

# “Climate Change and its Impact on Extreme Weather over South Asia”



**Dr. D. R. Pattanaik**

Email : [dr.pattanaik@imd.gov.in](mailto:dr.pattanaik@imd.gov.in)

[drpattanaik@gmail.com](mailto:drpattanaik@gmail.com)

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***15 – 17 October, 2019***  
***GIDM, Ahmedabad***



**भारत मौसम विज्ञान विभाग**  
**INDIA METEOROLOGICAL DEPARTMENT**

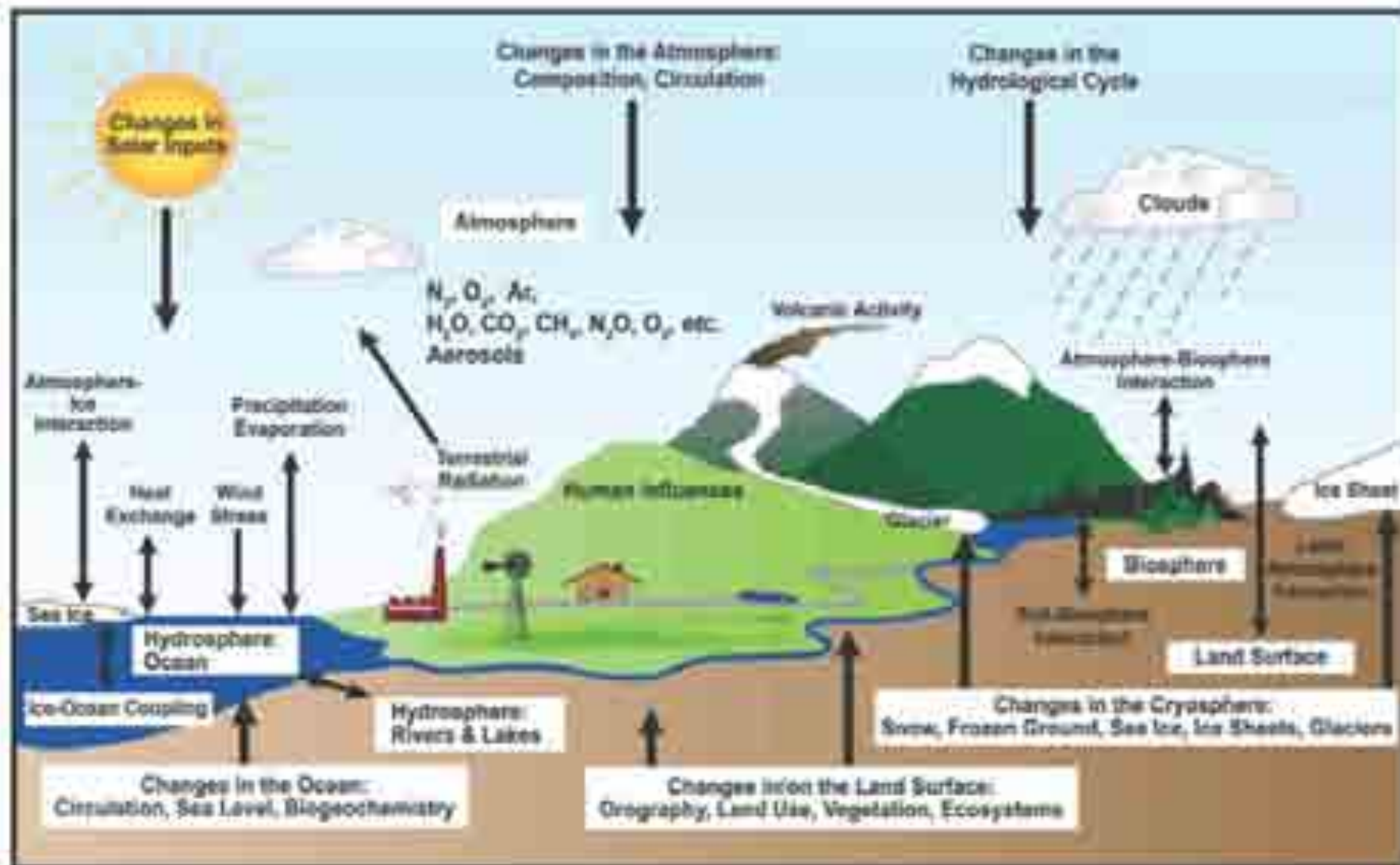


# Points to be discussed

- ❖ Climate System;
- ❖ Climate Variability and Climate Change
- ❖ Observed Climate Change over India
- ❖ Climate Change and Extreme Weather
- ❖ Future Climate Scenario
- ❖ **Early Warning & Impact Based Forecasting for Effective Disaster Management**
- ❖ Summary



# Climate System

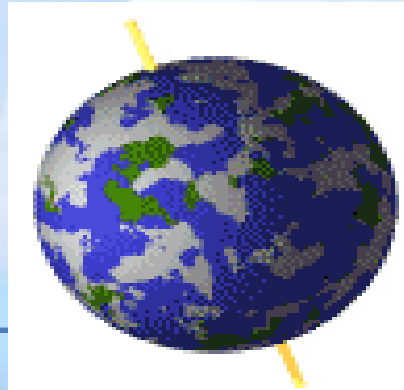
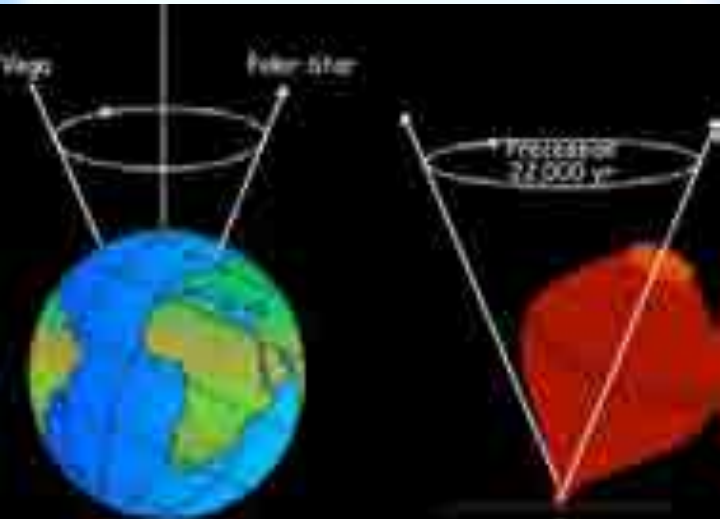


# Climate Variability and Climate Change

- **Climate Variability:** The temporal variations of the atmosphere– ocean system around a mean state.
  - Typically, this term is used for timescales longer than those associated with synoptic weather events (i.e., months to millennia and longer).
  - The term "natural climate variability" is further used to identify climate variations that are not attributable to or influenced by any activity related to humans.
- **Climate Change:** Any systematic change in the long-term statistics of climate elements (such as Temperature, pressure, or winds) sustained over several decades or longer.
  - Climate change may be due to natural external forcings, such as changes in solar emission or slow changes in the earth's orbital elements; natural internal processes of the climate system; or anthropogenic forcing.

# Climate Change

- ❖ Milankovitch cycles (Long-term climate change)
- ❖ Climate Change Due to Anthropogenic factors (Green house increase)



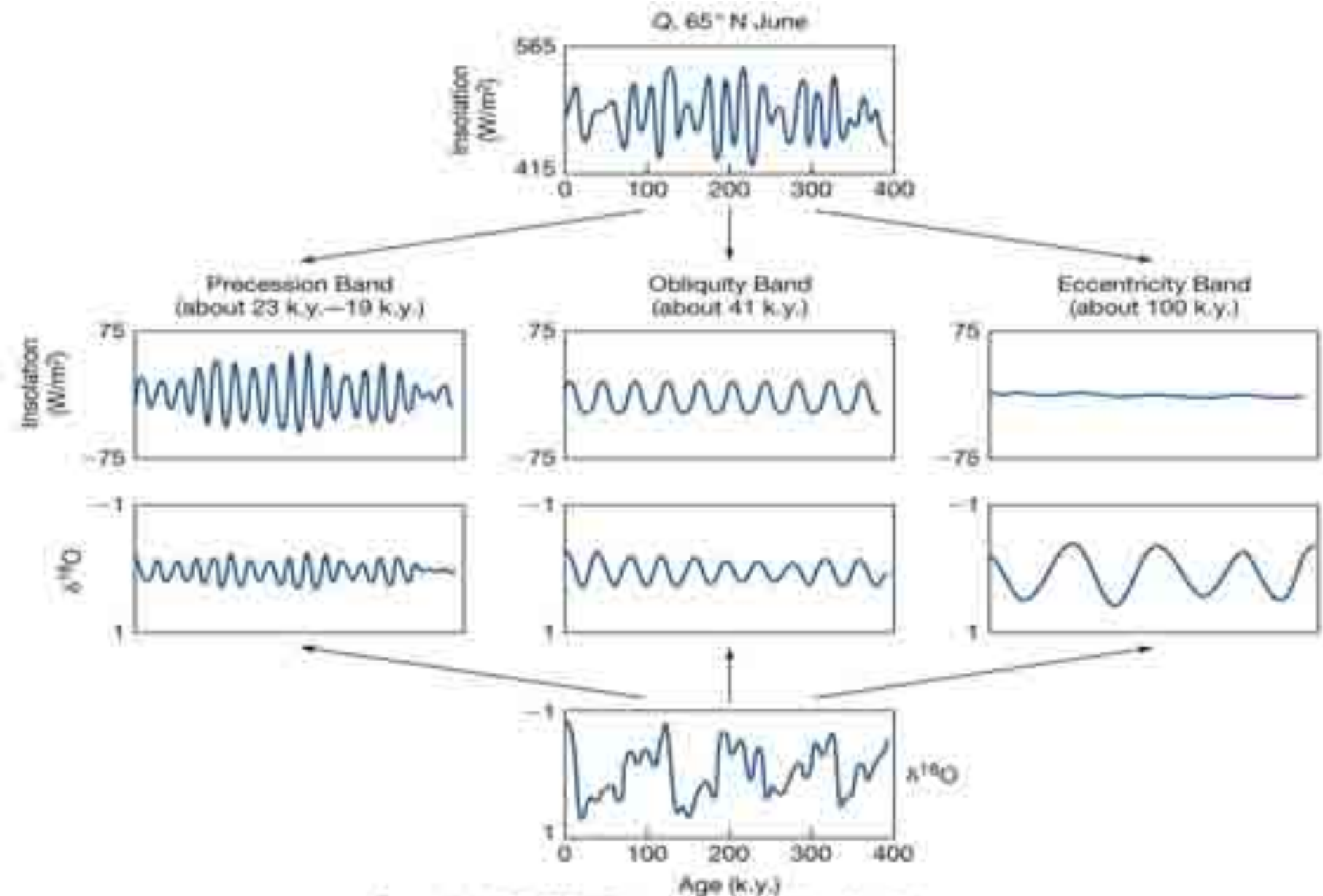
Paleo-climatic variations

Milankovitch cycles: Effect of orbital variations on solar insolation





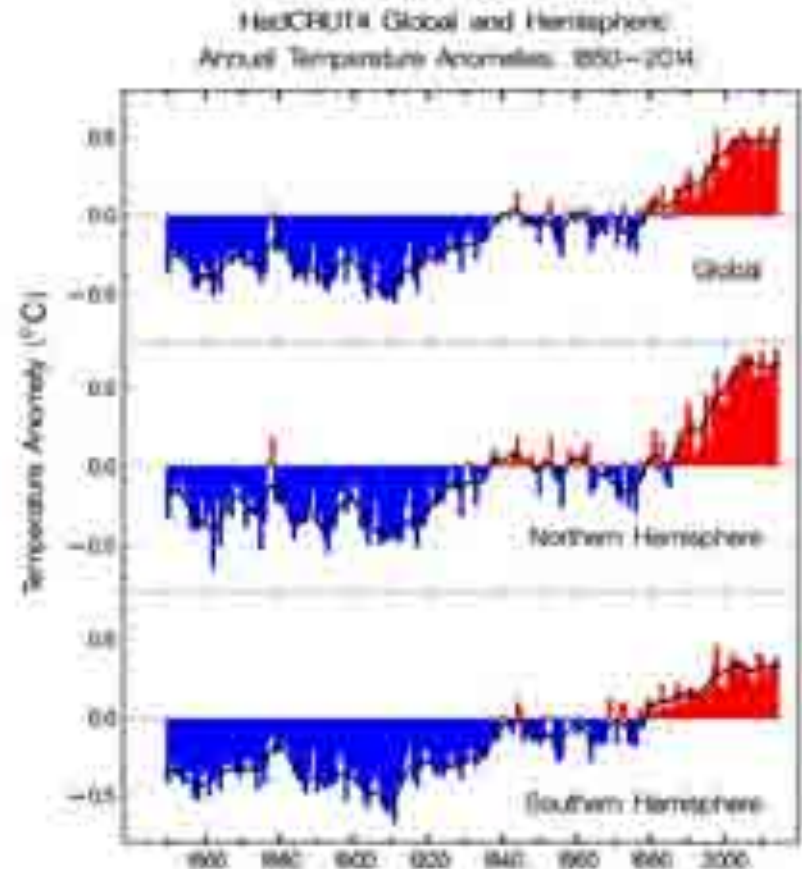
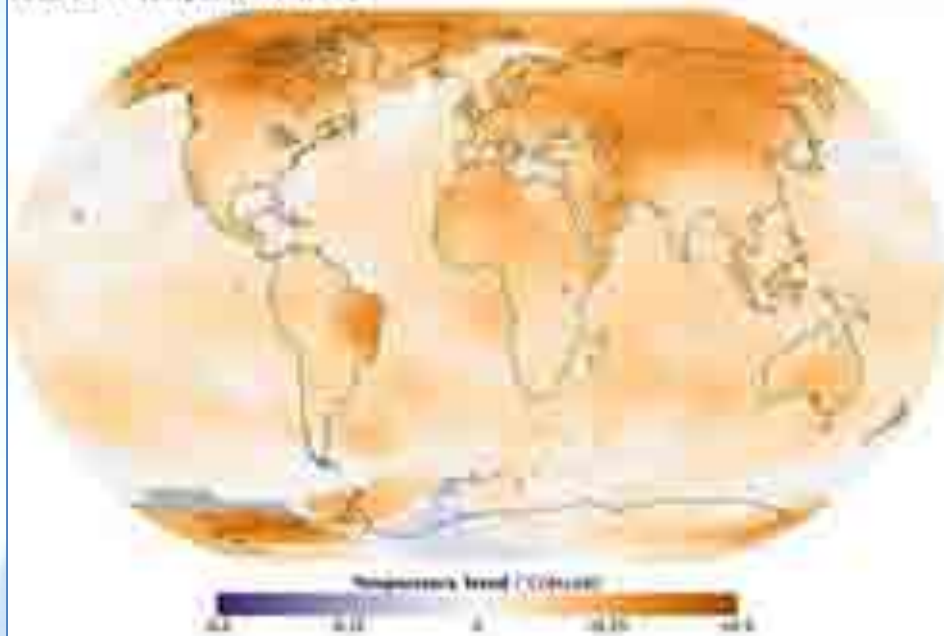
# Milankovitch cycles



# Global Warming (Climate Change)

## Global Temperature Trends

1850-2014 Temperature Trend

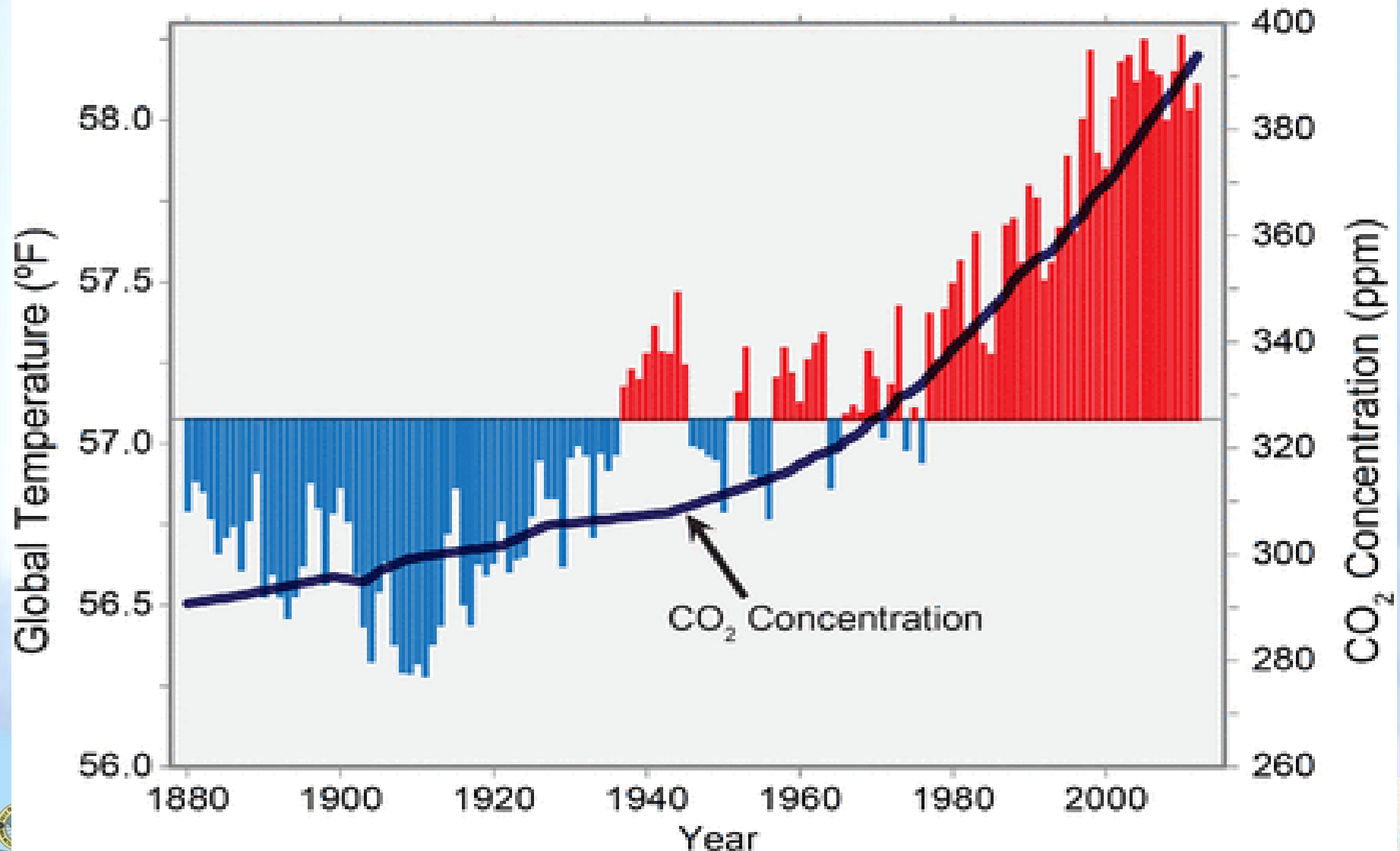


Source: P. D. Jones, T. J. Osborn, and K. R. Jolliffe  
University of East Angles, Norwich, UK  
G. S. Parker, Met. Office, Bracknell, Berkshire, UK

Increase in greenhouse gases has resulted in increase in surface air temperatures and thus global warming due to the Greenhouse Effect. Global instrumental temperature data suggests unprecedented warming during the recent decades (since mid 1970s).

