Climate Change and Indian Summer Monsoon Rainfall

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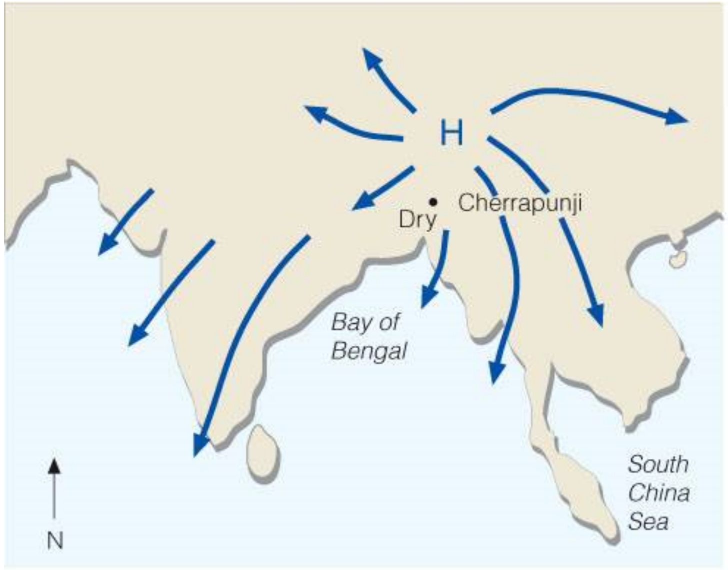
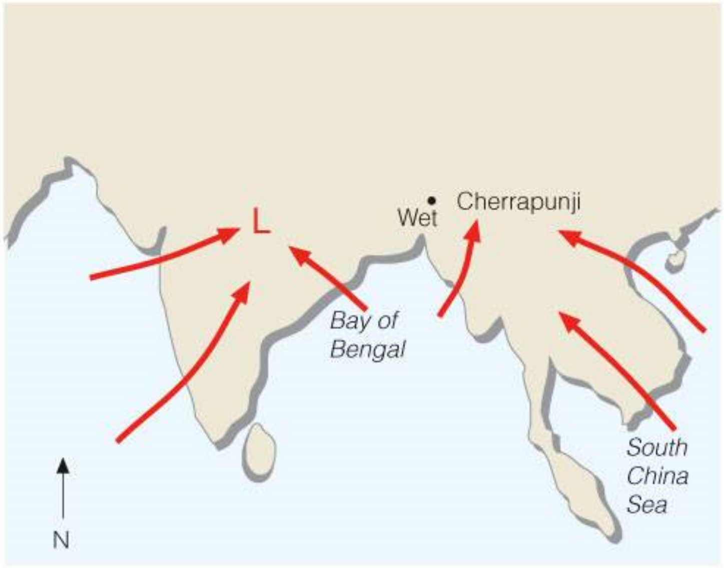
Monsoon

* Monsoon: Arabic word "*Mausim*" (meaning-season)
* Monsoon wind system: changes direction seasonally



(a) Winter Monsoon



(b) Summer Monsoon

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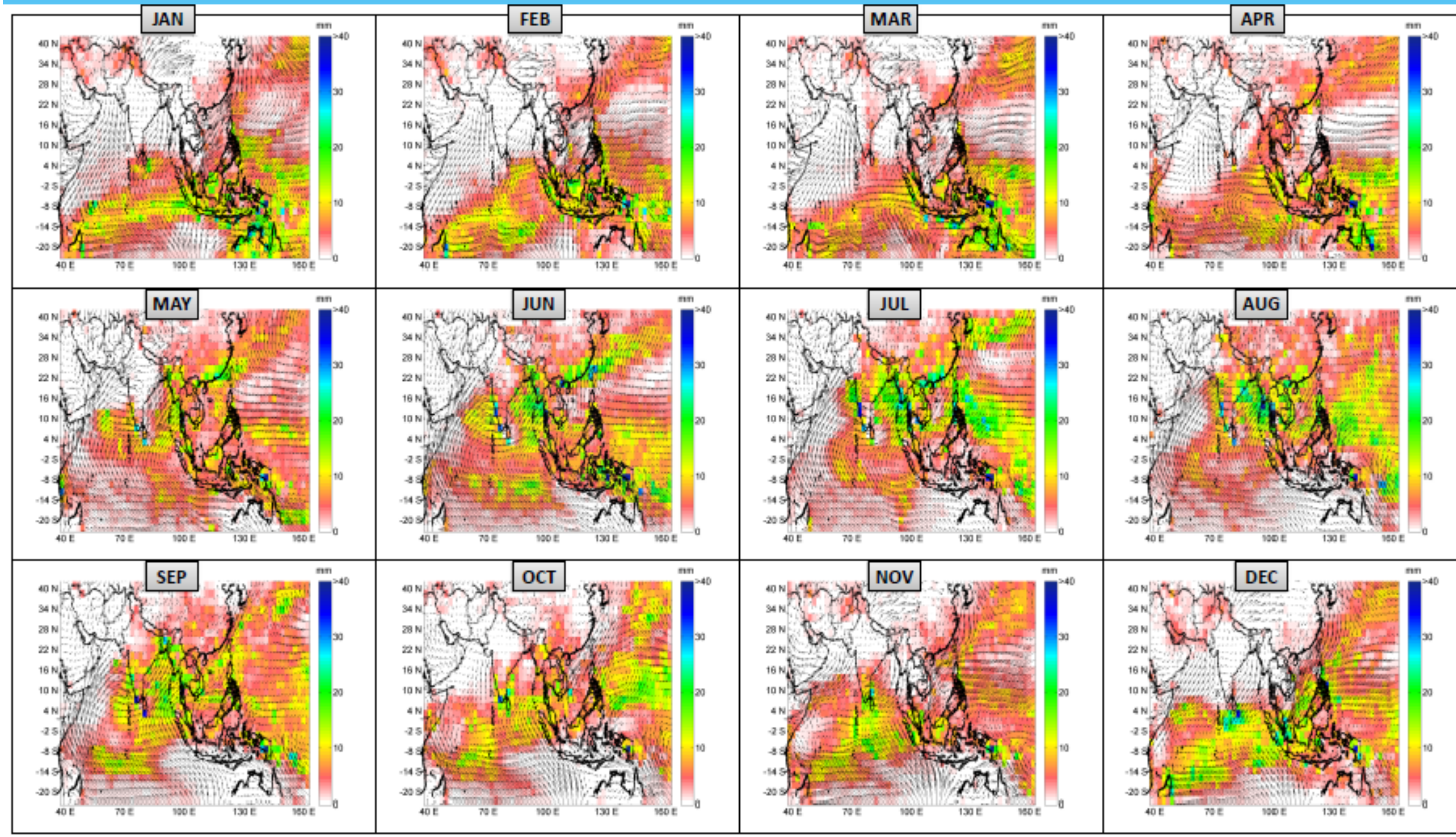
Source: IMD, IITM

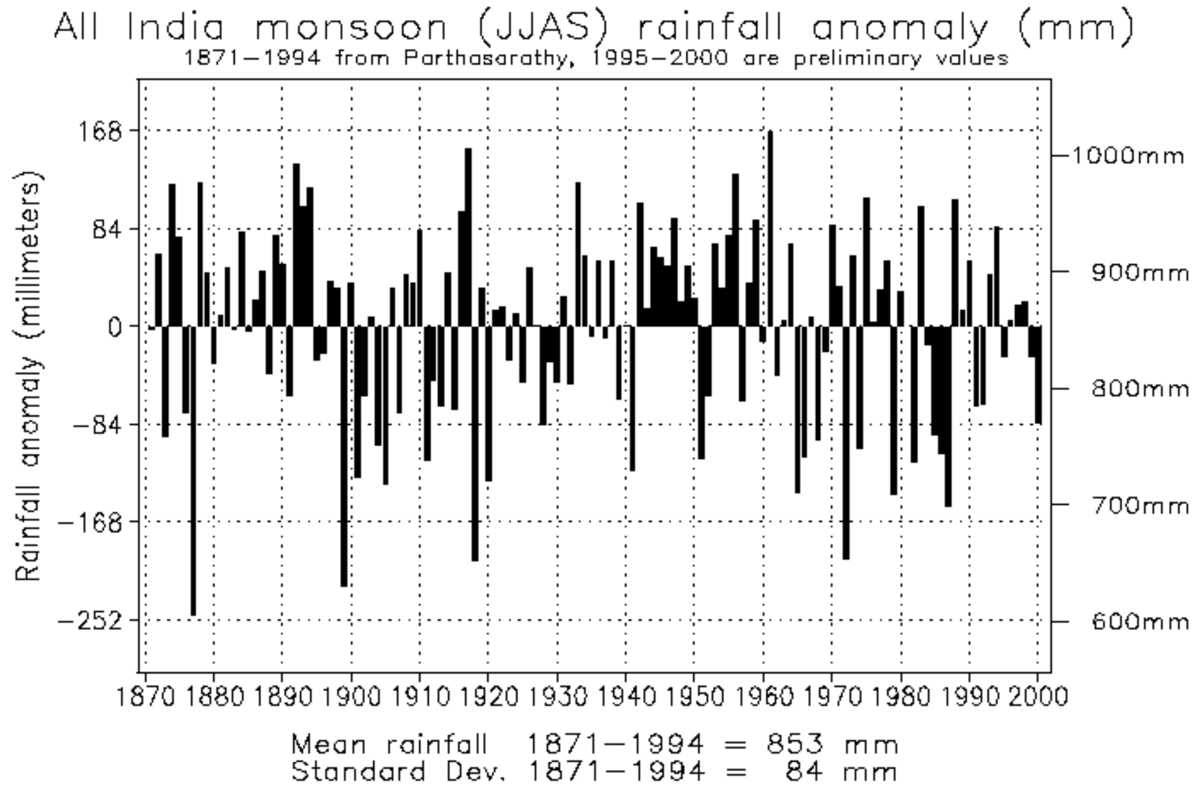
Wind Circulation



Characteristics of Indian Monsoon

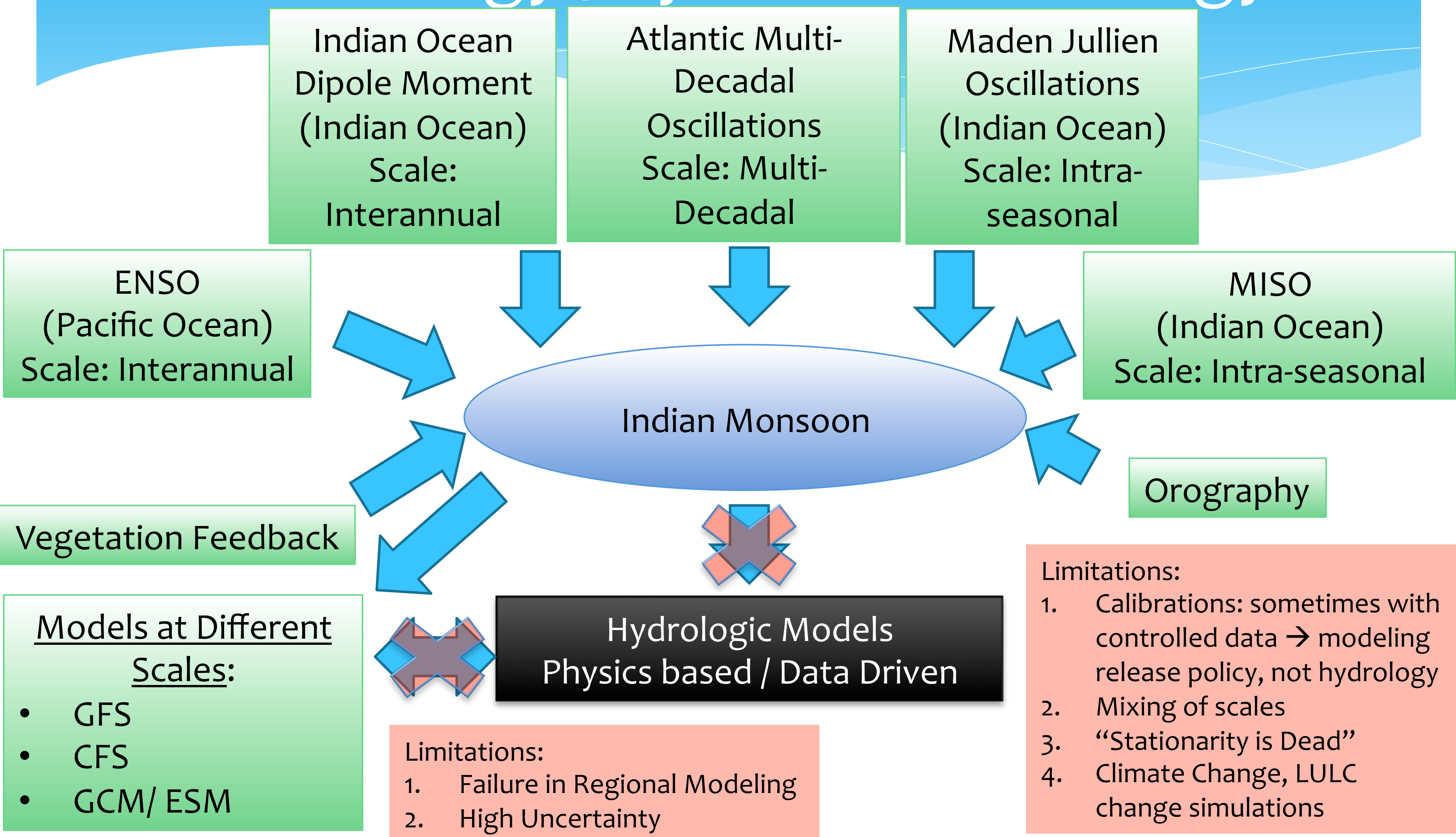
- Shift in prevailing wind direction by more than 120^{0} between January to July
- Season: June to September (Except few places in South India)
- Monsoon region extends from Lat 35^{0} N to 25^{0}S and long 30^{0} W to 170^{0} E

Time Series: All India Monsoon Rainfall



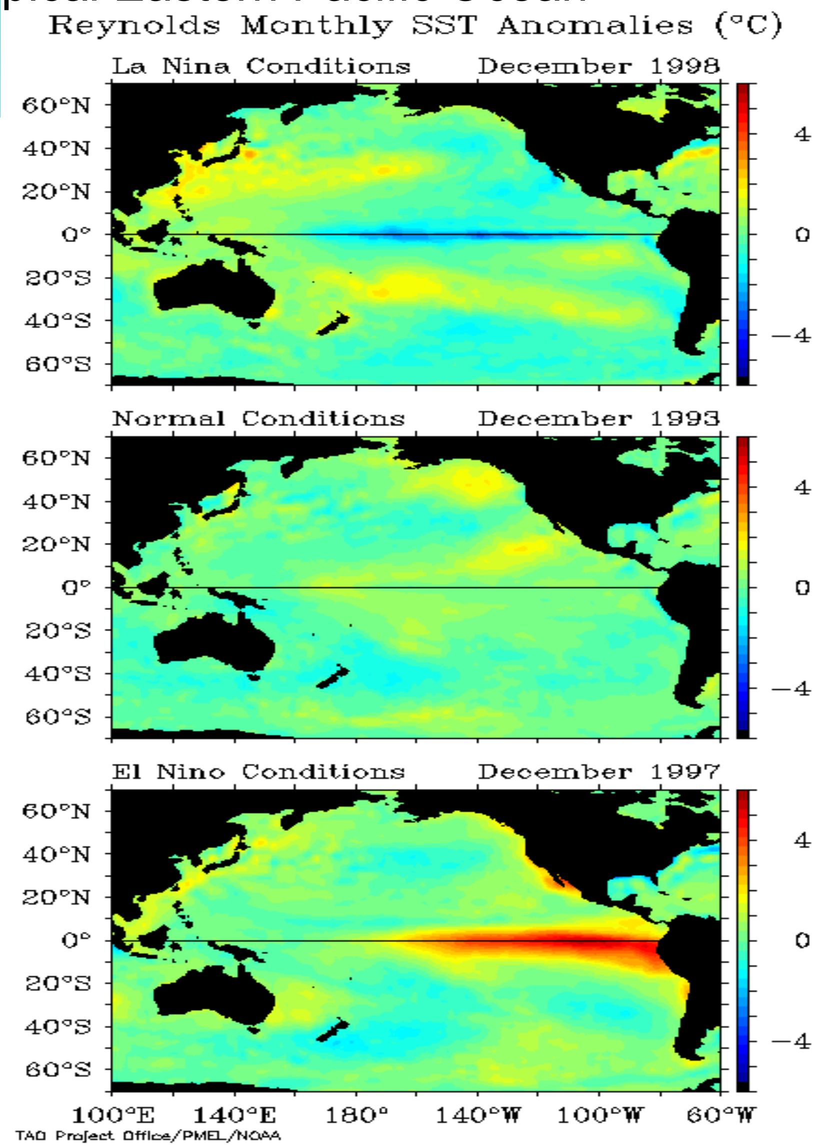
Source: IMD, IITM

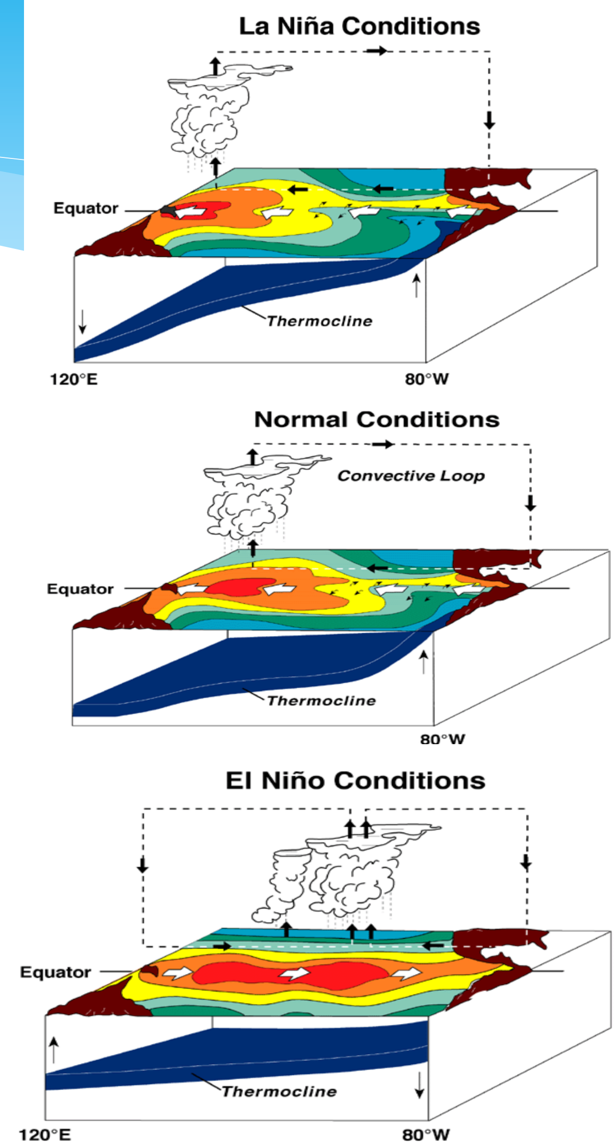
Introduction to the Topic: Why Hydro-climatology /Hydro-meteorology?



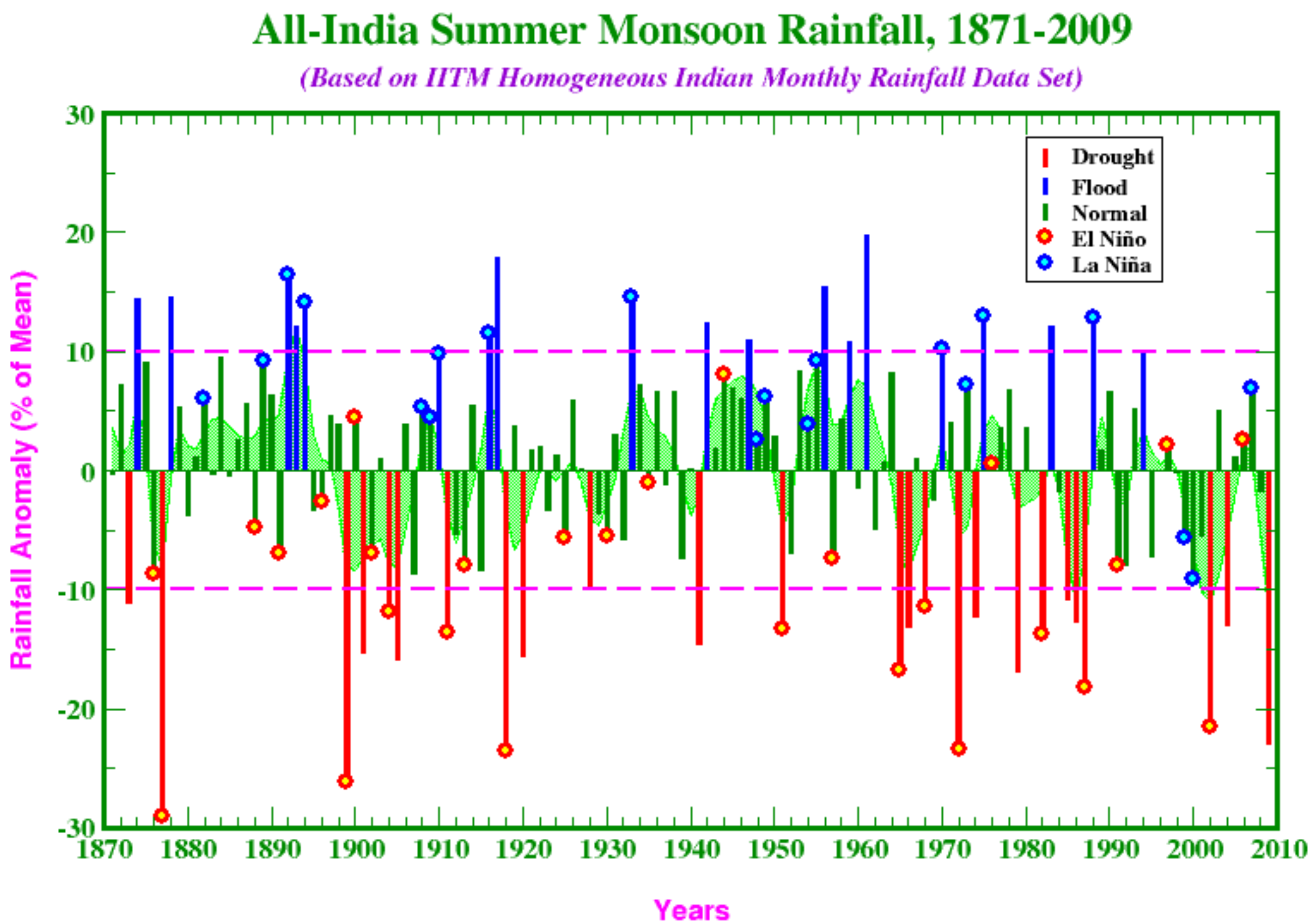
What is El Nino and La-Nina?

