



The Indian Summer Monsoon: Past, Present and Future

**with special thanks to Andy Turner, Nick Klingaman and
Hilary Weller**

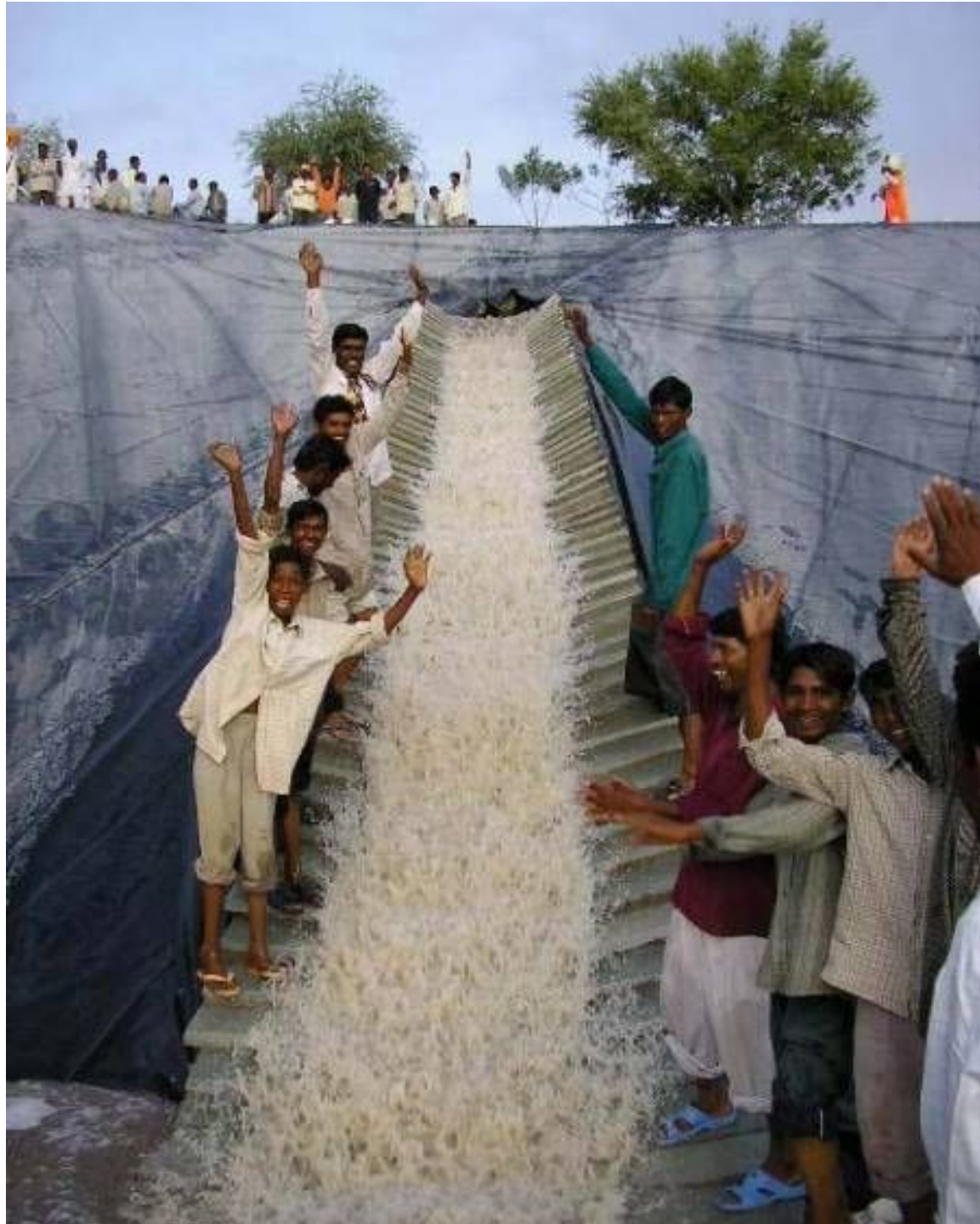
Outline

- What the monsoon means for the people of India
- Basic science of the monsoon
- History of the UK's interest in the Indian monsoon
- Monsoon weather
- Challenges of climate change for India

Some basic facts

- 1.13 billion people - one-sixth of the world's population - live in a country one-third the size of the U.S. Over 37% live below the poverty line.
- Population projected to rise to 1.8 billion by 2050.
- World's eleventh largest economy and second most rapidly growing economy with GDP growth rate last year of 6.7%.
- Sustained by annual rainfall of around 1100mm, 80% of which arrives in the summer.
- Agriculture accounts for nearly 20% of the GDP and employs over 50% of the total workforce.
- 60% of agricultural production is rainfed and hence vulnerable.







Many states in state of worry over late rains



A farmer shows the state of his paddy that has dried up due to insufficient rain and water supply in Gidder village of Punjab.











































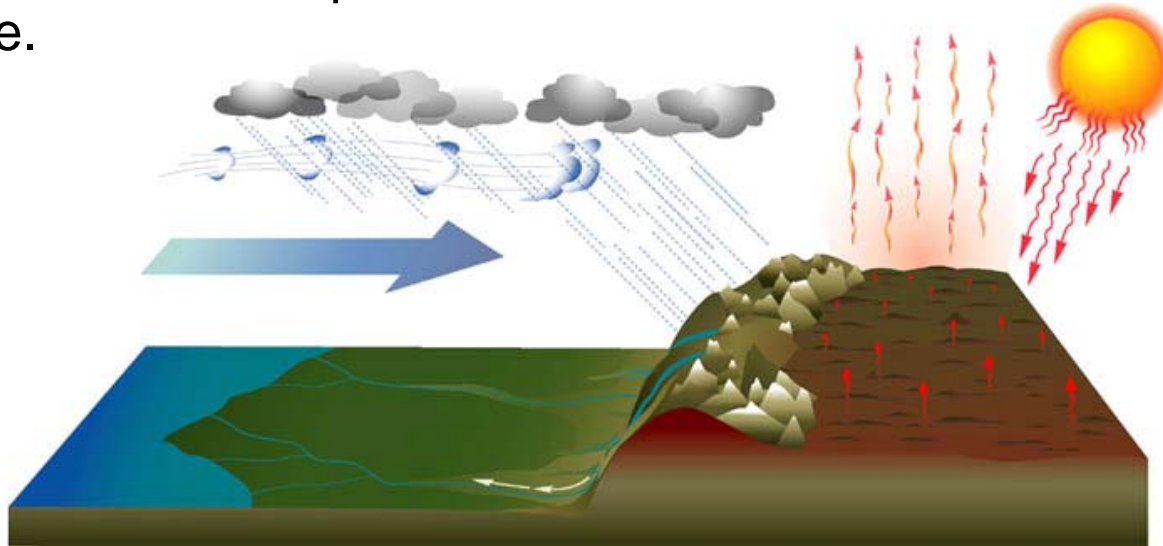






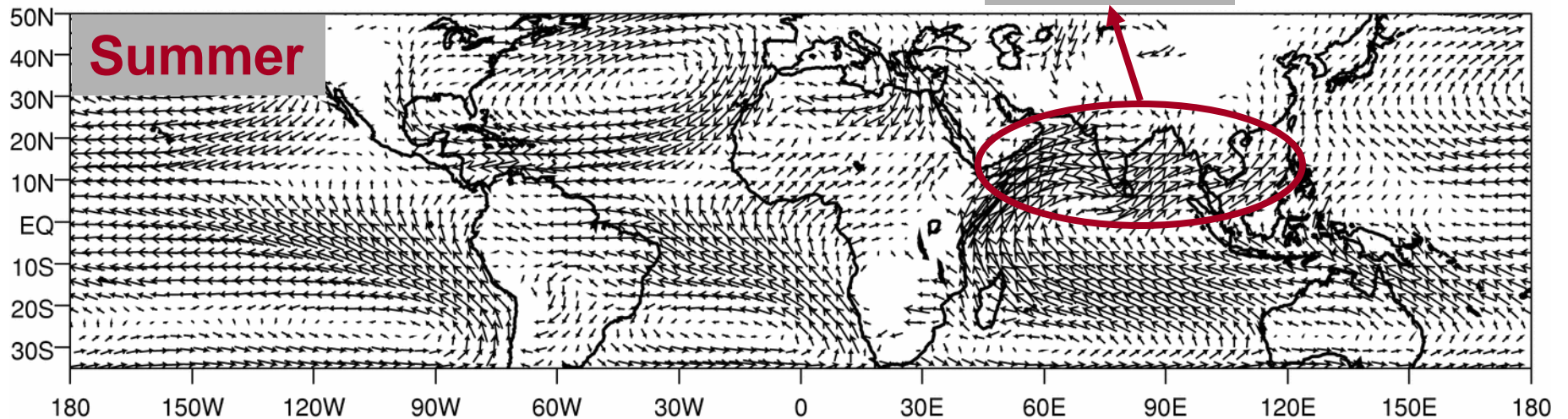
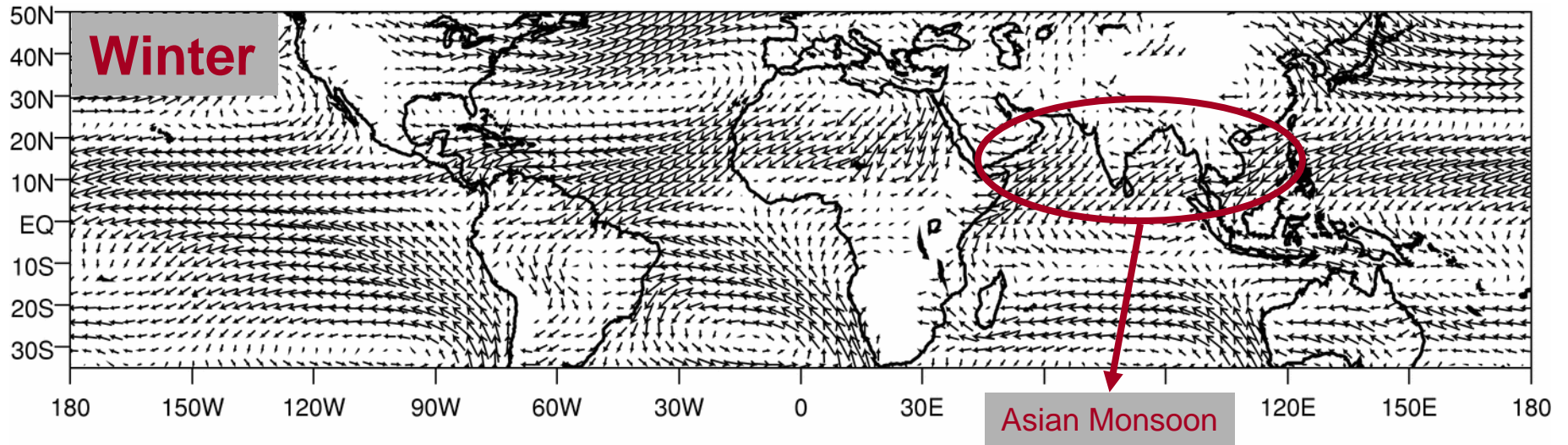
What are Monsoons?

- ‘Monsoon’ means ‘season’, and describes a complete reversal of wind regimes during the seasonal cycle. Monsoons are characterised by a pronounced rainy season.
- Monsoons are driven by changes in the distribution of heating driven primarily by the seasonal cycle of the sun. A thermal contrast between land and sea is required to set up a monsoon.
- In winter, the wind blows from the cold land over the warm sea. In summer, the warm land pulls in the wind from the ocean like a massive sea breeze.



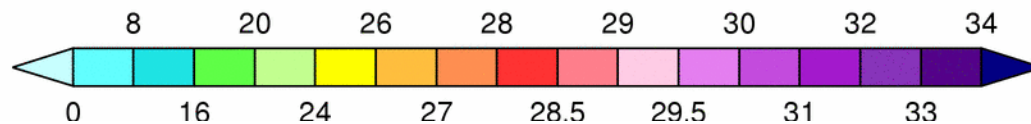
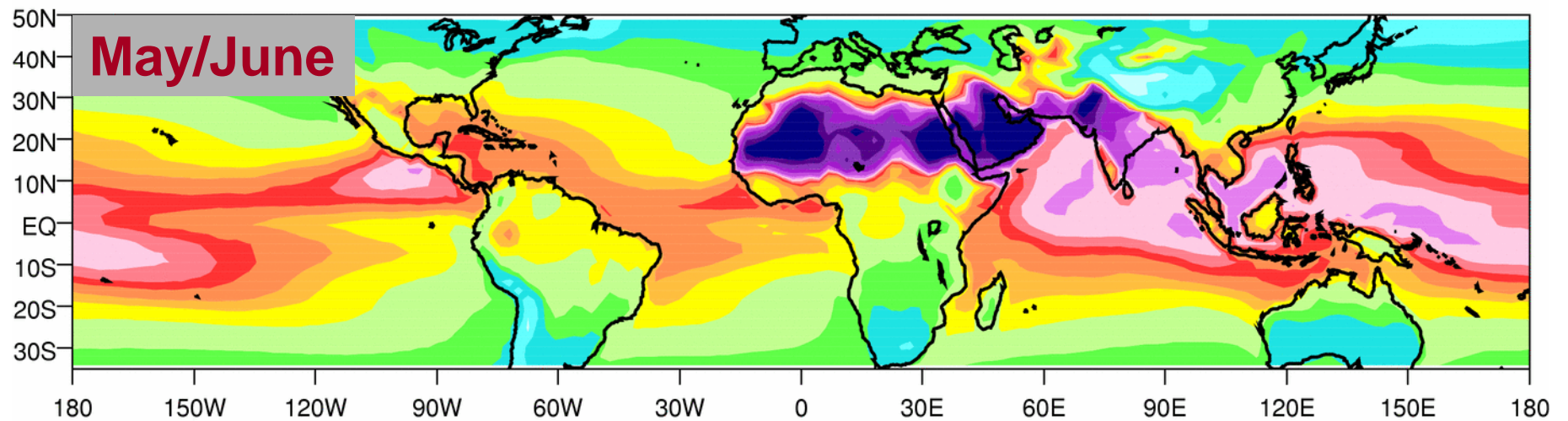
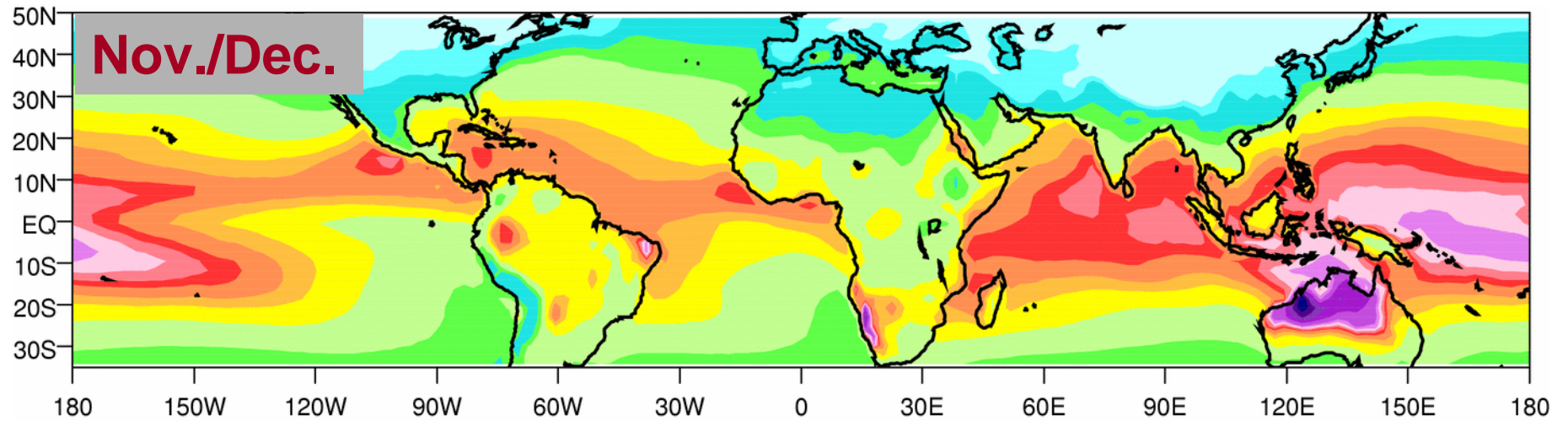
- Once established, the positive feedback between the circulation and latent heat release in the rain clouds maintains the monsoon

Winds near the surface (925hPa)

