Changing Climate: Need for Sustainable & Resilient Water Infrastructure

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Water Stress Map (IPCC Technical Report)

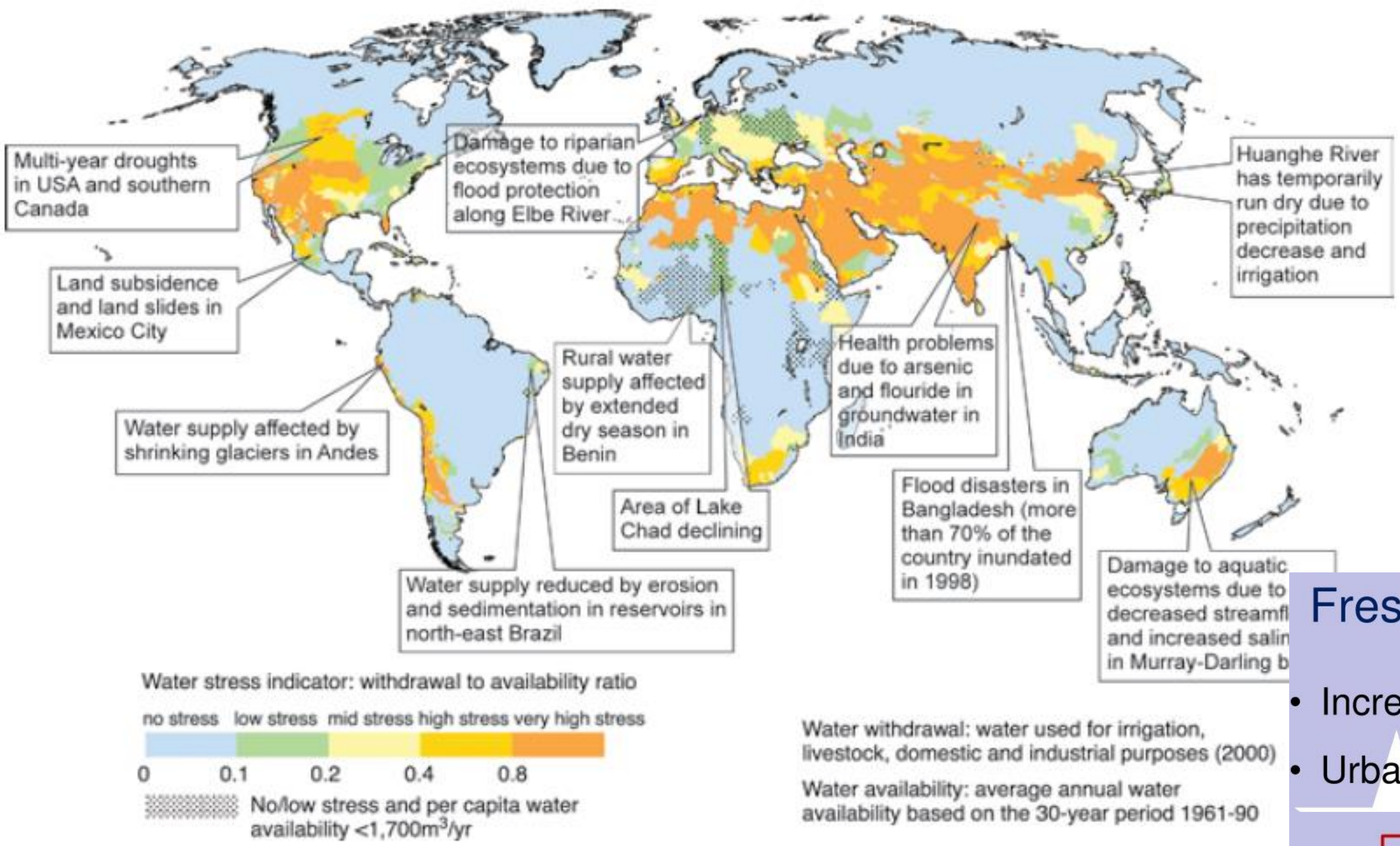
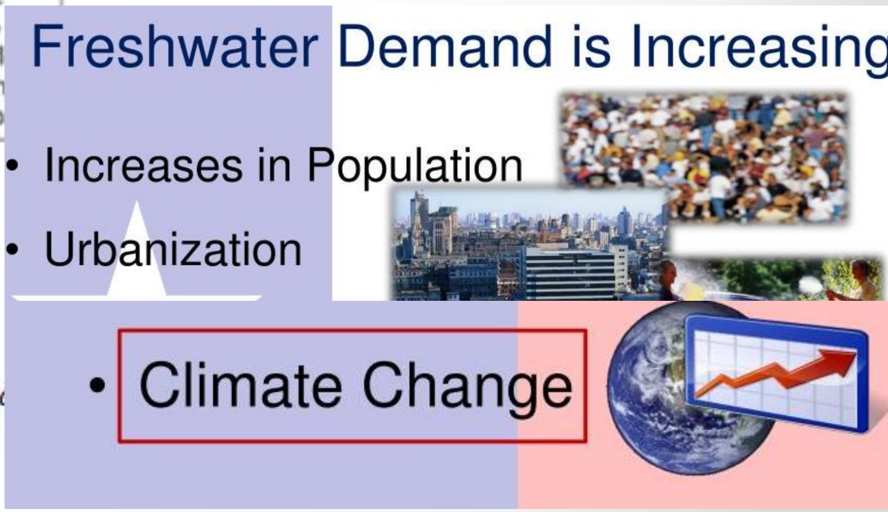
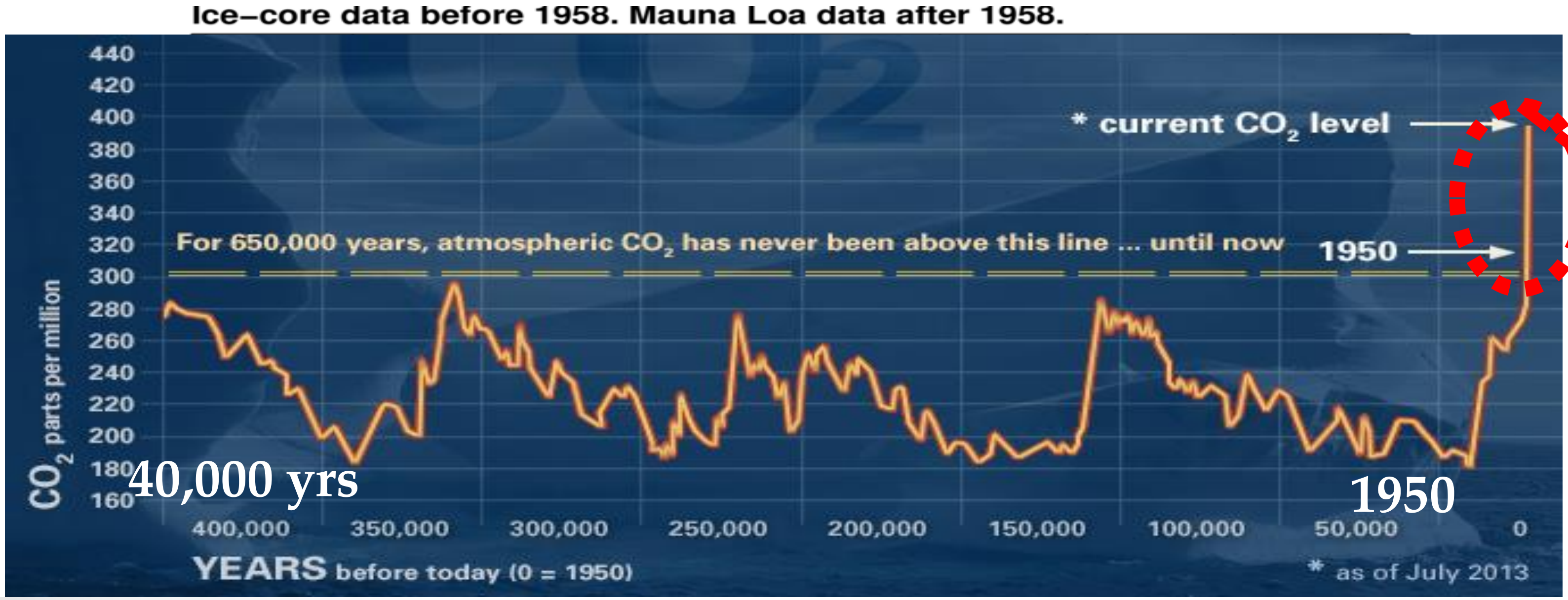
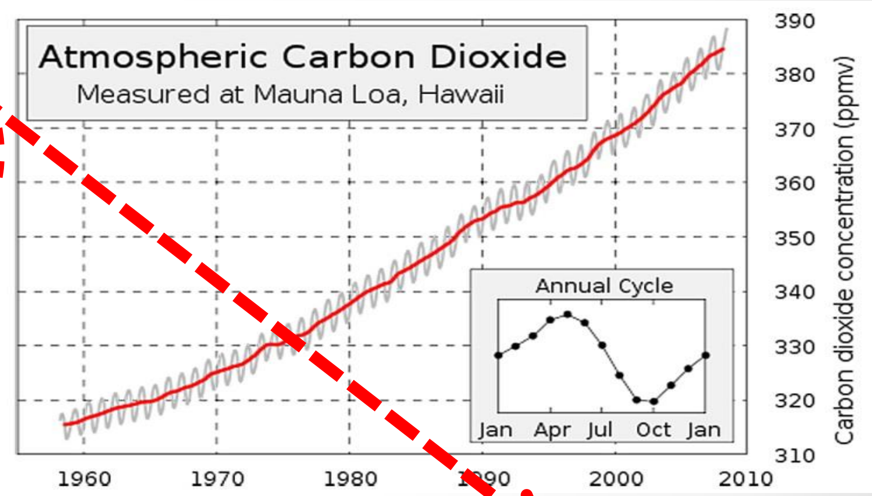


Figure 1.1: Examples of current vulnerabilities of freshwater resources and their management; in the backgroun stress map based on WaterGAP (Alcamo et al., 2003a). See text for relation to climate change. [WGII Figure 3.2]

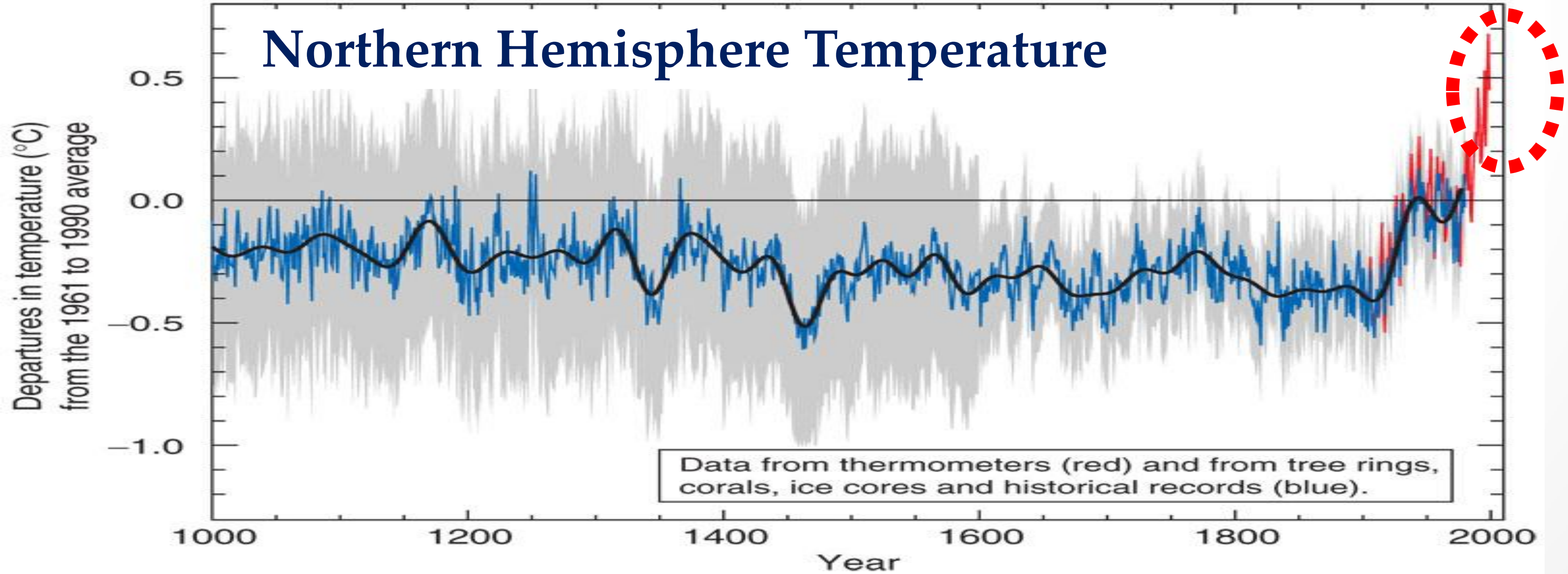


Why we need to worry about climate change ?



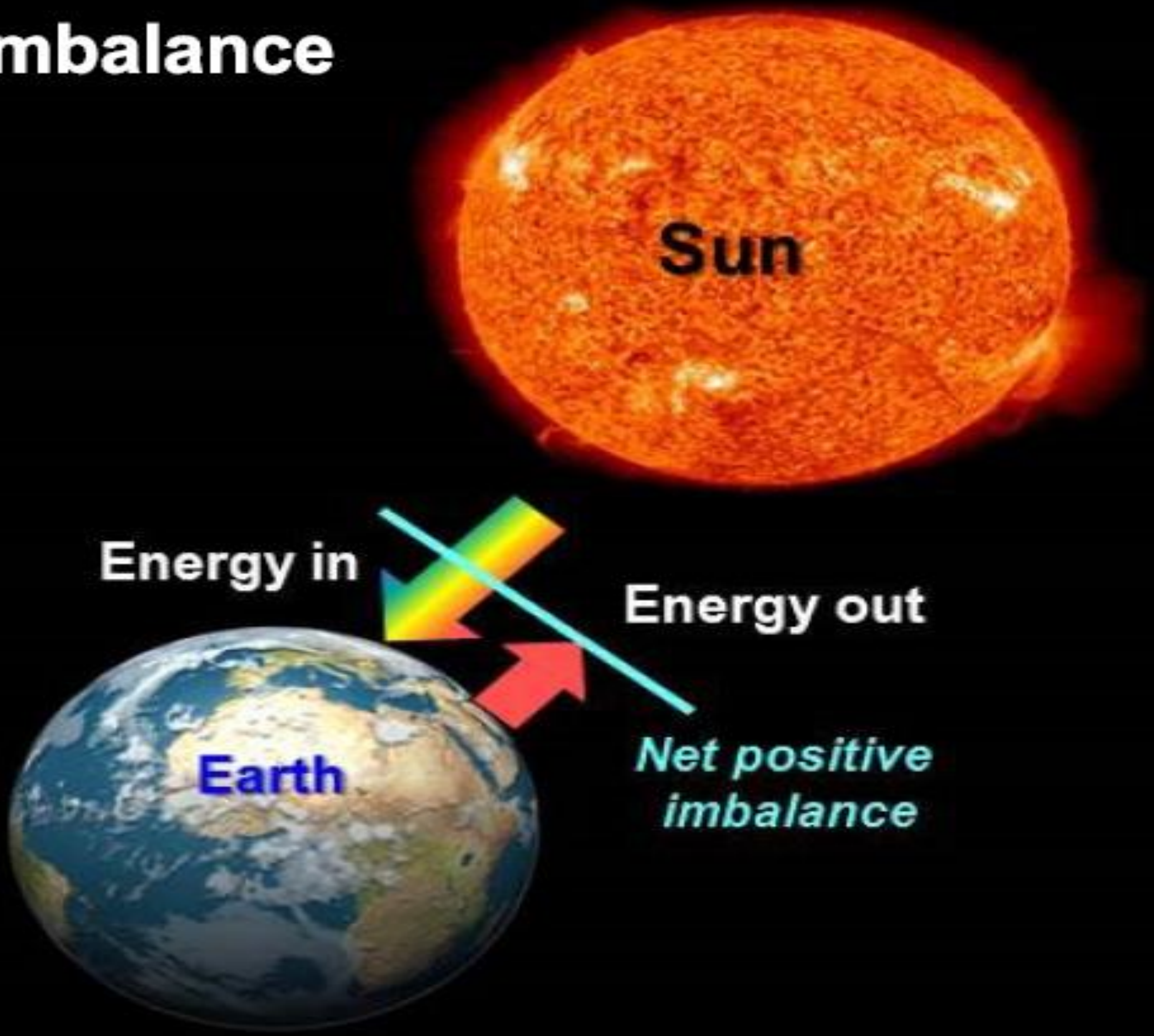


428 ppm
March 2025



CO_2 and temperature are closely linked on geologic timescales

Earth's Energy Imbalance



Today → Energy imbalance
→ 0.5 -1 Wm^{-2}

Average temperature anomaly 2024 *(1850–1900 baseline)*

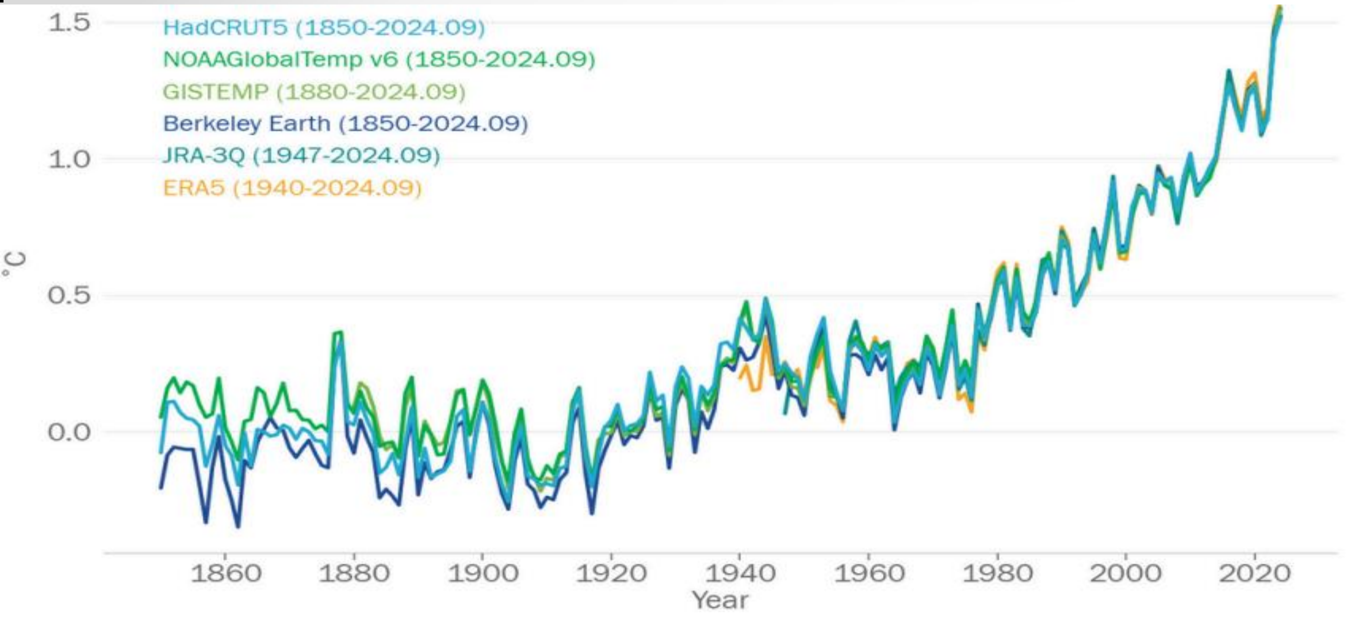


Figure 1: Annual global mean temperature anomalies (relative to 1850–1900) from 1850 to 2024 from six datasets. The 2024 average is based on data from January-September.

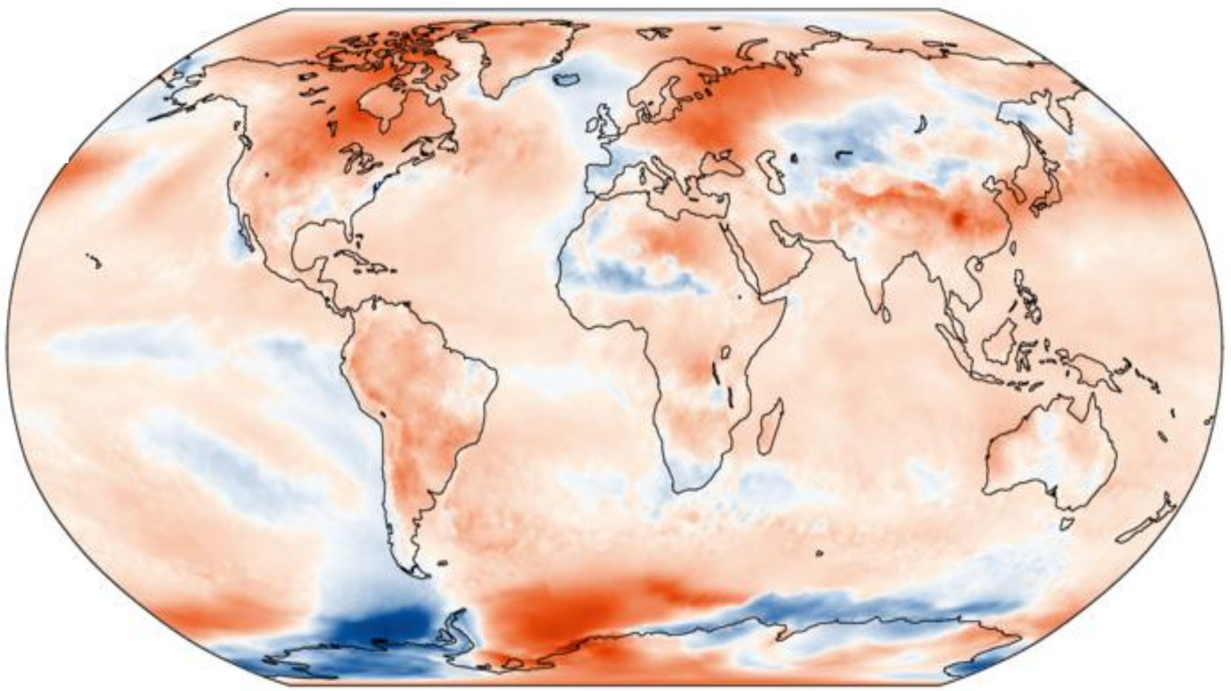
January-September 2024 was 1.54±0.13°C above the pre-industrial average.

