Creating Innovative Solutions for a Sustainable Future

Climate Change Modelling:

Basics and Case Studies

TERI-APN's Training program on Urban Climate Change Resilience

22nd – 23rd January, 2014

Goa

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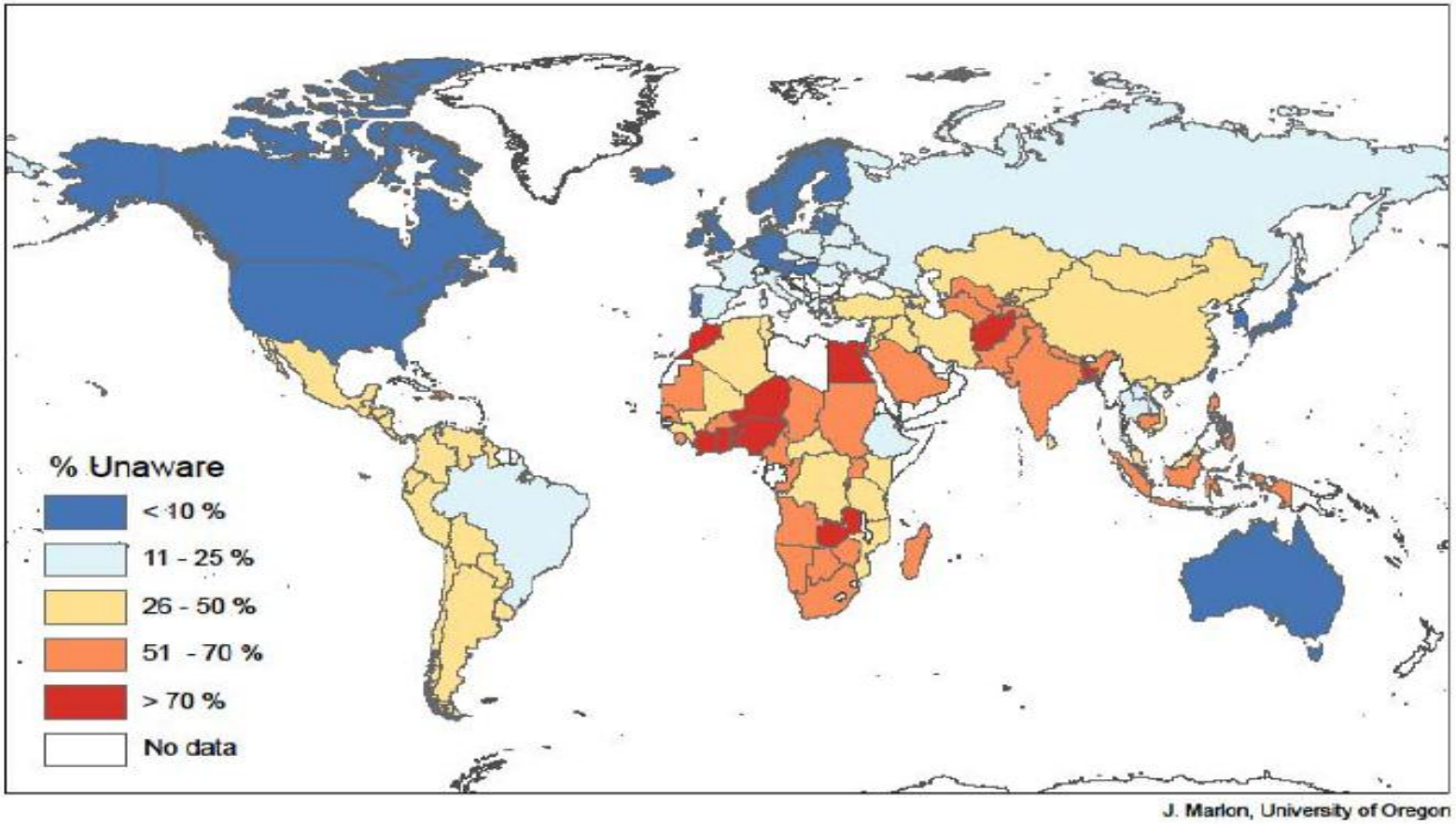
“Unaware” of Climate Change

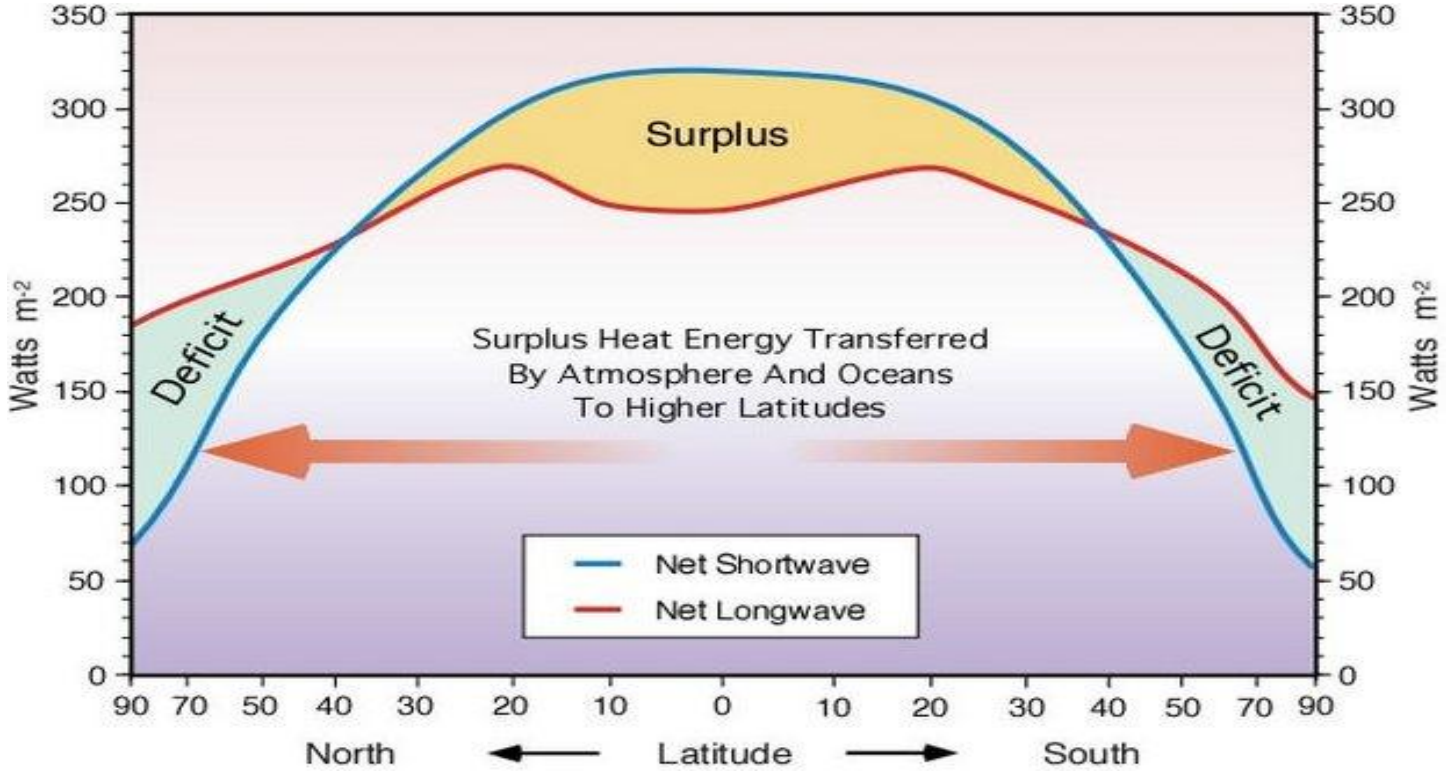
“How much do you know about global warming or climate change?”
(*I’ve never heard of it; don’t know; refused*)
n = 269,913 in 132 countries (2007-2009)



Leiserowitz (2011)

Factors influencing climate

- Incident solar radiation - variation with latitude
- Closeness to large water bodies - distribution of land & water
- Mountain barriers
- Altitude
- Ocean temperature and currents
- Land cover
- Atmospheric composition



Radiation is not evenly distributed over the surface of the earth. The high-latitudes have an energy deficit and the low latitudes has excess. But the low latitudes don't indefinitely get hotter and the high-latitudes don't get colder. Why?

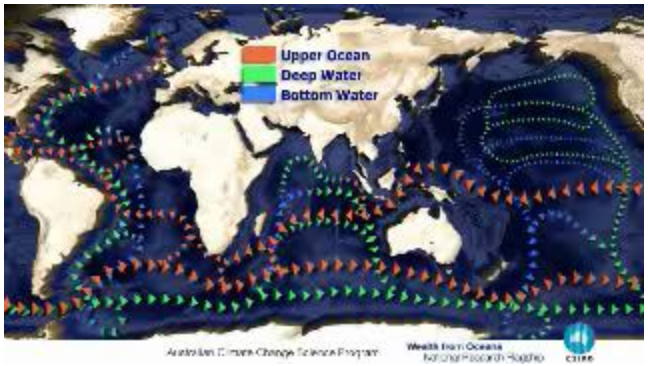
The atmosphere and ocean transfer energy from low to high latitudes

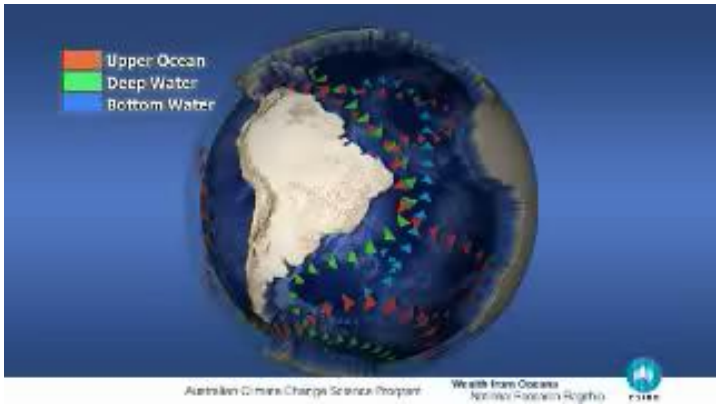
Circulation

Atmospheric

Circulation

Oceanic



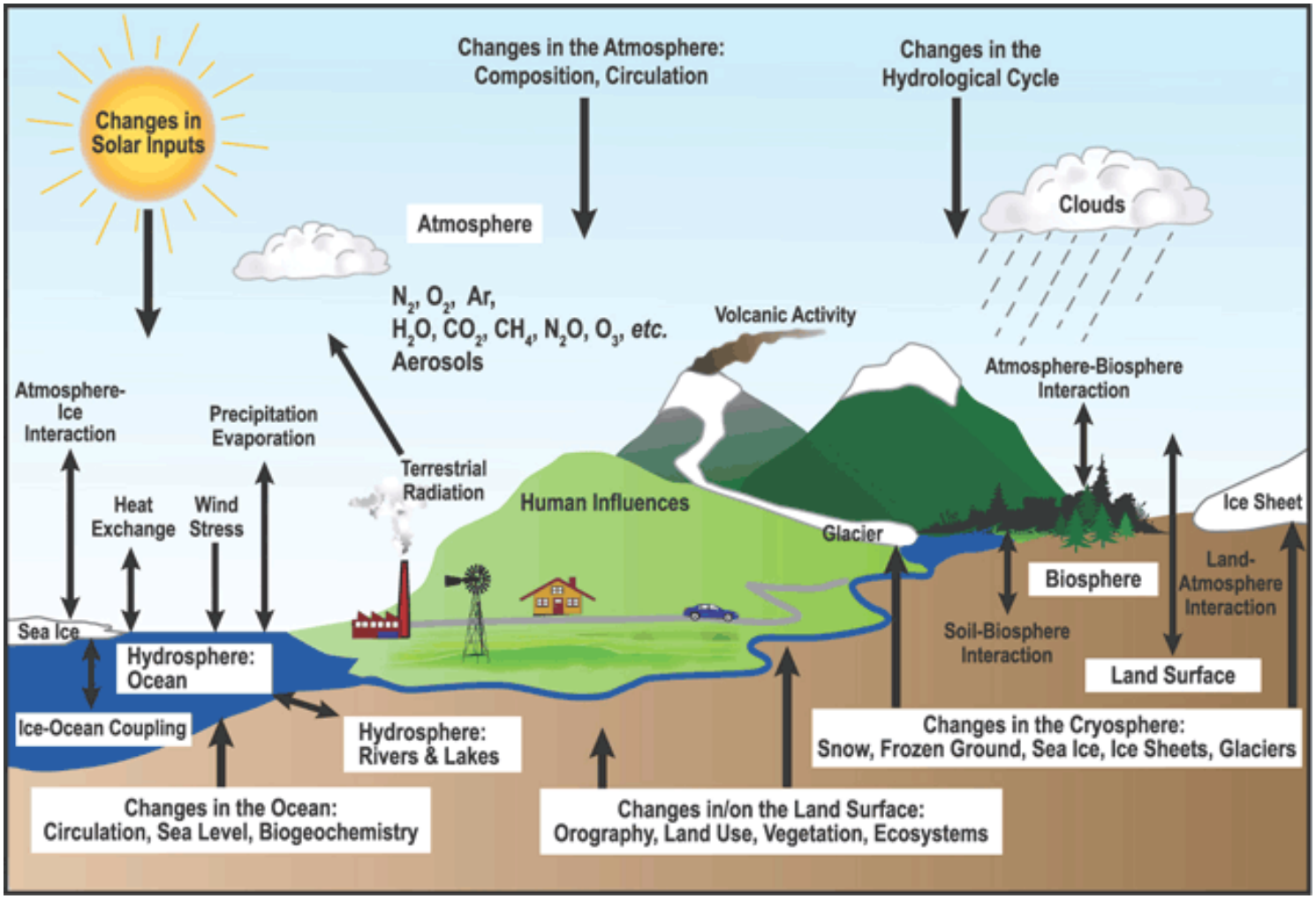


Sinking cool water, rising warm water and wind help to form global ocean current systems.

Pic courtesy NASA, CSIRO

The Great Ocean Conveyor

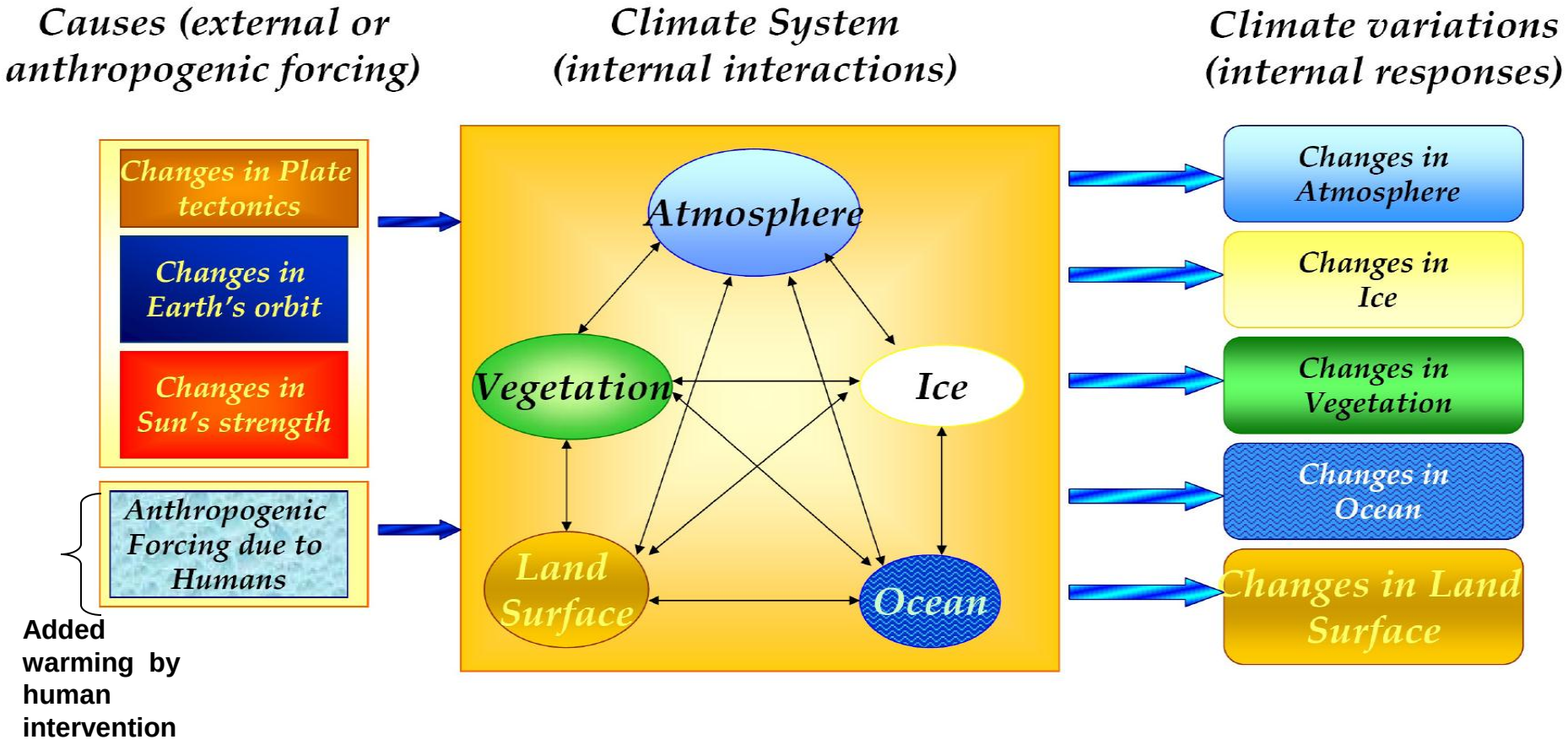
Interactions



The non-linear interaction among the components leads to climate variability at a range of spatial and temporal scales

Pic . NOAA

Review of Basics: Climate System



The non-linear interaction among the components leads to climate variability at a range of spatial and temporal scales

How do we quantify the response of the climate?

- The response of the climate system to this forcing agents is complicated by:
  - feedbacks
  - the non-linearity of many processes
  - different response times of the different components to a given perturbation

- The only means available to calculate the response is by using numerical models of the climate system.

What is a Model ?

"a simplified description, esp. a mathematical one, of a system or process, to assist calculations and predictions"

- dictionary

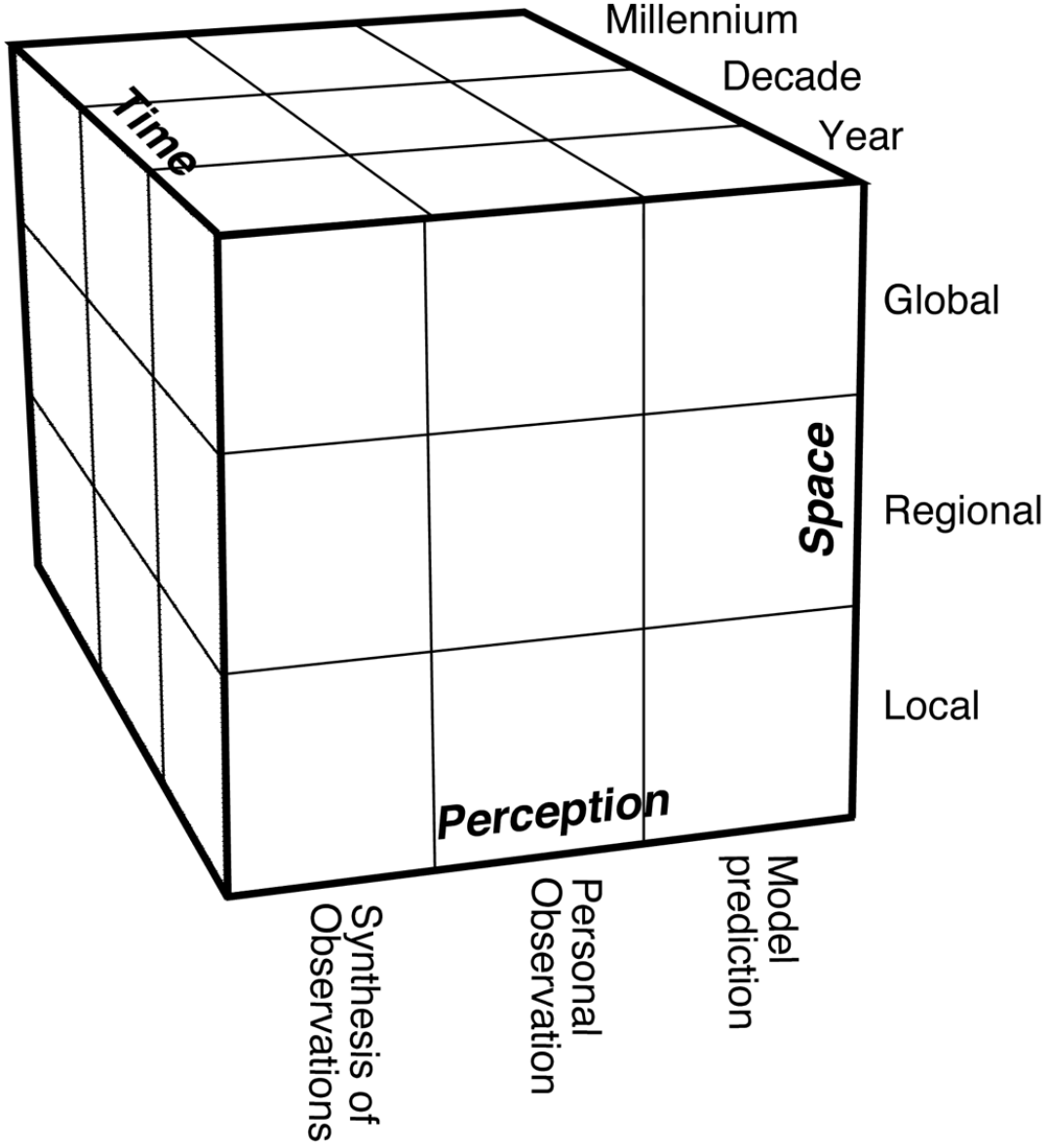
How do we define a Climate Model ?