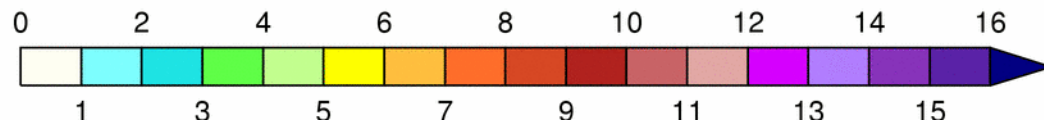
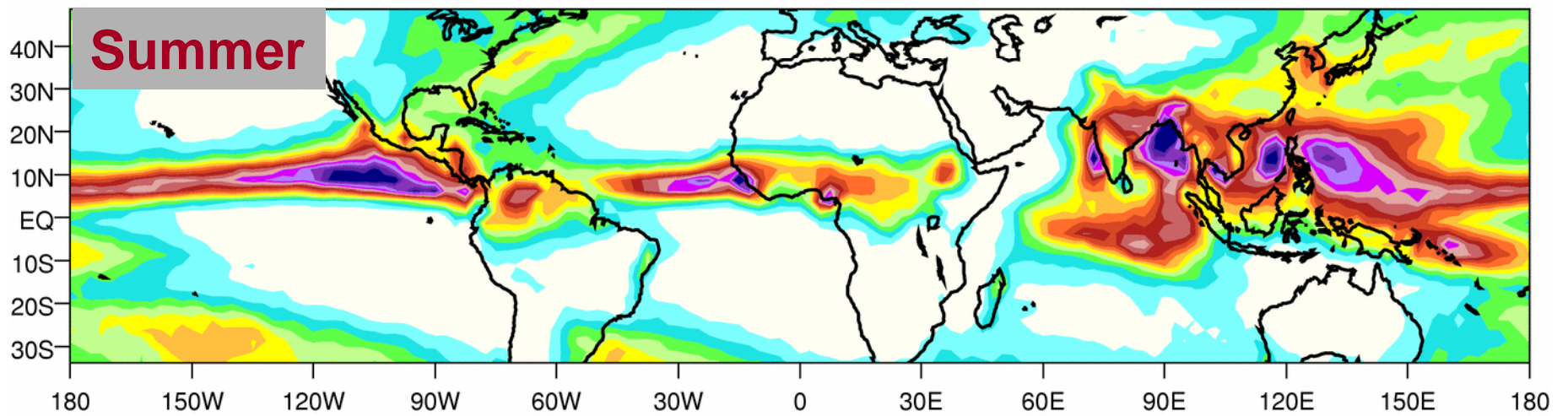
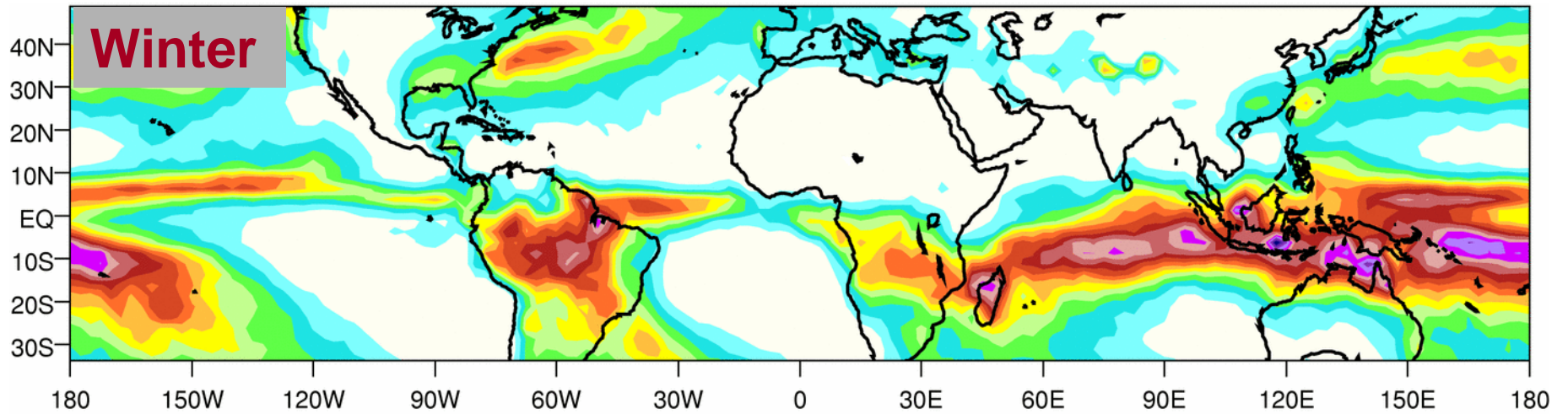


→ Indian Monsoon is part of a much larger circulation, the Asian Monsoon

Pre-Monsoon Land/Sea Temperature contrasts

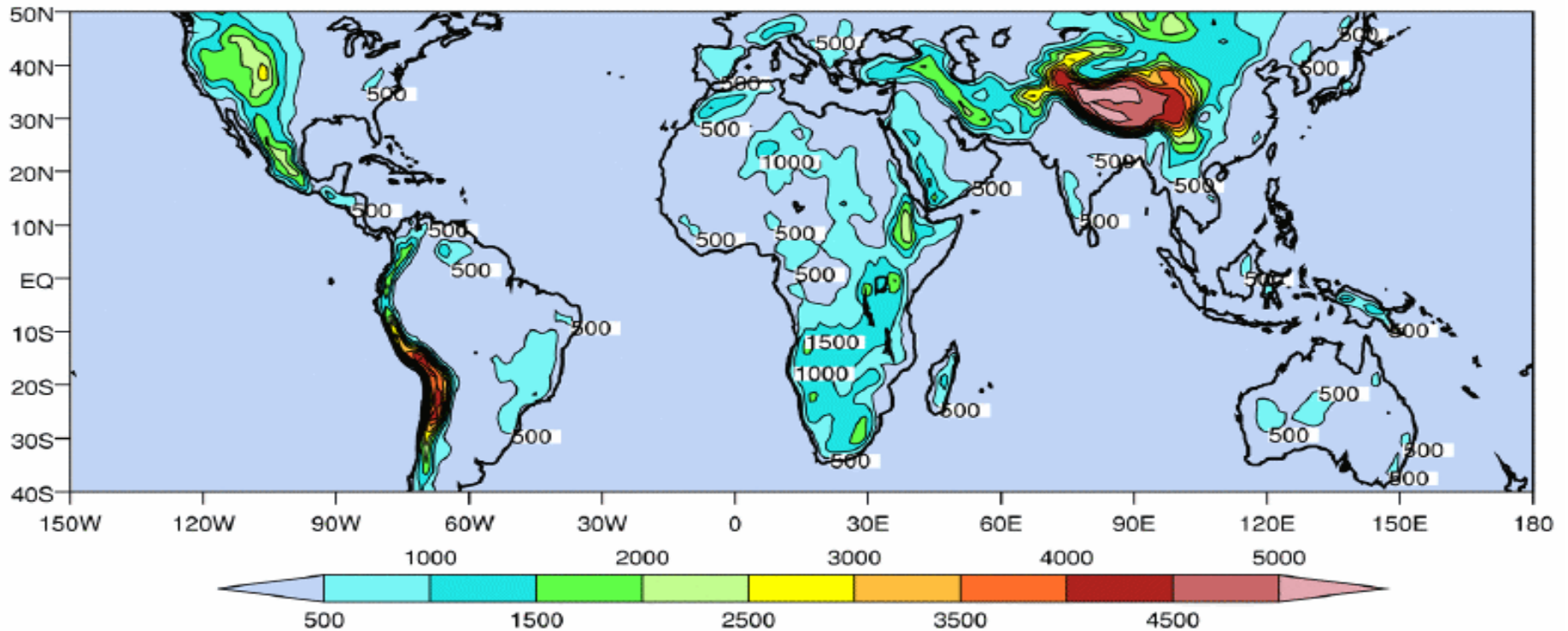


Rainfall (mm/day)



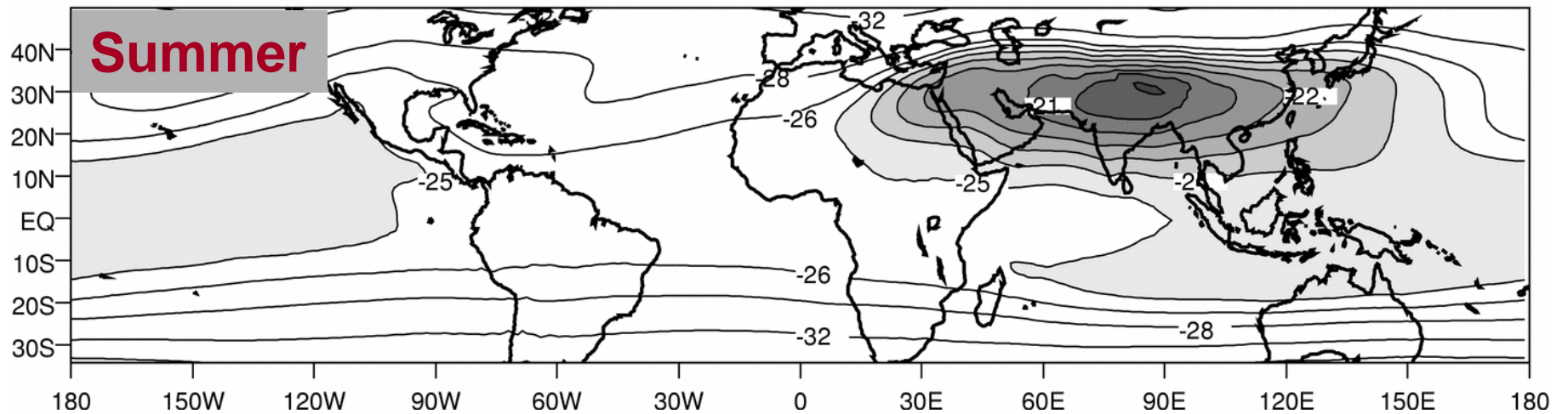
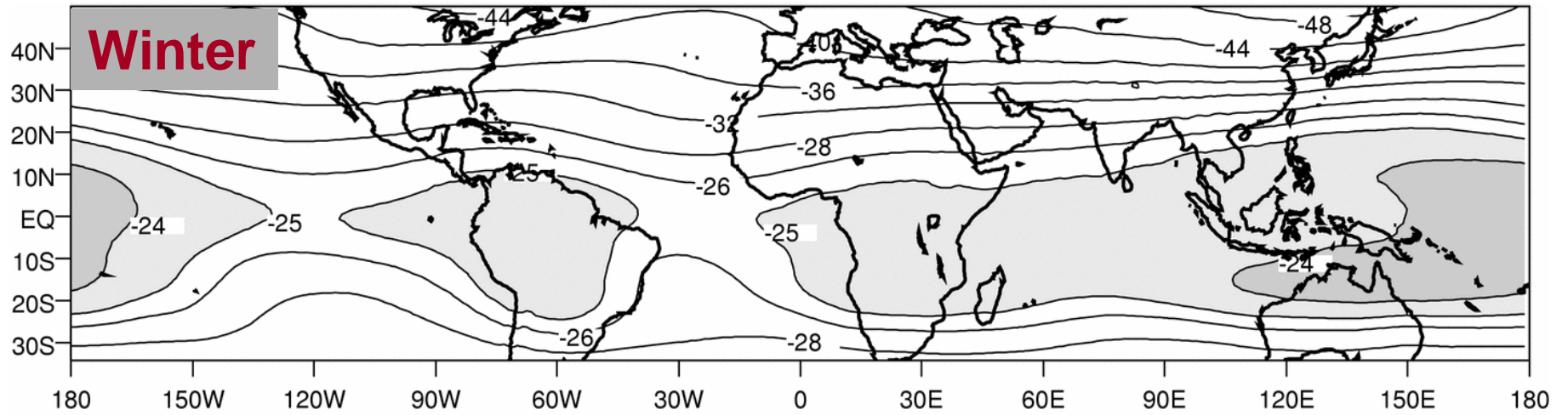
Mountains and Monsoons

Topography (metres)



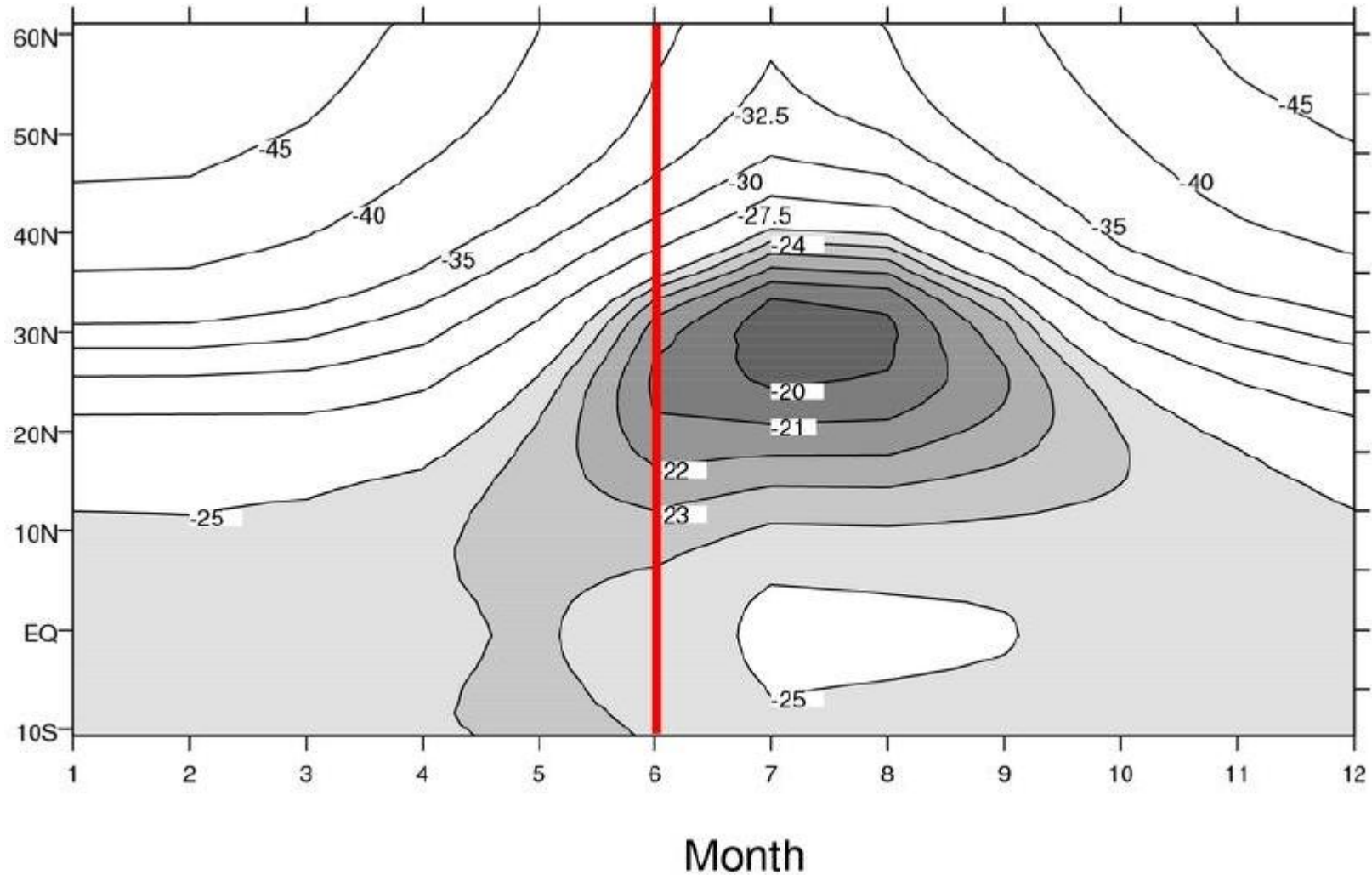
- Tibetan Plateau and the Asian Summer Monsoon
- East African Highlands and the Indian Summer Monsoon
- Andes and the South American Monsoon
- Sierra Madre and the North American Monsoon

Mean Temperature in the Upper Troposphere (500 – 200mb)



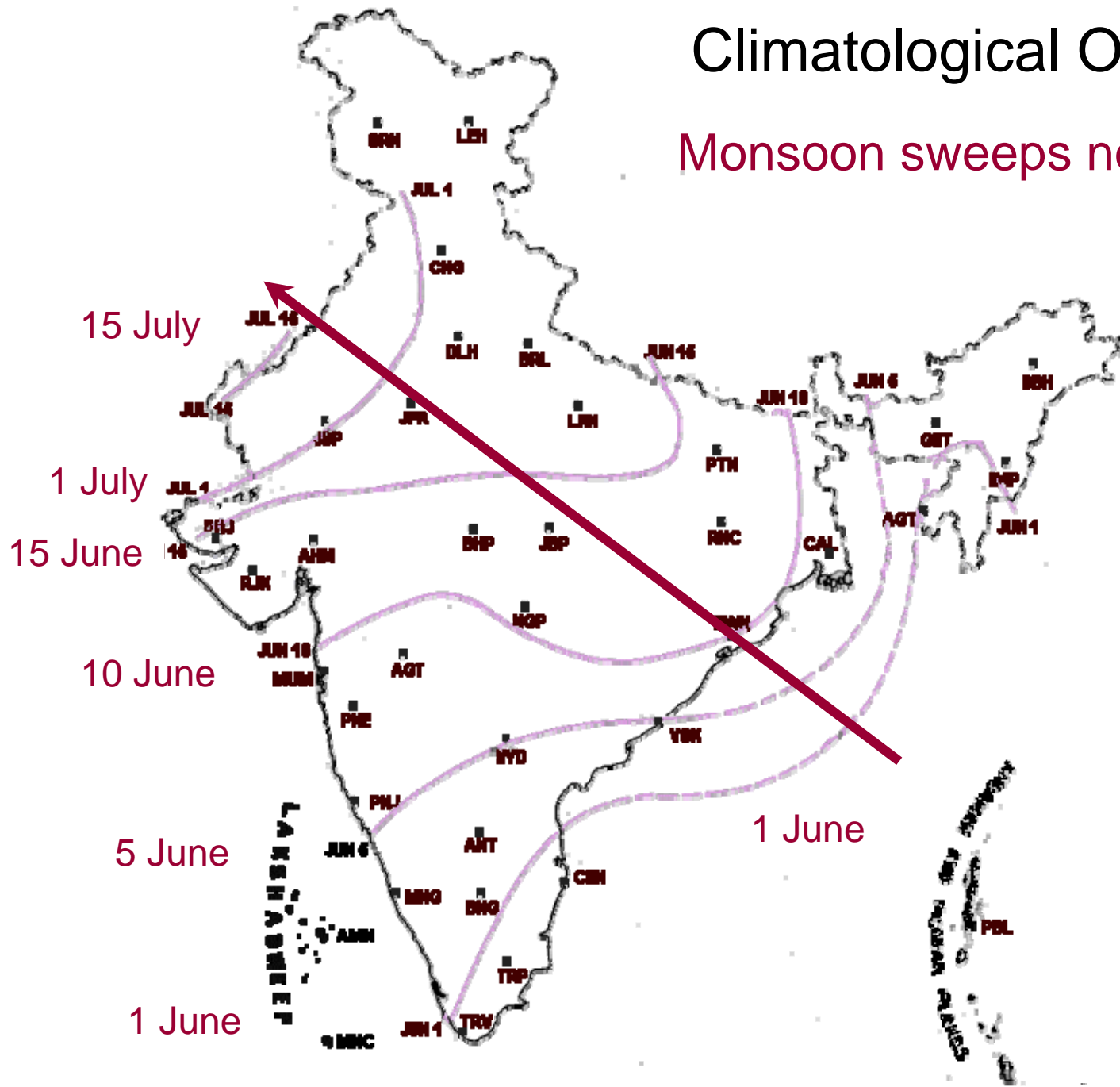
Seasonal evolution of North-South gradient in 200-500hPa temperature

