CORDEX community has grown to now include 13 domains;

- Arctic CORDEX
- North America CORDEX
- Central America CORDEX
- EURO-CORDEX
- MED-CORDEX
- CORDEX Africa
- MENA-CORDEX
- Central Asia CORDEX
- South Asia CORDEX
- East Asia CORDEX
- Australasia CORDEX
- South America CORDEX
- CORDEX Antarctica

Downscaling regional climate information for impact assessment studies



Centre for Climate Change Research

Indian Institute of Tropical Meteorology, Pune, India



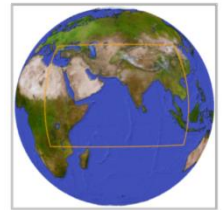
is leading CORDEX (Coordinated Regional Climate Downscaling Experiment) over South Asia Region

High Resolution (50 km)
Dynamical Downscaling of
CMIP5 Climate Projections
based on RCP Scenarios
during 1950-2100 using
multiple RCMs

More information for CORDEX South Asia data access from CCCR-IITM Climate Data Portal and ESGF datanode are provided at: http://cccr.tropmet.res.in/home/cordexsa_datasets.jsp

CORDEX simulations are stored in a distributed archive (the Earth System Grid Federation, ESGF) after standardization & curation: <https://cordex.org/data-access/regional-climate-change-simulations-for-cordex-domains/>

Region 6: South Asia



Domain	Res.	ESGF					
		models		scenarios			
		R	G	h	26	45	85
6: South Asia (WAS)	0.22	3	6	9	8	0	9
	0.44	3	12	17	6	17	17
	total	6	12	26	14	17	26

Climate Data Store (CDS)
CORDEX data subset



Home Search Datasets Applications Toolbox Support Live

#	Domain	GCM_run	RCM	Evaluation	Historical	RCP2.6	RCP4.5	RCP6.0	RCP8.5	Institution	Contact Info.	Access (1)	License
1	WAS-22	ECMWF-ERAINT	COSMO-crCLIM-v1-1_v1	1979-2015	N/A	N/A	N/A	N/A	N/A	CLMcom-ETH	silje.soerian	ESGF	unrestricted (*)
2	WAS-22	EC-EARTH_r11ip1	COSMO-crCLIM-v1-1_v1	N/A	1950-2005	N/A	N/A	N/A	N/A	2006-2099	CLMcom-ETH (*)	ESGF	unrestricted (*)
3	WAS-22	MPI-ESM-LR_r11ip1	COSMO-crCLIM-v1-1_v1	N/A	1950-2005	2006-2099	N/A	N/A	N/A	2006-2099	CLMcom-ETH (*)	ESGF	unrestricted (*)
4	WAS-22	NorESM1-M_r11ip1	COSMO-crCLIM-v1-1_v1	N/A	1950-2005	2006-2099	N/A	N/A	N/A	2006-2099	CLMcom-ETH (*)	ESGF	unrestricted (*)
5	WAS-22	ECMWF-ERAINT	REMO2015_v1	1979-2017	N/A	N/A	N/A	N/A	N/A	GERICS (*)	ESGF	unrestricted (*)	ESGF
6	WAS-22	HadGEM2-ES_r11ip1	REMO2015_v1	N/A	1970-2005	2006-2099	N/A	N/A	2006-2099	GERICS (*)	ESGF	unrestricted (*)	ESGF
7	WAS-22	MPI-ESM-LR_r11ip1	REMO2015_v1	N/A	1970-2005	2006-2100	N/A	N/A	2006-2100	GERICS (*)	ESGF	unrestricted (*)	ESGF
8	WAS-22	NorESM1-M_r11ip1	REMO2015_v1	N/A	1970-2005	2006-2100	N/A	N/A	2006-2100	GERICS (*)	ESGF	unrestricted (*)	ESGF
9	WAS-22	ECMWF-ERAINT	RegCM4-7_v0	1979-2016	N/A	N/A	N/A	N/A	N/A	ICTP (*)	ESGF	unrestricted (*)	ESGF
10	WAS-22	MIROCS_r11ip1	RegCM4-7_v0	N/A	1970-2005	2006-2099	N/A	N/A	2006-2099	ORNL (*)	ESGF	TBC (*)	ESGF
11	WAS-22	MPI-ESM-MR_r11ip1	RegCM4-7_v0	N/A	1970-2005	2006-2099	N/A	N/A	2006-2099	ORNL (*)	ESGF	TBC (*)	ESGF
12	WAS-22	NorESM1-M_r11ip1	RegCM4-7_v0	N/A	1970-2005	2006-2099	N/A	N/A	2006-2099	ORNL (*)	ESGF	TBC (*)	ESGF
13	WAS-44	CanESM2_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
14	WAS-44	CNRM-CMS_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
15	WAS-44	CSIRO-Mk3-6-0_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
16	WAS-44	ECMWF-ERAINT	RegCM4-4_v5	1979-2008	N/A	N/A	N/A	N/A	N/A	IITM (*)	ESGF	TBC (*)	ESGF
17	WAS-44	IPSL-CM5A-LR_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
18	WAS-44	MPI-ESM-MR_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
19	WAS-44	GFDL-ESM2M_r11ip1	RegCM4-4_v5	N/A	1951-2005	N/A	2006-2099	N/A	2006-2099	IITM (*)	ESGF	TBC (*)	ESGF
20	WAS-44	MPI-ESM-LR_r11ip1	REMO2009_v1	N/A	1961-2005	2006-2100	2006-2100	N/A	2006-2100	MPI-CSC (*)	ESGF	unrestricted (*)	ESGF
21	WAS-44	CanESM2_r11ip1	RCA4_v2	N/A	1951-2005	N/A	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
22	WAS-44	CNRM-CMS_r11ip1	RCA4_v2	N/A	1951-2005	N/A	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
23	WAS-44	CSIRO-Mk3-6-0_r11ip1	RCA4_v2	N/A	1951-2005	N/A	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
24	WAS-44	ECMWF-ERAINT	RCA4_v2	1980-2010	N/A	N/A	N/A	N/A	N/A	SMHI (*)	ESGF	unrestricted (*)	ESGF
25	WAS-44	EC-EARTH_r11ip1	RCA4_v2	N/A	1951-2005	2006-2100	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
26	WAS-44	IPSL-CM5A-MR_r11ip1	RCA4_v2	N/A	1951-2005	N/A	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
27	WAS-44	MIROCS_r11ip1	RCA4_v2	N/A	1951-2005	2006-2100	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
28	WAS-44	HadGEM2-ES_r11ip1	RCA4_v2	N/A	1951-2005	2006-2099	2006-2099	N/A	2006-2099	SMHI (*)	ESGF	unrestricted (*)	ESGF
29	WAS-44	MPI-ESM-LR_r11ip1	RCA4_v2	N/A	1951-2005	2006-2100	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
30	WAS-44	NorESM1-M_r11ip1	RCA4_v2	N/A	1951-2005	2006-2100	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
31	WAS-44	GFDL-ESM2M_r11ip1	RCA4_v2	N/A	1951-2005	N/A	2006-2100	N/A	2006-2100	SMHI (*)	ESGF	unrestricted (*)	ESGF
32	WAS-44	MPI-ESM-LR_r11ip1	REMO2009_v1	N/A	1961-2005	2006-2100	2006-2100	N/A	2006-2100	MPI-CSC (*)	ESGF	unrestricted (*)	ESGF

