Key Regional Climate Science Priorities:

Opportunities and Challenges

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INDIAN INSTITUTE OF TROPICAL METEOROLOGY, PUNE

WCRP World Climate Research Programme

WORLD METEOROLOGICAL ORGANIZATION

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Intergovernmental Oceanographic Commission

International Science Council

CCCR Centre for Climate Change Research

South Asia: Setting the Regional Earth System Context

Unique land-ocean geographical features: ***(1)*** High-elevation features (e.g., Himalayas, Tibetan Plateau, Western Ghats, Arakan Yoma, ….) ***(2)*** Indian Ocean, Arabian Sea and Bay of Bengal

Strongest regional monsoon in the world: Mean climate dominated by strong seasonal cycle

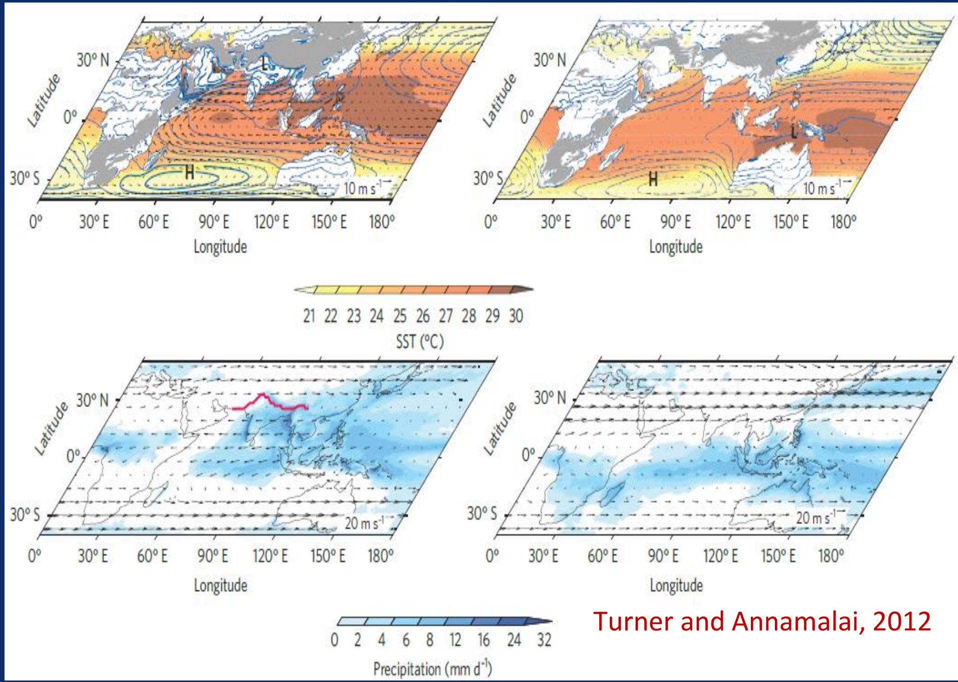
Coupled climate system with strong internal dynamics: (e.g., Monsoons – complex interactive processes, moist dynamics, organized convection and cloud systems, aerosol-cloud-radiation interactions, ocean-atmosphere-land-biosphere-cryosphere coupled interactions, ….) . Large internal variability on different space and time scales.

Climate teleconnections: Links to modes of variability (e.g., El Nino / Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Pacific Decadal Oscillation (PDO), Atlantic Multidecadal Oscillation (AMO), Madden Julian Oscillation (MJO), Polar and Extra-Tropical teleconnections, …)

Natural forcing: Climatic variations caused by large volcanic eruptions (injection of sulfate aerosols into stratosphere), solar irradiance changes, …

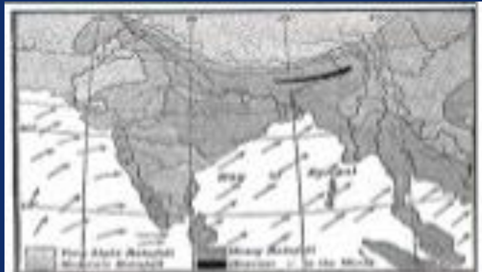
Anthropogenic forcing: Atmospheric greenhouse gases (GHGs, e.g., CO_2, CH_4, N_2O, …), Aerosols (e.g., sulfate, nitrates, organic carbon, black carbon, dust (coated), ….); Land use land cover (LULC) changes – Key external drivers of climate and involve different physical mechanisms