Indian Monsoon Onset



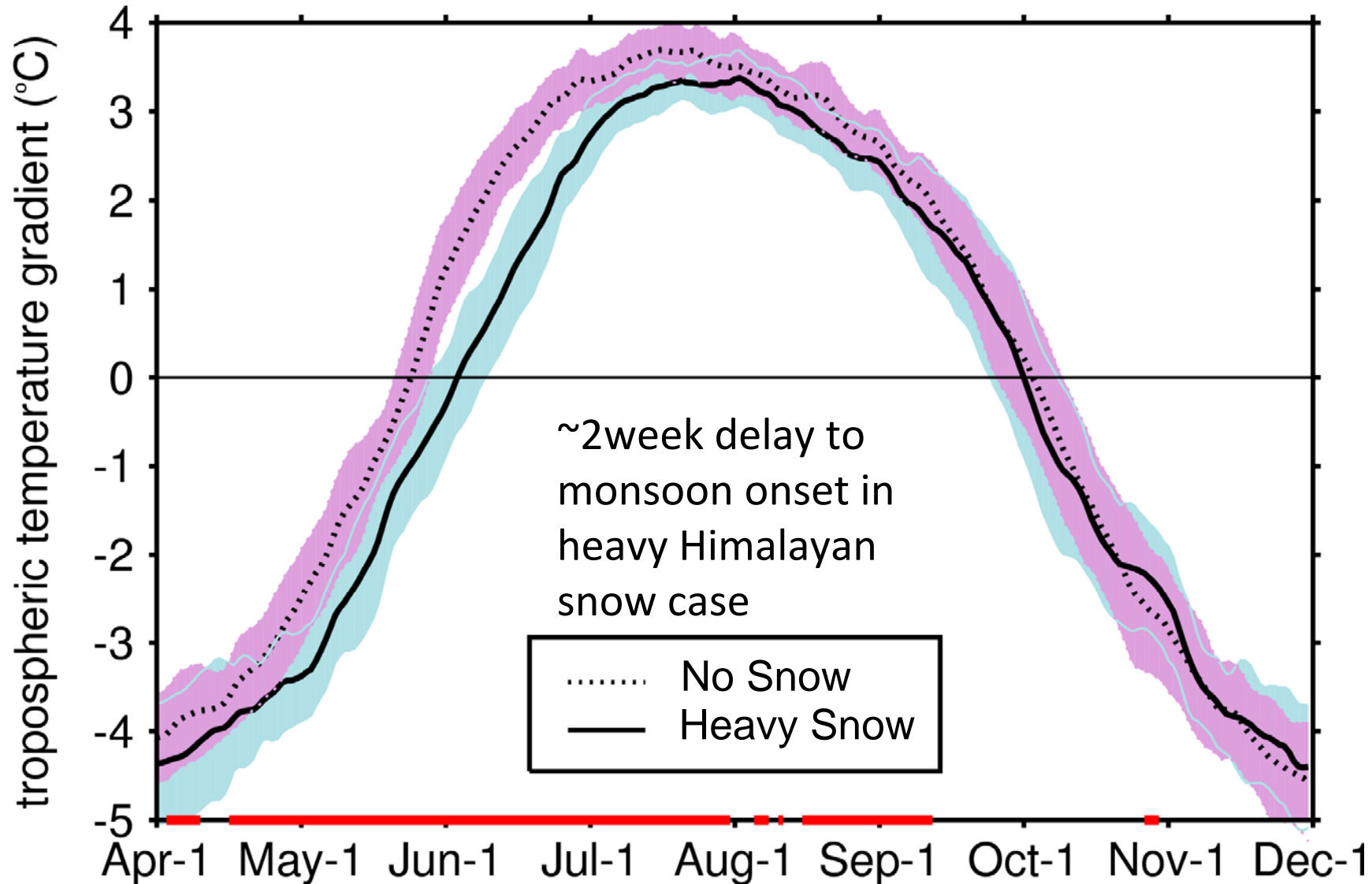
Climatological Onset Dates

Monsoon sweeps north and west



Snow-monsoon interactions

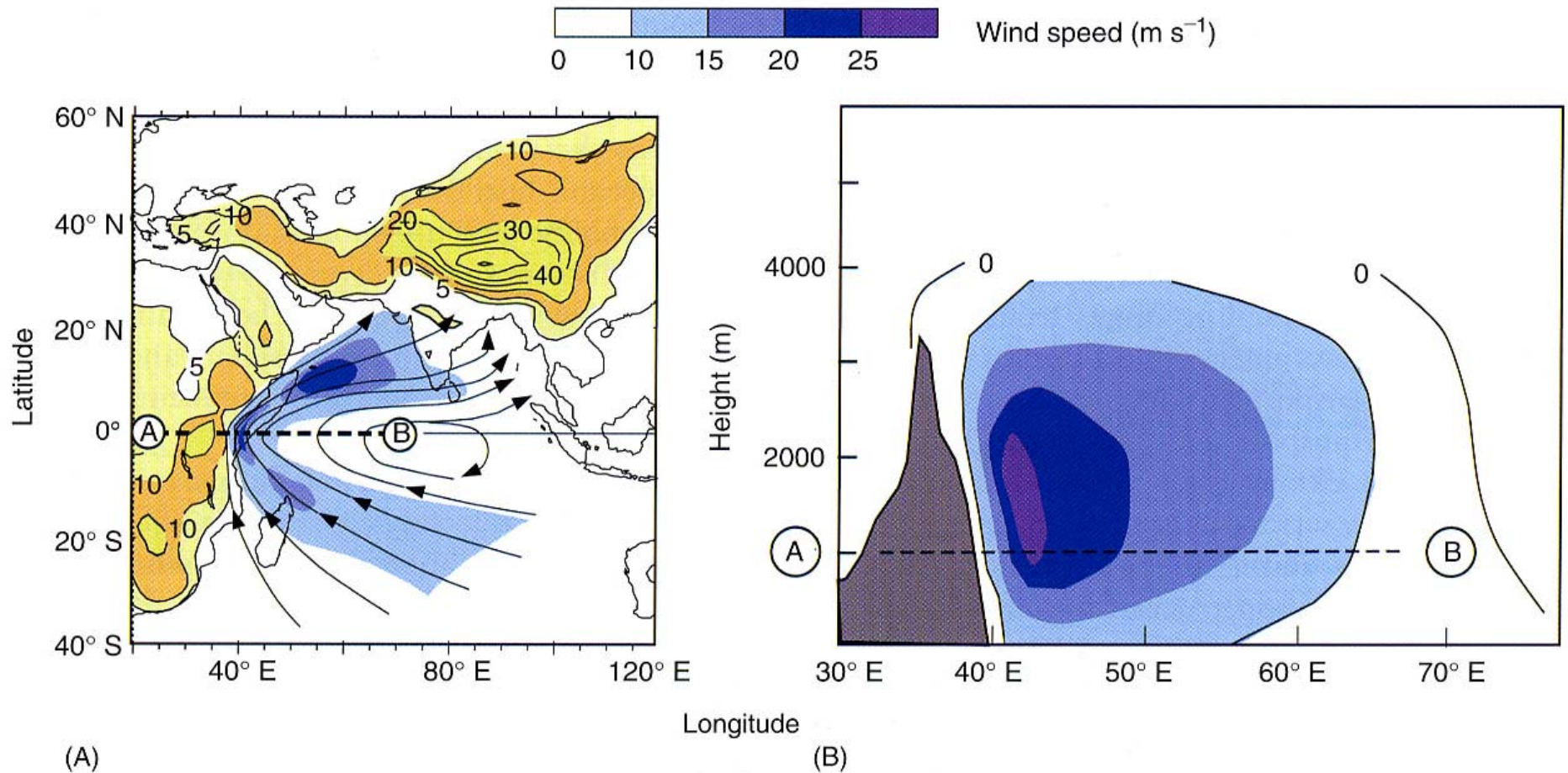
Model Sensitivity Study: No Snow versus Heavy Snow



~2week delay to monsoon onset in heavy Himalayan snow case

..... No Snow
— Heavy Snow

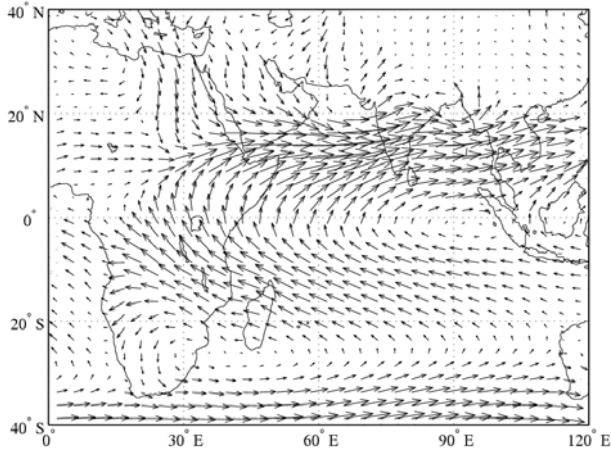
East African Highlands, Somali Jet and Indian Summer Monsoon



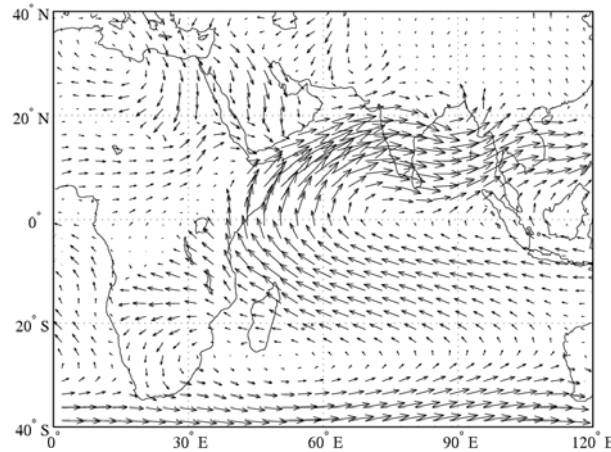
Impact of E. African Highlands on Asian Summer Monsoon

850 hPa winds

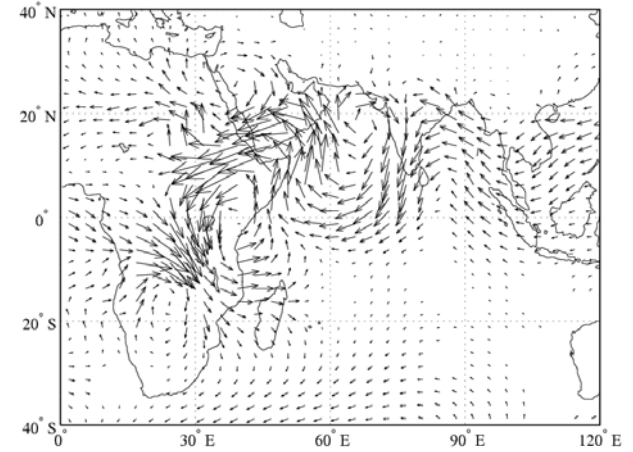
JJA: W/out Highlands



JJA: With Highlands



JJA: Impact of Highlands

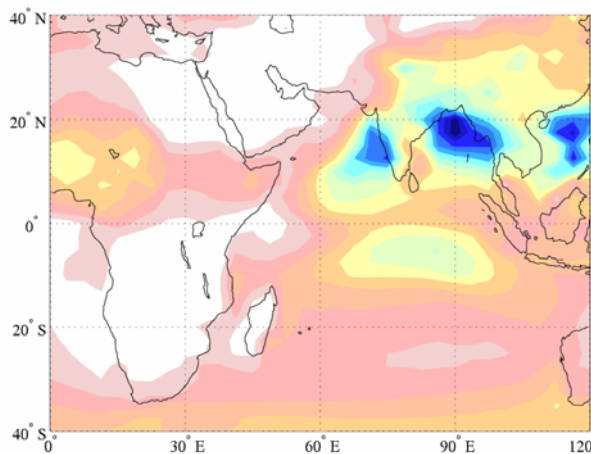


10 m/s →

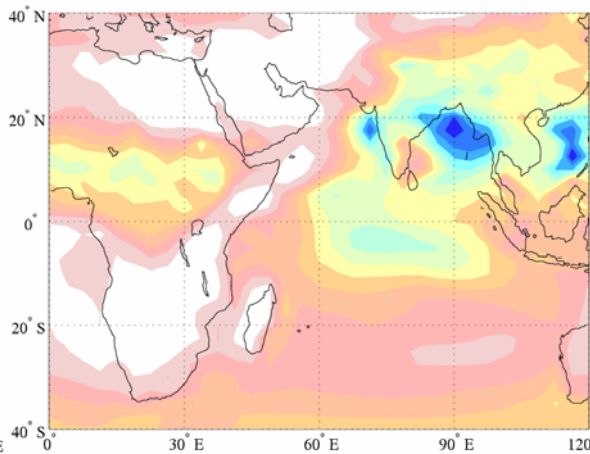
5 m/s →

Rainfall

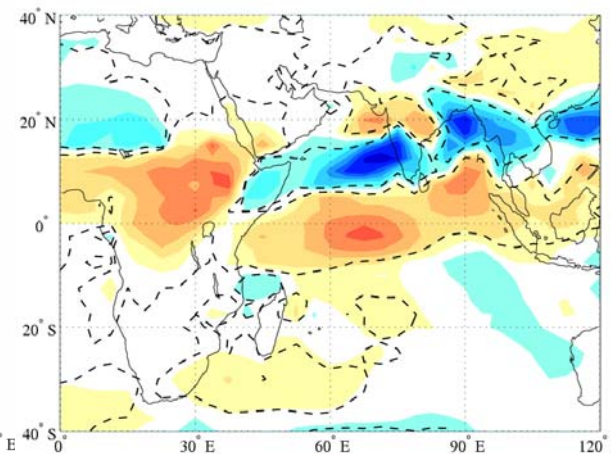
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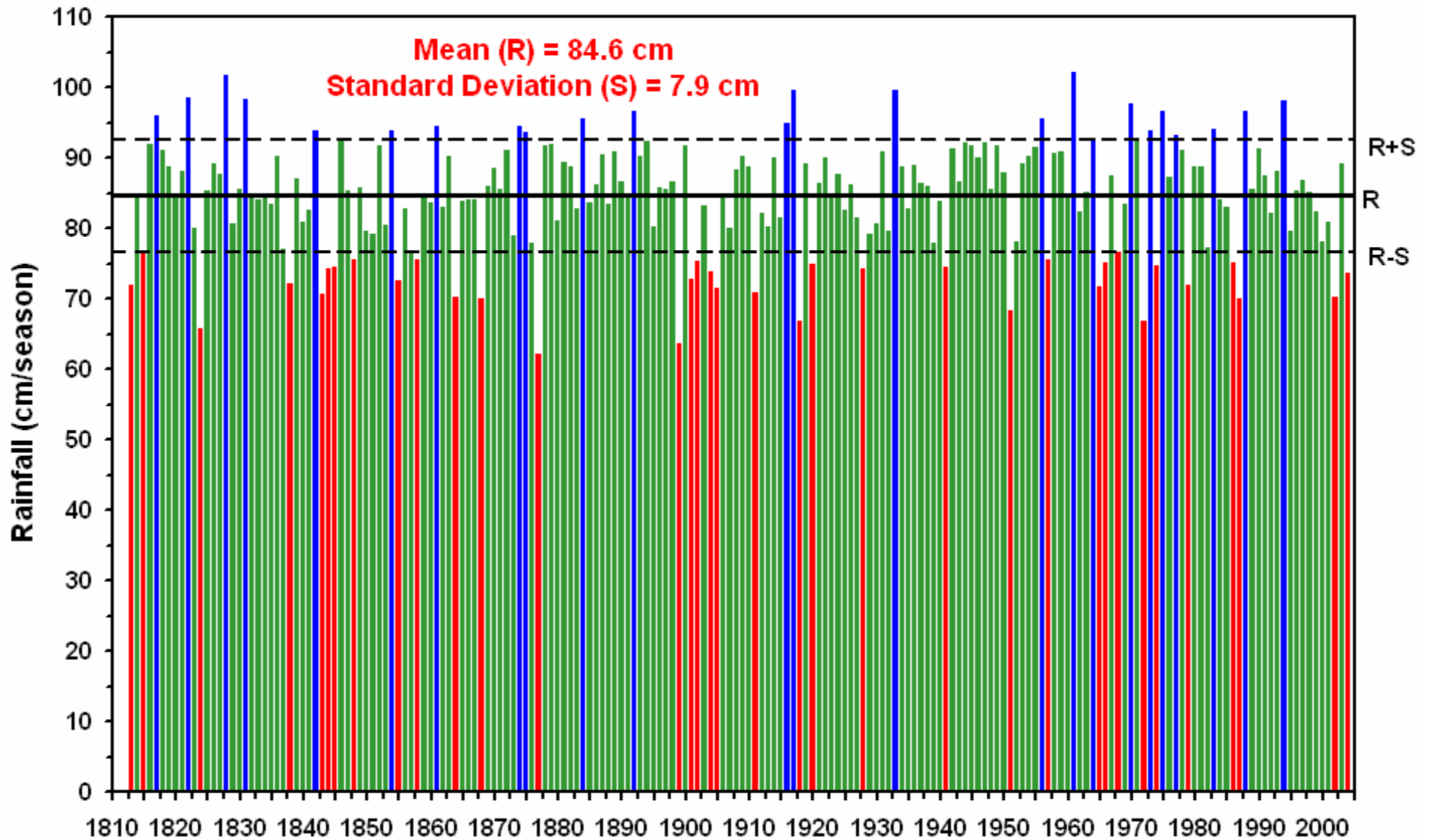


