Climate Change Over the Indian Landmass: Emerging Weather Extremes and Need of Strategic Planning Pathways

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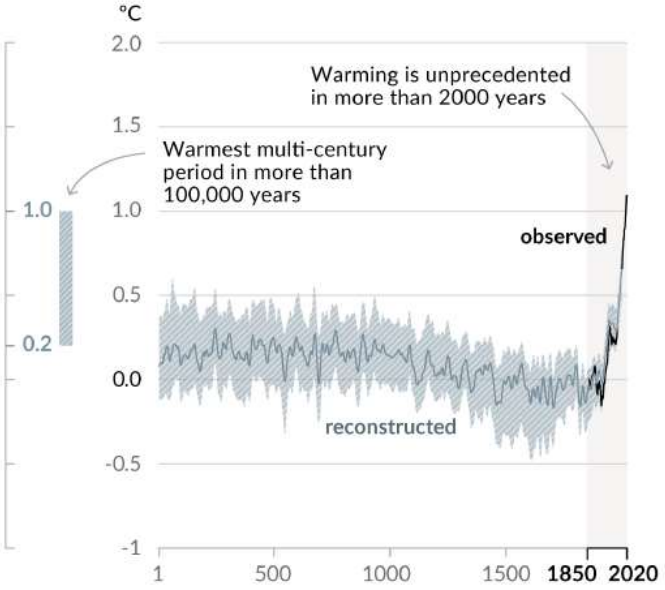
Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

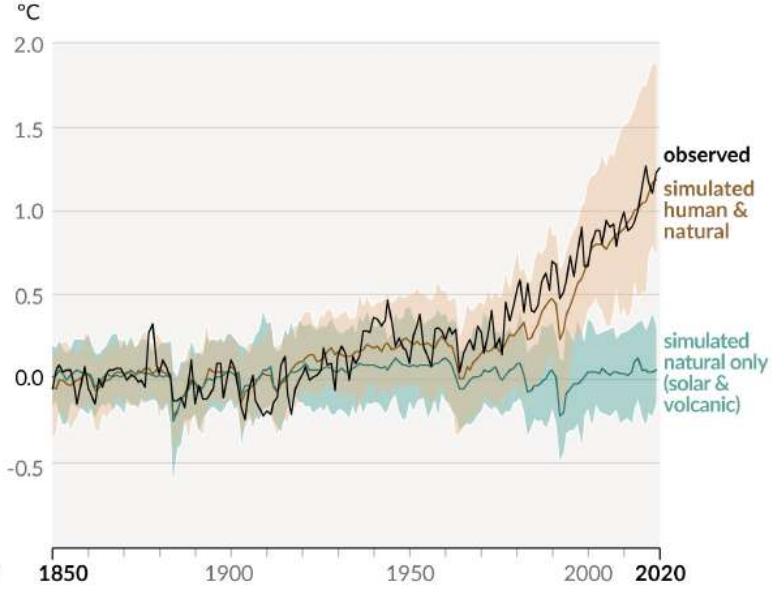
Figure SPM.1

Changes in global surface temperature relative to 1850-1900

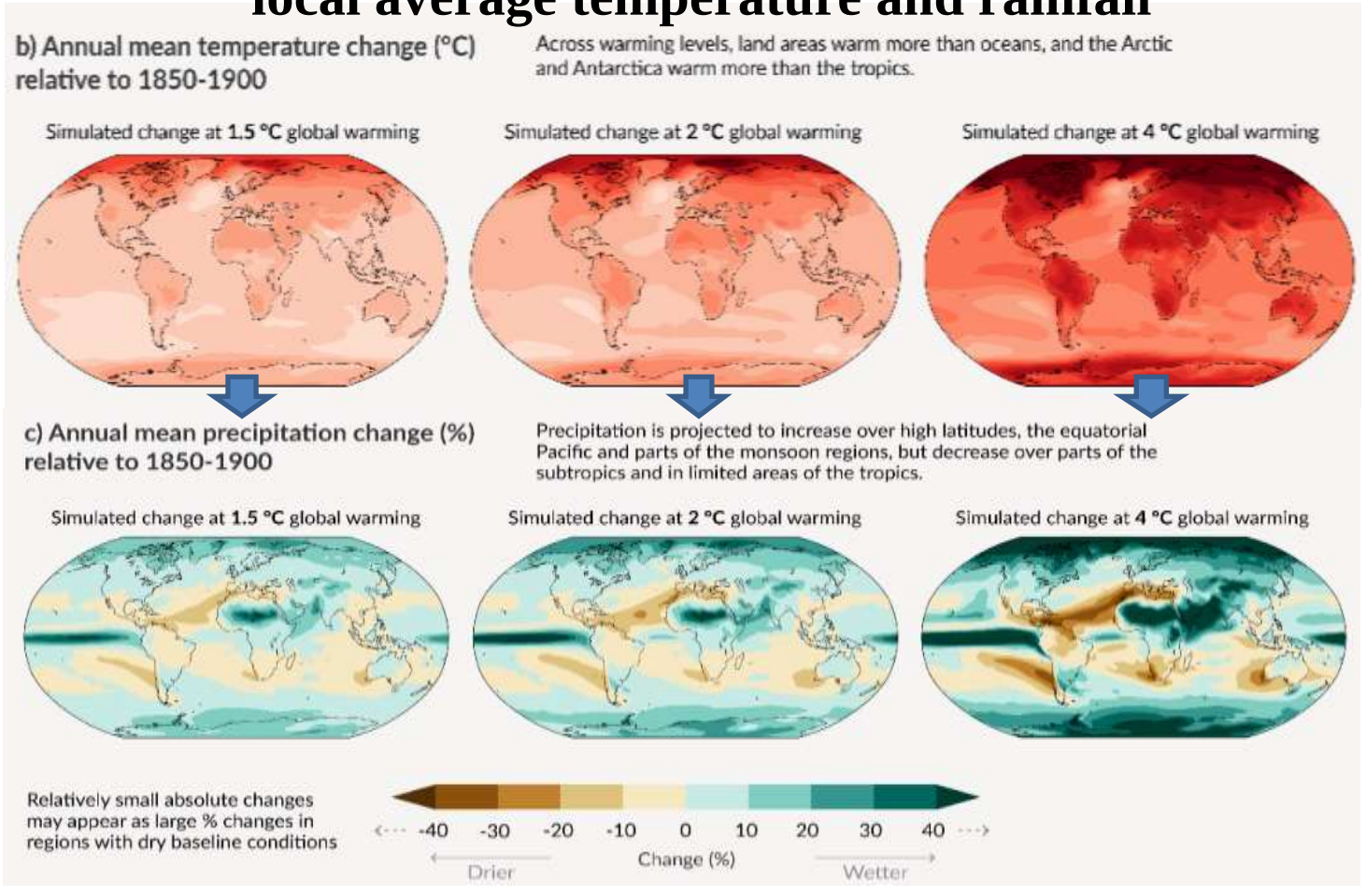
a) Change in global surface temperature (decadal average) as reconstructed (1-2000) and **observed** (1850-2020)



b) Change in global surface temperature (annual average) as **observed** and simulated using human & natural and only natural factors (both 1850-2020)



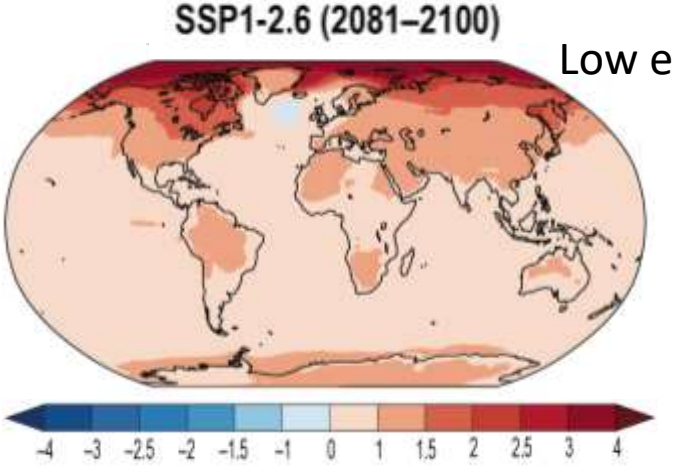
With each increase in global warming, there are significant changes in local average temperature and rainfall



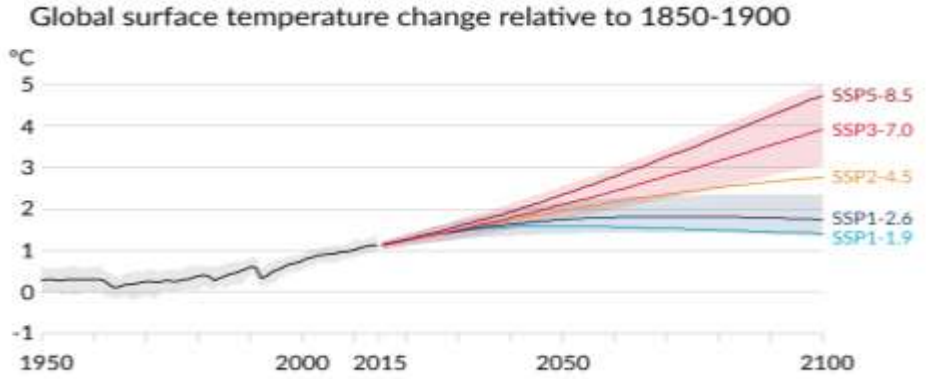
What are we communicating with the public and policymakers?

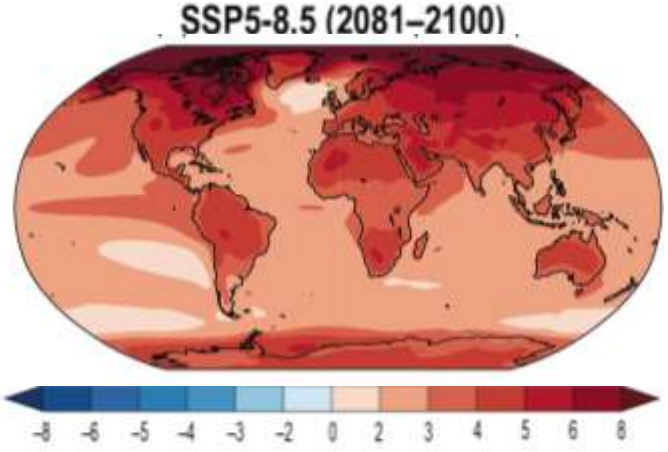
[2081-2100 relative to 1995-2015]

Projected change in global temperature



Low emission scenario





High emission scenario

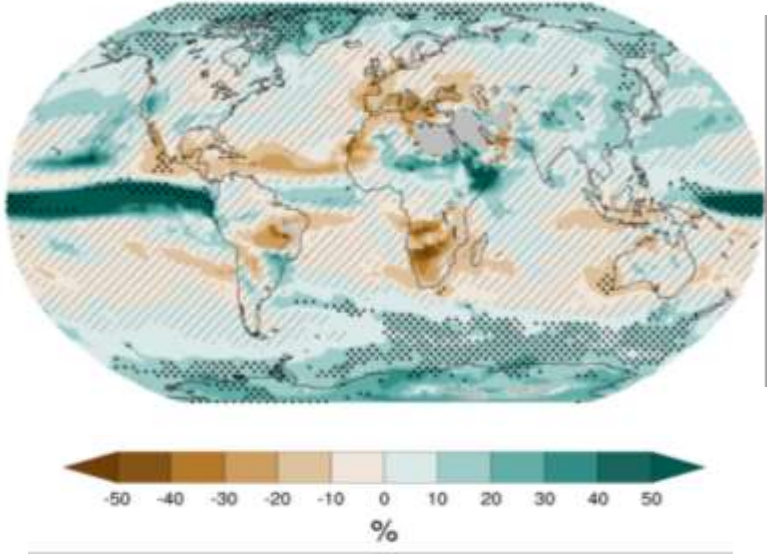
	Near term, 2021–2040		Mid-term, 2041–2060		Long term, 2081–2100	
Scenario	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)	Best estimate (°C)	*Very likely* range (°C)
SSP1-1.9	1.5	1.2 to 1.7	1.6	1.2 to 2.0	1.4	1.0 to 1.8
SSP1-2.6	1.5	1.2 to 1.8	1.7	1.3 to 2.2	1.8	1.3 to 2.4
SSP2-4.5	1.5	1.2 to 1.8	2.0	1.6 to 2.5	2.7	2.1 to 3.5
SSP3-7.0	1.5	1.2 to 1.8	2.1	1.7 to 2.6	3.6	2.8 to 4.6
SSP5-8.5	1.6	1.3 to 1.9	2.4	1.9 to 3.0	4.4	3.3 to 5.7

What are we communicating with the public and policymakers?

