Monsoons, Climate and Water Challenges in the South Asian Monsoon Region

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- Krishna Kumar et al. (1999, SCIENCE; 2006)
- Krishna Kumar et al. (2006, SCIENCE)
- Krishna Kumar et al. (2012, Climate Dynamics)
- Gill et al. (2015, JGR, 2016a,b, Paleoceanography)
- Broman et al. (2014, J. Climate, 2013 CUB MS thesis)

Outline

Indian Monsoon
- Why is it important?
- Monsoon Background

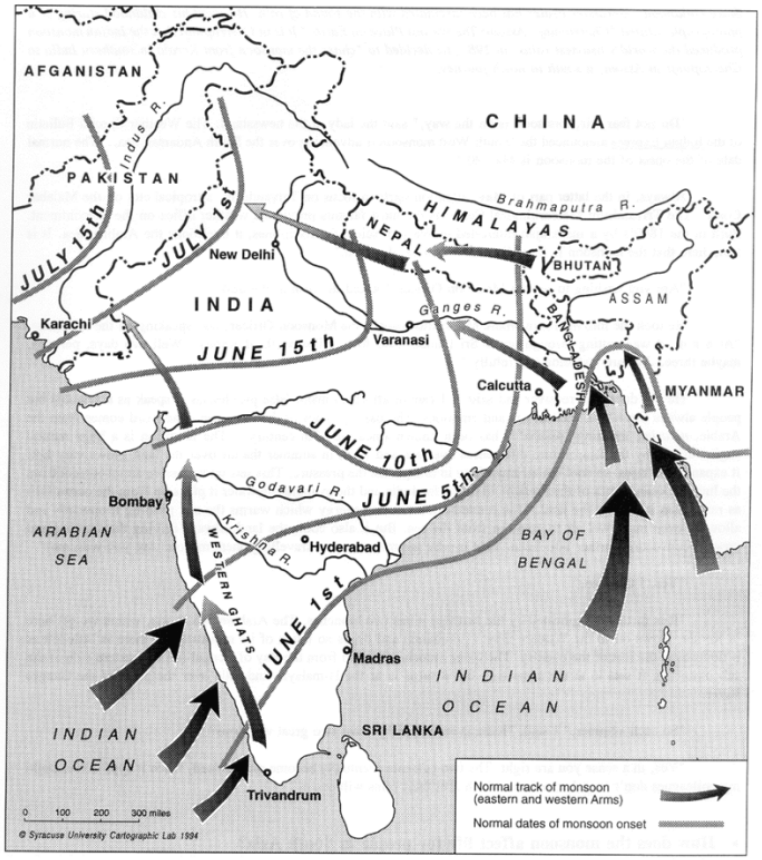
Past and Present Pulse
- Interannual
- Subseasonal

Future Pulse

Societal Impacts
- Agriculture
- Public health

Water Management
- Chennai Floods of 2015

Challenges / Parting Thoughts



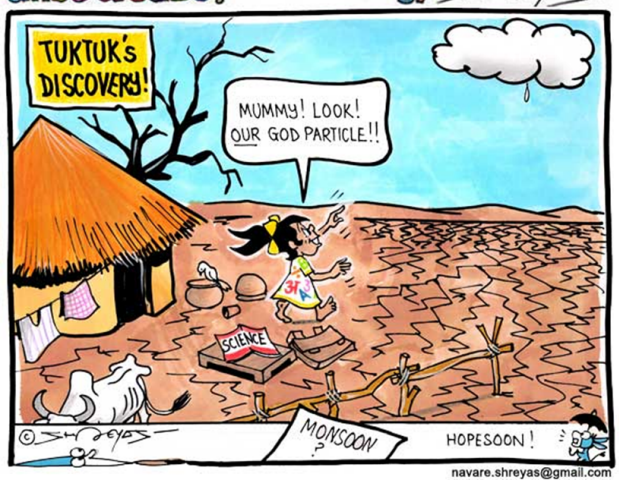
The air is on fire and the leaves are perfectly still as if holding their breath. Nature seems to be frozen in time. There is a curious sense of anticipation.

In a sudden moment, the sky darkens and…the leaves flutter excitedly in the cool breeze. The monsoon has arrived.

Rivers flow and flowers bloom in celebration of the monsoon, as the world is transformed under its spell. The wild monsoon winds blow with abandon swaying everything in their path.

Whether it's little children sailing paper boats on muddy rivers or people admiring the lush scenery, everyone is touched by the magic of the monsoon. With its life-giving rain and its wild storms, the monsoon is a mixed blessing - whimsical, unpredictable, and unmistakably Indian.

- Shantipriya, Indian author



Monsoon/Water *crucial* for civilizations in the subcontinent

Indus Valley Civilization

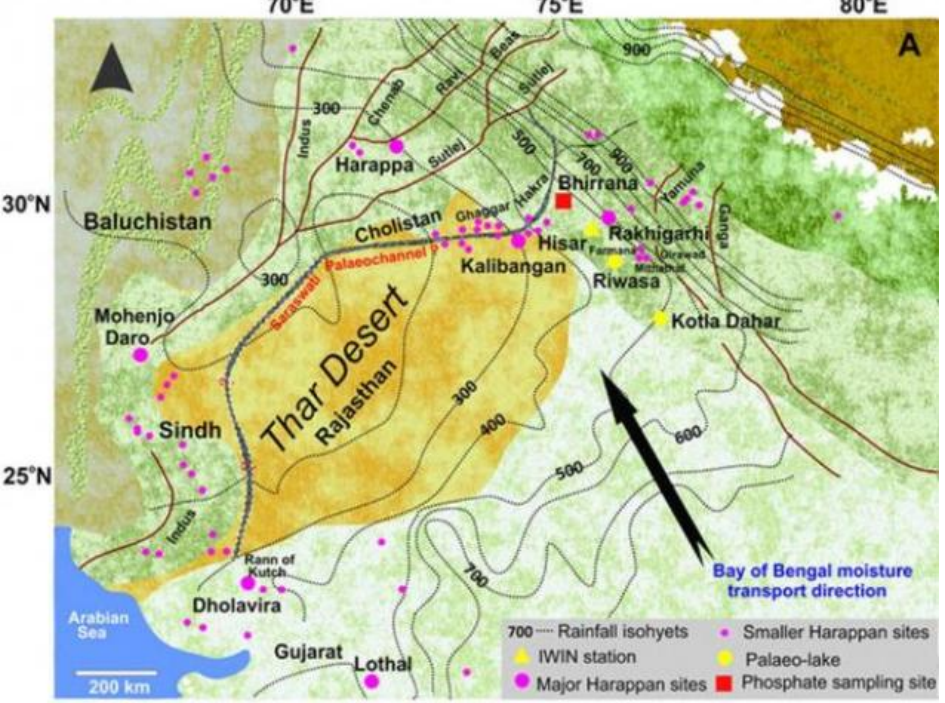
Early Period
5300 ~ 4600 BP

Agrarian Society – strongly dependent on Monsoon Rainfall

Mature Period
4600 ~ 3900 BP

Late Period
3900 ~ 3300 BP

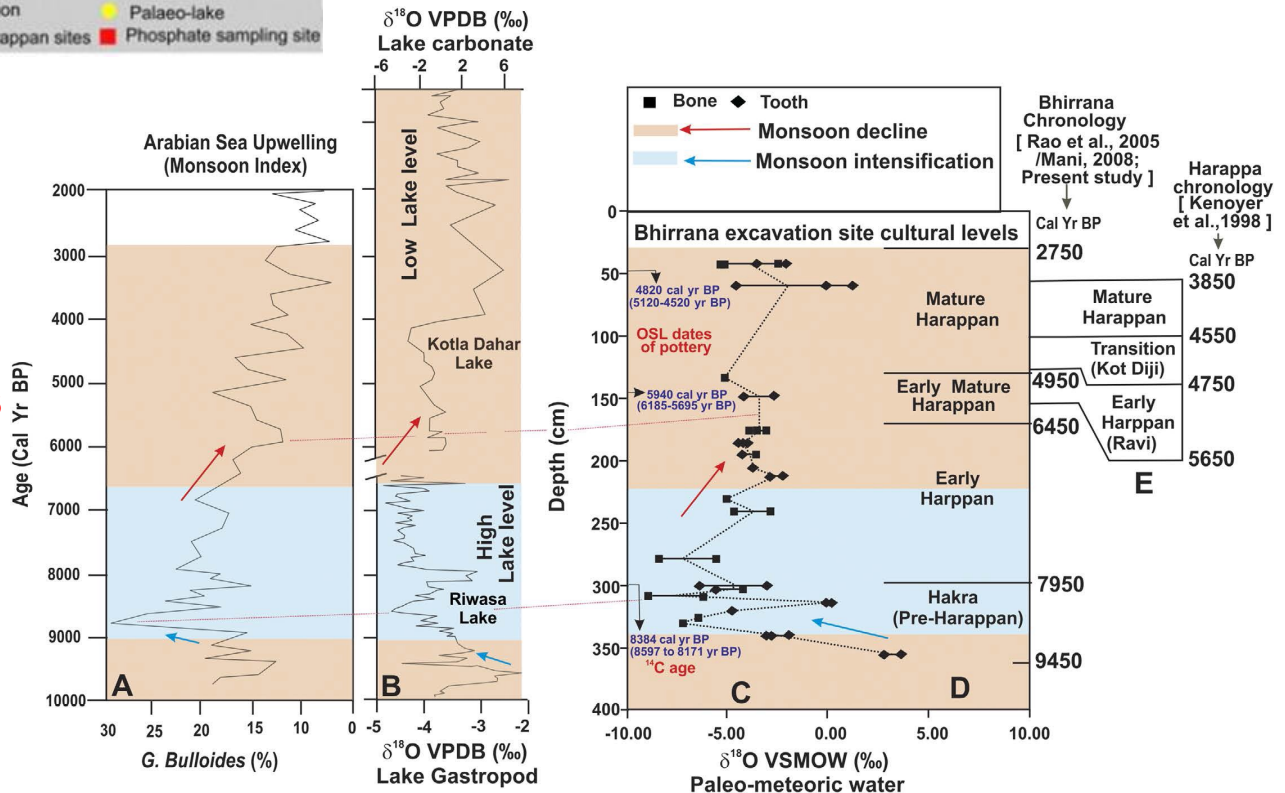
Why The Decline and Eastward Shift?
Monsoon Variations?



- During Early to Mid-Holocene Wetter North West India
- Gradual decrease of wetness during late Holocene
- Decline of Indus Civilization

What Caused the Wetness to sustain civilization?

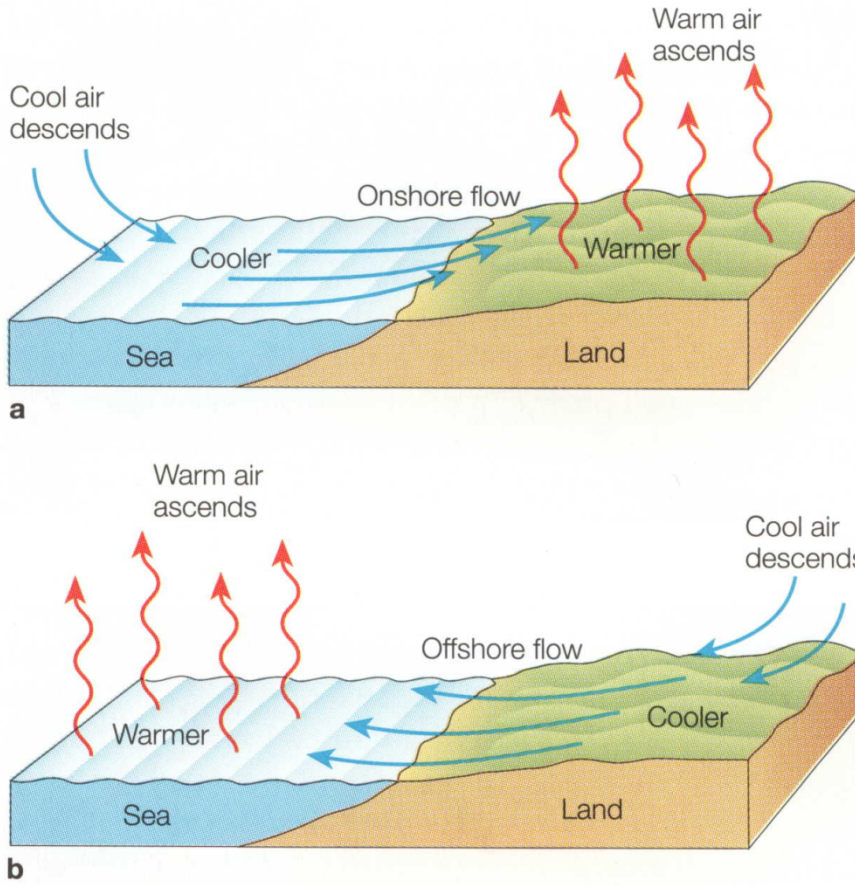
Gill et al. (2016a,b, Paleoceanography)



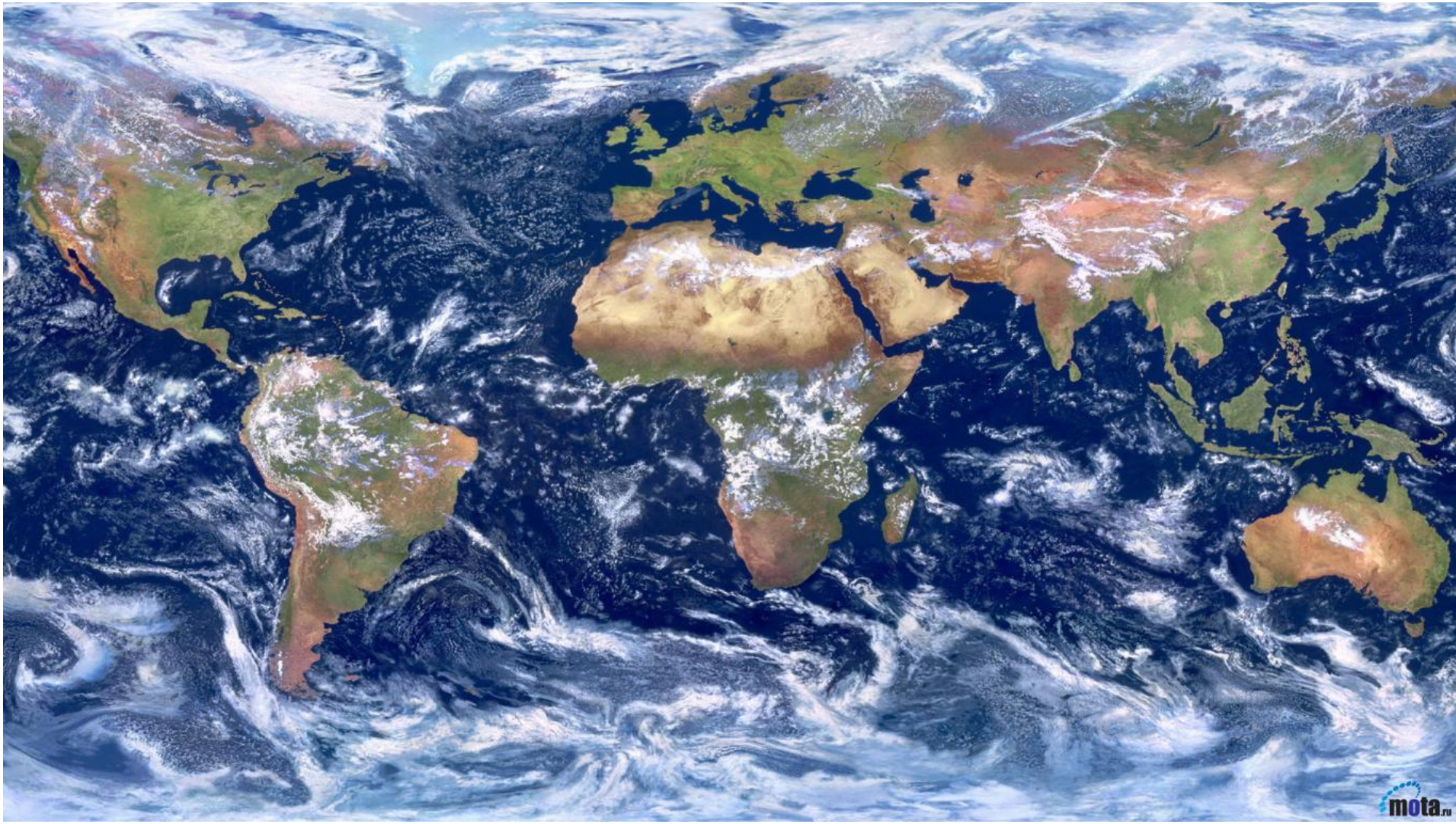
Monsoon - Basics

- Arabic word “mausim” means“season”
- Common definition: a wind or precipitation pattern that shifts seasonally
- The **primary cause** of monsoons
  - Hot Land
  - Cooler Ocean
    - Strong temperature between land and ocean

[Edmond Halley (of comet fame) was first to recognize this forcing]



Monsoon - Basics

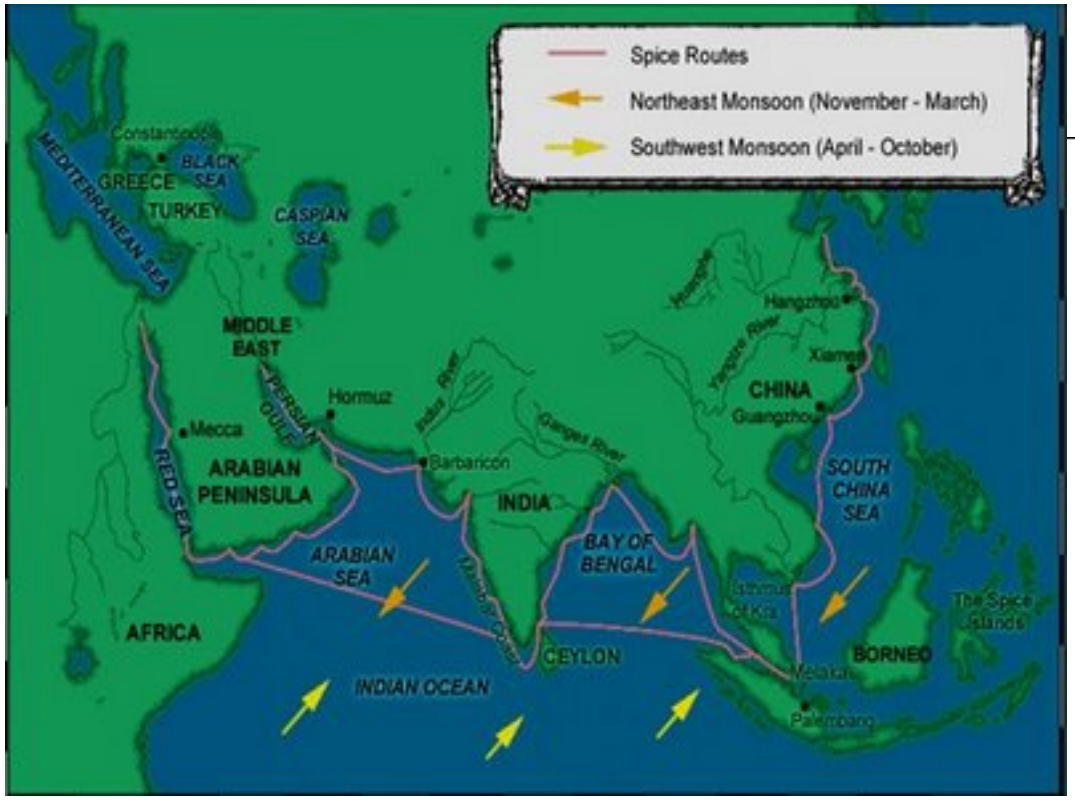


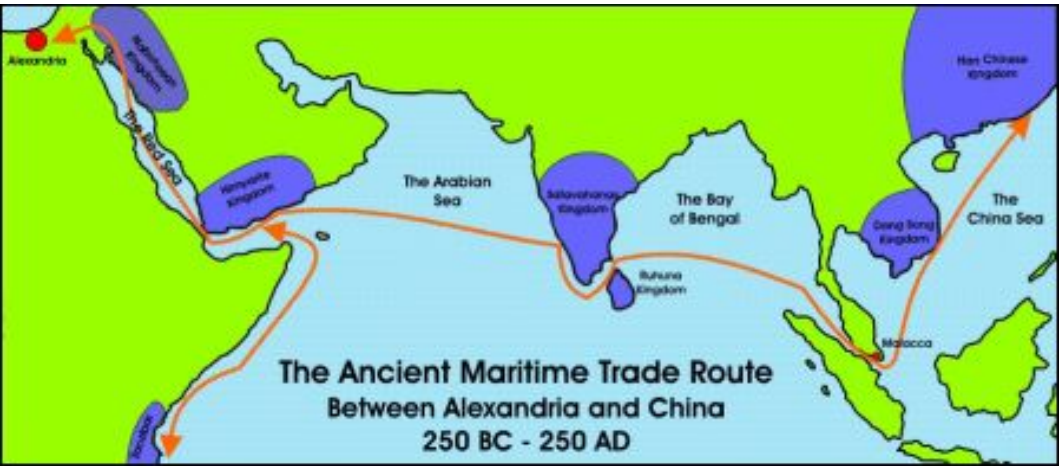
Which region(s) has?