Regional climate dominated by strong seasonal cycle

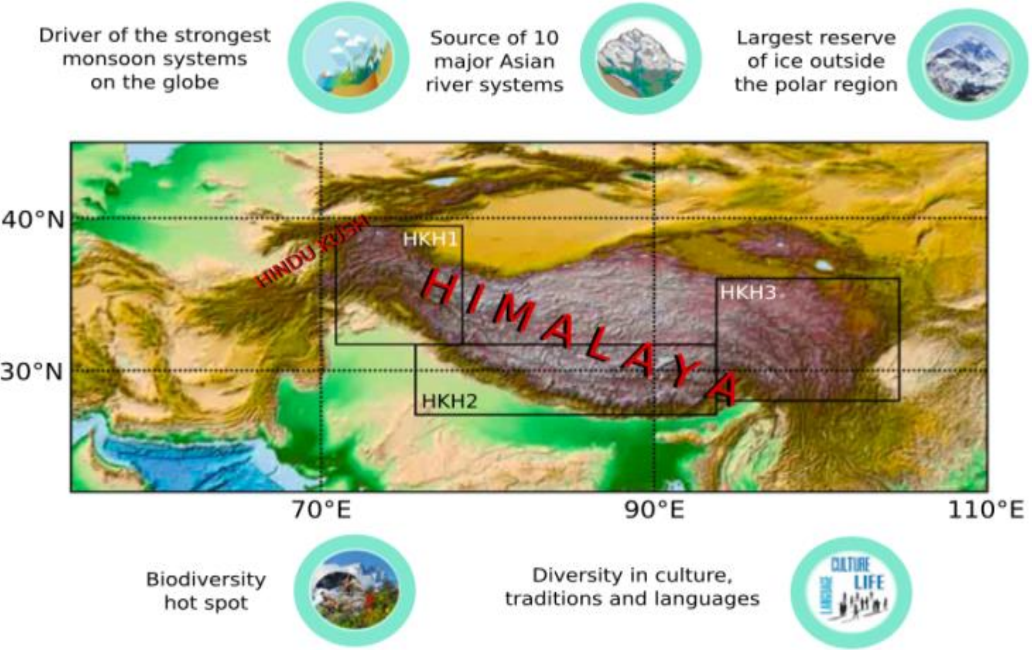


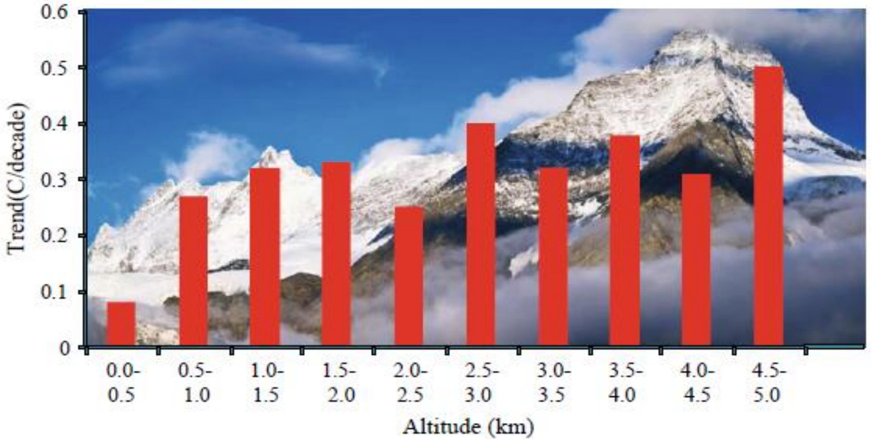
Turner and Annamalai, 2012

Southwest Monsoon

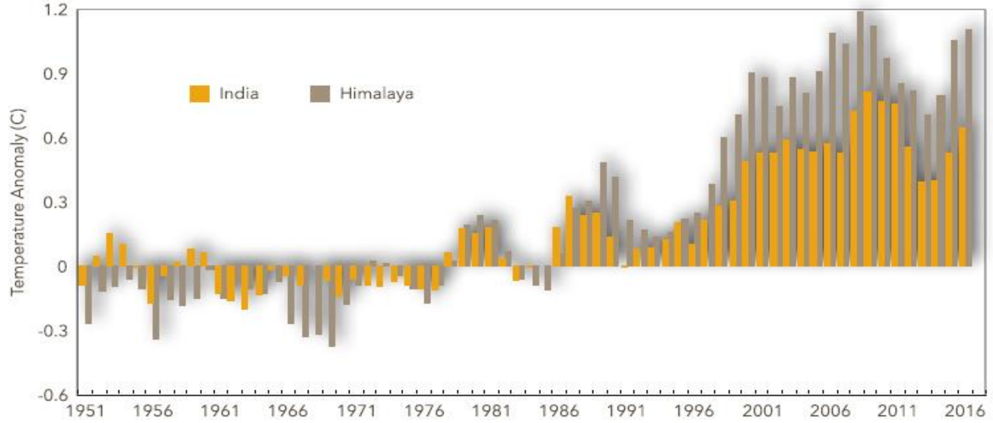


Northeast Monsoon





Faster warming rate over the Himalayas, especially in the high elevation regions



The Hindu Kush Himalayas (HKH) experienced a temperature rise of about 1.3°C during 1951–2015.