El Niño and La Niña are important temperature fluctuations in surface waters of the tropical Eastern Pacific Ocean





Inter-annual Variability



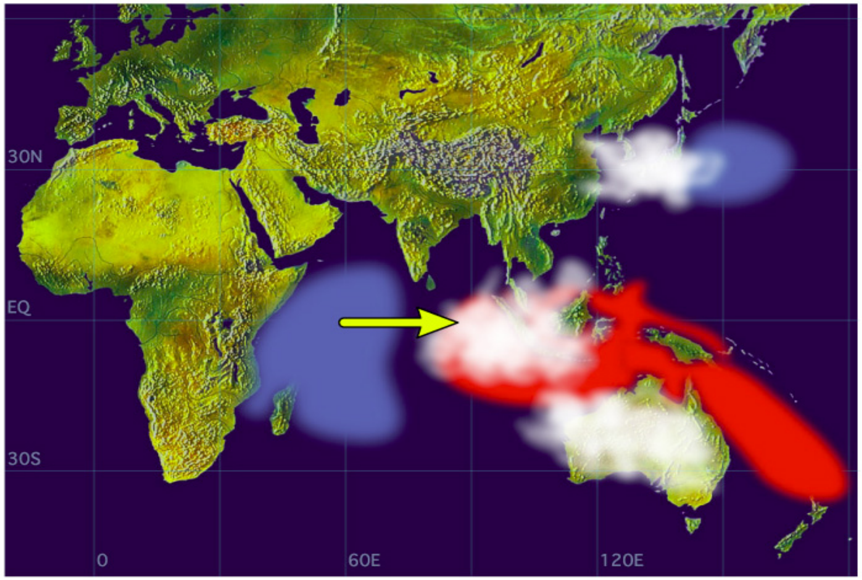
Source: IMD, IITM

Indian Ocean Dipole Moment

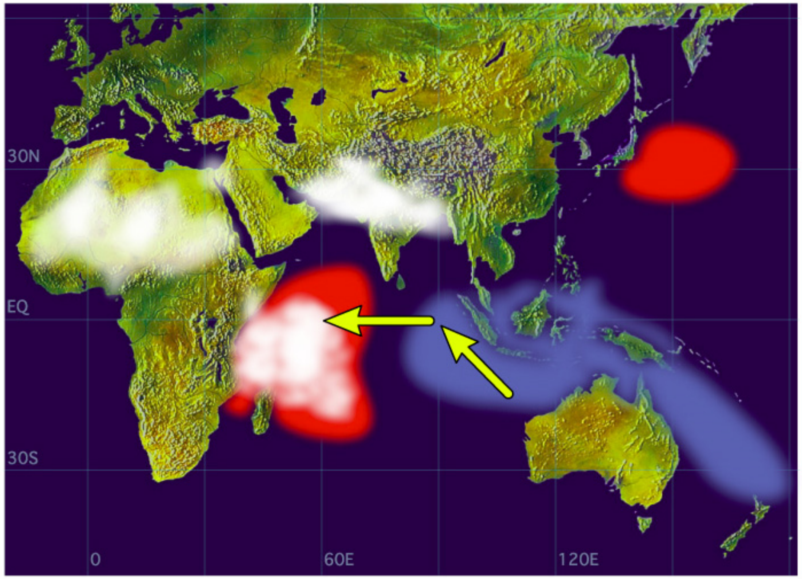
IOD is a pattern of internal variability with anomalously low sea surface temperatures off Sumatra and high sea surface temperatures in the western Indian Ocean (Saji et al.,1999)

DMI: Dipole mode index It is defined as the difference in SST anomaly between the tropical western Indian Ocean (50 °E–70 °E, 10 °S–10°N) and the tropical south-eastern Indian Ocean (90°E–110°E,10°S–0°).

Negative Dipole Mode

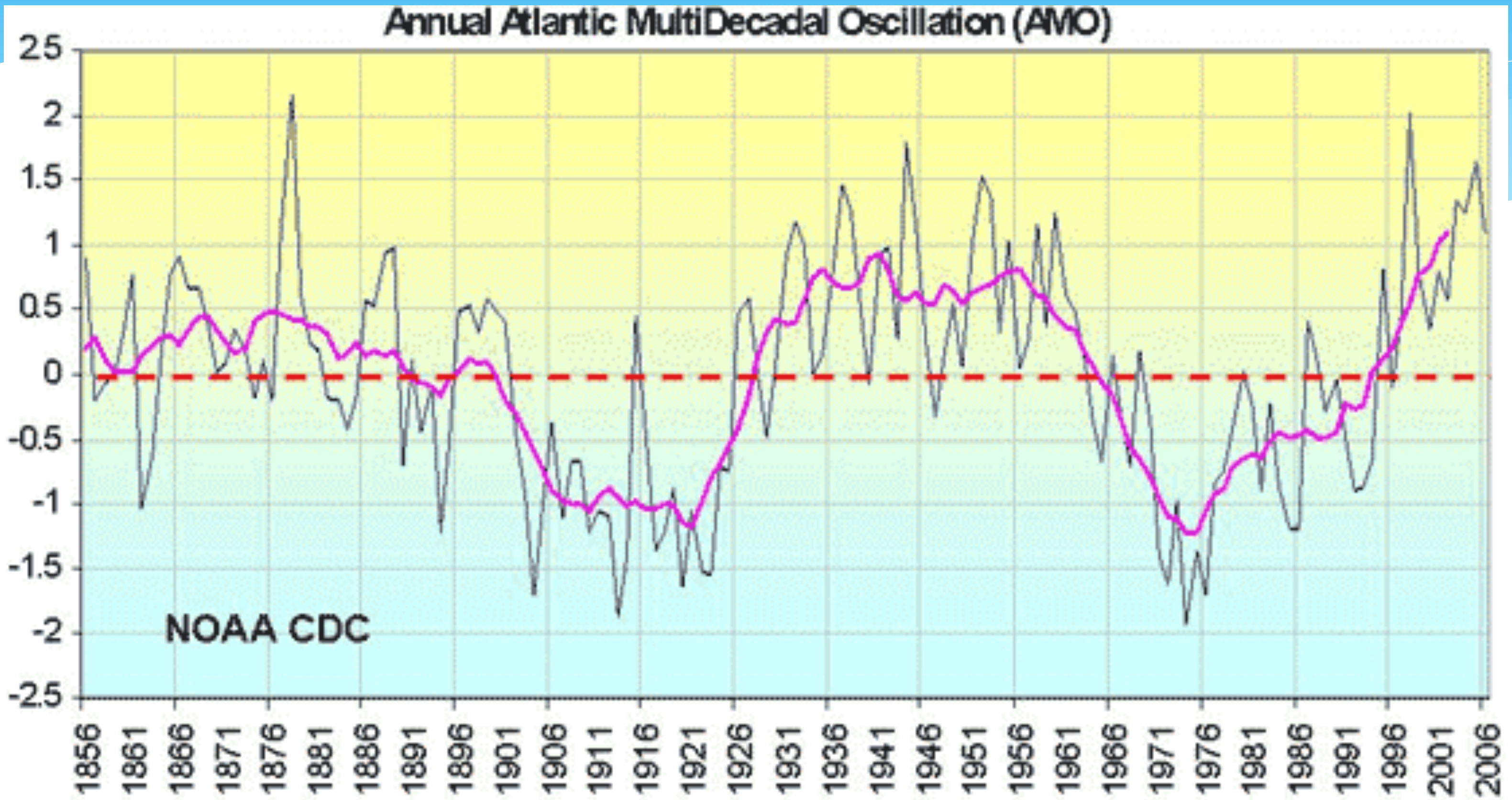


Positive Dipole Mode



Note: SST anomalies (red shading warming; blue cooling) during a Positive IOD event. White patches indicate increased convective activity. Wind direction is indicated by arrows. (Source: http://www.jamstec.go.jp)

Atlantic Multidecadal Oscillations (AMO)



Mean ocean temperature anomalies in the Atlantic from 0 to 70N

AMO and AIMR

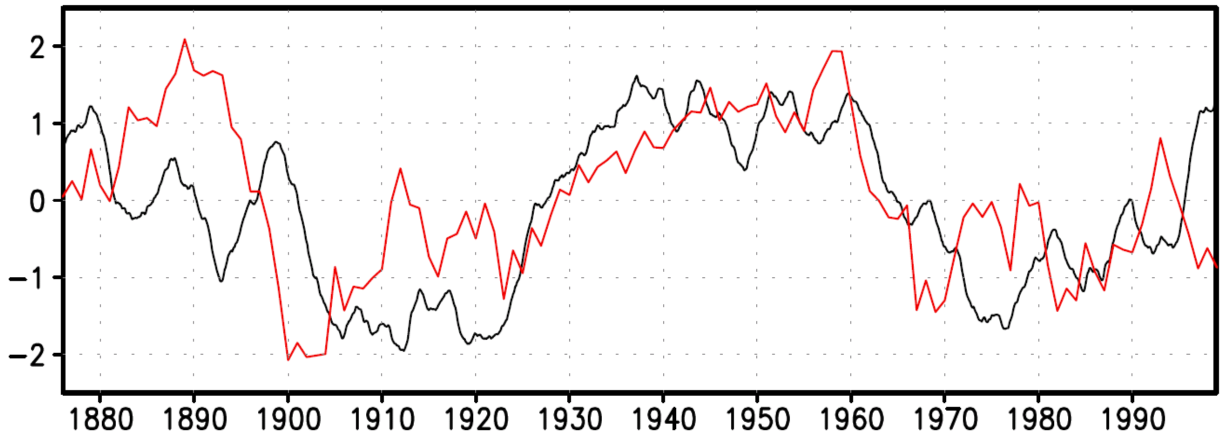
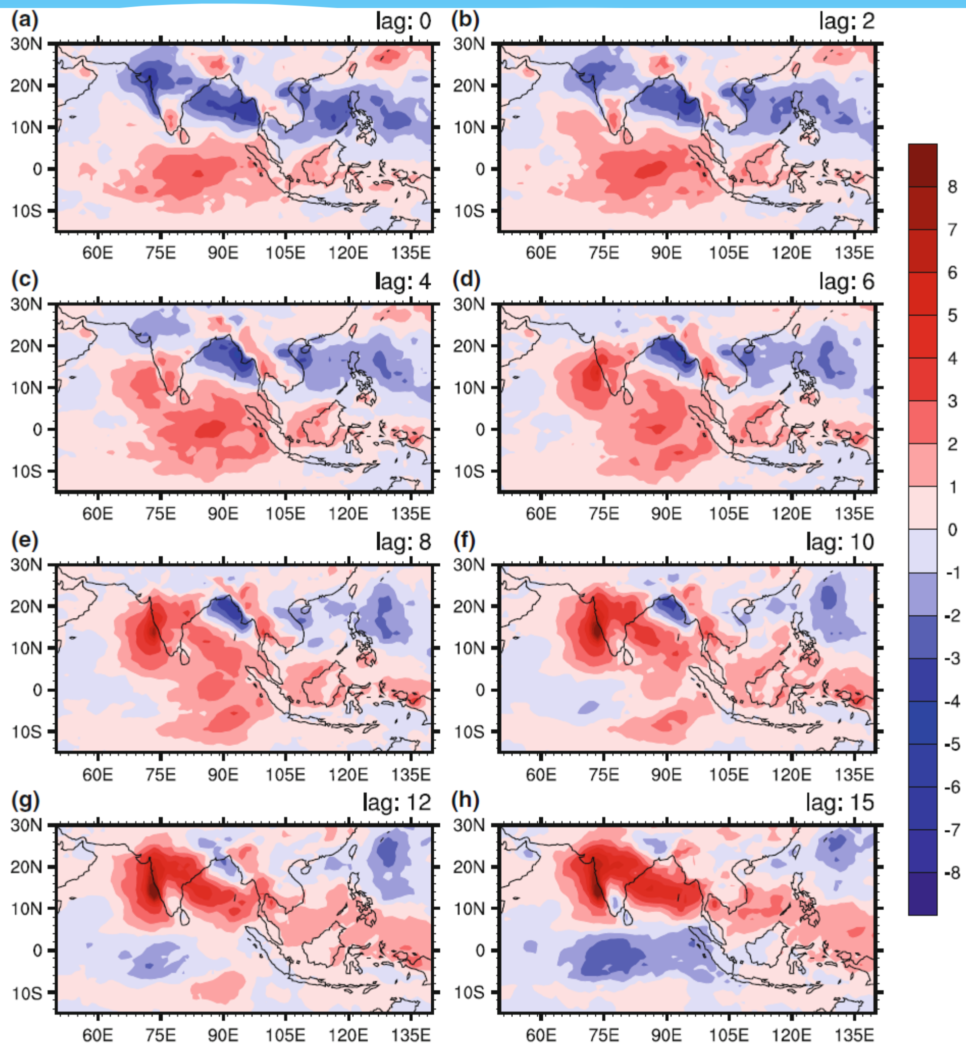


Figure 7: Multidecadal oscillation of AIR (red line, obtained from 11-yr running mean of JJAS mean all India rainfall) and Atlantic multidecadal oscillation (AMO, black line). AMO is based on 60-month running mean of monthly anomalies averaged over Atlantic north of Equator.

Goswami et al., (2006)

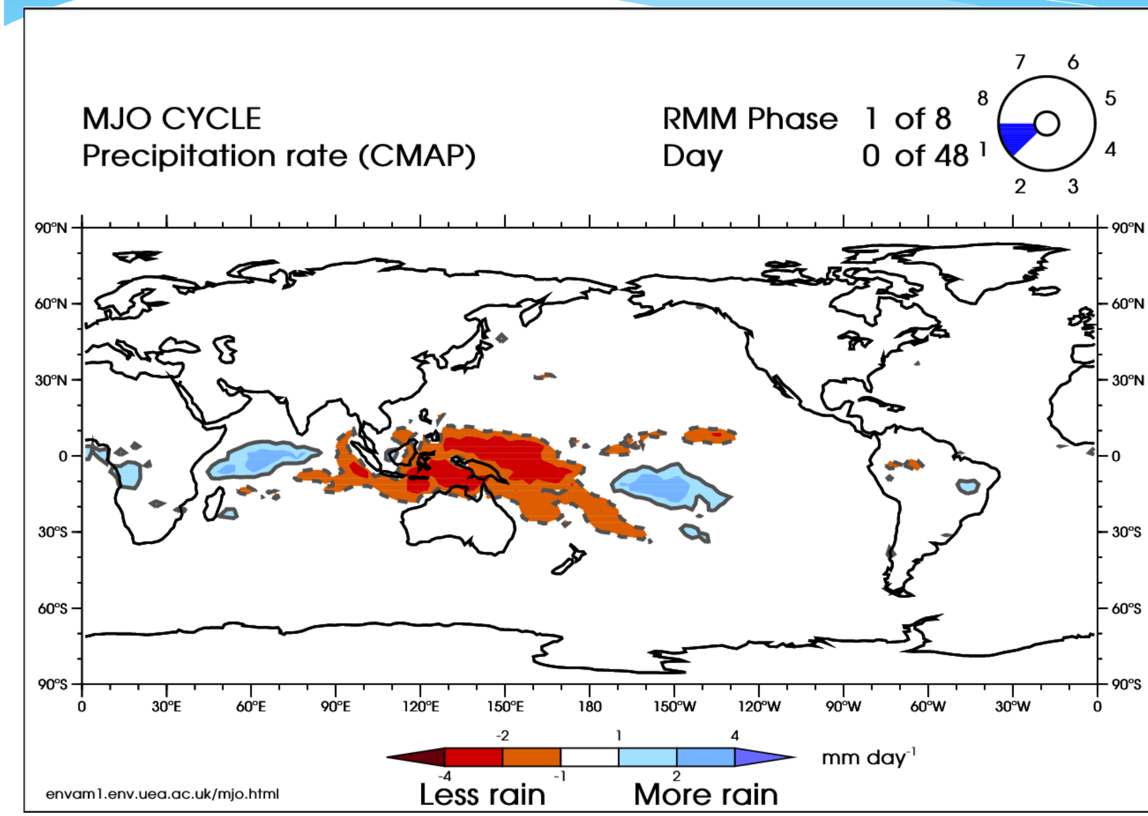
Monsoon Intra-Seasonal Oscillation (MISO) and Active – Break Period



Break to Active Period

Suhas et al. (2013)

Madden Julian Oscillations (MJO)



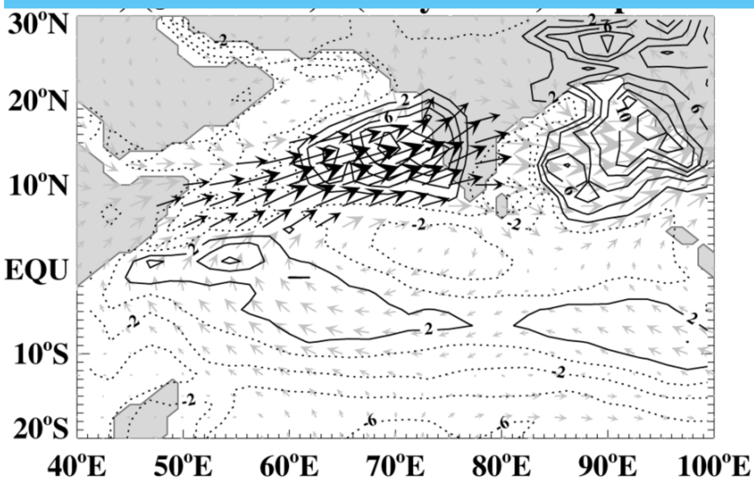
Source: http://envam1.env.uea.ac.uk/mjo.html

Onset of Monsoon

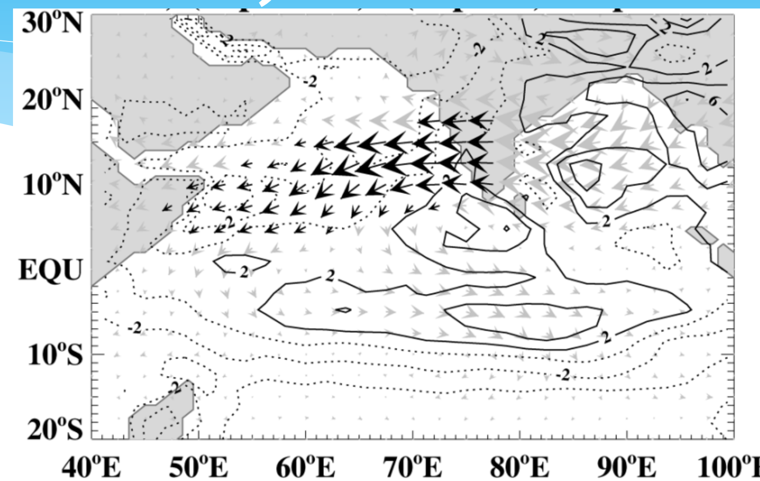
* Definitions
  * Hydrologic Onset and Withdrawal Index (HOWI) [Fasullo and Webster, 2003]
  * Onset Circulation Index (OCI) [Wang et al., 2009]
  * IMD Definition

Sahana et al. Manuscript under preparation

Hydrologic Onset and Withdrawal Index (HOWI)



June



Sept

VIMT Plot

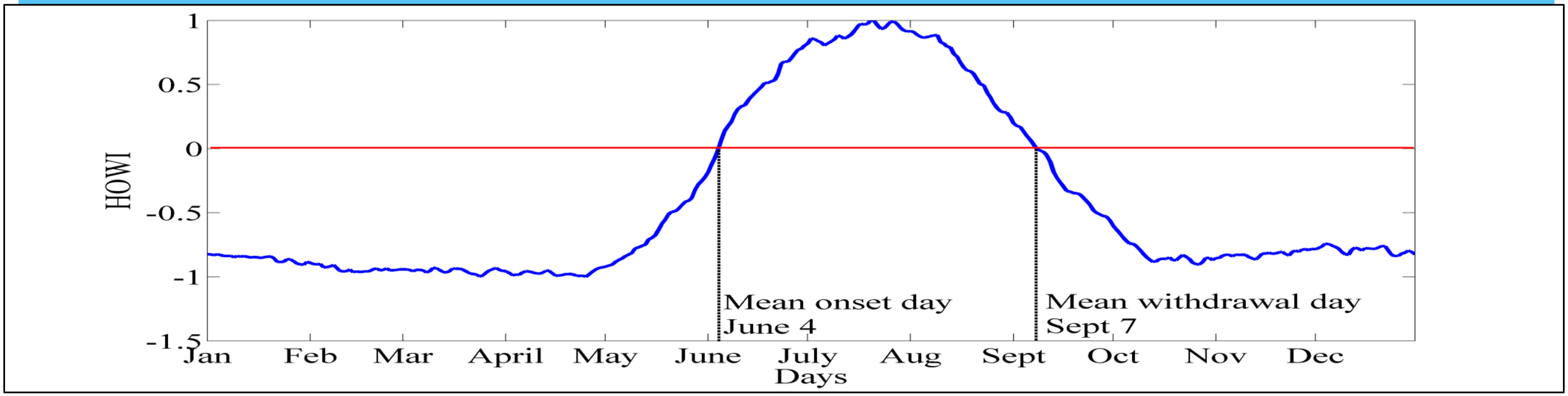
$$\text{VIMT} = \int_{\text{surface}}^{300\text{ mb}} q\mathbf{U}\, dp,$$

$$\bar{\chi} = 2 \times \left\{ \left[\chi - \min\left(\bar{X}\right) \right] / \left[\max\left(\bar{X}\right) - \min\left(\bar{X}\right) \right] \right\} - 1$$