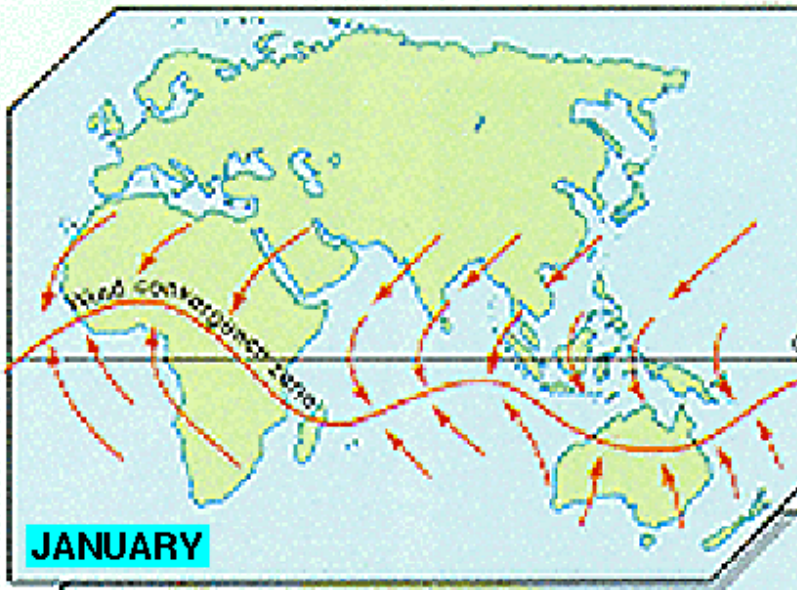
- Lot of land mass in the tropics
- Lot of water

Monsoon – ITCZ - Winds

- Trade
- Ideas
- Religion



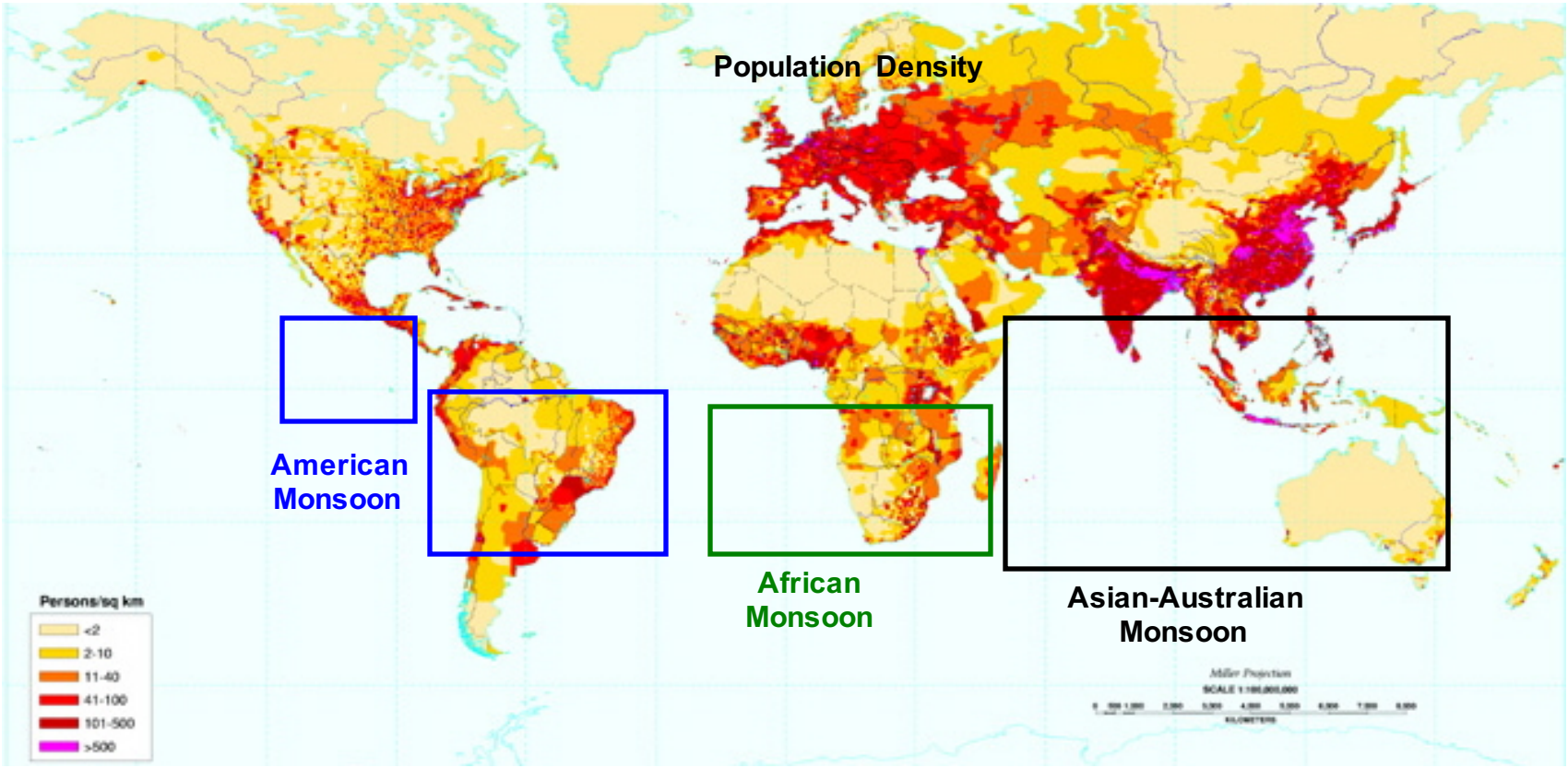




Monsoon Impacts

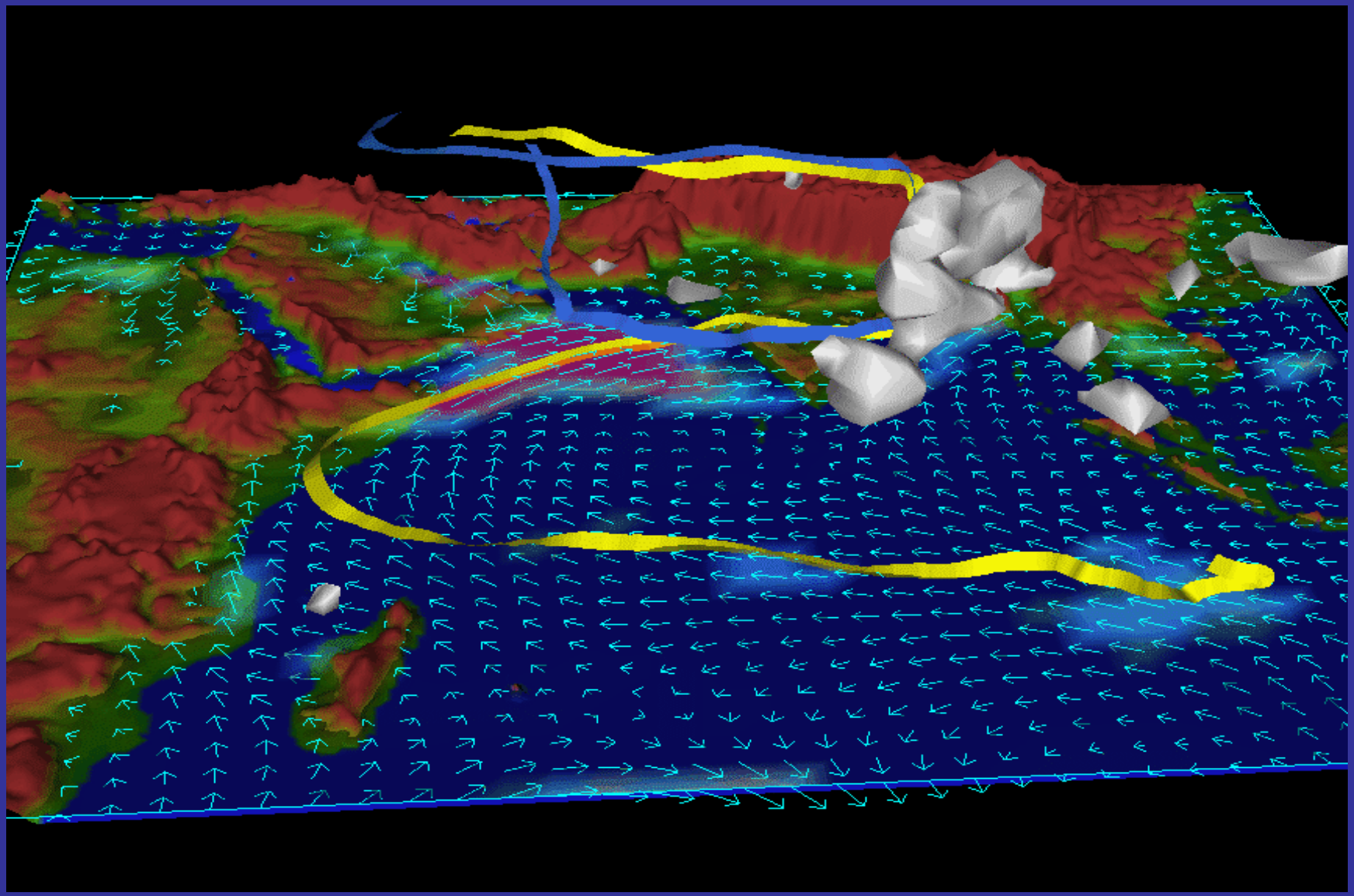
Large Societal Impact on Global Scale

- Monsoonal regions cover roughly ½ of the Tropics (or ¼ of the global surface area) and plays host to ~65% of the world's population



- Understanding Global Monsoon is *critical* for planning against climate hazards

Indian Summer Monsoon Flow
(Land-Sea Gradient)



Mean Rainfall Patterns

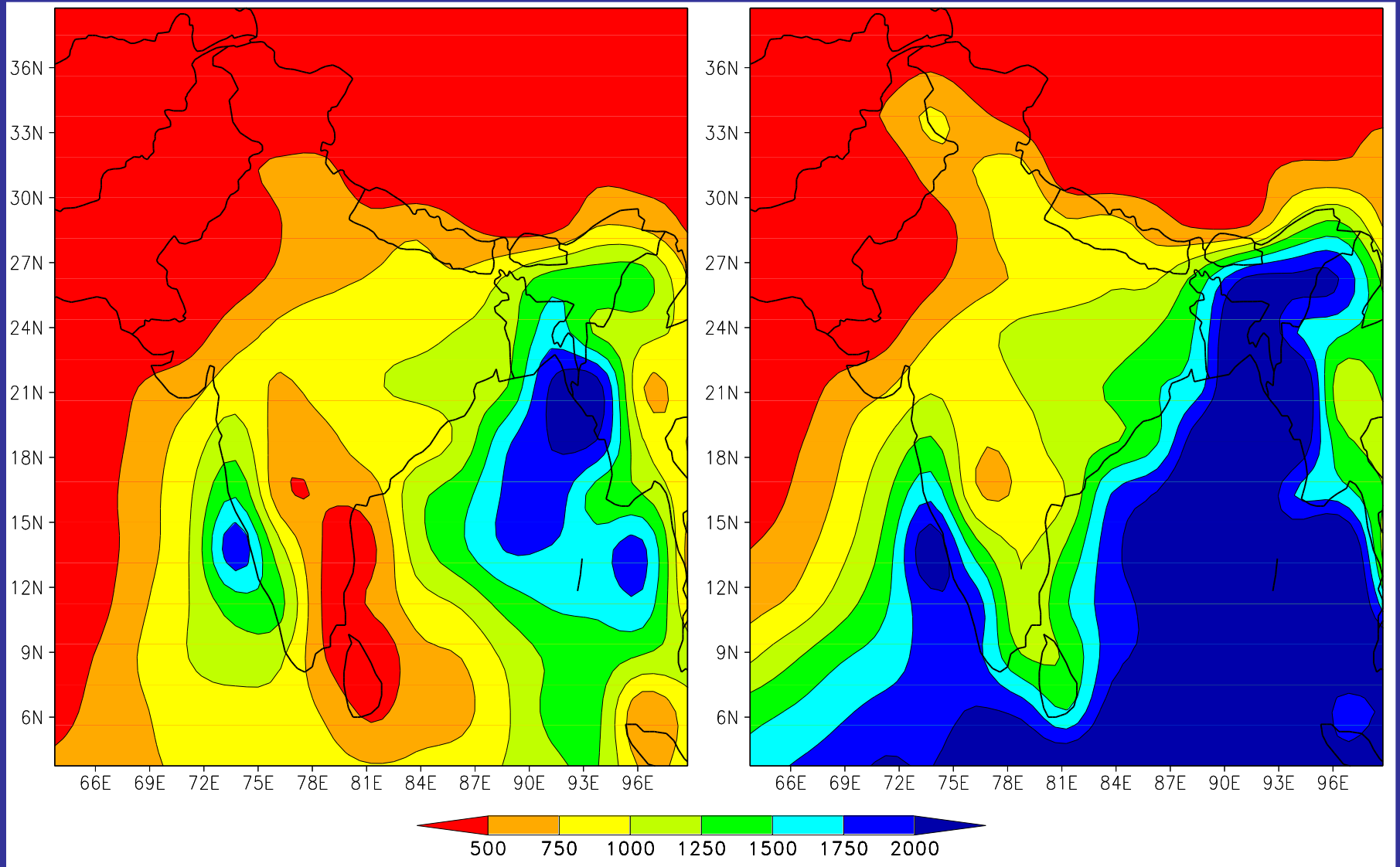
Data Source: CMAP (1979-2000)

Summer Monsoon

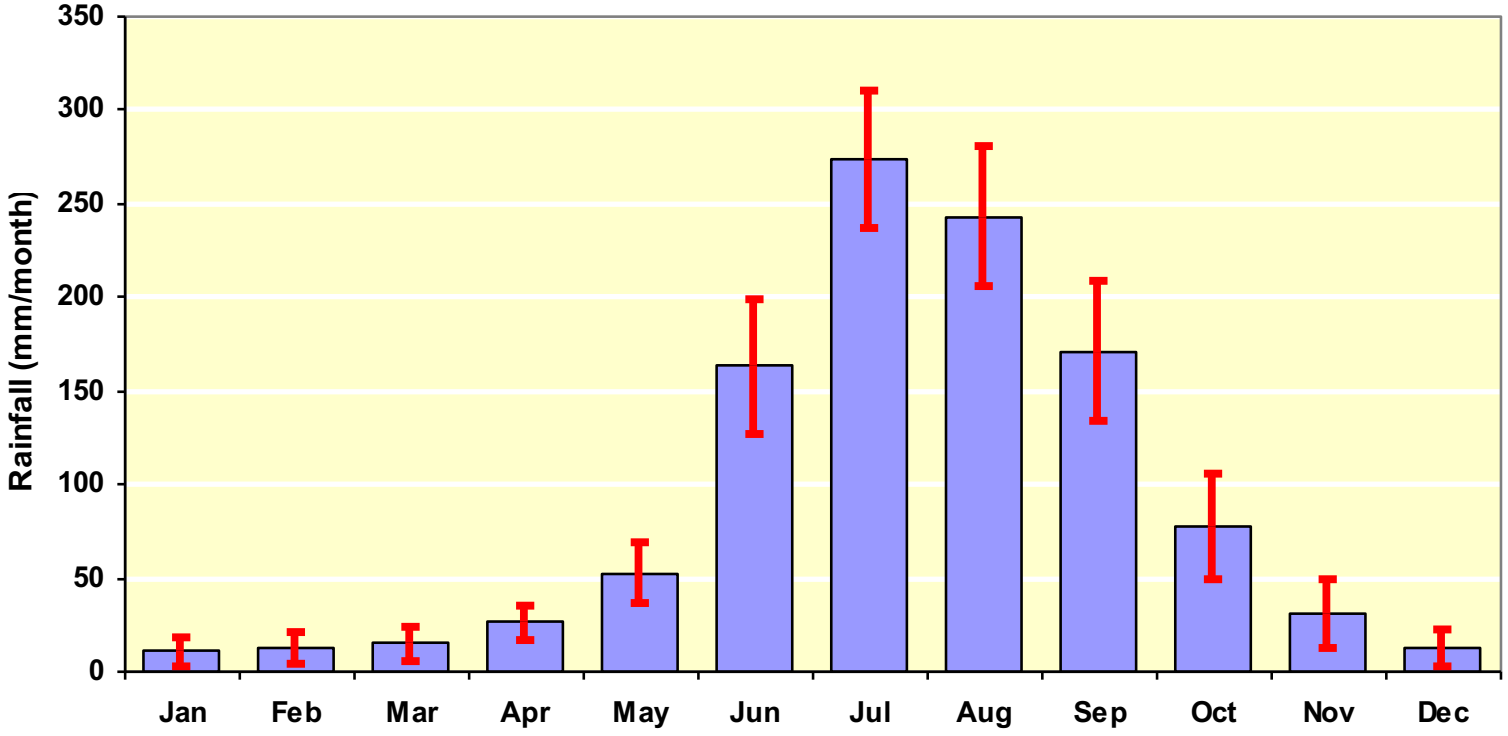
(mm/season)

