



**CLIMATE-RESILIENT DAMS AND
HYDROPOWER INFRASTRUCTURE
INTEGRATING
ENVIRONMENTAL SUSTAINABILITY
IN PLANNING AND DEVELOPMENT**

**Warming Climate, Escalating Extremes:
From Risk Assessment to Action**

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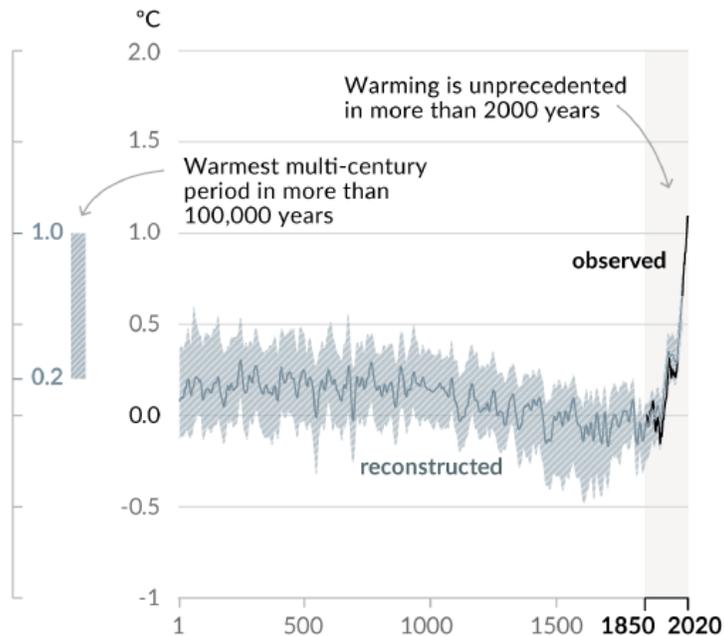
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Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

Changes in global surface temperature relative to 1850-1900

a) Change in global surface temperature (decadal average) as **reconstructed** (1-2000) and **observed** (1850-2020)



Type of observed change in hot extremes

- Increase (41)
- Decrease (0)
- Low agreement in the type of change (2)
- Limited data and/or literature (2)

Confidence in human contribution to the observed change

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

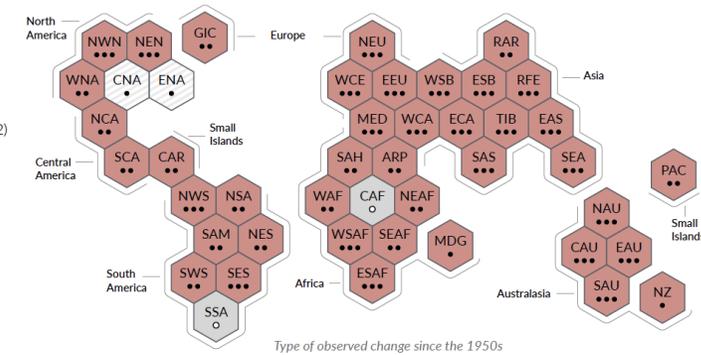
Type of observed change in heavy precipitation

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

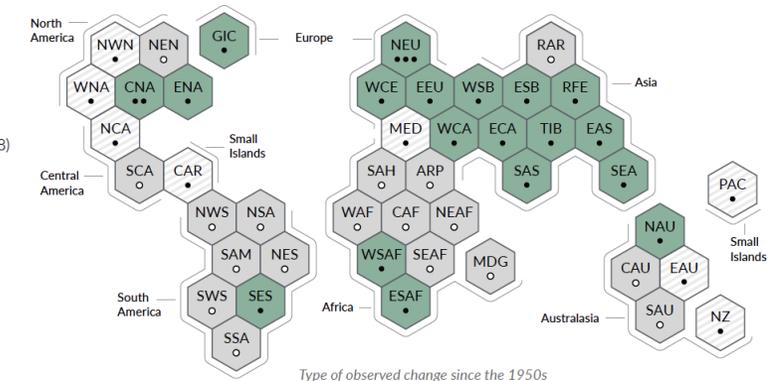
Confidence in human contribution to the observed change

- High
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a) Synthesis of assessment of observed change in **hot extremes** and confidence in human contribution to the observed changes in the world's regions



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



With each increase in global warming, there are significant changes in local average temperature and rainfall

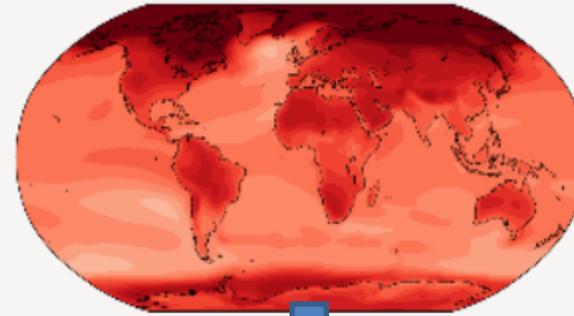
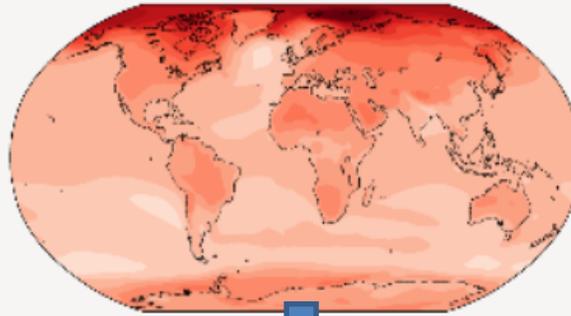
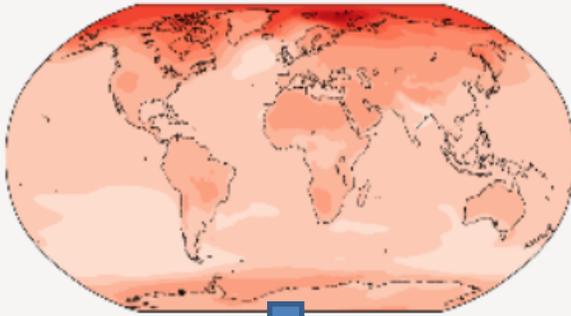
b) Annual mean temperature change (°C) relative to 1850-1900

Across warming levels, land areas warm more than oceans, and the Arctic and Antarctica warm more than the tropics.

Simulated change at 1.5 °C global warming

Simulated change at 2 °C global warming

Simulated change at 4 °C global warming



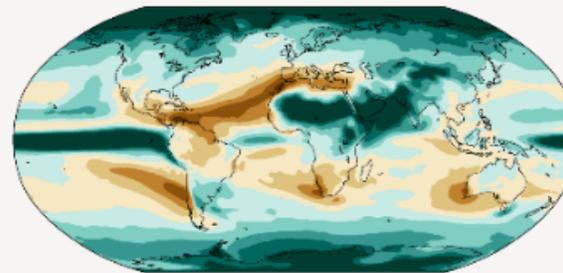
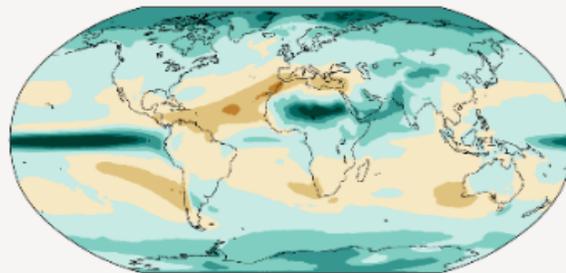
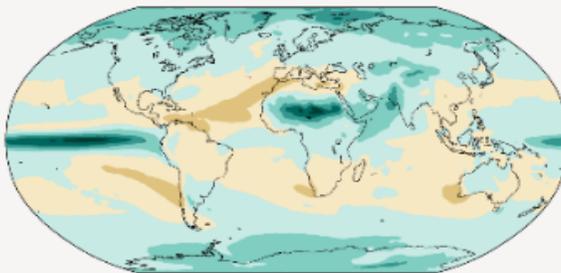
c) Annual mean precipitation change (%) relative to 1850-1900

Precipitation is projected to increase over high latitudes, the equatorial Pacific and parts of the monsoon regions, but decrease over parts of the subtropics and in limited areas of the tropics.