0 0.8 3.3 7.3 13.1 20.4 29.4 40 mm/day

15 11.5 8.4 5.9 3.8 2.1 0.9 0.2 -0.2 -0.9 -2.1 -3.8 -5.9 -8.4 -11.5 -15 mm/day

Slingo et al 2004

Long-Term Stability of the Indian Summer Monsoon



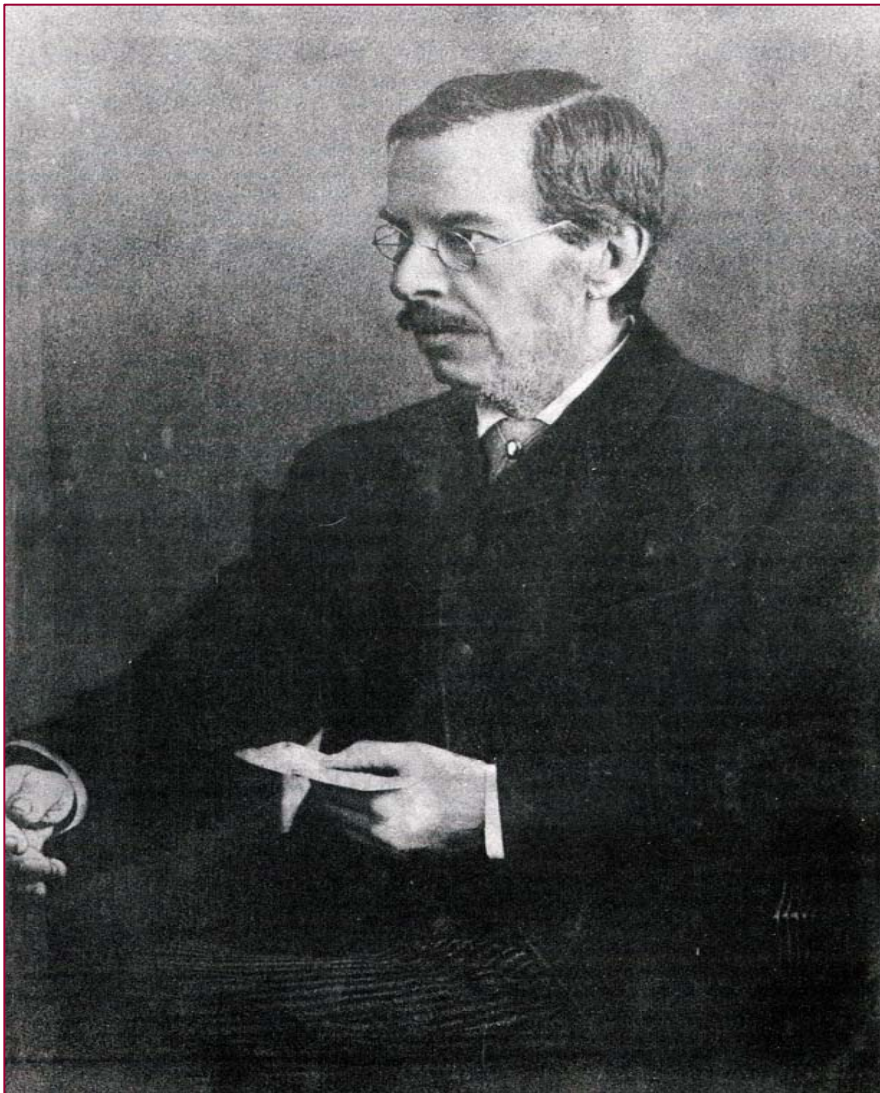
UK's fascination with the meteorology of India

- India was Britain's most important imperial and economic possession. By the late 1860s India absorbed 1/5th of all British exports, so its economic importance was profound.
- India appeared to offer an ideal natural laboratory for the science, and an ideal space in which to demonstrate the political importance of science in a global age.

Reference: *Predicting the Weather: Victorians and the Science of Meteorology*
by Katharine Anderson

Henry Francis Blanford

1st British Director (Imperial Meteorological Reporter) of the
Indian Meteorological Department (1875-1889)



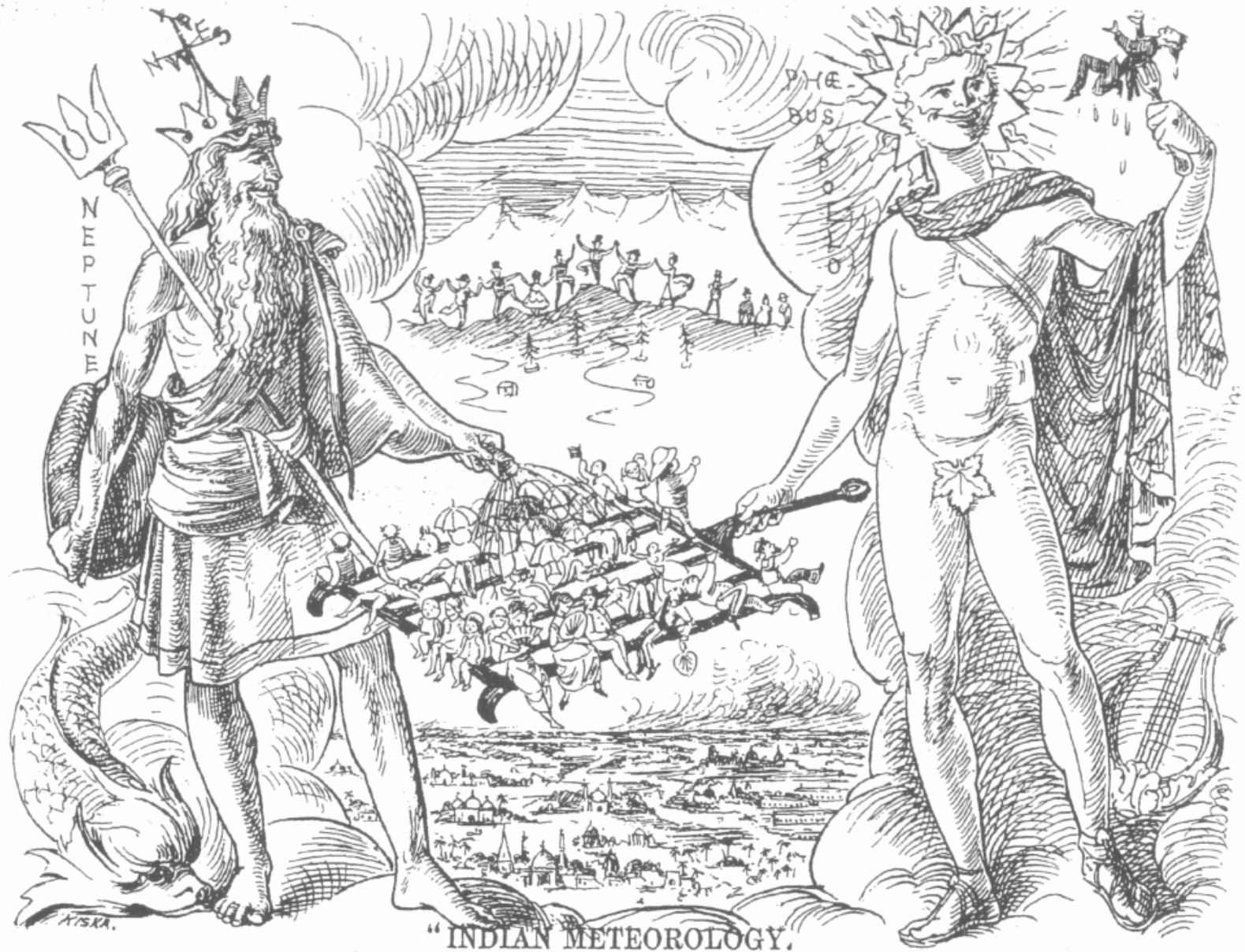
‘Order and regularity are as prominent characteristics of our (India’s) atmospheric phenomena, as are caprice and uncertainty those of their European counterparts.’

India holds the key to unraveling the laws of the atmosphere!

Blanford argued that India offered a special situation for the study of meteorology:

'We are in the position of a commander who can find no eminence from which he may gain a bird's eye view of the combat.'

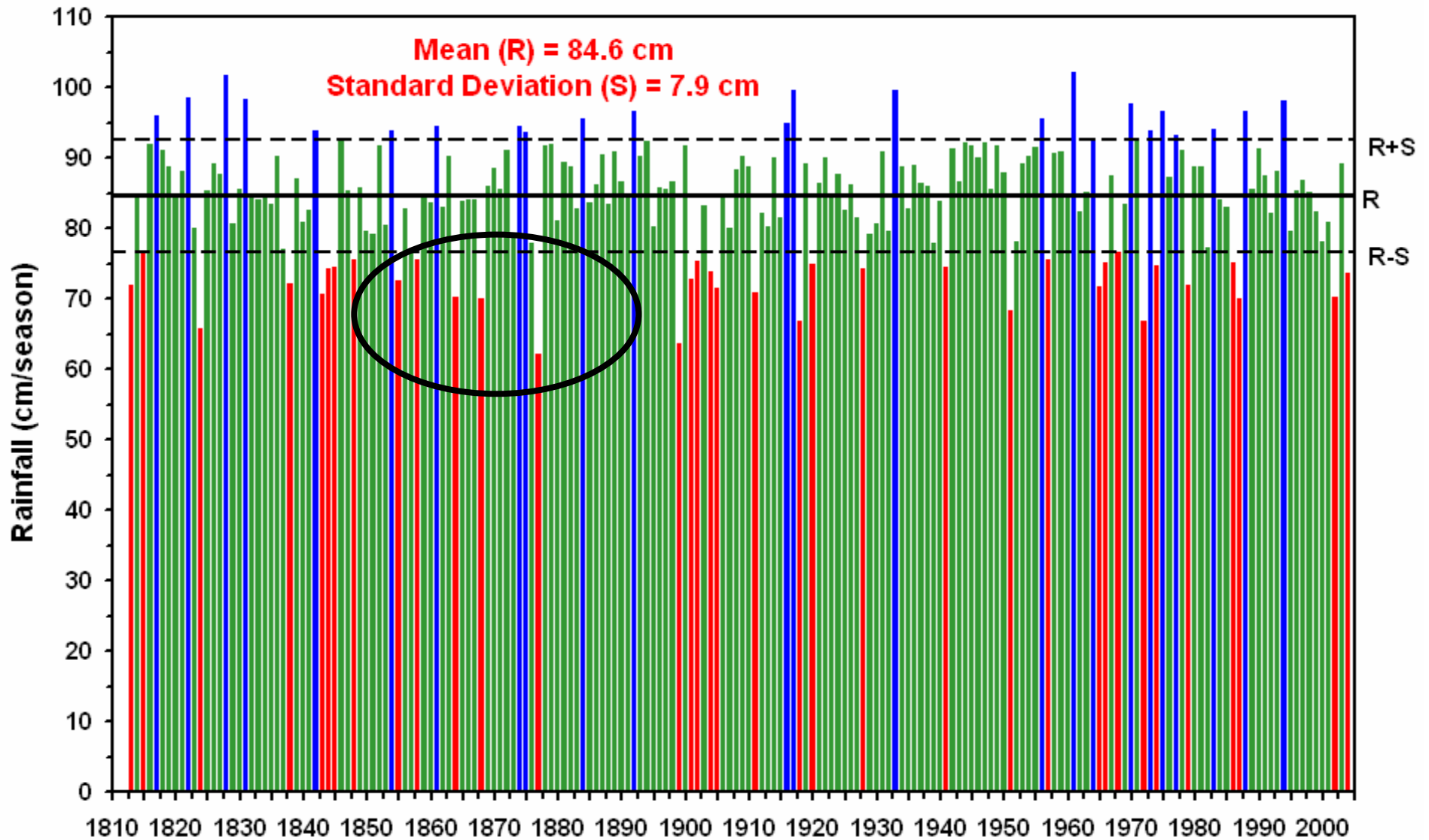
Could we but find some isolated tract of mountain, plain and ocean ... girdled round by a giant mountain chain that should completely shut in and isolate some millions of square miles of the atmosphere, resting on a surface vast and varied enough to exhibit within itself all those contrasts of desert and forest, of plain, plateau and mountain ridge, of continent and sea, then the progress of meteorology would be assured.'

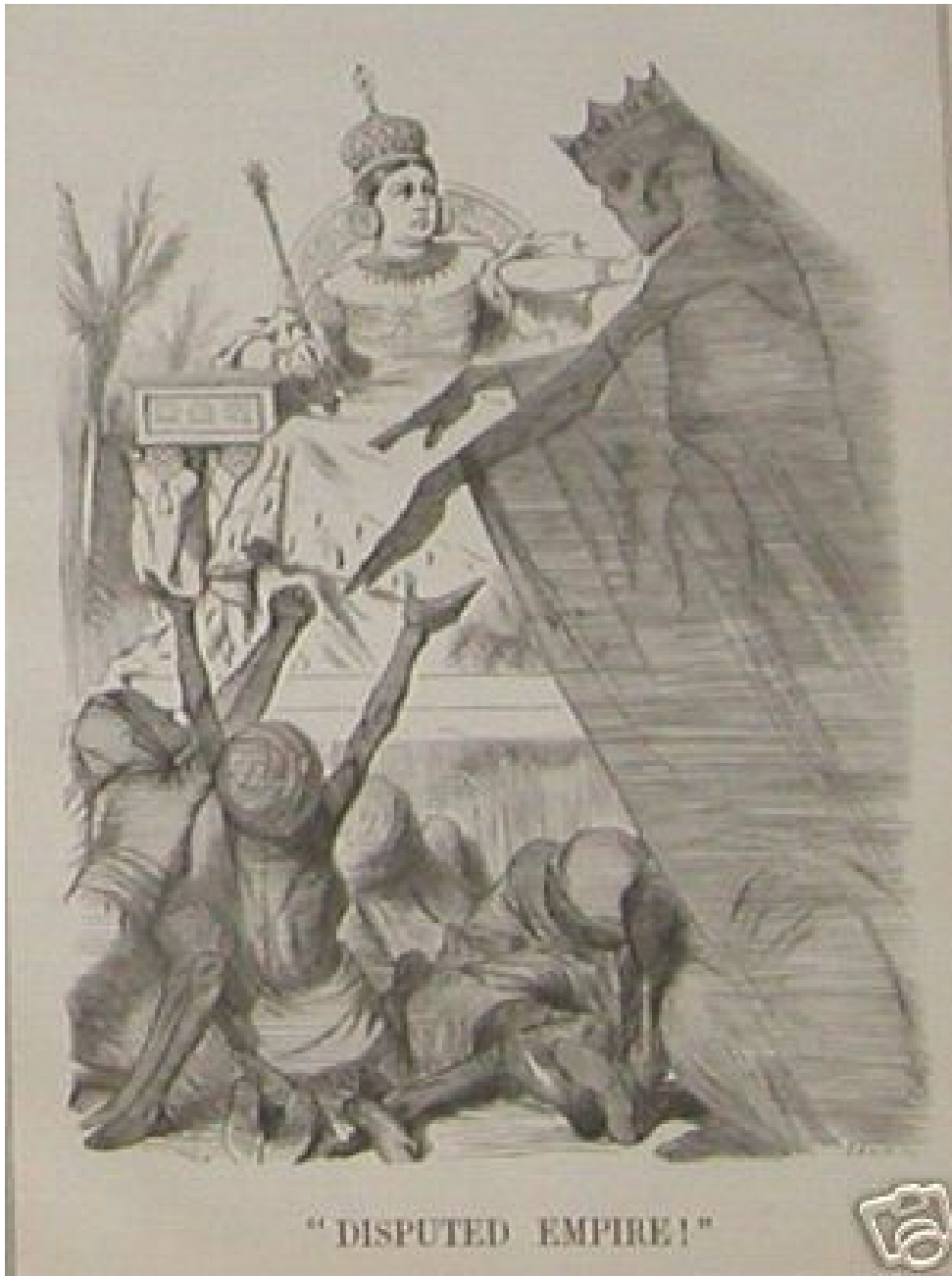


THE WEATHER CLASSICALLY TREATED. WITH CHARIVARI'S COMPLIMENTS TO MR. BLANFORD.

From 'The Indian Charivari' – India's equivalent of 'Punch': July 23, 1875

Long-Term Stability of the Indian Summer Monsoon





"Disputed Empire": Cartoon from Punch, 1877

Great Famine of 1877/78: Conjunction of Politics and Science

The Indian economy was single-mindedly focused on its grain harvests.

Indian taxes to administer the country and pay dividends to its investors depended entirely on the monsoon rains.

Control of famine through climate prediction would mean that India could be governed more effectively.