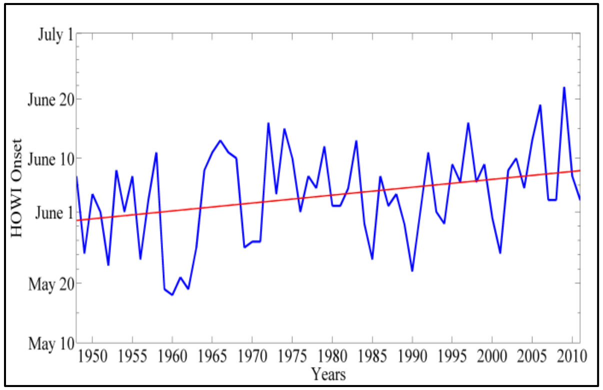
$\bar{X}$: mean annual cycle

$\bar{\chi}$:normalized time series

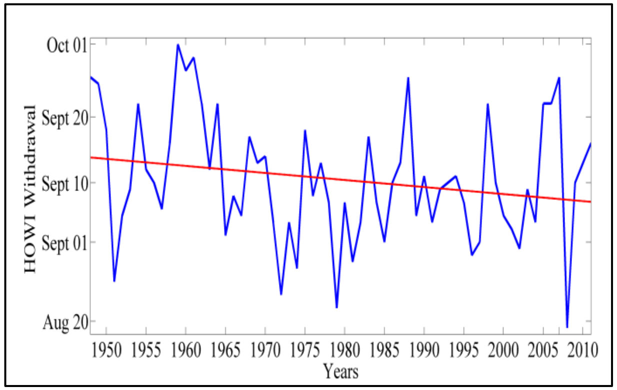
HOWI



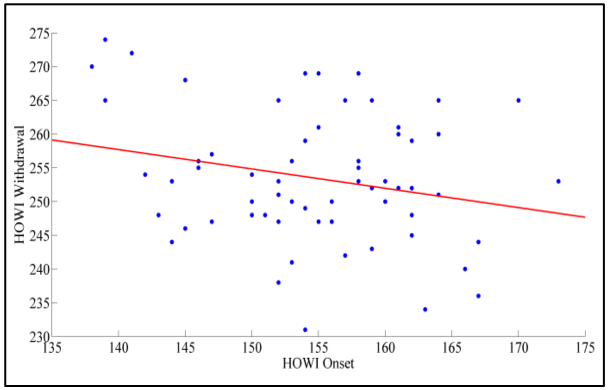
HOWI
1
0.5
0
-0.5
-1
-1.5
Jan
Feb
Mar
April
May
June
July
Aug
Sept
Oct
Nov
Dec
Days
Mean onset day
June 4
Mean withdrawal day
Sept 7



HOWI Onset
July 1
June 20
June 10
June 1
May 20
May 10
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010
Years

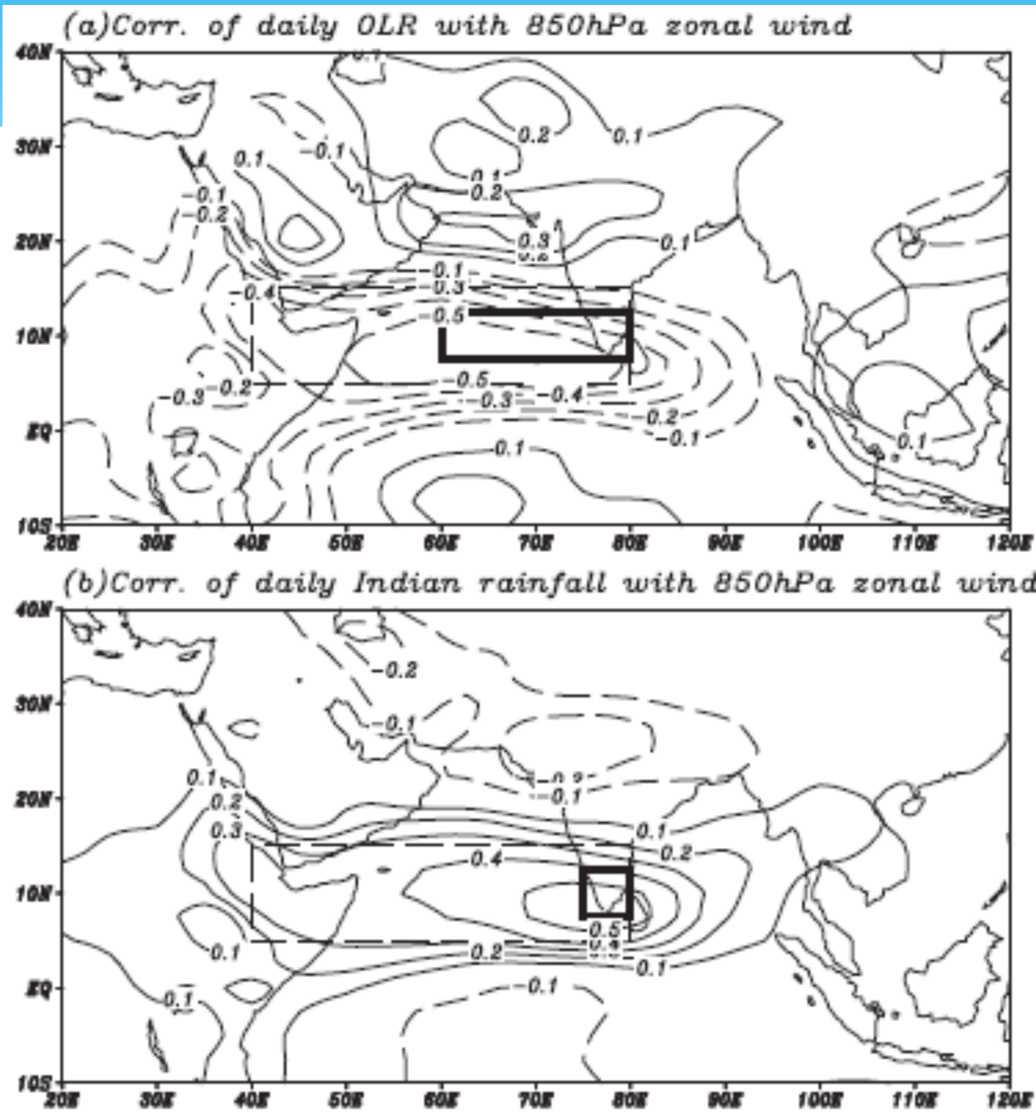


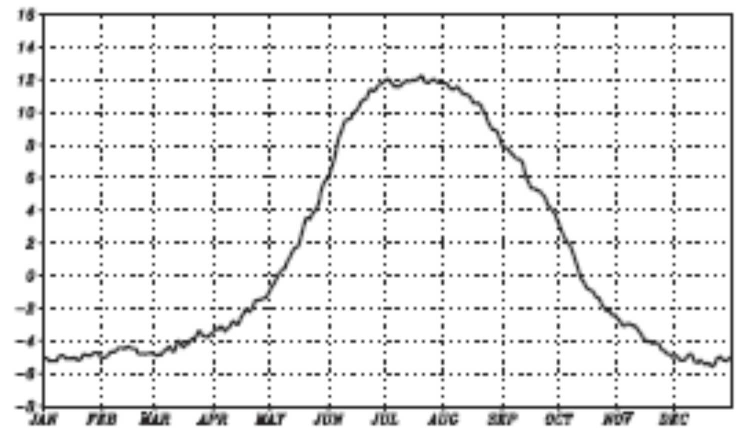
HOWI Withdrawal
Oct 01
Sept 20
Sept 10
Sept 01
Aug 20
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010
Years



HOWI Withdrawal
275
270
265
260
255
250
245
240
235
230
135 140 145 150 155 160 165 170 175
HOWI Onset

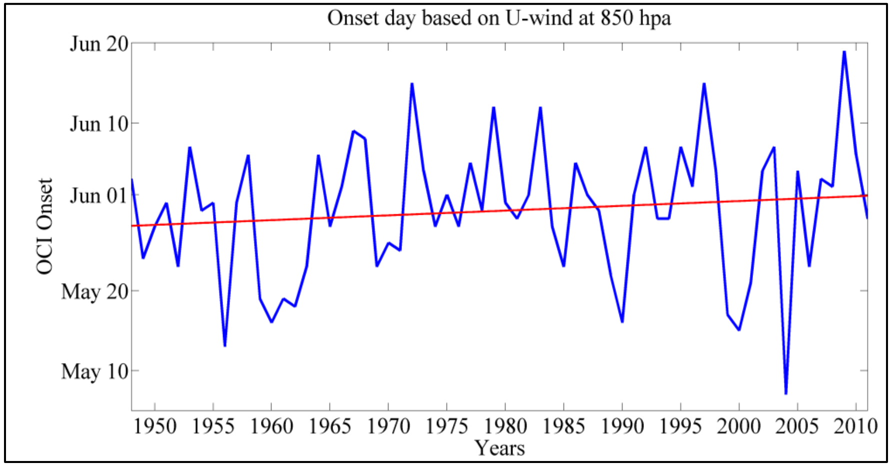
Onset Circulation Index (OCI)



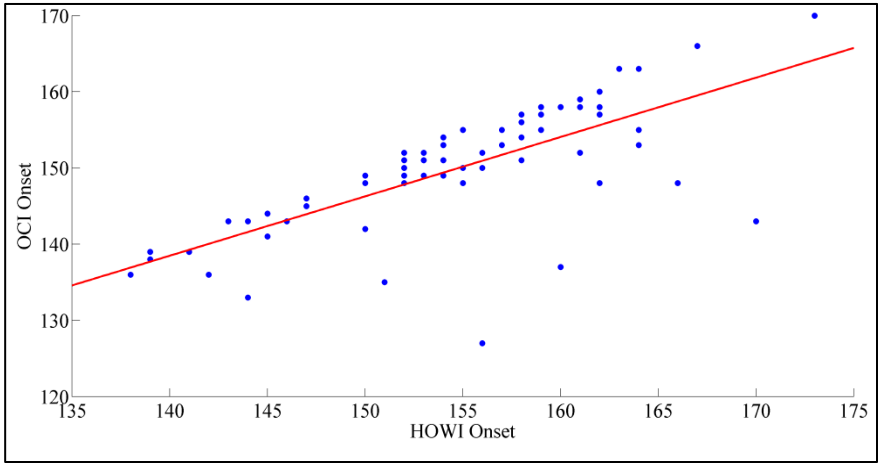


Threshold 6.2m/s

OCI trends



Onset day based on U-wind at 850 hpa
Jun 20
Jun 10
Jun 01
May 20
May 10
OCI Onset
1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010
Years

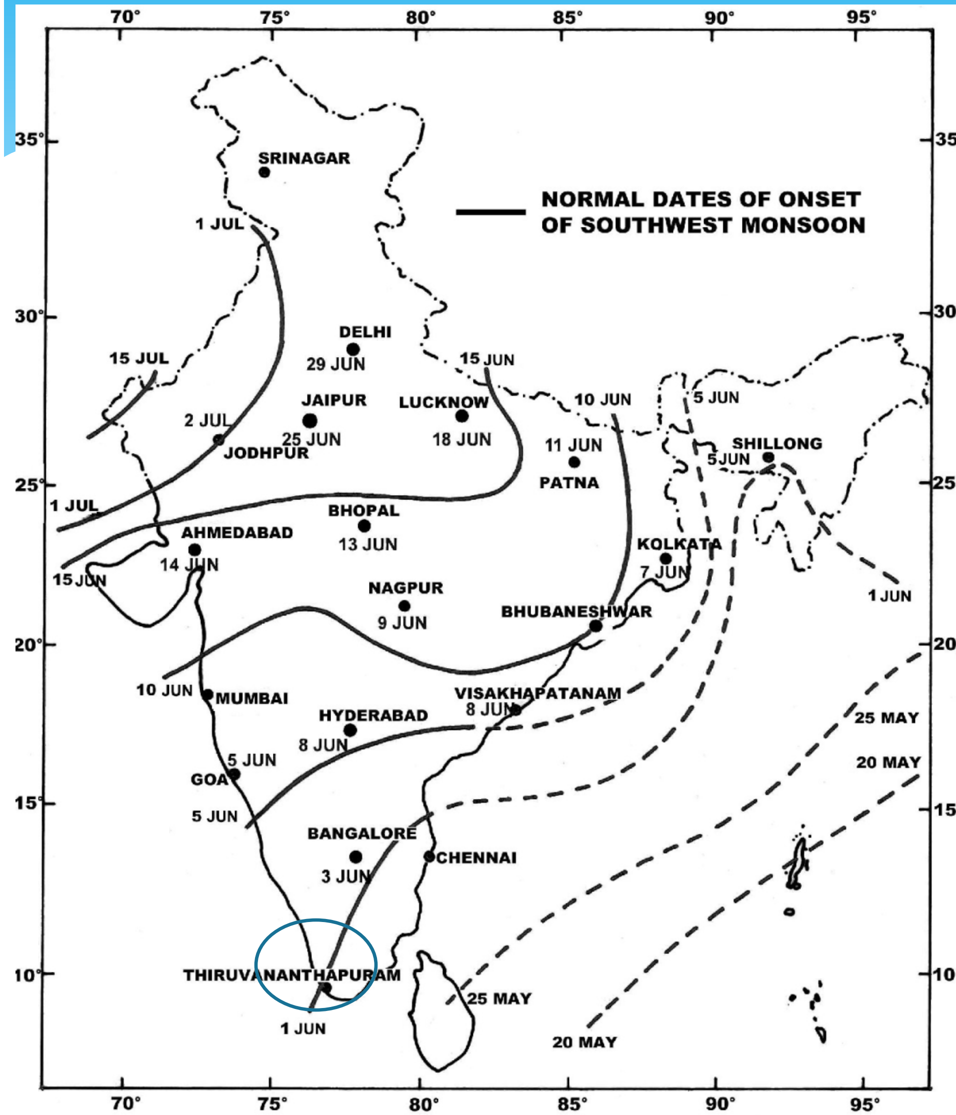


170
160
150
140
130
120
OCI Onset
135 140 145 150 155 160 165 170 175
HOWI Onset

IMD Definition of Onset

* 60% of the available 14 stations report rainfall of 2.5 mm or more for two consecutive days, the onset over Kerala be declared on the 2nd day
* Local Onset:
  * Simple definition with multiple conditions based on precipitation

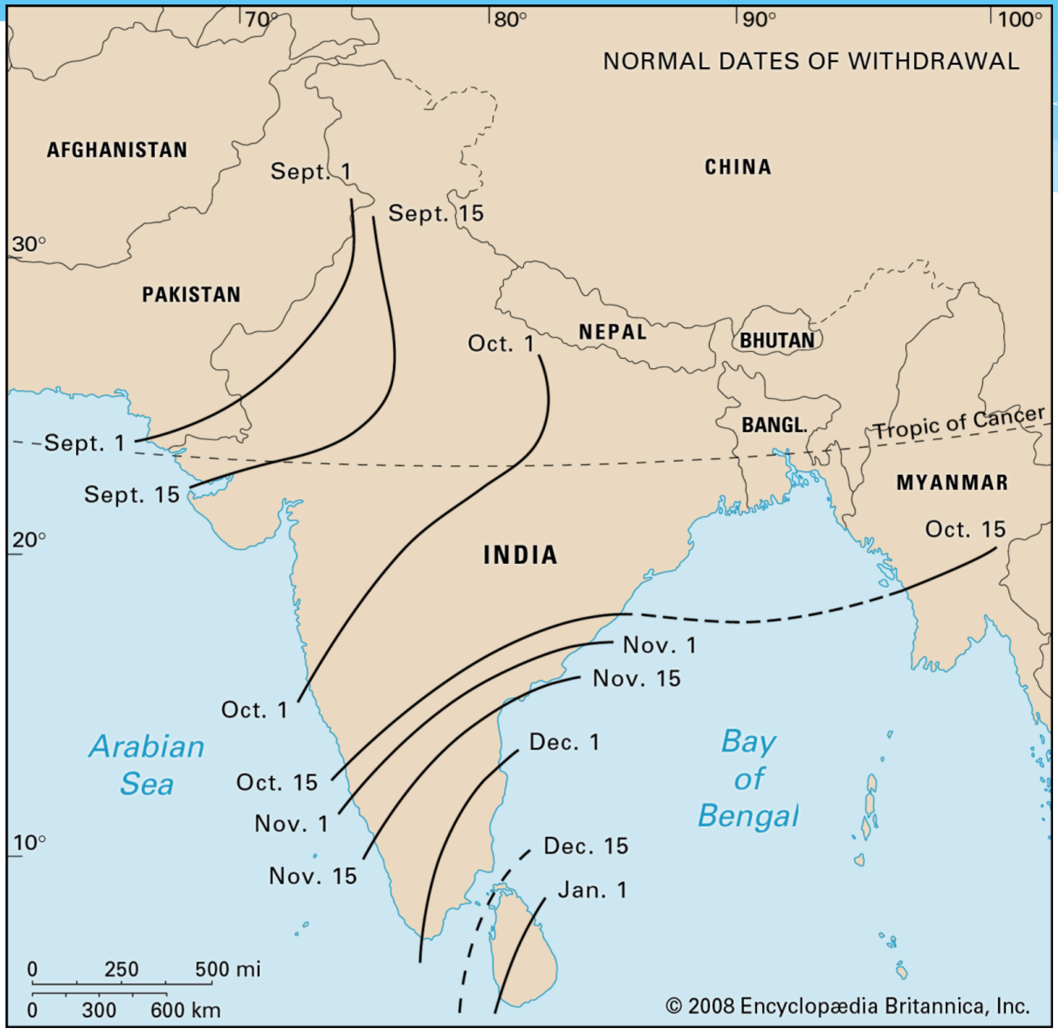
Onset of Monsoon



- In Kerala, if 5 stations out of 7 stations, get rainfall 1 mm or more for two consecutive days → IMD declared onset of monsoon
- Normal date: 1st June
- Standard deviation: 8 Days
- Before 24th May: Early onset
- After 9th June: Delayed onset