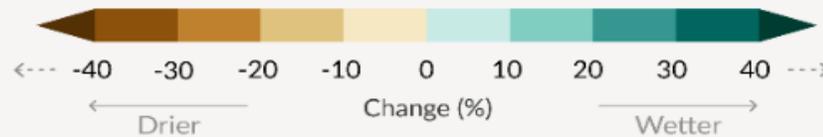
Simulated change at 1.5 °C global warming

Simulated change at 2 °C global warming

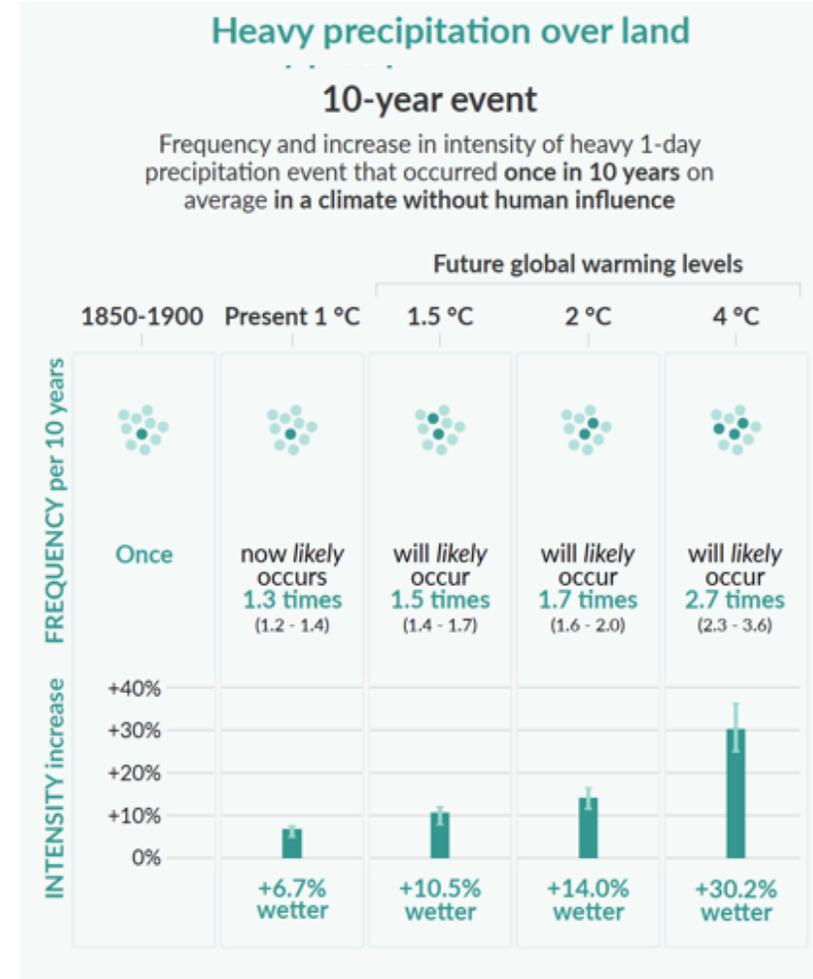
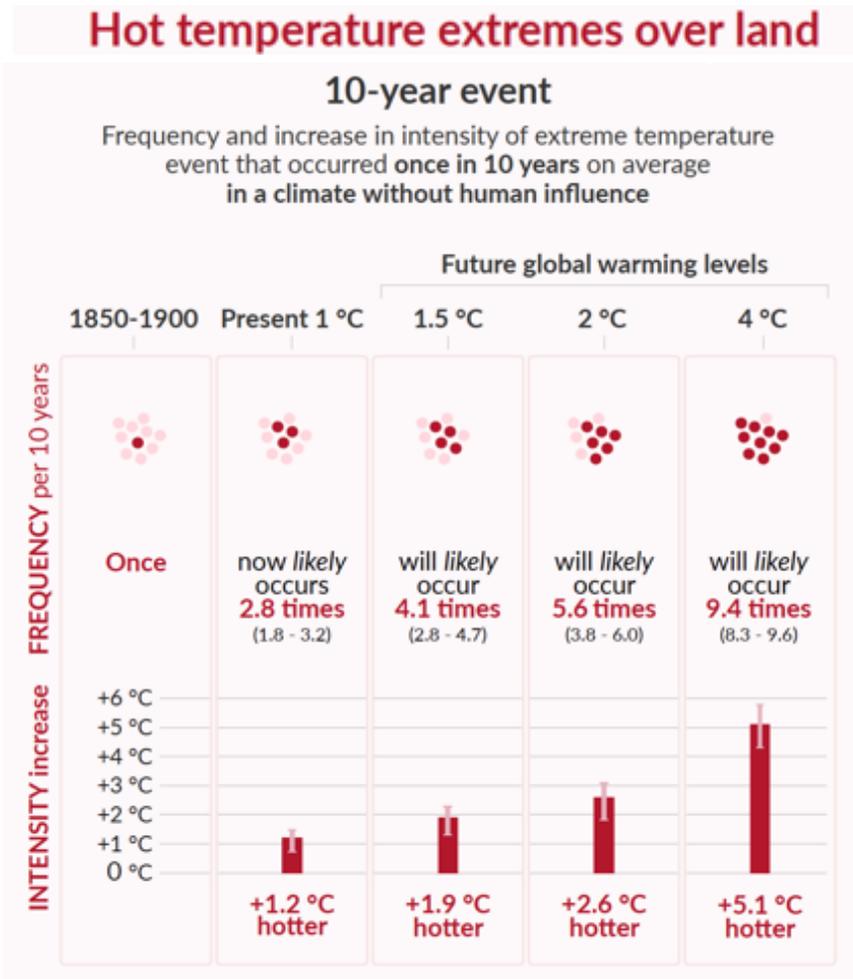
Simulated change at 4 °C global warming



Relatively small absolute changes may appear as large % changes in regions with dry baseline conditions

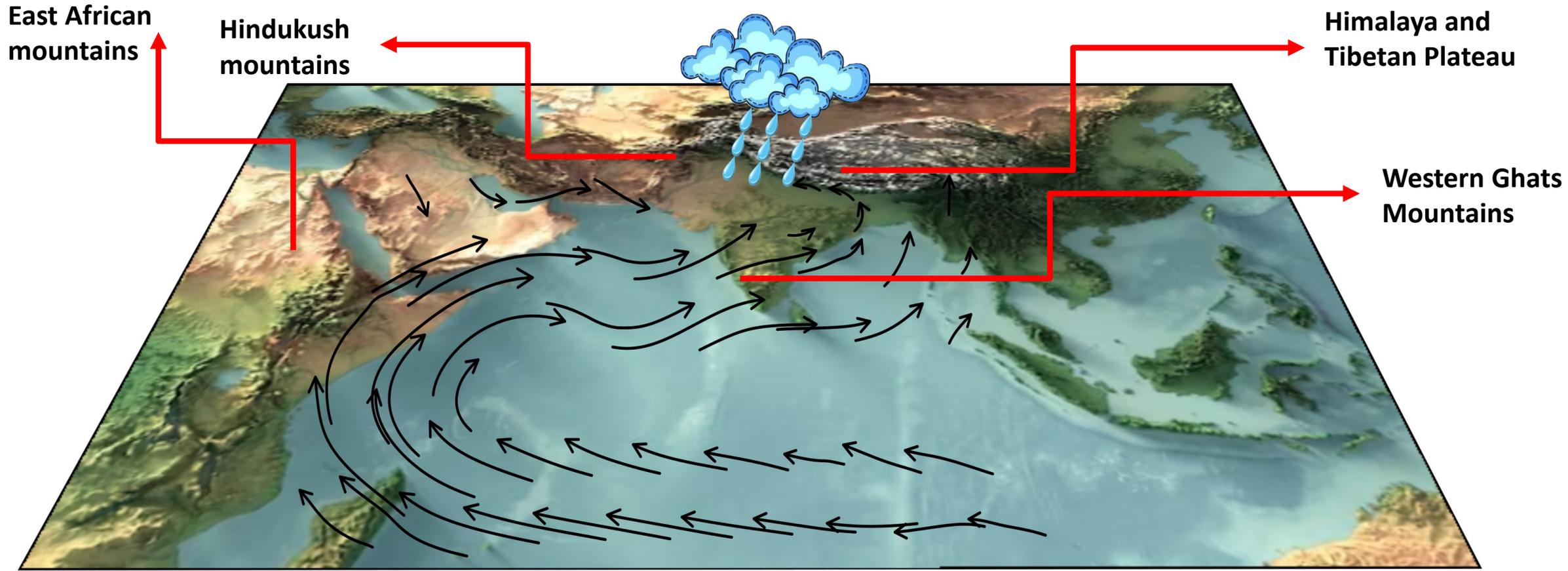


Projected changes in extremes increase in both frequency and intensity with every additional increment of global warming