"A climate model is a mathematical representation of the physical processes that determine climate"

Why do we need Climate Models ?

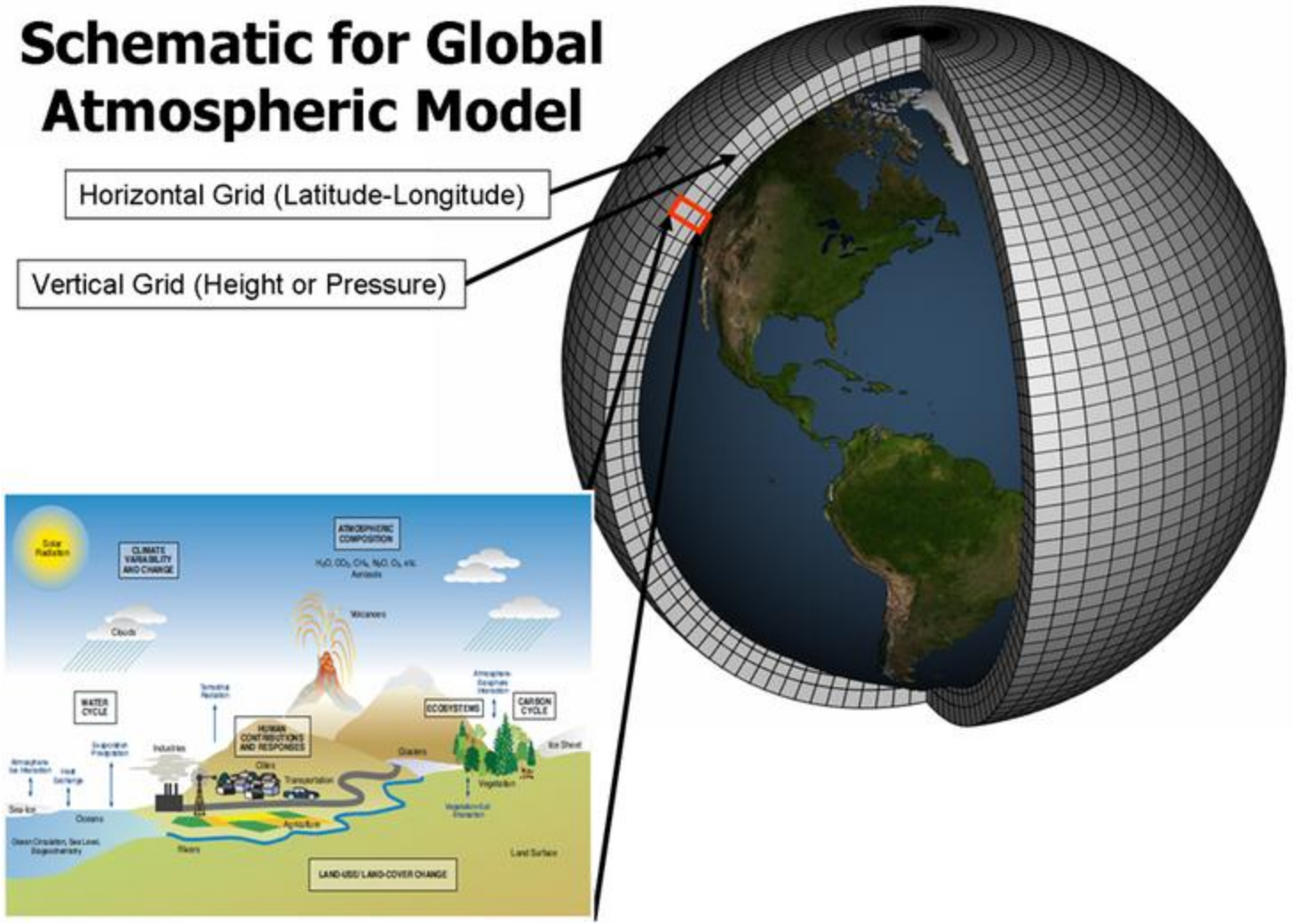
- **To create an understanding of the climate processes.**
- **To create plausible-scenarios, reflecting the current state of scientific understanding.**
- **To plan for the future.**

The Climate Cube



McGuffie, K. and Henderson-Sellers, A. (2005) A Climate Modelling Primer. 3rd ed., Wiley.

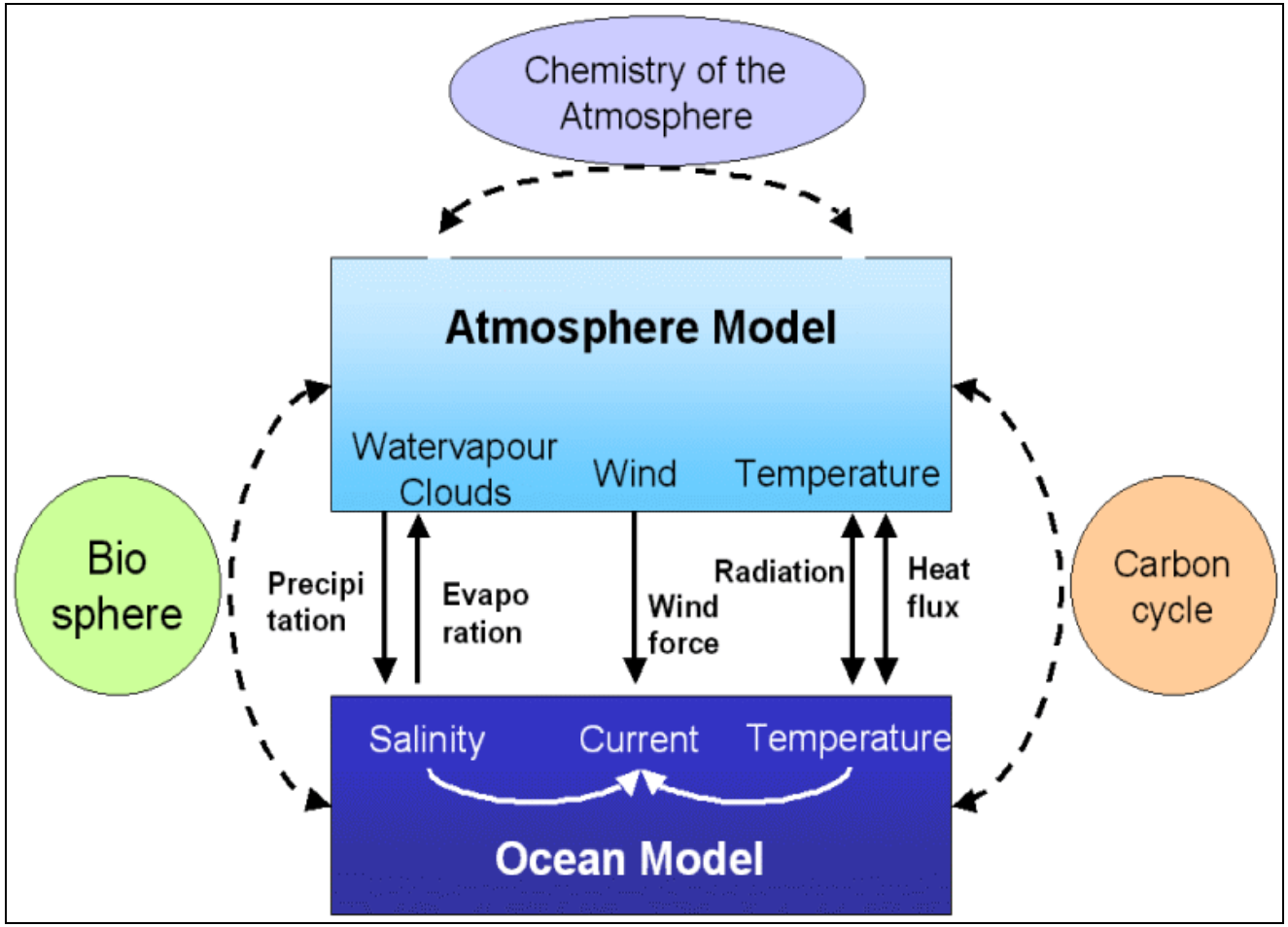
Numerical Solution: Time steps and Grid boxes



All the physical processes occurring in the climate system are resolved at individual grid and the coupling occurs at these grids.

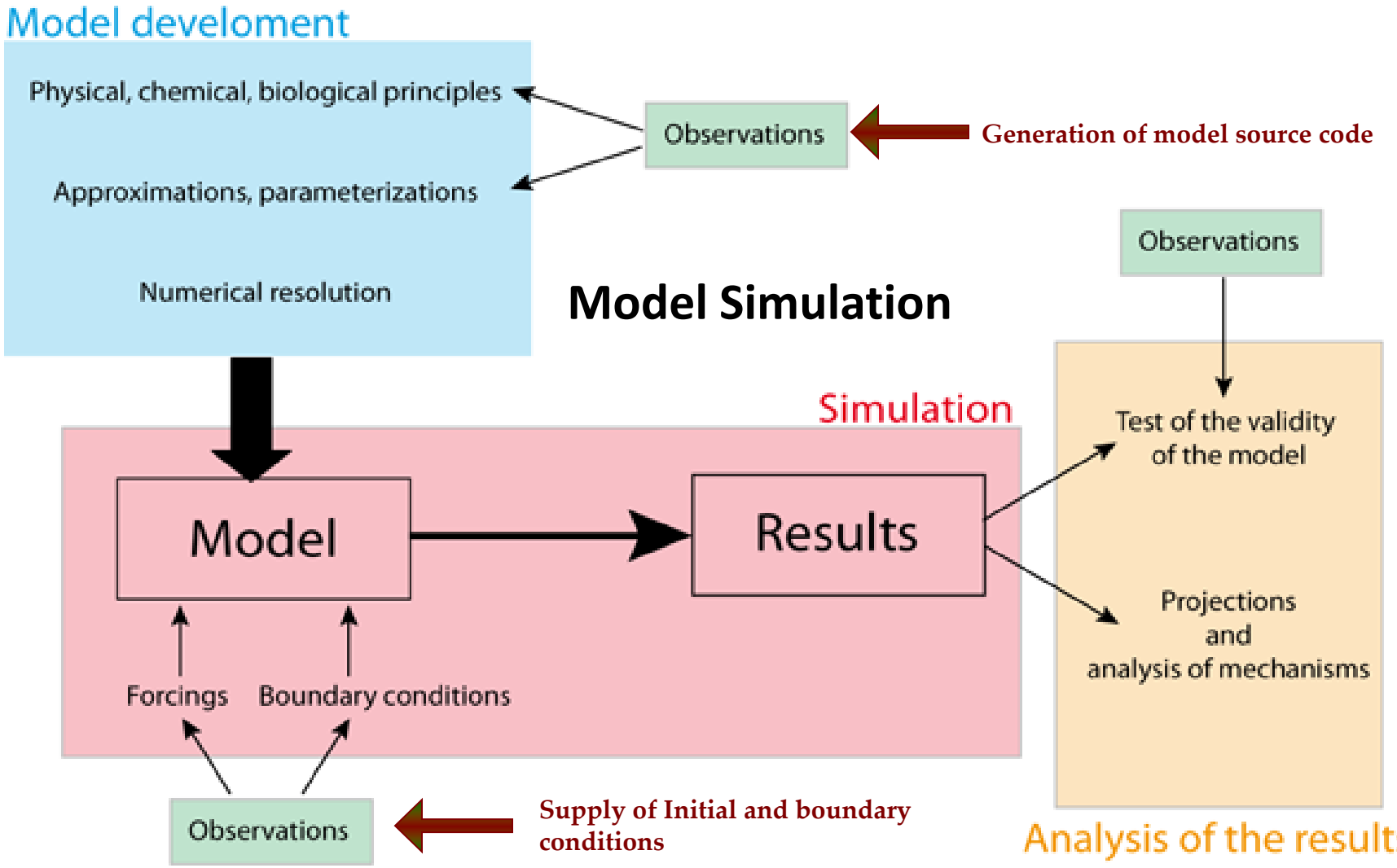
Source: NASA

Framework for a Model



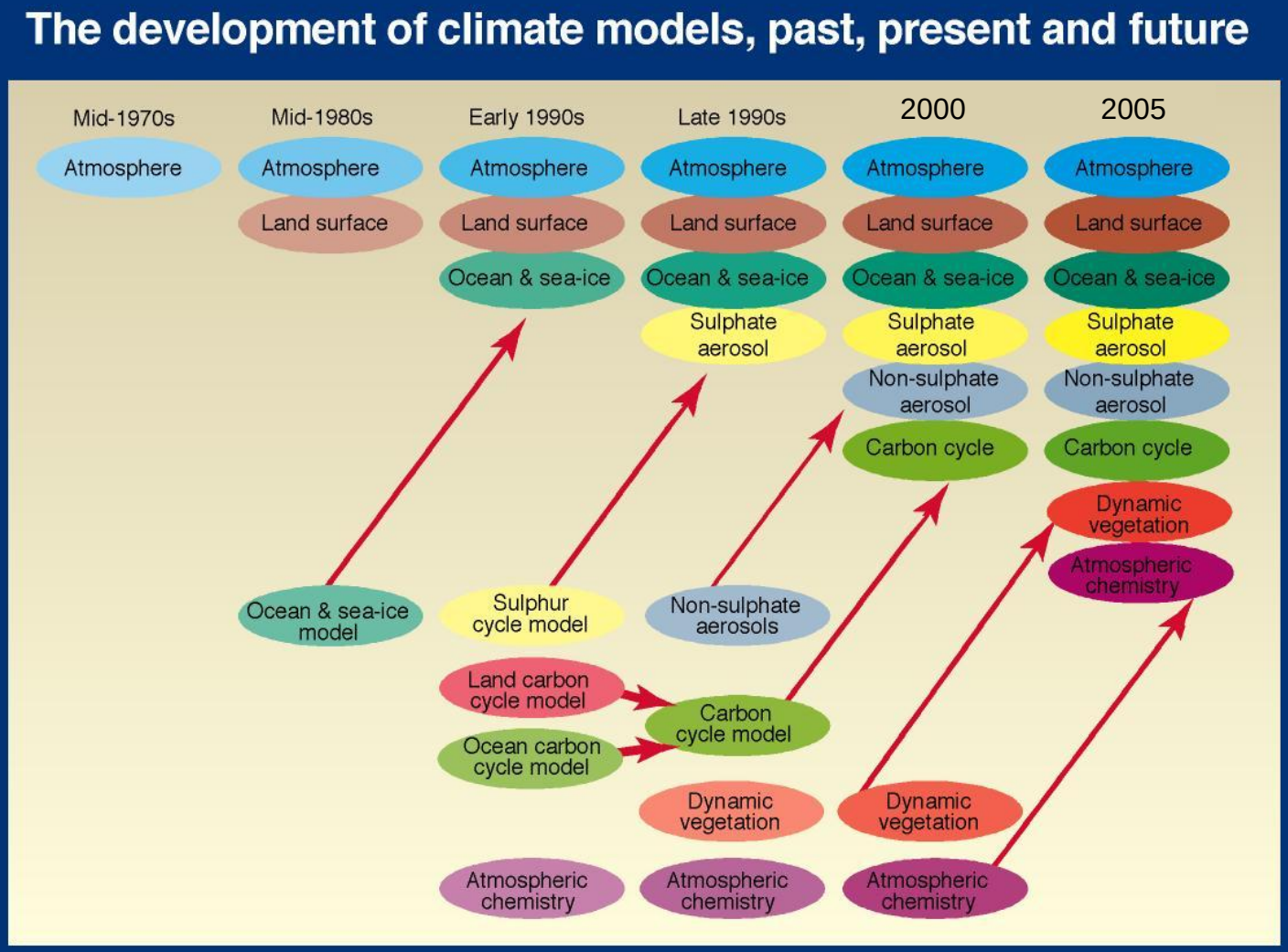
Source: MPI, Germany

Process of Model Simulation



Source: Goosse et al 2010

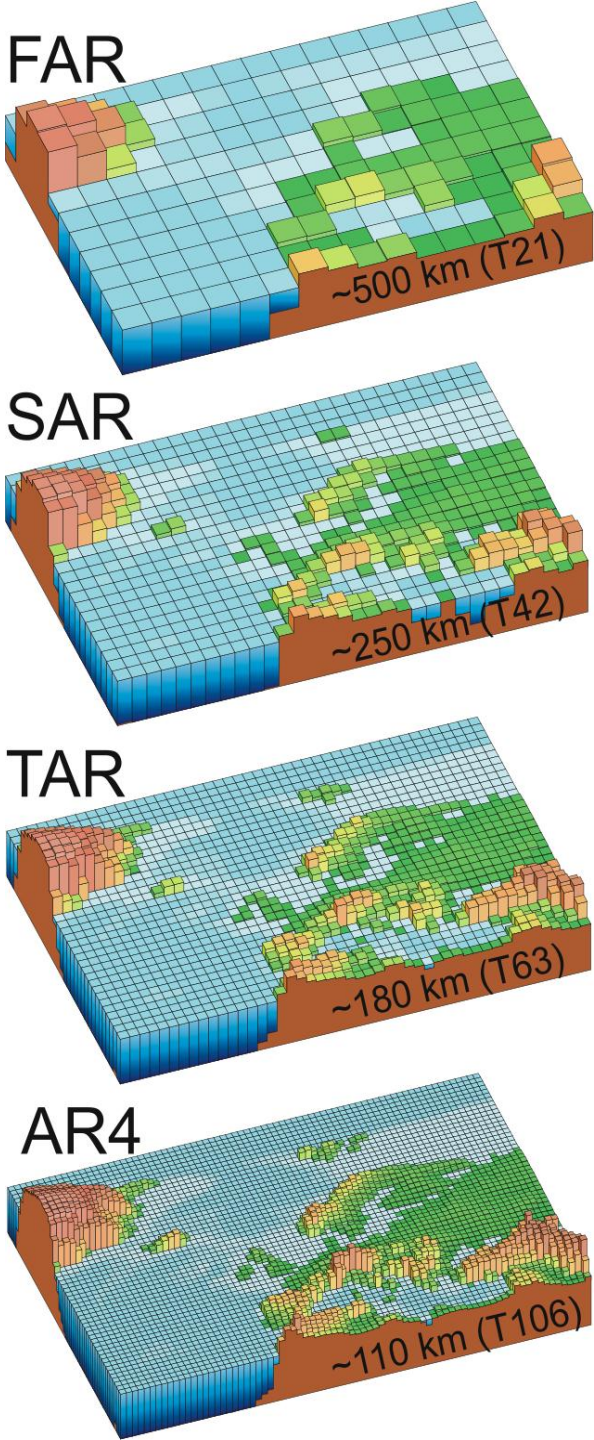
Development of climate models



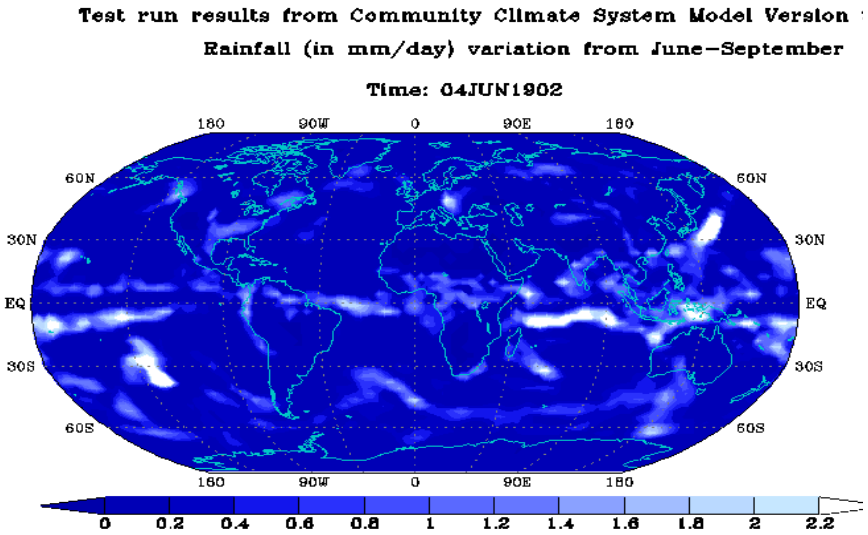
WG1 - TS BOX 3
FIGURE 1

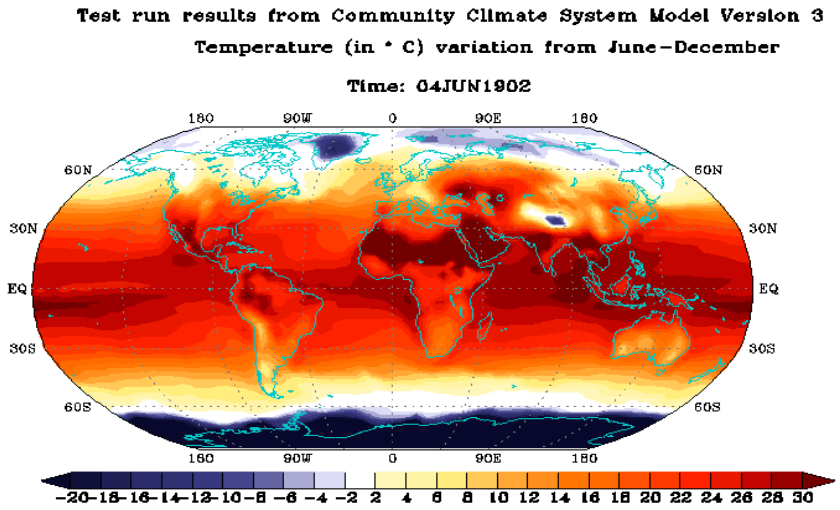
Improvements in Grid resolution

- The evaluation of the Climate models has become an essential pre-requisite to understand the Earth's climate system
- A Model Inter-comparison Project is an approach to model verification and they are part of community analysis and verification/activity.
- Intergovernmental Panel for Climate Change has started its MIP programs with Atmospheric Models in 1995 till today with CMIP (Coupled Ocean Atmospheric Models).