High elevations (> 4000 m) of the Tibetan Plateau have experienced stronger warming, as high as 0.3°C-0.5°C per decade, which is commonly referred to as elevation-dependent warming (EDW).

Several areas of HKH experienced declining trend of snowfall and retreat of glaciers in recent decades. In contrast, the high-elevation Karakoram Himalayas have experienced higher winter snowfall that has shielded the region from glacier shrinkage.

For comparison, the surface temperature over India increased by ~0.44°C during 1951–2015, with faster warming ~0.42°C during 1986-2015.

Sea surface temperature (SST) of the tropical Indian Ocean has risen by 1°C on average during 1951–2015.

Projections from the IITM ESM

Observations

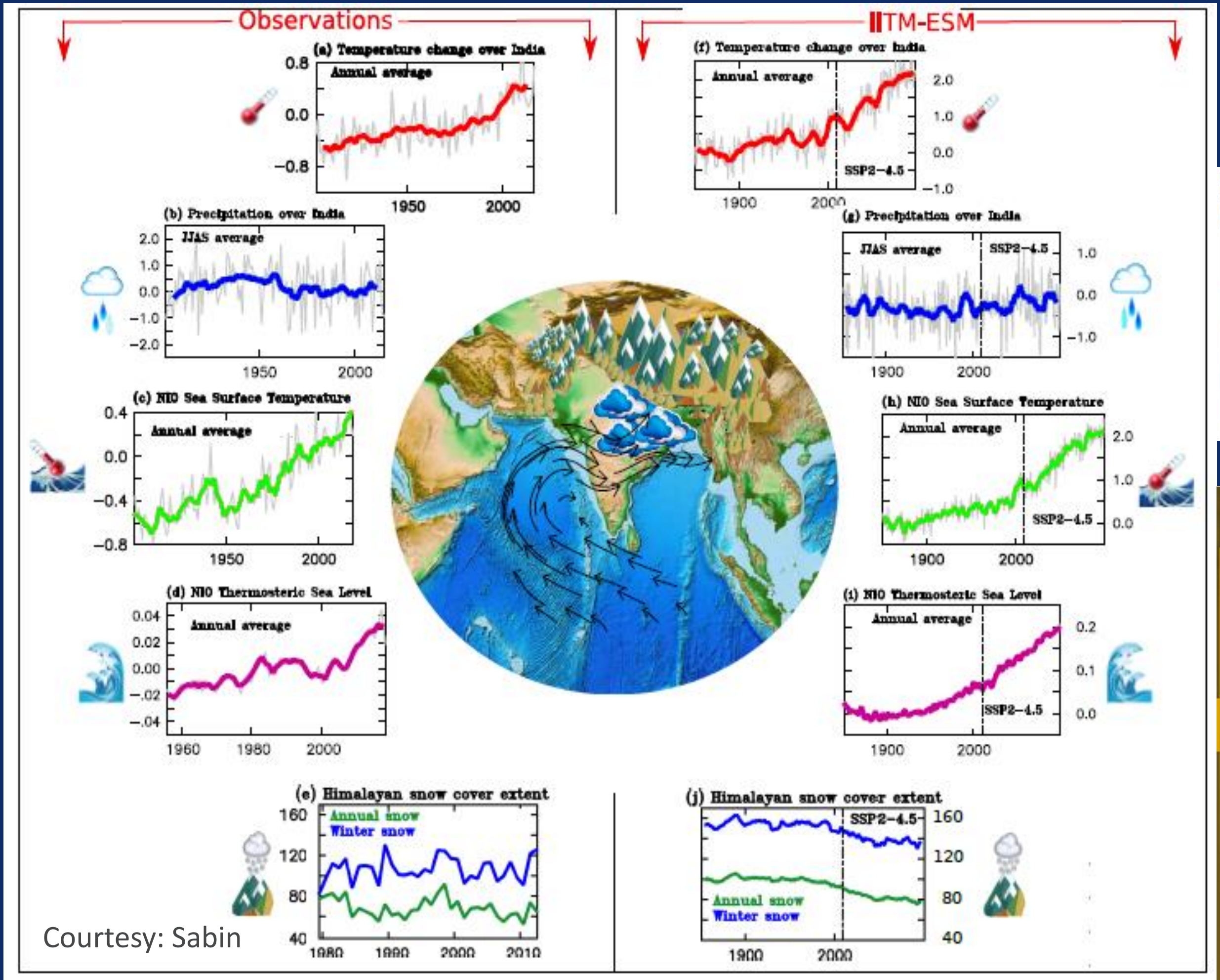
Temperature

Precipitation

SST North Indian Ocean

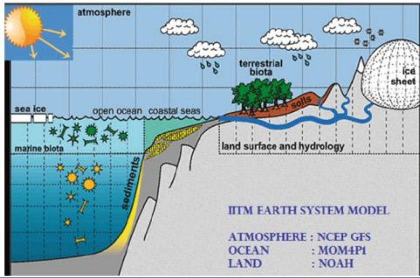
Sea Level North Indian Ocean

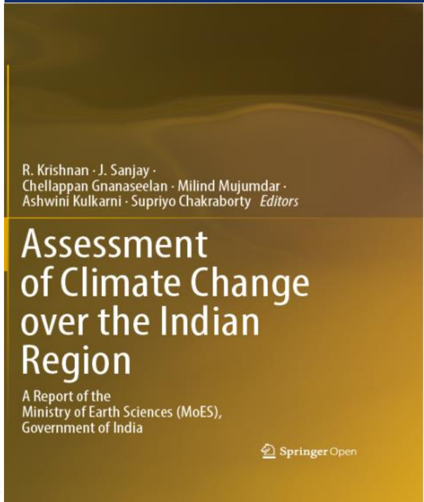
Himalayan snow cover extent



Courtesy: Sabin

IITM–ESM
(Historical + Future)





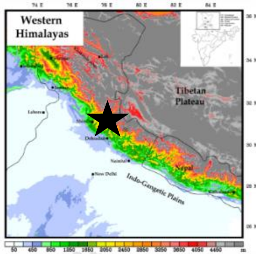
Key regional climate science priorities