Every additional 0.5°C of global warming causes clearly discernible increases in the intensity & frequency of hot extremes, including heatwaves (*very likely*)

Indian Peninsula, Monsoon and Its Complexity



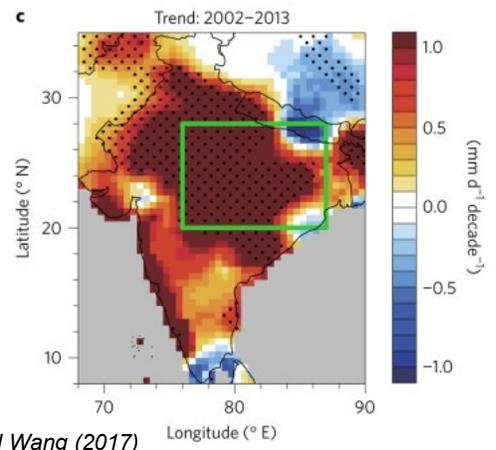
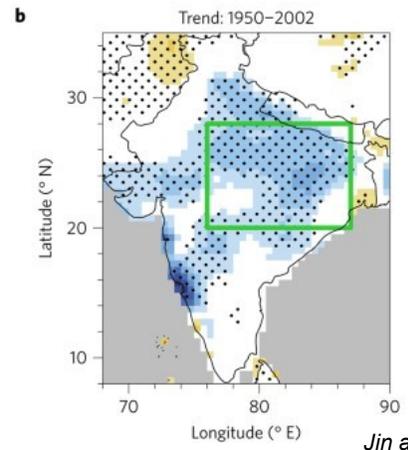
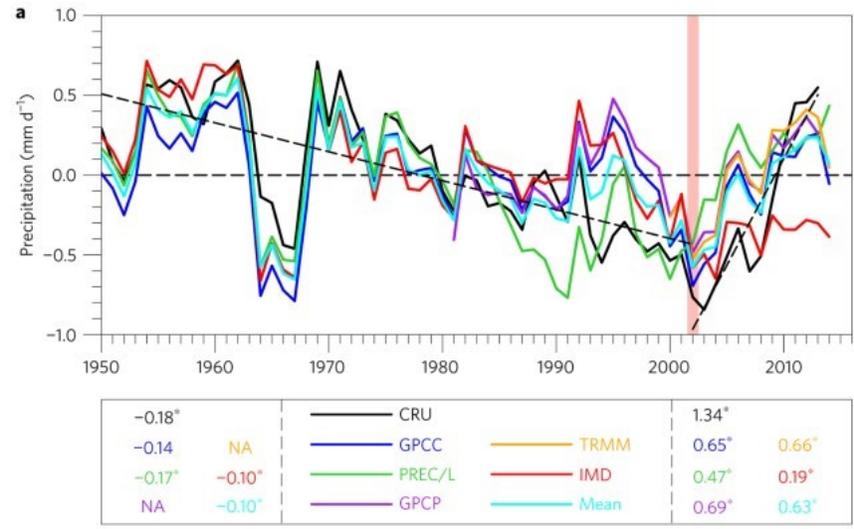
Monsoon circulation and rainfall: A convectively coupled phenomenon

Requires a thermal contrast between land & ocean to set up the monsoon circulation

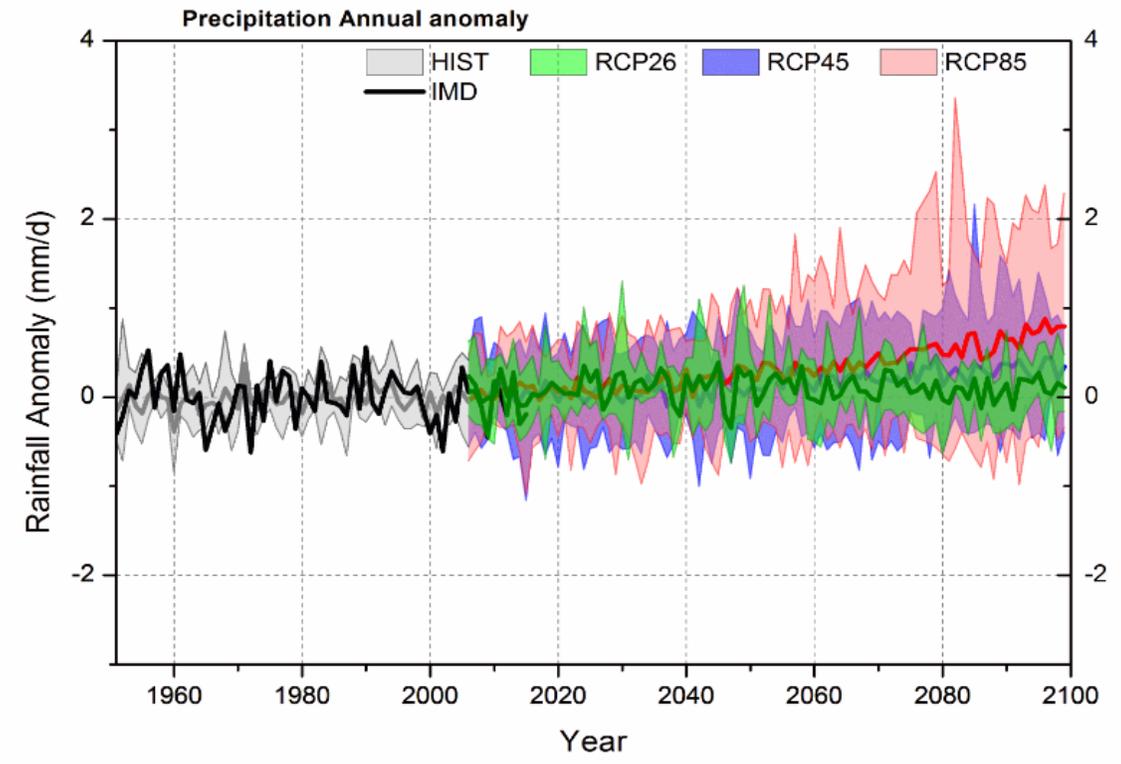
Once established, a positive feedback between circulation and latent heat release maintains the monsoon

Monsoon reviving ?

Precipitation time series and spatial trends: revival of summer monsoon...!!