Simulations using a Global Coupled Model:

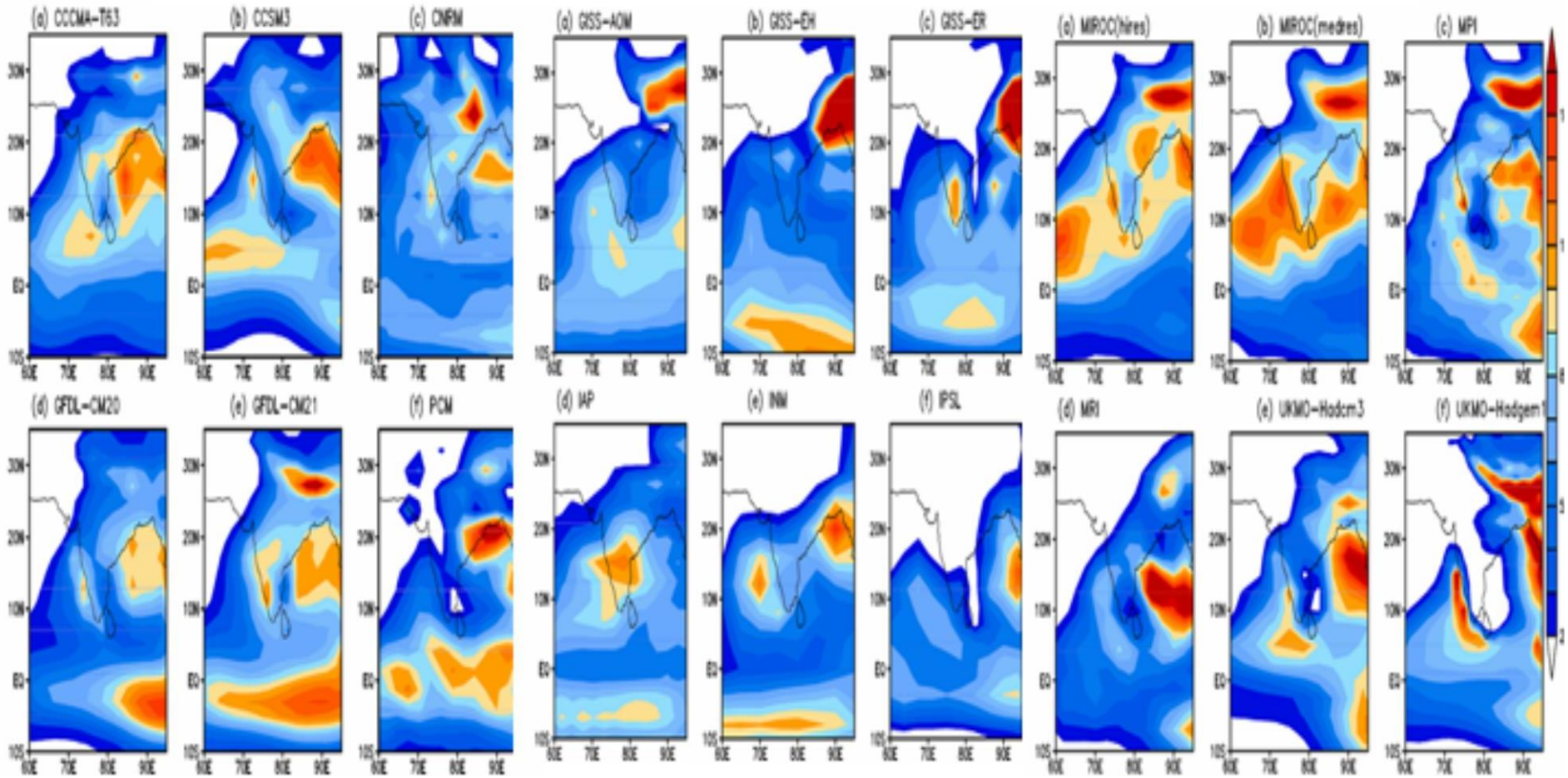




The simulations of a model should be comparable to the observations, this step is called as Validation of the model outputs

Source: TERI (2011)

Need for Regional Climate Modeling Tool

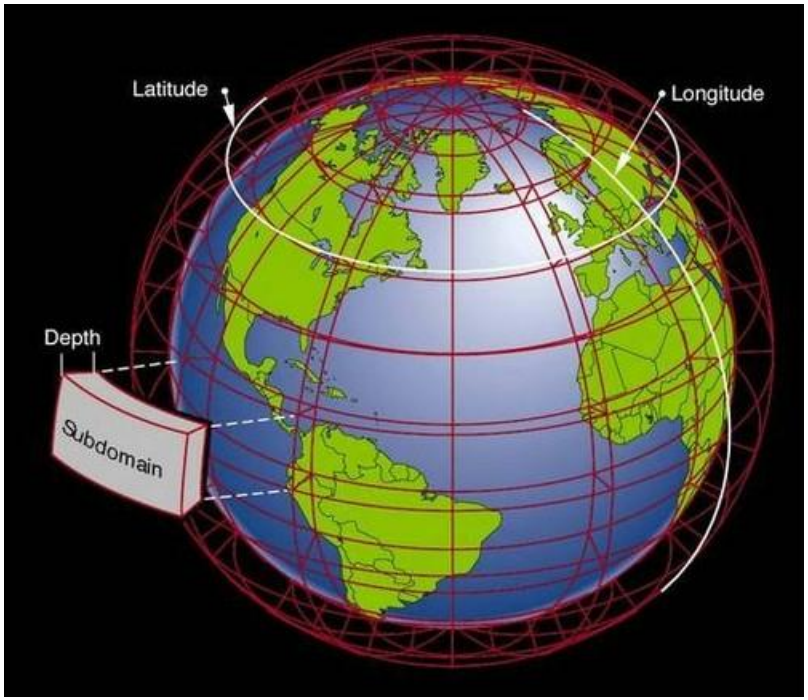


Most of AR4 coupled models even with high spatial resolution of 110km x 110km were unable to represent the mean monsoon pattern similar to observations.

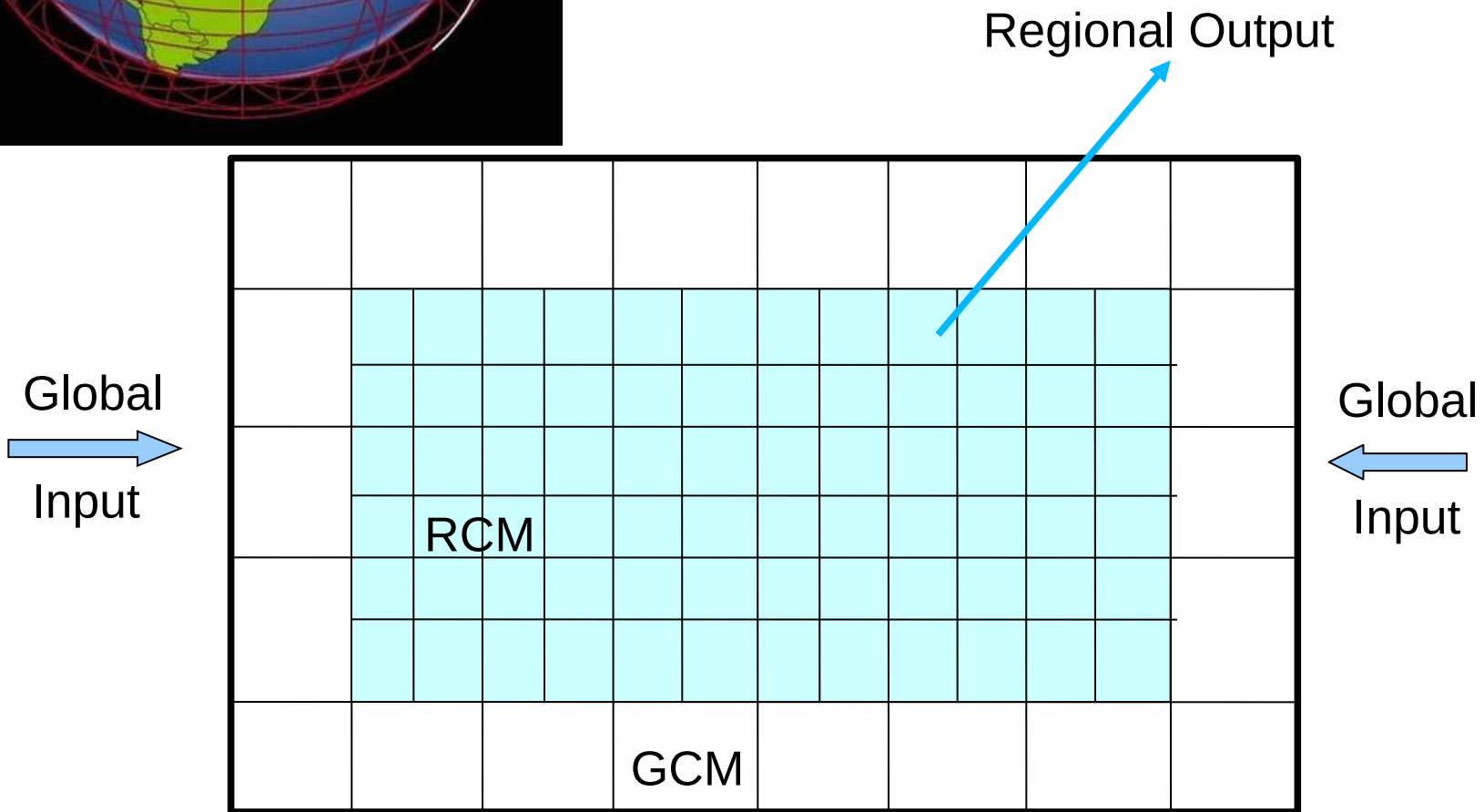
Downscaling from GCMs

- **Downscaling is a way to obtain higher spatial resolution output based on GCMs.**
- **Options include:**
  - **Combine low-resolution monthly GCM output with high-resolution observations**
  - **Use statistical downscaling**
    - **Easier to apply**
    - **Assumes fixed relationships across spatial scales**
  - **Use regional climate models (RCMs)**
    - **High resolution**
    - **Capture more complexity**
    - **Limited applications**
    - **Computationally very demanding**

Downscaling



Dynamical Downscaling

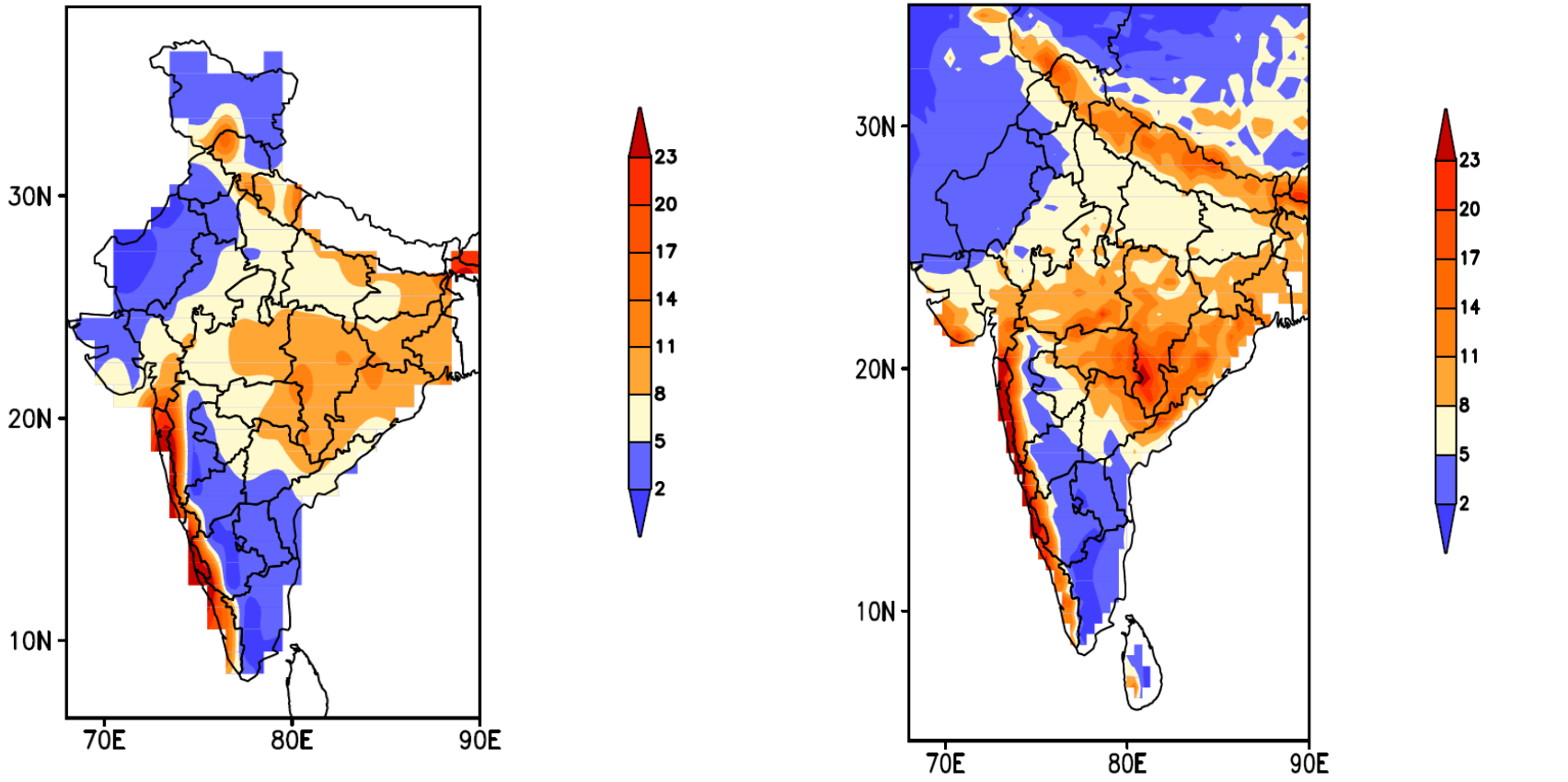


Regional Climate Models (RCMs)

- These are high resolution models that are "nested" within GCMs
- A common grid resolution is 50 km or lesser.
- RCMs are run with boundary conditions from GCMs
- They give much higher resolution output than GCMs
- Hence, much greater sensitivity to smaller scale factors such as mountains, lakes

Regional Modelling Product

IMD JJA rainfall mean of 50 years (1961–2007) PRECIS JJA rainfall mean of 30 years (1960–1990)

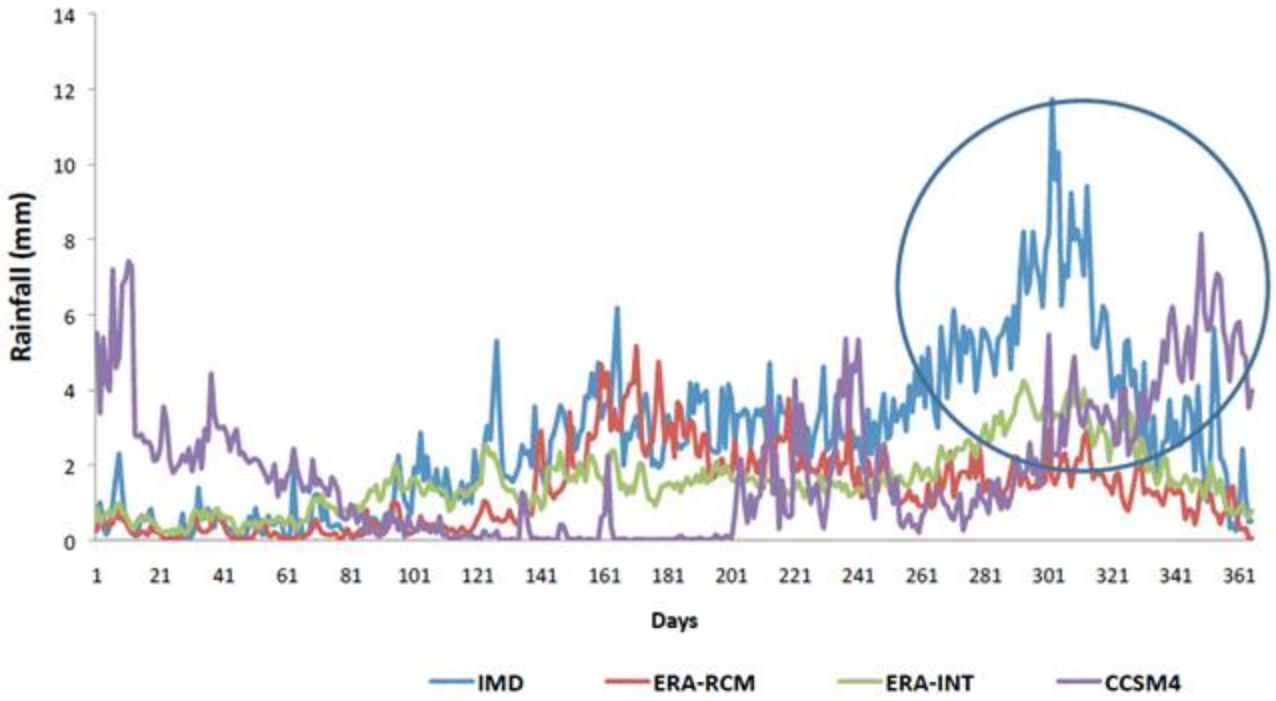


Source: TERI (2011)

RCM is able to capture the major features but overestimates the rainfall in few regions.

Lack of observations: poor model result

Observed rainfall climatology compared with IPRC_RegCM over peninsular India

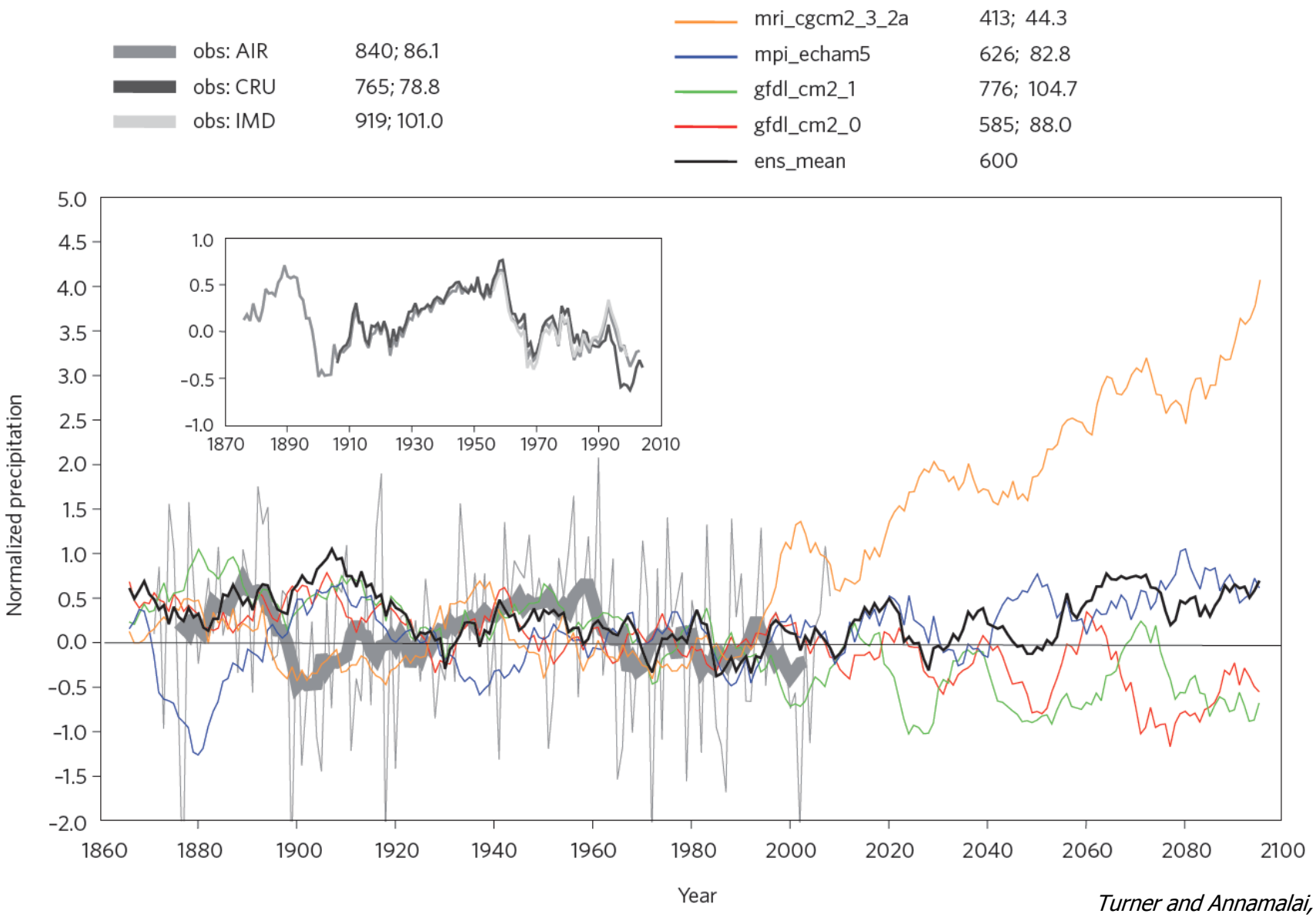


Reanalysis – temporal variability of atmospheric states and internal variability preserved – yet, results are not encouraging