CORDEX regional climate model data on single levels

Overview Download data Quality assessment Documentation

- The CDS subset of CORDEX data is an effort done by Copernicus to consolidate a World-wide CORDEX dataset, and has also contributed to the IPCC-AR6 WGI activities

<https://cds.climate.copernicus.eu/cdsapp#!/dataset/projections-cordex-domains-single-levels?tab=overview>

https://cordex.org/wp-content/uploads/2020/12/CORDEX_simulations_Dec_2020.xlsx

Highlights- CORDEX Science Advisory Team (SAT)

(<https://cordex.org/about/science-adv-team/>)

CORDEX experiment design for dynamical downscaling of CMIP6

- Experiment protocol for RCMs to downscale a subset of climate scenarios from the CMIP6 ensemble of projections generated in ScenarioMIP, and to make these downscaled regional scenarios publicly available

(<https://cordex.org/experiment-guidelines/cordex-cmip6/experiment-protocol-rcms/>)

The future scientific challenges for CORDEX

- Developed a White Paper with the purpose to point out scientific challenges in regional climate modelling for better informed decision making process in regions and setting the basis for the CORDEX science plan

(<https://cordex.org/publications/white-paper/>)

The Flagship Pilot Studies (FPSs)

- Established with the aim of improving the capability of the models in reproducing regional climate features with a focus on extreme events with large socioeconomic impacts and can for example handle intensive rain, droughts, floods and heatwaves

(<https://cordex.org/experiment-guidelines/flagship-pilot-studies/>)

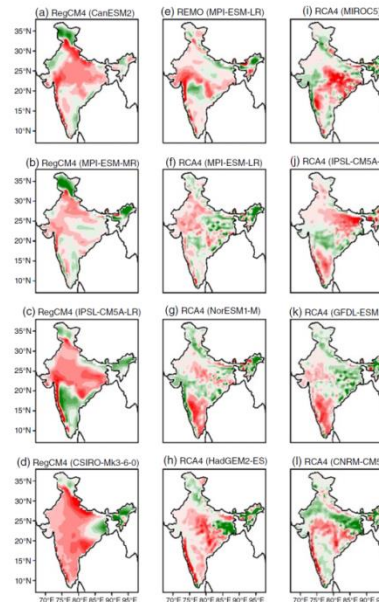
CORDEX South Asia (WAS) Activities

Opportunities and Challenges for better assessment of regional climate change

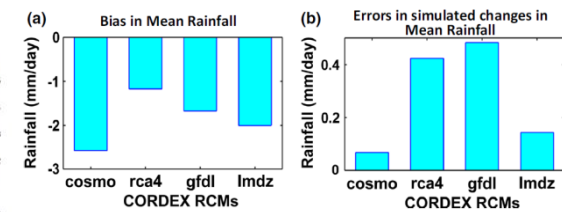
- More than 40 research publications (2014 onwards) analysed the RCM outputs from the CORDEX South Asia ensemble (see http://ccr.tropmet.res.in/home/cordexsa_pub.jsp)

- Future global **meteorological drought** hot spots: A study based on CORDEX Data (Spinoni et al., 2020)
- Contrasting regional and global climate simulations over South Asia (Rana et al., 2020)
- **Added value** of CORDEX-SA experiments in simulating monsoon precipitation over India (Choudhary et al. 2018)
- Understanding the cascade of GCM and downscaling (dynamical versus statistical) **uncertainties** in capturing the spatio-temporal variability of **hydro-climatic projections** over India (Sharma et al., 2017)
- Do dynamic regional models **add value** to the global model projections of **Indian monsoon**? (Singh et al. 2017)
- Climatic uncertainty in RCMs is far larger than observations over the **Himalayan water towers** (Mishra 2015)
- Reliability of regional and global climate models to simulate **precipitation extremes** over India

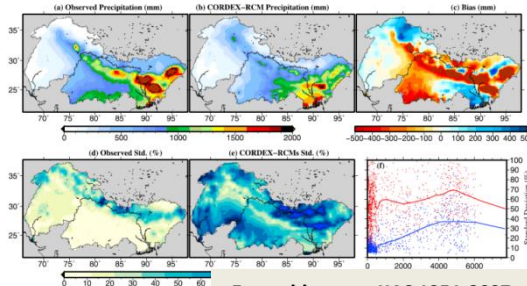
(Mishra et al., 2014)



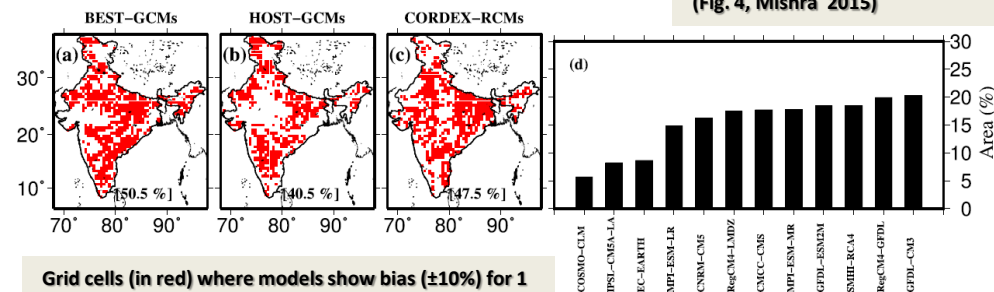
AV JJAS mean precip (Fig. 2, Choudhary et al., 2018)



ISMR (Fig. 16, Singh et al., 2017)



Ensemble mean JJAS 1951-2007 (Fig. 4, Mishra 2015)

