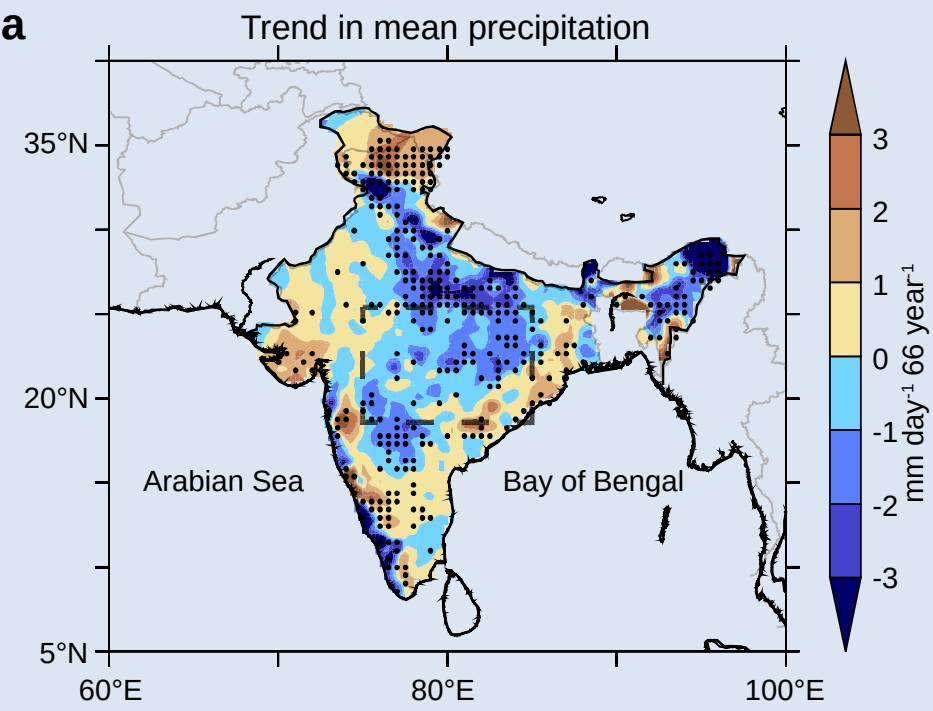
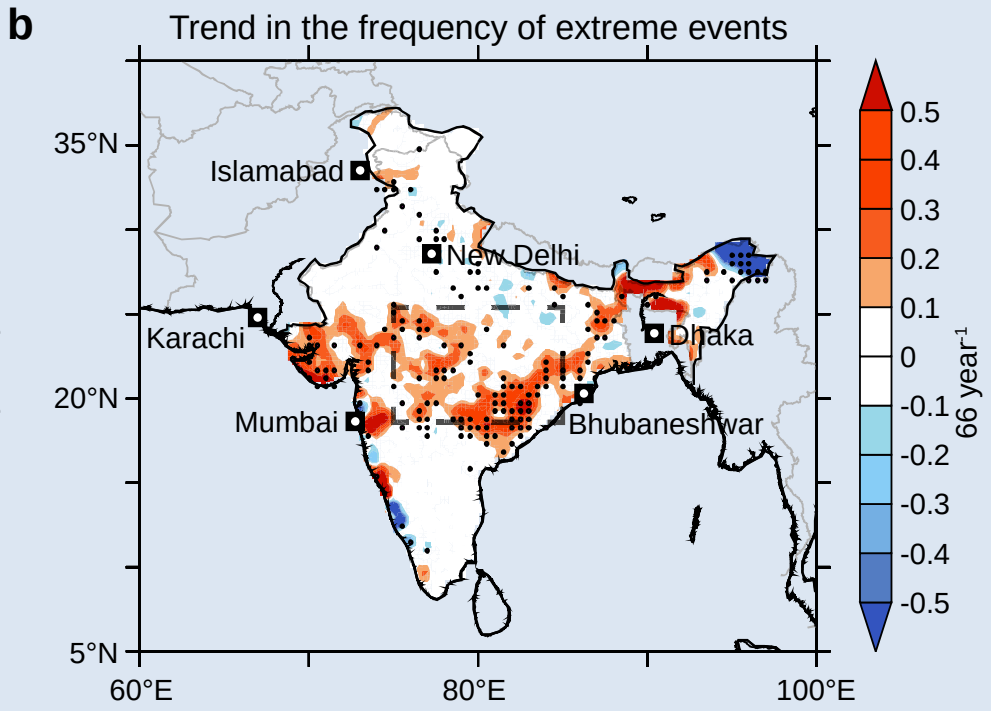
Increasing droughts and floods over India — source, mechanism and predictability

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





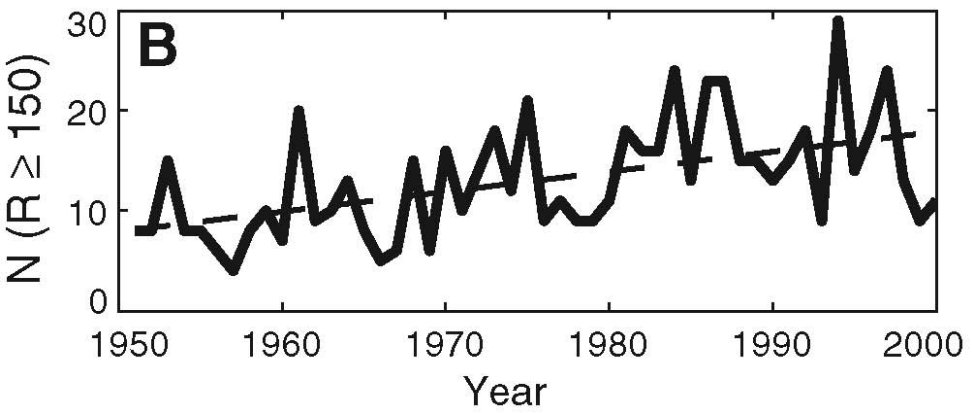
Prof. R. Ananthakrishnan Seminar
28 March 2018

Some background…

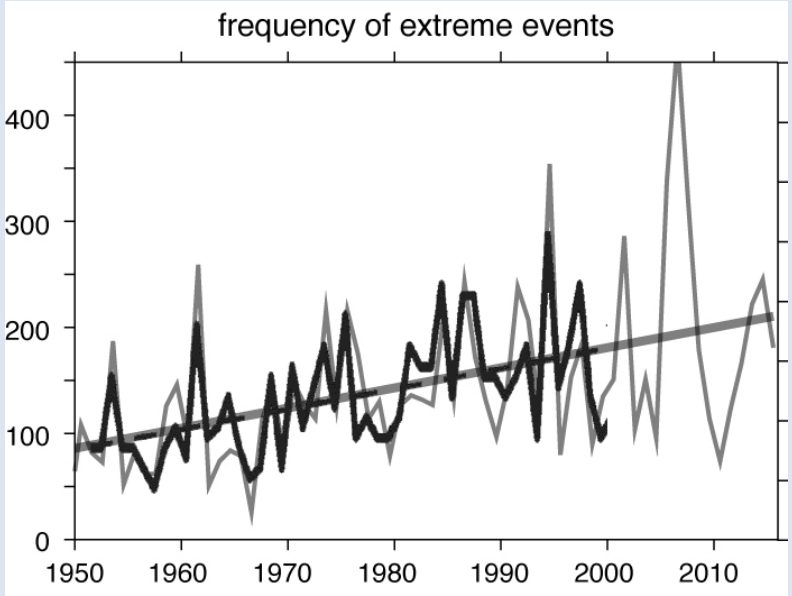
Science
AAAS

Increasing Trend of Extreme Rain Events Over India in a Warming Environment
B. N. Goswami, *et al.*
Science **314**, 1442 (2006);
DOI: 10.1126/science.1132027

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

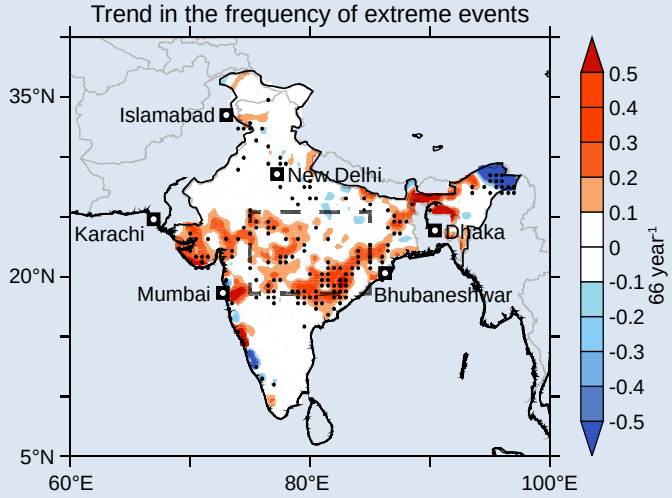
Goswami et al. *Science* 2006; Rajeevan et al. *GRL* 2008

"Widespread" Extremes

Widespread extremes:

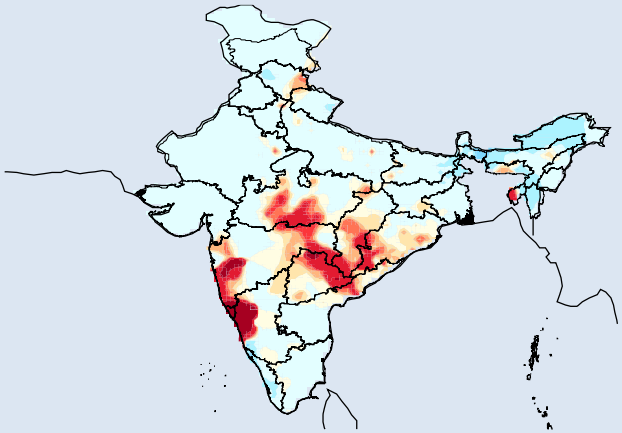
1. Extreme rain events (above 150 mm/day)
2. Over a large homogenous region over central India
3. Typically lasts for 2-3 days

Affected area: > 500,000 km^2
> 500 million people (larger than US population)