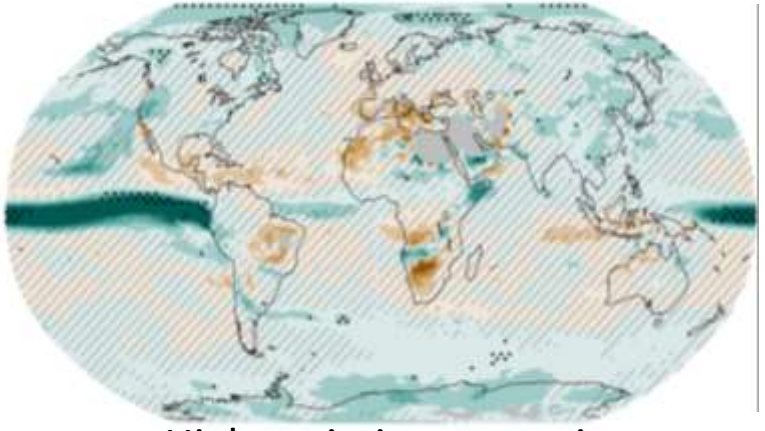
Future change in precipitation pattern

[2081-2100 relative to 1995-2015]

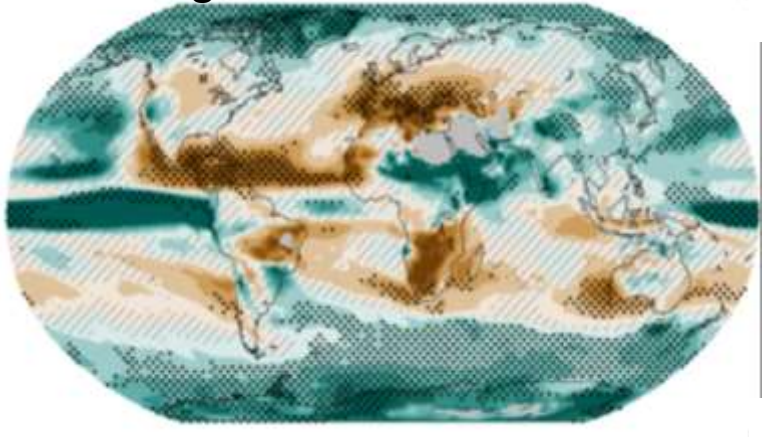
Moderate emission scenario



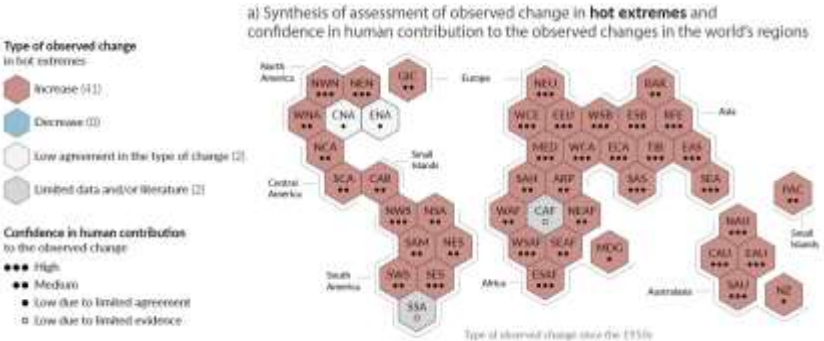
Low emission scenario



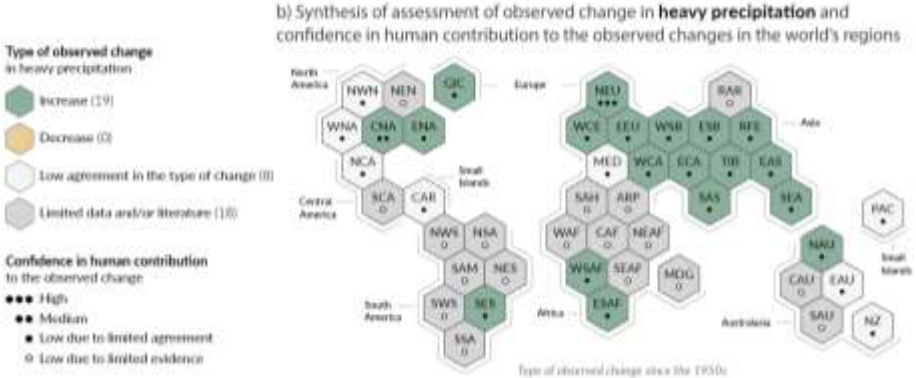
High emission scenario



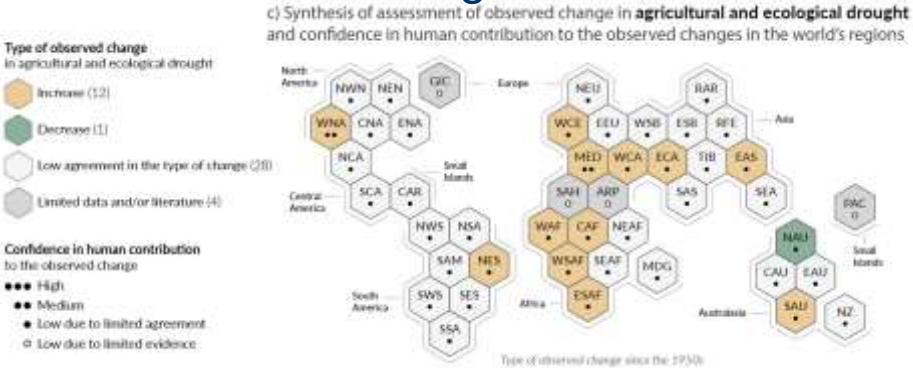
Hot Extremes



Heavy Precipitation

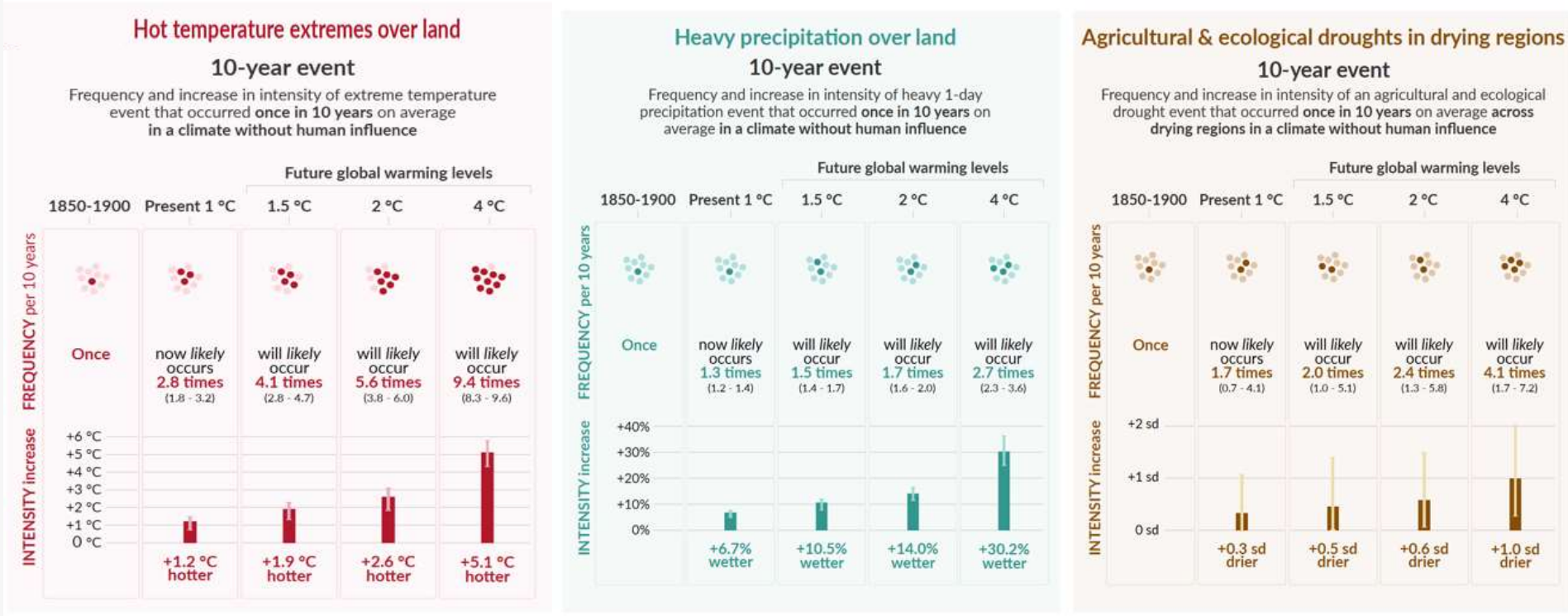


Drought

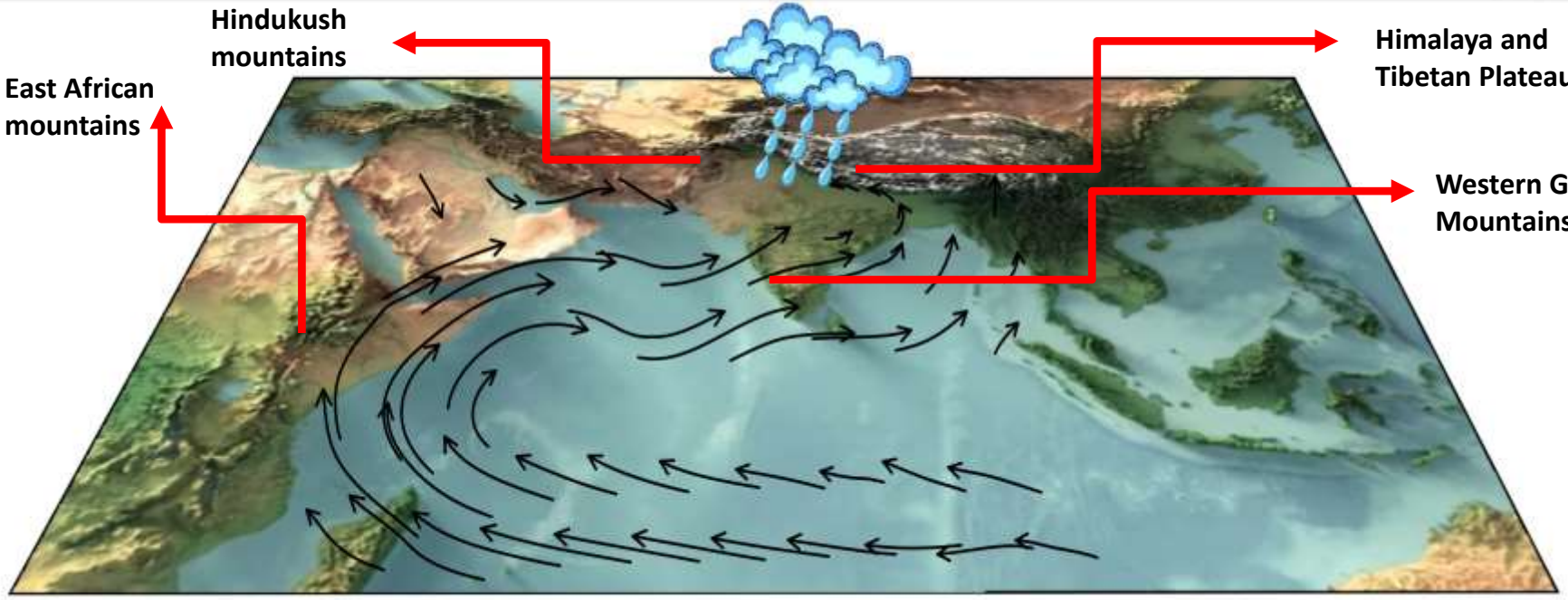


Projected changes in extremes are larger in frequency and intensity with every additional increment of global warming

Fig. SPM.6



Indian Peninsula, Monsoon and Its Complexity



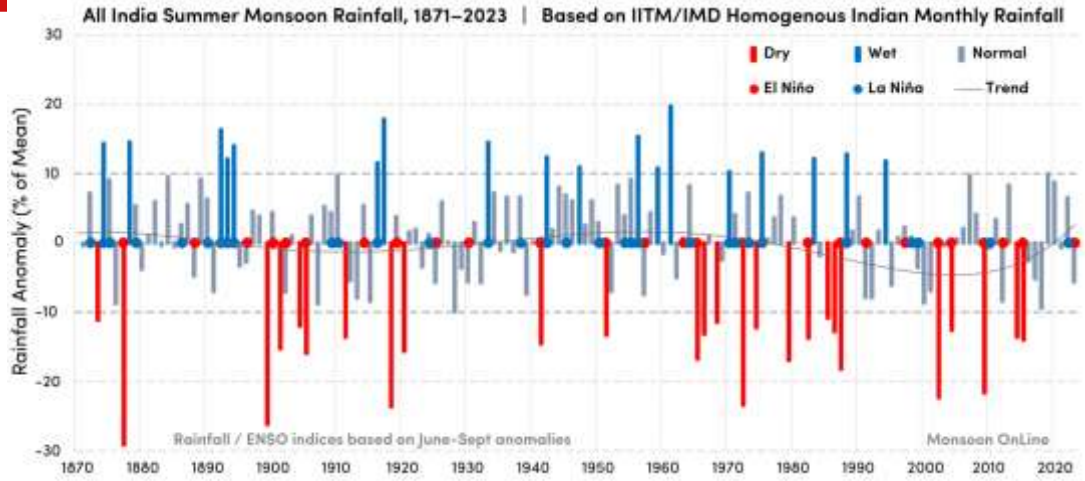
Monsoon circulation and rainfall: A convectively coupled phenomenon

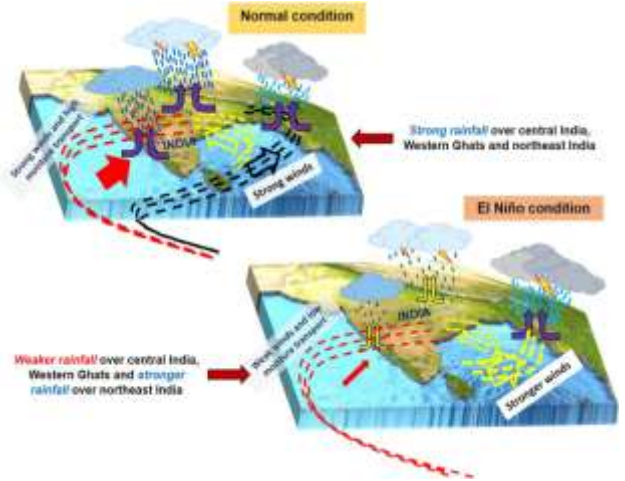
Requires a thermal contrast between land & ocean to set up the monsoon circulation