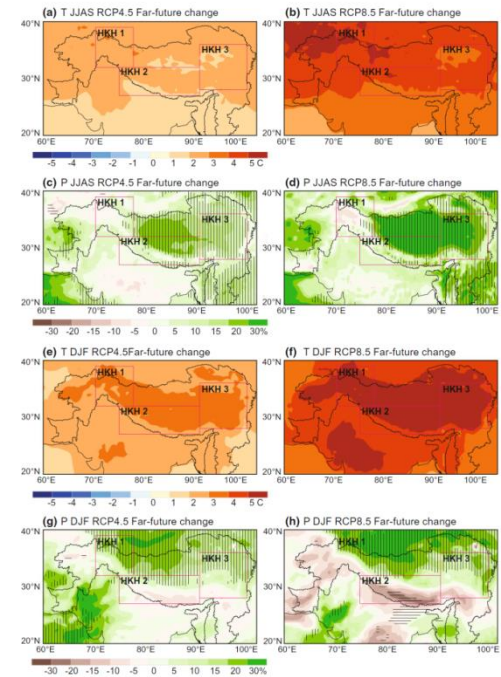


Grid cells (in red) where models show bias ($\pm 10\%$) for 1 day precip maxima at 25 year return period and (d) models and the area (%) (Fig. 9, Mishra et al. 2014)

CORDEX South Asia (WAS) Activities

Assessments of regional climate change

- Unravelling Climate Change in the Hindu Kush Himalaya: Rapid Warming in the Mountains and Increasing Extremes (Krishnan et al., 2019)



CORDEX South Asia RCM ensemble mean climate change in HKH region (Fig. 3.13, Krishnan et al., 2019)

- CORDEX South Asia future projections of regional climate change over India (In Krishnan et al., 2020)

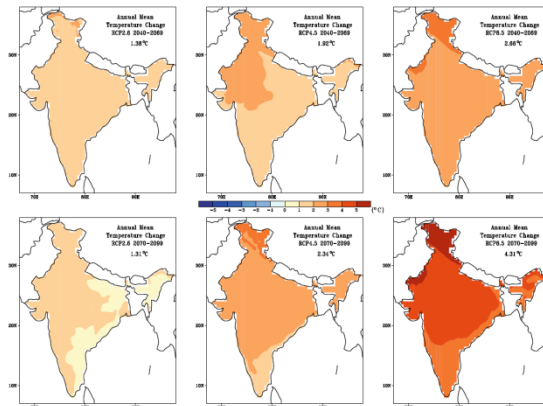


Fig. 2.7, Krishnan et al., (2020)

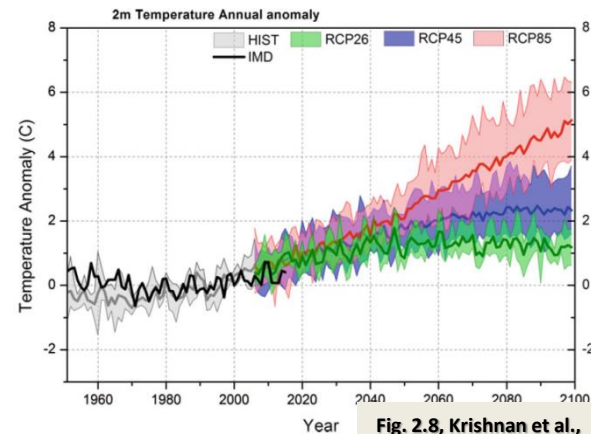
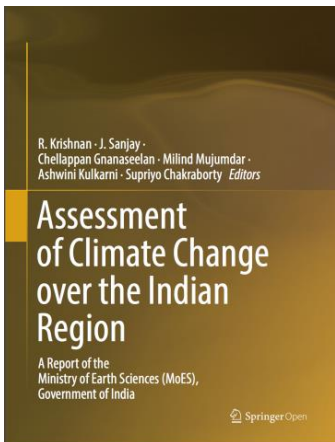
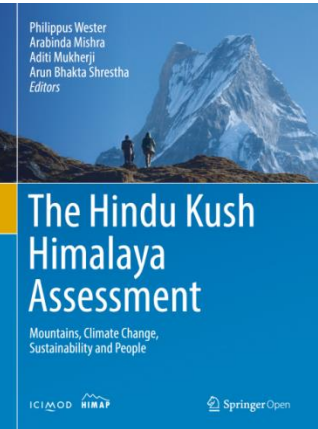


Fig. 2.8, Krishnan et al., (2020)



CORDEX South Asia (WAS) Activities

Development of regional capacity for assessment of regional climate change



ICIMOD



PROCEEDINGS OF THE TRAINING ON

Regional climate change projections

Climate change analysis using CORDEX regional climate models over South Asia (ICIMOD, UKMO, WCRP & CORDEX-IPO)

12-14 and 19-21 October 2020 | Platform: Microsoft Teams

First CORDEX South Asia Training Workshop- IITM, Pune, India, October 2012

(CCCR-IITM, START, ICTP, CSAG, SMHI & ICSU-ROAP)



Science & Training Workshop on Climate Change over the High Mountains of Asia- IITM, Pune, India, October 2018

(CCCR-IITM, MoES-GoI, DCCC-IISc, MAIRS-FE@DCCC)



Second CORDEX Science and Training Workshop in South Asia- ICIMOD, Kathmandu, Nepal, August 2013

(WCRP-CORDEX, MAIRS, APN, ICIMOD, CCCR-IITM & IAP)