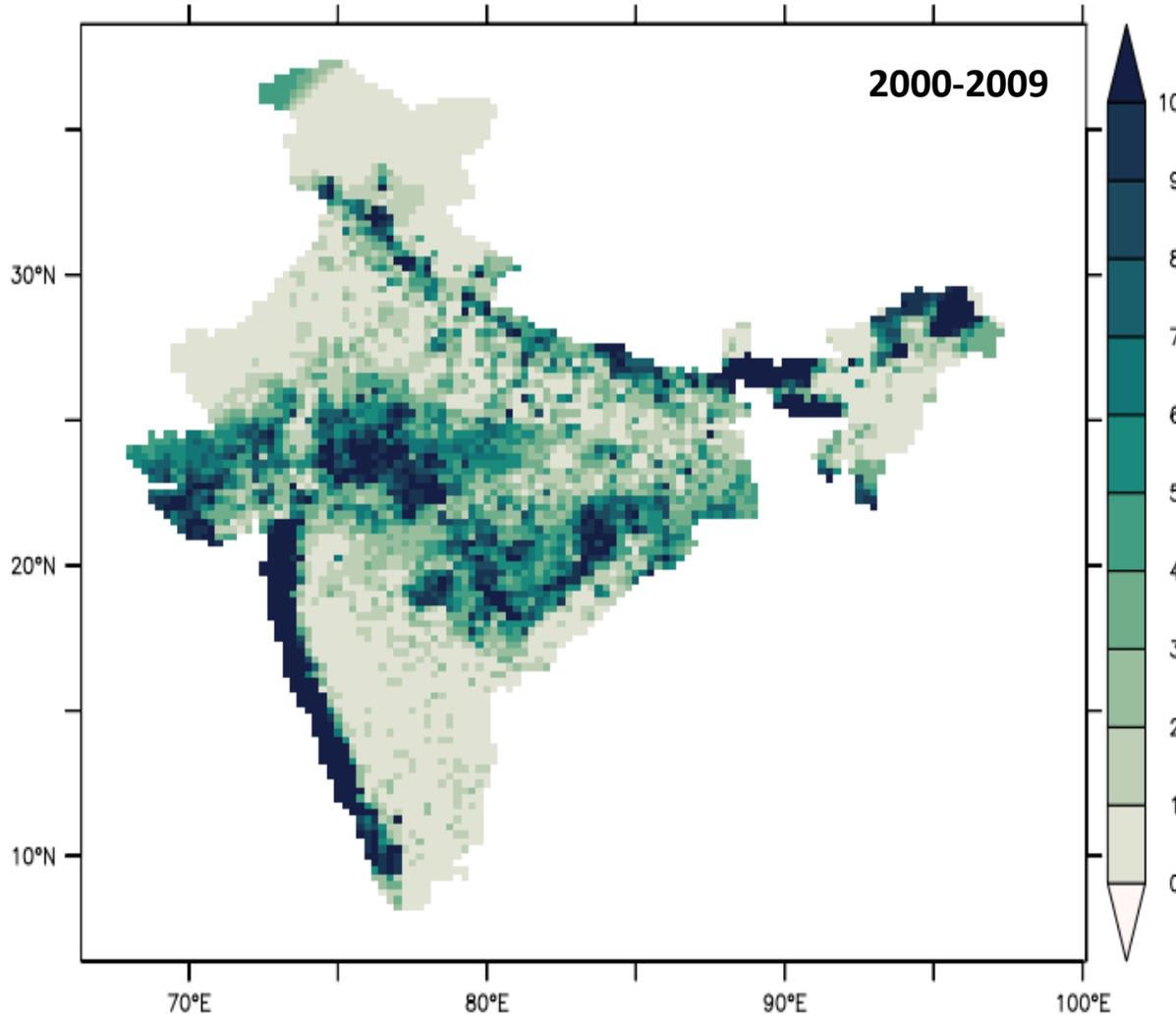
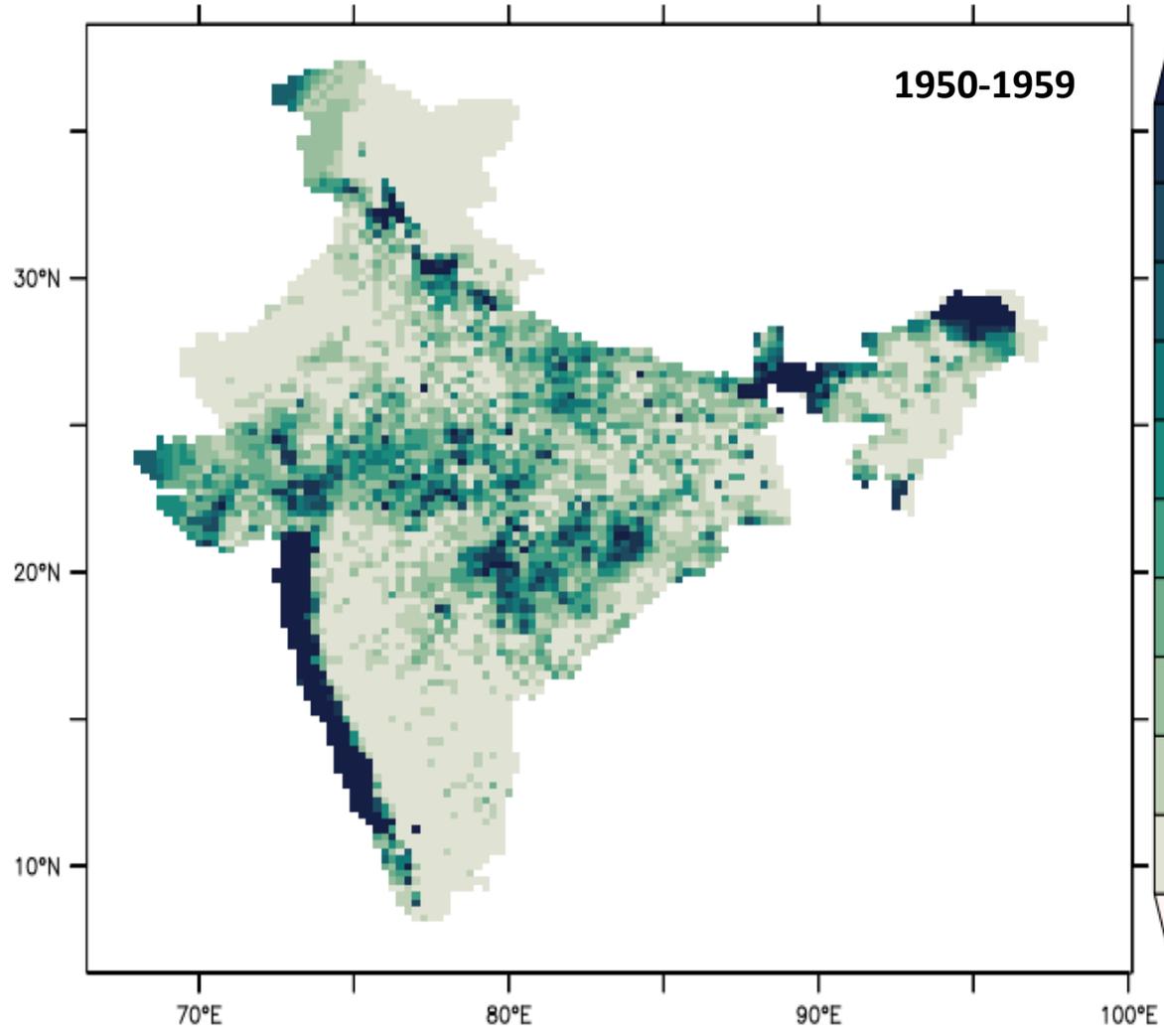


Jin and Wang (2017)