Annual

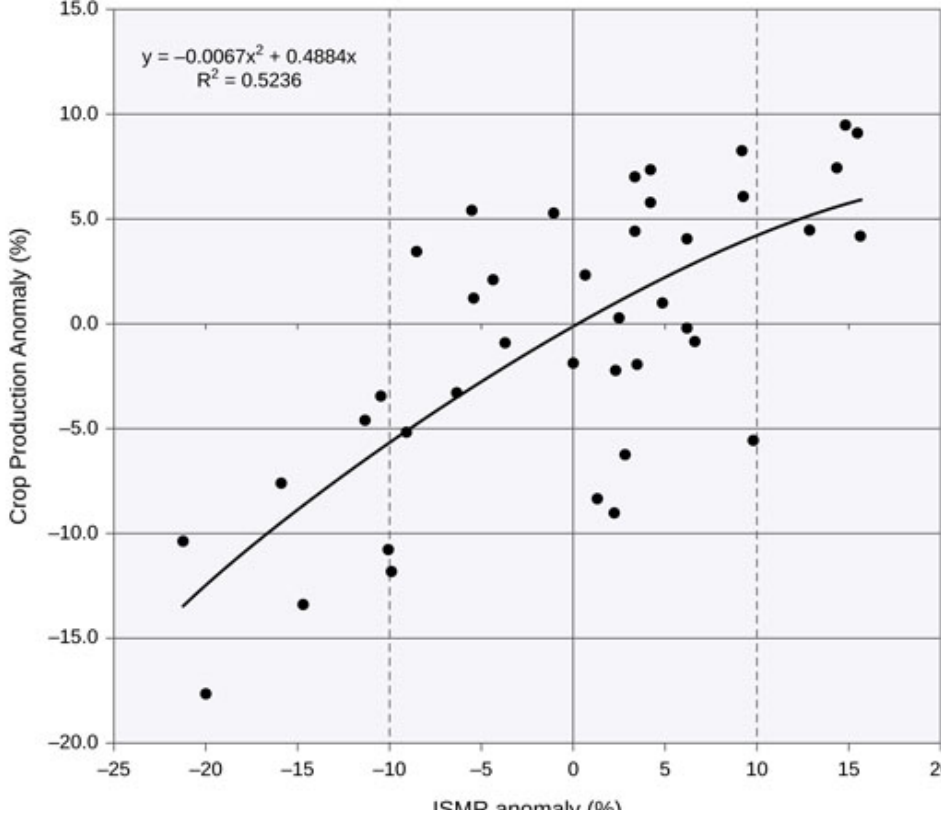
(mm/year)



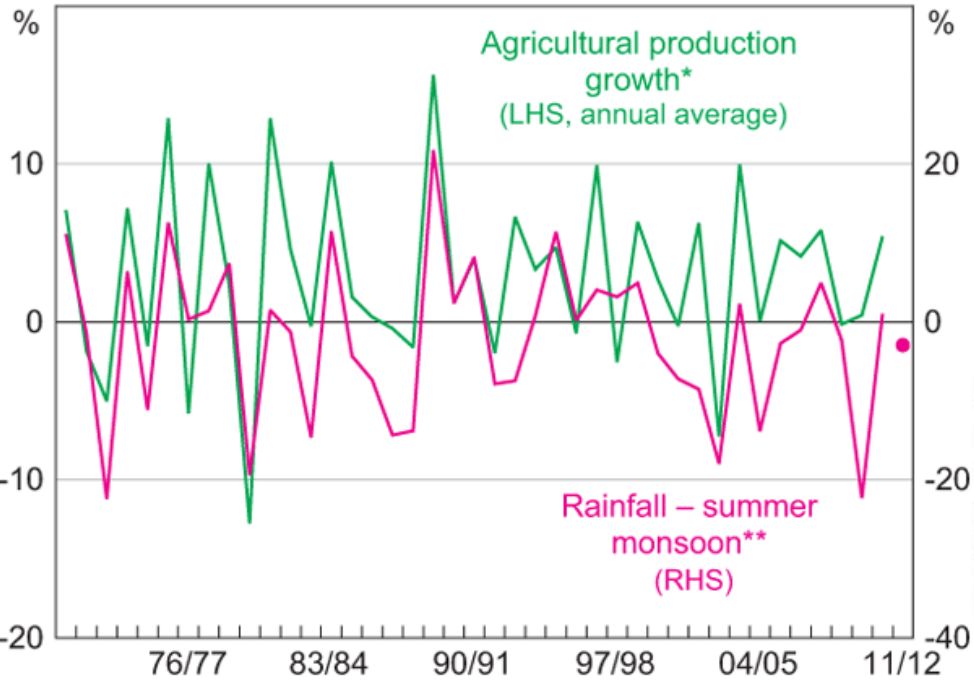
Mean Annual Cycle of All-India Mean Monthly Rainfall



- Total Food grain Production in India and its Relation to Indian Rainfall
- Impact on water resources
- ~20% of GDP is affected by monsoon
- 40% of irrigated area produces 70% of crops

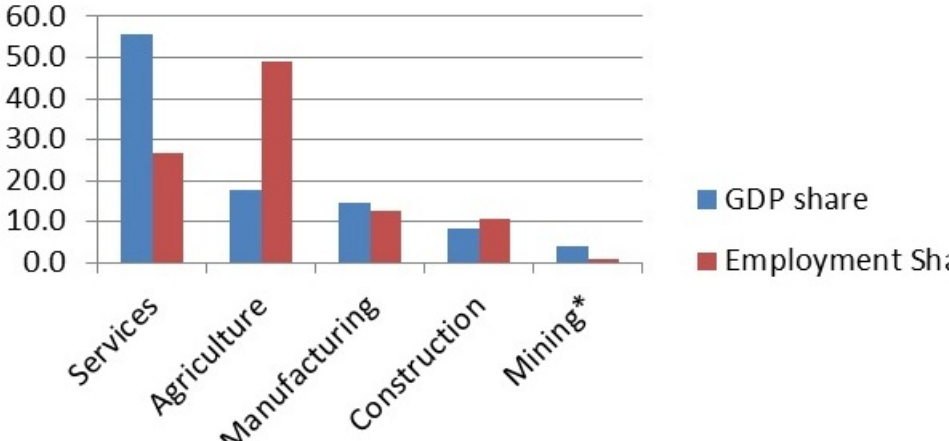


India – Rainfall and Agricultural Production

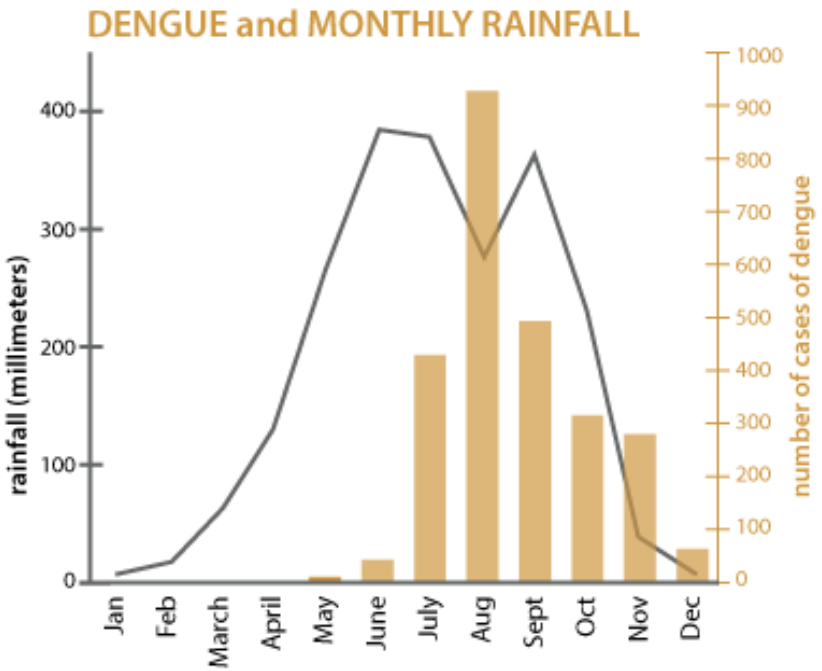


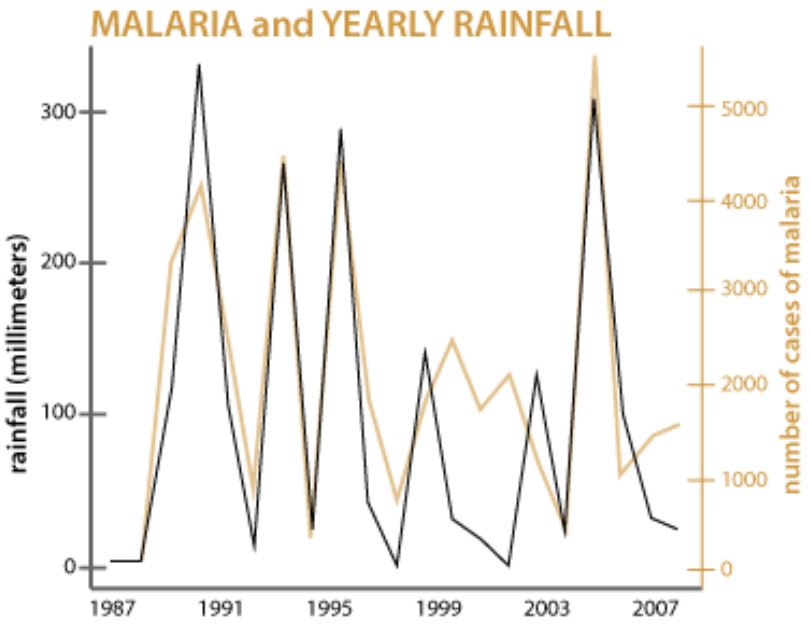
* Indian Government estimate for 2010/11
** Percentage deviation from long-run average; Indian Meteorological Department's first forecast for 2011/12 monsoon
Sources: CEIC; Indian Meteorological Department; RBA

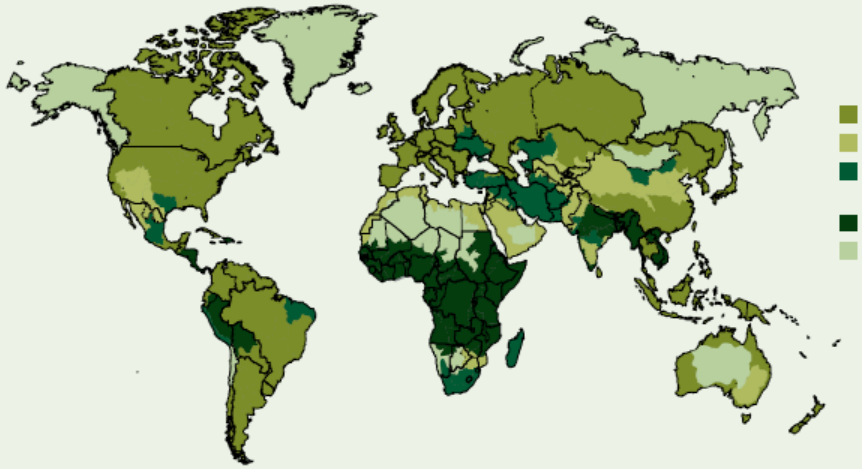
Share of GDP and employment 2011-12



Monsoon and Health





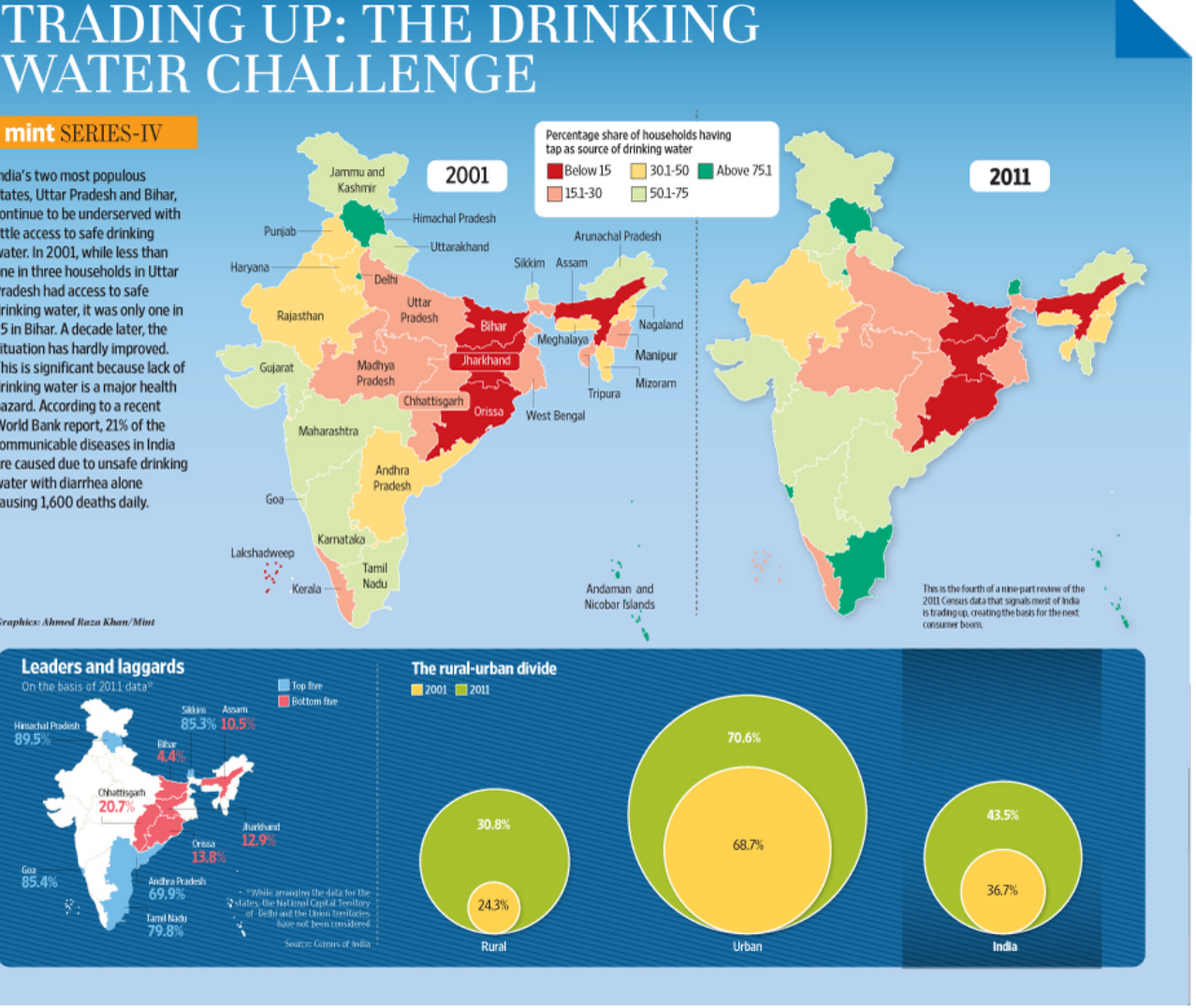


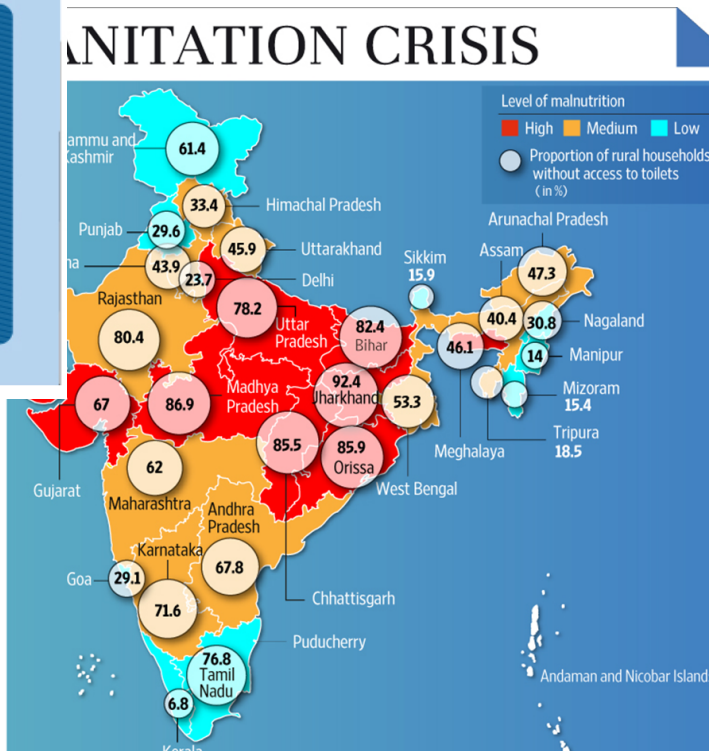
Definitions and Indicators

- Little or no water scarcity. Abundant water resources relative to use, with less than 25% of water from rivers withdrawn for human purposes.
- Physical water scarcity (water resources development is approaching or has exceeded sustainable limits). More than 75% of river flows are withdrawn for agriculture, industry, and domestic purposes (accounting for recycling of return flows). This definition—relating water availability to water demand—implies that dry areas are not necessarily water scarce.
- Approaching physical water scarcity. More than 60% of river flows are withdrawn. These basins will experience physical water scarcity in the near future.
- Economic water scarcity (human, institutional, and financial capital limit access to water even though water in nature is available locally to meet human demands). Water resources are abundant relative to water use, with less than 25% of water from rivers withdrawn for human purposes, but malnutrition exist

Source: Comprehensive Assessment of Water Management in Agriculture (2007) (from an International Water Management Institut using the Watersim model).