Monsoon region – lack of 3-D moisture observations – severe constraint

Annamalai, 2012

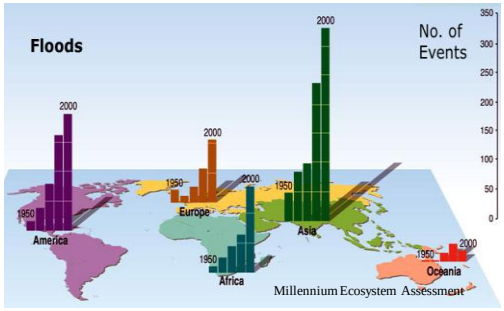
Uncertainties in Observation and Models

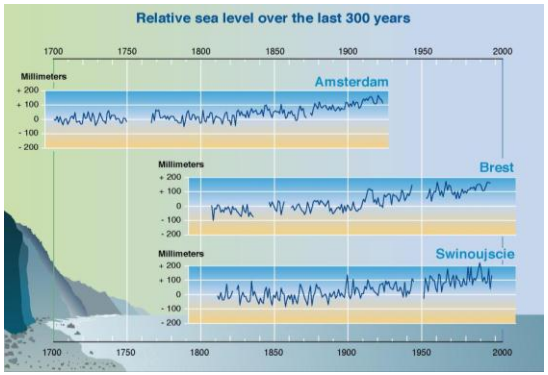


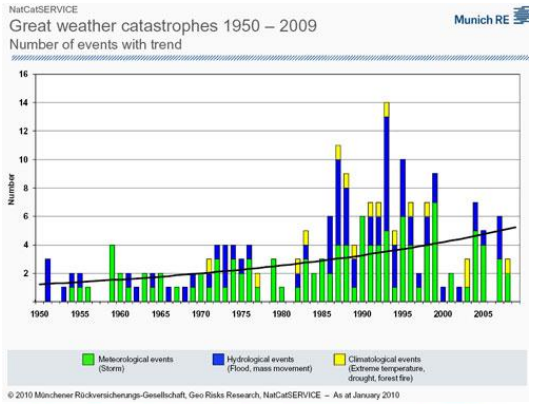
Turner and Annamalai, 2012

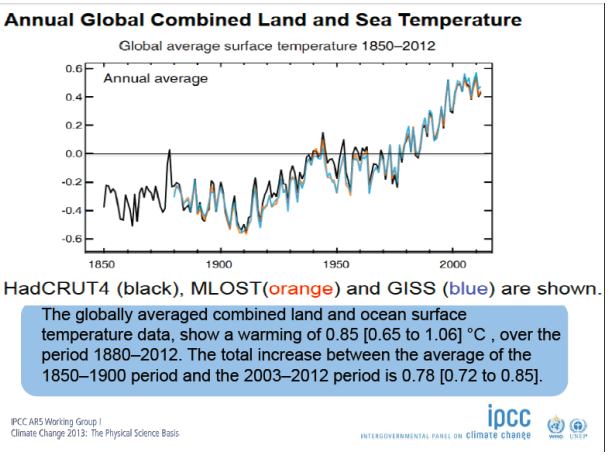
Climate Modelling: Global to Regional

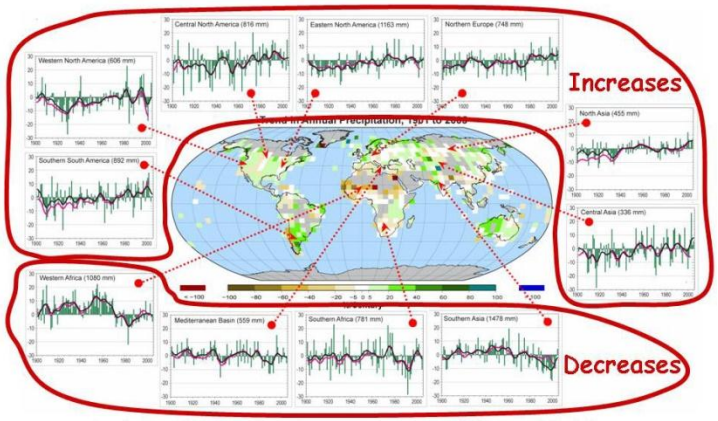
Evidences

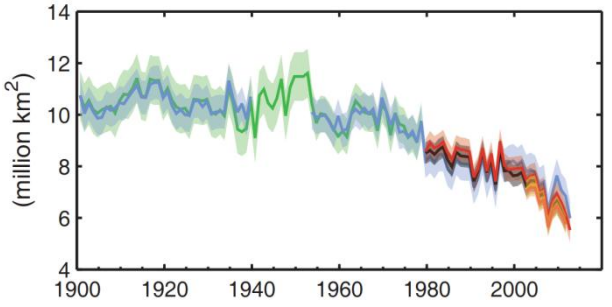




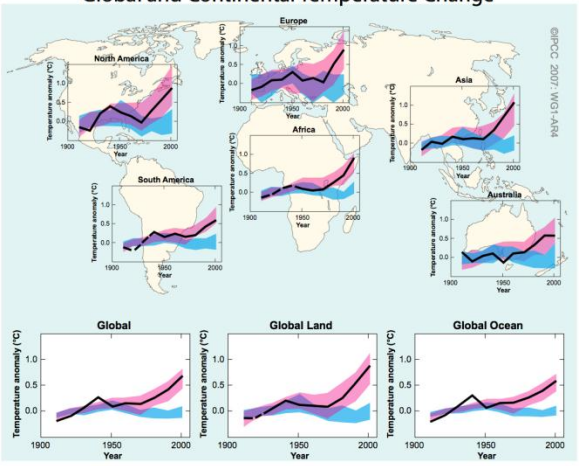


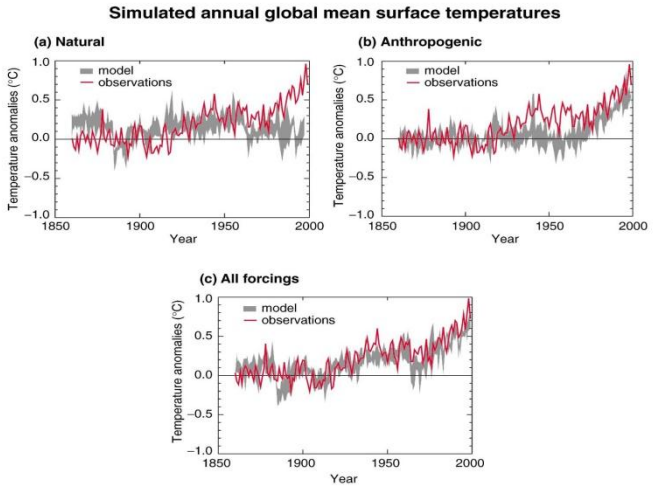


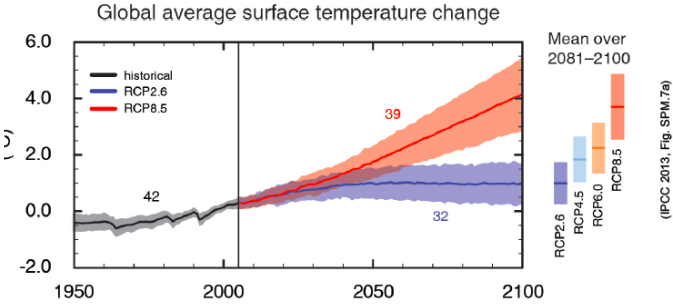




Human Attribution

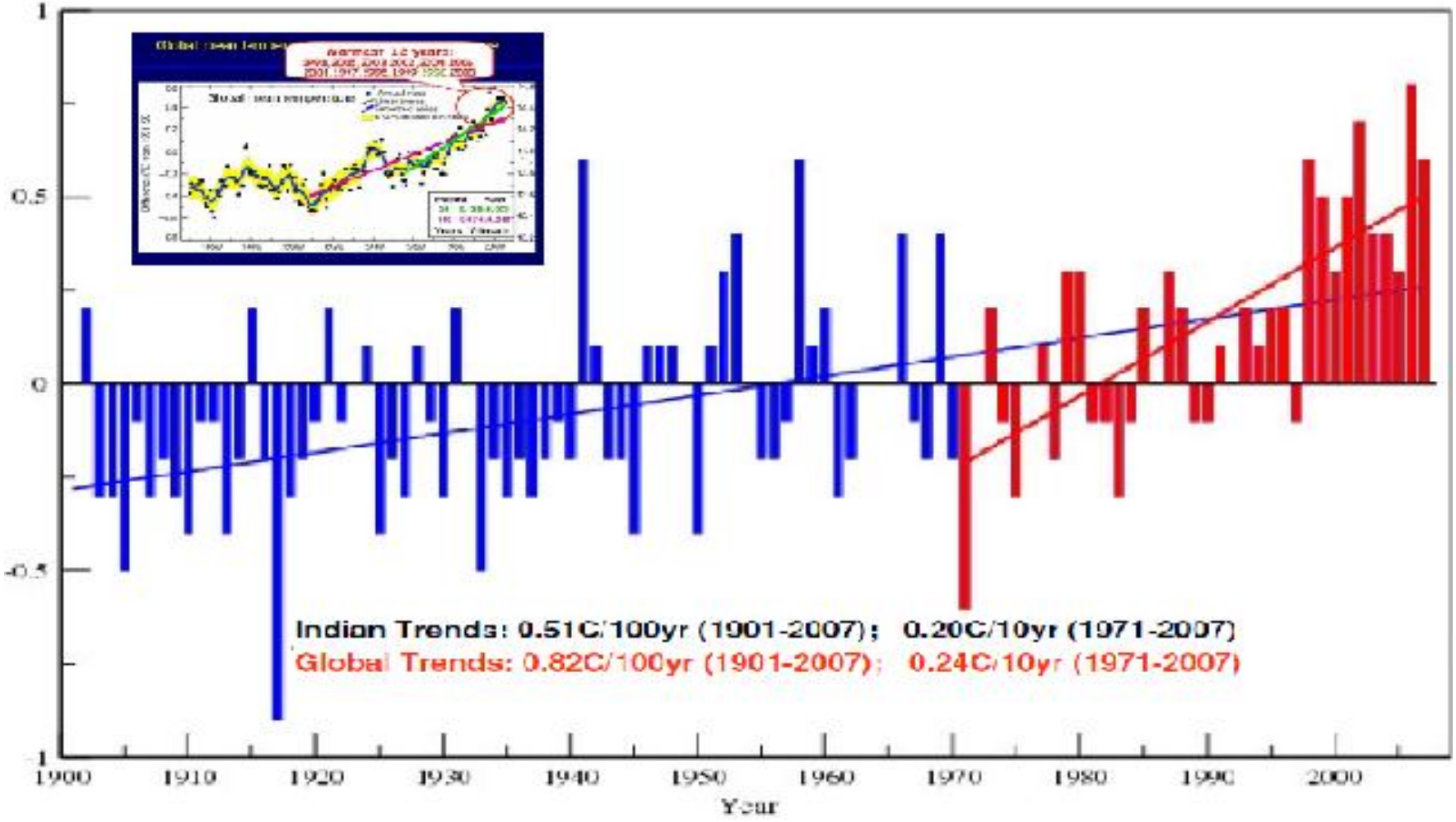






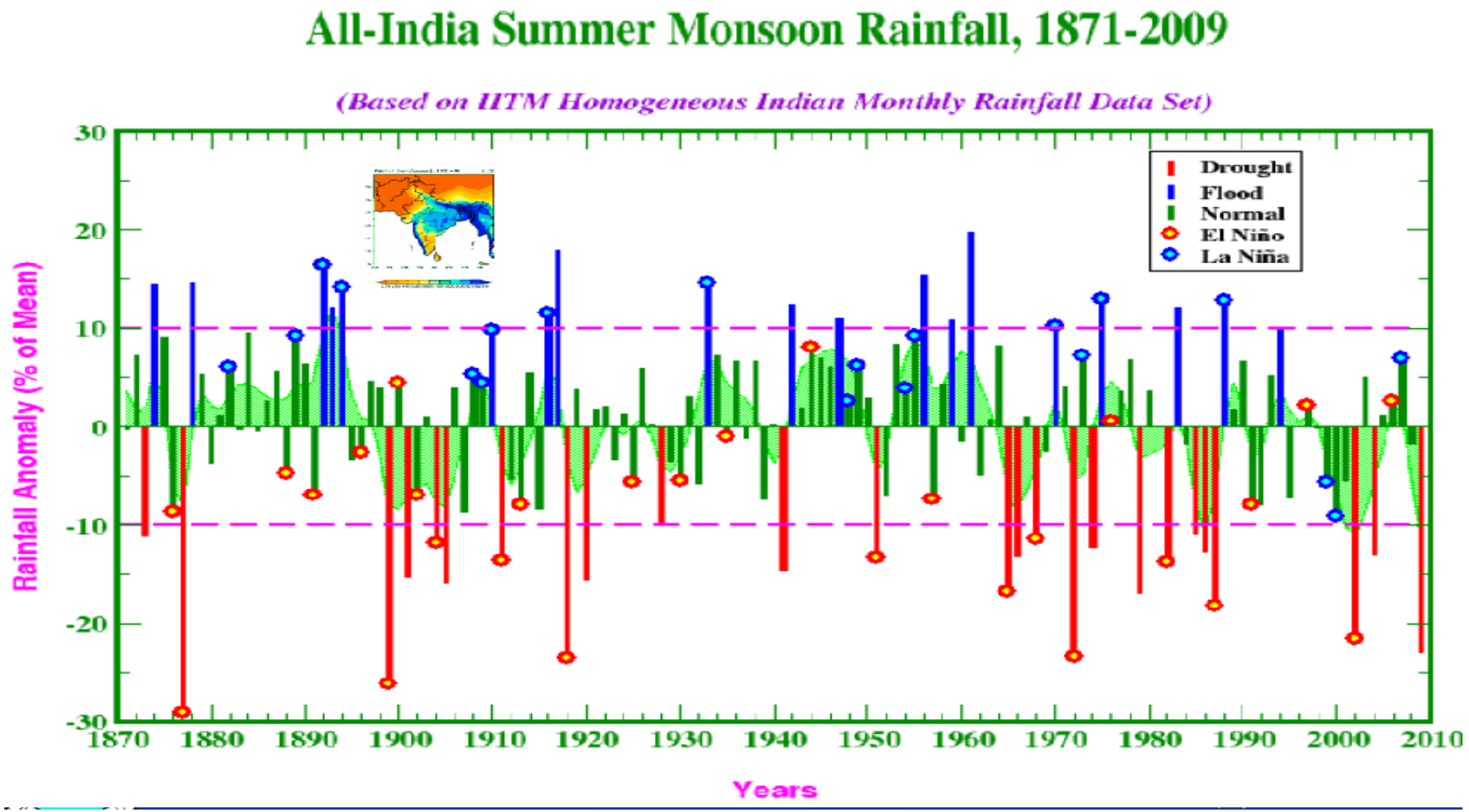
Global surface temperature change for the end of the 21st century is *likely* to exceed 1.5°C relative to 1850 for all scenarios

All India Mean Annual Temperature Anomalies (1901-2007) (Base: 1961-1990)

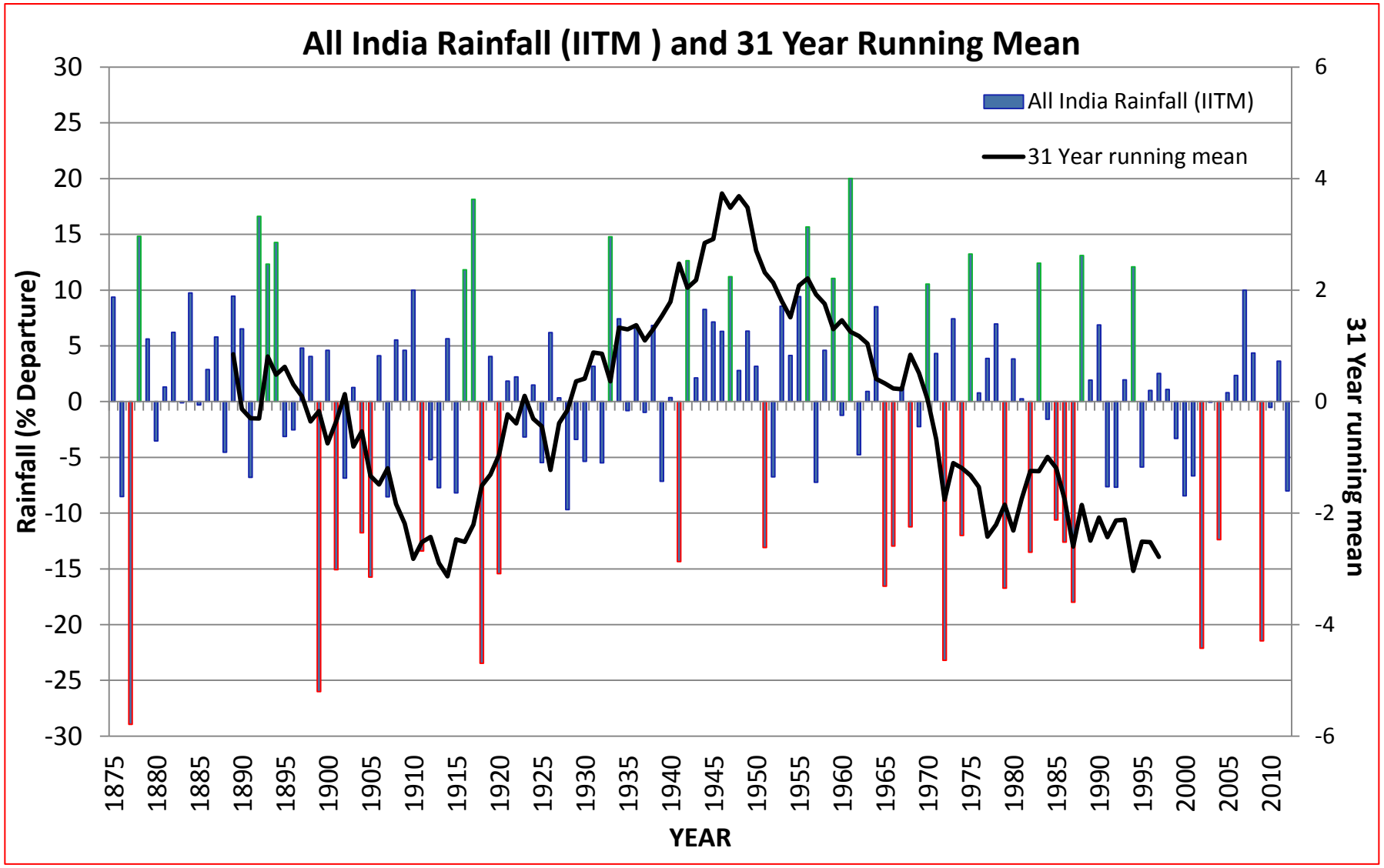


Krishna Kumar, 2009

Observed variability in India's Monsoonal Climate



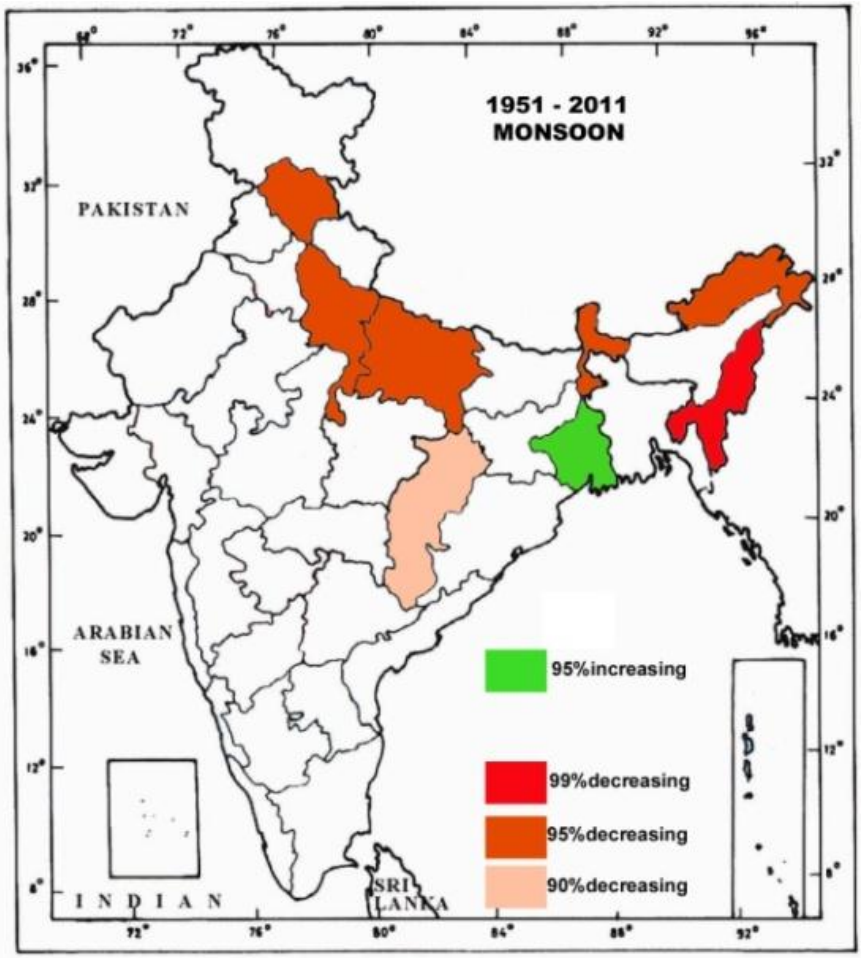
Krishna Kumar, 2009

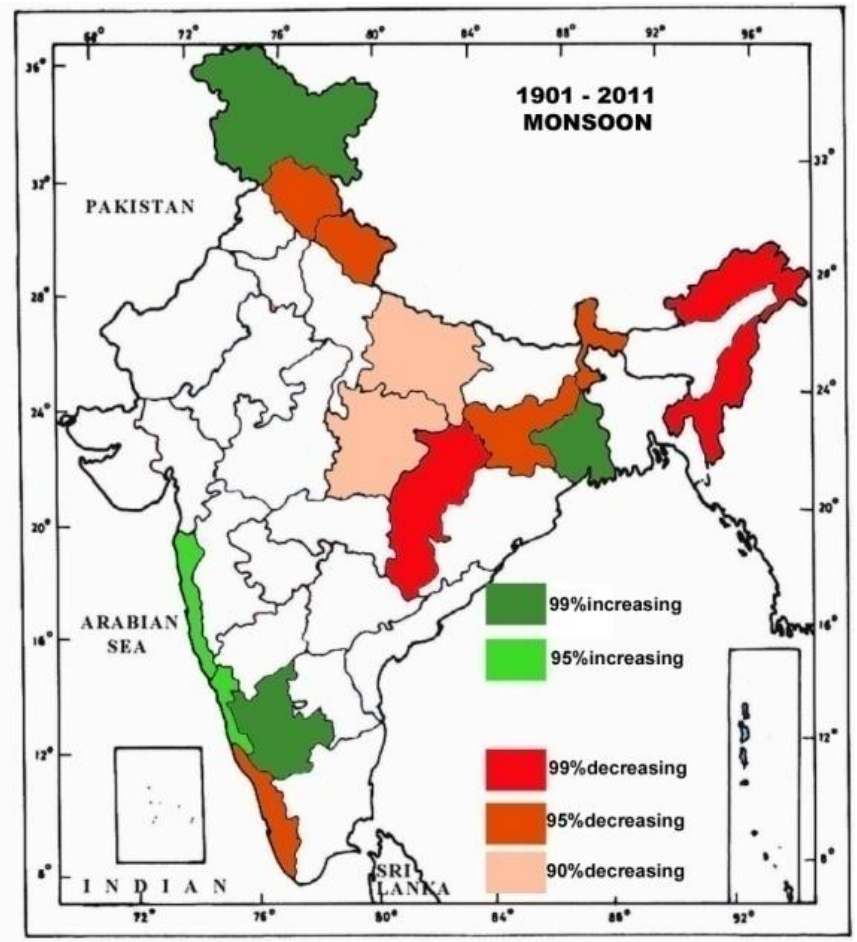


All-India monsoon season rainfall time series shows NO long term trends. It is marked by large year to year variations. There is a tendency of occurrence of more droughts in some epochs (for example, 1901-1930, 1961-1990).