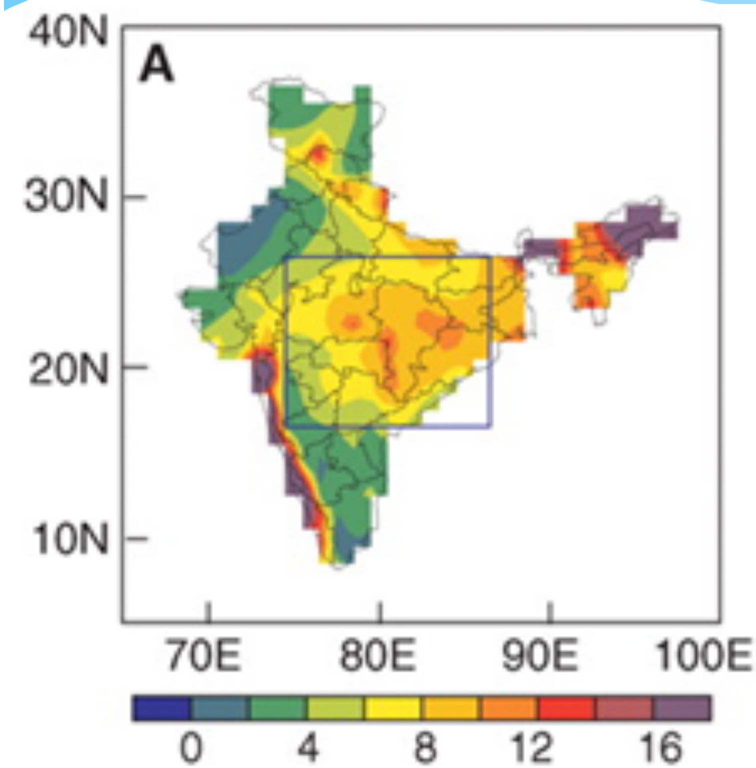
Source: IMD, IITM

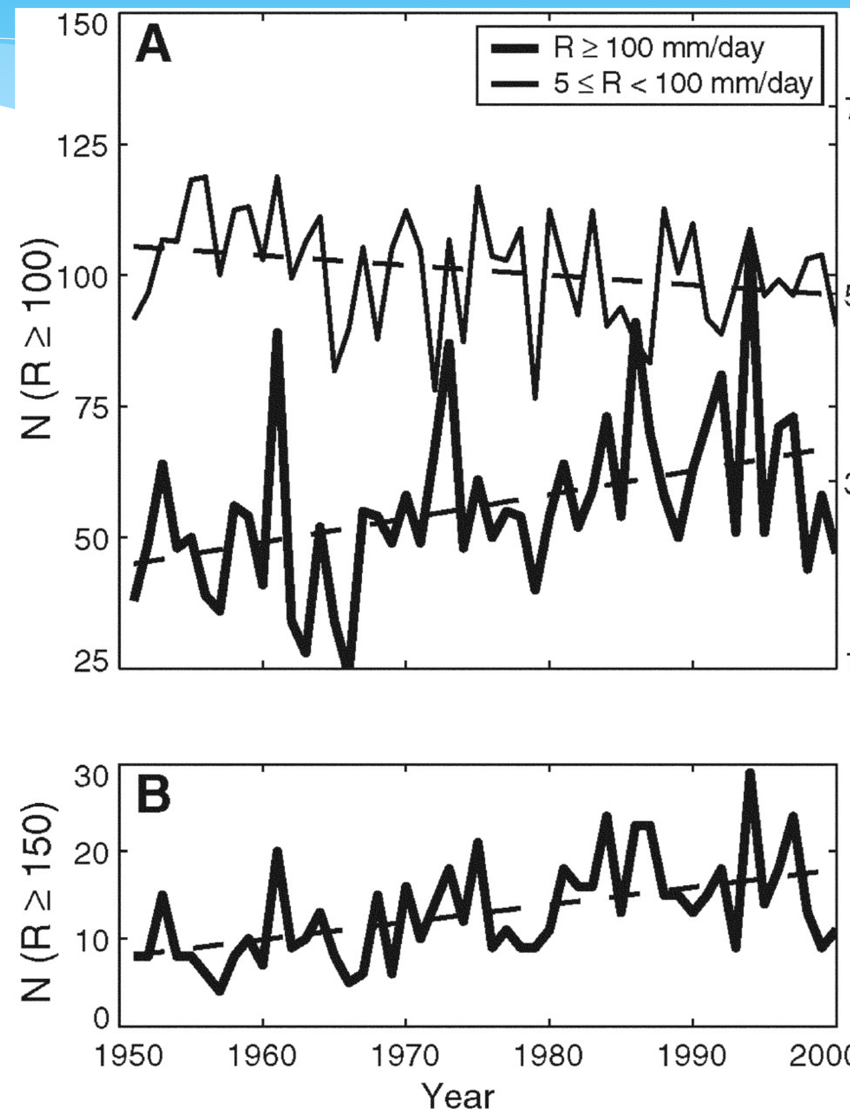
Withdrawal of Monsoon



Source: IMD, IITM

Rainfall Extremes

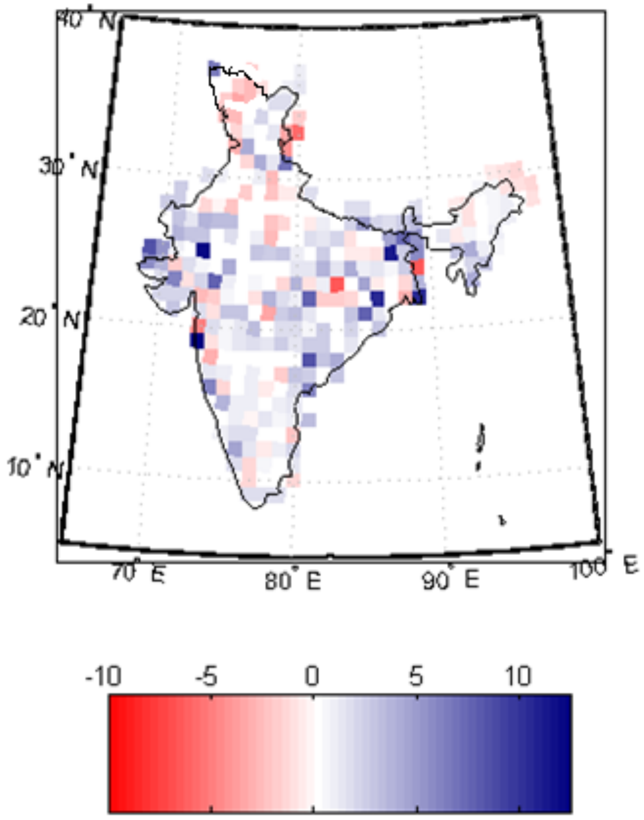




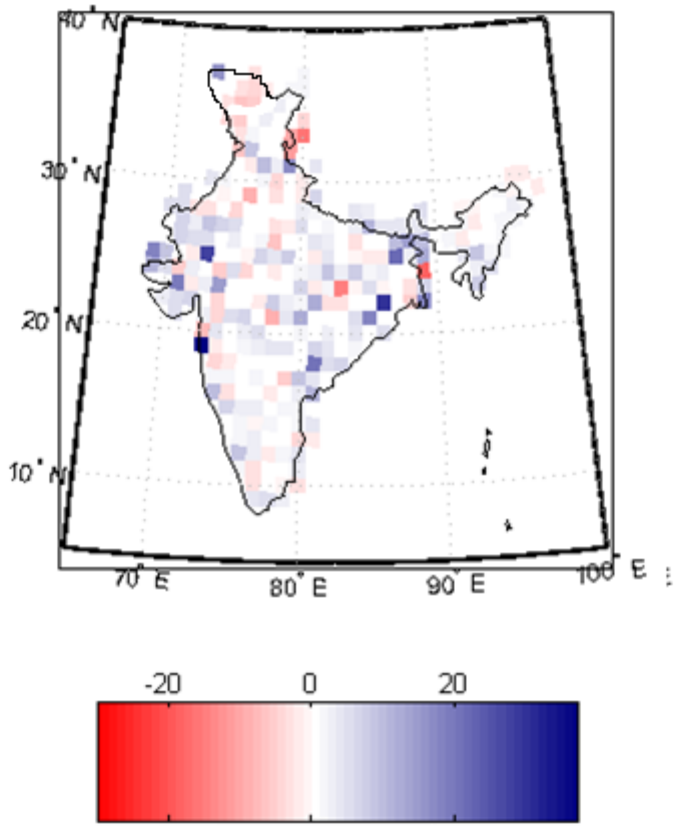
Goswami et al., (2006), Science

Spatial Variability of Indian Rainfall Extremes at Finer Scale

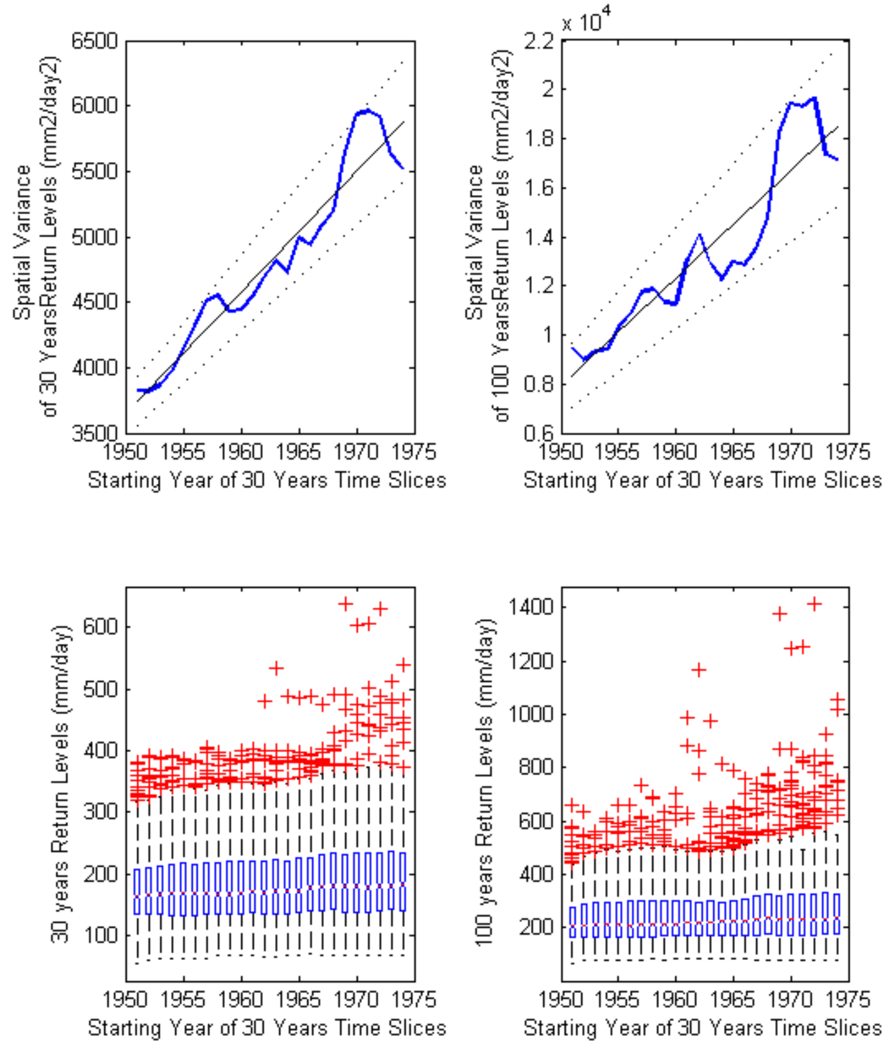
Trend of 30 year return levels



Trend of 100 year return levels

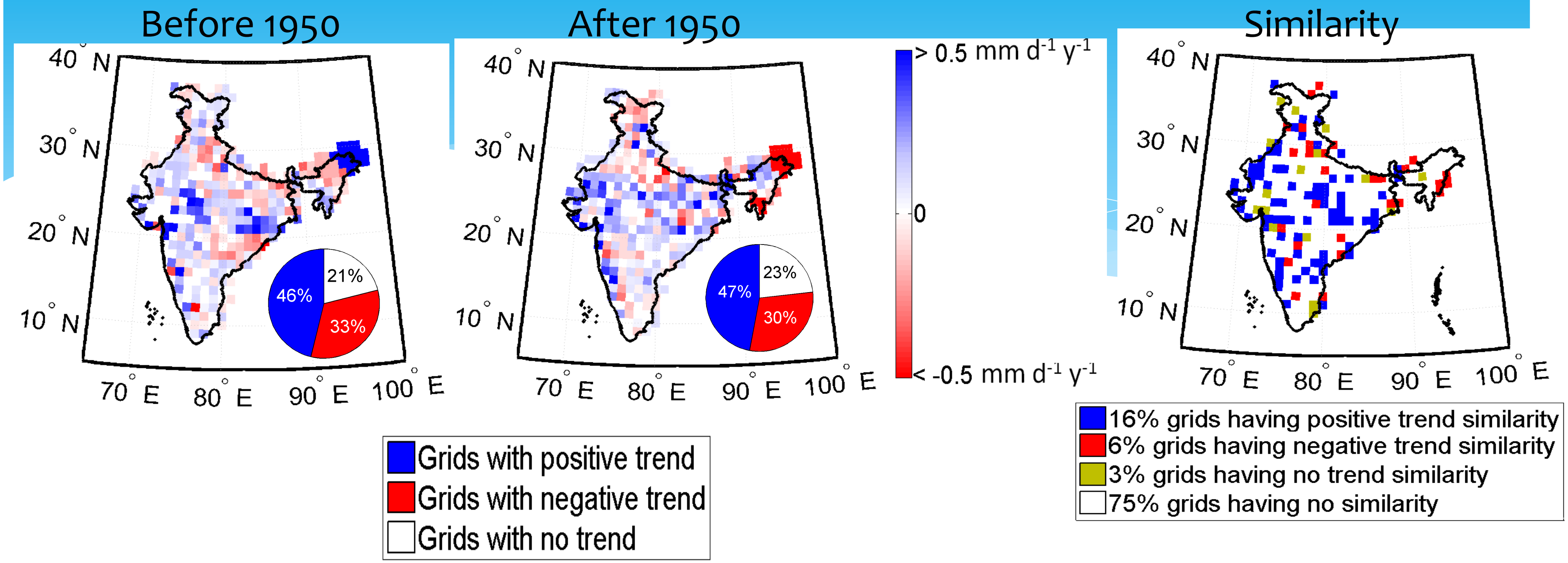


Increasing Trend in Spatial Variability

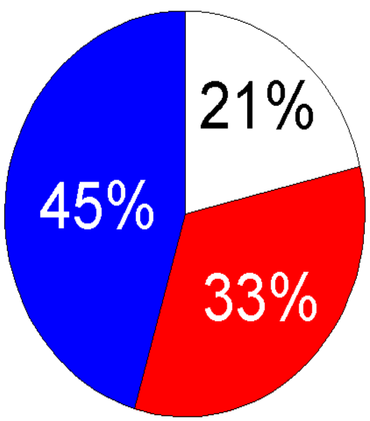


Ghosh et al. (2012)
NATURE Climate Change

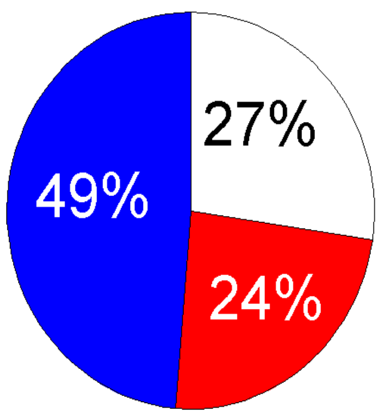
With Peak Over Threshold



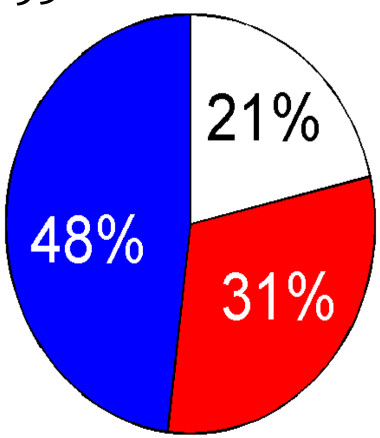
Before 1950: Increasing



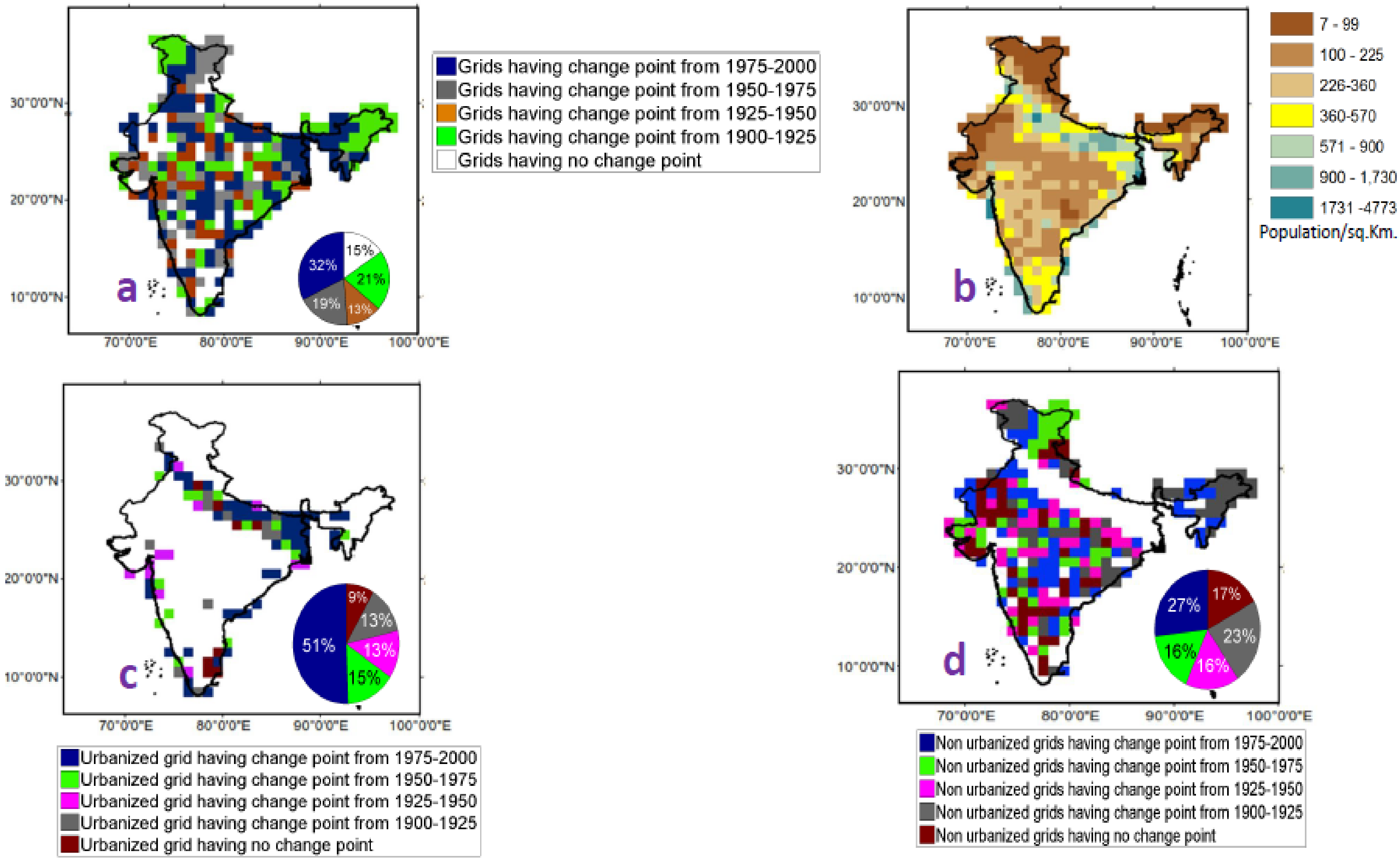
Before 1950: Decreasing



Before 1950: No trend



Change Point Analysis

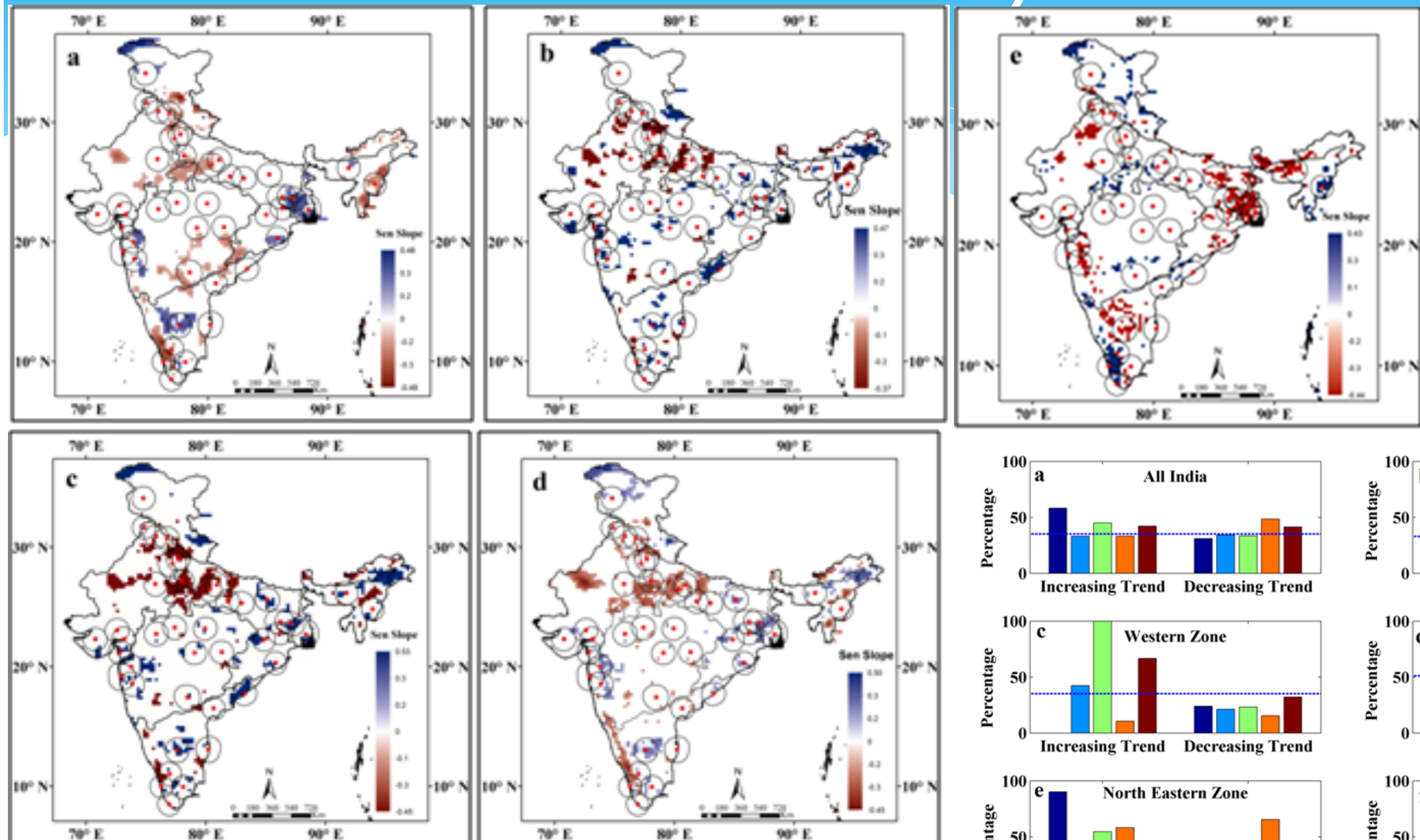


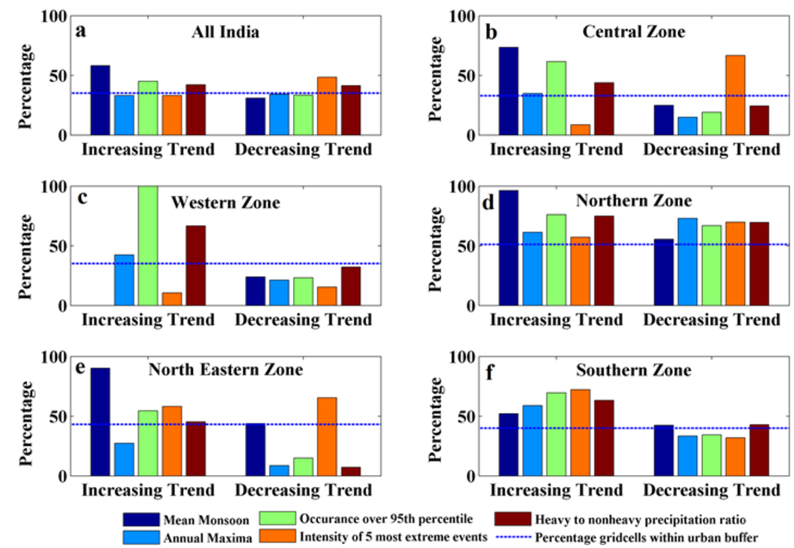
Vittal, Karmakar and Ghosh (2013) GRL

Local Changes

* Urbanization
* Feedback from Vegetation

Urbanization Impacts (Indian Rainfall)