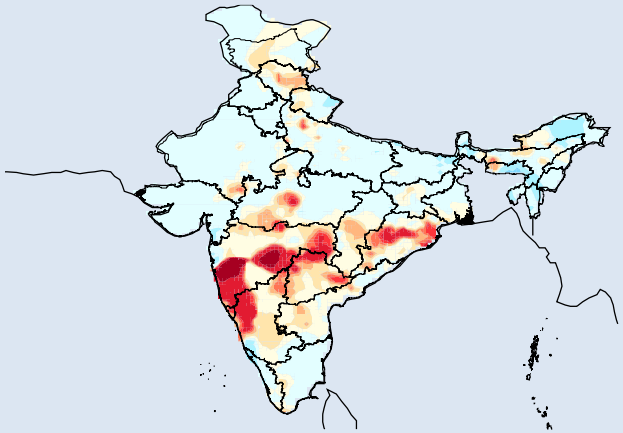


e.g., **Mumbai Floods, 2005**

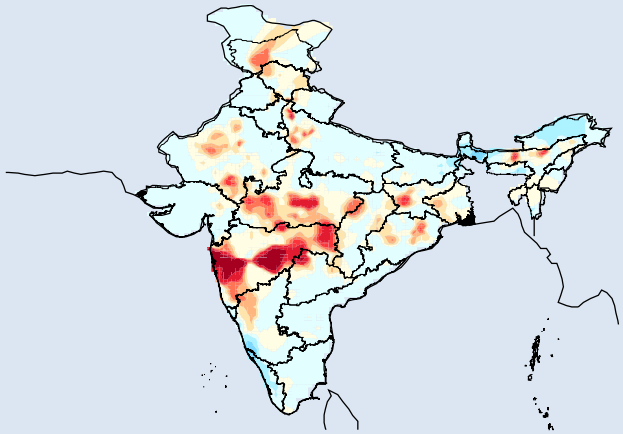
25 July 2005



26 July 2005

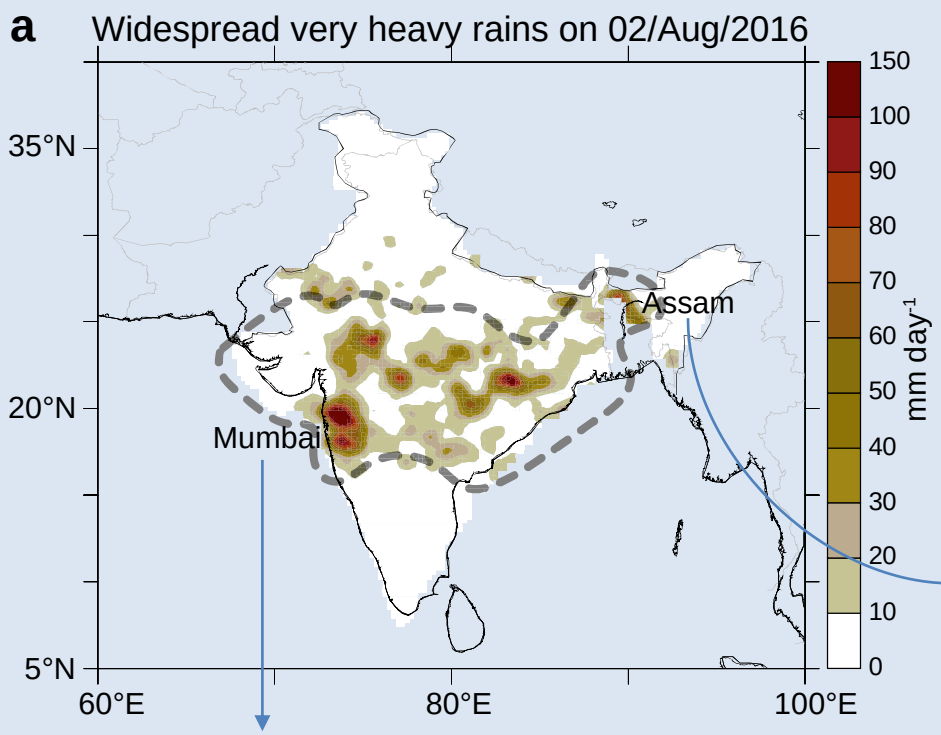


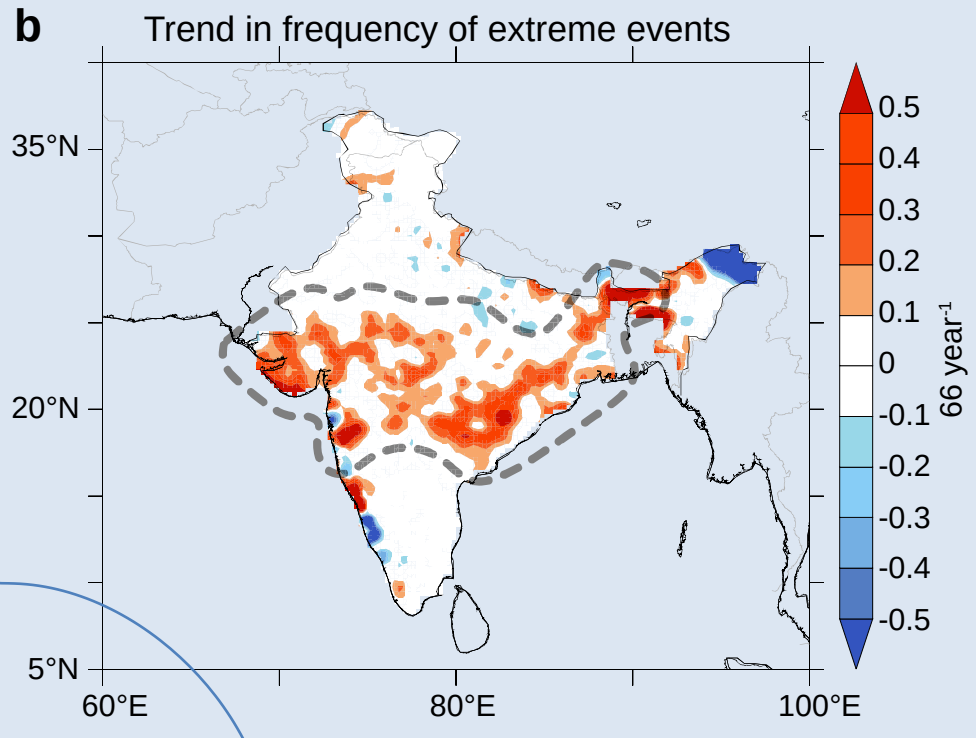
27 July 2005



Roxy et al, *Nature Communications*, 2017

"Widespread" Extremes – Recent Floods – Aug 2016





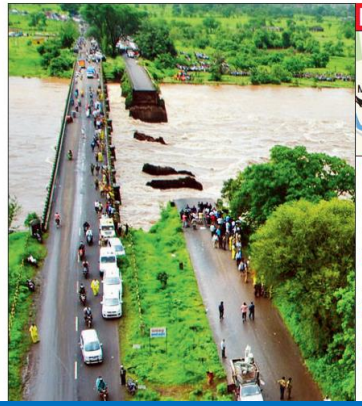
2 Buses, Unknown No. Of Cars Plunge Into Raging River At Night

Over 20 feared dead as bridge on Goa-Mum highway washed away

1927 Structure Safe, State Had Said In May

TIMES NEWS NETWORK

Mumbai: At least 22 people are feared to have drowned after a nearly 90-year-old bridge at Mahad on the Mumbai-Goa highway collapsed during a torrential downpour in the region on Tuesday night. The dead included passengers and crew of two Maharashtra state transport buses bound for Mumbai, which plunged into river Savitri after portions of the bridge fell. There were unconfirmed reports of other vehicles also being swept away in the floodwaters. No bodies were recovered when reports last came in.



MAHAD TRAGEDY

9.30pm Two Mumbai-bound buses from Jaigad and Rajapur reach Chiplun bus depot with 63 passengers. 45 passengers alight, 18 continue journey. Both buses leave 15 mins apart

10.30pm First bus reaches Poladpur, 30km away, leaves for Mahad; second bus follows

Around 11.30pm Bridge collapses and is washed away by the raging Savitri river

12am Officials at Mahad depot call counterparts in Poladpur, saying buses haven't arrived.

The Indian EXPRESS

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.

Written by Samudra Gupta Kashyap | Guwahati | Updated: August 2, 2016 7:26 am

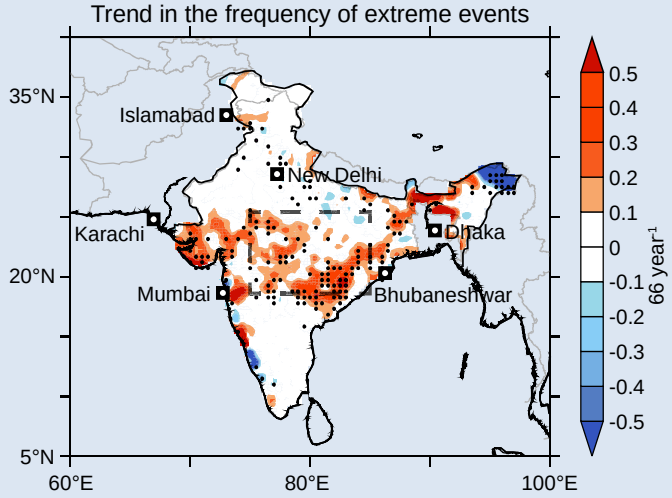
"Widespread" Extremes

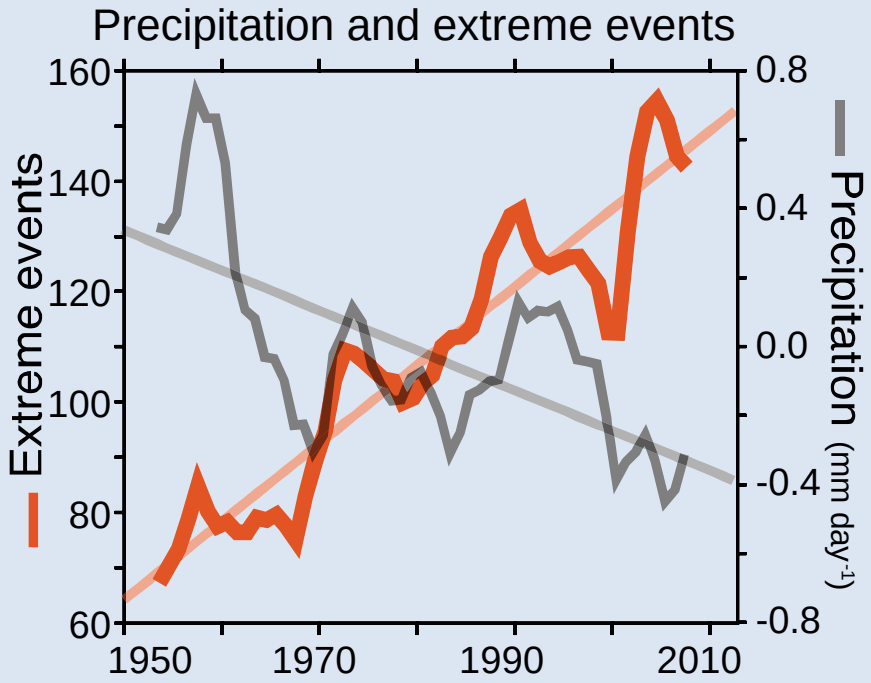
Widespread extreme rainfall events:

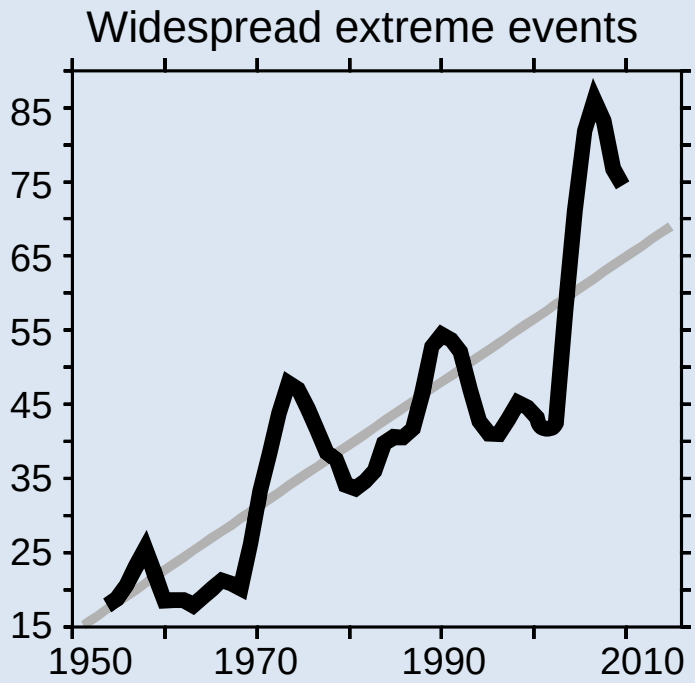
1. Extreme rain events (above 150 mm/day)
2. Over a large homogenous region over central India
3. Typically lasts for 2-3 days

Affected area: > 500,000 km^2
> 500 million people (larger than US population)

We see a three-fold rise in widespread extremes







Spatial variability Vs. "Widespread" Extremes

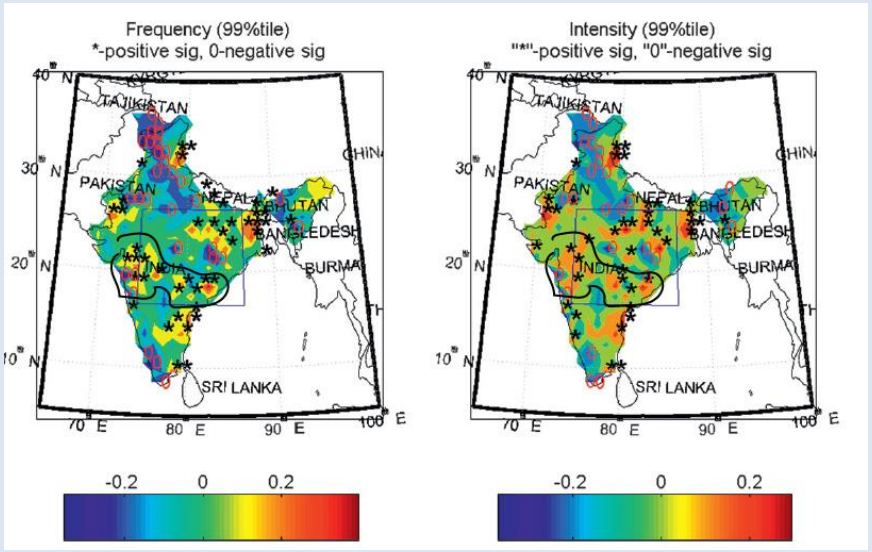
LETTERS
PUBLISHED ONLINE: 18 DECEMBER 2011 | DOI: 10.1038/NCLIMATE1327
nature climate change

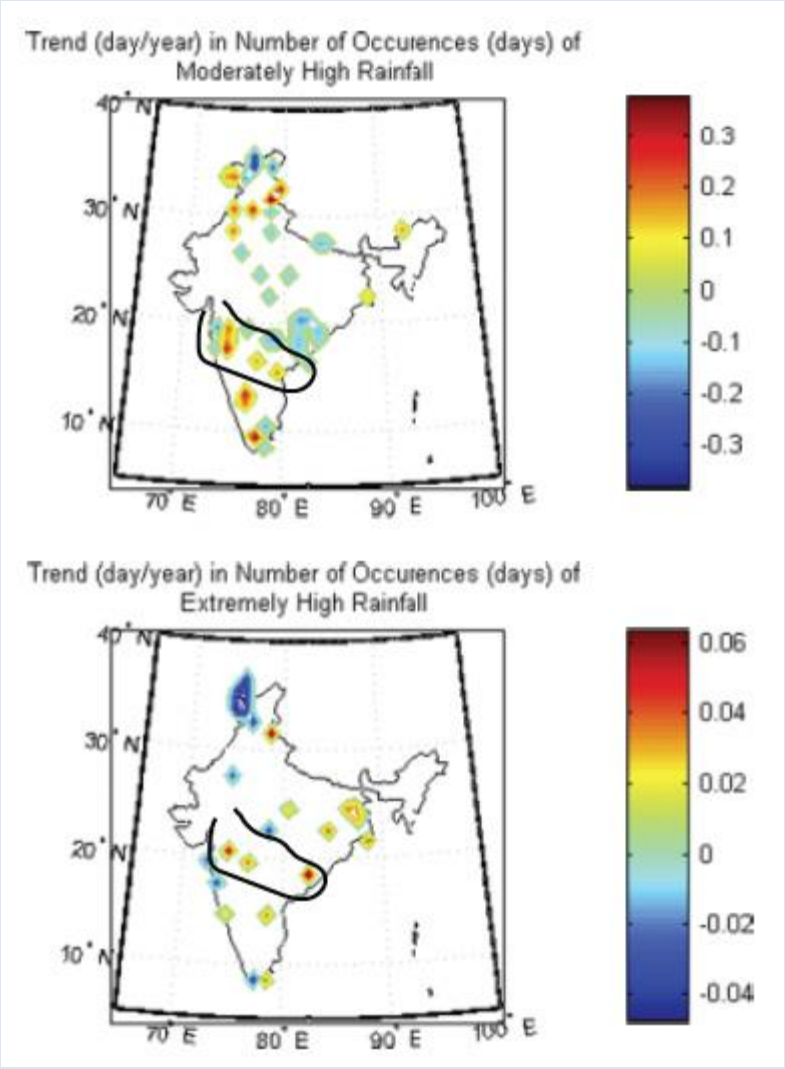
Lack of uniform trends but increasing spatial variability in observed Indian rainfall extremes

Subimal Ghosh[1], Debasish Das[2], Shih-Chieh Kao[3] and Auroop R. Ganguly[4]*

A couple of studies (Krishnamurthy et al. (2009), Ghosh et al. (2011), debated the validity of claims by Goswami et al. (2006).