Sir Gilbert Thomas Walker

3rd British Director (Director General of Observatories) of the
Indian Meteorological Department (1904-1924)

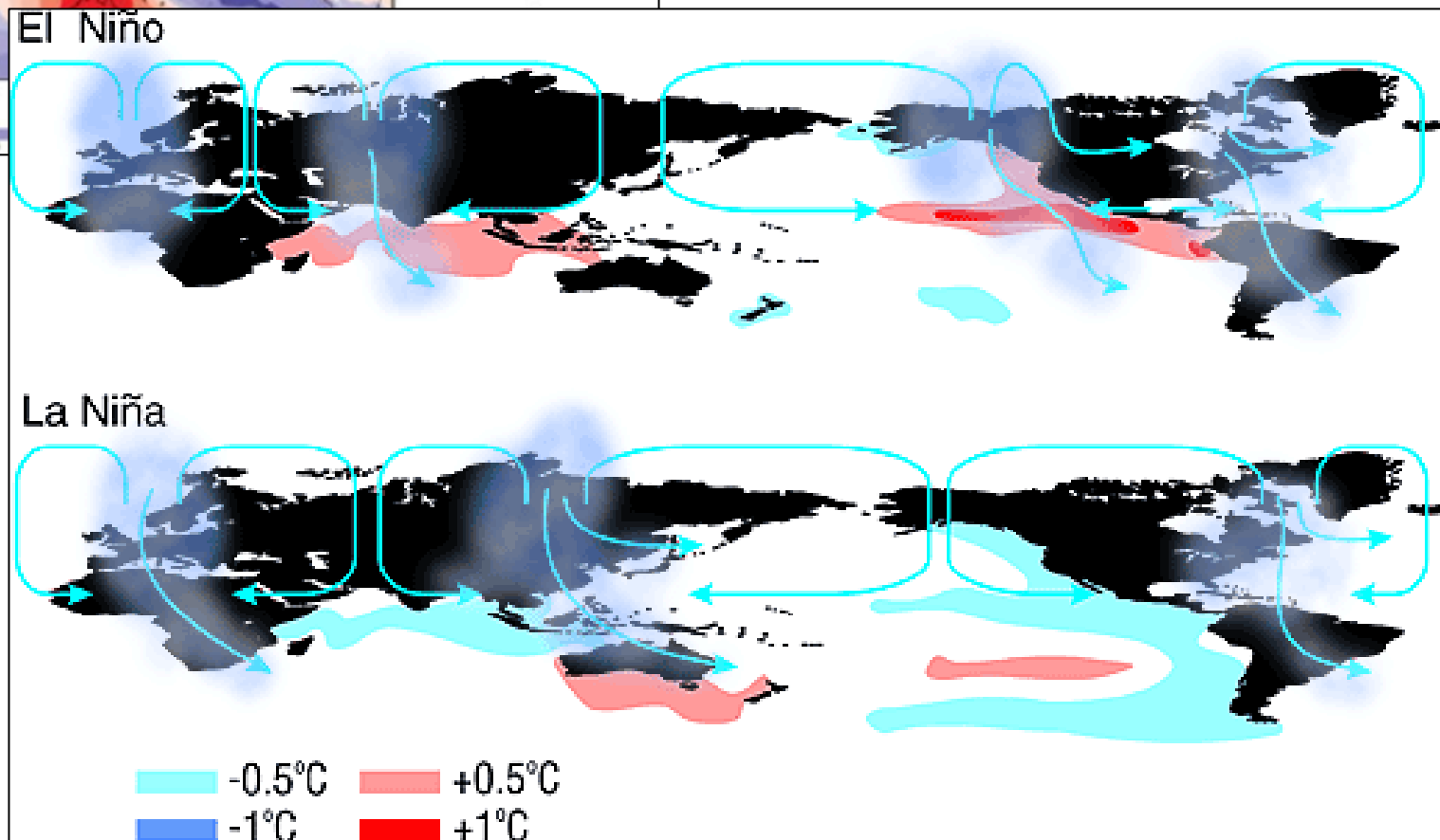
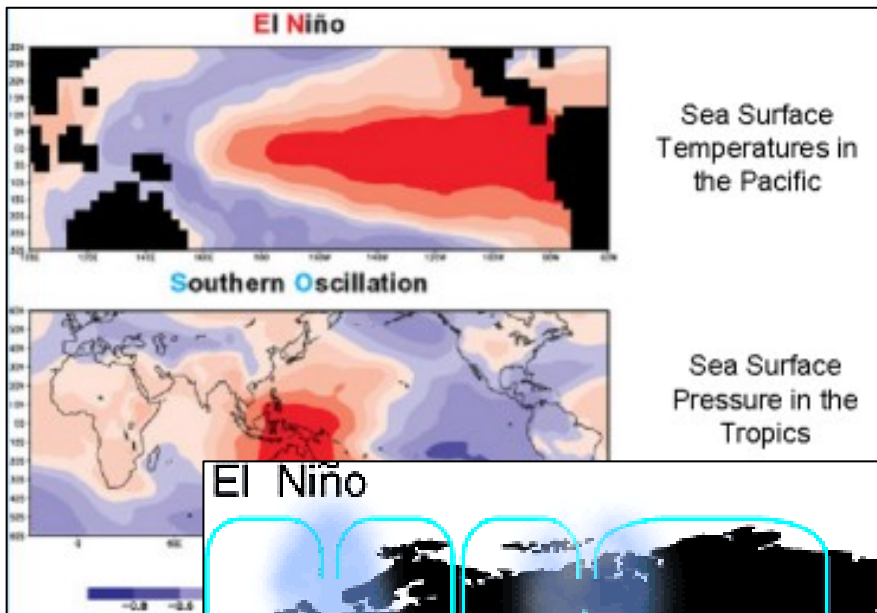


Pioneered statistical forecasting - formed
a 'human computer' with Indian staff
performing a mass of statistical
correlations using data from around the
world

*'I think that the relationships of world
weather are so complex that our only
chance of explaining them is to
accumulate the facts empirically.'*

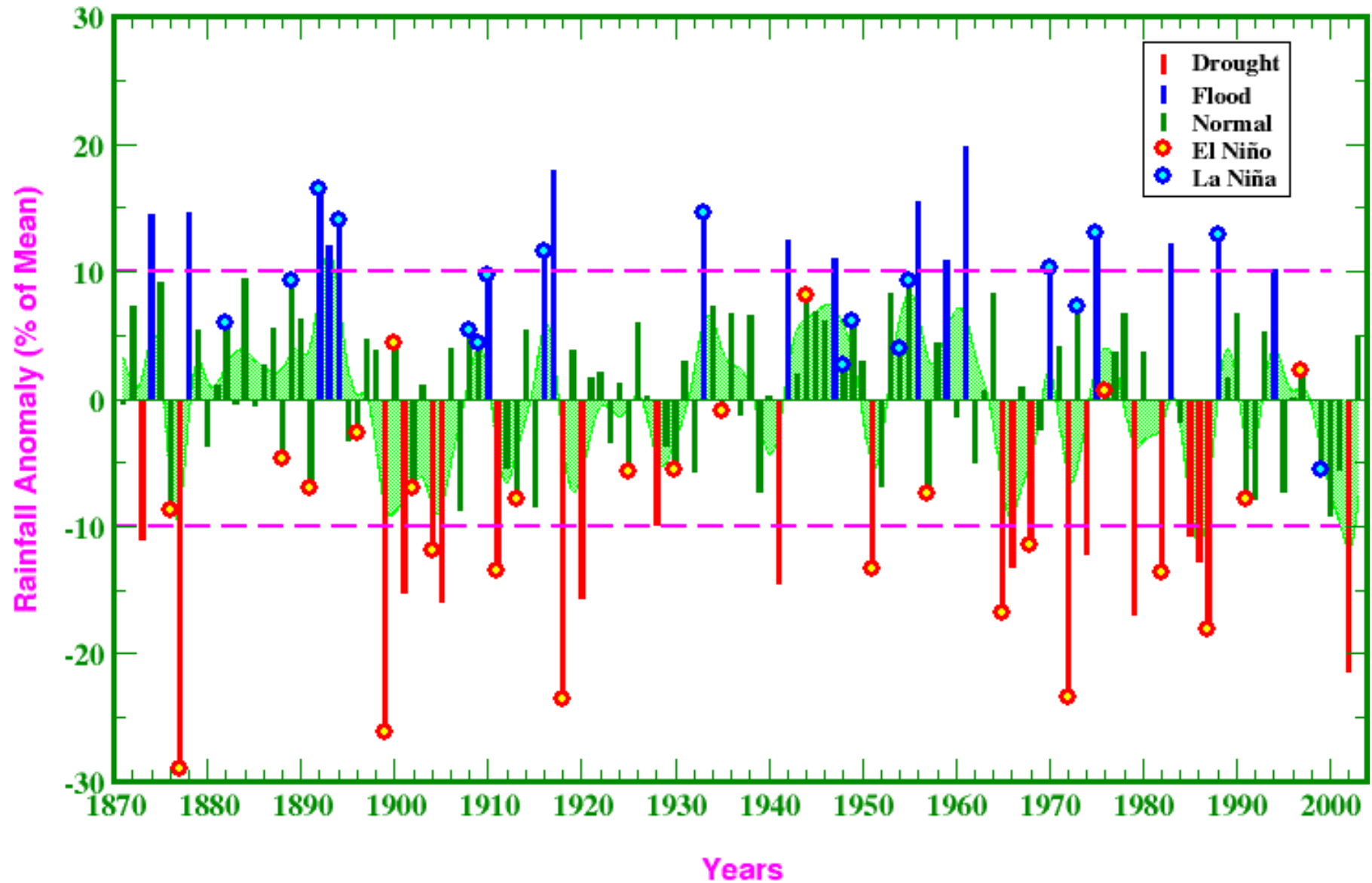
Introduced the terms Southern Oscillation,
North Atlantic Oscillation, and North
Pacific Oscillation

El Niño, Southern Oscillation and the Walker Circulation

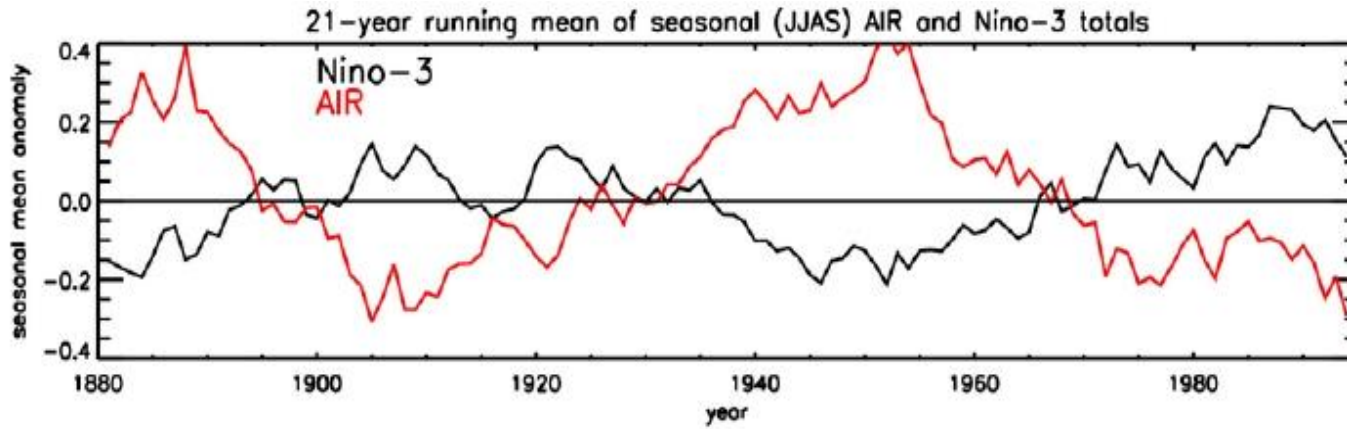


All-India Summer Monsoon Rainfall, 1871-2003

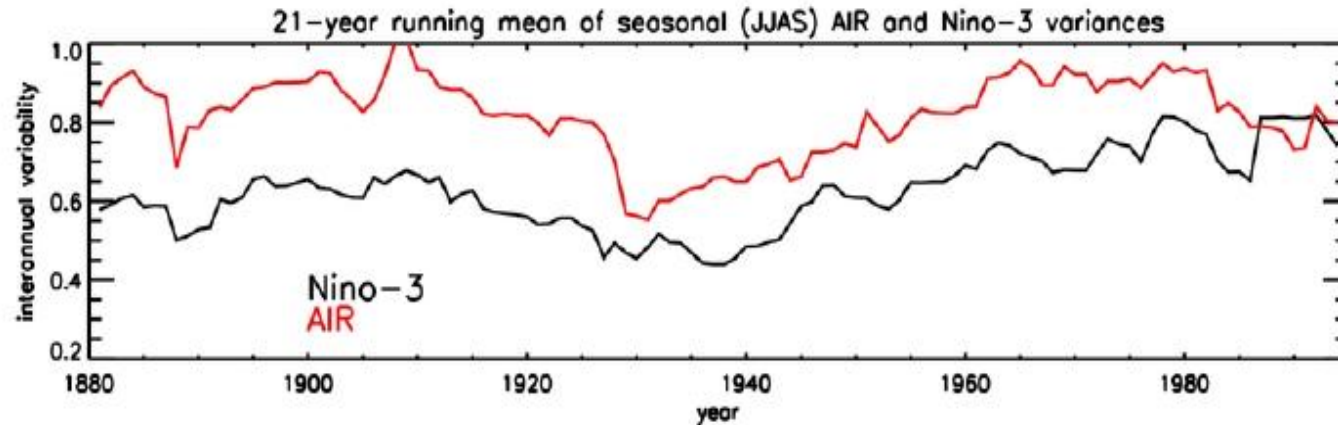
(Based on IITM Homogeneous Indian Monthly Rainfall Data Set)



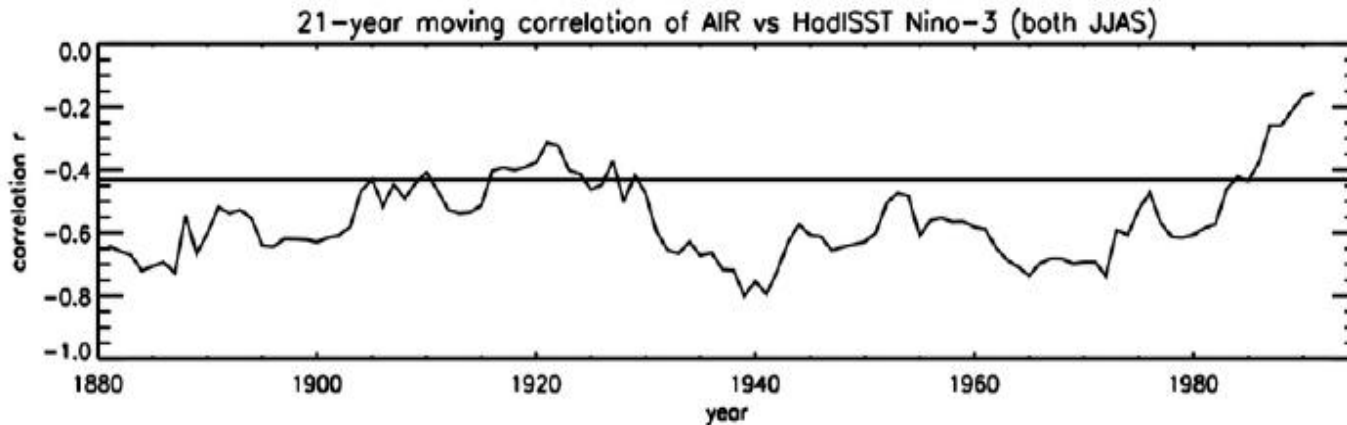
Decadal Variations in Indian Monsoon and El Nino



Seasonal mean



Interannual
Variability



ENSO-Monsoon
Teleconnections

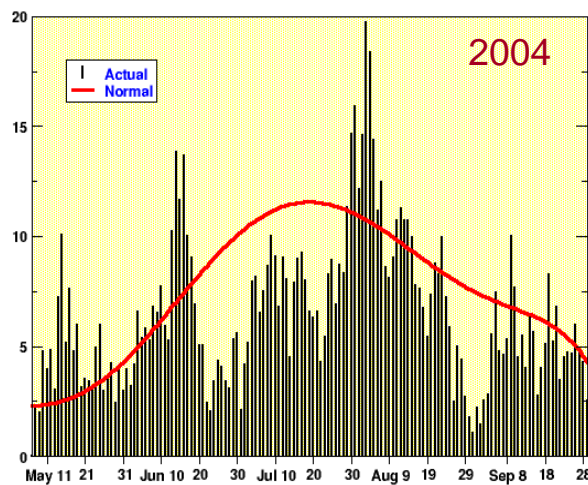
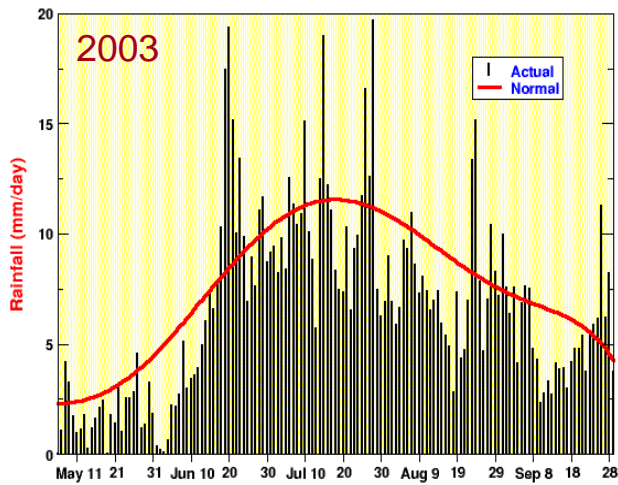
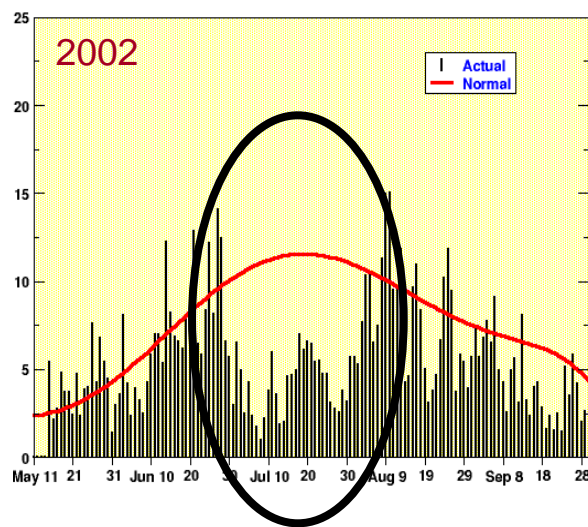
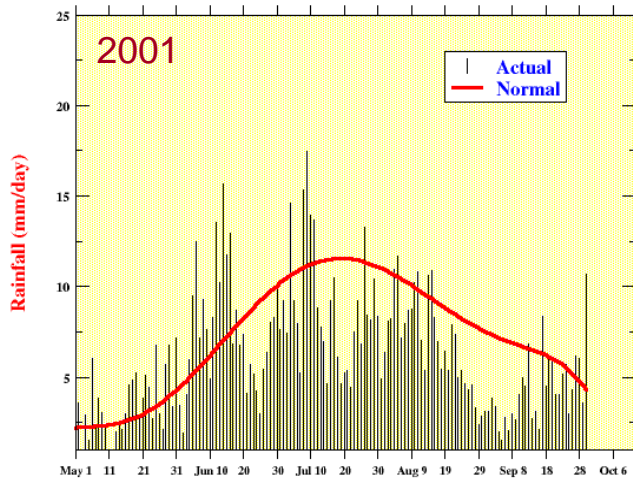
Updated from Slingo (1999)

Possible Players in Monsoon Variability

(+++ Level of confidence/knowledge)

- El Nino/Southern Oscillation (+++)
- Eurasian and Himalayan snow amounts (+)
- Indian Ocean sea surface temperatures and heat content (+)
- Intra-seasonal variability e.g. active/break cycles (++)

Diversity of All-India Daily Rainfall

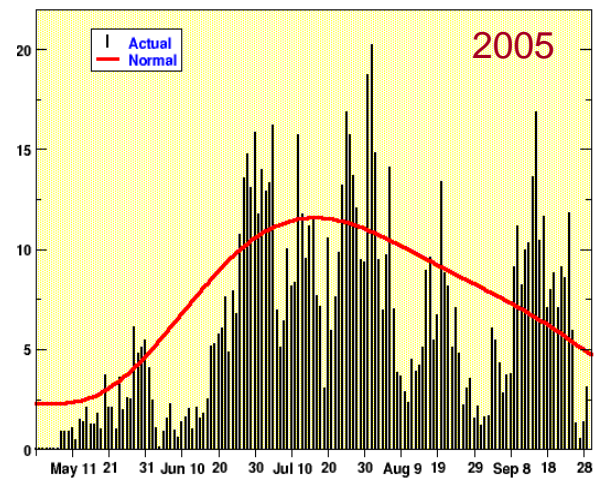


➤ What weather patterns are linked to daily rainfall variability?