Extreme weather and climate events lead to massive economic and human losses

State of the Climate 2024

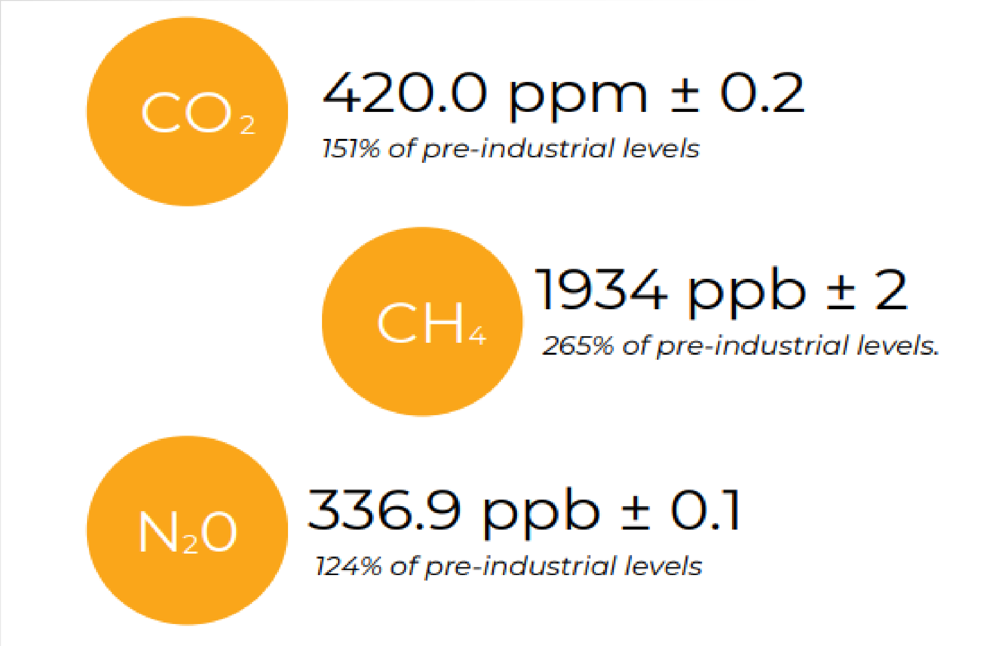
Global Mean Surface Temperature

- **2024 was the warmest year in 175-year observational record.**
- **The past ten years have all been among the warmest on record**
- **Global mean temperature is 1.5°C above 1850-1900 making the year crossing 1.5C**

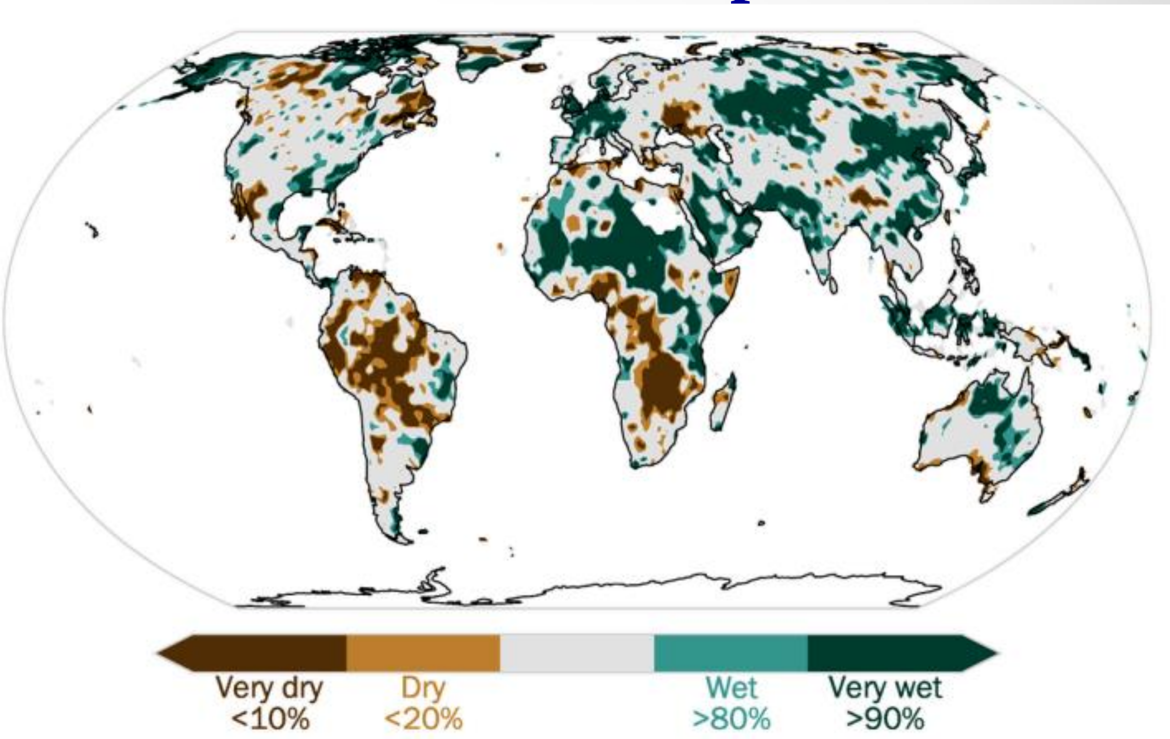


(WMO 2024)

GHG Concentrations



Extreme Precipitation

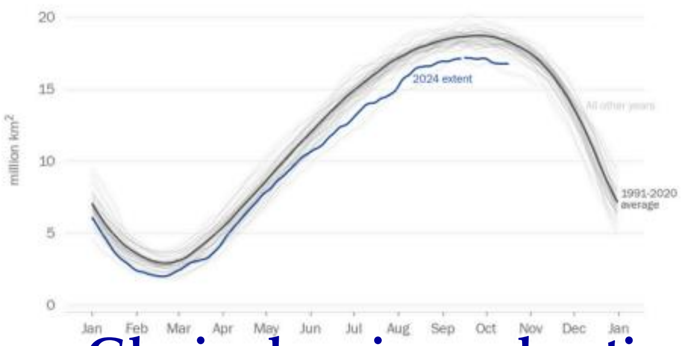


Ocean heat content

Ocean heat content was the highest on record.

Figure 5: Ocean heat content from 1960-2023, shown as a difference from the 2005-2020 average. Source: Miniere et al. 2023.

Antarctic Sea-Ice Extent



Arctic Sea-Ice Extent

Figure 3: Daily Antarctic (top) and Arctic (bottom) sea ice extents in

Glacier loss is accelerating. In 2023, glaciers lost an observed record 1.2 meter water equivalent of ice.

Occurrence of Extreme Events

Heatwaves

Worldwide throughout 2024

There were numerous significant heatwaves in 2024. Particularly affected areas included east Asia, southeast Europe, the Mediterranean and Middle East, the southwestern United States, southeast Asia, northern India, Central America, and West, East, and the Horn of Africa.

Cold Waves & Flooding - Afghanistan

February-May 2024

Abnormal cold and highland snow in late February and early March was followed by several flood events, the worst of which affected Afghanistan between 10 and 17 May.

- Several hundred deaths reported
- Up to 474,224 ha of land flooded
- 115,000 displaced

Wildfires in Canada & Western USA

It was a very active wildfire season in Canada, where the area burned was second only to 2023, and the western United States

- 45,000 displaced in Canada
- 240,000 displaced in USA

North Atlantic Hurricane Season

The United States and Caribbean were badly impacted by a number of major hurricanes in 2024. Beryl in July was the earliest Atlantic category 5 storm on record and affected several Caribbean countries, particularly Grenada and St. Vincent and the Grenadines. Helene in September led to catastrophic flooding in the interior southeast of the United States along with causing major damage at landfall, while Milton in October caused major storm surge, wind and flood damage in Florida.

Europe Floods

September-October 2024

Extreme rainfall impacted a large area of central Europe in mid-September. 5-day rainfall totals exceeding 400 mm occurred in northern Austria, eastern Czechia and southwestern Poland, far above previous records at many locations. In Spain, more than 150 casualties were reported as a result of flash flooding.

Drought - Americas

Drought affected many parts of the Americas; severe drought in Mexico and parts of central America in 2023 persisted into the early months of 2024, while there was also significant drought in much of interior South America. The Paraguay River at Asuncion reached record low observed levels in September, as did a number of rivers in the Amazon basin.

- In Mexico, a 20-40% reduction in corn production was estimated directly due to drought

Flooding - Sahel

September 2024

An abnormally active monsoon brought major flooding to many parts of the Sahel, including Chad, Mali, Niger and Nigeria.

- 716,473 people affected
- In Mali, 113,619 ha of cropland flooded.
  In Nigeria, 204,803 ha affected.
- Chad ≈ 1 million displaced & 40,000 refugees affected
  Mali ≈ 26,000 displaced
  Nigeria ≈ 366,000 displaced
  Cameroon ≈ 50,000 refugees affected

Typhoon Yagi

September 2024

The most significant tropical cyclone of 2024 to date in terms of impact was Typhoon Yagi in early September. Post-landfall flooding had major impacts on Vietnam, the Lao PDR, Thailand and Myanmar, while significant wind damage occurred in China and the Philippines.

- 233 deaths in Vietnam
- In Myanmar, resulting floods and landslides damaged agricultural lands and road networks, disrupting the food value chain.
- >1,580,000 displaced

Wildfires in Chile

2-3 February 2024

A fire around the city of Vina del Mar on 2-3 February resulted in over 14,000 properties affected, amongst the worst losses in a global wildfire this century.

- >130 deaths
  40,000 affected
- >3000 displaced

Flooding - Brazil

May 2024

Persistent heavy rainfall in Rio Grande do Sul state of southern Brazil resulted in flooding which inundated large parts of the city of Porto Alegre and many surrounding areas. Economic losses of several billion US dollars were reported.

- >180 deaths
  2.3 million affected
- Impacts on storage and transport had negative effects on rice commercialization. Artisanal fishing activities along the Patos Lagoon, were particularly affected.
- 630,000 displaced

Drought- Northwestern & Southern Africa

Early 2024

Dry conditions in what is usually the wet season in late 2023 and early 2024 resulted in significant drought in northwestern Africa and many parts of interior southern Africa. Combined with conflict, this led to a surge in displacement, disease outbreaks and food shortages

- In Zambia, cereal production is estimated to have fallen by 42 % in 2024 compared to the previous five-year average.

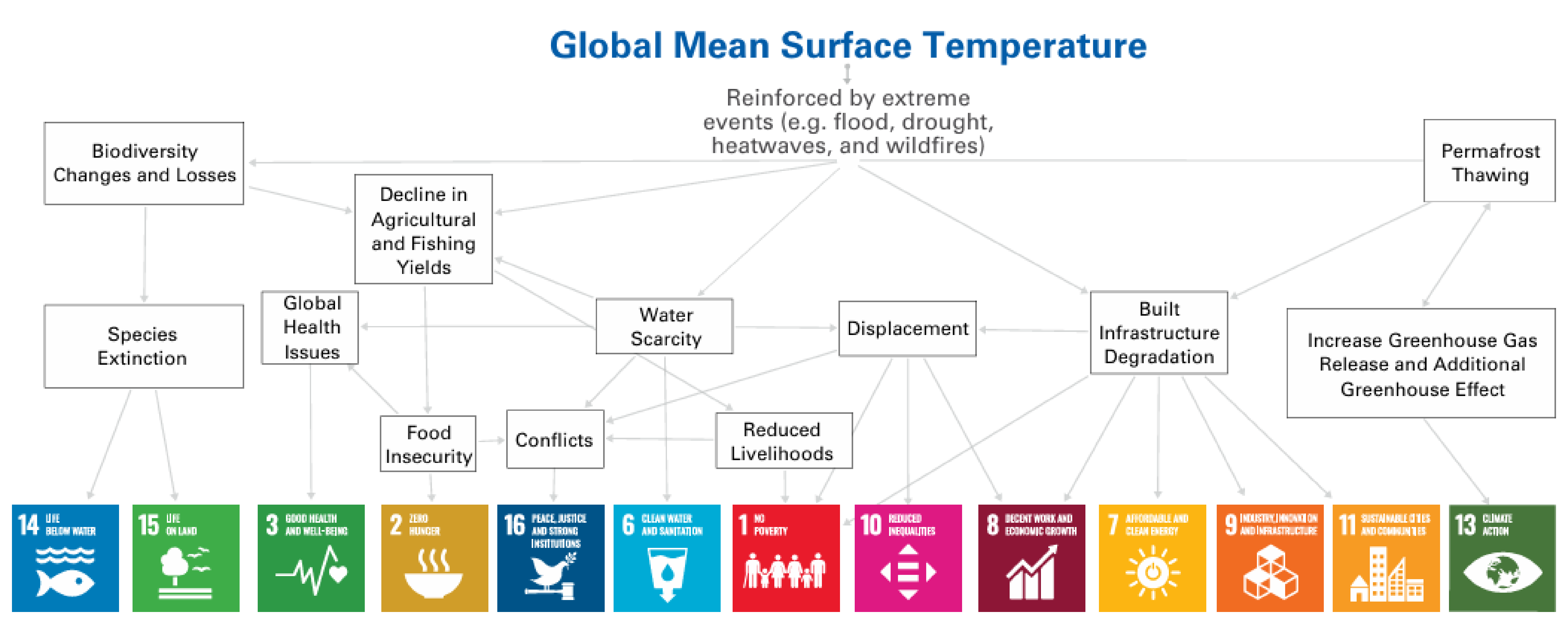
Flooding - East Africa

March-May 2024

Floods impacted equatorial east Africa, with major loss of life in countries including Kenya and Tanzania, and Lake Victoria reaching record high observed levels.

- >11,000 livestock deaths >25,000 ha of cropland destroyed in Kenya.
  ≈ 3.4 million people facing severe acute food insecurity in Somalia.
  Intensified severe acute food insecurity ≈ 15.8 million people in Ethiopia.
- 500,000 displaced across Somalia, Burundi, Tanzania and Kenya.

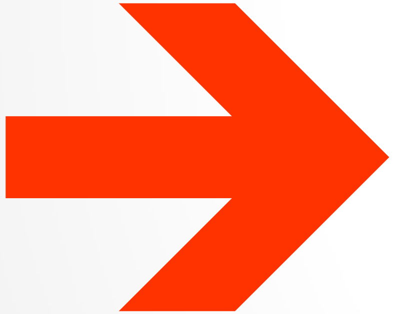
Associated Risk of Increased Surface Temperature and SDG

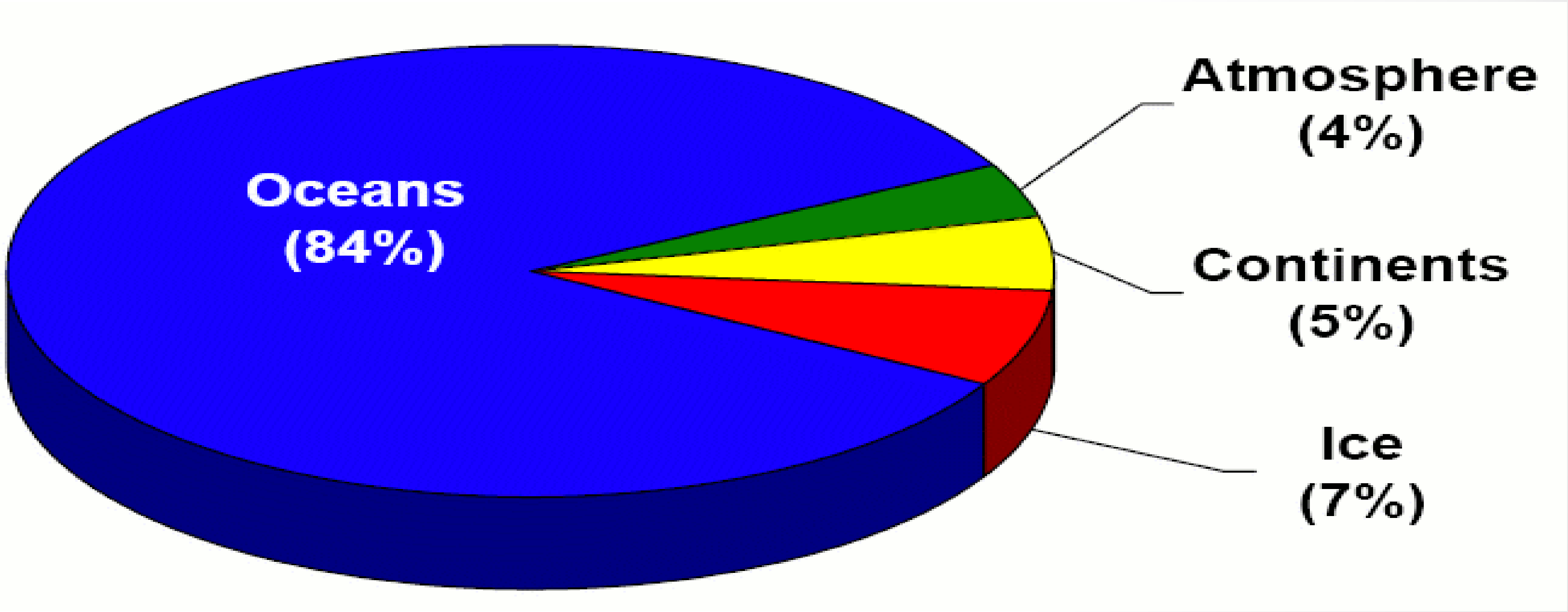


Oceans the largest absorber of heat

Amount of Heat Absorbed by Parts of Earth Climate System Over Past 40 Years

Net Heat Input to Earth System





> 90% -- Saved By The Oceans!

(Levitus et al. 2021)

Annual Global mean Ocean Temperature Anomaly

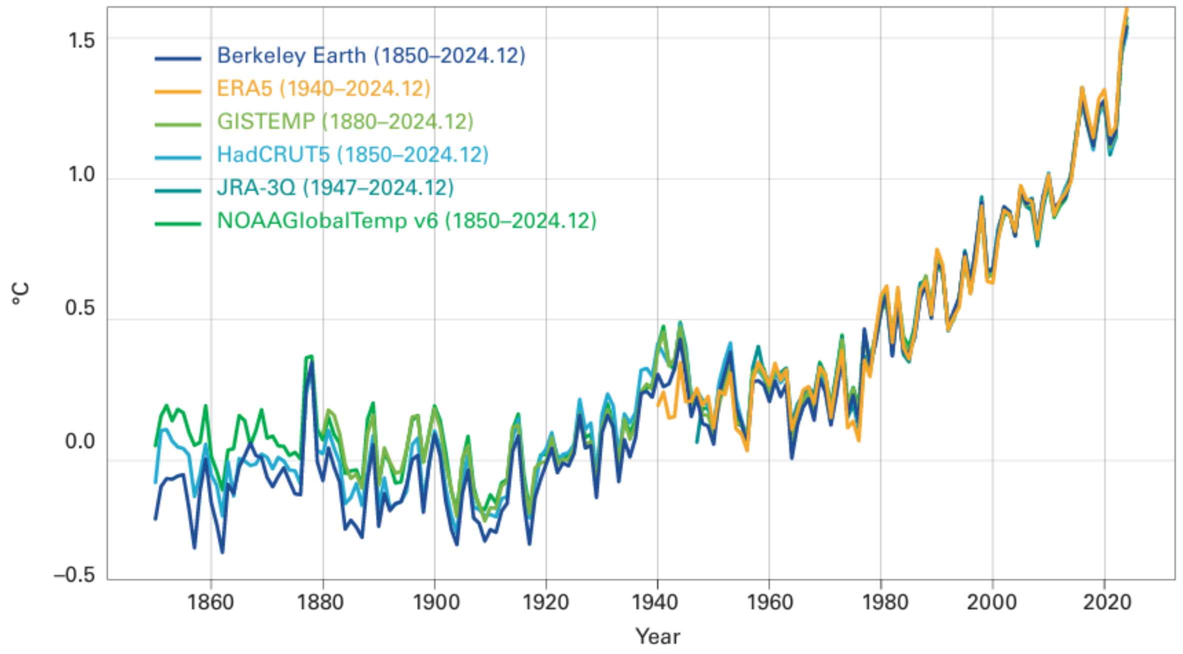


Figure 2. Annual global mean temperature anomalies relative to a pre-industrial (1850–1900) baseline shown from 1850 to 2024

Source: Data are from the six datasets indicated in the legend. For details see Datasets and methods.

Ocean heat content Anomaly

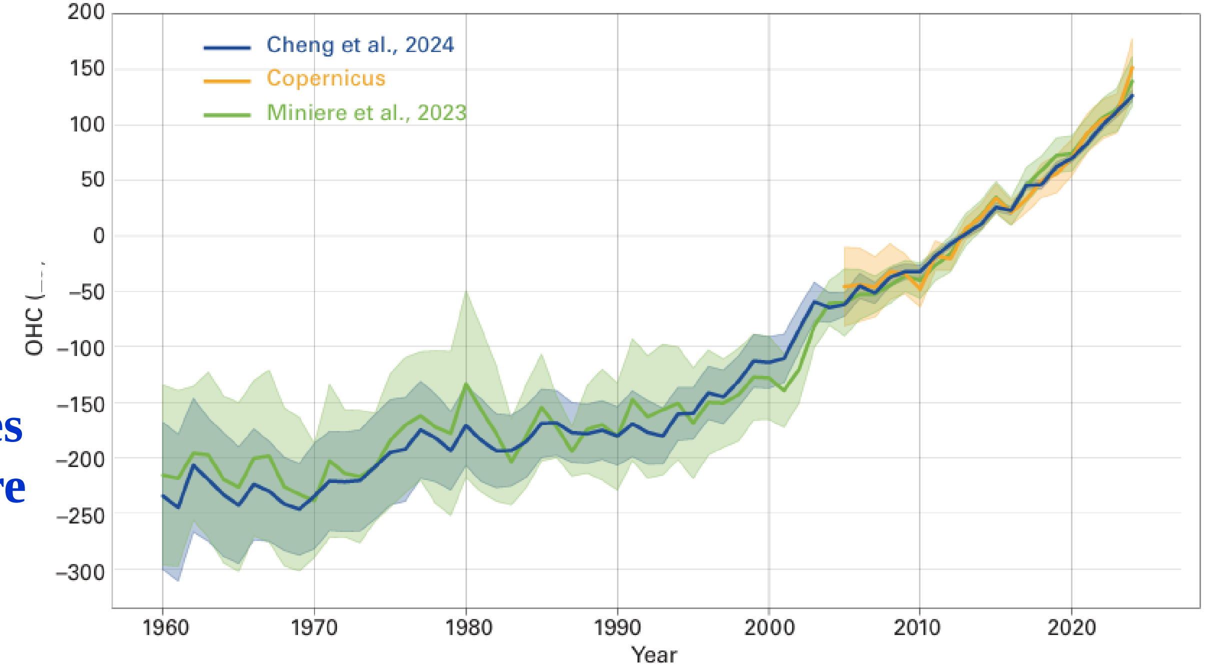
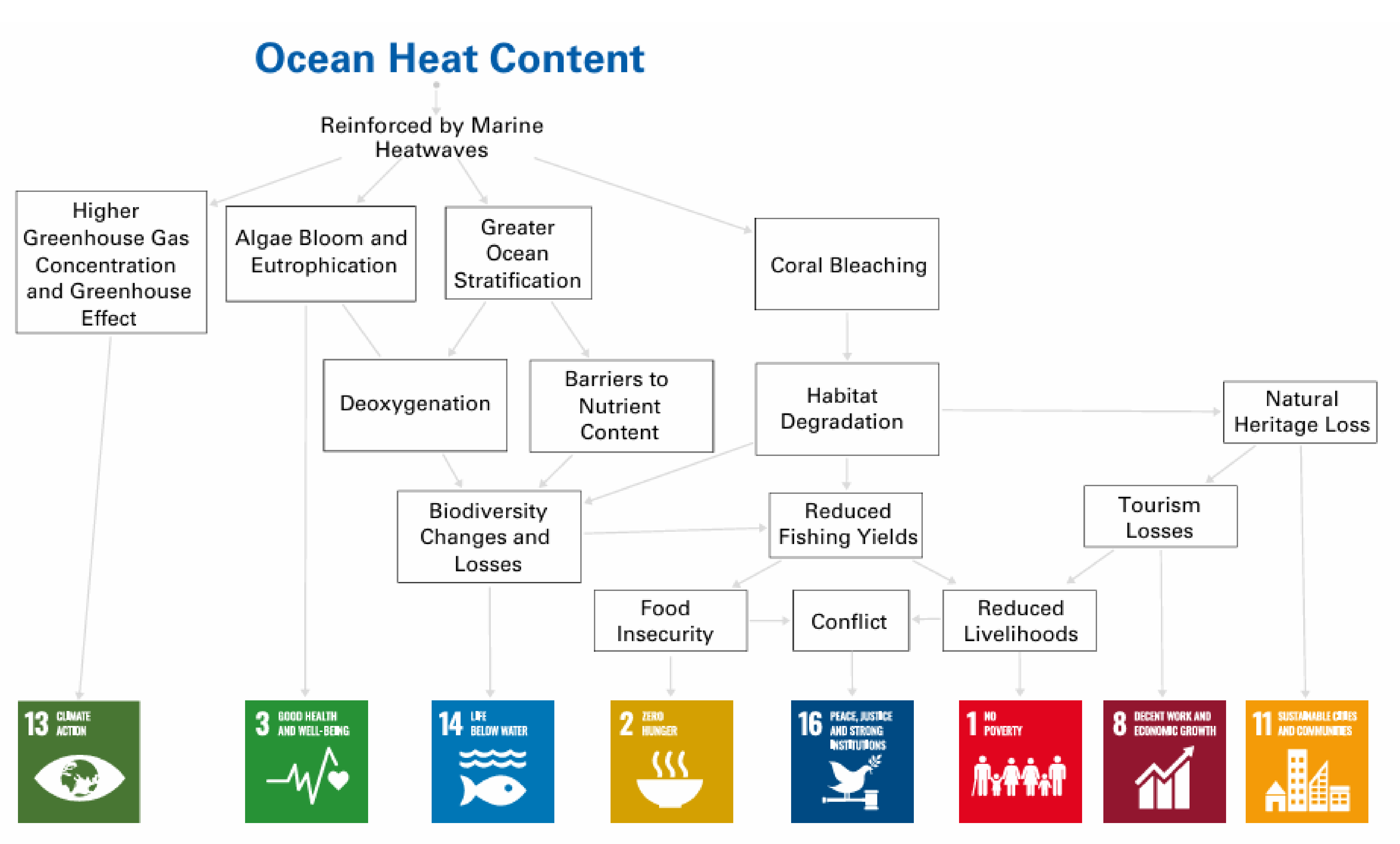