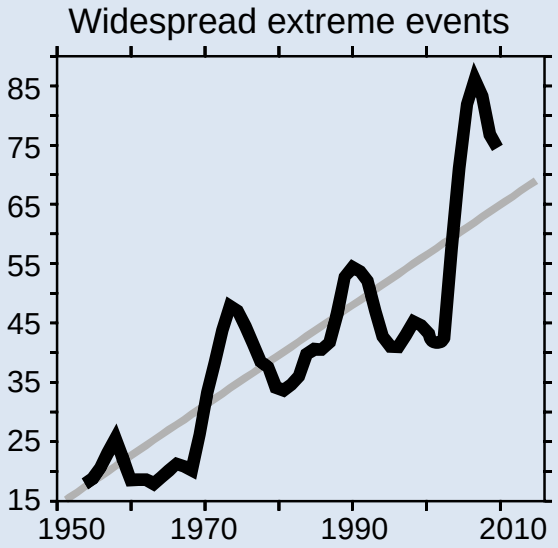
The issue comes when you analyze the extremes using a rigid box over central India.



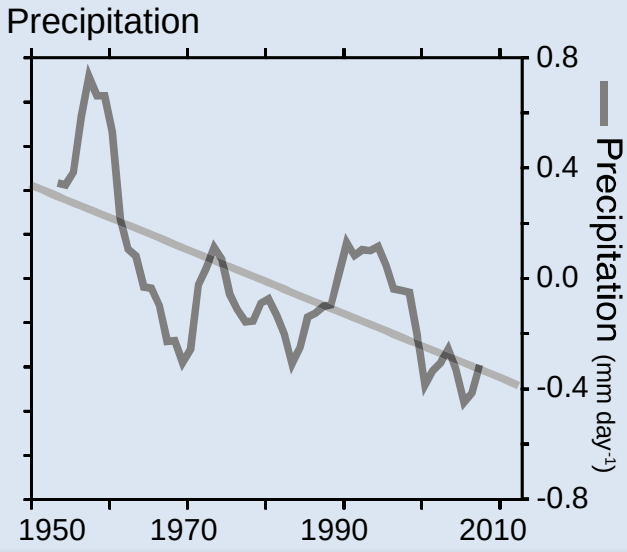


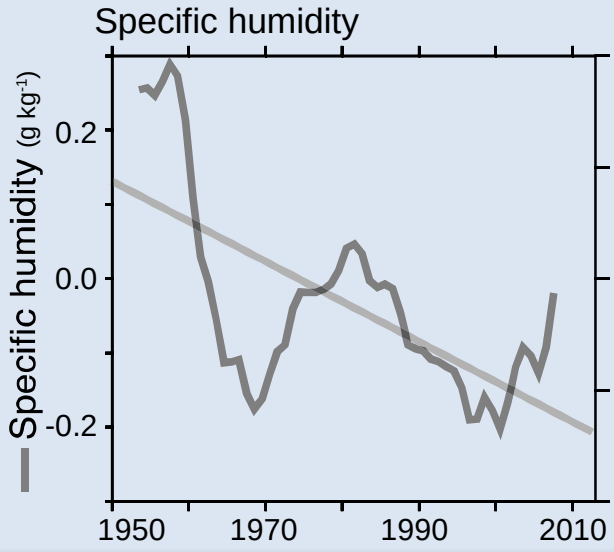
Ghosh et al, *Nature Climate Change*, 2011; Krishnamurthy, Lal et al. *J. Climate*, 2009

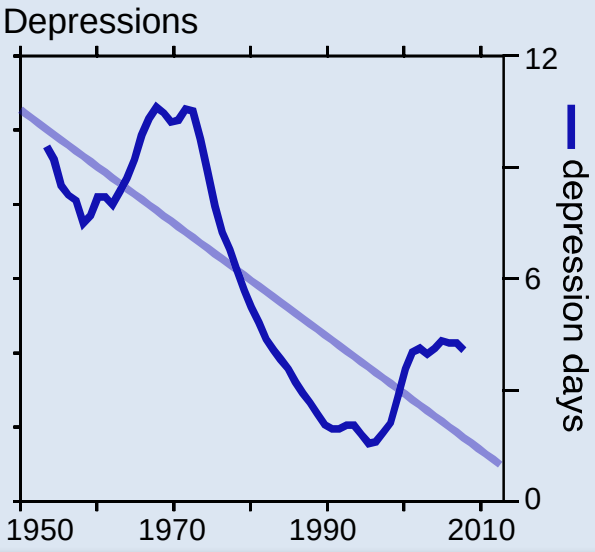
Precipitation, moisture and depressions are going down



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







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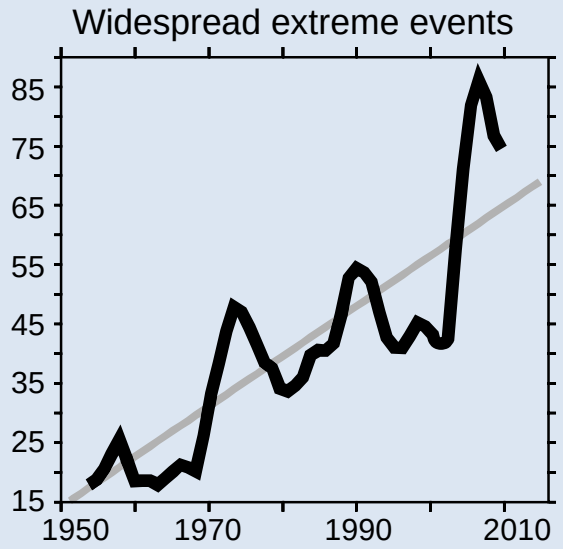
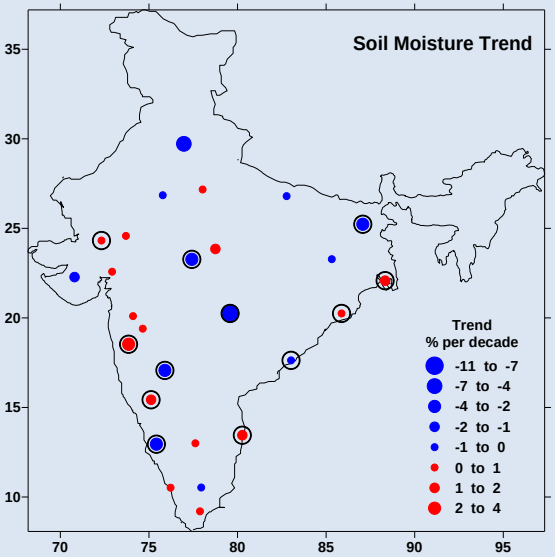


Mukhopadhyay et al. 2017



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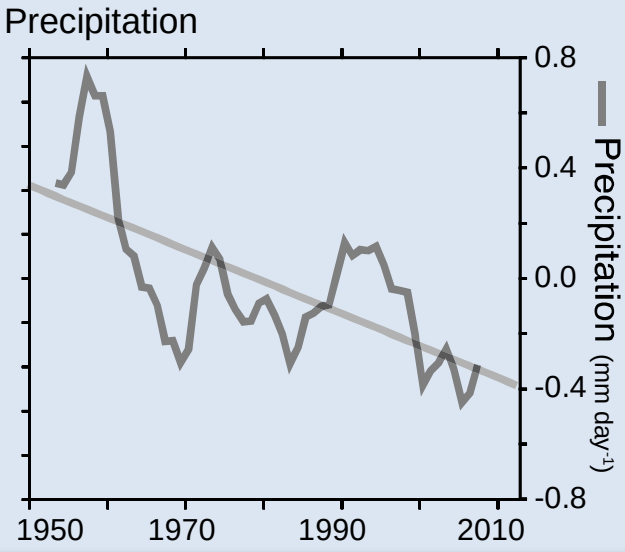
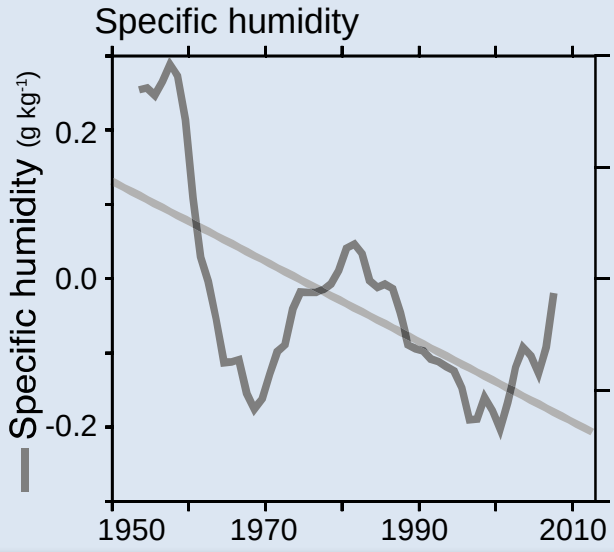
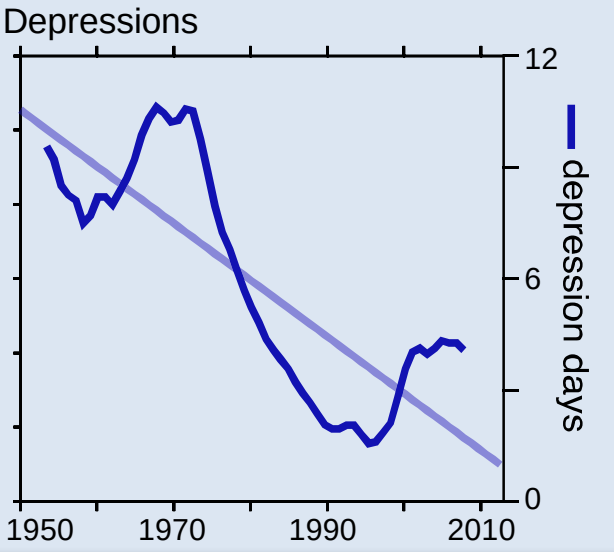
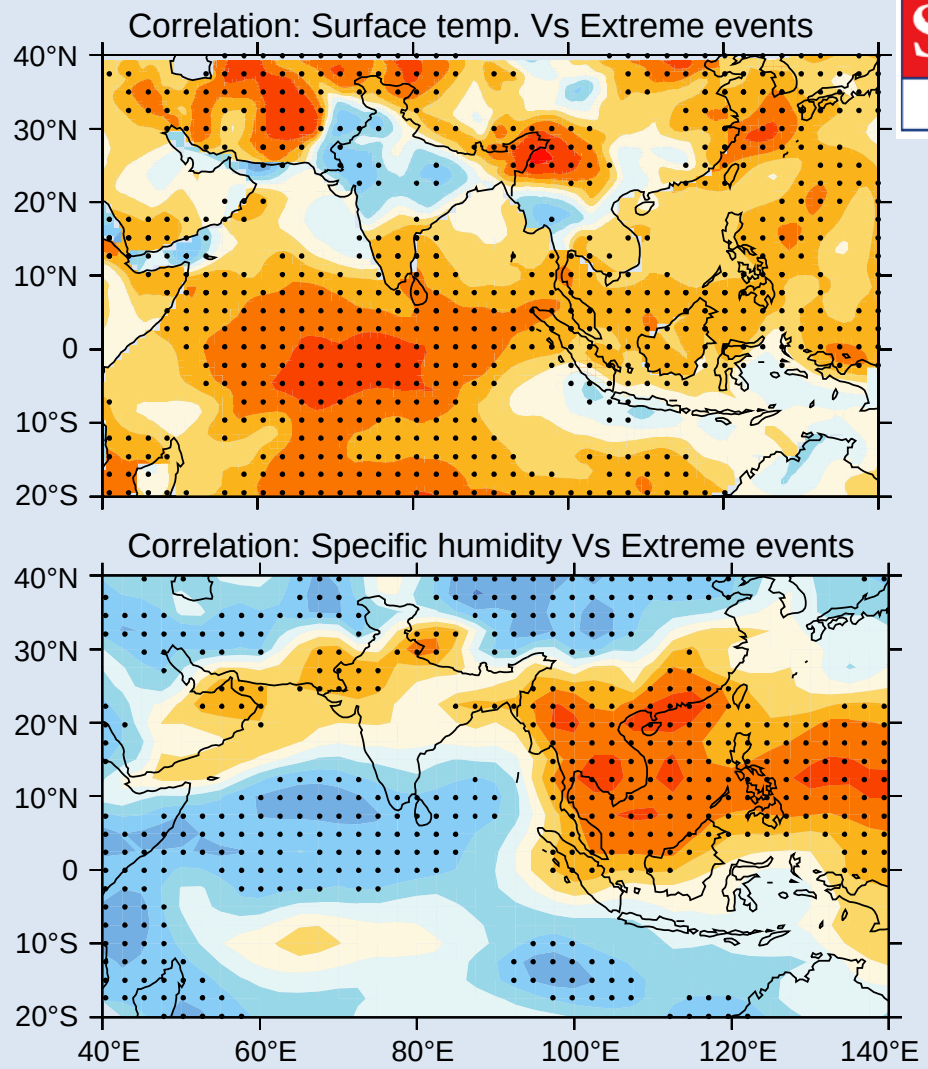






Roxy et al, *Nature Communications*, 2017; Mukhopadhyay et al., Springer 2017

What is behind the rise in Extreme rains? IO SST?