➤ How predictable are they and on what lead times?

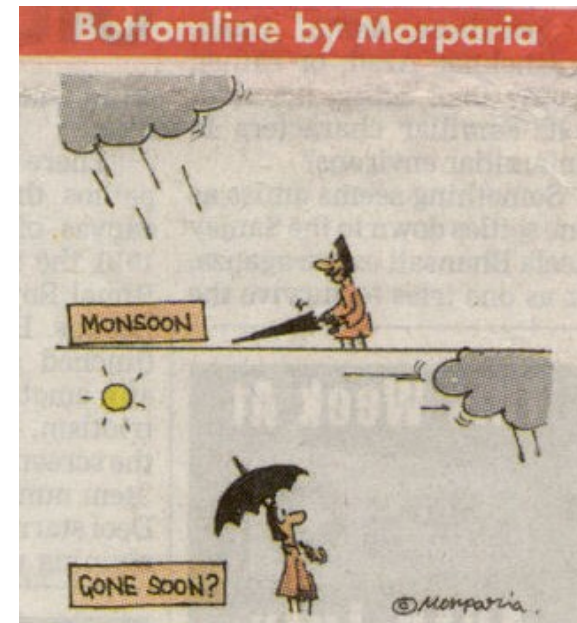
➤ How do they influence seasonal mean rainfall?

➤ What will happen under global warming?





July 2002: Drought in India

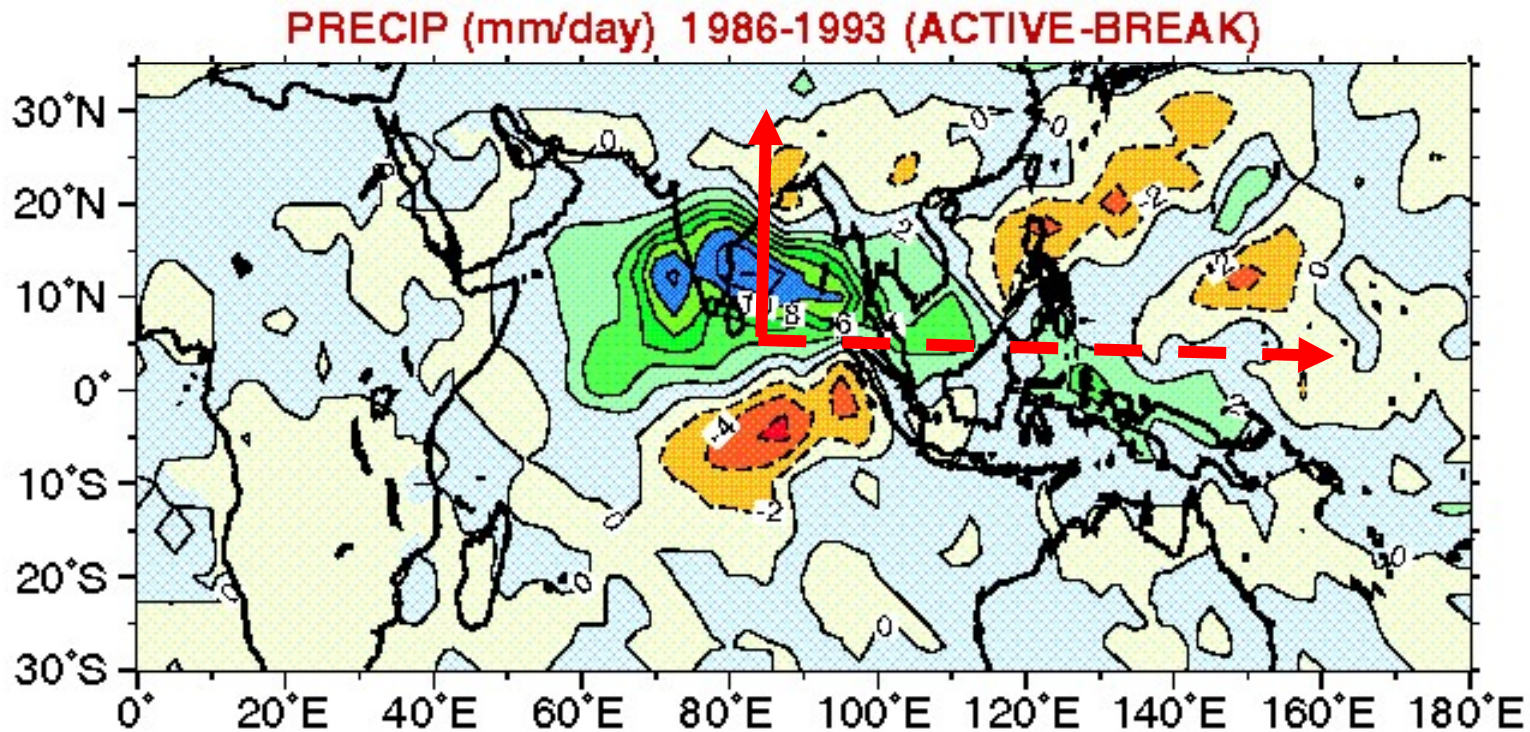


Many states in state of worry over late rains



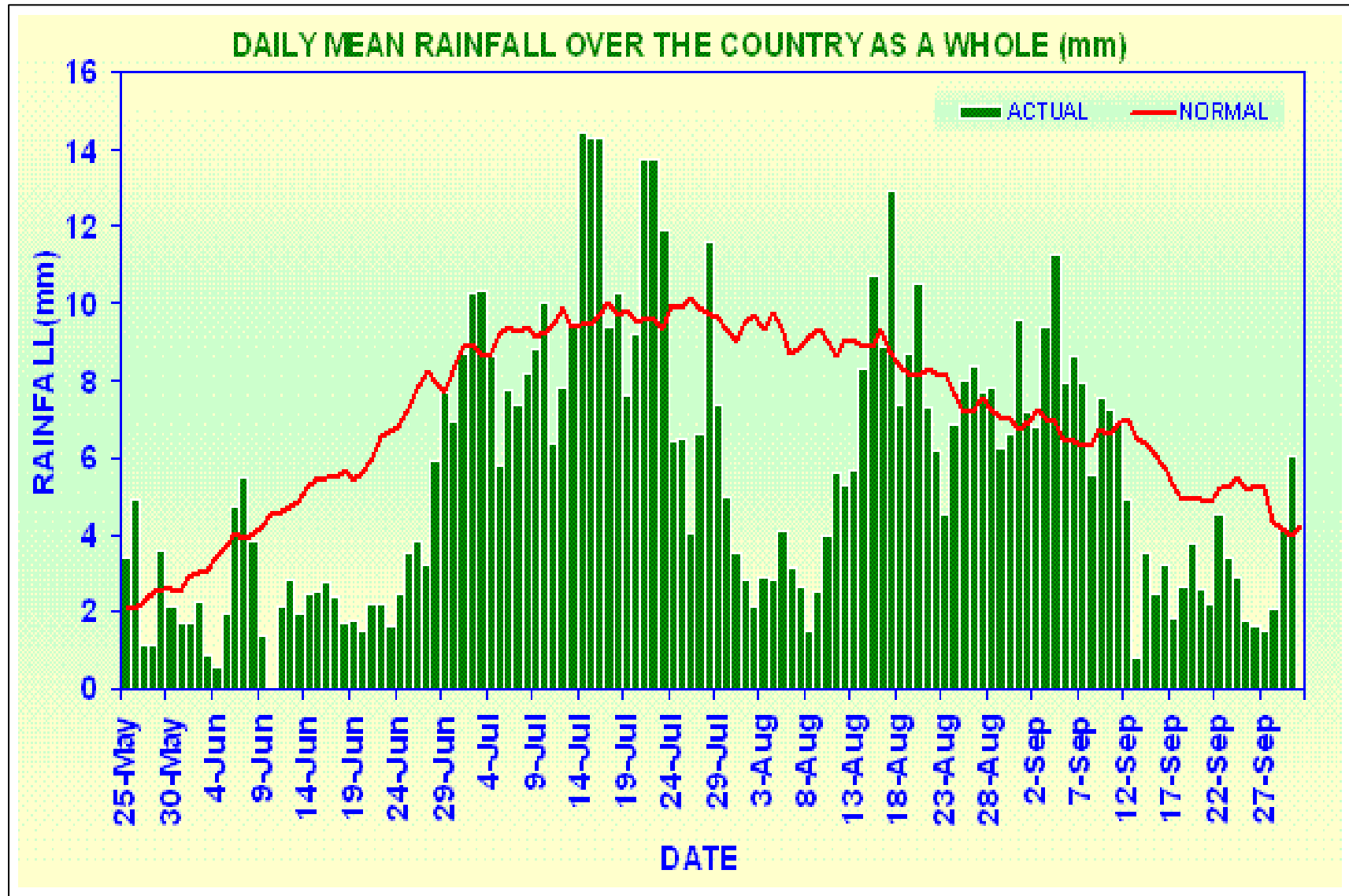
A farmer shows the state of his paddy that has dried up due to insufficient rain and water supply in Gidder village of Punjab.

Active-break cycles of the Indian Summer Monsoon



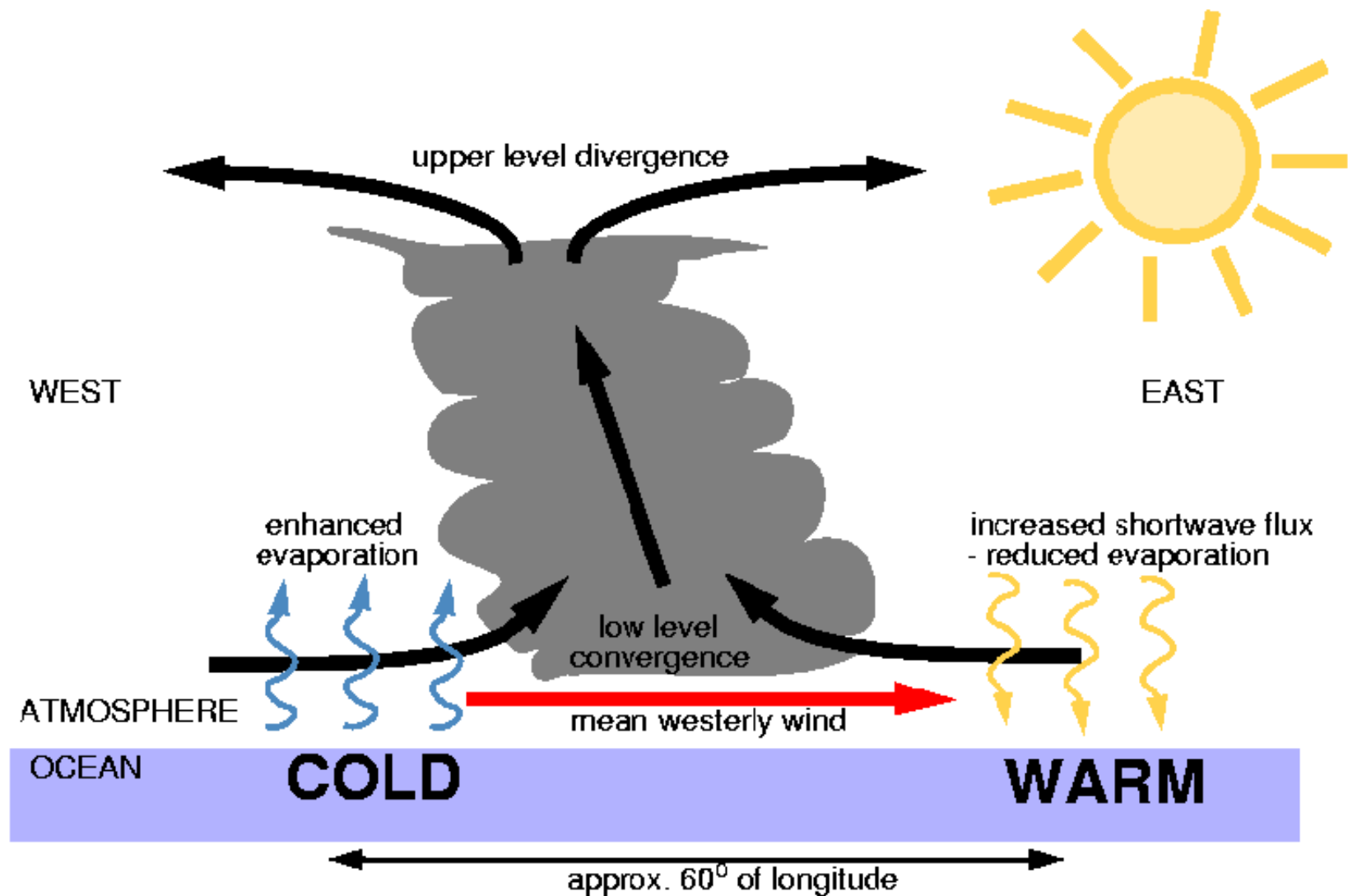
Northward and eastward propagation associated with the Madden Julian Oscillation (MJO)

MJO implicated in monsoon 2009



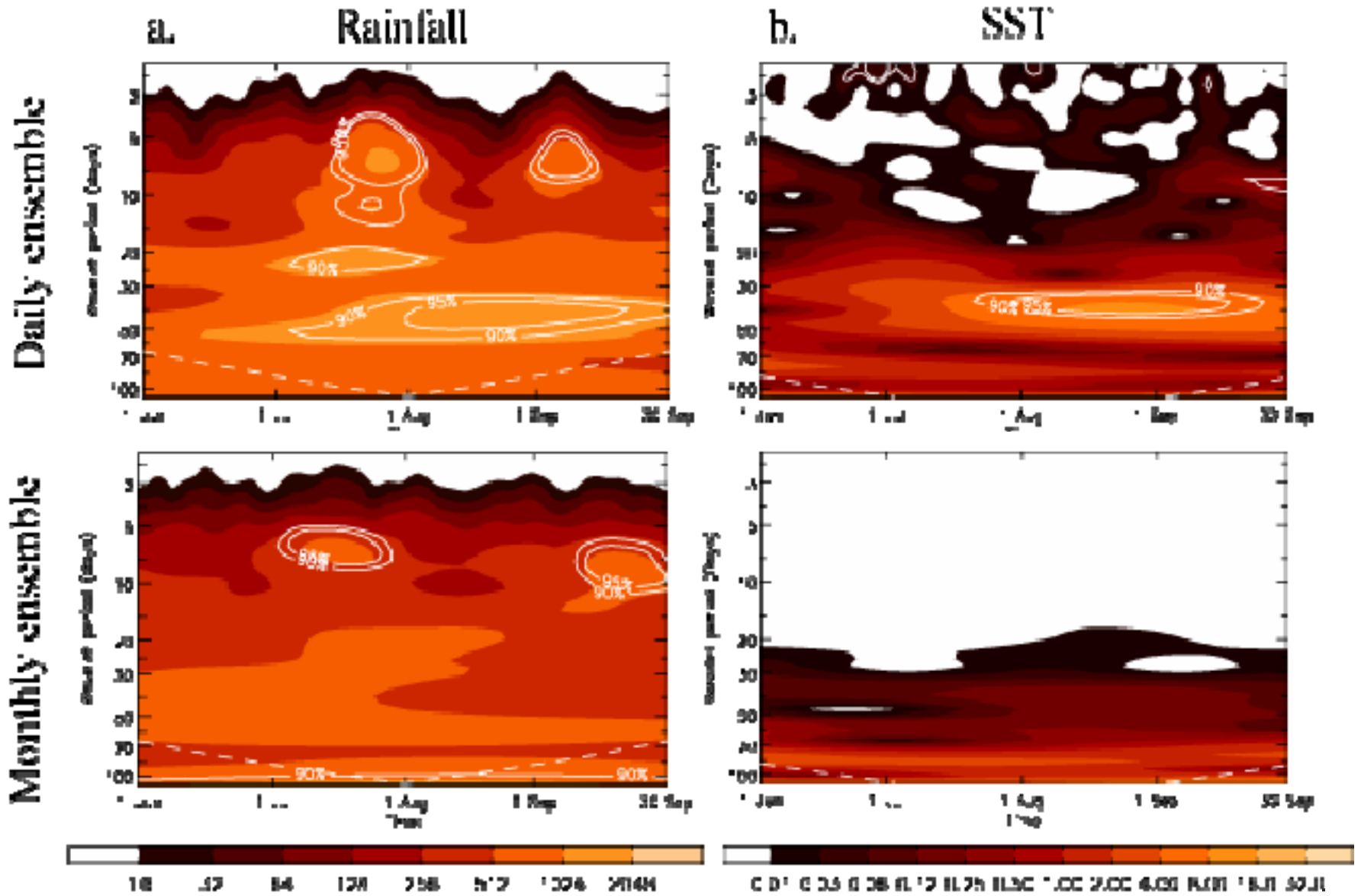
Major failure of monsoon rains: 23% below normal