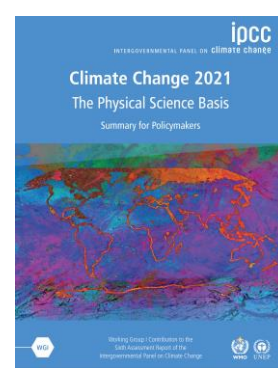


Climate information relevant to regional impact and risk assessment

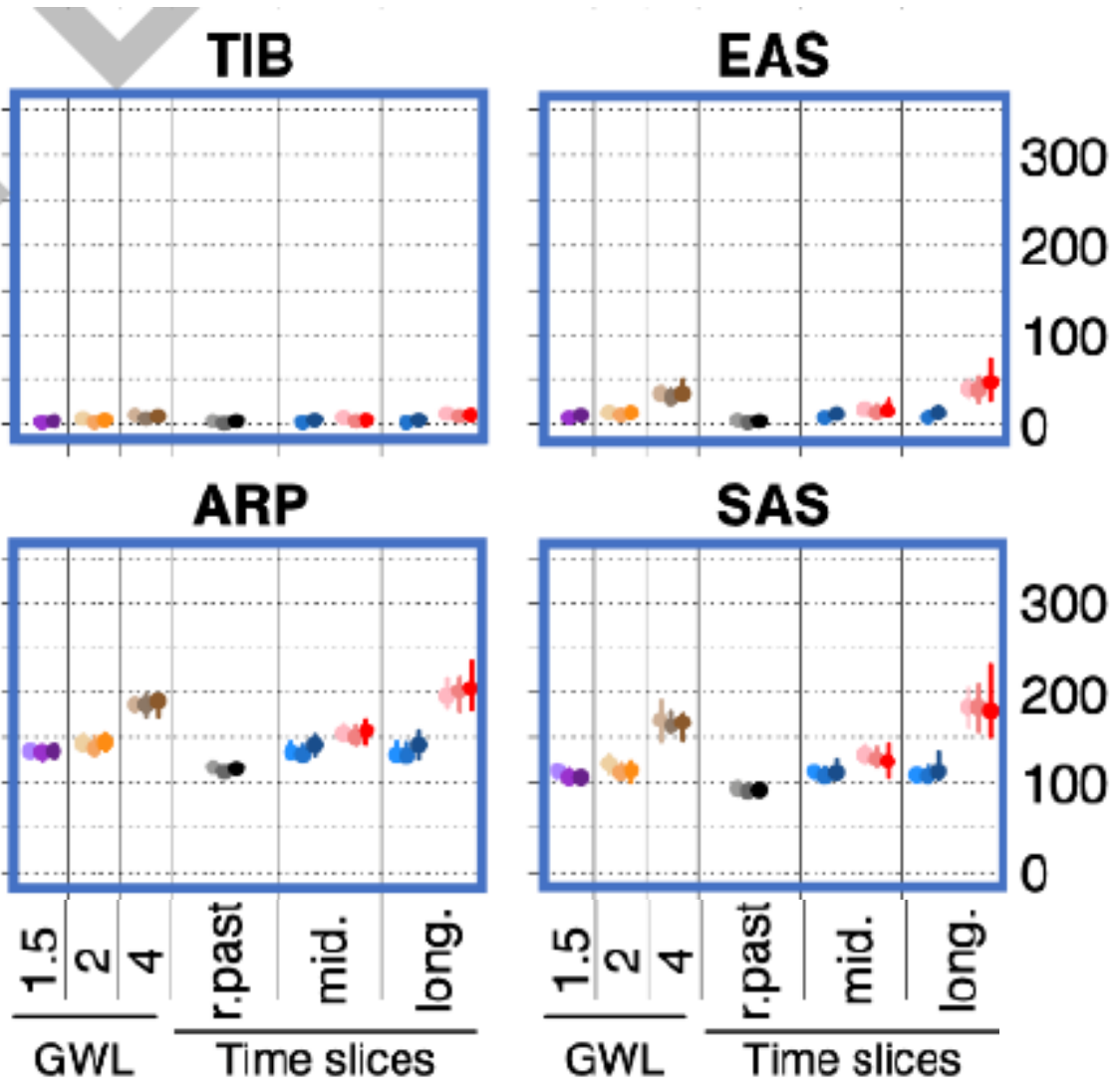
The chapter 12 of IPCC AR6 WG1 assesses climate information relevant to regional impact and risk assessment (Ranasinghe, et al. 2021;

https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_12.pdf)

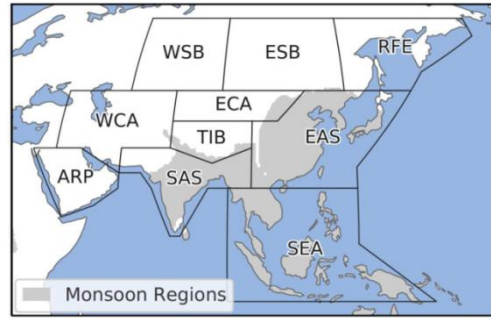
- It complements other WGI chapters which focus on the physical processes determining changes in the climate system and on methods for estimating regional changes
- Impacts of climate change are driven not only by changes in climate conditions, but also by changes in exposure and vulnerability (see Cross-Chapter Box 1.3: Risk framing in IPCC AR6; https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_01.pdf)
- This chapter concentrates on drivers of impacts that are of climatic origin, referred to in WGI as “climatic impact-drivers” (CIDs)
- CIDs are physical climate system conditions (e.g., means, events, extremes) that affect an element of society or ecosystems.
- Depending on system tolerance, CIDs and their changes can be detrimental, beneficial, neutral, or a mixture of each across interacting system elements and regions.
- In chapter 12 the CIDs that could lead to hazards or to opportunities are assessed from the literature and model results since IPCC AR5.
- This will particularly support the assessment of key risks related to climate change by WGII (forthcoming Chapter 16).



Number of days per year with daily maximum temperature > 35°C in AR6 selected Asia regions



- The uncertainty in the assessment of changes in Climatic-impact drivers (CIDs) due to climate models, time, scenarios and regional downscaling are illustrated in figures by comparing the CMIP5, CMIP6 and CORDEX ensembles for global warming levels (GWLs) 1.5°C, 2°C & 4°C