Roxy et al, *Nature Communications*, 2017 Fig. S2

Science AAAS

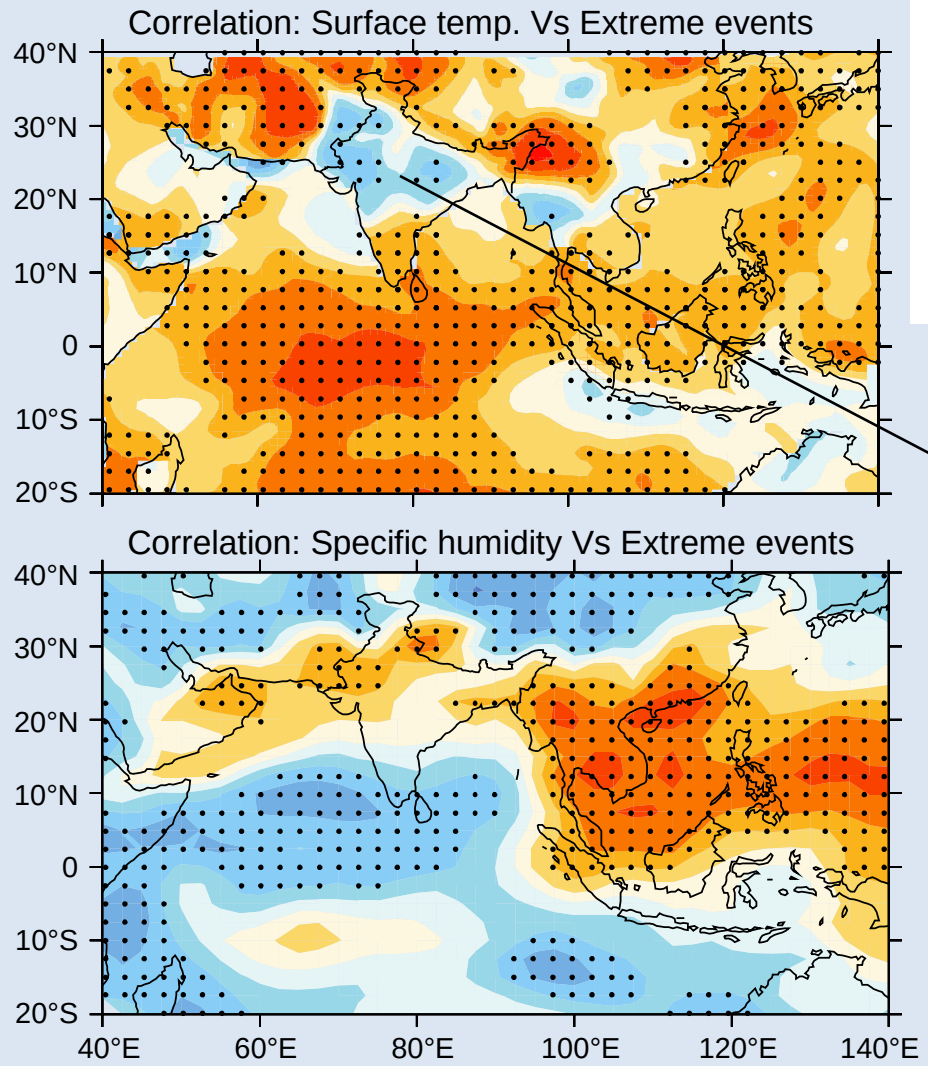
Increasing Trend of Extreme Rain Events Over India in a Warming Environment
B. N. Goswami, *et al.*
Science **314**, 1442 (2006);
DOI: 10.1126/science.1132027

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?



Roxy et al, *Nature Communications*, 2017 Fig. S2

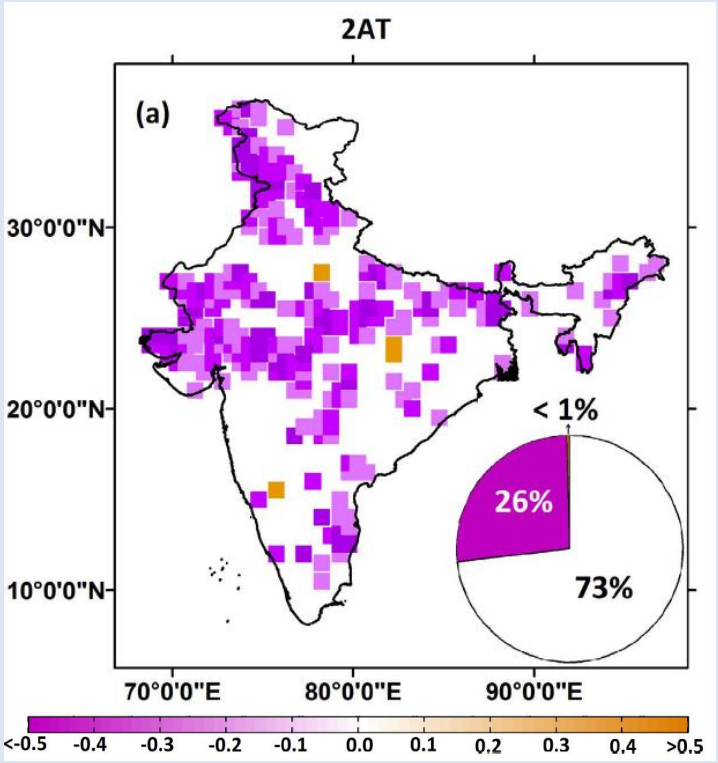
SCIENTIFIC REPORTS

OPEN

Lack of Dependence of Indian Summer Monsoon Rainfall Extremes on Temperature: An Observational Evidence

Received: 10 February 2016
Accepted: 13 July 2016
Published: 03 August 2016

H. Vittal[1], Subimal Ghosh[2,3], Subhankar Karmakar[1,3], Amey Pathak[2] & Raghu Murtugudde[3,4]



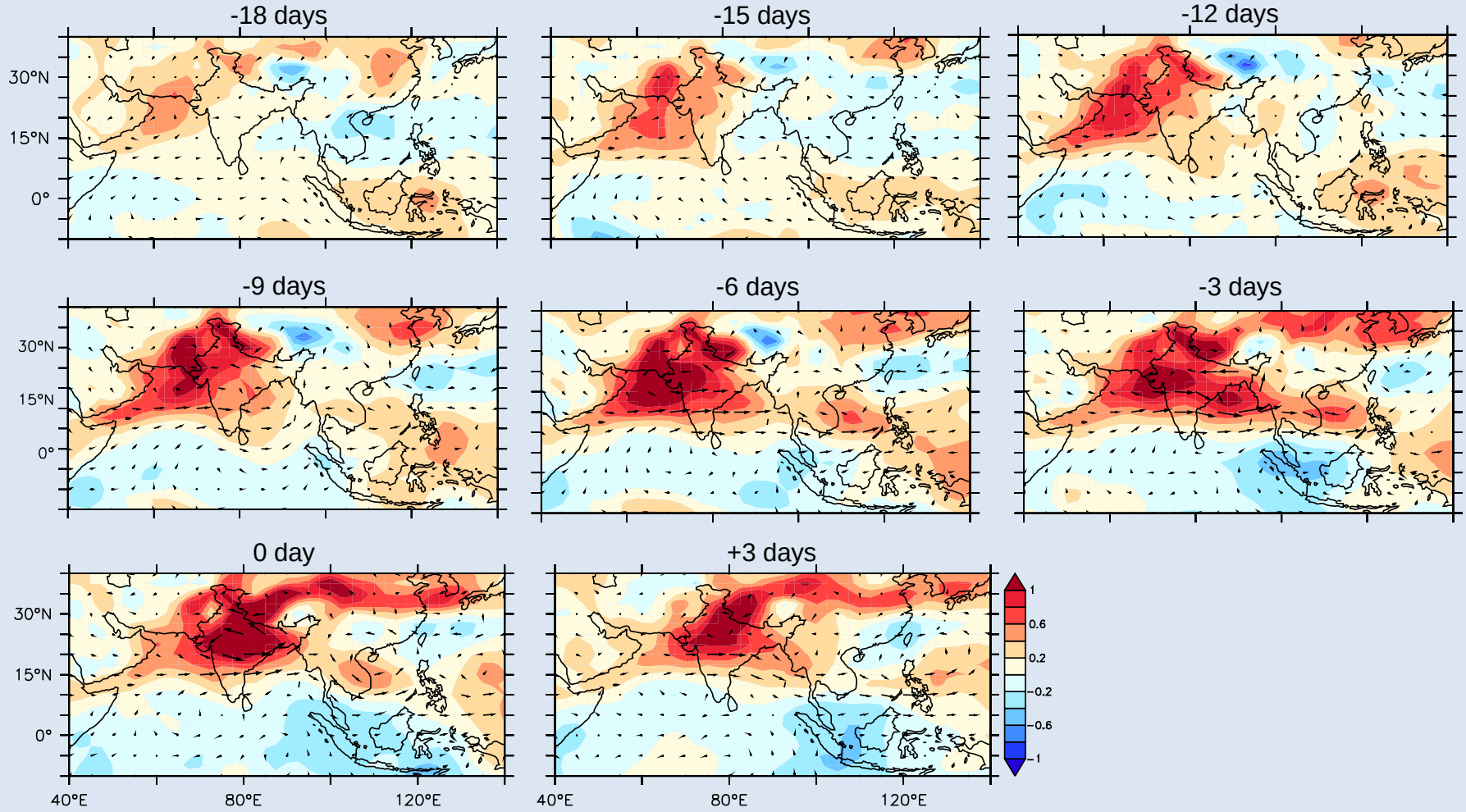
What is the cause and where's the moisture coming from?