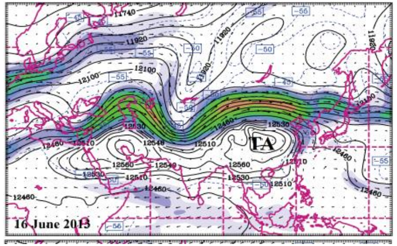
- Weather and Climate Extremes
- Monsoon rains becoming more unpredictable
- Indian Ocean Sea Level Rise
- Himalayan Cryosphere
- …

Weather & Climate Extremes – Global Drivers & Regional Impacts

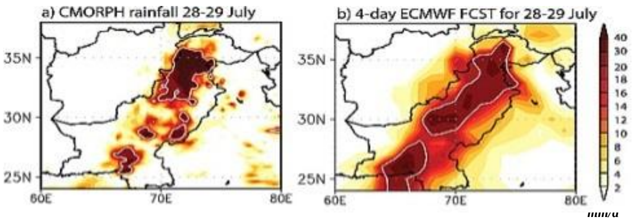
Uttarakhand Extreme Precipitation & Floods, 16-20 June 2013

Interaction of Monsoon and Extra-tropical Circulation



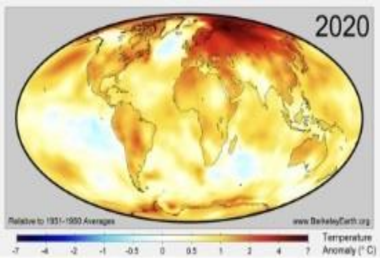


2010 Pakistan Floods



- Interaction between mid-latitude disturbance & monsoon surges *Hong et al 2011*
- Links to Russian heat wave, atmospheric blocking - *Lau & Kim, 2012*
- Westward shift of West Pacific Subtropical High *Mujumdar et. al. 2012*

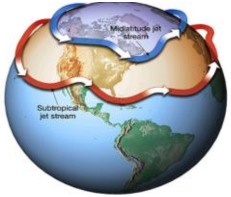
Rapid Arctic Warming

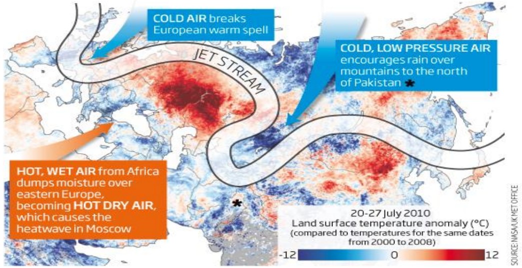


Monthly Arctic Sea Ice Extent Jan 1979-2021

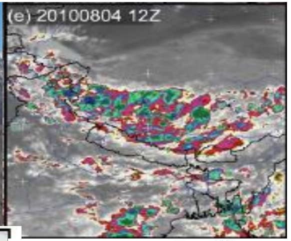
Atmospheric polar vortex strength

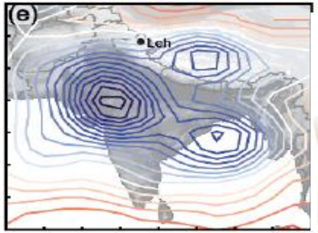
Creates large meanders of mid-latitude jet streams, increasing propensity of extreme weather (eg. Russian Heat Wave 2010, Atmospheric Blocking)