- Declining per capita water availability
- Large parts of India water stressed
- Limited Storage Capacity
- Woeful River Management

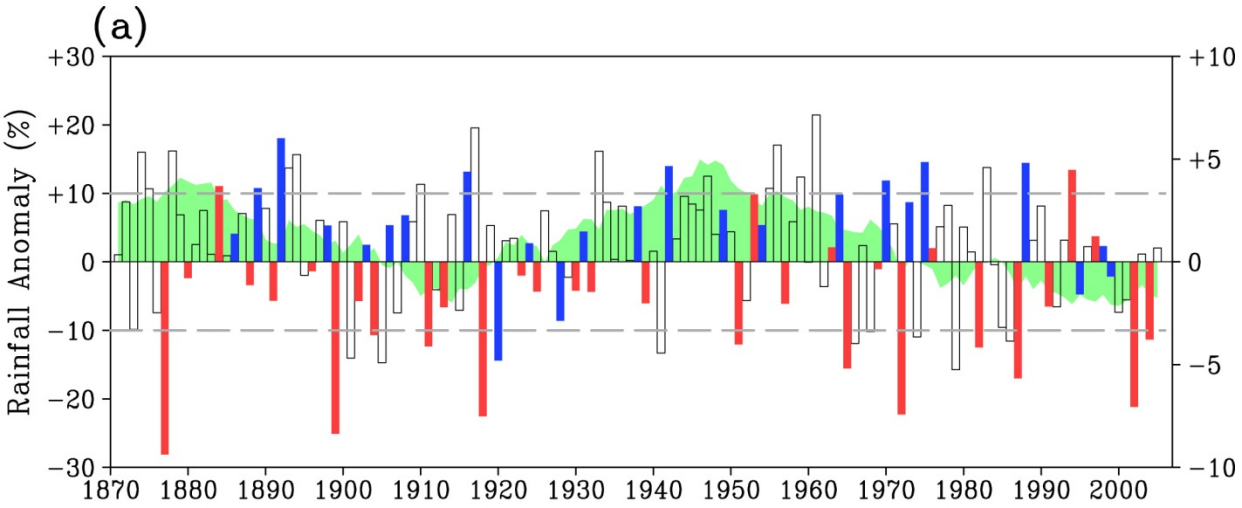


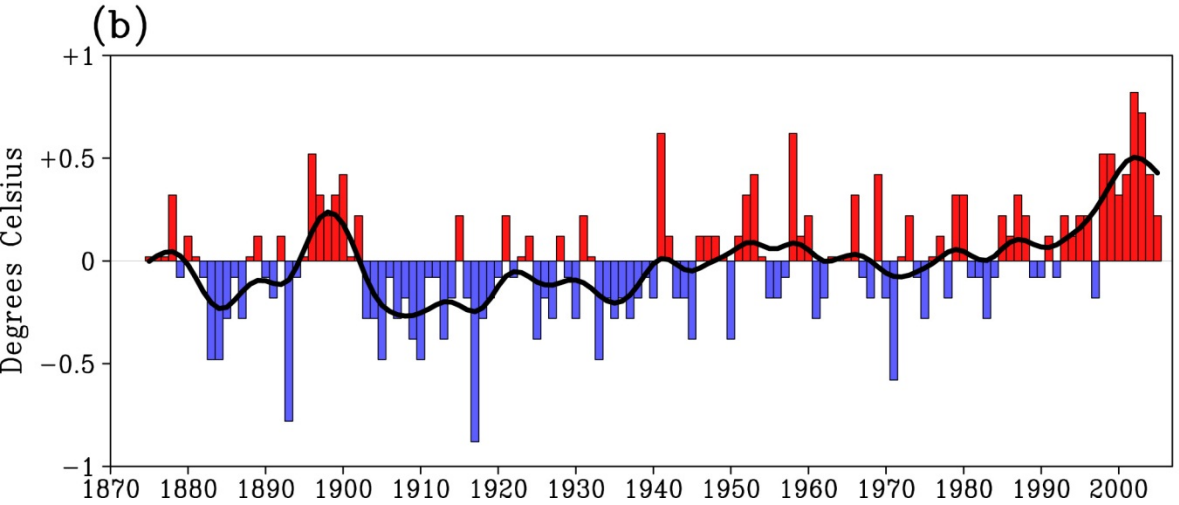


Monsoon Water, Health

- Lack of safe and reliable drinking water
- Lack of proper sanitation
- → Malnutrition, poor health

Current Monsoon Climate Pulse





All India Summer (June-Sep) Monsoon Rainfall % Anomalies

- Blue – La Nina years
- Red – El Nino years

- 25-yr smoother
  - Prolonged decline in Recent decades

Significant impact on Crop Yield, water resources and Socio-economy

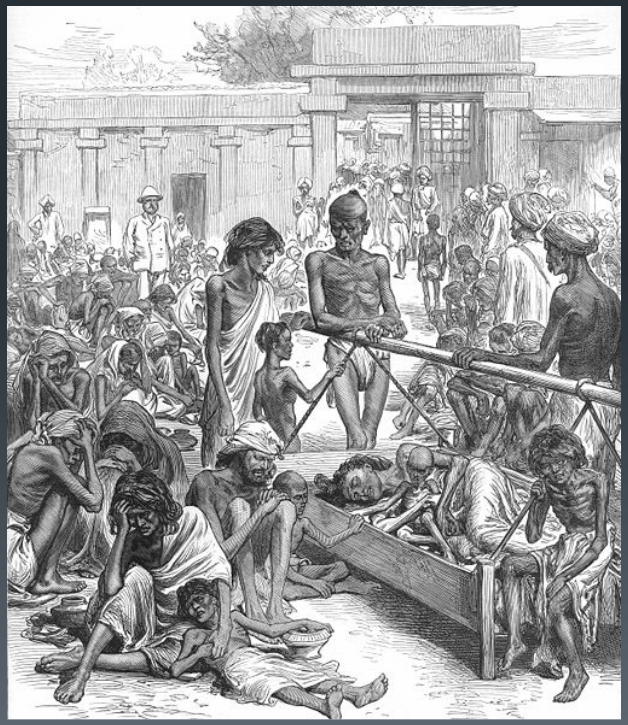
All India Annual Surface Temperature

Significant warming trend

What causes monsoon to vary from to year?

El Nino Southern Oscillation

India - great famine in 1876-78



Monsoon Variability/Prediction (Interannual)

Sir. Gilbert Walker

Head of the Indian Meteorological Service. After an 1899 famine that was caused by monsoon failure, was asked in 1904 to predict the vagaries of India's monsoons. Noticed a phenomenon associated with barometric pressure readings on the eastern and western sides of the pacific…

Meteorological Office, Pune (Built in 1928)

Long History

Blanford (1884) Himalayan Snow-Monsoon

Walker (1918,1924)

El Nino Southern Osc. (ENSO) - Monsoon

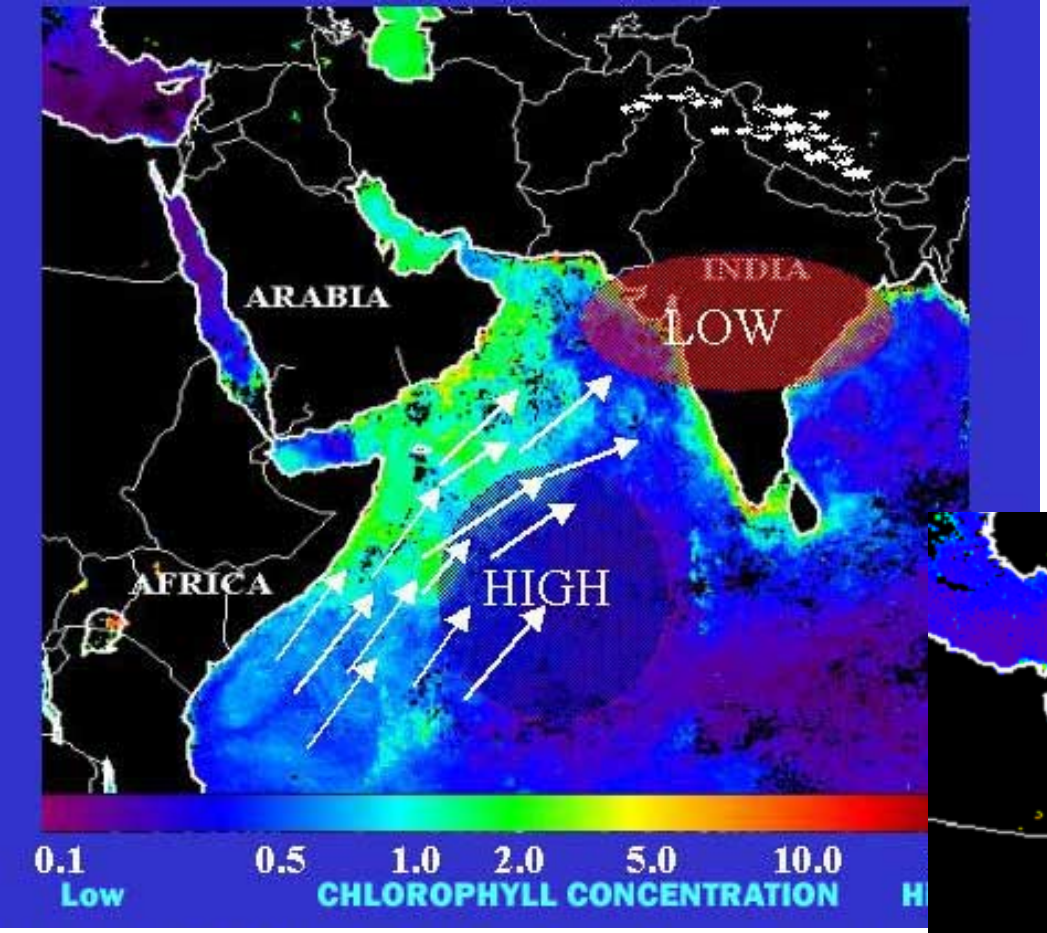
Normand (1953)

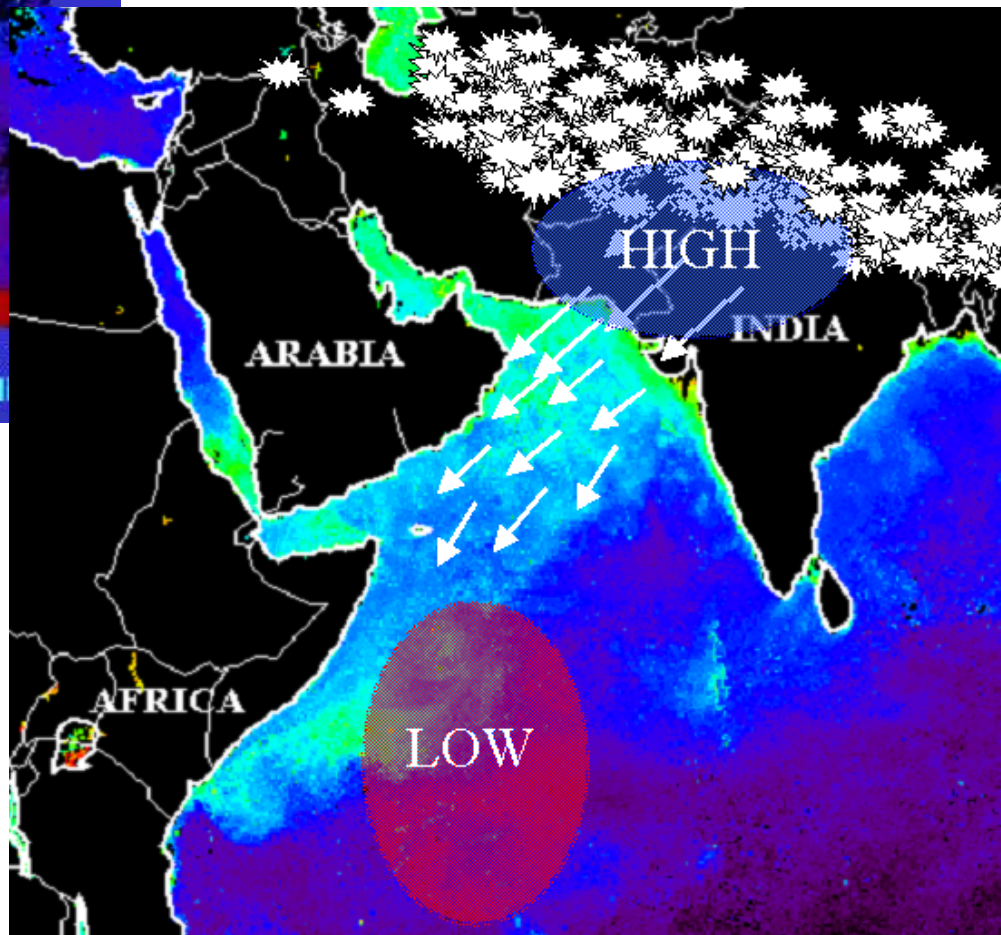
- Tibetal Plateau / Himalayan snow / Land heating

Eurasian Snowcover

- More – Weak monsoon
- Less – Strong monsoon

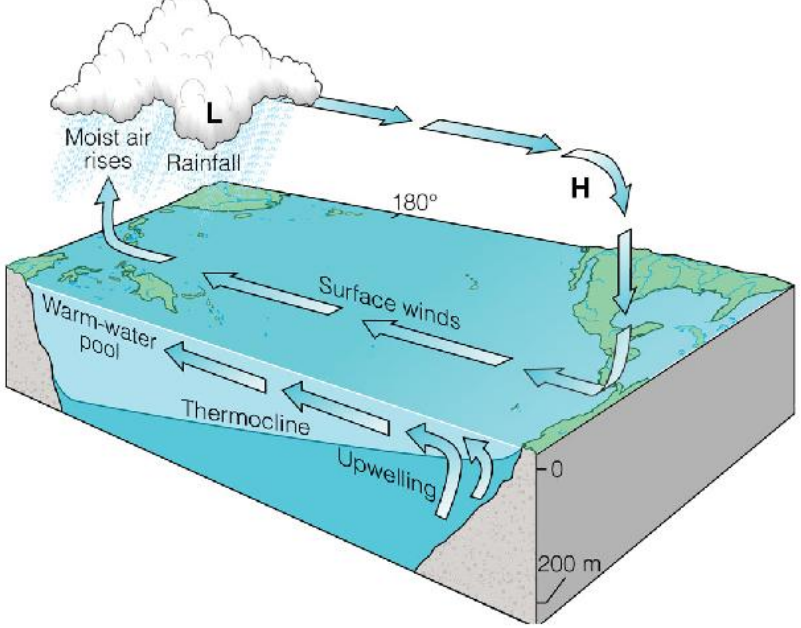
Via Land-Ocean Gradient



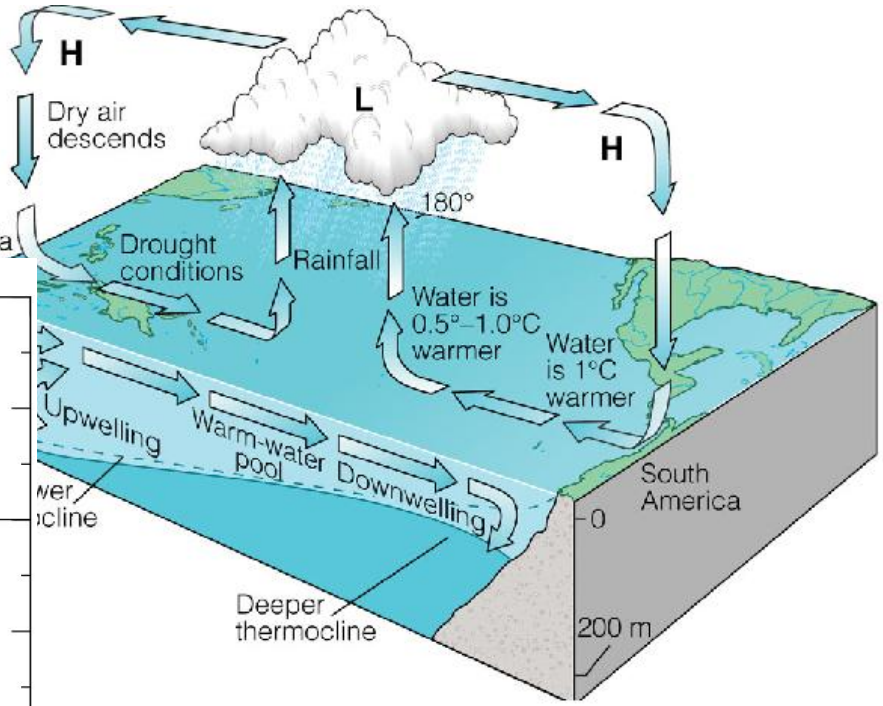


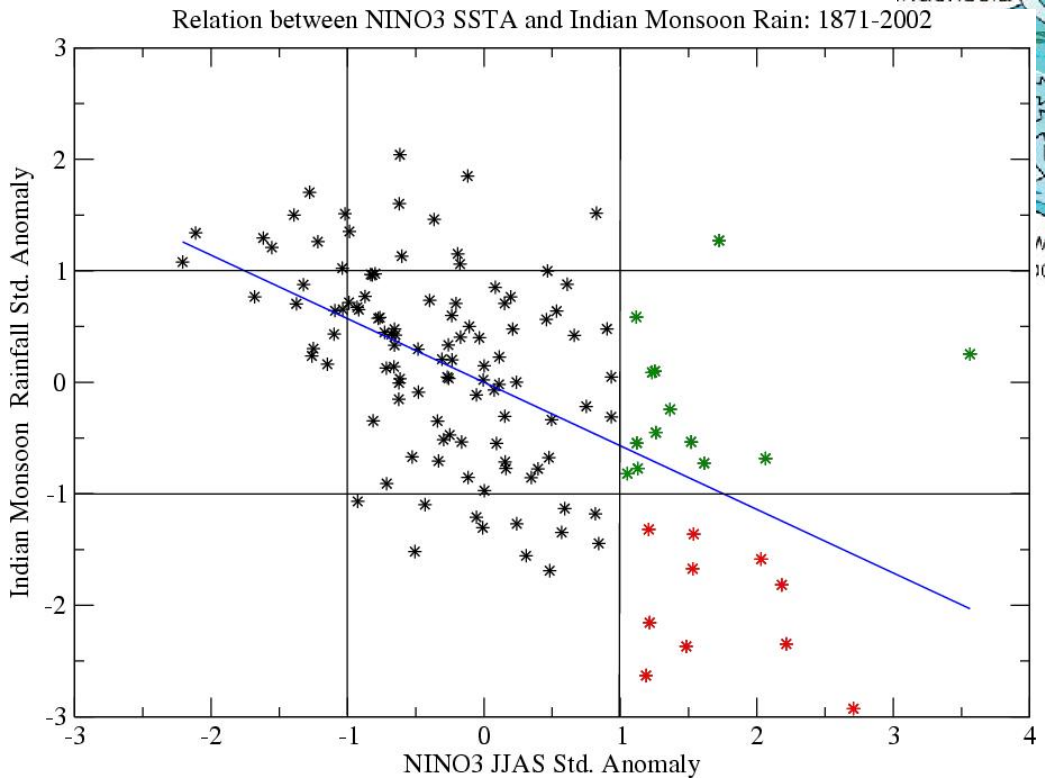
El Nino Southern Oscillation (ENSO)