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,

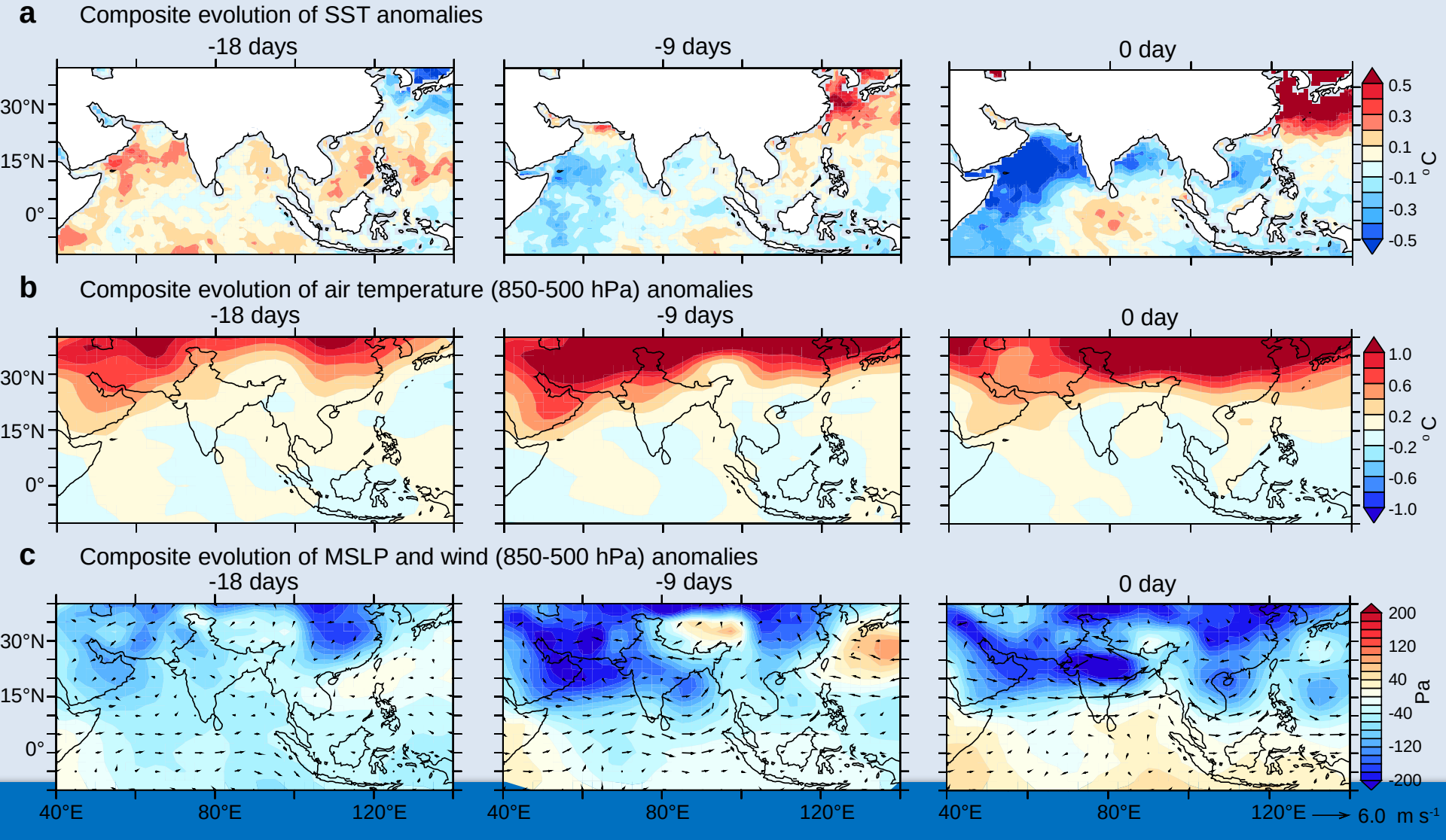
(c) and then by a short-lived low (cycir)



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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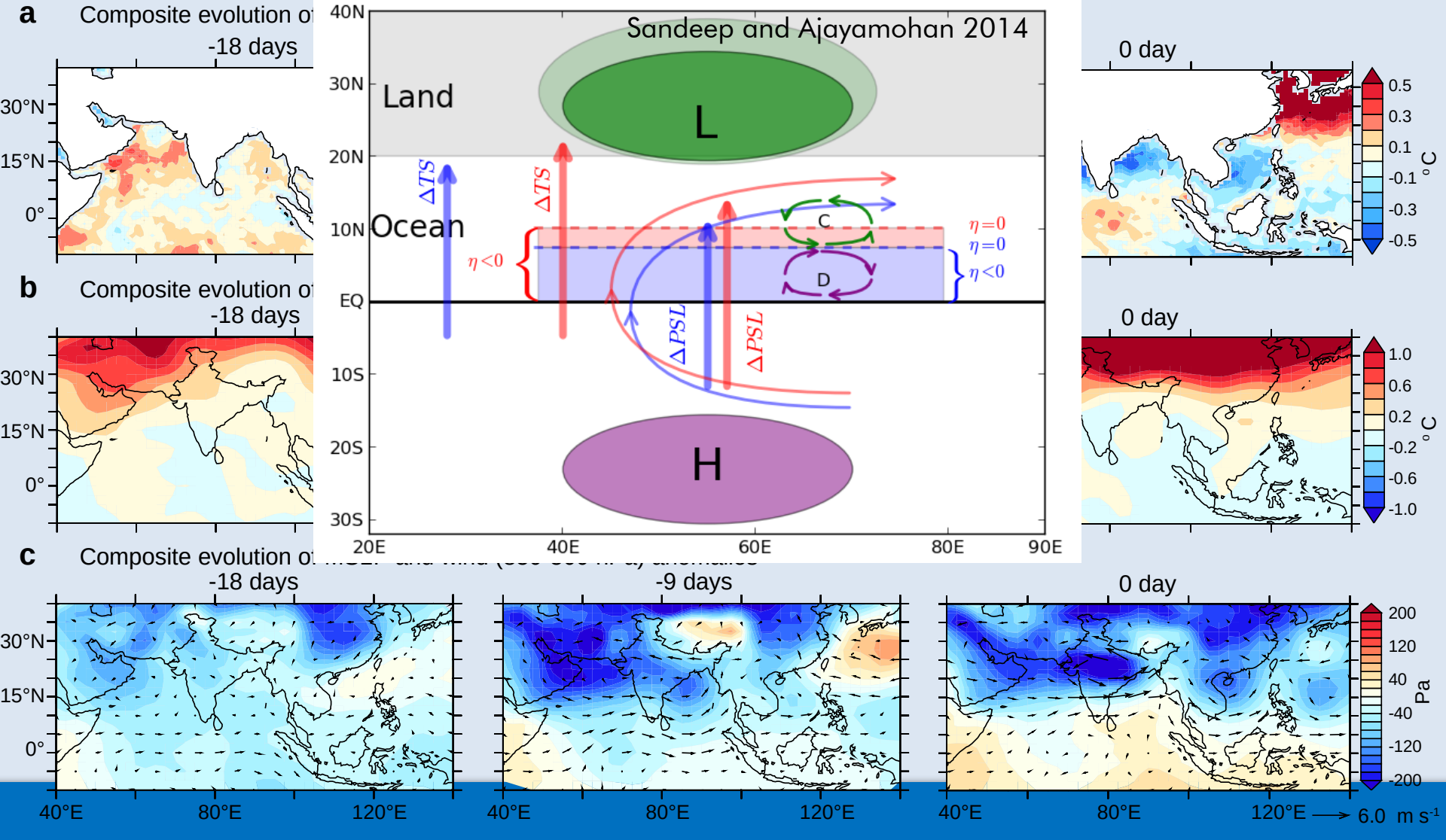
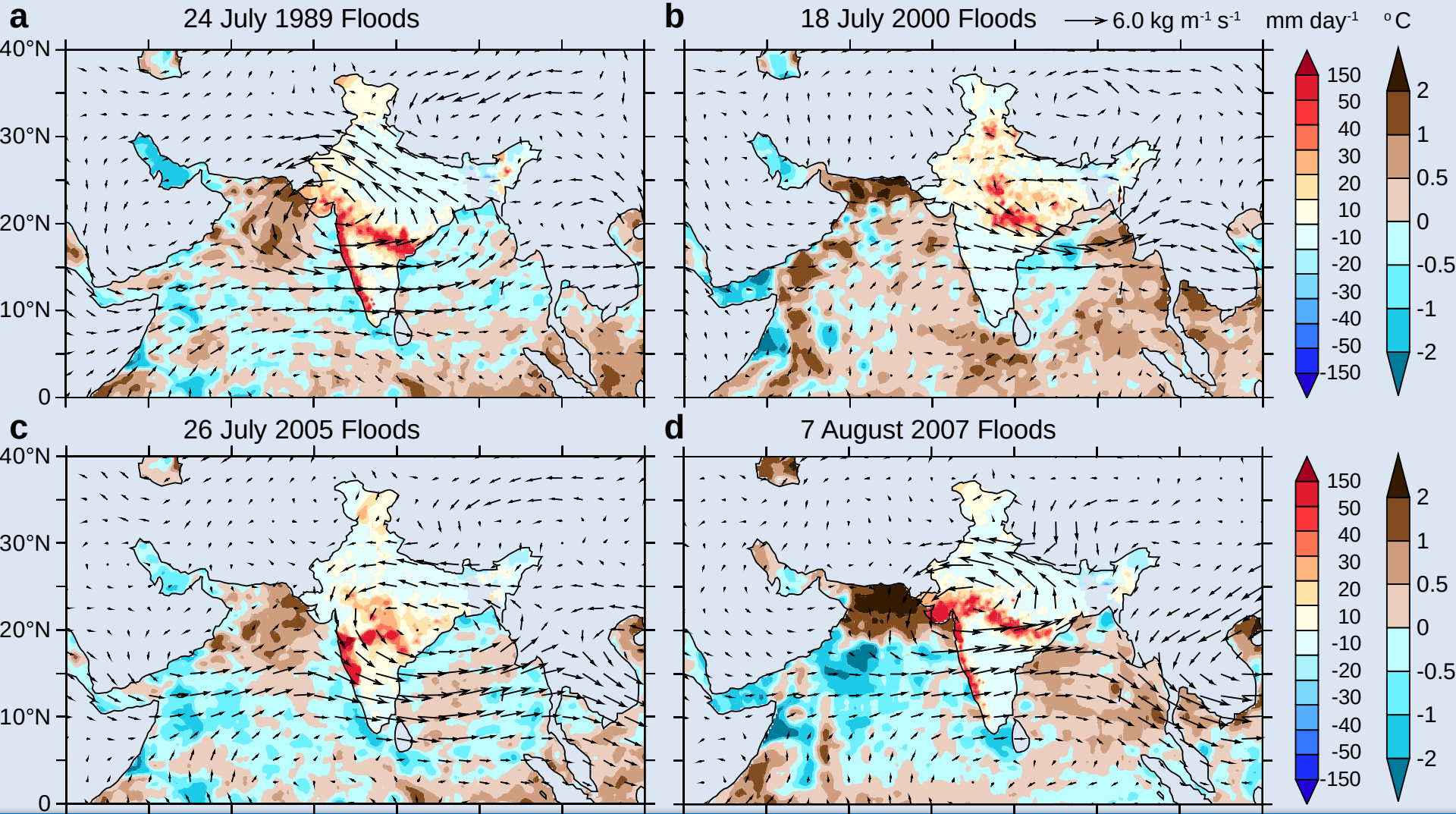