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

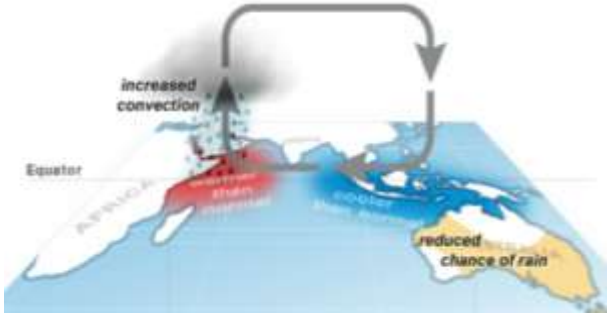
High resolution is needed to accurately simulate these regional characteristics

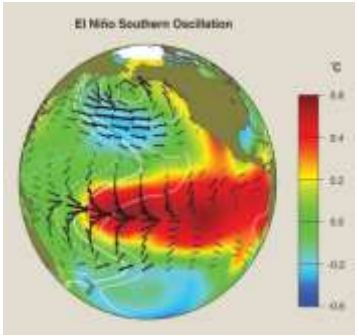
Monsoonal climate modulated by large-scale oceanic processes





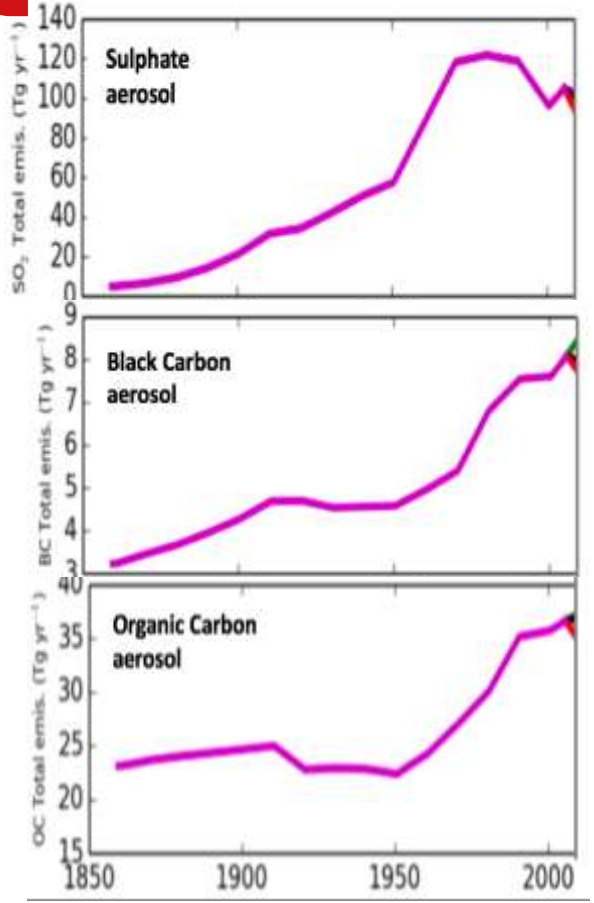
The year to year variations in the seasonal (June – September) summer monsoon rains over India are influenced internal dynamics and external drivers

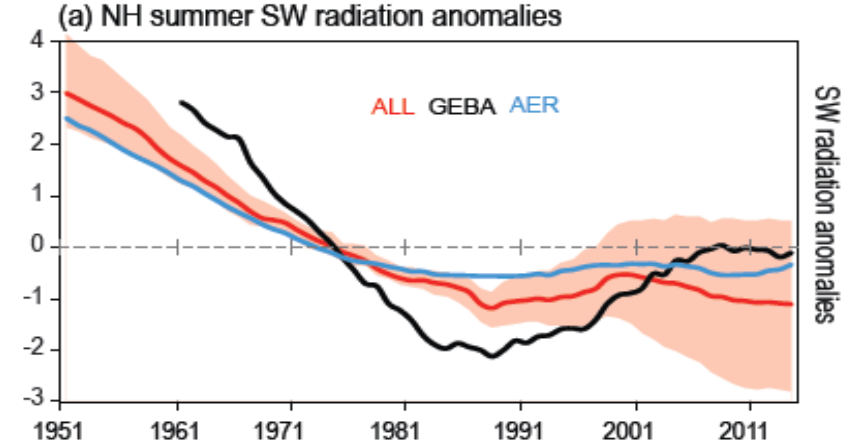


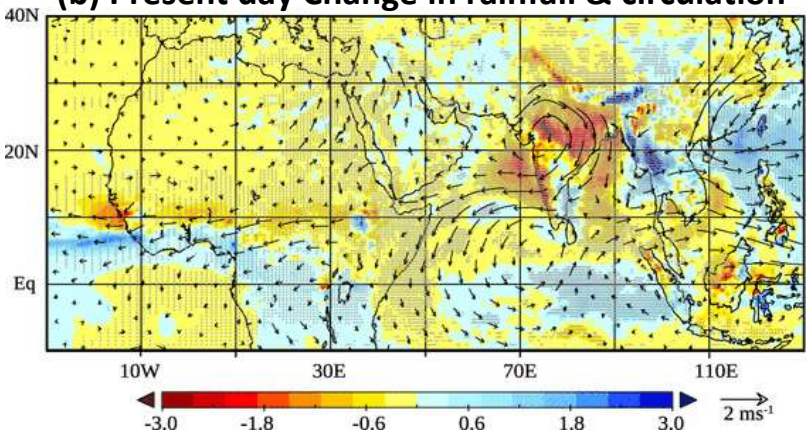


This implies the need for global models to better understand the monsoon

Aerosol-induced solar dimming and decreased monsoon rainfall over India







Aerosol-induced solar dimming

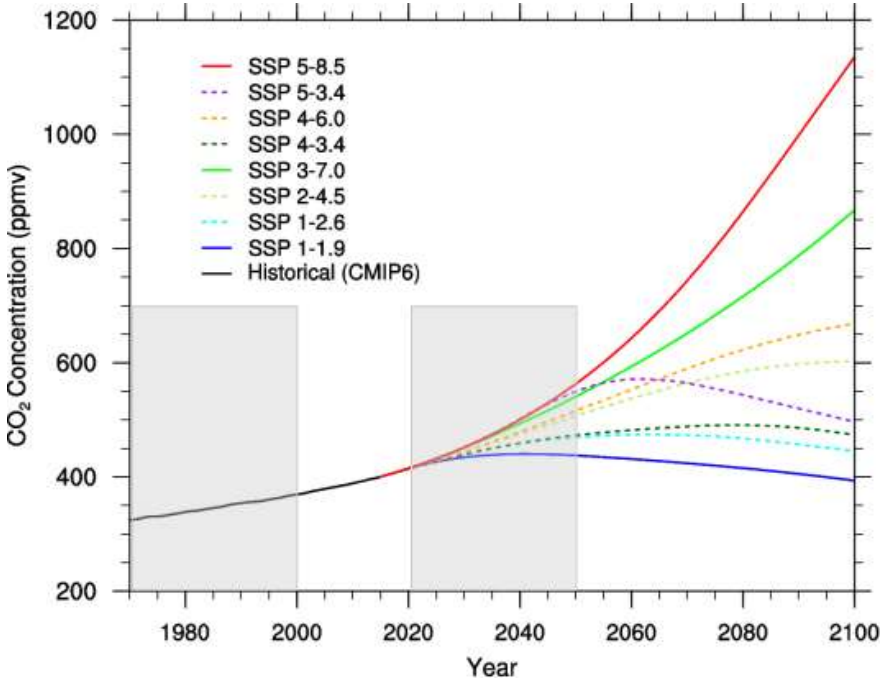
Decrease in monsoon rainfall

After 2000, aerosol loading has been decreasing, leading to a revival of the monsoon, as evident in recent years