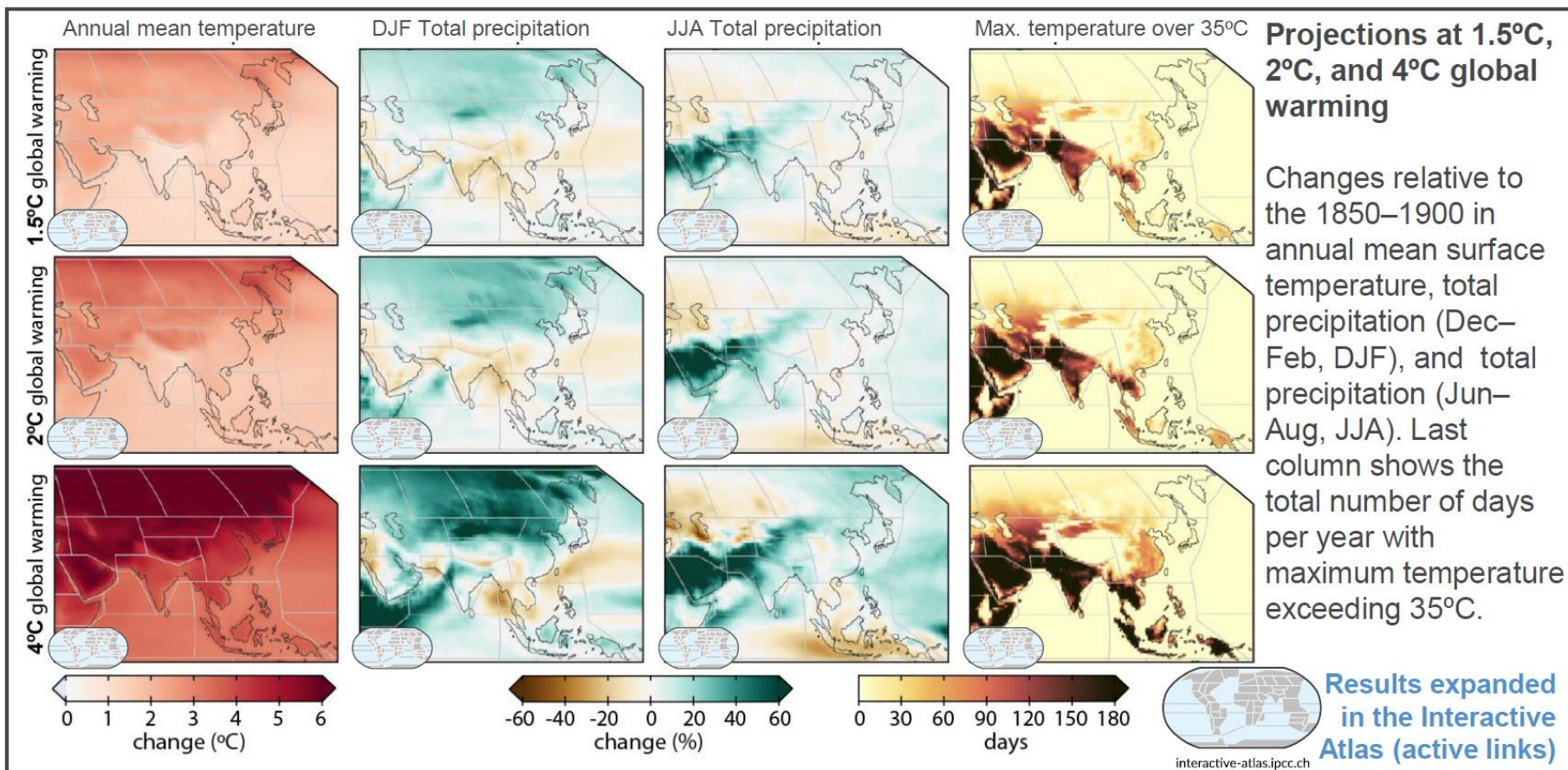


Adapted from IPCC AR6 WGI:
 Figure 12.SM.1: Regional projections for the number of days per year with maximum temperature exceeding 35°C.....
 (Ranasinghe, et al. 2021;
https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter_12.pdf)



Regional fact sheet - Asia

The novel IPCC AR6 WGI Interactive Atlas link: <https://interactive-atlas.ipcc.ch/>



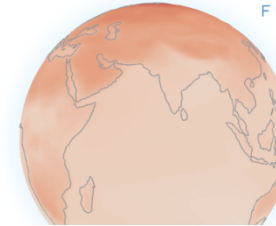
(active links) are available on the downloaded file:

https://www.ipcc.ch/report/ar6/wg1/downloads/factsheets/IPCC_AR6_WGI_Regional_Fact_Sheet_Asia.pdf

IPCC WGI Interactive Atlas

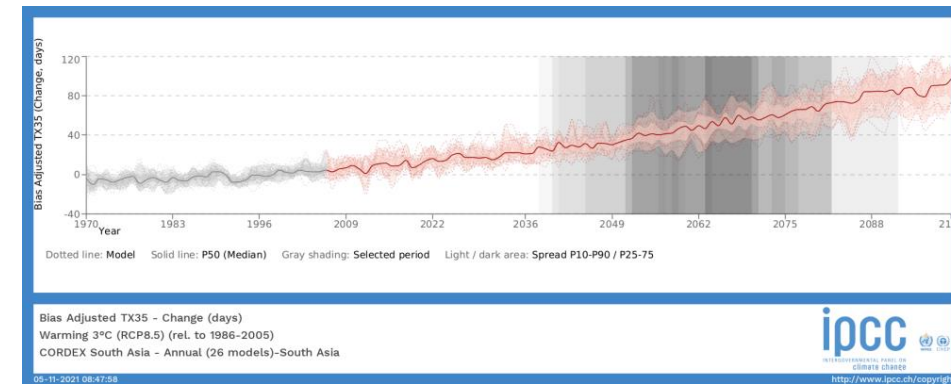
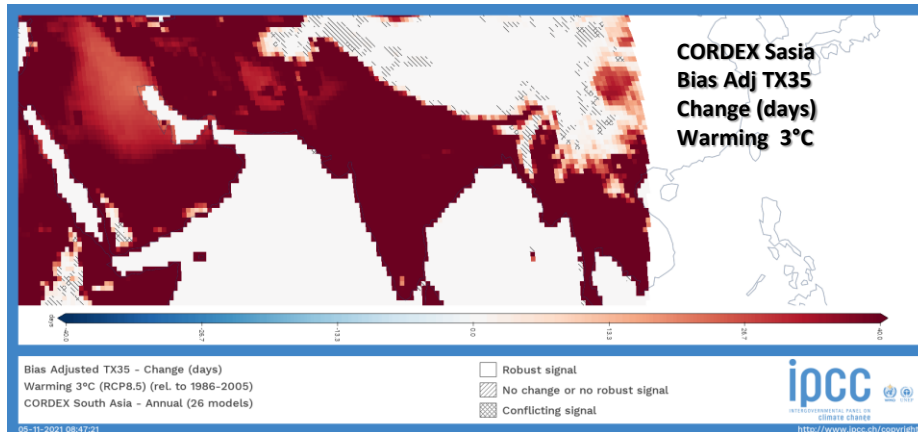
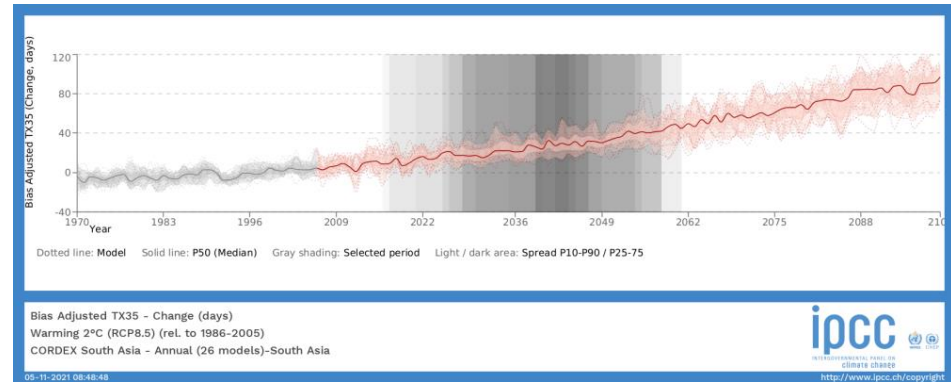
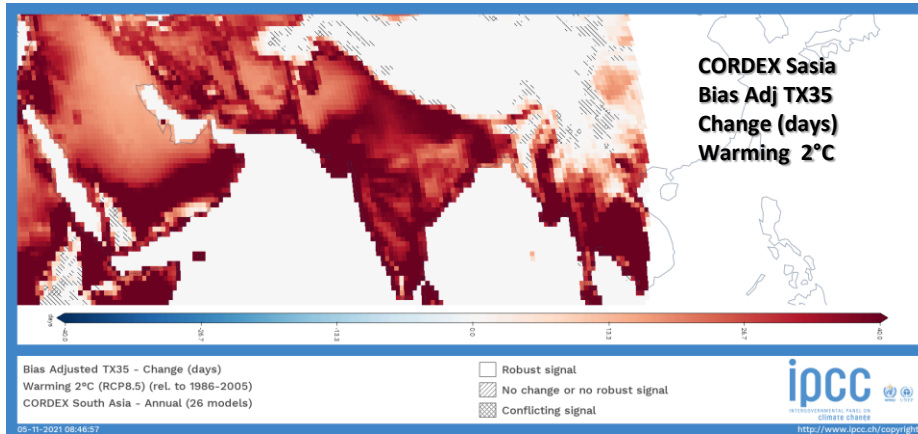
A novel tool for flexible spatial and temporal analyses of much of the observed and projected climate change information underpinning the Working Group I contribution to the Sixth Assessment Report, including regional synthesis for Climatic Impact-Drivers (CIDs).