# Increase in Greenhouse Gases

## Global Temperature and Carbon Dioxide

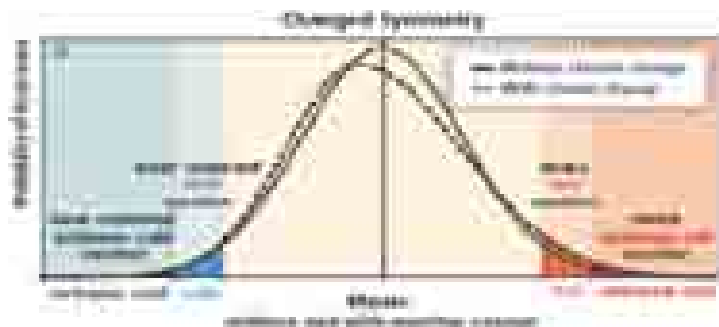
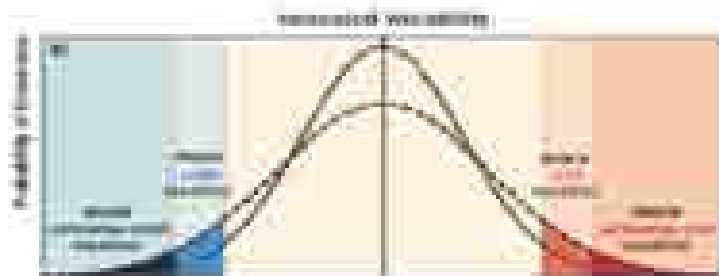
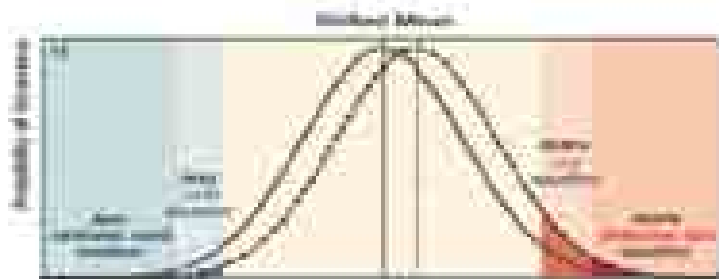




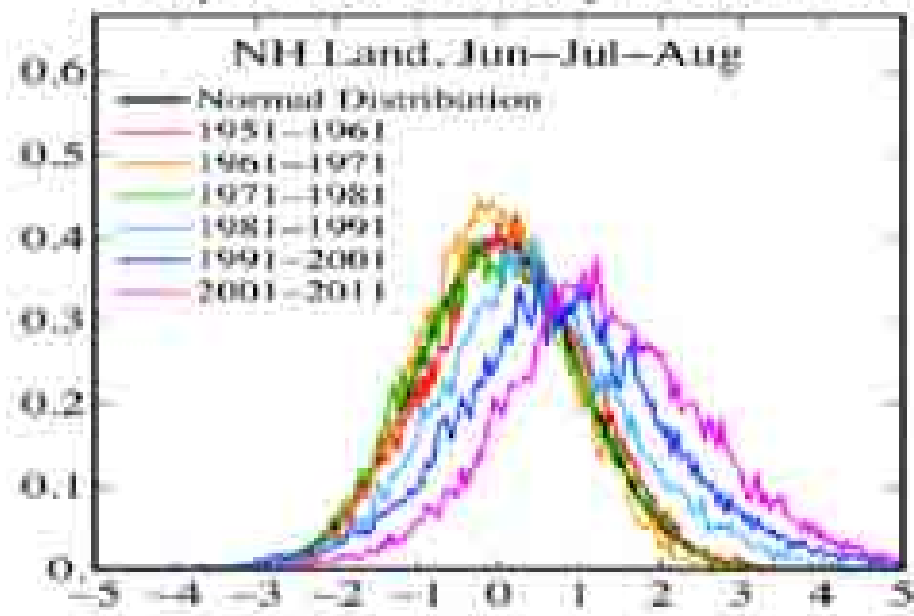
# Effects of Climate Change

## Effects of Climate Change

Global warming can cause changes in mean, variance or both.



## Temperature Anomaly Distribution



# Climate change and extreme weather events

Changes in extremes matter most for society and human health

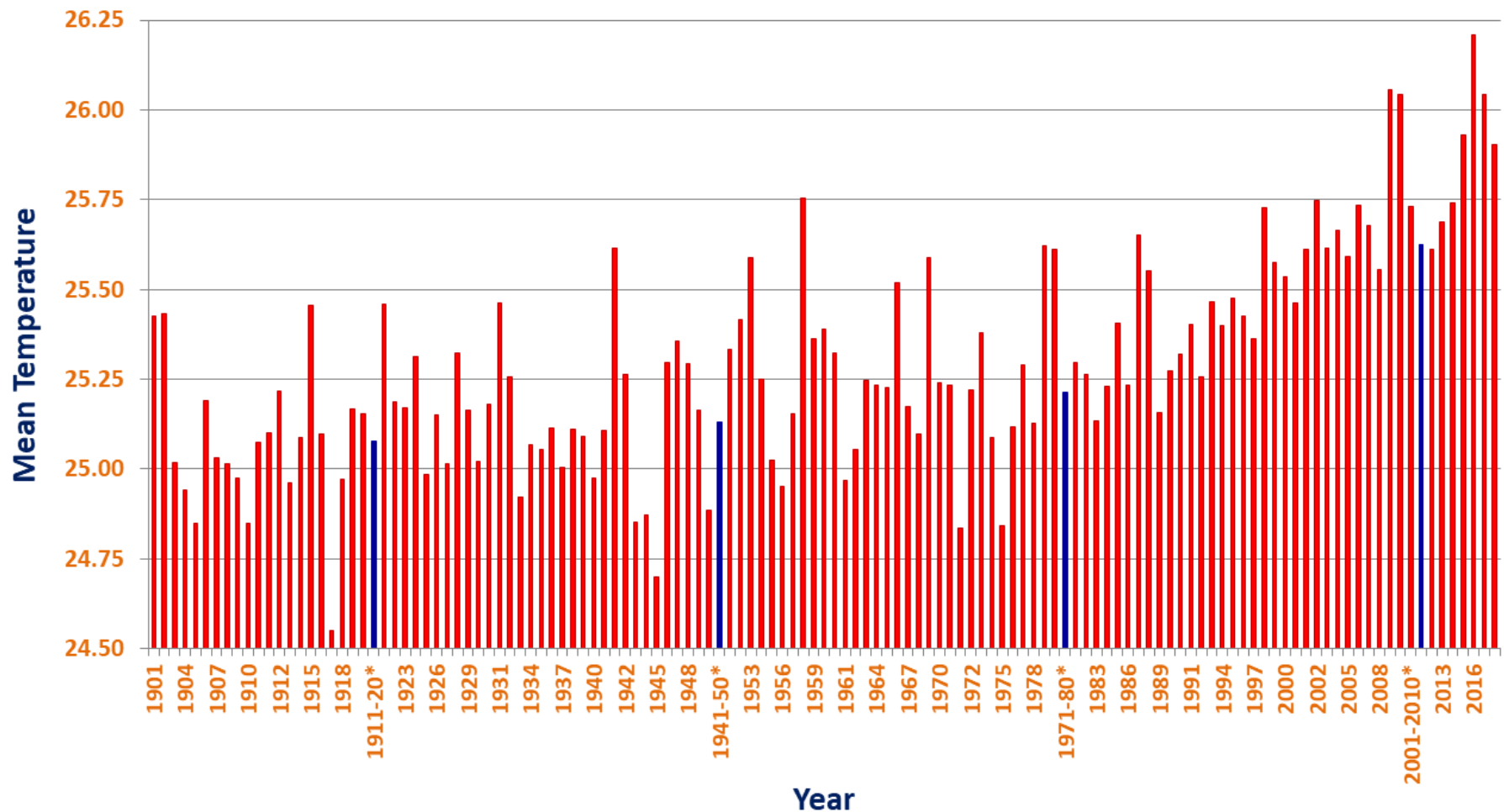
With a warming climate:

- ◆ More high temperatures, heat waves
- ◆ Wild fires and other consequences
- ◆ Fewer cold extremes.
- ◆ More extremes in hydrological cycle:
  - ◆ Drought
  - ◆ Heavy rains, floods
  - ◆ Intense storms, hurricanes, tornadoes

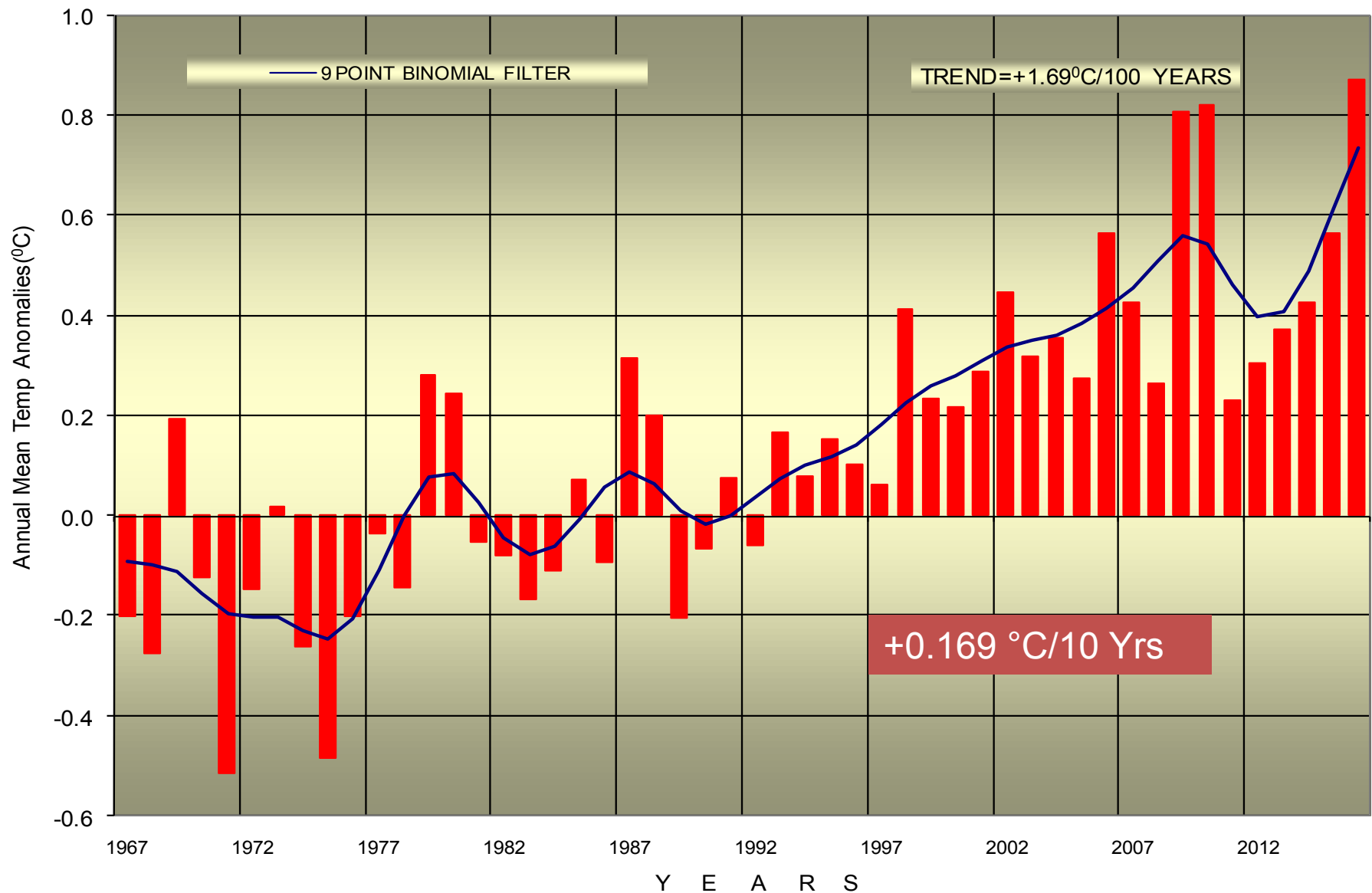


# Over Indian Landmass (1901-2018)

## Annual Mean Temperature (Deg C)



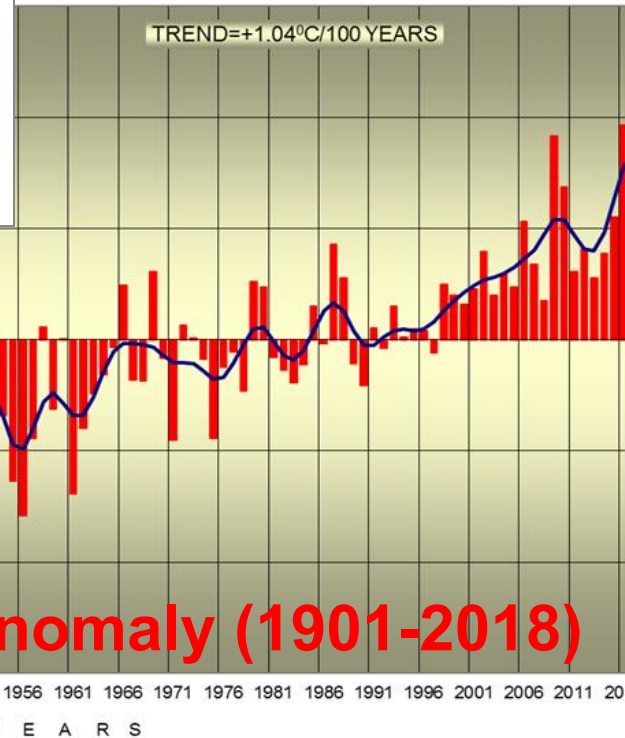
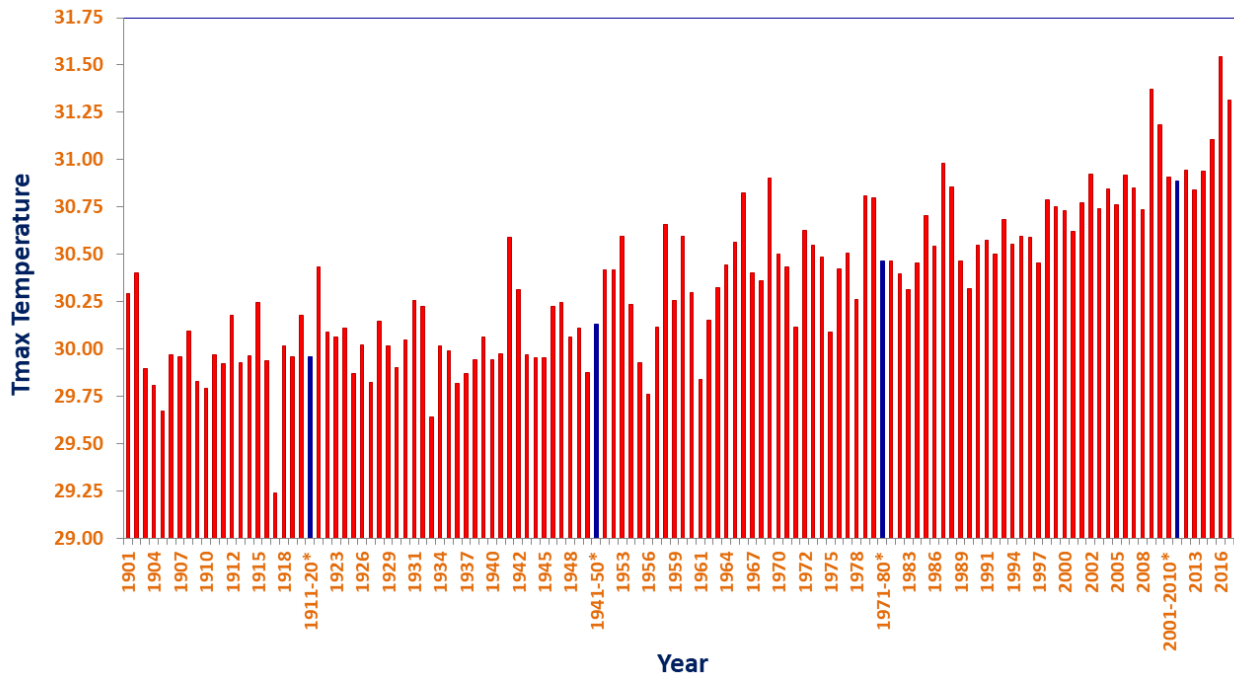
# Annual average temperature during recent period (1967-2018)



# Observed annual maximum temperature over India

Annual Tmax Temperature (Deg C)

+0.144 °C/10 Yrs



All India annual maximum temperature anomaly (1901-2018)