Rajeevan, 2013

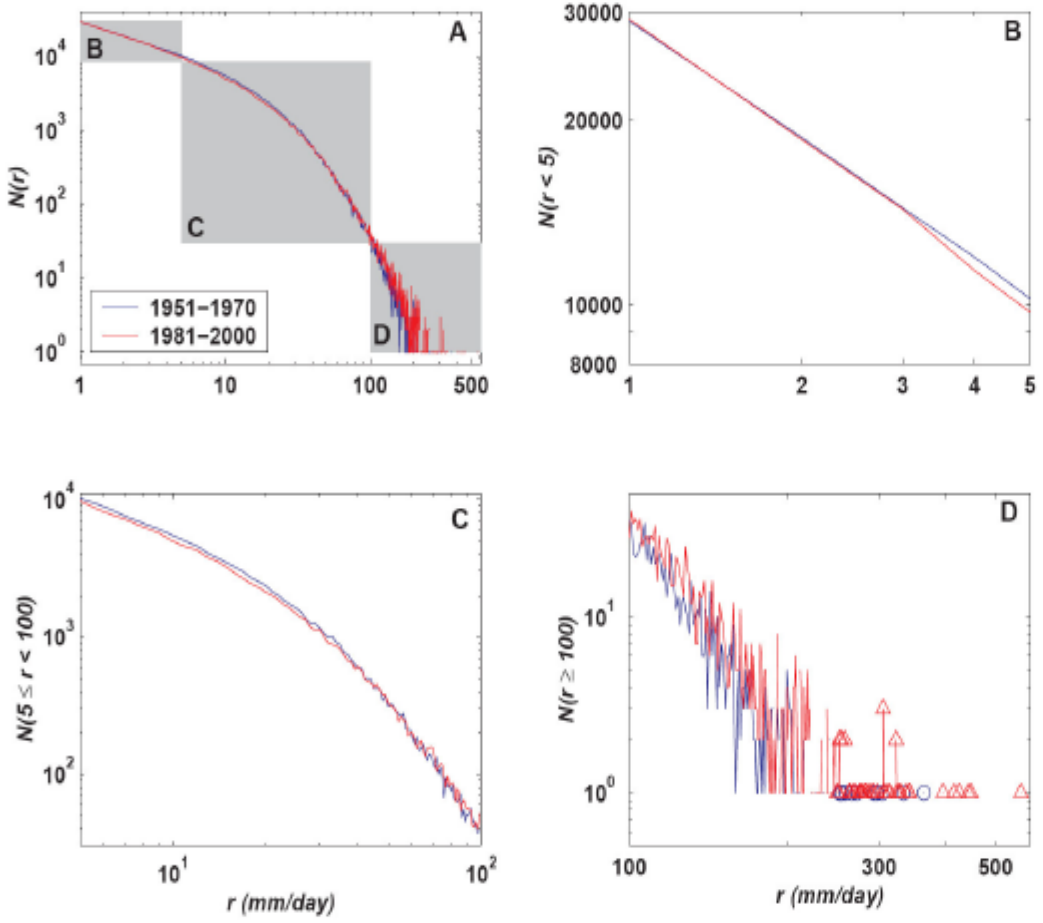
Regional Rainfall Trends

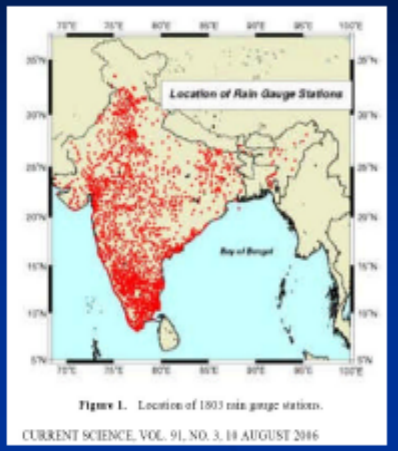




Guhathakurta et al. 2014, Int J. Climatology

Changes in the Frequency Distribution of Extremes during 1951-1970 and 1980-2000





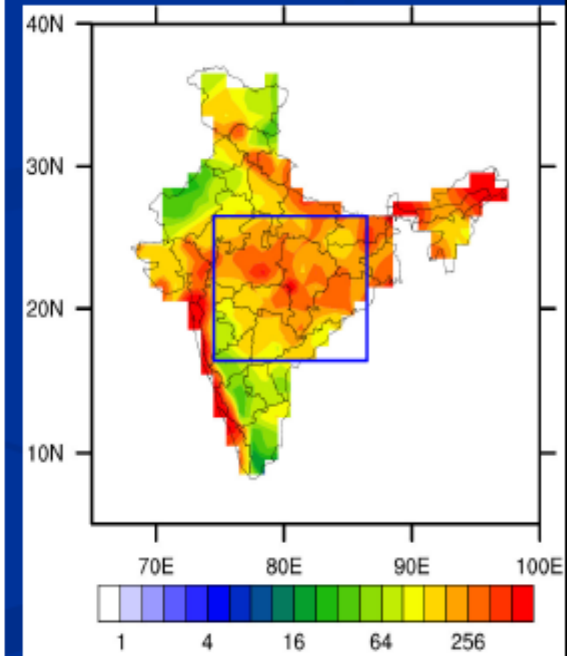
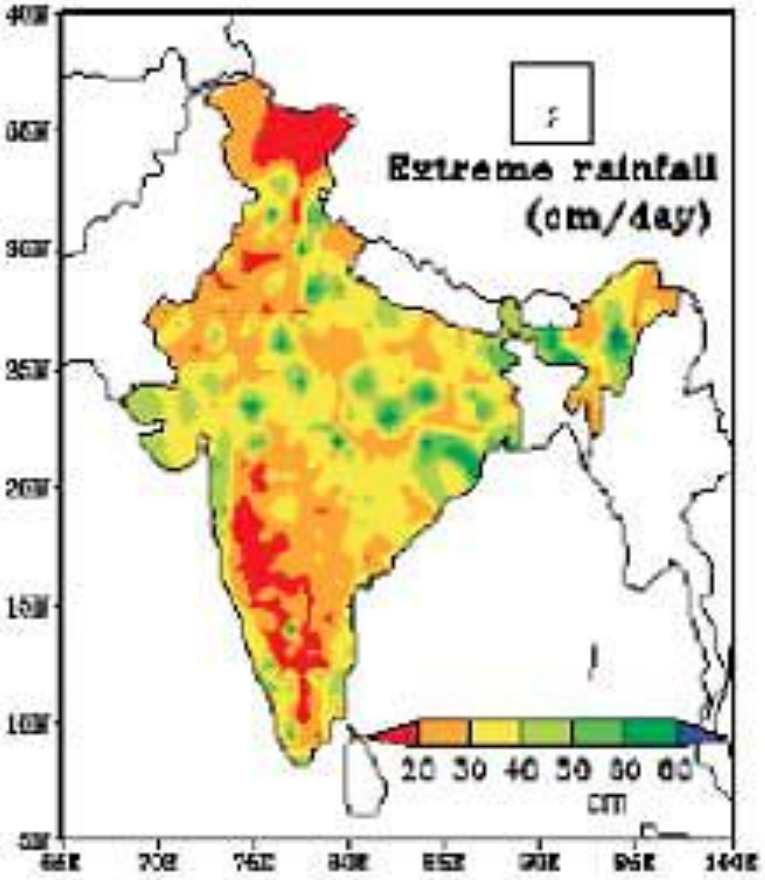
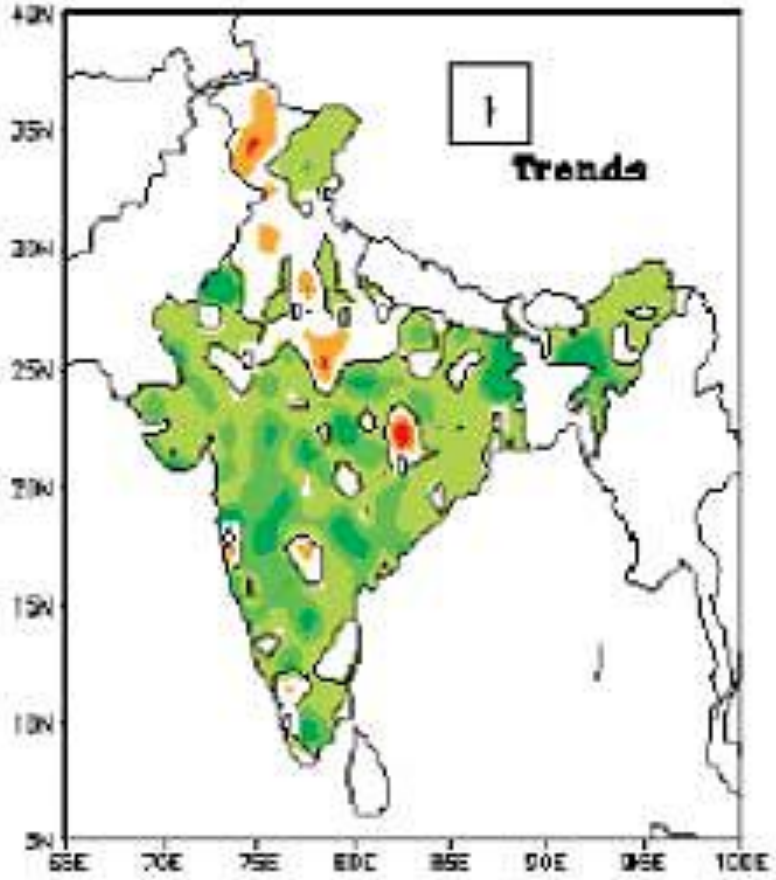


Fig. S2: (A) Frequency Histogram of daily rainfall over CI during summer monsoon for two periods, 1950-1970 and 1980-2000. The regions marked by the shaded rectangles in A are magnified in B, C, and D. For the sake of clarity, rain intensities larger than 250 mm/day have been shown by symbols (blue circles and red triangles) in panel (D).

Goswami et al., 2006

Rainfall Extremes and Trends for 1951-2004

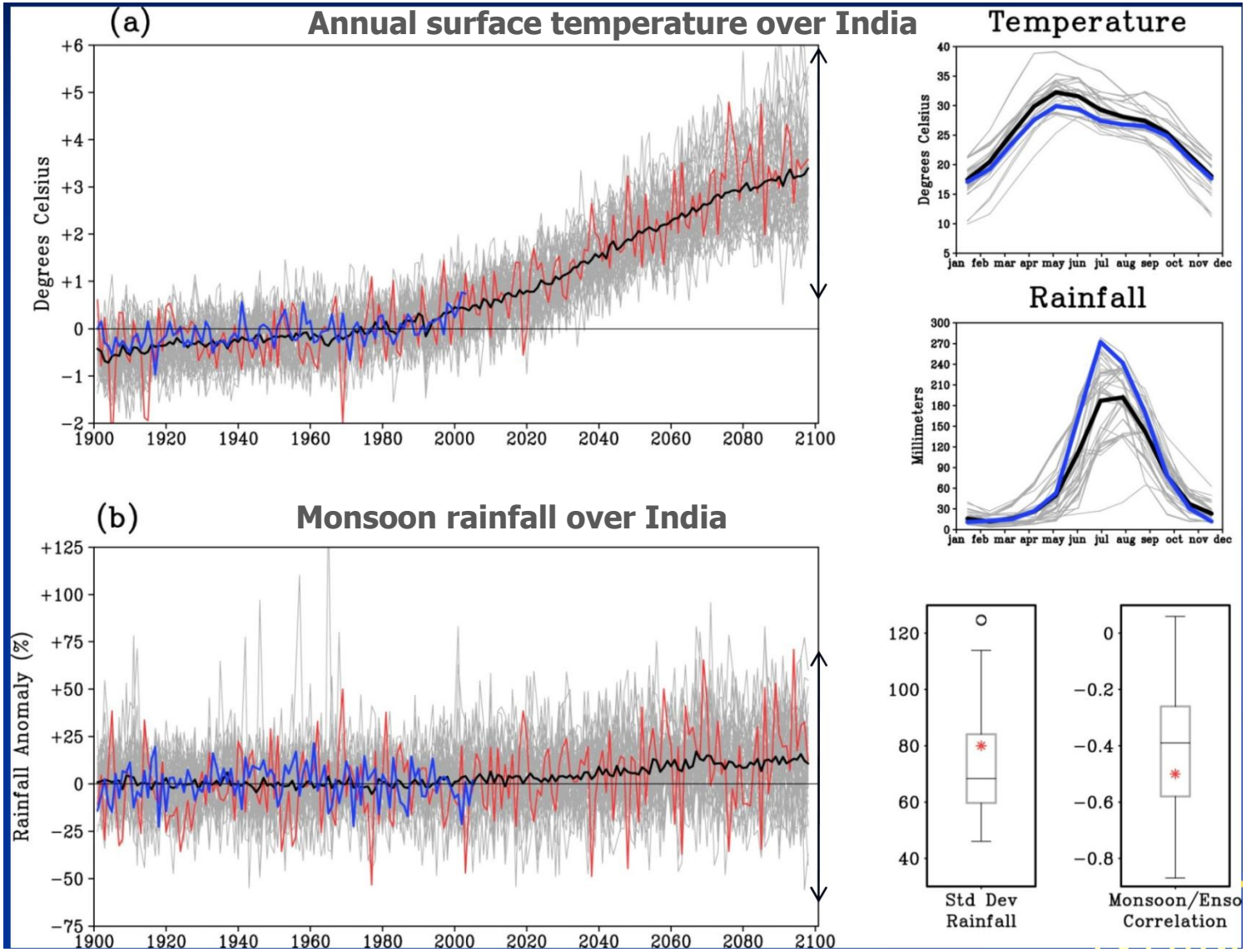




MoEF, 2010

PROJECTIONS

Simulations over India for the 1901–2098 period



Annual cycle of temperature and rainfall over India

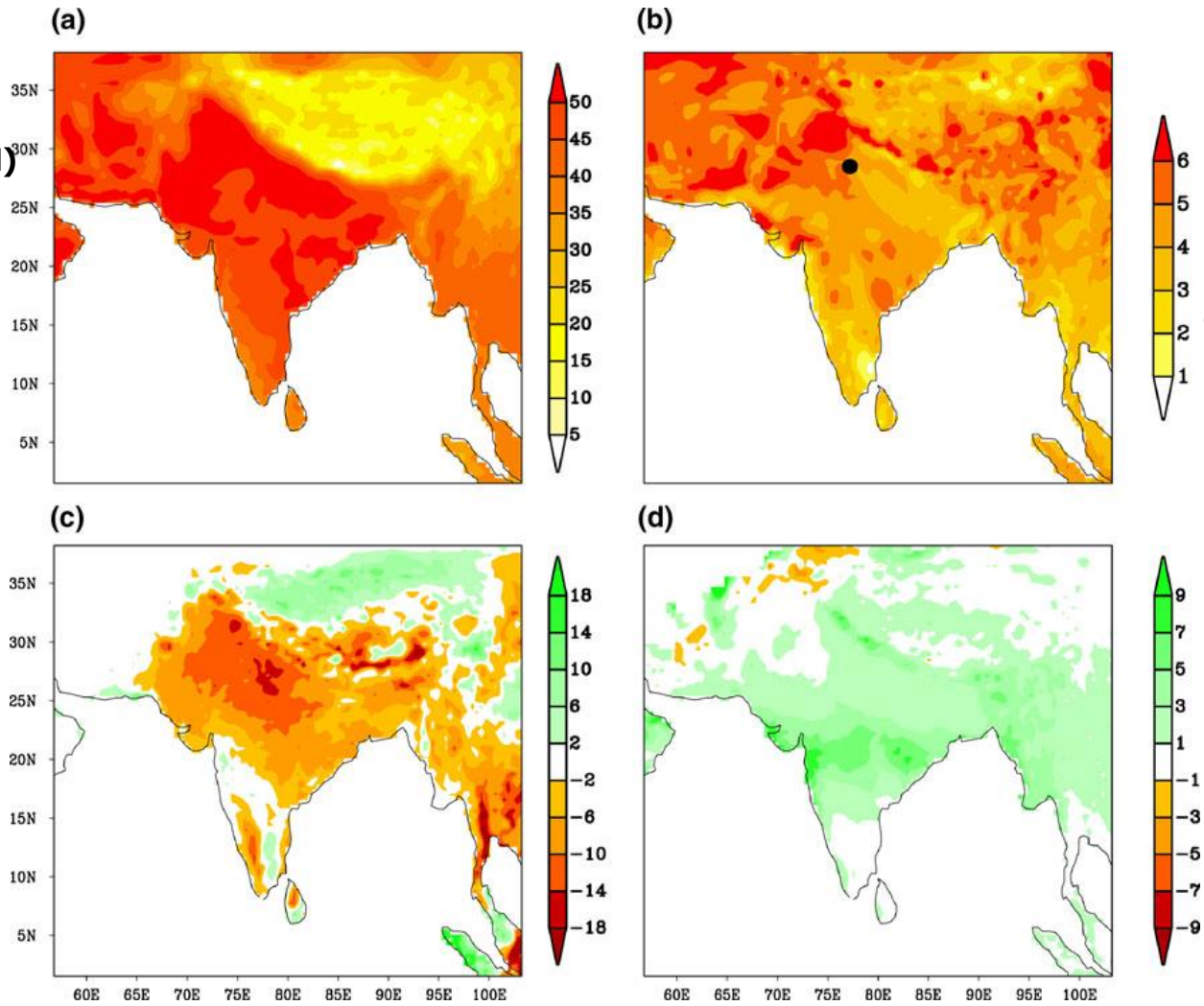
Standard deviation (mm) and monsoon-ENSO correlation, for the observational (1901–2000) period

The grey lines indicate the ensemble, the black line is the ensemble mean and the blue line is the observed. The red line is the ensemble member corresponding to the Hadley Center coupled model.

Krishna Kumar et al., 2009

Projected changes in daily maximum temperature and daily rainfall

Pre-monsoon (MAM) Tmax for the baseline period (1961–1990).



projected future (2071–2100 minus 1961–1990 mean) change.