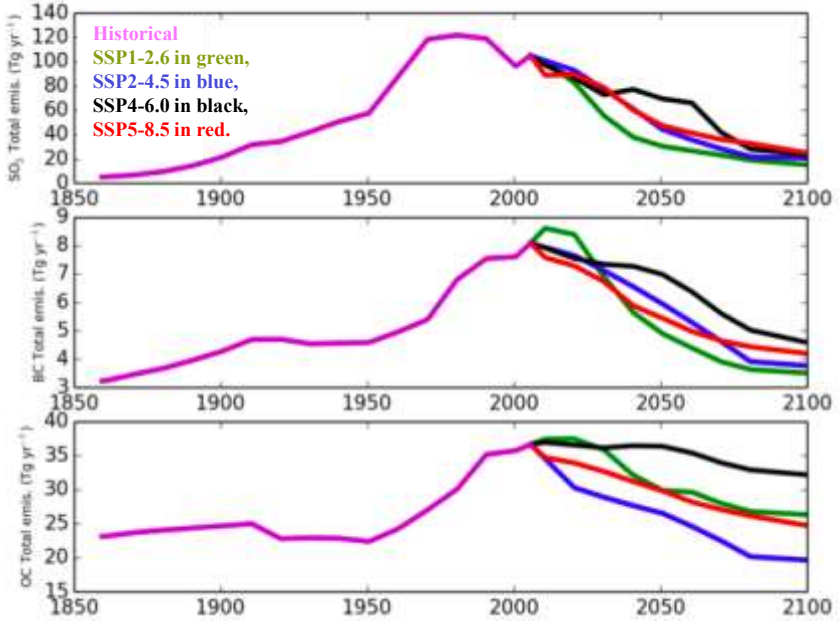
Future ?

Possible Future Changes in CO_2 and Aerosol concentration

Expected CO_2 concentrations under various future scenarios



Expected Aerosol concentrations under various future scenarios

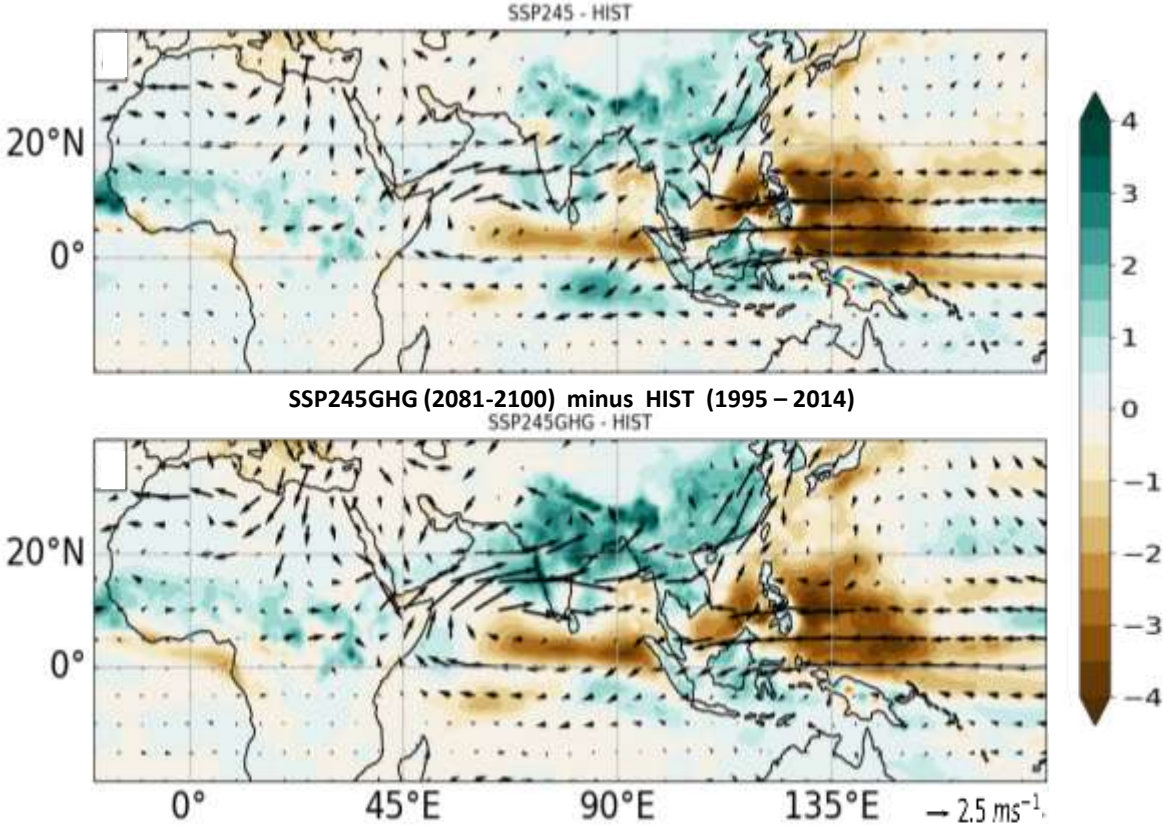


In the future, CO_2 is expected to increase irrespective of the scenario, whereas aerosol levels are expected to decrease

Strengthening of monsoon rainfall & cross-equatorial winds under global warming

Future – Present day

SSP245 (2081-2100) minus HIST (1995 – 2014)



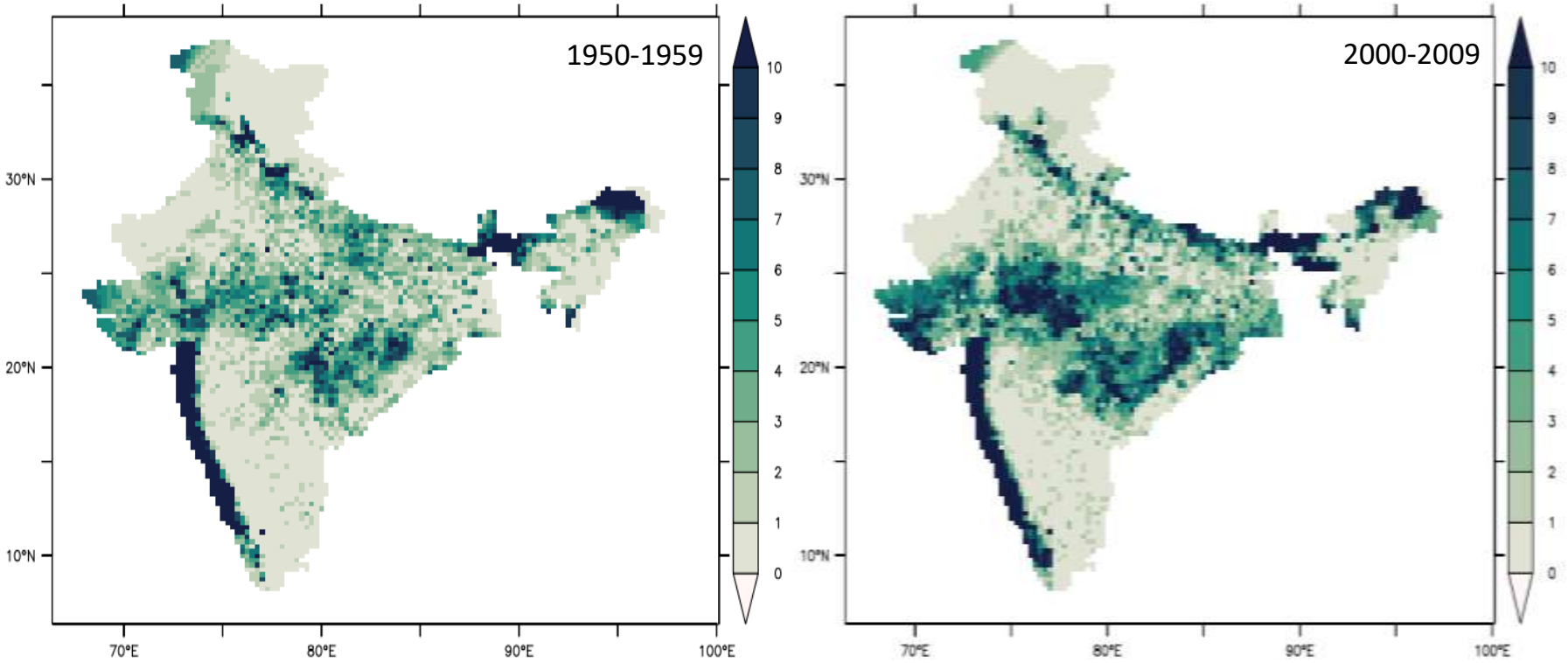
Future projections suggest a stronger monsoon and intensified Somali Jet Stream, mainly due to GHG-induced rainfall enhancement

GHG increase Temperature->More evaporation-> More Rainfall

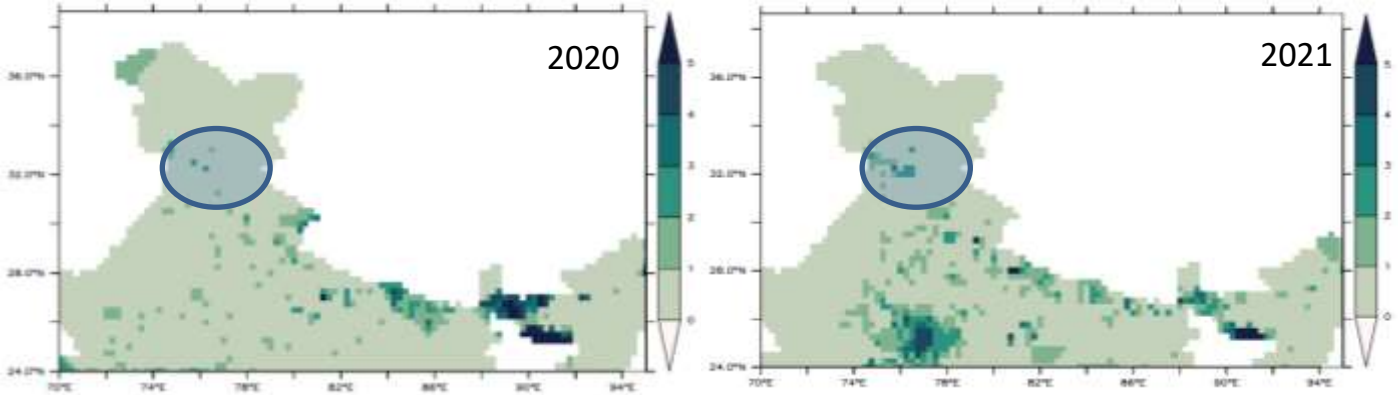
Aerosol decrease -> Increase insolation ->increase Temperature->More evaporation-> More Rainfall