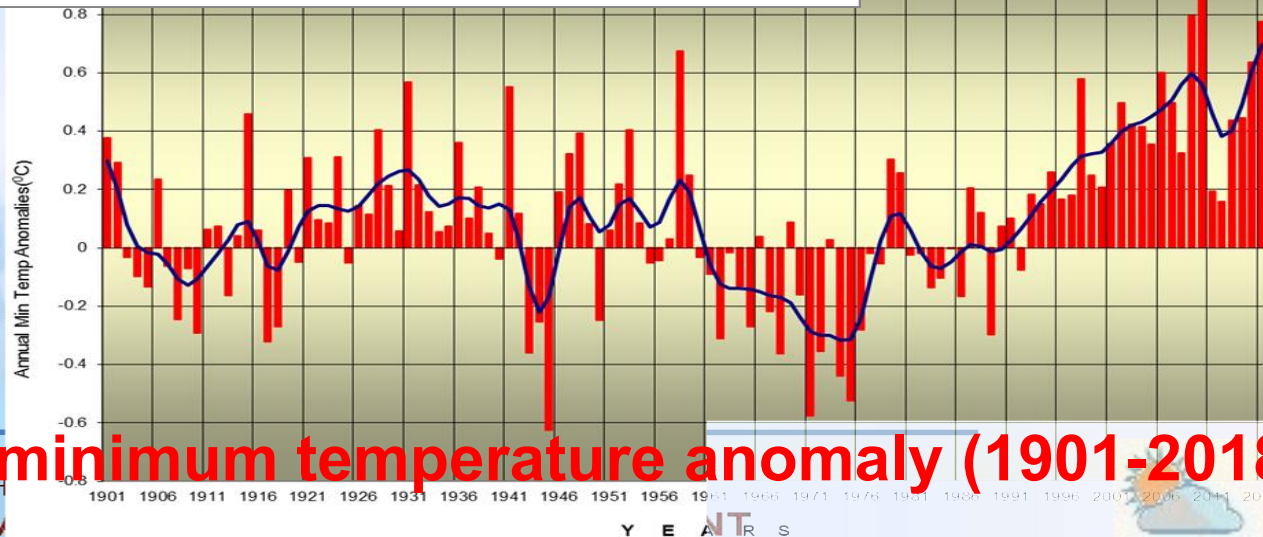
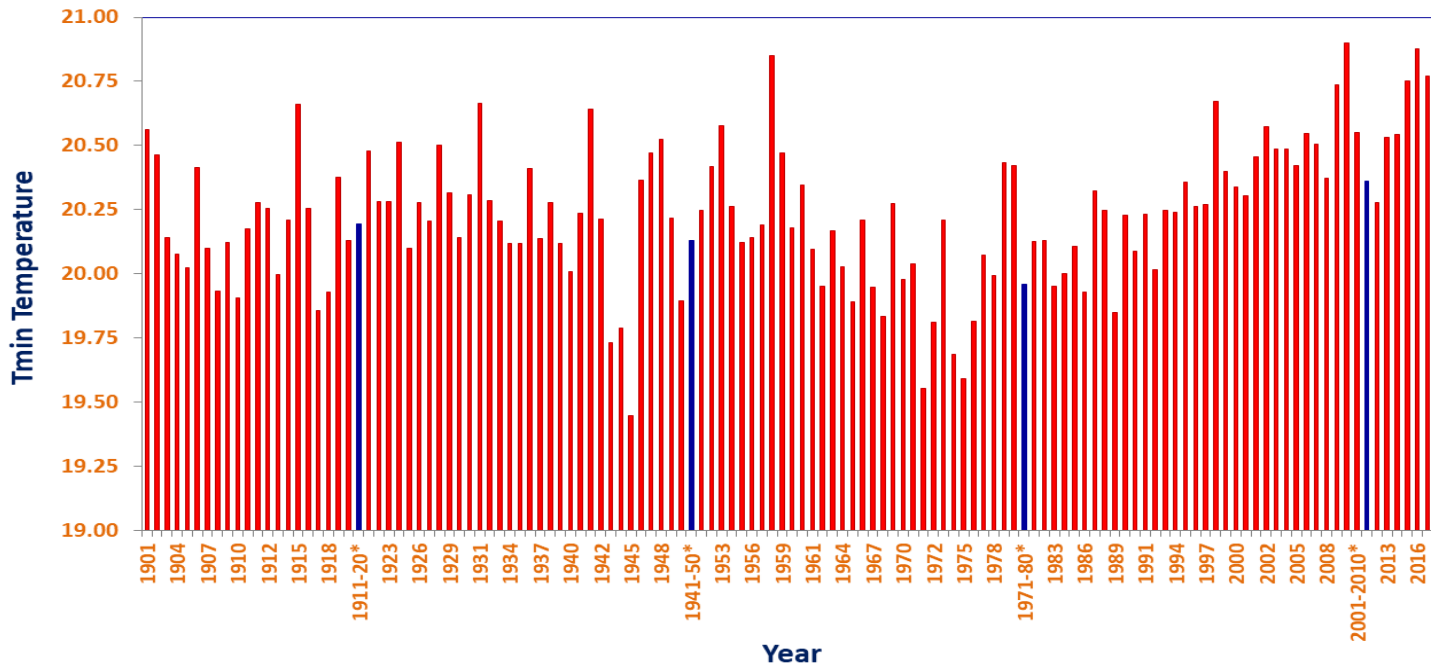
INDIA



# Observed annual minimum temperature over India

Annual Tmin Temperature (Deg C)

+0.193 °C/10 Yrs



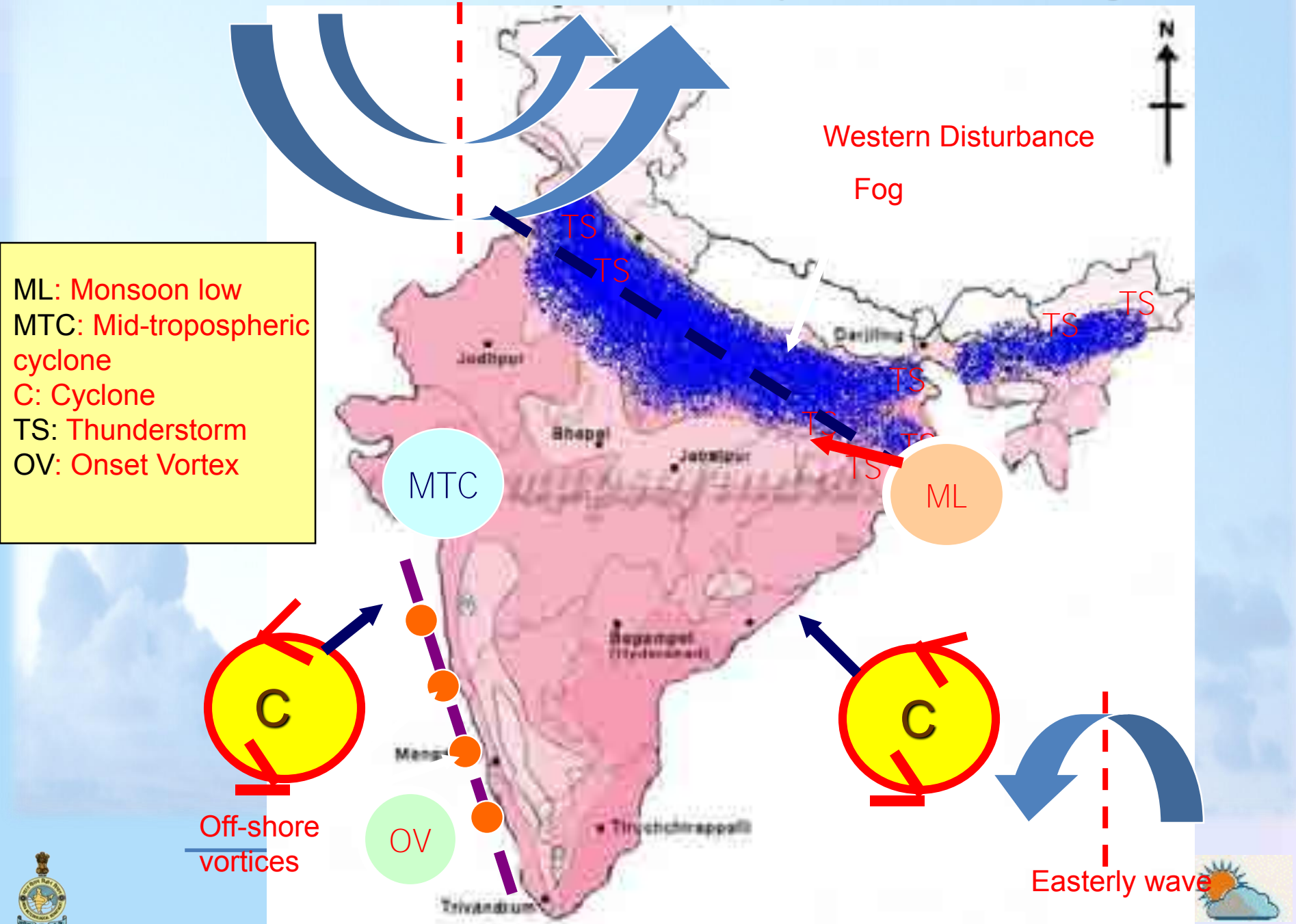
All India annual minimum temperature anomaly (1901-2016)



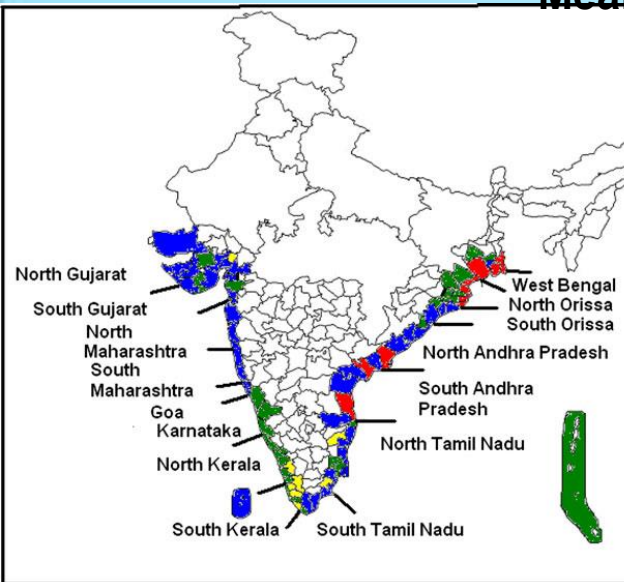
INDIA

YEARS

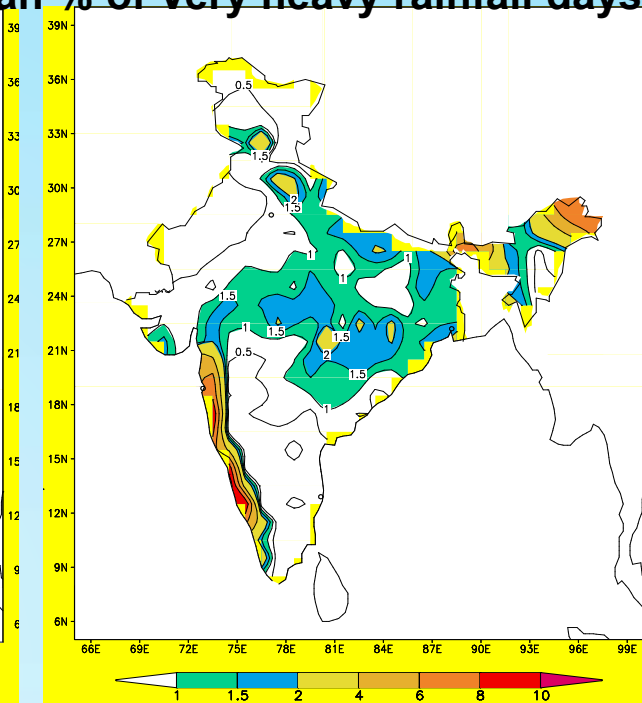
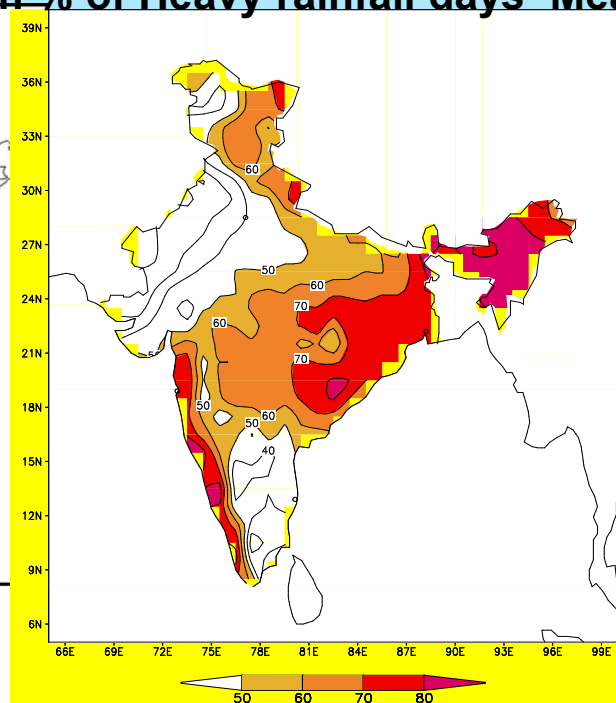
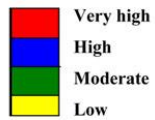
# Location and Normal movement of weather System in India & Neighbourhood



# Mean % of Heavy rainfall days    Mean % of Very heavy rainfall days

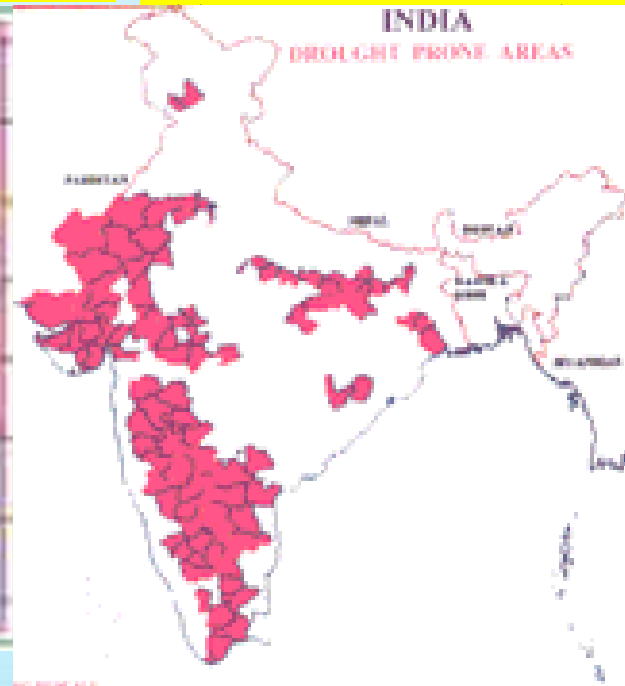
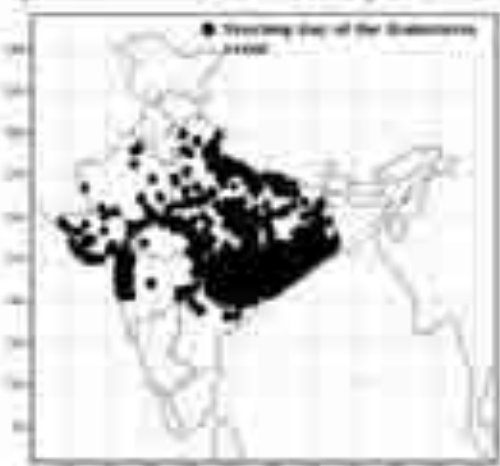


Degree of proneness

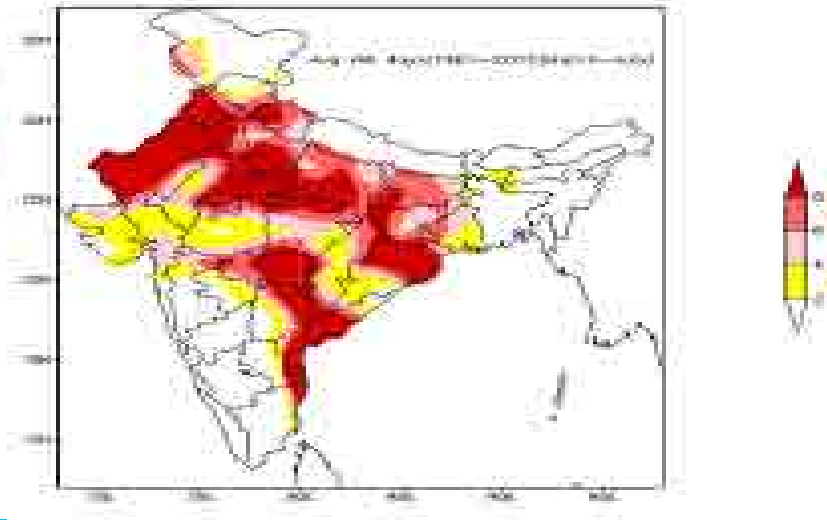
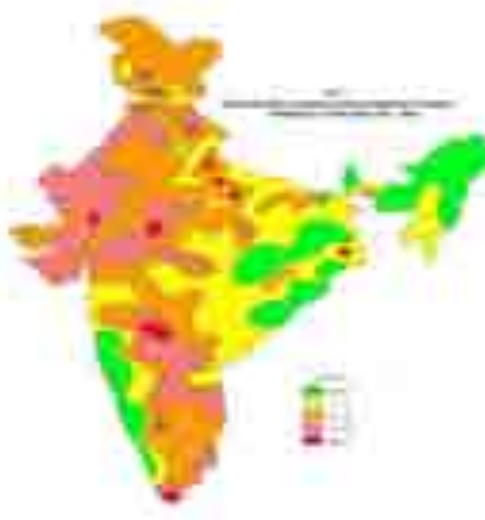


## Origin of Rainstorms

Spatial distribution of Rainstorms for the period 1981-2000

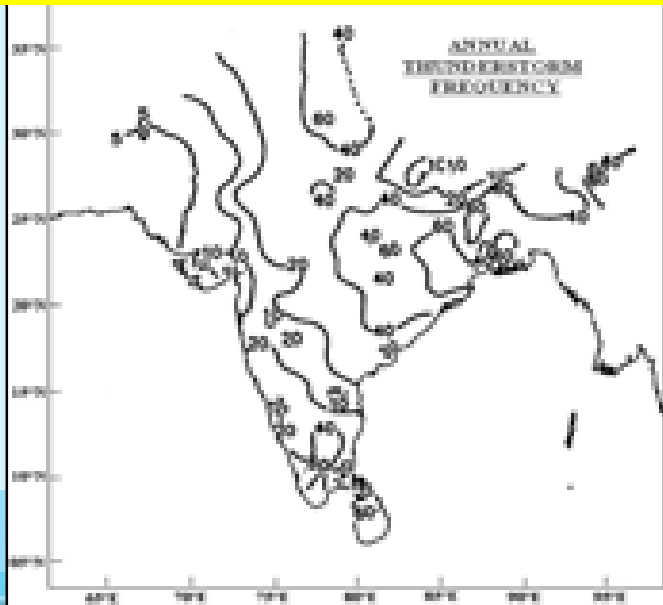


# Probability of Moderate and Severe Drought (1901-2000)



## Meso-scale severe weather events

Thunderstorm  
(Per year)



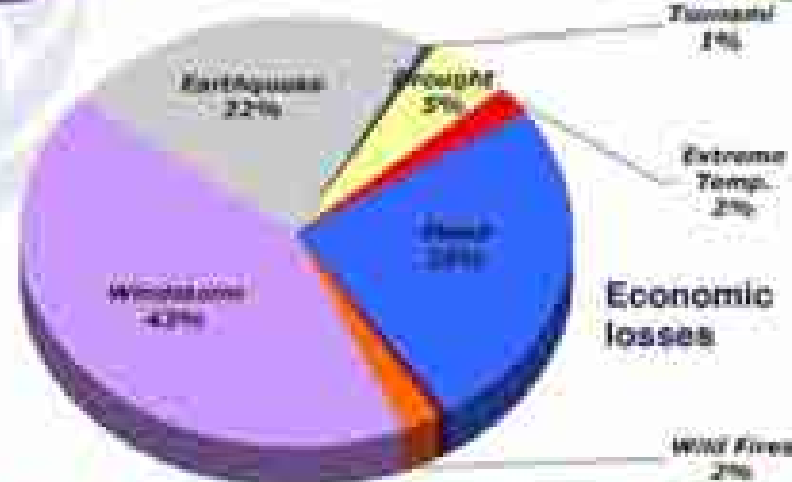
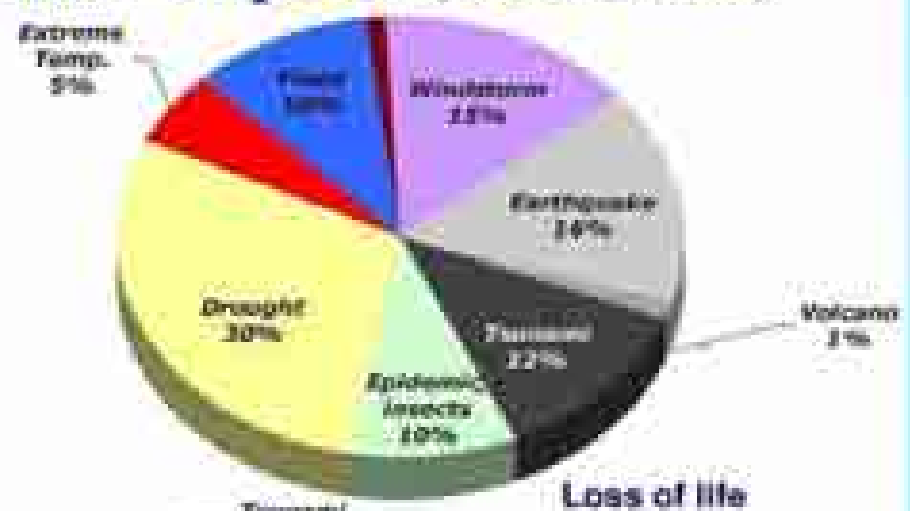
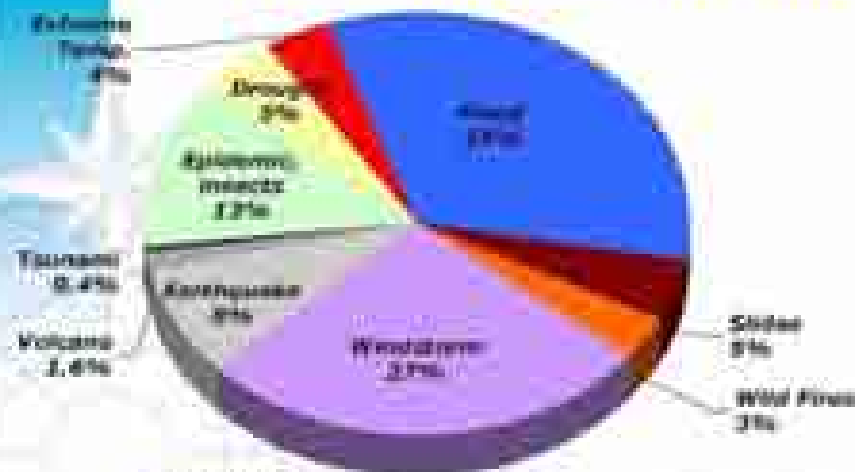
Hailstorm  
(in 100 years)