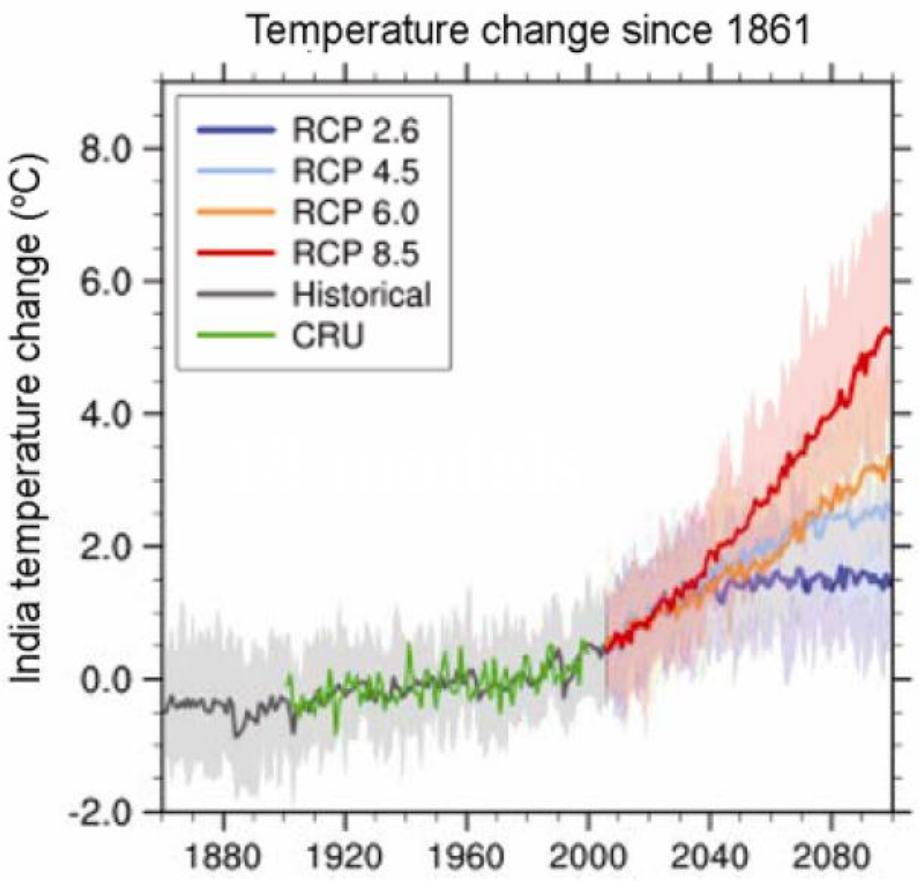
Projected future change in number of rainy days (rainfall >2.5 mm) during monsoon season (JJAS).

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

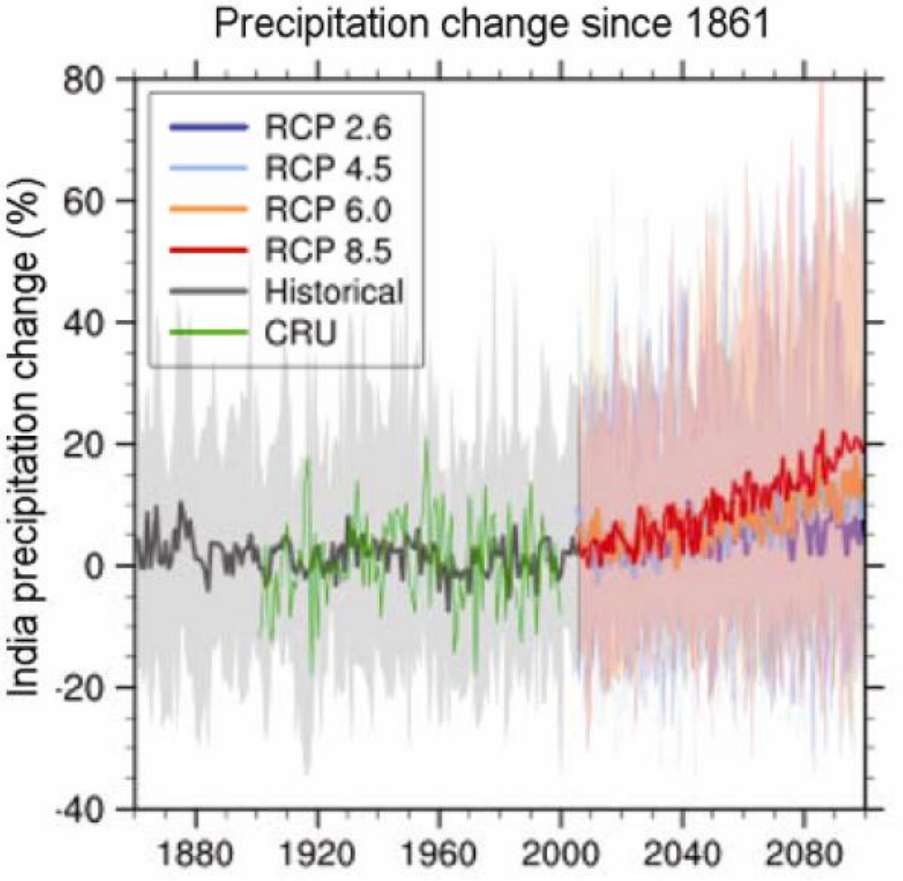
Krishna Kumar et al., 2009

CMIP5 projections for India

Temperature Change

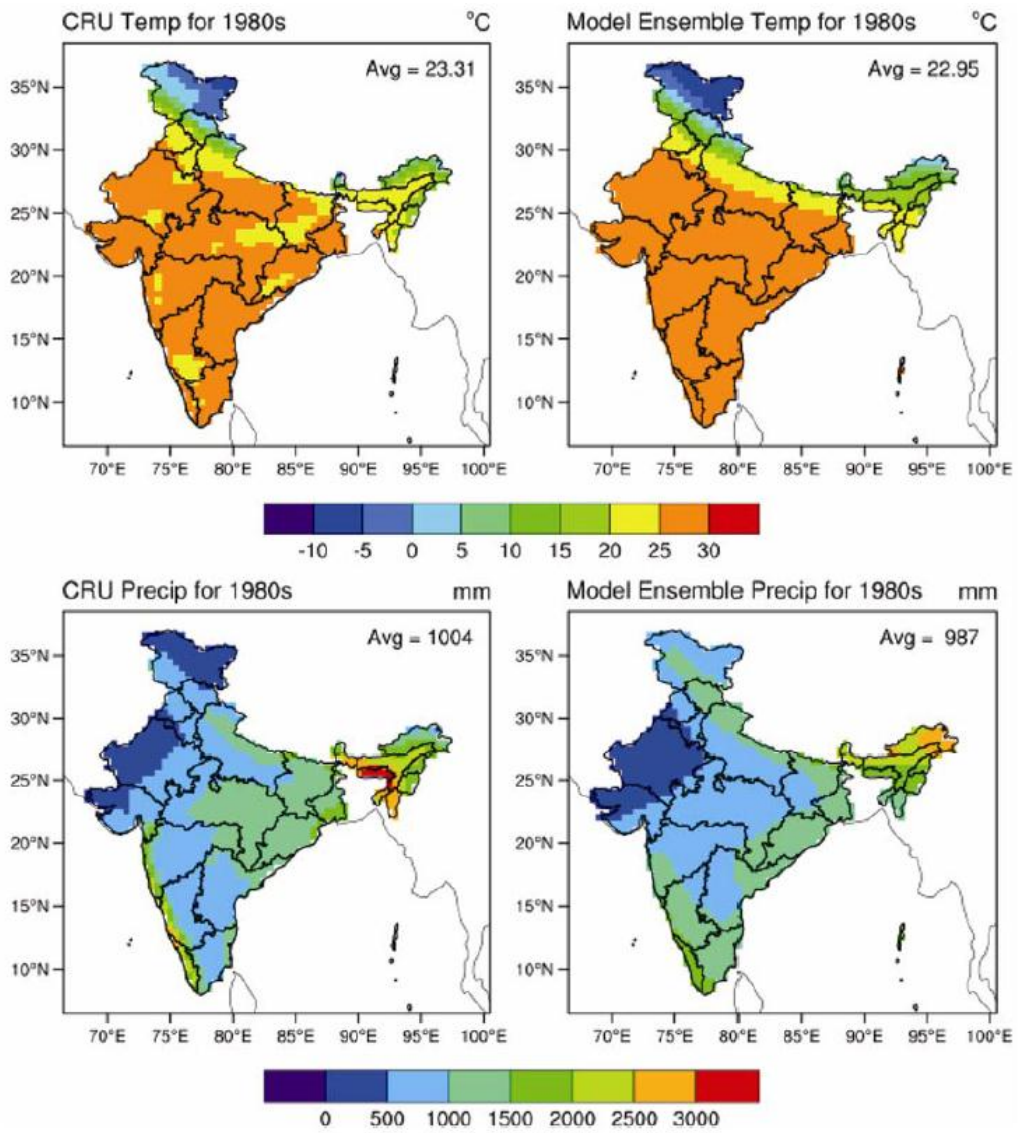


Rainfall Change



Chaturvedi etal. 2012, Current Science

But how good are the models?



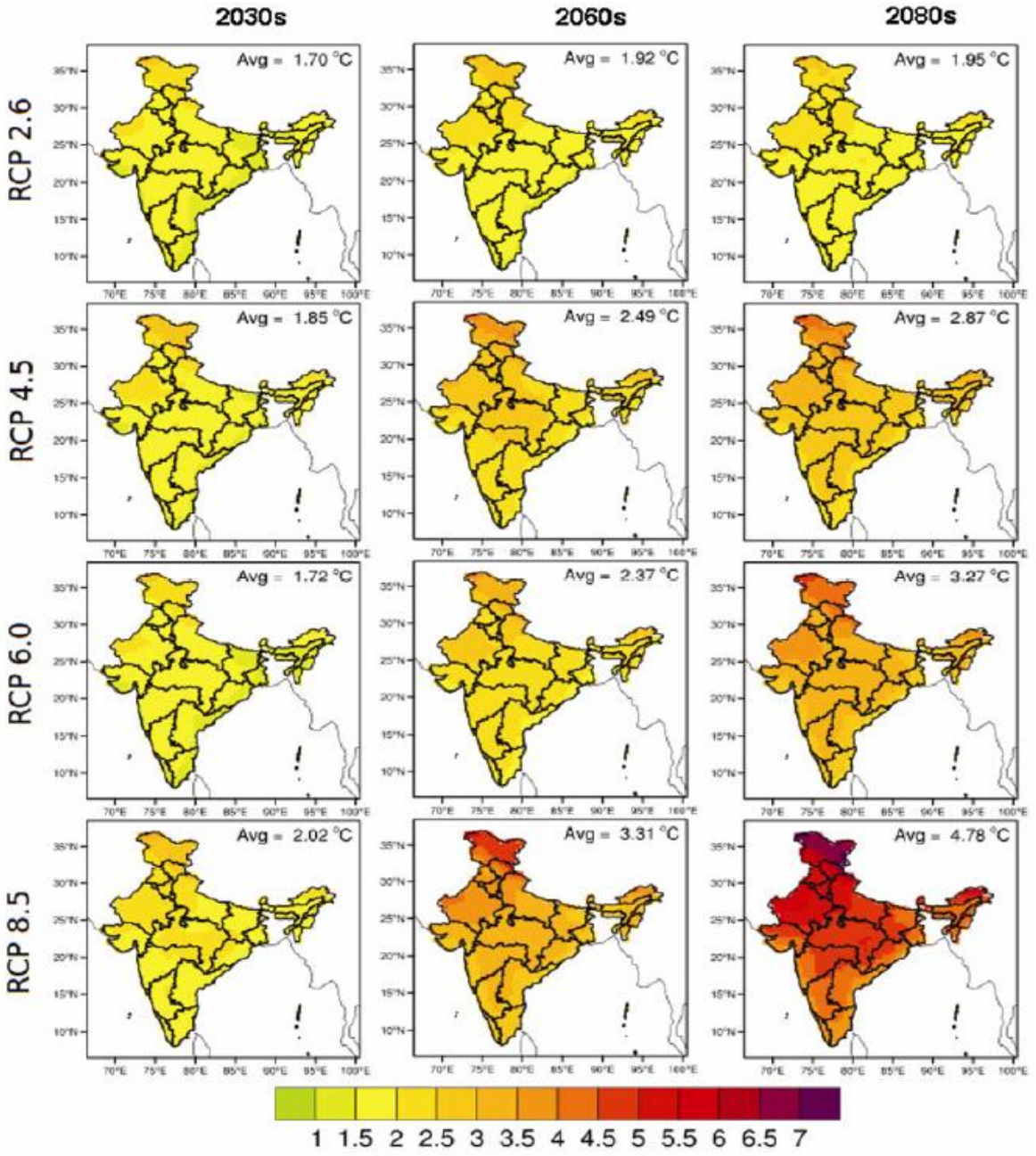
Observations Versus Ensemble mean for 1971-1990

Temperature

Rainfall

Chaturvedi etal. 2012, Current Science

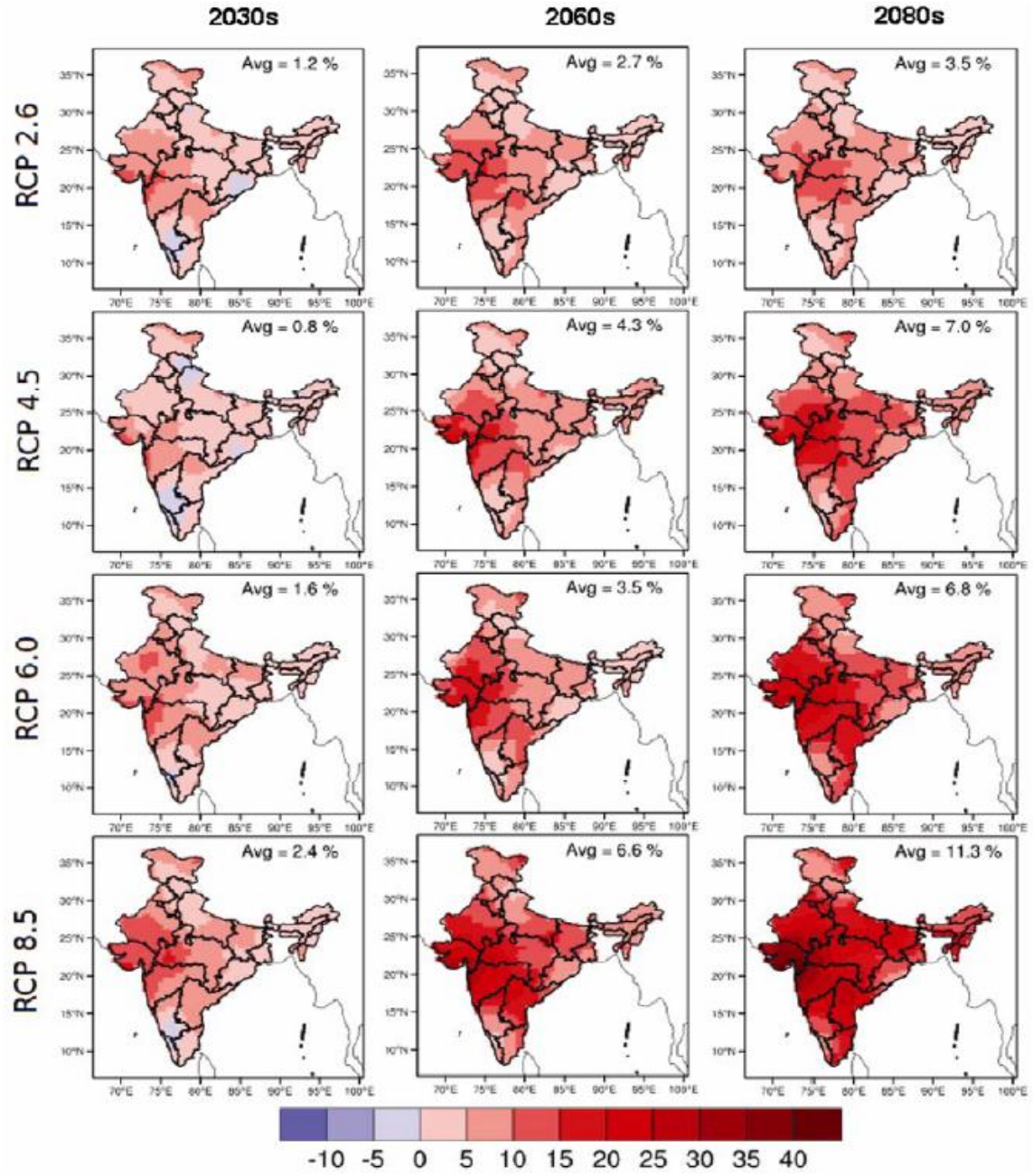
Clear indication of Warming



Ensemble mean from 18 models

Chaturvedi etal. 2012, Current Science

% change in rainfall



Ensemble mean from 18 models

Chaturvedi etal. 2012, Current Science

Modelling Products and Case studies

Approach

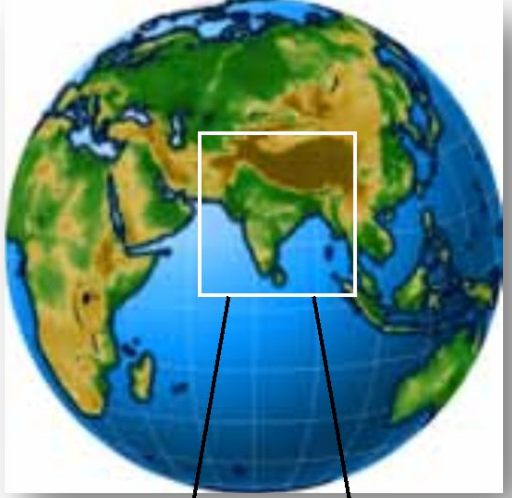
High Resolution Regional Model Selection

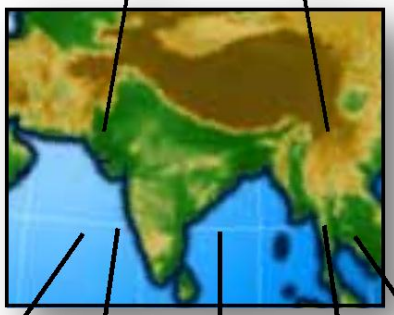
Initial conditions and Boundary conditions from Global Models and suitable scenario selection from IPCC scenarios

Grid resolution and model physics selection

Baseline and Future simulations for 2050s. using the similar LBCs as baseline for 2050s and 2080s.

Post-processing and analysis of baseline and future assessments.





Integrated Biosphere Simulator Model

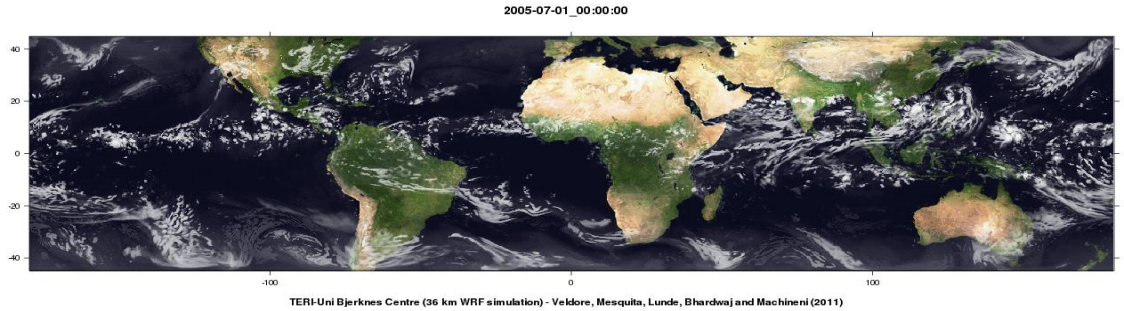
Dynamic Interactive Vulnerability Assessment

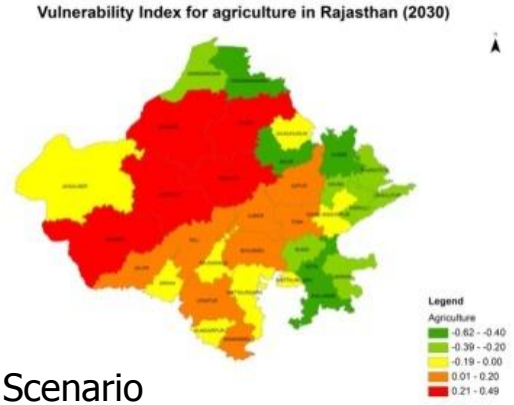
Decision Support System for Agrotechnology Transfer Model