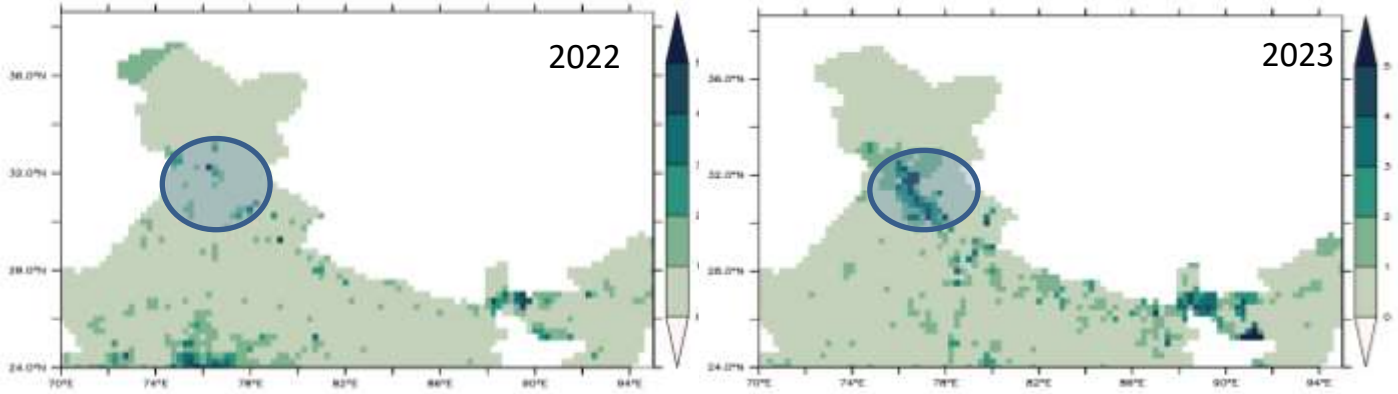
This is likely to alter water availability and increase associated risks in the region in the future

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

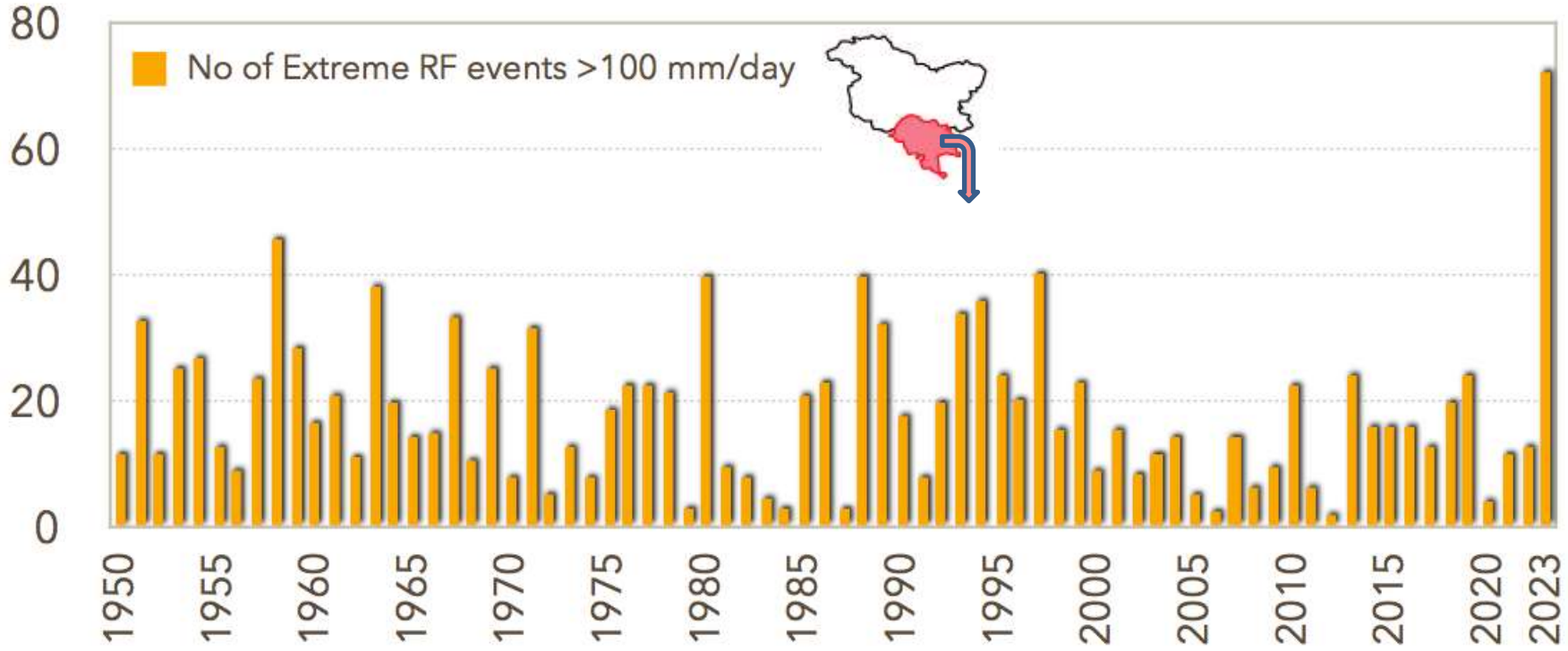


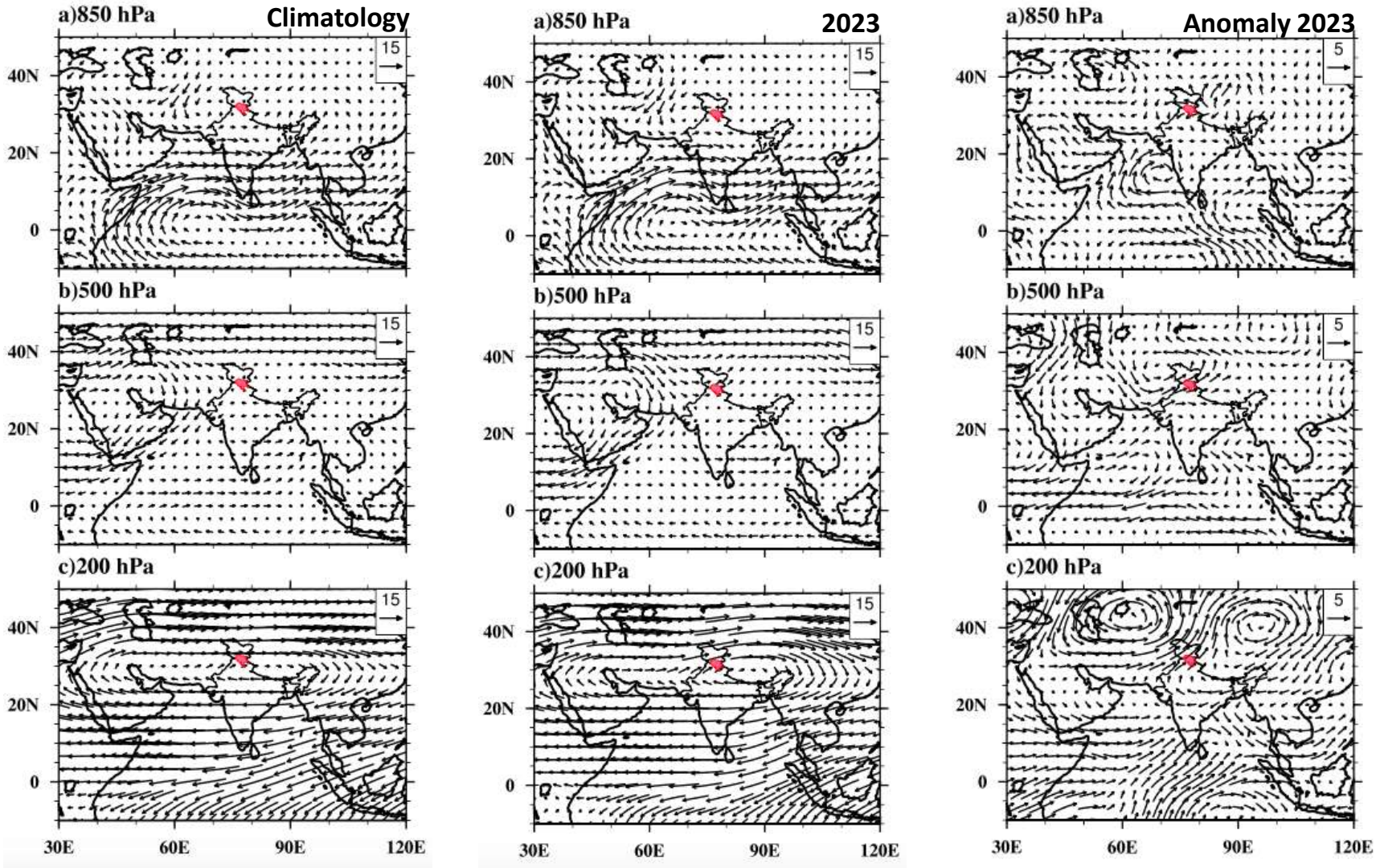
Cloud burst kind of torrential rainfall is becoming so frequent