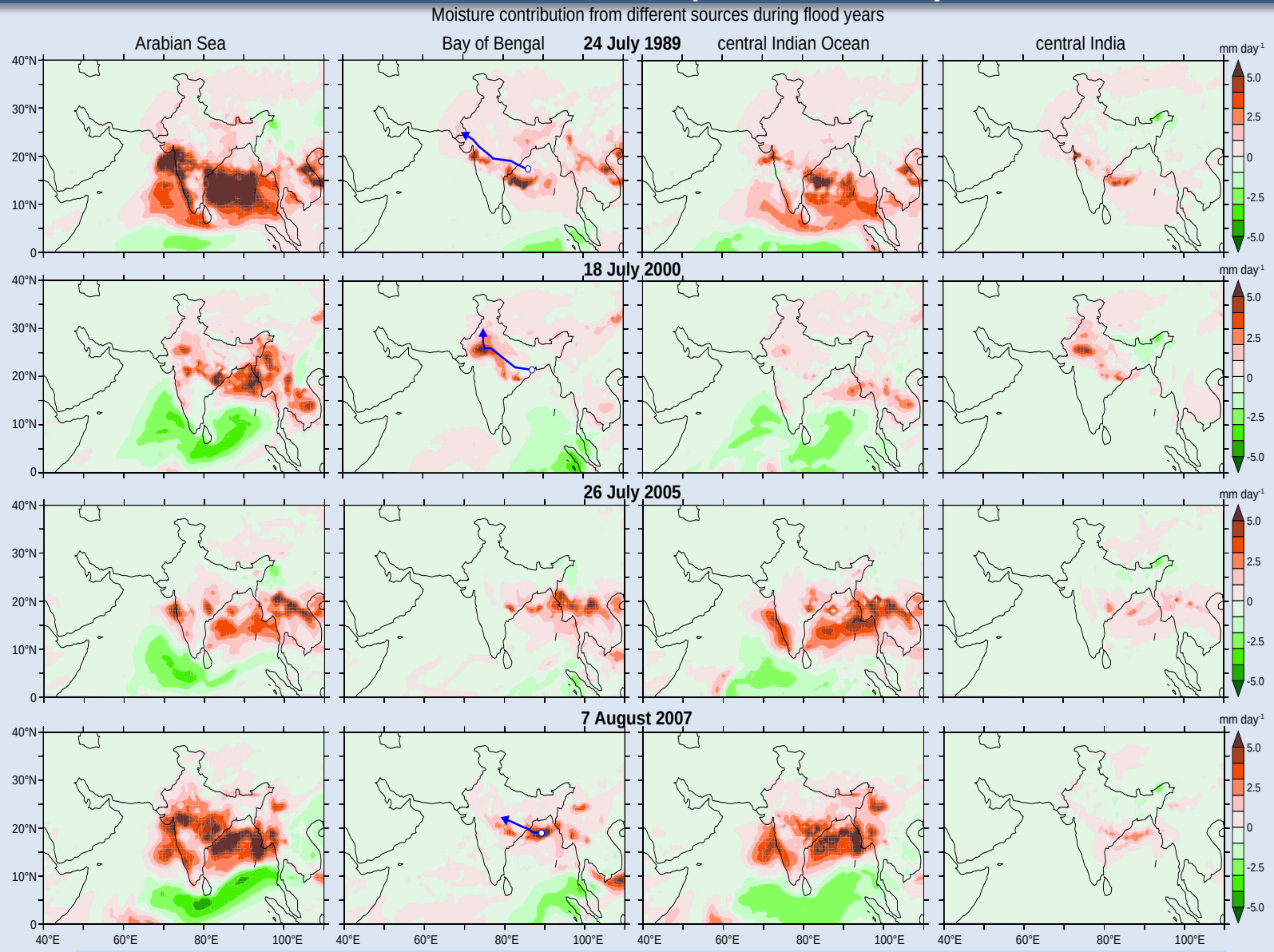
Historical Floods

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



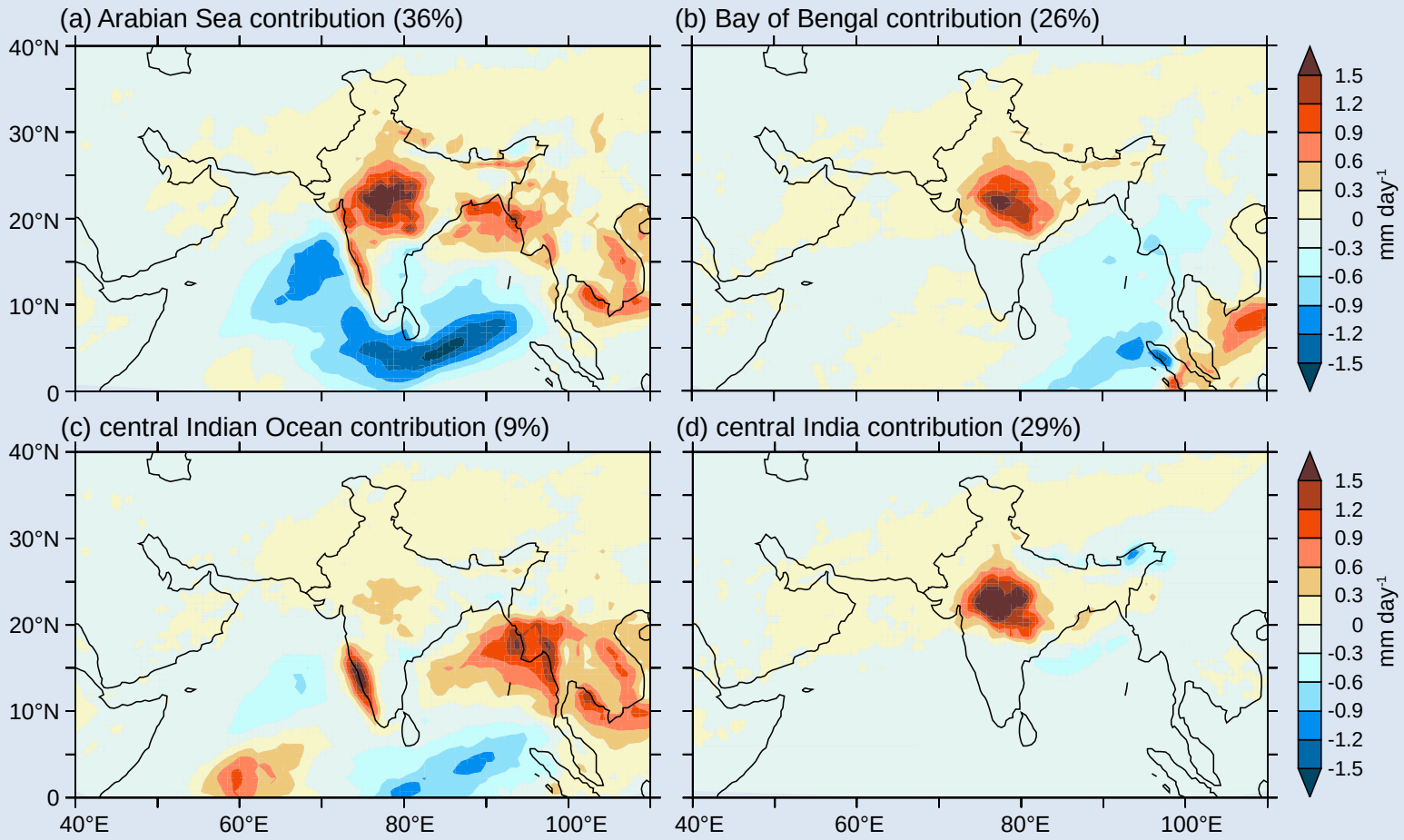
Historical Floods – Role of low pressure systems?



Individual events also show moisture contribution from Arabian Sea, and less from low pressure systems

Tracking the moisture using a Dynamic Recycling Model

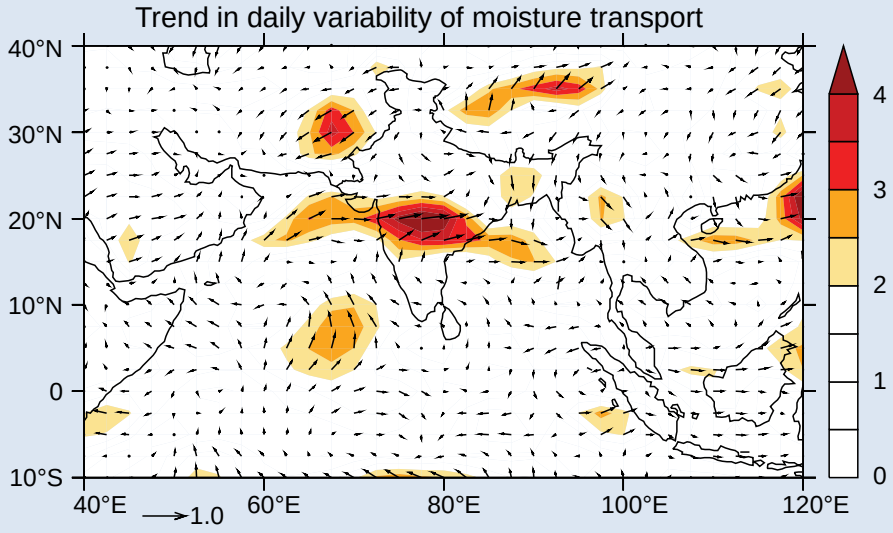
We used a Dynamic Recycling Model (DRM) based on a Lagrangian trajectory approach, where the water vapor prior to precipitation over a region is traced backward in time and the contribution from each source is quantified



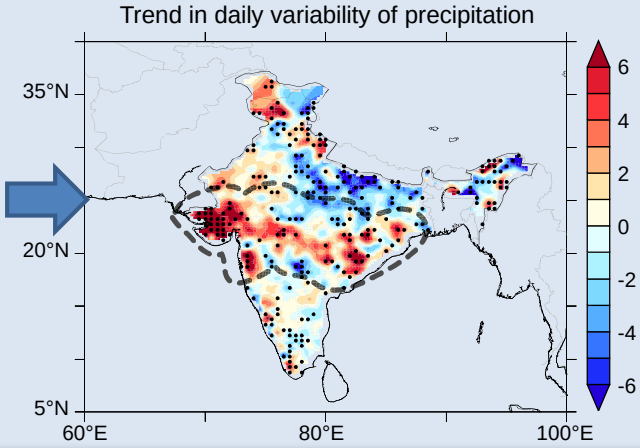
Important moisture contribution from Arabian Sea, and from moisture recycling!

So why are these widespread extremes increasing?

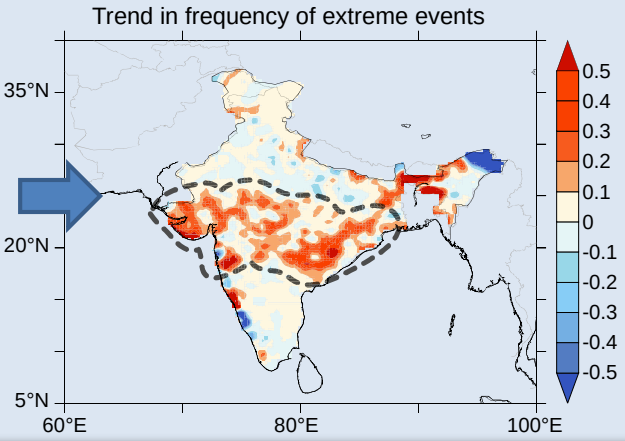
Increasing "daily" variability in the moist westerlies



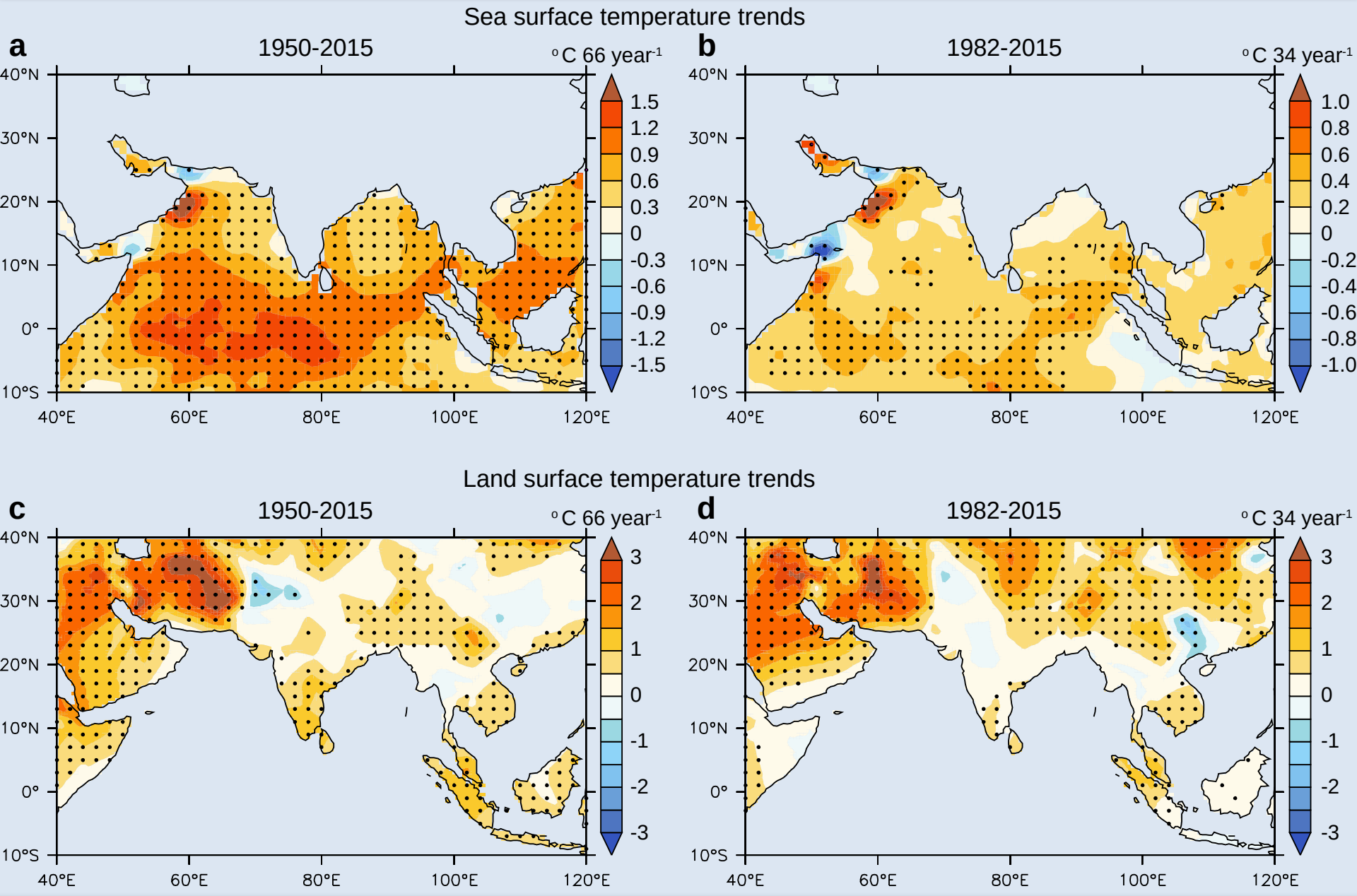
Increase in the daily variability of precipitation