Normal

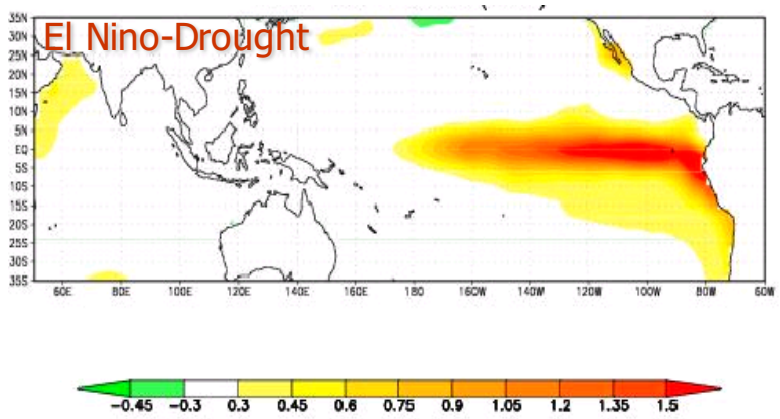


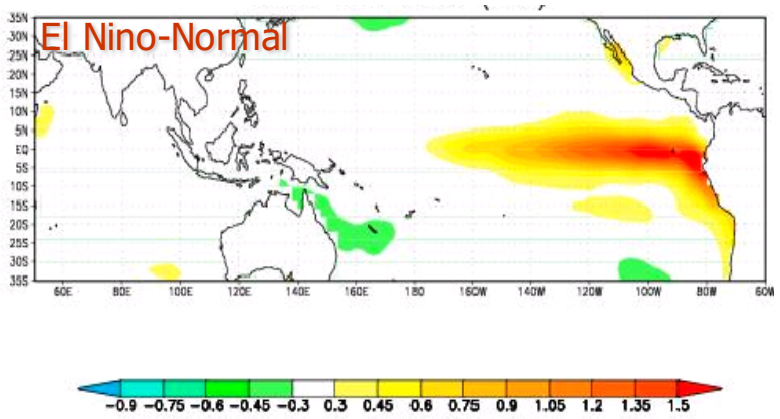
El Nino

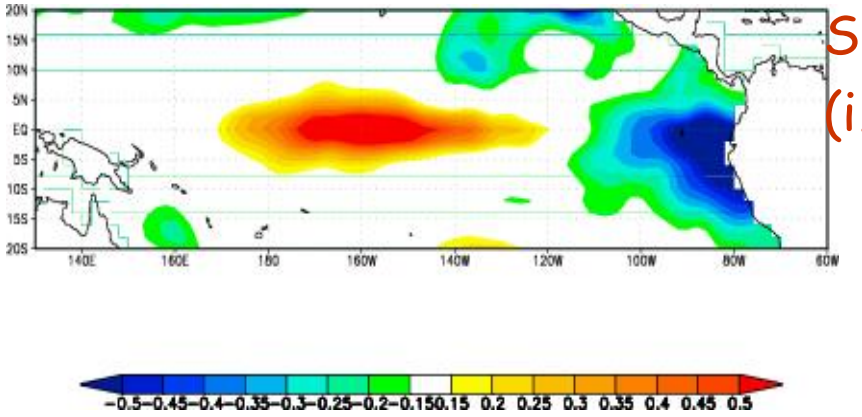




Composite SSTA of Drought (*) and Normal (*) Monsoon Years







Strength and Location of ENSO warming (i.e., "**Flavor**") Key to improved monsoon forecasting

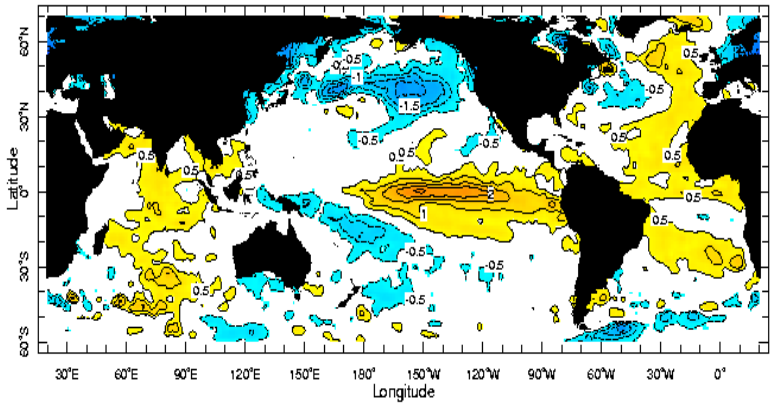
- Central Pacific warming → Indian drought
- Eastern Pacific warming → reduced impact on monsoon

KrishnaKumar et al., 2006 SCIENCE

Sea Surface Temp Anomalies: 1987 & 2002

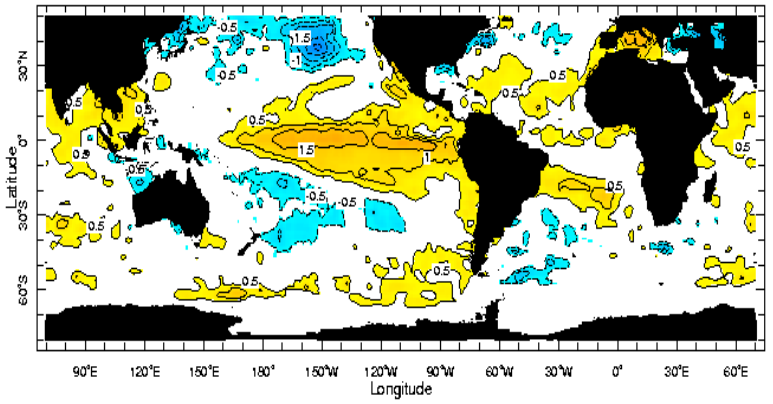
Monsoon Rainfall: -18%

JJA 87



Jun-Aug 1987

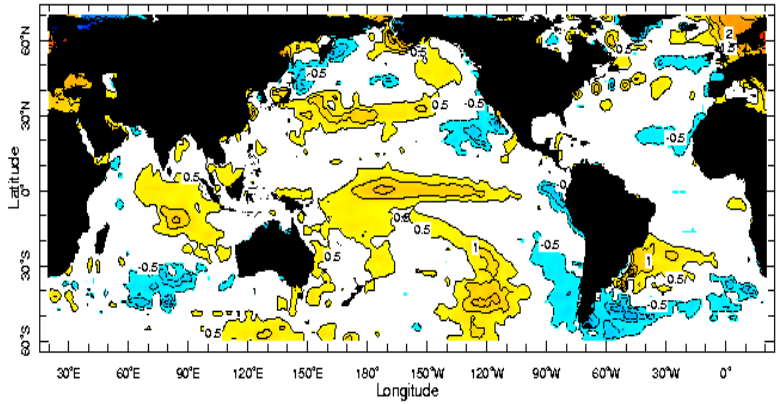
SON 87



Sep-Nov 1987

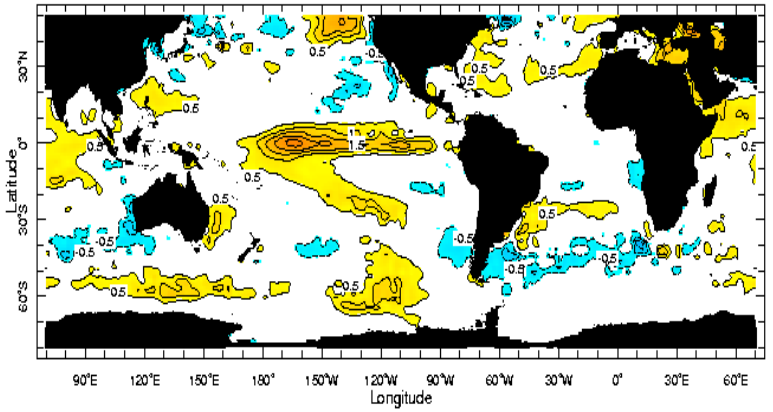
Monsoon Rainfall: -19%

JJA 02



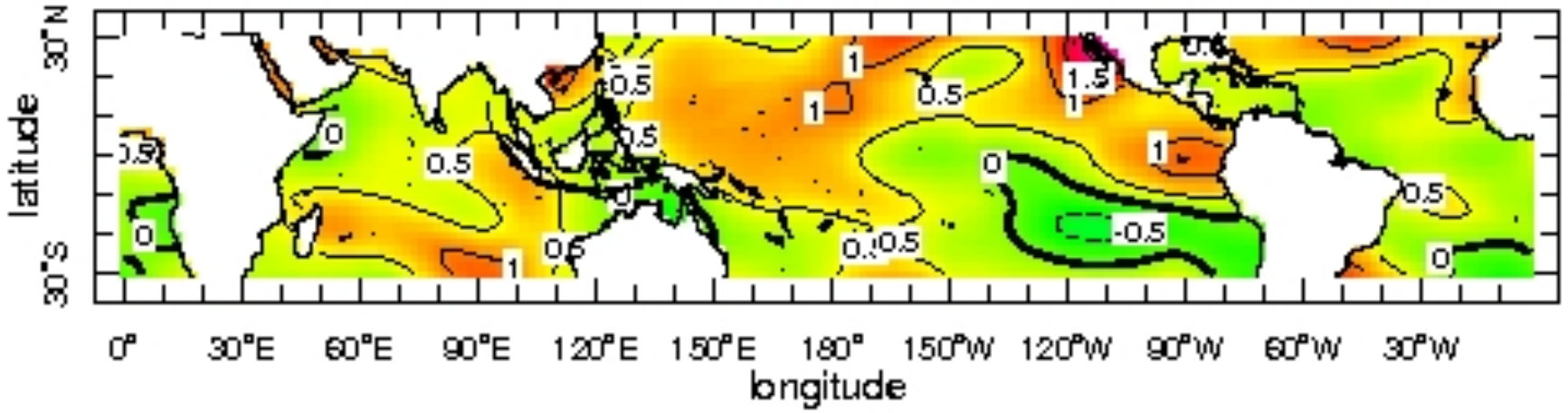
Jun-Aug 2002

SON 02

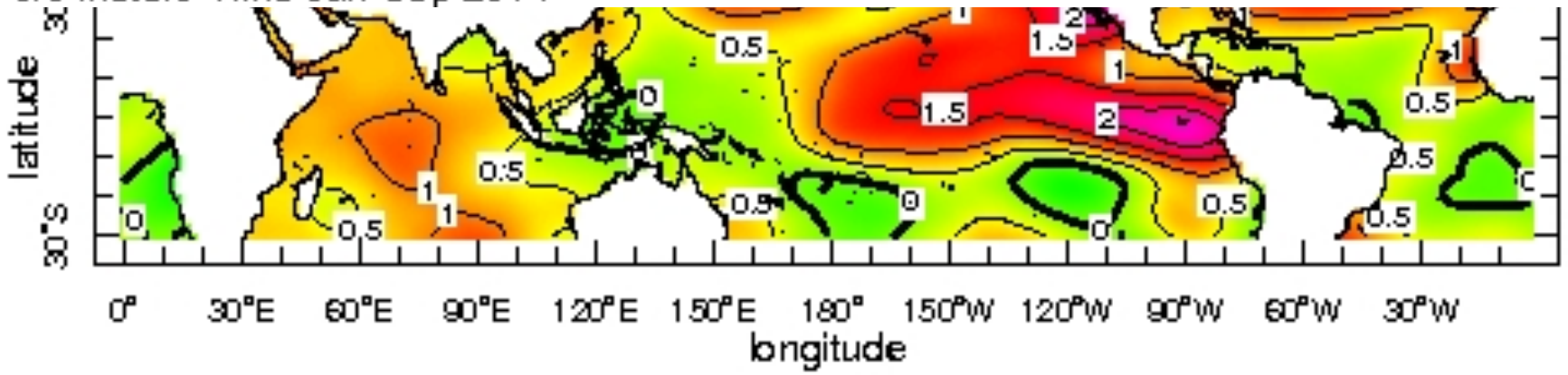


Sep-Nov 2002

Recent Years
Jun-Sep 2014, 2015



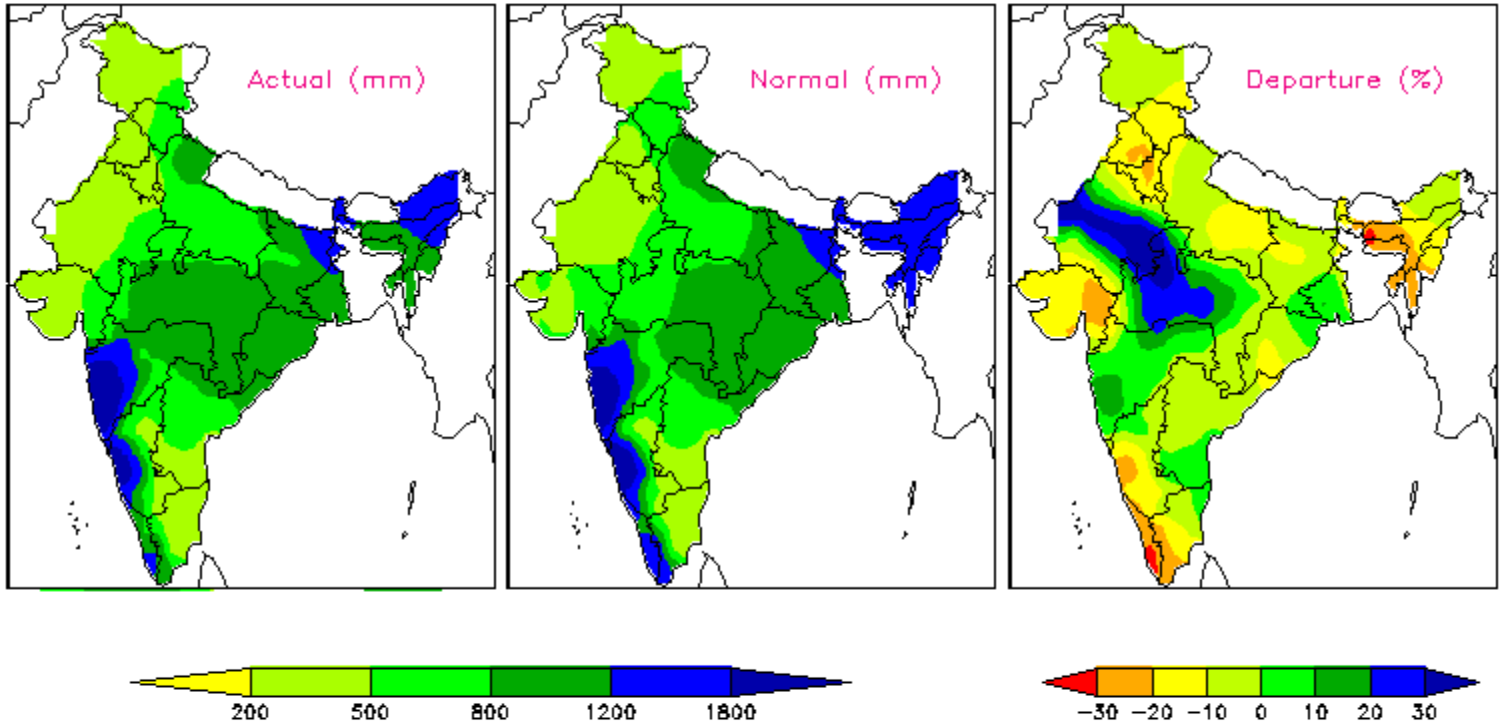
zlev 0.0 meters Time Jun-Sep 2014



zlev 0.0 meters Time Jun-Sep 2015

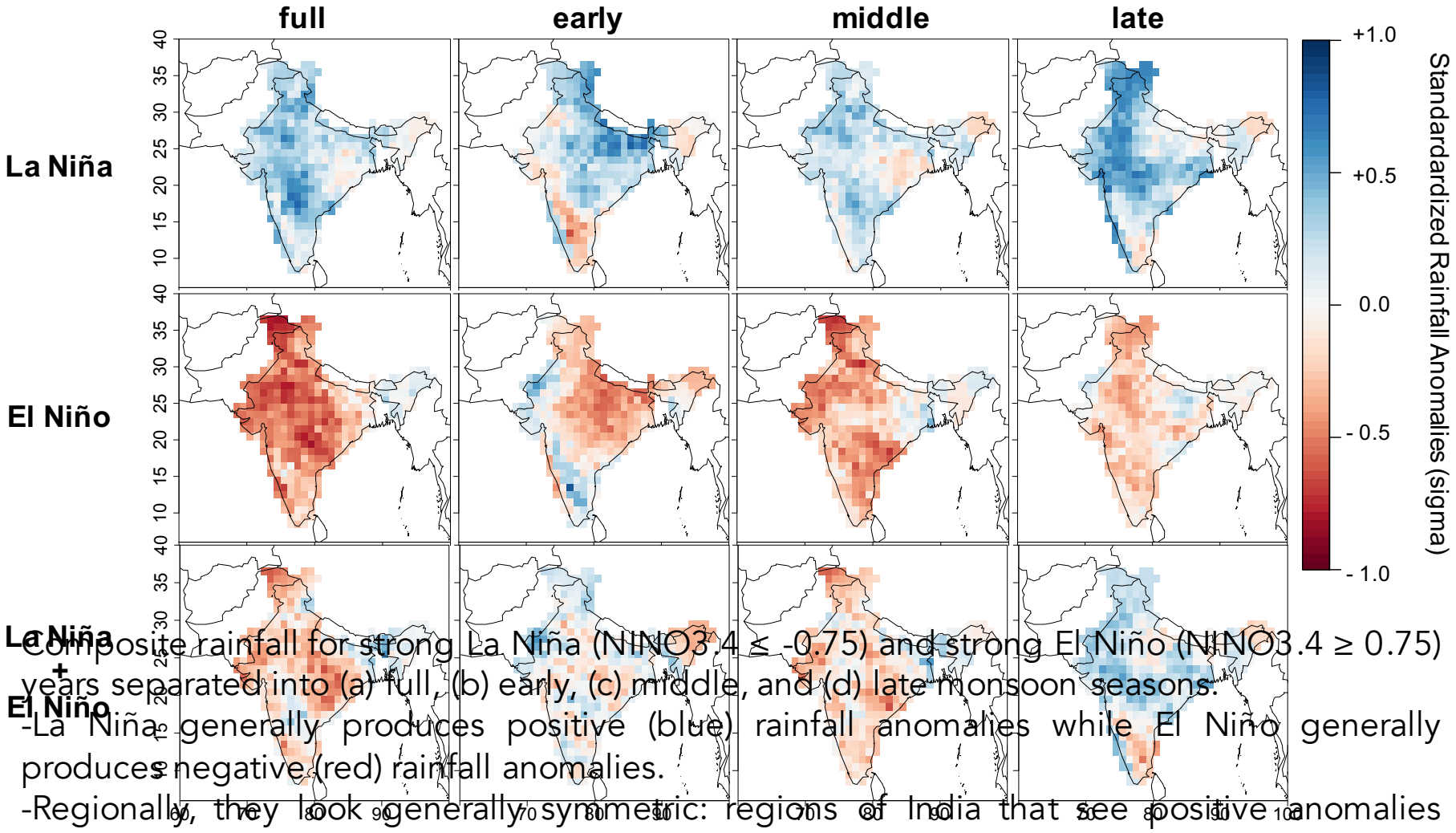
- Eastern Pacific warming
- But considerable central Pacific warming
  - Conducive for droughts over India
  - ~15% deficit (15); ~8% deficit (14)

RAINFALL FOR THE PERIOD JUN 01 TO SEP 07, 2016



- Negative ~3.5%
- But considerable central Pacific warming
  - Conducive for droughts over India
  - ~15% deficit (15); ~8% deficit (14)

Asymmetry in the monsoon-ENSO teleconnection



Composite rainfall for strong La Niña (NINO3.4 ≤ -0.75) and strong El Niño (NINO3.4 ≥ 0.75) years separated into (a) full, (b) early, (c) middle, and (d) late monsoon seasons.