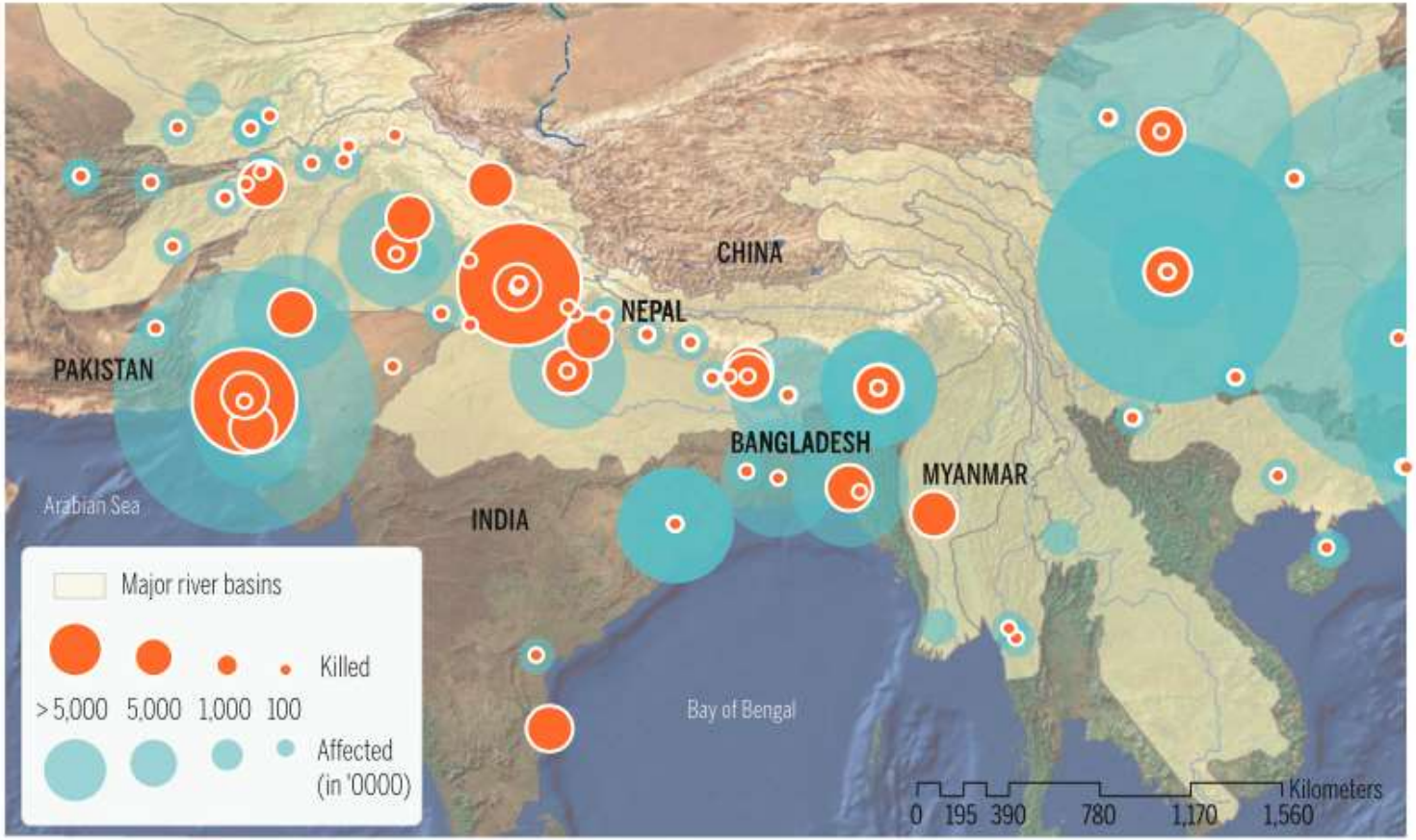


Frequency of heavy rainfall Events > 100mm/day during July & August

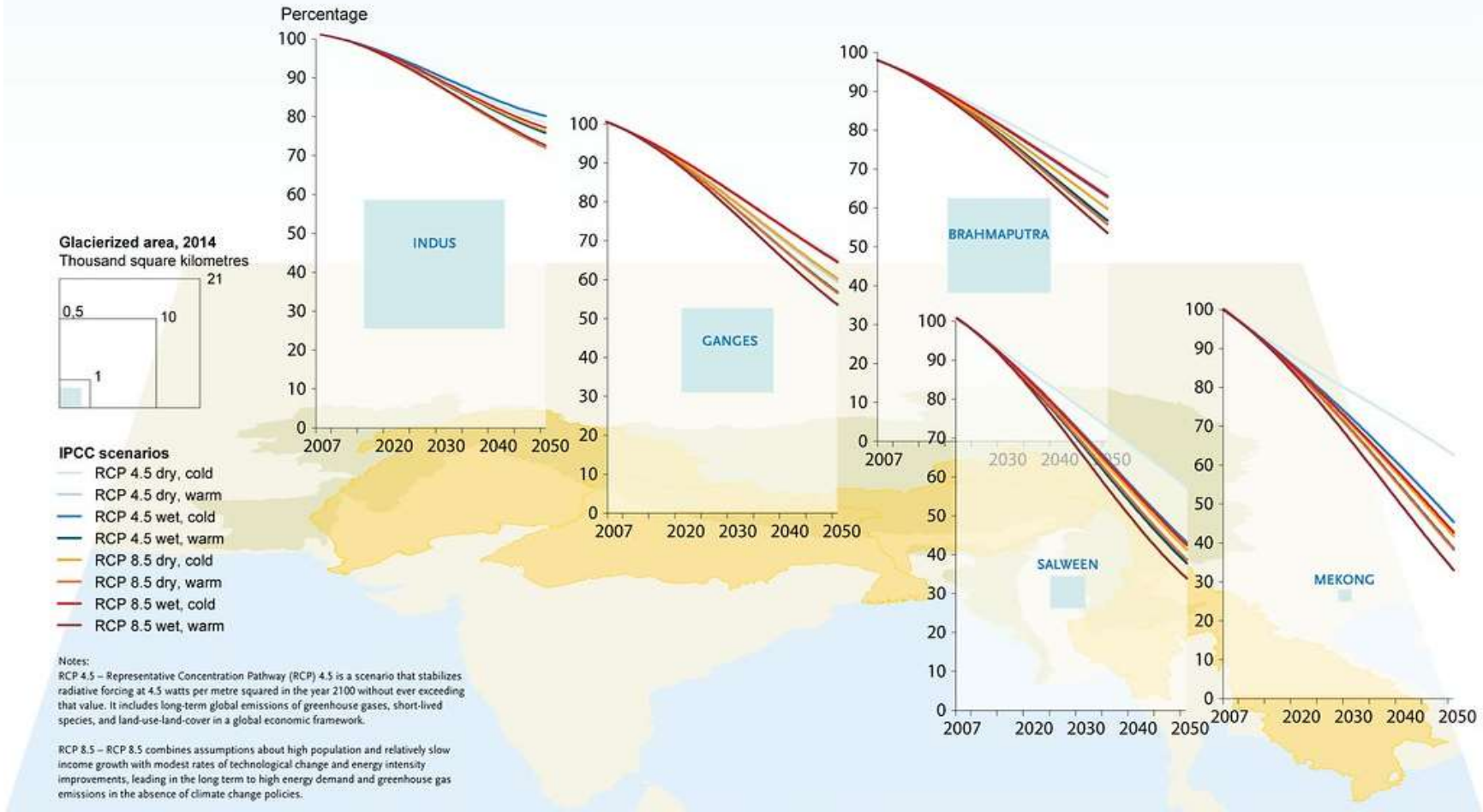

No of Extreme RF events >100 mm/day
80
60
40
20
0
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
2023


a)850 hPa
Climatology
b)500 hPa
c)200 hPa
2023
Anomaly 2023
15
5
40N
20N
0
30E
60E
90E
120E

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

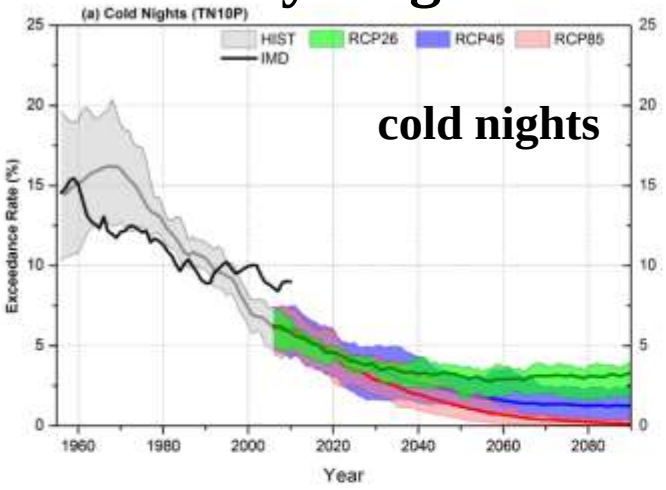


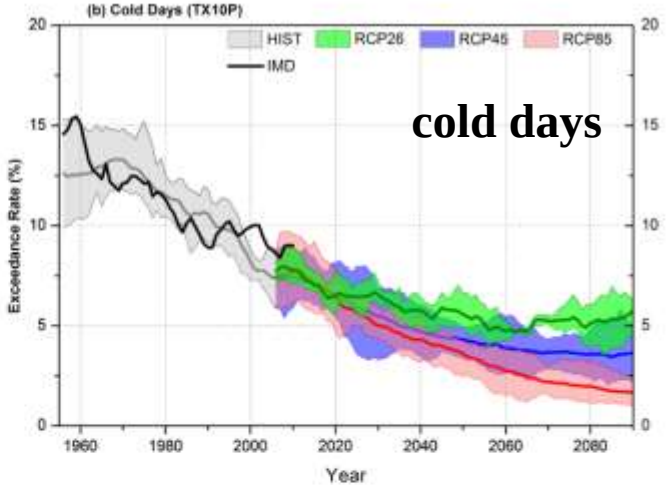
Notes:
RCP 4.5 – Representative Concentration Pathway (RCP) 4.5 is a scenario that stabilizes radiative forcing at 4.5 watts per metre squared in the year 2100 without ever exceeding that value. It includes long-term global emissions of greenhouse gases, short-lived species, and land-use-land-cover in a global economic framework.

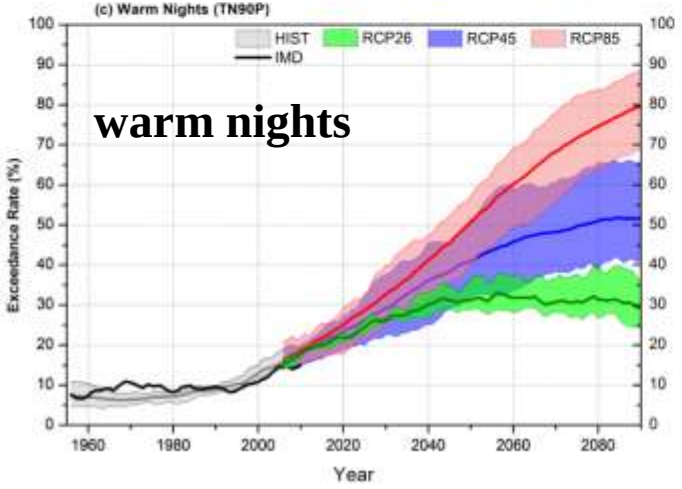
RCP 8.5 – RCP 8.5 combines assumptions about high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas emissions in the absence of climate change policies.