Increase in "widespread " extreme events



Surface Temperature Trends are increasing over n. Arabian Sea



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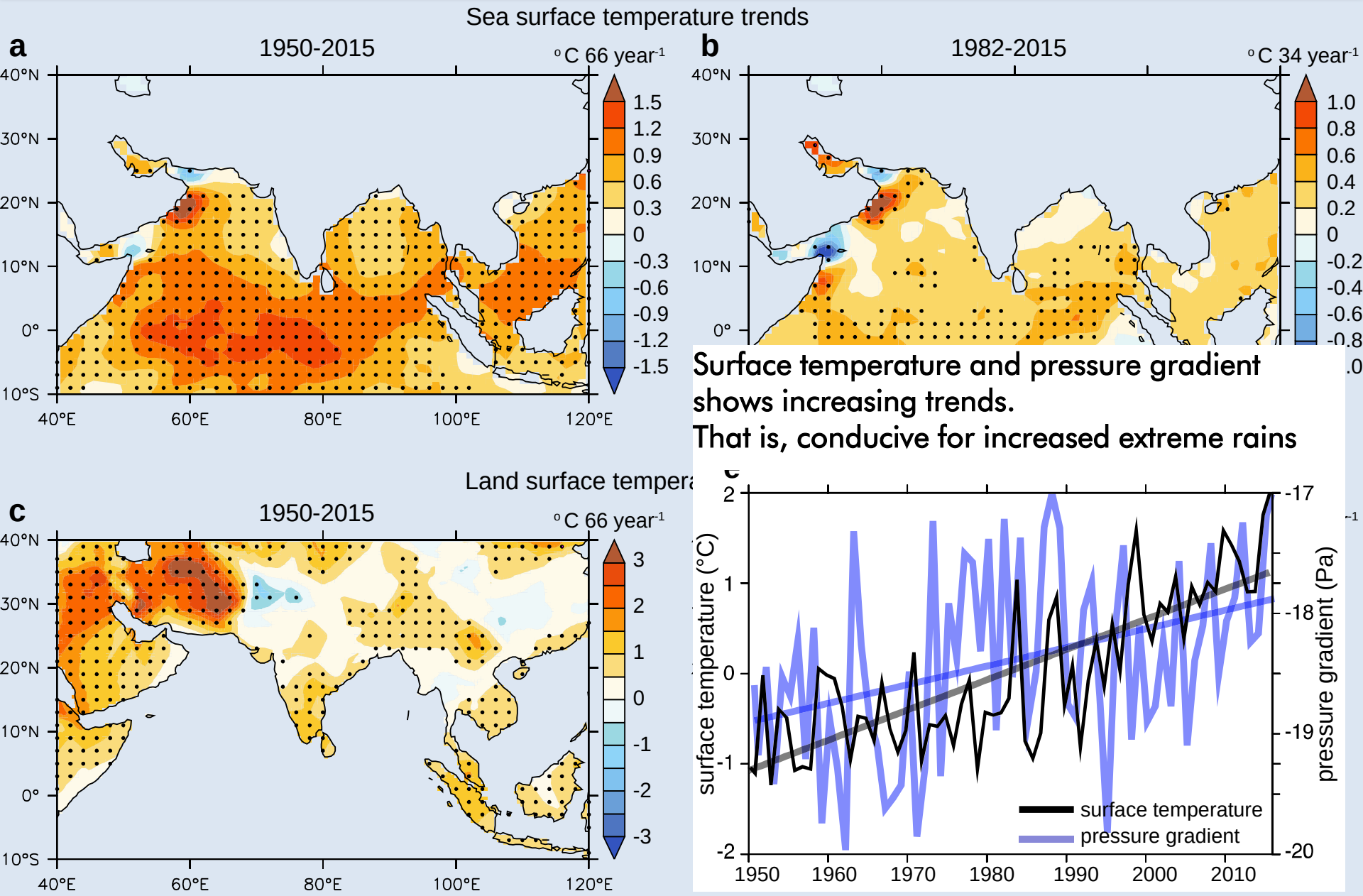
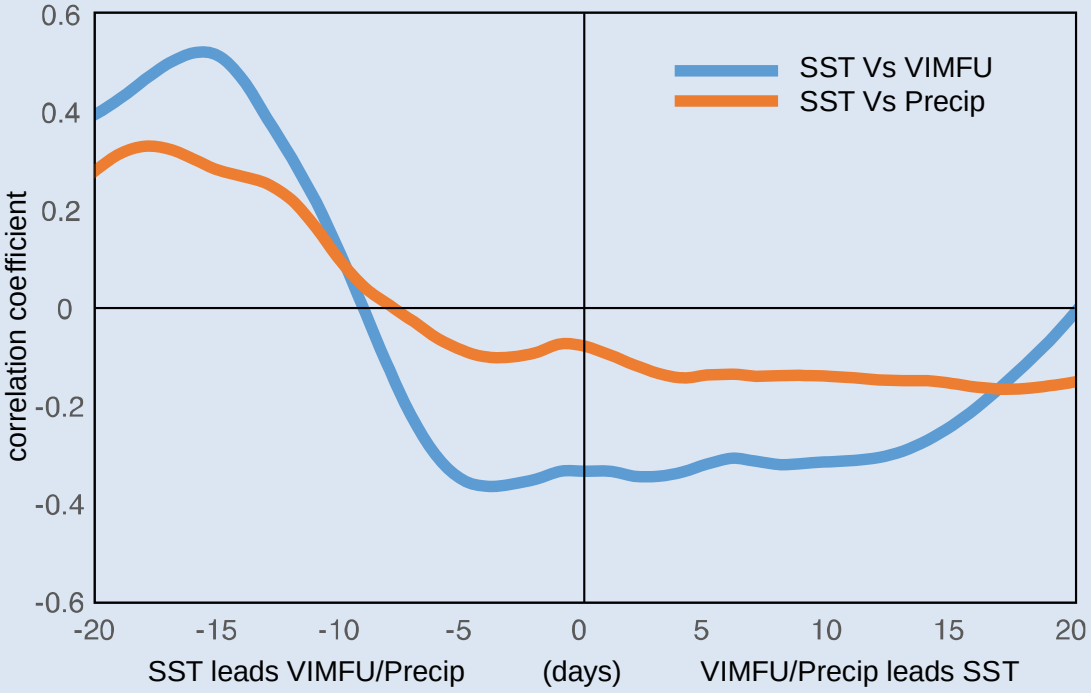
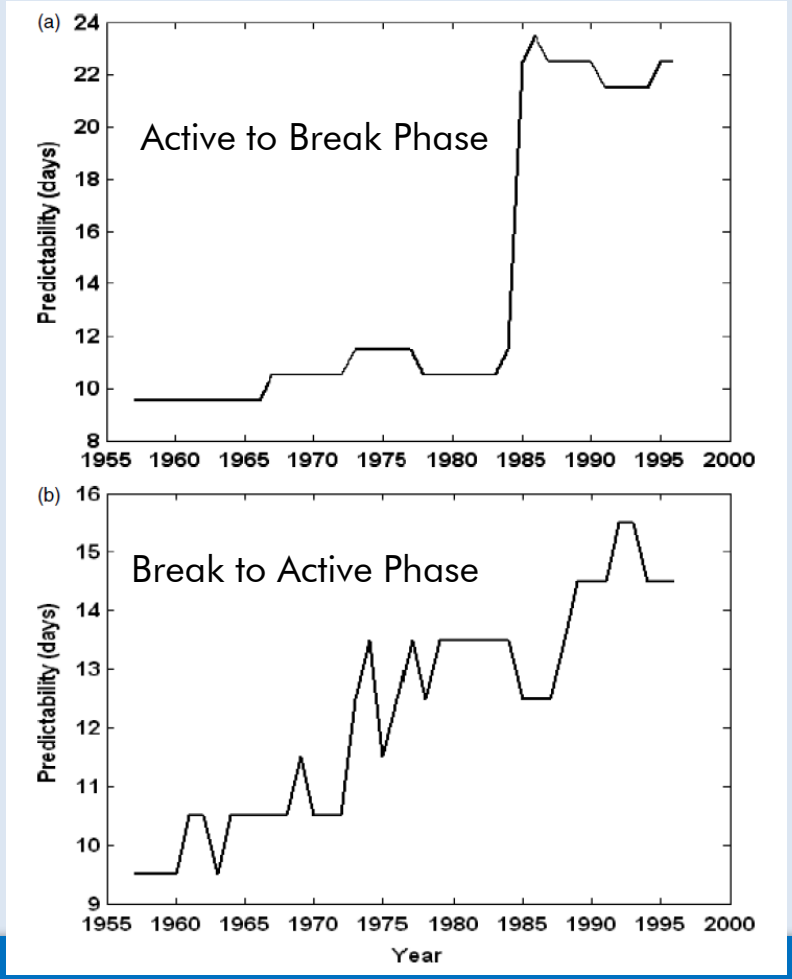


"Potential" predictability of 2-3 weeks

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



Neena et al. 2010



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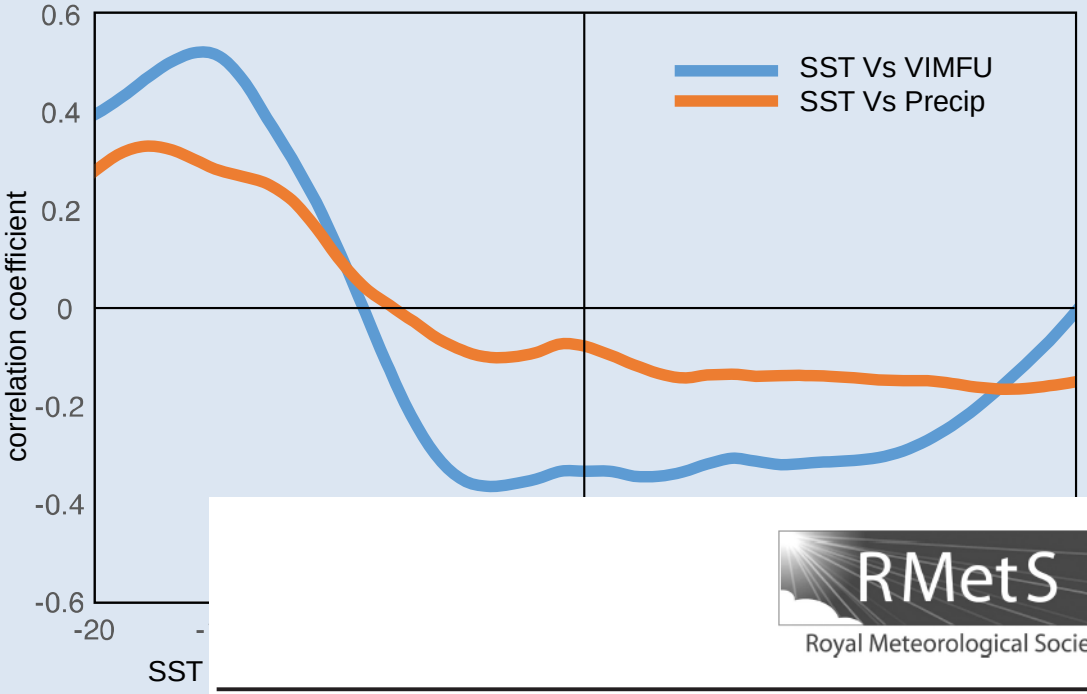

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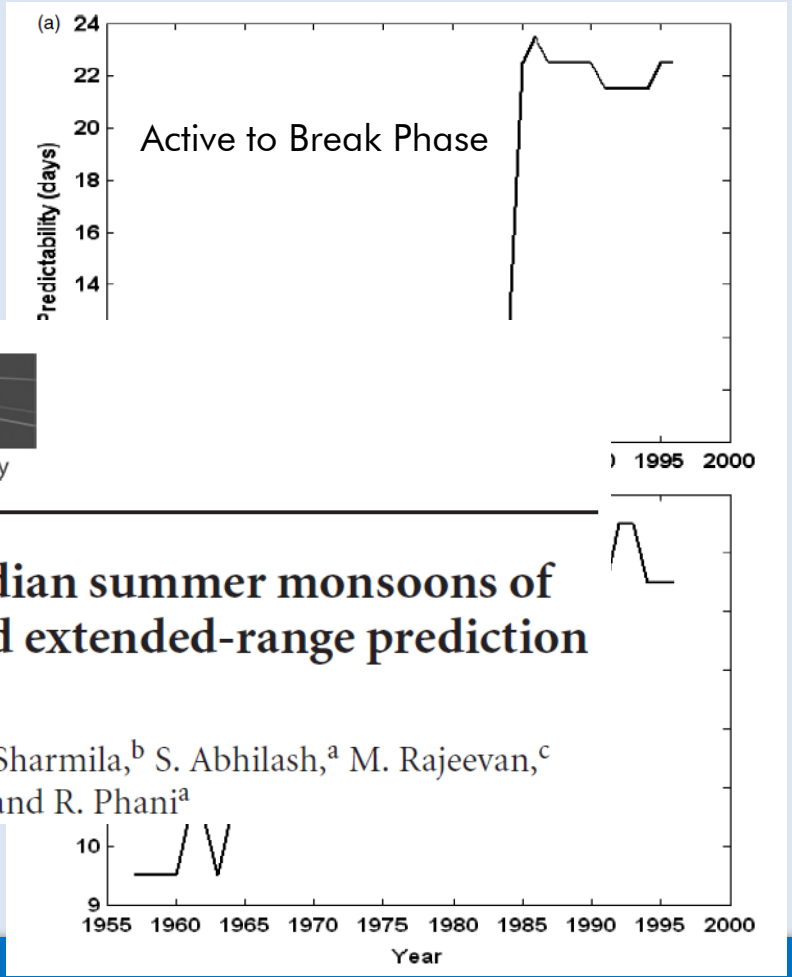


RMetS
Royal Meteorological Society

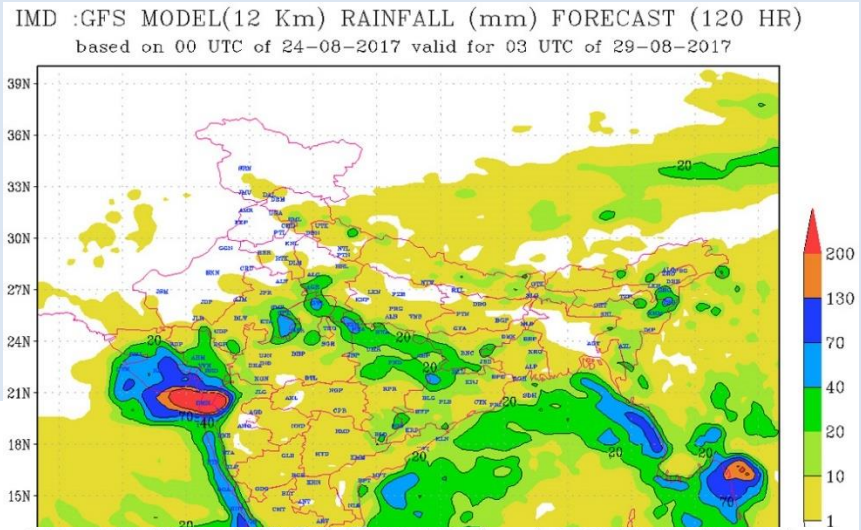
Extremes in June rainfall during the Indian summer monsoons of 2013 and 2014: observational analysis and extended-range prediction