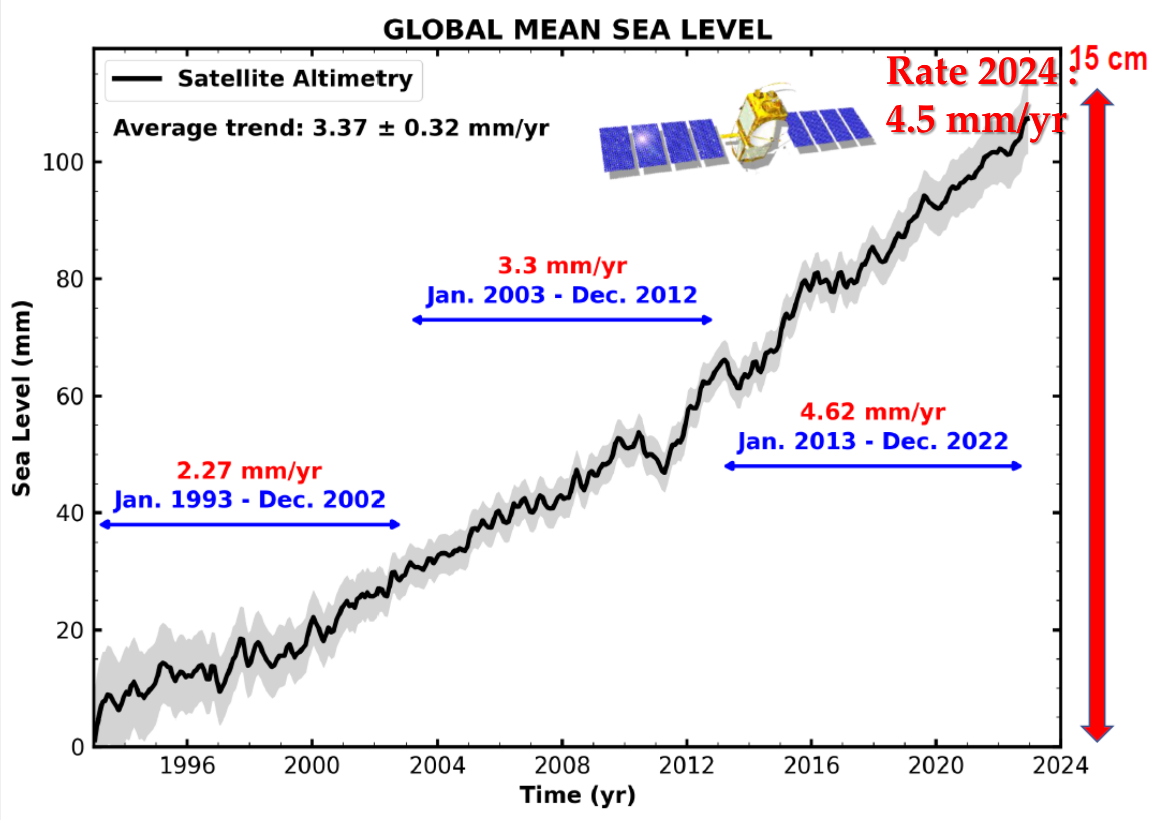
Figure 3. Annual global ocean heat content down to 2000 m depth for the period 1960–2024, in zettajoules (10^{21} J). The shaded area indicates the 2-sigma uncertainty range on each estimate. For details see Datasets and methods.

- The rate of ocean warming over the past two decades (2005–2024) is 0.99–1.07 W m–2 per year and is more than twice that observed over the period 1960–2005

Associated Risk of Increased Ocean Heat Content and SDG

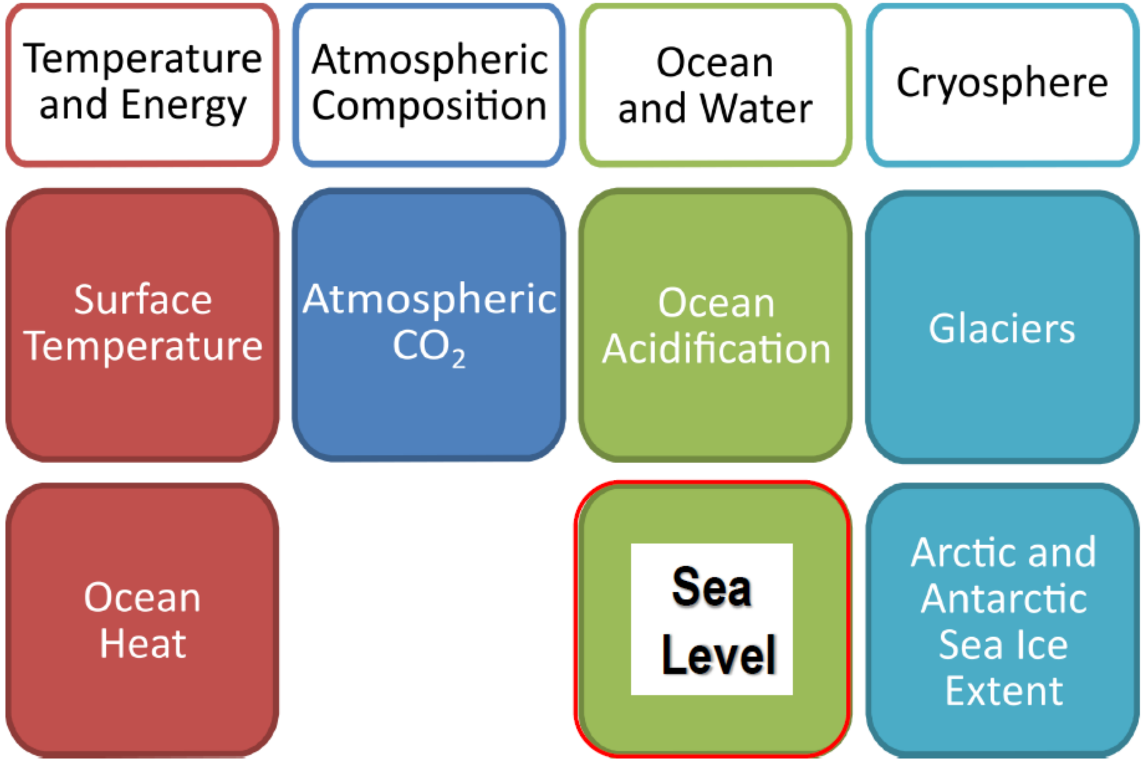


Global Mean Sea Level Rise



Source LEGOS

The 7 global indicators of present-day climate change



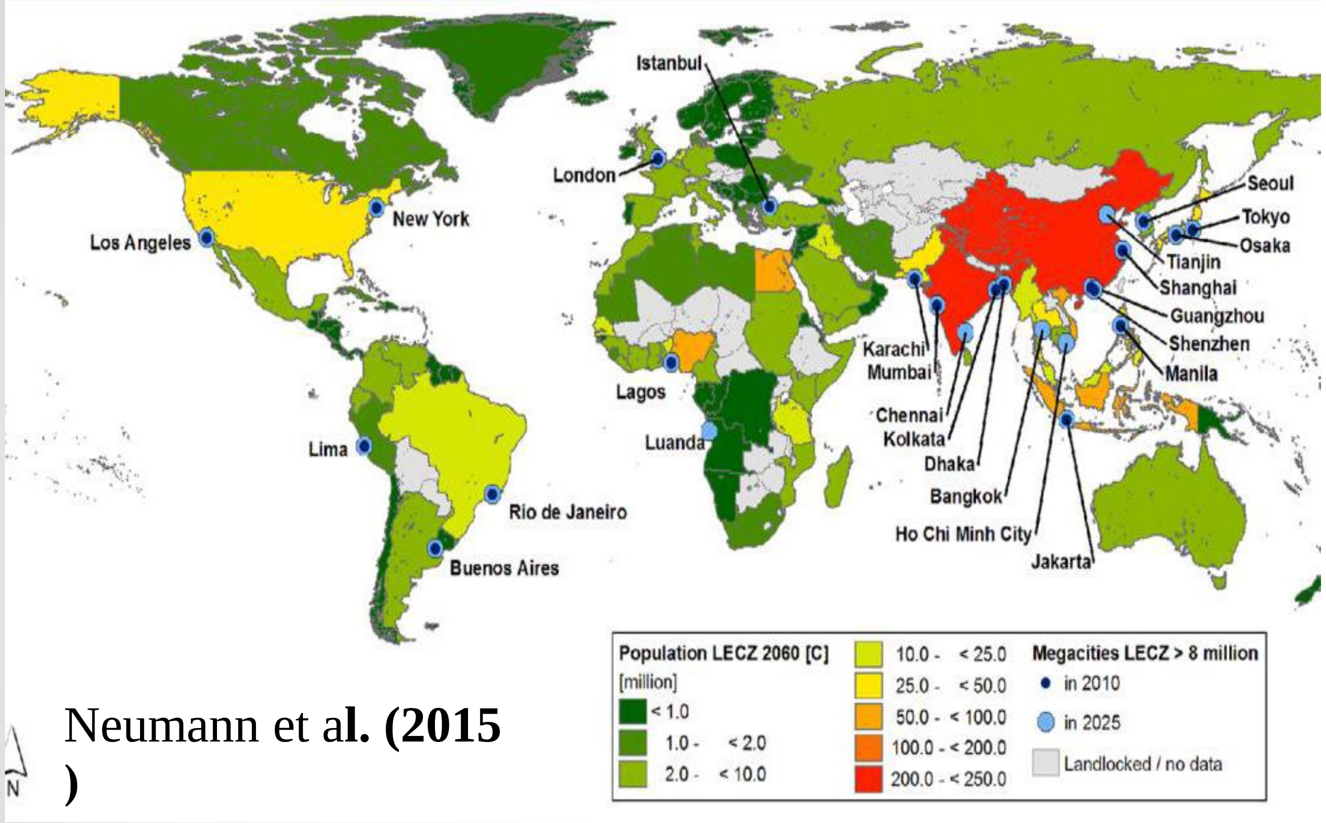
GCOS GLOBAL CLIMATE OBSERVING SYSTEM

defined by GCOS (Global Climate Observing System) and WMO (World Meteorological Organization)

WORLD METEOROLOGICAL ORGANIZATION

… A leading indicator of global climate changes
→integrated response to changes in ocean heat content, in land ice & land water storage to external forcings and internal variability
With extreme events, future sea level rise will be a major threat for many low-lying and highly- populated coastal regions of the world

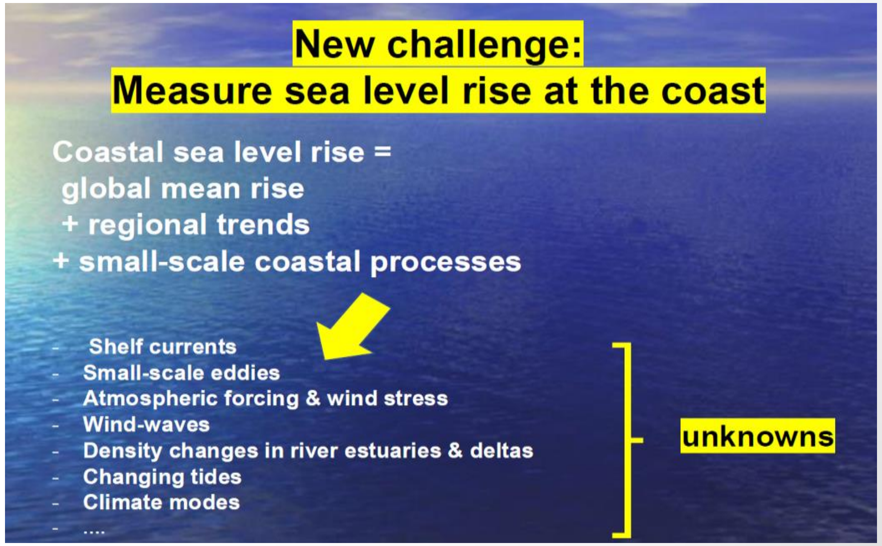
Why sea level rise study important ??



Neumann et a**l. (2015)**

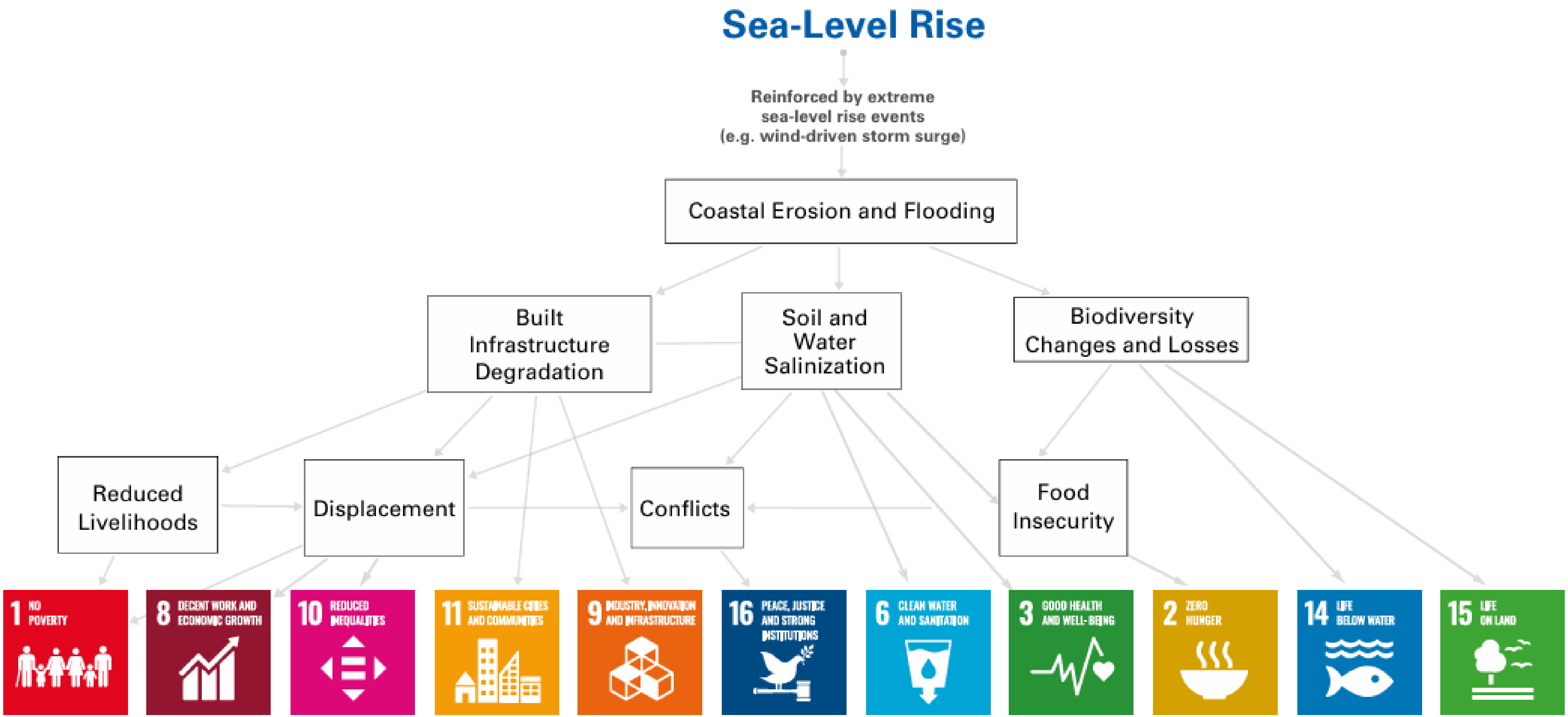
The world's coastal population

- Population projections for 2060.
- Up to 12 per cent of the global population is living in the LECZ:
- One third of Indian population and the majority of the Asian population are located near coastal regions

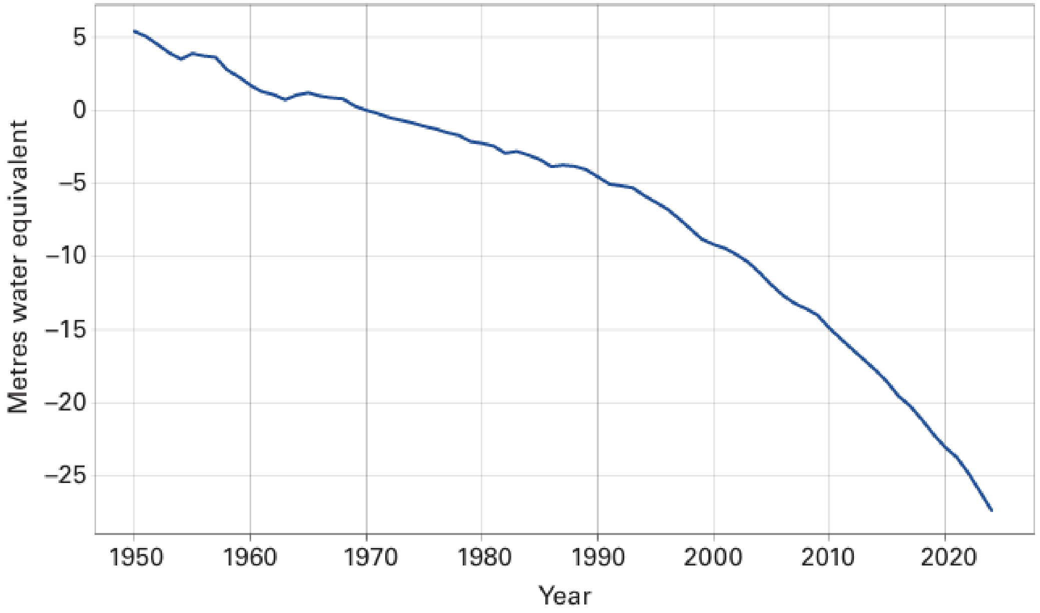


High population density => High climate related risk

Associated Risk of Increased Sea Level and SDG

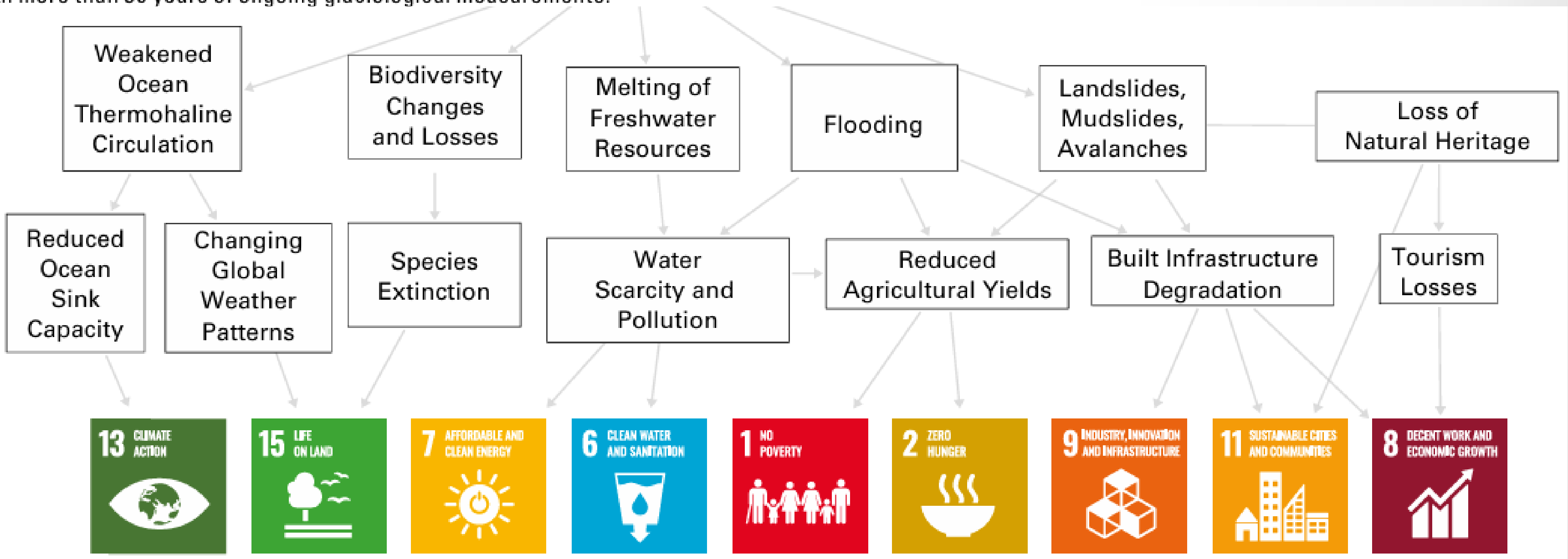


Glacier mass balance

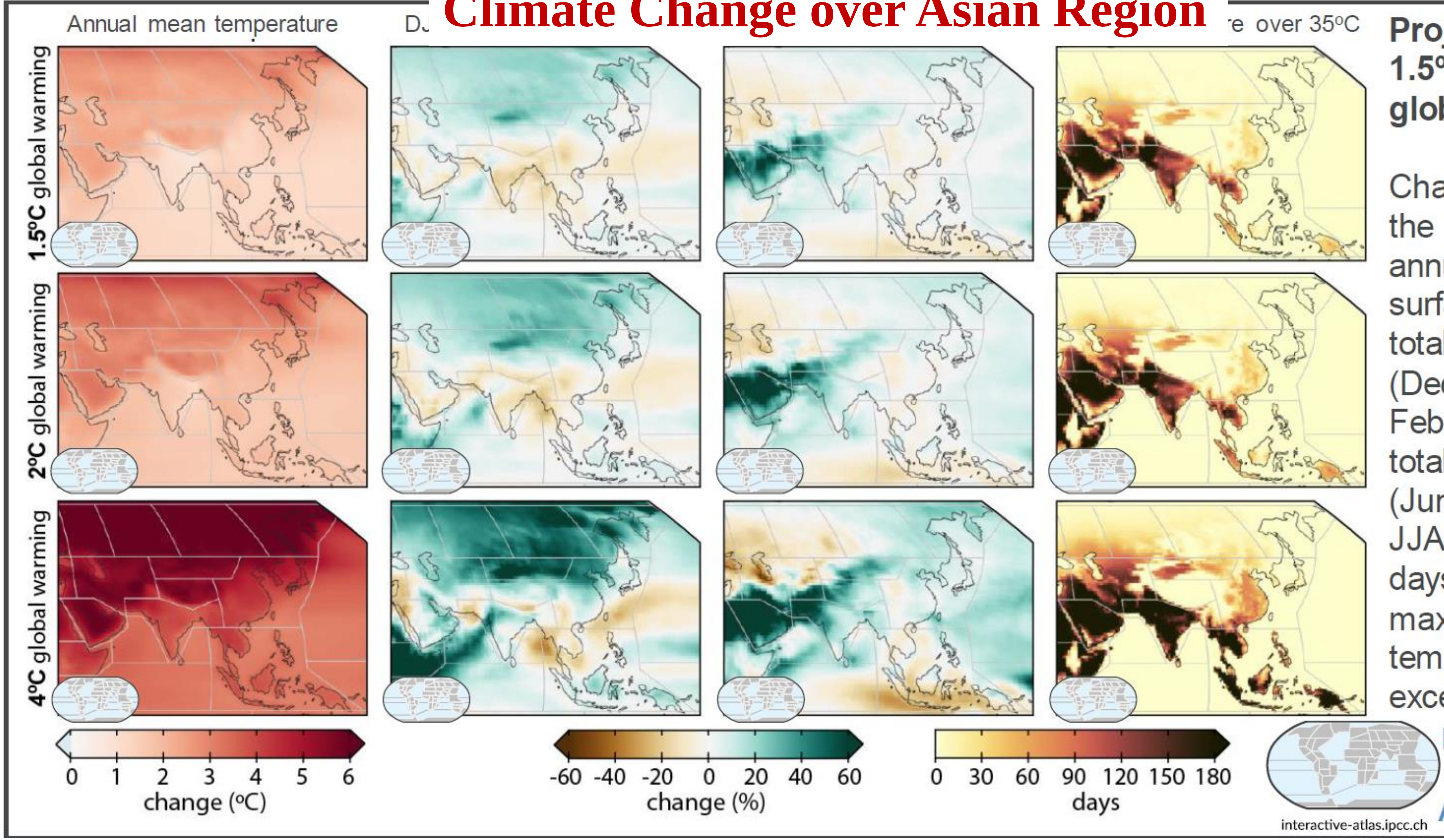


Associated Risk of Increased GMB

Figure 6. Cumulative annual mass balance of reference glaciers with more than 30 years of ongoing glaciological measurements. Annual mass change values are expressed in metres water equivale (1 000 kg m^{-2}). The 2024 value is preliminary. For details see Datase