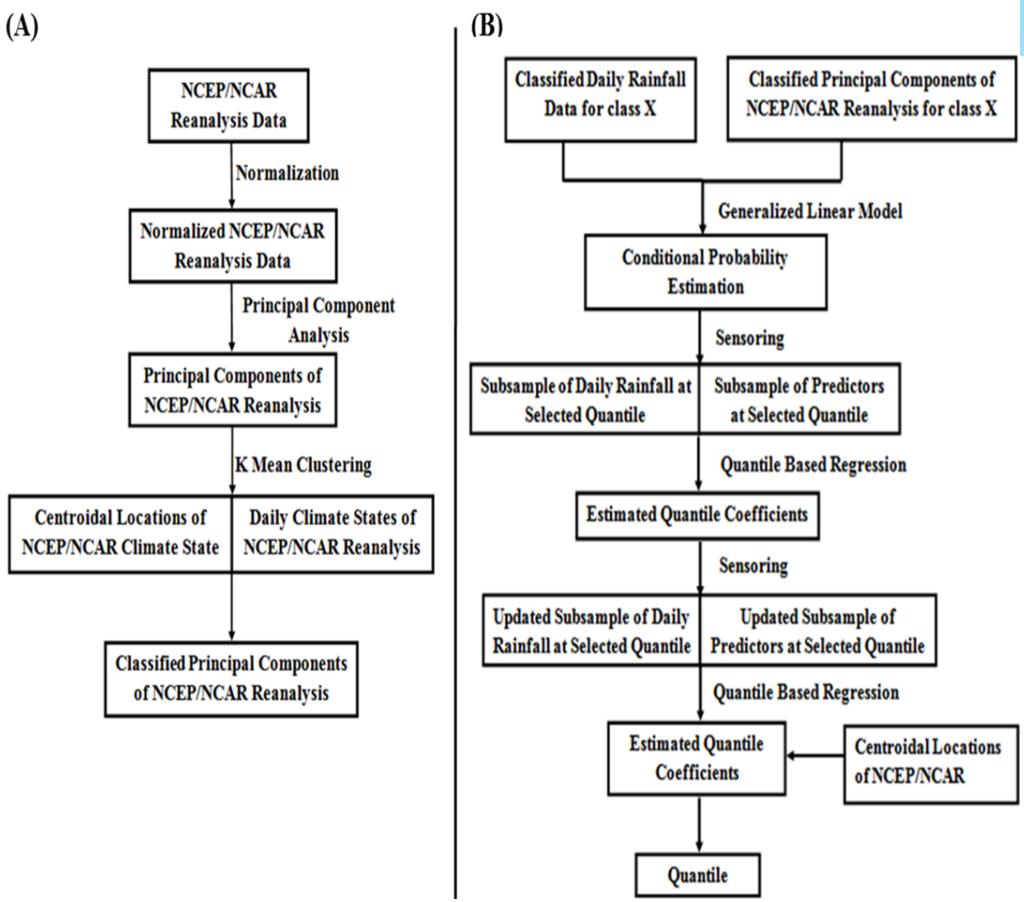


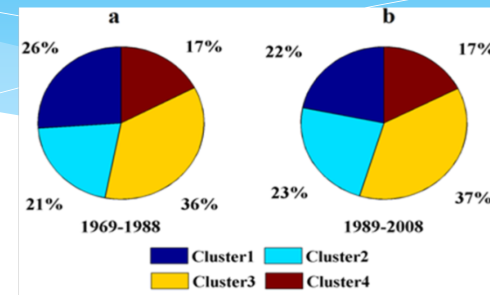
a. Mean rainfall,
b. Maximum 1-day precipitation amount,
c. Maximum 5-day precipitation amount,
d. Number of heavy precipitation events
e. Heavy to non heavy precipitation ratio.

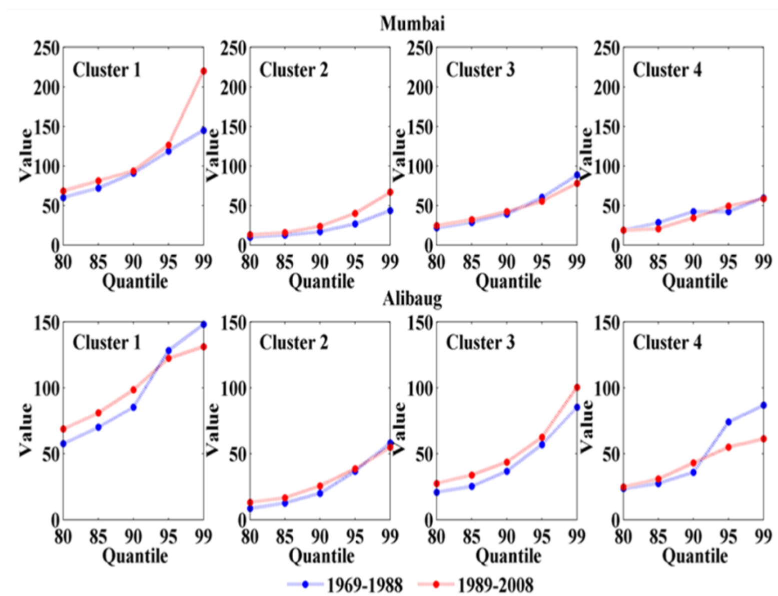
Shashtri, Ghosh and Karmakar (Under Review) Climate Dynamics

Case Study: Mumbai and Alibug

Quantile Regression







Shashtri, Ghosh and Karmakar (Under Review)
Climate Dynamics

Feedback from Vegetation (Precipitation Recycling)

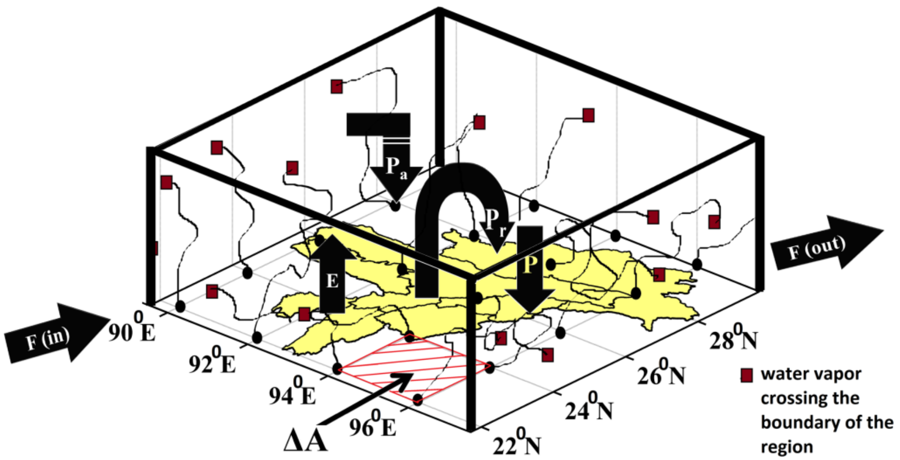


Figure 2: Schematic representation of zonal atmospheric fluxes for a single Zone. The fluxes represented by '*E*', '*P*', '*Pa*', and '*Pr*', 'F_{in}', 'F_{out}', are Evapotranspiration, Total Precipitation, Advective Precipitation, Recycled Precipitation, incoming moisture flux, and outgoing moisture flux respectively, and Δ*A* represents the area of individual grid.

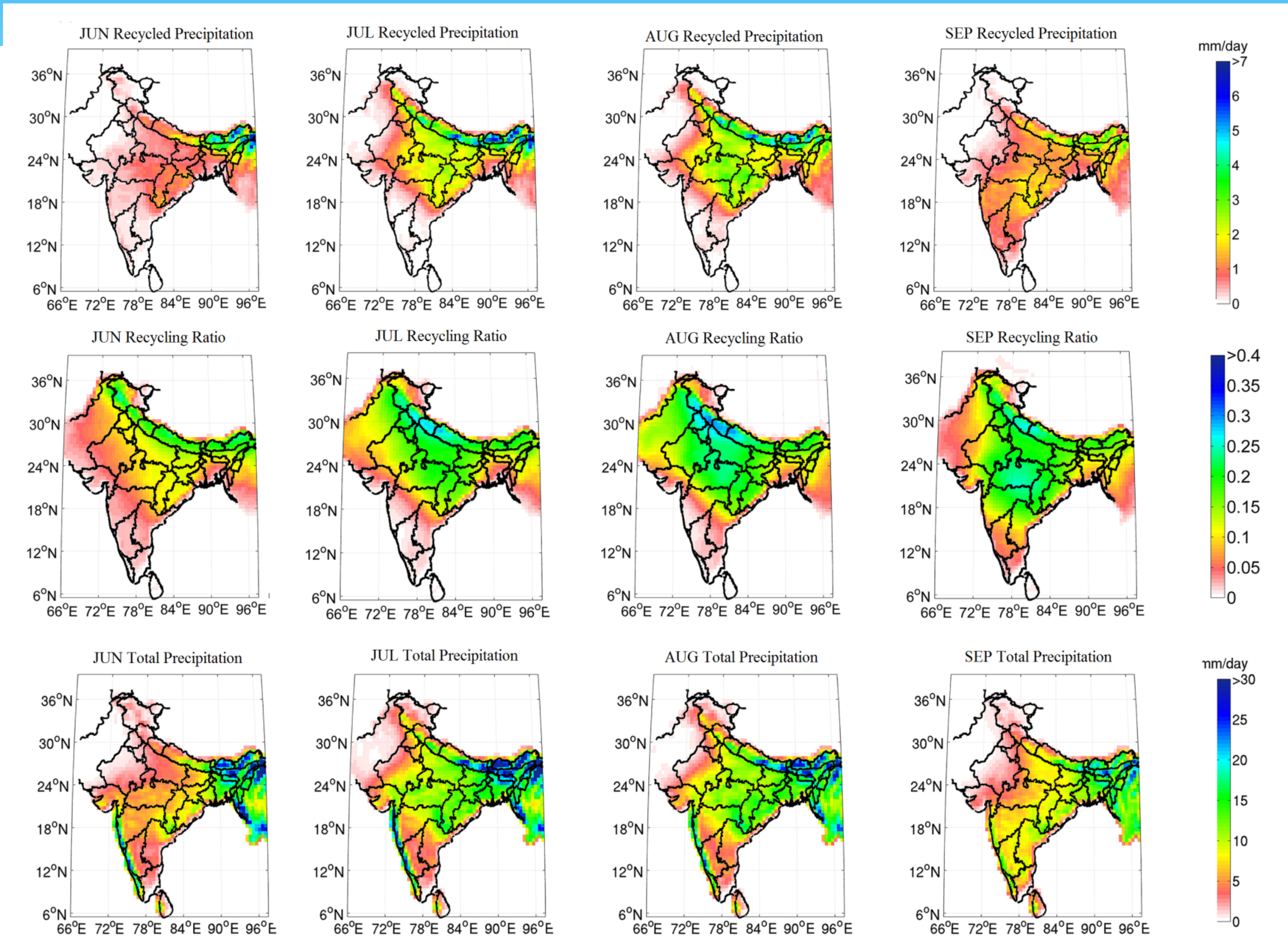
$$\frac{\partial w}{\partial t} + \frac{\partial (w u_m)}{\partial x} + \frac{\partial (w v_m)}{\partial y} = E - P$$

$$\frac{\partial w_r}{\partial t} + \frac{\partial (w_r u_m)}{\partial x} + \frac{\partial (w_r v_m)}{\partial y} = E - P_r$$

$$w * \frac{\partial R_l}{\partial t} + w * u_m \frac{\partial R_l}{\partial x} + w * v_m \frac{\partial R_l}{\partial y} = E(1 - R_l)$$

Pathak, Ghosh and Kumar (2014), tentatively accepted in JHM

Recycling Ratio in India



Impacts on Monsoon Withdrawal

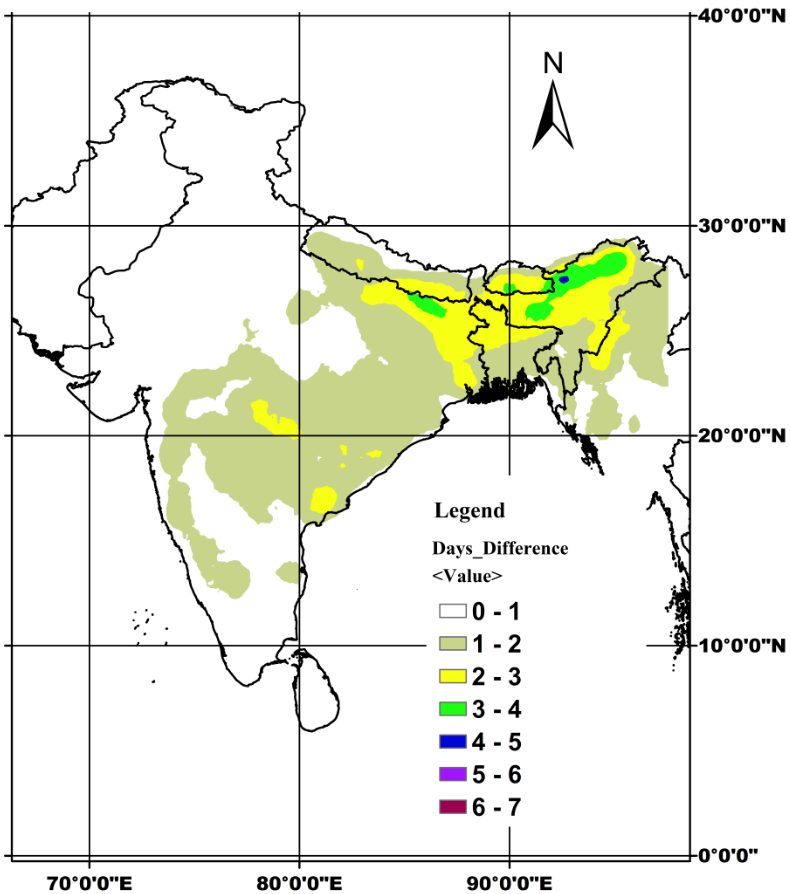
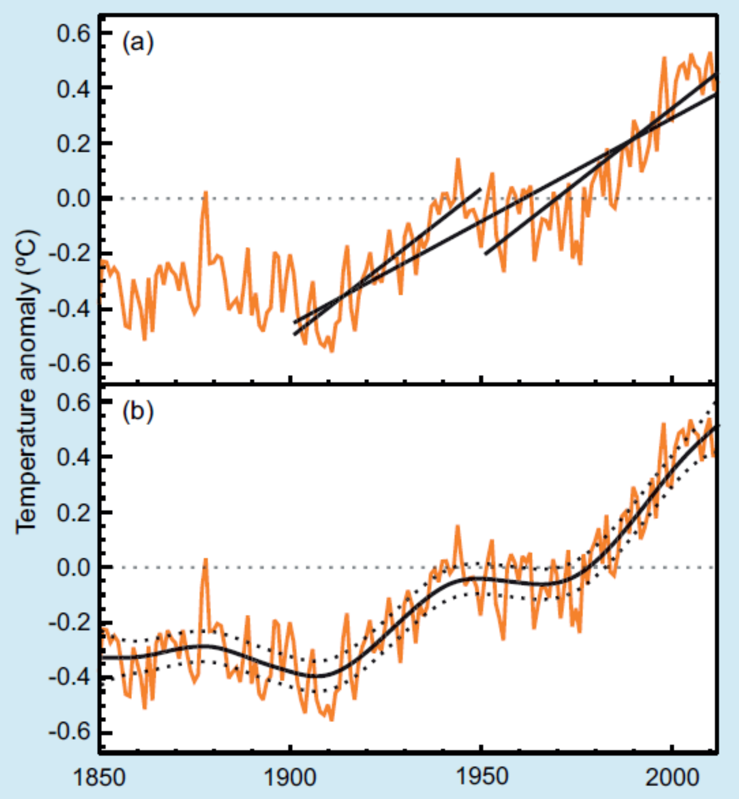


Figure 10: Impacts of precipitation recycling on summer monsoon withdrawal. Precipitation Recycling delays the monsoon withdrawal in North–East and East India.

Climate Change: Global Warming



	Trends in °C per decade		
Method	**1901–2012**	**1901–1950**	**1951–2012**
Least squares	0.075 ± 0.013	0.107 ± 0.026	0.106 ± 0.027
Smoothing spline	0.081 ± 0.010	0.070 ± 0.016	0.090 ± 0.018

Source: IPCC report, 2014

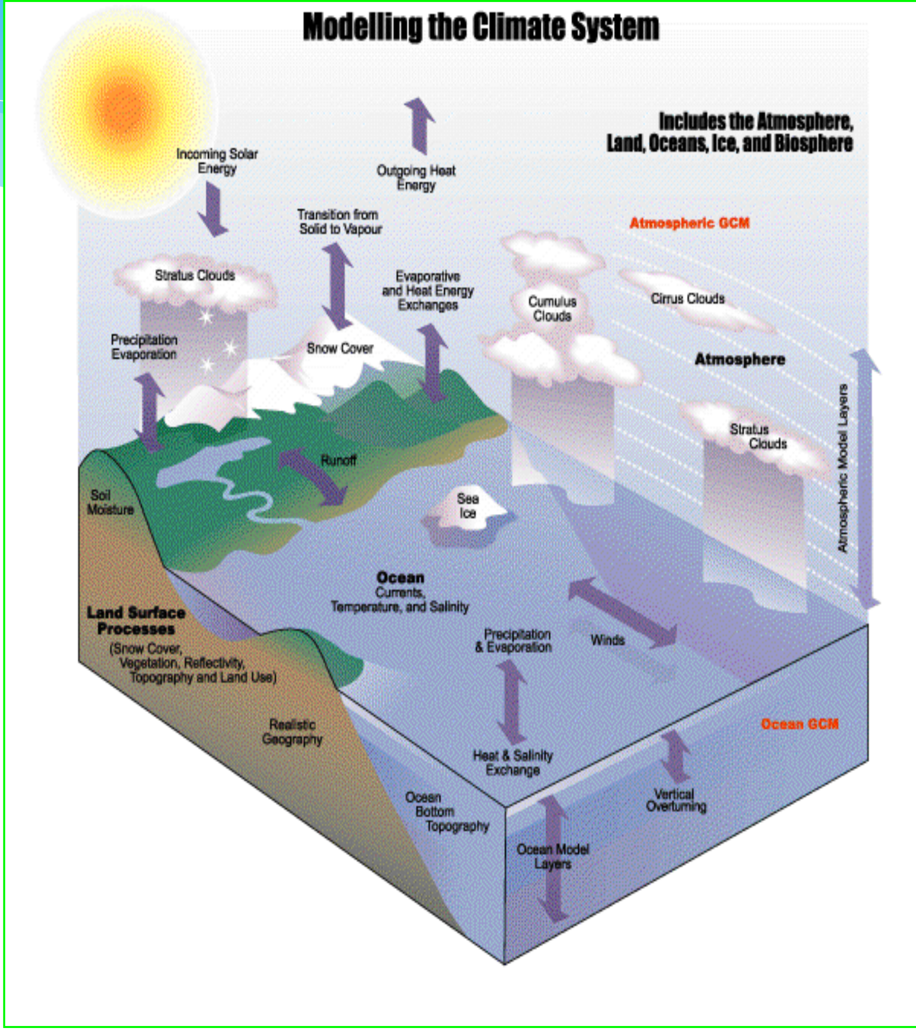
General Circulation Model *(GCM)*

General Circulation Model (GCM): Tools for simulating time series of *climate variables globally*, accounting for effects of *greenhouse gases* in the *atmosphere (using possible future GHG scenarios).*

can simulate *large scale circulation patterns (pressure, geo potential heights etc.)*

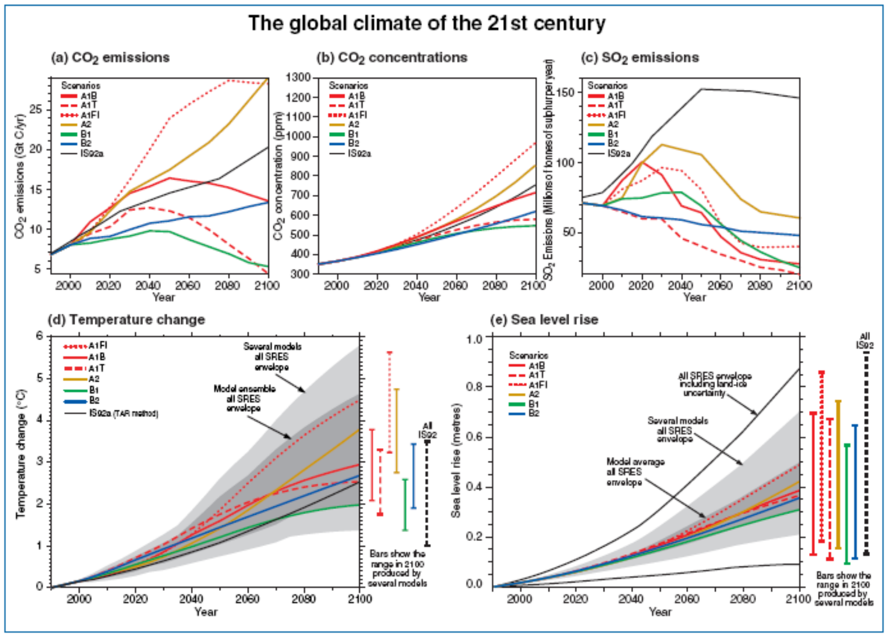
Scale Mismatch: spatial scale of a GCM: > 20, (e.g. For Coupled Global Climate Model (CGCM2) 3.75^0 in both latitude and longitude(375 Km.))
Scale for modeling hydrologic process (precipitation) :order of 10-100 Km