Tornado  
prone areas



# Global Distribution of Disasters Caused by Natural Hazards and their Impacts (1980-2007)

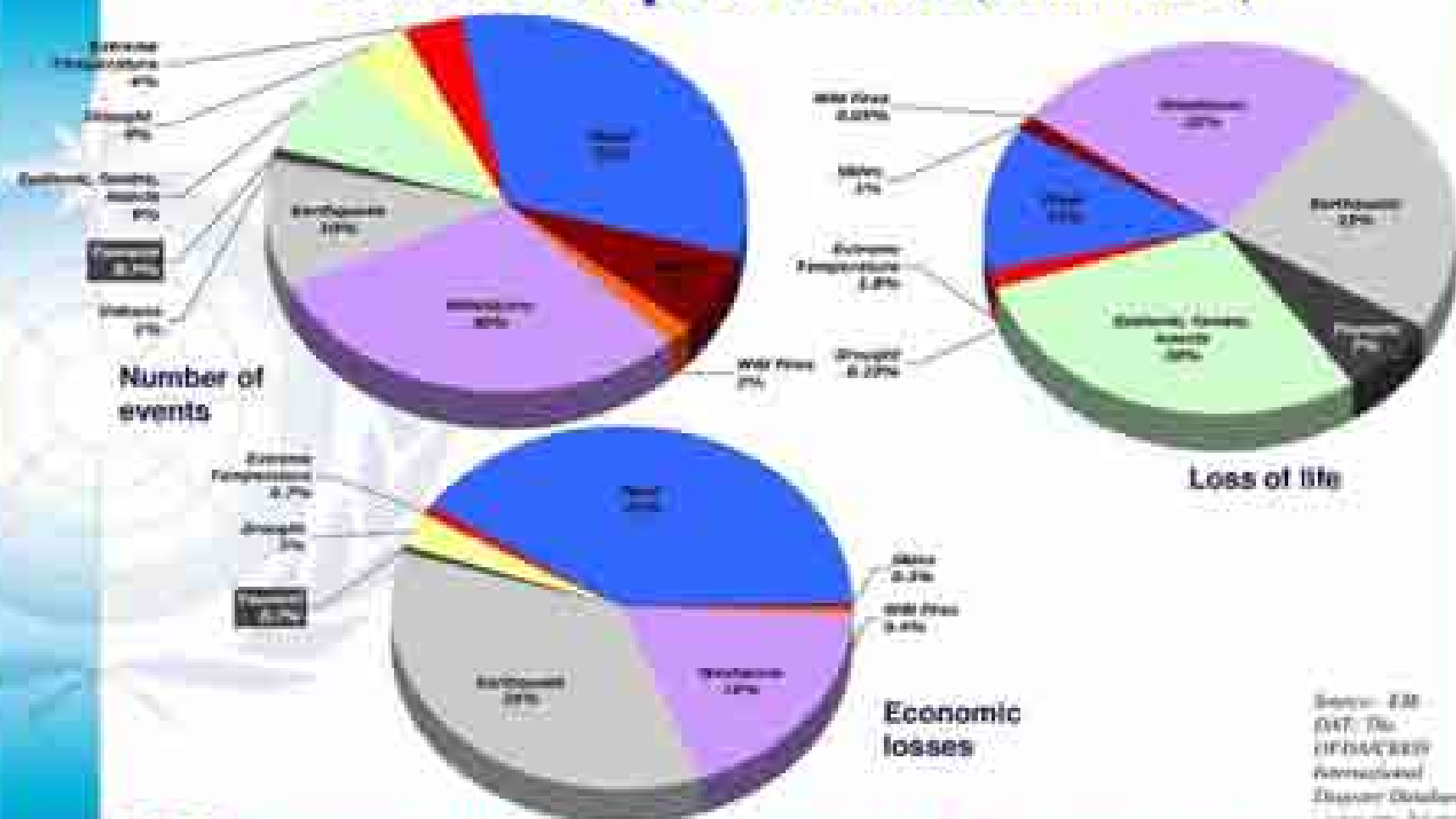


**90% of events, 70% of casualties and 75% of economic losses are related to hydro-meteorological hazards.**

Source: EM-DAT The OFDA/CRED International Disaster Database  
[www.emdat.net](http://www.emdat.net)  
 © International Collection of Experts - Brussels - Belgium



# Distribution of Disasters Caused by Natural Hazards and their Impacts in Asia (1980-2005)



**90% of events, 70% of casualties and 65% of economic losses are related to hydro-meteorological hazards.**

Source: UN  
 OAT: The  
 UN/ISDR  
 International  
 Disaster Database  
 (www.unisdr.org)  
 Prepared  
 by  
 J. B. B. B. B.  
 J. B. B. B.  
 J. B. B. B.

**Disaster risks are increasing, due to:**

- Increasing intensity and frequency of hydrometeorological hazards;**
- Increasing value of exposed elements due to development and demographic expansion.**

**Disaster risk management is a critical component of climate change adaptation.**

# Natural Hazards in India leading to disasters

## Drought

- 68% net sown area in 116 dist.

## Forest Fire

- 44 M ha ( $\approx$  65%: Deciduous) of India's 67.5 M ha (total) forest cover is prone to forest fires

## Earthquake

- 55% of area in Seismic Zone III-IV-V

## Flood

- 40 M ha flooding

## Heat Wave/Cold Wave

- Same areas affected in different seasons

## Landslide

- Himalayas and Western Ghats
- Mostly rainfall induced - 6 - 7 major landslide events Each monsoon,

## Cyclone - 2 seasons

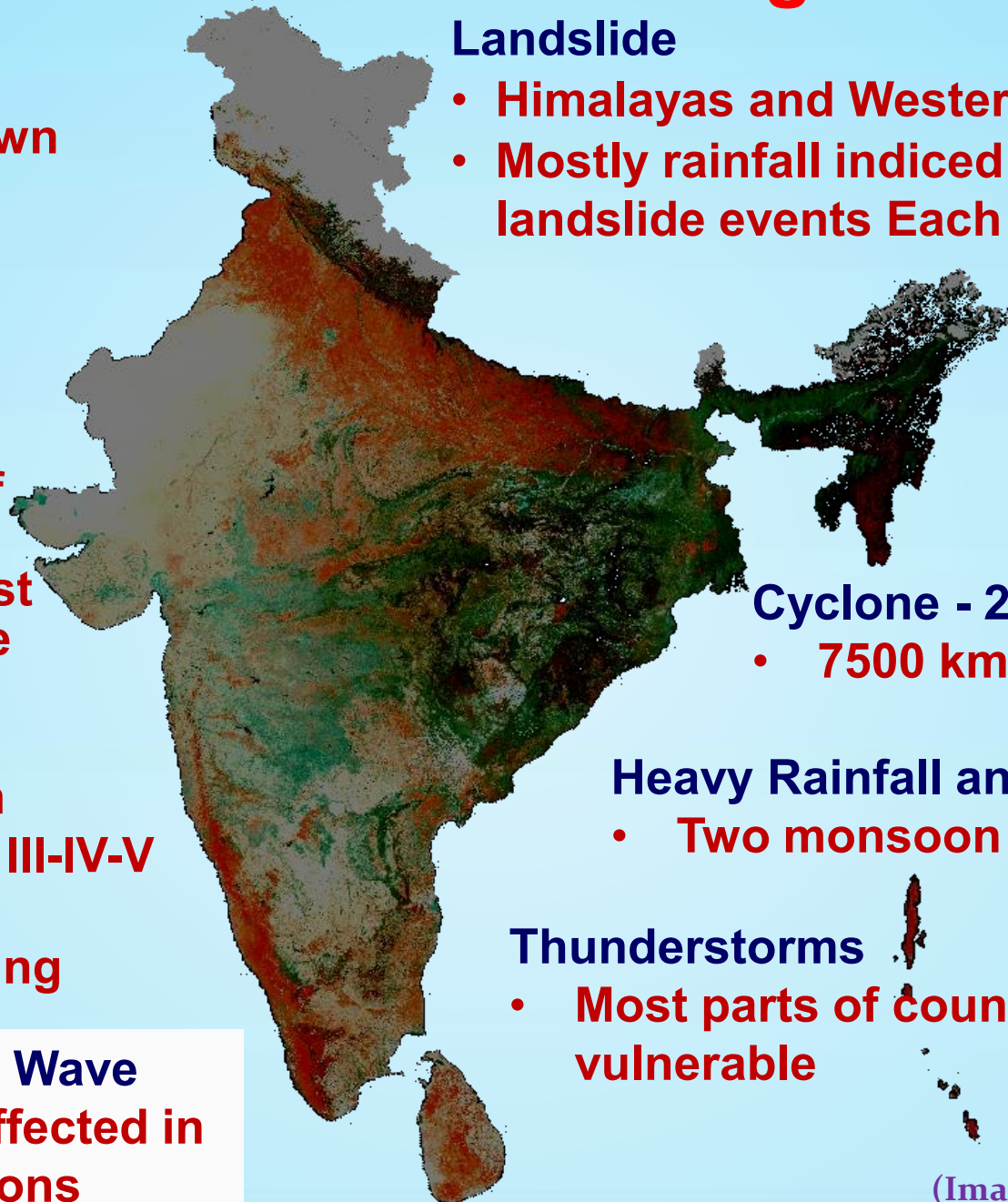
- 7500 km long coastline

## Heavy Rainfall and Flash Floods

- Two monsoon seasons

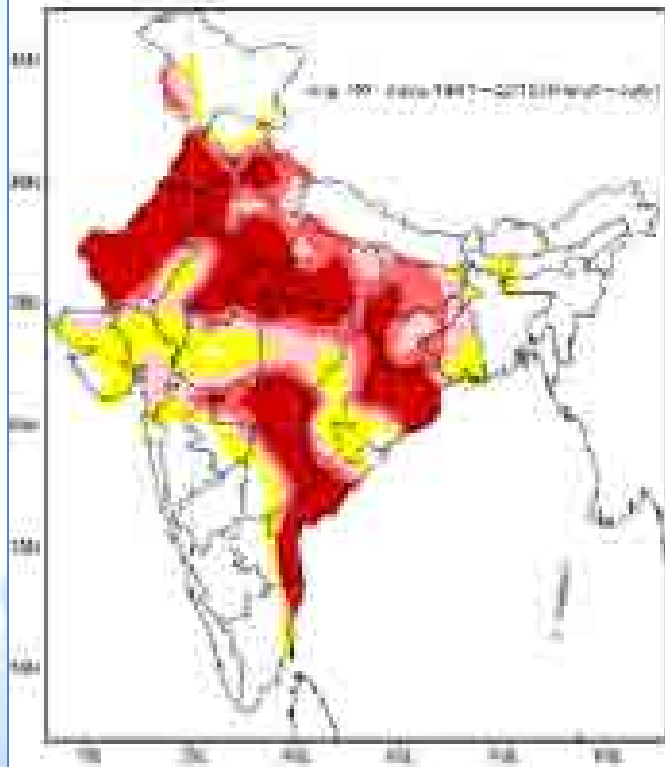
## Thunderstorms

- Most parts of country vulnerable

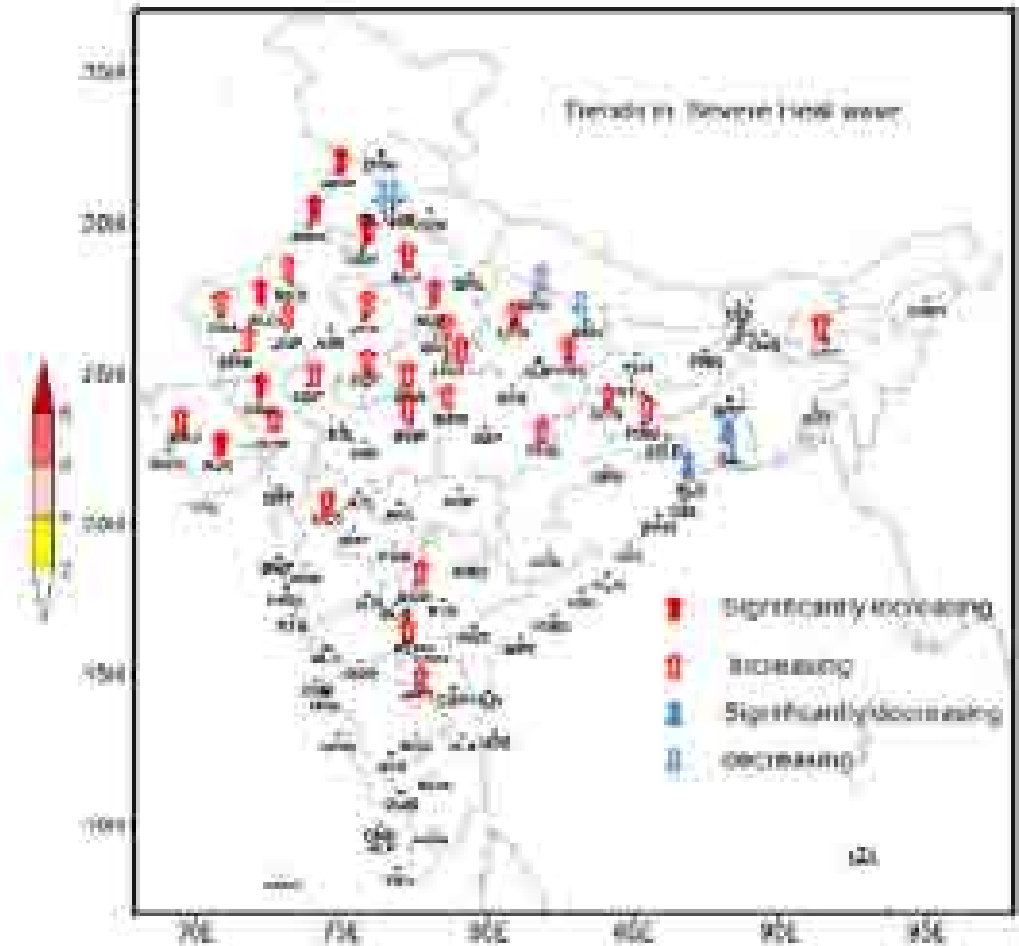


(Image Courtesy: ISRO)

# Heat waves over India



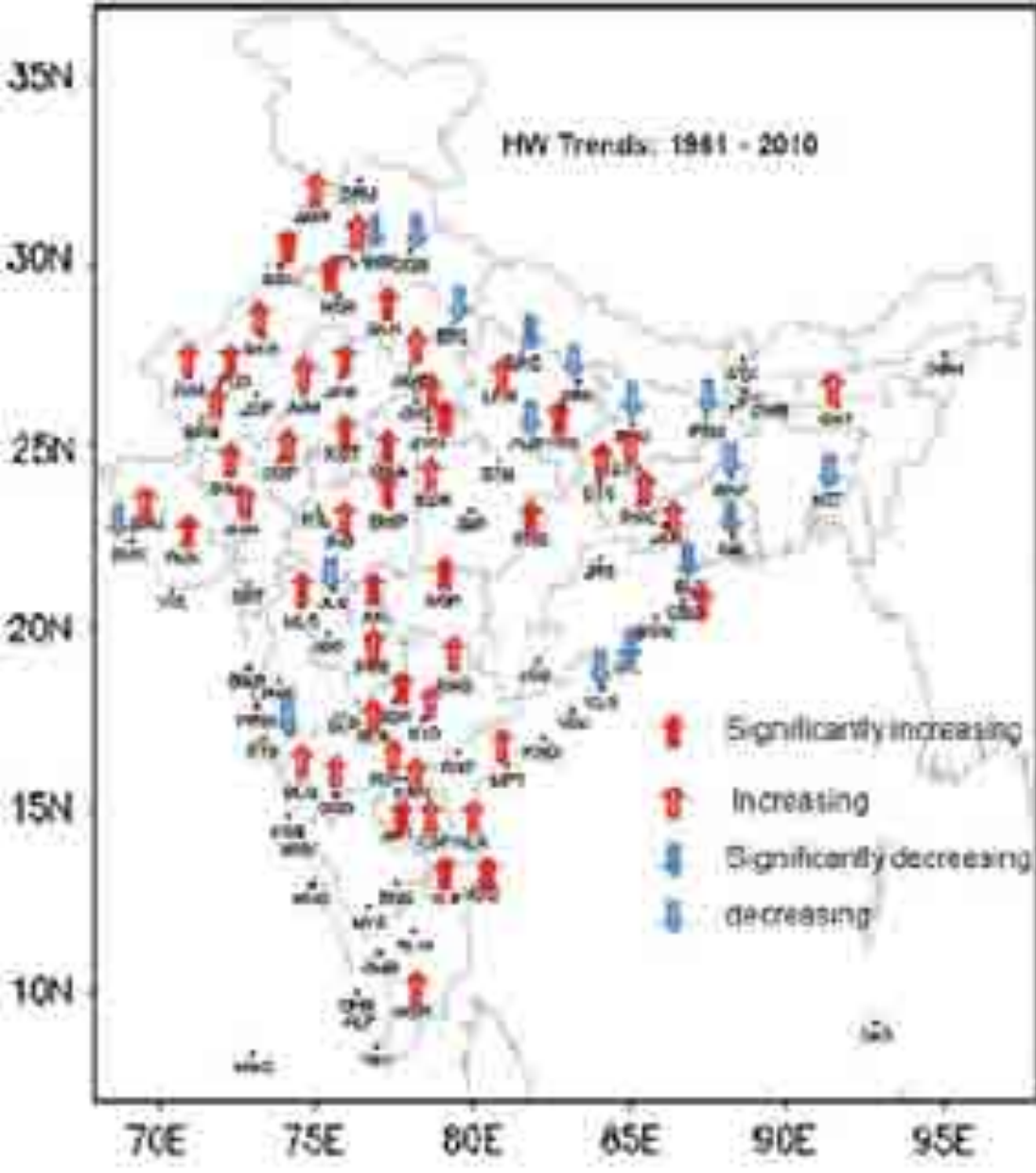
Average Frequency of Heat Wave Days



Trends in severe heat waves over India



## Trends in HW Days of 103 stations during AMJ Season (1961-2010)



➤ Non parametric Mann Kendall Test used to test the significance of trends.

