Increasing droughts and floods over India — source, mechanism and predictability

Increasing Droughts and Extreme Rainfall events over central India
IMD Rainfall data, 1950-2015

(a) Trend in mean precipitation
(b) Trend in the frequency of extreme events

Prof. R. Ananthakrishnan Seminar
28 March 2018
Some background…

Goswami et al. analysis using IMD 1x1deg data

Our analysis using IMD 0.2x0.25deg data, compared with Goswami et al.

Many of these studies explored the changes in the extreme events, but do not provide a step-by-step mechanism on how the extreme rains are increasing. Their suggestions

> Indian Ocean is warming
> local temperature/moisture is increasing

Goswami et al. Science 2006; Rajeevan et al. GRL 2008
"Widespread" Extremes

Widespread extremes:
1. Extreme rain events (above 150 mm/day)
2. Over a large homogenous region over central India
3. Typically lasts for 2-3 days

Affected area: > 500,000 km²
> 500 million people (larger than US population)

e.g., Mumbai Floods, 2005

25 July 2005
26 July 2005
27 July 2005

Roxy et al, Nature Communications, 2017
"Widespread" Extremes – Recent Floods – Aug 2016

a) Widespread very heavy rains on 02/Aug/2016

b) Trend in frequency of extreme events

2 Buses, Unknown No. Of Cars Plunge Into Raging River At Night
Over 20 feared dead as bridge on Goa-Mum highway washed away

Assam floods: 218 animals including 17 rhinos, 166 hog deer dead in Kaziranga

Assam floods: Of over 100 animals rescued by forest guards, NGOs and local people, 18 including eight rhinos are currently undergoing treatment at the CWRC, the country's only wildlife field hospital in Kaziranga.
"Widespread" Extremes

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We see a three-fold rise in widespread extremes
A couple of studies (Krishnamurthy et al. (2009), Ghosh et al. (2011), debated the validity of claims by Goswami et al. (2006).

The issue comes when you analyze the extremes using a rigid box over central India.

Precipitation, moisture and depressions are going down

> How are the extremes increasing despite a decrease in total rainfall, humidity and depressions?  
> Where is that extra moisture coming from?

![Graphs showing trends in precipitation, specific humidity, and depressions over time.](image-url)
Precipitation, moisture and depressions are going down

> How are the extremes increasing despite a decrease in total rainfall, humidity and depressions?
> Where is that extra moisture coming from?

Roxy et al, Nature Communications, 2017; Mukhopadhyay et al., Springer 2017
Goswami et al. (2006) and others attributed it to rising central Indian Ocean SSTs – which provide more moisture for the extreme rain events.

Correlation analysis need not indicate the cause. The high correlation may be because both (extreme and SSTs) show a monotonic increase.

In fact, the humidity anomalies over the central Indian Ocean show an insignificant correlation – which means that though increased SSTs result in more moisture, it does not get transported to the Indian subcontinent – due to a weakened monsoon circulation.
What is behind the rise in Extreme rains? Local Temp?

Correlation: Surface temp. Vs Extreme events
Correlation: Specific humidity Vs Extreme events

Roxy et al, Nature Communications, 2017 Fig. S2
What is the cause and where’s the moisture coming from?

Composite evolution of vertically integrated moisture transport and specific humidity shows:
(a) an increase in humidity over northern Arabian Sea,
(b) accompanied by a spurt in moist westerlies,
(c) and then by a short-lived low (cycir)

Note: Earlier studies did not use daily data to understand the mechanism behind extreme rains
Why is there a surge in moist westerlies prior to the extreme?

**Mechanism:**
Warm surface temperature anomalies appear north of Arabian Sea, prior to a widespread extreme event. This increases the pressure gradient between north and south of Arabian Sea, and intensifies the low-level westerlies.

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**a** Composite evolution of SST anomalies

-18 days

-9 days

0 day

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**b** Composite evolution of air temperature (850-500 hPa) anomalies

-18 days

-9 days

0 day

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**c** Composite evolution of MSLP and wind (850-500 hPa) anomalies

-18 days

-9 days

0 day
Why is there a surge in moist westerlies prior to the extreme?

Mechanism:
Warm surface temperature anomalies appear north of Arabian Sea, prior to a widespread extreme event. This increases the pressure gradient between north and south of Arabian Sea, and intensifies the low-level westerlies.
Historical Floods

Historical floods show similar evolution – warm north Arabian Sea SSTs, increase moisture transport from Arabian Sea and widespread central Indian precipitation

Precipitation, SST and vertically integrated moisture transport during widespread extreme rainfall events

24 July 1989 Floods

18 July 2000 Floods

26 July 2005 Floods

7 August 2007 Floods
Historical Floods – Role of low pressure systems?

Moisture contribution from different sources during flood years

- Arabian Sea
- Bay of Bengal
- Central Indian Ocean
- Central India

Individual events also show moisture contribution from Arabian Sea, and less from low pressure systems.
We used a Dynamic Recycling Model (DRM) based on a Lagrangian trajectory approach, where the water vapor prior to precipitation over a region is traced backward in time and the contribution from each source is quantified.

**Important moisture contribution from Arabian Sea, and from moisture recycling!**
So why are these widespread extremes increasing?

Increasing "daily" variability in the moist westerlies

Increase in the daily variability of precipitation

Increase in "widespread" extreme events

Trend in daily variability of moisture transport

Trend in daily variability of precipitation

Trend in frequency of extreme events
Surface Temperature Trends are increasing over the Arabian Sea.

Sea surface temperature trends

1950-2015

-1 °C 66 year

1982-2015

-1 °C 34 year

Land surface temperature trends

1950-2015

Land surface temperature trends

1982-2015
Surface Temperature Trends are increasing over the Arabian Sea.

Sea surface temperature trends:
- **1950-2015**: °C 66 year⁻¹
- **1982-2015**: °C 34 year⁻¹

Land surface temperature trends:
- **1950-2015**: °C 66 year⁻¹

Surface temperature and pressure gradient shows increasing trends. That is, conducive for increased extreme rains.
"Potential" predictability of 2-3 weeks

Warm SST leads increased moisture transport and extreme rains by about 16 days

Neena et al. 2010

(a) Predictability (days)

(b) Predictability (days)
"Potential" predictability of 2-3 weeks

Warm SST leads increased moisture transport and extreme rains by about 16 days

Excerpts from Neena et al. 2010:
- Active to Break Phase
- Break to Active Phase

Graphs illustrating correlation coefficients between SST, VIMFU, and Precipitation.
Mumbai Floods - 2017

IMD forecasted recent widespread extremes 5-6 days in advance

28 August (Day 5): Heavy to very heavy rain at isolated places over Gujarat region and north rain at isolated places very likely over Uttarakhand, Odisha, Assam & Meghalaya, Nagaland, Tripura, Saurashtra & Kutch, north Madhya Maharashtra and Coastal Karnataka.
Link the met. forecasts to the Flood Model and Alert System

- Monitoring and Data
- Forecasts
- Hydrological Model
- Inundation (Flood) Model
- Alert System
"Occurrence of extreme rainfall events, primarily in the break phase of an ISO cycle, reduce the intensity of the following active phase by stabilizing the atmosphere - through a reduction in vertical shear"
The central belt is vulnerable!

Map of Adaptive Capacity shows the lowest, and Climate Change Vulnerability shows the highest over central India.

Map of Composite Vulnerability of Agriculture to Climate Change, shows largest vulnerability over central India.

O’Brien et al. 2004; Sehgal et al. 2017
A threefold rise in widespread extreme rain events over central India

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Thank You!