OUR POSSIBLE
CLIMATE
FUTURES

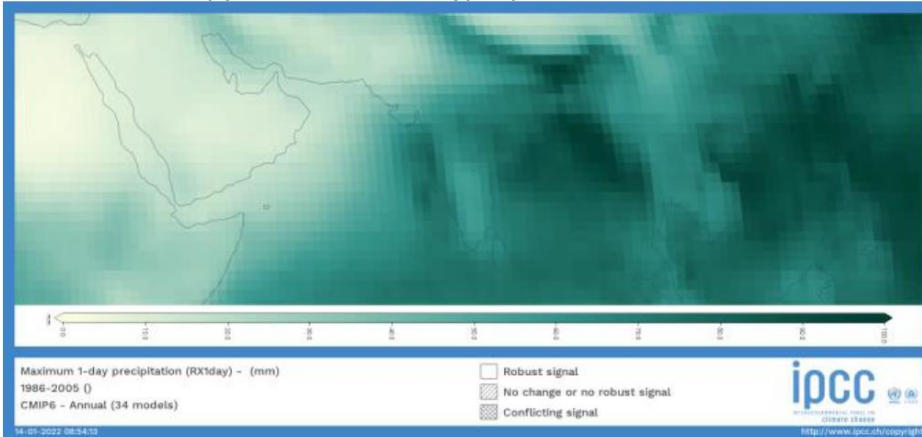


+1.5°C
+2°C
+3°C
+4°C

<https://interactive-atlas.ipcc.ch/>

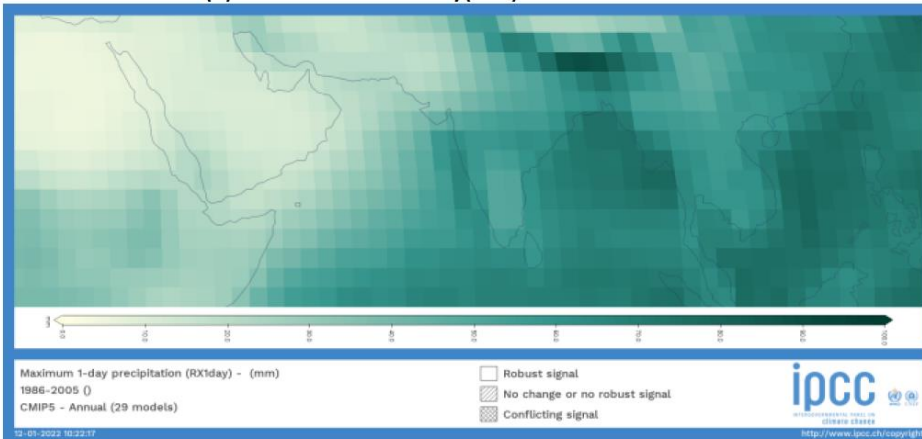


(a) CMIP6 Annual Rx1day(mm) 1986-2005 Historical



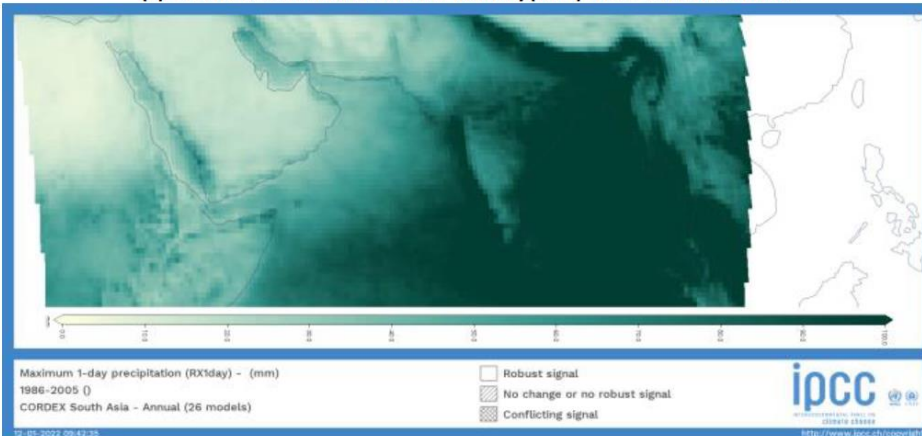
Spatial distribution of annual maximum 1-day precipitation (Rx1day, mm) over South Asia and adjoining regions averaged for the historical reference period 1986-2005 from the multi-model ensemble (MME) mean of global (CMIP6 and CMIP5) and downscaled regional (CORDEX South Asia) historical climate simulations.

(b) CMIP5 Annual Rx1day(mm) 1986-2005 Historical



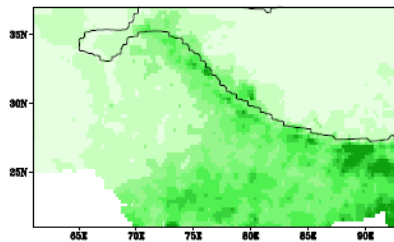
The spatial maps are drawn online using the IPCC Interactive Atlas (Gutiérrez et al., 2021; <https://interactive-atlas.ipcc.ch/>)