➤ Red rising/blue falling arrows indicate increasing/decreasing trend

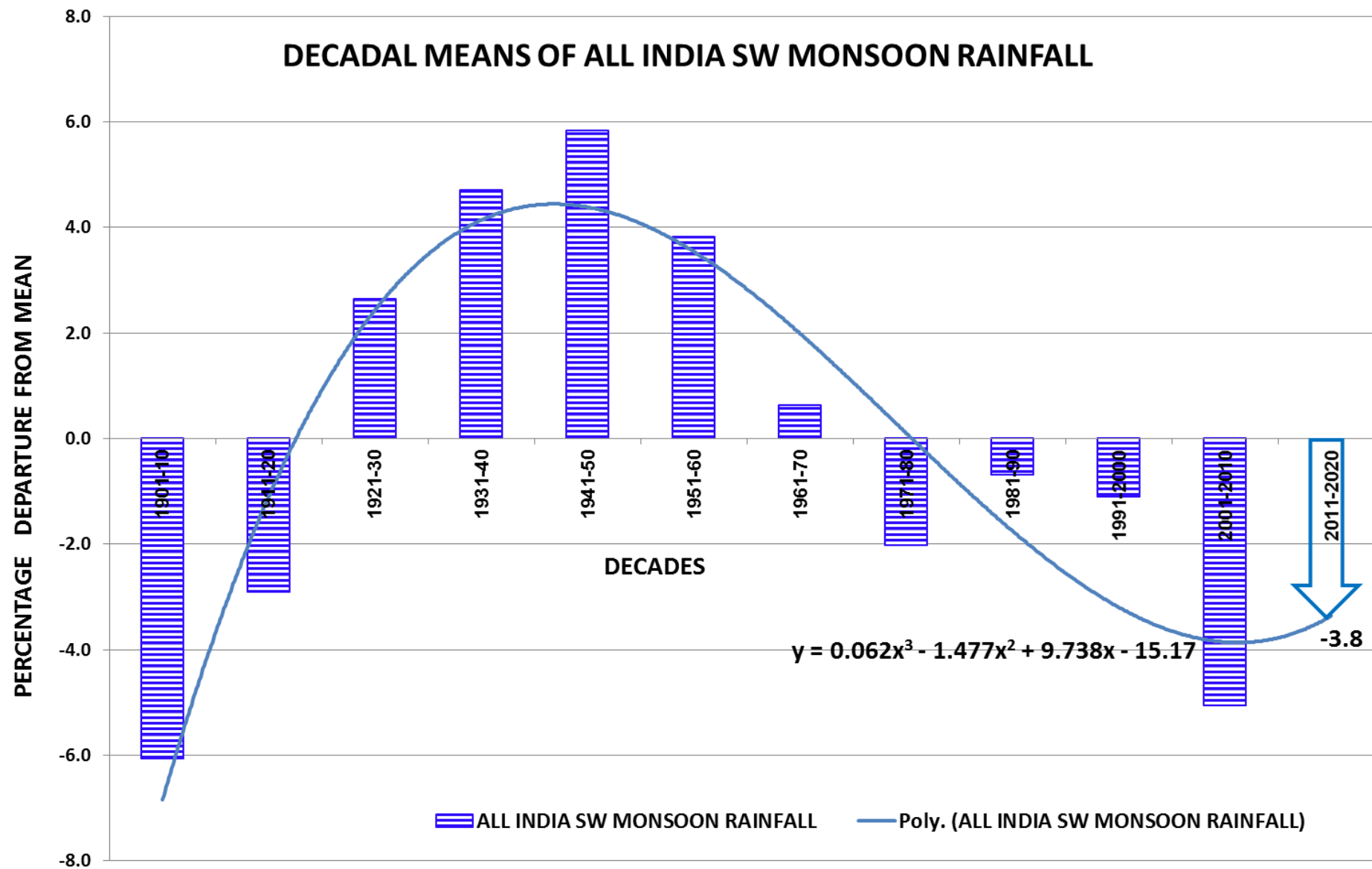
➤ Filled arrows represent trends significant at 5% level

D S Pai et al, 2017, Heat & Cold waves over India in book entitled Observed Climate variability & change over Indian Region Edited by M N Rajeevan & Shailesh Nayak

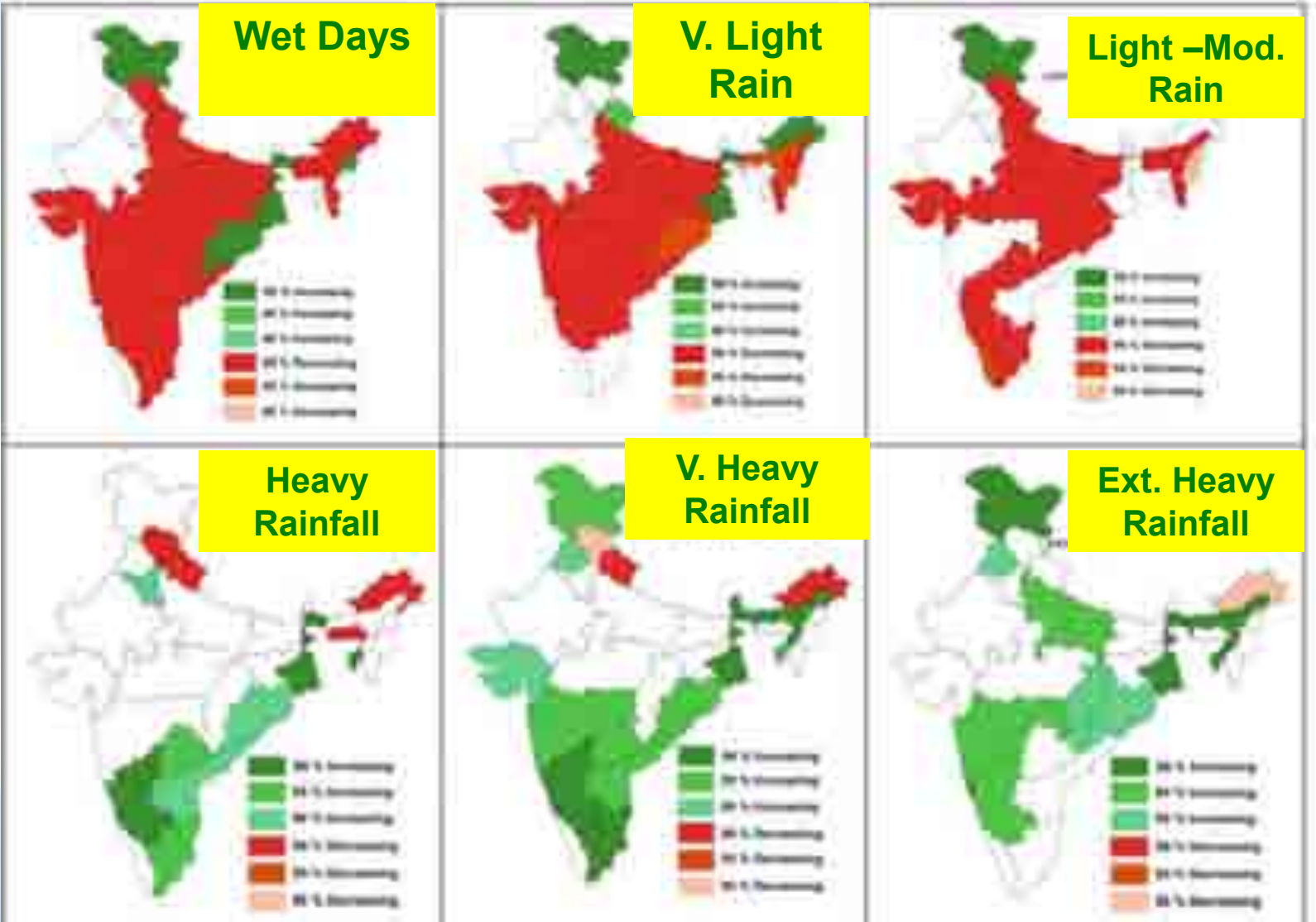




# Year to Year variability of Indian Southwest Monsoon rainfall (June to September); 1901-2018



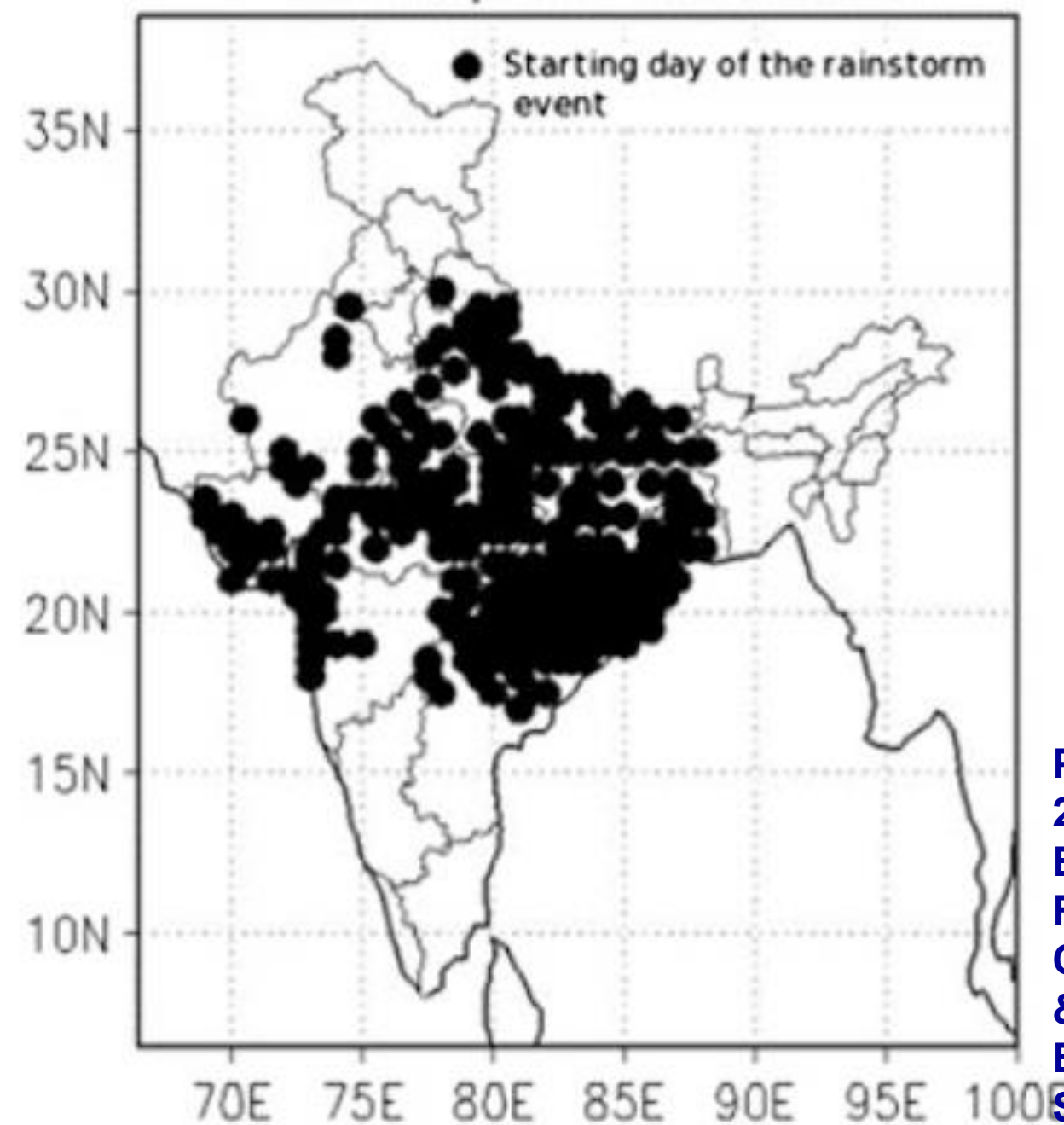
# Trends in frequencies of different rainfall events during Monsoon Season



Pulak Guhathukarta et al, 2017, Variability & Trends of Extreme Rainfall & Rainstorms in book entitled Observed Climate variability & change over Indian Region Edited by M N Rajeevan & Shailesh Nayak



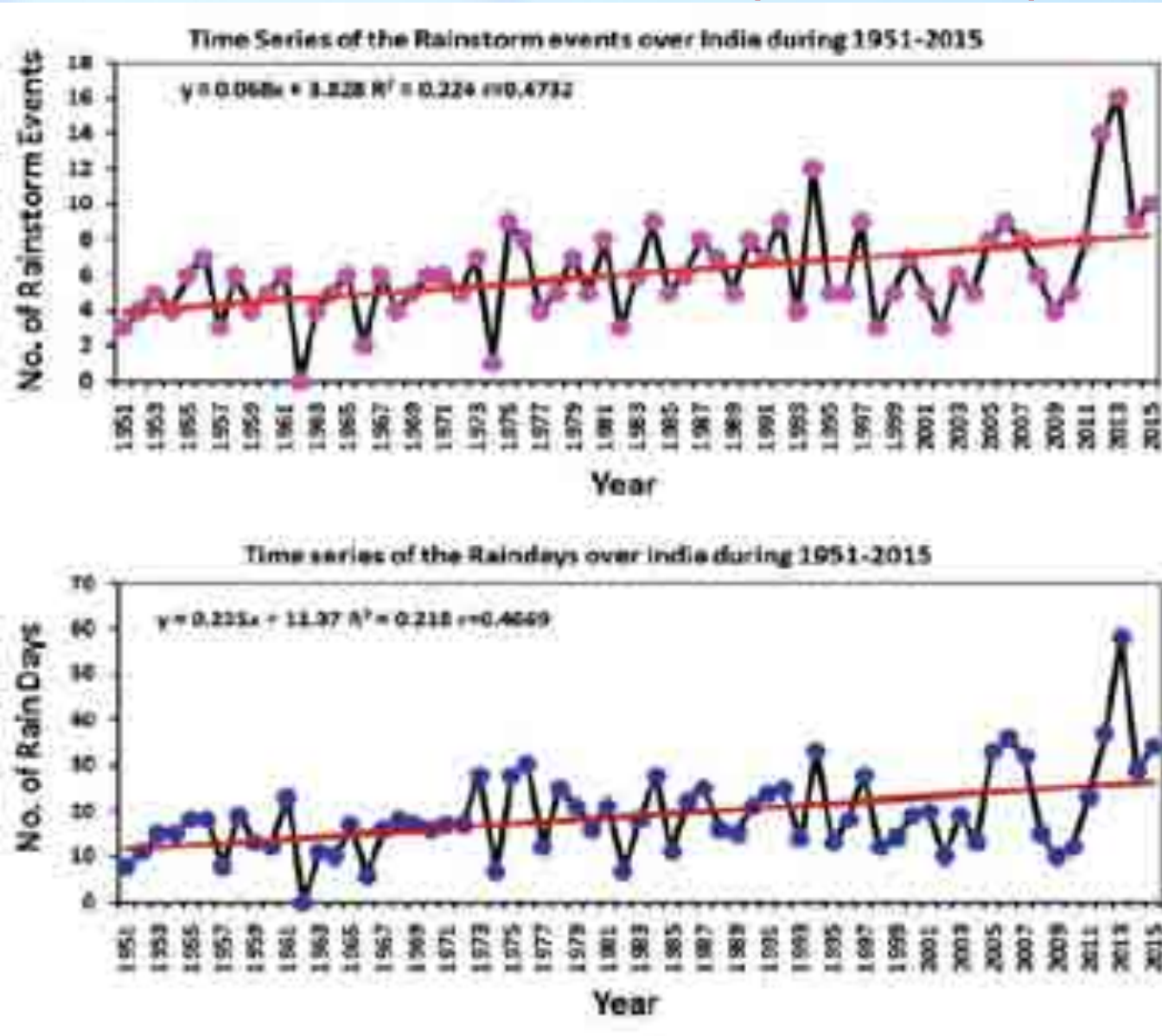
## Spatial Variation in Origin of Rainstorms over India during southwest Monsoon Season (1951-2015)



Pulak Guhathukarta et al, 2017, Variability & Trends of Extreme Rainfall & Rainstorms in book entitled Observed Climate variability & change over Indian Region Edited by M N Rajeevan & Shailesh Nayak



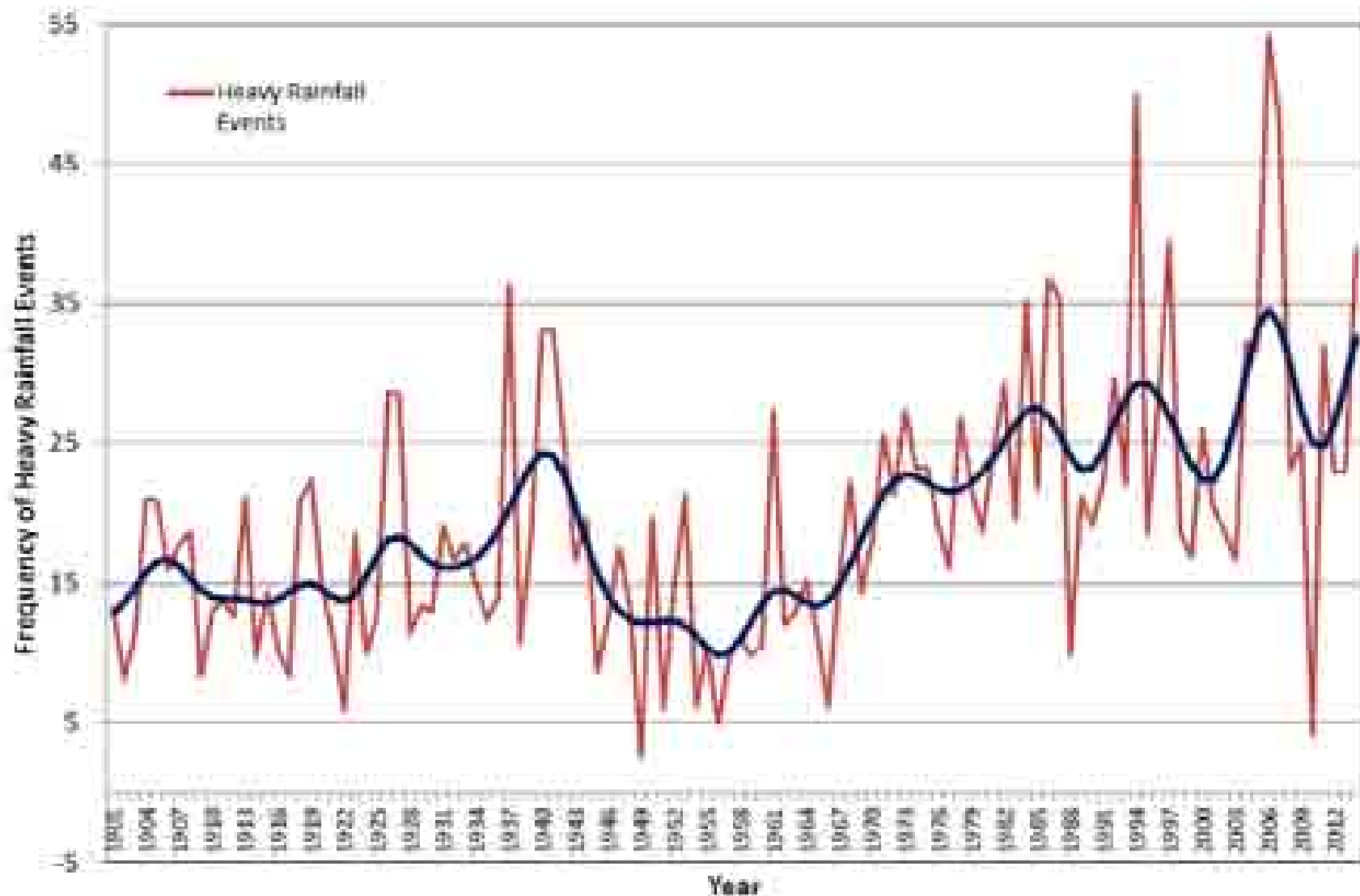
# Time Series of the Rainstorm events and Rain Days over India(1951-2015)