-La Niña generally produces positive (blue) rainfall anomalies while El Niño generally produces negative (red) rainfall anomalies.

-Regionally, they look generally symmetric: regions of India that see positive anomalies during La Niña tend to see negative anomalies during El Niño.

Asymmetries in the monsoon-ENSO teleconnection, however, are apparent in the magnitudes of positive and negative anomalies between La Niña and El Niño, respectively. Summing the rows highlights the asymmetry.

Gill et al., 2015, *JGR*

Land surface and the ISM

Increased pre-monsoon Irrigation

↓

Increased Vegetation, NDVI

↓

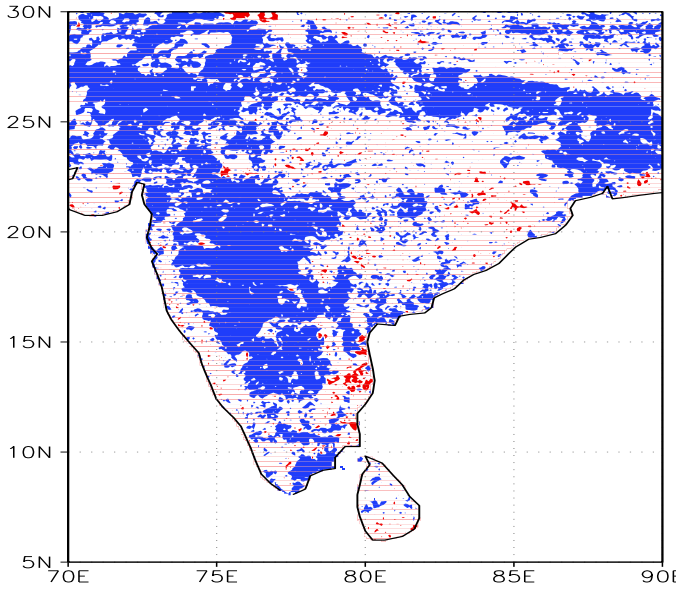
Increased Atmospheric moisture → Increased Pre-monsoon rainfall & Seasonal shift

↓

Decreased land-sea temperature contrast

↓

Decreased monsoon (July-Sep) Rainfall



MAM

NDVI Trends – blue = sig. increasing trend

Lee et al., (2009), Int. Journal of Climatology

Future Monsoon Pulse

Under warmer climate in the future what happens to the monsoon variability?

Will there be a tipping?

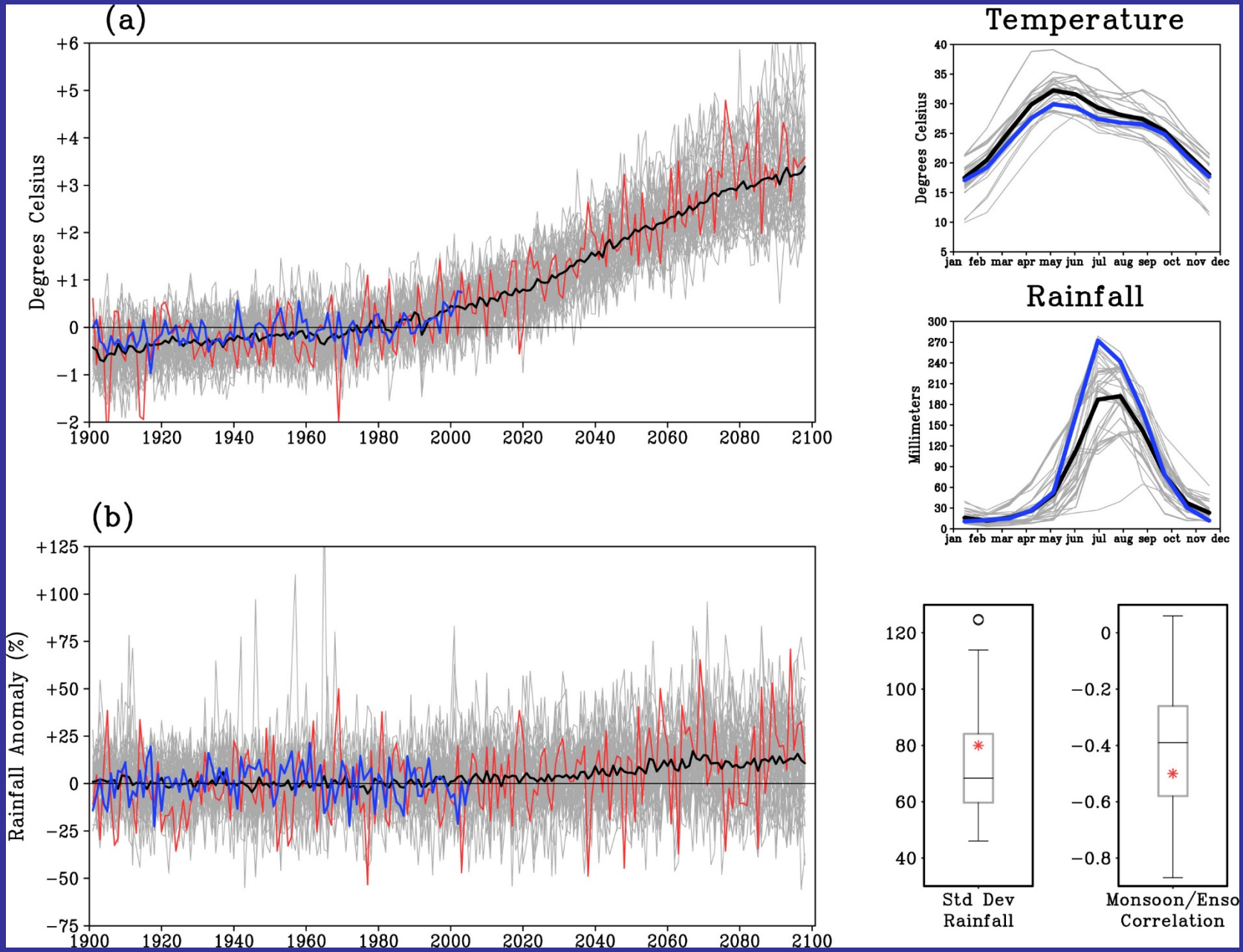
IPCC AR4 simulations

22 GCM, 48 ensemble members

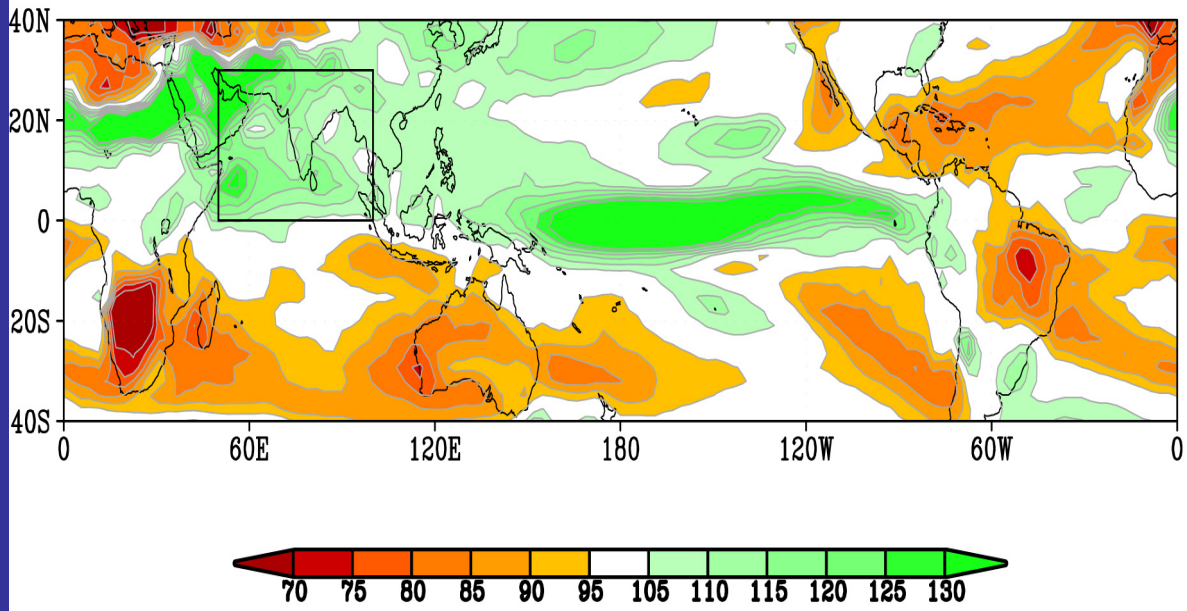
A1B scenario

UK HadCM model (PRECIS) for downcsaling

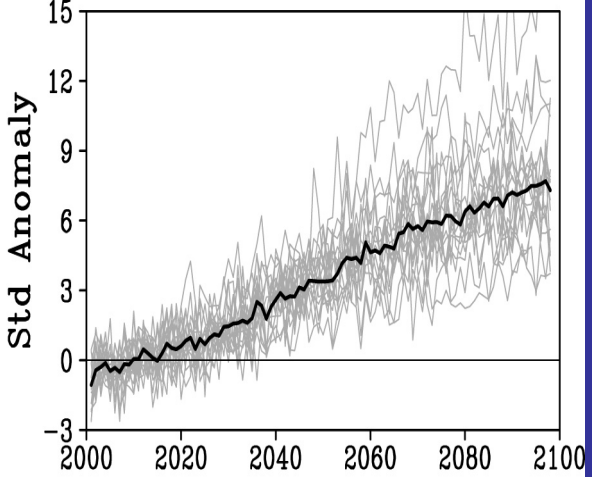
Sir. Gilbert Walker


(a)
Degrees Celsius
+6
+5
+4
+3
+2
+1
0
−1
−2
1900
1920
1940
1960
1980
2000
2020
2040
2060
2080
2100
(b)
Rainfall Anomaly (%)
+125
+100
+75
+50
+25
0
−25
−50
−75
Temperature
Degrees Celsius
40
35
30
25
20
15
10
5
jan feb mar apr may jun jul aug sep oct nov dec
Rainfall
Millimeters
300
270
240
210
180
150
120
90
60
30
0
Std Dev
Rainfall
120
100
80
60
40
Monsoon/Enso
Correlation
0
−0.2
−0.4
−0.6
−0.8

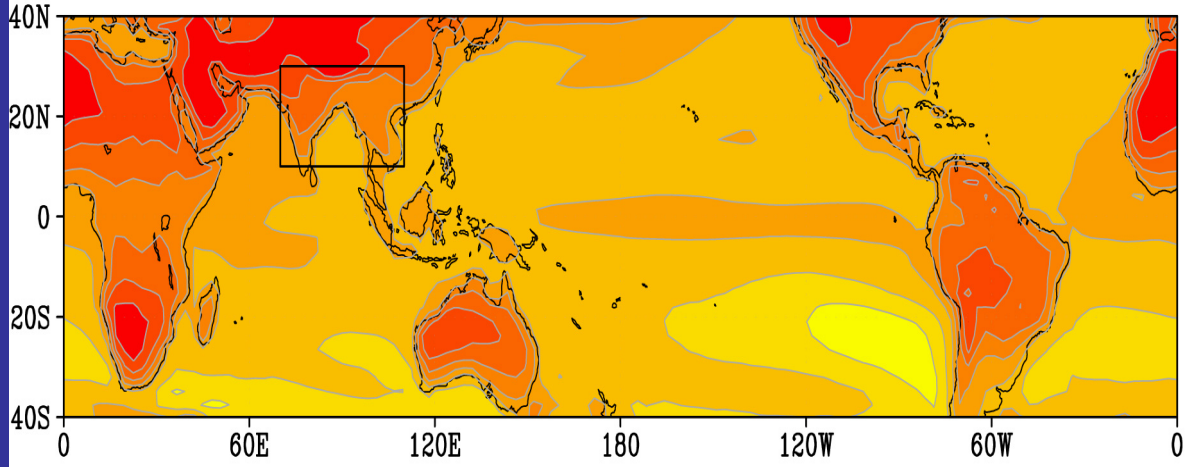
(a) % change in precip. during 2070-98 w.r.t. 1961-90



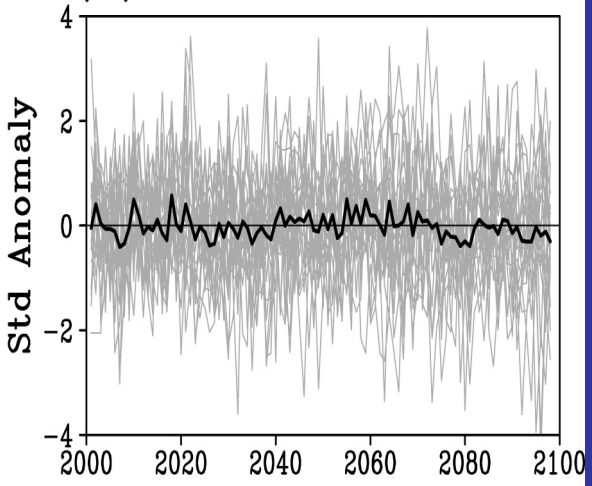
(c) Pcp. Water



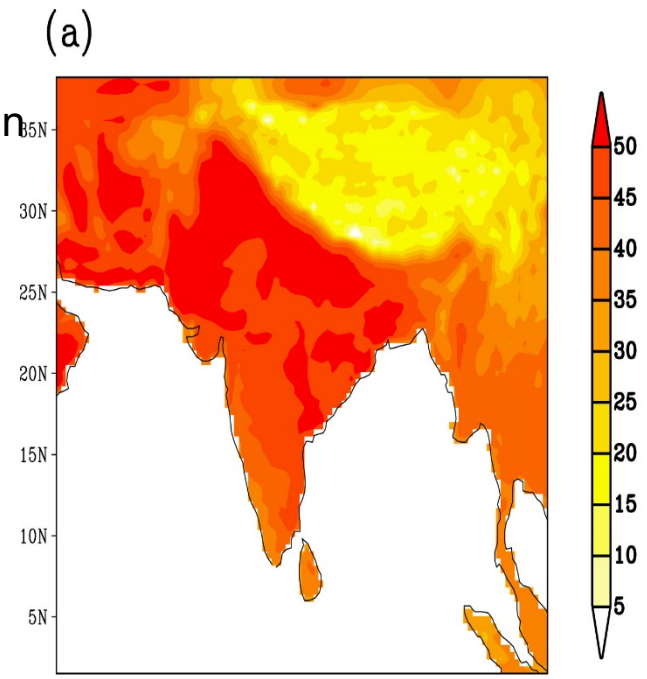
(b) Annual Temp. change during 2070-98 w.r.t. 1961-90