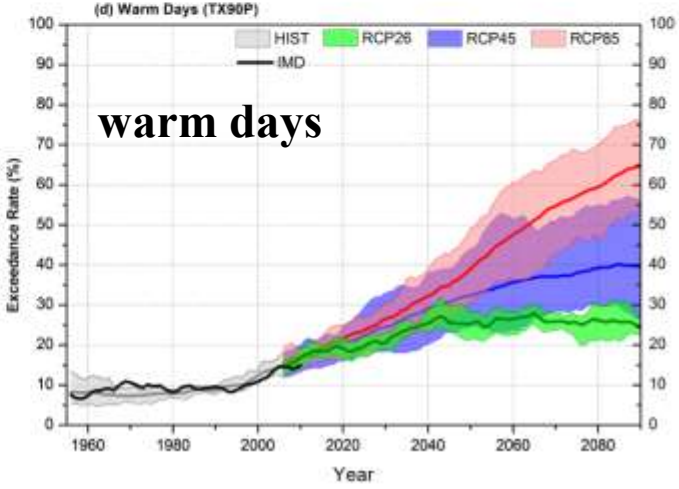
Projected cold & warm days/nights

India averages of temperature indices over land as simulated by the CORDEX South Asia multi-RCM ensemble

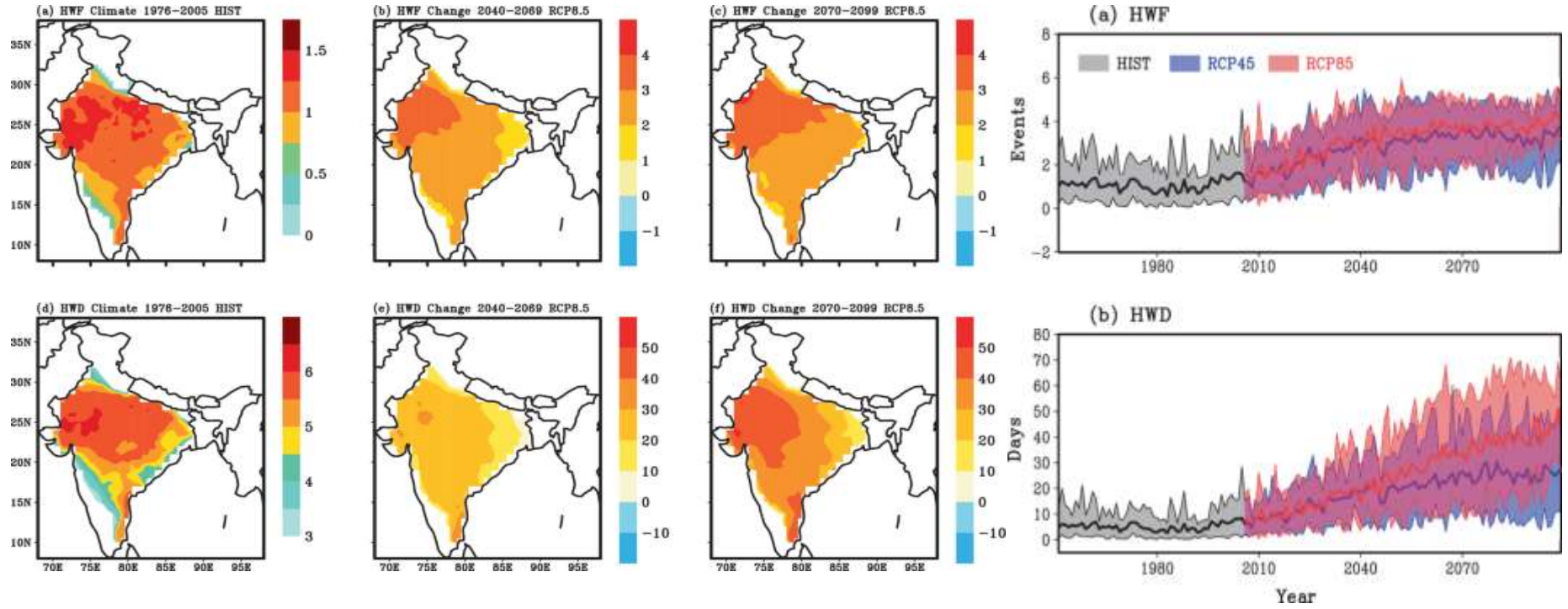








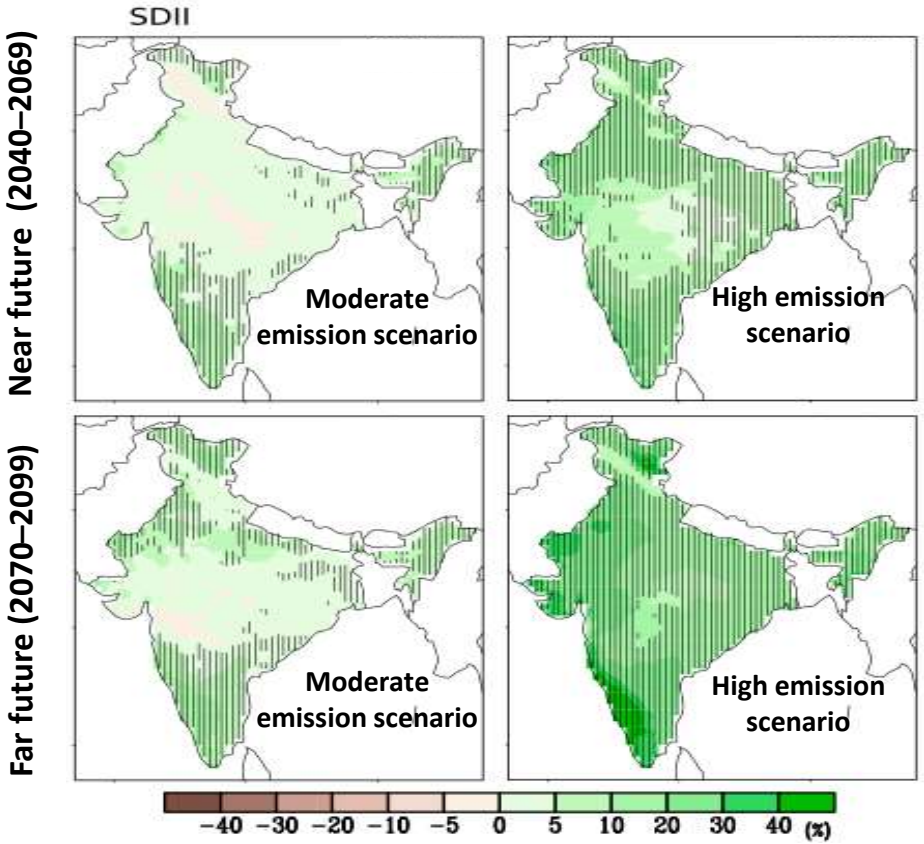
Heatwave frequency (HWF; events per season) and heatwave duration (HWD; days per season)



CORDEX South Asia multi-RCM projections of the summer (April–June) based on the historical simulations during 1951–2005

Relative changes in the Daily Intensity Index (SDII) for Near Future and Far Future with respect to 1976–2005 reference period

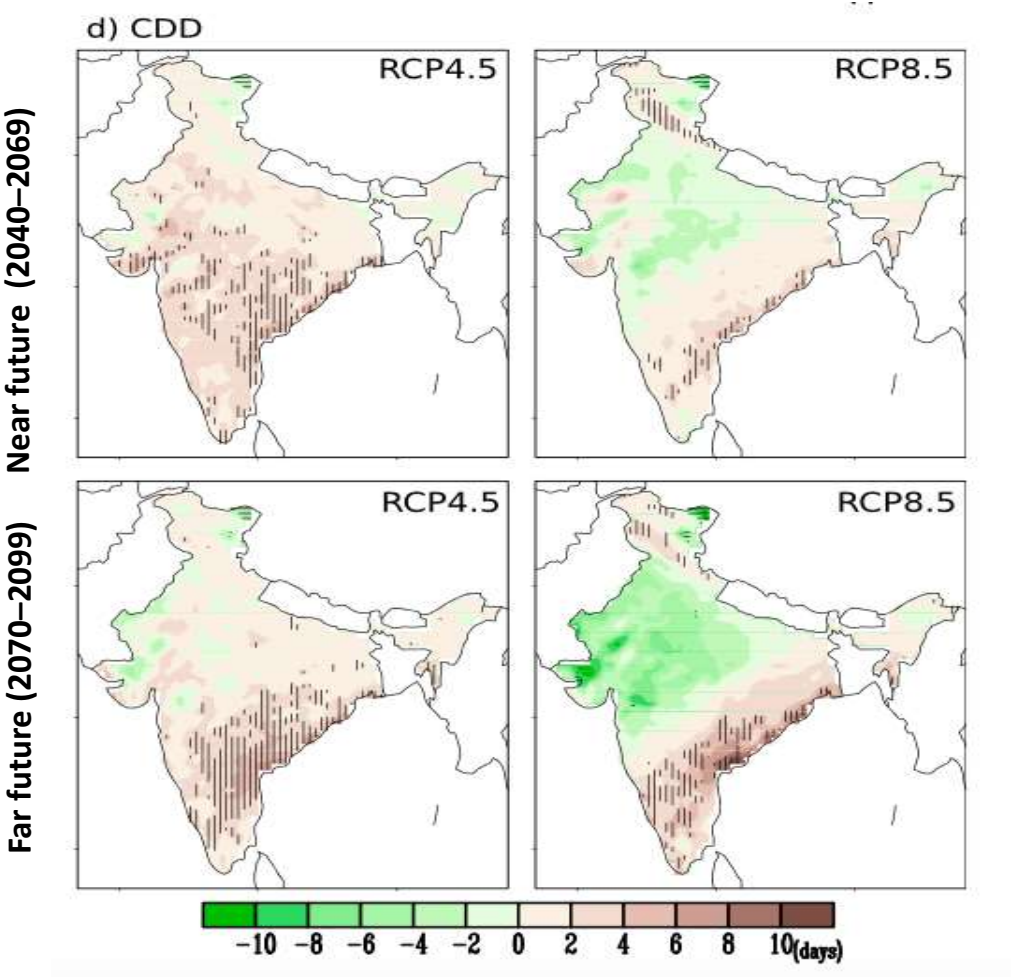
Inference from CORDEX simulations



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 intercity (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

Inference from CORDEX simulations

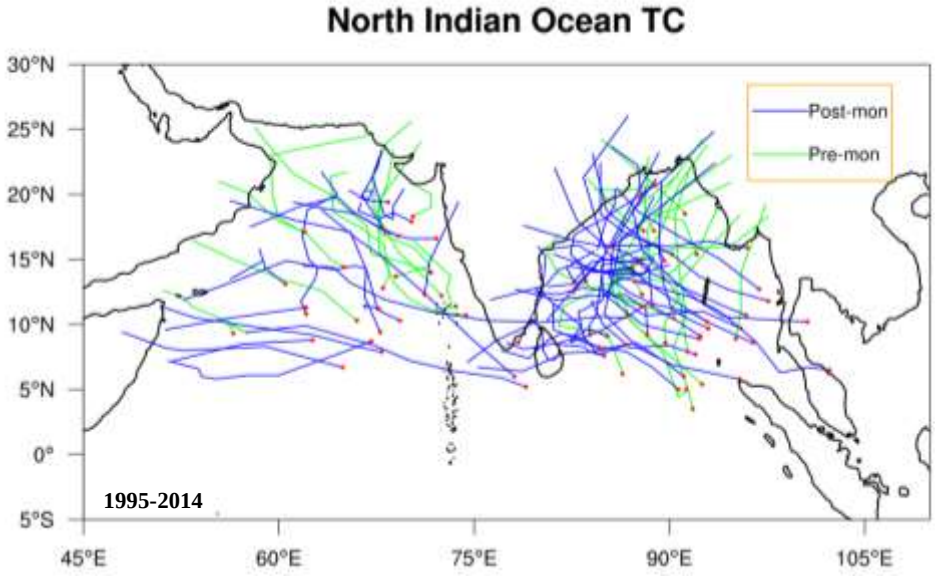


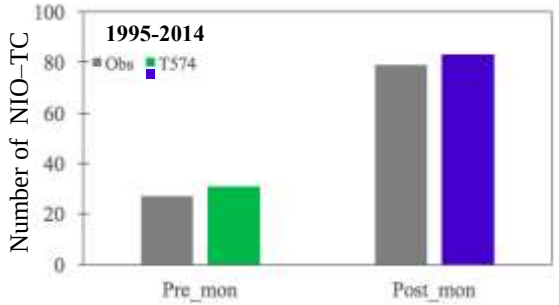
Consecutive dry days are used to describe the duration of precipitation extremes according to the daily precipitation.