Pulak  
Guhathukarta et al,  
2017, Variability &  
Trends of Extreme  
Rainfall &  
Rainstorms in  
book entitled  
Observed Climate  
variability &  
change over Indian  
Region Edited by  
M N Rajeevan &  
Shailesh Nayak



## Year to Year Variation of Heavy Rainfall Events (>15 cm) over Central India

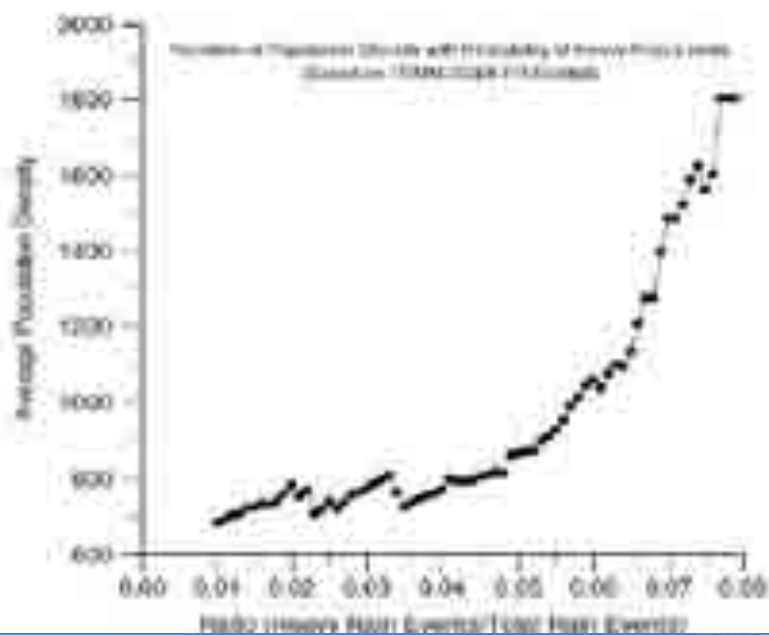
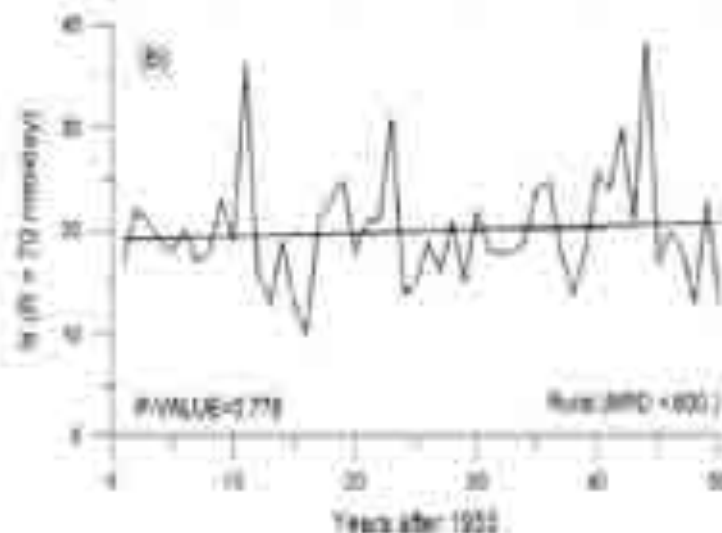
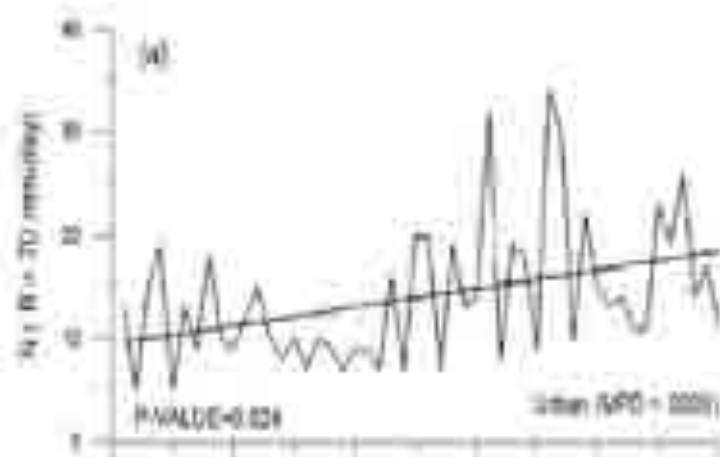
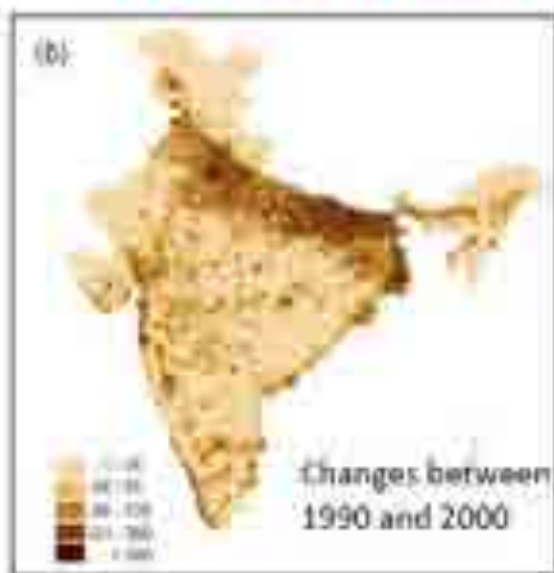


Rajeevan et al. 2008, GRL





# Urban vs Rural Differences in Heavy Rainfall Events

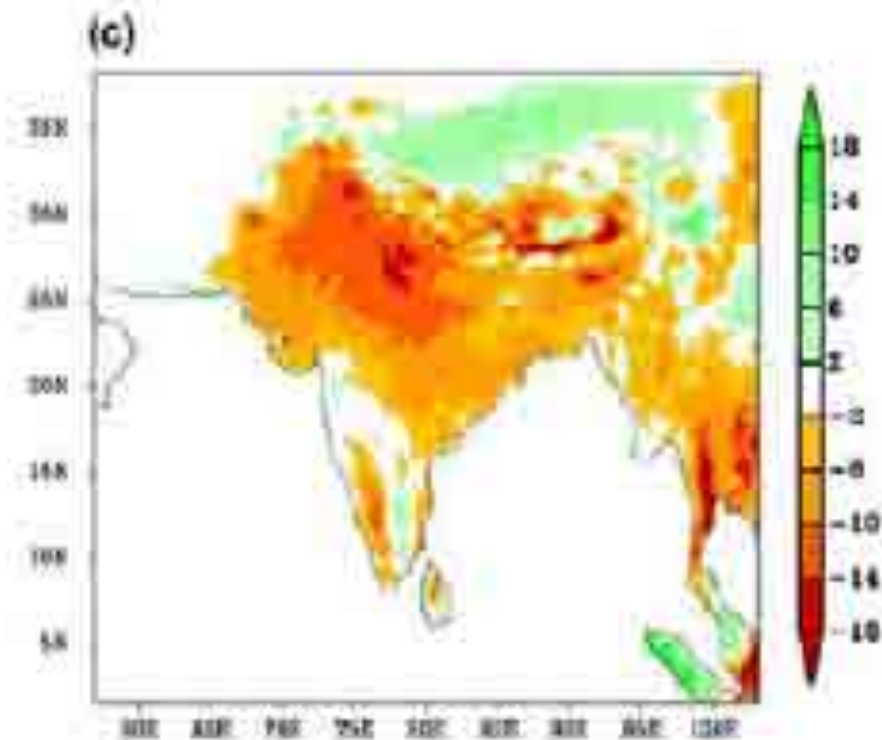


Kishtawal et al. 2010, Int J Climatology

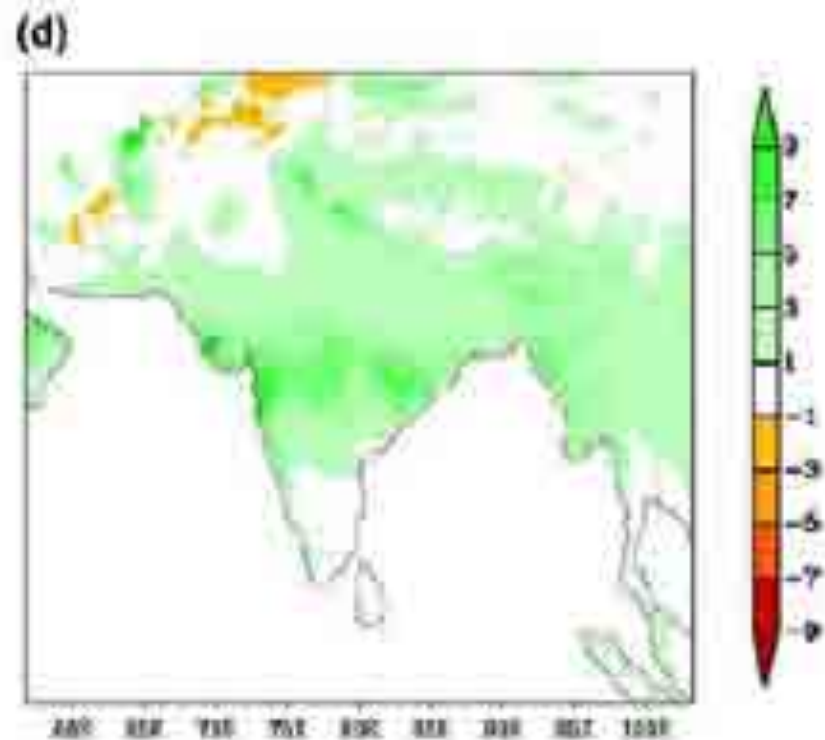
# IPCC Model Projections

- Intergovernmental Panel on Climate Change (IPCC) produces future climate change scenarios using different climate model results.
- For future climate change projections, complex climate models (coupled ocean-atmosphere models/earth system models) are used, in which we prescribe how the greenhouse gas emissions will evolve in future in different scenarios.
- The fourth report (AR4) was released in 2007 and the fifth report (AR5) was released in September 2013.
- The detailed report available at <http://www.ipcc.ch/>





Projected change in  
number of rainy days



Projected change in intensity  
(mm/day) of rainfall on a rainy day

IPCC models suggest decrease in number of rainy days and an  
increase in intensity of rainfall during the monsoon season

Krishna kumar et al. 2012

# Future Climate Change Projections over the Indian Region

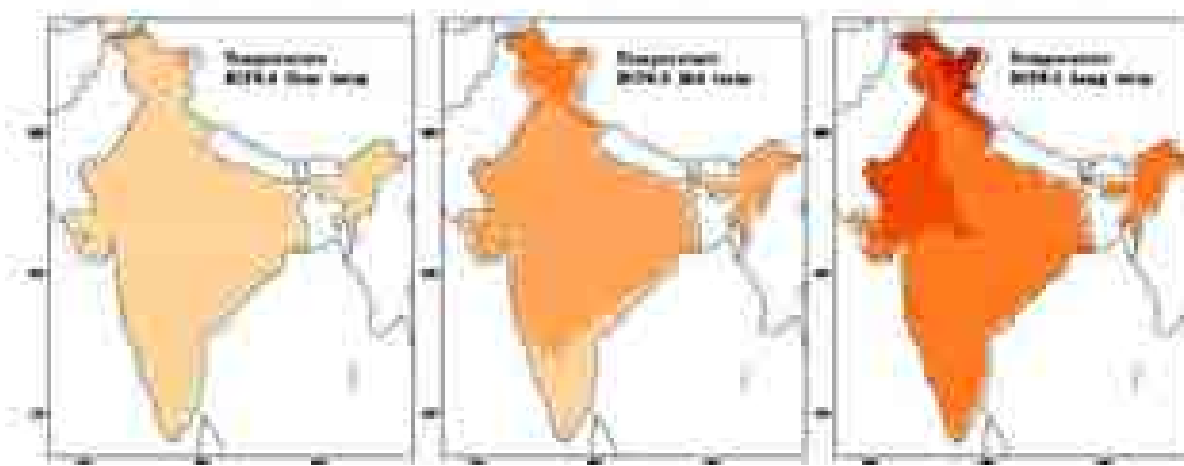
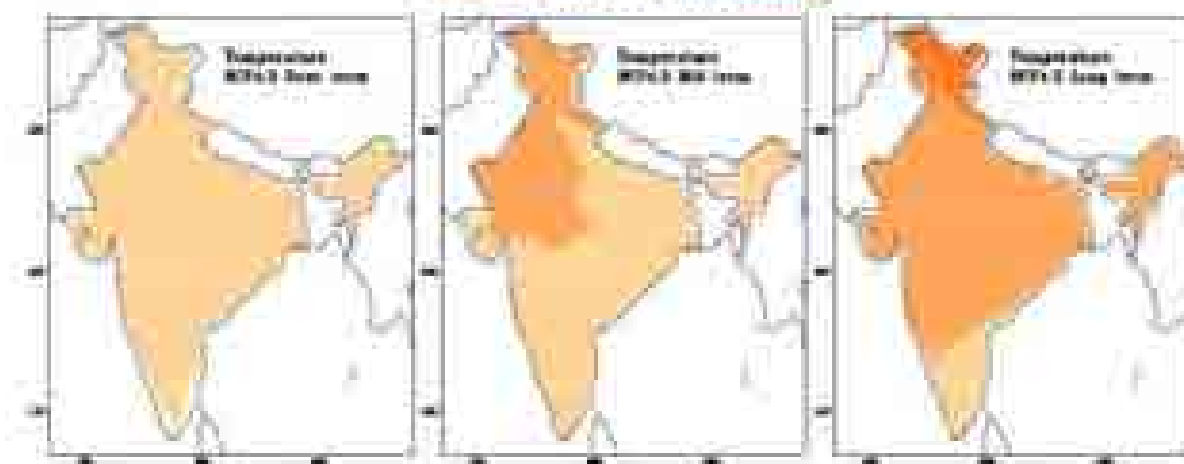
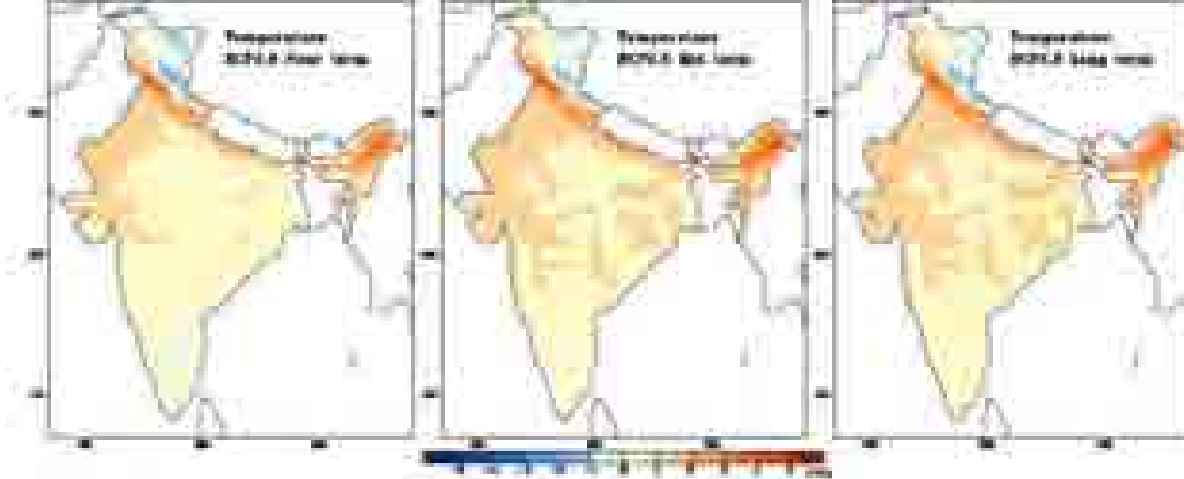
Lead Author: J. Sanjay

Co-authors: R. Krishnan, M.V.S. Ramarao, R. Mahesh, Bhupendra Singh, Jayashri Patel, Sandip Ingle, Preethi Bhaskar, J.V. Revadekar, T.P. Sabin, M. Mujumdar

- The all India mean surface air temperature change for the near-term period 2016–2045 relative to 1976–2005 is projected to be in the range of 1.08°C to 1.44°C, and is larger than the natural internal variability. This assessment is based on a reliability ensemble average (REA) estimate incorporating each RCM performance and convergence, and is associated with less than 16% uncertainty range (Table 2.1, Box 2.4).
- The all India mean surface air temperature is projected to increase in the far future (2066–2095) by  $1.35 \pm 0.23^\circ\text{C}$  under RCP2.6,  $2.41 \pm 0.40^\circ\text{C}$  under RCP4.5 and  $4.19 \pm 0.46^\circ\text{C}$  under RCP8.5 scenario respectively. These changes are relative to the period 1976–2005. The semi-arid north-west and north India will likely warm more rapidly than the all India mean (Table 2.1, Fig. 2.1).