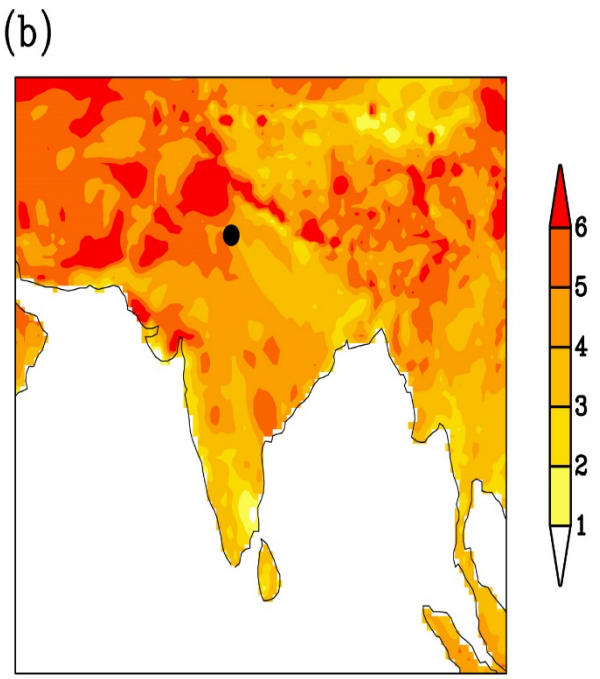


(d) Mer. Wind Index



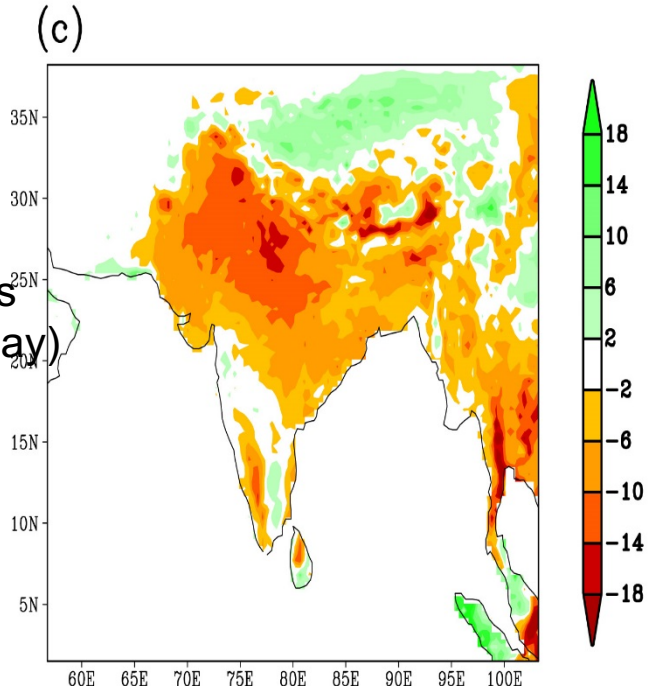
Premonsoon (Mar-Jun) Tmax for 1961-1990

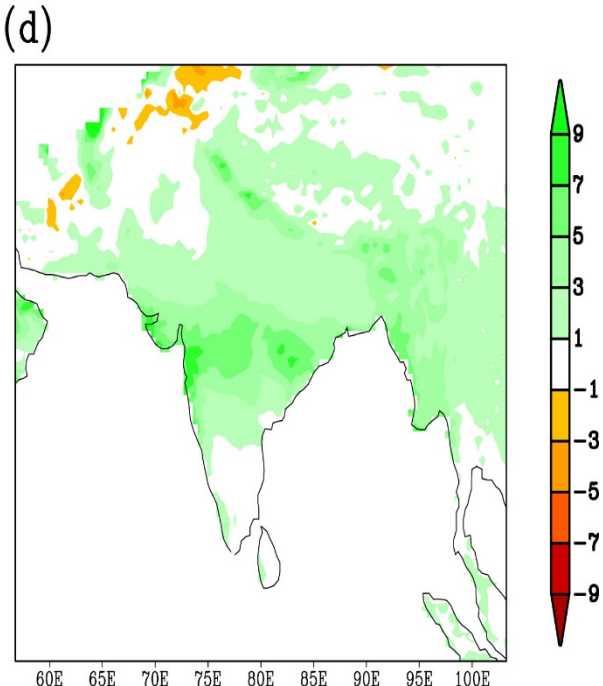




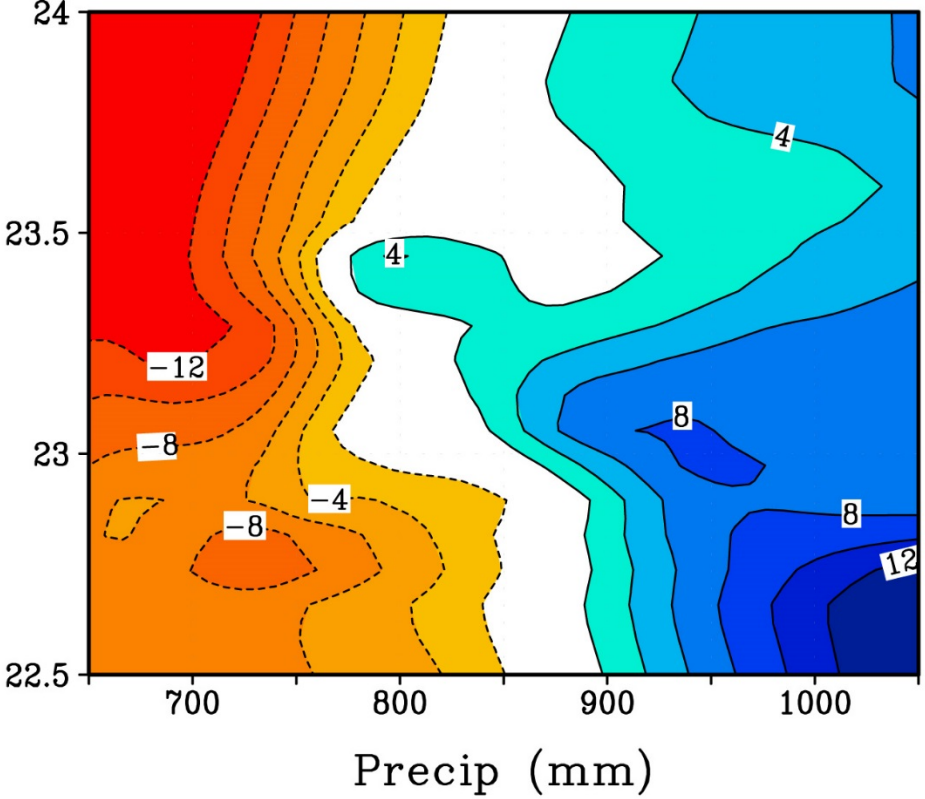
Future (2071-2100) Change w.r.t baseline (1961-1990)

rainy days (> 2.5 mm/day) 2071-2100

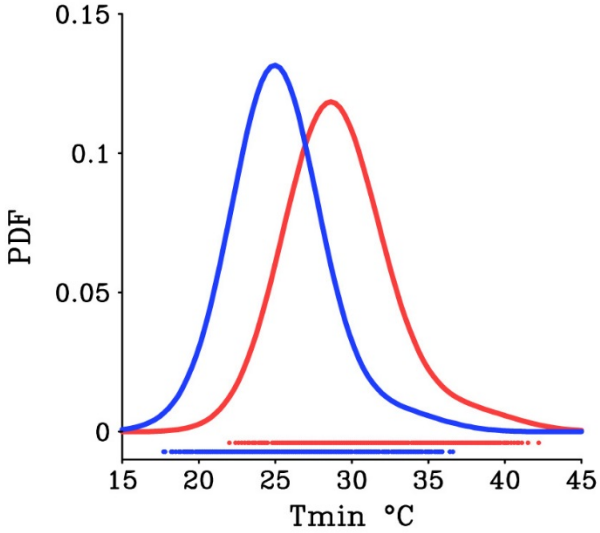




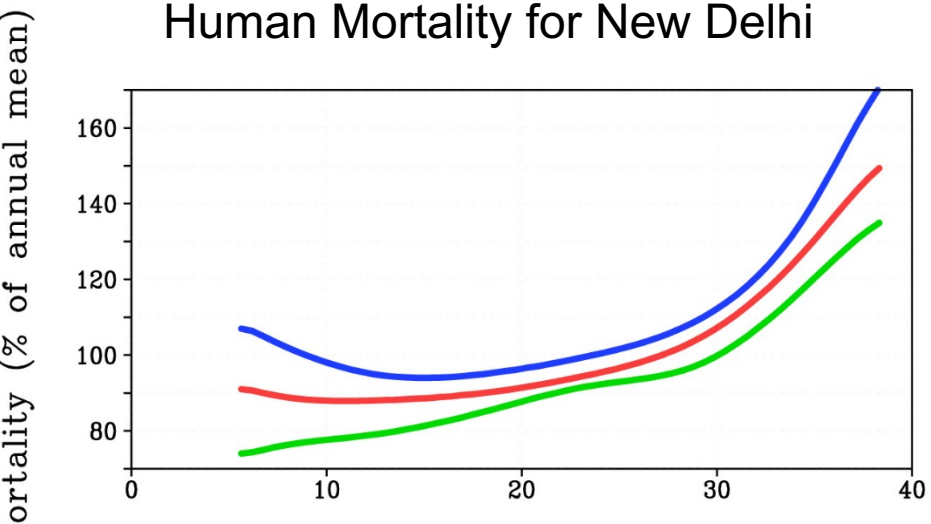
Future (2071-2100) Change in Intensity w.r.t baseline (1961-1990)

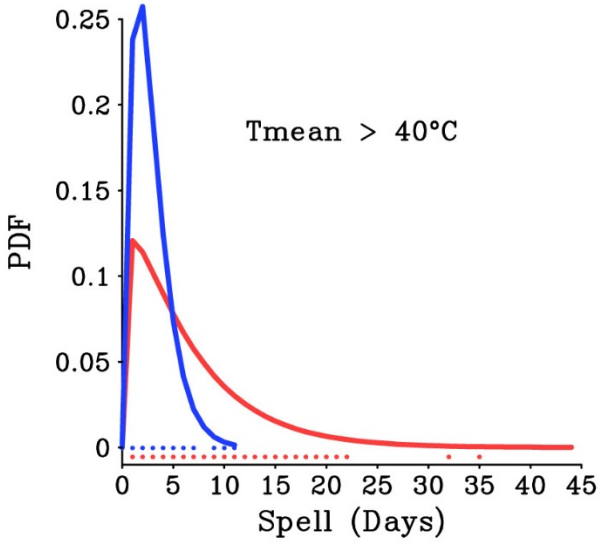


Rice Yield Change in %



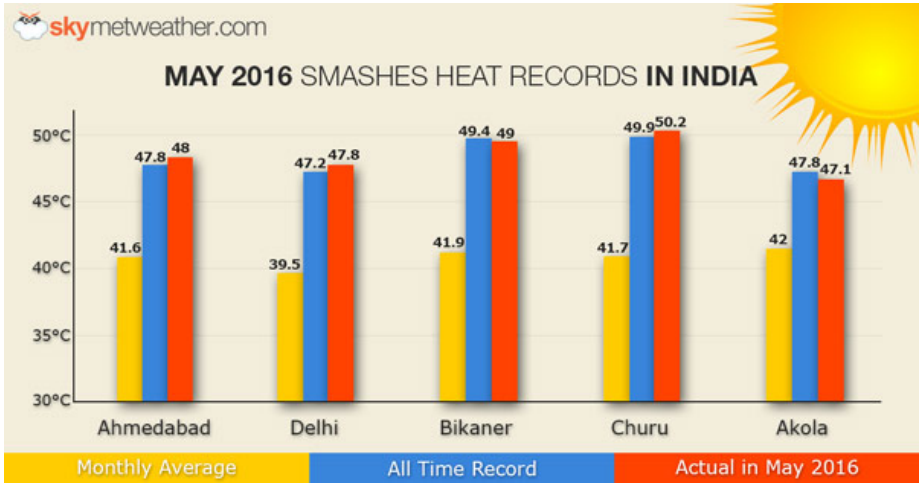
Human Mortality for New Delhi





Future Monsoon Summary

- Indian Monsoon likely to increase modestly (with a large uncertainty) in the 21st century
- Future ENSO teleconnections remain unclear
- Temperatures (both maximum and minimum) are projected to increase substantially (with smaller uncertainty)



- Increase in extreme rainfall, hot spells → significant stress on water resources, agriculture and health
- Temperature and water impacts on crop yield and health are significant

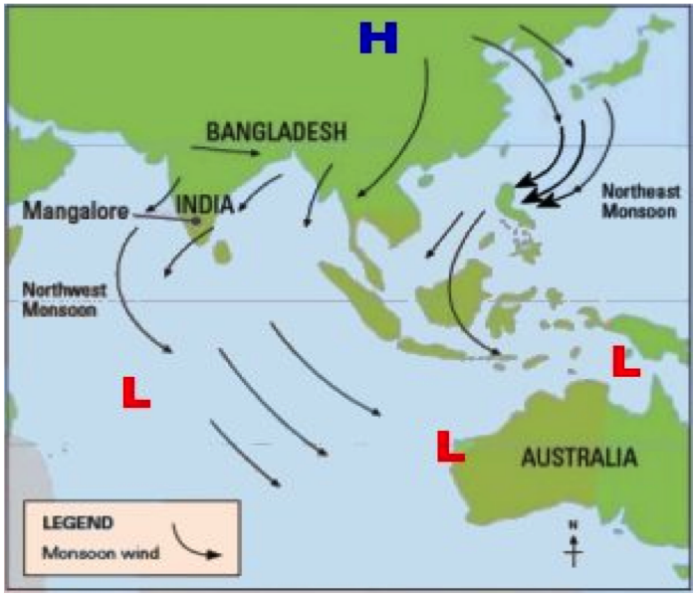
In combination has the potential for a 'societal tipping'.

K. Krishna Kumar et al. (1996, 2006) SCIENCE
K. Krishna Kumar et al. (2012, Climate Dynamics)

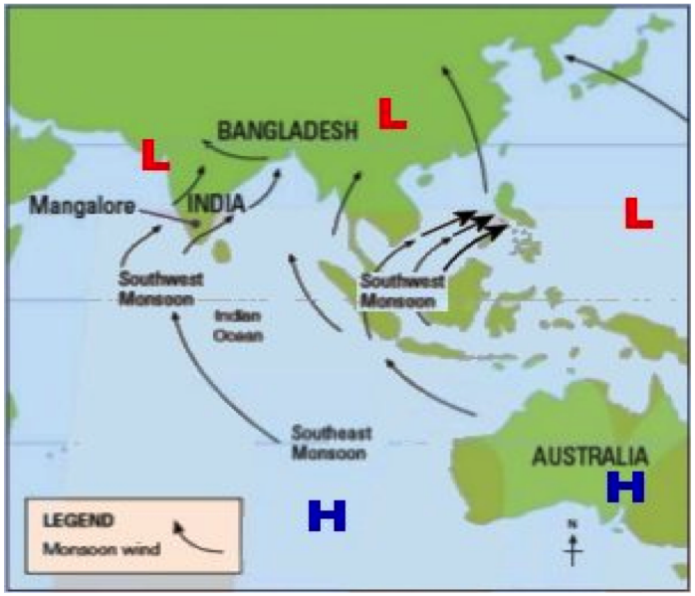
Water Management (or lack thereof)
2015 Chennai Floods

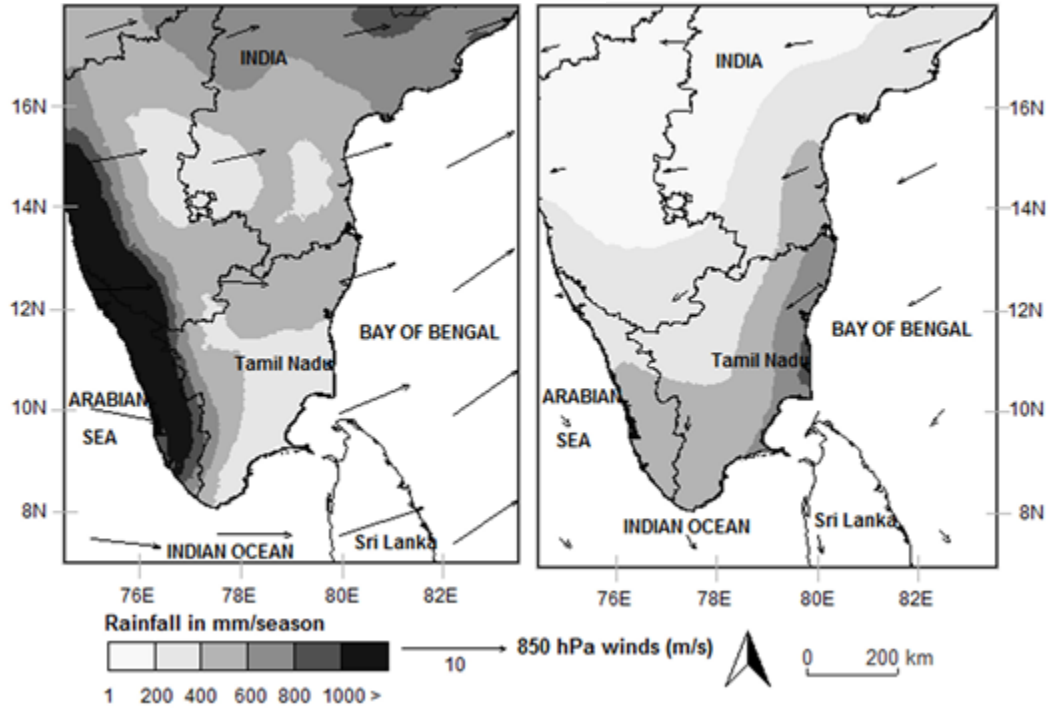
North East Indian Monsoon (Oct-Dec)

NORTHEAST MONSOON (AMIHAN)
November to March

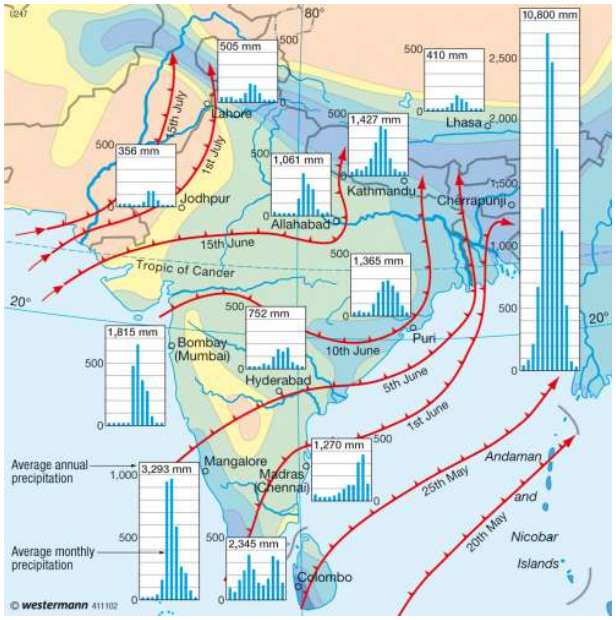


SOUTHWEST MONSOON (HABAGAT)
June to September



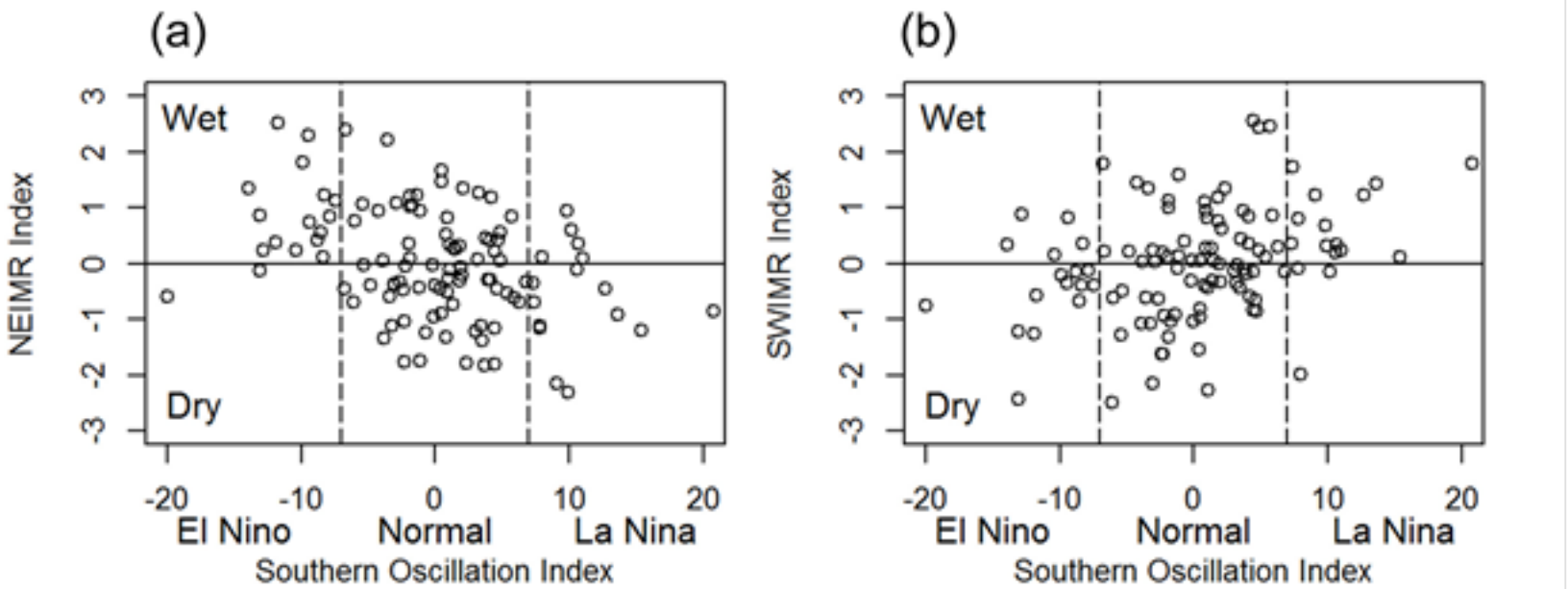


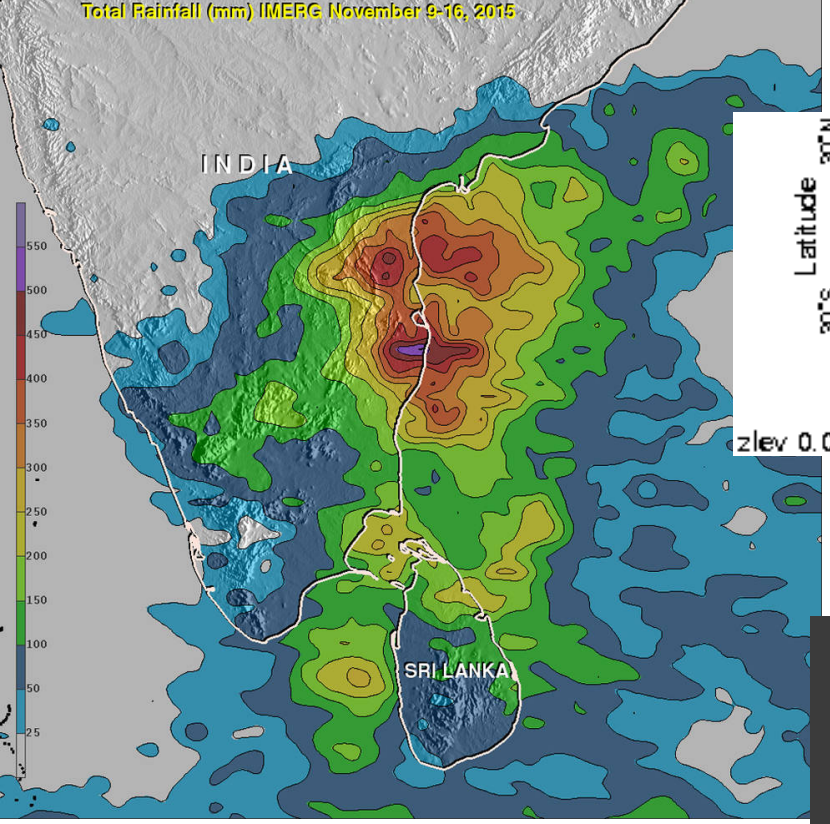
North East Indian Monsoon Interannual Variability