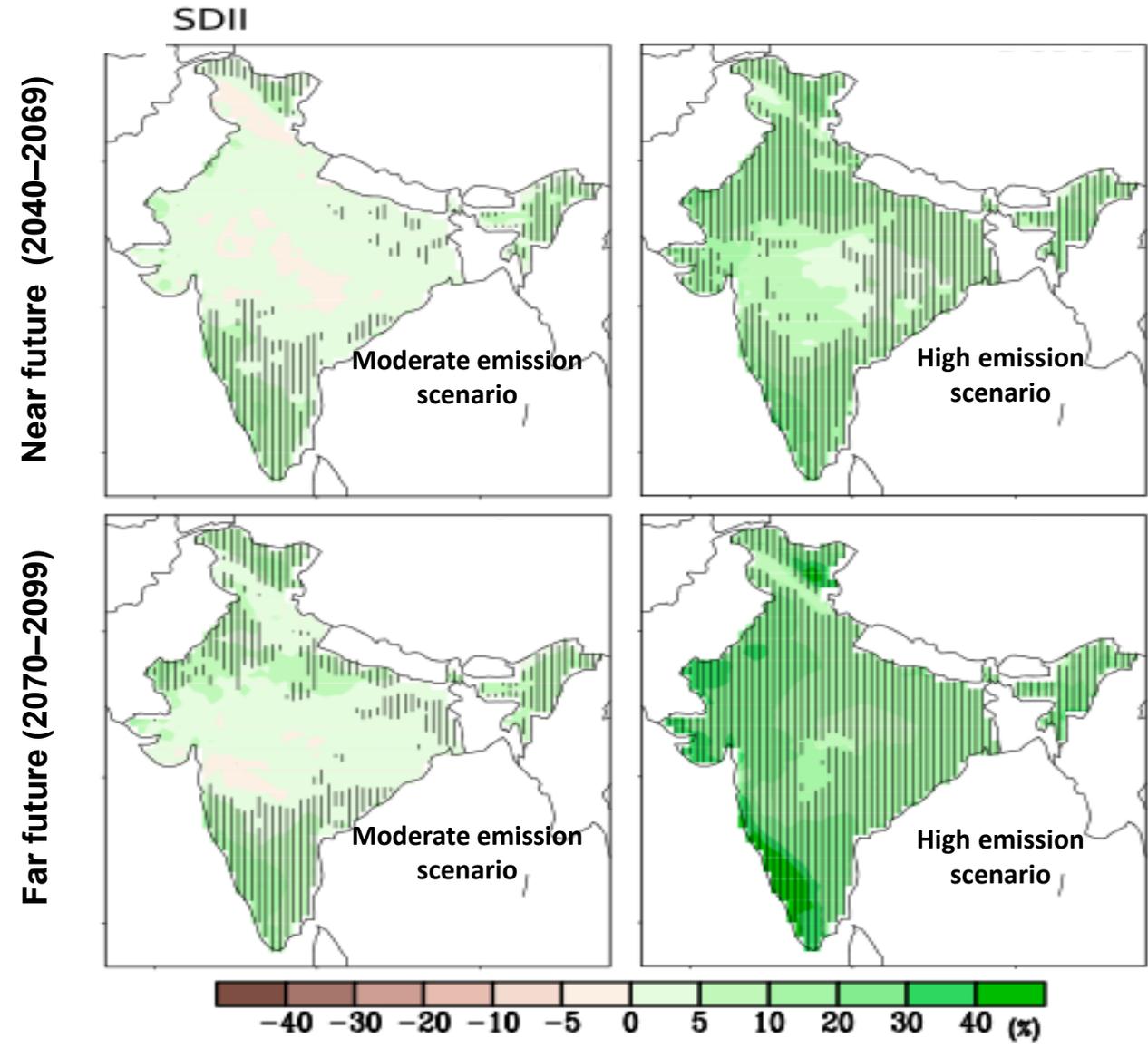




Frequency of heavy rainfall events > 100mm/day during July & August



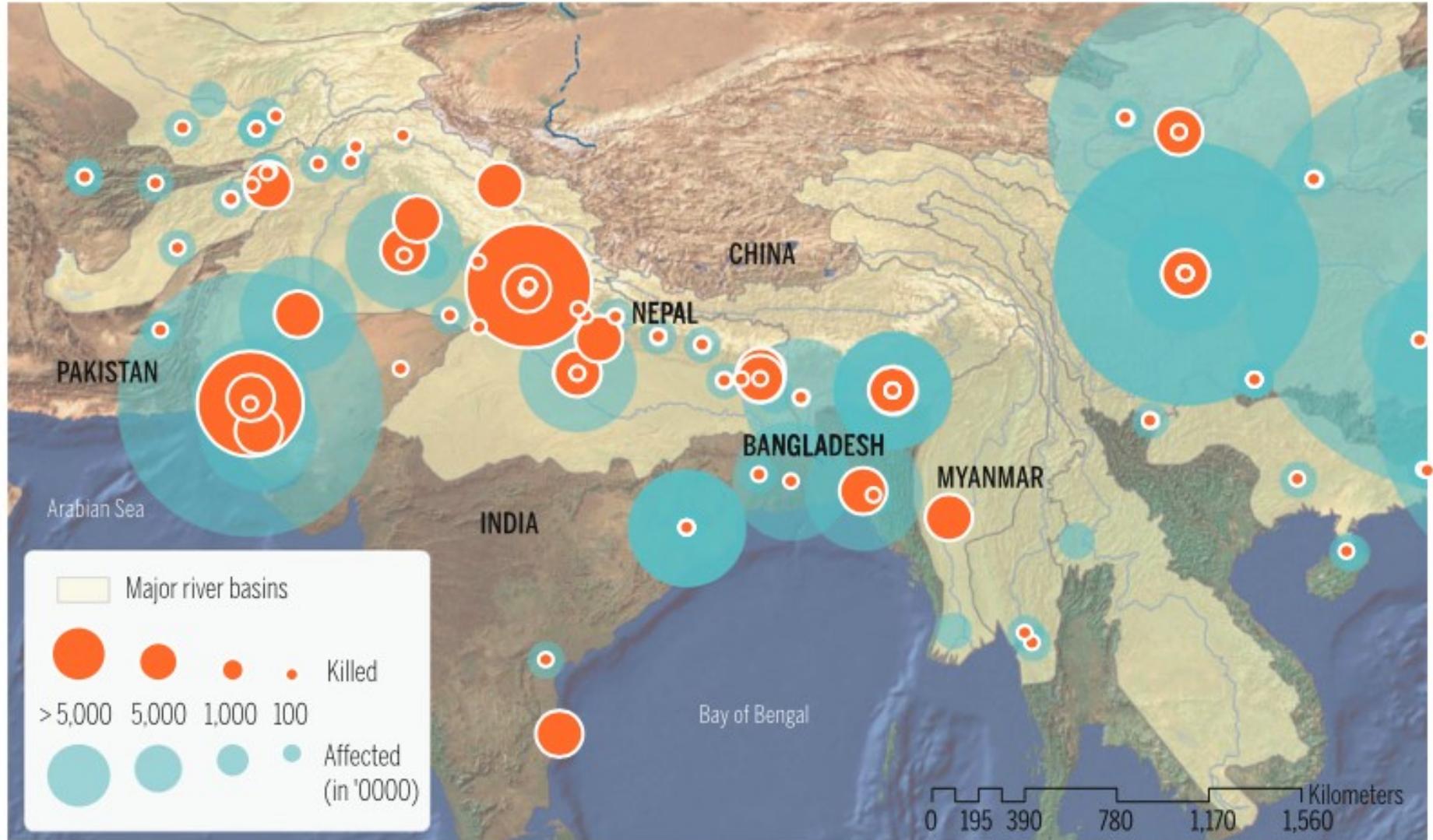
Relative changes in the Daily Intensity Index (SDII) with respect to 1976–2005 reference period



The value obtained by dividing the total rainfall in a season by the number of rainy days in a season. **If the SDII is increasing, it can be assumed that it has rained more in a few days.** It has to be assumed that conditions such as **floods may increase** Models estimate that rainfall intensity (SDII) may increase by 21% by the end of the 21st century