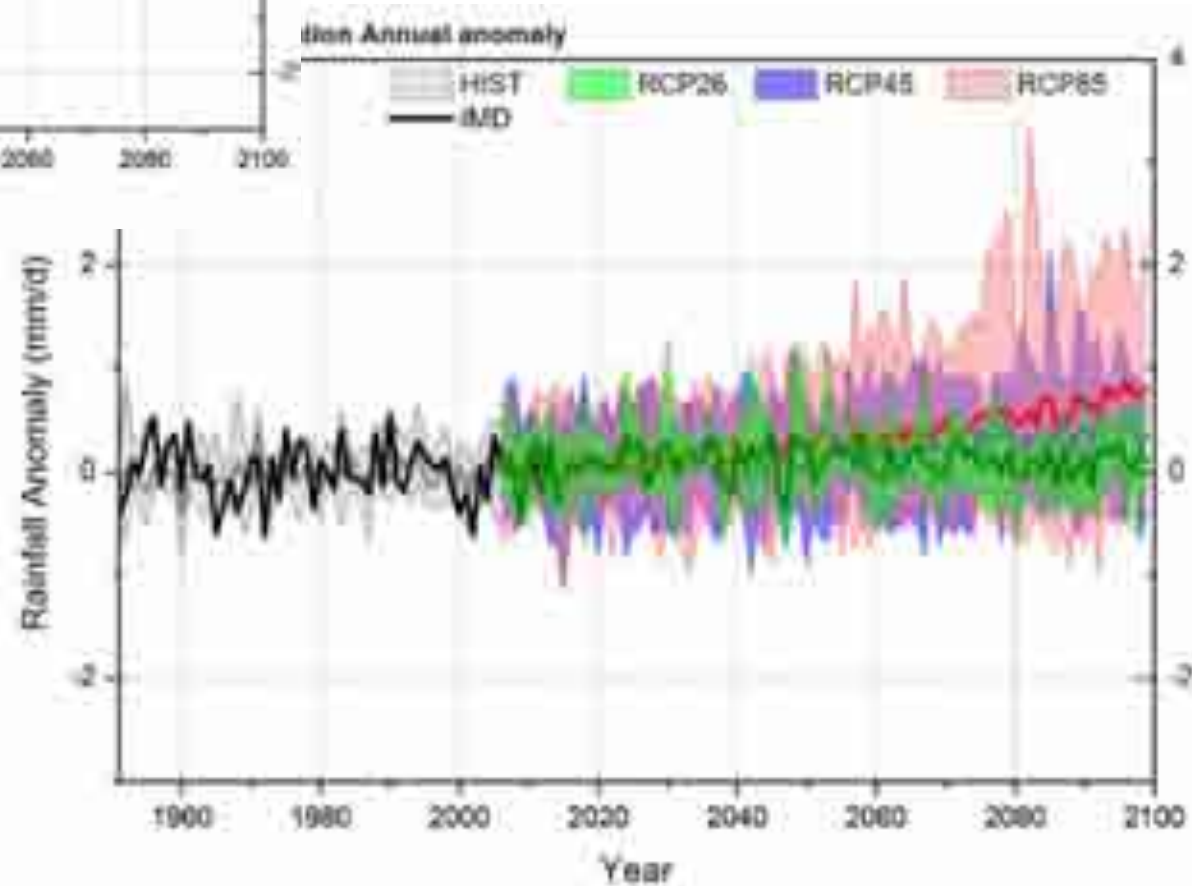
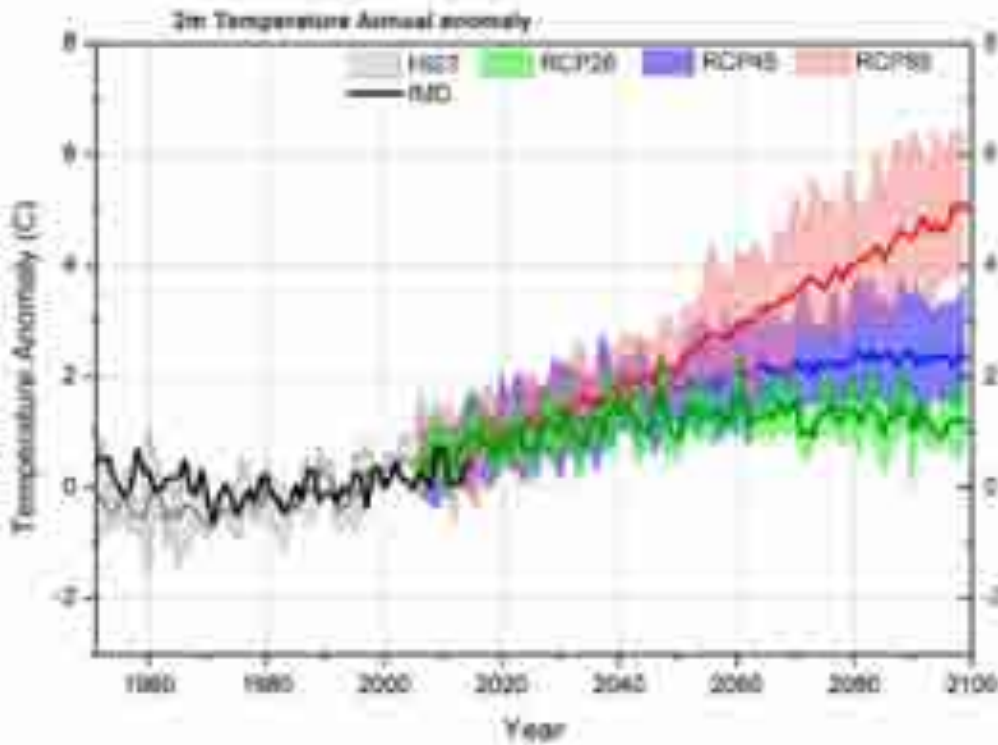
**Available for download at**  
**<http://cccr.tropmet.res.in/home/reports.jsp>**



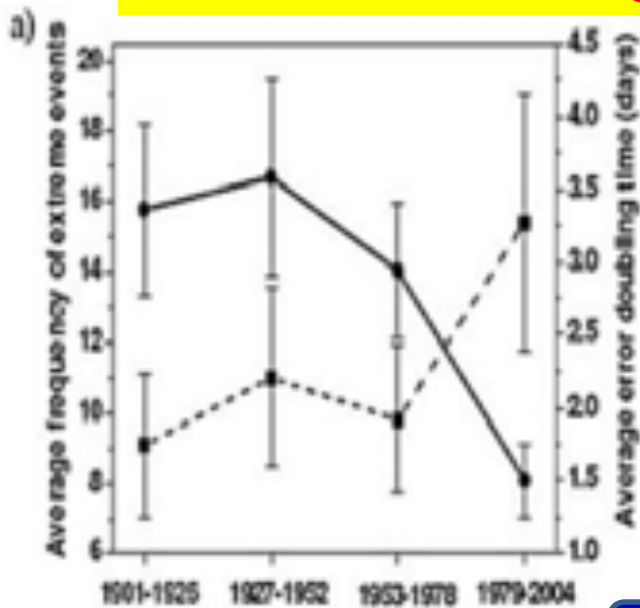




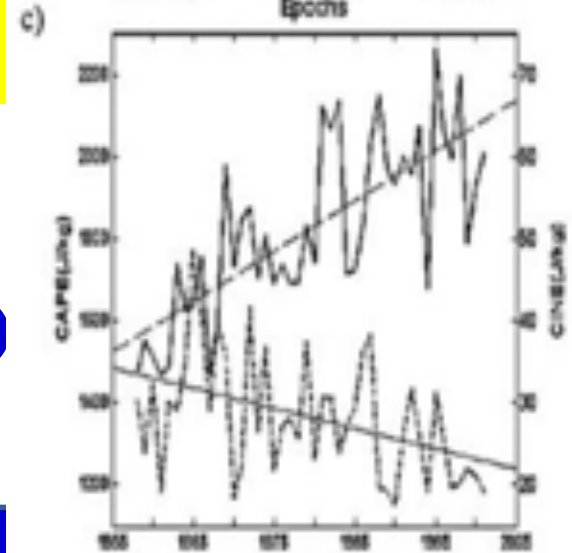
# Indian annual mean anomalies (relative to 1976-2005) from CORDEX South Asia concentration-driven experiments



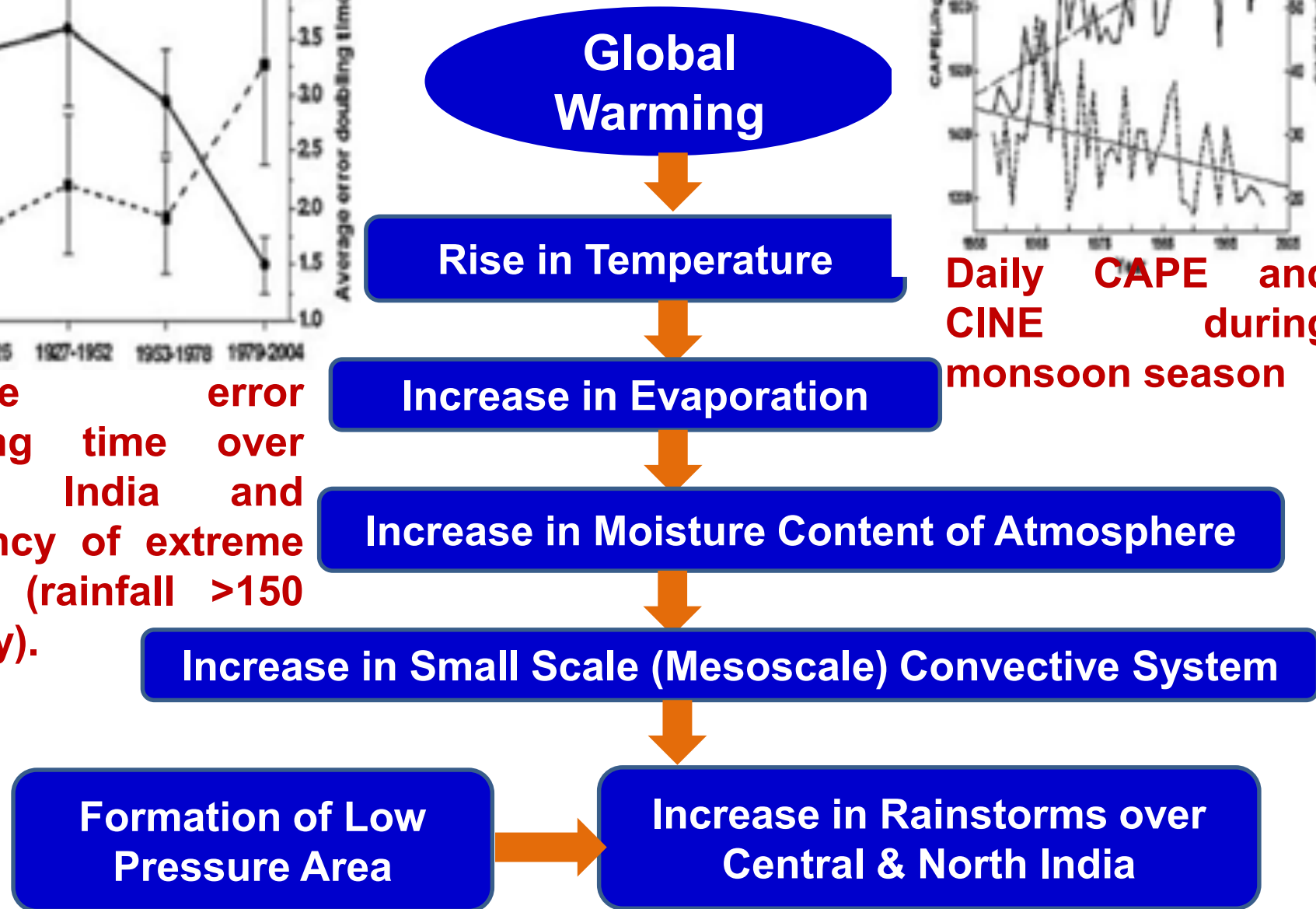
# Global Warming on Rainfall Activity



Average frequency of extreme events (rainfall >150 mm/day) and error doubling time over central India.



Daily CAPE and CINE during monsoon season



# Challenges in Predictability of Mesoscale Events

- Predictability of meso scale system is less
- Due to Global Warming the prediction of Extreme Rainfall Events likely to decrease
- Error doubling time of extreme rainfall event during last 30 years decreased from about 3 days to 1.5 days

## Solutions to improve Predictability of Mesoscale Events

- Enhancement of observational network to detect mesoscale systems
- Improve data assimilation of models for these systems
- Use High Resolution Models
- To address uncertainty, provide probabilistic forecast
- Warning system & dissemination be made smarter to utilise reduced lead time to reach the last mile
- Capacity building of forecasters, disaster managers, media & general public

# CLIMATE CHANGE

90%

of disasters related  
to extreme climate and  
weather

- **National Policy on Disaster Management (2009) (Source , NDMA)**

**“To build a Safe and Disaster Resilient India by developing a holistic, proactive, multi-disaster and technology-driven strategy through a culture of prevention, mitigation, preparedness and efficient response.”**



# Global Framework of Climate Services (GFCS)

## Priorities

In the first four years give priority to:

- Agriculture
- **Disaster risk reduction**
- Water
- Health
- Energy



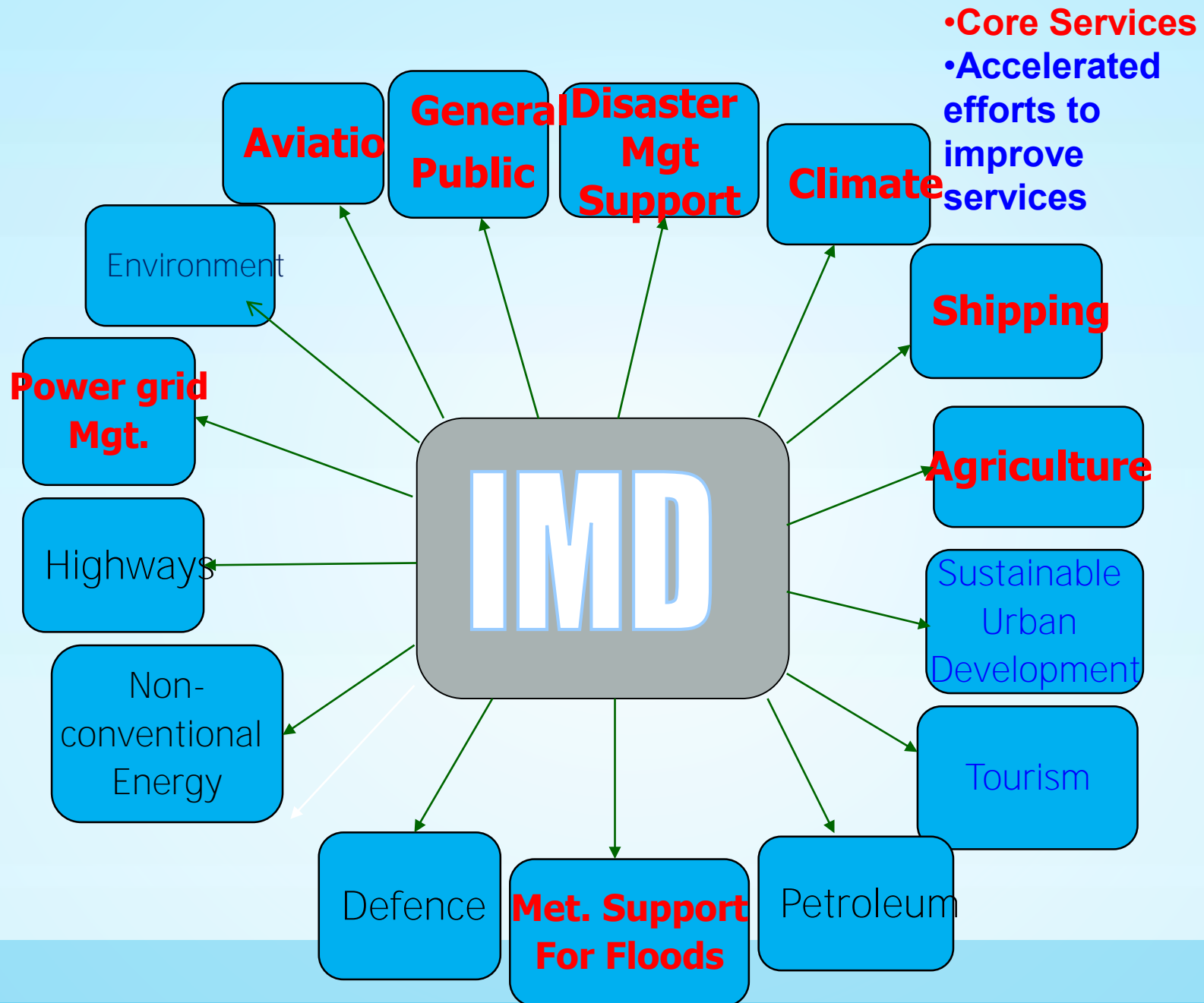


# Major science themes/applications/services of IMD

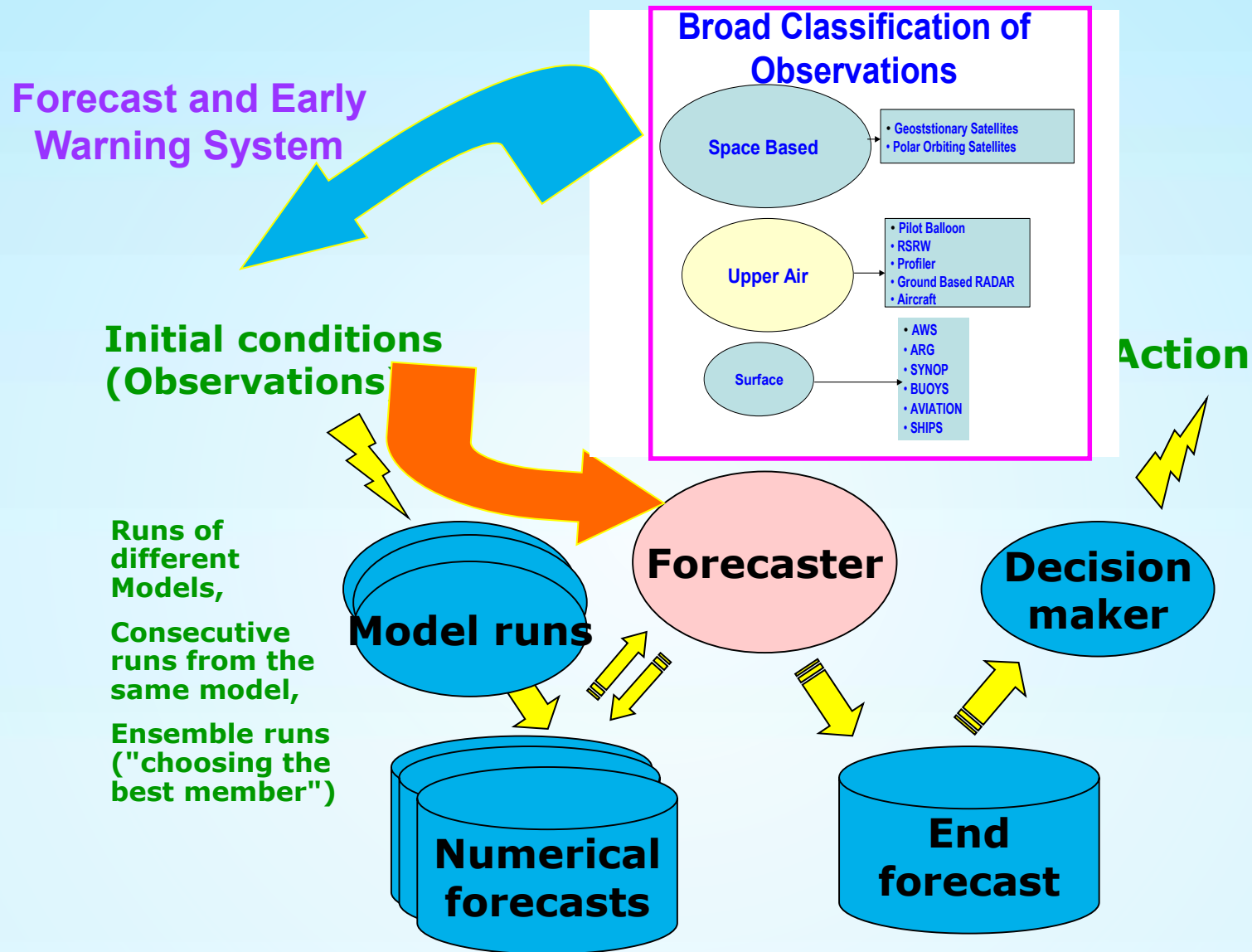
- Prediction of land, atmospheric and Oceanic states at different scales to provide weather and climate forecast in different spatial and temporal range
  - Nowcasting (few hours)
  - Short range (1-2 days)
  - Medium range (few days – week)
  - Extended Range (Week-Month)
  - Seasonal (Few months, e.g. Jun-Sep Monsoon)
  - Climate Scales