CDD means the maximum number of consecutive days with precipitation less than a certain threshold

Applications

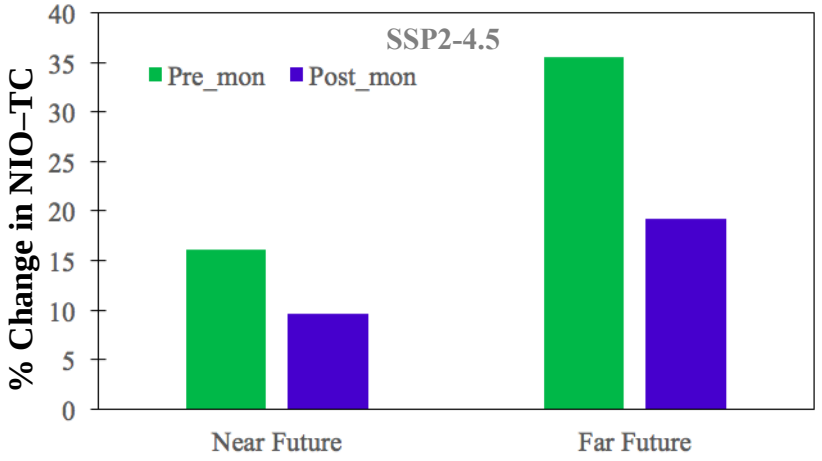
Tropical Cyclone simulated by High resolution Model (T574, ~27 Km)





- **27 km model is able to capture the NIO – TC frequency reasonably well**

Near (2021-2040) and Far future (2081-2100) change (%) with respect to present day (1995-



- **Significant changes in the frequency of pre- and post-monsoon cyclones are visible over the NIO region in the near and far future under the SSP2-4.5 scenario**
- **Using this simulation, we will be able to make a critical assessment of changes in future cyclone frequency over the Bay of Bengal and the Arabian Sea**

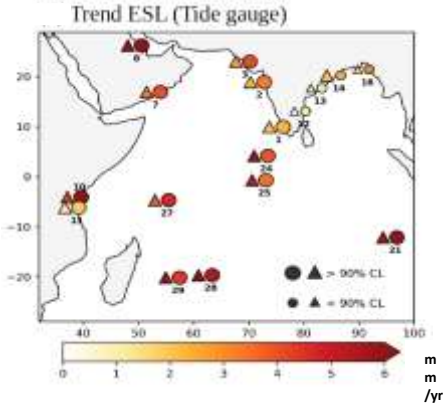
Changes in TC's can pose a significant threat to costal structure

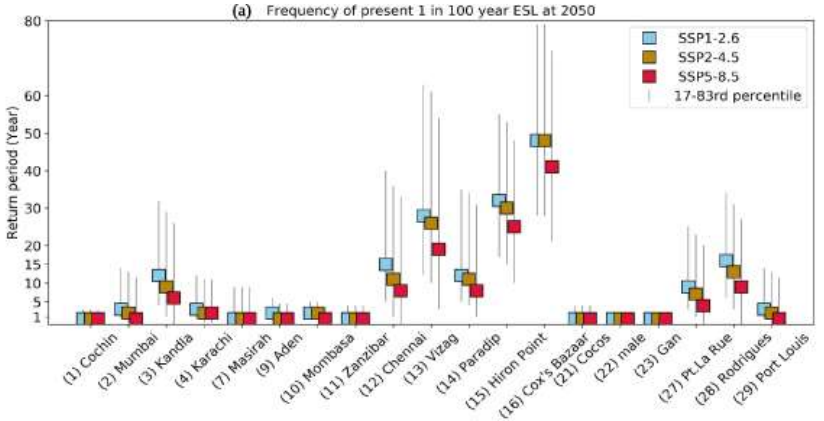
Applications

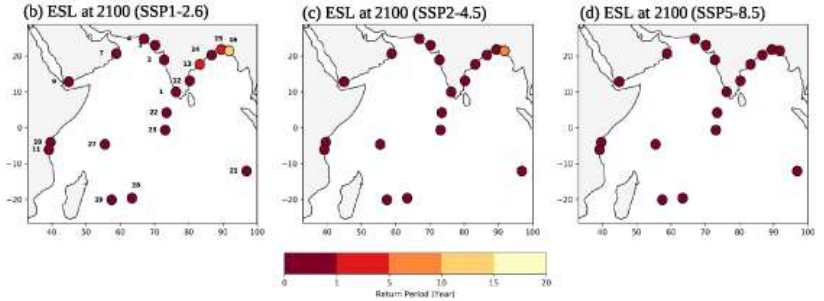
ESLs are short span coastal flooding events caused by the combination of MSL, tides, surges and waves

Extreme sea level rise along the Indian Ocean coastline: observations and 21st century projections

Using hourly TD data, the study showed that ESL has become more frequent, long-lasting and intense along the Indian Ocean coastline with a 2–3-fold increase in the Probability Ratio and Fraction of Attributable Risk.







- **The study also found that the region will be exposed to the present-day 100-year ESL event annually by 2050 under the moderate-emission scenario**
- **The study found that the Indian Ocean region will be exposed annually to the present-day 100-year ESL event by 2100, irrespective of the greenhouse-gas emission pathways**

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Sea level rise can have significant threat to costal structures and management..

Carbon Mitigation and Carbon Reduction Strategies

CO2 cannot be reduced so quickly. A phase-out from fossil fuels and a shift to green energy can be impactful if accelerated. However, it may take many more years to reduce the current levels of CO2 in the atmosphere.

We can reduce the amount of aerosols in the atmosphere to some extent. Improving the quality of vehicles and controlling industrial pollution are both factors contributing to this.

GHG increase -> Temperature increase -> More evaporation -> More Rainfall

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

This combination creates a paradox, and make a region more susceptible to extreme events

Actions to reduce Hazards

Examples include:

- Ecosystem-based measures to reduce coastal flooding
- Mangroves to alleviate coastal storm energy
- Water reservoirs to buffer low-flows and water scarcity

Actions to reduce Vulnerability

Examples include:

- Social protection
- Livelihood diversification
- Insurance solutions
- Hazard-proof housing and infrastructure

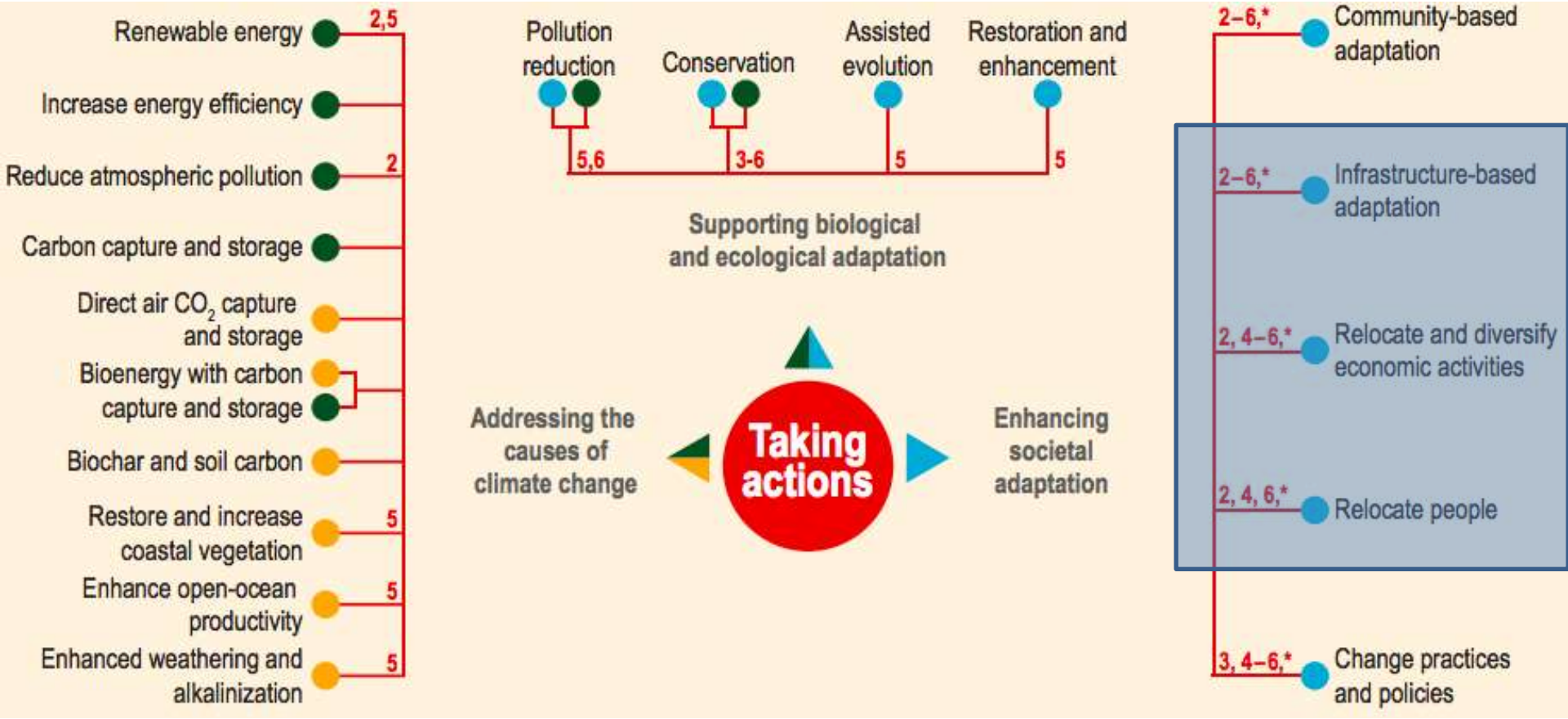
Actions to reduce Exposure

Examples include:

- Coastal retreat and resettlement
- Risk sensitive land use planning
- Early warning systems and evacuations

Limits to Adaptation

- E.g. physical, ecological, technological, economic, political, institutional, psychological, and/or socio-cultural


Renewable energy
2,5
Increase energy efficiency
Reduce atmospheric pollution
2
Carbon capture and storage
Direct air CO_2 capture and storage
Bioenergy with carbon capture and storage
Biochar and soil carbon
Restore and increase coastal vegetation
5
Enhance open-ocean productivity
5
Enhanced weathering and alkalinization
5
Pollution reduction
Conservation
Assisted evolution
Restoration and enhancement
5,6
3-6
5
5
Supporting biological and ecological adaptation
Addressing the causes of climate change
Taking actions
Enhancing societal adaptation
2–6,*
Community-based adaptation
2–6,*
Infrastructure-based adaptation
2, 4–6,*
Relocate and diversify economic activities
2, 4, 6,*
Relocate people
3, 4–6,*
Change practices and policies

Summary

- **In summary, climate change is a present and undeniable reality.**
- **While reducing emissions remains the core long-term solution, it carries significant economic implications.**
- **Therefore, strengthening climate-resilient infrastructure, adopting sustainable urban planning, and enhancing preparedness are essential for mitigating future impacts.**

Thank you