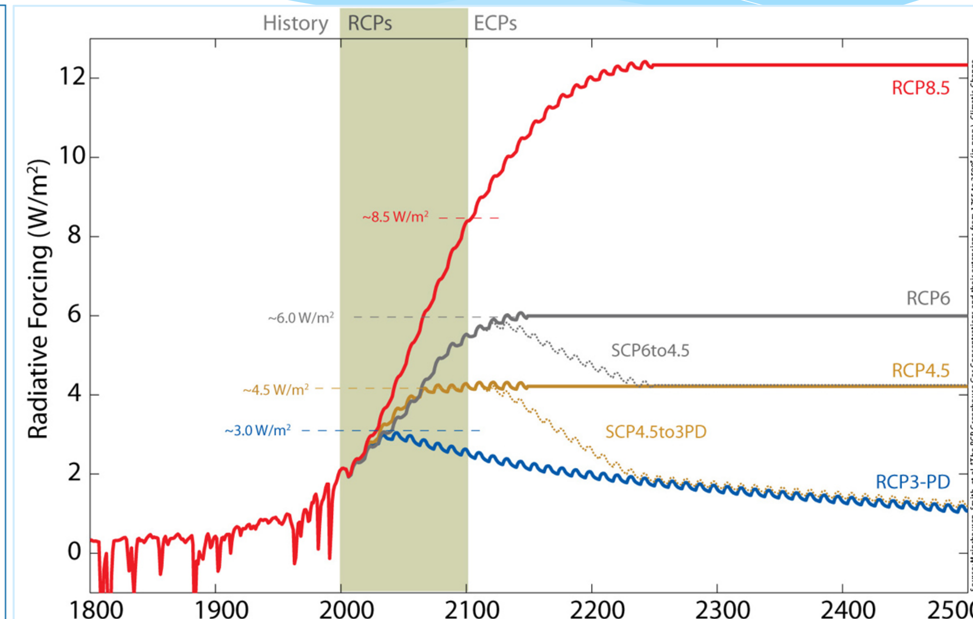
can not reproduce non-smooth fields such as *precipitation.*



Scenarios

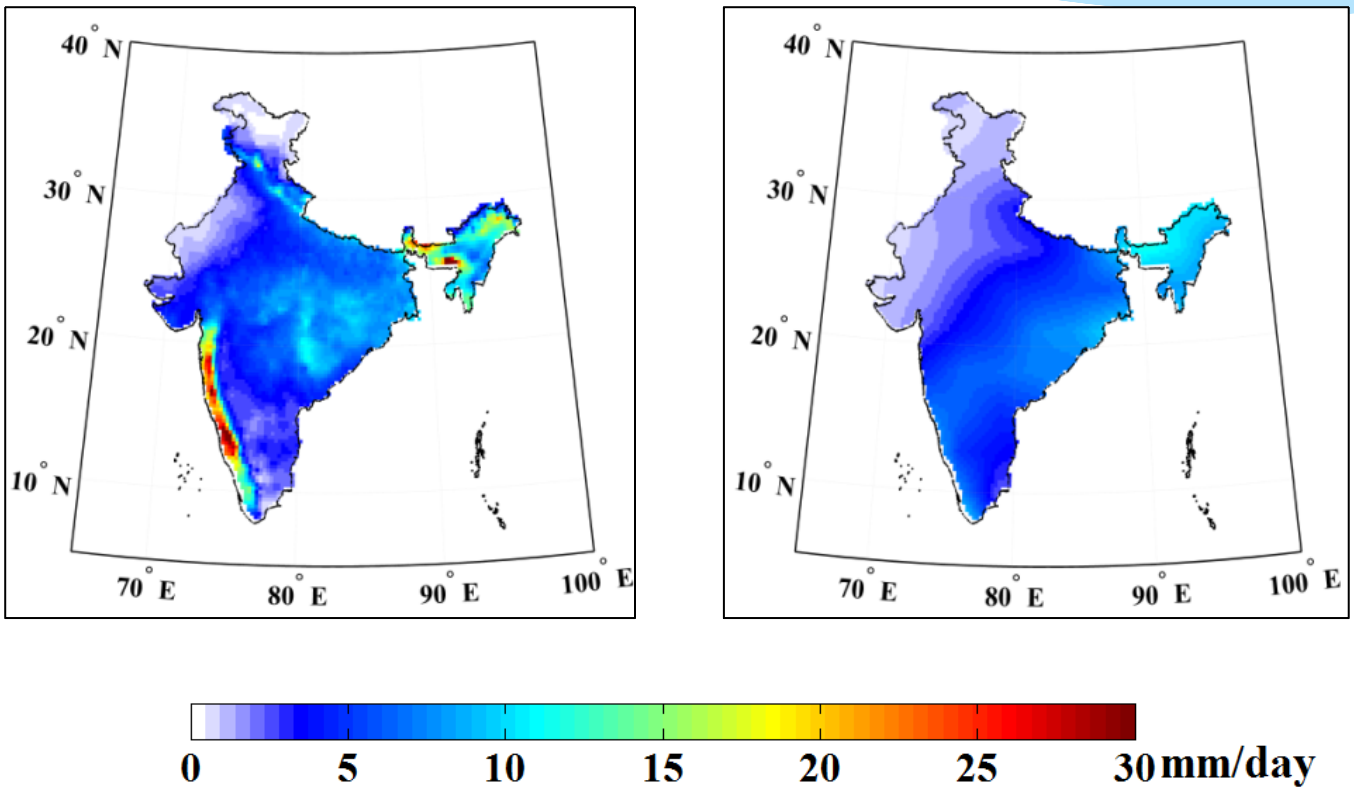
- Scenarios are alternative images of how the future might unfold and are an appropriate tool with which to analyze how driving forces may influence future emission outcomes.





Regional Modeling: Why?

Observed | Simulated



Downscaling

GCM Output

Large Scale Climate Variables

Regional Scale Hydro-meteorologic Variables, e.g., Rainfall in a city

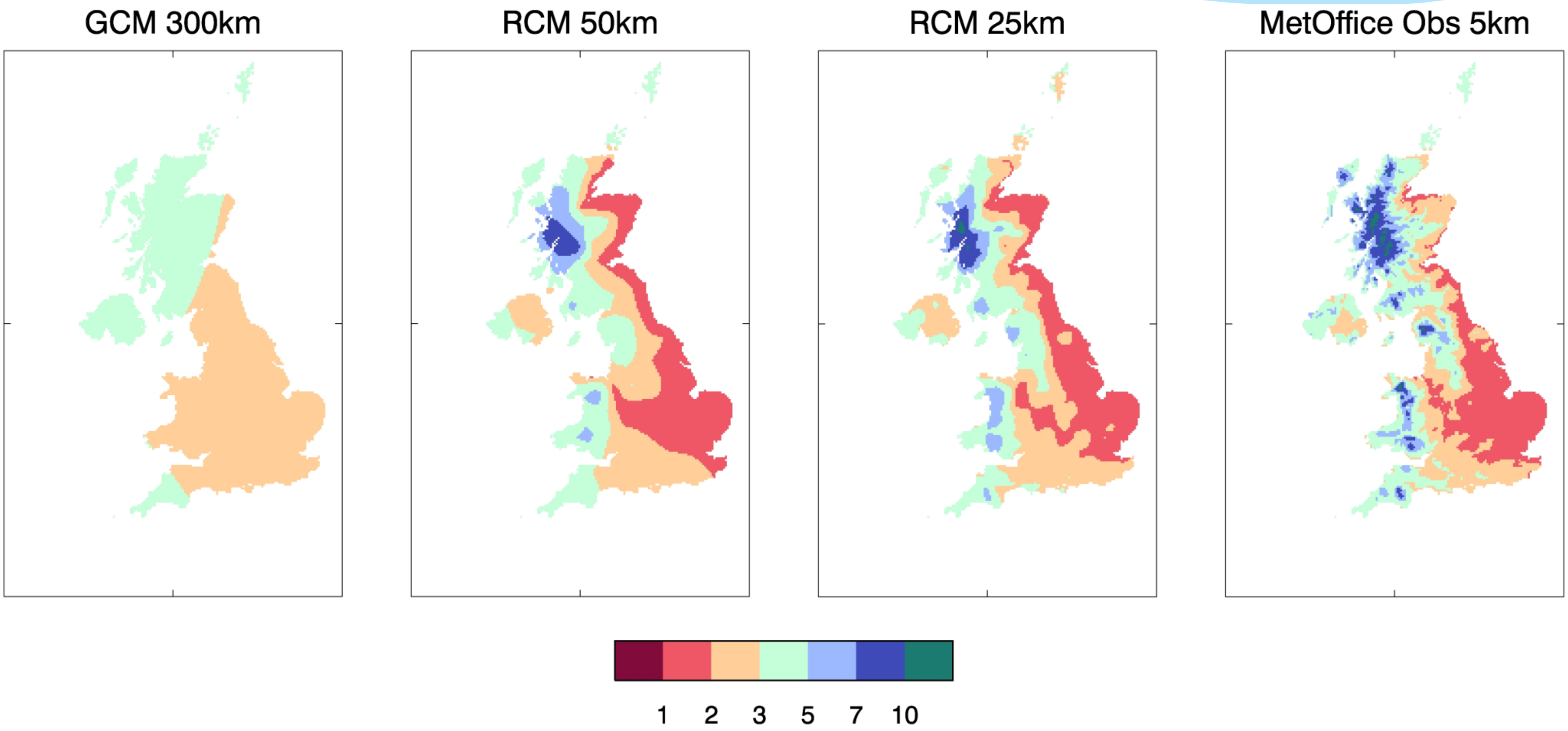
Impacts Assessment

- Drought Analysis
- Agricultural Management
- Water Demand Availability Analysis
- Water Resources Management
- Hydraulic Structure Design
- Ecological Impacts
- Risk and Vulnerability Assessment of Extreme Events

Downscaling

- Statistical Downscaling
- Dynamic Downscaling

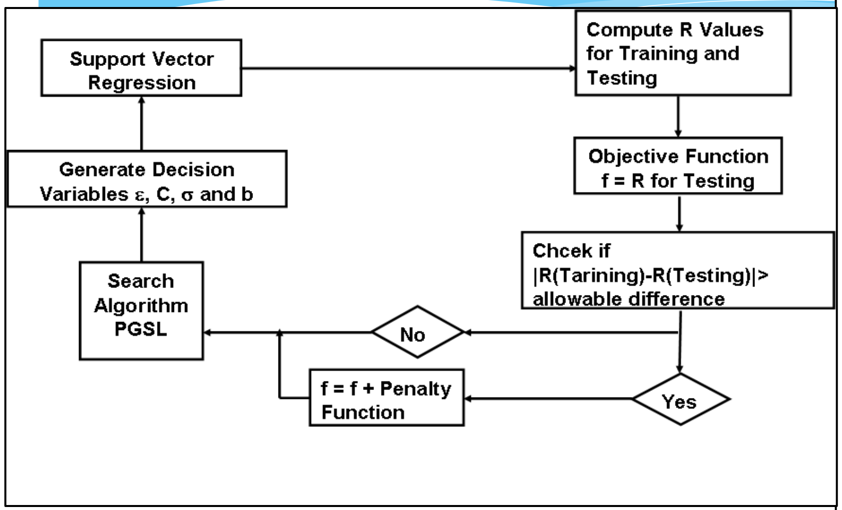
Typical Example (UK Winter Precipitation) [Maraun et al., 2010]

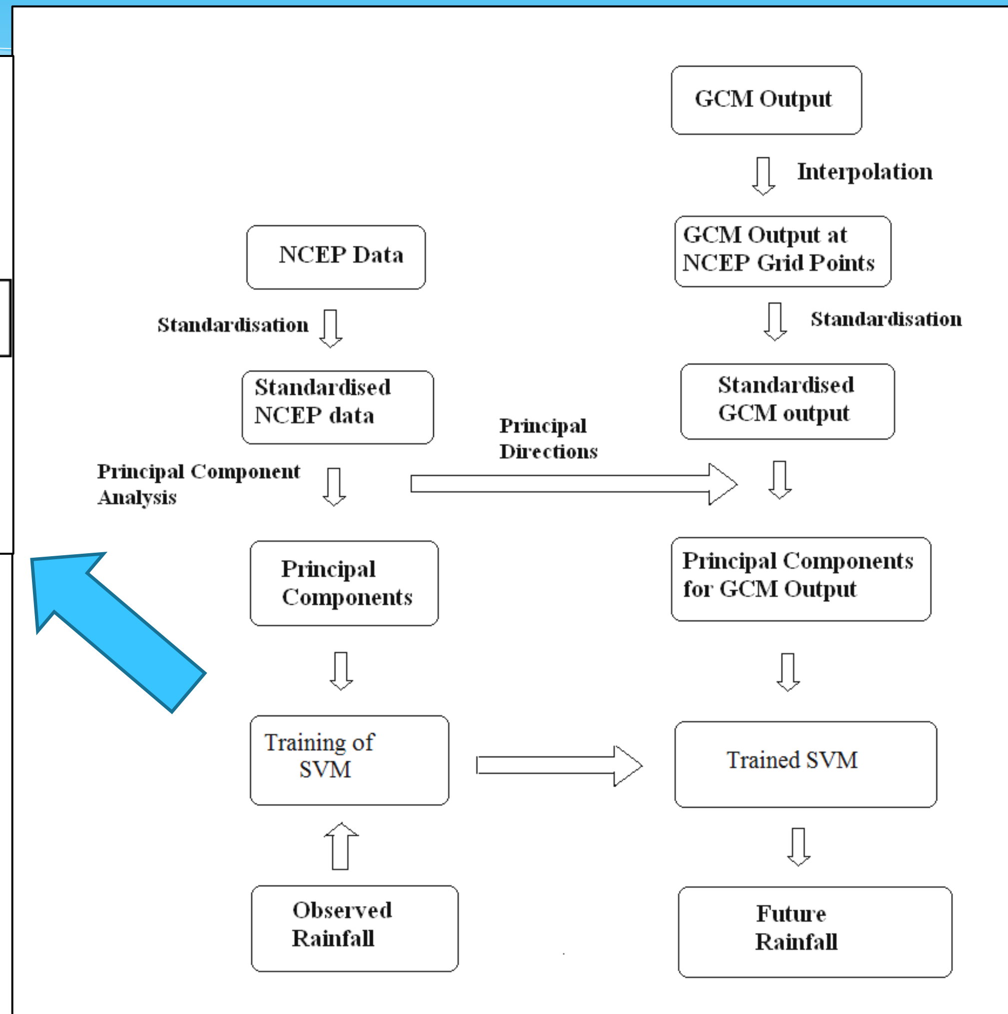


Statistical Downscaling

* Philosophy:
  * GCMs can not simulate rainfall very well as rainfall is a regional scale phenomena
  * But GCMs simulate well some of the large scale variables, which affects rainfall.
  * Those large scale variables: Predictor
  * Rainfall: Predictand
  * Derive and apply the relationship between predictor and predictand

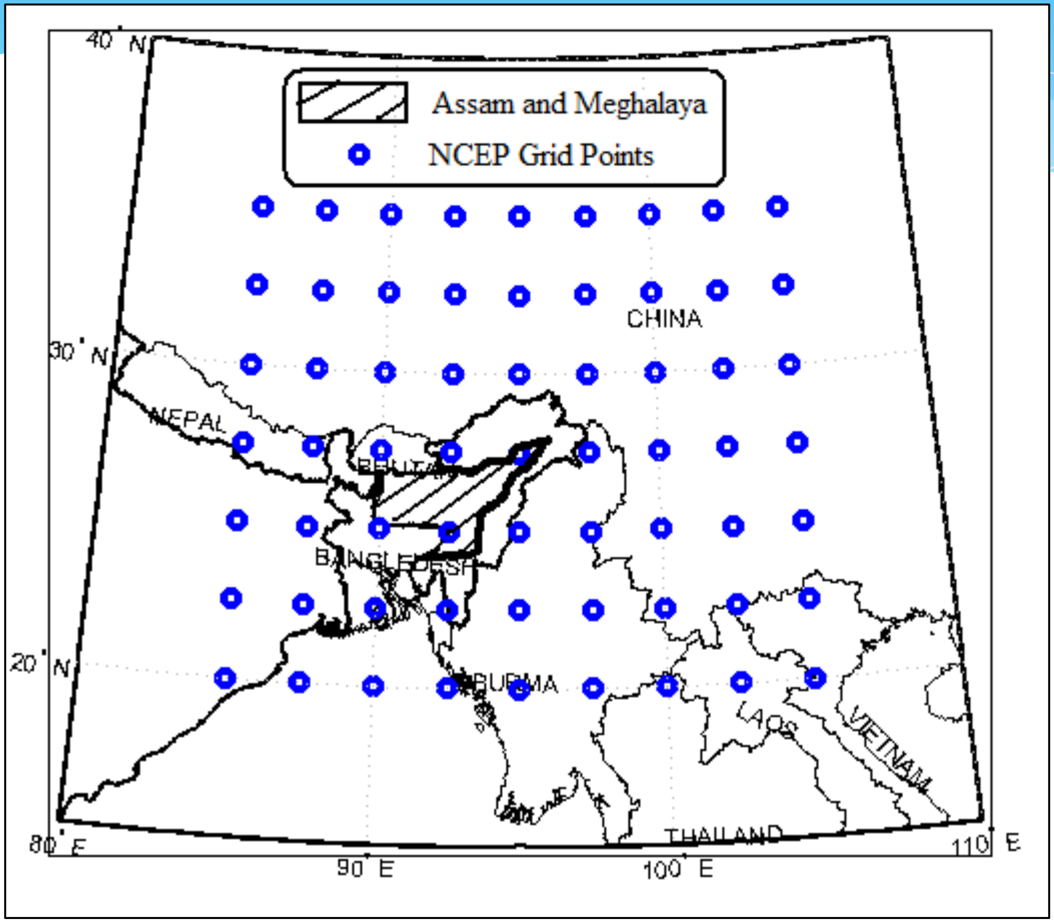
Single-site Downscaling Model





Ghosh, S. (2010), JGR-Atm (AGU)

Case-Study

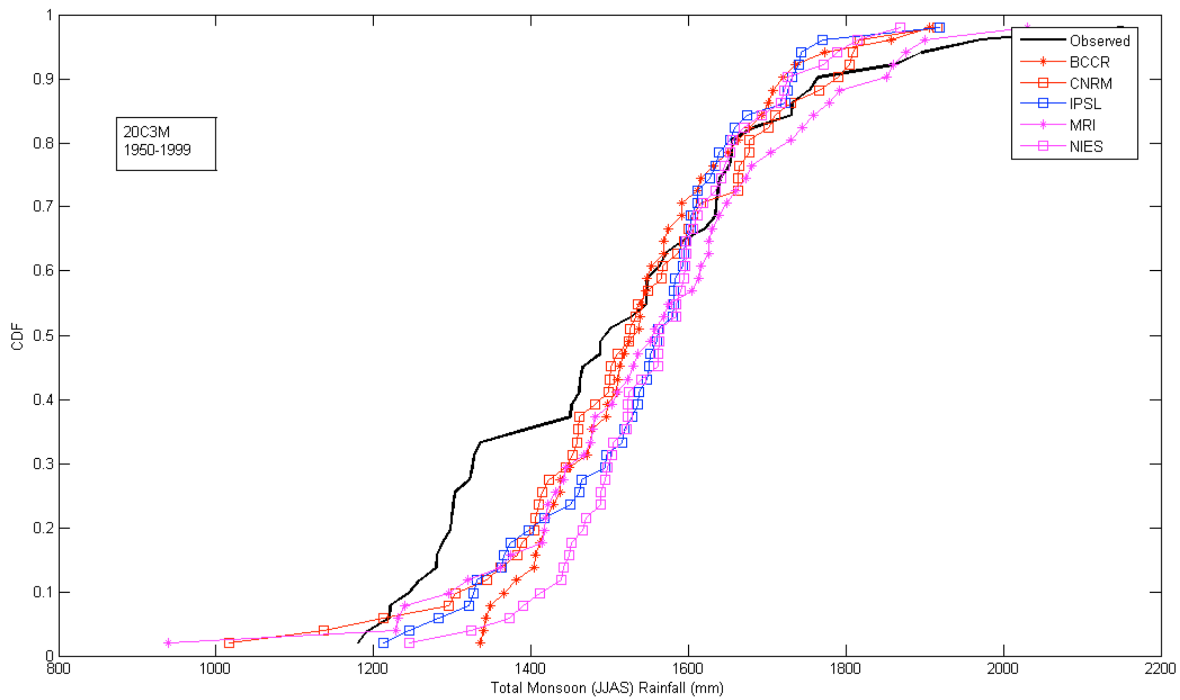


Predictors preliminary selected based on availability in GCM data archive:

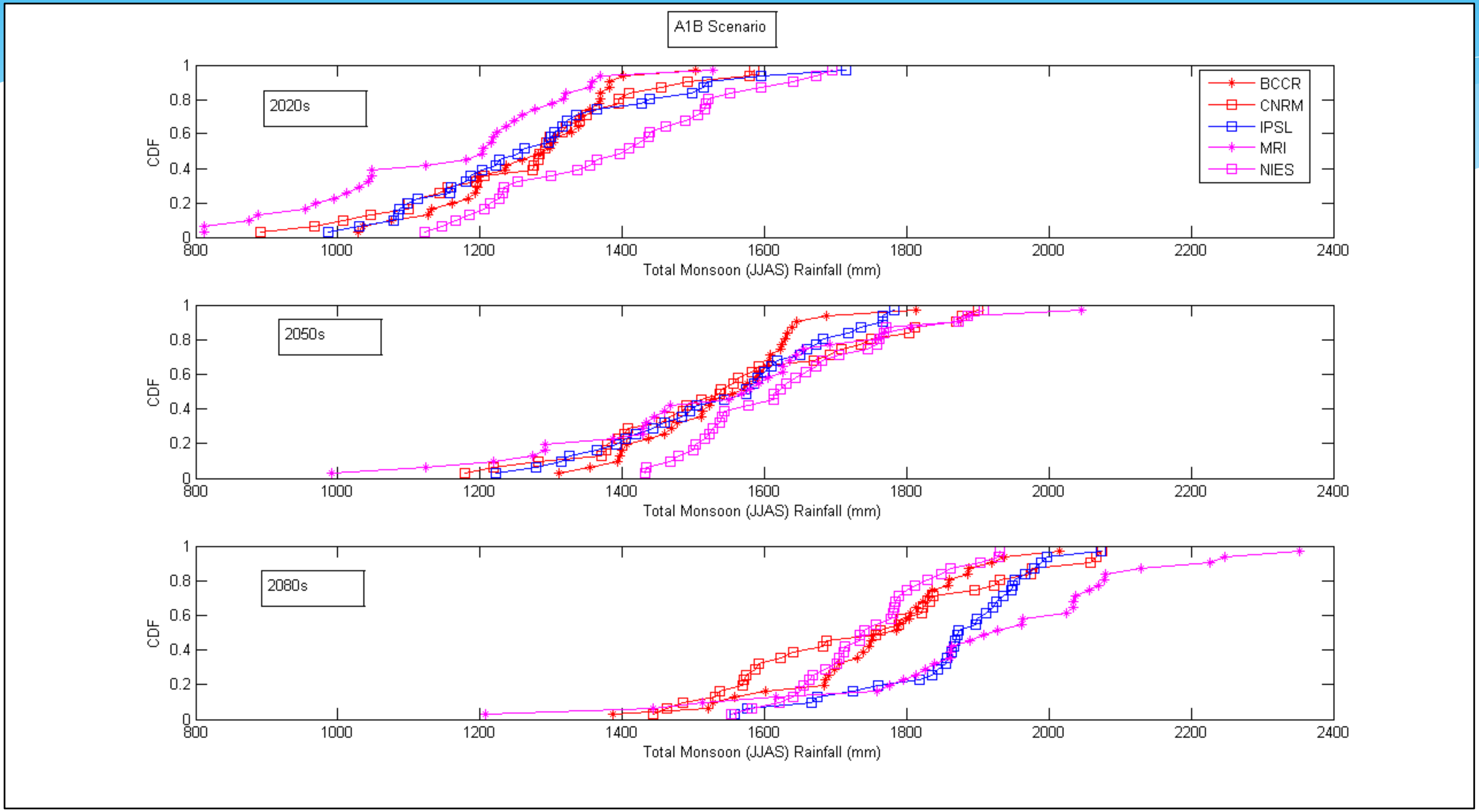
- Mean Sea Level Pressure
- Near Surface Temperature
- Surface Humidity
- Zonal Wind Speed
- Meridional Wind Speed

GCMs Considered and 20C3M Results

GCM	Institute	Spatial Resolution
BCCR	Bjerknes Centre for Climate Research, Norway	$2.80^0 \times 2.80^0$
CNRM	Centre National de Recherches Meteorologiques, France	$2.80^0 \times 2.80^0$
CM4	Institut Pierre Simon Laplace, France	$2.50^0 \times 3.75^0$
MIROC3.2 medres	National Institute for Environmental Studies, Japan	$2.80^0 \times 2.80^0$
CGCM2.3.2	Meteorological Research Institute, Japan	$2.80^0 \times 2.80^0$

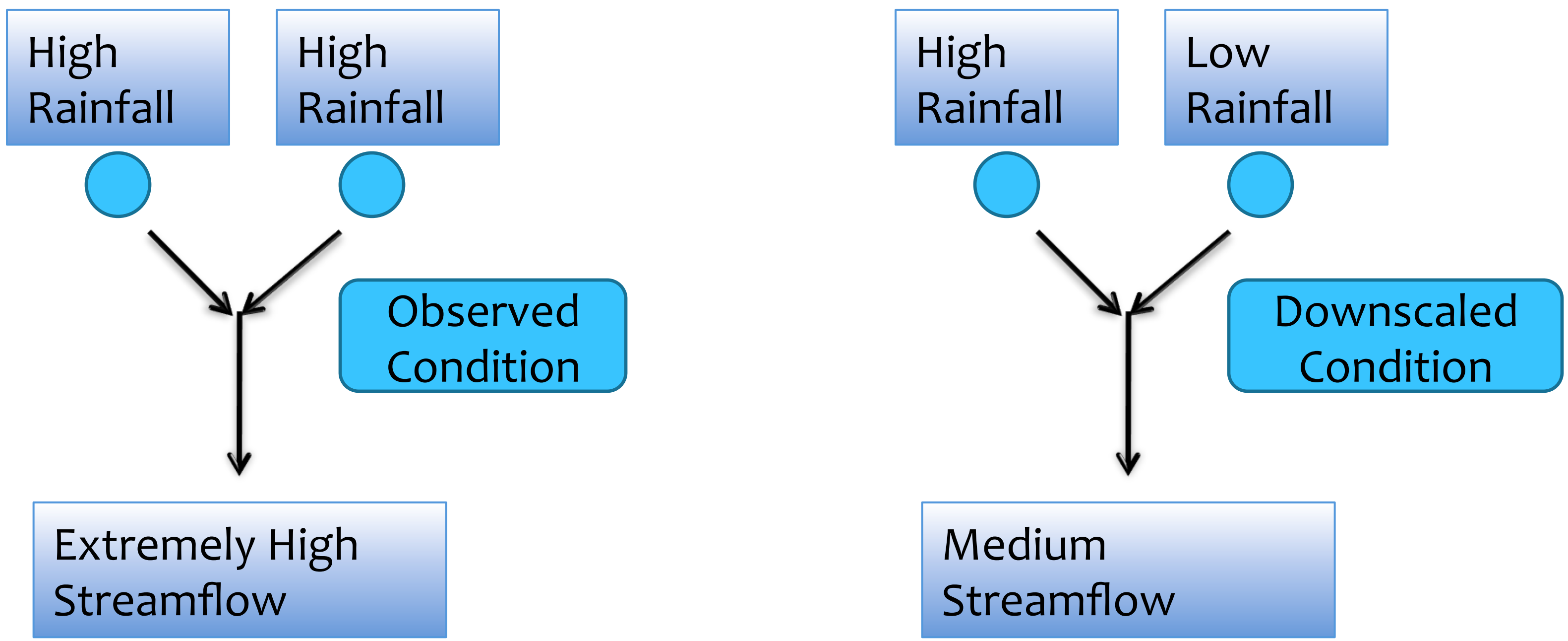


Results with A2 Scenario

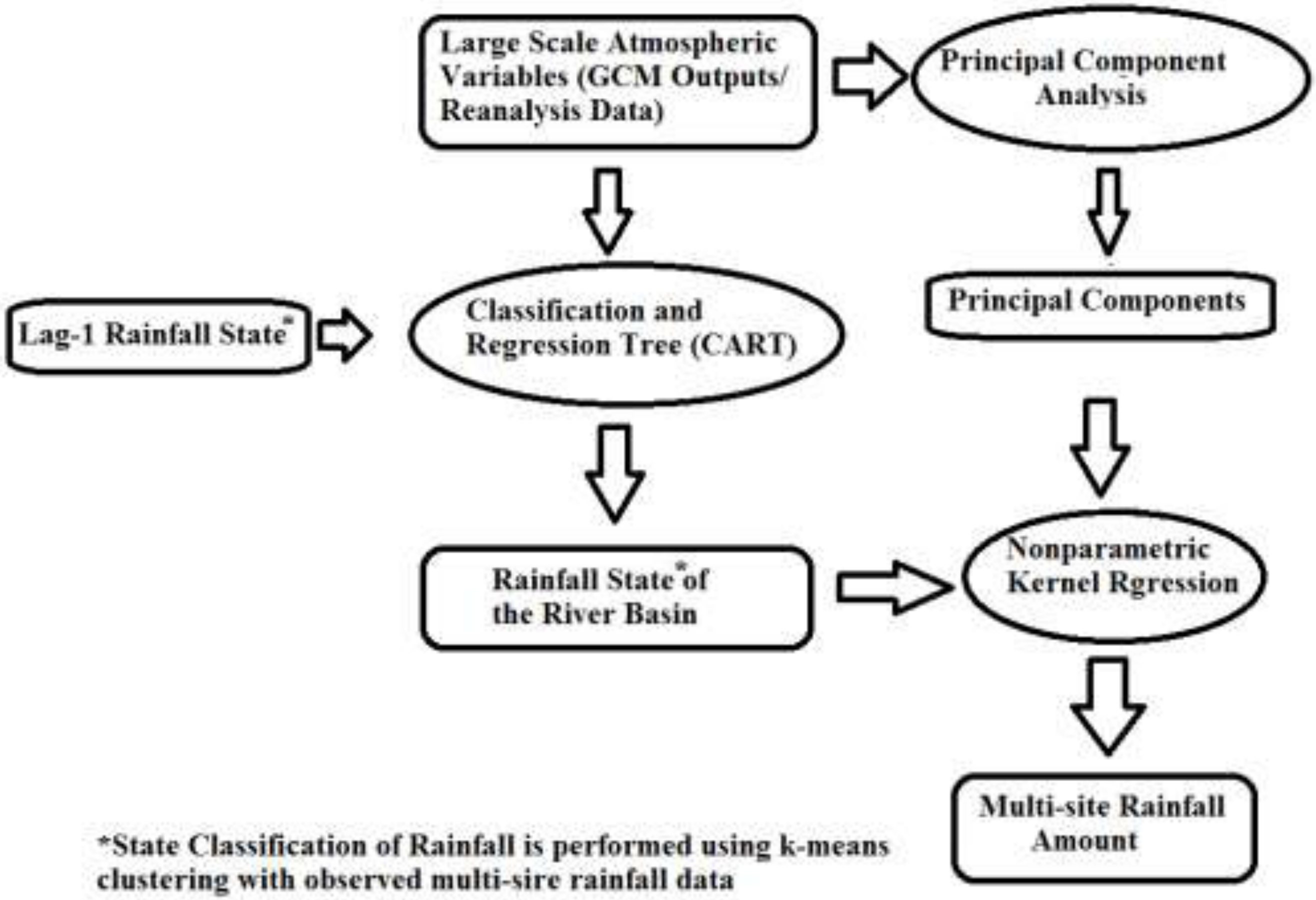


Multi-site Downscaling

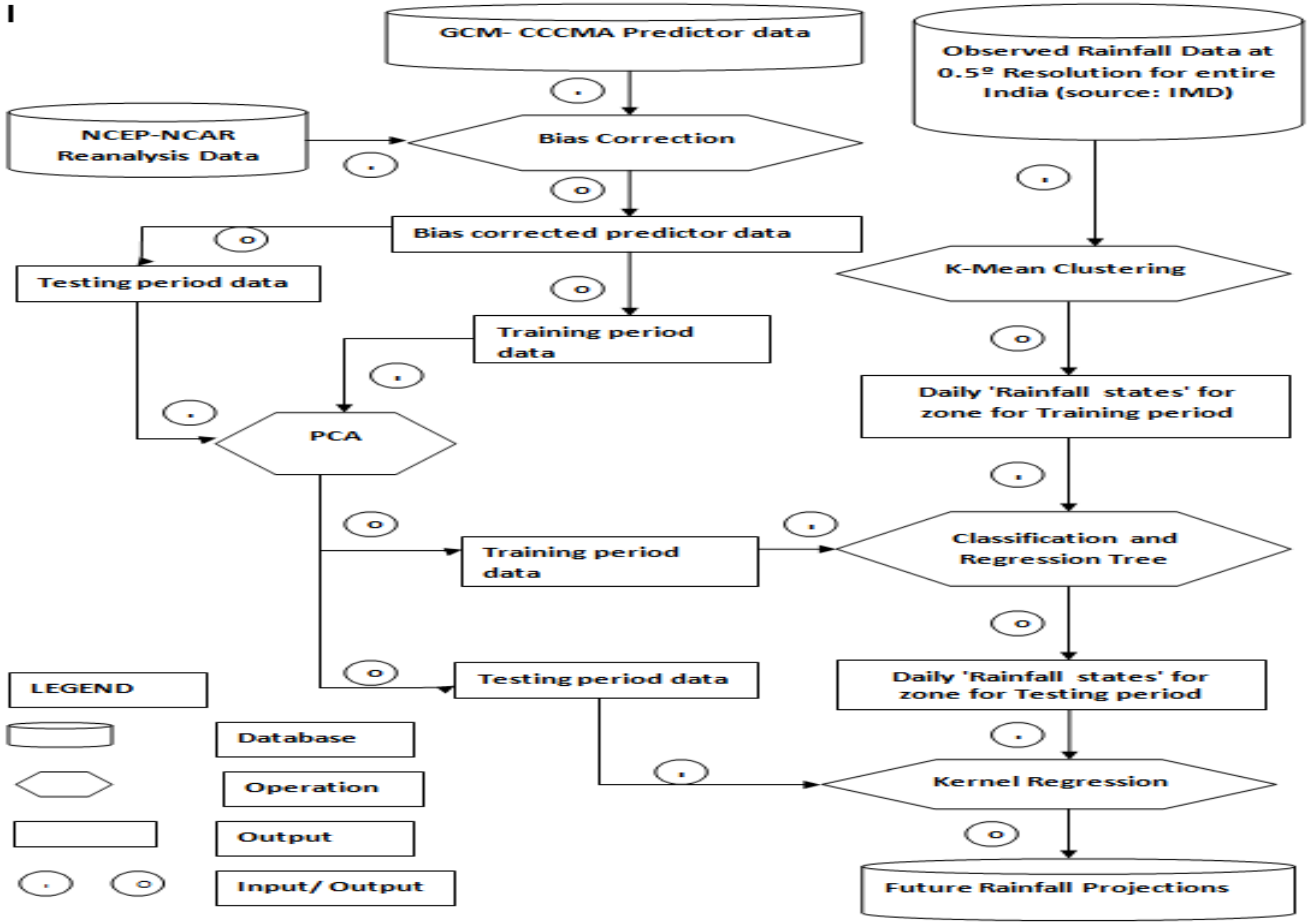
* Challenges
  * Cross correlation
  * Variability for daily scale



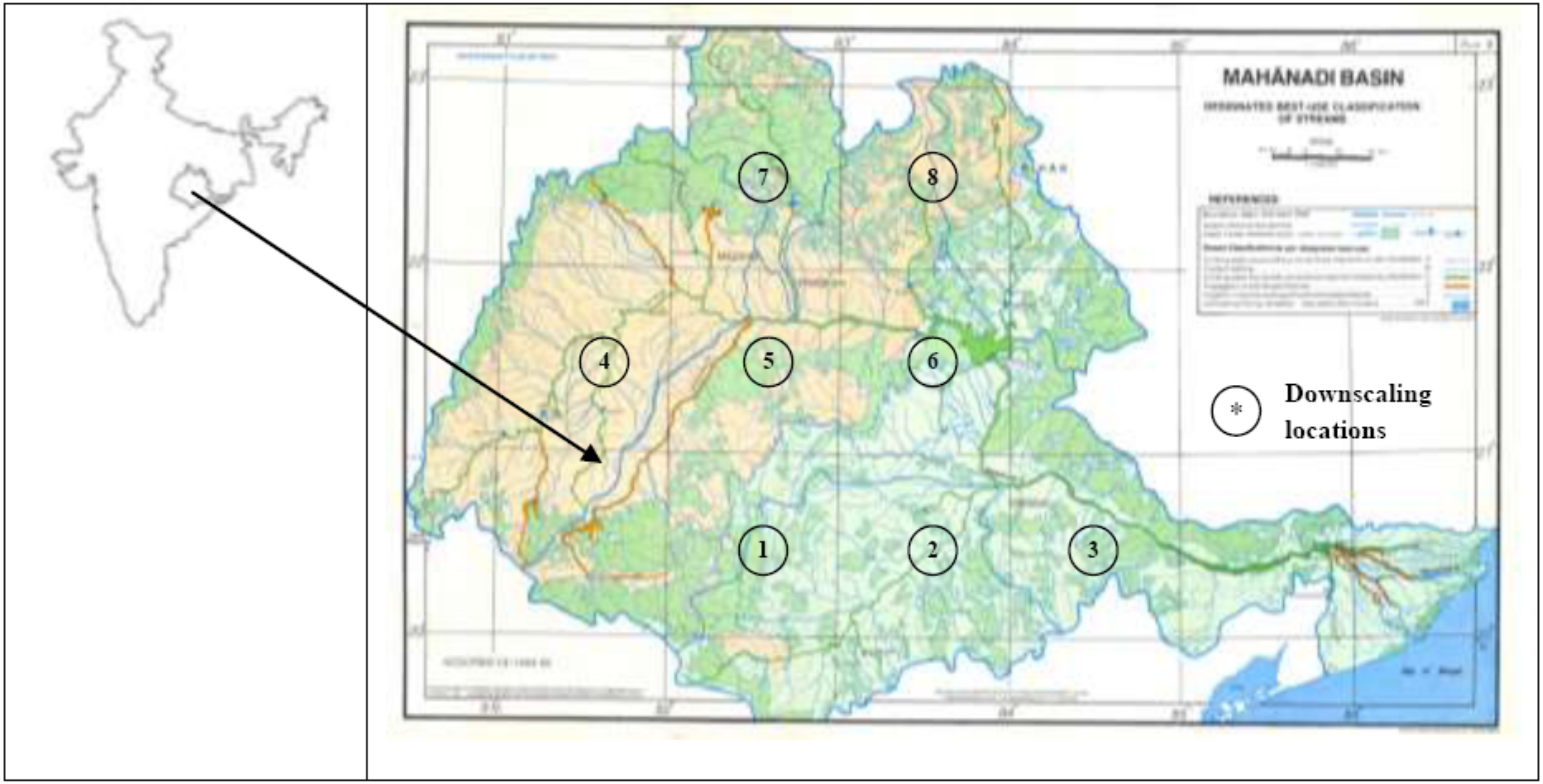
Our Approach



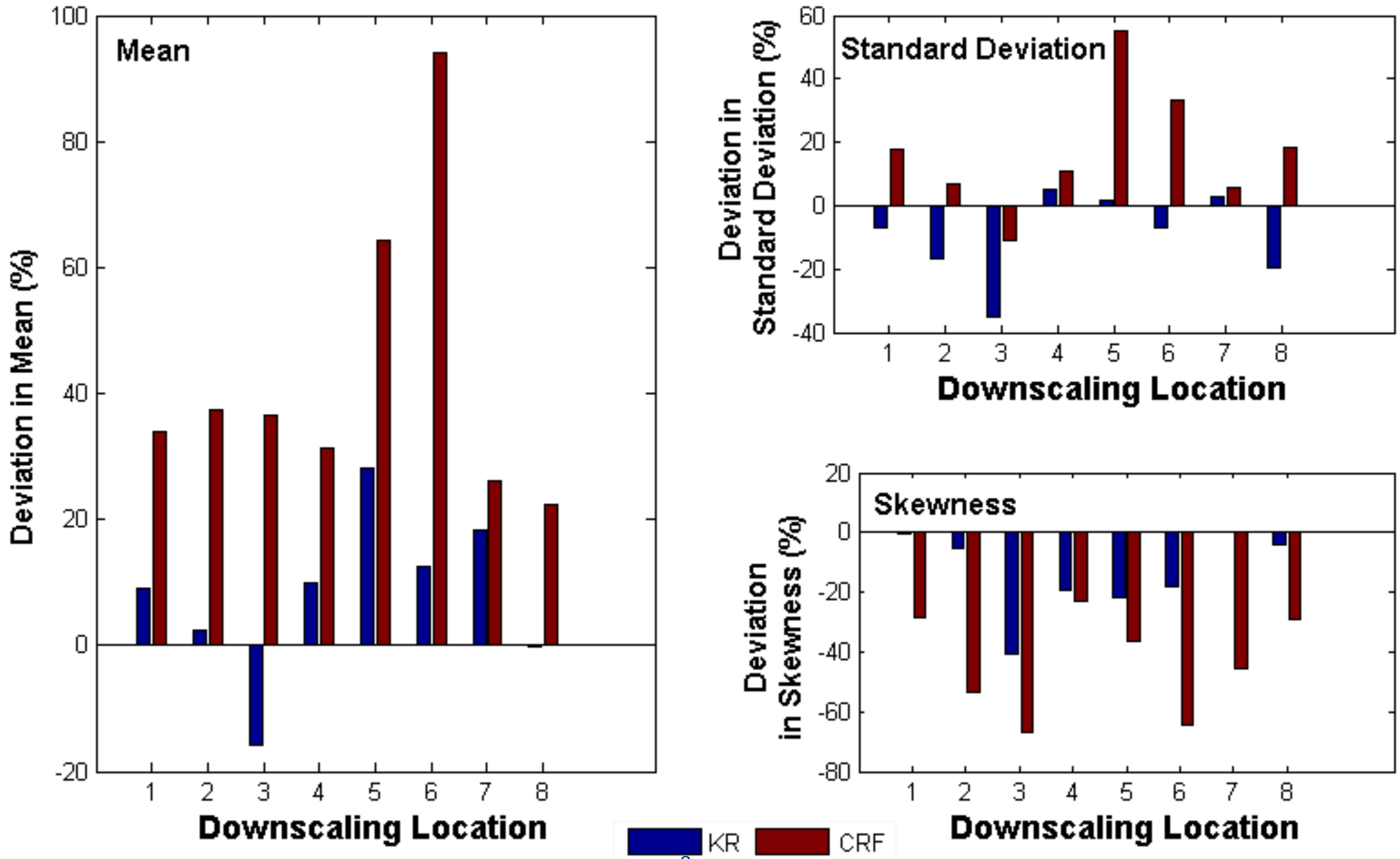
Downscaling Framework for Multi-site Rainfall Projections