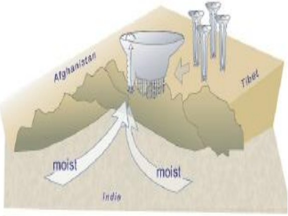




Leh Flash Floods, Aug 2010

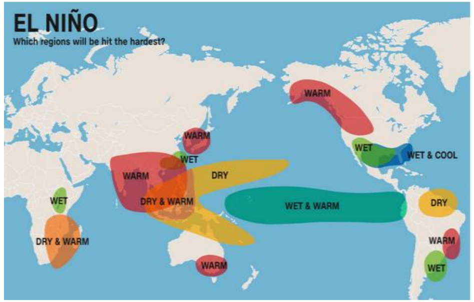


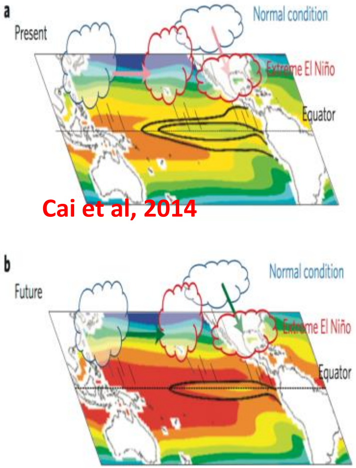




Convective cells on the Tibetan Plateau organize upscale and propagate to the west. The mesoscale convective systems (MCS) on the edge of the Himalayas taps into the upslope low-level moisture – **Rasmussen and Houze, 2012**

El Nino events have global impact

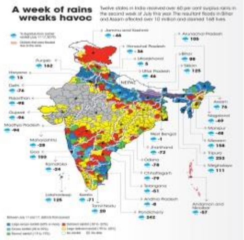


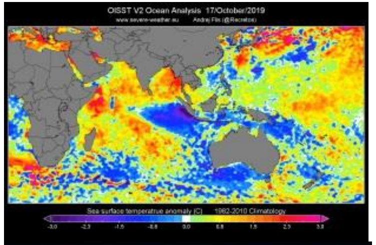


Cai et al, 2014

Incidences of extreme El Nino events are thought to increase from 1:6 through 1:3 under future GHG scenarios

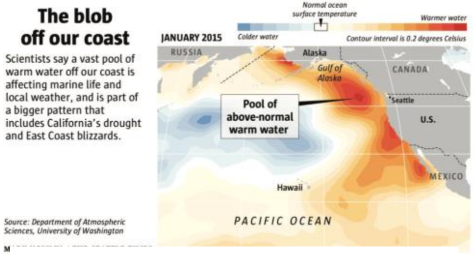
Extreme Indian Ocean Dipole (IOD) - 2019

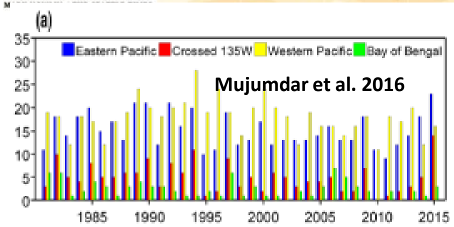


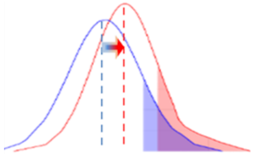


Kerala Floods -2018, 2019

Extreme El Nino 2015

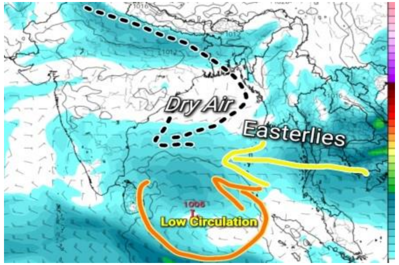




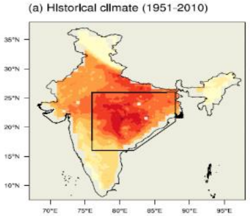


Increase in extreme temperature over NCI under dry soil moisture conditions Naresh et al. 2021