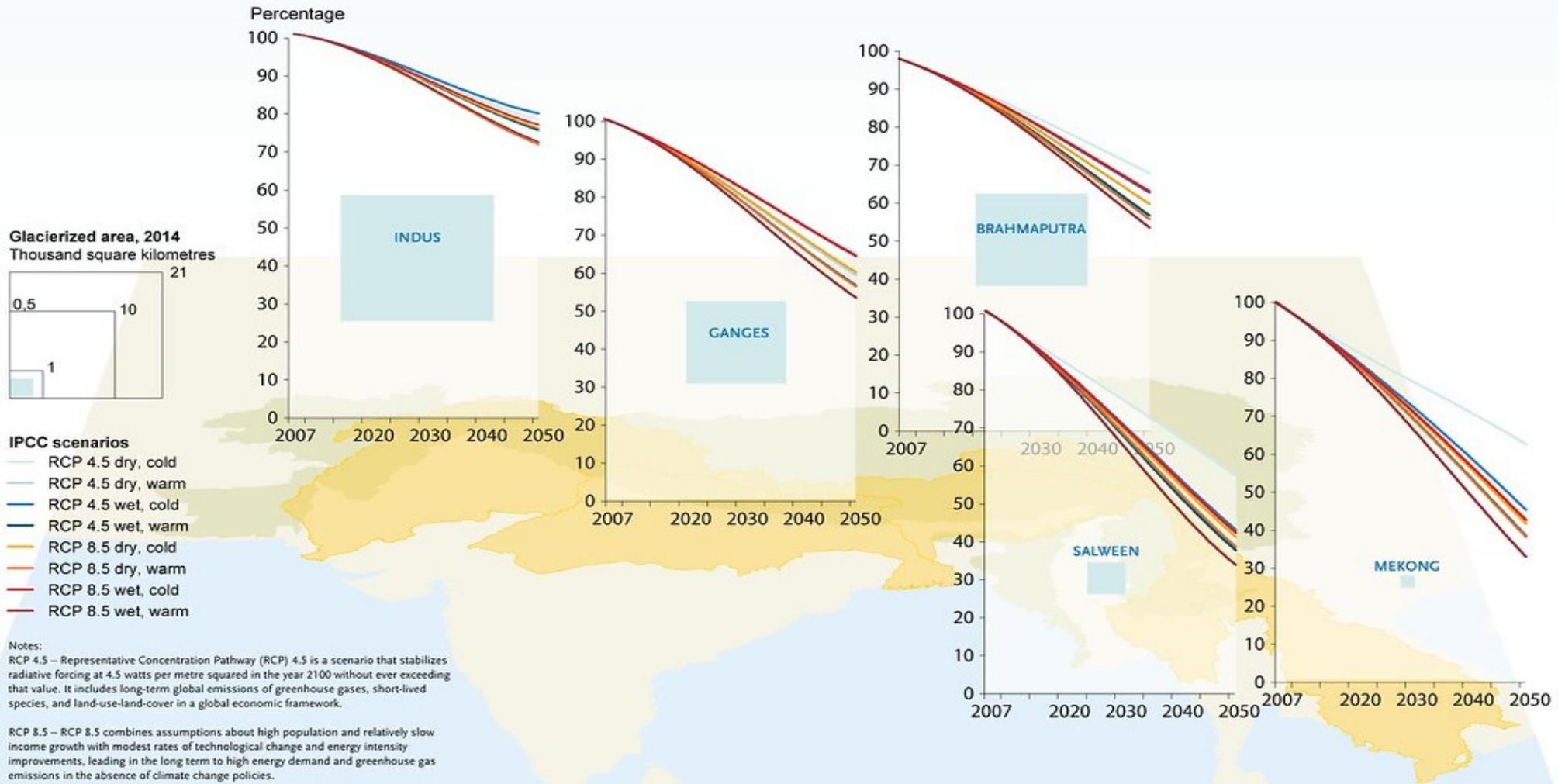
Sum of precipitation in wet days, and dividing that by the number of wet days

Spatial extent and impact of flood disasters in the major river basins originating in HKH from 2010 to 2014

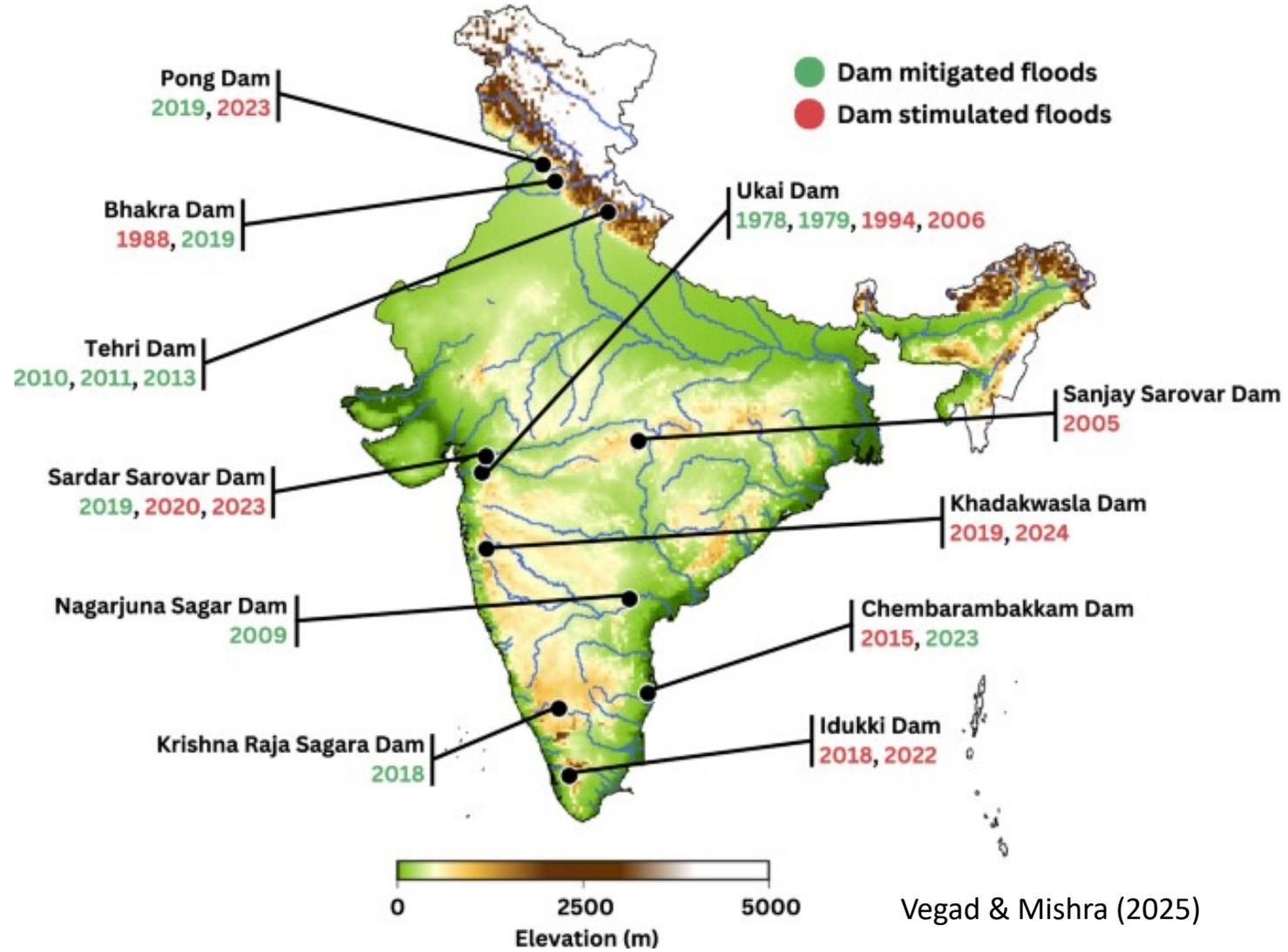


(Source EM-DAT: The Emergency Events Database—Université catholique de Louvain (UCL)—CRED, D. Guha-Sapir—www.emdat.be, Brussels, Belgium)