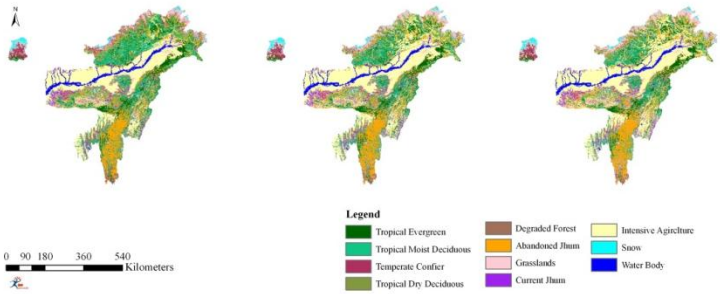
Soil Water Assessment Tool

ADvanced Circulation Model for Storm surge Inundations

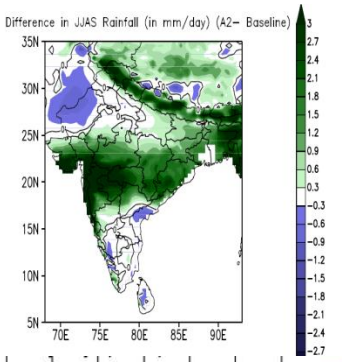
Modelling Products/Services



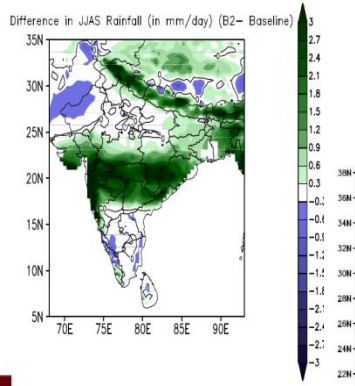


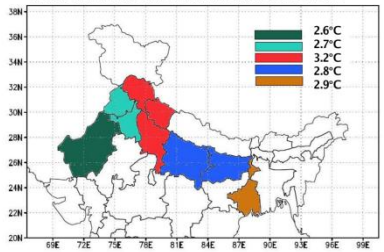


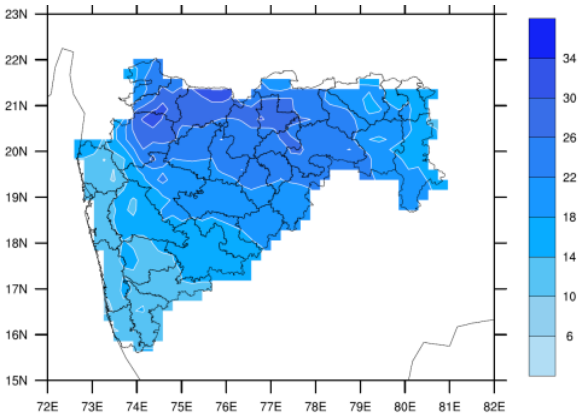
Extreme Scenario

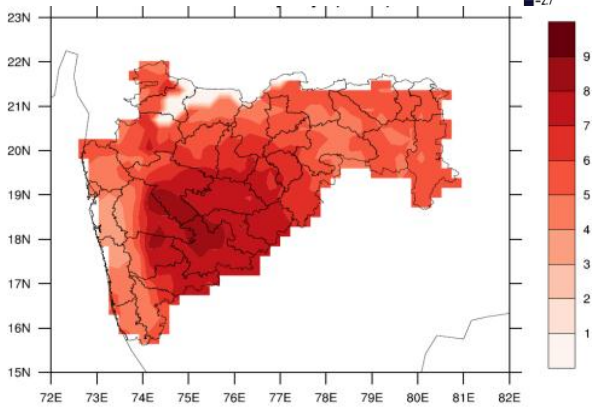


Moderate Scenario



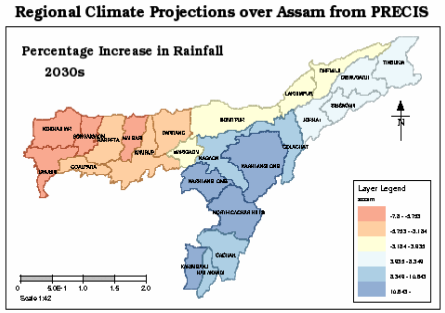






Increase in Extreme rainfall in 2030s relative to baseline (in %)

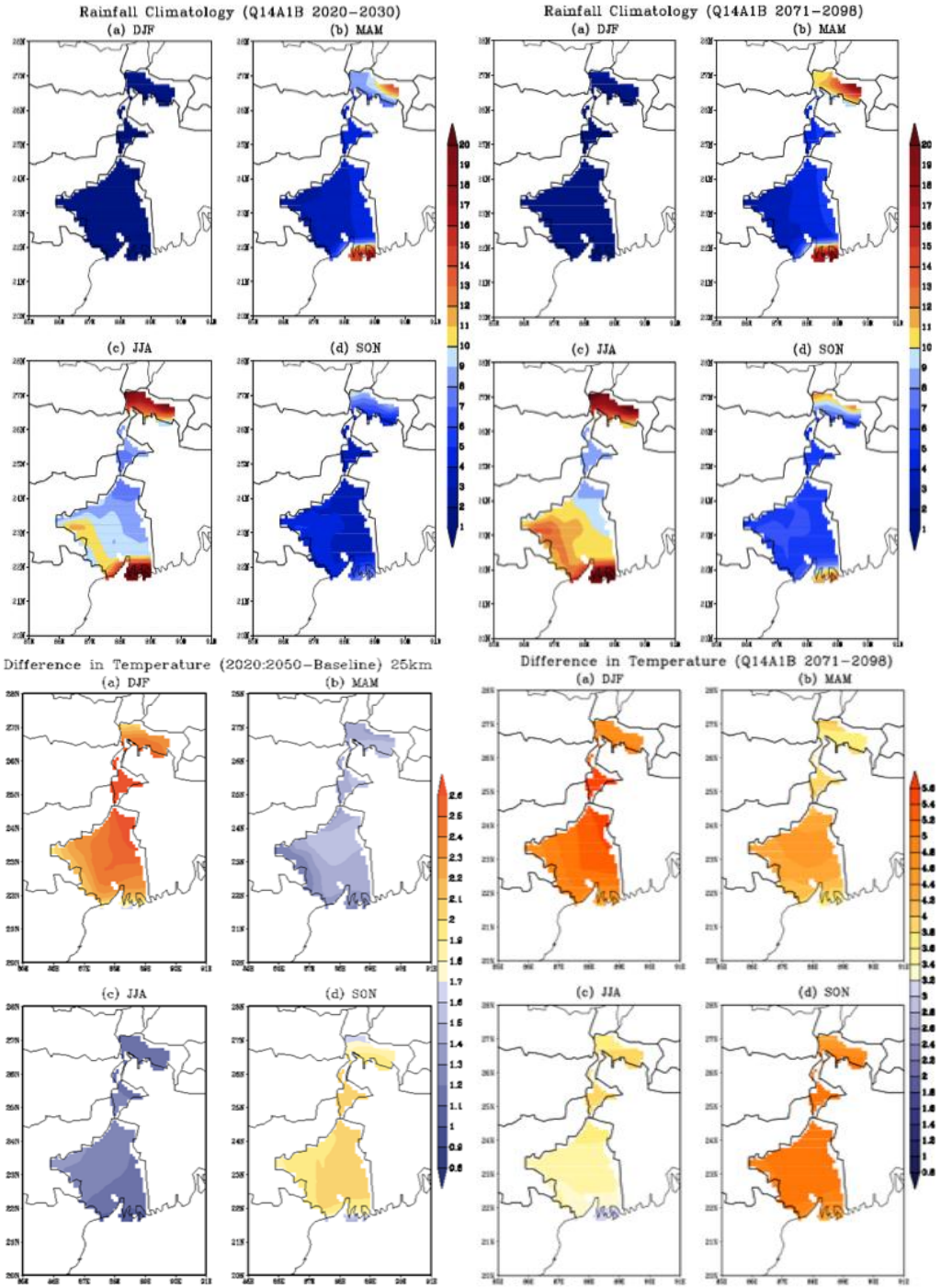
Number of low rainfall days in 2030s relative to baseline

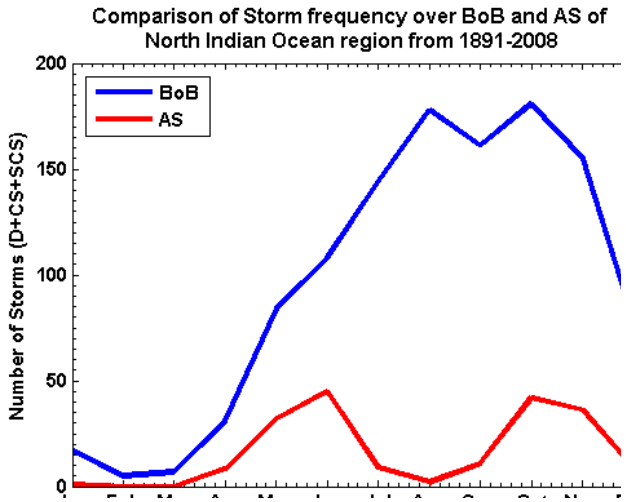


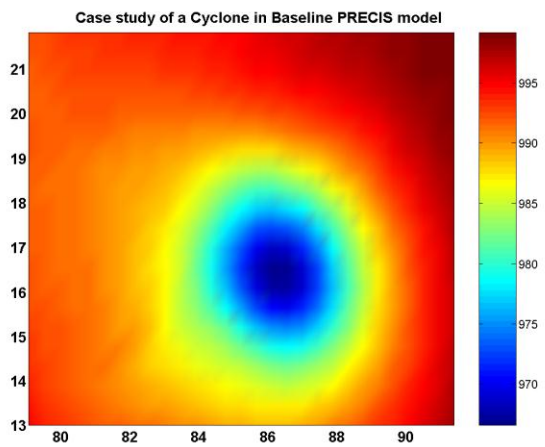
Coastal vulnerability assessment and strategies for better preparedness towards impacts of climate change and sea level rise:

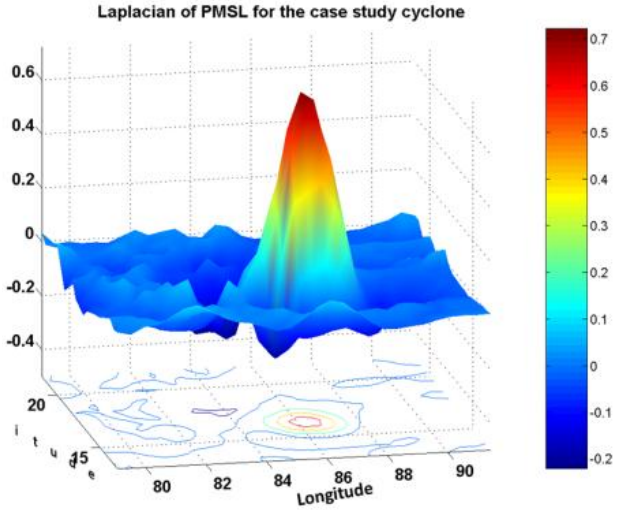
State of West Bengal

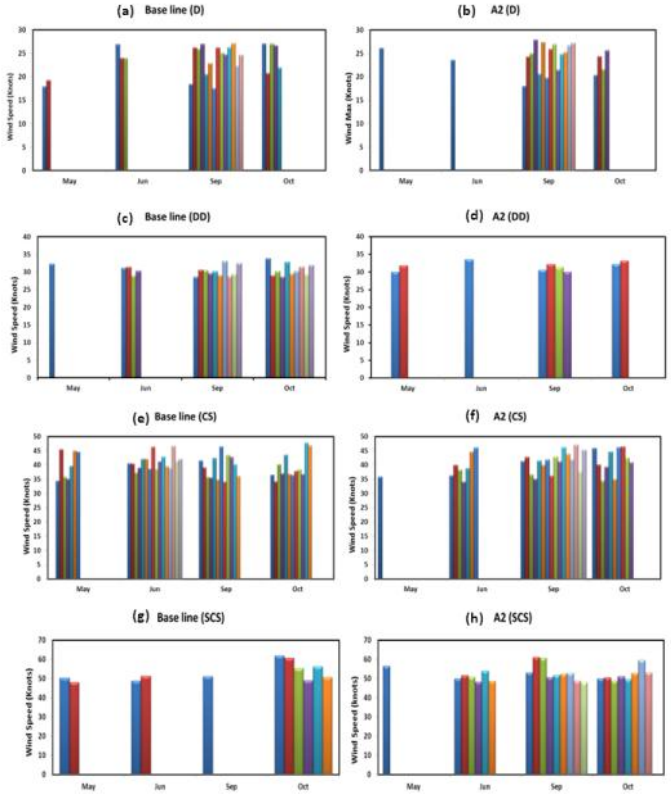
Rainfall and Temperature (Future)
A1B scenario

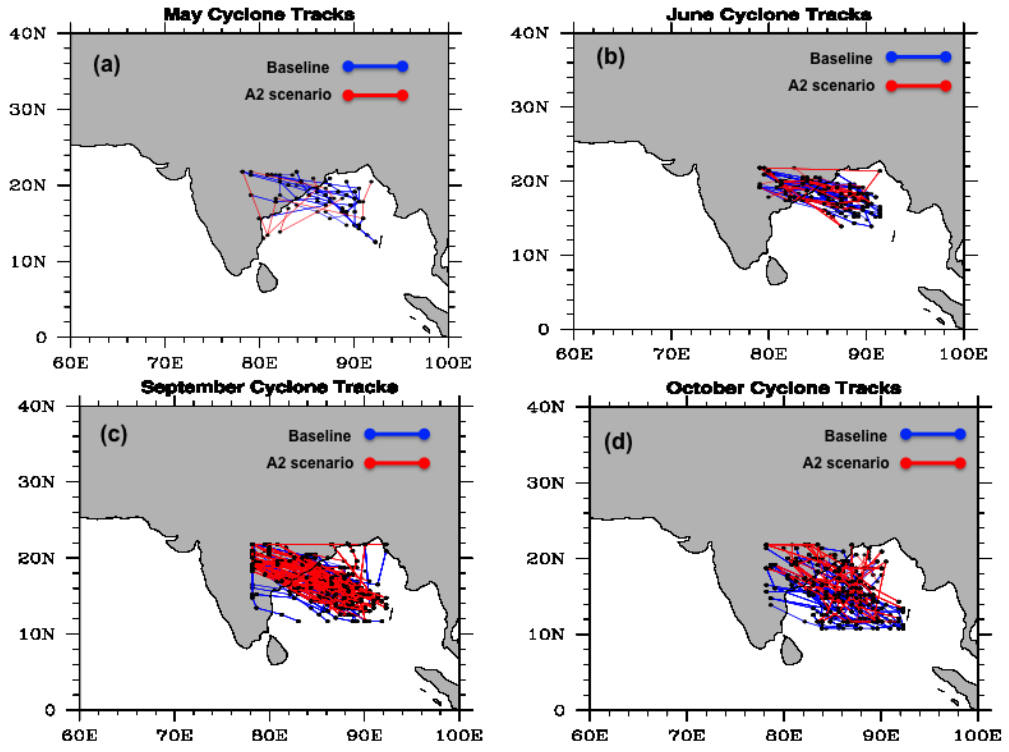


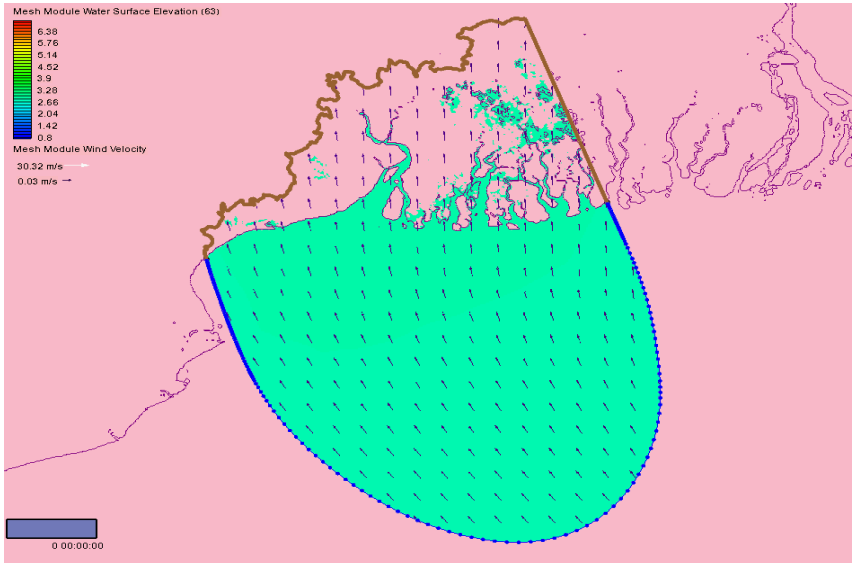

Comparison of Storm frequency over BoB and AS of North Indian Ocean region from 1891-2008
BoB
AS
Number of Storms (D+CS+SCS)
200
150
100
50
0

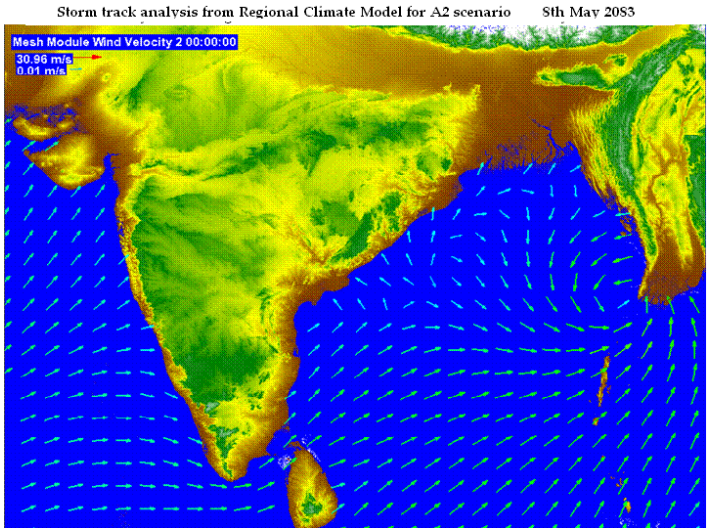

Case study of a Cyclone in Baseline PRECIS model
21
20
19
18
17
16
15
14
13
80
82
84
86
88
90
995
990
985
980
975
970


Laplacian of PMSL for the case study cyclone
0.6
0.4
0.2
0
-0.2
-0.4
20
15
80
82
84
86
88
90
Longitude
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2

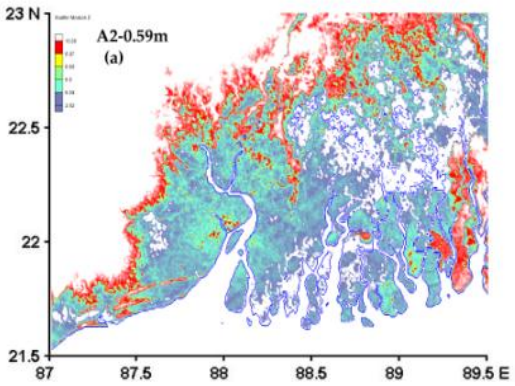

(a) Base line (D)
(b) A2 (D)
(c) Base line (DD)
(d) A2 (DD)
(e) Base line (CS)
(f) A2 (CS)
(g) Base line (SCS)
(h) A2 (SCS)
May
Jun
Sep
Oct

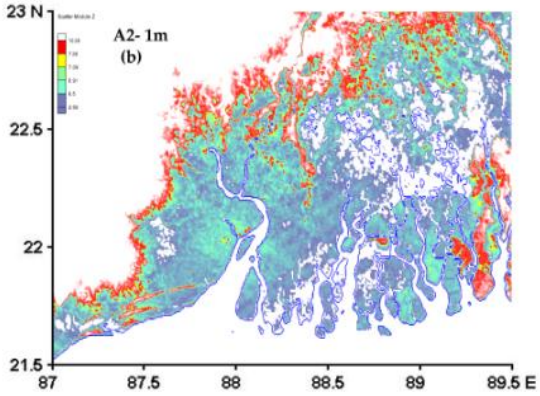

May Cyclone Tracks
June Cyclone Tracks
September Cyclone Tracks
October Cyclone Tracks
(a)
(b)
(c)
(d)
Baseline
A2 scenario
40N
30N
20N
10N
0
60E
70E
80E
90E
100E

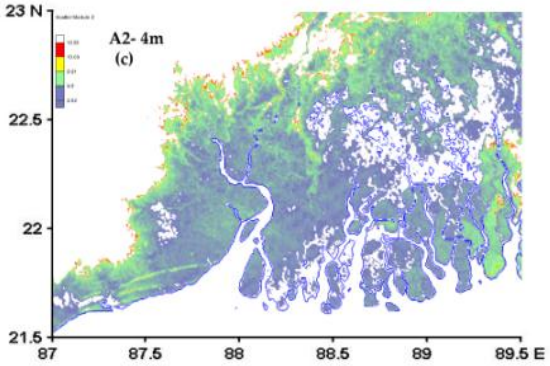




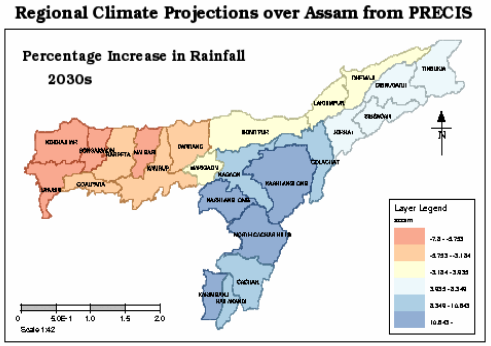
Storm Surge Modelling

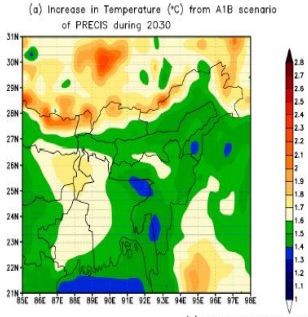


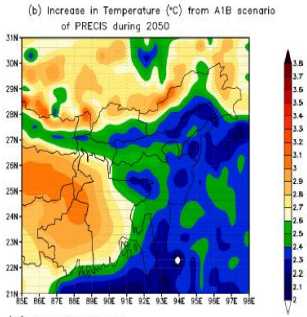


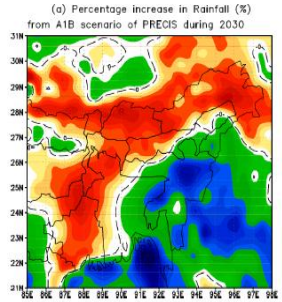


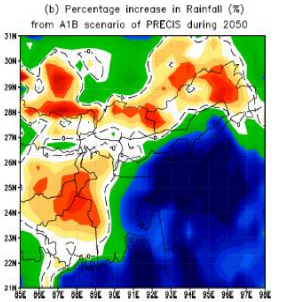
An integrated impacts and vulnerabilities assessment of communities dependent on forest resources for livelihoods (NER-India)