(c) CORDEX South Asia Annual Rx1day(mm) 1986-2005 Historical

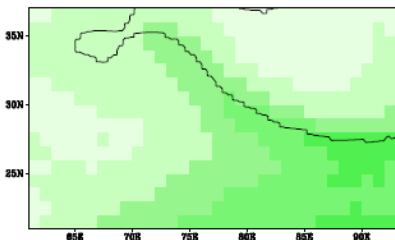


Climate Models Simulated Regional to Local Precipitation Extremes

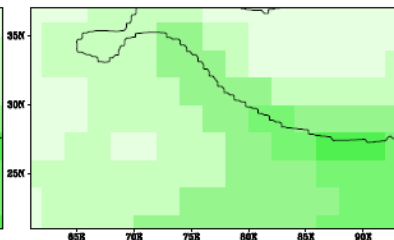
(a) APHRO 1986-2005 ANN



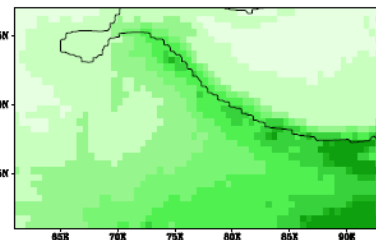
(b) CMIP6 1986-2005 Hist



(c) CMIP5 1986-2005 Hist



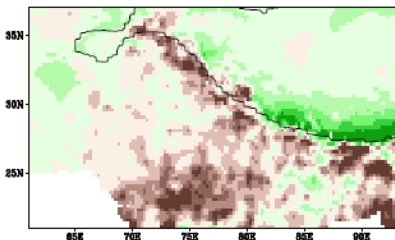
(d) CORDEX 1986-2005 Hist



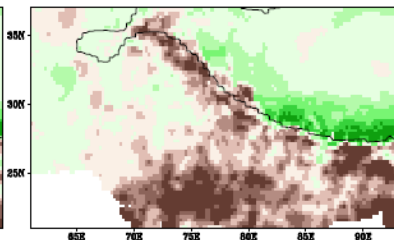
Annual Maximum 1-day Precipitation(R1day, mm)

Contours:
2500m topography

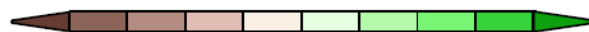
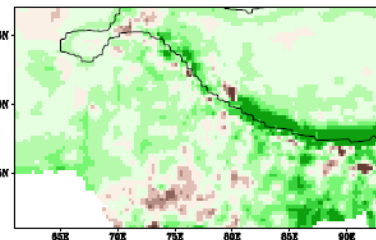
(e) CMIP6 1986-2005 Hist - APHRO



(f) CMIP5 1986-2005 Hist - APHRO



(g) CORDEX 1986-2005 Hist - APHRO



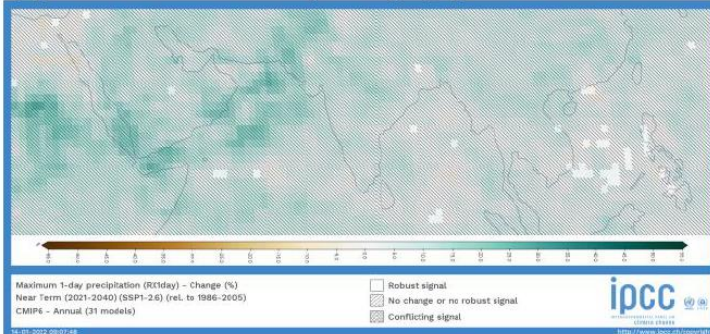
R1day Bias (mm)

- Analysis of the climatological spatial distribution of heavy precipitation magnitudes over the South Asia region using the IPCC online Interactive Atlas shows that the downscaled high resolution CORDEX MME mean simulated the intense precipitation extremes along slopes of Himalayan mountains relatively closer to observed (APHRODITE) estimates of R1day index than the coarse resolution CMIP5 and CMIP6 MME means.

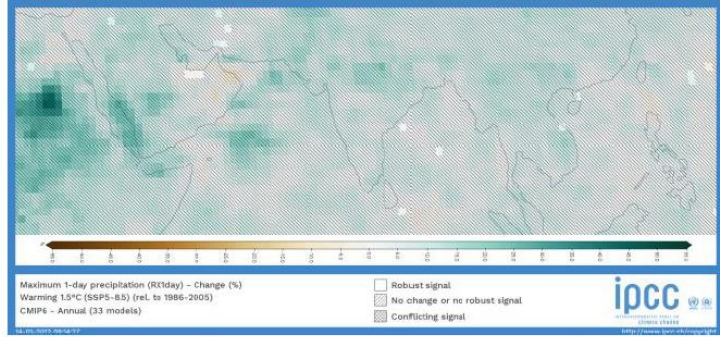
The spatial maps are drawn using the data extracted from IPCC Interactive Atlas (Gutiérrez et al., 2021; <https://interactive-atlas.ipcc.ch/>)

Spatial distribution of annual maximum 1-day precipitation (RX1day) from the CMIP6 multi-model ensemble (MME) mean simulations over South Asia & adjoining regions, (left columns) average change (%) projected for the near-term future period 2021-2040 relative to historical period 1986-2005 under 3 greenhouse gas emission scenarios, and (right columns) at 3 global warming levels under SSP5-8.5 scenario. The spatial maps are drawn online using the IPCC Interactive Atlas (Gutiérrez et al., 2021; <https://interactive-atlas.ipcc.ch/>)

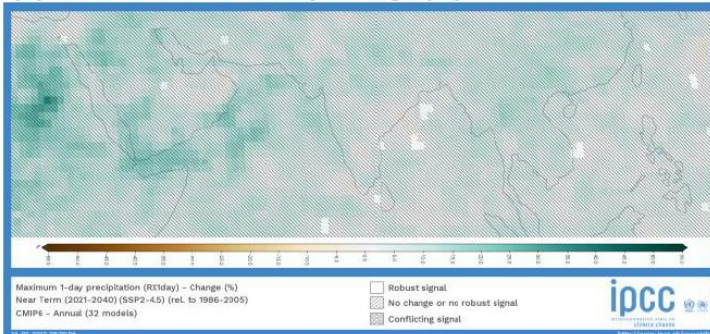
(a) CMIP6 Annual RX1day Change (%) 2021-2040 SSP1-2.6



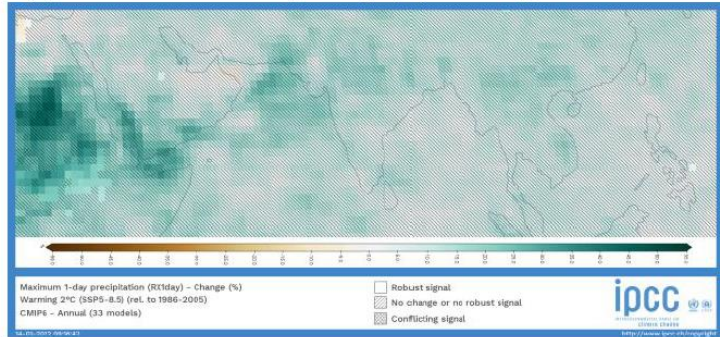
(d) CMIP6 Annual RX1day Change (%) Warming 1.5°C SSP5-8.5