Heavy rains in Peninsular India: **Nov 2021. Active Northeast Monsoon**



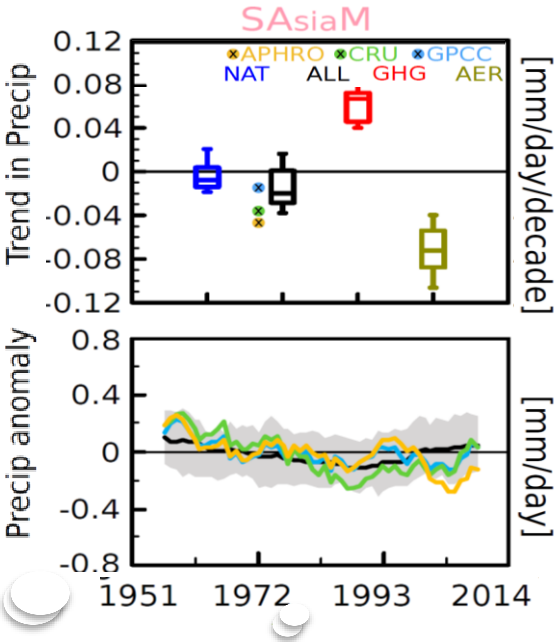
Consecutive Indian Monsoon Droughts 2014, 2015



Strong Coupling of Soil-Moisture and Temperature over North-Central India (NCI) – Naresh et al. 2021

Chennai floods Dec 2015

Observed (1951-2014) and projected changes in South & Southeast Asian Monsoon (SAsiaM) Precipitation



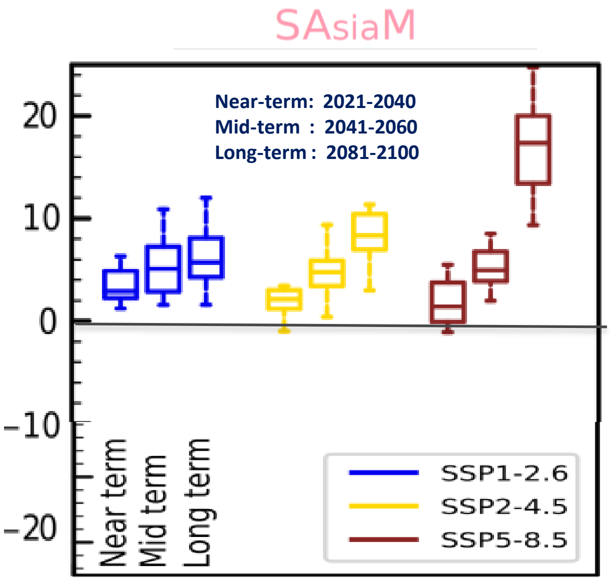
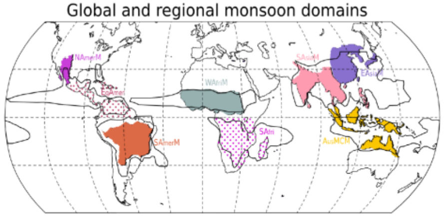
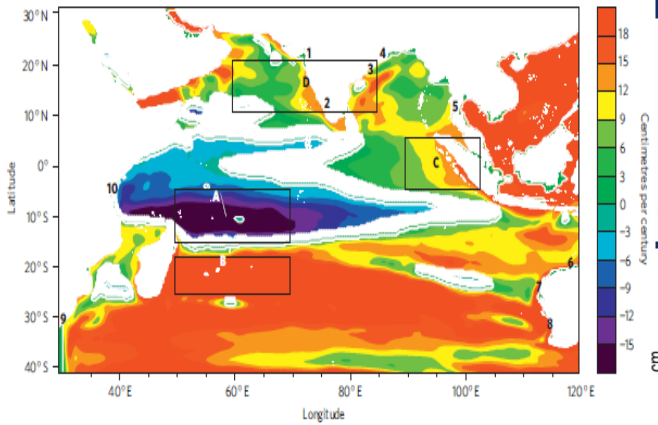


Figure 8.11



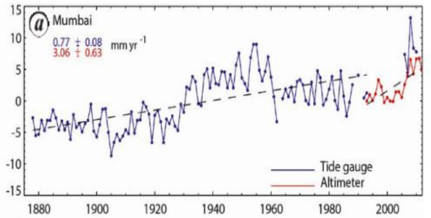
- The South and Southeast Asian monsoon precipitation (SAsiaM) decreased since the mid-20th century (*high confidence*), the dominant cause being anthropogenic aerosol forcing
- In the near-term (2021-2040), SAsiaM precipitation will be dominated by the effects of internal variability (*medium confidence*), but will increase in the long-term (2081-2100) (*medium confidence*)

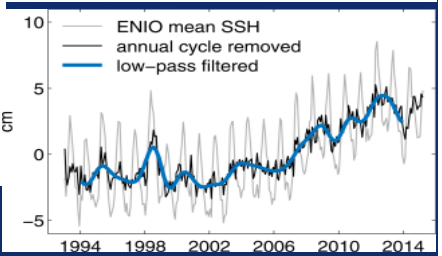
Indian Ocean Sea Level Rise



Regional sea levels are affected by atmospheric and ocean circulation. Sea level has decreased substantially in the South Tropical Indian Ocean, whereas it has increased elsewhere during **1961-2008** – **Weiqing Han et al. (2010)** – Nature Geoscience- based on *in situ* and satellite data and climate model simulations