Air-sea interaction and the MJO



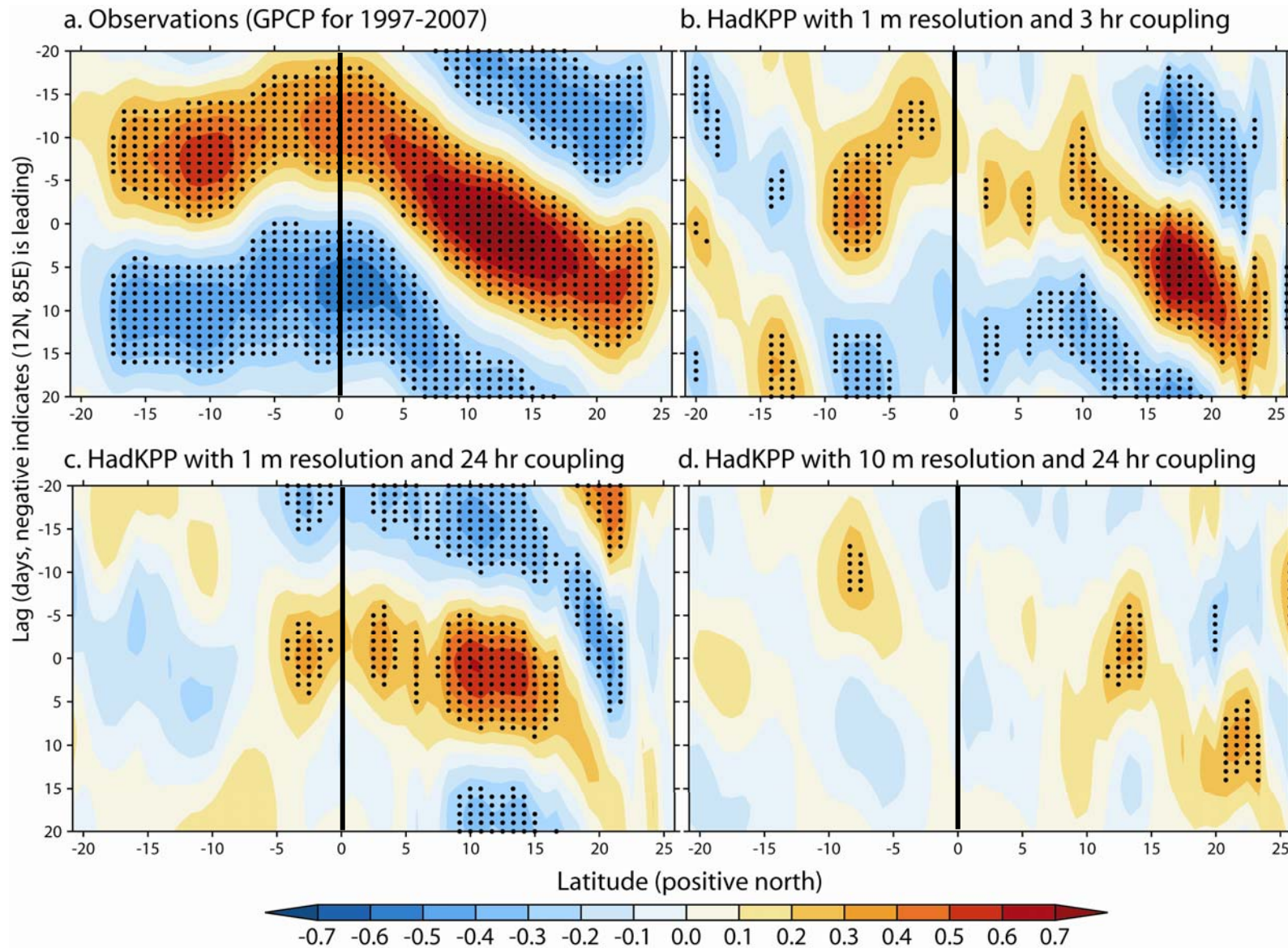
Courtesy: Pete Inness

High Frequency Sea Surface Temperatures drive stronger active-break cycles



The importance of interactive upper-ocean thermodynamics for monsoon active-break cycles

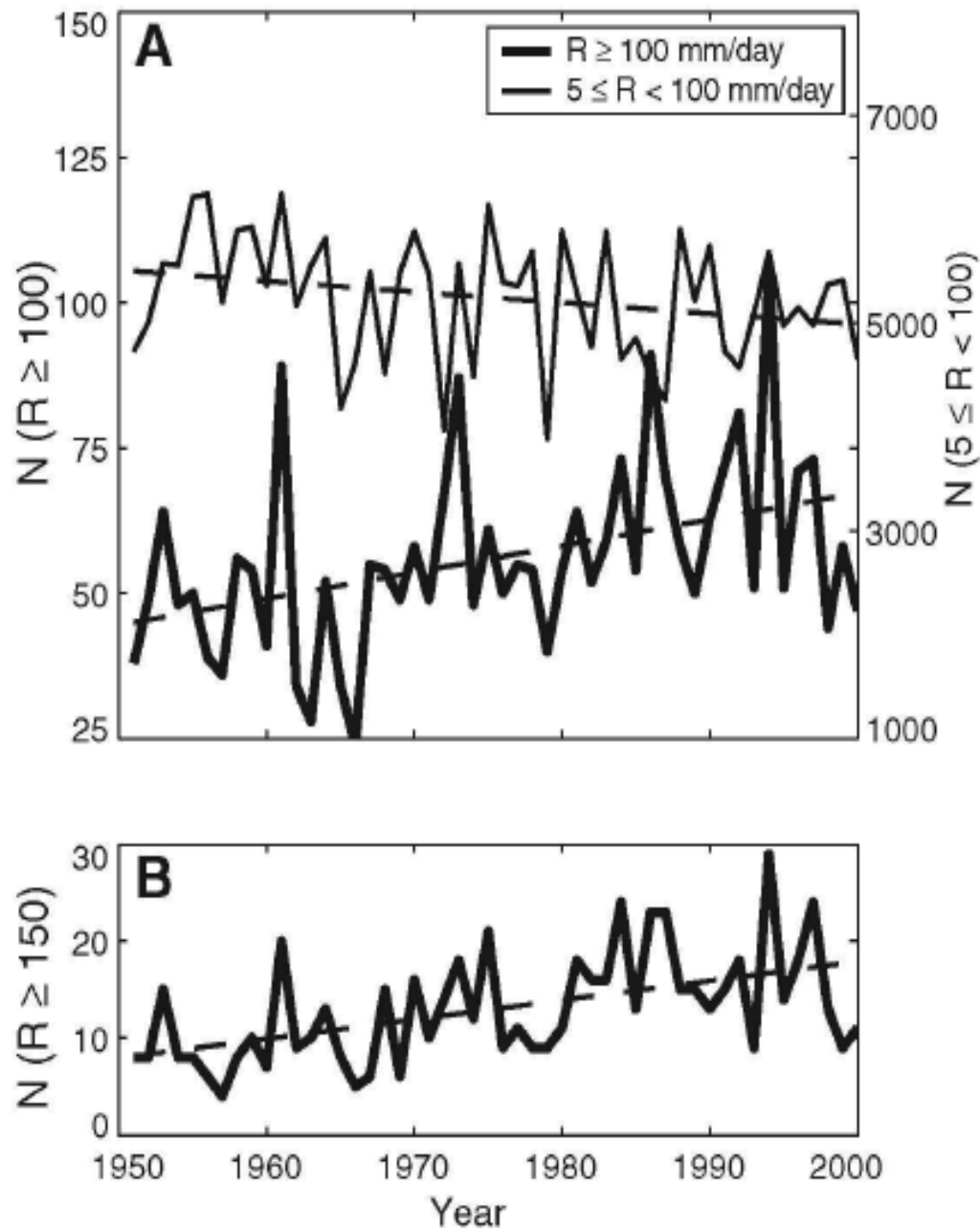
Lag correlations of intra-seasonally (30-50 day) filtered July and August rainfall





Mumbai flooding: July 26 2005
942 mm (37 inches) of rain in 24 hours

Changing nature of Indian rainfall (R)



(A) Number (N) of heavy ($R > 100$ mm/day, bold line) and moderate ($5 < R < 100$ mm/day, thin line) daily rain events

(B) Number (N) of very heavy events ($R > 150$ mm/day) during the summer monsoon season over Central India.

From Goswami et al. 2006, Science

India and Climate Change

Indian Summer Monsoon is remarkably stable:
High societal vulnerability to small changes.

India is developing rapidly: Will there be enough
water to sustain that development?



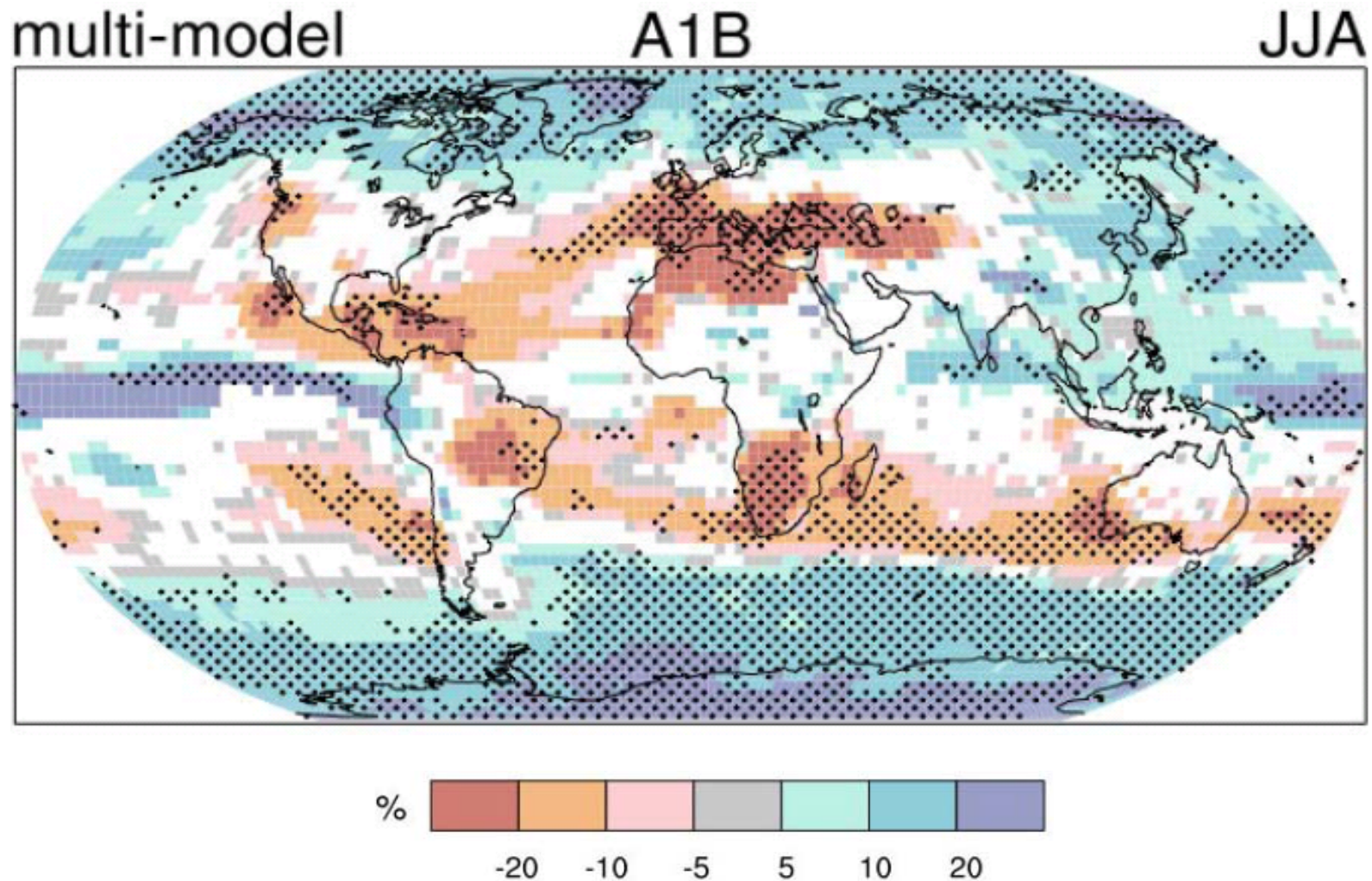




The Scientific Challenges

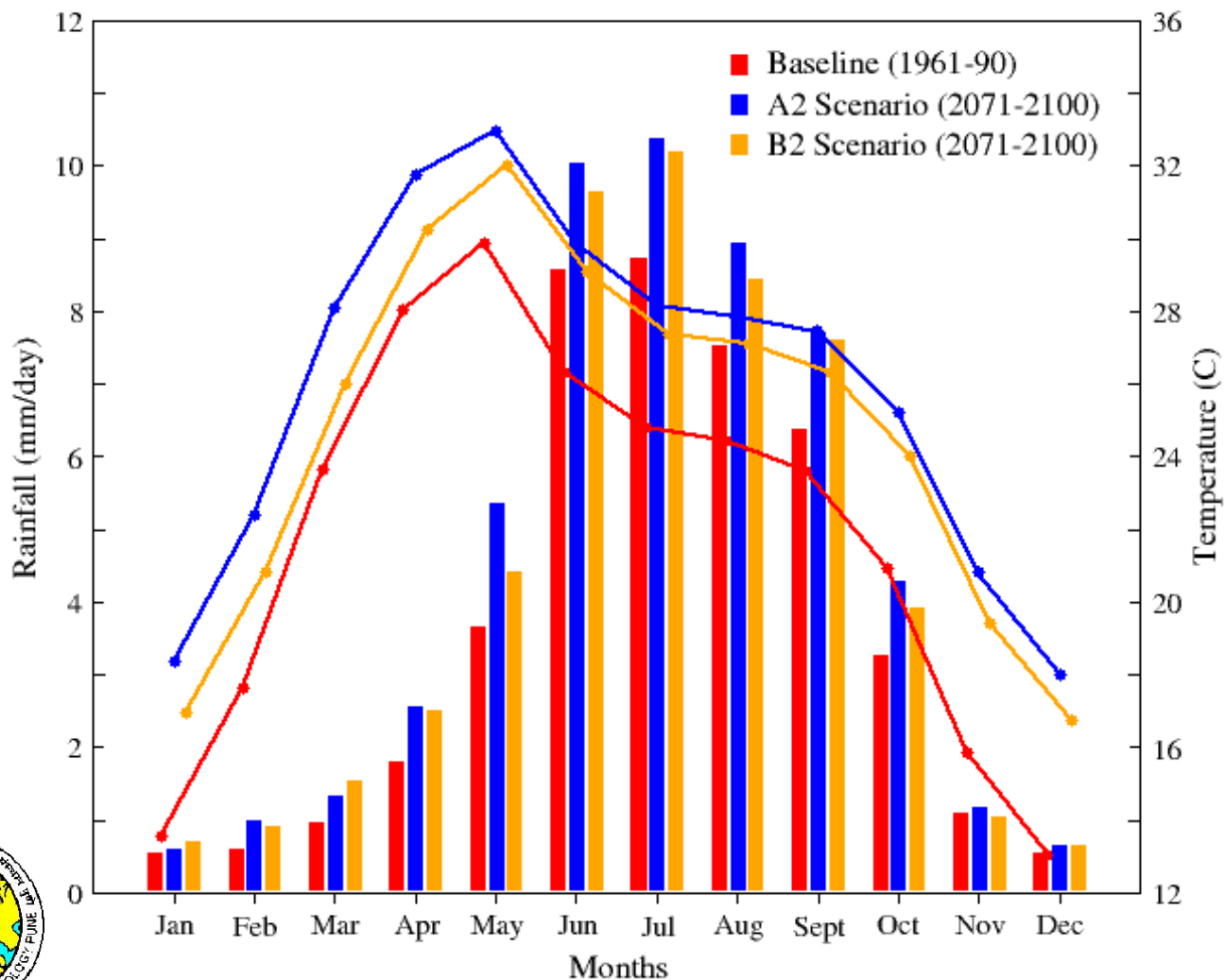
- **How will the mean monsoon behave?**
- **How will climate change affect the stability of the monsoon?**
 - Will it become more variable?
 - Will it be less predictable?
- **What will climate change mean for extreme events?**
- **How will changes in atmospheric composition affect the monsoon?**

IPCC 4th Assessment Report: Projections of likely shifts in rainfall patterns by 2080



% change in rainfall by end of 21st century, where more than 2/3 of the models agree on the **sign** of the change.

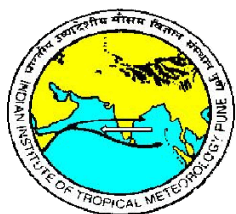
Mean Annual Cycles of All-India Rainfall and Temperature for end of 21st century