Climate Change over Asian Region

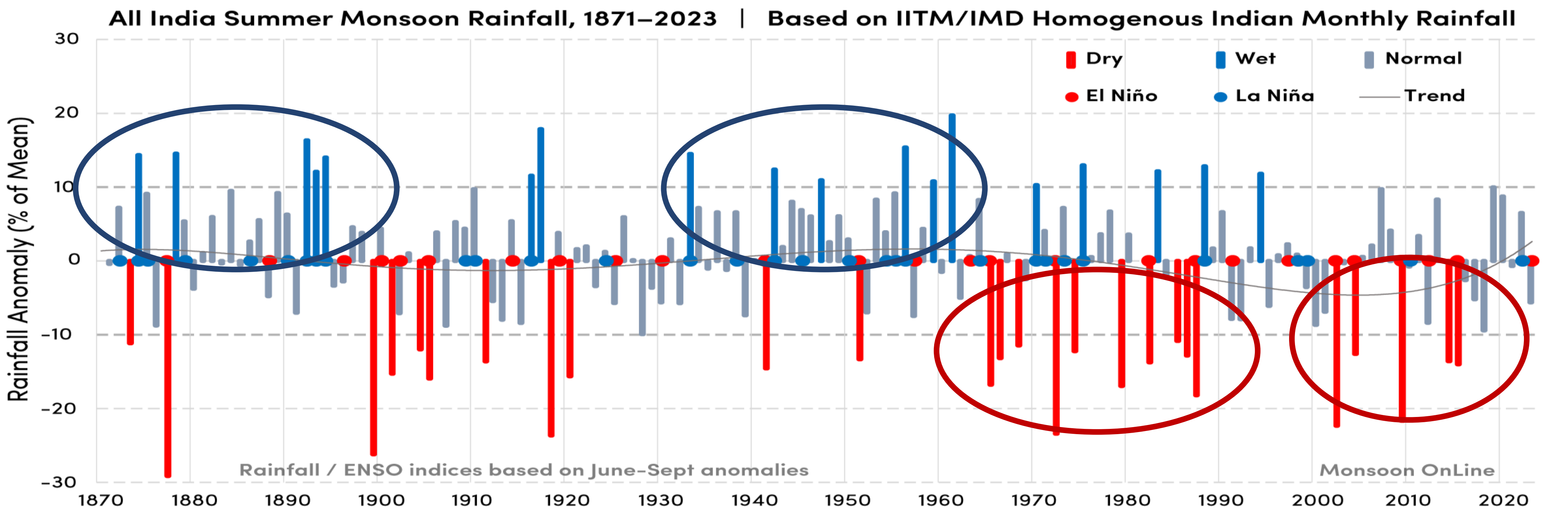


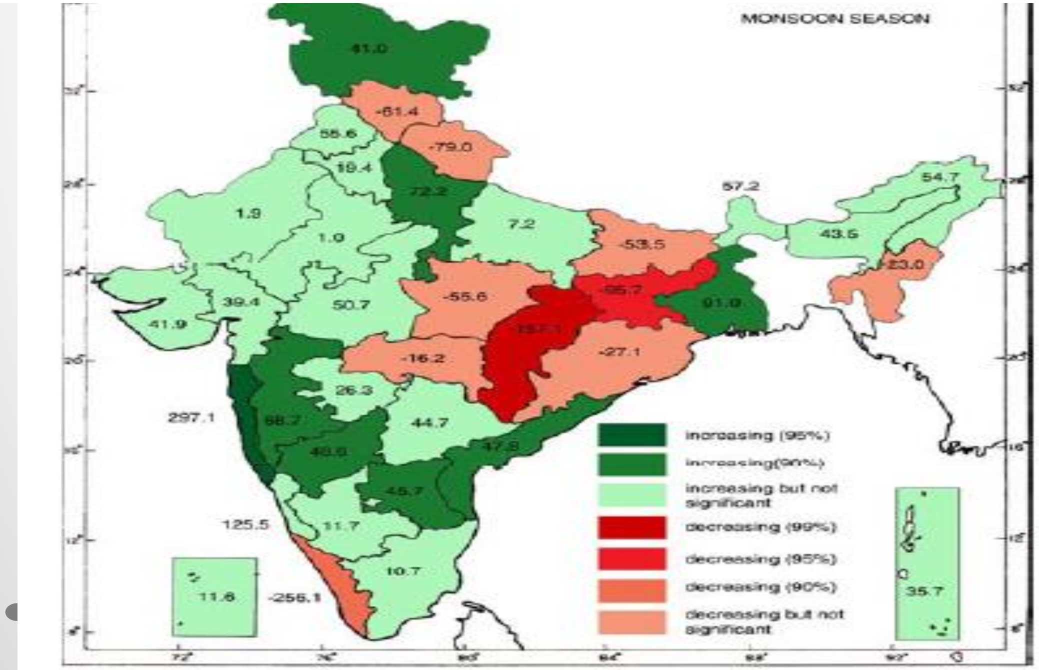
Projections at 1.5ºC, 2ºC, and 4ºC global warming

Changes relative to the 1850-1900 in annual mean surface temperature; total precipitation (December to February, DJF); total precipitation (June to August, JJA) and number of days per year with maximum temperature exceeding 35ºC.

Results expanded in the Interactive Atlas (active links)

interactive-atlas.ipcc.ch





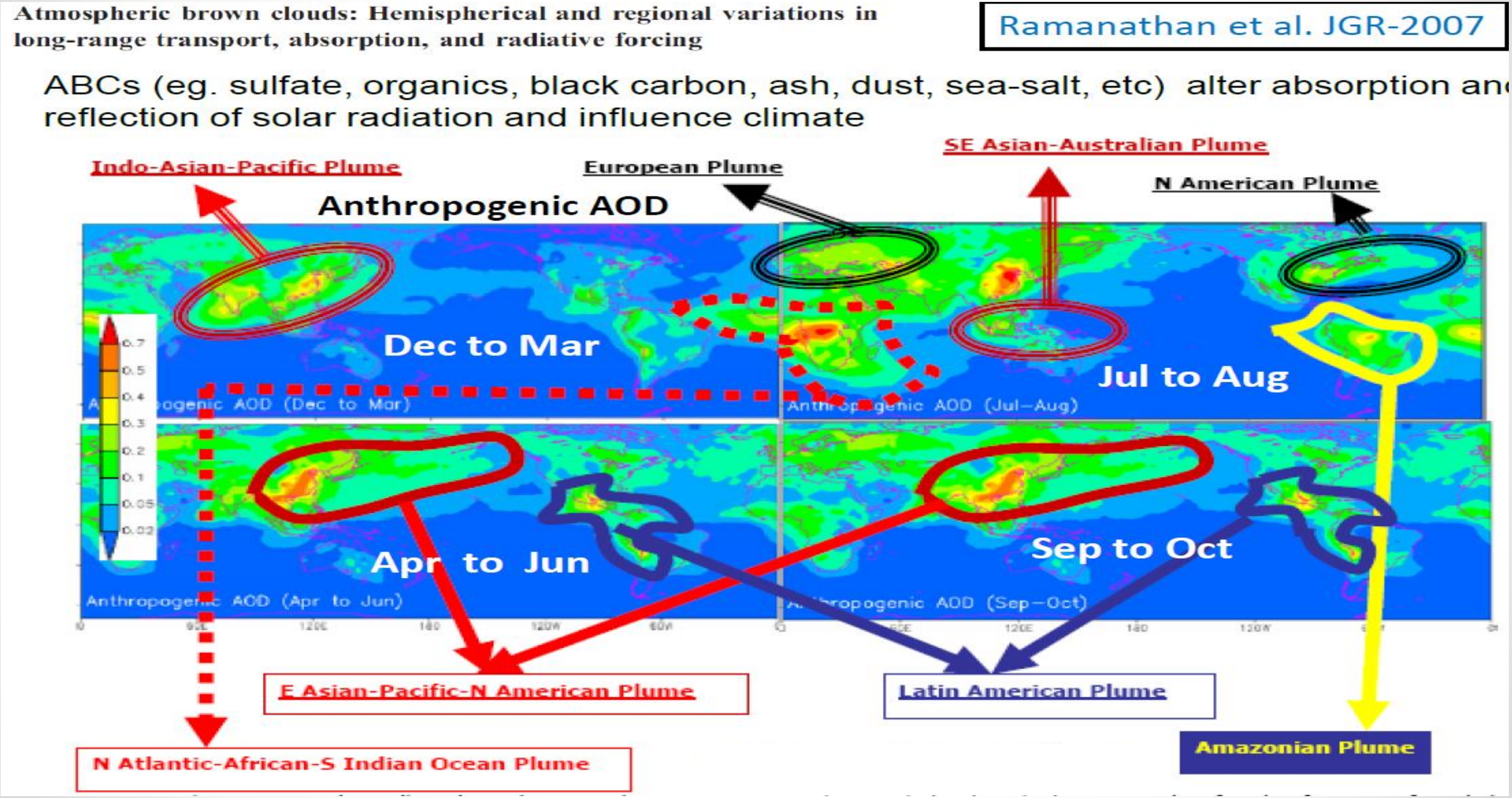
The 142-yr (1871-2023) record of all-India monsoon rainfall indicates increase in the frequency of monsoon-droughts during the second half relative to the first half of the period

Long-term trends in the Indian monsoon rainfall

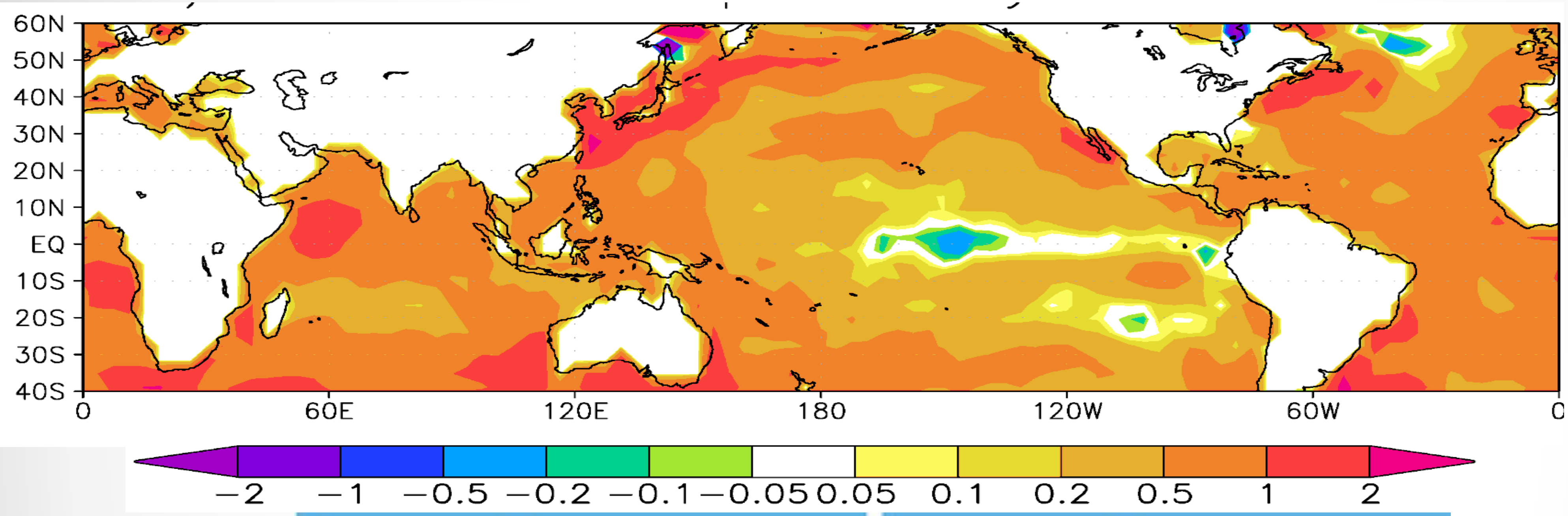
Guhathakurtha and Rajeevan, 2006: Trends in monsoon rainfall over India (1901-2003)

Significant negative trends: Kerala, Jharkhand, Chattisgarh

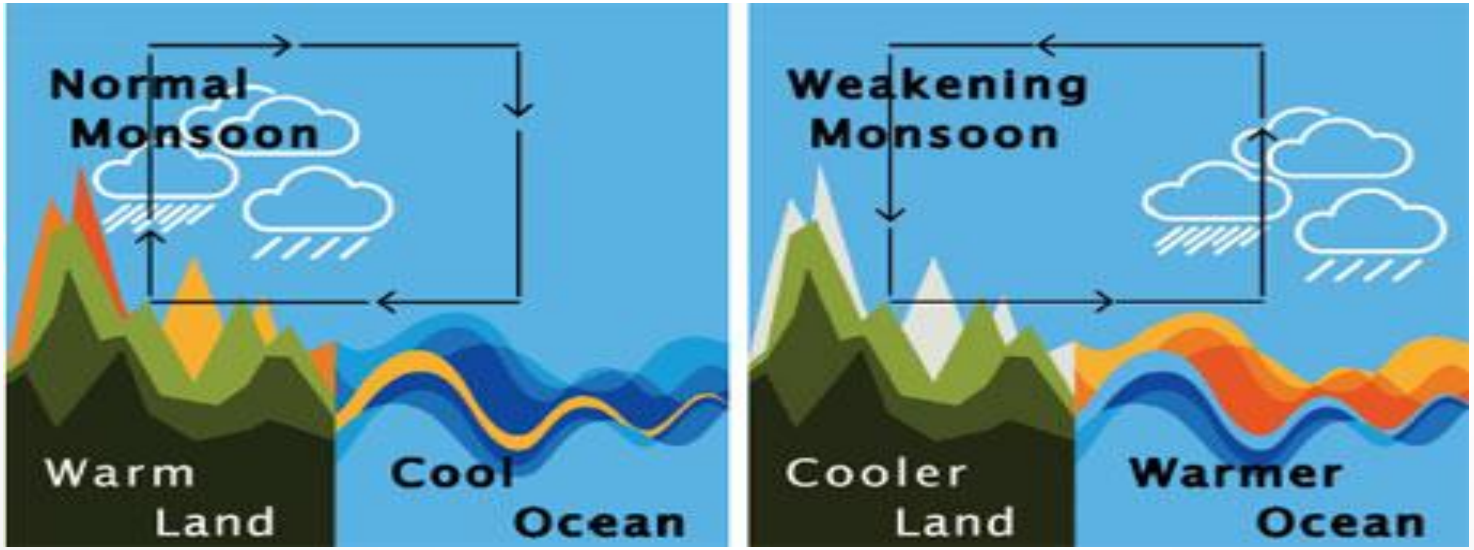
Aerosol and Monsoon



Indian Ocean warming and monsoon weakening

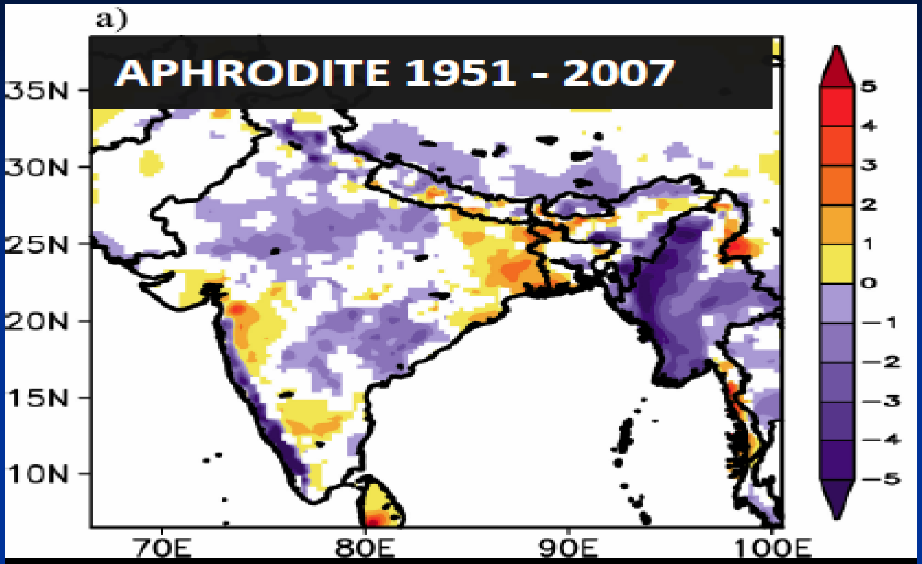


SST trend (1900-2010)

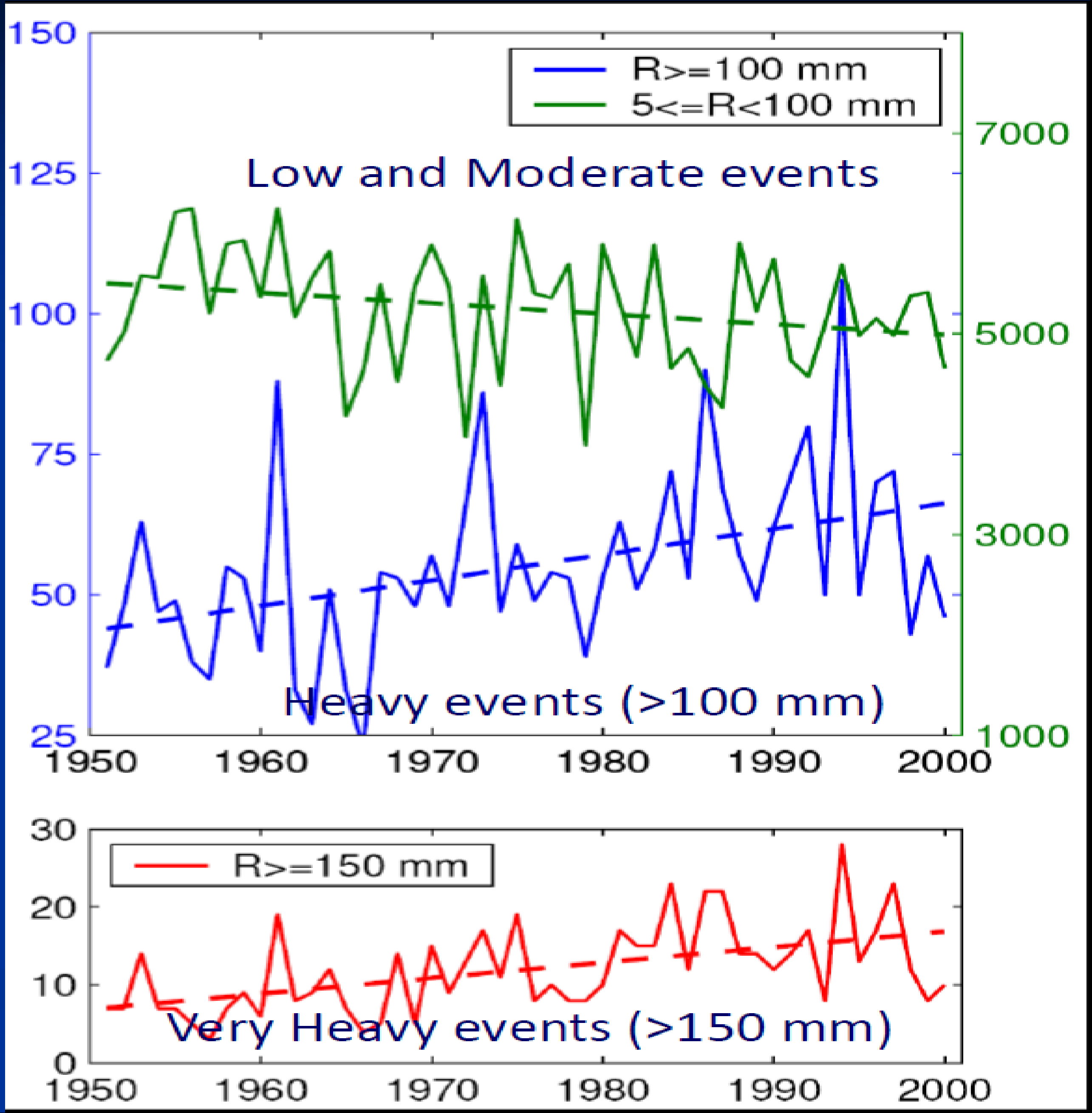


Roxy et al., 2014

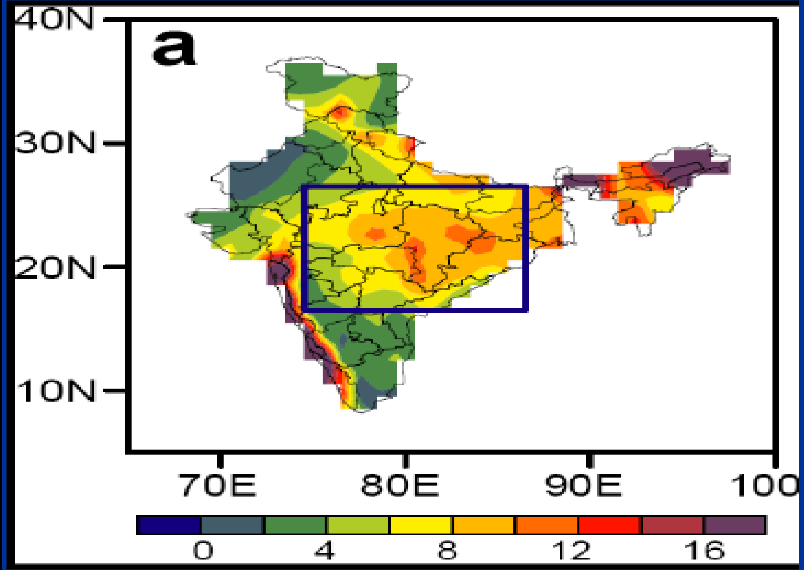
Spatial map of linear trend of JJAS rainfall (1951 – 2007)