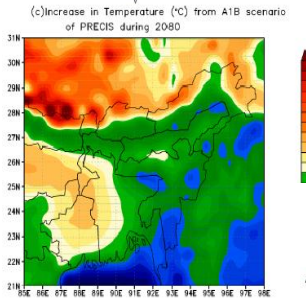


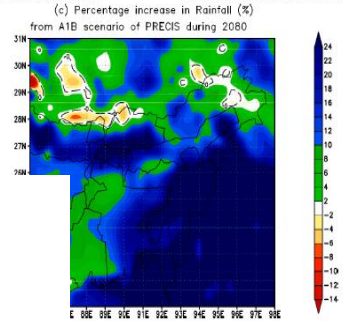


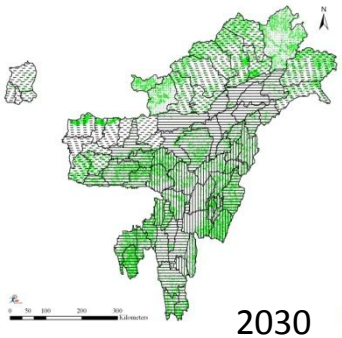




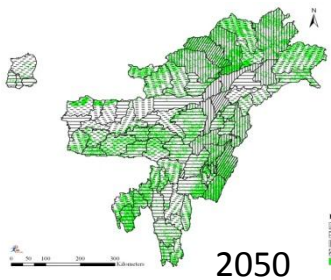




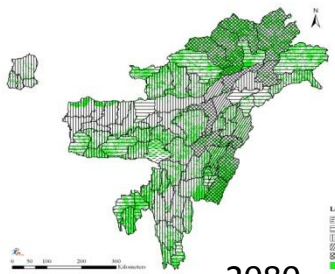




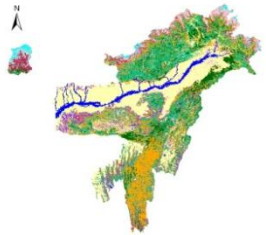
2030

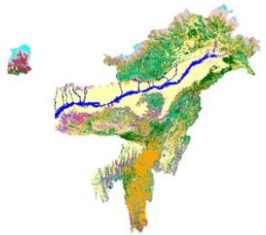


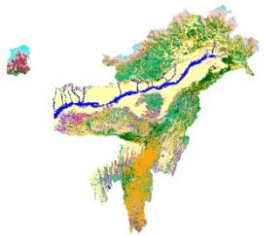
2050



2080





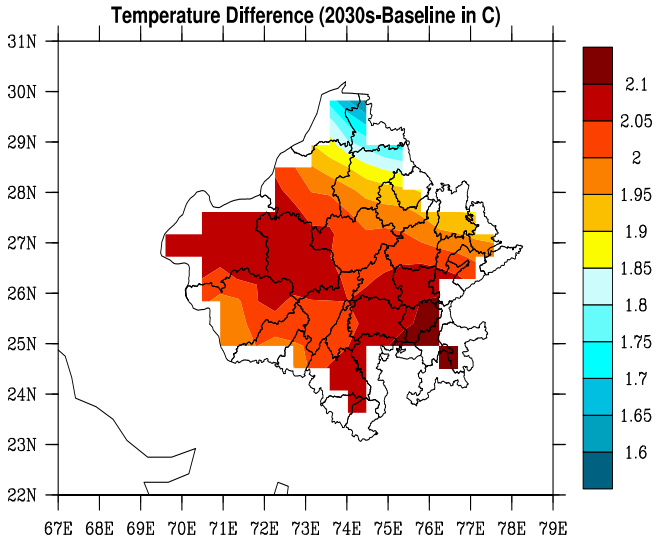


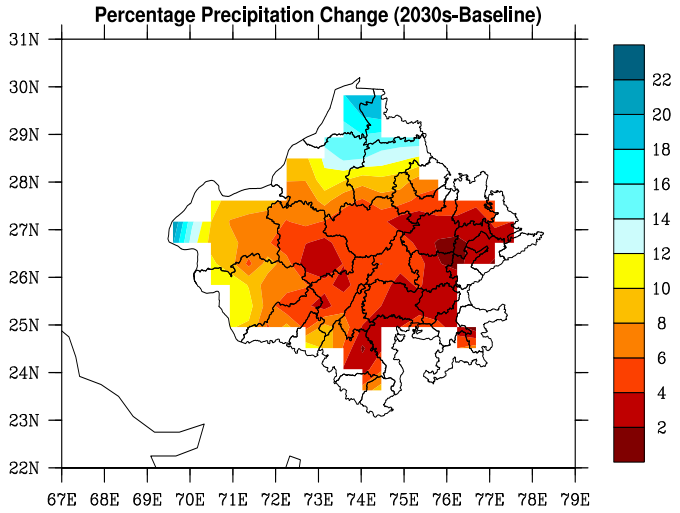
Legend

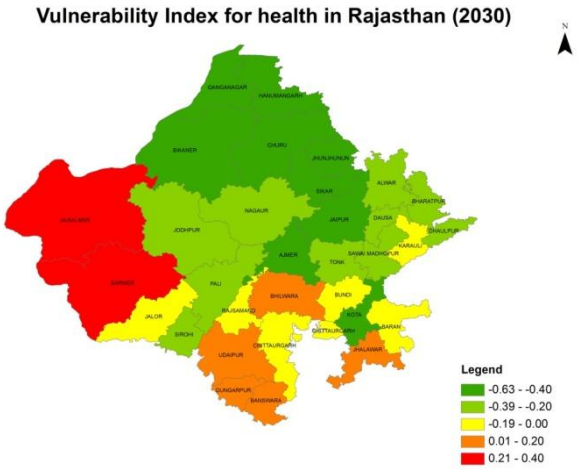
- Tropical Evergreen
- Tropical Moist Deciduous
- Temperate Conifer
- Tropical Dry Deciduous
- Degraded Forest
- Abandoned Jhum
- Grasslands
- Current Jhum
- Intensive Agriclture
- Snow
- Water Body

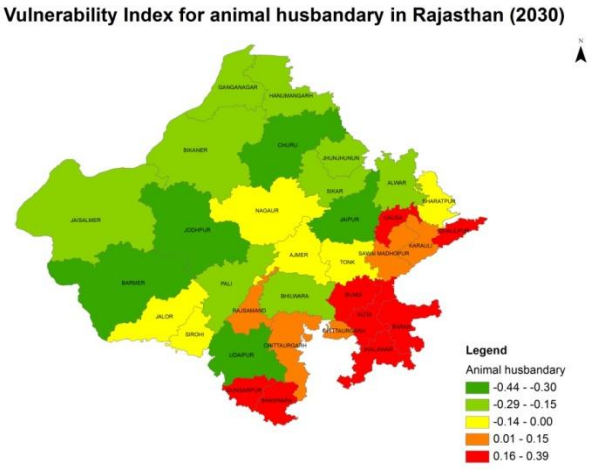
0 90 180 360 540 Kilometers

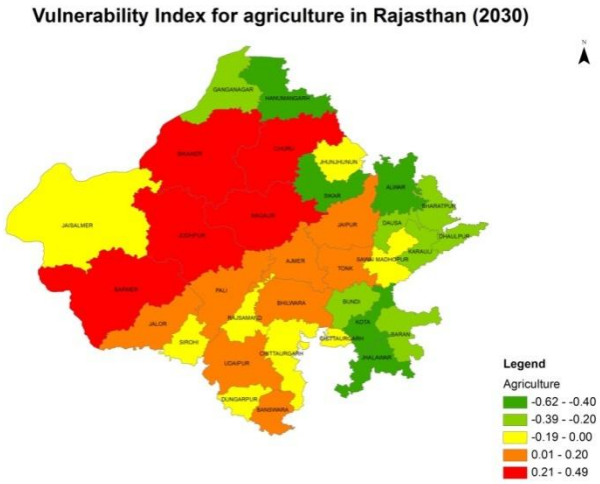
Rajasthan Vulnerability Assessment











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Thematic focus: Environmental governance, Disasters and conflicts

Cyclone Phailin in India: Early warning and timely actions saved lives

Forecast on Cyclone Phailin was "more or less" accurate: IMD

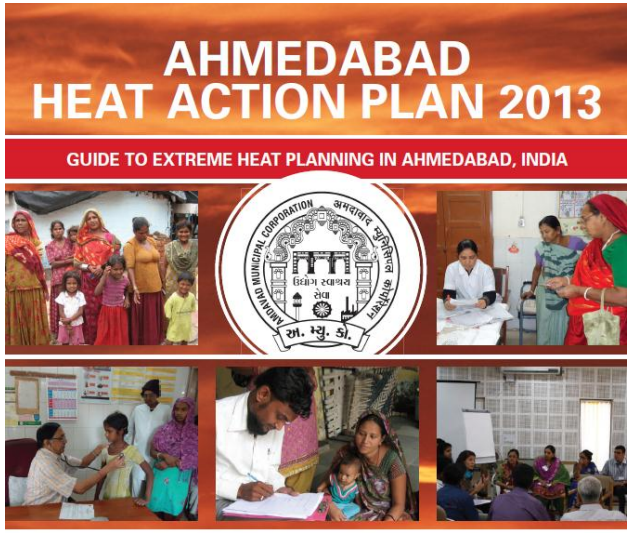
PTI Oct 13, 2013, 02.10PM IST

PM's address at 101st Indian Science Congress in Jammu

"Our advances in meteorology were evident during the recent cyclone in Odisha, when we received accurate forecasts of the landfall point that were more accurate than the forecasts of well known international bodies. Our decision to set up a new Ministry of Earth Sciences following the Indian Ocean Tsunami in 2004 and to invest in world-class tsunami forewarning systems in 2007 has been amply rewarded. We now have the ability to issue alerts within 13 minutes of a tsunami-genic event. This has established India's scientific leadership in the Indian Ocean region.

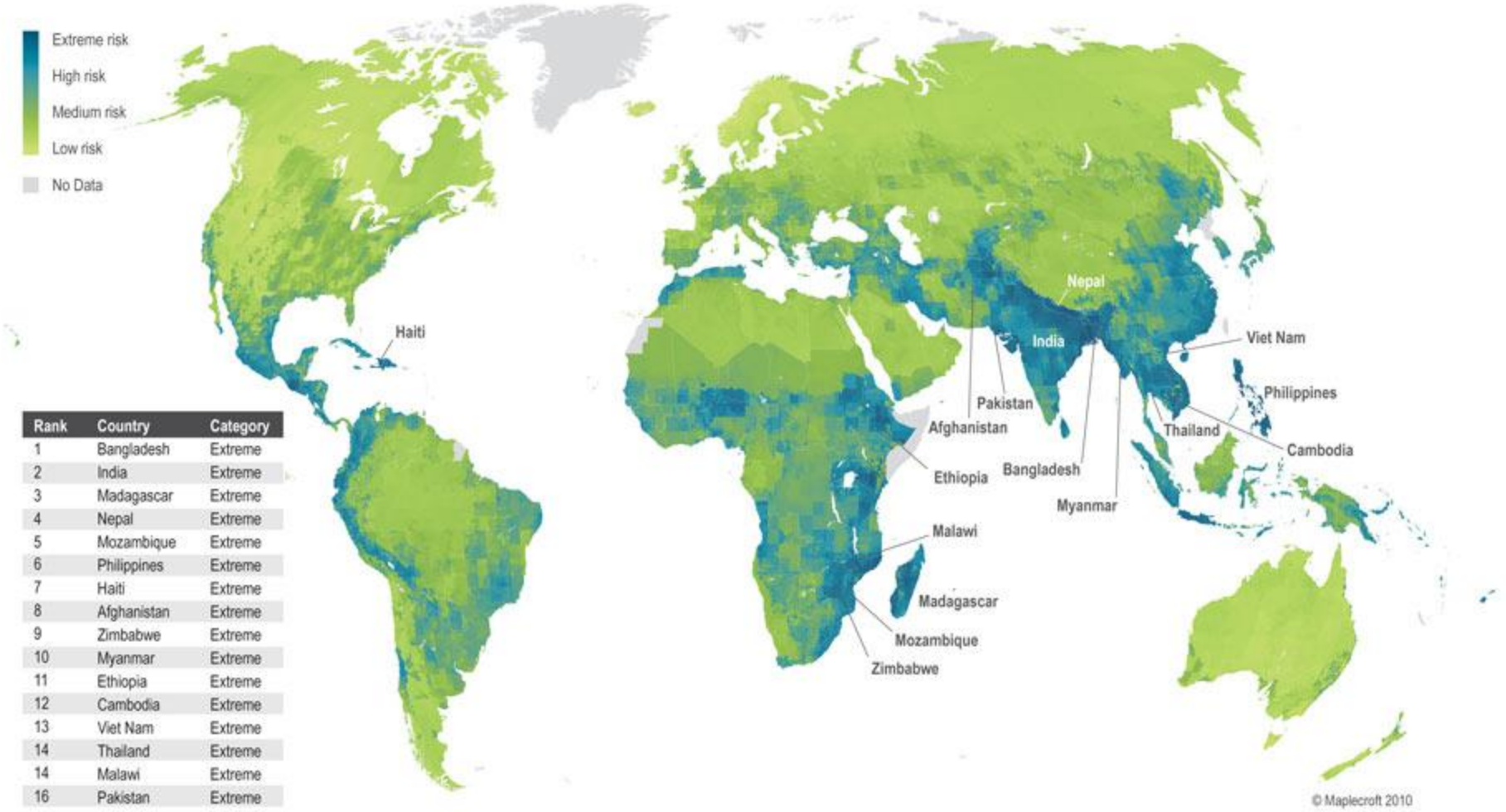
I would also like to see continuous improvement in our monsoon prediction capability through the recently launched Monsoon Mission so that we avert the kind of calamities that we saw in Uttarakhand last year. "

Source-IMD



Climate Change Vulnerability Index 2011

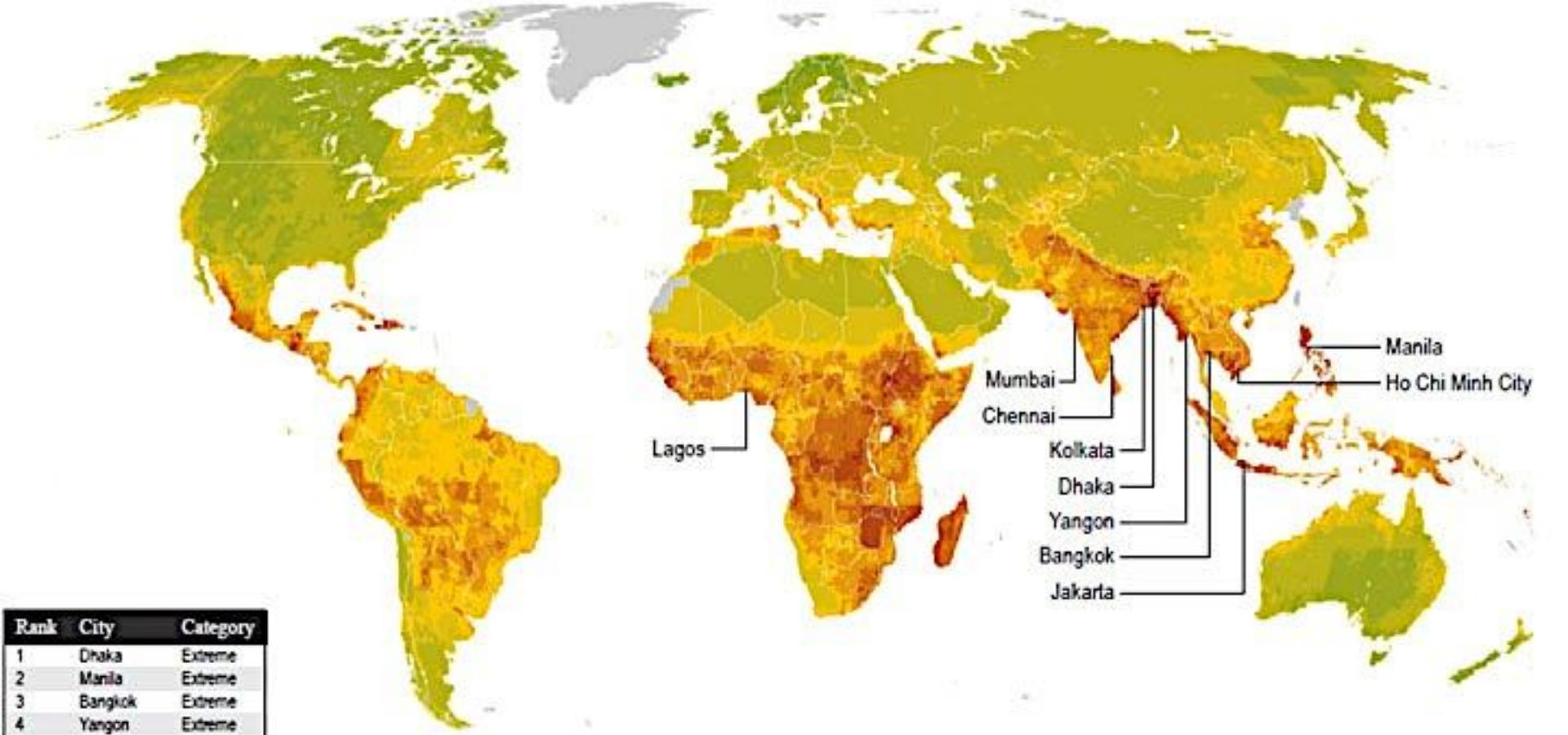
maplecroft
risk responsibility reputation



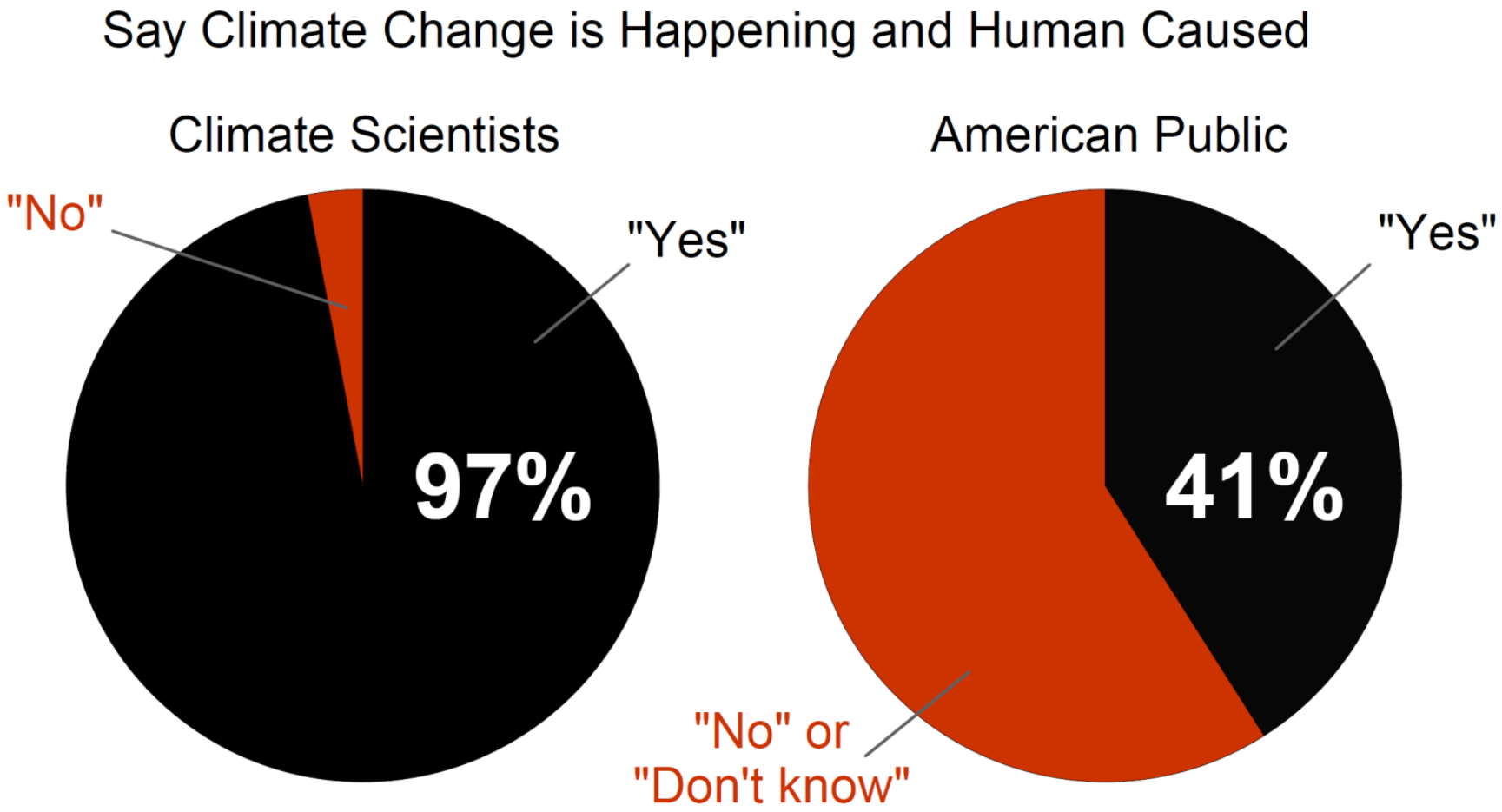
Rank	Country	Category
1	Bangladesh	Extreme
2	India	Extreme
3	Madagascar	Extreme
4	Nepal	Extreme
5	Mozambique	Extreme
6	Philippines	Extreme
7	Haiti	Extreme
8	Afghanistan	Extreme
9	Zimbabwe	Extreme
10	Myanmar	Extreme
11	Ethiopia	Extreme
12	Cambodia	Extreme
13	Viet Nam	Extreme
14	Thailand	Extreme
14	Malawi	Extreme
16	Pakistan	Extreme

Climate Change Vulnerability Index 2013 – Most at risk cities

maplecroft



Rank	City	Category
1	Dhaka	Extreme
2	Manila	Extreme
3	Bangkok	Extreme
4	Yangon	Extreme
5	Djakarta	Extreme
6	Ho Chi Minh	Extreme
7	Kolkata	Extreme
8	Mumbai	High
9	Chennai	High
10	Lagos	High



Cook *et al.*, (2013) examined ~12000 peer-reviewed papers in climate science literature and found that 97% of the papers said that global warming is happening and human-caused, at least in part.

Thank you

saurabh.bhardwaj@teri.res.in