Current

A2: High Emissions

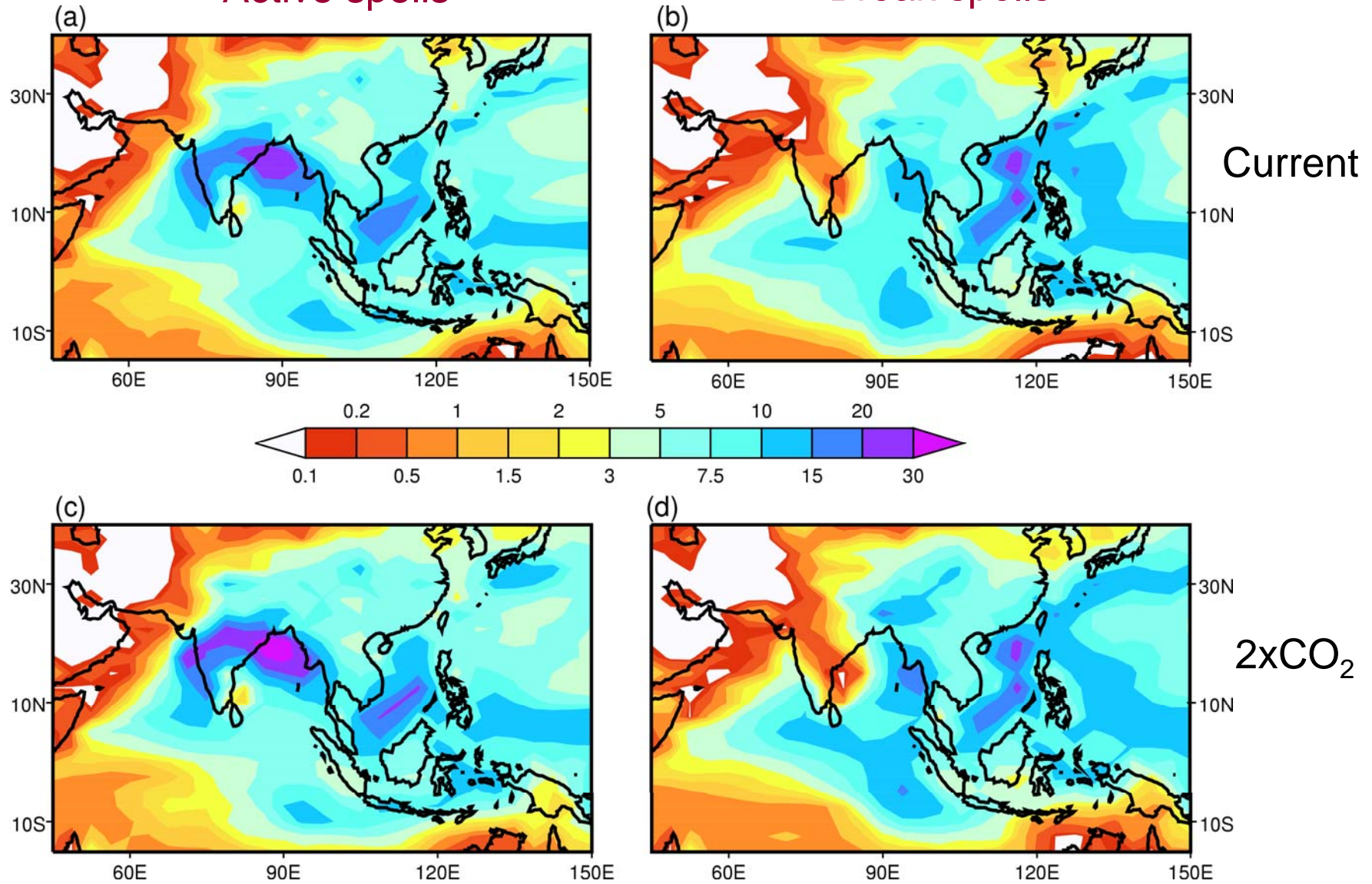
B2: Low Emissions



Changes in rainfall during active and break phases

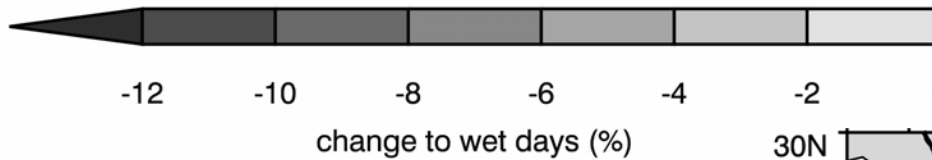
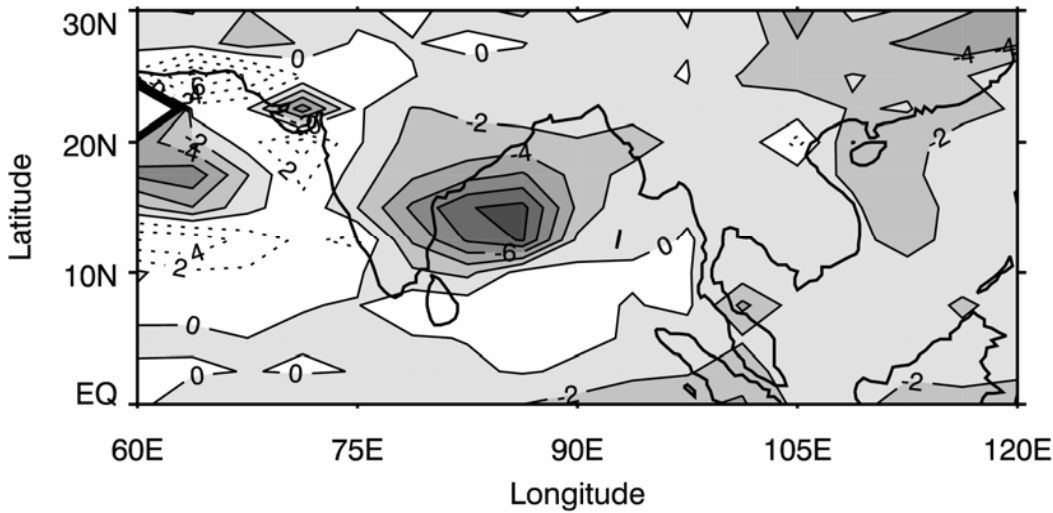
Active spells

Break spells



Monsoon breaks may become more severe – impacts on agriculture

Change in number of wet days

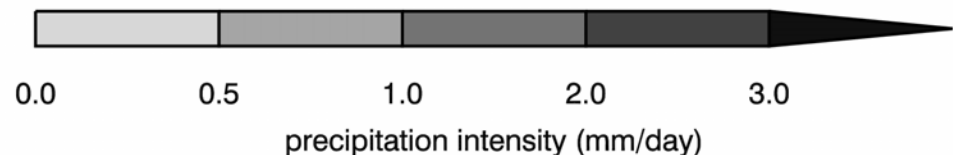
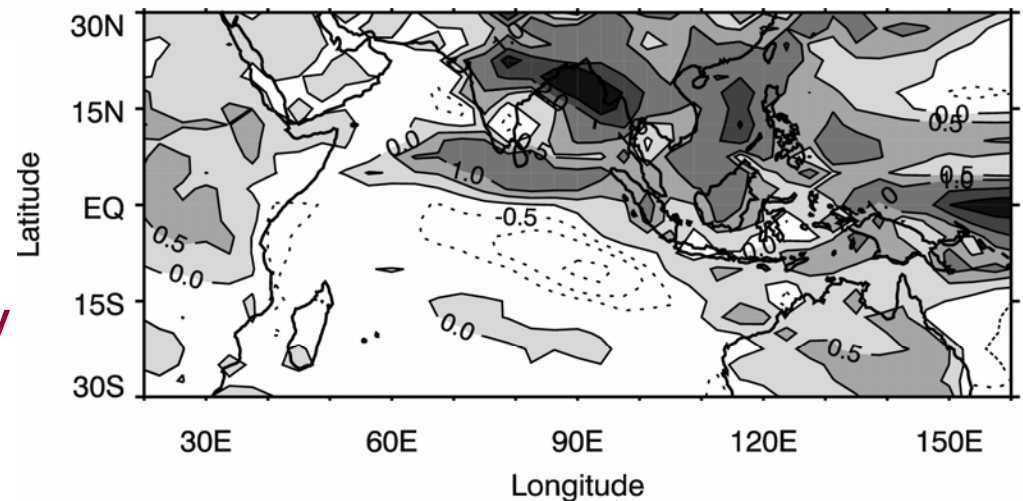


- Decrease in number of rain days
- Increase in rain intensity on days when raining

Changing nature of Indian rainfall with climate change:

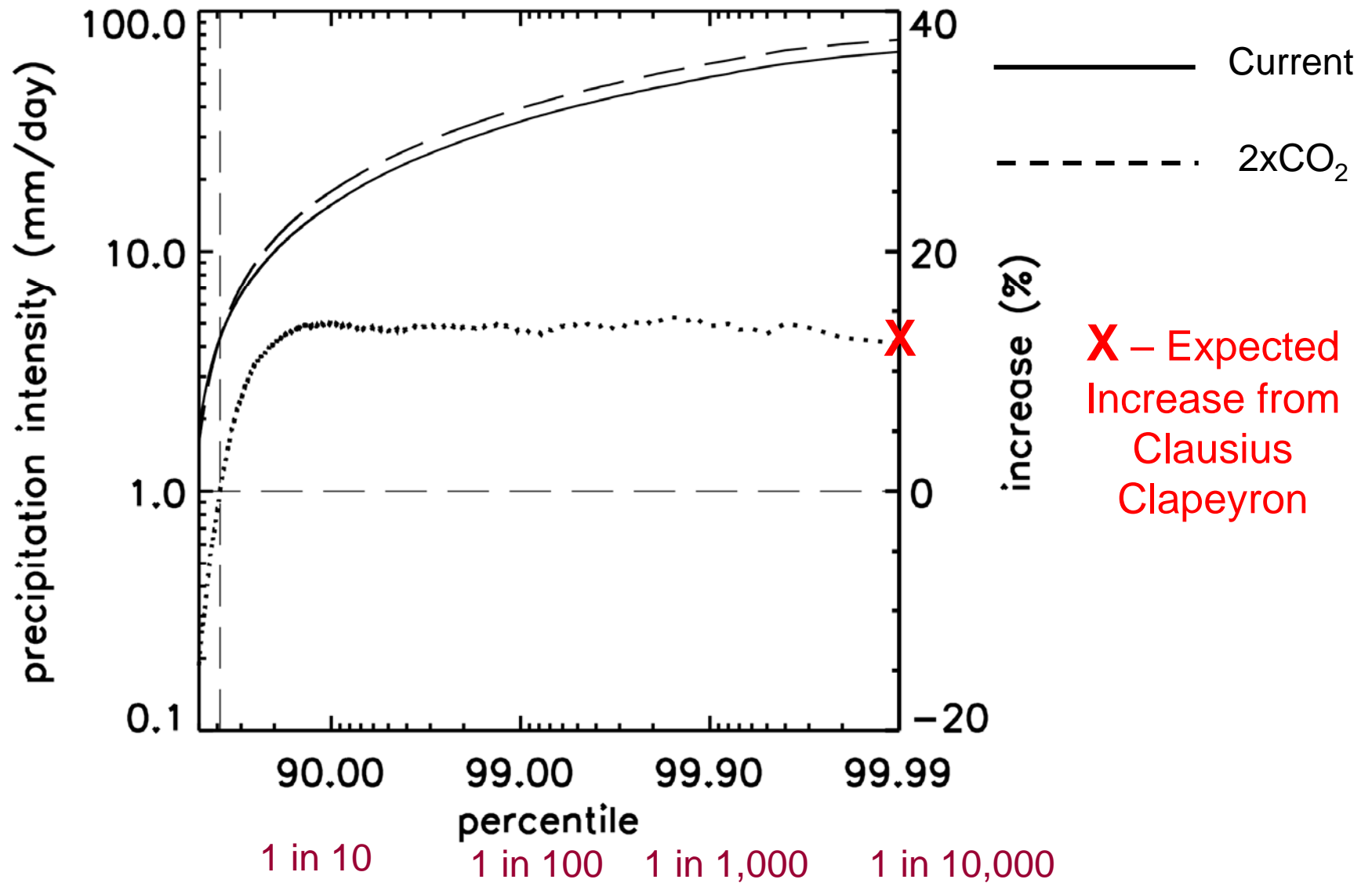
Impact of 2xCO₂ on number of rain days and rainfall intensity

Change in rainfall intensity



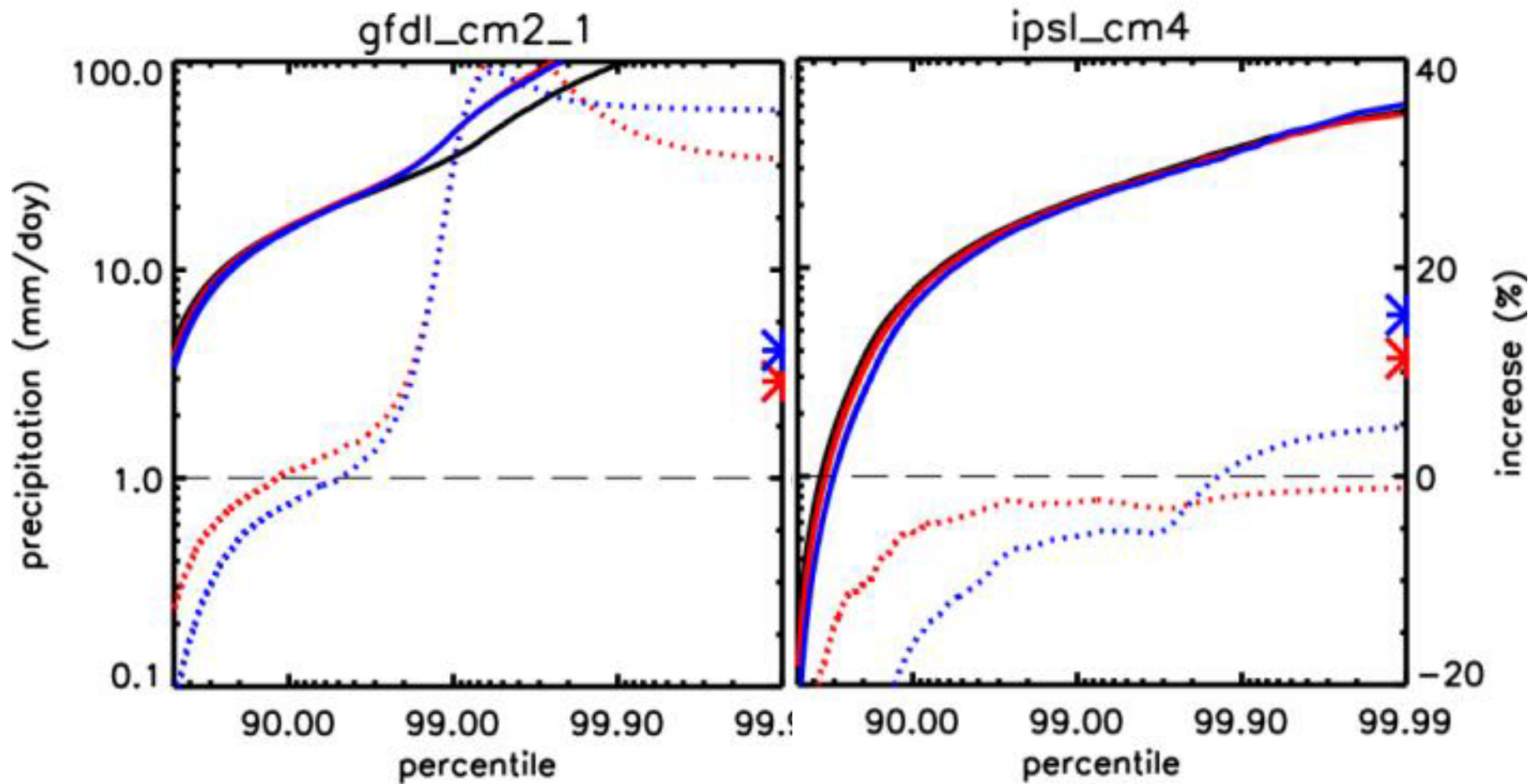
From: Turner & Slingo 2008

Changes in the intensity of extreme Indian daily rainfall with climate change



From: Turner & Slingo 2008

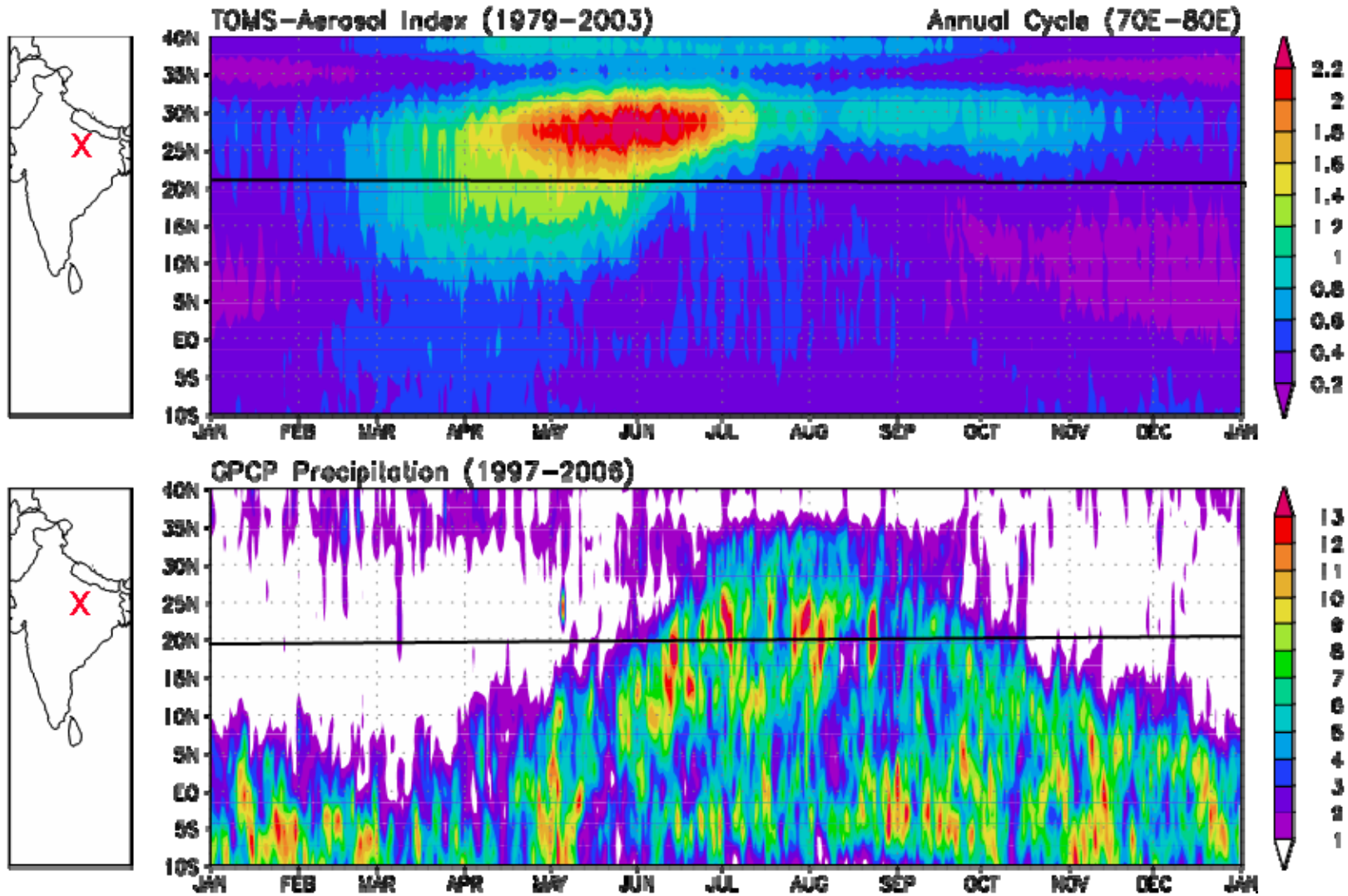
But not all models agree with this simple hypothesis.....



A satellite image of South Asia, showing the Indian subcontinent and surrounding regions. The image displays a significant concentration of aerosols, appearing as a dense, light-colored haze over the landmass, particularly in the northern and central parts. The surrounding oceans and parts of the surrounding landmasses are visible, with some cloud cover over the Indian Ocean. The text "Impact of aerosols on the monsoon" is overlaid on the image.

Impact of aerosols on the monsoon

Pre-monsoon build up of absorbing aerosol from Arabian and Saharan dust, Thar dust and local black carbon sources.



Aerosol is not all washed out during monsoon: gaps in rainfall allow burden to build up.

Concluding Remarks

- Much still to learn about what controls the monsoon and its variability
- Model improvements are vital for making progress in monsoon prediction
- Impacts of climate change remain hugely uncertain for those reasons
- 2010: Normal (98%) predicted by Indian Meteorological Department



Tropical Cyclone Gonu:
4 June 2007