Time series of count over Central India

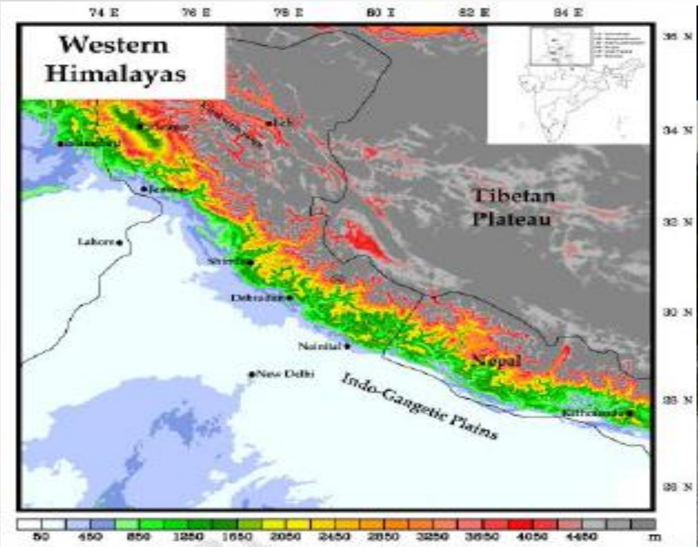


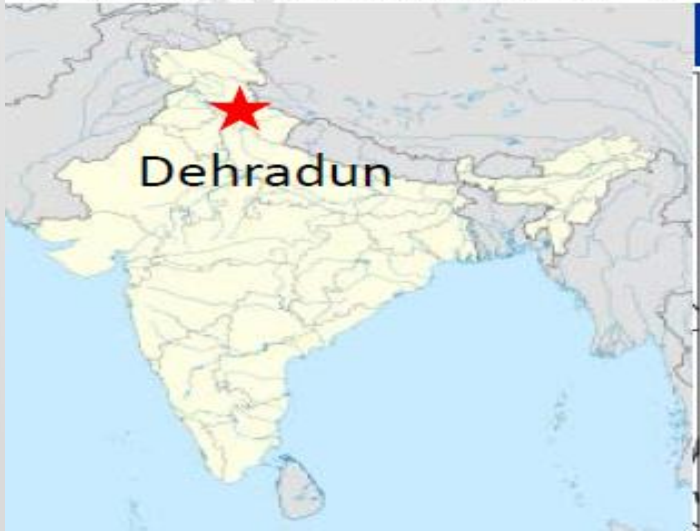
Increasing Trend of Extreme Rain Events over India in a Warming Environment

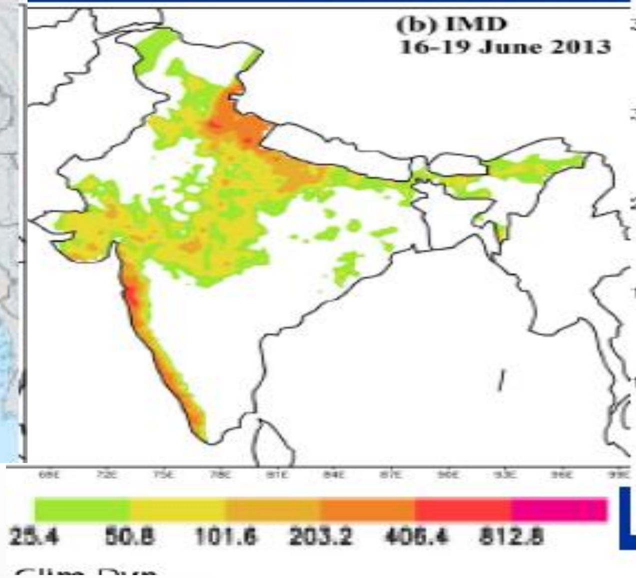


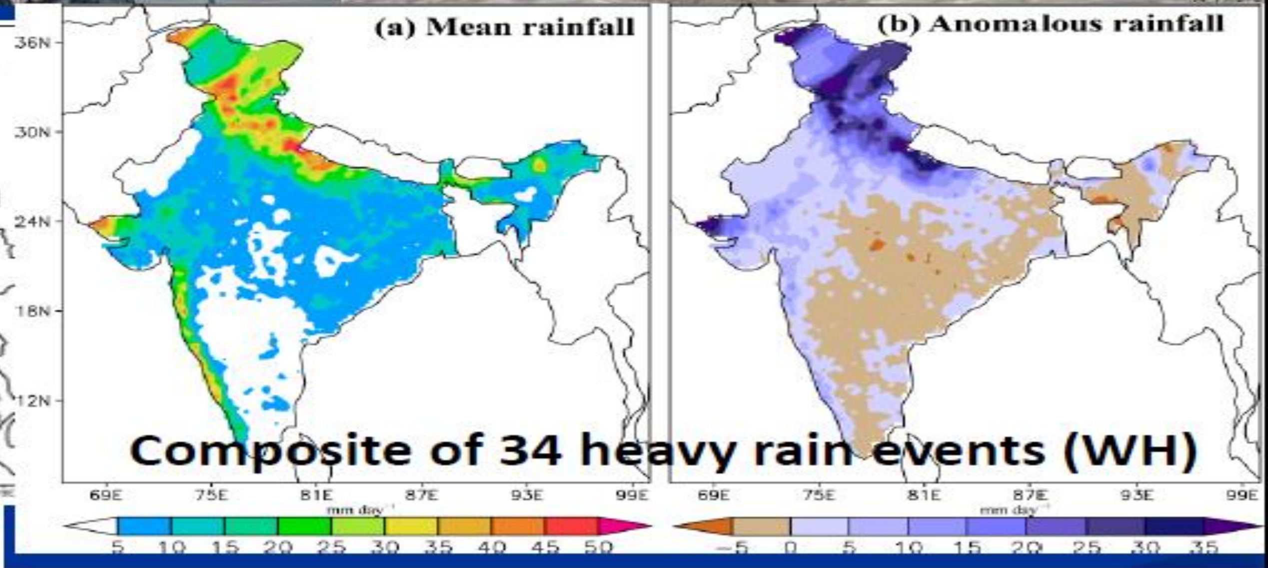
Goswami et al. 2006, Science

Heavy Rainfall Events over India









Kerala Flood and Landslide 2024

Mumbai Extreme Rainfall 2005

On 26-27 July 2005, the city received unprecedented precipitation of 944 mm over 24 h, with 190.3 mm of rainfall in a single hour

On July 30, 2024, Wayanad was hit by a severe cloudburst, resulting in three major landslides within four hours. The epicentre of this disaster, Mundakkai, experienced an extraordinary 572 mm of rainfall over 48 hours.

- **The heavy rain events and resulting urban flooding in cities such as Chennai and Mumbai have been**

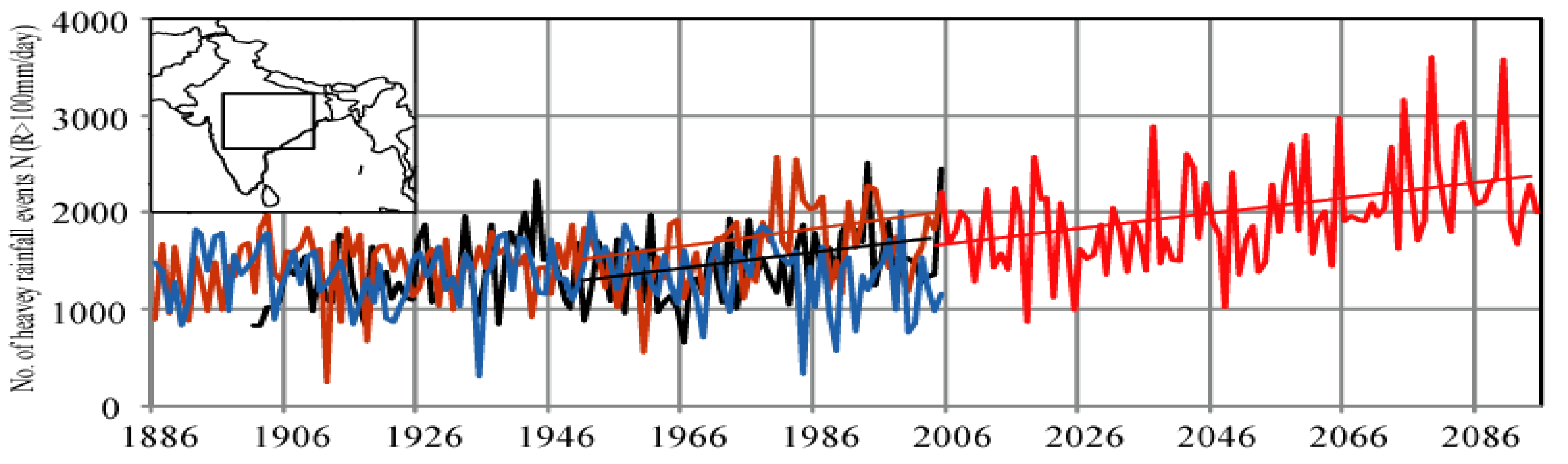
Terminology (Rainfall range in mm)

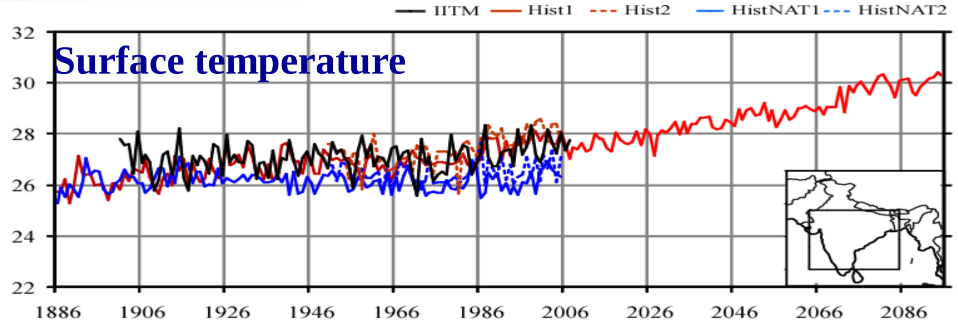
Heavy Rainfall : 64.5- 115.5

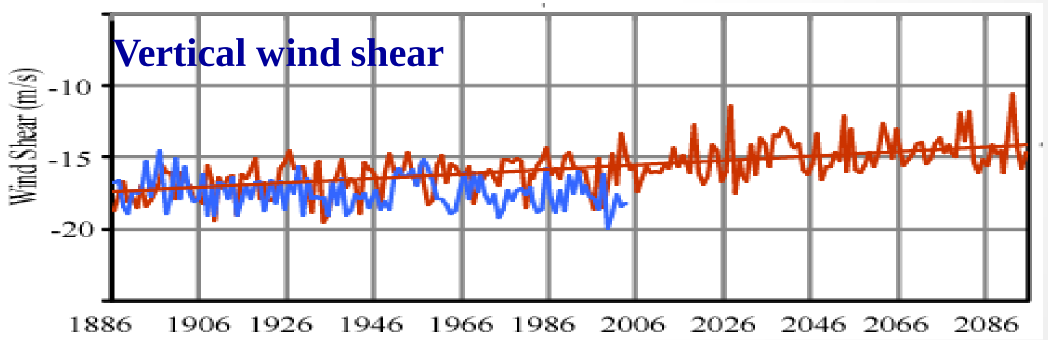
Very Heavy Rainfall : 115.6-204.4

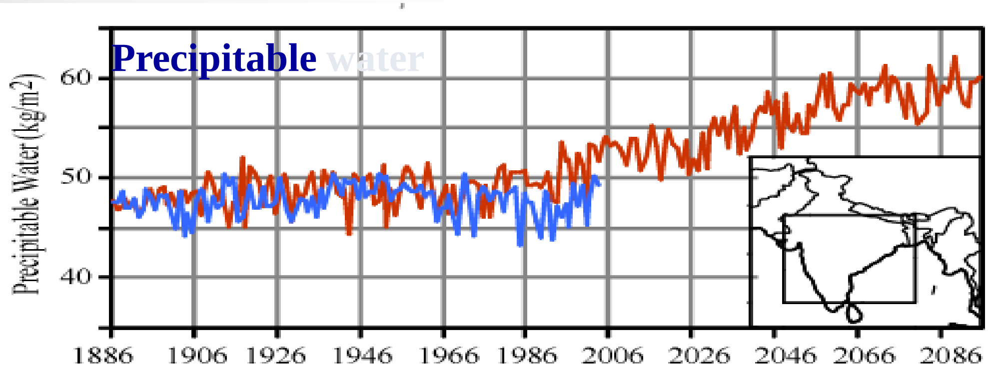
Extremely Heavy rainfall :Greater or equal to 204.5

Time series of extremes in precipitation (>100mm/day over MT region)





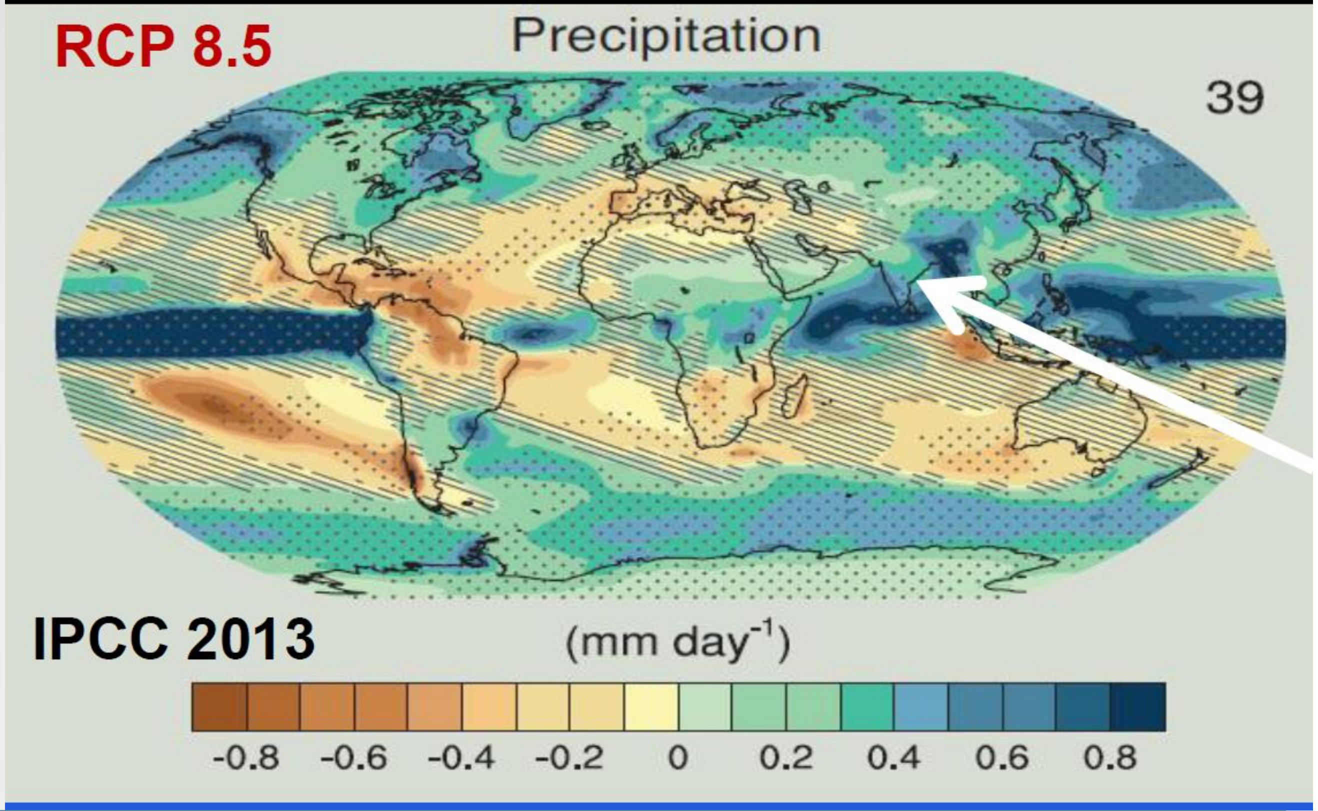




With rising surface temperatures, the simulated atmospheric moisture content over the subcontinent increased substantially by ~24% during 1886-2095. The vertical wind shear reduced nearly by the same amount. Such a weakly sheared environment with high humidity levels favors enhanced localized convection and leads to the increasing frequency of precipitation extremes .

Krishnan et al., 2015

Projected rainfall Change (2081-2100)



Clausius-Clapeyron relation suggest that specific humidity and hence atmospheric moisture would increase roughly exponentially with temperature.
~ 7% per deg C.

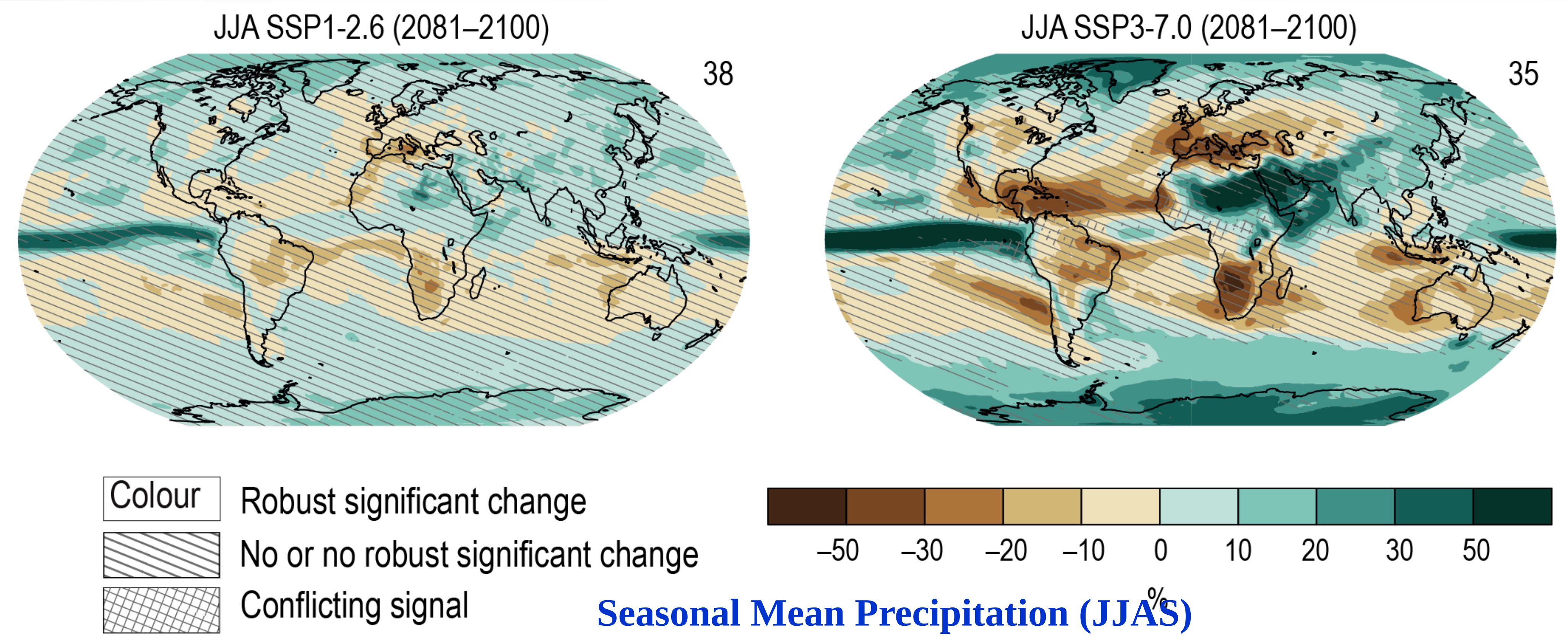
Observations and climate model project precipitation to increase at a rate of 1-3% per deg C.

The Water Vapor Feedback

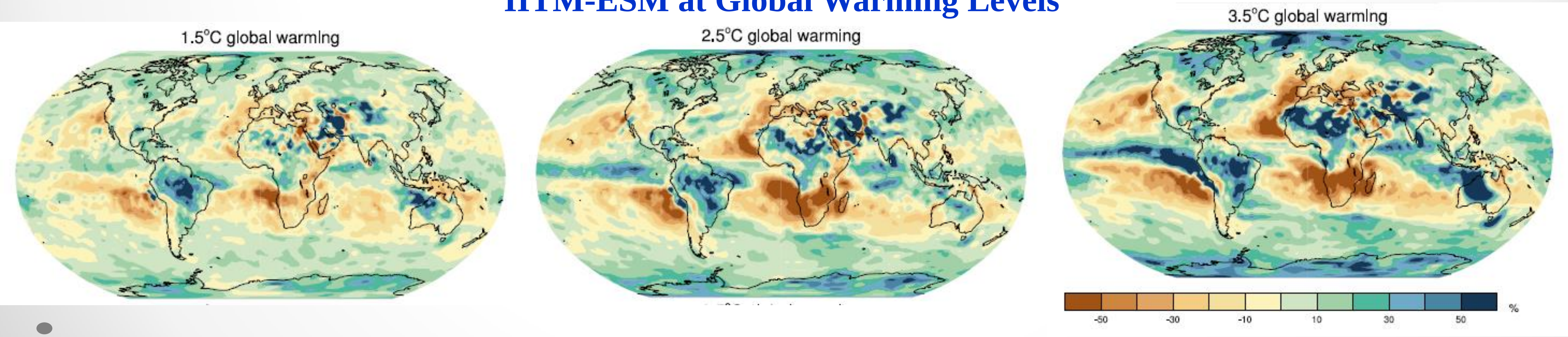
Temp dependence of saturation vapor pressure

$$e_s : e^{-5400/T}$$

Seasonal mean Precipitation (JJAS) AR6 MME



Seasonal Mean Precipitation (JJAS) IITM-ESM at Global Warming Levels



Climate change is already affecting every inhabited region across the globe, with human influence contributing to many observed changes in weather and climate extremes