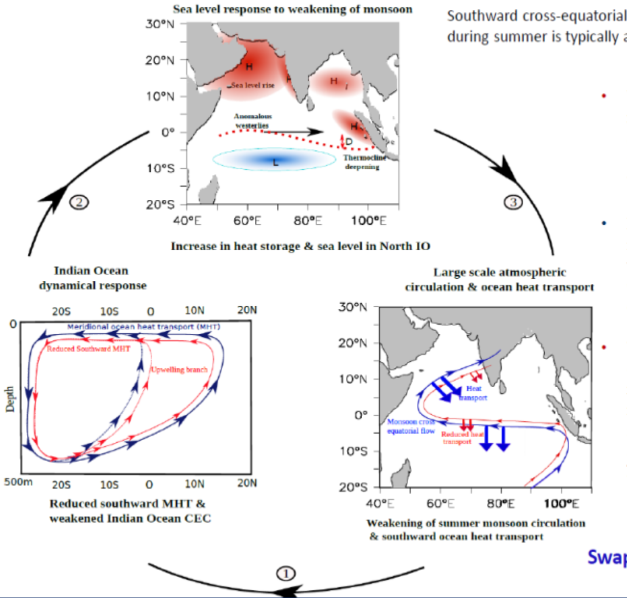
Sea level rise: North Indian Ocean - Tide gauge data *(Unnikrishnan et al., 2014)*





Decadal rate of SSH change in NIO increased by 6 mm/yr from 1993–2003 to 2004–2013 *(Thompson et al.,2017)*

Dynamics of multi-decadal sea level rise in the North Indian Ocean



- Weakening of summer monsoon circulation and associated reduction in southward ocean heat transport (red arrows).
- Decreased southward meridional heat transport weakens the Indian Ocean cross-equatorial cell.
- Weakened cross-equatorial cell with reduced southward meridional heat transport increases heat storage and sea level rise in the North Indian Ocean.

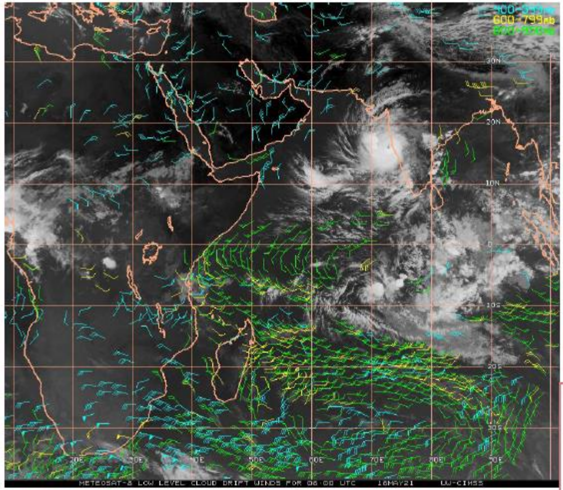
Swapna et al, GRL (2017)

- The global mean sea level (GMSL) has risen at a rate of 1.7 (1.5 to 1.9) mm per year since 1901, and the rate of rise has accelerated to 3.3 mm per year since 1993.
- Sea-level rise (SLR) in the Indian Ocean is non-uniform and the rate of SLR in the north Indian Ocean is 1.06-1.75 mm per year from 1874-2004 and is 3.3 mm per year during (1993-2015), which is comparable to the GMSL rise
- Indian Ocean SLR is dominated by ocean thermal expansion, while the addition of water mass from terrestrial ice-melting is the major contributor to GMSL rise
- Interannual to decadal variability in the Indian Ocean sea level – links to ENSO, PDO, IOD and Monsoon Circulation
- Steric sea level in the Indian Ocean is projected to rise by about 20-30 cm at the end of the 21st century under RCP4.5.
- Extreme sea-level events are projected to occur frequently over the tropical regions (high confidence) and along the Indian coast (medium confidence) associated with an increase in the mean sea level and climate extremes.

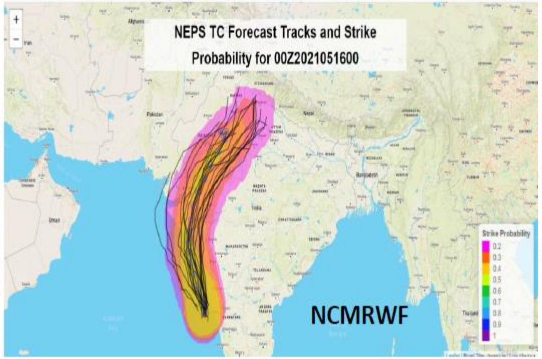
Ref: Swapna et al., 2020, MoES Report (Chap 9)