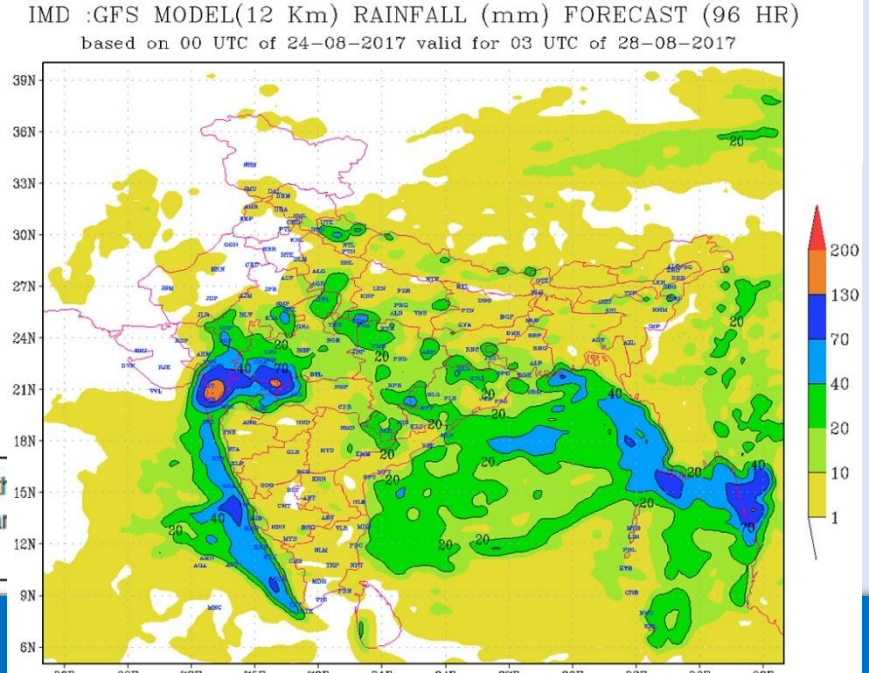
Susmitha Joseph,[a] A. K. Sahai,[a*] R. Chattopadhyay,[a] S. Sharmila,[b] S. Abhilash,[a] M. Rajeevan,[c] R. Mandal,[a] A. Dey,[a] N. Borah[a] and R. Phani[a]

Mumbai Floods - 2017

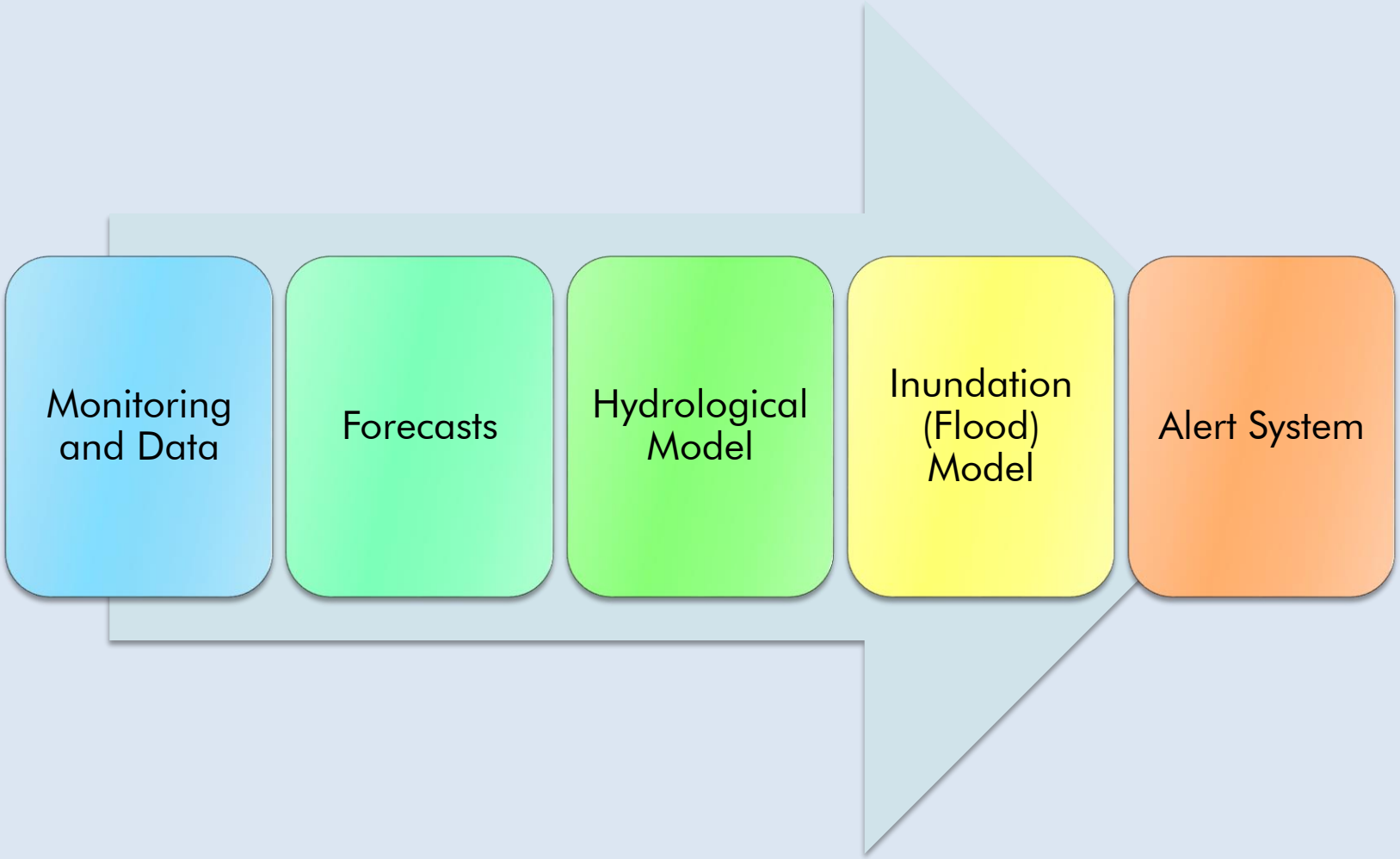
28 August (Day 5):♦ Heavy to very heavy rain at isolated places over Gujarat region and nort
rain at isolated places very likely over Uttrakhand, Odisha, Assam & Meghalaya, Nagaland, Ma
Tripura, Saurashtra & Kutch, north Madhya Maharashtra and Coastal Karnataka.

IMD forecasted recent widespread extremes 5-6 days in advance





Link the met. forecasts to the Flood Model and Alert System



Extreme rain events – feedback on the ISO

Reduces the ISO intensity

SCIENTIFIC REPORTS

OPEN

Increased sporadic extremes decrease the intraseasonal variability in the Indian summer monsoon rainfall

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Accepted: 29 June 2017
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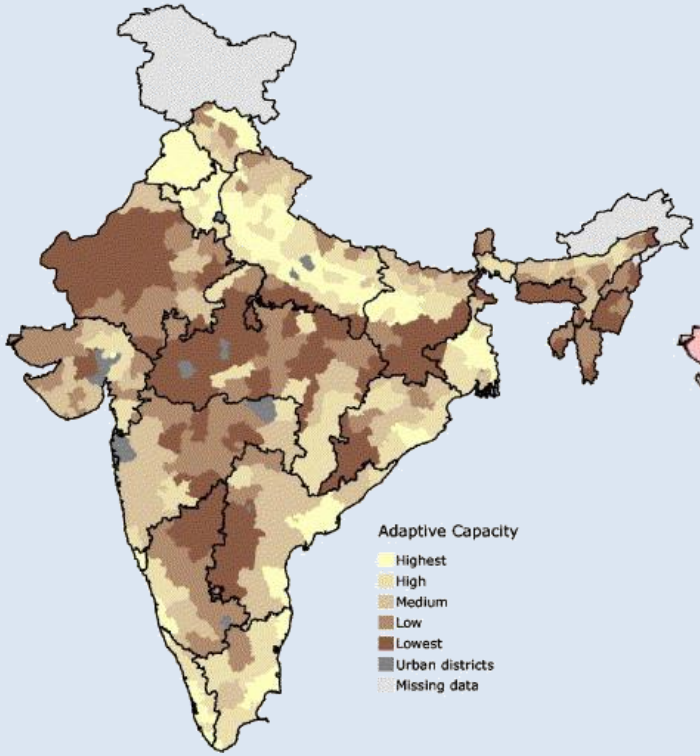
Nirupam Karmakar[1,4], Arindam Chakraborty[1,2] & Ravi S. Nanjundiah[1,2,3]

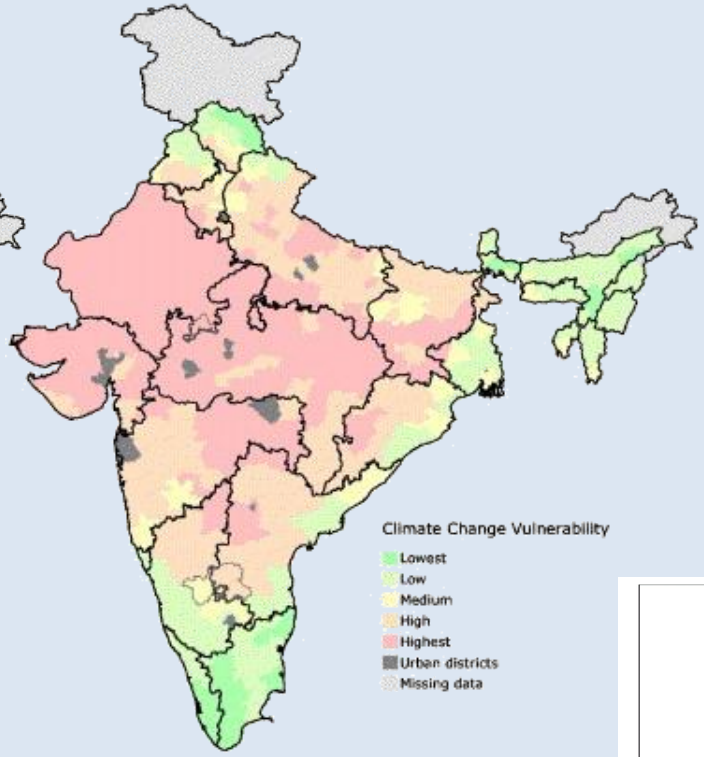
"Occurrence of extreme rainfall events, primarily in the break phase of an ISO cycle, reduce the intensity of the following active phase by stabilizing the atmosphere - through a reduction in vertical shear"

The central belt is vulnerable!

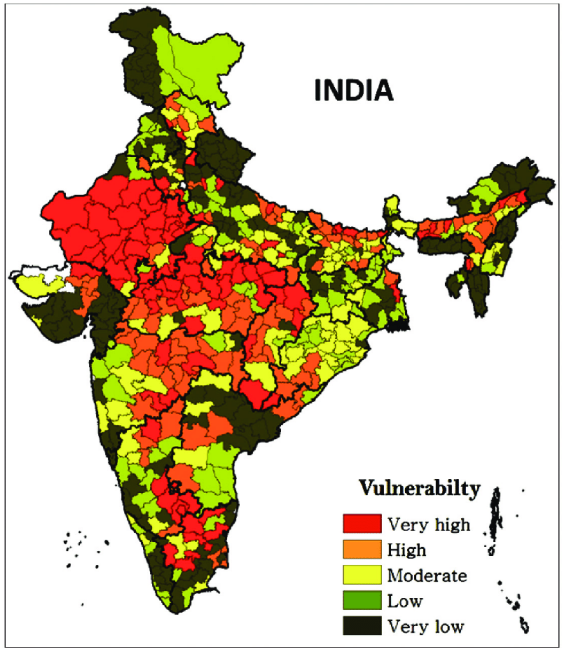
Adaptive Capacity



Climate Change Vulnerability



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

Thank You!

nature COMMUNICATIONS

A threefold rise in widespread extreme rain events over central India

M.K. Roxy[1], Subimal Ghosh[2], Amey Pathak[2], R. Athulya[1,3], Milind Mujumdar[1], Raghu Murtugudde[4], Pascal Terray[5,6] & M. Rajeevan[1,7]

research highlights

HYDROCLIMATE

Extreme rain in India

Nat. Commun. http://doi.org/cd58 (2017)

northern Arabian Sea,
to patterns of surface v
on land–sea thermal c
consequence, these lov
bring surges of moistu
continent, promoting

Trend in extreme rain events over India