Figure SPM.3

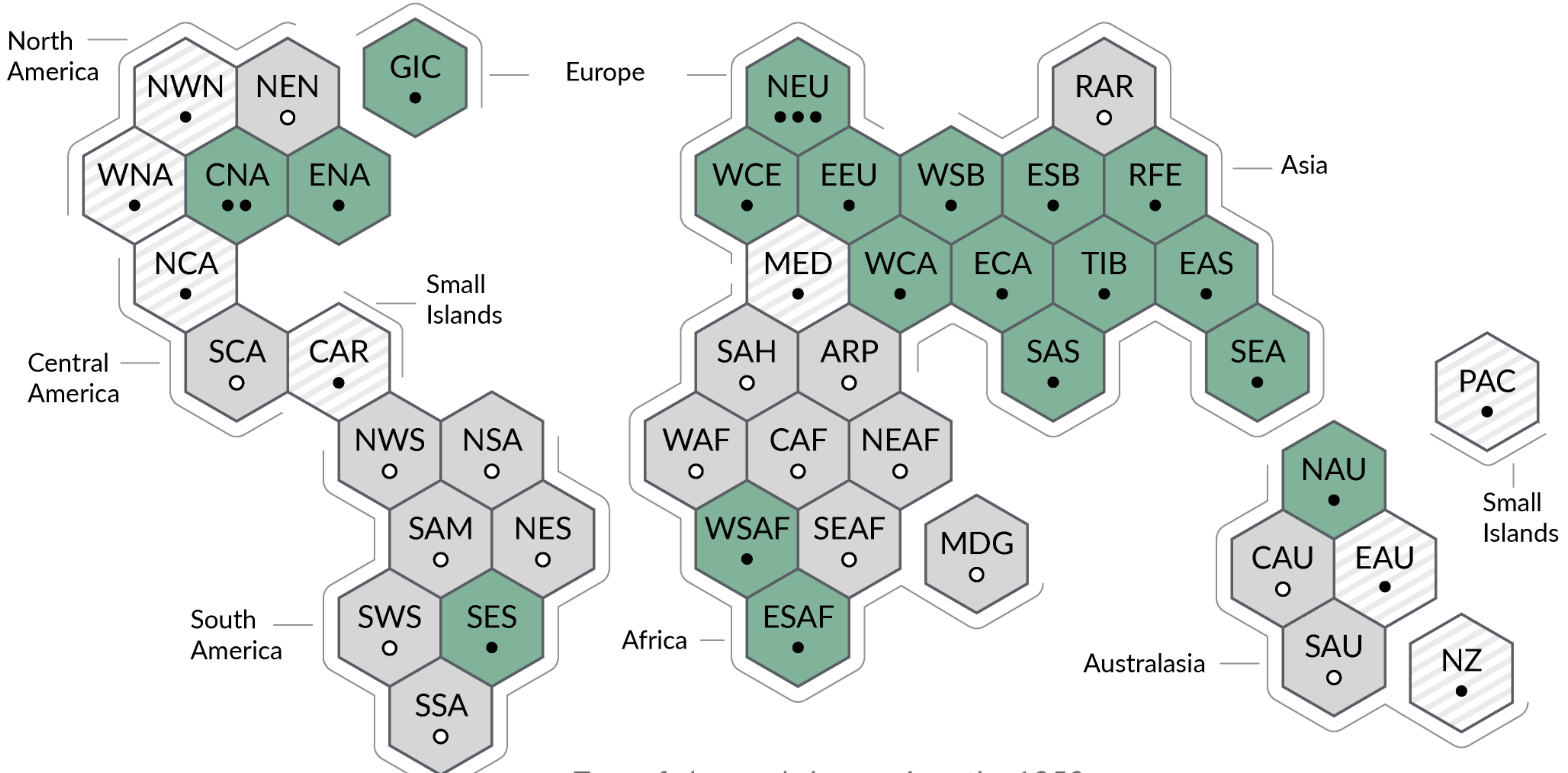
b) Synthesis of assessment of observed change in **heavy precipitation** and confidence in human contribution to the observed changes in the world's regions

Type of observed change in heavy precipitation

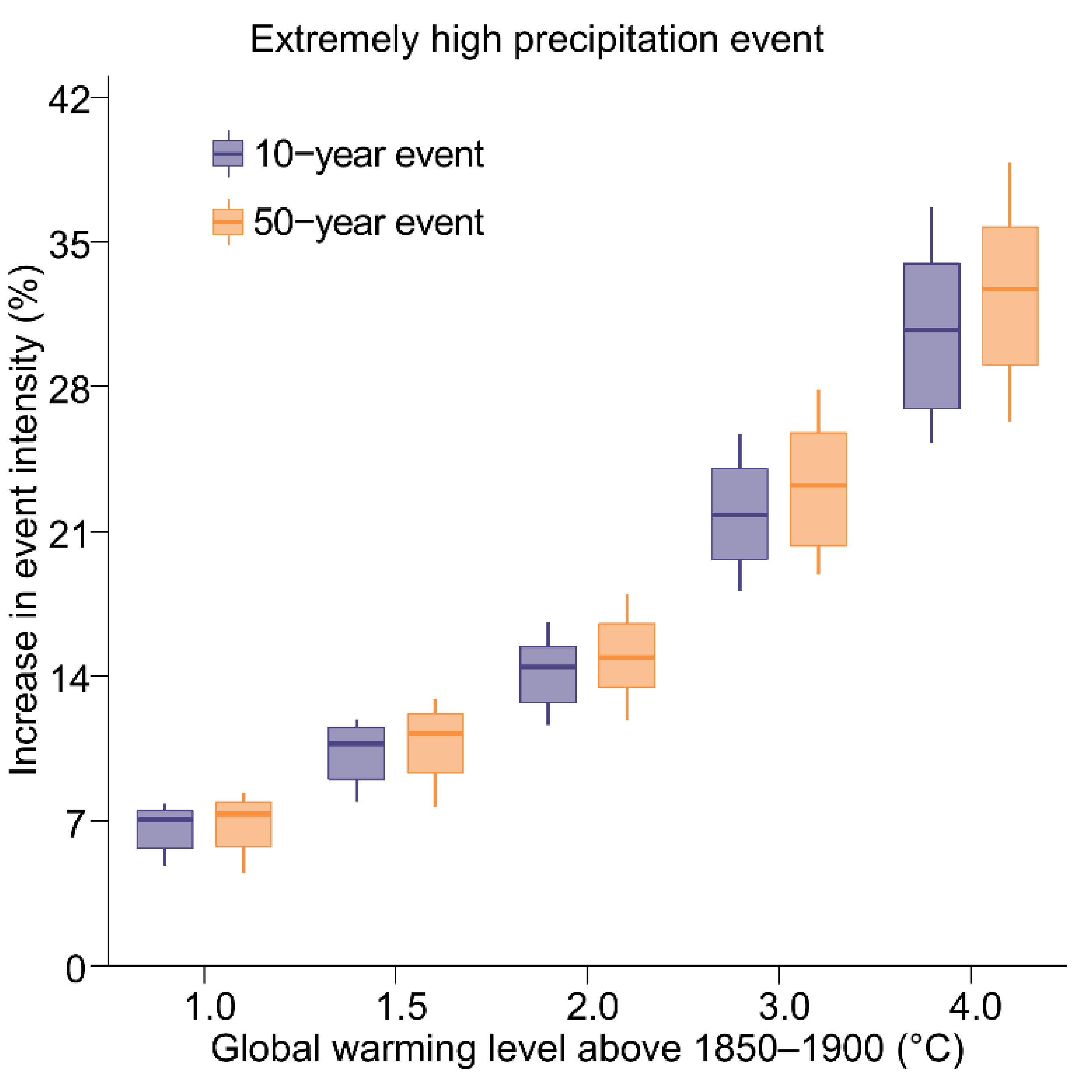
- Increase (19)
- Decrease (0)
- Low agreement in the type of change (8)
- Limited data and/or literature (18)

Confidence in human contribution to the observed change

- ●●● High
- ●● Medium
- ● Low due to limited agreement
- ○ Low due to limited evidence

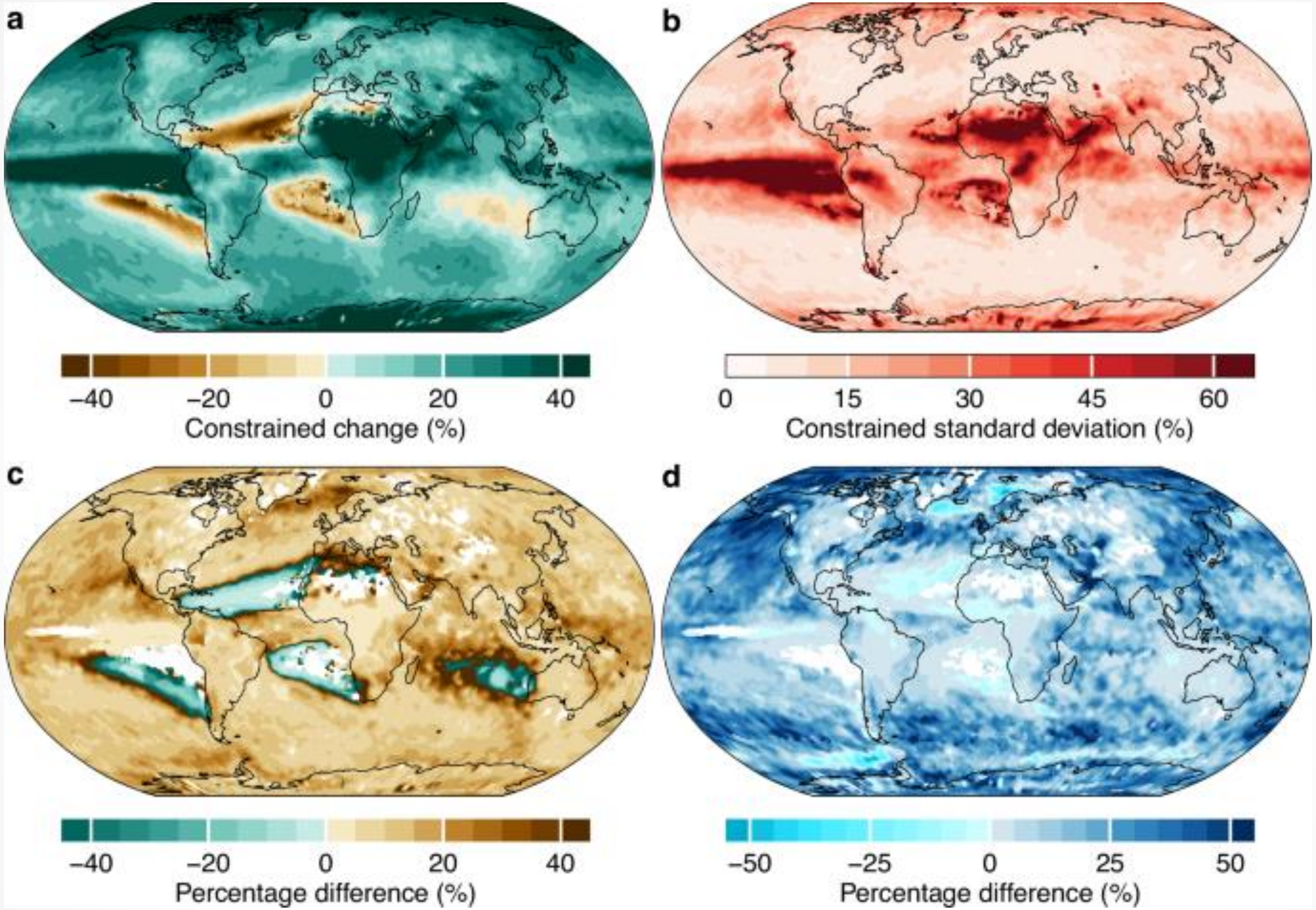


Type of observed change since the 1950s



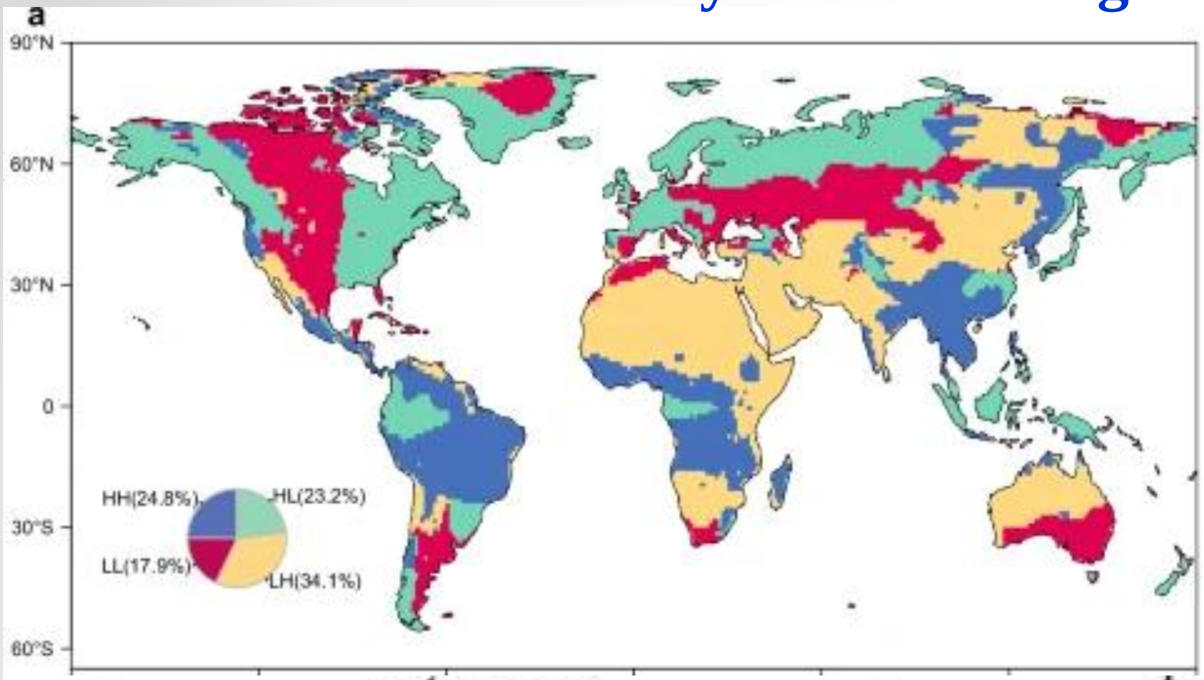
Extremely high precipitation event
10−year event
50−year event
Increase in event intensity (%)
42
35
28
21
14
7
0
1.0
1.5
2.0
3.0
4.0
Global warming level above 1850–1900 (°C)

Constrained projections of future extreme precipitation

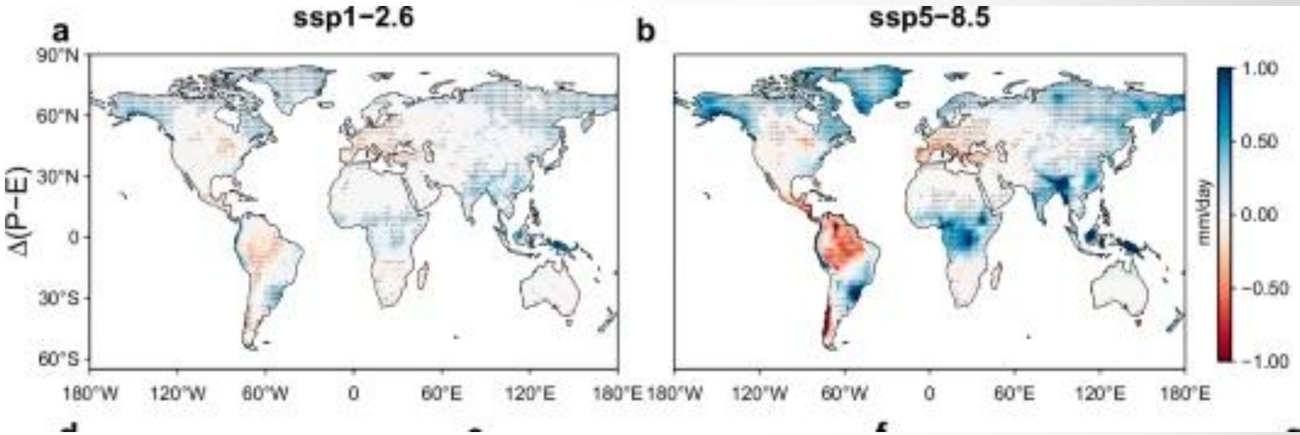


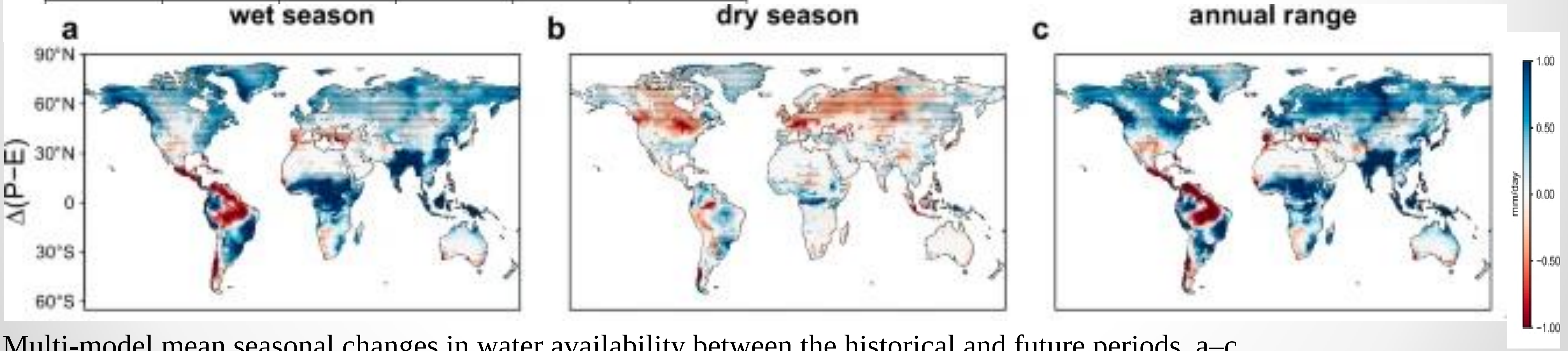
The constrained best estimates (in %; a) and standard deviations (in %; b) of projected changes in annual maximum daily precipitation during 2071–2100 relative to 1985–2014 under the SSP5-8.5

Global distribution of hydroclimate regimes



Multi-model mean changes in water availability between the historical and future periods.





Multi-model mean seasonal changes in water availability between the historical and future periods. a–c Changes in water availability (Δ(P-E)) in the wet season (a) and the dry season (b), and their differences (i.e. the annual range of P-E, c) between the historical (1971–2000) and future (2071–2100, ssp5-8.5) periods.

Gu et al., 2025

Centre for Climate Change Research
Indian Institute of Tropical Meteorology, Pune

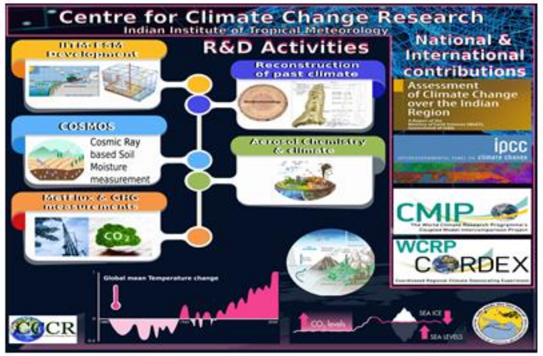
https://cccr.tropmet.res.in

IITM Earth System Model

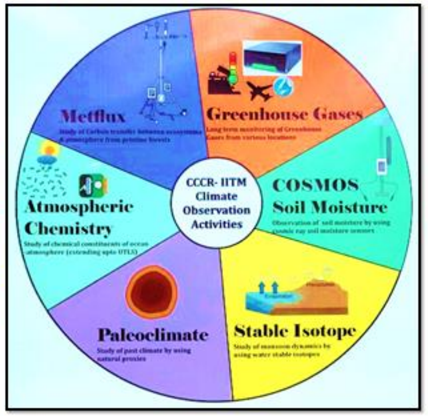
The CCCR is a centre for excellence in climate change research located at the IITM, Pune. The mission of CCCR is envisioned to address all key aspects relating to the science of climate change and enable improved assessments of regional climate response to global climate change

Sub Programmes of CCCR

- Earth System Model Development and Research
- Climate Observations
- Atmospheric Chemistry and Climate



CCCR Observational activities

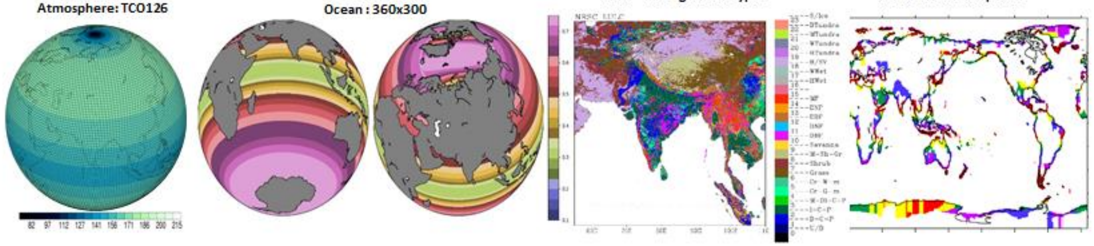


IITM Earth System Model (IITM-ESM) Development & Research

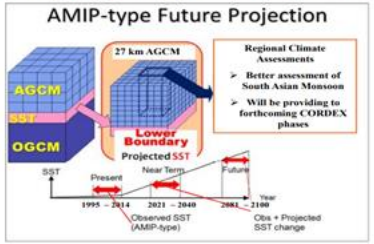
IITM-ESM Development for Contribution to CMIP7 & IPCC AR7

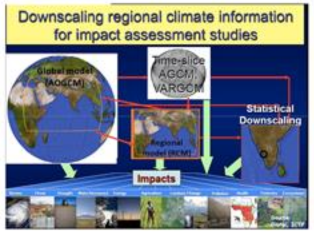
Atmosphere: TCO126 (67 Km, ~0.7 degree) Ocean: Variable resolution across latitude 360x300

LULC –24 Vegetation types (NRSC & USGS) Addition of river destination points

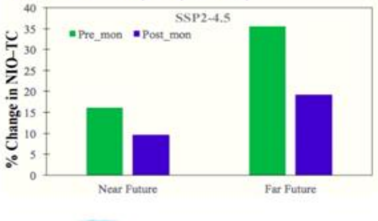


High resolution AGCM Simulations for Climate Applications





Tropical Cyclone simulated by High resolution IITM-ESM AGCM (T574, ~27 Km)



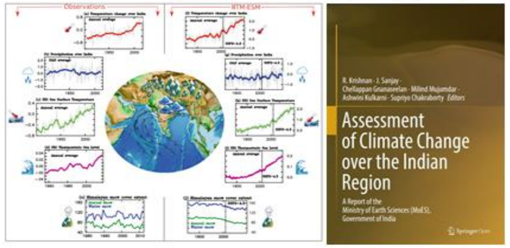
Earth System Grid Federation (ESGF) Node

CCCR_IITM Data Archival and distribution System - CDAS

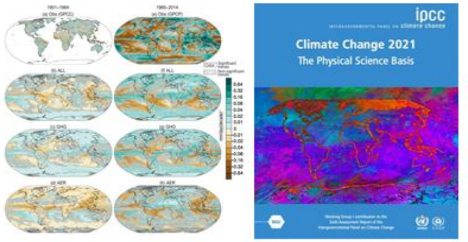
High-Capacity Cluster Storage System	
Storage Capacity	2 Peta Byte (2 PB)
Cluster Storage System	Dell PowerScale H7000 with 6 nodes
Each single Node	400 TB (20 x 20TB) storage
Average throughput	9 – 10 GBps
PowerScale Chassis	2 x Base Chassis - Deep H-Series
Dell Networking Switches	2 x S5232F Dell Networking Switch ROW
PowerScale OE Software	6 x PowerScale Hybrid OESW Virtual Base
PowerScale Additional Software	6 x PowerScale Hybrid ADDSW Virtual Base

CCCR, IITM Contributions

MoES Climate Change Assessment Report (2020) by CCCR, IITM

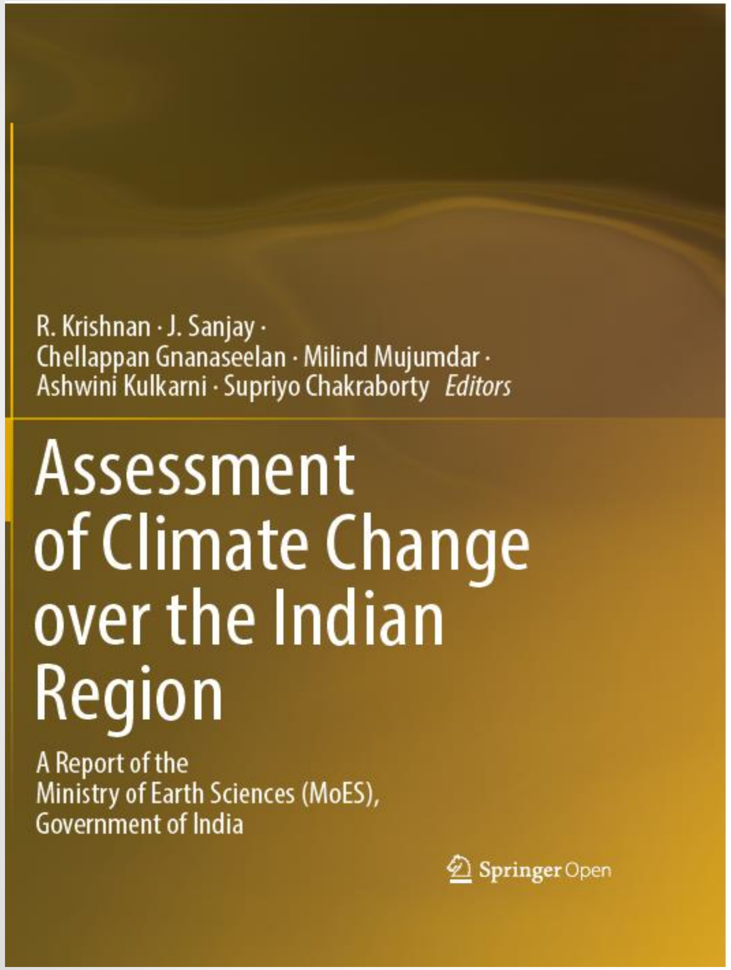


IPCC AR6 WG1 Report (2021)