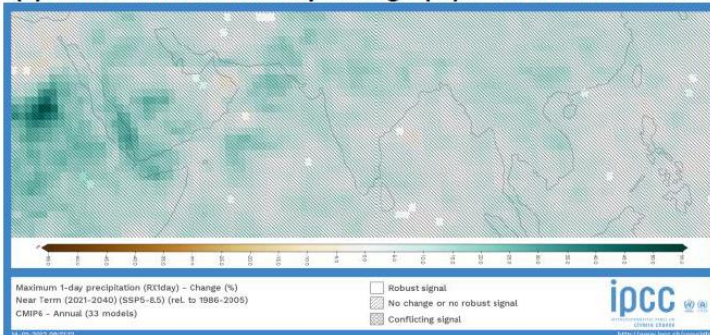
(b) CMIP6 Annual RX1day Change (%) 2021-2040 SSP2-4.5



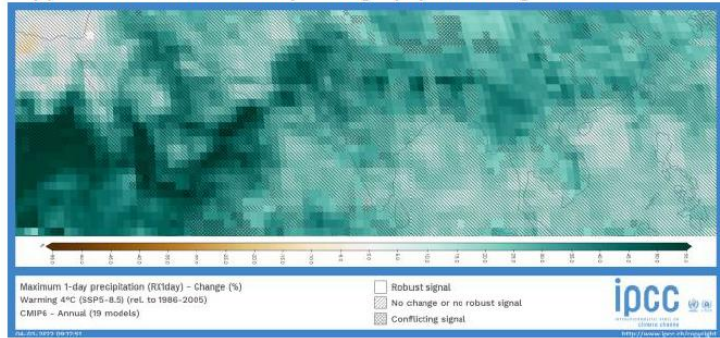
(e) CMIP6 Annual RX1day Change (%) Warming 2.0°C SSP5-8.5



(c) CMIP6 Annual RX1day Change (%) 2021-2040 SSP5-8.5

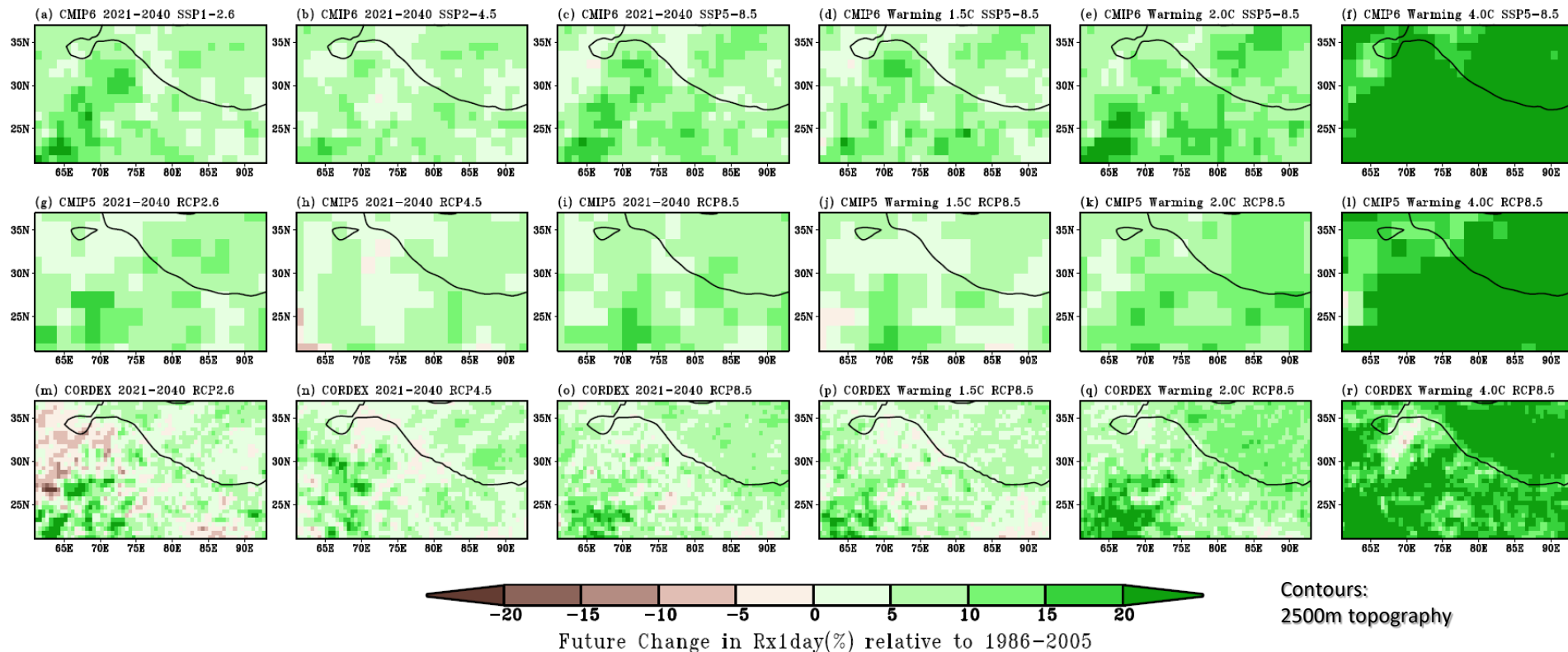


(f) CMIP6 Annual RX1day Change (%) Warming 4.0°C SSP5-8.5



Climate Change Driven Changes in Precipitation Extremes

- Analyses of MME mean global and downscaled regional climate projections using the online IPCC Interactive Atlas implied that scenarios with low GHG emissions (RCP2.6 and SSP1-2.6) would lead to substantially smaller changes in annual Rx1day index beyond 2040 than under very high GHG emissions scenarios (RCP8.5 and SSP5-8.5) over the South Asia region.



The spatial maps are drawn using the data extracted from IPCC Interactive Atlas (Gutiérrez et al., 2021; <https://interactive-atlas.ipcc.ch/>)

.....Concluding Remarks

- Future scenarios with low GHG emissions (RCP2.6 and SSP1-2.6) would lead to substantially smaller changes in annual Rx1day index beyond 2040 than under very high GHG emissions scenarios (RCP8.5 and SSP5-8.5) over the South Asia region.
- However it is suggested that additional information on the range of projected outcomes of Rx1day for parts of South Asia available across the CORDEX South Asia MME will be essential for integration of climate information needed for informing local future adaptation decisions, which is not available from the IPCC Interactive Atlas.

Thanks for your attention

sanjay@tropmet.res.in

Thank You

- Training organisers ICIMOD, UK Aid-funded ARRCC
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- Director IITM
- CORDEX South Asia Team Members