Case-study: Mahanadi River Basin

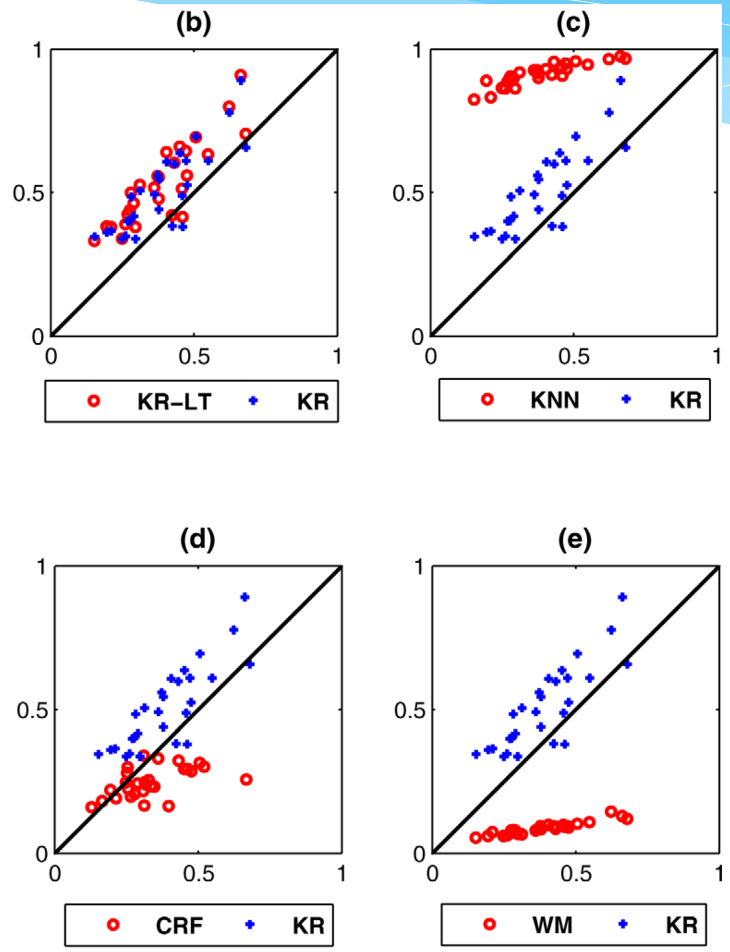


Comparison with CRF [Raje and Mujumdar, 2009] (Error Plot)

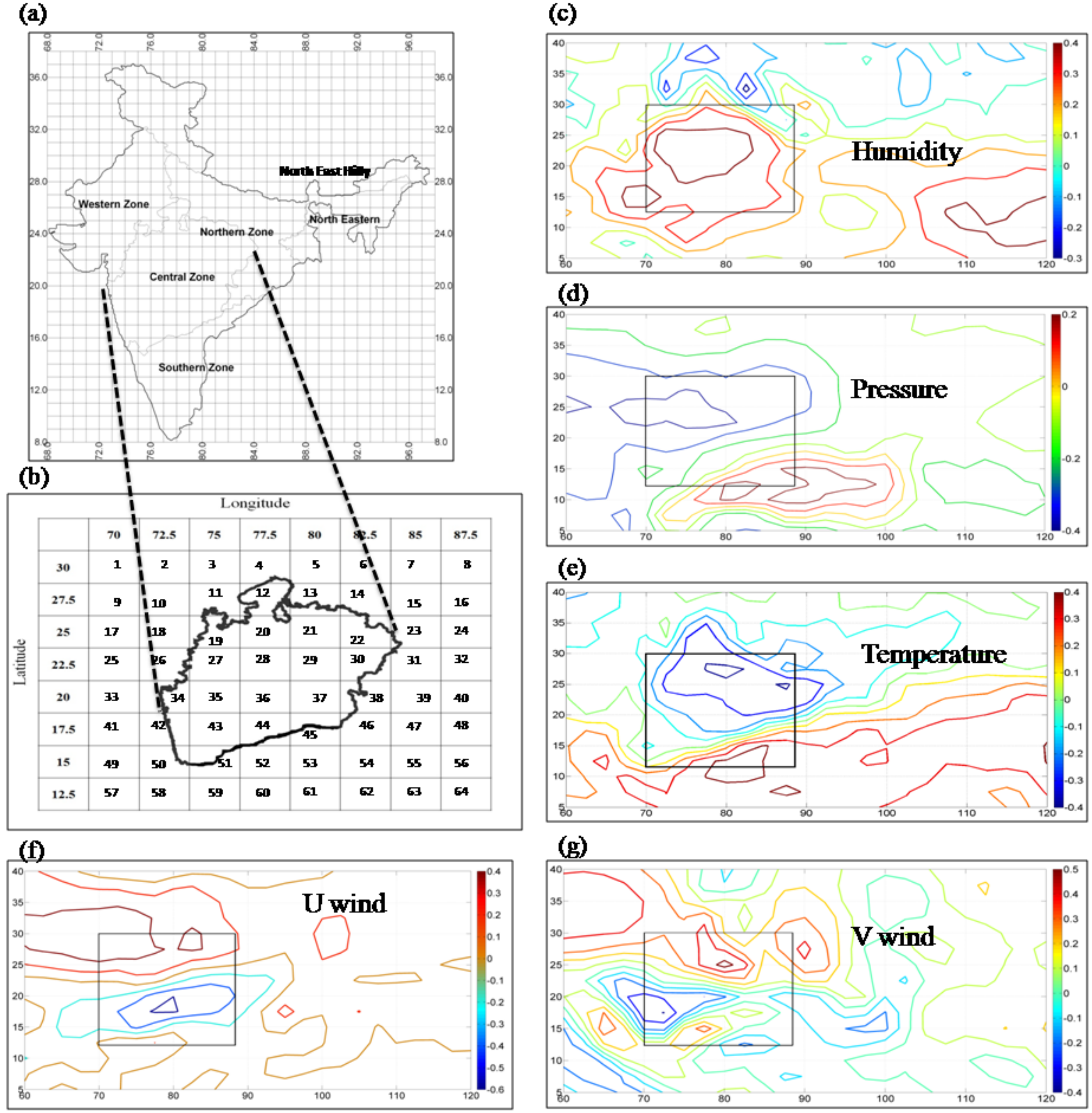


Kannan and Ghosh (2013), WRR

Comparison with CRF: Spatial Correlation



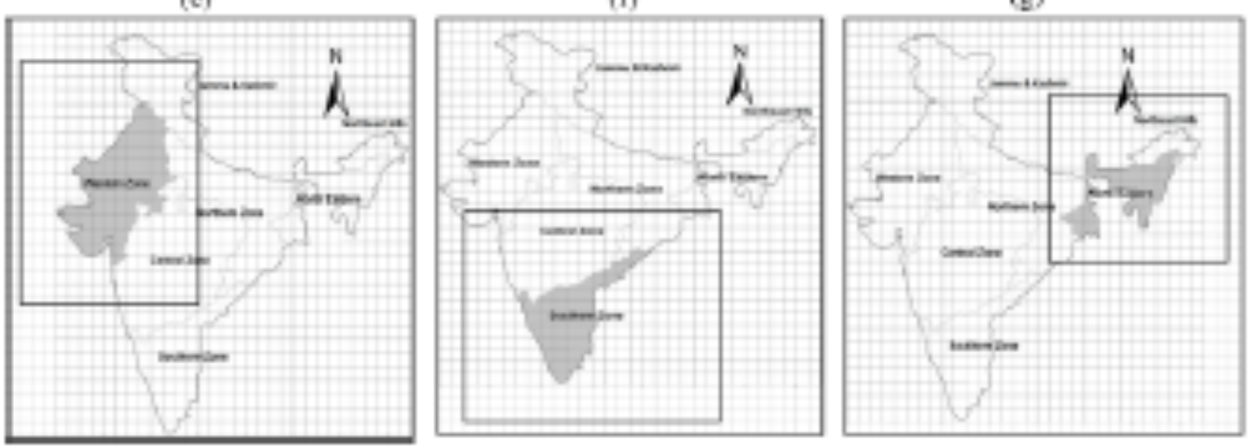
Application to All India



Predictor: spatial domain

(a) (b) (c) (d)

(e) (f) (g)

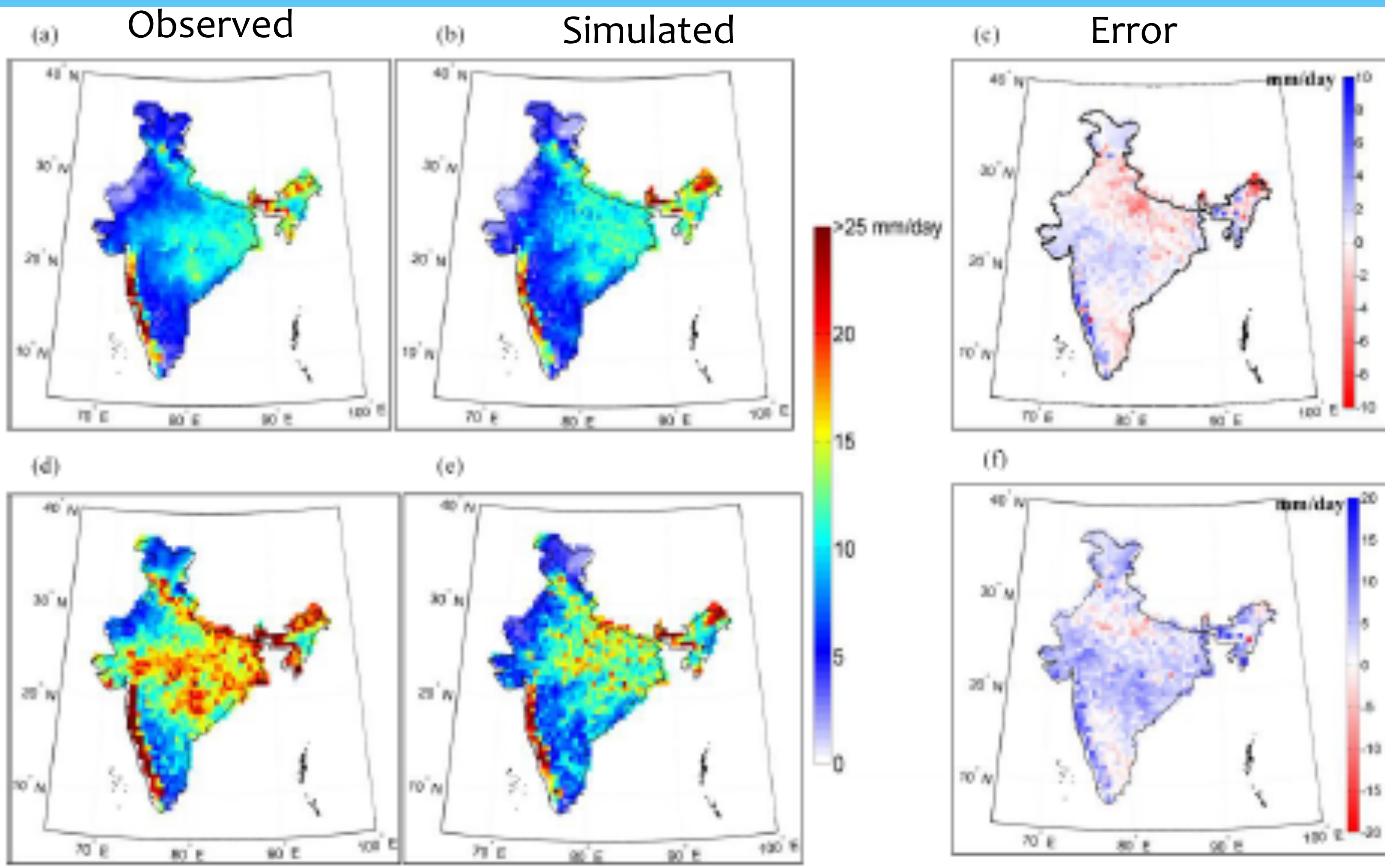


(h)

Zone	Latitude		Longitude	
	From	To	From	To
Southern	8	22.5	70	90
Central	12.5	30	70	87.5
Western	17.5	35	65	80
Northern	15	32.5	72.5	92.5
Northeastern	20	32.5	85	100
JK*	27.5	40	70	82.5
NEH**	25	32.5	90	100

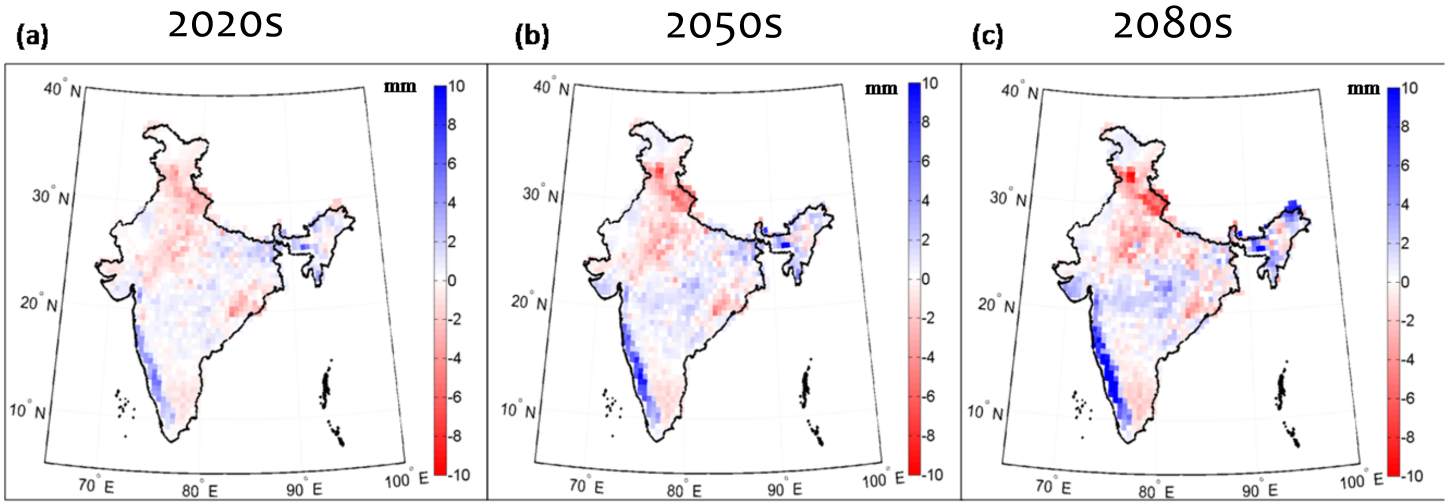
* : Jammu and Kashmir
**: North Eastern hills

Mean and Standard deviation of simulated data

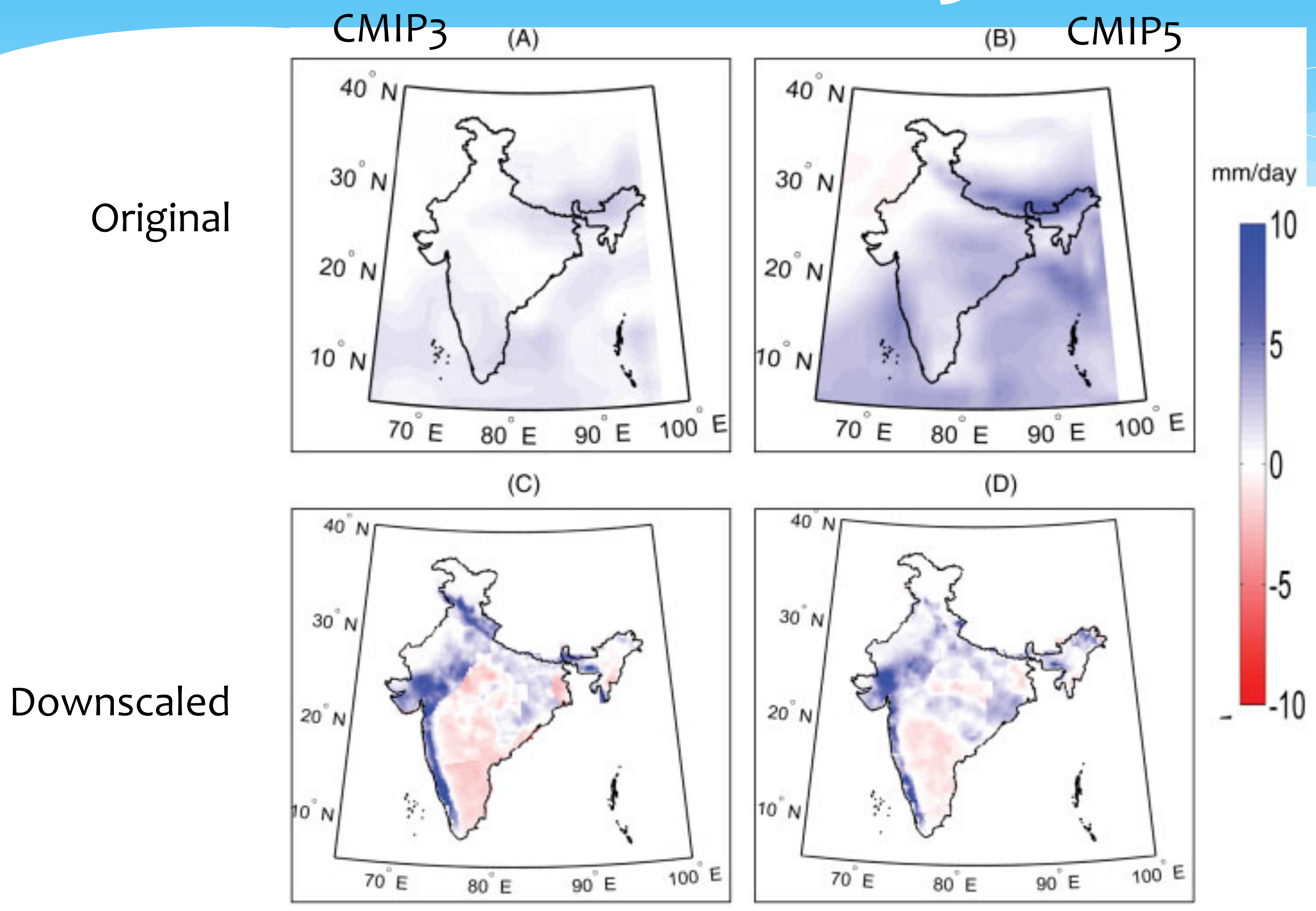


Salvi, Kannan and Ghosh (2013), JGR

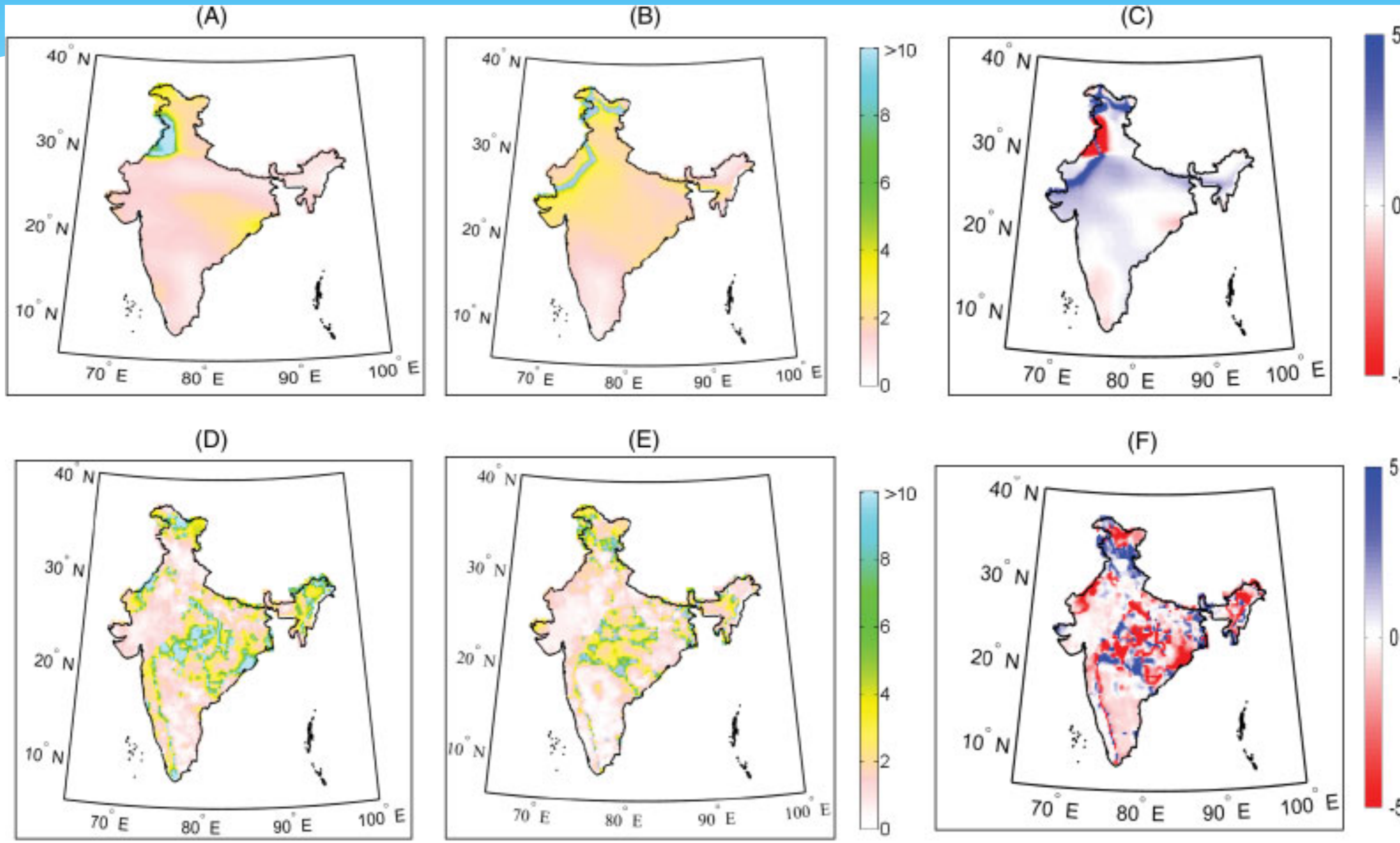
A2 Scenario (Future)



Multi-model projections with CMIP3 and CMIP5



Uncertainty



Shashikanth et al. (2013), ASL

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Thank You