Assessment of Climate Change over the Indian Region

A Report of the Ministry of Earth Sciences (MoES)
Government of India



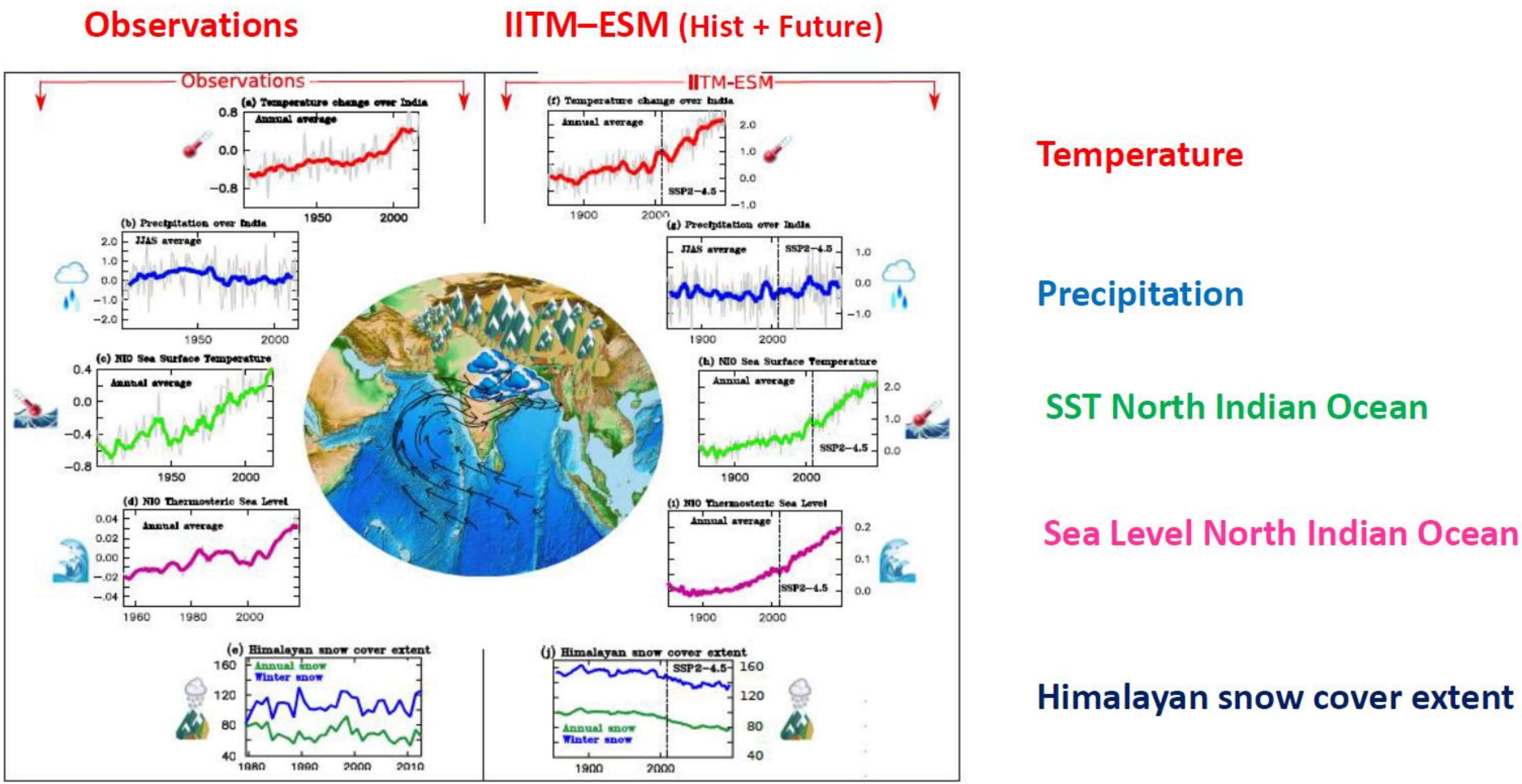
- Discusses the influence of human-induced global climate change over the Indian subcontinent

- Presents a synthesis of historical and future projected changes in the global and regional climate over the India subcontinent - based on scientific literature, observations, climate model projections and published IPCC reports

- Serves as a reference resource for researchers, practitioners in academia and industry, and policymakers

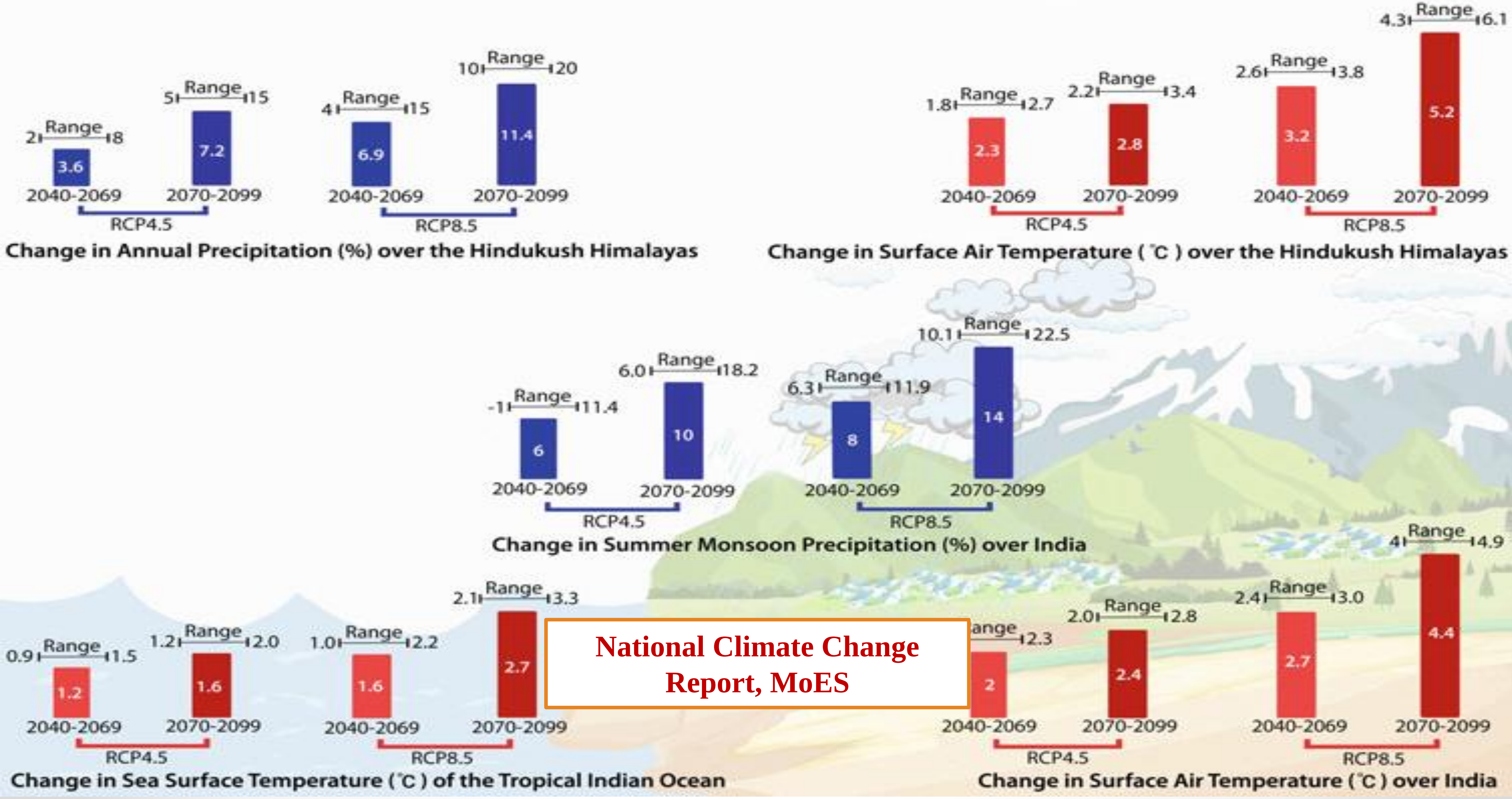
Contribution to "Assessment of Climate Change over the Indian Region", Ministry of Earth Sciences (MoES), Govt. of India

Projections from the IITM Earth System Model (IITM ESM)



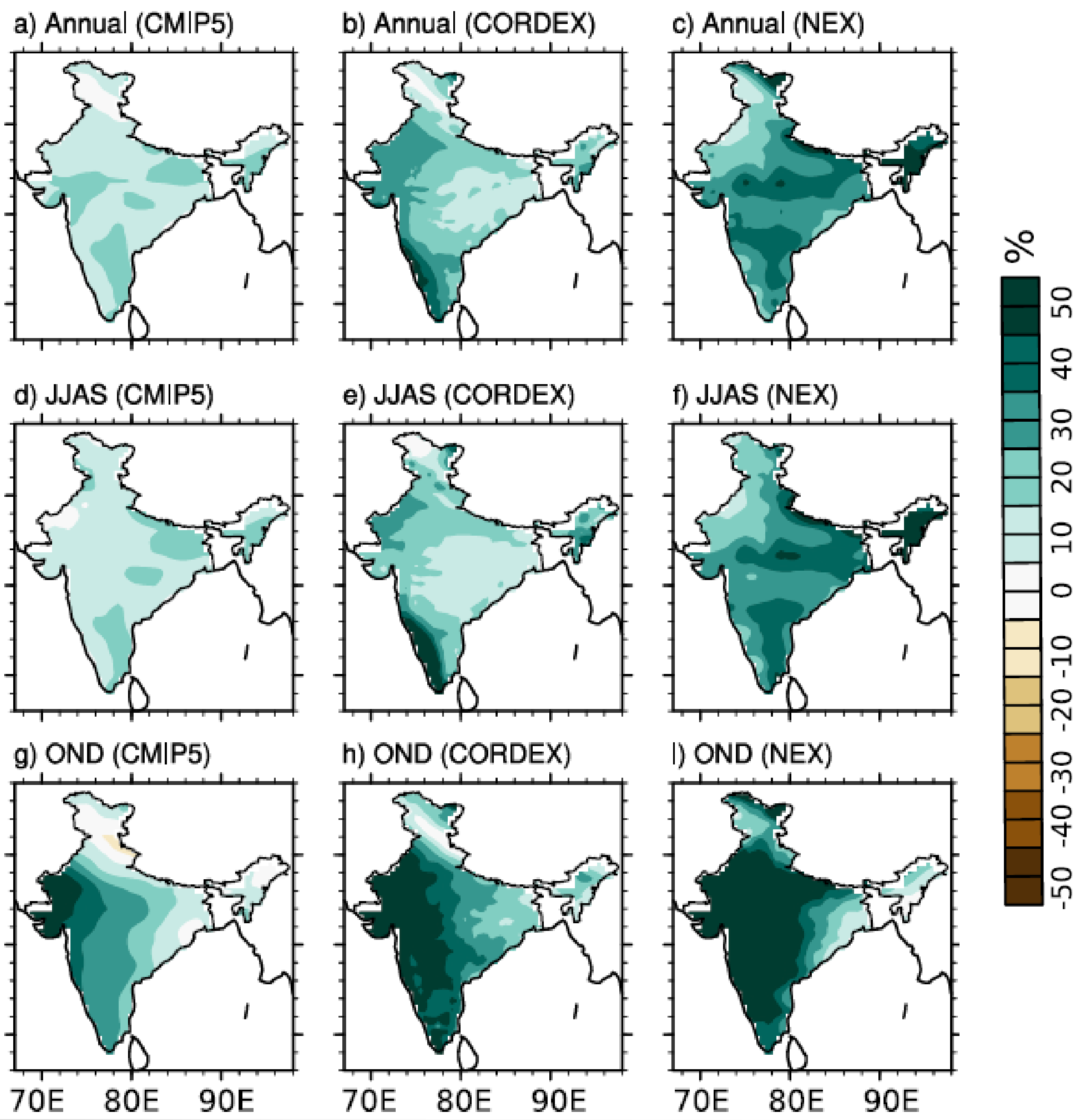
https://link.springer.com/book/10.1007/978-981-15-4327-2

Projected Changes over the Indian Region

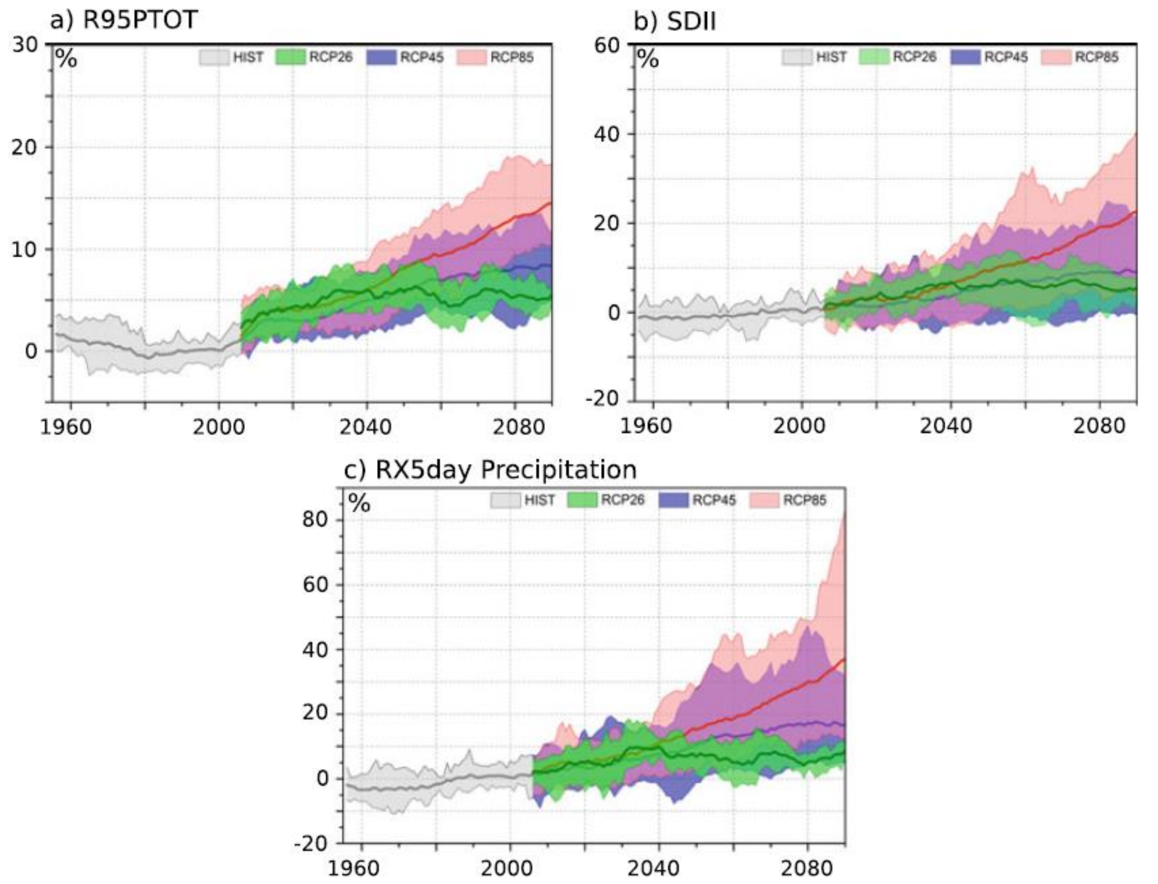


National Climate Change Report, MoES

Precipitation (RCP8.5, 2070-2100)



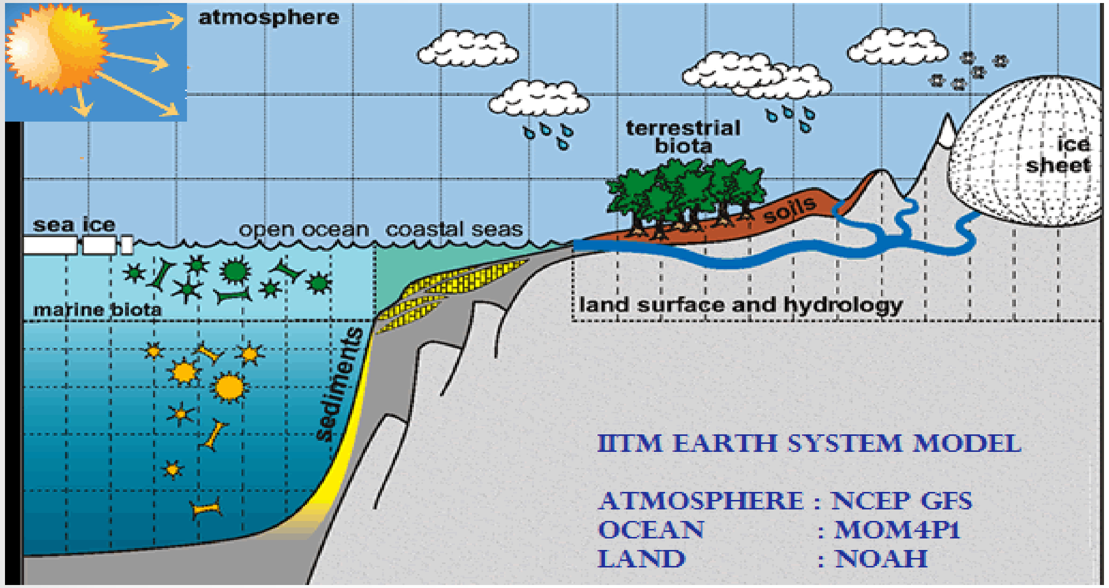
Precipitation Indices



National Climate Change Assessment Report, MoES, Govt. of India

Global Climate Modeling at CCCR, IITM, India

The IITM Earth System Model (IITM-ESM) for addressing long-term changes in the global and regional climate



CCCR-IITM Earth System Grid Federation (ESGF) node
(http://cccr.tropmet.res.in/home/esgf_node.jsp)

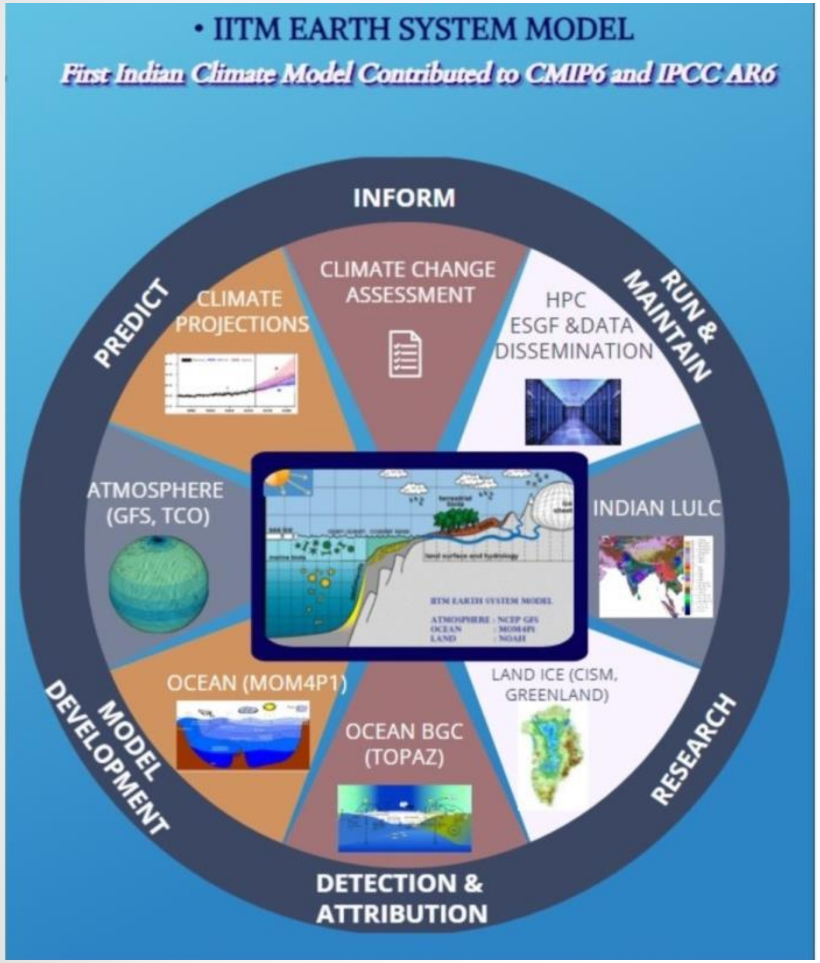
IITM-ESM Experiments:

More than 3000-year climate simulations performed

Experiments	Details of Simulation	No. of years of integration
PI-Control	PI control simulation	1850 (800 yrs)
Transient CO_2	1% /Yr increase in CO_2	1850 till quadrupling (140 yrs)
	Abruptly Quadruple CO_2	
CMIP6	Historical	1850-2014 Emission-or concentration-driven simulation of recent past
GMIP & AMIP	AMIP Simulation	`1850-2104
Future Scenario	Future projections	2015-2100
DAMIP	Detection and attribution exp	1850-2014
FAFMIP	Fresh water forcing exp	2015 to 70 yr ctrl

IITM Earth System Model version 3 (IITM-ESMv3)

IITM Contribution to Coupled Model Intercomparison Project Phase 7 (CMIP7), CORDEX and IPCC AR7



Objective :

Towards development of

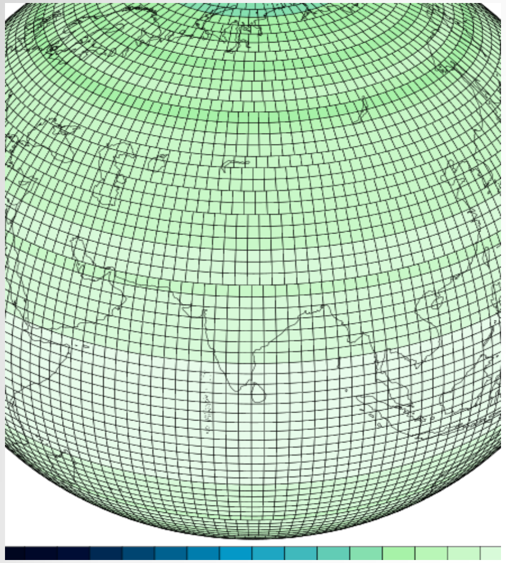
CLIMATE SERVICES INFORMATION SYSTEM

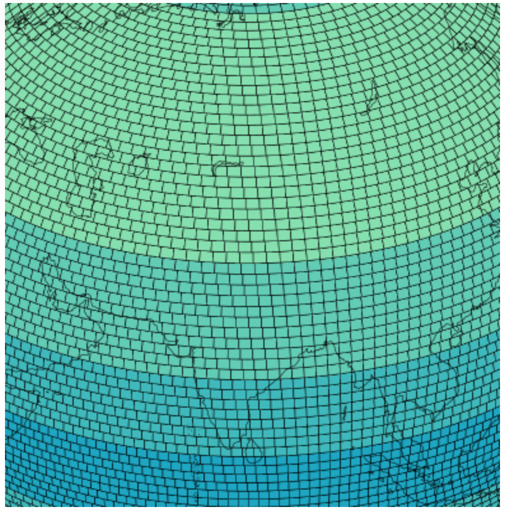
to address Increasing Climate Extremes

Climate Modeling Group @CCCR-IITM : Swapna P; Ayantika D.C, Sandeep N, Praveen V, Priya P, Umakanth U, Moumita B, Sandip. I, Shamal M, Pritam D, Aditi M, Sabin T.P and Sooraj K.P