Projected glacial area change by 2050

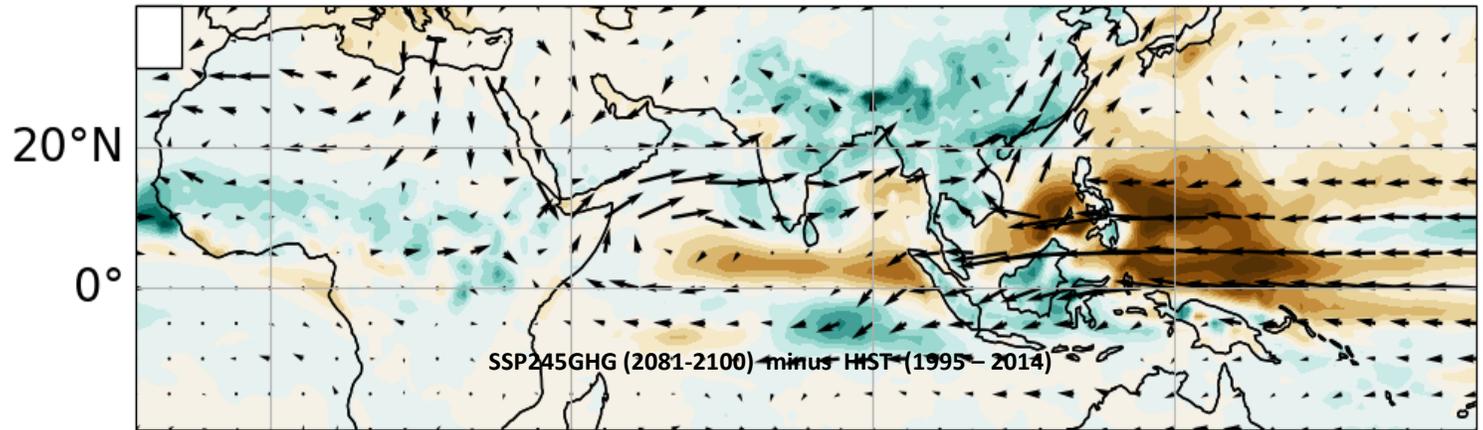


Map illustrating the reported cases where dams played a major role in either mitigating or stimulating floods

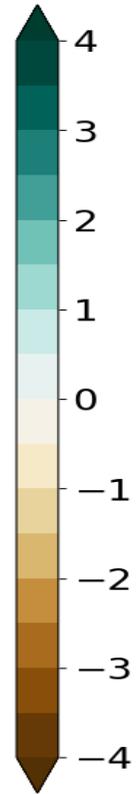
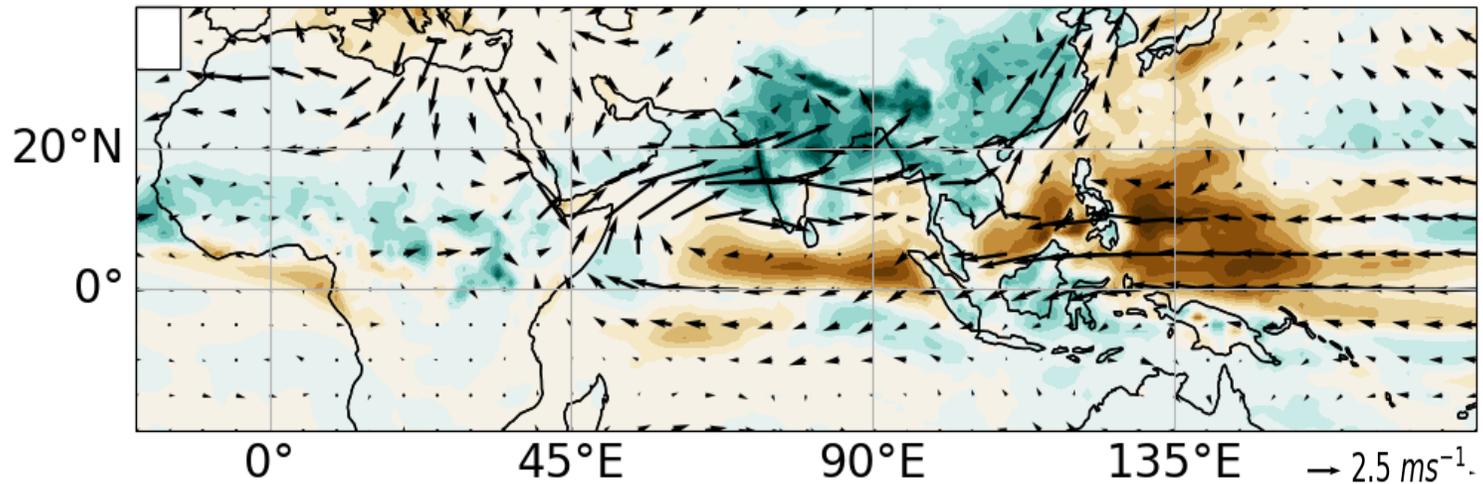


Future – Present day
SSP245 (2081-2100) minus HIST (1995 – 2014)

SSP245 - HIST



SSP245GHG - HIST

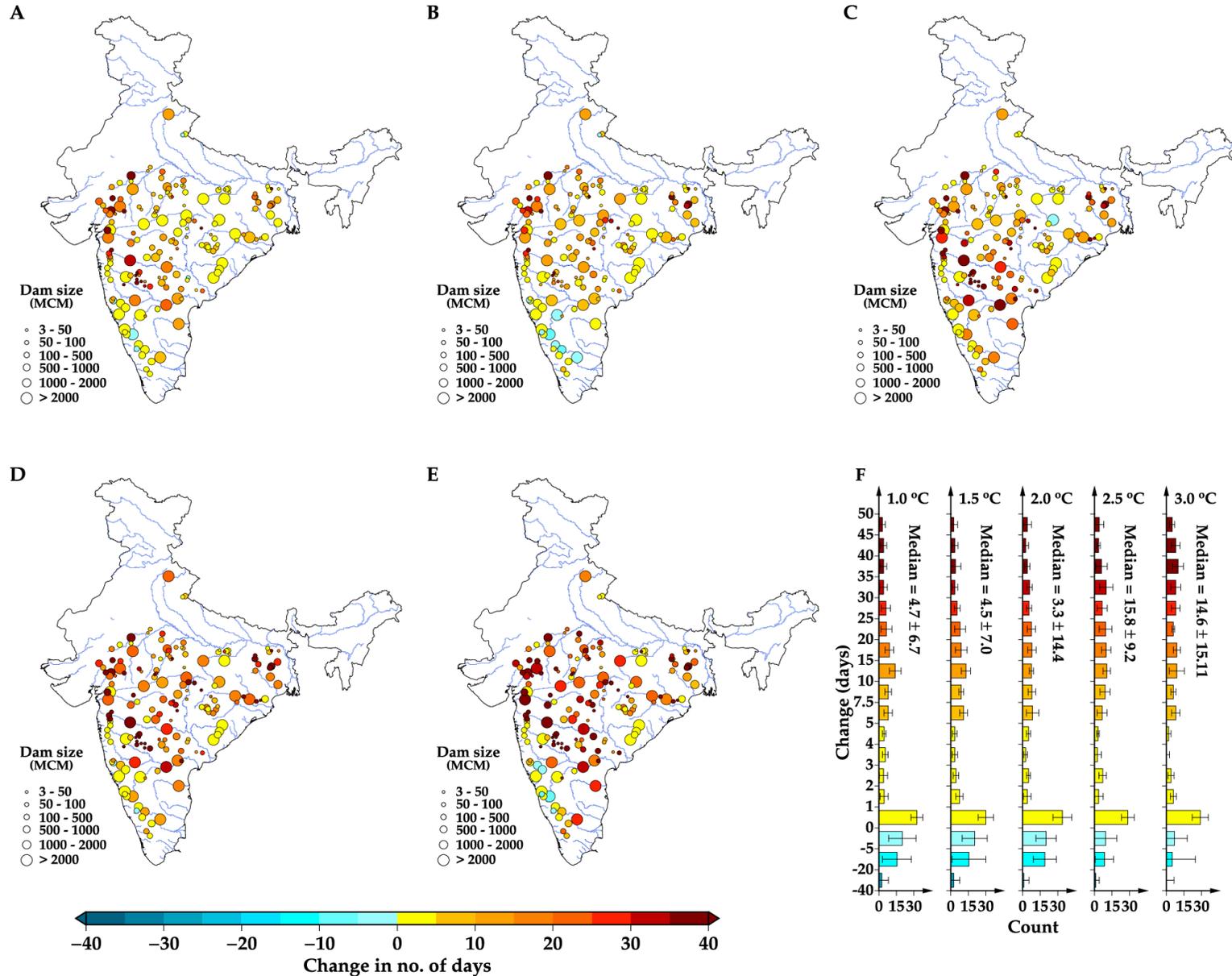


Future projections suggest a stronger monsoon and intensified Somali Jet Stream, mainly due to GHG-induced rainfall enhancement