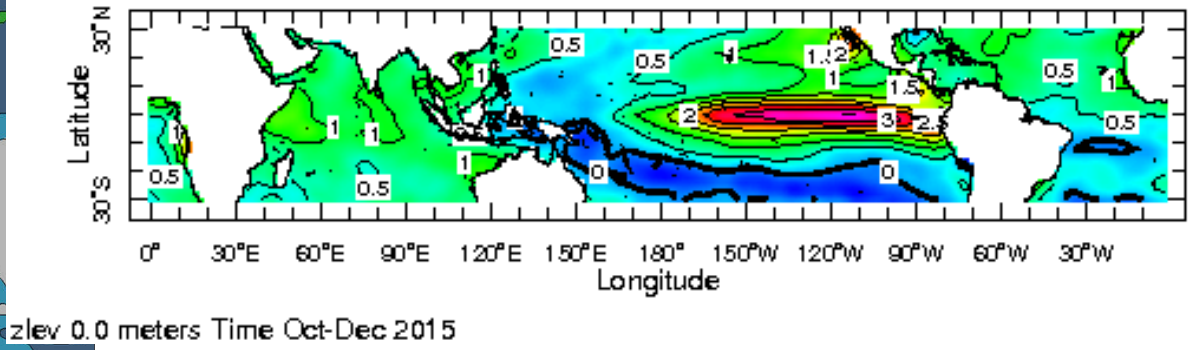
El Nino → Weaker summer monsoon

El Nino → stronger winter monsoon



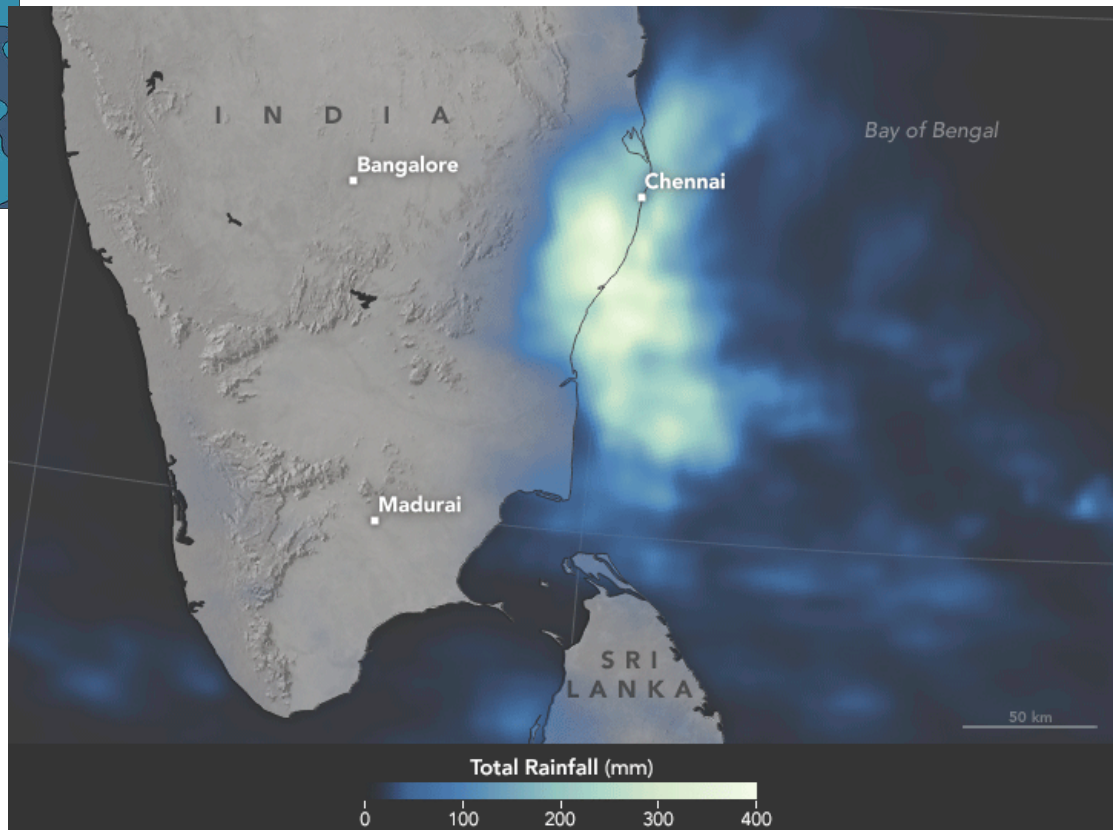


SST Oct-Dec, 2015 – El Nino



Nov 9 – 16, 2015

Nov 28 – Dec 4, 2015



https://youtu.be/DkrlykuWPYI


மழை
வெள்ளத்தில்
மூழ்கியது
பஸ்

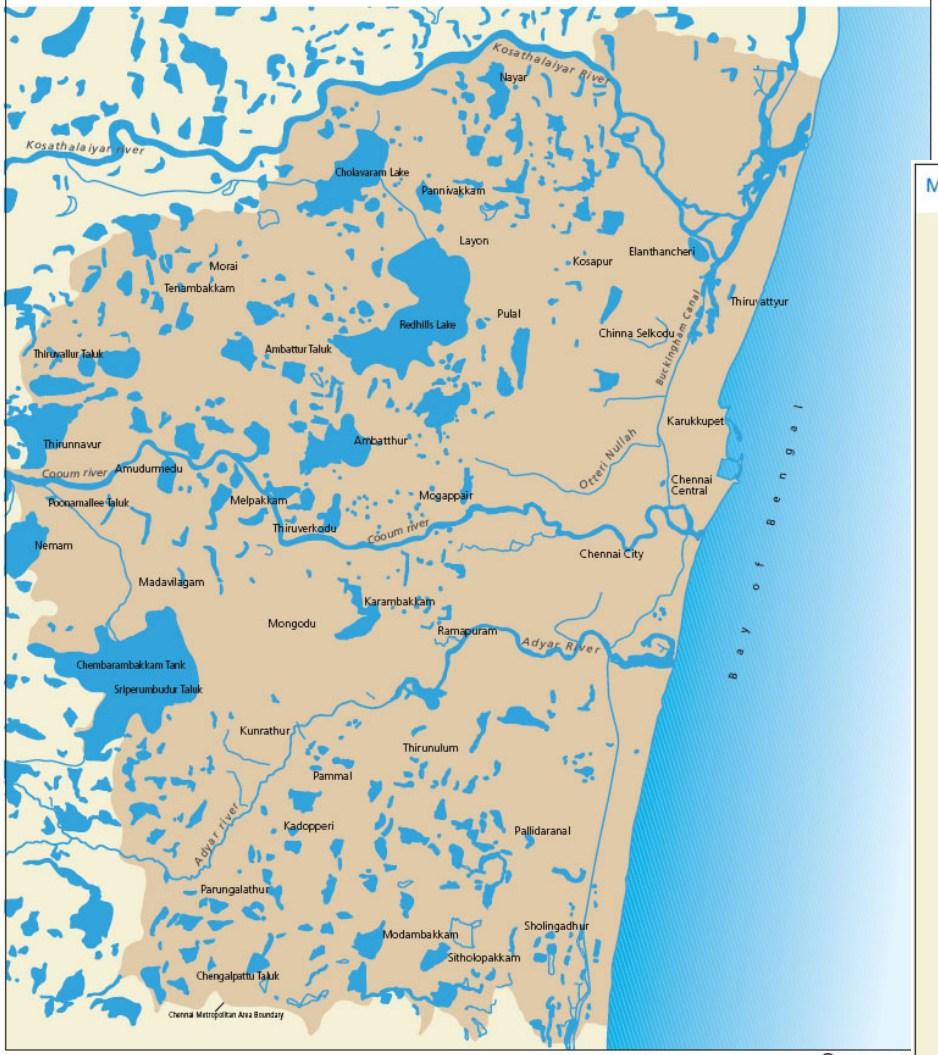

RAMCO

1. Geographical Area	: 176 Sq.Km
2. Latitude / Longitude	: 13°04' Minutes North / 80°15' Minutes East
3. Population	: 5.37 Million (2009) - Projected
4. Topography	: Flat
5. Drainage	: Adayar & Cooum Rivers
6. Average Rain fall	: 1100 mm to 1300 mm per year
7. Temperature	: 30° c to 40° c
8. Climate	: Tropical
9. Humidity	: Vary between 65% and 80%
10. Water Supply Sources	: Surface and Ground water
11. Water Supply (per day) Normal year	: 350 - 450 Mld
12. Supply Rate (Per Day per Head) (Normal year)	: 70 – 100 lpcd
13. Current Water Supply (from 2006)	: 570 Mld (Domestic 490 mld + Others 80 mld)
14. Current Supply Rate	: 91 lpcd

CHENNAI METROPOLITAN AREA (CMA)

MAP: **WATERWAYS IN CHENNAI METROPOLITAN REGION**

The entire region is literally flooded with waterbodies



Source: Anon 2006, *Development Plan for Chennai Metropolitan Area*, government of Tamil Nadu, Chennai

Enlarge Vie

MAP: **THE WASTEWATER MAZE**

The city's sewage is first pumped in a relay through its pumping station to nine STPs located in its periphery. The treated sewage is then dumped into its rivers, which flow from west to east and finally, into the Bay of Bengal. But before the sewage reaches the sea, 400-700 outfalls add untreated sewage into the waterways. By the time the rivers meet the sea, they get highly polluted, thereby defeating the purpose of operating a centralised sewerage system

Source: Anon 2011, *71-City Water-Excreta Survey, 2005-06*, Centre for Science and Environment, New Delhi

Enlarge View

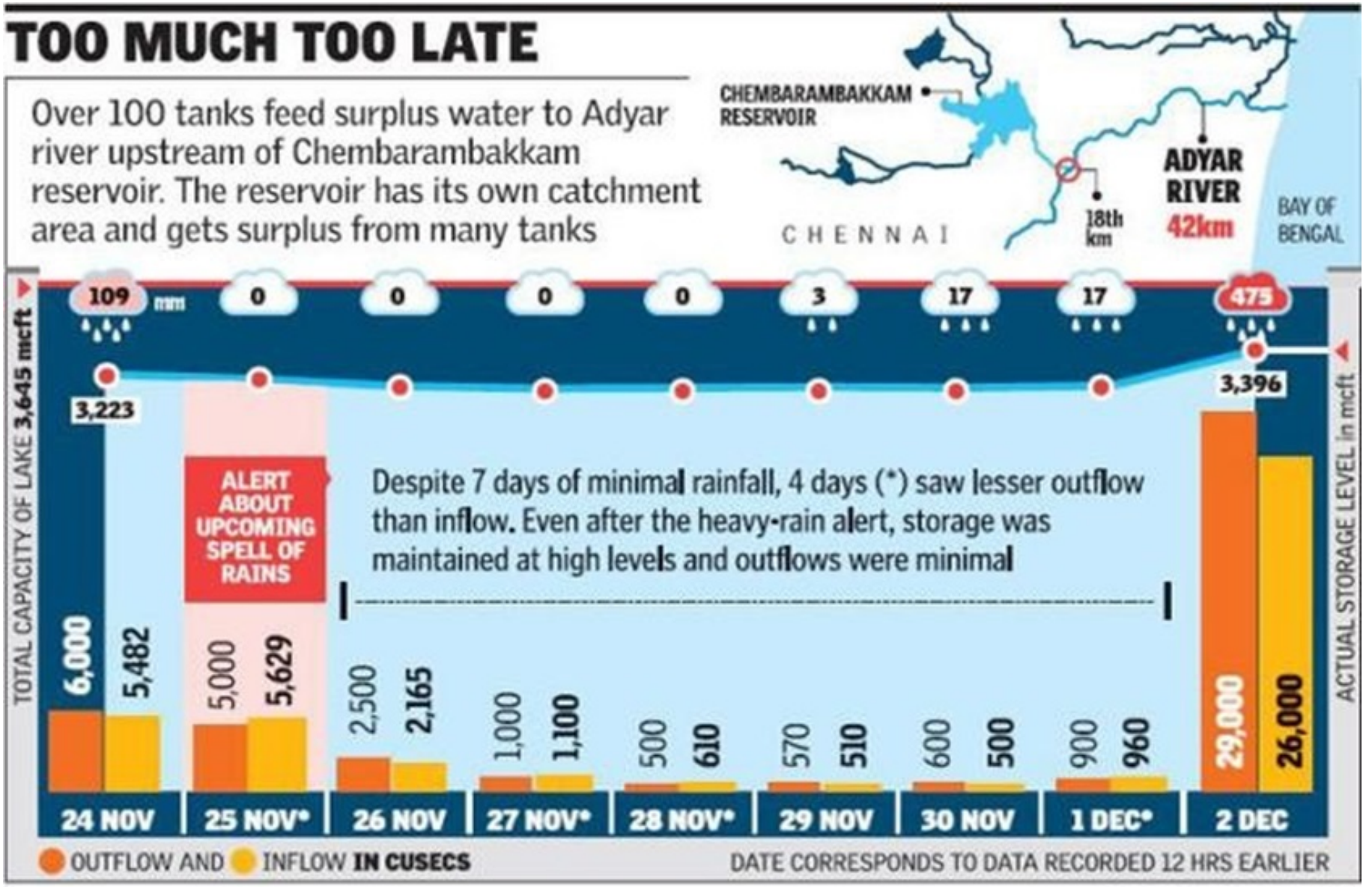
2000

2015

Massive Urbanization

Lack of Urban Planning

Mis-Management of Water Resources Leading to Massive Floods



Way Forward: Lessons from Colorado

FRONTLINE

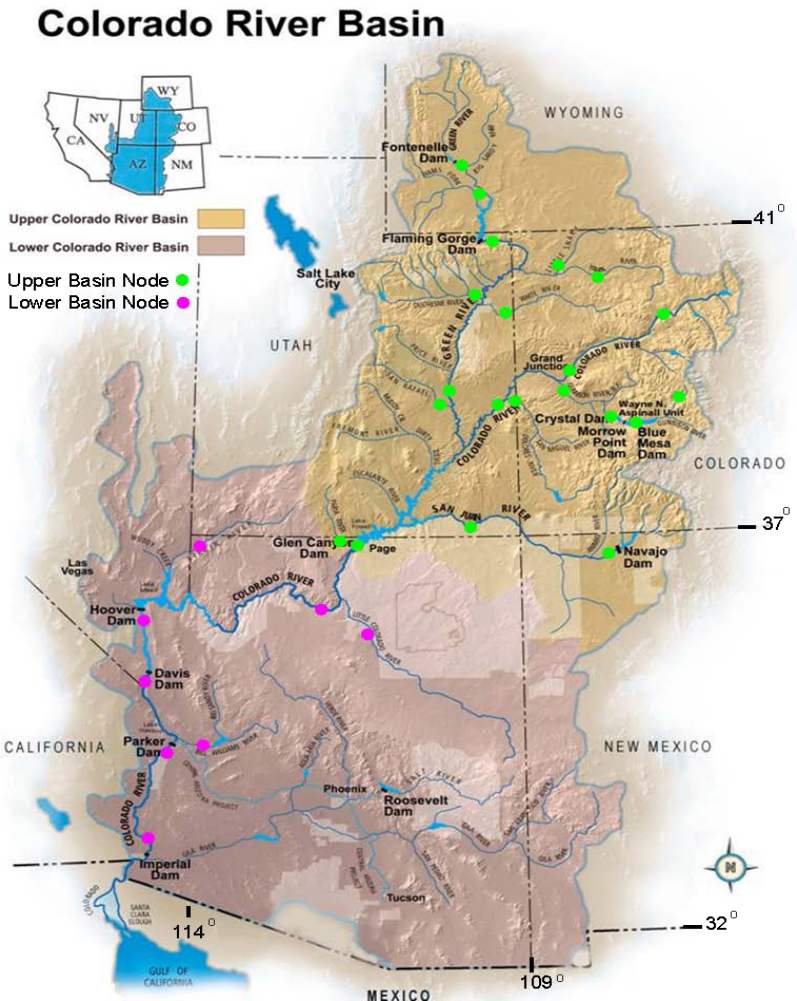
THE NATION
Published: January 6, 2016 12:30 IST | Updated: January 5, 2016 15:28 IST
WATER RESOURCES

Lessons from Colorado

A plan for sustainable management strategies drawing from experiences in the Colorado River Basin in western U.S. By BALAJI RAJAGOPALAN

Lessons from Colorado River Basin Management

- Holistic Approach
  - River Basin Management
    - Rivers Don't Respect Boundaries'
- Data Management
  - If you can't measure you can't manage
- Participatory Management
- Transparency
- Capacity Building
  - The future is in our classrooms



Challenges / Needs

- Impacts of Year to Year Climate Variability is enormous
  - Need for skillful predictions
- Poor Infrastructure likely to be overwhelmed with climate extremes
- Near term forecast of climate extremes is crucial
  - Short term Floods (like Chennai Floods), Heat waves etc.
- **Data Collection and Management**
- Science based policy
- Overcoming culture and tradition and tradition in developing robust natural hazard mitigation strategies

Dig the well before you are thirsty!