IIITM ESM CMIP7

Atmosphere

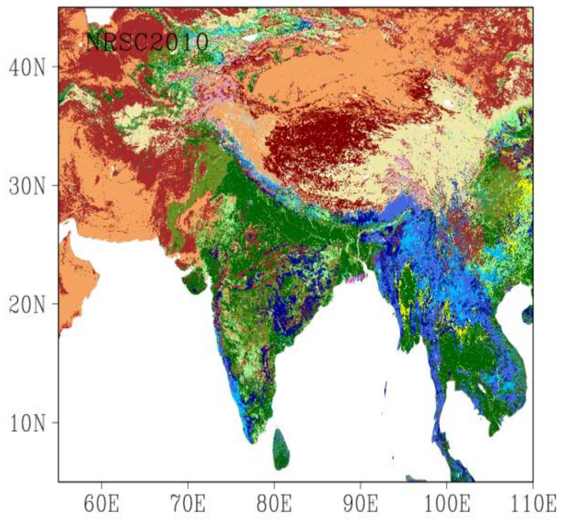




CMIP6:
ATM: T62 ; ~200km
(~2deg at equator)

CMIP7
TCO126 ; 67Km
(~0.7 Deg at equator)

Incorporation of Land Use Land cover (NRSC)



Himalayan glacier

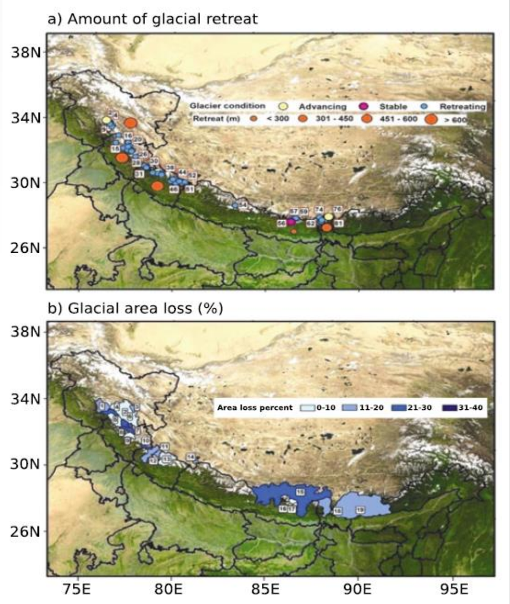
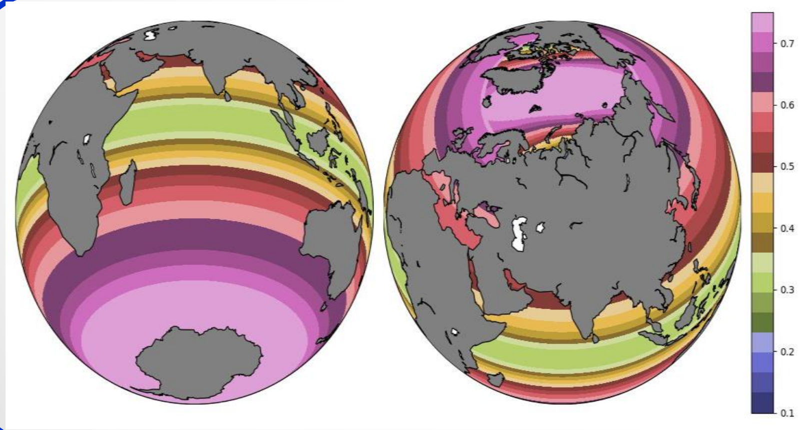
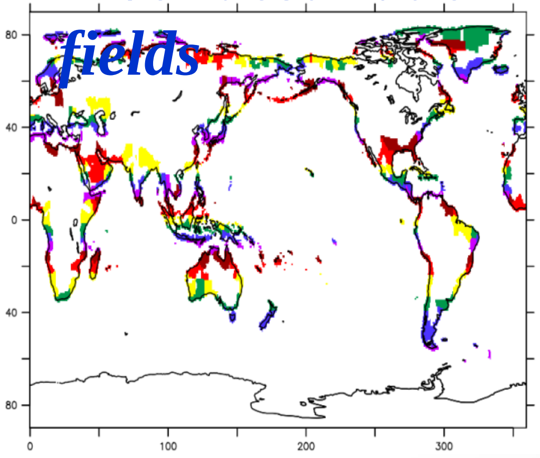


Fig. 11.8 **a** Amount of glacial retreat between 1960 and 2000. **b** Glacial area loss in different regions of the Himalaya from 1960 to 2000. The number represents names of glaciers/basins/regions as given in Tables 1 and 2 of Kulkarni and Karyakarte (2014). From Kulkarni and Karyakarte (2014)

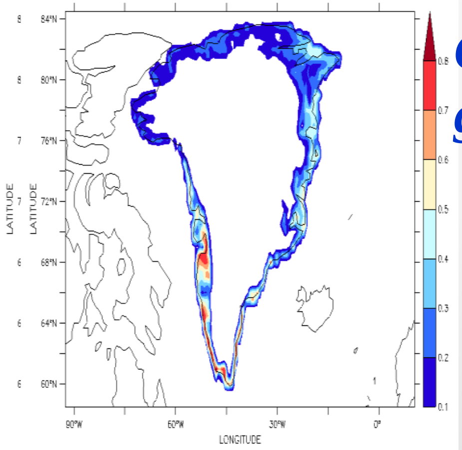
Ocean



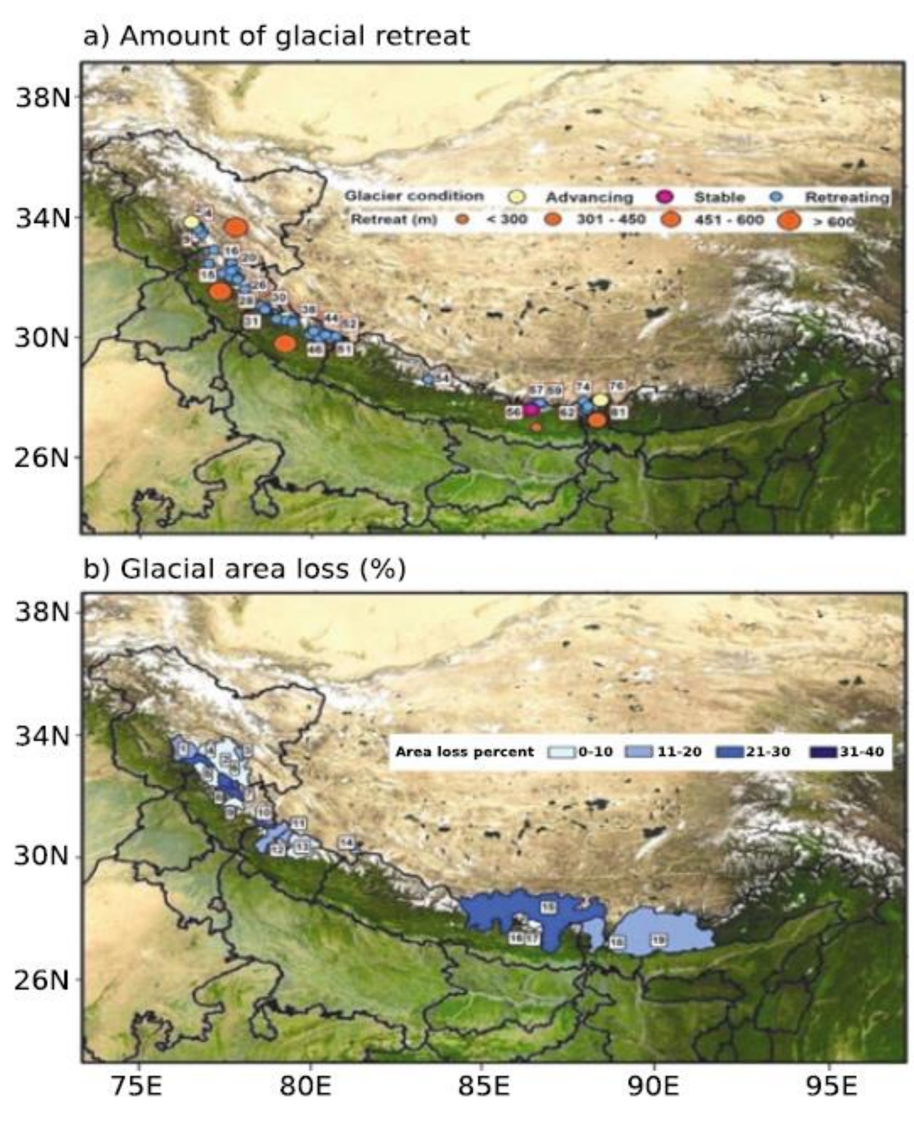
River destination fields



Greenland glacial ice

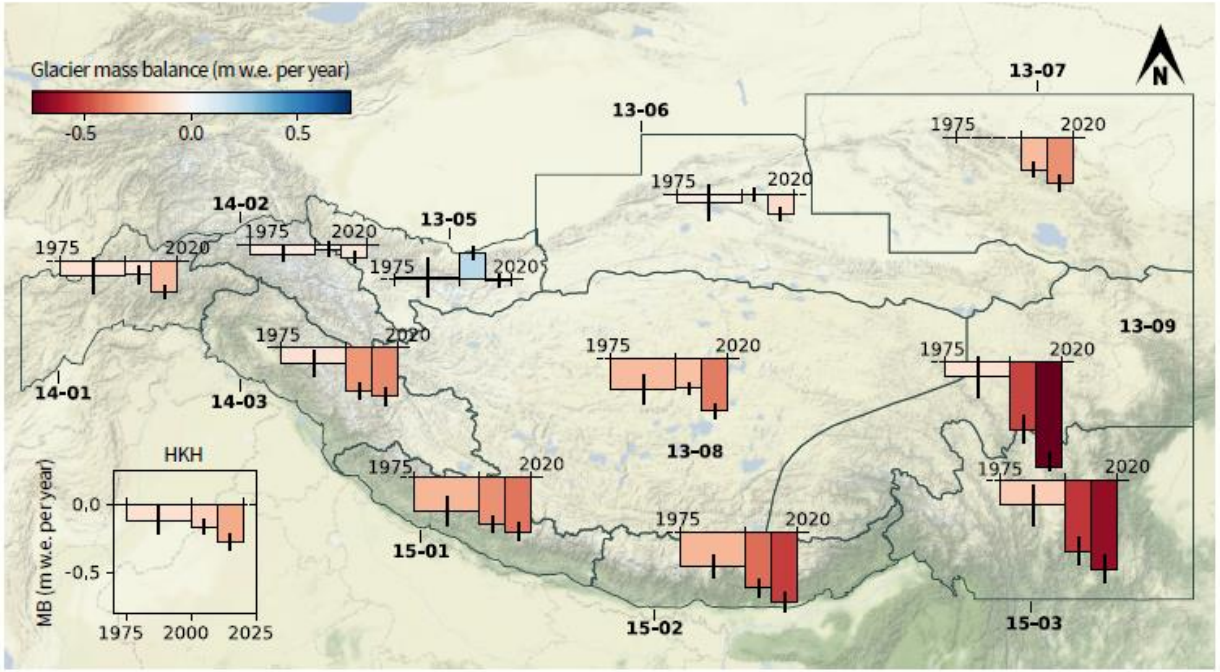


Amount of glacier retreat between 1960 and 2000



Kulkarni and Kayakarte (2014)
Krishnan et al (2019)

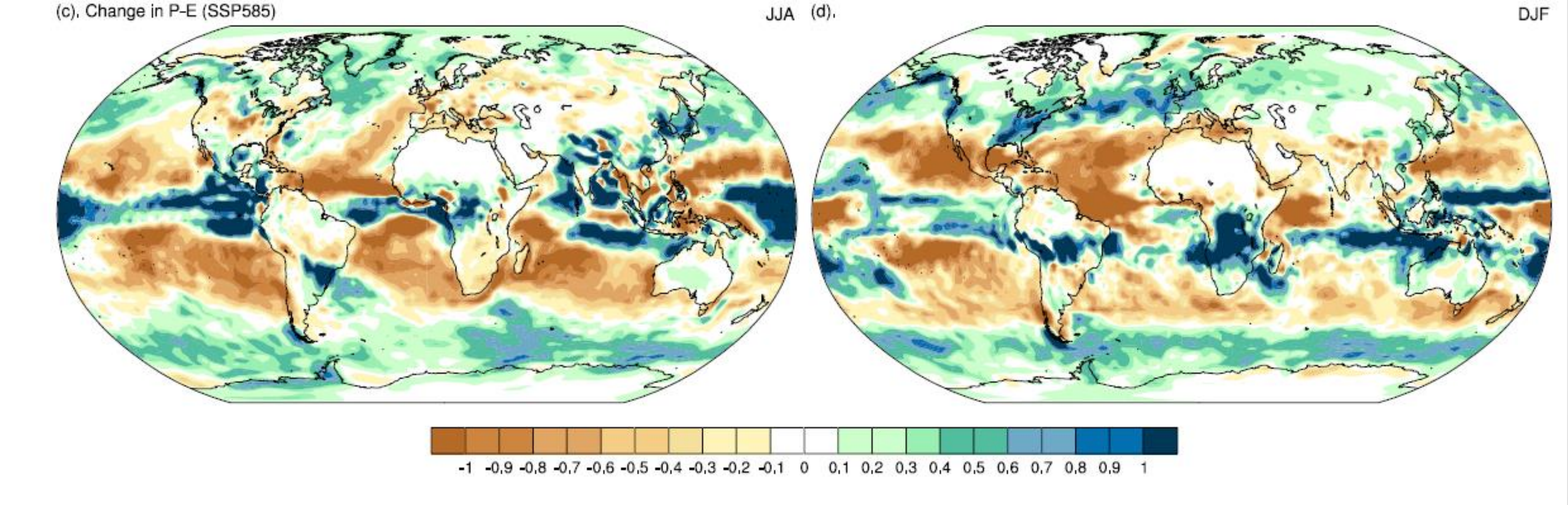
Mass Balance



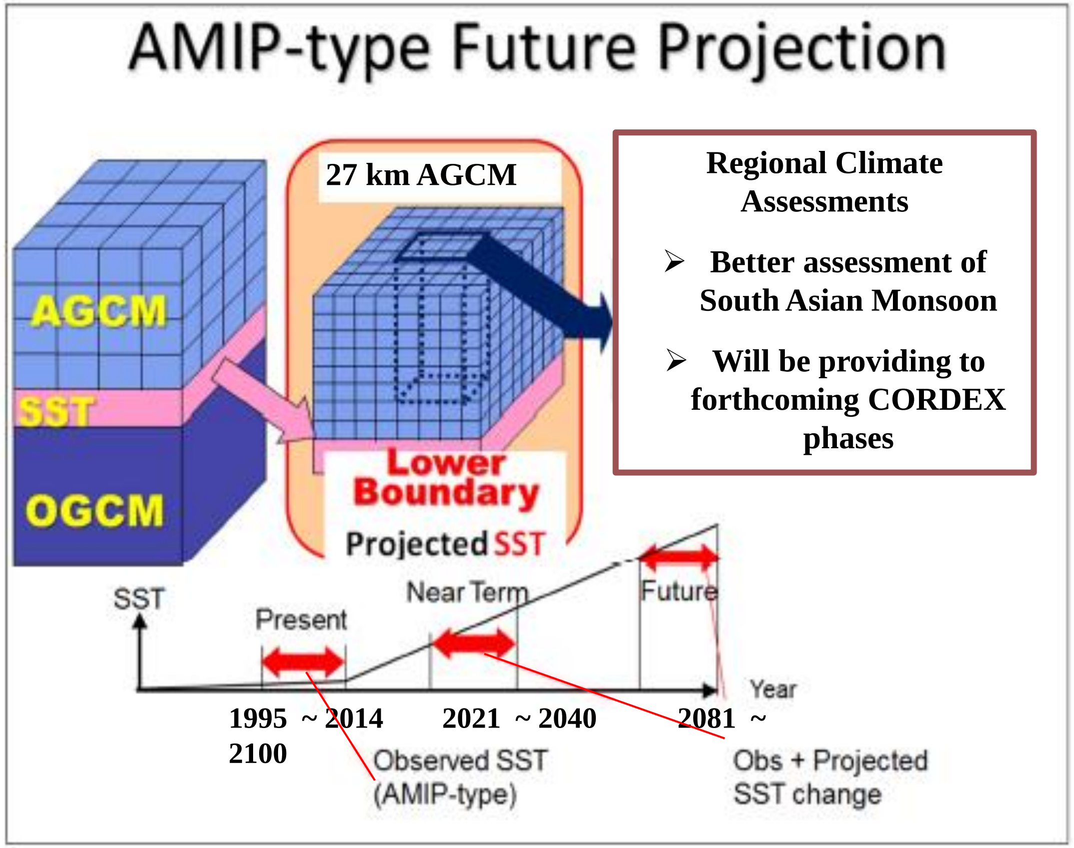
Notes and sources: The size of the bars and their colour depend on changes in the average mass balance, expressed in metres water equivalent per year (m w.e. per year). The vertical black lines show the uncertainty. The bold numbers beside each basin give the glacier region in the Randolph Glacier Inventory. For 1975–1999, we rely on a compilation of data from the literature; for the other periods, we rely solely on Hugonnet et al. (2021). Note that the spatial coverage for 1975–1999 is generally much lower than for the following two periods, during which the spatial coverage is always higher than 92% of the total glacier-covered regional area (see Table 2.2 for the spatial coverage for each region). The source data used to compile the region-wide mean mass balances for 1975–1999 are listed in Appendix 1.

Mass balance expressed in meres water equivalent per year (Jackson et al., 2023)

Projected Water Availability

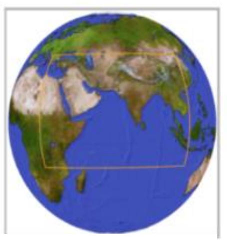


High resolution IITM-ESM AGCM (T574, ~27 Km)

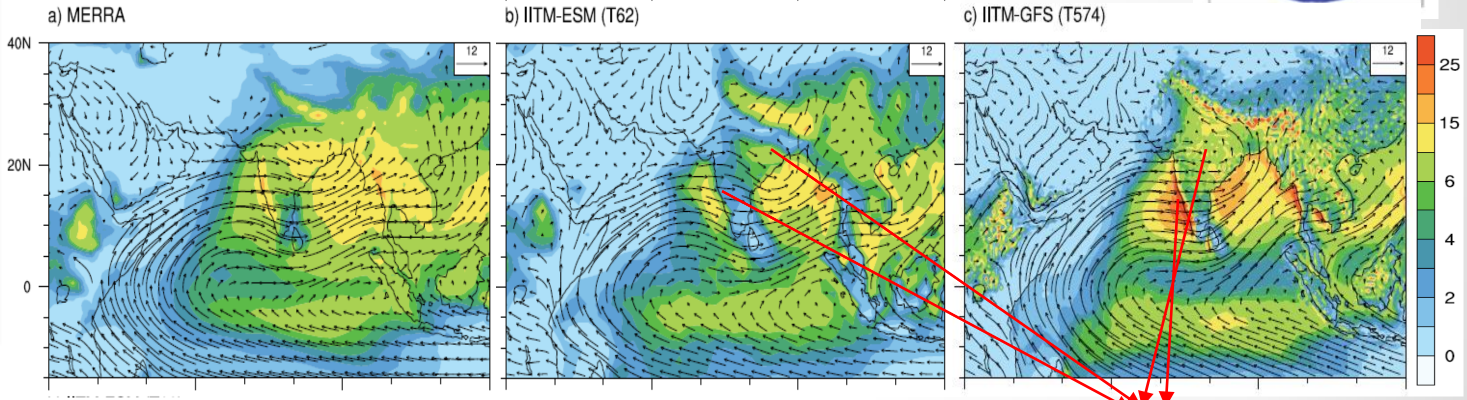


- ➢ **Dynamical downscaling of IITM-ESM CMIP6 historical simulation (1951-2015) using the high-resolution (27 km) atmospheric component of IITM-ESM. Committed to contributing to CORDEX**

Region 6: South Asia



JJAS Mean Precipitation



Dry bias is reduced over central India, & orographic precipitation is improved

The following experiments are completed

1.	AMIP	1981-2014	(Completed)	
2.	Historical	1951-2014	(Completed)	
3.	SSP 2-4.5		2021-2040 (Completed)	2081-2100 (Completed)

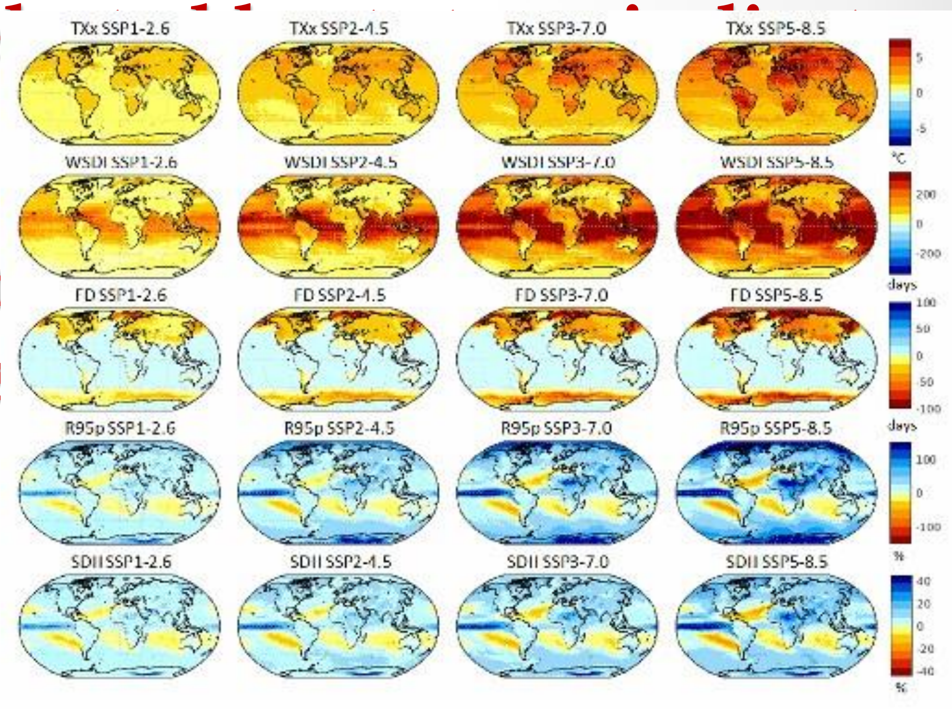
Courtesy : Sabin

Towards Climate Services

- **Climate extreme indices from CMIP7 IITM-ESM and high-res 27km projections will be developed and disseminated through CDAS**

- **The climate extreme indices related to temperature and precipitation as defined by the Expert Team on Climate Change Detection and Indices (ETCCDI) and se s (HSI) will be generated.**

- **The indices will be developed based o historical and future climate projection**



Ref : Coperninus CDS: https://cds.climate.copernicus.eu/cdsapp#!/dataset/sis-extreme-indices-cmip6?tab=overview

Take Away Message

Increasing global temperature is projected to amplify the hydrological cycle and intensify extreme events demanding sustainable and resilient water infrastructure

Mitigation measures can reduce the magnitude of impacts of global warming on water resources, in turn reducing adaptation needs.


THANK
YOU!