GHG increase Temperature → More evaporation → More Rainfall

Aerosol decrease → Increase insolation → increase Temperature → More evaporation → More Rainfall

This is likely to alter water availability and increase associated risks in the region in the future

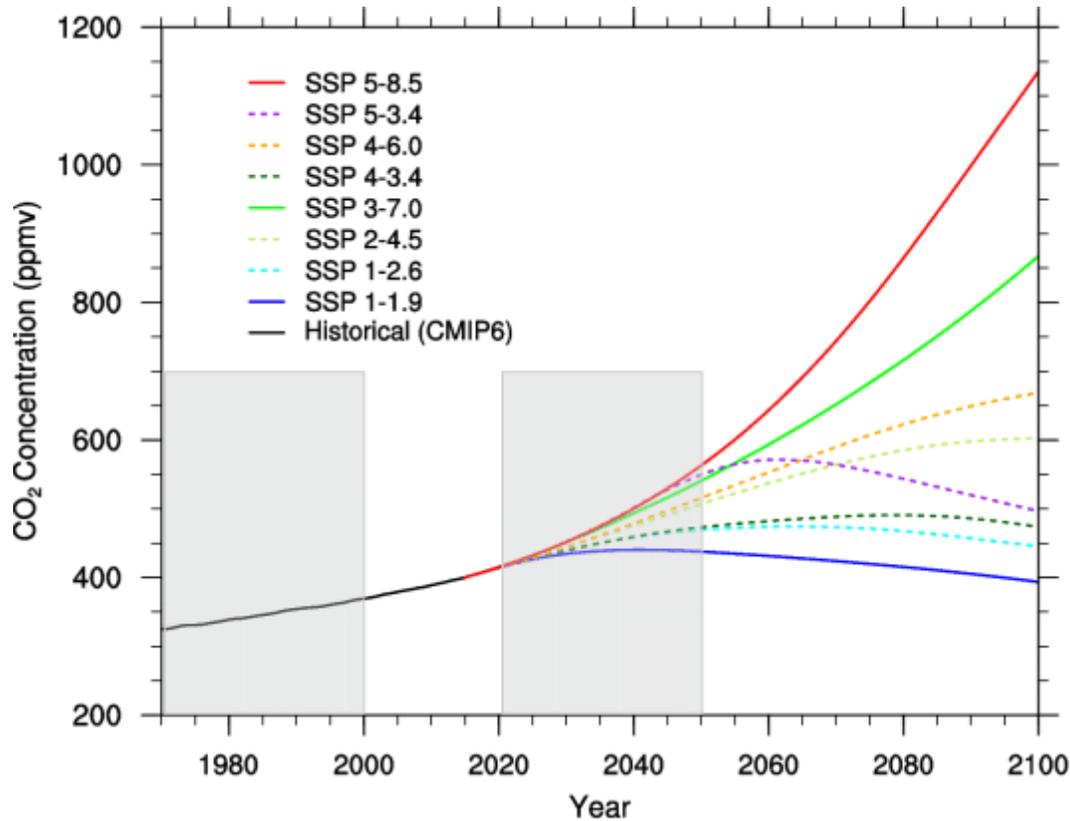


Change in the number of days when dam storage remains full more than 90% of their live storage capacity for the selected global warming levels (**A** 1.0 °C, **B** 1.5 °C, **C** 2.0 °C, **D** 2.5 °C, **E** 3.0 °C). The change is computed against the historical reference period (1995–2014). **F** Distribution of change in the number of days when dam storage remains full more than 90% of their live storage capacity for the global warming levels shown through (**A–E**).

Future ?

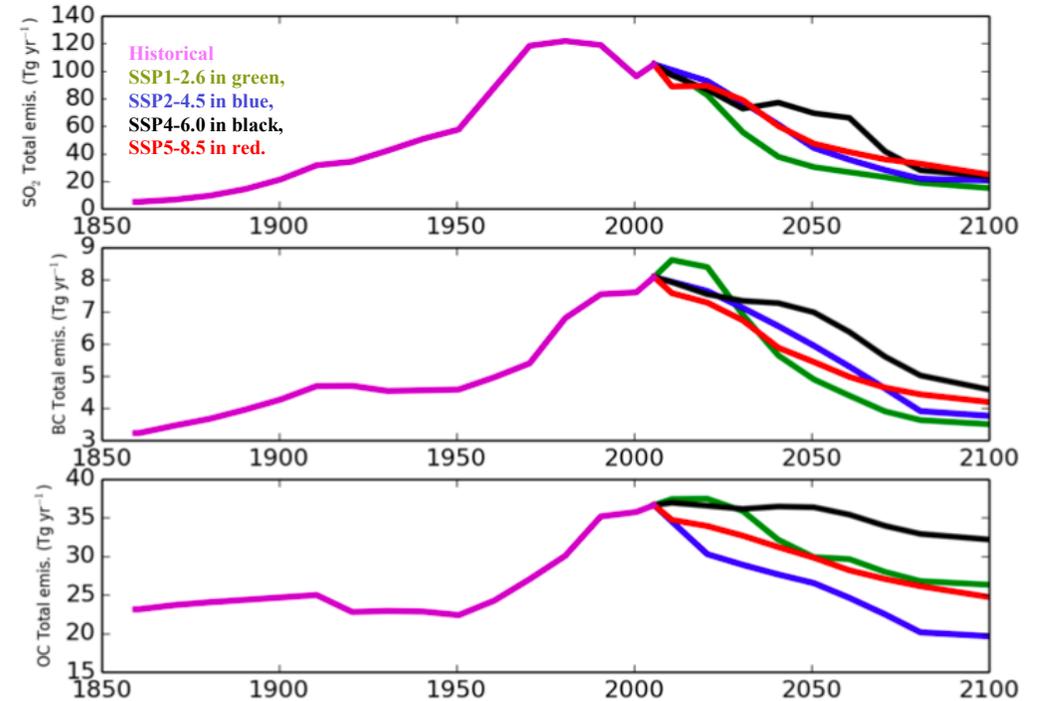
Possible Future Changes in CO₂ and Aerosol Concentrations

Expected CO₂ concentrations under various future scenarios



GHG increase Temperature->More evaporation-> More Rainfall

Expected Aerosol concentrations under various future scenarios



Aerosol decrease -> Increase insolation ->increase Temperature->More evaporation-> More Rainfall

This combined effect will create a paradox, making the region more susceptible to extreme events



Key points

Climate change is no longer a future concern—it is already reshaping hydrological extremes. India is witnessing a clear rise in cloudbursts, flash floods, GLOFs, landslides, and compound events driven by evolving monsoon–western disturbance interactions.

Rainfall intensification and variability pose growing risks to dam safety and operations. Projected increases in extreme precipitation challenge design assumptions and flood-handling capacities.

Dams are at the frontline of climate impacts in India. Globally and nationally, **dam infrastructure is increasingly exposed to cascading risks**, threatening storage integrity, downstream safety, and energy security.

Conventional risk assessment is no longer sufficient. Stationarity assumptions must give way to **climate-informed, dynamic risk frameworks that integrate extremes, uncertainty, and compound hazards**.

Climate-resilient dam and hydropower systems demand urgent action. This includes updated **design standards, real-time monitoring, early-warning systems, adaptive reservoir operations, and basin-scale planning**.

From risk to resilience—action is the priority. Strengthening policy, engineering practices, and institutional coordination is essential to safeguard lives, infrastructure, and sustainable hydropower in a warming climate.





Thank You