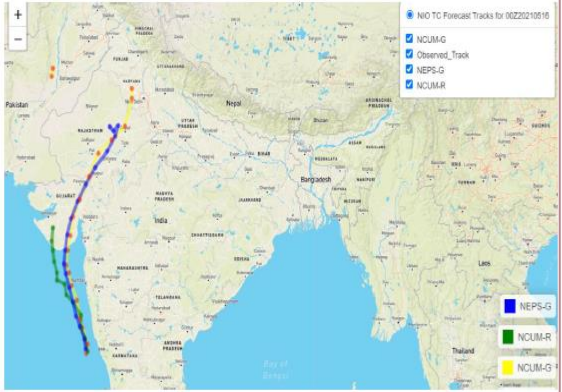
Coastal sea-level response to changing Tropical Cyclones?
Future projections of coastal response to Tropical Cyclones

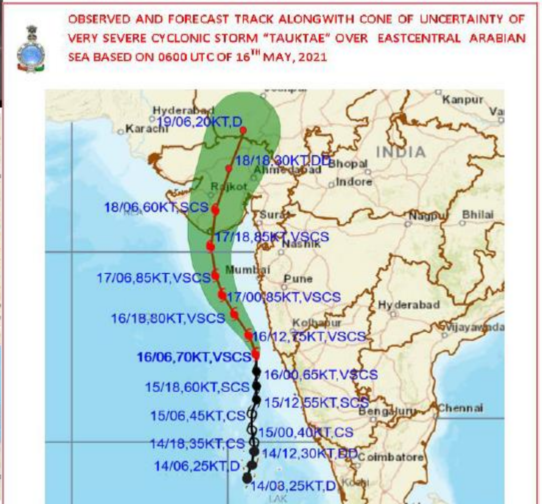
Very severe cyclonic storm Tauktae – 0600 UTC, 16 May 2021



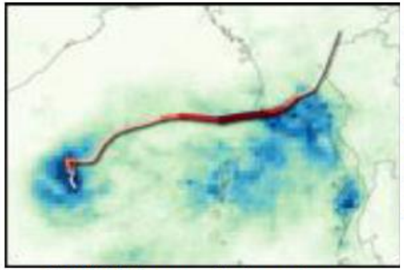
Strike probability obtained from NEPSG based on IC of 00UTC16May2021



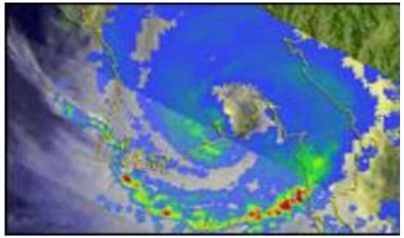




TC Nargis
April – May, 2008

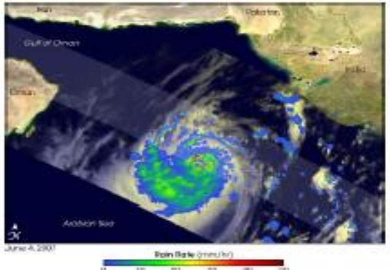


TRMM precipitation
3 May 2008



TC Gonu
June 2007

TRMM precipitation
4 June 2007



Science Priorities and Implementation

WCRP Lighthouse Activities

Integrated Strategy

Digital Earths

Explaining and Predicting Earth System Change

My Climate Risk

WCRP Academy

Weather & Climate Extremes

Monsoon Hydrological Cycle

Himalayan Cryosphere

Indian Ocean warming & Sea level rise

Process understanding & representation in models: Tropical Convection, ITCZ and rainbelts, Mesosale convective systems (MCS), Cloud & Aerosol Interaction, Energy and Water Cycle; Atmosphere and Ocean Dynamics; Cryospheric processes, Coupled Climate System (Ocean-Atmosphere-Land-Cryosphere)

- Detection and Attribution – Natural versus Human caused changes
- Understanding & reducing model systematic errors, uncertainties
- Improving physical parameterization schemes
- Ultra-high resolution climate models (Global and Regional)
- Large ensemble experiments
- Enhancing skill of S2S, Internal-to-Decadal Prediction experiments
- Human capacity building
- Linking Research-to-Operations

Advancing predictions: Early warning systems, Coupled data assimilation, Combine observations and model simulations of atmosphere, ocean, land, cryosphere systems.

SPARC TROPOSPHERE-STRATOSPHERE

WCRP CORDEX REGIONAL CLIMATE DOWNSCALING

CliC CRYOSPHERE-CLIMATE

GEWEX LAND-ATMOSPHERE

CLIVAR OCEAN-ATMOSPHERE

WCRP World Climate Research Programme

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UNESCO United Nations Educational, Scientific and Cultural Organization

Intergovernmental Oceanographic Commission

International Science Council

Thanks for your kind attention!