**Spatial range :** Location, Block, District, Meteorological Sub-division, River catchment, State and Homogeneous regions

# Major science themes/applications/services of IMD



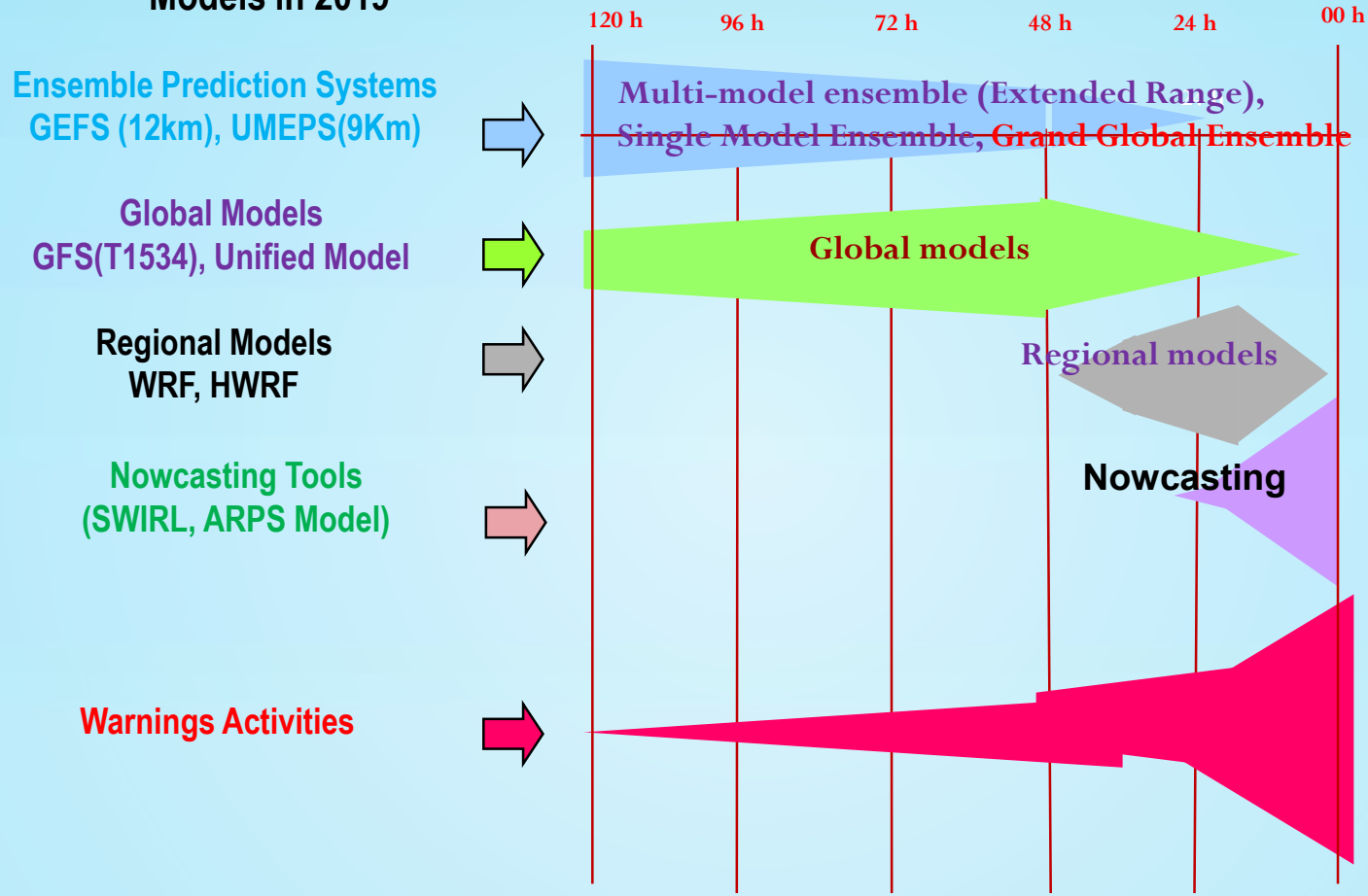
# Major science themes/applications/services of IMD



Improved Forecast and Early warning system with respect to all the above components

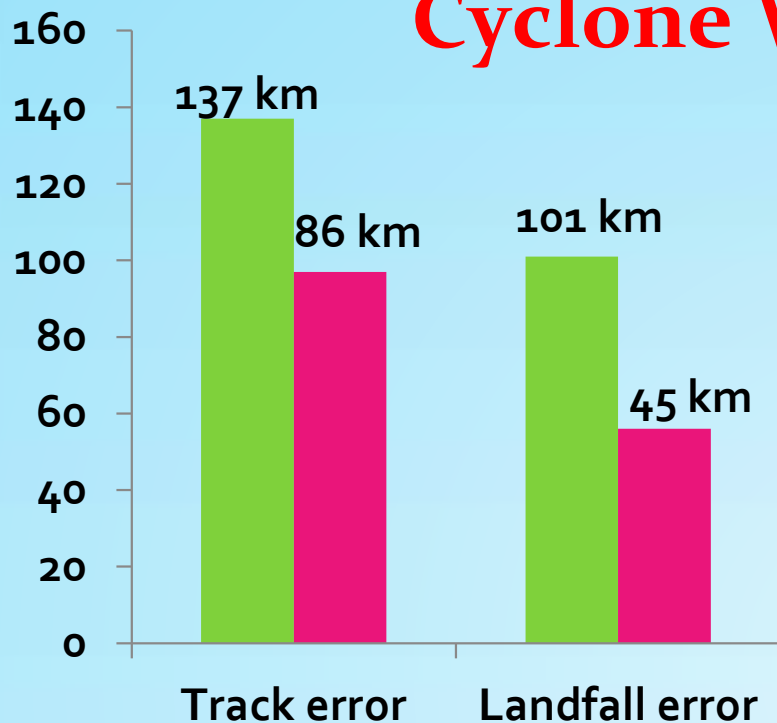
# Numerical Weather Prediction (NWP) Modeling: Backbone for Forecasting and Warning Services

## Models in 2019



❖ By 2020: 1-3 km Regional multi-model prediction system, ocean-atmosphere-land surface coupled severe weather pred. systems, Parametric models and Expert systems – severe weather Warning up to 5-7 days, Forecast outlook up to 10-15 days.

# Cyclone Warning Services



24 hr forecast errors

IMD acts as **WMO recognized Regional Centre** to provide cyclone advisories to all countries in north Indian Ocean region.

Noteworthy improvement in track and intensity forecast of the tropical cyclones (**24 hour forecast error in track prediction reduced from 137 km to 97 km and Landfall error from 101 Km to 56 Km during 2007-11 to 2012-16**).

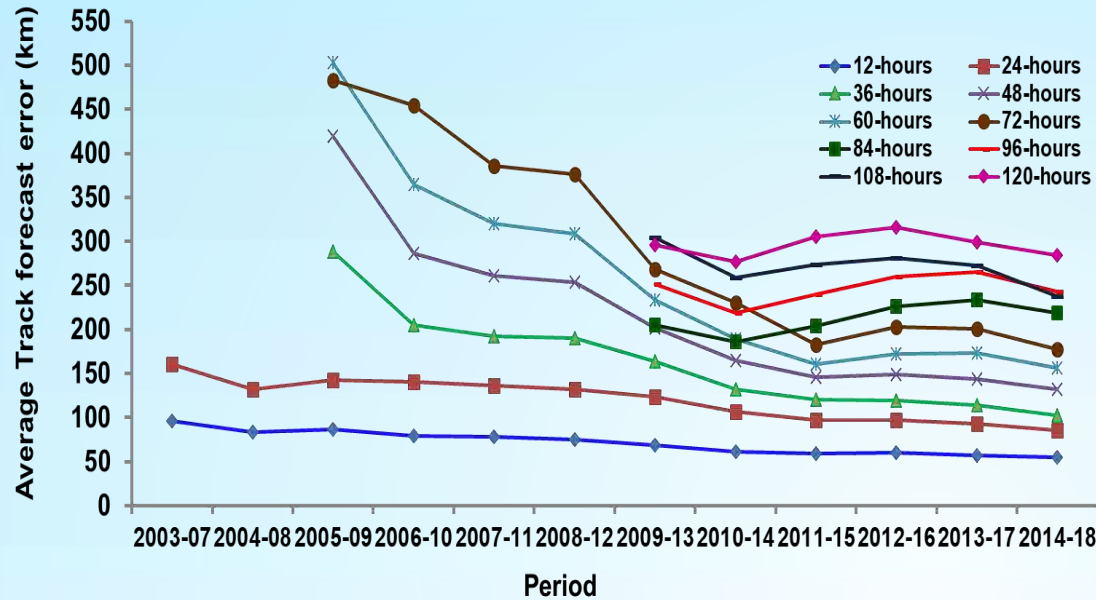
Probabilistic genesis Forecast up to 3 days and Track and intensity forecast up to 5 days in text and graphics

**Target for 2024 : Reduction in error and Improvement of skill by 20% up to 7 days**

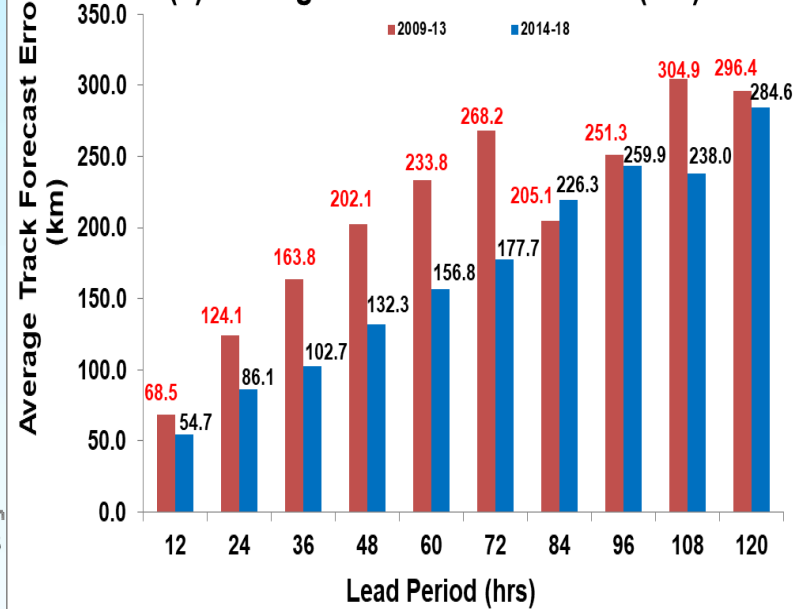


# Cyclone Warning Services

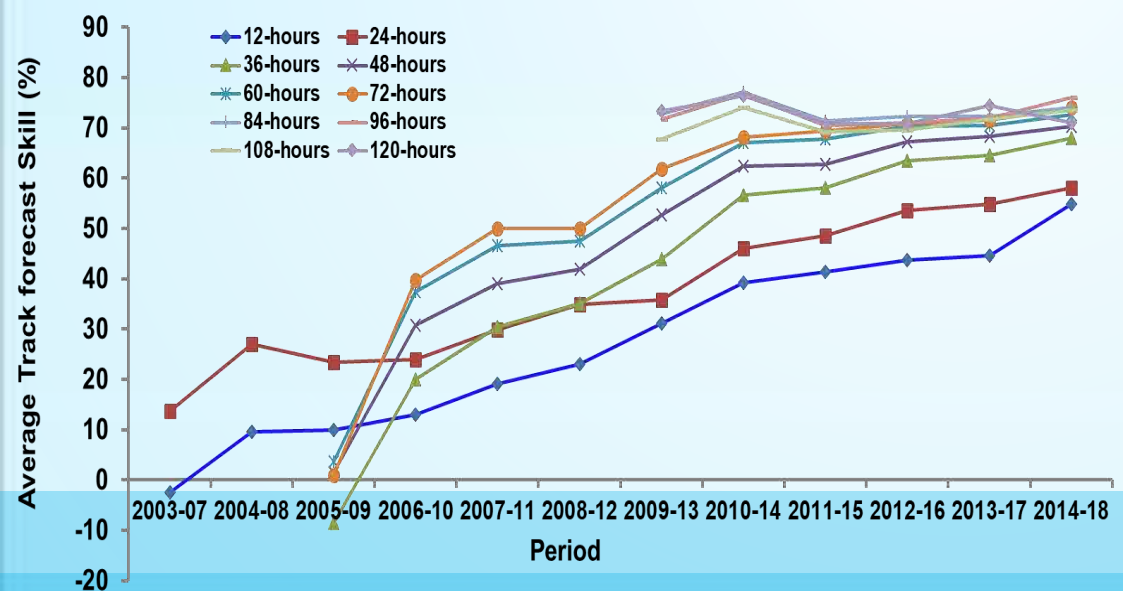
(a) Five Year Moving Average-Track forecast Error (km)



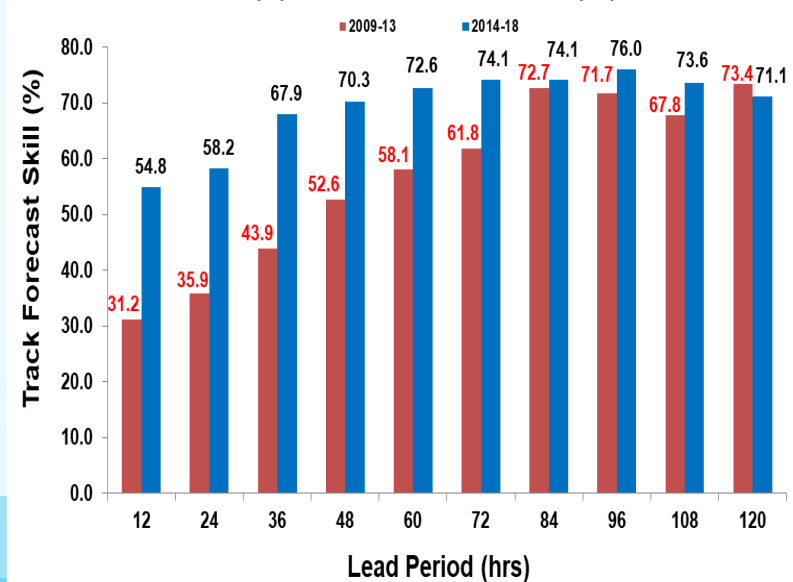
(a) Average Track Forecast Error (km)



(b) Five Year Moving Average-Track forecast Skill (%)

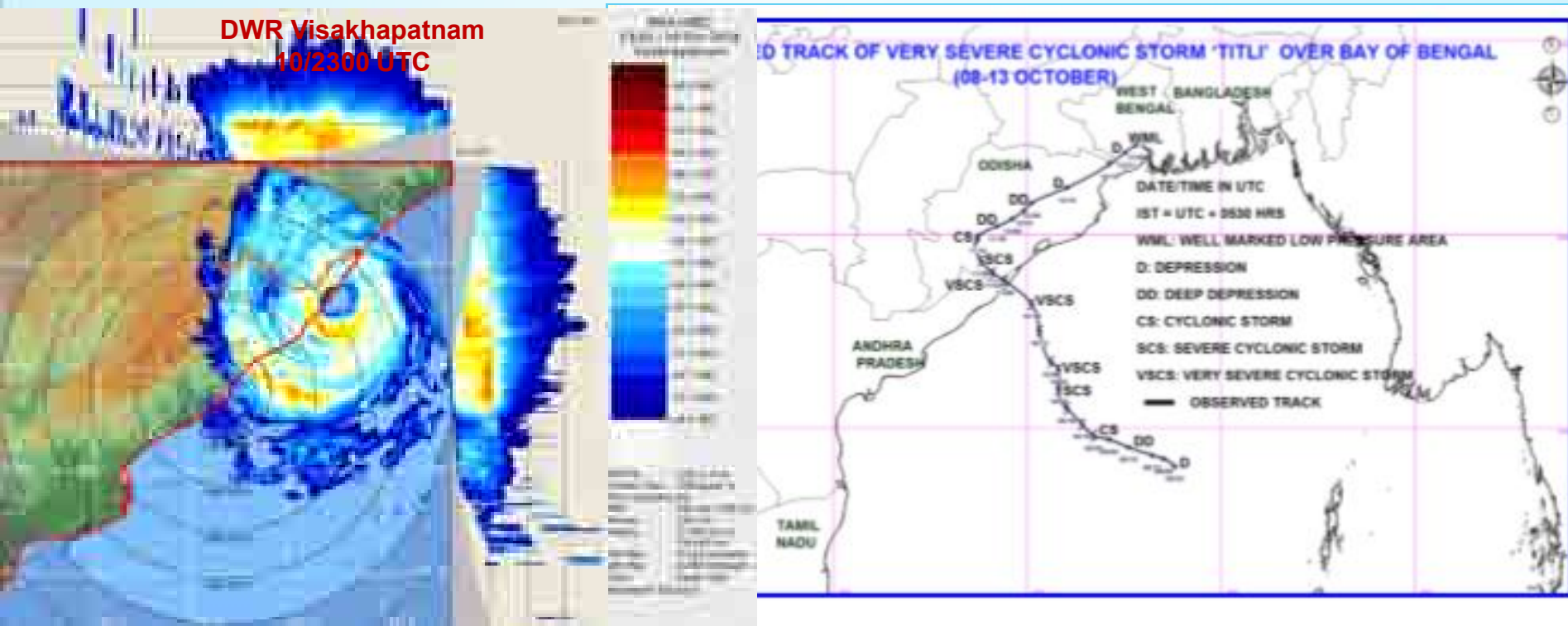


(b) Track Forecast Skill (%)



# Why Impact-Based Forecast and Warnings Services?

- Experience of Tropical Cyclone, Titli
- Good quality forecasts from IMD
- 77 people died in Odisha due to landslides and floods
  - Disaster managers and people expected the wind and rainfall – they did not expect the land slide and flood in south interior Odisha



# Why Impact-Based Forecast and Warnings Services?

- Experience of the 2013 flooding in Uttarakhand, India
  - Again, the forecasts were reasonable for such an extreme event
  - Thousands killed
  - Many were tourists / pilgrims who were not familiar with the local environment
  - Poor coordination between Met Service, local administration and national administration
  - Impact could not be anticipated



# What is Impact-based Forecasting?

- A fundamental change in focus

**From**

What the weather will **BE**

**To**

What the weather will **DO**

# Why Impact-based Forecasting?

- Arises naturally from a focus on **users needs**
- Weather information normally **just one “input”** into decision-making by users
- Increasing the **relevance** of weather information to users
- Increasing the **awareness of forecasters** and others within meteorology on users needs and concerns.



# SUMMARY

- ❖ Climate Change is leading to increasing frequency of extreme weather.
- ❖ The risks of Climate Change are inequitable, with developing country like India will be impacted more.
- ❖ IMD has taken many steps towards improving the early warning of disastrous weather in recent time.
- ❖ Impact based forecasting will be very useful in minimizing the adverse impacts of adverse weather through effective Disaster Management.

THANK YOU